

# An assessment for eastern Bering Sea snow crab

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**Appendix A: Population dynamics model**

1. Stock: Eastern Bering Sea snow crab, *Chionoecetes opilio*.
2. Catches: trends and current levels

Retained catches increased from relatively low levels in the early 1980s (e.g. 11.85 kt during 1982) to historical highs in 1990s (retained catch during 1991, 1992, and 1998 were 143.02, 104.68, and 88.09 kt, respectively). The stock was declared overfished in 1999 at which time retained catches dropped to levels similar to the early 1980s (e.g. 11.46 kt). Retained catches have slowly increased since 1999 as the stock rebuilt, and retained catch during the 2020/2021 was the highest in the last 6 years (20.41 kt). However, total allowable catches were slashed with the collapse of the population in 2021 and retained catches from the 2021/2022 season were the lowest on record (2.48 kt).

Discard mortality is the next largest source of mortality after retained catch and approximately tracks the retained catch. The highest estimated discard mortality occurred during 1992 at 17.06 kt which was 16% of the retained catch during that year. The most recent estimated discard mortality was 1.16 kt which was 47% of the retained catch.

3. Stock Biomass:

Observed mature male biomass (MMB) at the time of the survey increased from an average of 161.68 kt in the early to mid-1980s to historical highs in the 1990s (observed MMB during 1990, 1991, and 1997 were 443.79, 466.61, and 326.75 kt, respectively). The stock was declared overfished in 1999 in response to the total mature biomass dropping below the 1999 minimum stock size threshold. MMB in that year decreased to 95.85 kt. Observed MMB slowly increased after 1999, and the stock was declared rebuilt in 2011 when estimated MMB at mating was above  $B_{35\%}$ . However, after 2011, the stock declined and the observed MMB at the time of survey dropped to 63.21 kt in 2016. Recently, MMB was increasing again as a large recruitment moved through the size classes, but that recruitment has since disappeared and the observed mature male biomass at the time of the 2022 survey was 37.5 kt, a new all-time low and 40% less than the previous all-time low seen in the 2021 survey.

4. Recruitment

Estimated recruitment shifted from a period of high recruitment to a period of low recruitment in the mid-1990s (corresponding with a late 1980s fertilization). A large year class recruited to the survey gear in 2015 and was tracked until 2018 and 2019, but it appears to have since disappeared from the eastern Bering Sea shelf before reaching commercial size.

## 5. Management

Table 1: Historical status and catch specifications for snow crab (1,000t).

| Year      | MSST | Biomass (MMB) | TAC  | Retained catch | Total catch | OFL  | ABC   |
|-----------|------|---------------|------|----------------|-------------|------|-------|
| 2015/2016 | 75.8 | 91.6          | 18.4 | 18.4           | 21.4        | 83.1 | 62.3  |
| 2016/2017 | 69.7 | 96.1          | 9.7  | 9.7            | 11          | 23.7 | 21.3  |
| 2017/2018 | 71.4 | 99.6          | 8.6  | 8.6            | 10.5        | 28.4 | 22.7  |
| 2018/2019 | 63   | 123.1         | 12.5 | 12.5           | 15.4        | 29.7 | 23.8  |
| 2019/2020 | 56.8 | 167.3         | 15.4 | 15.4           | 20.8        | 54.9 | 43.9  |
| 2020/2021 | 76.7 | 26.74         | 20.4 | 20.4           | 26.2        | 95.4 | 71.55 |
| 2021/2022 | 91.6 | 41.2          | 2.5  | 2.5            | 3.6         | 7.5  | 5.6   |
| 2022/2023 |      | 55.0          |      |                |             | 10.3 | 7.7   |

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

| Year      | MSST   | Biomass (MMB) | TAC   | Retained catch | Total catch | OFL    | ABC    |
|-----------|--------|---------------|-------|----------------|-------------|--------|--------|
| 2015/2016 | 167.11 | 201.94        | 40.57 | 40.57          | 47.18       | 183.2  | 137.35 |
| 2016/2017 | 153.66 | 211.86        | 21.38 | 21.38          | 24.25       | 52.25  | 46.96  |
| 2017/2018 | 157.41 | 219.58        | 18.96 | 18.96          | 23.15       | 62.61  | 50.04  |
| 2018/2019 | 138.89 | 271.39        | 27.56 | 27.56          | 33.95       | 65.48  | 52.47  |
| 2019/2020 | 125.22 | 368.83        | 33.95 | 33.95          | 45.86       | 121.03 | 96.78  |
| 2020/2021 | 169.09 | 58.95         | 44.97 | 44.97          | 57.76       | 210.32 | 157.74 |
| 2021/2022 | 201.94 | 90.83         | 5.51  | 5.51           | 7.94        | 16.53  | 12.35  |
| 2022/2023 |        | 121.25        |       |                |             | 22.71  | 16.98  |

## 6. Basis for the OFL

The OFL for 2022 from the author-preferred model (22.1ab) was 3.98 kt fishing at  $F_{OFL} = 0.67$  (30% of the calculated  $F_{35\%}$ , 2.26). The calculated OFL was an 37% change from the 2021 OFL of 7.5 kt. The projected ratio of MMB at the time of mating in 2023 to  $B_{35\%}$  is 0.39 under no directed fishing and 0.37 fishing at the  $F_{OFL}$ .

However, the CPT selected model 22.1a, for which the OFL for 2022 was 10.32 kt fishing at  $F_{OFL} = 0.32$  (22% of the calculated  $F_{35\%}$ , 1.5). The calculated OFL was an 37% change from the 2021 OFL of 7.5 kt. The projected ratio of MMB at the time of mating in 2023 to  $B_{35\%}$  is 0.37 under no directed fishing and 0.3 fishing at the  $F_{OFL}$ .

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. Proj\_Status represents the projected fishery status after the coming fishery removes the OFL and is used in the harvest control rule. ‘Years’ indicates the year range over which recruitment is averaged for use in calculation of  $B_{35}$ . ‘M’ is the natural mortality for immature crab, mature female crab, and mature male crab, respectively. (continued below)

| Year      | Tier | BMSY  | MMB  | Status | Proj_Status | FOFL | Years     |
|-----------|------|-------|------|--------|-------------|------|-----------|
| 2022/2023 | 3b   | 183.1 | 41.2 | 0.23   | 0.3         | 0.32 | 1982-2021 |

|            |
|------------|
| M          |
| 0.28, 0.29 |

## 7. Probability Density Function of the OFL

The probability density function of the OFL is not presented here.

## 8. Basis for ABC

The ABC for the chosen model was 7.74 kt, calculated by subtracting a 25% buffer from the OFL as recommended by the SSC.

## A. Summary of Major Changes

### 1. Management:

The eastern Bering Sea snow crab population was declared over-fished in October 2021 and a rebuilding plan is currently being formalized.

### 2. Input data:

Data added to the assessment included: 2022 eastern Bering Sea survey biomass and length composition data, 2021 directed fishery retained and discard catch, length composition for retained and discard catch, and groundfish discard length frequency and discard from 2021.

### 3. Assessment methodology:

Management quantities were derived from maximum likelihood estimates of model parameters in a size-based, integrated assessment method. Only GMACS models are presented with updated data, following the adoption of GMACS as the new assessment platform for snow crab by the SSC in June 2022. Jittering was performed for the author-preferred model. An application of tier 4 methodologies for calculating the OFL are also included. Incorporating the new data in the integrated model resulted in appreciable changes in estimated survey catchability, which increased the estimated scale of the population and had direct effects on the calculated OFL.

### 4. Assessment results

The updated estimate from the author-preferred model of MMB on February 15, 2022 was 96.67 kt which placed the stock at 49% of  $B_{35\%}$ . Projected MMB on February 15, 2023 from this year's author preferred model is 55.04 kt after fishing at the OFL, which would place the stock at 30% of  $B_{35\%}$ .

However, the CPT selected a different model than the author-preferred model. The updated estimate from the CPT-selected model of MMB on February 15, 2022 was 41.21 kt which placed the stock at 23% of  $B_{35\%}$ . Projected MMB on February 15, 2023 from this year's author preferred model is 71.88 kt after fishing at the OFL, which would place the stock at 37% of  $B_{35\%}$ .

Tables have been modified to reflect the CPT-selected model output.

## B. Comments, responses and assessment summary

### SSC and CPT comments + author responses

*SSC comment: The SSC strongly recommends that the urgency of accounting for snow crab in the northern Bering Sea requires that analysts prioritize working towards a model-based survey index that incorporates the NBS data*

The fishery interacts primarily with males larger than 101 mm carapace width, but the mean fraction of commercially-sized individuals in the northern Bering Sea during the limited number of years for which we have data is less than one percent (Table 5). Historically, the observed commercial biomass has not been near the NBS boundary (Figure 1). Further, currents are generally such that if there were any mature biomass in the NBS, the larvae originating from the NBS would be unlikely to contribute to the biomass in the EBS. Given the lack of fishery impacts in the NBS, current discussion about the appropriate currency of management, other pressing issues in the assessment model (e.g. treatment of maturity data and BSFRF experimental selectivity data), and uncertainty around the connection between the biomass in the NBS and the EBS, developing indices of extrapolated data for the NBS should remain low priority. Continued monitoring of the NBS to assess the fraction of the stock with which the fishery interacts, however, will be important under rapidly shifting environmental conditions.

Table 5: Statistics related to the number of commercial males in the northern Bering Sea. The first column is the number of stations in the NBS with crab >101 mm carapace width. The second column is the total number of stations in the EBS and NBS that reported >101 mm carapace width crab. The third column is the percent of the total area-swept abundance in the NBS. The mean fraction of the abundance over years of available data was 0.68%.

| Year | NBS.stations.w..crab | Total.stations.with.crab | Percent.in.the.NBS |
|------|----------------------|--------------------------|--------------------|
| 2010 | 0                    | 197                      | 0                  |
| 2017 | 1                    | 157                      | 0.1                |
| 2018 | 1                    | 151                      | 0.1                |
| 2019 | 8                    | 156                      | 1.3                |
| 2021 | 4                    | 165                      | 0.9                |

*SSC comment: The SSC highlights the importance of assessing the current definition of male snow crab maturity given the possibility of snow crab maturing at smaller sizes and the sensitivity of reference points to assumptions about growth and maturity, as previously illustrated by the author*

I agree, but did not have time to redo my previous analyses with updated data.

*SSC comment: The SSC strongly recommends including uncertainty intervals on estimates of biomass and abundances*

Included.

*SSC comment: The SSC continues to request an explanation for why the GMACS model estimates such a skewed sex-ratio for recruitment*

The potential reasons in the past include potential differences in growth, spatial distribution, and maturity. More importantly, the fishery interacts with the large males and management is based on mature male biomass. Consequently, understanding the dynamics of MMB and commercially-sized males should be the primary focus of the assessment in order to provide appropriate management advice. If, for some currently unknown reason (given the data available), the dynamics of the females appear to be different than that of the males, making assumptions that force the dynamics to be the same can impede the modeling of the

dynamics of the portion of the stock with which the fishery interacts and on which the overfishing level is based. The retrospective patterns seen in previous assessments when males and female recruitment had 50/50 sex ratios are an example of this.

*SSC comment: The SSC recommends that the author work with BSFRF to summarize observations from harvesters*

Fishery catch-per-unit-effort provided by the State of Alaska are included in this assessment document.

*SSC comment: SSC requests to see Tier 4 calculations with the value for M (not including the elevated values in 2018-2019) from the last accepted model as a fall back for specifications*

Tier 4 calculations are now included. However, using morphometrically mature male biomass (the current currency of management) in the tier 4 HCR results in the calculated OFL exceeding the estimated biomass of commercially targeted males in some years, which would seem to disqualify it from consideration. So, if tier 4 rules are to be pursued, a discussion needs to be had (or continued) about an appropriate currency of management.



## Assessment summary

Five assessment models are presented here:

- 21.1 – Last year’s accepted model (status quo) fit to last year’s data
- 21.g – Last year’s GMACS model fit to last year’s data with a prior on M similar to 21.1
- 22.1 – 21.g fit to this year’s data
- 22.1a – 22.1 with alternate configuration of estimation of initial size comps in which all parameters are freely estimated rather than estimating an ogive and a scaling parameter. This model is from the mode of the jittering analysis with the larger OFL
- 22.1ab – 22.1a from the mode of the jittering analysis with the smaller OFL

GMACS was accepted as the official model for assessing eastern Bering Sea snow crab by the SSC in June of 2022 on the basis of better fits, projection capabilities, and improved convergence, transparency, and reproducibility. Following this adoption, only GMACS models are presented with updated data in this assessment cycle. Model 22.1ab is the author’s preferred model from those presented based on improvements in fits to size composition data from adjusting the way the initial numbers at size are estimated and more realistic estimates of fishing mortality in recent years. However, updating the data produced some consequential changes in estimates of population processes compared to the GMACS model accepted in June. For example, survey catchability decreased from ~0.7 in 21.g to ~0.4 in 22.1ab, the estimated probability of having undergone terminal molt increased slightly at smaller sizes, and fits to recent size composition data deteriorated.

In addition to the lowest observed mature male biomass on record reported this year (~40% lower than last year), a few other concerning signals arose around the population dynamics in the previous two years. The observed probability of having undergone terminal molt was much higher for smaller sizes in 2021 than historically observed (Figure 2) and the lowest average clutch fullness scores ever were observed in 2022. Beyond biological concerns, the fishery posted the lowest catch per unit efforts ever observed in the 2021/2022 season.

Models 22.1a and 22.1ab resulted from jittering analyses and represent the models associated with the modes of a bimodal distribution of management quantities. The two modes had similar average objective function values (approximately -23204 vs. -23200) but fairly large differences in the calculated OFLs (~10 kt vs. ~4 kt). The author-preferred model (22.1ab) presented here is based on a model within the cloud of jittered models that produced an OFL of ~ 4 kt because the model associated with the 10 kt OFL produced unreasonably high estimates of fishing mortality in the 2020/2021 directed fishery (i.e. removal of >99% of commercial crab).

A draft manuscript describing efforts at explaining the recent collapse of snow crab is included with this assessment (see appendices B and C). Based on the currently available data, high temperatures and densities of crab and the resulting metabolic demand appear to have contributed to mortality events that precipitated the collapse of eastern Bering Sea snow crab. Although not quite as extreme, similar temperatures to 2018 were experienced by the snow crab population in 2003. Mortality in this period was elevated, but not as high as in 2018 and 2019, presumably as a result of lower crab densities. This information paired with projections from Szuwalski et al. 2020 may help inform selection of mortality and recruitment scenarios for rebuilding analyses (see appendix D).

A tier 4 harvest control rule was applied to four measures of male biomass observed in the survey (morphometrically mature male biomass, legal male biomass [ $>78$  mm carapace width],  $>95$  mm carapace width crab, and commercial biomass [ $>101$  mm carapace width]) and adoption of a tier 4 rule using any of these metrics would result in a closure of the fishery. Using morphometrically mature biomass and legal biomass both do not seem to be viable options because in some years they would have set the OFL at a value greater than the survey estimate of the total amount of commercial biomass in the Bering Sea.

The author’s preferred model is 22.1ab given the available options, but several concerning issues arose with this model when updating the data. Given the current status of the stock, concerns around model output,

changes in biological processes, and poor fishery performance, caution in management is likely warranted. A discussion of other modeling options and/or alternative buffers may be useful at the plan team meeting.

The CPT selected model 22.1a because it returned the lowest negative log likelihood.

## C. Introduction

### Distribution

Snow crab (*Chionoecetes opilio*) are distributed on the continental shelf of the Bering Sea, Chukchi Sea, and in the western Atlantic Ocean as far south as Maine. In the Bering Sea, snow crab are distributed widely over the shelf and are common at depths less than ~200 meters (Figure 3 & Figure 4 for 2021 distribution). Smaller crabs tend to occupy more inshore northern regions (Figure 5) and mature crabs occupy deeper areas to the south of the juveniles (Figure 6 & Figure 7; Zheng et al. 2001). The eastern Bering Sea population within U.S. waters is managed as a single stock; however, the distribution of the population may extend into Russian waters to an unknown degree.

### Life history characteristics

Studies relevant to key population and fishery processes are discussed below to provide background for the model description in appendix A.

### Natural Mortality

Relatively few targeted studies exist to determine natural mortality for snow crab in the Bering Sea. In one of these studies, Nevissi, et al. (1995) used radiometric techniques to estimate shell age from last molt (Figure 8). The total sample size was 21 male crabs (a combination of Tanner and snow crab) from a collection of 105 male crabs from various hauls in the 1992 National Marine Fishery Service (NMFS) Bering Sea survey. Representative samples for the 5 shell condition categories were collected from the available crab. Shell condition 5 crab (SC5 = very, very old shell) had a maximum age of 6.85 years (s.d. 0.58, 95% CI approximately 5.69 to 8.01 years; carapace width of 110 mm). The average age of 6 crabs with SC4 (very old shell) and SC5, was 4.95 years (range: 2.70 to 6.85 years). Given the small sample size, this maximum age may not represent the 1.5% percentile of the population that is approximately equivalent to Hoenig's method (1983). Tag recovery evidence from eastern Canada revealed observed maximum ages in exploited populations of 17-19 years (Nevissi, et al. 1995, Sainte-Marie 2002). A maximum time at large of 11 years for tag returns of terminally molted mature male snow crab in the North Atlantic has been recorded since tagging started about 1993 (Fonseca, et al. 2008). Fonseca, et al. (2008) estimated a maximum age of 7.8 years post terminal molt using data on dactal wear.

In recent years, the mean for the prior for natural mortality used in the eastern Bering Sea snow crab assessment was based on the assumption that longevity would be at least 20 years in a virgin population of snow crab, informed by the studies above. Under negative exponential depletion, the 99th percentile corresponding to age 20 of an unexploited population corresponds to a natural mortality rate of 0.23. Using Hoenig's (1983) method a natural mortality equal to 0.23 corresponds to a maximum age of 18 years.

In contrast to the implied natural mortalities from the methodology used above, Murphy et al. (2018) estimated time-varying natural mortality for eastern Bering Sea snow crab with a mean of 0.49 for females and 0.36 for males (based on the output of state-space models fit to NMFS survey data; Figure 9). Further, natural mortality estimates produced from empirical analyses by Then et al. (2015) and Hamel (2015) using similar assumed maximum ages as the methodology above produced natural mortalities larger than 0.23 (Table 6). Then et al. (2015) compared several major empirical estimation methods for M (including Hoenig's method) with an updated data set and found that maximum age was the best available predictor. A maximum age of 20 years corresponded to an M of ~0.315 in Then et al.'s analysis. Hamel (2015) developed priors in a similar manner to Then et al., but forced the regression of observed natural mortality onto maximum age through the intercept, which resulted in an M of ~0.27 for an assumed maximum age of 20 years.

Table 6: Empirical estimates of natural mortality for a range of methods over a range of assumed maximum ages (column header).

|                       | 23    | 20    | 17    |
|-----------------------|-------|-------|-------|
| <b>Then</b>           | 0.277 | 0.315 | 0.365 |
| <b>Hoening (1983)</b> | 0.19  | 0.212 | 0.257 |
| <b>Hoening (2015)</b> | 0.194 | 0.223 | 0.261 |
| <b>Hamel</b>          | 0.235 | 0.271 | 0.318 |

In addition to the results of empirical estimates of  $M$  from updated methodologies and state-space modeling by Murphy et al. (2018), inspection of the survey data suggests that natural mortality for mature individuals is higher than assumed. A fraction of the mature population (which are assumed not to grow, given evidence for a terminal molt) are not selected in the fishery (e.g. sizes 50-80 mm; Figure 10). Consequently, all mortality observed is ‘natural’. The collapse in recruitment in the 1990s can be used as an instrument to understand natural mortality for mature individuals. The last large recruitment enters these size classes in the mid- to late-1990s and numbers of crab in these size classes return to low levels in less than 5 years.

The median value of the priors used in this assessment are set equal to values resulting from assuming a maximum age of 20 years and applying Hamel’s methodology. A standard error of 0.054 was used for initial priors and was estimated using the 95% CI of  $\pm 1.7$  years on maximum age estimates from dactal wear and tag return analysis in Fonseca, et al. (2008). Mortality events in 2018 and 2019 are estimated as additional mortality parameters applied by sex and maturity state to allow the model to fit recent population trends.

## Weight at length

Weight at length is calculated by a power function, the parameters for which were recalculated by the Shellfish Assessment Program in August 2016 and resulted in very small changes in weight at length for males, but rather large changes for females. New weight at length parameters were applied to all years of data, rather than just the most recent observations and were used starting in 2016 for calculation of the OFL. To provide context for the change, a juvenile female crab of carapace width 52.5 mm was previously estimated to weigh 65 g and is now 48 g; a mature female crab of carapace width 57.5 mm was estimated to previously weigh 102 g and is now 67.7 g; and a male of carapace width 92.5 mm was previously estimated to weigh 450 g and now weighs 451 g.

## Maturity

Maturity of females collected during the NMFS summer survey was determined by the shape of the abdomen, by the presence of brooded eggs, or egg remnants. Maturity for males was determined by chela height measurements, which were available most years starting from the 1989 survey (Otto 1998). Mature male biomass referenced throughout this document refers to a morphometrically mature male (i.e. large-clawed). A maturity curve for males was estimated using the average fraction mature based on chela height data and applied to years of survey data to estimate mature survey numbers that do not have chela height data available. The separation of mature and immature males by chela height may not be adequately refined given the current measurement to the nearest millimeter. Chela height measured to the nearest tenth of a millimeter by Canadian researchers on North Atlantic snow crab showed a clear break in chela height at small and large widths and fewer mature animals at small widths than the Bering Sea data measured to the nearest millimeter. Measurements taken in 2004-2005 on Bering Sea snow crab chela to the nearest tenth of a millimeter show a similar break in chela height to the Canadian data (Rugolo et al. 2005). The probability of maturing (which is different from the fraction mature at length) is a freely estimated (but smoothed) function of length for both sexes within the assessment model.

Bering Sea male snow crab appear to have a terminal molt to maturity based on hormone level data and findings from molt stage analysis via setagenesis (Tamone et al. 2005). The models presented here assume a terminal molt for both males and females, which is supported by research on populations in the Bering Sea and the Atlantic Ocean (e.g. Dawe, et al. 1991).

Male snow crabs that do not molt (old shell) may be important in reproduction. Paul et al. (1995) found that old shell mature male Tanner crab out-competed new shell crab of the same size in breeding in a laboratory study. Recently molted males did not breed even with no competition and may not breed until after ~100 days from molting (Paul et al. 1995). Sainte-Marie et al. (2002) stated that only old shell males take part in mating for North Atlantic snow crab. If molting precludes males from breeding for a three month period, then males that are new shell at the time of the survey (June to July), would have molted during the preceding spring (March to April), and would not have participated in mating. The fishery targets new shell males, resulting in those animals that molted to maturity and to a size acceptable to the fishery of being removed from the population before the chance to mate. However, new shell males will be a mixture of crab less than 1 year from terminal molt and 1+ years from terminal molt due to the inaccuracy of shell condition as a measure of shell age. Crabs in their first few years of life may molt more than once per year, however, the smallest crabs included in the model are approximately 4 years old and would be expected to molt annually.

## **Mating ratio and reproductive success**

Bering Sea snow crabs are managed using morphometrically mature male biomass (MMB) as a proxy for reproductive potential. MMB is used as the currency for management because the fishery only retains large male crabs, which are nearly 100% mature. Male snow crabs are sperm conservers, using less than 4% of their sperm at each mating and females also will mate with more than one male. The amount of stored sperm and clutch fullness varies with sex ratio (Sainte-Marie 2002). If mating with only one male is inadequate to fertilize a full clutch, then females will need to mate with more than one male, necessitating a sex ratio closer to 1:1 in the mature population, than if one male is assumed to be able to adequately fertilize multiple females. Although mature male biomass is currently the currency of management, female biomass may also be an important indicator of reproductive potential of the stock.

Clutch fullness is recorded for the females measured in the survey (Figure 11). However, quantifying the reproductive potential of the female population from survey data can be difficult. For example, full clutches of unfertilized eggs may be extruded and appear normal to visual examination, and may be retained for several weeks or months by snow crab. Resorption of eggs may occur if not all eggs are extruded resulting in less than a full clutch. Female snow crab at the time of the survey may have a full clutch of eggs that are unfertilized, resulting in overestimation of reproductive potential. Barren females may be a more obvious indication of low reproductive potential and increased in the early 1990s, decreased in the mid-1990s, then increased again in the late 1990s. The highest levels of barren females coincided with periods of high fishing mortality, but the even then the proportion of barren females was low (Figure 12). The average clutch fullness score was the lowest on record and the proportion of females with full clutches was the smallest on record from the 2022 NMFS survey. Biennial spawning is another confounding factor in determining the reproductive potential of snow crab. Laboratory analyses showed that female snow crab collected in waters colder than 1.5 degrees C from the Bering Sea spawn only every two years.

Further complicating the process of quantifying reproductive capacity, clutch fullness and fraction of unmated females may not account for the fraction of females that may have unfertilized eggs, since these cannot be detected by eye at the time of the survey. The fraction of barren females observed in the survey may not be an accurate measure of fertilization success because females may retain unfertilized eggs for months after extrusion. To examine this hypothesis, NMFS personnel sampled mature females from the Bering Sea in winter and held them in tanks until their eggs hatched in March of the same year (Rugolo et al. 2005). All females then extruded a new clutch of eggs in the absence of males. All eggs were retained until the crabs were euthanized near the end of August. Approximately 20% of the females had full clutches of unfertilized eggs. The unfertilized eggs could not be distinguished from fertilized eggs by visual inspection at the time

they were euthanized. Indices of fertilized females based on the visual inspection method of assessing clutch fullness and percent unmated females may overestimate fertilized females.

## Growth

Several studies are available to estimate the growth per molt of male and female snow crab in the Bering Sea (Table 8). These studies include:

1. Transit study (2003); 14 crab
2. Cooperative seasonality study; 6 crab
3. Dutch harbor holding study; 9 crab
4. NMFS Kodiak holding study held less than 30 days; 6 crab
5. NMFS Kodiak holding study 2016; 5 crab
6. NMFS Kodiak holding study 2017; 70 crab.
7. BSFRF/NMFS holding study 2018; 4 crab.

In the “Transit study”, pre- and post-molt measurements of 14 male crabs that molted soon after being captured were collected. The crabs were measured when shells were still soft because all died after molting, so measurements may be underestimates of post-molt width (L. Rugolo, pers. com.). The holding studies include only data for crab held less than 30 days because growth of crabs held until the next spring’s molting was much lower. Crab missing more than two limbs were excluded due to other studies showing lower growth. Crab from the seasonal study were excluded that were measured less than 3 days after molting due to difficulty in measuring soft crab accurately (L. Rugolo, pers. comm.). In general, growth of snow crab in the Bering Sea appears to be greater than growth of some North Atlantic snow crab stocks (Sainte-Marie 1995).

## Management history

### ADFG harvest strategy

Before the year 2000, the Guideline Harvest Level (GHL) for retained crab only was a 58% harvest rate of the number of male crab over 101 mm CW estimated from the survey. The minimum legal size limit for snow crab is 78 mm, however, the snow crab market generally only accepts crab greater than 101 mm. In 2000, due to the decline in abundance and the declaration of the stock as overfished, the harvest rate for calculation of the GHL was reduced to 20% of male crab over 101 mm. After 2000, a rebuilding strategy was developed based on simulations by Zheng et al. (2002) using survey biomass estimates. The realized retained catch typically exceeded the GHL historically, resulting in exploitation rates for the retained catch on males >101mm ranging from about 10% to 80%.

The Alaska Department of Fish and Game (ADFG) harvest strategy since 2000 sets harvest rate based on estimated mature biomass. The harvest rate scales with the status of the population relative to  $B_{MSY}$ , which is calculated as the average total mature biomass at the time of the survey from 1983 to 1997 and MSST is one half  $B_{MSY}$ . The harvest rate begins at 0.10 when total mature biomass exceeds 50% MSST (230 million lbs) and increases linearly to 0.225 when biomass is equal to or greater than  $B_{MSY}$  (Zheng et al. 2002).

$$u = \begin{cases} \text{Bycatch} & \text{if } \frac{TMB}{TMB_{MSY}} \leq 0.25 \\ \frac{0.225(\frac{TMB}{TMB_{MSY}} - \alpha)}{1 - \alpha} & \text{if } 0.25 < \frac{TMB}{TMB_{MSY}} < 1 \\ 0.225 & \text{if } TMB > TMB_{MSY} \end{cases} \quad (1)$$

Where  $TMB$  is the total mature biomass and  $TMB_{BMSY}$  is the  $TMB$  associated with maximum sustainable yield. The maximum retained catch is set as the product of the exploitation rate,  $u$ , calculated from the above control rule and survey mature male biomass. If the retained catch in numbers is greater than 58% of the estimated number of new shell crabs greater than 101 mm plus 25% of the old shell crab greater than 101 mm, the catch is capped at 58%.

## History of BMSY

Prior to adoption of Amendment 24,  $B_{MSY}$  was defined as the average total mature biomass (males and females) estimated from the survey for the years 1983 to 1997 (921.6 million lbs; NPFMC 1998) and MSST was defined as 50% of  $B_{MSY}$ . Currently, the biological reference point for biomass is calculated using a spawning biomass per recruit proxy,  $B_{35\%}$  (Clark, 1993).  $B_{35\%}$  is the biomass at which spawning biomass per recruit is 35% of unfished levels and has been shown to provide close to maximum sustainable yield for a range of stock productivities (Clark, 1993). Consequently, it is an often used target when a stock recruit relationship is unknown or unreliable. The range of years of recruitment used to calculate biomass reference points is from 1982 to the present assessment year, minus 1.

## Fishery history

Snow crab were harvested in the Bering Sea by the Japanese from the 1960s until 1980 when the Magnuson Act prohibited foreign fishing. After the closure to foreign fleets, retained catches increased from relatively low levels in the early 1980s (e.g. retained catch of 11.85 kt during 1982) to historical highs in the early and mid-1990s (retained catches during 1991, 1992, and 1998 were 143.02, 104.68, and 88.09 kt, respectively; Table 9). The stock was declared overfished in 1999 at which time retained catches dropped to levels similar to the early 1980s (e.g. retained catch during 2000 was 11.46 kt). Retained catches slowly increased after 1999 as the stock rebuilt. However, retained catch in the most recent year was 2.48 kt, the lowest on record following the collapse of 2021.

Discard mortality is the next largest source of mortality after retained catch and approximately tracks the retained catch. The highest estimated discard mortality occurred during 1992 at 17.06 kt, which was 16% of the retained catch.

Discard from the directed pot fishery has been estimated from observer data since 1992 and has ranged from 11-100% of the magnitude of retained catch by numbers. In recent years, discards have reached 50-100% of the magnitude of retained catch because of the large year class entering the population. Female discard catch has been very low compared to male discard catch and has not been a significant source of mortality. Discard mortality rates for the directed fishery are assumed to be 30%. Discard of snow crab in groundfish fisheries has been highest in the yellowfin sole trawl fishery, and decreases down through the flathead sole trawl fishery, Pacific cod bottom trawl fishery, rock sole trawl fishery, and the Pacific cod hook-and-line and pot fisheries, respectively (Figure 13). Bycatch in fisheries other than the groundfish trawl fishery has historically been relatively low. Discard mortality rates from non-directed fisheries are assumed to be 80%. Size frequency data and catch per pot have been collected by observers on snow crab fishery vessels since 1992. Observer coverage has been 10% on catcher vessels larger than 125 ft (since 2001), and 100% coverage on catcher processors (since 1992).

Several modifications to pot gear have been introduced to reduce bycatch mortality. In the 1978/79 season, escape panels were required on pots used in the snow crab fishery to prevent ghost fishing. Escape panels consist of an opening with one-half the perimeter of the tunnel eye laced with untreated cotton twine. The size of the cotton laced panel was increased in 1991 to at least 18 inches in length. No escape mechanisms for undersized crab were required until the 1997 season when at least one-third of one vertical surface of pots had to contain not less than 5 inches stretched mesh webbing or have no less than four circular rings of no less than 3 3/4 inches inside diameter. In the 2001 season the escapement provisions for undersized crab was increased to at least eight escape rings of no less than 4 inches placed within one mesh measurement from

the bottom of the pot, with four escape rings on each side of the two sides of a four-sided pot, or one-half of one side of the pot must have a side panel composed of not less than 5 1/4 inch stretched mesh webbing.

## D. Data

Updated time series of survey indices and size compositions were calculated from data downloaded from the AKFIN database. Bycatch data (biomass and size composition) were updated for the most recent year from the AKFIN database. Retained, total, and discarded catch (in numbers and biomass) and size composition data for each of these data sources were updated for the most recent year based on files provided by the State of Alaska.

### Catch data

Catch data and size composition of retained crab from the directed snow crab pot fishery from survey year 1982 to 2021 were used in this analysis (Table 9). Discard size composition data from 1992 to 2017 were estimated from observer data and then combined with retained catch size compositions to become the ‘total catch’ size composition data, which are fit in the assessment. In 2018, observer data collection changed and only total catch size composition data and retained size composition data are produced. This is a sensible step in data collection, but the current formulation of the snow crab model accepts discarded size composition data as an input. So, from 2018 onward the discarded size compositions were calculated by subtracting the retained size compositions from the total size compositions. This mismatch of input data types will be addressed in an upcoming data overhaul for the assessment.

The discard male catch was estimated for survey years 1982 to 1991 in the model using the estimated fishery selectivities based on the observer data for the period of survey year 1992 to 2021. The discard catch estimate was multiplied by the assumed mortality of discards from the pot fishery. The assumed mortality of discarded crab was 30% for all model scenarios. This estimate differs from the strategy used since 2001 to the present by ADFG to set the TAC, which assumes a discard mortality of 25% (Zheng, et al. 2002). The discards prior to 1992 may be underestimated due to the lack of escape mechanisms for undersized crab in the pots before 1997. See Table 7 for a summary of catch data.

Table 7: Data included in the assessment. Dates indicate survey year.

| Data component   | Years       |
|--|-------------|
| Retained male crab pot fishery size frequency by shell condition                   | 1982 - 2021 |
| Discarded Males and female crab pot fishery size frequency                         | 1992 - 2021 |
| Trawl fishery bycatch size frequencies by sex                                      | 1991 - 2021 |
| Survey size frequencies by, maturity, sex and shell condition                      | 1982 - 2022 |
| Retained catch estimates   | 1982 - 2021 |
| Discard catch estimates from crab pot fishery                                      | 1992 - 2021 |
| Trawl bycatch estimates  | 1993 - 2021 |
| Total survey abundance estimates and coefficients of variation                     | 1982 - 2022 |
| 2009 study area biomass estimates, CVs, and size frequency for BSFRF and NMFS tows | 2009        |
| 2010 study area biomass estimates, CVs, and size frequency for BSFRF and NMFS tows | 2010        |



## Survey biomass and size composition data

Estimates from the annual eastern Bering Sea (EBS) bottom trawl survey conducted by NMFS serve as the primary index of abundance in this assessment (see Lang et al., 2018). Additional survey stations were added in 1989, which could alter the interpretation of catchability coefficient for the survey. Consequently, survey selectivity has been historically modeled in two ‘eras’ in the assessment (1982-1988, 1989-present). All survey data in this assessment used measured net widths instead of the fixed 50 ft net width based on Chilton et al.’s (2009) survey estimates. Carapace width and shell conditions were measured and reported for snow crab caught in the survey. Numbers of crab in several size groups are currently at or near all-time lows (Figure 14 & Figure 15).

Mature biomass for males and females at the time of the survey were the primary indices of population size fit to here. In the status quo assessment, total survey numbers were input to the model via the .DAT file (e.g. Figure 16), after which MMB and FMB at the time of the survey were calculated based on the size composition data, which were delineated by shell condition, maturity state, and sex.

Distinguishing between mature and immature crab for the size composition was accomplished by demarcating any female that had eggs reported in the survey as ‘mature’. Mature male size composition data were calculated by multiplying the total numbers at length for new shell male crab by a vector of observed proportion of mature males at length. The observed proportions of mature males at length were calculated by chelae height and therefore refers only to ‘morphometrically’ mature males. All old shell crab of both sexes were assumed to be mature. New shell crab were demarcated as any crab with shell condition index  $\leq 2$ . The biomass of new and old shell mature individuals was calculated by multiplying the vector of numbers at length by weight at length. These vectors were then summed by sex to provide the input for assessment (Table 10).

The NMFS summer surveys were canceled in 2020 due to the coronavirus pandemic, which presents challenges in understanding the recent stock dynamics.

## Spatial distribution of survey abundance and catch

Spatial gradients exist in the survey data by maturity and size for both sexes. For example, larger males have been more prevalent on the southwest portion of the shelf (Figure 6) while smaller males have been more prevalent on the northwest portion of the shelf (Figure 3). Females have exhibited a similar pattern (compare Figure 4 to Figure 7). In addition to changing spatially over the shelf and by size class, distributions of crab by size and maturity have also changed temporally. The centroids of abundance in the summer survey have moved over time (Figure 17 & Figure 18). Centroids of mature female abundance early in the history of the survey were farther south, but moved north during the 1990s. Since the late 1990s and early 2000s, the centroids moved south again, but not to the extent seen in the early 1980s. This phenomenon was mirrored in centroids of abundance for large males (Figure 18).

Fishing effort has generally been south of 58.5 N, even when ice cover did not restrict the fishery moving farther north (Figure 19). This is possibly due to proximity to port and practical constraints of meeting delivery schedules. In general, the majority of catch was taken west and north of the Pribilof Islands, but this rule has had exceptions. Fishing effort in 2020 was located farther north than usual as a result of higher CPUEs (Figure 20).

The observed distribution of large males during the summer survey and the fishery catch have historically been different, and the origin of this difference is unknown. It is possible that crab move between the fishery and the survey, but it is also possible that fishers do not target all portions of the distribution of large male crab equally. The underlying explanation of this phenomenon could hold implications for relative exploitation rates spatially and it has been suggested that high exploitation rates in the southern portion of the snow crab range may have resulted in a northward shift in snow crab distribution (Orensanz, 2004). Snow crab larvae likely drift north and east after hatching in spring. Snow crab appear to move south and west as they age (Parada et al., 2010); however, little tagging data exists to fully characterize the ontogenetic or annual migration patterns of this stock (Murphy et al. 2010).

## Experimental study of survey selectivity

The Bering Sea Fisheries Research Foundation (BSFRF) has conducted supplementary surveys in the Bering Sea in which snow crab were caught during 2009, 2010, 2016, 2017, and 2018. The location and extent of these surveys varied over the years as the survey goals changed. In 2009, the survey consisted of 108 tows around 27 survey stations and the goal was to improve understanding snow crab densities and the selectivity of NMFS survey gear (Figure 21). In 2010, the survey area was larger and still focused on snow crab. The mature biomass and size composition data gleaned from each of these experiments (and their complimentary NMFS survey observations; Figure 22 & Figure 23) are incorporated into the model by fitting them as an extra survey that is linked to the NMFS survey through a shared selectivity (see appendix A for a description of the way in which the surveys are related in the assessment model). Abundances estimated by the industry surveys were generally higher than the NMFS estimates, which suggests that the catchability of the NMFS survey gear is less than 1.

In 2016, 2017, and 2018, snow crab were not the focus of the BSFRF surveys, yet were still caught in the BSFRF gear. Comparing the ratio of the number of crab caught at length in the BSFRF gear (which is assumed to have a catchability/selectivity of 1 over all size classes) to the number of crab caught at length within the same area in the NMFS survey gear (which is assumed to have a catchability/selectivity  $\leq 1$  for at least some of the size classes) can provide an empirical estimate of catchability/selectivity (Figure 24). Empirical estimates of catchability/selectivity vary by year and size class across the different BSFRF data sets (Figure 25 & Figure 26). The number of snow crab used to develop estimates of numbers at length likely contribute to these differences among years (Figure 27), but other factors may also influence catchability/selectivity at size of the NMFS survey gear (e.g. Somerton et al. 2013 show substrate type can influence selectivity). The assessments presented either treat these data as an additional survey with selectivity nested within the NMFS survey or directly as priors on survey selectivity (see appendix A for details).

The assessment model estimates a vector that represents the ‘availability’ of crab to the BSFRF experiments (see appendix A for a discussion of how this is modeled). Availability in this case means how much of the population was in the area surveyed in the BSFRF experiments. Some candidate models in the past had an ‘empirical’ availability specified, rather than estimated. Because the size composition of the total NMFS survey and the size composition of the NMFS survey stations associated with the BSFRF experiments are known, the ‘empirical availability’ can be directly calculated simply by dividing the size composition of the subset of stations within the BSFRF survey area by the size composition of all the NMFS summer survey stations.

## E. Analytic approach

### History of modeling approaches for the stock

Historically, survey estimates of large males ( $>101$  mm) were the basis for calculating the Guideline Harvest Level (GHL) for retained catch. A harvest strategy was developed using a simulation model that pre-dated the current stock assessment model (Zheng et al. 2002). This model has been used to set the GHL (renamed total allowable catch, ‘TAC’, since 2009) by ADFG since the 2000/2001 fishery. Currently, NMFS uses an integrated size-structured assessment to calculate the overfishing level (OFL), which may constrain the ADFG harvest strategy.

### Model description

The status quo integrated size-structured model used by NMFS (and presented here) was developed following Fournier and Archibald’s (1982) methods, with many similarities to Methot (1990). The model was implemented using automatic differentiation software developed as a set of libraries under C++ (ADModel

Builder). ADModel Builder can estimate a large number of parameters in a non-linear model using automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries. Recently, the Generalized Model for Assessing Crustacean Stocks (GMACS) was adopted as the assessment platform after a demonstration that GMACS could effectively reproduce the dynamics of the status quo model and offered structural improvements.

The snow crab population dynamics model tracked the number of crab of sex  $s$ , maturity state  $m$ , during year  $y$  at length  $l$ ,  $N_{s,m,y,l}$ . A terminal molt was modeled in which crab move from an immature to a mature state, after which no further molting occurred. The mid-points of the size bins tracked in the model spanned from 27.5 to 132.5 mm carapace width, with 5 mm size classes. For the author-preferred model, 431 parameters were estimated. Parameters estimated within the assessment included those associated with the population processes recruitment, growth, natural mortality (subject to an informative prior and two years of additional ‘mortality events’ estimated in 2018 and 2019), fishing mortality, selectivity (fishery, survey, and BSFRF experiments), catchability, and maturity. Weight at length, discard mortality, bycatch mortality, and parameters associated with proportion of recruitment allocated to size bin were estimated outside of the model or specified. See appendix A for a more complete description of the population dynamics.

A ‘jittering’ approach has been historically used to explore the impact of different starting values on the assessment output (Turnock, 2016). Jittering was implemented for the first time this year for a GMACS model for snow crab using recently developed functionality. Retrospective analyses were performed in which the terminal year of data was removed sequentially from the model fitting for the author-preferred model. Then time series of estimated MMB were compared between the most recent model and successive ‘peels’ of the data to identify retrospective patterns. A retrospective pattern is a consistent directional change in assessment estimates of management quantities (e.g. MMB) in a given year when additional years of data are added to an assessment.

## Model selection and evaluation

Models were evaluated based on their fit to the data, evidence of non-convergence, the credibility of the estimated population processes, and the strength of the influence of the assumptions of the model on the outcomes of the assessment.

## Results

All GMACS models converged with the addition of the new data with maximum gradient components of 0.009 or smaller. The author-preferred model displayed positive retrospective patterns (Figure 28). Retrospective patterns suggest that a process is varying over time that is not allowed to vary within the model (e.g. catchability or maturity) or the data are incomplete (e.g. not all catch is reported). Jittering analyses revealed bimodality in model output and a model from each mode is presented here (Figure 29). The two modes had similar average objective function values (approximately -23204 vs. -23200) but fairly large differences in the calculated OFLs (~10 kt vs. ~4 kt). The author-preferred model (22.1ab) presented here belongs to the cloud of jittered models that produced an OFL of ~ 4 kt. Model 22.1ab is the author-preferred model in spite of slightly poorer fits (particularly to recent male size composition data) than models from the other cloud in the jitter analysis because those models produced unreasonable estimates of fishing mortality in recent years.

Below, the fits to the data and estimated population processes are described for all considered models that include the most recent data (see contribution of likelihood components to the objective function in Table 11 and parameter estimates and standard deviations in Table 12).

## **Fits to data**

### **Survey biomass data**

Fits to the survey mature male biomass were fairly similar for all GMACS models for the majority of years in the the time series (Figure 30 & Figure 31) with the same data. However, differences in the estimated survey MMB in the final four years existed. Model 22.1a fit 2019 and 2022 well, but fit 2021 poorly. Model 22.1ab fit 2021 and 2022 well, but fit 2019 worse than model 22.1a. Differences in fit among the models were also seen around the transition from survey era 1 to survey era 2. Small differences in negative log likelihoods existed among models (Table 11).

### **Growth data**

Small differences existed in the estimates of the relationship between pre- and post-molt increment in the GMACS models, with model 22.1ab estimating slightly larger growth increments for males at size than the other models with updated data. The status quo model historically estimated growth outside of the model and specified it because of convergence issues (Figure 32).

### **Catch data**

All catch data were well-fit by all models, with few visually discernible differences among GMACS models (Figure 33). Small differences in male discards were apparent in the models representing the modes of the jittered model, with 22.1a overestimating discards in 2020 and model 22.1ab underestimating discards in 2019. Existing differences in fit were amplified in the objective function by the small CVs placed on the different sources of catch data (Table 11).

### **Size composition data**

Most years of retained and total catch size composition data were visually well fit by all models (Figure 34 & Figure 35). Key differences among models occurred at the beginning and end of the time series. Model 21.g and 22.1 (both GMACS models) overestimated the proportion of animals in the largest size bins in 1982-1984. Model 22.1a and 22.1ab addressed this issue by using an alternate method for estimating the initial size composition. The other obvious change in model fits arose at the end of the time series (particularly 2019-2021) with the addition of new data to the GMACS model. More variability was seen among the fits to the bycatch size composition data, but the general shapes of the predicted size compositions were similar within years (Figure 36).

Fits to size composition data for the BSFRF survey selectivity experiments produced some runs of positive and negative residuals for the males in particular (Figure 37). The number of males was generally underestimated by the industry survey in 2009 and overestimated by the NMFS survey, while the opposite pattern was seen for females. Fits to the 2010 survey size composition data were better than the 2009 fits.

Size composition data for the NMFS survey were generally acceptably fit and fits were visually similar for most models in most years (Figure 38, Figure 39, Figure 40 & Figure 41). Some of the largest departures occurred for immature males and females in 2019-2022. For males, a potential reason this occurred is the large difference in the probability of terminally molting observed in 2021 compared to other years (Figure 2) and the use of a single estimated ogive over all years in the assessment. The distribution of residuals for male and female survey composition data for the author-preferred model varied by sex. Size composition data for females tended to be overestimated for larger size classes (Figure 42), whereas a pattern for males was less clear (Figure 43).

## Estimated population processes and derived quantities

Estimated population processes and derived quantities varied among models and the GMACS models with updated data produced populations with more pronounced declines in MMB (Figure 44). Model 22.1 and 22.1a had almost identical trends from 1989-present, but diverged during 1982-1988 as a result of differences in estimated catchability during that era. Uncertainty in estimates of MMB during the first survey era (1982-1988) was larger than in later years (Figure 45). Estimated MMB at the time of mating in the past several years was distinctly different for the models representing the two modes of bimodality from the jittering analysis. Model 22.1a estimates of MMB declined continually from 2017 to 2020, but estimates from model 22.1ab declined in 2018, rose in 2019, then continually declined to the present. The trend of estimated MMB in these models is closely related to the estimates of additional mortality in 2018 and 2019. Model 22.1ab estimated very little additional mortality for mature males in 2019, which allowed the increase in MMB. Model 22.1a, however had the highest estimates of additional mortality for mature males in 2019 and these differences in estimated MMB and additional M had large consequences for the fishing mortality estimated in 2020 (see below). Estimated fishing mortality in the recent past was above  $F_{35\%}$  during 2020 for all models (Figure 46).

Estimates of selectivity and catchability varied among models (Figure 47). In era 1 (1982-1988), selectivity curves all had similar shapes, but the catchability coefficients ranged from  $\sim 0.2$  to  $\sim 0.9$  between males and females. In era 2 (1989-present), catchability ranged from  $\sim 0.4$  -  $\sim 0.7$  for males; for females, estimated catchability was much lower ( $< 0.4$ ) for all GMACS models than the historically assumed 1 in the status quo model. The models with updated data estimated catchabilities closer to the catchability implied by the BSFRF experiments (Figure 26). The BSFRF ‘availability’ curves varied from 2009 to 2010 and among models, with the availability of crab to the experimental survey generally increasing in 2010 (Figure 48).

Small differences in the estimated shape of the curve representing the probability of having undergone terminal molt existed among models (Figure 49). The GMAC models (except 22.1ab) generally estimated slightly lower probabilities of having undergone terminal molt for male crab in the 85-100 mm carapace width range than the status quo model. In general, model 22.1ab estimated the highest probabilities of having undergone terminal molt at size across models. No models estimated a probability of having undergone terminal molt similar to the observed probability of new shell male crab having undergone terminal molt—estimated probabilities were somewhat lower than the observed probabilities in the middle size ranges (Figure 2).

Trends in estimated fishing mortality in the directed fishery were similar for all models, though the scale differed (Figure 50). GMACS models 22.1 and 22.1a estimated unreasonably high fishing mortalities in 2020 with  $> 99\%$  of the exploitable males being captured. Estimates of  $F$  during 2020 from model 22.1ab were more reasonable, but still high (exploitation rates  $\sim 85-90\%$ ). Total and retained fishery selectivity was similar for all GMACS models (Figure 50). Estimated size at 50% selection in the trawl fishery varied across models more than selectivity in the directed fishery (Figure 50). Size at 50% selection for discarded females was similar for all models (Figure 50). Predicted mortalities from discards and bycatch were very small relative to estimated fishing mortality associated with the directed fleet.

Patterns in recruitment by sex varied somewhat among models, particularly with respect to the size and timing of the recent large pseudocohort (Figure 51). Generally, the models estimated a period of high recruitment in which 3 large male cohorts passed through the population during the 1980s and into the early 1990s. Following that, a period of low recruitment persisted from the early 1990s to 2014. The addition of the new data advanced the peak of recent estimated recruitment one year, from 2015 to 2016. This change may be related to the need for the model to accommodate the large difference between the observed probability of having undergone terminal molt in 2021 and the estimated values from the assessment. Recruitment entering the model was placed primarily in the first three size bins (Figure 51).

Estimated natural mortality ranged from 0.27 to 0.29 for immature and mature crab (Figure 52). Estimated mortality events in 2018 and 2019 were most intense for immature females and mature males, but even the less ‘intense’ mortality events for mature females and immature males resulted in  $> 80\%$  of crab dying, except for model 22.1ab, which estimated almost no additional mortality for mature males in 2019 and very little for immature females.

## F. Calculation of the OFL

### Methodology for OFL

#### Tier 3

The tier 3 OFL was calculated using proxies for biomass and fishing mortality reference points and a sloped control rule. Proxies for biomass and fishing mortality reference points were calculated using spawner-per-recruit methods (e.g. Clark, 1991). After fitting the assessment model to the data and estimating population parameters, the model was projected forward 100 years using the estimated parameters under no exploitation and constant recruitment to determine ‘unfished’ mature male biomass-per-recruit. Projections were repeated in which the bisection method was used to identify a fishing mortality that reduced the mature male biomass-per-recruit to 35% of the unfished level (i.e.  $F_{35\%}$  and  $B_{35\%}$ ). Calculations of  $F_{35\%}$  were made under the assumption that bycatch fishing mortality was equal to the estimated average value over the last 8 years.

Calculated values of  $F_{35\%}$  and  $B_{35\%}$  were used in conjunction with a Tier 3 control rule to adjust the proportion of  $F_{35\%}$  that is applied based on the status of the population relative to  $B_{35\%}$  (Amendment 24, NMFS). To determine the  $F_{OFL}$ , the population is projected to the time of fishing for the upcoming fishery under no fishing. If the MMB at that time exceeds 25% of  $B_{35\%}$ , a fishery can occur and the  $F_{OFL}$  is calculated as:

$$F_{OFL} = \begin{cases} \text{Bycatch} & \text{if } \frac{MMB}{MMB_{35}} \leq 0.25 \\ \frac{F_{35}(\frac{MMB}{MMB_{35}} - \alpha)}{1 - \alpha} & \text{if } 0.25 < \frac{MMB}{MMB_{35}} < 1 \\ F_{35} & \text{if } MMB > MMB_{35} \end{cases} \quad (2)$$

Where MMB is the projected mature male biomass in the current survey year after fishing at the  $F_{OFL}$ ,  $MMB_{35\%}$  is the mature male biomass at the time of mating resulting from fishing at  $F_{35\%}$ ,  $F_{35\%}$  is the fishing mortality that reduces the mature male biomass per recruit to 35% of unfished levels, and  $\alpha$  determines the slope of the descending limb of the harvest control rule (set to 0.1 here).

#### Tier 4

Tier 4 OFLs were calculated based on four time series of male biomass of different sizes of observed crab in the survey and decremented by six months of natural mortality. Natural mortality was specified as 0.27 based on an assumed maximum age of 20 years and Hamel’s (2015) analyses. The four time series used were morphometrically mature males (based on chelae height data), legal males (>78 mm carapace width), males >95 mm carapace width, and commercial sized males (>101 mm carapace width). The FMP is not explicit about what measure of biomass is to be used in a tier 4 rule, but states that ‘biomass’ should be a ‘measure of the productive capacity of the stock, such as spawning biomass or fertilized egg production’. It also states ‘a proxy of ‘B’ (biomass) may be used’ (e.g. mature male biomass). Although morphometrically mature male biomass is the historically used currency of management for snow crab, alternative measures may be useful to explore.

A tier 4 proxy for  $B_{MSY}$  for each time series was calculated as the average of the time series from 1982 to present. The  $F_{OFL}$  was calculated using the same control rule as for the tier 3 rule above, but replacing natural mortality for  $F_{35\%}$  and the tier 4  $B_{MSY}$  proxy for  $B_{35\%}$ . Given tier 4 rules have not been used in the recent past, time series of the OFLs that would have resulted from applying this harvest control rule to the available data in all years were calculated for context.

## Calculated OFLs and interpretation

### Tier 3

Calculated OFLs ranged from 3.98 to 10.32 kt (Table 13). Differences in OFLs were a result of differences in estimated MMB, calculated  $B_{35\%}$  (which ranged from 183.15.9 - 196.38 kt),  $F_{35\%}$  (which ranged from 1.37 - 2.26  $\text{yr}^{-1}$ ), and  $F_{OFL}$  (which ranged from 0.28 - 0.67  $\text{yr}^{-1}$ ; Table 13).

### Tier 4

Calculated tier 4 OFLs for 2022/2023 were all 0 kt and the adoption of a tier 4 rule would result in a closure of the fishery. The calculated OFLs using the currently employed currency of management (morphometrically mature male biomass) and legal biomass would have exceeded the biomass of the commercially viable snow crab in the Bering Sea in some years based on the historical analysis (Figure 53). Consequently, neither of these harvest control rule definitions seem appropriate for use with snow crab.

## G. Calculation of the ABC

The acceptable biological catch (ABC) was set by subtracting a 25% buffer from the OFL to account for scientific uncertainty, as recommended by the SSC.

### Author recommendations

Model 22.1ab is the author's preferred model among the integrated models presented based on improvements in fits to size composition data from adjusting the way the initial numbers at size are estimated and more reasonable estimates of fishing mortality than other models. However, the output of this model includes consequential changes in estimates of population processes compared to the GMACS model accepted in June: survey catchability decreased from  $\sim 0.7$  in 21.g to  $\sim 0.5$  in 22.1, the estimated probability of having undergone terminal molt increased at smaller sizes, and fits to recent male size composition data are poor. The bimodality in this model is also a point for concern, and models from the other mode fit the data slightly better, but do so by estimating unreasonable fishing mortality. In addition to modeling issues, the observed survey MMB declined by 40% compared to last year, the observed probability of having undergone terminal molt was much higher than historically seen for smaller sizes in 2021, average clutch fullness was the lowest on record, and the median fishery CPUE in 2021 was the lowest observed (Figure 54). The sum of these observations suggest that uncertainty related to the modeling and management of eastern Bering Sea snow crab is currently high.

In spite of this uncertainty, the stock is now under a rebuilding plan and a model is required for the projection analyses. Appendix D uses model 22.1ab as the basis for projections. Although some concerns exist with the recent dynamics of this model, it is still useful as a projection model because the key driver of uncertainty in future trajectories is projected recruitment and natural mortality. Estimated parameters for growth, maturity, and selectivity (which are the key drivers of population dynamics) are relatively similar among models. See Appendix D for further discussion.

## H. Data gaps and research priorities

Incorporating maturity data into the assessment and more appropriately incorporating the BSFRF data into the assessment to inform survey selectivity and catchability should be high priorities moving forward and may address some of the lack of fit in recent years. A male-only model may also be useful to consider in order to focus on the portion of the stock the fishery interacts with and reduce the number of uncertainties

and assumptions required by modeling both sexes. An enumeration of the ramifications of management with an F35% that can allow all males of industry-preferred size to be harvested needs to be performed, with particular attention paid to the appropriateness of the use of morphometrically mature males as the currency of management and the relative contribution to reproduction of males by size. A more thorough evaluation of the best way to re-weight size composition would be useful given the variety of shapes of the survey selectivity curves resulting from changes in the weighting of survey size composition data. Further consideration of the way in which the probability of having undergone terminal molt may be useful. It appears as though fewer old shell males are observed in the 60-80 mm carapace width size ranges than would be expected given observed estimates of having undergone terminal molt of ~20-40% for that size range (Figure 2 & Figure 57).

## **I. Ecosystem considerations and fishery performance**

The most important ecosystem consideration for snow crab in the EBS centers around what happened to the 2015 pseudocohort. It was observed for 4 years before being halved from the 2018 survey to the 2019 survey. In 2020, no survey occurred, and we grappled with two hypotheses for the decline in 2019—did the crab move or did the crab die? The 2021 survey data suggest that the crab died—they did not reappear in the EBS 2021 or 2022 NMFS surveys and they were not found in the NBS. It is possible the crab moved off the shelf into deeper waters, but data to support or refute this are sparse. NMFS performs an EBS slope survey in some years, but there have generally been very few snow crab observed in these surveys and the area of the slope relative to the shelf is much smaller (Figure 55 & Figure 56). No slope survey was not performed in 2020 or 2021. If the trend of few crab on the slope was maintained and a mortality event(s) is the only remaining culprit for the declines seen in 2018 and 2019, what was the cause of mortality?

Appendices B and C outline analyses aimed at understanding the context around the recent collapse of snow crab. Given the available data, it appears that the mortality events were a function of unprecedented temperatures and high densities of crab. The investigation into the disappearance of the 2015 pseudocohort will be an on-going process. Regardless of the outcome, the disappearance underscores the importance of a yearly survey for snow crab in the Bering Sea and uninterrupted survey effort in the northern Bering Sea.



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## Appendix A: Population dynamics model

This section will be updated with the GMACS population dynamics equations when available. Until the equations are available, the basic model structure is very similar to the status quo model (below), but not identical. Appendices F, G, and H are the .DAT, .CTL, and .PRJ file used for the author preferred model.

Numbers of sex  $s$  of shell condition  $v$  and maturity state  $m$  at length  $l$  in the initial year of the assessment,  $N_{s,v,m,y=1,l}$ , were calculated from an estimated vector of numbers at length  $l$  by sex  $s$  and maturity state  $m$  for males,  $\lambda_{s,m,l}$  and numbers at length  $l$  by sex  $s$  and shell condition  $v$  for females (i.e. 2 vectors for each sex were estimated). Estimated vectors of initial numbers at length by maturity for females were calculated by splitting the estimated vectors at length by the observed proportion mature in the first year of the survey.

$$N_{s,v,m,y=1,l} = \begin{cases} \Omega_{s,l}^{obs} \lambda_{s,1,l} & \text{if } v = \text{new}; m = \text{mat}, s = \text{fem} \\ 1 - \Omega_{s,l}^{obs} \lambda_{s,1,l} & \text{if } v = \text{new}; m = \text{imat}, s = \text{fem} \\ \lambda_{s,2,l} & \text{if } v = \text{old}; m = \text{mat}, s = \text{fem} \\ 0 & \text{if } v = \text{old}; m = \text{imat} \end{cases} \quad (3)$$

Initial numbers at length for males were all assumed to be new shell.

$$N_{s,v,m,y=1,l} = \begin{cases} \lambda_{s,1,l} & \text{if } v = \text{new}; m = \text{mat}, s = \text{male} \\ \lambda_{s,2,l} & \text{if } v = \text{new}; m = \text{imat}, s = \text{male} \\ 0 & \text{if } v = \text{old}; m = \text{mat}, s = \text{male} \\ 0 & \text{if } v = \text{old}; m = \text{imat}, s = \text{male} \end{cases} \quad (4)$$

The dynamics after the initial year were described by:

$$N_{s,v,m,y+1,l} = \begin{cases} \Omega_{s,l} \kappa_{s,l'} Q_{s,imat,y,l'} X_{s,l',l} & \text{if } v = \text{new}; m = \text{mat} \\ 1 - \Omega_{s,l} \kappa_{s,l'} Q_{s,imat,y,l'} X_{s,l',l} + Rec_y^\epsilon Pr_l & \text{if } v = \text{new}; m = \text{imat} \\ Q_{s,mat,y,l'} & \text{if } v = \text{old}; m = \text{mat} \\ (1 - \kappa_{s,l'}) Q_{s,imat,y,l'} & \text{if } v = \text{old}; m = \text{imat} \end{cases} \quad (5)$$

Where  $\Omega_{s,l}$  was the probability of maturing at length  $l$  for sex  $s$  (a freely estimated vector for both males and females constrained by penalties on smoothness),  $\kappa_{s,l'}$  was the probability of molting for an immature crab of sex  $s$  at length  $l'$  (set to 1 for all immature crab), and  $X_{s,l,l'}$  was the size transition matrix describing the probability of transitioning from size  $l'$  to size  $l$  for sex  $s$ .  $Q_{s,m,y,l'}$  was the number of crab of sex  $s$ , maturity state  $m$ , and length  $l'$  surviving natural and fishing mortality during year  $y$ :

$$Q_{s,m,y,l} = \sum_v N_{s,v,m,y,l} e^{Z_{s,v,m,y,l}} \quad (6)$$

Where  $N_{s,v,m,y,l}$  represented the numbers,  $N$ , of sex  $s$  during year  $y$  of shell condition  $v$  and maturity state  $m$  at length  $l$ .  $Z_{s,v,m,y,l}$  represented the total mortality experienced by the population and consisted of the sum of instantaneous rates of natural mortality by sex and maturity state,  $M_{s,m}$ , and fishing mortality,  $F_{s,f,y,l}$  from each fishery. Each fishing mortality was subject to selectivity by length  $l$ , which varied between sexes

$s$  and fisheries  $f$  (and by year  $y$  if specified) .  $M_{s,m}$  was specified in the model and a multiplier  $\gamma_{natM,m}$  was estimated subject to constraints (see this formulation effectively specified a mean and standard deviation for a prior distribution for  $M$ ).

$$Z_{s,v,m,y,l} = \gamma_{natM,m} M_{s,m} + \sum_f S_{s,f,y,l} F_{s,f,y,l} \quad (7)$$

Selectivities in the directed and bycatch fisheries were estimated logistic functions of size. Different selectivity parameters were estimated for females and males in the directed fisheries ( $S_{fem,dir,l}$  and  $S_{male,dir,l}$ , respectively), a single selectivity for both sexes was estimated for bycatch in the groundfish trawl fishery ( $S_{trawl,l}$ ), and a retention selectivity was estimated for the directed fishery for males ( $R_{dir,l}$ ; all females were discarded).

$$S_{male,dir,l} = \frac{1}{1 + e^{-S_{slope,m,d}(L_l - S_{50,m,d})}} \quad (8)$$

$$S_{fem,dir,l} = \frac{1}{1 + e^{-S_{slope,f,d}(L_l - S_{50,f,d})}} \quad (9)$$

$$S_{trawl,l} = \frac{1}{1 + e^{-S_{slope,t}(L_l - S_{50,t})}} \quad (10)$$

$$R_{dir,l} = \frac{1}{1 + e^{-S_{slope,m,d}(L_l - S_{50,m,d})}} \quad (11)$$

Where  $S_{slope,s,f}$  was the slope of the logistic curve for sex  $s$  in fishery  $f$  and  $S_{50,s,f}$  was the length at 50% selection for sex  $s$  in fishery  $f$ . Catches for all fisheries were modeled as pulse fisheries in which all catch was removed instantaneously (i.e. no natural mortality occurred during the fishery). Catch in fishery  $f$  during year  $y$  was calculated as the fraction of the total fishing mortality,  $F_{s,f,y,l}$ , applied to a given sex  $s$  in a fishery  $f$  times the biomass removed by all fisheries for that sex.

$$C_{male,dir,y} = \sum_l \sum_v \sum_m w_{male,l} \frac{R_l F_{male,dir,y,l}}{F_{male,dir,y,l} + F_{trawl,y,l}} N_{male,v,m,y,l} e^{-\delta_y M_{s,m}} (1 - e^{-(F_{male,dir,y,l} + F_{trawl,y,l})}) \quad (12)$$

$$C_{male,tot,y} = \sum_l \sum_v \sum_m w_{male,l} \frac{F_{male,dir,y,l}}{F_{male,dir,y,l} + F_{trawl,y,l}} N_{male,v,m,y,l} e^{-\delta_y M_{s,m}} (1 - e^{-(F_{male,dir,y,l} + F_{trawl,y,l})}) \quad (13)$$

$$C_{fem,dir,y} = \sum_l \sum_v \sum_m w_{fem,l} \frac{F_{fem,dir,y,l}}{F_{fem,dir,y,l} + F_{trawl,y,l}} N_{fem,v,m,y,l} e^{-\delta_y M_{s,m}} (1 - e^{-(F_{fem,dir,y,l} + F_{trawl,y,l})}) \quad (14)$$

$$C_{m+f,trawl,y} = \sum_s \sum_l \sum_v \sum_m w_{s,l} N_{s,v,m,y,l} e^{-\delta_y M_{s,m}} (1 - e^{-(F_{trawl,y,l})}) \quad (15)$$

Where  $\delta_y$  was the mid point of the fishery (all fisheries were assumed to occur concurrently and the midpoint was based on the directed fishery, which accounts for the vast majority of the fishing mortality) and  $w_{s,l}$  was the weight at length  $l$  for sex  $s$ . Trawl data and discard data were entered into the model with an assumed mortality of 80% and 30%, respectively. Fully-selected fishing mortality parameters for fishery  $f$  were estimated as a logged average over a given time period ( $F_{avg}^{log}$ ) with yearly deviations around that mean ( $F_{dev,y}^{log}$ ).

$$F_{f,y} = e^{(F_{avg,f}^{log} + F_{dev,f,y}^{log})} \quad (16)$$

Selectivity for the survey was estimated for 2 eras in the base model: 1982-1988 and 1989-present. Selectivity was assumed to be logistic and separate parameters representing the length at which selection probability equal 50% and 95% ( $s_{50,s,e}$  and  $s_{95,s,e}$ , respectively) were estimated for males and females in the third era (1989-present). Separate catchability coefficients ( $q_{s,e}$ ) were estimated for males and females in all eras.

$$S_{surv,s,l,e} = \frac{q_{s,e}}{1 + e^{-\log(19) \frac{L_l - s_{50,s,e}}{s_{95,s,e} - s_{50,s,e}}}} \quad (17)$$

Survey selectivity was informed by experimental surveys during the years 2009 and 2010. A portion of the NMFS summer survey tows were accompanied by an industry vessel using nephrops trawls with an assumed selectivity of 1 for all size classes. To represent the proportion of the population covered by the experiment, a vector was freely estimated by sex,  $S_{ind,s,l,y}$ . For some model iterations, an ‘empirical’ availability was calculated. The total NMFS survey size composition of males and females in 2009 and 2010 are known and the fraction of the NMFS survey size composition of males and females in the BSFRF experimental area are also known. Consequently, the ‘empirical availability’ can simply be calculated as the ratio of the experimental size composition to the total size composition data.

After identifying the fraction of the crab at length covered by the experimental surveys (either by estimating and ogive or inputting the empirical availability), the length frequencies of the NMFS data collected simultaneously with the experimental trawls can be calculated by multiplying the numbers at length ‘available’ to the experimental trawls by the overall survey selectivity,  $S_{surv,s,l,y}$ . The predicted numbers at length for the NMFS and industry data from the selectivity experiment were calculated by multiplying the respective selectivities by the survey numbers at length.

$$S_{nmfs,s,l,y} = S_{ind,s,l,y} S_{surv,s,l,y} \quad (18)$$

For some models, survey selectivity in the second survey era (1989-present) was modeled as a non-parametric function of size (i.e. an estimated vector of parameters equal in length to the number of size classes in the model). Priors placed on the selectivity at size were based on either a weighted average of the observed selectivity from the BSFRF experiments from 2009, 2010, 2016-2018 or a generalized additive model (GAM) fit to these same data. The standard errors used in the normal likelihood to fit selectivity in the objective function were derived either from the weighted variances when calculating the averages or the standard errors generated from the fitting of the GAM.

Mature male and female biomass (MMB and FMB, respectively) were fitted in the objective function and were the product of mature numbers at length during year  $y$  and the weight at length,  $w_{s,l}$ :

$$MMB_y = \sum_{l,v} w_{male,l} N_{male,v,mat,y,l} \quad (19)$$

$$FMB_y = \sum_{l,v} w_{fem,l} N_{fem,v,mat,y,l} \quad (20)$$

$$w_{s,l} = \alpha_{wt,s} L_l^{\beta_{wt,s}} \quad (21)$$

Mature biomass can be calculated for different time through out the year, in which case the numbers at length are decremented by the estimated natural mortality. Parameters  $\alpha_{wt,s}$  and  $\beta_{wt,s}$  were estimated outside of the assessment model and specified in the control file.

Molting and growth occur before the survey. Immature crab were assumed to molt every year with an estimated probability of molting to maturity based on length  $l$  (in all the scenarios presented here, the probability of molting was 1 for all immature animals). For crab that do molt, the growth increment within the size-transition matrix,  $X_{s,l,l'}$ , was based on a linear relationship between predicted pre- and post-molt length, ( $\hat{L}_{s,l}^{pred}$  and  $\hat{L}_{s,l}^{post}$ , respectively) and the variability around that relationship was characterized by a discretized and renormalized gamma function,  $Y_{s,l,l'}$ .

$$X_{s,l,l'} = \frac{Y_{s,l,l'}}{\sum_{l'} Y_{s,l,l'}} \quad (22)$$

$$Y_{s,l,l'} = (\Delta_{l,l'})^{\frac{\hat{L}_{s,l} - (\bar{L}_l - 2.5)}{\hat{\beta}_s}} \quad (23)$$

$$\hat{L}_{s,l}^{post} = \alpha_s + \beta_{s,1} L_l \quad (24)$$

$$\Delta_{l,l'} = \bar{L}_{l'} + 2.5 - L_l \quad (25)$$

$\hat{L}_{s,l}^{post,1}$  and  $\hat{L}_{s,l}^{post,2}$  were predicted post-molt lengths from each piece of the piece-wise relationship, and  $\Phi()$  was a cumulative normal distribution in which  $\delta_{a,x}$  was an estimated change point. The model in which linear growth was estimated removed equations 26 and 27 from the model.

An average recruitment for the assessment period (1982-present) and yearly deviations around this average were estimated within the assessment for models in which only a single vector of recruitment deviations was estimated. The sex ratio of recruitment was assumed to be 50/50 male to female. Each year's estimated recruitment was allocated to length bins based on a discretized and renormalized gamma function with parameters specified in the control file.

$$Rec_y = e^{(Rec_{avg} + Rec_{dev,y})} \quad (26)$$

$$Pr_l = \frac{(\Delta_{1,l})^{\alpha_{rec}/\beta_{rec}} e^{-\Delta_{1,l}/\beta_{rec}}}{\sum_{l'} (\Delta_{1,l'})^{\alpha_{rec}/\beta_{rec}} e^{(-\Delta_{1,l'}/\beta_{rec})}} \quad (27)$$

For models in which separate vectors of recruitment deviations were estimated for males and females, a separate average recruitment was also estimated (in log space). Each vector of deviations was also subject to a smoothing penalty, but were not linked directly in any way (e.g. priors on the ratio of estimated male to female average recruitment).

Three general types of likelihood components were used to fit to the available data. Multinomial likelihoods were used for size composition data, log-normal likelihoods were used for indices of abundance data, and normal likelihoods were used for catch data, growth data, priors, and penalties. Multinomial likelihoods were implemented in the form:

$$L_x = \lambda_x \sum_y N_{x,y}^{eff} \sum_l p_{x,y,l}^{obs} \ln(\hat{p}_{x,y,l}/p_{x,y,l}^{obs}) \quad (28)$$

$L_x$  was the likelihood associated with data component  $x$ , where  $\lambda_x$  represented an optional additional weighting factor for the likelihood,  $N_{x,y}^{eff}$  was the effective sample sizes for the likelihood,  $p_{x,y,l}^{obs}$  was the observed proportion in size bin  $l$  during year  $y$  for data component  $x$ , and  $\hat{p}_{x,y,l}$  was the predicted proportion in size bin  $l$  during year  $y$  for data component  $x$ .

Log normal likelihoods were implemented in the form:

$$L_x = \lambda_x \sum_y \frac{(\ln(\hat{I}_{x,y}) - \ln(I_{x,y}))^2}{2(\ln(CV_{x,y}^2 + 1))} \quad (29)$$

$L_x$  was the contribution to the objective function of data component  $x$ ,  $\lambda_x$  was any additional weighting applied to the component,  $\hat{I}_{x,y}$  was the predicted value of quantity  $I$  from data component  $x$  during year  $y$ ,  $I_{x,y}$  was the observed value of quantity  $I$  from data component  $x$  during year  $y$  and  $CV_{x,y}$  was the coefficient of variation for data component  $x$  during year  $y$ .

Normal likelihoods were implemented in the form:

$$L_x = \lambda_x \sum_y (\hat{I}_{x,y} - I_{x,y})^2 \quad (30)$$

$L_x$  was the contribution to the objective function of data component  $x$ ,  $\lambda_x$  was represents the weight applied to the data component (and can be translated to a standard deviation),  $\hat{I}_{x,y}$  was the predicted value of quantity  $I$  from data component  $x$  during year  $y$ ,  $I_{x,y}$  was the observed value of quantity  $I$  from data component  $x$  during year  $y$ .

Smoothing penalties were also placed on some estimated vectors of parameters in the form of normal likelihoods on the second differences of the vector.



Table 8: Observed growth increment data by sex

| Female premolt length (mm) | Female postmolt length (mm) | Male premolt length (mm) | Male postmolt length (mm) |
|----------------------------|-----------------------------|--------------------------|---------------------------|
| 20.7                       | 27                          | 57.63                    | 68.6                      |
| 25.2                       | 32                          | 20.6                     | 28.9                      |
| 28.7                       | 37.1                        | 25.6                     | 31.4                      |
| 28.2                       | 36.22                       | 25.9                     | 31.1                      |
| 25.9                       | 32.7                        | 20                       | 26.3                      |
| 26.9                       | 34.4                        | 25.2                     | 32.8                      |
| 26.4                       | 31.8                        | 21                       | 27.8                      |
| 29                         | 36.7                        | 20.3                     | 26.4                      |
| 23                         | 31.2                        | 21.9                     | 28.4                      |
| 21.6                       | 27.7                        | 20.7                     | 27.7                      |
| 24.2                       | 30.9                        | 20.1                     | 28                        |
| 20.8                       | 27.3                        | 19.8                     | 26.5                      |
| 20.3                       | 26.2                        | 26                       | 32.2                      |
| 22.2                       | 29.7                        | 62.3                     | 81.8                      |
| 21.4                       | 28                          | 56.5                     | 70                        |
| 19.3                       | 25.2                        | 57                       | 70                        |
| 26.9                       | 34.5                        | 58.7                     | 72.5                      |
| 25.7                       | 32.5                        | 60.8                     | 78.4                      |
| 19.8                       | 26.9                        | 59.3                     | 75.1                      |
| 27.4                       | 35.1                        | 64                       | 84.7                      |
| 20.4                       | 26.4                        | 60.3                     | 75.1                      |
| 25.5                       | 34.6                        | 20.7                     | 29.2                      |
| 34.9                       | 44.8                        | 24                       | 32.3                      |
| 18.6                       | 25.2                        | 16.1                     | 23                        |
| 28.2                       | 35.8                        | 19.2                     | 26.6                      |
| 22.8                       | 29.6                        | 21.23                    | 26.41                     |
| 26.5                       | 33.9                        | 22.2                     | 28.1                      |
| 25.5                       | 32.9                        | 23.48                    | 28.27                     |
| 24.2                       | 31.4                        | 29.9                     | 39.9                      |
| 24.4                       | 30.7                        | 30.3                     | 40.3                      |
| 22.3                       | 29.4                        | 30.7                     | 40.5                      |
| 20.8                       | 27.3                        | 44.2                     | 58.7                      |
| 22.8                       | 30.2                        | 44.7                     | 57.3                      |
| 26.2                       | 32.6                        | 64.7                     | 82.7                      |
| 29.4                       | 36.7                        | 67.6                     | 86                        |
| 20.2                       | 24.9                        | 67.9                     | 85.3                      |
| 27.5                       | 34.8                        | 74.5                     | 93.9                      |
| 20.4                       | 26.7                        | 79.9                     | 97.8                      |
| 25.4                       | 31.7                        | 89.8                     | 110                       |
| 28.1                       | 34.5                        | 89.9                     | 112.1                     |
| 28.7                       | 36                          | 89.9                     | 112.3                     |
| 29.5                       | 38.4                        | 93.8                     | 117.6                     |
| 30.9                       | 38.4                        | 20                       | 26.3                      |
| 26                         | 33.1                        |                          |                           |
| 29.1                       | 38.4                        |                          |                           |
| 19.37                      | 24.24                       |                          |                           |
| 20.7                       | 27.4                        |                          |                           |
| 21.25                      | 28.73                       |                          |                           |
| 21.94                      | 28.71                       |                          |                           |
| 23.09                      | 29.26                       |                          |                           |

| Female premolt length (mm) | Female postmolt length (mm) | Male premolt length (mm) | Male postmolt length (mm) |
|----------------------------|-----------------------------|--------------------------|---------------------------|
| 32.8                       | 44.9                        |                          |                           |
| 35.3                       | 47.6                        |                          |                           |
| 38.3                       | 50.9                        |                          |                           |
| 38.9                       | 53                          |                          |                           |
| 41                         | 55.8                        |                          |                           |
| 42.1                       | 54.6                        |                          |                           |
| 44.2                       | 59.5                        |                          |                           |
| 44.3                       | 59.3                        |                          |                           |
| 44.8                       | 59.7                        |                          |                           |
| 45.2                       | 59.6                        |                          |                           |
| 46.9                       | 60.4                        |                          |                           |
| 47                         | 61.4                        |                          |                           |
| 47.9                       | 61.4                        |                          |                           |
| 20.6                       | 25.1                        |                          |                           |
| 20.8                       | 27.6                        |                          |                           |
| 22                         | 28.2                        |                          |                           |
| 22.9                       | 28.6                        |                          |                           |

Table 9: Observed retained catches, discarded catch, and bycatch.  
Discards and bycatch have assumed mortalities applied.

| Survey year | Retained catch<br>(kt) | Discarded<br>females (kt) | Discarded males<br>(kt) | Trawl<br>bycatch (kt) |
|-------------|------------------------|---------------------------|-------------------------|-----------------------|
| 1982        | 11.85                  | 0.02                      | 1.47                    | 0.37                  |
| 1983        | 12.16                  | 0.01                      | 1.43                    | 0.47                  |
| 1984        | 29.94                  | 0.01                      | 3.2                     | 0.5                   |
| 1985        | 44.45                  | 0.01                      | 4.65                    | 0.43                  |
| 1986        | 46.22                  | 0.02                      | 4.92                    | 0                     |
| 1987        | 61.4                   | 0.03                      | 6.4                     | 0                     |
| 1988        | 67.79                  | 0.04                      | 6.74                    | 0                     |
| 1989        | 73.4                   | 0.05                      | 7.74                    | 0.1                   |
| 1990        | 149.1                  | 0.05                      | 17.62                   | 0.71                  |
| 1991        | 143                    | 0.06                      | 13.9                    | 1.5                   |
| 1992        | 104.7                  | 0.12                      | 17.06                   | 2.28                  |
| 1993        | 67.94                  | 0.08                      | 5.32                    | 1.57                  |
| 1994        | 34.13                  | 0.06                      | 4.03                    | 2.67                  |
| 1995        | 29.81                  | 0.02                      | 5.75                    | 1.01                  |
| 1996        | 54.22                  | 0.07                      | 7.44                    | 0.66                  |
| 1997        | 114.4                  | 0.01                      | 5.73                    | 0.82                  |
| 1998        | 88.09                  | 0.01                      | 4.67                    | 0.54                  |
| 1999        | 15.1                   | 0                         | 0.52                    | 0.47                  |
| 2000        | 11.46                  | 0                         | 0.62                    | 0.41                  |
| 2001        | 14.8                   | 0                         | 1.89                    | 0.31                  |
| 2002        | 12.84                  | 0                         | 1.47                    | 0.17                  |
| 2003        | 10.86                  | 0                         | 0.57                    | 0.46                  |
| 2004        | 11.29                  | 0                         | 0.51                    | 0.63                  |
| 2005        | 16.77                  | 0                         | 1.36                    | 0.2                   |
| 2006        | 16.49                  | 0                         | 1.78                    | 0.42                  |
| 2007        | 28.59                  | 0.01                      | 2.53                    | 0.18                  |
| 2008        | 26.56                  | 0.01                      | 2.06                    | 0.18                  |
| 2009        | 21.78                  | 0.01                      | 1.23                    | 0.47                  |
| 2010        | 24.61                  | 0.01                      | 0.62                    | 0.14                  |
| 2011        | 40.29                  | 0.18                      | 1.69                    | 0.15                  |
| 2012        | 30.05                  | 0.03                      | 2.32                    | 0.22                  |
| 2013        | 24.49                  | 0.07                      | 3.27                    | 0.11                  |
| 2014        | 30.82                  | 0.17                      | 3.52                    | 0.13                  |
| 2015        | 18.42                  | 0.07                      | 2.96                    | 0.13                  |
| 2016        | 9.67                   | 0.02                      | 1.31                    | 0.06                  |
| 2017        | 8.6                    | 0.02                      | 1.93                    | 0.04                  |
| 2018        | 12.51                  | 0.02                      | 2.86                    | 0.23                  |
| 2019        | 15.43                  | 0.02                      | 5.07                    | 0.24                  |
| 2020        | 20.41                  | 0                         | 5.8                     | 0.07                  |
| 2021        | 2.48                   | 0                         | 1.16                    | 0.06                  |

Table 10: Observed mature male and female biomass (1000 t) at the time of the survey and coefficients of variation.

| Survey year | Female mature biomass | Female CV | Mature male biomass | Male CV | Males >101mm (kt) | Males >101mm (million) |
|-------------|-----------------------|-----------|---------------------|---------|-------------------|------------------------|
| 1982        | 144.4                 | 0.15      | 176.8               | 0.14    | 33.34             | 60.91                  |
| 1983        | 90.13                 | 0.2       | 161.6               | 0.13    | 38.09             | 70.09                  |
| 1984        | 42.32                 | 0.19      | 177.7               | 0.12    | 88.73             | 151.8                  |
| 1985        | 6.12                  | 0.2       | 71.84               | 0.11    | 43.39             | 72.84                  |
| 1986        | 15.74                 | 0.18      | 89.81               | 0.11    | 46.7              | 77.91                  |
| 1987        | 122.6                 | 0.16      | 194.6               | 0.11    | 74.44             | 128.6                  |
| 1988        | 169.9                 | 0.17      | 259.4               | 0.15    | 104.7             | 173.1                  |
| 1989        | 264.2                 | 0.25      | 299.2               | 0.11    | 92.31             | 158.9                  |
| 1990        | 182.9                 | 0.19      | 443.8               | 0.14    | 224.7             | 386.4                  |
| 1991        | 214.9                 | 0.19      | 466.6               | 0.15    | 292.2             | 452.9                  |
| 1992        | 131.4                 | 0.18      | 235.5               | 0.09    | 143.9             | 227.3                  |
| 1993        | 132.1                 | 0.16      | 183.9               | 0.1     | 78.11             | 126.7                  |
| 1994        | 126.2                 | 0.15      | 171.3               | 0.08    | 44.78             | 72.57                  |
| 1995        | 168.7                 | 0.14      | 220.5               | 0.13    | 37.75             | 65.18                  |
| 1996        | 107.3                 | 0.14      | 288.4               | 0.12    | 87.57             | 155.2                  |
| 1997        | 103.8                 | 0.2       | 326.8               | 0.1     | 168.7             | 280.6                  |
| 1998        | 72.73                 | 0.25      | 206.4               | 0.09    | 126.7             | 209.7                  |
| 1999        | 30.89                 | 0.21      | 95.85               | 0.09    | 52.53             | 85.2                   |
| 2000        | 96.46                 | 0.52      | 96.39               | 0.14    | 41.88             | 69.83                  |
| 2001        | 77.24                 | 0.28      | 136.5               | 0.12    | 41.51             | 70.69                  |
| 2002        | 30.22                 | 0.28      | 93.17               | 0.23    | 36.56             | 64.16                  |
| 2003        | 41.71                 | 0.31      | 79.07               | 0.12    | 32.57             | 55.61                  |
| 2004        | 50.16                 | 0.26      | 79.57               | 0.14    | 35.99             | 57.42                  |
| 2005        | 64.85                 | 0.17      | 123.5               | 0.11    | 40.67             | 63.26                  |
| 2006        | 51.93                 | 0.17      | 139.3               | 0.26    | 71.13             | 120.9                  |
| 2007        | 55.89                 | 0.22      | 153.1               | 0.15    | 73.62             | 127.5                  |
| 2008        | 57.15                 | 0.19      | 142                 | 0.1     | 66.56             | 113.6                  |
| 2009        | 52.16                 | 0.21      | 148.2               | 0.13    | 78.92             | 129.9                  |
| 2010        | 98.01                 | 0.17      | 162.8               | 0.12    | 88.35             | 138.3                  |
| 2011        | 175.8                 | 0.18      | 167.1               | 0.11    | 94.67             | 147.6                  |
| 2012        | 149.4                 | 0.2       | 122.2               | 0.12    | 53.17             | 85.35                  |
| 2013        | 131.4                 | 0.17      | 97.46               | 0.12    | 42.93             | 71.79                  |
| 2014        | 119.7                 | 0.19      | 163.5               | 0.16    | 81.39             | 138.8                  |
| 2015        | 85.13                 | 0.17      | 80.04               | 0.12    | 35.77             | 56.11                  |
| 2016        | 55.39                 | 0.21      | 63.21               | 0.11    | 21.96             | 36.51                  |
| 2017        | 106.8                 | 0.21      | 83.96               | 0.13    | 20.52             | 35.02                  |
| 2018        | 165.9                 | 0.18      | 198.4               | 0.17    | 26.75             | 48.08                  |
| 2019        | 110.4                 | 0.2       | 169.1               | 0.17    | 28.12             | 51.27                  |
| 2021        | 31.66                 | 0.43      | 62.25               | 0.13    | 12.43             | 23.17                  |
| 2022        | 22.44                 | 0.31      | 37.5                | 0.15    | 13.36             | 23.89                  |

Table 11: Contribution to the objective function by individual likelihood component by model

| Component  | Fishery                                | 22.1        | 22.1a       | 22.1ab      |
|------------|--|-------------|-------------|-------------|
| catch      | Retained                               | -6.6897     | -8.8231     | -9.1501     |
| catch      | Discard (male)                         | 142.1084    | 139.3299    | 122.0342    |
| catch      | Discard (female)                       | -69.6612    | -69.6608    | -69.6607    |
| catch      | Trawl                                  | -50.6422    | -50.6439    | -50.6438    |
| cpue       | NMFS survey (era 1; females)           | 51.7841     | 43.9095     | 43.6293     |
| cpue       | NMFS survey (era 2, females)           | -27.6439    | -30.8034    | -31.2336    |
| cpue       | NMFS survey (era 1, males)             | 28.7505     | 31.6677     | 29.7573     |
| cpue       | NMFS survey (era 2, males)             | 8.7418      | 8.022       | -5.4007     |
| cpue       | BSFRF 2009                             | -0.5375     | -0.5799     | -0.6052     |
| cpue       | BSFRF 2010                             | -0.5307     | -1.9527     | -3.6876     |
| growth_inc | 1                                      | 1020.7269   | 1021.2552   | 1016.8876   |
| growth_inc | 2                                      | 0           | 0           | 0           |
| rec_dev    | 1                                      | 0.7575      | 0.7575      | 0.7575      |
| rec_dev    | 2                                      | 0           | 0           | 0           |
| rec_dev    | 3                                      | 86.1706     | 89.1284     | 91.2242     |
| size_comp  | Retained males                         | -3666.4763  | -3701.8747  | -3699.7386  |
| size_comp  | Survey mature females (1982-1988)      | -664.0213   | -688.4905   | -688.4737   |
| size_comp  | Survey mature females (1989-present)   | -3071.3976  | -3071.9284  | -3070.3273  |
| size_comp  | Survey mature males (1982-1988)        | -589.1354   | -595.4243   | -596.1709   |
| size_comp  | Survey mature males (1989-present)     | -2738.861   | -2741.4501  | -2721.3733  |
| size_comp  | BSFRF 2009                             | -175.868    | -176.1576   | -176.4514   |
| size_comp  | NMFS 2009                              | -184.5293   | -184.5963   | -184.6168   |
| size_comp  | BSFRF 2010                             | -173.8314   | -173.4927   | -173.4626   |
| size_comp  | NMFS 2010                              | -170.3389   | -170.3836   | -171.7761   |
| size_comp  | Total males                            | -2711.3257  | -2711.7745  | -2688.7734  |
| size_comp  | Discard females                        | -2282.9278  | -2282.6251  | -2282.1564  |
| size_comp  | Trawl bycatch (females)                | -2449.8648  | -2467.1116  | -2466.9757  |
| size_comp  | Trawl bycatch (male)                   | -2360.4382  | -2358.0865  | -2333.903   |
| size_comp  | Survey immature females (1982-1988)    | -596.184    | -623.0579   | -624.694    |
| size_comp  | Survey immature females (1989-present) | -2875.5278  | -2876.5912  | -2878.3031  |
| size_comp  | Survey immature males (1982-1988)      | -573.3505   | -577.3463   | -577.3848   |
| size_comp  | Survey immature males (1989-present)   | -2733.5207  | -2733.1505  | -2755.917   |
| Total      | Total                                  | -26834.2641 | -26961.9354 | -26956.5897 |

Table 12: Parameter estimates and standard deviations from considered models.

| Parameter | Model 22.1 |        | Model 22.1a |        | Model 22.1ab |        |
|-----------|------------|--------|-------------|--------|--------------|--------|
|           | est        | SD     | est         | SD     | est          | SD     |
| theta[1]  | 0.28       | 0      | 0.28        | 0      | 0.29         | 0      |
| theta[2]  | 0.28       | 0      | 0.28        | 0      | 0.28         | 0      |
| theta[4]  | 16.23      | 0.12   | NA          | NA     | NA           | NA     |
| theta[5]  | 5.78       | 198.42 | 21.01       | 1472.5 | 5.92         | 409.68 |
| theta[13] | -0.15      | 0.3    | 10.46       | 0.7    | 10.56        | 0.7    |
| theta[14] | -0.26      | 0.3    | 10.47       | 0.56   | 10.58        | 0.56   |
| theta[15] | -0.01      | 0.3    | 10.56       | 0.44   | 10.67        | 0.44   |
| theta[16] | 0.48       | 0.31   | 11.02       | 0.4    | 11.12        | 0.4    |
| theta[17] | 0.99       | 0.29   | 11.68       | 0.37   | 11.79        | 0.37   |
| theta[18] | 1.37       | 0.26   | 12.23       | 0.31   | 12.34        | 0.31   |
| theta[19] | 1.42       | 0.24   | 12.6        | 0.27   | 12.67        | 0.27   |
| theta[20] | 1.35       | 0.23   | 12.6        | 0.25   | 12.64        | 0.25   |
| theta[21] | 1.39       | 0.23   | 12.43       | 0.25   | 12.52        | 0.25   |
| theta[22] | 1.44       | 0.22   | 12.43       | 0.24   | 12.52        | 0.24   |
| theta[23] | 1.32       | 0.22   | 12.44       | 0.24   | 12.49        | 0.24   |
| theta[24] | 1.26       | 0.22   | 12.28       | 0.24   | 12.31        | 0.25   |
| theta[25] | 1.27       | 0.2    | 12.17       | 0.25   | 12.2         | 0.25   |
| theta[26] | 1.29       | 0.19   | 12.11       | 0.25   | 12.16        | 0.25   |
| theta[27] | 1.11       | 0.2    | 12.18       | 0.24   | 12.27        | 0.24   |
| theta[28] | 0.8        | 0.2    | 12.16       | 0.2    | 12.21        | 0.2    |
| theta[29] | 0.22       | 0.23   | 11.87       | 0.21   | 11.84        | 0.21   |
| theta[30] | -0.61      | 0.26   | 11.36       | 0.24   | 11.26        | 0.24   |
| theta[31] | -1.32      | 0.28   | 10.51       | 0.28   | 10.36        | 0.28   |
| theta[32] | -1.52      | 0.33   | 9.48        | 0.33   | 9.32         | 0.33   |
| theta[33] | -1.43      | 0.36   | 8.53        | 0.36   | 8.38         | 0.36   |
| theta[34] | 0.45       | 0.45   | 7.98        | 0.41   | 7.85         | 0.41   |
| theta[35] | 0.64       | 0.36   | 11.82       | 0.46   | 11.89        | 0.46   |
| theta[36] | 1.08       | 0.28   | 11.97       | 0.31   | 12.03        | 0.31   |
| theta[37] | 2.35       | 0.33   | 12.73       | 0.29   | 12.78        | 0.29   |
| theta[38] | 2.73       | 0.25   | 13.27       | 0.23   | 13.32        | 0.23   |
| theta[39] | 2.04       | 0.22   | 12.65       | 0.21   | 12.73        | 0.21   |
| theta[40] | 1.86       | 0.23   | 12.71       | 0.2    | 12.78        | 0.21   |
| theta[41] | 1.61       | 0.25   | 12.61       | 0.2    | 12.7         | 0.2    |
| theta[42] | 1.45       | 0.26   | 12.35       | 0.22   | 12.44        | 0.22   |
| theta[43] | 1.23       | 0.25   | 12.16       | 0.24   | 12.25        | 0.24   |
| theta[44] | 0.77       | 0.28   | 11.95       | 0.24   | 12.03        | 0.24   |
| theta[45] | 0.43       | 0.31   | 11.55       | 0.28   | 11.63        | 0.28   |
| theta[46] | 0.28       | 0.31   | 11.22       | 0.31   | 11.29        | 0.31   |
| theta[47] | -0.11      | 0.28   | 11.06       | 0.32   | 11.1         | 0.32   |
| theta[48] | -0.71      | 0.29   | 10.54       | 0.34   | 10.48        | 0.34   |
| theta[49] | -1.14      | 0.33   | 9.59        | 0.38   | 9.45         | 0.38   |
| theta[50] | -1.43      | 0.32   | 8.63        | 0.42   | 8.47         | 0.42   |
| theta[51] | -1.62      | 0.31   | 7.82        | 0.44   | 7.66         | 0.44   |
| theta[52] | -1.74      | 0.3    | 7.21        | 0.47   | 7.07         | 0.47   |
| theta[53] | -1.81      | 0.3    | 6.78        | 0.51   | 6.65         | 0.51   |
| theta[54] | -1.59      | 0.33   | 6.48        | 0.56   | 6.36         | 0.56   |
| theta[55] | -1.52      | 0.37   | 6.29        | 0.62   | 6.17         | 0.62   |
| theta[56] | 0.5        | 0.48   | 6.2         | 0.7    | 6.08         | 0.71   |
| theta[57] | 0.7        | 0.41   | 13.56       | 0.79   | 13.47        | 0.79   |

| Parameter | Model 22.1 |      | Model 22.1a |        | Model 22.1ab |      |
|-----------|------------|------|-------------|--------|--------------|------|
|           | est        | SD   | est         | SD     | est          | SD   |
| theta[58] | 1.18       | 0.39 | 13.55       | 0.64   | 13.46        | 0.65 |
| theta[59] | 2.13       | 0.35 | 13.56       | 0.48   | 13.46        | 0.48 |
| theta[60] | 3.65       | 0.21 | 13.76       | 0.36   | 13.67        | 0.36 |
| theta[61] | 4.27       | 0.15 | 14.5        | 0.29   | 14.4         | 0.29 |
| theta[62] | 3.62       | 0.16 | 14.66       | 0.27   | 14.56        | 0.27 |
| theta[63] | 2.26       | 0.23 | 13.75       | 0.26   | 13.67        | 0.26 |
| theta[64] | 0.83       | 0.31 | 12.55       | 0.28   | 12.47        | 0.28 |
| theta[65] | -0.22      | 0.3  | 11.4        | 0.33   | 11.31        | 0.34 |
| theta[66] | -0.64      | 0.3  | 10.17       | 0.37   | 10.08        | 0.37 |
| theta[67] | -0.76      | 0.31 | 9.42        | 0.41   | 9.33         | 0.41 |
| theta[68] | -0.75      | 0.31 | 8.98        | 0.46   | 8.89         | 0.46 |
| theta[69] | -0.75      | 0.31 | 8.73        | 0.52   | 8.63         | 0.52 |
| theta[70] | -0.79      | 0.3  | 8.53        | 0.56   | 8.43         | 0.56 |
| theta[71] | -0.91      | 0.29 | 8.35        | 0.58   | 8.24         | 0.59 |
| theta[72] | -0.97      | 0.29 | 8.15        | 0.59   | 8.04         | 0.59 |
| theta[73] | -1.02      | 0.29 | 8           | 0.61   | 7.88         | 0.61 |
| theta[74] | -1.05      | 0.29 | 7.89        | 0.63   | 7.75         | 0.63 |
| theta[75] | -1.1       | 0.3  | 7.8         | 0.67   | 7.66         | 0.66 |
| theta[76] | -1.2       | 0.31 | 7.73        | 0.71   | 7.59         | 0.7  |
| theta[77] | -1.39      | 0.33 | 7.69        | 0.77   | 7.54         | 0.75 |
| theta[78] | 0.05       | 0.42 | 7.67        | 0.84   | 7.52         | 0.83 |
| theta[79] | 0.2        | 0.4  | -12.65      | 7110.5 | 7.15         | 1.27 |
| theta[80] | 0.16       | 0.35 | -12.66      | 7110.5 | 7.12         | 1.17 |
| theta[81] | 0.67       | 0.33 | -12.72      | 7110.5 | 7.05         | 1.05 |
| theta[82] | 1.38       | 0.22 | -12.7       | 7110.5 | 7.14         | 1    |
| theta[83] | 1.7        | 0.17 | -12.61      | 7110.5 | 7.22         | 1    |
| theta[84] | 0.56       | 0.22 | -12.47      | 7110.5 | 7.36         | 1.02 |
| theta[85] | -0.45      | 0.25 | -13.68      | 7110.5 | 6.15         | 1.04 |
| theta[86] | -1.13      | 0.26 | -15         | 7110.5 | 4.84         | 1.06 |
| theta[87] | -1.6       | 0.27 | -16.04      | 7110.5 | 3.8          | 1.07 |
| theta[88] | -1.83      | 0.27 | -16.8       | 7110.5 | 3.04         | 1.09 |
| theta[89] | -1.89      | 0.27 | -17.29      | 7110.5 | 2.55         | 1.11 |
| theta[90] | -1.94      | 0.27 | -17.6       | 7110.5 | 2.24         | 1.14 |
| theta[91] | -1.97      | 0.27 | -17.84      | 7110.5 | 2            | 1.16 |
| theta[92] | -2.01      | 0.27 | -18.02      | 7110.5 | 1.82         | 1.18 |
| theta[93] | -2.04      | 0.27 | -18.16      | 7110.5 | 1.68         | 1.21 |
| theta[94] | -2.08      | 0.27 | -18.28      | 7110.5 | 1.56         | 1.23 |
| theta[95] | -2.1       | 0.27 | -18.37      | 7110.5 | 1.47         | 1.25 |
| theta[96] | -2.11      | 0.27 | -18.44      | 7110.5 | 1.4          | 1.28 |
| theta[97] | -2.11      | 0.27 | -18.49      | 7110.5 | 1.35         | 1.31 |
| theta[98] | -2.11      | 0.27 | -18.53      | 7110.5 | 1.31         | 1.34 |
| theta[99] | -2.11      | 0.3  | -18.56      | 7110.5 | 1.28         | 1.39 |
| Grwth[1]  | 2.23       | 0.08 | 2.24        | 0.08   | 2.12         | 0.08 |
| Grwth[2]  | -0.22      | 0    | -0.22       | 0      | -0.22        | 0    |
| Grwth[4]  | -0.14      | 0.11 | -0.15       | 0.11   | -0.15        | 0.11 |
| Grwth[5]  | -0.3       | 0    | -0.3        | 0      | -0.3         | 0    |
| Grwth[10] | 0.03       | 0    | 0.03        | 0      | 0.03         | 0    |
| Grwth[11] | 0.06       | 0.01 | 0.06        | 0.01   | 0.06         | 0.01 |
| Grwth[12] | 0.09       | 0.01 | 0.1         | 0.01   | 0.1          | 0.01 |
| Grwth[13] | 0.14       | 0.01 | 0.14        | 0.01   | 0.15         | 0.01 |
| Grwth[14] | 0.19       | 0.01 | 0.2         | 0.01   | 0.21         | 0.01 |

| Parameter        | Model 22.1 |      | Model 22.1a |      | Model 22.1ab |      |
|------------------|------------|------|-------------|------|--------------|------|
|                  | est        | SD   | est         | SD   | est          | SD   |
| Grwth[15]        | 0.2        | 0.01 | 0.21        | 0.01 | 0.21         | 0.01 |
| Grwth[16]        | 0.23       | 0.01 | 0.24        | 0.01 | 0.24         | 0.01 |
| Grwth[17]        | 0.27       | 0.02 | 0.28        | 0.02 | 0.3          | 0.02 |
| Grwth[18]        | 0.26       | 0.02 | 0.27        | 0.02 | 0.3          | 0.02 |
| Grwth[19]        | 0.23       | 0.02 | 0.24        | 0.02 | 0.28         | 0.02 |
| Grwth[20]        | 0.24       | 0.02 | 0.25        | 0.02 | 0.32         | 0.02 |
| Grwth[21]        | 0.4        | 0.02 | 0.41        | 0.02 | 0.5          | 0.02 |
| Grwth[22]        | 0.81       | 0.02 | 0.81        | 0.02 | 0.85         | 0.02 |
| Grwth[30]        | 0.04       | 0.03 | 0.05        | 0.04 | 0.05         | 0.04 |
| Grwth[31]        | 0.05       | 0.02 | 0.06        | 0.02 | 0.06         | 0.02 |
| Grwth[32]        | 0.36       | 0.04 | 0.38        | 0.05 | 0.36         | 0.04 |
| Grwth[33]        | 0.79       | 0.02 | 0.79        | 0.02 | 0.78         | 0.02 |
| Grwth[34]        | 0.92       | 0.01 | 0.92        | 0.01 | 0.92         | 0.01 |
| Grwth[35]        | 0.95       | 0.01 | 0.96        | 0    | 0.96         | 0    |
| log_slx_pars[1]  | 4.63       | 0    | 4.63        | 0.01 | 4.65         | 0.01 |
| log_slx_pars[2]  | 1.56       | 0.03 | 1.57        | 0.03 | 1.58         | 0.03 |
| log_slx_pars[3]  | 4.25       | 0.01 | 4.26        | 0.01 | 4.26         | 0.01 |
| log_slx_pars[4]  | 0.96       | 0.03 | 0.97        | 0.03 | 0.97         | 0.03 |
| log_slx_pars[5]  | 4.54       | 0.01 | 4.55        | 0.01 | 4.58         | 0.02 |
| log_slx_pars[6]  | 2.21       | 0.03 | 2.19        | 0.03 | 2.23         | 0.03 |
| log_slx_pars[7]  | 3.75       | 0.04 | 3.76        | 0.05 | 3.78         | 0.05 |
| log_slx_pars[8]  | 1.93       | 0.13 | 2.05        | 0.14 | 2.09         | 0.14 |
| log_slx_pars[9]  | 3.87       | 0.01 | 3.94        | 0.02 | 3.94         | 0.02 |
| log_slx_pars[10] | 1.02       | 0.05 | 1.25        | 0.05 | 1.25         | 0.05 |
| log_slx_pars[11] | 3.72       | 0.02 | 3.72        | 0.02 | 3.71         | 0.02 |
| log_slx_pars[12] | 1.62       | 0.07 | 1.62        | 0.07 | 1.55         | 0.07 |
| log_slx_pars[13] | 3.86       | 0.01 | 3.86        | 0.01 | 3.86         | 0.01 |
| log_slx_pars[14] | 1.32       | 0.03 | 1.31        | 0.03 | 1.32         | 0.03 |
| log_slx_pars[15] | -3.89      | 0.94 | -3.91       | 0.95 | -3.95        | 0.95 |
| log_slx_pars[16] | -3.89      | 0.85 | -3.91       | 0.85 | -3.95        | 0.86 |
| log_slx_pars[17] | -3.89      | 0.75 | -3.91       | 0.75 | -3.95        | 0.75 |
| log_slx_pars[18] | -3.88      | 0.63 | -3.9        | 0.64 | -3.95        | 0.64 |
| log_slx_pars[19] | -3.86      | 0.52 | -3.88       | 0.52 | -3.93        | 0.52 |
| log_slx_pars[20] | -3.71      | 0.44 | -3.74       | 0.44 | -3.79        | 0.45 |
| log_slx_pars[21] | -3.36      | 0.41 | -3.39       | 0.41 | -3.46        | 0.41 |
| log_slx_pars[22] | -2.9       | 0.39 | -2.93       | 0.39 | -3           | 0.38 |
| log_slx_pars[23] | -2.47      | 0.36 | -2.5        | 0.36 | -2.55        | 0.37 |
| log_slx_pars[24] | -2.02      | 0.35 | -2.06       | 0.35 | -2.11        | 0.35 |
| log_slx_pars[25] | -1.83      | 0.33 | -1.87       | 0.33 | -1.97        | 0.33 |
| log_slx_pars[26] | -1.63      | 0.32 | -1.68       | 0.32 | -1.81        | 0.32 |
| log_slx_pars[27] | -1.2       | 0.32 | -1.24       | 0.32 | -1.43        | 0.32 |
| log_slx_pars[28] | -0.83      | 0.32 | -0.86       | 0.32 | -1.12        | 0.32 |
| log_slx_pars[29] | -0.95      | 0.31 | -0.97       | 0.31 | -1.19        | 0.3  |
| log_slx_pars[30] | -1.43      | 0.3  | -1.43       | 0.3  | -1.52        | 0.3  |
| log_slx_pars[31] | -1.69      | 0.31 | -1.69       | 0.31 | -1.71        | 0.31 |
| log_slx_pars[32] | -1.81      | 0.32 | -1.79       | 0.32 | -1.77        | 0.32 |
| log_slx_pars[33] | -1.78      | 0.33 | -1.76       | 0.33 | -1.71        | 0.33 |
| log_slx_pars[34] | -1.6       | 0.37 | -1.58       | 0.37 | -1.51        | 0.37 |
| log_slx_pars[35] | -1.5       | 0.45 | -1.48       | 0.45 | -1.4         | 0.45 |
| log_slx_pars[36] | -1.42      | 0.59 | -1.4        | 0.6  | -1.33        | 0.6  |
| log_slx_pars[37] | -3.19      | 1.19 | -3.22       | 1.21 | -3.11        | 1.21 |



| Parameter        | Model 22.1 |      | Model 22.1a |      | Model 22.1ab |      |
|------------------|------------|------|-------------|------|--------------|------|
|                  | est        | SD   | est         | SD   | est          | SD   |
| log_slx_pars[38] | -3.19      | 1.12 | -3.22       | 1.14 | -3.11        | 1.14 |
| log_slx_pars[39] | -3.24      | 1.02 | -3.29       | 1.03 | -3.19        | 1.03 |
| log_slx_pars[40] | -3.44      | 0.88 | -3.53       | 0.89 | -3.44        | 0.89 |
| log_slx_pars[41] | -3.67      | 0.85 | -3.72       | 0.86 | -3.66        | 0.85 |
| log_slx_pars[42] | -2.76      | 0.84 | -2.79       | 0.84 | -2.74        | 0.84 |
| log_slx_pars[43] | -2.24      | 0.84 | -2.25       | 0.84 | -2.21        | 0.84 |
| log_slx_pars[44] | -1.97      | 0.84 | -1.96       | 0.84 | -1.92        | 0.84 |
| log_slx_pars[45] | -2.05      | 0.85 | -2          | 0.86 | -1.97        | 0.86 |
| log_slx_pars[46] | -2.29      | 0.88 | -2.2        | 0.88 | -2.16        | 0.88 |
| log_slx_pars[47] | -2.37      | 0.93 | -2.26       | 0.94 | -2.23        | 0.94 |
| log_slx_pars[48] | -2.37      | 1.01 | -2.25       | 1.02 | -2.22        | 1.02 |
| log_slx_pars[49] | -2.37      | 1.09 | -2.25       | 1.1  | -2.22        | 1.1  |
| log_slx_pars[50] | -2.37      | 1.16 | -2.25       | 1.17 | -2.22        | 1.17 |
| log_slx_pars[51] | -2.37      | 1.23 | -2.25       | 1.24 | -2.22        | 1.24 |
| log_slx_pars[52] | -2.37      | 1.3  | -2.25       | 1.31 | -2.22        | 1.31 |
| log_slx_pars[53] | -2.37      | 1.36 | -2.25       | 1.37 | -2.22        | 1.37 |
| log_slx_pars[54] | -2.37      | 1.42 | -2.25       | 1.43 | -2.22        | 1.43 |
| log_slx_pars[55] | -2.37      | 1.48 | -2.25       | 1.48 | -2.22        | 1.48 |
| log_slx_pars[56] | -2.37      | 1.53 | -2.25       | 1.54 | -2.22        | 1.54 |
| log_slx_pars[57] | -2.37      | 1.59 | -2.25       | 1.59 | -2.22        | 1.59 |
| log_slx_pars[58] | -2.37      | 1.64 | -2.25       | 1.64 | -2.22        | 1.64 |
| log_slx_pars[61] | 0          | 0.01 | 0           | 0.01 | -0.01        | 0.57 |
| log_slx_pars[62] | -0.37      | 0.25 | -0.35       | 0.25 | -0.37        | 0.32 |
| log_slx_pars[63] | -0.68      | 0.22 | -0.67       | 0.22 | -0.69        | 0.23 |
| log_slx_pars[64] | -0.35      | 0.19 | -0.35       | 0.19 | -0.36        | 0.19 |
| log_slx_pars[69] | -0.38      | 0.22 | -0.39       | 0.22 | -0.41        | 0.22 |
| log_slx_pars[70] | -0.46      | 0.26 | -0.48       | 0.26 | -0.52        | 0.26 |
| log_slx_pars[71] | -0.53      | 0.27 | -0.56       | 0.27 | -0.64        | 0.27 |
| log_slx_pars[72] | -0.63      | 0.27 | -0.66       | 0.27 | -0.77        | 0.27 |
| log_slx_pars[73] | -0.55      | 0.3  | -0.58       | 0.3  | -0.71        | 0.3  |
| log_slx_pars[74] | -0.53      | 0.31 | -0.55       | 0.31 | -0.7         | 0.3  |
| log_slx_pars[75] | -0.57      | 0.29 | -0.59       | 0.29 | -0.73        | 0.28 |
| log_slx_pars[76] | -0.7       | 0.25 | -0.72       | 0.25 | -0.82        | 0.26 |
| log_slx_pars[77] | -0.79      | 0.24 | -0.8        | 0.24 | -0.86        | 0.25 |
| log_slx_pars[78] | -0.77      | 0.25 | -0.77       | 0.25 | -0.81        | 0.26 |
| log_slx_pars[79] | -0.7       | 0.27 | -0.71       | 0.28 | -0.74        | 0.29 |
| log_slx_pars[80] | -0.63      | 0.34 | -0.64       | 0.34 | -0.67        | 0.37 |
| log_slx_pars[81] | -0.56      | 0.47 | -0.57       | 0.47 | -0.61        | 0.5  |
| log_slx_pars[82] | -0.53      | 0.62 | -0.54       | 0.62 | -0.59        | 0.64 |
| log_slx_pars[83] | -0.48      | 0.54 | -0.32       | 0.53 | -0.26        | 0.53 |
| log_slx_pars[84] | -1.1       | 0.31 | -0.95       | 0.32 | -0.89        | 0.31 |
| log_slx_pars[85] | -1.39      | 0.28 | -1.24       | 0.28 | -1.19        | 0.28 |
| log_slx_pars[86] | -0.74      | 0.26 | -0.6        | 0.26 | -0.55        | 0.25 |
| log_slx_pars[87] | -0.47      | 0.16 | -0.37       | 0.16 | -0.33        | 0.16 |
| log_slx_pars[88] | -0.59      | 0.16 | -0.55       | 0.16 | -0.51        | 0.16 |
| log_slx_pars[89] | -0.62      | 0.18 | -0.6        | 0.18 | -0.57        | 0.18 |
| log_slx_pars[90] | -0.76      | 0.23 | -0.76       | 0.23 | -0.73        | 0.23 |
| log_slx_pars[91] | -0.69      | 0.35 | -0.69       | 0.36 | -0.67        | 0.36 |
| log_slx_pars[92] | -0.71      | 0.47 | -0.72       | 0.49 | -0.7         | 0.49 |
| log_slx_pars[93] | -0.71      | 0.62 | -0.72       | 0.63 | -0.7         | 0.63 |
| log_slx_pars[94] | -0.71      | 0.74 | -0.71       | 0.75 | -0.7         | 0.75 |

| Parameter          | Model 22.1 |      | Model 22.1a |        | Model 22.1ab |      |
|--------------------|------------|------|-------------|--------|--------------|------|
|                    | est        | SD   | est         | SD     | est          | SD   |
| log_slx_pars[95]   | -0.71      | 0.85 | -0.71       | 0.85   | -0.7         | 0.85 |
| log_slx_pars[96]   | -0.71      | 0.94 | -0.71       | 0.95   | -0.7         | 0.95 |
| log_slx_pars[97]   | -0.71      | 1.02 | -0.71       | 1.03   | -0.7         | 1.03 |
| log_slx_pars[98]   | -0.71      | 1.1  | -0.71       | 1.11   | -0.7         | 1.11 |
| log_slx_pars[99]   | -0.71      | 1.18 | -0.71       | 1.18   | -0.7         | 1.18 |
| log_slx_pars[100]  | -0.71      | 1.25 | -0.71       | 1.25   | -0.7         | 1.25 |
| log_slx_pars[101]  | -0.71      | 1.31 | -0.71       | 1.31   | -0.7         | 1.32 |
| log_slx_pars[102]  | -0.71      | 1.37 | -0.71       | 1.38   | -0.7         | 1.38 |
| log_slx_pars[103]  | -0.71      | 1.43 | -0.71       | 1.44   | -0.7         | 1.44 |
| log_slx_pars[104]  | -0.71      | 1.49 | -0.71       | 1.49   | -0.7         | 1.49 |
| log_slx_pars[107]  | 4.58       | 0    | 4.58        | 0      | 4.58         | 0    |
| log_slx_pars[108]  | 0.29       | 0.23 | 0.33        | 0.2    | 0.29         | 0.22 |
| log_fbar[1]        | -0.95      | 0.08 | -0.98       | 0.09   | -0.95        | 0.09 |
| log_fbar[2]        | -6.5       | 0.09 | -6.47       | 0.09   | -6.46        | 0.1  |
| log_fdev[1]        | NA         | NA   | NA          | NA     | NA           | NA   |
| log_fdev[2]        | NA         | NA   | NA          | NA     | NA           | NA   |
| log_foff[1]        | -6.52      | 0.13 | -5.96       | 0.16   | -5.93        | 0.16 |
| log_fdov[1]        | NA         | NA   | NA          | NA     | NA           | NA   |
| rec_dev_est        | NA         | NA   | NA          | NA     | NA           | NA   |
| logit_rec_prop_est | NA         | NA   | NA          | NA     | NA           | NA   |
| m_dev_est[1]       | 1.8        | 0.13 | 1.78        | 0.14   | 2.06         | 0.09 |
| m_dev_est[2]       | 2.39       | 0.09 | 2.39        | 0.09   | 0            | 0.01 |
| m_dev_est[3]       | 0          | 1.41 | NA          | NA     | NA           | NA   |
| m_dev_est[4]       | 0.61       | 0.39 | 0.62        | 0.39   | 1.12         | 0.19 |
| m_dev_est[5]       | 2.18       | 0.09 | 2.19        | 0.09   | 2.66         | 0.07 |
| m_dev_est[6]       | 0          | 1.41 | NA          | NA     | NA           | NA   |
| m_dev_est[7]       | 0.6        | 0.5  | 0.51        | 0.51   | 0.4          | 0.57 |
| m_dev_est[8]       | 1.72       | 0.25 | 1.75        | 0.25   | 1.8          | 0.24 |
| m_dev_est[9]       | 0          | 1.41 | NA          | NA     | NA           | NA   |
| m_dev_est[10]      | 2.62       | 0.26 | 2.52        | 0.3    | 2.58         | 0.27 |
| m_dev_est[11]      | 1.3        | 1.21 | 1.11        | 1.37   | 0.46         | 1.74 |
| m_dev_est[12]      | 0          | 1.41 | NA          | NA     | NA           | NA   |
| m_mat_mult[1]      | 0.02       | 0.05 | 0.01        | 0.05   | 0.01         | 0.05 |
| m_mat_mult[2]      | 0.07       | 0.05 | 0.04        | 0.05   | 0.04         | 0.05 |
| survey_q[1]        | 0.18       | 0.03 | 0.35        | 0.08   | 0.38         | 0.09 |
| survey_q[2]        | 0.33       | 0.03 | 0.4         | 0.04   | 0.42         | 0.05 |
| survey_q[3]        | 0.32       | 0.03 | 0.24        | 0.03   | 0.23         | 0.03 |
| survey_q[4]        | 0.54       | 0.03 | 0.53        | 0.03   | 0.45         | 0.03 |
| sd_log_recruits    | NA         | NA   | NA          | NA     | NA           | NA   |
| ParsOut            | NA         | NA   | NA          | NA     | NA           | NA   |
| sd_log_ssb         | NA         | NA   | NA          | NA     | NA           | NA   |
| sd_last_ssb        | 53.6       | 4.45 | 53.86       | 4.47   | 71.97        | 6.07 |
| theta[100]         | NA         | NA   | -18.57      | 7110.5 | 1.27         | 1.44 |

Table 13: Changes in management quantities for each model 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 |
|---|--------|-------|--------|------|------|-------|------|---------|--------|
| 1 | 21.sq  | 26.74 | 153.42 | 1.43 | 0.37 | 7.50  | 0.27 | 106.14  | 0.17   |
| 3 | 21.g   | 23.71 | 153.33 | 1.59 | 0.36 | 7.89  | 0.28 | 131.71  | 0.15   |
| 4 | 22.1   | 39.85 | 189.12 | 1.37 | 0.28 | 9.06  | 0.28 | 161.82  | 0.21   |
| 5 | 22.1a  | 41.21 | 183.15 | 1.50 | 0.32 | 10.32 | 0.28 | 164.02  | 0.23   |
| 6 | 22.1ab | 96.67 | 196.38 | 2.26 | 0.67 | 3.98  | 0.29 | 180.36  | 0.49   |

Table 14: Maximum likelihood estimates of predicted mature male (MMB), mature female (FMB), and males >101mm biomass (1000 t) and numbers (in millions) at the time of the survey from the CPT-selected model. Columns 2-5 are subject to survey selectivity; columns 6-9 are the population values (i.e. the numbers at length are not modified by multiplying them by a selectivity curve—they are estimates of the underlying population).

| Survey year | FMB   | MMB   | Male >101 biomass | Male >101 (millions) | FMB   | MMB   | Male >101 biomass | Male >101 (millions) |
|-------------|-------|-------|-------------------|----------------------|-------|-------|-------------------|----------------------|
| 1982        | 92.77 | 272.8 | 87.19             | 155.1                | 381.6 | 701.1 | 219.6             | 390.7                |
| 1983        | 70.34 | 258   | 91.07             | 158.5                | 289.4 | 662.2 | 229.4             | 399.2                |
| 1984        | 53.54 | 256.3 | 107.3             | 181.9                | 220.2 | 656.8 | 270.3             | 458.2                |
| 1985        | 41.61 | 242   | 108.9             | 181.2                | 171.1 | 620.6 | 274.2             | 456.4                |
| 1986        | 37.55 | 220.5 | 96.05             | 158.8                | 154   | 567   | 241.9             | 399.8                |
| 1987        | 121.3 | 213   | 86.04             | 142.9                | 495.3 | 549.4 | 216.7             | 359.9                |
| 1988        | 222.1 | 227.2 | 90.97             | 151.6                | 885.4 | 586.5 | 229.1             | 381.8                |
| 1989        | 193.7 | 337.6 | 136.6             | 226.9                | 920.7 | 640.4 | 257.6             | 427.7                |
| 1990        | 161.3 | 368.1 | 163.8             | 272.1                | 764.4 | 697.5 | 308.8             | 512.9                |
| 1991        | 128.4 | 333.9 | 151.2             | 250                  | 608.4 | 632.5 | 285.1             | 471.3                |
| 1992        | 104.3 | 267.2 | 113.2             | 186.4                | 494.3 | 506.5 | 213.4             | 351.3                |
| 1993        | 89.91 | 206.4 | 73.53             | 121.5                | 426.7 | 392.3 | 138.6             | 229                  |
| 1994        | 85.59 | 187.4 | 52.82             | 87.24                | 406.8 | 356.8 | 99.57             | 164.4                |
| 1995        | 88.85 | 211.5 | 59.46             | 100.4                | 422.8 | 402.2 | 112.1             | 189.2                |
| 1996        | 86.03 | 267.3 | 104.2             | 175.2                | 408.6 | 506.9 | 196.4             | 330.2                |
| 1997        | 72.4  | 294.6 | 143.5             | 236.7                | 342.9 | 557.6 | 270.5             | 446.1                |
| 1998        | 56.29 | 243.8 | 122.7             | 199.7                | 266.4 | 461.3 | 231.2             | 376.5                |
| 1999        | 42.86 | 170.3 | 78                | 126.4                | 202.8 | 322.7 | 147               | 238.3                |
| 2000        | 43.35 | 137.4 | 59.95             | 96.74                | 206.3 | 260.5 | 113               | 182.4                |
| 2001        | 47.06 | 116.3 | 45.2              | 73.46                | 223.9 | 220.7 | 85.21             | 138.5                |
| 2002        | 42.04 | 110   | 42.25             | 70.35                | 199.2 | 208.5 | 79.64             | 132.6                |
| 2003        | 33.42 | 115.6 | 53.11             | 87.59                | 158.1 | 219.1 | 100.1             | 165.1                |
| 2004        | 25.98 | 114   | 53.97             | 87.53                | 122.9 | 216.3 | 101.7             | 165                  |
| 2005        | 44.73 | 112.8 | 47.29             | 76.82                | 214.3 | 214.4 | 89.14             | 144.8                |
| 2006        | 63.87 | 125   | 48                | 79.63                | 304.8 | 237.3 | 90.48             | 150.1                |
| 2007        | 59.5  | 153.7 | 67.29             | 111.8                | 281.9 | 291.5 | 126.8             | 210.8                |
| 2008        | 46.94 | 170.2 | 83.24             | 137                  | 222   | 322.3 | 156.9             | 258.2                |
| 2009        | 38.63 | 169.3 | 89.77             | 146.5                | 183   | 320.4 | 169.2             | 276.2                |
| 2010        | 69.26 | 154.1 | 85.64             | 138.6                | 332   | 291.6 | 161.4             | 261.3                |
| 2011        | 102.1 | 128.4 | 68.57             | 110.4                | 487.3 | 243.2 | 129.2             | 208                  |
| 2012        | 101.2 | 97    | 42.32             | 69.13                | 479.9 | 183.9 | 79.78             | 130.3                |
| 2013        | 89.68 | 85.07 | 33.68             | 56.35                | 425.1 | 161.3 | 63.5              | 106.2                |
| 2014        | 76.66 | 80.97 | 33.86             | 56.22                | 363.2 | 153.6 | 63.82             | 106                  |
| 2015        | 61.17 | 68.9  | 25.01             | 41.33                | 289.4 | 130.9 | 47.15             | 77.9                 |
| 2016        | 51.98 | 70.59 | 21.33             | 35.51                | 246.4 | 134.7 | 40.21             | 66.94                |
| 2017        | 70.34 | 102.1 | 28.04             | 46.81                | 336   | 195.5 | 52.86             | 88.24                |
| 2018        | 123.8 | 173.6 | 43.35             | 72.53                | 592.6 | 332.5 | 81.71             | 136.7                |
| 2019        | 80.36 | 170.4 | 53.27             | 90.94                | 384.6 | 324.5 | 100.4             | 171.4                |
| 2020        | 18.31 | 25.4  | 9.74              | 16.75                | 87.63 | 48.11 | 18.37             | 31.58                |
| 2021        | 18.42 | 28.88 | 11.35             | 19.84                | 88.22 | 54.63 | 21.39             | 37.4                 |
| 2022        | 18.07 | 41.05 | 23.55             | 38.74                | 86.3  | 77.57 | 44.39             | 73.03                |

Table 15: Maximum likelihood estimates of predicted total numbers (billions), not subject to survey selectivity at the time of the survey. These are maximum likelihood estimates from the CPT-selected model.

| Survey year | Total numbers |
|-------------|---------------|
| 1983        | 14.71         |
| 1984        | 13.39         |
| 1985        | 14.69         |
| 1986        | 43.81         |
| 1987        | 40.97         |
| 1988        | 33.54         |
| 1989        | 26.05         |
| 1990        | 21.13         |
| 1991        | 20.05         |
| 1992        | 21.53         |
| 1993        | 21.12         |
| 1994        | 20.22         |
| 1995        | 16.03         |
| 1996        | 12.22         |
| 1997        | 9.275         |
| 1998        | 8.795         |
| 1999        | 10.7          |
| 2000        | 8.978         |
| 2001        | 7.202         |
| 2002        | 7.284         |
| 2003        | 7.365         |
| 2004        | 16.08         |
| 2005        | 13.59         |
| 2006        | 10.45         |
| 2007        | 8.003         |
| 2008        | 7.526         |
| 2009        | 20.76         |
| 2010        | 17.82         |
| 2011        | 14.91         |
| 2012        | 13.91         |
| 2013        | 11.61         |
| 2014        | 9.705         |
| 2015        | 15.2          |
| 2016        | 27.76         |
| 2017        | 47.15         |
| 2018        | 37.73         |
| 2019        | 17.58         |
| 2020        | 3.73          |
| 2021        | 3.3           |
| 2022        | 2.584         |

Table 16: Maximum likelihood estimates of predicted mature male biomass at mating, male recruitment (billions) from the CPT-selected model, and estimated fully-selected total fishing mortality.

| Survey year | Mature male biomass | Male recruits | Fishing mortality |
|-------------|---------------------|---------------|-------------------|
| 1982        | 557.4               | 3.27          | 0.07              |
| 1983        | 525.6               | 2.07          | 0.07              |
| 1984        | 504                 | 3.07          | 0.16              |
| 1985        | 458.1               | 5.14          | 0.24              |
| 1986        | 412.8               | 0.59          | 0.29              |
| 1987        | 386.9               | 2.25          | 0.42              |
| 1988        | 410.9               | 0.14          | 0.43              |
| 1989        | 449.1               | 0.67          | 0.42              |
| 1990        | 418.1               | 3.1           | 0.86              |
| 1991        | 370.8               | 4.37          | 0.91              |
| 1992        | 290.8               | 1.69          | 1.06              |
| 1993        | 253.9               | 0.28          | 0.79              |
| 1994        | 252.1               | 0.07          | 0.54              |
| 1995        | 293                 | 0.15          | 0.42              |
| 1996        | 356.2               | 0.14          | 0.43              |
| 1997        | 354.7               | 1.95          | 0.6               |
| 1998        | 290.7               | 0.1           | 0.6               |
| 1999        | 249.6               | 0.36          | 0.13              |
| 2000        | 200.1               | 0.32          | 0.14              |
| 2001        | 161.8               | 1.84          | 0.29              |
| 2002        | 156.1               | 1.77          | 0.24              |
| 2003        | 168.6               | 1.23          | 0.14              |
| 2004        | 165.3               | 1.12          | 0.15              |
| 2005        | 156.8               | 0.17          | 0.29              |
| 2006        | 175.9               | 0.08          | 0.27              |
| 2007        | 208.8               | 0.52          | 0.33              |
| 2008        | 236                 | 1.19          | 0.25              |
| 2009        | 240.2               | 0.16          | 0.18              |
| 2010        | 217.6               | 0.44          | 0.18              |
| 2011        | 158.6               | 0.43          | 0.48              |
| 2012        | 118.5               | 1.05          | 0.63              |
| 2013        | 104.5               | 0.87          | 0.69              |
| 2014        | 91.41               | 6.07          | 0.96              |
| 2015        | 84.78               | 6.87          | 0.78              |
| 2016        | 100.2               | 11.43         | 0.38              |
| 2017        | 149.6               | 0.09          | 0.28              |
| 2018        | 99.66               | 0.04          | 0.56              |
| 2019        | 29.88               | 0.03          | 2.22              |
| 2020        | 19.06               | 0.4           | 5.09              |
| 2021        | 41.21               | 0.08          | 0.22              |

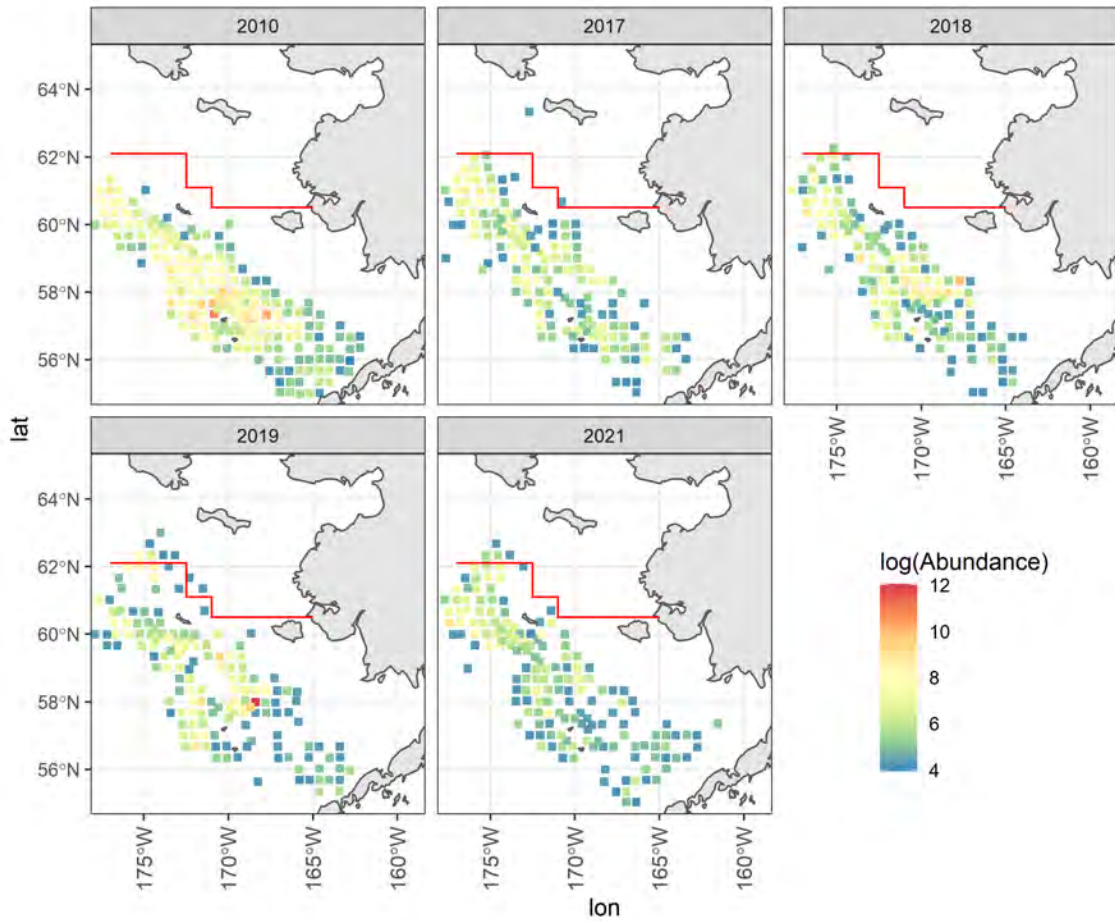


Figure 1: Abundances (in log space) of male crab with carapaced wider than 101 mm from years in which the northern Bering Sea was surveyed. The red line represents the border between the northern and eastern Bering Sea survey grids. Colored squares are survey tows in which large males were captured.

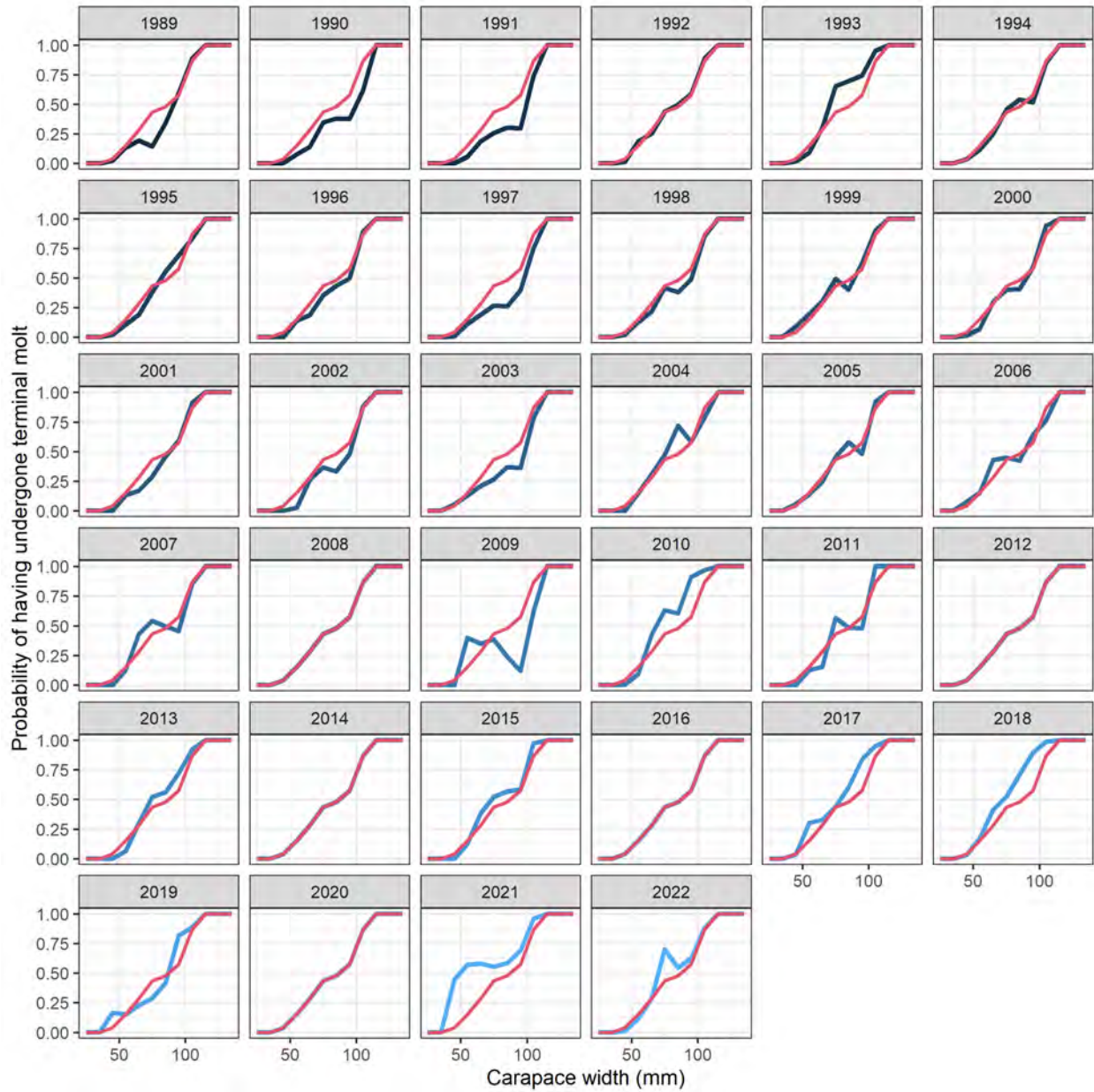


Figure 2: Observed probability of having undergone terminal molt for new shell male crab. Blue lines are the yearly data and red lines are the averages over all years.



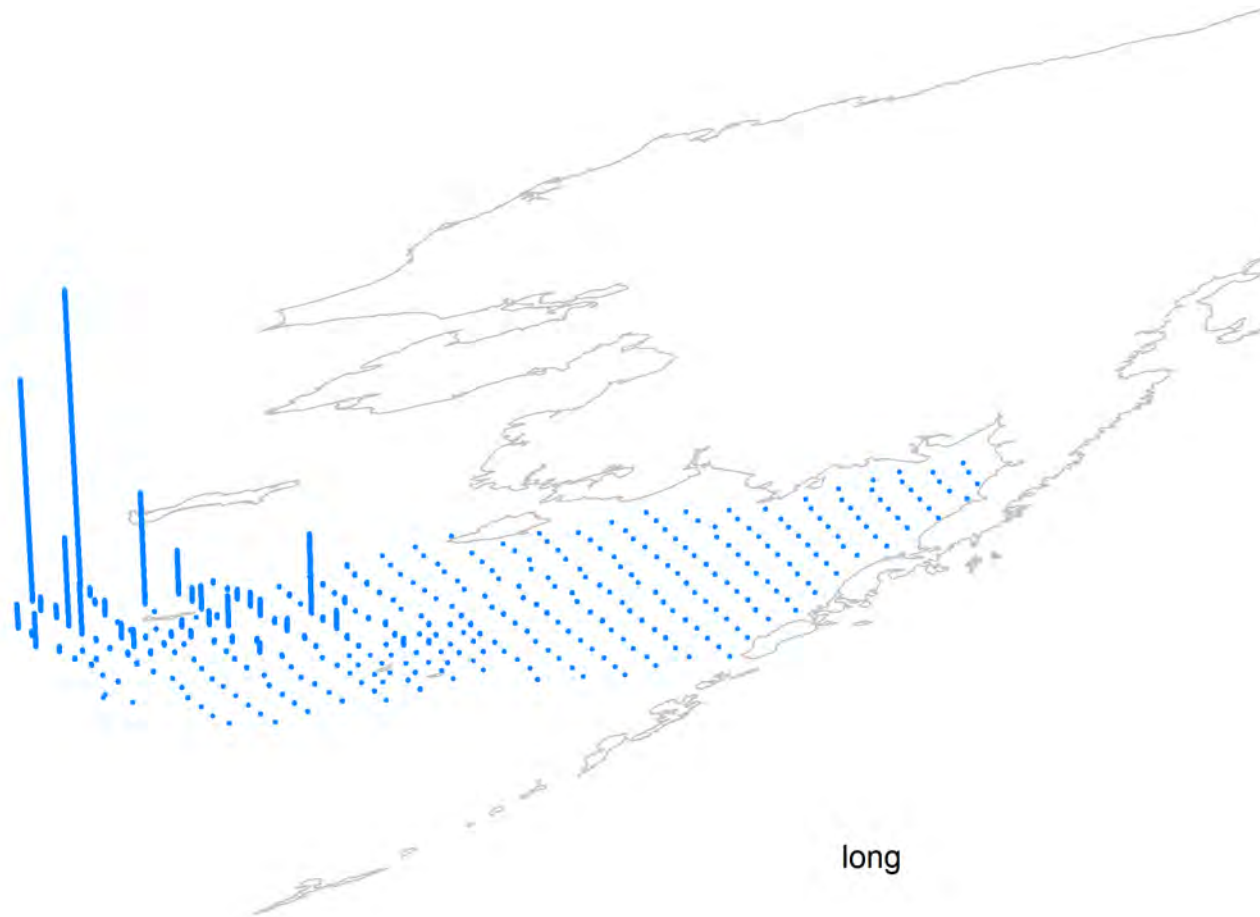


Figure 3: Observed relative density of all males at the time of the 2022 NMFS summer survey

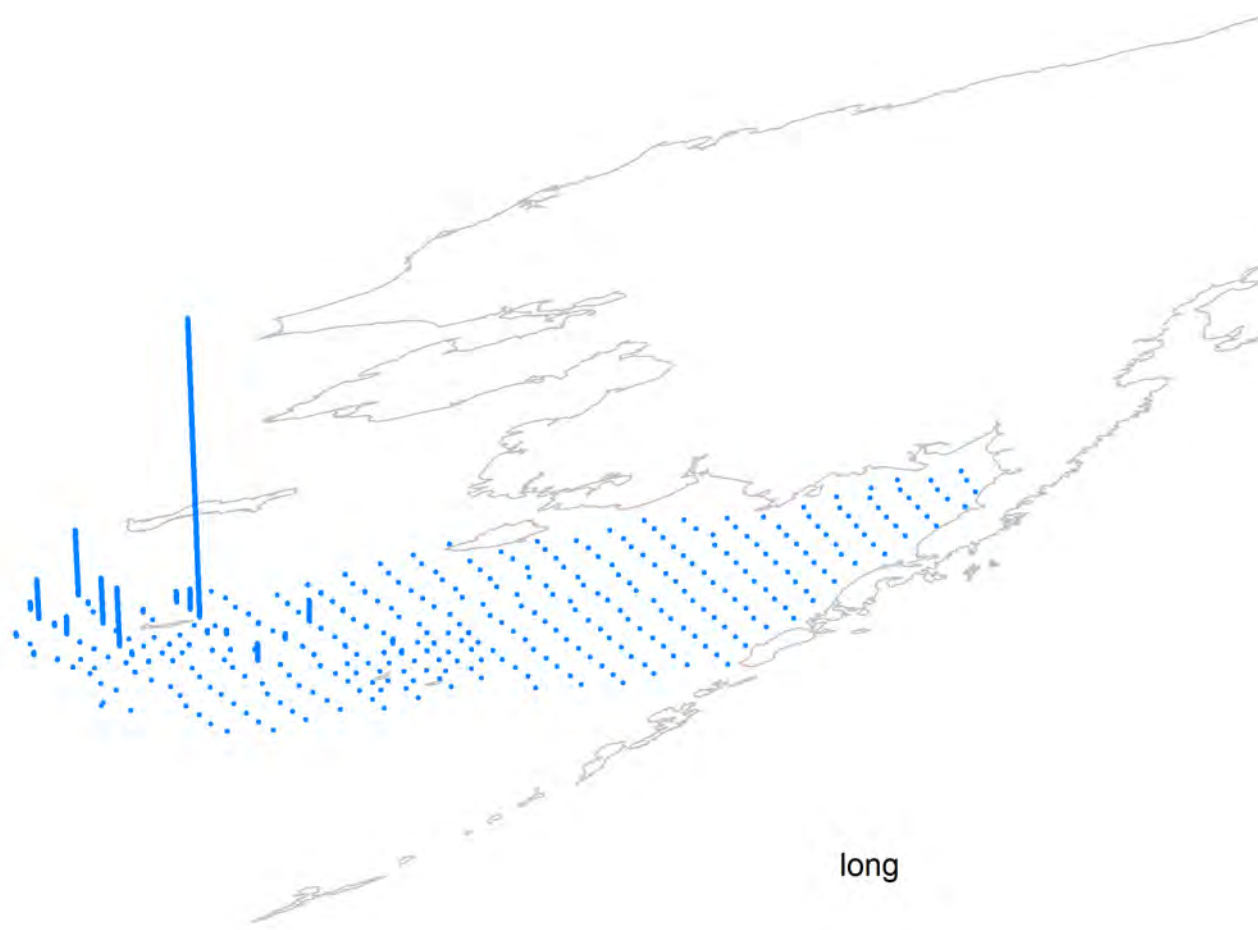


Figure 4: Observed relative density of all females at the time of the 2022 NMFS summer survey

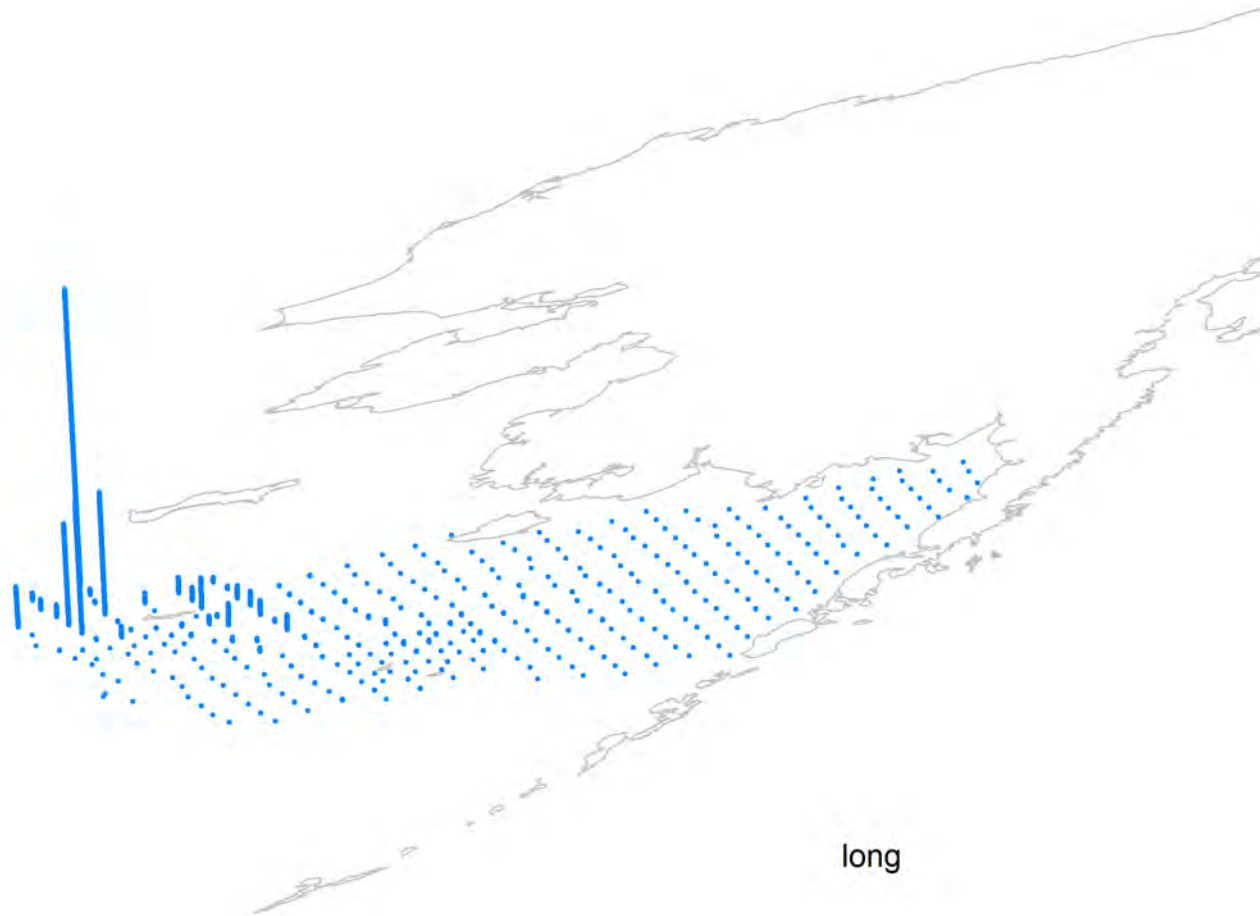


Figure 5: Observed relative density of males <70 mm carapace width at the time of the 2022 NMFS summer survey

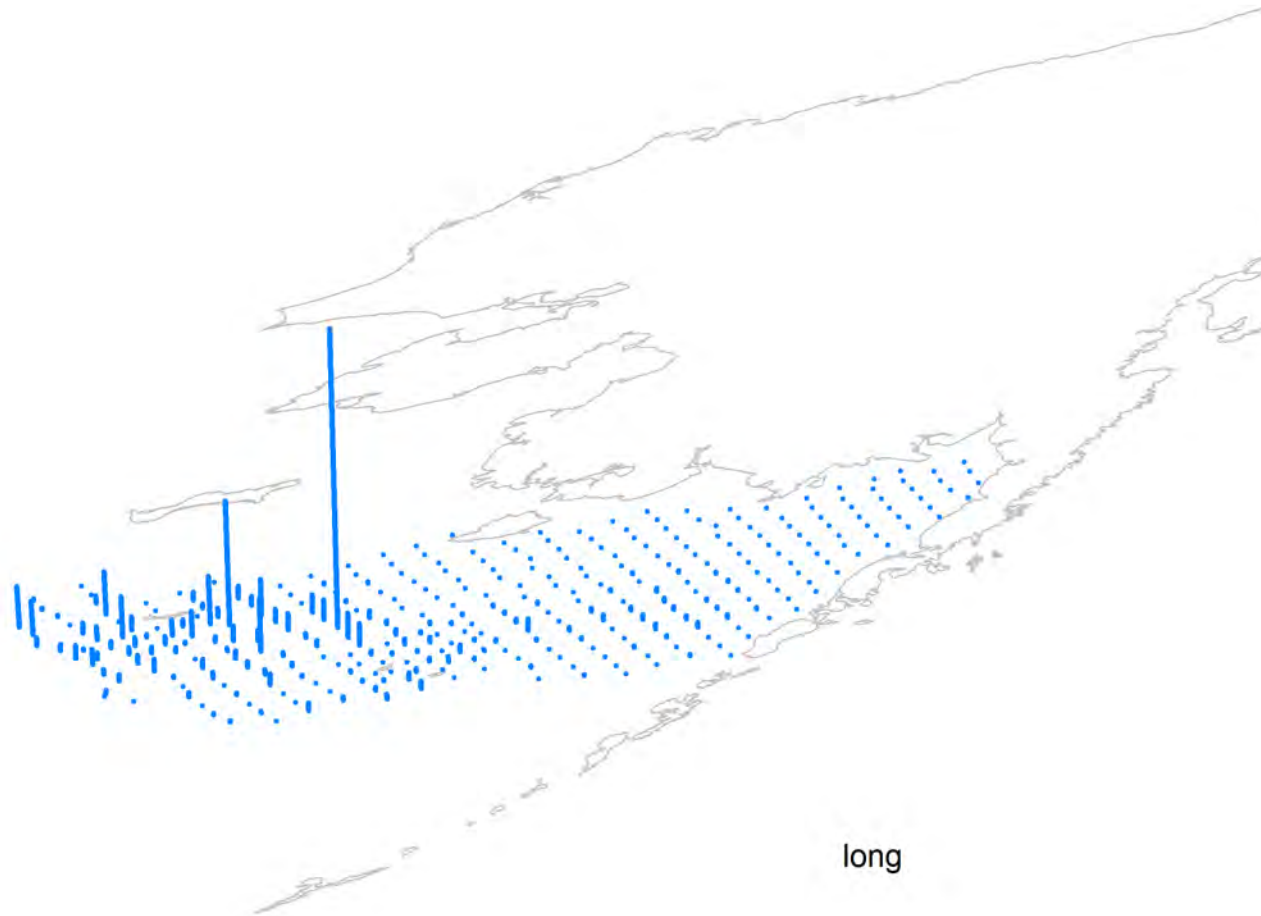


Figure 6: Observed relative density of males greater than 101 mm carapace width at the time of the 2022 NMFS summer survey

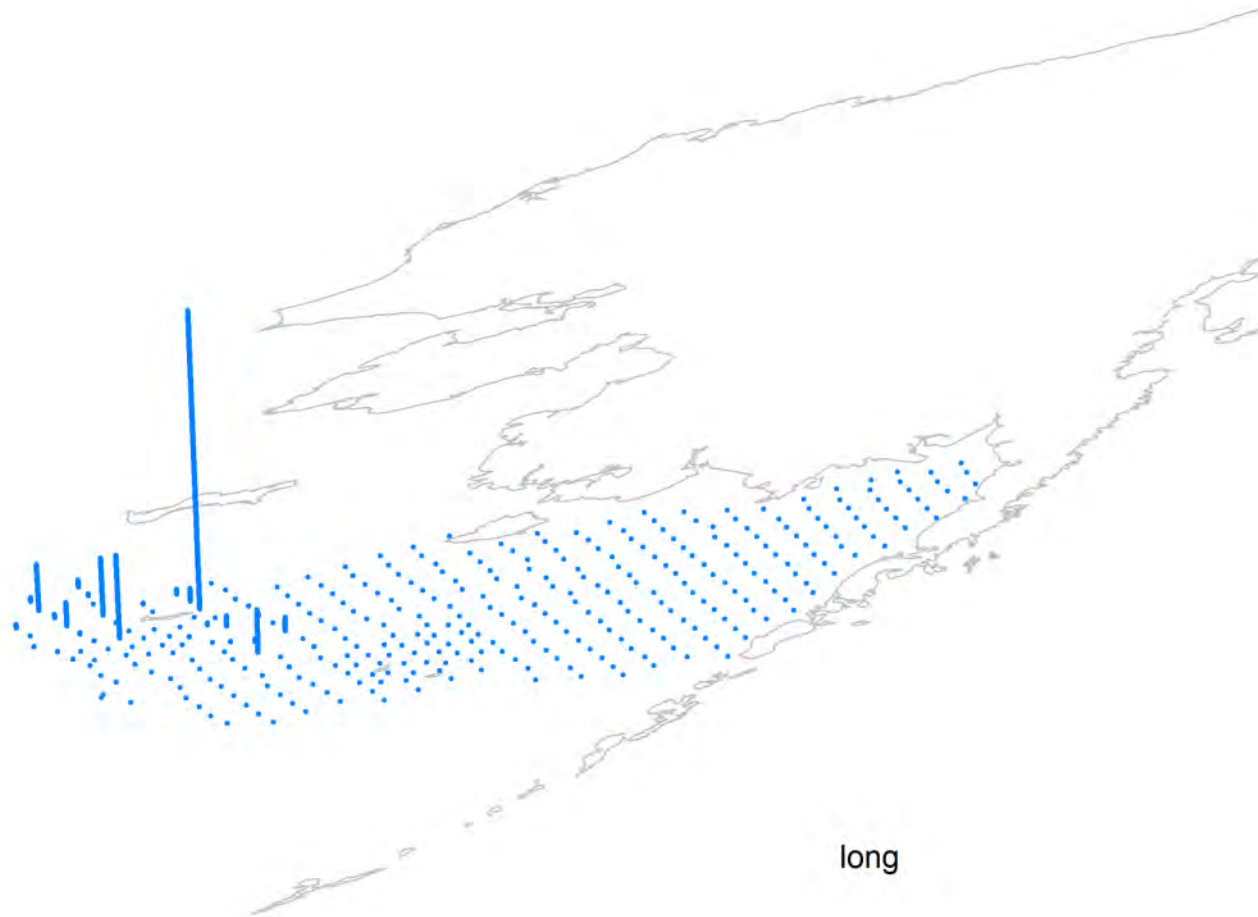


Figure 7: Observed relative density of mature females at the time of the 2022 NMFS summer survey

| Shell condition | CW (mm) | Age (years) | Error (years) | Coordinates       | Depth (m) | Species          |
|-----------------|---------|-------------|---------------|-------------------|-----------|------------------|
| 0+              | 121     | 0.05        | 0.26          | 59°20'N, 171°49'W | 43        | <i>C. opilio</i> |
| 0+              | 110     | 0.11        | 0.27          | 59°20'N, 171°49'W | 43        | <i>C. opilio</i> |
| 0+              | 132     | 0.11        | 0.19          | 59°20'N, 171°49'W | 43        | <i>C. opilio</i> |
| 1               | 118     | 0.15        | 0.26          | 59°20'N, 171°49'W | 43        | <i>C. opilio</i> |
| 1               | 130     | 0.23        | 0.27          | 59°20'N, 171°49'W | 43        | <i>C. opilio</i> |
| 1               | 116     | 0.25        | 0.24          | 59°20'N, 171°49'W | 43        | <i>C. opilio</i> |
| 2+              | 93      | 0.33        | 0.28          | 57°00'N, 167°43'W | 42        | <i>C. bairdi</i> |
| 2+              | 122     | 0.42        | 0.26          | 57°00'N, 167°43'W | 42        | <i>C. bairdi</i> |
| 2+              | 97      | 0.66        | 0.30          | 59°00'N, 171°47'W | 46        | <i>C. opilio</i> |
| 2+              | 123     | 0.78        | 0.32          | 59°00'N, 171°47'W | 46        | <i>C. opilio</i> |
| 2+              | 121     | 0.85        | 0.27          | 57°00'N, 167°43'W | 42        | <i>C. opilio</i> |
| 2+              | 66      | 1.07        | 0.29          | 59°00'N, 171°47'W | 46        | <i>C. opilio</i> |
| 3               | 117     | 0.92        | 0.34          | 59°00'N, 171°47'W | 46        | <i>C. opilio</i> |
| 3               | 69      | 1.04        | 0.28          | 59°00'N, 171°47'W | 46        | <i>C. opilio</i> |
| 3               | 78      | 1.10        | 0.30          | 59°00'N, 171°47'W | 46        | <i>C. opilio</i> |
| 4               | 100     | 4.43        | 0.33          | 57°21'N, 167°45'W | 39        | <i>C. opilio</i> |
| 4               | 93      | 4.89        | 0.37          | 58°20'N, 171°38'W | 52        | <i>C. bairdi</i> |
| 4               | 100     | 6.60        | 0.33          | 57°00'N, 167°43'W | 42        | <i>C. opilio</i> |
| 5               | 111     | 2.70        | 0.44          | 58°60'N, 169°12'W | 28        | <i>C. opilio</i> |
| 5               | 100     | 4.21        | 0.34          | 59°00'N, 171°47'W | 46        | <i>C. bairdi</i> |
| 5               | 110     | 6.85        | 0.58          | 58°60'N, 169°12'W | 28        | <i>C. opilio</i> |

Figure 8: Radiometric estimates of shell age in male snow and tanner crabs collected during the NMFS survey of 1992. Reproduced from Ernst et al. 2005's presentation of Nevissi et al. 1995.

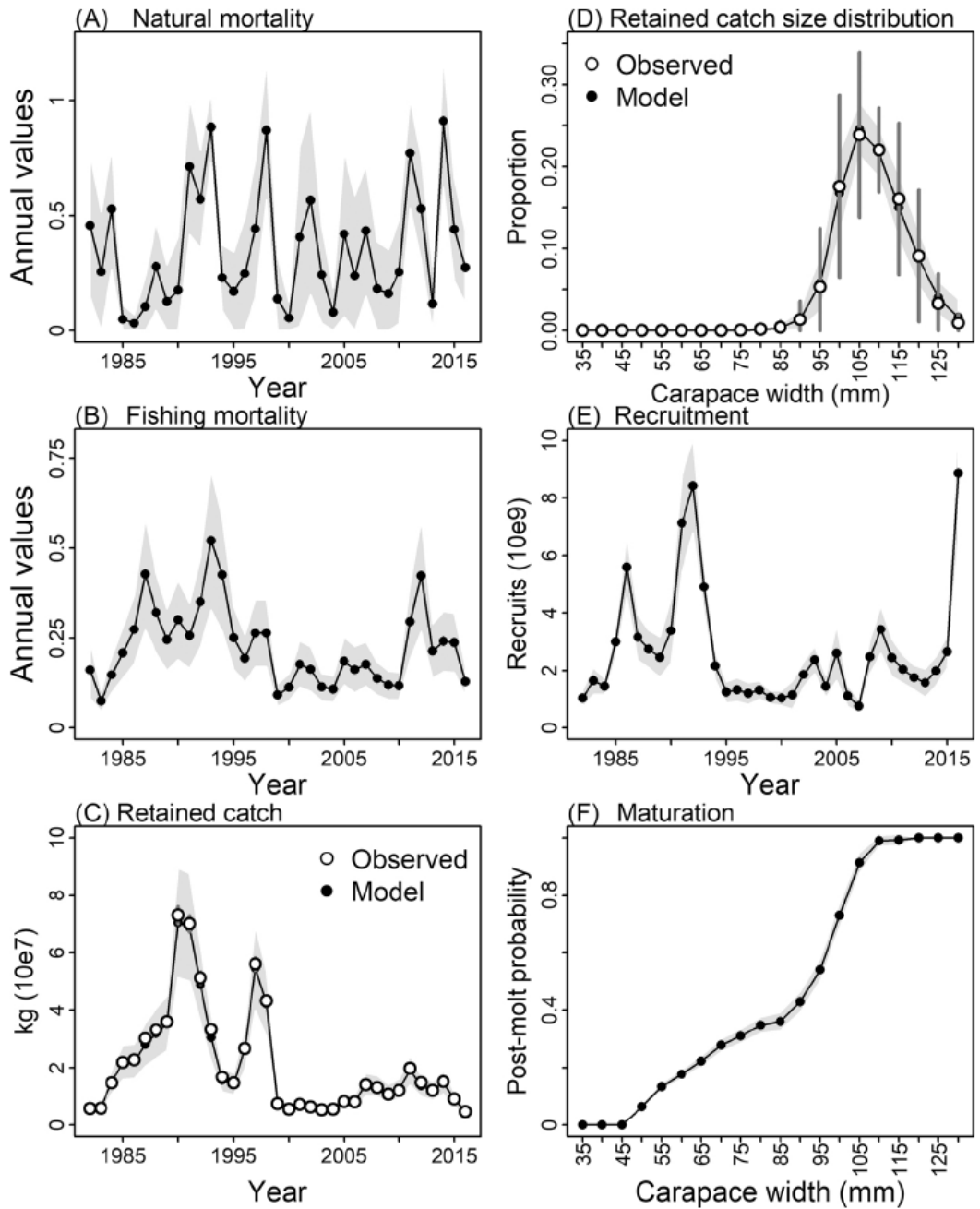


Figure 9: Estimated time-variation in natural mortality and other model output from Murphy et al. 2018.

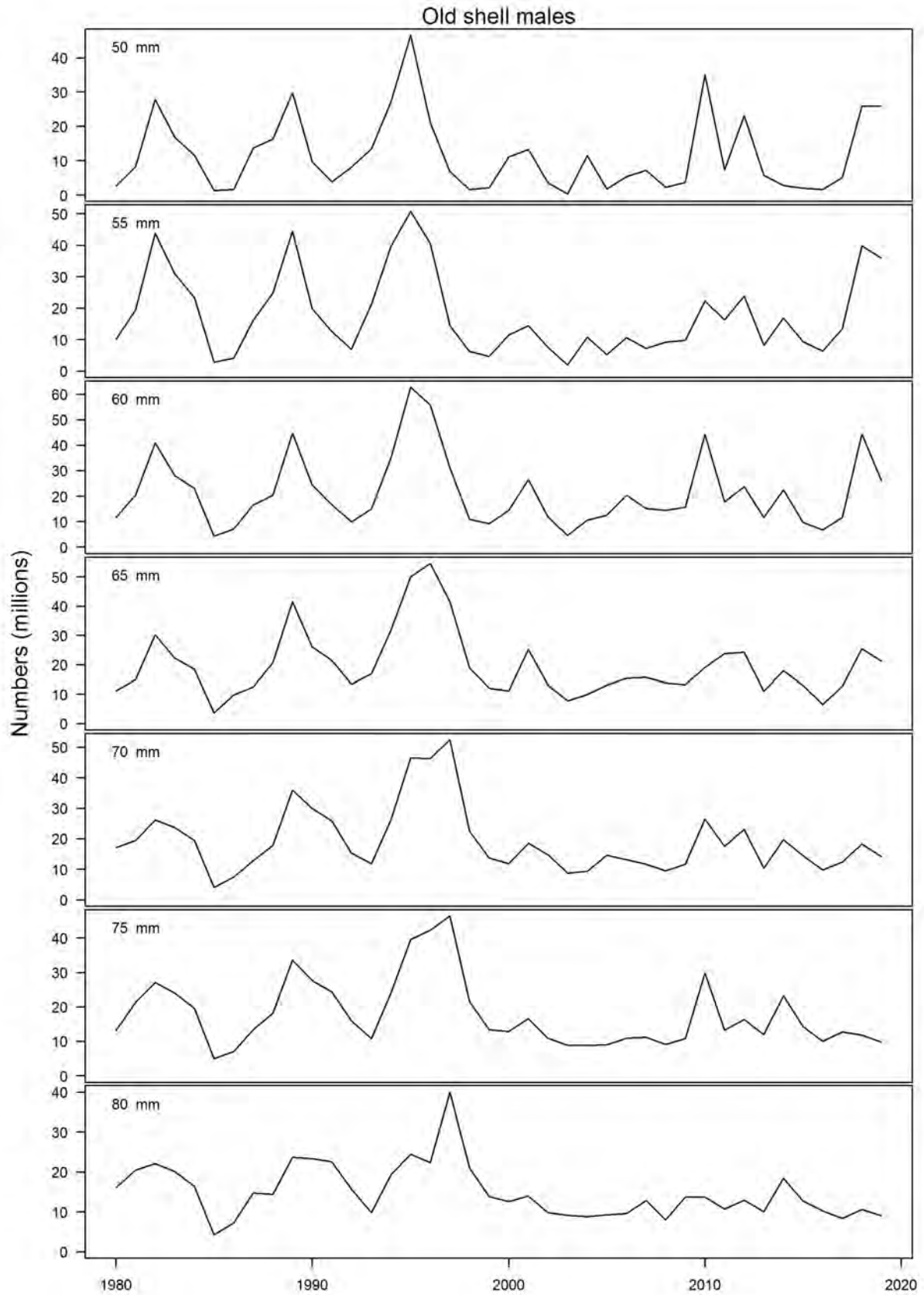


Figure 10: Observed numbers at length of old shell mature males by size class. The presented size bins are not vulnerable to the fishery, so all mortality is 'natural'. The decline in numbers in a size class after the recruitment collapse in the early 1990s demonstrates expected natural mortality for mature male individuals.



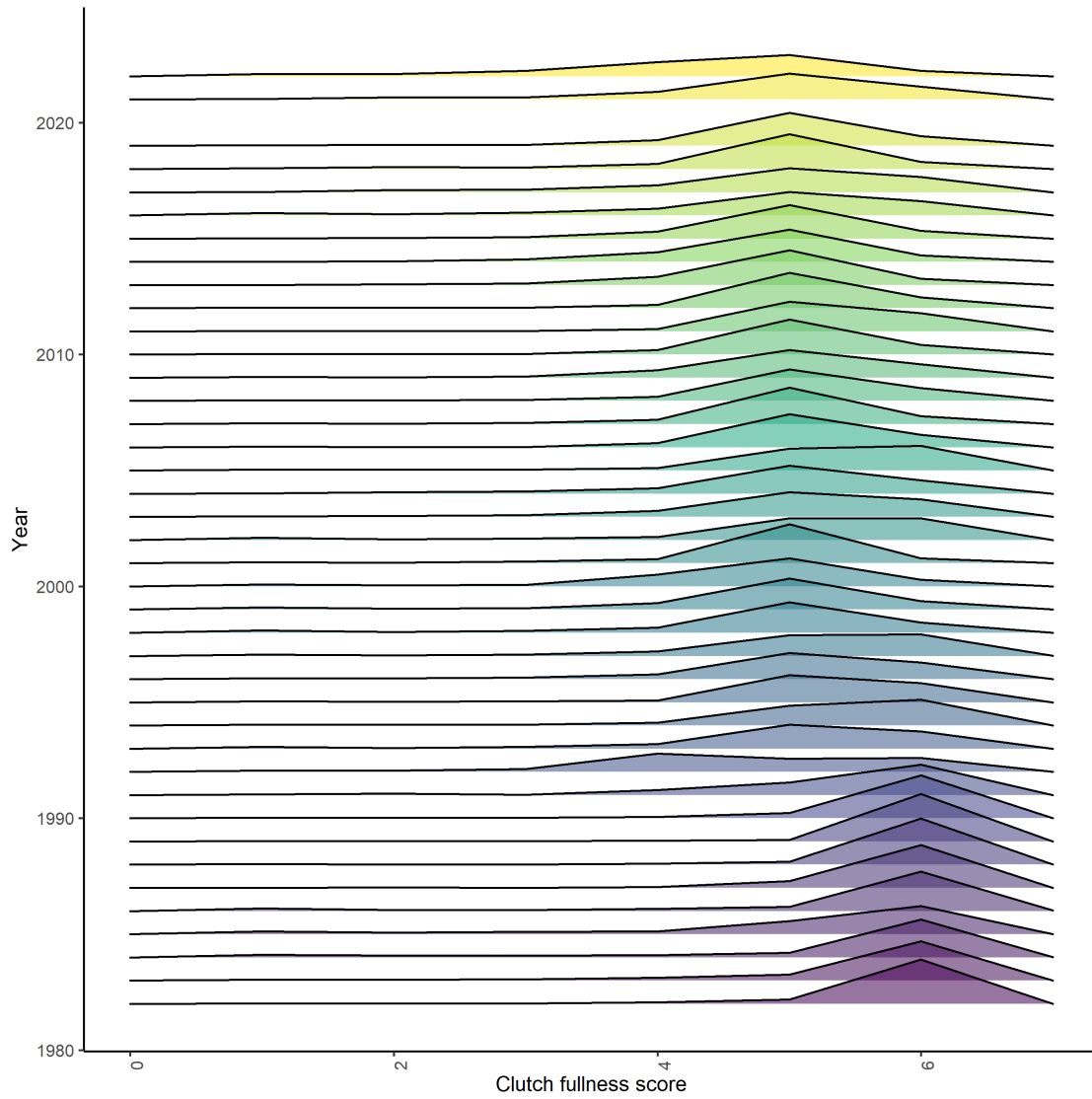


Figure 11: Clutch fullness scores from the 1982-2021 NMFS summer survey. Scores: 0 = immature, 1 = mature no eggs, 2 = trace to 0.125, 3 = 0.25, 4 = 0.5, 5 = 0.75, 6 = full of eggs; 7 = overflowing.

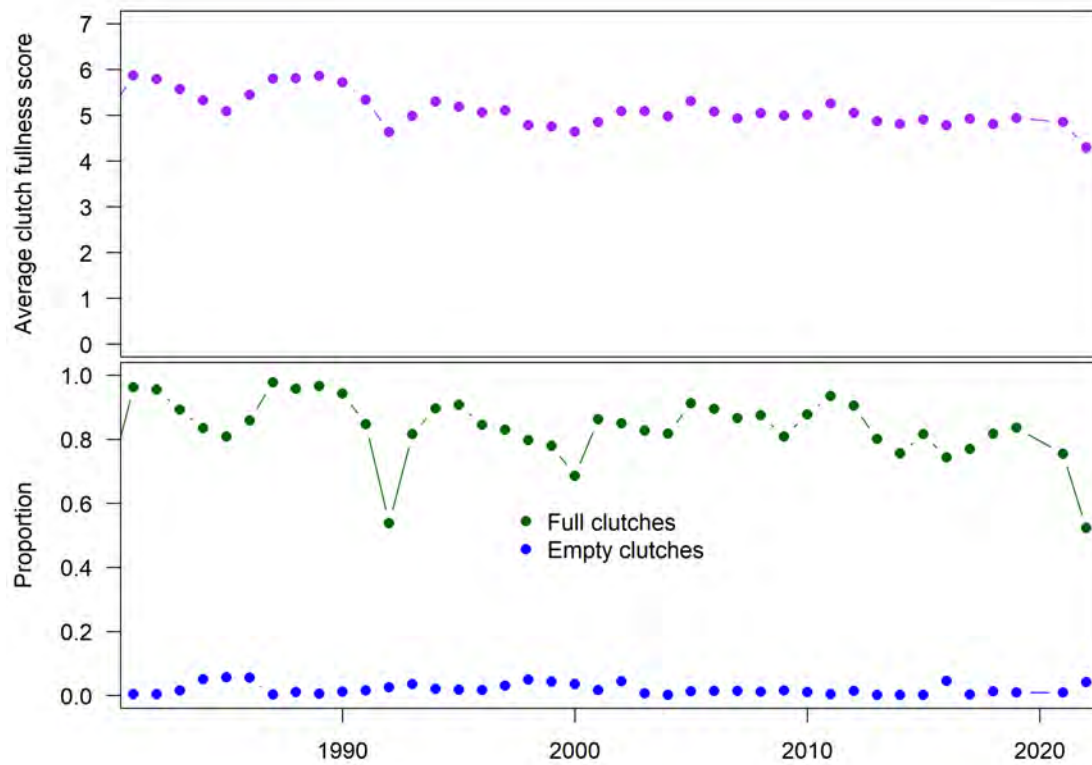


Figure 12: Time series of the average clutch fullness score (top) and the proportion of observed crab with full clutches (green) and empty clutches (blue) in the NMFS summer survey (bottom). Scores: 0 = immature, 1 = mature no eggs, 2 = trace to 0.125, 3 = 0.25, 4 = 0.5, 5 = 0.75, 6 = full of eggs; 7 = overflowing..

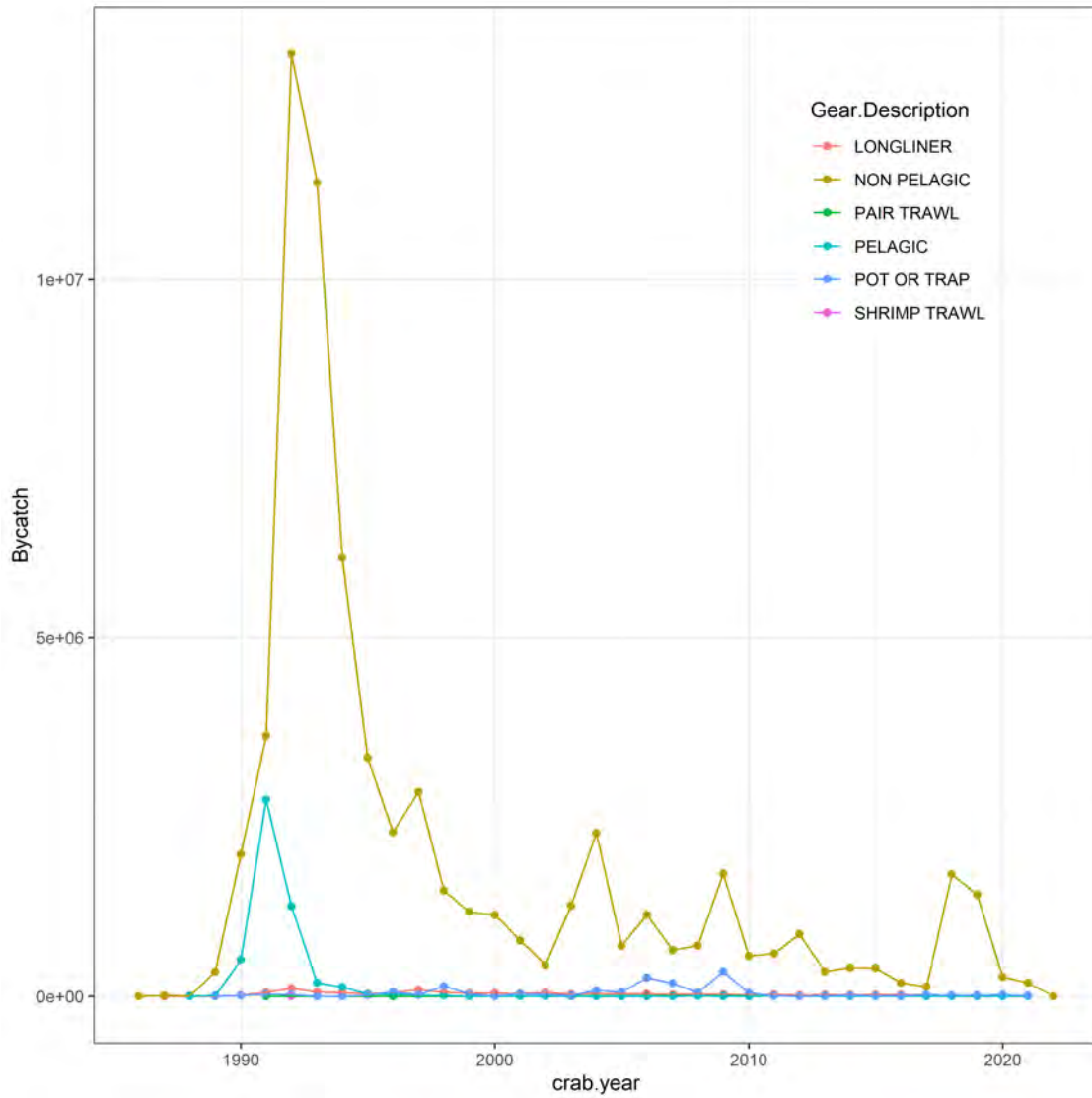


Figure 13: Time series of bycatch by gear in numbers of crab.

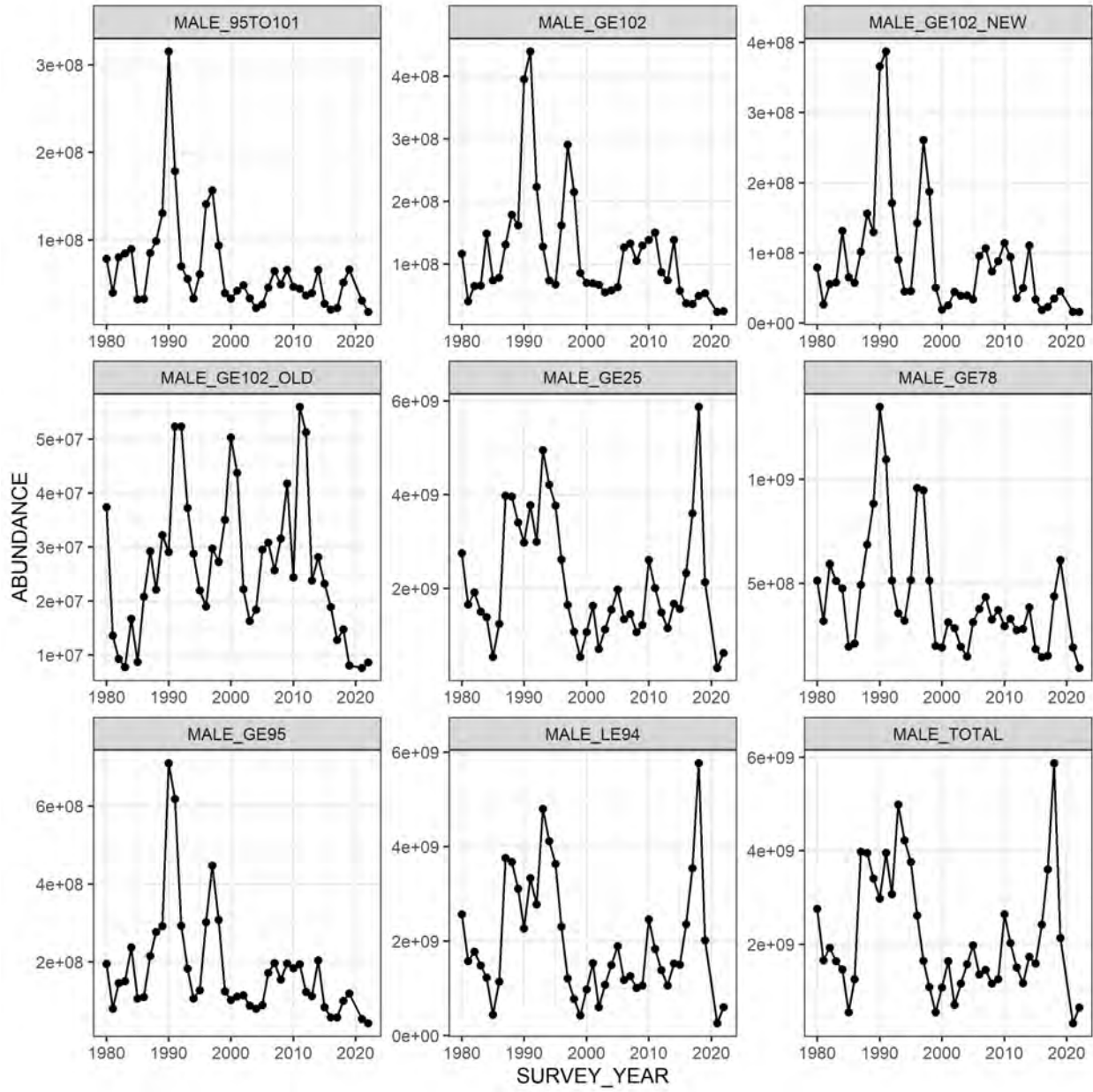


Figure 14: Abundance of males estimated from the NMFS summer survey over time for different size classes. GE102 means greater than or equal to 102 mm carapace width.

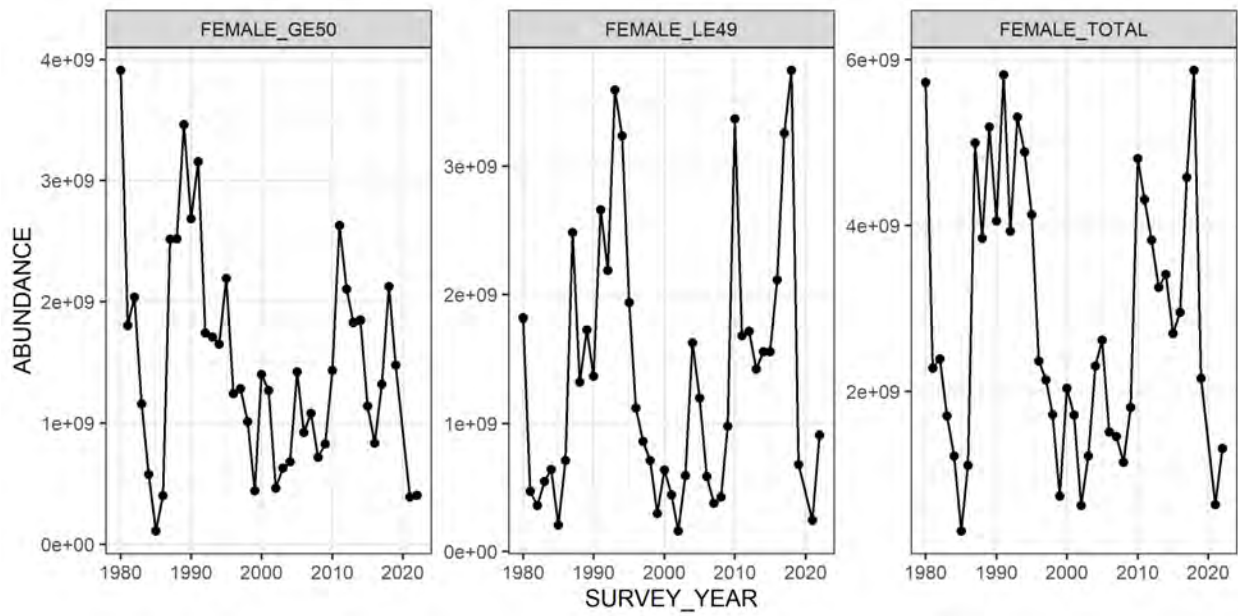


Figure 15: Abundance of females estimated from the NMFS summer survey over time for different size classes. GE50 means greater than or equal to 50 mm carapace width.

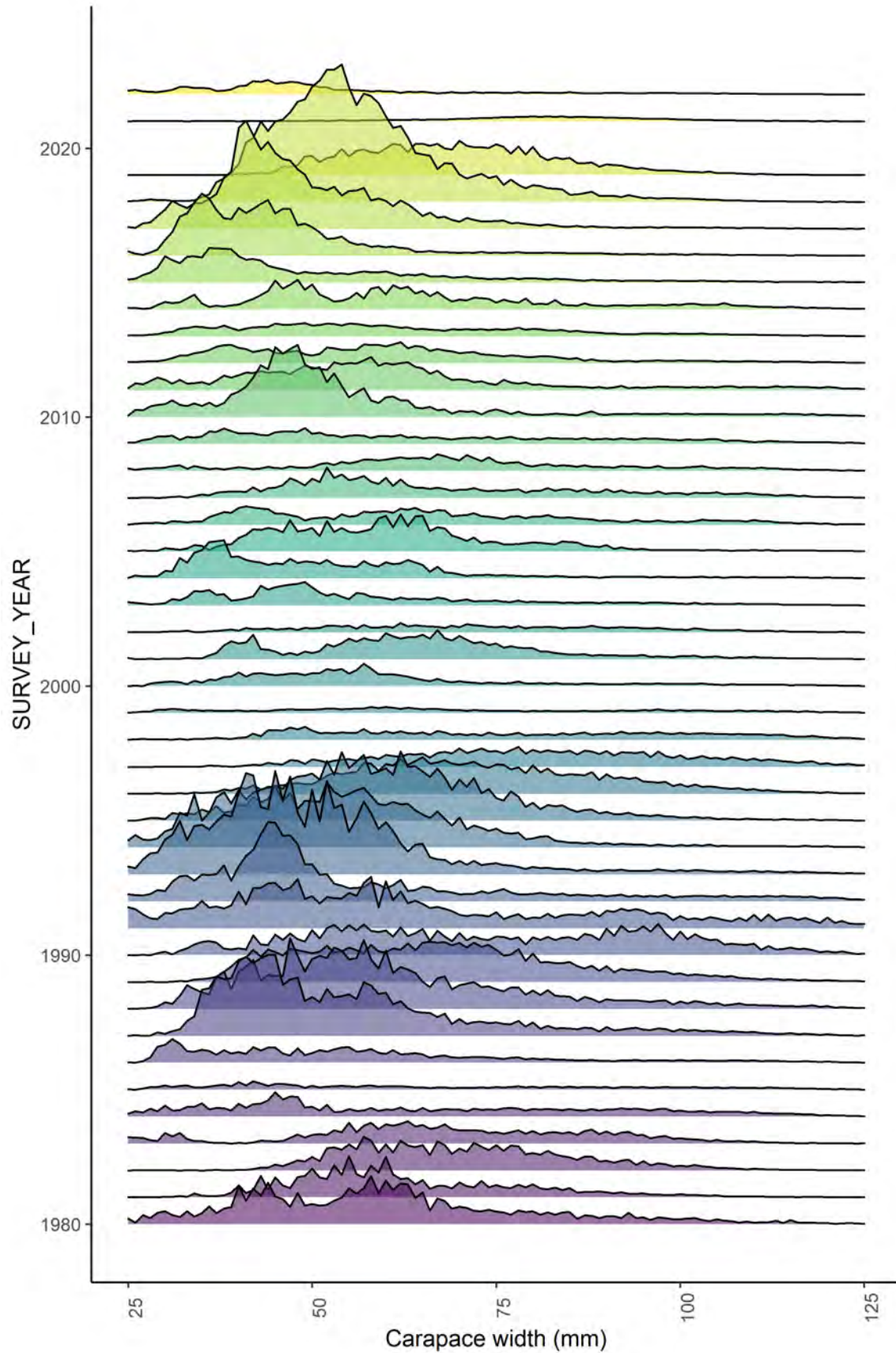


Figure 16: Raw total numbers at size of male crab observed in the survey.

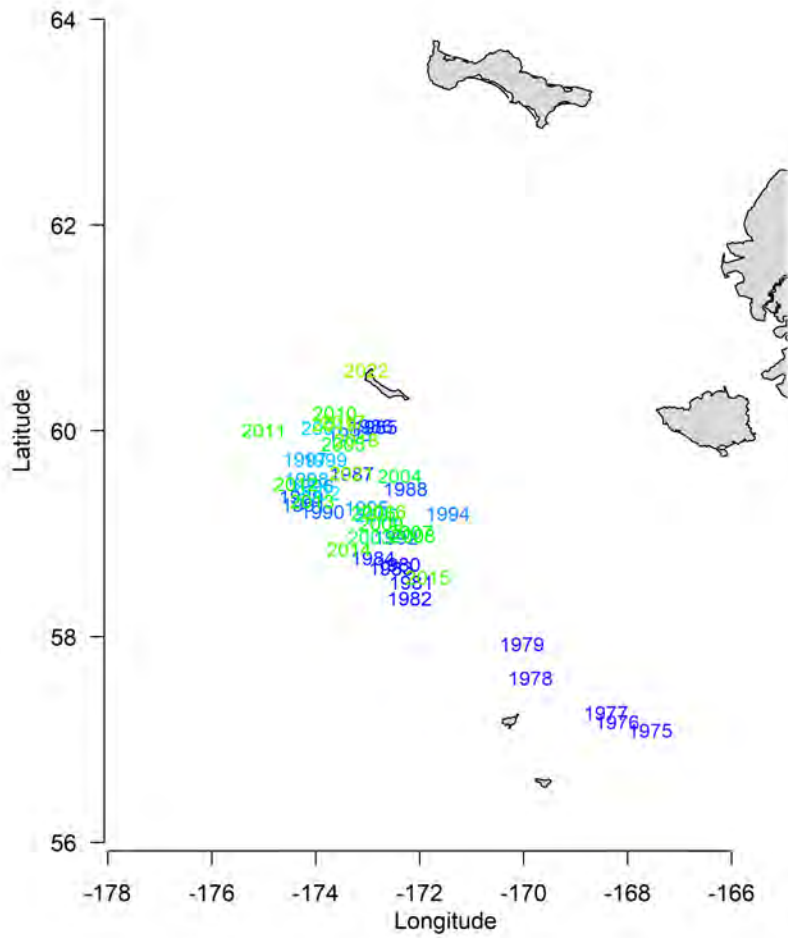


Figure 17: Centroids of abundance for mature females over time.

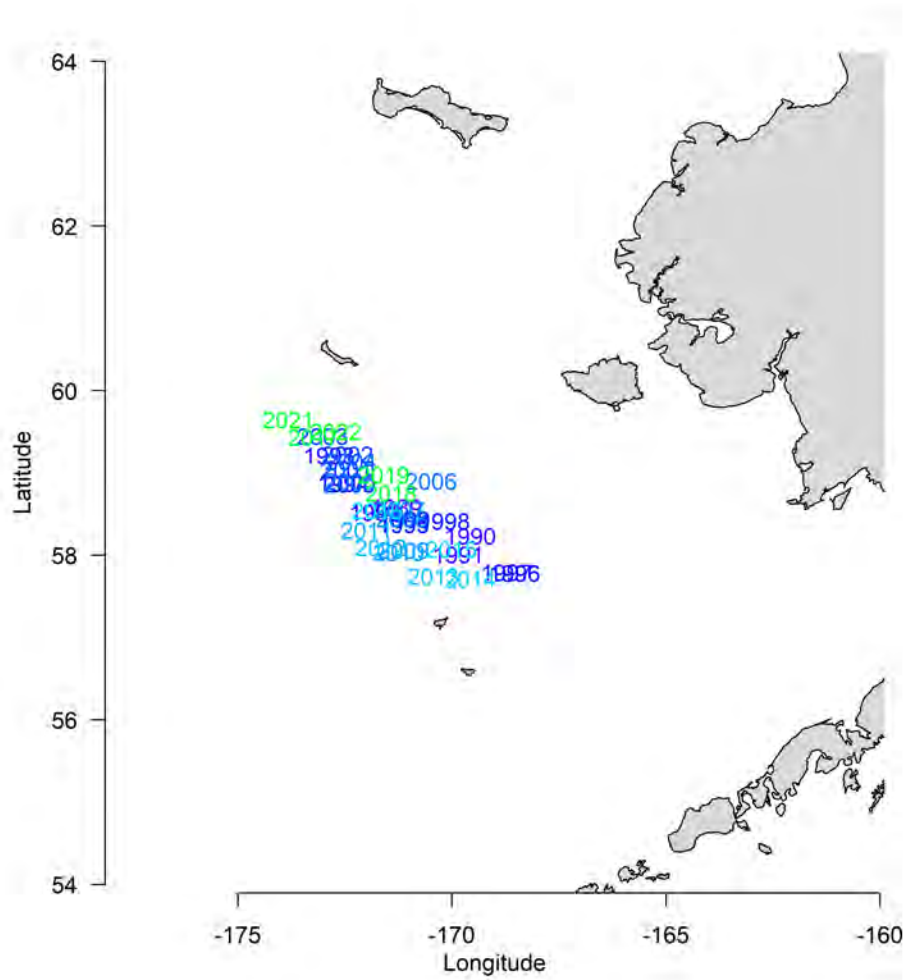


Figure 18: Centroids of abundance for males greater than 101 mm carapace width.



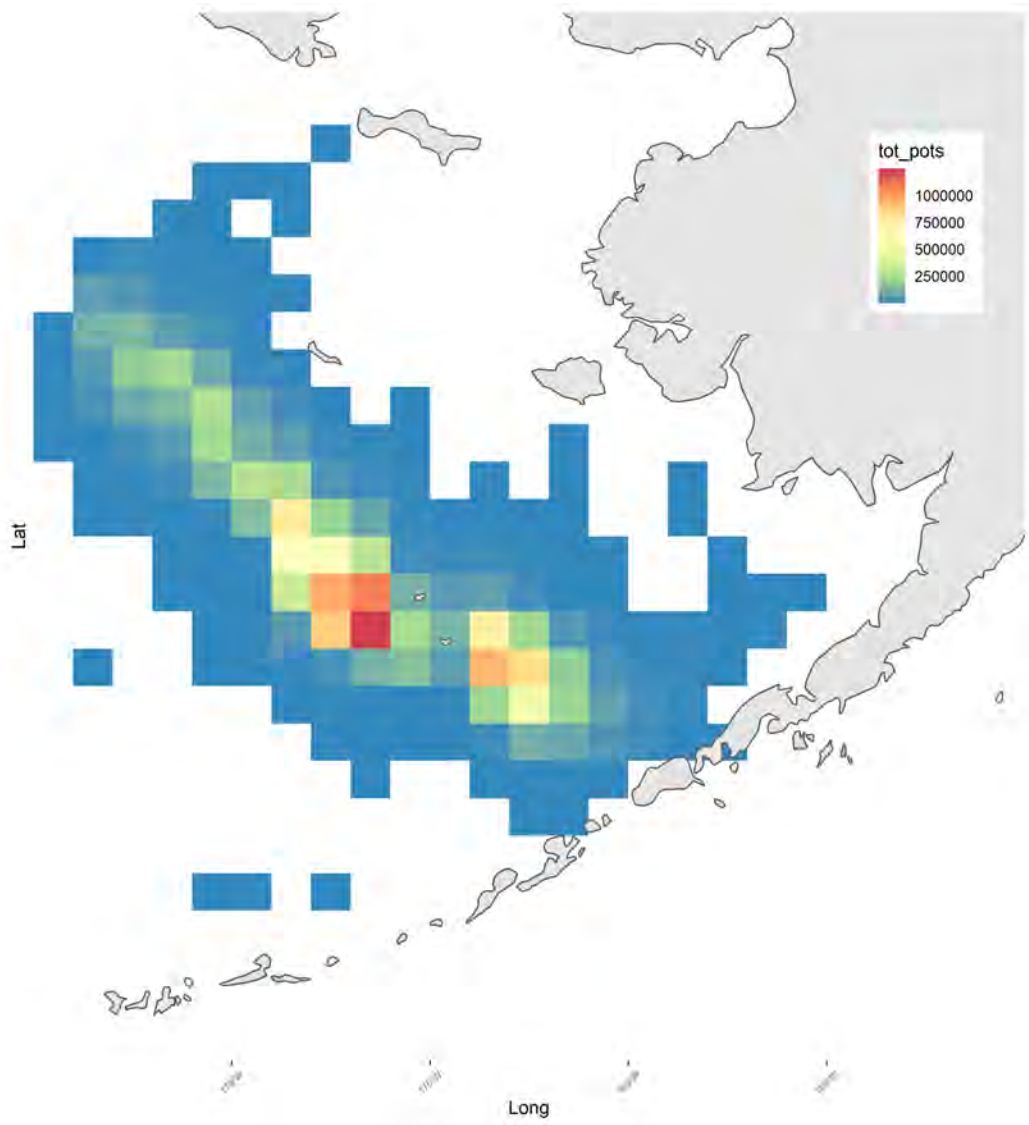


Figure 19: Heatmap of effort in terms of potlifts summed over time.

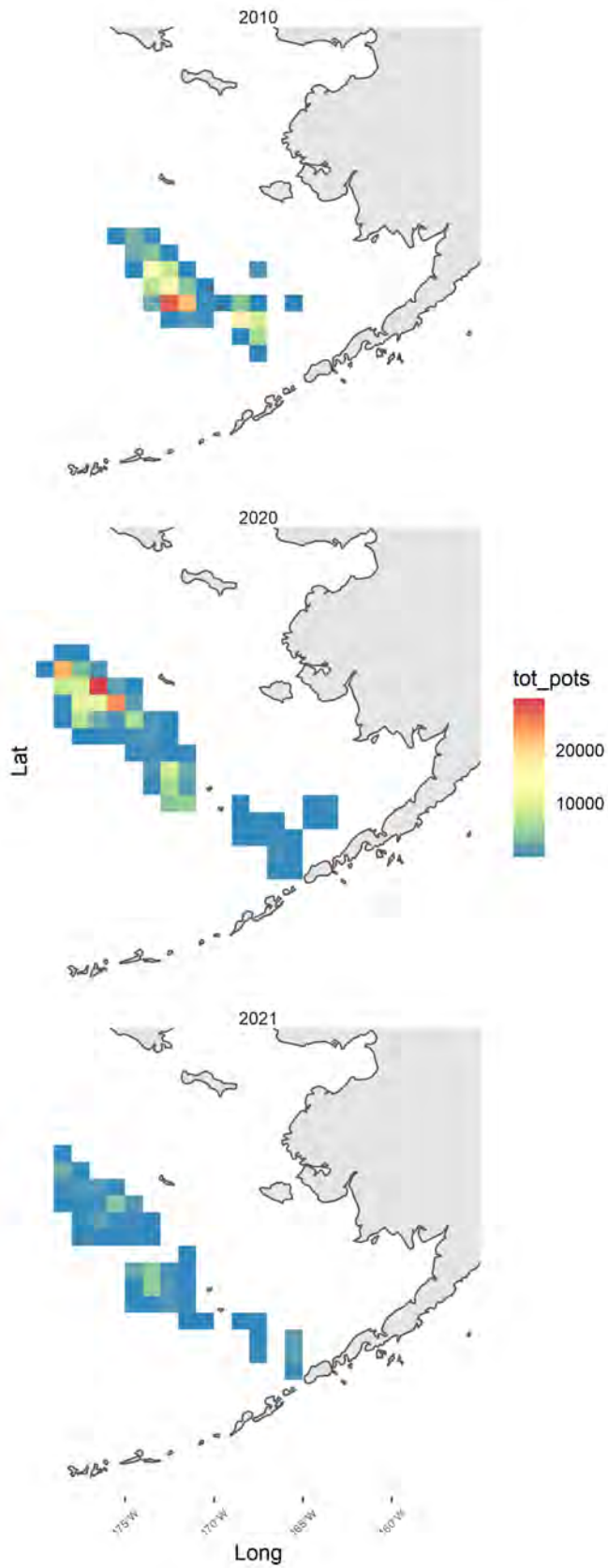


Figure 20: Spatial distribution of effort in selected years.

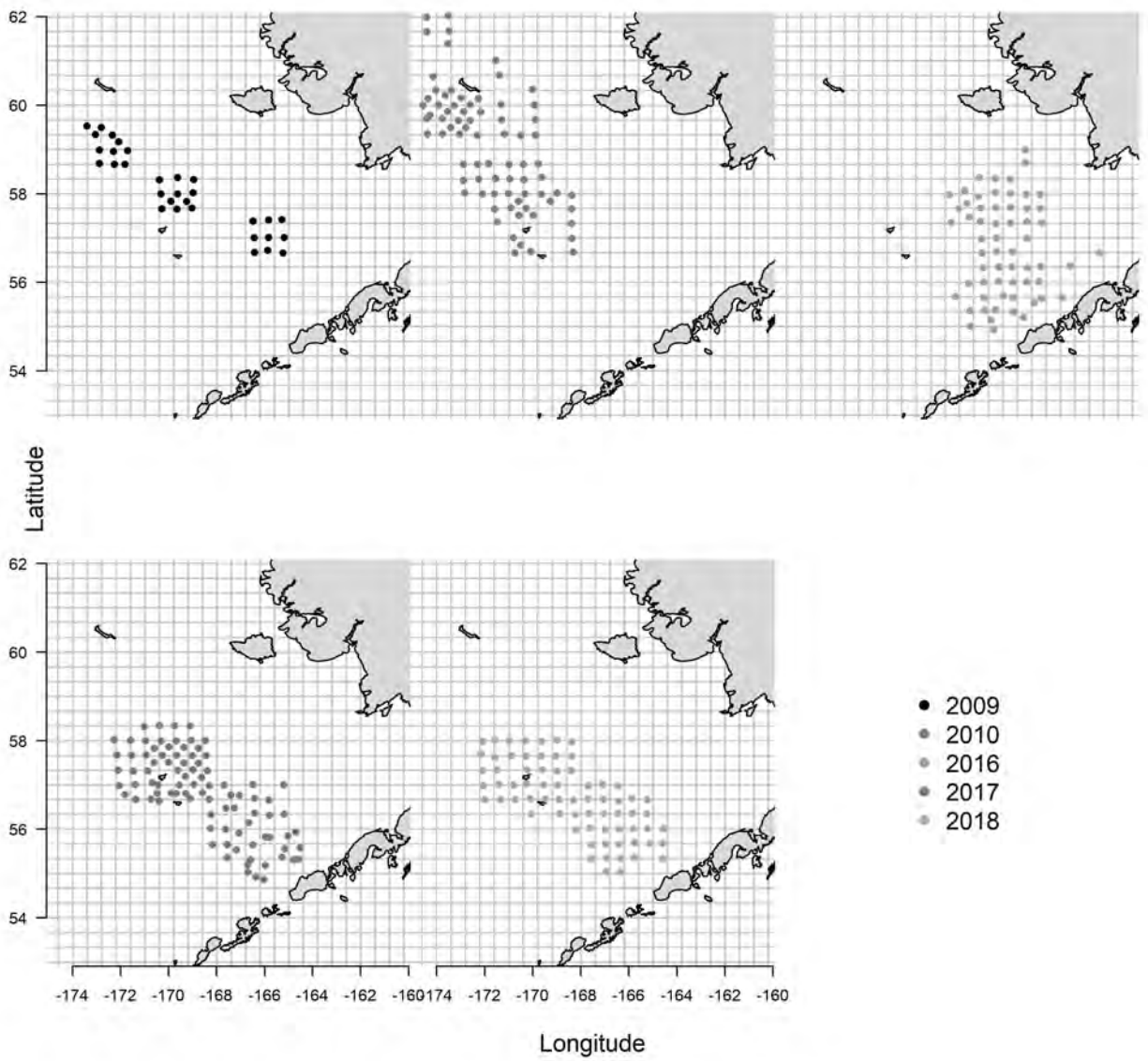


Figure 21: Location of BSFRF survey selectivity experiments.

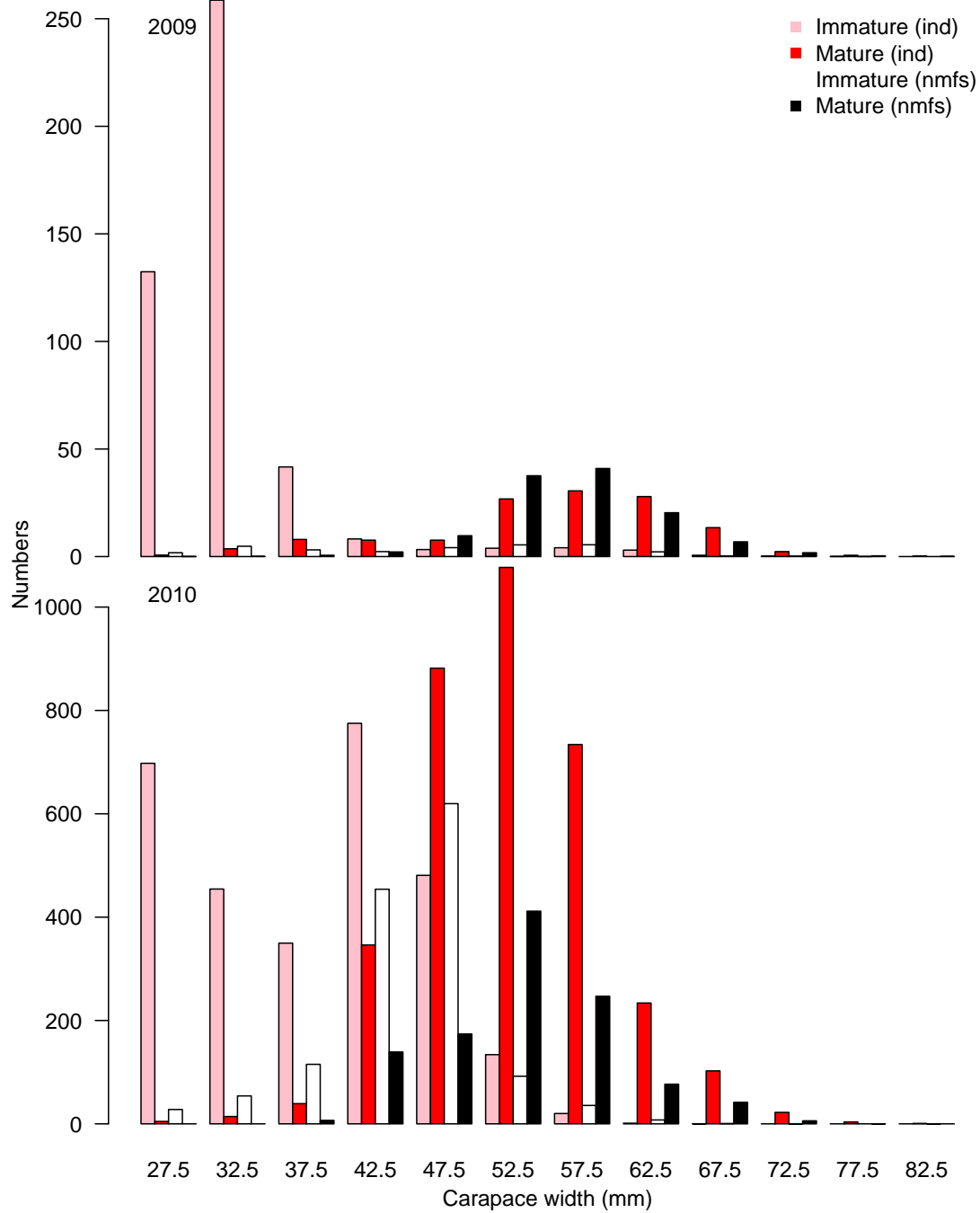


Figure 22: Raw female numbers from BSFRF survey selectivity experiments (2009 & 2010). Note a change in scale on the y-axis from 2009 to 2010

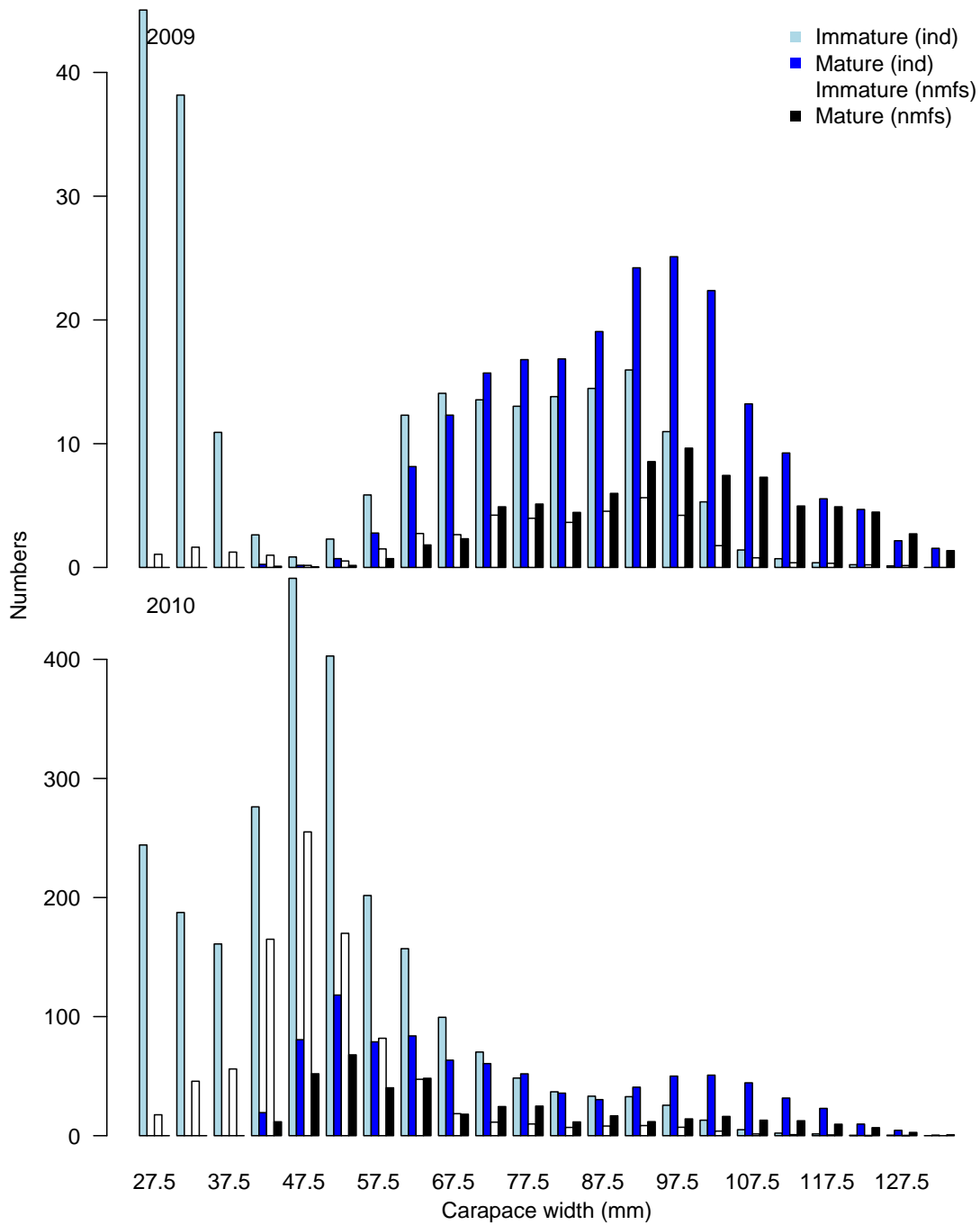


Figure 23: Raw male numbers from BSFRF survey selectivity experiments (2009 & 2010). Note a change in scale from 2009 to 2010 on the y-axis.

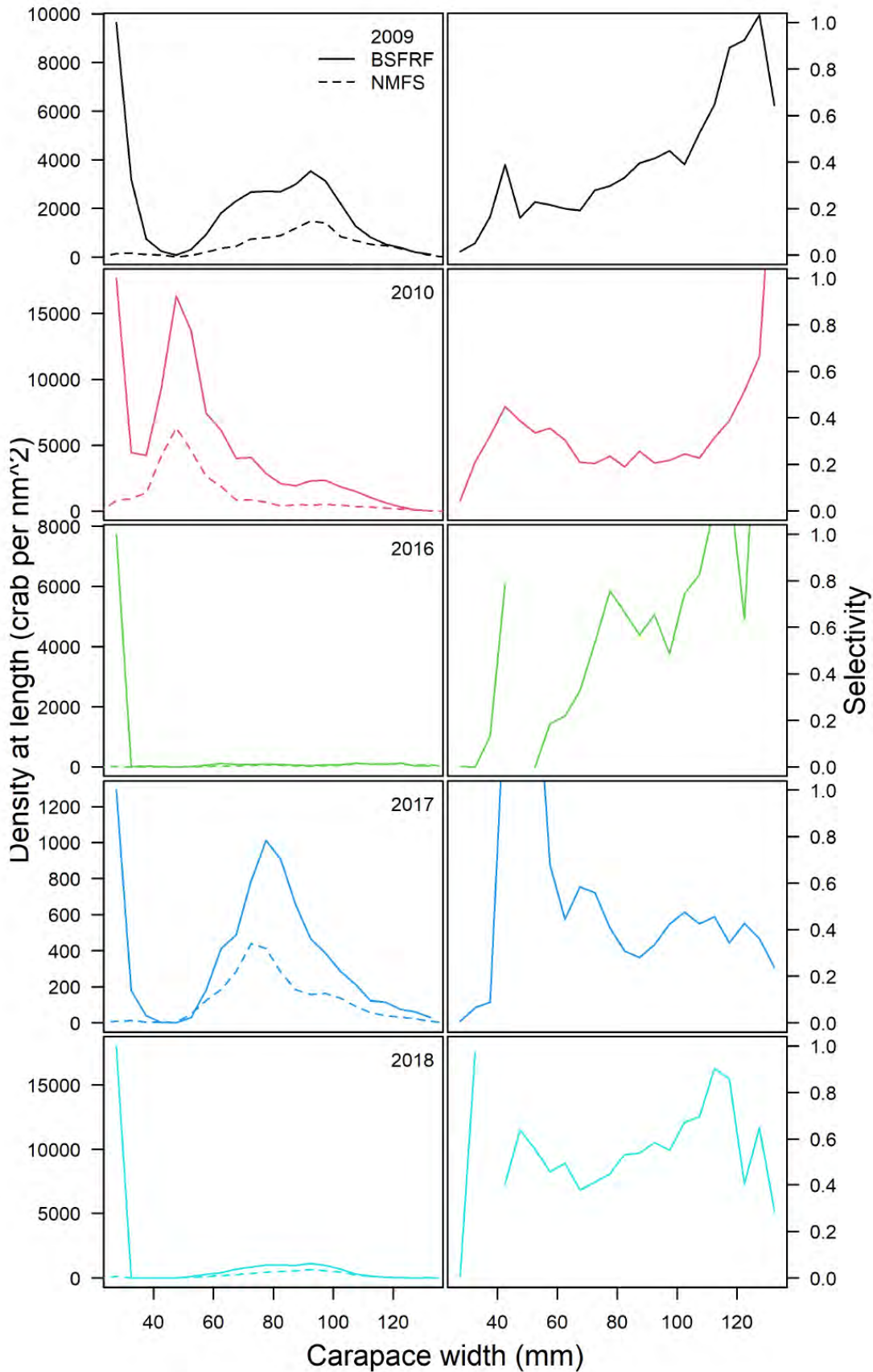


Figure 24: Observed numbers at length extrapolated from length composition data and estimates of total numbers within the survey selectivity experimental areas by year (left). Inferred selectivity (i.e. the ratio of crab at length in the NMFS gear to crab at length in the BSFRF gear).

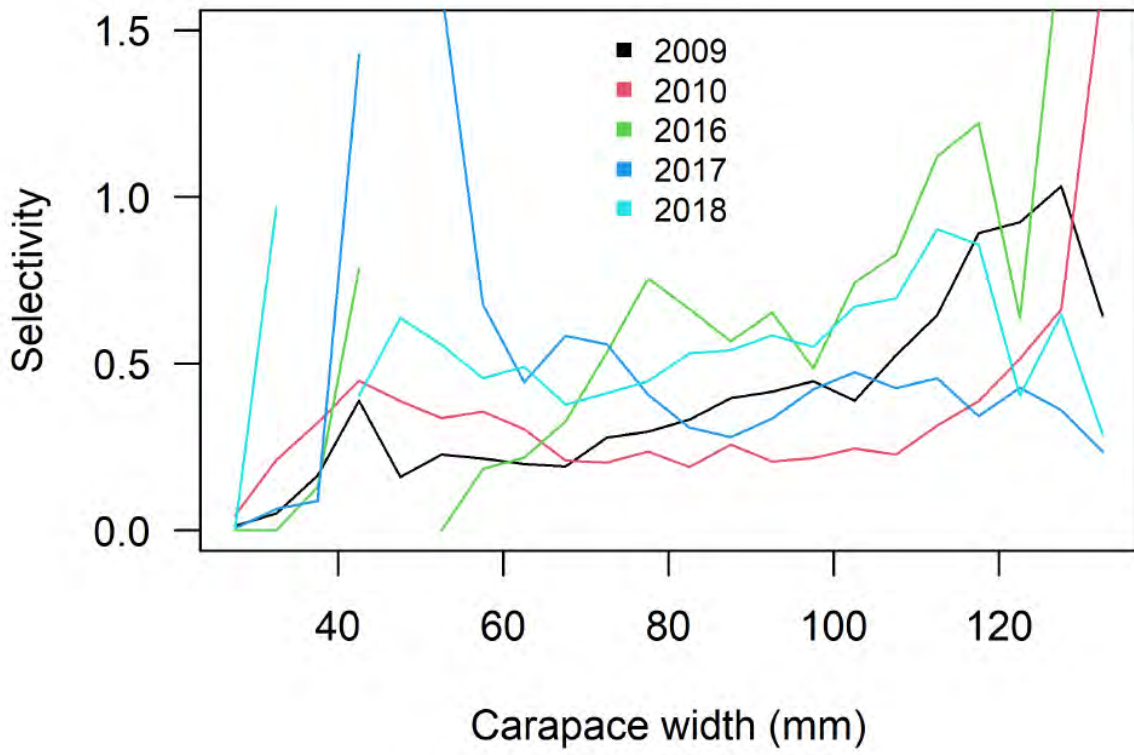


Figure 25: Inferred selectivity for all available years of BSFRF data.

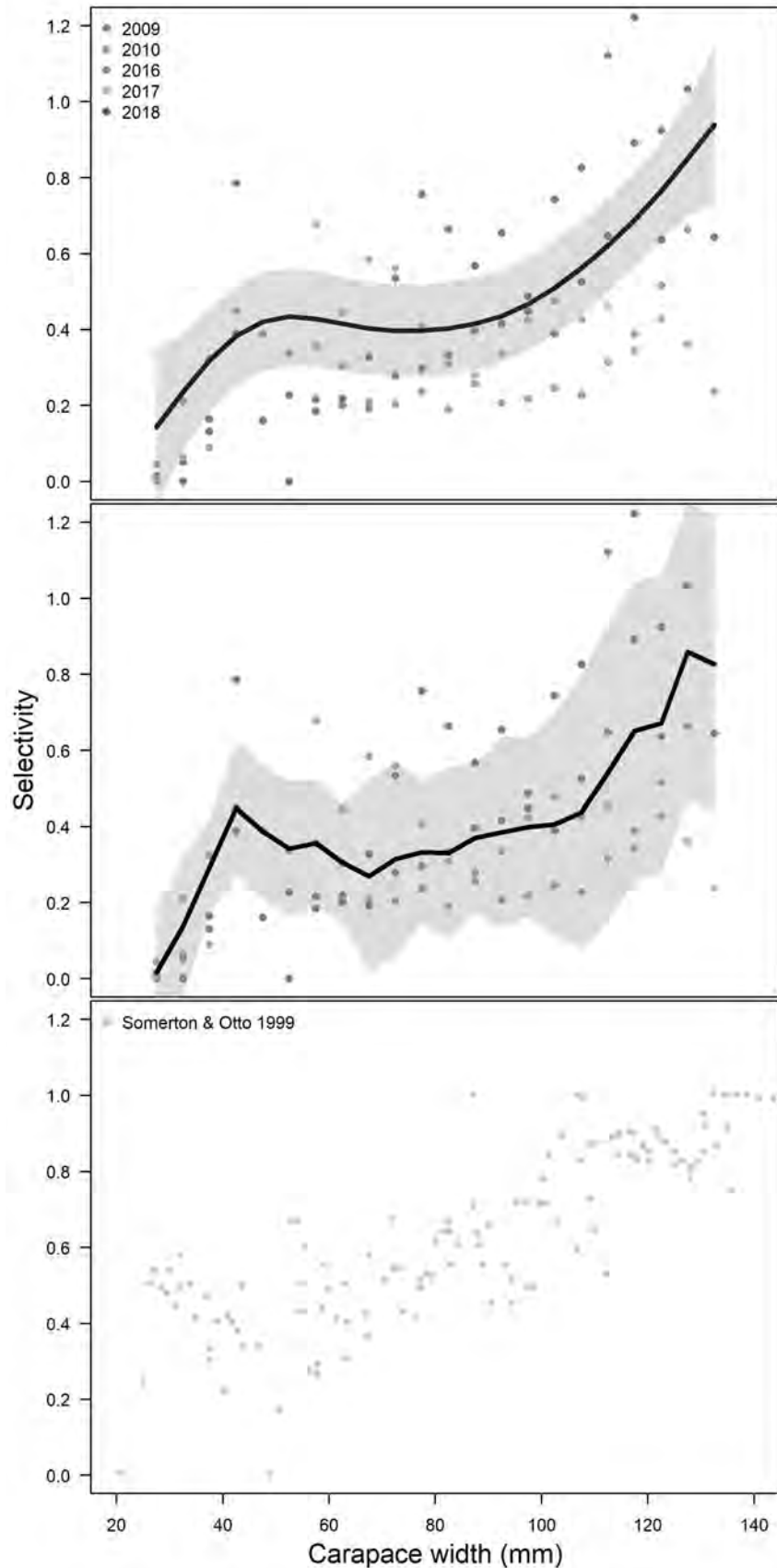


Figure 26: Implied selectivity from BSFRF experiments with selectivity at size class estimated by generalized additive model (top). Implied selectivity from BSFRF experiments with selectivity at size class estimated by sample size-weighted means and variances (middle). Somerton and Otto (1998) underbag experimental data.



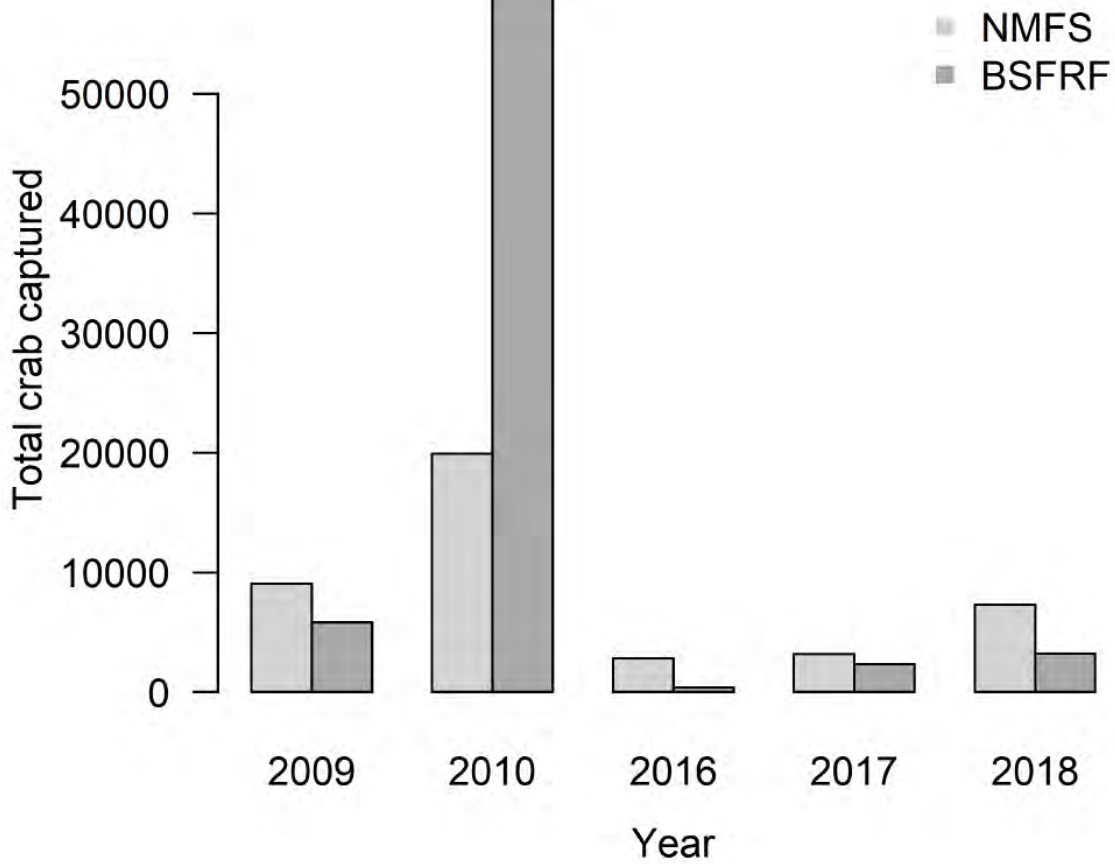


Figure 27: Number of crab from which estimates of biomass and length composition data were inferred within the survey selectivity experimental area.

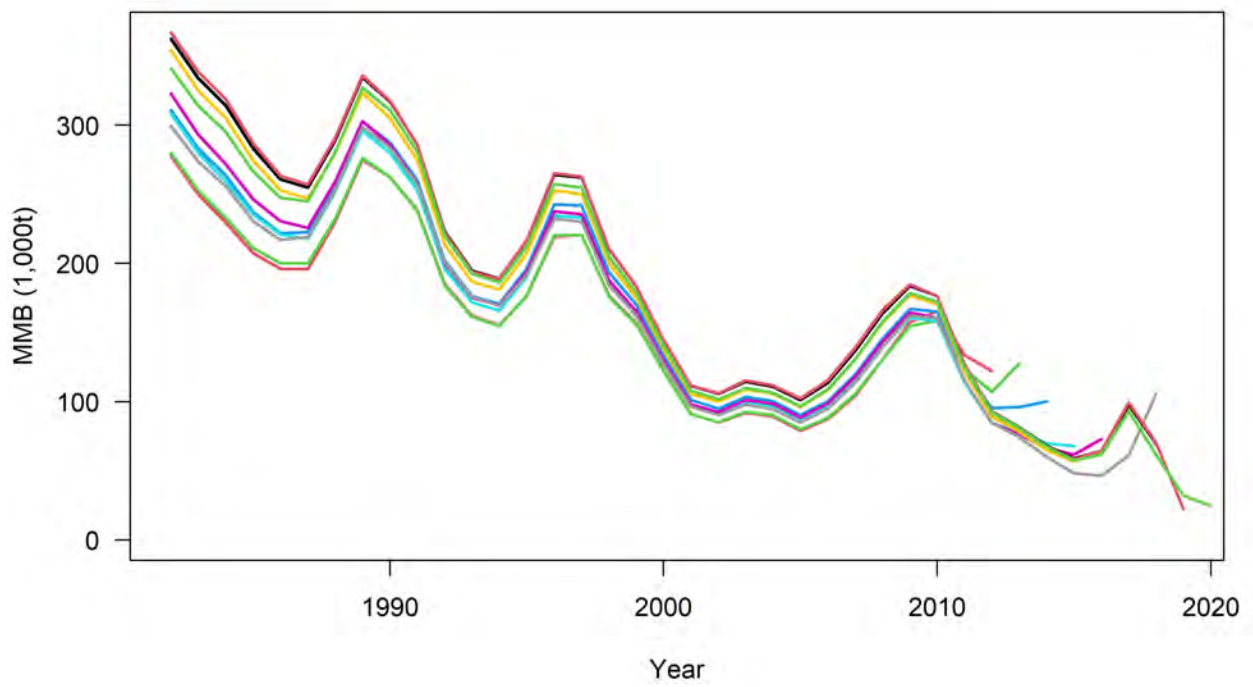


Figure 28: Retrospective patterns in estimated mature male biomass at the time of mating for model 22.1a/22.1ab.

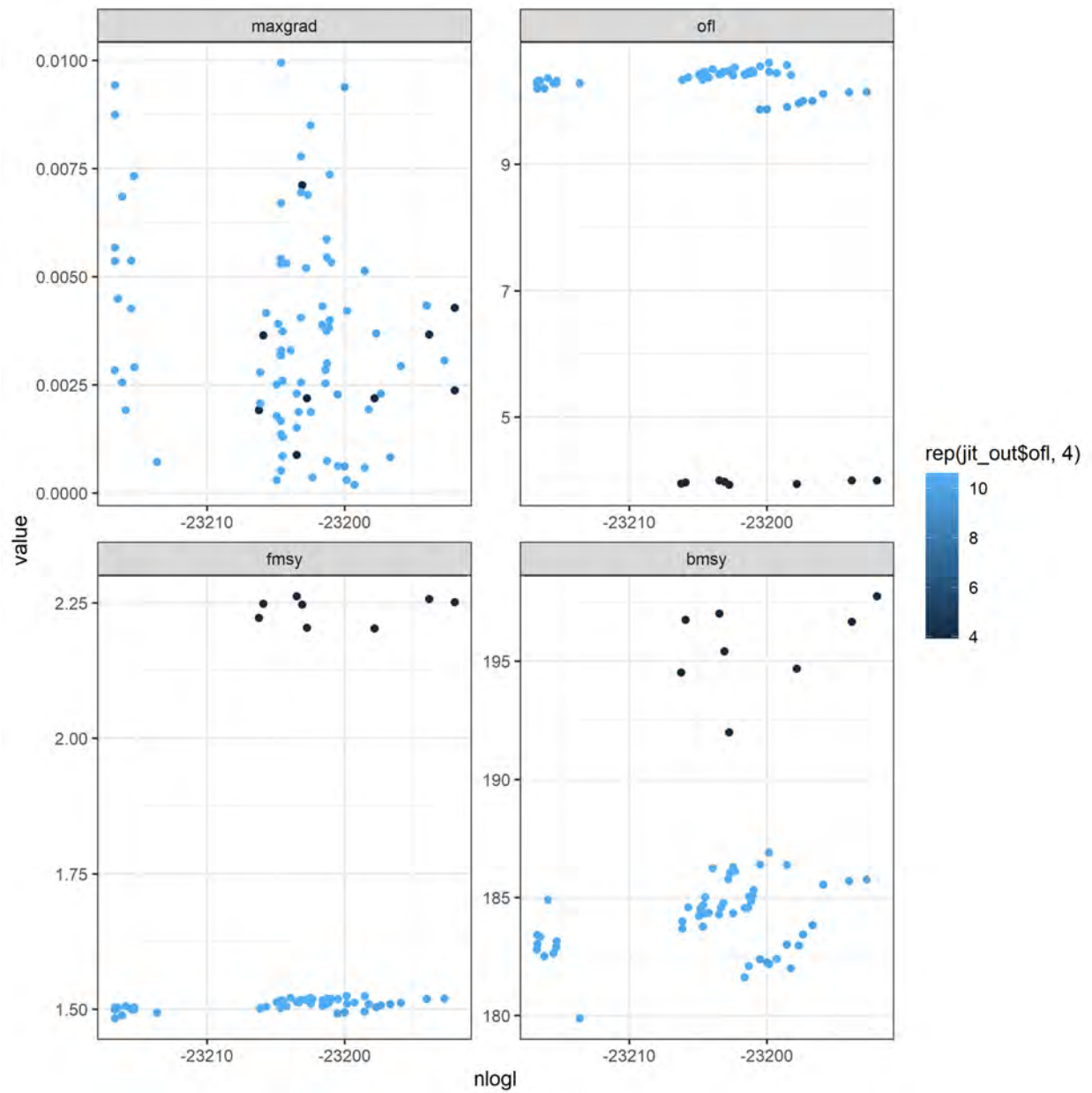


Figure 29: Output of 100 jittered model fittings for the model from which 22.1a and 22.1ab are derived. Top left is the maximum gradient component, top right is the overfishing level, bottom left is F35, and bottom right is B35. Each dot represent an instance of a jittered fitted model and are colored based on the OFL resulting from that run.

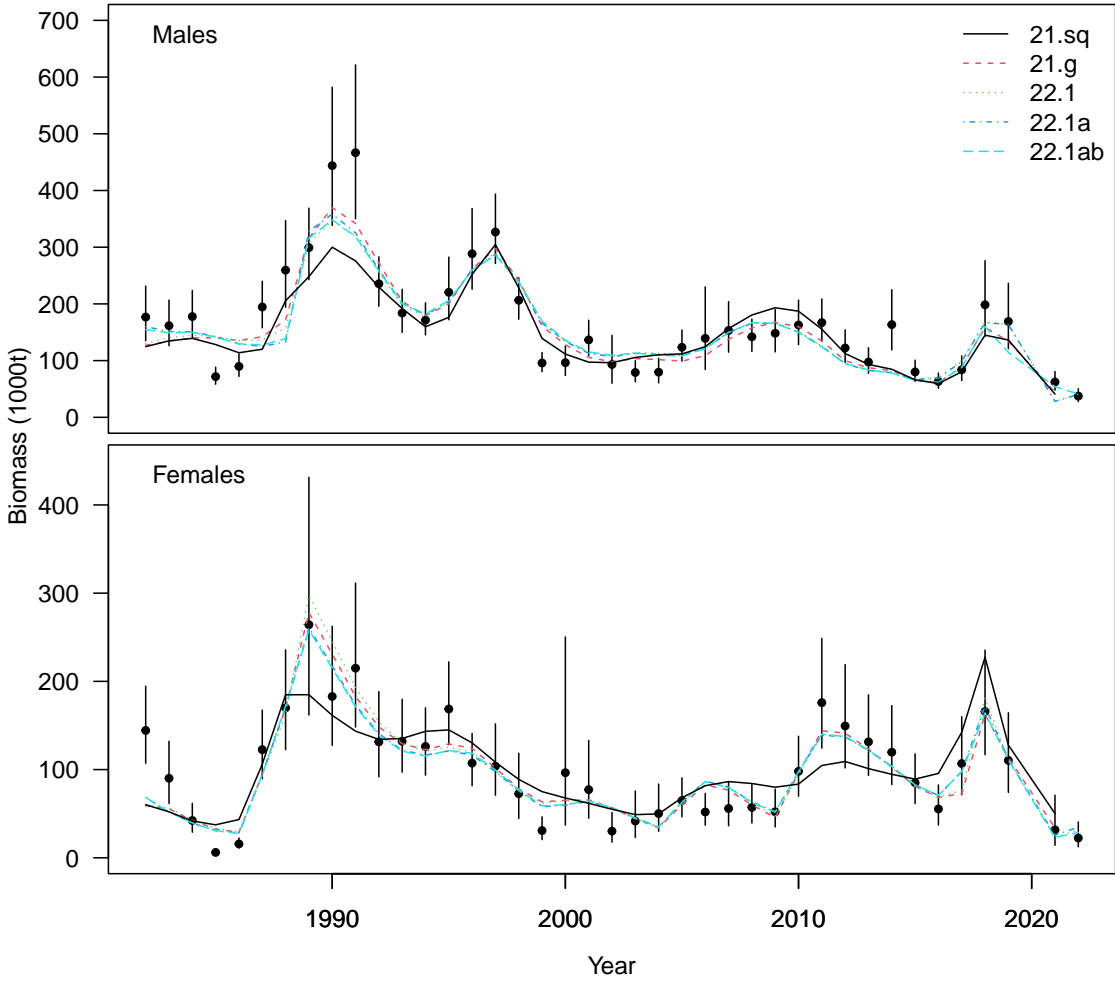


Figure 30: Model fits to the observed mature biomass at survey

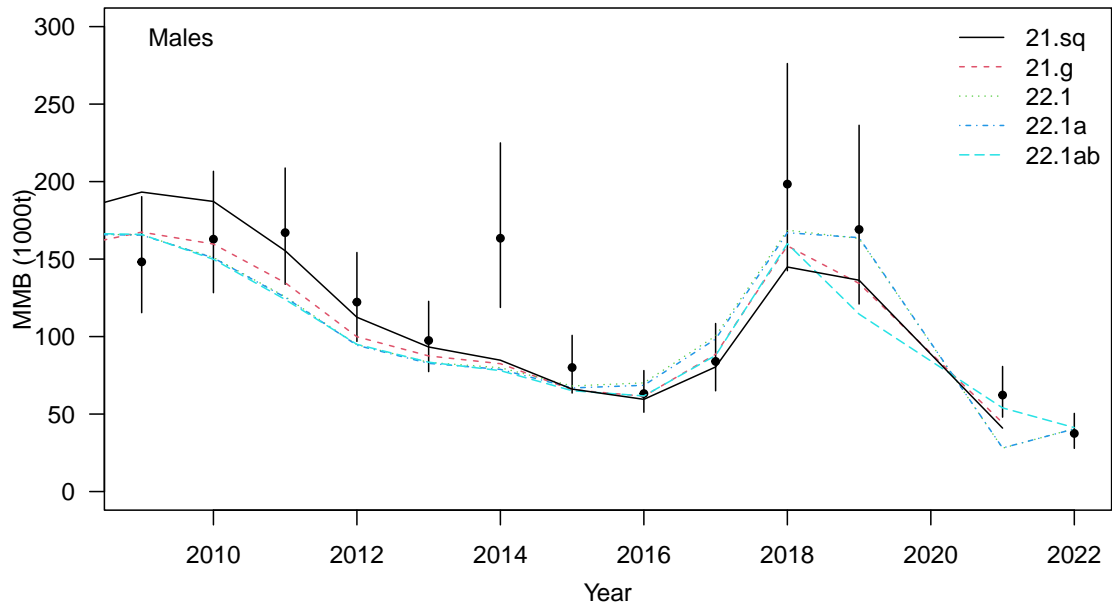


Figure 31: Model fits to the observed mature biomass at survey 2009-present

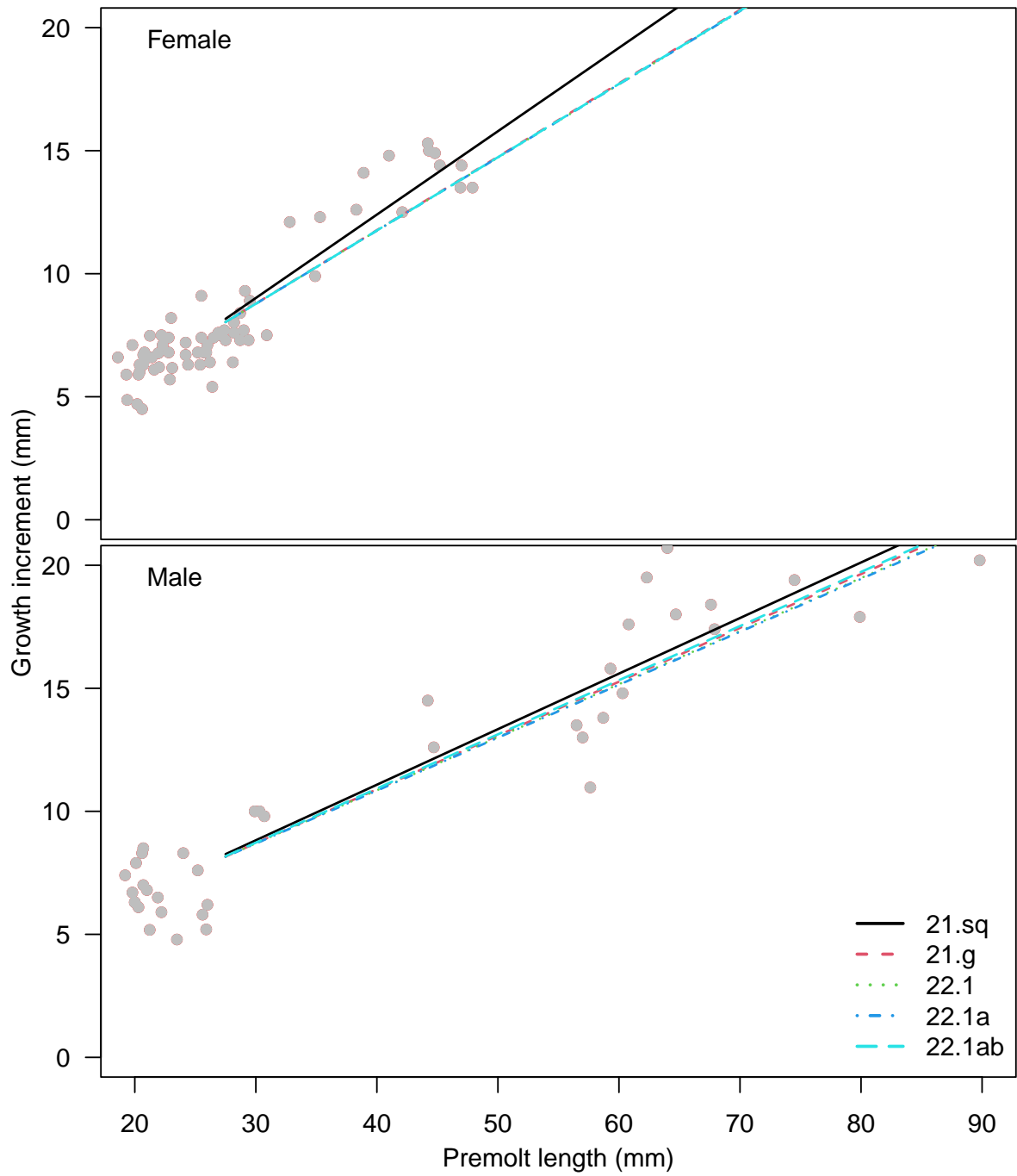


Figure 32: Model fits to the growth data

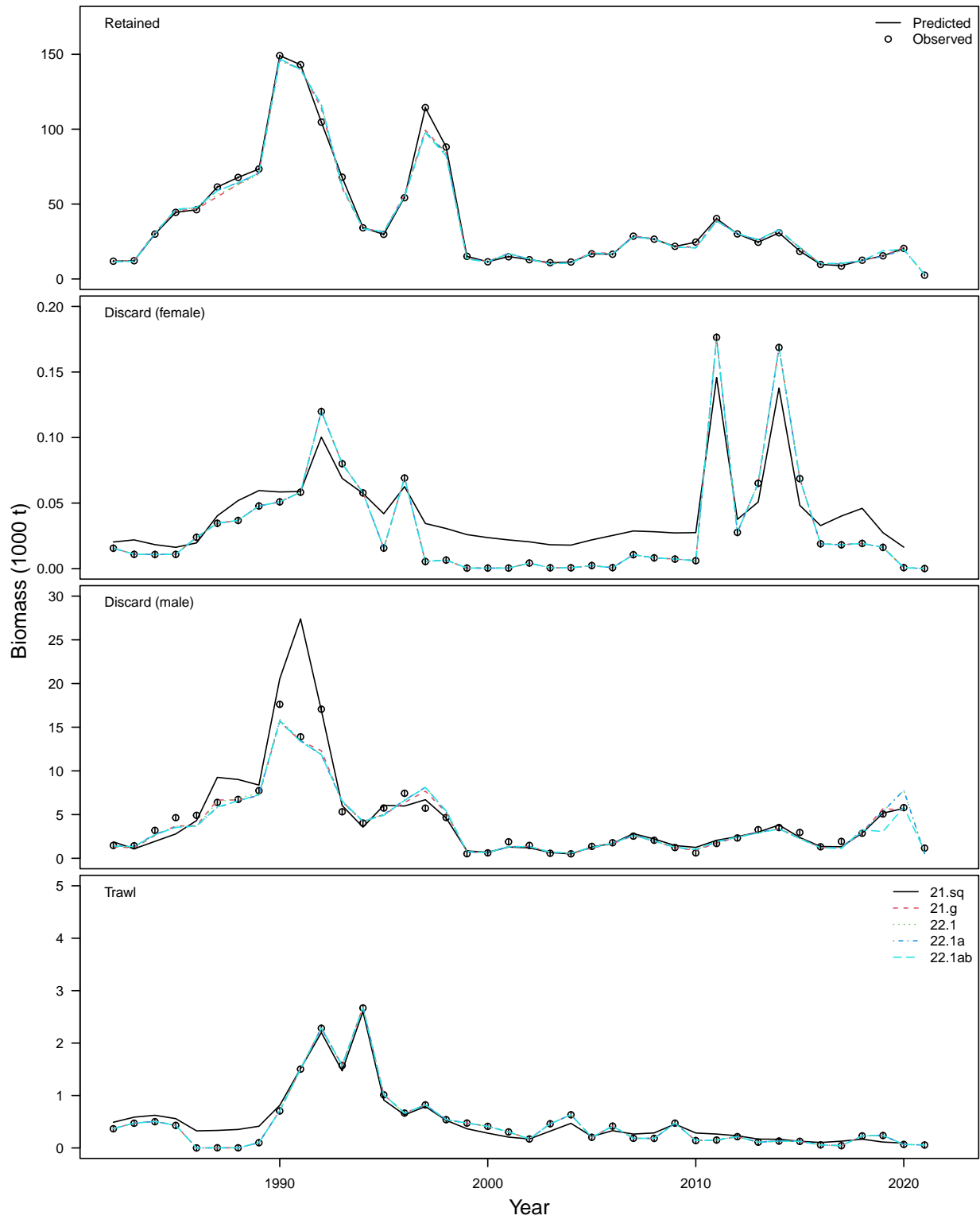


Figure 33: Model fits to catch data

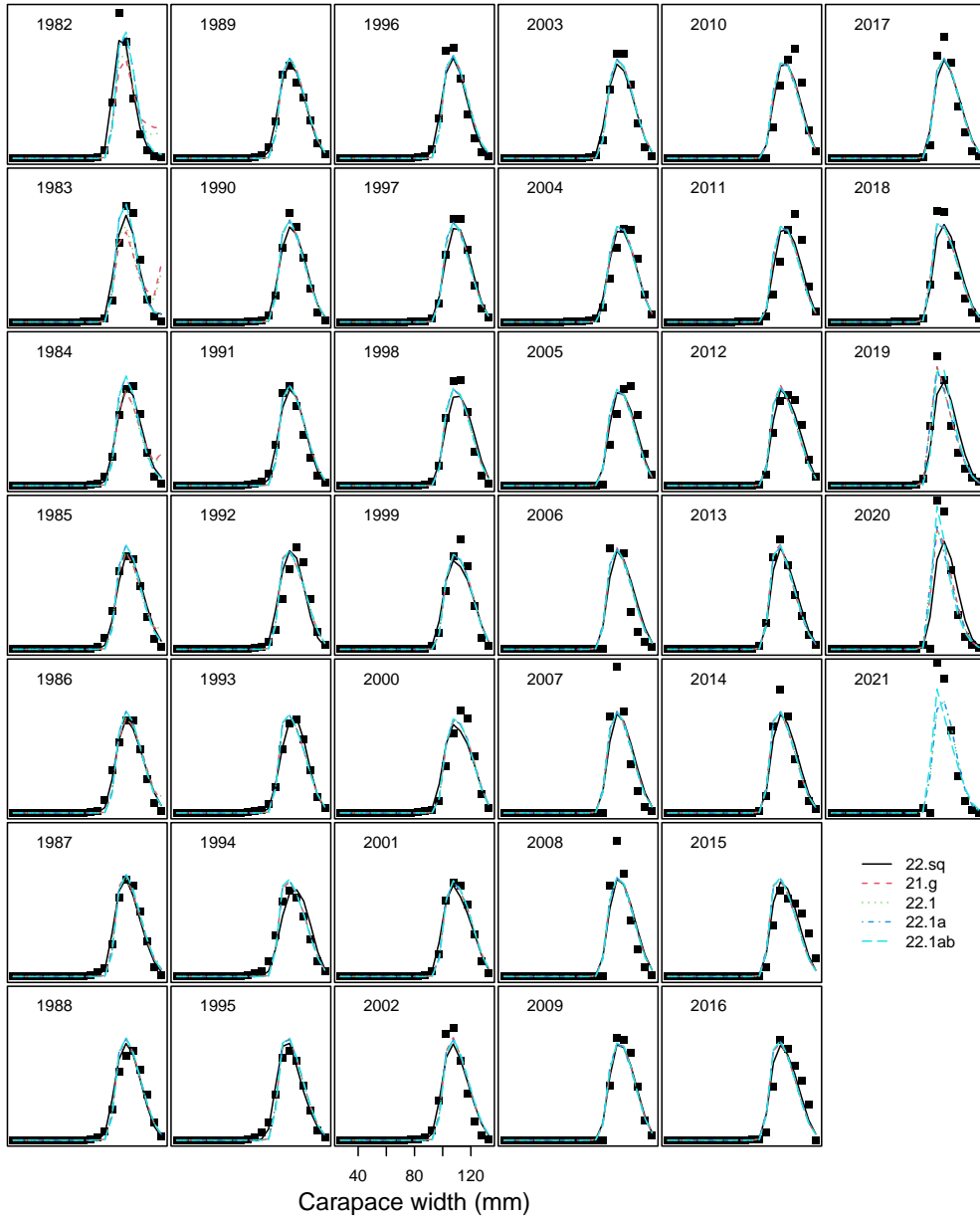


Figure 34: Model fits to retained catch size composition data



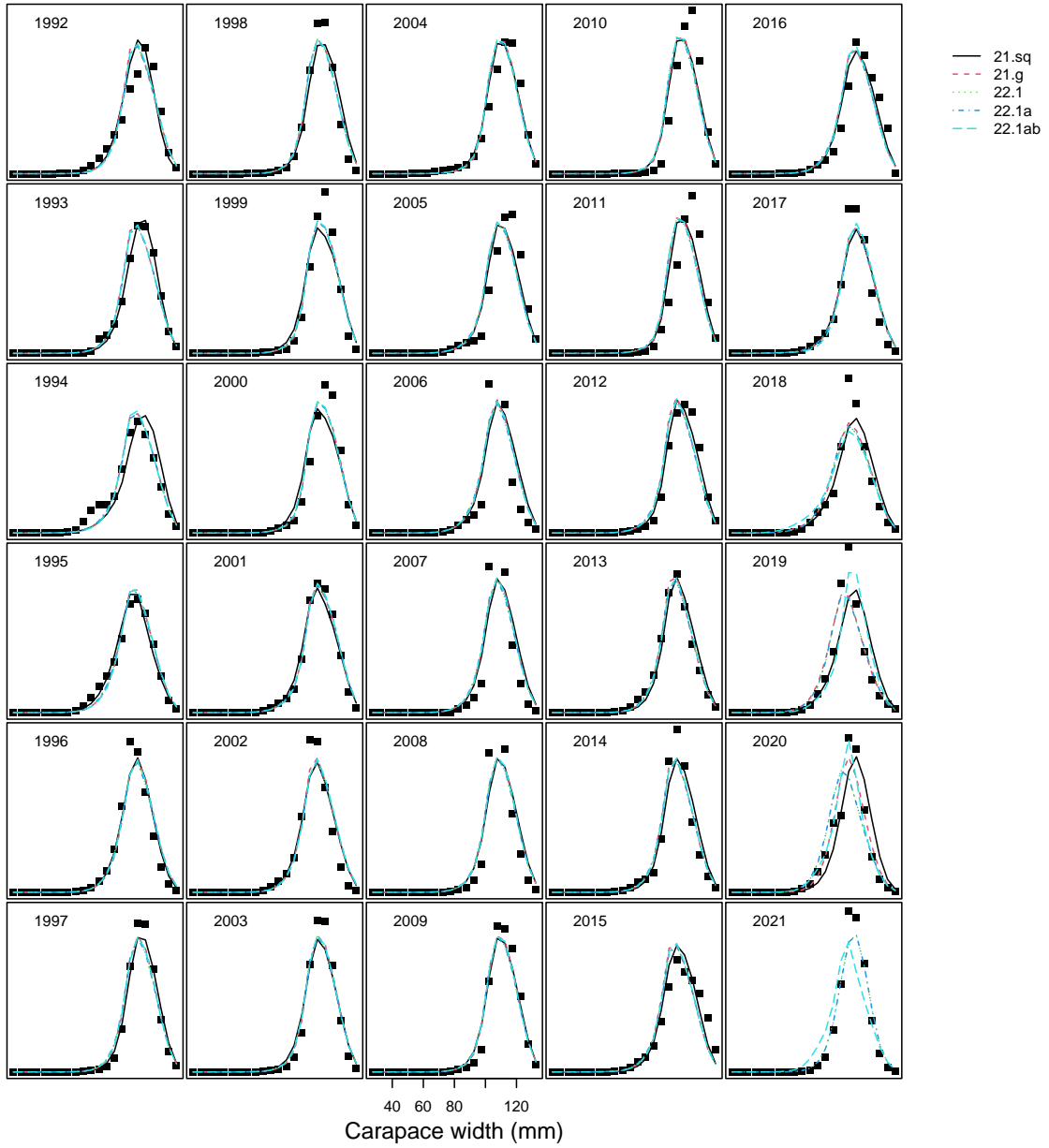


Figure 35: Model fits to total catch size composition data

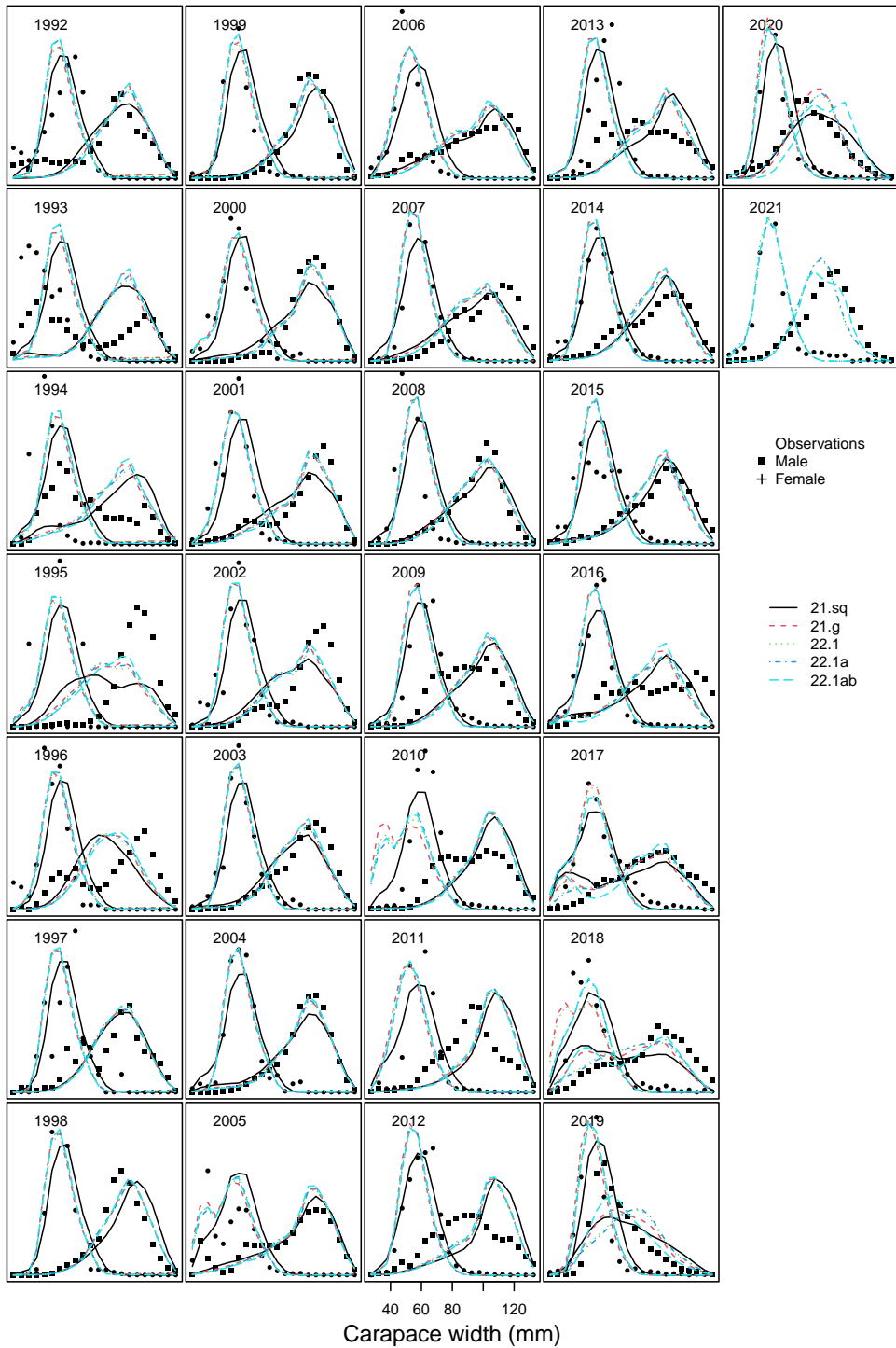


Figure 36: Model fits to trawl catch size composition data

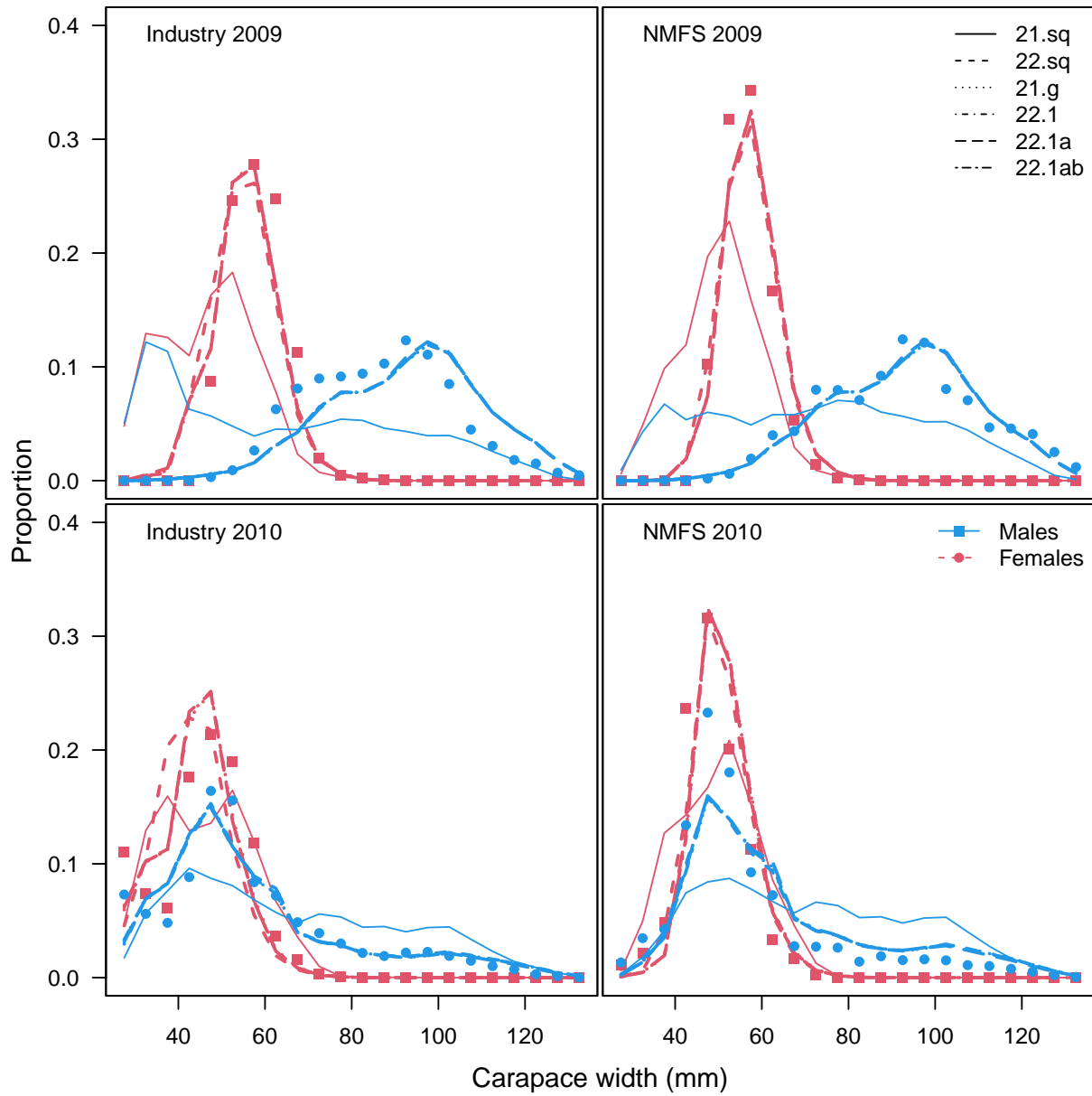


Figure 37: Model fits to size composition data from summer survey experiments (2009 & 2010)

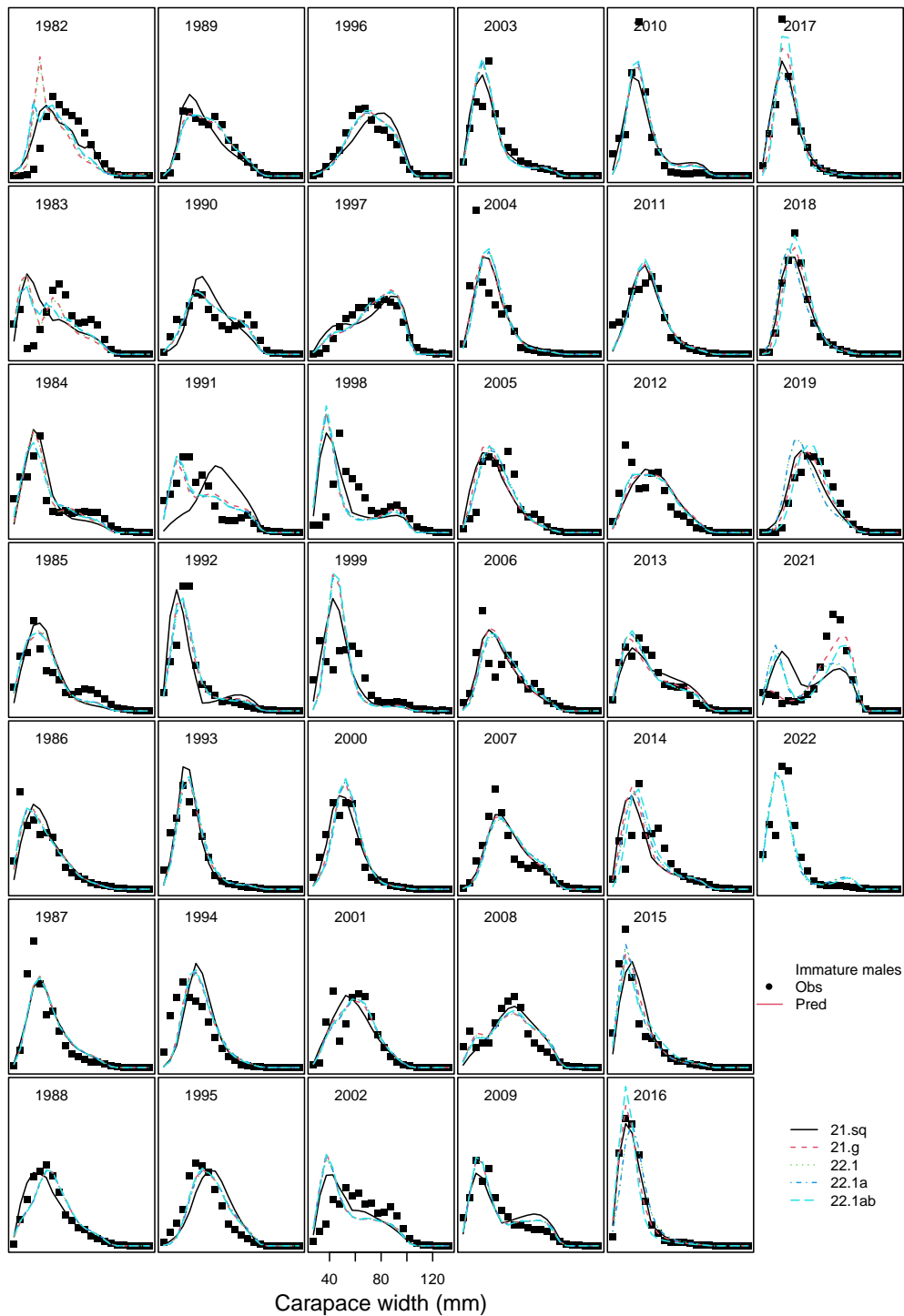


Figure 38: Model fits to immature male survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

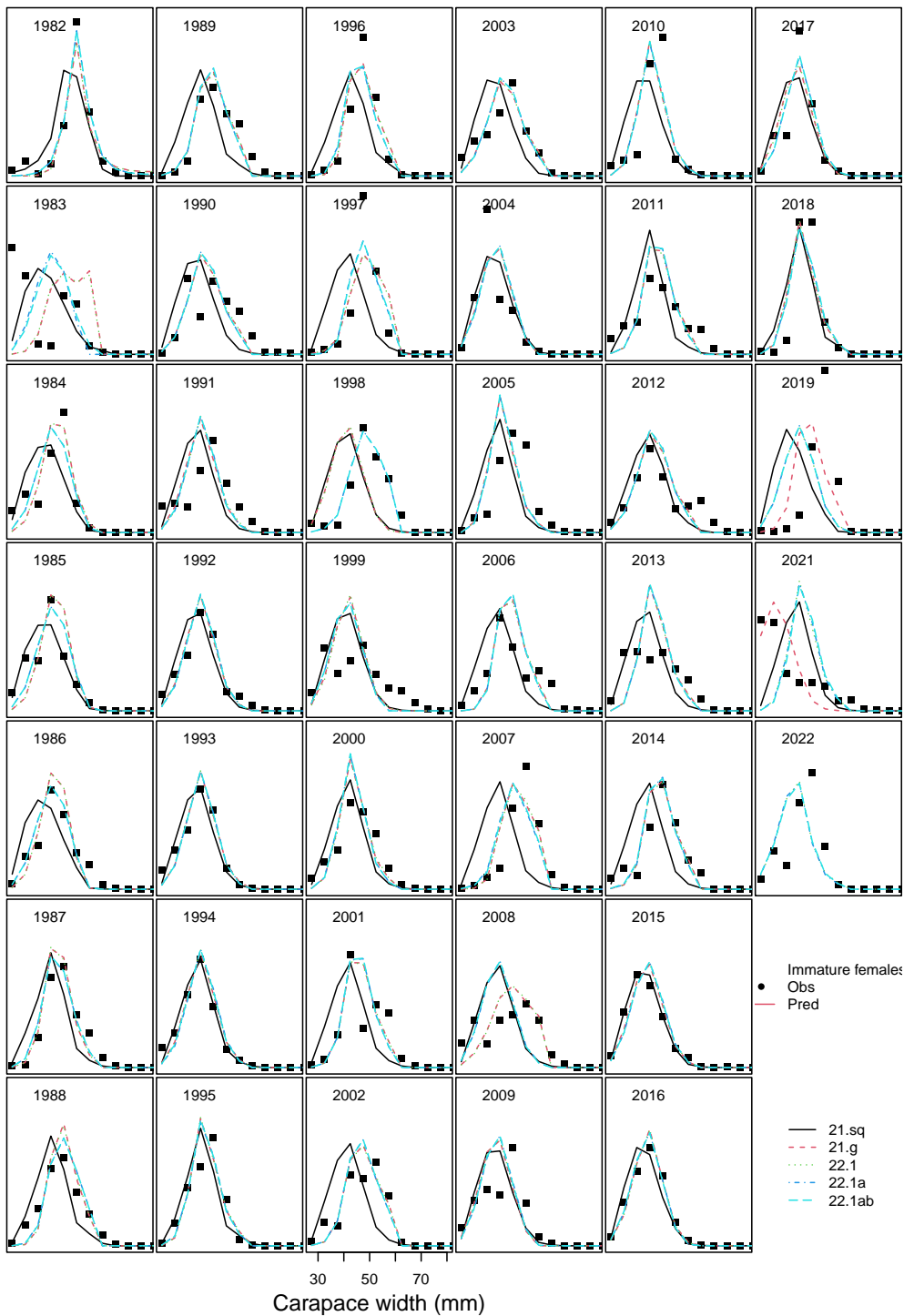


Figure 39: Model fits to immature female survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

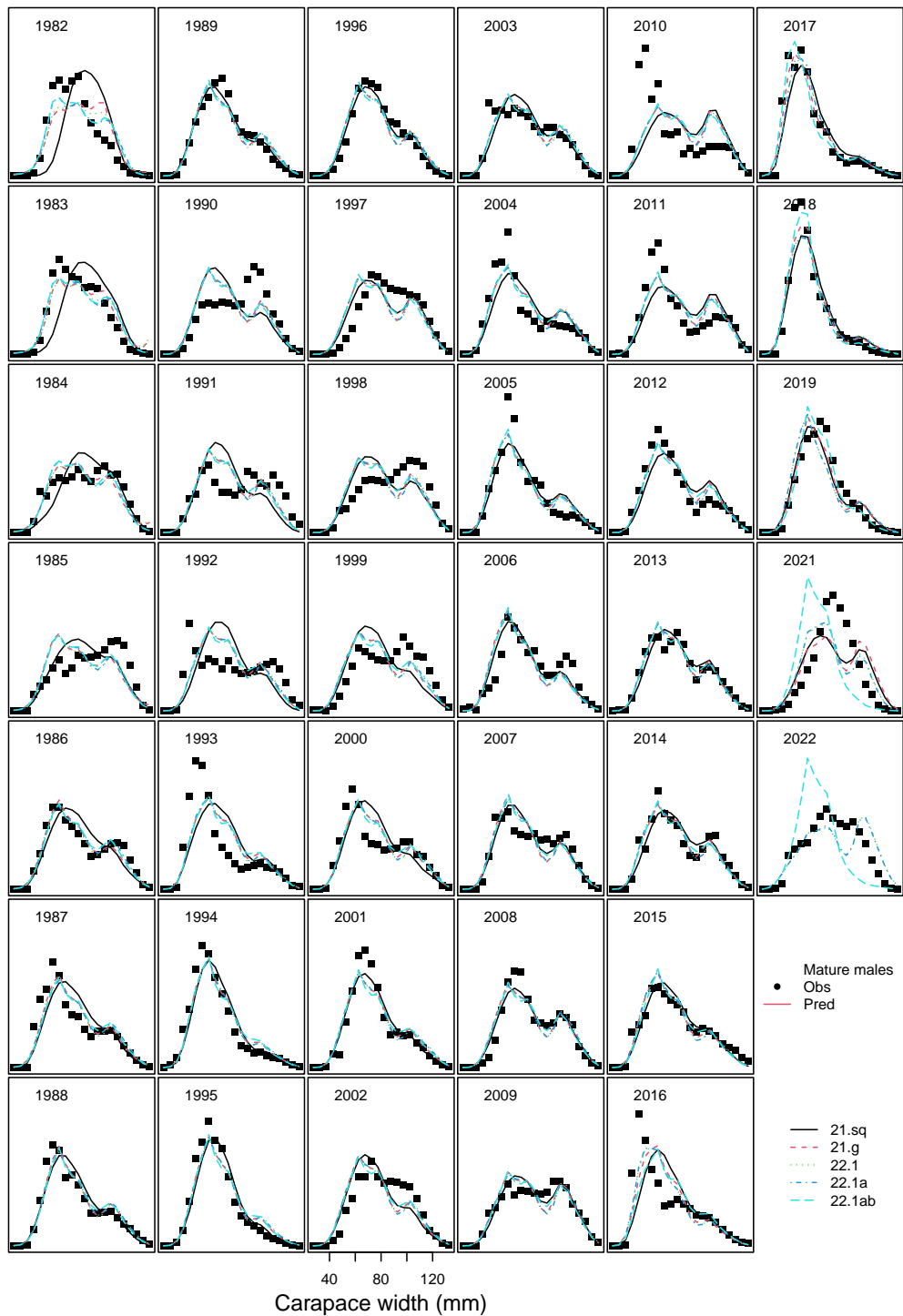


Figure 40: Model fits to mature male survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

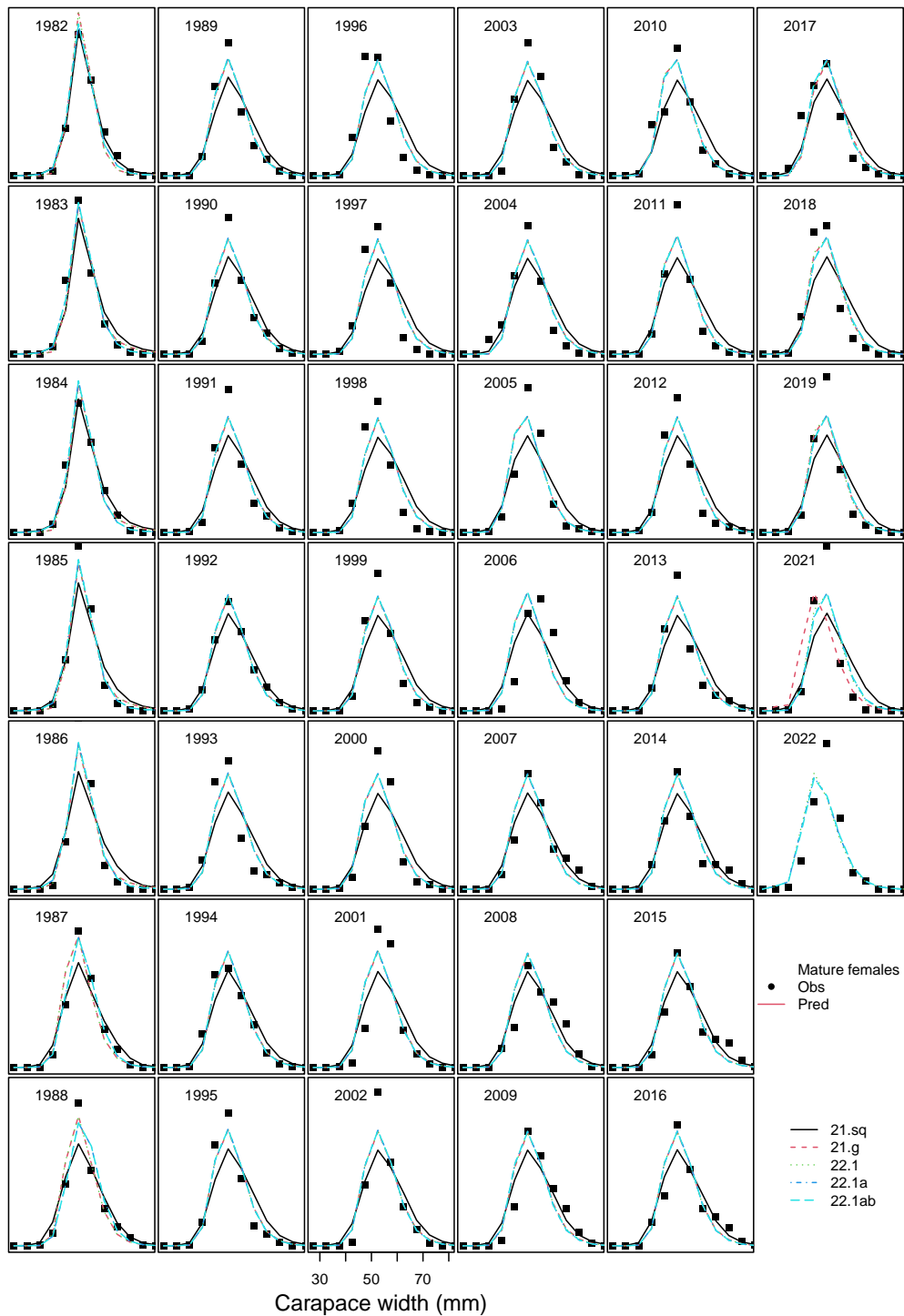


Figure 41: Model fits to mature female survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

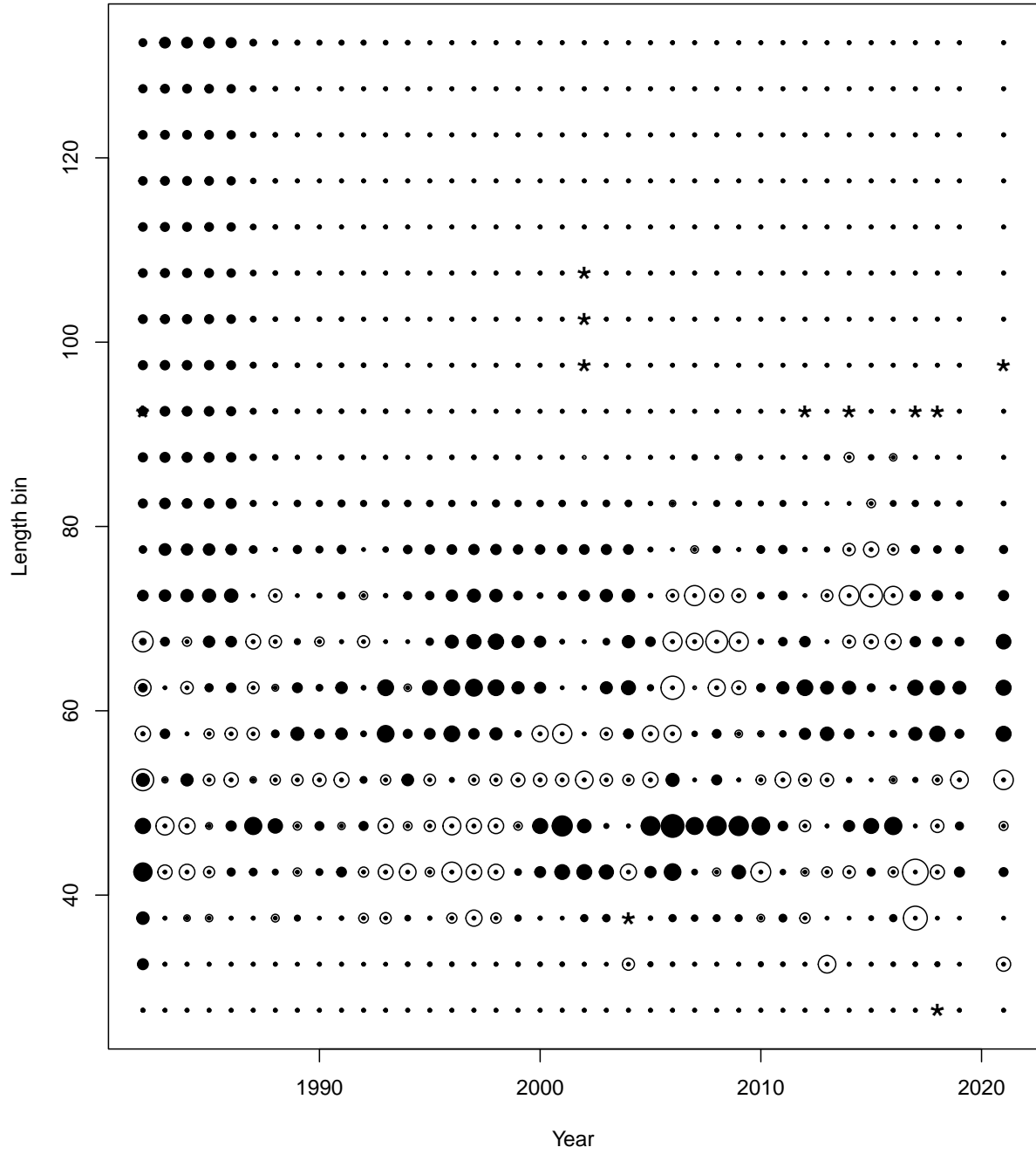


Figure 42: Residual bubble plot of the fits to the NMFS mature female for the author-preferred model. Open circles represent positive residuals; closed circles represent negative residuals.



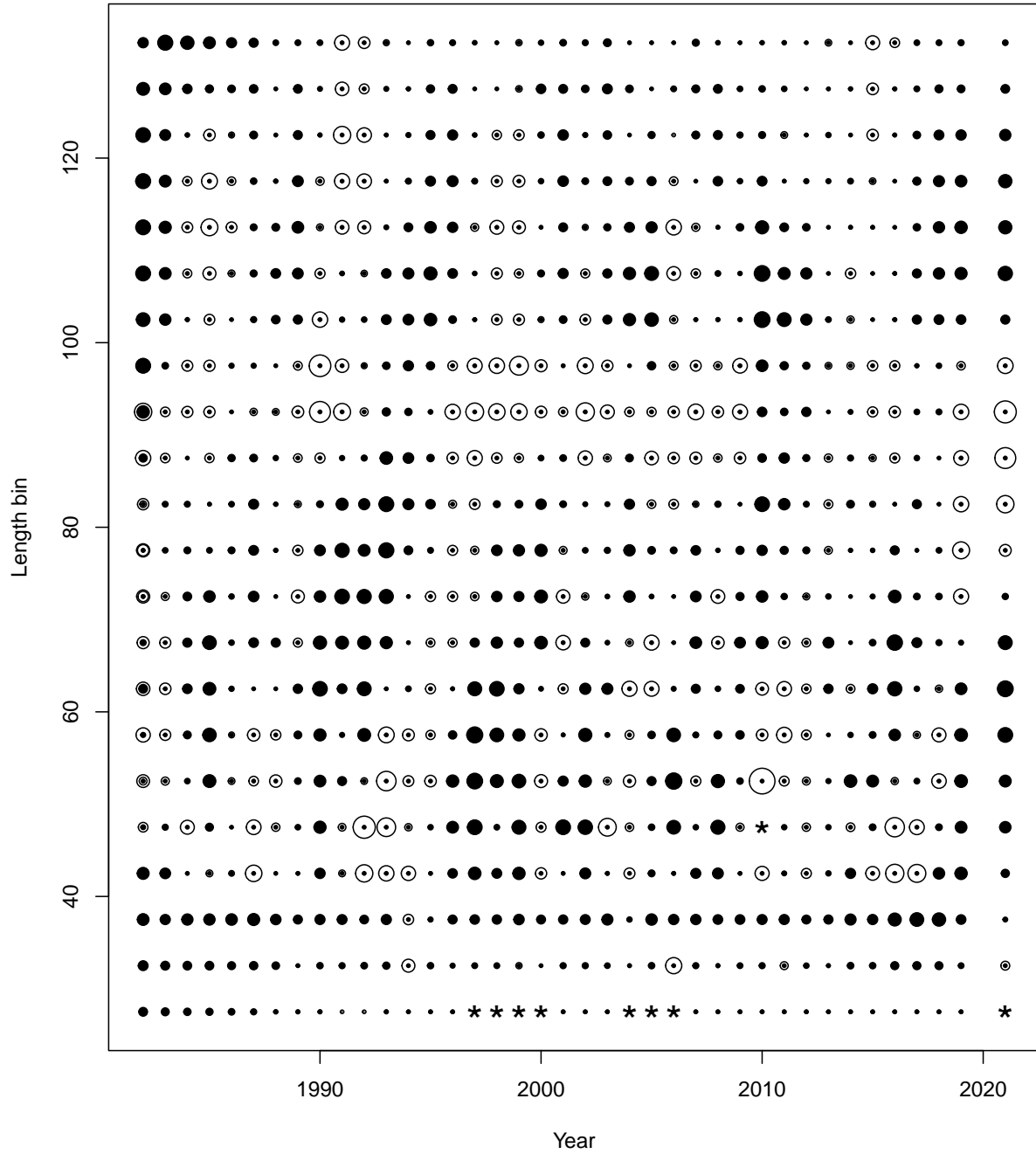


Figure 43: Residual bubble plot of the fits to the NMFS mature male for the author-preferred model. Open circles represent positive residuals; closed circles represent negative residuals.

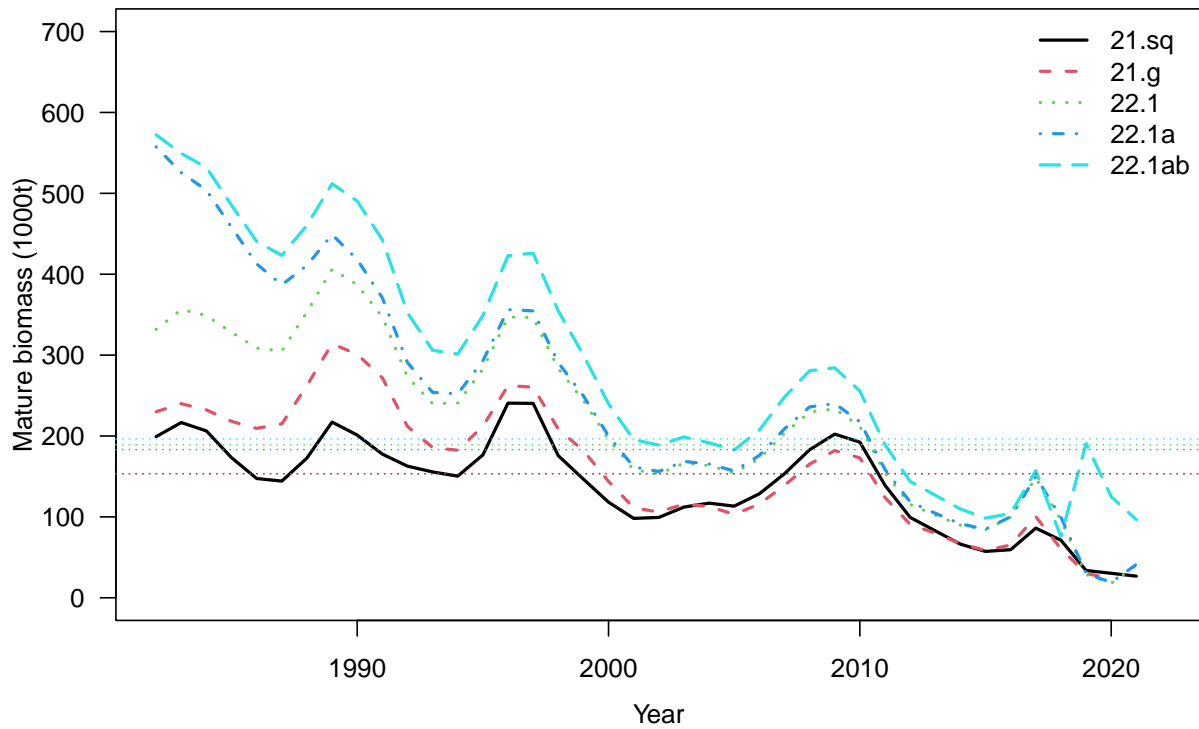


Figure 44: Model predicted mature biomass at mating time. Dotted horizontal lines are target biomasses.

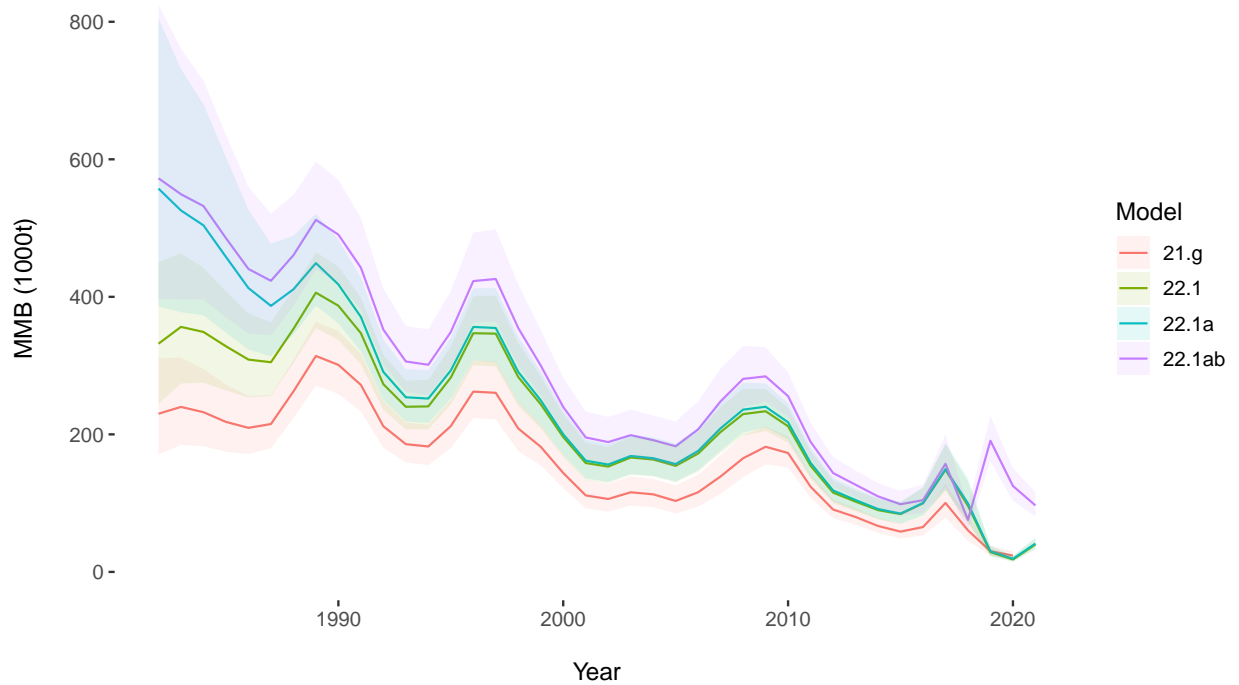


Figure 45: Trajectories of estimated MMB at the time of mating with 95% log-normal confidence intervals.

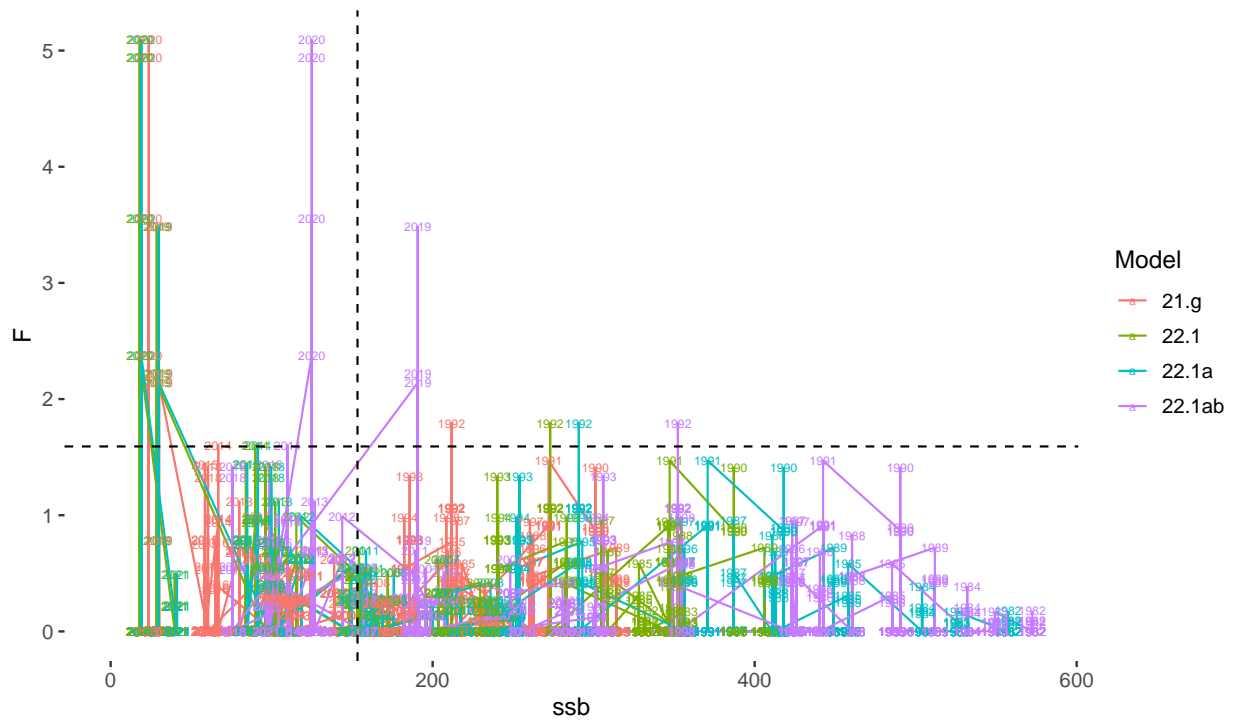


Figure 46: Kobe plots. Vertical dashed black line represents the MLE value for B35%; horizontal dashed black line represents F35%

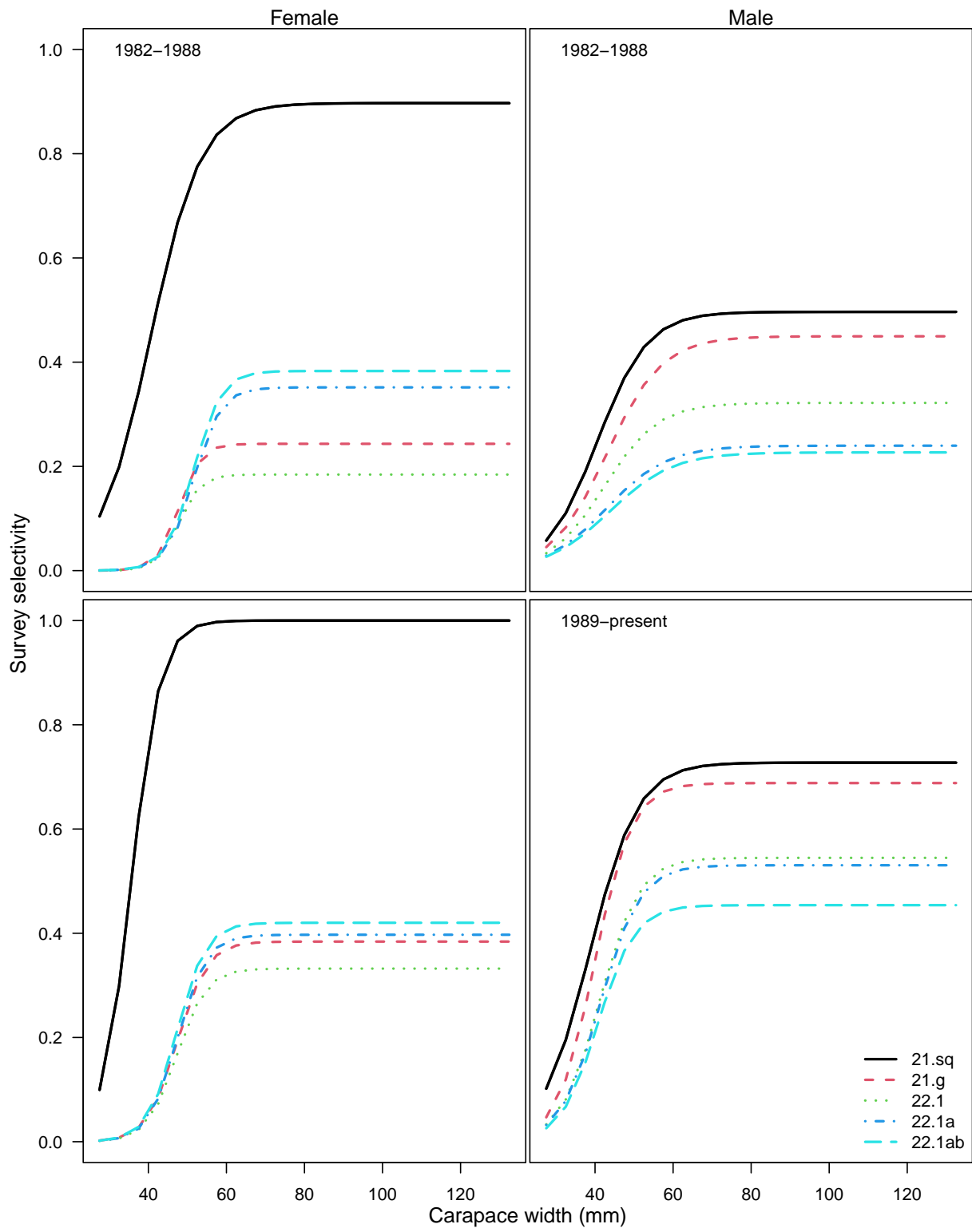


Figure 47: Estimated survey selectivity

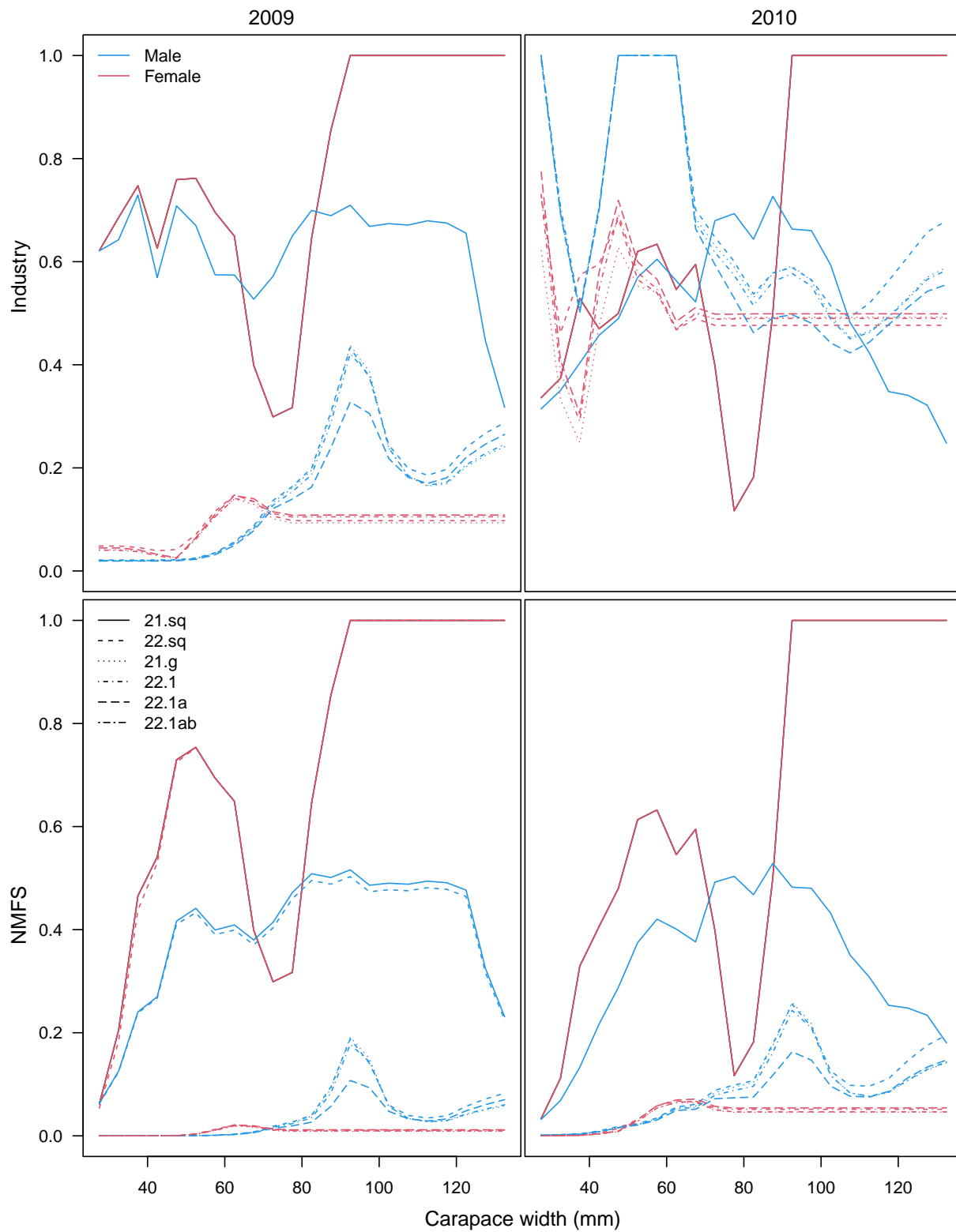


Figure 48: Estimated or specified availability (top row) and estimated experimental survey selectivity (availability \* survey selectivity; bottom row).

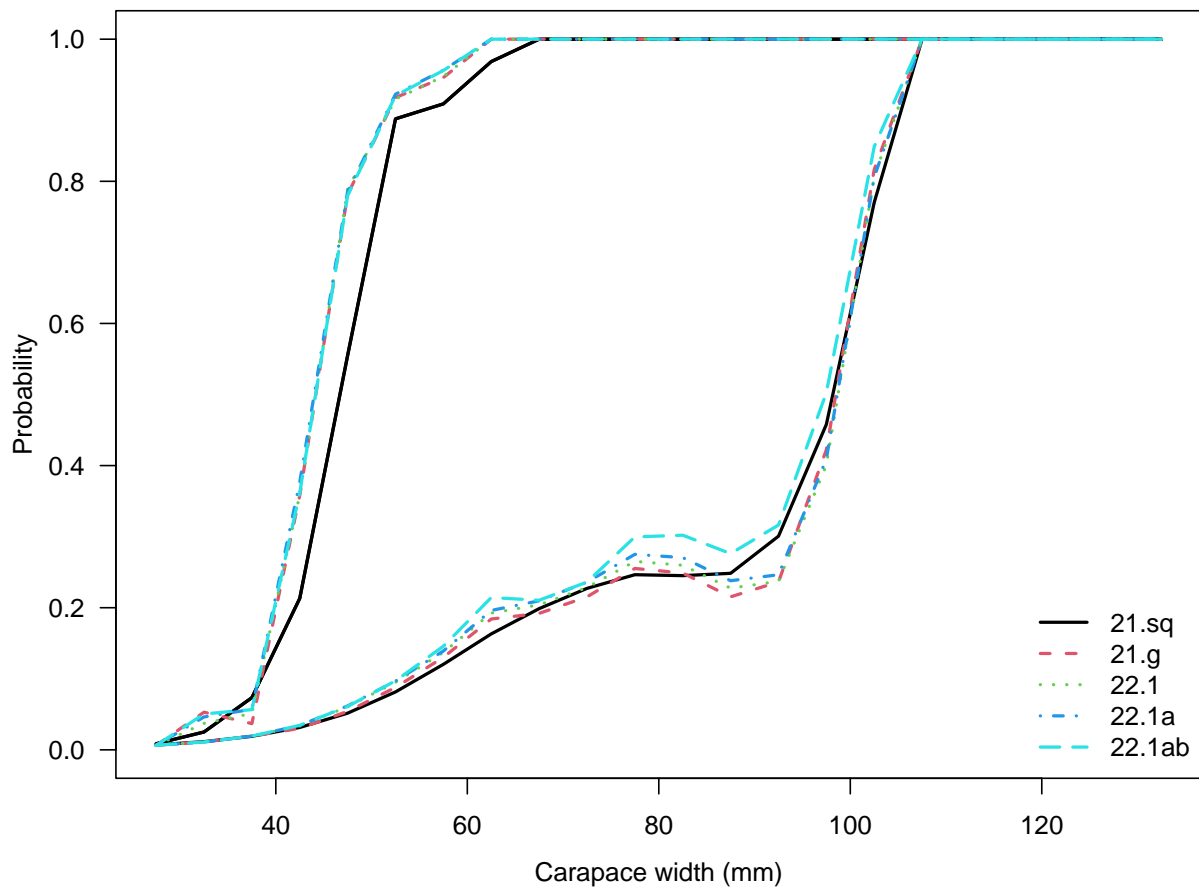


Figure 49: Estimated probability of maturing

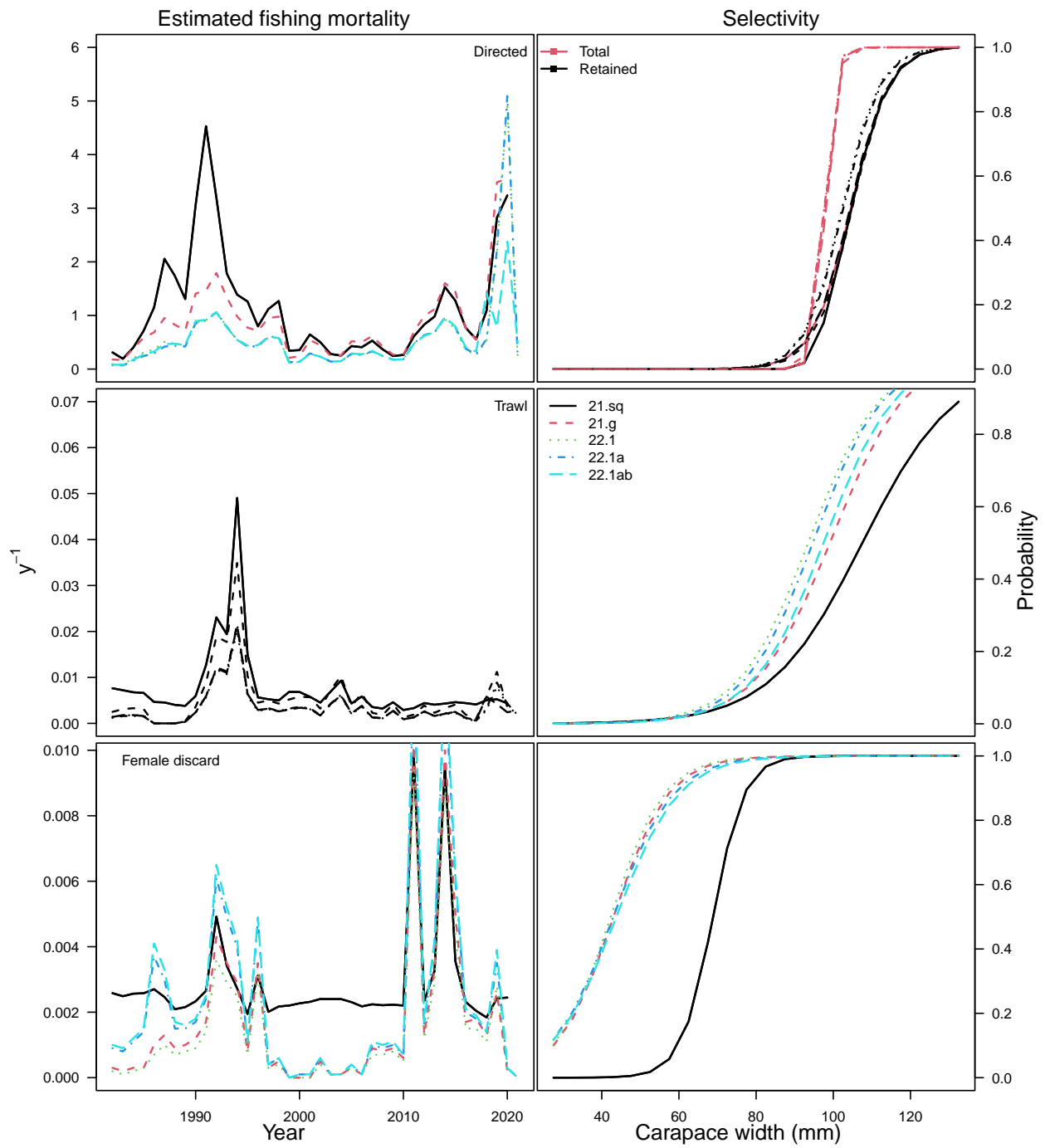


Figure 50: Model predicted fishing mortalities and selectivities for all sources of mortality

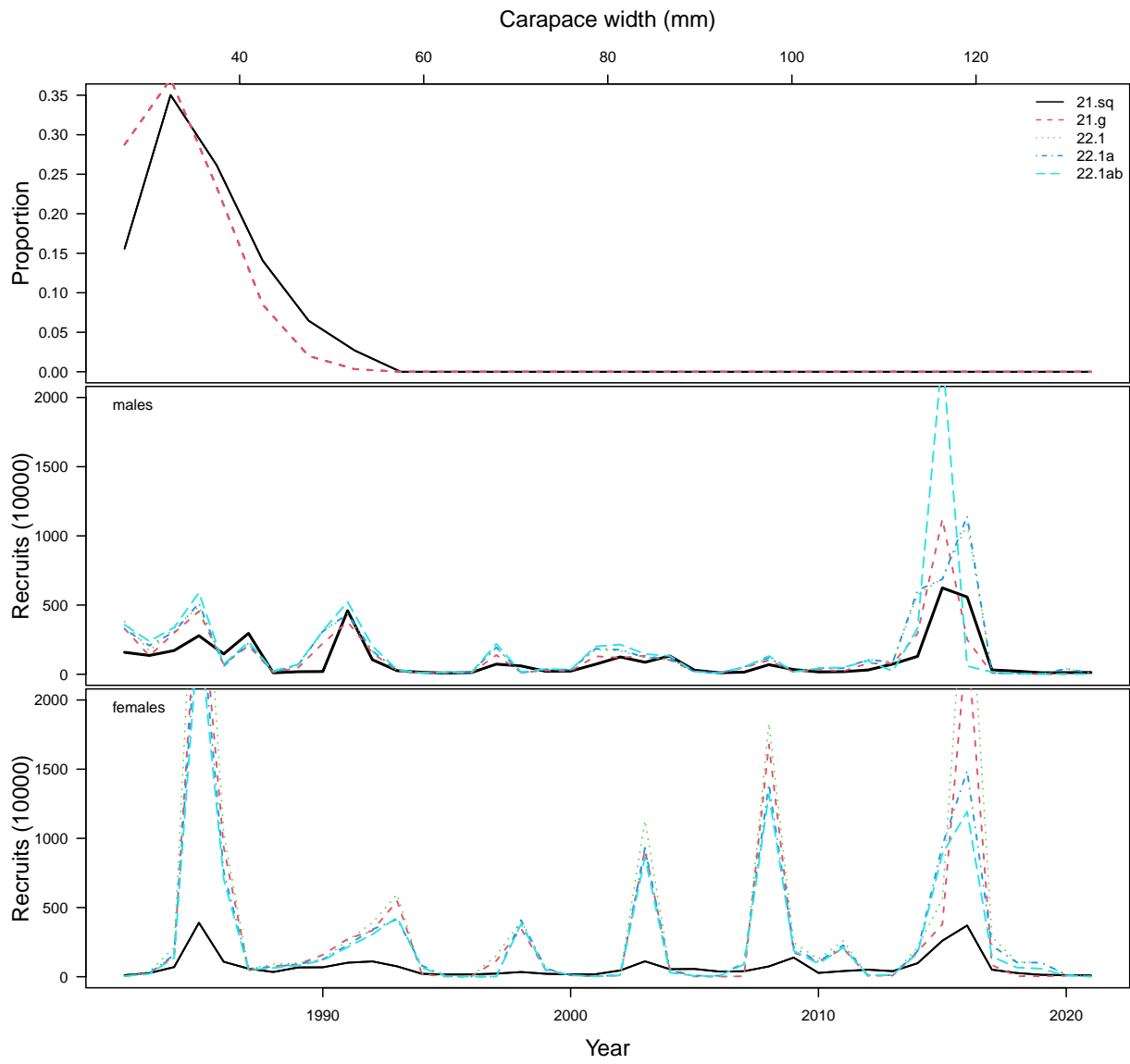


Figure 51: Estimated recruitment and proportions recruiting to length bin.



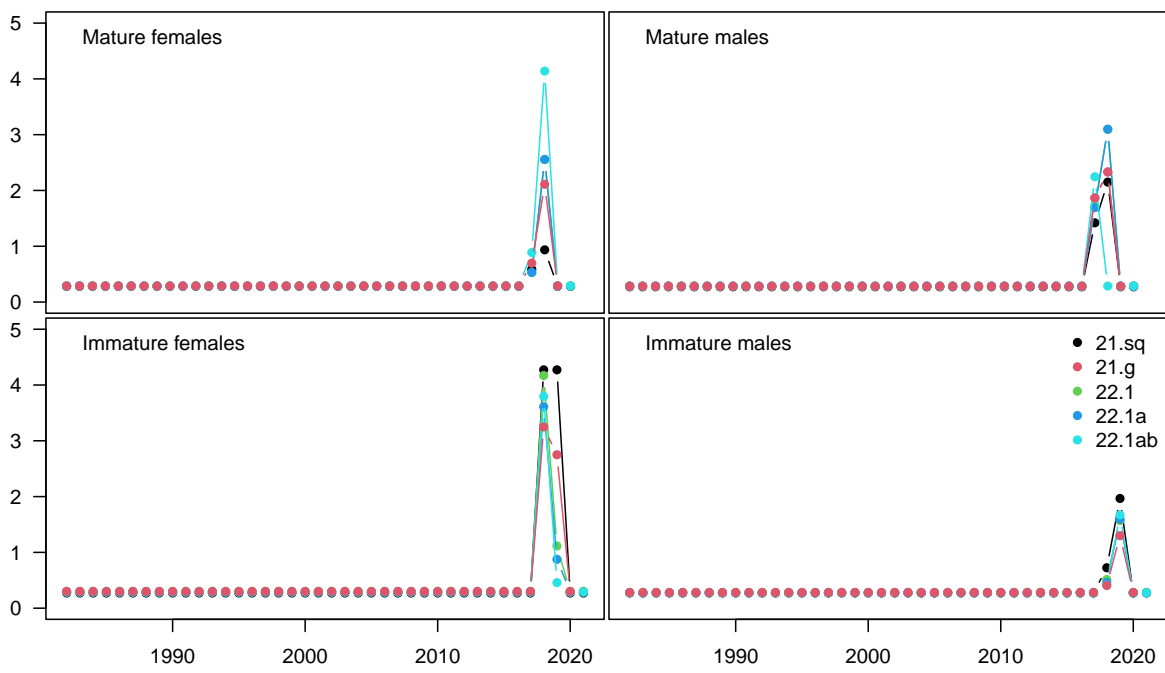


Figure 52: Estimated natural mortality by sex and maturity state.

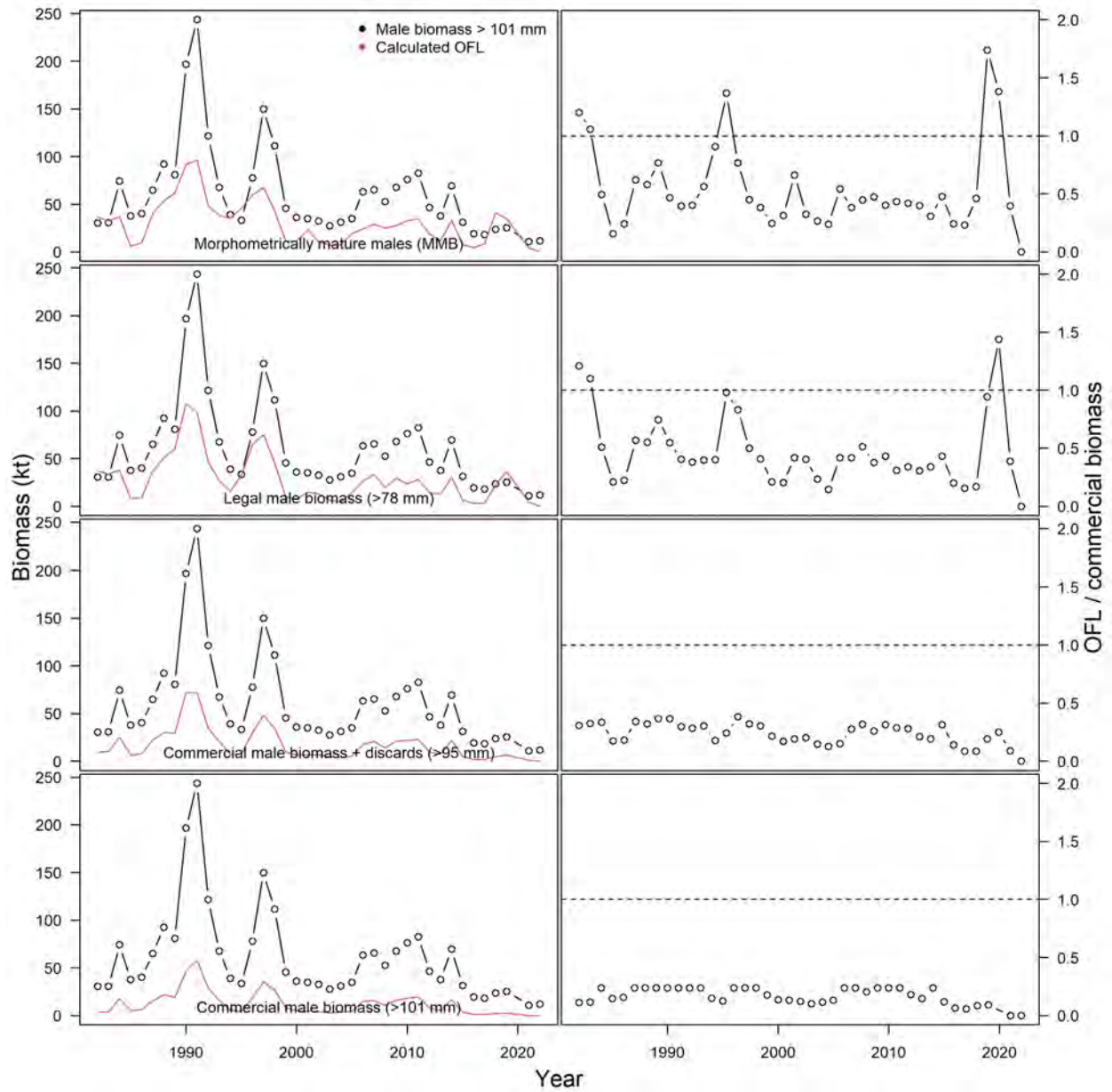


Figure 53: Application of tier 4 harvest control rules to different currencies of management for snow crab.

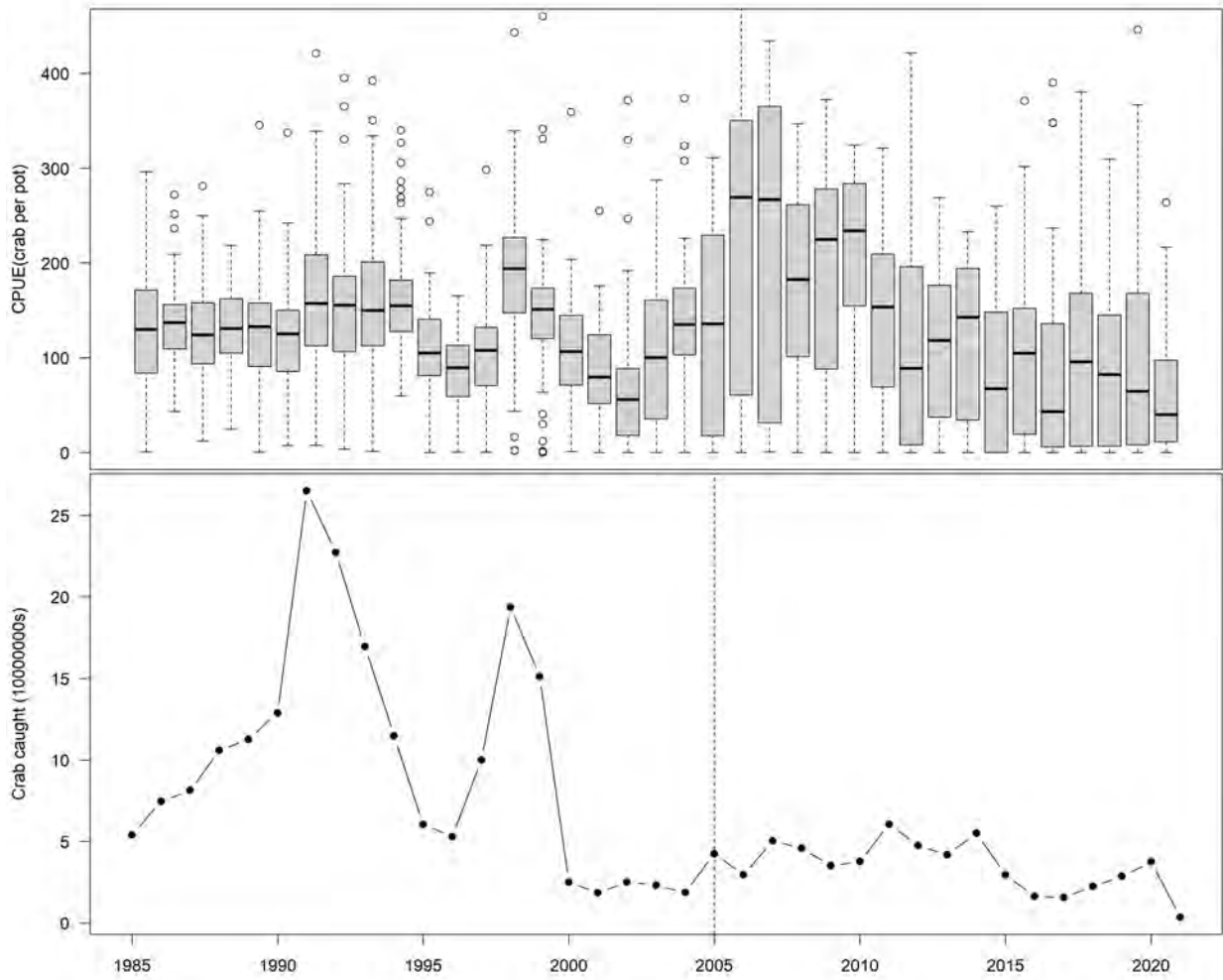


Figure 54: Catch per unit effort in the snow crab fleet, courtesy of Ben Daly.



Figure 55: Location of the survey strata on the eastern Bering Sea slope.

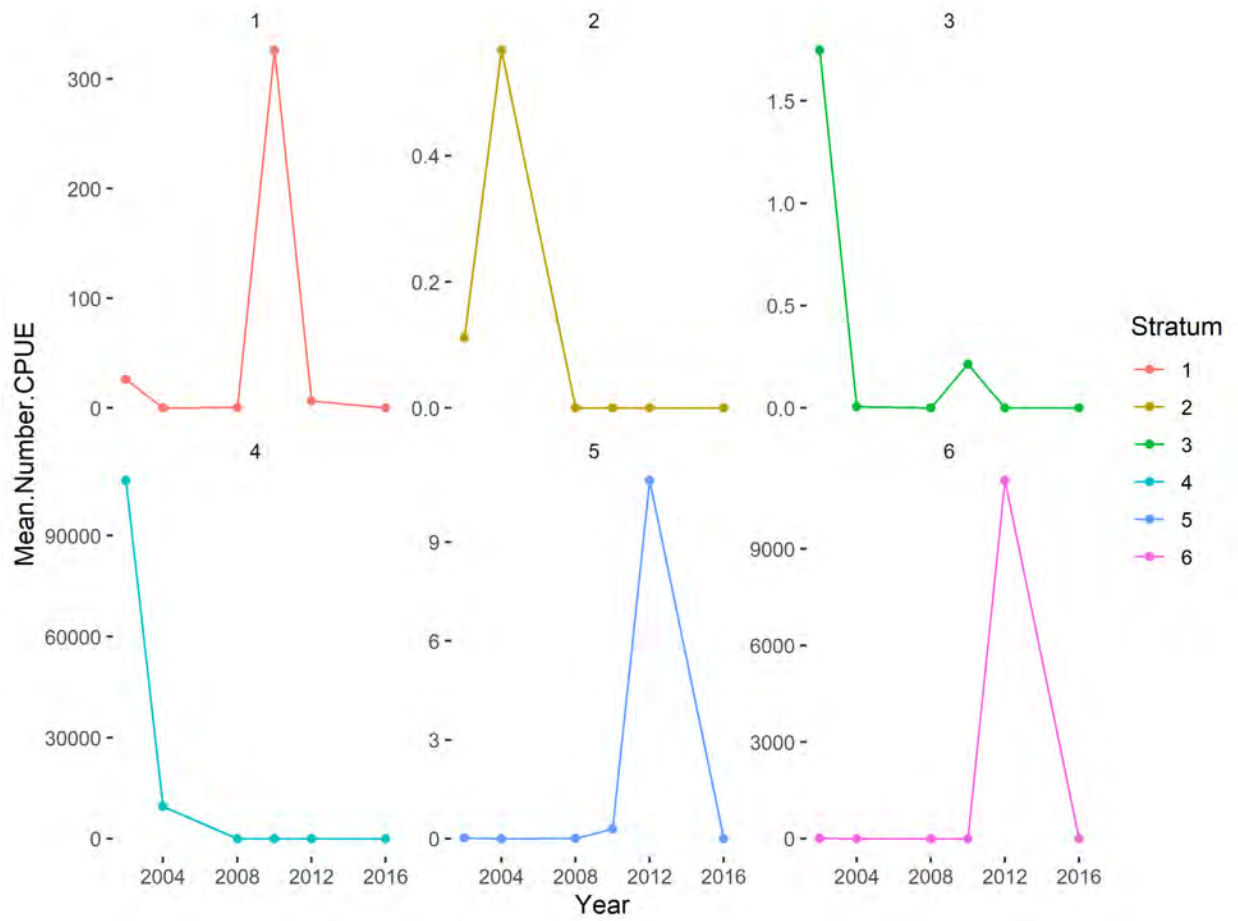


Figure 56: Mean catch per unit effort by strata over time in the EBS slope survey.

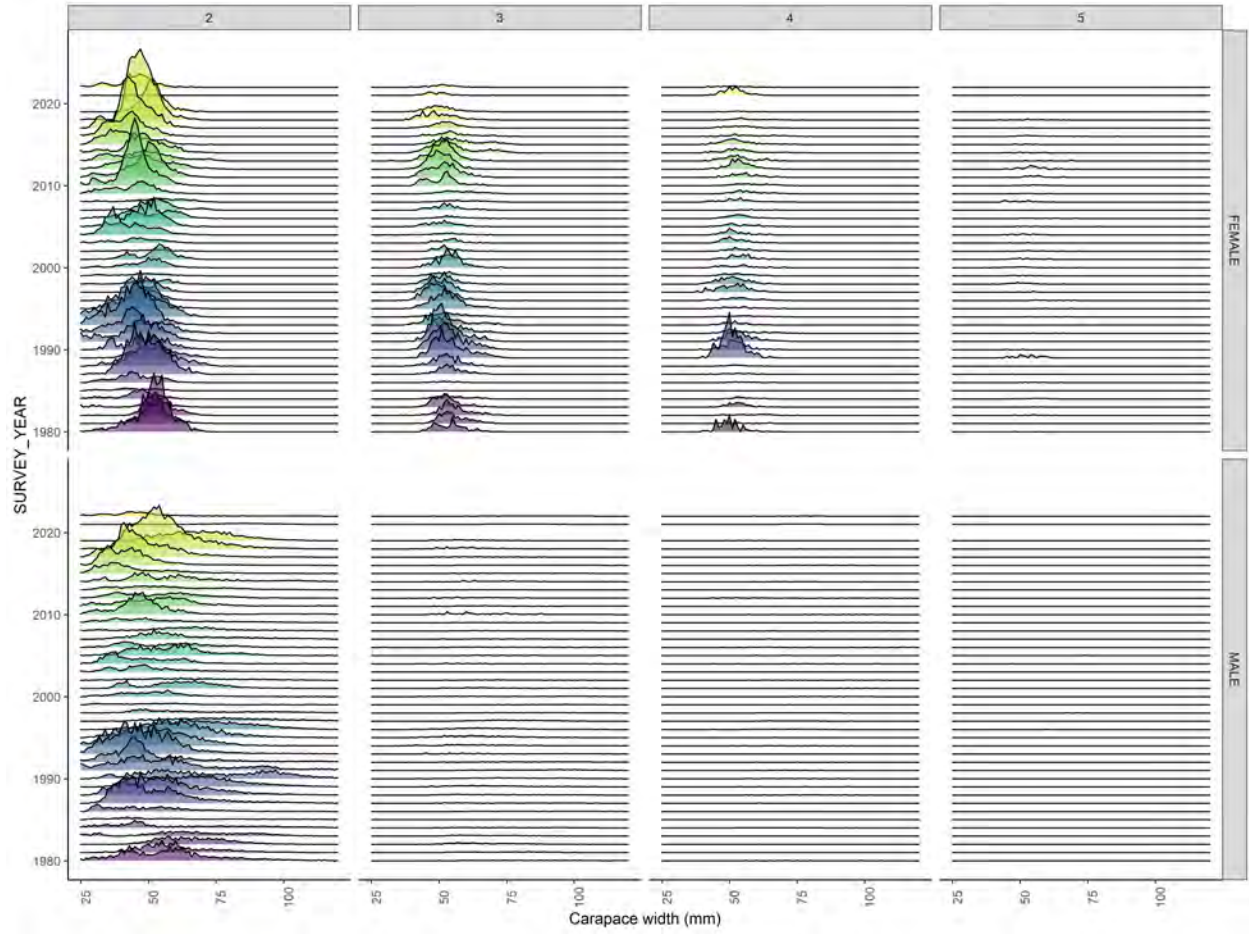


Figure 57: Relative numbers at size by shell condition and sex observed in the NMFS summer survey.

1 Appendix B: Canaries of the Arctic: the collapse of eastern Bering  
2 Sea snow crab

3 Cody Szuwalski (and others to come)

4 Snow crab are an iconic species the Bering Sea that support an economically important fishery and undergo  
5 extensive monitoring and management. However, since 2018 more than 10 billion snow crab have disappeared  
6 from the Bering Sea shelf and the population collapsed to historical lows in 2021. We link this collapse to  
7 a marine heatwave that occurred in the Bering Sea during 2018 and 2019. Calculated caloric requirements  
8 and observed body condition suggests that starvation may have played a role in the collapse. Fisheries  
9 disaster funds were requested in 2022 after allowable catches in the fisheries were slashed by ~90% in 2021  
10 and short-term prospects for snow crab in the Bering Sea are grim. The collapse of snow crab foreshadows  
11 climate-related fisheries management problems that will be more frequently faced around the globe. Losing  
12 a frame of reference for future ecosystems as environmental conditions move beyond historical observations  
13 shifts our management paradigm from predictive to reactive. New managements paradigms will be needed  
14 to face this challenge.

15  
16  
17  
18 THIS IS A DRAFT MANUSCRIPT INTENDED FOR SUBMISSION TO A PEER-REVIEWED JOURNAL

19  
20  
21 ALL CONCLUSIONS ARE PRELIMINARY

## 22 Introduction

23 Snow crab are one of the most abundant species in the benthic ecosystem of the eastern Bering Sea and have  
24 supported an iconic fishery valued at over US\$250 million that is the focus of “Deadliest catch”, a widely  
25 viewed reality television show. The implementation of quota-based fisheries management in 2005 has made  
26 the fishery less ‘deadly’ (NPFMC, 2010) and fisheries management in Alaska is considered to be some of  
27 the most effective in the world (Hilborn et al., 2021). Snow crab are distributed widely over the Bering  
28 Sea shelf (Figure 1a) and yearly bottom trawl surveys monitor the size and number of crab in the ocean.  
29 Myriad field and laboratory studies aimed at understanding population processes like growth and maturity  
30 have been performed (e.g. Copeman et al., 2021), but in spite of this attention and effort, the stock collapsed  
31 unexpectedly in 2021.

32 The collapse in 2021 occurred three years after the observed abundance of snow crab was at historical  
33 highs (Figure 1c). Groups of crab of similar sizes are called ‘pseudocoherths’ because true cohorts cannot be  
34 identified as a result of difficulties in aging crab associated with the loss of the hard body parts during the  
35 molting process. The largest pseudocohort on record was observed in the summer survey beginning in 2015  
36 and unexpectedly declined by roughly half from 2018 to 2019 (Figure 1d). The survey was cancelled in 2020  
37 because of the coronavirus pandemic, but the 2021 survey found the fewest snow crab on the eastern Bering  
38 Sea shelf since the survey began in 1975. More than 10 billion crab went missing from the eastern Bering  
39 Sea shelf from 2018 to 2021 (Szuwalski, 2021).

40 Hypotheses to explain the disappearance of these crab fall under two categories: either the crab are still alive  
41 but the survey did not see them or the crab have died. It is possible the crab are in the eastern Bering Sea,  
42 but were poorly captured by the most recent surveys. If this were the case, one would expect estimates for  
43 other similar species like Tanner crab to have declined unexpectedly, but the population trends for Tanner  
44 crab increased (figures S1). Movement to the northern Bering Sea could account for declines in the eastern  
45 Bering Sea, but surveys in the northern Bering Sea did not find crab in the quantities or of the correct sizes  
46 to explain declines in the south (Figure 1a). Movement west into Russian waters is another possibility, but  
47 Russian scientists reported declines in catch per unit effort in 2020 (Chernienko, 2021), which one might not  
48 expect if crab from Alaska emigrated. Finally, it is possible that the crab moved into deeper waters on the  
49 Bering Sea slope. High fishery catch per unit effort in deeper waters during the 2021 fishery supports this  
50 possibility to some extent, but the amount of available habitat is less than 10% that on the shelf (figures S2)  
51 and fishery catch per unit effort from 2022 were the lowest on record (figure S3). Consequently, it is unlikely  
52 that all of the missing crab from the shelf are on the slope. Given these observations, although movement  
53 off of the shelf could have played some role in the decline, mortality is a likely culprit for the bulk of the  
54 collapse.

55 Mortality could be affected via several pathways. Snow crab are generally cold-water loving, but they can  
56 function in waters up to 12 degrees in the laboratory (Foyle et al., 1989). An intense marine heatwave  
57 occurred in the Bering Sea during 2018 and 2019 and the ‘cold pool’ (a mass of water <2 degrees C on the  
58 sea floor with which juvenile snow crab are associated) disappeared during this period (Figure 1b). While  
59 not fatal, the resulting bottom temperatures could affect metabolic costs and alter intra- and inter-specific  
60 interactions. Smaller crab are a main component of the diet of Pacific cod in the Bering Sea (Lang and  
61 Livingston, 1996) and recent changes in the distribution and abundance of cod and crab has resulted in  
62 increased consumption. Removals from the snow crab fishery and incidental mortality in fisheries for other  
63 species in the Bering Sea also may also impact the dynamics of snow crab. Larger snow crab are known  
64 to cannibalize smaller snow crab and cannibalism has been suggested as an important driver of population  
65 dynamics in eastern Canadian populations (Lovrich et al., 1997). Finally, bitter crab syndrome, a fatal  
66 disease resulting from infection by a dinoflagellate (Meyers et al. 1996), has been observed more frequently  
67 in the summer survey in the last several years and is generally associated with warmer conditions and high  
68 densities of immature crab.

69 To understand the recent collapse, we first attempt to understand the historical variability in mortality. We  
70 fit a population dynamics model to the abundance and size composition data for male crab and estimated  
71 recruitment (small crab entering the population) and a maturity- and year-specific total mortality. ‘Total  
72 mortality’ represents the fraction of crab dying in a given year due to any cause. We then collated maturity-



73 specific time series of potential stressors from 1991 to 2019 and used them in generalized additive models  
74 (GAMs; Woods, 2011) to predict total mortality estimated from the population dynamics models (see SI for  
75 detailed methodology, sensitivities, and simulation testing).

76 The population dynamics model fit the indices of abundance and size composition data from the survey  
77 well, which is not unexpected, given the flexibility of the model (Figure 2a & b). Estimated mortality was  
78 higher and more varied for mature crab than for immature crab and estimated mortalities in 2018 and  
79 2019 were the some of the highest for both immature and mature crab in the time series. We simulated  
80 snow crab populations with time-variation in mortality to understand the ability of our population dynamics  
81 model to estimate these quantities with the available data. The correlation between estimated mortality and  
82 simulated mortality were high which suggests that analyses relating estimates of mortality and environmental  
83 covariates are justifiable (see SI for details). GAMs fit to estimated immature and mature mortality both  
84 returned at least one significant relationship with environmental stressors and explained ~72% and ~66%  
85 of the variability, respectively (Figure 2c). Higher temperatures and higher densities of mature crab were  
86 associated with higher mortality for both immature and mature crab. These relationships were robust to  
87 leave-one-out-cross validation and the deviance explained was ‘significant’ under randomization trials (see  
88 SI).

89 Assessing the predictive skill of a model is an important check on over-fitting and relevant to providing  
90 management advice. After an ecologically damaging and economically costly collapse, it is natural to ask  
91 if we could have foreseen the collapse. To explore this question, we excluded 1, 2, and 3 years of data  
92 from the end of the time series, refit the models, then tried to predict the last years of mortality with the  
93 covariates from those years. The model for immature mortality contained enough information in 2016 to  
94 forecast an increase in mortality, but never was able to reach the magnitude of the estimated mortality in  
95 2019 (Figure 2c). The model for mature mortality performed similarly, forecasting an increase in mortality  
96 over the projection period, but was not able to reach the estimated mortalities until the most recent data  
97 was in the model. This suggests that the circumstances underpinning the recent collapse were unprecedented  
98 in the Bering Sea in recent history.

99 The collapse of eastern Bering Sea snow crab appears to be one of the largest reported losses of marine  
100 macrofauna to marine heatwaves globally, exacerbated by the record number of snow crab in the system.  
101 Temperatures and density of mature crab were the most extreme covariates in 2018 and 2019. However,  
102 temperature and density alone are not a very satisfying explanation for what happened to the crab because  
103 the physiological thermal limits for snow crab far exceed the observed temperatures (Foyle et al., 1998).  
104 Temperature dependent caloric requirements are a potential explanation to relate temperature to mortality.  
105 Foyle et al. (1998) showed the caloric requirements for snow crab in the lab nearly double from 0 degrees  
106 to 3 degrees, which is roughly the change experienced by immature crab from 2017 to 2018 (Figure 3).  
107 Extrapolating the caloric requirements based on temperature occupied, abundance of crab at size, and  
108 weight at size suggests that the caloric requirements for snow crab in the eastern Bering Sea during 2018  
109 quadrupled from 2017 and were double the previous maximum value in 1998. The impact of increased caloric  
110 demands can also be seen in the observed weight at size. A 75 mm carapace width crab in 2018 weighed on  
111 average 156 grams and was ~25 grams lighter (~15% of its bodyweight) than a crab in 2017 of the same size  
112 in the same temperature waters (Figure 3). Given this information, starvation likely played a role in the  
113 disappearance of the ~10 billion snow crab, similar to the marine-heatwave related collapse of Pacific cod in  
114 the Gulf of Alaska in 2016 (Barbeaux et al., 2020).

115 Snow crab previously collapsed in the late 1990s, but the collapse arose from a lack of recruitment, not a  
116 sudden mortality event. Snow crab recruitment has been linked to changes in the Arctic Oscillation and sea  
117 ice (Szuwalski et al., 2020). Recent projections of recruitment suggest snow crab abundances will decline in  
118 the future as sea ice disappears from the eastern Bering Sea (Szuwalski et al., 2021). However, these declines  
119 were projected for at least twenty years from now. Given the recent collapse, the short-term future of snow  
120 crab in the eastern Bering Sea is precariously uncertain. Long-term the northern Bering Sea is a prospective  
121 climate refugia for snow crab (and potentially a fishery; Mullowney, in review), but the possibility of a fishery  
122 rests on the uncertain probability of crab growing to a larger size in the north and the currents retaining  
123 pelagic larvae released in the northern Bering Sea.

124 In 2021, 59 boats fished for snow crab and brought \$219 million (ex-vessel) into fishing communities (Garber-

125 Yonts, 2022). The disappearance of snow crab will be a staggering blow to the functioning of some com-  
126 munities in rural Alaska like St. Paul, which relies strongly on the revenue derived from the capture and  
127 processing of snow crab to support the functioning of local communities. The Magnuson-Stevens Act includes  
128 provisions for fisheries disaster assistance which were designed to provide economic support for communities  
129 facing hardship as a result of collapsed fisheries. The number of applications in the U.S. has been increasing  
130 in recent years (Bellquist et al., 2021) and an application for snow crab was received in early 2022. These  
131 funds are a boon in the medium-term, but can take years from disaster to dispersal. Consequently, Alaskan  
132 crabbers face an uncertain short-term future as the disaster funds may not arrive in time to forestall the  
133 bankruptcy of long-standing family businesses.

134 Beyond the fishery for snow crab, Alaskan fisheries are some of the most productive in the world, producing  
135 5.27 billion tons of seafood in 2021 valued at \$1.9 billion (NOAA FOSS, 2022). When snow crab populations  
136 declined in 1999, the Bering Sea walleye pollock population (which supports the largest fishery in the Bering  
137 Sea and one of the largest in the world, FAO, 2022) also declined shortly after (Figure 4). This relationship  
138 is captured by the significant correlation between the time series of pollock and snow crab abundance at a  
139 lag of 1 year (Figure 4d). While this correlation is suggestive, it is ultimately uncertain how the massive loss  
140 of crab will affect the benthic ecosystem and the fisheries dependent upon it. However, it is virtually certain  
141 that the benthic community in the eastern Bering Sea during not-too-distant future will look different than  
142 today's given the rapid pace of warming (Rantanen et al., 2022).

143 Overfishing has historically been the largest threat to global fisheries, but, in many parts of the world, this  
144 problem has been solved (Hilborn et al., 2022). Climate change is the next existential crisis for fisheries,  
145 and snow crab is a prime example for how quickly the outlook can change for a population. In 2018, catches  
146 were projected to increase to levels not seen in decades. Three years later, the population had collapsed.  
147 Our current management tools base projected sustainable yields on the historical dynamics of a population.  
148 However, projections based on assumptions relying on historical dynamics are not reliable when the future  
149 of a region will not resemble the past. Beyond reconsidering how allowable catches are calculated, the  
150 practical matters of efficient disaster response, implementing management institutions that allow fishers to  
151 pursue diverse portfolios of species, and support for the development of alternative marine-based livelihoods  
152 (e.g. mariculture) need close attention from management and stakeholders. The Bering Sea is on the front  
153 lines of climate-driven ecosystem change and the problems currently faced in the Bering Sea foreshadow the  
154 problems that will need to be confronted globally.

## 155 **Acknowledgments**

156 I'd like to thank DATA COLLECTION & THESE FOLKS.

## 157 **Supplementary materials**

158 The github repository including the code used to perform the analysis can be found at: [https://github.com/szuwalski/snow\\_down](https://github.com/szuwalski/snow_down).  
159

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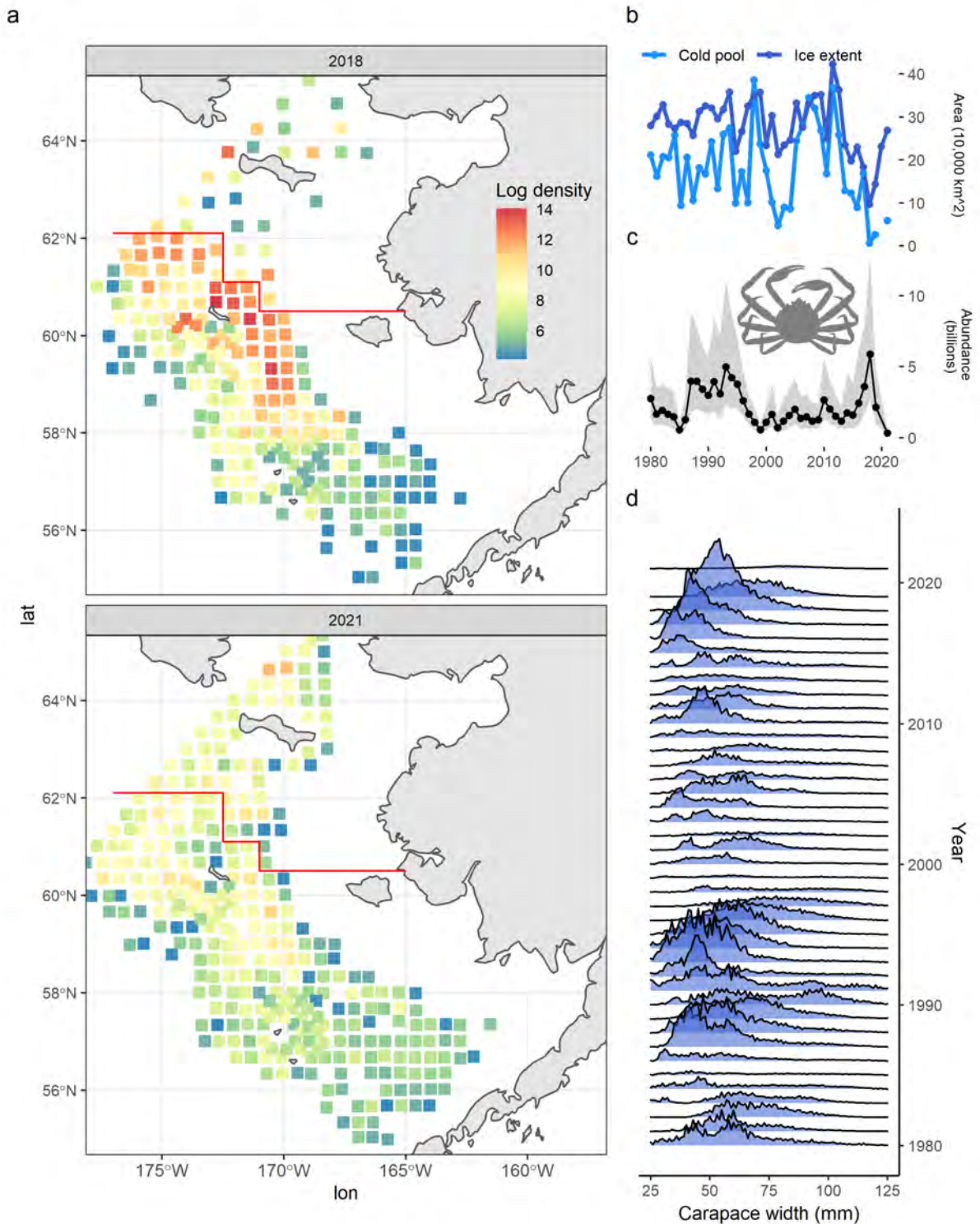
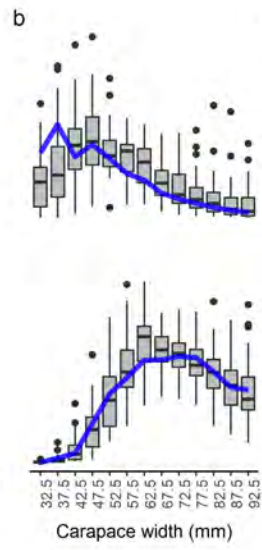
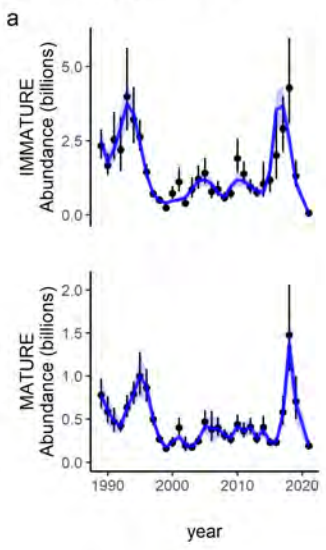


Figure 1: The collapse of snow crab in the eastern Bering Sea. Snow crab are widely distributed on the eastern Bering Sea shelf (a, each square represents a survey tow with snow crab present) and densities of crab were an order of magnitude lower in 2021 compared to 2018 (a). Changes in ice extent and the resulting cold pool (b) influence the population dynamics (c) of snow crab (only male abundance is plotted). The collapse of crab was not size dependent; crab of all sizes disappeared from 2018 to 2021 (d shows the relative numbers at size at crab observed in the NMFS survey over time).

Population Dynamics



Generalized Additive Models

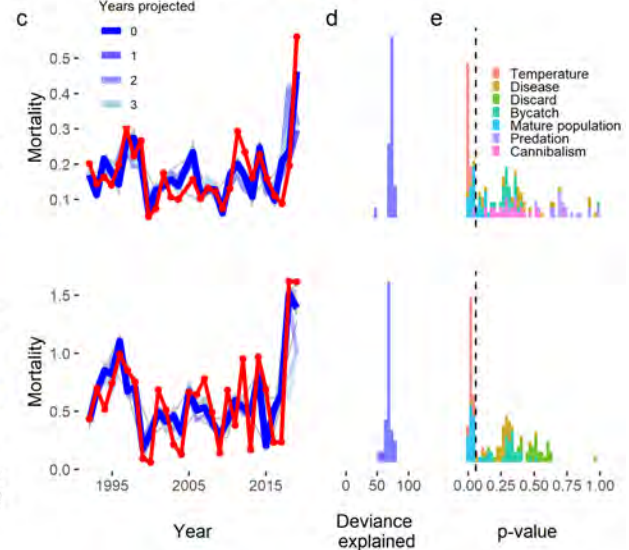


Figure 2: Population dynamics model fits to the data (abundance and confidence intervals (a), size composition data (b)). Fits (c; in blue) to estimated mortality (c; in red) from GAMs with the deviance explained (d) and the significance of covariates (e) resulting from replicates over leave-one out cross validation.

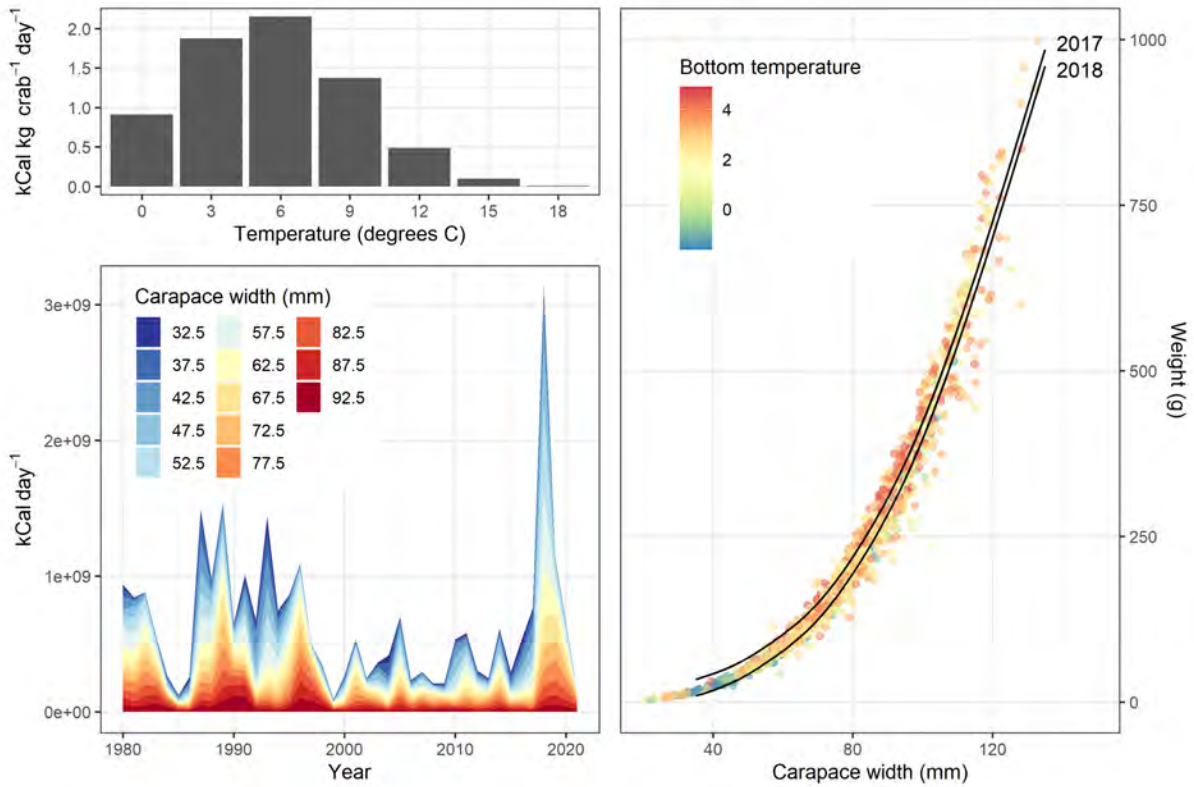


Figure 3: Impact of temperature on caloric requirements for snow crab in the lab (a; reproduced from Foyle et al., 1998), the extrapolated caloric requirements for crab in the eastern Bering Sea based on temperature, abundance at size, and weight at size (b), and the observed weight at size colored by the temperature at which the crab was collected (c). The lines represent the relationship between weight at size in 2017 and 2018 while holding temperature at 1 degree.



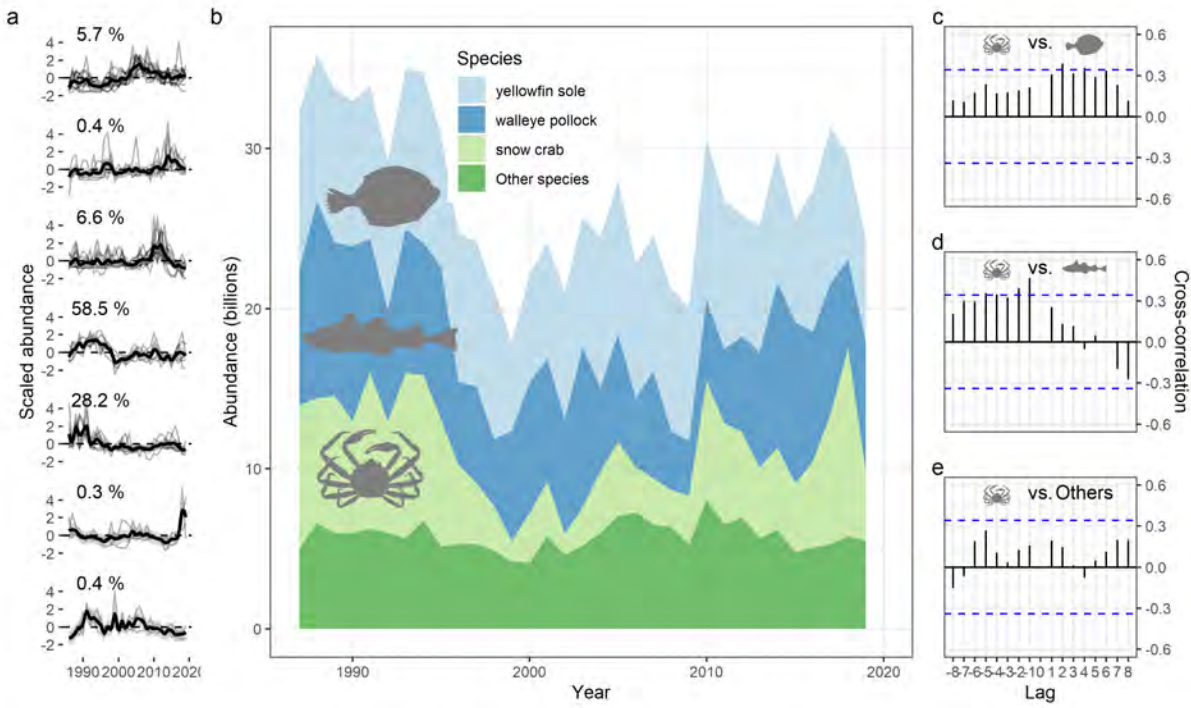


Figure 4: Time-series of scaled abundances of animals captured in the NMFS summer bottom trawl survey clustered using hierarchical clustering (a; 55 species represented, percentage in the top left of the panel represents the average proportion of the total abundance in that cluster) and total abundances over time for the three most abundance species in the bottom trawl survey and all 'other species' combined (b). Panels c-e are the cross-correlation between the time series of abundance for snow crab against yellowfin sole, walleye pollock, and other species, respectively.

# Appendix C: Supplementary materials for: Canaries of the Arctic: the collapse of eastern Bering Sea snow crab

Cody Szuwalski (and others to come)

## Supplementary materials

### Methods overview

We used an integrated population model to estimate variation in mortality over time for snow crab in the eastern Bering Sea and generalized additive models (GAMs) to relate the estimated variation in mortality to potential stressors in the environment. The population dynamics model was fit to abundance and size composition data from the National Marine Fisheries Service (NMFS) summer bottom trawl survey in the eastern Bering Sea shelf to estimate total mortality by maturity state and year for male snow crab. We then developed indices for temperature occupied, disease prevalence, cannibalism, and density dependent effects from the NMFS survey to test as covariates in GAMs. Indices for fishery related effects were collated from fisheries statistics from the Alaska Department of Fish and Wildlife and also included in the GAMs. Below we describe each of these components, discuss the rationale behind our modeling decisions, and provide sensitivities and simulation tests of our models.

### Population dynamics model

The population dynamics model presented here incorporates the best available information on relevant population processes to estimate total mortality for male snow crab on the eastern Bering Sea shelf and is similar in structure to the model used to assess eastern Bering Sea snow crab for management (Szuwalski, 2021). The model tracked numbers of male crab at size at maturity state over time with size bins ranging from 30-95 mm carapace width with 5 mm bin widths. Only male crab were modeled because male and female crab appear to have somewhat different dynamics and the male crab in the modeled size range are better selected by the survey gear (Szuwalski, 2021). Snow crab are sexually dimorphic, with male snow crab growing to nearly twice the size of females, which accounts for the better selection in the survey. Only crab smaller than 95 mm were modeled for two reasons: 1) to attempt to isolate the effect of the directed fishery (crabs of >101 mm carapace width are targeted in the fishery; discussed further below) and 2) almost all of the crab that disappeared since 2018 are in this size range. The population dynamics model operates on a half year time step, starting in July at the time of the NMFS survey. The fishery is assumed to occur in February. Total mortality ( $Z$ ) is estimated by year ( $y$ ) and maturity state ( $m$ ). Other estimated parameters include the initial numbers at size by maturity state, yearly log recruitments, a vector of scalars that determine the proportions of estimated recruitment split into the first two size bins, and a variance component for the penalty on total mortality. Parameters determining growth, maturity, and survey selectivity were estimated outside of the model and specified when estimating mortality and catchability. Mortality is the only population process that occurs in the first half of a given year:

$$N_{t=y+0.5,s,m} = N_{t=y,s,m} e^{-Z_{t,s,m}/2} \quad (1)$$

Growth occurs at the beginning of the second half of the year for immature crab and is represented in the model by multiplying the vector of immature crab at size by a size-transition matrix  $X_{s,s'}$  that defines the

37 size to which crab grow given an initial size. Snow crab are observed to undergo a ‘terminal molt’ to maturity  
 38 after which growth ceases (Dawe et al., 1991). Accordingly, all immature crab are assumed to molt and no  
 39 mature crab molt in our model. The newly molted crab are assigned to a maturity state based on observed  
 40 ogives of the proportion of mature new shell males by size calculated from chelae height measured in the  
 41 NMFS survey data (Otto, 1998), which varies over time ( $\rho_{y,s}$ ; Figure 4). The average probability of having  
 42 undergone terminal molt is used in years during which data were not collected. This process results in two  
 43 temporary vectors of numbers at size:

$$n_{t=y+0.5,s,m=1} = \rho_{y,s} X_{s,s'} N_{t=y+0.5,s,m=1} \quad (2)$$

$$n_{t=y+0.5,s,m=2} = (1 - \rho_{y,s}) X_{s,s'} N_{t=y+0.5,s,m=2} \quad (3)$$

45 The size transition matrix  $X_{s,s'}$  was constructed using growth increment data collected over several years  
 46 (see Szuwalski, 2021 for a summary) to estimate a linear relationship pre- and post-molt carapace width  
 47 (Figure 5), ( $\hat{W}_{s,w}^{pre}$  and  $\hat{W}_{s,w}^{post}$ , respectively) and the variability around that relationship was characterized by  
 48 a discretized and renormalized normal distribution with a size-varying standard deviation,  $Y_{s,w,w'}$  (Figure 5).

$$X_{s,w,w'} = \frac{Y_{s,w,w'}}{\sum_{w'} Y_{s,w,w'}} \quad (4)$$

$$Y_{s,w,w'} = (\Delta_{w,w'})^{\frac{L_{s,w} - (\bar{W}_w - 2.5)}{\beta_s}} \quad (5)$$

$$\hat{L}_{s,w}^{post} = \alpha_s + \beta_{s,1} \text{hat} W_{s,w}^{pre} \quad (6)$$

$$\Delta_{w,w'} = \bar{L}_{w'} + 2.5 - W_w \quad (7)$$

49 It is important to note that crab can ‘outgrow’ this model, which is represented by the pre-molt-carapace  
 50 widths (e.g. 87.5 and 92.5 mm carapace width in Figure 5) that have low probability of molting to any of  
 51 the sizes that are included in the population dynamics model.

52 Recruitment by year,  $\tau_y$ , was estimated as a vector in log space and added to the first two size of classes of  
 53 immature crab based on another estimated vector  $\delta_y$  that determines the proportion allocated to each size  
 54 bin.

$$n_{t=y+0.5,s=1,m=1} = n_{t=y+0.5,s,m=1} + \delta_y e_y^\tau \quad (8)$$

$$n_{t=y+0.5,s=2,m=1} = n_{t=y+0.5,s,m=1} + (1 - \delta_y) e_y^\tau \quad (9)$$

56 Finally, the last half of the year of mortality is applied to the population after growth, maturity, and  
 57 recruitment occurs. Note that this allows a crab to experience two different mortalities within a given year  
 58 as it undergoes terminal molt.

$$N_{t=y+1,s,m=1} = n_{t=y+0.5,s,m=1} e^{-Z_{t,s,m}/2} \quad (10)$$

$$N_{t=y+1,s,m=2} = (N_{t=y+0.5,s,m=2} + n_{t=y+0.5,s,m=2}) e^{-Z_{t,s,m}/2} \quad (11)$$

60 **Survey selectivity**

61 The observed numbers of crab at size by year in the NMFS survey reflect the ability of the trawl gear to  
 62 capture the crab, also known as ‘selectivity’. The selectivity of trawl gear can change according to size,  
 63 and consequently needs to be accounted for in the population dynamics model when fitting to the survey  
 64 data. Values for survey selectivity at size were specified using data from experimental trawls conducted  
 65 by the Bering Sea Fisheries Research Foundation in collaboration with the NMFS summer survey. The  
 66 experimental trawls were performed at the same time and location as the NMFS summer survey tows to  
 67 evaluate the efficiency of the NMFS survey trawl gear at capturing snow crab (Somerton et al., 2013).  
 68 The nephrops gear used by the BSFRF was assumed to capture all crab in its path given strong bottom  
 69 contact. The resulting area-swept estimates of numbers of crab at size from the BSFRF and NMFS surveys  
 70 ( $\hat{N}_{y,s,NMFS}$  and  $\hat{N}_{y,s,BSFRF}$ , respectively) can be used to infer the selectivity of the NMFS gear in year  $y$   
 71 as:

$$S_{y,NMFS} = \frac{N_{y,s,\hat{N}NMFS}}{\hat{N}_{y,s,BSFRF}} \quad (12)$$

72 The experimental trawls captured snow crab in the years 2010, 2011, 2016, 2017, and 2018, but the spatial  
 73 foot print and sample sizes varied by year (Figure 6). The calculated selectivities by size and by year were  
 74 fairly consistent for snow crab of carapace widths 40 - 95 mm, but the signal was less consistent for crab  
 75 larger than ~100 mm carapace width (Figure 7). The selectivity of large crab determines the estimated scale  
 76 of the population in a population dynamics models, but the information we have on selectivity of is poor and  
 77 different assumptions about selectivity lead to very different inference about the stock (Szuwalski, 2021b).  
 78 The lack of clear information on the scale of the population exploited by the fishery is one of the key reasons  
 79 we used the range of sizes included in this model and excluded the directed fishery data from the analysis. A  
 80 GAM was fit through the estimates of selectivity and the resulting estimates by size were directly specified  
 81 in the population dynamics model.

82 ‘Catchability’ represents the fraction of the population available to the survey gear (either as a result of  
 83 spatial mis-match or the inability of the gear to come in contact with the animals as a result of burrowing  
 84 or hiding in untrawlable habitat). The capability for modeling time-varying catchability was built into the  
 85 model in the form of a vector of parameters equal to the length of the time series of data. When time-  
 86 varying catchability was estimated, the yearly catchability parameters were used to scale the selectivity  
 87 curve described above up or down.

88 **Objective function**

89 The objective function for the population dynamics model consists of likelihood components and penalty  
 90 components that are summed and minimized in log space to estimate parameters within the model. Several  
 91 data sources were fit to using the following likelihoods. Observed size composition data for immature and  
 92 mature males were fit using multinomial likelihoods and were implemented in the form:

$$L_x = \lambda_x \sum_y N_{x,y} \sum_l p_{x,y,l}^{obs} \ln(\hat{p}_{x,y,l} / p_{x,y,l}^{obs}) \quad (13)$$

93  $L_x$  was the likelihood associated with data component  $x$ , where  $\lambda_x$  represented an optional additional weight-  
 94 ing factor for the likelihood,  $N_{x,y}$  was the sample sizes for the likelihood,  $p_{x,y,l}^{obs}$  was the observed proportion  
 95 in size bin  $l$  during year  $y$  for data component  $x$ , and  $\hat{p}_{x,y,l}$  was the predicted proportion in size bin  $l$  during  
 96 year  $y$  for data component  $x$ . Sample sizes were input as 100, which is the value currently used in the stock  
 97 assessment (Szuwalski, 2021).

98 Observed indices of abundance for immature and mature males were fit with log normal likelihoods imple-  
 99 mented in the form:

$$L_x = \lambda_x \sum_y \frac{(\ln(\hat{I}_{x,y}) - \ln(I_{x,y}))^2}{2(\ln(CV_{x,y}^2 + 1))} \quad (14)$$

100  $L_x$  was the contribution to the objective function of data component  $x$ ,  $\lambda_x$  was any additional weighting  
 101 applied to the component,  $\hat{I}_{x,y}$  was the predicted value of quantity  $I$  from data component  $x$  during year  $y$ ,  
 102  $I_{x,y}$  was the observed value of quantity  $I$  from data component  $x$  during year  $y$  and  $CV_{x,y}$  was the coefficient  
 103 of variation for data component  $x$  during year  $y$ .

#### 104 Penalties and priors

105 Smoothing penalties were placed on estimated vectors of deviations for immature and mature natural mor-  
 106 tality and immature and mature catchability. A prior value of 0.27 is used for the average natural mortality  
 107 based on assumed maximum age of 20 and Hamel’s (2015) empirical analysis of life history correlates with  
 108 natural mortality. The priors used for catchability were derived from the selectivity experiments described  
 109 above. Penalties were implemented using normal likelihoods on the second differences of the vector. A  
 110 separate normal prior was placed on the estimated mean value of immature and mature mortality in the  
 111 form:

$$L_x = \lambda_x \sum_y \frac{((\hat{I}_{x,y}) - (I_{x,y}))^2}{CV_{x,y}^2} \quad (15)$$

112  $L_x$  was the contribution to the objective function of data component  $x$ ,  $\lambda_x$  was any additional weighting  
 113 applied to the component,  $\hat{I}_{x,y}$  was the predicted value of quantity  $I$  from data component  $x$  during year  $y$ ,  
 114  $I_{x,y}$  was the observed value of quantity  $I$  from data component  $x$  during year  $y$  and  $CV_{x,y}$  was the coefficient  
 115 of variation for data component  $x$  during year  $y$ .

#### 116 Population dynamics model sensitivities

117 Modeling decisions are necessarily made in the process of writing population dynamics models and it is  
 118 possible for these decisions to influence the outcome of an analysis. Within the context of our model, these  
 119 decisions include what processes to allow to vary over time, the weights assigned to different data sources  
 120 and portions of the objective function, which parameters to place priors or penalties on, and what those  
 121 priors or penalties should be. We ran several sensitivity analyses to understand the implications of these  
 122 modeling decisions on the outcome of our analysis.

#### 123 Does allowing mortality or catchability to vary over time improve model fits?

124 Catchability and mortality are somewhat confounded within population dynamics models (Thompson, 1994).  
 125 Fewer crab observed in a given year can be attributed to either crab dying or by crab moving out of the  
 126 surveyed area either by walking out of the boundaries or burying themselves into the substrate. At the same  
 127 time, it is also clear that catchability and mortality likely vary over time in reality in spite of the fact that  
 128 they are often assumed to be time-invariant in population dynamics models (Johnson et al., 2014). Somerton  
 129 et al. (2013) showed that catchability varied somewhat by substrate and depth for snow crab in the EBS.  
 130 The spatial distribution of snow crab varies over time and substrate and depth vary over space, so it follows  
 131 that catchability should also vary over time.

132 We started exploring the impacts of including time-variation in mortality and catchability on model output  
 133 by fitting a model with no time-variation in mortality or catchability. Then we compared the output of  
 134 this model to models that allow time-variation in mortality, catchability, and both processes simultaneously  
 135 (Figure 8 & Figure 9). The model with no time-variation in mortality or catchability was able to capture the

136 general trend in immature and mature survey abundance solely through estimating variability in recruitment.  
137 Allowing time-variation in catchability improved the fits to immature survey abundances more than time-  
138 varying mortality, but time-variation in either process improved fits in a similar manner for mature survey  
139 abundances. Mature size composition data were fit similarly for all models, but immature size composition  
140 data were better fit by the models that allowed time-varying catchability (Figure 8). Part of the reason  
141 this difference in fits to immature size composition data occurs is the variability in the first several size bins  
142 resulting from the poor selectivity of the survey for small animals. Sometimes the peaks seen in larger size  
143 classes are reflected in the preceding years' data for the smallest size classes, sometimes those peaks are not  
144 reflected (compare Figure 10 to Figure 11). As a consequence, positive residuals occur in the smallest size  
145 classes when a pseudocohort is consistently seen in large size classes, but not observed in the smallest size  
146 bins (e.g. 1991 vs. 1992; 1997 vs 1998).

147 The model without time-variation in mortality or catchability explained 67% of the deviation in the abun-  
148 dance indices, time-varying mortality explained 77%, time-varying catchability explained 94%, and both  
149 processes varying explained 99% of the historical deviance. Model selection based on information criteria  
150 (e.g. AIC; Akaike, 1974) are often used to identify a model within a suite of models that most parsimoniously  
151 fits the data. Adding time-variation in natural mortality or catchability alone improved model fits parsimo-  
152 niously (AIC of 3434.15 for base model vs. 1593.836 and 1321.486 for time-varying mortality and catchability,  
153 respectively). However, adding time-variation in both processes resulted in a higher AIC (1449.275) than  
154 implementing time-variation in catchability, owing to the large number of parameters estimated. While  
155 catchability and mortality are somewhat confounded, catchability is also confounded with other sorts of  
156 error (e.g. observation) and allowing a relatively unconstrained estimation of catchability over time resulted  
157 in over-fitting the data, the consequences of which will be seen in simulations below. Even with this paring of  
158 potential models, there are several assumptions that could influence the output of our models. The following  
159 sensitivities are aimed at exploring the impacts of those assumptions on model output.

## 160 **How well can the model estimate mortality and selectivity with simulated data?**

161 One of the most essential exercises to perform with a population dynamics model before using its output is  
162 to perform a 'self-test' in which data are simulated from the population dynamics model with appropriate  
163 error and then fit to with the model. The goal of this test is to determine whether or not a model can return  
164 the parameter values underlying the simulated data with the available quantity and quality of data. For our  
165 analysis, the ability of the model to estimate mortality and catchability are of particular interest because  
166 they are candidates for use as input into GAMs to attempt to link the estimates to environmental stressors.  
167 Recruitment is also of interest because of its confounding with the other processes.

168 Log-normal error was added to the true underlying abundance from the simulation model with three different  
169 coefficients of variation: 0.01, 0.10, and 0.30. Simulated data sets were generated 100 times under each  
170 observation error scenario and the population dynamics models were fit to them. Two population dynamics  
171 models were fit: one in which time-varying natural mortality was estimated and one in which time-varying  
172 natural mortality and time-varying catchability were estimated. Estimates of mortality were closer to the  
173 true underlying values than estimates of catchability (compare Figure 12 to Figure 13). Mature mortality was  
174 better estimated than immature mortality regardless of data quality or model configuration. The correlation  
175 between estimated and simulated mortality was 0.65 and 0.96 for immature and mature mortality for the  
176 0.01 observation error scenarios, respectively. The ability of the models to estimate mortality became more  
177 similar as data quality decreased. Overall, the model was best able to estimate mature mortality and this is  
178 likely a consequence of its separation from estimated recruitment in time. In general, estimates of catchability  
179 for both maturity states were unreliable.

180 As a result of these simulation analyses, two modeling decisions arose. First, we used estimated variation in  
181 mortality from models that only estimate time-variation in mortality because the estimates of mortality from  
182 models that estimated time-variation in both mortality and catchability were less reliable. This precludes  
183 attempts to identify relationships between estimated catchability and environmental variables. Second, the  
184 inability of the model to capture the scale of the population (Figure 14) underscores the need to relate  
185 mortality to the environmental covariates outside of the model, rather than attempting to build them into

186 the model (similar to Dorn and Barnes, 2022). The covariates described below are indices of a particular  
187 environmental stressor, not absolute quantities that could provide scale to the model.

## 188 **How do the assumptions about weighting and priors influence the estimated quantities?**

189 Some aspects of the model that may influence the outcome of the fitting are specified by the user with no  
190 clear ‘correct’ value. These include the weights assigned to the size composition data, some priors placed  
191 on population processes, and the weights assigned to the smoothness penalties. We performed sensitivity  
192 analyses for these parameters to check how different specifications changed the fits to the data and the  
193 estimates of mortality and catchability. We input a range of values for the size composition weights (25, 50,  
194 100), the prior on the mean natural mortality in log space (-1.6, -1.2, -0.8), the input standard deviation for  
195 the penalties on natural mortality (0.01, 0.1, 0.2) and the smoothness penalty on the estimated time series’  
196 of mortalities and catchabilities (0.001, 0.1, 0.5, 0.1).

197 Differences among sensitivity scenarios resulted in very small changes in the fits to the data (Figure 15), but  
198 larger changes in estimated mortalities and catchabilities (Figure 16). The smoothness penalty placed on  
199 mortality over time appeared to be the largest driver of changes in estimates of  $M$  and  $q$ , so we looked at a  
200 wider range of smoothness penalties (i.e. 0.001, 0.1, 0.25, 0.5, 1, 5, 10, 1000). Trajectories of mortalities were  
201 roughly preserved across this range. The prior on mean natural mortality predictably scaled the estimated  
202 time series up or down. The best available information suggests natural mortality should be approximately  
203 0.27 given an assumed (but based on a range of studies; see Szuwalski, 2021 for a summary) maximum  
204 age of 20 years for wild snow crab. Based on these analyses, we elected to use small smoothing penalties  
205 because there is no evidence to suggest that mortality should be particularly smooth from year to year.  
206 These analyses also underscore the fact that the scale of the population is difficult to estimate with the  
207 data available and the need to relate mortality to the environmental covariates outside of the population  
208 dynamics model. This likely comes from the fact that recruitment and immature mortality are confounded  
209 (i.e. fewer immature crab in a given year can be because of increased immature mortality or because of lower  
210 recruitment) and the lack of data (like removals) given in an absolute (rather than relative) metric.

## 211 **Covariate construction**

212 A wide range of factors could potentially influence mortality of snow crab on the eastern Bering Sea shelf,  
213 including temperature, predation, disease, cannibalism, and fisheries effects. The NMFS summer trawl  
214 survey provides a rich spatio-temporal data set to develop time series of temperature occupied, predation,  
215 disease, and cannibalism. The fisheries-dependent observer data provide spatio-temporal information on  
216 bycatch.

217 Currently, estimating spatially-explicit, time-varying mortality is not computationally feasible, nor are data  
218 on movement available to inform such a model. Consequently, our analysis aggregates the spatial data  
219 for snow crab into time-series. The end goal is to use these time-series in predictive models to identify  
220 relationships between estimated mortality and stressors, so attention has to be paid to creating appropriate  
221 comparisons. For example, a predation index needs to consider not only the total consumption of crab by  
222 cod, but also the total number of crab in the ocean of the size that can be consumed by cod to be comparable  
223 to changes in mortality rates (discussed more below).

224 Another important point for consideration in covariate construction is the estimation of mortality by maturity  
225 state. Snow crab in the EBS undergo an ontogenetic migration in which juvenile crab settle on the northeast  
226 portion of the shelf after their pelagic phase, then migrate southwest into deeper and (usually) warmer waters  
227 (Ernst et al., 2005; Parada et al., 2010). This means that the conditions and stressors felt by immature  
228 crab can be different than the stressors felt by mature crab. To address this issue, the spatial data sets  
229 for temperature, disease, and cannibalism were split based on the size above which half of the population  
230 was mature. The size at which more than half of the population is mature changes by year, depending on  
231 recruitment dynamics and other demographic processes (Figure 17). After the survey data were split at the  
232 50% at maturity size, time series of maturity-specific environmental stressors (Figure 18) were created as  
233 described below.

## 234 Temperature

235 Temperature is one of the key physical variables that structures the benthic ecosystem of the EBS (Mueter  
236 and Litzow, 2088). The cold pool, a mass of water <2 degrees Celsius, acts as a barrier to species interaction  
237 based on temperature preferences of different species. Snow crab are a stenothermic species, preferring cold  
238 water and juvenile snow crab in particular are rarely found outside of the cold pool (Dionne, 2003). The  
239 cold pool is directly related to the winter ice extent in the Bering Sea and has varied dramatically over time  
240 as the ecosystem moves between cool and warm stanzas (e.g. 2006-2010 vs. 2014-2019; Figure 1b of the main  
241 text and Figure 19). As the cold pool changes from year to year, so does the spatial distribution of snow crab  
242 (Figure 20). The ontogenetic migration of snow crab results in crab of different sizes and maturity states  
243 experiencing different temperatures in a given year (Figure 21). The ‘temperature occupied’ for different  
244 sizes of crab by year  $T_{s,y}$  was calculated here as an average of the observed bottom temperatures at the  
245 stations at which crab of a given size were captured  $t_i$ , weighted by the area-swept density of crab at a given  
246 station  $d_i$ :

$$T_{s,y} = \frac{\sum_i d_i t_i}{\sum_i d_i} \quad (16)$$

247 The resulting time series of temperatures occupied by size were then split by maturity state by identifying a  
248 cutoff beyond which half of the population was mature and aggregating the temperatures above and below  
249 the cutoff to represent immature and mature temperature occupied (Figure 22).

## 250 Predation

251 Pacific cod (*Gadus macrocephalus*) are the largest predator of snow crab based on stomach content data  
252 collected in the NMFS summer bottom trawl survey (Long and Livingston, 1998). Immature crab under  
253 the size of 55 mm carapace width are the primary sizes consumed by cod in the Bering Sea (Burgos et al.,  
254 2010). Changes in the cold pool have altered the interaction between snow crab and Pacific cod over time.  
255 Decreases in the size of the cold pool coincide with more northerly positions of the centroids of abundance of  
256 cod (e.g. 2003 and 2018-2019; Figure 23 & Figure 24). This increased interaction coincided with increased  
257 numbers of crab consumed by cod in the last several years (Figure 25). However, this period of time also  
258 coincided with the appearance of the largest pseudo-cohort of snow crab ever seen in the Bering Sea. Given  
259 the generalist nature of Pacific cod, one would expect to see an increase in the amount of crab consumed by  
260 cod during this period of time even if there weren’t differences in the interactions between the species as a  
261 result of changes in the cold pool. Further, a large fraction of the missing crab from the recent collapse were  
262 not of the sizes typically eaten by cod (Figure 26). To evaluate the possibility cod consumption has influenced  
263 the mortality of snow crab over time, the relative impact of consumption with respect to the population size  
264 must be considered. Consequently, predation indices were calculated for mature and immature animals by  
265 year  $P_{m,y}$  by calculating the ratio of the extrapolated biomass of crab consumed by cod to the biomass of  
266 the estimated numbers of crab by maturity state,  $N_{y,m,s} * w_s$ :

$$P_{m,y} = \frac{cod_{y,m}}{\sum_s N_{y,m,s} * w_s} \quad (17)$$

267 The exact amount of crab eaten cannot be calculated from the diet data because the diet data are a snap-  
268 shot of the consumption at one point during the year and consumption would be expected to change with  
269 spatial overlap and temperature-driven changes in metabolism occurring throughout the year. Consequently,  
270 removals due to predation cannot be directly incorporated into the model as fishery removals might be. How-  
271 ever, the predation index developed here represents the best available information on the relative impact of  
272 cod predation on snow crab mortality for use in correlative models like the GAMs below.



## 273 **Disease**

274 Bitter crab syndrome is a fatal disease in snow crab caused by a parasitic dinoflagellate. The presence of  
275 disease is recorded in the NMFS summer trawl survey data for the subset of crab that are individually  
276 measured based on a visual inspection. Portions of the shells of diseased crab present as a milky white,  
277 which is different from their usual more translucent state. The spatial distribution of bitter crab disease is  
278 predominantly on the northeastern shelf where smaller immature animals are found (Figure 27). For this  
279 analysis, disease prevalence was calculated simply as the number of infected individuals identified in the  
280 survey divided by the total number of individuals caught in the survey (Figure 18).

## 281 **Cannibalism**

282 Cannibalism has been proposed as a potential driver of the dynamics of snow crab in eastern Canada (Lovrich  
283 et al., 1997). In laboratory studies, crab smaller than 55 mm carapace width were at high risk of being  
284 cannibalized when housed with larger crab (Lovrich et al., 1997). Crab larger than 55 mm carapace width  
285 were much less likely to be cannibalized, but the frequency of injury could be high. Here we developed an  
286 index of cannibalism based on two aspects of the spatial distribution of snow crab: the overlap of crab smaller  
287 than 55 mm carapace width with crab larger than 95 mm carapace width (Figure 28) and the density of  
288 crab larger than 95 mm carapace width within the shared space. The proportion of 55 mm carapace width  
289 crab in the overlapping area represents the ‘exposure’ of the smaller population to cannibalism and the  
290 density of crab larger than 95 mm carapace width within that area represents the potential ‘intensity’ of  
291 cannibalism in the shared area. We calculated an index of cannibalism over time as the product of exposure  
292 and intensity. Consequently, a scenario in which there was large overlap, but low densities of large crab  
293 would result in a low cannibalism index value. Similarly, a scenario in which there was low overlap, but high  
294 densities would result in a low cannibalism index value. This produces an index that is comparable with  
295 estimated mortality—a higher cannibalism index would be expected to be associated with higher mortality if  
296 cannibalism is a strong driver of mortality in the size ranges of crabs modeled here.

297 The proportion of 55 mm carapace width crab overlapping with larger than 95 mm carapace width crab was  
298 calculated by finding the intersection of the station IDs at which at least one crab of both size classes was  
299 observed. The density of crab larger than 95 mm carapace width was calculated as the number of >95 mm  
300 carapace width crab observed at those stations multiplied by the area swept. This exercise was also done  
301 by 5 mm size bins to show the overlap of small crab of different sizes with large crab (Figure 29). The final  
302 index aggregated all crab smaller than 55 mm carapace width (Figure 30).

## 303 **Fisheries data**

304 Snow crab are caught both in a directed fishery (i.e. a fishery aimed at capturing snow crab) and non-directed  
305 fisheries (i.e. fisheries with targets other than snow crab). In the directed fishery, under-sized and/or dirty  
306 shelled crab are often discarded. Snow crab are discarded from non-directed fisheries using a variety of  
307 gear types (including trawl, pots, hook-and-line) and targeting a variety of species (e.g. Pacific cod, walleye  
308 pollock, and yellowfin sole) that operate over a wide fraction of the Bering Sea shelf (Figure 31). Figure 31 is  
309 plotted in log space, so it appears that the bycatch is spread widely over the shelf, but in normal space, the  
310 bycatch is more concentrated (e.g. Figure 32). The location of the centroids of the bycatch have moved over  
311 time and increases in latitude correspond with warm years in which reduced ice extent allowed for fishing  
312 farther north (Figure 33). Bycatch in groundfish trawl fisheries are by far the largest sources of bycatch  
313 mortality (Figure 34). Data on discards and bycatch of snow crab are collected by at-sea observers on fishing  
314 boats and the percent observer coverage ranges from 10% to 100%, depending on the fishery. Indices of the  
315 relative mortality imposed by fisheries discards and bycatch were calculated here as the ratio of the observed  
316 numbers of crab discarded or bycaught in a given year divided by the estimated population numbers in a  
317 given year. Only discard mortality is considered for the directed fishery in our models because the range of  
318 sizes modeled exclude the largest males, which are the targets of the commercial fishery for snow crab.

319 **Generalized additive models**

320 Generalized additive models (GAMs) were used in the R programming language (package mgcv; Wood,  
 321 2011) to relate changes estimated mortality by maturity state and year,  $m_{p,y}$  to environmental covariates  
 322 by maturity state,  $\phi_{m,y}$ , because of their flexibility in fitting potential non-linear relationships. Models were  
 323 first fitted in which all relevant covariates were included in the model of the form:

$$m_{p,y} = s(\phi_{m,y}) + \epsilon_i \tag{18}$$

324 where ‘s()’ is a smoothing function based on thin-plate splines,  $\phi$  is a matrix of environmental covariates  
 325 scaled to mean 0 and standard deviation 1, and  $\epsilon$  is normally distributed error. The number of knots allowed  
 326 in the thin-plate splines were restricted to 3 given the relatively short time series and number of potential  
 327 stressors. Significance of covariates for the full models can be seen in Table 1 and Table 2 and the resulting  
 328 smooths in Figure 35 and Figure 36. Model diagnostics were acceptable given relatively short time series  
 329 (Figure 37 & Figure 38). Leave-one out cross validation was performed for the models by systematically  
 330 excluding a year of data, refitting the model, and recording the deviance explained and significance of the  
 331 covariates. The consistent significance of specific covariates in this exercise lends some credence that those  
 332 covariates’ influence in the model was not the result of outliers (Figure 2e). Some collinearity existed among  
 333 covariates (Figure 39 & Figure 40), but none of the collinear variables were significant in the models.

| A. parametric coefficients | Estimate | Std. Error | t-value | p-value  |
|----------------------------|----------|------------|---------|----------|
| (Intercept)                | 0.6052   | 0.0505     | 11.9819 | < 0.0001 |
| B. smooth terms            | edf      | Ref.df     | F-value | p-value  |
| s(temperature)             | 1.9964   | 2.3824     | 4.5850  | 0.0204   |
| s(disease)                 | 1.0000   | 1.0000     | 1.3152  | 0.2650   |
| s(discard)                 | 1.0000   | 1.0000     | 0.4639  | 0.5036   |
| s(bycatch)                 | 1.0000   | 1.0000     | 1.1509  | 0.2961   |
| s(mat_pop)                 | 1.8356   | 1.9601     | 4.0153  | 0.0261   |

Table 1: GAM output for full model predicting mature mortality. Deviance explained = 66.8%

| A. parametric coefficients | Estimate | Std. Error | t-value | p-value  |
|----------------------------|----------|------------|---------|----------|
| (Intercept)                | 0.1750   | 0.0121     | 14.4737 | < 0.0001 |
| B. smooth terms            | edf      | Ref.df     | F-value | p-value  |
| s(disease)                 | 1.6017   | 1.8194     | 1.3939  | 0.3717   |
| s(temperature)             | 1.5788   | 1.7957     | 6.0398  | 0.0067   |
| s(mat_pop)                 | 1.9039   | 1.9757     | 4.5453  | 0.0352   |
| s(predation)               | 1.0000   | 1.0000     | 0.1465  | 0.7064   |
| s(bycatch)                 | 1.0000   | 1.0000     | 1.1798  | 0.2917   |
| s(cannibalism)             | 1.6038   | 1.8388     | 1.5158  | 0.3215   |

Table 2: GAM output for full model predicting immature mortality. Deviance explained = 72.2%

334 Models that excluded insignificant variables from each full model were used in out-of-sample prediction and  
 335 randomization tests (see Table 3 & Table 4 for covariate significance and deviance explained and Figure 41  
 336 & Figure 42 for model diagnostics). One thousand iterations of a randomization test were performed in  
 337 which the covariate time series were randomized, the models refit, and the deviance explained recorded.  
 338 This test was aimed at understanding if the explanatory power of the model was a result of the number of  
 339 covariates considered and the flexibility of the model or if the results were an indication of some underlying  
 340 signal in the data. If the deviance explained by the model using the non-randomized data exceeded the 95th  
 341 quantile of the randomization trials, the deviance explained from the fitted model is less likely to be a result  
 342 of over-fitting resulting from too many covariates or too flexible smooths. The deviance explained from both  
 343 of the trimmed models exceeded the 95th quantile of deviance explained from the randomization (Figure 43  
 344 & Figure 44). Out-of-sample predictions were made by excluding the last 1,2, and 3 years of data, refitting

345 the model, then attempting to predict the held out data based on the covariates observed in those years (see  
 346 figure 2 of the main text for a discussion).

| A. parametric coefficients | Estimate | Std. Error | t-value | p-value  |
|----------------------------|----------|------------|---------|----------|
| (Intercept)                | 0.6052   | 0.0497     | 12.1798 | < 0.0001 |
| B. smooth terms            | edf      | Ref.df     | F-value | p-value  |
| s(temperature)             | 1.8723   | 2.2591     | 4.5071  | 0.0212   |
| s(mat_pop)                 | 1.8819   | 1.9750     | 7.4877  | 0.0025   |

Table 3: GAM output for trimmed model predicting mature mortality. Deviance explained = 62.9%

| A. parametric coefficients | Estimate | Std. Error | t-value | p-value  |
|----------------------------|----------|------------|---------|----------|
| (Intercept)                | 0.1750   | 0.0130     | 13.4588 | < 0.0001 |
| B. smooth terms            | edf      | Ref.df     | F-value | p-value  |
| s(temperature)             | 1.6929   | 1.9043     | 8.0575  | 0.0016   |
| s(mat_pop)                 | 1.9760   | 1.9981     | 6.2179  | 0.0077   |

Table 4: GAM output for full model predicting immature mortality. Deviance explained = 59.1%

## 347 How could temperature relate to mortality mechanistically?

348 Increased temperature was consistently correlated with increased estimated mortality in our models, but the  
 349 range of temperatures observed were not beyond the thermal tolerances of snow crab. Foyle et al. (1989)  
 350 captured 20 snow crab of carapace size 85-95 mm in 1986 and raised them in the lab in a range of thermal  
 351 regimes to understand the impacts of increased temperatures on mortality and caloric requirements for  
 352 snow crab. In addition to identifying the thermal tolerances of snow crab (crab stop eating around 12  
 353 degrees C), Foyle et al. observed a doubling of caloric requirements for snow crab held in 3 degrees Celsius  
 354 water as compared to those in 0 degree waters. Here we calculated an index of the caloric requirements  
 355 for the population of snow crab in the eastern Bering Sea over time using the abundance at size of snow  
 356 crab observed in the NMFS survey, the temperature occupied of crab at size calculated from observations  
 357 of bottom temperature in the NFMS survey, and the observations of caloric requirements of snow crab  
 358 by temperature produced by Foyle et al. (1989). The relationship between temperature and the caloric  
 359 requirements of snow crab ( $kCal_t$ ) reported by Foyle et al. was:

$$kCal_{s=90mm,t} = 2.2 * e^{\frac{-(t-5.2)^2}{30.7}} \quad (19)$$

360 Snow crab numbers at size (s) by year (y) ( $N_{s,y}$ ) and the temperature occupied at size by year ( $T_{s,y}$ ) were  
 361 calculated as described above. The caloric requirements reported in Foyle et al. were based on observations  
 362 of crab that were 85-95 mm carapace width, so these results need to be extrapolated to the range of sizes  
 363 used in this analysis. Kleiber's law (Kleiber, 1947) states there is a consistent relationship between the body  
 364 mass and metabolic requirements of organisms (kCal). The relationship has been generalized as:

$$kCal_m = mass^{0.75} \quad (20)$$

365 Calculating the metabolic requirements for snow crab at size by year,  $kCal_{s,y}^{snow}$ , can be calculated by  
 366 evaluating the caloric requirements of 90mm carapace width crab at a given temperature were calculated,  
 367 then scaling that up or down based on Kleiber's law:

$$kCal_{s,y}^{snow} = \frac{2.2 * e^{\frac{-(t-5.2)^2}{30.7}}}{300^{0.75}} w_s^{0.75} \quad (21)$$

368 The resulting caloric requirements by size and temperature can be seen in Figure 3b of the main text.  
 369 The population-wide caloric requirements increased sharply in 2018 and to explore potential impacts of this  
 370 increase, we analyzed the weight at size data available (Figure 45). GAMs were used to predict observed  
 371 weights at size  $w_{i,s,y}$  using the bottom temperature in which the crab was collected,  $t_i$ , measured carapace  
 372 width  $cw_i$ , and year as a factor:

$$w_{i,s,y} = s(cw_i) + s(t_i) + year + \epsilon \quad (22)$$

373 The GAMs explained 97.4% of the deviance in the weights of snow crab and all covariates were significant  
 374 (Table 5).

| A. parametric coefficients       | Estimate | Std. Error | t-value   | p-value  |
|----------------------------------|----------|------------|-----------|----------|
| (Intercept)                      | 218.5199 | 2.2252     | 98.2019   | < 0.0001 |
| as.factor(AKFIN_SURVEY_YEAR)2015 | 6.4525   | 3.1690     | 2.0361    | 0.0419   |
| as.factor(AKFIN_SURVEY_YEAR)2017 | 12.6093  | 2.4840     | 5.0763    | < 0.0001 |
| as.factor(AKFIN_SURVEY_YEAR)2018 | -11.9217 | 6.2536     | -1.9064   | 0.0568   |
| as.factor(AKFIN_SURVEY_YEAR)2019 | 4.0886   | 2.7473     | 1.4882    | 0.1369   |
| B. smooth terms                  | edf      | Ref.df     | F-value   | p-value  |
| s(WIDTH)                         | 6.4225   | 7.5862     | 6340.9617 | < 0.0001 |
| s(GEAR_TEMPERATURE)              | 1.9362   | 2.3359     | 17.0800   | < 0.0001 |

Table 5: GAM output for model predicting male snow crab weight. Deviance explained = 97.4%

375 In general, higher temperatures were associated with higher weight at size (Figure 46). The weight at size  
 376 curves for 2015 and 2017 were scaled significantly higher than the base year of 2011, whereas the year 2018  
 377 was marginally significantly lower (p=0.057). The marginal significance likely resulted from the relatively  
 378 small sample size of weight at size available in 2018 (N=27), but the effect size was large (the coefficient  
 379 associated with 2017 was 12.60; the coefficient associated with 2018 was -11.92) which translated to large  
 380 differences in estimated weight at size between the years reported in the main document.

381 References:

382 Alaska Fisheries Science Center, 2022: AFSC/REFM: North Pacific Groundfish Diet Data 1981-present,  
383 Aydin, K., <https://www.fisheries.noaa.gov/inport/item/20485>.

384 Mueter, F.J., Litzow, M.A. 2008. Sea ice retreat alters the biogeography of the Bering Sea continental shelf.  
385 *Ecological Applications*. 18(2): 309-320.

386 (more to come)

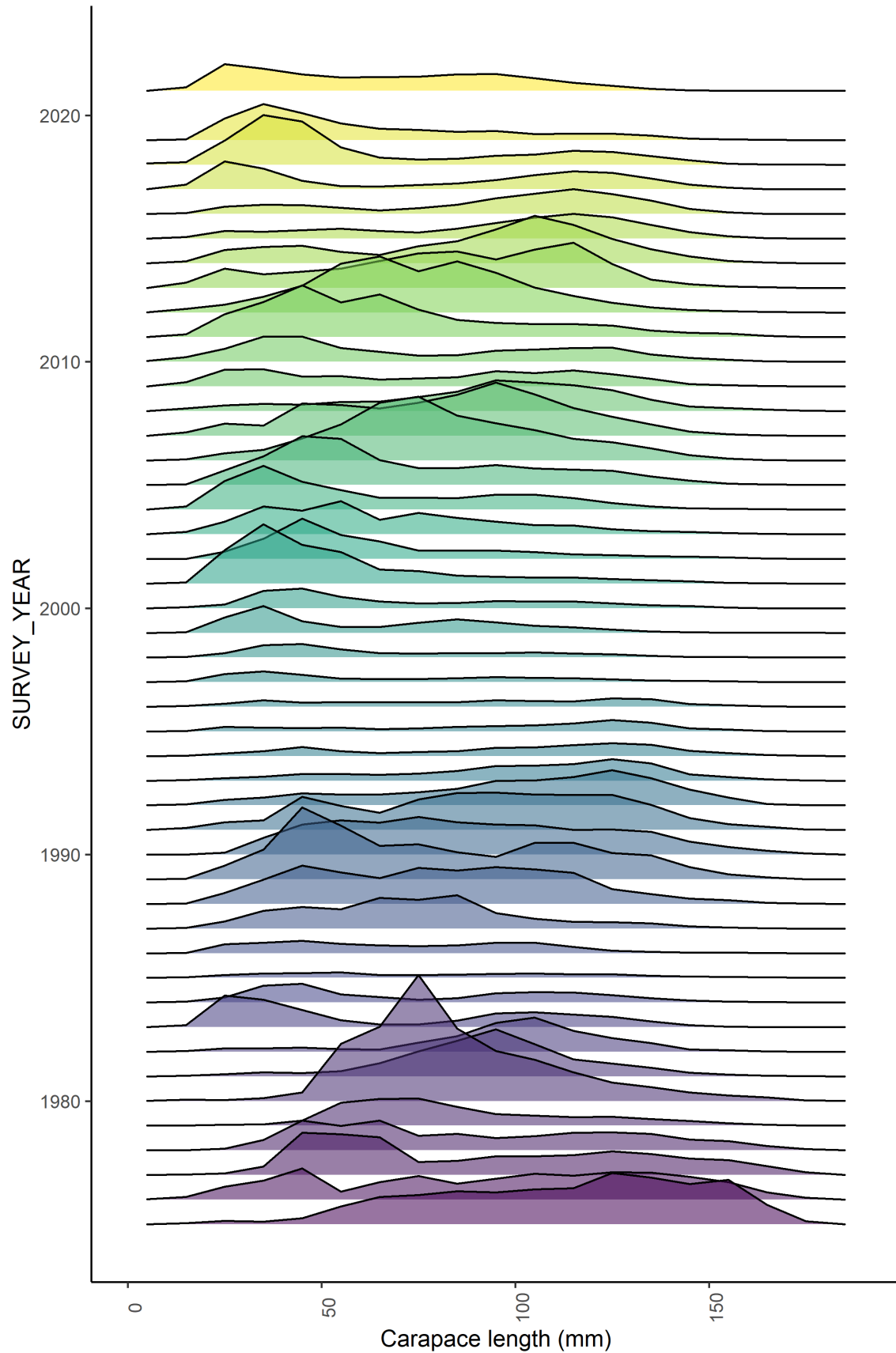


Figure 1: Observed Tanner crab.



Figure 2: Map of slope habitat.

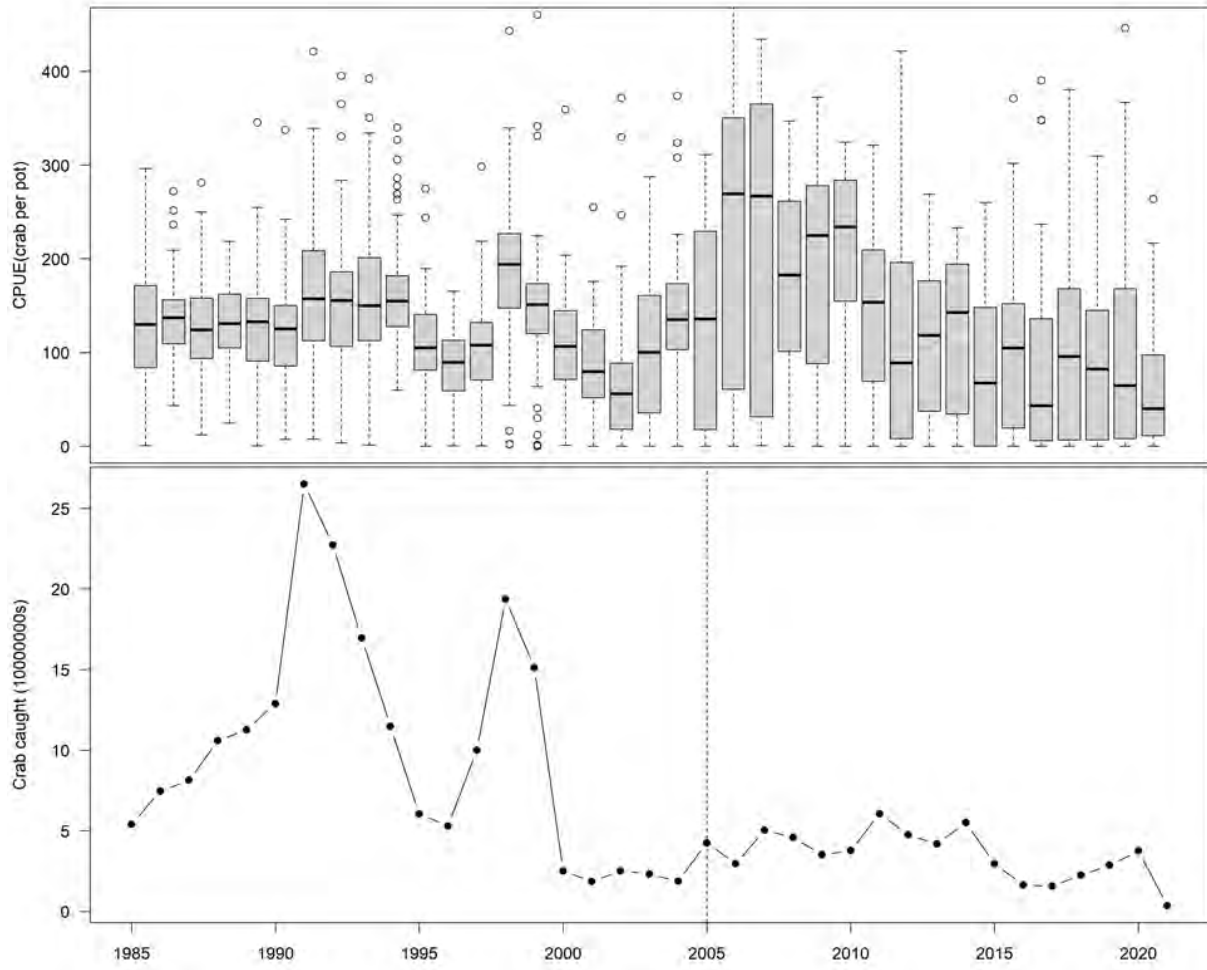


Figure 3: Fishery cpue.



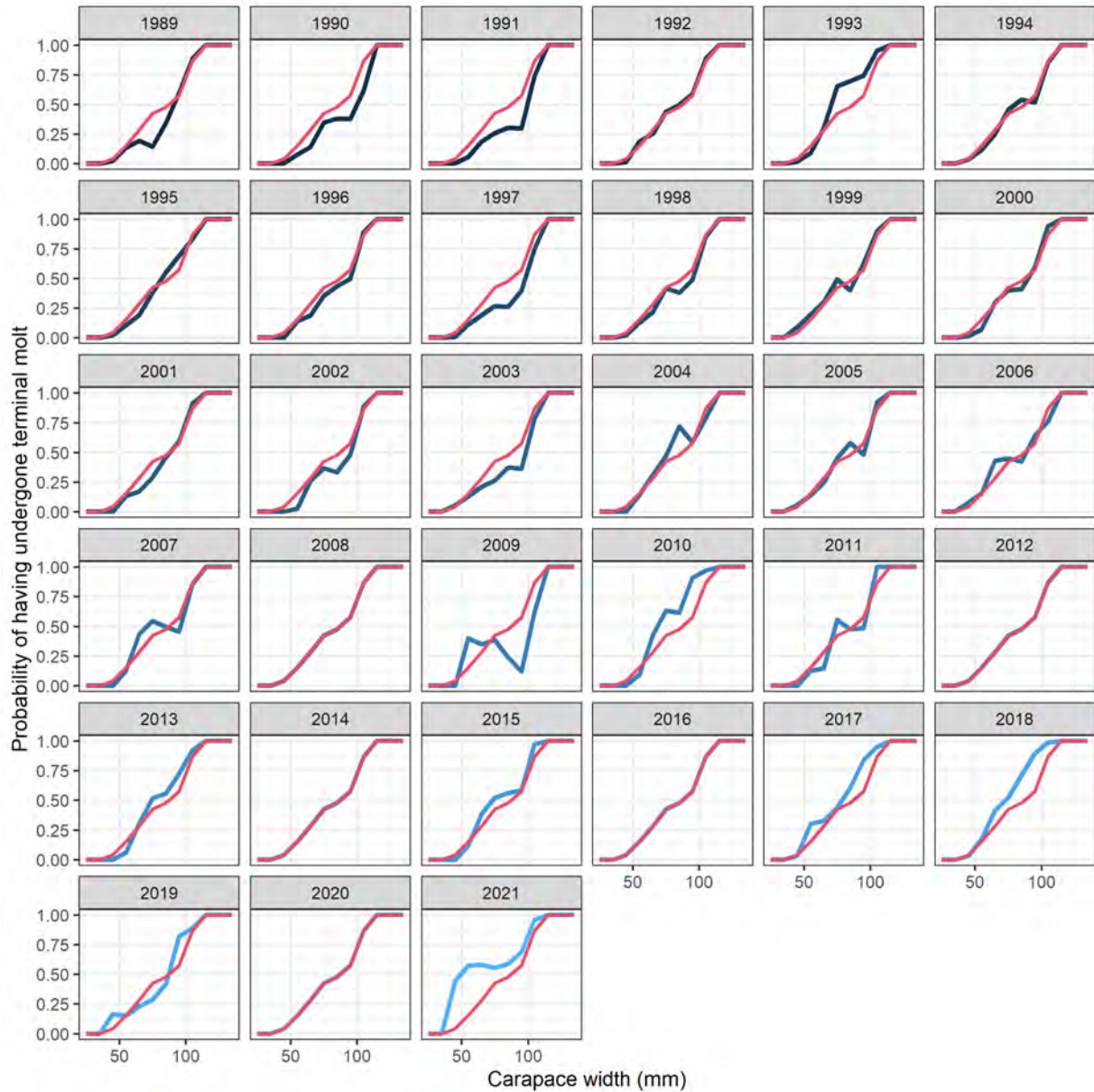


Figure 4: Observed proportion of mature new shell mature crab in the NMFS summer survey. Red line represents the median over years and the blue lines are the observed data. Chela height data were not collected in years without a blue line. These data are used to separate the numbers at size into mature and immature states for the input data to the population dynamics model.

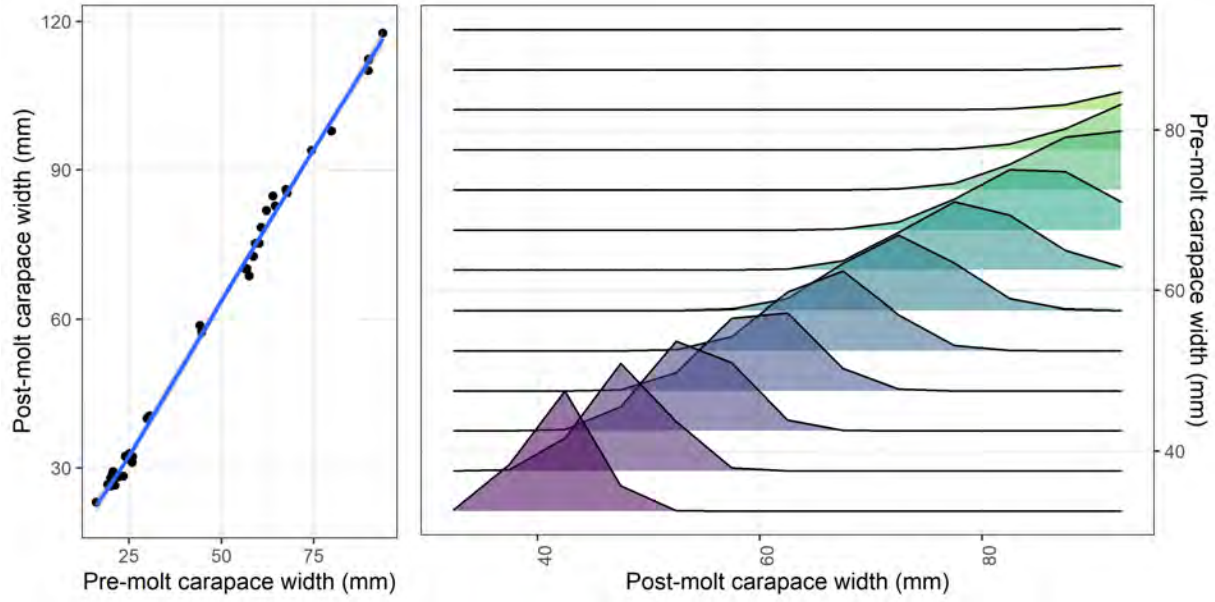


Figure 5: Empirical relationship between pre- and post-molt size (left) derived from crab capture in the wild pre-molt and observations in the lab. Calculated size-transition matrix used in the population dynamics model (right).

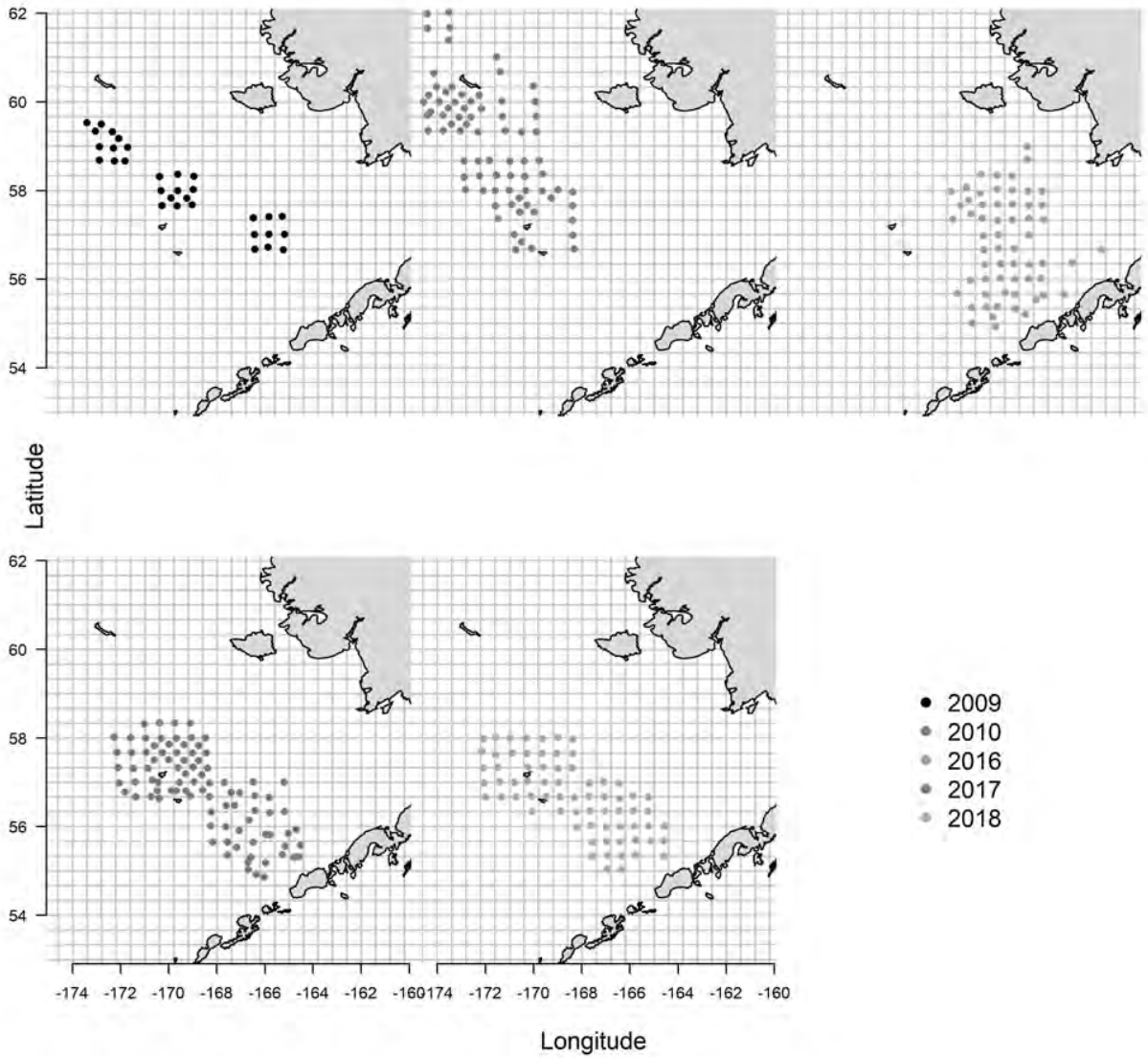


Figure 6: Locations of the BSFRF experimental trawls to evaluate the capture efficiency of the NMFS summer trawl survey for snow crab in the eastern Bering Sea.

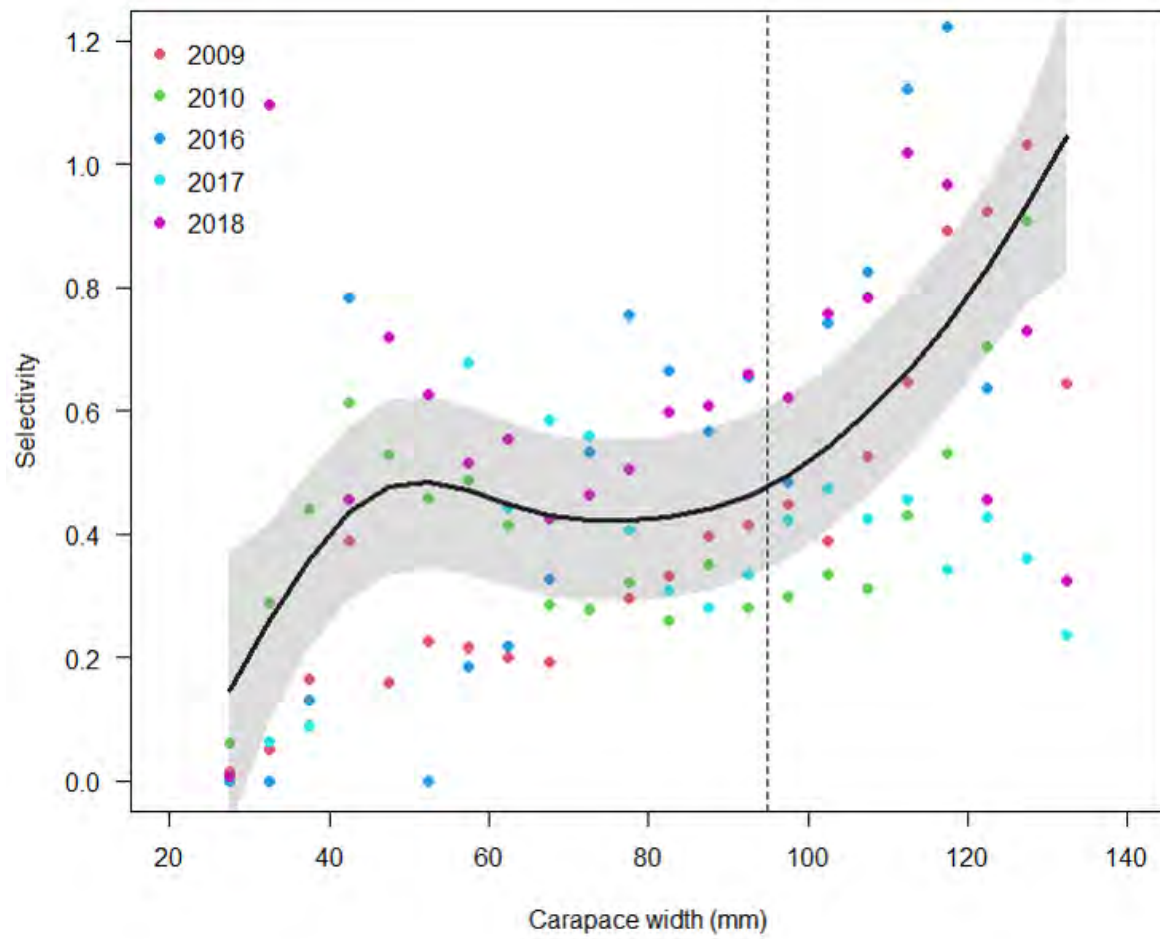


Figure 7: Inferred selectivity from the BSFRF experimental trawls.

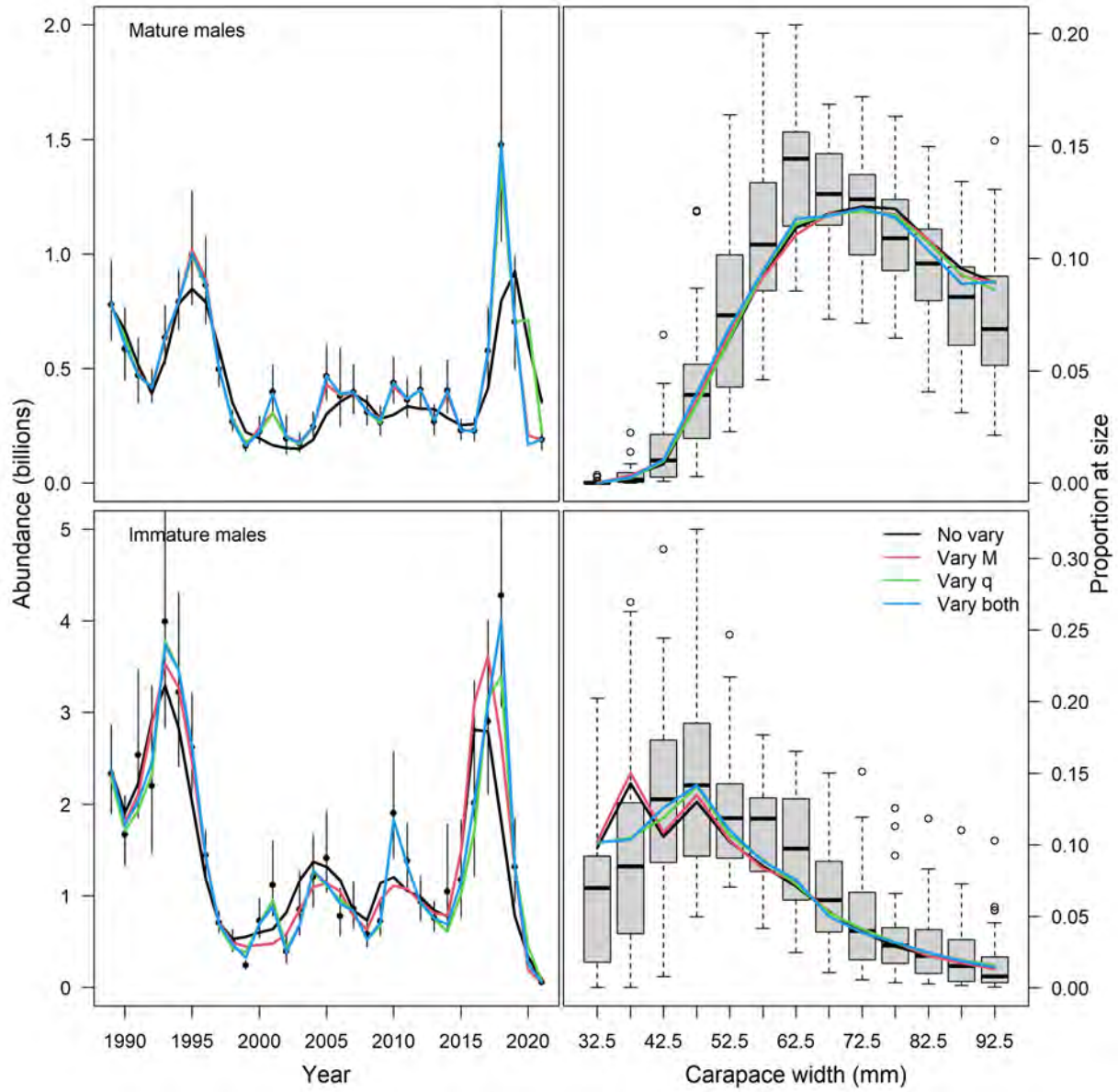


Figure 8: Fits of models with increasing complexity.

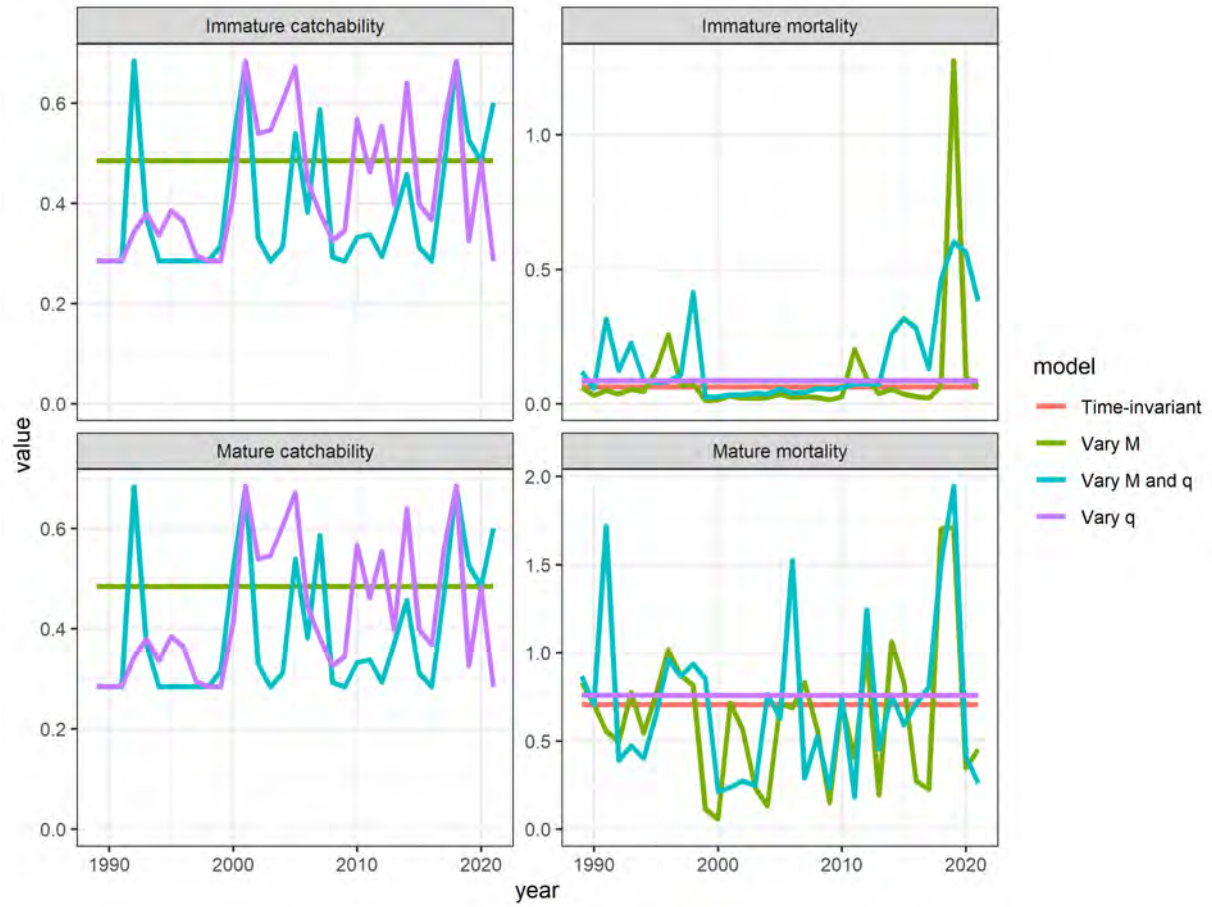


Figure 9: Estimated processes from model with increasingly complex time-variation.

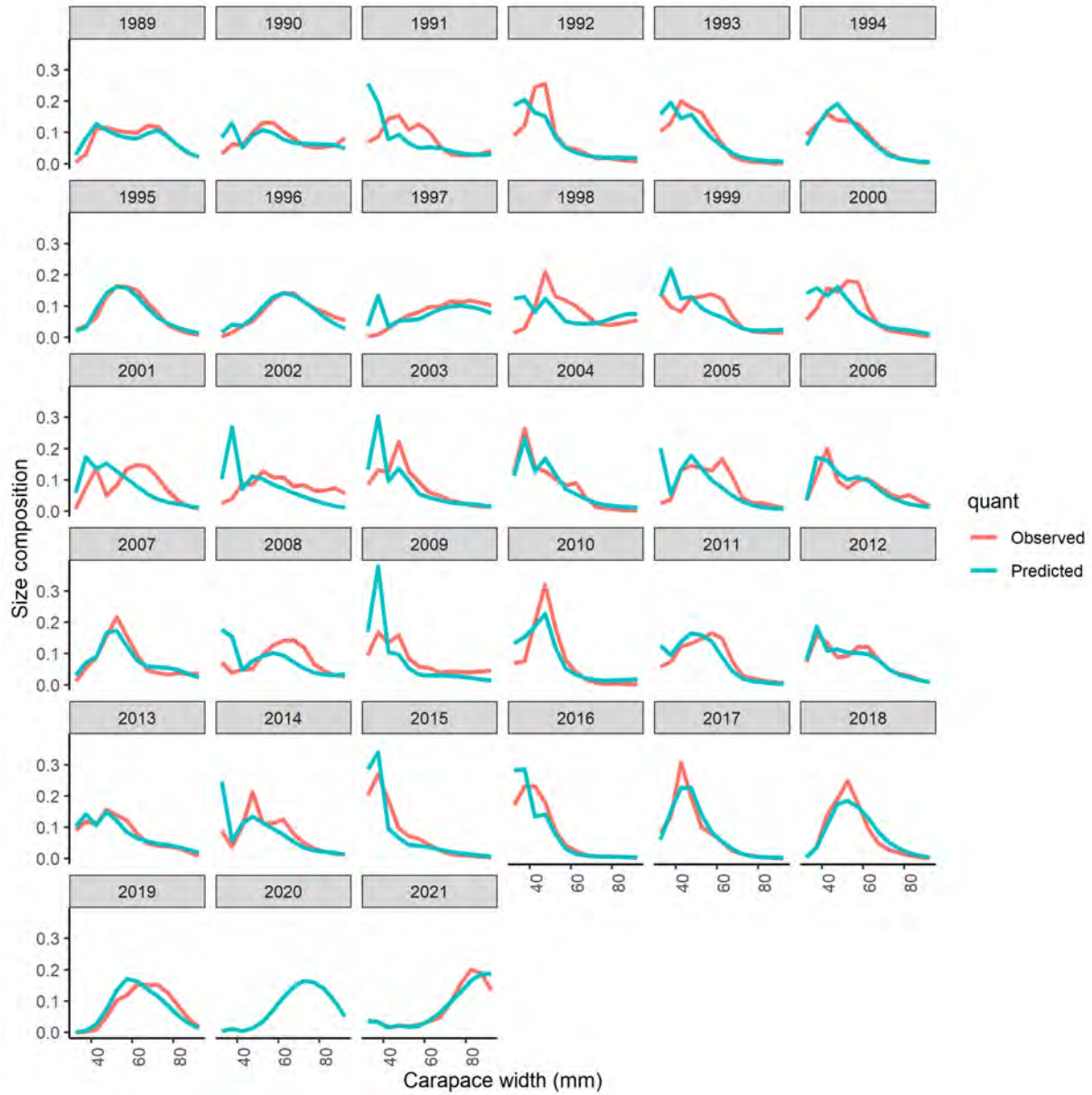


Figure 10: Fits from all years to immature size composition data from a model in which mortality varies over time.

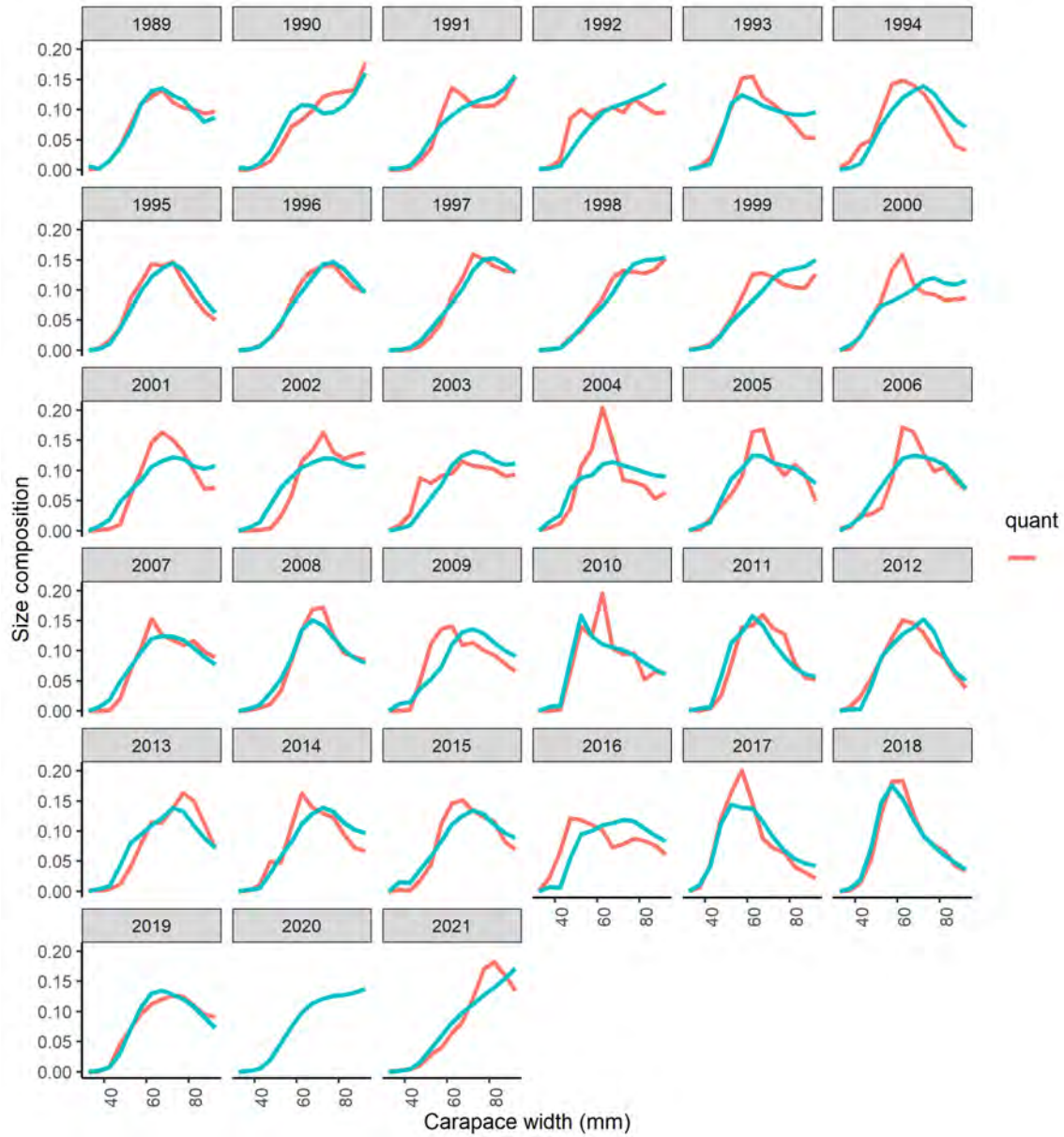


Figure 11: Fits from all years to mature size composition data.



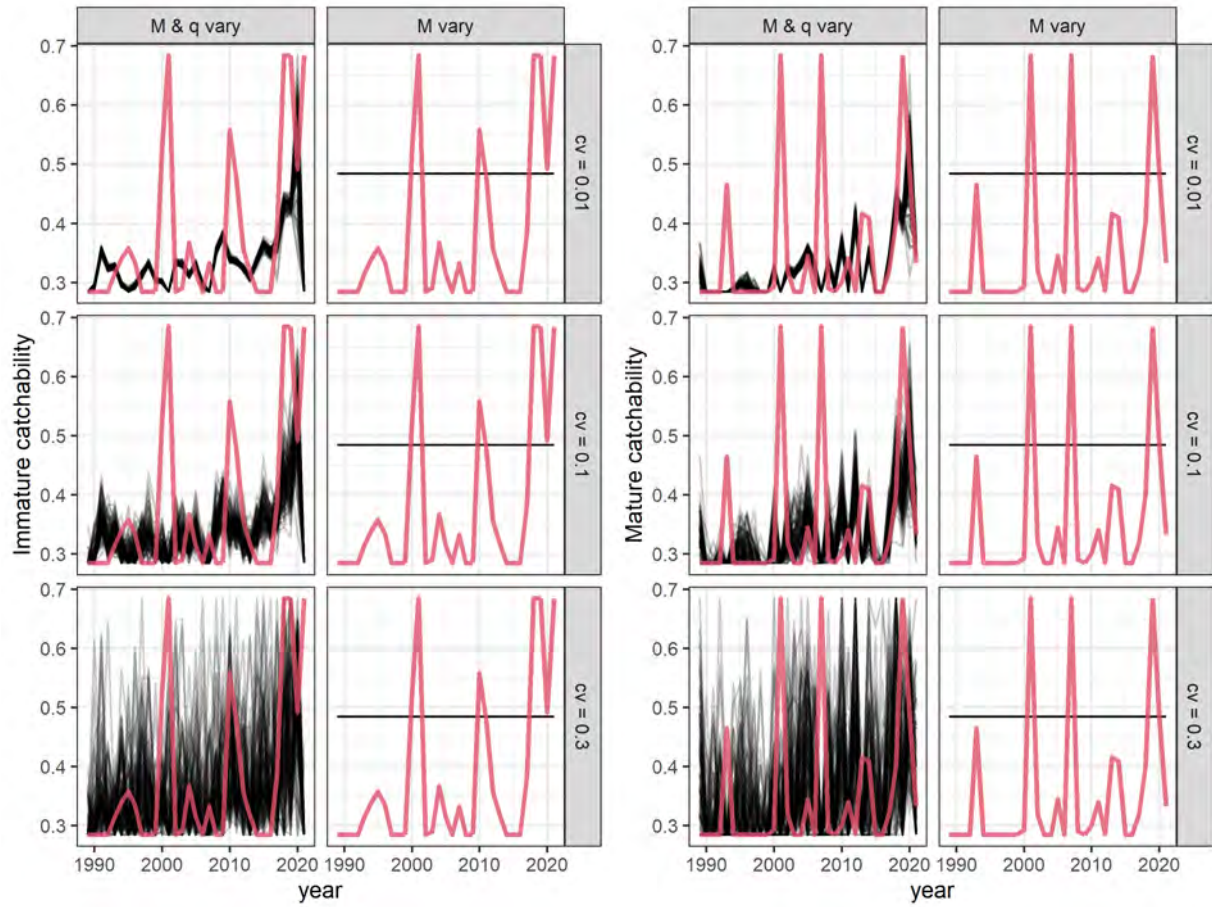


Figure 12: Estimates of catchability by maturity state (black lines) compared to the underlying values (red line) from simulations testing the estimation ability of the population dynamics models.

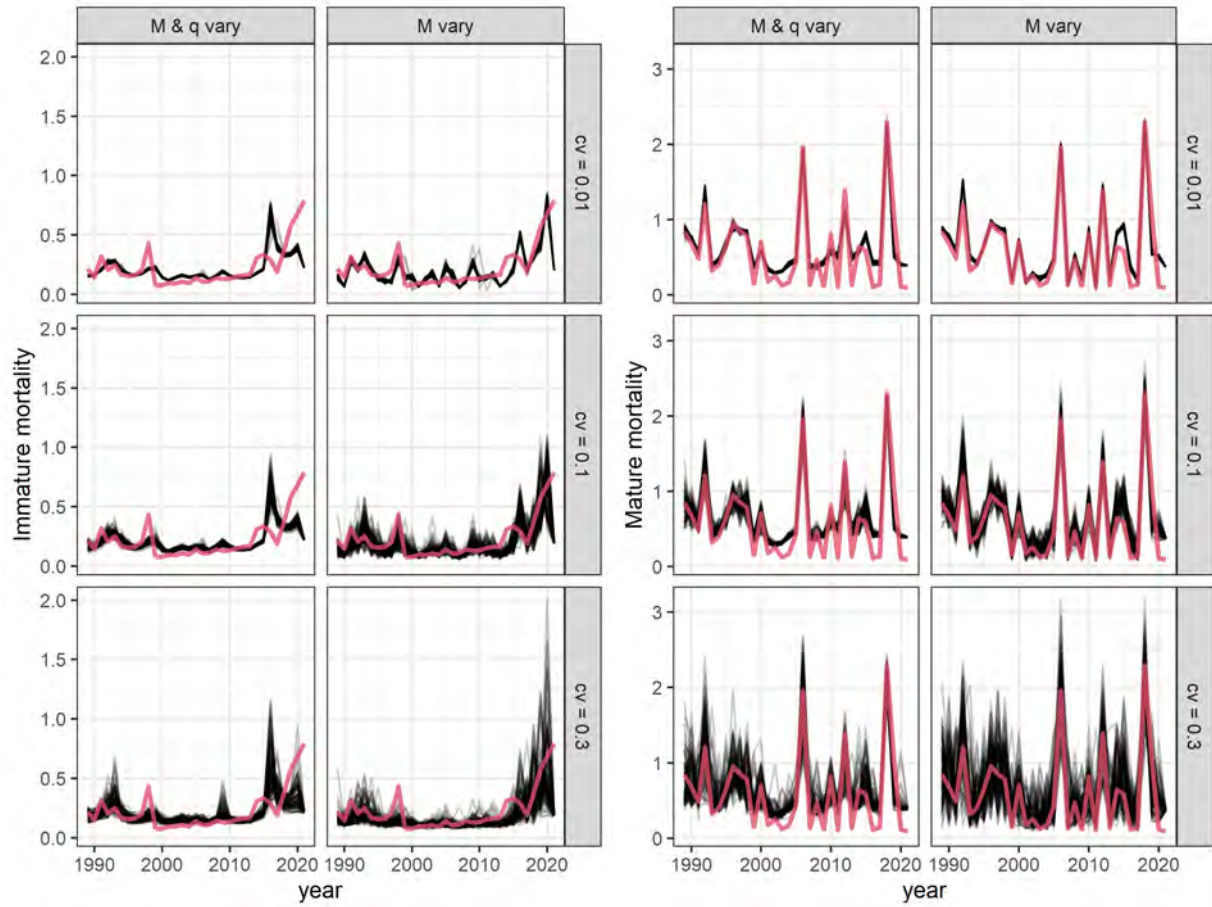


Figure 13: Estimates of mortality by maturity state (black lines) compared to the underlying values (red line) from simulations testing the estimation ability of the population dynamics models.

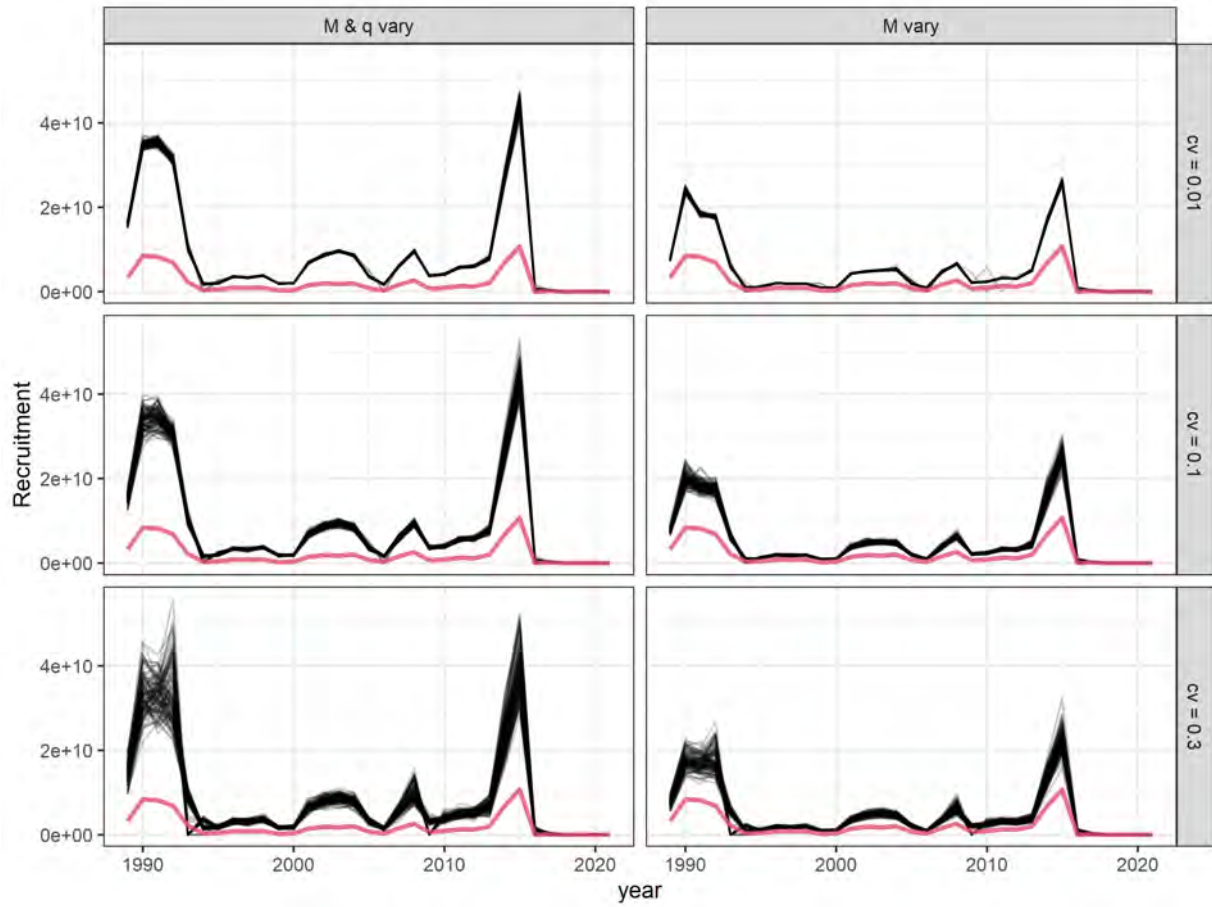


Figure 14: Estimates of recruitment (black lines) compared to the underlying values (red line) from simulations testing the estimation ability of the population dynamics models.

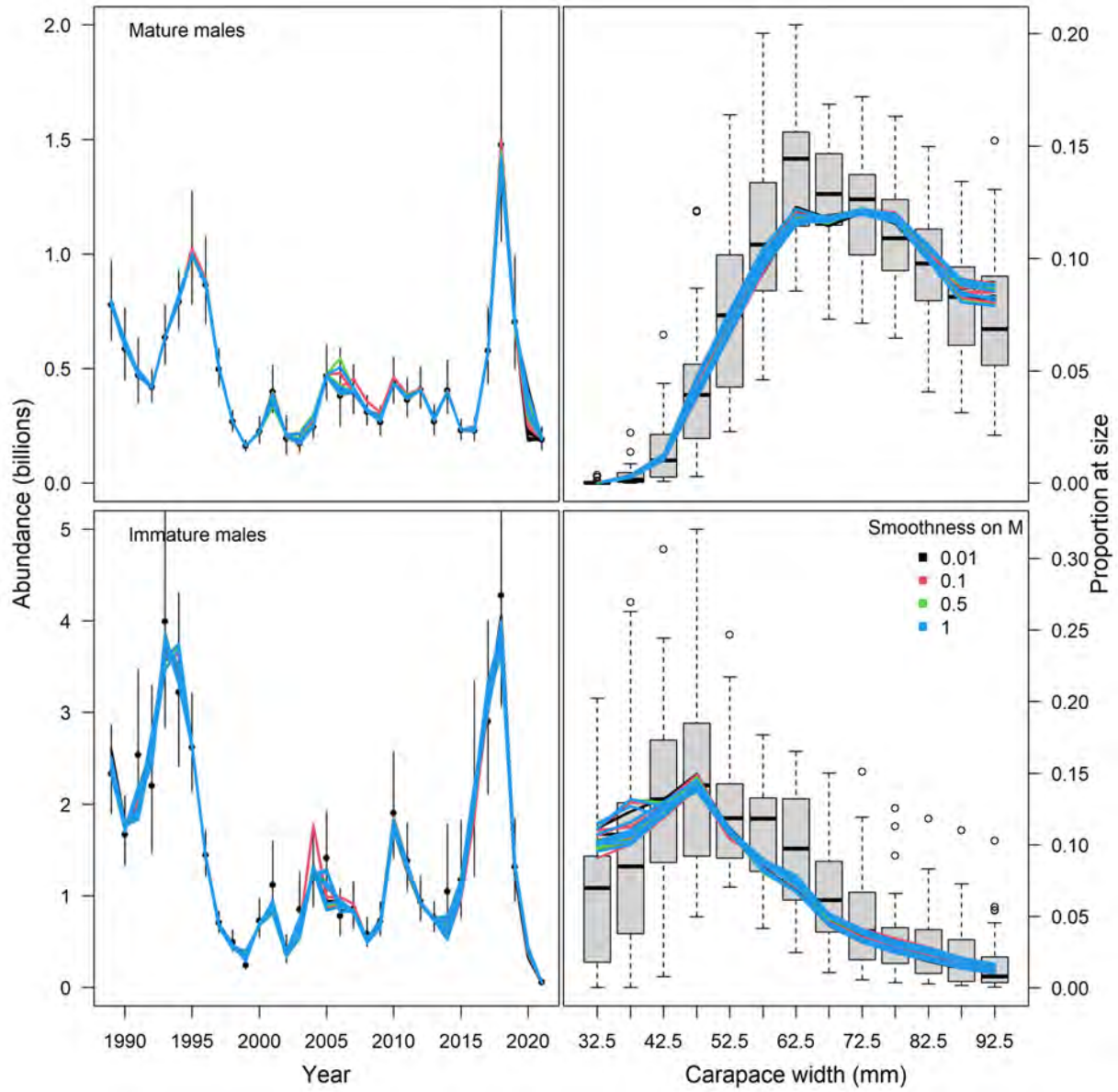


Figure 15: Model fits from sensitivity tests.

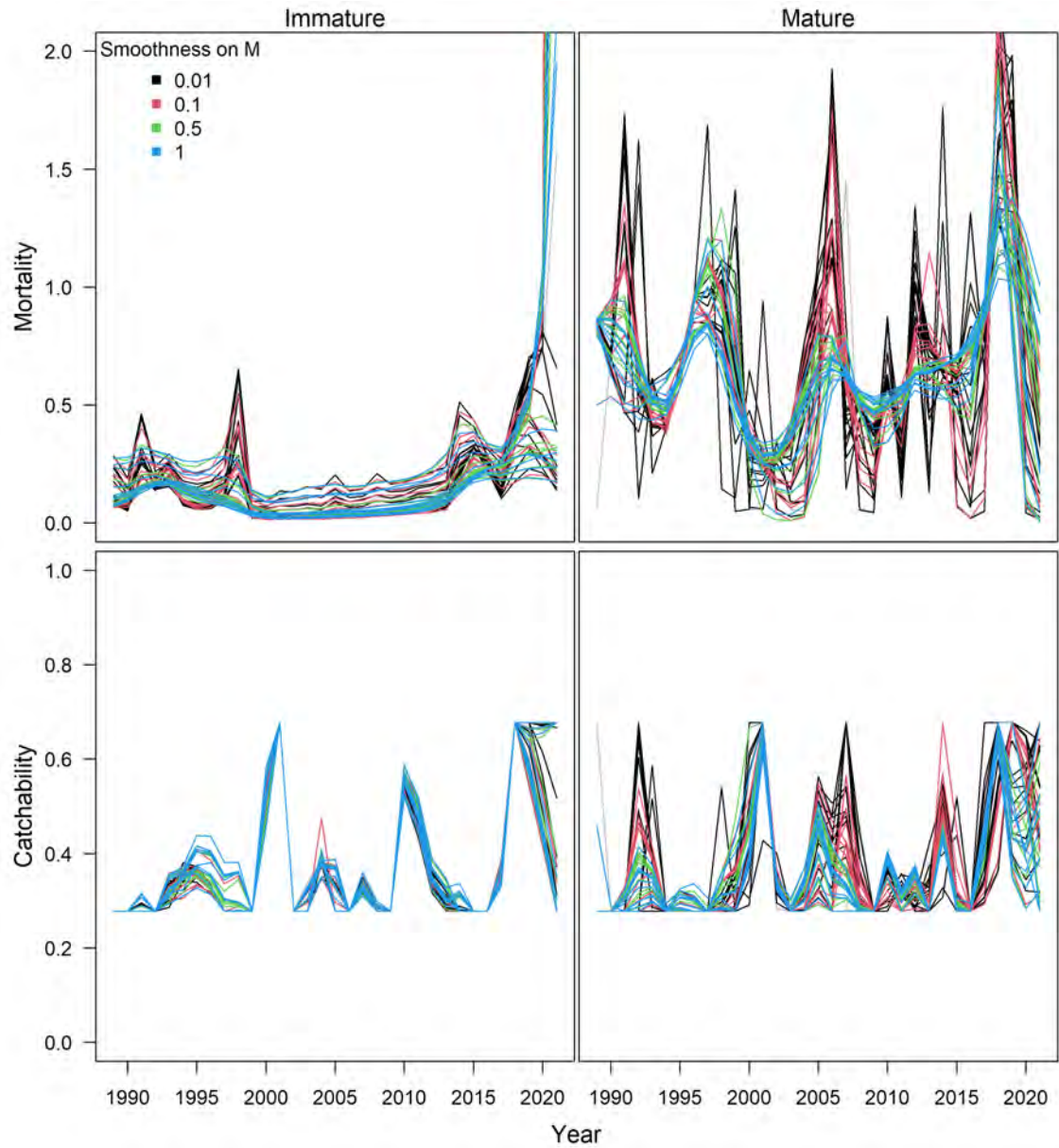


Figure 16: Estimates of mortality and catchability by maturity state over sensitivity runs.

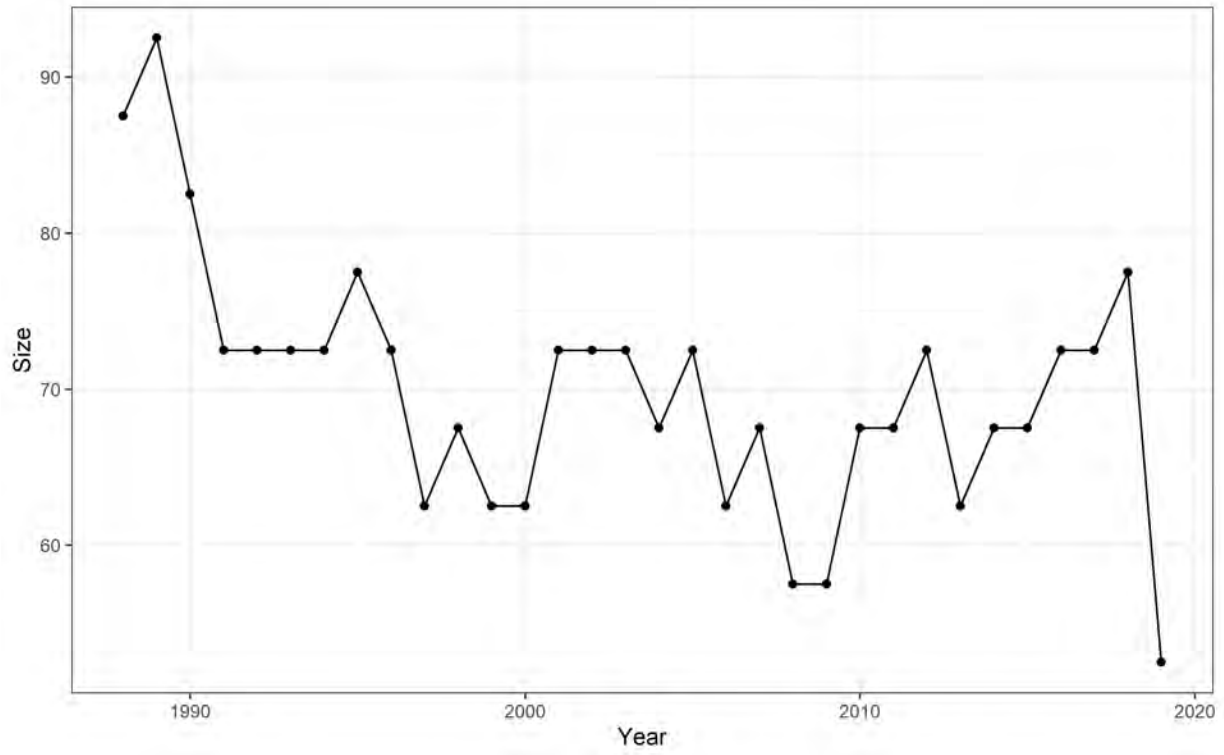


Figure 17: Size at which half of the crab in the population are mature over time. (note, this is not the probability of undergoing terminal molt, rather the proportion of the number of mature vs. immature crab at size in the population)

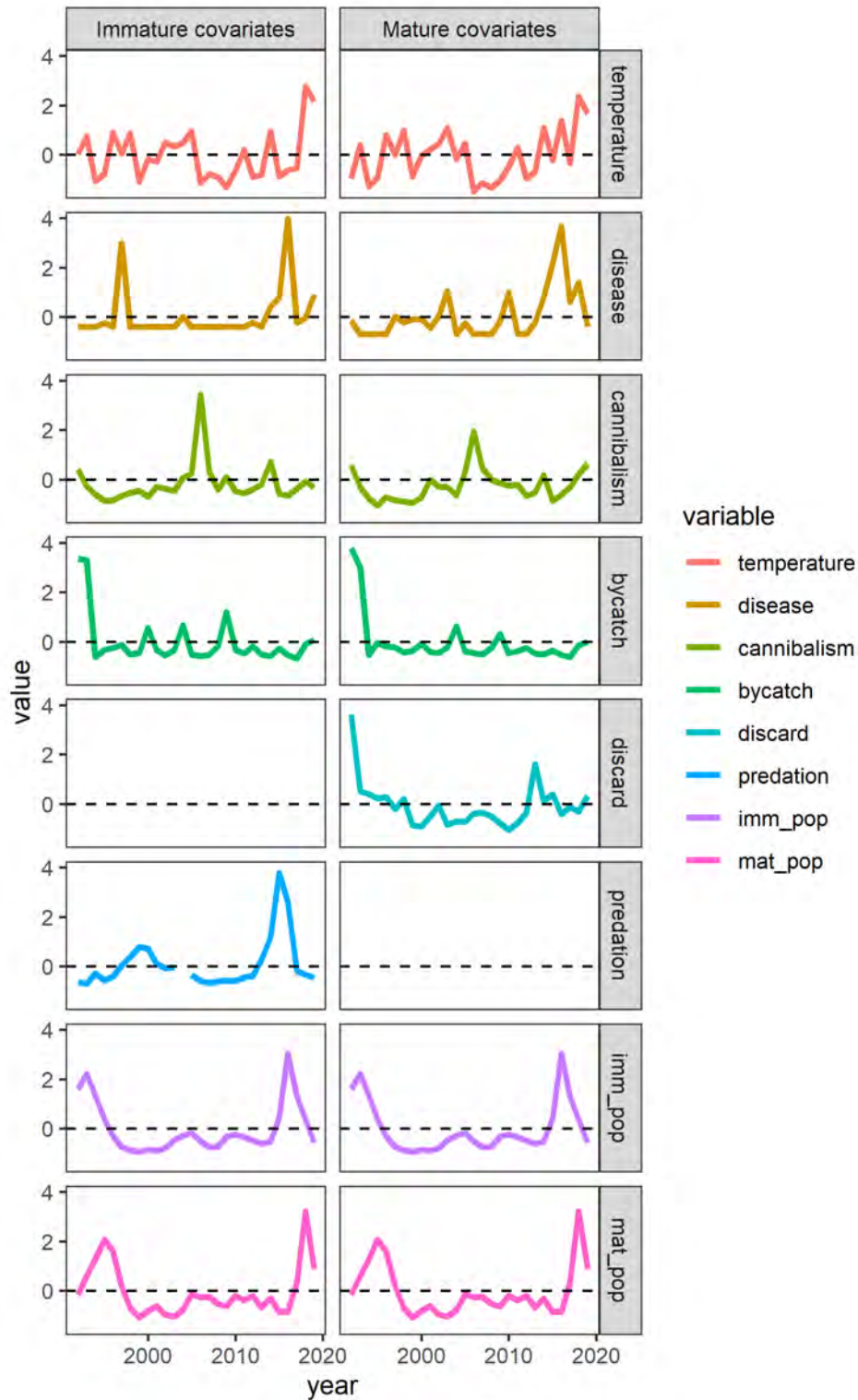


Figure 18: Calculated covariates incorporated into GAMs to relate stressors to estimated mortality. Two covariates (discard and predation) are only relevant for one maturity state based on the critical role size plays in the process (i.e. discards are primarily relatively large crab and predation is primarily smaller crab).

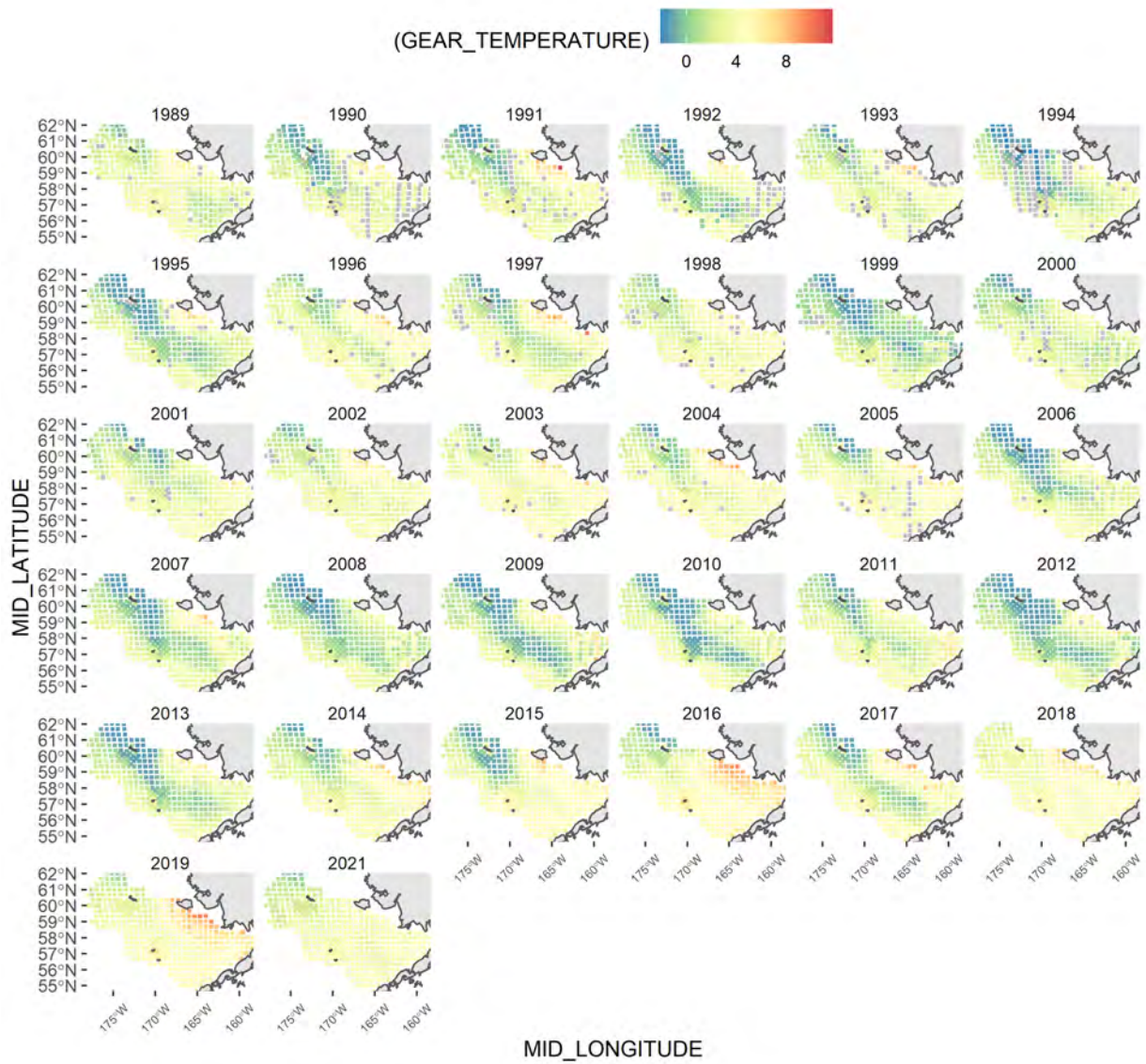


Figure 19: Bottom temperature at the time of the NMFS summer survey.



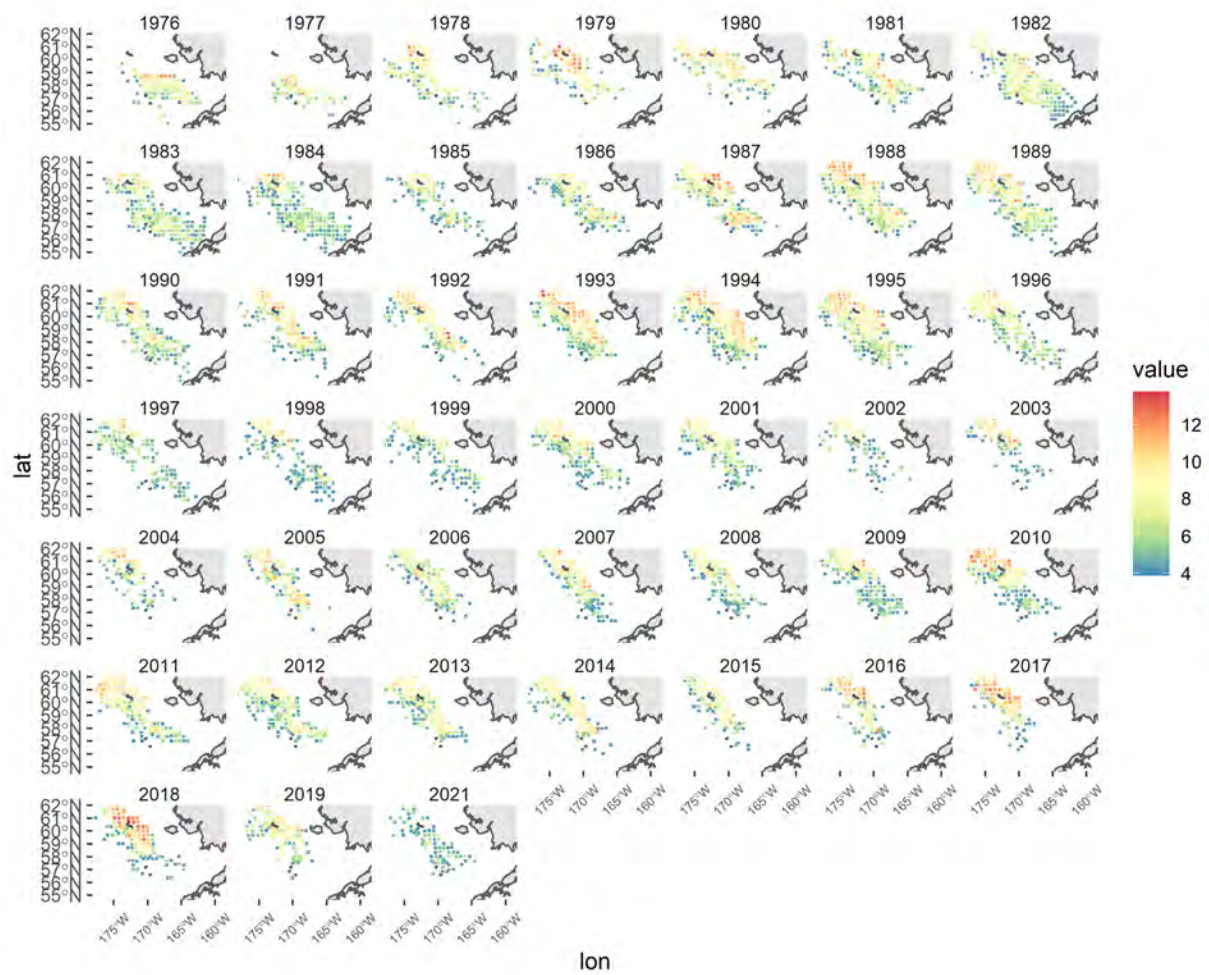


Figure 20: Distribution and intensity of densities of crab <55 mm carapace width in the NMFS summer survey.

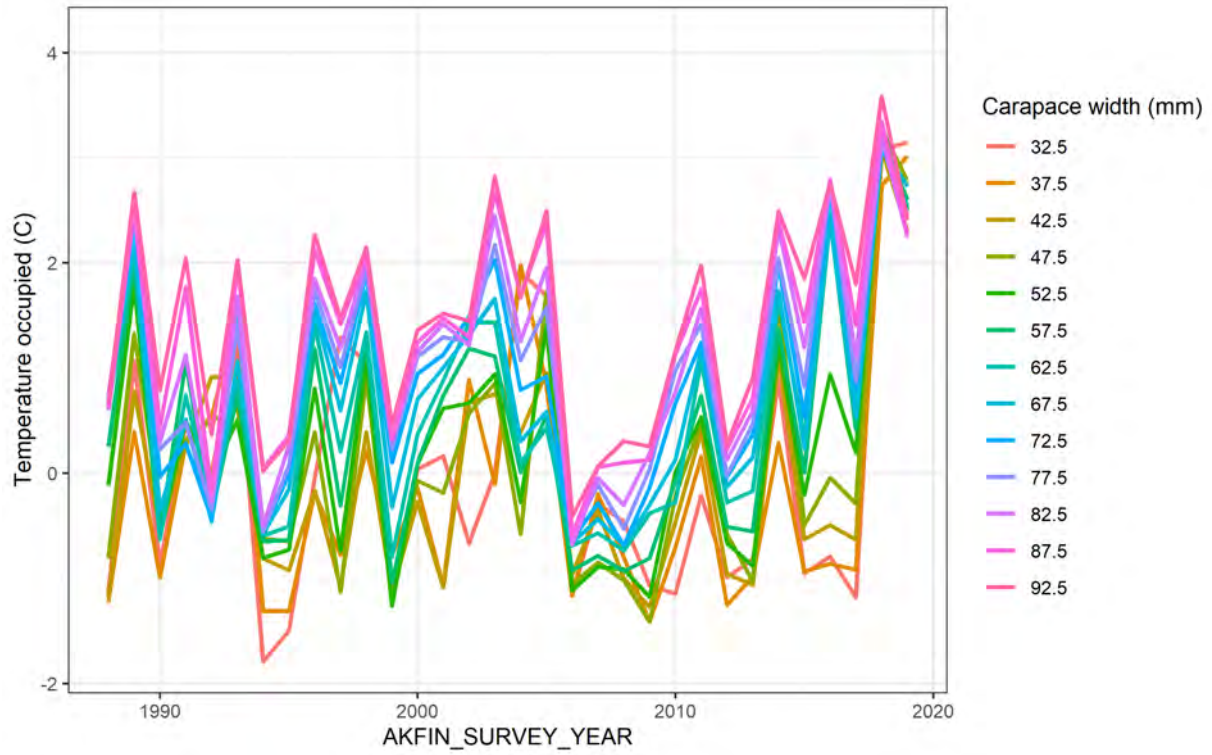


Figure 21: Temperature occupied over time of crab by 5 mm size bin.

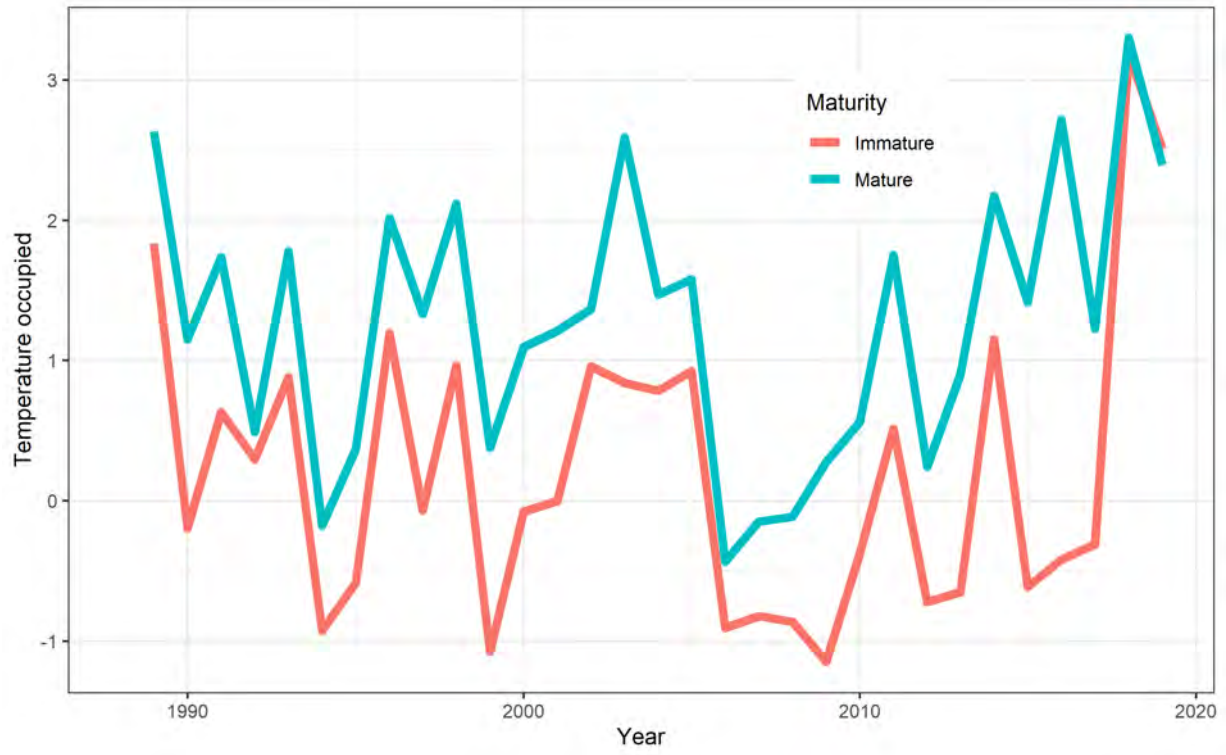


Figure 22: Temperature occupied over time of crab by maturity state.

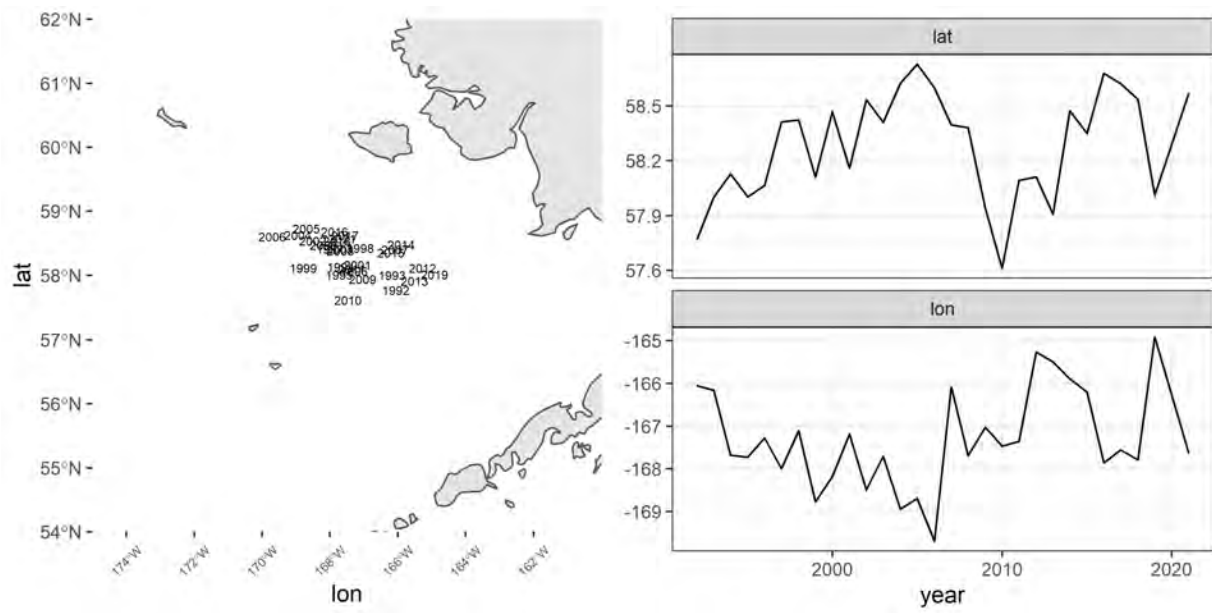


Figure 23: Centroids of abundance for Pacific cod in the Bering Sea over time (left). Right panels show the time series of the centroids broken down by latitudinal and longitudinal components.

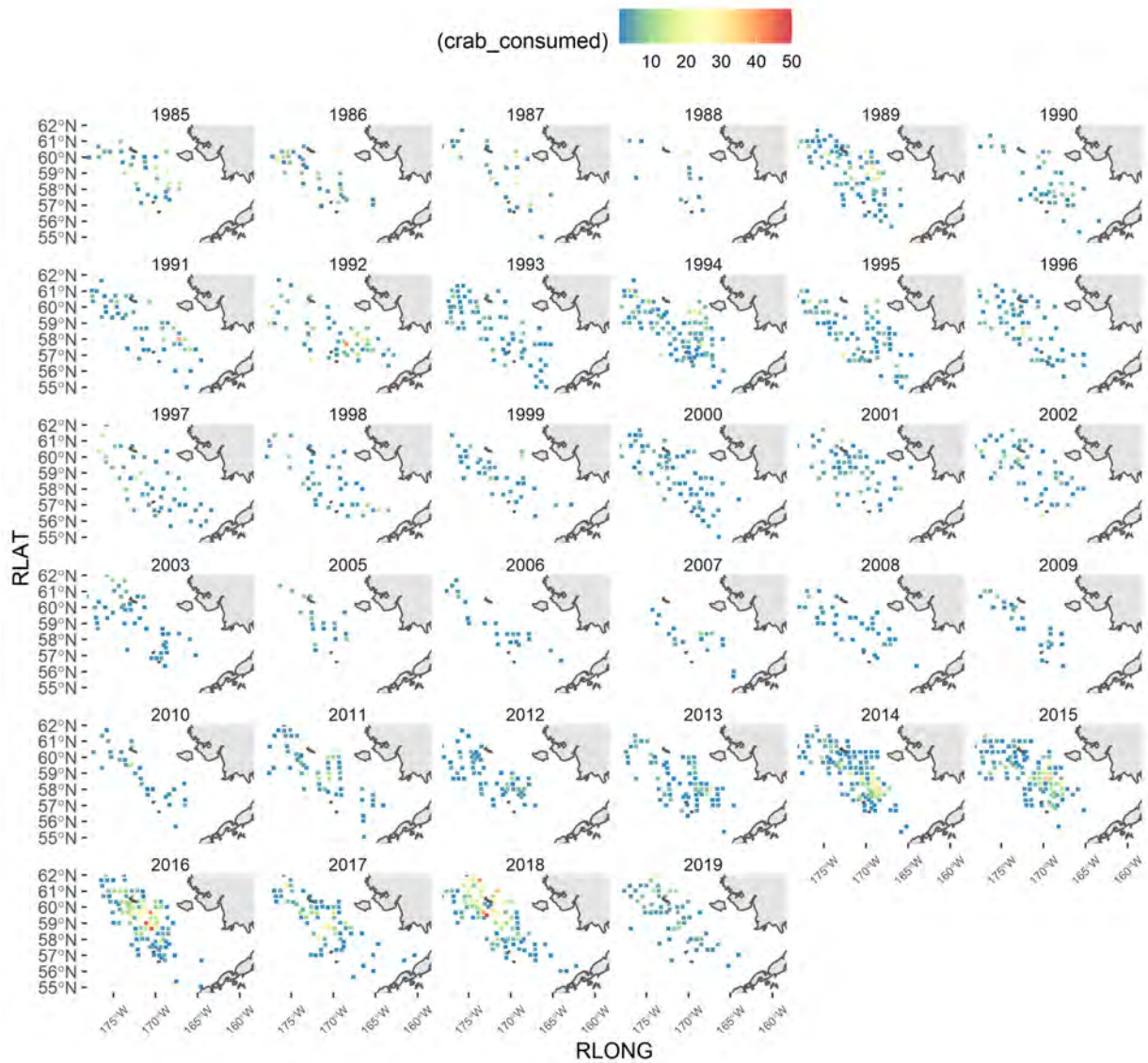


Figure 24: Location and number of crab observed in cod stomachs over time. These are the raw data used to calculate crab consumption by cod and have not been adjusted for sampling effort, but provide background for the spatial distribution of predation over time.

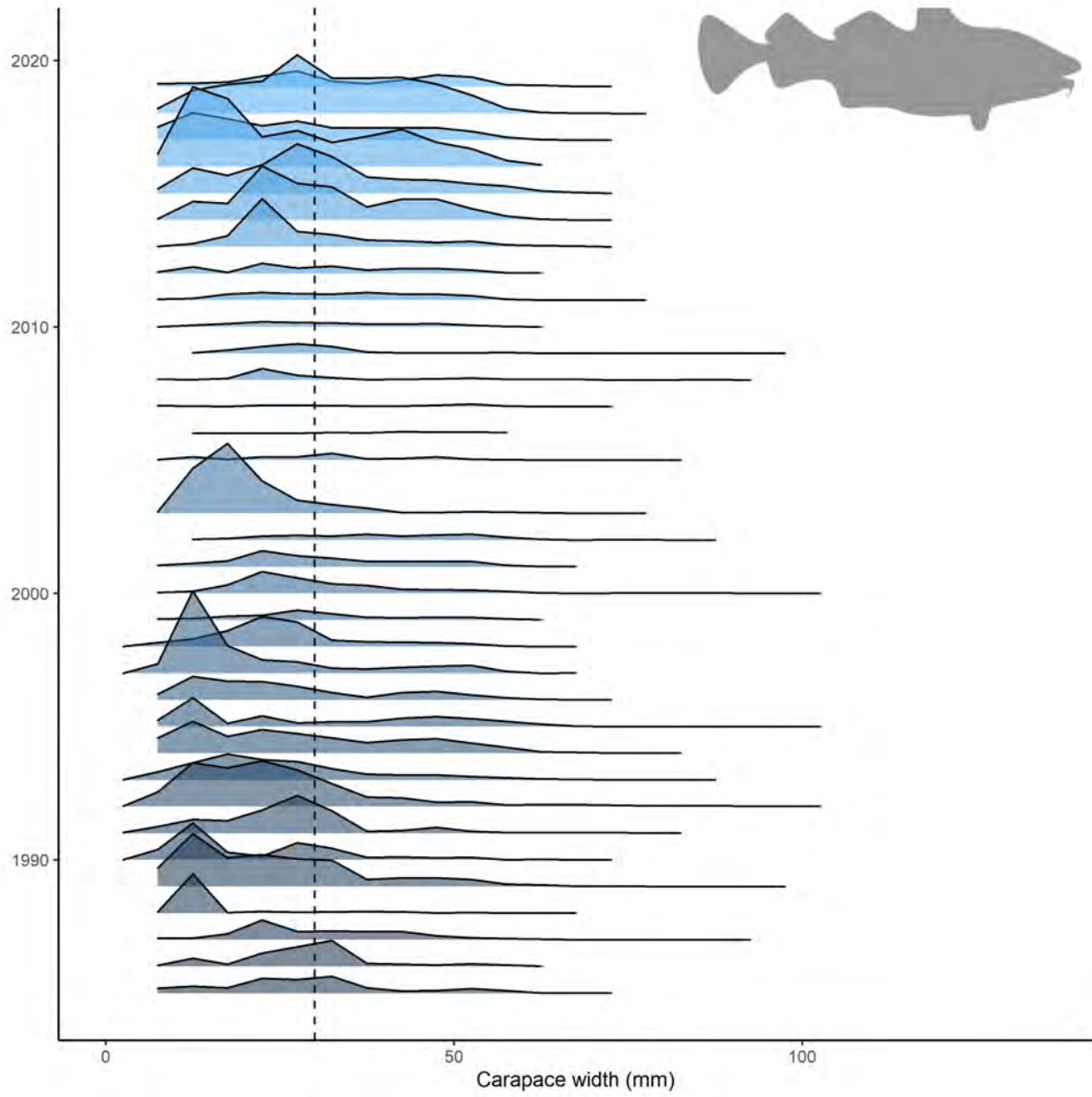


Figure 25: Consumption of crab by Pacific cod at size over time.

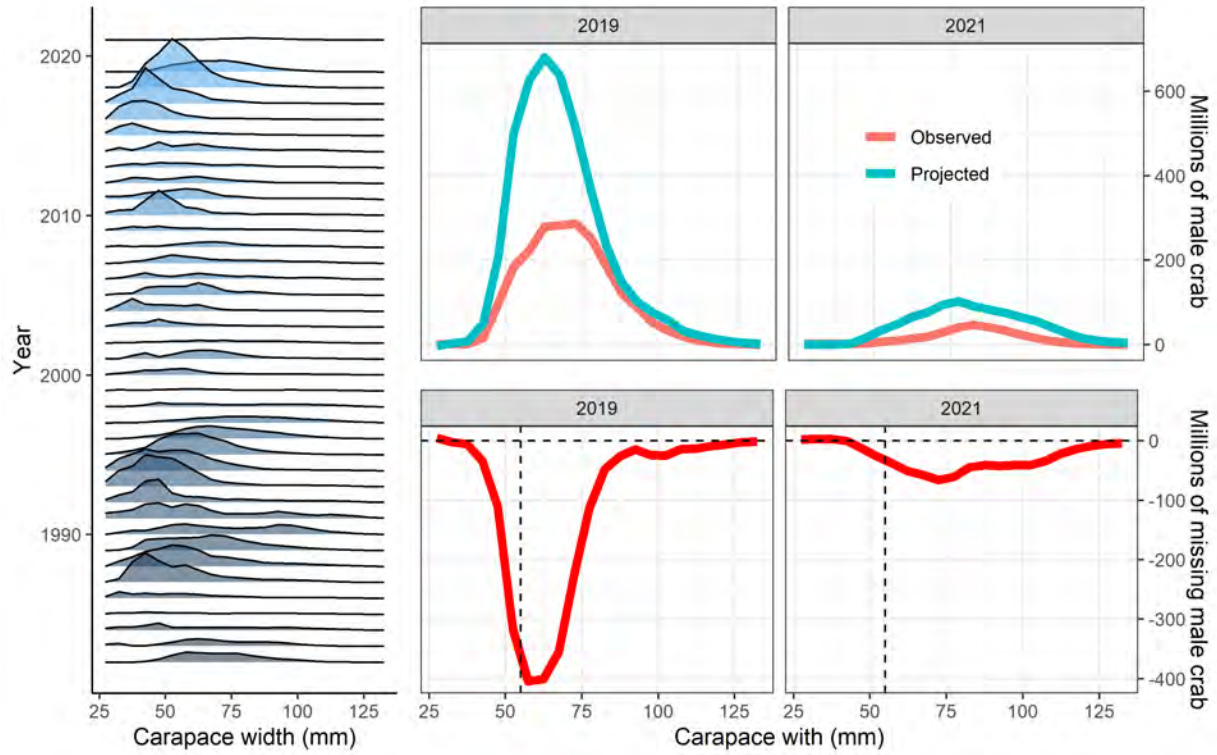


Figure 26: Numbers at size over time of snow crab (left). Observed numbers of crab (red line) in 2019 and 2021 vs. projected numbers of crab from 2018 and 2019 given a mortality equal to 0.27 (the assumed value in the assessment; top left). Numbers of missing crab at size (red line) with the size of crab beneath which cod predate upon (dashed vertical black line).

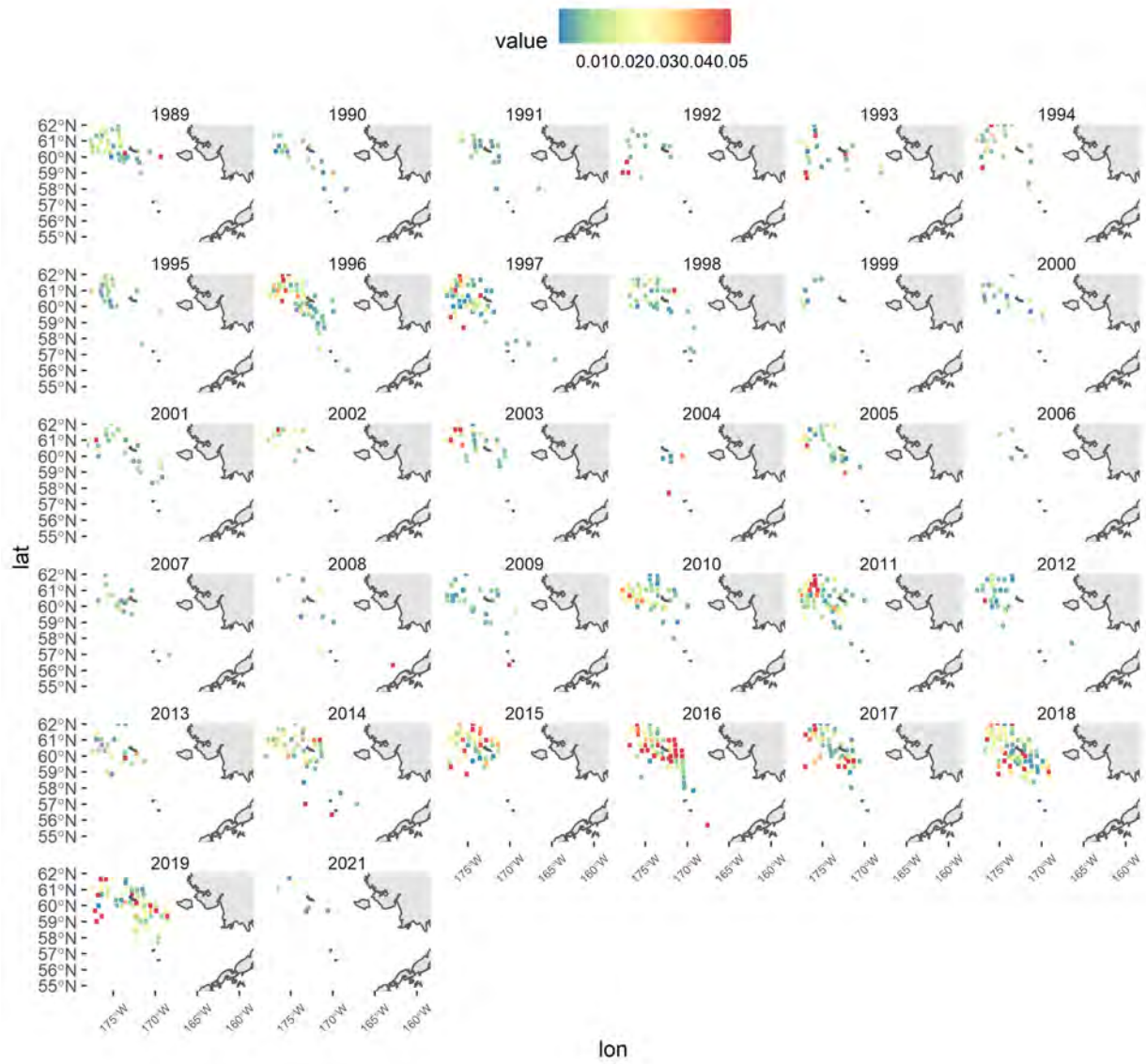


Figure 27: Location and intensity of bitter crab disease over time from visual prevalence observations in the NMFS summer survey.



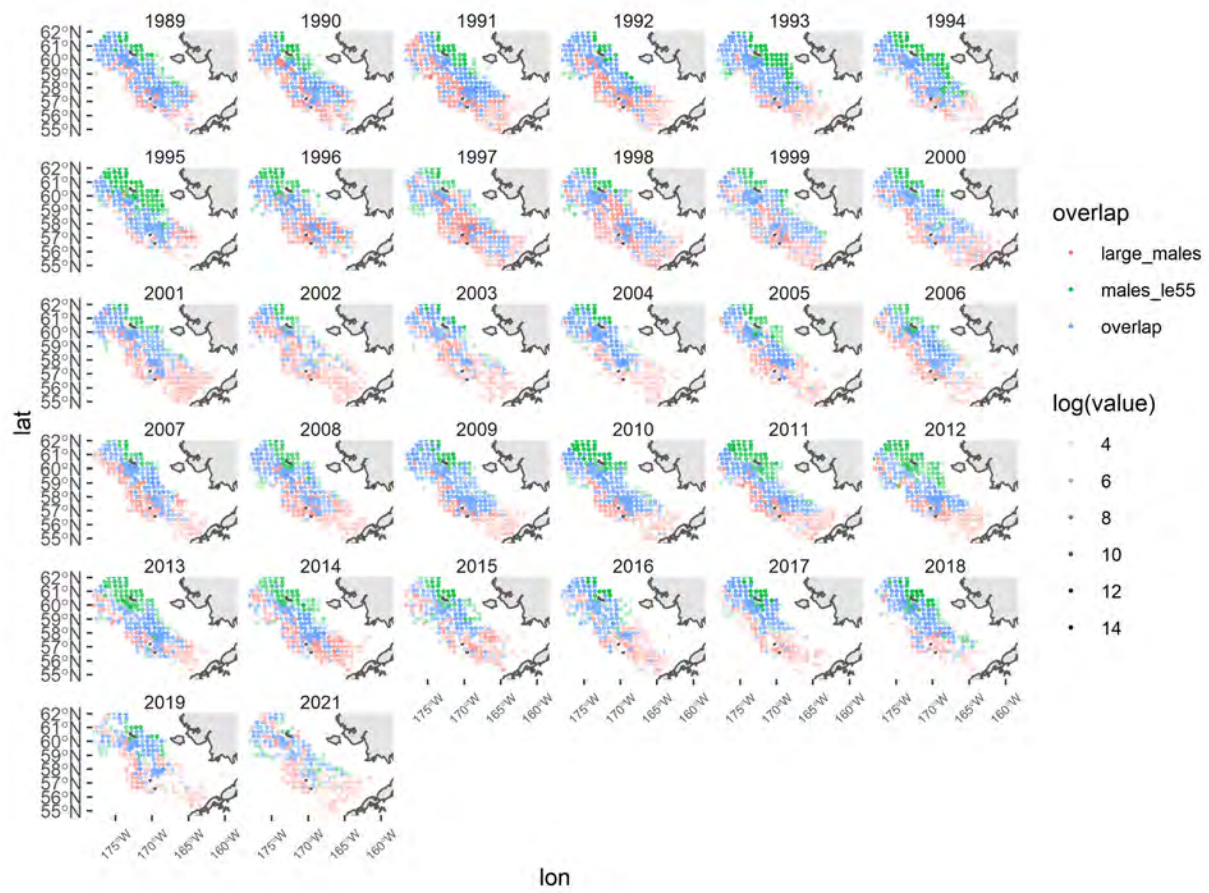


Figure 28: Overlap of large males (>95 mm carapace width) and males smaller than 55 mm carapace width. Opacity of the dot represents the density of crab. Blue represents overlapping distribution. Green and red represent non-overlapping observations of small and large males, respectively.

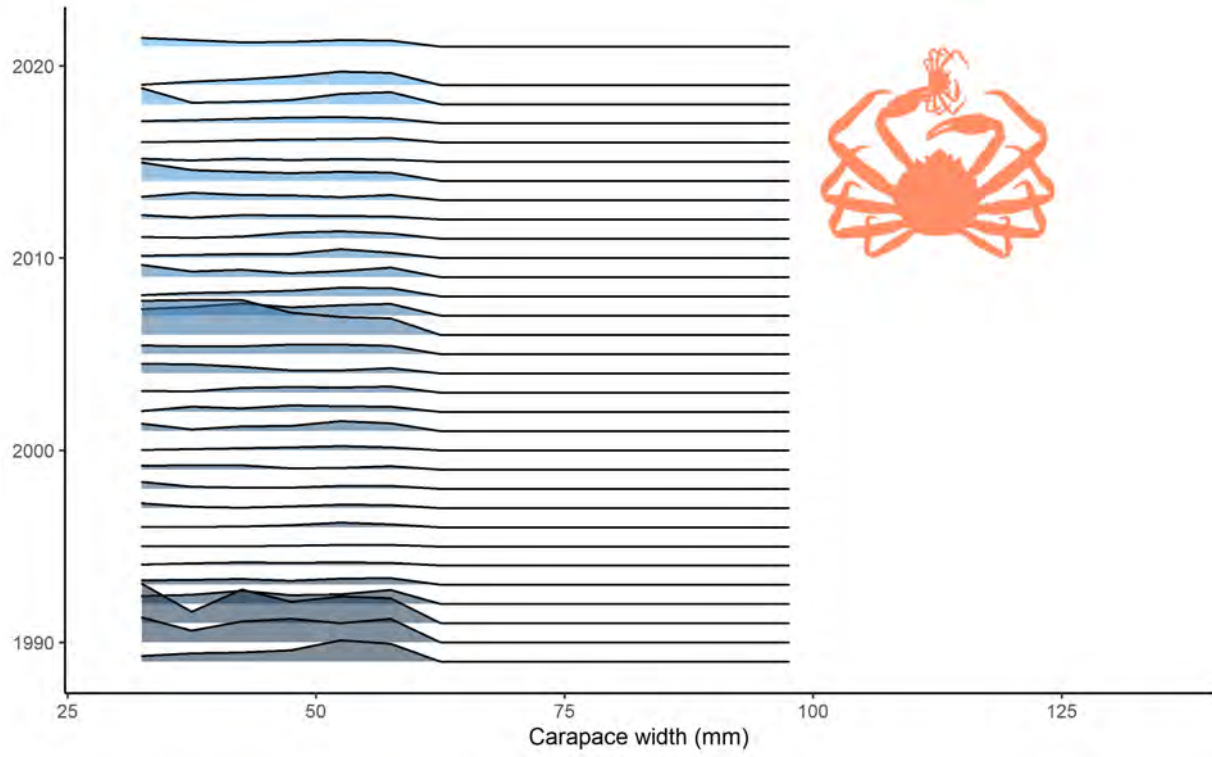


Figure 29: Relative risk at size for cannibalism over time.

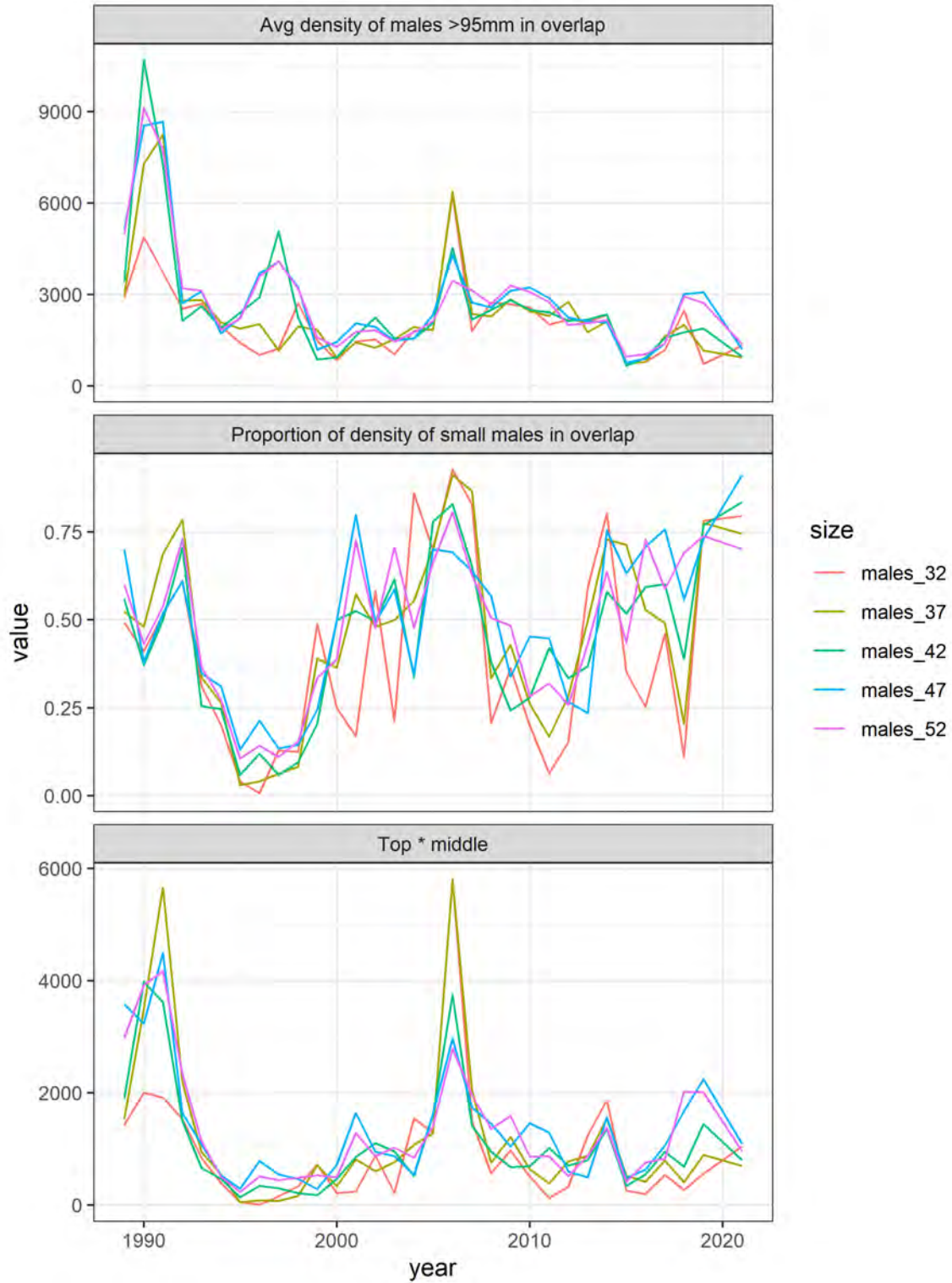


Figure 30: Times series by size of the density of large males in overlapping space (top), the proportion of small males in the overlapping area (middle), and the product of the two (bottom), which is used as an index of cannibalism in the models relating estimated mortality to environmental stressors.

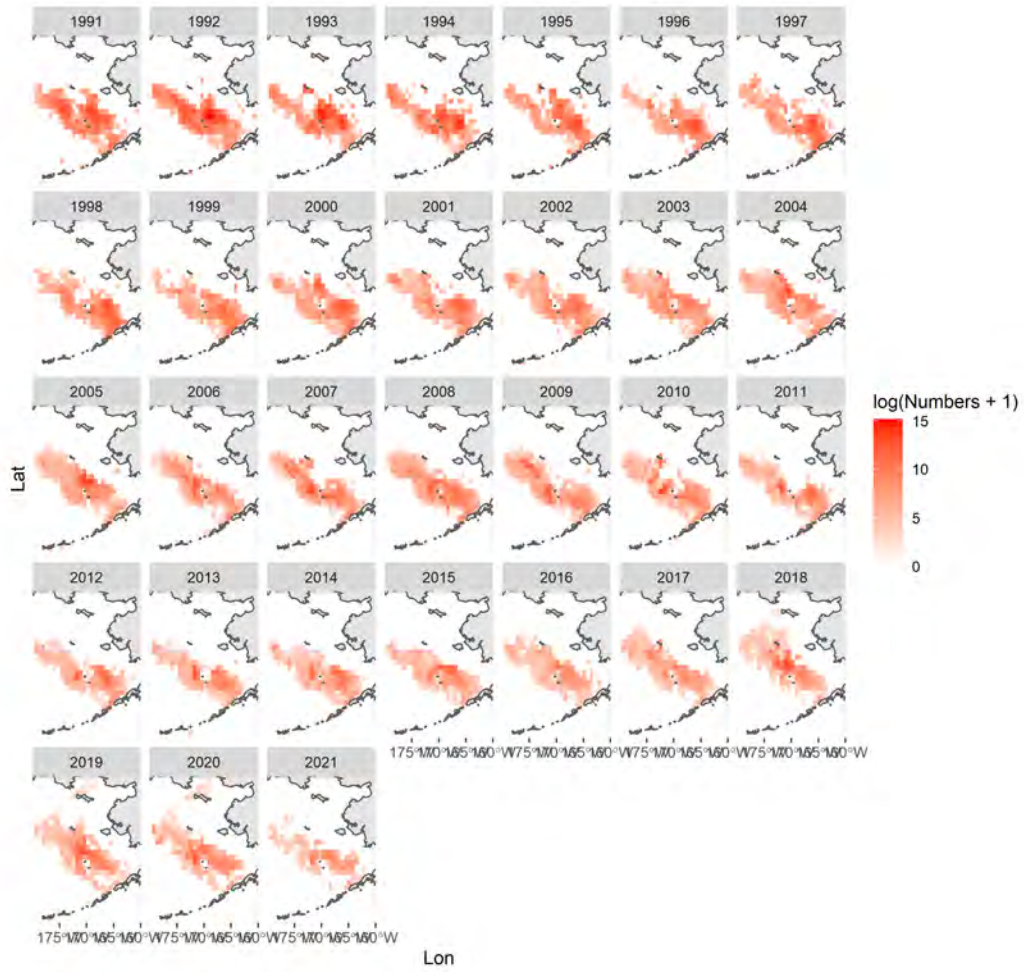


Figure 31: Location and intensity of bycatch of snow crab over time in log space.

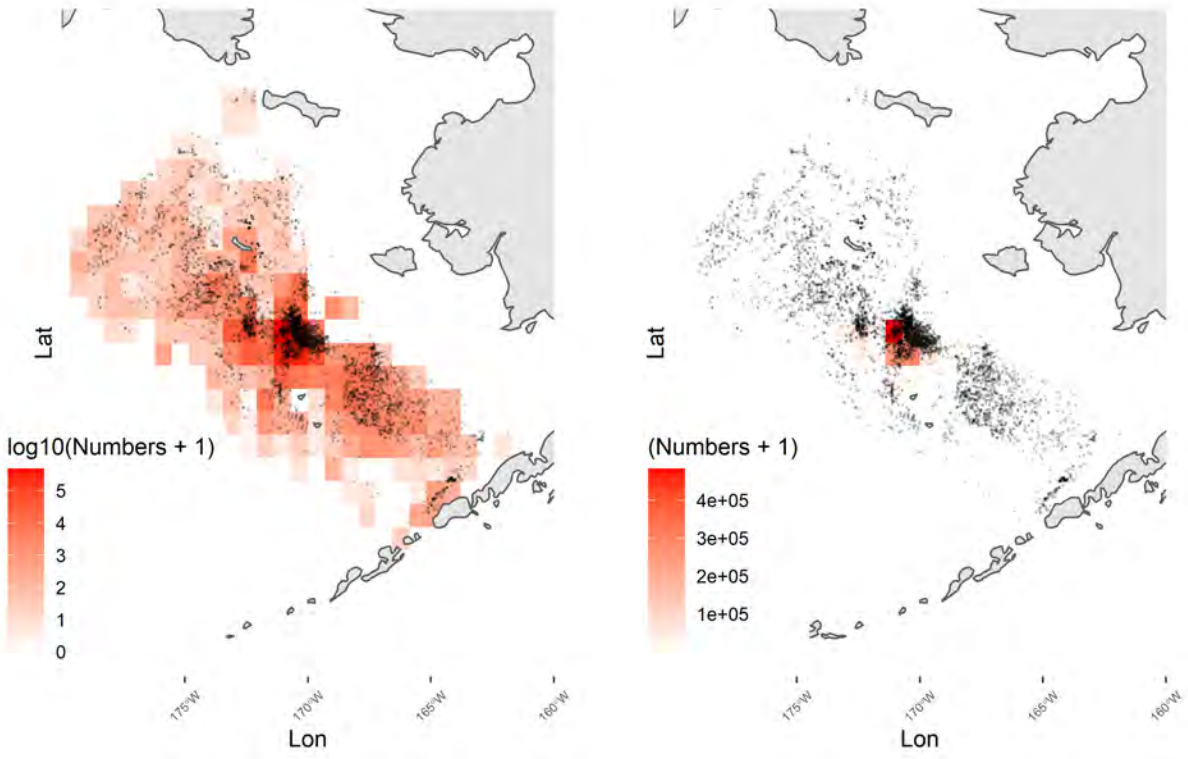


Figure 32: Comparison of location and intensity of bycatch in 2018 for natural and log space.

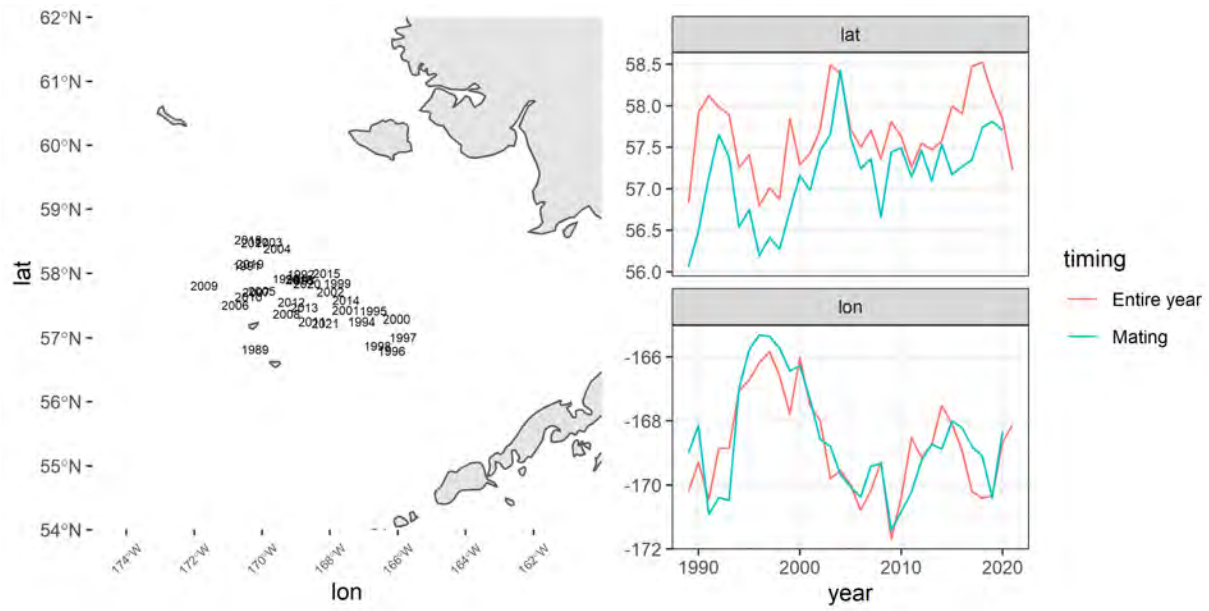


Figure 33: Centroids of bycatch over time calculated over the entire year (left). Centroids broken into time series of latitudinal and longitudinal components calculated over the entire year and during the months December through March which should roughly overlap with mating.

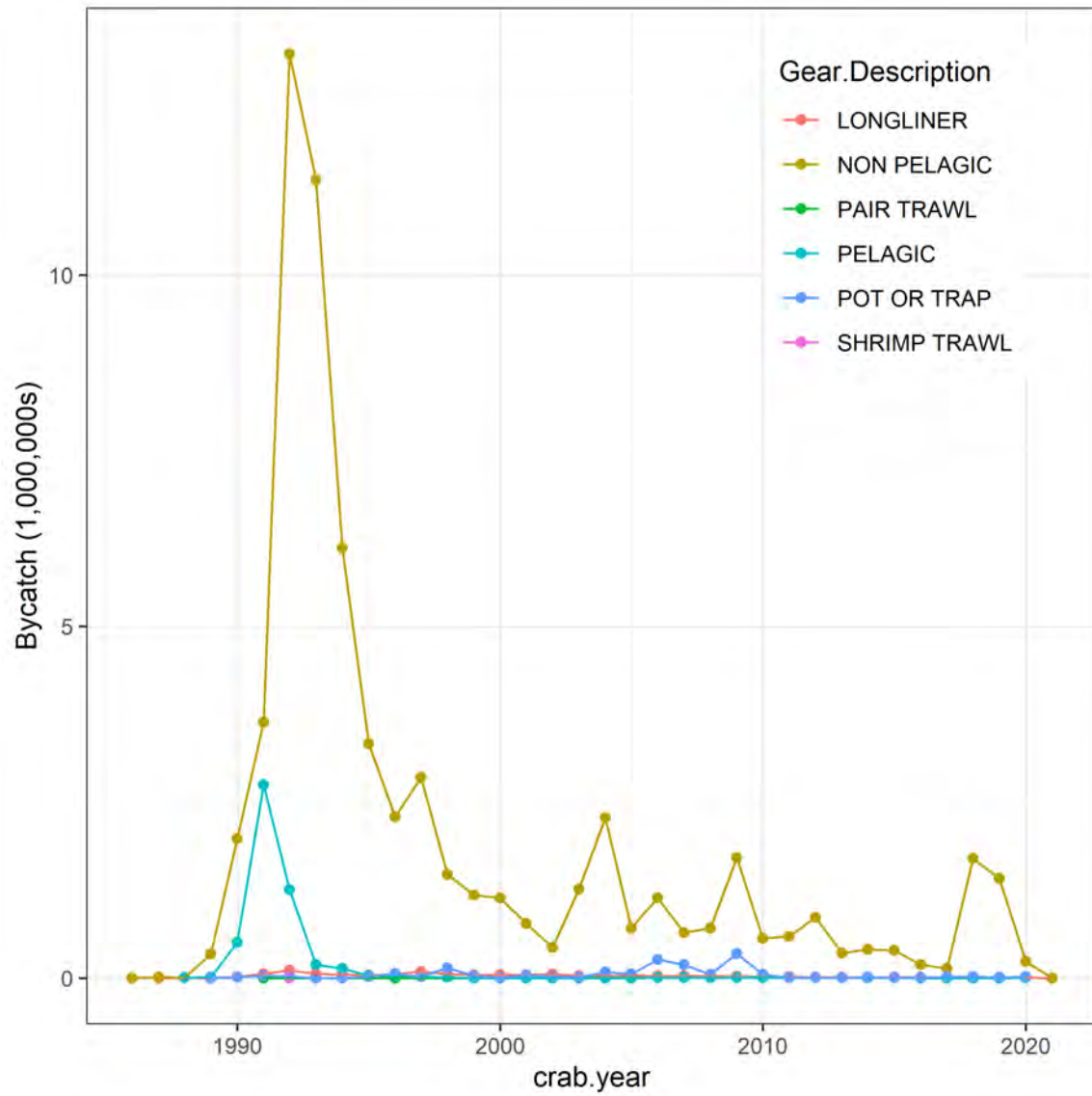


Figure 34: Bycatch by gear types reported from observer programs.

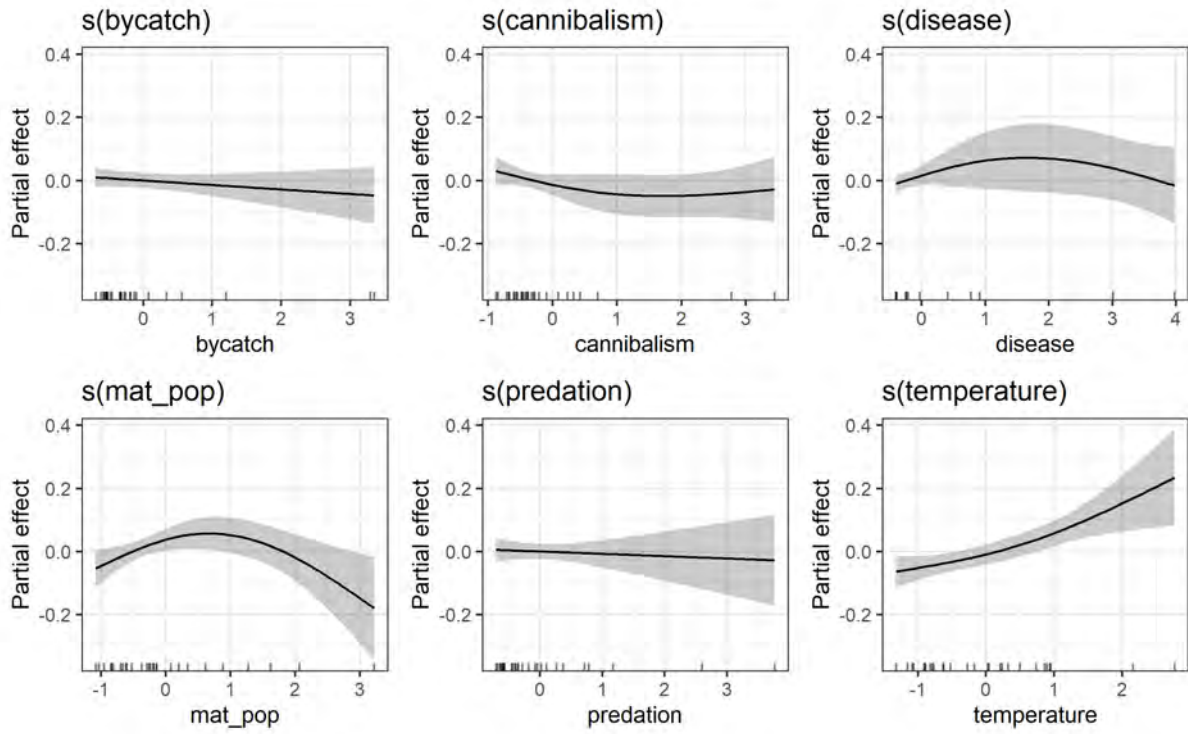


Figure 35: Smooths resulting from the full model estimating the relationship between environmental covariates and immature mortality.



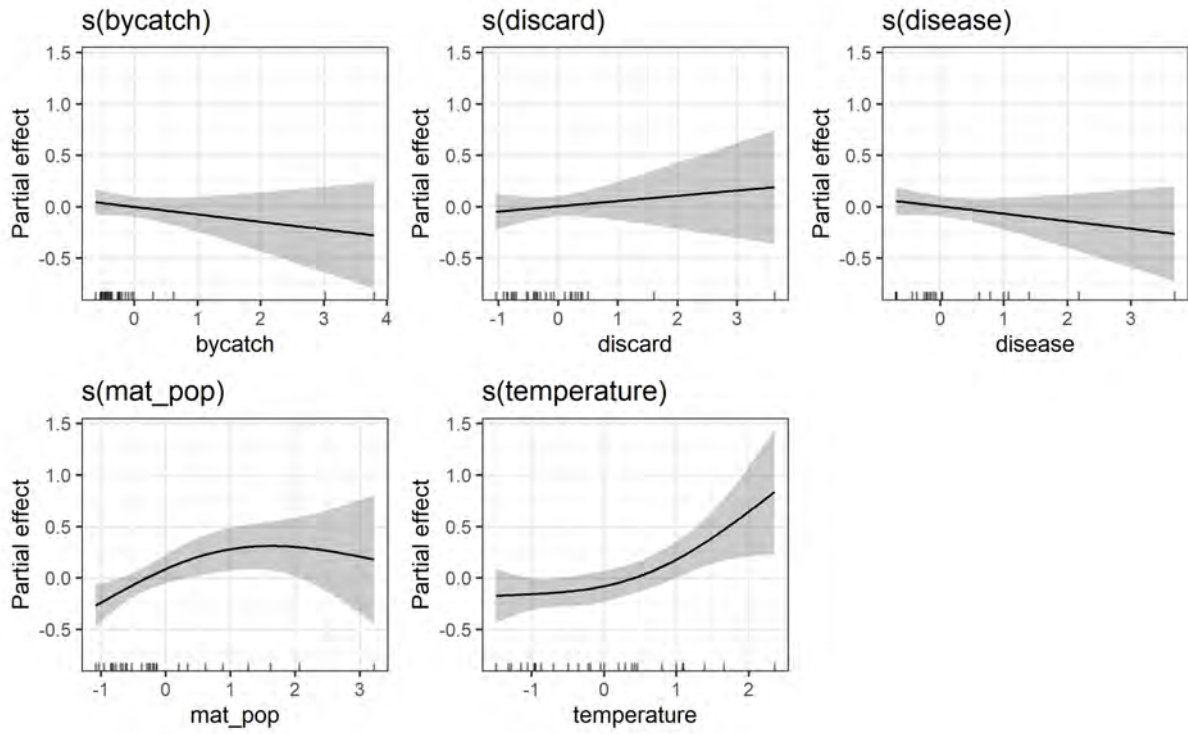


Figure 36: Smooths resulting from the full model estimating the relationship between environmental covariates and mature mortality.

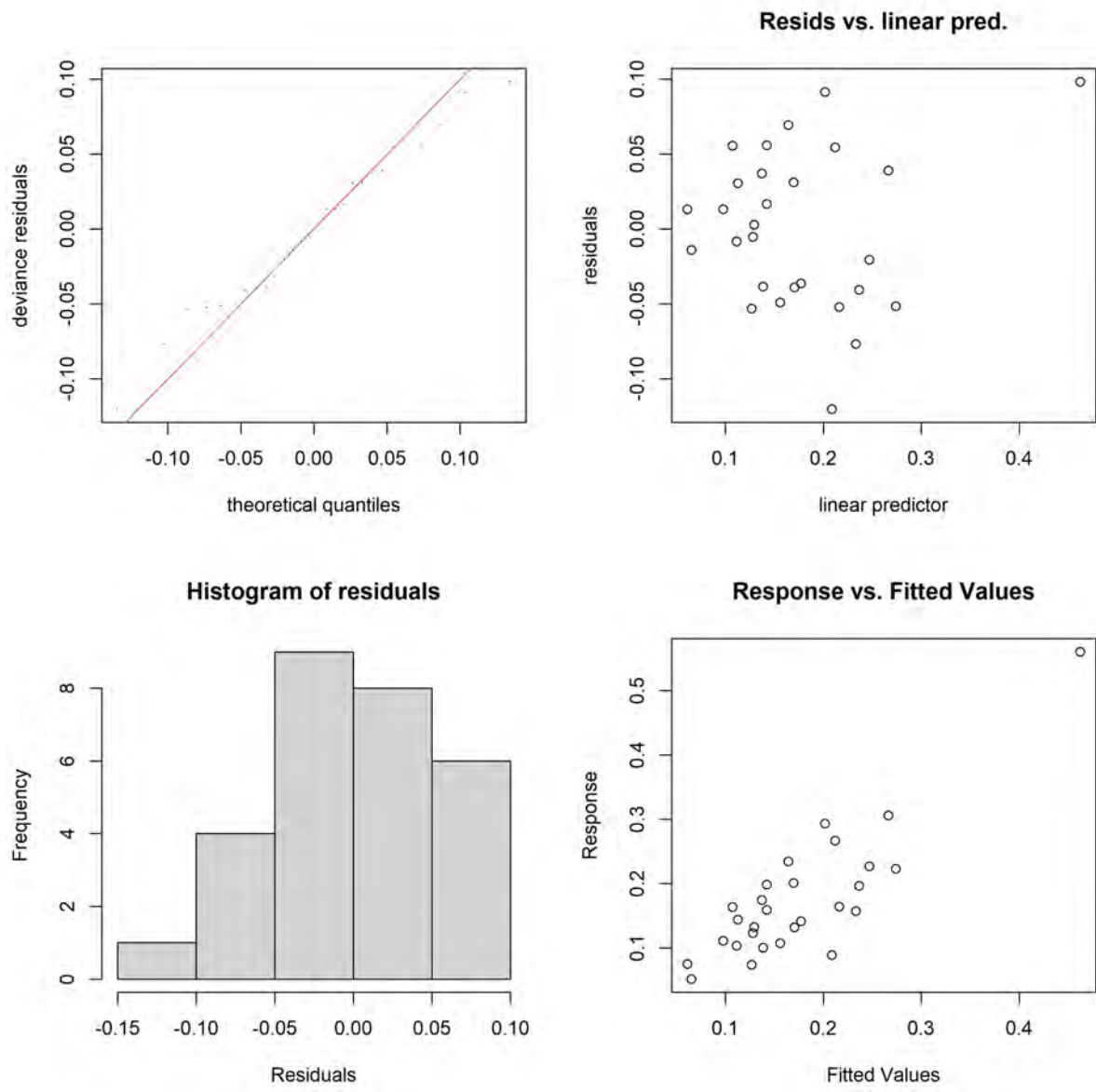


Figure 37: Diagnostic plots for the full models relating immature mortality and environmental stressors.

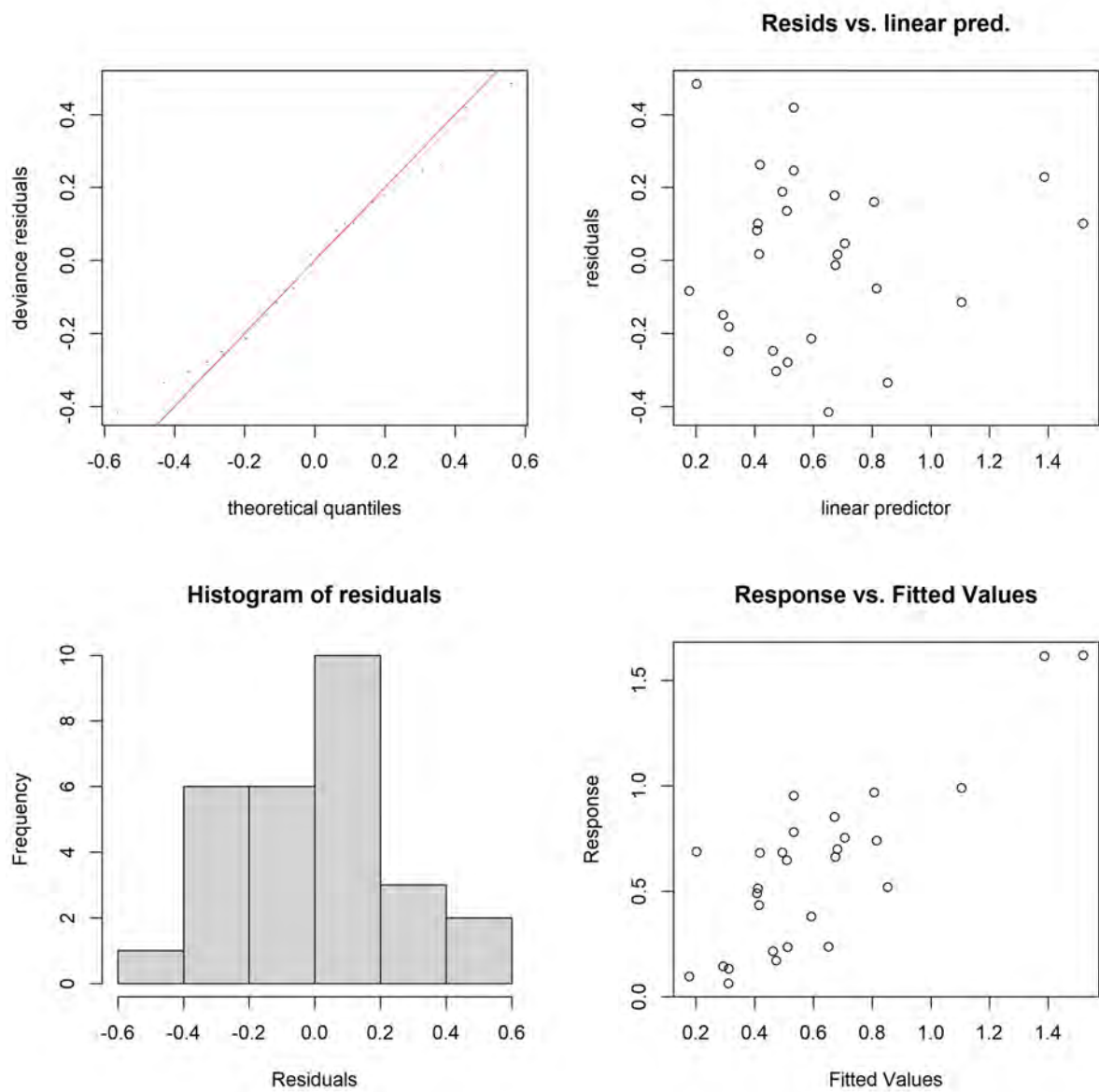


Figure 38: Diagnostic plots for the full models relating mature mortality and environmental stressors

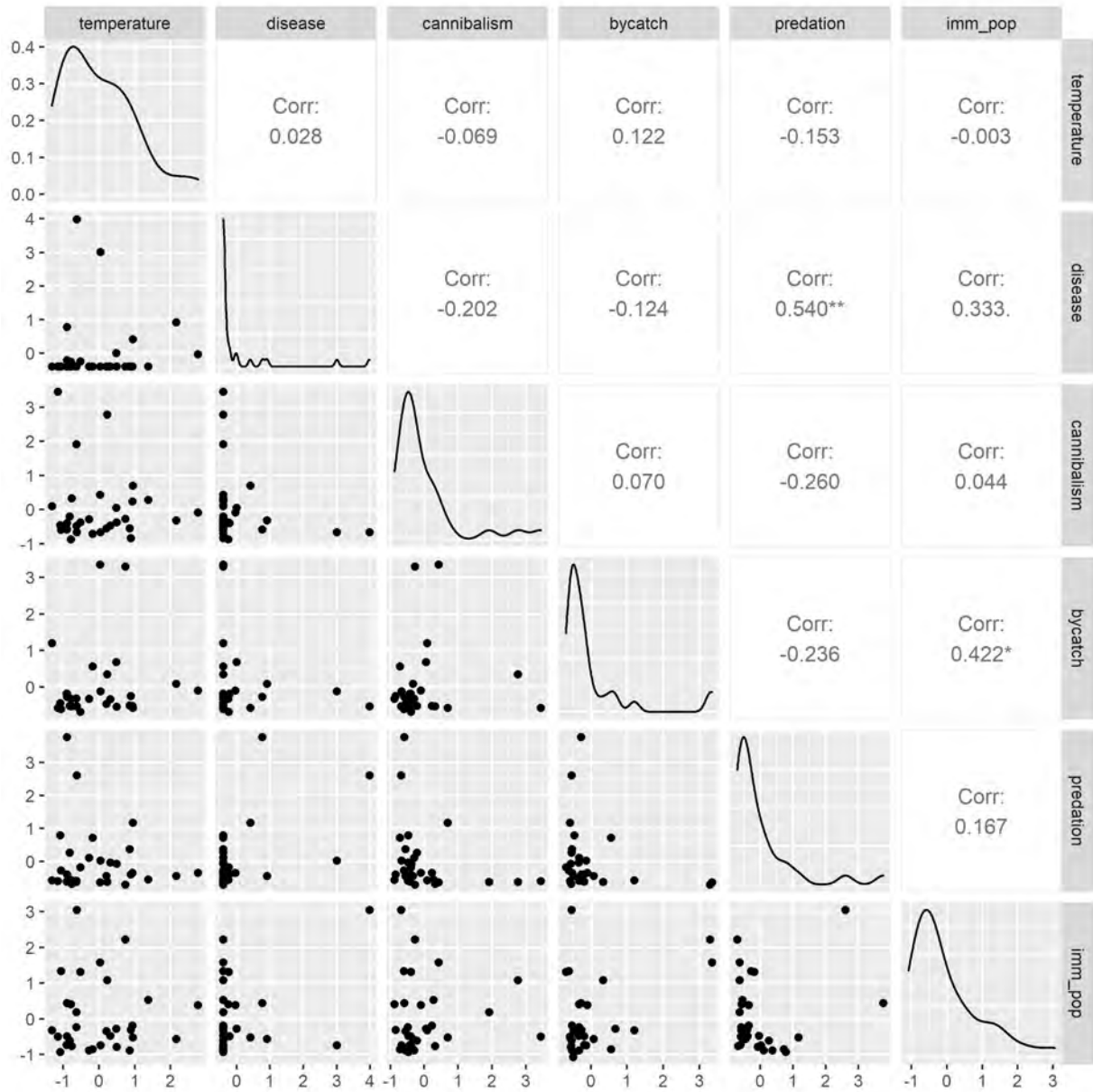


Figure 39: Pairs plots displaying the correlation between covariates for immature crab.

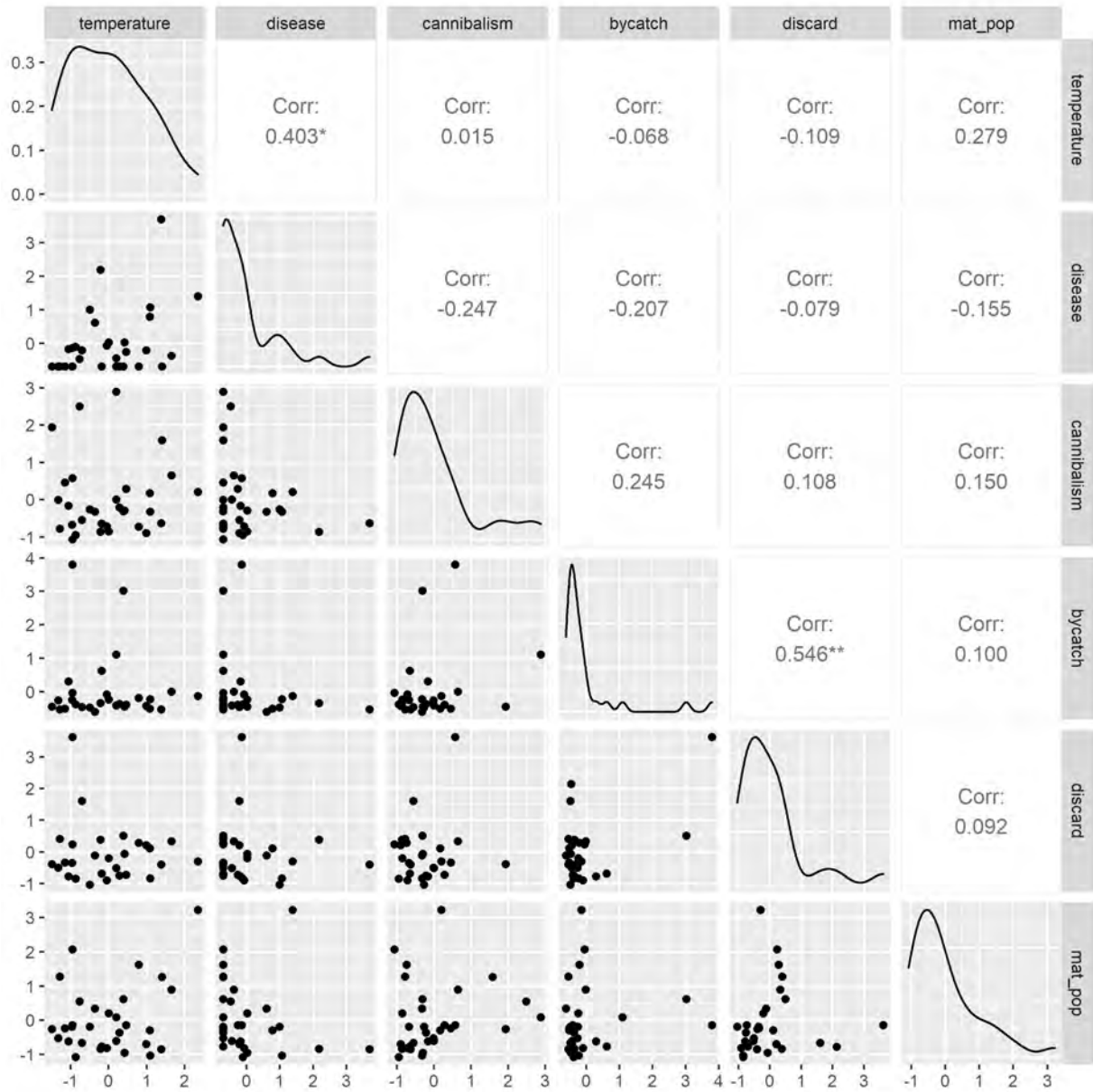


Figure 40: Pairs plots displaying the correlation between covariates for mature crab.

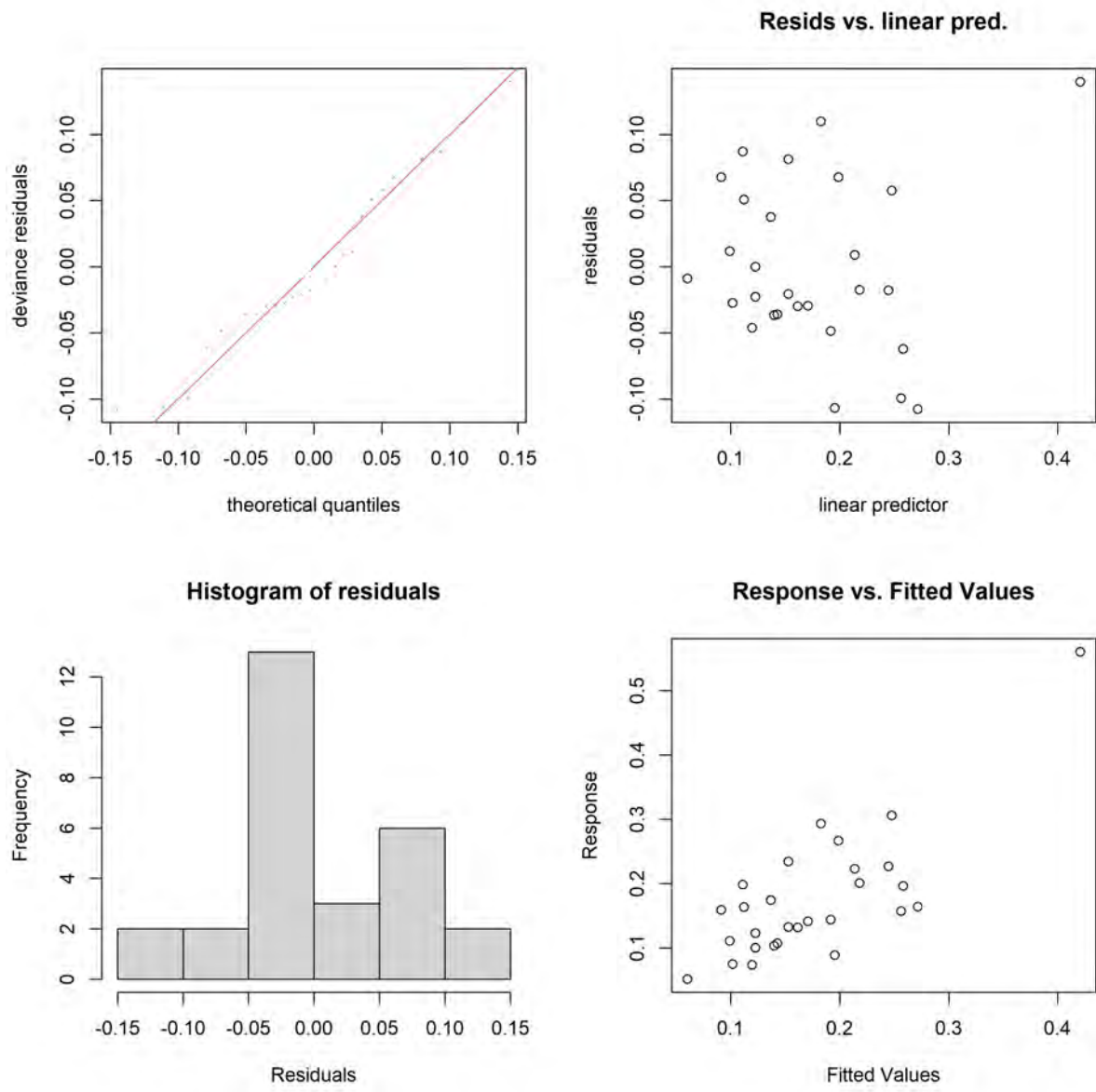


Figure 41: Diagnostic plots for the trimmed models relating immature mortality and environmental stressors.

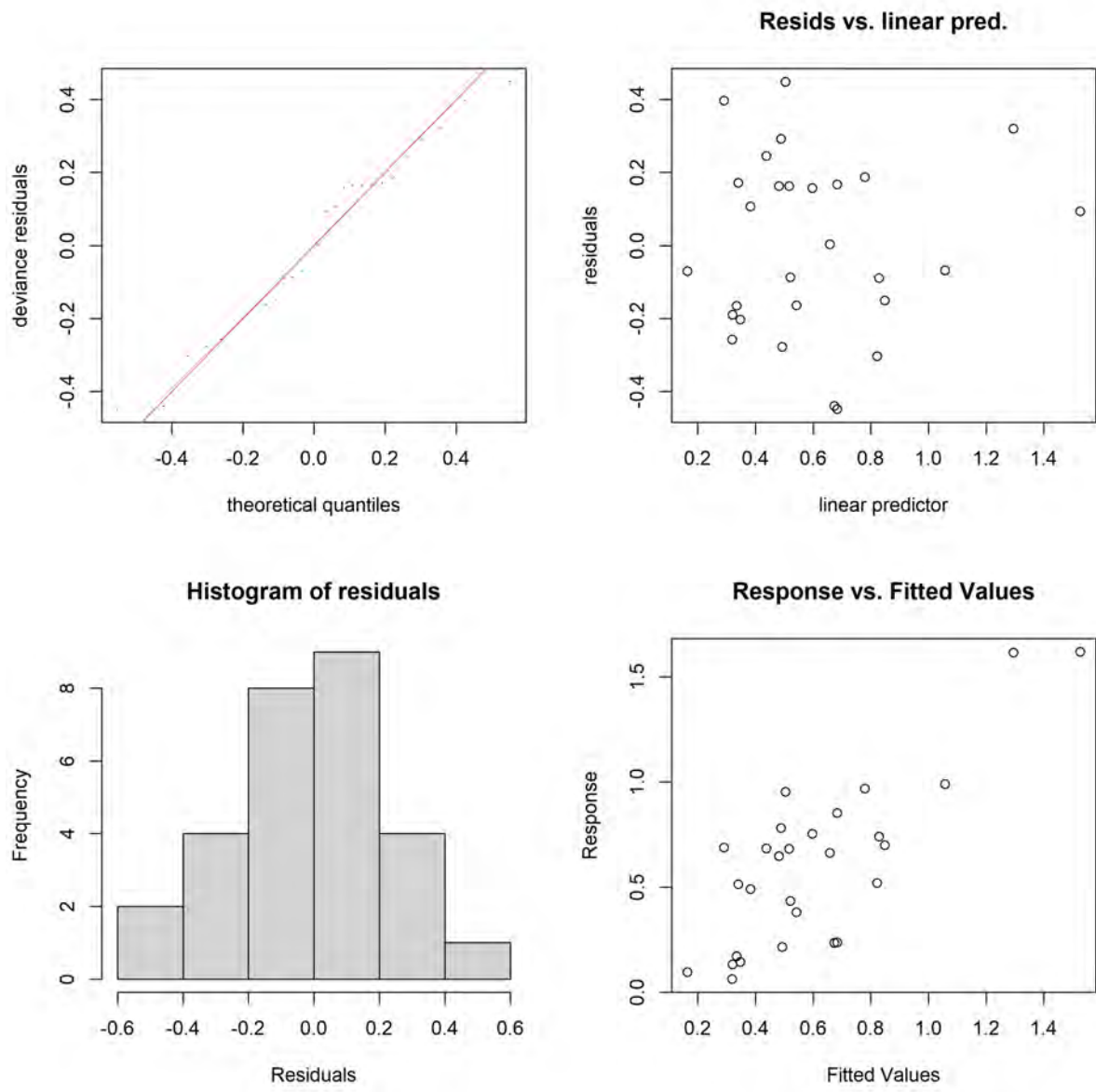


Figure 42: Diagnostic plots for the trimmed models relating mature mortality and environmental stressors.

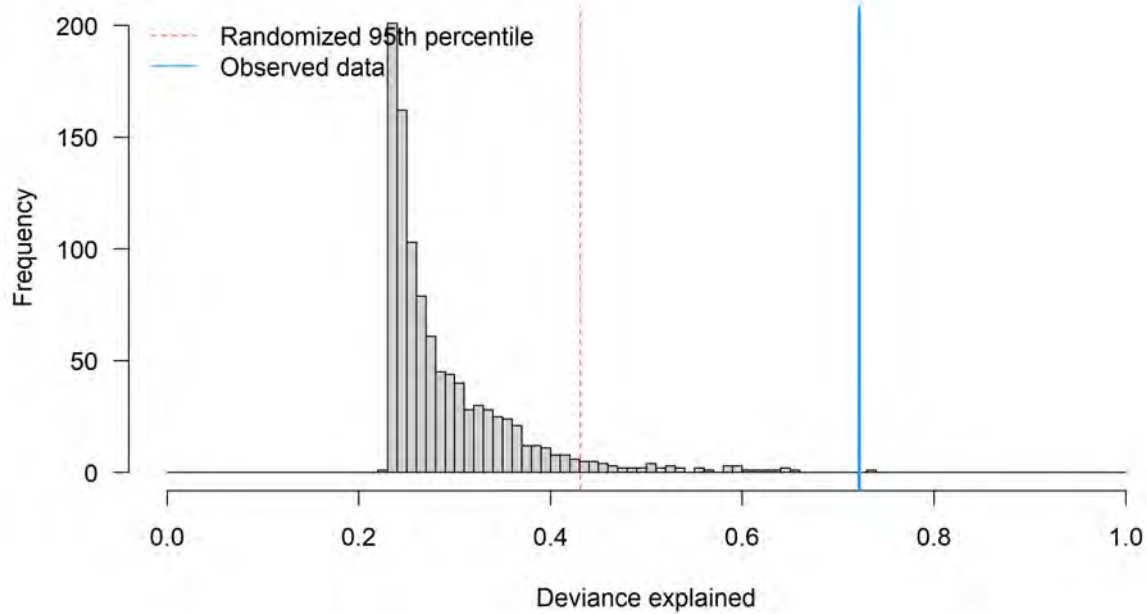


Figure 43: Results of randomization trials for the trimmed models relating estimated immature mortality to environmental stressors. Grey bars represent the number of trials in which the randomized model explained the deviance on the x-axis. Dashed vertical red line represents the 95th quantile of the deviance explained by the randomized trials. Blue line represents the deviance explained with the real data.



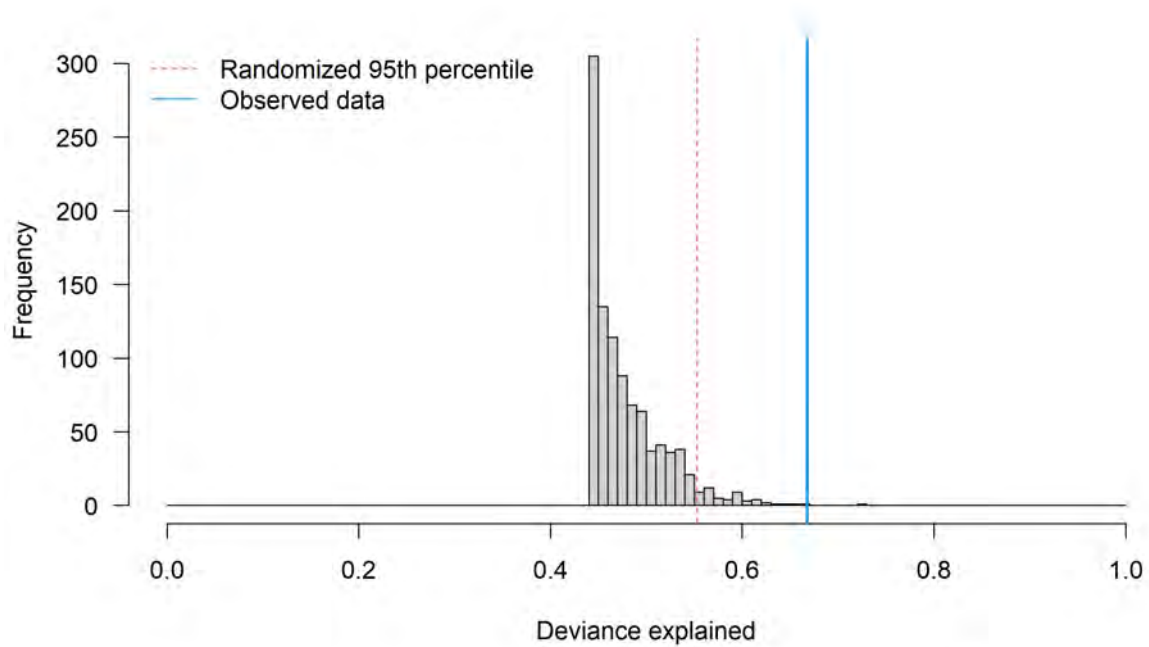


Figure 44: Results of randomization trials for the trimmed models relating estimated immature mortality to environmental stressors. Grey bars represent the number of trials in which the randomized model explained the deviance on the x-axis. Dashed vertical red line represents the 95th quantile of the deviance explained by the randomized trials. Blue line represents the deviance explained with the real data.

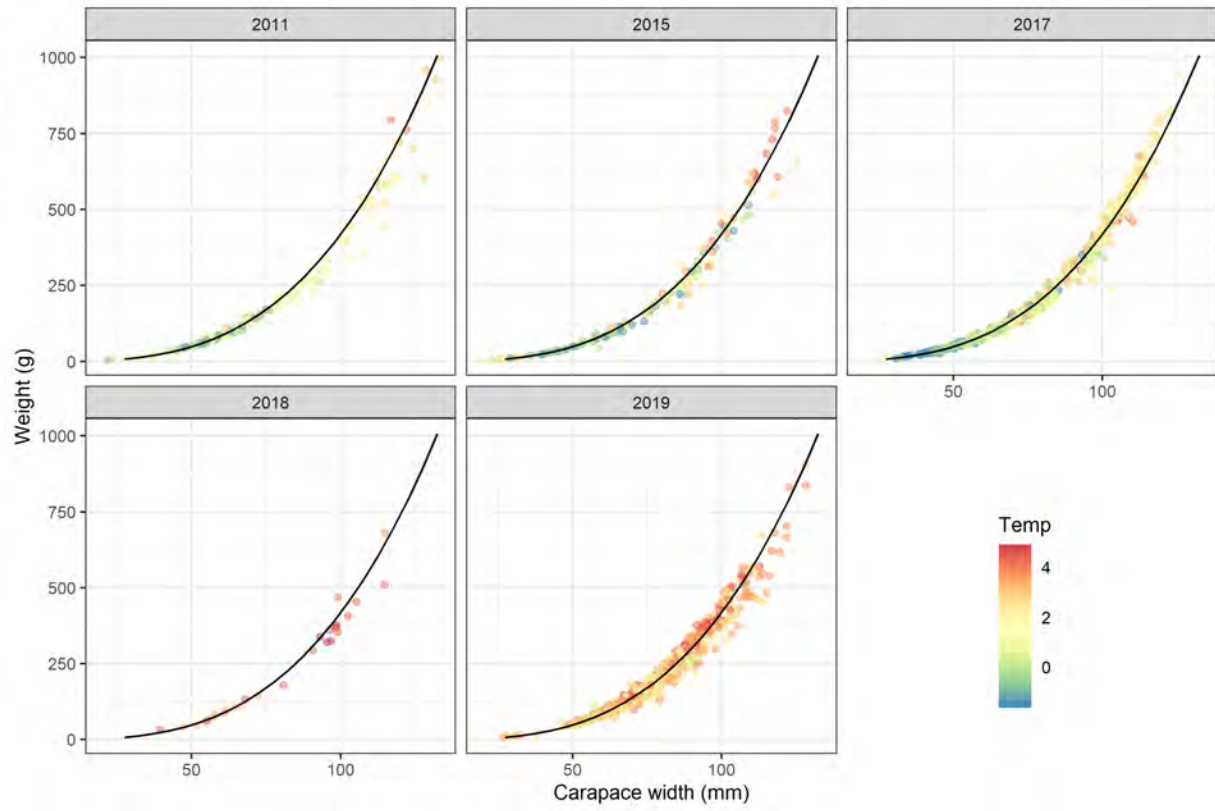


Figure 45: Observed weight at size over time colored by temperature at which the crab was collected.

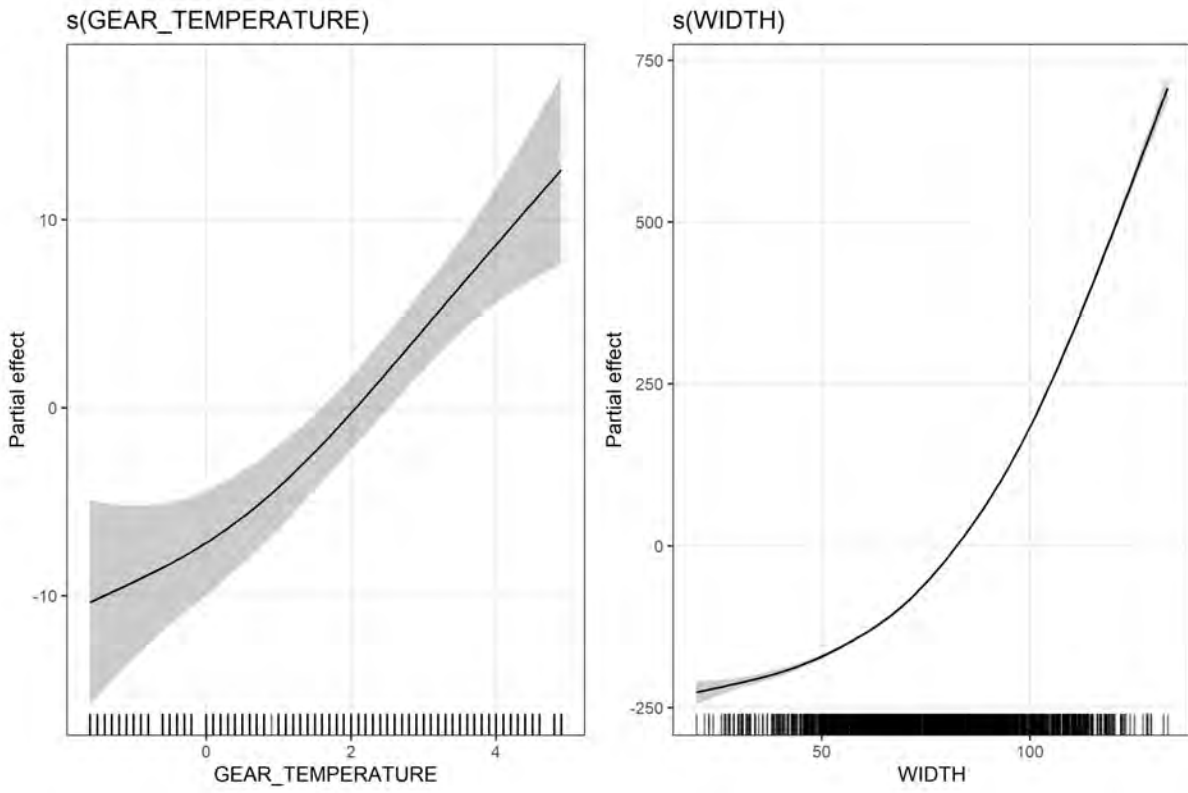


Figure 46: GAM estimated influence of temperature and carapace width on observed weights of crab.

# Appendix D: Preliminary rebuilding projections for eastern Bering Sea snow crab

Cody Szuwalski

September 13, 2022

## Contents

- A. Executive summary
- B. Comments and responses
- C. Projection specifications
- D. Projection results
- E. Author recommendations
- F. References

## A. Executive summary

A rebuilding analysis was performed for snow crab in the eastern Bering Sea based on the author-preferred model from the 2022 SAFE document (22.1ab). The model was projected to the year 2040 under different scenarios for fishing mortality, recruitment, and natural mortality. Analyses aimed at understanding the relationships between mortality and environmental conditions (included in Appendix B and C) suggest that high temperatures and high densities of crab were key conditions related to mortality events observed in 2018 and 2019. Previous analyses have linked ice cover and the Arctic Oscillation to recruitment. Given projected temperatures and population densities, a scenario in which mortality is close to average and recruitment is low are the most defensible scenarios in the opinion of the author. Under the lower recruitment scenario prioritized by the SSC and the average natural mortality scenario, the stock could rebuild under zero fishing mortality in less than 10 years (i.e.  $t_{\min}$  would be 10 years). When unobserved mortality was assumed to be small, the state harvest strategy could return the stock to above  $B_{\text{MSY}}$  within the  $t_{\min}$  of 10 years.

The potential for unobserved mortality to impact rebuilding outcomes was evaluated by multiplying the time series of input bycatch biomass by 5 and 100 and refitting the model. The refitted models were then projected under the same scenarios as above. The management advice (i.e. the OFL) resulting from models with and without unobserved mortality included were similar. The key difference between the models was how much of the OFL was allocated to the non-directed fisheries. Models with unobserved bycatch included allocated more of the OFL to non-directed fisheries, decreasing the catches of the directed fishery. It is clear that there must be unobserved mortality occurring as a result of crab killed by fishing gear, but not captured and brought to the surface. At the same time, it is difficult to reconcile the potential for unobserved mortality to play a large role in the recent population dynamics of snow crab and the appearance of the largest pseudocohort in the history of the survey in 2015-2018. Given uncertainties around unobserved mortality, similar OFLs under different assumptions about unobserved mortality, and impacts on projected directed fleet catches based allocation of the OFL under different assumptions about unobserved mortality, the author-preferred unobserved mortality scenario for rebuilding projections is the status quo. That said, additional research on unobserved mortality is warranted and non-directed bycatch is most intense around the Pribilof Islands, which would be a potentially useful area in which to focus research.

### ADDENDUM:

The CPT selected a model different than the author-preferred model. The projections contained within this document are derived from the author-preferred model, but a single run for the CPT-selected model was performed. The projection figure and table from that run are appended to the end of this document.

## B. Comments and responses

*SSC comment: SSC supports the CPT recommendation to use GMACS as the basis for rebuilding analyses but was not able to select appropriate rebuilding parameters given the information currently available. Therefore, the SSC provided guidance on rebuilding projections and fishing mortality alternatives that should be included in the next iteration of the analysis*

The prioritized scenarios were completed with updated data and the author-preferred model from the 2022 SAFE.

*SSC comment: The top priority for the rebuilding analysis is to use the tighter prior on M that is consistent with both last year's model and the preferred model recommended for the 2022 harvest specifications cycle by the CPT.*

The author-preferred model uses a prior consistent with the previous status quo model.

*SSC comment: The SSC recommends a stochastic treatment of M, resampling of annual M values from the same period of years used for recruitment resampling*

This functionality was built into GMACS for these rebuilding projections.

*SSC comment: To bracket a range of plausible trajectories, four time periods were recommended:*

- 1982-2017: This period was recommended by the CPT, and will be similar to the results already provided, except for the use of the tighter prior on M during estimation. The SSC notes that this will likely be the most optimistic case, as it does not include the high estimated M associated with the apparent mortality event in 2018-2019.
- 1982-2019: This period matches the fully observed time series, including the elevated mortality in 2018-2019, but does not reflect the anticipated increased frequency of mortality events due to climate change.
- 1994-2019: This period follows the author's rationale for a break in the recruitment time series, reflecting more recent conditions while still allowing for the possibility of some high recruitment
- 2005-2019: This period corresponds to the most recent period of alternating warm and cool conditions in the Bering Sea and approximates a one in seven chance of an elevated mortality event, consistent with estimates of near-term future temperature variability in the Bering Sea.

*Noting the compressed timeline for this rebuilding analysis, the SSC suggests if all of the four projection time-periods cannot be evaluated that the first and fourth would be the highest priority.*

Given unexpected issues with the jittering analysis (see main SAFE document), only the prioritized scenarios were performed.

*SSC comment: Consistent with the treatment of mortality events for other crab stocks and for GOA Pacific cod, the SSC recommends using only the 'base' mortality rate (not including the 2018-2019 event), for each projection period, along with the resampled recruitments to calculate the BMSY for determining rebuilding parameters*

Three  $B_{MSY}$ s are presented on each graph and table: one that corresponds to the currently used  $B_{MSY}$  with which management advice is set (i.e. average recruitment from 1982-2021), one that corresponds to 1982-2017, and one that corresponds to 2005-2019.

*SSC comment: The SSC supports the CPT recommendations of fishing mortality alternatives to include in each projection, with two additions for a total of five alternatives:*

- No fishing mortality ( $F=0$ )
- Average bycatch over a recent period (including both groundfish and other crab fisheries)

- An approximation of the State of Alaska’s Harvest Control Rule (HCR) with recent bycatch
- An approximation of the State of Alaska’s HCR without recent bycatch
- $F = F_{ABC}$

These fishing scenarios were performed for each of the 4 productivity scenarios, but an issue was discovered with the State of Alaska harvest control rule without recent bycatch when writing this document (discussed below). This primarily impacts the unobserved mortality sensitivities because it is related to how the fishing mortality is allocated between among the directed and non-directed fleets capturing snow crab.

*SSC comment: The SSC requests that future rebuilding analyses provide a summary of the technical specifications of how the projections are being run (e.g., how many forward simulations, which sources of uncertainty are included, whether Monte-Carlo error has been evaluated and is negligible for the quantities of interest). To aid in specific evaluation and comparison of rebuilding parameters, the SSC also requests that they be provided in tabular format including:  $T_{min}$ ,  $T_{max}$ , mean generation time, and specific rebuilding times for fishing alternatives (potential  $T_{target}$  values).*

Each of these points has been addressed below.

## C. Projection specifications

The projection model used here was based on the author-preferred model 22.1ab from the 2022 SAFE document. Several points of concern were raised about the model fits for model 22.1ab in the SAFE document. These issues are important to address for tactical management, but for strategic management projections, the issues are less important for several reasons. First, projections use average values for population processes to project forward. Estimates of population processes were similar across models. The key drivers of rebuilding time are the initial status of the stock (i.e. the ratio of current MMB to  $B_{MSY}$ ) and assumptions about future recruitment and natural mortality. The estimated status from all of the models with the most up-to-date data are in an over-fished state. The purpose of multiple recruitment and natural mortality scenarios is to evaluate the impact of different assumptions about future productivity on rebuilding trajectories. One strong caveat is that the projections models assume that the OFLs and ABCs are set with perfect estimates of the scale of the population, which have been historically uncertain. Still, given similar starting statuses and similar estimated population processes, this projection model is best available framework to evaluate rebuilding trajectories for eastern Bering Sea snow crab.

Projections were performed by starting at the local minima from model 22.1ab. Recruitment and natural mortalities were sampled from the estimated recruitments and natural mortalities based on user input range of years. Four future productivity scenarios were analyzed by crossing the periods 1982-2017 and 2005-2019 for sampling recruitment and natural mortality. The model was projected to 2040 in each of 2000 projections performed for each combination of recruitment and natural mortality scenarios. Five fishing scenarios were performed within those four productivity scenarios based on the SSC requests: zero fishing mortality, only bycatch mortality, an approximation of the State of Alaska’s harvest with no bycatch, an approximation of the State of Alaska’s harvest including bycatch, and the federally set acceptable biological catch (ABC). Markov Chain Monte Carlo (MCMC) simulations were performed for model 22.1 before discovering the bimodality in management quantities. Once the bimodality was discovered, there was not time to run MCMC, so the starting points of the forward projections do not incorporate stochasticity in parameter estimates or initial conditions.

Bycatch mortality was specified in the model as the average of the estimated bycatch fishing mortality over the last ten years. The State of Alaska’s harvest control rule was approximated by averaging the ratio of the total allowable catch (TAC) set by the State and the ABC over the last 10 years (Daly, personal communication). The ratio (equal to 0.40) was used to scale the ABC calculated in the projections; the ABC was based on a 25% buffer of the OFL calculated using the current  $B_{MSY}$  proxy.

Three proxies for  $B_{MSY}$  were calculated to evaluate rebuilding progress. These target biomasses correspond to the currently used  $B_{35\%}$  (recruitment years 1982-2021), a target biomass calculated using expected recruitment based on the years 1982-2017, and a target based on the recruitment estimates for the years 2005-2019. All biomass targets were calculated without incorporating the potential for mortality events to occur (i.e. the base estimate of natural mortality was used in projections).

Sensitivities about the assumptions of unobserved mortality were explored in which the observed time series of bycatch was multiplied by 5 and 100 before the model was fit to the data. The projection methodology described above was then repeated for each of those models.

Estimates of mean generation time from the Kodiak lab were  $\sim 7$  years, based on the approximate time to maturity (Fedewa, personal communication).

## D. Projection results

### *Author-preferred model*

Assumed future conditions of recruitment and natural mortality impacted the time to rebuilding under no fishing, as did the target biomass used (Figure 28 & Figure 29). Scenarios in which future recruitment and natural mortality were drawn from 2005-2019 never rebuilt under zero fishing regardless of the target. Scenarios in which future recruitment and natural mortality were drawn from 1982-2017 rebuilt the fastest of the scenarios, rebuilding to the currently used  $B_{MSY}$  in 2029 under no fishing and during 2029-2030 while fishing at the State harvest control rule plus bycatch.

Uncertainty around the future population size was larger under recruitment projections sampling from 2005-2019 than from 1982 to 2017 because the 2005-2019 period is comprised of one very large recruitment among many small recruitments, resulting in a smaller standard deviation of recruitment during the years 1982 to 2017 compared to that from 2005-2019. Consequently, although the overall potential scale of the populations under 2005-2019 recruitment is larger, the slope of the rebuilding trajectory is somewhat more shallow than when recruitment is drawn from 1982-2017. The currently used  $B_{35\%}$  is lower than both other biomass targets, which can result in faster times to rebuilding if it is used as the rebuilding target.

### *Unobserved mortality sensitivities*

Altering the input bycatch biomasses to represent potential unobserved mortality resulted in changes in the estimates of some population processes. See Figure 7 through Figure 26 for differences in fits and estimated population processes among the models with different assumptions about unobserved mortality. Changes in individual contribution of likelihood component to the objective function and the resulting management advice can be seen in Table 1 and Table 2. Fairly large changes were seen in the scale of the population and resulting estimates of MMB,  $B_{35\%}$  and  $F_{35\%}$ . However, estimates of status of the population and OFLs were less different than the other management quantities.

As with the author-preferred model, assumed future conditions of recruitment and natural mortality impacted the time to rebuilding under no fishing, as did the target biomass used (Figure 3 through Figure 6). The general trends of the timing of rebuilding under a given productivity scenario and zero fishing mortality were similar to the results from modeling when no additional unobserved mortality was modeled. However, there were more scenarios in which the stock never rebuilt with higher unobserved mortality.

An error in the projection model occurs for the ‘State - bycatch’ scenario and is most apparent in the 100x bycatch scenarios. The ‘State - bycatch’ scenario should be close to the ‘No fishing’ line because under these models, the entire allocation of the OFL should be to the bycatch fleets based on current calculations of the OFL. The fishing mortality allocated to the bycatch fleets is an average of the last ten years in the calculation of the OFL, then a fishing mortality for the directed fleet is estimated to allow the remaining portion of the OFL to be caught by the directed fleet. This dynamic would need to be considered more carefully if additional unobserved mortality were to be included in the assessment or projections. Currently, very little bycatch occurs in the author-preferred models, so the allocations to bycatch fleets when calculating the OFL



are small. If unobserved mortality is included in the assessment and the OFLs do not change appreciably, it would result in the directed fishery being allocated less of the OFL than historically seen.

If one of the unobserved mortality scenarios are selected, the methodology for calculating the ‘State - bycatch’ scenario will need to be revised.

## E. Author recommendations

### *Scenario selection*

Selection  $t_{\min}$  is the first step in developing a rebuilding plan and to do that, probable scenarios for future conditions must be established. Appendix B and C detail analyses aimed at understanding the dynamics of mortality for snow crab over time. One of the conclusions from the draft manuscript was that the mortality events in 2018 and 2019 appear to have been a result of high population-wide caloric demand as a result of high temperatures and high densities of crab. Bottom temperatures in the Bering Sea are projected to warm as ice cover is less of a permanent feature of the ecosystem (Jones et al., 2020). However, densities of crab will likely not be high in the short- and medium-term future (e.g. the next ten years), based on the current status of the population. Temperatures occupied by mature crab in 2003 were similar to temperatures in 2018 and 2019 as a result of similarly small cold pools (figure 1; Appendix B). However, estimated mortalities were not exceptional in 2003, potentially because of low densities of mature crab (figure 2: Appendix B). In light of these observations, more average natural mortalities may be an appropriate assumption over the projection period because, even though the Bering Sea is likely to be warm, densities of crab will be low.

Models predicting and projecting recruitment for crab in the eastern Bering Sea were published by Szuwalski et al. (2020) and linked estimated recruitment for snow crab to ice cover (positive relationship) and the Arctic Oscillation (AO; a negative relationship). Linking these recruitment models to projections of ice and the AO from global climate models produced declining trajectories of recruitment under warming scenarios. Consequently, the author-preferred projection of recruitment for the rebuilding analyses is the lower average recruitment scenario prioritized by the SSC (i.e. 1982-2017). That said, lower recruitment than this scenario projects is possible, which would impact rebuilding timelines.

### *Unobserved mortality*

It is clear that there is some unobserved mortality on snow crab in the Bering Sea imposed by non-directed fleets; Rose et al.’s studies demonstrated that a small fraction of the crab in the path of groundfish fisheries are caught and brought to the surface (see Dr. Rose’s May 2022 CPT meeting presentations for a summary). However, it is difficult to make a case for large impacts of non-directed fisheries on the recent population dynamics of snow crab. If the non-directed fisheries were a large driver of population dynamics, it is hard to explain how the largest pseudo-cohort ever observed would have occurred recently and developed through the size ranges that are impacted by the non-directed fleets. Still, managers only have two levers for impacting the population dynamics of snow crab in the Bering Sea: adjusting fishing mortality in the directed fishery or adjusting fishing mortality in the non-directed fleets. The other apparent drivers of snow crab dynamics (e.g. sea ice) are outside of the control of managing bodies. Consequently, it is important to carefully consider potential effects of the non-directed fisheries on the dynamics and rebuilding prospects of snow crab.

Given uncertainties around unobserved mortality, similar OFLs under different assumptions about unobserved mortality, and impacts on projected directed fleet catches based allocation of the OFL under different assumptions about unobserved mortality, the author-preferred unobserved mortality scenario for rebuilding projections is the status quo.

Future research aimed at understanding unobserved mortality could be focused on two areas. First, trawl bycatch is most intense around the Pribilof Islands (Figure 27) and this area has been suggested to be important to reproductive dynamics (e.g. Parada et al., 2010). This area would be a good candidate for research aimed at evaluating the impacts of potential modifications of non-directed fishery bycatch on snow crab population dynamics. Second, evaluation of the potential impacts of incorporating unobserved mortality into the assessment and management would be useful. If incorporating unobserved mortality results

ultimately similar OFLs in a given year, the current methodology of allocating an average recent fishing mortality in the calculation of the OFL to the non-directed fleet then solving for the fishing mortality in the directed fleet that 'completes' the OFL could result in unanticipated impacts on the OFL allocated to the directed fleet.

## F. References

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Parada, C., Armstrong, D.A., Ernst, B., Hinckley, S., and Orensanz, J.M. 2010. Spatial dynamics of snow crab (*Chionoecetes opilio*) in the eastern Bering Sea—Putting together the pieces of the puzzle. *Bulletin of Marine Science*. 86(2): 413-437.

Rose, G. 2021. Research estimating unobserved mortality. Presentation to Crab Plan Team. See <https://meetings.npfmc.org/Meeting/Details/2913> for link to powerpoint and recordings.

Szuwalski, C.S., Cheng, W., Foy, R., Hermann, A.J., Hollowed, A., Holsman, K., Lee, J., Stockhausen, W., Zheng, J. 2021. Climate change and the future productivity and distribution of crab in the Bering Sea. 78(2): 502-515.

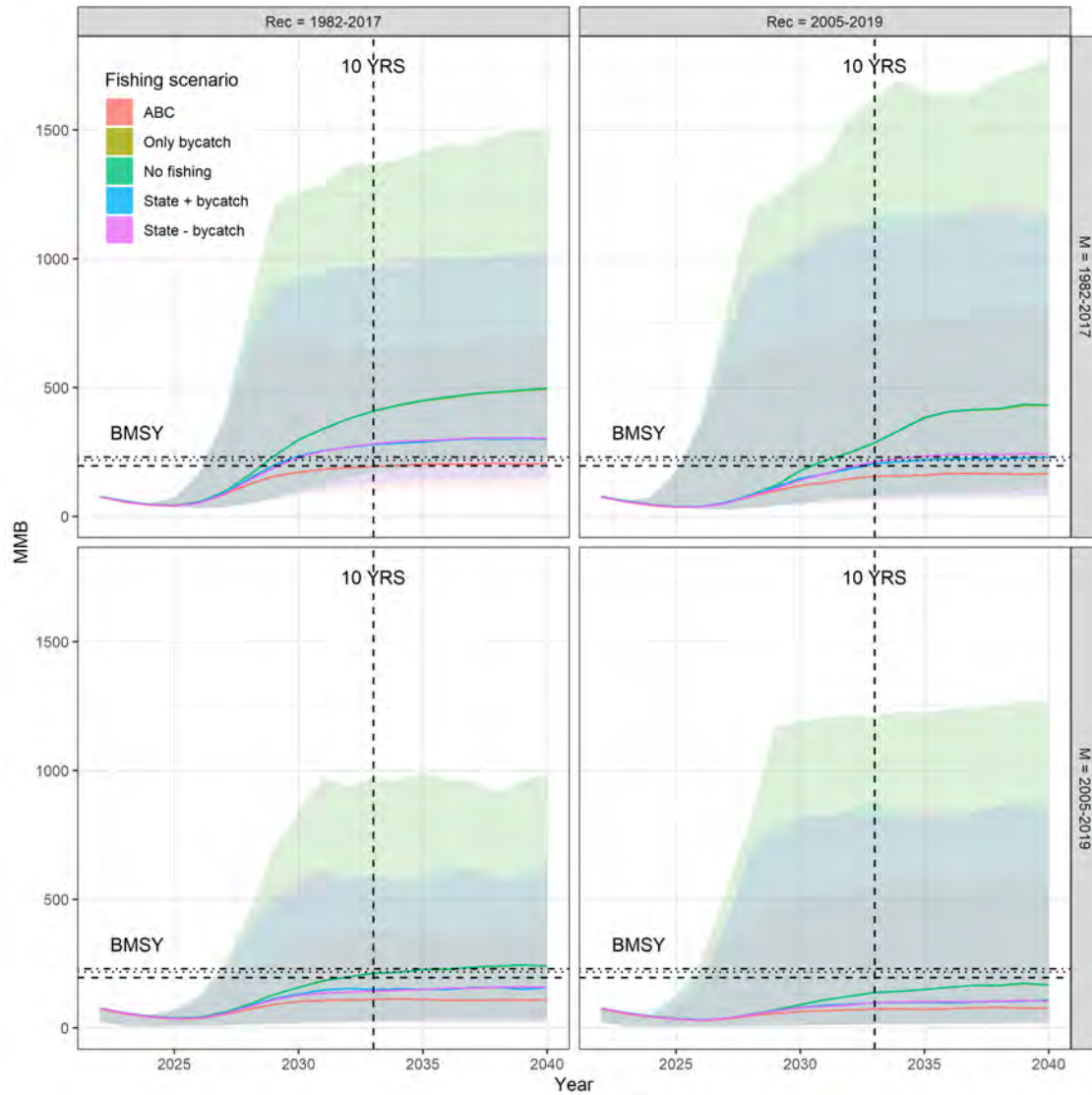


Figure 1: Projections of rebuilding trajectories under different productivity scenarios (recruitment and mortality), fishing strategies, and target biomasses (three horizontal lines corresponding to 1982-2021, 1982-2017, and 2005-2019, in ascending order). Bycatch time series are those used in the status quo assessment.

| <b>Fishing</b>         | <b>Recruitment</b>     | <b>Natural mortality</b> | <b>BMSY_sq</b> | <b>BMSY_17</b> | <b>BMSY_19</b> |
|------------------------|------------------------|--------------------------|----------------|----------------|----------------|
| <b>No fishing</b>      | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2029           | 2029           | 2029           |
| <b>No fishing</b>      | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | 2032           | 2035           | 2037           |
| <b>No fishing</b>      | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2031           | 2032           | 2032           |
| <b>No fishing</b>      | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
|                        |                        |                          |                |                |                |
| <b>ABC</b>             | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2034           | Inf            | Inf            |
| <b>ABC</b>             | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>ABC</b>             | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | Inf            | Inf            | Inf            |
| <b>ABC</b>             | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>bycatch</b>         | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2029           | 2029           | 2029           |
| <b>bycatch</b>         | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | 2032           | 2035           | 2037           |
| <b>bycatch</b>         | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2031           | 2032           | 2032           |
| <b>bycatch</b>         | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>State + bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2029           | 2030           | 2030           |
| <b>State + bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>State + bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2033           | 2035           | Inf            |
| <b>State + bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>State - bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2030           | 2030           | 2030           |
| <b>State - bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>State - bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2033           | 2034           | 2035           |
| <b>State - bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |

Figure 2: Table of time to rebuild under different productivity scenarios (recruitment and mortality), fishing strategies (fishing), and target biomasses (right three columns). BMSY\_sq uses recruitment from 1982-2021, BMSY.17 uses recruitment from 1982-2017, BMSY.19 uses recruitment from 2005-2019.

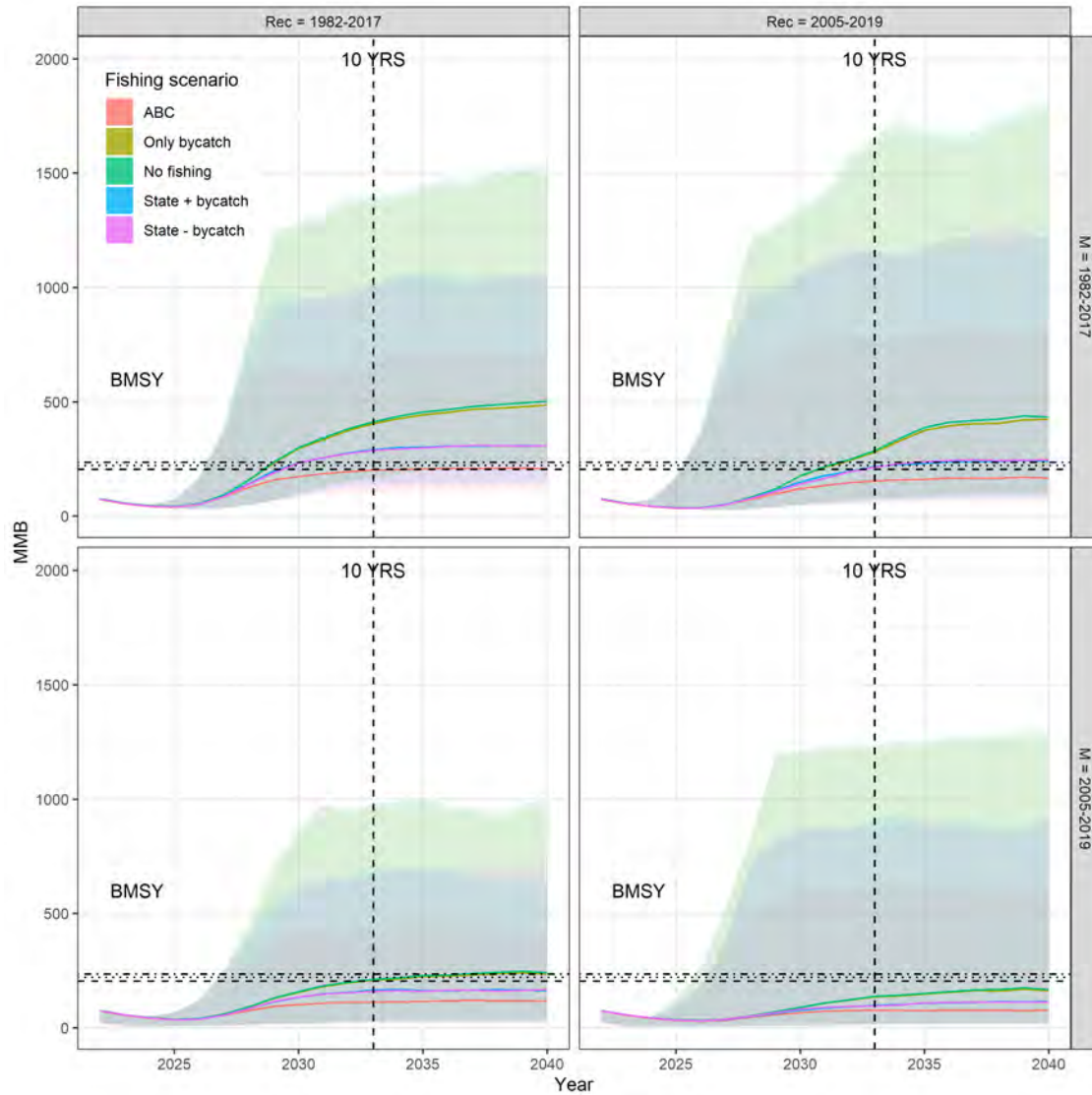


Figure 3: Projections of rebuilding trajectories under different productivity scenarios (recruitment and mortality), fishing strategies, and target biomasses (three horizontal lines corresponding to 1982-2021, 1982-2017, and 2005-2019, in ascending order). Bycatch time series are 5x those used in the status quo assessment.

| <b>Fishing</b>         | <b>Recruitment</b>     | <b>Natural mortality</b> | <b>BMSY_sq</b> | <b>BMSY_17</b> | <b>BMSY_19</b> |
|------------------------|------------------------|--------------------------|----------------|----------------|----------------|
| <b>No fishing</b>      | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2029           | 2029           | 2029           |
| <b>No fishing</b>      | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | 2033           | 2035           | 2037           |
| <b>No fishing</b>      | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2031           | 2032           | 2032           |
| <b>No fishing</b>      | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
|                        |                        |                          |                |                |                |
| <b>ABC</b>             | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2035           | Inf            | Inf            |
| <b>ABC</b>             | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>ABC</b>             | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | Inf            | Inf            | Inf            |
| <b>ABC</b>             | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>bycatch</b>         | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2029           | 2029           | 2030           |
| <b>bycatch</b>         | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | 2033           | 2035           | 2038           |
| <b>bycatch</b>         | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2031           | 2032           | 2032           |
| <b>bycatch</b>         | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>State + bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2030           | 2030           | 2031           |
| <b>State + bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>State + bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2033           | 2034           | 2036           |
| <b>State + bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>State - bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2030           | 2030           | 2031           |
| <b>State - bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>State - bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2033           | 2034           | 2035           |
| <b>State - bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |

Figure 4: Table of time to rebuild under different productivity scenarios (recruitment and mortality), fishing strategies (fishing), and target biomasses (right three columns). Bycatch time series are 5x those used in the status quo assessment. BMSY\_sq uses recruitment from 1982-2021, BMSY.17 uses recruitment from 1982-2017, BMSY.19 uses recruitment from 2005-2019.

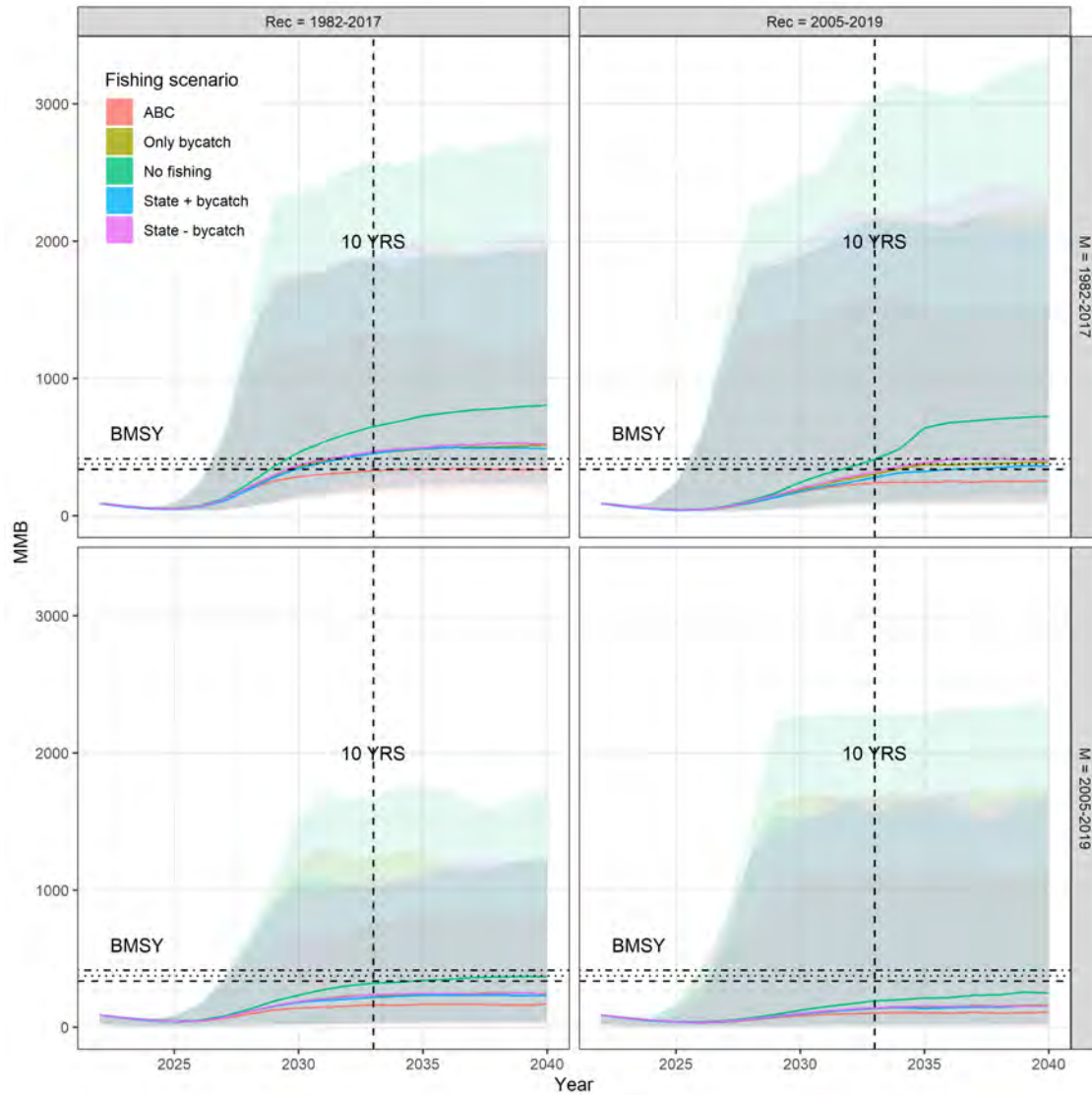


Figure 5: Projections of rebuilding trajectories under different productivity scenarios (recruitment and mortality), fishing strategies, and target biomasses (three horizontal lines corresponding to 1982-2021, 1982-2017, and 2005-2019, in ascending order). Bycatch time series are 100x those used in the status quo assessment.



| <b>Fishing</b>         | <b>Recruitment</b>     | <b>Natural mortality</b> | <b>BMSY_sq</b> | <b>BMSY_17</b> | <b>BMSY_19</b> |
|------------------------|------------------------|--------------------------|----------------|----------------|----------------|
| <b>No fishing</b>      | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2029           | 2030           | 2030           |
| <b>No fishing</b>      | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | 2035           | Inf            | Inf            |
| <b>No fishing</b>      | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2032           | 2033           | 2034           |
| <b>No fishing</b>      | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
|                        |                        |                          |                |                |                |
| <b>ABC</b>             | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2035           | Inf            | Inf            |
| <b>ABC</b>             | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>ABC</b>             | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | Inf            | Inf            | Inf            |
| <b>ABC</b>             | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>bycatch</b>         | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2030           | 2031           | 2032           |
| <b>bycatch</b>         | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>bycatch</b>         | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2034           | 2037           | Inf            |
| <b>bycatch</b>         | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>State + bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2030           | 2031           | 2032           |
| <b>State + bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>State + bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2036           | Inf            | Inf            |
| <b>State + bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>State - bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2030           | 2031           | 2032           |
| <b>State - bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>State - bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2034           | 2035           | Inf            |
| <b>State - bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |

Figure 6: Table of time to rebuild under different productivity scenarios (recruitment and mortality), fishing strategies (fishing), and target biomasses (right three columns). Bycatch time series are 100x those used in the status quo assessment. BMSY.sq uses recruitment from 1982-2021, BMSY.17 uses recruitment from 1982-2017, BMSY.19 uses recruitment from 2005-2019.

Table 1: Contribution to the objective function by individual likelihood component by modeling scenario.

| Component  | Fishery                                | 22.1a       | 22.1ab      | 22.1ab_100x | 22.1ab_5x   |
|------------|--|-------------|-------------|-------------|-------------|
| catch      | Retained                               | -8.8231     | -9.1501     | -16.8981    | -25.4244    |
| catch      | Discard (male)                         | 139.3299    | 122.0342    | 103.3297    | 88.7727     |
| catch      | Discard (female)                       | -69.6608    | -69.6607    | -69.661     | -69.6607    |
| catch      | Trawl                                  | -50.6439    | -50.6438    | -41.187     | -50.6248    |
| cpue       | NMFS survey (era 1; females)           | 43.9095     | 43.6293     | 40.457      | 43.6963     |
| cpue       | NMFS survey (era 2, females)           | -30.8034    | -31.2336    | -30.7698    | -29.3823    |
| cpue       | NMFS survey (era 1, males)             | 31.6677     | 29.7573     | 18.6982     | 27.8424     |
| cpue       | NMFS survey (era 2, males)             | 8.022       | -5.4007     | 21.7178     | -3.617      |
| cpue       | BSFRF 2009                             | -0.5799     | -0.6052     | -0.512      | -0.6105     |
| cpue       | BSFRF 2010                             | -1.9527     | -3.6876     | -3.93       | -3.0414     |
| growth_inc | 1                                      | 1021.2552   | 1016.8876   | 1015.4424   | 1018.2729   |
| growth_inc | 2                                      | 0           | 0           | 0           | 0           |
| rec_dev    | 1                                      | 0.7575      | 0.7575      | 0.7575      | 0.7575      |
| rec_dev    | 2                                      | 0           | 0           | 0           | 0           |
| rec_dev    | 3                                      | 89.1284     | 91.2242     | 92.4832     | 92.3561     |
| size_comp  | Retained males                         | -3701.8747  | -3699.7386  | -3713.192   | -3632.6982  |
| size_comp  | Survey mature females (1982-1988)      | -688.4905   | -688.4737   | -687.6832   | -688.553    |
| size_comp  | Survey mature females (1989-present)   | -3071.9284  | -3070.3273  | -3075.6692  | -3071.0868  |
| size_comp  | Survey mature males (1982-1988)        | -595.4243   | -596.1709   | -594.2792   | -594.2116   |
| size_comp  | Survey mature males (1989-present)     | -2741.4501  | -2721.3733  | -2718.848   | -2708.4459  |
| size_comp  | BSFRF 2009                             | -176.1576   | -176.4514   | -176.2182   | -175.8758   |
| size_comp  | NMFS 2009                              | -184.5963   | -184.6168   | -184.606    | -184.3002   |
| size_comp  | BSFRF 2010                             | -173.4927   | -173.4626   | -174.274    | -168.3816   |
| size_comp  | NMFS 2010                              | -170.3836   | -171.7761   | -171.2706   | -174.2002   |
| size_comp  | Total males                            | -2711.7745  | -2688.7734  | -2704.6184  | -2549.1906  |
| size_comp  | Discard females                        | -2282.6251  | -2282.1564  | -2289.3986  | -2284.9493  |
| size_comp  | Trawl bycatch (females)                | -2467.1116  | -2466.9757  | -2472.3342  | -2464.0533  |
| size_comp  | Trawl bycatch (male)                   | -2358.0865  | -2333.903   | -2293.4968  | -2336.6351  |
| size_comp  | Survey immature females (1982-1988)    | -623.0579   | -624.694    | -625.071    | -623.5216   |
| size_comp  | Survey immature females (1989-present) | -2876.5912  | -2878.3031  | -2876.8664  | -2888.0398  |
| size_comp  | Survey immature males (1982-1988)      | -577.3463   | -577.3848   | -582.7908   | -570.1027   |
| size_comp  | Survey immature males (1989-present)   | -2733.1505  | -2755.917   | -2749.2228  | -2753.6437  |
| Total      | Total                                  | -26961.9354 | -26956.5897 | -26959.9115 | -26778.5526 |

Table 2: 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 |
|---|-------------|--------|--------|------|------|-------|------|---------|--------|
| 1 | 21.sq       | 26.74  | 153.42 | 1.43 | 0.37 | 7.50  | 0.27 | 106.14  | 0.17   |
| 3 | 22.1a       | 41.21  | 183.15 | 1.50 | 0.32 | 10.32 | 0.28 | 164.02  | 0.23   |
| 4 | 22.1ab      | 96.67  | 196.38 | 2.26 | 0.67 | 3.98  | 0.29 | 180.36  | 0.49   |
| 5 | 22.1ab_5x   | 83.31  | 204.62 | 1.49 | 0.35 | 2.79  | 0.28 | 181.00  | 0.41   |
| 6 | 22.1ab_100x | 115.65 | 336.36 | 1.12 | 0.19 | 4.79  | 0.28 | 265.29  | 0.34   |

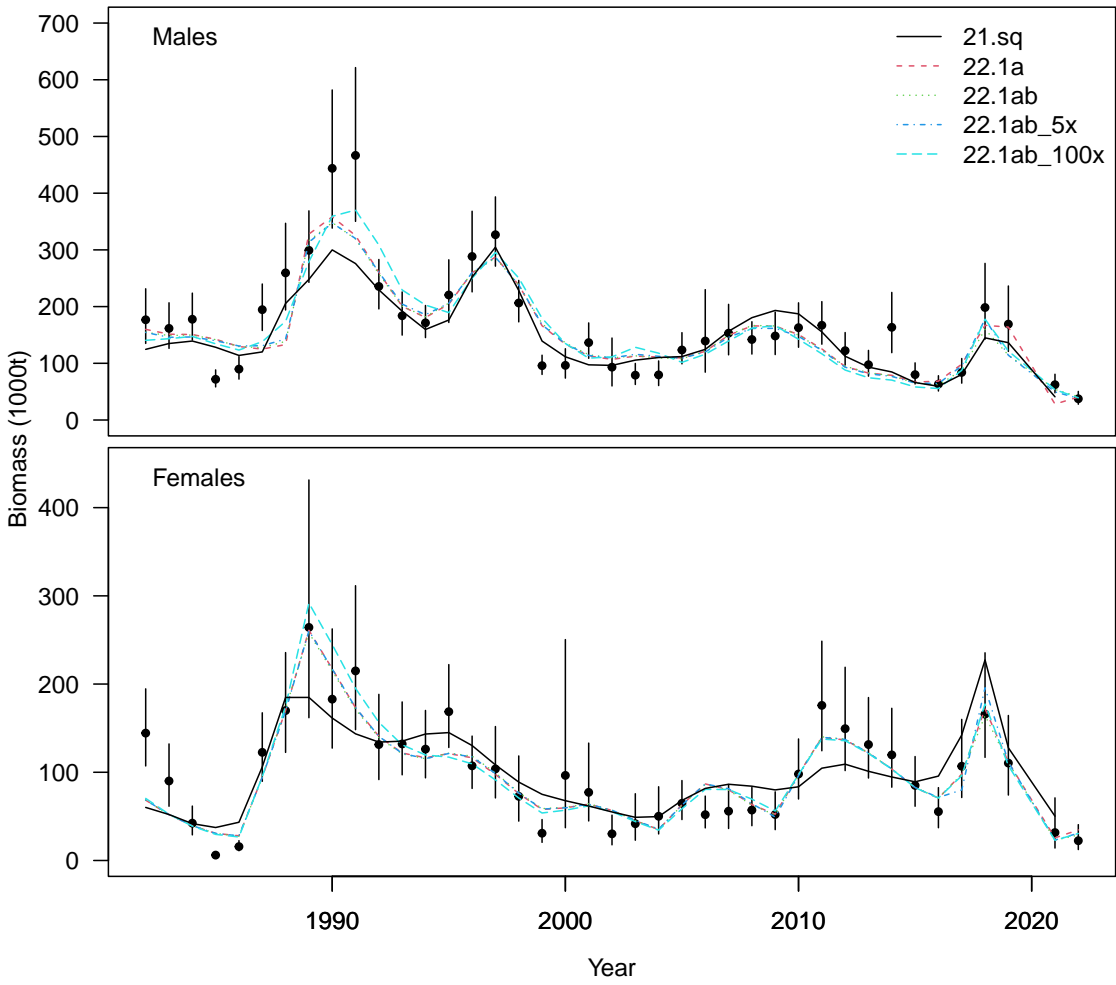


Figure 7: Model fits to the observed mature biomass at survey

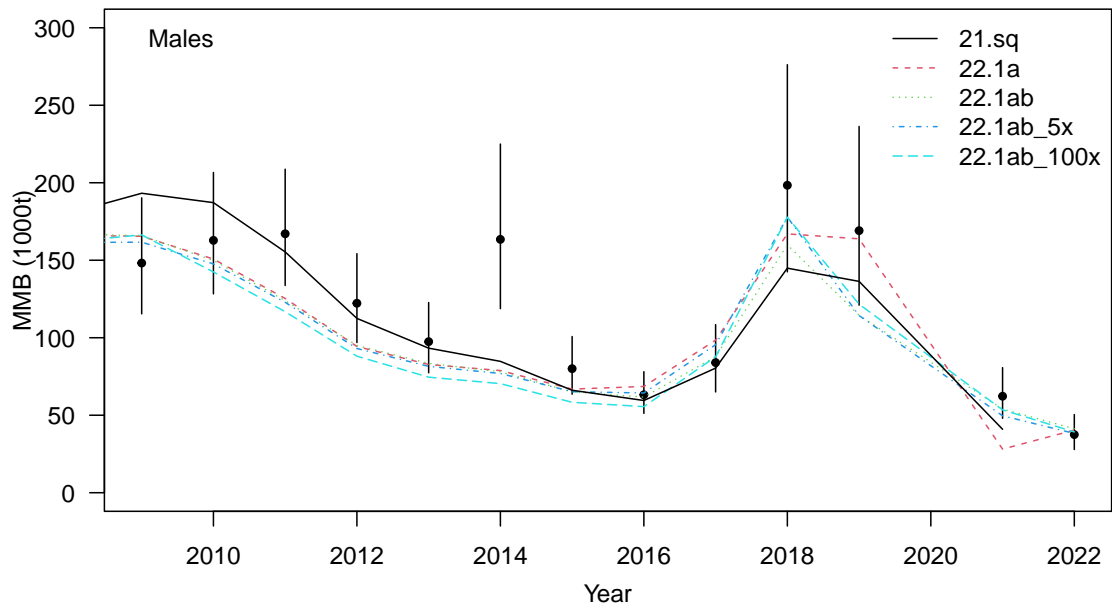


Figure 8: Model fits to the observed mature biomass at survey 2009-present

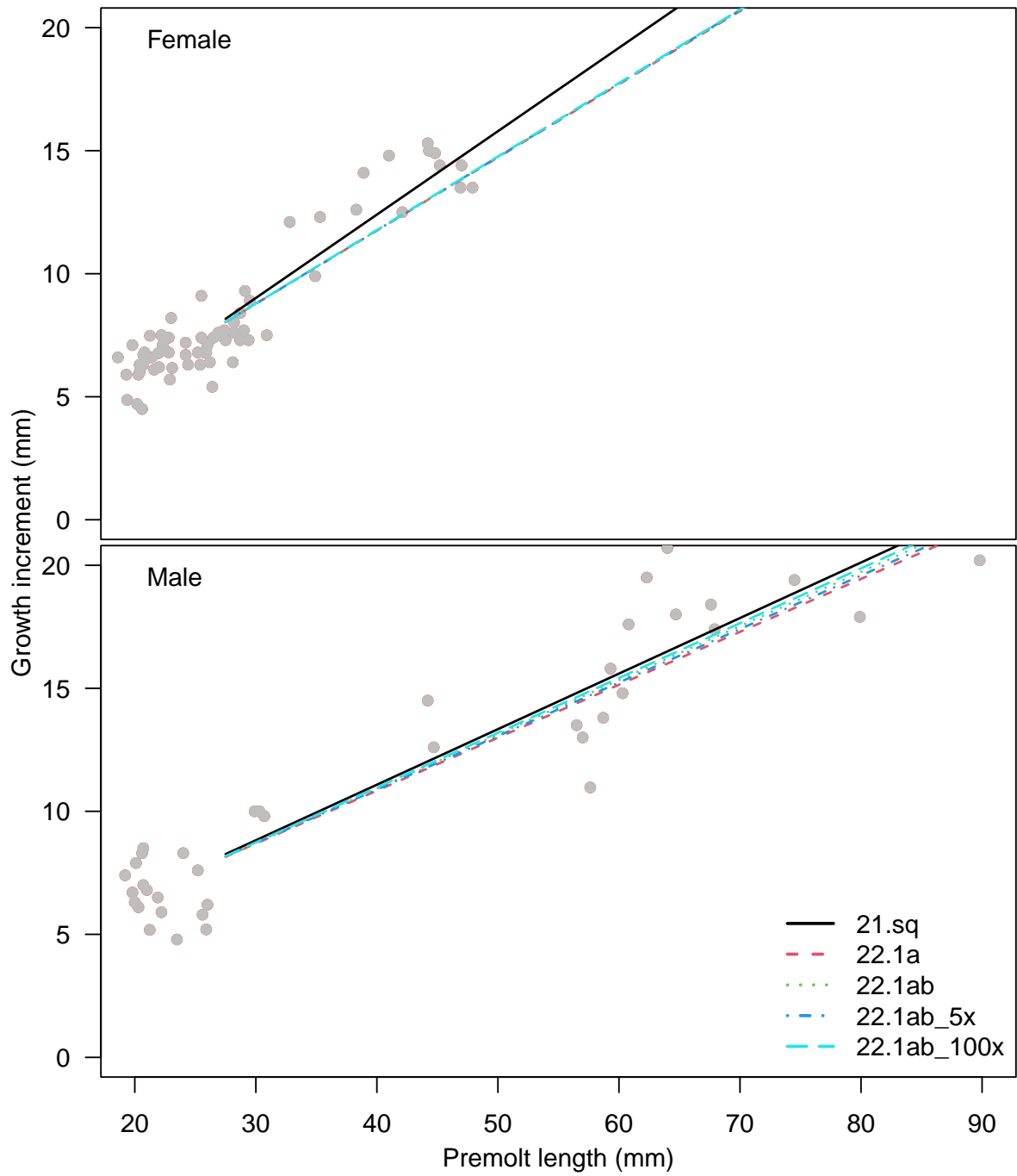


Figure 9: Model fits to the growth data

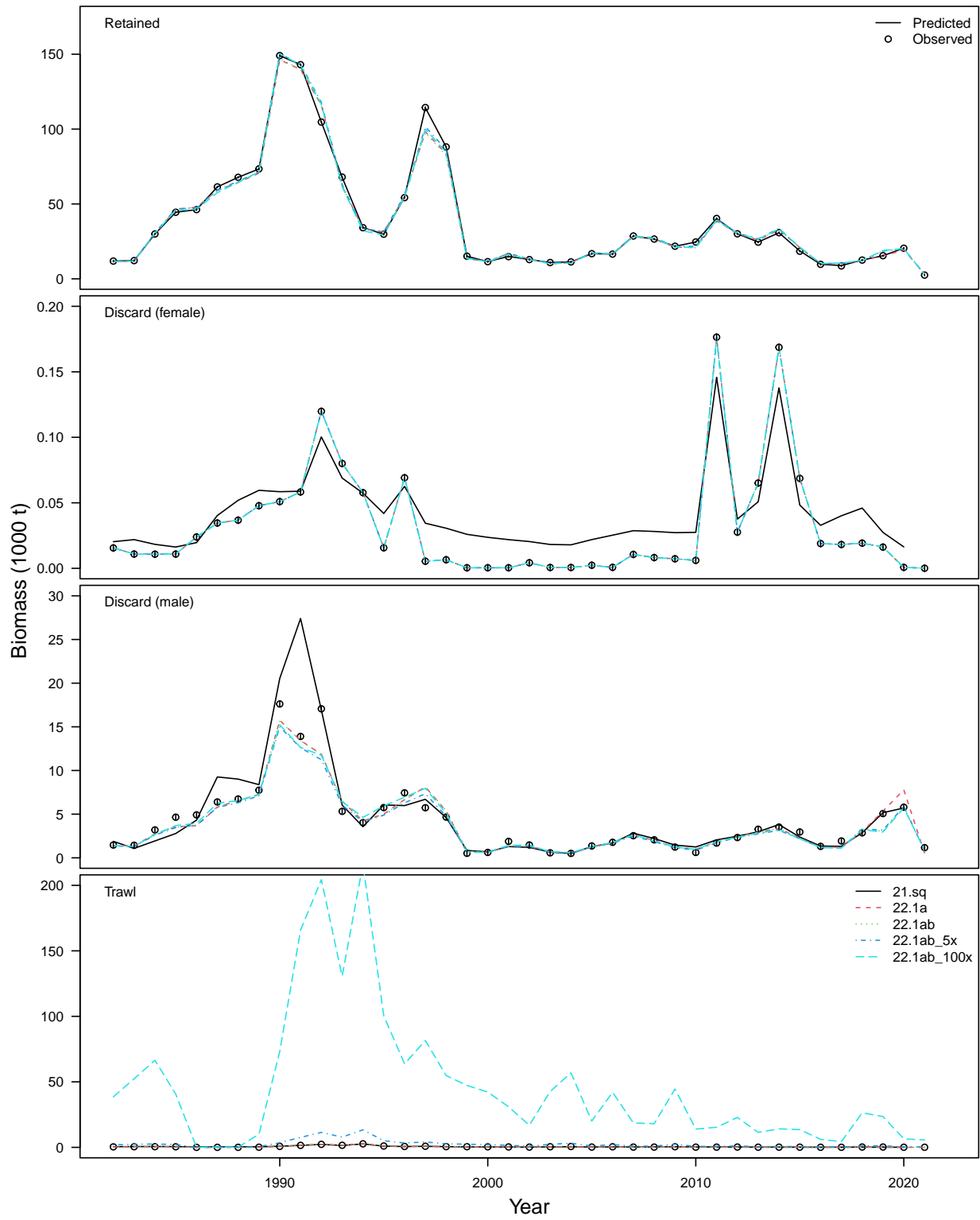


Figure 10: Model fits to catch data

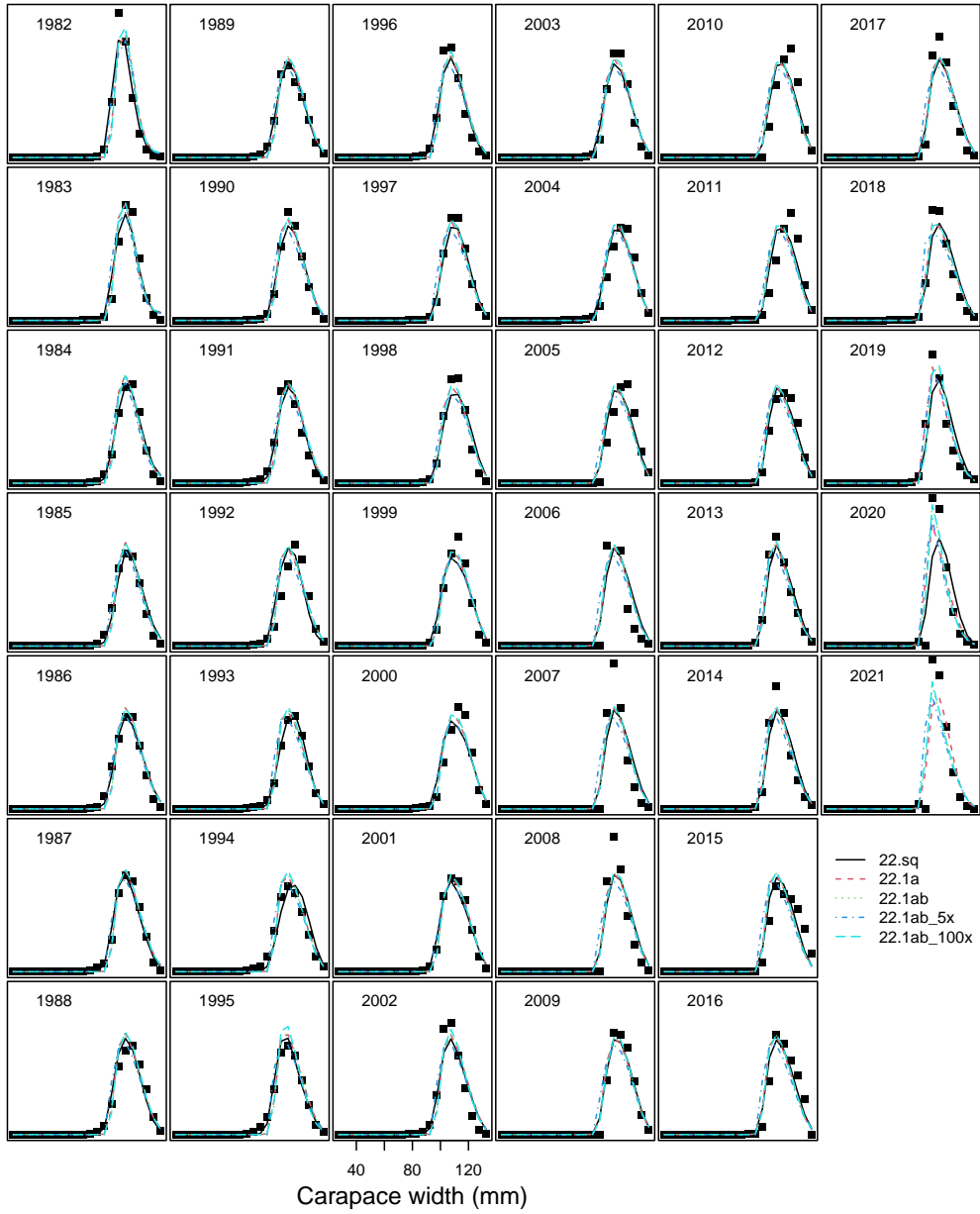


Figure 11: Model fits to retained catch size composition data



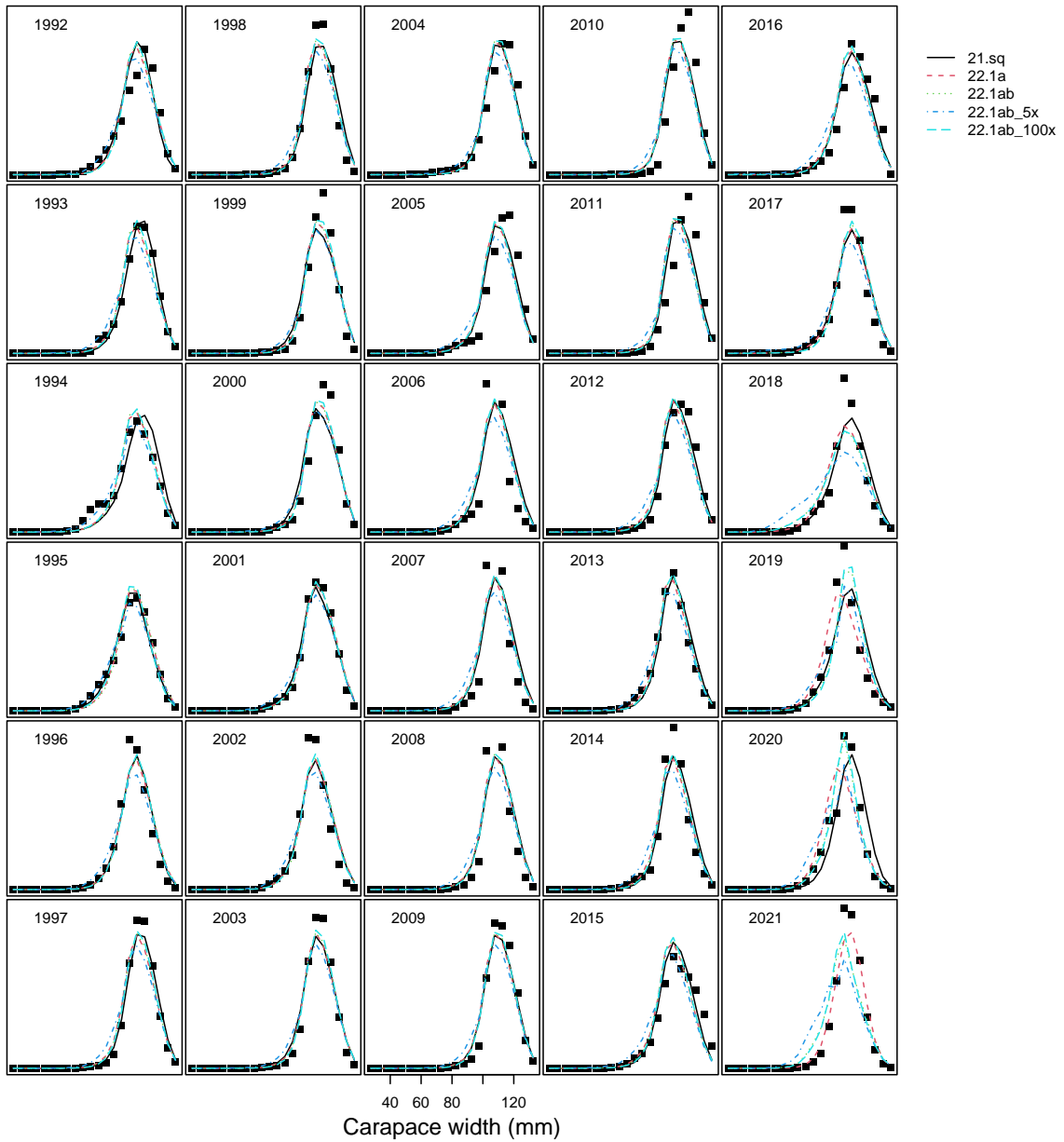


Figure 12: Model fits to total catch size composition data

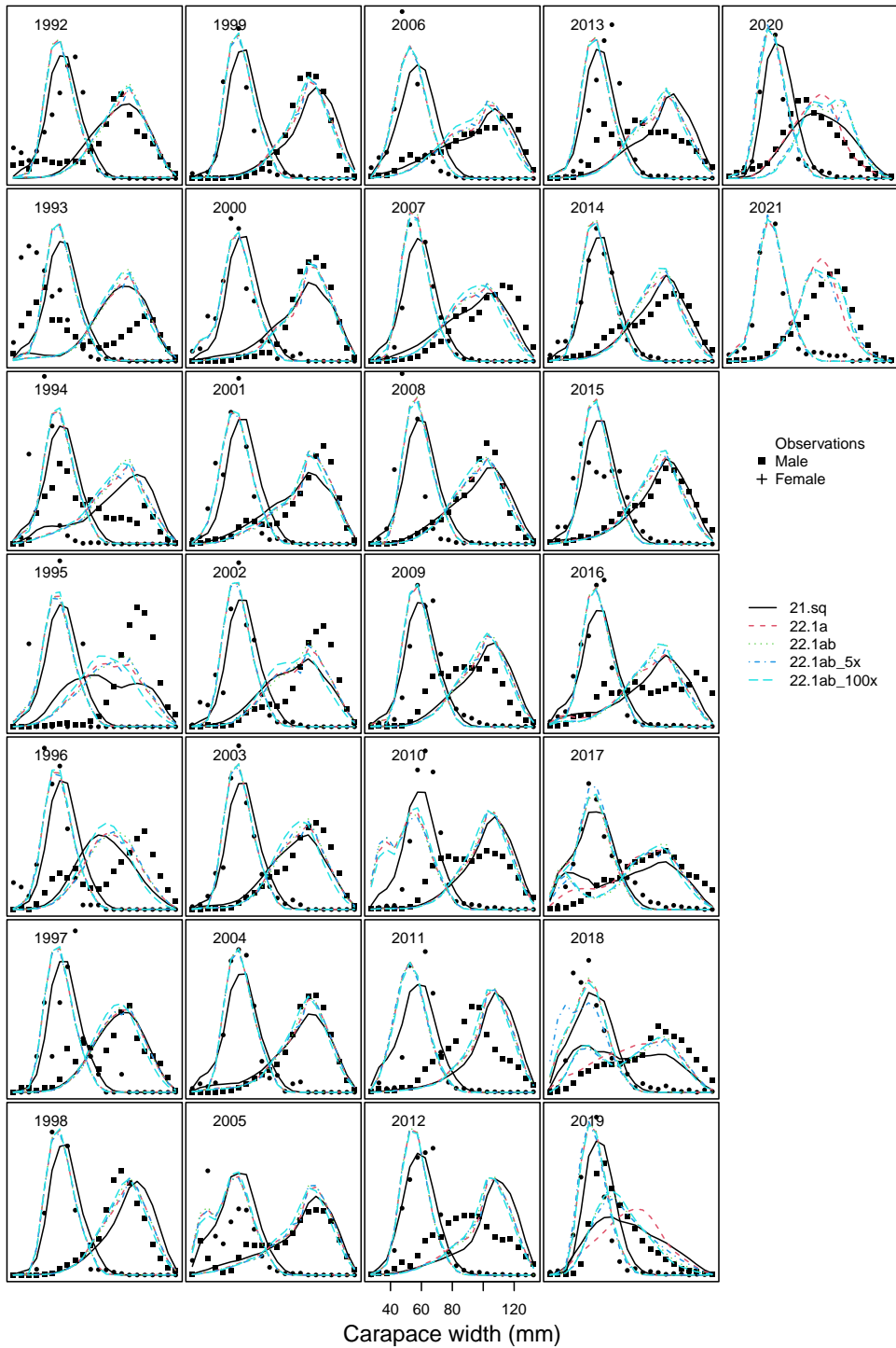


Figure 13: Model fits to trawl catch size composition data

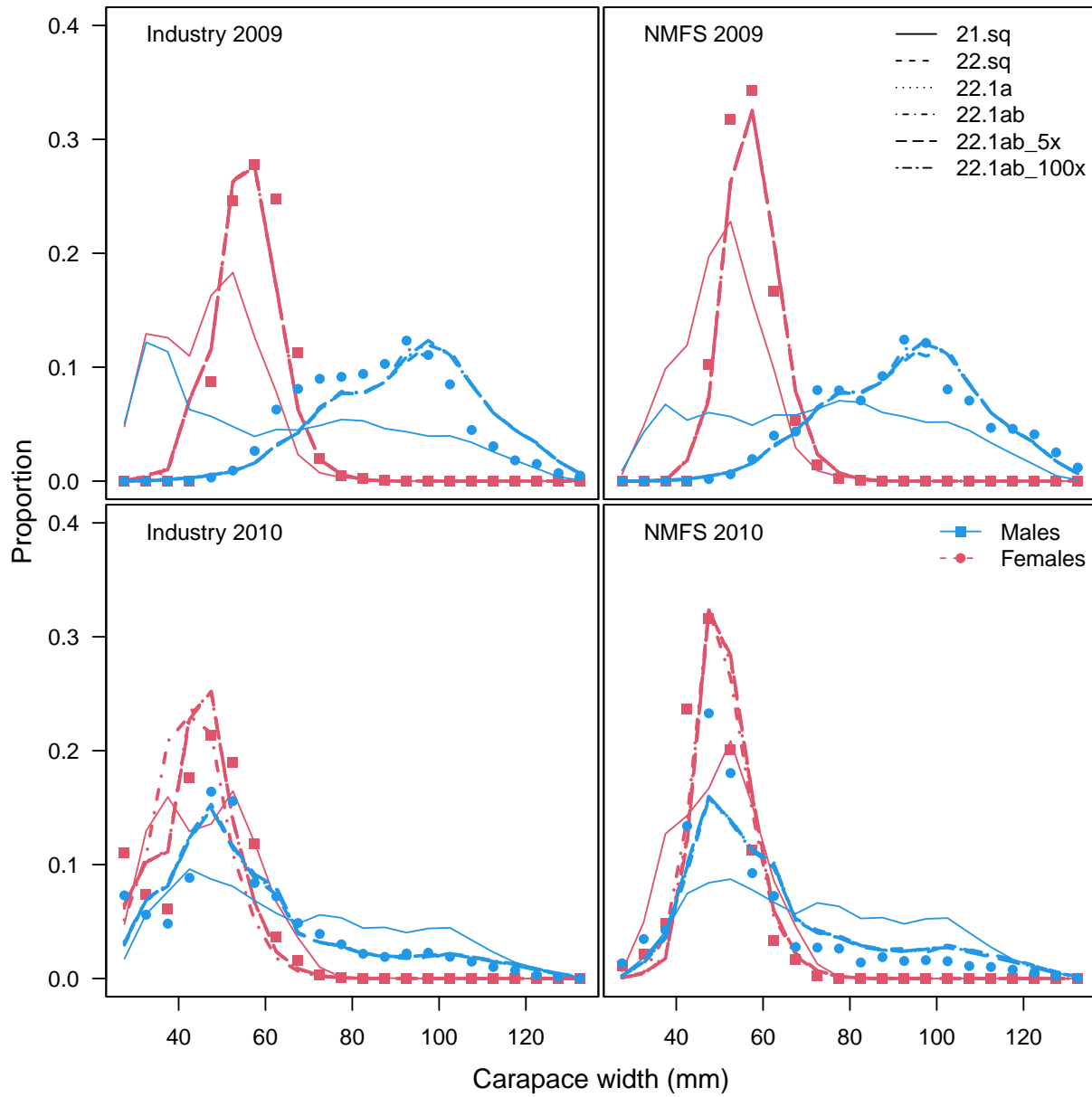


Figure 14: Model fits to size composition data from summer survey experiments (2009 & 2010)

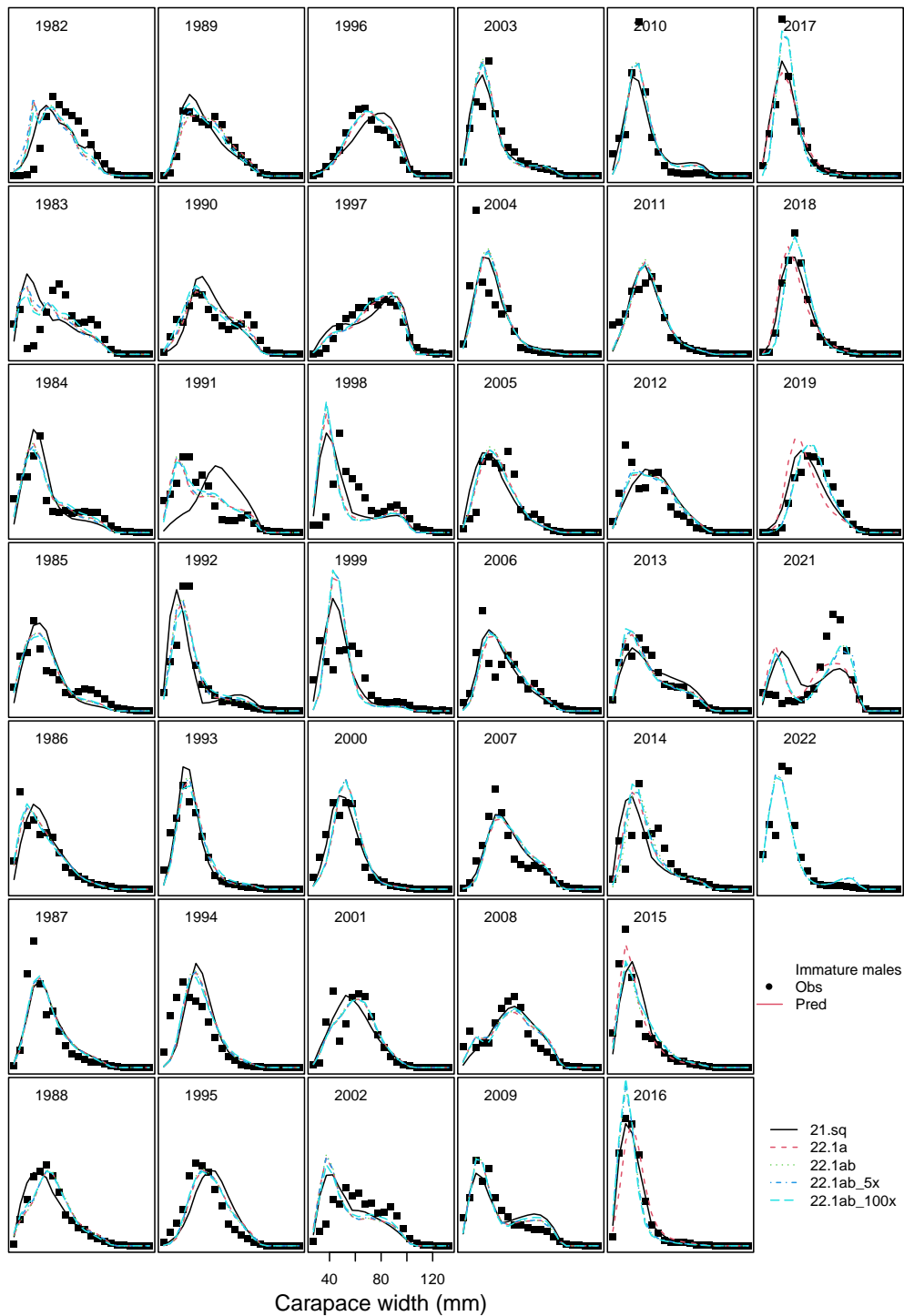


Figure 15: Model fits to immature male survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

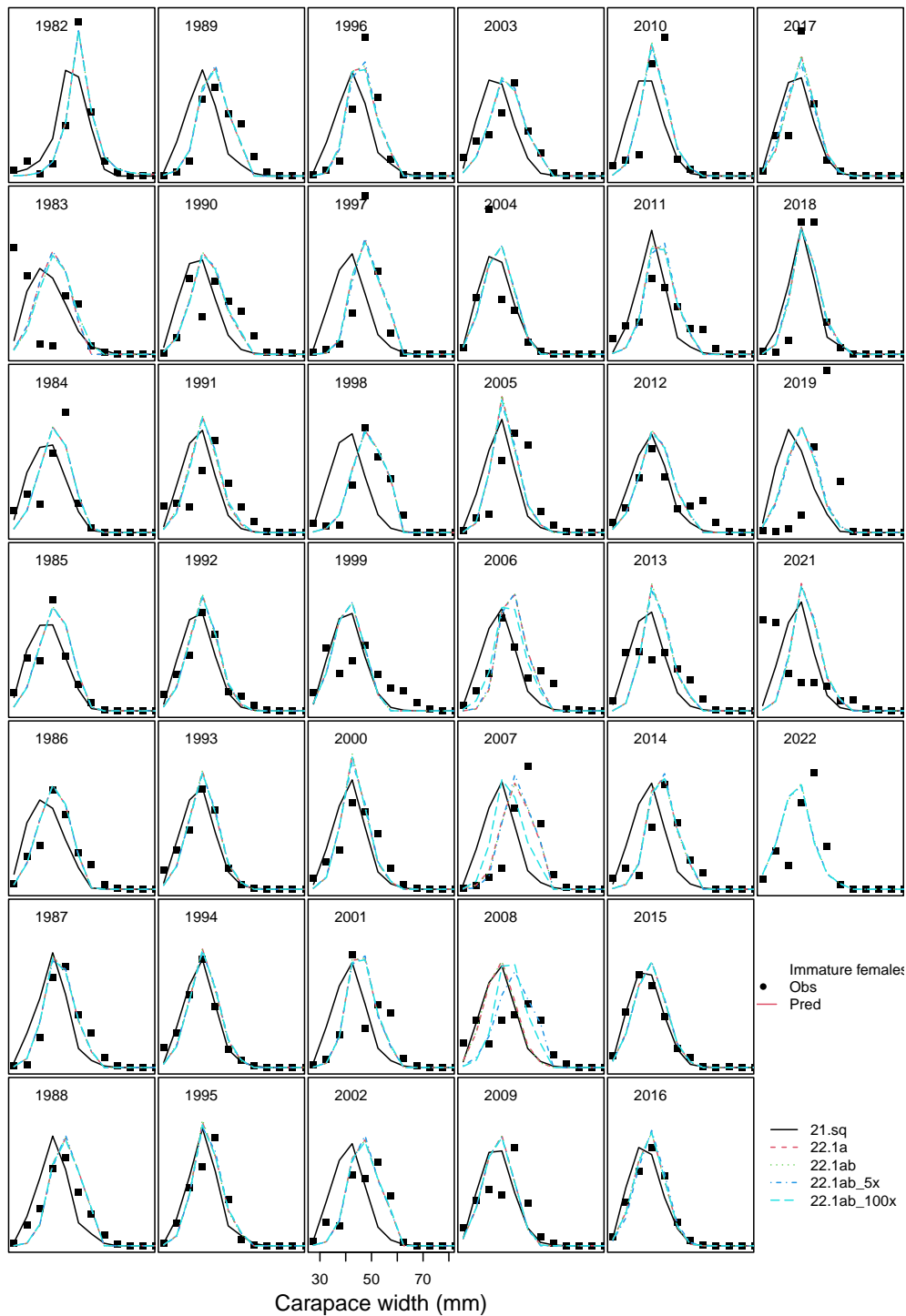


Figure 16: Model fits to immature female survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

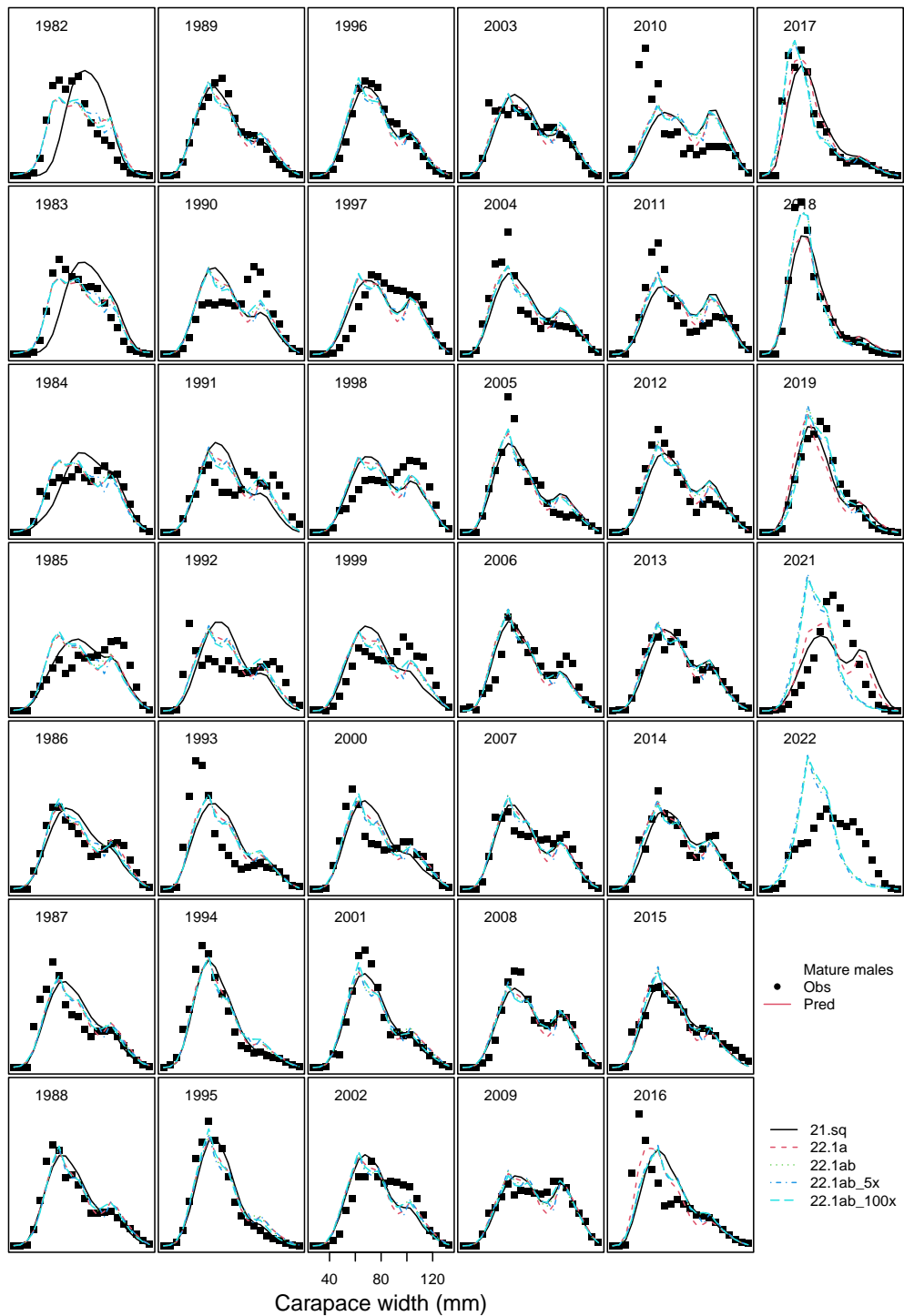


Figure 17: Model fits to mature male survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

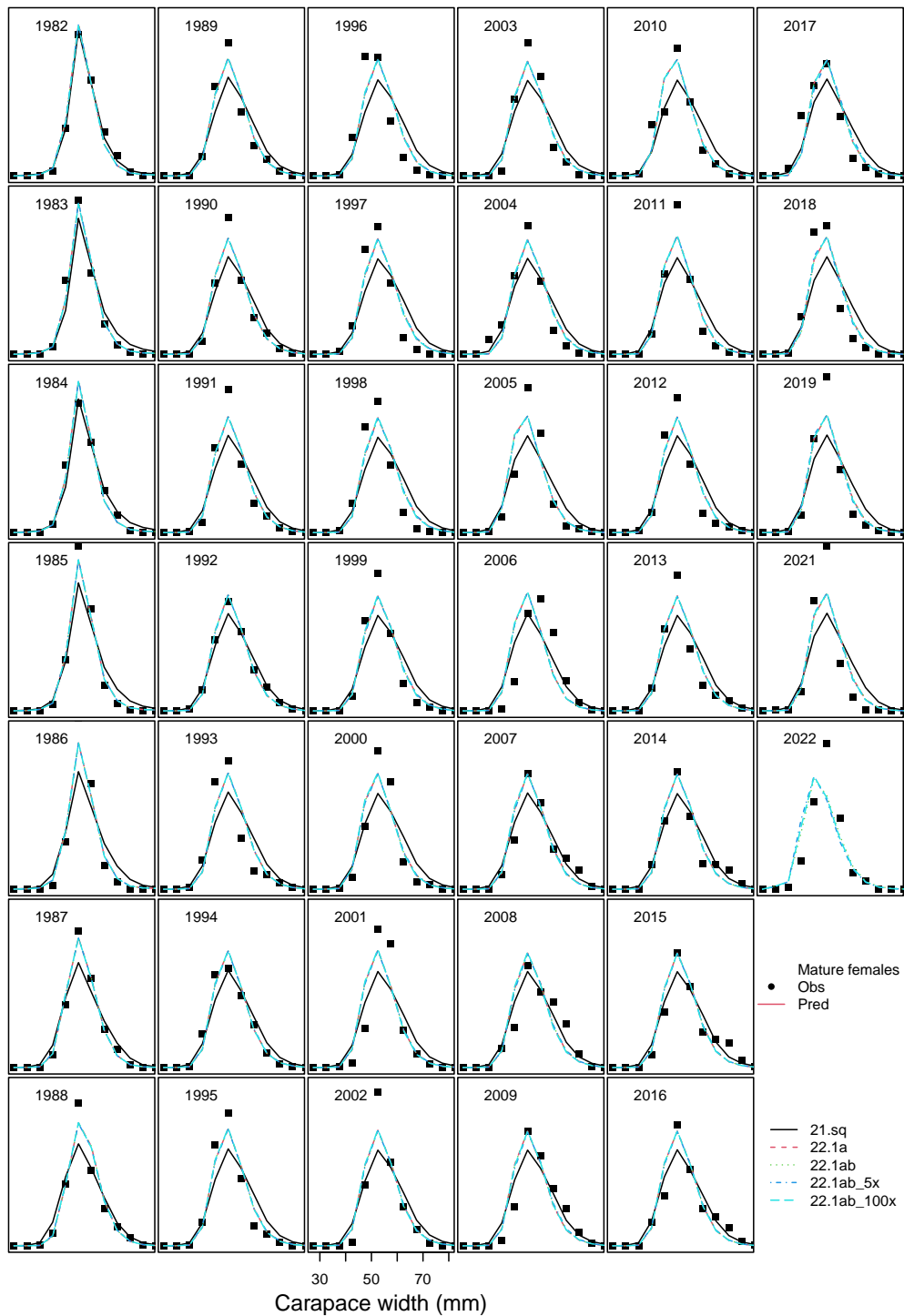


Figure 18: Model fits to mature female survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

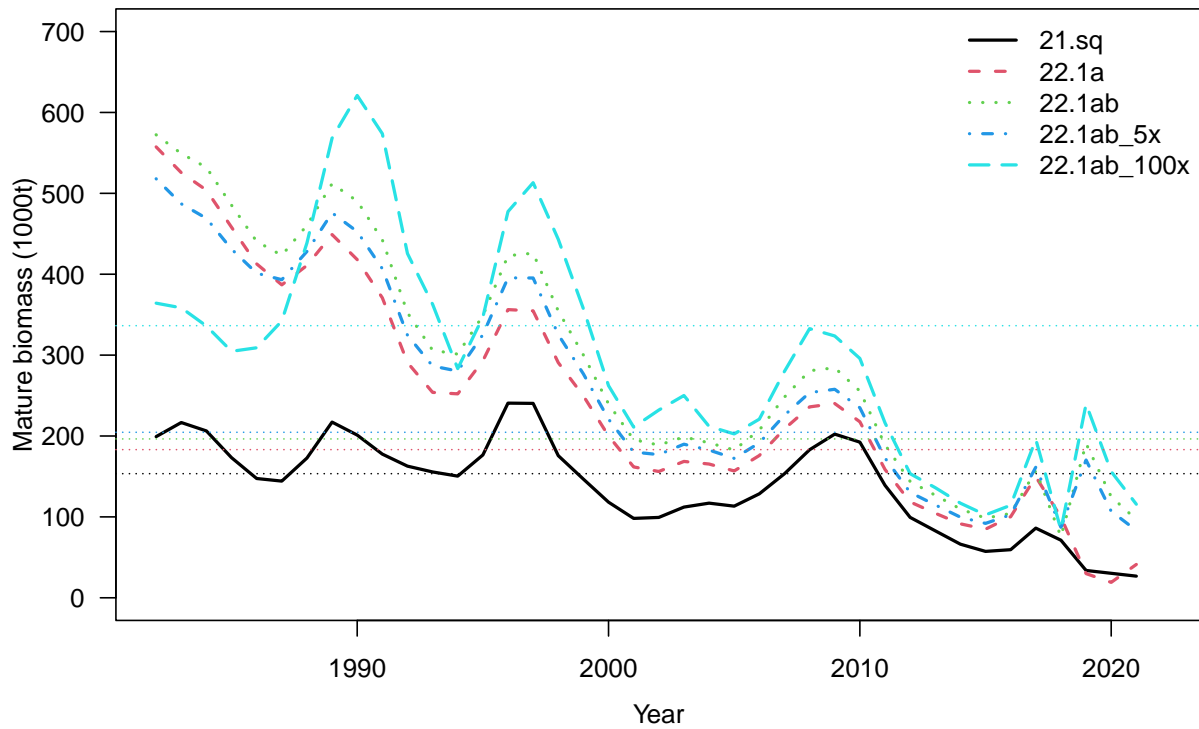


Figure 19: Model predicted mature biomass at mating time. Dotted horizontal lines are target biomasses.

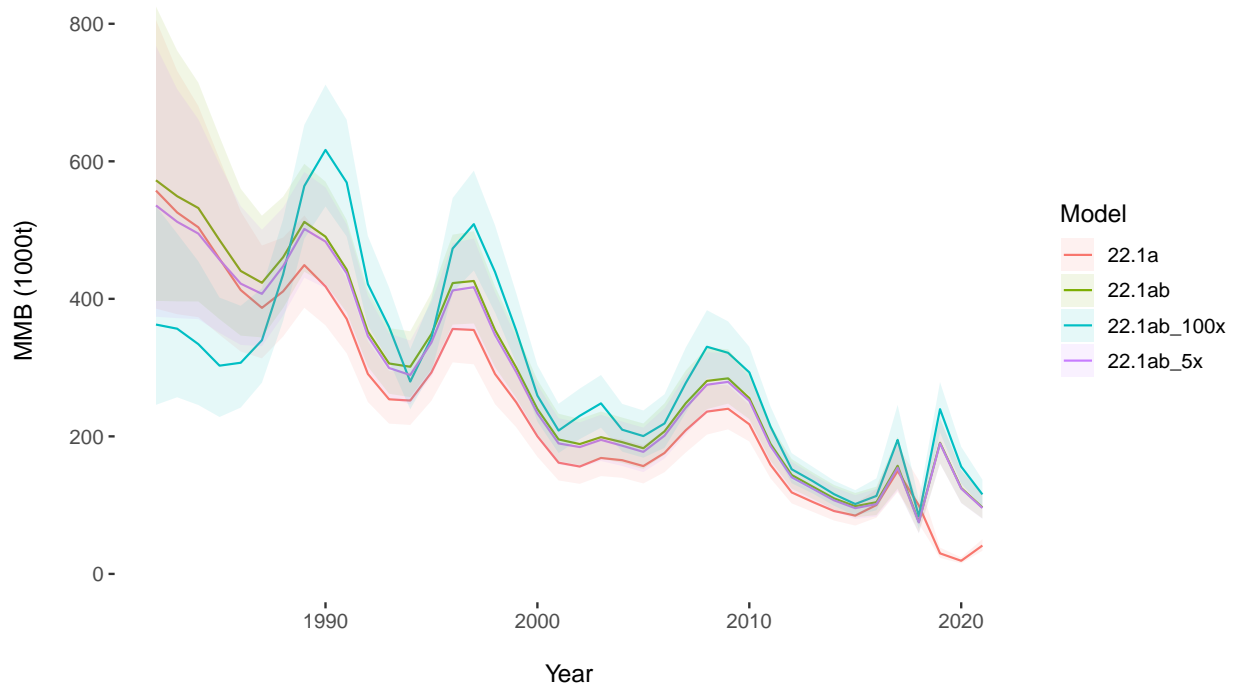


Figure 20: Trajectories of estimated MMB at the time of mating with 95% log-normal confidence intervals.



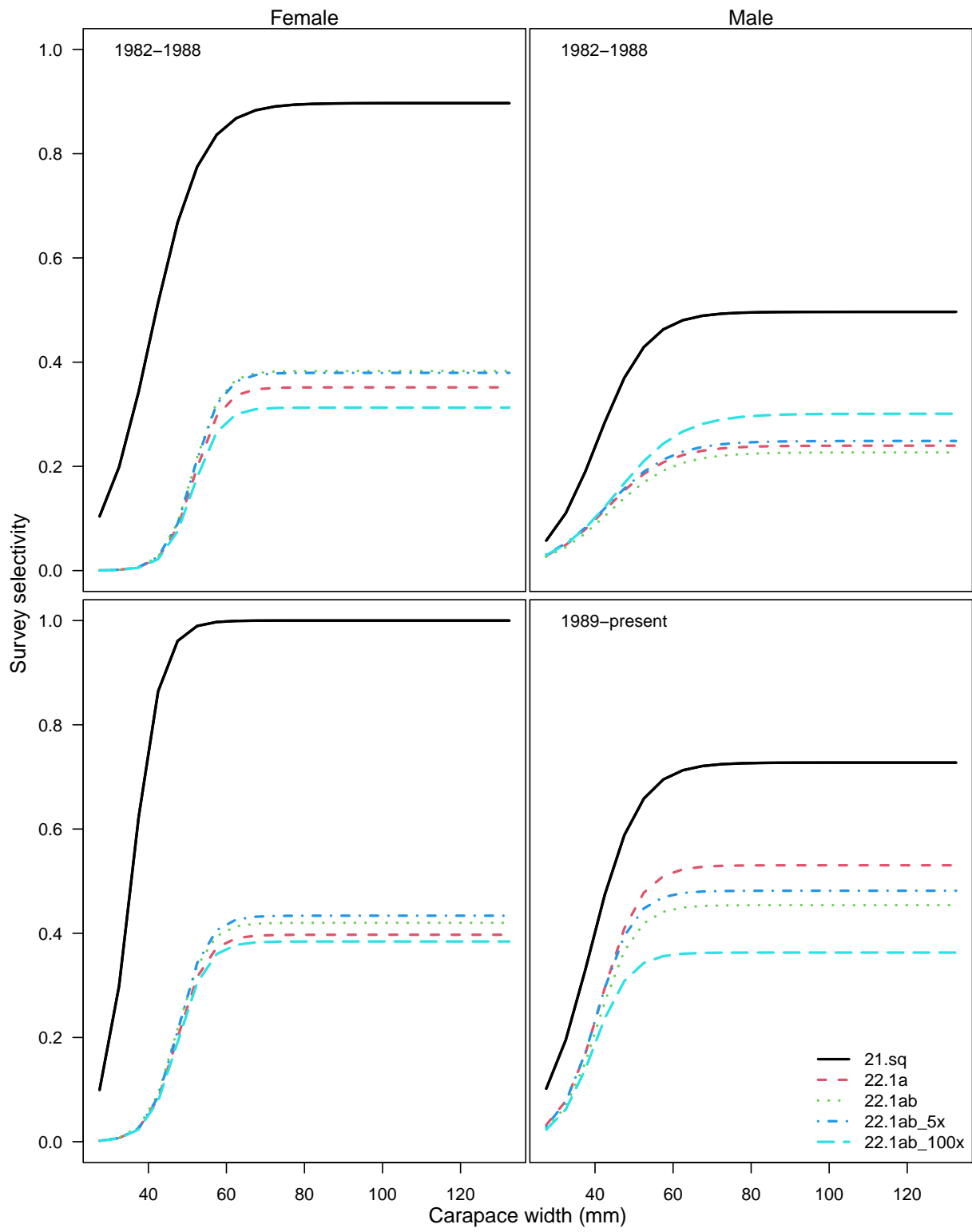


Figure 21: Estimated survey selectivity

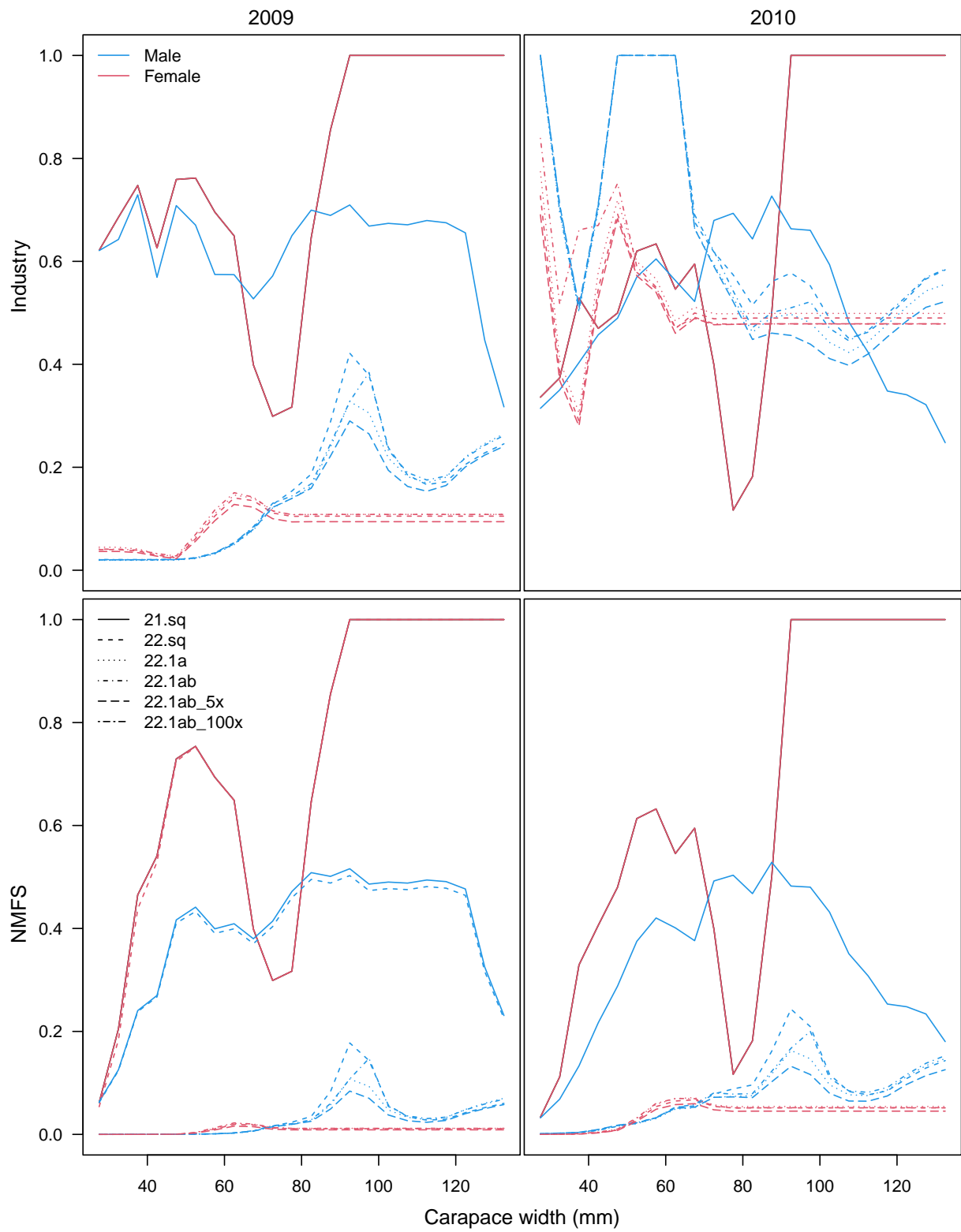


Figure 22: Estimated or specified availability (top row) and estimated experimental survey selectivity (availability \* survey selectivity; bottom row).

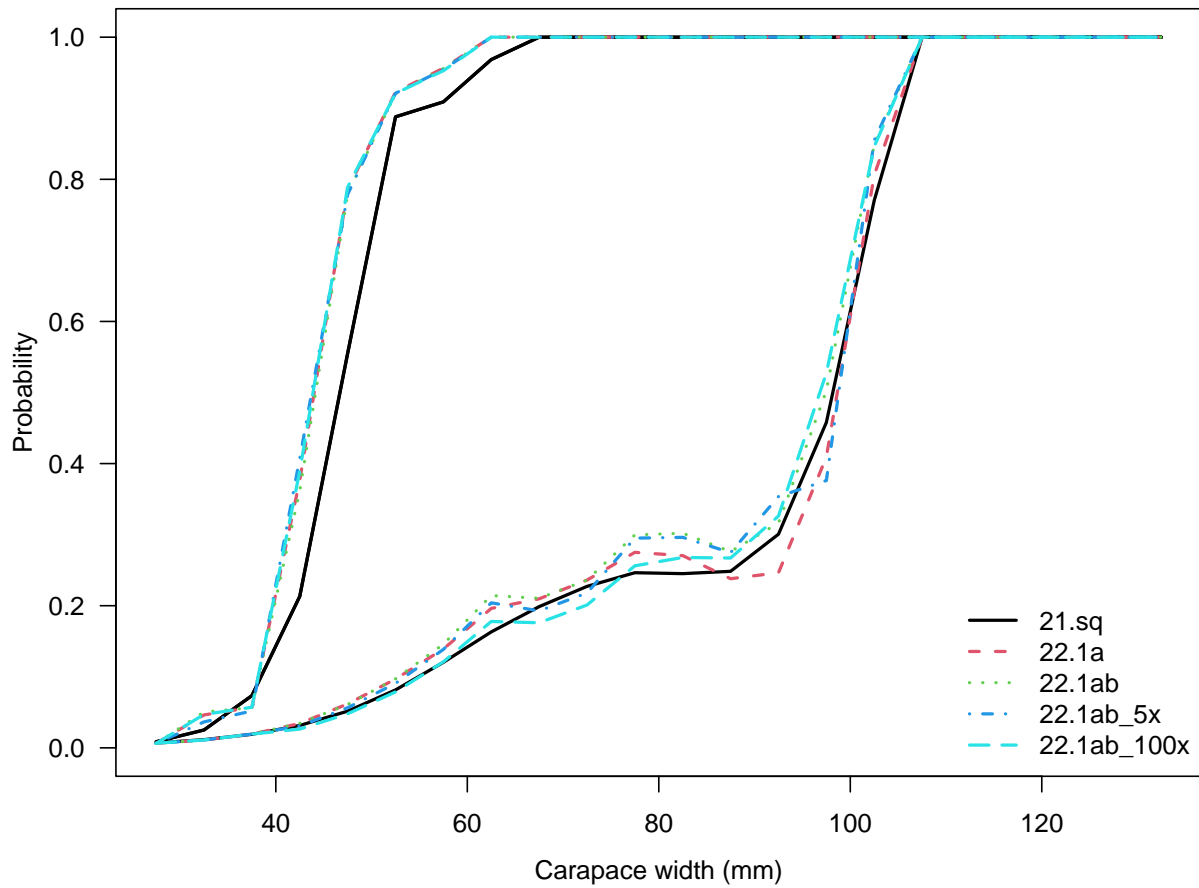


Figure 23: Estimated probability of maturing

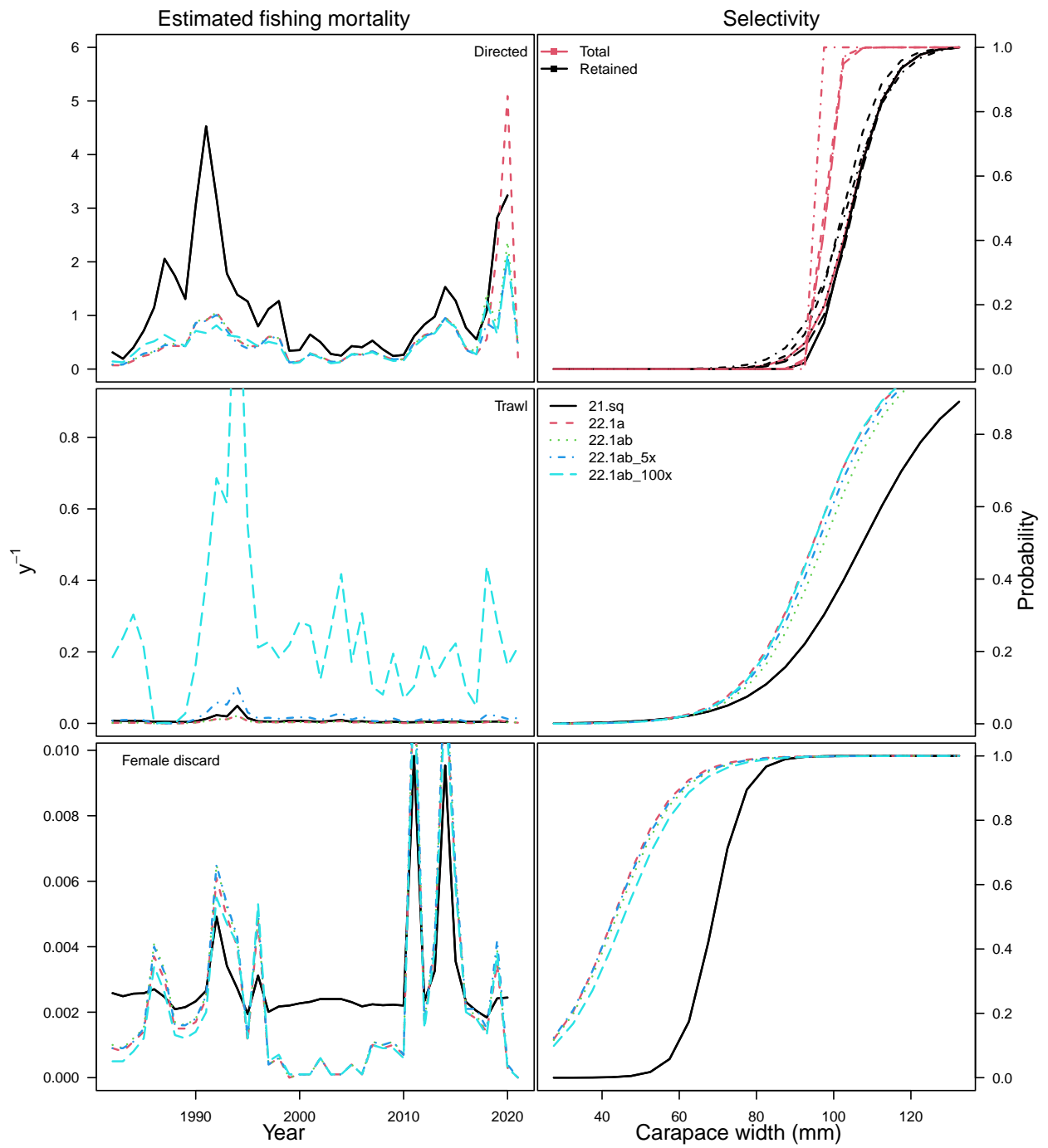


Figure 24: Model predicted fishing mortalities and selectivities for all sources of mortality

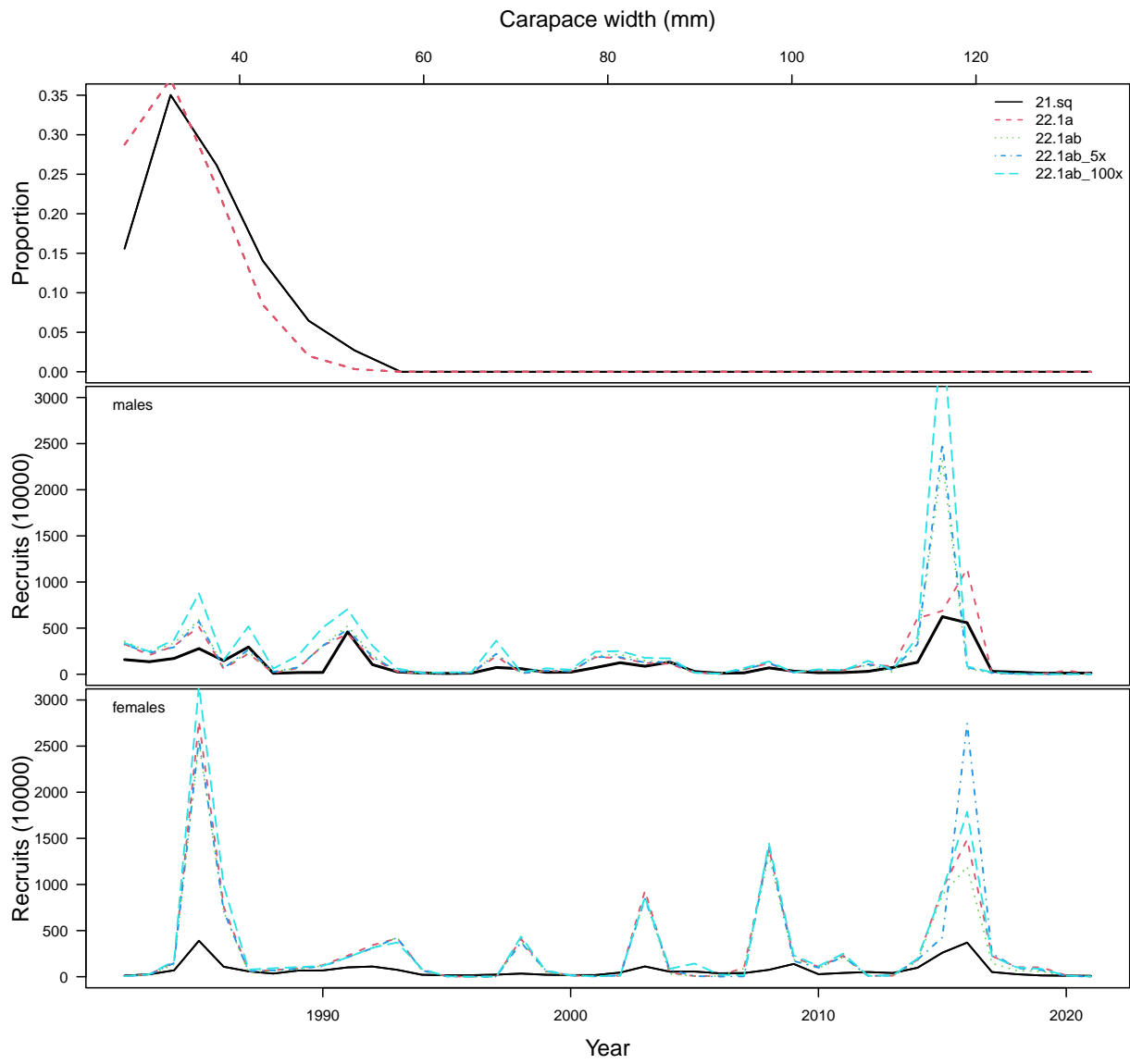


Figure 25: Estimated recruitment and proportions recruiting to length bin.

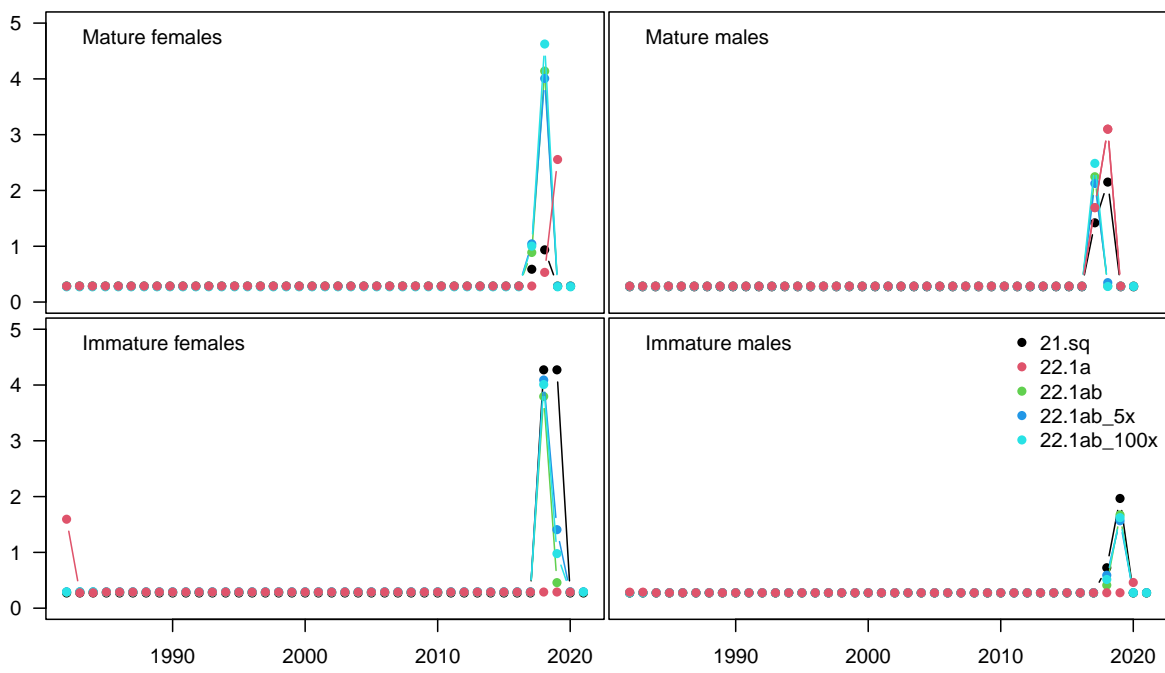


Figure 26: Estimated natural mortality by sex and maturity state.

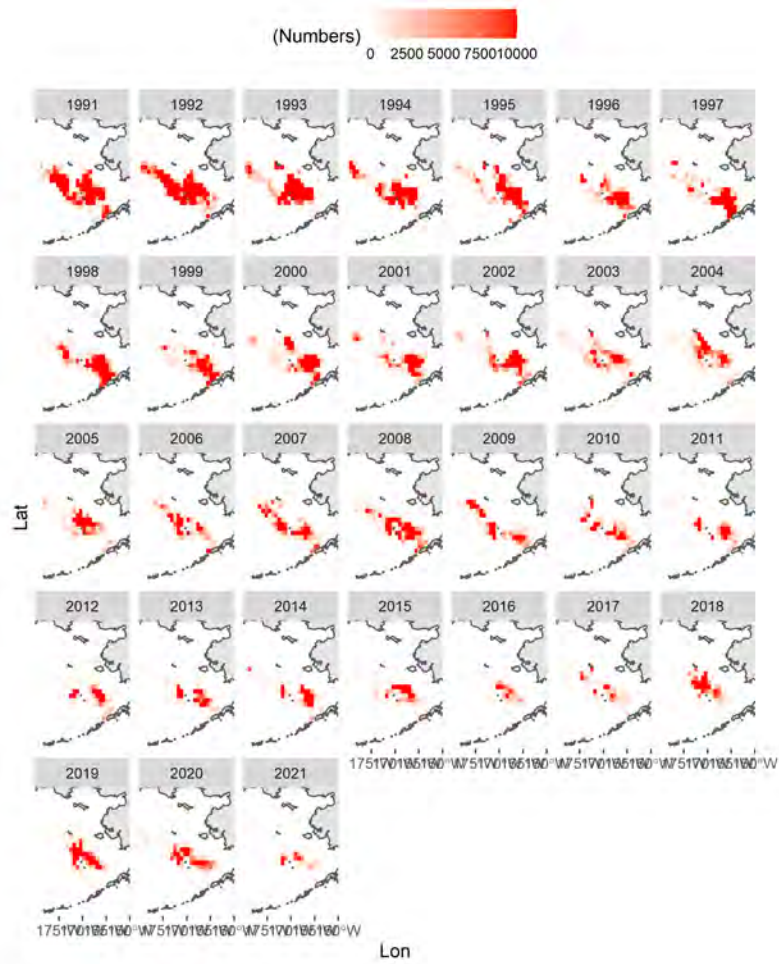


Figure 27: Spatial distribution of observer bycatch in non-directed fisheries over time.

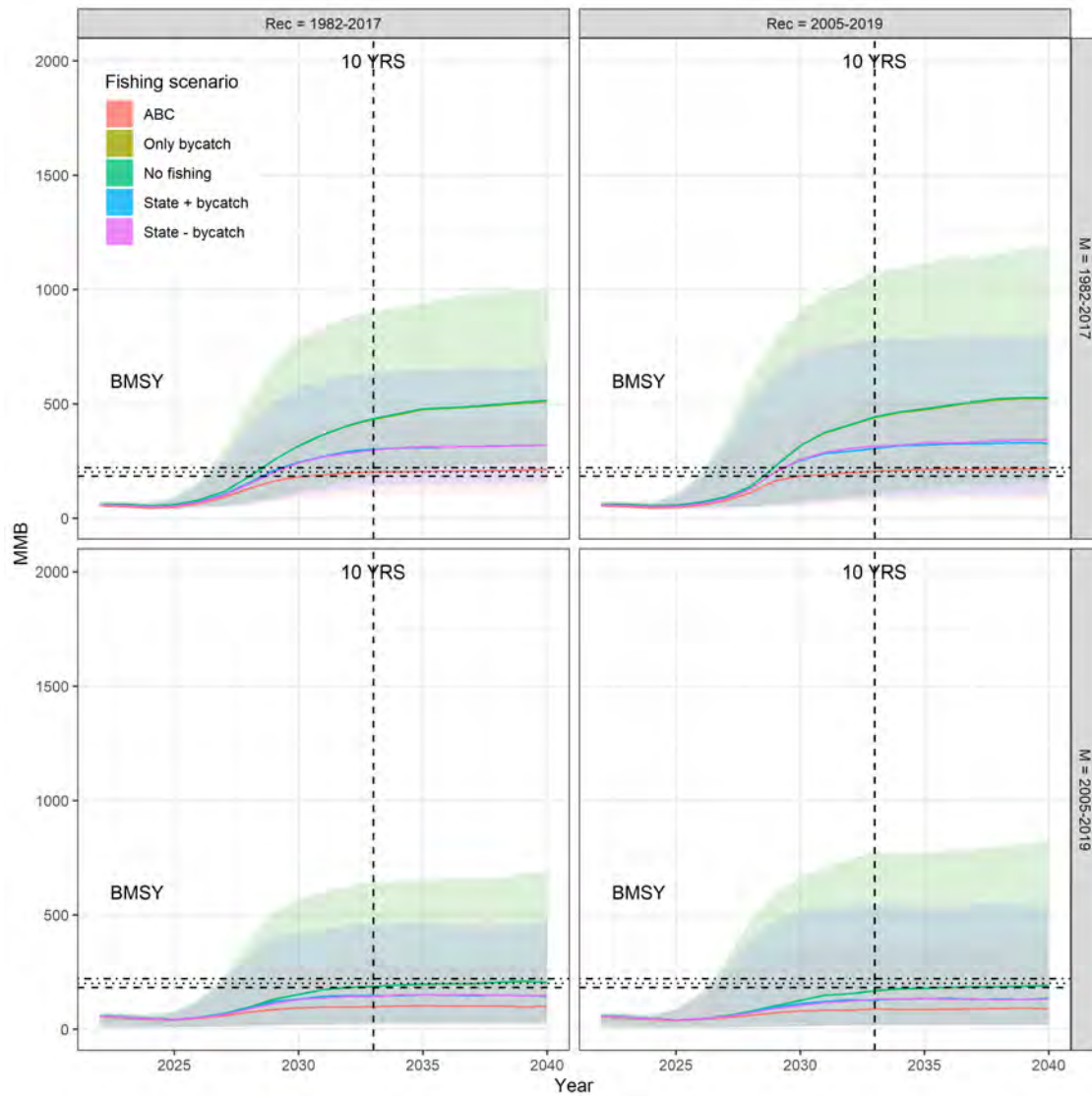


Figure 28: Projections of rebuilding trajectories under different productivity scenarios (recruitment and mortality), fishing strategies, and target biomasses (three horizontal lines corresponding to 1982-2021, 1982-2017, and 2005-2019, in ascending order). Bycatch time series are those used in the status quo assessment and the projection model used is based on the model output from model 22.1a (the CPT-selected model).



| <b>Fishing</b>         | <b>Recruitment</b>     | <b>Natural mortality</b> | <b>BMSY_sq</b> | <b>BMSY_17</b> | <b>BMSY_19</b> |
|------------------------|------------------------|--------------------------|----------------|----------------|----------------|
| <b>No fishing</b>      | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2029           | 2029           | 2029           |
| <b>No fishing</b>      | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | 2032           | 2038           | Inf            |
| <b>No fishing</b>      | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2029           | 2029           | 2029           |
| <b>No fishing</b>      | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | 2036           | Inf            | Inf            |
|                        |                        |                          |                |                |                |
| <b>ABC</b>             | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2031           | 2034           | Inf            |
| <b>ABC</b>             | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>ABC</b>             | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2031           | 2033           | Inf            |
| <b>ABC</b>             | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>bycatch</b>         | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2029           | 2029           | 2029           |
| <b>bycatch</b>         | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | 2032           | 2038           | Inf            |
| <b>bycatch</b>         | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2029           | 2029           | 2029           |
| <b>bycatch</b>         | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | 2036           | Inf            | Inf            |
| <b>State + bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2029           | 2029           | 2030           |
| <b>State + bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>State + bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2029           | 2030           | 2030           |
| <b>State + bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>State - bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 1982-2017</b>     | 2029           | 2030           | 2030           |
| <b>State - bycatch</b> | <b>Rec = 1982-2017</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |
| <b>State - bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 1982-2017</b>     | 2029           | 2030           | 2030           |
| <b>State - bycatch</b> | <b>Rec = 2005-2019</b> | <b>M = 2005-2019</b>     | Inf            | Inf            | Inf            |

Figure 29: Table of time to rebuild under different productivity scenarios (recruitment and mortality), fishing strategies (fishing), and target biomasses (right three columns). BMSY\_sq uses recruitment from 1982-2021, BMSY.17 uses recruitment from 1982-2017, BMSY.19 uses recruitment from 2005-2019. The underlying projection model is based on the model output from model 22.1a (the CPT-selected model)

# APPENDIX E

```

## ----- ##
LEADING PARAMETER CONTROLS          ##
Controls for leading parameter vector (theta)      ##
LEGEND          ##
prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma      ##"
----- ##
ntheta          ##
100##

lb  ub  phz  prior  p1  p2  # parameter  ##          ## ival
----- ##          ## ---
0.271  0.15  0.7  4  1  0.271  0.00454  # M (male)
0.271  0.15  0.7  4  1  0.271  0.00454  # M (female)
16.5   -10   20   -2  0 -10.0  20.0  # logR0
15.0   -10   30   -1  0  10.0  20.0  # logRini, to estimate if NOT initialized at unfished (n68)"
13.26245375 -10  30  1  0  10.0  20.0  # logRbar, to estimate if NOT initialized at unfished #1"
.5          7.5  42.5  -4  0  32.5  2.25  # recruitment expected value (males or combined)
1.0        0.1  10  -4  0  0.1  5.0  # recruitment scale (variance component) (males or combined)
0.0   -10  10  -4  0  0.0  20.00  # recruitment expected value (females)
0.00          -10  10  -3  0  0.0  20.0  # recruitment scale (variance component) (females)
-0.9          -10  0.75  -4  0 -10.0  0.75  # ln(sigma_R)
0.75        0.20  1.00  -2  3  3.0  2.00  # steepness
0.01        0.0001  1.00  -3  3  1.01  1.01  # recruitment autocorrelation
0.0   -10  25  1  0  10.0  20.00  # Deviation for size-class 1 # mature males      (normalization class)
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 2
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 3
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 4
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 5
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 6
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 7
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 8
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 9
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 10
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 11
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 12
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 13
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 14
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 15
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 16
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 17
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 18
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 19
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 20
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 21
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 22
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 1
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 2 # immature males
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 3
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 4
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 5
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 6
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 7
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 8
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 9
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 10
0.0   -20  25  1  0  10.0  20.00  # Deviation for size-class 11

```



```

# Proportion legal by sex
0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
## ----- ##
## ----- ##
## ----- ##
## GROWTH PARAMETER CONTROLS                                ##
##   Two lines for each parameter if split sex, one line if not   ##"
##   Currently if growth parameters change, moltin gprobabilities also must" ##
## ----- ##
# Use growth transition matrix option (1=read in growth-increment matrix; 2=read in size-transition; 3=gamma distribution for size-
increment; 4=gamma distribution for size after increment)
4
# growth increment model (1=alpha/beta; 2=estimated by size-class;3=pre-specified/emprical)
1
# molt probability function (0=pre-specified; 1=flat;2=declining logistic; 3=free parameters)
3
# Maximum size-class for recruitment(males then females)
6 6
## number of size-increment periods
1 1
## Year(s) size-incremnt period changes (blank if no changes)

## number of molt periods
1 1
## Year(s) molt period changes (blank if no changes)

## Beta parameters are relative (1=Yes;0=no)
0
## ----- ##
## ival  lb  ub  phz  prior  p1  p2  # parameter  ##
## ----- ##
##9.1989 0 50 -33 0 0.999 # Males
##11.0586 0 50 -33 0 0.999 # Males
##11.8828 0 50 -33 0 0.999 # Males
##12.7004 0 50 -33 0 0.999 # Males
##13.5179 0 50 -33 0 0.999 # Males
##14.3355 0 50 -33 0 0.999 # Males
##15.153 0 50 -33 0 0.999 # Males
##15.9705 0 50 -33 0 0.999 # Males
##16.7881 0 50 -33 0 0.999 # Males
##17.6056 0 50 -33 0 0.999 # Males
##18.4231 0 50 -33 0 0.999 # Males
##19.241 0 50 -33 0 0.999 # Males
##20.058 0 50 -33 0 0.999 # Males
##20.876 0 50 -33 0 0.999 # Males
##21.693 0 50 -33 0 0.999 # Males
##22.511 0 50 -33 0 0.999 # Males
##23.328 0 50 -33 0 0.999 # Males
##24.146 0 50 -33 0 0.999 # Males
##24.963 0 50 -33 0 0.999 # Males
##25.781 0 50 -33 0 0.999 # Males
##26.599 0 50 -33 0 0.999 # Males
##27.416 0 50 -33 0 0.999 # Males
##0.75 0.5 3 -6 0 0 999 # Males (beta)
##8.1092 0 50 -33 0 0.999 # Females
##9.7081 0 50 -33 0 0.999 # Females
##11.0191 0 50 -33 0 0.999 # Females
##11.0098 0 50 -33 0 0.999 # Females
##11.0098 0 50 -33 0 0.999 # Females
##11.0098 0 50 -33 0 0.999 # Females
##11.0098 0 50 -33 0 0.999 # Females

```





```

## 2.00E-11 4.19E-08 1.95E-05 0.000884949 0.0228838 0.250005 0.641455 0.0847513 5.08E-07 0 0 0 0 0 0 0 0 0 0
## 0 3.61E-10 2.84E-07 1.93E-05 0.000884949 0.0228838 0.250005 0.641455 0.0847513 5.08E-07 0 0 0 0 0 0 0 0 0 0
## 0 0 3.05E-09 2.81E-07 1.93E-05 0.00088495 0.0228838 0.250005 0.641455 0.0847513 5.08E-07 0 0 0 0 0 0 0 0 0 0
## 0 0 0 3.00E-09 2.81E-07 1.93E-05 0.00088495 0.0228838 0.250005 0.641455 0.0847512 5.08E-07 0 0 0 0 0 0 0 0 0 0
## 0 0 0 0 3.00E-09 2.81E-07 1.93E-05 0.00088495 0.0228838 0.250005 0.641455 0.0847512 5.08E-07 0 0 0 0 0 0 0 0 0 0
## 0 0 0 0 0 3.00E-09 2.81E-07 1.93E-05 0.00088495 0.0228838 0.250005 0.641455 0.0847512 5.08E-07 0 0 0 0 0 0 0 0 0 0
## 0 0 0 0 0 0 3.00E-09 2.81E-07 1.93E-05 0.00088495 0.0228838 0.250005 0.641455 0.0847511 5.08E-07 0 0 0 0 0 0 0 0 0 0
## 0 0 0 0 0 0 0 3.00E-09 2.81E-07 1.93E-05 0.00088495 0.0228838 0.250005 0.641455 0.0847511 5.08E-07 0 0 0 0 0 0 0 0 0 0
## 0 0 0 0 0 0 0 0 3.00E-09 2.81E-07 1.93E-05 0.00088495 0.0228839 0.250005 0.641455 0.0847527 5.09E-07 0 0 0 0 0 0 0 0 0 0
## 0 0 0 0 0 0 0 0 0 3.00E-09 2.81E-07 1.93E-05 0.00088495 0.0228839 0.250005 0.641467 0.0848278 5.21E-07 0 0 0 0 0 0 0 0 0 0
## 0 0 0 0 0 0 0 0 0 0 3.00E-09 2.81E-07 1.93E-05 0.00088495 0.0228839 0.25001 0.642036 0.0868162 7.00E-07 0 0 0 0 0 0 0 0 0 0
## 0 0 0 0 0 0 0 0 0 0 0 3.00E-09 2.81E-07 1.93E-05 0.00088495 0.0228843 0.250232 0.657086 0.116704 6.00E-06 0 0 0 0 0 0 0 0 0 0
## 0 0 0 0 0 0 0 0 0 0 0 3.00E-09 2.81E-07 1.93E-05 0.00088497 0.0229046 0.256097 0.883296 0.999994 1
# custom molt probability matrix (if any)
## -----
##
## SELECTIVITY CONTROLS
## Selectivity P(capture of all sizes). Each gear must have a selectivity and a
## retention selectivity. If a uniform prior is selected for a parameter then the
## lb and ub are used (p1 and p2 are ignored)
## LEGEND
## sel type: 0 = parametric, 1 = coefficients (NIY), 2 = logistic, 3 = logistic95,
## 4 = double normal (NIY)
## gear index: use +ve for selectivity, -ve for retention
## sex dep: 0 for sex-independent, 1 for sex-dependent
## -----
##
## Gear-1 Gear-2 Gear-3 Gear-4 Gear-5 Gear-6 Gear-7 Gear-8
## PotFshry TrawlByc NMFS NMFS BSFRF NMFS_study BSFRF_10 NMFS_study
1 1 1 1 1 1 1 1 # selectivity periods
1 0 1 1 1 1 1 1 # sex specific selectivity
2 2 2 2 0 -4 0 -4 # male selectivity type (slx_type_in, to mirror, make negative and equal to the fleet to be mirrored)
2 2 2 2 0 -4 0 -4 # female selectivity type
0 0 0 0 0 0 5 0 7 # within another gear
0 0 0 0 0 0 0 # extra parameters for each pattern by fleet (males)
0 0 0 0 0 0 0 # extra parameters for each pattern by fleet (females)
## Gear-1 Gear-2 Gear-3 Gear-4 Gear-5 Gear-6 Gear-5 Gear-6
1 1 1 1 1 1 1 1 # retention periods
1 0 0 0 0 0 0 0 # sex specific retention
2 6 6 6 6 6 6 6 # male retention type
6 6 6 6 6 6 6 6 # female retention type
1 0 0 0 0 0 0 0 # male retention flag (0 = no, 1 = yes)
0 0 0 0 0 0 0 0 # female retention flag (0 = no, 1 = yes)
0 0 0 0 0 0 0 # extra parameters for each pattern by fleet (males)
0 0 0 0 0 0 0 # extra parameters for each pattern by fleet (females)
1 1 1 1 0 0 0 0 # determines if maximum selectivity at size is forced to equal 1 or not
## -----
##
## gear par sel start end
## index index par sex ival lb ub prior p1 p2 phz period period
## -----
##
# Gear-1
1 1 1 1 105.7114 5 186 0 1 999 4 1982 2021 #4
1 2 2 1 4.997241 0.01 20 0 1 999 4 1982 2021 #4
1 3 1 2 74.85672 5 150 0 1 999 4 1982 2021
1 4 2 2 4.187324 0.01 20 0 1 999 4 1982 2021
# Gear-2
2 5 1 0 109.931 5 185 0 1 999 4 1982 2021
2 6 2 0 11.86826 0.01 20 0 1 999 4 1982 2021
# Gear-3- NMFS
3 7 1 1 42.19018 5 300 0 1 999 4 1982 2021
3 8 2 1 4.997241 0.01 20 0 1 999 4 1982 2021
3 9 1 2 42.19018 5 300 0 1 999 4 1982 2021

```

```

3 10 2 2 4.997241 0.01 20 0 1 999 4 1982 2021
# Gear 4 NMFS
4 11 1 1 36.25999 5 300 0 1 999 4 1982 2021
4 12 2 1 4.997241 0.01 20 0 1 999 4 1982 2021
4 13 1 2 36.29074 5 100 0 1 999 4 1982 2021
4 14 2 2 4.997241 0.01 20 0 1 999 4 1982 2021
# Gear 5 BSFRF
5 15 1 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 16 2 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 17 3 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 18 4 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 19 5 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 20 6 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 21 7 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 22 8 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 23 9 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 24 10 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 25 11 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 26 12 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 27 13 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 28 14 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 29 15 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 30 16 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 31 17 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 32 18 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 33 19 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 34 20 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 35 21 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 36 22 1 0.5 0.00001 1 0 0 999 1 1982 2021
5 37 1 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 38 2 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 39 3 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 40 4 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 41 5 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 42 6 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 43 7 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 44 8 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 45 9 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 46 10 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 47 11 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 48 12 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 49 13 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 50 14 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 51 15 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 52 16 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 53 17 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 54 18 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 55 19 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 56 20 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 57 21 2 0.5 0.00001 1 0 0 999 1 1982 2021
5 58 22 2 0.5 0.00001 1 0 0 999 1 1982 2021
# Gear 6 -NMFS (mirrored)
6 59 1 1 0.01 0.00001 100 0 1 999 -6 1982 2021
6 60 1 2 0.01 0.00001 100 0 1 999 -6 1982 2021
# Gear 5 BSFRF
7 61 1 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 62 2 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 63 3 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 64 4 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 65 5 1 0.999999 0.00001 1 0 0 999 -1 1982 2021
7 66 6 1 0.999999 0.00001 1 0 0 999 -1 1982 2021
7 67 7 1 0.999999 0.00001 1 0 0 999 -1 1982 2021
7 68 8 1 0.999999 0.00001 1 0 0 999 -1 1982 2021
7 69 9 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 70 10 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 71 11 1 0.5 0.00001 1 0 0 999 1 1982 2021

```



```

7 72 12 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 73 13 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 74 14 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 75 15 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 76 16 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 77 17 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 78 18 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 79 19 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 80 20 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 35 21 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 36 22 1 0.5 0.00001 1 0 0 999 1 1982 2021
7 37 1 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 38 2 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 39 3 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 40 4 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 41 5 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 42 6 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 43 7 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 44 8 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 45 9 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 46 10 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 47 11 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 48 12 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 49 13 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 50 14 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 51 15 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 52 16 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 53 17 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 54 18 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 55 19 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 56 20 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 57 21 2 0.5 0.00001 1 0 0 999 1 1982 2021
7 58 22 2 0.5 0.00001 1 0 0 999 1 1982 2021
# Gear 6 -NMFS (mirrored)
  8 59 1 1 0.01 0.00001 100 0 1 999 -6 1982 2021
  8 59 1 2 0.01 0.00001 100 0 1 999 -6 1982 2021
## ----- ##
## Retained ##
## gear par sel start end ##
## index index par sex ival lb ub prior p1 p2 phz period period ##
## ----- ##
# Gear-1
-1 61 1 1 96.03919 1 190 1 96 10 4 1982 2021
-1 62 2 1 2.197131 0.001 20 0 1 999 4 1982 2021
-1 63 1 2 595 1 999 0 1 999 -3 1982 2021
# Gear-2
-2 64 1 0 595 1 999 0 1 999 -3 1982 2021
# Gear-3
-3 65 1 0 595 1 999 0 1 999 -3 1982 2021
# Gear-4
-4 66 1 0 595 1 999 0 1 999 -3 1982 2021
# Gear-5
-5 67 1 0 595 1 999 0 1 999 -3 1982 2021
# Gear-6
-6 68 1 0 595 1 999 0 1 999 -3 1982 2021
# Gear-7
-7 67 1 0 595 1 999 0 1 999 -3 1982 2021
# Gear-8
-8 68 1 0 595 1 999 0 1 999 -3 1982 2021
## ----- ##
# Number of asymptotic parameters
0
# Fleet Sex Year ival lb ub phz

```

```

# 1 1 1982 0.000001 0 1 -3
## ----- ##
## PRIORS FOR CATCHABILITY
## If a uniform prior is selected for a parameter then the lb and ub are used (p1 ##
## and p2 are ignored). ival must be >0 ##
## LEGEND ##
## prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma ##"
## ----- ##
## ival lb ub phz prior p1 p2 Analytic? LAMBDA Emphasis
0.6 0.01 1 5 0 0.843136 0.03 0 1 1 # NMFS_TRAWL_1982 FEMALES
0.6 0.01 1 5 0 0.843136 0.03 0 1 1 # NMFS_TRAWL_1989 FEMALES
0.6 0.01 1 5 0 0.45136 0.5 0 1 1 # NMFS_TRAWL_1982 MALES
0.6 0.01 1 5 0 0.453136 0.5 0 1 1 # NMFS_TRAWL_1989 MALES (fixed to one because that where it wants to
go)
0.9999 0.01 1 -5 0 0.843136 0.03 0 1 1 # BSFRF_TRWL_2009 MALES + FEMALES (fixed to 1)
0.9999 0.01 1 -5 0 0.843136 0.03 0 1 1 # BSFRF_TRWL_2010 MALES + FEMALES (fixed to 1)
## ----- ##
## ----- ##
## ADDITIONAL CV FOR SURVEYS/INDICES ##
## If a uniform prior is selected for a parameter then the lb and ub are used (p1 ##
## and p2 are ignored). ival must be >0 ##
## LEGEND ##
## prior type: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma ##"
## ----- ##
## ival lb ub phz prior p1 p2
0.0001 0.00001 10.0 -4 0 1.0 100 # NMFS era 1
0.0001 0.00001 10.0 -4 0 1.0 100 # NMFS era 2
0.0001 0.00001 10.0 -4 0 1.0 100 # NMFS era 1
0.0001 0.00001 10.0 -4 0 1.0 100 # NMFS era 2
0.0001 0.00001 10.0 -4 0 1.0 100 # BSFRF 2009
0.0001 0.00001 10.0 -4 0 1.0 100 # BSFRF 2010
### Pointers to how the the additional CVs are used (0 ignore; >0 link to one of the parameters
0 0 0 0 0
#####

## PENALTIES FOR AVERAGE FISHING MORTALITY RATE FOR EACH GEAR
## ----- ##
## Mean_F Female Offset STD_PHZ1 STD_PHZ2 PHZ_M PHZ_F
1 0.0505 0.5 45.50 1 1 -12 4 -10 10 -10 10 # Pot
0.018 1.0 0.5 45.50 1 -1 -12 4 -10 10 -10 10 # Trawl
0.00 0.0 2.0 20.00 -1 -1 -12 4 -10 10 -10 10 # NMFS trawl survey era 1 (0 catch)
0.00 0.0 2.0 20.00 -1 -1 -12 4 -10 10 -10 10 # NMFS trawl survey era 2 (0 catch)
0.00 0.0 2.0 20.00 -1 -1 -12 4 -10 10 -10 10 # BSFRF 2009 (0 catch)
0.00 0.0 2.0 20.00 -1 -1 -12 4 -10 10 -10 10 # NMFS 2009 (0 catch)
0.00 0.0 2.0 20.00 -1 -1 -12 4 -10 10 -10 10 # BSFRF 2009 (0 catch)
0.00 0.0 2.0 20.00 -1 -1 -12 4 -10 10 -10 10 # NMFS 2009 (0 catch)
# ----- ##
## ----- ##
## OPTIONS FOR SIZE COMPOSTION DATA ##
## One column for each data matrix ##
## LEGEND ##
## Likelihood: 1 = Multinomial with estimated/fixed sample size ##
## 2 = Robust approximation to multinomial ##
## 3 = logistic normal (NIY) ##
## 4 = multivariate-t (NIY) ##
## 5 = Dirichlet ##
## AUTO TAIL COMPRESSION ##
## pmin is the cumulative proportion used in tail compression ##
## ----- ##

```

```

# Pot    Trawl  NMFS
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 # Type of likelihood
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 # Auto tail compression (pmin)
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 # Initial value for effective sample size multiplier
-4 -4 -4 -4 -4 -4 -4 -4 -4 -4 -4 -4 -4 -4 -4 # Phz for estimating effective sample size (if appl.)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 # Composition aggregator
## #
1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 # Set to 2 for survey-like predictions; 1 for catch-like predictions
## #
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 # LAMBDA
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 # Emphasis AEP
## ----- ##
## TIME VARYING NATURAL MORTALITY RATES          ##
## LEGEND          ##
## Type: 0 = constant natural mortality          ##
## 1 = Random walk (deviates constrained by variance in M)          ##
## 2 = Cubic Spline (deviates constrained by nodes & node-placement)          ##
## 3 = Blocked changes (deviates constrained by variance at specific knots)          ##
## 4 = Time blocks          ##
## ----- ##
## Type
6
# 0
## M is relative (YES=1; NO=0)
0
## Phase of estimation
4
# -3
## STDEV in m_dev for Random walk
2
# 0.25
## Number of nodes for cubic spline or number of step-changes for option 3
3
3
# 0
## Year position of the knots (vector must be equal to the number of nodes)
2018 2019 2020
2018 2019 2020
# 0
# number of breakpoints in M by size
0
#
## Specific initial values for the natural mortality devs (0=no, 1=yes)"
1
## ----- ##
## ival    lb    ub    phz  extra  prior  p1  p2    # parameter  ##
## ----- ##
1.000000  0    3    4    0
1.000000  0    3    4    0
0.000010  0    3   -4    0
1.000000  0    3    4    0
1.000000  0    3    4    0
0.000010  0    3   -4    0
1.000000  0    3    4    0
1.000000  0    3    4    0
0.000010  0    3   -4    0
1.000000  0    3    4    0
1.000000  0    3    4    0
0.000010  0    3   -4    0
## ----- ##
## ----- ##
##

```

```

## TAGGING controls CONTROLS
## ----- ##
1 # emphasis on tagging data
## ----- ##
## Maturity specific natural mortality
## ----- ##
# maturity specific natural mortality? (yes = 1; no = 0; only for use if nmature > 1)
1
## ----- ##
## ival lb ub phz prior p1 p2 # parameter ##
## ----- ##
0.000000 -4 4 4 1 0 0.05 # offset for immature male natural mortality
0.000000 -4 4 4 1 0 0.05 # offset for immature female natural mortality
#0.000000 -2 2 4 # offset for immature male natural mortality
#0.000000 -2 2 4 # offset for immature female natural mortality
## ----- ##
## OTHER CONTROLS
## ----- ##
1982 # First rec_dev
2021 # last rec_dev
1 # Terminal molting (0 = off, 1 = on). If on, the calc_stock_recruitment_relationship() isn't called in the procedure
1 # Estimated rec_dev phase
2 # Estimated sex_ratio phase
0.5 # Initial sex ratio
-3 # Estimated rec_ini phase
1 # VERBOSE FLAG (0 = off, 1 = on, 2 = objective func; 3 diagnostics)"
2 # Initial conditions (0 = Unfished, 1 = Steady-state fished, 2 = Free parameters, 3 = Free parameters (revised))"
1 # Lambda (proportion of mature male biomass for SPR reference points).
0 # Stock-Recruit-Relationship (0 = none, 1 = Beverton-Holt)"
10 # Maximum phase (stop the estimation after this phase).
-1 # Maximum number of function calls, if 1, stop at fn1 call; if -1 run as long as it takes
1 # Calculate reference points (0=no)
0 # Use average sex ratio for computing recruitment for reference points (0 = off -i.e. Rec based on End year, 1 = on)
200 # Years to compute equilibria
## ----- ##
## EMPHASIS FACTORS (CATCH)
## ----- ##
#Ret_male Disc_male Disc_female Disc_trawl
1 1 1 1
# 500 100 100 50
## ----- ##
## EMPHASIS FACTORS (Priors) by fleet: fdev_total, Fdov_total, Fdev_year, Fdov_year
## ----- ##
#
1 1 0 0 # Pot_Fishery
1 0 0 0 # Trawl_Bycatch
0 0 0 0 # NMFS_Trawl_1982
0 0 0 0 # NMFS_Trawl_1989
0 0 0 0 # BSFRF_2009
0 0 0 0 # NMFS_2009
0 0 0 0 # BSFRF_2010
0 0 0 0 # NMFS_2010
#
## ----- ##

```

```

## EMPHASIS FACTORS (Priors)
## -----
##
# Log_fdevs  meanF    Mdevs Rec_devs Initial_devs Fst_dif_dev Mean_sex-Ratio Molt_prob Free selectivity Init_n_at_len Fdevs Fdovs
# 10000    0      1      1      15      1      3      60      3      5
# 10000    0      1      1      15      1      3      60      3      5 0 0
## EOF
9999

```

## Appendix F

```

=====
=====
#      Gmacs Main Data File Version      1.1: BBRKC Example      #
GEAR_INDEX DESCRIPTION                      #
1      :      Pot fishery      retained      catch.          #
1      :      Pot fishery      with discarded catch.        #
2      :      Trawl bycatch                      #
3      :      Trawl survey                      #
#      Fisheries: 1      Pot "Fishery," 2      Pot "Discard," 3
Trawl "by-catch," 4      Tanner bycatch 5 fixed gear          #
Surveys: 6      NMFS Trawl "Survey," 7      BSFRF Survey
#=====
=====

1982 # Start      year
2021 # End year
3     # Number of seasons
8     # Number of fleets (fishing fleets and surveys)
2     # Number of sexes
1     # Number of shell condition types
2     # Number of maturity types
22    # Number of size-classes in the      model
3     # Season recruitment occurs
3     # Season molting and growth occurs
3     # Season to calculate SSB
1     # Season for N output
# maximum size-class (males then females)

22 22
#      size_breaks (a      vector      giving      the      break points
between      size "intervals,"      dim=nclass+1)
25    30      35      40      45      50      55      60      65      70      75      80      85
90      95      100      105      110      115      120      125      130      135

#      Natural      mortality per      season      input type (1      =
vector      by      "season," 2      =      matrix      by
season/year)
1
#      Proportion of the total      natural      mortality to be      applied
each      season
#0.625 0.00 0.375
0.62 0.01 0.37
# Fishing fleet      names (delimited with spaces; no spaces in names)

Pot_Fishery Trawl_Bycatch
# Survey names (delimited with spaces; no spaces in names)
NMFS_Trawl_1982 NMFS_Trawl_1989      BSFRF_2009 NMFS_2009 BSFRF_2010
NMFS_2010
# Are the seasons instantaneous (0) or continuous (1)

```

1 1 1

#1 1 1 1 1 1 1

# Number of catch data frames

4

# Number of rows in each data frame

40 40 40 40

## ##

## CATCH DATA

## Type of "catch: 1 = retained, 2" "= discard, 0 =" total

## Units of catch: "1 = biomass, 2 = numbers"

## for snow Units are in 1000 mt for landed & discards.

## Male retained pot fishery (tonnes)

#year seas fleet sex obs cv type units mult effort  
discard\_mortality

|      |   |   |   |         |      |   |   |   |   |   |
|------|---|---|---|---------|------|---|---|---|---|---|
| 1982 | 2 | 1 | 1 | 11.8518 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1983 | 2 | 1 | 1 | 12.1623 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1984 | 2 | 1 | 1 | 29.9369 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1985 | 2 | 1 | 1 | 44.4455 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1986 | 2 | 1 | 1 | 46.2231 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1987 | 2 | 1 | 1 | 61.3965 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1988 | 2 | 1 | 1 | 67.7927 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1989 | 2 | 1 | 1 | 73.4017 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1990 | 2 | 1 | 1 | 149.073 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1991 | 2 | 1 | 1 | 143.02  | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1992 | 2 | 1 | 1 | 104.684 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1993 | 2 | 1 | 1 | 67.9378 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1994 | 2 | 1 | 1 | 34.1344 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1995 | 2 | 1 | 1 | 29.8071 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1996 | 2 | 1 | 1 | 54.2244 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1997 | 2 | 1 | 1 | 114.392 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1998 | 2 | 1 | 1 | 88.0885 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 1999 | 2 | 1 | 1 | 15.1009 | 0.04 | 1 | 1 | 1 | 0 | 1 |

|      |   |   |   |         |      |   |   |   |   |   |
|------|---|---|---|---------|------|---|---|---|---|---|
| 2000 | 2 | 1 | 1 | 11.4562 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2001 | 2 | 1 | 1 | 14.8021 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2002 | 2 | 1 | 1 | 12.8445 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2003 | 2 | 1 | 1 | 10.8602 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2004 | 2 | 1 | 1 | 11.291  | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2005 | 2 | 1 | 1 | 16.7712 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2006 | 2 | 1 | 1 | 16.4908 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2007 | 2 | 1 | 1 | 28.592  | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2008 | 2 | 1 | 1 | 26.5571 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2009 | 2 | 1 | 1 | 21.779  | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2010 | 2 | 1 | 1 | 24.6136 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2011 | 2 | 1 | 1 | 40.2933 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2012 | 2 | 1 | 1 | 30.0529 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2013 | 2 | 1 | 1 | 24.4867 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2014 | 2 | 1 | 1 | 30.8181 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2015 | 2 | 1 | 1 | 18.4212 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2016 | 2 | 1 | 1 | 9.67089 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2017 | 2 | 1 | 1 | 8.60177 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2018 | 2 | 1 | 1 | 12.5094 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2019 | 2 | 1 | 1 | 15.4334 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2020 | 2 | 1 | 1 | 20.4124 | 0.04 | 1 | 1 | 1 | 0 | 1 |
| 2021 | 2 | 1 | 1 | 2.48430 | 0.04 | 1 | 1 | 1 | 0 | 1 |

| ##    | Male              | discard | pot | fishery |      |      |       |      |        |   |
|-------|-------------------|---------|-----|---------|------|------|-------|------|--------|---|
| #year | seas              | fleet   | sex | obs     | cv   | type | units | mult | effort |   |
|       | discard_mortality |         |     |         |      |      |       |      |        |   |
| 1982  | 2                 | 1       | 1   | 1.2665  | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1983  | 2                 | 1       | 1   | 1.23826 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1984  | 2                 | 1       | 1   | 2.75873 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1985  | 2                 | 1       | 1   | 4.01467 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1986  | 2                 | 1       | 1   | 4.24531 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1987  | 2                 | 1       | 1   | 5.52241 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1988  | 2                 | 1       | 1   | 5.81669 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1989  | 2                 | 1       | 1   | 6.68474 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1990  | 2                 | 1       | 1   | 15.2104 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1991  | 2                 | 1       | 1   | 12.0007 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1992  | 2                 | 1       | 1   | 17.0594 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1993  | 2                 | 1       | 1   | 5.32105 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1994  | 2                 | 1       | 1   | 4.03107 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1995  | 2                 | 1       | 1   | 5.75369 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1996  | 2                 | 1       | 1   | 7.43796 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1997  | 2                 | 1       | 1   | 5.73442 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1998  | 2                 | 1       | 1   | 4.66529 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1999  | 2                 | 1       | 1   | 0.51769 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2000  | 2                 | 1       | 1   | 0.61915 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2001  | 2                 | 1       | 1   | 1.88619 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2002  | 2                 | 1       | 1   | 1.47237 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2003  | 2                 | 1       | 1   | 0.57274 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2004  | 2                 | 1       | 1   | 0.50851 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2005  | 2                 | 1       | 1   | 1.35931 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2006  | 2                 | 1       | 1   | 1.77529 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2007  | 2                 | 1       | 1   | 2.53489 | 0.07 | 2    | 1     | 1    | 0      | 1 |



|      |   |   |   |         |      |   |   |   |   |   |
|------|---|---|---|---------|------|---|---|---|---|---|
| 2008 | 2 | 1 | 1 | 2.06014 | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2009 | 2 | 1 | 1 | 1.22884 | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2010 | 2 | 1 | 1 | 0.61629 | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2011 | 2 | 1 | 1 | 1.68996 | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2012 | 2 | 1 | 1 | 2.32367 | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2013 | 2 | 1 | 1 | 3.27274 | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2014 | 2 | 1 | 1 | 3.52222 | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2015 | 2 | 1 | 1 | 2.955   | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2016 | 2 | 1 | 1 | 1.3119  | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2017 | 2 | 1 | 1 | 1.93176 | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2018 | 2 | 1 | 1 | 2.86297 | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2019 | 2 | 1 | 1 | 5.07027 | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2020 | 2 | 1 | 1 | 5.79557 | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2021 | 2 | 1 | 1 | 1.16418 | 0.07 | 2 | 1 | 1 | 0 | 1 |

| ##    | Female            | discard | pot | fishery     |      |      |       |      |        |   |
|-------|-------------------|---------|-----|-------------|------|------|-------|------|--------|---|
| #year | seas              | fleet   | sex | obs         | cv   | type | units | mult | effort |   |
|       | discard_mortality |         |     |             |      |      |       |      |        |   |
| 1982  | 2                 | 1       | 2   | 0.015556    | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1983  | 2                 | 1       | 2   | 0.0108887   | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1984  | 2                 | 1       | 2   | 0.010782    | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1985  | 2                 | 1       | 2   | 0.0108527   | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1986  | 2                 | 1       | 2   | 0.0239127   | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1987  | 2                 | 1       | 2   | 0.0345783   | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1988  | 2                 | 1       | 2   | 0.0367518   | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1989  | 2                 | 1       | 2   | 0.0477847   | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1990  | 2                 | 1       | 2   | 0.0509047   | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1991  | 2                 | 1       | 2   | 0.058299    | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1992  | 2                 | 1       | 2   | 0.119838    | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1993  | 2                 | 1       | 2   | 0.0800336   | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1994  | 2                 | 1       | 2   | 0.0577576   | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1995  | 2                 | 1       | 2   | 0.0156582   | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1996  | 2                 | 1       | 2   | 0.0691276   | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1997  | 2                 | 1       | 2   | 0.00539956  | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1998  | 2                 | 1       | 2   | 0.00652564  | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 1999  | 2                 | 1       | 2   | 0.000398846 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2000  | 2                 | 1       | 2   | 0.000419268 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2001  | 2                 | 1       | 2   | 0.000419268 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2002  | 2                 | 1       | 2   | 0.00424435  | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2003  | 2                 | 1       | 2   | 0.000623222 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2004  | 2                 | 1       | 2   | 0.000623222 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2005  | 2                 | 1       | 2   | 0.00234871  | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2006  | 2                 | 1       | 2   | 0.000740955 | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2007  | 2                 | 1       | 2   | 0.0106352   | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2008  | 2                 | 1       | 2   | 0.00819622  | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2009  | 2                 | 1       | 2   | 0.00726154  | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2010  | 2                 | 1       | 2   | 0.00604923  | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2011  | 2                 | 1       | 2   | 0.17645     |      | 2    | 0.07  | 1    | 1      | 0 |
| 2012  | 2                 | 1       | 2   | 0.0276122   | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2013  | 2                 | 1       | 2   | 0.0651188   | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2014  | 2                 | 1       | 2   | 0.168694    | 0.07 | 2    | 1     | 1    | 0      | 1 |
| 2015  | 2                 | 1       | 2   | 0.0686591   | 0.07 | 2    | 1     | 1    | 0      | 1 |

1

|      |   |   |   |           |      |   |   |   |   |   |
|------|---|---|---|-----------|------|---|---|---|---|---|
| 2016 | 2 | 1 | 2 | 0.0189331 | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2017 | 2 | 1 | 2 | 0.0181628 | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2018 | 2 | 1 | 2 | 0.0192255 | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2019 | 2 | 1 | 2 | 0.0161846 | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2020 | 2 | 1 | 2 | 0.000744  | 0.07 | 2 | 1 | 1 | 0 | 1 |
| 2021 | 2 | 1 | 2 | 0.0000642 | 0.07 | 2 | 1 | 1 | 0 | 1 |

## Trawl fishery discards

| #year | seas | fleet | sex | obs               | cv   | type | units | mult | effort |   |   |
|-------|------|-------|-----|-------------------|------|------|-------|------|--------|---|---|
|       |      |       |     | discard_mortality |      |      |       |      |        |   |   |
| 1982  | 2    | 2     | 0   | 0.367285          | 0.20 | 2    | 1     | 1    | 0      | 1 |   |
| 1983  | 2    | 2     | 0   | 0.473323          | 0.20 | 2    | 1     | 1    | 0      | 1 |   |
| 1984  | 2    | 2     | 0   | 0.502882          | 0.20 | 2    | 1     | 1    | 0      | 1 |   |
| 1985  | 2    | 2     | 0   | 0.431674          | 0.20 | 2    | 1     | 1    | 0      | 1 |   |
| 1986  | 2    | 2     | 0   | 4.31E-05          | 0.20 | 2    | 1     | 1    | 0      | 1 |   |
| 1987  | 2    | 2     | 0   | 0.002804          | 0.20 | 2    | 1     | 1    | 0      | 1 |   |
| 1988  | 2    | 2     | 0   | 0.001931          | 0.20 | 2    | 1     | 1    | 0      | 1 |   |
| 1989  | 2    | 2     | 0   | 0.100212          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 1990  | 2    | 2     | 0   | 0.708383          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 1991  | 2    | 2     | 0   | 1.50323           |      | 0.10 | 2     | 1    | 1      | 0 | 1 |
| 1992  | 2    | 2     | 0   | 2.28349           |      | 0.10 | 2     | 1    | 1      | 0 | 1 |
| 1993  | 2    | 2     | 0   | 1.57242           |      | 0.10 | 2     | 1    | 1      | 0 | 1 |
| 1994  | 2    | 2     | 0   | 2.66952           |      | 0.10 | 2     | 1    | 1      | 0 | 1 |
| 1995  | 2    | 2     | 0   | 1.01257           |      | 0.10 | 2     | 1    | 1      | 0 | 1 |
| 1996  | 2    | 2     | 0   | 0.66498           |      | 0.10 | 2     | 1    | 1      | 0 | 1 |
| 1997  | 2    | 2     | 0   | 0.82108           |      | 0.10 | 2     | 1    | 1      | 0 | 1 |
| 1998  | 2    | 2     | 0   | 0.538527          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 1999  | 2    | 2     | 0   | 0.474335          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2000  | 2    | 2     | 0   | 0.411285          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2001  | 2    | 2     | 0   | 0.305451          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2002  | 2    | 2     | 0   | 0.170231          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2003  | 2    | 2     | 0   | 0.460629          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2004  | 2    | 2     | 0   | 0.632716          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2005  | 2    | 2     | 0   | 0.202814          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2006  | 2    | 2     | 0   | 0.41606           |      | 0.10 | 2     | 1    | 1      | 0 | 1 |
| 2007  | 2    | 2     | 0   | 0.183532          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2008  | 2    | 2     | 0   | 0.182103          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2009  | 2    | 2     | 0   | 0.472613          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2010  | 2    | 2     | 0   | 0.140577          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2011  | 2    | 2     | 0   | 0.15079           |      | 0.10 | 2     | 1    | 1      | 0 | 1 |
| 2012  | 2    | 2     | 0   | 0.215381          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2013  | 2    | 2     | 0   | 0.109951          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2014  | 2    | 2     | 0   | 0.131403          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2015  | 2    | 2     | 0   | 0.125312          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2016  | 2    | 2     | 0   | 0.058278          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2017  | 2    | 2     | 0   | 0.043184          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2018  | 2    | 2     | 0   | 0.229956          | 0.10 | 2    | 1     | 1    | 0      | 1 |   |
| 2019  | 2    | 2     | 0   | 0.23697           |      | 0.10 | 2     | 1    | 1      | 0 | 1 |

2020 2 2 0 0.066747 0.10 2 1 1 0 1  
 2021 2 2 0 0.056034 0.10 2 1 1 0 1

##

## RELATIVE ABUNDANCE DATA

## Number of relative abundance indices

6

# Index Type (1=Selecivity; 2=retention)

1 1 1 1 1 1

## Number of rows of index data

88

## Survey data

## Mature: 1=mature; 2=immature; 0=combined

## Index: indicates if a different q is estimated for the survey

| #Index | Year | Season | Fleet | Sex | Mature | Obs | CV      | Units   |
|--------|------|--------|-------|-----|--------|-----|---------|---------|
| 1      | 1982 | 1      | 3     |     | 2      | 1   | 144.395 | 0.153 1 |
|        |      | 0      |       |     |        |     |         |         |
| 1      | 1983 | 1      | 3     |     | 2      | 1   | 90.1343 | 0.197 1 |
|        |      | 0      |       |     |        |     |         |         |
| 1      | 1984 | 1      | 3     |     | 2      | 1   | 42.316  | 0.194 1 |
|        |      | 0      |       |     |        |     |         |         |
| 1      | 1985 | 1      | 3     |     | 2      | 1   | 6.1218  | 0.199 1 |
|        |      | 0      |       |     |        |     |         |         |
| 1      | 1986 | 1      | 3     |     | 2      | 1   | 15.7424 | 0.183 1 |
|        |      | 0      |       |     |        |     |         |         |
| 1      | 1987 | 1      | 3     |     | 2      | 1   | 122.592 | 0.160 1 |
|        |      | 0      |       |     |        |     |         |         |
| 1      | 1988 | 1      | 3     |     | 2      | 1   | 169.954 | 0.168 1 |
|        |      | 0      |       |     |        |     |         |         |
| 2      | 1989 | 1      | 4     |     | 2      | 1   | 264.231 | 0.254 1 |
|        |      | 0      |       |     |        |     |         |         |
| 2      | 1990 | 1      | 4     |     | 2      | 1   | 182.879 | 0.186 1 |
|        |      | 0      |       |     |        |     |         |         |
| 2      | 1991 | 1      | 4     |     | 2      | 1   | 214.924 | 0.191 1 |
|        |      | 0      |       |     |        |     |         |         |
| 2      | 1992 | 1      | 4     |     | 2      | 1   | 131.436 | 0.185 1 |
|        |      | 0      |       |     |        |     |         |         |
| 2      | 1993 | 1      | 4     |     | 2      | 1   | 132.11  | 0.158 1 |
|        |      | 0      |       |     |        |     |         |         |
| 2      | 1994 | 1      | 4     |     | 2      | 1   | 126.234 | 0.153 1 |
|        |      | 0      |       |     |        |     |         |         |
| 2      | 1995 | 1      | 4     |     | 2      | 1   | 168.677 | 0.141 1 |
|        |      | 0      |       |     |        |     |         |         |
| 2      | 1996 | 1      | 4     |     | 2      | 1   | 107.315 | 0.140 1 |
|        |      | 0      |       |     |        |     |         |         |
| 2      | 1997 | 1      | 4     |     | 2      | 1   | 103.775 | 0.196 1 |
|        |      | 0      |       |     |        |     |         |         |

|   |      |   |   |   |   |         |       |   |
|---|------|---|---|---|---|---------|-------|---|
| 2 | 1998 | 1 | 4 | 2 | 1 | 72.7295 | 0.253 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 1999 | 1 | 4 | 2 | 1 | 30.8892 | 0.210 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2000 | 1 | 4 | 2 | 1 | 96.4577 | 0.517 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2001 | 1 | 4 | 2 | 1 | 77.2373 | 0.283 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2002 | 1 | 4 | 2 | 1 | 30.2215 | 0.276 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2003 | 1 | 4 | 2 | 1 | 41.7109 | 0.311 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2004 | 1 | 4 | 2 | 1 | 50.155  | 0.265 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2005 | 1 | 4 | 2 | 1 | 64.8537 | 0.172 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2006 | 1 | 4 | 2 | 1 | 51.9282 | 0.175 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2007 | 1 | 4 | 2 | 1 | 55.8924 | 0.223 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2008 | 1 | 4 | 2 | 1 | 57.1508 | 0.191 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2009 | 1 | 4 | 2 | 1 | 52.1622 | 0.206 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2010 | 1 | 4 | 2 | 1 | 98.0135 | 0.175 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2011 | 1 | 4 | 2 | 1 | 175.838 | 0.178 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2012 | 1 | 4 | 2 | 1 | 149.423 | 0.197 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2013 | 1 | 4 | 2 | 1 | 131.415 | 0.175 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2014 | 1 | 4 | 2 | 1 | 119.716 | 0.188 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2015 | 1 | 4 | 2 | 1 | 85.1268 | 0.167 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2016 | 1 | 4 | 2 | 1 | 55.3853 | 0.206 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2017 | 1 | 4 | 2 | 1 | 106.847 | 0.208 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2018 | 1 | 4 | 2 | 1 | 165.895 | 0.18  | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2019 | 1 | 4 | 2 | 1 | 110.429 | 0.205 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2021 | 1 | 4 | 2 | 1 | 31.6629 | 0.43  | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 2 | 2022 | 1 | 4 | 2 | 1 | 22.4408 | 0.43  | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 3 | 1982 | 1 | 3 | 1 | 1 | 176.797 | 0.138 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 3 | 1983 | 1 | 3 | 1 | 1 | 161.618 | 0.126 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 3 | 1984 | 1 | 3 | 1 | 1 | 177.691 | 0.118 | 1 |
|   |      | 0 |   |   |   |         |       |   |

|   |      |   |   |   |   |         |       |   |
|---|------|---|---|---|---|---------|-------|---|
| 3 | 1985 | 1 | 3 | 1 | 1 | 71.837  | 0.106 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 3 | 1986 | 1 | 3 | 1 | 1 | 89.8051 | 0.112 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 3 | 1987 | 1 | 3 | 1 | 1 | 194.578 | 0.107 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 3 | 1988 | 1 | 3 | 1 | 1 | 259.439 | 0.149 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 1989 | 1 | 4 | 1 | 1 | 299.223 | 0.107 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 1990 | 1 | 4 | 1 | 1 | 443.789 | 0.139 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 1991 | 1 | 4 | 1 | 1 | 466.607 | 0.147 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 1992 | 1 | 4 | 1 | 1 | 235.515 | 0.094 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 1993 | 1 | 4 | 1 | 1 | 183.876 | 0.105 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 1994 | 1 | 4 | 1 | 1 | 171.326 | 0.084 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 1995 | 1 | 4 | 1 | 1 | 220.466 | 0.127 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 1996 | 1 | 4 | 1 | 1 | 288.408 | 0.125 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 1997 | 1 | 4 | 1 | 1 | 326.752 | 0.095 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 1998 | 1 | 4 | 1 | 1 | 206.382 | 0.09  | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 1999 | 1 | 4 | 1 | 1 | 95.8489 | 0.09  | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2000 | 1 | 4 | 1 | 1 | 96.3889 | 0.136 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2001 | 1 | 4 | 1 | 1 | 136.5   | 0.116 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2002 | 1 | 4 | 1 | 1 | 93.1737 | 0.227 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2003 | 1 | 4 | 1 | 1 | 79.0687 | 0.119 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2004 | 1 | 4 | 1 | 1 | 79.5727 | 0.138 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2005 | 1 | 4 | 1 | 1 | 123.509 | 0.113 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2006 | 1 | 4 | 1 | 1 | 139.268 | 0.26  | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2007 | 1 | 4 | 1 | 1 | 153.115 | 0.147 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2008 | 1 | 4 | 1 | 1 | 141.962 | 0.102 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2009 | 1 | 4 | 1 | 1 | 148.189 | 0.128 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2010 | 1 | 4 | 1 | 1 | 162.827 | 0.122 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2011 | 1 | 4 | 1 | 1 | 167.07  | 0.114 | 1 |
|   |      | 0 |   |   |   |         |       |   |

|   |      |   |   |   |   |         |       |   |
|---|------|---|---|---|---|---------|-------|---|
| 4 | 2012 | 1 | 4 | 1 | 1 | 122.255 | 0.119 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2013 | 1 | 4 | 1 | 1 | 97.4605 | 0.118 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2014 | 1 | 4 | 1 | 1 | 163.467 | 0.164 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2015 | 1 | 4 | 1 | 1 | 80.0362 | 0.118 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2016 | 1 | 4 | 1 | 1 | 63.2106 | 0.108 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2017 | 1 | 4 | 1 | 1 | 83.9572 | 0.131 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2018 | 1 | 4 | 1 | 1 | 198.384 | 0.170 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2019 | 1 | 4 | 1 | 1 | 169.108 | 0.172 | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2021 | 1 | 4 | 1 | 1 | 62.2462 | 0.13  | 1 |
|   |      | 0 |   |   |   |         |       |   |
| 4 | 2022 | 1 | 4 | 1 | 1 | 37.4956 | 0.13  | 1 |
|   |      | 0 |   |   |   |         |       |   |

## 2009 BSFRF + NMFS survey in the study area (BSFRF then NMFS; females then males)

|   |      |   |   |   |   |         |      |   |
|---|------|---|---|---|---|---------|------|---|
| 5 | 2009 | 1 | 5 | 2 | 1 | 8.01001 | 1.64 | 1 |
|   |      | 0 |   |   |   |         |      |   |
| 5 | 2009 | 1 | 5 | 1 | 1 | 68.4855 | 0.46 | 1 |
|   |      | 0 |   |   |   |         |      |   |
| 2 | 2009 | 1 | 6 | 2 | 1 | 7.88725 | 1.79 | 1 |
|   |      | 0 |   |   |   |         |      |   |
| 4 | 2009 | 1 | 6 | 1 | 1 | 32.2487 | 0.32 | 1 |
|   |      | 0 |   |   |   |         |      |   |

## 2010 BSFRF + NMFS survey in the study area (BSFRF then NMFS; females then males)

|   |      |   |   |   |   |         |      |   |
|---|------|---|---|---|---|---------|------|---|
| 6 | 2010 | 1 | 7 | 2 | 1 | 187.588 | 0.10 | 1 |
|   |      | 0 |   |   |   |         |      |   |
| 6 | 2010 | 1 | 7 | 1 | 1 | 194.058 | 0.10 | 1 |
|   |      | 0 |   |   |   |         |      |   |
| 2 | 2010 | 1 | 8 | 2 | 1 | 61.3995 | 0.10 | 1 |
|   |      | 0 |   |   |   |         |      |   |
| 4 | 2010 | 1 | 8 | 1 | 1 | 78.0273 | 0.10 | 1 |
|   |      | 0 |   |   |   |         |      |   |

## Number of length frequency matrices

17

## Number of rows in each matrix

40 30 27 31 31 7 33 7 33 7 33 7 33  
 2 2 2 2 2

## Number of bins in each matrix (columns of size data)  
 22 22 22 22 22 22 22 22 22 22 22 22 22  
 22 22 22 22

## SIZE COMPOSITION DATA FOR ALL FLEETS

## SIZE COMP LEGEND  
 ## Sex: 1 "= male," "2 = female, 0" #NAME?

## Type of composition: 1 "= retained, 2 =" "discard, 0 = total composition"  
 ## Maturity state: 1 = "mature," 2 = "immature," 0 = both states combined

## Shell condition: 1 = new "shell," 2 = old "shell," 0 = both shell types combined

## ##

#Retained males

| #Year | Season      | Fleet       | Sex         | Type        | Shell       | Maturity    | Nsamp       | Data        | Vec        |
|-------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|------------|
| 1982  | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0           | 0          |
|       | 0           | 0           | 0           | 0           | 0.000194628 | 0.000389257 | 0.000973141 |             |            |
|       | 0.003697937 | 0.01985206  | 0.1329311   | 0.3435186   | 0.2763725   | 0.1405216   |             |             |            |
|       | 0.05663681  | 0.01848965  | 0.004865703 | 0.001557026 |             |             |             |             |            |
| 1983  | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0           | 0          |
|       | 0           | 0           | 0           | 0           | 0           | 0.000238284 | 0.00039714  | 0.00127085  |            |
|       | 0.00833996  | 0.0518665   | 0.1884829   | 0.2749805   | 0.2584595   | 0.1475775   |             |             |            |
|       | 0.05409058  | 0.01199365  | 0.002303416 |             |             |             |             |             |            |
| 1984  | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0           | 0          |
|       | 0           | 0           | 6.74E-05    | 0           | 0.000202265 | 0.000134844 | 0.001685545 |             |            |
|       | 0.005326318 | 0.02117045  | 0.068568    | 0.1681495   | 0.2284249   | 0.2343583   |             |             |            |
|       | 0.1687563   | 0.0788161   | 0.02009168  | 0.00424758  |             |             |             |             |            |
| 1985  | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0           | 0          |
|       | 0           | 0           | 0           | 0           | 5.20E-05    | 0.000311705 | 0.00135072  | 0.00493532  |            |
|       | 0.02613126  | 0.09081     | 0.1857234   | 0.22105     | 0.2136211   | 0.149203    |             |             |            |
|       | 0.0753285   | 0.02576755  | 0.00571458  |             |             |             |             |             |            |
| 1986  | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0           | 0          |
|       | 0           | 0           | 0           | 0           | 0           | 0           | 0.001191021 | 0.00458085  | 0.03041682 |
|       | 0.100962    | 0.166193    | 0.2188732   | 0.2183231   | 0.1511677   | 0.0790655   |             |             |            |
|       | 0.02382047  | 0.00540541  |             |             |             |             |             |             |            |
| 1987  | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0           | 0          |
|       | 0           | 0           | 0           | 0           | 0           | 0           | 0.002413513 | 0.010324468 | 0.01863771 |
|       | 0.0754894   | 0.1863766   | 0.2288815   | 0.2153393   | 0.1543311   | 0.0821936   |             |             |            |
|       | 0.02252612  | 0.003486185 |             |             |             |             |             |             |            |

|      |   |          |             |             |             |             |             |             |             |             |             |            |
|------|---|----------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|------------|
| 1988 | 2 | 1        | 1           | 1           | 0           | 0           | 100         | 0           | 0           | 0           | 0           | 0          |
|      | 0 | 0        | 0           | 0           | 0           | 0           | 0.00274904  | 0.00655697  | 0.02184975  |             |             |            |
|      |   |          |             |             |             |             | 0.0728395   | 0.1607883   | 0.2005376   | 0.2102102   | 0.1661033   | 0.1072941  |
|      |   |          |             |             |             |             | 0.041256    | 0.00981511  |             |             |             |            |
| 1989 | 2 | 1        | 1           | 1           | 0           | 0           | 100         | 0           | 0           | 0           | 0           | 0          |
|      | 0 | 0        | 6.23E-05    | 0.000218007 | 0.000342583 | 0.001463768 |             |             |             |             |             |            |
|      |   |          |             |             |             |             | 0.002616093 | 0.006882809 | 0.026129722 | 0.08770124  | 0.19701647  | 0.21859907 |
|      |   |          |             |             |             |             | 0.17951344  | 0.14366726  | 0.08944532  | 0.035753259 | 0.010588944 |            |
| 1990 | 2 | 1        | 1           | 1           | 0           | 0           | 100         | 0           | 0           | 0           | 0           | 0          |
|      | 0 | 0        | 5.15E-05    | 0.000103034 | 0.000103034 | 0.000231828 |             |             |             |             |             |            |
|      |   |          |             |             |             |             | 0.001133378 | 0.002910724 | 0.01586732  | 0.06279941  | 0.1744109   | 0.2589513  |
|      |   |          |             |             |             |             | 0.22495006  | 0.1528253   | 0.07802274  | 0.023311551 | 0.00432744  |            |
| 1991 | 2 | 1        | 1           | 1           | 0           | 0           | 100         | 0           | 0           | 0           | 0           | 0          |
|      | 0 | 0        | 8.63E-06    | 6.04E-05    | 0.00044891  | 0.00164457  |             |             |             |             |             |            |
|      |   |          |             |             |             |             | 0.004307819 | 0.008853038 | 0.02823387  | 0.09598057  | 0.2194569   | 0.2354923  |
|      |   |          |             |             |             |             | 0.1873771   | 0.12119732  | 0.06490647  | 0.02451313  | 0.007519251 |            |
| 1992 | 2 | 1        | 1           | 1           | 0           | 0           | 100         | 0           | 0           | 0           | 0           | 0          |
|      | 0 | 0        | 4.39E-05    | 2.39E-05    | 0.000159625 | 0.000706339 |             |             |             |             |             |            |
|      |   |          |             |             |             |             | 0.002498121 | 0.006520659 | 0.01686039  | 0.04560471  | 0.1193354   | 0.1895703  |
|      |   |          |             |             |             |             | 0.2408261   | 0.206191    | 0.11916401  | 0.0408958   | 0.011600738 |            |
| 1993 | 2 | 1        | 1           | 1           | 0           | 0           | 100         | 0           | 0           | 0           | 0           | 0          |
|      | 0 | 0        | 1.16E-05    | 8.67E-05    | 0.000392866 | 0.001230595 |             |             |             |             |             |            |
|      |   |          |             |             |             |             | 0.003582011 | 0.007140915 | 0.02004771  | 0.06094621  | 0.1506876   | 0.2116684  |
|      |   |          |             |             |             |             | 0.2207442   | 0.1743752   | 0.10031945  | 0.03753603  | 0.01123135  |            |
| 1994 | 2 | 1        | 1           | 1           | 0           | 0           | 100         | 0           | 0           | 0           | 0           | 0          |
|      | 0 | 0        | 1.92E-05    | 8.66E-05    | 0.000875303 | 0.003049135 |             |             |             |             |             |            |
|      |   |          |             |             |             |             | 0.007550693 | 0.013062235 | 0.03589706  | 0.09653342  | 0.1772922   | 0.2024356  |
|      |   |          |             |             |             |             | 0.1859587   | 0.1414533   | 0.08755915  | 0.03620487  | 0.012023422 |            |
| 1995 | 2 | 1        | 1           | 1           | 0           | 0           | 100         | 0           | 0           | 0           | 0           | 0          |
|      | 0 | 0        | 4.12E-05    | 0.000164675 | 0.000566071 | 0.002181944 |             |             |             |             |             |            |
|      |   |          |             |             |             |             | 0.007008981 | 0.01779523  | 0.04186866  | 0.1066478   | 0.1942345   | 0.212534   |
|      |   |          |             |             |             |             | 0.1875756   | 0.1290539   | 0.0694723   | 0.02375439  | 0.00710162  |            |
| 1996 | 2 | 1        | 1           | 1           | 0           | 0           | 100         | 0           | 0           | 0           | 0           | 0          |
|      | 0 | 0        | 3.92E-05    | 0.000101795 | 0.000501144 | 0.001667866 |             |             |             |             |             |            |
|      |   |          |             |             |             |             | 0.005426437 | 0.021995534 | 0.09553046  | 0.25378234  | 0.26240355  | 0.18853199 |
|      |   |          |             |             |             |             | 0.10470758  | 0.04646536  | 0.01499511  | 0.003852541 |             |            |
| 1997 | 2 | 1        | 1           | 1           | 0           | 0           | 100         | 0           | 0           | 0           | 0           | 0          |
|      | 0 | 0        | 5.79E-06    | 2.32E-05    | 0.00013322  | 0.00034753  |             |             |             |             |             |            |
|      |   |          |             |             |             |             | 0.000648722 | 0.001905626 | 0.007599317 | 0.04340065  | 0.15892557  | 0.24448163 |
|      |   |          |             |             |             |             | 0.24362449  | 0.16989594  | 0.08586883  | 0.033021099 | 0.010118883 |            |
| 1998 | 2 | 1        | 1           | 1           | 0           | 0           | 100         | 0           | 0           | 0           | 0           | 0          |
|      | 0 | 0        | 2.04E-05    | 2.72E-05    | 8.84E-05    | 0.000217505 |             |             |             |             |             |            |
|      |   |          |             |             |             |             | 0.000672906 | 0.001896371 | 0.009175992 | 0.04698112  | 0.16115777  | 0.24642648 |
|      |   |          |             |             |             |             | 0.24868972  | 0.17474506  | 0.08030698  | 0.024047925 | 0.005546384 |            |
| 1999 | 2 | 1        | 1           | 1           | 0           | 0           | 100         | 0           | 0           | 0           | 0           | 0          |
|      | 0 | 0        | 0.000115662 | 0.00019277  | 0.000154216 | 0.000462608 |             |             |             |             |             |            |
|      |   |          |             |             |             |             | 0.001117987 | 0.001464934 | 0.00713185  | 0.03777944  | 0.1369695   | 0.2209718  |
|      |   |          |             |             |             |             | 0.26087113  | 0.19568198  | 0.10269848  | 0.02725523  | 0.007131857 |            |
| 2000 | 2 | 1        | 1           | 1           | 0           | 0           | 100         | 0           | 0           | 0           | 0           | 0          |
|      | 0 | 0        | 0           | 0           | 0.000111771 | 0.00059606  |             |             |             |             |             |            |
|      |   |          |             |             |             |             | 0.003502005 | 0.007413731 | 0.02917074  | 0.1106102   | 0.1888829   | 0.2416361  |
|      |   |          |             |             |             |             | 0.2240517   | 0.13475139  | 0.0454884   | 0.012331374 |             |            |
| 2001 | 2 | 1        | 1           | 1           | 0           | 0           | 100         | 0           | 0           | 0           | 0           | 0          |
|      | 0 | 3.54E-05 | 0           | 0.000106259 | 0.000247911 | 0.00081452  |             |             |             |             |             |            |



|      |             |             |             |             |             |             |             |            |             |          |   |
|------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|------------|-------------|----------|---|
|      | 0.001841482 | 0.004037127 | 0.01274875  | 0.05209288  | 0.1786244   | 0.2222889   |             |            |             |          |   |
|      | 0.2148166   | 0.1694528   | 0.0986614   | 0.0357674   | 0.00846377  |             |             |            |             |          |   |
| 2002 | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0          | 0           | 0        | 0 |
|      | 0           | 0           | 0           | 0           | 0.000133109 | 0.000843021 | 0.002351588 | 0.00732097 |             |          |   |
|      | 0.02342715  | 0.0932647   | 0.2515753   | 0.2647083   | 0.1867517   | 0.1094596   |             |            |             |          |   |
|      | 0.0448576   | 0.01237909  | 0.00292839  |             |             |             |             |            |             |          |   |
| 2003 | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0          | 0           | 0        | 0 |
|      | 0           | 0           | 4.53E-05    | 0.000135943 | 0.000181258 | 0.000362516 |             |            |             |          |   |
|      | 0.000543774 | 0.001721951 | 0.00783941  | 0.04332066  | 0.1635401   | 0.2471451   |             |            |             |          |   |
|      | 0.2466923   | 0.1736453   | 0.0826989   | 0.0265543   | 0.005573685 |             |             |            |             |          |   |
| 2004 | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0          | 0           | 0        | 0 |
|      | 0           | 0           | 5.96E-05    | 5.96E-05    | 0.000357313 | 0.000595522 |             |            |             |          |   |
|      | 0.001191044 | 0.002858507 | 0.009409238 | 0.03400433  | 0.1037399   | 0.1752023   |             |            |             |          |   |
|      | 0.2204624   | 0.2190924   | 0.1505477   | 0.0653883   | 0.017031922 |             |             |            |             |          |   |
| 2005 | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0          | 0           | 0        | 0 |
|      | 0           | 0           | 0           | 0           | 0.000330754 | 0.000236253 | 0.000330754 |            |             |          |   |
|      | 0.000507944 | 0.003260292 | 0.09551709  | 0.1702088   | 0.2282795   | 0.2348474   |             |            |             |          |   |
|      | 0.1664052   | 0.0746678   | 0.02540903  |             |             |             |             |            |             |          |   |
| 2006 | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0          | 0           | 0        | 0 |
|      | 0           | 0           | 0           | 0           | 9.68E-06    | 8.71E-05    | 0.000193575 |            |             |          |   |
|      | 0.000261327 | 0.000871089 | 0.23982037  | 0.3782075   | 0.2259125   | 0.0880768   |             |            |             |          |   |
|      | 0.0415799   | 0.0180896   | 0.00689128  |             |             |             |             |            |             |          |   |
| 2007 | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0          | 0           | 0        | 0 |
|      | 0           | 0           | 0           | 0           | 0           | 0           | 0           | 0          | 0.000019935 |          |   |
|      | 0.000777465 | 0.2282624   | 0.3459186   | 0.2409614   | 0.11564253  | 0.05050204  |             |            |             |          |   |
|      | 0.01456589  | 0.003349085 |             |             |             |             |             |            |             |          |   |
| 2008 | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0          | 0           | 0        | 0 |
|      | 0           | 0           | 0           | 0           | 0           | 0           | 1.48E-05    | 5.18E-05   |             |          |   |
|      | 0.000836956 | 0.2140314   | 0.3201024   | 0.2421985   | 0.13306147  | 0.06469005  |             |            |             |          |   |
|      | 0.02092393  | 0.004088491 |             |             |             |             |             |            |             |          |   |
| 2009 | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0          | 0           | 0        | 0 |
|      | 0           | 0           | 0           | 0           | 0           | 0           | 0           | 0          | 3.32E-05    | 9.14E-05 |   |
|      | 0.12975046  | 0.242029    | 0.2383311   | 0.20556687  | 0.12551958  | 0.04709265  |             |            |             |          |   |
|      | 0.011586184 |             |             |             |             |             |             |            |             |          |   |
| 2010 | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0          | 0           | 0        | 0 |
|      | 0           | 0           | 0           | 0           | 0           | 0           | 0           | 0          | 4.23E-05    |          |   |
|      | 0.07396027  | 0.17169453  | 0.23428185  | 0.25903662  | 0.17872381  | 0.06618067  |             |            |             |          |   |
|      | 0.016079384 |             |             |             |             |             |             |            |             |          |   |
| 2011 | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0          | 0           | 0        | 0 |
|      | 0           | 0           | 0           | 1.71E-05    | 0           | 0.000188038 | 0.000529924 | 0.00116241 |             |          |   |
|      | 0.002119697 | 0.012376244 | 0.06553954  | 0.1421047   | 0.2175424   | 0.2559364   |             |            |             |          |   |
|      | 0.1942765   | 0.08312959  | 0.02507738  |             |             |             |             |            |             |          |   |
| 2012 | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0          | 0           | 0        | 0 |
|      | 0           | 0           | 0           | 2.16E-05    | 0           | 6.48E-05    | 0.000280596 |            |             |          |   |
|      | 0.000798619 | 0.003496659 | 0.02577164  | 0.12439049  | 0.2012736   | 0.2148499   |             |            |             |          |   |
|      | 0.2035398   | 0.144507    | 0.06088926  | 0.02011651  |             |             |             |            |             |          |   |
| 2013 | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0          | 0           | 0        | 0 |
|      | 0           | 0           | 0           | 5.13E-05    | 0.000128166 | 0.000128166 |             |            |             |          |   |
|      | 0.000974059 | 0.007126016 | 0.06300626  | 0.21834305  | 0.2590225   | 0.1983752   |             |            |             |          |   |
|      | 0.1289861   | 0.07969343  | 0.03355377  | 0.010612117 |             |             |             |            |             |          |   |
| 2014 | 2           | 1           | 1           | 1           | 0           | 0           | 100         | 0          | 0           | 0        | 0 |
|      | 0           | 0           | 0           | 2.19E-05    | 2.19E-05    | 2.19E-05    | 2.19E-05    |            |             |          |   |
|      | 0.000350263 | 0.00061296  | 0.00442207  | 0.04001753  | 0.2035682   | 0.2926005   |             |            |             |          |   |
|      | 0.2274296   | 0.1270362   | 0.06696588  | 0.02784588  | 0.00906305  |             |             |            |             |          |   |

|      |   |          |   |   |             |             |             |             |             |             |   |   |
|------|---|----------|---|---|-------------|-------------|-------------|-------------|-------------|-------------|---|---|
| 2015 | 2 | 1        | 1 | 1 | 0           | 0           | 100         | 0           | 0           | 0           | 0 | 0 |
|      | 0 | 0        | 0 | 0 | 0.000172921 | 0.000518762 | 0.000691683 |             |             |             |   |   |
|      |   |          |   |   | 0.000172921 | 0.00190213  | 0.02213387  | 0.1201802   | 0.2030092   | 0.1845063   |   |   |
|      |   |          |   |   | 0.172748    | 0.14923043  | 0.10236906  | 0.04236554  |             |             |   |   |
| 2016 | 2 | 1        | 1 | 1 | 0           | 0           | 100         | 0           | 0           | 0           | 0 | 0 |
|      | 0 | 0        | 0 | 0 | 0.000255363 | 0           | 0           | 0.000766088 | 0.0020429   |             |   |   |
|      |   |          |   |   | 0.01762004  | 0.127681    | 0.2372316   | 0.2150155   | 0.1762003   | 0.1399391   |   |   |
|      |   |          |   |   | 0.0832482   | 0           |             |             |             |             |   |   |
| 2017 | 2 | 1        | 1 | 1 | 0           | 0           | 100         | 0           | 0           | 0           | 0 | 0 |
|      | 0 | 0        | 0 | 0 | 0.000331675 | 0           | 0           | 0.000331675 |             |             |   |   |
|      |   |          |   |   | 0.003648425 | 0.0315091   | 0.2437815   | 0.288225    | 0.2271969   | 0.1217247   |   |   |
|      |   |          |   |   | 0.0623548   | 0.0169154   | 0.00398009  |             |             |             |   |   |
| 2018 | 2 | 1        | 1 | 1 | 0           | 0           | 100         | 0           | 0           | 0           | 0 | 0 |
|      | 0 | 9.09E-05 | 0 | 0 | 0           | 0.000227242 | 0.00054538  | 0.00109076  |             |             |   |   |
|      |   |          |   |   | 0.001727037 | 0.00740808  | 0.0881698   | 0.262419    | 0.261283    | 0.1818385   |   |   |
|      |   |          |   |   | 0.1093941   | 0.0553106   | 0.02313321  | 0.00736264  |             |             |   |   |
| 2019 | 2 | 1        | 1 | 1 | 0           | 0           | 100         | 0           | 0           | 0           | 0 | 0 |
|      | 0 | 0        | 0 | 0 | 9.65686E-05 | 0.000128758 | 0.000450653 |             |             |             |   |   |
|      |   |          |   |   | 0.001223202 | 0.015547544 | 0.140185412 | 0.305575227 | 0.24895384  | 0.14234211  |   |   |
|      |   |          |   |   | 0.076643276 | 0.040075967 | 0.019603425 | 0.009174017 |             |             |   |   |
| 2020 | 2 | 1        | 1 | 1 | 0           | 0           | 100         | 0           | 0           | 0           | 0 | 0 |
|      | 0 | 0        | 0 | 0 | 8.72982E-05 | 0.000174596 | 0.000392841 |             |             |             |   |   |
|      |   |          |   |   | 0.001091228 | 0.01117416  | 0           | 0.350851    | 0.3250979   | 0.1878216   |   |   |
|      |   |          |   |   | 0.0805325   | 0.0300306   | 0.00995198  | 0.002793536 |             |             |   |   |
| 2021 | 2 | 1        | 1 | 1 | 0           | 0           | 100         | 0           | 0           | 0           | 0 | 0 |
|      | 0 | 0        | 0 | 0 | 0           | 0           | 0.000158078 | 0.000632311 |             |             |   |   |
|      |   |          |   |   | 0.011065444 | 0           | 0.35441037  | 0.317894404 | 0.195700285 | 0.086152387 |   |   |
|      |   |          |   |   | 0.027189377 | 0.006006955 | 0.000790389 |             |             |             |   |   |

| #     | Total  | males |     |      |       |          |       |      |      |      |      |      |   |
|-------|--------|-------|-----|------|-------|----------|-------|------|------|------|------|------|---|
| #Year | Season | Fleet | Sex | Type | Shell | Maturity | Nsamp | Data | Vec  |      |      |      |   |
| 1992  | 2      | 1     | 1   | 0    | 0     | 0        | 100   | 0    | 0    | 0    | 0    | 0    | 0 |
|       | 0      | 0     | 0   | 0    | 0.01  | 0.01     | 0.02  | 0.04 | 0.06 | 0.08 | 0.13 | 0.15 |   |
|       |        |       |     |      | 0.19  | 0.16     | 0.1   | 0.03 | 0.01 |      |      |      |   |
| 1993  | 2      | 1     | 1   | 0    | 0     | 0        | 100   | 0    | 0    | 0    | 0    | 0    | 0 |
|       | 0      | 0     | 0   | 0    | 0     | 0        | 0.02  | 0.03 | 0.04 | 0.08 | 0.15 | 0.2  |   |
|       |        |       |     |      | 0.19  | 0.15     | 0.09  | 0.03 | 0.01 |      |      |      |   |
| 1994  | 2      | 1     | 1   | 0    | 0     | 0        | 100   | 0    | 0    | 0    | 0    | 0    | 0 |
|       | 0      | 0     | 0   | 0    | 0.02  | 0.03     | 0.04  | 0.04 | 0.06 | 0.1  | 0.15 | 0.17 |   |
|       |        |       |     |      | 0.15  | 0.12     | 0.07  | 0.03 | 0.01 |      |      |      |   |
| 1995  | 2      | 1     | 1   | 0    | 0     | 0        | 100   | 0    | 0    | 0    | 0    | 0    | 0 |
|       | 0      | 0     | 0   | 0    | 0.01  | 0.02     | 0.04  | 0.06 | 0.08 | 0.11 | 0.17 | 0.17 |   |
|       |        |       |     |      | 0.15  | 0.1      | 0.06  | 0.02 | 0.01 |      |      |      |   |
| 1996  | 2      | 1     | 1   | 0    | 0     | 0        | 100   | 0    | 0    | 0    | 0    | 0    | 0 |
|       | 0      | 0     | 0   | 0    | 0     | 0.01     | 0.02  | 0.03 | 0.07 | 0.13 | 0.23 | 0.21 |   |
|       |        |       |     |      | 0.15  | 0.09     | 0.04  | 0.01 | 0    |      |      |      |   |
| 1997  | 2      | 1     | 1   | 0    | 0     | 0        | 100   | 0    | 0    | 0    | 0    | 0    | 0 |
|       | 0      | 0     | 0   | 0    | 0     | 0        | 0     | 0.01 | 0.02 | 0.07 | 0.16 | 0.23 |   |
|       |        |       |     |      | 0.23  | 0.16     | 0.08  | 0.03 | 0.01 |      |      |      |   |
| 1998  | 2      | 1     | 1   | 0    | 0     | 0        | 100   | 0    | 0    | 0    | 0    | 0    | 0 |
|       | 0      | 0     | 0   | 0    | 0     | 0        | 0     | 0.01 | 0.03 | 0.07 | 0.16 | 0.23 |   |
|       |        |       |     |      | 0.23  | 0.16     | 0.07  | 0.02 | 0.01 |      |      |      |   |

|      |      |      |      |      |      |      |      |      |      |      |      |      |
|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 1999 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.02 | 0.06 | 0.13 | 0.21 |
|      | 0.25 | 0.19 | 0.1  | 0.03 | 0.01 |      |      |      |      |      |      |      |
| 2000 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.01 | 0.02 | 0.05 | 0.11 | 0.18 |
|      | 0.23 | 0.21 | 0.13 | 0.04 | 0.01 |      |      |      |      |      |      |      |
| 2001 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.01 | 0.02 | 0.04 | 0.08 | 0.17 | 0.2  |
|      | 0.19 | 0.15 | 0.09 | 0.03 | 0.01 |      |      |      |      |      |      |      |
| 2002 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.02 | 0.03 | 0.05 | 0.12 | 0.23 | 0.23 |
|      | 0.16 | 0.09 | 0.04 | 0.01 | 0    |      |      |      |      |      |      |      |
| 2003 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.02 | 0.06 | 0.16 | 0.23 |
|      | 0.23 | 0.16 | 0.08 | 0.02 | 0.01 |      |      |      |      |      |      |      |
| 2004 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.05 | 0.1  | 0.16 |
|      | 0.2  | 0.2  | 0.14 | 0.06 | 0.02 |      |      |      |      |      |      |      |
| 2005 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.1  | 0.16 |
|      | 0.21 | 0.21 | 0.15 | 0.07 | 0.02 |      |      |      |      |      |      |      |
| 2006 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.01 | 0.02 | 0.03 | 0.04 | 0.23 | 0.33 |
|      | 0.2  | 0.08 | 0.04 | 0.02 | 0.01 |      |      |      |      |      |      |      |
| 2007 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.01 | 0.02 | 0.04 | 0.22 | 0.31 |
|      | 0.22 | 0.1  | 0.05 | 0.01 | 0    |      |      |      |      |      |      |      |
| 2008 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.02 | 0.04 | 0.21 | 0.29 |
|      | 0.22 | 0.12 | 0.06 | 0.02 | 0    |      |      |      |      |      |      |      |
| 2009 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.01 | 0.03 | 0.14 | 0.22 |
|      | 0.22 | 0.19 | 0.12 | 0.04 | 0.01 |      |      |      |      |      |      |      |
| 2010 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.08 | 0.17 |
|      | 0.23 | 0.25 | 0.17 | 0.06 | 0.02 |      |      |      |      |      |      |      |
| 2011 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.04 | 0.08 | 0.14 |
|      | 0.21 | 0.24 | 0.18 | 0.08 | 0.02 |      |      |      |      |      |      |      |
| 2012 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.01 | 0.02 | 0.05 | 0.13 | 0.18 |
|      | 0.2  | 0.19 | 0.13 | 0.06 | 0.02 |      |      |      |      |      |      |      |
| 2013 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.02 | 0.03 | 0.06 | 0.11 | 0.18 | 0.21 |
|      | 0.16 | 0.1  | 0.06 | 0.03 | 0.01 |      |      |      |      |      |      |      |
| 2014 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.02 | 0.02 | 0.03 | 0.08 | 0.2  | 0.25 |
|      | 0.19 | 0.11 | 0.06 | 0.02 | 0.01 |      |      |      |      |      |      |      |
| 2015 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.02 | 0.02 | 0.04 | 0.08 | 0.13 | 0.17 |
|      | 0.15 | 0.14 | 0.12 | 0.08 | 0.03 |      |      |      |      |      |      |      |
| 2016 | 2    | 1    | 1    | 0    | 0    | 0    | 100  | 0    | 0    | 0    | 0    | 0    |
|      | 0    | 0    | 0    | 0    | 0    | 0.01 | 0.01 | 0.02 | 0.03 | 0.07 | 0.13 | 0.2  |
|      | 0.18 | 0.15 | 0.12 | 0.07 | 0    |      |      |      |      |      |      |      |

|      |             |             |             |             |             |             |        |        |        |        |        |       |
|------|-------------|-------------|-------------|-------------|-------------|-------------|--------|--------|--------|--------|--------|-------|
| 2017 | 2           | 1           | 1           | 0           | 0           | 0           | 100    | 0      | 0      | 0      | 0      | 0     |
|      | 0           | 0           | 0           | 0           | 0           | 0.01        | 0.02   | 0.03   | 0.05   | 0.1    | 0.22   | 0.22  |
|      | 0.17        | 0.09        | 0.05        | 0.01        | 0           |             |        |        |        |        |        |       |
| 2018 | 2           | 1           | 1           | 0           | 0           | 0           | 100    | 0      | 0      | 0      | 0      | 0     |
|      | 0           | 0           | 0           | 0           | 0.01        | 0.02        | 0.03   | 0.04   | 0.06   | 0.13   | 0.24   | 0.2   |
|      | 0.13        | 0.08        | 0.04        | 0.02        | 0.01        |             |        |        |        |        |        |       |
| 2019 | 2           | 1           | 1           | 0           | 0           | 0           | 100    | 0.000  | 0.000  | 0.000  | 0.000  | 0.000 |
|      | 0.000       | 0.000       | 0.000       | 0.001       | 0.002       | 0.007       | 0.021  | 0.053  | 0.095  | 0.162  | 0.250  |       |
|      | 0.209       | 0.095       | 0.052       | 0.028       | 0.015       | 0.007       | 0.003  |        |        |        |        |       |
| 2020 | 2           | 1           | 1           | 0           | 0           | 0           | 100    | 0.0000 |        | 0.0000 |        |       |
|      | 0.0000      |             | 0.0000      |             | 0.0000      |             | 0.0000 |        | 0.0000 |        | 0.0002 |       |
|      | 0.0011      |             | 0.0050      |             | 0.0132      |             | 0.0319 |        | 0.0578 |        | 0.1057 |       |
|      | 0.1183      |             | 0.2370      |             | 0.2196      |             | 0.1269 |        | 0.0544 |        | 0.0203 |       |
|      | 0.0067      |             | 0.0019      |             |             |             |        |        |        |        |        |       |
| 2021 | 2           | 1           | 1           | 0           | 0           | 0           | 100    | 0      | 0      | 0      | 0      | 0     |
|      | 0           | 0           | 2.88245E-05 | 0.000172947 | 0.000807087 | 0.003016968 |        |        |        |        |        |       |
|      | 0.009579354 | 0.023338266 | 0.064230673 | 0.13487961  | 0.246267223 |             |        |        |        |        |        |       |
|      | 0.236409232 | 0.166625031 | 0.078354696 |             |             |             |        |        |        |        |        |       |
|      | 0.028372951 | 0.006975538 | 0.000941601 |             |             |             |        |        |        |        |        |       |

# Discard females

| #Year | Season     | Fleet      | Sex       | Type      | Shell    | Maturity  | Nsamp  | Data   | Vec |
|-------|------------|------------|-----------|-----------|----------|-----------|--------|--------|-----|
| 1995  | 2          | 1          | 2         | 2         | 0        | 0         | 100    | 0      | 0   |
|       | 0.00277778 | 0.0277778  | 0.105556  | 0.186111  | 0.216667 | 0.241667  |        |        |     |
|       | 0.0916667  | 0.0277778  | 0.0333333 | 0.0666667 | 0        | 0         | 0      | 0      |     |
|       | 0          | 0          | 0         | 0         |          |           |        |        |     |
| 1996  | 2          | 1          | 2         | 2         | 0        | 0         | 100    | 0      | 0   |
|       | 0.00769231 | 0.0230769  | 0.123077  | 0.176923  | 0.315385 | 0.184615  |        |        |     |
|       | 0.0846154  | 0.0615385  | 0.0230769 | 0         | 0        | 0         | 0      | 0      | 0   |
|       | 0          | 0          | 0         |           |          |           |        |        |     |
| 1997  | 2          | 1          | 2         | 2         | 0        | 0         | 100    | 0      | 0   |
|       | 0.0017301  | 0.0017301  | 0.108997  | 0.243945  | 0.297578 | 0.271626  |        |        |     |
|       | 0.0553633  | 0.00519031 | 0.0138408 | 0         | 0        | 0         | 0      | 0      | 0   |
|       | 0          | 0          | 0         |           |          |           |        |        |     |
| 1998  | 2          | 1          | 2         | 2         | 0        | 0         | 100    | 0      | 0   |
|       | 0          | 0.0375     | 0.125     | 0.2375    | 0.25     | 0.275     | 0.0375 | 0.0125 | 0   |
|       | 0          | 0          | 0         | 0         | 0        | 0         | 0      | 0      | 0   |
| 1999  | 2          | 1          | 2         | 2         | 0        | 0         | 100    | 0      | 0   |
|       | 0.0422535  | 0.084507   | 0.253521  | 0.309859  | 0.28169  | 0.0140845 |        |        |     |
|       | 0          | 0          | 0         | 0         | 0        | 0         | 0      | 0      | 0   |
| 2000  | 2          | 1          | 2         | 2         | 0        | 0         | 100    | 0      | 0   |
|       | 0.0422535  | 0.084507   | 0.253521  | 0.309859  | 0.28169  | 0.0140845 |        |        |     |
|       | 0          | 0          | 0         | 0         | 0        | 0         | 0      | 0      | 0   |
| 2001  | 2          | 1          | 2         | 2         | 0        | 0         | 100    | 0      | 0   |
|       | 0.0422535  | 0.084507   | 0.253521  | 0.309859  | 0.28169  | 0.0140845 |        |        |     |
|       | 0          | 0          | 0         | 0         | 0        | 0         | 0      | 0      | 0   |

|      |             |             |            |             |             |            |     |   |   |             |            |   |
|------|-------------|-------------|------------|-------------|-------------|------------|-----|---|---|-------------|------------|---|
| 2002 | 2           | 1           | 2          | 2           | 0           | 0          | 100 | 0 | 0 | 0           | 0          | 0 |
|      | 0.0322581   | 0.193548    | 0.274194   | 0.354839    | 0.112903    | 0.0322581  |     |   |   |             |            |   |
|      | 0           | 0           | 0          | 0           | 0           | 0          | 0   | 0 | 0 | 0           | 0          | 0 |
| 2003 | 2           | 1           | 2          | 2           | 0           | 0          | 100 | 0 | 0 | 0           | 0          | 0 |
|      | 0.0322581   | 0.193548    | 0.274194   | 0.354839    | 0.112903    | 0.0322581  |     |   |   |             |            |   |
|      | 0           | 0           | 0          | 0           | 0           | 0          | 0   | 0 | 0 | 0           | 0          | 0 |
| 2004 | 2           | 1           | 2          | 2           | 0           | 0          | 100 | 0 | 0 | 0           | 0          | 0 |
|      | 0.222222    | 0.222222    | 0.111111   | 0.222222    | 0           | 0.111111   | 0   |   |   |             |            |   |
|      | 0           | 0.111111    | 0          | 0           | 0           | 0          | 0   | 0 | 0 | 0           | 0          | 0 |
| 2005 | 2           | 1           | 2          | 2           | 0           | 0          | 100 | 0 | 0 | 0           | 0          | 0 |
|      | 0.0629921   | 0.259843    | 0.291339   | 0.228346    | 0.0787402   | 0.0708661  |     |   |   |             |            |   |
|      | 0.00787402  | 0           | 0          | 0           | 0           | 0          | 0   | 0 | 0 | 0           | 0          | 0 |
| 2006 | 2           | 1           | 2          | 2           | 0           | 0          | 100 | 0 | 0 | 0           | 0          | 0 |
|      | 0           | 0.0350877   | 0.140351   | 0.333333    | 0.263158    | 0.157895   |     |   |   |             |            |   |
|      | 0.0175439   | 0.0526316   | 0          | 0           | 0           | 0          | 0   | 0 | 0 | 0           | 0          | 0 |
|      | 0           |             |            |             |             |            |     |   |   |             |            |   |
| 2007 | 2           | 1           | 2          | 2           | 0           | 0          | 100 | 0 | 0 | 0           | 0          | 0 |
|      | 0           | 0.0109589   | 0.205479   | 0.257534    | 0.30411     | 0.134247   |     |   |   |             |            |   |
|      | 0.0383562   | 0.0328767   | 0.0109589  | 0.00273973  | 0.00273973  | 0          | 0   |   |   |             |            |   |
|      | 0           | 0           | 0          | 0           |             |            |     |   |   |             |            |   |
| 2008 | 2           | 1           | 2          | 2           | 0           | 0          | 100 | 0 | 0 | 0           | 0          | 0 |
|      | 0           | 0.021692    | 0.164859   | 0.264642    | 0.368764    | 0.160521   |     |   |   |             |            |   |
|      | 0.0130152   | 0.00433839  | 0.0021692  | 0           | 0           | 0          | 0   | 0 | 0 | 0           | 0          | 0 |
|      | 0           | 0           |            |             |             |            |     |   |   |             |            |   |
| 2009 | 2           | 1           | 2          | 2           | 0           | 0          | 100 | 0 | 0 | 0           | 0          | 0 |
|      | 0.00406504  | 0.00406504  | 0.0934959  | 0.321138    | 0.386179    | 0.150407   |     |   |   |             |            |   |
|      | 0.0284553   | 0.00406504  | 0.00813008 | 0           | 0           | 0          | 0   | 0 | 0 | 0           | 0          | 0 |
|      | 0           | 0           |            |             |             |            |     |   |   |             |            |   |
| 2010 | 2           | 1           | 2          | 2           | 0           | 0          | 100 | 0 | 0 | 0           | 0          | 0 |
|      | 0.0172414   | 0.0905172   | 0.237069   | 0.284483    | 0.273707    | 0.0668103  |     |   |   |             |            |   |
|      | 0.0150862   | 0.0107759   | 0          | 0.00431034  | 0           | 0          | 0   | 0 | 0 | 0           | 0          | 0 |
|      | 0           | 0           |            |             |             |            |     |   |   |             |            |   |
| 2011 | 2           | 1           | 2          | 2           | 0           | 0          | 100 | 0 | 0 | 0.000356697 |            |   |
|      | 0.00481541  | 0.0304976   | 0.264848   | 0.299269    | 0.190476    | 0.15231    |     |   |   |             |            |   |
|      | 0.0458356   | 0.00784733  | 0.00178348 | 0.000535045 | 0.000535045 |            |     |   |   |             |            |   |
|      | 0.000891742 | 0           | 0          | 0           | 0           | 0          | 0   | 0 |   |             |            |   |
| 2012 | 2           | 1           | 2          | 2           | 0           | 0          | 100 | 0 | 0 | 0           | 0.00186683 |   |
|      | 0.00808961  | 0.0304916   | 0.0584941  | 0.0920971   | 0.146857    | 0.338519   |     |   |   |             |            |   |
|      | 0.242688    | 0.0653391   | 0.0136901  | 0.000622278 | 0.00124456  | 0          | 0   |   |   |             |            |   |
|      | 0           | 0           | 0          | 0           |             |            |     |   |   |             |            |   |
| 2013 | 2           | 1           | 2          | 2           | 0           | 0          | 100 | 0 | 0 | 0           | 0          | 0 |
|      | 0.000341064 | 0.00989086  | 0.0443383  | 0.0985675   | 0.183151    | 0.380286   |     |   |   |             |            |   |
|      | 0.232947    | 0.0405866   | 0.00750341 | 0.00204638  | 0.000341064 | 0          | 0   |   |   |             |            |   |
|      | 0           | 0           | 0          | 0           |             |            |     |   |   |             |            |   |
| 2014 | 2           | 1           | 2          | 2           | 0           | 0          | 100 | 0 | 0 | 0           | 0          | 0 |
|      | 0.00017337  | 0.0109223   | 0.0353675  | 0.0788835   | 0.227982    | 0.394764   |     |   |   |             |            |   |
|      | 0.215326    | 0.028086    | 0.00572122 | 0.00208044  | 0.000520111 | 0.00017337 |     |   |   |             |            |   |
|      | 0           | 0           | 0          | 0           |             |            |     |   |   |             |            |   |
| 2015 | 2           | 1           | 2          | 2           | 0           | 0          | 100 | 0 | 0 | 0           | 0          | 0 |
|      | 0.000434405 | 0.0186794   | 0.050391   | 0.116855    | 0.256299    | 0.365769   |     |   |   |             |            |   |
|      | 0.163771    | 0.0208514   | 0.00521286 | 0.000434405 | 0.000434405 |            |     |   |   |             |            |   |
|      | 0.000434405 | 0.000434405 | 0          | 0           | 0           | 0          | 0   | 0 | 0 | 0           | 0          | 0 |

|      |   |   |   |   |   |   |     |   |   |   |            |   |
|------|---|---|---|---|---|---|-----|---|---|---|------------|---|
| 2016 | 2 | 1 | 2 | 2 | 0 | 0 | 100 | 0 | 0 | 0 | 0          | 0 |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
| 2017 | 2 | 1 | 2 | 2 | 0 | 0 | 100 | 0 | 0 | 0 | 0.0019084  |   |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
| 2018 | 2 | 1 | 2 | 2 | 0 | 0 | 100 | 0 | 0 | 0 | 0.00357143 |   |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
| 2019 | 2 | 1 | 2 | 2 | 0 | 0 | 100 | 0 | 0 | 0 | 0          | 0 |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
| 2020 | 2 | 1 | 2 | 2 | 0 | 0 | 100 | 0 | 0 | 0 | 0.0526316  |   |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
| 2021 | 2 | 1 | 2 | 2 | 0 | 0 | 100 | 0 | 0 | 0 | 0          | 0 |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
|      | 1 | 0 | 0 | 0 | 0 | 0 | 0   | 0 | 0 | 0 | 0          | 0 |
|      |   |   |   |   |   |   |     |   |   |   |            |   |
|      | 0 | 0 | 0 | 0 | 0 | 0 | 0   | 0 | 0 | 0 | 0          | 0 |

# Trawl bycatch female

| #Year | Season | Fleet | Sex | Type | Shell | Maturity | Nsamp | Data        | Vec         |
|-------|--------|-------|-----|------|-------|----------|-------|-------------|-------------|
| 1991  | 2      | 2     | 2   | 2    | 0     | 0        | 100   | 0.0102514   | 0.00863643  |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
| 1992  | 2      | 2     | 2   | 2    | 0     | 0        | 100   | 0.0080061   | 0.0443195   |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
| 1993  | 2      | 2     | 2   | 2    | 0     | 0        | 100   | 0.000588235 | 0.00294118  |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
| 1994  | 2      | 2     | 2   | 2    | 0     | 0        | 100   | 0           | 0.000738007 |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
| 1995  | 2      | 2     | 2   | 2    | 0     | 0        | 100   | 0.002849    | 0.00237417  |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
| 1996  | 2      | 2     | 2   | 2    | 0     | 0        | 100   | 0           | 0.0040404   |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
| 1997  | 2      | 2     | 2   | 2    | 0     | 0        | 100   | 0           | 0.000149298 |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |
|       |        |       |     |      |       |          |       |             |             |

|      |             |             |             |             |             |            |     |             |             |
|------|-------------|-------------|-------------|-------------|-------------|------------|-----|-------------|-------------|
|      | 0.00492684  | 0.00149298  | 0.00141833  | 0.00134368  | 0.000746491 |            |     |             |             |
|      | 0.000373246 | 0           | 0           | 0           | 0           | 0          | 0   | 0           |             |
| 1998 | 2           | 2           | 2           | 2           | 0           | 0          | 100 | 0.00046804  | 0.000267451 |
|      | 0.000601765 | 0.00213961  | 0.00909334  | 0.0192565   | 0.0141081   | 0.00855844 |     |             |             |
|      | 0.00447981  | 0.00147098  | 0.000668628 | 0.000334314 | 0.000534902 |            |     |             |             |
|      | 0.000200588 | 0.000200588 | 0           | 0           | 0           | 0          | 0   | 0           | 0           |
| 1999 | 2           | 2           | 2           | 2           | 0           | 0          | 100 | 0.000286266 | 0.000357833 |
|      | 0.0012882   | 0.00121663  | 0.00229013  | 0.0040793   | 0.00379303  | 0.00207543 |     |             |             |
|      | 0.0017176   | 0.000572533 | 0.000572533 | 7.16E-05    | 0.000286266 |            |     |             |             |
|      | 0.000143133 | 0.0002147   | 0           | 0           | 0           | 0          | 0   | 0           | 0           |
| 2000 | 2           | 2           | 2           | 2           | 0           | 0          | 100 | 0.000428837 | 0.000714728 |
|      | 0.00347834  | 0.00795731  | 0.00681374  | 0.0129604   | 0.0162958   | 0.00957736 |     |             |             |
|      | 0.00466956  | 0.00104827  | 0.000428837 | 0.000524134 | 0.000238243 |            |     |             |             |
|      | 0.000142946 | 0           | 0           | 0           | 0           | 0          | 0   | 0           | 0           |
| 2001 | 2           | 2           | 2           | 2           | 0           | 0          | 100 | 0.000131173 | 0.00170525  |
|      | 0.00150849  | 0.00360727  | 0.00236112  | 0.00819833  | 0.0114121   | 0.00708336 |     |             |             |
|      | 0.00603397  | 0.00222995  | 0.00078704  | 0.000327933 | 0.000327933 |            |     |             |             |
|      | 0.000327933 | 0.000131173 | 0           | 0           | 0           | 0          | 0   | 0           | 0           |
| 2002 | 2           | 2           | 2           | 2           | 0           | 0          | 100 | 0.000169062 | 0.00028177  |
|      | 0.000788955 | 0.00214145  | 0.00247957  | 0.00777684  | 0.00969287  | 0.00631164 |     |             |             |
|      | 0.00433925  | 0.00208509  | 0.00135249  | 0.000676247 | 0.000338123 |            |     |             |             |
|      | 0.000563539 | 0.00028177  | 0           | 0           | 0           | 0          | 0   | 0           | 0           |
| 2003 | 2           | 2           | 2           | 2           | 0           | 0          | 100 | 0.000193555 | 0.000435498 |
|      | 0.000290332 | 0.000483887 | 0.00295171  | 0.00677441  | 0.00735508  | 0.00706474 |     |             |             |
|      | 0.00445176  | 0.00159683  | 0.00072583  | 0.000870996 | 4.84E-05    |            |     |             |             |
|      | 0.000435498 | 0.000532275 | 0           | 0           | 0           | 0          | 0   | 0           | 0           |
| 2004 | 2           | 2           | 2           | 2           | 0           | 0          | 100 | 0.00290698  | 0.0418707   |
|      | 0.0208078   | 0.00775194  | 0.00622195  | 0.0106079   | 0.0132089   | 0.0129539  |     |             |             |
|      | 0.00912893  | 0.00377397  | 0.00152999  | 0.000815993 | 0.000254998 |            |     |             |             |
|      | 0.000305998 | 0.000356997 | 0           | 0           | 0           | 0          | 0   | 0           | 0           |
| 2005 | 2           | 2           | 2           | 2           | 0           | 0          | 100 | 0.00321469  | 0.00619699  |
|      | 0.00778496  | 0.020605    | 0.0495372   | 0.065262    | 0.0280026   | 0.00697161 |     |             |             |
|      | 0.00495759  | 0.00220768  | 0.00131686  | 0.000580968 | 0.000116194 |            |     |             |             |
|      | 0.000154925 | 3.87E-05    | 0           | 0           | 0           | 0          | 0   | 0           | 0           |
| 2006 | 2           | 2           | 2           | 2           | 0           | 0          | 100 | 0.00019977  | 0.000399541 |
|      | 0.000599311 | 0.00209759  | 0.00804075  | 0.0206263   | 0.0274684   | 0.0179793  |     |             |             |
|      | 0.011287    | 0.00659242  | 0.0030465   | 0.000998851 | 0.000349598 |            |     |             |             |
|      | 0.000349598 | 9.99E-05    | 0           | 0           | 0           | 0          | 0   | 0           | 0           |
| 2007 | 2           | 2           | 2           | 2           | 0           | 0          | 100 | 0.000111346 | 0.00129904  |
|      | 0.00386     | 0.018966    | 0.043425    | 0.0501058   | 0.0318821   | 0.0120625  |     |             |             |
|      | 0.00389712  | 0.00129904  | 0.00103923  | 0.000371154 | 0.000222692 |            |     |             |             |
|      | 0.000371154 | 0.000259808 | 0           | 0           | 0           | 0          | 0   | 0           | 0           |
| 2008 | 2           | 2           | 2           | 2           | 0           | 0          | 100 | 0.000463213 | 0.000772022 |
|      | 0.00069482  | 0.00146684  | 0.00579016  | 0.0160581   | 0.028256    | 0.0240099  |     |             |             |
|      | 0.0251679   | 0.014514    | 0.00586737  | 0.0035513   | 0.00231607  | 0.00169845 |     |             |             |
|      | 0.000849224 | 0.000386011 | 0.000154404 | 0.000231607 | 0.000154404 | 0          |     |             |             |
|      | 7.72E-05    | 0           |             |             |             |            |     |             |             |
| 2009 | 2           | 2           | 2           | 2           | 0           | 0          | 100 | 0.000126662 | 0.00050665  |
|      | 0.000886637 | 0.0010133   | 0.0050665   | 0.0172261   | 0.0352122   | 0.0400253  |     |             |             |
|      | 0.0347055   | 0.0193794   | 0.00620646  | 0.0020266   | 0.00151995  | 0.00126662 |     |             |             |
|      | 0.0010133   | 0.000379987 | 0.00050665  | 0.000253325 | 0           |            |     |             |             |
|      | 0.000126662 | 0           |             |             |             |            |     |             |             |
| 2010 | 2           | 2           | 2           | 2           | 0           | 0          | 100 | 0.000375432 | 0.00337889  |
|      | 0.00135155  | 0.0016519   | 0.0125394   | 0.0456525   | 0.0649497   | 0.0506833  |     |             |             |

|      |             |             |             |             |             |             |       |             |             |       |
|------|-------------|-------------|-------------|-------------|-------------|-------------|-------|-------------|-------------|-------|
|      | 0.035666    | 0.0144166   | 0.00360414  | 0.00142664  | 0.00135155  |             |       |             |             |       |
|      | 0.000675777 | 0.00082595  | 0.000150173 | 0.000150173 | 0           | 7.51E-05    |       |             |             |       |
|      | 0           | 0.000150173 |             |             |             |             |       |             |             |       |
| 2011 | 2           | 2           | 2           | 2           | 0           | 0           | 100   | 0           | 0.000635901 |       |
|      | 0.000817587 | 0.0065407   | 0.0178052   | 0.025436    | 0.0313408   | 0.0326126   |       |             |             |       |
|      | 0.0337936   | 0.0160792   | 0.00608648  | 0.00245276  | 0.0012718   |             |       |             |             |       |
|      | 0.000635901 | 0.000726744 | 0.000363372 | 0.000090843 | 0.000181686 | 0           |       |             |             |       |
|      | 0           | 0           |             |             |             |             |       |             |             |       |
| 2012 | 2           | 2           | 2           | 2           | 0           | 0           | 100   | 0.000350355 | 0.000262766 |       |
|      | 0.000525532 | 0.00175177  | 0.00420426  | 0.0164667   | 0.0238241   | 0.0333713   |       |             |             |       |
|      | 0.0372252   | 0.0230358   | 0.0112114   | 0.00455461  | 0.00140142  |             |       |             |             |       |
|      | 0.000613121 | 0.000613121 | 0.000700709 | 8.76E-05    | 8.76E-05    | 8.76E-05    |       |             |             |       |
|      | 0.000175177 | 0           | 8.76E-05    |             |             |             |       |             |             |       |
| 2013 | 2           | 2           | 2           | 2           | 0           | 0           | 100   | 0.00110718  | 0.0035617   |       |
|      | 0.00366534  | 0.00641308  | 0.0108039   | 0.0185542   | 0.0244213   | 0.0197524   |       |             |             |       |
|      | 0.016307    | 0.00879428  | 0.00393581  | 0.0019717   | 0.00127655  |             |       |             |             |       |
|      | 0.000879681 | 0.000586454 | 0           | 0           | 0           | 0           |       |             |             |       |
| 2014 | 2           | 2           | 2           | 2           | 0           | 0           | 100   | 0.000318801 | 0.00310831  |       |
|      | 0.00310831  | 0.0120347   | 0.0183311   | 0.014904    | 0.0131506   | 0.0123536   |       |             |             |       |
|      | 0.0133897   | 0.01331     | 0.00852793  | 0.00414442  | 0.00231131  | 0.0010361   |       |             |             |       |
|      | 0.000398502 | 0.000478202 | 0.000239101 | 0.000159401 | 0.000159401 | 0           |       |             |             |       |
|      | 0           |             |             |             |             |             |       |             |             |       |
| 2015 | 2           | 2           | 2           | 2           | 0           | 0           | 100   | 0.000854476 | 0.00170895  |       |
|      | 0.00256343  | 0.00854476  | 0.0139345   | 0.0153806   | 0.0239911   | 0.0248455   |       |             |             |       |
|      | 0.0099908   | 0.00598133  | 0.00190614  | 0.000854476 | 0.000328645 |             |       |             |             |       |
|      | 0.000394374 | 0.000394374 | 0.000131458 | 0.000262916 | 0.000197187 | 6.57E-05    |       |             |             |       |
|      | 0           | 0           | 6.57E-05    |             |             |             |       |             |             |       |
| 2016 | 2           | 2           | 2           | 2           | 0           | 0           | 100   | 0.000194212 | 0.000582637 |       |
|      | 0.00320451  | 0.00640901  | 0.0113614   | 0.0177704   | 0.015537    | 0.0102933   |       |             |             |       |
|      | 0.00757429  | 0.00679744  | 0.00446689  | 0.00378714  | 0.00203923  | 0.00106817  |       |             |             |       |
|      | 0.000873956 | 0.000291319 | 0.000582637 | 0.000388425 | 0.000194212 |             |       |             |             |       |
|      | 0.000194212 | 0           | 0           |             |             |             |       |             |             |       |
| 2017 | 2           | 2           | 2           | 2           | 0           | 0           | 100   | 0.000283527 | 0.000567054 |       |
|      | 0.00378036  | 0.0142709   | 0.0131368   | 0.015783    | 0.010396    | 0.0073717   |       |             |             |       |
|      | 0.00406389  | 0.00321331  | 0.00217371  | 0.000567054 | 0.0010396   |             |       |             |             |       |
|      | 0.000567054 | 0.000378036 | 0.000756072 | 0.000283527 | 0.000094509 |             |       |             |             |       |
|      | 0.000283527 | 0           | 0.000283527 | 0.000094509 |             |             |       |             |             |       |
| 2018 | 2           | 2           | 2           | 2           | 0           | 0           | 100   | 0.000256715 | 0.000385072 |       |
|      | 0.000545519 | 0.0036261   | 0.00888875  | 0.0186118   | 0.0143439   | 0.00709174  |       |             |             |       |
|      | 0.00311267  | 0.00121939  | 0.000417161 | 0.000577608 | 0.000224625 |             |       |             |             |       |
|      | 0.000320893 | 0.000224625 | 6.42E-05    | 0.000128357 | 0.000096268 | 0           |       |             |             |       |
|      | 6.42E-05    | 3.21E-05    | 6.42E-05    |             |             |             |       |             |             |       |
| 2019 | 2           | 2           | 2           | 2           | 0           | 0           | 100   | 0.003       | 0.007       | 0.017 |
|      | 0.130       | 0.309       | 0.216       | 0.119       | 0.079       | 0.029       | 0.019 | 0.017       | 0.011       | 0.008 |
|      | 0.001       | 0.001       | 0.002       | 0.000       | 0.000       | 0.001       | 0.000 |             |             |       |
|      |             |             |             |             |             |             |       |             |             |       |
| 2020 | 2           | 2           | 2           | 2           | 0           | 0           | 100   | 0.000755915 | 0.00113387  |       |
|      | 0.00151183  | 0.00415753  | 0.0126238   | 0.0221483   | 0.0159498   | 0.00786152  |       |             |             |       |
|      | 0.00438431  | 0.00143624  | 0.000831507 | 0.00105828  | 0.00098269  |             |       |             |             |       |
|      | 0.000680324 | 0.000604732 | 0.000680324 | 0           | 7.56E-05    | 0.000151183 |       |             |             |       |
|      | 0           | 0           |             |             |             |             |       |             |             |       |
| 2021 | 2           | 2           | 2           | 2           | 0           | 0           | 100   | 0           | 0.024875622 |       |
|      | 0.054726368 | 0.059701493 | 0.089552239 | 0.179104478 | 0.07960199  |             |       |             |             |       |
|      | 0.129353234 | 0.089552239 | 0.064676617 | 0.054726368 | 0.029850746 |             |       |             |             |       |



0.054726368 0.024875622 0.034825871 0.009950249 0.004975124 0  
 0.004975124 0.004975124 0.004975124 0

# Trawl bycatch male

| #Year | Season | Fleet | Sex | Type | Shell | Maturity | Nsamp | DataVec   |
|-------|--------|-------|-----|------|-------|----------|-------|---|
| 1991  | 2      | 2     | 1   | 2    | 0     | 0        | 100   | 0.0154473 0.0181154   |
|       |        |       |     |      |       |          |       | 0.0110237 0.0197304 0.0216964 0.0186069 0.0182559 0.0195899         |
|       |        |       |     |      |       |          |       | 0.0195197 0.0192389 0.032369 0.0406544 0.0641764 0.093456           |
|       |        |       |     |      |       |          |       | 0.0986519 0.0747086 0.0547676 0.0495015 0.0412863 0.0254178         |
|       |        |       |     |      |       |          |       | 0.016009 0.00554697   |
| 1992  | 2      | 2     | 1   | 2    | 0     | 0        | 100   | 0.0080061 0.0382196   |
|       |        |       |     |      |       |          |       | 0.0510865 0.0632863 0.0801563 0.0441289 0.044796 0.0329775          |
|       |        |       |     |      |       |          |       | 0.0264011 0.0171559 0.021159 0.0147732 0.0171559 0.0190621          |
|       |        |       |     |      |       |          |       | 0.0260198 0.0331681 0.0408883 0.0485132 0.0442242 0.027926          |
|       |        |       |     |      |       |          |       | 0.0130576 0.00438429  |
| 1993  | 2      | 2     | 1   | 2    | 0     | 0        | 100   | 0 0.000588235 0.00441176  |
|       |        |       |     |      |       |          |       | 0.0326471 0.05 0.0582353 0.0841176 0.0761765 0.0482353              |
|       |        |       |     |      |       |          |       | 0.0414706 0.0458824 0.0373529 0.0276471 0.0267647 0.0273529         |
|       |        |       |     |      |       |          |       | 0.0252941 0.0211765 0.0402941 0.0282353 0.0123529 0.00470588        |
|       |        |       |     |      |       |          |       | 0.000882353   |
| 1994  | 2      | 2     | 1   | 2    | 0     | 0        | 100   | 0 0 0   |
|       |        |       |     |      |       |          |       | 0.000738007 0.000738007 0.00295203 0.00442804 0.00516605 0.00295203 |
|       |        |       |     |      |       |          |       | 0.00295203 0.00811808 0.0147601 0.0369004 0.0597786 0.107749        |
|       |        |       |     |      |       |          |       | 0.15203 0.178598 0.17048 0.133579 0.0656827 0.0287823               |
|       |        |       |     |      |       |          |       | 0.0177122   |
| 1995  | 2      | 2     | 1   | 2    | 0     | 0        | 100   | 0.000474834 0.002849  |
|       |        |       |     |      |       |          |       | 0.000474834 0.00759734 0.022792 0.0436847 0.0503324 0.0441595       |
|       |        |       |     |      |       |          |       | 0.0569801 0.0356125 0.0294397 0.02849 0.0356125 0.0541311           |
|       |        |       |     |      |       |          |       | 0.0660019 0.0797721 0.0992403 0.110161 0.0764482 0.0470085          |
|       |        |       |     |      |       |          |       | 0.0270655 0.011396  |
| 1996  | 2      | 2     | 1   | 2    | 0     | 0        | 100   | 0 0.00606061 0.00606061   |
|       |        |       |     |      |       |          |       | 0.0020202 0.00606061 0.00606061 0.0181818 0.0606061 0.0424242       |
|       |        |       |     |      |       |          |       | 0.0686869 0.0626263 0.0323232 0.0585859 0.0787879 0.111111          |
|       |        |       |     |      |       |          |       | 0.121212 0.0747475 0.0565657 0.0505051 0.040404 0.020202            |
|       |        |       |     |      |       |          |       | 0.0020202   |
| 1997  | 2      | 2     | 1   | 2    | 0     | 0        | 100   | 0.000223947 0.000223947   |
|       |        |       |     |      |       |          |       | 0.000223947 0 0.000522544 0.00209018 0.00776351 0.0130636           |
|       |        |       |     |      |       |          |       | 0.0178411 0.0253807 0.036802 0.0454613 0.0809197 0.11802            |
|       |        |       |     |      |       |          |       | 0.130263 0.114885 0.0892057 0.070842 0.0378471 0.0202299            |
|       |        |       |     |      |       |          |       | 0.00955509 0.00507614   |
| 1998  | 2      | 2     | 1   | 2    | 0     | 0        | 100   | 0.000601765 0.000334314   |
|       |        |       |     |      |       |          |       | 0.000601765 0.00046804 0.000534902 0.00140412 0.00213961 0.00341    |
|       |        |       |     |      |       |          |       | 0.00829099 0.013172 0.0213961 0.037042 0.060444 0.102634            |
|       |        |       |     |      |       |          |       | 0.141214 0.146764 0.144557 0.123362 0.0820407 0.0325622             |
|       |        |       |     |      |       |          |       | 0.012169 0.00247392   |
| 1999  | 2      | 2     | 1   | 2    | 0     | 0        | 100   | 0.0004294 0.000357833   |
|       |        |       |     |      |       |          |       | 0.000644099 0.0004294 0.000500966 0.00207543 0.00543906 0.00658413  |
|       |        |       |     |      |       |          |       | 0.00701353 0.0121663 0.0128104 0.0256924 0.0493094 0.0918915        |
|       |        |       |     |      |       |          |       | 0.132112 0.145853 0.154011 0.141344 0.108996 0.0578258              |
|       |        |       |     |      |       |          |       | 0.0201102 0.00543906  |

|      |             |             |             |            |            |           |     |             |             |
|------|-------------|-------------|-------------|------------|------------|-----------|-----|-------------|-------------|
| 2000 | 2           | 2           | 1           | 2          | 0          | 0         | 100 | 0.000476485 | 0.00119121  |
|      | 0.00438367  | 0.0066708   | 0.00633726  | 0.0106256  | 0.0234431  | 0.0325916 |     |             |             |
|      | 0.0312574   | 0.027922    | 0.0268261   | 0.0291133  | 0.0413589  | 0.0568447 |     |             |             |
|      | 0.0716634   | 0.092867    | 0.12422     | 0.138228   | 0.116405   | 0.0647067 |     |             |             |
|      | 0.021966    | 0.00562253  |             |            |            |           |     |             |             |
| 2001 | 2           | 2           | 1           | 2          | 0          | 0         | 100 | 0.000459107 | 0.000459107 |
|      | 0.00209877  | 0.00150849  | 0.00183643  | 0.00321375 | 0.00996917 | 0.0198072 |     |             |             |
|      | 0.0255132   | 0.0284646   | 0.0323342   | 0.0299731  | 0.0365974  | 0.0549616 |     |             |             |
|      | 0.0861153   | 0.120352    | 0.137404    | 0.144881   | 0.118712   | 0.0668328 |     |             |             |
|      | 0.0253165   | 0.00701777  |             |            |            |           |     |             |             |
| 2002 | 2           | 2           | 1           | 2          | 0          | 0         | 100 | 0.000225416 | 0.00028177  |
|      | 0.000676247 | 0.00152156  | 0.000958016 | 0.0021978  | 0.00879121 | 0.017357  |     |             |             |
|      | 0.0248521   | 0.0333052   | 0.0477318   | 0.053818   | 0.0591152  | 0.0779374 |     |             |             |
|      | 0.103409    | 0.118287    | 0.125895    | 0.1153     | 0.0903353  | 0.0531981 |     |             |             |
|      | 0.0195548   | 0.00597351  |             |            |            |           |     |             |             |
| 2003 | 2           | 2           | 1           | 2          | 0          | 0         | 100 | 4.84E-05    | 0.000241943 |
|      | 0.000387109 | 0.000338721 | 0.00116133  | 0.00280654 | 0.00600019 | 0.0124359 |     |             |             |
|      | 0.0198393   | 0.0258879   | 0.0322752   | 0.0409852  | 0.0586471  | 0.0841479 |     |             |             |
|      | 0.125181    | 0.139698    | 0.141488    | 0.123536   | 0.0840027  | 0.045195  |     |             |             |
|      | 0.0172748   | 0.00420981  |             |            |            |           |     |             |             |
| 2004 | 2           | 2           | 1           | 2          | 0          | 0         | 100 | 0.00117299  | 0.0442166   |
|      | 0.0219808   | 0.00902693  | 0.00331497  | 0.00566095 | 0.0226948  | 0.0402387 |     |             |             |
|      | 0.0384537   | 0.0390147   | 0.0381477   | 0.0359547  | 0.0420747  | 0.0550286 |     |             |             |
|      | 0.0721644   | 0.0825683   | 0.0853223   | 0.0832823  | 0.0705324  | 0.0458996 |     |             |             |
|      | 0.0236638   | 0.00708894  |             |            |            |           |     |             |             |
| 2005 | 2           | 2           | 1           | 2          | 0          | 0         | 100 | 0.00209148  | 0.00317596  |
|      | 0.00352454  | 0.00937294  | 0.022619    | 0.0290096  | 0.0223866  | 0.0259499 |     |             |             |
|      | 0.0309462   | 0.031411    | 0.0388861   | 0.0455091  | 0.0531004  | 0.0541849 |     |             |             |
|      | 0.0570123   | 0.0616213   | 0.0615438   | 0.0721174  | 0.0765328  | 0.0596073 |     |             |             |
|      | 0.0314884   | 0.0109609   |             |            |            |           |     |             |             |
| 2006 | 2           | 2           | 1           | 2          | 0          | 0         | 100 | 0.000249713 | 0.000399541 |
|      | 0.000249713 | 0.00114868  | 0.00289667  | 0.00369575 | 0.0070419  | 0.0141837 |     |             |             |
|      | 0.0222244   | 0.0262698   | 0.0401538   | 0.0607801  | 0.0697198  | 0.0571842 |     |             |             |
|      | 0.0664236   | 0.0858513   | 0.089547    | 0.103032   | 0.100235   | 0.0844529 |     |             |             |
|      | 0.0453978   | 0.0187285   |             |            |            |           |     |             |             |
| 2007 | 2           | 2           | 1           | 2          | 0          | 0         | 100 | 0.000111346 | 0.000334039 |
|      | 0.000371154 | 0.00152173  | 0.00330327  | 0.00664366 | 0.0133615  | 0.0181865 |     |             |             |
|      | 0.027354    | 0.0301377   | 0.0403444   | 0.0562669  | 0.0610919  | 0.0808744 |     |             |             |
|      | 0.10667     | 0.126823    | 0.114687    | 0.0726348  | 0.0391567  | 0.019634  |     |             |             |
|      | 0.00809116  | 0.00322904  |             |            |            |           |     |             |             |
| 2008 | 2           | 2           | 1           | 2          | 0          | 0         | 100 | 0.000463213 | 0.00177565  |
|      | 0.000540415 | 0.00115803  | 0.00185285  | 0.00586737 | 0.0196094  | 0.0468617 |     |             |             |
|      | 0.0659307   | 0.0700996   | 0.0657763   | 0.0750405  | 0.078283   | 0.0765846 |     |             |             |
|      | 0.0760442   | 0.0894001   | 0.0728017   | 0.0566664  | 0.0322705  | 0.0165213 |     |             |             |
|      | 0.00802903  | 0.00594457  |             |            |            |           |     |             |             |
| 2009 | 2           | 2           | 1           | 2          | 0          | 0         | 100 | 0.000633312 | 0.0010133   |
|      | 0.000633312 | 0.00126662  | 0.0010133   | 0.0030399  | 0.0120329  | 0.0345788 |     |             |             |
|      | 0.0550982   | 0.0642179   | 0.0664978   | 0.0629512  | 0.0633312  | 0.0613046 |     |             |             |
|      | 0.0666244   | 0.0732109   | 0.0699177   | 0.0662445  | 0.0534516  | 0.039392  |     |             |             |
|      | 0.0205193   | 0.0155795   |             |            |            |           |     |             |             |
| 2010 | 2           | 2           | 1           | 2          | 0          | 0         | 100 | 0.000600691 | 0.00390449  |
|      | 0.00150173  | 0.00232768  | 0.0049557   | 0.00473044 | 0.0135906  | 0.0266557 |     |             |             |
|      | 0.0352155   | 0.0400961   | 0.0500826   | 0.0589428  | 0.0811683  | 0.0985884 |     |             |             |

|      |             |             |             |             |             |            |       |             |             |       |
|------|-------------|-------------|-------------|-------------|-------------|------------|-------|-------------|-------------|-------|
|      | 0.0970116   | 0.0659258   | 0.0485058   | 0.0379186   | 0.0362667   | 0.0290584  |       |             |             |       |
|      | 0.0159934   | 0.00788407  |             |             |             |            |       |             |             |       |
| 2011 | 2           | 2           | 1           | 2           | 0           | 0          | 100   | 0.000545058 | 0.00145349  |       |
|      | 0.00236192  | 0.00826672  | 0.0162609   | 0.0110828   | 0.0236192   | 0.0420603  |       |             |             |       |
|      | 0.0493278   | 0.0467842   | 0.0639535   | 0.0703125   | 0.0740371   | 0.0740371  |       |             |             |       |
|      | 0.072311    | 0.0593205   | 0.0476017   | 0.0442406   | 0.0446039   | 0.0339753  |       |             |             |       |
|      | 0.0232558   | 0.0137173   |             |             |             |            |       |             |             |       |
| 2012 | 2           | 2           | 1           | 2           | 0           | 0          | 100   | 0.000525532 | 0.000788298 |       |
|      | 0.000963476 | 0.00192695  | 0.00499255  | 0.0166418   | 0.0490497   | 0.0689323  |       |             |             |       |
|      | 0.0561443   | 0.0442323   | 0.0590348   | 0.0732241   | 0.0700709   | 0.058772   |       |             |             |       |
|      | 0.0578085   | 0.0589472   | 0.0536919   | 0.0478234   | 0.0453709   | 0.0344224  |       |             |             |       |
|      | 0.0215468   | 0.0144521   |             |             |             |            |       |             |             |       |
| 2013 | 2           | 2           | 1           | 2           | 0           | 0          | 100   | 0.00144086  | 0.00378414  |       |
|      | 0.00402176  | 0.00593532  | 0.00769215  | 0.0100228   | 0.0197271   | 0.0312413  |       |             |             |       |
|      | 0.040162    | 0.0458319   | 0.0478996   | 0.0472525   | 0.0521615   | 0.0616661  |       |             |             |       |
|      | 0.0759129   | 0.0850459   | 0.0895126   | 0.0867825   | 0.0724776   | 0.049841   |       |             |             |       |
|      | 0.024856    | 0.0147018   |             |             |             |            |       |             |             |       |
| 2014 | 2           | 2           | 1           | 2           | 0           | 0          | 100   | 0.00215191  | 0.00326771  |       |
|      | 0.00183311  | 0.00541962  | 0.00956404  | 0.00844823  | 0.01331     | 0.0215191  |       |             |             |       |
|      | 0.0293297   | 0.0392126   | 0.0431179   | 0.0512473   | 0.0518052   | 0.0633618  |       |             |             |       |
|      | 0.0828883   | 0.100741    | 0.0977126   | 0.0832071   | 0.0689408   | 0.0517255  |       |             |             |       |
|      | 0.0314019   | 0.0183311   |             |             |             |            |       |             |             |       |
| 2015 | 2           | 2           | 1           | 2           | 0           | 0          | 100   | 0.00170895  | 0.000985934 |       |
|      | 0.00414092  | 0.0141974   | 0.0153148   | 0.0164322   | 0.0400289   | 0.0575785  |       |             |             |       |
|      | 0.0450243   | 0.0452872   | 0.0481793   | 0.0594847   | 0.0524517   | 0.0448271  |       |             |             |       |
|      | 0.047522    | 0.0512686   | 0.0556067   | 0.0505456   | 0.0559353   | 0.0723676  |       |             |             |       |
|      | 0.0635599   | 0.0451558   |             |             |             |            |       |             |             |       |
| 2016 | 2           | 2           | 1           | 2           | 0           | 0          | 100   | 0.000873956 | 0.00106817  |       |
|      | 0.00252476  | 0.00708876  | 0.0116527   | 0.0200039   | 0.0328219   | 0.0412701  |       |             |             |       |
|      | 0.039328    | 0.0428238   | 0.0589435   | 0.0650612   | 0.0672946   | 0.0736065  |       |             |             |       |
|      | 0.077685    | 0.0801126   | 0.0715673   | 0.0586522   | 0.0469023   | 0.0442804  |       |             |             |       |
|      | 0.0362206   | 0.0266071   |             |             |             |            |       |             |             |       |
| 2017 | 2           | 2           | 1           | 2           | 0           | 0          | 100   | 0.000283527 | 0.000850581 |       |
|      | 0.00548152  | 0.0124752   | 0.0252339   | 0.0301484   | 0.0361024   | 0.0388432  |       |             |             |       |
|      | 0.0386542   | 0.0400718   | 0.0435687   | 0.0452698   | 0.0511294   | 0.0747566  |       |             |             |       |
|      | 0.0916738   | 0.0843021   | 0.0776864   | 0.0724884   | 0.057745    | 0.0447028  |       |             |             |       |
|      | 0.0327946   | 0.0163501   |             |             |             |            |       |             |             |       |
| 2018 | 2           | 2           | 1           | 2           | 0           | 0          | 100   | 0.000385072 | 0.000352983 |       |
|      | 0.00109104  | 0.00253506  | 0.0151462   | 0.0721368   | 0.143151    | 0.157912   |       |             |             |       |
|      | 0.122453    | 0.0986747   | 0.0829188   | 0.0656869   | 0.0490325   | 0.0360684  |       |             |             |       |
|      | 0.0320252   | 0.0222058   | 0.0149215   | 0.00911337  | 0.00596862  | 0.00429997 |       |             |             |       |
|      | 0.00198954  | 0.00163656  |             |             |             |            |       |             |             |       |
| 2019 | 2           | 2           | 1           | 2           | 0           | 0          | 100   | 0.004       | 0.008       | 0.011 |
|      | 0.018       | 0.023       | 0.044       | 0.069       | 0.097       | 0.117      | 0.119 | 0.099       | 0.091       | 0.081 |
|      | 0.054       | 0.034       | 0.022       | 0.014       | 0.007       | 0.003      | 0.003 |             |             |       |
| 2020 | 2           | 2           | 1           | 2           | 0           | 0          | 100   | 0.000151183 | 0.00128506  |       |
|      | 0.00151183  | 0.00332603  | 0.00400635  | 0.0109608   | 0.02109     | 0.0319752  |       |             |             |       |
|      | 0.037569    | 0.0505707   | 0.0616071   | 0.0909366   | 0.106282    | 0.121173   |       |             |             |       |
|      | 0.124424    | 0.100083    | 0.071434    | 0.0470935   | 0.0219215   | 0.0098269  |       |             |             |       |
|      | 0.00415753  | 0.00158742  |             |             |             |            |       |             |             |       |
| 2021 | 2           | 2           | 1           | 2           | 0           | 0          | 100   | 0.000346901 | 0.000578168 |       |
|      | 0.001618871 | 0.001734505 | 0.003237743 | 0.004162812 | 0.008556892 |            |       |             |             |       |
|      | 0.015032377 | 0.023126735 | 0.031567993 | 0.050300648 | 0.090309898 | 0.1476642  |       |             |             |       |

0.16373728 0.157261795 0.125462535 0.086378353 0.049144311  
 0.022201665 0.009250694 0.003931545 0.00439408

# Survey immature females

| #    | Year | Season | Fleet | Sex | Type | Shell | Maturity | Nsamp       | DataVec     |
|------|------|--------|-------|-----|------|-------|----------|-------------|-------------|
| 1982 | 1    | 3      | 2     | 2   | 0    | 2     | 100      | 0.000314638 | 0.000833882 |
|      |      |        |       |     |      |       |          | 0.000116163 | 0.000687518 |
|      |      |        |       |     |      |       |          | 0.00282138  | 0.0085966   |
|      |      |        |       |     |      |       |          | 0.00356032  | 0.000857423 |
|      |      |        |       |     |      |       |          | 0.000207891 | 3.46E-05    |
|      |      |        |       |     |      |       |          | 0           | 7.60E-06    |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
| 1983 | 1    | 3      | 2     | 2   | 0    | 2     | 100      | 0.0146813   | 0.010802    |
|      |      |        |       |     |      |       |          | 0.00137597  | 0.00114959  |
|      |      |        |       |     |      |       |          | 0.00800712  | 0.00685992  |
|      |      |        |       |     |      |       |          | 0.00121444  | 0.000264071 |
|      |      |        |       |     |      |       |          | 0.000019101 | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
| 1984 | 1    | 3      | 2     | 2   | 0    | 2     | 100      | 0.0131051   | 0.0227003   |
|      |      |        |       |     |      |       |          | 0.0168713   | 0.0469107   |
|      |      |        |       |     |      |       |          | 0.0711187   | 0.0173365   |
|      |      |        |       |     |      |       |          | 0.00257555  | 0.000349813 |
|      |      |        |       |     |      |       |          | 1.13E-05    | 3.43E-05    |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
| 1985 | 1    | 3      | 2     | 2   | 0    | 2     | 100      | 0.0136092   | 0.0390155   |
|      |      |        |       |     |      |       |          | 0.0372294   | 0.0822572   |
|      |      |        |       |     |      |       |          | 0.0408367   | 0.0199561   |
|      |      |        |       |     |      |       |          | 0.00586677  | 0.000980922 |
|      |      |        |       |     |      |       |          | 9.70E-05    | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
| 1986 | 1    | 3      | 2     | 2   | 0    | 2     | 100      | 0.0060485   | 0.0359736   |
|      |      |        |       |     |      |       |          | 0.0481016   | 0.108693    |
|      |      |        |       |     |      |       |          | 0.0812898   | 0.0396557   |
|      |      |        |       |     |      |       |          | 0.0273153   | 0.00486951  |
|      |      |        |       |     |      |       |          | 0.000617806 | 0.000302489 |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
| 1987 | 1    | 3      | 2     | 2   | 0    | 2     | 100      | 0.00159416  | 0.00258074  |
|      |      |        |       |     |      |       |          | 0.0307435   | 0.0911306   |
|      |      |        |       |     |      |       |          | 0.102144    | 0.0532387   |
|      |      |        |       |     |      |       |          | 0.0349025   | 0.0103161   |
|      |      |        |       |     |      |       |          | 0.0015471   | 0.000109047 |
|      |      |        |       |     |      |       |          | 0.000018078 | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
| 1988 | 1    | 3      | 2     | 2   | 0    | 2     | 100      | 0.00116092  | 0.00867847  |
|      |      |        |       |     |      |       |          | 0.0153454   | 0.0319263   |
|      |      |        |       |     |      |       |          | 0.0361875   | 0.0219066   |
|      |      |        |       |     |      |       |          | 0.0129179   | 0.0043787   |
|      |      |        |       |     |      |       |          | 0.000647538 | 0.000051278 |
|      |      |        |       |     |      |       |          | 6.24E-06    | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
| 1989 | 1    | 4      | 2     | 2   | 0    | 2     | 100      | 0.000118014 | 0.000860846 |
|      |      |        |       |     |      |       |          | 0.00292847  | 0.0153477   |
|      |      |        |       |     |      |       |          | 0.0177565   | 0.0125407   |
|      |      |        |       |     |      |       |          | 0.0104599   | 0.00389136  |
|      |      |        |       |     |      |       |          | 0.000720192 | 0.000108222 |
|      |      |        |       |     |      |       |          | 6.16E-05    | 1.56E-05    |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
| 1990 | 1    | 4      | 2     | 2   | 0    | 2     | 100      | 0.000387957 | 0.00772522  |
|      |      |        |       |     |      |       |          | 0.0347138   | 0.0170036   |
|      |      |        |       |     |      |       |          | 0.0332739   | 0.023985    |
|      |      |        |       |     |      |       |          | 0.0196702   | 0.00822257  |
|      |      |        |       |     |      |       |          | 0.000817141 | 0.00108438  |
|      |      |        |       |     |      |       |          | 0.000513012 | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |
|      |      |        |       |     |      |       |          | 0           | 0           |

|      |   |             |             |           |            |            |            |             |             |   |   |
|------|---|-------------|-------------|-----------|------------|------------|------------|-------------|-------------|---|---|
|      | 0 | 0           | 0           | 0         | 0          |            |            |             |             |   |   |
| 1991 | 1 | 4           | 2           | 2         | 0          | 2          | 100        | 0.0179712   | 0.0197087   |   |   |
|      |   | 0.0171511   | 0.0415559   | 0.0620691 | 0.0334836  | 0.0174108  | 0.0078115  |             |             |   |   |
|      |   | 0.000875408 | 0.00010493  | 0         | 0          | 0          | 0          | 0           | 0           | 0 | 0 |
|      |   | 0           | 0           | 0         | 0          |            |            |             |             |   |   |
| 1992 | 1 | 4           | 2           | 2         | 0          | 2          | 100        | 0.0130381   | 0.0284182   |   |   |
|      |   | 0.0435951   | 0.0772228   | 0.0599409 | 0.0149183  | 0.0113109  | 0.0045093  |             |             |   |   |
|      |   | 0.000583525 | 2.88E-05    | 1.98E-05  | 0          | 0          | 0          | 0           | 0           | 0 | 0 |
|      |   | 0           | 0           | 0         | 0          |            |            |             |             |   |   |
| 1993 | 1 | 4           | 2           | 2         | 0          | 2          | 100        | 0.016706    | 0.0340279   |   |   |
|      |   | 0.0509173   | 0.0869153   | 0.0683568 | 0.0182913  | 0.00406734 |            |             |             |   |   |
|      |   | 0.000832583 | 5.73E-05    | 2.17E-05  | 0          | 0          | 0          | 0           | 0           | 0 | 0 |
|      |   | 0           | 0           | 0         | 0          |            |            |             |             |   |   |
| 1994 | 1 | 4           | 2           | 2         | 0          | 2          | 100        | 0.0181026   | 0.031213    |   |   |
|      |   | 0.0653277   | 0.0971891   | 0.0545582 | 0.0163084  | 0.00631137 | 0.00193026 |             |             |   |   |
|      |   | 0.000328496 | 4.38E-05    | 0         | 0          | 0          | 0          | 0           | 0           | 0 | 0 |
|      |   | 0           | 0           | 0         | 0          |            |            |             |             |   |   |
| 1995 | 1 | 4           | 2           | 2         | 0          | 2          | 100        | 0.00104376  | 0.00889275  |   |   |
|      |   | 0.0230549   | 0.0311642   | 0.0428486 | 0.0182067  | 0.00232706 |            |             |             |   |   |
|      |   | 0.000289051 | 8.54E-05    | 2.97E-05  | 1.70E-05   | 0          | 0          | 0           | 0           | 0 | 0 |
|      |   | 0           | 0           | 0         | 0          |            |            |             |             |   |   |
| 1996 | 1 | 4           | 2           | 2         | 0          | 2          | 100        | 0.000167431 | 0.000818176 |   |   |
|      |   | 0.00217065  | 0.00991975  | 0.0206371 | 0.0116529  | 0.00253335 |            |             |             |   |   |
|      |   | 0.000205013 | 5.39E-05    | 3.92E-06  | 0          | 0          | 0          | 0           | 0           | 0 | 0 |
|      |   | 0           | 0           | 0         | 0          |            |            |             |             |   |   |
| 1997 | 1 | 4           | 2           | 2         | 0          | 2          | 100        | 0.000229417 | 0.000582913 |   |   |
|      |   | 0.00119523  | 0.00469075  | 0.0180567 | 0.00952952 | 0.00247309 |            |             |             |   |   |
|      |   | 0.000139355 | 4.02E-05    | 0         | 0          | 0          | 0          | 0           | 0           | 0 | 0 |
|      |   | 0           | 0           | 0         | 0          |            |            |             |             |   |   |
| 1998 | 1 | 4           | 2           | 2         | 0          | 2          | 100        | 0.00347767  | 0.00250876  |   |   |
|      |   | 0.00280017  | 0.0169291   | 0.0377432 | 0.0271928  | 0.0193031  | 0.00632601 |             |             |   |   |
|      |   | 4.57E-05    | 2.02E-05    | 0         | 0          | 0          | 0          | 0           | 0           | 0 | 0 |
|      |   | 0           | 0           | 0         | 0          |            |            |             |             |   |   |
| 1999 | 1 | 4           | 2           | 2         | 0          | 2          | 100        | 0.00792904  | 0.0276906   |   |   |
|      |   | 0.0162823   | 0.0218842   | 0.0285865 | 0.0161171  | 0.00993065 | 0.00876907 |             |             |   |   |
|      |   | 0.003559    | 0.000897171 | 6.36E-05  | 0          | 0          | 0          | 0           | 0           | 0 | 0 |
|      |   | 0           | 0           | 0         | 0          |            |            |             |             |   |   |
| 2000 | 1 | 4           | 2           | 2         | 0          | 2          | 100        | 0.00415494  | 0.0102677   |   |   |
|      |   | 0.0149912   | 0.0327293   | 0.0294997 | 0.0210419  | 0.00781699 | 0.00179226 |             |             |   |   |
|      |   | 0.000237793 | 9.80E-05    | 2.00E-05  | 0          | 0          | 0          | 0           | 0           | 0 | 0 |
|      |   | 0           | 0           | 0         | 0          |            |            |             |             |   |   |

|      |   |             |             |             |           |            |            |             |            |   |   |
|------|---|-------------|-------------|-------------|-----------|------------|------------|-------------|------------|---|---|
| 2001 | 1 | 4           | 2           | 2           | 0         | 2          | 100        | 0.00122714  | 0.00356421 |   |   |
|      |   | 0.0135989   | 0.0473682   | 0.0162972   | 0.0263137 | 0.0229126  | 0.00368468 |             |            |   |   |
|      |   | 0.000833059 | 2.67E-05    | 0           | 0         | 0          | 0          | 0           | 0          | 0 | 0 |
|      |   | 0           | 0           | 0           | 0         |            |            |             |            |   |   |
| 2002 | 1 | 4           | 2           | 2           | 0         | 2          | 100        | 0.00122761  | 0.00648626 |   |   |
|      |   | 0.0055034   | 0.0192742   | 0.0183633   | 0.0226075 | 0.0134546  |            |             |            |   |   |
|      |   | 0.000929036 | 6.10E-05    | 0           | 0         | 0          | 0          | 0           | 0          | 0 | 0 |
|      |   | 0           | 0           | 0           | 0         |            |            |             |            |   |   |
| 2003 | 1 | 4           | 2           | 2           | 0         | 2          | 100        | 0.0117675   | 0.0220405  |   |   |
|      |   | 0.0264463   | 0.040123    | 0.0590354   | 0.0286824 | 0.0146679  | 0.00221537 |             |            |   |   |
|      |   | 0.000301804 | 4.85E-05    | 0           | 0         | 0          | 0          | 0           | 0          | 0 | 0 |
|      |   | 0           | 0           | 0           | 0         |            |            |             |            |   |   |
| 2004 | 1 | 4           | 2           | 2           | 0         | 2          | 100        | 0.00703027  | 0.061585   |   |   |
|      |   | 0.157597    | 0.0600355   | 0.0480766   | 0.0136728 | 0.00313825 |            |             |            |   |   |
|      |   | 0.000429286 | 0.000153951 | 6.70E-05    | 0         | 0          | 0          | 0           | 0          | 0 | 0 |
|      |   | 0           | 0           | 0           | 0         |            |            |             |            |   |   |
| 2005 | 1 | 4           | 2           | 2           | 0         | 2          | 100        | 0.00238084  | 0.0147599  |   |   |
|      |   | 0.0181648   | 0.0728706   | 0.100035    | 0.0887932 | 0.0212498  | 0.00759045 |             |            |   |   |
|      |   | 0.000852986 | 2.25E-05    | 0           | 0         | 0          | 0          | 0           | 0          | 0 | 0 |
|      |   | 0           | 0           | 0           | 0         |            |            |             |            |   |   |
| 2006 | 1 | 4           | 2           | 2           | 0         | 2          | 100        | 0.0045469   | 0.0166212  |   |   |
|      |   | 0.0302857   | 0.0758614   | 0.0518943   | 0.0271265 | 0.0330248  | 0.0223012  |             |            |   |   |
|      |   | 0.00187199  | 0.00064582  | 0.000320169 | 8.76E-06  | 0          | 0          | 0           | 0          | 0 | 0 |
|      |   | 0           | 0           | 0           | 0         |            |            |             |            |   |   |
| 2007 | 1 | 4           | 2           | 2           | 0         | 2          | 100        | 0.000724633 | 0.00233752 |   |   |
|      |   | 0.00757934  | 0.0134405   | 0.0528384   | 0.0797438 | 0.0425293  | 0.00956352 |             |            |   |   |
|      |   | 0.00109224  | 0.000289594 | 7.19E-05    | 0         | 2.87E-05   | 0          | 0           | 0          | 0 | 0 |
|      |   | 0           | 0           | 0           | 0         |            |            |             |            |   |   |
| 2008 | 1 | 4           | 2           | 2           | 0         | 2          | 100        | 0.00867704  | 0.0166312  |   |   |
|      |   | 0.00838939  | 0.0164611   | 0.0183714   | 0.0222382 | 0.0164453  | 0.004276   |             |            |   |   |
|      |   | 0.00127734  | 0.0001021   | 2.74E-05    | 0         | 1.42E-05   | 0          | 0           | 0          | 0 | 0 |
|      |   | 0           | 0           | 0           | 0         |            |            |             |            |   |   |
| 2009 | 1 | 4           | 2           | 2           | 0         | 2          | 100        | 0.0191262   | 0.0478541  |   |   |
|      |   | 0.0594415   | 0.0534824   | 0.10273     | 0.0448844 | 0.00969289 | 0.00249467 |             |            |   |   |
|      |   | 0.000232959 | 0.000120542 | 3.84E-05    | 0         | 0          | 8.62E-06   | 0           | 0          | 0 | 0 |
|      |   | 0           | 0           | 0           | 0         |            |            |             |            |   |   |
| 2010 | 1 | 4           | 2           | 2           | 0         | 2          | 100        | 0.0124749   | 0.0201811  |   |   |
|      |   | 0.0271119   | 0.139977    | 0.172625    | 0.0212825 | 0.00819477 | 0.00203621 |             |            |   |   |
|      |   | 0.000112547 | 2.41E-05    | 3.51E-06    | 6.33E-06  | 0          | 0          | 0           | 0          | 0 | 0 |
|      |   | 0           | 0           | 0           | 0         |            |            |             |            |   |   |
| 2011 | 1 | 4           | 2           | 2           | 0         | 2          | 100        | 0.00902057  | 0.0162309  |   |   |
|      |   | 0.0180045   | 0.0430038   | 0.0376325   | 0.0266779 | 0.0146925  | 0.0137842  |             |            |   |   |
|      |   | 0.00301595  | 0.000367495 | 1.86E-05    | 2.65E-06  | 0          | 0          | 0           | 0          | 0 | 0 |

|      |             |             |             |             |             |            |     |             |             |   |   |
|------|-------------|-------------|-------------|-------------|-------------|------------|-----|-------------|-------------|---|---|
|      | 0           | 0           | 0           | 0           | 0           | 0          |     |             |             |   |   |
| 2012 | 1           | 4           | 2           | 2           | 0           | 2          | 100 | 0.00659826  | 0.0167339   |   |   |
|      | 0.0362887   | 0.0555033   | 0.0369648   | 0.0158614   | 0.0175375   | 0.0212409  |     |             |             |   |   |
|      | 0.00700331  | 0.000810077 | 5.83E-05    | 0           | 0.000110974 | 0          | 0   | 0           | 0           | 0 |   |
|      | 0           | 0           | 0           | 0           | 0           | 0          |     |             |             |   |   |
| 2013 | 1           | 4           | 2           | 2           | 0           | 2          | 100 | 0.00734763  | 0.041259    |   |   |
|      | 0.0415815   | 0.0360724   | 0.0408267   | 0.0295402   | 0.0217884   | 0.00812527 |     |             |             |   |   |
|      | 0.000881251 | 6.39E-05    | 0.000132887 | 6.27E-06    | 3.22E-05    | 0          | 0   | 0           | 0           | 0 |   |
|      | 0           | 0           | 0           | 0           | 0           | 0          |     |             |             |   |   |
| 2014 | 1           | 4           | 2           | 2           | 0           | 2          | 100 | 0.00992217  | 0.0189154   |   |   |
|      | 0.0126916   | 0.0562081   | 0.0948255   | 0.0600437   | 0.0262138   | 0.0152596  |     |             |             |   |   |
|      | 0.00015169  | 0.000013893 | 2.86E-05    | 3.40E-06    | 0           | 0          | 0   | 0           | 0           | 0 | 0 |
|      | 0           | 0           | 0           | 0           | 0           | 0          |     |             |             |   |   |
| 2015 | 1           | 4           | 2           | 2           | 0           | 2          | 100 | 0.0125945   | 0.0584528   |   |   |
|      | 0.0977707   | 0.0855654   | 0.05307     | 0.0203379   | 0.0102276   | 0.00118534 |     |             |             |   |   |
|      | 5.86E-06    | 0.000498176 | 3.91E-06    | 7.80E-06    | 0           | 0          | 0   | 0           | 0           | 0 | 0 |
|      | 0           | 0           | 0           | 0           | 0           | 0          |     |             |             |   |   |
| 2016 | 1           | 4           | 2           | 2           | 0           | 2          | 100 | 0.0105235   | 0.0523929   |   |   |
|      | 0.0907103   | 0.119308    | 0.0848236   | 0.0285666   | 0.00652754  |            |     |             |             |   |   |
|      | 0.000391023 | 5.89E-06    | 0           | 0           | 0           | 0          | 0   | 0           | 0           | 0 | 0 |
|      | 0           | 0           | 0           | 0           | 0           | 0          |     |             |             |   |   |
| 2017 | 1           | 4           | 2           | 2           | 0           | 2          | 100 | 0.00500295  | 0.0377983   |   |   |
|      | 0.0379614   | 0.136134    | 0.0681213   | 0.0145168   | 0.00437007  |            |     |             |             |   |   |
|      | 0.000382464 | 3.09E-05    | 2.40E-05    | 3.43E-06    | 0           | 0          | 0   | 0           | 0           | 0 | 0 |
|      | 0           | 0           | 0           | 0           | 0           | 0          |     |             |             |   |   |
| 2018 | 1           | 4           | 2           | 2           | 0           | 2          | 100 | 0.0019704   | 0.00170873  |   |   |
|      | 0.00938725  | 0.0902796   | 0.0900914   | 0.0219137   | 0.0046017   |            |     |             |             |   |   |
|      | 0.000281913 | 3.96E-06    | 0           | 1.90E-05    | 0           | 0          | 0   | 0           | 0           | 0 | 0 |
|      | 0           | 0           | 0           | 0           | 0           | 0          |     |             |             |   |   |
| 2019 | 1           | 4           | 2           | 2           | 0           | 2          | 100 | 0.008945866 | 0.00775788  |   |   |
|      | 0.042619391 | 0.409881518 | 0.409027293 | 0.099491325 | 0.020892369 |            |     |             |             |   |   |
|      | 0.001279926 | 1.79857E-05 | 0           | 8.64475E-05 | 0           | 0          | 0   | 0           | 0           | 0 | 0 |
|      | 0           | 0           | 0           | 0           | 0           | 0          |     |             |             |   |   |
| 2021 | 1           | 4           | 2           | 2           | 0           | 2          | 100 | 0.281595772 | 0.274025612 |   |   |
|      | 0.115790239 | 0.088946305 | 0.08644583  | 0.077000313 | 0.030508042 |            |     |             |             |   |   |
|      | 0.034304987 | 0.006859427 | 0.004523473 | 0           | 0           | 0          | 0   | 0           | 0           | 0 | 0 |
|      | 0           | 0           | 0           | 0           | 0           | 0          |     |             |             |   |   |
| 2022 | 1           | 4           | 2           | 2           | 0           | 2          | 100 | 0.031684929 | 0.118339902 |   |   |
|      | 0.074372017 | 0.267482668 | 0.361385792 | 0.132181266 | 0.013891048 |            |     |             |             |   |   |
|      | 0.000564384 | 6.54822E-05 | 3.25122E-05 | 0           | 0           | 0          | 0   | 0           | 0           | 0 | 0 |
|      | 0           | 0           | 0           | 0           | 0           | 0          |     |             |             |   |   |

# Survey immature males

| #    | Year | Season | Fleet | Sex | Type | Shell | Maturity | Nsamp       | DataVec     |
|------|------|--------|-------|-----|------|-------|----------|-------------|-------------|
| 1982 | 1    | 3      | 1     | 2   | 0    | 2     | 100      | 0.000272564 | 0.000279821 |
|      |      |        |       |     |      |       |          | 0.000589246 | 0.00297579  |
|      |      |        |       |     |      |       |          | 0.0122403   | 0.0263732   |
|      |      |        |       |     |      |       |          | 0.0349596   | 0.0314437   |
|      |      |        |       |     |      |       |          | 0.0284088   | 0.0265197   |
|      |      |        |       |     |      |       |          | 0.0241071   | 0.0189574   |
|      |      |        |       |     |      |       |          | 0.0138643   | 0.00909671  |
|      |      |        |       |     |      |       |          | 0.0052054   | 0.00213869  |
|      |      |        |       |     |      |       |          | 0.000408616 | 0.000151394 |
|      |      |        |       |     |      |       |          | 4.58E-05    | 1.37E-05    |
|      |      |        |       |     |      |       |          | 1.57E-05    | 7.35E-07    |
| 1983 | 1    | 3      | 1     | 2   | 0    | 2     | 100      | 0.0150765   | 0.0220969   |
|      |      |        |       |     |      |       |          | 0.0030183   | 0.00436202  |
|      |      |        |       |     |      |       |          | 0.0123052   | 0.0207457   |
|      |      |        |       |     |      |       |          | 0.0316753   | 0.0348826   |
|      |      |        |       |     |      |       |          | 0.0292638   | 0.0190184   |
|      |      |        |       |     |      |       |          | 0.0152457   | 0.0160456   |
|      |      |        |       |     |      |       |          | 0.0172218   | 0.0145271   |
|      |      |        |       |     |      |       |          | 0.00712568  | 0.00260002  |
|      |      |        |       |     |      |       |          | 0.000764962 | 0.000235006 |
|      |      |        |       |     |      |       |          | 8.10E-05    |             |
|      |      |        |       |     |      |       |          | 0.000019865 | 1.68E-05    |
|      |      |        |       |     |      |       |          | 4.14E-07    |             |
| 1984 | 1    | 3      | 1     | 2   | 0    | 2     | 100      | 0.0198307   | 0.0329218   |
|      |      |        |       |     |      |       |          | 0.0330259   | 0.0450942   |
|      |      |        |       |     |      |       |          | 0.0570382   | 0.0188784   |
|      |      |        |       |     |      |       |          | 0.0122291   | 0.0119353   |
|      |      |        |       |     |      |       |          | 0.0128937   | 0.0112346   |
|      |      |        |       |     |      |       |          | 0.0118518   | 0.0122711   |
|      |      |        |       |     |      |       |          | 0.0119187   | 0.0121592   |
|      |      |        |       |     |      |       |          | 0.00813695  | 0.00372649  |
|      |      |        |       |     |      |       |          | 0.00168659  | 0.000869427 |
|      |      |        |       |     |      |       |          | 0.000498452 |             |
|      |      |        |       |     |      |       |          | 0.000117886 | 9.95E-05    |
|      |      |        |       |     |      |       |          | 2.37E-06    |             |
| 1985 | 1    | 3      | 1     | 2   | 0    | 2     | 100      | 0.0172279   | 0.0397042   |
|      |      |        |       |     |      |       |          | 0.0422901   | 0.0650361   |
|      |      |        |       |     |      |       |          | 0.0444483   | 0.0287452   |
|      |      |        |       |     |      |       |          | 0.027563    | 0.0224977   |
|      |      |        |       |     |      |       |          | 0.0131135   | 0.0118784   |
|      |      |        |       |     |      |       |          | 0.0139018   | 0.0151424   |
|      |      |        |       |     |      |       |          | 0.0158686   | 0.012298    |
|      |      |        |       |     |      |       |          | 0.00869814  | 0.00490333  |
|      |      |        |       |     |      |       |          | 0.00219921  | 0.00130358  |
|      |      |        |       |     |      |       |          | 0.000880476 |             |
|      |      |        |       |     |      |       |          | 0.000212428 | 0.000149271 |
|      |      |        |       |     |      |       |          | 3.26E-06    |             |
| 1986 | 1    | 3      | 1     | 2   | 0    | 2     | 100      | 0.0202351   | 0.0695116   |
|      |      |        |       |     |      |       |          | 0.0455958   | 0.0489972   |
|      |      |        |       |     |      |       |          | 0.0385252   | 0.0401428   |
|      |      |        |       |     |      |       |          | 0.0369982   | 0.0257777   |
|      |      |        |       |     |      |       |          | 0.0154852   | 0.0118843   |
|      |      |        |       |     |      |       |          | 0.0089527   | 0.0072785   |
|      |      |        |       |     |      |       |          | 0.0045736   | 0.00340931  |
|      |      |        |       |     |      |       |          | 0.00268693  | 0.00173724  |
|      |      |        |       |     |      |       |          | 0.000730033 | 0.000422745 |
|      |      |        |       |     |      |       |          | 0.000244421 | 6.60E-05    |
|      |      |        |       |     |      |       |          | 5.19E-05    | 9.35E-07    |
| 1987 | 1    | 3      | 1     | 2   | 0    | 2     | 100      | 0.00116673  | 0.0105819   |
|      |      |        |       |     |      |       |          | 0.0582717   | 0.0782206   |
|      |      |        |       |     |      |       |          | 0.0521037   | 0.0326007   |
|      |      |        |       |     |      |       |          | 0.0346542   | 0.0227909   |
|      |      |        |       |     |      |       |          | 0.0133137   | 0.00819774  |
|      |      |        |       |     |      |       |          | 0.0066773   | 0.00492819  |
|      |      |        |       |     |      |       |          | 0.00357683  | 0.00326254  |
|      |      |        |       |     |      |       |          | 0.00209688  | 0.00109617  |
|      |      |        |       |     |      |       |          | 0.000373493 | 0.000161834 |
|      |      |        |       |     |      |       |          | 0.000099774 | 2.36E-05    |
|      |      |        |       |     |      |       |          | 2.61E-05    | 4.68E-07    |
| 1988 | 1    | 3      | 1     | 2   | 0    | 2     | 100      | 0.00116532  | 0.0171963   |
|      |      |        |       |     |      |       |          | 0.0302211   | 0.044658    |
|      |      |        |       |     |      |       |          | 0.048016    | 0.0522765   |
|      |      |        |       |     |      |       |          | 0.0454711   | 0.0346247   |
|      |      |        |       |     |      |       |          | 0.0199993   | 0.0166156   |
|      |      |        |       |     |      |       |          | 0.0119949   | 0.0104058   |
|      |      |        |       |     |      |       |          | 0.0063303   | 0.00485905  |
|      |      |        |       |     |      |       |          | 0.0030068   | 0.00162749  |
|      |      |        |       |     |      |       |          | 0.000532419 | 0.000271832 |
|      |      |        |       |     |      |       |          | 0.000200033 | 6.56E-05    |
|      |      |        |       |     |      |       |          | 0.000102697 | 1.84E-06    |
| 1989 | 1    | 4      | 1     | 2   | 0    | 2     | 100      | 0.000127934 | 0.00117652  |
|      |      |        |       |     |      |       |          | 0.00855203  | 0.0284692   |
|      |      |        |       |     |      |       |          | 0.0279578   | 0.0250503   |
|      |      |        |       |     |      |       |          | 0.023435    | 0.0223035   |
|      |      |        |       |     |      |       |          | 0.0259684   | 0.0224195   |
|      |      |        |       |     |      |       |          | 0.0156364   | 0.0125971   |
|      |      |        |       |     |      |       |          | 0.0089614   | 0.00630152  |
|      |      |        |       |     |      |       |          | 0.00366329  | 0.00151765  |
|      |      |        |       |     |      |       |          | 0.000497567 | 0.000186327 |
|      |      |        |       |     |      |       |          | 0.000120734 | 3.93E-05    |
|      |      |        |       |     |      |       |          | 4.19E-05    | 1.68E-06    |
| 1990 | 1    | 4      | 1     | 2   | 0    | 2     | 100      | 0.000868692 | 0.00737188  |
|      |      |        |       |     |      |       |          | 0.0145584   | 0.0134179   |
|      |      |        |       |     |      |       |          | 0.0202073   | 0.025762    |
|      |      |        |       |     |      |       |          | 0.0251105   | 0.0190136   |



|      |             |             |             |             |             |            |
|------|-------------|-------------|-------------|-------------|-------------|------------|
|      | 0.0154196   | 0.0117899   | 0.0104273   | 0.0118505   | 0.012856    | 0.0164116  |
|      | 0.0124244   | 0.00569906  | 0.00160832  | 0.000663878 | 0.000462695 |            |
|      | 0.000111795 | 0.000123963 | 5.09E-06    |             |             |            |
| 1991 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.015298    |             | 0.0185223   |             |            |
|      | 0.0234374   | 0.0362142   | 0.0360535   | 0.0239034   | 0.0274995   | 0.0222589  |
|      | 0.0126308   | 0.0062923   | 0.00562597  | 0.00593889  | 0.00692955  | 0.00826671 |
|      | 0.00458092  | 0.00191235  | 0.00077101  | 0.00066889  | 0.000518392 |            |
|      | 0.000191936 | 0.000272342 | 1.06E-05    |             |             |            |
| 1992 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.0110118   |             | 0.0292915   |             |            |
|      | 0.0393384   | 0.0746336   | 0.0745582   | 0.027213    | 0.0156411   | 0.0133641  |
|      | 0.00958731  | 0.00551324  | 0.00606154  | 0.00510417  | 0.00382473  | 0.00294657 |
|      | 0.00188059  | 0.00121217  | 0.000578045 | 0.000405955 | 0.000311331 |            |
|      | 0.000102425 | 0.000124726 | 4.26E-06    |             |             |            |
| 1993 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.0138157   |             | 0.0402688   |             |            |
|      | 0.0505759   | 0.0738608   | 0.0618509   | 0.0540997   | 0.0376217   | 0.0225439  |
|      | 0.00995898  | 0.00584442  | 0.00399394  | 0.00308389  | 0.00176491  | 0.00145378 |
|      | 0.00101704  | 0.000627907 | 0.000211962 | 0.000127335 | 0.000107148 |            |
|      | 0.000031243 | 0.000034046 | 1.58E-06    |             |             |            |
| 1994 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.00956701  |             | 0.0330057   |             |            |
|      | 0.0446488   | 0.0544644   | 0.0443544   | 0.0421672   | 0.0387076   | 0.0287119  |
|      | 0.018899    | 0.0118969   | 0.00713753  | 0.00443217  | 0.0018069   | 0.00128242 |
|      | 0.000558247 | 0.000389361 | 0.000109063 | 7.00E-05    | 0.000057627 | 1.68E-05   |
|      | 2.45E-05    | 5.27E-07    |             |             |             |            |
| 1995 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.00188797  |             | 0.00737351  |             |            |
|      | 0.0124761   | 0.0203183   | 0.0389085   | 0.0461345   | 0.0447714   | 0.0411042  |
|      | 0.0312803   | 0.0222919   | 0.0123486   | 0.00911466  | 0.00583923  | 0.00381344 |
|      | 0.00185477  | 0.000726524 | 0.000153343 | 7.08E-05    | 4.25E-05    | 1.33E-05   |
|      | 1.19E-05    | 2.27E-07    |             |             |             |            |
| 1996 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.000348149 |             | 0.000957316 |             |            |
|      | 0.00457967  | 0.00963723  | 0.0131669   | 0.021674    | 0.0305827   | 0.0338655  |
|      | 0.0343629   | 0.0281687   | 0.0237417   | 0.0234251   | 0.0195713   | 0.0156449  |
|      | 0.00801816  | 0.0035325   | 0.00101034  | 0.000376381 | 0.000179559 | 3.65E-05   |
|      | 0.00003968  | 1.38E-06    |             |             |             |            |
| 1997 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.000176188 |             | 0.000483259 |             |            |
|      | 0.00169754  | 0.00487351  | 0.00876051  | 0.0112227   | 0.0125858   | 0.0149097  |
|      | 0.0148382   | 0.0167135   | 0.0158097   | 0.0173971   | 0.016656    | 0.0154448  |
|      | 0.0102987   | 0.00516069  | 0.00198486  | 0.00106435  | 0.000670577 |            |
|      | 0.000182053 | 0.000255249 | 6.99E-06    |             |             |            |
| 1998 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.00243925  |             | 0.00245975  |             |            |
|      | 0.00507461  | 0.016051    | 0.0330314   | 0.0202321   | 0.0179687   | 0.014979   |
|      | 0.0114208   | 0.00741806  | 0.00652847  | 0.00710925  | 0.00840619  | 0.00920961 |
|      | 0.00743778  | 0.0045492   | 0.00191974  | 0.00111522  | 0.000687699 |            |
|      | 0.000189889 | 0.000202427 | 5.54E-06    |             |             |            |
| 1999 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.0118159   |             | 0.0263231   |             |            |
|      | 0.0187055   | 0.0155286   | 0.0227457   | 0.0229828   | 0.0244088   | 0.0216297  |

|      |             |             |             |             |             |            |
|------|-------------|-------------|-------------|-------------|-------------|------------|
|      | 0.0124162   | 0.00588255  | 0.00382618  | 0.00322781  | 0.00303866  | 0.0035243  |
|      | 0.00317376  | 0.00194016  | 0.000870183 | 0.00063415  | 0.000487179 |            |
|      | 0.000156841 | 0.000220148 | 6.25E-06    |             |             |            |
| 2000 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.00466328  | 0.0128735   |             |             |            |
|      | 0.0220007   | 0.0346399   | 0.0296759   | 0.0348844   | 0.0345076   | 0.0191617  |
|      | 0.00885483  | 0.00487404  | 0.00358711  | 0.00279995  | 0.00165749  | 0.00106849 |
|      | 0.0006229   | 0.000343241 | 0.00012032  | 0.00010209  | 8.55E-05    |            |
|      | 0.000030032 | 2.46E-05    | 9.59E-07    |             |             |            |
| 2001 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.00155571  | 0.00256946  |             |             |            |
|      | 0.0251035   | 0.0418723   | 0.0146368   | 0.0237691   | 0.0385938   | 0.0402393  |
|      | 0.038834    | 0.0281398   | 0.0178007   | 0.0108165   | 0.00583644  | 0.00303108 |
|      | 0.00160703  | 0.000916049 | 0.000223491 | 9.93E-05    | 6.53E-05    | 1.59E-05   |
|      | 1.99E-05    | 1.10E-06    |             |             |             |            |
| 2002 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.00234756  | 0.00737198  |             |             |            |
|      | 0.0113349   | 0.0238934   | 0.0213687   | 0.0299532   | 0.0253784   | 0.0271244  |
|      | 0.0215055   | 0.0219186   | 0.0168715   | 0.017262    | 0.0197545   | 0.0154749  |
|      | 0.00862687  | 0.00375357  | 0.00120271  | 0.000462729 | 0.000169451 | 5.72E-05   |
|      | 6.80E-05    | 5.22E-07    |             |             |             |            |
| 2003 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.00905642  | 0.0313262   |             |             |            |
|      | 0.0486591   | 0.0457926   | 0.0754884   | 0.0411324   | 0.0295013   | 0.0187314  |
|      | 0.0155351   | 0.0101131   | 0.00784445  | 0.00628801  | 0.00522738  | 0.00470385 |
|      | 0.00326928  | 0.00124616  | 0.00051187  | 0.000271981 | 0.000166446 |            |
|      | 0.000044275 | 3.59E-05    | 4.80E-07    |             |             |            |
| 2004 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.00562194  | 0.0392287   |             |             |            |
|      | 0.0821272   | 0.0409387   | 0.0348942   | 0.0282481   | 0.0230792   | 0.0263041  |
|      | 0.0129726   | 0.00403747  | 0.0030035   | 0.00219864  | 0.00109699  | 0.00124327 |
|      | 0.000872614 | 0.000470688 | 0.000220641 | 0.000154702 | 0.000133094 | 5.06E-05   |
|      | 0.000056067 | 1.89E-06    |             |             |             |            |
| 2005 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.00191871  | 0.00770091  |             |             |            |
|      | 0.0112209   | 0.0388494   | 0.0413226   | 0.0375068   | 0.0351388   | 0.0443045  |
|      | 0.0316199   | 0.0125456   | 0.00850033  | 0.00982304  | 0.00720331  | 0.00327436 |
|      | 0.00104305  | 0.000414527 | 0.00012157  | 0.000096553 | 8.56E-05    | 3.33E-05   |
|      | 7.44E-05    | 2.41E-06    |             |             |             |            |
| 2006 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.00438882  | 0.00925637  |             |             |            |
|      | 0.0313973   | 0.0535691   | 0.0252872   | 0.0180337   | 0.0251416   | 0.0298946  |
|      | 0.0249104   | 0.0166404   | 0.0117489   | 0.0145987   | 0.01011     | 0.00554414 |
|      | 0.00380686  | 0.00269226  | 0.00128361  | 0.000595433 | 0.000219708 |            |
|      | 0.000031776 | 3.97E-05    | 9.08E-07    |             |             |            |
| 2007 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.000582125 | 0.00331465  |             |             |            |
|      | 0.0157749   | 0.0243318   | 0.0402839   | 0.0554204   | 0.0422132   | 0.0299928  |
|      | 0.0165569   | 0.013713    | 0.0115133   | 0.0131757   | 0.0114181   | 0.00980502 |
|      | 0.00523321  | 0.00311219  | 0.00133955  | 0.000578811 | 0.000308278 | 5.20E-05   |
|      | 5.42E-05    | 6.15E-07    |             |             |             |            |
| 2008 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.0114112   | 0.0198232   |             |             |            |
|      | 0.0110663   | 0.0133695   | 0.0132872   | 0.0243794   | 0.0319997   | 0.0362767  |

|      |             |             |             |             |             |            |
|------|-------------|-------------|-------------|-------------|-------------|------------|
|      | 0.0385816   | 0.0326221   | 0.0184354   | 0.0134578   | 0.0102909   | 0.00837577 |
|      | 0.00521577  | 0.00296193  | 0.00104864  | 0.000596271 | 0.000302001 | 7.71E-05   |
|      | 0.000100796 | 3.67E-06    |             |             |             |            |
| 2009 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.0129661   | 0.0224401   |             |             |            |
|      | 0.039973    | 0.0300686   | 0.036089    | 0.0225883   | 0.0167328   | 0.0136982  |
|      | 0.00956489  | 0.00963947  | 0.00847686  | 0.00777855  | 0.00755756  | 0.00668949 |
|      | 0.00436567  | 0.00189412  | 0.000706571 | 0.000401652 | 0.000334135 |            |
|      | 0.000130855 | 0.000146673 | 4.78E-06    |             |             |            |
| 2010 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.0103954   | 0.0177776   |             |             |            |
|      | 0.0194017   | 0.048196    | 0.0722267   | 0.039529    | 0.0181314   | 0.0111273  |
|      | 0.00492092  | 0.00204842  | 0.00145495  | 0.00118226  | 0.00122421  | 0.00157043 |
|      | 0.00131452  | 0.000745056 | 0.000311739 | 0.000220451 | 0.000208722 | 0.00007235 |
|      | 0.000103247 | 2.73E-06    |             |             |             |            |
| 2011 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.0117051   | 0.0127134   |             |             |            |
|      | 0.0159465   | 0.0249721   | 0.0255874   | 0.027926    | 0.030495    | 0.0260531  |
|      | 0.0144137   | 0.00667211  | 0.00553368  | 0.00345609  | 0.00215384  | 0.00154697 |
|      | 0.00128703  | 0.000643509 | 0.000324987 | 0.000214572 | 0.000203723 | 7.19E-05   |
|      | 9.04E-05    | 2.95E-06    |             |             |             |            |
| 2012 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.00361632  | 0.0127183   |             |             |            |
|      | 0.0286055   | 0.022895    | 0.0143198   | 0.0146618   | 0.0192976   | 0.0195711  |
|      | 0.0136659   | 0.00854205  | 0.00604223  | 0.00554643  | 0.00319498  | 0.00149455 |
|      | 0.00119346  | 0.000593719 | 0.000194982 | 0.000091095 | 5.99E-05    |            |
|      | 0.000018003 | 3.82E-05    | 1.44E-06    |             |             |            |
| 2013 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.00356481  | 0.0155648   |             |             |            |
|      | 0.0203786   | 0.0176191   | 0.0235044   | 0.01962     | 0.0177265   | 0.0123756  |
|      | 0.00840228  | 0.00787547  | 0.00776973  | 0.00748751  | 0.0051304   | 0.00240086 |
|      | 0.00192289  | 0.00103322  | 0.000360823 | 0.000153566 | 0.000100334 | 2.73E-05   |
|      | 3.49E-05    | 1.33E-06    |             |             |             |            |
| 2014 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.00399161  | 0.0188829   |             |             |            |
|      | 0.00795806  | 0.0210559   | 0.0413837   | 0.0210729   | 0.021556    | 0.0239474  |
|      | 0.015908    | 0.0100498   | 0.00678183  | 0.00507904  | 0.00375761  | 0.00317965 |
|      | 0.00286268  | 0.00191294  | 0.000807572 | 0.000289831 | 0.000201923 | 5.01E-05   |
|      | 5.56E-05    | 1.25E-06    |             |             |             |            |
| 2015 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.0184782   | 0.0558645   |             |             |            |
|      | 0.0743684   | 0.0481665   | 0.0234887   | 0.0167888   | 0.0155118   | 0.0120592  |
|      | 0.00798994  | 0.00464518  | 0.00347654  | 0.00348636  | 0.00199077  | 0.0013534  |
|      | 0.000953626 | 0.000433192 | 0.000162612 | 7.75E-05    | 8.90E-05    | 4.17E-05   |
|      | 8.62E-05    | 3.46E-06    |             |             |             |            |
| 2016 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.00647017  | 0.0656403   |             |             |            |
|      | 0.0900984   | 0.0860334   | 0.0639428   | 0.0310969   | 0.0145337   | 0.0087533  |
|      | 0.00405842  | 0.00243455  | 0.00248432  | 0.00218462  | 0.00157355  |            |
|      | 0.000841554 | 0.000481345 | 0.000297023 | 0.000105555 | 4.87E-05    | 2.90E-05   |
|      | 7.16E-06    | 0.000014386 | 8.47E-07    |             |             |            |
| 2017 | 1           | 4           | 1           | 2           | 0           | 2          |
|      | 100         | 0.00676357  | 0.0281919   |             |             |            |
|      | 0.0475412   | 0.104799    | 0.0666216   | 0.0364082   | 0.0298115   | 0.0191918  |

|      |   |             |             |             |             |             |            |             |             |
|------|---|-------------|-------------|-------------|-------------|-------------|------------|-------------|-------------|
|      |   | 0.00866347  | 0.00510498  | 0.00350821  | 0.00194449  | 0.00104316  | 0.00046023 |             |             |
|      |   | 0.000470392 | 0.000260991 | 9.57E-05    | 0.000046143 | 0.000024106 | 5.11E-06   |             |             |
|      |   | 7.02E-06    | 9.79E-08    |             |             |             |            |             |             |
| 2018 | 1 | 4           | 1           | 2           | 0           | 2           | 100        | 0.00135269  | 0.00118035  |
|      |   | 0.0141107   | 0.048223    | 0.0634479   | 0.0817199   | 0.0617677   | 0.0373229  |             |             |
|      |   | 0.0209286   | 0.0118184   | 0.00842058  | 0.00656239  | 0.00346663  | 0.00228178 |             |             |
|      |   | 0.0010999   | 0.000486386 | 0.000111118 | 3.14E-05    | 1.31E-05    | 3.42E-06   |             |             |
|      |   | 5.46E-06    | 1.96E-07    |             |             |             |            |             |             |
| 2019 | 1 | 4           | 1           | 2           | 0           | 2           | 100        | 0.000531301 | 0.000412219 |
|      |   | 0.000578281 | 0.008991572 | 0.054411405 | 0.100983803 | 0.112282055 |            |             |             |
|      |   | 0.141557089 | 0.139712871 | 0.131859835 | 0.110627144 | 0.085592237 |            |             |             |
|      |   | 0.054977778 | 0.034655003 | 0.015059768 | 0.005766169 | 0.001300357 |            |             |             |
|      |   | 0.000413442 | 0.000181804 | 3.49089E-05 | 7.02256E-05 | 7.34066E-07 |            |             |             |
| 2021 | 1 | 4           | 1           | 2           | 0           | 2           | 100        | 0.034220051 | 0.030670862 |
|      |   | 0.028648348 | 0.014496796 | 0.01867399  | 0.016845694 | 0.02130752  |            |             |             |
|      |   | 0.030874582 | 0.041253212 | 0.081886049 | 0.13839306  | 0.179809103 |            |             |             |
|      |   | 0.168233781 | 0.111588414 | 0.057267181 | 0.021649453 | 0.003968925 |            |             |             |
|      |   | 0.000212982 | 0           | 0           | 0           |             |            |             |             |
| 2022 | 1 | 4           | 1           | 2           | 0           | 2           | 100        | 0.064232416 | 0.120129984 |
|      |   | 0.100048478 | 0.228733234 | 0.219559707 | 0.11828691  | 0.059686978 | 0.03370236 |             |             |
|      |   | 0.014871144 | 0.008902281 | 0.006659139 | 0.006570098 | 0.006363778 |            |             |             |
|      |   | 0.004634273 | 0.003738294 | 0.002186048 | 0.001095291 | 0.000471177 |            |             |             |
|      |   | 0.000113775 | 1.46341E-05 | 0           | 0           |             |            |             |             |

# Survey mature females

| #    | Year | Season      | Fleet       | Sex        | Type        | Shell      | Maturity   | Nsamp | DataVec |
|------|------|-------------|-------------|------------|-------------|------------|------------|-------|---------|
| 1982 | 1    | 3           | 2           | 2          | 0           | 1          | 100        | 0     | 0       |
|      |      | 0.00684438  | 0.0700815   | 0.2092903  | 0.1416973   | 0.0657965  | 0.0307524  |       |         |
|      |      | 0.00611227  | 0.000925449 | 4.94E-05   | 1.45E-05    | 0          | 0          | 0     | 0       |
|      |      | 0           | 0           | 0          | 0           | 0          |            |       |         |
| 1983 | 1    | 3           | 2           | 2          | 0           | 1          | 100        | 0     | 0       |
|      |      | 0.00965767  | 0.095971    | 0.199466   | 0.106034    | 0.0392924  | 0.01263748 |       |         |
|      |      | 0.003125557 | 0.00017019  | 2.76E-05   | 0           | 0          | 0          | 0     | 0       |
|      |      | 0           | 0           | 0          | 0           |            |            |       |         |
| 1984 | 1    | 3           | 2           | 2          | 0           | 1          | 100        | 0     | 0       |
|      |      | 0.00617941  | 0.0491874   | 0.0934634  | 0.0654466   | 0.03066384 | 0.01295197 |       |         |
|      |      | 0.001276434 | 0.000332379 | 0.00031611 | 2.26E-05    | 0          | 0          | 0     | 0       |
|      |      | 0           | 0           | 0          | 0           |            |            |       |         |
| 1985 | 1    | 3           | 2           | 2          | 0           | 1          | 100        | 0     | 0       |
|      |      | 0.002110762 | 0.0170356   | 0.05522958 | 0.03433918  | 0.00871329 |            |       |         |
|      |      | 0.002416302 | 0.000296327 | 0.00008052 | 0.000132025 | 0          | 0          | 0     | 0       |
|      |      | 0           | 0           | 0          | 0           |            |            |       |         |
| 1986 | 1    | 3           | 2           | 2          | 0           | 1          | 100        | 0     | 0       |
|      |      | 0.001160254 | 0.01509796  | 0.0539788  | 0.0332276   | 0.00759989 | 7.10E-05   |       |         |

|      |             |             |             |             |            |            |     |   |             |
|------|-------------|-------------|-------------|-------------|------------|------------|-----|---|-------------|
|      | 0.002289292 | 4.67E-05    | 0.000122083 | 0           | 0          | 0          | 0   | 0 | 0           |
|      | 0           | 0           | 0           | 0           |            |            |     |   |             |
| 1987 | 1           | 3           | 2           | 2           | 0          | 1          | 100 | 0 | 0.000257188 |
|      | 0.00773678  | 0.03936112  | 0.0860584   | 0.0562858   | 0.0238535  | 0.01168685 |     |   |             |
|      | 0.001747234 | 8.26E-05    | 4.00E-05    | 3.18E-06    | 0          | 0          | 0   | 0 |             |
|      | 0           | 0           | 0           | 0           |            |            |     |   |             |
| 1988 | 1           | 3           | 2           | 2           | 0          | 1          | 100 | 0 | 3.86E-06    |
|      | 0.000692432 | 0.01287012  | 0.0616472   | 0.1419804   | 0.075386   | 0.03717621 |     |   |             |
|      | 0.01859018  | 0.008292821 | 0.000841648 | 0.000168624 | 1.34E-05   | 3.47E-06   |     |   |             |
|      | 2.26E-06    | 0           | 0           | 0           | 0          | 0          | 0   | 0 |             |
| 1989 | 1           | 4           | 2           | 2           | 0          | 1          | 100 | 0 | 4.29E-05    |
|      | 0.000307571 | 0.02933808  | 0.1330917   | 0.1988117   | 0.095268   | 0.0454837  |     |   |             |
|      | 0.02431077  | 0.0077339   | 0.000901218 | 0.000100861 | 3.85E-05   | 0          | 0   |   |             |
|      | 0           | 0           | 0           | 0           | 0          | 0          |     |   |             |
| 1990 | 1           | 4           | 2           | 2           | 0          | 1          | 100 | 0 | 0.000669225 |
|      | 0.015360573 | 0.08415461  | 0.1627094   | 0.0873271   | 0.04335715 | 0.02477969 |     |   |             |
|      | 0.0065812   | 0.001483645 | 0.000227221 | 3.03E-05    | 6.89E-06   | 0          | 0   |   |             |
|      | 0           | 0           | 0           | 0           | 0          |            |     |   |             |
| 1991 | 1           | 4           | 2           | 2           | 0          | 1          | 100 | 0 | 0.000749828 |
|      | 0.0108773   | 0.0892839   | 0.150077    | 0.0720951   | 0.03056654 | 0.01774053 |     |   |             |
|      | 0.0050158   | 0.000860878 | 0.000093839 | 1.46E-05    | 0          | 0          | 0   | 0 |             |
|      | 0           | 0           | 0           | 0           |            |            |     |   |             |
| 1992 | 1           | 4           | 2           | 2           | 0          | 1          | 100 | 0 | 2.03E-05    |
|      | 0.001266375 | 0.0179458   | 0.0600454   | 0.0925764   | 0.0673017  | 0.0351003  |     |   |             |
|      | 0.02028762  | 0.00737803  | 0.001830214 | 0.000152522 | 2.75E-05   | 6.85E-06   |     |   |             |
|      | 0           | 0           | 0           | 0           | 0          | 0          | 0   |   |             |
| 1993 | 1           | 4           | 2           | 2           | 0          | 1          | 100 | 0 | 3.41E-05    |
|      | 0.001236352 | 0.01882336  | 0.070102    | 0.0832568   | 0.0332588  | 0.01210749 |     |   |             |
|      | 0.00980041  | 0.004333706 | 0.001011593 | 4.71E-05    | 1.45E-05   | 7.12E-06   |     |   |             |
|      | 0           | 0           | 0           | 0           | 0          | 0          | 0   |   |             |
| 1994 | 1           | 4           | 2           | 2           | 0          | 1          | 100 | 0 | 0.000637212 |
|      | 0.02237396  | 0.06241748  | 0.0665228   | 0.0486057   | 0.02850907 | 0.01005393 |     |   |             |
|      | 0.002421006 | 0.000382116 | 5.90E-05    | 1.89E-05    | 8.85E-06   | 1.75E-06   |     |   |             |
|      | 0           | 0           | 0           | 0           | 0          | 0          |     |   |             |
| 1995 | 1           | 4           | 2           | 2           | 0          | 1          | 100 | 0 | 0.000913426 |
|      | 0.0253944   | 0.1102714   | 0.1443457   | 0.073039    | 0.02149626 | 0.01233847 |     |   |             |
|      | 0.003337805 | 0.000171936 | 3.54E-05    | 1.35E-05    | 3.41E-06   | 0          | 0   |   |             |
|      | 0           | 0           | 0           | 0           | 0          |            |     |   |             |

|      |   |             |             |             |             |            |            |   |            |             |  |
|------|---|-------------|-------------|-------------|-------------|------------|------------|---|------------|-------------|--|
| 1996 | 1 | 4           | 2           | 2           | 0           | 1          | 100        | 0 | 0          | 0.001996553 |  |
|      |   | 0.0452682   | 0.1397966   | 0.1391805   | 0.064179    | 0.02150141 | 0.00707159 |   |            |             |  |
|      |   | 0.001735331 | 0.000166513 | 9.63E-05    | 1.69E-05    | 0          | 0          | 0 | 0          |             |  |
|      |   | 0           | 0           | 0           | 0           |            |            |   |            |             |  |
| 1997 | 1 | 4           | 2           | 2           | 0           | 1          | 100        | 0 | 0          | 0.00472811  |  |
|      |   | 0.04188219  | 0.1525432   | 0.1858315   | 0.1039386   | 0.02427202 | 0.00728089 |   |            |             |  |
|      |   | 0.000694272 | 0.000120639 | 0.00031768  | 6.96E-06    | 0          | 0          | 0 | 0          |             |  |
|      |   | 0           | 0           | 0           | 0           |            |            |   |            |             |  |
| 1998 | 1 | 4           | 2           | 2           | 0           | 1          | 100        | 0 | 0          | 0.002279124 |  |
|      |   | 0.039597344 | 0.14435228  | 0.1796168   | 0.092283    | 0.02757255 | 0.00505145 |   |            |             |  |
|      |   | 0.001591538 | 0.000165664 | 3.45E-05    | 0           | 0          | 0          | 0 | 0          |             |  |
|      |   | 0           | 0           | 0           | 0           |            |            |   |            |             |  |
| 1999 | 1 | 4           | 2           | 2           | 0           | 1          | 100        | 0 | 0          | 0.000228322 |  |
|      |   | 0.01691929  | 0.1064362   | 0.1627048   | 0.0915384   | 0.03251956 | 0.00947247 |   |            |             |  |
|      |   | 0.00441993  | 0.000525888 | 0.000117669 | 0           | 0          | 0          | 0 | 0          |             |  |
|      |   | 0           | 0           | 0           | 0           |            |            |   |            |             |  |
| 2000 | 1 | 4           | 2           | 2           | 0           | 1          | 100        | 0 | 0          | 0.00074789  |  |
|      |   | 0.01769133  | 0.0916848   | 0.2022967   | 0.1575735   | 0.0397142  | 0.01130038 |   |            |             |  |
|      |   | 0.006142775 | 0.000194009 | 0.000061951 | 8.99E-06    | 0          | 0          | 0 | 0          |             |  |
|      |   | 0           | 0           | 0           | 0           |            |            |   |            |             |  |
| 2001 | 1 | 4           | 2           | 2           | 0           | 1          | 100        | 0 | 0          | 0.000482047 |  |
|      |   | 0.00493171  | 0.039996    | 0.1422313   | 0.1269365   | 0.0385148  | 0.01359271 |   |            |             |  |
|      |   | 0.00332899  | 0.00018524  | 2.91E-05    | 0           | 0          | 0          | 0 | 0          |             |  |
|      |   | 0           | 0           | 0           | 0           |            |            |   |            |             |  |
| 2002 | 1 | 4           | 2           | 2           | 0           | 1          | 100        | 0 | 0          | 2.46E-05    |  |
|      |   | 0.003998093 | 0.06329399  | 0.1599032   | 0.0874641   | 0.04023323 | 0.01692791 |   |            |             |  |
|      |   | 0.002528197 | 0.000218579 | 0.000151559 | 0.000037573 | 0          | 1.94E-05   |   |            |             |  |
|      |   | 1.94E-05    | 3.88E-05    | 0           | 0           | 0          | 0          | 0 |            |             |  |
| 2003 | 1 | 4           | 2           | 2           | 0           | 1          | 100        | 0 | 2.61E-05   | 7.47E-06    |  |
|      |   | 0.003899128 | 0.06373048  | 0.1100795   | 0.0825709   | 0.02379331 | 0.01164812 |   |            |             |  |
|      |   | 0.001019985 | 0.000160464 | 5.37E-05    | 1.18E-05    | 0          | 0          | 0 | 0          |             |  |
|      |   | 0           | 0           | 0           | 0           |            |            |   |            |             |  |
| 2004 | 1 | 4           | 2           | 2           | 0           | 1          | 100        | 0 | 0.00028176 |             |  |
|      |   | 0.009867331 | 0.01999368  | 0.05291     | 0.0866044   | 0.0489999  | 0.016319   |   |            |             |  |
|      |   | 0.00550273  | 0.000658788 | 0.0002366   | 5.67E-05    | 1.36E-05   | 0          |   |            |             |  |
|      |   | 4.27E-06    | 0           | 0           | 0           | 0          | 0          | 0 |            |             |  |
| 2005 | 1 | 4           | 2           | 2           | 0           | 1          | 100        | 0 | 0          | 0.000476885 |  |
|      |   | 0.01071527  | 0.03915719  | 0.096896    | 0.0666304   | 0.01915517 | 0.00471411 |   |            |             |  |
|      |   | 0.002760833 | 0.000477688 | 5.14E-05    | 9.74E-06    | 0          | 0          | 0 | 0          |             |  |
|      |   | 0           | 0           | 0           | 0           |            |            |   |            |             |  |
| 2006 | 1 | 4           | 2           | 2           | 0           | 1          | 100        | 0 | 0          | 6.49E-05    |  |
|      |   | 0.001565817 | 0.02109436  | 0.0703375   | 0.0809127   | 0.0568565  | 0.02170535 |   |            |             |  |

|      |             |             |             |             |             |            |     |          |             |
|------|-------------|-------------|-------------|-------------|-------------|------------|-----|----------|-------------|
|      | 0.00607423  | 0.000889902 | 0.000385502 | 0           | 0           | 0          | 0   | 0        | 0           |
|      | 0           | 0           | 0           | 0           |             |            |     |          |             |
| 2007 | 1           | 4           | 2           | 2           | 0           | 1          | 100 | 0        | 0.000127547 |
|      | 0.011369934 | 0.0394078   | 0.0919995   | 0.0689482   | 0.0318764   | 0.02462481 |     |          |             |
|      | 0.01563442  | 0.00244723  | 0.000279141 | 8.70E-05    | 0           | 0          | 0   | 0        |             |
|      | 0           | 0           | 0           | 0           |             |            |     |          |             |
| 2008 | 1           | 4           | 2           | 2           | 0           | 1          | 100 | 0        | 7.50E-05    |
|      | 0.019128136 | 0.0398735   | 0.1020381   | 0.07573     | 0.0661909   | 0.0434517  |     |          |             |
|      | 0.0133554   | 0.001259755 | 0.000148198 | 2.79E-05    | 0           | 1.47E-05   | 0   |          |             |
|      | 8.65E-06    | 0           | 0           | 0           | 0           |            |     |          |             |
| 2009 | 1           | 4           | 2           | 2           | 0           | 1          | 100 | 0        | 5.31E-05    |
|      | 0.00385496  | 0.0266867   | 0.0791057   | 0.061908    | 0.03945303  | 0.02554402 |     |          |             |
|      | 0.009203165 | 0.001757721 | 0.00011779  | 9.62E-05    | 8.95E-06    | 9.15E-06   |     |          |             |
|      | 0           | 0           | 0           | 0           | 0           | 0          |     |          |             |
| 2010 | 1           | 4           | 2           | 2           | 0           | 1          | 100 | 0        | 0.001180684 |
|      | 0.0343415   | 0.0427016   | 0.0851022   | 0.049617    | 0.01723748  | 0.00805667 |     |          |             |
|      | 0.001574059 | 0.00012533  | 2.53E-05    | 6.09E-06    | 0           | 0          | 0   | 0        |             |
|      | 0           | 0           | 0           | 0           |             |            |     |          |             |
| 2011 | 1           | 4           | 2           | 2           | 0           | 1          | 100 | 0        | 1.49E-05    |
|      | 0.02820358  | 0.1110993   | 0.2073079   | 0.1036688   | 0.03256359  | 0.01219587 |     |          |             |
|      | 0.00295766  | 0.000243451 | 1.77E-05    | 9.31E-06    | 4.23E-06    | 3.05E-06   |     |          |             |
|      | 0           | 0           | 0           | 0           | 0           | 0          |     |          |             |
| 2012 | 1           | 4           | 2           | 2           | 0           | 1          | 100 | 0        | 4.58E-05    |
|      | 0.002409767 | 0.02823706  | 0.1365586   | 0.1891128   | 0.0963104   | 0.02652857 |     |          |             |
|      | 0.01301558  | 0.00771203  | 0.00301864  | 0.000306032 | 3.07E-05    | 4.55E-05   |     |          |             |
|      | 0           | 5.08E-06    | 0           | 0           | 0           | 0          | 0   | 0        |             |
| 2013 | 1           | 4           | 2           | 2           | 0           | 1          | 100 | 6.18E-06 | 0.001795325 |
|      | 0.000733816 | 0.03259207  | 0.1157507   | 0.192255    | 0.087205    | 0.0367353  |     |          |             |
|      | 0.02211524  | 0.01487509  | 0.003558517 | 0.000577047 | 0.000130027 | 1.25E-05   |     |          |             |
|      | 0           | 0           | 0           | 0           | 0           | 0          | 0   |          |             |
| 2014 | 1           | 4           | 2           | 2           | 0           | 1          | 100 | 0        | 0.000463827 |
|      | 0.02492479  | 0.0696182   | 0.120199    | 0.074399    | 0.0264601   | 0.0250442  |     |          |             |
|      | 0.02002069  | 0.005178659 | 0.000496062 | 0.00029703  | 3.94E-05    | 0          |     |          |             |
|      | 1.16E-05    | 0           | 0           | 0           | 0           | 0          | 0   |          |             |
| 2015 | 1           | 4           | 2           | 2           | 0           | 1          | 100 | 0        | 0.000252327 |
|      | 0.009980638 | 0.04497381  | 0.0928607   | 0.0653066   | 0.02902458  | 0.02278386 |     |          |             |
|      | 0.019763401 | 0.005754516 | 0.000950069 | 7.85E-05    | 0           | 0          | 0   | 0        |             |
|      | 0           | 0           | 0           | 0           |             |            |     |          |             |

|      |   |             |   |   |   |   |     |          |             |  |
|------|---|-------------|---|---|---|---|-----|----------|-------------|--|
| 2016 | 1 | 4           | 2 | 2 | 0 | 1 | 100 | 0        | 0           | 3.45E-05   |
|      |   |             |   |   |   |   |     |          |             | 0.01012658 0.02199713 0.0529428 0.03346241 0.01613146 0.01277006       |
|      |   |             |   |   |   |   |     |          |             | 0.007804554 0.00194233 0.000318399 8.53E-05 0 0 0 0                    |
|      |   |             |   |   |   |   |     |          |             | 0 0 0 0 0  |
| 2017 | 1 | 4           | 2 | 2 | 0 | 1 | 100 | 0        | 0           | 0.005426999  |
|      |   |             |   |   |   |   |     |          |             | 0.04276009 0.0645853 0.07984 0.0423367 0.01272471 0.00586714           |
|      |   |             |   |   |   |   |     |          |             | 0.001358798 0.000329759 2.93E-05 3.40E-06 0.000232515 0 0              |
|      |   |             |   |   |   |   |     |          |             | 0 0 0 0 0 0  |
| 2018 | 1 | 4           | 2 | 2 | 0 | 1 | 100 | 1.42E-05 | 2.29E-06    |  |
|      |   |             |   |   |   |   |     |          |             | 0.000843977 0.0295648 0.0949984 0.1002402 0.0359154 0.01214187         |
|      |   |             |   |   |   |   |     |          |             | 0.00520076 0.000535108 0.000117431 1.01E-05 0 1.90E-05 0               |
|      |   |             |   |   |   |   |     |          |             | 0 0 0 0 0 0  |
| 2019 | 1 | 4           | 2 | 2 | 0 | 1 | 100 | 0        | 0.000292268 |  |
|      |   |             |   |   |   |   |     |          |             | 0.002299736 0.043133506 0.22861078 0.380800224 0.154440577             |
|      |   |             |   |   |   |   |     |          |             | 0.045686714 0.017792406 0.004591042 0.000190114 0 0 0 0                |
|      |   |             |   |   |   |   |     |          |             | 0 0 0 0 0 0 0  |
| 2021 | 1 | 4           | 2 | 2 | 0 | 1 | 100 | 0        | 0.00286236  |  |
|      |   |             |   |   |   |   |     |          |             | 0.002416123 0.052887251 0.307794948 0.457761601 0.132358845            |
|      |   |             |   |   |   |   |     |          |             | 0.038754183 0.002787746 0.002052069 5.00183E-05 0.000137099 4.52625E-  |
| 05   | 0 | 9.24928E-05 | 0 | 0 | 0 | 0 | 0   | 0        | 0           | 0  |
| 2022 | 1 | 4           | 2 | 2 | 0 | 1 | 100 | 0        | 0.004438188 |  |
|      |   |             |   |   |   |   |     |          |             | 0.078965335 0.243403405 0.405350149 0.198040757 0.045610778 0.02389383 |
|      |   |             |   |   |   |   |     |          |             | 0 0.00023932 0 0 5.82394E-05 0 0 0 0 0                                 |
|      |   |             |   |   |   |   |     |          |             | 0 0 0  |

# Survey mature male

| # Year | Season | Fleet | Sex | Type | Shell | Maturity | Nsamp | Data        | Vec      |  |
|--------|--------|-------|-----|------|-------|----------|-------|-------------|----------|--|
| 1982   | 1      | 3     | 1   | 2    | 0     | 1        | 100   | 0           | 0        |  |
|        |        |       |     |      |       |          |       |             |          | 0.000715395 0.00459804 0.01473394 0.0237057 0.024996 0.02266428    |
|        |        |       |     |      |       |          |       |             |          | 0.02481753 0.02600805 0.01879454 0.01390479 0.01100927 0.00945191  |
|        |        |       |     |      |       |          |       |             |          | 0.00784434 0.004050627 0.002441672 0.000934569 0.000644255         |
|        |        |       |     |      |       |          |       |             |          | 0.000262847 0.000133288  |
| 1983   | 1      | 3     | 1   | 2    | 0     | 1        | 100   | 0.000019553 | 3.79E-05 |  |
|        |        |       |     |      |       |          |       |             |          | 3.76E-05 0.000495746 0.00383098 0.01195609 0.0222489 0.0260861     |
|        |        |       |     |      |       |          |       |             |          | 0.02330665 0.0213331 0.02058387 0.01824672 0.01855513 0.0181751    |
|        |        |       |     |      |       |          |       |             |          | 0.01405182 0.01016676 0.00730687 0.003639988 0.001443505           |
|        |        |       |     |      |       |          |       |             |          | 0.000750247 0.000257024 6.78E-05                                   |
| 1984   | 1      | 3     | 1   | 2    | 0     | 1        | 100   | 1.99E-05    | 4.53E-05 | 0  |
|        |        |       |     |      |       |          |       |             |          | 0.003229343 0.01164377 0.01037561 0.01440341 0.01550943 0.01480933 |
|        |        |       |     |      |       |          |       |             |          | 0.0159983 0.0178246 0.01560947 0.01455272 0.01776419 0.01891537    |
|        |        |       |     |      |       |          |       |             |          | 0.01651178 0.01659312 0.01301658 0.008096678 0.004001669           |
|        |        |       |     |      |       |          |       |             |          | 0.001097984 0.00038404   |
| 1985   | 1      | 3     | 1   | 2    | 0     | 1        | 100   | 0           | 0        | 0  |
|        |        |       |     |      |       |          |       |             |          | 0.005236598 0.007687759 0.00957537 0.01343338 0.01588318 0.0117129 |



|      |             |             |             |             |             |            |     |          |             |            |
|------|-------------|-------------|-------------|-------------|-------------|------------|-----|----------|-------------|------------|
|      | 0.01332532  | 0.01738176  | 0.0165541   | 0.01673751  | 0.01726759  | 0.01912157 |     |          |             |            |
|      | 0.02166981  | 0.02174294  | 0.02046074  | 0.014302587 | 0.007405339 |            |     |          |             |            |
|      | 0.001609141 | 0.000462611 |             |             |             |            |     |          |             |            |
| 1986 | 1           | 3           | 1           | 2           | 0           | 1          | 100 | 0        | 2.39E-05    | 1.62E-05   |
|      | 0.003458551 | 0.006579193 | 0.011805191 | 0.01516861  | 0.01521456  | 0.01279407 |     |          |             |            |
|      | 0.01165273  | 0.01039479  | 0.00849219  | 0.00607986  | 0.0063721   | 0.00740388 |     |          |             |            |
|      | 0.00844839  | 0.008678    | 0.00804637  | 0.00536796  | 0.003080868 |            |     |          |             |            |
|      | 0.000887937 | 0.000266359 |             |             |             |            |     |          |             |            |
| 1987 | 1           | 3           | 1           | 2           | 0           | 1          | 100 | 0        | 0           | 0          |
|      | 0.005635831 | 0.009281599 | 0.01070815  | 0.01442069  | 0.01251023  | 0.00851677 |     |          |             |            |
|      | 0.0072063   | 0.0069424   | 0.0052403   | 0.00424937  | 0.0049589   | 0.00499367 |     |          |             |            |
|      | 0.00513451  | 0.00420857  | 0.002943353 | 0.001986174 | 0.000978001 |            |     |          |             |            |
|      | 0.000334854 | 0.000087915 |             |             |             |            |     |          |             |            |
| 1988 | 1           | 3           | 1           | 2           | 0           | 1          | 100 | 1.53E-05 | 0           |            |
|      | 0.000124031 | 0.003226712 | 0.009019019 | 0.01674493  | 0.01982753  | 0.01879058 |     |          |             |            |
|      | 0.01344457  | 0.01392156  | 0.01206481  | 0.00925844  | 0.00640123  | 0.00650902 |     |          |             |            |
|      | 0.00653949  | 0.00676333  | 0.00549059  | 0.004339521 | 0.003393962 |            |     |          |             |            |
|      | 0.002259939 | 0.001071024 | 0.000276204 |             |             |            |     |          |             |            |
| 1989 | 1           | 4           | 1           | 2           | 0           | 1          | 100 | 7.64E-06 | 0.000169021 |            |
|      | 0.000248503 | 0.002906972 | 0.00682588  | 0.01092242  | 0.01413506  | 0.01607682 |     |          |             |            |
|      | 0.01900235  | 0.01999642  | 0.01671892  | 0.01179665  | 0.00894008  | 0.00845443 |     |          |             |            |
|      | 0.00818653  | 0.00701679  | 0.00550945  | 0.003350392 | 0.002259744 |            |     |          |             |            |
|      | 0.001470886 | 0.000490446 | 0.0002519   |             |             |            |     |          |             |            |
| 1990 | 1           | 4           | 1           | 2           | 0           | 1          | 100 | 0        | 0           | 8.29E-06   |
|      | 0.001389623 | 0.00412186  | 0.00867058  | 0.0121174   | 0.01262726  | 0.01224652 |     |          |             |            |
|      | 0.01280381  | 0.01265188  | 0.01193173  | 0.01234658  | 0.01841986  | 0.02168836 |     |          |             |            |
|      | 0.02028047  | 0.01486485  | 0.009989744 | 0.0075955   | 0.003855493 |            |     |          |             |            |
|      | 0.001385984 | 0.000756098 |             |             |             |            |     |          |             |            |
| 1991 | 1           | 4           | 1           | 2           | 0           | 1          | 100 | 2.01E-05 | 0           | 0          |
|      | 0.002535808 | 0.00618102  | 0.007013707 | 0.01134107  | 0.01220096  | 0.00918471 |     |          |             |            |
|      | 0.00734729  | 0.00735359  | 0.00680097  | 0.00780619  | 0.01105662  | 0.01040867 |     |          |             |            |
|      | 0.00898656  | 0.00839473  | 0.01038046  | 0.008588686 | 0.006648509 |            |     |          |             |            |
|      | 0.002886788 | 0.001548298 |             |             |             |            |     |          |             |            |
| 1992 | 1           | 4           | 1           | 2           | 0           | 1          | 100 | 7.08E-06 | 0           |            |
|      | 0.000217581 | 0.005372624 | 0.012921496 | 0.00887243  | 0.00675174  | 0.00775677 |     |          |             |            |
|      | 0.00725151  | 0.00628277  | 0.00743115  | 0.00613099  | 0.00552109  | 0.00573818 |     |          |             |            |
|      | 0.00591083  | 0.0065162   | 0.00694434  | 0.0072786   | 0.00616137  |            |     |          |             |            |
|      | 0.004209257 | 0.001645098 | 0.000845203 |             |             |            |     |          |             |            |
| 1993 | 1           | 4           | 1           | 2           | 0           | 1          | 100 | 4.81E-06 | 0           |            |
|      | 0.000204726 | 0.005284842 | 0.01185135  | 0.01634675  | 0.01579975  | 0.01196551 |     |          |             |            |
|      | 0.007067    | 0.00527617  | 0.00433104  | 0.00320817  | 0.00259489  | 0.00276596 |     |          |             |            |
|      | 0.00305757  | 0.00328478  | 0.00279964  | 0.002695523 | 0.002212437 |            |     |          |             |            |
|      | 0.001354961 | 0.000471816 | 0.00029977  |             |             |            |     |          |             |            |
| 1994 | 1           | 4           | 1           | 2           | 0           | 1          | 100 | 0        | 0.000471396 | 0.00152972 |
|      | 0.00584043  | 0.00897067  | 0.01504799  | 0.01870911  | 0.01749286  | 0.01382192 |     |          |             |            |

0.01134804 0.00860422 0.00543123 0.00333556 0.00289055 0.00217883  
 0.00240876 0.001787687 0.001600877 0.001424395 0.000900346  
 0.000424941 0.0001478

1995 1 4 1 2 0 1 100 0 0 0.000697993  
 0.0034153 0.00989174 0.01949756 0.02314638 0.02773629 0.0234418  
 0.02173667 0.01529875 0.00974453 0.00667876 0.00519501 0.00434428  
 0.00343508 0.002176722 0.001615804 0.001195708 0.000630202  
 0.000202743 6.28E-05

1996 1 4 1 2 0 1 100 0 1.83E-05  
 0.000176427 0.002127635 0.00567072 0.01087716 0.01993676 0.0281026  
 0.0302815 0.0295496 0.02818978 0.02120318 0.0172545 0.01678447  
 0.01371703 0.01248006 0.00969655 0.00612136 0.00328717  
 0.001609129 0.000566644 0.000257606

1997 1 4 1 2 0 1 100 2.75E-05 0 0  
 0.000419625 0.002107496 0.00515426 0.00868419 0.01597334 0.01997848  
 0.0265404 0.0260252 0.0237055 0.022008 0.02131957 0.02117558  
 0.01988144 0.01924786 0.01658137 0.011101538 0.006451197  
 0.002779594 0.001093347

1998 1 4 1 2 0 1 100 2.75E-05 0 1.36E-05  
 0.001164223 0.00582139 0.006209103 0.00890741 0.01127599 0.01358163  
 0.01387863 0.0137172 0.01327288 0.01402288 0.0157569 0.01729332  
 0.01898161 0.018685 0.01754368 0.0119075 0.00719061  
 0.002491207 0.000930529

1999 1 4 1 2 0 1 100 0.000175885 0.00028681  
 3.06E-05 0.001260816 0.004091068 0.0081937 0.01271882 0.01776749  
 0.01693715 0.01560499 0.01452504 0.01413579 0.01425796 0.01676683  
 0.02109827 0.01828212 0.01555833 0.01520599 0.01140666 0.00730783  
 0.00306567 0.001186247

2000 1 4 1 2 0 1 100 1.67E-05 7.67E-05  
 0.000171035 0.00391666 0.00798012 0.01369158 0.01643586 0.01399394  
 0.00863271 0.00750123 0.00741088 0.00644964 0.0066686  
 0.006816117 0.007775392 0.00786878 0.00574 0.00543193 0.00367083  
 0.002185599 0.000588796 0.000332519

2001 1 4 1 2 0 1 100 0 0 0.000184319  
 0.003254814 0.003216434 0.01115726 0.01861476 0.02731439 0.02874562  
 0.02539942 0.01956315 0.01214099 0.00801126 0.00867316 0.00768954  
 0.00809626 0.0059246 0.00482655 0.002848912 0.001532291 0.00073678  
 0.000268304

2002 1 4 1 2 0 1 100 0 0 4.29E-05  
 0.001800441 0.003915113 0.01130919 0.01524318 0.0222977 0.0223172  
 0.0271861 0.02237707 0.02010563 0.02071236 0.02064298 0.01969782  
 0.01892624 0.01523865 0.00994774 0.00506448 0.00322451 0.00098349  
 0.000301749

2003 1 4 1 2 0 1 100 0 2.22E-05 0  
 0.003196693 0.012923646 0.011408479 0.011553255 0.01085168 0.01194074

|      |   |             |             |             |             |             |            |             |             |          |
|------|---|-------------|-------------|-------------|-------------|-------------|------------|-------------|-------------|----------|
|      |   | 0.01116851  | 0.01049539  | 0.00881332  | 0.00777232  | 0.00857858  | 0.00865158 |             |             |          |
|      |   | 0.00736249  | 0.00670386  | 0.00546224  | 0.003368331 | 0.001873379 |            |             |             |          |
|      |   | 0.000452947 | 0.000124847 |             |             |             |            |             |             |          |
| 2004 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 7.28E-05    | 7.67E-05    |          |
|      |   | 0.00053884  | 0.003724299 | 0.006911521 | 0.01120283  | 0.01137156  | 0.01512455 |             |             |          |
|      |   | 0.00966699  | 0.00541434  | 0.00492764  | 0.00408919  | 0.003192606 | 0.00404876 |             |             |          |
|      |   | 0.00374825  | 0.00349742  | 0.00336884  | 0.003145612 | 0.002633339 |            |             |             |          |
|      |   | 0.002099031 | 0.000648192 | 0.000307122 |             |             |            |             |             |          |
| 2005 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 4.99E-05    | 1.18E-05    | 0        |
|      |   | 0.002859124 | 0.007501038 | 0.010702382 | 0.01385681  | 0.02333634  | 0.01970699 |             |             |          |
|      |   | 0.01211296  | 0.00887925  | 0.00903237  | 0.00812044  | 0.00504663  | 0.00349556 |             |             |          |
|      |   | 0.00319887  | 0.00272966  | 0.00294662  | 0.00254477  | 0.001768555 |            |             |             |          |
|      |   | 0.001105648 | 0.000428395 |             |             |             |            |             |             |          |
| 2006 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 0.000470785 | 0.000941535 |          |
|      |   | 0.000155871 | 0.003920522 | 0.005187489 | 0.00712943  | 0.01311927  | 0.02170787 |             |             |          |
|      |   | 0.01904204  | 0.01644483  | 0.01350829  | 0.01384887  | 0.01040011  | 0.00820249 |             |             |          |
|      |   | 0.00819896  | 0.01078511  | 0.01260423  | 0.01087991  | 0.00548445  | 0.00249052 |             |             |          |
|      |   | 0.001468935 | 0.000421229 |             |             |             |            |             |             |          |
| 2007 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 0           | 0           | 0        |
|      |   | 0.001873709 | 0.00819391  | 0.01803918  | 0.01785253  | 0.01952337  | 0.01471448 |             |             |          |
|      |   | 0.01377639  | 0.01334747  | 0.01403654  | 0.01250196  | 0.01269555  | 0.0114461  |             |             |          |
|      |   | 0.01276309  | 0.01388455  | 0.01011571  | 0.00589531  | 0.002439023 |            |             |             |          |
|      |   | 0.000876148 | 0.000208951 |             |             |             |            |             |             |          |
| 2008 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 0           | 4.14E-05    | 0        |
|      |   | 0.001241636 | 0.002924849 | 0.00791407  | 0.01636698  | 0.02444052  | 0.02772169 |             |             |          |
|      |   | 0.027395    | 0.01944537  | 0.01367336  | 0.01267223  | 0.01212042  | 0.0127633  |             |             |          |
|      |   | 0.01549459  | 0.01427119  | 0.01229337  | 0.00603818  | 0.003405685 |            |             |             |          |
|      |   | 0.001254463 | 0.000626297 |             |             |             |            |             |             |          |
| 2009 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 0           | 0           | 0        |
|      |   | 0.002229908 | 0.006387384 | 0.00760981  | 0.0096056   | 0.01211755  | 0.00999291 |             |             |          |
|      |   | 0.01089498  | 0.01071908  | 0.01049089  | 0.01025879  | 0.01059357  | 0.01276781 |             |             |          |
|      |   | 0.01276084  | 0.01152749  | 0.00819998  | 0.00636866  | 0.004866039 |            |             |             |          |
|      |   | 0.001698212 | 0.000758165 |             |             |             |            |             |             |          |
| 2010 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 0           | 0           | 2.94E-05 |
|      |   | 0.003389673 | 0.01427575  | 0.01636266  | 0.00982564  | 0.01185469  | 0.00546908 |             |             |          |
|      |   | 0.00533989  | 0.00566894  | 0.002886386 | 0.003609561 | 0.00276244  | 0.00322524 |             |             |          |
|      |   | 0.00374135  | 0.00374899  | 0.003841945 | 0.003622828 | 0.002572594 |            |             |             |          |
|      |   | 0.001183941 | 0.000425667 |             |             |             |            |             |             |          |
| 2011 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 0           | 0.000145743 | 7.12E-06 |
|      |   | 0.00197094  | 0.004835472 | 0.00880298  | 0.01352179  | 0.01475358  | 0.01129303 |             |             |          |
|      |   | 0.00736687  | 0.0064581   | 0.00409402  | 0.00298693  | 0.00299636  | 0.0038363  |             |             |          |
|      |   | 0.00416638  | 0.00496634  | 0.00489807  | 0.00478571  | 0.00349335  |            |             |             |          |
|      |   | 0.001248053 | 0.000596029 |             |             |             |            |             |             |          |
| 2012 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 0           | 7.47E-06    |          |
|      |   | 0.000129527 | 0.0026827   | 0.00544892  | 0.0083968   | 0.01142447  | 0.01344001 |             |             |          |

|      |   |             |             |             |             |             |            |            |             |             |
|------|---|-------------|-------------|-------------|-------------|-------------|------------|------------|-------------|-------------|
|      |   | 0.01172092  | 0.01024016  | 0.00785551  | 0.00629385  | 0.00405838  | 0.00268037 |            |             |             |
|      |   | 0.0037688   | 0.00425677  | 0.00372203  | 0.00348211  | 0.002821165 |            |            |             |             |
|      |   | 0.001849168 | 0.000950519 | 0.000360097 |             |             |            |            |             |             |
| 2013 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 0          | 6.68E-05    | 9.76E-05    |
|      |   | 0.001413417 | 0.004276551 | 0.00668578  | 0.00823014  | 0.00832944  | 0.00688276 |            |             |             |
|      |   | 0.0077612   | 0.00885186  | 0.00748829  | 0.0052946   | 0.00345043  | 0.00459297 |            |             |             |
|      |   | 0.00495397  | 0.0045616   | 0.00329066  | 0.00239475  | 0.001468158 |            |            |             |             |
|      |   | 0.000534657 | 0.000320836 |             |             |             |            |            |             |             |
| 2014 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 0          | 4.47E-06    | 5.44E-06    |
|      |   | 0.001587664 | 0.007715547 | 0.006327774 | 0.011124    | 0.01549107  | 0.0119291  |            |             |             |
|      |   | 0.01087172  | 0.01003663  | 0.00724746  | 0.00533498  | 0.00500129  | 0.00629459 |            |             |             |
|      |   | 0.00834043  | 0.00842686  | 0.00507065  | 0.003800884 | 0.002096241 |            |            |             |             |
|      |   | 0.000796853 | 0.000280023 |             |             |             |            |            |             |             |
| 2015 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 0          | 1.09E-05    | 0.00010142  |
|      |   | 0.003437111 | 0.004136025 | 0.005058451 | 0.00774866  | 0.00778863  | 0.00723241 |            |             |             |
|      |   | 0.00658887  | 0.00610558  | 0.00541071  | 0.00394529  | 0.00349187  | 0.0037873  |            |             |             |
|      |   | 0.00356816  | 0.00312048  | 0.00228844  | 0.001941615 | 0.001721301 | 0.00097553 |            |             |             |
|      |   | 0.000576656 |             |             |             |             |            |            |             |             |
| 2016 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 0          | 0           | 8.08E-05    |
|      |   | 0.006120958 | 0.011092245 | 0.008827908 | 0.00642359  | 0.00530206  | 0.00337357 |            |             |             |
|      |   | 0.0035396   | 0.00387707  | 0.00349053  | 0.0031525   | 0.002575216 |            |            |             |             |
|      |   | 0.002531382 | 0.002345382 | 0.001952879 | 0.001340059 | 0.000937114 |            |            |             |             |
|      |   | 0.000510714 | 0.000297928 | 0.000233912 |             |             |            |            |             |             |
| 2017 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 0          | 0           | 3.37E-06    |
|      |   | 0.007323365 | 0.011770628 | 0.010596164 | 0.01233414  | 0.01019852  | 0.00607241 |            |             |             |
|      |   | 0.00501137  | 0.00432304  | 0.00237014  | 0.001779719 | 0.001247453 |            |            |             |             |
|      |   | 0.001473234 | 0.001443055 | 0.001224473 | 0.000977696 | 0.000561649 |            |            |             |             |
|      |   | 0.000302249 | 0.000152729 | 3.09E-05    |             |             |            |            |             |             |
| 2018 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 0          | 2.33E-06    | 2.94E-05    |
|      |   | 0.003877062 | 0.01240101  | 0.02458453  | 0.02554343  | 0.02085545  | 0.01309665 |            |             |             |
|      |   | 0.00966548  | 0.00765076  | 0.005446634 | 0.003202116 | 0.002612093 |            |            |             |             |
|      |   | 0.002124895 | 0.002014265 | 0.001286292 | 0.00071415  | 0.000351133 |            |            |             |             |
|      |   | 0.000184716 | 0.000097095 | 4.51E-05    |             |             |            |            |             |             |
| 2019 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 0          | 0           | 0.000316139 |
|      |   | 0.005281089 | 0.033797896 | 0.065671416 | 0.093456637 | 0.11571058  |            |            |             |             |
|      |   | 0.121428184 | 0.137231949 | 0.128171018 | 0.08954018  | 0.059943606 |            |            |             |             |
|      |   | 0.048827389 | 0.036438496 | 0.0290241   | 0.017829314 | 0.009035911 |            |            |             |             |
|      |   | 0.004659675 | 0.002113226 | 0.001206178 | 0.000317017 |             |            |            |             |             |
| 2021 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 8.0688E-05 | 0.000620002 |             |
|      |   | 0.001753815 | 0.002912295 | 0.007912864 | 0.022581365 | 0.031988003 |            |            |             |             |
|      |   | 0.050742748 | 0.06545682  | 0.098114157 | 0.13490498  | 0.143210414 |            |            |             |             |
|      |   | 0.127198645 | 0.108338545 | 0.08380269  | 0.057987113 | 0.032600898 |            |            |             |             |
|      |   | 0.020275694 | 0.006584646 | 0.002150984 | 0.000553528 | 0.000229104 |            |            |             |             |
| 2022 | 1 | 4           | 1           | 2           | 0           | 1           | 100        | 0          | 0.000188698 |             |
|      |   | 0.000945636 | 0.006721666 | 0.041476479 | 0.049543336 | 0.056562344 |            |            |             |             |
|      |   | 0.057397906 | 0.075435757 | 0.09060668  | 0.098926563 | 0.087263001 |            |            |             |             |

0.081495549 0.078204049 0.083080187 0.070914144 0.056581643 0.03608285  
0.019621059 0.006878199 0.001498866 0.000575387

## BSFRF 2009

| #    | Year | Season | Fleet | Sex | Type | Shell | Maturity | Nsamp       | DataVec   |
|------|------|--------|-------|-----|------|-------|----------|-------------|---|
| 2009 | 1    | 5      | 1     | 2   | 0    | 1     | 100      | 0           | 0   |
|      |      |        |       |     |      |       |          |             | 0.001238947 0.000863698 0.003541424 0.013832538 0.040572165           |
|      |      |        |       |     |      |       |          |             | 0.061263678 0.078212734 0.083598598 0.08387656 0.094884929            |
|      |      |        |       |     |      |       |          |             | 0.120534571 0.125000136 0.111366863 0.065795705 0.046040002           |
|      |      |        |       |     |      |       |          |             | 0.027618562 0.023329151 0.010734941 0.0076948                         |
| 2009 | 1    | 5      | 2     | 2   | 0    | 1     | 100      | 0.005244473 | 0.027968646   |
|      |      |        |       |     |      |       |          |             | 0.061469755 0.058928557 0.058916633 0.206907532 0.235966912           |
|      |      |        |       |     |      |       |          |             | 0.215468783 0.103766741 0.01778026 0.004575706 0.002301392 0.00070461 |
|      |      |        |       |     |      |       |          |             | 0 0 0 0 0 0 0 0 0   |

## NMFS 2009

|      |   |   |   |   |   |   |     |          |   |
|------|---|---|---|---|---|---|-----|----------|---|
| 2009 | 1 | 6 | 1 | 2 | 0 | 1 | 100 | 0        | 0   |
|      |   |   |   |   |   |   |     |          | 0.001214828 0.000443192 0.002102358 0.009233429 0.02362759  |
|      |   |   |   |   |   |   |     |          | 0.030123358 0.063721265 0.066604129 0.057802771 0.077791272 |
|      |   |   |   |   |   |   |     |          | 0.111177899 0.125339991 0.096670341 0.094776647 0.064544205 |
|      |   |   |   |   |   |   |     |          | 0.063722833 0.058146179 0.035320778 0.017636936             |
| 2009 | 1 | 6 | 2 | 2 | 0 | 1 | 100 | 7.57E-05 | 0.000557172   |
|      |   |   |   |   |   |   |     |          | 0.004940749 0.017821048 0.080461649 0.311844431 0.339763322 |
|      |   |   |   |   |   |   |     |          | 0.169157587 0.056882959 0.014807228 0.002834872 0.000590569 |
|      |   |   |   |   |   |   |     |          | 0.000262684 0 0 0 0 0 0 0 0                                 |

## BSFRF 2010

| #    | Year | Season | Fleet | Sex | Type | Shell | Maturity | Nsamp       | DataVec   |
|------|------|--------|-------|-----|------|-------|----------|-------------|---|
| 2010 | 1    | 7      | 1     | 2   | 0    | 0     | 100      | 0.072979352 | 0.056036062   |
|      |      |        |       |     |      |       |          |             | 0.048133957 0.088344894 0.164039913 0.155726159 0.083859452   |
|      |      |        |       |     |      |       |          |             | 0.071995111 0.048674592 0.039098872 0.029999875 0.021699688   |
|      |      |        |       |     |      |       |          |             | 0.018976497 0.021962859 0.022602993 0.019086628 0.014781185   |
|      |      |        |       |     |      |       |          |             | 0.010093492 0.007298429 0.003006989 0.001465856 0.000137143   |
| 2010 | 1    | 7      | 2     | 2   | 0    | 0     | 100      | 0.110213977 | 0.073524426   |
|      |      |        |       |     |      |       |          |             | 0.061011145 0.175944422 0.213832402 0.189988868 0.118321633   |
|      |      |        |       |     |      |       |          |             | 0.036878488 0.016100333 0.003480034 0.000576815 0.000127459 0 |
|      |      |        |       |     |      |       |          |             | 0 0 0 0 0 0 0 0   |

## NMFS 2010

|      |   |   |   |   |   |   |     |             |  |
|------|---|---|---|---|---|---|-----|-------------|--|
| 2010 | 1 | 8 | 1 | 2 | 0 | 0 | 100 | 0.013305258 | 0.03465644   |
|      |   |   |   |   |   |   |     |             | 0.042476199 0.133925083 0.232818136 0.180317982 0.092515571    |
|      |   |   |   |   |   |   |     |             | 0.072463889 0.027665737 0.027159881 0.026279654 0.014026628    |
|      |   |   |   |   |   |   |     |             | 0.018798187 0.015370712 0.016069646 0.015180421 0.010982202    |
|      |   |   |   |   |   |   |     |             | 0.010148068 0.00776998 0.005268418 0.002256744 0.000545166     |
| 2010 | 1 | 8 | 2 | 2 | 0 | 0 | 100 | 0.011075347 | 0.021530168  |
|      |   |   |   |   |   |   |     |             | 0.048546887 0.236365777 0.316237552 0.200713802 0.112622041    |
|      |   |   |   |   |   |   |     |             | 0.033589046 0.016878889 0.002374627 4.43E-05 1.14E-05 1.02E-05 |
|      |   |   |   |   |   |   |     |             | 0 0 0 0 0 0 0 0 0  |

## Growth data

# Type of growth increment (0=ignore; 1=growth increment with a CV;2=size-at-release; 3= size-at-release values)

1

# nobs\_growth

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| ##    | Premolt | Sex   | Molt | Inc  | CV   |
|-------|---------|-------|------|------|------|
| 16.1  | 1       | 6.9   |      | 0.03 |      |
| 19.2  | 1       | 7.4   |      | 0.03 |      |
| 19.8  | 1       | 6.7   |      | 0.03 |      |
| 20    |         | 1     | 6.3  |      | 0.03 |
| 20    |         | 1     | 6.3  |      | 0.03 |
| 20.1  | 1       | 7.9   |      | 0.03 |      |
| 20.3  | 1       | 6.1   |      | 0.03 |      |
| 20.6  | 1       | 8.3   |      | 0.03 |      |
| 20.7  | 1       | 7     |      | 0.03 |      |
| 20.7  | 1       | 8.5   |      | 0.03 |      |
| 21    |         | 1     | 6.8  |      | 0.03 |
| 21.23 | 1       | 5.18  | 0.03 |      |      |
| 21.9  | 1       | 6.5   |      | 0.03 |      |
| 22.2  | 1       | 5.9   |      | 0.03 |      |
| 23.48 | 1       | 4.79  | 0.03 |      |      |
| 24    |         | 1     | 8.3  |      | 0.03 |
| 25.2  | 1       | 7.6   |      | 0.03 |      |
| 25.6  | 1       | 5.8   |      | 0.03 |      |
| 25.9  | 1       | 5.2   |      | 0.03 |      |
| 26    |         | 1     | 6.2  |      | 0.03 |
| 29.9  | 1       | 10    |      | 0.03 |      |
| 30.3  | 1       | 10    |      | 0.03 |      |
| 30.7  | 1       | 9.8   |      | 0.03 |      |
| 44.2  | 1       | 14.5  | 0.03 |      |      |
| 44.7  | 1       | 12.6  | 0.03 |      |      |
| 56.5  | 1       | 13.5  | 0.03 |      |      |
| 57    |         | 1     | 13   |      | 0.03 |
| 57.63 | 1       | 10.97 | 0.03 |      |      |
| 58.7  | 1       | 13.8  | 0.03 |      |      |
| 59.3  | 1       | 15.8  | 0.03 |      |      |
| 60.3  | 1       | 14.8  | 0.03 |      |      |
| 60.8  | 1       | 17.6  | 0.03 |      |      |
| 62.3  | 1       | 19.5  | 0.03 |      |      |
| 64    |         | 1     | 20.7 | 0.03 |      |
| 64.7  | 1       | 18    |      | 0.03 |      |
| 67.6  | 1       | 18.4  | 0.03 |      |      |
| 67.9  | 1       | 17.4  | 0.03 |      |      |
| 74.5  | 1       | 19.4  | 0.03 |      |      |
| 79.9  | 1       | 17.9  | 0.03 |      |      |
| 89.8  | 1       | 20.2  | 0.03 |      |      |

|       |   |      |      |      |
|-------|---|------|------|------|
| 89.9  | 1 | 22.2 | 0.03 |      |
| 89.9  | 1 | 22.4 | 0.03 |      |
| 93.8  | 1 | 23.8 | 0.03 |      |
| 18.6  | 2 | 6.6  |      | 0.03 |
| 19.3  | 2 | 5.9  |      | 0.03 |
| 19.37 | 2 | 4.87 | 0.03 |      |
| 19.8  | 2 | 7.1  |      | 0.03 |
| 20.2  | 2 | 4.7  |      | 0.03 |
| 20.3  | 2 | 5.9  |      | 0.03 |
| 20.4  | 2 | 6    |      | 0.03 |
| 20.4  | 2 | 6.3  |      | 0.03 |
| 20.6  | 2 | 4.5  |      | 0.03 |
| 20.7  | 2 | 6.3  |      | 0.03 |
| 20.7  | 2 | 6.7  |      | 0.03 |
| 20.8  | 2 | 6.5  |      | 0.03 |
| 20.8  | 2 | 6.5  |      | 0.03 |
| 20.8  | 2 | 6.8  |      | 0.03 |
| 21.25 | 2 | 7.48 | 0.03 |      |
| 21.4  | 2 | 6.6  |      | 0.03 |
| 21.6  | 2 | 6.1  |      | 0.03 |
| 21.94 | 2 | 6.77 | 0.03 |      |
| 22    |   | 2    | 6.2  | 0.03 |
| 22.2  | 2 | 7.5  |      | 0.03 |
| 22.3  | 2 | 7.1  |      | 0.03 |
| 22.8  | 2 | 6.8  |      | 0.03 |
| 22.8  | 2 | 7.4  |      | 0.03 |
| 22.9  | 2 | 5.7  |      | 0.03 |
| 23    |   | 2    | 8.2  | 0.03 |
| 23.09 | 2 | 6.17 | 0.03 |      |
| 24.2  | 2 | 6.7  |      | 0.03 |
| 24.2  | 2 | 7.2  |      | 0.03 |
| 24.4  | 2 | 6.3  |      | 0.03 |
| 25.2  | 2 | 6.8  |      | 0.03 |
| 25.4  | 2 | 6.3  |      | 0.03 |
| 25.5  | 2 | 9.1  |      | 0.03 |
| 25.5  | 2 | 7.4  |      | 0.03 |
| 25.7  | 2 | 6.8  |      | 0.03 |
| 25.9  | 2 | 6.8  |      | 0.03 |
| 26    |   | 2    | 7.1  | 0.03 |
| 26.2  | 2 | 6.4  |      | 0.03 |
| 26.4  | 2 | 5.4  |      | 0.03 |
| 26.5  | 2 | 7.4  |      | 0.03 |
| 26.9  | 2 | 7.5  |      | 0.03 |
| 26.9  | 2 | 7.6  |      | 0.03 |
| 27.4  | 2 | 7.7  |      | 0.03 |
| 27.5  | 2 | 7.3  |      | 0.03 |
| 28.1  | 2 | 6.4  |      | 0.03 |
| 28.2  | 2 | 8.02 | 0.03 |      |
| 28.2  | 2 | 7.6  |      | 0.03 |
| 28.7  | 2 | 8.4  |      | 0.03 |
| 28.7  | 2 | 7.3  |      | 0.03 |
| 29    |   | 2    | 7.7  | 0.03 |
| 29.1  | 2 | 9.3  |      | 0.03 |
| 29.4  | 2 | 7.3  |      | 0.03 |

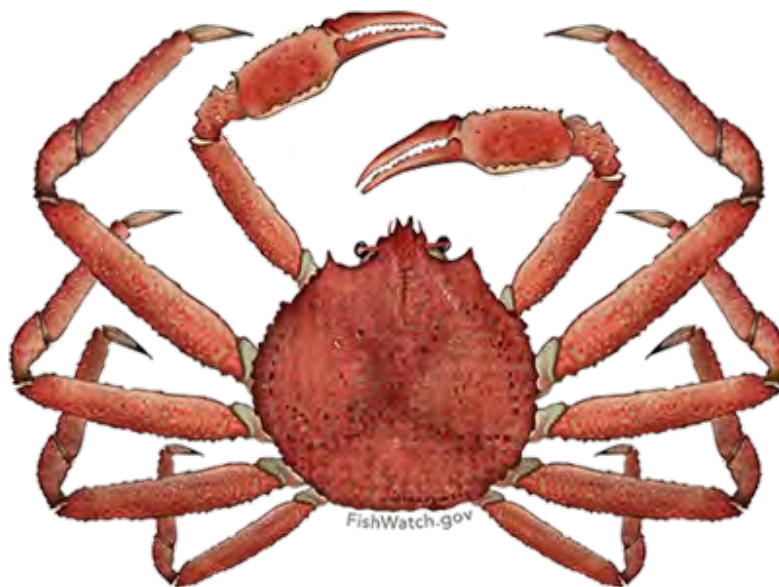
|      |     |      |      |      |
|------|-----|------|------|------|
| 29.5 | 2   | 8.9  |      | 0.03 |
| 30.9 | 2   | 7.5  |      | 0.03 |
| 32.8 | 2   | 12.1 | 0.03 |      |
| 34.9 | 2   | 9.9  |      | 0.03 |
| 35.3 | 2   | 12.3 | 0.03 |      |
| 38.3 | 2   | 12.6 | 0.03 |      |
| 38.9 | 2   | 14.1 | 0.03 |      |
| 41   |     | 2    | 14.8 | 0.03 |
| 42.1 | 2   | 12.5 | 0.03 |      |
| 44.2 | 2   | 15.3 | 0.03 |      |
| 44.3 | 2   | 15   |      | 0.03 |
| 44.8 | 2   | 14.9 | 0.03 |      |
| 45.2 | 2   | 14.4 | 0.03 |      |
| 46.9 | 2   | 13.5 | 0.03 |      |
| 47   |     | 2    | 14.4 | 0.03 |
| 47.9 | 2   | 13.5 | 0.03 |      |
| ##   | eof |      |      |      |
| 9999 |     |      |      |      |



# **Appendix G. Ecosystem and Socioeconomic Profile of the snow crab stock in the Eastern Bering Sea**

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*With Contributions from:*

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## Executive Summary

National initiatives and North Pacific Fishery Management Council (NPFMC) recommendations suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for the eastern Bering Sea (EBS) snow crab stock. In addition, annual guidelines for the Alaska Fisheries Science Center (AFSC) support research that improves our understanding of environmental and climate forcing of ecosystem processes with a focus on variables that can provide direct input into or improve stock assessment and management. The EBS snow crab ESP follows the new standardized framework for evaluating ecosystem and socioeconomic considerations for EBS snow crab, and may be considered a proving ground for potential use in the main stock assessment.

We use information from a variety of data streams available for the EBS snow crab stock and present results of applying the ESP process through a metric and subsequent indicator assessment. Analysis of the ecosystem and socioeconomic processes for EBS snow crab by life history stage along with information from the literature identified a suite of indicators for testing and continued monitoring within the ESP. Results of the metric and indicator assessment are summarized below as ecosystem and socioeconomic considerations that can be used for evaluating concerns in the main stock assessment or other management decisions.

### Management Considerations

The following are the summary considerations from the current updates to the ecosystem and socioeconomic indicators evaluated for EBS snow crab:

- While the Arctic Oscillation index remains in a positive phase in 2022 following the highest Arctic Oscillation index in history, near-normal cold pool extent and sea ice concentration indicate a return to average environmental conditions in the Bering Sea.
- Temperatures occupied by juvenile snow crab decreased by nearly 3°C from 2021 to 2022, suggesting optimal cold-water habitat availability for predator refuge.
- Following a dramatic increase in the prevalence of bitter crab syndrome and Pacific cod predation in 2016, disease prevalence remains near-average in 2022. Pacific cod consumption on snow crab has remained near-average in 2019 and 2021.
- The average center of abundance of mature male snow crab from 2021-2022 was the most northerly in the 34-year time series, indicative of a large-scale distribution shift from historic mid-shelf habitats.
- Vessel participation in the EBS snow crab fishery declined to 42 in 2022, the lowest level since 1977 and approximately 68% of the average fleet size over the previous five years. Although driven by the historically low TAC level set for the 2021-2022 fishery, the contraction of the active fleet was limited relative to the 80% reduction in TAC.
- Fishery performance indicators, including low CPUE during 2022 and the extreme northerly shift of the center of distribution of fishing activity observed in 2021 and 2022, combined with results of a survey of snow crab vessel captains, were indicative of adverse fishing conditions during 2022.
- Economic performance indicators reported for 2021 (the most recent year available) increased, reflecting historically high ex-vessel value of snow crab landings, however, recent market trends combined with adverse fishery performance indicators reported for 2022 are evidence of severe economic stresses in the fishery and dependent stakeholders during the current period.

### Modeling Considerations

The following are the summary considerations from the intermediate and advanced stage monitoring analyses for EBS snow crab:

- The highest ranked predictor for the recruitment regression model was the cold pool extent, although effect sizes were relatively small (<0.2) and marginal inclusion probabilities were < 0.5 for all predictors.
- Overall, intermediate stage monitoring analyses explained little variation in snow crab recruitment using both survey design-based and assessment model output estimates for recruitment. Future efforts should refine model covariates and lags pre-assigned to indicators.

## Responses to SSC and Plan Team Comments

*“The stage 2 indicator analysis uses a Bayesian approach and scales effect and inclusion probability for indicators where there are longer time series. Some indicators have different lags, and the CPT requested that these be explained in the final ESP document. The CPT also noted that the IBM and benthic cohort model results are not yet ready for inclusion as ESP indicators” (CPT, May 2022)*

Lags assigned to indicators for use in statistical analyses are now detailed in indicator description text of the current document. Based on CPT recommendation, the ecosystem indicator suite does not include indicators developed from the snow crab IBM model.

*“With regards to the Ecosystem and Socio-economic Profile (ESP) for snow crab, the SSC highlights previous requests to ESP analysts and Plan Teams to consider carefully the addition of social and community indicators in appropriate documents to meet requirements of National Standard 2. This is especially important for this stock in the context of upcoming rebuilding analyses and will be critical to track changes during rebuilding to account for the needs of affected communities and to ensure a fair and equitable distribution of rebuilding benefits and costs. The SSC highlights in particular the cascading effects of the snow crab collapse on communities that strongly depend on the resource, such as St. Paul.” (SSC, June 2022)*

Community indicators are currently available in the Annual Community and Participation Overview (ACEPO) report (Wise et al., 2021), which presents social and economic information for communities that are substantially engaged in and/or dependent on the commercial groundfish and crab fisheries in Alaska, as well as in the annual Crab Economic SAFE. Moving forward, we plan to concentrate development of socioeconomic indicators in the ESP that are most directly associated with the condition or health of the stock and the conduct of the fishery, and therefore have the most direct bearing on the scope of stock assessment development and harvest specification decision processes that are the focus of ESP documents. Effort has also been made to incorporate fishery-derived community indicators in this document that were developed from Alaska Bering Sea Crabber’s Skipper Surveys distributed to the snow crab fleet following the 2020-2021 and 2021-2022 directed fisheries. We see the Skipper Survey as a means to extract local stakeholder knowledge through industry collaborations to potentially inform better decision making and improve socioeconomic outcomes for the snow crab fleet.

## Introduction

Ecosystem-based science is becoming a component of effective marine conservation and resource management; however, the gap remains between conducting ecosystem research and integrating it with the stock assessment. A consistent approach has been lacking for deciding when and how to incorporate ecosystem and socioeconomic information into a stock assessment and how to test the reliability of this information for identifying future change. This new standardized framework termed the ecosystem and socioeconomic profile (ESP) has recently been developed to serve as a proving ground for testing ecosystem and socioeconomic linkages within the stock assessment process (Shotwell et al., *In Review*). The ESP uses data collected from a variety of national initiatives, literature, process studies, and laboratory analyses in a four-step process to generate a set of standardized products that culminate in a

focused, succinct, and meaningful communication of potential drivers on a given stock. The ESP process and products are supported in several strategic documents (Sigler et al., 2017; Lynch et al., 2018) and recommended by the NPFMC groundfish and crab Plan Teams and the Scientific and Statistical Committee (SSC).

This ESP for EBS snow crab (*Chionoecetes opilio*) follows the template for ESPs (Shotwell et al., *In Review*) and replaces the previous ecosystem considerations section in the main EBS snow crab stock assessment and fishery evaluation (SAFE) report. Information from the original ecosystem considerations section may be found in Szuwalski (2021).

The ESP process consists of the following four steps:

- Evaluate national initiative and stock assessment classification scores (Lynch et al., 2018) along with regional research priorities to assess the priority and goals for conducting an ESP.
- Perform a metric assessment to identify potential vulnerabilities and bottlenecks throughout the life history of the stock and provide mechanisms to refine indicator selection.
- Select a suite of indicators that represent the critical processes identified in the metric assessment and monitor the indicators using statistical tests appropriate for the data availability of the stock.
- Generate the standardized ESP report following the guideline template and report ecosystem and socioeconomic considerations, data gaps, caveats, and future research priorities.

## **Justification**

National initiatives and NPFMC recommendations support conducting an ESP for the EBS snow crab stock. The high commercial importance and constituent demand of the stock and cold water habitat dependence throughout the life cycle created a high score for both stock assessment and habitat assessment prioritization (Methot, 2015; McConnaughey et al., 2017). The vulnerability scores were low to moderate based on productivity, susceptibility (Patrick et al., 2010), and high sensitivity with low exposure based on future climate exposure (Spencer et al., 2019). The new data classification scores for EBS snow crab suggest a data-moderate stock with high quality data for catch and abundance, and moderate quality data for size/age composition, life history categories, and ecosystem linkages (Lynch et al., 2018). These initiative scores and data classification levels suggest a moderate to high priority for conducting an ESP for EBS snow crab. Additionally, AFSC research priorities support studies that improve our understanding of environmental and climate forcing of ecosystem processes with focus on variables that provide direct input into stock assessment and management. Finally the Crab Plan Team and SSC have requested an ESP be conducted for EBS snow crab as time allows to consider what indicators directly affect the EBS snow crab stock, and to better understand potential drivers of the 2021 snow crab stock collapse.

## **Data**

Initially, information on EBS snow crab was gathered through a variety of national initiatives that were conducted by AFSC personnel in 2015 and 2016. These include (but are not limited to) stock assessment prioritization, habitat assessment prioritization, climate vulnerability analysis, and stock assessment categorization. Data derived from this effort served as the initial starting point for developing the ESP metrics for stocks in the Bering Sea and Aleutian Islands (BSAI) and Gulf of Alaska (GOA) groundfish fishery management plans (FMP) and the BSAI king and tanner crab FMP. Please see Shotwell et al., *In Review*, for more details.

Data used to generate ecosystem metrics and indicators for the EBS snow crab ESP were collected from a variety of laboratory studies, remote sensing databases, fisheries surveys, regional reports and fishery observer data collections (Table 1). Results from laboratory studies were specifically used to inform

metrics and indicators relating to thermal tolerances, phenology and energetics across EBS snow crab life history stages (Table 2a). Larval indicator development utilized blended satellite data products from NOAA, NASA and ESA. Data for late-juvenile through adult EBS snow crab stages were derived from the annual NOAA eastern Bering Sea bottom trawl survey and fishery observer data collected during the EBS snow crab fishery. Data from the NOAA Resource Ecology and Ecosystem Modeling (REEM) food habits database were used to determine Pacific cod consumption rates.

Data used to generate socioeconomic metrics and indicators were derived from fishery-dependent sources, including commercial landings data for EBS snow crab collected in ADFG fish tickets and the BSAI Crab Economic Data Report (EDR) database (both sourced from AKFIN), and effort statistics reported in the most recent ADFG Annual Management Report for BSAI shellfish fisheries estimated from ADF&G Crab Observer program data (Leon et al. 2017). Community indicators were developed from Alaska Bering Sea Crabber's Skipper Surveys distributed to the snow crab fleet following the 2020-2021 and 2021-2022 directed fisheries.

## Metrics Assessment

We first provide the analysis of the national initiative data used to generate the baseline metrics for this second step of the ESP process and then provide more specific analyses on relevant ecosystem and/or socioeconomic processes. Metrics are quantitative stock-specific measures that identify vulnerability or resilience of the stock with respect to biological or socioeconomic processes. Where possible, evaluating these metrics by life history stage can highlight potential bottlenecks and improve mechanistic understanding of ecosystem or socioeconomic pressures on the stock.

### National Metrics

The national initiative data were summarized into a metric panel (Figure 1) that acts as a first pass ecosystem and socioeconomic synthesis. Metrics ranged from estimated values to qualitative scores of population dynamics, life history, or economic data for a given stock (see Shotwell et al., *In Review* for more details). To simplify interpretation, the metrics were rescaled by using a percentile rank for EBS snow crab relative to all other stocks in the groundfish and crab FMPs. Additionally, some metrics were inverted so that all metrics could be compared on a low to high scale between all stocks in the FMPs. These adjustments allowed for initial identification of vulnerable (percentile rank value is high) and resilient (percentile rank value is low) traits for EBS snow crab. Data quality estimates were also provided from the lead stock assessment author (0 or green shaded means no data to support answer, 4 or purple shaded means complete data), and if there were no data available for a particular metric then an "NA" would appear in the panel. EBS snow crab did have a few data gaps for the metric panel namely mean trophic level, growth rate, and recruitment variability as these categories were not well understood for crab stocks. Data quality ranged from no data to good for the remaining metrics. The metric panel gives context for how EBS snow crab relate to other groundfish and crab stocks in the FMPs and highlights the potential vulnerabilities for the EBS snow crab stock.

The 80<sup>th</sup> and 90<sup>th</sup> percentile rank areas are provided to highlight metrics indicating a high level of vulnerability for EBS snow crab (Figure 1). Spawning cycle and fecundity fell within the 80<sup>th</sup> percentile rank when compared to other stocks in the groundfish and crab FMPs. Latitude range, ocean acidification sensitivity, commercial importance, habitat dependence, early life history survival and settlement, complexity in reproductive strategy, spawning duration, and temperature sensitivity all fell within the 90<sup>th</sup> percentile rank. EBS snow crab were relatively resilient for breeding strategy, geographic concentration, maximum length, length at 50% maturity, predation stressors, prey specificity, and dispersal during early life history.

## Ecosystem Processes

Data evaluated over ontogenetic shifts (e.g., embryo, larvae, juvenile, adult) may be helpful for identifying specific bottlenecks in productivity and relevant indicators for monitoring. As a first attempt, we summarized important ecosystem processes or potential bottlenecks across snow crab life history stages from the literature, process studies and laboratory rearing experiments (Table 2) and created a summary conceptual model of this information (Figure 2). Details on why these processes were highlighted, as well as the potential relationship between ecosystem processes and stock productivity, are described below.

After molting to maturity, female snow crab mate and extrude new egg clutches each spring, which remain attached to pleopods on the female's abdomen for a full year prior to hatching (Watson, 1970). Fecundity is positively correlated with female size, and primiparous females have a lower fecundity than multiparous females (Sainte-Marie, 1993). The optimal range for embryo development is 0 to 3°C, although laboratory studies indicate that incubation temperatures below 0°C can trigger diapause or a biennial reproduction cycle (Webb et al., 2007). Peak hatching of snow crab larvae occurs in April (Armstrong et al., 1981) and phyto-detritus may act as a chemical cue for larval release (Starr et al., 1994). Larval duration for each of the two zoeal stages is approximately 30 days (Incze et al., 1982). A longer larval stage associated with cooler temperatures may leave larvae more vulnerable to pelagic predators for a prolonged period. Furthermore, historical larval year-class failures have coincided with low zooplankton abundance over the middle shelf and low water column stability, suggesting that increased larval mortality is related to less favorable feeding conditions (Incze et al., 1987) and mismatches between larval release and the spring bloom (Somerton 1982). Likewise, laboratory studies suggest that relatively high prey densities are required for successful feeding in snow crab zoeae (Paul et al., 1979). Major predators of larval snow crab include yellowfin sole (Armstrong et al., 1981), walleye pollock, jellyfish and juvenile salmon (Kruse et al., 2007).

Snow crab larvae settle from late August to the end of October (Conan et al., 1992). Early benthic instars are cryptic and concentrate in shallow, cold water habitats (Lovrich et al., 1995; Murphy et al., 2010). Previous laboratory studies have shown that adequate energetic stores are prerequisites for molting, growth, and survival in snow crab early life history stages (e.g. Lovrich and Ouellet, 1994), indicating that variability in energetic reserves could represent a potential recruitment bottleneck in snow crab. Likewise, increased warming and declines in sea ice are expected to decrease benthic juvenile snow crab prey resources supplied to the benthos through decreased benthic-pelagic flux (Copeman et al., 2021). Both settlement intensity and early benthic survival are likely critical determinants of year-class strength in snow crab (Sainte-Marie et al., 1996), and successful advection to areas of suitable temperature and muddy substrate are thought to be critical criteria for juvenile survival (Dionne et al., 2003). Density-dependence may also play a regulatory role due to high rates of cannibalism and potential prey resource limitation in juvenile nurseries (Lovrich and Sainte-Marie 1997). Previous studies have shown that Pacific cod, sculpin, skates and halibut are major predators of juvenile snow crab (Livingston et al., 1993; Livingston and deReynier, 1996; Lang et al., 2003) and the cold pool may provide refuge from predators like Pacific cod that avoid waters less than 2°C (Ciannelli and Bailey, 2005). Juvenile snow crab are especially vulnerable to predation and cannibalism during and immediately following molting.

Spatial patterns in juvenile and adult snow crab distribution are determined largely by ontogenetic migrations linked to size- and sex-specific thermal requirements. Immature snow crab concentrate in colder, shallow waters of the NBS and EBS middle shelves, historically avoiding thermal habitats >2°C (Kolts et al., 2015; Murphy, 2020). Likewise, primiparous female snow crab appear to track near-bottom temperature during a northeast to southwest ontogenetic migration to warmer waters near the shelf break (Ernst et al., 2005; Parada et al., 2010). Shifts in centers of abundance of mature female snow crab relative to prevailing currents may affect larval supply to nursery areas (Zheng and Kruse, 2006) and thermal occupancy patterns of snow crab depend on the availability of cold water habitat (Fedewa et al.,

2020). While 2°C may represent a critical temperature threshold for immature snow crab (Murphy, 2020), negative effects on metabolic processes are not apparent in mature snow crab until temperatures exceed 7°C (Foyle et al., 1989). Temperature also influences molt timing (Dutil et al., 2010), growth rates (Yamamoto et al., 2015), energy stores (Hardy et al., 2000), and body condition (Dutil et al., 2010) of snow crab in the laboratory.

## **Socioeconomic Processes**

As described below, the set of socioeconomic indicators proposed in this ESP are categorized as Fishery Performance and Economic Performance indicators. Fishery Performance indicators are intended to represent processes most directly involved in prosecution of the EBS snow crab fishery, and thus have the potential to differentially affect the condition of the stock depending on how they influence the timing, spatial distribution, selectivity, and other aspects of fishing pressure. Economic Performance indicators are intended to capture observable dimensions of key economic drivers of fishery performance and fleet behavior. This ESP also summarizes results from an industry-led Skipper Survey as a means to provide community indicators through extracting local stakeholder knowledge. The fifteen question survey distributed to snow crab skippers following the 2021/2022 fishing season focused on comparisons to the previous 2020/2021 snow crab season in regards to 1) perceived abundance of industry preferred males, sub-legal males, immature males and females, 2) changes in fishing behavior (e.g. fishing deeper, longer soak times), 3) motivation for changes in fishing behavior (e.g. weather, empty pots, heavy sorting), and 4) the amount of sorting. Questions directed at perceived abundance and catch sorting comparisons between seasons were recorded with quantitative responses including a) >25% increase, b) 10 - 25% increase, c) within +/- 10%, d) 10 - 25% decrease, or e) >25% decrease. We see the Skipper Survey as a means to provide context for the development of meaningful community indicators in the near-future, and to identify socioeconomic outcomes for the snow crab fleet.

Notwithstanding these categorical distinctions of indicators, the social and economic processes that affect -- and are affected by -- the condition of the stock are complex and interrelated at different time scales. While the complex of reciprocal linkages between condition of the EBS snow crab stock and fishery and economic performance-related processes may be hypothesized in principal, no conceptual model currently exists that is adequate to support practical predictive application of socioeconomic indicators comparable to that of ecosystem indicators for informing the snow crab assessment. A further distinction of most observable socioeconomic processes from ecosystem processes associated with the EBS snow crab fishery is that data collection and monitoring of many aspects of socioeconomic processes is conducted during or following the fishing season, such that the most recent available data point may be lagged by up to two years behind the current assessment, and as such, cannot be captured in indicators that provide advance information for use in informing the current stock assessment. As such, in the context of the ESP, available time series of socioeconomic indicators are largely limited to providing a general frame of reference regarding socioeconomic factors associated with historic fishery management, to inform interpretation of historic patterns observed in other data series captured in the assessment and, potentially, stimulating research on linkages between socioeconomic processes and stock condition.

Socioeconomic processes associated with fisheries are strongly influenced by the institutional structures of fishery management, which develop over time and include both measures undertaken in the course of in-season management, as well as comprehensive changes in management and industry structures that induce complex, multidimensional change affecting numerous social and economic processes. Implementation of the Crab Rationalization (CR) Program, including the shift from GHL to TAC management (effectively controlling harvest overages) beginning in 2005 is an example of the latter, and arguably represents a regime shift in management and economic structure of the fishery (a full summary of the management history of the EBS snow crab fishery is beyond the scope of the ESP; see NPFMC, 2017 and Nichols, et al., 2021). Among other changes, the CR program resulted in rapid consolidation of the EBS snow crab fleet, from a high of 272 vessels in 1994 to 78 during the first year of the CR program.

Allocation of tradable crab harvest quota shares, with leasing of annual harvest quota, facilitated fleet consolidation and improved operational and economic efficiency of the fleet, changing the timing of the fishery from short derby seasons to more extended seasons, and inducing extensive and ongoing changes in harvest sector ownership, employment, and income. Crab processing sector provisions of the CR program include allocation of transferable processing quota shares (PQS), leasing of annual processing quota and custom-processing arrangements that enable PQS holders that do not operate a processing plant to purchase IFQ crab landings and direct them to a processing plant for custom processing, and community protection measures, including regional designation on harvest quota, requiring associated catch to be landed to ports within a specified region.

While these and other elements of CR program design facilitated similar operational and economic efficiencies in the harvest sector, with more limited consolidation of processing capacity to somewhat fewer locations, and fewer plants in some ports, they have also limited some economic adjustments that would likely have occurred in their absence. Most notably, North regional designation of a large fraction of EBS snow crab IFQ has likely maintained a larger proportion of landings to St. Paul Island than would have occurred otherwise. St. Paul Island has historically and to-date received the largest share of EBS snow crab landings, with Akutan, King Cove, and Unalaska/Dutch Harbor representing the other principal landing ports for EBS landings historically and to-date. See the Council's 10-Year Program Review for the CR Program for detailed description and analysis of program structure and management (Council, 2017).

These and other institutional changes continue to influence the geographic and inter-sectoral distribution of benefits produced by the EBS snow crab fishery, both through direct ownership and labor income in the EBS snow crab harvest and processing sectors, and indirect social and economic effects on fishery-dependent communities throughout Alaska and greater Pacific Northwest region. The full range of available metrics reflecting fishery, economic, and social processes cannot be captured within the scope of the ESP framework. A more comprehensive suite of metrics and indicators intended to inform Bering Sea crab fishery management, including annual harvest specifications as well as consideration of management measures addressing distributional issues or mitigation of social and economic effects of stock declines, low TAC levels and fishery closures, are provided in the annual Crab Economic SAFE and ACEPO reports.

## Indicators Assessment

We first provide information on how we selected the indicators for the third step of the ESP process and then provide results on the indicators analysis. In this indicator assessment a time-series suite is first created that represents the critical processes identified by the metric assessment. These indicators must be useful for stock assessment in that they are regularly updated, reliable, consistent, and long-term. The indicator suite is then monitored in a series of stages that are statistical tests that gradually increase in complexity depending on the data availability of the stock (Shotwell et al., In Review). A short description and contact name for the indicator contributor are provided below. We also include the anticipated lag and sign of the proposed relationship between the indicator and the stock population dynamics for indicator analyses where relevant.

### Indicator Suite

#### *Ecosystem Indicators*

##### Physical Indicators (Figure 3a.a-c)

- a) Winter-spring Arctic Oscillation index from the NOAA National Climate Data Center (contact: E. Fedewa). Proposed sign of relationship is negative and the time series is lagged five years for intermediate stage indicator analysis



- b) The areal extent of the summer cold pool as EBS bottom trawl survey stations with bottom temperatures < 2°C (contact: E. Fedewa). Proposed sign of relationship is positive and the time series is lagged two years for intermediate stage indicator analysis.
- c) January winter sea ice concentration in the Bering Sea (contact: E. Fedewa). Proposed sign of relationship is positive and the time series is lagged two years for intermediate stage indicator analysis.

Lower Trophic Indicators (Figure 3a.d-e)

- d) Derived chlorophyll-*a* concentration during spring and summer season (April, May, June) in the northern middle southeastern Bering Sea from the MODIS satellite (contact: M. Callahan and J. Nielsen). Proposed sign of relationship is positive.
- e) Summer benthic invertebrate density, determined from EBS bottom trawl survey stations included in the 50<sup>th</sup> percentile of mean snow crab CPUE. Invertebrates include brittle stars, sea stars, sea cucumber, bivalves, non-commercial crab species, shrimp and polychaetes. (contact: E. Fedewa). Proposed sign of relationship is positive.

Upper Trophic Indicators (Figure 3a.f-k)

- f) Mean bottom temperature weighted by immature snow crab CPUE at each station of the EBS summer bottom trawl survey (contact: E. Fedewa). Proposed sign of relationship is negative.
- g) Prevalence of immature snow crab showing visual evidence of Bitter Crab Syndrome during the summer EBS bottom trawl survey (contact: E. Fedewa). Proposed sign of relationship is negative.
- h) Mean carapace width of male snow crab at 50% probability of maturation, as determined from maturity curves developed from EBS bottom trawl survey data (contact: J. Richar). Proposed sign of relationship is positive.
- i) Area occupied, calculated as the minimum area containing 95% of the cumulative mature male snow crab (>95mm) CPUE during the EBS summer bottom trawl survey (contact: E. Fedewa). Proposed sign of relationship is positive.
- j) CPUE-weighted average latitude of the mature male snow crab stock (>95mm) during the EBS summer bottom trawl survey (contact: E. Fedewa). Proposed sign of relationship is positive.
- k) The daily summer consumption of snow crab by Pacific cod in the EBS, estimated from Pacific cod diet compositions, EBS trawl survey CPUE, and temperature adjusted length-specific maximum consumption rates (contact: K. Aydin). Proposed sign of relationship is negative and the time series is lagged two years for intermediate stage indicator analysis.

*Socioeconomic Indicators*

Fishery Performance Indicators (Figure 3b.a-e)

- a.) Annual number of active vessels in the snow crab fishery, representing the level of fishing effort assigned to the fishery (contact: J. Lee)
- b.) Annual catch-per-unit-effort (CPUE), expressed as mean number of crabs per potlift, in the snow crab fishery, representing relative efficiency of fishing effort (contact: B. Daly)
- c.) Center of gravity, expressed in latitude, as an index of spatial distribution for the snow crab fishery to monitor spatial shifts in fishery behavior (contact: B. Daly)
- d.) Annual incidental catch of snow crab in EBS groundfish fisheries (contact: J. Lee)
- e.) Annual total potlifts in the snow crab fishery, representing the level of fishing effort expended by the active fleet (contact: B. Daly)

Economic Indicators (Figure 3b.f-i)

- f.) Percentage of the annual EBS snow crab total allowable catch (TAC) (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing (contact: B. Daly)

- g.) Annual snow crab ex-vessel price per pound, representing per-unit gross economic returns to the harvest sector, as a principal driver of fishery behavior (contact: J. Lee)
- h.) Annual snow crab ex-vessel revenue share, expressed as vessel-average proportion of annual gross landings revenue earned from the EBS snow crab fishery (contact: J. Lee)
- i.) Annual snow crab ex-vessel value of the snow crab fishery landings, representing gross economic returns to the harvest sector, as a principal driver of fishery behavior (contact: J. Lee)

#### Community Indicators

- j.) Alaska Bering Sea Crabbers (ABSC) Skipper Survey, distributed to captains following the 2021/2022 snow crab season. Although not yet an established time series, the questionnaire is designed to extract both qualitative and quantitative information on perceived abundance, fisher behavior and gear performance (contact: C. Lescher)

## Indicator Monitoring Analysis

There are up to three stages (beginning, intermediate, and advanced) of statistical analyses for monitoring the indicator suite listed in the previous section. These analyses gradually increase in complexity depending on the stability of the indicator for monitoring the ecosystem or socioeconomic process and the data availability for the stock (Shotwell et al., *In Review*). The beginning stage is a relatively simple score based on the current year trends relative to the mean of the whole time series, and provides a historical perspective on the utility of the whole indicator suite. The intermediate stage uses importance methods related to a stock assessment variable of interest (e.g., recruitment, biomass, catchability). These regression techniques provide a simple predictive performance for the variable of interest and are run separate from the stock assessment model. They provide the direction, magnitude, uncertainty of the effect, and an estimate of inclusion probability. The advanced stage is used for testing a research ecosystem linked model and output can be compared with the current operational model to understand information on retrospective patterns, prediction performance, and comparisons of other model output such as terminal spawning stock biomass or mean recruitment. This stage provides an on-ramp for introducing an alternative ecosystem linked stock assessment model to the current operational stock assessment model and can be used to understand the potential reduction in uncertainty by including the ecosystem information.

At this time, we report the results of the beginning and intermediate stages of the indicator monitoring analysis for EBS snow crab and a review of current ecosystem linked modeling developments for the advanced stage.

### *Beginning Stage: Simple Score*

We use a simple scoring calculation for the beginning stage evaluation. Indicator status is evaluated based on being greater than (“high”), less than (“low”), or within (“neutral”) one standard deviation of the long-term mean. A sign based on the anticipated relationship between the indicator and the stock (Figure 2) is also assigned to the indicator where possible for ecosystem indicators only. If a high value of an indicator generates good conditions for the stock and is also greater than one standard deviation above the mean, then that value receives a +1 score. If a high value generates poor conditions for the stock and is greater than one standard deviation above the mean, then that value receives a -1 score. All values less than or equal to one standard deviation from the long-term mean are average and receive a 0 score. The scores are summed by the three organizational categories within the ecosystem (physical, lower trophic, and upper trophic) or socioeconomic (fishery performance, economic, and community) indicators and divided by the total number of indicators available in that category for a given year. We provide the category scores for the past twenty years as the majority of indicators were available throughout this time period (Figure 4).

The scores over time allow for comparison of the indicator performance and the history of stock productivity. We also provide five year indicator status tables with a color or text code for the relationship with the stock (Table 3) and evaluate the current year status in the historical indicator time series graphic (Figure 3) for each ecosystem and socioeconomic indicator.

We evaluate the status and trends of the ecosystem and socioeconomic indicators to understand the pressures on the EBS snow crab stock regarding recruitment, stock productivity, and stock health. We start with the physical indicators and proceed through the increasing trophic levels for the ecosystem indicators then evaluate the fishery performance and economic indicators as listed above. Here, we concentrate on updates since the last ESP. Overall, the physical indicators were average, while the lower and upper trophic indicators were above average (Figure 4). The fishery performance and economic indicators scored average for 2022, but the economic score is based on only one indicator. Compared to the previous data point, this is an increase from below average for the physical indicators, an increase from average for the lower trophic indicators, an increase from below average for the upper trophic indicators, a decrease for the fishery performance indicators, and a decrease for the economic indicators.

Following the 2019-2020 highest Arctic Oscillation index in history (Zhang et al., 2021), the winter-spring Arctic Oscillation index returned to near-normal in 2022, although still remains in a positive phase. Poor snow crab recruitment has been associated with positive values of the Arctic Oscillation (Szuwalski et al., 2021), suggesting that large-scale weather and climate anomalies in 2019/2020 could have impacted stock productivity. Cold pool spatial extent and sea ice concentration in 2022 were average, indicating a return to near-normal conditions in the Bering Sea following anomalously warm temperatures and record low sea ice concentration in 2018-2019.

Lower trophic level indicators include chlorophyll-*a* biomass and benthic invertebrate biomass, both of which represent potential prey resources for pelagic and benthic snow crab stages. Chlorophyll-*a* biomass was well above average in 2022, characteristic of a large, productive spring bloom. Although 2022 benthic invertebrate density estimates are not yet available, 2021 density increased due to large catches of purple-orange sea stars. For the upper trophic level indicators, male snow crab area occupied and juvenile disease prevalence remained near-average in 2022. The mature male snow crab center of distribution shifted north in 2021 and has remained north in 2022, potentially indicating temperature-driven distributional shifts (Orensanz et al., 2005). Temperatures occupied by immature snow crab declined dramatically in 2022 from record-high temperatures in 2018-2021, suggesting that cold-water habitat critical for evading groundfish predators was widely available to juveniles. Following a dramatic reduction in male size at 50% probability of maturation in 2021, size at maturity increased by over 10mm in 2022 to remain just below the long-term average. While this indicator is indicative of population-level shifts in the average size at maturity, temporal trends may be driven by recruitment variability and cohort effects (Murphy 2021).

Fishery performance indicators are reported through calendar year 2022 (corresponding to the 2021-2022 crab season), with the exception of incidental catch in the (currently ongoing) EBS groundfish fisheries, reported through 2021. The active snow crab fleet during 2022 declined to 42 vessels, the lowest level since 1977 at the beginning of the time series, and approximately 68% of the average number of vessels participating during the previous five years. Relative to the substantially reduced TAC (less than 13% of the previous year and less than 20% of the previous five-year average), less consolidation of fishing activity occurred than would be expected based on economic efficiency, and it is unclear if other factors driving this level of vessel participation will persist if TAC levels remain comparably low. CPUE in the fishery declined from 218 the previous year to 124 legal crab per potlift, and total potlifts declined from 172 thousand in 2021 to 37 thousand, with both indicators approaching the lower bound of one standard deviation below the long term (1991-current) average, respectively. The latitude of the center of gravity of fishing activity during 2022 shifted somewhat south compared to the previous year, but remained approximately two standard deviations greater than the long-term average. Incidental catch in EBS

groundfish fisheries during 2021 declined for a fourth consecutive year to 77 thousand kg, approaching the lower bound of the long-term range of variation. TAC utilization reached 99% for the 2021-2022 snow crab fishery, however, fishing extended later than usual, with four vessels making landings later than May 15.

Economic performance indicators included in this ESP are reported through calendar year 2021, the most recent year for which data are available. With a TAC of 18.37 thousand metric tons, the highest since the 2014-2015 crab season, combined with historically high market values for snow crab driven by high consumer demand during the first two years of the covid-19 pandemic, estimated ex-vessel revenue in the snow crab fishery during 2021 exceeded \$219 million, approaching the upper bound of one standard deviation above the long-term (1991-2021) average. Average ex-vessel price per pound reached a historical high in 2021, increasing by 25% from 2020, to \$4.97 per pound, greater than two standard deviations higher than the historical average since 1991 (adjusted for inflation). As a result of the historically high ex-vessel value of the snow crab fishery during 2021, combined with the closure or reduced TAC levels in most crab and other fisheries targeted by the snow crab fleet, ex-vessel revenue share increased to an unprecedented 85% of total annual ex-vessel landings revenue, summed across all fisheries in which snow crab vessel landed catch during the 2021 calendar year. Although 2022 data is not yet available for economic performance indicators, news reports and other information indicate that market demand for crab and other premium seafood products contracted sharply in 2022, suggesting that economic returns for most or all of the fleet active during the 2021-2022 snow crab season were poor and many vessels likely operated at a loss.

While results from the 2021/2022 ABSC Skipper Survey were precluded from indicator monitoring analyses, we report summarized responses from thirteen skippers directed at comparisons between the 2021/2022 fishery and the prior 2020/2021 season. When asked to compare perceived abundances of snow crab on the fishing grounds, 38% of skippers reported that commercial sized males had decreased more than 25% and 31% of skippers reported that sub-commercial sized males had decreased more than 25%. While 23% of skippers noted that they fished deeper compared to the previous season, another 23% noted no significant changes in behavior and attributed their motivation to fish historic grounds to smaller quotas during the 2021/2022 season. In response to the sorting of dirty shell or small crab, 38% of skippers replied that discarding decreased more than 25% from last season. Finally, 70% of skippers noted an increase in Pacific cod in crab pots compared to the past season.

#### *Intermediate Stage: Importance Analysis*

Bayesian adaptive sampling (BAS) was used for the intermediate stage statistical analysis to quantify the association between hypothesized predictors and EBS snow crab recruitment, and to assess the strength of support for each hypothesis. BAS explores model space, or the full range of candidate combinations of predictor variables, to calculate marginal inclusion probabilities for each predictor, model weights for each combination of predictors, and generate Bayesian model averaged predictions for outcomes (Clyde et al., 2011). In this intermediate analysis, the full set of indicators is first winnowed to the predictors that could directly relate to recruitment, indicators are lagged to reflect hypothesized relationships with recruitment, and highly correlated covariates are removed (Figure 5). Prior to model runs, winter sea ice extent and immature snow crab temperature of occupancy were removed from the dataset as they are highly correlated with cold pool extent, and all three covariates likely represent similar linkages to the stock. We further restrict potential covariates to those that can provide the longest model run and through the most recent estimate of recruitment that is well estimated. This resulted in a model run from 1995 through 2021 (excluding 2007 and 2020) for EBS snow crab. We then provide the mean relationship between each predictor variable and log EBS snow crab recruitment over time (Figure 5, left side), with error bars describing the uncertainty (95% confidence intervals) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Figure 5, right side). A higher probability indicates that the variable is a better candidate predictor of EBS snow crab recruitment. The highest ranked predictor

variable based on this process was cold pool extent, although all marginal inclusion probabilities were < 0.5 and the model had very little explanatory power in predicting snow crab recruitment (Figure 5).

The BAS method requires observations of all predictor variables in order to fit a given data point. This method estimates the inclusion probability for each predictor, generally by looking at the relative likelihood of all model combinations (subsets of predictors). If the value of one predictor is missing in a given year, all likelihood comparisons cannot be computed. When the model is run, only the subset of observations with complete predictor and response time series are fit. It is possible to effectively trick the model into fitting all years by specifying a 0 (the long-term average in z-score space) for missing predictor values. However, this may bias inclusion probabilities for time series that have more zeros and result in those time series exhibiting low inclusion probability, independent of the strength of the true relationship. Due to this consideration of bias, we only fit years with complete observations for each covariate at the longest possible time frame. This resulted in a smaller final subset of covariates. We plan to explore alternate model runs to potentially include more covariates in the future.

We also compared results from two different BAS models: one model using estimates of male snow crab recruitment from the 2021 approved assessment model, and another model using NOAA bottom trawl survey design-based recruitment estimates. Design-based recruitment estimates were calculated as area-swept abundance of 50-65mm immature male snow crab to account for lower catchability of smaller crab in NOAA survey gear (Somerton et al., 2013), whereas estimates of recruitment from the assessment incorporate catchability and length composition data to determine cohort size. Overall, results indicated improved fits to recruitment estimates from the assessment, thus only results from this BAS model are presented.

#### *Advanced Stage: Research Model*

New research models are currently being explored to assess potential mechanisms for increased mortality (e.g. bitter crab syndrome, cod predation, cannibalism) in 2018-2019 (Szuwalski et al., *in prep*).

## **Conclusion**

The EBS snow crab ESP follows the standardized framework for evaluating the various ecosystem and socioeconomic considerations for this stock (Shotwell et al., *In Review*). Given the metric and indicator assessment we provide the following summary for ecosystem and socioeconomic indicators:

### **Ecosystem Indicators**

In summary, physical indicators reveal much more favorable conditions for snow crab in 2022 following the 2018-2019 heat wave. Sub-0°C temperatures occupied by immature snow crab suggest that survival may be optimal for a new cohort of juveniles evident in the 2022 NOAA bottom trawl survey (Zacher et al., *in review*). Likewise, above-average chlorophyll-*a* biomass and benthic invertebrate density may be indicative of increased prey resources for larval and benthic stages of snow crab. Pacific cod consumption and bitter crab syndrome prevalence reached all-time highs in 2016 and may have been attributed to 2018-2019 mortality events, although both indices have returned to near-average in recent years. Northerly shifts in male snow crab centers of abundance in 2021-2022 have coincided with continued declines in mature male biomass, and may be a distributional response to recent warming in the Bering Sea.

### **Socioeconomic Indicators**

All of the socioeconomic indicators associated with the snow crab target fishery included in this ESP exhibited substantial deviation from historical patterns during the most recent period for which data are

available. During 2022, the number of active vessels in the fishery fell to 42, the lowest level since 1977, but, with the historically low TAC set for the 2021-2022 season and early evidence of sharply reduced market value, likely exceeding the number of vessels that could be financially sustained at similarly reduced production levels. Results from an industry skipper survey highlight concerns with perceived low abundance on the fishing grounds and changes in fishing behavior attributed to reductions in the 2021/2022 snow crab TAC. Historically low CPUE in 2022, and the continued spatial shift of fishing activity far to the north of historical fishing grounds, reflected adverse fishing conditions. A historically high ex-vessel price during 2021, combined with a relatively high TAC level, contributed to strong economic performance in the snow crab fishery during 2021. However, the ex-vessel revenue share indicator increased for 2021 to an unprecedented 85% share of the fleet's total gross landings revenue for the year, reflecting increased dependence on the snow crab fishery. The continued limited availability of alternative fishing targets for the fleet, combined with high operating costs associated with adverse fishery performance indicators noted above, without the mitigating (though limited) effect of high ex-vessel price observed for the previous year, is evidence of severe economic stress on the snow crab fleet and dependent stakeholders and communities during 2022.

### **Data Gaps and Future Research Priorities**

Future research should support the development of indicators that quantify snow crab physiological and biological responses to rapidly changing ecosystem conditions in the Bering Sea. Recent, dramatic population declines emphasize the importance of understanding proximate causes and mechanisms for mortality including predator-prey interactions, disease dynamics, shifts in benthic production, physiological condition and responses to thermal stress.

Refinements or updates to existing indicators may also be warranted given the limited inference resulting from stage 2 modeling efforts. Spatial scales for physical and lower trophic level indicators may need to be refined to overlap with spatial distributions across ontogeny. The development of Essential Fish Habitat maps for snow crab by life history stage would provide spatial bounds to subset physical and lower trophic level datasets. Furthermore, replacing chlorophyll-*a* biomass estimates with size fractionation data might better clarify the role of diatoms in enhancing larval survival.

The limited scope and timeliness of socioeconomic indicators reported in the ESP provide limited information regarding the economic stresses on the harvest and processing sectors of the Bering Sea crab fisheries and associated communities resulting from the recent declines in the two principal Bering Sea crab fisheries. These stresses, if persistent, have the potential to induce substantial structural changes in crab harvest and processing industries, as well as management changes intended to mitigate adverse social and economic effects, ultimately inducing systematic operational changes in the behavior of snow crab fishing vessels. Lacking a conceptual framework for capturing linkages between social and economic drivers, fishing behavior, and condition of the crab stock, it is difficult to conceive how a narrow suite of socioeconomic indicators in the context of the ESP may meaningfully inform the snow crab stock assessment or harvest specification process, beyond providing important context. Research in spatial aspects of the EBS snow crab fishery with direct relation to the stock assessment may provide the basis for further development of relevant and informative socioeconomic indicators for use in the ESP. As well, improving the timeliness of socioeconomic indicators should be explored, including use of models for nowcast/forecast of time series, and or alternate or proxy measures that track key socioeconomic indicators.

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## Tables

Table 1: List of data sources used in the ESP evaluation. Please see the main EBS snow crab SAFE document, the Ecosystem Considerations Report (Siddon, 2021) and the Economic Status Report (Garber-Yonts *et al.*, 2021) for more details.

| Title                                | Description   | Years          | Extent                |
|--------------------------------------|---|----------------|-----------------------|
| AFSC Bottom Trawl Survey             | Bottom trawl survey of groundfish in June through August, eastern Bering Sea using Poly Nor'Eastern trawl on stratified random sample grid, catch per unit of effort in metric tons | 1982 – present | Gulf of Alaska annual |
| REEM Diet Database                   | Food habits data and associated analyses collected by the Resource Ecology and Ecosystem Modeling (REEM) Program, AFSC on multiple platforms  | 1990 – present | Gulf of Alaska annual |
| MODIS                                | 4 km Moderate Resolution Imaging Spectroradiometer (MODIS) ocean color data aggregated 8-day composites.  | 2003-present   | Global                |
| Copernicus Earth Observation Program | Time series of monthly sea ice extent for Arctic and Antarctic, produced from the ERA5 Reanalysis   | 1979-present   | Arctic/Antarctic      |
| NOAA National Climate Data Center    | Monthly large-scale climate indices constructed by the National Oceanic and Atmospheric Administration (NOAA) National Weather Service's Climate Prediction Center                  | 1950-present   | North Pacific annual  |
| ADF&G Crab Observer program data     | Snow crab catch and effort data (number of active vessels, total pots lifted, and CPUE), sourced from Alaska Department of Fish and Game (ADF&G) Annual Fishery Management Report   | 1980-2019      | Alaska                |
| ADF&G fish ticket database           | Volume, value, and port of landing for Alaska crab and groundfish commercial landings; data processed and provided by Alaska Fisheries Information Network                          | 1992-2019      | Alaska                |
| ABSC Skipper Survey                  | Fishery-dependent survey from Alaska Bering Sea Crabbers (ABSC) delivered to captains of the EBS snow crab fleet following the conclusion of the fishery for a given year           | 2000-2002      | Bering Sea            |

Table 2a: Ecological information by life history stage for EBS snow crab.

| Stage           | Habitat & Distribution  | Phenology   | Age, Length, Growth   | Energetics                                   | Diet  | Predators/Competitors                                |
|-----------------|---|---|---|--|---|--|
| <b>Egg</b>      | Clutch of embryos brooded under the female's abdomen until hatching                 | 240 days at 6°C to 353 days at -1°C; cold temperatures trigger a 2-year reproductive cycle <sub>(1)</sub> | Egg diameter: 644.4-772.1 µm <sub>(2)</sub>   | Optimal: 0°C – 3°C <sub>(3)</sub>            | Yolk  | Nemertean worms and amphipods feed on egg clutches   |
| <b>Larvae</b>   | Pelagic; concentrated in the upper 20m over the middle shelf <sub>(4)</sub>         | April-June hatch  | Mean carapace length: 1.25mm  | Optimal: 6.9°C – 9.1°C <sub>(5)</sub>        | Diatoms, small copepods   | Jellyfish, juvenile pollock and Pacific salmon       |
| <b>Juvenile</b> | Benthic; found in mud and gravel habitat in 1°C bottom temperatures (50-100m depth) | Peak settlement in October, later benthic stages molt annually in the spring                              | 10-12 benthic instar stages until final molt to maturity <sub>(6)</sub>                     | Growth indices highest at 5°C <sub>(7)</sub> | Crustaceans, bivalves, polychaetes <sub>(8)</sub>               | Pacific cod, flatfish, sculpins, crab <sub>(9)</sub> |
| <b>Adult</b>    | Benthic: sand and mud bottoms (70-200m depth)                                       | 6-7+ years, migration to shallow waters in spring to mate   | Average size range at terminal molt: females 47-59 mm CW, males 73-101mm CW <sub>(10)</sub> | Growth is optimum at 4°C <sub>(11)</sub>     | Polychaetes, crustaceans, echinoderms, mollusks <sub>(12)</sub> | Pacific cod, halibut, skates <sub>(13)</sub>         |

Note: Subscripts in table correspond to the following citations in sequential order 1. Webb et al., 2006, 2. Moriyasu and Lanteigne, 1998, 3. Webb et al., 2007, 4. Armstrong et al., 1981, 5. Yamamoto et al., 2017, 6. Sainte-Marie et al., 1995, 7. Yamamoto et al., 2015, 8. Kolts et al., 2013, 9. Lang et al., 2003, 10. Murphy 2021, 11. Foyle et al., 1989, 12. Divine et al., 2017, 13. Livingston et al., 1993

Table 2b. Key processes affecting survival by life history stage for EBS snow crab.

| Stage           | Processes Affecting Survival                            | Relationship to EBS snow crab   |
|-----------------|---|---|
| <b>Egg</b>      | 1. Temperature  | Temperature direct affects the duration of incubation <sub>(1)</sub>  |
| <b>Larvae</b>   | 1. Synchrony with spring bloom<br>2. Offshore advection | Larval growth and survival is dependent on high concentrations of diatoms <sub>(2)</sub> . Advection to areas overlying suitable bottom temperatures and substrate likely improves larval survival <sub>(3)</sub>           |
| <b>Juvenile</b> | 1. Cold pool and sea ice extent<br>2. Predation         | Pacific cod predation is a major source of immature snow crab mortality and the cold pool provides predator refuge for juvenile snow crab <sub>(4)</sub>  |
| <b>Adult</b>    | 1. Benthic production<br>2. Temperature                 | Food availability may drive patterns in growth, energetic condition and survival of snow crab. Shifts in the spatial extent of snow crab are driven by bottom temperatures and cold pool dynamics in the EBS <sub>(5)</sub> |

Note: Subscripts in table correspond to the following citations in sequential order 1. Webb et al., 2007, 2. Paul et al., 1979, 3. Parada et al., 2010, 4. Livingston, 1989, 5. Fedewa et al., 2020

Table 3a: First stage ecosystem indicator analysis for EBS snow crab, including indicator title and the indicator status of the last five available years. The indicator status is designated with text, (greater than = “high”, less than = “low”, or within 1 standard deviation = “neutral” of time series mean). Fill color of the cell is based on the sign of the anticipated relationship between the indicator and the stock (blue or italicized text = good conditions for the stock, red or bold text = poor conditions, white = average conditions). A gray fill and text = “NA” will appear if there were no data for that year

| Indicator category | Indicator  | 2018 Status | 2019 Status | 2020 Status | 2021 Status | 2022 Status |
|--------------------|--|-------------|-------------|-------------|-------------|-------------|
| Physical           | Winter Spring Arctic Oscillation Index-Model           | neutral     | neutral     | <b>high</b> | neutral     | neutral     |
|                    | Summer Cold Pool-SEBS Survey                           | <b>low</b>  | <b>low</b>  | NA          | <b>low</b>  | neutral     |
|                    | Winter Sea Ice Advance BS- Satellite                   | <b>low</b>  | neutral     | neutral     | neutral     | neutral     |
| Lower Trophic      | Chlorophyll- <i>a</i> Biomass SEBS-Satellite           | neutral     | neutral     | <i>high</i> | neutral     | <i>high</i> |
|                    | Summer Benthic Invertebrate Density-SEBS Survey        | neutral     | neutral     | NA          | neutral     | NA          |
| Upper Trophic      | Summer Snow Crab Juvenile Temperature Occupancy        | <b>high</b> | <b>high</b> | NA          | <b>high</b> | neutral     |
|                    | Summer Snow Crab Juvenile Disease Prevalence           | neutral     | neutral     | NA          | neutral     | neutral     |
|                    | Annual Snow Crab Male Size Maturity-Model              | <b>low</b>  | neutral     | NA          | <b>low</b>  | neutral     |
|                    | Summer Snow Crab Male Area Occupied-SEBS Survey        | <b>low</b>  | <b>low</b>  | NA          | neutral     | neutral     |
|                    | Summer Snow Crab Male Center Distribution- SEBS Survey | neutral     | neutral     | NA          | <i>high</i> | <i>high</i> |
|                    | Summer Snow Crab Consumption Pacific Cod- Model        | <b>high</b> | neutral     | NA          | neutral     | NA          |

Table 3b: First stage socioeconomic indicator analysis for EBS snow crab, including indicator title and the indicator status of the last five available years. The indicator status is designated with text, (greater than = “high”, less than = “low”, or within 1 standard deviation = “neutral” of time series mean). A gray fill and text = “NA” will appear if there were no data for that year.

| <b>Indicator category</b> | <b>Indicator</b>                                    | <b>2018 Status</b> | <b>2019 Status</b> | <b>2020 Status</b> | <b>2021 Status</b> | <b>2022 Status</b> |
|---------------------------|---|--------------------|--------------------|--------------------|--------------------|--------------------|
| Fishery Performance       | Annual Snow Crab Active Vessels EBS Fishery         | neutral            | neutral            | neutral            | neutral            | low                |
|                           | Annual Snow Crab CPUE Fishery                       | neutral            | neutral            | neutral            | neutral            | neutral            |
|                           | Annual Snow Crab Potlift Fishery                    | neutral            | neutral            | neutral            | neutral            | neutral            |
|                           | Annual Snow Crab Center Distribution EBS Fishery    | neutral            | high               | neutral            | high               | high               |
|                           | Annual Snow Crab Incidental Catch EBS Fishery       | neutral            | neutral            | neutral            | neutral            | NA                 |
| Economic                  | Annual Snow Crab TAC Utilization EBS Fishery        | neutral            | neutral            | neutral            | neutral            | neutral            |
|                           | Annual Snow Crab Exvessel Value EBS Fishery         | neutral            | neutral            | neutral            | neutral            | NA                 |
|                           | Annual Snow Crab Exvessel Price EBS Fishery         | high               | high               | high               | high               | NA                 |
|                           | Annual Snow Crab Exvessel Revenue Share EBS Fishery | neutral            | neutral            | high               | high               | NA                 |

## Figures

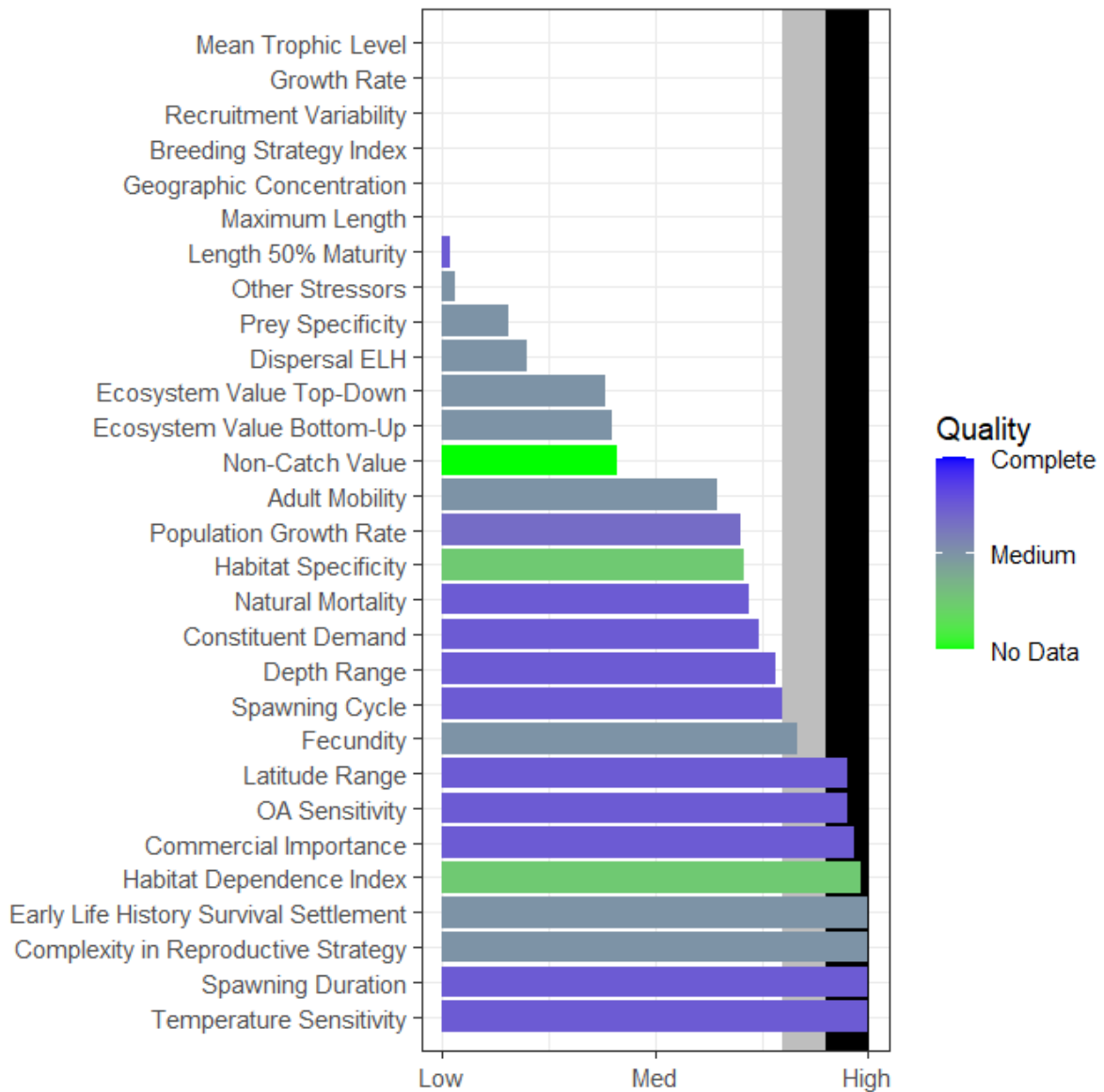


Figure 1: Baseline metrics for EBS snow crab graded as percentile rank over all groundfish and crab in the FMPs. Gray and black vertical bars indicate 80<sup>th</sup> and 90<sup>th</sup> percentile over all stocks. Higher rank values indicate a vulnerability and color of the horizontal bar describes data quality of the metric (see Shotwell et al., *In Review*, for more details on the metric definitions and thresholds).



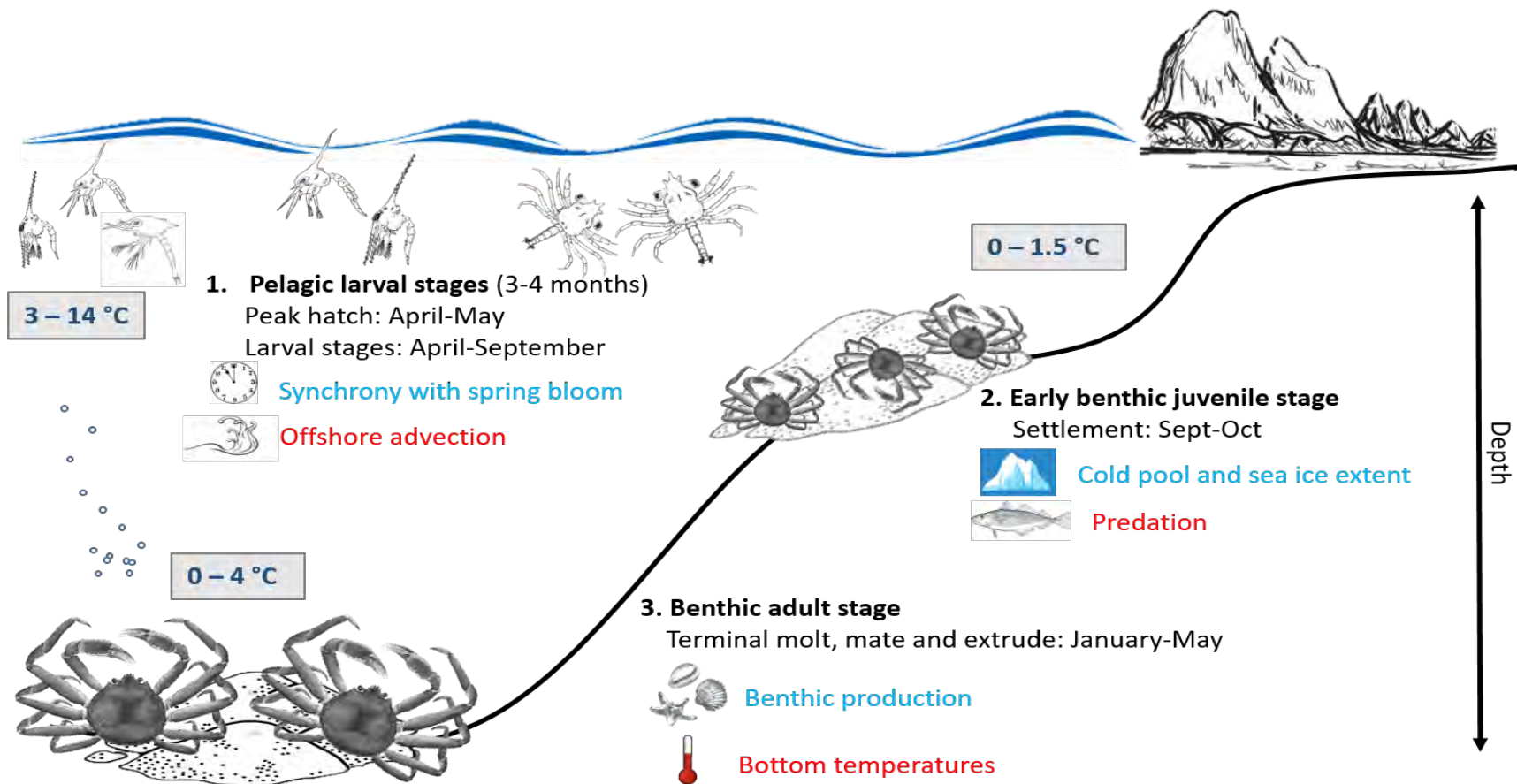


Figure 2. Life history conceptual model for EBS snow crab summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text means increases in process negatively affect survival, while blue text means increases in process positively affect survival.

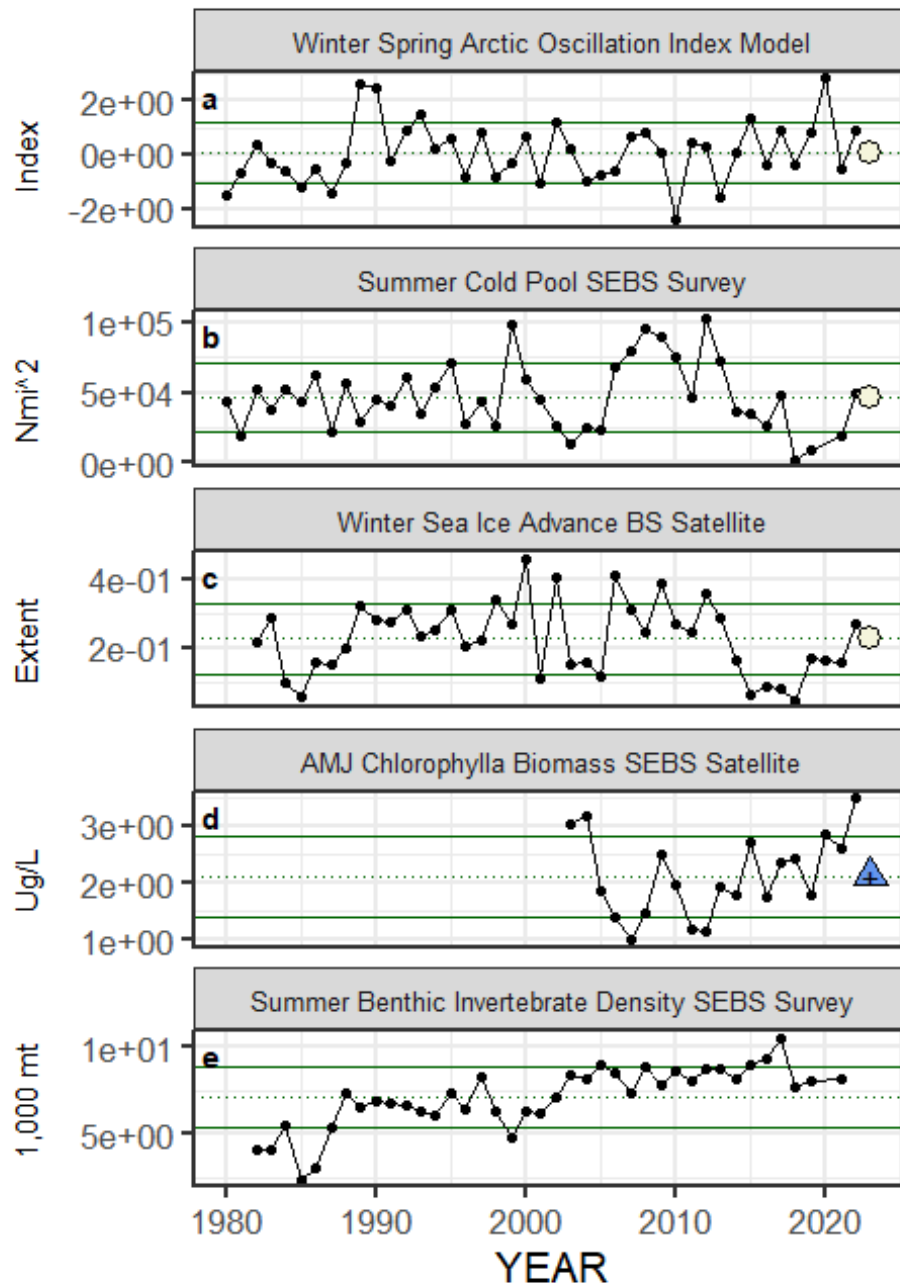


Figure 3a. Selected ecosystem indicators for EBS snow crab with time series ranging from 1980 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation of the time series mean, color represents proposed relationship for stock, white circle for neutral).

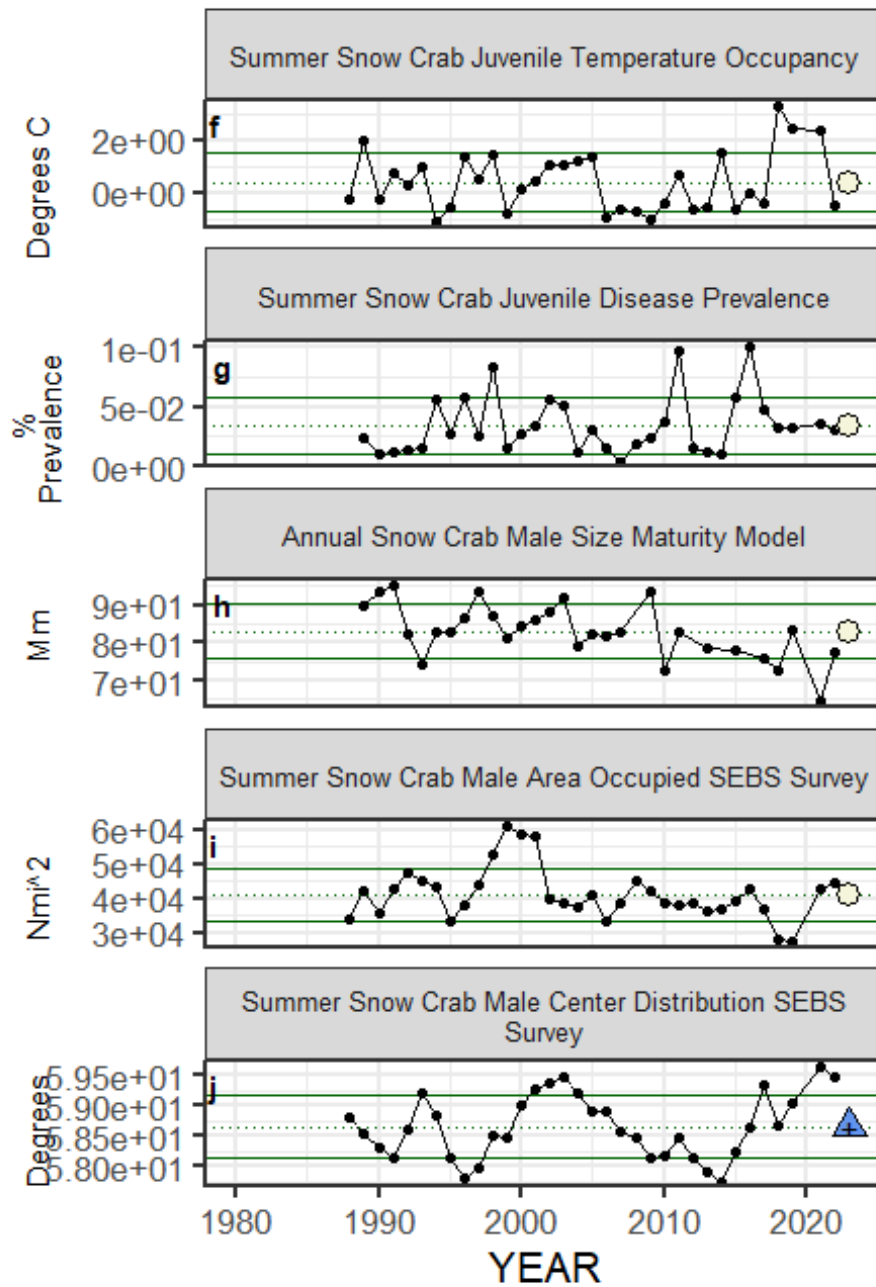


Figure 3a (cont.). Selected ecosystem indicators for EBS snow crab with time series ranging from 1980 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation of the time series mean, color represents proposed relationship for stock, white circle for neutral).

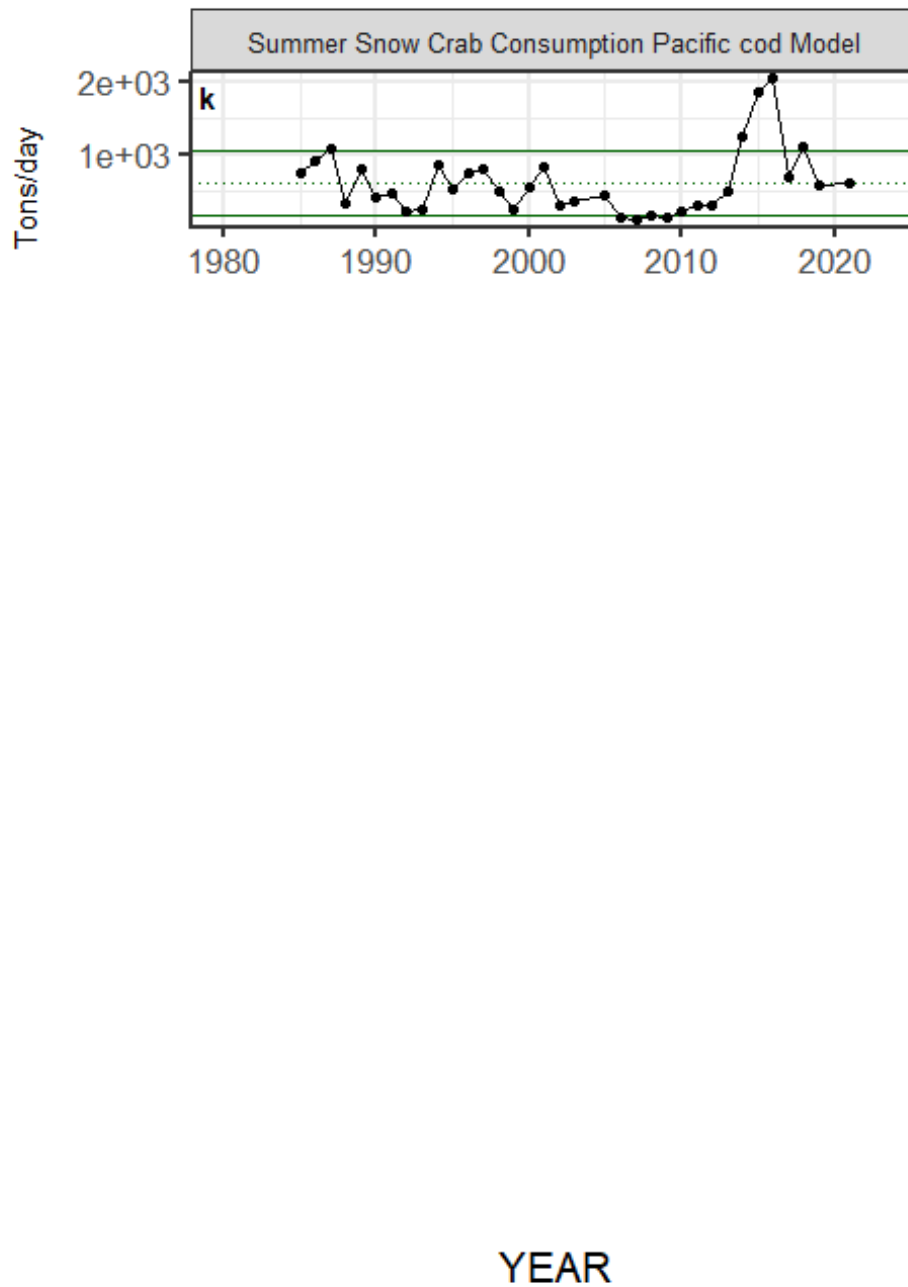


Figure 3a (cont.). Selected ecosystem indicators for EBS snow crab with time series ranging from 1980 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation of the time series mean, color represents proposed relationship for stock, white circle for neutral).

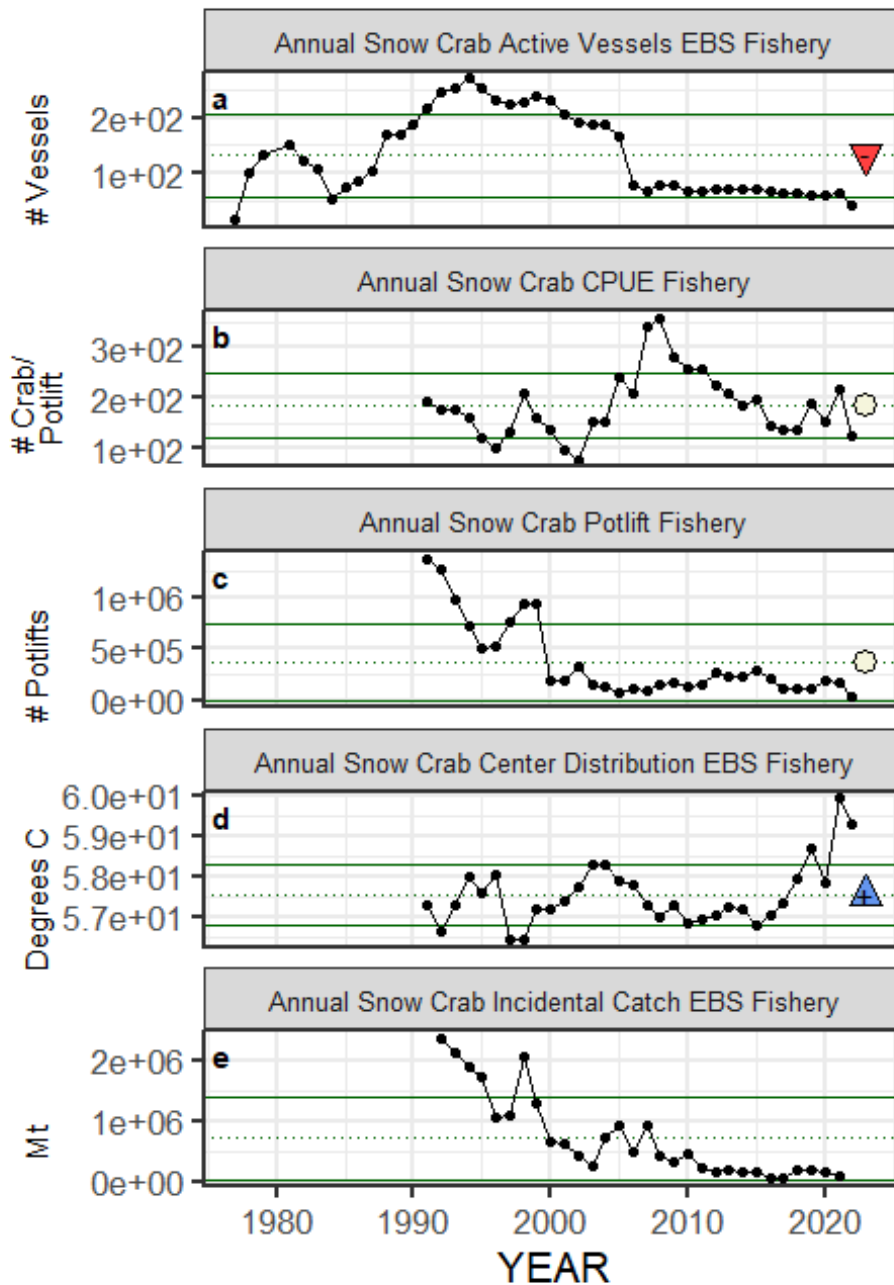


Figure 3b. Selected socioeconomic indicators for EBS snow crab with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation from the time series mean, color represents proposed relationship for stock, white circle for neutral).

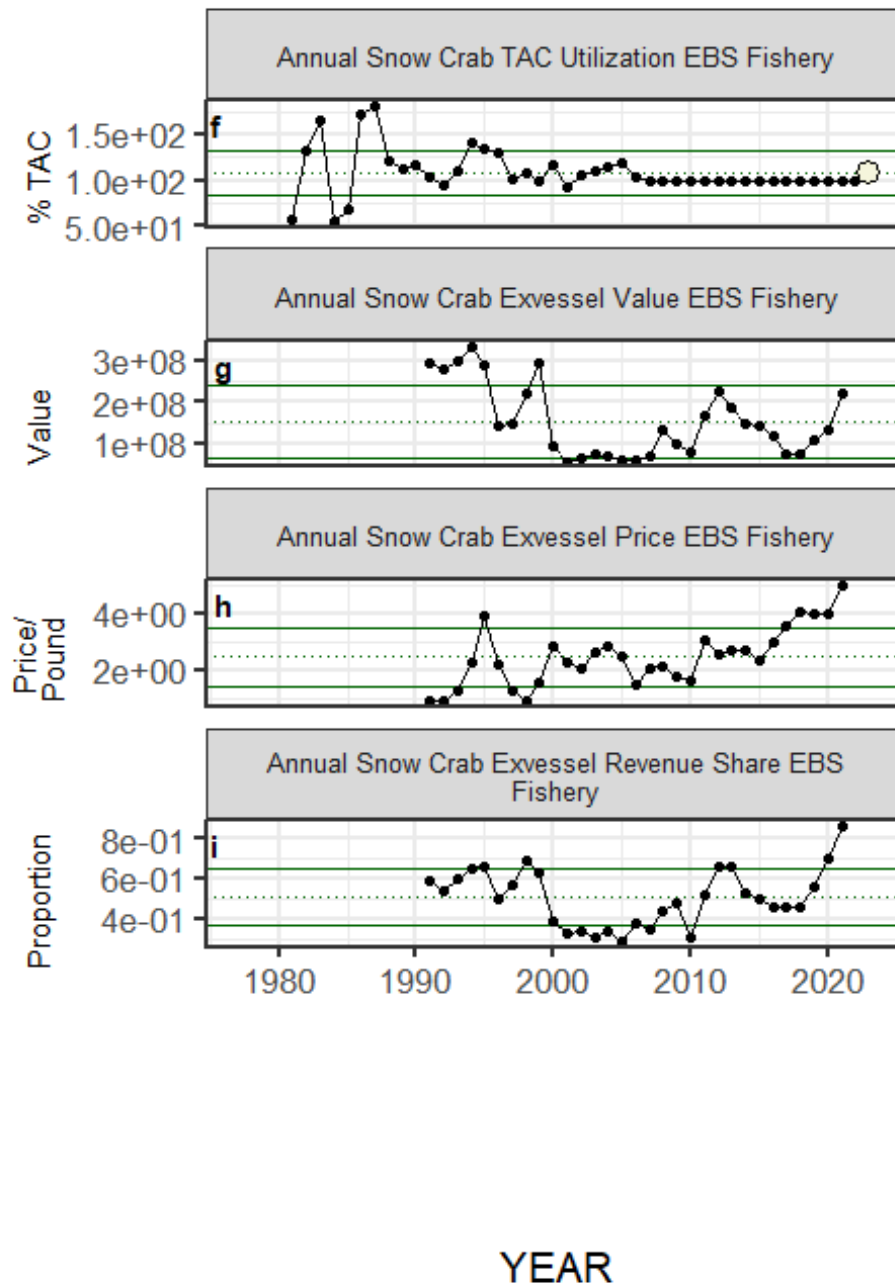


Figure 3 (cont.). Selected socioeconomic indicators for EBS snow crab with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation from the time series mean, color represents proposed relationship for stock, white circle for neutral).

### Overall Stage 1 Score for Eastern Bering Sea Snow Crab

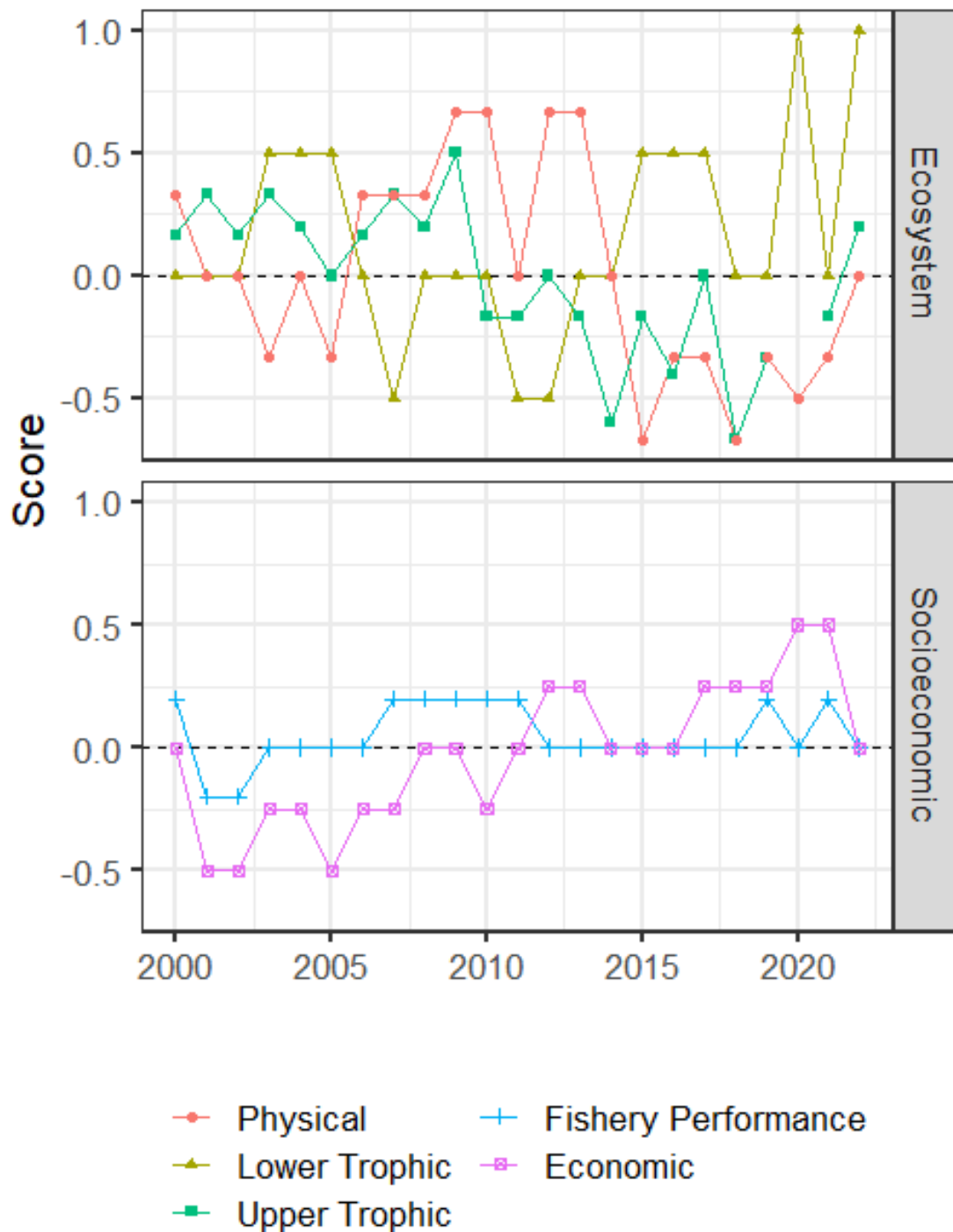


Figure 4. Simple score from beginning stage indicator analysis for ecosystem and socioeconomic categories from 2000 to present.

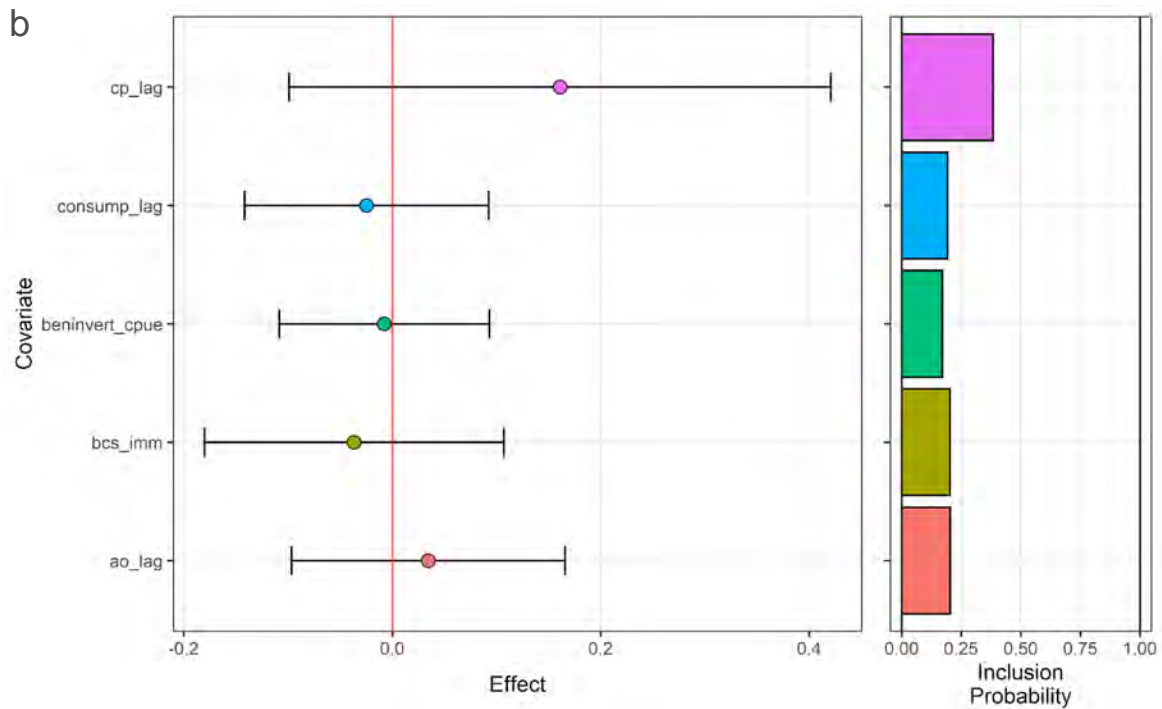
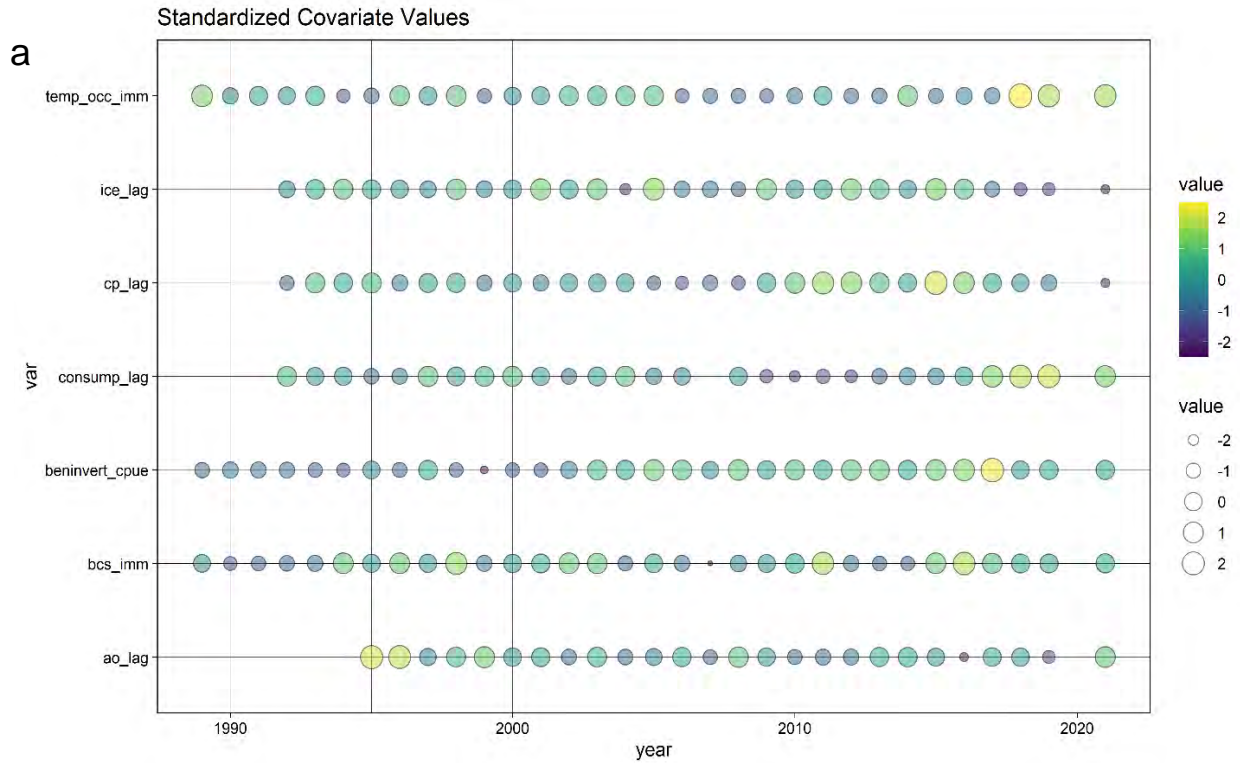


Figure 5. Bayesian adaptive sampling output showing (a) standardized covariates prior to subsetting and (b) the mean relationship and uncertainty (95% confidence intervals) with log EBS male snow crab model estimated recruitment (left bottom graph), and marginal inclusion probabilities (right bottom graph) for each predictor variable of the subsetted covariate set.