Chapter 1: Assessment of the Walleye Pollock Stock in the Eastern Bering Sea

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Executive summary

This chapter covers the Eastern Bering Sea (EBS) region—the Aleutian Islands region (Chapter 1A) and the Bogoslof Island area (Chapter 1B) are presented separately. A multi-species stock assessment is provided separately and available here.

Summary of changes in assessment inputs

Relative to last year's BSAI SAFE report, the following substantive changes have been made in the EBS pollock stock assessment. This includes the 2022 NMFS bottom-trawl survey (BTS) covering the EBS and NBS. As before, these data were treated with a spatio temporal model for index standardization. Age data from this survey effort was compiled and included (also with an extensive spatio-temporal model treatment). The NMFS acoustic-trawl survey (ATS) was completed covering the EBS and a northern extension region north of the core shelf survey area. The BTS chartered boats also collected acoustic data and the series was updated this year (AVO).

Changes in the data

1. Observer data for catch-at-age and average weight-at-age from the 2021 fishery were finalized and included.
2. Total catch as reported by NMFS Alaska Regional office was updated and included through 2022.

3. In summer 2022, the AFSC conducted the bottom trawl survey in the EBS and extended into the NBS. A VAST model evaluation (including the cold-pool extent) was used as the main index.
4. An improved treatment of the weight-at-age data from the BTS was presented to the Plan Team and SSC in September 2022 and these have replaced values used in the past where constant length-weight parameters had been assumed.
5. The bottom trawl survey collected acoustic data opportunistically with the index covering 2006-2022 (except for 2020).
6. The MACE Program completed an acoustic-trawl survey (ATS) aboard the NOAA ship Oscar Dyson in 2022. Pollock numbers and biomass at length estimates were generated and a preliminary age composition was included based on the BTS age-length data plus a juvenile sample from the ATS. Transects were also extended northward to investigate the presence of pollock beyond the core EBS shelf area.

Changes in the assessment methods

There were some minor changes to the assessment model to enhance some of the output variables and to accommodate evaluating the posterior distribution via MCMC.

Summary of EBS pollock results

The concern over low survey abundance estimates in 2021 was alleviated since the three main indices all show an increase over the previous observations. This also coincides with data indicating that the 2018 year class was one of the most abundant on record.

The following table is based on results from Model "20", as used for last year's assessment. The ABC recommendation is based on Tier 3 calculation as a proxy for Tier 1 because of the variability indicated by the very high value based on the F_{MSY} estimate and the large but uncertain 2018 year class.

Response to SSC and Plan Team comments

General comments

From several SSC comments in the past few years related to reviewing the support for retaining the EBS Pollock assessment in Tier 1 versus reclassifying it as Tier 3.

- Consideration of whether the observed sensitivity in the SRR to prior specification should constitute an increased risk level specification within the assessment or population dynamics related considerations. This could provide a clearer justification for the use of the Tier 3 calculation as the basis for harvest specification.
  - *We evaluated factors affecting the Tier classification in the 2020 assessment and showed that the priors used reflect the SRR curve were conservative and justified based on residual patterns near the origin (as opposed to alternatives that fit data on the descending slope of the Ricker SRR.*

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2022	2023	2023	2024
M (natural mortality rate, ages 3+)	0.3	0.3	0.3	0.3
Tier	1b	1b	1a	1a
Projected total (age 3+) biomass (t)	6,839,000 t	6,969,000 t	12,389,000 t	11,445,000 t
Projected female spawning biomass (t)	1,881,000 t	1,905,000 t	4,171,000 t	3,944,000 t
B_0	5,575,000 t	5,575,000 t	6,653,000 t	6,653,000 t
B_{msy}	2,220,000 t	2,220,000 t	2,674,000 t	2,674,000 t
F_{OFL}	0.392	0.415	0.491	0.491
$maxF_{ABC}$	0.334	0.353	0.434	0.434
F_{ABC}	0.296	0.314	0.365	0.365
OFL	1,469,000 t	1,704,000 t	3,381,000 t	4,639,000 t
$maxABC$	1,251,000 t	1,451,000 t	2,987,000 t	4,099,000 t
ABC	1,111,000 t	1,289,000 t	1,688,000 t	1,815,000 t
Status	2020	2021	2021	2022
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

- The SSC recommends that if the assessment is considered in the appropriate Tier, buffers should be based on the use of the Risk Table rather than the continued use of Tier 3 calculations for a Tier 1 stock.
  - *We agree.*
- The SSC also notes that an alternative approach to consider for a buffer below the maximum permissible would be apply Tier 2 control rule. This tier uses the SR relationship for stock status and OFL, but uses the ratio of SPR rates for adjustments when the stock is below B_{MSY}.
  - *An examination of Tier 2 as an option resulted in a value of 2,518,000 t (or a hybrid of Tier 1 and 2 of 2,224,000 t) for 2023 ABC values. We note that selecting Tier 2 would require similar reliance on the underlying productivity estimates (via the stock-recruitment relationship) and how that affects the reference fishing rate (F_{MSY}).*

The SSC had a number of recommendations for additional research supporting this assessment:

From previous requests:

The SSC also looks forward to estimates of movement and abundance along the US-Russia EEZ boundary based on echosounders fixed to moorings in this area.

- *The data evaluation from the moored sounders is presently underway. Initial results hold promise and should be available in early 2023.*

Introduction

General

Walleye pollock (*Gadus chalcogrammus*; hereafter referred to as pollock) are broadly distributed throughout the North Pacific with the largest concentrations found in the Eastern Bering Sea. Also known as Alaska pollock, this species continues to play important roles ecologically and economically.

Review of Life History

In the EBS pollock spawn generally in the period March-May and in relatively localized regions during specific periods (Bailey 2000). Generally spawning begins nearshore north of Unimak Island in March and April and later near the Pribilof Islands (Jung et al. 2006, Bacheler et al. 2010). Females are batch spawners with up to 10 batches of eggs per female per year (during the peak spawning period). Eggs and larvae of EBS pollock are planktonic for a period of about 90 days and appear to be sensitive to environmental conditions. These conditions likely affect their dispersal into favorable areas (for subsequent separation from predators) and also affect general food requirements for over-wintering survival (Gann et al. 2015, Heintz et al., 2013, Hunt et al. 2011, Ciannelli et al. 2004). Duffy-Anderson et al. (2015) provide a review of the early life history of EBS pollock.

Throughout their range juvenile pollock feed on a variety of planktonic crustaceans, including calanoid copepods and euphausiids. In the EBS shelf region, one-year-old pollock are found throughout the water column, but also commonly occur in the NMFS bottom trawl survey. Ages 2 and 3 year old pollock are rarely caught in summer bottom trawl survey gear and are more common in the midwater zone as detected by mid-water acoustic trawl surveys. Younger pollock are generally found in the more northern parts of the survey area and appear to move to the southeast as they age (Buckley et al. 2009). Euphausiids, principally *Thysanoessa inermis* and *T. raschii*, are among the most important prey items for pollock in the Bering Sea (Livingston, 1991; Lang et al., 2000; Brodeur et al., 2002; Cianelli et al., 2004; Lang et al., 2005). Pollock diets become more piscivorous with age, and cannibalism has been commonly observed in this region. However, Buckley et al. (2015) showed spatial patterns of pollock foraging by size of predators. For example, the northern part of the shelf region between the 100 and 200 m isobaths (closest to the shelf break) tends to be more piscivorous than counterparts in other areas.

Stock structure

Stock structure for EBS pollock was evaluated in Ianelli et al. (2015). In that review past work on genetics (e.g., Bailey et al. 1999, Canino et al. 2005) provided insight on genetic differentiation. The investigation also compared synchrony in year-classes and growth patterns. Pollock samples from areas including Zhemchug Canyon, Japan, Prince William Sound, Bogoslof, Shelikof, and the Northern Bering Sea were processed and results presented in 2021. This analysis included 617 walleye pollock from Japan, Bering Sea, Chukchi Sea, Aleutian Islands, Alaska Peninsula, and Gulf of Alaska. Results suggests there is temporally stable stock structure with a latitudinal gradient, i.e., Bering Sea pollock are distinguishable from those in the Gulf of Alaska and Aleutian Islands (I. Spies, personal communication, 2021). Notably, Bogoslof samples appeared genetically distinct from other spawning regions. In addition, there appeared to be genetic connectivity between the eastern Bering Sea and the western Gulf of Alaska spawning samples. Samples from the eastern Gulf of Alaska are currently undergoing sequencing to determine whether eastern Gulf of Alaska pollock are genetically distinct from those in the western Gulf of Alaska. The ongoing goals of the project include investigating the genetic stock structure of walleye pollock, testing if patterns are temporally stable, and evaluating if distributional shifts under climate change can be detected.

For management purposes, the preliminary conclusions from these genetics results are: 1)there is stock structure in pollock that appears to be stable through time and 2) Some aspect of stock structure is latitudinal—Bering Sea pollock appear distinct from fish collected from the Gulf of Alaska and the Aleutian Islands. The results appear strong enough that a GTseq panel could be designed in the future to determine stock of origin of walleye pollock, the scale of which may be relatively large, such as “Bering Sea” or “GOA”. The scope and funding sources for this project will be planned in 2022 with sampling designs developed for implementation as early as 2023.

Fishery

Description of the directed fishery

Historically, EBS pollock catches were low until directed foreign fisheries began in 1964. Catches increased rapidly during the late 1960s and reached a peak in 1970–75 when they ranged from 1.3 to 1.9 million t annually. Following the peak catch in 1972, bilateral agreements with Japan and the USSR resulted in reductions. During a 10-year period, catches by foreign vessels operating in the “Donut Hole” region of the Aleutian Basin were substantial totaling nearly 7 million t (Table 1). A fishing moratorium for this area was enacted in 1993 and only trace amounts of pollock have been harvested from the Aleutian Basin region since then. Since the late 1970s, the average EBS pollock catch has been about 1.2 million t, ranging from 0.810 million t in 2009 to nearly 1.5 million t during 2002–2006 (Table 1). United States vessels began fishing for pollock in 1980 and by 1988 the fishery became fully domestic. The current observer program for the domestic fishery formally began in 1991 and prior to that, observers were deployed aboard the foreign and joint-venture operations since the late 1970s. From the period 1991 to 2011 about 80% of the catch was observed at sea or during dockside offloading. Since 2011, regulations require that all vessels participating in the pollock fishery carry at least one observer so nearly 100% of the pollock fishing operations are monitored by scientifically trained observers. Historical catch estimates used in the assessment, along with management measures (i.e., OFLs, ABCs and TACs) are shown in Table 2.

Catch patterns

The “A-season” for directed EBS pollock fishing opens on January 20th and fishing typically extends into early-mid April. During this season the fishery targets pre-spawning pollock and produces pollock roe that, under optimal conditions, can comprise over 4% of the catch in weight. The summer, or “B-season” presently opens on June 10th and fishing extends through noon on November 1st. The A-season fishery concentrates primarily north and west of Unimak Island depending on ice conditions and fish distribution. There has also been effort along the 100m depth contour (and deeper) between Unimak Island and the Pribilof Islands. The general pattern by season (and area) has varied over time with recent B-season catches occurring in the southeast portion of the shelf (east of 170°W longitude; Fig. 1). Since 2011, regulations and industry-based measures to reduce Chinook salmon bycatch have affected the spatial distribution of the fishery and to some degree, the way individual vessel operators fish (Stram and Ianelli, 2014). In 2020, the fishing fleet encountered higher than normal bycatch of herring and this has further constrained the fishing grounds due to area closures. Additionally, sablefish appear to be highly abundant in the region and have comprised a significant proportion of the incidental catches in the pollock fishery (proportionally still less than 1% of the total landings). Comparing encounters of bycatch relative to the effort (total duration of all tows) the pollock fleet had a relatively flat trend in the Chinook salmon bycatch while sablefish and herring was down from the relatively high levels last year (Fig. 2).

The catch estimates by sex for the seasons indicate that over time, the number of males and females has been fairly equal but in the period 2017-2020 the A-season catch of females has been slightly higher and conversely, in the B-season there has been a slightly higher number of males taken (Fig. 3). This figure is updated through 2021 and shows the high numbers of fish taken in that year because they were smaller than average. The 2022 A-season fishery spatial pattern had a higher concentrations of fishing near Unimak and east compared to 2020 and 2021 (Fig. 4). The amount of fishing near the Pribilof Islands was much lower than commonly observed in 2022. The 2022 A-season nominal catch rates were lower than the 2020 peak (for the fleet in aggregate) (Fig. 5). Beginning in 2017, due to a regulatory change, up to 45% of the TAC could be taken in the A-season (previously only 40% of the TAC could be taken). This conservation measure was made to allow greater flexibility to avoid Chinook salmon in the B-season. The pollock fleet as a whole continues to take advantage of this flexibility (Fig. 6). However, this figure indicates that in 2022, the proportion of catch in February increased over the 2021 pattern and this was consistent in subsequent months as well. This suggests that fishing conditions were improved. Pollock roe is an important product coming from the winter fishery. The amount produced in the 2022 A-season was the lowest since 2013 and continued the big drop from the previous year (Fig. 7).

The summer-fall fishing conditions for 2022 improved considerably over 2021 and was about average on nominal catch rates (Fig. 5). The number of hours the fleet required to catch the same tonnage of pollock was also improved relative to 2020. In the B-season catches in the northwestern area dropped relative to the previous two years (Fig. 8). In addition, we present an approach first shown in 2019 to evaluate how concentrated the fleet was on average. We called this a measure of fleet dispersion: the relative distance or spread of the fishery in space. Briefly, the calculation computes for a given day, the distance between all trawl tows (within and across boats). These distances are then averaged for year and season. Updated to this year, results indicated that in both seasons the fleet was less dispersed than last year suggesting that fishing was fairly concentrated without a need to fish in more places (Fig 9).

We continued to investigate the tow specific mean weight of fish. These provide a direct mean somatic mass (pollock body weight) for pollock within a tow. The data arise from the sampled total weight (e.g., of several baskets of pollock) divided by the enumerated number of fish in that sample. Such records exist for each tow. Summing these by extrapolated weight of the pollock catch within that tow, and binning by weight increments (here by 50 gram intervals), allows us to obtain some additional fine-scale information on the size trends in the pollock fishery. The annual patterns of these data show that overall, the B-season of 2020 was different with the small mode of fish persisting into the 2021 B-season (Fig. 10). Compiling the data by week we show that the fish size was consistent the growth of the 2018 year class during this B-season (Fig. 11).

The catch of EBS pollock has averaged 1.26 million t in the period since 1979. The lowest catches occurred in 2009 and 2010 when the limits were set to 0.81 million t due to stock declines (Table 2). The recent 5-year average (2018-2022) catch has been 1.326 million t. Pollock catches that are retained or discarded (based on NMFS observer estimates) in the Eastern Bering Sea and Aleutian

Islands for 1991–2022 are shown in Table 3. Since 1991, estimates of discarded pollock have ranged from a high of 9.6% of total pollock catch in 1991 to recent lows of around 0.6% to 1.1%. These low values reflect the implementation of the NMFS' Improved Retention /Improved Utilization program. Prior to the implementation of the American Fisheries Act (AFA) in 1999, higher discards may have occurred under the "race for fish" and pollock marketable sizes were caught incidentally. Since implementation of the AFA, the vessel operators have more time to pursue optimal sizes of pollock for market since the quota is allocated to vessels (via cooperative arrangements). In addition, several vessels have made gear modifications to avoid retention of smaller pollock. In all cases, the magnitude of discards counts as part of the total catch for management (to ensure the TAC is not exceeded) and within the assessment. Bycatch of other non-target, target, and prohibited species is presented in the section titled Ecosystem Considerations below. In that section it is noted that the bycatch of pollock in other target fisheries is more than double the bycatch of other target species (e.g., Pacific cod) in the pollock fishery.

Management measures

The EBS pollock stock is managed by NMFS regulations that provide limits on seasonal catch. The NMFS observer program data provide near real-time statistics during the season and vessels operate within well-defined limits. In most years, the TACs have been set well below the ABC value and catches have stayed within these constraints (Table 2). Allocations of the TAC split first with 10% to western Alaska communities as part of the Community Development Quota (CDQ) program and the remainder between at-sea processors and shore-based sectors. For a characterization of the CDQ program see Haynie (2014). Seung and Ianelli (2016) combined a fish population dynamics model with an economic model to evaluate regional impacts.

Due to concerns that groundfish fisheries may impact the rebuilding of the Steller sea lion population, a number of management measures have been implemented over the years. Some measures were designed to reduce the possibility of competitive interactions between fisheries and Steller sea lions. For the pollock fisheries, seasonal fishery catch and pollock biomass distributions (from surveys) indicated that the apparent disproportionately high seasonal harvest rates within Steller sea lion critical habitat could lead to reduced sea lion prey densities. Consequently, management measures redistributed the fishery both temporally and spatially according to pollock biomass distributions. This was intended to disperse fishing so that localized harvest rates were more consistent with estimated annual exploitation rates. The measures include establishing: 1) pollock fishery exclusion zones around sea lion rookery or haulout sites; 2) phased-in reductions in the seasonal proportions of TAC that can be taken from critical habitat; and 3) additional seasonal TAC releases to disperse the fishery in time.

Prior to adoption of the above management measures, the pollock fishery occurred throughout each of the three major NMFS management regions of the North Pacific Ocean: the Aleutian Islands (1,001,780 km^2 inside the EEZ), the Eastern Bering Sea (968,600 km^2), and the Gulf of Alaska (1,156,100 km^2). The marine portion of Steller sea lion critical habitat in Alaska west of 150°W encompasses 386,770 km^2 of ocean surface, or 12% of the fishery management regions.

From 1995–1999 84,100 km^2, or 22% of the Steller sea lion critical habitat was closed to the pollock fishery. Most of this closure consisted of the 10 and 20 nm radius all-trawl fishery exclusion zones around sea lion rookeries (48,920 km^2, or 13% of critical habitat). The remainder was largely management area 518 (35,180 km^2, or 9% of critical habitat) that was closed pursuant to an international agreement to protect spawning stocks of central Bering Sea pollock. In 1999, an additional 83,080 km^2 (21%) of critical habitat in the Aleutian Islands was closed to pollock fishing along with 43,170 km^2 (11%) around sea lion haulouts in the GOA and Eastern Bering Sea. In 1998, over 22,000 t of pollock were caught in the Aleutian Island region, with over 17,000 t taken within critical habitat region. Between 1999 and 2004 a directed fishery for pollock was prohibited in this region. Subsequently, 210,350 km^2 (54%) of critical habitat in the Aleutian Islands was closed to the pollock fishery. In 2000 the remaining phased-in reductions in the proportions of seasonal TAC that could be caught within the BSAI Steller sea lion Conservation Area (SCA) were implemented.

On the EBS shelf, an estimate (based on observer at-sea data) of the proportion of pollock caught in the SCA has averaged about 44% annually. During the A-season, the average is also about 44%. Nonetheless, the proportion of pollock caught within the SCA varies considerably, presumably due to temperature regimes and the relative population age structure. The annual proportion of catch has ranged from an annual low of 11% in 2010 to high of 60% in 1998–the 2019 annual value was 58% and quite high again in the A-season (68%; Ianelli et al. 2020). The higher values in recent years were likely due to good fishing conditions close to the main port. The recent transition from at-sea observer sampling of many catcher vessels to a combination of at-sea electronic monitoring and shore-based observer sampling has resulted in a temporary hiatus in to associate catches with specific areas. Work has progressed to link the position information to offloads so that haul records could be used to evaluate fishing patterns.

The AFA reduced the capacity of the catcher/processor fleet and permitted the formation of cooperatives in each industry sector by the year 2000. Because of some of its provisions, the AFA gave the industry the ability to respond efficiently to changes mandated for sea lion conservation and salmon bycatch measures. Without such a catch-share program, these additional measures would likely have been less effective and less economical (Strong and Criddle 2014).

An additional strategy to minimize potential adverse effects on sea lion populations is to disperse the fishery throughout more of the pollock range on the Eastern Bering Sea shelf. While the distribution of fishing during the A-season is limited due to ice and weather conditions, there appears to be some dispersion to the northwest area (Fig. 4).

The majority (about 56%) of Chinook salmon caught as bycatch in the pollock fishery originate from western Alaskan rivers. This was updated at the June 2022 Council meeting and is activities are monitored and reported closely at the Council (at this website. In summary, Chinook salmon bycatch management measures went into effect in 2011 which imposed revised prohibited species catch (PSC) limits. These limits, when reached, close the fishery by sector and season (Amendment 91 to the BSAI Groundfish Fishery Management Plan (FMP) resulting from the NPFMC's 2009 action). Previously, all measures for salmon bycatch imposed seasonal area closures when PSC levels reached the limit (fishing could continue outside of the closed areas). The current program imposes a dual cap system by fishing sector and season. A goal of this system was to maintain incentives to avoid bycatch at a broad range of relative salmon abundance (and encounter rates). Participants are also required to take part in an incentive program agreement (IPA). These IPAs are approved and reviewed annually by NMFS to ensure individual vessel accountability. The fishery has been operating under rules to implement this program since January 2011.

Further measures to reduce salmon bycatch in the pollock fishery were developed and the Council took action on Amendment 110 to the BSAI Groundfish FMP in April 2015. These additional measures were designed to add protection for Chinook salmon by imposing more restrictive PSC limits in times of low western Alaskan Chinook salmon abundance. This included provisions within the IPAs that reduce fishing in months of higher bycatch encounters and mandate the use of salmon excluders in trawl nets. These provisions were also included to provide more flexible management measures for chum salmon bycatch within the IPAs rather than through regulatory provisions implemented by Amendment 84 to the FMP. The new measure also included additional seasonal flexibility in pollock fishing so that more pollock (proportionally) could be caught during seasons when salmon bycatch rates were low. Specifically, an additional 5% of the pollock can be caught in the A-season (effectively changing the seasonal allocation from 40% to 45% (as noted above in the discussion assosciated with Fig. 6). These measures are all part of Amendment 110 and a summary of this and other key management measures is provided in Table 4.

There are three time/area closures in regulation to minimize herring PSC impacts: *Summer Herring Savings Area 1* an area south of 57°N latitude and between 162°W and 164°W longitude from June 15 through July 1st. *Summer Herring Savings Area 2* an area south of 56° 30' N latitude and between 164°W and 167°W longitude from July 1 through August 15. *Winter Herring Savings Area* an area between 58° and 60°N latitude and between 172°W and 175°W longitude from September 1st through March 1st of the next fishing year.

Data

The following lists the data used in this assessment:

Source	Type	Years
Fishery	Catch biomass	1964–2022
Fishery	Catch age composition	1964–2021
Fishery	Japanese trawl CPUE	1965–1976
EBS bottom trawl	Area-swept biomass and age-specific proportions	1982–2019, 2021-2022
Acoustic trawl survey	Biomass index and age-specific proportions	1994, 1996, 1997, 1999, 2000, 2002, 2004, 2006–2010, 2012, 2014, 2016, 2018, 2020, 2022
Acoustic vessels of opportunity (AVO)	Biomass index	2006–2019, 2021-2022

Note the 2020 acoustic survey data based on unmanned surface vessel (USV) transects and age-specific proportions were unavailable in this year

Fishery

Catch

Biological sampling by scientifically trained observers form the basis of a major data component of this assessment (as evaluated in Barbeaux et al. 2005). The catch-at-age composition was estimated using the methods described by Kimura (1989) and modified by Dorn (1992). Length-stratified age data are used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates are then weighted by the catch biomass within each stratum to arrive at an overall age composition for each year. Data were collected through shore-side sampling and at-sea observers. The three strata for the EBS were: i) January–June (all areas, but mainly east of 170°W); ii) INPFC area 51 (east of 170°W) from July–December; and iii) INPFC area 52 (west of 170°W) from July–December. This method was used to derive the age compositions from 1991–2021 (the period for which all the necessary information is readily available). Prior to 1991, we used the same catch-at-age composition estimates as presented in Wespestad et al. (1996).

The catch-at-age estimation method uses a two-stage bootstrap re-sampling of the data. Observed tows were first selected with replacement, followed by re- sampling actual lengths and age specimens given that set of tows. This method allows an objective way to specify the starting values for the input sample size for fitting fishery age composition data within the assessment model. In addition, estimates of stratum-specific fishery mean weights-at-age (and variances) are provided which are useful for evaluating general patterns in growth and growth variability. For example, Ianelli et al. (2007) showed that seasonal aspects of pollock condition factor could affect estimates of mean weight-at-age. They showed that within a year, the condition factor for pollock varies by more than 15%, with the heaviest pollock caught late in the year from October-December (although most fishing occurs during other times of the year) and the thinnest fish at length tending to occur in late winter. They also showed that spatial patterns in the fishery affect mean weights, particularly when the fishery is shifted more towards the northwest where pollock tend to be smaller at age. Grüss et al. (2021) showed cold-pool-extent impacts on the spatial map of summer condition and relating environmental conditions to fish condition continues to be an active area of research.

In 2011 the winter fishery catch consisted primarily of age 5 pollock (the 2006 year class) and later in that year age 3 pollock (the 2008 year class) were present. In 2012–2016 the 2008 year class was prominent in the catches with 2015 showing the first signs of the 2012 year-class as three year-olds in the catch (Fig. 13; Table 5). However, by 2017 the 2013 year-class began to be also evident and surpassed the 2012 year-class in dominance and persist through to 2021. The unusual pattern of switching adjacent year-classes was examined in 2021 to see if there was a pattern of spatial differences. There was a distinct spatial distribution of the different year-classes. Having adjacent strong year-classes appears to be a new characteristic of the stock. In 2020, an unusual presence of age-2 pollock appeared in the catch, along with some from the 2014 year-class while the 2012 year-class was a smaller part of the catch (Fig. 13). By 2021, the predominance of 3-year olds in the catch seems to confirm that there is an abundant year-class from 2018.

The sampling effort for age determinations, weight-length measurements, and length frequencies is shown in Tables 6, 7, and 8. Sampling for pollock lengths and ages by area has been shown to be relatively proportional to catches (e.g., Fig. 1.8 in Ianelli et al. 2004). The precision of total pollock catch biomass is considered high with estimated CVs to be on the order of 1% (Miller 2005).

Scientific research catches are reported to fulfill requirements of the Magnuson-Stevens Fisheries Conservation and Management Act. The annual estimated research catches (1963–2020) from NMFS surveys in the Bering Sea and Aleutian Islands Region are given in (Table 9). Since these values represent extremely small fractions of the total removals (about 0.02%) they are ignored for assessment purposes.

Surveys

Bottom trawl survey (BTS)

Trawl surveys have been conducted annually by the AFSC to assess the abundance of crab and groundfish in the Eastern Bering Sea since 1979 and since 1982 using standardized gear and methods. For pollock, this survey has been instrumental in providing an abundance index and information on the population age structure. This survey is complemented by the acoustic trawl (AT) surveys that sample mid-water components of the pollock stock. Between 1991 and 2022 the BTS biomass estimates ranged from 2.28 to 8.39 million t (Table 10 for the design-based estimates). The values used for the assessment (VAST index, see appendix for details) are provided in Fig. 14). In the mid-1980s and early 1990s several years resulted in above-average biomass estimates. The stock appeared to be at lower levels during 1996–1999 then increased moderately until about 2003 and since then has averaged just over 4 million t (from the standard EBS region using design-based estimators). These surveys also provide consistent measurements of environmental conditions, such as the sea surface and bottom temperatures. Large-scale zoogeographic shifts in the EBS shelf documented during a warming trend in the early 2000s were attributed to temperature changes (e.g., Mueter and Litzow 2008). However, after the period of relatively warm conditions ended in 2005, the next eight years were mainly below average, indicating that the zoogeographic responses may be less temperature-dependent than they initially appeared (Kotwicki and Lauth 2013). Bottom temperatures increased in 2011 to about average from the low value in 2010 but declined again in 2012–2013. However, in the period 2014–2016, bottom temperatures increased and reached a new high in 2016. In 2018 bottom temperatures were nearly as warm (after 2017 was slightly above average) but was highly unusual due to the complete lack of "cold pool" (i.e., a defined area where water near bottom was less than zero degrees. In 2019, the mean bottom temperature was the warmest during the period the survey has occurred (since 1982; Fig. 15). In 2022, the temperatures on bottom were more average with a relatively extensive cold pool extent.

The AFSC has expanded the area covered by the bottom trawl survey over time. In 1987 the "standard survey area" comprising 6 main strata was increased farther to the northwest and covered in all subsequent years. These two northern strata have varied in estimated pollock abundance. In 2022 about 9% of the pollock biomass was found in these strata compared to a long term average of 5% (Table 10). Importantly, this region is contiguous with the Russian border and the NBS region, and treatment of the extent stock shifts between regions continues (e.g., O'leary et al. 2021).

The 2022 survey estimate increased 35% from the 2021 value and is about 95% of the long term mean estimate. This coincided with a return to more average cold water on the bottom throughout the survey area (Fig. 16). In 2022, pollock appeared to be mainly distributed over the outer shelf area compared to recent years (Fig. 17).

The BTS abundance-at-age estimates show variability in year-class strengths with substantial consistency over time (Fig. 18). Pollock above 40 cm in length generally appear to be fully selected and in some years many 1-year olds occur on or near the bottom (with modal lengths around 10–19 cm). Generally speaking, age 2 or 3 pollock (lengths around 20–29 cm and 30–39 cm, respectively) are relatively rare in this survey because they tend to be more pelagic as juveniles. Compared to 2021, this year showed size compositions consistent with the mid-range categories and consistent with the age data (Fig. 19). The relatively high abundance of 4-year old pollock in this years survey indicates that the 2018 year class persisted, despite that group comprising much of the fishery as 3-year olds in 2021.

Observed fluctuations in survey estimates may be attributed to a variety of sources including unaccounted-for variability in natural mortality, survey catchability, and **horizontal** migrations and **vertical availability** (Monnahan et al., 2021; O'Leary et al., 2022). As an example, some strong year classes appear in the surveys over several ages (e.g., the 1989 year class) while others appear only at older ages (e.g., the 1992 and 2008 year class). Sometimes initially strong year classes appear to wane in successive assessments (e.g., the 1996 year class estimate (at age 1) dropped from 43 billion fish in 2003 to 32 billion in 2007 (Ianelli et al. 2007)). Retrospective analyses (e.g., Parma

1993) have also highlighted these patterns, as presented in Ianelli et al. (2006, 2011). Kotwicki et al. (2013) also found that the catchability of either the BTS or AT survey for pollock is variable in space and time because it depends on environmental variables, and is density-dependent in the case of the BTS survey.

The 2022 survey age compositions were developed from age-structures collected during the survey (June-July) and processed at the AFSC labs within a few weeks after the survey was completed. The level of sampling for lengths and ages in the BTS is shown in Table 11. The estimated numbers-at-age from the BTS for strata 1–9 (except for 1982–84 and 1986, when only strata 6 were surveyed) are presented in Table 12 (based on the method in Kotwicki et al. 2014 and then using VAST–see appendix for those details). Compared to the previous design-based age composition estimates, those derived from the spatio-temporal model were generally very similar (Fig. 20).

In the previous assessments, the BTS mean body mass-at-ages was computed based on the sex-specific mean length-at-age in each year and converted to weight using sex-specific length-weight parameters that were estimated from data prior to 1999. In reconsidering this approach, data on weight-at-age from intervening years have become available and some new methods applied including those corrected by spatio-temporal modeling (J. Indivero, pers. comm). This work was presented to the Plan Team and SSC for the October 2022 Council meeting. As the results from this new study is in review, the Council advised to use the available data in a basic way prior to advancing to the full spatio-temporal approach. As such, the revised survey station-specific density estimates applied to the weight-at-age data resulted in revised estimates. These are compared in Figure 21 and provided in Table 13. The time series of BTS survey indices is shown in Table 14.

The NBS survey area was sampled in 2010, 2017, 2018 (limited to 49 stations), in 2019, 2021 and again this year. Given that the pollock abundance was quite high in 2017 and 2018, a method for incorporating this information as part of the standard survey was desired. One approach for constructing a full time series that included the NBS area is to use observed spatial and temporal correlations. We used the vector-autoregressive spatial temporal (VAST) model of Thorson (2018b) together with the density- dependent corrected CPUE values from each station (including stations where pollock were absent; Table 14). Please refer to the appendix for further details on the implementation. The appendix also shows results that indicate the VAST model diagnostics are reasonable and provide consistent interpretations relative to the observations. Notably, results indicate increased uncertainty in years and areas when stations were missing. As noted in past assessments, application of this index within the stock assessment model required accounting for the time-series covariance estimate.

To date, given other commitments work on comparing the age-and-growth from NBS samples has stalled. We hope to evaluate these data when they become available in the near future to look at maturity and growth conditions from this region.

Acoustic trawl surveys

Acoustic trawl surveys are typically conducted every other year and are designed to estimate the off-bottom component of the pollock stock (compared to the BTS which are conducted annually and provide an abundance index of the near-bottom pollock). Estimated pollock biomass for the EBS shelf has averaged over 3.2 million t since the time-series was revised to include the water column to 0.5 m (from the historical midwater pollock index to 3 m off bottom) starting in 1994 (Table 14). The early 2000s (a relatively 'warm' period) were characterized by low pollock recruitment, which was subsequently reflected in lower pollock biomass estimates between 2006 and 2012 (a 'cold' period; Honkalehto and McCarthy 2015). In 2014 and 2016 (another 'warm' period) with the growth of the strong 2012 year class, AT biomass estimates increased to over 4 million t (Table 14). The number of trawl hauls, lengths, and ages sampled from the AT survey are presented in Table 15. These surveys have also provided insight on the relative abundance of pollock in areas considered critical to Steller sea lions (the "SCA"; Table 16).

Eastern Bering Sea shelf walleye pollock (Gadus chalcogrammus) midwater abundance and distribution were assessed from Bristol Bay to the U.S.-Russia Convention Line from 1 June to 5 August 2022 using acoustic-trawl (AT) survey methods aboard the NOAA ship *Oscar Dyson*. In addition to the traditional (core) survey area, a region north of most transects (the northern extension) was surveyed. Transect spacing, typically 20 nmi, ranged from 40 nmi in the east and middle shelf to 20 nmi in the western shelf due to ship staffing constraints and uncertainties over the survey schedule.

The estimated amount of pollock in midwater (between 16 m from the sea surface and 0.5 m off the sea floor) in the U.S. EEZ core survey area was 9.67 billion fish with a biomass of 3.834 million metric tons (t), just over a 50% increase from the estimate of 5.57 billion fish with a biomass of 2.499 million t in 2018, the last time a standard acoustic-trawl survey was conducted on the Eastern Bering Sea shelf. This is a 6% increase over the estimate of 3.605 million t in 2020 made by the acoustics-only Saildrone survey. Pollock east of 170^ $W numbered 2.99 billion fish and weighed 1.361 million t (36% of the total biomass found in the core survey area, and 31% of the biomass found shelf-wide, including the northern extension). Pollock abundance west of 170W was 6.68 billion fish weighing 2.473 million t (64% of total core survey area biomass and 57% of the shelf-wide biomass). Preliminary age results using age-length information from the BT survey and 100 AT survey juvenile ages indicated that four year-old pollock (34 to 40 cm mean fork length (FL)) composed 57% of the biomass in the core survey area (Fig. 22). Slightly more than one-half million t (0.539 million t) of pollock were observed distributed sparsely along the northern extension transects, 12% of the shelf-wide total.

Relative estimation errors for the total biomass were derived from a one-dimensional (1D) geostatistical method, which accounts for observed spatial structure for sampling along transects (Petitgas 1993, Walline 2007, Williamson and Traynor 1996). The 2022 relative estimation error for the core survey area was 0.068, slightly higher than the time series mean of 0.043, likely due to increased transect spacing. As in previous assessments, the other sources of error (e.g., target strength, trawl selectivity) were accounted for by inflating the annual error estimates to have an overall average CV of 20% for application within the assessment model. The age composition data from the ATS sampling are provided in Table 17).

Other time series used in the assessment

Japanese fishery CPUE index

An available time series relating the abundance of pollock during the period 1965–1976 was included. This series is based on Japanese fishery catch rates which used the same size class of trawl vessels as presented in Low and Ikeda (1980). A coefficient of variation of 20% was applied.

Biomass index from Acoustic-Vessels-of-Opportunity (AVO)

Acoustic backscatter data (Simrad ES60, 38 kHz) were collected aboard two fishing vessels chartered for the AFSC summer 2022 bottom trawl surveys (F/V Alaska Knight, F/V Vesteraalen). These

Acoustic Vessels of Opportunity (AVO) data were processed according to Honkalehto et al. (2011) to provide an index of age-1+ midwater pollock abundance in each year.

The 2022 AVO index of midwater pollock abundance on the eastern Bering Sea shelf increased by 16% from 2021 and is the highest value on record (14% higher than the next highest value recorded in 2015) (Table 18; note the AVO data were unavailable in 2020 since the BTS was canceled). Spatially, the total pollock backscatter observed east of the Pribilof Islands during the summers of 2010-2012 ranged from 4-9%. Since 2013 the backscatter from this area ranged between 15% and 25% (Fig. 23).

Analytic approach

General model structure

A statistical age-structured assessment model conceptually outlined in Fournier and Archibald (1982) and like Methot's (1990) stock synthesis model was applied over the period 1964–2022. A technical description is presented in the "EBS Pollock Model Description" appendix. The analysis was first introduced in the 1996 SAFE report and compared to the cohort analyses that had been used previously and was later documented in Ianelli and Fournier (1998). The model was written in ADMB—a library for non-linear estimation and statistical applications (Fournier et al. 2012). The data updated from last year's analyses include:

- The 2021 fishery age composition data were added
- The catch biomass estimates were updated through to the current year
- The 2022 bottom-trawl survey index, weight, and age composition data were revised and added
- The 2022 acoustic-trawl survey index, weight, and preliminary age composition data were added
- The AVO backscatter data collected opportunistically from the 2022 bottom trawl survey and post processed into the AVO backscatter index were included.

A simplified version of the assessment (with mainly the same data and likelihood-fitting method) is included as a supplemental multi-species assessment model. As presented since 2016, it allows for trophic interactions among key prey and predator species and for pollock, and it can be used to evaluate age and time-varying natural mortality estimates in addition to alternative catch scenarios and management targets (see this volume: EBS multi-species model).

Description of alternative models

In the 2019 assessment, the spatio-temporal model fit to BTS CPUE data *including stations from the NBS* was expanded using the VAST methods detailed in Thorson (2018). This data treatment was included as a model alternative and adopted for ABC/OFL specifications by the SSC in 2020 along with other modifications including a spatio-temporal treatment of the age composition data.

This year, we used the same model configuration and simply examined the influence of additional data that became available this year. For projections we added the ability to test alternative Tier scenarios. The current base model is Model 20.0a, which was adopted last year by the SSC, and which differed from the previous base model (Model 16.2) in that it included the 2020 USV acoustic biomass estimate as an extension of the standard AT survey biomass time series and excluded the 1978 year class from the estimation of the stock-recruitment relationship. We examined the following alternative models:

20.0 The model selected last year which omitted the 1978 year-class from affecting the SRR (referred to as "Base")

20.1 As 20.0 but estimating M with a prior distribution (referred to as "Est. M")

20.2 As 20.0 but updating the Francis weights (referred to as "Wt Comp").

In an effort to test different stock assessment software, we adopted the pollock data and used some of the model software that was simulation tested in Li et al. (2021). While preliminary, the results were consistent with the bespoke model used here. However, the impact of missing features in the more generalized models tested in this paper requires more investigation. Specifically, the bespoke model used here includes an informed fixed-effects model for projecting weight-at-age and uses a covariance matrix for index time series that is unavailable in the models tested in Li et al. (2021).

Input sample size

Sample sizes for age-composition data were re-evaluated in 2016 against the trade-off with flexibility in time and age varying selectivity. In subsequent assessment years the values have changed significantly from the 4-periods of fishery data from which these weights were applied and calculated. Principally, this work resulted in tuning the recent era (1991-present year) to an average sample sizes of 350 for the fishery and then using estimated values for the period 1978-1990 and as earlier (Table 19). We assumed average values of 100 and 50 for the BTS and ATS data, respectively with inter-annual variability reflecting the variability in the number of hauls sampled for ages. This year we re-evaluated one-step tuning as a sensitivity following Francis 2011 (equation TA1.8, hereafter referred to as Francis weights).

Recent work has shown ways to improve estimation schemes that deal with the interaction between flexibility in fishery selectivity and statistical properties of composition data sample size. Specifically, the Dirichlet-multinomial using either Laplace approximation (Thorson et al., 2015) or adnuts (Monnahan and Kristensen, 2018) should be implemented (e.g., as shown by Xu et al., 2020). We hope to evaluate these and alternatives in the coming year.

Parameters estimated outside of the assessment model

Natural mortality and maturity at age

The baseline model specification has been to use constant natural mortality rates at age (M=0.9, 0.45, and 0.3 for ages 1, 2, and 3+ respectively (Wespestad and Terry 1984). When predation was explicitly considered estimates tended to be higher and more variable (Holsman et al. *this volume*;

Holsman et al. 2015; Livingston and Methot 1998; Hollowed et al. 2000). Clark (1999) found that specifying a conservative (lower) natural mortality rate may be advisable when natural mortality rates are uncertain. More recent studies confirm this (e.g., Johnson et al. 2015).

In the supplemental multi-species assessment model alternative values of age and time-varying natural mortality are presented. As in past years the estimates indicate higher values than used here. In the 2018 assessment we evaluated natural mortality, and it was noted that the survey age compositions favored lower values of M while the fishery age composition favored higher values. This is consistent with the patterns seen in the BTS survey data as they show increased abundances of "fully selected" cohorts. Hence, given the model specification (asymptotic selectivity for the BTS age composition data), lower natural mortality rates would be consistent with those data. Given these trade-offs, structural model assumptions were held to be the same as previous years for consistency (i.e., the mortality schedule presented below).

Maturity-at-age values used for the EBS pollock assessment were originally based on Smith (1981) and were later reevaluated (e.g., Stahl 2004; Stahl and Kruse 2008a; and Ianelli et al. 2005). These studies found inter-annual variability but general consistency with the original schedule of proportion mature at age.

Based on results from a distinct (apparently) but adjacent stock (Bogoslof assessment, this volume) where fishing has been curtailed since 1992 and spawning surveys have taken place with regularity since then (and included age data) we evaluate as a sensitivity estimated natural mortality for pollock age 3-yrs and older. For the "base" model (model 2020) we continue to use assumed natural mortality-at-age and maturity-at-age (for all models; Smith 1981) as in previous assessments:

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
M	0.90	0.45	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
P_{mat}	0.00	0.008	0.29	0.64	0.84	0.90	0.95	0.96	0.97	1.00	1.00	1.00	1.00	1.00	1.00

Length and weight-at-age

Age determination methods have been validated for pollock (Kimura et al. 1992; Kimura et al. 2006, and Kastelle and Kimura 2006). EBS pollock size-at-age show important differences in growth with differences by area, year, and year class. Pollock in the northwest area are typically smaller at age than pollock in the southeast area. The differences in average weight-at-age are taken into account by stratifying estimates of catch-at-age by year, area, season, and weighting estimates proportional to catch.

The assessment model for EBS pollock accounts for numbers of individuals in the population. As noted above, management recommendations are based on allowable catch levels expressed as tons of fish. While estimates of pollock catch-at-age are based on large data sets, the data are only available up until the most recent completed calendar year of fishing (e.g., 2021 for this year). Consequently, estimates of weight-at-age in the current year are required to map total catch biomass (typically equal to the quota) to numbers of fish caught (in the current year). Therefore, if there are errors (or poorly accounted uncertainty) in the current and future mean weight-at-age, this can translate directly into errors between the expected fishing mortality and what mortality occurs. For example, if the mean weight-at-age is biased high, then an ABC (and OFL) value will result in greater numbers of fish being caught (and fishing mortality being higher due to more fish fitting within the ABC).

As in previous assessments, we explored patterns in size-at-age and fish condition. Using the NMFS fishery observer data on weight given length we:

1. extracted all data where non-zero measurements of pollock length and weight were available between the lengths of 35 and 60 cm for the EBS region
2. computed the mean value of body mass (weight) for each cm length bin over all areas and time
3. divided each weight measurement by that mean cm-specific value (the "standardization" step)
4. plotted these standardized values by different areas, years, months etc. to evaluate condition differences (pooling over ages is effective as there were no size-specific biases apparent)

In the first instance, the overarching seasonal pattern in body mass relative to the mean shows that as the winter progresses prior to peak spawning, pollock are generally skinnier than average whereas in July, the median is about average (Fig. 24). As the summer/fall progresses, fish were at their heaviest given length (Fig. 24). This is also apparent when the data are aggregated by A- and B-seasons (and by east and west of 170°W; referred to as SE and NW respectively) when plotted over time (Fig. 25, where stratum 1 = A season, stratum 2 = B season SE, and stratum 3 = B season NW). Combining across seasons, the fishery data shows that recent years were below average weight given length (Fig. 26; note that the anomalies are based on the period 1991-2022).

Examining the weight-at-age, there are also patterns of variability that vary due to environmental conditions in addition to spatial and temporal patterns of the fishery. Based on the bootstrap distributions and large sample sizes, the within-year sampling variability for pollock is small. However, the between-year variability in mean weights-at-age is relatively high (Table 20). The coefficients of variation between years are on the order of 6% to 9% (for the ages that are targeted) whereas the sampling variability is generally around 1% or 2%. The approach to account for the identified mean weight-at-age having clear year and cohort effects was continued (e.g., Fig. 27). Details were provided in appendix 1A of Ianelli et al. (2016). The results from this method showed the relative variability between years and cohorts and provide estimates for 2022–2024 (Table 20). How these fishery weights-at-age estimates can be supplemented using survey weights-at-age is further illustrated in Fig. 28.

In the 2020 and 2021 fishery, the average weight-at-age for ages 6-8 (the 2012-2014 year classes) was below the time series average. These cohorts have fluctuated around their means in recent years (Fig. 27). To examine this more closely, we split the bootstrap results into area-season strata and were able to get an overall picture of the pattern by strata (Fig. 29 and Fig. 30). This showed that the mean weight-at-age is higher in the the B-season in the area east of 170°W compared to the A-season and B-season in the area west of 170°W.

Parameters estimated within the assessment model

For the selected model, 1106 parameters were estimated conditioned on data and model assumptions. Initial age composition, subsequent recruitment, and stock- recruitment parameters account for 79 parameters. This includes vectors describing the initial age composition (and deviation from the equilibrium expectation) in the first year (as ages 2–15 in 1964) and the recruitment mean and deviations (at age 1) from 1964–2022 and projected recruitment variability (using the variance of past recruitments) for five years (2023–2028). The two- parameter stock-recruitment curve is included in addition to a term that allows the average recruitment before 1964 (that comprises the initial age composition in that year) to have a mean value different from subsequent years. Note that the stock-recruit relationship is fit only to stock and recruitment estimates from 1979 year-class through to the 2020 year-class.

Fishing mortality is parameterized to be semi-separable with year and age (selectivity) components. The age component is allowed to vary over time; changes are allowed in each year. The mean value of the age component is constrained to equal one and the last 5 age groups (ages 11–15) are specified to be equal. This latter specification feature is intended to reduce the number of parameters while acknowledging that pollock in this age-range are likely to exhibit similar life-history characteristics (i.e., unlikely to change their relative availability to the fishery with age). The annual components of fishing mortality result in 59 parameters and the age-time selectivity schedule forms a 10x59 matrix of 590 parameters bringing the total fishing mortality parameters to 649. The rationale for including time- varying selectivity has recently been supported as a means to improve retrospective patterns (Szuwalski et al. 2017) and as best practice (Martell and Stewart, 2013).

For surveys and indices, the treatment of the catchability coefficient, and interactions with age-specific selectivity require consideration. For the BTS index, selectivity-at-age is estimated with a logistic curve in which year specific deviations in the parameters is allowed. Such time-varying survey selectivity is estimated to account for changes in the availability of pollock to the survey gear and is constrained by pre-specified variance terms. Presently, these variance terms have been set based on balancing input data-based variances and are somewhat subjective. For the AT survey, which originally began in 1979 (the current series including data down to 0.5 m from bottom begins in 1994), optional parameters to allow for age and time-varying patterns exist but for this assessment and other recent assessments, ATS selectivity is constant over time. Overall, four catchability coefficients were estimated: one each for the early fishery catch-per-unit effort (CPUE) data (from Low and Ikeda, 1980), the VAST combined bottom trawl survey index, the AT survey data, and the AVO data. An uninformative prior distribution is used for all of the indices. The selectivity parameters for the 2 main indices (BTS and ATS) total 135 (the CPUE and AVO data mirror the fishery and AT survey selectivities, respectively).

Additional fishing mortality rates used for recommending harvest levels are estimated conditionally on other outputs from the model. For example, the values corresponding to the $F_{40\%}$ $F_{35\%}$ and F_{MSY} harvest rates are found by satisfying the constraint that, given age-specific population parameters (e.g., selectivity, maturity, mortality, weight-at-age), unique values exist that correspond to these fishing mortality rates. The likelihood components that are used to fit the model can be categorized as:

- Total catch biomass (log-normal, $\sigma = 0.05$)
- Log-normal indices of pollock biomass; bottom trawl surveys assume annual estimates of sampling error, as represented in Fig. 14 along with the covariance matrices (for the density-dependent and VAST index series); for the AT index the annual errors were specified to have a mean CV of 0.20; while for the AVO data, a value relative to the AT index was estimated and scaled to have a mean CV of 0.3).
- Fishery and survey proportions-at-age estimates (multinomial with effective sample sizes presented Table 19).
- Age 1 index from the AT survey (CV set equal to 30% as in prior assessments).

- Selectivity constraints: penalties/priors on age-age variability, time changes, and decreasing (with age) patterns.
- Stock-recruitment: penalties/priors involved with fitting a stochastic stock-recruitment relationship within the integrated model.
- "Fixed effects" terms accounting for cohort and year sources of variability in fishery mean weights-at-age estimated based on available data from 1991-2021 from the fishery (and 1982-2022 for the bottom-trawl survey data) and externally estimated variance terms as described in Appendix 1A of Ianelli et al. (2016; see Fig. 28).

Work evaluating temperature and predation-dependent effects on the stock- recruitment estimates continues (Spencer et al. 2016). This approach modified the estimation of the stock-recruitment relationship by including the effect of temperature and predation mortality. A relationship between recruitment residuals and temperature was noted(similar to that found in Mueter et al., 2011 and subsequently noted in Thorson et al., 2020a) and lower pollock recruitment during warmer conditions might be expected. Similar results relating summer temperature conditions to subsequent pollock recruitment for recent years were also found by Yasumiishi et al. (2015) where research suggests that summer warmth is associated with earlier diapause of copepods (Thorson et al., 2020b), such that a fall (but not spring) survey of copepod densities is also associated with cold conditions and elevated recruitment (Eisner et al., 2020).

Results

Model evaluation

A sequential sensitivity of available new data showed that adding the 2021 fishery catch-at-age data and the 2022 catch biomass information increased the spawning biomass estimates (Fig. 31). Adding the new 2022 bottom-trawl survey estimates increased the spawning biomass estimate further, as did adding in this years acoustic-trawl survey data and AVO data (Fig. 31). Diagnostics of model fits between the set evaluated are given in Table 21 and comparisons of management quantities are given in Table 22).

For setting advice, we selected the same Model 20 from the 2020 assessment. Borrowing an estimate of M from the Bogoslof assessment (this volume) as a prior increased the value slightly but results were similar. Additionally, we updated the statistical weighting of composition data (the relative weights had been tuned last in 2016). This model had very little impact on the results (Table 21).

In the 2020 assessment, SRR evaluations related to Tier 1 classification showed that dropping the influence of the 1978 year-class in the estimation lowered the steepness of the curve and that when the influence of the prior distribution was removed the residual pattern for estimates near the origin was particularly bad (all below the curve). From those results we conclude that the prior specification was appropriate because we place priority on fitting estimated recruits near the slope at the origin better. Last year's assessment also showed that conditioning the SRR to fit the condition of having the "actual" F_{MSY} equal some F_{MSY} proxies (e.g., equal $F_{35\%}$) shows that the results were more conservative (shallower initial slopes). A conclusion from these exercises was that the SPR proxy for F_{MSY} implies a reasonable "shape" to the SRR.

The fit to the early Japanese fishery CPUE data (Low and Ikeda 1980) was consistent with the estimated population trends for this period (Fig. 32). The model fits the fishery-independent index from the 2006–2021 AVO data well through most of the period but the model predicts lower biomass than the index data indicate in 2021 (Fig. 33). The model fits to the bottom-trawl survey biomass (the density-dependent corrected series) were reasonable and within the observation error bounds (Fig. 34). The model fit to the BTS biomass index predicts fewer pollock than observed in the 2014 and 2015 survey but then varied in subsequent years (Fig. 34). The fit to the acoustic-trawl survey biomass series (including the USV data from 2020) was consistent with the specified observation uncertainty (Fig. 35).

The estimated parameters and standard errors are provided online. The code for the model (with dimensions and links to parameter names) and input files are available on request.

The input sample size (as tuned in 2016 using "Francis Weights") can be evaluated visually for consistency with expectations of mean annual age for the different gear types (Fig. 36; Francis 2011). The estimated selectivity pattern changes over time and reflects to some degree the extent to which the fishery is focused on particularly prominent year-classes (Fig. 37). The model fits the fishery age-composition data quite well under this form of selectivity (Fig. 38).

Bottom-trawl survey selectivity estimates are shown in Fig. 39. The pattern of bottom trawl survey age composition data in recent years shows a decline in the abundance of age 10+ pollock since 2011 (Fig. 40). Through the time series of the available data, the model predicted proportions of the 2012 and 2013 year classes varied in terms of under- and over- estimates as the 2013 year-class became more common in the data (Fig. 40). The AT age compositions consistently track large year classes through the population and the model fits these patterns reasonably well (Fig. 41).

As in past assessments, we evaluated the multivariate posterior distribution using Monte-Carlo Markov chain (MCMC) simulation methods. This year we adopted the no-uturn sampling approach from ADMB but upgraded and packaged within R (adnuts, Monnahan 2019). This allowed thorough sampling diagnostics and was able to sample the posterior efficiently within a few hours (or less). This new package also demonstrated that the asymptotic parameter standard deviations were reasonable approximations of the marginal densities from the integrated posterior distribution (Fig. 42). As before, we evaluated how selected parameters relate by doing a pairwise (along with their marginal distributions; Fig. 43). This illustrates how key parameters relate to management parameters of interest. For example, the stock recruitment steepness is negatively correlated to the resulting B_{MSY} estimate. We also compare the point estimates (highest posterior density) with the mean of the posterior marginal distribution of the 2022 spawning biomass. This showed that the point estimate was similar to the mean of the marginal posterior distribution (Fig. 44). As an additional part of the Tier 1 consideration, we evaluated the posterior density of F_{MSY} and is provided in Fig. 45 for reference.

Progress on developing methods for estimating random-effect variances within the model has been slow. We added code for producing posterior predictive distributions (e.g., for the two acoustic indices in Fig. 46. Additionally, we developed some preliminary diagnostics to evaluate how the model's posterior components affect key parameters of interest. For example, it is useful to know the relative impact of the 2018 year-class on the next year's spawning biomass (Fig. 47). Additionally, what different components (in negative log-likelihood terms) conflict or interact with such a critical parameter (Fig. 48)

Retrospective analysis

Running the assessment model over a grid with progressively fewer years included (going back to 10 years, i.e., assuming the data extent ended in 2012) results in a fair amount of variability in spawning biomass (Fig. 49). Last year with the lower than expected survey biomass estimate followed by an increase this year, the retrospective pattern degraded with an average bias (Mohns ρ equal to 0.18 for the 10 year retrospective).

For the recruitment side, the retrospective pattern shows two key results. First, the 2018 year-class (age 1 recruits in 2019) shows up as a big estimate just this year (Fig. 50). Second, the retrospective pattern shows how an equally abundant year-class occurred from the 2012 year-class for three years (with data terminating in 2016, 2017, and 2018). Then, in 2019 and in subsequent years that estimate dropped by over 10% and became the 2012 *and* the 2013 year-class. For this reason, we considered it reasonable to adjust the 2018 year-class to be similar to what appears to occur in subsequent years when more data become available.

In response to previous SSC requests to evaluate how selectivity is used for ABC and catch advice, we used the retrospective runs to show how the "projected" selectivity compared with subsequent estimates which had the benefit of more data (Fig. 51). To explain this figure, and taking the 2022 panel as an example, the blue line in that panel represents the projected estimate from the 2021 "peel" (the current model projecting to 2022 using only data up until 2021). The dots represent estimates from each "peel" and the dots in the 2022 panel are based on this year's estimated selectivity. In general, the projected selectivity conformed reasonably well with subsequent estimates. To further summarize these results, we also computed a summary statistic as the mean age of selection (independent of any age-specific stock size):

$$\bar{a} = \frac{\sum S_a a}{\sum S_a}$$

where S_a is the selectivity at age (ages 1 to 11). This statistic showed that recently the projection was biased towards younger pollock but earlier on, the bias was toward older fish (Fig. 52).

Since selectivity varies over time, and the fact that fishing mortality rates for management advice depend on the assumed future selectivity, we evaluate the pattern of F_{MSY} rates given different selectivity assumptions (i.e., Fig. 37). In the 2020 and 2021 assessment, because of the indications of small pollock being unusually present in the fishery, we chose a selectivity pattern from history that reflected tendency towards younger fish (specifically, that from 2005). Using the statistic on mean selected age, we found that the corresponding F_{MSY} showed a correlation (Fig. 53). This figure reveals how shifts in the relative age of fish selected impact F_{MSY} estimates.

Time series results

The time series of begin-year biomass estimates (ages 3 and older) suggests that the abundance of Eastern Bering Sea pollock remained at a high level from 1982–88, with estimates ranging from 8 to 12 million t (Table 23). Historically, biomass levels increased from 1979 to the mid-1980s due to the strong 1978 and relatively strong 1982 and 1984 year classes recruiting to the fishable population. The stock is characterized by peaks in the mid-1980s, the mid-1990s and again appears to be increasing to a peak of more than 12 million t in 2016 following the low in 2008 of 4.45 million t. The estimate for 2022 is trending downward and at 13.39 million t with 2023 estimated at 12.39 million t.

The level of fishing relative to biomass estimates shows that the spawning exploitation rate (SER, defined as the percent removal of egg production in each spawning year) has been mostly below 20% since 1980 (Fig. 54). During 2006 and 2007 the rate averaged more than 20% and the average fishing mortality increased during the period of stock decline. The estimate for 2009 through 2018 was below 20% due to the reductions in TACs relative to the maximum permissible ABC values and increases in the spawning biomass. The fishing mortality has fluctuated since 2010-2015 but, unlike last year's upward trend, the improved spawning biomass condition has held this rate tending toward lower levels. Age specific fishing mortality rates reflect these patterns and show some increases in the oldest ages from 2011–2013 but relatively stable (Fig. 55). The estimates of age 3+ pollock biomass showed a large drop last year compared to several of the earlier years but this has reversed in the current assessment (Fig. 56, Table 23).

Estimated numbers-at-age are presented in (Table 24) and estimated catch-at-age values are presented in (Table 25). Estimated summary biomass (age 3+), female spawning biomass, and age-1 recruitment are given in (Table 26).

To evaluate past management and assessment performance it can be useful to examine estimated fishing mortality relative to reference values. For EBS pollock, we computed the reference fishing mortality from Tier 1 (unadjusted) and recalculated the historical values for F_{MSY} (since selectivity has changed over time). Since 1977 the current estimates of fishing mortality suggest that during the early period, harvest rates were above F_{MSY} until about 1980. Since that time, the levels of fishing mortality have averaged about 35% of the F_{MSY} level (Fig. 57). Projections of spawning stock biomass given the 2023 estimate of fishing mortality rate given catches equal to the 2022 values shows a decline through 2021 and then an increase after; albeit with considerable uncertainty due to uncertainty in recruitment (Fig. 58).

Recruitment

Model estimates indicate that the 2008, 2012, 2013, and now the 2018 year classes are above average (Fig. 59). The 2018 year class is nearly 4 times bigger than average with a CV of about 16%. The stock-recruitment curve as fit within the integrated model shows the variability of the estimated curve (Fig. 60). Note that the 2020 and 2021 year classes (as age 1 recruits in 2021 and 2022) were excluded from the stock-recruitment curve estimation. Separate from fitting the stock-recruit relationship within the model, examining the estimated recruits-per-spawning biomass shows variability over time but seems to lack trend and also is consistent with the Ricker stock- recruit relationship used within the model (Fig. 61).

Environmental factors affecting recruitment are considered important and contribute to the variability. Previous studies linked strong Bering Sea pollock recruitment to years with warm sea temperatures and northward transport of pollock eggs and larvae (Wespestad et al. 2000; Mueter et al. 2006). As part of the Bering-Aleutian Salmon International Survey (BASIS) project research has also been directed toward the relative density and quality (in terms of condition for survival) of young-of-year pollock. For example, Moss et al. (2009) found age-0 pollock were very abundant and widely distributed to the north and east on the Bering Sea shelf during 2004 and 2005 (warm sea temperature; high water column stratification) indicating high northern transport of pollock eggs and larvae during those years. Mueter et al. (2011) found that warmer conditions tended to result in lower pollock recruitment in the EBS. This is consistent with the hypothesis that when sea temperatures on the eastern Bering Sea shelf are warm and the water column is highly stratified during summer, age-0 pollock appear to allocate more energy to growth than to lipid storage (presumably due to a higher metabolic rate), leading to low energy density prior to winter. This then may result in increased over-winter mortality (Swartzman et al. 2005, Winter et al. 2005). Ianelli et al. (2011) evaluated the consequences of current harvest policies in the face of warmer conditions with the link to potentially lower pollock recruitment and noted that the current management system is likely to face higher chances of ABCs below the historical average catches. Also, as part of the evaluation of stationarity given periods of "regimes", we revisited estimated mean recruitment during different periods previously identified as being unique (Fig. 62). This shows that given the revised estimate of the 2018 year class, the impact of the recent warm conditions suggest that the recent period (2000-present) is similar to the mean since 1977.

Harvest recommendations

Status summary

The estimate of B_{MSY} is 2,674 kt (with a CV of 20%) which is less than the projected 2023 spawning biomass of 4,200 kt; (Table 27). For 2023, the estimates put the stock in Tier 1a. The corresponding maximum permissible ABC would thus be 2,987,000 t with a fishable biomass estimated at around 6,889 kt (Table 28). For the current year spawning biomass this corresponds to 148% of the B_{MSY} level. A diagnostic (see the EBS Pollock Model Description appendix below) on the impact of fishing shows that the 2022 spawning stock size is about 62% of the predicted value had no fishing occurred since 1978 (Table 27).

Noting the relatively high uncertainty in the estimated 2018 year class, we developed an alternative Tier 3 projection. We specified the age 4 numbers at age in 2022 to be equal to the average of the 2012 and 2013 year classes (at age 4). The rationale was that these were recent and well above-average estimates. Although the signs for a large 2018 year class are positive, given the uncertainty in the estimate it seemed prudent to lower the expectation that that year-class is the most abundant ever. Lowering this expection slightly still resulted in optimistic near-term conditions and suggests that the spawning biomass in 2023 will be about 65% of $B_{100\%}$. These values are based on the usual SPR expansion using mean 1978–2020 recruitment. This would put the stock in Tier 3a and above $B_{40\%}$ and result in a 2022 ABC of 1,688,000 t. The Tier 3 run with the 2018 year-class (as age 4-yr olds) from the unadjusted projection configuration increased the ABC to 1,910,000 t (and 2,275,000 for 2024); a difference of 222,000 t. This alternative was provided and represents a 12% decline from the unadjusted projection configuration.

The probability that the current stock size is below 20% of B_0 (a level important for additional management measures related to Steller sea lion recovery) is <0.1% for 2023 and 2024.

In response to a request from the SSC, we added results from projections based on Tier 2. We report the "standard" Tier 2 ABC calculation using the point estimate (the mean of the posterior distribution) of F_{MSY}. Therefore, for 2023 the Tier 2a ABC would be 2,518,000 t. Since we have estimates of the harmonic mean (from Tier 1 calculations) an alternative Tier 2 estimate using that in place of the arithmetic mean F_{MSY} results in an ABC of 2,224,000 t.

In summary, the criterion for Tier 1 depends on a reliable estimate of F_{MSY} and the uncertainty (the PDF). Tier 2 also requires a reliable estimate of F_{MSY} (without the PDF requirement). Given the seemingly reasonable posterior marginal density for F_{MSY}, it seems if Tier 1 criterion is unmet, then so would the requirement for Tier 2. Adopting Tier 3, while in principle may result in more conservative catch advice, uses less information available about the stock productivity and requires adopting more assumptions (i.e., that $F_{35\%}$ is a reasonable proxy for F_{MSY}). As noted below in the section on risk evaluations, there are reasons for increased concerns. However, these seem to be unrelated to overall stock productivity as relates to the SRR and estimates of F_{MSY}. Consequently, our overall analysis continues to support the SSC's classification of this stock to be within Tier 1.

Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines overfishing level (OFL), the fishing mortality rate used to set OFL (FOFL), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. Estimates of reference points related to maximum sustainable yield (MSY) are currently available. However, we present both reference points for pollock in the BSAI to retain the option for consideration of either Tier 1, 2, or Tier 3 values from the harvest control rules provided in Amendment 56. These Tiers require reference point estimates for biomass level determinations. Consistent with other groundfish stocks, the following values are based on recruitment estimates from post-1976 spawning events (recognizing the the 1978 year class is excluded from the MSY calculations but included in the SPR calculations):

B_{MSY} = 2,674 kt female spawning biomass
B_0 = 6,653 kt female spawning biomass
$B_{100\%}$ = 6,061 kt female spawning biomass
$B_{40\%}$ = 2,424 kt female spawning biomass
$B_{35\%}$ = 2,121 kt female spawning biomass

Specification of OFL and Maximum Permissible ABC

Under Amendment 56 of the BSAI Groundfish FMP, the SSC qualified this stock as satisfying the Tier 1 conditions. As such, the harmonic mean value of F_{MSY} —here computed as an exploitation rate—is applied to the fishable biomass for computing ABC levels. For details on the risk-averse properties of this approach see Thompson (1996). For a future year, the fishable biomass is defined as the sum over ages of predicted begin-year numbers multiplied by age specific fishery selectivity and estimated mean body mass-at-age. The uncertainty in the average weights-at-age projected for the fishery and "future selectivity" has been demonstrated to affect the buffer between ABC and OFL (computed as 1-ABC/OFL) for Tier 1 maximum permissible ABC (Ianelli et al. 2015). The uncertainty in future mean weights-at-age had a relatively large impact as did the selectivity estimation (see the section above on retrospective behavior and Fig. 53).

Since the 2023 female spawning biomass is estimated to be above the B_{MSY} level (2,674 kt) and above the $B_{40\%}$ value (2,424 kt) in 2023 and if the 2022 catch is as specified above, then the OFL and maximum permissible ABC values by the different Tier categorizations would be:

Tier	Year	MaxABC	OFL
1a	2023	2,987,000	3,381,000
1a	2024	4,099,000	4,639,000
2a	2023	2,517,590	3,381,000
2a	2024	3,454,750	4,639,000
3a	2023	1,688,000	2,132,000
3a	2024	1,815,000	2,301,000

Note that the values presented for 2023 assumed a catch of 1,111,000 t in 2022.

Standard Harvest Scenarios and Projection Methodology

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56 to the FMP. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). While EBS pollock is generally considered to fall within Tier 1, the standard projection model requires knowledge of future uncertainty in F_{MSY} . Since this would require a number of additional assumptions that presume future knowledge about stock-recruit uncertainty, the projections in this subsection are based on Tier 3.

For each scenario, the projections begin with the vector of 2022 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2023 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch assumed for 2022. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. Annual recruits are simulated from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from the estimated age-1 recruits. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times to obtain distributions of possible future stock sizes and catches under alternative fishing mortality rate scenarios.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2023, are as follows ("$maxFABC$" refers to the maximum permissible value of FABC under Amendment 56):

Scenario 1: In all future years, F is set equal to maxF_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs).

Scenario 2: In 2023 and 2024 the catch is set equal to 1.30 million t and in future years F is set equal to the Tier 3 estimate (Rationale: this has been about equal to the catch level in recent years).

Scenario 3: In all future years, F is set equal to the 2021 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 4: In all future years, F is set equal to $F_{60\%}$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) below its MSY level in 2022 or 2) below half of its MSY level in 2022 or below its MSY level in 2032 under this scenario, then the stock is overfished.)

Scenario 7: In 2023 and 2024, F is set equal to $maxFABC$, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) below its MSY level in 2024 or 2) below 1/2 of its MSY level in 2024 and expected to be below its MSY level in 2034 under this scenario, then the stock is approaching an overfished condition).

The latter two scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$).

Projections and status determination

For the purposes of these projections, we present results based on selecting the $F_{40\%}$ harvest rate as the F_{ABC} value and use $F_{35\%}$ as a proxy for F_{MSY}. Scenarios 1 through 7 were projected 14 years from 2022 (Table 32 for Model 20.0–including the 1978 year-class as is convention for Tier 3 estimates). Under catches set to Tier 3 ABC estimates, the expected spawning biomass is well above $B_{35\%}$ and is expected to be drop below $B_{40\%}$ by 2026 (given mean recruitment; Fig. 63 and assuming catches >2 million t in 2025).

Any stock that is below its minimum stock size threshold (MSST) is defined to be overfished. Any stock that is expected to fall below its MSST in the next two years is defined to be approaching an overfished condition. Harvest scenarios 6 and 7 are used in these determinations as follows:

Is the stock overfished? This depends on the stock's estimated spawning biomass in 2022:

- If spawning biomass for 2022 is estimated to be below 1/2 $B_{35\%}$ the stock is below its MSST.
- If spawning biomass for 2022 is estimated to be above $B_{35\%}$, the stock is above its MSST.
- If spawning biomass for 2022 is estimated to be above 1/2 $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest scenario 6 (Tables 29 through 32). If the mean spawning biomass for 2032 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario 7:

- If the mean spawning biomass for 2022 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.
- If the mean spawning biomass for 2022 is above $B_{35\%}$, the stock is not approaching an overfished condition.

- If the mean spawning biomass for 2024 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2034. If the mean spawning biomass for 2034 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

For scenarios 6 and 7, we conclude that pollock is above MSST for the year 2022, and it is expected to be above the "overfished condition" based on Scenario 7 (the mean spawning biomass in 2022 is between the 1/2 $B_{35\%}$ and $B_{35\%}$ estimate but by 2034 the stock is above $B_{35\%}$; (Table 32). Based on this, the EBS pollock stock is being fished below the overfishing level and is not approaching an overfished condition.

To fulfill reporting requirements for NOAA's Species Information System, we computed the fishing mortality rate corresponding to the specified OFL for the last complete year (2021). This hypothetical 2021 F_{OFL} from this year's model was estimated to be 0.5431 for EBS pollock (assuming this year's estimated 2022 selectivity and weight-at-age).

ABC Recommendation

ABC levels are affected by estimates of F_{MSY} which depend principally on the estimated stock-recruitment steepness parameter, demographic schedules such as selectivity-at-age, maturity, and growth. The current stock size (both spawning and fishable) is estimated to be above average levels and projections indicate the potential for further declines. Updated data and analysis result in an estimate of 2022 spawning biomass (3,950 kt) which is about 148% of B_{MSY} (2,674 kt). This follows a short period of decline from 2017-2020 followed by a previously unexpected increase due to revised estimates of the 2018 year class. Treating all new data the same way as in the past, this estimate suggests that it would be the biggest year-class on record (79,900 age 1 numbers), but with considerable uncertainty.

Given the same estimated aggregate fishing effort as in 2022 and given the estimated stock trend, the constant-F scenario would yield about 1.3 million t. To obtain 2023 catches on the order of 1.45 million t, given the base model estimates, would require about 18% more effort than what was estimated from 2022.

Should the ABC be reduced below the maximum permissible ABC?

The SSC in its September 2018 minutes recommended that assessment authors and Plan Teams use the risk table below when determining whether to recommend an ABC lower than the maximum permissible. The details of the risk table are provided below. Given the concerns listed there, we recommend reducing the ABC to the value provided under Tier 3 projections.

	Considerations			
	Assessment-related	**Population dynamics**	**Environmental & ecosystem**	Fishery performance
Level 1 Normal	Typical to moderately increased uncertainty & minor unresolved issues in assessment	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental & ecosystem concerns	No apparent fishery/resource-use performance and/or behavior concerns
Level 2 Substantially increased concerns	Substantially increased assessment uncertainty unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing an adverse signals but the pattern is inconsistent across all indicators.	Some indicators showing adverse signals but the pattern is inconsistent across all indicators.
Level 3 Major Concern	Major problems with the stock assessment, very poor fits to data, high level of uncertainty, strong retrospective bias.	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns.	Multiple indicators showing consistent adverse signals a) across the same trophic level, and/or b) up or down trophic levels (i.e., predators and prey of stock)	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types
Level 4 Extreme concern	Severe problems with the stock assessment, severe retrospective bias. Assessment considered unreliable.	Stock trends are unprecedented. More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock. Potential for cascading effects on other ecosystem components	Extreme anomalies in multiple performance indicators that are highly like to impact the stock.

The table is applied by evaluating the severity of four types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. Examples of the types of concerns that might be relevant include the following (as identified by the work-group):

1. Assessment considerations

- *Data-inputs:* biased ages, skipped surveys, lack of fishery-independent trend data
- *Model fits:* poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs.
- *Model performance:* poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds.
- *Estimation uncertainty:* poorly-estimated but influential year classes.
- Retrospective bias in biomass estimates.

2. Population dynamics considerations—decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.
3. Environmental/ecosystem considerations–trends in environmental/ecosystem indicators, ecosystem model results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.
4. Fisheries considerations–fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings."

Assessment considerations

The EBS pollock assessment model has appeared to track the stock from year-to-year based on retrospective analysis in previous assessments. This year however, there was a substantial increase relative to the lower than expected survey observation from 2021; this affected the retrospective analyses which last year indicated a tendency to over estimate the stock trend. The model tracks the available data reasonably well except for the strong increase in the AVO index relative to the last two years. We also recognize that the stock-recruitment relationship selected for this cannibalistic species requires a relatively informative prior distribution in order to have the residuals of the estimates relative to the curve to be less biased nearer the slope of the origin. This could be interpreted as being undesirable and having undue influence on the underlying stock productivity (noting that it has been demonstrated that the prior leads to increased conservativism). **We therefore rated the assessment-related concern as level 2, substantially increased concern.**

Population dynamics considerations

The age structure of EBS pollock has exhibited some peculiarities over time. On the positive side, some strong year-classes appear to have increased in abundance based on the bottom-trawl survey data (e.g., the 1992, 2012, 2013 and 2018 year classes). Conversely, the period from 2000–2007 had relatively poor year-class strengths which resulted in declines in stock below B_{msy} and reduced TACs due to lower ABC values. Given the strong year-class strength from 2018, it appears that the mean recruitment since 2000 has been nearly average but with greater variability than earlier years (Fig. 62). The stock is estimated to be above B_{msy} at present, and projections indicate a increases given recent catch levels. Recruitment in the near term is well above average but are hightly uncertain. Additional age-specific aspects of the spawning population indicate that the stock has increased from a low diversity of ages (for both the population and the mean age of the spawning stock weighted by spawning output Fig. 65). **We therefore rated the population-dynamics concern as level 1, Normal: No apparent environmental/ecosystem concerns.**

Environmental/Ecosystem considerations

Environmental processes The extended warm phase experienced in the eastern Bering Sea (EBS) that began in approximately 2014 largely relaxed to normal conditions over the past year (August 2021 - August 2022). The North Pacific Index (NPI) was positive during 5 out of the last 6 winters, with the exception being the winter of 2018 - 2019. Positive values mean a weak Aleutian Low Pressure System and generally calmer conditions. Sea surface temperature (SST) was within one standard deviation of the long term average and marine heatwaves were relatively weak and short-lived compared to recent years. Estimates of bottom temperature derived from the ROMS model suggest that bottom temperatures in the northern Bering Sea (NBS) over the past year were within normal ranges while the southeastern Bering Sea (SEBS) was significantly cooler than average. The Bering Sea ice extent was generally higher than average throughout much of the 2021-2022 winter. Ice advanced rapidly in November, though there was an abrupt springtime retreat beginning in mid-April (Hennon et al., 2022).

These cool-to-normal winter conditions were favorable to cold pool formation, though not to the areal extent in the years preceding 2014. The 2022 cold pool was near the historical average and the spatial footprint was similar to the most recent near-average years in 2011 and 2017. North of ~57°C, the cold pool covered nearly the entire middle domain of the survey area between 50-m and 100-m isobaths. The extents of the <= -1°C, <= 0°C, and <= 1°C isotherms were larger than during the three prior surveys and near their time-series averages (Hennon et al., 2022).

Age-0 fish experiencing warm temperatures during late summer followed by relatively cooler temperatures in spring of age-1 are thought to have below average survival. Based on this Temperature Change index, the 2018 year class was predicted to have above-average recruitment to age-4 in 2022 (Yasumiishi, 2019) while the 2021 year class is predicted to have average recruitment to age-4 in 2025 (Yasumiishi, 2022).

The ecosystem 'red flags' that occurred in the NBS in 2021, notably the crab population declines (Richar 2021) and salmon run failures in the Arctic-Yukon-Kuskokwim region (Liller 2021), continued into 2022 (Richar 2022; Whitehouse 2022b).

Prey Spring bloom peak timing suggests that 2022 was average in the south inner, south middle, and south outer shelf regions. For the south middle shelf region, there was evidence of 2 peaks (Nielsen et al., 2022), while chlorophyll-a biomass varied spatially over the shelf. Persistently low chlorophyll-a biomass within the outer shelf region has occurred since 2015 (Nielsen et al., 2022). Depending on the spatial and temporal overlap of productivity, this can result in a match or mismatch with favorable feeding conditions for larval pollock. Additionally, in 2022, the coccolithophore index for both the inner and middle shelf was among the highest ever observed in the timeseries. The striking milky aquamarine color of the water during a coccolithophore bloom can reduce foraging success for visual predators, such as fish and surface-feeding seabirds (Nielsen and Eisner, 2022). Small copepods form the prey base for larval to early juvenile pollock during spring. Late juvenile pollock feed on a variety of planktonic crustaceans, including calanoid copepods and euphausiids. Pollock diets become more piscivorous with age and cannibalism is commonly observed. The Rapid Zooplankton Assessment (Kimmel et al., 2022) noted reduced overall zooplankton productivity in the EBS in spring and late- summer 2022, though euphausiid abundances were higher than recent years, supporting the hypothesis that increased euphausiid abundances during warm years may compensate for lower large copepod abundances (Duffy-Anderson et al., 2017). The acoustic euphausiid survey documented an increase in euphausiid density from 2018 (last available estimate), but the 2022 value still remains below the time series average (Ressler, 2022). Over the northern shelf in late summer, small copepods declined by nearly an order of magnitude on average compared to prior years, large copepods were higher than those observed over the southern shelf and greater than those observed in 2018 and 2019, and euphausiid abundances were higher compared to prior years and have increased every year since 2018 (Kimmel et al., 2022).

A significant relationship exists between the abundance of large, lipid-rich copepods and the recruitment and survival of juvenile pollock to age-3 (Eisner et al., 2020). Low availability of large copepod prey in 2019 and 2020 may have resulted in reduced overwinter survival and recruitment to age-3 (in 2022 and 2023). That said, in 2018 there was an increase in euphausiids in BASIS age-0 pollock diets (Andrews et al., 2019), which may have mitigated the lack of large copepods, and enhanced overwinter survival and subsequent recruitment of the 2018 year class (Yasumiishi et al., 2022b).

Fish condition, as measured by length-weight residuals, varied between juvenile (100 - 250 mm) and adult (>250 mm) pollock. In the southern Bering Sea, juvenile pollock had above-average condition in 2022, continuing a trend of positive condition anomalies since 2016. Conversely, adult pollock had below-average condition, which has also been the case since 2015 (except 2019 when adult pollock had a positive condition anomaly). In the northern Bering Sea, both juvenile and adult pollock had slightly below-average condition, though the mean for both groups fell within one standard deviation of the historical mean (Rohan et al., 2022).

Competitors Jellyfish feed primarily on zooplankton and small fish, and therefore may compete for prey resources for both juvenile and adult life stages of pollock. Trends in jellyfish abundance (Yasumiishi et al., 2022c) track those of forage fish (Yasumiishi et al., 2022d), and specifically age-0 pollock (Andrews et al., 2022). The 2022 Bristol Bay sockeye salmon inshore run was the largest on record since 1963 (Cunningham et al., 2022). Juvenile sockeye salmon feed on zooplankton (competitors with age-0 pollock) and age-0 pollock (competitors with adult pollock) in warm years; adults feed on zooplankton and krill. Western Alaska salmon runs, however, have experienced a precipitous and concurrent decline in recent years, leading to potential reduced competition for prey resources where these stocks overlap (Liller, 2021; Whitehouse, 2022). The biomass of pelagic foragers measured during the standard EBS bottom trawl survey increased sharply from 2021 to 2022, up more than 70%. The guild is largely driven by trends in pollock, although it is worth noting that Pacific herring were up more than 200% from 2021, well above their long-term mean (Whitehouse, 2022). The impacts of recent large year classes of sablefish to the EBS ecosystem (as prey, predators, and competitors) remains largely unknown at this time. The large 2019 year class of sablefish (see Goethel et al. 2021) may compete with pollock for prey resources as juveniles.

Predators Pollock are cannibalistic and rates of cannibalism might be expected to increase as the biomass of older, larger fish increases. In 2022, with an average cold pool extent over the shelf, predation pressure from cannibalism may have been mitigated by this thermal barrier as adult pollock tend to avoid the cold bottom waters. In 2021, a small retracted cold pool likely offered no thermal refuge or barrier for juvenile pollock. However, the biomass of pelagic foragers, including adult pollock dropped in 2021 to their second lowest value over the time series (Whitehouse, 2021). Fur seal consumption of adult pollock generally increases in years when juvenile pollock are less abundant (Kuhn et al., 2019). However, Northern fur seal pup production at St. Paul Island in 2021 continued a declining trend since 1998 that may be partially attributed to low pup growth rates (see 2022 Report Card in Siddon, 2022). Other potential predators of juvenile pollock include jellyfish and chum salmon. Jellyfish abundance estimated from surface trawl surveys remained low from 2021 to 2022 (Yasumiishi et al., 2022c); estimates from the bottom trawl survey increased 75% from 2021 to 2022 and have been variable over the past 5 years (Buser, 2022). Chum salmon abundance has been declining in the Arctic-Yukon-Kuskokwim Region since 2017 to their lowest level in the time series in 2021 (Liller, 2021), a trend also reflected in the commercial harvest data (Whitehouse, 2022b).

Summary for Environmental/Ecosystem considerations

- The extended warm phase experienced by the EBS that began in approximately 2014 has largely relaxed to normal conditions over the past year (August 2021 - August 2022).
- The 2022 cold pool spatial extent was near the historical average.

- The 2022 spring bloom peak timing was average over the southern shelf; chlorophyll-a biomass varied spatially over the shelf.
- The 2022 coccolithophore index was among the highest ever observed
- Reduced overall zooplankton productivity in the south in spring and late- summer 2022; euphausiid abundances higher than recent years. In the north, small copepods declined while large copepods and euphausiids were more abundant than in recent years.
- In the south, juvenile pollock had above-average condition in 2022, continuing a trend of positive condition anomalies since 2016, while adult pollock had below-average condition, which has also been the case since 2015 (except 2019). In the north, both juvenile and adult pollock had slightly below-average condition.
- Trends in potential competitors are mixed over the shelf, with record high run size of Bristol Bay sockeye salmon and run failures of across western Alaska salmon stocks. The abundance of Pacific herring and juvenile sablefish increased, but their impact as competitors is not well understood at this time.
- In 2022, with an average cold pool extent over the shelf, predation pressure from cannibalism may have been mitigated as adult pollock avoid the cold pool.
- Northern fur seal pup production at St. Paul Island in 2021 continued a declining trend since 1998.
- Trends in other potential predators are mixed over the shelf, with increased jellyfish abundance and decreased chum salmon abundance.

Together, the most recent data available suggest an ecosystem risk Level 1 – Normal: "No apparent environmental/ecosystem concerns."

Fishery performance

As noted above, the 2022 fishery improved over 2020 and 2021 and the past concerns about small pollock in the fishery is alleviated. The fleet dispersion (the relative distance or spread of the fishery in space) as shown in the past has indicated that the seasonal dispersion levels were low (indicating relatively good fishing; Fig 9).

The CPUE of PSC species and other bycatch declined in 2022. Sablefish, herring and Chinook salmon bycatch rates (per hour of fishing) all decreased from 2021 (except for a slight increase in herring CPUE during the B season from low levels; Fig. 2).

The way the ABC control rule interacts with actual fishing is worth considering. Specifically, given the 2 million t OY cap for all of groundfish, when the EBS pollock stock is above target levels, the fishing effort is lower (a lower F). As it approaches the target (B_{MSY}), it increases and then when it drops below, the fishing mortality rate is ratcheted downwards rapidly. This can be exacerbated when there are sudden unanticipated changes in survey estimates (like what was apparently the case in 2021 which caused the retrospective pattern to degrade). The mean weight-at-age for the 2021 B-season was near average, but in general, pollock were skinny given their length. However, concerns over the amount of 2-year old pollock in the 2020 fishery data has been ameliorated with continued positive signs of that year-class which is projected to be an abundant number of 5-year olds in 2023. For this reason, we **conclude that that the fishery performance warrants a score of 1, normal: no apparent fishery performance concerns.**

These results are summarized as:

Considerations			
Assessment-related	Population dynamics	Environmental or ecosystem	Fisheries
Level 2: Substantially increased concerns	Level 1: Normal	Level 1: Normal	Level 1: Normal

Having a score at level 2 suggests that adjustments to the ABC may be prudent. In the past, the SSC has considered factors similar to those presented above and selected an ABC based on Tier 3 estimates. Last year the SSC requested examining Tier 2 values as an alternative. Unlike Tier 3, using Tier 2 would have a constant buffer relative to the Tier 1 value (at about 11%). Setting the ABC to Tier 3 levels provides a very large buffer but one that could be warrented given that the impact on subsequent spawning biomass levels will be much more variable and have a high probability of dropping below the target stock size and result in much reduced future ABCs under the current FMP. It is worth noting that fishing at the full Tier 1 ABC would imply a more than doubling of effort and well exceed the 2 million t groundfish catch limit. Even fishing at a full Tier 3 ABC shows there is a relatively high probability of falling below B_{MSY} values or proxies thereof. Under our standard scenarios, Alternative 3 shows trajectories if fishing effort is held equal to the recent 5-year average. It is noteworthy that this provides stock sizes that have a good probability of being above targets and avoiding drastic reductions in yeild (lower overall variability in ABC/yields; Fig. 64).

The SSC has requested "an explicit set of concerns that explain the ABC adjustment." In response, we direct attention to the decision table 34) and the fact that the biological basis for the continued stock productivity has most to do with the OY constraint which has effectively maintained fishery production at around 1.3 million t since 1990. Demonstrations that would allow fishing to near F_{MSY} catch quantities would show that catch variability would be extremely high (and unrealistic given current capacity and OY limits for combined BSAI groundfish; Ianelli 2005). Furthermore, the frequency of being at much lower spawning stock sizes would be much higher, and would likely be riskier and fishing effort would need to be much higher. While the biological basis for ABC setting is founded in sound conservation of spawning biomass, the history of the current fishery productivity should inform desirable biomass. In only 6 of the 41 years since 1981 has the stock been below the B_{MSY} level (15% of the years). The mean spawning biomass over this period has averaged about 6% higher than the estimated B_{MSY}. In terms of an actual "management target", Punt et al. (2013) developed some robust estimators for B_{MEY} (Maximum Economic Yield) noting that a typical target would be $1.2 \times B_{MSY}$ or about -11% lower than the mean value or a target female spawning biomass at 3.209 million t. It therefore seems worth considering developing an explicit harvest control rule that achieves the level of productivity observed over the past 30 years.

In recent years when the pollock biomass was estimated to be well above average, the catch was constrained by other factors. Specifically, the 2 million t BSAI groundfish catch limit and bycatch avoidance measures has an impact on the potential for large increases in catch. As the stock is presently estimated to be below B_{MSY}, the maximum permissible ABC under the FMP can become the limiting factor for TAC specification. Unfortunately, this ABC can ratchet down quickly because as the stock declines further below this target stock size, the ABC fishing mortality rate is adjusted downwards nearly proportionately. This part of the FMP control rule can create high variability in the TAC. Less variability in the catch, accordingly, would also result in less spawning stock variability and reduce risks to the fishery should the period of poor recruitment continue.

To more fully evaluate these considerations performance indicators as modified from Ianelli et al. (2012) were developed to evaluate some near-term risks given alternative 2023 catch values. These indicators and rationale for including them are summarized in Table 33). Model 20 (the "base") results for these indicators are provided in Table 34. Each column of this table uses a fixed 2023 catch and assumes the same effort for the four additional projection years (2024–2027). Given this specification , there is a low probability that any of the catches shown in the first row would exceed the F_{MSY} level. Also, in the near term it appears unlikely that the spawning stock will be below B_{MSY} (rows 3 and 4). Relative to the historical mean spawning biomass, by 2023 it is more likely than not that the spawning biomass will be lower than the historical mean (fifth row). The range of catches examined have relatively small or no impact on the age diversity indicators. However, for catch to equal the 2021 value, more fishing effort will likely be required and there is a good chance that the proportion of the stock less than age 6 will be greater than the historical average. In terms of catch advice, the results presented in the decision table indicates that catches above 1.0 million t will very likely result in 2024 spawning stock estimates being below the long term mean (but above B_{MSY}).

In the past, another approach/rationale for stabilizing effort by setting the fishing mortality equal to the current year. Doing so this year suggests setting the fishing mortality to 2022 levels results in a catch of 1,150,000 kt. Given the revisions to last year's model results and the positive increases in stock size, maintaining a constant fishing mortality rate seems unnecessary at this time.

Additional ecosystem considerations

In general, a number of key issues for ecosystem conservation and management can be highlighted. These include:

- Preventing overfishing;
- Avoiding habitat degradation;
- Minimizing incidental bycatch;
- Monitoring bycatch and the level of discards; and
- Considering multi-species trophic interactions relative to harvest policies.

For the case of pollock in the Eastern Bering Sea, the NPFMC and NMFS continue to manage the fishery on the basis of these issues in addition to the single- species harvest approach (Hollowed et al. 2011). The prevention of overfishing is clearly set out as the main guideline for management. Habitat degradation has been minimized in the pollock fishery by converting the industry to pelagic-gear only. Bycatch in the pollock fleet is closely monitored by the NMFS observer program and managed on that basis. Discard rates of many species have been reduced in this fishery and efforts to minimize bycatch continue.

In comparisons of the Western Bering Sea (WBS) with the Eastern Bering Sea using mass-balance food-web models based on 1980–85 summer diet data, Aydin et al. (2002) found that the production in these two systems is quite different. On a per-unit-area measure, the western Bering Sea has higher productivity than the EBS. Also, the pathways of this productivity are different with much of the energy flowing through epifaunal species (e.g., sea urchins and brittlestars) in the WBS whereas for the EBS, crab and flatfish species play a similar role. In both regions, the keystone species in 1980–85 were pollock and Pacific cod. This study showed that the food web estimated for the EBS ecosystem appears to be relatively mature due to the large number of interconnections among species. In a more recent study based on 1990–93 diet data, pollock remain in a central role in the ecosystem. The diet of pollock is similar between adults and juveniles with the exception that adults become more piscivorous (with consumption of pollock by adult pollock representing their third largest prey item).

Regarding specific small-scale ecosystems of the EBS, Ciannelli et al. (2004a, 2004b) presented an application of an ecosystem model scaled to data available around the Pribilof Islands region. They applied bioenergetics and foraging theory to characterize the spatial extent of this ecosystem. They compared energy balance, from a food web model relevant to the foraging range of northern fur seals and found that a range of 100 nautical mile radius encloses the area of highest energy balance representing about 50% of the observed foraging range for lactating fur seals. This has led to a hypothesis that fur seals depend on areas outside the energetic balance region. This study develops a method for evaluating the shape and extent of a key ecosystem in the EBS (i.e., the Pribilof Islands). Furthermore, the overlap of the pollock fishery and northern fur seal foraging habitat has been identified (see Sterling and Ream 2004, Zeppelin and Ream 2006).

A brief summary of these two perspectives (ecosystem effects on pollock stock and pollock fishery effects on ecosystem) is given in (Table 39). Unlike the food-web models discussed above, examining predators and prey in isolation may overly simplify relationships. This table serves to highlight the main connections and the status of our understanding or lack thereof.

Ecosystem effects on the EBS pollock stock

The pollock stock trends appear to be responding to ecosystem conditions in the EBS. The conditions on the shelf during 2008 apparently affected age-0 northern rock sole due to cold conditions and apparently unfavorable currents that retain them into the over- summer nursery areas (Cooper et al. 2014). It may be that such conditions favor pollock recruitment. Hollowed et al. (2012) provided an extensive review of habitat and density for age-0 and age-1 pollock based on survey data. They noted that during cold years, age-0 pollock were distributed primarily in the outer domain in waters greater than 1°C and during warm years, age-0 pollock were distributed mostly in the middle domain. This temperature relationship, along with interactions with available food in early-life stages, appears to have important implications for pollock recruitment success (Coyle et al. 2011).

A separate section presented again this year updates a multispecies model with more recent data and is presented as a supplement to the BSAI SAFE report. This approach incorporates a number of simplifications for the individual species data and fisheries processes (e.g., constant fishery selectivity and the use of design-based survey indices for biomass). However, that model mimics the biomass levels and trends with the single species reasonably well. It also allows specific questions to be addressed regarding pollock TACs. For example, since predation (and cannibalism) is explicitly modeled, the impact of relative stock sizes on subsequent recruitment to the fishery can be now be directly estimated and evaluated (in the model presented here, cannibalism is explicitly accounted for in the assumed Ricker stock-recruit relationship).

EBS pollock fishery effects on the ecosystem.

Since the pollock fishery is primarily pelagic in nature, the bycatch of non- target species is small relative to the magnitude of the fishery (Table 38). Jellyfish represent the largest component of the bycatch of non-target species and had averaged around 5–6 kt per year but more than doubled in 2014, then dropping again in 2015. The 2018 value was high, dropped and then was again high in 2021. The data on non-target species shows a high degree of inter-annual variability, which reflects the spatial variability of the fishery and high observation error. This variability may reduce the ability to detect significant trends for bycatch species.

The catch of other target species in the pollock fishery (defined as any trawl set where the catch represents more than 80% of the catch) represents about 1% of the total pollock catch. Incidental catch of Pacific cod has varied but after a period of low catch levels it increased to over 9,000 t in 2020 and 2021 but in 2022 was under 4 thousand t (Table 35). There has been a marked increase in the incidental catch of Pacific ocean perch in the since 2014 with a peak just under 8 thousand t in 2019. The incidental catch of sablefish peaked in 2020 at about 3.5 thousand t but was less that 300 t in 2022. The incidental catch of pollock in other target fisheries is more than double the bycatch of target species in the pollock fishery with the largest pollock catches in the yellofin sole and Pacific cod fisheries (Table 36).

The number of non-Chinook salmon (nearly all made up of chum salmon) taken incidentally varies considerably over time. increased since 2014 with the 2017 number in excess of 465 thousand fish, the third highest non-Chinook salmon bycatch that's been observed since 1991. Since then, 7 of the top 10 highest bycatch years have occurred with nearly 550 thousand taken in 2021 (Table **??**). Chinook salmon bycatch has varied (42% CV since 2011) and averaged just under 19 thousand fish from 2011-2022 (Table **??**). After a recent high bycatch of over 32,000 fish in 2020, the 2022 bycatch was just over 6,400 Chinook salmon. Ianelli and Stram (2014) provided estimates of the bycatch impact on Chinook salmon runs to the coastal west Alaska region and found that the peak bycatch levels exceeded 7% of the total run return. Since 2011, the impact has been estimated to be below 2%. Updated estimates given new genetic information and these levels of PSC as provided to the Council continue to suggest that the impact is low.

Data gaps and research priorities

The available data for EBS pollock are extensive yet many processes behind the observed patterns continue to be poorly understood.
The recent patterns of abundance observed in the northern Bering Sea provide an example. As such, we recommend the following research priorities:

- Support developing a team of analysts to evaluate all aspects of the current model against alternatives (e.g., Rceattle, WHAM, Stock Synthesis, etc.).
- Continue to investigate using spatial processes for estimation purposes (e.g., combining acoustic and bottom trawl survey data). The application of the geostatistical methods seems like a reasonable approach to statistically model disparate data sources for generating better abundance indices. Also, examine the potential to use pelagic samples from the BASIS survey to inform recruitment and subsequent spatial patterns.

- Develop methods to use spatio-temporal models to estimate composition information (specifically, weight-at-age in the survey).
- Study the relationship between climate and recruitment and trophic interactions of pollock within the ecosystem. This would be useful for improving ways to evaluate the current and alternative fishery management systems. In particular, a careful re-evaluation of the current FMP harvest control rule should be undertaken.
- Exploration of alternative methods for estimating time-varying selectivity-at-age, in particular where the variance is estimated jointly with identifying the effective sample size of associated composition data. Properly weighting fishery and survey age-composition data is likely to be important for interpreting the strength of the 2018 year class again in the 2023 assessment.
- Apply new technologies (e.g., bottom-moored echosounders) to evaluate pollock movement between regions and supplement this work with analytical approaches.
- Expand genetic sample collections for pollock (and process available samples) and apply high resolution genetic tools for stock structure analyses.

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Tables

Table 1-1. Pollock catch from the Eastern Bering Sea by area, and season (through October 25th 2022). The A season starts January 20th and B season starts on June 10th. The Southeast area refers to the EBS region east of 170W; the Northwest is west of 170W.

Year	Northwest A	Northwest B	Southeast A	Southeast B	NW	SE	A	B	Total
1991	12,191	529,897	297,202	356,353	542,088	653,555	309,393	886,250	1,195,643
1992	101,597	458,143	454,947	375,612	559,740	830,559	556,544	833,755	1,390,299
1993	93,013	139,160	475,143	619,287	232,173	1,094,430	568,156	758,447	1,326,603
1994	11,026	165,751	586,105	566,470	176,777	1,152,575	597,131	732,221	1,329,352
1995	3,631	88,310	600,499	571,807	91,941	1,172,306	604,130	660,117	1,264,247
1996	1,804	104,135	549,297	537,545	105,939	1,086,842	551,101	641,680	1,192,781
1997	2,363	302,180	557,106	262,784	304,543	819,890	559,469	564,964	1,124,433
1998	1,508	131,007	476,214	410,353	132,515	886,567	477,722	541,360	1,019,082
1999	4,139	202,558	414,030	368,953	206,697	782,983	418,169	571,511	989,680
2000	19,363	274,170	439,023	400,154	293,533	839,177	458,386	674,324	1,132,710
2001	108,013	317,207	444,565	517,412	425,220	961,977	552,578	834,619	1,387,197
2002	36,693	283,747	561,061	599,272	320,440	1,160,333	597,754	883,019	1,480,773
2003	151,465	406,123	446,152	487,039	557,588	933,191	597,617	893,162	1,490,779
2004	50,661	339,883	556,469	533,538	390,544	1,090,007	607,130	873,421	1,480,551
2005	120,320	560,548	476,970	325,184	680,868	802,154	597,290	885,732	1,483,022
2006	18,789	642,034	585,507	241,700	660,823	827,207	604,296	883,734	1,488,030
2007	62,504	563,748	505,306	222,943	626,252	728,249	567,810	786,691	1,354,501
2008	44,801	463,079	358,936	123,762	507,880	482,698	403,737	586,841	990,578
2009	81,575	370,957	247,944	110,307	452,532	358,251	329,519	481,264	810,783
2010	199,011	356,061	124,670	130,443	555,072	255,113	323,681	486,504	810,185
2011	102,252	348,897	401,755	346,128	451,149	747,883	504,007	695,025	1,199,032
2012	104,926	481,418	380,373	238,497	586,344	618,870	485,299	719,915	1,205,214
2013	94,763	480,331	415,014	280,652	575,094	695,666	509,777	760,983	1,270,760
2014	50,465	388,712	469,973	388,267	439,177	858,240	520,438	776,979	1,297,417
2015	258,574	366,752	267,095	429,153	625,326	696,248	525,669	795,905	1,321,574
2016	81,531	104,078	458,044	709,028	185,609	1,167,072	539,575	813,106	1,352,681
2017	37,730	143,430	544,028	633,993	181,160	1,178,021	581,758	777,423	1,359,181
2018	3,842	326,753	598,533	450,160	330,595	1,048,693	602,375	776,913	1,379,288
2019	2,649	304,532	614,949	487,217	307,181	1,102,166	617,598	791,749	1,409,347
2020	85,717	421,102	560,438	299,978	506,819	860,416	646,155	721,080	1,367,235
2021	56,779	295,470	554,774	469,234	352,249	1,024,008	611,553	764,704	1,376,257
2022	9,019	196,249	487,216	405,200	205,268	892,416	496,235	601,449	1,097,684

Table 1-2. Time series of 1964–1976 catch (left) and ABC, TAC, and catch for EBS pollock, 1977–2021 in t. Source: compiled from NMFS Regional office web site and various NPFMC reports. Note that the 2022 value is based on catch reported to October 25th 2022 plus an added component due to bycatch of pollock in other fisheries.

Year	Catch	Year	OFL	ABC	TAC	Catch
1964	174,792	1977	-	950,000	950,000	978,370
1965	230,551	1978	-	950,000	950,000	979,431
1966	261,678	1979	-	1,100,000	950,000	935,714
1967	550,362	1980	-	1,300,000	1,000,000	958,280
1968	702,181	1981	-	1,300,000	1,000,000	973,502
1969	862,789	1982	-	1,300,000	1,000,000	955,964
1970	1,256,565	1983	-	1,300,000	1,000,000	981,450
1971	1,743,763	1984	-	1,300,000	1,200,000	1,092,055
1972	1,874,534	1985	-	1,300,000	1,200,000	1,139,676
1973	1,758,919	1986	-	1,300,000	1,200,000	1,141,993
1974	1,588,390	1987	-	1,300,000	1,200,000	859,416
1975	1,356,736	1988	-	1,500,000	1,300,000	1,228,721
1976	1,177,822	1989	-	1,340,000	1,340,000	1,229,600
		1990	-	1,450,000	1,280,000	1,455,193
		1991	-	1,676,000	1,300,000	1,195,664
		1992	1,770,000	1,490,000	1,300,000	1,390,299
		1993	1,340,000	1,340,000	1,300,000	1,326,602
		1994	1,590,000	1,330,000	1,330,000	1,329,352
		1995	1,500,000	1,250,000	1,250,000	1,264,247
		1996	1,460,000	1,190,000	1,190,000	1,192,781
		1997	1,980,000	1,130,000	1,130,000	1,124,433
		1998	2,060,000	1,110,000	1,110,000	1,102,159
		1999	1,720,000	992,000	992,000	989,680
		2000	1,680,000	1,139,000	1,139,000	1,132,710
		2001	3,536,000	1,842,000	1,400,000	1,387,197
		2002	3,530,000	2,110,000	1,485,000	1,480,776
		2003	3,530,000	2,330,000	1,491,760	1,490,779
		2004	2,740,000	2,560,000	1,492,000	1,480,552
		2005	2,100,000	1,960,000	1,478,500	1,483,022
		2006	2,090,000	1,930,000	1,485,000	1,488,031
		2007	1,640,000	1,394,000	1,394,000	1,354,502
		2008	1,440,000	1,000,000	1,000,000	990,578
		2009	977,000	815,000	815,000	810,784
		2010	918,000	813,000	813,000	810,206
		2011	2,450,000	1,270,000	1,252,000	1,199,041
		2012	2,474,000	1,220,000	1,200,000	1,205,293
		2013	2,550,000	1,375,000	1,247,000	1,270,827
		2014	2,795,000	1,369,000	1,267,000	1,297,849
		2015	3,330,000	1,637,000	1,310,000	1,322,317
		2016	3,910,000	2,090,000	1,340,000	1,353,686
		2017	3,640,000	2,800,000	1,345,000	1,359,367
		2018	4,797,000	2,592,000	1,364,341	1,379,301
		2019	3,914,000	2,163,000	1,397,000	1,409,235
		2020	4,085,000	2,043,000	1,425,000	1,325,792
		2021	2,594,000	1,626,000	1,375,000	1,339,000
		2022	1,469,000	1,111,000	1,111,000	1,100,000
1977–2022 mean			2,439,000	1,486,674	1,219,535	1,202,075

Table 1-3. Estimates of discarded and retained pollock (t) for the Northwest and Southeastern Bering Sea, 1991–2022. SE represents the EBS east of 170W, NW is the EBS west of 170W, source: NMFS Blend and catch-accounting system database. 2022 data are preliminary.

Year	NW Discarded	SE Discarded	NW Retained	SE Retained	Total	Discarded %
1991	48,257	66,792	493,852	586,763	1,195,664	9.6%
1992	57,578	71,194	502,163	759,365	1,390,299	9.3%
1993	26,100	83,986	206,073	1,010,443	1,326,602	8.3%
1994	16,084	88,098	160,693	1,064,476	1,329,352	7.8%
1995	9,715	87,492	82,226	1,084,814	1,264,247	7.7%
1996	4,838	71,368	101,100	1,015,474	1,192,781	6.4%
1997	22,557	71,032	281,986	748,858	1,124,433	8.3%
1998	1,581	14,291	130,934	957,098	1,103,903	1.4%
1999	1,912	26,912	204,786	756,071	989,680	2.9%
2000	1,942	19,678	291,591	819,499	1,132,710	1.9%
2001	2,450	14,874	422,770	947,103	1,387,197	1.2%
2002	1,441	19,430	319,002	1,140,904	1,480,776	1.4%
2003	2,959	13,795	554,629	919,397	1,490,779	1.1%
2004	2,781	20,380	387,763	1,069,628	1,480,552	1.6%
2005	2,586	14,838	678,282	787,316	1,483,022	1.2%
2006	3,677	11,877	657,147	815,330	1,488,031	1.0%
2007	3,769	12,334	622,484	715,915	1,354,502	1.2%
2008	1,643	5,968	506,237	476,730	990,578	0.8%
2009	1,936	4,014	450,596	354,238	810,784	0.7%
2010	1,270	2,490	553,802	252,623	810,186	0.5%
2011	1,376	3,444	449,773	744,438	1,199,031	0.4%
2012	1,190	4,080	585,154	614,791	1,205,214	0.4%
2013	1,225	4,084	573,869	691,582	1,270,760	0.4%
2014	1,786	12,556	437,391	845,684	1,297,417	1.1%
2015	2,418	7,055	622,907	689,193	1,321,574	0.7%
2016	1,036	8,124	184,574	1,158,948	1,352,681	0.7%
2017	1,356	6,848	179,803	1,171,173	1,359,181	0.6%
2018	2,005	9,170	328,590	1,039,523	1,379,288	0.8%
2019	1,979	7,126	305,202	1,095,040	1,409,346	0.6%
2020	2,450	9,364	504,370	851,053	1,367,236	0.9%
2021	1,534	12,379	350,715	1,011,629	1,376,258	1.0%
2022	3,341	8,956	201,927	883,461	1,097,684	1.1%

Table 1-4. Highlights of some management measures affecting the pollock fishery.

Year	Management
1977	Preliminary BSAI FMP implemented with several closure areas
1982	FMP implement for the BSAI
1982	Chinook salmon bycatch limits established for foreign trawlers
1984	2 million t groundfish OY limit established
1984	Limits on Chinook salmon bycatch reduced
1990	New observer program established along with data reporting
1992	Pollock CDQ program commences
1994	NMFS adopts minimum mesh size requirements for trawl codends
1994	Voluntary retention of salmon for foodbank donations
1994	NMFS publishes individual vessel bycatch rates on internet
1995	Trawl closures areas and trigger limits established for chum and Chinook salmon
1998	Improved utilization and retention in effect (reduced discarded pollock)
1998	American Fisheries Act (AFA) passed
1999	The AFA was implemented for catcher/processors
1999	Additional critical habitat areas around sea lion haulouts in the GOA and Eastern Bering Sea are closed.
2000	AFA implemented for remaining sectors (catcher vessel and motherships)
2001	Pollock industry adopts voluntary rolling hotspot program for chum salmon
2002	Pollock industry adopts voluntary rolling hotspot program for Chinook salmon
2005	Rolling hotspot program adopted in regulations to exempt fleet from triggered time/area closures for Chinook and chum salmon
2011	Amendment 91 enacted, Chinook salmon management under hard limits
2015	Amendment 110 (BSAI) Salmon prohibited species catch management in the Bering Sea pollock fishery (additional measures that change limits depending on Chinook salmon run-strength indices) and includes additional provisions for reporting requirements (see https://alaskafisheries.noaa.gov/fisheries/chinook-salmon-bycatch-management for update and general information)
2016	Measures of amendment 110 go into effect for 2017 fishing season; Chinook salmon runs above the 3-run index value so bycatch limits stay the same
2017	Due to amendment 110 about 45% of the TAC is taken in the A-season (traditionally only 40% was allowed).
2018	In-river estimates of Chinook salmon (three river index) fell below the threshold and therefore a lower PSC limit applies (from a performance standard of 47,491 to 33,318 and a PSC limit from 60,000 to 45,000 Chinook salmon overall). Additionally, squid have been recategorized as an ecosystem component.
2019	Some pollock sectors experienced high bycatch levels for chum and Chinook salmon and also for sablefish.
2020	Bycatch rates unusually high again for sablefish. Herring PSC occurred in the A season and triggered area closures that will persist into 2021. Salmon bycatch rates (relative to hours fished) was lower than last year for both chum and Chinook.
2021	Bycatch rates for sablefish and herring moderate (but above average). Chinook salmon bycatch rates (relative to hours fished) was lower than last year but there was a marked increase in the rate for chum salmon (2nd highest since 1991). In-river estimates of Chinook salmon (three river index) fell below the threshold and therefore a lower PSC limit applies (from a performance standard of 47,491 to 33,318 and a PSC limit from 60,000 to 45,000 Chinook salmon overall).
2022	Chum and Chinook salmon bycatch dropped by more than half of the 2021 levels while the rate (salmon per ton of pollock) were about 59% of the 2021 rates.

Table 1-5. Eastern Bering Sea pollock catch at age estimates based on observer data, 1979–2021. Units are in millions of fish.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14+	Total
1979	101.4	543.0	719.8	420.1	392.5	215.5	56.3	25.7	35.9	27.5	17.6	7.9	3.0	1.1	2,567
1980	9.8	462.2	822.9	443.3	252.1	210.9	83.7	37.6	21.7	23.9	25.4	15.9	7.7	3.7	2,421
1981	0.6	72.2	1,012.7	637.9	227.0	102.9	51.7	29.6	16.1	9.3	7.5	4.6	1.5	1.0	2,175
1982	4.7	25.3	161.4	1,172.2	422.3	103.7	36.0	36.0	21.5	9.1	5.4	3.2	1.9	1.0	2,004
1983	5.1	118.6	157.8	312.9	816.8	218.2	41.4	24.7	19.8	11.1	7.6	4.9	3.5	2.1	1,745
1984	2.1	45.8	88.6	430.4	491.4	653.6	133.7	35.5	25.1	15.6	7.1	2.5	2.9	3.7	1,938
1985	2.6	55.2	381.2	121.7	365.7	321.5	443.2	112.5	36.6	25.8	24.8	10.7	9.4	9.1	1,920
1986	3.1	86.0	92.3	748.6	214.1	378.1	221.9	214.3	59.7	15.2	3.3	2.6	0.3	1.2	2,041
1987	-	19.8	111.5	77.6	413.4	138.8	122.4	90.6	247.2	54.1	38.7	21.4	28.9	14.1	1,379
1988	-	10.7	454.0	421.6	252.1	544.3	224.8	104.9	39.2	96.8	18.2	10.2	3.8	11.7	2,192
1989	-	4.8	55.1	149.0	451.1	166.7	572.2	96.3	103.8	32.4	129.0	10.9	4.0	8.5	1,784
1990	1.3	33.0	57.0	219.5	200.7	477.7	129.2	368.4	65.7	101.9	9.0	60.1	8.5	13.9	1,746
1991	1.0	111.6	43.5	85.1	156.1	184.5	500.5	76.2	289.2	28.0	139.5	18.3	93.6	76.9	1,804
1992	1.1	84.6	675.1	129.9	79.5	108.6	133.6	253.4	102.2	146.9	57.9	46.3	13.4	78.2	1,911
1993	0.1	7.4	260.3	1,145.5	102.9	66.1	66.3	56.4	86.1	21.1	32.7	12.3	13.5	22.9	1,893
1994	0.7	30.2	55.1	360.8	1,058.6	175.5	53.5	19.1	13.1	20.1	9.7	9.4	7.5	12.3	1,826
1995	-	0.5	72.8	146.6	395.1	760.3	136.1	34.5	12.3	7.5	17.5	5.0	5.8	10.6	1,605
1996	-	21.6	48.0	71.7	160.8	361.5	481.2	184.5	33.6	13.4	7.9	8.8	4.3	11.1	1,409
1997	1.0	77.6	40.3	118.9	454.7	288.7	256.1	198.4	64.0	13.3	6.0	4.6	2.9	13.9	1,540
1998	0.3	42.0	84.4	70.4	153.2	702.1	199.4	131.6	110.6	27.8	6.1	5.6	2.6	7.0	1,543
1999	0.2	10.3	298.4	224.8	102.9	156.9	469.3	130.9	56.4	33.1	4.0	2.2	0.9	2.5	1,493
2000	-	16.1	82.4	428.1	346.2	106.6	168.2	357.4	84.8	29.7	22.0	5.2	1.4	1.6	1,650
2001	-	3.2	42.7	154.3	580.5	414.6	137.0	128.9	157.1	57.8	33.6	16.2	5.5	5.0	1,736
2002	0.8	47.0	107.9	217.6	287.3	605.7	267.7	98.4	85.8	93.8	34.6	14.4	11.0	4.8	1,877
2003	-	14.5	411.4	323.8	360.0	301.2	337.3	158.4	49.4	39.2	35.7	22.9	6.6	6.8	2,067
2004	-	0.5	89.5	830.3	480.2	236.6	169.1	156.1	64.9	16.1	17.0	25.2	9.4	12.8	2,108
2005	-	4.8	52.1	392.5	862.9	484.1	159.3	68.0	66.6	30.1	10.0	9.1	3.2	5.9	2,149
2006	-	9.9	84.1	295.5	619.0	597.0	278.3	107.2	48.0	38.3	17.7	8.2	8.3	12.5	2,124
2007	1.7	15.7	59.1	139.0	389.0	511.5	300.5	136.9	47.6	27.5	21.8	8.9	6.5	14.2	1,680
2008	-	25.2	58.8	79.1	146.9	309.4	242.0	148.6	84.2	22.2	17.5	14.4	8.6	15.4	1,172
2009	-	1.3	175.3	200.4	82.5	114.3	124.2	104.2	66.6	40.2	23.5	7.6	7.5	11.4	959
2010	1.1	26.4	31.8	558.8	220.3	54.7	43.0	57.6	51.7	31.8	15.9	8.6	6.0	9.5	1,117
2011	0.4	10.3	193.1	115.3	808.4	284.4	63.5	37.5	38.5	41.4	25.8	12.5	1.8	8.3	1,641
2012	-	22.2	116.6	945.8	172.6	432.1	141.4	36.6	17.4	14.6	15.9	13.5	7.4	9.5	1,946
2013	1.8	1.0	63.9	342.1	954.9	194.2	156.4	69.9	20.7	12.7	12.7	10.8	7.8	10.5	1,859
2014	-	39.2	31.0	167.6	398.9	751.0	210.0	86.1	29.8	9.0	4.5	4.5	4.6	8.8	1,745
2015	-	15.5	631.8	196.2	228.3	383.9	509.6	88.7	42.1	17.6	2.9	2.1	3.1	3.9	2,126
2016	-	0.5	90.5	1,388.9	159.7	174.3	174.6	224.5	34.0	13.8	8.0	0.5	1.2	1.7	2,272
2017	-	2.2	28.1	548.5	898.1	215.3	147.4	122.0	97.2	21.7	7.2	5.6	0.5	0.4	2,094
2018	-	1.3	13.8	114.9	1,214.9	506.1	104.7	81.9	60.6	25.9	4.3	1.1	0.4	1.1	2,131
2019	0.7	10.9	12.3	18.3	157.4	915.9	422.0	93.1	52.1	52.9	10.0	2.9	0.8	-	1,749
2020	3.7	245.9	85.6	99.2	134.1	548.5	598.3	126.6	53.0	37.8	27.0	6.9	1.7	1.2	1,970
2021	-	111.3	1295.7	144.0	110.0	107.1	309.3	295.8	72.1	26.5	16.1	8.5	2.0	0.4	2,499
Mean	6	58	220	354	390	339	220	117	65	33	22	11	8	11	1,851

Table 1-6. Numbers of pollock NMFS observer samples measured for fishery catch length frequency (by sex and strata), 1977–2021.

Length Frequency samples							
	A Season		B Season SE		B Season NW		
Year	Males	Females	Males	Females	Males	Females	Total
1977	26,411	25,923	4,301	4,511	29,075	31,219	121,440
1978	25,110	31,653	9,829	9,524	46,349	46,072	168,537
1979	59,782	62,512	3,461	3,113	62,298	61,402	252,568
1980	42,726	42,577	3,380	3,464	47,030	49,037	188,214
1981	64,718	57,936	2,401	2,147	53,161	53,570	233,933
1982	74,172	70,073	16,265	14,885	181,606	163,272	520,273
1983	94,118	90,778	16,604	16,826	193,031	174,589	585,946
1984	158,329	161,876	106,654	105,234	243,877	217,362	993,332
1985	119,384	109,230	96,684	97,841	284,850	256,091	964,080
1986	186,505	189,497	135,444	123,413	164,546	131,322	930,727
1987	373,163	399,072	14,170	21,162	24,038	22,117	853,722
-	–	–	–	–	–	–	–
1991	143,625	165,393	122,241	162,352	132,539	184,394	910,544
1992	148,024	163,971	94,701	110,798	152,003	175,282	844,779
1993	126,635	150,315	26,057	29,863	137,384	151,361	621,615
1994	146,067	140,351	26,380	29,727	148,497	164,389	655,411
1995	125,847	133,438	16,327	16,203	150,323	183,514	625,652
1996	139,905	149,616	18,288	18,341	149,814	207,452	683,416
1997	102,619	126,426	51,498	61,974	106,001	118,224	566,742
1998	109,119	138,144	39,475	33,529	174,676	211,900	706,843
1999	32,407	36,480	18,321	16,316	35,084	39,426	178,034
2000	58,030	64,634	39,105	40,922	41,027	63,968	307,686
2001	75,491	79,509	45,766	44,414	51,179	54,312	350,671
2002	69,467	72,083	39,285	37,760	64,243	65,564	348,402
2003	77,533	75,073	53,435	51,838	52,899	49,535	360,313
2004	75,811	75,619	44,220	47,403	61,957	63,234	368,244
2005	68,665	75,962	63,022	68,976	33,917	43,326	353,868
2006	63,349	72,602	67,219	78,082	27,939	35,416	344,607
2007	63,969	66,622	70,504	77,557	29,558	38,221	346,431
2008	46,296	51,382	60,678	65,070	20,462	23,555	267,443
2009	41,540	43,538	47,926	45,695	16,148	17,355	212,202
2010	39,495	41,054	40,449	41,323	19,194	20,591	202,106
2011	58,481	62,318	50,927	48,237	60,208	65,107	345,278
2012	53,557	57,985	49,968	53,448	45,024	46,962	306,944
2013	51,984	62,170	49,161	49,781	37,307	44,835	295,238
2014	55,954	58,097	46,642	46,204	46,568	51,950	305,415
2015	55,646	56,507	45,117	41,266	46,853	43,757	289,146
2016	57,478	59,000	10,264	9,016	72,973	69,669	278,400
2017	55,965	64,728	15,871	14,136	70,285	66,026	287,011
2018	57,156	64,639	35,811	32,842	56,243	49,671	296,362
2019	49,191	64,730	34,955	27,993	59,416	55,450	291,735
2020	60,018	65,805	53,985	49,865	53,160	48,851	331,684
2021	59,580	75,688	14,590	12,416	16,816	13,441	192,531

Table 1-7. Number of EBS pollock measured for weight and length by sex and strata as collected by the NMFS observer program, 1977-2021

	Weight-length samples						
	A Season		B Season SE		B Season NW		
	Males	Females	Males	Females	Males	Females	Total
1977	1,222	1,338	137	166	1,461	1,664	5,988
1978	1,991	2,686	409	516	2,200	2,623	10,425
1979	2,709	3,151	152	209	1,469	1,566	9,256
1980	1,849	2,156	99	144	612	681	5,541
1981	1,821	2,045	51	52	1,623	1,810	7,402
1982	2,030	2,208	181	176	2,852	3,043	10,490
1983	1,199	1,200	144	122	3,268	3,447	9,380
1984	980	1,046	117	136	1,273	1,378	4,930
1985	520	499	46	55	426	488	2,034
1986	689	794	518	501	286	286	3,074
1987	1,351	1,466	25	33	72	63	3,010
-	–	–	–	–	–	–	–
1991	2,893	2,791	1,209	1,116	2,536	2,408	12,953
1992	1,605	1,537	556	600	2,003	1,940	8,241
1993	1,278	1,205	451	437	1,412	1,459	6,242
1994	1,638	1,553	174	166	1,591	1,584	6,706
1995	1,258	1,220	232	223	1,352	1,331	5,616
1996	2,165	2,117	-	-	1,393	1,421	7,096
1997	629	630	552	536	674	620	3,641
1998	1,958	1,865	357	335	936	982	6,433
1999	4,813	5,337	3,767	3,546	7,182	7,954	32,599
2000	11,346	12,457	7,736	7,991	7,800	12,463	59,793
2001	14,411	14,965	9,064	8,803	10,460	10,871	68,574
2002	13,564	14,098	7,648	7,213	13,004	12,988	68,515
2003	15,535	14,857	10,272	10,031	10,111	9,437	70,243
2004	7,924	7,742	4,318	4,617	6,868	6,850	38,319
2005	7,039	7,428	6,426	6,947	4,114	5,139	37,093
2006	6,566	7,381	6,442	7,406	3,045	4,006	34,846
2007	6,640	6,695	7,081	7,798	3,202	4,305	35,721
2008	4,501	4,865	5,855	6,264	2,236	2,624	26,345
2009	4,033	4,382	4,655	4,511	1,723	1,934	21,238
2010	4,258	4,536	3,883	4,125	2,012	2,261	21,075
2011	5,845	6,388	4,954	4,647	5,929	6,456	34,219
2012	5,494	5,979	4,923	5,346	4,507	4,774	31,023
2013	5,689	6,525	4,844	4,920	3,599	4,313	29,890
2014	5,675	5,871	4,785	4,652	4,753	5,180	30,916
2015	5,310	5,323	4,648	4,194	4,365	4,064	27,904
2016	5,312	5,725	1,077	909	6,872	6,635	26,530
2017	5,238	6,047	1,586	1,343	6,575	6,254	27,043
2018	5,583	6,174	3,430	3,172	5,506	4,850	28,715
2019	4,513	6,086	3,594	2,953	5,809	5,499	28,454
2020	6,116	6,846	5,325	4,815	5,376	4,900	33,378
2021	5,852	7,368	6,247	5,468	2,886	2,698	30,519
2022	4,862	5,817	2,240	1,858	531	506	15,814

Table 1-8. Numbers of pollock fishery samples used for age determination estimates by sex and strata, 1977–2021, as sampled by the NMFS observer program.

	A Season		B Season SE		B Season NW		
	Males	Females	Males	Females	Males	Females	Total
1977	1,229	1,344	137	166	1,415	1,613	5,904
1978	1,992	2,686	407	514	2,188	2,611	10,398
1979	2,647	3,088	152	209	1,464	1,561	9,121
1980	1,854	2,158	93	138	606	675	5,524
1981	1,819	2,042	51	52	1,620	1,807	7,391
1982	2,030	2,210	181	176	2,865	3,062	10,524
1983	1,200	1,200	144	122	3,249	3,420	9,335
1984	980	1,046	117	136	1,272	1,379	4,930
1985	520	499	46	55	426	488	2,034
1986	689	794	518	501	286	286	3,074
1987	1,351	1,466	25	33	72	63	3,010
-	–	–	–	–	–	–	–
1991	439	431	367	349	263	289	2,138
1992	399	396	178	180	391	375	1,919
1993	476	445	122	124	496	507	2,170
1994	201	200	142	132	574	571	1,820
1995	313	299	131	123	420	439	1,725
1996	465	479	-	-	436	443	1,823
1997	437	434	343	341	313	286	2,154
1998	663	595	237	222	311	316	2,344
1999	506	541	298	308	748	750	3,151
2000	629	667	293	254	596	847	3,286
2001	563	603	205	178	697	736	2,982
2002	672	663	247	202	890	839	3,513
2003	653	588	274	262	701	671	3,149
2004	547	561	221	245	698	600	2,872
2005	599	617	420	422	490	614	3,162
2006	528	609	507	568	367	459	3,038
2007	627	642	552	568	485	594	3,468
2008	513	497	538	650	342	368	2,908
2009	404	484	440	432	240	299	2,299
2010	545	624	413	466	418	505	2,971
2011	581	808	404	396	582	660	3,431
2012	517	571	485	579	480	533	3,165
2013	666	703	525	568	401	518	3,381
2014	609	629	413	407	475	553	3,086
2015	653	642	511	493	508	513	3,320
2016	488	599	157	125	929	969	3,267
2017	604	778	179	163	777	753	3,254
2018	569	662	366	358	621	591	3,167
2019	552	778	387	332	558	531	3,138
2020	757	899	405	420	450	408	3,339
2021	760	910	588	542	270	256	3,326

Table 1-9. NMFS total pollock research catch by year in t, 1964–2021.

Year	Bering Sea	Year	Bering Sea	Year	Bering Sea
1964	0	1983	508	2002	440
1965	18	1984	208	2003	285
1966	17	1985	435	2004	363
1967	21	1986	163	2005	87
1968	7	1987	174	2006	251
1969	14	1988	467	2007	333
1970	9	1989	393	2008	168
1971	16	1990	369	2009	156
1972	11	1991	465	2010	226
1973	69	1992	156	2011	1322
1974	83	1993	221	2012	219
1975	197	1994	267	2013	183
1976	122	1995	249	2014	308
1977	35	1996	206	2015	256
1978	94	1997	262	2016	198
1979	458	1998	121	2017	363
1980	139	1999	299	2018	269
1981	466	2000	313	2019	338
1982	682	2001	241	2020	13
				2021	897

Table 1-10. Survey biomass estimates (age 1+, t) of Eastern Bering Sea pollock based on design-based area-swept expansion methods from NMFS bottom trawl surveys 1982–2022 .

	Survey biomass			
Year	Strata 1-6	Strata 8-9	Total	%NW
1982	2,854,067	54,333	2,908,400	1.9%
1983	5,910,351	-	5,910,351	
1984	4,538,253	-	4,538,253	
1985	4,543,845	1,388,121	5,931,966	23.4%
1986	4,830,239	-	4,830,239	
1987	5,101,495	386,312	5,487,807	7.0%
1988	6,988,785	179,531	7,168,316	2.5%
1989	5,891,474	642,812	6,534,286	9.8%
1990	7,086,231	189,055	7,275,286	2.6%
1991	5,060,594	62,291	5,122,885	1.2%
1992	4,310,567	208,971	4,519,538	4.6%
1993	5,196,757	98,257	5,295,014	1.9%
1994	4,974,941	49,563	5,024,503	1.0%
1995	5,408,305	68,377	5,476,682	1.2%
1996	2,988,107	143,394	3,131,501	4.6%
1997	2,866,779	692,854	3,559,633	19.5%
1998	2,141,303	550,487	2,691,790	20.5%
1999	3,592,006	199,345	3,791,350	5.3%
2000	4,981,435	118,285	5,099,720	2.3%
2001	4,141,748	51,030	4,192,778	1.2%
2002	4,744,887	197,356	4,942,242	4.0%
2003	8,107,657	285,661	8,393,318	3.4%
2004	3,745,935	118,370	3,864,305	3.1%
2005	4,723,494	137,326	4,860,820	2.8%
2006	2,842,370	199,328	3,041,698	6.6%
2007	4,152,074	179,550	4,331,625	4.1%
2008	2,829,351	188,832	3,018,183	6.3%
2009	2,226,322	51,057	2,277,379	2.2%
2010	3,542,594	186,598	3,729,191	5.0%
2011	2,942,823	166,349	3,109,172	5.4%
2012	3,280,469	205,701	3,486,170	5.9%
2013	4,286,060	276,788	4,562,848	6.1%
2014	6,549,316	876,186	7,425,501	11.8%
2015	5,943,128	449,089	6,392,217	7.0%
2016	4,698,980	211,474	4,910,454	4.3%
2017	4,690,053	125,651	4,815,704	2.6%
2018	3,016,181	97,024	3,113,204	3.1%
2019	4,968,072	483,937	5,452,009	8.9%
2020				
2021	2,694,658	336,330	3,030,988	11.1%
2022	4,006,148	147,823	4,153,971	3.6%
Average	4,434,946	250,086	4,685,032	5.9%

Table 1-11. Sampling effort for pollock in the EBS from the NMFS bottom trawl survey 1982–2022.

Year	Number of Hauls	Lengths	Aged	Year	Number of Hauls	Lengths	Aged
1982	329	40,001	1,611	1999	373	32,532	1,385
1983	354	78,033	1,931	2000	372	41,762	1,545
1984	355	40,530	1,806	2001	375	47,335	1,641
1985	434	48,642	1,913	2002	375	43,361	1,695
1986	354	41,101	1,344	2003	376	46,480	1,638
1987	356	40,144	1,607	2004	375	44,102	1,660
1988	373	40,408	1,173	2005	373	35,976	1,676
1989	373	38,926	1,227	2006	376	39,211	1,573
1990	371	34,814	1,257	2007	376	29,679	1,484
1991	371	43,406	1,083	2008	375	24,635	1,251
1992	356	34,024	1,263	2009	375	24,819	1,342
1993	375	43,278	1,385	2010	376	23,142	1,385
1994	375	38,901	1,141	2011	376	36,227	1,734
1995	376	25,673	1,156	2012	376	35,782	1,785
1996	375	40,789	1,387	2013	376	35,908	1,847
1997	376	35,536	1,193	2014	376	43,042	2,099
1998	375	37,673	1,261	2015	376	54,241	2,320
				2016	376	50,857	1,766
				2017	376	47,873	1,623
				2018	376	48,673	1,486
				2019	376	42,382	1,519
				–	–	–	–
				2021	376	53,545	1,528
				2022	376	36,687	1,578

Table 1-12. Bottom-trawl survey estimated numbers (in tens of millions) at age used for the stock assessment model. Note that in 1982–84 and 1986 only strata 1–6 were surveyed. Note these estimates are based on design-based procedures.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
1982	1,094	3,193	3,536	4,808	1,571	203	128	62	38	24	15	9	3	1	1	14,684
1983	4,354	1,011	2,906	4,665	9,489	2,726	457	203	93	84	61	22	8	7	3	26,091
1984	439	419	772	2,152	2,620	5,941	1,040	210	91	31	20	8	5	6	3	13,757
1985	4,661	745	3,048	1,265	4,570	3,034	2,016	372	89	74	26	8	9	1	1	19,915
1986	2,822	1,081	932	3,789	1,854	2,798	2,256	1,847	534	82	37	16	2	5	2	18,056
1987	448	697	1,288	1,022	6,255	1,559	1,390	527	1,635	257	79	30	6	3	3	15,199
1988	1,509	821	2,136	4,246	2,089	6,399	1,798	1,297	723	1,693	159	92	21	25	15	23,022
1989	1,023	504	723	2,918	6,883	1,305	4,494	631	725	272	857	147	130	60	96	20,768
1990	2,380	300	117	1,166	2,666	8,566	1,537	3,440	325	559	85	796	69	51	68	22,126
1991	2,883	811	356	139	887	802	2,419	865	1,749	437	587	119	350	52	59	12,515
1992	1,520	516	3,541	471	617	998	795	1,062	447	813	278	352	151	119	95	11,773
1993	2,530	426	1,163	4,999	1,113	836	426	569	718	435	372	266	208	113	137	14,310
1994	1,464	564	492	1,863	5,278	867	216	179	200	368	225	312	117	114	192	12,453
1995	1,545	191	513	2,286	2,778	4,751	1,770	404	236	152	278	110	202	81	130	15,427
1996	1,824	427	196	424	1,151	1,466	1,267	424	106	115	77	148	49	86	126	7,888
1997	2,254	371	185	257	2,797	1,542	954	1,142	191	99	70	76	128	40	151	10,256
1998	892	697	397	262	497	2,728	730	460	353	90	41	14	31	33	82	7,308
1999	1,008	958	1,062	1,529	882	1,451	3,346	813	379	349	129	54	21	31	114	12,128
2000	1,005	376	657	1,940	2,004	1,099	964	3,041	1,165	604	255	163	50	23	100	13,445
2001	1,928	1,236	728	691	1,656	1,685	715	348	1,019	720	275	213	81	30	82	11,407
2002	1,274	415	820	1,190	1,348	1,816	933	460	610	1,142	561	259	151	47	55	11,080
2003	562	161	1,048	1,805	2,274	1,955	2,432	1,211	499	637	1,240	553	227	91	98	14,794
2004	415	274	203	1,686	1,688	1,232	689	731	362	226	226	413	181	46	38	8,409
2005	399	146	242	1,189	3,430	2,196	1,103	503	383	278	77	160	265	107	121	10,601
2006	810	87	129	531	1,429	1,728	1,027	463	255	212	101	63	90	120	123	7,168
2007	2,465	65	226	717	2,307	2,670	1,748	1,225	480	209	196	167	77	94	198	12,843
2008	481	135	148	287	905	1,959	1,411	870	509	181	149	112	49	26	176	7,400
2009	791	210	448	522	352	500	664	506	362	169	109	36	36	18	82	4,804
2010	495	128	312	4,415	1,968	562	411	408	406	276	234	84	50	30	71	9,852
2011	1,293	135	292	434	2,272	1,112	311	170	258	254	215	164	71	33	97	7,109
2012	1,176	221	448	3,814	1,139	1,680	503	182	119	160	128	111	95	34	64	9,874
2013	1,241	127	282	1,361	6,998	1,463	815	276	92	81	106	80	76	43	60	13,103
2014	2,519	467	295	465	2,110	7,393	3,717	803	434	159	62	89	91	45	135	18,785
2015	1,457	885	2,703	779	1,587	2,842	5,273	1,542	387	190	27	26	47	29	68	17,843
2016	810	428	743	4,304	1,756	1,188	1,736	2,624	528	217	77	18	19	6	13	14,466
2017	800	326	543	2,751	3,606	1,646	1,268	1,188	1,513	433	166	56	8	5	17	14,325
2018	1,107	485	259	352	2,470	1,547	542	391	402	327	92	14	2	0	6	7,996
2019	2,648	854	532	616	1,855	6,636	2,640	625	445	261	138	63	24	7	3	17,347
2020	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2021	958	596	1,185	728	763	505	1,314	1,683	362	135	88	58	12	7	4	8,396
2022	787	391	650	4,023	1,925	773	857	1,126	874	263	100	84	33	15	2	11,903
Avg	1,502	547	906	1,822	2,496	2,304	1,453	872	502	327	200	139	81	42	72	13,266

Table 1-13. Mean EBS pollock body mass (kg) at age as estimated for the summer NMFS bottom trawl survey, 1982–2022.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1982	0.032	0.077	0.181	0.340	0.411	0.777	1.051	1.188	1.401	1.567	2.235	1.990	1.904	1.524	2.946
1983	0.021	0.101	0.209	0.342	0.536	0.774	1.016	1.453	1.406	1.667	1.529	1.577	2.013	2.127	1.834
1984	0.017	0.084	0.215	0.314	0.432	0.603	0.926	1.313	1.268	1.473	1.985	1.688	1.905	1.426	2.122
1985	0.031	0.093	0.229	0.368	0.481	0.715	0.910	1.213	1.723	1.436	1.532	1.777	2.038	1.652	2.634
1986	0.019	0.073	0.169	0.310	0.414	0.608	0.767	1.018	1.304	1.650	1.276	1.381	1.983	2.233	2.223
1987	0.023	0.123	0.253	0.332	0.422	0.547	0.718	0.849	1.008	1.261	1.581	1.612	2.202	2.045	2.395
1988	0.019	0.133	0.281	0.330	0.446	0.494	0.590	0.814	0.908	1.040	1.230	1.285	1.571	0.686	1.740
1989	0.022	0.082	0.169	0.277	0.371	0.549	0.662	0.837	1.027	1.000	1.115	1.014	1.260	1.144	1.103
1990	0.029	0.097	0.187	0.356	0.478	0.545	0.614	0.735	1.029	0.979	1.023	1.188	0.855	1.390	1.714
1991	0.030	0.145	0.201	0.333	0.565	0.650	0.777	0.856	1.016	1.105	1.287	1.370	1.347	1.733	1.691
1992	0.030	0.134	0.255	0.400	0.464	0.570	0.756	0.771	0.929	1.008	1.138	1.520	1.539	1.426	1.563
1993	0.016	0.098	0.250	0.409	0.464	0.548	0.662	0.783	0.987	0.999	1.149	1.285	1.509	1.576	1.909
1994	0.025	0.117	0.212	0.401	0.536	0.672	0.648	1.046	1.166	1.107	1.219	1.241	1.367	1.436	1.451
1995	0.018	0.105	0.169	0.363	0.478	0.648	0.624	0.785	0.911	1.281	1.222	1.254	1.399	1.422	1.740
1996	0.021	0.112	0.151	0.300	0.487	0.583	0.758	0.820	0.979	1.023	1.350	1.461	1.487	1.639	1.964
1997	0.017	0.095	0.189	0.277	0.382	0.530	0.674	0.776	0.996	0.966	1.211	1.465	1.090	1.566	1.951
1998	0.016	0.081	0.213	0.332	0.446	0.519	0.811	0.887	1.078	1.293	1.592	1.415	1.516	1.669	1.905
1999	0.020	0.097	0.216	0.351	0.392	0.526	0.616	0.882	1.038	1.008	1.279	1.132	1.666	1.760	2.192
2000	0.017	0.085	0.219	0.398	0.470	0.521	0.722	0.759	0.925	1.035	1.236	1.338	1.782	1.626	2.048
2001	0.022	0.092	0.201	0.356	0.617	0.729	0.750	1.000	0.982	1.031	1.278	1.419	1.474	1.766	1.539
2002	0.025	0.107	0.269	0.402	0.544	0.685	0.713	0.904	1.006	1.053	1.010	1.139	1.474	1.410	2.108
2003	0.032	0.109	0.342	0.419	0.648	0.710	0.886	0.869	1.124	1.239	1.269	1.285	1.369	1.747	1.780
2004	0.035	0.202	0.284	0.516	0.595	0.750	0.895	0.932	1.119	1.027	1.279	1.552	1.537	2.375	1.712
2005	0.034	0.112	0.231	0.394	0.539	0.698	0.859	0.931	0.993	1.223	1.383	1.229	1.401	1.504	1.682
2006	0.010	0.087	0.179	0.457	0.605	0.679	0.789	0.866	1.058	1.171	1.279	1.336	1.669	1.519	1.704
2007	0.015	0.100	0.294	0.493	0.637	0.810	0.928	1.060	1.002	1.315	1.309	1.268	1.417	1.367	1.385
2008	0.019	0.059	0.220	0.491	0.601	0.730	0.857	0.946	0.987	1.154	1.640	1.372	1.708	1.540	1.682
2009	0.019	0.070	0.241	0.509	0.688	0.815	1.010	1.068	1.121	1.359	1.449	1.769	1.767	2.049	2.486
2010	0.023	0.069	0.244	0.496	0.657	0.804	1.097	1.140	1.260	1.376	1.190	1.389	1.629	2.161	2.221
2011	0.018	0.081	0.216	0.511	0.653	0.785	0.907	1.066	1.159	1.246	1.358	1.419	1.365	1.496	2.016
2012	0.017	0.076	0.285	0.410	0.592	0.738	0.865	1.008	1.354	1.203	1.340	1.424	1.500	1.711	1.981
2013	0.020	0.067	0.228	0.516	0.577	0.721	0.973	1.173	1.265	1.461	1.513	1.404	1.717	1.822	1.965
2014	0.019	0.113	0.393	0.445	0.567	0.693	0.737	0.978	1.136	1.336	1.534	1.484	1.638	1.638	2.012
2015	0.020	0.091	0.347	0.442	0.566	0.675	0.742	0.864	1.064	1.270	1.545	1.455	1.446	1.482	1.596
2016	0.022	0.090	0.278	0.524	0.574	0.688	0.764	0.795	0.883	0.919	1.193	1.846	1.244	1.228	1.393
2017	0.026	0.096	0.242	0.488	0.621	0.649	0.740	0.782	0.889	0.923	0.998	1.013	1.323	1.020	1.813
2018	0.024	0.101	0.210	0.442	0.575	0.665	0.756	0.750	0.845	0.886	0.722	0.838	0.876	1.074	0.964
2019	0.026	0.112	0.292	0.505	0.642	0.715	0.823	0.899	0.901	0.989	0.986	1.043	1.068	1.120	1.390
2020	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2021	0.023	0.148	0.278	0.440	0.590	0.696	0.774	0.854	0.960	1.233	1.023	1.350	1.307	0.927	1.389
2022	0.020	0.104	0.347	0.452	0.583	0.668	0.764	0.853	0.945	0.972	1.122	1.474	1.242	0.895	1.247
Avg	0.022	0.100	0.240	0.406	0.534	0.662	0.798	0.938	1.079	1.182	1.315	1.388	1.515	1.548	1.830

Table 1-14. Biomass (age 1+) of Eastern Bering Sea pollock as estimated by surveys 1979–2022 (thousands of t). Note that the bottom-trawl survey data only represent biomass from the survey strata (1–6) areas in 1982–1984, and 1986. For all other years the estimates include strata 8–9. DDC indicates the values obtained from the Kotwicki et al. Density-dependence correction method and the VAST column is for the standard survey area including the Northern Bering Sea extension and uses the cold pool as a covariate. BTS=Bottom trawl survey, DB=Design-based, ATS=acoustic trawl survey. The ATS estimate from 2020 arises from data collected aboard uncrewed sailing vessels with acoustic backscatter scaled to be consistent with previous years. BTS estimates include northern Bering Sea extensions.

Year	DB BTS	DDC	VAST	ATS
1982	2,908	4,065	3,821	
1983	5,910	8,393	8,981	
1984	4,538	6,405	6,473	
1985	5,932	8,225	7,559	
1986	4,830	6,818	7,158	
1987	5,488	7,875	7,833	
1988	7,168	11,062	11,680	
1989	6,534	9,770	9,976	
1990	7,275	11,864	11,408	
1991	5,123	7,383	7,235	
1992	4,520	6,201	6,643	
1993	5,295	7,092	7,823	
1994	5,025	7,093	6,887	3,629
1995	5,477	9,103	6,555	
1996	3,132	4,090	3,991	2,945
1997	3,560	5,016	4,459	3,591
1998	2,692	3,515	3,455	
1999	3,791	5,442	5,593	4,141
2000	5,100	7,347	7,053	3,626
2001	4,193	5,434	6,014	
2002	4,942	6,754	6,721	4,306
2003	8,393	13,516	11,176	
2004	3,864	5,109	5,633	4,010
2005	4,861	6,685	6,883	
2006	3,042	3,881	4,113	1,873
2007	4,332	6,137	6,867	2,278
2008	3,018	3,987	4,276	1,406
2009	2,277	2,983	2,852	1,325
2010	3,750	5,141	5,174	2,642
2011	3,109	3,945	4,541	
2012	3,486	4,614	5,173	2,296
2013	4,563	6,098	6,658	
2014	7,426	10,329	11,693	4,730
2015	6,392	8,584	10,654	
2016	4,910	6,611	8,427	4,829
2017	6,135	7,922	8,915	
2018	3,113	4,186	4,039	2,499
2019	6,619	8,767	9,444	
2020	–	–	–	3,605
2021	3,505	4,154	4,808	
2022	4,549	5,891	6,509	3,834
Avg.	4,769	6,687	6,879	3,198

Table 1-15. Number of (age 1+) hauls and sample sizes for EBS pollock collected by the AT surveys. Sub-headings E and W represent collections east and west of 170W (within the US EEZ) and US represents the US sub-total and RU represents the collections from the Russian side of the surveyed region.

	Hauls				Lengths				Otoliths				Number aged			
Year	E	W	US	RU	E	W	US	RU	E	W	US	RU	E	W	US	RU
1979			25				7,722				0				2,610	
1982	13	31	48		1,725	6,689	8,687		840	2,324	3,164		783	1,958	2,741	
1985			73				19,872				2,739				2,739	
1988			25				6,619				1,471				1,471	
1991			62				16,343				2,062				1,663	
1994	25	51	76	19	4,553	21,011	25,564	8,930	1,560	3,694	4,966	1,270	612	932	1,770	455
1996	15	42	57		3,551	13,273	16,824		669	1,280	1,949		815	1,111	1,926	
1997	25	61	86		6,493	23,043	29,536		966	2,669	3,635		936	1,349	2,285	
1999	41	77	118		13,841	28,521	42,362		1,945	3,001	4,946		946	1,500	2,446	
2000	29	95	124		7,721	36,008	43,729		850	2,609	3,459		850	1,403	2,253	
2002	47	79	126		14,601	25,633	40,234		1,424	1,883	3,307		1,000	1,200	2,200	
2004	33	57	90	15	8,896	18,262	27,158	5,893	1,167	2,002	3,169	461	798	1,192	2,351	461
2006	27	56	83		4,939	19,326	24,265		822	1,871	2,693		822	1,870	2,692	
2007	23	46	69	4	5,492	14,863	20,355	1,407	871	1,961	2,832	319	823	1,737	2,560	315
2008	9	53	62	6	2,394	15,354	17,748	1,754	341	1,698	2,039	177	338	1,381	1,719	176
2009	13	33	46	3	1,576	9,257	10,833	282	308	1,210	1,518	54	306	1,205	1,511	54
2010	11	48	59	9	2,432	20,263	22,695	3,502	653	1,868	2,521	381	652	1,598	2,250	379
2012	17	60	77	14	4,422	23,929	28,351	5,620	650	2,045	2,695	418	646	1,483	2,129	416
2014	52	87	139	3	28,857	8,645	37,502	747	1,739	849	2,588	72	845	1,735	2,580	72
2016	37	71	108		10,912	24,134	35,046		880	1,514	2,394		876	1,513	2,388	
2018	36	55	91		11,031	18,654	29,685		1,105	1,675	2,780		1,100	1,668	2,768	
2022	15	31	46		4,973	10,859	15,832		572	1,528	2,100					

Table 1-16. Mid-water pollock biomass (millions of t; near surface down to 0.5m from the bottom) by area as estimated from summer acoustic-trawl surveys on the U.S. EEZ portion of the Bering Sea shelf, 1994–2022 (Honkalehto et al. 2015, McCarthy et al. 2020, and De Robertis et al. 2021). Note that in 2020 the survey was carried out by uncrewed sailing vessels.

		Area		Biomass		
Year	Date	(nmi)^2	SCA	E170-SCA	W170	0.5m total
1994	9 Jul - 19 Aug	78,251	0.378	0.656	2.595	3.629
1996	20 Jul - 30 Aug	93,810	0.272	0.490	2.182	2.944
1997	17 Jul - 4 Sept	102,770	0.274	0.853	2.463	3.59
1999	7 Jun - 5 Aug	103,670	0.323	0.758	3.060	4.141
2000	7 Jun - 2 Aug	106,140	0.457	0.717	2.452	3.626
2002	4 Jun - 30 Jul	99,526	0.755	0.946	2.605	4.306
2004	4 Jun - 29 Jul	99,659	0.546	0.920	2.543	4.009
2006	3 Jun - 25 Jul	89,550	0.144	0.342	1.387	1.873
2007	2 Jun - 30 Jul	92,944	0.136	0.244	1.898	2.278
2008	2 Jun - 31 Jul	95,374	0.122	0.087	1.197	1.406
2009	9 Jun - 7 Aug	91,414	0.153	0.057	1.115	1.325
2010	5 Jun - 7 Aug	92,849	0.098	0.193	2.351	2.642
2012	7 Jun - 10 Aug	96,852	0.195	0.320	1.782	2.297
2014	12 Jun - 13 Aug	94,361	0.561	1.462	2.707	4.73
2016	12 Jun - 17 Aug	100,674	0.540	1.267	3.022	4.829
2018	12 Jun - 22 Aug	92,283	0.231	0.513	1.755	2.499
2020	4 Jul - 20 Aug	102,320	-	0.462	-	3.605
2022	1 Jun - 5 Aug	103,942	0.538	0.823	2.473	3.834

Table 1-17. AT survey estimates of EBS pollock abundance-at-age (millions), 1979–2022. Age-1s were modeled as a separate index, ages 2+ modeled as proportions at age.

					Age						Age	
Year	1	2	3	4	5	6	7	8	9	10+	2+	Total
1979	69,110	41,132	3,884	413	534	128	30	4	28	161	46,314	115,424
1982	108	3,401	4,108	7,637	1,790	283	141	178	90	177	17,805	17,913
1985	2,076	929	8,149	898	2,186	1,510	1,127	130	21	15	14,965	17,041
1988	11	1,112	3,586	3,864	739	1,882	403	151	130	414	12,280	12,292
1991	639	5,942	967	215	224	133	120	39	37	53	7,730	8,369
1994	1,140	4,969	1,424	1,819	2,252	389	109	96	56	221	11,335	12,475
1996	1,800	567	552	2,741	915	634	585	142	39	165	6,338	8,139
1997	13,227	2,881	440	536	2,330	546	313	290	75	220	7,633	20,860
1999	607	1,780	3,717	1,810	652	398	1,548	526	180	249	10,859	11,466
2000	460	1,322	1,230	2,588	1,012	327	308	950	278	252	8,266	8,726
2002	796	4,944	3,385	1,295	661	935	538	140	162	493	12,554	13,351
2004	83	313	1,217	3,123	1,634	567	288	283	121	265	7,811	7,894
2006	525	217	291	654	783	659	390	145	75	171	3,386	3,910
2007	5,775	1,041	345	478	794	729	407	241	98	135	4,267	10,042
2008	71	2,915	1,047	166	161	288	235	136	102	120	5,169	5,240
2009	5,197	816	1,734	281	77	94	129	111	77	114	3,433	8,630
2010	2,568	6,404	984	2,295	446	73	33	37	38	91	10,400	12,968
2012	177	1,989	1,693	2,710	280	367	113	36	25	103	7,315	7,492
2014	4,751	8,655	969	1,161	1,119	1,770	740	170	79	99	14,762	19,513
2016	174	1,038	4,496	4,476	715	348	392	420	96	64	12,046	12,220
2018	450	517	249	621	2,268	944	198	112	107	104	5,120	5,570
2022	143	236	1,090	5,938	1,311	275	211	216	168	87	9,532	9,674
Mean	4,995	4,233	2,071	2,078	1,040	604	380	207	95	172	10,878	15,873
Median	623	1,551	1,223	1,552	789	393	298	143	84	148	8,899	10,754

Table 1-18. An abundance index derived from acoustic data collected opportunistically aboard bottom-trawl survey vessels (AVO index; Stienessen et al. 2022). Note values in parentheses are the coefficients of variation from using 1-D geostatistical estimates of sampling variability (Petitgas, 1993). See Honkalehto et al. (2011) for the derivation of these estimates. The column "CV_{AVO}" was assumed to have a mean value of 0.30 for model fitting purposes (scaling relative to the AT and BTS indices).

Year	AT scaled biomass index	AVO index	Relative error	CV_{AVO}
2006	1.8729	0.555	5%	27.8%
2007	2.2779	0.638	9%	47.2%
2008	1.4056	0.316	6%	35.1%
2009	1.3248	0.285	12%	65.6%
2010	2.6423	0.679	9%	46.8%
2011	—*no survey*—	0.543	6%	31.2%
2012	2.2958	0.661	6%	34.1%
2013	—*no survey*—	0.694	4%	21.3%
2014	4.73	0.897	4%	23.3%
2015	—*no survey*—	0.953	5%	24.9%
2016	4.829	0.776	4%	19.9%
2017	—*no survey*—	0.73	3%	18.6%
2018	2.4994	0.672	3%	18.3%
2019	—*no survey*—	0.68	3%	17.4%
2020	3.62			
2021	—*no survey*—	0.936	4%	23.6%
2022	3.834	1.089	4%	25.0%

Table 1-19. Pollock sample sizes assumed for the age-composition data likelihoods from the fishery, bottom-trawl survey, and AT surveys, 1964–2022. Note fishery sample size for 1964–1977 was fixed at 10.

Year	Fishery	BTS	ATS
1978	39		
1979	39		
1980	39		
1981	39		
1982	39	105	
1983	39	126	
1984	39	118	
1985	39	125	
1986	39	88	
1987	39	105	
1988	39	76	
1989	39	80	
1990	39	82	
1991	129	71	
1992	125	82	
1993	106	90	
1994	149	74	43
1995	92	75	
1996	107	90	32
1997	116	78	49
1998	197	82	
1999	386	90	67
2000	613	101	70
2001	640	107	
2002	667	110	72
2003	657	107	
2004	602	108	51
2005	651	109	
2006	653	102	47
2007	716	97	39
2008	563	82	35
2009	471	87	26
2010	593	90	34
2011	715	113	
2012	598	116	44
2013	694	120	
2014	631	137	79
2015	683	151	
2016	689	115	61
2017	676	105	
2018	611	100	50
2019	620	107	
2020	623		
2021	620	100	
2022	600	100	25

Table 1-20. Mean weight-at-age (kg) estimates from the fishery (1991–2021; plus projections 2022–2024) showing the between-year variability (bottom row).

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1964-1990	0.007	0.17	0.303	0.447	0.589	0.722	0.84	0.942	1.029	1.102	1.163	1.212	1.253	1.286	1.312
1991	0.007	0.15	0.288	0.485	0.606	0.729	0.844	0.883	1.016	1.124	1.141	1.232	1.222	1.295	1.252
1992	0.007	0.179	0.397	0.465	0.651	0.714	0.819	0.986	1.03	1.2	1.237	1.269	1.193	1.357	1.431
1993	0.007	0.331	0.495	0.612	0.652	0.775	0.934	1.062	1.198	1.24	1.423	1.54	1.576	1.609	1.508
1994	0.007	0.233	0.4	0.652	0.732	0.746	0.727	1.07	1.38	1.325	1.335	1.409	1.397	1.278	1.37
1995	0.007	0.153	0.386	0.505	0.729	0.843	0.847	0.97	1.232	1.296	1.401	1.402	1.392	1.095	1.306
1996	0.007	0.293	0.336	0.445	0.684	0.797	0.948	0.956	1.025	1.1	1.418	1.489	1.521	1.702	1.602
1997	0.007	0.187	0.327	0.477	0.559	0.748	0.889	1.074	1.095	1.236	1.287	1.4	1.561	1.363	1.338
1998	0.007	0.191	0.369	0.589	0.618	0.622	0.78	1.04	1.169	1.276	1.316	1.428	1.448	1.437	1.528
1999	0.007	0.188	0.404	0.507	0.643	0.702	0.729	0.894	1.038	1.253	1.224	1.422	0.995	0.616	1.239
2000	0.007	0.218	0.353	0.526	0.63	0.732	0.78	0.807	0.968	1.015	1.253	1.286	1.108	1.084	1.359
2001	0.006	0.227	0.329	0.505	0.668	0.786	0.964	0.986	1.061	1.133	1.32	1.411	1.568	1.472	1.495
2002	0.007	0.231	0.385	0.51	0.667	0.799	0.911	1.026	1.113	1.102	1.284	1.442	1.579	1.29	1.568
2003	0.006	0.276	0.489	0.549	0.652	0.769	0.863	0.953	1.086	1.202	1.212	1.194	1.374	1.355	1.709
2004	0.007	0.135	0.408	0.584	0.641	0.76	0.888	0.924	1.036	1.176	1.127	1.167	1.31	1.254	1.185
2005	0.007	0.283	0.351	0.508	0.641	0.742	0.88	0.96	1.062	1.074	1.216	1.268	1.217	1.075	1.342
2006	0.007	0.174	0.306	0.448	0.606	0.755	0.858	0.959	1.06	1.117	1.19	1.218	1.28	1.384	1.417
2007	0.007	0.155	0.349	0.507	0.642	0.783	0.961	1.1	1.192	1.266	1.327	1.488	1.444	1.729	1.512
2008	0.007	0.208	0.328	0.519	0.653	0.774	0.9	1.054	1.117	1.289	1.452	1.528	1.56	1.874	1.645
2009	0.007	0.136	0.34	0.525	0.705	0.879	0.999	1.13	1.398	1.479	1.558	1.576	1.807	2.026	2.222
2010	0.05	0.175	0.381	0.49	0.668	0.909	1.114	1.277	1.374	1.586	1.679	1.923	1.948	2.077	2.271
2011	0.031	0.205	0.29	0.508	0.666	0.809	0.971	1.224	1.342	1.513	1.582	1.623	2.08	1.707	2.242
2012	0.029	0.142	0.271	0.409	0.643	0.824	0.974	1.17	1.303	1.509	1.599	1.637	1.68	2.031	2.062
2013	0.095	0.144	0.29	0.442	0.564	0.781	1.13	1.281	1.44	1.685	1.827	1.786	1.934	2.159	2.182
2014	0.014	0.193	0.319	0.454	0.617	0.751	0.894	1.156	1.307	1.386	1.669	1.773	1.704	1.623	2.215
2015	0.025	0.181	0.404	0.462	0.571	0.69	0.786	0.887	1.141	1.195	1.315	1.671	1.389	1.559	2.6
2016	0.025	0.181	0.409	0.531	0.557	0.646	0.732	0.8	0.941	1.043	1.178	0.788	0.911	1.684	1.429
2017	0.025	0.191	0.408	0.499	0.65	0.694	0.752	0.827	0.894	0.911	1.028	0.961	0.312	0.701	0.688
2018	0.025	0.186	0.377	0.467	0.573	0.734	0.809	0.853	0.906	1.039	0.936	1.11	0.568	1.454	1.13
2019	0.025	0.186	0.422	0.565	0.643	0.759	0.878	0.962	1.007	1.065	1.035	1.182	0.754	1.454	1.593
2020	0.025	0.186	0.387	0.522	0.632	0.716	0.799	0.955	1.006	1.04	1.189	1.072	1.208	0.961	1.593
2021	0.025	0.186	0.393	0.48	0.574	0.69	0.757	0.841	1.011	1.13	1.16	1.269	1.214	1.4	1.408
2022	0.025	0.186	0.394	0.548	0.626	0.732	0.842	0.911	0.998	1.126	1.142	1.172	1.255	1.333	1.472
2023	-	-	0.38	0.52	0.677	0.754	0.856	0.96	1.022	1.101	1.221	1.228	1.25	1.326	1.396
2024	-	-	0.38	0.506	0.648	0.805	0.878	0.974	1.071	1.125	1.196	1.307	1.307	1.321	1.389
Mean	0.007	0.176	0.317	0.462	0.602	0.728	0.839	0.95	1.051	1.123	1.186	1.237	1.269	1.292	1.322
CV	-	-	17%	11%	7%	8%	12%	13%	14%	16%	17%	20%	29%	28%	30%

Table 1-21. Goodness-of-fit measures to primary data for different assessment model configurations. RMSE=root-mean square log errors, NLL=negative log-likelihood, SDNR=standard deviation of normalized residuals, Eff. N=effective sample size for composition data)

Component	Last year	Base	Est M	Wt comp
RMSE BTS	0.17	0.17	0.17	0.17
RMSE ATS	0.23	0.20	0.20	0.21
RMSE AVO	0.26	0.22	0.22	0.22
RMSE CPUE	0.09	0.09	0.09	0.10
SDNR BTS	1.84	1.80	1.80	1.86
SDNR ATS	1.10	1.05	1.05	1.05
SDNR AVO	0.74	0.63	0.63	0.64
Eff. N Fishery	1229.98	1236.96	1234.27	1239.85
Eff. N BTS	206.55	225.29	224.20	241.07
Eff. N ATS	216.82	205.58	202.25	211.13
Catch NLL	1.97	2.29	2.14	2.77
BTS NLL	28.04	31.82	31.78	35.99
ATS NLL	9.77	9.24	9.29	9.34
AVO NLL	10.11	10.32	10.32	10.43
Fish Age NLL	143.19	144.36	145.02	159.65
BTS Age NLL	156.87	159.15	159.79	195.23
ATS Age NLL	28.69	34.43	34.68	43.16
NLL selectivity	165.69	157.90	159.16	169.64
NLL Priors	20.05	20.08	20.33	20.13
Data NLL	395.60	404.64	406.09	470.55
Total NLL	617.10	617.79	620.54	698.11

Table 1-22. Summary of different model results and the stock condition for EBS pollock. Biomass units are thousands of t.

Component	Base	Est M	Wt comp
B_{2023}	4,200	4,300	4,200
$CV_{B_{2023}}$	0.14	0.14	0.14
B_{MSY}	2,674	2,542	2,660
$CV_{B_{MSY}}$	0.2	0.19	0.2
B_{2023}/B_{MSY}	156%	169%	157%
B_0	6,653	6,363	6,630
$B_{35\%}$	2,121	2,118	2,124
SPR rate at F_{MSY}	33%	32%	33%
Steepness	0.61	0.62	0.62
Est. $B_{2022}/B_{2022,nofishing}$	0.62	0.66	0.62
B_{2022}/B_{MSY}	148%	161%	149%

Table 1-23. Estimates of begin-year age 3 and older biomass (thousands of tons) and coefficients of variation (CV) for the current assessment compared to 2015–2021 assessments for EBS pollock.

Year	Current	CV	2021	CV	2020	CV	2019	CV	2018	CV	2017	CV	2016	CV
1964	1,691	21	1,659	21	1,855	22	1,866	22	1,744	22	1,779	22	1,834	22
1965	2,056	19	2,021	20	2,256	20	2,270	20	2,124	20	2,165	20	2,229	20
1966	2,215	19	2,188	19	2,419	19	2,433	19	2,277	19	2,326	19	2,404	19
1967	3,436	17	3,416	17	3,679	17	3,695	17	3,504	17	3,566	17	3,667	17
1968	3,950	17	3,943	17	4,201	17	4,217	17	4,011	17	4,082	17	4,198	17
1969	5,039	16	5,045	16	5,297	15	5,316	15	5,105	16	5,174	15	5,294	15
1970	5,693	15	5,713	15	5,937	14	5,957	14	5,757	15	5,820	14	5,936	14
1971	6,144	13	6,173	13	6,367	13	6,390	13	6,209	13	6,260	13	6,360	13
1972	5,838	12	5,873	12	6,038	12	6,063	12	5,902	12	5,940	12	6,024	12
1973	4,674	13	4,719	13	4,855	13	4,880	13	4,729	13	4,765	13	4,845	13
1974	3,425	16	3,481	16	3,594	16	3,619	16	3,474	16	3,510	16	3,589	16
1975	3,519	12	3,592	12	3,710	12	3,740	12	3,585	12	3,611	12	3,679	12
1976	3,428	9	3,534	10	3,670	10	3,708	10	3,515	10	3,538	10	3,608	10
1977	3,317	8	3,470	9	3,646	9	3,690	9	3,426	8	3,446	8	3,535	8
1978	3,122	8	3,333	8	3,564	8	3,607	8	3,250	8	3,273	8	3,375	8
1979	2,935	7	3,221	8	3,557	8	3,595	8	3,087	8	3,116	8	3,239	8
1980	3,594	6	4,039	7	4,537	6	4,578	6	3,856	6	3,896	6	4,068	6
1981	6,738	4	7,493	5	8,422	4	8,451	4	7,314	5	7,453	5	7,813	4
1982	7,791	4	8,541	5	9,542	4	9,569	4	8,448	5	8,645	5	9,056	4
1983	8,968	4	9,615	5	10,807	4	10,832	4	9,556	4	9,849	4	10,240	4
1984	8,967	5	9,516	5	10,622	4	10,645	4	9,428	4	9,731	4	10,033	4
1985	11,304	4	11,658	4	12,566	3	12,592	3	11,615	4	11,887	4	12,237	3
1986	10,796	4	10,997	4	11,766	3	11,790	3	11,039	3	11,278	4	11,531	3
1987	11,510	3	11,499	3	12,114	2	12,143	2	11,734	3	11,922	3	12,143	3
1988	10,913	3	10,828	3	11,217	2	11,245	2	11,125	3	11,291	3	11,497	3
1989	9,247	3	9,103	3	9,344	2	9,370	2	9,422	3	9,568	3	9,755	3
1990	7,400	3	7,232	3	7,406	3	7,431	3	7,536	3	7,671	3	7,812	3
1991	5,862	4	5,706	4	5,818	3	5,841	3	5,920	4	6,054	4	6,183	4
1992	9,121	3	8,953	3	9,252	2	9,286	2	9,065	3	9,276	3	9,476	3
1993	11,257	2	11,098	2	11,552	2	11,599	2	11,181	2	11,427	2	11,627	2
1994	11,042	2	10,883	2	11,296	2	11,342	2	10,957	2	11,188	2	11,313	2
1995	12,625	2	12,488	2	12,886	2	12,926	2	12,508	2	12,757	2	13,000	2
1996	10,996	2	10,866	2	11,257	2	11,292	2	10,751	2	10,979	2	11,239	2
1997	9,468	2	9,350	2	10,042	3	10,074	3	9,395	2	9,603	2	9,837	2
1998	9,435	2	9,316	2	9,712	2	9,738	2	9,422	2	9,609	2	9,908	2
1999	10,337	2	10,238	2	10,652	2	10,673	2	10,390	2	10,561	2	10,751	2
2000	9,495	2	9,420	2	9,796	2	9,821	2	9,582	2	9,735	2	9,955	2
2001	9,205	2	9,147	2	9,527	2	9,559	2	9,335	2	9,479	2	9,702	2
2002	9,478	2	9,448	2	9,829	2	9,877	2	9,698	2	9,811	2	10,025	2
2003	11,419	2	11,397	2	11,779	2	11,816	2	11,657	2	11,750	2	12,080	2
2004	10,749	2	10,731	2	11,087	2	11,121	2	10,999	2	11,073	2	11,401	2
2005	8,967	2	8,958	2	9,271	2	9,302	2	9,197	2	9,272	2	9,598	2
2006	6,838	2	6,837	2	7,108	2	7,135	2	7,035	2	7,110	2	7,390	2
2007	5,495	2	5,495	2	5,753	3	5,782	3	5,683	3	5,762	3	6,046	3
2008	4,452	3	4,455	3	4,699	3	4,733	3	4,651	3	4,726	3	4,945	3
2009	5,574	2	5,562	2	5,883	3	5,941	3	5,837	3	5,943	3	6,374	3
2010	5,890	3	5,849	3	6,272	3	6,356	3	6,185	3	6,327	3	6,657	3
2011	8,342	2	8,169	2	9,001	3	9,176	3	8,788	3	9,107	3	9,637	3
2012	8,372	2	8,124	2	9,111	3	9,248	3	8,722	3	9,051	4	9,626	4
2013	8,273	3	7,963	3	9,130	4	9,225	4	8,547	4	8,873	4	9,504	5
2014	7,666	3	7,324	3	8,622	4	8,624	4	7,855	4	8,143	5	8,947	6
2015	9,870	3	9,521	3	12,073	5	11,801	5	11,345	6	11,913	8	12,407	10
2016	12,681	3	11,967	3	15,486	7	14,558	6	13,293	7	13,549	10	13,495	12
2017	11,840	3	10,782	4	13,794	7	12,963	7	11,785	8	12,049	11	13,033	13
2018	9,343	4	8,373	5	10,964	8	10,484	8	10,202	9	10,965	11	NA	NA
2019	8,497	5	7,413	6	9,892	10	9,864	9	9,110	10	NA	NA	NA	NA
2020	7,299	7	6,111	9	8,693	10	9,128	10	NA	NA	NA	NA	NA	NA
2021	12,867	12	6,811	11	8,145	11	NA	NA	NA	NA	NA	NA	NA	NA
2022	13,393	12	6,839	14	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 1-24. Estimated billions of EBS pollock at age (columns 2–11) from the current assessment model.

Year	1	2	3	4	5	6	7	8	9	10+
1964	6.34	3.34	2.06	0.44	0.19	0.38	0.17	0.05	0.03	0.21
1965	20.79	2.57	2.10	1.45	0.27	0.12	0.24	0.11	0.03	0.16
1966	15.00	8.43	1.62	1.48	0.89	0.17	0.07	0.15	0.07	0.12
1967	25.44	6.08	5.30	1.13	0.93	0.56	0.11	0.05	0.09	0.12
1968	22.10	10.30	3.77	3.45	0.65	0.53	0.32	0.06	0.03	0.12
1969	26.14	8.95	6.36	2.46	1.98	0.37	0.31	0.19	0.04	0.09
1970	23.51	10.57	5.50	4.02	1.43	1.16	0.22	0.18	0.11	0.07
1971	14.43	9.47	6.35	3.27	2.28	0.79	0.64	0.12	0.09	0.09
1972	11.75	5.79	5.54	3.55	1.71	1.12	0.39	0.31	0.05	0.08
1973	26.75	4.72	3.28	2.87	1.71	0.80	0.53	0.18	0.13	0.05
1974	19.46	10.76	2.59	1.57	1.27	0.74	0.34	0.23	0.07	0.07
1975	16.44	7.84	5.70	1.09	0.66	0.53	0.31	0.14	0.09	0.05
1976	12.51	6.64	4.41	2.52	0.49	0.30	0.24	0.14	0.06	0.06
1977	12.88	5.07	3.82	2.15	1.16	0.23	0.14	0.11	0.07	0.05
1978	22.90	5.22	2.94	2.06	1.07	0.56	0.11	0.07	0.06	0.05
1979	54.09	9.29	3.05	1.57	1.01	0.49	0.26	0.05	0.03	0.05
1980	24.96	21.94	5.58	1.72	0.79	0.45	0.21	0.11	0.02	0.03
1981	29.95	10.13	13.56	3.44	0.88	0.35	0.19	0.09	0.05	0.02
1982	17.40	12.16	6.35	9.13	1.97	0.43	0.17	0.09	0.04	0.03
1983	51.67	7.07	7.68	4.50	5.81	1.13	0.24	0.09	0.05	0.04
1984	14.06	21.00	4.47	5.51	3.01	3.57	0.65	0.14	0.05	0.05
1985	34.10	5.71	13.31	3.21	3.74	1.86	2.12	0.38	0.08	0.06
1986	13.68	13.86	3.62	9.53	2.20	2.40	1.09	1.24	0.22	0.08
1987	7.61	5.56	8.79	2.60	6.52	1.44	1.45	0.65	0.76	0.18
1988	5.69	3.09	3.53	6.34	1.82	4.42	0.93	0.93	0.41	0.59
1989	10.98	2.31	1.96	2.47	4.36	1.18	2.78	0.56	0.56	0.60
1990	48.24	4.46	1.47	1.39	1.68	2.82	0.73	1.63	0.33	0.70
1991	25.17	19.61	2.83	1.04	0.90	0.99	1.60	0.40	0.89	0.57
1992	22.28	10.23	12.43	2.02	0.69	0.55	0.56	0.82	0.21	0.75
1993	44.61	9.06	6.47	8.62	1.33	0.42	0.29	0.26	0.36	0.43
1994	15.18	18.13	5.75	4.62	5.49	0.85	0.24	0.15	0.13	0.41
1995	10.48	6.17	11.53	4.19	3.13	3.21	0.50	0.13	0.08	0.31
1996	22.27	4.26	3.92	8.44	2.98	1.99	1.73	0.27	0.07	0.22
1997	30.19	9.05	2.71	2.86	6.11	2.03	1.14	0.85	0.14	0.16
1998	14.74	12.27	5.74	1.97	2.04	4.15	1.24	0.61	0.43	0.15
1999	15.80	5.99	7.80	4.16	1.39	1.38	2.50	0.74	0.34	0.31
2000	24.67	6.42	3.81	5.55	2.89	0.94	0.89	1.47	0.44	0.38
2001	34.52	10.03	4.09	2.75	3.75	1.85	0.60	0.52	0.79	0.48
2002	23.00	14.03	6.38	2.98	1.90	2.26	1.01	0.33	0.28	0.72
2003	14.04	9.35	8.92	4.63	2.02	1.15	1.14	0.51	0.16	0.54
2004	6.34	5.71	5.95	6.28	3.13	1.19	0.60	0.55	0.25	0.38
2005	4.51	2.58	3.63	4.32	3.93	1.89	0.67	0.30	0.28	0.35
2006	11.39	1.83	1.64	2.64	2.85	2.15	1.00	0.36	0.16	0.35
2007	24.39	4.63	1.17	1.16	1.70	1.59	1.06	0.50	0.18	0.28
2008	13.08	9.91	2.94	0.82	0.74	0.94	0.76	0.52	0.25	0.24
2009	48.84	5.32	6.31	2.12	0.54	0.42	0.43	0.36	0.25	0.24
2010	22.10	19.85	3.38	4.53	1.39	0.32	0.21	0.21	0.18	0.24
2011	13.40	8.99	12.64	2.47	2.87	0.84	0.19	0.11	0.11	0.22
2012	11.48	5.45	5.72	9.19	1.71	1.41	0.39	0.09	0.05	0.15
2013	43.87	4.67	3.47	4.14	6.00	1.10	0.65	0.18	0.04	0.09
2014	49.72	17.84	2.97	2.51	2.76	3.60	0.65	0.33	0.08	0.06
2015	18.68	20.21	11.35	2.16	1.71	1.70	2.00	0.32	0.16	0.07
2016	7.34	7.59	12.87	7.89	1.42	1.06	0.93	1.01	0.16	0.11
2017	9.63	2.98	4.84	9.43	4.65	0.89	0.63	0.54	0.53	0.14
2018	16.95	3.91	1.90	3.56	6.49	2.62	0.49	0.35	0.29	0.36
2019	79.89	6.89	2.49	1.40	2.53	3.78	1.48	0.28	0.19	0.37
2020	21.40	32.48	4.39	1.83	1.01	1.74	2.01	0.70	0.14	0.31
2021	17.51	8.70	20.52	3.17	1.28	0.64	0.84	0.98	0.37	0.22
2022	18.68	7.12	5.46	14.11	2.20	0.85	0.38	0.39	0.48	0.30

Table 1-25. Estimated millions of EBS pollock caught at age (columns 2–11) from the current assessment model.

Year	1	2	3	4	5	6	7	8	9	10+
1964	8.54	38.00	89.41	63.28	27.15	51.88	22.59	6.98	4.28	24.67
1965	28.69	29.93	93.55	212.36	39.31	16.78	31.89	13.98	4.37	18.77
1966	20.59	101.51	77.91	197.59	117.13	21.29	9.11	17.57	7.87	13.74
1967	65.02	140.83	551.05	222.00	185.43	110.09	20.77	9.11	18.02	23.11
1968	64.10	263.18	393.73	673.80	124.08	98.82	59.74	11.43	5.11	23.67
1969	91.51	257.65	809.03	456.74	363.01	67.55	55.79	35.85	7.01	17.89
1970	142.19	494.18	941.43	817.90	320.73	260.17	52.26	47.30	29.82	20.62
1971	122.89	626.82	1356.57	846.07	674.16	229.45	191.44	40.90	34.19	34.63
1972	89.73	519.05	1450.40	1081.21	544.59	357.14	125.88	114.61	21.15	32.04
1973	181.57	530.88	1015.00	1011.32	624.51	294.69	193.35	73.43	57.87	23.19
1974	115.52	1480.51	978.62	601.18	493.07	286.10	133.28	94.97	32.29	31.73
1975	65.02	749.57	2008.00	376.55	222.02	176.85	102.74	50.60	33.74	19.95
1976	36.03	526.42	1310.47	840.19	159.36	94.80	75.91	45.24	22.11	20.65
1977	27.11	361.06	910.49	616.33	351.70	68.74	41.72	33.77	21.07	17.61
1978	41.02	346.36	713.27	602.03	353.08	182.81	36.73	22.54	19.53	19.87
1979	81.06	427.85	641.35	445.87	354.05	181.02	93.71	18.66	12.01	18.45
1980	27.20	546.19	818.01	465.26	273.97	168.60	79.10	41.31	8.31	12.32
1981	19.69	134.39	1074.24	672.61	254.63	108.33	58.53	27.91	14.71	7.13
1982	6.40	90.09	236.01	1111.74	391.59	97.21	37.60	20.54	9.81	7.67
1983	13.37	45.76	207.85	377.69	857.05	217.90	45.74	17.88	9.88	8.47
1984	3.00	106.31	116.83	402.08	435.72	621.79	120.92	25.39	10.11	10.29
1985	6.19	29.48	378.35	208.77	436.37	338.69	380.93	69.38	14.91	11.99
1986	1.97	63.14	101.18	639.66	225.01	384.50	181.69	194.58	38.41	14.63
1987	0.67	16.87	197.10	115.59	472.80	153.74	164.82	84.29	100.94	23.86
1988	0.58	11.70	173.10	397.73	199.98	583.94	155.75	148.97	65.75	92.26
1989	0.95	8.13	69.48	179.63	476.18	165.49	496.14	94.46	90.50	98.59
1990	5.12	21.34	56.58	151.70	293.40	569.47	170.71	380.46	74.65	158.21
1991	2.56	96.48	86.61	91.42	142.18	200.08	432.36	97.79	230.60	156.21
1992	2.62	62.81	680.69	200.50	112.81	138.42	188.91	289.44	73.82	261.09
1993	3.25	28.51	210.42	1047.51	156.88	79.18	76.52	68.51	95.42	108.95
1994	0.80	41.51	80.66	334.02	1006.60	152.41	52.75	32.11	28.28	86.18
1995	0.48	14.88	119.09	147.27	383.84	761.20	111.69	30.05	18.14	63.81
1996	0.98	14.43	52.15	167.69	210.71	390.50	513.08	80.17	19.51	50.42
1997	1.21	38.54	45.19	96.80	433.18	305.18	274.63	233.97	37.15	39.43
1998	0.46	37.43	111.03	79.64	153.10	674.98	212.09	139.61	107.11	34.82
1999	0.35	11.45	266.11	220.63	106.28	157.11	454.39	130.64	59.70	54.54
2000	0.51	11.21	81.41	424.37	347.65	115.24	166.07	343.32	84.29	67.91
2001	0.72	14.08	55.25	165.10	602.95	423.63	135.80	118.75	169.03	95.43
2002	0.52	33.04	119.98	218.45	296.59	628.28	278.88	91.22	73.54	161.76
2003	0.32	16.38	387.49	342.68	362.13	303.13	349.68	154.94	45.62	120.26
2004	0.12	7.26	108.05	845.19	501.59	250.96	165.89	151.43	61.67	75.56
2005	0.07	3.50	63.77	400.88	894.57	478.30	160.15	68.95	62.33	64.02
2006	0.21	3.74	68.95	292.22	616.99	632.15	280.26	99.48	43.21	83.71
2007	0.46	10.63	49.37	136.81	379.82	497.73	313.13	137.30	48.24	71.07
2008	0.24	20.89	69.68	84.18	152.81	309.58	239.63	156.75	75.74	68.19
2009	0.81	7.16	169.81	209.55	89.72	119.86	125.94	101.97	70.28	72.86
2010	0.30	23.83	39.74	562.81	224.16	61.50	47.40	55.88	45.79	61.89
2011	0.24	13.39	201.91	141.10	848.29	273.12	58.88	37.10	36.23	71.80
2012	0.20	10.13	113.64	952.70	194.55	464.73	128.15	29.74	17.66	51.11
2013	0.70	6.51	64.35	353.61	989.55	194.60	179.26	59.95	13.50	31.63
2014	0.73	27.20	49.96	179.40	406.53	785.12	186.71	94.63	25.15	19.64
2015	0.31	21.36	603.12	210.20	240.57	386.36	555.26	92.86	51.42	24.17
2016	0.09	5.02	118.06	1406.04	187.71	181.00	180.90	258.31	39.35	26.77
2017	0.11	2.11	33.39	578.82	966.70	200.90	142.09	124.20	128.01	34.00
2018	0.16	2.68	11.14	117.30	1207.52	547.21	99.24	73.01	58.37	67.39
2019	0.87	10.97	16.03	25.90	165.39	930.94	457.39	78.87	49.62	79.41
2020	0.42	242.90	88.46	95.31	130.43	526.80	596.98	173.97	44.72	87.00
2021	0.34	106.76	1275.42	173.21	113.32	112.46	272.32	295.32	103.83	57.97
2022	0.32	77.17	301.05	682.29	173.58	133.35	111.02	105.92	119.19	73.19

Table 1-26. Estimated EBS pollock age 3+ biomass, female spawning biomass, and age 1 recruitment for 1964–2022. Biomass units are thousands of t, age-1 recruitment is in millions of pollock.

Year	SSB	CV.SSB	Recruitment	CV.Rec...	Age.3..Biomass	CV..
1964	503	27	6,337	38	1,691	22
1965	591	23	20,787	25	2,056	20
1966	686	22	14,996	32	2,215	20
1967	870	19	25,441	26	3,436	17
1968	1,086	19	22,104	28	3,950	17
1969	1,339	19	26,139	26	5,039	16
1970	1,572	18	23,507	27	5,693	15
1971	1,666	18	14,428	33	6,144	13
1972	1,581	17	11,754	33	5,838	12
1973	1,322	19	26,747	19	4,674	14
1974	972	22	19,457	20	3,425	16
1975	820	20	16,441	18	3,519	12
1976	826	15	12,513	17	3,428	10
1977	847	12	12,877	15	3,317	9
1978	838	11	22,902	10	3,122	8
1979	783	11	54,088	6	2,935	8
1980	849	9	24,958	9	3,594	6
1981	1,379	6	29,948	9	6,738	5
1982	2,106	5	17,395	11	7,791	5
1983	2,656	5	51,672	6	8,968	5
1984	2,922	6	14,059	12	8,967	5
1985	3,271	5	34,098	7	11,304	4
1986	3,592	5	13,681	11	10,796	4
1987	3,790	4	7,605	13	11,510	3
1988	3,826	4	5,689	14	10,913	3
1989	3,454	4	10,981	10	9,247	3
1990	2,780	4	48,236	4	7,400	4
1991	2,089	5	25,170	6	5,862	4
1992	2,205	4	22,282	6	9,121	3
1993	3,058	3	44,608	4	11,257	3
1994	3,384	3	15,177	6	11,042	3
1995	3,573	3	10,484	7	12,625	3
1996	3,615	3	22,267	4	10,996	3
1997	3,368	3	30,192	4	9,468	3
1998	3,100	3	14,736	5	9,435	3
1999	3,120	3	15,802	5	10,337	3
2000	3,134	3	24,670	4	9,495	3
2001	3,138	3	34,516	3	9,205	3
2002	2,940	3	23,002	4	9,478	3
2003	3,090	3	14,037	5	11,419	2
2004	3,187	3	6,338	6	10,749	2
2005	2,914	3	4,510	8	8,967	2
2006	2,384	3	11,386	5	6,838	3
2007	1,963	3	24,385	4	5,495	3
2008	1,449	3	13,075	6	4,452	3
2009	1,527	3	48,836	4	5,574	3
2010	1,761	3	22,100	5	5,890	3
2011	2,122	3	13,404	6	8,342	3
2012	2,457	3	11,484	6	8,372	3
2013	2,738	3	43,869	4	8,273	3
2014	2,627	4	49,716	4	7,666	3
2015	2,581	4	18,676	7	9,870	3
2016	3,175	4	7,339	16	12,681	3
2017	3,610	4	9,628	17	11,840	4
2018	3,263	4	16,951	17	9,343	4
2019	2,977	6	79,891	16	8,497	6
2020	2,347	7	21,402	18	7,299	8
2021	2,813	10	17,510	20	12,867	12
2022	3,948	13	18,676	22	13,393	13

Table 1-27. Summary of model results and the stock condition for EBS pollock. Biomass units are thousands of t.

Component	Base	Est M	Wt comp
B_{2023}	4,200	4,300	4,200
$CV_{B_{2023}}$	0.14	0.14	0.14
B_{MSY}	2,674	2,542	2,660
$CV_{B_{MSY}}$	0.2	0.19	0.2
B_{2023}/B_{MSY}	156%	169%	157%
B_0	6,653	6,363	6,630
$B_{35\%}$	2,121	2,118	2,124
SPR rate at F_{MSY}	33%	32%	33%
Steepness	0.61	0.62	0.62
Est. $B_{2022}/B_{2022,nofishing}$	0.62	0.66	0.62
B_{2022}/B_{MSY}	148%	161%	149%

Table 1-28. Summary results of Tier 1 2022 yield projections for EBS pollock.

Component	Base	Est M	Wt comp
2023 fishable biomass (GM)	6,889,000	7,198,000	6,932,000
Equilibrium fishable biomass at MSY	4,983,000	4,644,000	4,936,000
MSY R (HM)	0.434	0.473	0.441
2023 Tier 1 ABC	2,987,000	3,402,000	3,057,000
2023 Tier 1 F_{OFL} unadjusted	0.491	0.539	0.499
2023 Tier 1 OFL	3,381,000	3,882,000	3,456,000
Recommended ABC	1,688,000	1,855,000	1,712,000

Table 1-29. For the configuration named Base, Tier 3 projections of EBS pollock catch for the 7 scenarios.

Catch	Scenario.1	Scenario.2	Scenario.3	Scenario.4	Scenario.5	Scenario.6	Scenario.7
2023	1,350	1,350	1,350	1,350	1,350	1,350	1,350
2024	1,350	1,350	1,350	1,350	1,350	2,300	1,814
2025	2,156	2,156	1,494	895	0	2,267	1,995
2026	1,810	1,810	1,484	1,001	0	1,670	2,081
2027	1,435	1,435	1,313	955	0	1,443	1,542
2028	1,413	1,413	1,278	960	0	1,494	1,525
2029	1,510	1,510	1,336	1,014	0	1,624	1,631
2030	1,575	1,575	1,393	1,069	0	1,684	1,683
2031	1,583	1,583	1,413	1,095	0	1,679	1,678
2032	1,590	1,590	1,428	1,115	0	1,680	1,679
2033	1,591	1,591	1,433	1,128	0	1,677	1,677
2034	1,570	1,570	1,422	1,126	0	1,651	1,651
2035	1,568	1,568	1,418	1,124	0	1,654	1,654
2036	1,565	1,565	1,415	1,123	0	1,650	1,650

Table 1-30. For the configuration named Base, Tier 3 projections of EBS pollock ABC for the 7 scenarios. Note: scenario 2 results for 2023 and 2024 are conditioned on catches in that scenario listed in Table 29).

ABC	Scenario.1	Scenario.2	Scenario.3	Scenario.4	Scenario.5	Scenario.6	Scenario.7
2023	1,687	1,687	1,158	689	0	2,131	2,131
2024	1,814	1,814	1,239	734	0	2,300	2,300
2025	2,156	2,156	1,494	895	0	2,267	2,500
2026	1,810	1,810	1,484	1,001	0	1,670	2,081
2027	1,435	1,435	1,313	955	0	1,443	1,542
2028	1,413	1,413	1,278	960	0	1,494	1,525
2029	1,510	1,510	1,336	1,014	0	1,624	1,631
2030	1,575	1,575	1,393	1,069	0	1,684	1,683
2031	1,583	1,583	1,413	1,095	0	1,679	1,678
2032	1,590	1,590	1,428	1,115	0	1,680	1,679
2033	1,591	1,591	1,433	1,128	0	1,677	1,677
2034	1,570	1,570	1,422	1,126	0	1,651	1,651
2035	1,568	1,568	1,418	1,124	0	1,654	1,654
2036	1,565	1,565	1,415	1,123	0	1,650	1,650

Table 1-31. For the configuration named Base, Tier 3 projections of EBS pollock fishing mortality for the 7 scenarios.

F	Scenario.1	Scenario.2	Scenario.3	Scenario.4	Scenario.5	Scenario.6	Scenario.7
2023	0.348	0.348	0.348	0.348	0.348	0.348	0.348
2024	0.322	0.322	0.322	0.322	0.322	0.612	0.455
2025	0.455	0.455	0.292	0.164	0.000	0.601	0.455
2026	0.438	0.438	0.292	0.164	0.000	0.512	0.560
2027	0.407	0.407	0.292	0.164	0.000	0.500	0.511
2028	0.407	0.407	0.292	0.164	0.000	0.511	0.514
2029	0.411	0.411	0.292	0.164	0.000	0.522	0.522
2030	0.414	0.414	0.292	0.164	0.000	0.526	0.526
2031	0.413	0.413	0.292	0.164	0.000	0.524	0.524
2032	0.412	0.412	0.292	0.164	0.000	0.521	0.521
2033	0.412	0.412	0.292	0.164	0.000	0.521	0.521
2034	0.411	0.411	0.292	0.164	0.000	0.519	0.519
2035	0.411	0.411	0.292	0.164	0.000	0.519	0.519
2036	0.410	0.410	0.292	0.164	0.000	0.518	0.518

Table 1-32. For the configuration named Base, Tier 3 projections of EBS pollock spawning biomass (kt) for the 7 scenarios.

SSB	Scenario.1	Scenario.2	Scenario.3	Scenario.4	Scenario.5	Scenario.6	Scenario.7
2023	3,016	3,016	3,016	3,016	3,016	3,016	3,016
2024	3,056	3,056	3,056	3,056	3,056	2,921	2,993
2025	2,784	2,784	2,881	2,961	3,068	2,394	2,626
2026	2,413	2,413	2,725	3,032	3,518	2,069	2,274
2027	2,334	2,334	2,701	3,144	3,972	2,080	2,137
2028	2,418	2,418	2,783	3,302	4,403	2,190	2,206
2029	2,500	2,500	2,873	3,449	4,798	2,266	2,268
2030	2,547	2,547	2,937	3,553	5,097	2,300	2,299
2031	2,558	2,558	2,963	3,611	5,329	2,301	2,301
2032	2,546	2,546	2,960	3,634	5,510	2,287	2,286
2033	2,534	2,534	2,953	3,646	5,658	2,274	2,274
2034	2,516	2,516	2,936	3,640	5,764	2,258	2,258
2035	2,516	2,516	2,932	3,639	5,839	2,260	2,260
2036	2,528	2,528	2,942	3,652	5,909	2,273	2,273

Table 1-33. Details and explanation of the decision table factors selected in response to the Plan Team requests (as originally proposed in the 2012 assessment).

Term	Description	Rationale
$P[F_{2023} > F_{MSY}]$	Probability that the fishing mortality in 2023 exceeds F_{MSY}	OFL definition is based on F_{MSY}
$P[B_{2024} < B_{MSY}]$	Probability that the spawning biomass in 2024 is less than B_{MSY}	B_{MSY} is a reference point target and biomass in 2021 provides an indication of the impact of 2023 fishing
$P[B_{2025} < B_{MSY}]$	Probability that the spawning biomass in 2025 is less than B_{MSY}	B_{MSY} is a reference point target and biomass in 2023 provides an indication of the impact of fishing in 2023 and 2024
$P\left[B_{2025} < \bar{B}\right]$	Probability that the spawning biomass in 2024 is less than the 1978–2022 mean	To provide some perspective of what the stock condition might be relative to historical estimates after fishing in 2023.
$P\left[B_{2027} < \bar{B}\right]$	Probability that the spawning biomass in 2027 is less than the long term mean	To provide some perspective of what the stock condition might be relative to historical estimates after fishing in 2023.
$P[B_{2027} < B_{2023}]$	Probability that the spawning biomass in 2027 is less than that estimated for 2023	To provide a medium term expectation of stock status relative to 2023 levels
$P[B_{2025} < B_{20\%}]$	Probability that the spawning biomass in 2025 is less than $B_{20\%}$	$B_{20\%}$ had been selected as a Steller Sea Lion lower limit for allowing directed fishing
$P\left[p_{a_5,2025} > \bar{p}_{a_5}\right]$	Probability that in 2025 the proportion of age 1–5 pollock in the population exceeds the long-term mean	To provide some relative indication of the age composition of the population relative to the long term mean.
$P[D_{2024} < D_{1994}]$	Probability that the diversity of ages represented in the spawning biomass (by weight) in 2024 is less than the value estimated for 1994	To provide a relative index on the abundance of different age classes in the 2024 population relative to 1994 (a year identified as having low age composition diversity)
$P[D_{2027} < D_{1994}]$	Probability that the diversity of ages represented in the spawning biomass (by weight) in 2027 is less than the value estimated for 1994	To provide a medium-term relative index on the abundance of different age classes in the population relative to 1994 (a year identified as having low age composition diversity)
$P[E_{2023} > E_{2022}]$	Probability that the theoretical fishing effort in 2023 will be greater than that estimated in 2022.	To provide the relative effort that is expected (and hence some idea of costs).

Table 1-34. Outcomes of decision (expressed as chances out of 100) given different 2023 catches (first row, in kt). Note that for the 2020 and later year-classes average values were assumed. Constant Fs based on the 2023 catches were used for subsequent years.

	10	850	1000	1110	1150	1300	1450	1600
$P[F_{2023} > F_{MSY}]$	0	0	0	0	0	0	0	0
$P[B_{2024} < B_{MSY}]$	4	7	8	9	9	10	12	14
$P[B_{2025} < B_{MSY}]$	2	8	10	12	12	15	19	23
$P\left[B_{2024} < \bar{B}\right]$	0	1	1	1	1	2	3	4
$P\left[B_{2027} < \bar{B}\right]$	0	7	9	12	12	15	19	22
$P[B_{2027} < B_{2023}]$	9	45	52	56	58	63	68	72
$P[B_{2025} < B_{20\%}]$	0	0	0	0	0	0	0	0
$P\left[p_{a_5,2024} > \bar{p}_{a_5}\right]$	1	36	44	50	52	58	64	69
$P[D_{2024} < D_{1994}]$	53	71	74	76	77	80	83	85
$P[D_{2027} < D_{1994}]$	0	2	3	5	5	8	11	15
$P[E_{2023} > E_{2022}]$	0	0	3	18	27	62	85	95

Table 1-35. Bycatch estimates (t) of other target species caught in the BSAI directed pollock fishery, 1997–2022 based on then NMFS Alaska Regional Office reports from observers (2022 data are preliminary).

Year	Pacific.Cod	Rock.Sole	Flathead.Sole	Arrowtooth.Flounder	Pacific.Ocean.Perch	Yellowfin.Sole	Sablefish	Sharks	Atka.Mackerel	Skates	Other
1991	24,310	5,120	0	5,719	418	417	9	0	24	0	10,973
1992	24,005	7,233	2	4,311	173	892	7	0	260	0	15,551
1993	20,930	8,713	0	1,222	282	1,102	1	0	39	0	8,126
1994	14,409	3,009	0	2,010	170	1,207	1	0	43	0	4,435
1995	19,776	2,179	2,175	1,177	142	675	12	0	210	0	1,896
1996	15,174	2,042	3,207	1,844	303	1,797	7	0	384	0	3,717
1997	8,262	1,522	2,350	984	428	605	2	0	83	0	3,186
1998	6,255	770	2,047	1,712	616	1,744	2	0	10	0	2,448
1999	3,220	1,058	1,885	272	120	349	7	0	157	0	1,877
2000	3,432	2,687	2,510	978	21	1,465	12	0	1	0	6,406
2001	3,879	1,672	2,199	529	574	594	21	0	40	0	5,678
2002	5,886	1,885	1,844	607	543	768	34	0	221	0	3,680
2003	5,968	1,418	1,501	617	935	209	48	0	762	0	2,799
2004	6,436	2,553	2,104	556	393	841	16	0	1,052	0	2,649
2005	7,413	1,125	2,351	651	652	63	11	0	677	0	2,758
2006	7,291	1,360	2,862	1,088	735	256	8	0	788	0	4,093
2007	5,629	510	4,225	2,795	624	85	11	0	315	0	3,731
2008	6,971	2,149	4,315	1,715	335	552	4	0	14	0	5,217
2009	7,875	7,591	4,665	2,202	114	270	2	0	25	0	4,968
2010	6,907	2,239	4,356	1,453	230	1,057	1	0	54	0	2,877
2011	10,042	8,480	4,885	1,601	658	1,082	1	65	899	2,352	1,155
2012	10,065	6,701	3,968	748	705	1,516	0	54	263	2,018	1,482
2013	8,954	6,379	3,146	965	610	2,096	0	43	70	1,750	745
2014	5,242	4,360	2,553	757	1,300	1,953	1	75	116	812	2,526
2015	8,303	1,709	2,259	402	2,525	863	0	51	202	823	2,874
2016	4,980	1,094	1,553	290	3,190	870	18	59	68	422	1,716
2017	6,150	1,707	908	204	4,438	577	95	91	60	447	2,119
2018	4,270	1,077	973	270	3,803	743	396	61	543	507	2,047
2019	6,213	1,117	1,087	421	7,971	443	1,236	100	367	508	789
2020	9,184	865	1,970	687	5,969	1,211	3,452	132	569	827	1,465
2021	9,103	830	1,531	413	2,468	753	1,106	169	544	911	566
2022	3,743	670	944	187	1,346	813	291	56	156	555	335

Table 1-36. Bycatch estimates (t) of pollock caught in the other non-pollock EBS directed fisheries, 1997–2022 based on then NMFS Alaska Regional Office reports from observers.

Year	Atka.Mackerel	Other.flatfish	Other.Species	Pacific.cod	Rock.sole	Yellowfin.sole
1991	129	7,992	661,886	10,695	9,711	NA
1992	108	1,371	520	20,778	9,824	13,100
1993	18	2,581	604	31,292	18,582	15,253
1994	0	6,770	89	26,594	15,784	33,200
1995	NA	5,211	63	25,691	7,766	27,041
1996	60	5,456	744	22,382	7,698	22,254
1997	NA	3,480	14	33,658	9,123	24,100
1998	58	3,011	882	10,468	3,960	15,339
1999	246	4,771	951	21,131	5,207	8,701
2000	16	7,068	503	14,508	5,480	13,425
2001	238	4,739	249	11,570	4,577	16,502
2002	2	2,220	49	15,255	9,942	14,489
2003	92	3,672	167	15,926	4,924	11,578
2004	117	6,396	80	18,650	8,975	10,383
2005	195	5,057	25	14,109	7,235	10,312
2006	121	3,826	21	15,168	6,986	5,966
2007	147	4,353	128	20,319	3,245	4,020
2008	1	4,822	15	9,533	4,930	9,827
2009	7	3,505	6	7,875	6,171	7,036
2010	NA	3,316	85	6,575	6,074	5,179
2011	144	2,301	157	8,981	6,931	8,673
2012	41	1,751	371	8,377	6,703	11,197
2013	9	4,048	228	9,801	7,326	20,171
2014	NA	6,404	202	11,502	11,258	24,712
2015	19	4,993	410	9,062	9,386	21,281
2016	1	3,687	448	9,071	11,850	22,306
2017	13	3,613	494	8,319	5,616	23,414
2018	137	3,525	819	8,008	5,182	28,235
2019	54	7,972	1,311	7,593	3,176	23,153
2020	57	2,374	668	5,512	6,399	31,653
2021	53	5,131	1,328	4,316	2,398	24,844
2022	479	5,485	1,477	5,361	2,976	21,052

Table 1-37. Bycatch estimates (t) of non-target species caught in the BSAI directed pollock fishery, 2003–2022 based on observer data as processed through the catch accounting system (NMFS Regional Office, Juneau, Alaska).

Year	Scypho.jellies	Misc.fish	Sea.star	Eulachon.Osmerid	Grenadier	Eelpouts	Sea.pen	Sea.anemone.unidentified	Snails	All.other
2003	5,643	101	89	9	20	7	0	0	1	1
2004	6,590	89	7	21	14	0	1	0	0	0
2005	5,197	158	9	12	14	1	1	0	6	2
2006	2,717	154	11	99	15	21	1	0	0	16
2007	2,403	204	5	138	27	118	3	0	0	12
2008	4,184	121	19	4	27	8	1	0	1	8
2009	8,117	135	9	5	4	4	2	1	1	3
2010	2,517	150	12	0	4	0	2	2	1	10
2011	8,232	277	27	1	1	1	2	1	1	8
2012	3,521	142	7	1	2	1	3	1	1	3
2013	5,294	121	15	0	1	1	2	2	0	9
2014	12,767	44	29	1	10	7	3	1	1	8
2015	4,950	90	41	24	4	10	2	2	1	4
2016	2,203	75	54	5	4	22	1	0	0	3
2017	6,152	48	12	3	2	18	0	1	0	1
2018	8,251	52	24	0	9	4	0	0	0	3
2019	3,889	73	50	0	8	2	0	0	0	5
2020	3,149	93	61	1	42	6	1	5	0	26
2021	7,829	35	19	0	54	0	1	3	1	3
2022	7,612	22	184	0	9	0	1	1	0	9

Table 1-38. Bycatch estimates of prohibited species caught in the BSAI directed pollock fishery, 1997–2022 based on the AKFIN (NMFS Regional Office) reports from observers. Herring and halibut units are in t, all others represent numbers of individuals caught. Data for 2022 are preliminary.

Year	Bairdi.Tanner.Crab	Chinook.Salmon	Halibut	Halibut.mort	Herring	Non.Chinook.Salmon	Snow.Crab	Red.King.Crab	Blue.King.Crab	Golden..King.Crab
1991	1,397,836	36,348	2,155	NA	3,158	28,657	4,378,007	17,777	NA	NA
1992	1,500,764	33,672	2,220	NA	646	40,186	4,569,662	43,873	NA	NA
1993	1,649,086	36,615	1,326	NA	527	241,971	738,250	58,139	NA	NA
1994	371,213	31,880	963	688	1,626	91,764	811,733	42,360	NA	NA
1995	153,992	13,403	491	397	904	17,754	206,651	4,644	NA	NA
1996	89,415	55,467	382	320	1,241	77,173	63,398	5,933	NA	NA
1997	17,046	44,312	257	200	1,134	65,414	216,152	137	NA	NA
1998	57,036	51,244	352	278	800	60,676	123,400	14,286	NA	NA
1999	2,397	10,381	153	124	799	44,610	15,829	90	NA	NA
2000	1,484	4,242	110	90	482	56,866	6,480	0	NA	NA
2001	5,060	30,933	242	199	225	53,901	5,653	105	NA	NA
2002	2,112	32,381	165	137	108	77,167	2,697	16	NA	NA
2003	732	43,095	88	74	967	179,987	608	52	8	NA
2004	1,091	48,799	96	81	1,095	441,188	640	26	4	1
2005	601	66,208	119	100	593	703,076	2,016	0	NA	1
2006	1,288	80,915	132	111	433	305,793	2,567	288	NA	3
2007	1,465	116,329	312	269	351	86,380	3,033	7	NA	3
2008	9,025	20,602	373	311	127	15,119	8,894	670	8	33
2009	6,155	12,284	541	436	64	45,960	7,312	1,136	19	NA
2010	12,787	9,833	335	267	348	13,728	9,444	1,122	28	NA
2011	10,973	25,499	459	378	376	193,754	6,493	577	25	NA
2012	5,620	11,343	462	388	2,352	22,297	6,189	343	NA	NA
2013	12,426	13,091	333	271	958	125,525	8,605	507	34	107
2014	12,521	15,135	239	199	159	219,837	19,454	368	NA	NA
2015	8,872	18,329	152	130	1,487	237,776	8,339	0	NA	NA
2016	2,295	22,204	121	102	1,431	343,208	1,166	439	NA	26
2017	7,269	30,078	97	88	963	467,750	3,406	202	0	67
2018	2,249	13,726	75	61	473	295,818	5,142	565	0	53
2019	3,146	25,038	133	112	1,101	348,631	6,228	453	99	445
2020	10,745	32,204	128	102	3,861	343,625	40,004	479	1	521
2021	8,417	13,852	144	131	1,708	546,472	4,668	52	0	115
2022	4,758	6,414	169	155	1,716	242,357	1,952	310	58	88

Table 1-39. Ecosystem considerations for BSAI pollock and the pollock fishery.

Indicator	Observation	Interpretation	Evaluation
	Ecosystem effects on EBS pollock		
Prey availability or abundance trends			
Zooplankton	Stomach contents, AT and ichthyoplankton surveys, changes mean wt-at-age	Data improving, indication of increases from 2004–2009 and subsequent decreasees (for euphausiids in 2012 and 2014)	Variable abundance-indicates important recruitment (for prey)
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	Possibly lower mortality on pollock	Probably no concern
Birds	Stable, some increasing some decreasing	Affects young-of-year mortality	Probably no concern
Fish (Pollock, Pacific cod, halibut)	Stable to increasing	Possible increases to pollock mortality	
Changes in habitat quality			
Temperature regime	Cold years pollock distribution towards NW on average	Likely to affect surveyed stock	Some concern, the distribution of pollock availability to different surveys may change systematically
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability
Production	Fairly stable nutrient flow from upwelled BS Basin	Inter-annual variability low	No concern
	Fishery effects on ecosystem		
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Likely to be safe	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	Likely to be safe	No concern
HAPC biota	Likely minor impact	Likely to be safe	No concern
Marine mammals and birds	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Generally more diffuse	Mixed potential impact (fur seals vs Steller sea lions)	Possible concern
Fishery effects on amount of large size target fish	Depends on highly variable year-class strength	Natural fluctuation	Probably no concern
Fishery contribution to discards and offal production	Decreasing	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	Maturity study (gonad collection) continues	NA	Possible concern

Figures

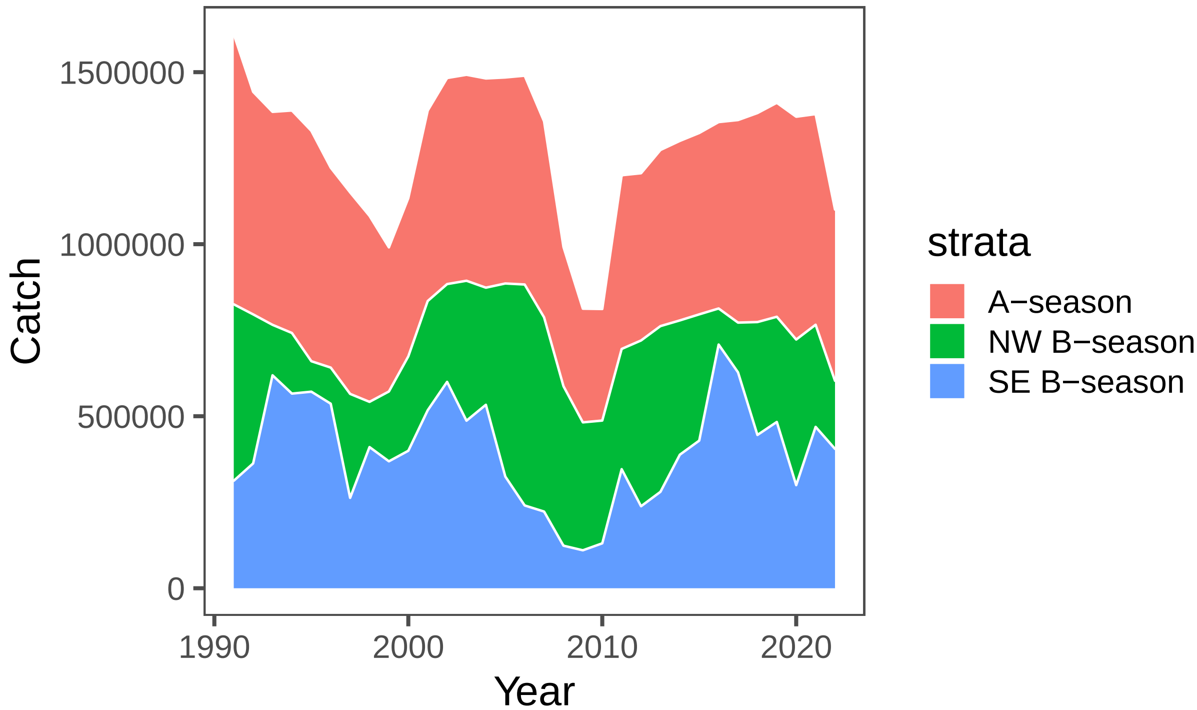

Figure 1-1. Pollock catch estimates (t) from the Eastern Bering Sea by season and region. The A-season is defined as from Jan-May and B-season from June-October.

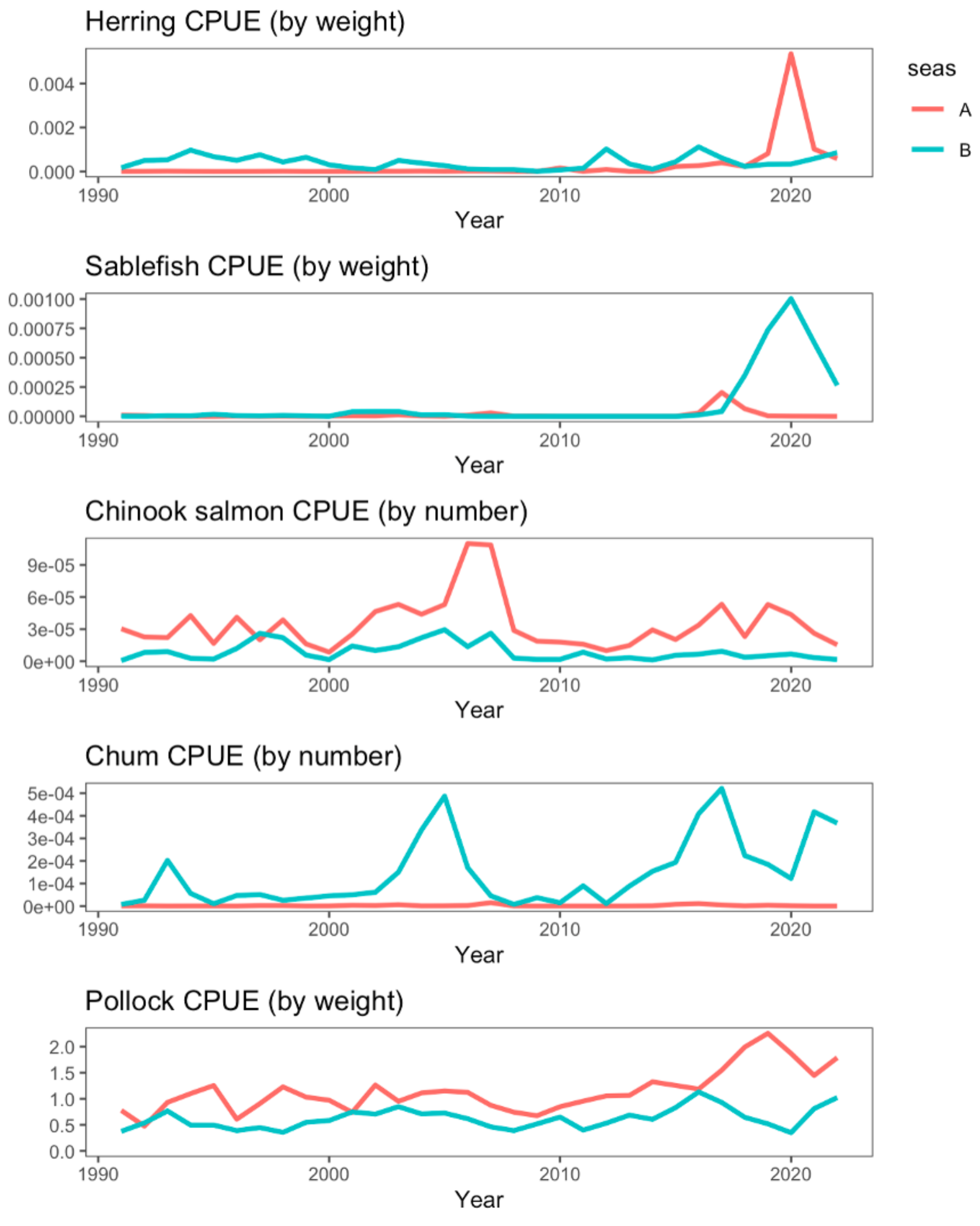

Figure 1-2. Nominal catch divided by effort (hours towed) for some bycatch species and pollock for the EBS pollock fleet (sectors combined), 2000-2022.

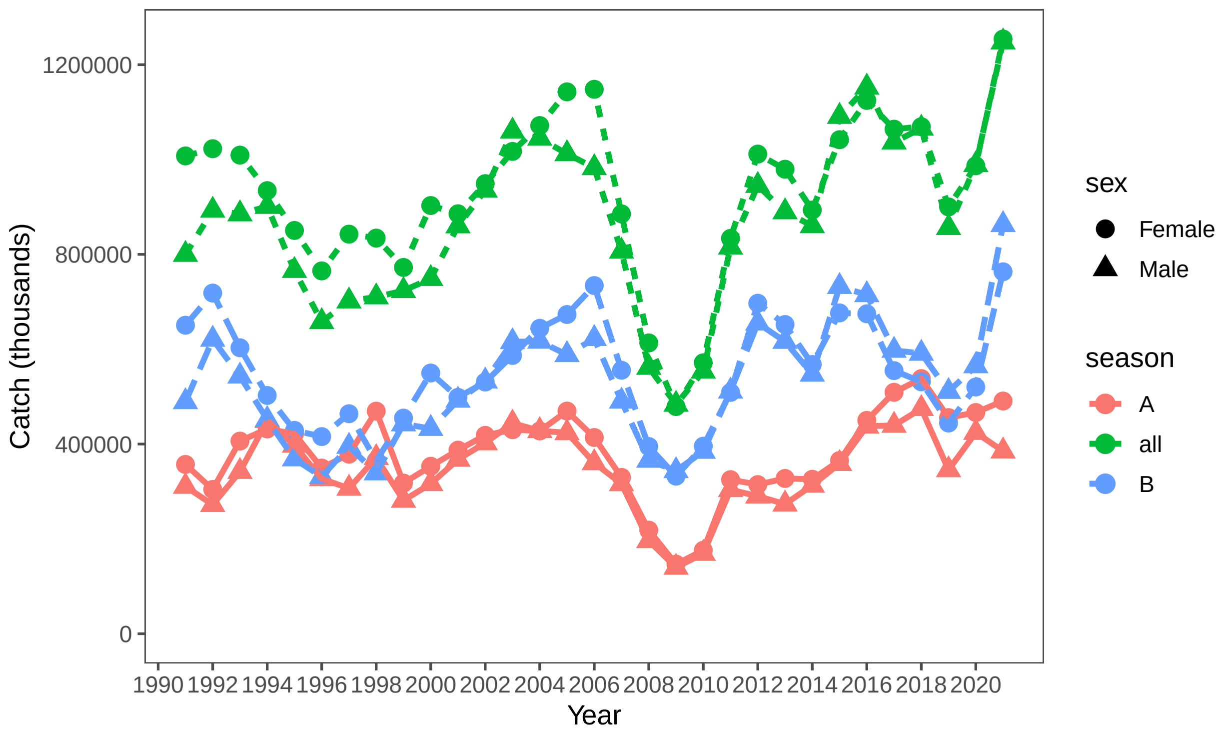

Figure 1-3. Estimate of EBS pollock catch numbers by sex for the A season (January-May) and B seasons (June-October) and total.

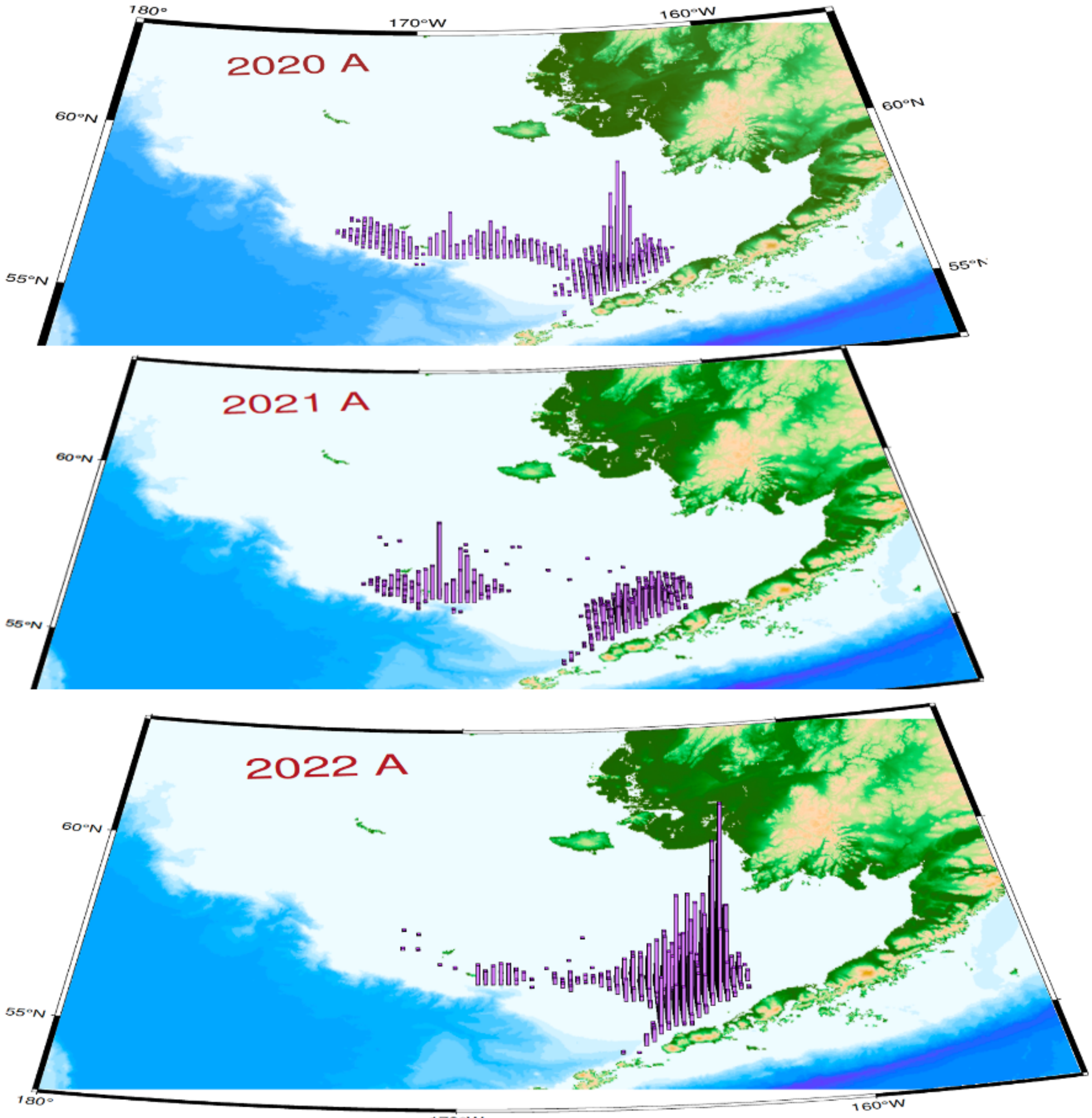

Figure 1-4. EBS pollock catch distribution during A-season, 2020–2022. Column height is proportional to total catch.

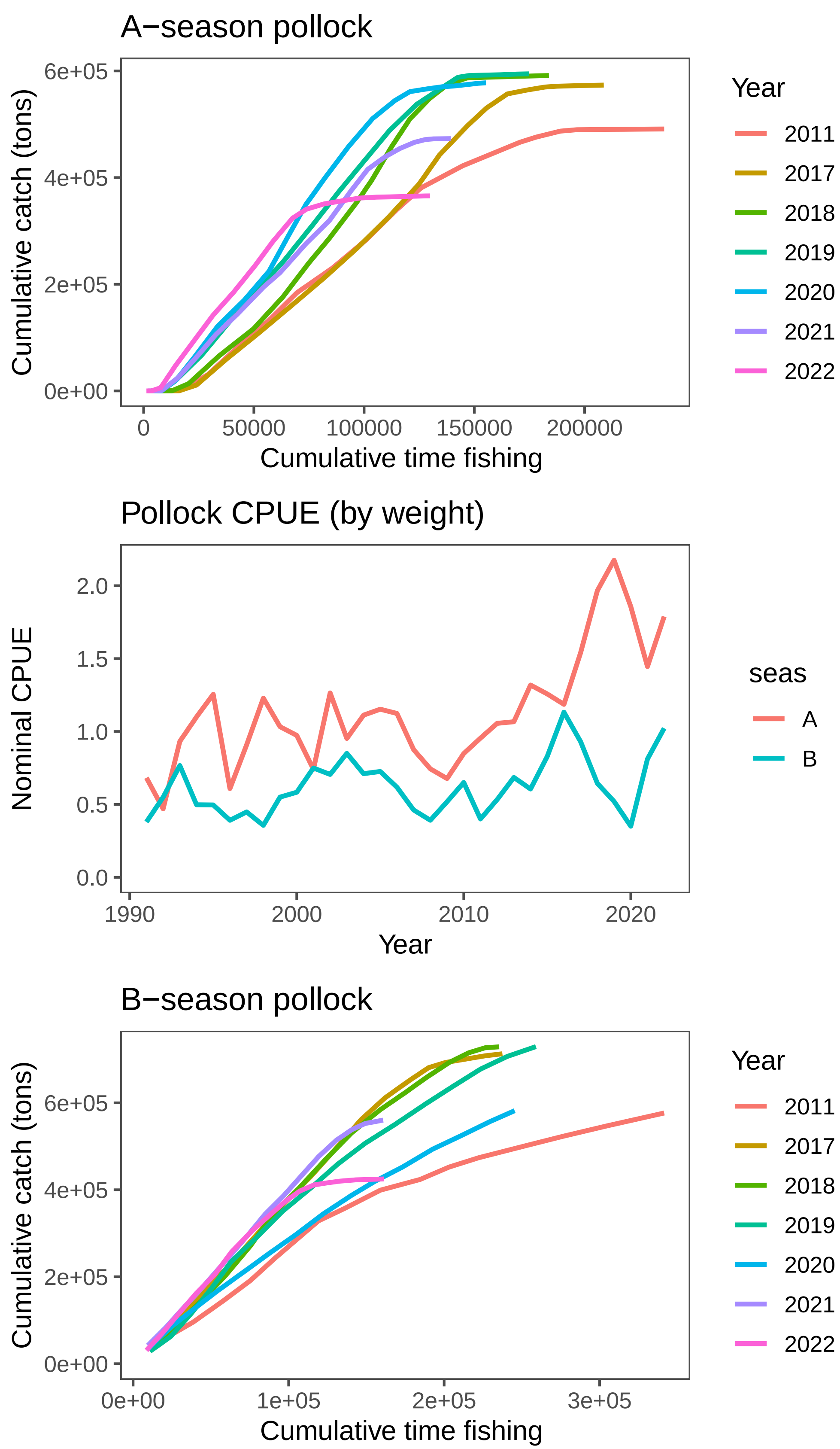

Figure 1-5. A-season (top) and B-season (bottom) EBS fleet-wide cumulative catch by hours observed fishing and relative pollock catch per hour of fishing (middle). Data were recorded by NMFS scientific observers.

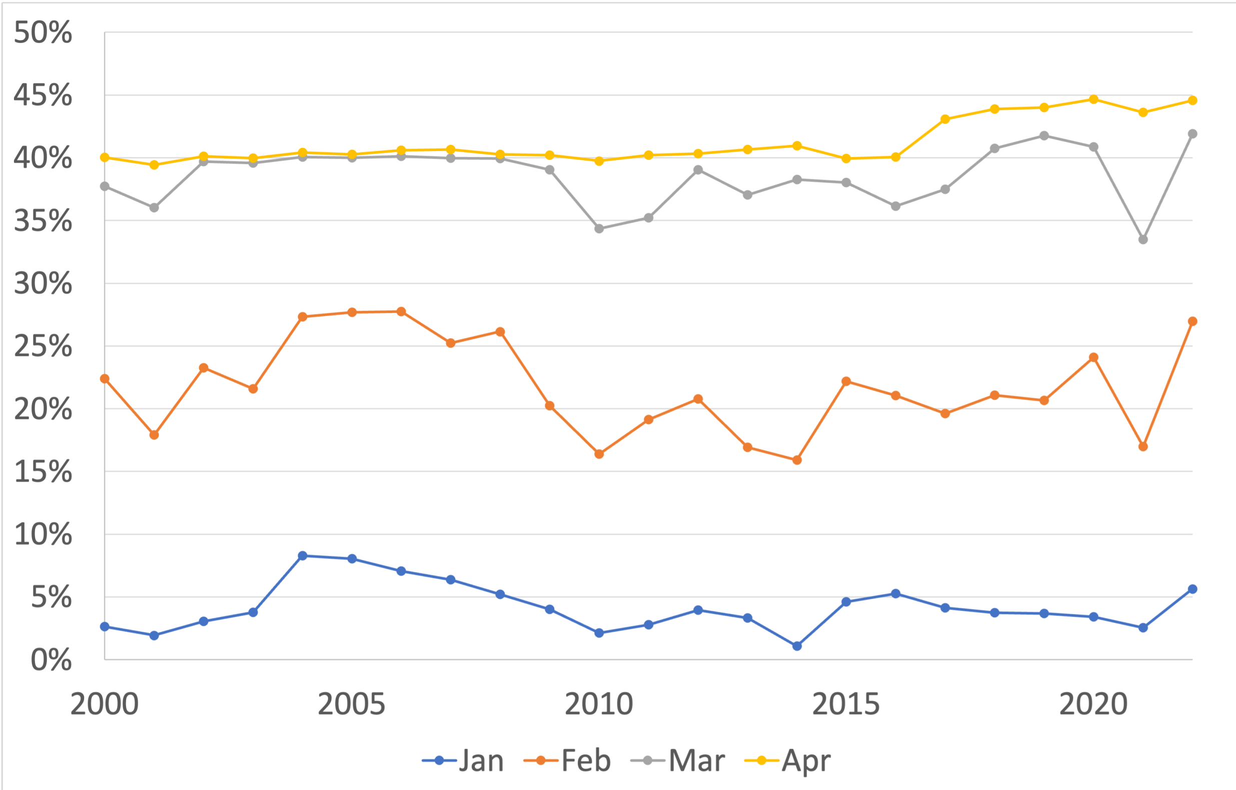

Figure 1-6. Proportion of the annual EBS pollock TAC by month during the A-season, 2000–2022. The higher value observed since 2017 was due to Amendment 110 of the FMP to allow greater flexibility to avoid Chinook salmon.

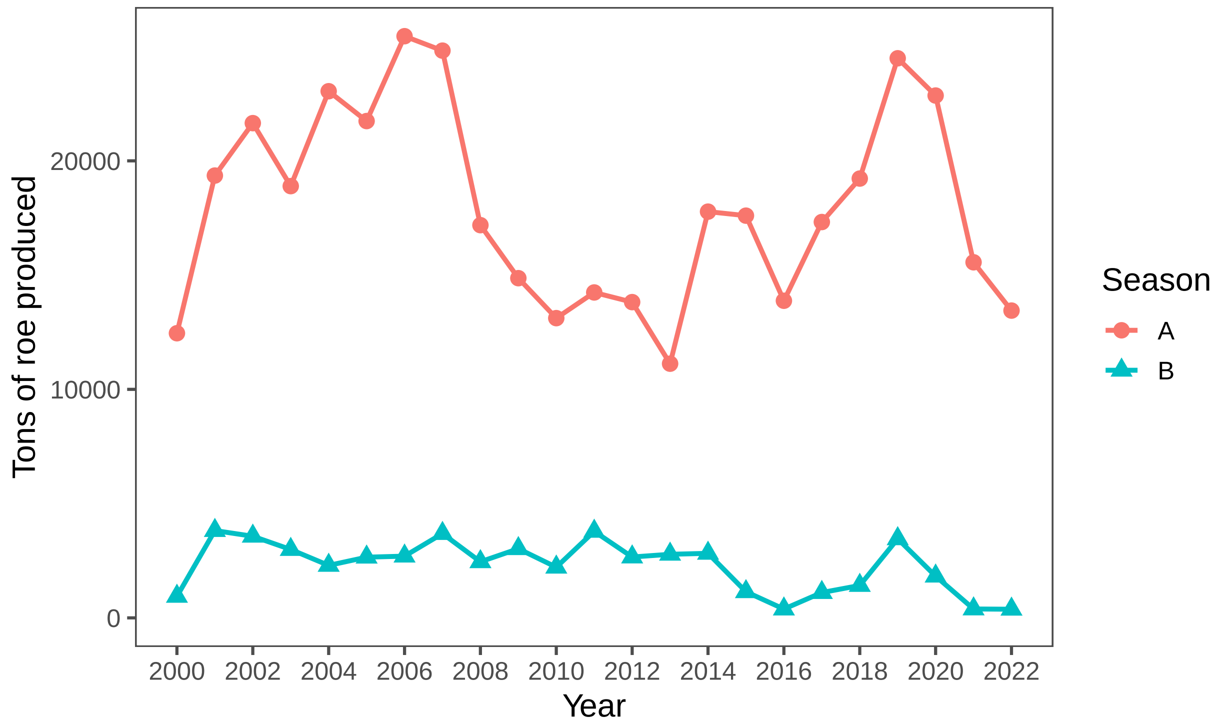

Figure 1-7. EBS pollock roe production in A and B seasons , 2000-2022.

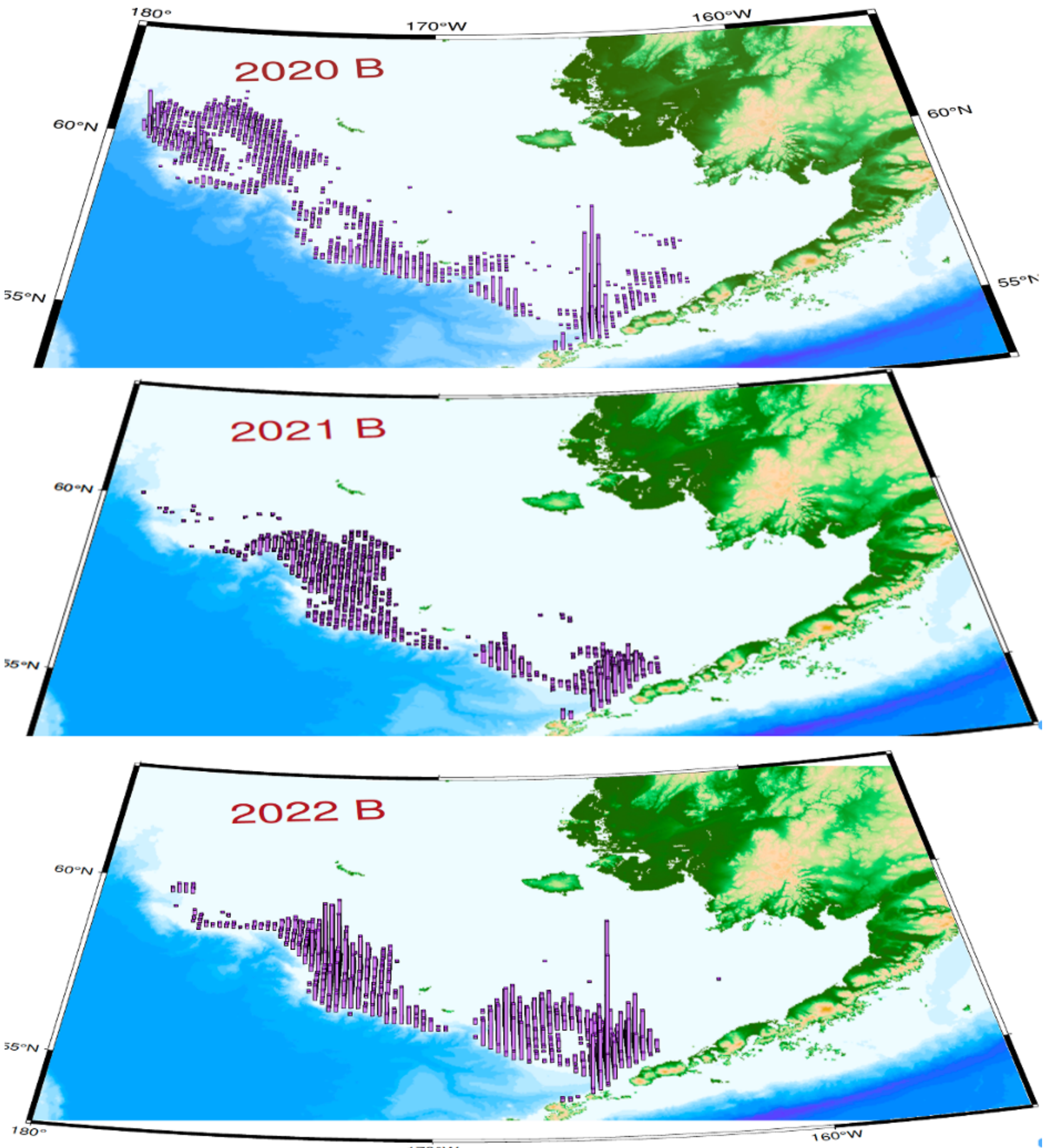

Figure 1-8. EBS pollock catch distribution during B-season, 2020–2022. Column height is proportional to total catch. Note that directed fishery for pollock generally is finished prior to October; the labels are indicative full-year catches.

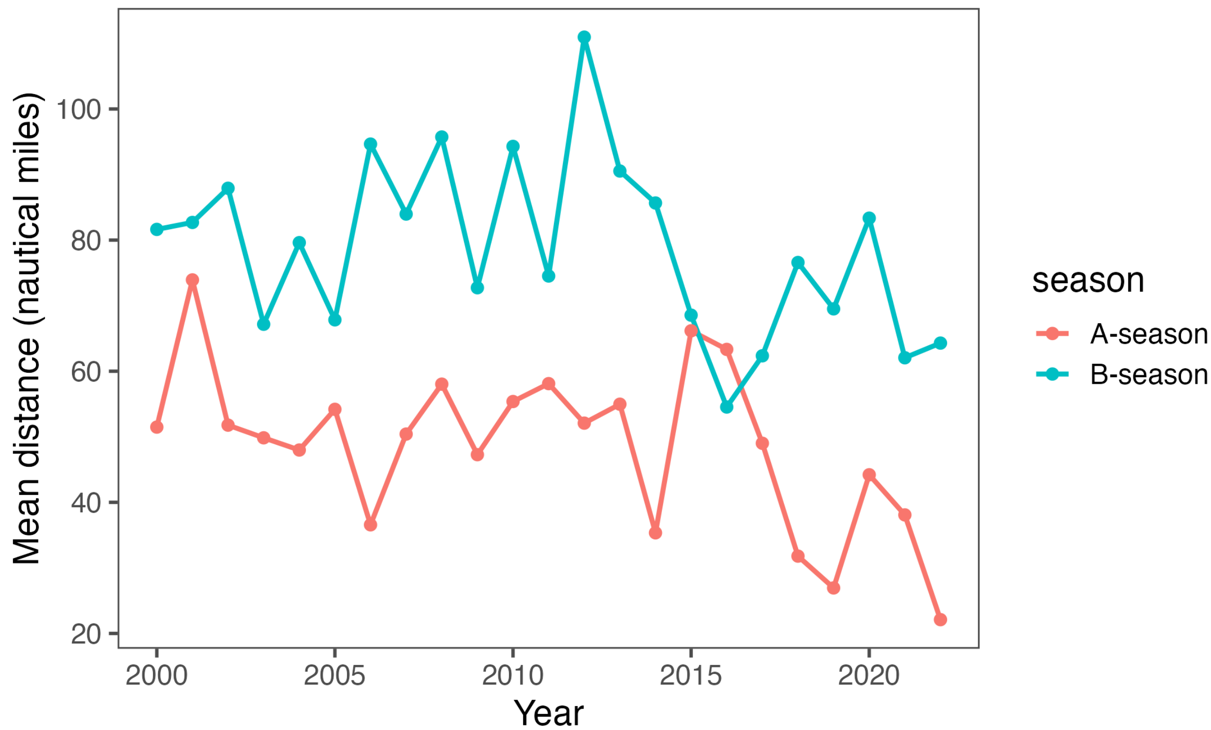

Figure 1-9. Estimated mean daily distance between operations, 2000-2022.

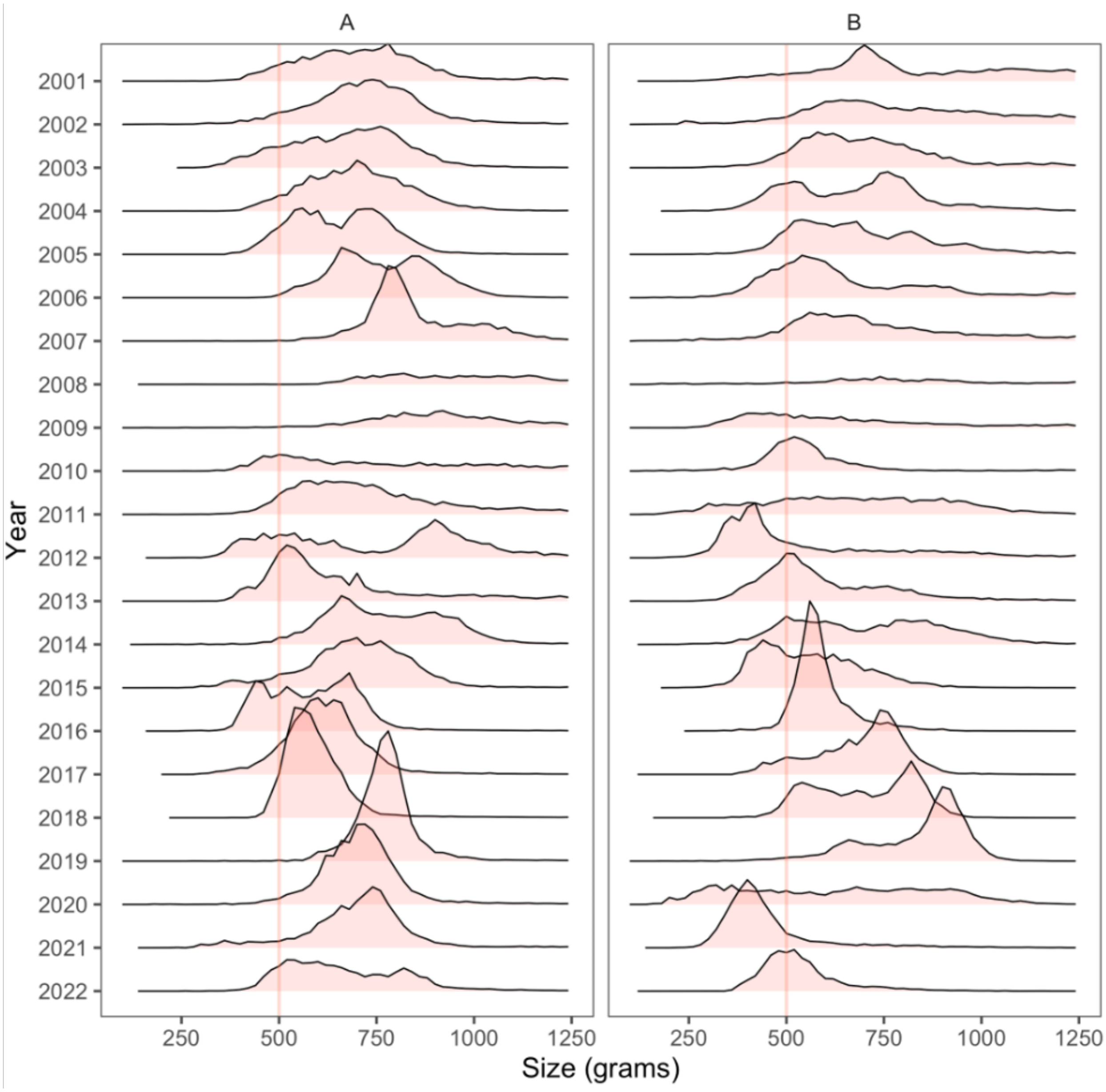

Figure 1-10. Pollock fishery data showing the frequency of mean pollock weight within a tow (in 50 g increments) by year and season.

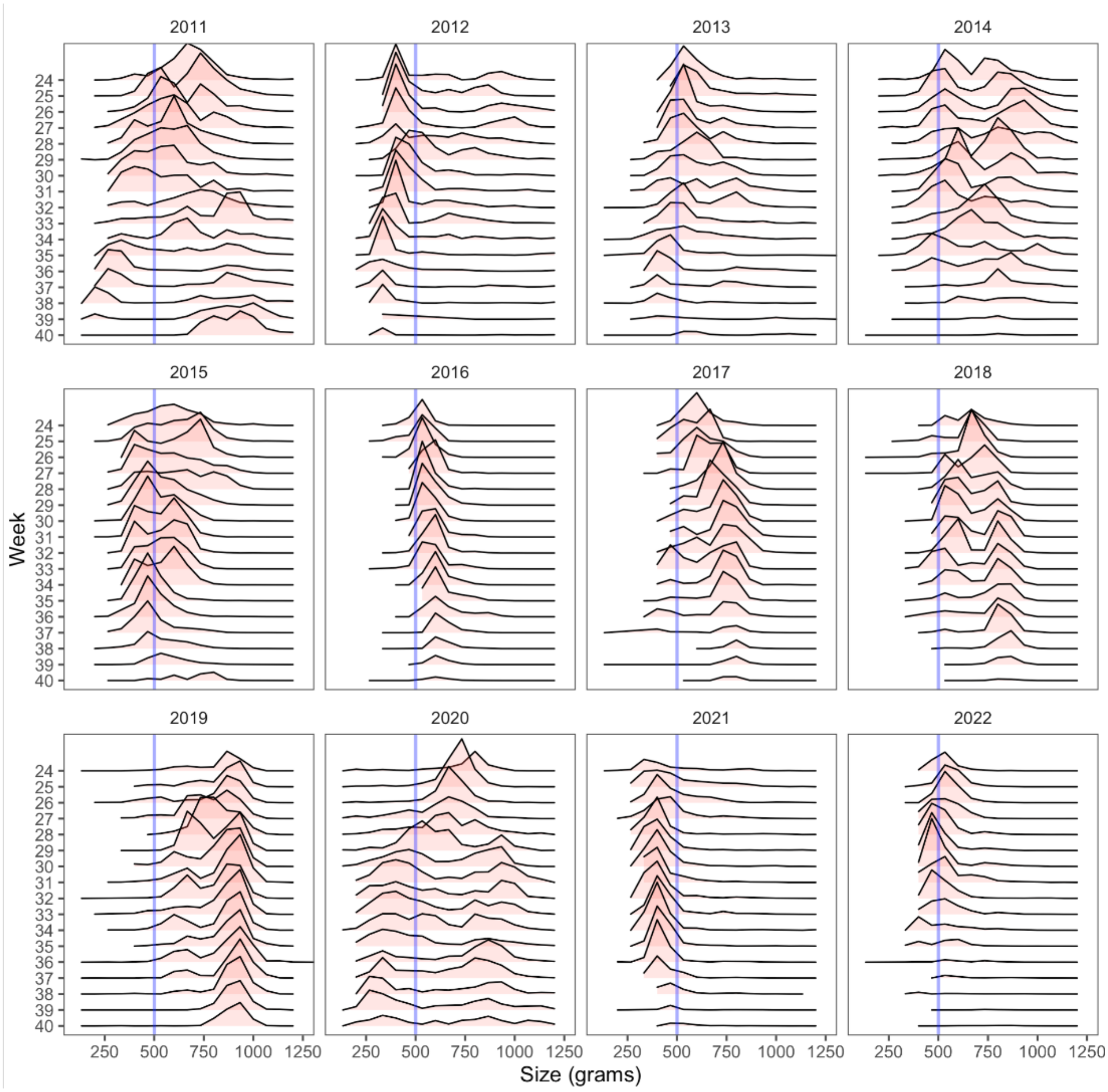

Figure 1-11. Pollock fishery data showing the frequency of mean pollock weight within a tow (in 50 g increments) by recent years and weeks of the B-season.

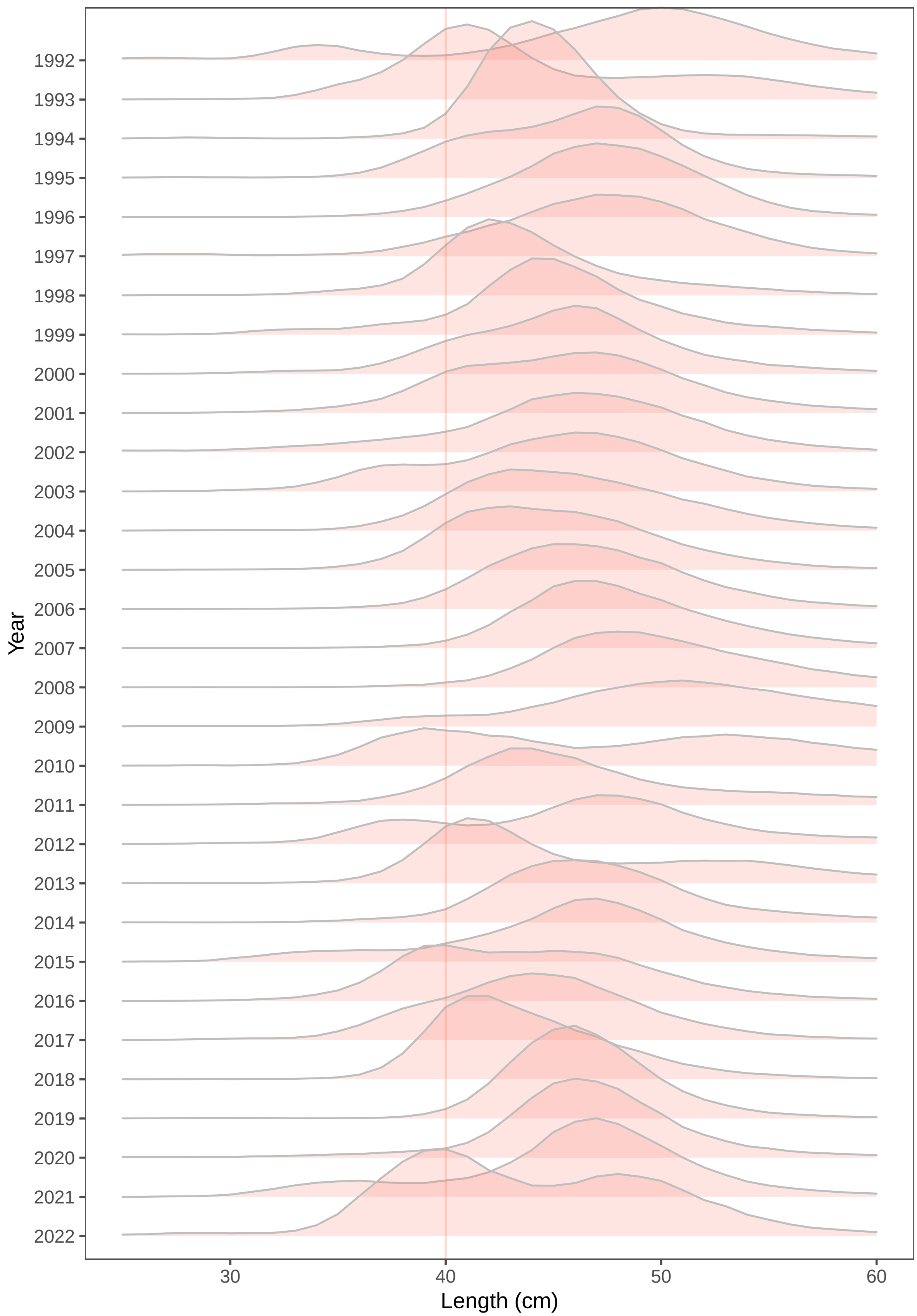

Figure 1-12. Fishery catch-at-length (cm) by the pollock fishery, 1992-2022.

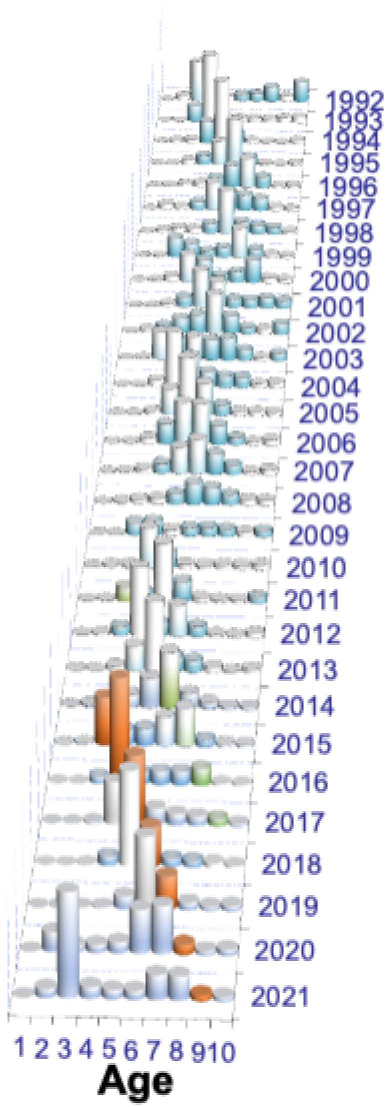

Figure 1-13. EBS pollock fishery estimated catch-at-age data (in number) for 1992–2021. Age 10 represents pollock age 10 and older. The 2012 year-class is shaded in orange.

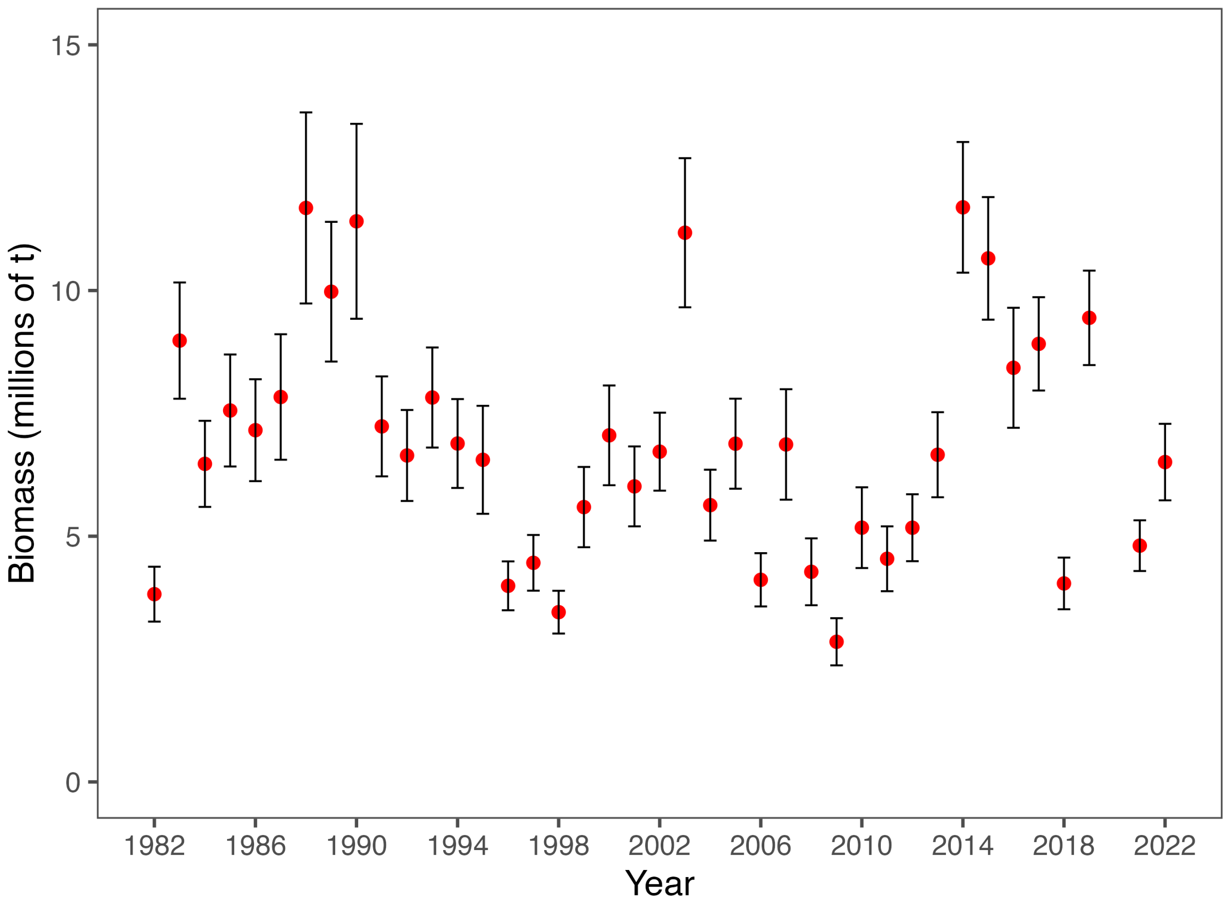

Figure 1-14. Bottom-trawl survey biomass estimates with error bars representing 95% confidence intervals for the VAST model-based methods for EBS pollock.

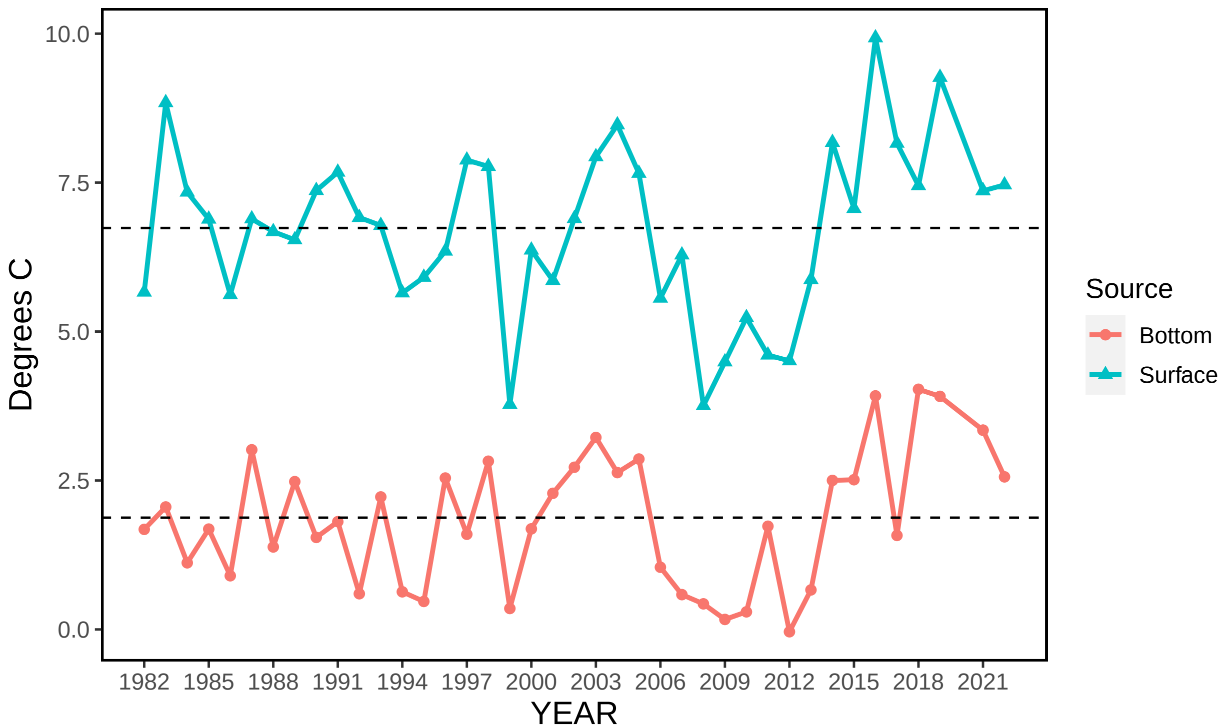

Figure 1-15. Bottom and surface temperatures for the Bering Sea from the NMFS summer bottom-trawl surveys (1982–2019, 2021-2022). Dashed lines represent mean values.

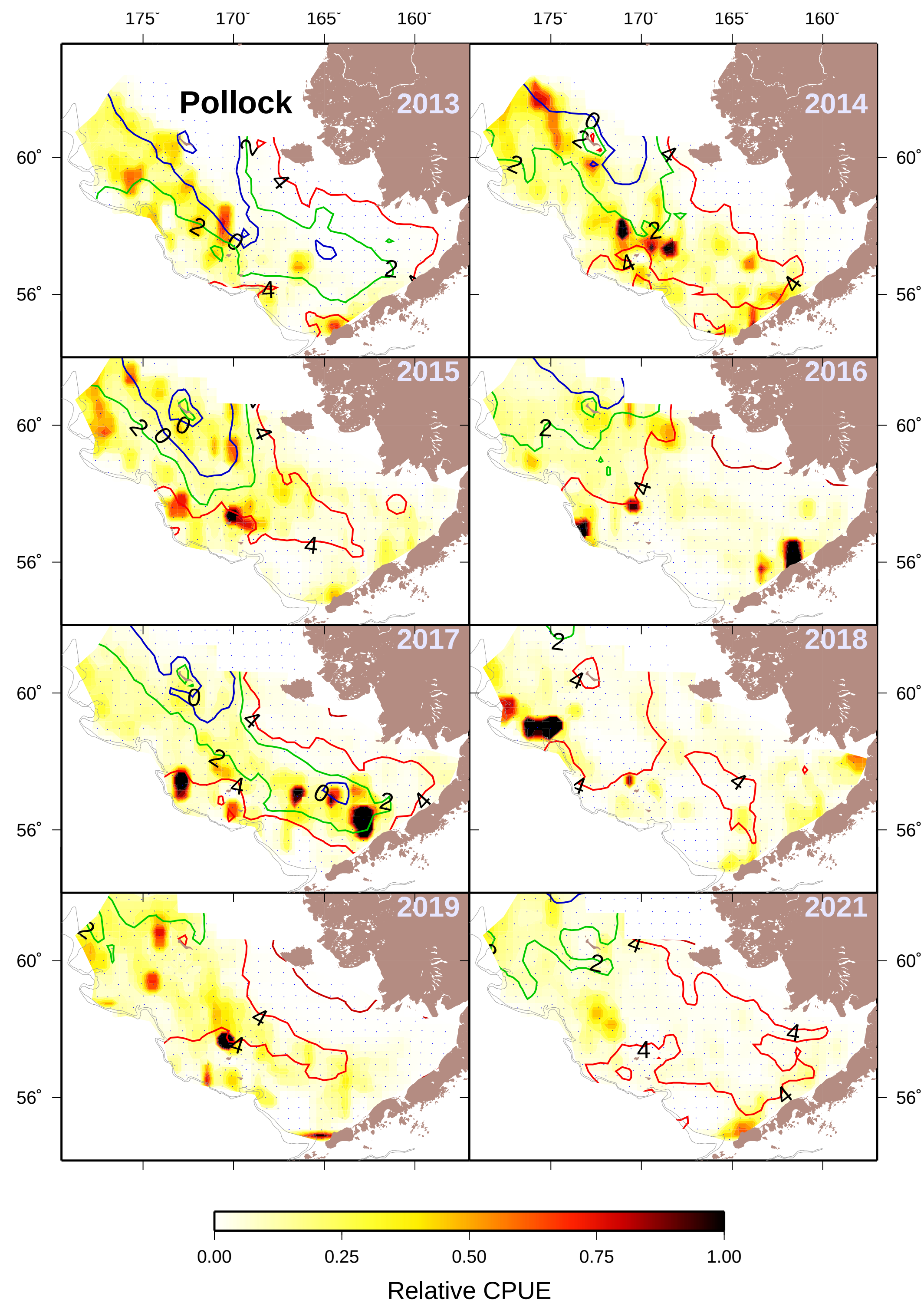

Figure 1-16. EBS pollock CPUE (shades = relative kg/hectare) and bottom temperature isotherms in degrees C; from the bottom trawl survey data 2011–2019 and 2021.

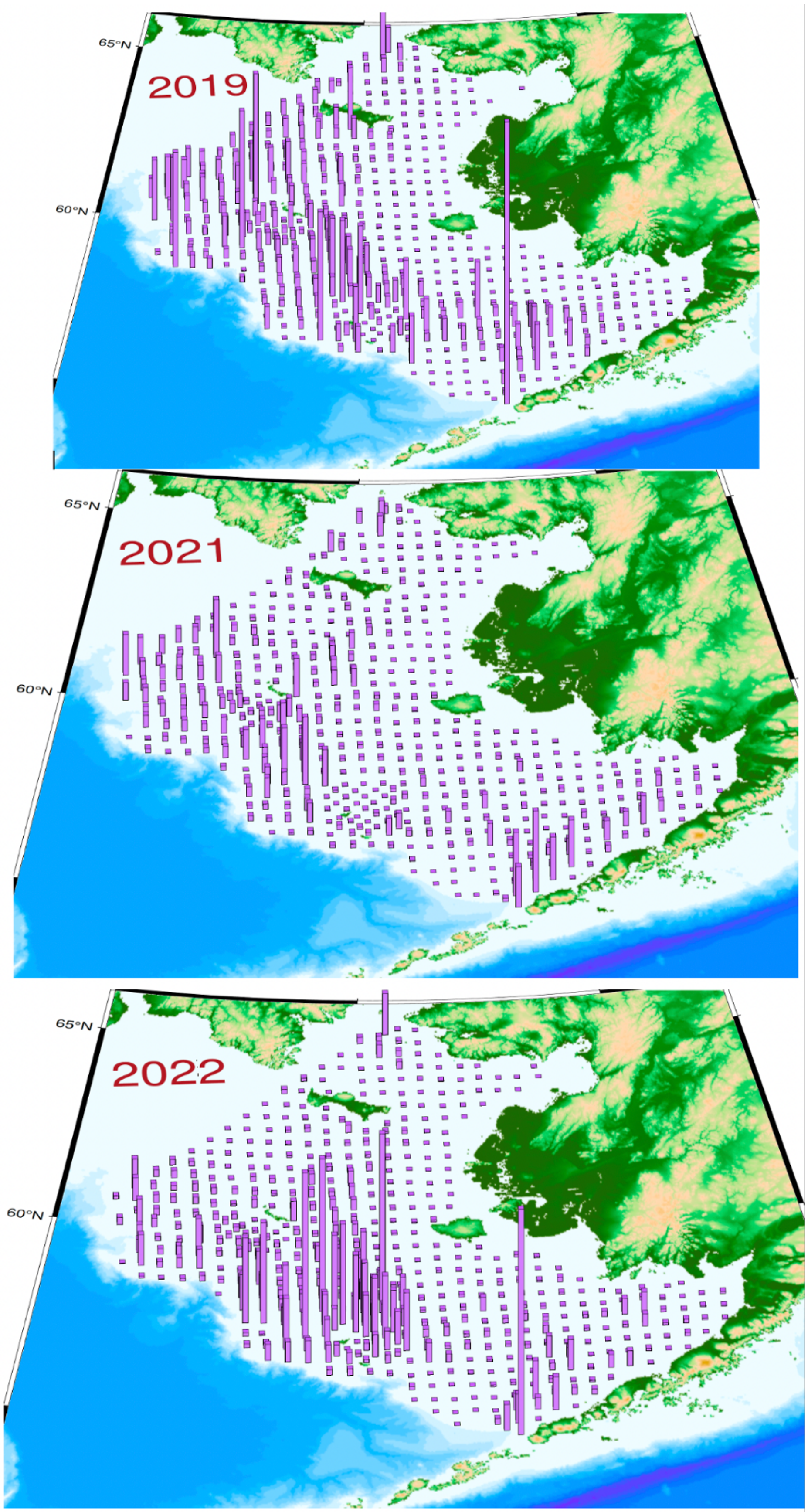

Figure 1-17. Bottom trawl survey pollock catch in kg per hectare for 2019

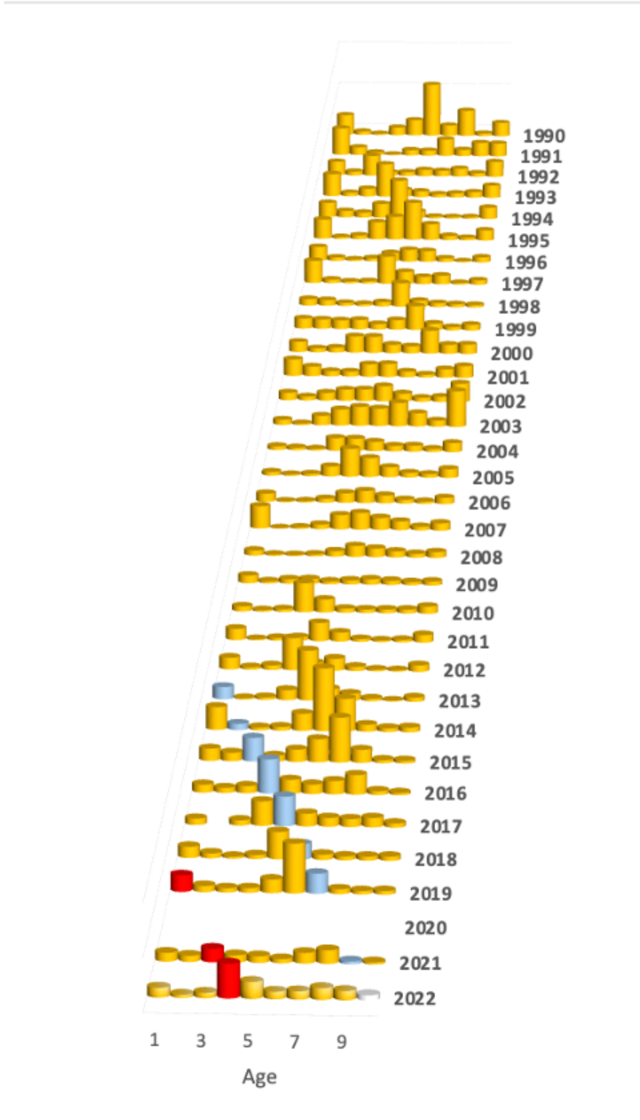

Figure 1-18. Pollock abundance levels by age and year as estimated directly from the NMFS bottom-trawl surveys (1990–2019,2021-2022). The 2012 and 2018 year-classes are shaded differently.

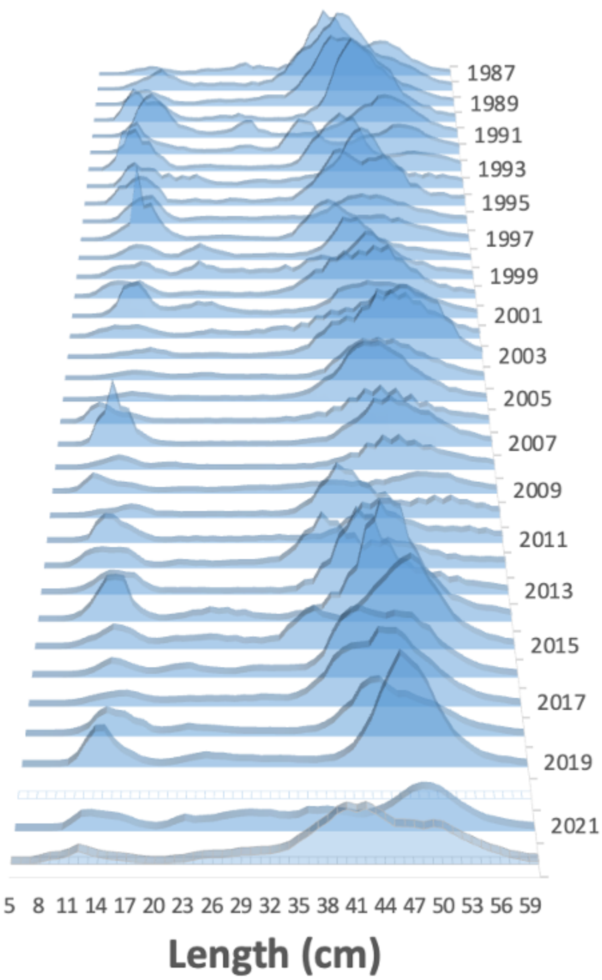

Figure 1-19. Pollock abundance levels by size and year as estimated from the NMFS bottom-trawl surveys (1990–2019, 2021, and 2022).

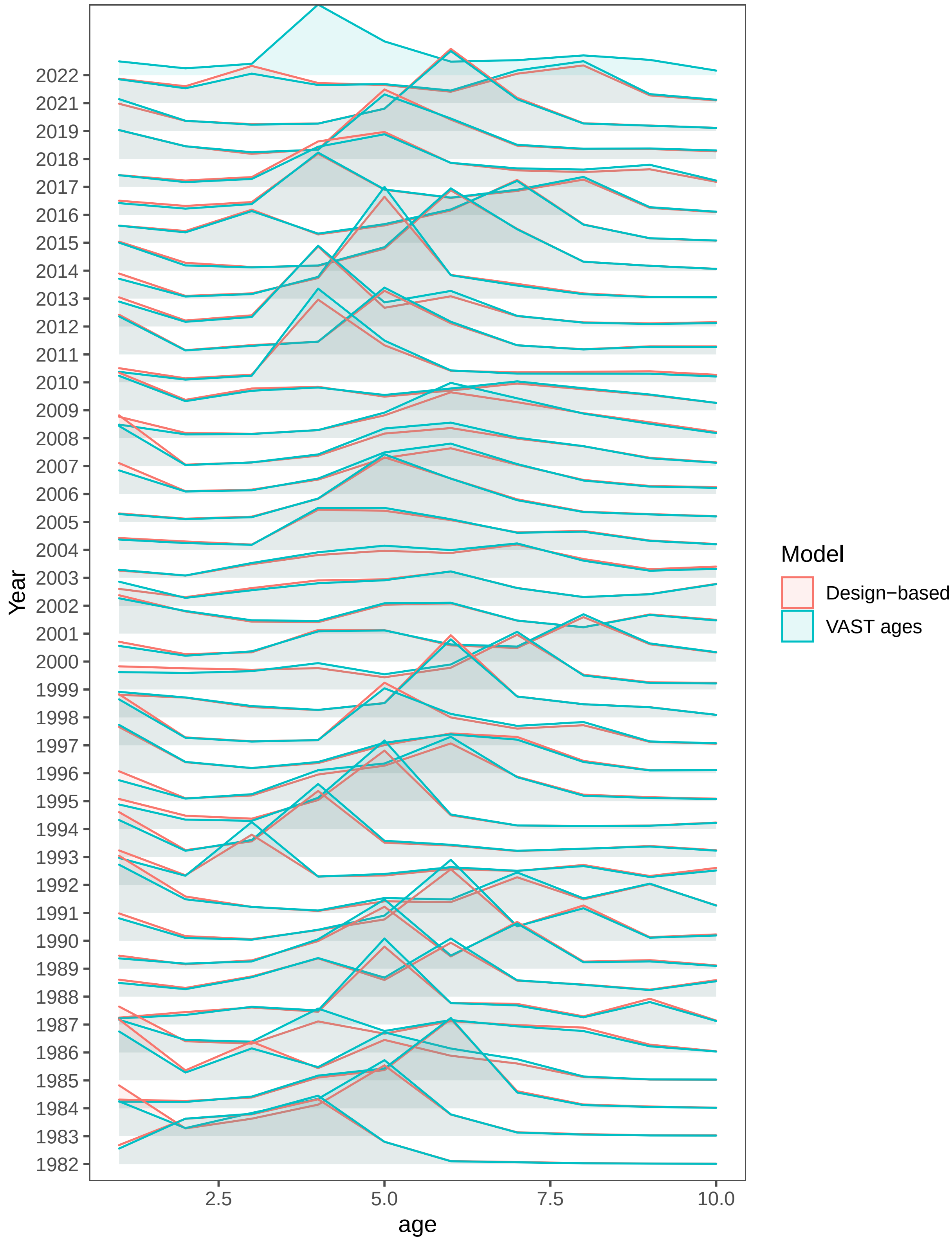

Figure 1-20. Comparison of EBS pollock estimated proportions-at-age from the bottom trawl surveys using the standard design-based estimates and those using the VAST spatio-temporal model, 1982-2022 (no data from 2020).

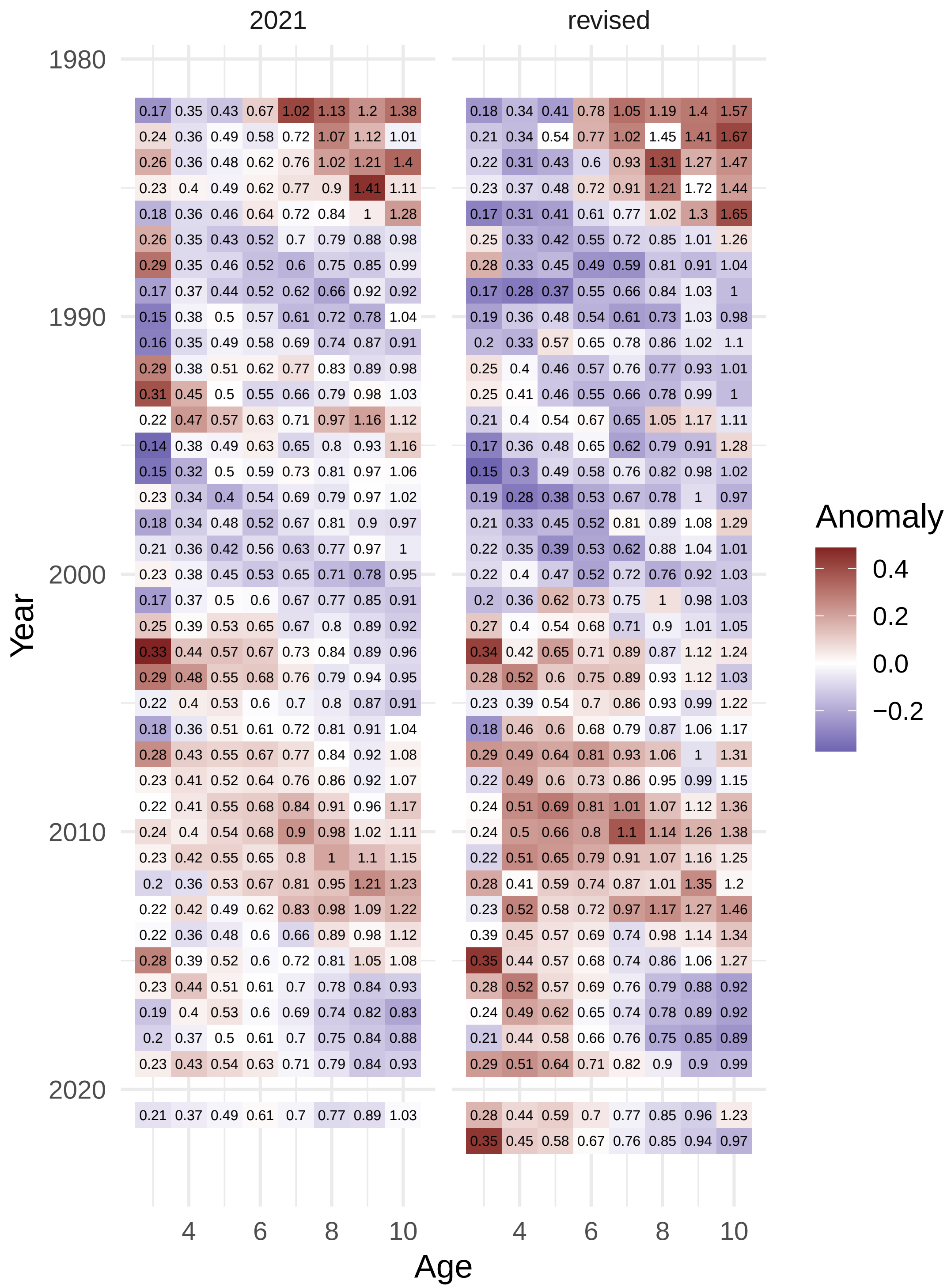

Figure 1-21. Panels showing the values for mean pollock weight-at-age used in the previous assessment (left panel) and the values revised for this assessment as based on more data and appropriate CPUE weighting (right panel). the shadings indicate anomalies over time within ages (columns).

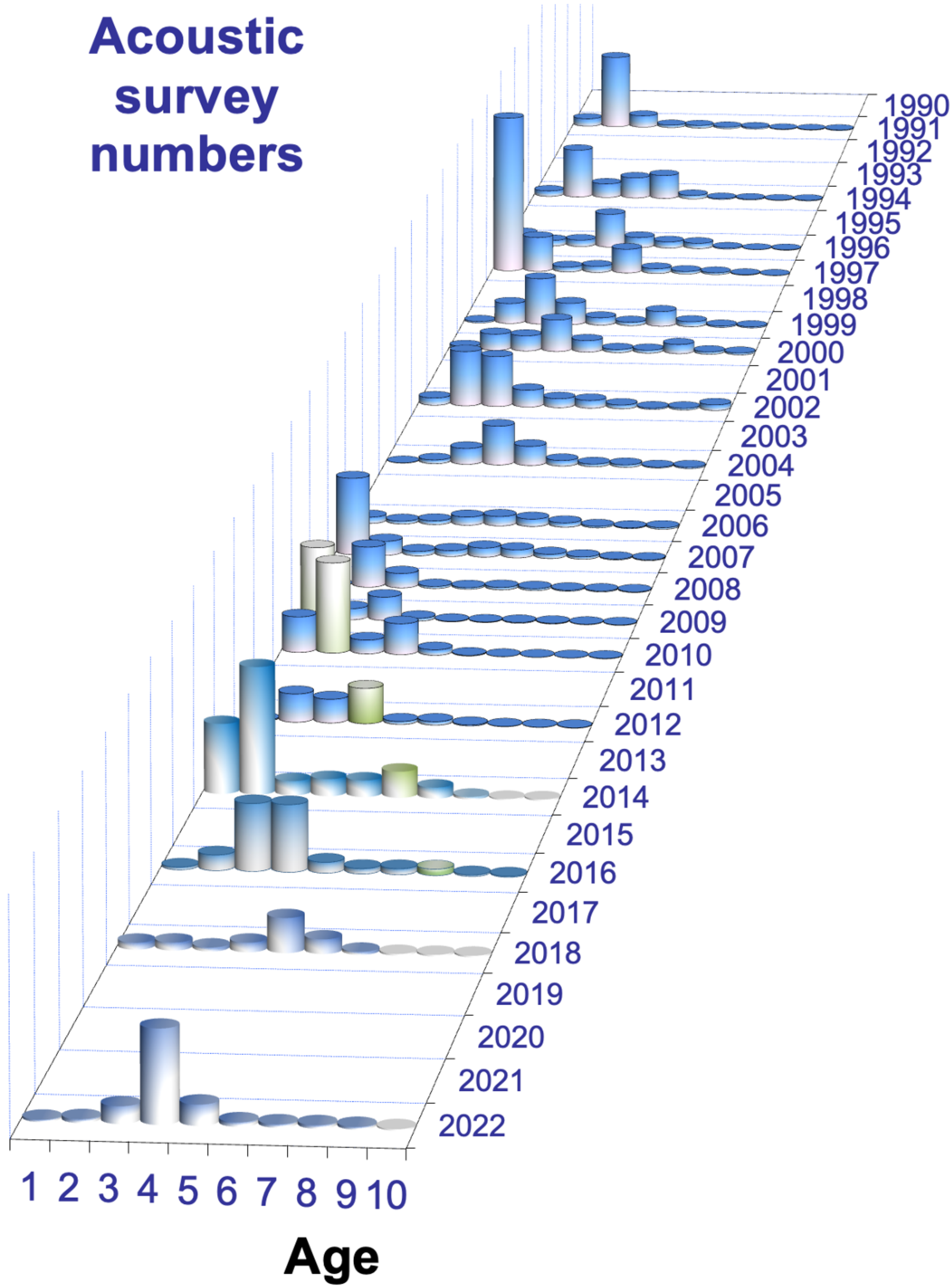

Figure 1-22. Acoustic-trawl survey pollock numbers-at-age estimates, 1994-2022. Note that data for 2022 are preliminary and based on age-length composition from the bottom trawl survey (plus some supplemental samples from the present survey).

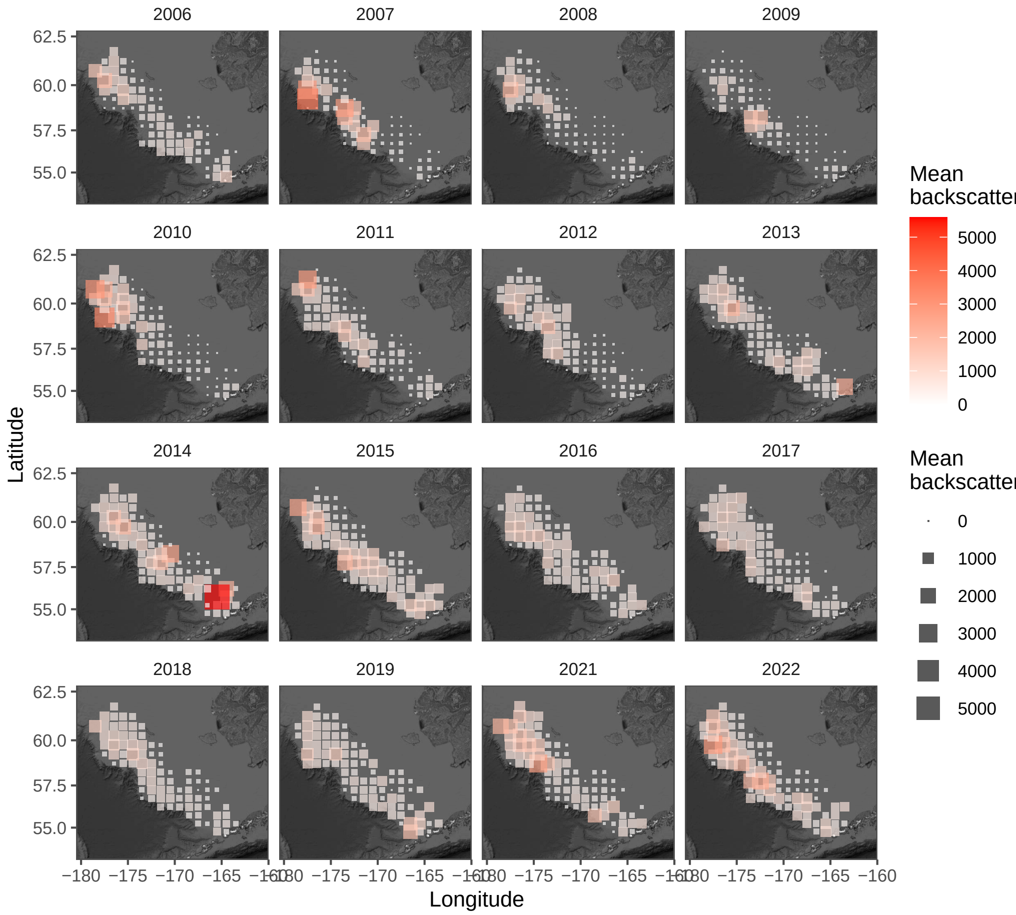

Figure 1-23. Maps of acoustic vessel-of-opportunity (AVO) index data 2006-2022. Grid cell size and shading is proportional to pollock backscatter.

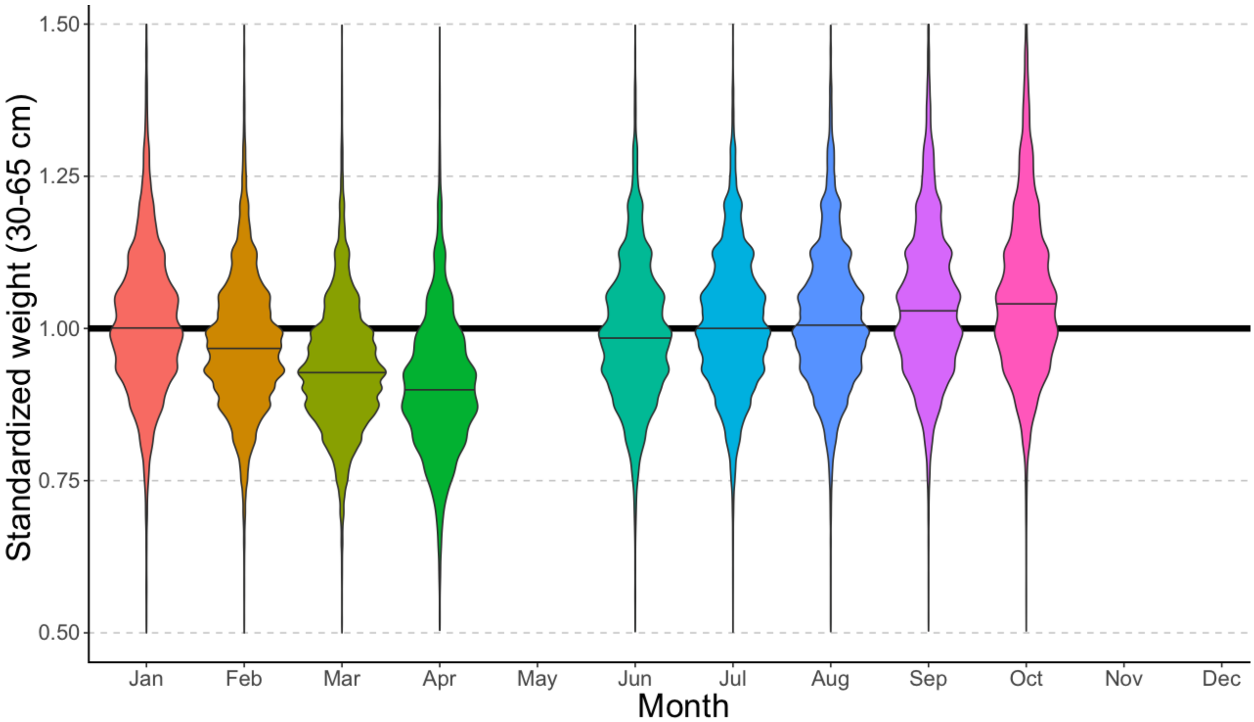

Figure 1-24. EBS pollock fishery body mass (given length) anomaly (standardized by overall mean body mass at each length) by month based on some over 700 thousand fish measurements from 1991–2022.

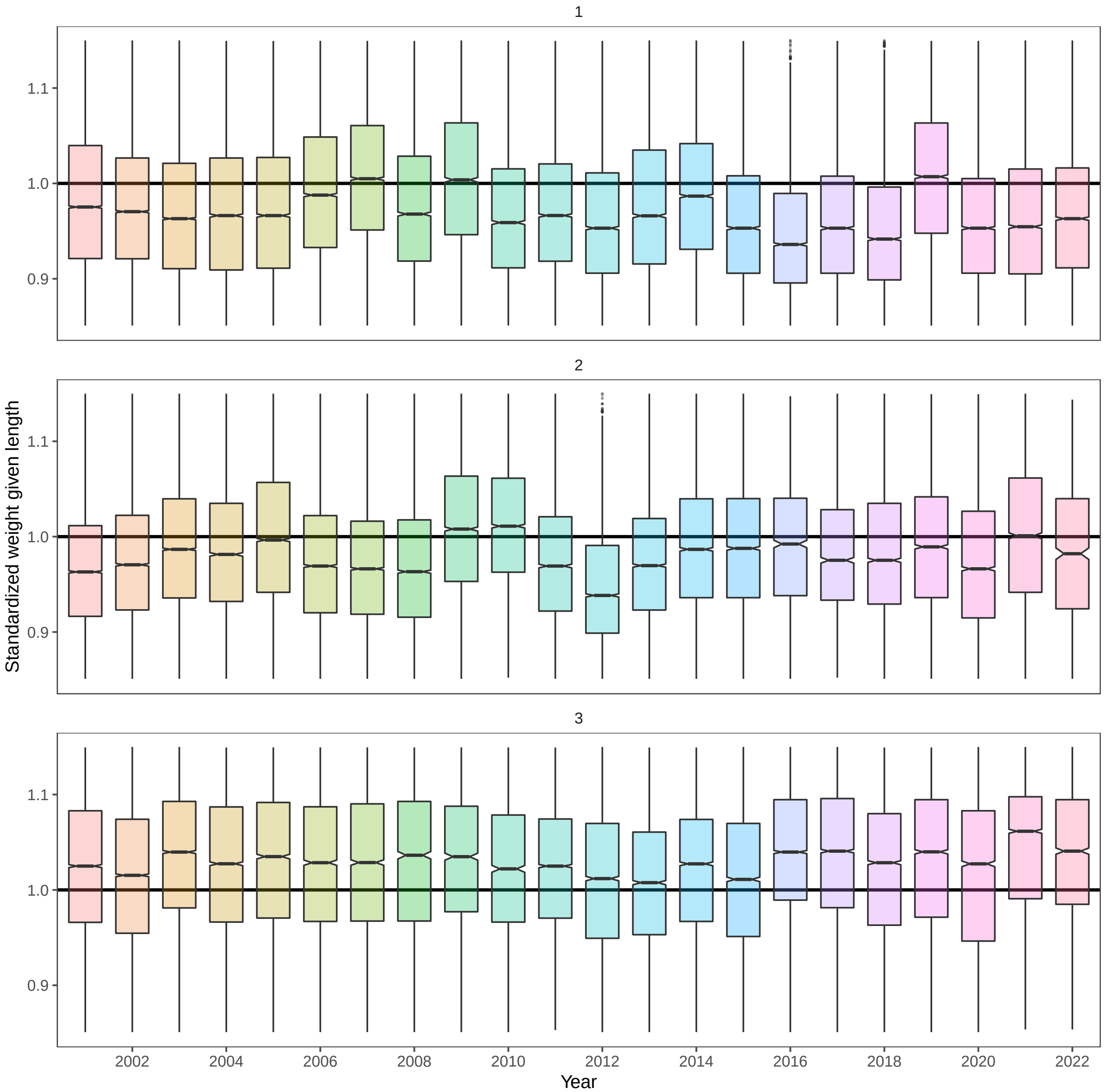

Figure 1-25. EBS pollock fishery body mass (given length) anomaly (standardized by overall mean body mass at each length) by year and season/area strata, 1991–2022.

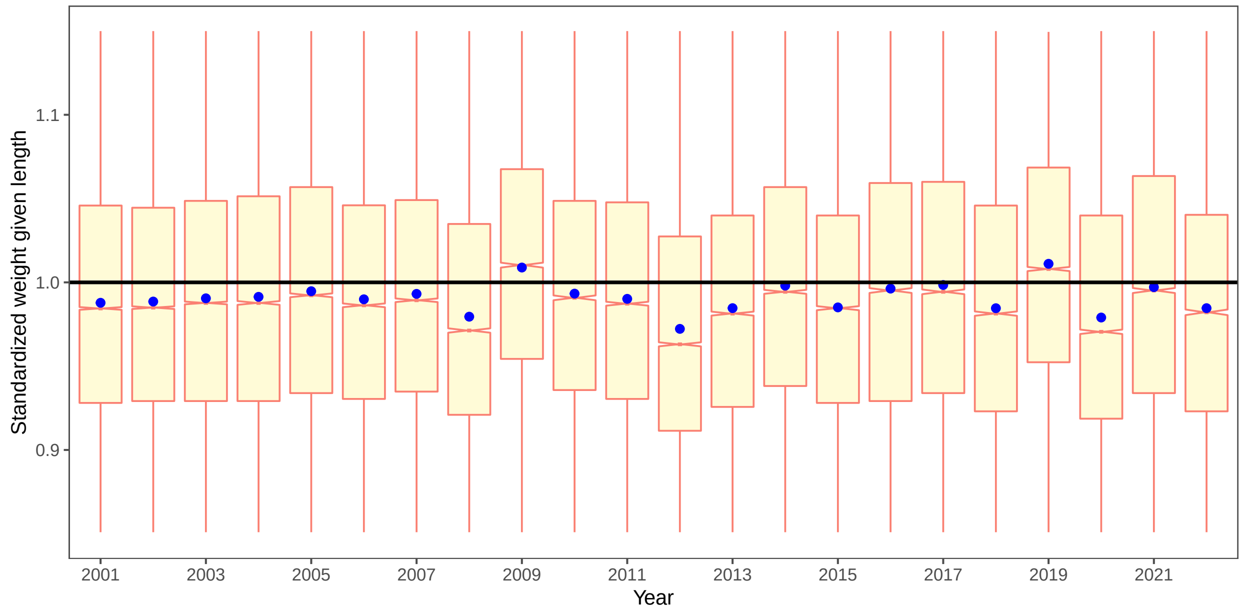

Figure 1-26. EBS pollock body mass (given length) anomaly (standardized by overall mean body mass at each length) by year, 1991–2022.

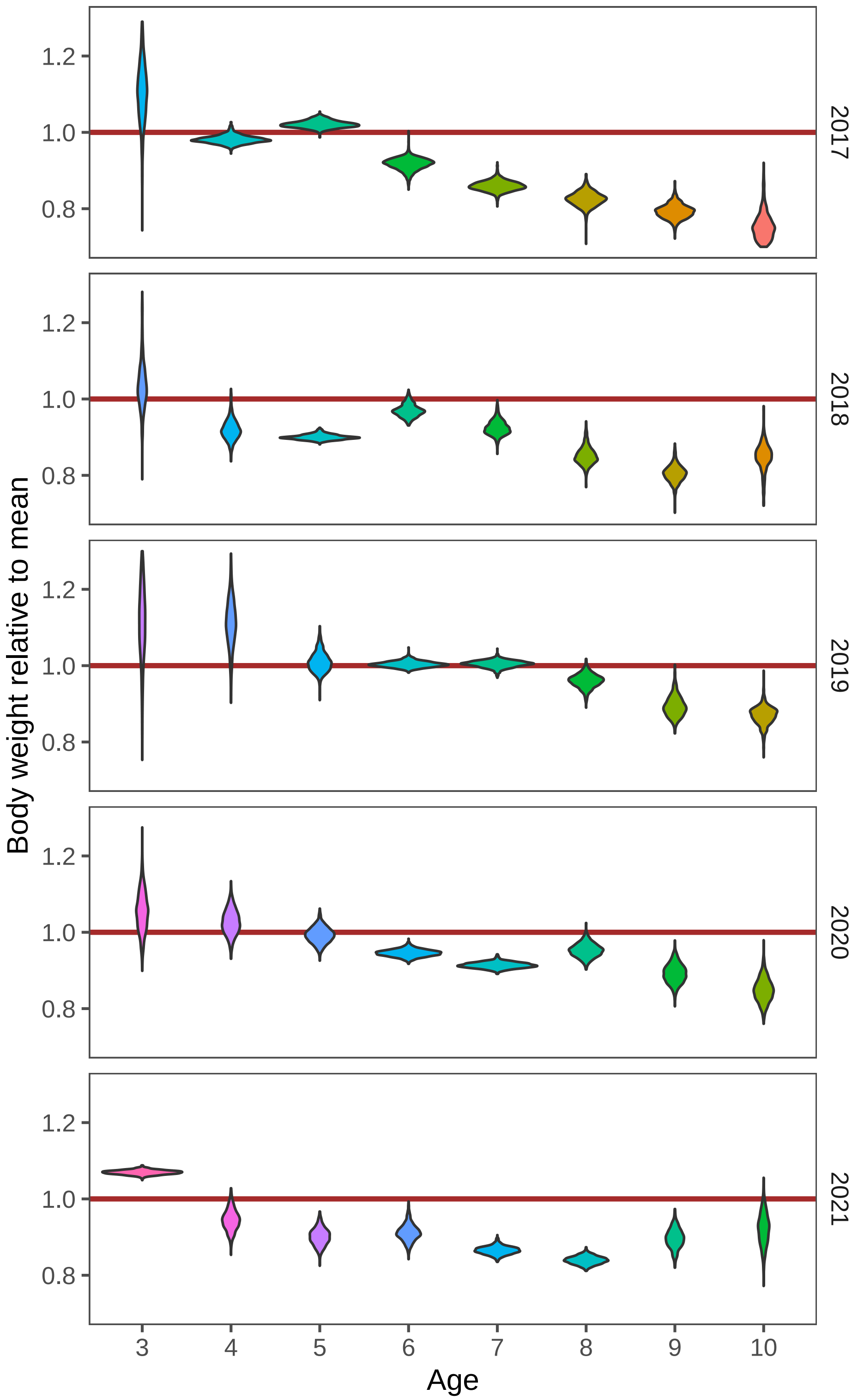

Figure 1-27. Recent fishery average weight-at-age anomaly (relative to mean) by strata for ages 3–10, 2017–2021. Vertical shape reflects uncertainty in the data (wider shapes being more precise), colors are consistent with cohorts.

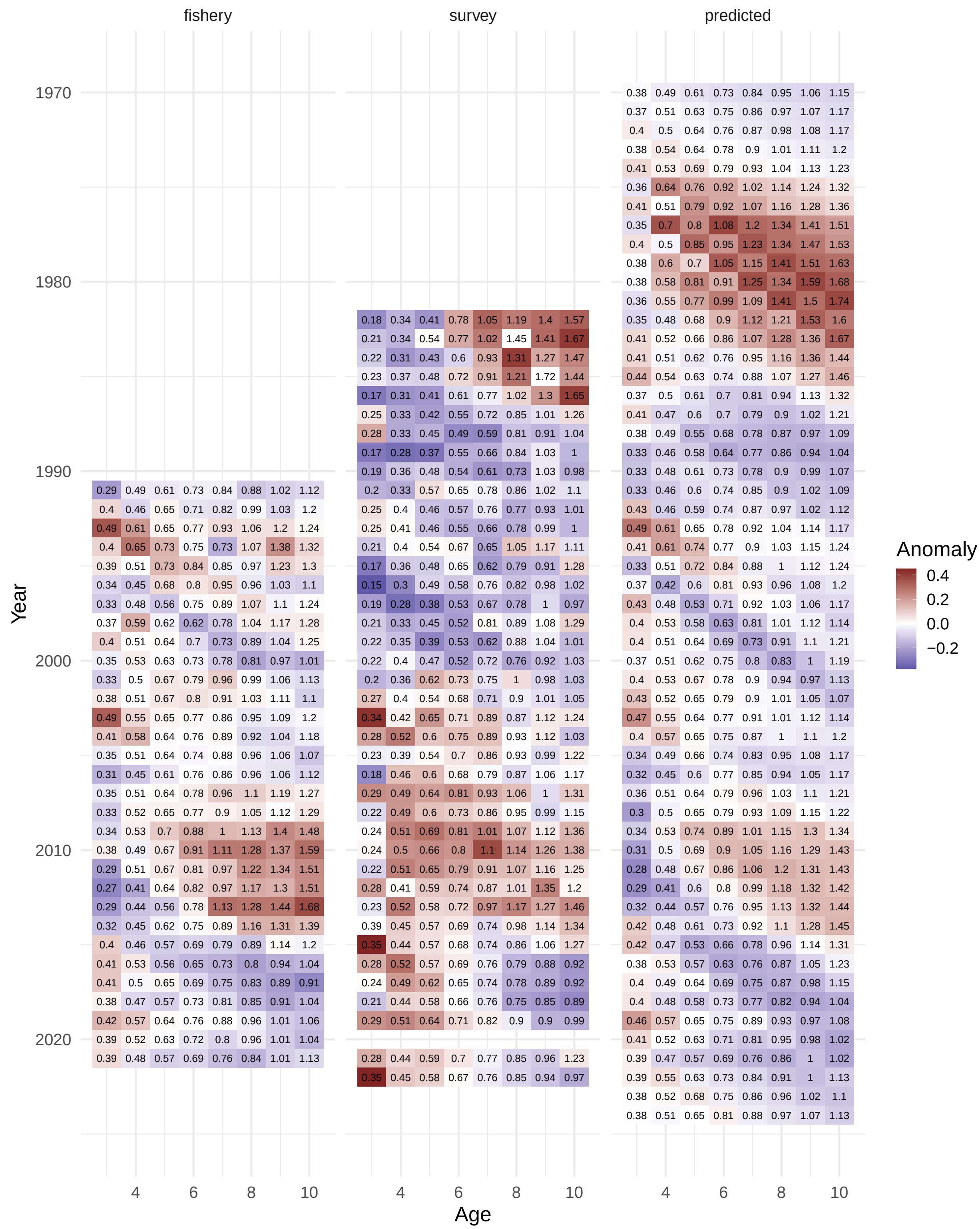

Figure 1-28. Data input and model predictions for the weight-at-age random-effects model fit separately to obtain variance estimates for cohort and year effect contributions to changes in incremental growth from one age to the next. Shadings reflect the anomaly from the mean while the numbers are the weight-at-age in kg.

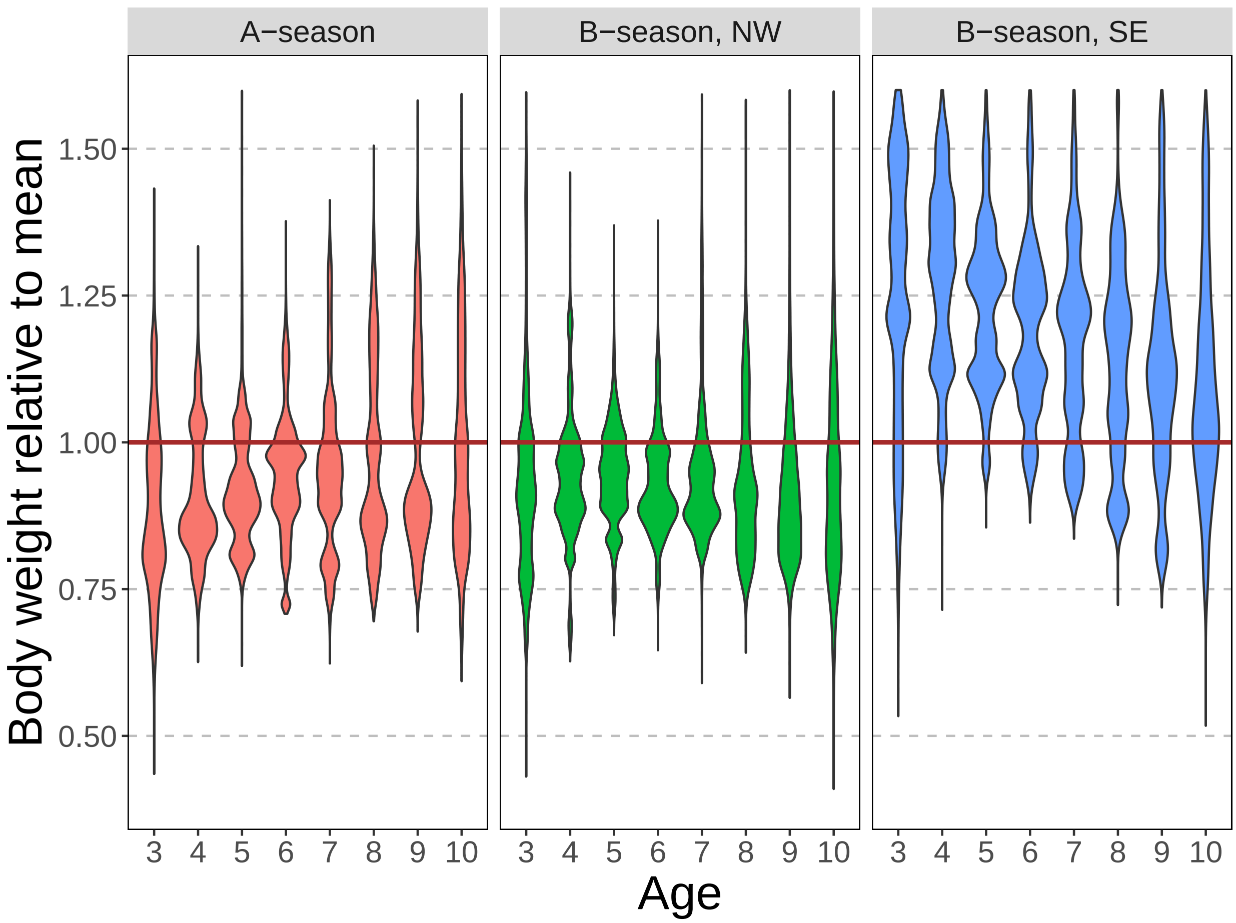

Figure 1-29. Fishery average weight-at-age anomaly (relative to mean) across strata and combined for all ages (3–10), and available years (1991–2020). Vertical shape reflects uncertainty in the data (wider shapes being more precise), colors are consistent with cohorts.

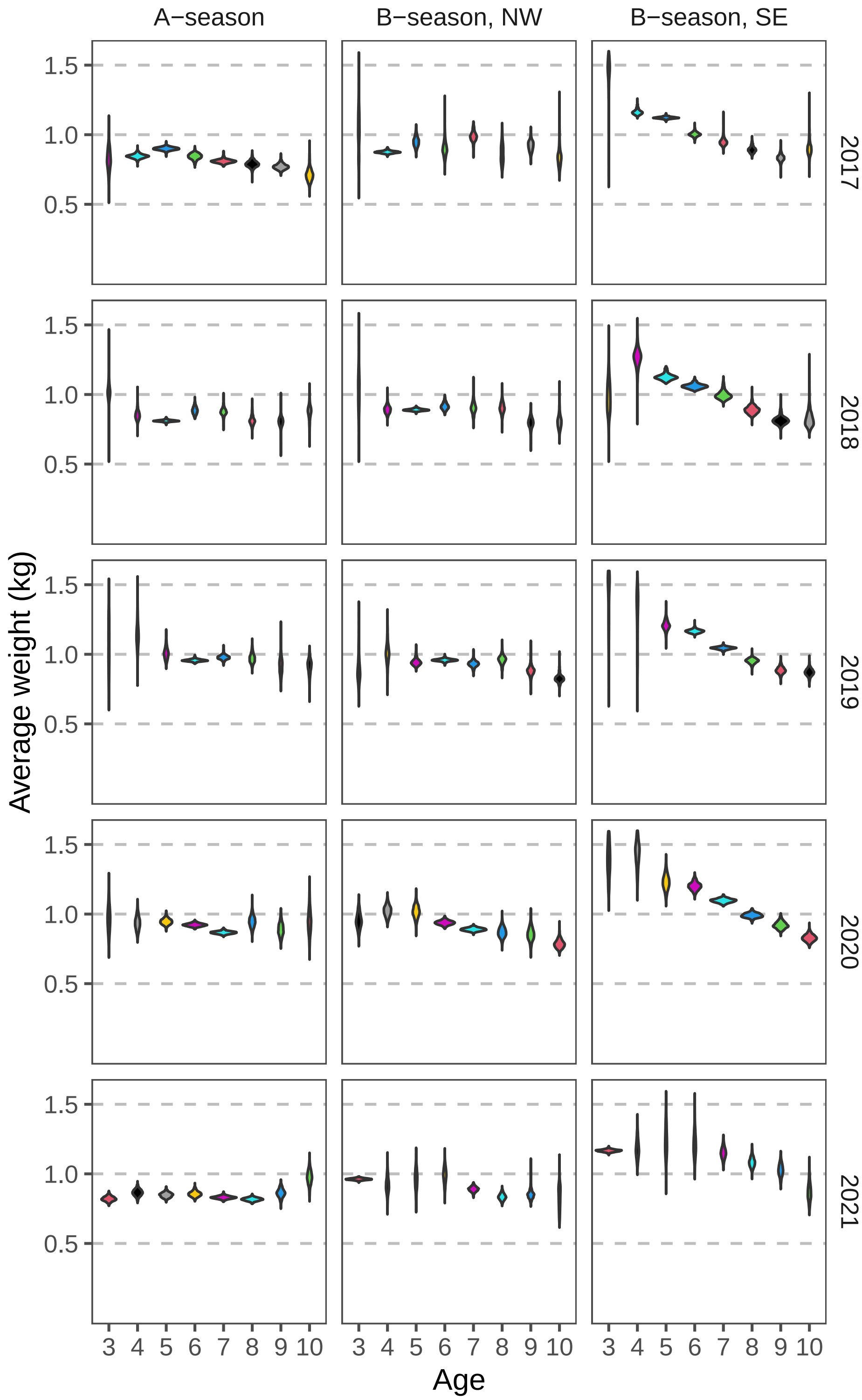

Figure 1-30. Recent fishery average weight-at-age anomaly (relative to mean) by strata for ages 3–10, 2016–2021. Vertical shape reflects uncertainty in the data (wider shapes being more precise), colors are consistent with cohorts.

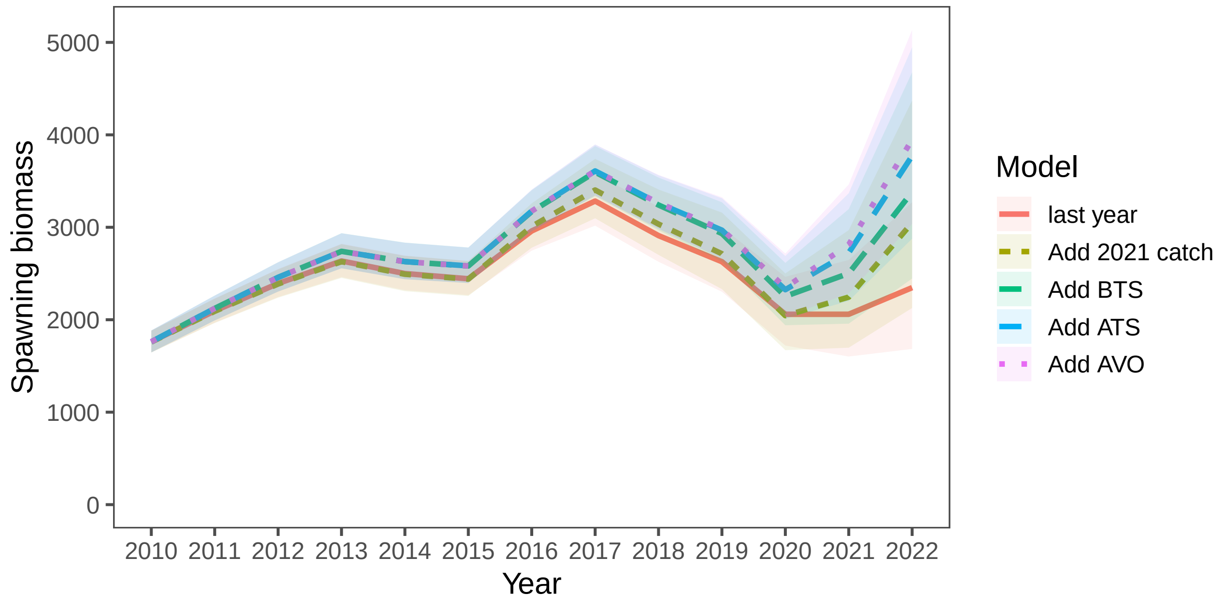

Figure 1-31. Model runs comparing last year's assessment with the impact of sequentially adding new data (first 2022 catch and 2021 fishery catch-at-age, then the 2022 bottom trawl survey data point, then the acoustic-trawl and finally the AVO data.

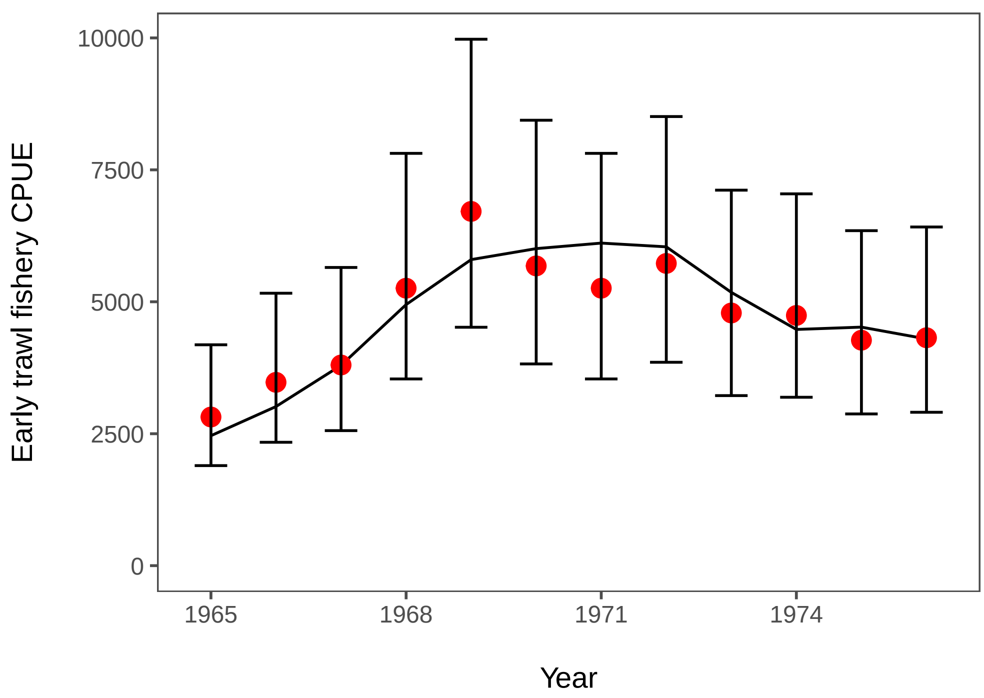

Figure 1-32. EBS pollock model fits to the Japanese fishery CPUE.

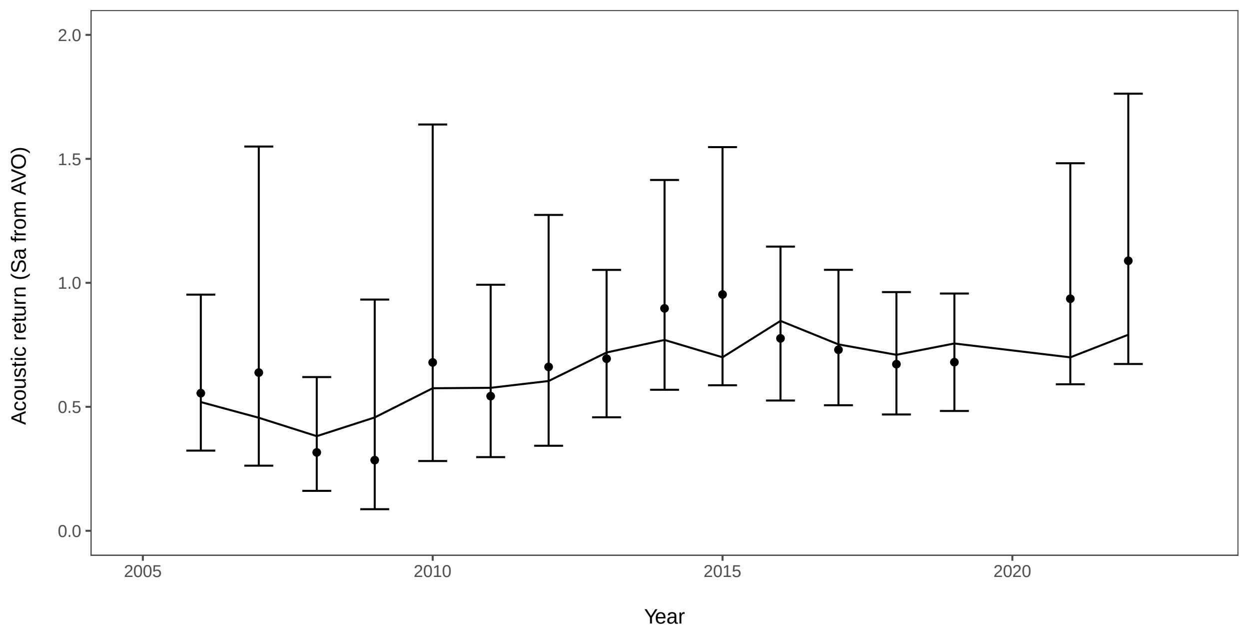

Figure 1-33. Model results of predicted and observed AVO index. Error bars represent assumed 95% confidence bounds of the input series.

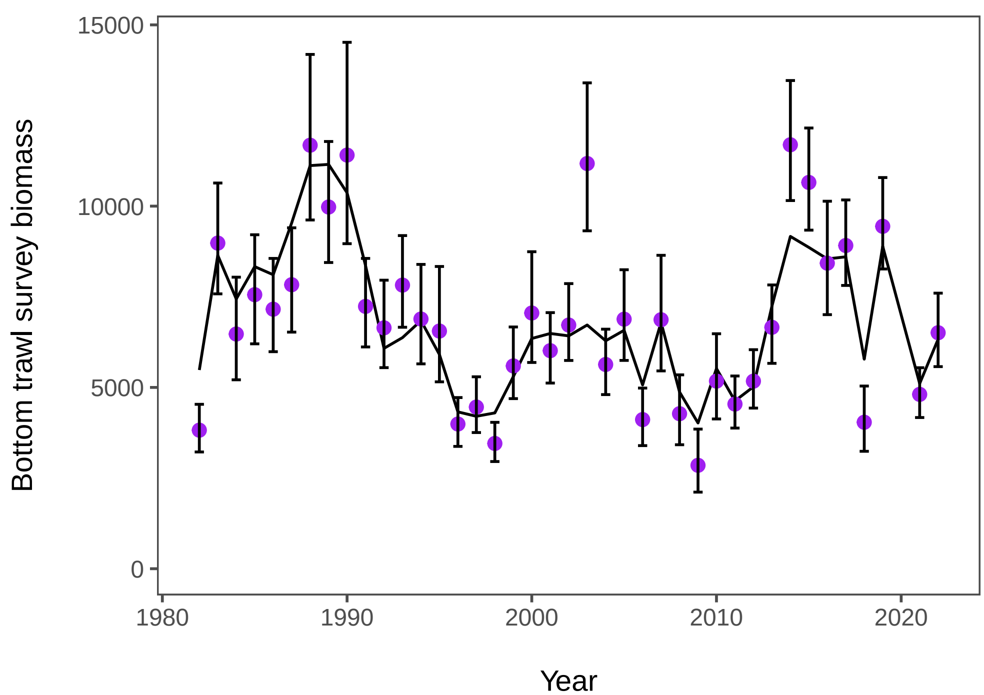

Figure 1-34. EBS pollock model fit to the BTS survey data (VAST estimates based on density dependence-corrected CPUE by station), 1982–2019, 2021-2022. Units are relative biomass.

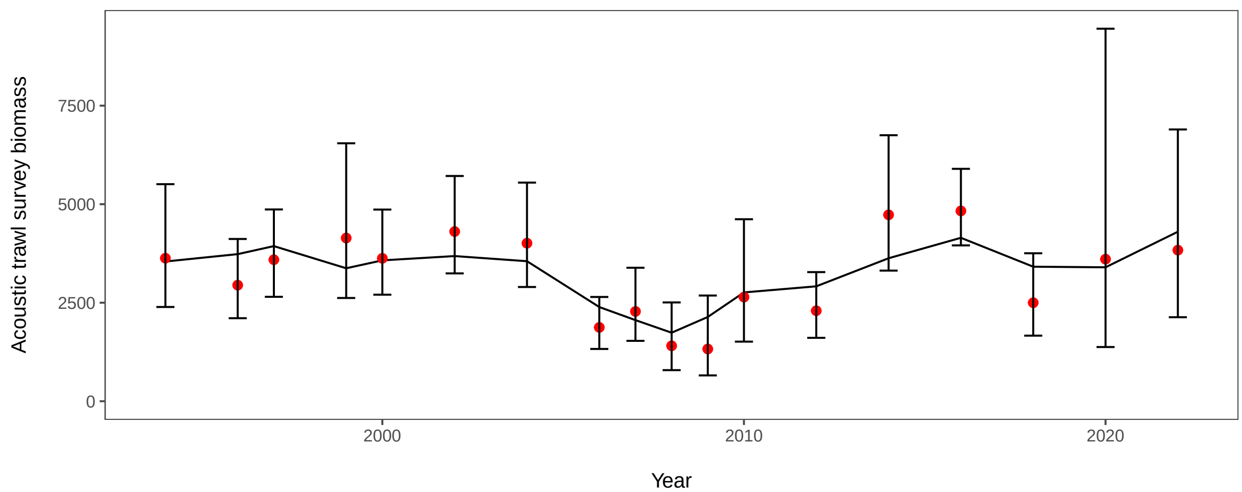

Figure 1-35. EBS pollock model fit to the ATS biomass index, 1994–2022.

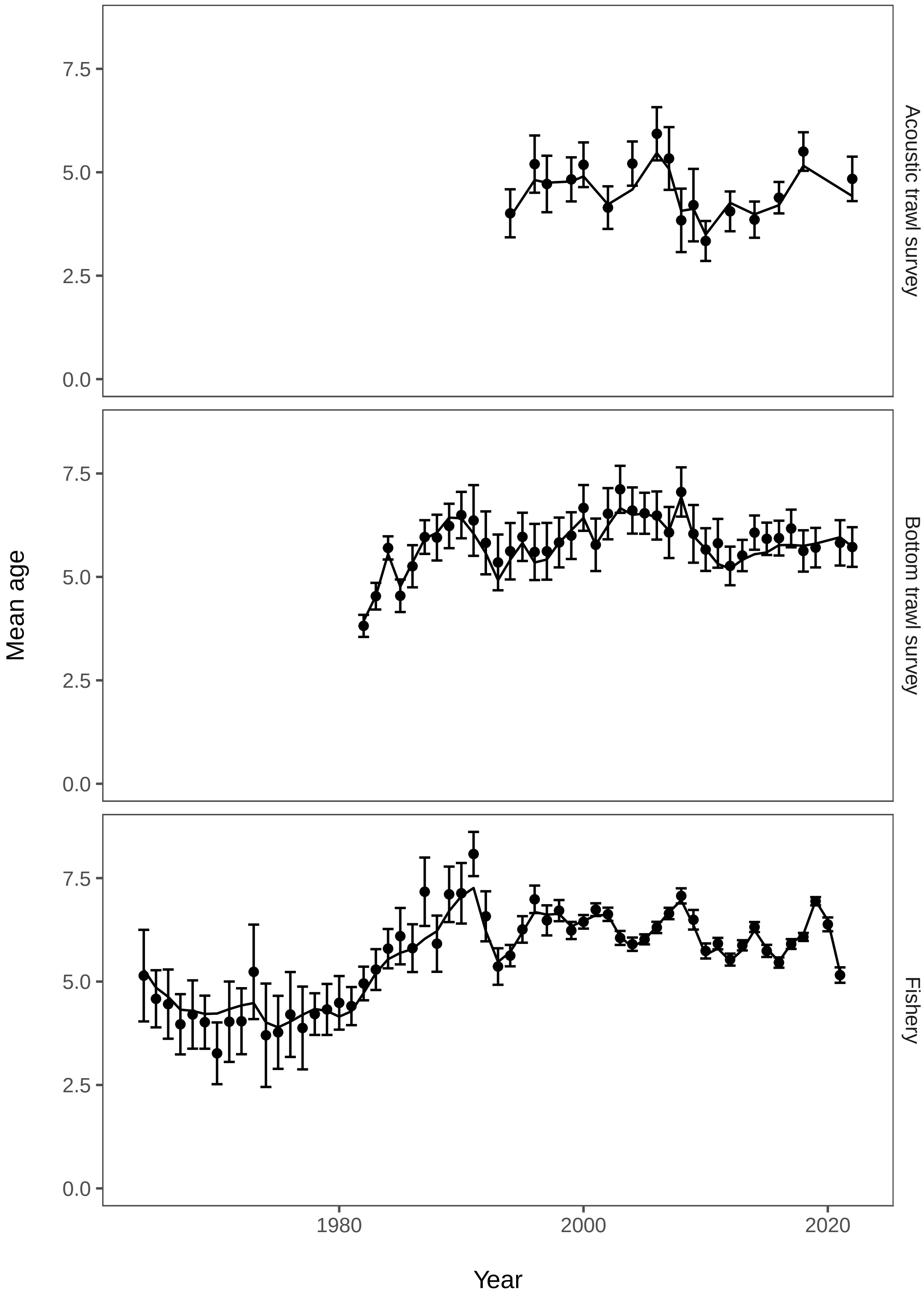

Figure 1-36. EBS pollock model fits to observed mean age for the Acoustic trawl survey (top), the bottom trawl survey (middle) and fishery (bottom)

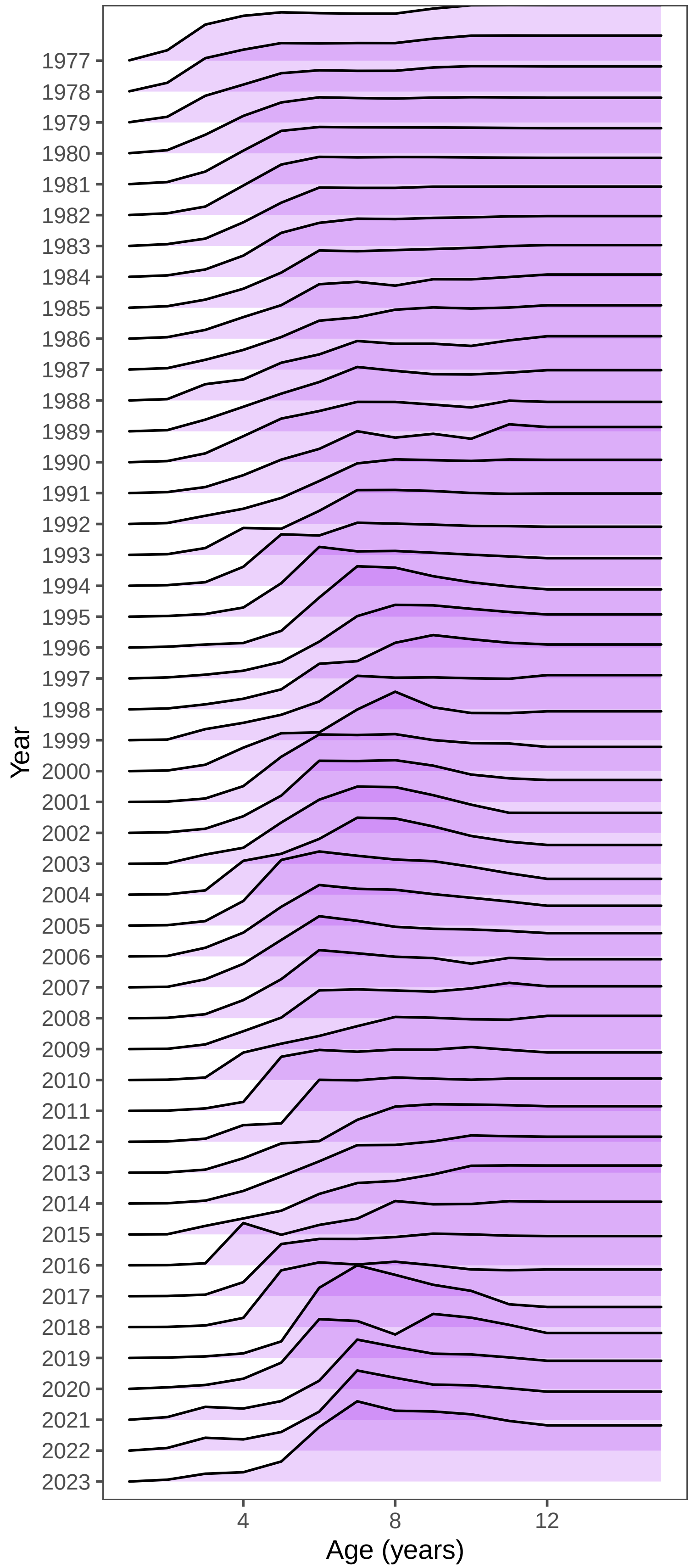

Figure 1-37. Selectivity at age estimates for the EBS pollock fishery; note that the values for the terminal year is used for ABC and OFL projections.

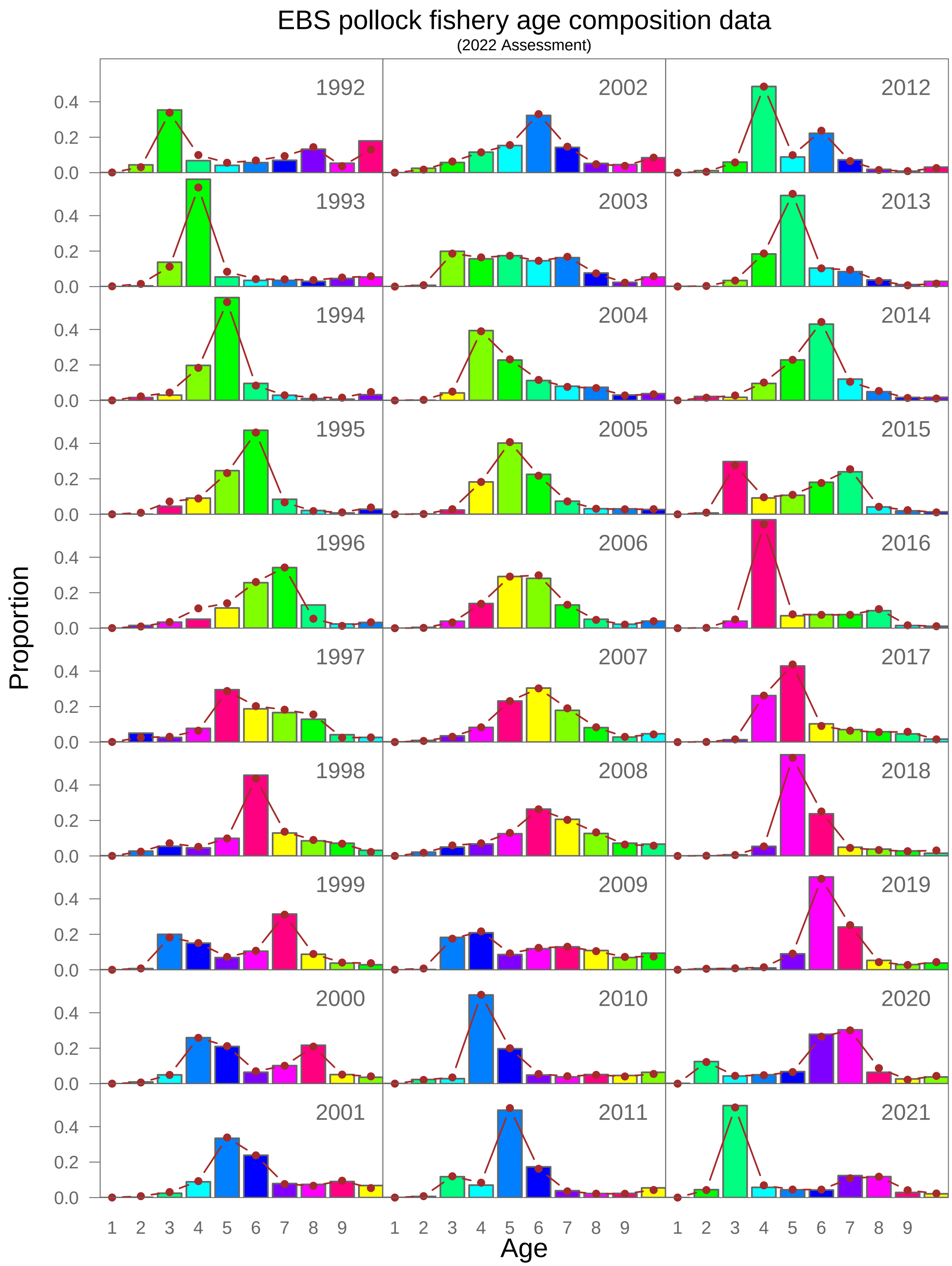

Figure 1-38. Model fit (dots) to the EBS pollock fishery proportion-at-age data (columns; 1992–2021). The 2021 data are new to this year's assessment. Colors coincide with cohorts progressing through time.

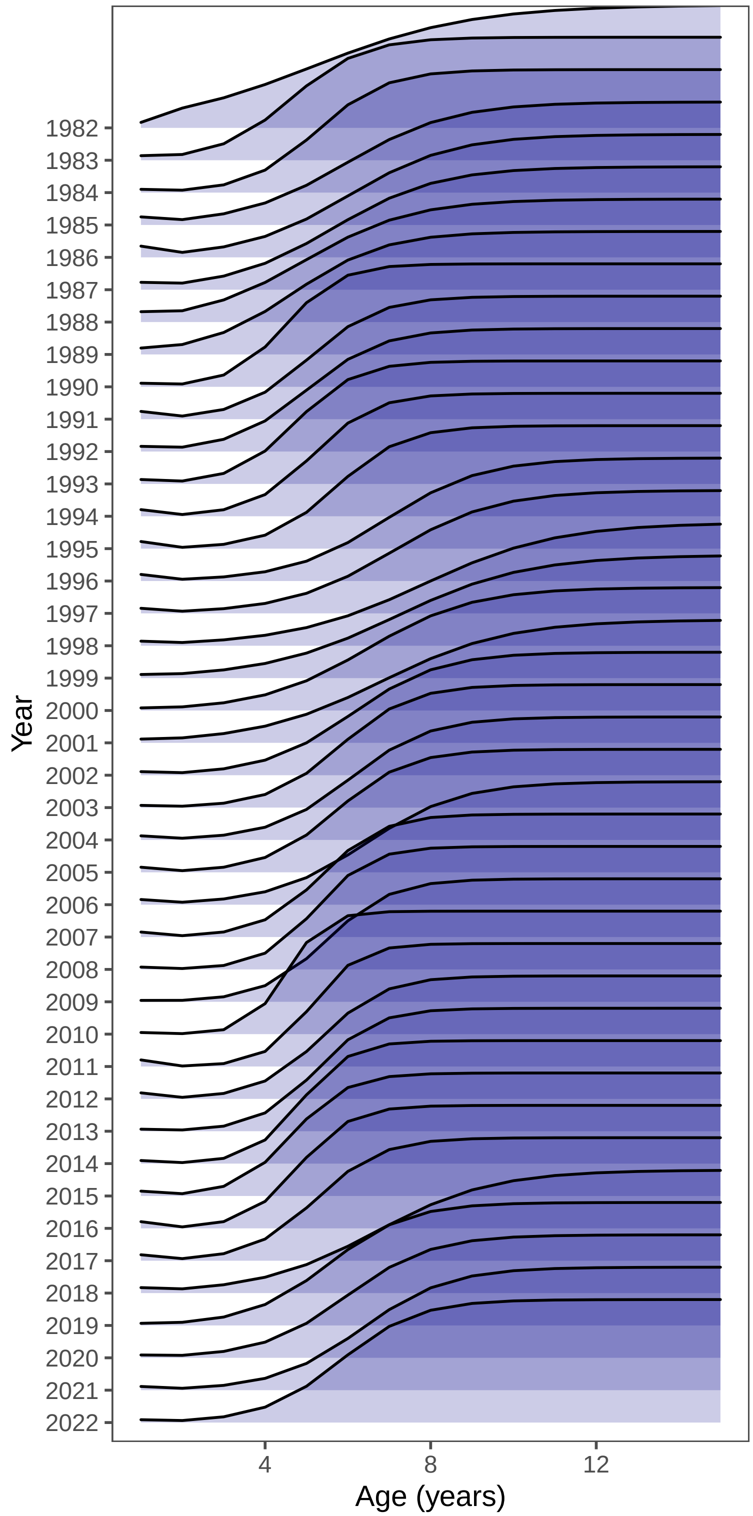

Figure 1-39. Model estimates of bottom-trawl survey selectivity, 1982–2022.

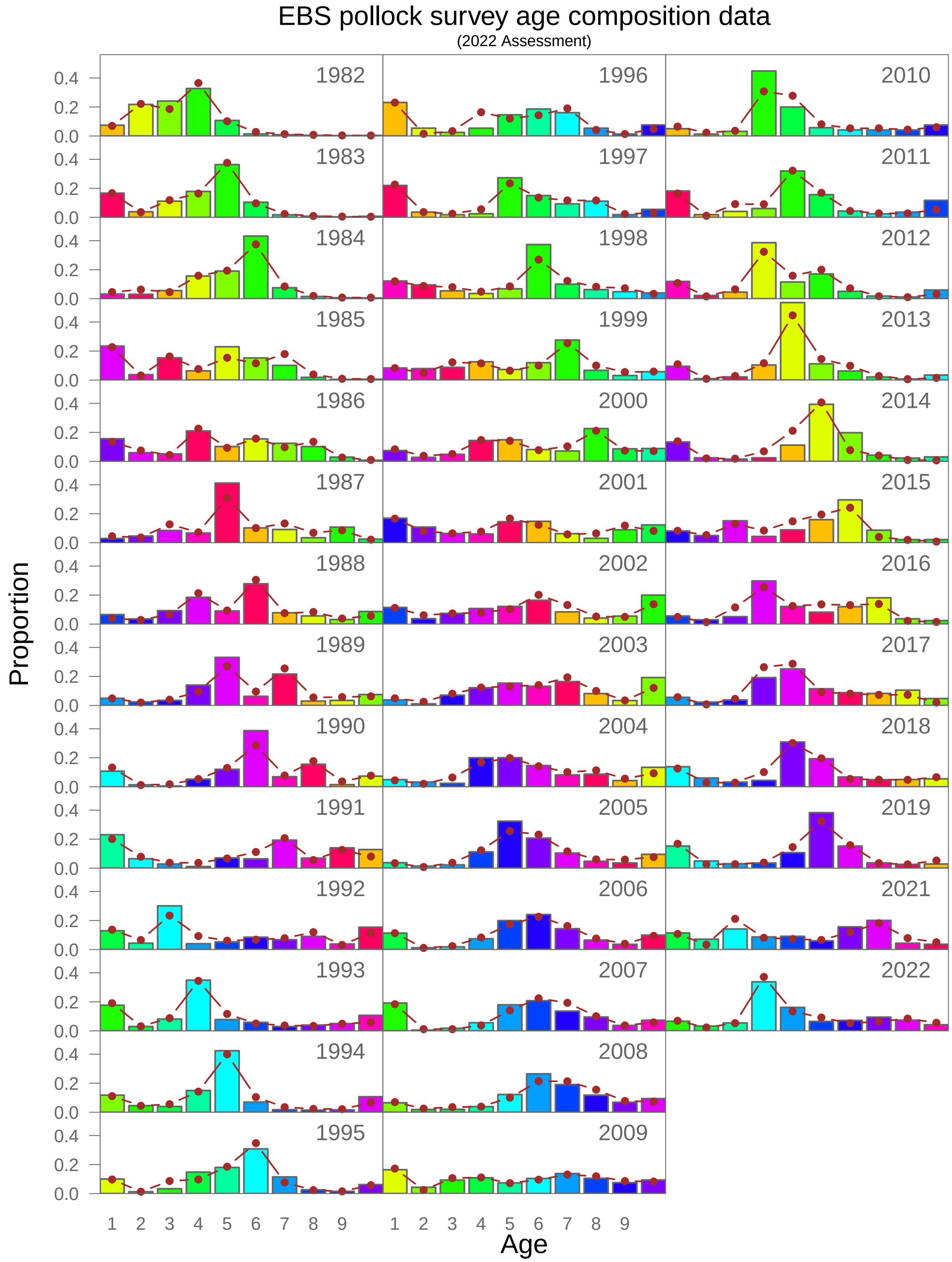

Figure 1-40. Model fit (dots) to the bottom trawl survey proportion-at-age composition data (columns) for EBS pollock. Colors correspond to cohorts over time.

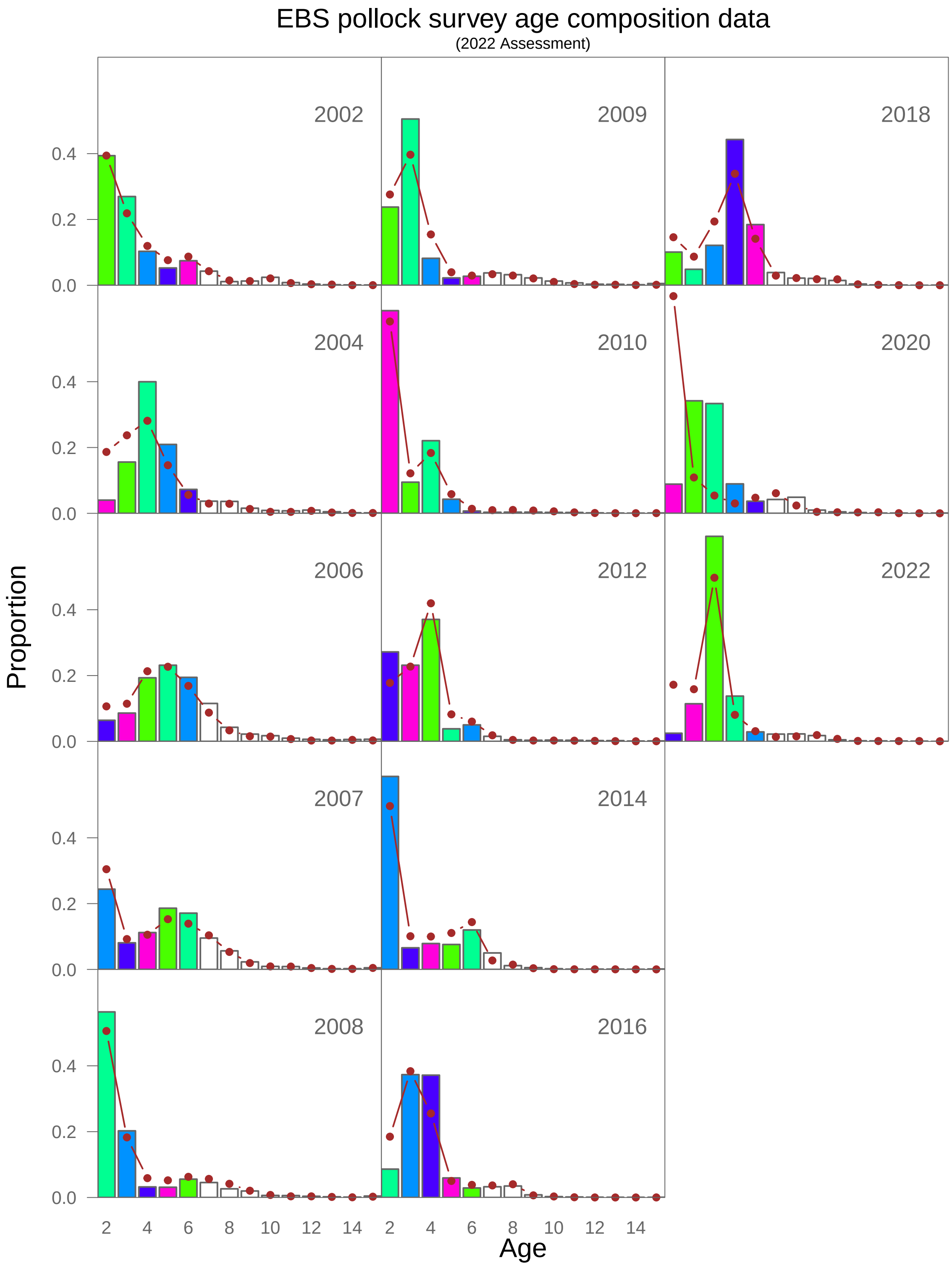

Figure 1-41. Model fit (dots) to the acoustic-trawl survey proportion-at-age composition data (columns) for EBS pollock. Colors correspond to cohorts over time (for years with consecutive surveys).

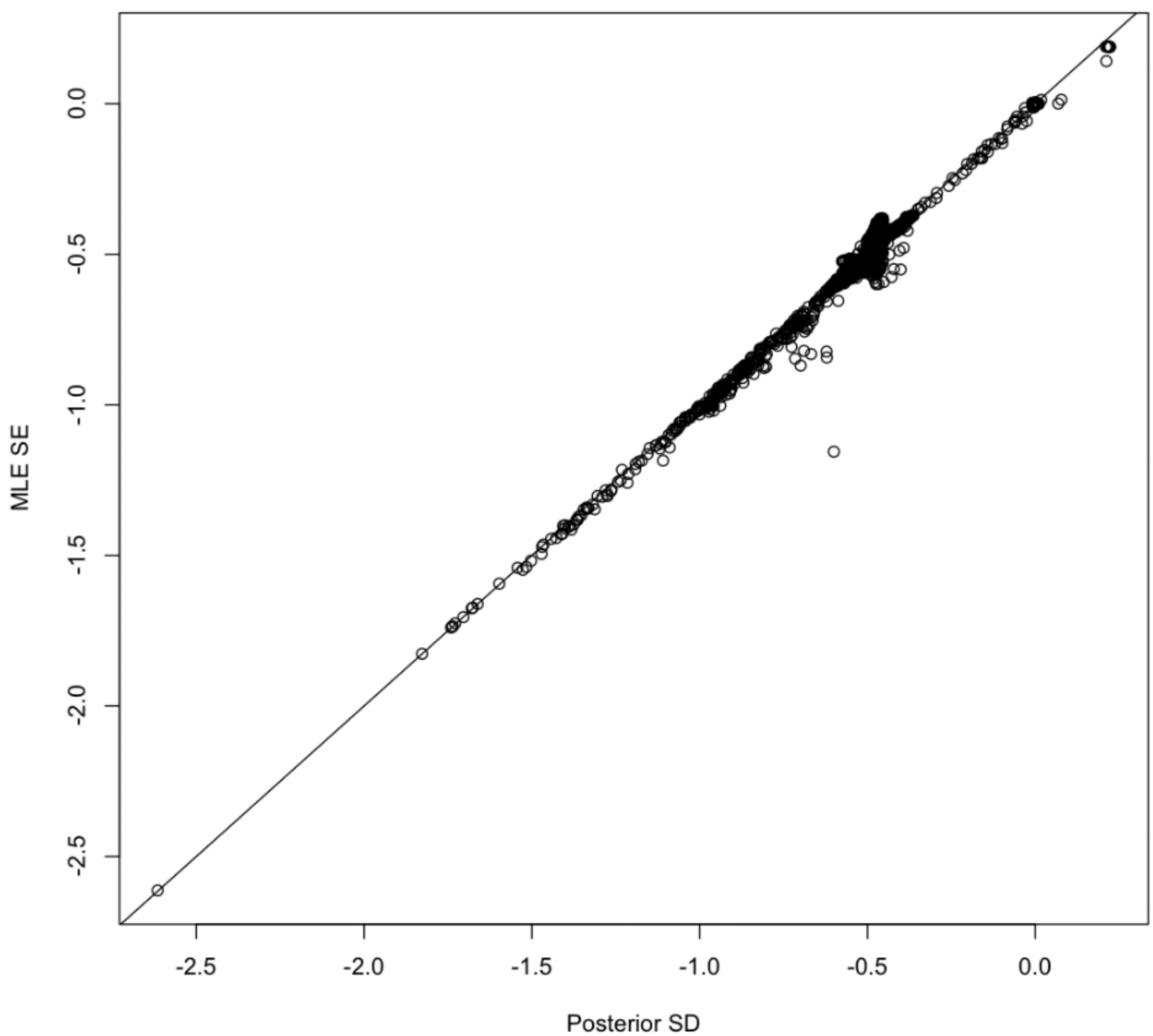

Figure 1-42. Comparison of the asymptotic parameter standard errors (from inverting the Hessian; vertical axis) with the marginals from the MCMC draws (horizontal axis).

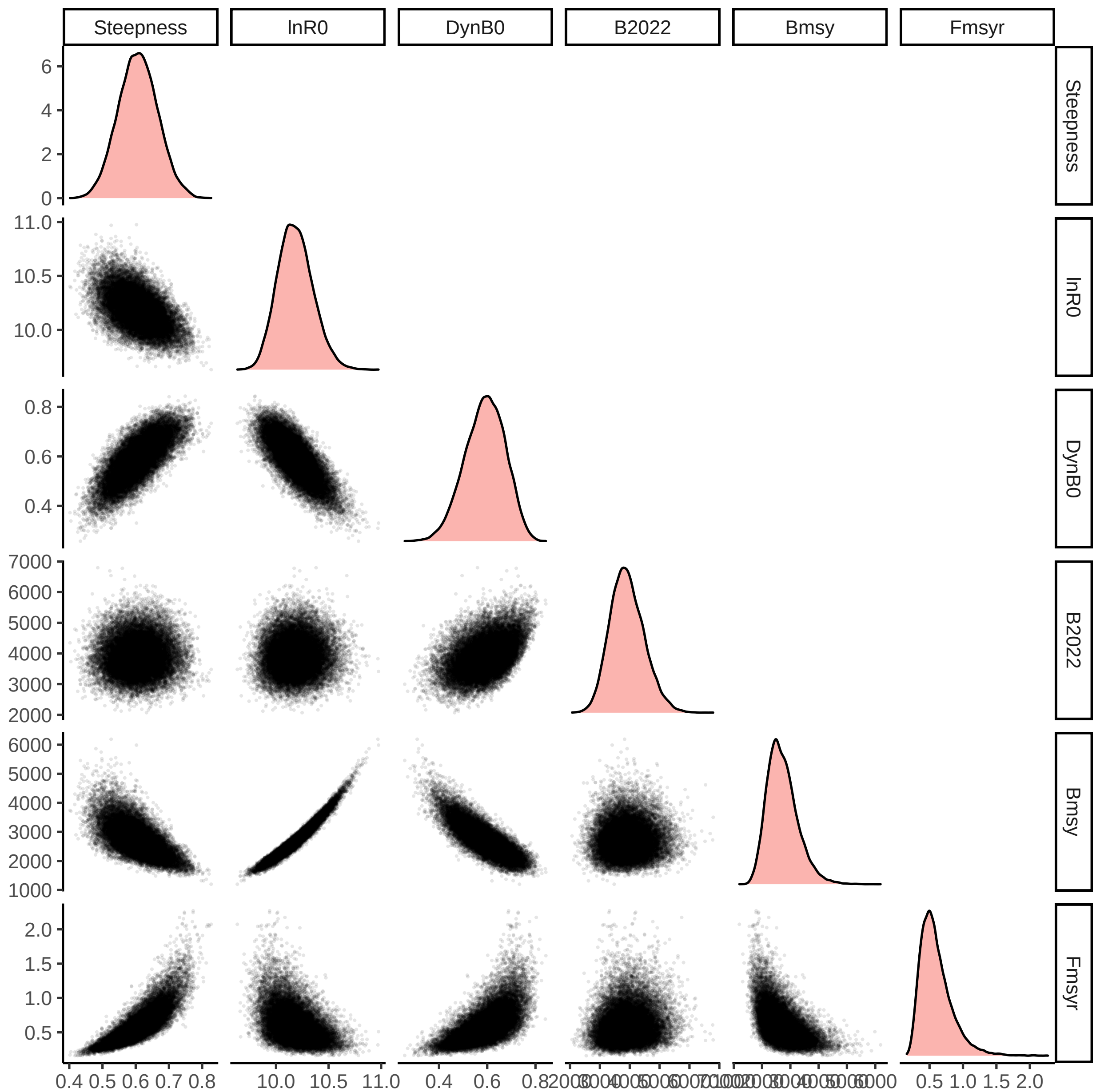

Figure 1-43. Pairwise plot of selected EBS pollock parameters and output from 3 million MCMC iterations thinned such that 5 thousand draws were saved as an approximation to the multivariate posterior distribution. Note that the figures on the diagonal represent the marginal posterior distributions. Key: lnR0 is the parameter that scales the stock-recruit relationship, B_Bmsy is estimated B_{2021}/B_{MSY}, DynB0 is the ratio of spawning biomass estimated for in 2022 over the value estimated that would occur if there had been no fishing, B2022 is the spawning biomass in 2022, and B_Bmean is $B_{2022}/\bar{B}$.

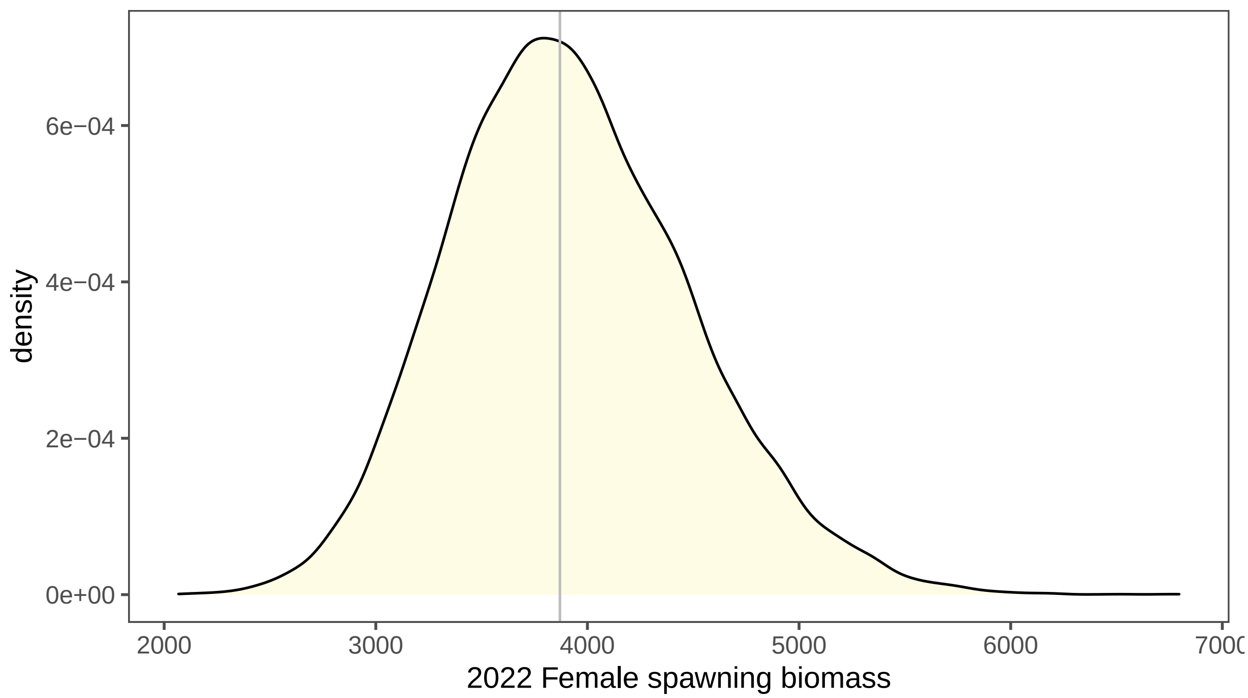

Figure 1-44. Integrated marginal posterior density (based on MCMC results) for the 2021 EBS pollock female spawning biomass compared to the point estimate (dashed red line).

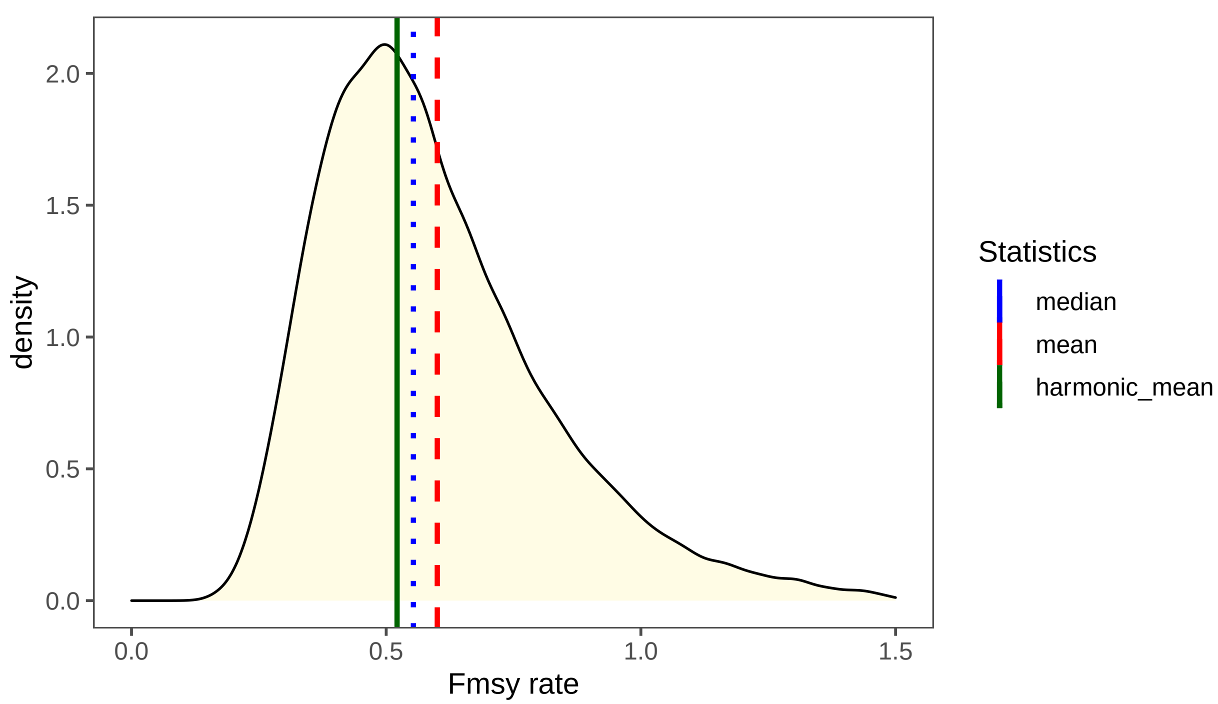

Figure 1-45. Integrated marginal posterior density (based on MCMC results) for the F_{MSY} for EBS pollock and different central tendency values.

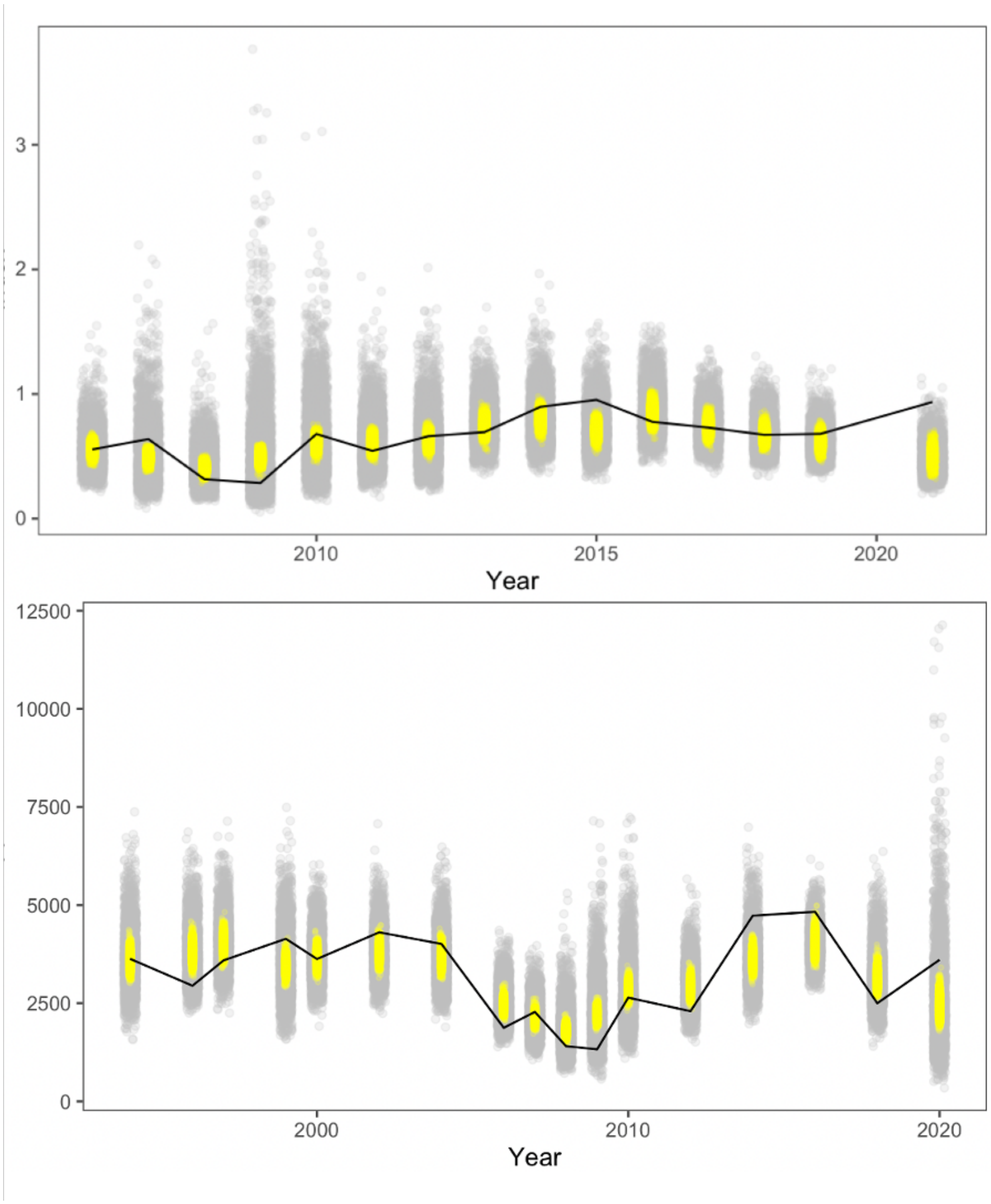

Figure 1-46. Plot of the observed index values (solid line) for the ATS (top) and AVO (bottom), the distribution of the expected value (yellow dots) and the posterior predictive distribution (grey points).

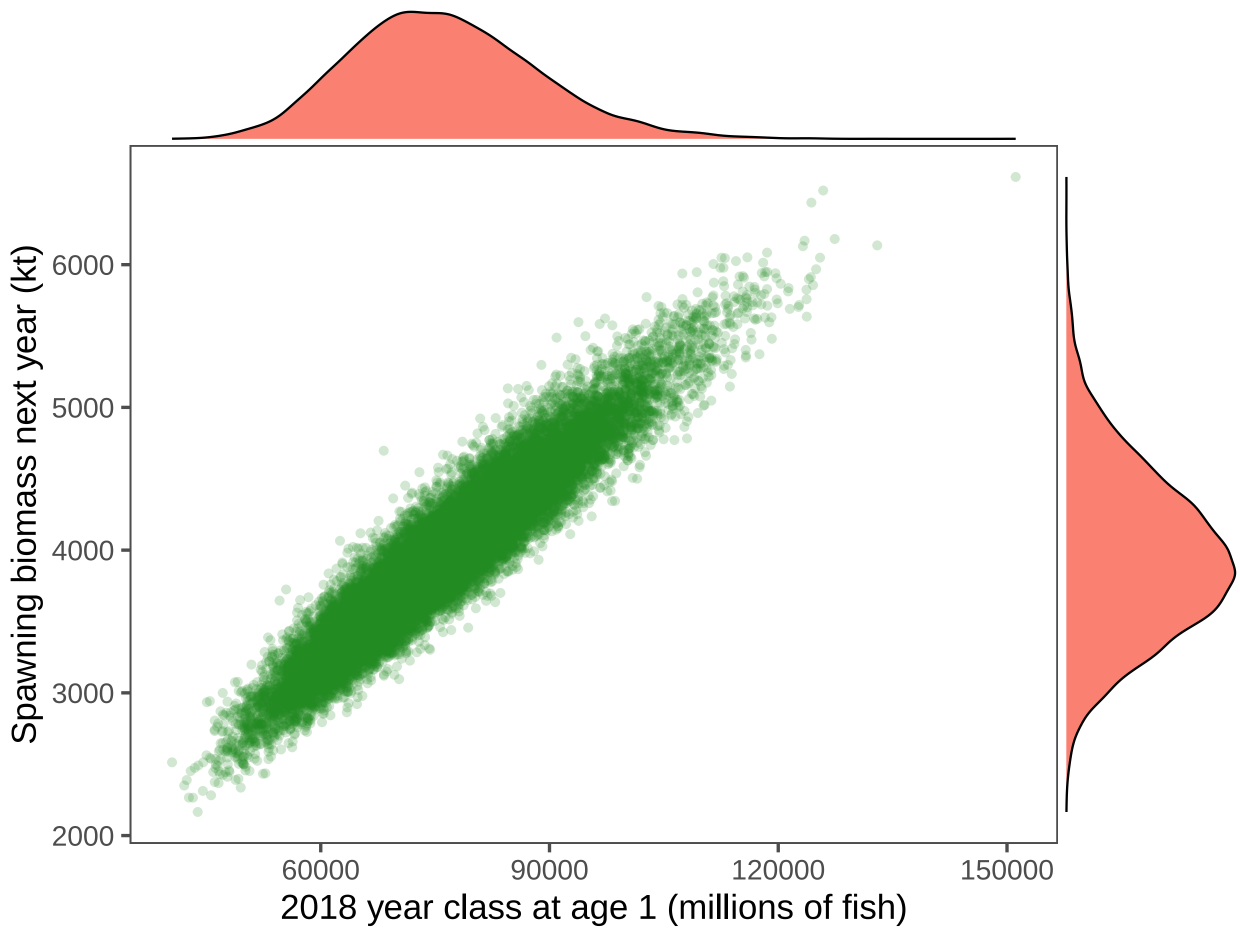

Figure 1-47. Plot of a representation of the posterior marginal distributions of spawning biomass in 2023 (vertical scale and right-side distribution) versus the size of the 2018 year-class (horizontal scale and the top distribution).

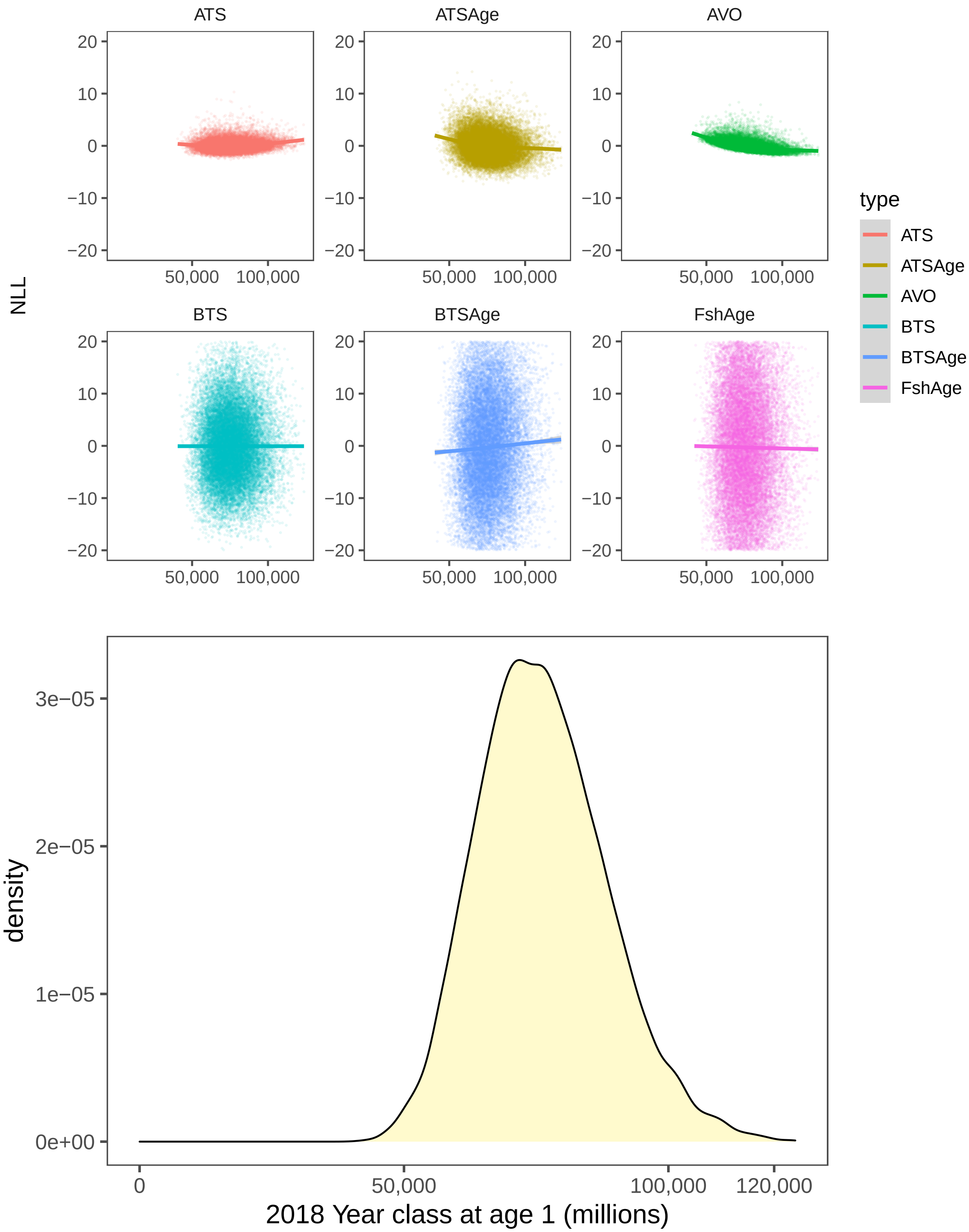

Figure 1-48. Distribution depicting the uncertainty of the 2018 year-class (bottom) and the scatter of posterior likelihood values (with the mean negative log-likelihood subtracted off).

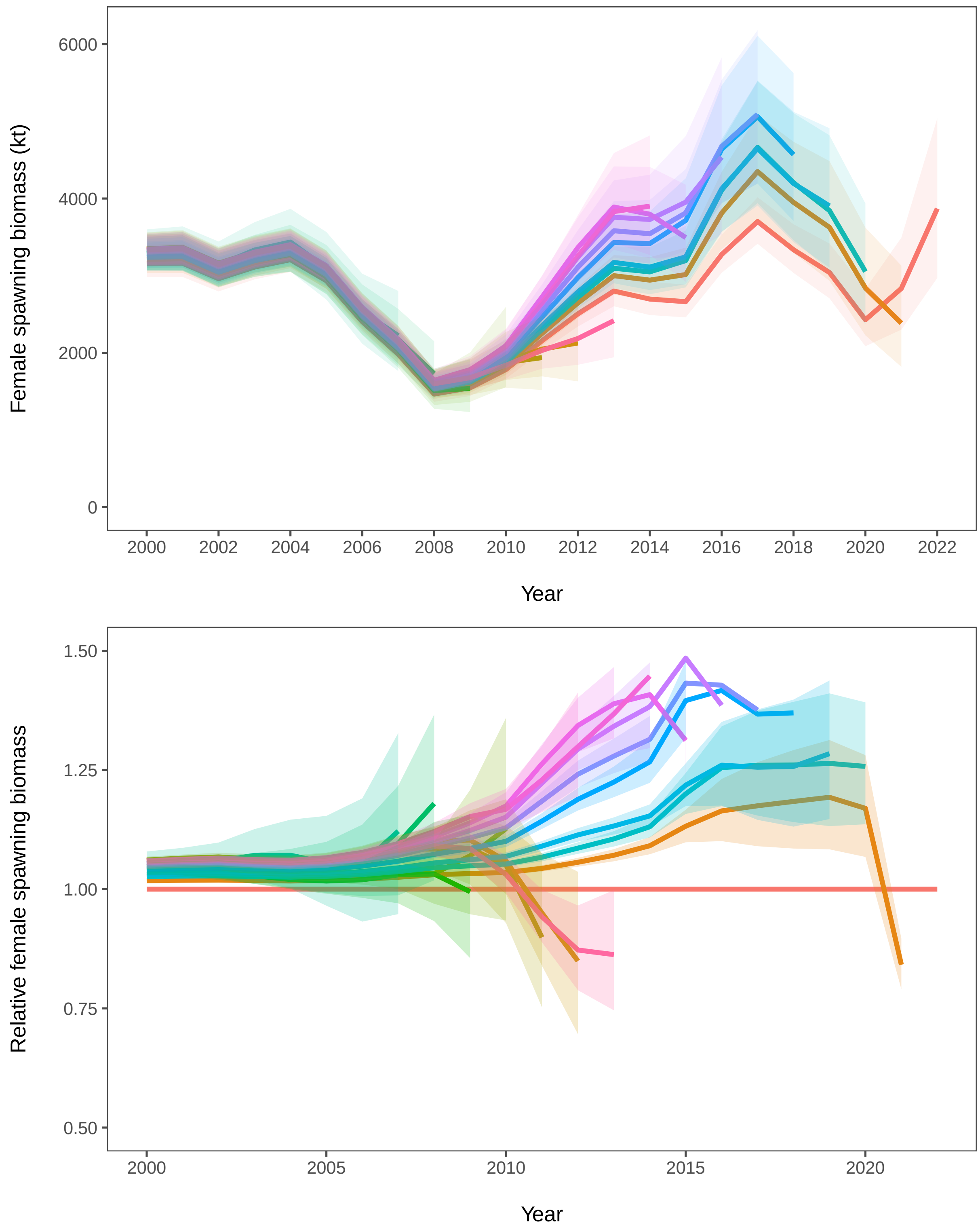

Figure 1-49. Retrospective patterns for EBS pollock spawning biomass showing the point estimates relative to the terminal year (top panel) and approximate confidence bounds on absolute scale (+2 standard deviations).

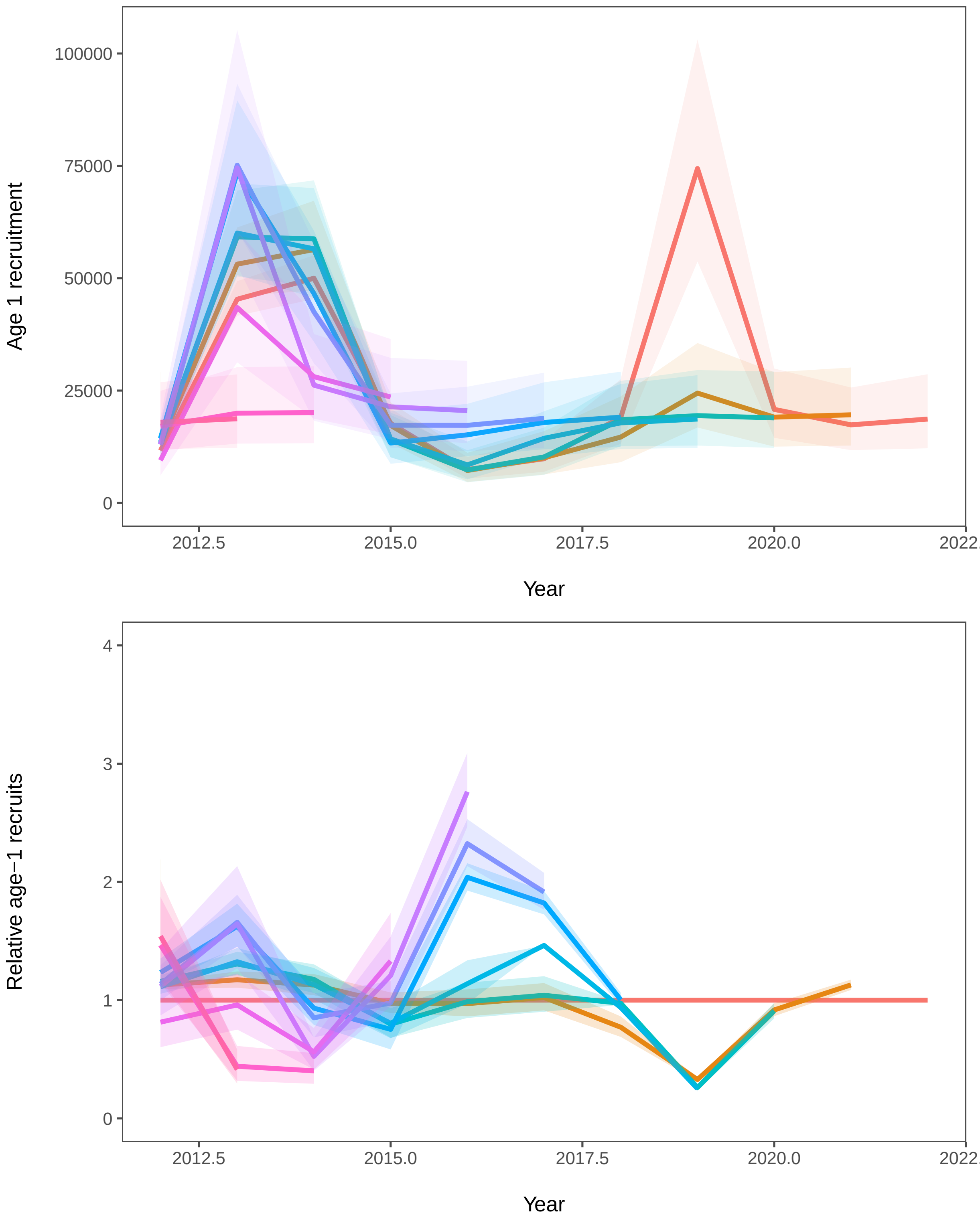

Figure 1-50. Retrospective patterns for EBS pollock recruitment showing the point estimates relative to the terminal year (top panel) and approximate confidence bounds on absolute scale (+2 standard deviations).

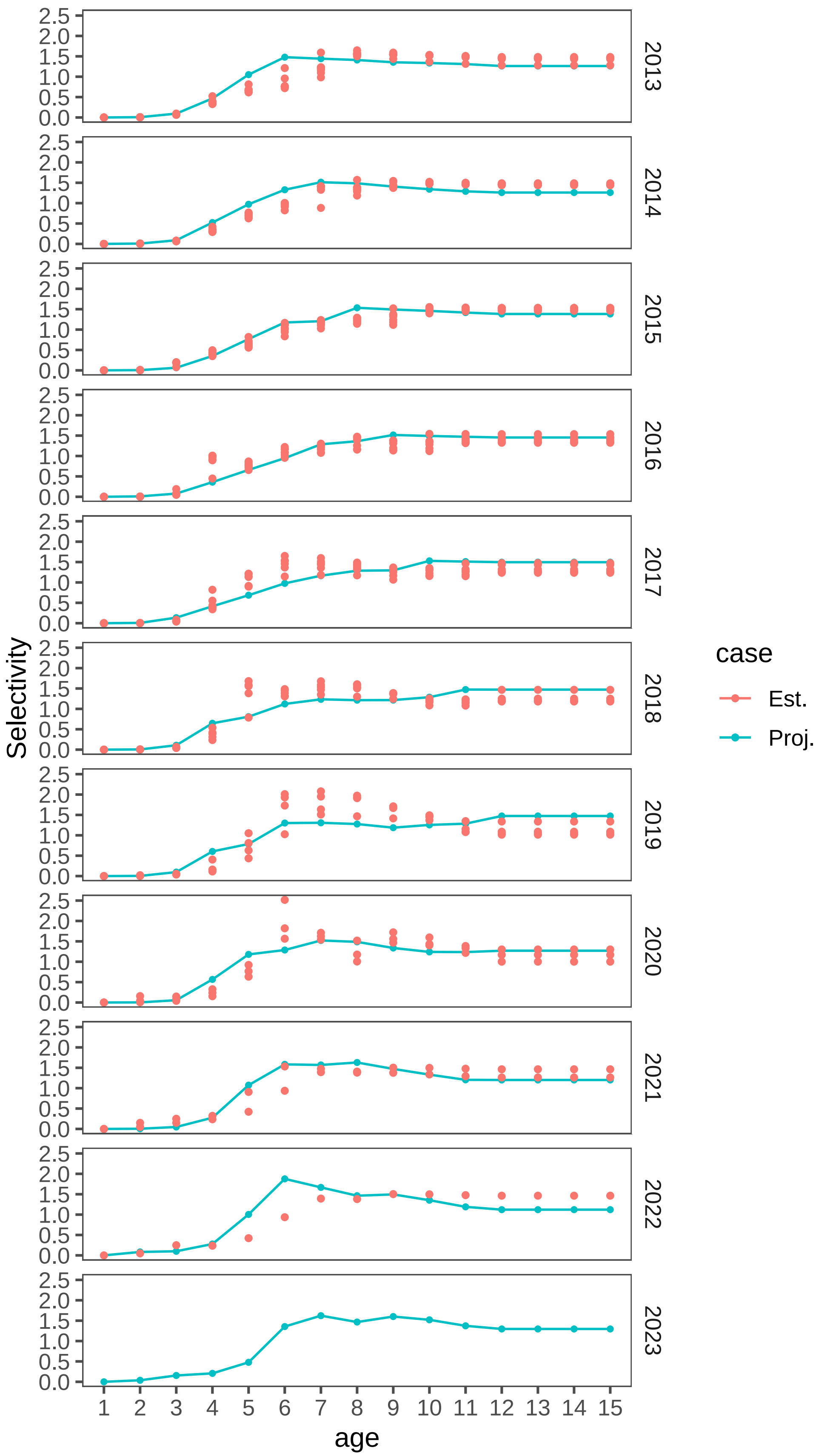

Figure 1-51. Retrospective pattern for estimated EBS pollock fishery selectivity (dots) compared to the projected selectivity from the year prior (solid line).

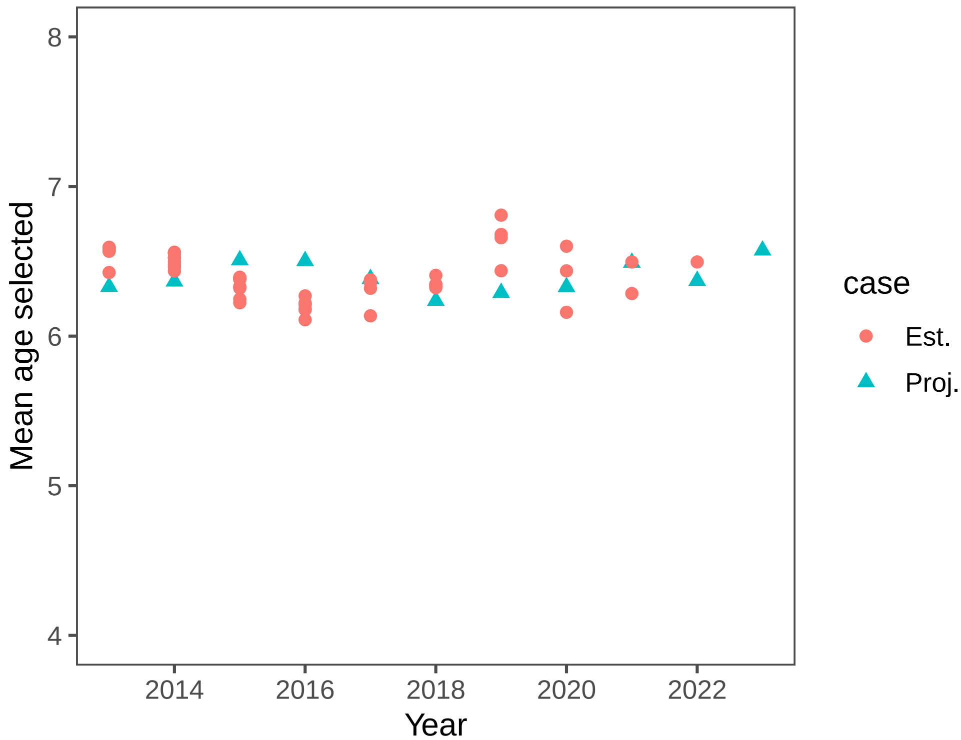

Figure 1-52. Retrospective pattern for the mean selected age (ages 1-8) based on estimated EBS pollock fishery selectivity compared to the projected selectivity from the year prior.

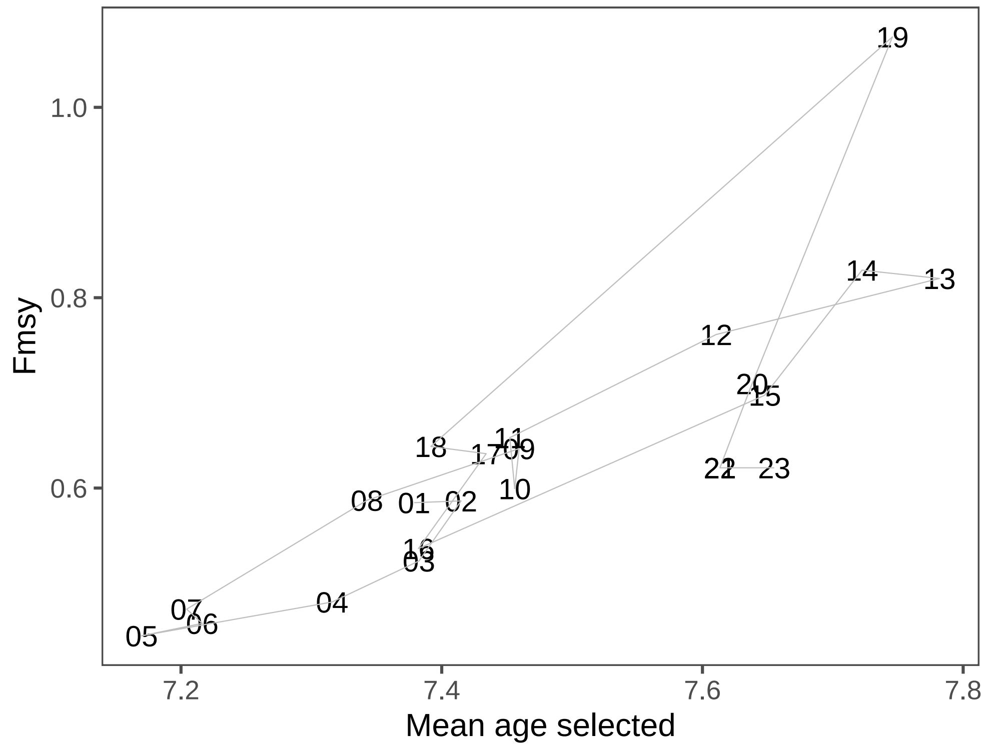

Figure 1-53. Comparison of F_{MSY} and mean selected age. The horizontal axis is a way to summarize if selectivity tends towards younger or older fish. Labels indicate the year that demographic parameters (weight-at-age, selectivity-at-age) were used to compute F_{MSY}.

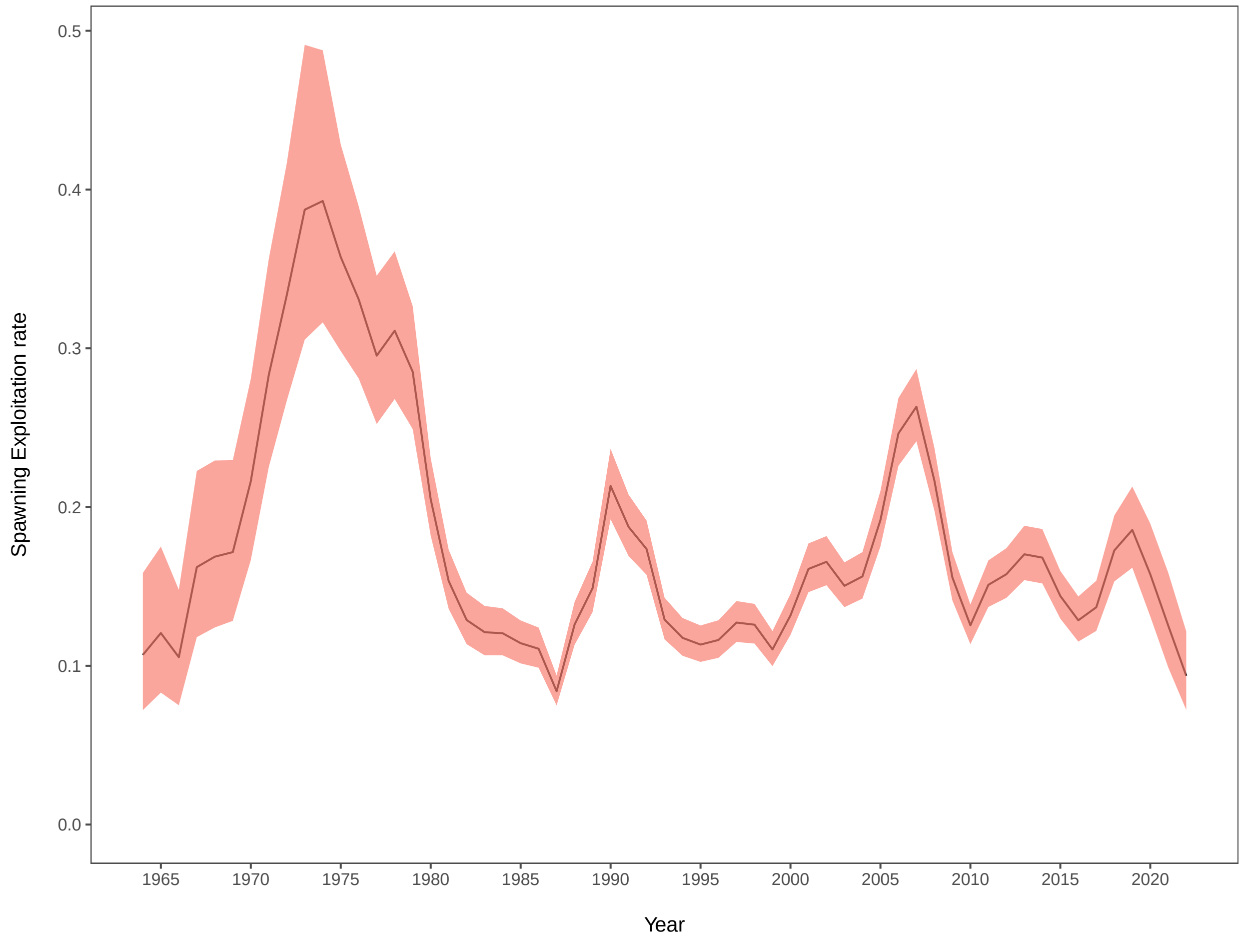

Figure 1-54. Estimated spawning exploitation rate (defined as the percent removal of egg production in a given spawning year).

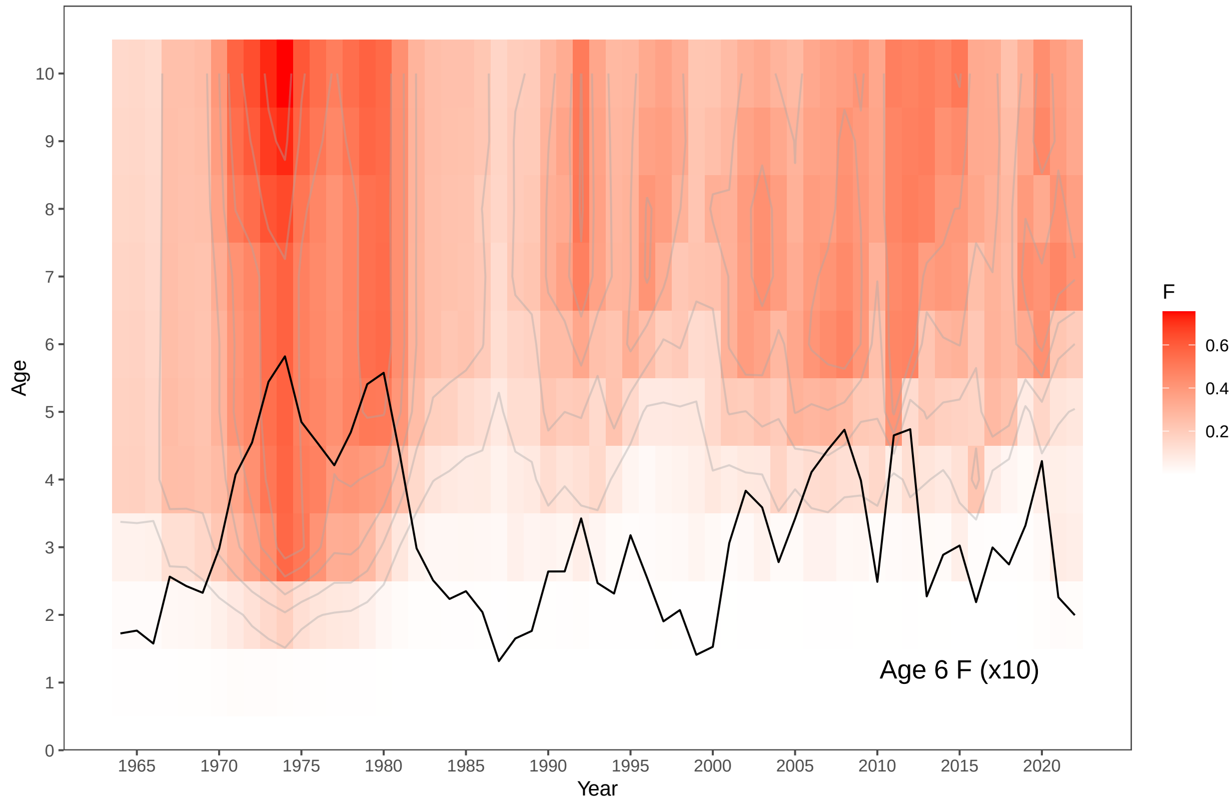

Figure 1-55. Estimated instantaneous age-specific fishing mortality rates for EBS pollock.

Figure 1-56. Comparison of the current assessment results with past assessments of begin-year EBS age-3+ pollock biomass.

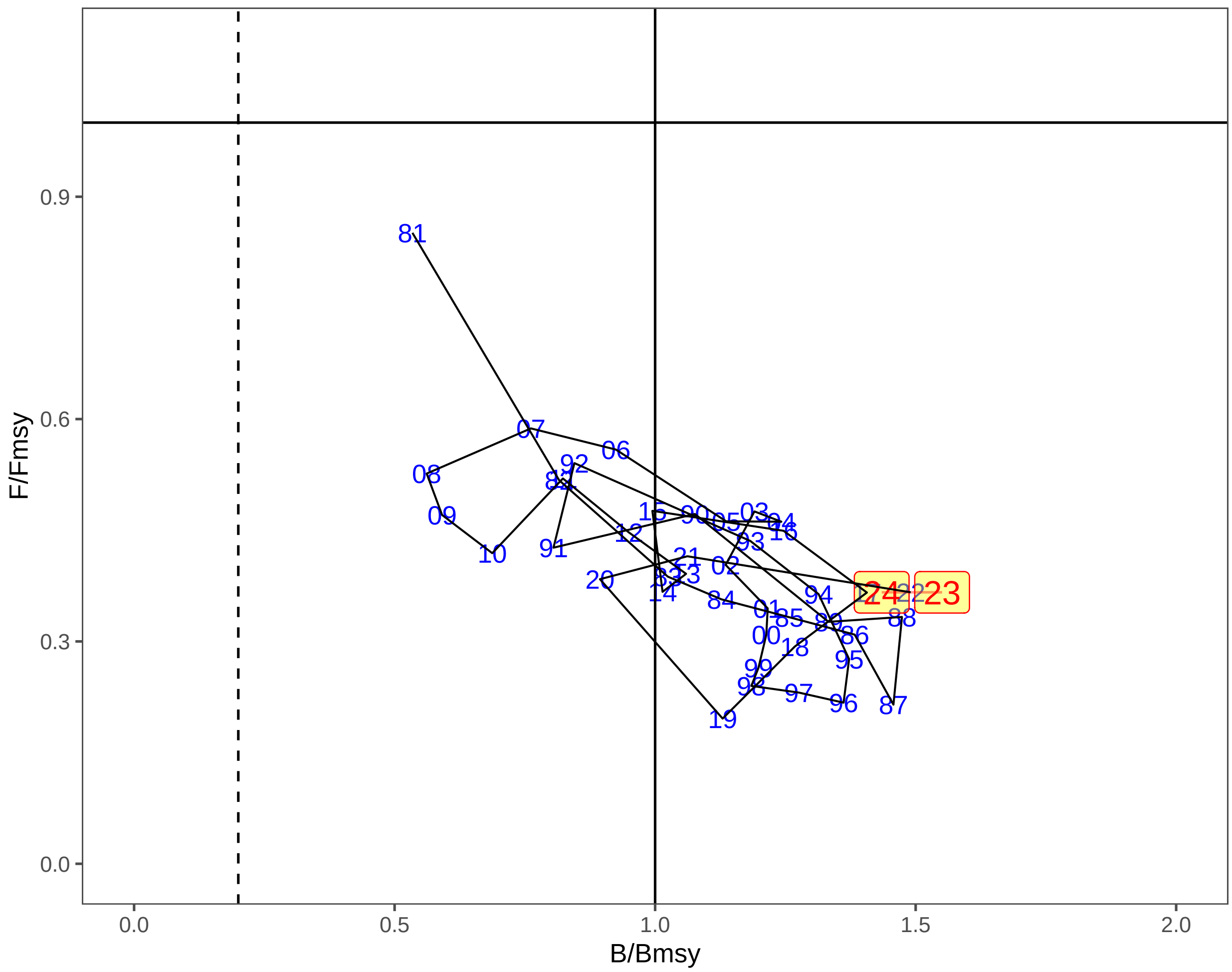

Figure 1-57. Estimated spawning biomass relative to annually estimated F_{MSY} values and fishing mortality rates for EBS pollock. Two projection years are shaded in yellow.

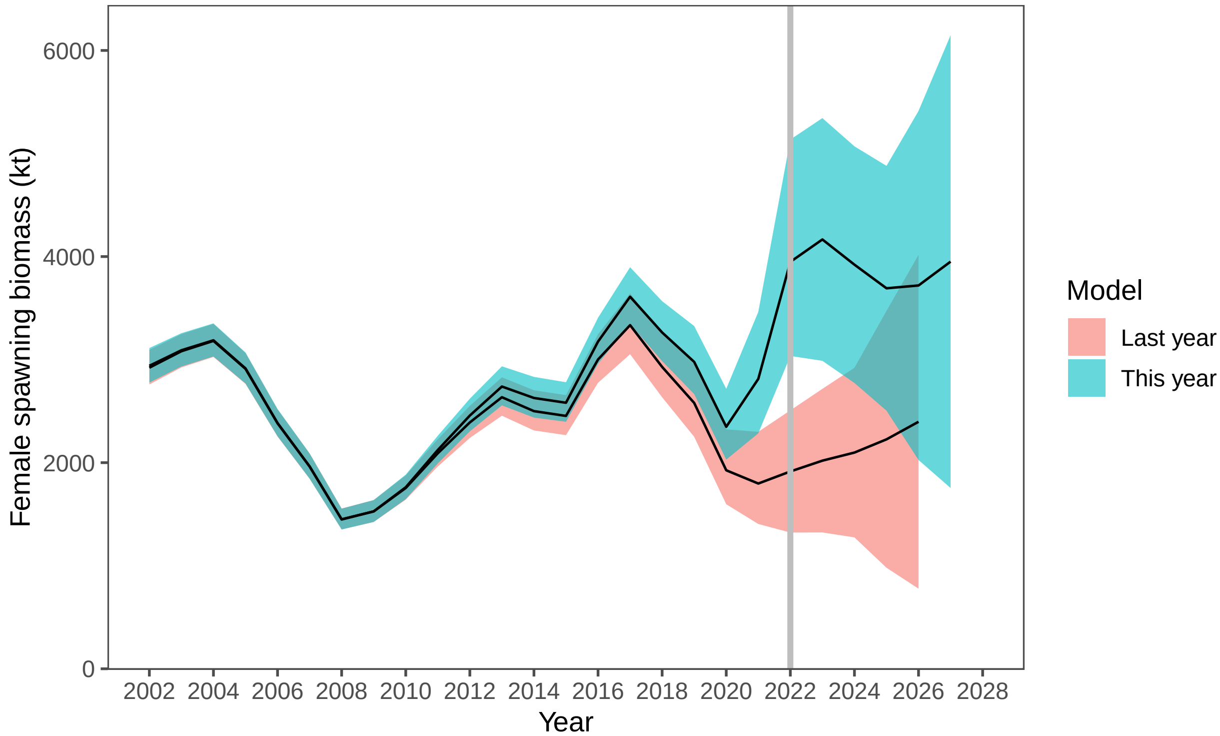

Figure 1-58. The estimated EBS pollock spawning stock biomass for model 20 last year and this with projections equal to the estimated fishing mortality from 2022.

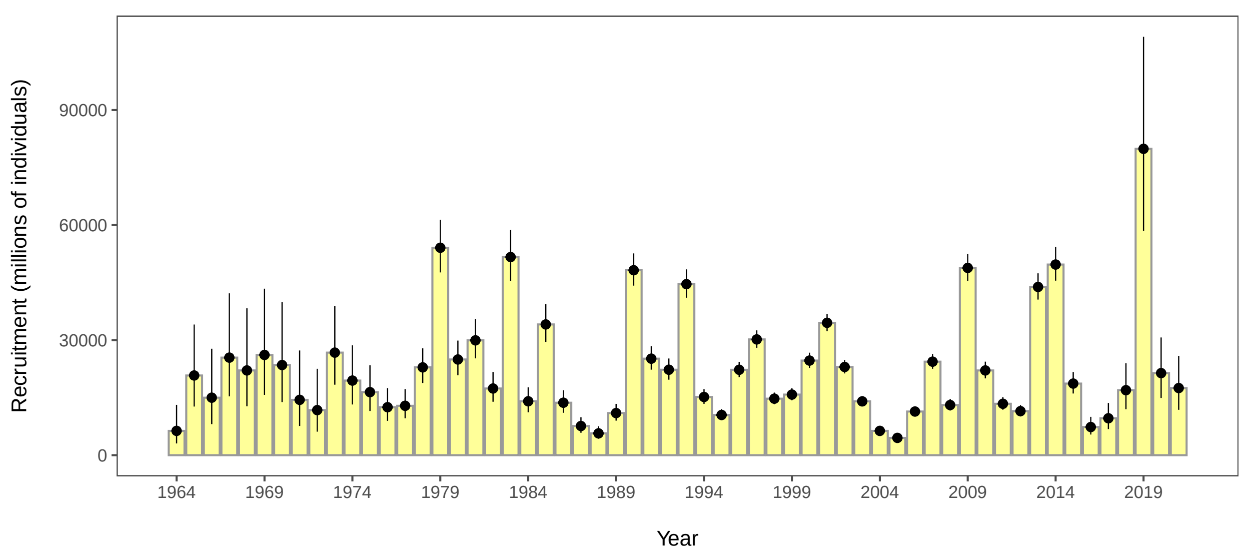

Figure 1-59. Recruitment estimates (age-1 recruits) for EBS pollock for all years since 1964 (1963–2021 year classes) for Model 20. Error bars reflect 90% credible intervals based on model estimates of uncertainty.

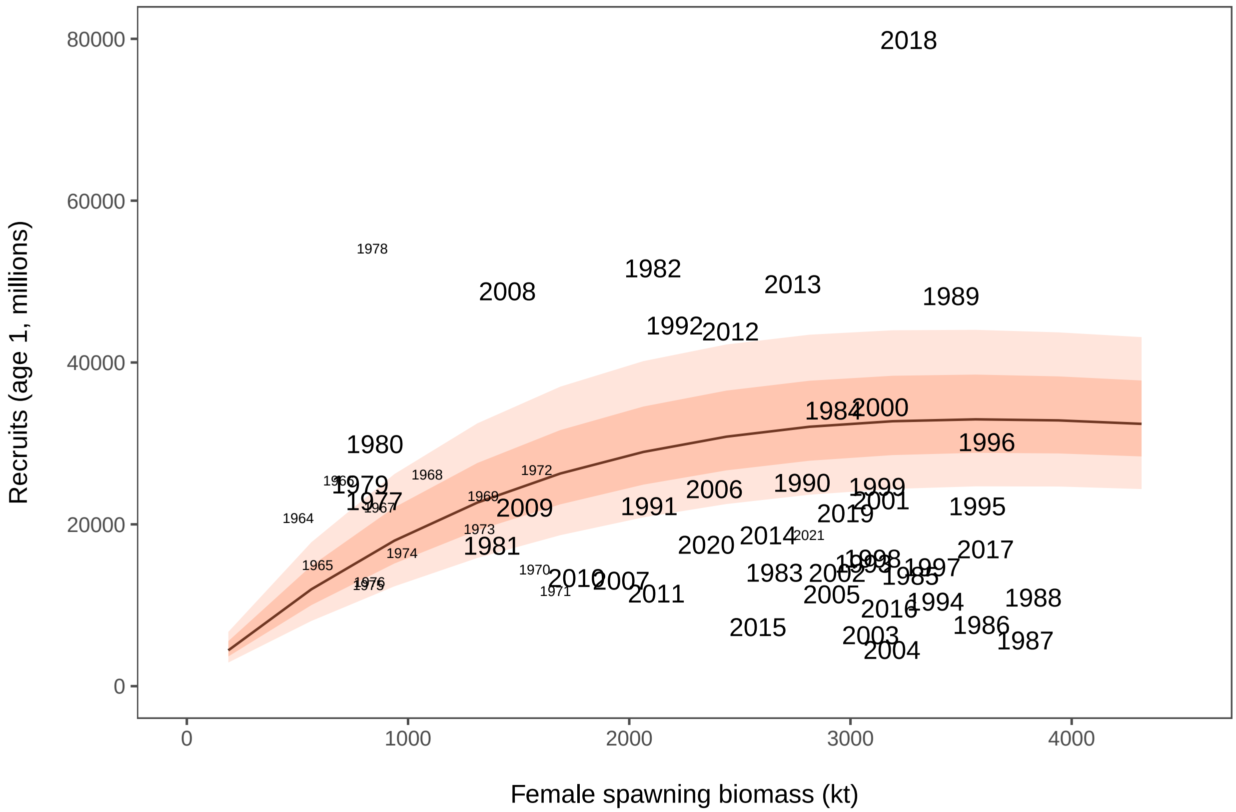

Figure 1-60. Stock-recruitment estimates (shaded represents structural uncertainty) and age-1 EBS pollock estimates labeled by year-classes.

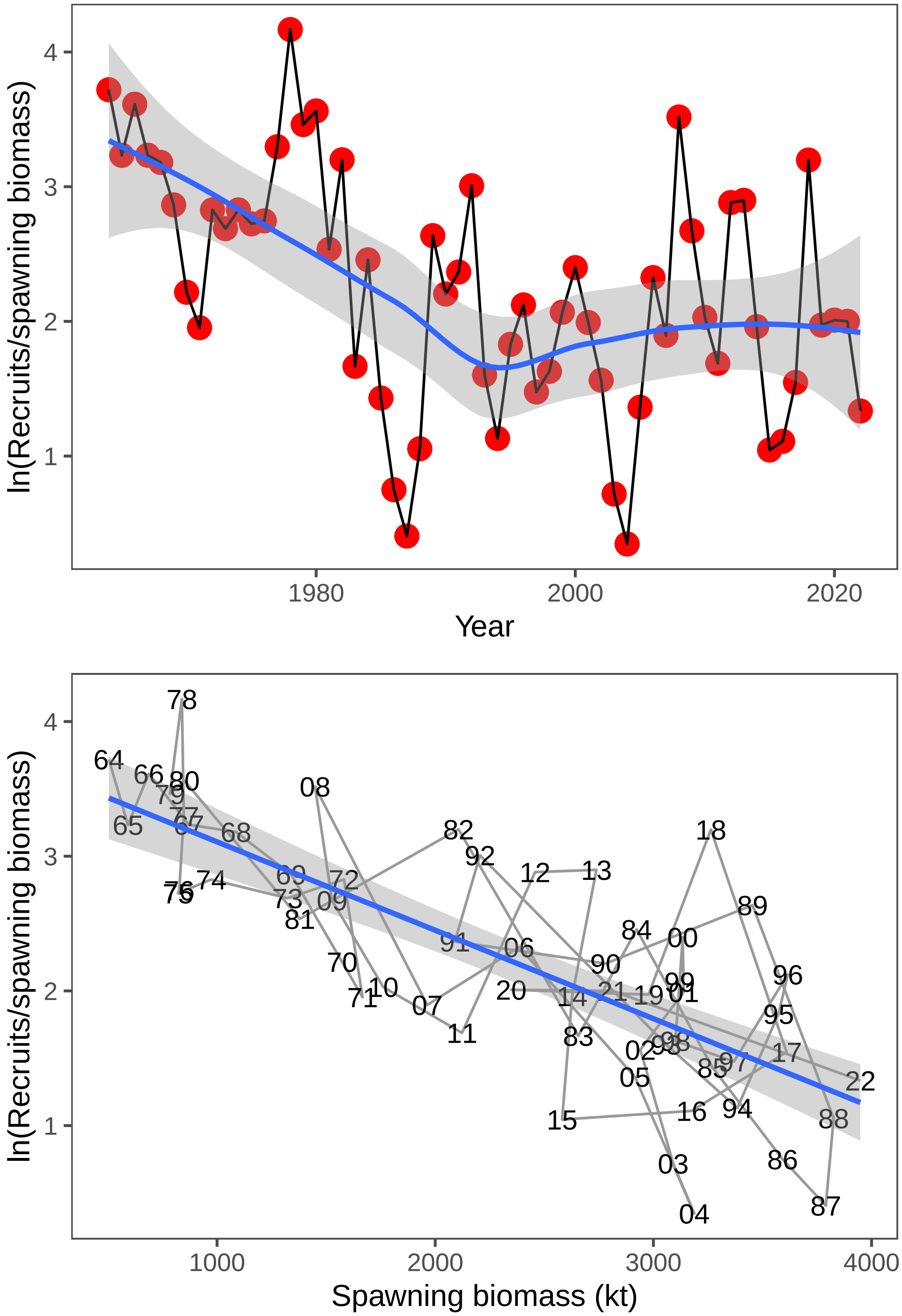

Figure 1-61. EBS pollock productivity as measured by logged recruits per spawning biomass, log(R/S), as a function of spawning biomass with a linear fit (bottom) and over time, 1964–2022 (top).

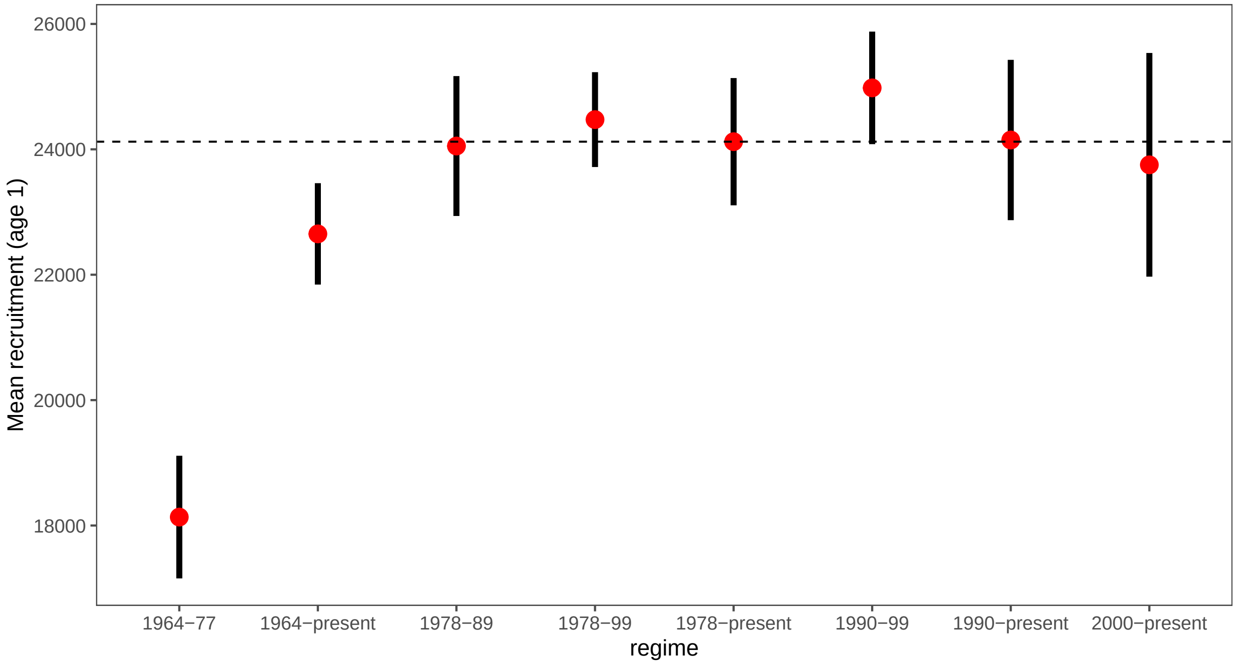

Figure 1-62. Mean recruitment estimates (age-1) for EBS pollock for different periods with error bars representing 95% credible intervals.

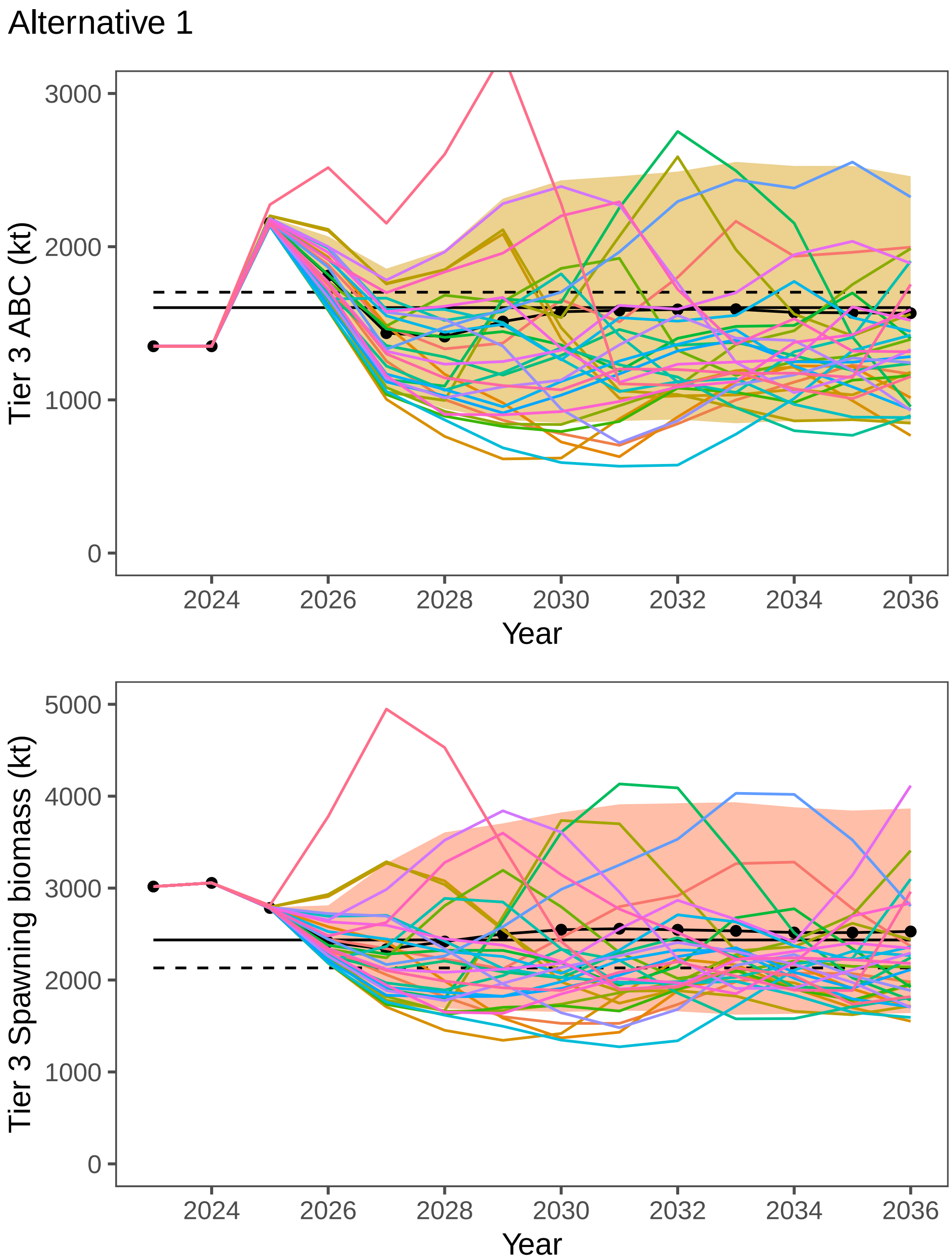

Figure 1-63. Projected EBS Tier 3 pollock yield (top) and female spawning biomass (bottom) relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines). $B_{40\%}$ is computed from average recruitment from 1978–2020. Future harvest rates follow the guidelines specified under Tier 3 Scenario 1.

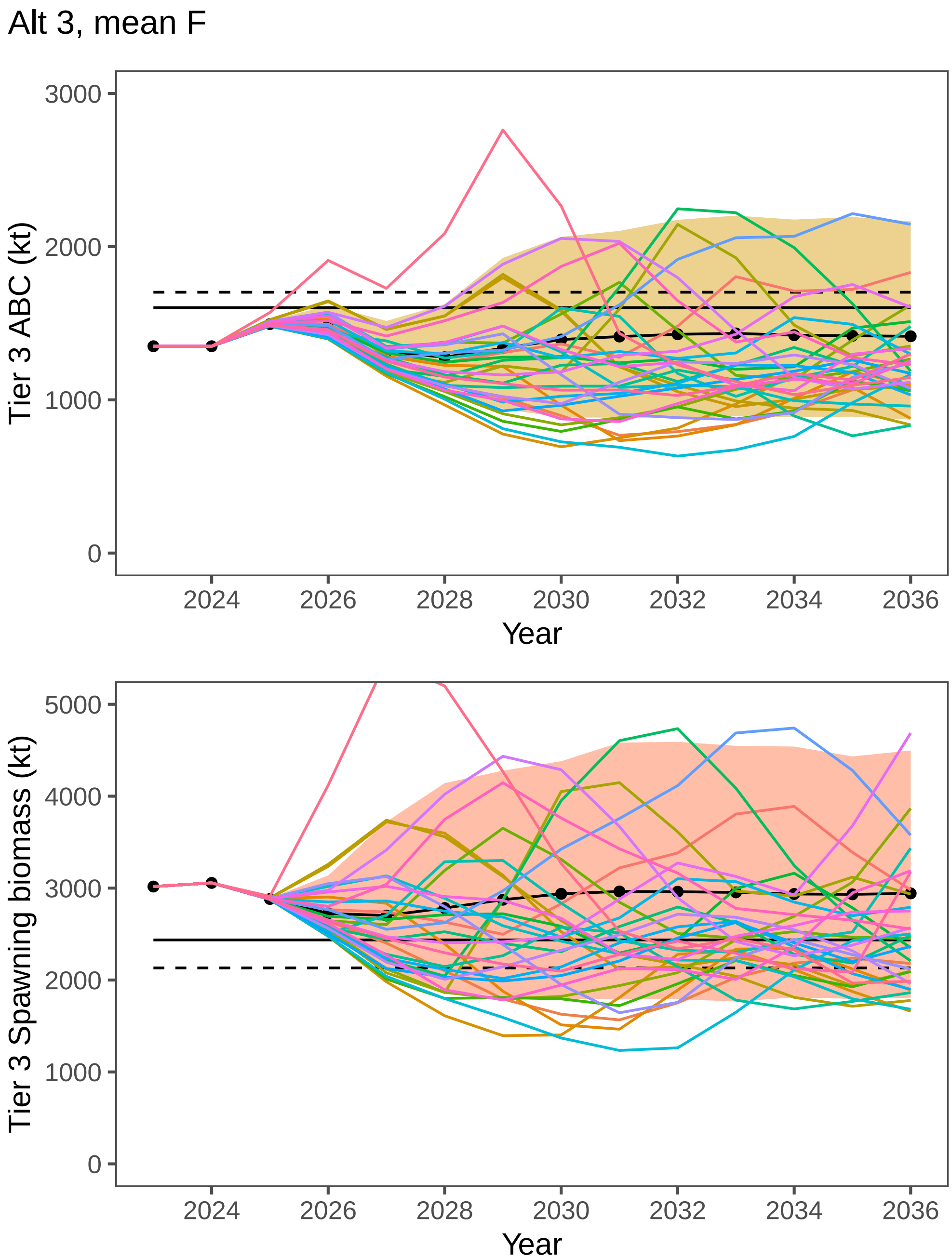

Figure 1-64. Projected pollock yield (top) and female spawning biomass (bottom) under Alternative 3—fishing under the recent 5-year average fishing mortality. The long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines) $B_{40\%}$ are computed from average recruitment from 1978–2020.

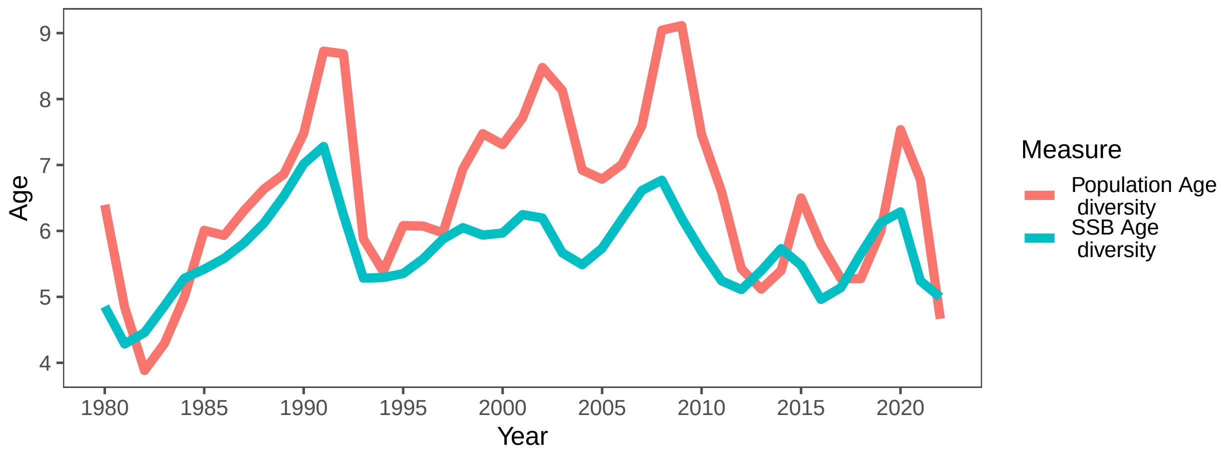

Figure 1-65. For the mature component of the EBS pollock stock, time series of estimated average age and diversity of ages (using the Shannon-Wiener H statistic), 1980–2022.

EBS Pollock Model Description

Dynamics

This assessment is based on a statistical age-structured model with the catch equation and population dynamics model as described in Fournier and Archibald (1982) and elsewhere (e.g., Hilborn and Walters 1992, Schnute and Richards 1995, McAllister and Ianelli 1997). The catch in numbers at age in year $t(C_{t,a})$ and total catch biomass (Y_t) can be described as:

$$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}\left(1 - e^{-Z_{t,a}}\right) N_{t,a}, \qquad 1 \le t \le T, 1 \le a \le A \tag{1}$$

$$N_{t+1,a+1} = N_{t,a-1} e^{-Z_{t,a-1}} \qquad 1 \le t \le T, 1 \le a < A \tag{2}$$

$$N_{t+1,A} = N_{t,A-1} e^{-Z_{t,A-1}} + N_{t,A} e^{-Z_{t,A}}, \qquad 1 \le t \le T \tag{3}$$

$$Z_{t,a} = F_{t,a} + M_{t,a} \tag{4}$$

$$C_{t,.} = \sum_{a=1}^{A} C_{t,a} \tag{5}$$

$$p_{t,a} = \frac{C_{t,a}}{C_{t,.}} \tag{6}$$

$$Y_t = \sum_{a=1}^{A} w_{t,a} C_{t,a} \tag{7}$$

$$\tag{8}$$

where

T	is the number of years,
A	is the number of age classes in the population,
$N_{t,a}$	is the number of fish age a in year t,
$C_{t,a}$	is the catch of age class a in year t,
$p_{t,a}$	is the proportion of the total catch in year t, that is in age class a,
C_t	is the total catch in year t,
w_a	is the mean body weight (kg) of fish in age class a,
Y_t	is the total yield biomass in year t,
$F_{t,a}$	is the instantaneous fishing mortality for age class a, in year t,
$M_{t,a}$	is the instantaneous natural mortality in year t for age class a, and
$Z_{t,a}$	is the instantaneous total mortality for age class a, in year t.

Fishing mortality $(F_{t,a})$ is specified as being semi-separable and non-parametric in form with restrictions on the variability following Butterworth et al. (2003):

$$F_{t,a} = s_{t,a}\, \mu^f e^{\epsilon_t}, \qquad \epsilon_t \sim \mathcal{N}(0,\, \sigma_E^2) \tag{9}$$

$$s_{t+1,a} = s_{t,a}\, e^{\gamma_t}, \qquad \gamma_t \sim \mathcal{N}(0,\, \sigma_s^2) \tag{10}$$

where $s_{t,a}$ is the selectivity for age class a in year t, and μ^f is the median fishing mortality rate over time.

If the selectivities ($s_{t,a}$) are constant over time then fishing mortality rate decomposes into an age component and a year component. A curvature penalty on the selectivity coefficients using the squared second-differences to provide smoothness between ages.

Bottom-trawl survey selectivity was set to be asymptotic yet retain the properties desired for the characteristics of this gear. Namely, that the function should allow flexibility in selecting age 1 pollock over time. The functional form of this selectivity was:

$$s_{t,a} = \left[1 + e^{-\alpha_t a - \beta_t}\right]^{-1}, \qquad a > 1 \tag{11}$$

$$s_{t,a} = \mu_s e^{-\delta_t^{\mu}}, \qquad a = 1 \tag{12}$$

$$\alpha_t = \bar{\alpha} e^{\delta_t^{\alpha}}, \tag{13}$$

$$\beta_t = \bar{\beta} e^{\delta_t^{\beta}}, \tag{14}$$

where the parameters of the selectivity function follow a random walk process as in Dorn et al. (2000):

$$\delta_t^{\mu} - \delta_{t+1}^{\mu} \sim \mathcal{N}(0,\, \sigma^2_{\delta^{\mu}}) \tag{15}$$

$$\tag{16}$$

$$\alpha_t^{\mu} - \alpha_{t+1}^{\mu} \sim \mathcal{N}(0,\, \sigma^2_{\alpha^{\mu}}) \tag{17}$$

$$\beta_t^{\mu} - \beta_{t+1}^{\mu} \sim \mathcal{N}(0,\, \sigma^2_{\beta^{\mu}}) \tag{18}$$

The parameters to be estimated in this part of the model are thus for t=1982 through to 2022. The variance terms for these process error parameters were specified to be 0.04.

In this assessment, the random-walk deviation penalty was optionally shifted to the changes in log-selectivity. that is, for the BTS estimates, the process error was applied to the logistic parameters as above, but the lognormal penalty was applied to the resulting selectivities-at-age directly. The extent of this variability was evaluated in the context of the impact on age-specific survey catchability/availability and contrasted with an independent estimate of pollock availability to the bottom trawl survey.

$$ln(s_{t,a}) - ln(s_{t+1,a}) \sim \mathcal{N}(0,\, \sigma^2_{sel}) \tag{19}$$

$$\tag{20}$$

In 2008 the AT survey selectivity approach was modified. As an option, the age one pollock observed in this trawl can be treated as an index and are not considered part of the age composition (which then ranges from age 2-15). This was done to improve some interaction with the flexible selectivity smoother that is used for this gear and was compared. Additionally, the annual specification of input observation variance terms was allowed for the AT data.

A diagnostic approach to evaluate input variance specifications (via sample size under multinomial assumptions) was added in the 2018 assessment. This method uses residuals from mean ages together with the concept that the sample variance of mean age (from a given annual data set) varies inversely with input sample size. It can be shown that for a given set of input proportions at age (up to the maximum age A) and sample size N_t for year t, an adjustment factor ν for input sample size can be computed when compared with the assessment model predicted proportions at age ($\hat{p}_{ta}$) and model predicted mean age ($\hat{\bar{a}}_t$):

$$\nu = \mathrm{var}\left(r_t^a\sqrt{\frac{N_t}{\kappa_t}}\right)^{-1} \quad (21)$$

$$r_t^a = \bar{a}_t - \hat{\bar{a}}_t \quad (22)$$

$$\kappa_t = \left[\sum_a^A \bar{a}_t - \hat{\bar{a}}_t\right]^{0.5} \quad (23)$$

where r_t^a is the residual of mean age and

$$\hat{\bar{a}}_t = \sum_a^A a\hat{p}_{ta} \quad (24)$$

$$\bar{a}_t = \sum_a^A a p_{ta} \quad (25)$$

Based on previous analyses, we used the above relationship as a diagnostic for evaluating input sample sizes by comparing model predicted mean ages with observed mean ages and the implied 95% confidence bands. This method provided support for modifying the frequency of allowing selectivity changes.

Recruitment

In these analyses, recruitment (R_t) represents numbers of age-1 individuals modeled as a stochastic function of spawning stock biomass.

$$R_t = f\left(B_{t-1}\right) \quad (26)$$

with mature spawning biomass during year t was defined as:

$$B_t = \sum_{a=1}^A w_{t,a}\phi_a N_{t,a} \quad (27)$$

and, ϕ_a is the proportion of mature females at age is as shown in the sub-section titled Natural mortality and maturity at age under “Parameters estimated independently” above.

A reparameterized form for the stock-recruitment relationship following Francis (1992) was used. For the optional Beverton-Holt form (the Ricker form presented in Eq. 12 was adopted for this assessment) we have:

$$R_t = \frac{B_{t-1}e^{\varepsilon_t}}{\alpha + \beta B_{t-1}} \quad (28)$$

where

R_t	is recruitment at age 1 in year t,
B_t	is the biomass of mature spawning females in year t,
ε_t	is the recruitment anomaly for year t, ($\varepsilon_t \sim \mathcal{N}(0,\, \sigma_R^2$)
α, β	are stock recruitment parameters.

Values for the stock-recruitment function parameters and are calculated from the values of (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the steepness of the stock-recruit relationship (h). The steepness is the fraction of R0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992), so that:

$$\alpha = \tilde{B}_0 \frac{1-h}{4h} \tag{29}$$

$$\beta = \frac{5h-1}{4hR_0} \tag{30}$$

where $\tilde{B}_0$ is the total egg production (or proxy, e.g., female spawning biomass) in the absence of exploitation (and recruitment variability) expressed as a fraction of R_0.

Some interpretation and further explanation follows. For steepness equal 0.2, then recruits are a linear function of spawning biomass (implying no surplus production). For steepness equal to 1.0, then recruitment is constant for all levels of spawning stock size. A value of $h = 0.9$ implies that at 20% of the unfished spawning stock size will result in an expected value of 90% unfished recruitment level. Steepness of 0.7 is a commonly assumed default value for the Beverton-Holt form (e.g., Kimura 1988). The prior distribution for steepness used a beta distribution as in Ianelli et al. (2016). The prior on steepness was specified to be a symmetric form of the Beta distribution with $\alpha = \beta = 14.93$ implying a prior mean of 0.5 and CV of 12% (implying that there is about a 14% chance that the steepness is greater than 0.6). This conservative prior is consistent with previous years' application and serves to constrain the stock-recruitment curve from favoring steep slopes (uninformative priors result in F_{MSY} values near an F_{SPR} of about $F_{18\%}$ a value considerably higher than the default proxy of $F_{35\%}$). The residual pattern for the post-1977 recruits used in fitting the curve with a more diffuse prior resulted in all estimated recruits being below the curve for stock sizes less than B_{MSY} (except for the 1978 year class). We believe this to be driven primarily by the apparent negative-slope for recruits relative to stock sizes above B_{MSY} and as such, provides a potentially unrealistic estimate of productivity at low stock sizes. This prior was elicited from the rationale that residuals should be reasonably balanced throughout the range of spawning stock sizes. Whereas this is somewhat circular (i.e., using data for prior elicitation), the point here is that residual patterns (typically ignored in these types of models) were qualitatively considered.

In model 16.1 (from the 2019 assessment), a Beverton Holt stock recruitment form was implemented using the prior value of 0.67 for steepness and a CV of 0.17. This resulted in beta distribution parameters (for the prior) at $\alpha = 6.339$ and
$\beta = 4.293$.

The value of σ_R was set at 1.0 to accommodate additional uncertainty in factors affecting recruitment variability.

To have the critical value for the stock-recruitment function (steepness, h) on the same scale for the Ricker model, we begin with the parameterization of Kimura (1990):

$$R_t = \frac{B_{t-1} e^{\alpha\left(1 - B_{t-1}\frac{R_0}{\psi_0}\right)}}{\psi_0} \tag{31}$$

It can be shown that the Ricker parameter a maps to steepness as:

$$h = \frac{e^{\alpha}}{e^{\alpha}+4} \tag{32}$$

so that the prior used on h can be implemented in both the Ricker and Beverton-Holt stock-recruitment forms. Here the term ψ_0 represents the equilibrium unfished spawning biomass per-recruit.

Diagnostics

In 2006 a replay feature was added where the time series of recruitment estimates from a particular model is used to compute the subsequent abundance expectation had no fishing occurred. These recruitments are adjusted from the original estimates by the ratio of the expected recruitment given spawning biomass (with and without fishing) and the estimated stock-recruitment curve. I.e., the recruitment under no fishing is modified as:

$$R'_t = \hat{R}_t \frac{f(B'_{t-1})}{f(B_{t-1})}$$

where R_t is the original recruitment estimate in year t with B'_{t-1} and B_{t-1} representing the stock-recruitment function given spawning biomass under no fishing and under the estimated fishing intensity, respectively.

The assessment model code allows retrospective analyses (e.g., Parma 1993, and Ianelli and Fournier 1998). This was designed to assist in specifying how spawning biomass patterns (and uncertainty) have changed due to new data. The retrospective approach simply uses the current model to evaluate how it may change over time with the addition of new data based on the evolution of data collected over the past several years.

Parameter estimation

The objective function was simply the sum of the negative log-likelihood function and logs of the prior distributions. To fit large numbers of parameters in nonlinear models it is useful to be able to estimate certain parameters in different stages. The ability to estimate stages is also important in using robust likelihood functions since it is often undesirable to use robust objective functions when models are far from a solution. Consequently, in the early stages of estimation we use the following log- likelihood function for the survey and fishery catch at age data (in numbers):

$$nll(i) = n \sum_{t,a} p_{ta} \ln \hat{p}_{ta} \tag{33}$$

$$p_{ta} = \frac{O_{ta}}{\sum_a O_{ta}} \qquad \hat{p}_{ta} = \frac{\hat{C}_{ta}}{\sum_a \hat{C}_{ta}} \tag{34}$$

$$\mathbf{C} = \mathbf{CE} \tag{35}$$

$$\mathbf{E} = \begin{matrix} b_{1,1} & b_{1,2} & \cdots & b_{1,15} \\ b_{2,1} & b_{2,2} & & b_{2,15} \\ \vdots & & \ddots & \vdots \\ b_{15,1} & b_{15,2} & \cdots & b_{15,15} \end{matrix} \tag{36}$$

where A, and T, represent the number of age classes and years, respectively, n is the sample size, and represent the observed and predicted numbers at age in the catch. The elements bi,j represent ageing mis-classification proportions are based on independent agreement rates between otolith age readers. For the models presented this year, the option for including aging errors was re-evaluated.

Sample size values were revised and are shown in the main document. Strictly speaking, the amount of data collected for this fishery indicates higher values might be warranted. However, the standard multinomial sampling process is not robust to violations of assumptions (Fournier et al. 1990). Consequently, as the model fit approached a solution, we invoke a robust likelihood function which fit proportions at age as:

$$\prod_{a=1}^{A}\prod_{t=1}^{T}\left[\left(\exp\left(-\frac{\left(p_{ta}-\hat{p}_{ta}\right)^2}{2\left(\eta_{ta}+0.1/A\right)\tau_t^2}\right)+0.01\right)\times\frac{1}{\sqrt{2\pi\left(\eta_{ta}+0.1/A\right)\tau_t}}\right] \tag{37}$$

Taking the logarithm we obtain the log-likelihood function for the age composition data:

$$nll(i)=-0.5\sum_{a=1}^{A}\sum_{t=1}^{T}\ln 2\pi\left(\eta_{ta}+0.1/A\right)-\sum_{t}^{T}A\ln\tau_t+\sum_{a=1}^{A}\sum_{t=1}^{T}\ln\left\{\exp\left(-\frac{\left(p_{ta}-\hat{p}_{ta}\right)^2}{\left(2\eta_{ta}+0.1/A\right)\tau_t^2}\right)+0.01\right\} \tag{38}$$

where

$$\eta_{ta}=p_{ta}(1-p_{ta}) \tag{39}$$

$$\text{and} \tag{40}$$

$$\tau_t^2=1/n_t \tag{41}$$

which gives the variance for p_{ta}

$$(\eta_{ta}+0.1/A)\tau_t^2 \tag{42}$$

Completing the estimation in this fashion reduces the model sensitivity to data that would otherwise be considered outliers.

Within the model, predicted survey abundance accounted for within-year mortality since surveys occur during the middle of the year. As in previous years, we assumed that removals by the survey were insignificant (i.e., the mortality of pollock caused by the survey was considered insignificant). Consequently, a set of analogous catchability and selectivity terms were estimated for fitting the survey observations as:

$$\hat{N}_{ta}^{s}=e^{-0.5Z_{ta}}N_{ta}q_t^s s_{ta}^S \tag{43}$$

where the superscript s indexes the type of survey (AT or BTS). For the option to use the survey predictions in biomass terms instead of just abundance, the above was modified to include observed survey biomass weights-at-age:

$$\hat{N}_{ta}^{s}=e^{-0.5Z_{ta}}w_{ta}N_{ta}q_t^s s_{ta}^S \tag{44}$$

For the AVO index, the values for selectivity were assumed to be the same as for the AT survey and the mean weights at age over time was also assumed to be equal to the values estimated for the AT survey.

For these analyses we chose to keep survey catchabilities constant over time (though they are estimated separately for the AVO index and for the AT and bottom trawl surveys). The contribution to the negative log-likelihood function (ignoring constants) from the surveys is given by either the lognormal distribution:

$$nll(i) = \sum_t \frac{\ln(u_t^s/\hat{N}_t^s)^2}{2\sigma_{s,t}^2} \tag{45}$$

where u_t^s is the total (numerical abundance or optionally biomass) estimate with variance $\sigma_{s,t}$ from survey s in year t or optionally, the normal distribution can be selected:

$$nll(i) = \sum_t \frac{(u_t^s - \hat{N}_t^s)^2}{2\sigma_{s,t}^2}. \tag{46}$$

(47)

The AT survey and AVO index is modeled using a lognormal distribution whereas for the BTS survey, a normal distribution was applied.

For model configurations in which the BTS data are corrected for estimated efficiency, a multivariate lognormal distribution was used. For the negative- log likelihood component this was modeled as

$$nll_i = 0.5\mathbf{X}\Sigma^{-1}\mathbf{X}' \tag{48}$$

where is a vector of observed minus model predicted values for this index and Σ is the estimated covariance matrix provided from the method provided in Kotwicki et al. 2014. For the VAST estimates, the supplied covariance matrix was used in the same way.

The contribution to the negative log-likelihood function for the observed total catch biomass $(C_b^{obs}, \hat{C}_b)$ by the fishery is given by

$$nll_i = 0.5 \sum_t \frac{\ln(C_b^{obs}/\hat{C}_b)^2}{2\sigma_{C_b,t}^2} \tag{49}$$

where $\sigma_{C_b,t}$ is pre-specified (set to 0.05) reflecting the accuracy of the overall observed catch in biomass. Similarly, the contribution of prior distributions (in negative log-density) to the log-likelihood function include $\lambda_\varepsilon \sum_t \varepsilon_t^2 + \lambda_\gamma \sum_{ta} \gamma^2 + \lambda_\delta \sum_t \delta_t^2$ where the size of the 's represent prior assumptions about the variances of these random variables. Most of these parameters are associated with year-to- year and age specific deviations in selectivity coefficients. For a presentation of this type of Bayesian approach to modeling errors-in- variables, the reader is referred to Schnute (1994). To facilitate estimating such a large number of parameters, automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries was used. This software provided the derivative calculations needed for finding the posterior mode via a quasi-Newton function minimization routine (e.g., Press et al. 1992). The model implementation language (ADModel Builder) gave simple and rapid access to these routines and provided the ability estimate the variance-covariance matrix for all dependent and independent parameters of interest.

Uncertainty in mean body mass

The approach we use to solve for F_{MSY} and related quantities (e.g., B_{MSY} MSY) within a general integrated model context was shown in Ianelli et al. (2001). In 2007 this was modified to include uncertainty in weight-at-age as an explicit part of the uncertainty for F_{MSY} calculations. This involved estimating a vector of parameters (w_{ta}^{future}) on current (2022) and future mean weights for each age i, i= (1, 2,...,15), given actual observed mean and variances in weight-at-age over the period 1991-2021. The values of based on available data and (if this option is selected) estimates the parameters subject to the natural constraint:

$$w_{ta}^{future} \sim \mathcal{N}(\bar{w_a}, \sigma^2_{w_a})$$

Note that this converges to the mean values over the time series of data (no other likelihood component within the model is affected by future mean weights-at-age) while retaining the natural uncertainty that can propagate through estimates of F_{MSY} uncertainty. This latter point is essentially a requirement of the Tier 1 categorization.

Subsequently, this method was refined to account for current-year survey data and both cohort and year effects. The model for this is:

$$\hat{w}_{ta} = \bar{w}_a e^{\upsilon_t} \qquad a = 1,\, t \geq 1964 \qquad (50)$$

$$\hat{w}_{ta} = \hat{w}_{t-1,a-1} + \Delta_a e^{\psi_t} \qquad a > 1,\, t > 1964 \qquad (51)$$

$$\Delta_a = \bar{w}_{a+1} - \bar{w}_a \qquad a < A \qquad (52)$$

$$\bar{w}_a = \alpha \left\{ L_1 + (L_2 - L_1) \left(\frac{1 - K^{a-1}}{1 - K^{A-1}} \right) \right\}^3 \qquad (53)$$

$$(54)$$

where the fixed effects parameters are L_1, L_2, K, and α while the random effects parameters are υ_t and ψ_t.

Tier 1 projections

Tier 1 projections were calculated two ways. First, for 2023 and 2024 ABC and OFL levels, the harmonic mean F_{MSY} value was computed and the analogous harvest rate ($u_{\bar{HM}}$) applied to the estimated geometric mean fishable biomass at B_{MSY} :

$$ABC_t = B^f_{GM,t} \hat{u}_{HM} \zeta_t \qquad (55)$$

$$B^f_{GM,t} = e^{\ln \hat{B}^f_t - 0.5\sigma^2_{B^f}} \qquad (56)$$

$$u^f_{HM,t} = e^{\ln \hat{u}_{MSY,t} - 0.5\sigma^2_{u_{MSY}}} \qquad (57)$$

$$\zeta_t = \frac{B_t/B_{MSY} - 0.05}{1 - 0.05} \qquad B_t < B_{MSY} \qquad (58)$$

$$\zeta_t = 1.0 \qquad B_t \geq B_{MSY} \qquad (59)$$

where $\hat{B}^f_t$ is the point estimate of the fishable biomass defined (for a given year): $\sum_a N_a s_{ta} w_{ta}$ with N_{ta}, s_{ta}, and w_{ta} the estimated population numbers (begin year), selectivity and weights-at-age, respectively. B_{MSY} and B_t are the point estimates spawning biomass levels at equilibrium F_{MSY} and in year t (at time of spawning). For these projections, catch must be specified (or solved for if in the current year when $B_t < B_{MSY}$). For longer term projections a form of operating model (as has been presented for the evaluation of $B_{20\%}$) with feedback (via future catch specifications) using the control rule and assessment model would be required.

Appendix on spatio-temporal analysis of NMFS survey data

Overview

These applications of `VAST` were configured to model NMFS/AFSC bottom trawl survey (BTS) data and for acoustic backscatter data (next section). For the BTS, the station-specific CPUEs (kg per hectare) for pollock were compiled from 1982-2019. Further details can be found at the GitHub repo mainpage, wiki, and glossary. The R help files, e.g., `?make_data` for explanation of data inputs, or `?make_settings` for explanation of settings. VAST has involved many publications for developing individual features (see references section below). What follows is intended as a step by step documentation of applying the model to these data.

The software versions of dependent programs used to generate VAST estimates were:
- Microsoft R Open (4.0.2) - INLA (21.11.22) - TMB (1.9.0) - TMBhelper (1.4.0) - VAST (3.9.0) - FishStatsUtils (2.11.0)

For the model-based index time series, we used the same VAST model run (and associated results) as the 2019 SAFE. We include additional details regarding model settings here, as requested during the December 2019 SSC meeting.

Spatio-temporal treatment of survey data on pollock density

For model-based indices in the Bering Sea, we fitted observations of numerical abundance or biomass per unit area (where the use of abundance or biomass varied by stock at the request of assessors) from all grid cells and corner stations in the 83-112 bottom trawl survey of the EBS, 1982-2022, including exploratory northern extension samples in 2001, 2005, and 2006, as well as 83-112 samples available in the NBS in 1982, 1985, 1988, 1991, 2010, and 2017-2021. NBS samples collected prior to 2010 and in 2018 did not follow the 20 nautical mile sampling grid that was used in 2010, 2017, 2019, 2021 and 2022 surveys. Assimilating these data therefore required extrapolating into unsampled areas. This extrapolation was facilitated by including a spatially varying response to cold-pool extent (Thorson 2019). This spatially varying response was estimated for both linear predictors of the delta-model, and detailed comparison of results for EBS pollock has shown that it has a small but notable effect on these indices and resulting stock assessment outputs (O'Leary et al. 2020). For example, the NBS was not sampled between 2010 and 2017, and the cold-pool extent started to decrease substantially around 2014; therefore including this covariate results in estimates that depart somewhat from a "Brownian bridge" between 2010 and 2017, and instead indicates that population densities of walleye pollock in the NBS increased progressively after 2014 when cold-pool-extent declined prior to 2017. Rather than using the cold-pool covariate for yellowfin sole, we instead used the mean bottom temperature within the outer and middle domain strata from an interpolated temperature product. All environmental data used as covariates were computed within the R package coldpool (https://github.com/afsc-gap-products/coldpool; Rohan et al., in review).

We used a Poisson-link delta-model (Thorson 2018) involving two linear predictors, and a gamma distribution to model positive catch rates. We extrapolated population density to the entire EBS and NBS in each year, using extrapolation grids that are available within FishStatsUtils, which we note were updated since 2021 assessment cycle based on new shapefiles developed by J. Conner (https://github.com/James-Thorson-NOAA/FishStatsUtils). These extrapolation grids are defined using 3705 m (2 nmi) $\times$ 3705 m (2 nmi) cells; this results in 36,690 extrapolation-grid cells for the eastern Bering Sea and 15,079 in the northern Bering Sea. We used bilinear interpolation to interpolate densities from 750 "knots" to these extrapolation grid cells; knots were approximately evenly distributed over space, in proportion to the dimensions of the extrapolation grid. We estimated geometric anisotropy (how spatial autocorrelation declines with differing rates over distance in some cardinal directions than others), and included a spatial and spatio-temporal term for both linear predictors. To facilitate interpolation of density between unsampled years, we specified that the spatio-temporal fields were structured over time as an AR(1) process (where the magnitude of autocorrelation was estimated as a fixed effect for each linear predictor). However, we did not include any temporal correlation for intercepts, which we treated as fixed effects for each linear predictor and year. Finally, we used epsilon bias-correction to correct for retransformation bias (Thorson and Kristensen 2016).

We checked model fits for evidence of non-convergence by confirming that (1) the derivative of the marginal likelihood with respect to each fixed effect was sufficiently small and (2) that the Hessian matrix was positive definite. We then checked for evidence of model fit by computing Dunn-Smyth randomized quantile residuals (Dunn and Smyth 1996) and visualizing these using a quantile-quantile plot within the DHARMa R package. We also evaluated the distribution of these residuals over space in each year, and inspected them for evidence of residual spatio-temporal patterns.

Spatio-temporal treatment of survey age composition data

For model-based estimation of age compositions in the Bering Sea, we fitted observations of numerical abundance-at-age at each sampling location. This was made possible by applying a year-specific, region-specific (EBS and NBS) age-length key to records of numerical abundance and length-composition. We computed these estimates in VAST, assuming a Poisson-link delta-model (Thorson 2018) involving two linear predictors, and a gamma distribution to model positive catch rates. We did not include any density covariates in estimation of age composition for consistency with models used in the previous assessment, and due to computational limitations. We used the same extrapolation grid as implemented for abundance indices, but here we modeled spatial and spatiotemporal fields with a mesh with coarser spatial resolution than the index model, here using 50 "knots". This reduction in the spatial resolution of the model, relative to that used abundance indices, was necessary due to the increased computational load of fitting multiple age categories and using epsilon bias-correction. We implemented the same diagnostics to check convergence and model fit as those used for abundance indices.

Densities and biomass estimates

Relative densities over time suggests that the biomass of pollock can reflect abundances in the NBS even in years where samples are unavailable (all years except 2010, 2017–2019 and 2021; (Fig. 66). Index values and error terms (based on diagonal of covariance matrix over time) are shown in Figure 67

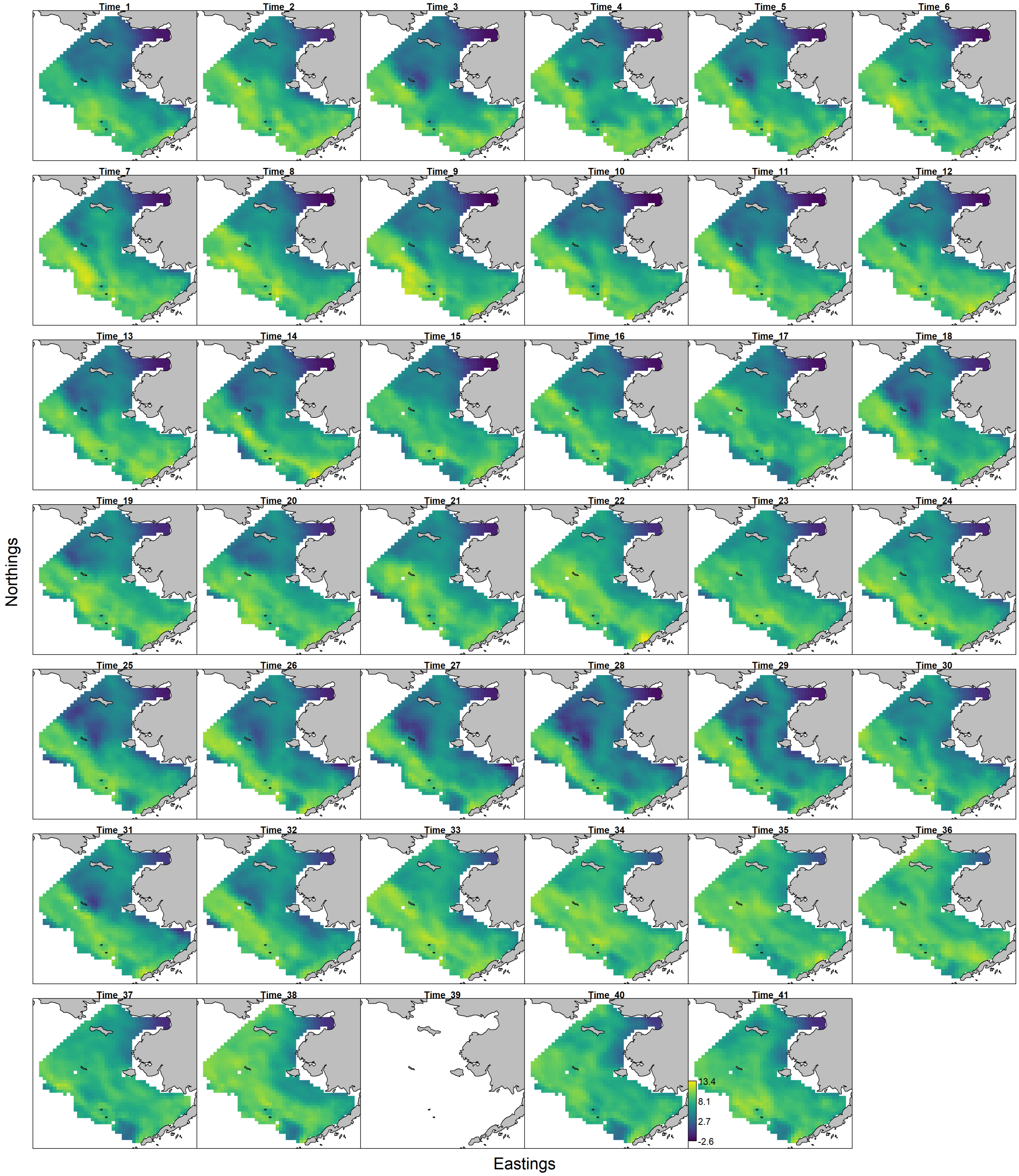

Figure 1-66. Pollock log density maps of the BTS data using the VAST model approach, 1982-2019,2021-2022.

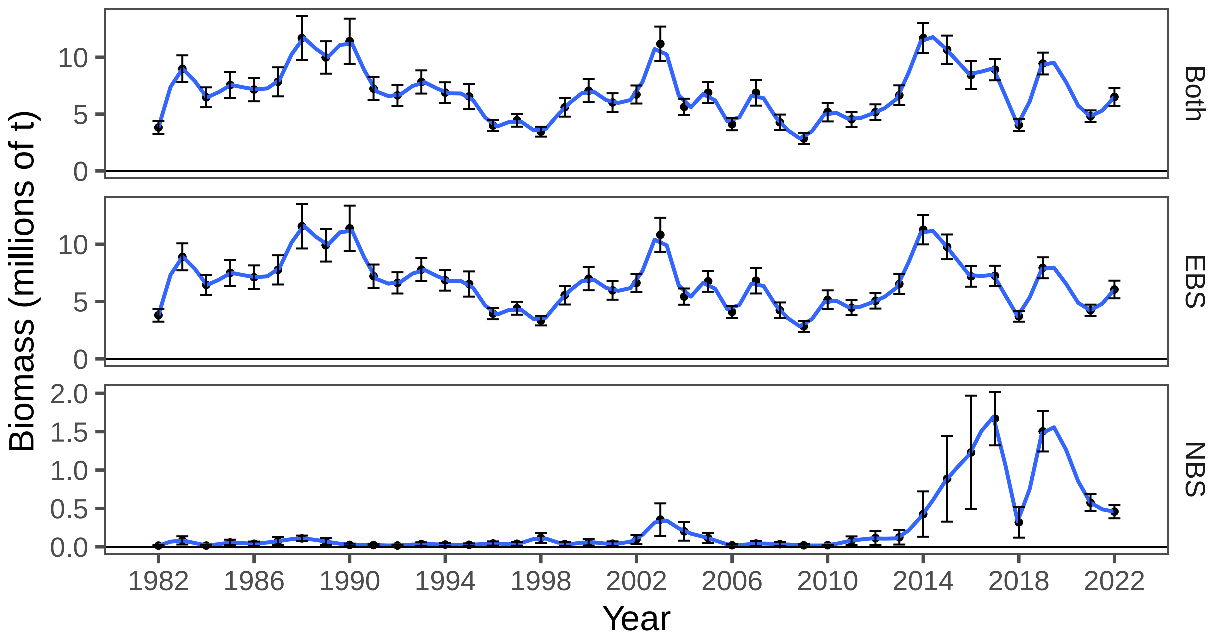

Figure 1-67. Pollock index values for the standard survey region, the NBS, and combined based on the VAST application to density-dependent corrected CPUE values from the BTS data, 1982–2019, 2021-2022.

Additional references

References

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