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; however, this year a number of refinements from the 2019 index were made which changed the time series used for tuning the assessment. 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. The bottom trawl survey collected acoustic data opportunistically with the index covering 2006-2019, and 2021.

5. Because of indications of smaller-than usual fish apparent in the 2021 fishery, length composition data from this year's fishery, along with a preliminary estimate of the catch-age composition for this year was used.

Changes in the assessment methods

There were some minor changes to the assessment model this year to accommodate requests from the SSC and Plan Team.

Summary of EBS pollock results

The following table is based on results from Model 20.0c, the same used for last year's assessment (with the addition of preliminary, and usually unavailable, current-year fishery data). The ABC recommendation includes an additional 10% buffer from the arithmetic mean F_{MSY} value under Tier 1 (the OFL). Along with the risk-averse buffer due to uncertainty in the F_{MSY} (about 14% lower because it is based on the harmonic mean) the recommendation results in a buffer of about 24% below F_{MSY}. This corresponds to a Tier 2 ABC. The Tier 3 ABC estimate for 2022 and 2023 would be 1,378,000 and 1,644,000 t, respectively.

	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	1a	1a	1a	1a
Projected total (age 3+) biomass (t)	8,145,000 t	7,641,000 t	12,119,000 t	12,506,000 t
Projected female spawning biomass (t)	2,602,000 t	2,406,000 t	3,900,000 t	3,901,000 t
B_0	5,792,000 t	5,792,000 t	5,922,000 t	5,922,000 t
B_{msy}	2,257,000 t	2,257,000 t	2,335,000 t	2,335,000 t
F_{OFL}	0.341	0.341	0.547	0.547
$maxF_{ABC}$	0.304	0.304	0.456	0.456
F_{ABC}	0.214	0.214	0.409	0.409
OFL	2,594,000 t	2,366,000 t	3,703,000 t	5,344,000 t
$maxABC$	2,307,000 t	2,105,000 t	3,087,000 t	4,455,000 t
ABC	1,626,000 t	1,484,000 t	2,766,000 t	3,992,000 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

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.*
- 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 2,766,000 t (or a hybrid of Tier 1 and 2 of 2,306,000 t) for 2022 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 had encouraged further investigation of the apparent shift between a clear 2012 year-class to mixed 2012-2013 year classes in the data, suggestive of potentially variable ageing bias.

- *The fishery and survey age data shows a similar relative proportion of these two year classes. This year we present a spatial map of where these year classes have appeared and note that there appears to be some separation in their average locations. This could indicate that the year-classes may have had sufficient separation to minimize spatial overlap and exposure to cannibalism.*

The work in deriving an external estimate of temporal variability in catchability for the bottom trawl survey (relative to the acoustic survey) due to vertical availability, the SSC noted that catchability would logically also vary for the acoustic survey. The SSC encourages further work to develop the simultaneous modelling of these two surveys, accounting for vertical and distributional shifts (including into the northern Bering Sea survey area; NBS). When sufficiently explored, the SSC looks forward to assessment model configurations that explore the use of a time-series from this method.

- *Work on this topic stalled as analysts focused their efforts on methods to incorporate the uncrewed surface vessels (USVs) to collect acoustic data in 2020. We anticipate this work to be pursued when the planned 2022 acoustic-trawl survey become available.*

The SSC supports ongoing genetic studies to determine the relationship between pollock in the NBS and EBS, as well as other surrounding regions (AI, GOA).

- *Some preliminary results showing the main genetic population components are presented below. Indications are that there is a high degree of separation of pollock from Japan compared to those sampled off of Alaska. Within Alaskan waters, the Bering Sea samples were relatively distinct from the Aleutian Islands and the Gulf of Alaska.*

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 moored sounders have been recovered in September 2020 but the data have yet to be processed.*

Re-examine the geographic subset of data currently used to develop the AVO index, specifically to see if including Bristol Bay data improves the correlation.

- *Work on this will require directed acoustic-trawl efforts in this region. Given other priorities for survey ship and staff time, the practicality of this effort may be delayed.*

Given the apparent disappearance of the second and large mode in fishery length compositions as the 2020 B-season progressed, exploration of within-season spatial variation in fishery length composition would be useful in evaluating whether these larger pollock simply moved out of the area of fishing effort, or died as a result of natural or fishing mortality.

- *Because of this concern, we re-estimated the length-at-age values in order to include the 2021 fishery data (conventionally, aspects of the current-year age structure of fishing are unavailable until samples can be returned from NMFS observers and aged). We also constructed a global age-length key to supplement age composition information from the 2021 fishery.*

From October 2021 (unless covered above):

The SSC provides a clarification that it is requesting a description of the method used for projecting selectivity when calculating the OFL/ABC and looks forward to a retrospective analysis on the performance of this projection method relative to the subsequently estimated selectivity in the next assessment. This request was motivated by the large change in FOFL observed from the 2019 to 2020 assessments.

- *These estimates are compared from the retrospective runs in addition to a review of how recent selectivity estimates impact F_{MSY} rates.*

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. 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 most recently 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. More recently, research and new genetic approaches are being pursued. Pollock samples from areas including Zhemchug Canyon, Japan, Prince William Sound, Bogoslof, Shelikof, and the Northern Bering Sea have now been processed. This study uses whole genome sequencing and is a collaboration between the Joint Institute for the Study of Atmosphere and Oceans (currently CICOES, the Cooperative Institute for Climate, Ocean, and Ecosystem Science) and the Alaska Fisheries Science Center Cooperative Research Program. The 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. Whole genome sequencing is a new approach to the study of pollock stock structure and is expected to yield higher statistical power than previous results using microsatellite DNA markers. This team [1] sequenced 617 pollock using "low-coverage whole genome sequencing." They identified 5,316,997 single nucleotide polymorphisms (i.e., sites in the genome with genetic variation). Of the samples that were genotyped, more than 70% had a minor allele frequency of more than 0.05. To visualize genetic differences between samples, they conducted principal components analysis (PCA) using all samples and found that samples from Japan were highly distinct. A separate PCA was run with Japan excluded and this showed a "three stripe" pattern (Fig. 1). In other systems, this pattern has been associated with the presence of chromosomal inversions, as homo- and heterokaryotypes for each inversion polymorphism form distinct clusters in a PCA. Such findings hold promise for more detailed information becoming available.

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 2003–2006 (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

[1] Eleni Petrou, Eleanor Bors, Lorenz Hauser, and Ingrid Spies

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. 2). 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. 3).

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. 4). The 2021 A-season fishery spatial pattern had a relatively higher concentrations of fishing near the Pribilof Islands and catches near Unimak and east compared to recent years (Fig. 5). The 2021 A-season nominal catch rates were lower than the 2020 peak (for the fleet in aggregate) (Fig. 6). 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. To date, it appears that the pollock fleet as a whole took advantage of this added flexibility (Fig. 7). However, this figure indicates that in 2021, the proportion of catch in February dropped relative to recent patterns but was made up by the end of April. Pollock roe is an important product coming from the winter fishery. The amount produced in the 2021 A-season was the lowest since 2016 and a considerable drop from the previous two years (Fig. 8).

The summer-fall fishing conditions for 2021 improved considerably over 2020 and was about average on nominal catch rates (Fig. 6). 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. 9). 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 disperse than last year and was roughly similar to the recent lower concentration levels compared to other years since 2000 (Fig 10).

In 2020 we investigated the preponderance of small pollock in the catch. This was pursued further this year. As noted last year, in addition to the extensive NMFS observer collections, a little used component of their data are estimates of observed tow tonnages compared to numbers of pollock. These can provide a direct mean somatic mass (pollock body weight) for pollock within that 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. 11). Compiling the data by week we show that the small fish were a consistent basis of the catch for this B-season (Fig. 12).

The catch of EBS pollock has averaged 1.21 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 (2017-2021) catch has been 1.378 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 9.1% of total pollock catch in 1992 to recent lows of around 0.6%. 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 the ability to associate catches with specific areas. However, this should once again become possible…"possible when the position information is fully operational and offloads can be easily linked to haul records. Initial investigations on configuring these data for this purpose were promising and should be possible retroactively when the routines for the new database are developed further.

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. 5).

The majority (about 56%) of Chinook salmon caught as bycatch in the pollock fishery originate from western Alaskan rivers. An Environmental Impact Statement (EIS) was completed in 2009 in conjunction with the Council's recommended bycatch management approach. This EIS evaluated the relative impacts of different bycatch management approaches as well as estimated the impact of bycatch levels on adult equivalent salmon (AEQ) returning to river systems (NMFS/NPFMC 2009). As a result, revised Chinook salmon bycatch management measures went into effect in 2011 which imposed new 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. 7). 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.

The pollock fishery exceeded the herring PSC limit late in the 2020 A season which invoked three directed pollock fishing closures: the Summer Herring Savings Area 1, the Summer Herring Savings Area 2, and the Winter Herring Savings Area (closed since September 1, 2020 through March 1, 2021). NMFS opened directed fishing for pollock for the American Fisheries Act (AFA) inshore sector, AFA mothership sector, and the Community Development Quota (CDQ) program in the Summer Herring Savings Area 2 of the BSAI from July 1, 2020 through August 15, 2020. This opening was necessary to prevent the underharvest of the 2020 pollock total allowable catch and facilitate pollock harvest by the AFA inshore sector, AFA mothership sector, and CDQ program in the Bering Sea subarea of the BSAI. Additionally, voluntary closure areas were announced throughout the B-season 2020 that were intended to minimize herring bycatch.

Economic conditions as of 2020

Alaska pollock is the dominant species in terms of catch in the BSAI region. In 2020 pollock accounted for 72% of the BSAI's FMP groundfish harvest and 93% of the total pollock harvest in Alaska. Retained catch of pollock decreased 2.9% to 1.37 million t in 2020 (Table 5). The decrease in 2020 catch was despite an increase in the TAC as poor fishing conditions resulted in only 95% of the TAC being harvested. BSAI pollock first-wholesale value was $1.37 billion 2020, which was a 12% decrease from 2019 and above the 2011–2015 average of $1.31 billion (Table 6). The decrease in 2020 revenues was largely driven by the decrease in catch and corresponding production as the average first-wholesale price was stable (Table 6). The increases in the average first-wholesale price of pollock products in 2016 and 2017 were largely due to increases in the price of surimi products while the price increase in 2018 was largely due to an increase in the price of fillets. Price increases in 2019 were the combined effect of price increases in both fillets and surimi. In 2020, price increases in fishmeal and minced fish offset decreases in the H&G, roe and surimi prices while fillet prices were stable. The primary revenue impact of the COVID-19 pandemic was increased demand for retail products which put upward pressure on retail focused products like single-frozen fillets, minced, and surimi. However, smaller average size of fish in catch limited the quantity and grades of product forms which generally put downward pressure on prices.

Pollock is targeted exclusively with pelagic trawl gear. The catch of pollock in the BSAI was rationalized with the passage of the AFA in 1998,[2] which, among other things, established a proportional allocation of the TAC among vessels in sectors which were allowed to form into cooperatives.[3]

Prior to 2008 pollock catches were high at approximately 1.4 million t in the BSAI for an extended period (Table 5). The U.S. accounted for over 50% of the global pollock catch. Between 2008–2010 conservation reductions in the pollock TAC trimmed catches to an average 867 kt. The supply reduction resulted in price increases for most pollock products, which mitigated the short-term revenue loss. Over this same period, the pollock catch in Russia increased from an average of 1 million t in 2005–2007 to 1.4 million t in 2008–2010 and Russia's share of global catch increased to over 50% and the U.S. share decreased to 35%. Since 2011 the U.S. has accounted for approximately 44% of the global pollock catch the majority of which comes from the BSAI (Table 7).

Russia has historically lacked the primary processing capacity of the U.S., with much of their catch being exported to China where it is re-processed as twice-frozen fillets. In recent years Russia has pursued upgrading its processing capacity of fillets, minced, roe, and surimi which could compete more directly with primary processed products made by the U.S.. Around the mid- to late- 2000s, buyers in Europe, an important segment of the fillet market, started to source fish products with the MSC sustainability certification, and retailers in the U.S. later began to follow suit. Asian markets, an important export destination for a number of pollock products, have shown less interest in requiring MSC certification. The U.S. was the only producer of MSC certified pollock until 2013 when roughly 50% of the Russian catch became MSC certified.[4] Since 2010 the U.S. pollock stock rebounded with catches in the BSAI ranging from 1.2–1.3 million t and Russia's catch has stabilized at 1.5 to 1.6 million t. The majority of pollock is exported; consequently exchange rates can have a significant impact on market dynamics[5] In 2015 the official U.S. market name changed from "Alaska pollock" to "pollock" enabling U.S. retailers to differentiate between pollock caught in Alaska and Russia. Additionally, pollock more broadly competes with other whitefish that, to varying degrees, can serve as substitutes depending on the product. The pollock industry has avoided U.S. tariffs that would have a significant negative impact on them in the U.S.-China trade war. However, Chinese tariffs on U.S. products could inhibit growth in that market.

[2]The AFA was implemented in 1999 for catcher/processors, and in 2000 for catcher vessel and motherships.

[3]The BSAI pollock TAC is divided between Community Development Program (10% off the top), with the remaining amount split among shore-based catcher vessels (50%), at-sea catcher/processors (40%) and motherships (10%).

[4]Alaska caught pollock in the BSAI became certified by the Marine Stewardship Council (MSC) in 2005, an NGO based third-party sustainability certification, which some buyers seek.

[5]Aggregate exports in Table 7, particularly the Dollar-Yen and Dollar-Euro. may not fully account for all pollock exports as products such as meal, minced fish and other ancillary product may be coded as generic fish type for export purposes.

This market environment accounts for some of the major trends in prices and production across product types. Fillet prices peaked in 2008–2010 but declined afterwards because of the greater supply from U.S. and Russia. The 2013 MSC certification of Russian-caught pollock enabled access to segments of European and U.S. fillet markets, which has put continued downward pressure on prices. Pollock roe prices and production have declined steadily over the last decade as international demand has waned with changing consumer preferences in Asia. Additionally, the supply of pollock roe from Russia has increased with catch. The net effect has been not only a reduction in the supply of roe from the U.S. industry, but also a significant reduction in roe prices which are roughly half pre-2008 levels. Prior to 2008, roe comprised 23% of the U.S. wholesale value share, and since 2011 it has been roughly 10% (Table 6). With the U.S. supply reduction in 2008–2010, surimi production from pollock came under increased pressure as U.S. pollock prices rose and markets sought cheaper sources of raw materials (see Guenneugues and Ianelli 2013 for a global review of surimi resources and market). This contributed to a growth in surimi from warm-water fish of southeast Asia. Surimi prices spiked in 2008–2010 and have since tapered off as production from warm-water species increased (as has pollock). Surimi is consumed globally, but Asian markets dominate the demand for surimi and demand has remained strong.

The catch of pollock can be broadly divided between the shore-based sector where catcher vessels make deliveries to inshore processors, and the at-sea sector where catch is processed at-sea by catcher/processors and motherships before going directly to the wholesale markets. The retained catch of the shore-based sector decreased 1% to 725 kt. The value of these deliveries (shore-based ex-vessel value) totaled $233.7 million in 2020, which was down 10% from the ex-vessel value in 2019 driven mostly by a 7% decrease in the ex-vessel price which was just below the 2011-2015 average (Table 5). The first-wholesale value of pollock products was $814 million for the at-sea sector and $552 million for the shore-based sector (Table 6). The average price of pollock products in 2020 increased 2% for the at-sea sector to $1.41 and decreased 4% for the shore-based sector to $1.08. Surimi prices decreased 8%, fillet prices increased 3%, and roe prices decreased 7% in 2020. Minced prices increased 11% and minced production rose 38% as demand for retail products increased as a result of COVID-19. Fishmeal prices rose 43% with a reduced Peruvian fishmeal supply because of a temporary fishery closure early in the year.

The portfolios of products shore-based and at-sea processors produce are similar. In both sectors the primary products processed from pollock are fillets, surimi and roe, with each accounting for approximately 40%, 40%, and 10% of first-wholesale value (Table 6). The price of products produced at-sea tend to be higher than comparable products produced by the shore-based processoers because of the shorter time span between catch, processing and freezing. Over the past 5 years the price of fillets produced at-sea tend to be about 7% higher, surimi prices tend to be about 25% higher and the price of roe about 50% higher. Average prices for fillets produced at-sea also tend to be higher because they produce proportionally more higher-priced fillet types (like deep-skin fillets). The at-sea price first wholesale premium averaged roughly $0.20 per pound between 2011–2015 and has increased to an average of $0.28 per pound between 2016–2020.[6]

Pollock fillets

A variety of different fillets are produced from pollock, with pin-bone-out (PBO) and deep-skin fillets typically accounting for approximately 70% and 30% of production in the BSAI, respectively.

[6]The at-sea price premium is the difference between the average price of first-wholesale products at-sea and the average price of first-wholesale products shore- based.

Deep-skin fillet's share of fillet production was 34% in 2020. Total fillet production decreased 20% to 149 kt in 2020, and was below the 2011–2015 average (Table 6). The average price of fillet products in the BSAI increased 3% to $1.56 per pound and is below the inflation adjusted average price of fillets in 2011–2015 of $1.63 per pound (2020 dollars). Media reports indicate that for single-frozen fillets increased retail demand stemming from COVID-19 supported strong prices, however, low double-frozen fillets prices (which have a strong foodservice component) put downward pressure on single-frozen prices. The decrease in fillet volumes was related to smaller fish size in the 2020 catch which are less suited to fillet production and better suited for minced which saw significant increases in both volume and value.

Pollock fillets sourced from Russia are a competitor to Alaska sourced pollock fillets. Although fillets were historically a relatively small portion of Russian primary production, Russia has recently been increasing its fillet production capacity. Russian catch goes to China for secondary processing into fillets so this would do little to increase the overall volume, however, increased primary fillet processing in Russia could increase competition with U.S. produced single-frozen fillet products. Using data through 2017 approximately 30% of the fillets produced in Alaska are estimated to remain in the domestic market, which accounts for roughly 45% of domestic pollock fillet consumption (AFSC 2020).[7] The U.S. industry has tried to maintain value over the years by increasing domestic marketing for fillet based product and creating product types that are better suited to the American palette, in addition to increased utilization of by-products.

Surimi seafood

Surimi production in 2020 was 171.7 kt, which was down 11% but above the 2011–2015 average. Prices have generally increased since 2013 and although they fell 8% in 2020 to $1.26 they remain strong (Table 6). Surimi is primarily a retail product, and demand in 2020 was strong with the increased focus on retail resulting from the COVID-19 pandemic. Furthermore, the supply of tropical species used to produce surimi has been tight. The smaller-sized fish caught by the U.S. in 2020 is better suited to production of low- to mid-grade surimi which puts downward pressure on surimi prices. Demand for high-grade surimi is high and supplies were tight. Because surimi and fillets are both made from pollock meat, activity in the fillet market can influence the decision of processors to produce surimi as smaller average size of fish can incentivize surimi production, particularly if it yields a higher value than fillets.

Pollock roe

Roe is a high priced product that is the focus of the A season catch destined primarily for Asian markets. Roe production in the BSAI averaged 27 kt in 2005–2007 and tapered off in the late–2000s and since has generally fluctuated at under or near 20 kt annually. Roe production decreased from the 12-year high exhibited in 2019 (Fig. 8). Prices peaked in the mid-2000s and have followed a decreasing trend over the last decade which continued until 2015, after which prices increased to $2.89 per pound in 2018. The Yen to U.S. Dollar exchange rate can influence prices and the dollar weakened against the Yen in 2020. The average roe price in the BSAI was down 7% in 2020 to

[7] Additionally, roughly 10% of the at-sea BSAI production is processed as H&G which is mostly exported, primarily to China, where is reprocessed as fillets and some share of which returns to the U.S.. China also processes H&G from Russia into fillets which are also imported into the domestic market. Current data collection does not allow us to estimate the share of U.S. returning imports.

\$2.01 per pound, the lowest observed. Value fell 17% with the decrease in production to \$109.1 million (Table 6).

Fish oil

Using oil production per 100 tons as a basic index (tons of oil per ton retained catch) shows increases for the at-sea sector. In 2005–2007 it was 0.3% and starting in 2008 it increased and leveled off after 2010 with over 1.5% of the catch being converted to fish oil (Table 8). This represents about a 5-fold increase in recorded oil production during this period. Oil production from the shore-based fleet was somewhat higher than the at-sea processors prior to 2008 but has been relatively stable. Oil production estimates from the shore-based fleet may be biased low because some production occurs at secondary processors (fishmeal plants) in Alaska. The increased production of oil beginning in 2008 can be attributed to the steady trend to add more value per ton of fish landed. The oil production index decreased 27% in 2020 and was at levels not seen since before 2012.

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, 2022
Acoustic trawl survey	Biomass index and age-specific proportions	1994, 1996, 1997, 1999, 2000, 2002, 2004, 2006–2010, 2012, 2014, 2016, 2018, 2020
Acoustic vessels of opportunity (AVO)	Biomass index	2006–2019, 2022

Note the 2020 acoustic survey data based on unmanned surface vessel (USV) transects

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 effective 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. 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. 14; Table 9). However, by 2017 the 2013 year-class began to be also evident, and surpassed the 2012 year-class in dominance and continued through to 2020. 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 small part of the catch (Fig. 14). The unusual pattern of switching adjacent year-classes was examined more closely to see if there was a pattern of spatial differences. Plotting the locales where the aged fish arose shows some separation with the 2013 year-class occuring further north (Fig. 15). This could be due to a number of factors including the relative concentrations of the original spawning fish and the relatively warm conditions which may have reduced the potential overlap and vulnerability to cannibalism.

The sampling effort for age determinations, weight-length measurements, and length frequencies is shown in Tables 10, 11, and 12. 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 13). 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 2021 the BTS biomass estimates ranged from 2.28 to 8.39 million t (Table 14; Fig. 16). 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. 17). In 2020 the survey was canceled and detailed data were unavailable (although the 2020 Ecosystem report (Siddon 2020) contains model estimates of temperature distributions for the region and indicates that the bottom temperatures and cold pool extent were about average). In 2021, the temperatures on bottom were above average again with a relatively constricted 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 2021 about 9% of the pollock biomass was found in these strata compared to a long term average of 5% (Table 14). 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 2021 survey estimate represents a substantial drop from the above-average 2019 estimate and is at 65% of the mean value and the 8^{th} lowest estimate since 1982 (using design-based, area swept estimates). This corresponded with a near-complete lack of cold water on the bottom throughout the survey area (Fig. 18). Pollock appeared to be distributed more broadly over the shelf in 2019, and in 2021, only a few stations had higher than average pollock densities compared to mean values (Fig. 19).

The BTS abundance-at-age estimates show variability in year-class strengths with substantial consistency over time (Fig. 20). 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. In 2021, the relative abundance of these size ranges was more apparent and this was unusual compared to the other years (Fig. 21).

Observed fluctuations in survey estimates may be attributed to a variety of sources including unaccounted-for variability in natural mortality, survey catchability, and migrations. 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 2021 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 15. 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 16 (based on the method in Kotwicki et al. 2014). Mean body mass at ages from the survey are shown in Table 17 and the different alternative time series of BTS survey indices is shown in Table 18.

The NBS survey area was sampled in 2010, 2017, 2018 (limited to 49 stations), in 2019 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 18). 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.

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). The number of trawl hauls, lengths, and ages sampled from the AT survey are presented in Table 19.

Estimated pollock biomass (to 0.5m from bottom) for the EBS shelf has averaged over 3.1 million t since the time-series was re-evaluated starting in 1994 (Table 18). 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, exceeding levels observed in 1994-2004 (Table 18). These surveys have also provided insight on the relative abundance of pollock in the areas considered critical to Steller sea lions (the "SCA"; Table 20). The 2020 AT survey biomass point estimate was computed from acoustic data collected by 3 uncrewed sailing vessels, using a backscatter to biomass conversion based on the entire AT time series (De Robertis et al. 2021; Table 20). The 2020 estimate (3.605 million t) indicated a 44% increase from the 2018 estimate (2.499 million t). A preliminary index developed in 2020 based on a spatio-temporal model-based approach is also shown (Table 20). This table also shows the preliminary index developed in 2020 based on a spatio-temporal model-based approach.

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). 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 21).

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 2021 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 2021 AVO index of midwater pollock abundance on the eastern Bering Sea shelf increased by 38% from 2019 and is the 2nd highest value on record (1.8% less than the highest value recorded in 2015) (Table 22; 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 and downweighted preliminary size and age composition data for 2021 were trialed
- The catch biomass estimates were updated through to the current year
- The AVO backscatter data collected opportunistically from the 2021 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. Following from last year the models examined were:

20.0a The model selected last year which omitted the 1978 year-class from affecting the SRR.

20.0b As last year but with added fishery length frequency data for 2021 to better reflect the apparent change in fish sizes (and ages) taken by the fishery.

20.0c As 20.0b but including the 2021 fishery preliminary age composition as derived from the application of a global age-length key.

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).

Tier 1 considerations

In the 2020 assessment we examined the factors affecting Tier 1 classifications including the required "reliability" of the estimated pdf of F_{MSY}, i.e., the influence of assumptions related to the uncertainties on the stock recruitment relationship, body mass-at-age, maturation, and fishery selectivity. For a number of years the Tier 1 ABC and OFL specifications for EBS pollock have been very high, in excess of the 2 million t OY for combined groundfish stocks managed within this FMP area. This has been because the spawning stock estimates have been well above target and mean levels. To add precaution to these estimates, ABC recommendations have been below the maximum permissible under Tier 1 but the rationale for such an adjustment could be improved. As such, the SSC requested an examination of the issues related to classifying this stock in Tier 1 versus Tier 3. The FMP (under amendment 56) guides this classification. It notes that a reliable estimate of F_{MSY} and its uncertainty (as expressed through a probability distribution or PDF) is required. Since these values depend primarily on the stock-recruitment relationship (SRR), the following sensitivities were pursued relative to the status quo (Model 20.0a) configuration:

- As status quo (i.e., ignoring the influence of the 1978 year class on the SRR).
- As in sensitivity a) but with a less informative prior on steepness
- As in status quo but the SRR conditioned such that $F_{MSY} = F_{35\%}$
- As in status quo but the SRR conditioned such that $F_{MSY} = F_{45\%}$

The first option was intended to reflect that the high value observed of the 1978 year-class occurred under an estimated low level of spawning biomass (designated Model 20.0a). The rationale for excluding this influential value was that the stock structure and environmental conditions may differ now, indicating non-stationarity in the relationship. Results showed that it mattered but was relatively minor and seemed unlikely to disqualify the estimates required for Tier 1. Sensitivity test b) was intended to illustrate the role of the prior mean and variance on the steepness estimate. Finally sensitivities c) and d) were considered as how the SRR may translate an implicit assumption under Tier 3 since $F_{35\%}$ is a proxy for F_{MSY} and $F_{45\%}$ is closer to the recent mean SPR rate.

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. This resulted in tuning the recent era (1991-present year) to average sample sizes of 350 for the fishery and then using estimated values for the period 1978-1990 and as earlier (Table 23). 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. The tuning aspects for these effective sample size weights were estimated in the 2016 assessment following Francis 2011 (equation TA1.8, hereafter referred to as Francis weights).

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 tend 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.

The values assumed for pollock natural mortality-at-age and maturity-at-age (for all models; Smith 1981) were kept the same 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., 2020 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 show that the 2020 and 2021 fish were well below average weight given length (Fig. 26; note that the anomalies are based on the period 1991-2021).

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 24). 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 24). How these fishery weights-at-age estimates can be supplemented using survey weights-at-age is further illustrated in Fig. 28.

In the 2020 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, 1119 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 1964–2021 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, five catchability coefficients were estimated: one each for the early fishery catch-per-unit effort (CPUE) data (from Low and Ikeda, 1980), the early bottom trawl survey data (where only 6 strata were surveyed), the main bottom trawl survey data (including all strata surveyed), 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 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. 16 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 23).
- 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 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).

Results

Model evaluation

A sequential sensitivity of available new data showed that adding the 2020 fishery catch-at-age data and the 2021 catch biomass information had a fairly big impact on the spawning biomass estimates (Fig. 31). As the new 2021 bottom-trawl survey estimates were added to the model (named Model 20.0a), the biomass estimate dropped further but adding the 2021 AVO data resulted in a slight increase (Fig. 31). Adding the 2021 length composition and preliminary catch-at-age data had a minor impact on biomass and recruitment (Fig. 32). Diagnostics of model fits between the set evaluated are given in Table 25 and comparisons of management quantities are given in Table 26).

For setting advice, we selected Model 20.0c which was the same model selected for 2020 but includes the preliminary 2021 fishery age and length composition data. As noted these data are preliminary, but we considered that including them was worthwhile since they reflect the younger fish taken by the fishery in recent years. This impacts the estimates of selectivity and consequently estimates of reference fishing mortality rates (e.g., F_{MSY}).

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. **??**). 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. **??**). The model fits to the bottom-trawl survey biomass (the density-dependent corrected series) were reasonable and within the observation error bounds (Fig. **??**). The fit to the acoustic-trawl survey biomass series (including the USV data from 2020) was consistent with the specified observation uncertainty (Fig. **??**).

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. **??**; 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. **??**). The model fits the fishery age-composition data quite well under this form of selectivity (Fig. **??**).

Bottom-trawl survey selectivity estimates are shown in Fig. **??**. 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. **??**). The pattern of bottom trawl survey age composition data in recent years shows a decline in the abundance of age 10+ pollock since 2011. 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. **??**). The AT age compositions consistently track large year classes through the population and the model fits these patterns reasonably well (Fig. **??**).

As in past assessments, an evaluation of the multivariate posterior distribution was performed by running a chain of 3 million Monte-Carlo Markov chain (MCMC) simulations and saving every 600th iteration (final posterior draws totaled 5,000). We evaluated how selected parameters relate by doing a pairwise (along with their marginal distributions) figure (Fig. **??**). 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. **??**). As an additional part of the Tier 1 consideration, we evaluated the posterior density of F_{MSY} and is provided in Fig. **??** for reference.

Relative to improving model selection processes, diagnostics and a method for estimating variance parameters internally, we added code for producing posterior predictive distributions. These are shown as an example for the two acoustic indices in Fig. **??**.

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. 33). This year with the lower than expected survey biomass estimate, the retrospective pattern degraded considerably with an increased average bias (Mohns ρ equal to 0.172 for the 10 year retrospective).

In response to the SSC's request 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. 34). To explain this figure, and taking the 2021 panel as an example, the blue line in that panel represents the projected estimate from the 2020 "peel" (the current model projecting to 2021 using only data up until 2020). The dots represent estimates from each "peel" and the dots in the 2021 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. 35).

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. **??**). In the 2020 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. 36). 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 9 to 12 million t (Table 27). 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 nearly 12 million t in 2016 following the low in 2008 of 4.45 million t. The estimate for 2022 is trending downward and at 12.55 million t with 2023 estimated at 12.12 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. 37). 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 has since increased steadily and been above 20% in the last three years. Age specific fishing mortality rates reflect these patterns and show some increases in the oldest ages from 2011–2013 and again in recent years (Fig. 38). The estimates of age 3+ pollock biomass show a large drop in this year compared to several of the earlier years (Fig. 39, Table 27).

Estimated numbers-at-age are presented in (Table 28) and estimated catch-at-age values are presented in (Table 29). Estimated summary biomass (age 3+), female spawning biomass, and age-1 recruitment are given in (Table 30).

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. 40). 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. 41).

Recruitment

Model estimates indicate that the 2008, 2012, and 2013 year classes are above average (Fig. 42). The stock-recruitment curve as fit within the integrated model shows the variability of the estimated curve (Fig. 43). Note that the 2019 and 2020 year classes (as age 1 recruits in 2020 and 2021) 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. 44).

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. 45). This shows a pattern consistent with the impact of warming on recruits with the average from 2000-present being below the current regime (since 1977) average.

Harvest recommendations

Status summary

The estimate of B_{MSY} is 2,335 kt (with a CV of 27%) which is less than the projected 2023 spawning biomass of 3,900 kt; (Table 31). For 2023, the estimates put the stock in Tier 1a. The corresponding maximum permissible ABC would thus be 3,087,000 t with a fishable biomass estimated at around 6,769 kt (Table 32). For the current year spawning biomass this corresponds to 155% 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 63% of the predicted value had no fishing occurred since 1978 (Table 31).

Compared to Tier 3 projections, the results indicate that spawning biomass in 2023 will be about 59% of $B_{100\%}$ (based on the SPR expansion using mean recruitment from 1978–2020). This would put the stock in Tier 3a and above $B_{40\%}$ and result in a 2022 ABC of 1,378,000 t.

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, this year 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 2,766,000 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 2,306,000 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}.

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} = 2,335 kt female spawning biomass
B_0 = 5,922 kt female spawning biomass
$B_{100\%}$ = 6,108 kt female spawning biomass
$B_{40\%}$ = 2,443 kt female spawning biomass
$B_{35\%}$ = 2,138 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. 36).

Since the 2023 female spawning biomass is estimated to be above the B_{MSY} level (2,335 kt) and above the $B_{40\%}$ value (2,443 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	3,087,000	3,703,000
1a	2024	4,455,000	5,344,000
2a	2023	2,766,110	3,703,000
2a	2024	3,991,810	5,344,000
3a	2023	1,378,000	1,728,000
3a	2024	1,644,000	2,024,000

Note that the values presented for 2023 assumed a catch of 1,200,000 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 36 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 will starts below $B_{35\%}$ and is expected to be above $B_{40\%}$ by 2026 (given mean recruitment; Fig. 46).

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 33 through 36). 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 36). 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 1.67 for EBS pollock (assuming this year's estimated 2020 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 below average levels and projections indicate the potential for further declines. Updated data and analysis result in an estimate of 2022 spawning biomass (3,610 kt) which is about 155% of B_{MSY} (2,335 kt). This follows a period of increases from 2008–2017. The extent that the stock will decline further depends on recruitment, which given the available information, is uncertain. Given the same estimated aggregate fishing effort in 2021, the estimated stock trend is downwards except at low catch levels. Furthermore, the ability to catch roughly the same amount as in 2022 through to 2023 will require more effort (effectively) and will result in further declines in spawning biomass.

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.

	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, the lower than expected survey observation lowered the recent biomass estimates and the retrospective analysis 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 2019. 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 and 2013 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. Presently it appears that the mean recruitment since 2000 has been below average (Fig. 45). There also are clear density-dependent effects on growth, in particular, the 2012 year class. The stock is estimated to be below B_{msy} at present, and projections indicate a reasonable chance that the stock will decline further given recent catch levels. The extent that the the lack of a cold pool and will impact pollock survival at egg, larval, and juvenile stages is uncertain. Recruitment in the near term could be below average yet projections assume average recruitment (with uncertainty). 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. 47). **We therefore rated the population-dynamics concern as level 2, substantially increased concern.**

Environmental/Ecosystem considerations

Environmental processes Beginning in approximately 2014, the eastern Bering Sea (EBS) entered a warm phase of unprecedented duration. The EBS remains in this warm phase, though to a lesser degree compared to the extreme years of 2018 and 2019. Sea ice formation in fall of 2020 was delayed due to residual warmth in the system. While the areal extent of sea ice was closer to the pre-2014 levels than at any point in the last 7 years, ice thickness differed between the northern (thicker ice) and southern (thinner/no ice) shelves due to opposing prevailing winds (see Physical Environment Synthesis in Siddon, 2021). The summer 2021 cold pool remained significantly reduced in area, and its southern boundary was shifted northwestward. The areal extent of the cold pool has increased since 2018, yet the 2021 extent was the 4th lowest on record and remains more than one standard deviation below the mean (Rohan and Barnett, 2021a). Summer bottom temperatures varied spatially over the shelf. Near-average conditions were present over the SEBS, while the NBS had a very warm inner domain (i.e., Norton Sound) and a small cold pool over the middle domain to the southwest of St. Lawrence Island (Rohan and Barnett, 2021b).

Multiple ecosystem 'red flags' occurred in the NBS this year: crab population declines (Richar, 2021), salmon run failures in the Arctic-Yukon-Kuskokwim region (Liller, 2021), and seabird die-offs combined with low colony attendance and poor reproductive success (see Integrated Seabird Information in Siddon, 2021). In addition, results from the bottom trawl survey demonstrate a substantial drop in total CPUE in the NBS between 2019 and 2021 that reflected large decreases in all of the dominant species, including pollock (Mueter and Britt, 2021). Whether a single or suite of mechanisms can be identified to explain these coincident events, the common thread in these collapses is the marine environment in the NBS. Concerns about the food web dynamics and carrying capacity in the NBS have existed since 2018, highlighted by the gray whale Unusual Mortality Event and short-tailed shearwater mass mortality event (Siddon and Zador, 2019).

Fish condition, as measured by length-weight residuals, trended downward from 2019 for multiple groundfish species, including benthic, pelagic, and apex predators, across both the southern and northern portions of the survey area (Rohan and Prohaska, 2021), indicating poor feeding conditions across trophic niches. While adult pollock (>25 cm) followed this trend of decreasing condition based on length/weight residuals in the southern and northern survey areas, juvenile pollock (100-250 mm) showed positive residuals in both regions (Rohan and Prohaska, 2021), indicating sufficient foraging conditions existed for juvenile pollock. The pollock condition based on fishery standardized mean weights-given-length was also relatively low during 2020 and 2021 (Fig. 26).

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 2020 year class is predicted to have below-average recruitment to age-4 in 2024 (Yasumiishi, 2021).

Prey The spring bloom over the south inner and middle domains occurred at or slightly later than the long-term average. In comparison, at mooring M2, 2017 was among the earliest spring blooms while 2018 was among the latest (Nielsen et al., 2021). Chlorophyll concentrations in these regions have been below the long-term median since 2016, although the south inner region was at the median value in 2021 (Nielsen et al., 2021). Depending on the spatial and temporal overlap of productivity, this can result in a match or mismatch with favorable feeding conditions for larval pollock.

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. In 2021, over the southern shelf, the springtime abundance of small copepods was within historical ranges and large copepods appeared on-track to be available for age-0 fish later in the year (Kimmel et al., 2021). In addition, higher abundances of adult euphausiids were observed which, if persistent through summer, would also provide a significant food source to forage fish (Kimmel et al., 2021). Over the northern shelf in late summer, similar zooplankton patterns were observed with low abundances of small copepods, but slight increases in the abundance of large copepods and euphausiids (Kimmel et al., 2021). The annual ration of EBS pollock (Holsman et al., 2021) has also increased in recent years under warmer conditions.

Predators Pollock are cannibalistic and rates of cannibalism might be expected to increase as the biomass of older, larger fish increases. In 2020, 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, 2021a). While all other species and functional groups within the pelagic forager guild were below their long term means, Pacific herring was above their long term mean (Whitehouse, 2021a); as plankton eaters, they are competitors with pollock for zooplankton prey.

Fur seal consumption of adult pollock generally increases in years when juvenile pollock are less abundant (Kuhn et al., 2019). However, no information on population trends for fur seals is available since 2019.

Other potential predators of juvenile pollock include jellyfish and chum salmon. Jellyfish abundance was high in 2019 (among the top 4 highest years since 1982), but declined to low abundance in 2021 (Britt, 2021). Chum salmon abundance has been declining precipitously 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, 2021b).

Competitors The 2021 Bristol Bay sockeye salmon inshore run was the largest on record since 1963 (Cunningham et al., 2021). 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. The widespread die-off event of short-tailed shearwaters in 2019 slowed in 2020 (Siddon, 2020), with an uptick in die-off numbers in 2021 especially in the northern Bering Sea (see Integrated Seabird Information in Siddon, 2021). Shearwaters are planktivorous birds and feed on euphausiids in the Bering Sea in summer. The die-off event of 2019 is thought to reflect poor foraging conditions for birds during summer 2018 as most sampled birds showed signs of emaciation; the event of 2021 may reflect strains on the carrying capacity of the northern Bering Sea region. With the exception of Pacific herring, the 2021 index for all other species and functional groups in the pelagic forager guild were below their long term means (Whitehouse, 2021a).

Summary for Environmental/Ecosystem considerations:

- The eastern Bering Sea has been in a prolonged warm phase since 2014;
- Extent of sea ice was closer to pre-2014 levels than at any point in the last 7 years,
- Sea ice thickness differed between the northern (thicker ice) and southern (thinner/no ice) shelves due to opposing prevailing winds;
- The cold pool was reduced in area and its southern boundary was shifted northwestward;
- Concerns about the food web dynamics and carrying capacity in the NBS have existed since 2018 and may reflect poor feeding conditions in the northern Bering Sea;
- Condition of adult pollock (as measured by length/weight residuals) trended down across the Bering Sea while juvenile pollock showed positive condition, indicating sufficient foraging conditions existed for juvenile pollock;
- The 2020 year class experienced unfavorable temperature conditions from age-0 to age-1 and is predicted to have below-average recruitment to age-4 in 2024;
- Spring bloom timing and chlorophyll concentrations over the southern shelf were average in 2021.
- Zooplankton composition in spring indicated potentially favorable foraging conditions for age-0 pollock through summer, especially over the southern shelf.
- Predation pressure from cannibalism may have been mitigated by declines in biomass of pelagic foragers, including adult pollock.

- Predation pressure from jellyfish and chum salmon was also reduced due to relative declines in the abundance of jellyfish and chum salmon over the shelf.
- Bristol Bay sockeye salmon compete with both juvenile and adult pollock for prey (zooplankton, euphausiids, age-0 pollock), therefore sustained high inshore runs of sockeye salmon may have system-wide impacts on foraging success of pollock.

We therefore rated the Ecosystem concern as Level 2, substantially increased concern.

Fishery performance

As noted above, the 2021 B-season fishery was improved over 2020 but there remains concern about small pollock in the catches. Also, an approach to computing fleet dispersion (the relative distance or spread of the fishery in space) was developed and indicated that the seasonal dispersion levels were below average (Fig 10).

The CPUE of PSC species and other bycatch moderated some relative to 2020. Sablefish, herring and Chinook salmon bycatch rates (per hour of fishing) decreased from 2020 but chum salmon had a marked increase (Fig. 3).

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 the case this year which caused the retrospective pattern to degrade). The mean weight-at-age for the 2020 B-season was near average, but in general pollock were skinny given their length, and the fact that in 2020 a significant component of the catch was 2-year old pollock which are rarely found in the catch led us to **conclude that the fishery performance scored a value of 2, substantially increased concerns.**

These results are summarized as:

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

Having all four scores at level 2 suggests that setting an ABC below the maximum permissible is warranted. The SSC recommended against using a table that showed example alternatives to select buffers based on that risk level. Thompson (unpublished Sept 2018 Plan Team document) tabulated the magnitude of buffers applied by the Plan Teams for the period 2003–2017, and found that the mode of the buffers recommended was 10–20%. Using this as a guideline, a buffer of 15% would give an ABC as 0.85 × ABC$_{max}$ = 2,624 kt). In the past, the SSC has considered factors similar to those presented above and selected an ABC based on Tier 3 estimates. This 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%). Tier 3 buffers (relative to Tier 1) are substantially larger and vary (i.e., for 2022 it would be 28% and in 2023 it increases to 29%. Given that the rationale for the SSC classifying this stock in Tier 1 seems likely to continue, and noting that Tier 1 has biological risk-aversion built in (based on uncertainty in the F_{MSY}), adopting a buffer based on Tier 2 might be appropriate given the increased concerns and has an appeal that the buffer is constant and more reasonably predictable. This gives ABC = 2,766 kt) which implies a buffer of 10%. It is worth noting that the level of effort (theoretically, based on the 2021 estimated fishing mortality) would be nearly equal to that estimated for 2021 (1,107,000 t). During the last drop in the pollock stock, holding "effort steady" was adopted as part of the rationale for recommending an ABC lower than the maximum.

The SSC has requested "an explicit set of concerns that explain the ABC adjustment." In response, we direct attention to the decision table 38) 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 40 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 22% 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 2% lower than the mean value or a target female spawning biomass at 2.802 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 37). Model 20.0c results for these indicators are provided in Table 38. 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}).

Another approach/rationale would be to stabilize effort from the 2021 levels and recommend that 2022 fishing mortality is set equal to the 2021 estimate. This gives an ABC of 1,150,000 kt. The Plan Teams and SSC may wish to consider this as an added measure of precaution for ABC considerations.

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 (see Appendix 1 of the Ecosystem Considerations chapter for methods), 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 43). 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 41). 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 less than 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 (Table 39). There has been a marked increase in the incidental catch of Pacific ocean perch, sablefish, and Atka mackerel and a decrease in flatfish species. Proportionately, the incidental catch decreased since the overall levels of pollock catch have increased since 2008. In fact, the bycatch of pollock in other target fisheries is more than double the bycatch of target species in the pollock fishery (Table 40).

The number of non-Chinook salmon (nearly all made up of chum salmon) taken incidentally has steadily increased since 2014 with the 2017 number in excess of 465 thousand fish, then was below 300 thousand, then increased a little and was high in 2021 at over 530 thousand (Table 42). Chinook salmon bycatch has varied but has mostly been below 30,000 fish since the high in 2007 (Table 42). 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:

- 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 (i.e., length and age).
- 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, studies investigating the processes affecting recruitment of pollock in the different regions of the EBS (including potential for influx from the GOA) should be pursued.
- 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. Catch from the Eastern Bering Sea by area, the Aleutian Islands, the Donut Hole, and the Bogoslof Island area, 1979–2020 (2020 values through October 25th 2020). The southeast area refers to the EBS region east of 170W; the Northwest is west of 170W. Note: 1979–1989 data are from Pacfin, 1990–2020 data are from NMFS Alaska Regional Office, and include discards. The 2020 EBS catch estimates are preliminary.

	Eastern Bering Sea					
Year	Southeast	Northwest	Total	Aleutians	Donut Hole	Bogoslof I.
1979	368,848	566,866	935,714	9,446		
1980	437,253	521,027	958,280	58,157		
1981	714,584	258,918	973,502	55,517		
1982	713,912	242,052	955,964	57,753		
1983	687,504	293,946	981,450	59,021		
1984	442,733	649,322	1,092,055	77,595	181,200	
1985	604,465	535,211	1,139,676	58,147	363,400	
1986	594,997	546,996	1,141,993	45,439	1,039,800	
1987	529,461	329,955	859,416	28,471	1,326,300	377,436
1988	931,812	296,909	1,228,721	41,203	1,395,900	87,813
1989	904,201	325,399	1,229,600	10,569	1,447,600	36,073
1990	640,511	814,682	1,455,193	79,025	917,400	151,672
1991	653,555	542,109	1,195,664	98,604	293,400	316,038
1992	830,559	559,741	1,390,299	52,352	10,000	241
1993	1,094,429	232,173	1,326,602	57,132	1,957	886
1994	1,152,575	176,777	1,329,352	58,659		556
1995	1,172,306	91,941	1,264,247	64,925		334
1996	1,086,843	105,939	1,192,781	29,062		499
1997	819,889	304,544	1,124,433	25,940		163
1998	969,644	132,515	1,102,159	23,798		8
1999	782,983	206,698	989,680	1,010		29
2000	839,177	293,532	1,132,710	1,244		29
2001	961,977	425,220	1,387,197	825		258
2002	1,160,334	320,442	1,480,776	1,177		1,042
2003	933,191	557,588	1,490,779	1,649		24
2004	1,090,008	390,544	1,480,552	1,158		0
2005	802,154	680,868	1,483,022	1,621		0
2006	827,207	660,824	1,488,031	1,745		0
2007	728,249	626,253	1,354,502	2,519		0
2008	482,698	507,880	990,578	1,278		9
2009	358,252	452,532	810,784	1,662		73
2010	255,114	555,072	810,186	1,289		176
2011	747,891	451,150	1,199,041	1,208		173
2012	618,872	586,350	1,205,222	975		71
2013	695,673	575,098	1,270,770	2,964		57
2014	858,243	439,180	1,297,422	2,375		427
2015	696,253	625,331	1,321,584	913		733
2016	1,167,072	185,609	1,352,681	1,257		1,005
2017	1,178,021	181,161	1,359,182	1,507		185
2018	1,048,693	330,595	1,379,287	1,860		14
2019	1,102,156	307,181	1,409,337	1,664		8
2020	859,903	506,629	1,366,532	3,205		9
2021	1,021,017	351,967	1,372,984	1,594		50
Avg.	803,842	412,668	1,216,510	23,896		

Table 1-2. Time series of 1964–1976 catch (left) and ABC, TAC, and catch for EBS pollock, 1977–2020 in t. Source: compiled from NMFS Regional office web site and various NPFMC reports. Note that the 2020 value is based on catch reported to October 25th 2020 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
1977–2021 mean			2,471,333	1,495,022	1,221,947	1,204,343

Table 1-3. Estimates of discarded pollock (t), percent of total (in parentheses) and total catch for the Aleutians, Bogoslof, Northwest and Southeastern Bering Sea, 1991–2020. SE represents the EBS east of 170W, NW is the EBS west of 170W, source: NMFS Blend and catch-accounting system database. 2020 data are preliminary. Note that the higher discard rates in the Aleutian Islands and Bogoslof region reflect the lack of directed pollock fishing.

	Discarded pollock					Total (retained plus discard)				
	Aleut. Is.	Bog.	NW	SE	Total	Aleut. Is.	Bog.	NW	SE	Total
	Discarded pollock					Total (retained plus discard)				
	Aleut. Is.	Bog.	NW	SE	Total	Aleut. Is.	Bog.	NW	SE	Total
1991	5,231 (5%)	20,327 (6%)	48,257 (9%)	66,792 (10%)	140,607 (9%)	98,604	316,038	542,109	653,555	1,610,306
1992	2,986 (6%)	240 (100%)	57,581 (10%)	71,194 (9%)	132,002 (9%)	52,362	241	559,750	830,559	1,442,912
1993	1,740 (3%)	308 (35%)	26,107 (11%)	83,986 (8%)	112,141 (8%)	57,138	886	232,180	1,094,429	1,384,633
1994	1,373 (2%)	11 (2%)	16,084 (9%)	88,098 (8%)	105,566 (8%)	58,659	556	176,777	1,152,575	1,388,567
1995	1,380 (2%)	267 (80%)	9,715 (11%)	87,492 (7%)	98,855 (7%)	64,925	334	91,941	1,172,306	1,329,506
1996	994 (3%)	7 (1%)	4,838 (5%)	71,368 (7%)	77,208 (6%)	29,062	499	105,939	1,086,843	1,222,342
1997	618 (2%)	13 (8%)	22,557 (7%)	71,032 (9%)	94,220 (8%)	25,940	163	304,544	819,889	1,150,536
1998	162 (1%)	3 (39%)	1,581 (1%)	14,291 (1%)	16,037 (1%)	22,054	8	132,515	969,644	1,124,221
1999	480 (48%)	11 (39%)	1,912 (1%)	26,912 (3%)	29,315 (3%)	1,010	29	206,698	782,983	990,719
2000	790 (64%)	20 (67%)	1,942 (1%)	19,678 (2%)	22,429 (2%)	1,244	10	293,532	819,499	1,133,984
2001	380 (46%)	28 (11%)	2,450 (1%)	14,874 (2%)	17,732 (1%)	825	231	425,220	947,103	1,388,280
2002	779 (66%)	12 (1%)	1,441 (tr)	19,430 (2%)	21,661 (1%)	1,177	1,031	320,442	1,140,904	1,482,995
2003	468 (28%)	19 (79%)	2,959 (1%)	13,795 (1%)	17,242 (1%)	1,649	5	557,588	919,397	1,492,452
2004	287 (25%)	0 (100%)	2,781 (1%)	20,380 (2%)	23,448 (2%)	1,158	-	390,544	1,069,628	1,481,710
2005	324 (20%)	0 (89%)	2,586 (tr)	14,838 (2%)	17,747 (1%)	1,621	0	680,868	787,316	1,484,643
2006	311 (18%)	0 (50%)	3,677 (1%)	11,877 (1%)	15,865 (1%)	1,745	0	660,824	815,330	1,489,776
2007	425 (17%)	- (%)	3,769 (1%)	12,334 (2%)	16,529 (1%)	2,519	0	626,253	715,915	1,357,021
2008	81 (6%)	0 (%)	1,643 (tr)	5,968 (1%)	7,692 (1%)	1,278	9	507,880	476,730	991,865
2009	395 (24%)	6 (8%)	1,936 (tr)	4,014 (1%)	6,351 (1%)	1,662	67	452,532	354,238	812,520
2010	146 (12%)	53 (30%)	1,270 (tr)	2,490 (1%)	3,959 (tr)	1,289	124	555,072	252,623	811,651
2011	75 (6%)	23 (13%)	1,377 (tr)	3,446 (tr)	4,919 (tr)	1,208	150	451,150	744,445	1,200,421
2012	95 (10%)	0 (%)	1,191 (tr)	4,080 (1%)	5,366 (tr)	975	71	586,350	614,792	1,206,268
2013	107 (4%)	0 (1%)	1,226 (tr)	4,085 (1%)	5,418 (tr)	2,964	56	575,098	691,588	1,273,791
2014	138 (6%)	54 (13%)	1,787 (tr)	12,556 (1%)	14,534 (1%)	2,375	373	439,180	845,687	1,300,224
2015	19 (2%)	138 (19%)	2,419 (tr)	7,056 (1%)	9,632 (1%)	913	595	625,331	689,197	1,323,230
2016	59 (5%)	7 (1%)	1,035 (1%)	8,124 (1%)	9,226 (1%)	1,257	997	185,609	1,158,948	1,354,942
2017	18 (1%)	1 (1%)	1,356 (1%)	6,848 (1%)	8,224 (1%)	1,507	184	181,161	1,171,173	1,360,874
2018	216 (12%)	2 (1%)	2,005 (1%)	9,170 (1%)	11,393 (1%)	1,860	11	330,595	1,039,523	1,381,161
2019	65 (4%)	0 (1%)	1,979 (1%)	7,118 (1%)	9,162 (1%)	1,663	8	307,177	1,094,931	1,410,897
2020	231 (8%)	2 (28%)	2,467 (0%)	9,138 (1%)	11,838 (1%)	2,828	6	496,080	820,566	1,328,620

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).

Table 1-5. BSAI pollock catch and ex-vessel data showing the total and retained catch (in kt), the number of vessels for all sectors and for trawl catcher vessels including ex-vessel value (million US$), price (US$ per pound), and catcher vessel shares. Years covered include the 2011-2015 average, and annual from 2016-2020.

	Avg 11-15	2016	2017	2018	2019	2020
All sectors						
Catch kt	1261	1355	1361	1381	1411	1370
Retained Catch kt	1252	1346	1353	1370	1402	1358
Vessels #	120	122	118	112	114	117
Catcher Vessels (Trawl)						
Retained Catch kt	656	704	710	718	736	725
Ex-vessel Value M $	228.70	209.40	205.50	236.70	259.80	233.70
Ex-vessel Price/lb $	0.16	0.14	0.14	0.16	0.17	0.15
CV share of Retained Catch	0.52	0.52	0.53	0.52	0.52	0.53
Vessels #	87	89	87	85	84	88

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

Table 1-6. BSAI pollock first-wholesale market data including production (kt), value (million US$), price (US$ per pound) for all products and then separately for other categories (head and gut, fillet, surimi, and roe production). Years covered include the 2011-2015 average, and annual from 2016-2020.

	Avg 11-15	2016	2017	2018	2019	2020
All Products volume kt	501.8	534.9	523.9	532.4	557.9	492.7
All Products value M $	$1,310	$1,352	$1,338	$1,383	$1,551	$1,366
All Products price lb $	$1.18	$1.15	$1.16	$1.18	$1.26	$1.26
At-sea value share	59%	60%	62%	59%	59%	60%
Fillets volume kt	164.3	161.3	157.0	167.6	186.8	149.4
Fillets value share	40%	37%	33%	36%	40%	38%
Fillets price lb $	$1.45	$1.41	$1.29	$1.37	$1.52	$1.56
Surimi volume kt	163.8	190.8	196.7	196.5	192.2	171.8
Surimi value share	33%	37%	43%	40%	38%	35%
Surimi price lb $	$1.19	$1.19	$1.33	$1.27	$1.37	$1.26
Roe volume kt	17.6	14.3	18.4	20.6	28.0	24.7
Roe value share	10%	7%	9%	10%	9%	8%
Roe price lb $	$3.26	$2.84	$2.88	$2.89	$2.15	$2.01
At-sea price premium ($/lb)	$0.20	$0.25	$0.37	$0.20	$0.26	$0.33

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; NMFS Alaska // Region At-sea Production Reports; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

Table 1-7. Alaska pollock U.S. trade and global market data showing global production (in kt) and the U.S. and Russian shares followed by U.S. export volumes (kt), values (million US$), export prices (US$ per pound), import values (million US$), and net exports (million US$). Subsequent rows show the breakout of export shares (of U.S. pollock) by country (Japan, China and Europe) and the share of U.S. export volume and value of fish (i.e., H&G and fillets), and other product categories (surimi and roe). Years covered include the 2011-2015 average, and annual from 2016-2020.

		Avg 11-15	2016	2017	2018	2019	2020
Global Pollock Catch kt		3,270	3,476	3,489	3,397	3,496	-
U.S. Share of Global Catch		42%	44%	44%	45%	43%	-
Russian Share of global catch		48%	50%	50%	49%	50%	-
BSAI share of global		39%	39%	39%	41%	40%	-
Export Volume kt		350.3	379.6	397.9	415.2	380.1	323.5
Export Value M US$		$990.1	$990.5	$1,007.5	$1,129.1	$1,119.9	$941.9
Export Price lb US$		$1.28	$1.18	$1.15	$1.23	$1.34	$1.32
Import Value M US$		$155.6	$92.5	$76.2	$78.7	$123.4	$100.4
Net Exports		$834.5	$898.0	$931.3	$1,050.4	$996.5	$841.5
Japan	Volume Share	22%	20%	22%	22%	23%	19%
	Value share	21%	20%	23%	26%	24%	20%
China	Volume Share	13%	12%	15%	14%	10%	10%
	Value share	11%	10%	13%	10%	7%	6%
Germany	Volume Share	38%	35%	32%	33%	35%	37%
	Value share	38%	35%	33%	33%	37%	39%
Meat/Fillets	Volume Share	50%	49%	49%	50%	47%	46%
	Value share	49%	46%	47%	45%	44%	44%
Surimi	Volume Share	44%	47%	47%	45%	46%	47%
	Value share	37%	42%	42%	42%	43%	42%
Roe	Volume Share	5%	4%	5%	5%	7%	7%
	Value share	14%	11%	11%	13%	13%	14%

Notes: Exports are from the US and are note specific to the BSAI region. 'Meat' includes fillets, H&G, minced and other non-surimi meat based products. Europe refers to Austria, Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and United Kingdom.

Source: FAO Fisheries & Aquaculture Dept. Statistics http://www.fao.org/fishery/statistics/en. NOAA Fisheries, Fisheries Statistics Division, Foreign Trade Division of the U.S. Census Bureau, http://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/index. U.S. Department of Agriculture http://www.ers.usda.gov/data-products/agricultural-exchange-rate-data-set.aspx.

Table 1-8. BSAI pollock fish oil production index (tons of oil per 100 tons of retained catch); 2011-2015 average, and annual from 2016-2020.

Sector	Avg 11-15	2016	2017	2018	2019	2020
All Sectors	2.04	2.06	1.92	1.93	2.22	1.61
Shoreside	2.27	2.28	2.09	2.08	2.32	1.83
At Sea	1.78	1.82	1.74	1.77	2.10	1.36

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; NMFS Alaska Region At-sea Production Reports; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

Table 1-9. Eastern Bering Sea pollock catch at age estimates based on observer data, 1979–2020. 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
Mean	6.3	56.6	194.1	358.7	396.8	344.7	218.3	113.1	64.6	33.5	22.4	11.2	7.7	11.0	1,836

Table 1-10. Numbers of pollock NMFS observer samples measured for fishery catch length frequency (by sex and strata), 1977–2020.

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 1-11. 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

Table 1-12. Numbers of pollock fishery samples used for age determination estimates by sex and strata, 1977–2020, 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

Table 1-13. NMFS total pollock research catch by year in t, 1964–2020.

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	76

Table 1-14. Survey biomass estimates (age 1+, t) of Eastern Bering Sea pollock based on design-based area-swept expansion methods from NMFS bottom trawl surveys 1982–2021.

	Survey biomass			
Year	Strata 1-6	Strata 8-9	Total	%NW
1982	2,858,400	54,469	2,912,869	2%
1983	5,921,380	-	5,921,380	-
1984	4,542,405	-	4,542,405	-
1985	4,560,122	637,881	5,198,003	12%
1986	4,835,722	-	4,835,722	-
1982	2,858,400	54,469	2,912,869	2%
1983	5,921,380	-	5,921,380	-
1984	4,542,405	-	4,542,405	-
1985	4,560,122	637,881	5,198,003	12%
1986	4,835,722	-	4,835,722	-
1987	5,111,645	386,788	5,498,433	7%
1988	7,003,983	179,980	7,183,963	3%
1989	5,906,477	643,938	6,550,415	10%
1990	7,107,218	189,435	7,296,653	3%
1991	5,067,092	62,446	5,129,538	1%
1992	4,316,660	209,493	4,526,153	5%
1993	5,196,453	98,363	5,294,816	2%
1994	4,977,639	49,686	5,027,325	1%
1995	5,409,297	68,541	5,477,838	1%
1996	2,981,680	143,573	3,125,253	5%
1997	2,868,734	693,429	3,562,163	19%
1998	2,137,049	550,706	2,687,755	20%
1999	3,598,688	199,786	3,798,474	5%
2000	4,985,064	118,565	5,103,629	2%
2001	4,145,746	51,108	4,196,854	1%
2002	4,755,668	197,770	4,953,438	4%
2003	8,106,358	285,902	8,392,261	3%
2004	3,744,501	118,473	3,862,974	3%
2005	4,731,068	137,548	4,868,616	3%
2006	2,845,553	199,827	3,045,380	7%
2007	4,158,234	179,986	4,338,220	4%
2008	2,834,093	189,174	3,023,267	6%
2009	2,231,225	51,185	2,282,410	2%
2010	3,550,981	186,898	3,737,878	5%
2011	2,945,641	166,672	3,112,312	5%
2012	3,281,223	206,005	3,487,229	6%
2013	4,297,970	277,433	4,575,403	6%
2014	6,552,849	877,104	7,429,952	12%
2015	5,944,325	450,034	6,394,359	7%
2016	4,698,430	211,650	4,910,080	4%
2017	4,688,500	125,873	4,814,373	3%
2018	3,015,612	97,185	3,112,797	3%
2019	4,973,872	484,494	5,458,366	9%
2021	2,697,644	336,673	3,034,317	11%
Average	4,450,903	253,280	4,684,699	5%

Table 1-15. Sampling effort for pollock in the EBS from the NMFS bottom trawl survey 1982–2021.

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

Table 1-16. Bottom-trawl survey estimated numbers *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	1,287	3,059	3,362	4,377	1,505	206	143	68	43	27	17	10	4	1	1	14,112
1983	4,798	734	1,656	2,980	6,690	2,042	371	198	89	77	58	20	8	7	3	19,731
1984	435	363	538	1,535	1,905	4,451	853	189	88	31	21	8	5	6	3	10,431
1985	6,078	997	3,845	1,222	4,031	2,455	1,679	331	84	70	24	8	9	1	0	20,832
1986	2,774	678	533	1,875	1,135	1,889	1,653	1,501	471	72	33	15	1	4	1	12,636
1987	440	793	1,083	817	4,956	1,371	1,313	519	1,640	253	74	29	5	3	2	13,299
1988	1,635	838	1,952	3,692	1,606	5,209	1,544	1,169	674	1,596	151	90	18	24	13	20,210
1989	1,051	347	672	2,218	4,981	989	3,761	571	687	267	837	145	128	64	90	16,808
1990	2,371	403	145	925	1,847	6,193	1,243	3,058	310	549	85	790	69	51	69	18,106
1991	3,184	913	333	106	643	600	1,986	747	1,606	420	568	117	353	50	45	11,671
1992	1,619	454	2,362	398	445	745	655	939	418	798	280	349	150	118	94	9,824
1993	2,613	402	910	3,844	833	667	345	474	643	396	347	253	199	110	132	12,168
1994	1,694	755	585	1,631	4,413	774	202	175	196	369	225	314	119	114	190	11,755
1995	2,239	218	427	1,995	2,654	4,323	1,835	483	296	185	349	140	258	102	147	15,651
1996	1,585	378	175	348	964	1,363	1,244	424	106	113	76	144	47	85	113	7,165
1997	2,536	393	202	259	3,109	1,383	828	997	169	85	64	70	115	37	128	10,374
1998	737	643	336	240	468	2,674	680	429	332	83	37	13	29	31	74	6,806
1999	1,137	1,043	968	1,050	599	1,069	2,691	725	350	326	119	50	20	29	98	10,275
2000	1,142	427	535	1,825	1,814	932	783	2,564	999	523	221	150	46	20	88	12,070
2001	1,832	1,057	572	546	1,381	1,444	621	308	918	659	252	201	80	29	77	9,977
2002	817	416	855	1,231	1,281	1,662	863	418	565	1,061	529	234	138	42	45	10,155
2003	559	171	1,045	1,752	2,078	1,908	2,555	1,445	660	861	1,752	758	286	148	108	16,085
2004	406	287	182	1,372	1,338	1,018	598	648	321	200	200	361	154	37	29	7,150
2005	397	152	247	1,073	3,008	2,023	1,055	479	364	268	72	152	248	96	99	9,735
2006	878	81	125	408	1,023	1,299	831	400	228	197	95	59	85	114	113	5,935
2007	2,359	67	170	483	1,511	1,768	1,275	920	388	174	161	140	64	80	155	9,716
2008	529	129	108	199	564	1,134	889	618	392	154	128	98	44	24	153	5,165
2009	800	221	463	500	290	420	569	446	323	157	103	34	34	18	72	4,448
2010	511	145	278	2,985	1,337	417	359	380	399	272	234	85	51	29	63	7,544
2011	1,160	125	272	372	1,859	910	267	151	237	236	197	151	64	30	80	6,111
2012	1,187	242	455	3,256	761	1,228	421	168	127	176	144	127	106	38	67	8,504
2013	1,234	133	256	1,008	5,011	1,162	725	254	86	78	102	77	71	39	52	10,290
2014	2,261	613	281	369	1,705	6,257	3,255	693	381	139	53	75	76	36	94	16,289
2015	1,205	828	2,332	586	1,222	2,276	4,434	1,293	306	147	19	18	31	18	39	14,753
2016	769	483	695	3,330	1,365	922	1,301	1,919	377	148	49	12	12	4	8	11,395
2017	616	332	511	2,374	2,869	1,250	862	775	920	264	95	34	5	3	8	10,916
2018	1,087	481	193	369	2,622	1,482	503	368	375	289	92	15	2	0	6	7,885
2019	1,571	584	398	432	1,284	4,722	1,910	446	316	181	103	45	17	3	1	12,015
2020	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2021	821	569	1,253	678	611	383	991	1,269	261	91	63	38	8	5	2	7,042
Avg	1,547	537	803	1,401	1,993	1,872	1,233	743	440	307	206	139	81	42	66	11,411

Table 1-17. Mean EBS pollock body mass (kg) at age as observed in the summer NMFS bottom trawl survey, 1982–2021.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1982	0.031	0.074	0.167	0.350	0.432	0.670	1.021	1.126	1.199	1.378	1.590	1.627	1.893	1.816	2.664
1983	0.013	0.133	0.241	0.361	0.493	0.576	0.722	1.069	1.118	1.011	1.112	1.120	1.551	1.102	1.911
1984	0.014	0.063	0.264	0.359	0.483	0.618	0.759	1.016	1.214	1.401	1.517	1.679	1.331	1.453	2.068
1985	0.014	0.100	0.232	0.396	0.487	0.624	0.769	0.896	1.411	1.114	1.278	1.717	1.617	1.607	2.562
1986	0.013	0.083	0.184	0.355	0.460	0.636	0.715	0.845	1.004	1.277	1.309	1.128	2.286	2.160	2.886
1987	0.018	0.111	0.264	0.354	0.433	0.524	0.700	0.785	0.881	0.981	1.168	1.382	1.713	1.997	2.254
1988	0.019	0.092	0.294	0.354	0.455	0.518	0.596	0.748	0.846	0.993	1.190	1.207	1.701	0.930	1.784
1989	0.015	0.089	0.174	0.369	0.439	0.522	0.622	0.665	0.917	0.916	1.036	1.071	1.116	1.177	1.261
1990	0.014	0.100	0.155	0.377	0.503	0.570	0.608	0.717	0.784	1.041	1.071	1.120	1.057	1.266	1.356
1991	0.019	0.110	0.156	0.354	0.485	0.578	0.693	0.739	0.870	0.908	1.084	1.187	1.254	1.405	1.908
1992	0.015	0.108	0.286	0.376	0.512	0.622	0.773	0.834	0.890	0.983	1.099	1.246	1.375	1.339	1.373
1993	0.011	0.065	0.310	0.453	0.500	0.551	0.660	0.794	0.976	1.028	1.151	1.253	1.387	1.541	1.690
1994	0.017	0.077	0.223	0.474	0.572	0.634	0.713	0.971	1.165	1.122	1.194	1.323	1.421	1.507	1.679
1995	0.015	0.065	0.144	0.379	0.487	0.628	0.654	0.798	0.932	1.160	1.120	1.288	1.333	1.416	1.665
1996	0.017	0.078	0.150	0.316	0.498	0.594	0.732	0.814	0.971	1.055	1.290	1.385	1.423	1.539	1.639
1997	0.016	0.059	0.228	0.337	0.404	0.544	0.691	0.790	0.967	1.023	1.160	1.303	1.273	1.464	1.581
1998	0.016	0.070	0.177	0.344	0.476	0.518	0.674	0.814	0.898	0.966	1.055	1.352	1.339	1.741	1.801
1999	0.015	0.075	0.210	0.356	0.424	0.561	0.634	0.770	0.973	0.999	1.098	1.181	1.607	1.737	1.910
2000	0.011	0.061	0.229	0.375	0.454	0.527	0.648	0.707	0.777	0.948	1.142	1.194	1.311	1.470	1.853
2001	0.015	0.071	0.172	0.374	0.504	0.600	0.671	0.767	0.854	0.906	1.092	1.198	1.402	1.388	1.672
2002	0.013	0.086	0.251	0.391	0.534	0.647	0.673	0.804	0.887	0.923	0.932	1.086	1.179	1.362	1.839
2003	0.023	0.094	0.333	0.437	0.567	0.673	0.732	0.837	0.892	0.960	0.970	1.023	1.029	1.129	1.178
2004	0.020	0.096	0.291	0.477	0.555	0.680	0.756	0.790	0.940	0.949	1.034	1.042	1.115	1.326	1.419
2005	0.019	0.077	0.215	0.402	0.526	0.602	0.700	0.801	0.873	0.912	1.015	1.064	1.098	1.191	1.322
2006	0.010	0.085	0.178	0.365	0.514	0.606	0.720	0.809	0.909	1.044	1.098	1.181	1.274	1.255	1.366
2007	0.013	0.096	0.280	0.428	0.546	0.669	0.774	0.841	0.923	1.078	1.123	1.108	1.326	1.298	1.422
2008	0.014	0.057	0.229	0.413	0.522	0.641	0.756	0.860	0.923	1.066	1.217	1.198	1.370	1.537	1.565
2009	0.011	0.108	0.223	0.408	0.551	0.676	0.840	0.913	0.959	1.168	1.165	1.434	1.437	1.538	1.769
2010	0.019	0.079	0.240	0.402	0.544	0.675	0.896	0.978	1.016	1.114	1.146	1.261	1.434	1.538	1.946
2011	0.014	0.106	0.230	0.425	0.549	0.645	0.802	1.004	1.104	1.151	1.249	1.305	1.426	1.463	1.658
2012	0.013	0.082	0.202	0.358	0.534	0.670	0.807	0.951	1.208	1.235	1.292	1.337	1.430	1.649	1.884
2013	0.017	0.071	0.224	0.417	0.491	0.619	0.831	0.976	1.087	1.220	1.291	1.339	1.456	1.596	1.716
2014	0.016	0.098	0.221	0.357	0.475	0.603	0.657	0.893	0.982	1.116	1.305	1.319	1.372	1.478	1.641
2015	0.019	0.092	0.285	0.390	0.519	0.597	0.720	0.807	1.045	1.078	1.332	1.588	1.371	1.579	1.790
2016	0.023	0.085	0.229	0.436	0.513	0.608	0.696	0.779	0.844	0.926	1.094	1.110	1.396	1.705	1.839
2017	0.022	0.097	0.193	0.398	0.530	0.598	0.690	0.741	0.824	0.829	0.962	0.857	1.343	1.519	1.705
2018	0.020	0.073	0.201	0.373	0.498	0.608	0.700	0.748	0.841	0.881	0.966	0.969	1.145	2.002	1.297
2019	0.018	0.107	0.233	0.431	0.541	0.634	0.707	0.787	0.842	0.927	0.900	0.981	0.950	1.383	1.858
2020	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2021	0.019	0.100	0.209	0.370	0.488	0.614	0.705	0.769	0.891	1.032	0.976	1.084	1.340	1.228	2.048
Avg	0.016	0.086	0.224	0.387	0.500	0.607	0.724	0.842	0.967	1.047	1.154	1.241	1.383	1.490	1.756

Table 1-18. Biomass (age 1+) of Eastern Bering Sea pollock as estimated by surveys 1979–2021 (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 columns are for the standard survey area including the Northern Bering Sea (NBS) extension. BTS=Bottom trawl survey, DB=Design-based, CPE=cold pool extent, ATS=acoustic trawl survey. The ATS data from 2020 was done from the uncrewed sailing vessels with acoustic backscatter scaled to be consistent with previous years.

Year	DB BTS	DDC	VAST+NBS+CPE	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	3629
1995	5,477	9,103	6,555	
1996	3,132	4,090	3,991	2945
1997	3,560	5,016	4,459	3591
1998	2,692	3,515	3,455	
1999	3,791	5,442	5,593	4141
2000	5,100	7,347	7,053	3626
2001	4,193	5,434	6,014	
2002	4,942	6,754	6,721	4306
2003	8,393	13,516	11,176	
2004	3,864	5,109	5,633	4010
2005	4,861	6,685	6,883	
2006	3,042	3,881	4,113	1873
2007	4,332	6,137	6,867	
2008	3,018	3,987	4,276	2278
2009	2,277	2,983	2,852	1406
2010	3,750	5,141	5,174	1325
2011	3,109	3,945	4,541	2642
2012	3,486	4,614	5,173	2296
2013	4,563	6,098	6,658	
2014	7,426	10,329	11,693	4730
2015	6,392	8,584	10,654	
2016	4,910	6,611	8,427	4829
2017	6,135	7,922	8,915	
2018	3,113	4,186	4,039	2499
2019	6,619	8,767	9,444	
2020	–	–	–	3605
2021	3,505	4,154	4,808	
2022	4,549	5,891	6,509	3834
Avg.	4,769	6,687	6,879	3198

Table 1-19. 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	1,515	2,620		1,071	1,632	2,703	

Table 1-20. Mid-water pollock biomass (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, 1994–2018 (Honkalehto et al. 2015), and for 2020 when uncrewed sailing vessels were used. The column labeled VAST represents a preliminary index developed and presented in 2020. CVs for biomass estimates were assumed to average 20 percent with the 1994-2018 inter-annual variability arising from the 1-dimensional variance estimation method. Note the last column reflects biomass index values based on a VAST model application applied to acoustic backscatter was rescaled to have the same mean as the total biomass to 0.5m.

		Area	Biomass				
Year	Date	$(\mathrm{nmi})^2$	SCA	E170-SCA	W170	0.5m total	VAST (sA)
1994	9 Jul - 19 Aug	78,251	0.378	0.656	2.595	3.629	3.704
1996	20 Jul - 30 Aug	93,810	0.272	0.490	2.182	2.944	2.870
1997	17 Jul - 4 Sept	102,770	0.274	0.853	2.463	3.59	3.526
1999	7 Jun - 5 Aug	103,670	0.323	0.758	3.060	4.141	3.665
2000	7 Jun - 2 Aug	106,140	0.457	0.717	2.452	3.626	3.292
2002	4 Jun - 30 Jul	99,526	0.755	0.946	2.605	4.306	4.477
2004	4 Jun - 29 Jul	99,659	0.546	0.920	2.543	4.009	3.612
2006	3 Jun - 25 Jul	89,550	0.144	0.342	1.387	1.873	1.728
2007	2 Jun - 30 Jul	92,944	0.136	0.244	1.898	2.278	2.073
2008	2 Jun - 31 Jul	95,374	0.122	0.087	1.197	1.406	1.429
2009	9 Jun - 7 Aug	91,414	0.153	0.057	1.115	1.325	1.378
2010	5 Jun - 7 Aug	92,849	0.098	0.193	2.351	2.642	2.585
2012	7 Jun - 10 Aug	96,852	0.195	0.320	1.782	2.297	2.375
2014	12 Jun - 13 Aug	94,361	0.561	1.462	2.707	4.73	5.122
2016	12 Jun - 17 Aug	100,674	0.540	1.267	3.022	4.829	5.381
2018	12 Jun - 22 Aug	92,283	0.231	0.513	1.755	2.499	2.819
2020	4 Jul - 20 Aug	102,320	-	0.462	-	3.605	3.695

Table 1-21. AT survey estimates of EBS pollock abundance-at-age (millions), 1979–2018. 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
Mean	5,226	4,423	2,118	1,894	1,027	619	388	206	91	176	10,942	16,168
Median	639	1,780	1,230	1,295	783	398	308	142	79	161	8,266	11,466

Table 1-22. An abundance index derived from acoustic data collected opportunistically aboard bottom-trawl survey vessels (AVO index; Stienessen et al. 2020). 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	CV_{AVO}
2006	1.8729	0.555 5%	28%
2007	2.2779	0.638 9%	47%
2008	1.4056	0.316 6%	35%
2009	1.3248	0.285 12%	65%
2010	2.6423	0.679 9%	46%
2011	*–no survey–*	0.543 6%	31%
2012	2.2958	0.661 6%	34%
2013	*–no survey–*	0.694 4%	21%
2014	4.7300	0.897 4%	23%
2015	*–no survey–*	0.953 5%	25%
2016	4.8290	0.776 4%	20%
2017	*–no survey–*	0.730 3%	18%
2018	2.4994	0.672 3%	18%
2019	*–no survey–*	0.680 3%	17%
2020	3.6200		
2021	*–no survey–*	0.936 4%	23%

Table 1-23. 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	100	
2020	623		
2021	100	100	

Table 1-24. Mean weight-at-age (kg) estimates from the fishery (1991–2020; plus projections 2021–2022) 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 1-25. Goodness of fit to primary data used for assessment model parameter estimation for different model configurations, EBS pollock.

Component	Last year	02	03	04	05	06	07
RMSE BTS	-999.000	-999.000	-999.000	-999.000	-999.000	-999.000	-999.000
RMSE ATS	-999.000	-999.000	-999.000	-999.000	-999.000	-999.000	-999.000
RMSE AVO	-999.000	-999.000	-999.000	-999.000	-999.000	-999.000	-999.000
RMSE CPUE	-999.000	-999.000	-999.000	-999.000	-999.000	-999.000	-999.000
SDNR BTS	1.810	1.810	1.800	1.820	1.800	1.800	1.800
SDNR ATS	1.100	1.080	1.080	1.080	1.060	1.030	1.030
SDNR AVO	0.700	0.640	0.640	0.620	0.600	0.600	0.640
Eff. N Fishery	1218.500	1223.280	1221.500	1207.490	1204.510	1203.410	1203.890
Eff. N BTS	199.850	197.980	197.220	202.470	217.990	218.210	218.240
Eff. N ATS	214.730	216.090	216.170	218.770	218.350	207.210	206.770
BTS NLL	27.930	28.040	27.960	29.860	31.980	31.990	31.990
ATS NLL	9.730	9.430	9.440	9.350	8.850	8.860	8.890
AVO NLL	10.350	10.110	10.100	10.200	10.170	46.170	46.110
Copepod NLL	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fish Age NLL	138.600	135.810	137.030	137.620	142.540	142.440	142.280
BTS Age NLL	157.830	159.360	159.650	161.850	158.490	158.530	158.670
ATS Age NLL	29.150	28.870	28.850	29.280	29.500	29.950	30.050
Data NLL	395.020	386.270	387.810	392.810	395.810	432.190	432.880
Total NLL	607.120	597.900	600.970	609.380	609.970	648.100	648.920

Table 1-26. Summary of different model results and the stock condition for EBS pollock. Biomass units are thousands of t.

Component	Last year	04	05	07
B_{2023}	2,400	3,500	3,600	3,900
$CV_{B_{2023}}$	0.19	0.17	0.17	0.15
B_{MSY}	2,301	2,298	2,320	2,335
$CV_{B_{MSY}}$	0.26	0.27	0.27	0.27
B_{2023}/B_{MSY}	105%	154%	156%	167%
B_0	5,695	5,824	5,884	5,922
$B_{35\%}$	2,004	2,082	2,101	2,138
SPR rate at F_{MSY}	32%	31%	31%	31%
Steepness	0.63	0.63	0.63	0.63
Est. $B_{2022}/B_{2022,nofishing}$	0.49	0.6	0.62	0.63
B_{2022}/B_{MSY}	98%	144%	147%	155%

Table 1-27. Estimates of begin-year age 3 and older biomass (thousands of tons) and coefficients of variation (CV) for the current assessment compared to 2015–2020 assessments for EBS pollock.

Year	Current	CV	2020	CV	2019	CV	2018	CV	2017	CV	2016	CV	2015	CV
1964	1,703	21	9,999	10	1,855	22	1,866	22	1,744	22	1,779	22	1,834	22
1965	2,070	19	9,999	10	2,256	20	2,270	20	2,124	20	2,165	20	2,229	20
1966	2,243	19	9,999	10	2,419	19	2,433	19	2,277	19	2,326	19	2,404	19
1967	3,482	17	9,999	10	3,679	17	3,695	17	3,504	17	3,566	17	3,667	17
1968	4,013	17	9,999	10	4,201	17	4,217	17	4,011	17	4,082	17	4,198	17
1969	5,112	16	9,999	10	5,297	15	5,316	15	5,105	16	5,174	15	5,294	15
1970	5,772	14	9,999	10	5,937	14	5,957	14	5,757	15	5,820	14	5,936	14
1971	6,218	13	9,999	10	6,367	13	6,390	13	6,209	13	6,260	13	6,360	13
1972	5,906	12	9,999	10	6,038	12	6,063	12	5,902	12	5,940	12	6,024	12
1973	4,745	13	9,999	10	4,855	13	4,880	13	4,729	13	4,765	13	4,845	13
1974	3,503	16	9,999	10	3,594	16	3,619	16	3,474	16	3,510	16	3,589	16
1975	3,601	12	9,999	10	3,710	12	3,740	12	3,585	12	3,611	12	3,679	12
1976	3,533	10	9,999	10	3,670	10	3,708	10	3,515	10	3,538	10	3,608	10
1977	3,460	9	9,999	10	3,646	9	3,690	9	3,426	8	3,446	8	3,535	8
1978	3,304	8	9,999	10	3,564	8	3,607	8	3,250	8	3,273	8	3,375	8
1979	3,169	8	9,999	10	3,557	8	3,595	8	3,087	8	3,116	8	3,239	8
1980	3,949	7	9,999	10	4,537	6	4,578	6	3,856	6	3,896	6	4,068	6
1981	7,335	5	9,999	10	8,422	4	8,451	4	7,314	5	7,453	5	7,813	4
1982	8,387	5	9,999	10	9,542	4	9,569	4	8,448	5	8,645	5	9,056	4
1983	9,477	4	9,999	10	10,807	4	10,832	4	9,556	4	9,849	4	10,240	4
1984	9,390	5	9,999	10	10,622	4	10,645	4	9,428	4	9,731	4	10,033	4
1985	11,567	4	9,999	10	12,566	3	12,592	3	11,615	4	11,887	4	12,237	3
1986	10,960	4	9,999	10	11,766	3	11,790	3	11,039	3	11,278	4	11,531	3
1987	11,593	3	9,999	10	12,114	2	12,143	2	11,734	3	11,922	3	12,143	3
1988	10,957	3	9,999	10	11,217	2	11,245	2	11,125	3	11,291	3	11,497	3
1989	9,265	3	9,999	10	9,344	2	9,370	2	9,422	3	9,568	3	9,755	3
1990	7,404	3	9,999	10	7,406	3	7,431	3	7,536	3	7,671	3	7,812	3
1991	5,859	4	9,999	10	5,818	3	5,841	3	5,920	4	6,054	4	6,183	4
1992	9,117	3	9,999	10	9,252	2	9,286	2	9,065	3	9,276	3	9,476	3
1993	11,255	2	9,999	10	11,552	2	11,599	2	11,181	2	11,427	2	11,627	2
1994	11,041	2	9,999	10	11,296	2	11,342	2	10,957	2	11,188	2	11,313	2
1995	12,623	2	9,999	10	12,886	2	12,926	2	12,508	2	12,757	2	13,000	2
1996	10,991	2	9,999	10	11,257	2	11,292	2	10,751	2	10,979	2	11,239	2
1997	9,463	2	9,999	10	10,042	3	10,074	3	9,395	2	9,603	2	9,837	2
1998	9,427	2	9,999	10	9,712	2	9,738	2	9,422	2	9,609	2	9,908	2
1999	10,327	2	9,999	10	10,652	2	10,673	2	10,390	2	10,561	2	10,751	2
2000	9,485	2	9,999	10	9,796	2	9,821	2	9,582	2	9,735	2	9,955	2
2001	9,193	2	9,999	10	9,527	2	9,559	2	9,335	2	9,479	2	9,702	2
2002	9,467	2	9,999	10	9,829	2	9,877	2	9,698	2	9,811	2	10,025	2
2003	11,410	2	9,999	10	11,779	2	11,816	2	11,657	2	11,750	2	12,080	2
2004	10,742	2	9,999	10	11,087	2	11,121	2	10,999	2	11,073	2	11,401	2
2005	8,962	2	9,999	10	9,271	2	9,302	2	9,197	2	9,272	2	9,598	2
2006	6,834	2	9,999	10	7,108	2	7,135	2	7,035	2	7,110	2	7,390	2
2007	5,491	2	9,999	10	5,753	3	5,782	3	5,683	3	5,762	3	6,046	3
2008	4,450	3	9,999	10	4,699	3	4,733	3	4,651	3	4,726	3	4,945	3
2009	5,575	2	9,999	10	5,883	3	5,941	3	5,837	3	5,943	3	6,374	3
2010	5,898	3	9,999	10	6,272	3	6,356	3	6,185	3	6,327	3	6,657	3
2011	8,374	2	9,999	10	9,001	3	9,176	3	8,788	3	9,107	3	9,637	3
2012	8,414	3	9,999	10	9,111	3	9,248	3	8,722	3	9,051	4	9,626	4
2013	8,324	3	9,999	10	9,130	4	9,225	4	8,547	4	8,873	4	9,504	5
2014	7,722	3	9,999	10	8,622	4	8,624	4	7,855	4	8,143	5	8,947	6
2015	10,019	3	9,999	10	12,073	5	11,801	5	11,345	6	11,913	8	12,407	10
2016	12,739	3	9,999	10	15,486	7	14,558	6	13,293	7	13,549	10	13,495	12
2017	11,685	3	9,999	10	13,794	7	12,963	7	11,785	8	12,049	11	13,033	13
2018	9,140	4	9,999	10	10,964	8	10,484	8	10,202	9	10,965	11	NA	NA
2019	8,180	5	9,999	10	9,892	10	9,864	9	9,110	10	NA	NA	NA	NA
2020	6,943	7	9,999	10	8,693	10	9,128	10	NA	NA	NA	NA	NA	NA
2021	11,808	12	9,999	10	8,145	11	NA	NA	NA	NA	NA	NA	NA	NA
2022	12,552	13	9,999	10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 1-28. 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	6.53	3.36	2.07	0.44	0.19	0.38	0.17	0.05	0.03	0.21
1965	21.02	2.65	2.11	1.46	0.27	0.12	0.24	0.11	0.03	0.16
1966	15.24	8.53	1.66	1.48	0.90	0.17	0.07	0.15	0.07	0.12
1967	25.59	6.18	5.36	1.17	0.93	0.57	0.11	0.05	0.09	0.12
1968	22.23	10.36	3.83	3.50	0.67	0.53	0.33	0.06	0.03	0.13
1969	26.16	9.00	6.40	2.50	2.02	0.39	0.31	0.19	0.04	0.09
1970	23.55	10.58	5.54	4.05	1.46	1.19	0.23	0.18	0.11	0.07
1971	14.60	9.49	6.36	3.30	2.31	0.81	0.66	0.12	0.10	0.09
1972	11.95	5.86	5.56	3.56	1.73	1.14	0.40	0.32	0.06	0.08
1973	26.87	4.80	3.32	2.89	1.73	0.82	0.54	0.19	0.14	0.05
1974	19.84	10.81	2.64	1.60	1.29	0.75	0.36	0.24	0.08	0.07
1975	17.00	7.99	5.74	1.13	0.68	0.54	0.32	0.15	0.09	0.05
1976	13.10	6.87	4.50	2.58	0.51	0.31	0.25	0.15	0.07	0.06
1977	13.67	5.30	3.96	2.23	1.20	0.24	0.15	0.12	0.07	0.06
1978	24.62	5.54	3.09	2.16	1.13	0.60	0.12	0.08	0.06	0.06
1979	57.31	9.98	3.26	1.69	1.09	0.54	0.29	0.06	0.04	0.05
1980	25.02	23.25	6.02	1.87	0.87	0.51	0.25	0.13	0.03	0.04
1981	29.43	10.16	14.40	3.76	0.99	0.42	0.24	0.12	0.06	0.03
1982	17.22	11.95	6.38	9.76	2.22	0.52	0.22	0.12	0.06	0.05
1983	50.61	7.00	7.55	4.53	6.29	1.31	0.30	0.12	0.07	0.06
1984	13.75	20.57	4.43	5.42	3.04	3.94	0.78	0.18	0.07	0.08
1985	33.75	5.59	13.03	3.18	3.69	1.90	2.38	0.47	0.11	0.09
1986	13.67	13.72	3.54	9.34	2.18	2.39	1.13	1.42	0.28	0.11
1987	7.54	5.56	8.70	2.54	6.39	1.43	1.46	0.68	0.87	0.23
1988	5.66	3.06	3.53	6.28	1.79	4.35	0.94	0.94	0.43	0.69
1989	10.96	2.30	1.94	2.47	4.32	1.16	2.74	0.56	0.57	0.68
1990	48.24	4.46	1.46	1.38	1.68	2.80	0.72	1.61	0.33	0.75
1991	25.19	19.61	2.82	1.03	0.90	0.99	1.59	0.39	0.88	0.59
1992	22.29	10.24	12.43	2.02	0.69	0.54	0.56	0.82	0.21	0.76
1993	44.60	9.06	6.48	8.63	1.32	0.41	0.29	0.26	0.36	0.43
1994	15.15	18.13	5.75	4.62	5.49	0.85	0.24	0.15	0.13	0.41
1995	10.48	6.16	11.53	4.19	3.14	3.21	0.50	0.13	0.08	0.31
1996	22.24	4.26	3.91	8.44	2.98	2.00	1.73	0.27	0.07	0.22
1997	30.17	9.04	2.70	2.86	6.11	2.03	1.14	0.85	0.13	0.16
1998	14.72	12.26	5.73	1.96	2.03	4.15	1.24	0.61	0.43	0.15
1999	15.78	5.99	7.79	4.15	1.39	1.38	2.50	0.74	0.34	0.31
2000	24.66	6.41	3.81	5.54	2.89	0.94	0.88	1.47	0.44	0.38
2001	34.52	10.03	4.08	2.75	3.74	1.84	0.60	0.51	0.79	0.47
2002	22.99	14.03	6.38	2.98	1.90	2.26	1.00	0.33	0.28	0.71
2003	14.04	9.35	8.92	4.62	2.02	1.15	1.14	0.51	0.16	0.54
2004	6.33	5.71	5.95	6.28	3.13	1.19	0.60	0.55	0.24	0.38
2005	4.51	2.57	3.63	4.31	3.93	1.89	0.67	0.30	0.28	0.34
2006	11.38	1.83	1.64	2.64	2.85	2.15	1.00	0.36	0.16	0.35
2007	24.42	4.63	1.17	1.15	1.70	1.59	1.06	0.50	0.18	0.28
2008	13.13	9.93	2.94	0.82	0.74	0.94	0.75	0.52	0.25	0.24
2009	49.15	5.34	6.31	2.12	0.54	0.42	0.43	0.36	0.25	0.24
2010	22.22	19.98	3.40	4.53	1.39	0.32	0.21	0.21	0.18	0.24
2011	13.48	9.03	12.72	2.48	2.88	0.84	0.19	0.11	0.11	0.22
2012	11.53	5.48	5.75	9.25	1.72	1.41	0.39	0.09	0.05	0.15
2013	44.84	4.69	3.49	4.16	6.04	1.11	0.65	0.18	0.04	0.09
2014	48.97	18.23	2.98	2.53	2.78	3.63	0.65	0.33	0.08	0.06
2015	16.69	19.91	11.60	2.17	1.72	1.71	2.02	0.33	0.17	0.07
2016	6.55	6.79	12.68	8.08	1.43	1.07	0.94	1.03	0.16	0.11
2017	8.76	2.66	4.32	9.29	4.79	0.90	0.64	0.54	0.54	0.15
2018	16.07	3.56	1.70	3.17	6.39	2.73	0.49	0.35	0.30	0.38
2019	72.37	6.53	2.27	1.25	2.25	3.72	1.55	0.28	0.20	0.39
2020	23.45	29.42	4.15	1.66	0.90	1.52	1.96	0.77	0.15	0.33
2021	22.30	9.54	18.58	3.00	1.15	0.56	0.69	0.94	0.42	0.24
2022	29.09	9.06	6.01	12.80	2.07	0.73	0.28	0.33	0.45	0.30

Table 1-29. 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	8.75	37.93	89.42	63.29	27.16	51.89	22.59	6.98	4.28	24.67
1965	28.81	30.62	93.29	212.21	39.32	16.79	31.90	13.98	4.37	18.77
1966	20.78	101.91	79.46	196.64	116.93	21.28	9.10	17.57	7.87	13.76
1967	64.82	141.67	550.38	225.20	183.96	109.60	20.71	9.09	18.00	23.12
1968	63.97	262.48	395.38	671.22	126.35	98.22	59.57	11.41	5.12	23.80
1969	90.96	257.30	806.07	456.98	362.94	69.02	55.56	35.82	7.04	18.07
1970	141.70	491.86	940.26	813.19	322.13	261.29	53.54	47.27	30.08	20.93
1971	123.88	624.76	1350.31	843.65	671.24	232.22	193.17	42.17	34.68	35.44
1972	90.99	522.27	1443.91	1073.81	542.83	358.48	128.16	116.60	22.26	33.09
1973	181.67	535.02	1015.75	1003.07	618.81	295.31	195.16	75.24	60.18	24.41
1974	116.87	1467.48	979.03	600.59	488.51	285.23	134.79	96.47	33.97	33.73
1975	66.80	751.52	1980.60	379.47	223.97	177.69	103.89	51.75	35.48	21.51
1976	37.33	530.99	1303.34	829.94	161.14	96.11	76.70	45.92	23.30	22.24
1977	28.17	364.68	909.68	612.50	347.66	69.61	42.35	34.17	22.02	18.90
1978	42.52	349.60	713.15	600.36	348.58	182.39	37.36	22.99	20.49	21.23
1979	81.36	432.07	640.35	443.68	350.66	179.77	94.34	19.29	12.96	19.84
1980	25.31	541.97	816.44	460.36	270.62	167.79	81.17	43.05	9.34	13.58
1981	17.77	126.88	1063.19	665.97	250.80	109.27	61.69	30.49	17.26	8.25
1982	5.93	85.13	227.02	1098.95	388.10	99.93	41.02	23.73	12.38	9.55
1983	12.66	44.60	200.29	363.04	846.89	223.60	50.98	21.41	12.95	11.26
1984	2.91	104.19	114.56	383.18	412.47	629.05	134.08	30.61	13.41	14.20
1985	6.13	28.90	366.09	201.50	408.14	324.17	402.51	81.06	19.35	16.64
1986	1.99	62.77	97.91	615.36	215.96	365.72	181.82	214.62	47.26	19.95
1987	0.68	16.97	192.66	111.18	451.48	148.38	161.33	86.49	115.91	30.68
1988	0.59	11.73	172.23	390.14	193.11	564.33	154.85	149.24	70.02	110.03
1989	0.97	8.13	68.55	178.31	468.26	160.38	487.89	94.69	91.66	112.05
1990	5.21	21.39	56.07	149.70	293.14	561.59	167.44	375.74	75.06	169.99
1991	2.59	96.26	86.05	90.54	140.79	199.30	429.00	96.23	227.97	163.55
1992	2.66	62.80	679.05	199.89	112.19	137.32	189.38	288.14	72.85	263.91
1993	3.28	28.52	210.40	1047.73	156.68	78.81	76.08	68.75	94.95	109.39
1994	0.81	41.53	80.64	334.24	1007.25	152.27	52.54	31.90	28.32	86.00
1995	0.48	14.86	119.00	147.28	384.26	761.90	111.60	29.89	18.00	63.66
1996	0.99	14.44	52.03	167.62	210.81	391.00	513.47	80.08	19.40	50.22
1997	1.22	38.54	45.15	96.59	433.18	305.43	275.06	234.11	37.10	39.26
1998	0.46	37.45	110.91	79.59	152.85	675.28	212.32	139.80	107.13	34.72
1999	0.35	11.45	266.02	220.47	106.26	156.96	454.61	130.74	59.76	54.49
2000	0.52	11.21	81.38	424.21	347.46	115.22	165.94	343.44	84.34	67.88
2001	0.73	14.08	55.19	165.00	602.67	423.35	135.78	118.61	169.04	95.39
2002	0.53	33.05	119.91	218.21	296.40	628.03	278.68	91.22	73.43	161.72
2003	0.32	16.39	387.36	342.50	361.75	303.00	349.62	154.84	45.62	120.18
2004	0.12	7.27	107.99	845.01	501.39	250.69	165.85	151.33	61.59	75.47
2005	0.07	3.50	63.75	400.65	894.52	478.24	159.96	68.89	62.24	63.88
2006	0.22	3.74	68.81	292.09	616.58	632.17	280.17	99.31	43.13	83.47
2007	0.48	10.63	49.32	136.58	379.70	497.48	313.13	137.23	48.14	70.85
2008	0.26	20.90	69.59	84.11	152.58	309.60	239.56	156.77	75.70	67.98
2009	0.87	7.18	169.70	209.34	89.66	119.68	125.98	101.95	70.30	72.71
2010	0.32	23.90	39.72	562.53	223.96	61.47	47.32	55.88	45.76	61.77
2011	0.26	13.46	201.84	141.00	847.73	272.76	58.81	36.97	36.19	71.54
2012	0.22	10.23	113.59	952.46	194.45	464.55	127.81	29.62	17.54	50.75
2013	0.80	6.59	64.34	353.48	989.34	194.51	179.10	59.74	13.36	31.23
2014	0.82	28.19	49.74	179.34	406.40	784.83	186.40	94.32	24.88	19.24
2015	0.32	22.57	603.48	209.59	240.32	385.92	553.80	92.21	50.86	23.59
2016	0.09	5.46	118.60	1404.07	186.12	180.67	180.08	255.27	38.64	26.27
2017	0.13	2.69	33.19	577.26	962.75	200.44	141.96	123.32	125.53	33.32
2018	0.20	4.27	12.15	112.74	1192.19	548.86	100.73	73.69	58.59	68.05
2019	1.04	14.80	19.74	31.85	177.47	933.88	445.62	73.44	46.74	77.26
2020	0.53	230.43	91.72	90.14	125.01	512.69	597.10	183.22	46.77	92.16
2021	0.60	92.06	1123.04	176.84	148.41	152.45	217.81	290.75	140.54	75.71
2022	0.64	73.01	325.09	808.40	218.88	168.84	64.95	74.22	129.15	84.97

Table 1-30. Estimated EBS pollock age 3+ biomass, female spawning biomass, and age 1 recruitment for 1964–2021. 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	507	27	6,528	37	1,703	22
1965	596	23	21,021	25	2,070	20
1966	693	22	15,236	31	2,243	20
1967	883	20	25,588	26	3,482	17
1968	1,105	20	22,234	28	4,013	17
1969	1,364	19	26,157	26	5,112	16
1970	1,600	18	23,545	27	5,772	15
1971	1,695	18	14,600	32	6,218	13
1972	1,608	17	11,953	33	5,906	13
1973	1,349	19	26,874	19	4,745	14
1974	1,000	22	19,835	19	3,503	16
1975	849	20	16,995	18	3,601	12
1976	859	16	13,102	17	3,533	10
1977	891	13	13,666	15	3,460	9
1978	897	12	24,615	10	3,304	9
1979	859	11	57,310	6	3,169	8
1980	954	10	25,020	9	3,949	7
1981	1,539	7	29,426	9	7,335	5
1982	2,318	6	17,221	11	8,387	5
1983	2,874	6	50,614	6	9,477	5
1984	3,112	6	13,753	12	9,390	5
1985	3,415	5	33,747	7	11,567	4
1986	3,686	5	13,672	11	10,960	4
1987	3,844	4	7,538	13	11,593	4
1988	3,854	4	5,656	14	10,957	3
1989	3,466	4	10,963	10	9,265	3
1990	2,785	4	48,242	4	7,404	4
1991	2,090	5	25,186	6	5,859	4
1992	2,203	4	22,285	6	9,117	3
1993	3,056	3	44,596	4	11,255	3
1994	3,383	3	15,148	6	11,041	3
1995	3,572	3	10,476	7	12,623	3
1996	3,614	3	22,238	4	10,991	3
1997	3,367	3	30,165	4	9,463	3
1998	3,097	3	14,722	5	9,427	3
1999	3,117	3	15,778	5	10,327	3
2000	3,130	3	24,661	4	9,485	3
2001	3,134	3	34,517	3	9,193	3
2002	2,936	3	22,993	4	9,467	3
2003	3,087	3	14,038	5	11,410	2
2004	3,184	3	6,327	7	10,742	2
2005	2,912	3	4,508	8	8,962	2
2006	2,382	3	11,381	5	6,834	3
2007	1,962	3	24,424	4	5,491	3
2008	1,448	4	13,129	6	4,450	3
2009	1,526	4	49,148	4	5,575	3
2010	1,762	3	22,218	5	5,898	3
2011	2,128	3	13,478	6	8,374	3
2012	2,470	3	11,534	7	8,414	3
2013	2,757	4	44,844	4	8,324	3
2014	2,649	4	48,969	5	7,722	4
2015	2,615	4	16,689	8	10,019	3
2016	3,212	4	6,554	15	12,739	3
2017	3,613	4	8,757	17	11,685	4
2018	3,225	4	16,066	19	9,140	4
2019	2,891	5	72,369	17	8,180	6
2020	2,235	7	23,453	19	6,943	8
2021	2,590	11	22,296	21	11,808	13
2022	3,613	14	29,085	22	12,552	14

Table 1-31. Summary of model results and the stock condition for EBS pollock. Biomass units are thousands of t.

Component	02	03	04
B_{2023}	3,200	3,300	3,500
$CV_{B_{2023}}$	0.2	0.19	0.17
B_{MSY}	2,323	2,263	2,298
$CV_{B_{MSY}}$	0.27	0.27	0.27
B_{2023}/B_{MSY}	136%	146%	154%
B_0	5,729	5,736	5,824
$B_{35\%}$	2,047	2,062	2,082
SPR rate at F_{MSY}	32%	31%	31%
Steepness	0.63	0.63	0.63
Est. $B_{2022}/B_{2022,nofishing}$	0.57	0.58	0.6
B_{2022}/B_{MSY}	125%	136%	144%

Table 1-32. Summary results of Tier 1 2022 yield projections for EBS pollock.

Component	02	03	04
2023 fishable biomass (GM)	5,136,000	5,284,000	5,517,000
Equilibrium fishable biomass at MSY	4,370,000	4,102,000	3,873,000
MSY R (HM)	0.436	0.473	0.509
2023 Tier 1 ABC	2,237,000	2,499,000	2,808,000
2023 Tier 1 F_{OFL} unadjusted	0.515	0.577	0.615
2023 Tier 1 OFL	2,643,000	3,051,000	3,391,000
Recommended ABC	1,981,000	2,256,000	2,523,000

Table 1-33. For the configuration named 07, 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
2022	1,200	1,200	1,200	1,200	1,200	1,200	1,200
2023	1,350	1,350	1,350	1,350	1,350	2,879	2,266
2024	3,032	3,032	2,545	1,293	0	3,107	2,707
2025	2,291	2,291	2,068	1,251	0	2,245	2,653
2026	1,913	1,913	1,797	1,196	0	1,816	2,017
2027	1,778	1,778	1,747	1,237	0	1,777	1,845
2028	1,660	1,660	1,639	1,203	0	1,712	1,730
2029	1,619	1,619	1,585	1,177	0	1,697	1,700
2030	1,600	1,600	1,559	1,161	0	1,686	1,686
2031	1,598	1,598	1,552	1,155	0	1,687	1,687
2032	1,597	1,597	1,544	1,151	0	1,683	1,683
2033	1,569	1,569	1,520	1,135	0	1,653	1,653
2034	1,570	1,570	1,518	1,131	0	1,658	1,658
2035	1,565	1,565	1,511	1,125	0	1,652	1,652

Table 1-34. For the configuration named 07, Tier 3 projections of EBS pollock ABC for the 7 scenarios. Note: scenario 2 results for 2022‘ and 2023 are conditioned on catches in that scenario listed in Table 33).

ABC	Scenario.1	Scenario.2	Scenario.3	Scenario.4	Scenario.5	Scenario.6	Scenario.7
2022	1,753	1,753	1,452	716	0	2,227	2,227
2023	2,266	2,266	1,877	925	0	2,879	2,879
2024	3,032	3,032	2,545	1,293	0	3,107	3,369
2025	2,291	2,291	2,068	1,251	0	2,245	2,653
2026	1,913	1,913	1,797	1,196	0	1,816	2,017
2027	1,778	1,778	1,747	1,237	0	1,777	1,845
2028	1,660	1,660	1,639	1,203	0	1,712	1,730
2029	1,619	1,619	1,585	1,177	0	1,697	1,700
2030	1,600	1,600	1,559	1,161	0	1,686	1,686
2031	1,598	1,598	1,552	1,155	0	1,687	1,687
2032	1,597	1,597	1,544	1,151	0	1,683	1,683
2033	1,569	1,569	1,520	1,135	0	1,653	1,653
2034	1,570	1,570	1,518	1,131	0	1,658	1,658
2035	1,565	1,565	1,511	1,125	0	1,652	1,652

Table 1-35. For the configuration named 07, 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
2022.000	0.286	0.286	0.286	0.286	0.286	0.286	0.286
2023.000	0.245	0.245	0.245	0.245	0.245	0.593	0.443
2024.000	0.443	0.443	0.356	0.163	0.000	0.593	0.443
2025.000	0.443	0.443	0.356	0.163	0.000	0.591	0.593
2026.000	0.438	0.438	0.356	0.163	0.000	0.540	0.558
2027.000	0.417	0.417	0.356	0.163	0.000	0.518	0.524
2028.000	0.408	0.408	0.356	0.163	0.000	0.511	0.512
2029.000	0.405	0.405	0.356	0.163	0.000	0.510	0.510
2030.000	0.403	0.403	0.356	0.163	0.000	0.507	0.507
2031.000	0.401	0.401	0.356	0.163	0.000	0.505	0.505
2032.000	0.401	0.401	0.356	0.163	0.000	0.505	0.505
2033.000	0.399	0.399	0.356	0.163	0.000	0.502	0.502
2034.000	0.399	0.399	0.356	0.163	0.000	0.502	0.502
2035.000	0.399	0.399	0.356	0.163	0.000	0.501	0.501

Table 1-36. For the configuration named 07, 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
2022	3,604	3,604	3,604	3,604	3,604	3,604	3,604
2023	3,882	3,882	3,882	3,882	3,882	3,676	3,763
2024	3,669	3,669	3,745	3,919	4,074	3,055	3,360
2025	3,121	3,121	3,350	3,968	4,650	2,577	2,876
2026	2,818	2,818	3,086	3,918	5,014	2,389	2,509
2027	2,666	2,666	2,928	3,871	5,303	2,328	2,366
2028	2,590	2,590	2,825	3,830	5,573	2,296	2,305
2029	2,570	2,570	2,778	3,786	5,709	2,298	2,299
2030	2,563	2,563	2,752	3,757	5,815	2,298	2,298
2031	2,546	2,546	2,723	3,726	5,903	2,283	2,283
2032	2,529	2,529	2,699	3,697	5,956	2,269	2,269
2033	2,510	2,510	2,675	3,667	5,994	2,252	2,252
2034	2,508	2,508	2,668	3,652	6,011	2,253	2,253
2035	2,521	2,521	2,678	3,656	6,038	2,267	2,267

Table 1-37. 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
$P\left[F_{2023} > F_{MSY}\right]$	Probability that the fishing mortality in 2023 exceeds F_{MSY}	OFL definition is based on F_{MSY}
$P\left[B_{2024} < B_{MSY}\right]$	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
$P\left[B_{2025} < B_{MSY}\right]$	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.
$P\left[B_{2027} < B_{2023}\right]$	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
$P\left[B_{2025} < B_{20\%}\right]$	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.
$P\left[D_{2024} < D_{1994}\right]$	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)
$P\left[D_{2027} < D_{1994}\right]$	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)
$P\left[E_{2023} > E_{2022}\right]$	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 1-38. Outcomes of decision (expressed as chances out of 100) given different 2023 catches (first row, in kt). Note that for the 2019 and later year-classes average values were assumed. Constant Fs based on the 2023 catches were used for subsequent years.

	10	850	1000	1150	1200	1300	1450	1600
$P\left[F_{2022} > F_{MSY}\right]$	0	0	0	0	0	0	0	0
$P\left[B_{2023} < B_{MSY}\right]$	5	8	8	9	9	10	11	12
$P\left[B_{2024} < B_{MSY}\right]$	3	6	7	8	9	10	11	13
$P\left[B_{2023} < \bar{B}\right]$	0	1	1	2	2	2	3	4
$P\left[B_{2026} < \bar{B}\right]$	0	6	9	12	13	15	18	22
$P\left[B_{2026} < B_{2021}\right]$	6	34	40	46	48	52	58	62
$P\left[B_{2024} < B_{20\%}\right]$	0	0	0	0	0	0	1	1
$P\left[p_{a_5,2024} > \bar{p}_{a_5}\right]$	0	13	19	26	28	32	39	46
$P\left[D_{2023} < D_{1994}\right]$	30	44	46	49	50	52	55	58
$P\left[D_{2026} < D_{1994}\right]$	0	0	1	2	3	4	6	9
$P\left[E_{2022} > E_{2021}\right]$	0	0	6	20	26	38	55	68

Table 1-39. Bycatch estimates (t) of other target species caught in the BSAI directed pollock fishery, 1997–2021 based on then NMFS Alaska Regional Office reports from observers (2021 data are preliminary).

Year	Pacific.Cod	Rock.Sole	Flathead.Sole	Arrowtooth.Flounder	Pacific.Ocean.Perch	Yellowfin.Sole	Sablefish	Sharks	Other
1991	24,310	5,120	0	5,719	418	417	9	0	10,722
1992	24,005	7,233	2	4,311	173	892	7	0	14,716
1993	20,930	8,713	0	1,222	282	1,102	1	0	7,548
1994	14,409	3,009	0	2,010	170	1,207	1	0	4,171
1995	19,776	2,179	2,175	1,177	142	675	12	0	1,021
1996	15,174	2,042	3,207	1,844	303	1,797	7	0	1,638
1997	8,262	1,522	2,350	984	428	605	2	0	1,026
1998	6,255	770	2,047	1,712	616	1,744	2	0	885
1999	3,220	1,058	1,885	272	120	349	7	0	610
2000	3,432	2,687	2,510	978	21	1,465	12	0	987
2001	3,879	1,672	2,199	529	574	594	21	0	1,312
2002	5,886	1,885	1,844	607	543	768	34	0	1,272
2003	5,968	1,418	1,501	617	935	209	48	0	1,861
2004	6,436	2,553	2,104	556	393	841	16	0	1,328
2005	7,413	1,125	2,351	651	652	63	11	0	1,234
2006	7,291	1,360	2,862	1,088	735	256	8	0	2,219
2007	5,629	510	4,225	2,795	624	85	11	0	2,028
2008	6,971	2,149	4,315	1,715	335	552	4	0	3,373
2009	7,875	7,591	4,665	2,202	114	270	2	0	4,495
2010	6,907	2,239	4,354	1,453	230	1,057	1	26	2,631
2011	10,042	8,480	4,885	1,601	658	1,082	1	65	4,230
2012	10,065	6,701	3,966	748	705	1,516	0	54	3,270
2013	8,954	6,379	3,145	965	610	2,096	0	43	2,449
2014	5,242	4,360	2,553	757	1,300	1,953	1	75	1,978
2015	8,303	1,709	2,257	402	2,525	863	0	51	1,696
2016	4,980	1,094	1,553	290	3,190	870	18	59	1,202
2017	6,150	1,707	908	204	4,438	577	95	91	961
2018	4,270	1,077	973	270	3,803	743	396	61	1,545
2019	6,213	1,117	1,087	421	7,971	443	1,236	100	1,665
2020	9,146	845	1,970	687	5,969	1,169	3,452	132	2,820
2021	9,065	825	1,524	363	2,443	697	1,097	305	1,976

Table 1-40. Bycatch estimates (t) of pollock caught in the other non-pollock EBS directed fisheries, 1997–2021 based on then NMFS Alaska Regional Office reports from observers.

Year	Other.flatfish	Other.Species	Pacific.Cod	Pollock	Rock.sole	Rockfish	Yellowfin.sole
1991	7,992	240	10,695	821,286	9,711	515	NA
1992	1,371	124	20,778	1,344,846	9,824	443	13,100
1993	2,581	47	31,298	1,259,155	18,582	476	15,253
1994	6,770	4	26,594	1,247,490	15,784	84	33,200
1995	5,211	4	25,691	1,198,806	7,766	52	27,041
1996	5,456	63	22,382	1,134,683	7,698	141	22,254
1997	3,480	2	33,658	1,054,218	9,123	9	24,100
1998	3,011	58	10,468	1,068,447	3,960	2	15,339
1999	4,771	248	21,131	948,700	5,207	9	8,701
2000	7,068	16	14,508	1,091,735	5,480	26	13,425
2001	4,739	488	11,570	1,349,576	4,577	NA	16,502
2002	2,220	27	15,255	1,439,858	9,942	23	14,489
2003	3,672	226	15,926	1,454,441	4,924	33	11,578
2004	6,396	178	18,650	1,435,947	8,975	15	10,383
2005	5,057	201	14,109	1,446,085	7,235	0	10,312
2006	3,826	138	15,168	1,455,939	6,986	4	5,966
2007	4,353	267	20,319	1,322,286	3,245	8	4,020
2008	4,822	11	9,533	961,455	4,930	5	9,827
2009	3,505	7	7,875	786,254	6,171	5	7,036
2010	3,316	0	6,575	789,130	6,074	85	5,179
2011	2,301	146	8,990	1,172,014	6,931	154	8,673
2012	1,752	41	8,383	1,176,842	6,703	371	11,197
2013	4,048	10	9,811	1,229,230	7,326	227	20,171
2014	6,404	2	11,507	1,243,763	11,258	199	24,712
2015	4,993	20	9,072	1,277,152	9,386	409	21,281
2016	3,687	48	9,071	1,306,321	11,850	401	22,306
2017	3,612	49	8,320	1,317,894	5,616	458	23,414
2018	3,530	194	8,007	1,333,393	5,182	762	28,229
2019	7,972	66	7,593	1,366,082	3,176	1,300	23,153
2020	2,371	60	5,460	1,320,495	6,295	665	31,190
2021	5,068	7	4,033	1,337,959	2,368	842	22,754

Table 1-41. Bycatch estimates (t) of non-target species caught in the BSAI directed pollock fishery, 2003–2021 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	7,820	33	19	0	60	0	1	3	1	3

Table 1-42. Bycatch estimates of prohibited species caught in the BSAI directed pollock fishery, 1997–2021 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 2021 are preliminary.

Year	Bairdi.Tanner.Crab	Chinook.Salmon	Halibut	Halibut.mort	Herring	Non.Chinook.Salmon	Snow.Crab	Other.King.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	33,320	17,777	NA	NA
1992	1,500,764	33,672	2,220	NA	646	40,186	4,569,662	20,384	43,873	NA	NA
1993	1,649,086	36,615	1,326	NA	527	241,971	738,250	1,925	58,139	NA	NA
1994	371,213	31,880	963	688	1,626	91,764	811,733	513	42,360	NA	NA
1995	153,992	13,403	491	397	904	17,754	206,651	941	4,644	NA	NA
1996	89,415	55,467	382	320	1,241	77,173	63,398	215	5,933	NA	NA
1997	17,046	44,312	257	200	1,134	65,414	216,152	393	137	NA	NA
1998	57,036	51,244	352	278	800	60,676	123,400	5,093	14,286	NA	NA
1999	2,397	10,381	153	124	799	44,610	15,829	7	90	NA	NA
2000	1,484	4,242	110	90	482	56,866	6,480	121	NA	NA	NA
2001	5,060	30,933	242	199	225	53,901	5,653	5,139	105	NA	NA
2002	2,112	32,381	165	137	108	77,167	2,697	193	16	NA	NA
2003	732	43,095	88	74	967	179,987	608	NA	52	8	NA
2004	1,091	48,799	96	81	1,095	441,188	640	NA	26	4	1
2005	601	66,208	119	100	593	703,076	2,016	NA	NA	NA	1
2006	1,288	80,915	132	111	433	305,793	2,567	NA	288	NA	3
2007	1,465	116,329	312	269	351	86,380	3,033	NA	7	NA	3
2008	9,025	20,602	373	311	127	15,119	8,894	NA	670	8	33
2009	6,155	12,284	541	436	64	45,960	7,312	NA	1,136	19	NA
2010	12,787	9,833	335	267	348	13,728	9,444	NA	1,122	28	NA
2011	10,973	25,499	459	378	376	193,754	6,493	NA	577	25	NA
2012	5,620	11,343	462	388	2,352	22,297	6,189	NA	343	NA	NA
2013	12,426	13,091	333	271	958	125,525	8,605	NA	507	34	107
2014	12,521	15,135	239	199	159	219,837	19,454	NA	368	NA	NA
2015	8,872	18,329	152	130	1,487	237,776	8,339	NA	NA	NA	NA
2016	2,295	22,204	121	102	1,431	343,208	1,166	NA	439	NA	26
2017	7,269	30,078	97	88	963	467,750	3,406	0	202	0	67
2018	2,232	13,726	75	62	472	295,818	5,142	0	565	0	53
2019	3,146	25,038	133	112	1,101	348,631	6,228	0	453	99	445
2020	10,406	32,204	127	101	3,861	320,282	40,002	0	432	1	521
2021	8,047	13,831	133	123	1,707	531,001	4,703	0	52	0	115

Table 1-43. 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

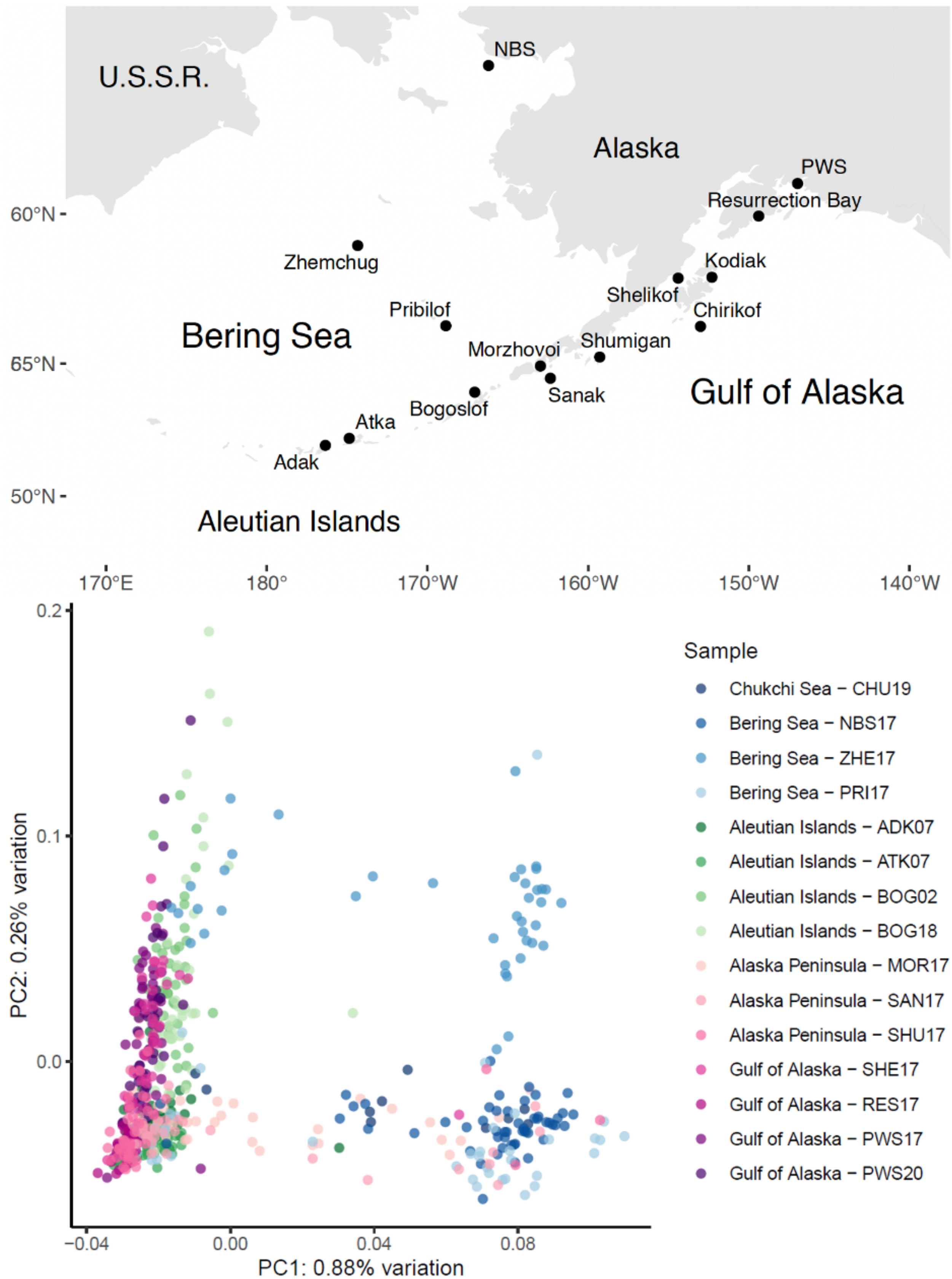

Figure 1-1. Principal Component Analysis of walleye pollock genetics. The color of each point indicates the sampling location and region shown in the map at top (Chukchi samples are further north).

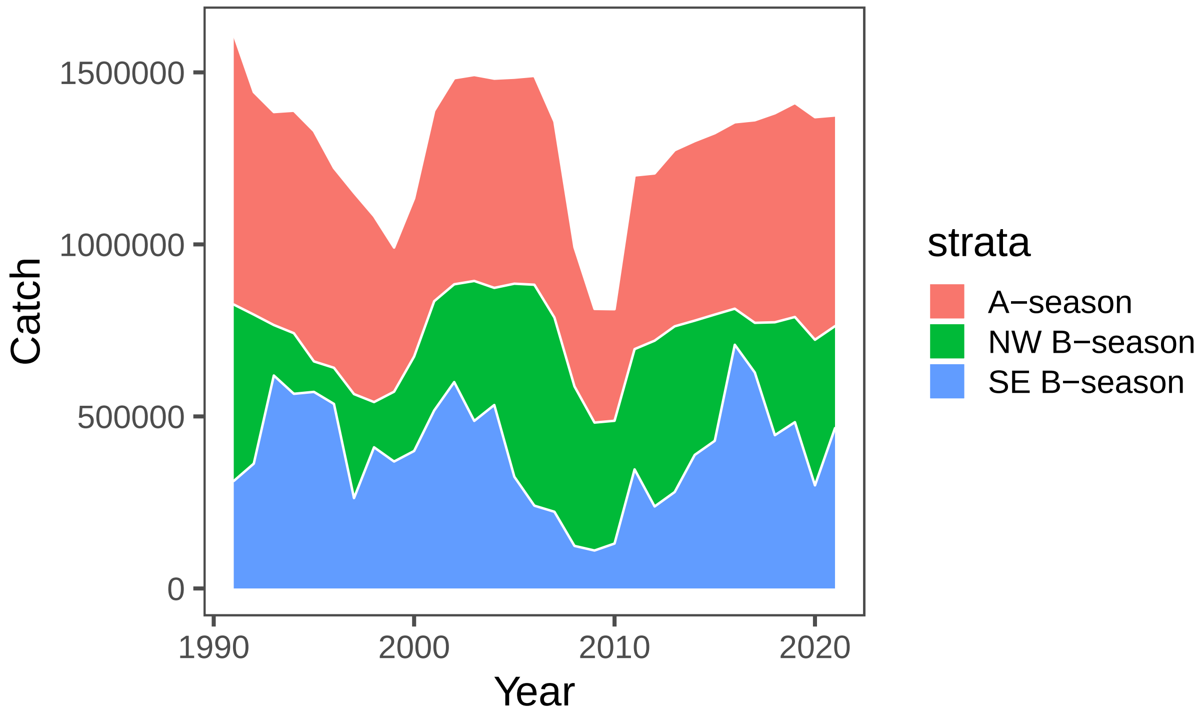

Figure 1-2. Pollock catch estimates (t) from the Eastern Bering Sea by season and region. The A-season is defined as from Jan-May and B-season from June-October.

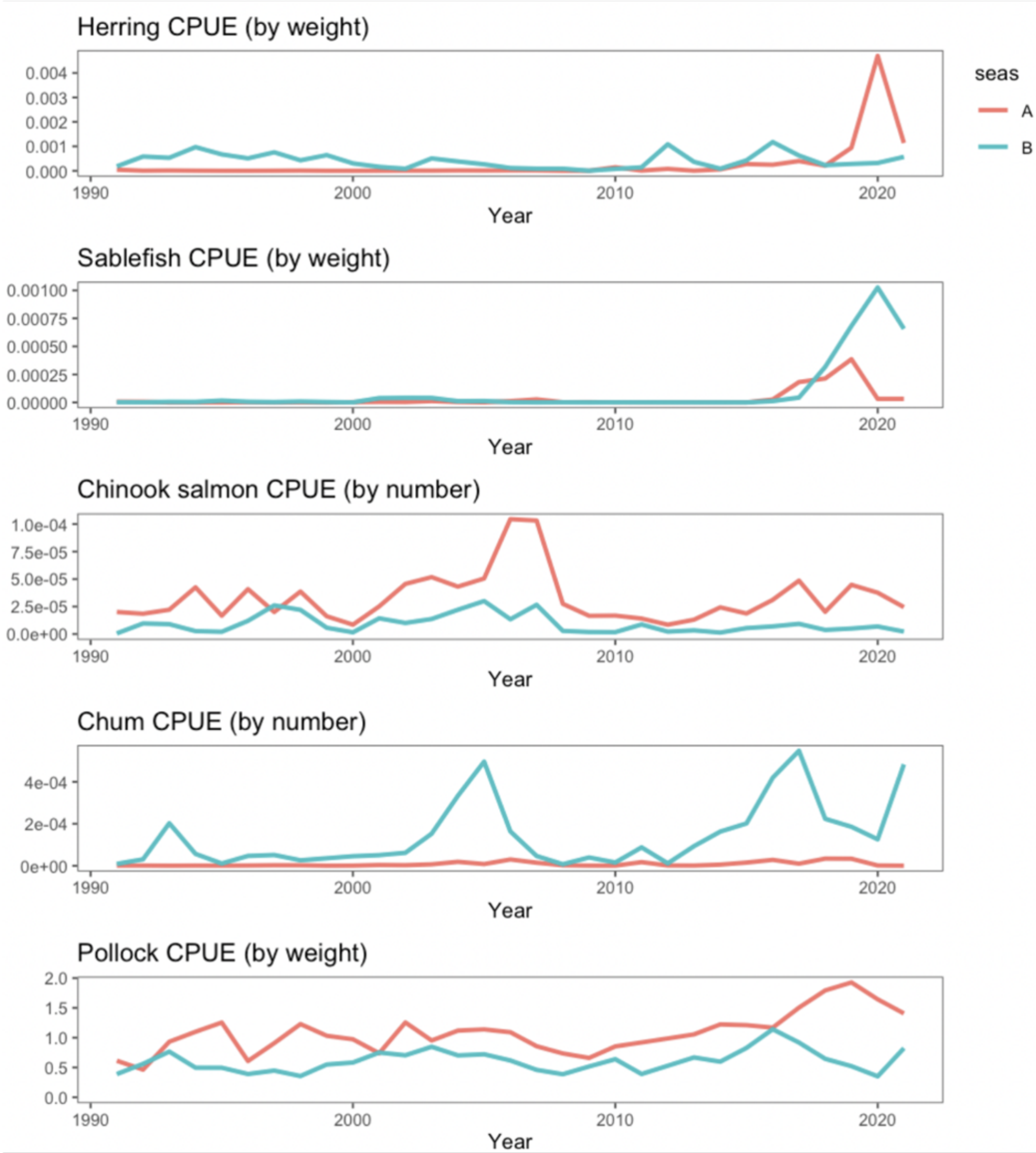

Figure 1-3. Nominal catch divided by effort (hours towed) for some bycatch species and pollock for the EBS pollock fleet (sectors combined), 2000-2021.

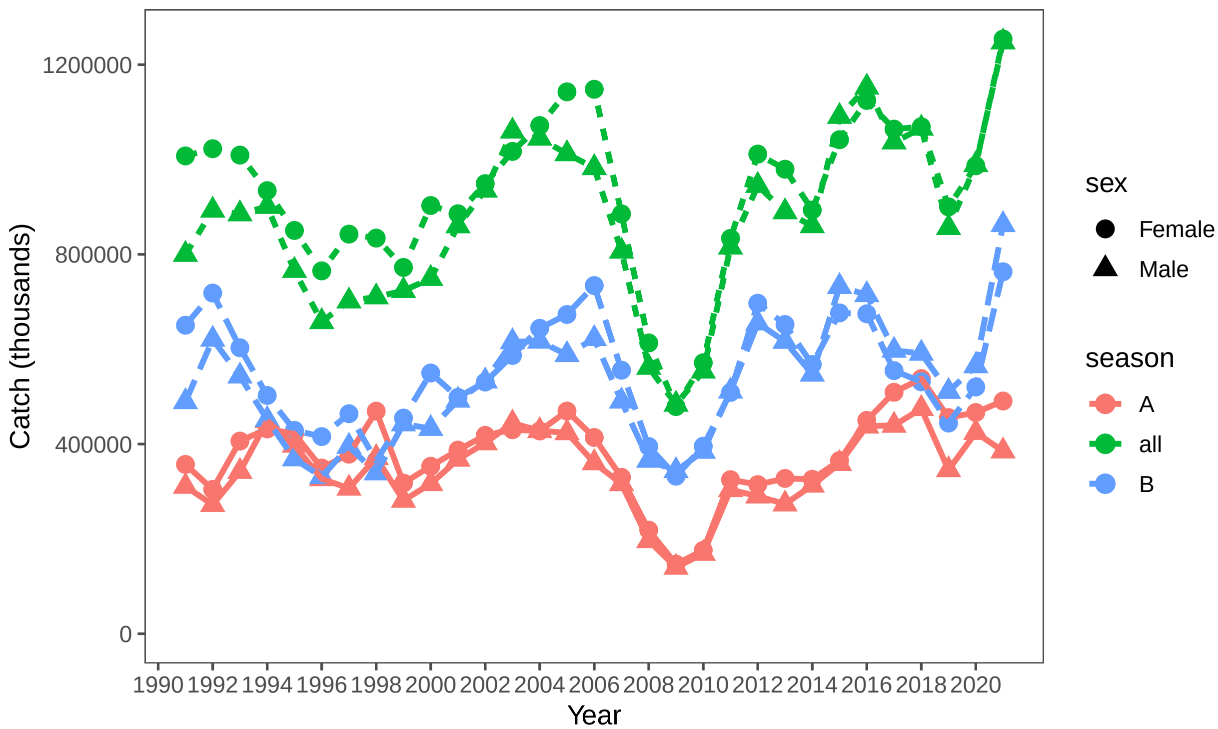

Figure 1-4. Estimate of EBS pollock catch numbers by sex for the A season (January-May) and B seasons (June-October) and total.

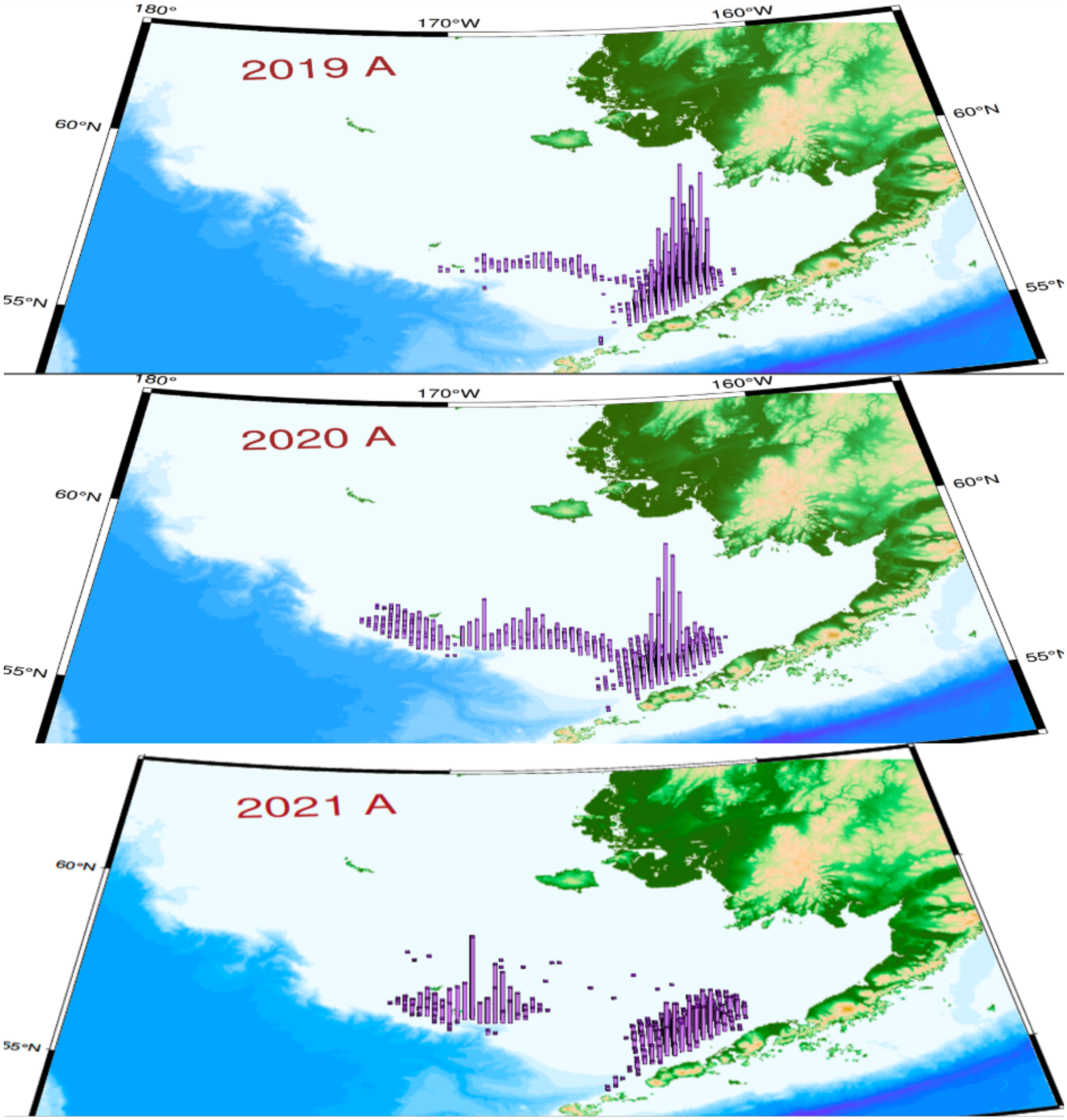

Figure 1-5. EBS pollock catch distribution during A-season, 2019–2021. Column height is proportional to total catch.

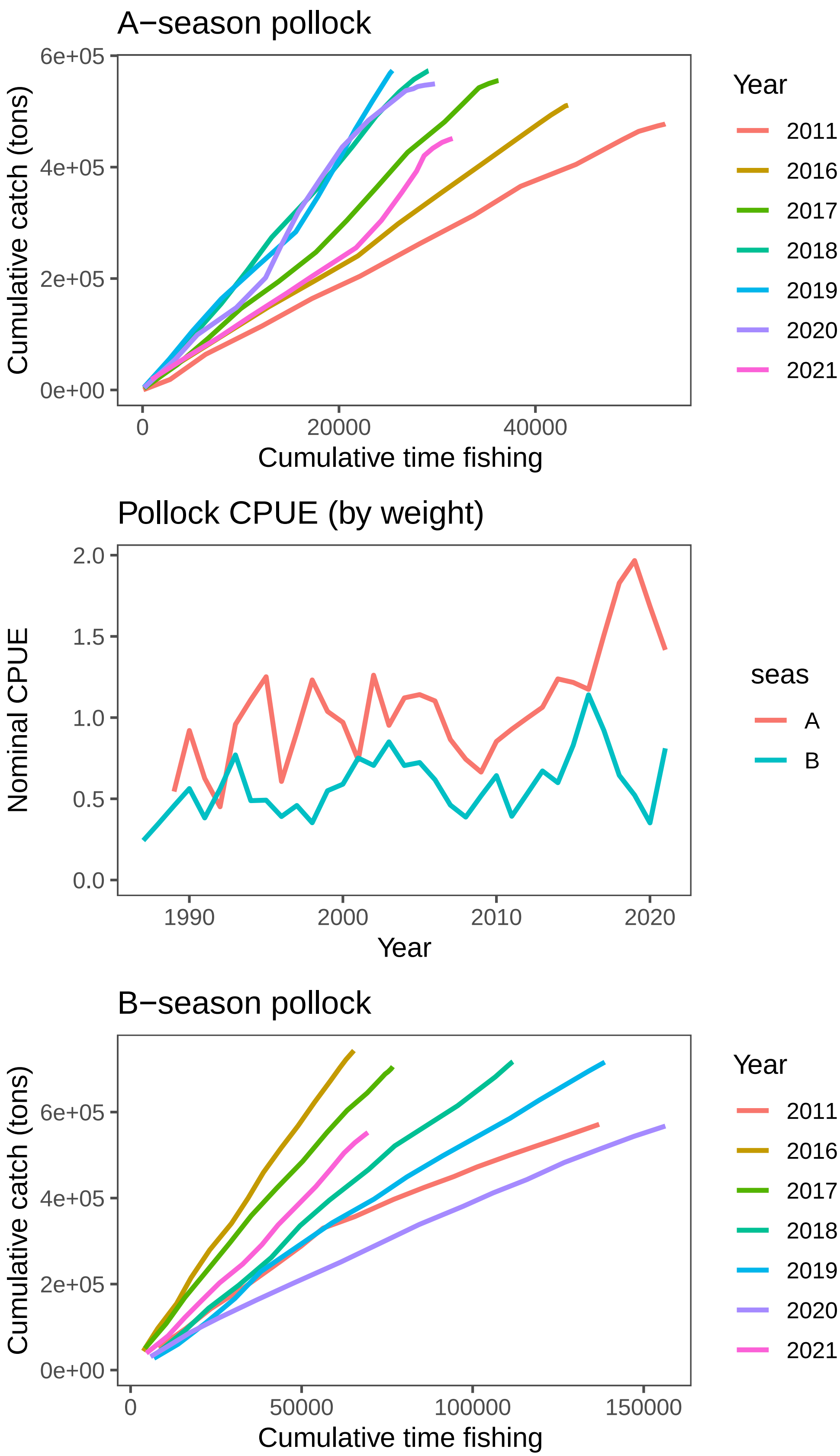

Figure 1-6. A-season (top) and B-season (bottom) EBS fleet-wide nominal pollock catch (kg) per hour of fishing recorded by NMFS scientific observers along with the catch divided by effort (hours) by season since 2000 (middle panel).

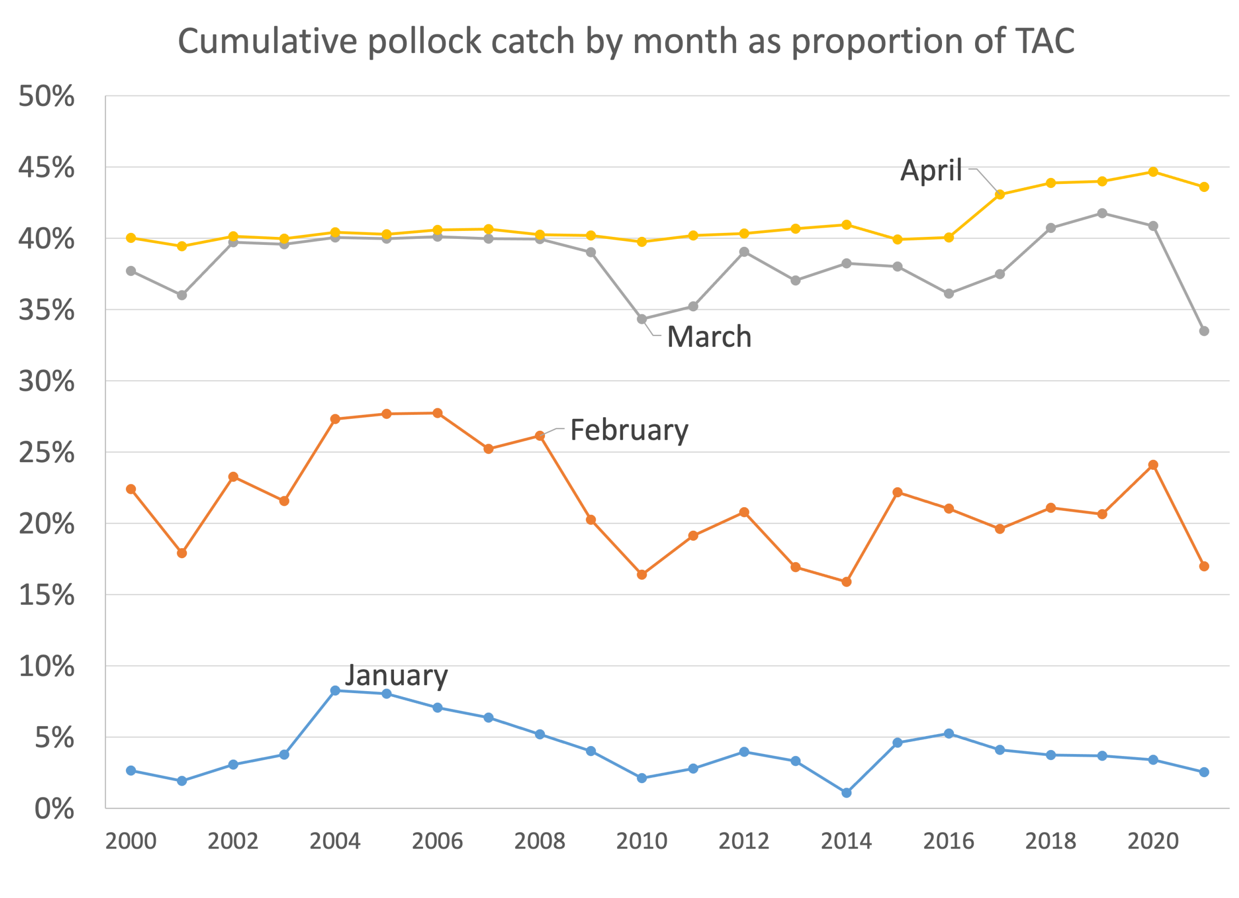

Figure 1-7. Proportion of the annual EBS pollock TAC by month during the A-season, 2000–2021. The higher value observed since 2017 was due to Amendment 110 of the FMP to allow greater flexibility to avoid Chinook salmon.

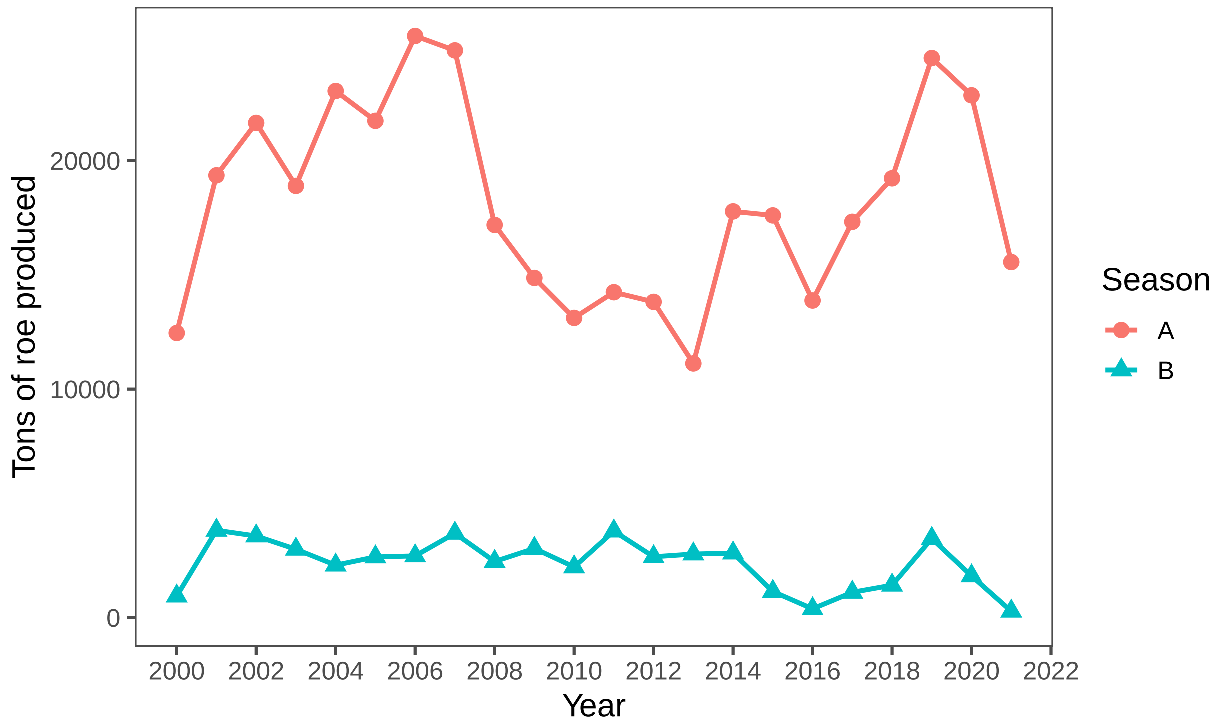

Figure 1-8. EBS pollock roe production in A and B seasons , 2000-2021.

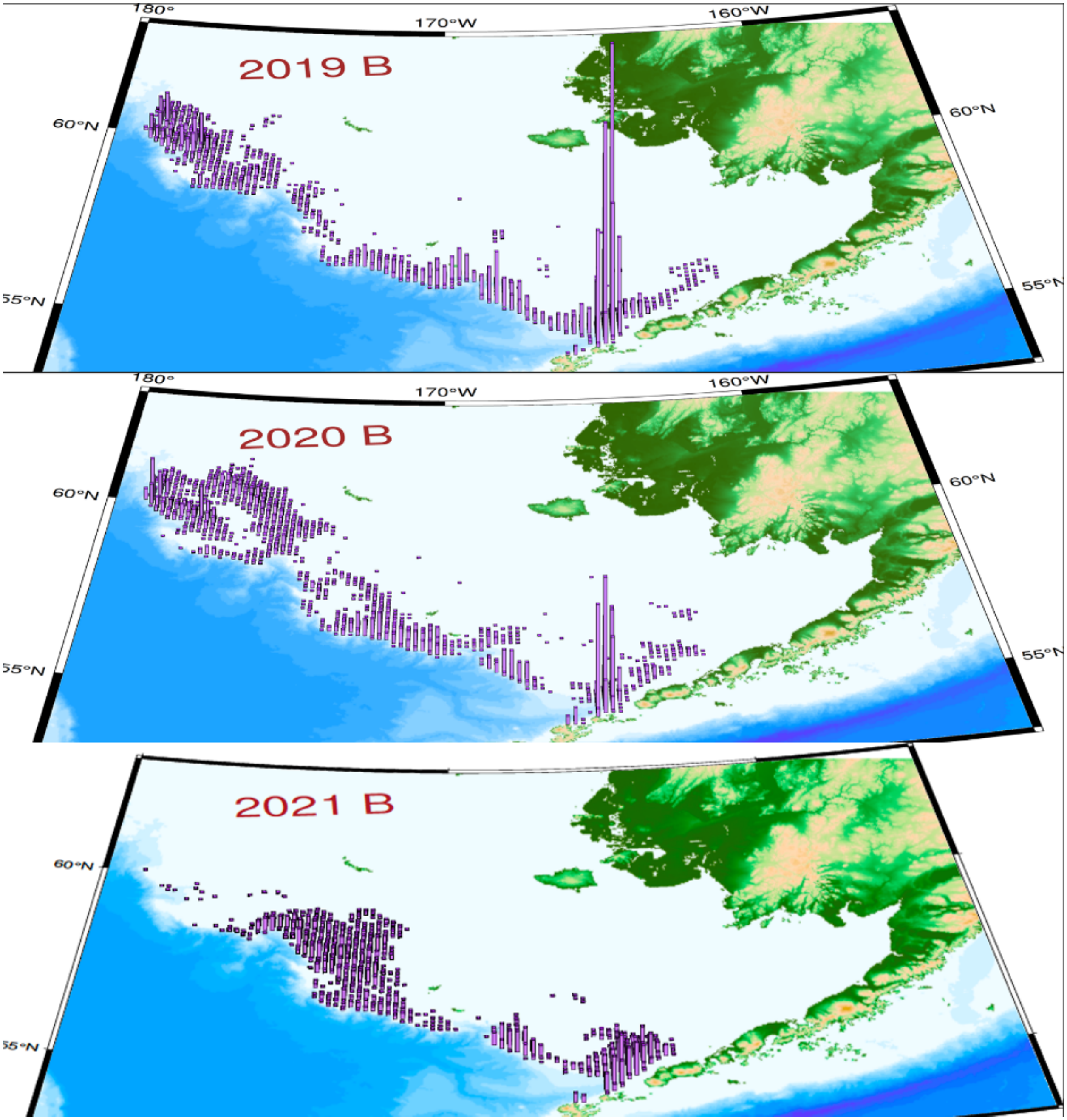

Figure 1-9. EBS pollock catch distribution during B-season, 2019–2021. Column height is proportional to total catch. Note that directed fishery for pollock generally is finished prior to October; the labels are indicative full-year catches.

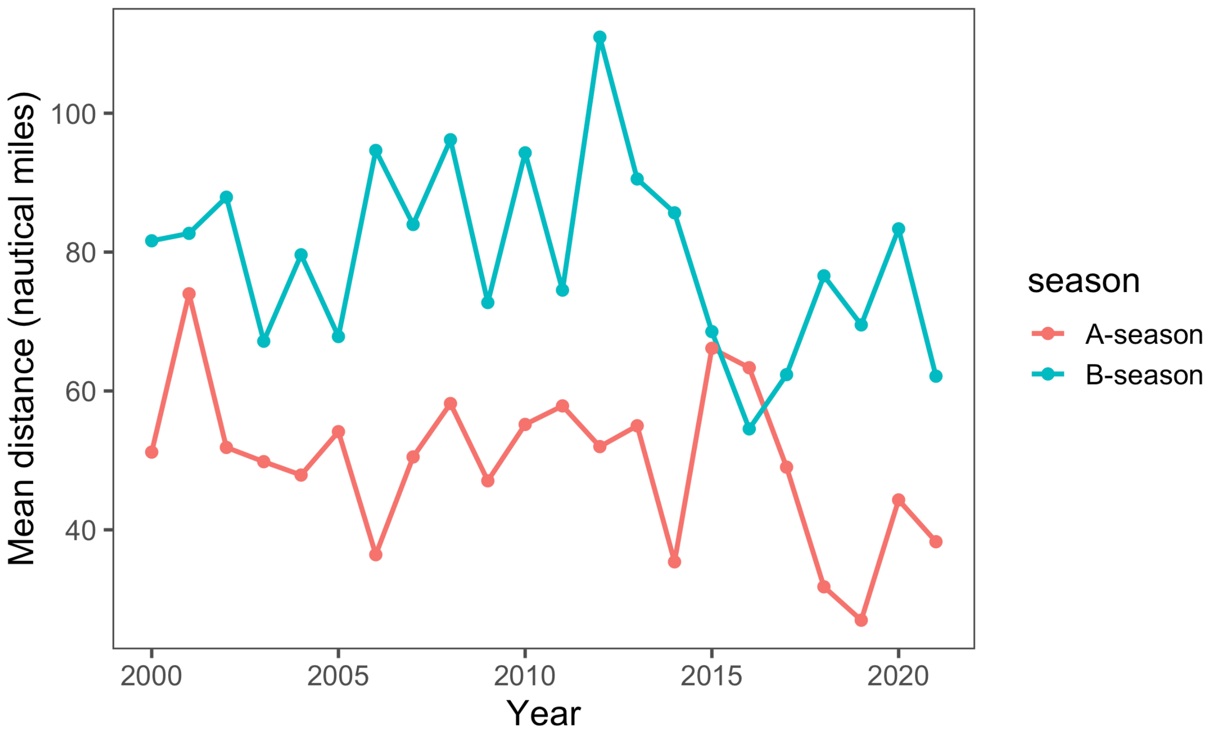

Figure 1-10. Estimated mean daily distance between operations, 2000-2021.

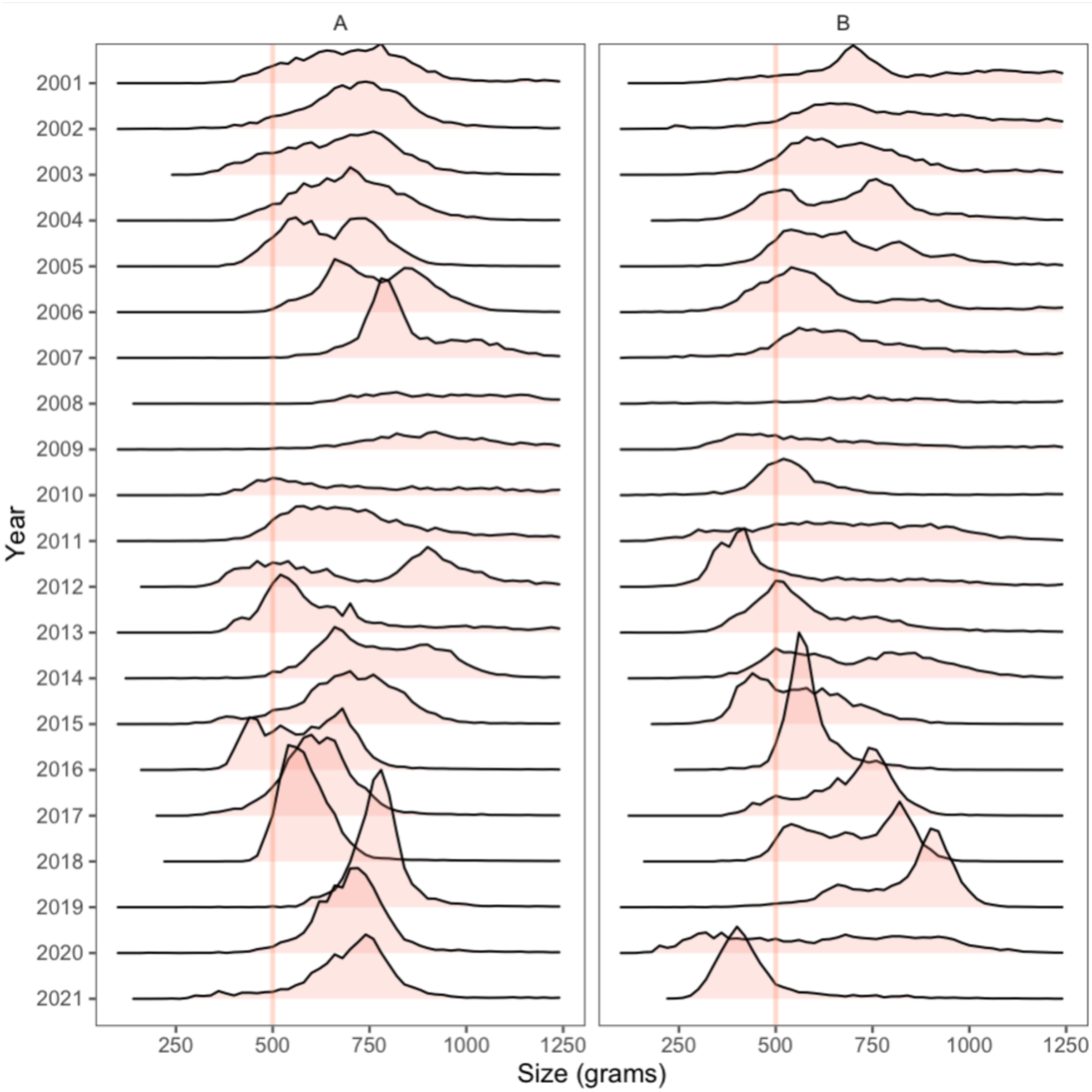

Figure 1-11. Pollock fishery data showing the frequency of mean pollock weight within a tow (in 50 g increments) by year and season.

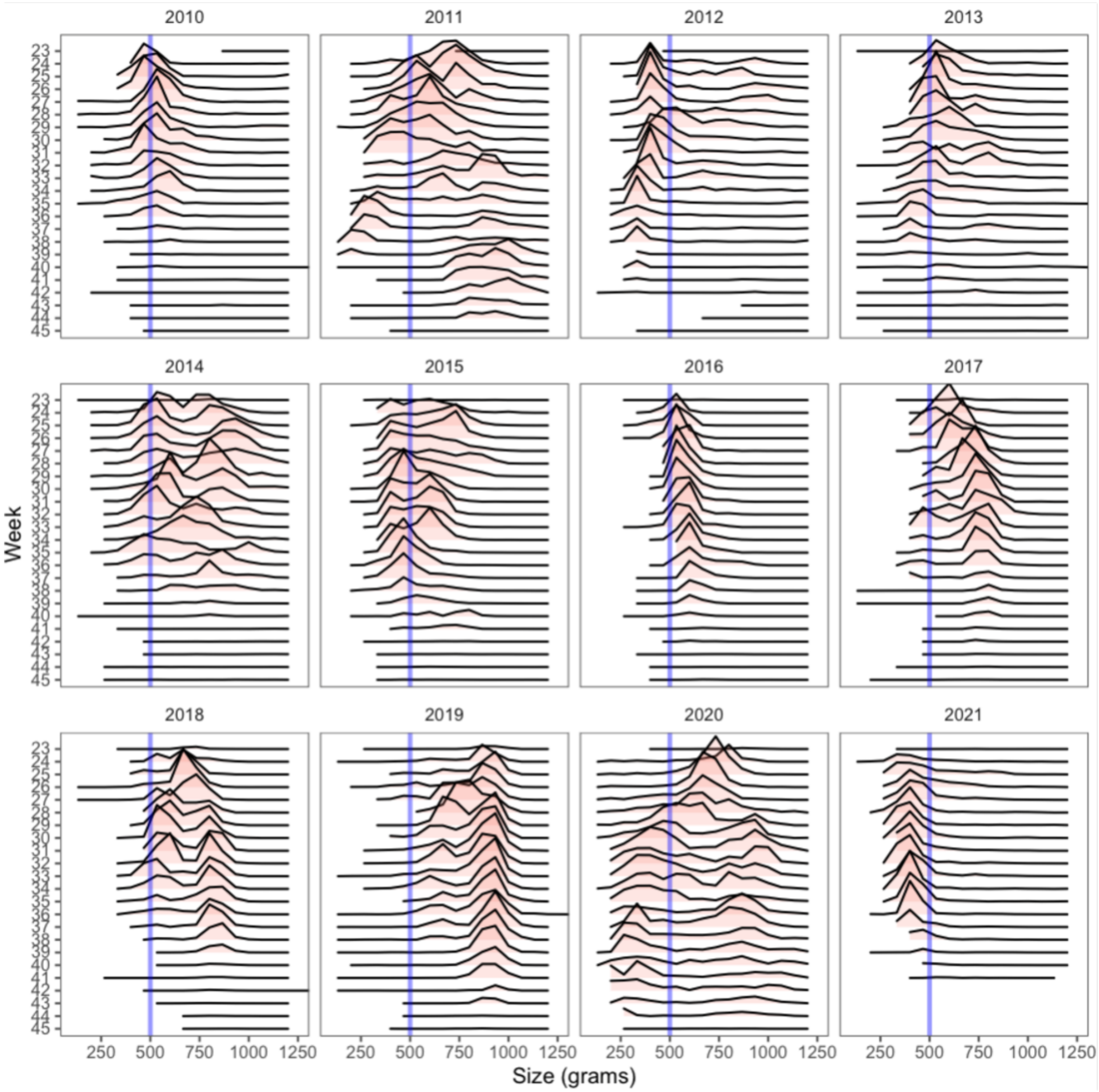

Figure 1-12. Pollock fishery data showing the frequency of mean pollock weight within a tow (in 50 g increments) by recent years and weeks of the B-season.

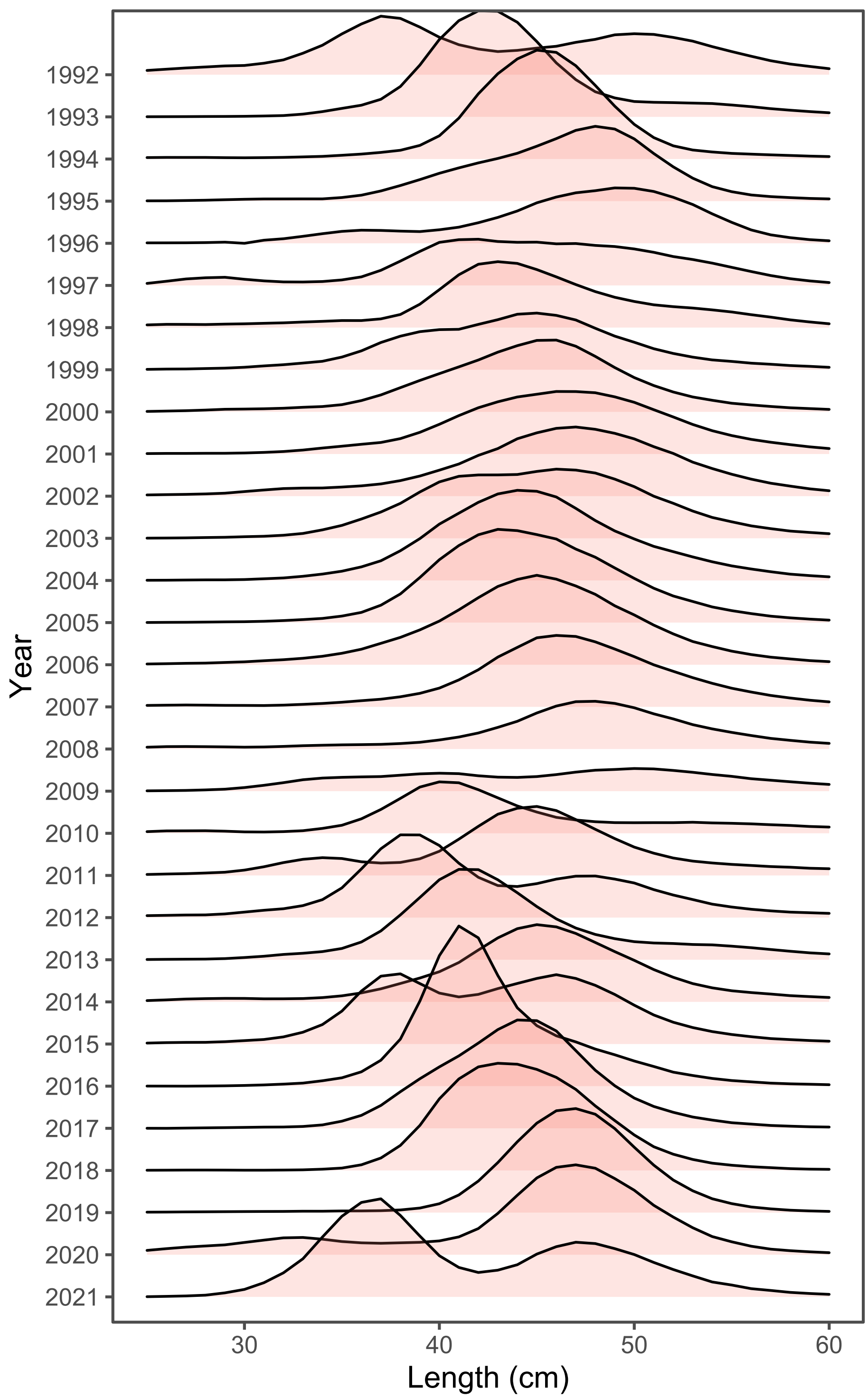

Figure 1-13. Fishery catch-at-length (cm) by the pollock fishery, 1992-2021.

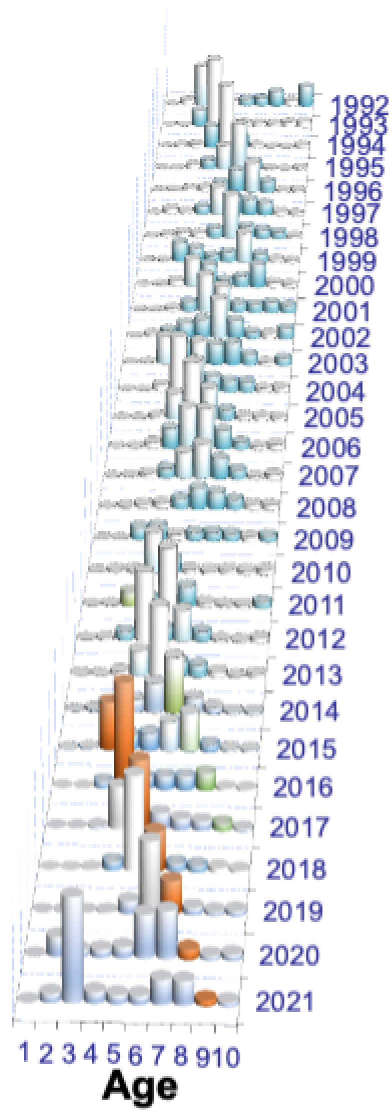

Figure 1-14. EBS pollock fishery estimated catch-at-age data (in number) for 1992–2020. Age 10 represents pollock age 10 and older. The 2012 year-class is shaded in orange.

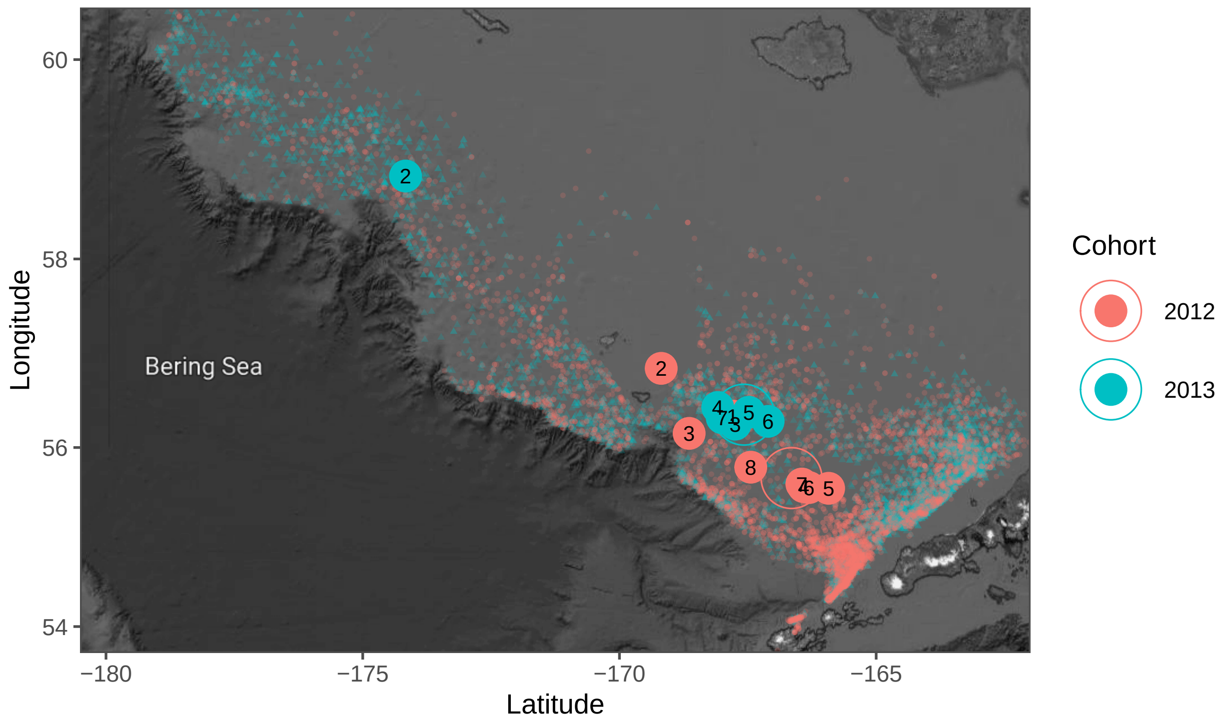

Figure 1-15. Pollock age sample locales (small dots) for two recent cohorts representing the 2012 and 2013 year-classes (from data through 2020). The large dots represent simple mean latitude and longitude of the samples.

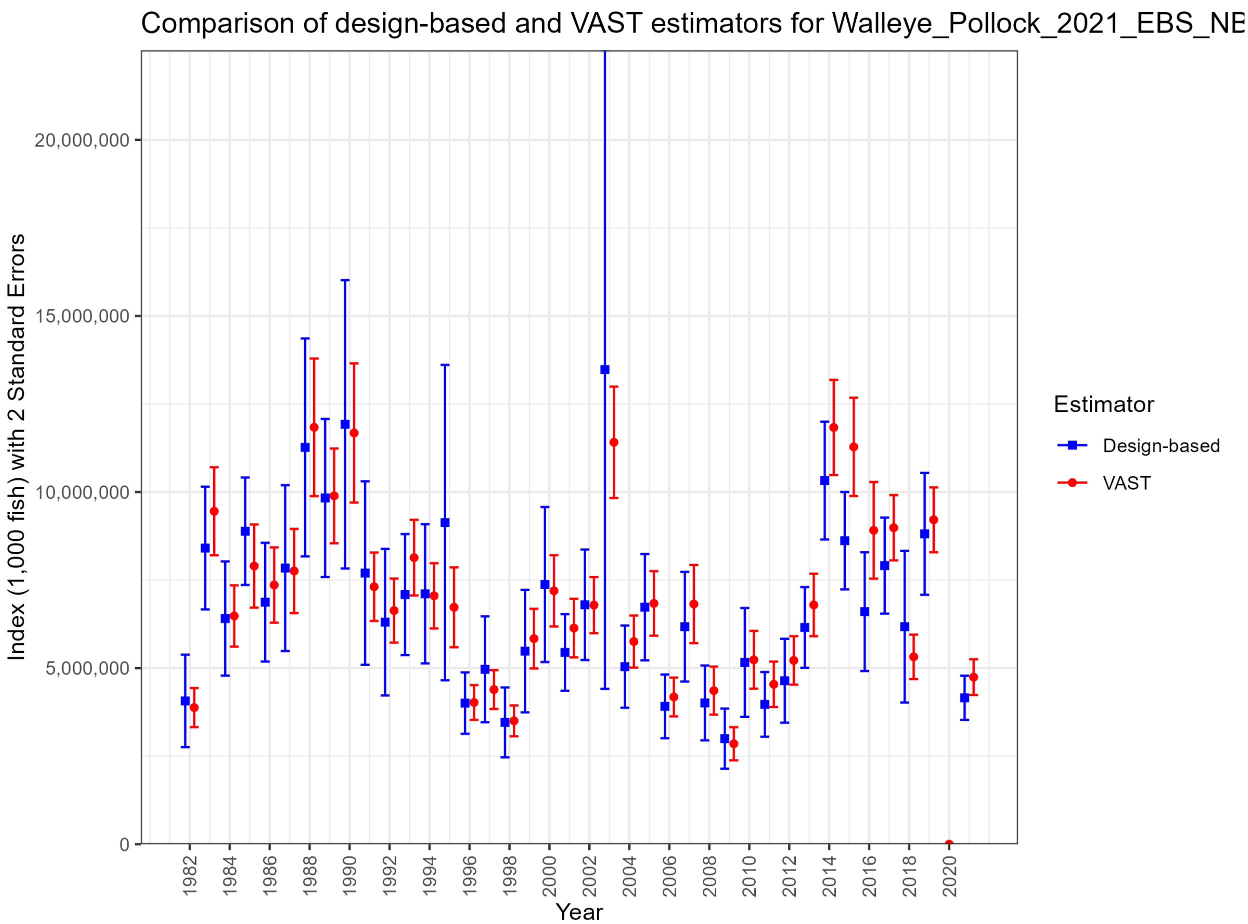

Figure 1-16. Bottom-trawl survey biomass estimates with error bars representing 95% credible interval (for design-based and VAST model-based methods) for EBS pollock.

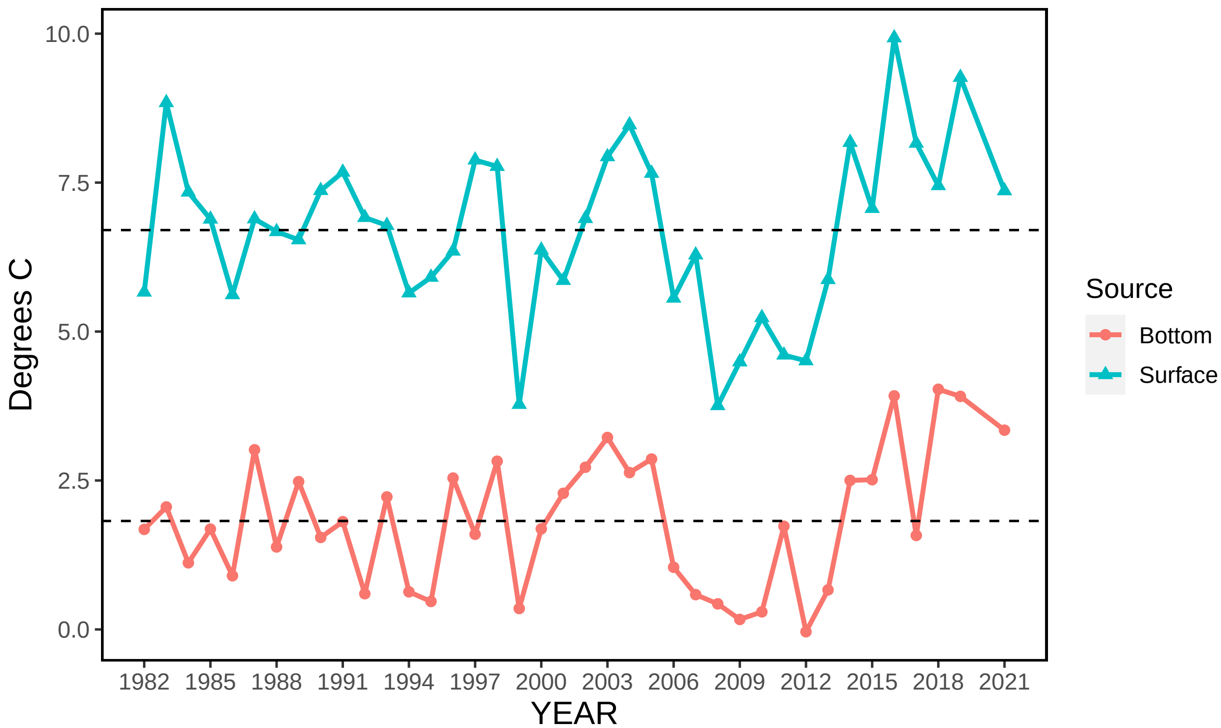

Figure 1-17. Bottom and surface temperatures for the Bering Sea from the NMFS summer bottom-trawl surveys (1982–2019, 2021). Dashed lines represent mean values.

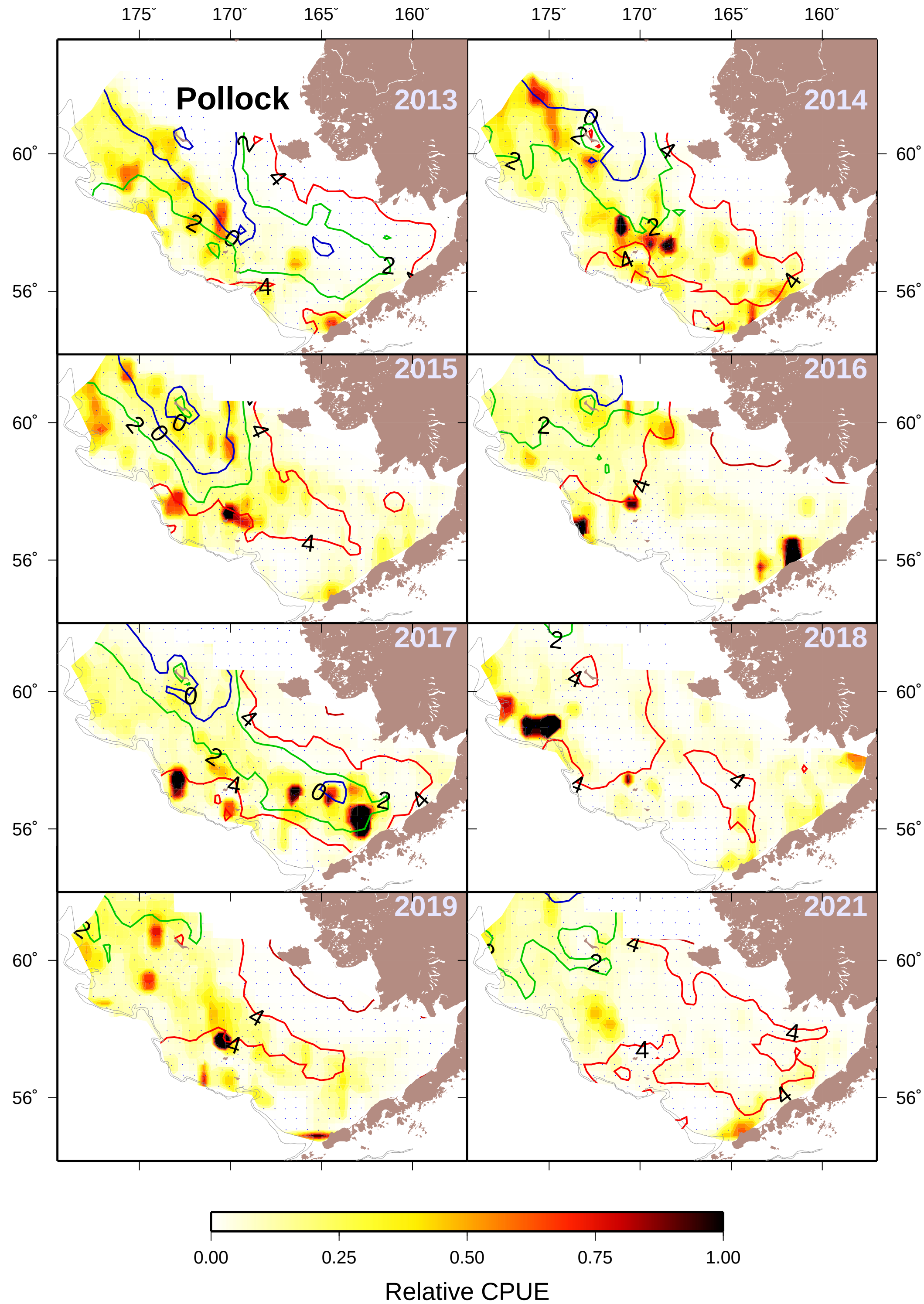

Figure 1-18. EBS pollock CPUE (shades = relative kg/hectare) and bottom temperature isotherms in degrees C; from the bottom trawl survey data 2011–2019 and 2021.

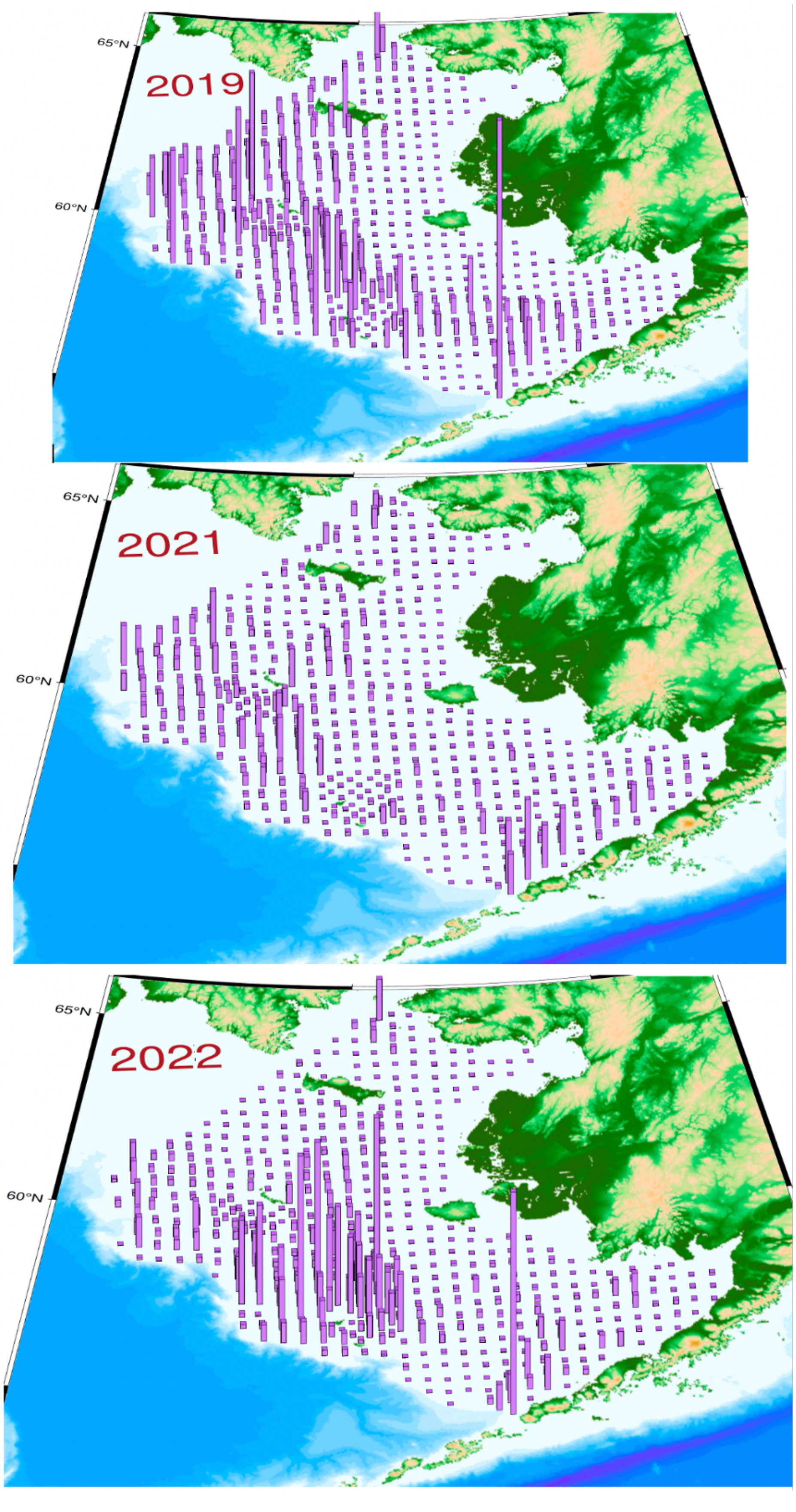

Figure 1-19. Bottom trawl survey pollock catch in kg per hectare for 2019 and 2021 (top and bottom)compared to the average station density (middle). Height of vertical lines are proportional to station-specific pollock densities by weight (kg per hectare) with constant scales for all years (red stars indicate tows where pollock were absent from the catch).

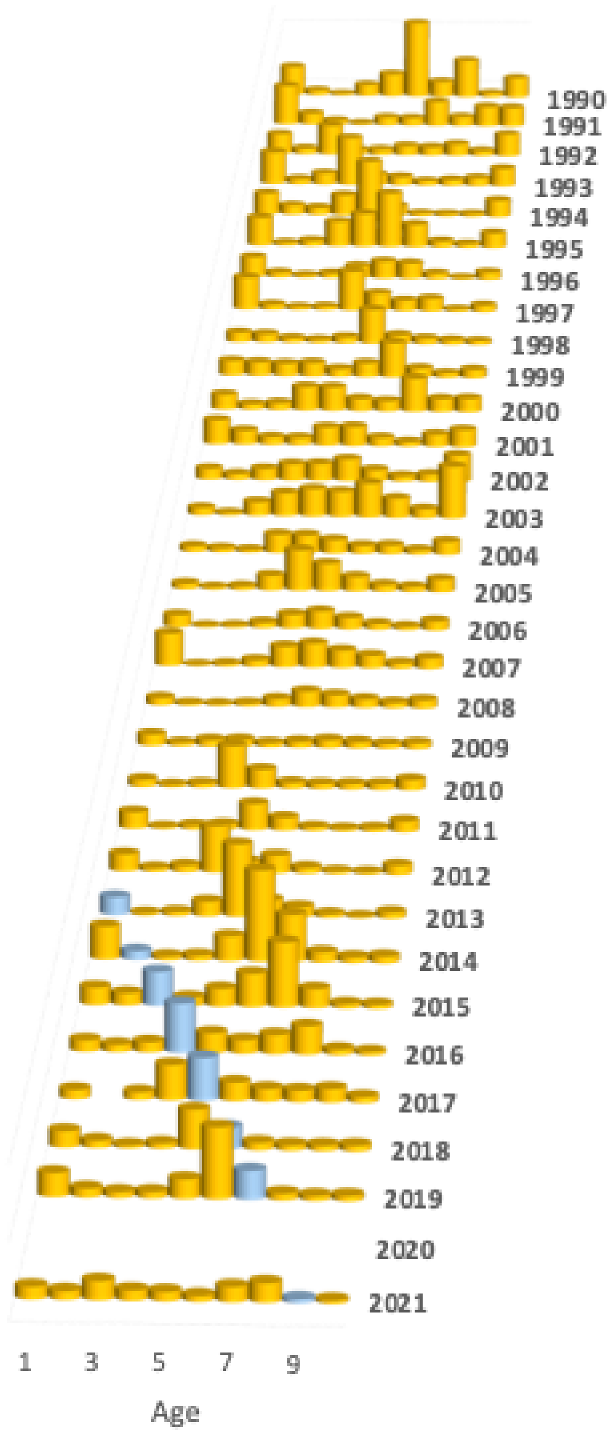

Figure 1-20. Pollock abundance levels by age and year as estimated directly from the NMFS bottom-trawl surveys (1990–2019,2021). The 2012 year-class is shaded differently.

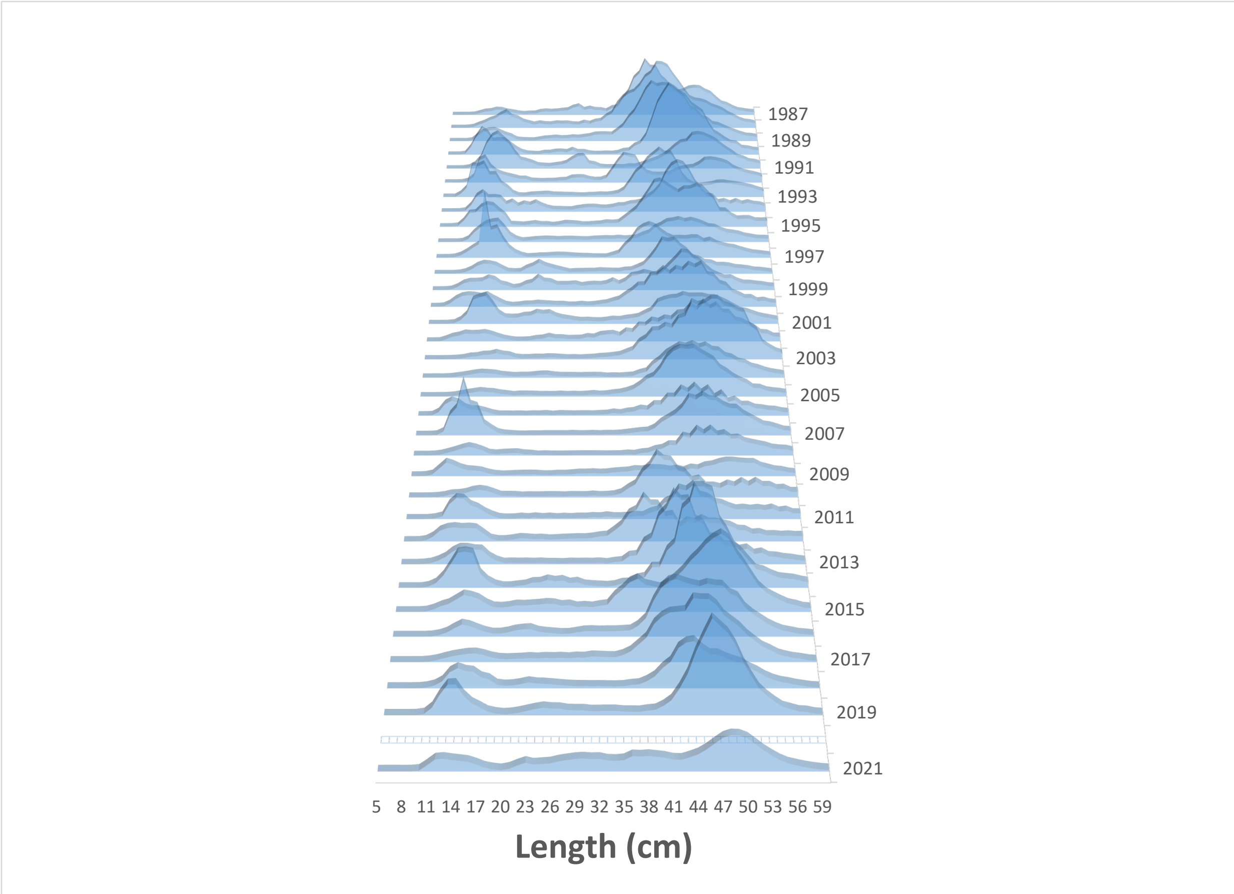

Figure 1-21. Pollock abundance levels by size and year as estimated directly from the NMFS bottom-trawl surveys (1990–2019, 2021).

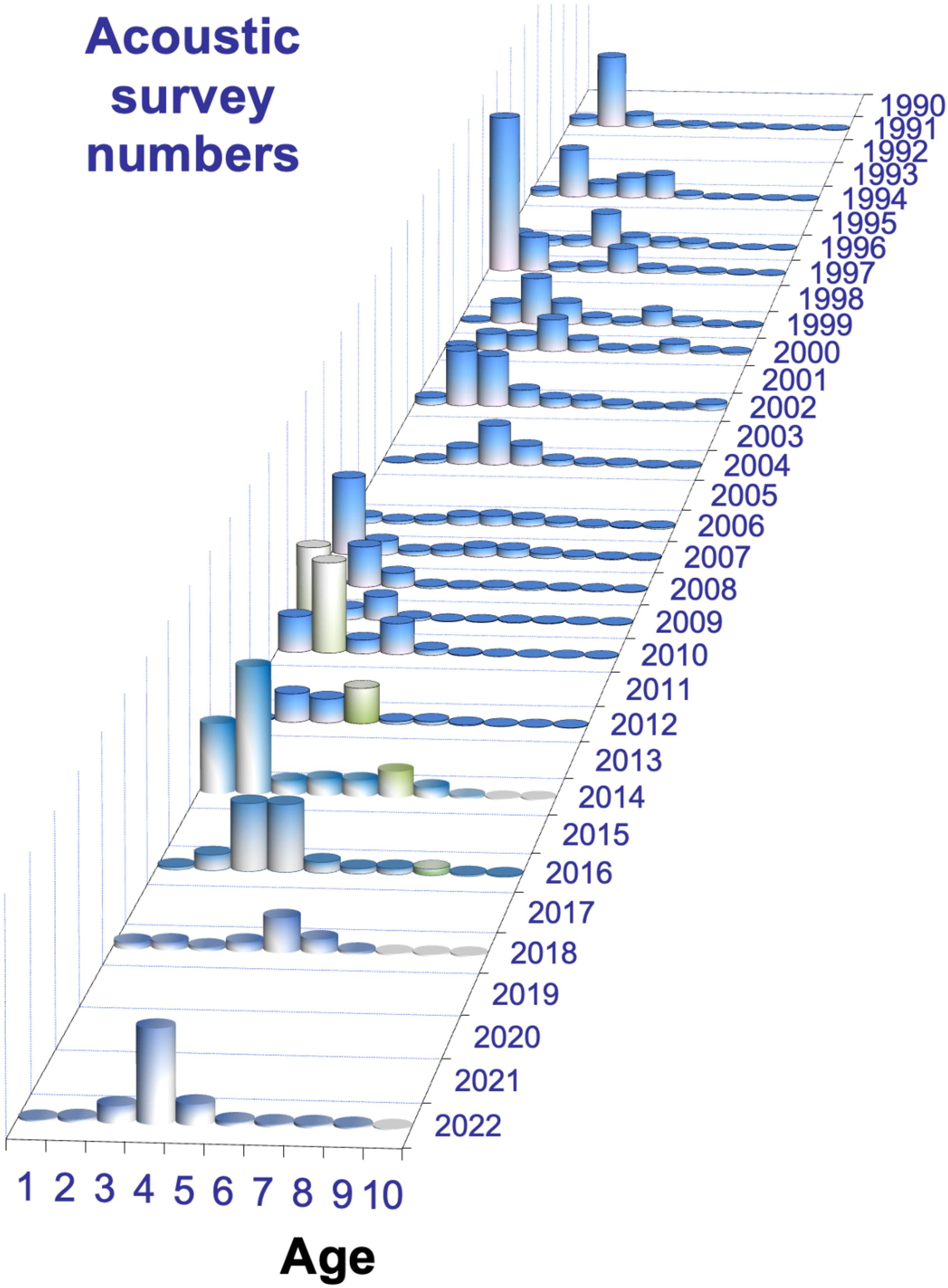

Figure 1-22. Acoustic-trawl survey pollock numbers-at-age estimates, 1994-2022. Note that data for 2022 are preliminary and based on age-length composition from the bottom trawl survey (plus some supplemental samples from the present survey).

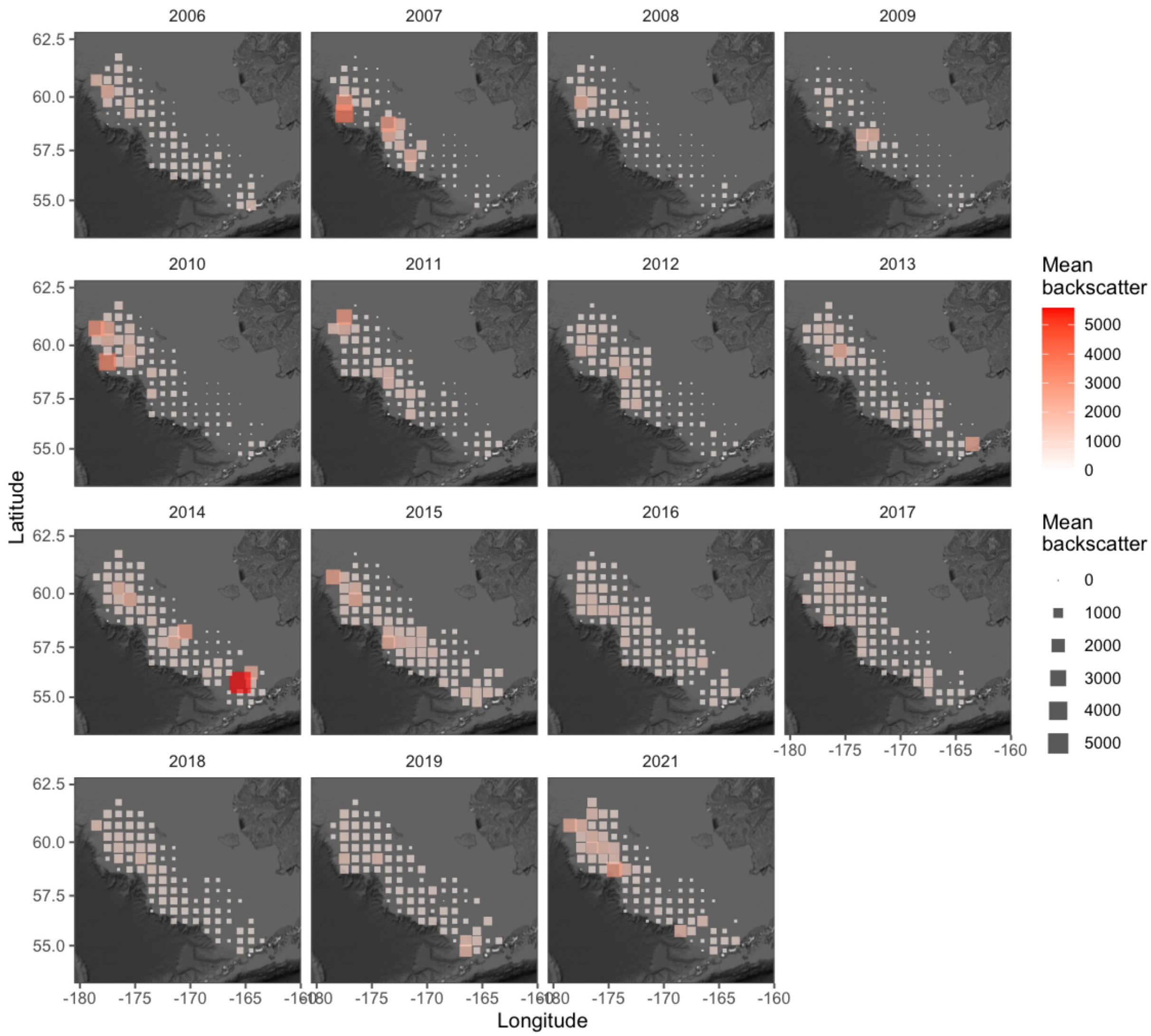

Figure 1-23. Maps of acoustic vessel-of-opportunity (AVO) index data 2006-2021. Grid cell size and shading is proportional to pollock backscatter.

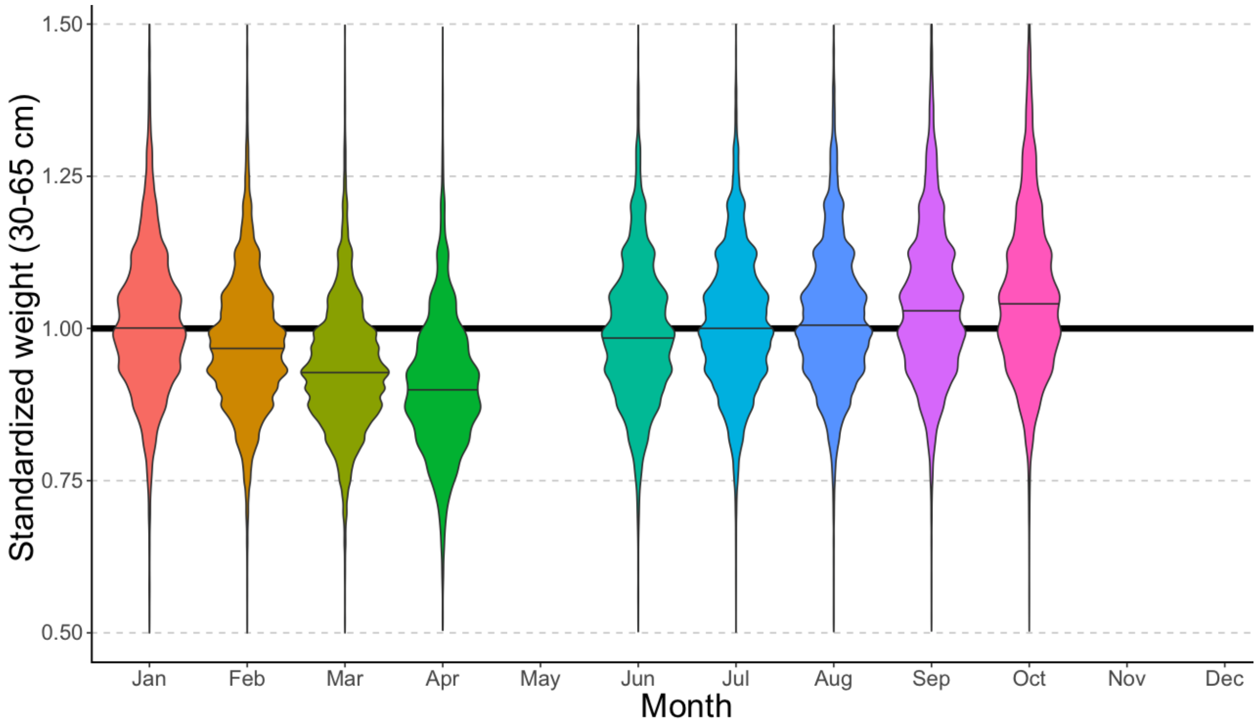

Figure 1-24. EBS pollock fishery body mass (given length) anomaly (standardized by overall mean body mass at each length) by month based on some over 700 thousand fish measurements from 1991–2021.

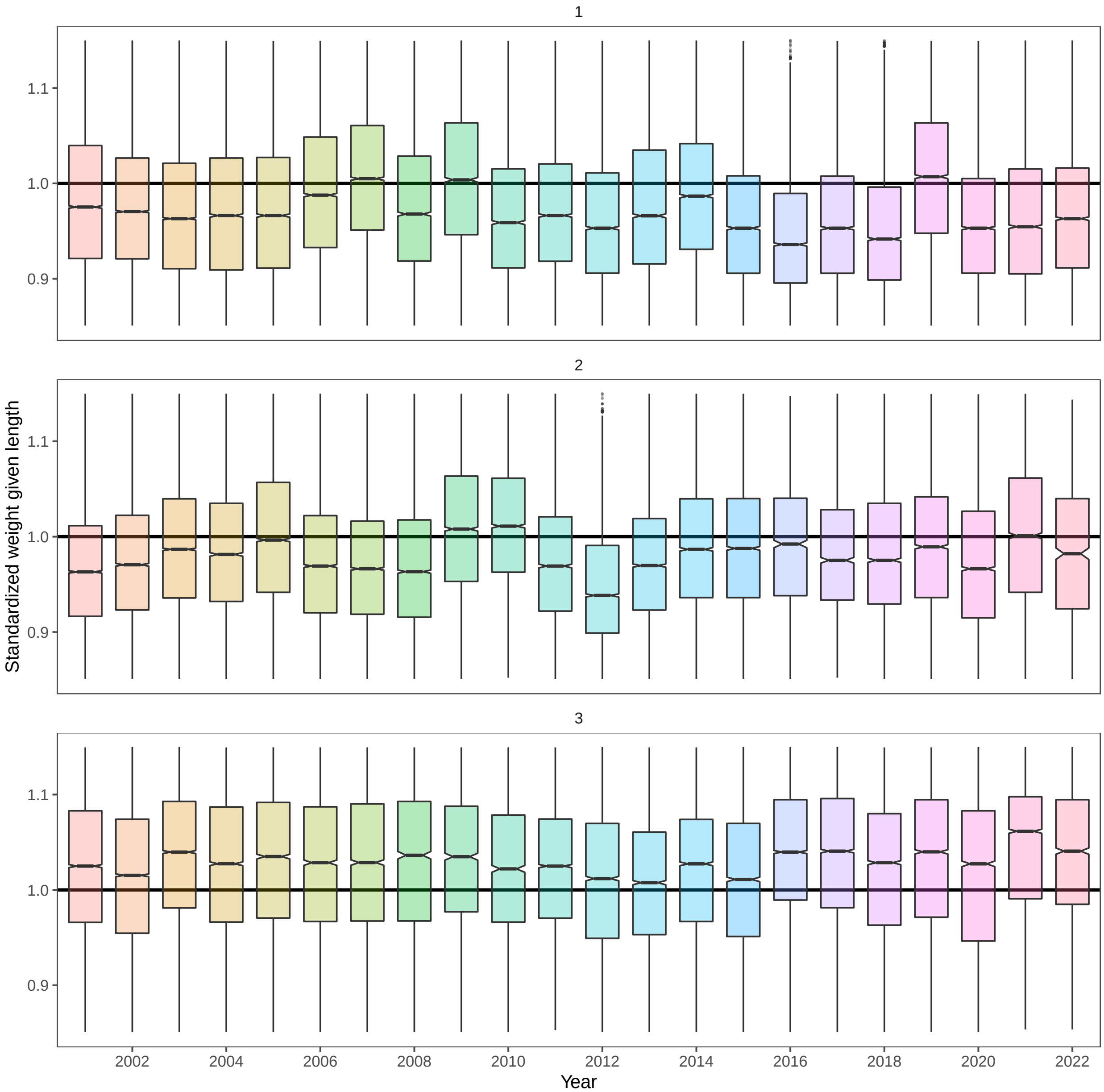

Figure 1-25. EBS pollock fishery body mass (given length) anomaly (standardized by overall mean body mass at each length) by year and season/area strata, 1991–2021.

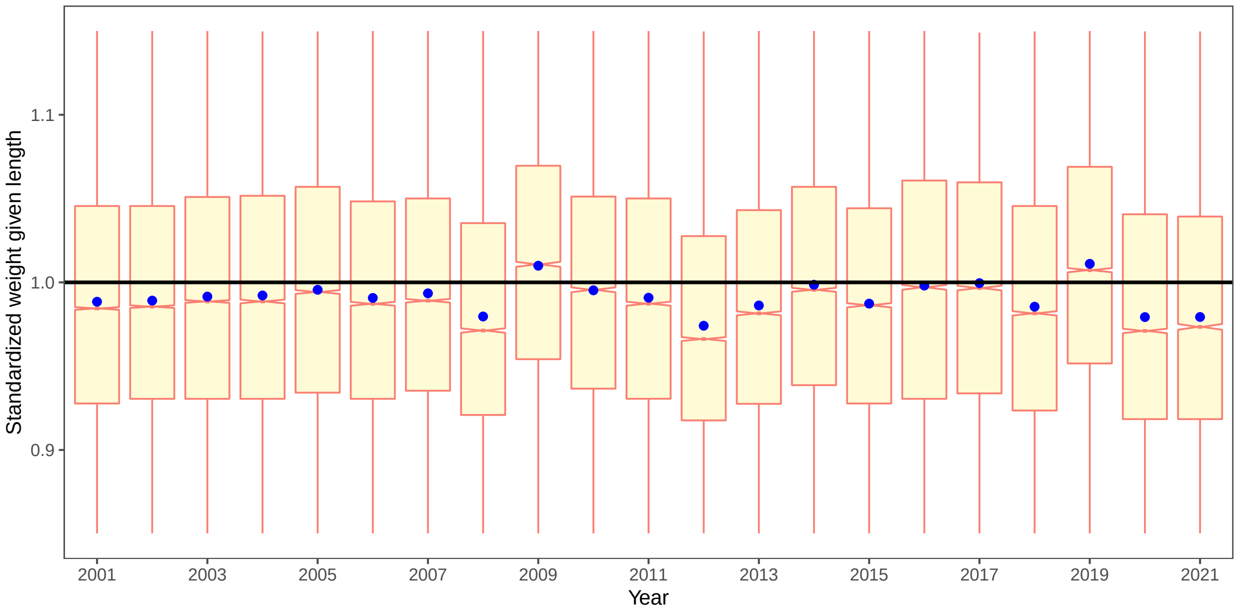

Figure 1-26. EBS pollock body mass (given length) anomaly (standardized by overall mean body mass at each length) by year, 1991–2021.

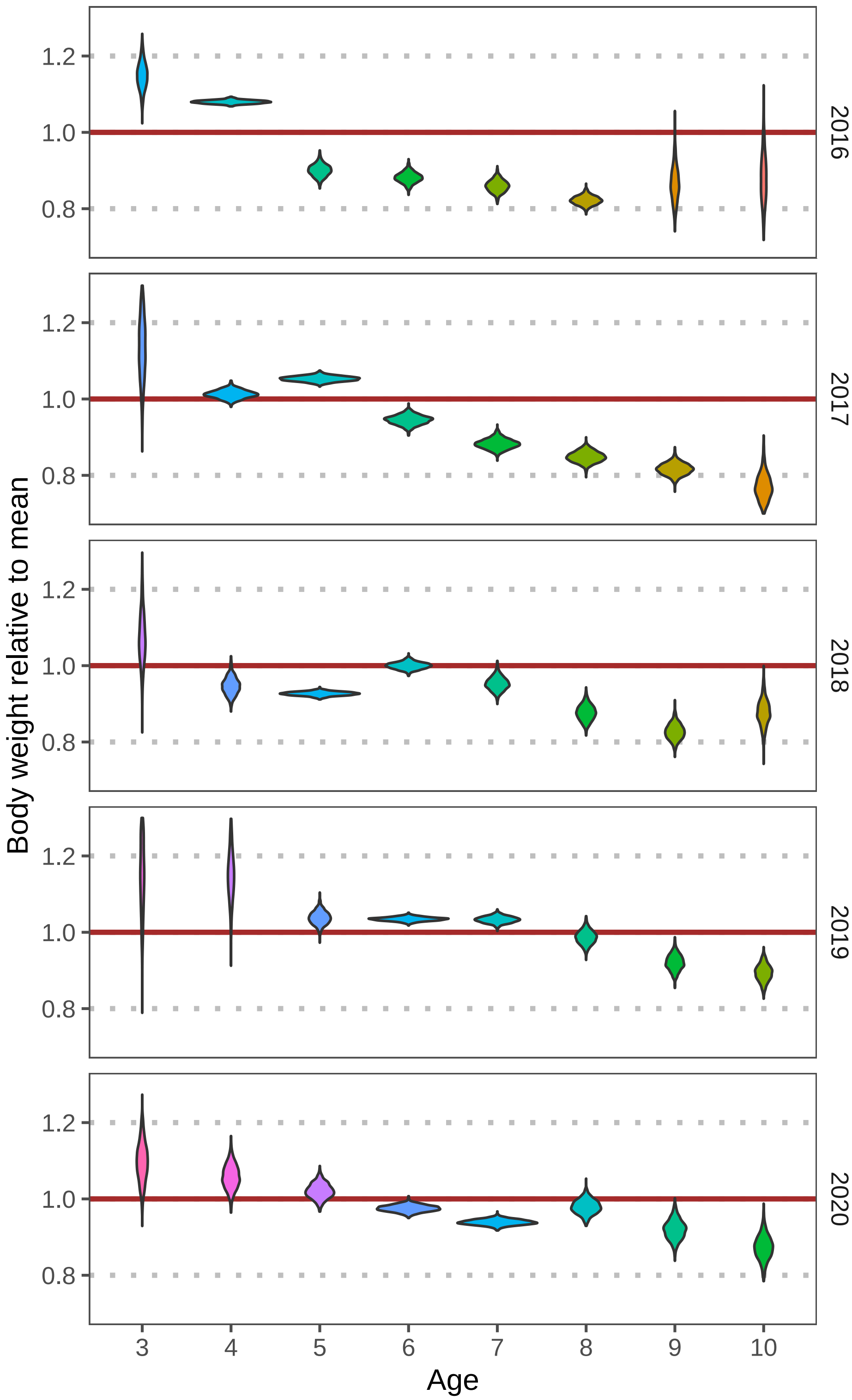

Figure 1-27. Recent fishery average weight-at-age anomaly (relative to mean) by strata for ages 3–10, 2016–2020. Vertical shape reflects uncertainty in the data (wider shapes being more precise), colors are consistent with cohorts.

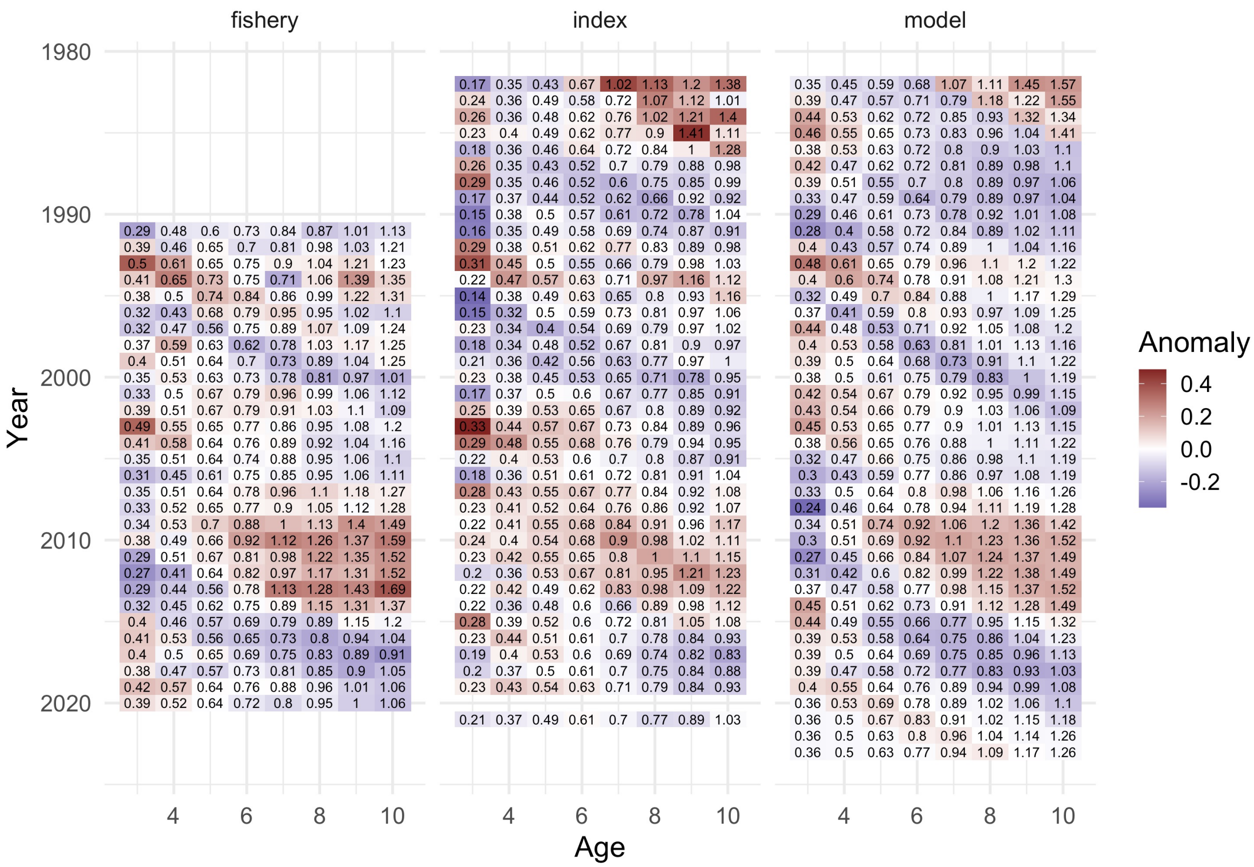

Figure 1-28. “Data input and model predictions for the weight-at-age random-effects model fit separately to obtain variance estimates for cohort and year effect contributions to changes in incremental growth from one age to the next. Shadings reflect the anomaly from the mean while the numbers are the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

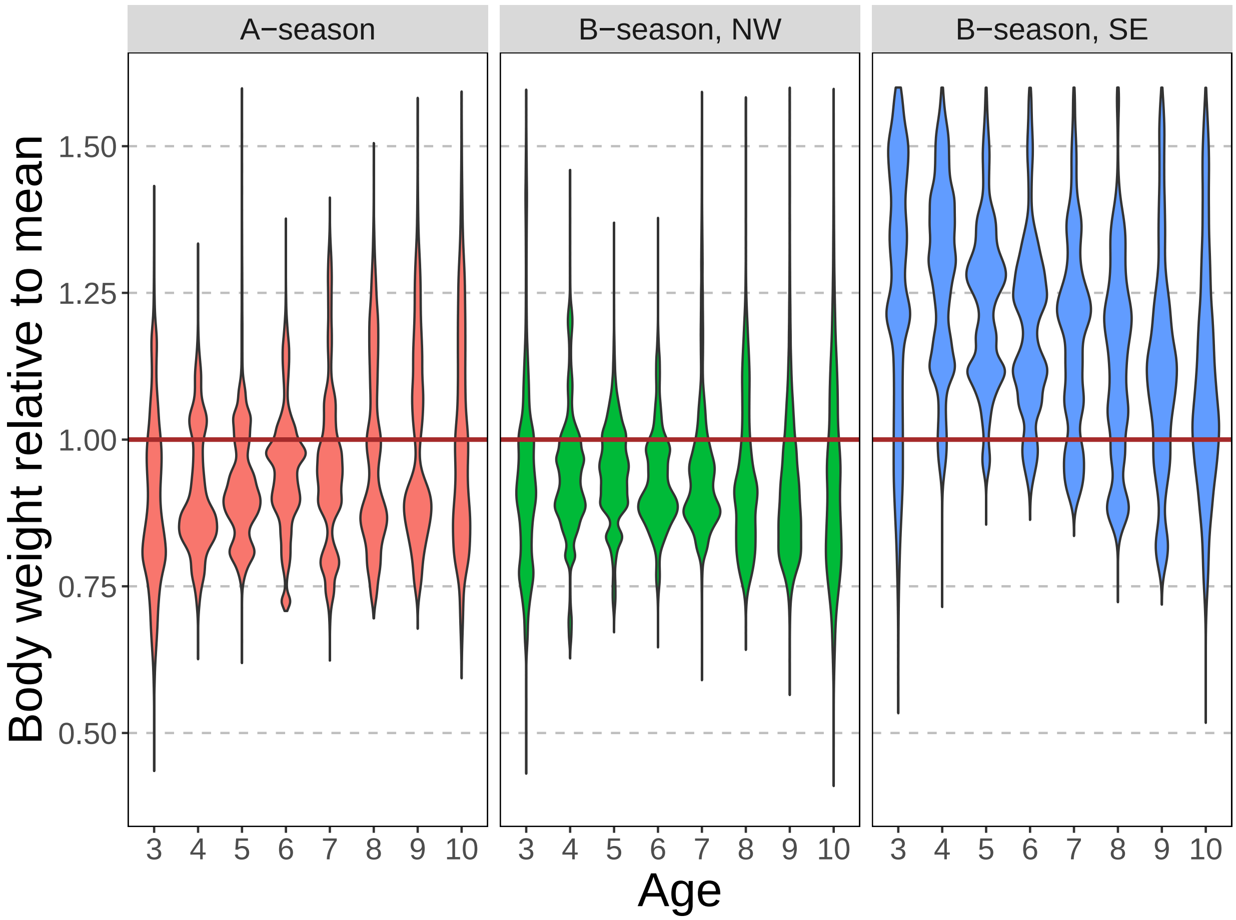

Figure 1-29. Fishery average weight-at-age anomaly (relative to mean) across strata and combined for all ages (3–10), and available years (1991–2020). Vertical shape reflects uncertainty in the data (wider shapes being more precise), colors are consistent with cohorts.

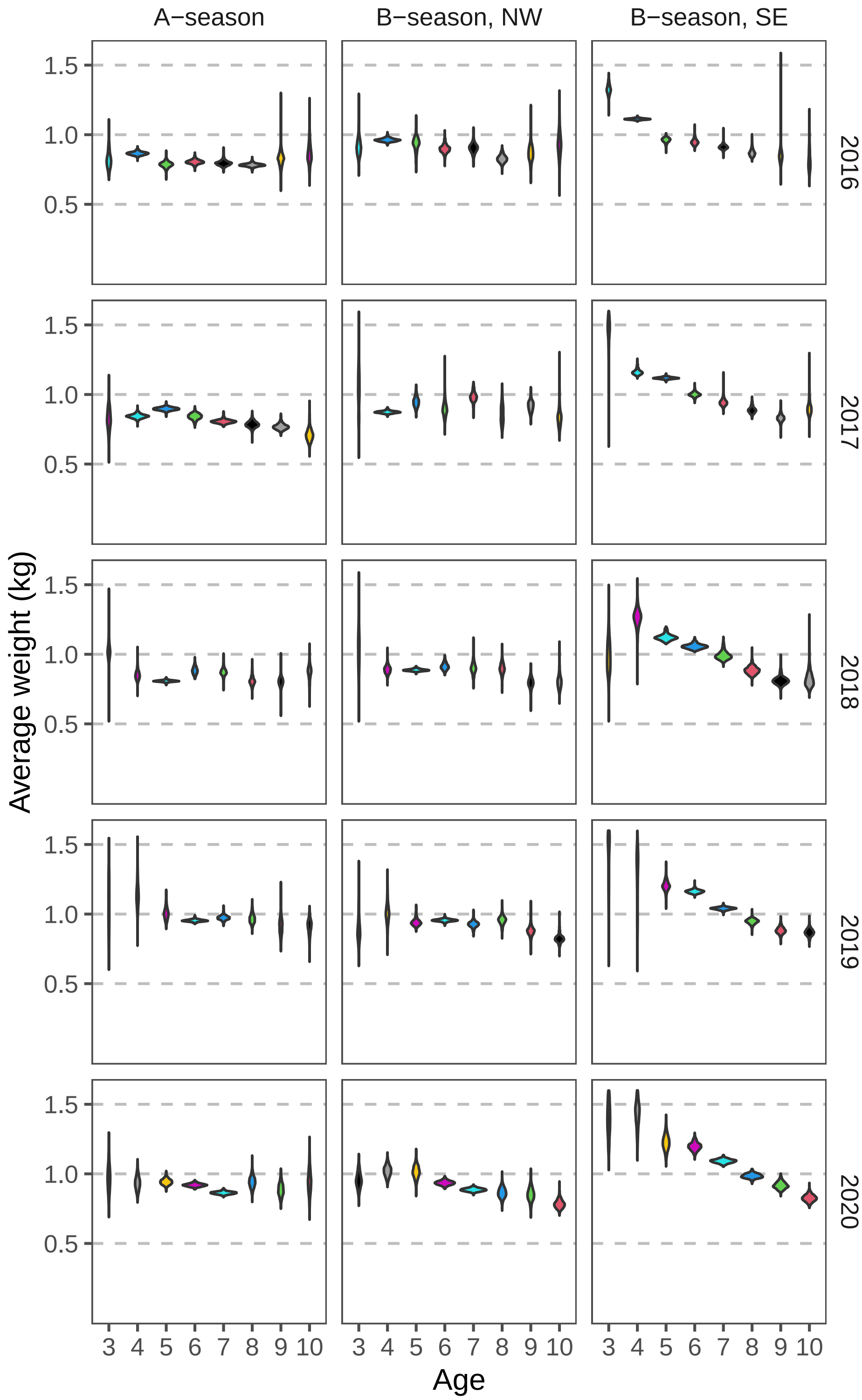

Figure 1-30. Recent fishery average weight-at-age anomaly (relative to mean) by strata for ages 3–10, 2014–2020. Vertical shape reflects uncertainty in the data (wider shapes being more precise), colors are consistent with cohorts.

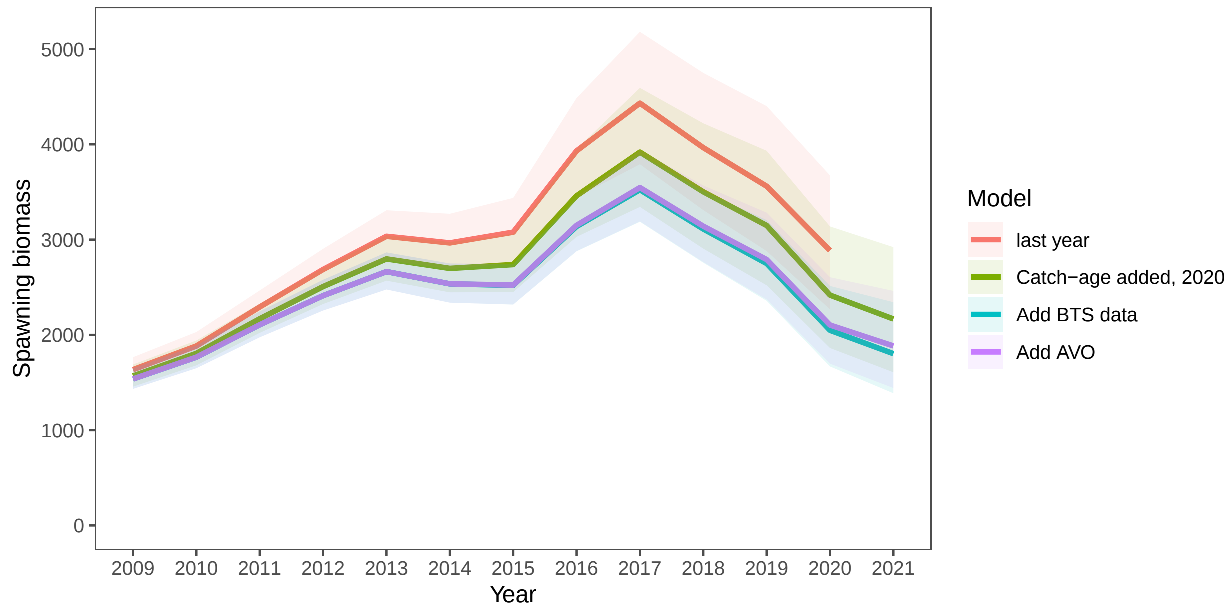

Figure 1-31. Model runs comparing last year's assessment with the impact of sequentially adding new data (first 2021 catch and 2020 fishery catch-at-age, then the 2021 bottom trawl survey data point, and finally the AVO data based on acoustic backscatter.

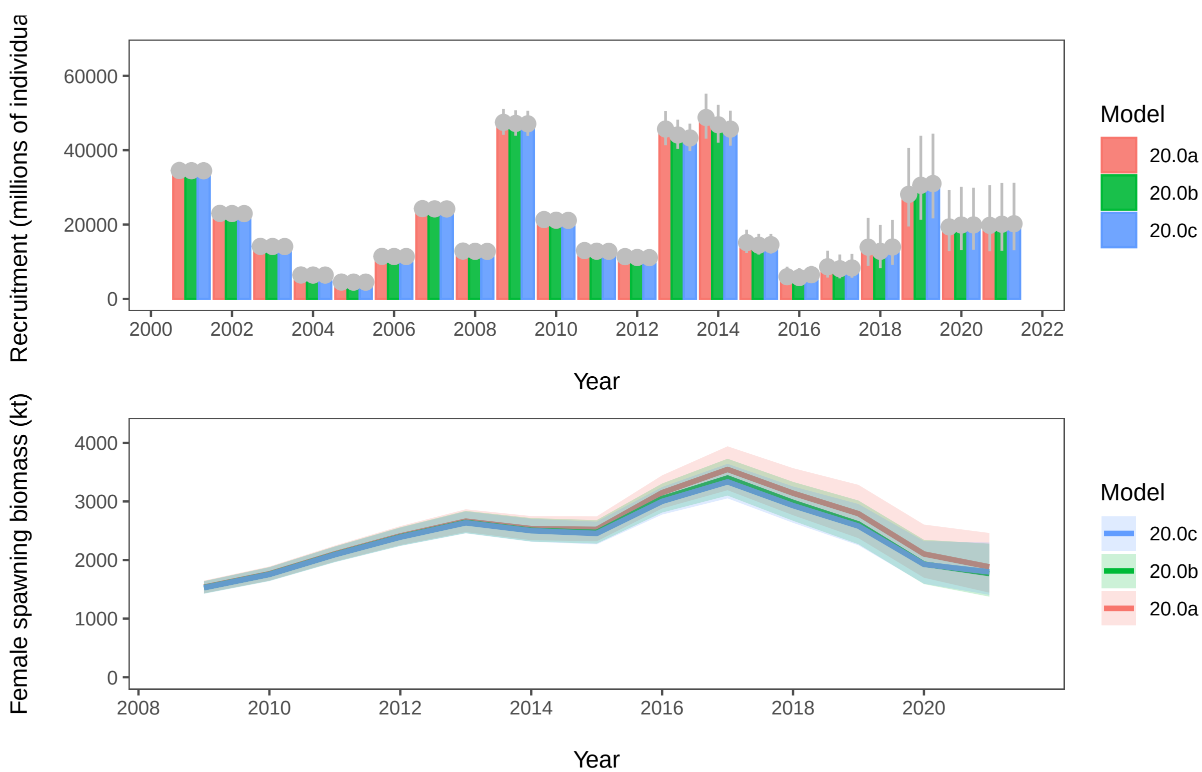

Figure 1-32. "Model results showing the impact of adding in preliminary fishery length and age composition data from 2021."

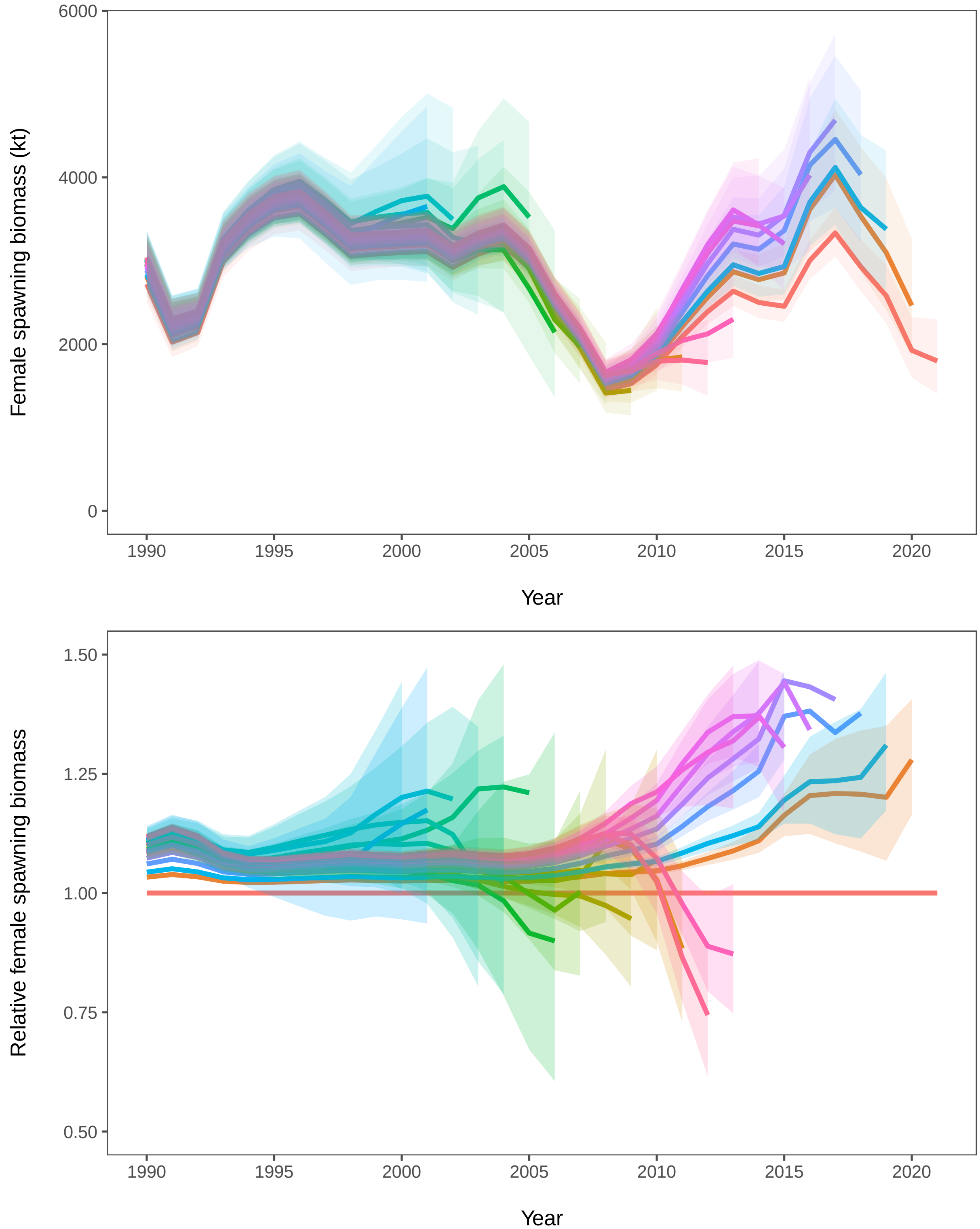

Figure 1-33. Retrospective patterns for EBS pollock spawning biomass showing the point estimates relative to the terminal year (top panel) and approximate confidence bounds on absolute scale (+2 standard deviations).

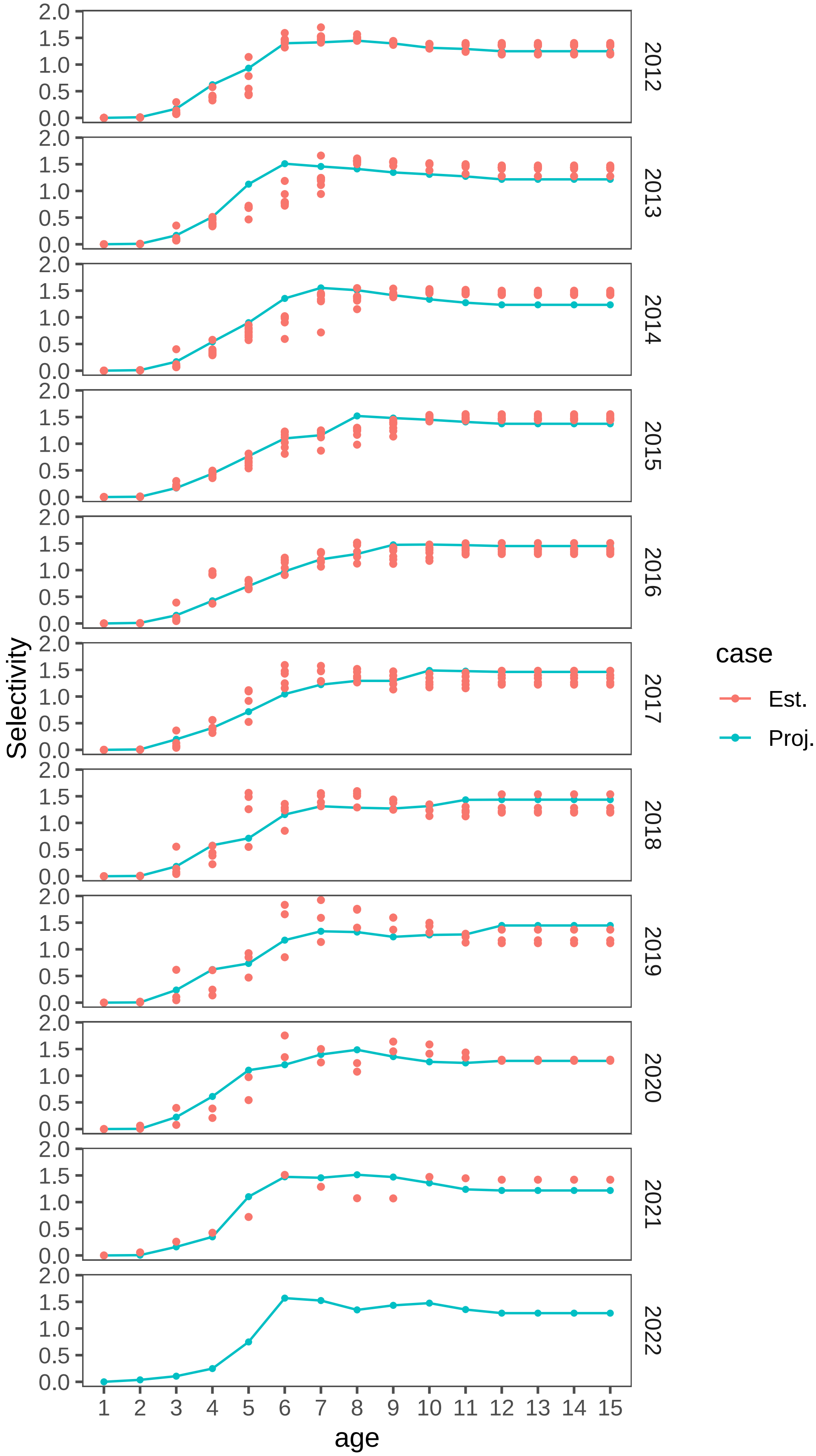

Figure 1-34. “Retrospective pattern for estimated EBS pollock fishery selectivity (dots) compared to the projected selectivity from the year prior (solid line).”

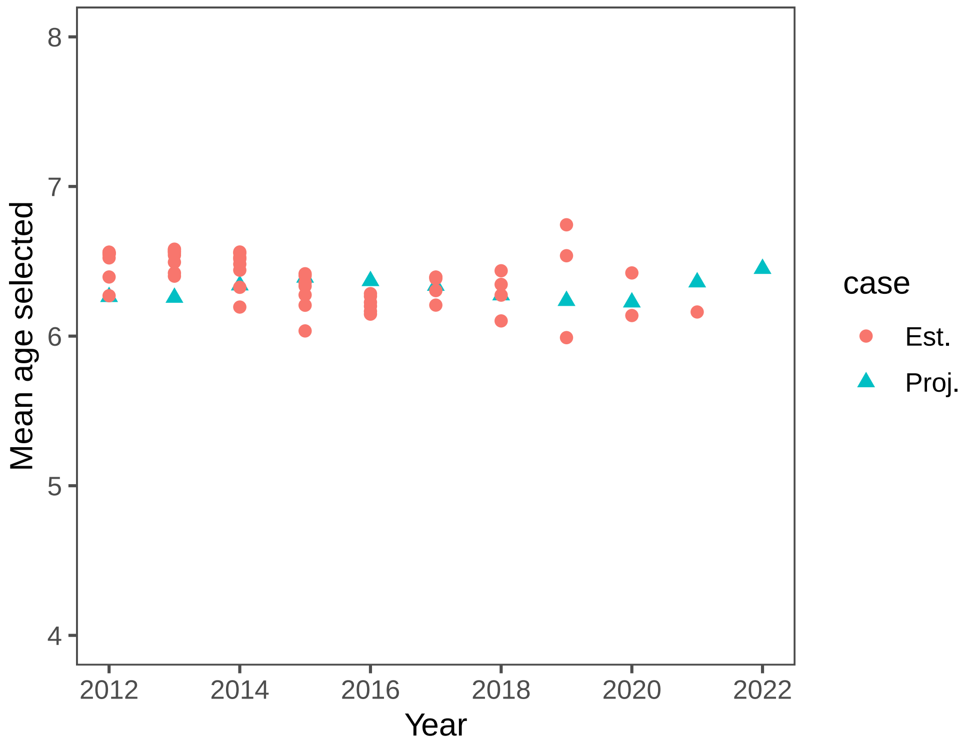

Figure 1-35. "Retrospective pattern for the mean selected age (ages 1-8) based on estimated EBS pollock fishery selectivity compared to the projected selectivity from the year prior."

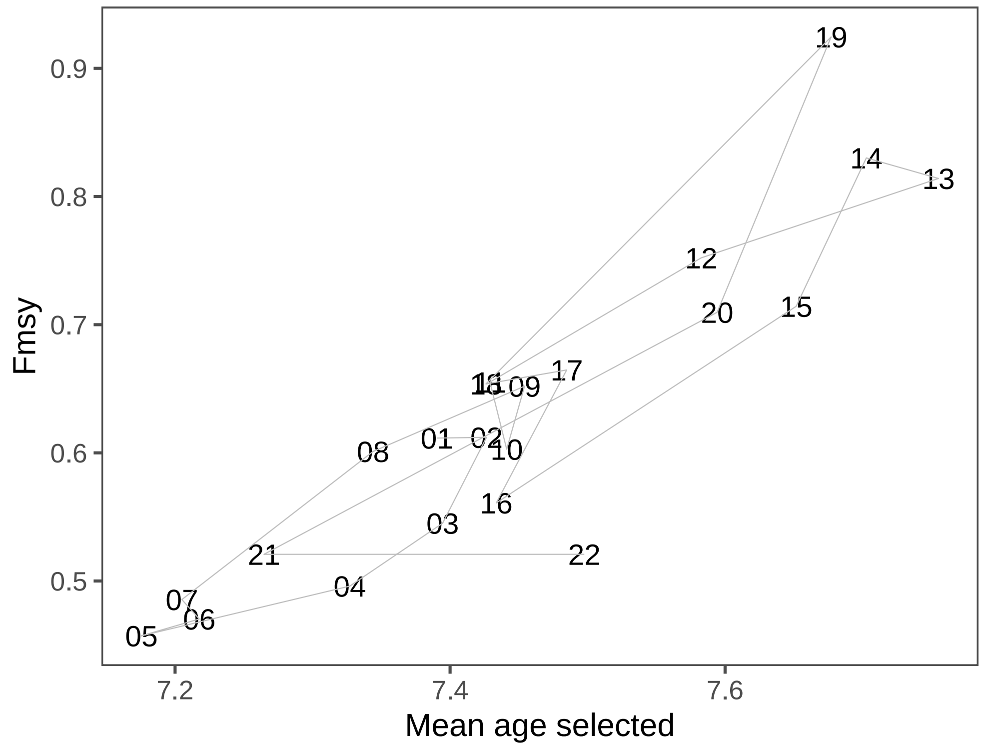

Figure 1-36. Comparison of F_{MSY} and mean selected age." The horizontal axis is a way to summarize if selectivity is tend towards younger or older fish. Labels indicate the year that demographic parameters (weight-at-age

Figure 1-37. Estimated spawning exploitation rate (defined as the percent removal of egg production in a given spawning year).

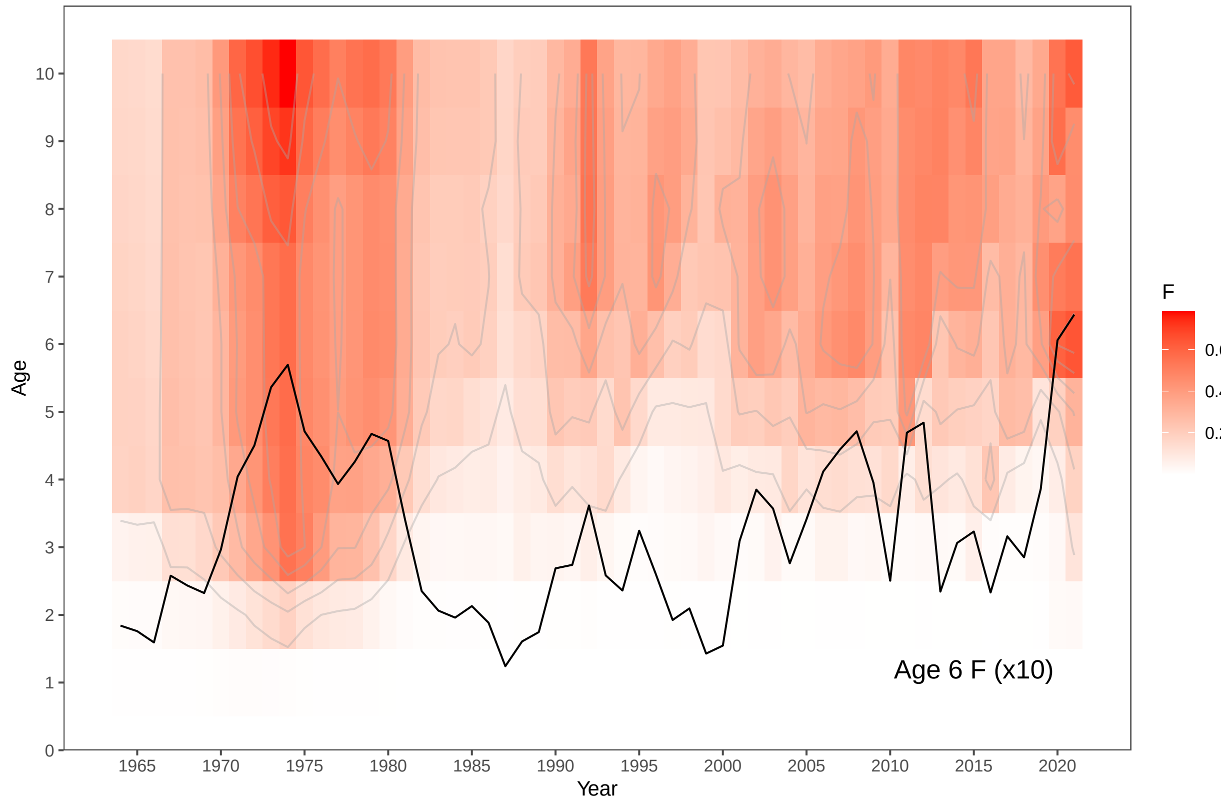

Figure 1-38. Estimated instantaneous age-specific fishing mortality rates for EBS pollock.

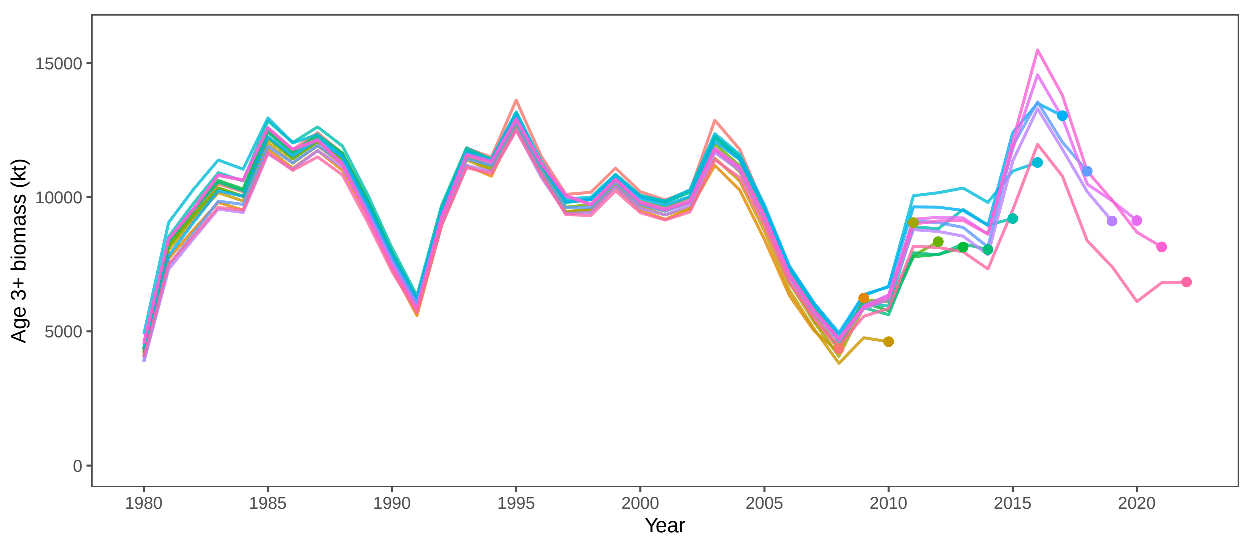

Figure 1-39. Comparison of the current assessment results with past assessments of begin-year EBS age-3+ pollock biomass.

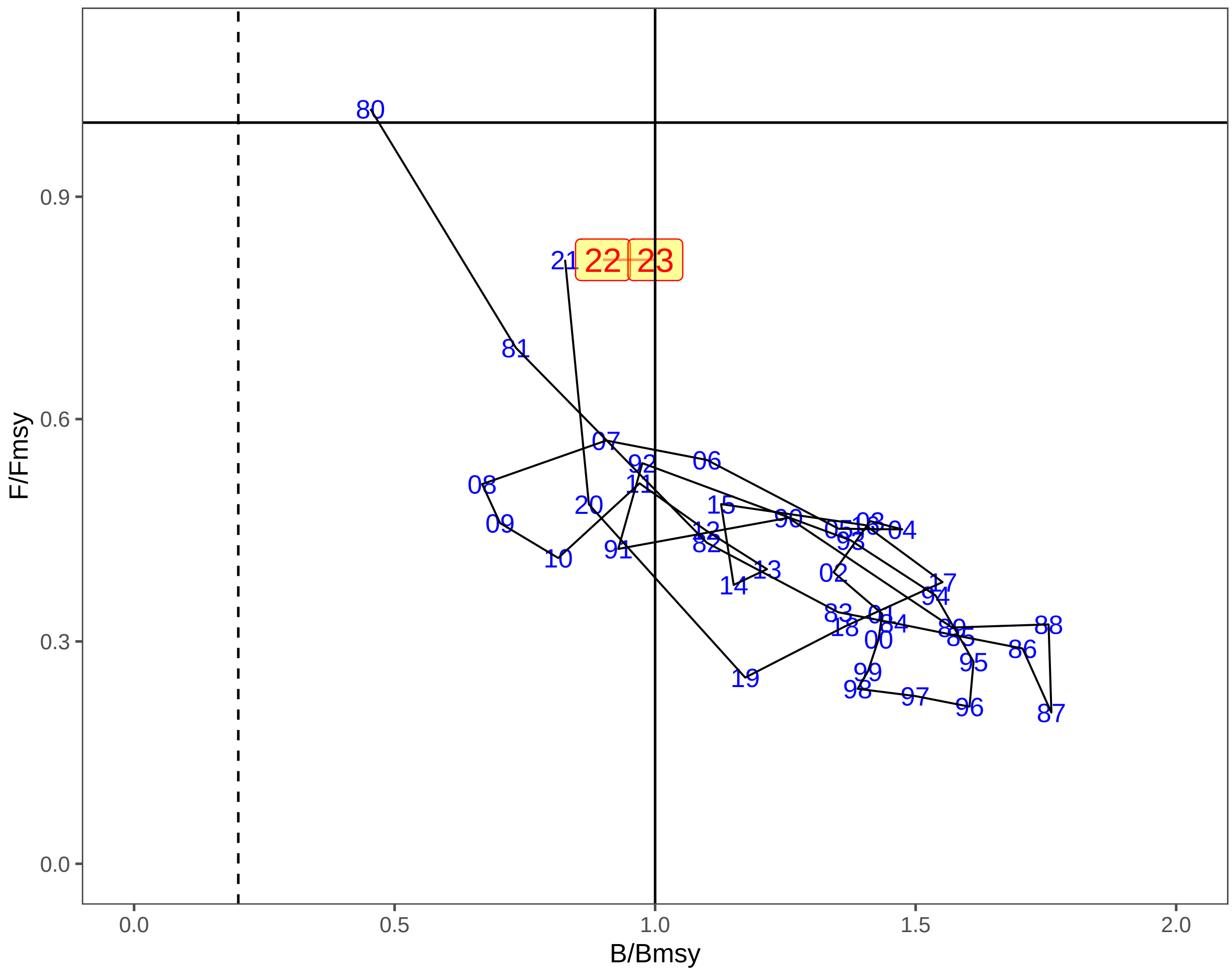

Figure 1-40. Estimated spawning biomass relative to annually estimated F_{MSY} values and fishing mortality rates for EBS pollock. Two projection years are shaded in yellow

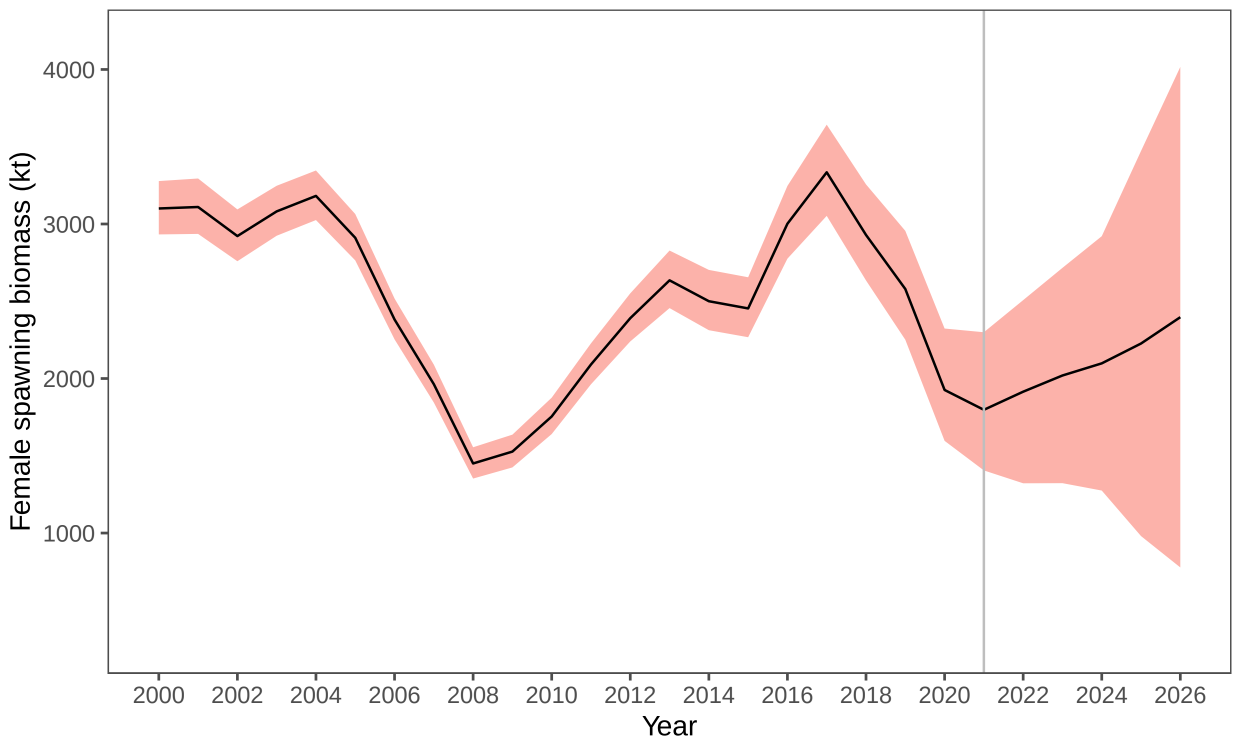

Figure 1-41. The estimated EBS pollock spawning stock biomass for model 20.0 with projections equal to the estimated fishing mortality from 2021.

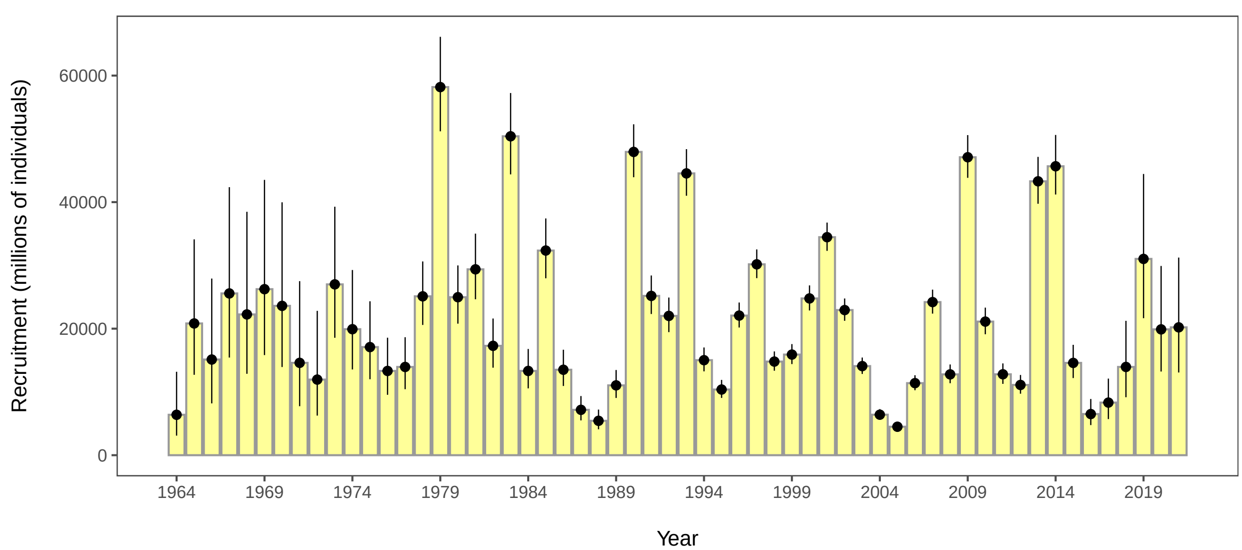

Figure 1-42. Recruitment estimates (age-1 recruits) for EBS pollock for all years since 1964 (1963–2020 year classes) for Model 20.0c. Error bars reflect 90% credible intervals based on model estimates of uncertainty.

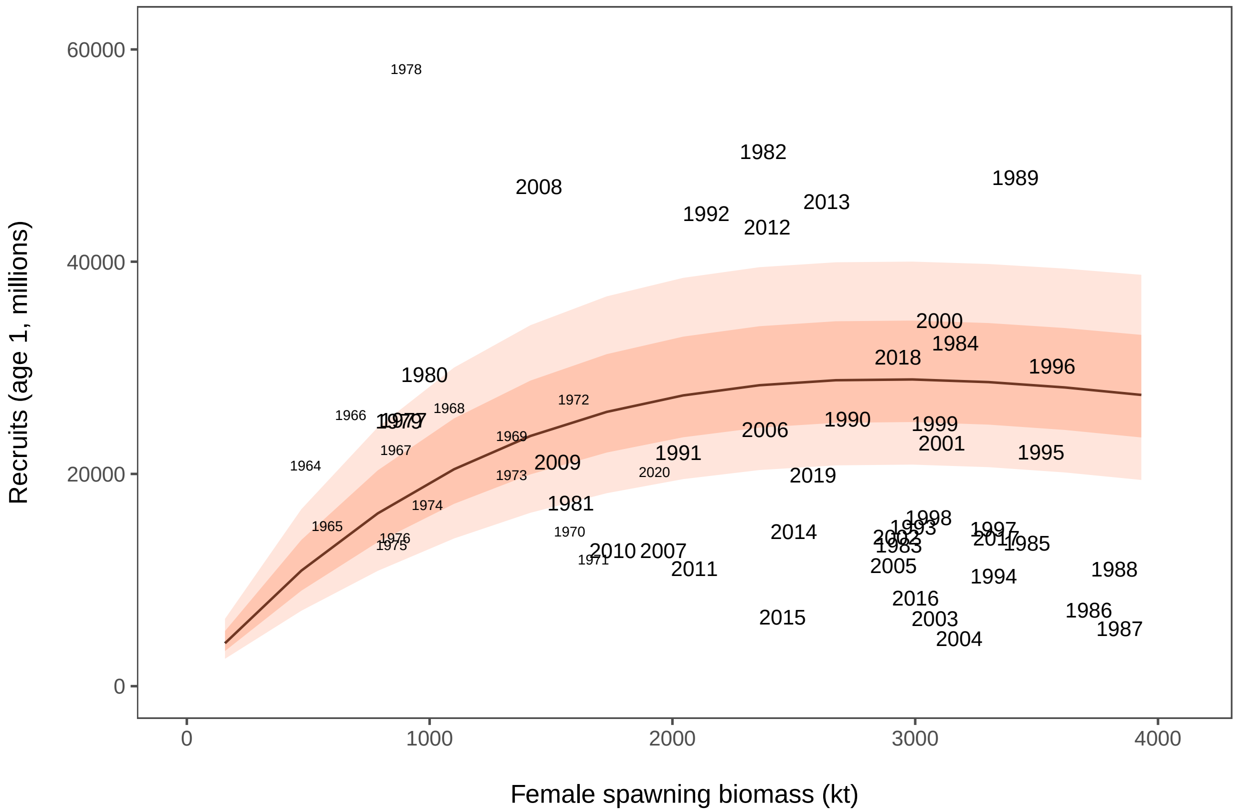

Figure 1-43. Stock-recruitment estimates (shaded represents structural uncertainty) and age-1 EBS pollock estimates labeled by year-classes

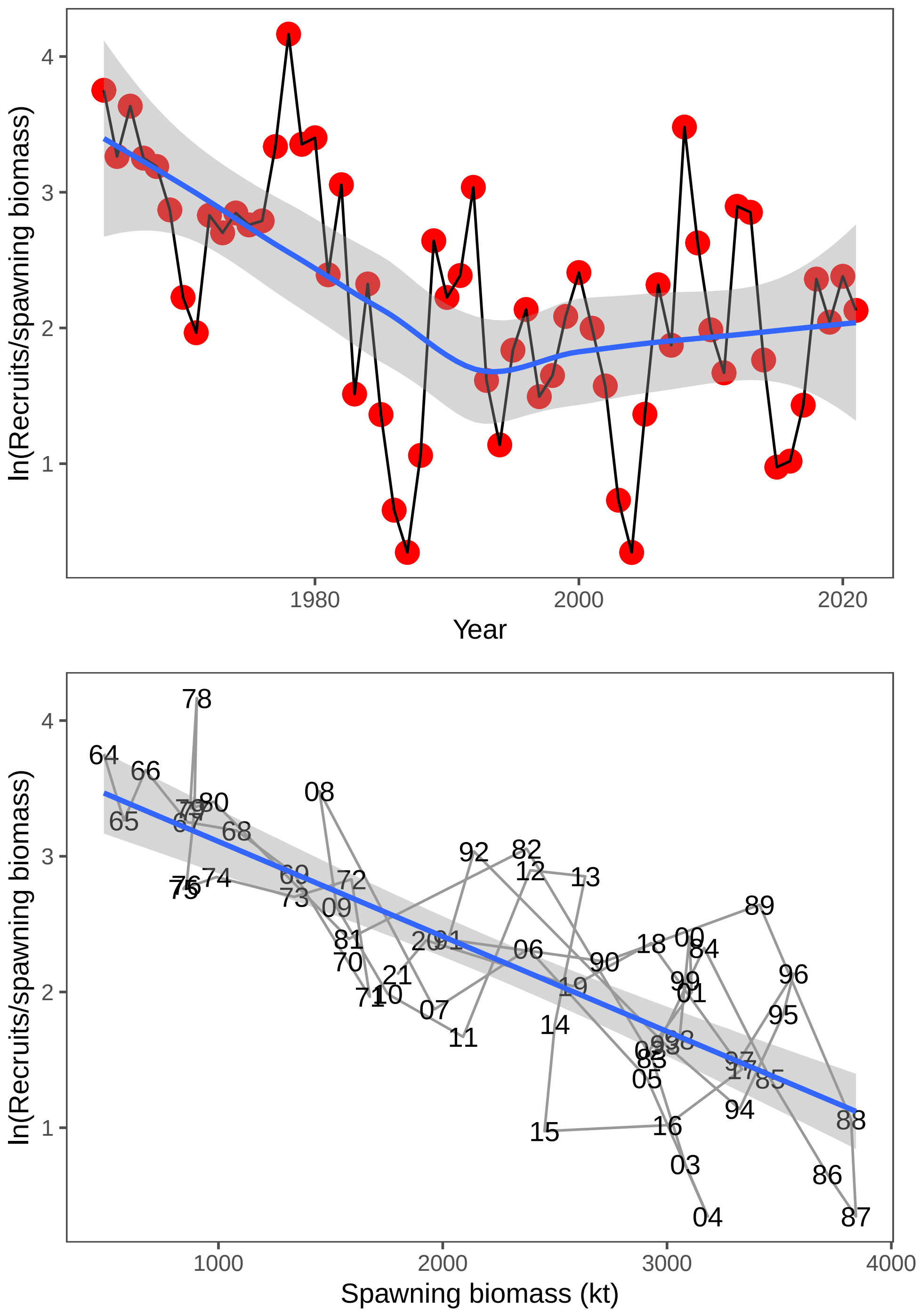

Figure 1-44. EBS pollock productivity as measured by logged recruits per spawning biomass, log(R/S), as a function of spawning biomass with a linear fit (bottom) and over time, 1964–2021 (top).

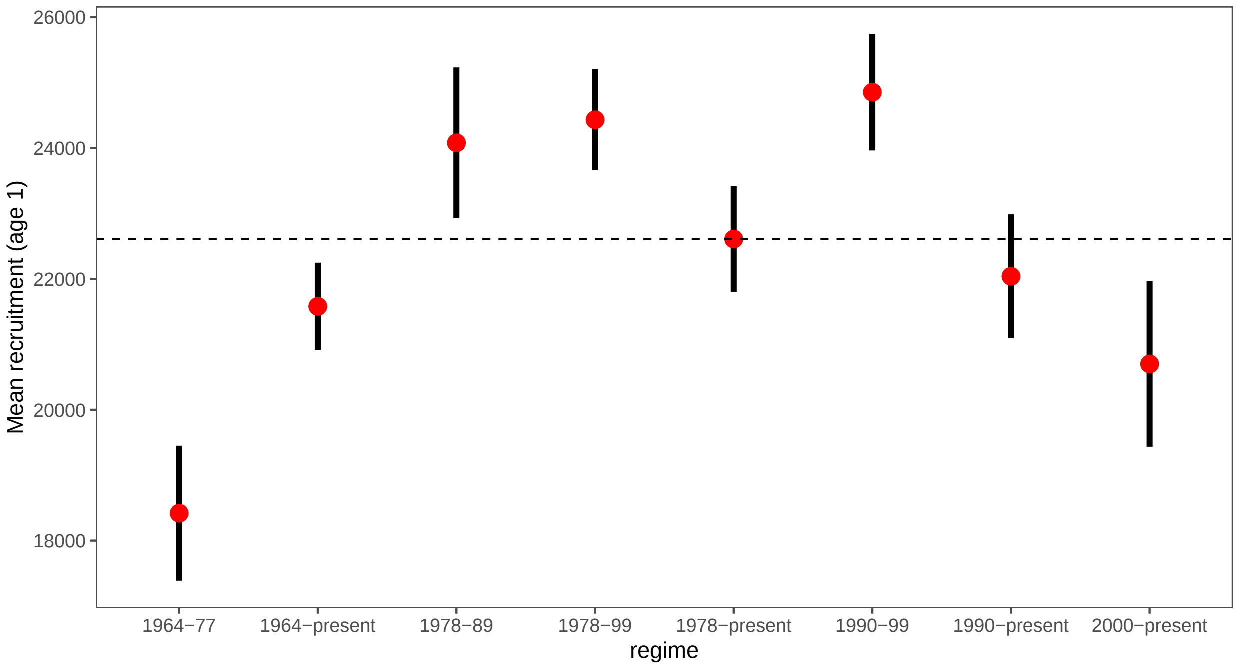

Figure 1-45. Mean recruitment estimates (age-1) for EBS pollock for different periods with error bars representing 95% credible intervals.

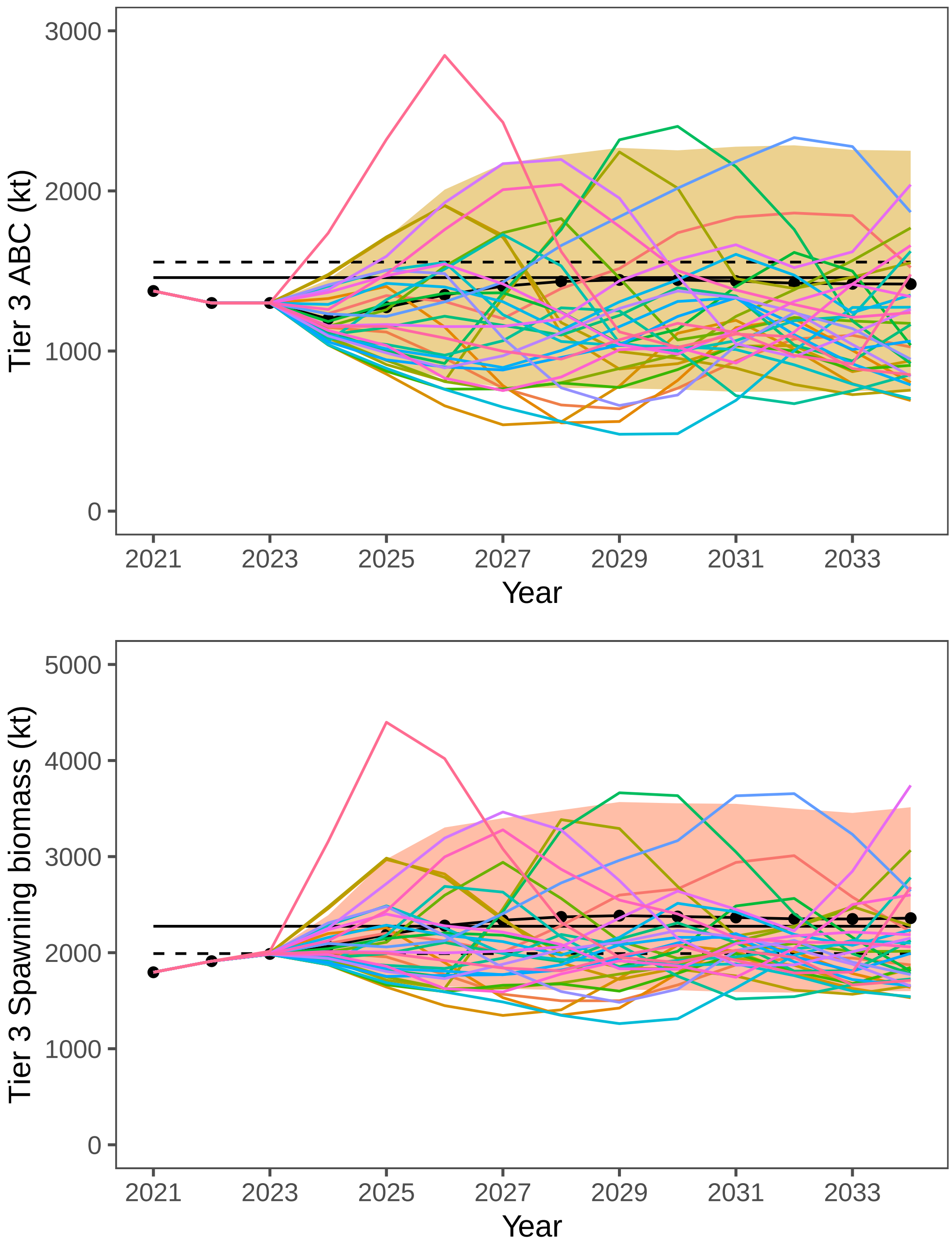

Figure 1-46. Projected EBS Tier 3 pollock yield (top) and female spawning biomass (bottom) relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines). $B_{40\%}$ is computed from average recruitment from 1978–2017. Future harvest rates follow the guidelines specified under Tier 3 Scenario 1.

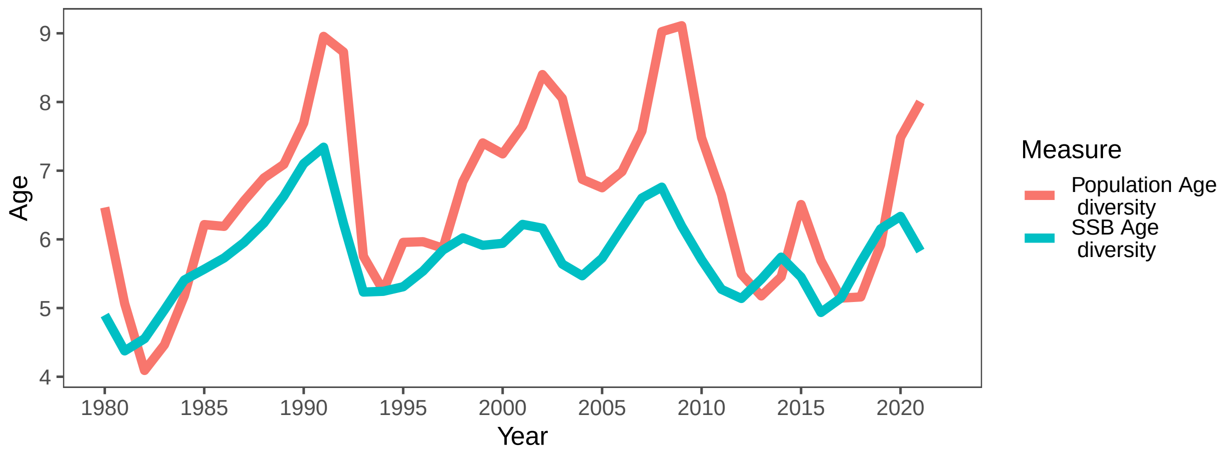

Figure 1-47. For the mature component of the EBS pollock stock, time series of estimated average age and diversity of ages (using the Shannon-Wiener H statistic), 1980–2021.

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:

$$
\begin{aligned}
C_{t,a} &= \frac{F_{t,a}}{Z_{t,a}}\left(1-e^{-Z_{t,a}}\right)N_{t,a}, & 1 \le t \le T, 1 \le a \le A \qquad (1)\\
N_{t+1,a+1} &= N_{t,a-1}e^{-Z_{t,a-1}} & 1 \le t \le T, 1 \le a < A \qquad (2)\\
N_{t+1,A} &= N_{t,A-1}e^{-Z_{t,A-1}} + N_{t,A}e^{-Z_{t,A}}, & 1 \le t \le T \qquad (3)\\
Z_{t,a} &= F_{t,a} + M_{t,a} & (4)\\
C_{t,.} &= \sum_{a=1}^{A} C_{t,a} & (5)\\
p_{t,a} &= \frac{C_{t,a}}{C_{t,.}} & (6)\\
Y_t &= \sum_{a=1}^{A} w_{t,a}C_{t,a} & (7)\\
& & (8)
\end{aligned}
$$

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):

$$
\begin{aligned}
F_{t,a} &= s_{t,a}\,\mu^f e^{\epsilon_t}, & \epsilon_t \sim \mathcal{N}(0,\,\sigma_E^2) \qquad (9)\\
s_{t+1,a} &= s_{t,a}\,e^{\gamma_t}, & \gamma_t \sim \mathcal{N}(0,\,\sigma_s^2) \qquad (10)
\end{aligned}
$$

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:

$$
\begin{aligned}
s_{t,a} &= \left[1 + e^{-\alpha_t a - \beta_t}\right]^{-1}, & a > 1 \qquad (11)\\
s_{t,a} &= \mu_s e^{-\delta_t^{\mu}}, & a = 1 \qquad (12)\\
\alpha_t &= \bar{\alpha} e^{\delta_t^{\alpha}}, & (13)\\
\beta_t &= \bar{\beta} e^{\delta_t^{\beta}}, & (14)
\end{aligned}
$$

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

$$
\begin{aligned}
\delta_t^{\mu} - \delta_{t+1}^{\mu} &\sim \mathcal{N}(0,\, \sigma^2_{\delta^{\mu}}) & (15)\\
& & (16)\\
\alpha_t^{\mu} - \alpha_{t+1}^{\mu} &\sim \mathcal{N}(0,\, \sigma^2_{\alpha^{\mu}}) & (17)\\
\beta_t^{\mu} - \beta_{t+1}^{\mu} &\sim \mathcal{N}(0,\, \sigma^2_{\beta^{\mu}}) & (18)
\end{aligned}
$$

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.

$$
\begin{aligned}
ln(s_{t,a}) - ln(s_{t+1,a}) &\sim \mathcal{N}(0,\, \sigma^2_{sel}) & (19)\\
& & (20)
\end{aligned}
$$

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 ($\hat{\bar{a}}_t$):

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

$$r_t^a = \bar{a}_t - \hat{\bar{a}}_t \tag{22}$$

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

where r_t^a is the residual of mean age and

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

$$\bar{a}_t = \sum_a^A a p_{ta} \tag{25}$$

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.

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

with mature spawning biomass during year t was defined as:

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

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:

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

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:

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

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:

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

$$\tag{47}$$

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:

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

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

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

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

$$\tag{54}$$

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} :

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

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

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

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

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

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. 48). Index values and error terms (based on diagonal of covariance matrix over time) are shown in Figure 49

Extending VAST to create estimates from acoustic backscatter data

In 2020 we presented an initial spatio-temporal model to the acoustic backscatter data collected to half meter from the seafloor from RV Oscar Dyson (1994-2018) and the USV in 2020 following the same extrapolation area as for the BTS analyses. We anticipate updating this for application as an alternative to the standard acoustic survey in 2022.

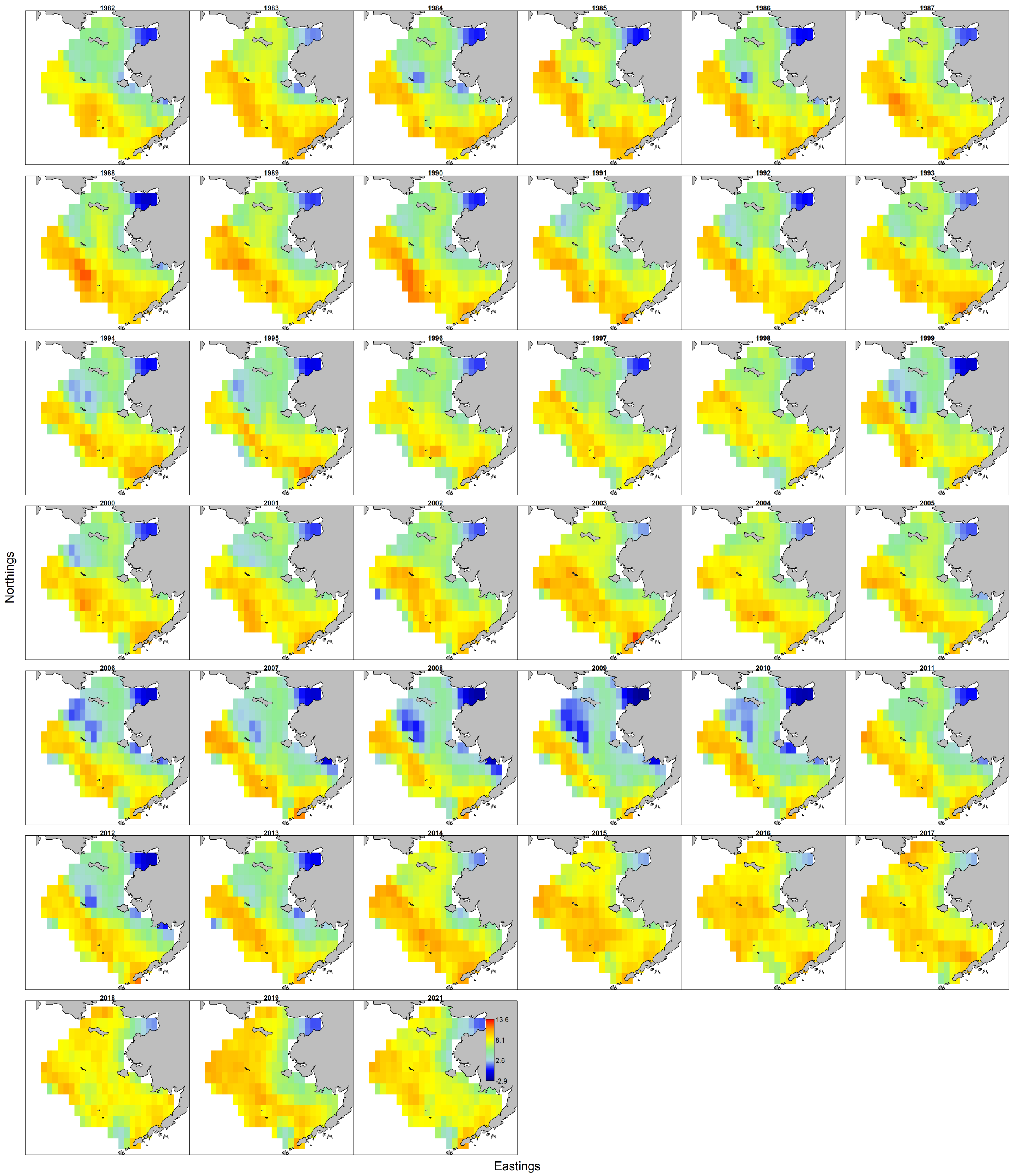

Figure 1-48. Pollock log density maps of the BTS data using the VAST model approach, 1982-2019,2021.

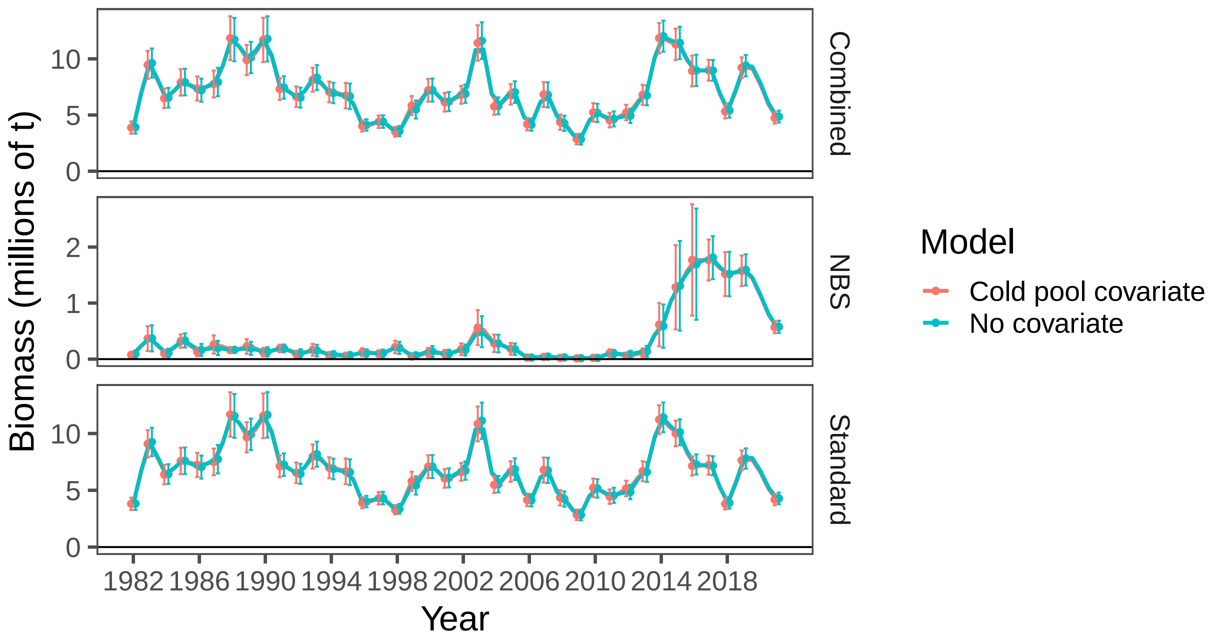

Figure 1-49. Pollock index values for the standard survey region, the NBS, and combined based on the VAST application to density-dependent corrected CPUE values from the BTS data, 1982–2019, 2021. The different lines are smoothed trends for with and without including the cold-pool extent as a covariate.

Additional references

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