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.

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.

Changes in the data

1. The 2019 NMFS bottom-trawl survey (BTS) biomass and abundance at age estimates were included.
2. The 2018 NMFS acoustic-trawl survey (ATS) age composition data were updated using samples from the ATS survey (in last year's assessment the age-length key was mainly composed of samples from the BTS)
3. The 2019 opportunistic acoustic data from vessels (AVO) conducting the bottom trawl survey was used as an added index of pollock biomass in mid- water.
4. Observer data for catch-at-age and average weight-at-age from the 2018 fishery were finalized and included.
5. Total catch as reported by NMFS Alaska Regional office was updated and included through 2019.

Changes in the assessment methods

There were some minor changes to the assessment model. We added the facility to incorporate a full time and age varying matrix of natural mortality rates to be specified (previously we used a time-constant vector of natural-mortality-at-age). This was done to provide an alternative evaluation of the output from the multi-species trophic model (CEATTLE; this volume). Also, new information is becoming available on the relative availability of pollock to our bottom trawl survey gear. To make comparisons, we added control over the way selectivity in that survey impacts the relative "catchability" for key age groups. The control allows an approach to approximate the relative amount of process error to allow for selectivity changes (previously, the process error variance was specified through the ascending logistic parameters). This allowed us to compare results from an availability study that is presently being completed.

We continued to refine treatment of survey data via spatial-temporal models for creating an alternative index including the broader region of the northern Bering Sea. Additionally, we applied the VAST model to age-specific data to derive alternative estimates of age composition data for the bottom-trawl survey. Preliminary results from applying spatial smoothers to the acoustic index was also provided as a sensitivity.

Summary of EBS pollock results

The following table applies for Model 16.1, the model used for last year's assessment advice. An alternative table is provided for this same model but uses the VAST-treated survey data and includes the Northern Bering Sea is provided at the end of this draft. Here, the ABC recommendation reflects the Tier 3 estimate.

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2019	2020	2020	2021
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)	9,110,000 t	8,156,000 t	8,580,000 t	7,990,000 t
Projected female spawning biomass (t)	3,107,000 t	2,725,000 t	2,781,000 t	2,476,000 t
B_0	5,866,000 t	5,866,000 t	5,748,000 t	5,748,000 t
B_{msy}	2,280,000 t	2,280,000 t	2,147,000 t	2,147,000 t
F_{OFL}	0.645	0.645	0.528	0.528
$maxF_{ABC}$	0.510	0.51	0.442	0.442
F_{ABC}	0.356	0.375	0.253	0.262
OFL	3,913,000 t	3,082,000 t	4,273,000 t	3,458,000 t
$maxABC$	3,096,000 t	2,437,000 t	3,578,000 t	2,895,000 t
ABC	2,163,000 t	1,792,000 t	2,045,000 t	1,716,000 t
Status	2017	2018	2018	2019
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

The SSC recommends that one additional column be added to include concerns related to fishery/resource-use performance and behavior, considering commercial as well as local/traditional knowledge for a broader set of observations. This additional column should not include socio-economic considerations, but rather indications of concern such as inability to catch the TAC, or dramatic changes in spatial or temporal distribution that could indicate anomalous biological conditions. The SSC requests that all authors fill out the risk table in 2019, and that the PTs provide comment on the author's results in any cases where a reduction to the ABC may be warranted (concern levels 2-4).

- *The risk table was again included, this year with the requested additional column on fishery performance*

The Plan Team noted that if the survey index is going to include the NBS, then inclusion of the NBS in compositional data should also be explored (although this should not make much of a difference since the size compositions in the EBS and NBS are sufficiently similar)

- *A model run with VAST processed age composition data was included and compared with the survey standard estimates.*

Conduct a sensitivity test of the VAST index, with environmental covariates, by omitting one or two years of NBS data at a time.

- *Thanks to the work of Thorson 2019 we were able to evaluate an index that included the extent of the cold pool as a covariate. Comparisons of index fitting out of sample as suggested has been done for several of the publications using VAST*

Regarding the apparent shift in year class dominance between 2012 and 2013, the possibility of a shift in mean length at age should be explored, as should the possible influence of ageing error

- *Age determination experts re-examined subsets of these data and age estimates seems to be consistent and correct.*

Full treatment of both the existing model and models with alternative treatments of the data should continue to be provided, along with maxABC values under Tier 3 for all models.

- *Summary tables for alternative treatments of data including Tier 3 are provided.*

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

- *Due to staffing issues, including the government shutdown, this was given low priority over other work.*

Explore “A” season trends in mean weight at length with a GAM or similar technique, to determine if the trends are either predominantly environmental or predominantly fishery-driven, Regarding σ_R, explore alternative fixed values or estimation methods.

- *Trends in mean weight given length are again presented. The extent that fishery affects this pattern was shown to be related to timing. Further work is needed to establish a mean baseline (in time and space) to try to sort out environmental effects hypotheses. Values of* σ_R *were explored in previous years, no further work was done on this in 2019.*

We included an expanded evaluation of fishery performance this year. Specifically, we examined the spatial pattern of the fishery and developed a statistic of dispersion of individual tows

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. (2016) 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

Data from the survey work in the Northern Bering Sea (NBS) region (north of Nunivak Island to the Russian convention line and into Norton Sound) from 2017 and 2018, as shown below and evaluated in the appendix, suggests that there are concentrations of pollock present which contrasts with the 2010 survey when relatively few pollock were present. The pattern of temperatures in the region likely affect the pollock distribution in ways that likely vary over time. However, there is evidence of a relationship between mean bottom temperatures in the US zone on the EBS shelf and subsequent biomass estimates in the Navarin basin (the Russian area adjacent to the Convention Line; e.g., Stepanenko and Gritsay 2018, Ianelli et al. 2015). Some genetic samples were taken from pollock and collections continue. Pending funding availability, analysis of these samples could help ascertain the extent that these fish are related to those observed in the normal EBS shelf survey area. Genetic samples taken from the 2017 summer bottom trawl survey from the Northern Bering Sea can be compared with samples from the standard Bering Sea Unimak, Pribilof, Bogoslof, and Zhemchug. This planned study should help improve stock structure evaluation (last done in Ianelli et al. 2015).

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 1987 they were able to take 99% of the quota. Since 1988, U.S. flagged vessels have been operating in this fishery. The current observer program for the domestic fishery formally began in 1991 and prior to that, observers were deployed aboard the foreign vessels 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., ABCs and TACs) are shown in Table 2.

Catch patterns

The "A-season" for directed EBS pollock fishing opens on January 20th and fishing typically extends into early-mid April. During this season the fishery targets pre-spawning pollock and produces pollock roe that, under optimal conditions, can comprise over 4% of the catch in weight. The summer, or "B-season" presently opens on June 10th and fishing extends through noon on November 1st. The A-season fishery concentrates primarily north and west of Unimak Island depending on ice conditions and fish distribution. There has also been effort along the 100m depth contour (and deeper) between Unimak Island and the Pribilof Islands. The general pattern by season (and area) has varied over time with recent B-season catches occurring in the southeast portion of the shelf (east of 170°W longitude; Fig. 1). Since 2011, regulations and industry-based measures to reduce Chinook salmon bycatch have affected the spatial distribution of the fishery and to some degree, the way individual vessel operators fish (Stram and Ianelli, 2014).

The catch estimates by sex for the seasons indicate that over time, the number of males and females has been fairly equal (Fig. 2). The 2019 A-season fishery spatial pattern had relatively high concentrations of fishing on the shelf north of Unimak Island and extended along the 200m depth contour (Fig. 3). The 2019 A-season catch rates was very high improving even on the good conditions observed in other recent A seasons (Fig. 4). 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. 5). While an important product from the winter fishery is the sale of pollock roe, production during the B-season is consistently about 10% of the annual production (Fig. 6).

The fishing in summer-fall 2019 was quite different than recent years with fishing much more broadly distributed and concentrated along the shelf break. Catches in the northwestern continued to increase relative 2017 and 2918 (Fig. 7).
The 2019 summer and fall (B-season) catch per hour fished was lower than the last few years (Fig. 8). Since 1979 the catch of EBS pollock has averaged 1.19 million t with the lowest catches occurring in 2009 and 2010 when the limits were set to 0.81 million t due to stock declines (Table 2). Pollock retained and discarded catch (based on NMFS observer estimates) in the Eastern Bering Sea and Aleutian Islands for 1991–2019 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.

As noted above, the 2019 B-season suggested that the fishery was dispersed and experienced relatively low catch rates compared to recent years. Also, an approach to computing fleet dispersion (the relative distance or spread of the fishery in space) was developed and indicated that while the A-season was the most intensely concentrated for the fleet during this season (since 2000), the B-season indicated the most dispersed fishing activity over the same period (Fig 9).

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 in 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 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 within the SCA varies and has ranged from an annual low of 11% in 2010 to high of 60% in 1998–the 2019 annual value was 58% but and quite high again in the A-season (68%; Table 4). The higher values in recent years were likely due to good fishing conditions close to the main port.

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. 3).

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 Fig. 5). These measures are all part of Amendment 110 and a summary of this and other key management measures is provided in Table 5.

Economic conditions as of 2018

Alaska pollock is the dominant species in terms of catch in the Bering Sea & Aleutian Island (BSAI) region. In 2018 pollock accounted for 70% of the BSAI's FMP groundfish harvest and 90% of the total pollock harvest in Alaska. Retained catch of pollock increased 1.5% to 1.38 million t in 2018 (Table 6). BSAI pollock first-wholesale value was $1.38 billion 2018, which was 3% increase from 2017 and above the 2005–2007 average of $1.25 billion (Table 7). The higher revenues in recent years is the combined effect of strong catch and production levels and a steady increase in the average first-wholesale price between 2016 and 2017. The increases in the average first-wholesale price of pollock products in 2016 and 2017 were largely due to increases the price of surimi products while the price increase in 2018 was largely due to an increase in the price of fillets.

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,[1] which, among other things, established a proportional allocation of the total allowable catch (TAC) among vessels in sectors which were allowed to form into cooperatives.[2]

Prior to 2008 pollock catches were high at approximately 1.4 million t in the BSAI for an extended period (Table 6). The U.S. accounted for over 50% of the global pollock catch (Table 8). Between 2008–2010 conservation reductions in the pollock total allowable catch (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 (Table 8). 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%. Russia lacks the primary processing capacity of the U.S. and much of their catch is exported to China and is re-processed as twice-frozen fillets. 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.[3] 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, particularly the Dollar-Yen and Dollar-Euro.[4] 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.

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 7). 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

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

[2] 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%).

[3] 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.

[4] Aggregate exports in Table 8 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.

warm-water species increased (as has pollock). A relatively small fraction of pollock caught in Russian waters is processed as surimi. 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 increased 1% to 718 kt. The value of these deliveries (shore-based ex-vessel value) totaled $236.7 million in 2018, which was up 15% from the ex-vessel value in 2017 driven mostly by a 14% increase in the ex-vessel price (Table 6). The first-wholesale value of pollock products was $811 million for the at-sea sector and $568 million for the shore-based sector (Table 7). The higher revenue in recent years is largely the result of increased catch levels as the average price of pollock products has declined since peaking in 2008–2010 and since 2013 has been close to the 2005–2007 average, though this varies across products types. The average price of pollock products in 2018 decreased for the at-sea sector and increased for the shore-based sectors. The increase in the at-sea sector revenues was largely due to an increase in surimi prices. Fillet product prices increased 6.5% in 2018. Roe prices also increased slightly however they remain low relative to levels roughly a decade ago.

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 7). The price of products produced at-sea tend to be higher than comparable products produced by the shore-based because of the shorter time span between catch, processing and freezing. Since 2014 the price of fillets produced at-sea tend to be about 10% higher, surimi prices tend to be about 30% 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 $0.30 per pound between 2005–2010 but has decreased to an average of $0.25 per pound between 2014–2018, in part, because the shore-based sector increased their relative share of surimi production.[5]

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. Deep-skin fillet's share of production decreased to 34% in 2018. Total fillet production increased 7% to 168 kt in 2018, but since 2010 has increased with aggregate production and catch and has been higher than the 2005–2007 average (Table 7). The average price of fillet products in the BSAI increased 7% to $1.37 per pound and is below the inflation adjusted average price of fillets in 2005–2007 of $1.49 per pound (2017 dollars). Media reports indicate that headed-and-gutted (H&G) and fillet prices tended to be strong throughout much of 2018 relative to 2017. Pollock fillets sourced from Russia are the direct competitor to Alaska sourced pollock fillets. Fillets were a relatively small portion of Russian primary production however, they plan to upgrade their fillet production capacity. Much of the 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. Approximately 30%

[5] 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.

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 2016).[6] As pollock markets in recent years have become increasingly tight, the industry has tried to maintain value 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. Reductions in whitefish supplies in 2018 may have put upward pressure on pollock fillet prices.

Surimi seafood

Surimi production in 2018 was 196.5 kt, which was approximately the same as 2017 and was above the 2005–2007 average. Prices which have been rising since 2013, decrased 3% to $1.26 per pound in the BSAI in 2018 (Table 7). 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. Additionally, the supply of raw surimi material in Japan has been limited.

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 tapered off in the late–2000s and since has generally fluctuated at under or near 20 kt annually. Production averaged 27 kt in 2005–2007 and was 20.6 kt in 2018, which was up 12% from 2017 (Fig. 6). Prices peaked in the mid-2000s and have followed a decreasing trend over the last decade which continued until 2015. The Yen to U.S. Dollar exchange rate can influence prices and relatively stable through 2018 relative to 2017. The average roe price in the BSAI was up 0.5% in 2018 to $2.89 per pound, and value rose 12% with the increase in production to $132 million (Table 7).

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 9). 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 remained stable in 2018.

Data

The following lists the data used in this assessment:

[6] 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.

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

Fishery

Catch

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 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 1991–2018 (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. 10; Table 10). The sampling effort for age determinations, weight-length measurements, and length frequencies is shown in Tables 11, 12, and 13. 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 (1963–2018) from NMFS surveys in the Bering Sea and Aleutian Islands Region are given in (Table 14). 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 2018 the BTS biomass estimates ranged from 2.28 to 8.39 million t (Table 15; Fig. 11). 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. These surveys 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. 12).

Beginning in 1987 NMFS expanded the standard survey area farther to the northwest. The pollock biomass levels found in the two northern strata in 2019 was 9%–considerably more than the 4.3% average for the four previous survey years and the long-term average of 5% (Table 15). In some years (e.g., 1997 and 1998) some stations had high catches of pollock in that region and this resulted in high estimates of sampling uncertainty (CVs of 95% and 65% for 1997 and 1998 respectively). This region is contiguous with the Russian border and the NBS region, and measures to increase consideration of those regions relative to exploited pollock stock continues.

The 2019 bottom-trawl survey biomass estimate (design-based, area swept) was 5.48 million t, above the average for this survey (4.7 million t). This is a substantial increase over the 3.11 million t estimated from the 2018 estimates. Both years were unusual in that there was a near-complete lack of cold water on the bottom throughout the survey area (Fig. 13). Pollock appeared to be distributed more broadly over the shelf in 2019, different than in 2017 and 2018 where fish were more concentrated (Fig. 14).

The BTS abundance-at-age estimates show variability in year-class strengths with substantial consistency over time (Fig. 15). 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). Age 2 or 3 pollock (lengths around 20–29 cm and 30–39 cm, respectively) are relatively rare in this survey presumably because they are more pelagic as juveniles. 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 2019 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 16). The estimated numbers-at- age from the BTS for strata (1–9 except for 1982–84 and 1986, when only strata 1–6 were surveyed) are presented in Table 17 (based on the method in Kotwicki et al. 2014). Mean body mass at ages from the survey are shown in (Table 18) and the different alternative time series of BTS survey indices is shown in Table 19.

The bottom trawl survey has extended to the north in 2010, 2017, 2018 (limited to 49 stations) 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 19). 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. Application of this index within the stock assessment model requires accounting for the temporal covariation. Since this has been part of the assessment for the time series of biomass used in past years, including the covariance specification was simple to implement and required no changes to the assessment model code.

Acoustic trawl (AT) surveys

The AT surveys are conducted biennially 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 20). Estimated pollock biomass (to 3m from bottom) for the shelf was above 4 million tons in the early years of the time series (Table 19). It dipped below 2 million t in 1991. Since 1994, the years for which AT survey estimates are available to within 0.5 m of bottom, the biomass increased and remained between about 3 and 4.5 million t for a decade (1994–2004). 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 (the '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 (Tables 19 and 21).

Relative estimation errors for the total biomass were derived from a one- dimensional (1D) geostatistical method, and accounts for observed spatial structure for sampling along transects (Table 21; 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 25% for application within the assessment model. In 2018 we estimated the 2018 EBS acoustic-trawl survey population numbers-at-age based primarily on the BT survey age samples with supplemental samples from the AT survey. In 2019 those data were updated using only the 2018 ATS age samples (Fig. 16; Table 22).

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)

The details of how acoustic backscatter data from the two commercial fishing vessels chartered for the eastern Bering Sea bottom trawl survey (BTS) were used to compute a midwater abundance index for pollock can be found in Honkalehto et al. (2011). We updated the data through 2019 and after a gradual decline since 2015, the biomass was about the same as from 2018 (Table 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 1964–2019. A technical description is presented in the Model Details section attached. The analysis was first introduced in the 1996 SAFE report and compared to the cohort analyses that had been used previously and was document Ianelli and Fournier 1998). The model was implemented using automatic differentiation software developed as a set of libraries under the C++ language ("ADMB," Fournier et al. 2012). The data updated from last year's analyses include:

- The 2019 EBS bottom trawl survey estimates of population numbers-at- age and biomass were added
- The 2019 AVO acoustic backscatter data (as collected from the EBS bottom trawl survey vessels) as a biomass index was added
- The 2019 EBS acoustic-trawl survey estimates of population numbers-at- age were updated
- The 2018 fishery age composition data were added
- The catch biomass estimates were updated through to the current year

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

Model configuration options continue to be developed for alternative data treatment. 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 application included a spatio-temporal treatment of the age composition data; differences were relatively minor compared to the standard design-based expansion of ages (Fig. 17).

A second data treatment also included the application of VAST in which the cold pool extent (CPE) was modeled as a covariate (Thorson 2019b). Comparisons of this effect were relatively minor (e.g., Fig. 66).

A third treatment included a preliminary evaluation of spatio-temporal smoothing from the ATS data (index value differences shown in Table 19).

Input sample size

Sample sizes assumed 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 intermediate and earliest period (Table 24). 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 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 16.1 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 based on earlier work of Wespestad and Terry 1984). These values have been applied to catch-age models and forecasts since 1982 and appear reasonable for pollock. When predation was explicitly considered estimates tend to be higher and more variable (Holsman et al. 2015; Livingston and Methot 1998; Hollowed et al. 2000). Clark (1999) noted 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 2014 assessment different natural mortality vectors were evaluated in which the "Lorenzen" approach and that of Gislason et al (2010) were tested. The values assumed for pollock natural mortality-at-age and maturity-at-age (for all models; Smith 1981) consistent with previous assessments were:

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

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

here. In last year's evaluation of natural mortality 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 above).

Maturity-at-age values used for the EBS pollock assessment are originally based on Smith (1981) and were 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 current assumed schedule of proportion mature at age.

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., 2018 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, these estimates can have large impacts on recommendations (e.g., ABC and OFL).

The mean weight at age in the fishery can vary due to environmental conditions in addition to spatial and temporal patterns of the fishery. Bootstrap distributions of the within-year sampling variability indicate it is relatively small compared to between-year variability in mean weights-at-age. This implies that processes determining mean weights in the fishery cause more variability than sampling (Table 25). 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. 19). 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 (and uncertainty) for 2019–2021 (Table 25). The changes in weight-at-age in the fishery can be substantial, especially for the apparent abundant year-classes (e.g., the 3–6 year-olds from 2015–2018 representing the 2012 year class; Fig. 19). 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. 20) and Fig. 21).

Extensive fishery observer data were available for examining patterns in length-weight condition (standardized for length over all years and areas, 1991–2018). The process for these data were:

1. extract 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. compute the mean value of body mass (weight) for each cm length bin over all areas and time
3. divide each weight measurement by that mean cm-specific value (the "standardization" step)
4. plot 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. 22). As the summer/fall progresses, fish were at their heaviest given length (Fig. 22). 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. 23. Last year we highlighted a concern of relatively poor condition (skinniness) of the A-season. However, as can be seen in Fig. 23, the 2019 weight given length for A-season fish improved.

Parameters estimated within the assessment model

For the selected model, 952 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 1964–2018 and projected recruitment variability (using the variance of past recruitments) for five years (2020–2025). 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 1978 year-class through to the 2017 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 56 parameters and the age-time selectivity schedule forms a 10x56 matrix of 560 parameters bringing the total fishing mortality parameters to 616. The rationale for including time- varying selectivity has recently been supported as a means to improve retrospective patterns (Szuwalski, Ianelli, and Punt 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. For the AT survey, which originally began in 1979 (the current series including data down to 0.5m 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. 11 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 of 0.20; while for the AVO data, a value relative to the AT index was estimated and gave a mean of about 0.25).
- Fishery and survey proportions-at-age estimates (multinomial with effective sample sizes presented Table 24).
- 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 1991-2018 from the fishery (and 1982-2019 for the bottom-trawl survey data) and externally estimated variance terms as described in Appendix 1A of Ianelli et al. (2016).

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 2018 fishery catch-at-age data and the 2019 catch biomass information was relatively uninformative with respect to spawning biomass estimates (Fig. 24). As the bottom trawl survey data was added to the model, the biomass estimate dropped lower (Fig. 24). We evaluated a number of different assessment configurations and present the following:

0. Last year's model ("Model 16.1") without any data update (only for comparison purposes)
1. The same as last year but with all data time series updated through the most recently available information
2. With Model 16.1 we evaluated the variability of the effective catchability of the bottom trawl survey for ages 3-8, the age range over which selectivity is allowed to vary. This pattern (and extent of variability) was compared with new independent analysis specifically dealing with the spatio-temporal patterns in 3 dimensions.
   - This work provides new evidence on the extent of variability in effective catchability for the different survey gears used for assessing pollock.
3. The same as last year but with the survey time series including an alternative treatment of the NBS indicative biomass (application of the VAST model for the bottom trawl survey index). This step included the revised VAST derived age compositions (Fig. 17).
   - The rationale for considering this is the likelihood that pollock in the NBS are related and contribute to the EBS fishery
4. As with 3 but based Thorson's (2019) evaluation of including the cold pool extent as a covariate in creating an index.
5. As with option 3 above including a preliminary treatment of using a spatio-temporal model on just the acoustic-trawl survey data.

The reference model (Model 16.1) differed from models with different data treatments. The recruitment and spawning biomass estimates were generally higher compared to last year, and higher with the new data treatments, (Fig. 25). The recent recruitment pattern (at age 1) shows an increase in the 2014 value (representing the 2013 year-class) and a decline in the 2013 estimate (the 2012 year-class; Fig. 26). Diagnostics of model fits between the set evaluated are given in Table 27 and comparisons of management quantities are given in Table 28).

The BTS and ATS sample from distinct overlapping subsets of the water column: the BT covers from bottom to midwater, and AT from midwater to surface. The proportion of fish available to each gear type depends on their vertical distribution, which varies in space and time. In the current and past assessments, this uncertainty counted as a type of process error (but with somewhat subjective approach to specifying the degree of variability allowed). A new method under development (Monnahan et al. in prep) that explicitly models the vertical distribution of fish in discrete, spatially-correlated depth strata. This model accounts for vertically-overlapping gears and is informed by both acoustic and bottom trawl data sets simultaneously. These capabilities were added to the spatio-temporal standardization software VAST (Thorson 2019) which provides a convenient analysis platform and allows inclusion of temporal smoothing and environmental covariates, among other features. Spatial patterns of pollock density for some selected years are shown in Fig. 28 and the relative availability to the gear types is shown in Fig. 29). As the results become available, a model configuration using the combined index will be meshed as a direct alternative survey data series fitting (e.g., by explicitly modeling survey availability).

This new study prompted an evaluation of the degree to which BTS selectivity (and effectively, catchability/availability) is allowed to vary over time. As before, the two parameters governing the ascending slope and age at 50% selected were modeled as random walk processes with a penalty (or prior constraint) specified to balance fitting composition and trend data from all sources reasonably. Profiling on the selectivity change constraint showed that, as parameterized via logistic parameters, a relatively high process error variance term (low penalty) still indicated that the model was not overfitting different data components (e.g., the standard deviation of the normalized residuals (SDNR) scores are near 1.0 and not below (which would indicate over-fitting; Table 26.). This provided some objective justification for this specification and is illustrated with the availability study (30.). The impact of the assumption to allow effective catchability to vary appears to be conservative, with more constraining selectivity changes resulting in higher spawning stock biomass estimates (Fig. 30.).

The fit to the early Japanese fishery CPUE data (Low and Ikeda 1980) was consistent with the estimated population trends for this period (Fig. 33). The model fits the fishery- independent index from the 2006–2019 AVO data well indicating a downward trend since 2015 but stabilizing compared to 2018 values (Fig. 34). The fits to the bottom-trawl survey biomass (the density-dependent corrected series) were reasonable (Fig. 35). Similarly, the fits to the acoustic-trawl survey biomass series was consistent with the specified observation uncertainty (Fig. 32).

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

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

Bottom-trawl survey selectivity (Fig. 39) and fits to the pollock biomass index indicate that the model predicts fewer pollock than observed in the 2014 and 2015 survey but slightly more than observed in the since then (Fig. 35). The pattern of bottom trawl survey age composition data in recent years shows a decline in the abundance of older pollock since 2011. The 2006 year-class observations are below model expectations in 2012 and 2013, partly due to the fact that in 2010 the survey estimates are greater than the model predictions (Fig. 40). The model predicted much higher proportions of age 6 (2012 year class) than observed in the 2018 survey data whereas the expectations of 5-year old pollock was much lower than observations (both surveys indicated that the 2013 year class was more abundant than the 2012 year-class).

The fit to the ATS biomass index survey generally falls within the confidence bounds of the survey sampling distributions (here assumed to have an average CV of 25%) with a reasonable pattern of residuals (Fig. 32). The AT age compositions consistently track large year classes through the population and the model fits these patterns reasonably well (Fig. 41).

As in past assessments, 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). A pairwise comparison for some key parameters could be evaluated (along with their marginal distributions; Fig. 42). To compare the point estimates (highest posterior density) with the mean of the posterior marginal distribution, overplotting the former on the latter for the 2019 spawning biomass estimate were similar (Fig. 43).

Time series results

The time series of begin-year biomass estimates (ages 3 and older) suggests that the abundance of Eastern Bering Sea pollock remained at a high level from 1982–88, with estimates ranging from 8 to 11 million t (Table 29). 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 new highs over 13 million t in 2016 following the low in 2008 of 4.68 million t. The estimate for 2019 is trending downward and at 9.33 million t. with 2020 estimated at round(M$age3plus1)/1000,2)‘ million t.

The level of fishing relative to biomass estimates show 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. 44). During 2006 and 2007 the rate averaged more than 20% and the average fishing mortality for ages 3–8 increased during the period of stock decline. The estimate for 2009 through 2019 was below 20% due to the reductions in TACs relative to the maximum permissible ABC values and increases in the spawning biomass. The average F (ages 3–8) increased in 2011 to above 0.25 when the TAC increased but has dropped since then and in 2019 is estimated at about 17%. Age specific fishing mortality rates reflect these patterns and show some increases in the oldest ages from 2011–2013 but also indicate a decline in recent years (Fig. 45). Last year’s estimates of age 3+ pollock biomass were similar to the estimates (Fig. 46, Table 29).

Estimated numbers-at-age are presented in (Table 30) and estimated catch-at-age values are presented in (Table 31). Estimated summary biomass (age 3+), female spawning biomass, and age-1 recruitment are given in (Table 32). To compare these estimates with mean values, and to show the relative age composition of the population, Fig. 59 shows the diminishing impact of the strong 2012 and 2013 year-classes in 2019 and 2020. Applying the weights-at-age estimates and accumulating over ages shows that by 2020, the biomass will be below-average (Fig. 48) and spawning biomass will trend downwards (Fig. 48).

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. 49). Projections of spawning stock biomass given the 2020 estimate of fishing mortality rate given catches equal to the 2019 values shows a decline through 2021 and then an increase after; albeit with considerable uncertainty due to uncertainty in recruitment (Fig. 50).

Recruitment

Model estimates indicate that the 2008, 2012, and 2013 year classes are above average (Fig. 51). The stock-recruitment curve as fit within the integrated model shows a fair amount of variability both in the estimated recruitments and in the uncertainty of the curve (Fig. 52). Note that the 2015 and 2016 year classes (as age 1 recruits in 2016 and 2017) are 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. 53).

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.

Retrospective analysis

Running the assessment model over a grid with progressively fewer years included (going back to 20 years, i.e., assuming the data extent ended in 1999) results in a fair amount of variability in both spawning biomass and recruitment (Fig. 54) Although the variability is high, the average bias appears to be low with Mohns ρ equal to 0.059 for the 10 year retrospective and 0.104 if extended back 20-years.

Harvest recommendations

Status summary

The estimate of B_{MSY} is 2,147 kt (with a CV of 25%) which is less than the projected 2020 spawning biomass of 2,800 kt; (Table 33). For 2019, the Tier 1 levels of yield are 3,578,000 t from a fishable biomass estimated at around 8,088 kt (Table 34; about 130% of the B_{MSY} level). A diagnostic (see section below on model details) on the impact of fishing shows that the 2019 spawning stock size is about 60% of the predicted value had no fishing occurred since 1978 (Table 33). This compares with the 52% of B_{100}% (based on the SPR expansion using mean recruitment from 1978–2016) and 150% of B_{MSY} (based on the estimated stock-recruitment curve). The latter two values are based on expected recruitment from the mean value since 1978 or from the estimated stock recruitment relationship.

Relative to Tier 3 indicators, the model indicates that spawning biomass will be above $B_{40\%}$ (2,800 kt) in 2020. 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 2020 and 2021.

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, their reliability is questionable. We therefore present both reference points for pollock in the BSAI to retain the option for classification in either Tier 1 or Tier 3 of 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:

B_{MSY} = 2,147 kt female spawning biomass
B_0 = 5,748 kt female spawning biomass
$B_{100\%}$ = 6,165 kt female spawning biomass
$B_{40\%}$ = 2,466 kt female spawning biomass
$B_{35\%}$ = 2,158 kt female spawning biomass

Specification of OFL and Maximum Permissible ABC

Assuming the stock-recruit relationship the 2020 spawning biomass is estimated to be 2,781,000 t (at the time of spawning, assuming the stock is fished at about recent catch levels). This is above the B_{MSY} value of 2,147,000 t. Under Amendment 56, this stock has qualified under Tier 1 and the harmonic mean value is considered a risk-averse policy since reliable estimates of F_{MSY} and its pdf are available (Thompson 1996). The exploitation- rate type value that corresponds to the F_{MSY} level was applied to the fishable biomass for computing ABC levels. 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 (normalized to the value at age 6) and mean body mass. 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.

Since the 2020 female spawning biomass is estimated to be above the B_{MSY} level (2,147 kt) and the $B_{40\%}$ value (2,466 kt) in 2020 and if the 2019 catch is as specified above, then the OFL and maximum permissible ABC values by the different Tiers would be:

Tier	Year	MaxABC	OFL
1a	2020	3,578,000	4,273,000
1a	2021	2,895,000	3,458,000
3a	2020	2,045,000	2,539,000
3a	2021	1,716,000	2,098,000

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 2019 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2020 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year- end) catch assumed for 2019. 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 2020, 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 2020 and 2021 the catch is set equal to 1.35 million t and in future years F is set equal to the Tier 3 estimate (Rationale: this was has been about equal to the catch level in recent years).

Scenario 3: In all future years, F is set equal to the 2018 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: 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: 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 2019 or 2) below half of its MSY level in 2019 or below its MSY level in 2029 under this scenario, then the stock is overfished.)

Scenario 7: In 2020 and 2021, 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 2021 or 2) below 1/2 of its MSY level in 2021 and expected to be below its MSY level in 2031 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 2019 (Tables 35 through 42 for Model 16.1 and for 16.2–the configuration that uses the NBS VAST data set). Under the catch set to Tier 3 ABC estimates, the expected spawning biomass will decline until 2020 and stabilize slightly above $B_{40\%}$ (in expectation, Fig. 55).

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 2019:

- If spawning biomass for 2019 is estimated to be below 1/2 $B_{35\%}$ the stock is below its MSST.
- If spawning biomass for 2019 is estimated to be above $B_{35\%}$, the stock is above its MSST.
- If spawning biomass for 2019 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 39 through 42). If the mean spawning biomass for 2029 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 2018 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.
- If the mean spawning biomass for 2018 is above $B_{35\%}$, the stock is not approaching an overfished condition.
- If the mean spawning biomass for 2021 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2028. If the mean spawning biomass for 2031 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 2019, and it is expected to be above the "overfished condition" based on Scenario 7 (the mean spawning biomass in 2019 is above the $B_{35\%}$ estimate; (Table 42). Based on this, the EBS pollock stock is being fished below the overfishing level and the stock size is estimated to be above, and stay above the overfished level.

ABC Recommendation

ABC levels are affected by estimates of F_{MSY} which depends 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 at above-average levels and projections indicate declines. Updated data and analysis result in an estimate of 2019 spawning biomass (3,220 kt) which is about 150% of B_{MSY} (2,147 kt). This follows a period of increases from 2008–2017 and is expected. The extent that the stock will decline further depends on recruitment, which is always uncertain. Some issues to consider in the medium-term are that

1. The conditions in summer 2019 were exceptional with another near absence of a "cold pool", very warm conditions on the inner part of the EBS shelf, and being a third consecutive year with significant abundances found outside of the standard survey area.
2. Recruitment since the 2013 year class is below average and this is expected to reduce spawning biomass below B_{MSY} by 2021.
3. The BTS data continue to show low abundances of pollock aged 10 and older (Table 17). Historically there had been good representation of older fish in data from this survey.
4. The multispecies model suggests that the B_{MSY} level is around 2.9 million t instead of the 2.1 million t estimated in the current assessment (noting that the total natural mortality is higher in the multispecies model).
5. Pollock are an important prey species for other species in the ecosystem and apparent changes in the distribution may shift their availability as prey.
6. Given the same estimated aggregate fishing effort in 2019, the estimated stock trend is downwards except at low catch levels. Furthermore, the ability to catch roughly the same amount as in 2019 through to 2022 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 matrix table below when determining whether to recommend an ABC lower than the maximum permissible.

	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 Substan-tially 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 three 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 workgroup):

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—adverse 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

Assessment considerations The EBS pollock assessment model appears to track the stock from year based on retrospective analysis (the pattern lacks tendency to over or under estimate the stock trend. The model tracks the available data well including multiple abundance indices. Of minor concern (presently) is the fact that the model estimate of declining abundance is somewhat less than that suggested by the survey data. The data and model appear to be consistent without big surprises relative to the ability to fit the information and provide a trade-off between process and observation errors (which combined, provide relatively high estimates of uncertainty). **We therefore rated the assessment-related concern as level 1, normal.**

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 and 2012 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. There also are clear density-dependent effects on growth, in particular, the 2012 year class. The stock is estimated to be well above B_{msy} at present, but projections indicate a decline given recent catch levels and future trends will depend on pollock survival at egg, larval, and juvenile stages which may be compromised given the lack of a cold pool and a considerable redistribution into the northern part of the Bering Sea. Recruitment in the near term could be below average yet projections assume average recruitment (with uncertainty). Additional age-specific aspects of the spawning population indicates that the stock has recovered somewhat from a low diversity of ages (for both the population and the mean age of the spawning stock weighted by spawning output Fig. 56). **We therefore rated the population-dynamic concern as level 2, a substantially increased concern.**

Environmental/Ecosystem considerations The winter of 2018/2019 began with near-average accumulation of sea ice in the Bering Sea during December and January, but warm moist winds from the southwest persisted throughout February and reduced sea ice extent to low levels (only 2018 was lower). Winter sea ice patterns and the resulting extent of the cold pool in summer were similar between 2018 and 2019 (Thoman in 2019 EBS ESR) due to these unusual wind patterns. Ecosystem indicators from 2018 may provide insights into 2019 conditions for pollock. In 2018, warm water temperatures and higher salinity north of St. Lawrence Island may have contributed to the northward movement of pollock into the northern Bering Sea (see Eisner et al. in 2019 EBS ESR). With warm conditions persisting through winter 2018/2019, pollock may have remained in the northern Bering Sea or moved along the shelf (north or south) early in the spring/summer of 2019. The 2018 year class apparently experienced favorable conditions between a cooler summer as age-0s (2018) followed by a warmer spring as age-1s in 2019 (see Yasumiishi in 2019 EBS ESR).

The 2018 year class was sampled using surface trawls in the southern and northern Bering Sea as age-0 in late summer 2018. Summer of 2018 was warm (above-average thermal conditions) and age-0 fish had low energy density across the shelf (see Siddon et al. and Sewall et al. 2019 EBS ESR). The mean size of the 2018 year class was average but their biomass index was below average (Whitehouse in 2019 EBS ESR). However, anomalous winds from the southwest during February 2019 may have bolstered productivity over the shelf, sustained metabolic demands, and subsidized overwinter survival of the 2018 year class of pollock.

The 2019 condition of juvenile (age-1) and adult pollock based on length-weight residuals was assessed in the southern and northern survey regions. Over the southern shelf, age-1 pollock have had positive length-weight residuals for the past 4 years while adult pollock had negative residuals in 2017-2018, but switched to positive residuals in 2019. The negative values are driven by fish sampled in the inner domain where unprecedentedly warm temperatures may have tested metabolic limits. Over the northern shelf, age-1 pollock had positive residuals (although less positive than 2018) while adult pollock continued negative residuals for the past 3 years (see Laman in 2019 EBS ESR). Over the southern shelf, abundance increased 53% while biomass increased 75%, indicating movement of adult fish back over the southern shelf. In the northern Bering Sea, abundance increased 59%, but biomass decreased 11%, indicating successful recruitment of younger age classes of pollock over the northern shelf.

Prey: 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 (principally *Thysanoessa inermis* and *T. raschii*). Pollock diets become more piscivorous with age and cannibalism is commonly observed.

The number of small copepods available to juvenile pollock across the shelf during spring 2019 was high compared to historical abundances and increased from spring to fall, indicating good foraging conditions for larval and juvenile pollock early in the year. However, the abundance of large (typically more lipid-rich) copepods was low overall (lower than in 2018). Although direct measurements of euphausiid abundances for both 2018 and 2019 indicate low abundances, age-0 fish diets from 2018 contained over 50% euphausiids, suggesting euphausiids may provide an alternative, lipid-rich prey source when large copepods are not as abundant. Indirect information on prey resources for pollock is discussed below under 'Competitors'.

Predators: Pollock are cannibalistic and rates of cannibalism might be expected to increase as the biomass of older, larger fish increases concurrent with increases in juvenile abundance. With the lack of a cold pool over the southern shelf or thermal barrier between the southern and northern shelves, spatial overlap and the potential for cannibalism are increased. Warmer waters also increase the metabolic demand and potentially increase foraging rates; the CEATTLE multispecies model indicates an increase in demand of individual predators, although total mortality is reduced relative to high levels in 2016 due to declines in abundance of older conspecifics and adult cod. Other predators of pollock include northern fur seals. At this time there are no indicators that suggest these populations are increasing in the eastern Bering Sea (although note that the Bogoslof Island population of northern fur seals is increasing while the Pribilof Islands populations are decreasing; see C. Kuhn 'Noteworthy' in the 2019 EBS ESR). Fur seal consumption of adult pollock generally increases in years when juvenile pollock are less abundant (Kuhn).

Competitors: While historical recruitment trends between Pacific cod and walleye pollock have mirrored each other, suggesting the species respond similarly to environmental conditions, the timeseries appear to decouple after approximately 2010 and may indicate broad-scale transitions in the southeastern Bering Sea ecosystem (e.g., from pelagic- to benthic-dominated production; Fig 58). The mechanisms driving early life history survival versus recruitment success of Pacific cod and walleye pollock may differ based on pelagic versus benthic habitat associations (e.g., prey availability). The decoupling of abundance timeseries after 2010 suggests a shift (or greater disparity) between drivers of survival in these two populations.

A widespread die-off event of short-tailed shearwaters began in the SEBS in June 2019 and extended into the NBS and Chukchi Sea in August. These events may reflect 2018 conditions as shearwaters feed in the Bering Sea in summer before migrating to the southern hemisphere for breeding during the winter. Most sampled birds showed signs of emaciation; shearwaters are planktivorous birds and feed on euphausiids.

The following are notes on ecosystem aspects that may affect the survival of recruits from the 2018 and 2019 year classes.

2018 year class:

- The 2018 year class experienced favorable conditions between a cooler summer as age-0s (2018) followed by a warmer spring as age-1s (2019);
- The 2018 year class of age-0 fish had low energy density across the shelf, average mean size, and below average biomass index;
- Anomalous winds from the southwest during February 2019 may have bolstered productivity over the shelf, sustained metabolic demands, and subsidized overwinter survival of the 2018 year class;
- The 2019 Shearwater die-off events could reflect feeding conditions (i.e., euphausiids) in the EBS in 2018.

2019 year class:

- Second winter of low sea ice extent in the eastern Bering Sea (only 2018 was lower);
- A small cold pool occurred in 2019 and may have impacted pollock movement and distribution;
- 2019 condition (length-weight residuals) of age-1 pollock was positive over the entire shelf; adult pollock condition was positive in the south, but negative in the north;
- Over the southern shelf, abundance increased 53% while biomass increased 75%, indicating movement of adult fish to the region;
- Over the northern shelf, abundance increased 59%, but biomass decreased 11%, indicating successful recruitment of younger age classes;
- Small copepod abundance was high, indicating good foraging conditions for larval and juvenile pollock early in the year;
- Large copepod abundance was low overall;
- Low abundances of euphausiids were observed in 2018 (MACE acoustic survey) and 2019 (RPA RZA), but age-0 fish diets from 2018 contained over 50% euphausiids;
- Lack of cold pool over the southern shelf and thermal barrier between the southern and northern shelves suggests spatial overlap and the potential for cannibalism are increased;
- the 2019 year class may experience higher rates of cannibalism due to adult biomass returning over the shelf (75% increase in 2019) and the apparent strong 2018 year class;
- Fur seal consumption of adult pollock increases in years when juvenile pollock are less abundant;
- The decoupling of abundance timeseries for Pacific cod and walleye pollock after 2010 suggests a shift in drivers of survival in these two populations. Mechanistic understanding of recruitment drivers is less well-known than for pollock.

We therefore rated the Ecosystem concern as Level 2, substantially increased concern. Some indicators showing adverse signals relevant to the stock but the pattern was inconsistent across indicators.

Fishery performance As noted above, the 2019 B-season suggested that the fishery was dispersed and experienced relatively low catch rates compared to recent years. Also, an approach to computing fleet dispersion (the relative distance or spread of the fishery in space) was developed and indicated that while the A-season was the most intensely concentrated for the fleet during this season (since 2000), the B-season indicated the most dispersed fishing activity over the same period (Fig 9).

The pollock fishery was challenged to simultaneously avoid a number of PSC species. Chinook salmon (a top priority) encounters were relatively high and some sectors exceeded their performance standard (which was lowered due to a 2018 index of Chinook salmon abundance from three key western Alaska rivers rivers falling below a specified threshold thus requiring lower cap limits in 2019). The encounter rates were high this year probably because the returning salmon were high (in fact, in 2019 the 3-river index was well above the threshold that triggers a lower performance standard). Chum salmon encounter rates were high as well during some periods of summer 2019 and the fleet moved to avoid them. Finally, a high abundance of sablefish and low region-specific OFL set for the EBS put them on PSC status and the fleet took active avoidance measures for the entire B-season.

Given the combination of pollock being broadly distributed into the EBS shelf region during the summer (based on survey data), and the fact that the pollock fleet were more widely dispersed than seen in recent decades indicates that **fishery performance could be scored a 2, substantially increased concerns.**

These results are summarized as:

	Considerations			
Assessment-related	Population dynamics	Environmental or ecosystem	Fisheries	Score (max of individual)
Level 1: No concern	Level 2: Substantially increased concerns	Level 2: Substantially increased concerns	Level 2: Substantially increased concerns	Level 2: Substantially increased concerns

The overall score is level 2, the maximum of the individual scores, 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} = 3,041 kt). In the past, the SSC has considered factors similar to those presented above and selected an ABC based on Tier 3 estimates. We recommend this added precaution again this year, (i.e., ABC = 2,045 kt) which implies a buffer of 43%. The SSC requested "an explicit set of concerns that explain the ABC adjustment." In response, we direct attention to the decision table 49) 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 give 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 5 of the 38 years since 1981 has the stock been below the B_{MSY} level (13% of the years). The mean spawning biomass over this period has averaged about 30% 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 $1.2 \times B_{MSY}$. In this case that would make the female spawning biomass target at 2.576 million t. It therefore seems worth considering making an explicit harvest control rule that achieves the productivity and ecosystem stability given the catches and biomass estimates observed over the past 30 years.

Recognizing that the actual catch will be constrained by other factors (the 2 million t BSAI groundfish catch limit and bycatch avoidance measures), applying the maximum permissible Tier 1a ABC seems clearly risky. Such high catches would result in unprecedented variability and removals from the stock (and require considerably more capacity and effort). Less variability in catch would also result in less spawning stock variability (and reduce risks to the fishery should another period of poor recruitments occur). 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 2020 catch values. These indicators and rationale for including them are summarized in Table 48). Model 16.1 results for these indicators are provided in Table 49. Each column of this table uses a fixed 2020 catch and assumes the same effort for the four additional projection years (2021–2024). 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 2020 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 2019 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 2021 spawning stock estimates being below the long term mean (but above B_{MSY}).

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 (see Sterling and Ream 2004, Zeppelin and Ream 2006). Currently, a multi-agency project is investigating diet properties and forage related issues for northern fur seals (See https://tinyurl.com/y3vcg54e).

A brief summary of these two perspectives (ecosystem effects on pollock stock and pollock fishery effects on ecosystem) is given in (Table 46). 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 condition appears to have benefited substantially from the recent 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). The fact that the 2012 year-class appears to be strong, as it ages that contribution to the stock will diminish.

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. In this approach, 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).

Euphausiids make up a large component of the pollock diet. The euphausiid abundance on the Bering Sea shelf is presented as a section of the 2017 Ecosystem Considerations Chapter of the SAFE report and shows a continued decline in abundance since the peak in 2009 (for details see De Robertis et al. (2010) and Ressler et al. (2012). The role that the apparent recent 2009 peak abundance had in the survival of the 2008 year class of EBS pollock is interesting. Contrasting this with how the feeding ecology of the 2012 year class (also apparently well above average) may differ is something to evaluate in the future.

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 45). 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 but has dropped in 2015 and been about average since then. 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 in the past three years it is about half of the 2011 and 2012 levels (Table 43). There has been a marked in 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 44).

The number of non-Chinook salmon (nearly all made up of chum salmon) taken incidentally has steadily increased since 2014 with 2017 number in excess of 465 thousand fish but the 2018 level was slightly more than the 2003–2017 average of 227 thousand fish; Table 46). Chinook salmon bycatch has also increased steadily since 2012 with the 2017 counts at just below 30,000 (which was 18% below the 2003–2017 mean value). In 2018 the bycatch dropped back down to 13.5 thousand fish (Table 46). 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 were provided to the Council in 2018 and impact levels remain 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 (presented for comparative purposes in this assessment) 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 would be useful for improving ways to evaluate the current and alternative fishery management system. 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.
- 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: Catch from the Eastern Bering Sea by area, the Aleutian Islands, the Donut Hole, and the Bogoslof Island area, 1979–2019 (2019 values through October 15th 2019). The southeast area refers to the EBS region east of 170W; the Northwest is west of 170W. Note: 1979–1989 data are from Pacfin, 1990–2019 data are from NMFS Alaska Regional Office, and include discards. The 2019 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	98,918	293,400	316,038
1992	830,559	559,741	1,390,299	52,559	10,000	241
1993	1,094,429	232,173	1,326,602	57,238	1,957	886
1994	1,152,575	176,777	1,329,352	58,853		556
1995	1,172,306	91,941	1,264,247	65,201		334
1996	1,086,843	105,939	1,192,781	29,158		499
1997	819,889	304,544	1,124,433	26,629		163
1998	971,388	132,515	1,103,903	23,823		8
1999	782,983	206,698	989,680	1,016		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	1,817		0
2006	827,207	660,824	1,488,031	1,775		0
2007	728,249	626,253	1,354,502	2,680		0
2008	482,698	507,880	990,578	1,428		9
2009	358,252	452,532	810,784	1,668		73
2010	255,132	555,075	810,207	1,460		176
2011	747,890	451,151	1,199,041	1,208		173
2012	618,869	586,343	1,205,212	975		71
2013	695,667	575,098	1,270,765	3,107		57
2014	858,240	439,180	1,297,419	2,375		427
2015	696,249	625,331	1,321,581	919		733
2016	1,167,088	185,571	1,352,659	1,329		1,005
2017	1,178,112	181,162	1,359,274	1,507		186
2018	1,061,598	333,169	1,394,767	1,962		133
2019	1,050,535	296,014	1,346,549	1,504		119
Avg.	796,279	411,646	1,207,925	25,012	697,696	29,584

Table 2: Time series of 1964–1976 catch (left) and ABC, TAC, and catch for EBS pollock, 1977–2019 in t. Source: compiled from NMFS Regional office web site and various NPFMC reports. Note that the 2019 value is based on catch reported to October 25th 2019 plus an added component due to bycatch of pollock in other fisheries.

Year	Catch	Year	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	1,490,000	1,300,000	1,390,299
		1993	1,340,000	1,300,000	1,326,602
		1994	1,330,000	1,330,000	1,329,352
		1995	1,250,000	1,250,000	1,264,247
		1996	1,190,000	1,190,000	1,192,781
		1997	1,130,000	1,130,000	1,124,433
		1998	1,110,000	1,110,000	1,102,159
		1999	992,000	992,000	989,680
		2000	1,139,000	1,139,000	1,132,710
		2001	1,842,000	1,400,000	1,387,197
		2002	2,110,000	1,485,000	1,480,776
		2003	2,330,000	1,491,760	1,490,779
		2004	2,560,000	1,492,000	1,480,552
		2005	1,960,000	1,478,500	1,483,022
		2006	1,930,000	1,485,000	1,488,031
		2007	1,394,000	1,394,000	1,354,502
		2008	1,000,000	1,000,000	990,578
		2009	815,000	815,000	810,784
		2010	813,000	813,000	810,206
		2011	1,270,000	1,252,000	1,199,041
		2012	1,220,000	1,200,000	1,205,212
		2013	1,375,000	1,247,000	1,270,768
		2014	1,369,000	1,267,000	1,297,420
		2015	1,637,000	1,310,000	1,321,581
		2016	2,090,000	1,340,000	1,352,707
		2017	2,800,000	1,345,000	1,343,217
		2018	2,592,000	1,364,341	1,379,306
		2019	2,163,000	1,397,000	1,387,000
1977–2019 mean			1,455,902	1,241,006	1,188,382

Table 3: Estimates of discarded pollock (t), percent of total (in parentheses) and total catch for the Aleutians, Bogoslof, Northwest and Southeastern Bering Sea, 1991–2019. SE represents the EBS east of 170W, NW is the EBS west of 170W, source: NMFS Blend and catch-accounting system database. 2019 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
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%)	22,430 (2%)	1,244	29	293,532	839,177	1,133,983
2001	380 (46%)	28 (11%)	2,450 (1%)	14,874 (2%)	17,732 (1%)	825	258	425,220	961,977	1,388,280
2002	779 (66%)	12 (1%)	1,441 (tr)	19,430 (2%)	21,661 (1%)	1,177	1,042	320,442	1,160,334	1,482,995
2003	468 (28%)	19 (79%)	2,959 (1%)	13,795 (1%)	17,241 (1%)	1,649	24	557,588	933,191	1,492,453
2004	287 (25%)	0 (100%)	2,781 (1%)	20,380 (2%)	23,448 (2%)	1,158	0	390,544	1,090,008	1,481,710
2005	324 (20%)	0 (89%)	2,586 (tr)	14,838 (2%)	17,748 (1%)	1,621	0	680,868	802,154	1,484,643
2006	311 (18%)	0 (50%)	3,677 (1%)	11,877 (1%)	15,865 (1%)	1,745	0	660,824	827,207	1,489,776
2007	425 (17%)	0 (%)	3,769 (1%)	12,334 (2%)	16,528 (1%)	2,519	0	626,253	728,249	1,357,021
2008	81 (6%)	0 (%)	1,643 (tr)	5,968 (1%)	7,692 (1%)	1,278	9	507,880	482,698	991,865
2009	395 (24%)	6 (8%)	1,936 (tr)	4,014 (1%)	6,352 (1%)	1,662	73	452,532	358,252	812,519
2010	142 (12%)	53 (30%)	1,271 (tr)	2,511 (1%)	3,976 (tr)	1,235	176	555,075	255,132	811,618
2011	75 (6%)	23 (13%)	1,378 (tr)	3,456 (tr)	4,932 (tr)	1,208	173	451,151	747,890	1,200,422
2012	95 (10%)	0 (%)	1,191 (tr)	4,187 (1%)	5,473 (tr)	975	71	586,343	618,869	1,206,258
2013	108 (4%)	0 (1%)	1,226 (tr)	4,144 (1%)	5,478 (tr)	2,964	57	575,098	695,667	1,273,786
2014	138 (6%)	54 (13%)	1,787 (tr)	12,568 (1%)	14,547 (1%)	2,375	427	439,180	858,240	1,300,221
2015	20 (2%)	138 (19%)	2,419 (tr)	7,053 (1%)	9,638 (1%)	916	733	625,331	696,250	1,323,230
2016	59 (5%)	7.24 (1%)	998 (1%)	8,141 (1%)	9,209 (1%)	1,257	1,004	185,572	1,167,089	1,354,922
2017	18 (1%)	2.46 (1%)	1,357 (1%)	6,940 (1%)	8,299 (1%)	1,507	186	181,161	1,178,113	1,360,968
2018	216 (12%)	2.12 (1%)	2,012 (1%)	9,195 (1%)	11,209 (1%)	1,860	14	330,588	1,048,718	1,381,180
2019	57 (4%)	0.129 (1%)	1,793 (1%)	6,475 (1%)	8,268 (1%)	1,462	117	292,339	1,035,640	1,329,559

Table 4: Total EBS shelf pollock catch recorded by observers (rounded to nearest 100 t) by year and season with percentages indicating the proportion of the catch that came from within the Steller sea lion conservation area (SCA), 1998–2019. The 2019 data are preliminary.

Year	A season	B-season	Total
1998	385,000 t (82%)	403,000 t (38%)	788,000 t (60%)
1999	339,000 t (54%)	468,000 t (23%)	807,000 t (36%)
2000	375,000 t (36%)	572,000 t (4%)	947,000 t (16%)
2001	490,000 t (27%)	674,000 t (46%)	1,164,000 t (38%)
2002	512,200 t (56%)	689,100 t (42%)	1,201,200 t (48%)
2003	532,400 t (47%)	737,400 t (40%)	1,269,800 t (43%)
2004	532,600 t (45%)	710,800 t (34%)	1,243,300 t (38%)
2005	530,300 t (45%)	673,200 t (17%)	1,203,500 t (29%)
2006	533,400 t (51%)	764,300 t (14%)	1,297,700 t (29%)
2007	479,500 t (57%)	663,200 t (11%)	1,142,700 t (30%)
2008	341,700 t (46%)	498,800 t (12%)	840,500 t (26%)
2009	282,700 t (39%)	388,800 t (13%)	671,500 t (24%)
2010	269,800 t (15%)	403,100 t (9%)	672,900 t (11%)
2011	477,600 t (54%)	666,600 t (32%)	1,144,200 t (41%)
2012	457,100 t (52%)	687,500 t (17%)	1,144,600 t (31%)
2013	472,200 t (22%)	708,100 t (19%)	1,180,300 t (20%)
2014	482,800 t (38%)	741,200 t (37%)	1,224,000 t (37%)
2015	490,400 t (15%)	765,900 t (45%)	1,256,300 t (33%)
2016	510,700 t (35%)	784,000 t (62%)	1,294,700 t (51%)
2017	555,300 t (51%)	750,800 t (54%)	1,306,100 t (53%)
2018	573,000 t (63%)	746,500 t (46%)	1,319,500 t (53%)
2019	573,400 t (68%)	762,800 t (51%)	1,336,200 t (58%)

Table 5: 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.

Table 6: 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 2005-2007 average, the 2008-2010 average, the 2011-2013 average, and annual from 2014-2018.

	Avg 05-07	Avg 08-10	Avg 11-13	2014	2015	2016	2017	2018
All sectors								
Catch	1,444	872	1,227	1,300	1,323	1,355	1,361	1,381
Retained catch	1,427	866	1,221	1,285	1,314	1,346	1,353	1,370
Vessels #	110.3	121	120.3	121	120	122	118	115
Catcher vessels (trawl)								
Retained catch	768.3	459.0	640.8	668.5	687.1	703.9	710.4	718.3
Ex-vessel value	$214.18	$184.89	$229.62	$226.54	$227.42	$209.36	$205.54	$236.67
Ex-vessel price	$0.13	$0.18	$0.16	$0.16	$0.15	$0.14	$0.14	$0.16
CV share of catch	54%	53%	52%	52%	52%	52%	53%	52%
Vessels #	89	89	88	87	87	89	87	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 7: 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 2005-2007 average, the 2008-2010 average, the 2011-2013 average, and annual from 2014-2018.

	Avg 05-07	Avg 08-10	Avg 11-13	2014	2015	2016	2017	2018
	BSAI							
All products volume	498.25	355.99	487.56	525.54	520.94	534.89	523.94	532.44
All products value	$1,246.4	$1,133.4	$1,324.7	$1,301.4	$1,275.0	$1,351.5	$1,338.1	$1,378.6
All products price	$1.13	$1.44	$1.23	$1.12	$1.11	$1.15	$1.16	$1.17
At-sea value share	59%	58%	59%	58%	60%	60%	62%	59%
Fillets volume	162.7	113.9	159.55	175.78	167.01	161.29	156.95	167.63
Fillets price	$1.24	$1.73	$1.51	$1.374	$1.355	$1.412	$1.286	$1.370
Fillets value share	36%	38%	40%	41%	39%	37%	33%	37%
Surimi volume	173.05	100.99	153.27	171.33	187.74	190.82	196.73	196.53
Surimi price	$0.96	$1.63	$1.23	$1.105	$1.142	$1.194	$1.331	$1.259
Surimi value share	29%	32%	32%	32%	37%	37%	43%	40%
Roe volume	27.03	17.63	16.14	20.60	18.75	14.26	18.43	20.64
Roe price	$4.84	$4.14	$3.78	$2.915	$2.291	$2.844	$2.877	$2.892
Roe value share	23%	14%	10%	10%	7%	7%	9%	10%
At-sea price premium	$0.30	$0.32	$0.19	0.15	0.25	0.25	0.37	0.21

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 8: 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 2005-2007 average, the 2008-2010 average, the 2011-2013 average, and annual from 2014-2019 (2019 through June).

	Avg 05-07	Avg 08-10	Avg 11-13	2014	2015	2016	2017	2018	2019*
Global pollock catch	2,854	2,662	3,241	3,245	3,373	3,476	3,488	-	-
U.S. share	52%	35%	40%	44%	44%	44%	44%	-	-
Russian share	37%	53%	49%	47%	48%	50%	50%	-	-
BSAI share	51%	33%	38%	40%	39%	39%	39%	-	-
Export volume	278.9	192.2	326.2	395	377.8	379.6	398	243.8	191.5
Export value	$867.4	$635.2	$943.6	$1,081.7	$1,038.2	$990.5	$1,007.6	$671.5	$586.8
Export price	$1.41	$1.50	$1.31	$1.24	$1.25	$1.18	$1.15	$1.25	$1.39
Import value	$173.40	$202.43	$166.58	$142.60	$130.48	$91.24	$74.98	$77.92	$53.70
Net exports	$694.00	$432.77	$777.03	$939.05	$907.76	$899.27	$932.51	$1,051.22	$533.07
Japan volume share	34%	27%	21%	22%	25%	20%	22%	23%	24%
Japan value share	38%	26%	19%	22%	26%	20%	23%	29%	27%
China volume share	3%	9%	13%	15%	13%	12%	15%	14%	14%
China value Share	2%	7%	11%	12%	11%	10%	13%	10%	9%
Europe volume share	34%	37%	39%	38%	36%	35%	33%	33%	29%
Europe value share	28%	37%	39%	39%	36%	35%	33%	33%	29%
Meat volume share	33%	46%	50%	54%	49%	49%	49%	49%	45%
Meat value share	27%	45%	48%	52%	46%	46%	47%	40%	39%
Surimi volume share	57%	46%	45%	41%	45%	47%	47%	43%	43%
Surimi value share	38%	33%	38%	34%	39%	42%	42%	39%	38%
Roe volume share	10%	8%	5%	6%	5%	4%	5%	9%	13%
Roe value share	35%	23%	14%	14%	15%	11%	11%	21%	23%

Notes: 2019 data thru June; 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 9: BSAI pollock fish oil production index (tons of oil per 100 tons of retained catch); 2005-2007 average, the 2008-2010 average, the 2011-2013 average, and annual from 2014-2018.

sector	Avg 05-07	Avg 08-10	Avg 11-13	2014	2015	2016	2017	2018
All sectors	1.25	2.03	1.76	2.19	1.84	2.06	1.92	1.93
Shoreside	2.07	2.58	2.00	2.42	1.94	2.28	2.09	2.07
At sea	0.30	1.41	1.50	1.94	1.72	1.82	1.74	1.77

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 10: Eastern Bering Sea pollock catch at age estimates based on observer data, 1979–2018. 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	2,567.0
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	2,421.0
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	2,175.0
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	2,004.0
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	1,745.0
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	1,938.0
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	1,920.0
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	2,041.0
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	1,379.0
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	2,192.0
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	1,784.0
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	1,746.0
1991	0.4	113.2	44.4	88.9	151.8	181.9	509.7	81.5	292.9	29.5	143.9	18.2	88.3	71.8	1,816.0
1992	2.0	88.2	670.8	130.3	82.9	110.2	136.2	254.8	102.7	152.5	57.9	45.4	13.7	75.5	1,923.0
1993	0.1	6.9	243.6	1,144.4	108.0	73.9	68.5	53.1	91.6	20.5	35.2	10.9	13.5	23.3	1,894.0
1994	1.2	35.6	58.6	347.4	1,067.2	180.5	57.7	18.7	12.4	20.2	9.2	10.2	7.6	12.1	1,839.0
1995	-	0.4	77.1	148.5	406.8	767.1	121.9	32.0	11.2	8.1	17.7	5.2	6.7	10.4	1,613.0
1996	-	16.7	51.9	82.6	161.5	362.8	481.6	186.0	32.6	14.1	8.4	8.7	4.5	11.0	1,422.0
1997	1.6	77.9	39.2	107.6	472.7	282.6	252.6	200.1	65.4	14.0	5.9	5.3	3.3	14.4	1,543.0
1998	0.2	42.3	85.6	70.9	154.8	697.0	202.0	131.0	107.5	29.1	6.1	6.2	2.4	9.2	1,544.0
1999	0.2	9.6	294.4	224.6	102.3	159.7	470.8	130.7	56.3	34.1	3.7	2.3	0.8	2.2	1,492.0
2000	-	15.3	80.3	425.8	347.0	105.2	170.4	357.6	86.0	29.5	22.3	5.3	1.3	1.6	1,648.0
2001	-	3.1	46.9	154.7	582.6	410.5	135.9	127.0	157.3	59.0	34.4	16.0	5.4	5.7	1,738.0
2002	0.9	47.0	108.6	213.4	287.4	602.3	270.2	100.6	86.3	96.8	33.9	15.3	11.0	4.5	1,878.0
2003	-	14.1	408.6	323.5	367.2	307.1	331.2	158.8	49.5	38.4	36.1	22.7	6.8	6.7	2,071.0
2004	-	0.5	90.1	825.4	483.7	239.0	168.5	155.2	63.2	15.5	18.6	26.8	8.9	14.0	2,109.0
2005	-	4.1	51.1	399.4	859.1	483.5	157.6	68.7	68.3	30.8	9.6	8.9	3.0	5.0	2,149.0
2006	-	10.0	83.2	293.3	615.3	592.6	283.6	109.9	49.5	40.7	17.0	8.3	8.4	11.6	2,123.0
2007	1.6	16.9	60.5	137.5	388.6	508.7	300.1	139.5	47.6	27.4	24.2	9.5	6.1	14.2	1,683.0
2008	-	25.9	57.6	79.4	148.8	308.4	242.0	149.3	82.5	21.8	18.4	14.0	8.9	15.7	1,173.0
2009	-	1.3	175.9	199.9	82.4	112.9	123.4	104.0	65.9	40.5	23.9	7.6	8.2	12.3	958.0
2010	1.0	27.2	30.8	557.9	220.6	55.0	42.5	56.6	52.9	31.8	16.0	8.8	6.2	10.3	1,118.0
2011	0.4	11.4	192.8	115.6	809.5	284.4	64.1	37.7	38.3	40.2	25.3	12.8	1.8	8.3	1,643.0
2012	-	23.7	117.8	943.8	173.7	433.1	139.9	37.0	17.6	14.7	16.2	13.8	7.8	8.9	1,948.0
2013	1.7	0.8	65.3	342.1	955.5	195.2	155.9	69.1	20.1	13.3	12.5	12.0	7.9	10.4	1,862.0
2014	-	39.6	31.4	168.6	397.4	752.2	210.3	86.3	29.2	9.0	4.6	4.7	4.5	9.0	1,747.0
2015	-	15.7	633.2	194.8	229.1	385.2	509.4	88.2	43.0	17.2	3.2	2.2	3.3	4.0	2,128.0
2016	-	0.5	91.7	1,389.7	159.3	175.3	175.5	223.1	34.7	13.2	7.9	0.5	1.3	-	2,273.0
2017	-	2.0	29.8	551.4	894.6	214.7	147.5	123.2	96.3	21.5	7.8	6.3	0.6	0.4	2,096.0
2018	-	1.4	13.8	114.1	1,216.7	504.0	105.5	82.2	60.9	26.6	4.2	1.2	0.3	1.1	2,131.99
Avg.	6.8	53.2	201.2	373.3	410.6	325.4	203.8	113.4	65.3	33.3	22.9	11.6	7.9	11.4	1,836.87

Table 11: Numbers of pollock NMFS observer samples measured for fishery catch length frequency (by sex and strata), 1977–2018.

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	160,491	148,236	166,117	150,261	141,085	139,852	906,042
1992	158,405	153,866	163,045	164,227	101,036	102,667	843,244
1993	143,296	133,711	148,299	140,402	27,262	28,522	621,490
1994	139,332	147,204	159,341	153,526	28,015	27,953	655,370
1995	131,287	128,389	179,312	154,520	16,170	16,356	626,032
1996	149,111	140,981	200,482	156,804	18,165	18,348	683,890
1997	124,953	104,115	116,448	107,630	60,192	53,191	566,527
1998	136,605	110,620	208,659	178,012	32,819	40,307	707,019
1999	36,258	32,630	38,840	35,695	16,282	18,339	178,044
2000	64,575	58,162	63,832	41,120	40,868	39,134	307,689
2001	79,333	75,633	54,119	51,268	44,295	45,836	350,483
2002	71,776	69,743	65,432	64,373	37,701	39,322	348,347
2003	74,995	77,612	49,469	53,053	51,799	53,463	360,390
2004	75,426	76,018	63,204	62,005	47,289	44,246	368,188
2005	76,627	69,543	43,205	33,886	68,878	63,088	355,225
2006	72,353	63,108	28,799	22,363	75,180	65,209	327,010
2007	62,827	60,522	32,945	25,518	75,128	69,116	326,054
2008	46,125	51,027	20,493	23,503	61,149	64,598	266,894
2009	46,051	44,080	19,877	18,579	50,451	53,344	232,379
2010	39,495	41,054	19,194	20,591	40,449	41,323	202,106
2011	58,822	62,617	60,254	65,057	51,137	48,084	345,971
2012	53,641	57,966	45,044	46,940	50,167	53,224	306,982
2013	52,303	62,336	37,434	44,709	49,484	49,903	296,168
2014	55,954	58,097	46,568	51,950	46,643	46,202	305,414
2015	55,646	56,507	45,074	41,218	46,237	43,084	287,766
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

Table 12: Number of EBS pollock measured for weight and length by sex and strata as collected by the NMFS observer program, 1977-2018

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	2,712	2,781	2,339	2,496	1,065	1,169	12,562
1992	1,517	1,582	1,911	1,970	588	566	8,134
1993	1,201	1,270	1,448	1,406	435	450	6,210
1994	1,552	1,630	1,569	1,577	162	171	6,661
1995	1,215	1,259	1,320	1,343	223	232	5,592
1996	2,094	2,135	1,409	1,384	1	1	7,024
1997	628	627	616	665	511	523	3,570
1998	1,852	1,946	959	923	327	350	6,357
1999	5,318	4,798	7,797	7,054	3,532	3,768	32,267
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

Table 13: Numbers of pollock fishery samples used for age determination estimates by sex and strata, 1977–2018, 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	420	423	272	265	320	341	2,041
1992	392	392	371	386	178	177	1,896
1993	444	473	503	493	124	122	2,159
1994	201	202	570	573	131	141	1,818
1995	298	316	436	417	123	131	1,721
1996	468	449	442	433	1	1	1,794
1997	433	436	284	311	326	326	2,116
1998	592	659	307	307	216	232	2,313
1999	540	500	730	727	306	298	3,100
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

Table 14: NMFS total pollock research catch by year in t, 1964–2019.

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

Table 15: Survey biomass estimates (age 1+, t) of Eastern Bering Sea pollock based on design-based area-swept expansion methods from NMFS bottom trawl surveys 1982–2019.

	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	-
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%
Average	4,489,986	245,123	4,735,108	5%

Table 16: Sampling effort for pollock in the EBS from the NMFS bottom trawl survey 1982–2019.

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

Table 17: 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	1,235	2,944	3,310	4,340	1,489	203	140	67	42	26	16	10	3	1	1	13,827
1983	4,798	734	1,656	2,980	6,689	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	5,340	430	1,492	692	2,653	2,011	1,501	298	79	64	23	8	9	1		14,600
1986	2,774	678	533	1,875	1,135	1,890	1,653	1,501	471	72	33	15	1	4	1	12,636
1987	379	759	1,032	780	4,741	1,297	1,202	479	1,521	237	71	28	5	2	2	12,535
1988	1,455	809	1,898	3,582	1,562	5,048	1,497	1,133	647	1,536	145	87	18	24	12	19,453
1989	972	304	467	1,564	3,884	875	3,474	534	663	258	812	142	124	63	87	14,223
1990	2,076	395	142	894	1,808	6,076	1,221	3,008	304	537	82	770	67	50	68	17,498
1991	3,025	899	326	103	629	591	1,964	740	1,594	417	563	116	349	49	44	11,408
1992	1,566	444	2,303	375	409	681	616	896	401	770	272	338	146	116	92	9,424
1993	2,553	382	835	3,752	818	657	340	467	634	390	343	251	197	109	130	11,856
1994	1,667	752	580	1,622	4,394	770	200	173	193	364	222	310	117	113	187	11,663
1995	2,231	206	385	1,940	2,615	4,293	1,824	481	294	184	346	139	256	101	145	15,439
1996	1,488	318	126	253	897	1,311	1,213	415	103	111	75	141	46	83	110	6,691
1997	2,502	361	84	100	1,459	992	731	923	160	82	62	67	111	36	123	7,793
1998	678	614	300	176	303	1,740	500	353	284	71	33	12	26	30	70	5,190
1999	1,123	1,038	966	1,041	589	1,031	2,554	680	322	301	110	47	19	27	93	9,939
2000	1,105	422	532	1,811	1,792	915	765	2,492	975	512	217	146	45	20	86	11,835
2001	1,812	1,051	569	542	1,369	1,432	615	305	908	651	249	199	79	28	76	9,885
2002	788	400	812	1,164	1,206	1,585	825	404	552	1,036	516	228	135	40	43	9,734
2003	535	150	969	1,680	2,021	1,862	2,495	1,411	646	839	1,714	740	278	146	105	15,591
2004	389	249	160	1,305	1,301	999	588	636	314	196	195	352	150	36	28	6,897
2005	353	119	226	1,042	2,940	1,981	1,035	470	357	262	70	148	241	92	95	9,431
2006	862	66	69	279	910	1,218	799	387	221	190	91	57	82	110	109	5,450
2007	1,945	66	165	463	1,436	1,691	1,231	887	377	168	157	137	62	78	151	9,014
2008	525	117	96	183	516	1,036	820	582	371	148	124	95	43	24	149	4,829
2009	791	220	462	499	289	417	558	435	316	152	101	33	33	17	69	4,391
2010	471	91	244	2,822	1,288	403	343	364	383	263	227	82	50	29	62	7,121
2011	1,128	114	212	340	1,779	872	252	141	221	221	185	142	60	28	76	5,770
2012	1,145	207	362	2,940	729	1,192	406	162	122	167	139	122	102	36	65	7,895
2013	1,189	116	223	903	4,639	1,099	695	245	83	76	100	75	70	38	50	9,602
2014	2,121	581	222	236	1,306	5,343	2,840	644	358	133	51	73	74	34	92	14,108
2015	1,056	670	2,161	538	1,083	2,043	4,110	1,221	295	141	18	17	29	18	36	13,435
2016	703	412	653	3,280	1,331	886	1,245	1,828	358	140	45	11	11	4	7	10,915
2017	574	242	451	2,346	2,834	1,231	844	758	893	256	91	33	5	2	7	10,565
2018	864	373	167	353	2,571	1,452	492	361	366	281	89	14	2		6	7,391
2019	1,449	388	333	363	1,111	4,294	1,774	418	298	171	98	43	16	3	1	10,761
Avg	1,476	486	686	1,334	1,853	1,787	1,173	702	429	303	204	138	81	42	65	10,697

Table 18: Mean EBS pollock body mass (kg) at age as observed in the summer NMFS bottom trawl survey, 1982–2019.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1982	0.032	0.075	0.167	0.349	0.429	0.666	1.023	1.124	1.202	1.378	1.588	1.626	1.881	1.802	2.668
1983	0.017	0.141	0.240	0.360	0.493	0.578	0.727	1.074	1.126	1.020	1.121	1.130	1.558	1.115	1.936
1984	0.014	0.072	0.264	0.359	0.483	0.617	0.757	1.018	1.220	1.407	1.528	1.689	1.345	1.468	2.079
1985	0.014	0.104	0.264	0.410	0.514	0.649	0.784	0.926	1.428	1.132	1.298	1.727	1.629	1.614	2.570
1986	0.012	0.102	0.183	0.356	0.462	0.638	0.718	0.851	1.012	1.291	1.322	1.149	2.295	2.165	2.422
1987	0.017	0.110	0.262	0.354	0.432	0.525	0.705	0.795	0.896	1.005	1.198	1.400	1.740	2.020	2.275
1988	0.018	0.108	0.296	0.355	0.457	0.521	0.601	0.754	0.851	1.002	1.203	1.216	1.712	0.952	1.802
1989	0.016	0.092	0.168	0.385	0.455	0.529	0.629	0.673	0.927	0.924	1.046	1.078	1.124	1.187	1.284
1990	0.013	0.102	0.153	0.378	0.505	0.572	0.612	0.723	0.794	1.049	1.079	1.137	1.081	1.287	1.386
1991	0.019	0.108	0.157	0.354	0.486	0.579	0.695	0.740	0.873	0.911	1.093	1.201	1.266	1.425	1.924
1992	0.014	0.113	0.285	0.371	0.512	0.625	0.780	0.841	0.900	0.990	1.107	1.260	1.393	1.350	1.391
1993	0.012	0.072	0.314	0.456	0.503	0.553	0.663	0.796	0.977	1.029	1.153	1.257	1.392	1.550	1.699
1994	0.015	0.086	0.223	0.474	0.573	0.635	0.716	0.976	1.172	1.128	1.200	1.331	1.433	1.521	1.698
1995	0.013	0.088	0.145	0.380	0.486	0.628	0.654	0.801	0.939	1.172	1.136	1.308	1.353	1.434	1.683
1996	0.017	0.081	0.142	0.340	0.506	0.597	0.733	0.815	0.972	1.059	1.299	1.393	1.437	1.548	1.659
1997	0.016	0.053	0.181	0.363	0.439	0.591	0.707	0.806	0.974	1.023	1.163	1.311	1.289	1.474	1.598
1998	0.016	0.070	0.173	0.334	0.474	0.523	0.698	0.837	0.925	0.997	1.081	1.359	1.357	1.750	1.804
1999	0.014	0.080	0.210	0.356	0.422	0.560	0.635	0.776	0.985	1.014	1.116	1.202	1.624	1.757	1.924
2000	0.010	0.063	0.228	0.376	0.456	0.530	0.650	0.709	0.782	0.956	1.160	1.212	1.342	1.500	1.868
2001	0.016	0.069	0.169	0.374	0.505	0.601	0.674	0.771	0.857	0.911	1.099	1.207	1.412	1.396	1.688
2002	0.011	0.097	0.252	0.390	0.536	0.650	0.678	0.808	0.891	0.928	0.939	1.097	1.189	1.370	1.835
2003	0.021	0.106	0.334	0.437	0.567	0.671	0.729	0.833	0.889	0.957	0.967	1.021	1.029	1.132	1.184
2004	0.019	0.099	0.297	0.481	0.556	0.680	0.756	0.791	0.942	0.951	1.038	1.048	1.123	1.343	1.438
2005	0.018	0.079	0.220	0.404	0.528	0.605	0.702	0.801	0.874	0.913	1.014	1.064	1.098	1.193	1.321
2006	0.009	0.081	0.156	0.387	0.524	0.612	0.723	0.811	0.914	1.045	1.100	1.184	1.279	1.257	1.375
2007	0.012	0.095	0.276	0.427	0.547	0.671	0.777	0.846	0.926	1.078	1.126	1.110	1.328	1.301	1.423
2008	0.014	0.054	0.232	0.413	0.522	0.643	0.762	0.867	0.934	1.071	1.222	1.206	1.379	1.544	1.577
2009	0.010	0.113	0.223	0.408	0.551	0.675	0.840	0.914	0.960	1.173	1.170	1.440	1.449	1.546	1.784
2010	0.018	0.078	0.237	0.404	0.546	0.678	0.899	0.984	1.021	1.124	1.157	1.274	1.457	1.559	1.966
2011	0.015	0.112	0.229	0.429	0.551	0.646	0.802	1.004	1.105	1.152	1.249	1.306	1.431	1.463	1.671
2012	0.013	0.080	0.205	0.362	0.535	0.669	0.805	0.948	1.211	1.239	1.296	1.343	1.440	1.658	1.913
2013	0.017	0.069	0.222	0.421	0.495	0.624	0.834	0.978	1.093	1.225	1.297	1.343	1.468	1.609	1.730
2014	0.016	0.100	0.212	0.367	0.489	0.610	0.667	0.905	0.996	1.126	1.327	1.332	1.382	1.497	1.664
2015	0.019	0.093	0.287	0.387	0.518	0.601	0.727	0.814	1.048	1.081	1.329	1.585	1.366	1.579	1.773
2016	0.023	0.083	0.234	0.435	0.512	0.607	0.695	0.777	0.842	0.922	1.079	1.096	1.395	1.708	1.839
2017	0.022	0.098	0.200	0.397	0.529	0.598	0.691	0.743	0.824	0.830	0.960	0.856	1.336	1.506	1.701
2018	0.020	0.073	0.204	0.375	0.501	0.614	0.706	0.752	0.843	0.883	0.965	0.963	1.133	1.175	1.218
2019	0.016	0.089	0.234	0.435	0.546	0.639	0.711	0.792	0.844	0.926	0.898	0.978	0.948	1.401	1.854
Avg	0.016	0.089	0.223	0.391	0.504	0.611	0.728	0.847	0.973	1.053	1.161	1.248	1.392	1.478	1.753

Table 19: Biomass (age 1+) of Eastern Bering Sea pollock as estimated by surveys 1979–2019 (millions 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.

Year	Design.Based	DDC	VAST.NBS	VAST.NBS.CPE	ATS	VAST.ATS
1982	2,912	4,069	3,916	3,946	-	-
1983	5,921	8,409	10,303	9,398	-	-
1984	4,542	6,408	7,791	6,886	-	-
1985	5,198	7,189	9,070	7,993	-	-
1986	4,835	6,825	7,658	7,276	-	-
1987	5,498	7,892	7,967	7,694	-	-
1988	7,183	11,088	11,561	11,784	-	-
1989	6,550	9,795	10,450	10,745	-	-
1990	7,296	11,899	12,964	11,815	-	-
1991	5,129	7,389	7,772	7,476	-	-
1992	4,526	6,210	7,121	6,628	-	-
1993	5,294	7,089	8,319	7,967	-	-
1994	5,027	7,100	7,952	7,513	3,640	3,640
1995	5,477	9,107	7,885	7,258	-	-
1996	3,125	4,079	4,387	4,268	2,955	2,955
1997	3,562	5,019	5,108	4,849	3,591	3,591
1998	2,687	3,509	3,731	3,586	-	-
1999	3,798	5,454	5,532	5,932	4,202	4,202
2000	5,103	7,355	8,255	7,747	3,614	3,614
2001	4,196	5,439	6,282	6,168	-	-
2002	4,953	6,770	7,392	6,878	4,330	4,330
2003	8,392	13,508	12,305	12,159	-	-
2004	3,862	5,105	5,866	5,866	4,016	4,016
2005	4,868	6,696	7,608	7,272	-	-
2006	3,045	3,886	4,582	4,251	1,887	1,887
2007	4,338	6,145	7,653	6,835	-	-
2008	3,023	3,994	4,751	4,830	2,288	2,083
2009	2,282	2,989	3,617	2,888	1,407	956
2010	3,737	5,131	5,829	5,328	1,323	556
2011	3,112	3,948	4,533	4,485	2,651	2,010
2012	3,487	4,613	5,186	5,076	2,299	2,337
2013	4,575	6,114	6,668	6,475	-	-
2014	7,429	10,331	12,172	12,007	4,727	4,905
2015	6,394	8,587	10,589	10,857	-	-
2016	4,910	6,607	9,128	9,539	4,829	5,514
2017	4,814	6,256	9,011	8,968	-	-
2018	3,112	4,187	5,826	5,823	2,499	3,663
2019	5,458	7,380	9,732	9,511	-	-
Avg.	4,728	6,673	7,539	7,262	3141.125	3141.1875

Table 20: 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		–	–	–	

Table 21: Mid-water pollock biomass (near surface down to 3m from the bottom unless otherwise noted) 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). CVs for biomass estimates were assumed to average 25% (inter-annual variability arises from the 1-dimensional variance estimation method). Note last column reflects biomass to 0.5m from bottom (as used in the model).

		Area	Biomass				
Year	Date	$(nmi)^2$	SCA	E170-SCA	W170	3m total	0.5m total
1994	9 Jul - 19 Aug	78,251	0.312	0.399	2.176	2.886	3.64
1996	20 Jul - 30 Aug	93,810	0.215	0.269	1.826	2.311	2.955
1997	17 Jul - 4 Sept	102,770	0.246	0.527	1.818	2.592	3.591
1999	7 Jun - 5 Aug	103,670	0.299	0.579	2.408	3.285	4.202
2000	7 Jun - 2 Aug	106,140	0.393	0.498	2.158	3.049	3.614
2002	4 Jun - 30 Jul	99,526	0.647	0.797	2.178	3.622	4.33
2004	4 Jun - 29 Jul	99,659	0.498	0.516	2.293	3.307	4.016
2006	3 Jun - 25 Jul	89,550	0.131	0.254	1.175	1.560	1.887
2007	2 Jun - 30 Jul	92,944	0.084	0.168	1.517	1.769	2.288
2008	2 Jun - 31 Jul	95,374	0.085	0.029	0.883	0.997	1.407
2009	9 Jun - 7 Aug	91,414	0.070	0.018	0.835	0.924	1.323
2010	5 Jun - 7 Aug	92,849	0.067	0.113	2.143	2.323	2.651
2012	7 Jun - 10 Aug	96,852	0.142	0.138	1.563	1.843	2.299
2014	12 Jun - 13 Aug	94,361	0.426	1.000	2.014	3.439	4.727
2016	12 Jun - 17 Aug	100,674	0.516	1.005	2.542	4.063	4.829
2018	12 Jun - 22 Aug	98,300	0.218	0.462	1.439	2.120	2.499

Table 22: AT survey estimates of EBS pollock abundance-at-age (millions), 1979–2019. Age 2+ totals and age-1s were modeled as separate indices.

					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	983	4,094	1,216	1,833	2,262	386	107	97	54	175	10,224	11,207
1996	1,800	567	552	2,741	915	634	585	142	39	129	6,303	8,103
1997	13,251	2,879	440	536	2,327	546	313	291	75	152	7,557	20,808
1999	607	1,780	3,717	1,810	652	398	1,548	526	180	228	10,839	11,446
2000	460	1,322	1,230	2,588	1,012	327	308	950	278	241	8,256	8,716
2002	723	4,281	3,931	1,435	839	772	389	149	184	637	12,617	13,340
2004	83	313	1,216	3,118	1,637	568	291	281	121	255	7,800	7,883
2006	525	217	291	654	783	659	390	145	75	149	3,364	3,888
2007	5,775	1,041	345	478	794	729	407	241	98	114	4,246	10,021
2008	71	2,915	1,047	166	161	288	235	136	102	98	5,147	5,218
2009	5,197	816	1,733	277	68	84	117	93	65	84	3,337	8,533
2010	2,568	6,404	984	2,295	446	73	33	37	38	81	10,390	12,958
2012	177	1,989	1,693	2,710	280	367	113	36	25	93	7,305	7,482
2014	4,751	8,655	969	1,161	1,119	1,770	740	170	79	80	14,743	19,494
2016	353	1,185	4,546	4,439	1,194	487	557	650	130	114	13,302	13,655
2018	450	517	249	621	2,268	944	198	112	107	104	5,120	5,570
Avg.	2,359	2,437	1,514	1,676	1,052	558	396	255	103	171	8,161	10,520
Med.	665	1,551	1,131	1,622	877	516	311	147	88	121	7,679	9,369

Table 23: An abundance index derived from acoustic data collected opportunistically aboard bottom-trawl survey vessels (AVO index; Honkalehto et al. 2014). 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	1.56 (4%)	0.555 9%	25%
2007	1.769 (4%)	0.638 14%	37%
2008	0.997 (8%)	0.316 20%	56%
2009	0.924 (9%)	0.285 42%	116%
2010	2.323 (6%)	0.679 13%	35%
2011	$-no\,survey-$	0.543 11%	29%
2012	1.843 (4%)	0.661 9%	26%
2013	$-no\,survey-$	0.694 6%	16%
2014	3.439 (5%)	0.897 5%	13%
2015	$-no\,survey-$	0.953 5%	13%
2016	4.063 (2%)	0.776 5%	13%
2017	$-no\,survey-$	0.730 5%	13%
2018	2.499 (2%)	0.672 5%	14%
2019	$-no\,survey-$	0.680 5%	13%

Table 24: Pollock sample sizes assumed for the age-composition data likelihoods from the fishery, bottom-trawl survey, and AT surveys, 1964–2019. 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	401	71	
1992	453	82	
1993	569	90	
1994	338	74	43
1995	572	75	
1996	254	90	32
1997	582	78	49
1998	426	82	
1999	519	90	67
2000	526	101	70
2001	390	107	
2002	513	110	72
2003	453	107	
2004	457	108	51
2005	482	109	
2006	469	102	47
2007	529	97	39
2008	464	82	35
2009	362	87	26
2010	602	90	34
2011	561	113	
2012	541	116	44
2013	625	120	
2014	513	137	79
2015	668	151	
2016	588	115	61
2017	587	105	
2018	545	100	25
2019		100	

Table 25: Mean weight-at-age (kg) estimates from the fishery (1991–2018; plus projections 2019–2021) 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	0.277	0.476	0.604	0.728	0.839	0.873	1.014	1.127	1.129	1.251	1.24	1.308	1.249
1992	0.007	0.179	0.394	0.462	0.647	0.701	0.812	0.982	1.031	1.21	1.226	1.272	1.199	1.34	1.43
1993	0.007	0.331	0.497	0.61	0.65	0.754	0.904	1.04	1.211	1.232	1.391	1.538	1.61	1.646	1.584
1994	0.007	0.233	0.405	0.651	0.728	0.747	0.707	1.057	1.395	1.347	1.347	1.391	1.394	1.301	1.341
1995	0.007	0.153	0.377	0.498	0.735	0.84	0.856	0.986	1.22	1.315	1.388	1.477	1.39	1.537	1.341
1996	0.007	0.293	0.368	0.427	0.679	0.794	0.949	0.953	1.02	1.096	1.362	1.5	1.52	1.71	1.598
1997	0.007	0.187	0.443	0.471	0.559	0.747	0.893	1.072	1.091	1.243	1.346	1.443	1.668	1.423	1.383
1998	0.007	0.191	0.368	0.589	0.627	0.621	0.775	1.029	1.169	1.253	1.327	1.452	1.414	1.523	1.537
1999	0.007	0.188	0.405	0.507	0.643	0.701	0.728	0.891	1.037	1.25	1.248	1.431	1.485	1.585	1.236
2000	0.007	0.218	0.353	0.526	0.629	0.731	0.782	0.806	0.966	1.007	1.242	1.321	1.418	1.551	1.644
2001	0.006	0.227	0.327	0.503	0.669	0.788	0.958	0.987	1.063	1.115	1.314	1.435	1.563	1.433	1.645
2002	0.007	0.231	0.386	0.509	0.666	0.795	0.91	1.03	1.104	1.095	1.288	1.448	1.597	1.343	1.683
2003	0.006	0.276	0.489	0.547	0.649	0.767	0.862	0.953	1.081	1.2	1.2	1.206	1.361	1.377	1.699
2004	0.007	0.135	0.409	0.583	0.64	0.758	0.889	0.924	1.035	1.162	1.11	1.16	1.333	1.281	1.213
2005	0.007	0.283	0.346	0.508	0.642	0.741	0.882	0.954	1.062	1.096	1.225	1.276	1.251	1.174	1.373
2006	0.007	0.174	0.305	0.447	0.606	0.755	0.853	0.952	1.065	1.114	1.219	1.234	1.282	1.399	1.462
2007	0.007	0.155	0.346	0.506	0.641	0.781	0.962	1.098	1.182	1.275	1.304	1.477	1.5	1.738	1.52
2008	0.007	0.208	0.33	0.52	0.652	0.774	0.903	1.049	1.119	1.282	1.421	1.524	1.553	1.921	1.66
2009	0.007	0.136	0.34	0.526	0.704	0.879	1.002	1.125	1.399	1.49	1.563	1.614	1.814	1.996	2.23
2010	0.05	0.175	0.383	0.489	0.664	0.915	1.119	1.261	1.371	1.587	1.659	1.924	1.923	2.079	2.316
2011	0.031	0.205	0.29	0.509	0.665	0.808	0.976	1.225	1.346	1.518	1.585	1.621	2.176	1.754	2.287
2012	0.029	0.142	0.27	0.41	0.643	0.824	0.974	1.172	1.306	1.519	1.614	1.644	1.717	2.04	2.086
2013	0.095	0.144	0.289	0.442	0.564	0.782	1.131	1.284	1.426	1.692	1.834	1.806	1.96	2.187	2.207
2014	0.014	0.193	0.316	0.455	0.617	0.751	0.894	1.154	1.31	1.37	1.692	1.815	1.733	1.658	2.236
2015	0.025	0.181	0.404	0.461	0.57	0.69	0.786	0.888	1.146	1.203	1.355	1.914	1.45	1.617	2.627
2016	0.025	0.181	0.407	0.531	0.557	0.648	0.732	0.801	0.943	1.044	1.206	1.592	1.729	1.816	1.908
2017	0.025	0.191	0.404	0.498	0.651	0.694	0.75	0.827	0.893	0.911	1.018	1.085	1.667	1.797	1.878
2018	0.025	0.186	0.38	0.466	0.573	0.734	0.81	0.855	0.904	1.045	0.983	1.388	1.531	1.721	1.846
2019	0.025	0.186	0.409	0.528	0.623	0.734	0.882	0.922	0.977	1.07	1.158	1.314	1.491	1.625	1.806
2020	-	-	0.363	0.539	0.663	0.76	0.868	1.012	1.046	1.093	1.178	1.257	1.405	1.574	1.7
2021	-	-	0.363	0.494	0.674	0.8	0.894	0.999	1.136	1.162	1.201	1.277	1.348	1.487	1.648
Mean	0.007	0.17	0.305	0.449	0.592	0.721	0.839	0.941	1.029	1.107	1.164	1.215	1.251	1.289	1.314
CV	-	-	19	12	8	8	12	14	15	16	17	18	19	21	29

Table 26: Goodness of fit to primary data used for assessment model parameter estimation profiling over different constraints on the extent bottom-trawl survey selectivity/availability is allowed to change; EBS pollock.

Component	CV70%	CV50%	CV20%	CV10%	CV05%
RMSE BTS	0.19	0.20	0.25	0.29	0.31
RMSE ATS	0.22	0.22	0.22	0.23	0.25
RMSE AVO	0.20	0.20	0.20	0.20	0.20
RMSE CPUE	0.09	0.09	0.09	0.09	0.09
SDNR BTS	1.02	1.19	1.79	2.23	2.47
SDNR ATS	1.10	1.10	1.11	1.14	1.22
SDNR AVO	0.76	0.75	0.74	0.72	0.71
Eff. N Fishery	1365.35	1372.25	1392.11	1372.08	1278.76
Eff. N BTS	208.52	203.81	178.76	159.66	141.47
Eff. N ATS	215.15	215.49	214.48	209.18	200.06
BTS NLL	20.82	28.35	64.62	99.67	122.72
ATS NLL	8.83	8.85	8.96	9.32	10.32
AVO NLL	9.55	9.54	9.53	9.60	9.71
Fish Age NLL	137.34	138.83	143.87	149.92	159.61
BTS Age NLL	146.42	149.95	168.85	191.00	239.73
ATS Age NLL	26.81	26.89	27.61	28.90	30.68

Table 27: Goodness of fit to primary data used for assessment model parameter estimation for different model configurations, EBS pollock.

Component	lastyr	Model 16.1	VAST	VAST+cold-pool	VAST ATS
RMSE BTS	0.240	0.200	0.160	0.170	0.170
RMSE ATS	0.220	0.220	0.220	0.220	0.380
RMSE AVO	0.210	0.200	0.200	0.200	0.220
RMSE CPUE	0.090	0.090	0.090	0.090	0.090
SDNR BTS	1.230	1.190	1.870	2.130	2.120
SDNR ATS	1.110	1.100	1.130	1.140	2.940
SDNR AVO	0.580	0.750	0.730	0.730	0.850
Eff. N Fishery	1438.800	1372.250	1381.800	1376.960	1373.430
Eff. N BTS	168.540	203.810	202.180	203.170	204.190
Eff. N ATS	213.530	215.490	212.720	212.560	220.060
BTS NLL	29.110	28.350	25.440	26.180	25.600
ATS NLL	8.940	8.850	9.000	9.140	26.960
AVO NLL	9.880	9.540	9.620	9.620	9.590
Fish Age NLL	115.290	138.830	139.130	139.550	139.040
BTS Age NLL	165.380	149.950	144.450	145.530	146.120
ATS Age NLL	28.220	26.890	27.030	27.110	25.970

Table 28: Summary of different model results and the stock condition for EBS pollock. Biomass units are thousands of t.

Component	Model 16.1	VAST	VAST+cold-pool	VAST ATS
B_{2020}	2,800	3,000	3,100	3,700
$CV_{B_{2020}}$	0.12	0.12	0.11	0.12
B_{MSY}	2,147	2,148	2,153	2,182
$CV_{B_{MSY}}$	0.25	0.24	0.24	0.24
B_{2020}/B_{MSY}	130%	139%	142%	168%
B_0	5,748	5,777	5,794	5,881
$B_{35\%}$	2,158	2,190	2,198	2,253
SPR rate at F_{MSY}	28%	27%	27%	27%
Steepness	0.66	0.66	0.66	0.67
Est. $B_{2018}/B_{2018,nofishing}$	0.6	0.64	0.64	0.7
B_{2018}/B_{MSY}	150%	161%	163%	193%

Table 29: Estimates of begin-year age 3 and older biomass (thousands of tons) and coefficients of variation (CV) for the current assessment compared to 2012–2018 assessments for EBS pollock.

Year	Current	CV	2018	CV	2017	CV	2016	CV	2015	CV	2014	CV	2013	CV
1964	1,833	22	1,744	22	1,779	22	1,834	22	1,869	24	1,622	21	1,602	21
1965	2,232	20	2,124	20	2,165	20	2,229	20	2,324	22	2,076	19	2,051	19
1966	2,391	19	2,277	19	2,326	19	2,404	19	2,563	22	2,186	19	2,149	19
1967	3,644	17	3,504	17	3,566	17	3,667	17	3,888	19	3,397	16	3,344	16
1968	4,163	17	4,011	17	4,082	17	4,198	17	4,495	18	3,870	16	3,800	16
1969	5,264	15	5,105	16	5,174	15	5,294	15	5,690	16	5,220	15	5,145	16
1970	5,911	14	5,757	15	5,820	14	5,936	14	6,424	15	6,252	15	6,178	15
1971	6,354	13	6,209	13	6,260	13	6,360	13	6,858	14	6,945	13	6,884	13
1972	6,037	12	5,902	12	5,940	12	6,024	12	6,431	13	6,353	13	6,299	13
1973	4,859	13	4,729	13	4,765	13	4,845	13	5,161	14	4,748	16	4,692	16
1974	3,601	16	3,474	16	3,510	16	3,589	16	3,846	17	3,348	19	3,291	20
1975	3,730	12	3,585	12	3,611	12	3,679	12	3,868	13	3,554	13	3,515	13
1976	3,704	10	3,515	10	3,538	10	3,608	10	3,872	11	3,609	10	3,577	10
1977	3,692	9	3,426	8	3,446	8	3,535	8	3,939	10	3,642	9	3,612	9
1978	3,612	8	3,250	8	3,273	8	3,375	8	3,888	9	3,556	9	3,524	9
1979	3,588	8	3,087	8	3,116	8	3,239	8	3,859	9	3,426	8	3,386	8
1980	4,534	7	3,856	6	3,896	6	4,068	6	4,887	8	4,372	7	4,307	7
1981	8,387	5	7,314	5	7,453	5	7,813	4	9,054	6	8,527	5	8,320	6
1982	9,535	4	8,448	5	8,645	5	9,056	4	10,289	5	9,766	5	9,496	5
1983	10,802	4	9,556	4	9,849	4	10,240	4	11,383	5	10,911	4	10,560	5
1984	10,632	4	9,428	4	9,731	4	10,033	4	11,040	5	10,601	4	10,239	5
1985	12,622	3	11,615	4	11,887	4	12,237	3	12,951	4	12,838	4	12,409	4
1986	11,821	3	11,039	3	11,278	4	11,531	3	12,019	4	12,036	4	11,621	4
1987	12,180	2	11,734	3	11,922	3	12,143	3	12,334	4	12,615	3	12,243	3
1988	11,267	2	11,125	3	11,291	3	11,497	3	11,536	4	11,906	3	11,583	3
1989	9,389	2	9,422	3	9,568	3	9,755	3	9,700	4	10,128	3	9,860	3
1990	7,445	3	7,536	3	7,671	3	7,812	3	7,701	4	8,101	3	7,891	4
1991	5,862	3	5,920	4	6,054	4	6,183	4	6,063	5	6,331	4	6,170	4
1992	9,352	2	9,065	3	9,276	3	9,476	3	9,472	3	9,704	3	9,561	3
1993	11,689	2	11,181	2	11,427	2	11,627	2	11,712	3	11,840	3	11,712	3
1994	11,424	2	10,957	2	11,188	2	11,313	2	11,418	3	11,402	3	11,306	3
1995	12,960	2	12,508	2	12,757	2	13,000	2	13,177	3	13,135	3	13,074	3
1996	11,318	2	10,751	2	10,979	2	11,239	2	11,358	3	11,235	3	11,198	3
1997	10,091	3	9,395	2	9,603	2	9,837	2	9,940	3	9,816	3	9,801	3
1998	9,746	2	9,422	2	9,609	2	9,908	2	9,990	3	9,906	3	9,902	3
1999	10,675	2	10,390	2	10,561	2	10,751	2	10,853	3	10,799	3	10,791	3
2000	9,815	2	9,582	2	9,735	2	9,955	2	10,068	3	10,031	3	10,020	3
2001	9,546	2	9,335	2	9,479	2	9,702	2	9,854	3	9,818	3	9,802	3
2002	9,858	2	9,698	2	9,811	2	10,025	2	10,276	3	10,221	3	10,182	3
2003	11,772	2	11,657	2	11,750	2	12,080	2	12,365	3	12,278	2	12,211	2
2004	11,070	2	10,999	2	11,073	2	11,401	2	11,591	3	11,493	2	11,416	2
2005	9,253	2	9,197	2	9,272	2	9,598	2	9,705	3	9,601	3	9,521	3
2006	7,090	2	7,035	2	7,110	2	7,390	2	7,446	3	7,343	3	7,261	3
2007	5,733	3	5,683	3	5,762	3	6,046	3	6,045	4	5,932	4	5,840	4
2008	4,675	3	4,651	3	4,726	3	4,945	3	4,849	4	4,721	4	4,607	4
2009	5,832	3	5,837	3	5,943	3	6,374	3	6,331	5	6,068	4	5,879	5
2010	6,160	3	6,185	3	6,327	3	6,657	3	6,680	5	5,936	5	5,622	6
2011	8,648	3	8,788	3	9,107	3	9,637	3	10,053	7	8,895	6	7,927	7
2012	8,576	3	8,722	3	9,051	4	9,626	4	10,164	8	8,822	7	7,853	9
2013	8,430	3	8,547	4	8,873	4	9,504	5	10,337	9	9,540	8	8,261	10
2014	7,777	4	7,855	4	8,143	5	8,947	6	9,805	10	8,960	9	8,045	11
2015	10,961	5	11,345	6	11,913	8	12,407	10	10,970	11	9,203	9	7,778	12
2016	13,837	7	13,293	7	13,549	10	13,495	12	11,292	12	NA	NA	NA	NA
2017	12,320	8	11,785	8	12,049	11	13,033	13	NA	NA	NA	NA	NA	NA
2018	9,912	9	10,202	9	10,965	11	NA	NA	NA	NA	NA	NA	NA	NA
2019	9,327	9	9,110	10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 30: Estimated billions of EBS pollock at age (columns 2–11) from the 2019 assessment model.

Year	1	2	3	4	5	6	7	8	9	10+
1964	6.47	3.55	2.24	0.48	0.21	0.41	0.18	0.06	0.04	0.22
1965	21.43	2.62	2.23	1.59	0.30	0.13	0.26	0.12	0.04	0.17
1966	15.27	8.70	1.65	1.57	0.99	0.19	0.08	0.16	0.07	0.13
1967	25.85	6.19	5.46	1.16	1.00	0.63	0.12	0.05	0.11	0.14
1968	22.30	10.47	3.84	3.57	0.68	0.58	0.37	0.07	0.03	0.14
1969	26.33	9.03	6.47	2.51	2.09	0.40	0.34	0.22	0.04	0.10
1970	23.66	10.65	5.55	4.10	1.48	1.24	0.24	0.21	0.13	0.09
1971	14.53	9.53	6.40	3.32	2.35	0.83	0.69	0.13	0.11	0.11
1972	11.90	5.83	5.59	3.60	1.75	1.18	0.42	0.35	0.06	0.10
1973	27.42	4.78	3.32	2.93	1.76	0.84	0.57	0.20	0.16	0.07
1974	20.44	11.03	2.64	1.62	1.32	0.78	0.37	0.25	0.08	0.09
1975	17.87	8.24	5.89	1.15	0.70	0.57	0.34	0.16	0.10	0.07
1976	14.18	7.22	4.67	2.70	0.53	0.33	0.27	0.16	0.07	0.07
1977	15.27	5.74	4.19	2.36	1.30	0.26	0.16	0.13	0.08	0.07
1978	26.98	6.19	3.37	2.33	1.23	0.66	0.13	0.08	0.07	0.07
1979	63.53	10.94	3.67	1.89	1.22	0.62	0.34	0.07	0.04	0.07
1980	26.33	25.78	6.64	2.17	1.03	0.61	0.31	0.17	0.03	0.05
1981	32.57	10.69	16.01	4.23	1.22	0.53	0.31	0.16	0.09	0.04
1982	17.43	13.23	6.72	10.96	2.58	0.69	0.30	0.17	0.09	0.07
1983	50.11	7.08	8.37	4.79	7.19	1.58	0.42	0.18	0.11	0.10
1984	13.42	20.37	4.48	6.02	3.25	4.60	0.99	0.26	0.12	0.13
1985	32.32	5.46	12.91	3.23	4.13	2.06	2.88	0.62	0.17	0.15
1986	12.06	13.14	3.46	9.26	2.22	2.71	1.27	1.79	0.38	0.20
1987	6.75	4.90	8.33	2.48	6.35	1.47	1.71	0.79	1.12	0.36
1988	5.65	2.75	3.12	6.02	1.75	4.33	0.97	1.13	0.51	0.96
1989	11.82	2.30	1.74	2.18	4.13	1.13	2.74	0.59	0.70	0.92
1990	50.41	4.81	1.46	1.24	1.47	2.66	0.71	1.63	0.36	1.00
1991	26.29	20.49	3.05	1.04	0.81	0.85	1.52	0.39	0.88	0.77
1992	22.20	10.69	12.99	2.20	0.71	0.49	0.49	0.78	0.21	0.83
1993	45.81	9.03	6.76	9.04	1.49	0.44	0.26	0.23	0.35	0.43
1994	15.29	18.62	5.74	4.81	5.74	0.98	0.26	0.14	0.12	0.41
1995	10.50	6.22	11.85	4.19	3.27	3.36	0.59	0.15	0.08	0.31
1996	22.77	4.27	3.96	8.70	2.98	2.07	1.83	0.34	0.09	0.23
1997	30.87	9.26	2.71	2.89	6.32	2.04	1.20	0.91	0.16	0.17
1998	15.16	12.55	5.86	1.97	2.06	4.29	1.27	0.67	0.49	0.17
1999	16.37	6.16	7.97	4.25	1.40	1.39	2.59	0.76	0.38	0.36
2000	25.50	6.66	3.92	5.68	2.96	0.95	0.90	1.54	0.46	0.45
2001	34.87	10.37	4.24	2.84	3.84	1.90	0.60	0.52	0.85	0.54
2002	23.31	14.18	6.60	3.08	1.96	2.33	1.05	0.33	0.29	0.80
2003	14.27	9.48	9.01	4.78	2.10	1.20	1.19	0.54	0.17	0.61
2004	6.51	5.80	6.03	6.36	3.24	1.24	0.62	0.59	0.27	0.43
2005	4.62	2.65	3.69	4.37	4.00	1.97	0.70	0.32	0.31	0.39
2006	11.59	1.88	1.69	2.68	2.89	2.21	1.06	0.39	0.18	0.41
2007	24.93	4.71	1.19	1.19	1.74	1.62	1.10	0.54	0.20	0.32
2008	13.48	10.14	3.00	0.84	0.77	0.97	0.79	0.55	0.28	0.28
2009	49.85	5.48	6.45	2.16	0.55	0.44	0.46	0.38	0.27	0.29
2010	21.28	20.27	3.49	4.63	1.42	0.33	0.22	0.23	0.20	0.29
2011	13.21	8.65	12.90	2.55	2.95	0.86	0.19	0.13	0.13	0.26
2012	11.57	5.37	5.51	9.39	1.76	1.46	0.41	0.09	0.06	0.19
2013	53.60	4.70	3.42	3.98	6.14	1.14	0.69	0.19	0.04	0.12
2014	50.76	21.79	2.99	2.47	2.65	3.71	0.68	0.36	0.09	0.08
2015	13.17	20.64	13.87	2.17	1.68	1.62	2.08	0.35	0.18	0.09
2016	8.42	5.35	13.14	9.76	1.43	1.04	0.87	1.08	0.18	0.14
2017	14.81	3.42	3.41	9.63	6.04	0.91	0.62	0.50	0.59	0.17
2018	17.49	6.02	2.18	2.50	6.64	3.68	0.51	0.34	0.27	0.43
2019	18.52	7.11	3.84	1.61	1.76	3.93	2.26	0.29	0.19	0.42

Table 31: Estimated millions of EBS pollock caught at age (columns 2–11) from the 2019 assessment model.

Year	1	2	3	4	5	6	7	8	9	10+
1964	8.85	38.09	85.60	62.28	27.20	52.56	22.94	7.07	4.31	25.16
1965	28.90	29.05	98.87	213.63	39.65	16.38	30.67	13.46	4.23	18.50
1966	20.65	101.19	78.72	192.86	119.35	21.96	9.23	17.55	7.83	13.76
1967	64.87	139.09	555.67	211.40	183.20	114.09	21.86	9.43	18.37	23.37
1968	64.04	262.67	395.26	657.11	121.19	101.75	64.43	12.48	5.46	24.65
1969	91.02	255.28	809.14	442.71	361.04	67.55	58.60	39.06	7.73	19.06
1970	140.67	487.52	934.39	804.35	316.10	264.04	52.79	49.89	32.97	23.00
1971	121.26	615.17	1341.78	833.39	666.61	231.43	196.24	41.76	37.11	40.90
1972	89.03	508.00	1428.91	1068.29	537.51	361.05	128.71	119.31	22.49	38.33
1973	181.96	519.13	992.95	998.13	618.22	295.65	198.70	75.96	62.74	27.96
1974	118.18	1454.82	954.95	592.28	489.17	288.25	137.05	98.57	34.90	37.42
1975	68.49	744.86	1967.22	373.40	222.24	179.38	105.91	52.61	36.53	24.09
1976	38.99	529.50	1290.61	828.98	159.44	95.90	77.87	46.86	23.69	24.22
1977	29.75	366.97	902.39	609.94	347.99	69.00	42.29	34.69	22.28	20.29
1978	42.82	355.82	710.07	597.76	345.06	183.93	37.21	23.07	20.68	22.58
1979	79.76	428.90	641.51	441.22	347.65	178.97	95.99	19.43	13.08	21.32
1980	22.47	537.18	804.70	459.68	269.20	167.05	82.84	44.96	9.62	15.08
1981	15.87	119.36	1054.55	654.12	251.51	110.42	63.99	32.58	18.75	9.54
1982	4.71	84.73	218.67	1092.03	380.53	101.36	44.00	26.14	13.85	11.44
1983	9.66	41.48	204.68	353.82	844.92	212.71	55.78	24.40	14.89	14.00
1984	2.13	96.87	111.10	390.48	407.18	614.73	134.18	35.45	15.91	18.21
1985	4.27	26.31	354.36	194.31	408.17	303.20	410.51	87.15	23.07	21.78
1986	1.23	56.13	93.59	597.02	206.63	352.02	177.97	232.70	51.64	26.37
1987	0.42	14.09	184.32	108.20	436.86	141.05	163.17	88.00	123.14	38.06
1988	0.40	9.82	150.64	380.00	187.21	545.98	147.31	160.11	72.29	129.59
1989	0.71	7.65	56.08	163.63	465.92	153.45	473.68	94.77	100.88	127.76
1990	3.61	21.71	44.74	129.74	283.69	525.36	162.17	381.45	79.57	202.70
1991	1.72	94.59	62.20	76.83	124.63	163.84	408.92	86.96	246.89	213.00
1992	1.76	71.64	683.95	165.77	98.25	121.10	162.51	274.80	83.70	316.48
1993	1.98	20.04	231.12	1118.84	142.31	75.85	67.70	57.61	90.44	105.77
1994	0.47	32.23	69.87	339.48	1042.04	165.22	52.40	26.70	22.39	75.90
1995	0.28	9.75	89.23	144.03	409.45	778.33	116.53	28.89	14.32	53.27
1996	0.69	14.56	48.10	141.64	194.99	390.69	521.18	100.18	22.13	51.67
1997	0.94	58.87	40.70	98.88	464.75	286.82	262.04	216.85	47.45	44.10
1998	0.36	42.85	100.20	76.03	154.38	682.17	205.55	137.43	113.27	37.31
1999	0.29	11.67	266.31	219.21	103.65	157.43	452.04	127.60	61.72	58.00
2000	0.46	11.66	81.64	421.87	348.84	114.38	166.18	337.01	83.41	73.70
2001	0.67	15.95	62.52	168.46	609.83	419.69	131.77	112.35	168.60	99.79
2002	0.51	32.65	124.69	215.20	297.40	628.54	281.58	88.53	70.33	167.30
2003	0.32	17.00	372.49	348.11	367.97	307.02	345.77	152.91	43.76	130.59
2004	0.12	7.76	111.39	830.41	508.41	255.34	162.06	149.16	60.87	84.40
2005	0.08	3.69	65.15	404.47	883.73	473.83	159.12	69.19	62.48	70.25
2006	0.23	3.84	65.54	288.35	608.47	629.82	286.34	100.97	43.97	90.57
2007	0.49	10.89	48.22	135.38	377.07	490.47	315.29	141.54	49.75	76.89
2008	0.25	21.38	69.80	84.72	154.66	306.03	237.87	157.60	77.00	72.02
2009	0.82	7.72	167.38	210.13	90.85	118.79	123.98	101.09	71.11	76.56
2010	0.28	25.16	39.13	562.42	225.26	61.47	47.06	55.56	46.54	65.95
2011	0.23	13.92	203.54	147.12	851.02	270.10	58.65	37.41	36.80	75.49
2012	0.19	10.11	112.76	945.13	196.68	462.81	127.25	29.11	18.36	56.91
2013	0.79	6.20	65.16	350.95	984.48	195.07	179.68	59.16	13.48	36.96
2014	0.69	28.38	51.05	181.94	403.43	786.04	184.03	97.49	25.41	23.33
2015	0.19	19.02	604.75	207.72	238.17	384.21	546.95	92.17	51.90	26.99
2016	0.09	2.82	120.62	1388.14	174.29	180.72	174.96	242.66	38.06	28.67
2017	0.14	1.59	28.56	577.58	935.27	201.00	139.72	111.69	121.64	35.33
2018	0.13	1.90	12.90	112.92	1165.09	549.78	101.04	65.82	49.16	68.83
2019	0.16	2.57	25.93	82.56	347.43	662.79	507.44	63.30	39.27	75.80

Table 32: Estimated EBS pollock age 3+ biomass, female spawning biomass, and age 1 recruitment for 1964–2019. 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	546	27	6,468	38	1,833	22
1965	647	23	21,430	25	2,232	20
1966	752	22	15,268	32	2,391	20
1967	943	20	25,849	26	3,644	17
1968	1,165	19	22,300	28	4,163	17
1969	1,422	18	26,329	26	5,264	16
1970	1,657	18	23,656	27	5,911	15
1971	1,749	17	14,531	33	6,354	13
1972	1,659	17	11,900	34	6,037	13
1973	1,396	18	27,415	19	4,859	14
1974	1,042	22	20,439	19	3,601	16
1975	891	20	17,865	18	3,730	13
1976	912	16	14,179	17	3,704	11
1977	963	13	15,271	14	3,692	9
1978	994	12	26,979	10	3,612	9
1979	990	11	63,526	6	3,588	8
1980	1,133	9	26,328	9	4,534	7
1981	1,816	6	32,567	8	8,387	5
1982	2,704	6	17,430	10	9,535	5
1983	3,336	5	50,111	6	10,802	5
1984	3,601	5	13,423	10	10,632	5
1985	3,876	5	32,323	6	12,622	4
1986	4,076	4	12,061	10	11,821	4
1987	4,146	4	6,753	10	12,180	3
1988	4,055	3	5,653	10	11,267	3
1989	3,572	3	11,823	7	9,389	3
1990	2,826	3	50,409	3	7,445	3
1991	2,091	4	26,294	5	5,862	3
1992	2,237	3	22,203	6	9,352	3
1993	3,163	3	45,808	4	11,689	3
1994	3,518	3	15,290	6	11,424	3
1995	3,709	3	10,502	7	12,960	3
1996	3,719	3	22,768	5	11,318	3
1997	3,544	3	30,871	4	10,091	3
1998	3,223	3	15,163	6	9,746	3
1999	3,242	3	16,374	5	10,675	3
2000	3,254	3	25,496	4	9,815	3
2001	3,270	3	34,867	4	9,546	3
2002	3,073	3	23,307	4	9,858	3
2003	3,221	3	14,265	5	11,772	2
2004	3,310	3	6,513	7	11,070	2
2005	3,034	3	4,621	8	9,253	3
2006	2,488	3	11,588	5	7,090	3
2007	2,064	3	24,929	4	5,733	3
2008	1,540	4	13,477	6	4,675	3
2009	1,624	4	49,854	4	5,832	3
2010	1,859	4	21,280	6	6,160	3
2011	2,226	4	13,205	8	8,648	3
2012	2,552	4	11,572	9	8,576	3
2013	2,819	4	53,600	8	8,430	4
2014	2,683	5	50,758	10	7,777	5
2015	2,755	6	13,168	17	10,961	6
2016	3,518	7	8,423	25	13,837	7
2017	3,954	8	14,806	18	12,320	8
2018	3,538	10	17,486	20	9,912	9
2019	3,220	11	18,517	21	9,327	10

Table 33: Summary of model 16.1 results and the stock condition for EBS pollock. Biomass units are thousands of t.

Component	Model 16.1	VAST
B_{2020}	2,800	3,000
$CV_{B_{2020}}$	0.12	0.12
B_{MSY}	2,147	2,148
$CV_{B_{MSY}}$	0.25	0.24
B_{2020}/B_{MSY}	130%	139%
B_0	5,748	5,777
$B_{35\%}$	2,158	2,190
SPR rate at F_{MSY}	28%	27%
Steepness	0.66	0.66
Est. $B_{2019}/B_{2019,nofishing}$	0.6	0.64
B_{2019}/B_{MSY}	150%	161%

Table 34: Summary results of Tier 1 2019 yield projections for EBS pollock.

Component	Model 16.1	VAST
2020 fishable biomass (GM)	8,088,000	9,094,000
Equilibrium fishable biomass at MSY	4,858,000	5,749,000
MSY R (HM)	0.442	0.383
2020 Tier 1 ABC	3,578,000	3,485,000
2020 Tier 1 F_{OFL}	0.528	0.449
2020 Tier 1 OFL	4,273,000	4,085,000
MSY R (HM)	0.376	0.326
Recommended ABC	2,045,000	2,043,000

Table 35: For the configuration named Model 16.1, 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
2019	1,390	1,390	1,390	1,390	1,390	1,390	1,390
2020	2,045	1,350	1,542	904	0	2,538	2,045
2021	1,374	1,324	1,260	828	0	1,427	1,374
2022	1,201	1,471	1,137	792	0	1,262	1,493
2023	1,265	1,360	1,159	825	0	1,370	1,440
2024	1,429	1,462	1,274	915	0	1,564	1,584
2025	1,514	1,521	1,346	978	0	1,645	1,650
2026	1,559	1,563	1,397	1,028	0	1,678	1,680
2027	1,583	1,585	1,431	1,063	0	1,692	1,693
2028	1,590	1,587	1,447	1,084	0	1,694	1,694
2029	1,570	1,569	1,433	1,083	0	1,666	1,666
2030	1,567	1,570	1,436	1,089	0	1,664	1,664
2031	1,555	1,556	1,428	1,087	0	1,652	1,652
2032	1,553	1,551	1,425	1,086	0	1,649	1,649

Table 36: For the configuration named Model 16.1, Tier 3 projections of EBS pollock ABC for the 7 scenarios. Note: scenario 2 results for 2020 and 2021 are conditioned on catches in that scenario listed in Table 39).

SSB	Scenario.1	Scenario.2	Scenario.3	Scenario.4	Scenario.5	Scenario.6	Scenario.7
2019	3,225	3,225	3,225	3,225	3,225	3,225	3,225
2020	2,696	2,803	2,775	2,866	2,981	2,610	2,696
2021	2,213	2,496	2,429	2,741	3,204	2,011	2,213
2022	2,177	2,386	2,395	2,821	3,547	1,988	2,135
2023	2,323	2,408	2,537	3,039	3,988	2,133	2,183
2024	2,459	2,494	2,688	3,251	4,405	2,251	2,267
2025	2,532	2,549	2,791	3,415	4,775	2,301	2,307
2026	2,581	2,592	2,870	3,547	5,104	2,333	2,335
2027	2,594	2,601	2,904	3,623	5,352	2,337	2,338
2028	2,583	2,588	2,905	3,655	5,532	2,321	2,322
2029	2,571	2,576	2,899	3,671	5,669	2,309	2,309
2030	2,558	2,563	2,890	3,676	5,774	2,297	2,297
2031	2,557	2,559	2,888	3,684	5,865	2,297	2,297
2032	2,570	2,572	2,900	3,702	5,952	2,311	2,311

Table 37: For the configuration named Model 16.1, 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
2019	0.180	0.180	0.180	0.180	0.180	0.180	0.180
2020	0.349	0.212	0.248	0.135	0.000	0.462	0.349
2021	0.310	0.251	0.248	0.135	0.000	0.371	0.310
2022	0.301	0.327	0.248	0.135	0.000	0.365	0.392
2023	0.307	0.315	0.248	0.135	0.000	0.380	0.387
2024	0.312	0.315	0.248	0.135	0.000	0.390	0.392
2025	0.316	0.316	0.248	0.135	0.000	0.396	0.396
2026	0.318	0.318	0.248	0.135	0.000	0.398	0.399
2027	0.318	0.317	0.248	0.135	0.000	0.397	0.397
2028	0.317	0.316	0.248	0.135	0.000	0.395	0.395
2029	0.317	0.317	0.248	0.135	0.000	0.395	0.395
2030	0.316	0.316	0.248	0.135	0.000	0.394	0.394
2031	0.316	0.316	0.248	0.135	0.000	0.393	0.393
2032	0.316	0.315	0.248	0.135	0.000	0.393	0.393

Table 38: For the configuration named Model 16.1, Tier 3 projections of EBS pollock spawning biomass (kt) for the 7 scenarios.

ABC	Scenario.1	Scenario.2	Scenario.3	Scenario.4	Scenario.5	Scenario.6	Scenario.7
2019	2,440	2,440	1,838	1,076	0	3,033	3,033
2020	2,045	2,045	1,542	904	0	2,538	2,538
2021	1,374	1,715	1,260	828	0	1,427	1,694
2022	1,201	1,471	1,137	792	0	1,262	1,493
2023	1,265	1,360	1,159	825	0	1,370	1,440
2024	1,429	1,464	1,274	915	0	1,564	1,584
2025	1,514	1,528	1,346	978	0	1,645	1,650
2026	1,559	1,567	1,397	1,028	0	1,678	1,680
2027	1,583	1,589	1,431	1,063	0	1,692	1,693
2028	1,590	1,594	1,447	1,084	0	1,694	1,694
2029	1,570	1,574	1,433	1,083	0	1,666	1,666
2030	1,567	1,571	1,436	1,089	0	1,664	1,664
2031	1,555	1,558	1,428	1,087	0	1,652	1,652
2032	1,553	1,554	1,425	1,086	0	1,649	1,649

Table 39: For the configuration named VAST, 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
2019	1,390	1,390	1,390	1,390	1,390	1,390	1,390
2020	2,043	1,350	1,592	929	0	2,523	2,043
2021	1,500	1,324	1,318	855	0	1,578	1,500
2022	1,289	1,586	1,214	832	0	1,359	1,585
2023	1,320	1,431	1,231	866	0	1,426	1,496
2024	1,472	1,513	1,343	955	0	1,604	1,626
2025	1,545	1,557	1,405	1,013	0	1,673	1,680
2026	1,581	1,588	1,442	1,054	0	1,698	1,701
2027	1,602	1,606	1,470	1,084	0	1,712	1,713
2028	1,607	1,604	1,482	1,101	0	1,712	1,713
2029	1,585	1,584	1,464	1,095	0	1,682	1,682
2030	1,583	1,586	1,466	1,100	0	1,681	1,681
2031	1,572	1,573	1,458	1,098	0	1,670	1,670
2032	1,569	1,566	1,455	1,096	0	1,667	1,667

Table 40: For the configuration named VAST, Tier 3 projections of EBS pollock ABC for the 7 scenarios. Note: scenario 2 results for 2020 and 2021 are conditioned on catches in that scenario listed in Table 39).

SSB	Scenario.1	Scenario.2	Scenario.3	Scenario.4	Scenario.5	Scenario.6	Scenario.7
2019	3,452	3,452	3,452	3,452	3,452	3,452	3,452
2020	2,911	3,015	2,980	3,073	3,190	2,831	2,911
2021	2,397	2,698	2,602	2,928	3,405	2,196	2,397
2022	2,303	2,559	2,533	2,986	3,737	2,105	2,260
2023	2,410	2,524	2,636	3,175	4,165	2,211	2,267
2024	2,522	2,576	2,754	3,361	4,567	2,308	2,329
2025	2,581	2,610	2,831	3,503	4,923	2,346	2,355
2026	2,624	2,642	2,893	3,620	5,240	2,373	2,377
2027	2,635	2,646	2,917	3,685	5,478	2,376	2,378
2028	2,622	2,630	2,913	3,711	5,649	2,359	2,360
2029	2,610	2,617	2,905	3,724	5,780	2,347	2,347
2030	2,598	2,603	2,894	3,728	5,880	2,336	2,336
2031	2,597	2,600	2,893	3,735	5,968	2,336	2,336
2032	2,610	2,612	2,905	3,754	6,052	2,350	2,350

Table 41: For the configuration named VAST, 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
2019	0.153	0.153	0.153	0.153	0.153	0.153	0.153
2020	0.303	0.186	0.225	0.123	0.000	0.396	0.303
2021	0.289	0.216	0.225	0.123	0.000	0.343	0.289
2022	0.273	0.296	0.225	0.123	0.000	0.326	0.350
2023	0.272	0.280	0.225	0.123	0.000	0.332	0.339
2024	0.274	0.277	0.225	0.123	0.000	0.337	0.339
2025	0.276	0.277	0.225	0.123	0.000	0.341	0.341
2026	0.277	0.277	0.225	0.123	0.000	0.342	0.343
2027	0.277	0.277	0.225	0.123	0.000	0.341	0.341
2028	0.276	0.275	0.225	0.123	0.000	0.339	0.339
2029	0.276	0.276	0.225	0.123	0.000	0.339	0.339
2030	0.276	0.276	0.225	0.123	0.000	0.338	0.338
2031	0.275	0.275	0.225	0.123	0.000	0.338	0.338
2032	0.275	0.275	0.225	0.123	0.000	0.337	0.337

Table 42: For the configuration named VAST, Tier 3 projections of EBS pollock spawning biomass (kt) for the 7 scenarios.

ABC	Scenario.1	Scenario.2	Scenario.3	Scenario.4	Scenario.5	Scenario.6	Scenario.7
2019	2,502	2,502	1,953	1,141	0	3,085	3,085
2020	2,043	2,043	1,592	929	0	2,523	2,523
2021	1,500	1,766	1,318	855	0	1,578	1,831
2022	1,289	1,586	1,214	832	0	1,359	1,585
2023	1,320	1,431	1,231	866	0	1,426	1,496
2024	1,472	1,516	1,343	955	0	1,604	1,626
2025	1,545	1,565	1,405	1,013	0	1,673	1,680
2026	1,581	1,593	1,442	1,054	0	1,698	1,701
2027	1,602	1,610	1,470	1,084	0	1,712	1,713
2028	1,607	1,613	1,482	1,101	0	1,712	1,713
2029	1,585	1,590	1,464	1,095	0	1,682	1,682
2030	1,583	1,587	1,466	1,100	0	1,681	1,681
2031	1,572	1,574	1,458	1,098	0	1,670	1,670
2032	1,569	1,570	1,455	1,096	0	1,667	1,667

Table 43: Bycatch estimates (t) of other target species caught in the BSAI directed pollock fishery, 1997–2019 based on then NMFS Alaska Regional Office reports from observers (2019 data are preliminary).

Year	Pacific.Cod	Rock.Sole	Flathead.Sole	Arrowtooth.Flounder	Pacific.Ocean.Perch	Yellowfin.Sole	Sablefish	Sharks	Sculpin	Other
1991	24,310	5,120	0	5,719	418	417	9	0	0	10,722
1992	24,005	7,233	2	4,311	173	892	7	0	0	14,716
1993	20,930	8,713	0	1,222	282	1,102	1	0	0	7,548
1994	14,409	3,009	0	2,010	170	1,207	1	0	0	4,171
1995	19,776	2,179	2,175	1,177	142	675	12	0	0	1,021
1996	15,174	2,042	3,207	1,844	303	1,797	7	0	0	1,638
1997	8,262	1,522	2,350	984	428	605	2	0	0	1,026
1998	6,255	770	2,047	1,712	616	1,744	2	0	0	885
1999	3,220	1,058	1,885	272	120	349	7	0	0	610
2000	3,432	2,687	2,510	978	21	1,465	12	0	0	987
2001	3,879	1,672	2,199	529	574	594	21	0	0	1,312
2002	5,886	1,885	1,844	607	543	768	34	0	0	1,272
2003	5,968	1,418	1,501	617	935	209	48	0	0	1,861
2004	6,436	2,553	2,104	556	393	841	16	0	0	1,328
2005	7,413	1,125	2,351	651	652	63	11	0	0	1,234
2006	7,291	1,360	2,862	1,088	735	256	8	0	0	2,219
2007	5,629	510	4,225	2,795	624	85	11	0	0	2,028
2008	6,971	2,149	4,315	1,715	335	552	4	0	0	3,373
2009	7,875	7,591	4,665	2,202	114	270	2	0	0	4,495
2010	6,964	2,241	4,357	1,466	230	1,056	2	0	0	2,338
2011	10,040	8,480	4,885	1,599	659	1,082	1	65	315	310
2012	10,061	6,701	3,968	748	705	1,496	0	54	286	356
2013	8,957	6,319	3,146	965	610	2,087	0	43	219	339
2014	5,213	4,359	2,553	757	1,300	1,953	1	75	190	724
2015	8,302	1,709	2,259	402	2,516	863	0	51	186	412
2016	4,980	1,141	1,629	297	3,273	895	18	58	124	470
2017	5,955	1,825	956	208	4,818	623	101	92	81	324
2018	4,271	1,150	1,038	278	4,122	788	447	62	60	350
2019	6,160	1,192	1,086	390	6,463	440	1,245	93	55	464

Table 44: Bycatch estimates (t) of pollock caught in the other non-pollock EBS directed fisheries, 1997–2019 based on then NMFS Alaska Regional Office reports from observers.

Year	Pacific.Cod	Yellowfin.Sole	Rock.Sole	Flathead.Sole	Other.flatfish	Other.fisheries	Total
1991	10,695	NA	9,711	NA	6,219	2,528	29,154
1992	20,778	13,100	9,824	NA	1,242	757	45,704
1993	31,299	15,253	18,582	NA	2,572	632	68,339
1994	26,594	33,200	15,784	NA	6,751	108	82,438
1995	25,691	27,041	7,766	1,851	3,309	113	65,773
1996	22,382	22,254	7,698	4,082	1,338	840	58,597
1997	33,658	24,100	9,123	2,983	421	90	70,376
1998	10,468	15,339	3,960	2,369	298	1,283	33,720
1999	21,131	8,701	5,207	4,040	324	1,604	41,009
2000	14,508	13,425	5,480	6,467	372	748	41,003
2001	11,570	16,502	4,577	4,337	131	759	37,879
2002	15,255	14,489	9,942	1,934	75	262	41,959
2003	15,926	11,578	4,924	2,983	306	642	36,362
2004	18,650	10,383	8,975	5,162	607	819	44,599
2005	14,109	10,312	7,235	3,662	261	1,334	36,917
2006	15,168	5,966	6,986	2,663	53	1,252	32,090
2007	20,319	4,020	3,245	3,417	319	892	32,214
2008	9,533	9,827	4,930	4,102	6	730	29,131
2009	7,875	7,036	6,171	3,160	20	338	24,602
2010	6,406	5,156	6,097	2,997	3	402	21,063
2011	8,991	8,673	6,931	1,473	1	1,128	27,200
2012	8,383	11,199	6,703	903	14	1,248	28,452
2013	9,101	20,171	7,327	2,010	33	2,242	40,886
2014	11,511	24,700	11,270	4,106	8	2,491	54,089
2015	9,077	21,281	9,381	2,632	27	2,762	45,163
2016	9,094	22,306	11,848	1,666	49	2,422	47,387
2017	8,346	23,414	5,616	1,956	149	2,014	41,497
2018	8,061	28,235	5,182	2,833	4	1,643	45,961
2019	4,936	19,828	3,085	6,851	73	979	35,754

Table 45: Bycatch estimates (t) of non-target species caught in the BSAI directed pollock fishery, 2003–2019, 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	Eelpouts	Grenadier	Sea.pen	Lanternfish	Snails	All.other
2003	5,591	98	88	9	1	20	0	0	0	1
2004	6,490	87	7	20	0	14	0	0	0	1
2005	5,084	146	9	12	1	14	1	0	6	2
2006	2,657	147	8	92	20	15	1	9	0	6
2007	2,150	198	4	136	118	27	3	5	0	6
2008	3,711	103	6	4	7	27	1	0	0	6
2009	3,703	58	4	4	2	3	1	0	0	1
2010	2,153	116	4	0	0	1	1	0	0	1
2011	6,571	216	18	2	0	1	2	0	0	1
2012	2,454	124	3	1	0	0	2	0	0	1
2013	4,734	101	2	0	0	0	1	0	0	2
2014	12,767	43	29	1	7	10	3	0	1	10
2015	4,950	90	41	21	10	4	2	0	1	6
2016	2,203	75	54	1	22	1	1	0	0	3
2017	6,156	48	12	1	18	1	0	0	0	2
2018	7,943	50	22	0	4	9	1	0	0	4
2019	3,815	68	47	0	0	7	0	0	0	3

Table 46: Bycatch estimates of prohibited species caught in the BSAI directed pollock fishery, 1997–2019 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 2019 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	1,398,106	39,054	2,156	NA	3,159	28,709	4,380,022	33,345	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	1,649,103	36,618	1,326	NA	527	241,979	738,259	1,925	58,140	NA	NA
1994	371,213	31,889	963	688	1,626	92,010	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	55,472	382	320	1,241	77,173	63,398	215	5,933	NA	NA
1997	17,046	44,320	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	30,937	242	199	225	53,903	5,653	5,139	105	NA	NA
2002	2,112	32,401	165	137	108	77,177	2,697	193	16	NA	NA
2003	732	43,095	88	74	967	179,987	608	NA	52	8	0
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	0	0	1
2006	1,288	80,915	132	111	433	305,793	2,567	NA	288	0	3
2007	1,465	116,329	312	269	351	86,380	3,033	NA	7	0	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	0
2010	12,734	9,816	334	266	351	13,649	9,445	NA	1,122	28	0
2011	10,964	25,499	459	378	376	193,754	6,471	NA	577	25	0
2012	5,547	11,349	462	388	2,352	22,387	6,189	NA	343	0	0
2013	12,426	13,109	334	271	958	125,525	8,605	NA	316	34	107
2014	12,521	15,135	239	199	159	219,837	19,454	NA	368	0	148
2015	8,872	18,329	152	130	1,488	237,803	8,339	NA	0	0	0
2016	2,293	22,203	116	103	1,431	343,208	1,165	NA	439	0	106
2017	7,235	30,076	85	88	965	467,749	3,392	NA	186	0	64
2018	2,249	13,726	55	62	474	295,818	5,142	NA	565	0	53
2019	2,557	22,374	100	109	1,017	336,091	6,024	NA	413	99	445

Table 47: 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) underway	NA	Possible concern

Table 48: Details and explanation of the decision table factors selected in response to the Plan Team requests (as originally proposed in the 2012 assessment).

Term	Description	Rationale
$P[F_{2020} > F_{MSY}]$	Probability that the fishing mortality in 2020 exceeds F_{MSY}	OFL definition is based on F_{MSY}
$P[B_{2021} < B_{MSY}]$	Probability that the spawning biomass in 2021 is less than B_{MSY}	B_{MSY} is a reference point target and biomass in 2021 provides an indication of the impact of 2020 fishing
$P[B_{2022} < B_{MSY}]$	Probability that the spawning biomass in 2022 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 2020 and 2021
$P\left[B_{2022} < \bar{B}\right]$	Probability that the spawning biomass in 2021 is less than the 1978–2019 mean	To provide some perspective of what the stock condition might be relative to historical estimates after fishing in 2020.
$P\left[B_{2024} < \bar{B}\right]$	Probability that the spawning biomass in 2024 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 2020.
$P[B_{2024} < B_{2020}]$	Probability that the spawning biomass in 2024 is less than that estimated for 2020	To provide a medium term expectation of stock status relative to 2020 levels
$P[B_{2022} < B_{20\%}]$	Probability that the spawning biomass in 2022 is less than $B_{20\%}$	$B_{20\%}$ had been selected as a Steller Sea Lion lower limit for allowing directed fishing
$P[p_{a_5,2022} > \bar{p}_{a_5}]$	Probability that in 2022 the proportion of age 1–5 pollock in the population exceeds the long-term mean	To provide some relative indication of the age composition of the population relative to the long term mean.
$P[D_{2021} < D_{1994}]$	Probability that the diversity of ages represented in the spawning biomass (by weight) in 2021 is less than the value estimated for 1994	To provide a relative index on the abundance of different age classes in the 2021 population relative to 1994 (a year identified as having low age composition diversity)
$P[D_{2024} < D_{1994}]$	Probability that the diversity of ages represented in the spawning biomass (by weight) in 2024 is less than the value estimated for 1994	To provide a medium-term relative index on the abundance of different age classes in the population relative to 1994 (a year identified as having low age composition diversity)
$P[E_{2020} > E_{2019}]$	Probability that the theoretical fishing effort in 2020 will be greater than that estimated in 2019.	To provide the relative effort that is expected (and hence some idea of costs).

Table 49: Outcomes of decision (expressed as chances out of 100) given different 2020 catches (first row, in kt). Note that for the 2017 and later year-classes average values were assumed. Constant Fs based on the 2020 catches were used for subsequent years.

	10	500	1000	1250	1387	1500	1750	2000
$P\left[F_{2020} > F_{MSY}\right]$	0	0	0	0	0	1	4	12
$P\left[B_{2021} < B_{MSY}\right]$	10	16	23	28	31	34	40	48
$P\left[B_{2022} < B_{MSY}\right]$	6	10	19	25	28	31	39	48
$P\left[B_{2021} < \bar{B}\right]$	15	44	77	88	92	94	98	99
$P\left[B_{2024} < \bar{B}\right]$	3	11	24	31	36	39	47	55
$P\left[B_{2024} < B_{2020}\right]$	4	11	22	28	32	34	40	46
$P\left[B_{2022} < B_{20\%}\right]$	0	0	0	1	1	1	2	3
$P\left[p_{a5,2022} > \bar{p}_{a5}\right]$	17	44	68	75	79	81	85	88
$P\left[D_{2021} < D_{1994}\right]$	0	0	0	0	0	0	0	0
$P\left[D_{2024} < D_{1994}\right]$	0	1	5	9	12	15	24	35
$P\left[E_{2020} > E_{2019}\right]$	0	0	13	95	100	100	100	100

Figures

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

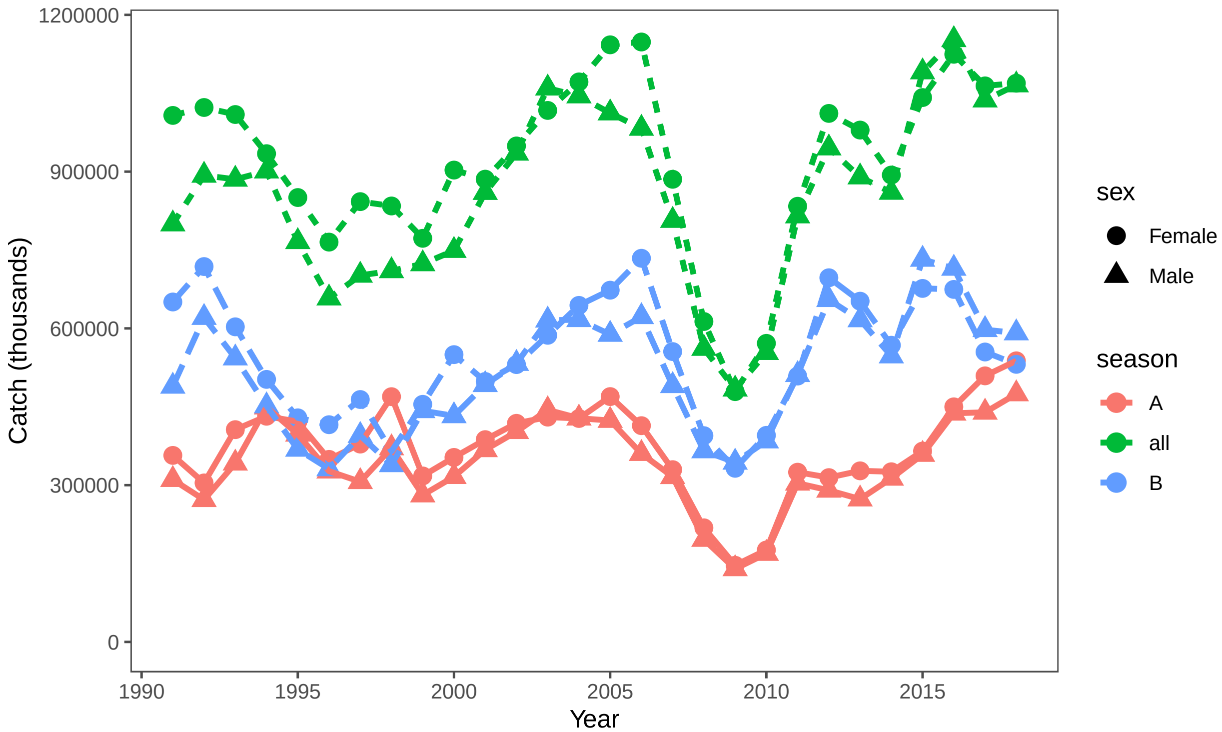


Figure 2: Estimate of EBS pollock catch numbers by sex for the A season (January-May) and B seasons (June-October) and total.

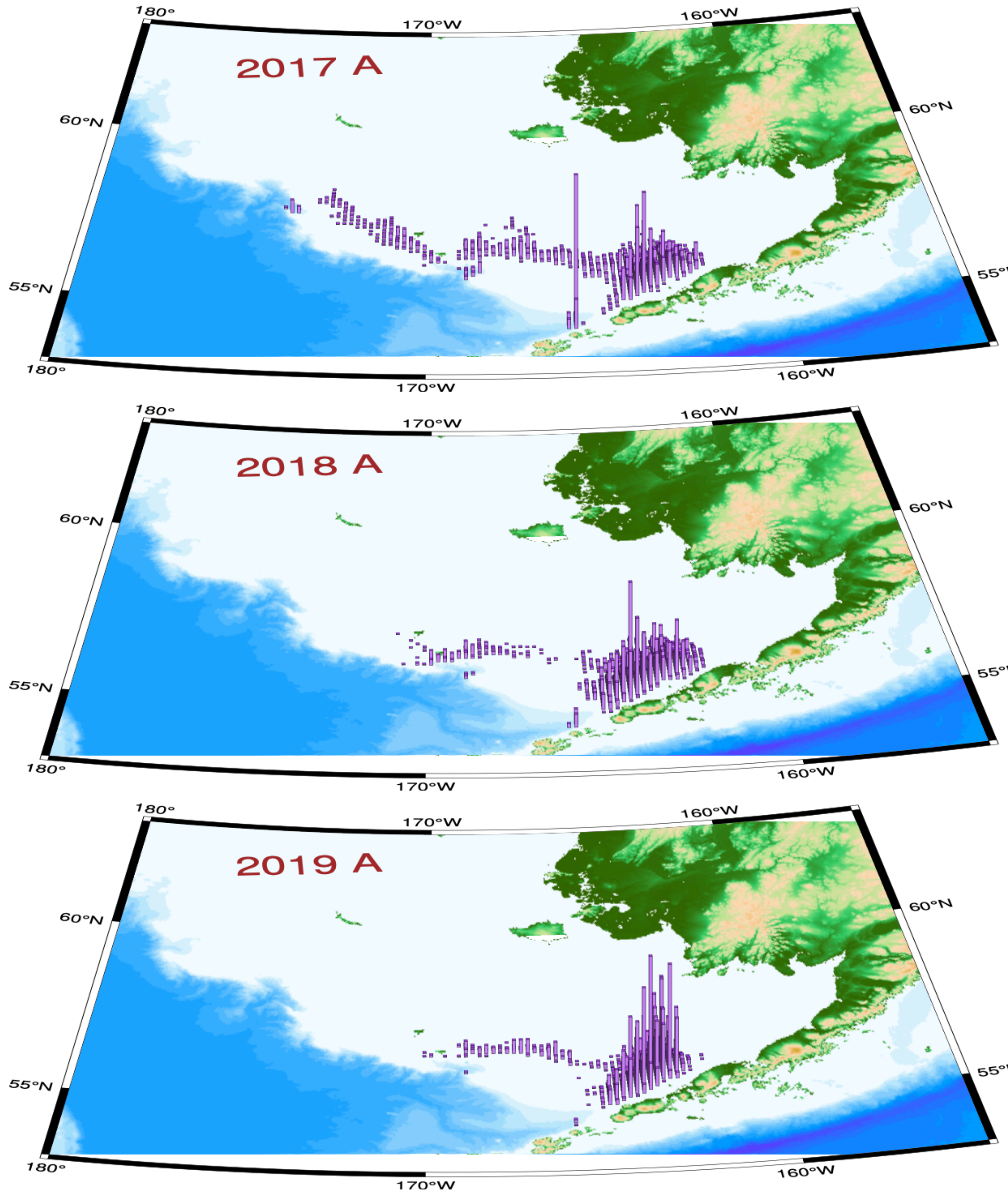


Figure 3: EBS pollock catch distribution during A-season, 2017–2019. Column height is proportional to total catch.

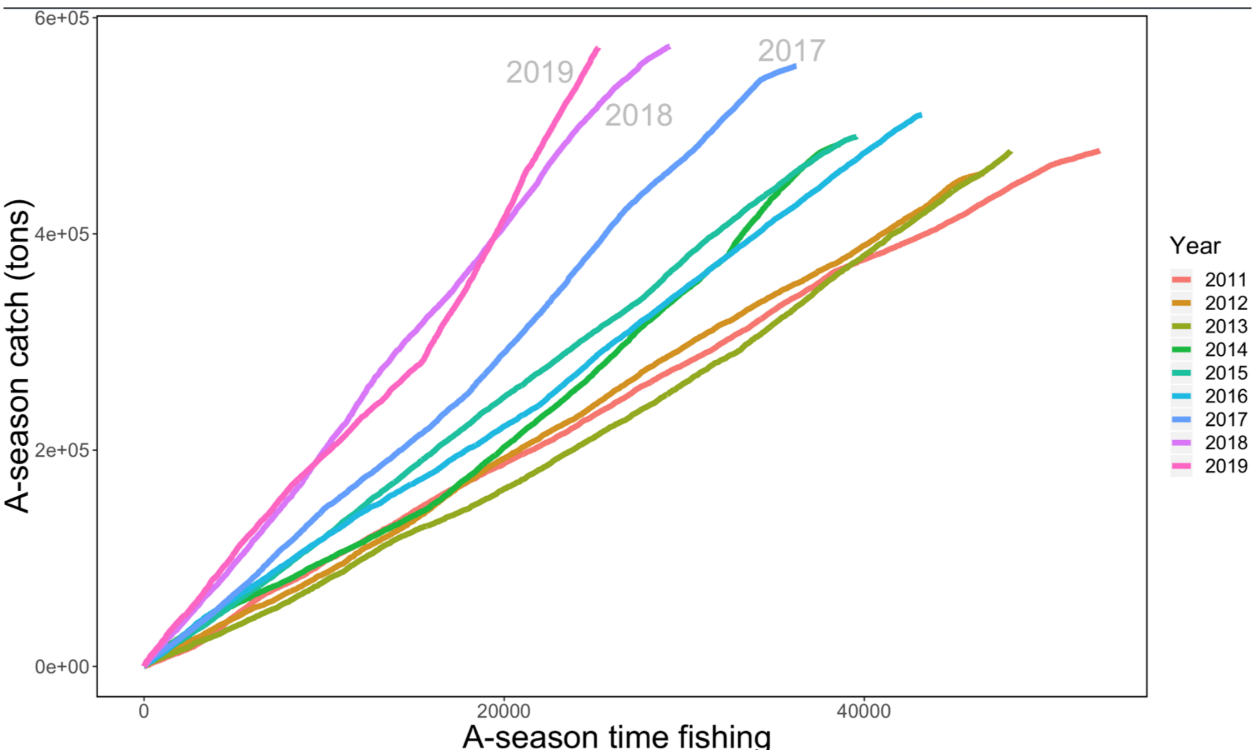


Figure 4: A-season EBS fleet-wide nominal pollock catch (kg) per hour of fishing recorded by NMFS scientific observers.

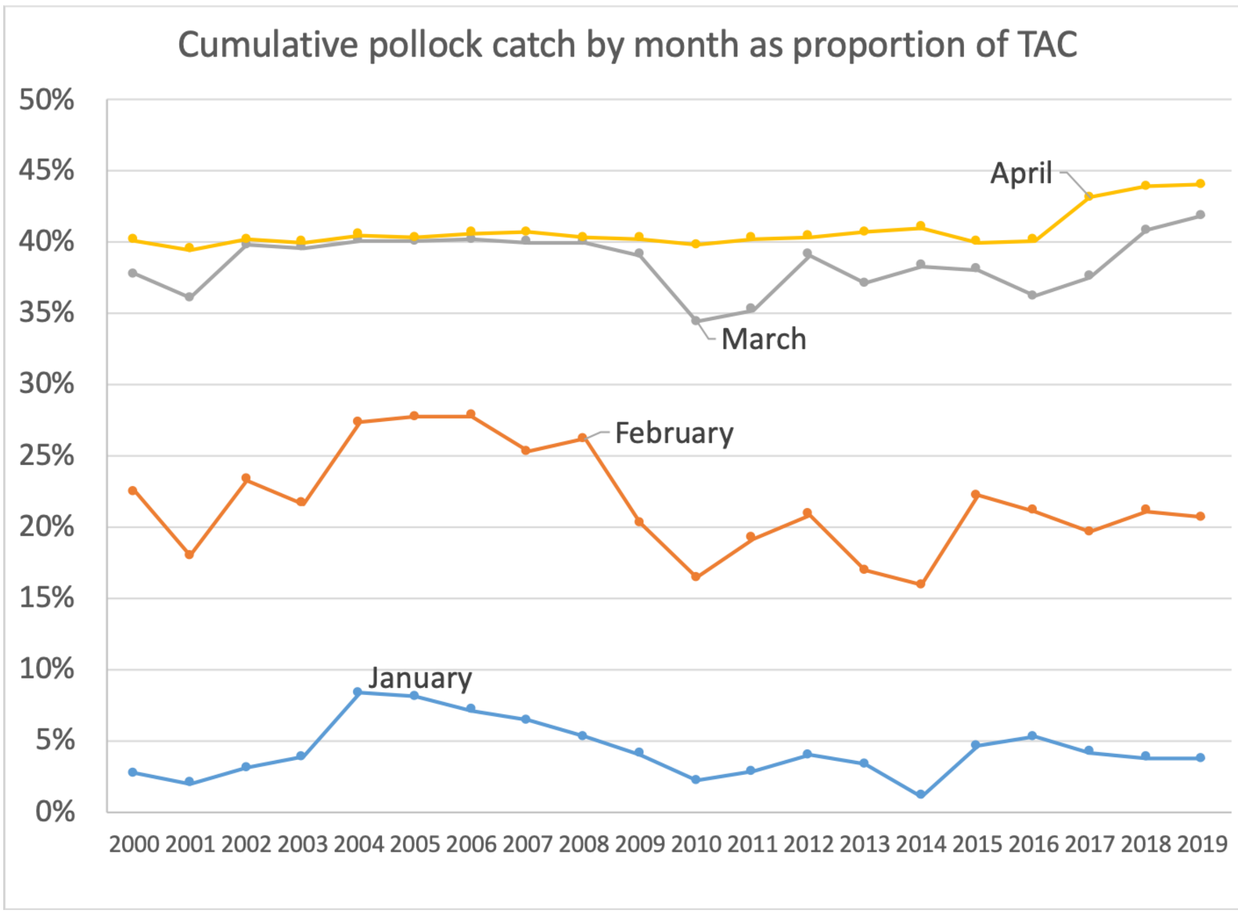


Figure 5: Proportion of the annual EBS pollock TAC by month during the A-season, 2000–2019. The higher value observed since 2017 was due to Amendment 110 of the FMP to allow greater flexibility to avoid Chinook salmon.

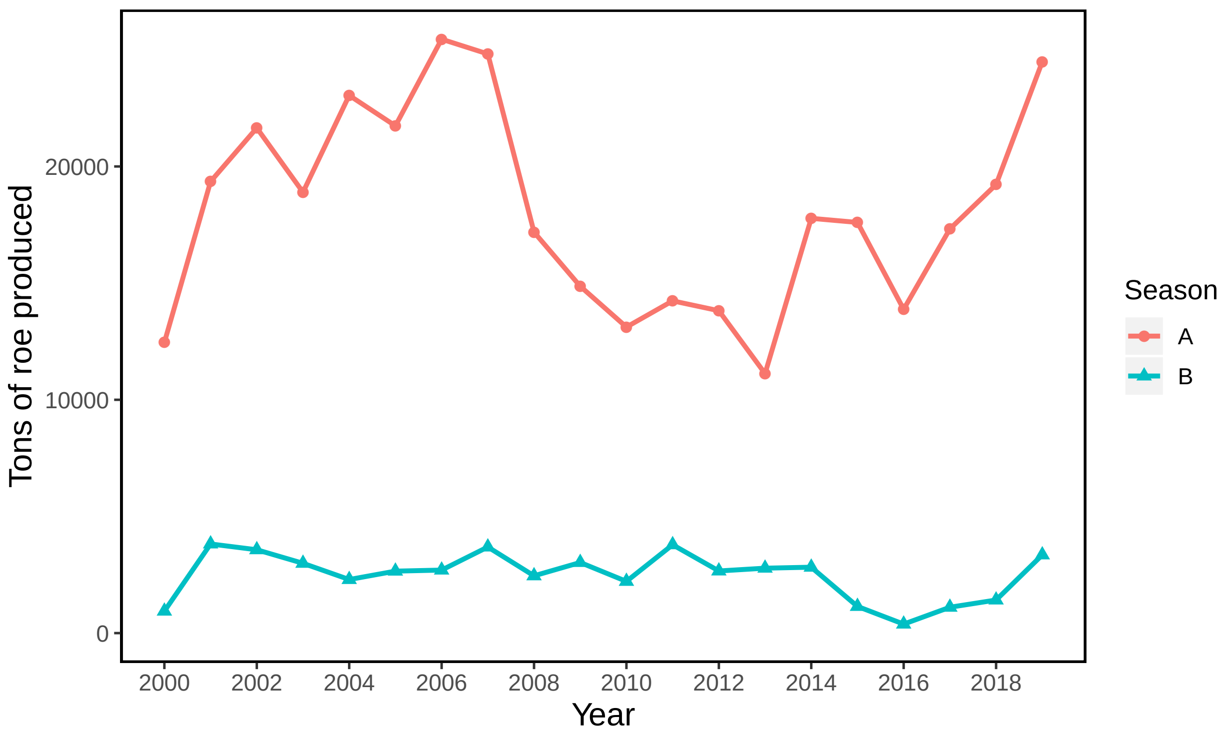


Figure 6: EBS pollock roe production in A and B seasons , 2000-2019.

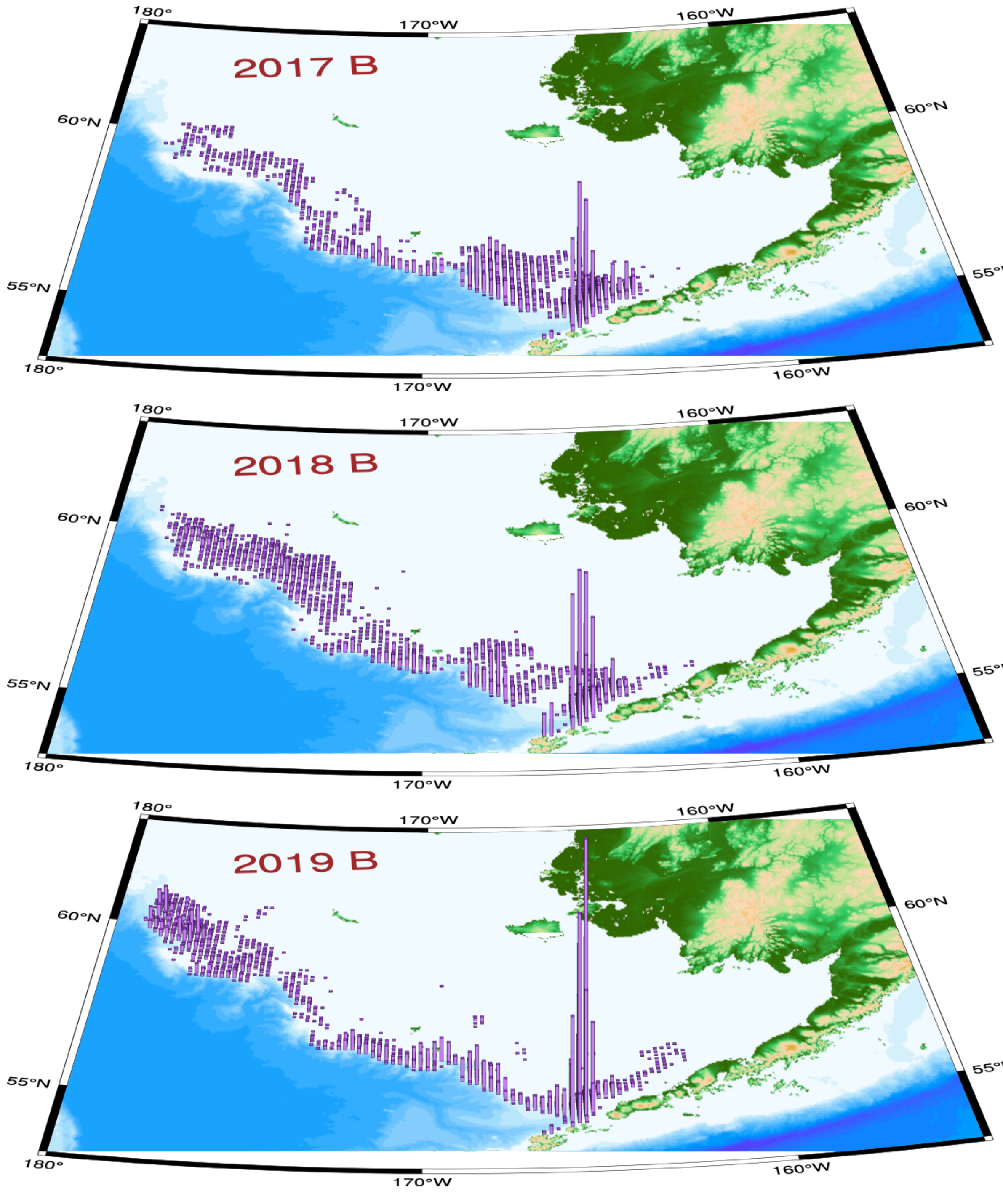


Figure 7: EBS pollock catch distribution during B-season, 2017–2019. Column height is proportional to total catch. Note that directed fishery for pollock generally is finished prior to October; the labels are indicative full-year catches.

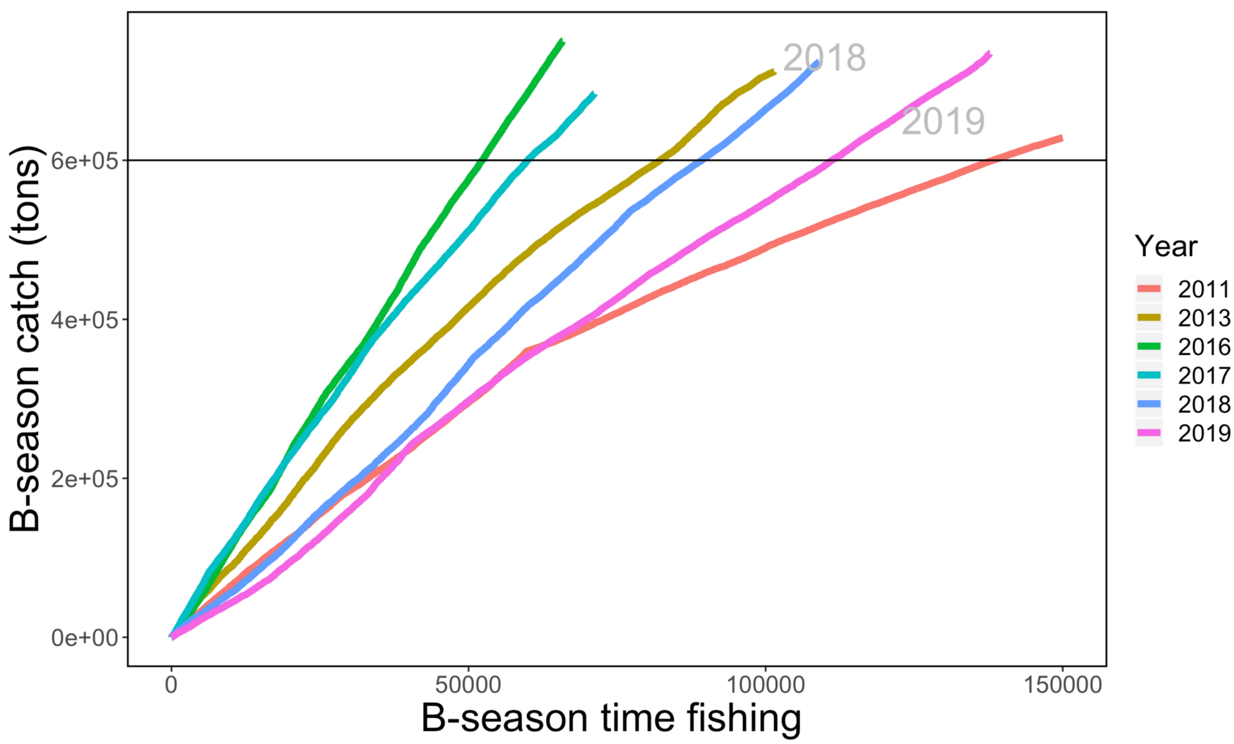


Figure 8: B-season EBS fleet-wide nominal pollock catch (kg) per hour of fishing recorded by NMFS scientific observers.

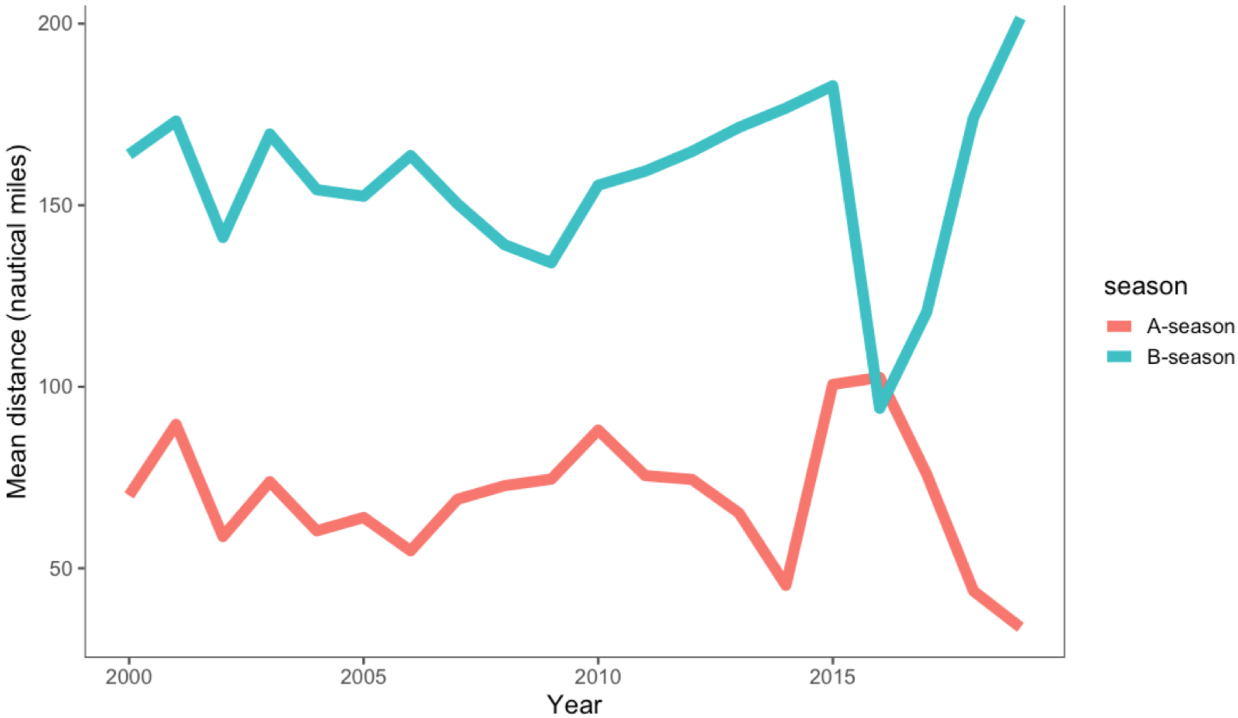


Figure 9: Estimated mean daily distance between operations, 2000-2019.

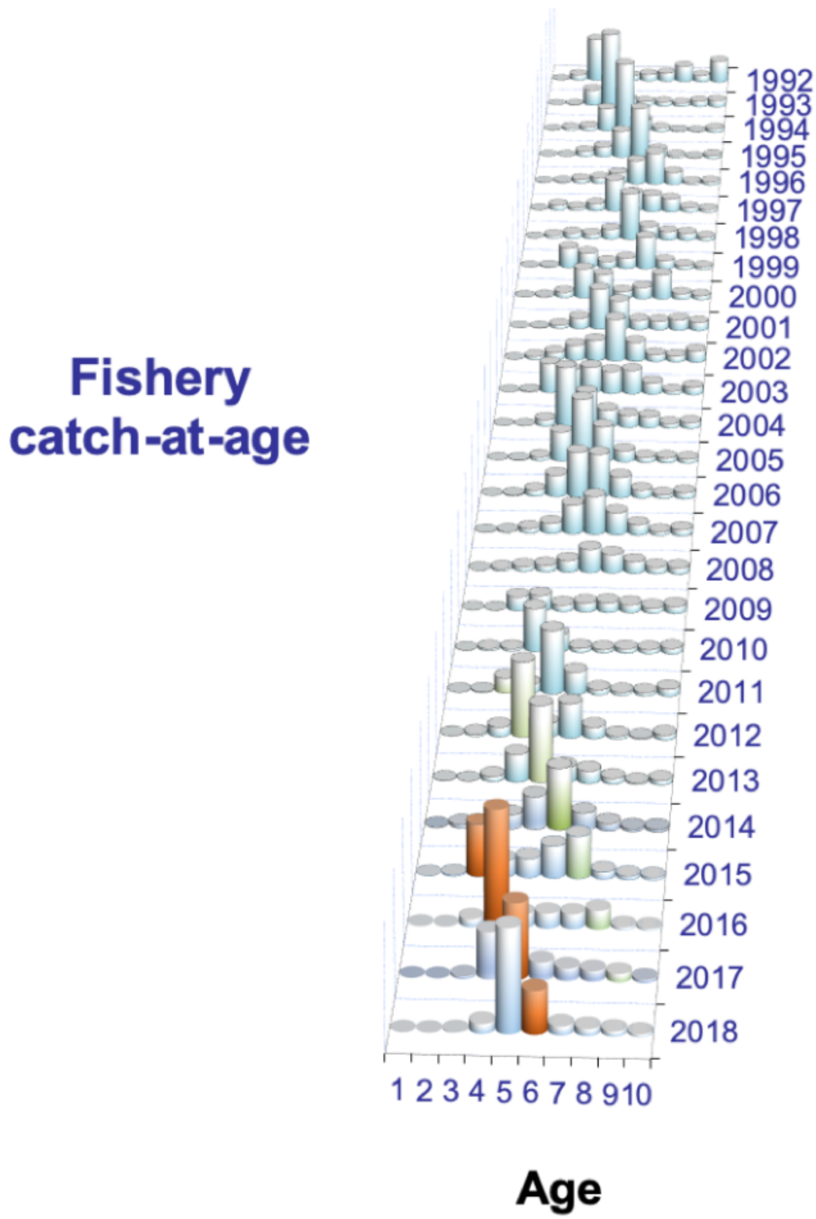


Figure 10: EBS pollock fishery estimated catch-at-age data (in number) for 1992–2018. Age 10 represents pollock age 10 and older. The 2008 year-class is shaded in green.

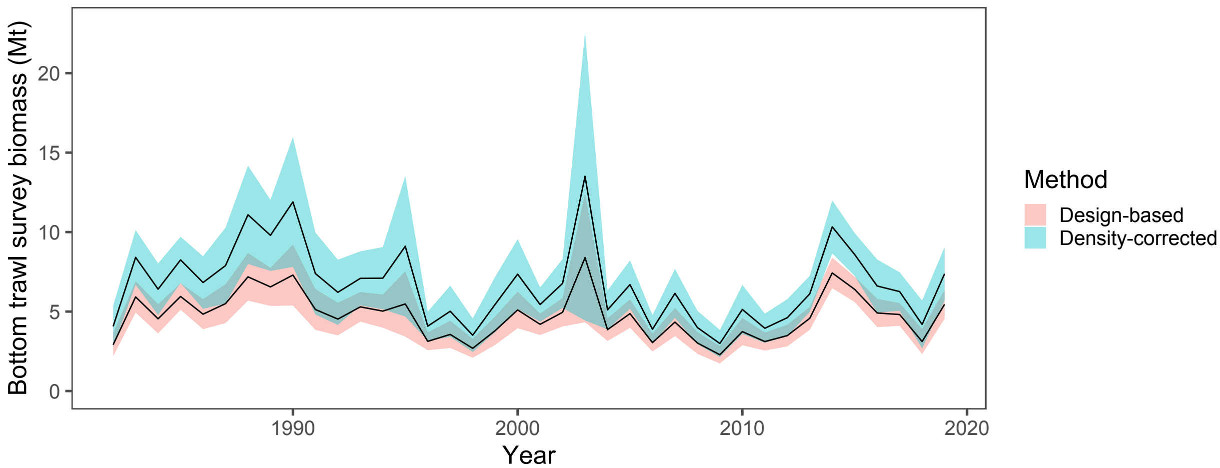


Figure 11: Bottom-trawl survey biomass estimates with error bars representing 1 standard deviation (for design-based and density-dependent correction method) for EBS pollock.

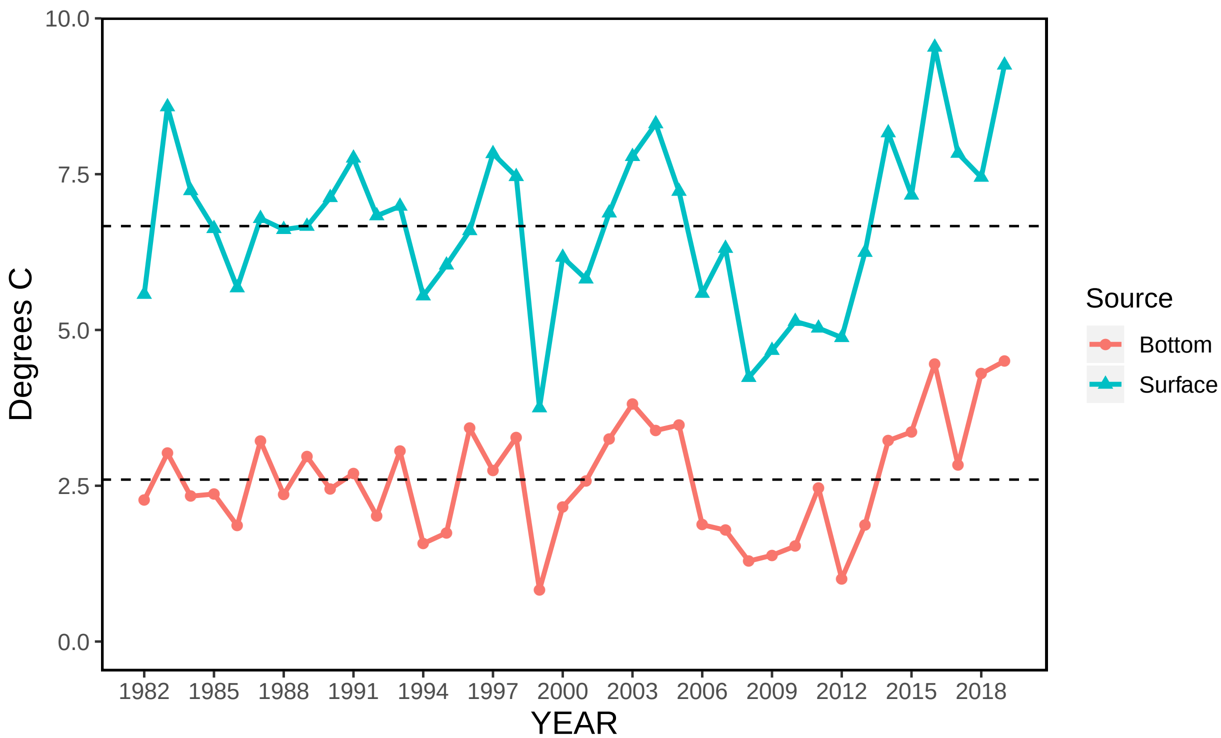


Figure 12: Bottom and surface temperatures for the Bering Sea from the NMFS summer bottom-trawl surveys (1982–2018). Dashed lines represent mean values.

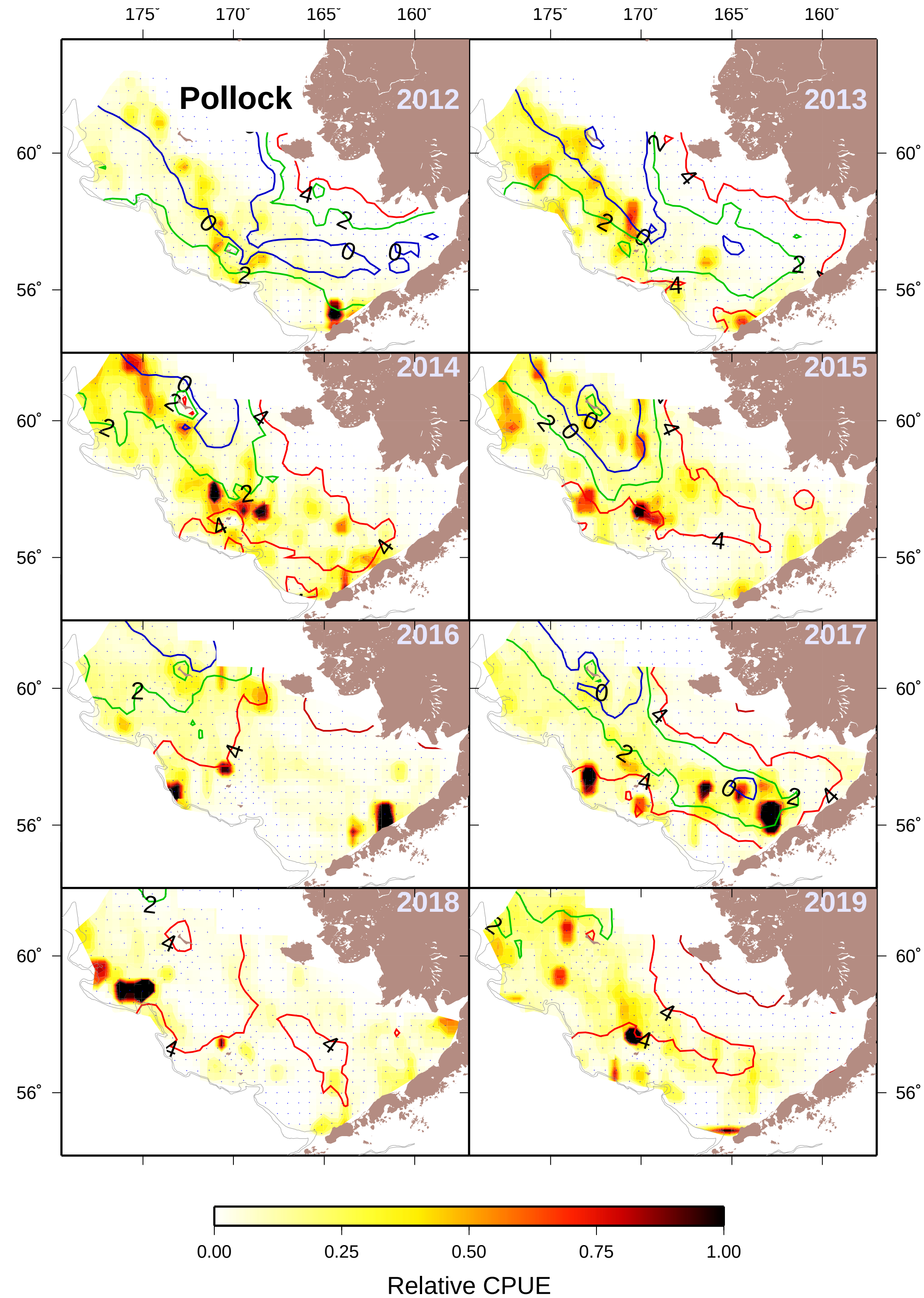


Figure 13: EBS pollock CPUE (shades = relative kg/hectare) and bottom temperature isotherms in degrees C; from the bottom trawl survey data 2011–2018.

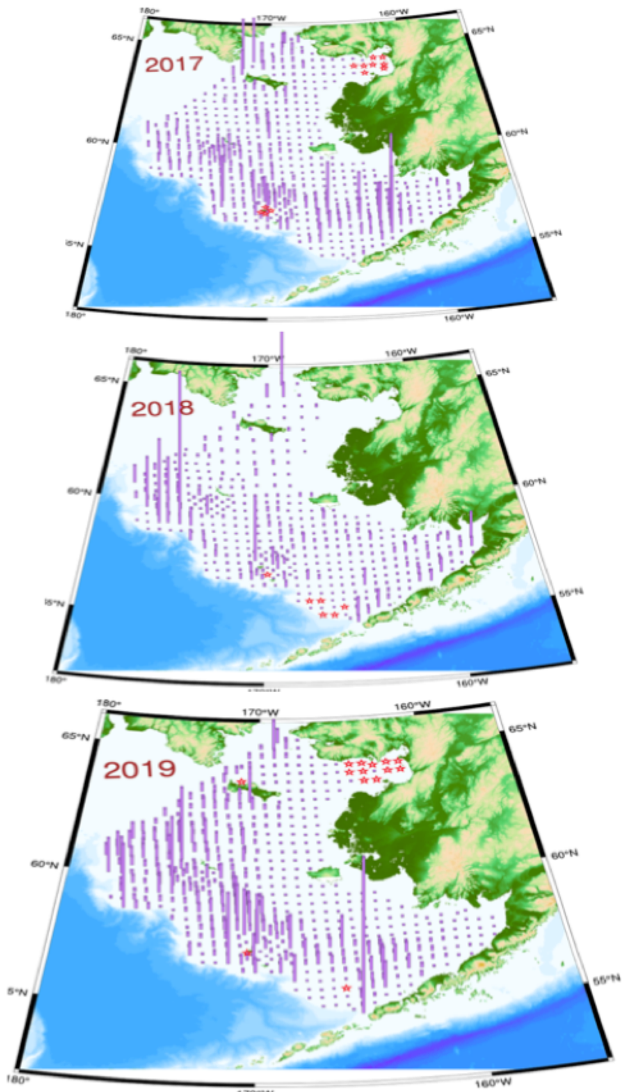


Figure 14: Bottom trawl survey pollock catch in kg per hectare for 2017 - 2019. Height of vertical lines are proportional to station-specific pollock densities by weight (kg per hectare) with constant scales for all years (red stars indicate tows where pollock were absent from the catch).

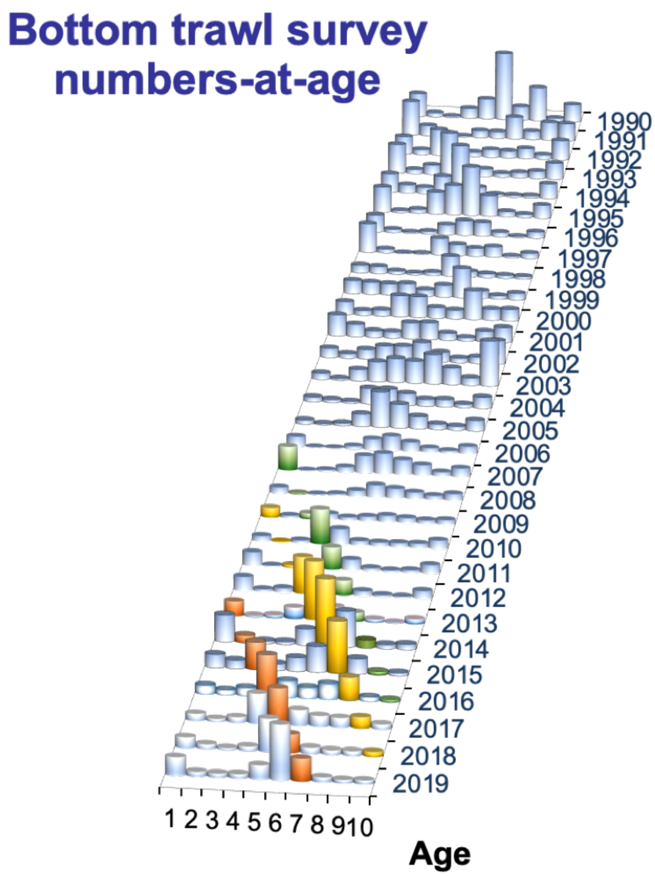


Figure 15: Pollock abundance levels by age and year as estimated directly from the NMFS bottom-trawl surveys (1990–2019). The 2006,2008, and 2012 year-classes are shaded differently.

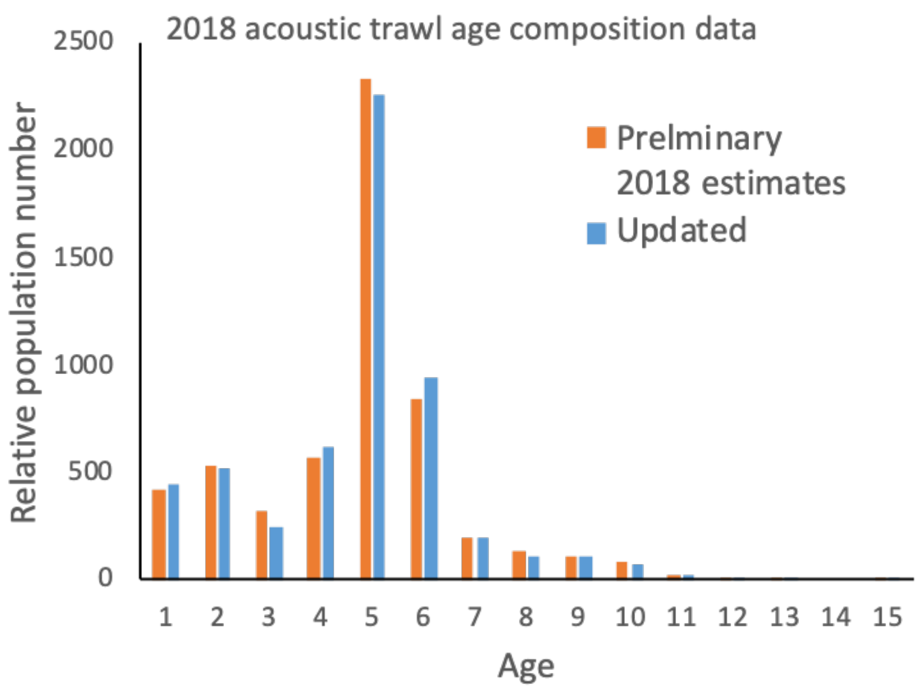


Figure 16: Pollock abundance at age estimates from the AT survey comparing the estimates based primarily on BTS age data used last year and the updates for this year's assessment.

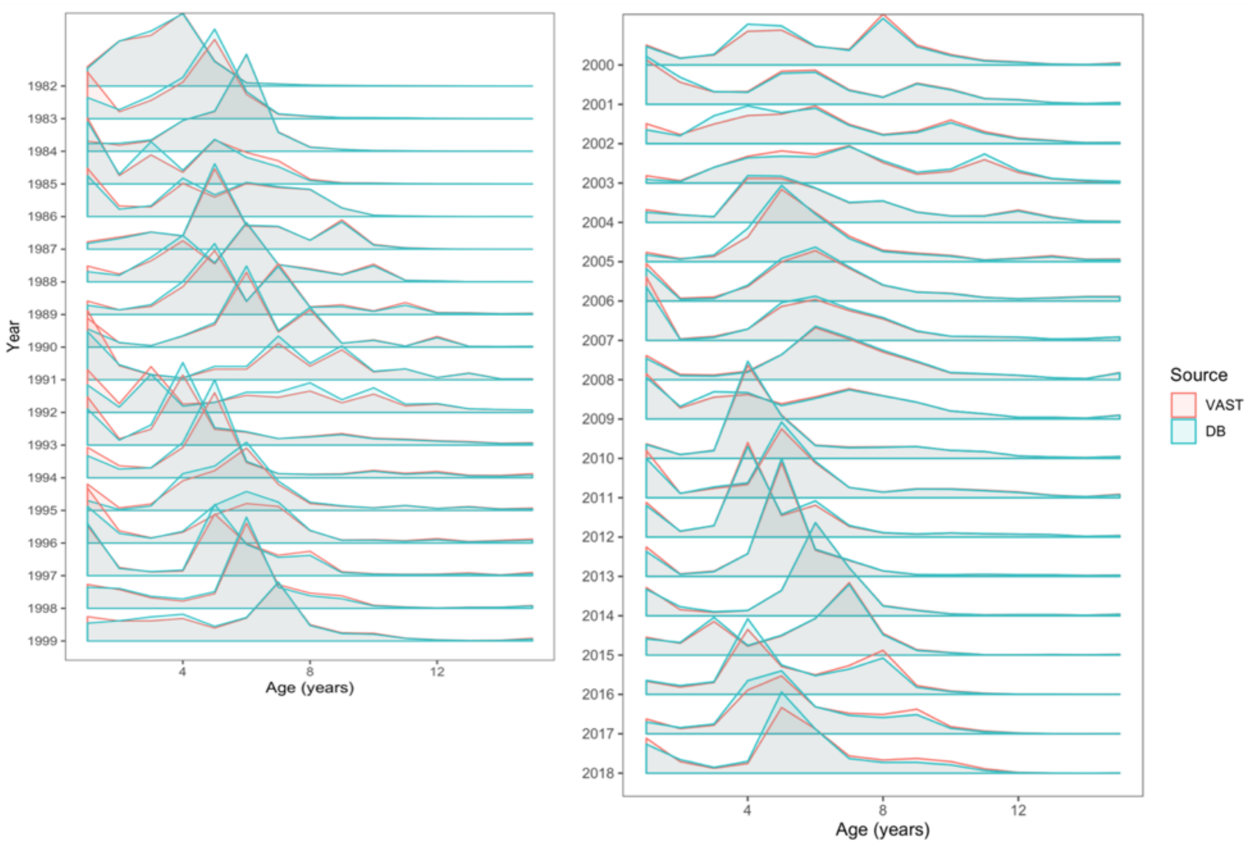


Figure 17: Pollock abundance levels by age and year as estimated directly from the NMFS bottom-trawl surveys (1990–2019) using standard 'design-based' (DB) and VAST approaches.

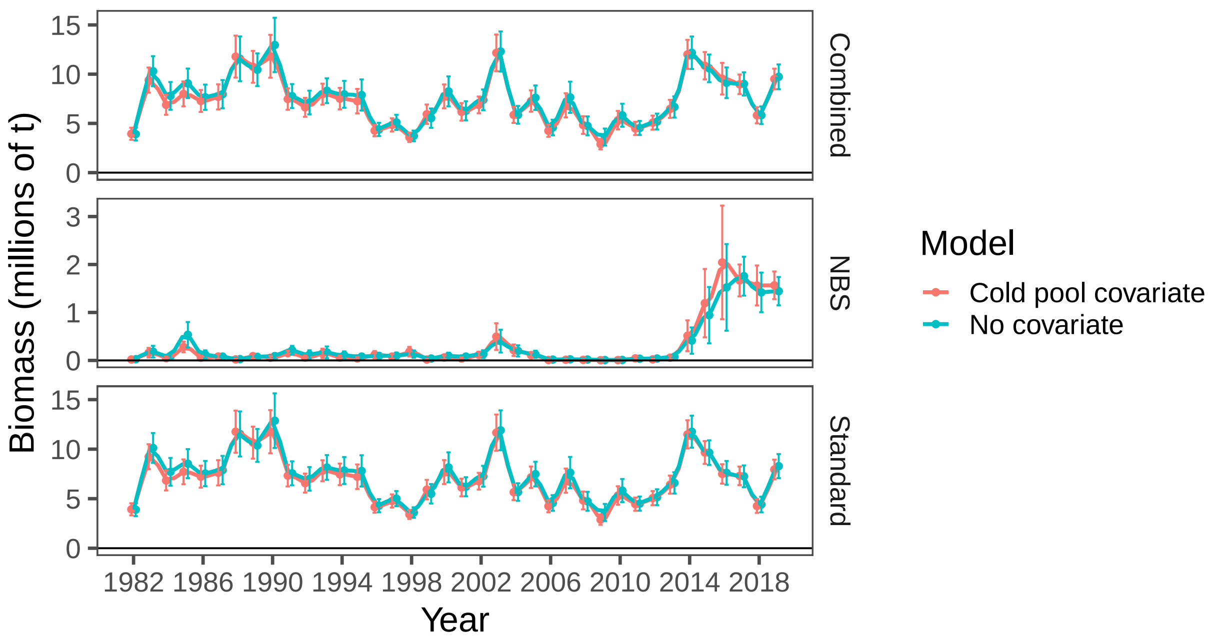


Figure 18: Pollock index values for the standard survey region, the NBS, and combined based on the VAST application to density-dependent corrected CPUE values from the BTS data, 1982–2019. The different lines are smoothed trends for with and without including the cold-pool extent as a covariate.

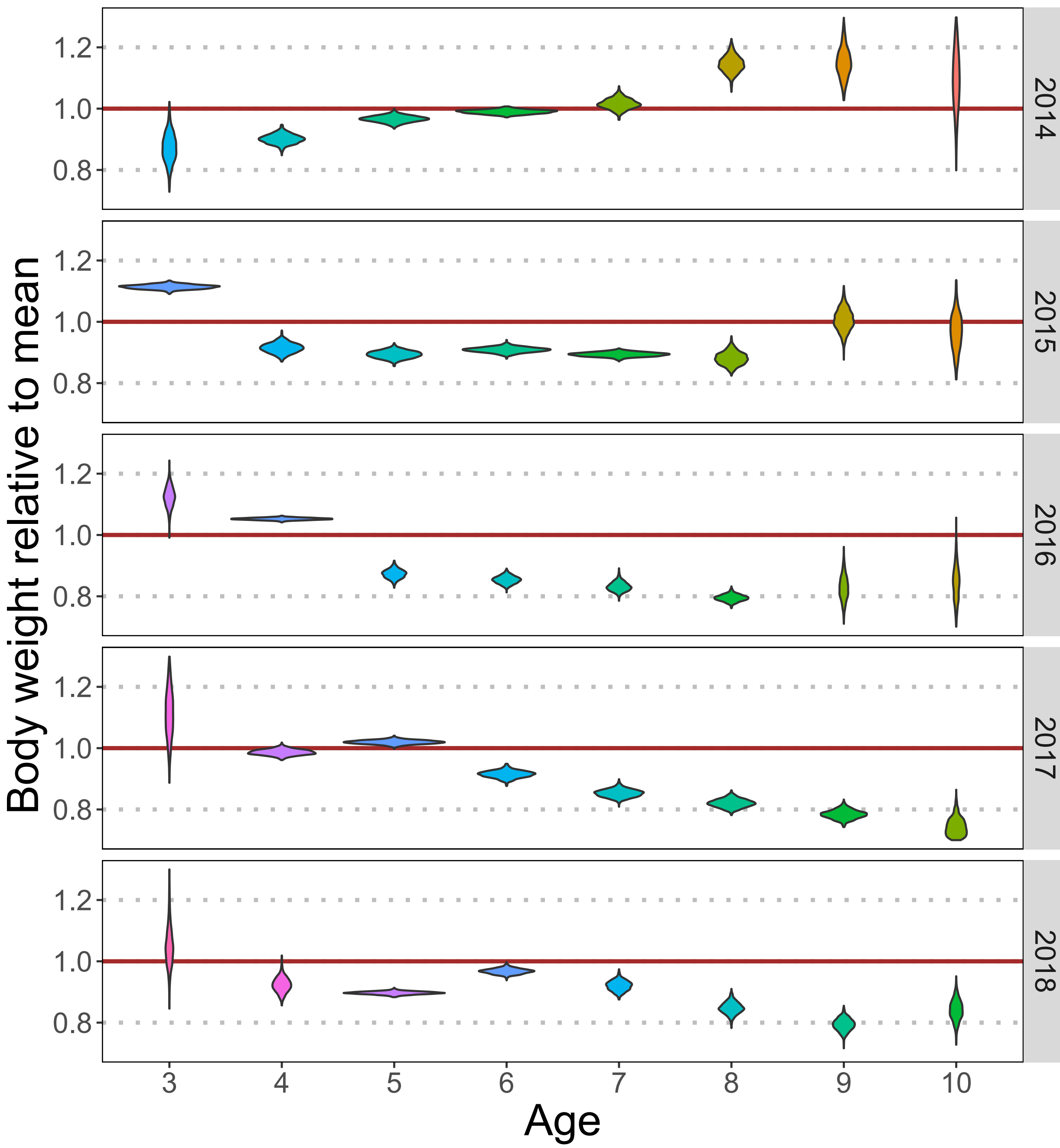


Figure 19: Recent fishery average weight-at-age anomaly (relative to mean) by strata for ages 3–10, 2014–2018. Vertical shape reflects uncertainty in the data (wider shapes being more precise), colors are consistent with cohorts.

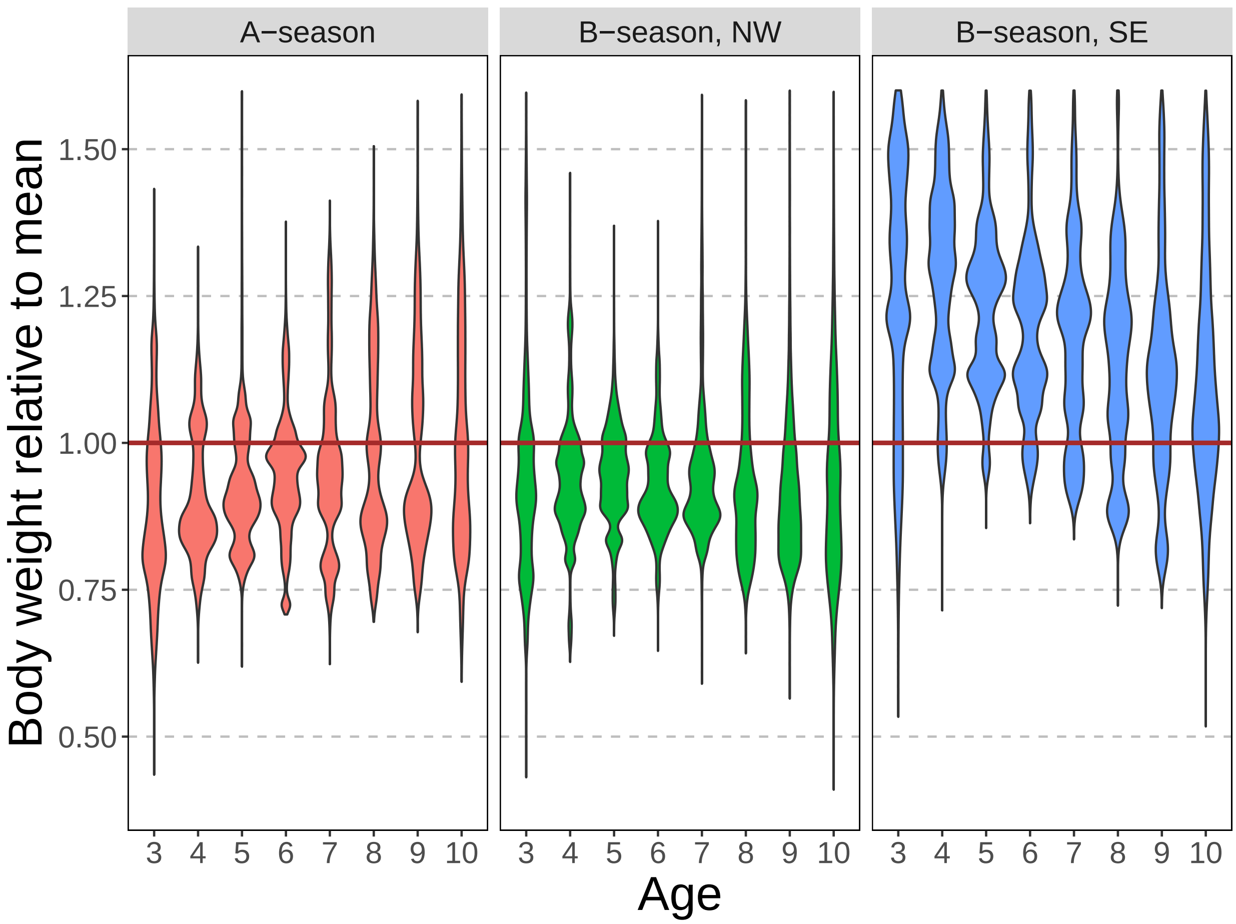


Figure 20: Fishery average weight-at-age anomaly (relative to mean) across strata and combined for all ages (3–10), and available years (1991–2018). Vertical shape reflects uncertainty in the data (wider shapes being more precise), colors are consistent with cohorts.

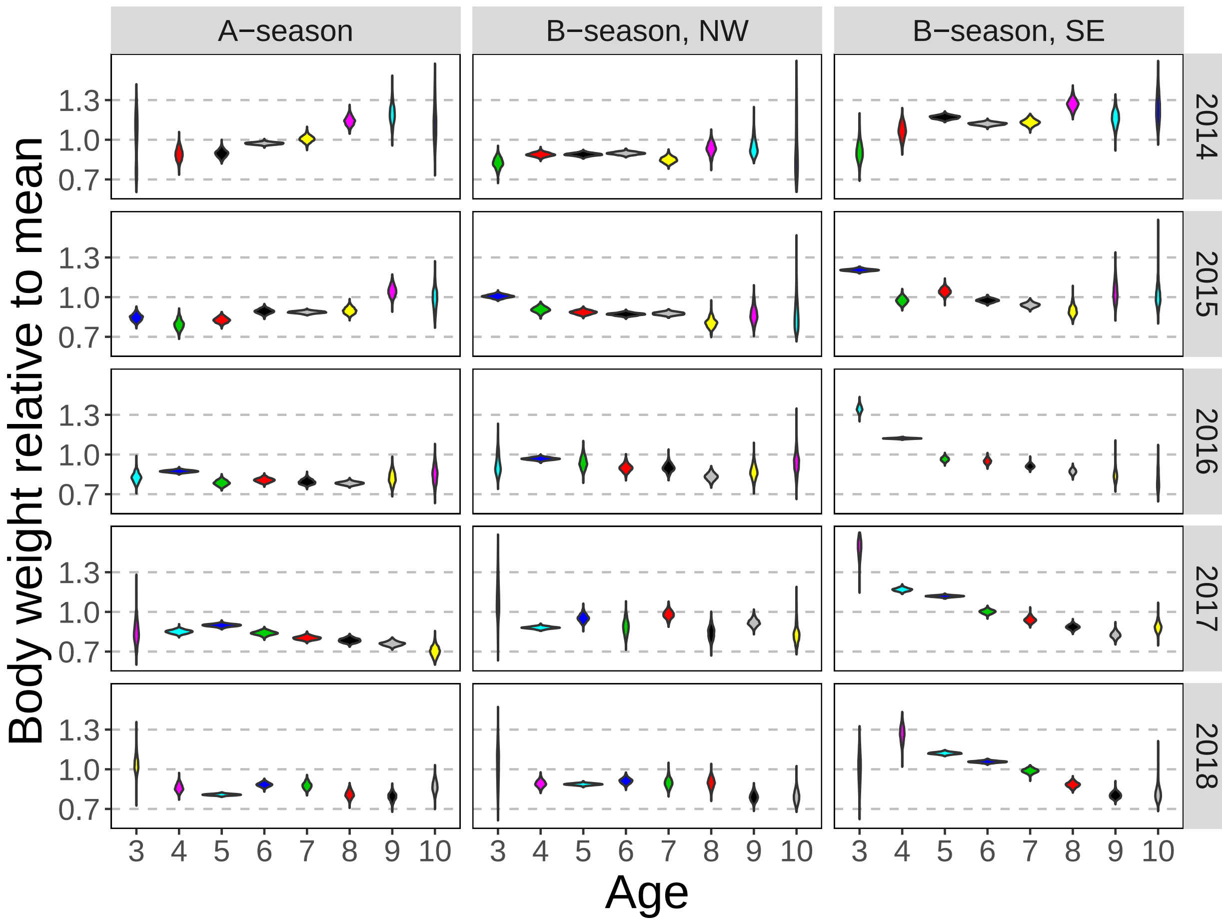


Figure 21: Recent fishery average weight-at-age anomaly (relative to mean) by strata for ages 3–10, 2014–2018. Vertical shape reflects uncertainty in the data (wider shapes being more precise), colors are consistent with cohorts.

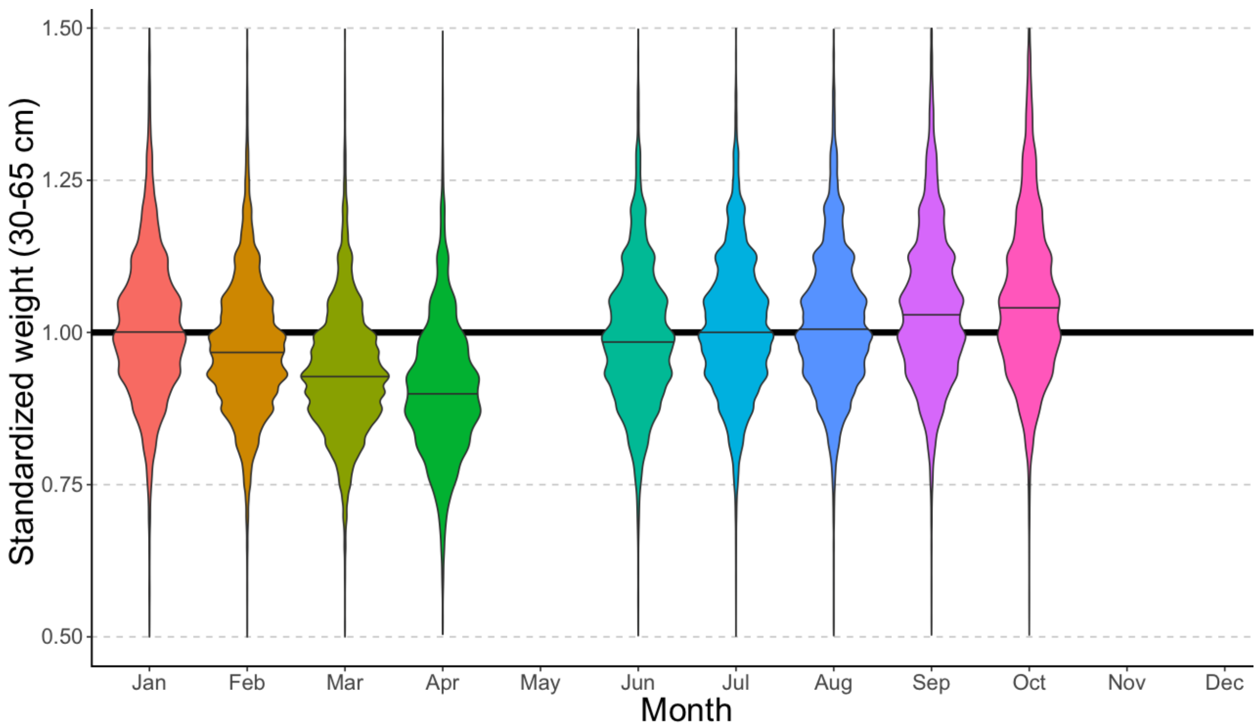


Figure 22: EBS pollock fishery body mass (given length) anomaly (standardized by overall mean body mass at each length) by month based on some over 700 thousand fish measurements from 1991–2018.

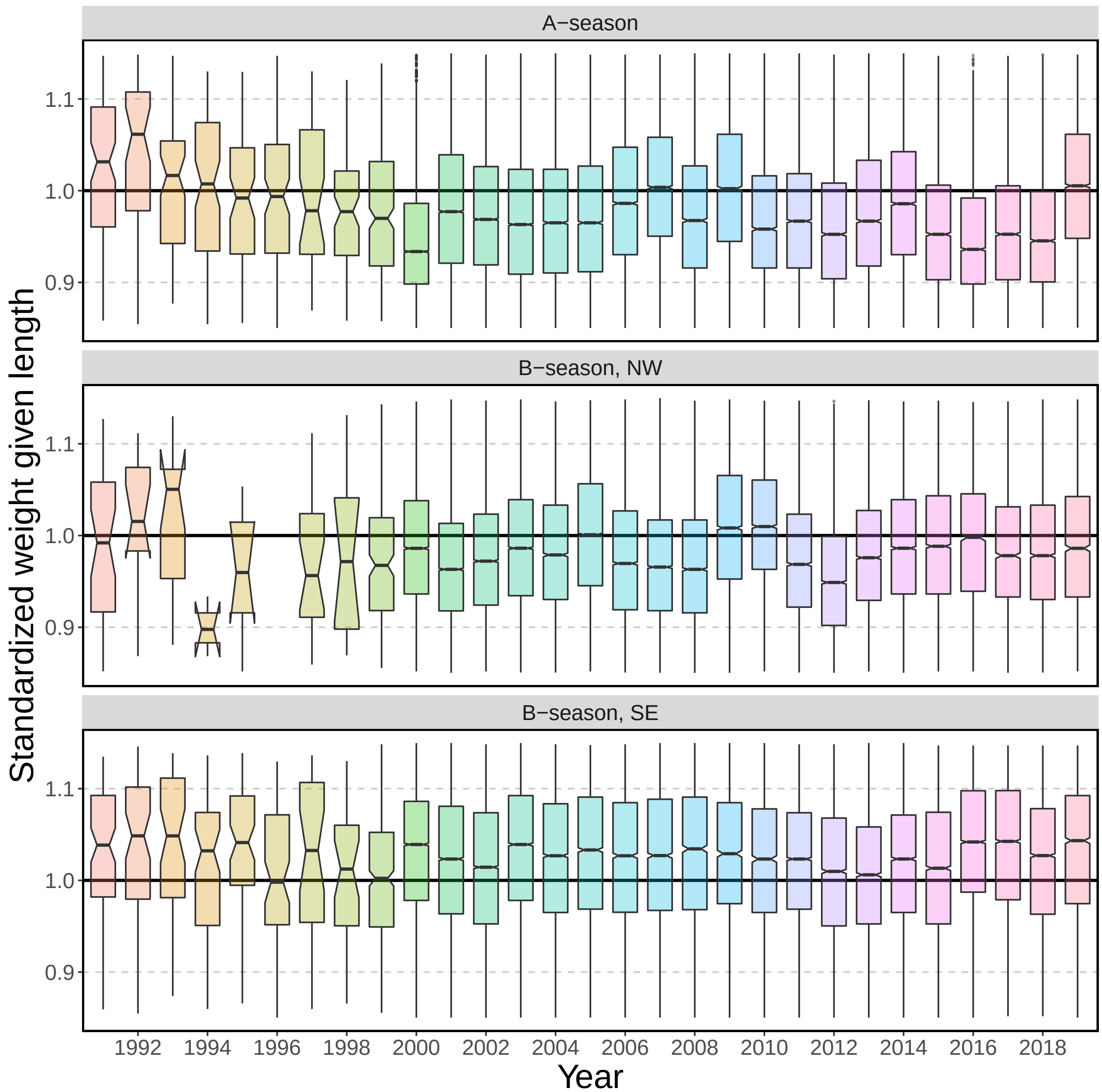


Figure 23: EBS pollock fishery body mass (given length) anomaly (standardized by overall mean body mass at each length) by year and season/area strata, 1991–2019.

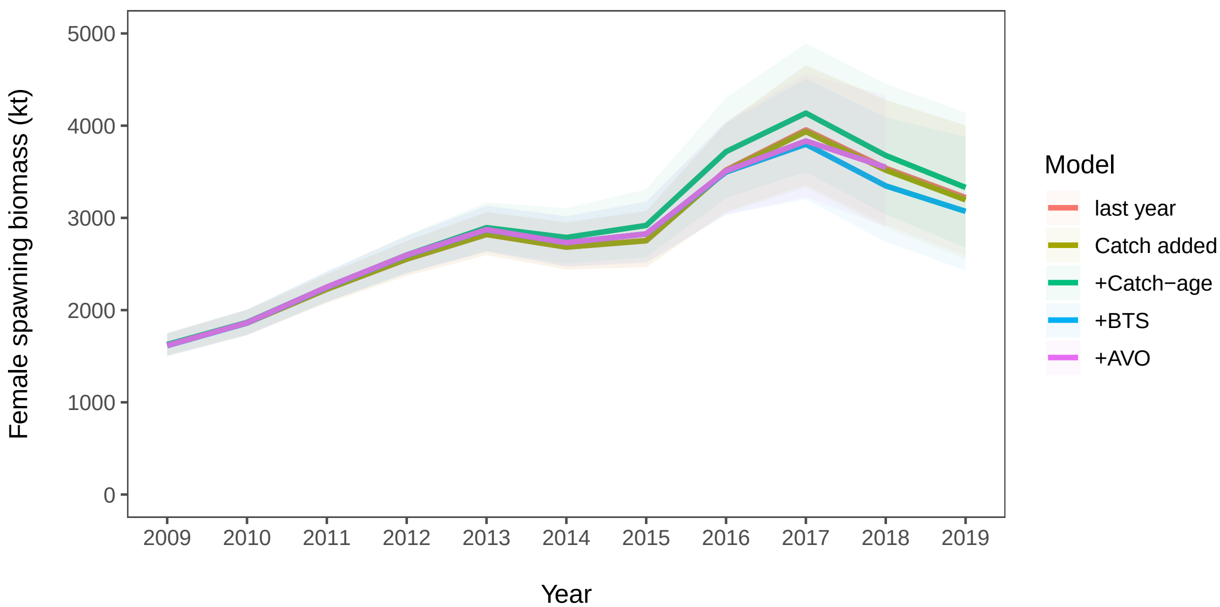


Figure 24: Model runs comparing last year's assessment with the impact of sequentially adding new data (first 2019 catch and 2018 fishery catch-at-age, then the bottom trawl survey (BTS) and the acoustic AVO data for model 16.1.

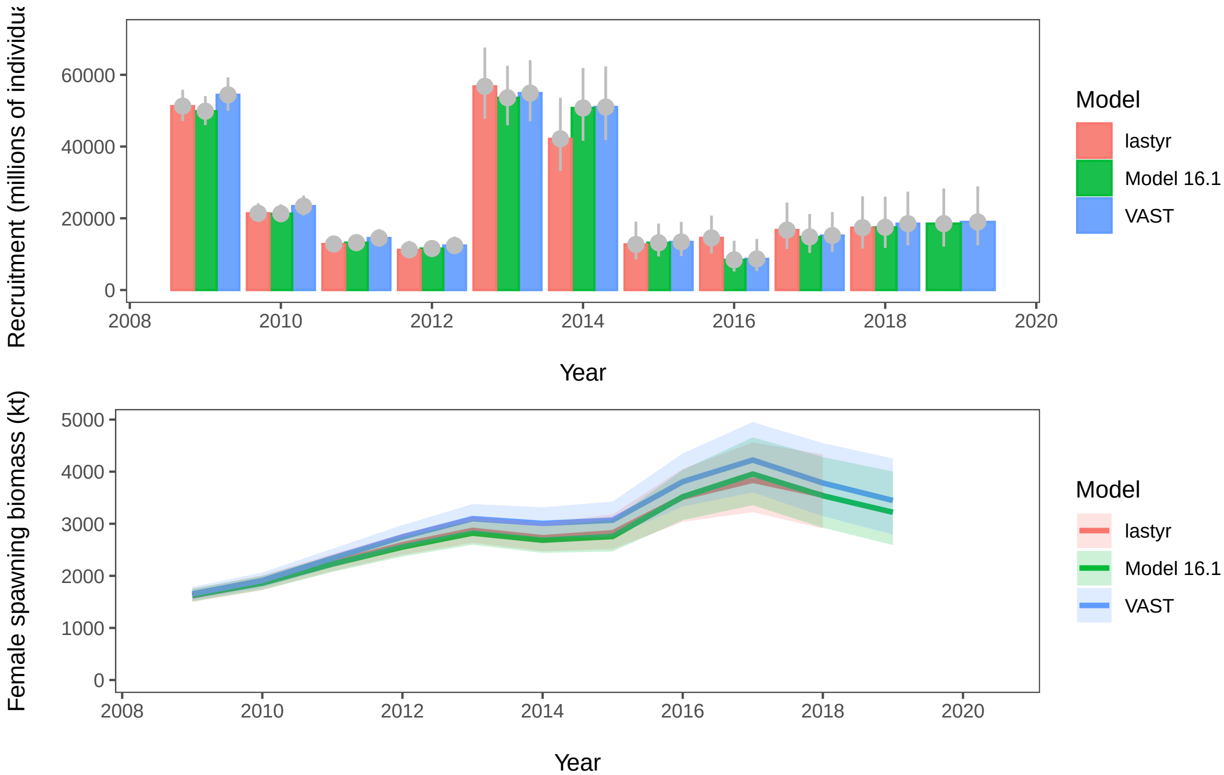


Figure 25: EBS pollock model evaluation results of recruitment comparing last year's model with this year.

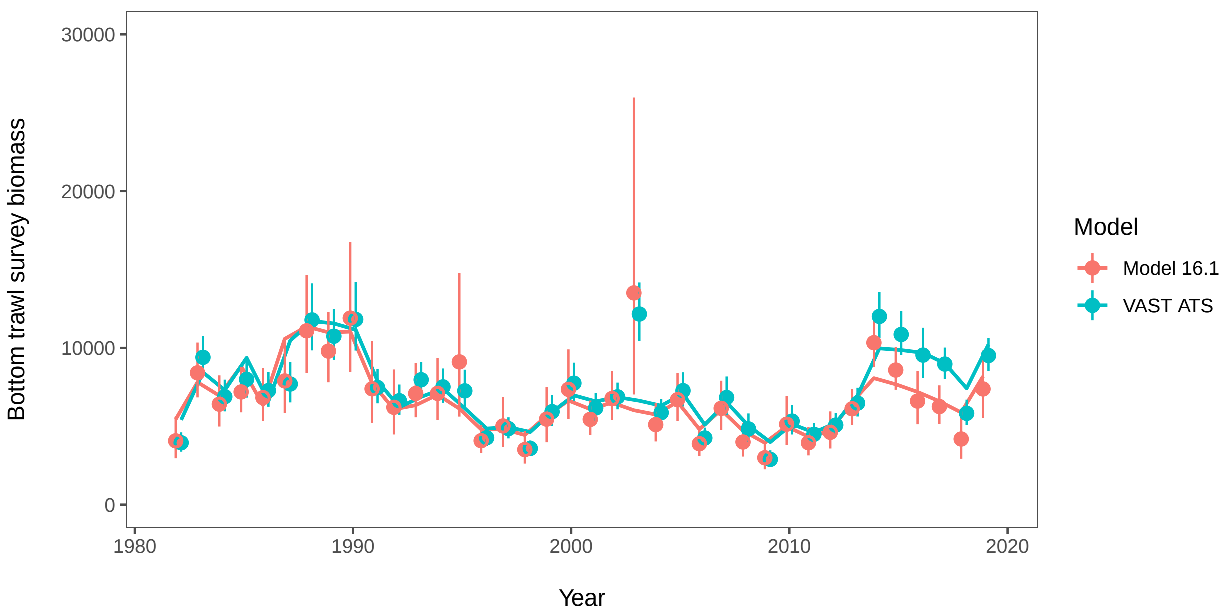


Figure 26: EBS pollock model evaluation results of female spawning biomass comparing model results with different data treatments.

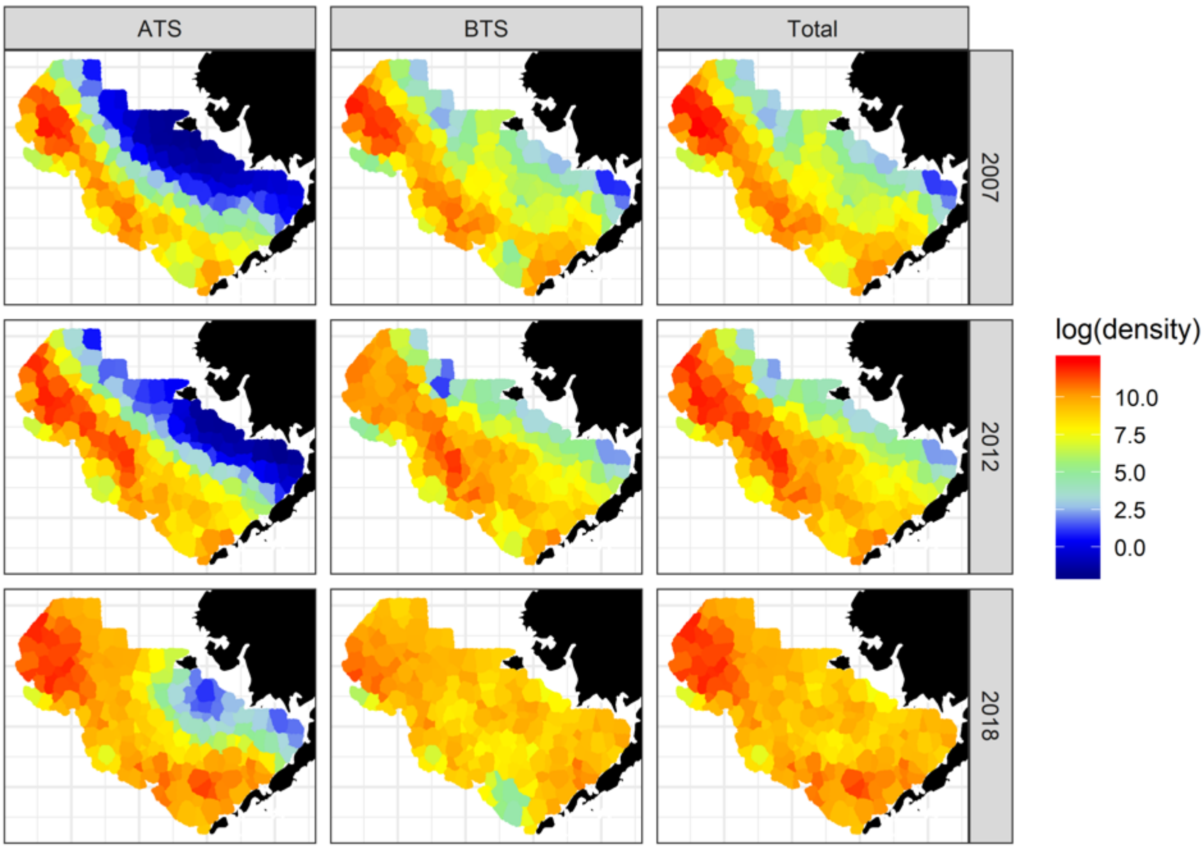


Figure 27: Estimated log-density (color) of pollock for three select years (rows) for the base case combined model. Columns represent the density available to the gear types, which for the ATS is the sum of strata 2 and 3, and for the BTS is the sum of strata 1 and 2, while the total is the sum of all three.

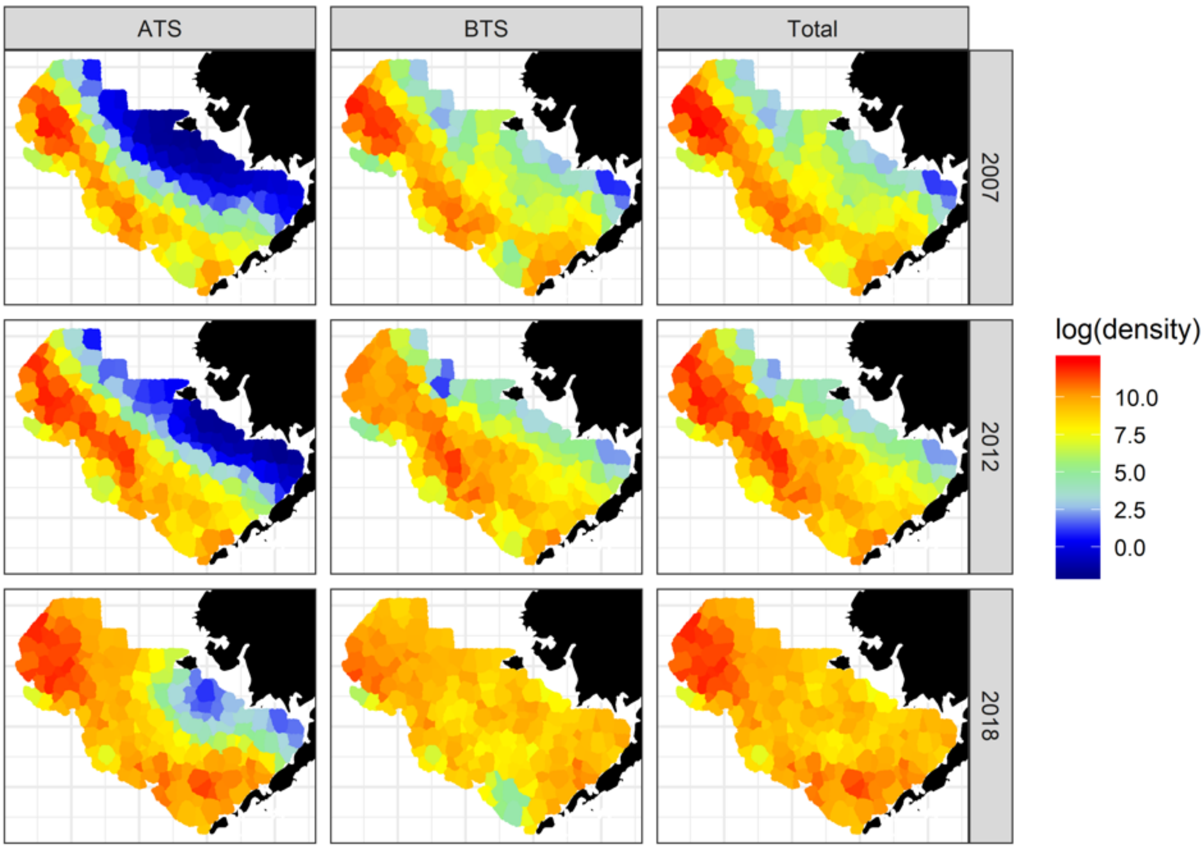


Figure 28: Estimated log-density (color) of pollock for three select years (rows) for the base case combined model. Columns represent the density available to the gear types, which for the ATS is the sum of strata 2 and 3, and for the BTS is the sum of strata 1 and 2, while the total is the sum of all three.

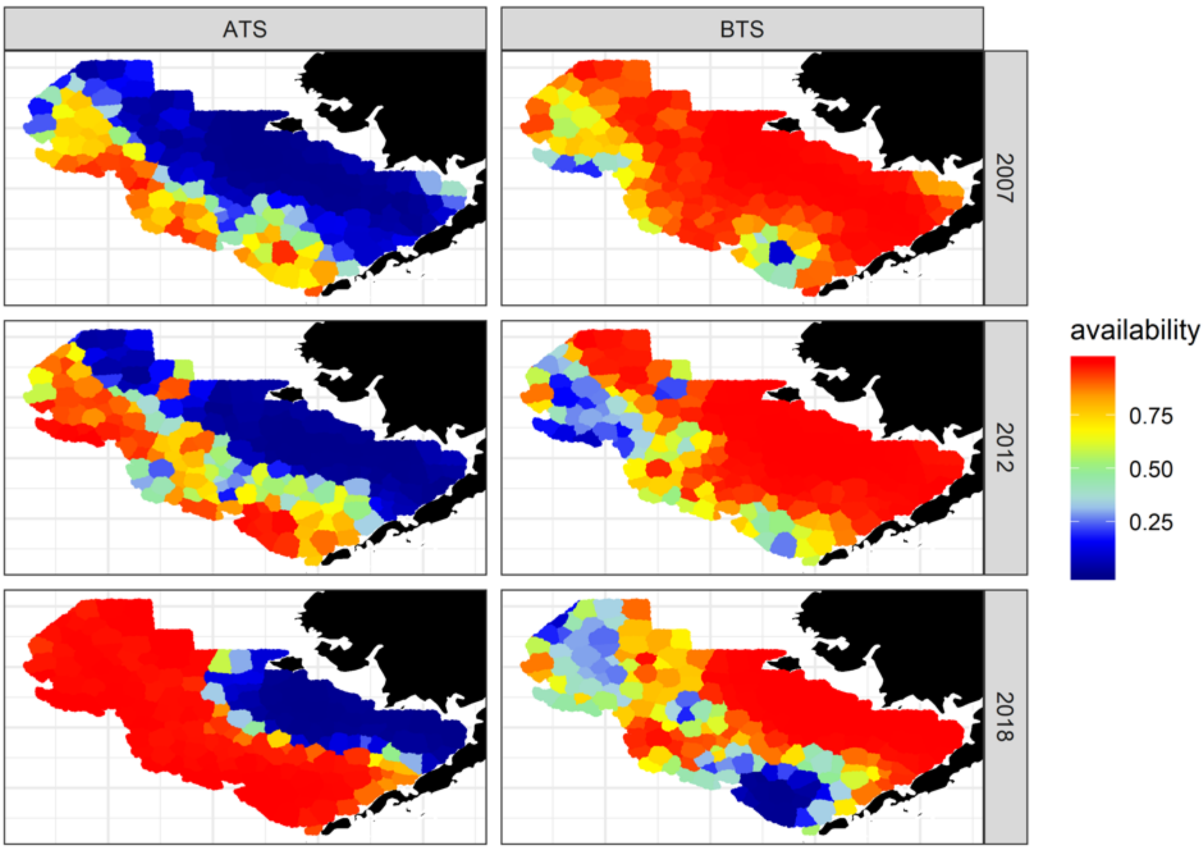


Figure 29: Estimated availability (i.e., fraction of pollock available to a survey gear type) for three select years (rows) for the bottom (BT) and acoustic (AT) trawl surveys (columns) from the combined base case model.

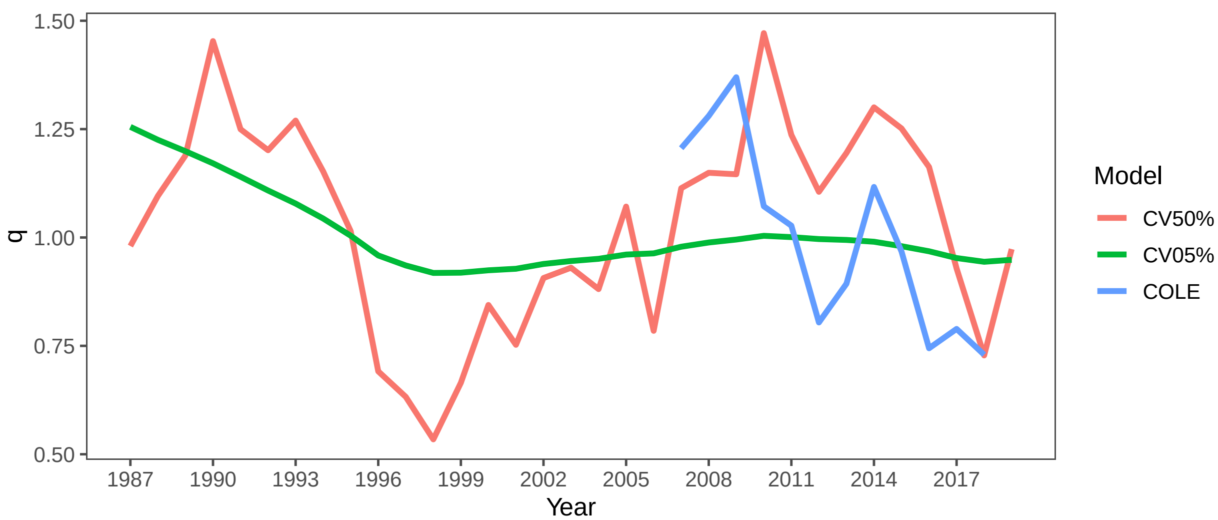
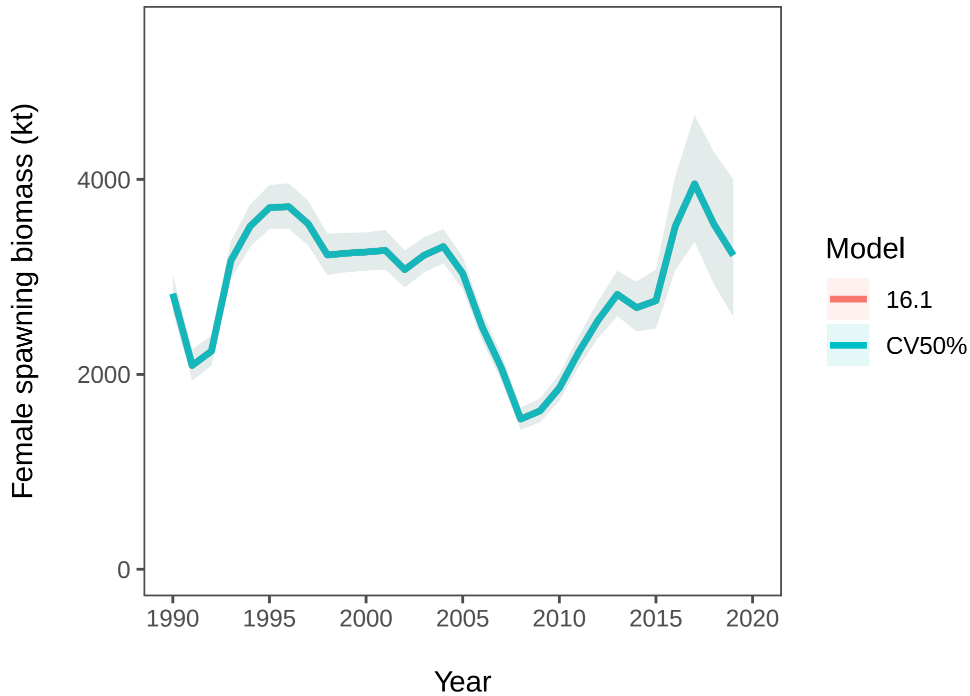


Figure 30: Results of effective BTS survey catchability/availability for different levels of constraints on time-varying selectivity parameters, together with the estimate from the COLE model.



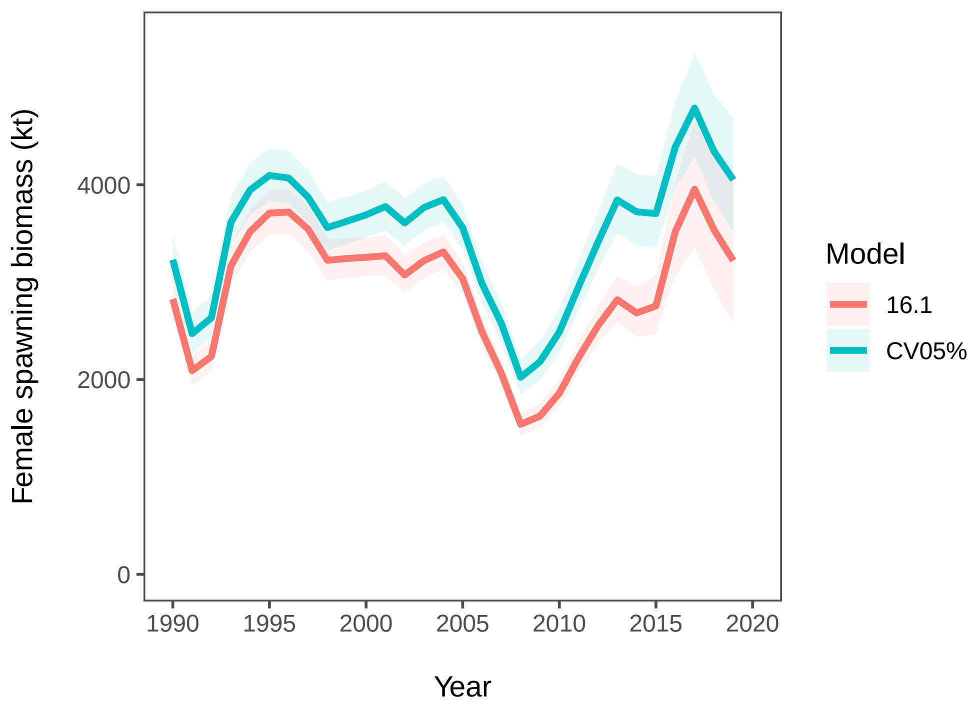


Figure 31: The estimated spawning stock biomass for different constraints on time-varying selectivity parameters.

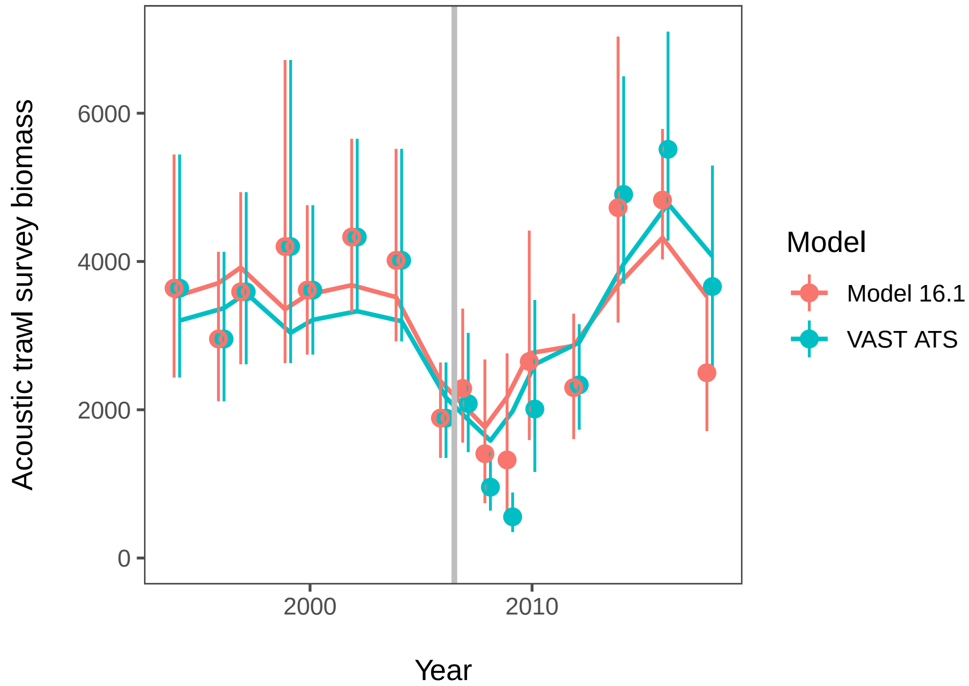


Figure 32: EBS pollock model fit to the ATS biomass data, 1994–2018; green points to the right of vertical grey line are a preliminary treatment of applying a VAST model to the acoustic trawl survey data.

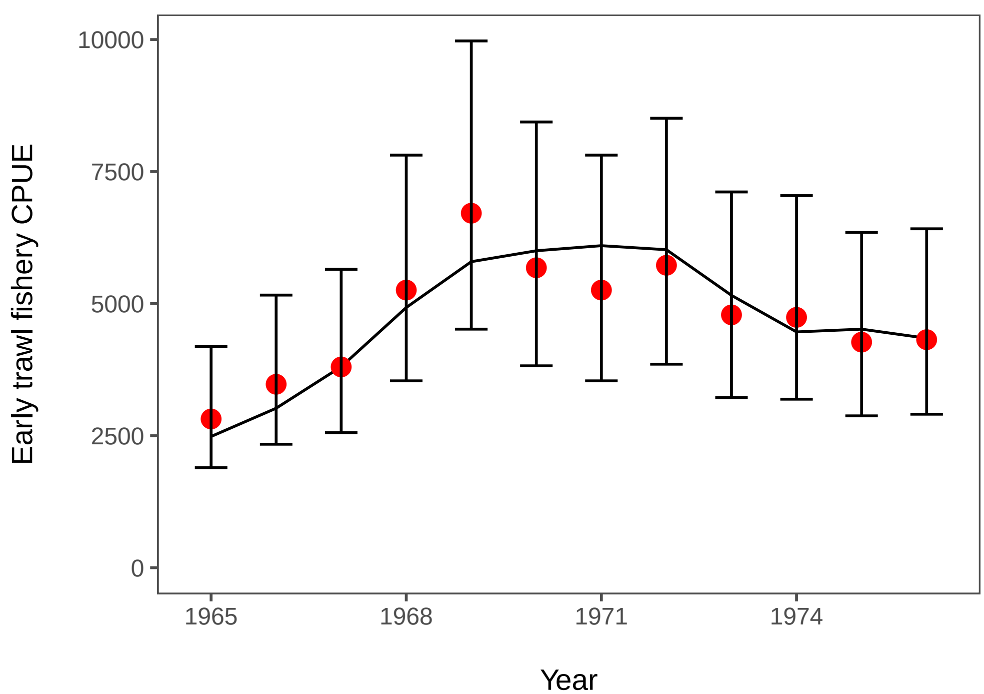


Figure 33: EBS pollock model fits to the Japanese fishery CPUE.

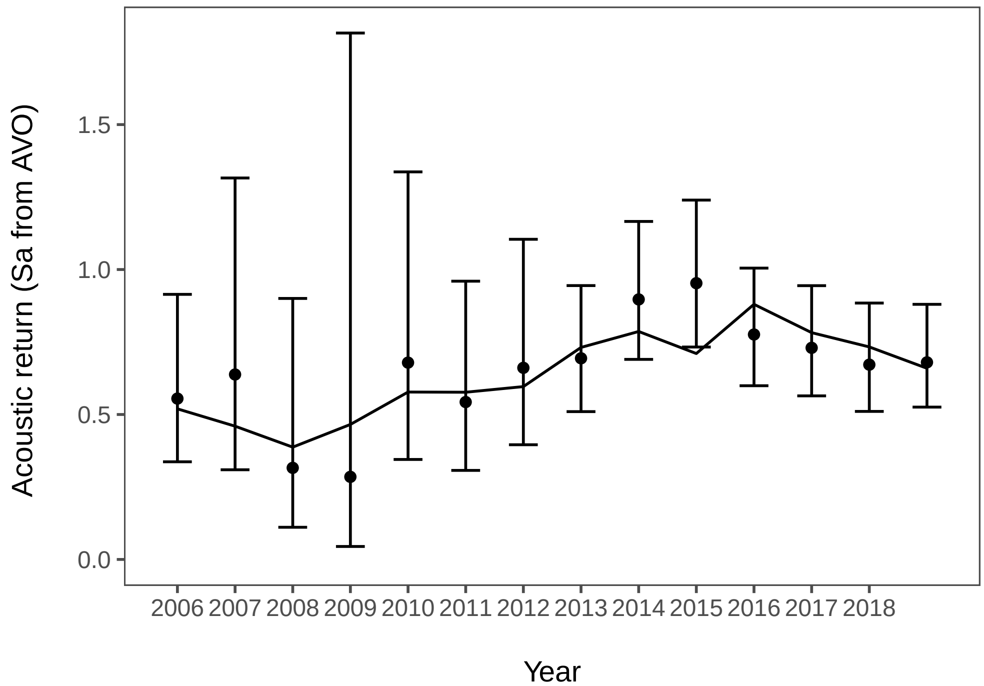


Figure 34: Model results of predicted and observed AVO index. Error bars represent assumed 95% confidence bounds of the input series.

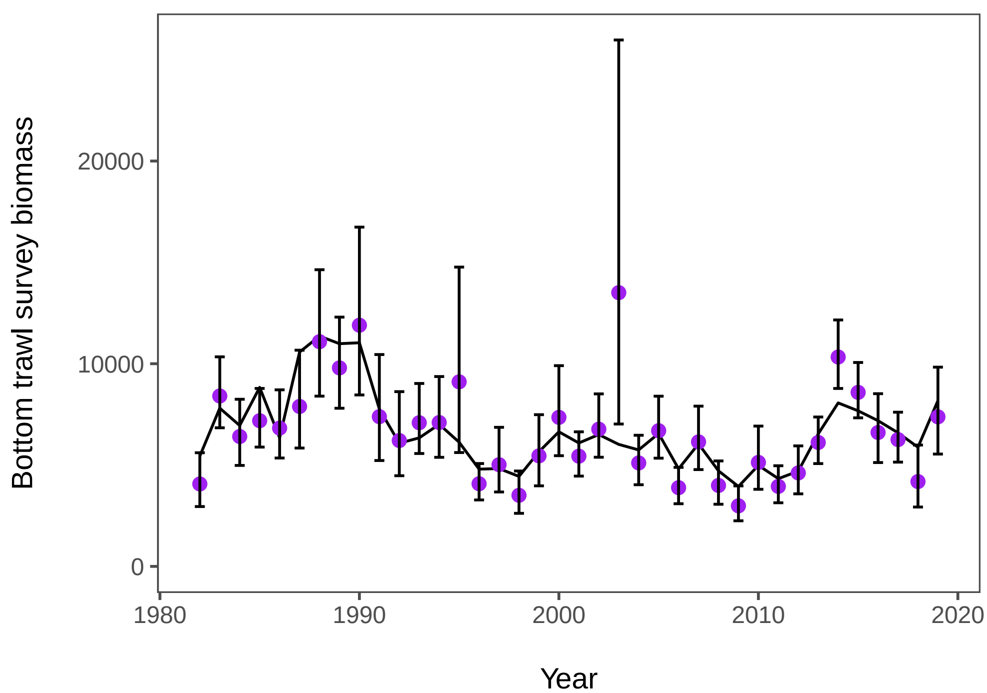


Figure 35: EBS pollock model fit to the BTS survey data (density dependence corrected estimates), 1982–2019. Units are relative biomass.

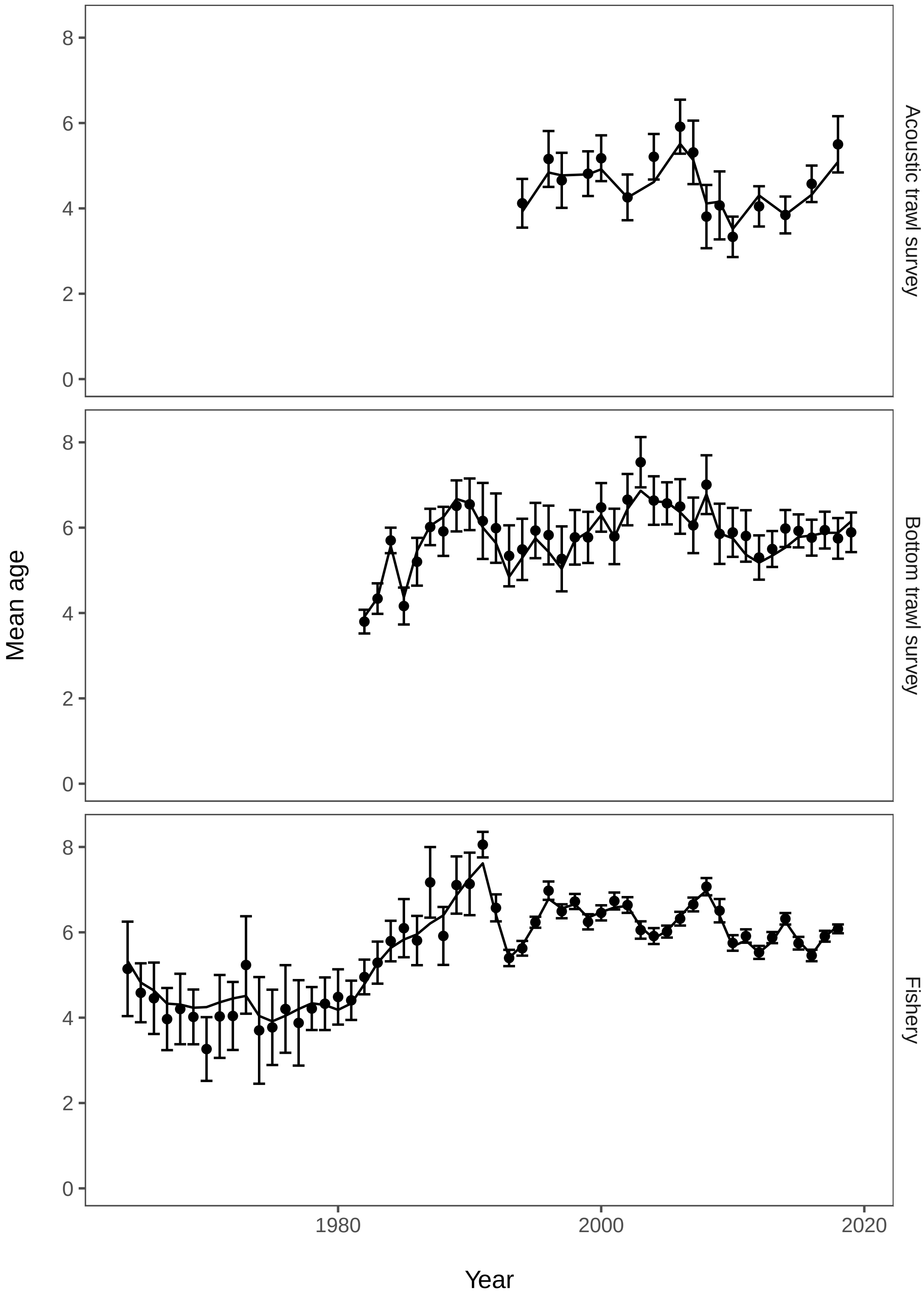


Figure 36: EBS pollock model fits to observed mean age for the Acoustic trawl survey (top), the bottom trawl survey (middle) and fishery (bottom)

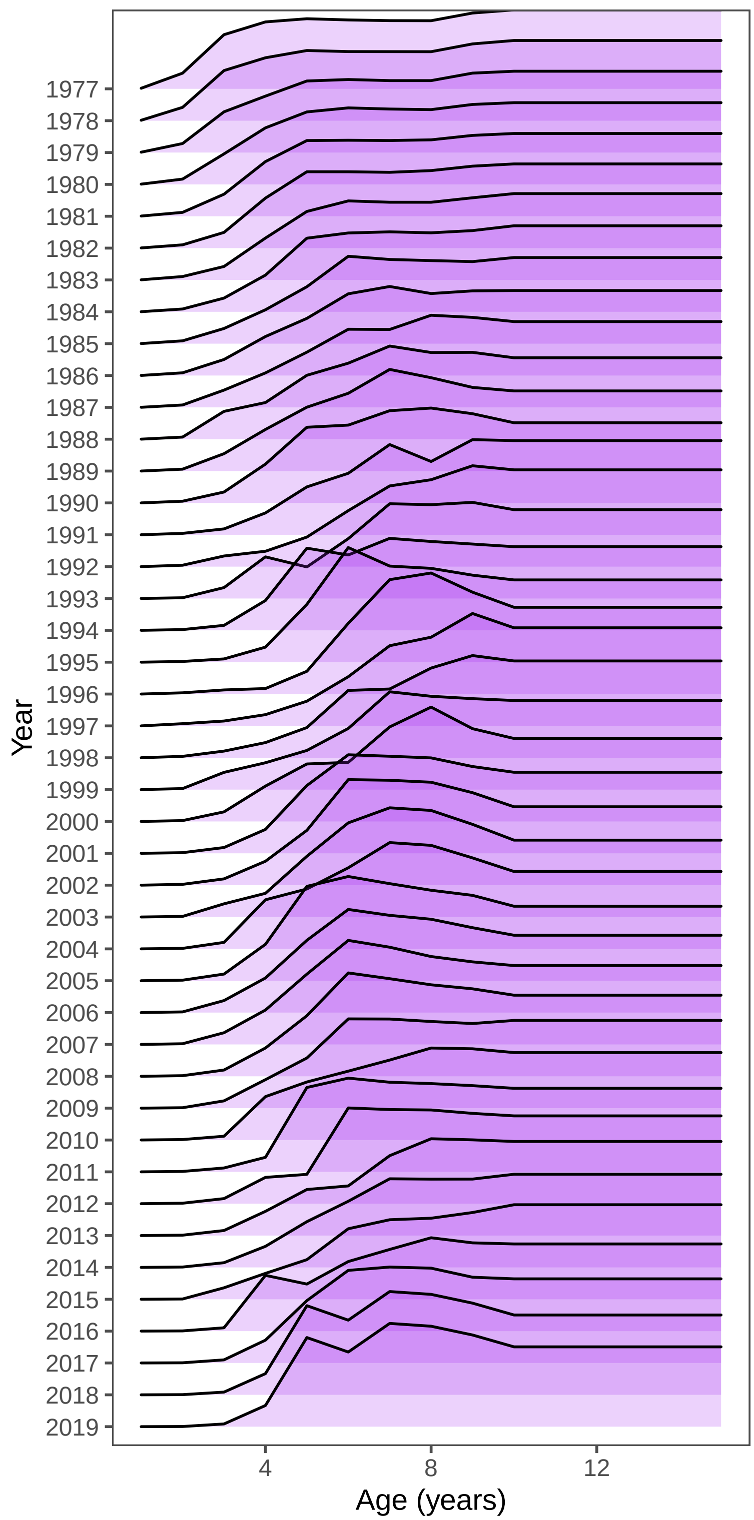


Figure 37: Selectivity at age estimates for the EBS pollock fishery.

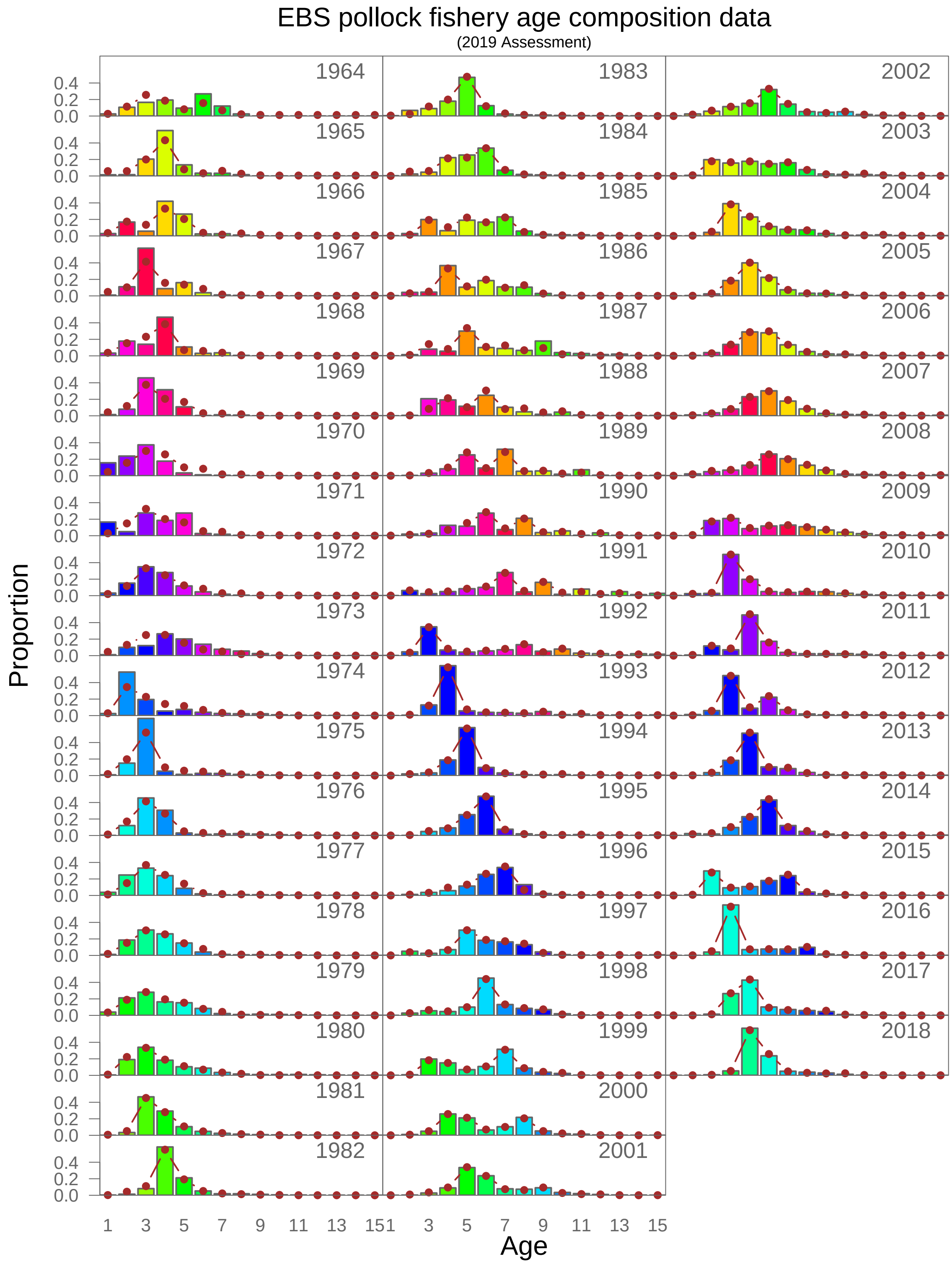


Figure 38: Model fit (dots) to the EBS pollock fishery proportion-at-age data (columns; 1964–2018). The 2018 data are new to this year's assessment. Colors coincide with cohorts progressing through time.

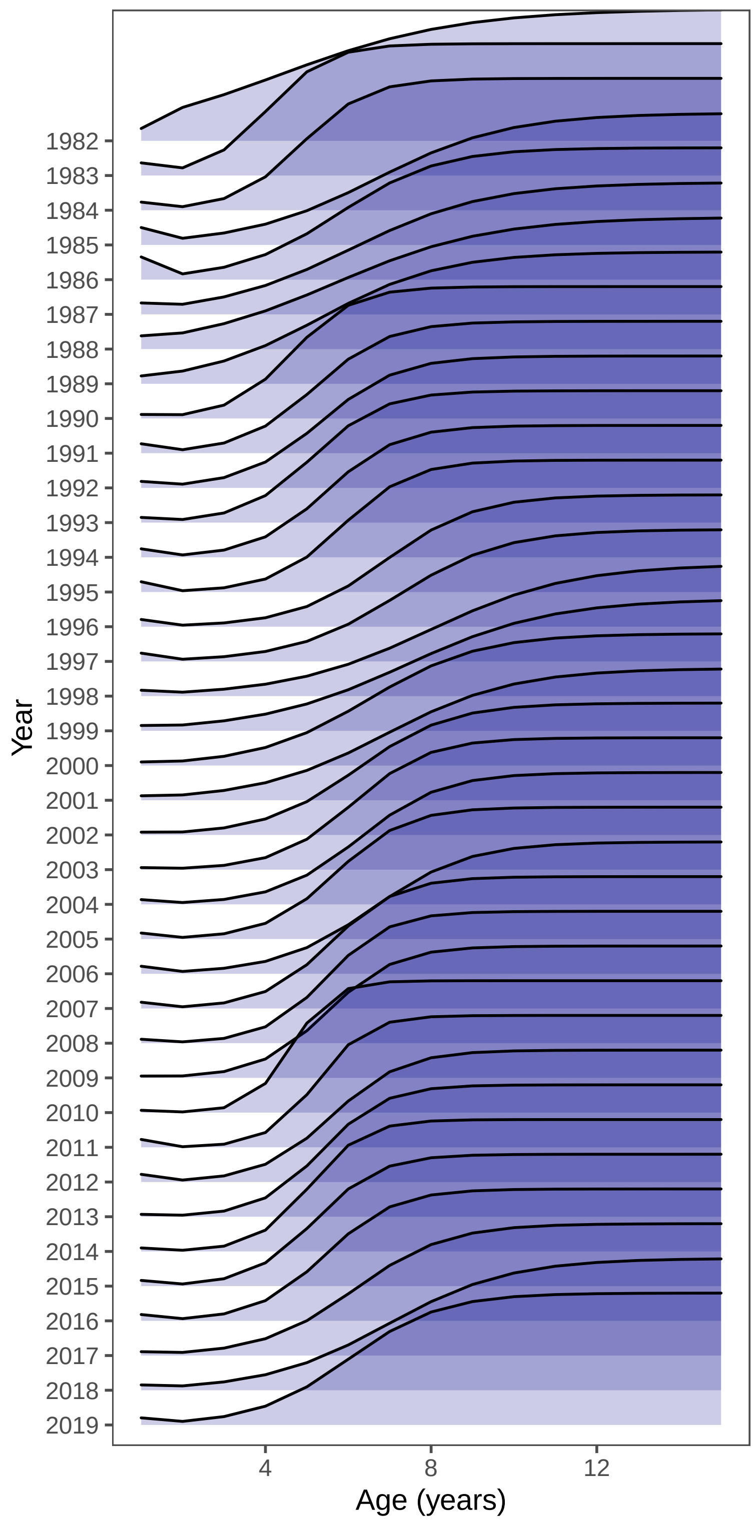


Figure 39: Model estimates of bottom-trawl survey selectivity, 1982–2019.

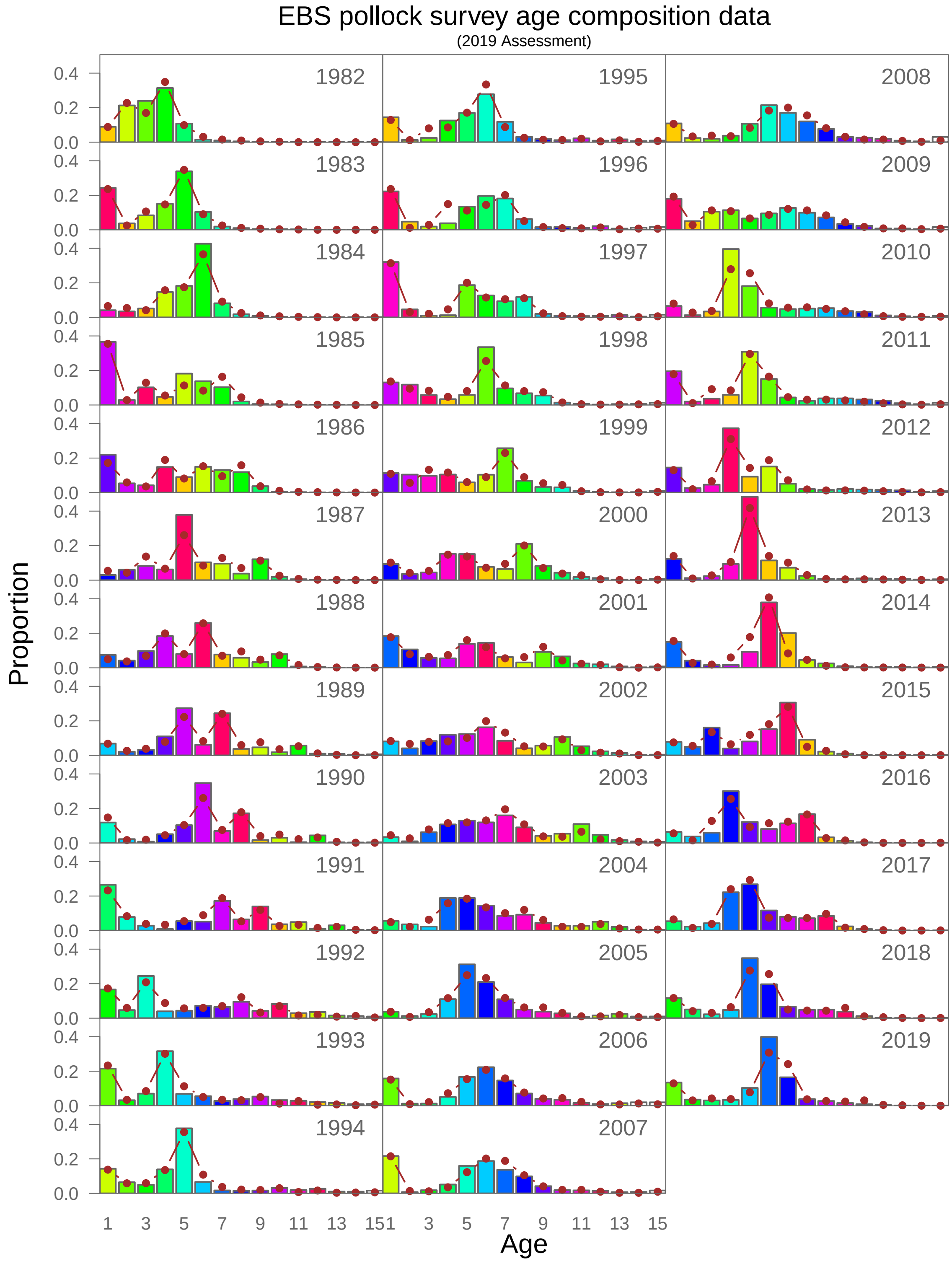


Figure 40: Model fit (dots) to the bottom trawl survey proportion-at-age composition data (columns) for EBS pollock. Colors correspond to cohorts over time. Data new to this assessment are from 2018.

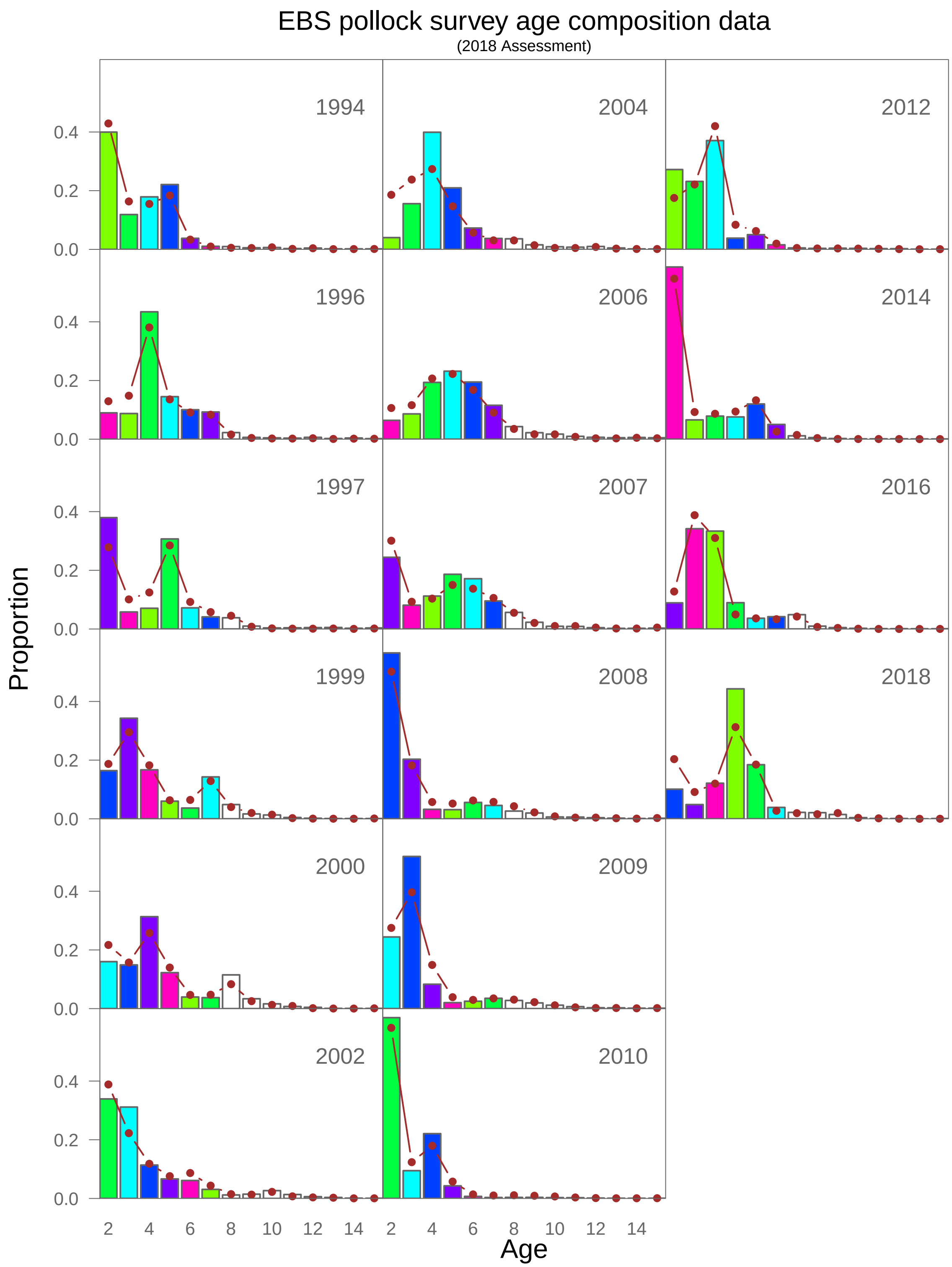


Figure 41: Model fit (dots) to the acoustic-trawl survey proportion-at-age composition data (columns) for EBS pollock. Colors correspond to cohorts over time (for years with consecutive surveys).

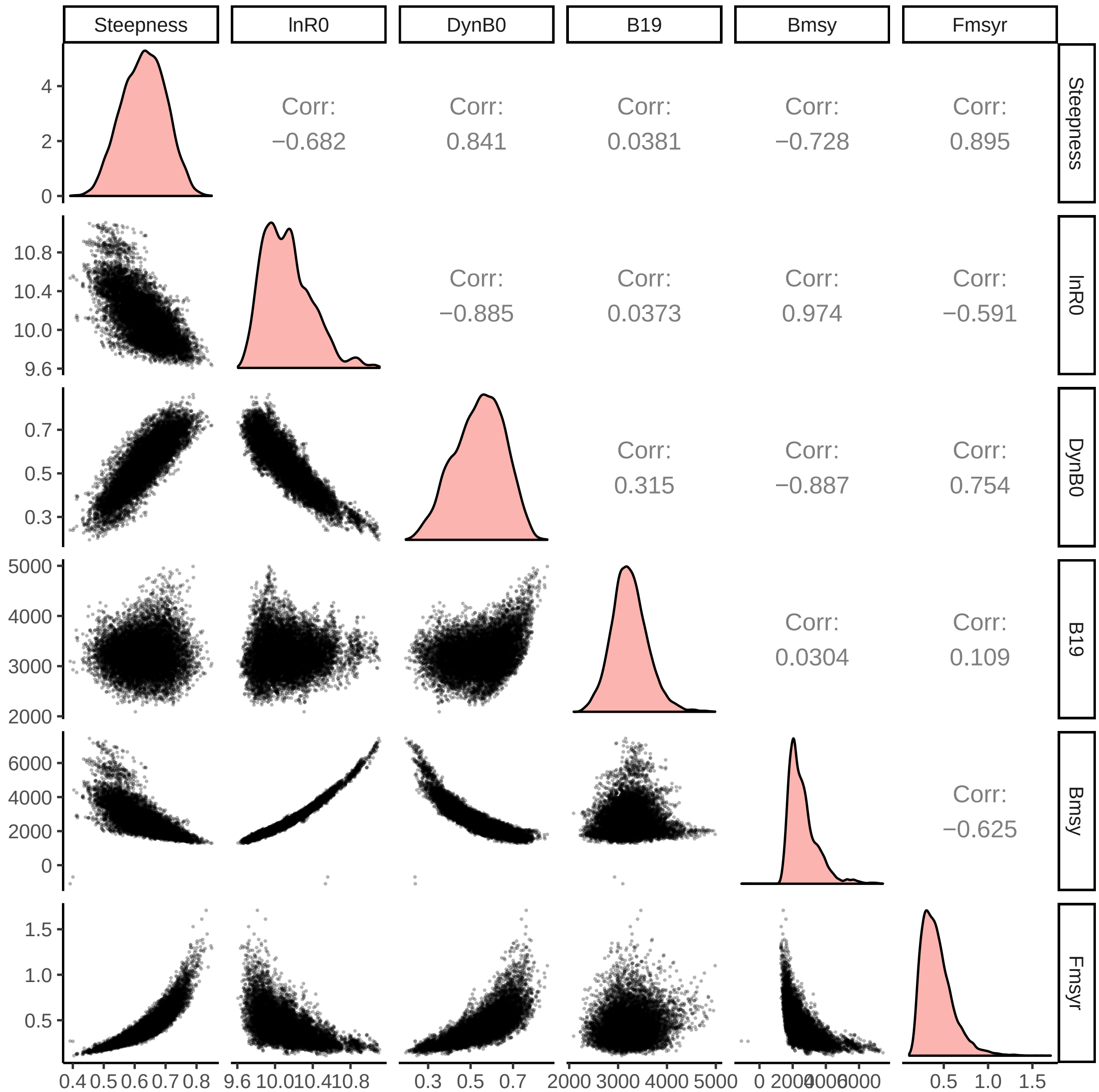


Figure 42: Pairwise plot of selected EBS pollock parameters and output from 3 million MCMC iterations thinned such that 5 thousand draws were saved as an approximation to the multivariate posterior distribution. Note that the figures on the diagonal represent the marginal posterior distributions. Key: lnR0 is the parameter that scales the stock-recruit relationship, B_Bmsy is estimated B_{2018}/B_{MSY}, DynB0 is the ratio of spawning biomass estimated for in 2018 over the value estimated that would occur if there had been no fishing, B19 is the spawning biomass in 2019, and B_Bmean is $B_{2019}/\bar{B}$.

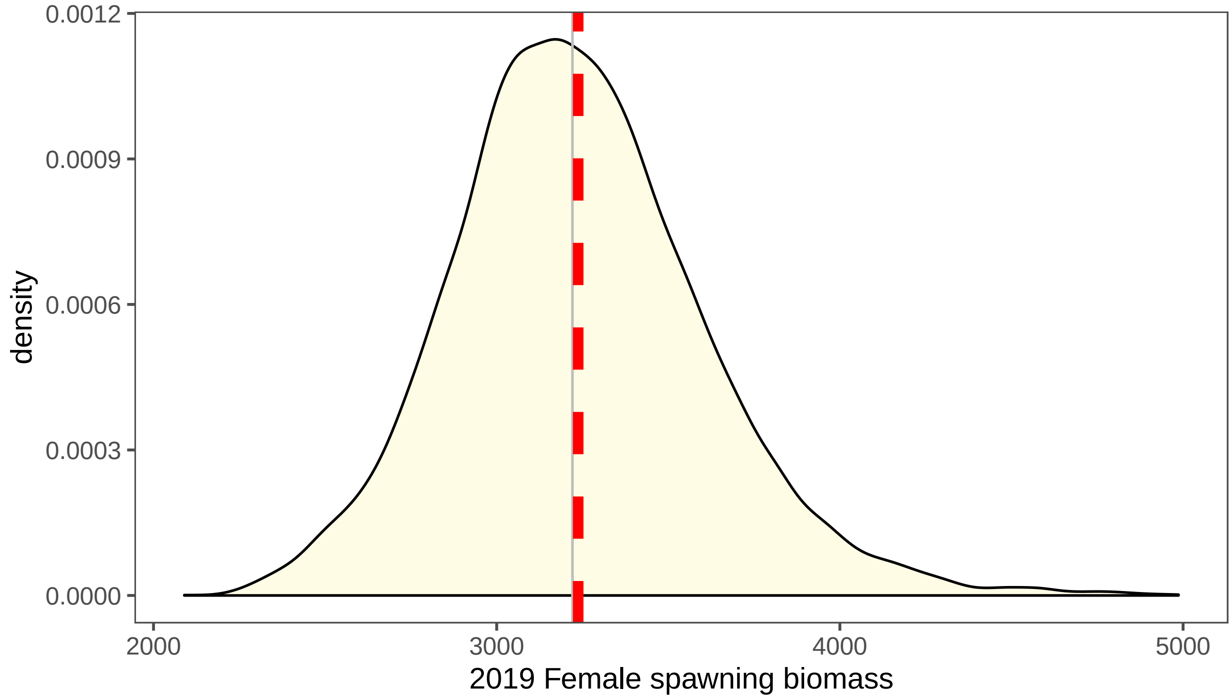


Figure 43: Integrated marginal posterior density (based on MCMC results) for the 2019 EBS pollock female spawning biomass compared to the point estimate (dashed red line). The mean of the posterior is shown in green (under the dashed line).

Figure 44: Estimated spawning exploitation rate (defined as the percent removal of egg production in a given spawning year).

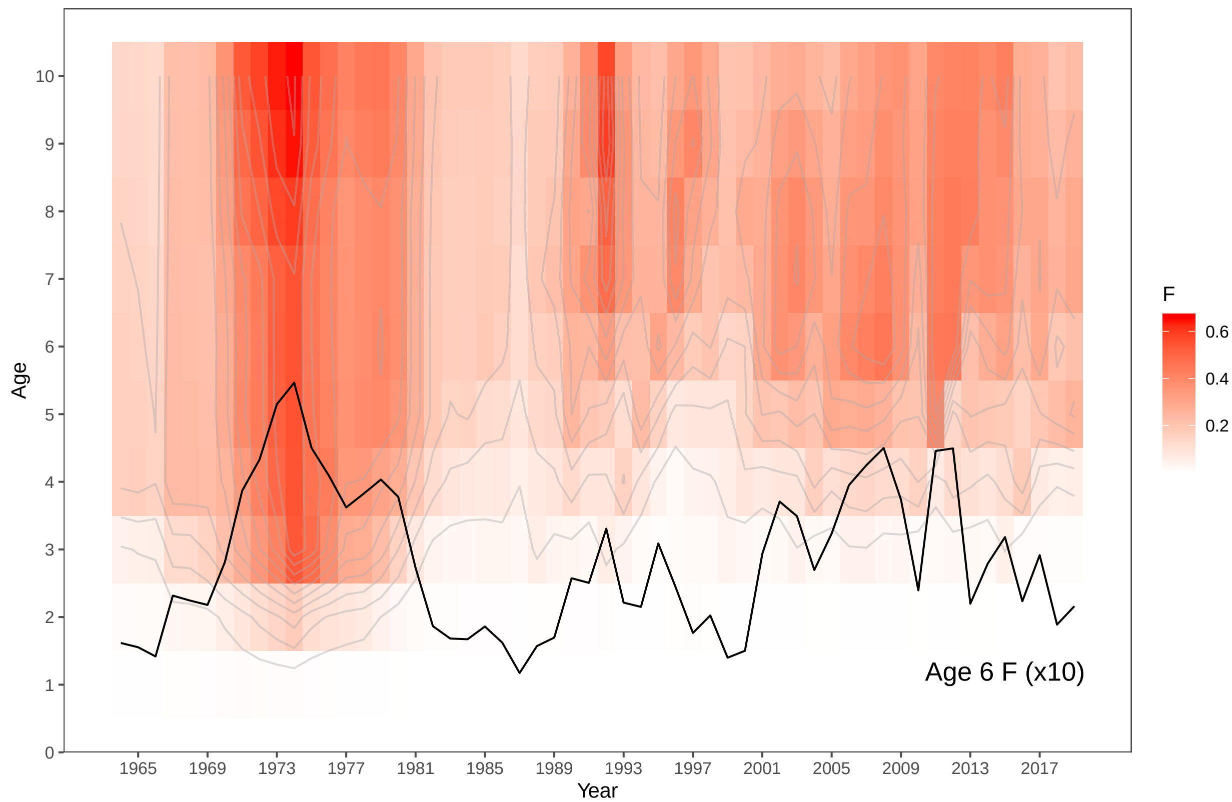


Figure 45: Estimated instantaneous age-specific fishing mortality rates for EBS pollock.

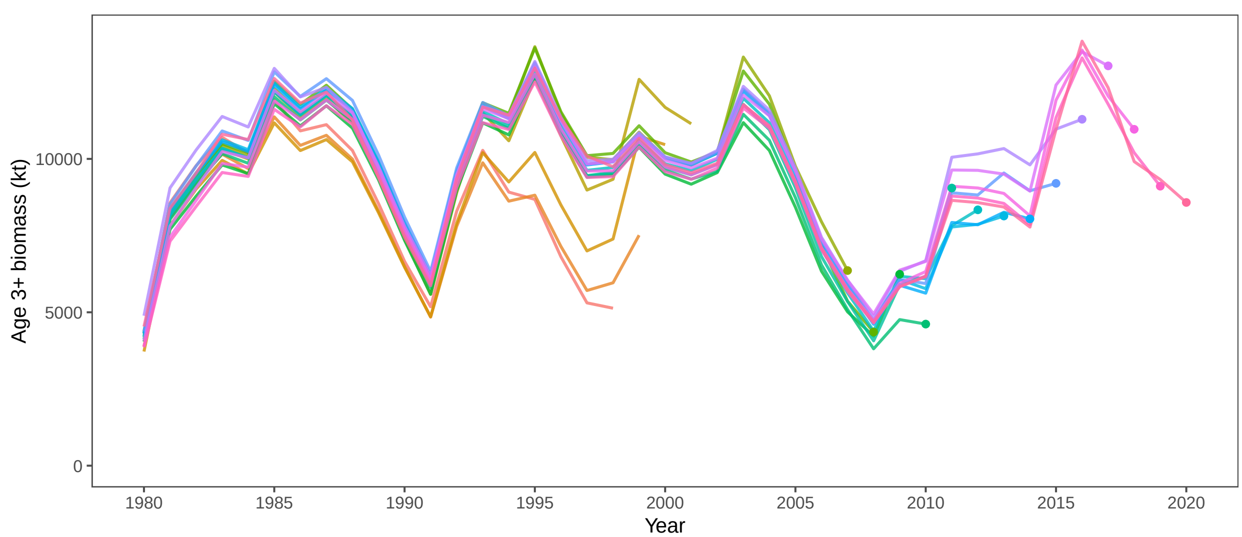


Figure 46: Comparison of the current assessment results with past assessments of begin-year EBS age-3+ pollock biomass.

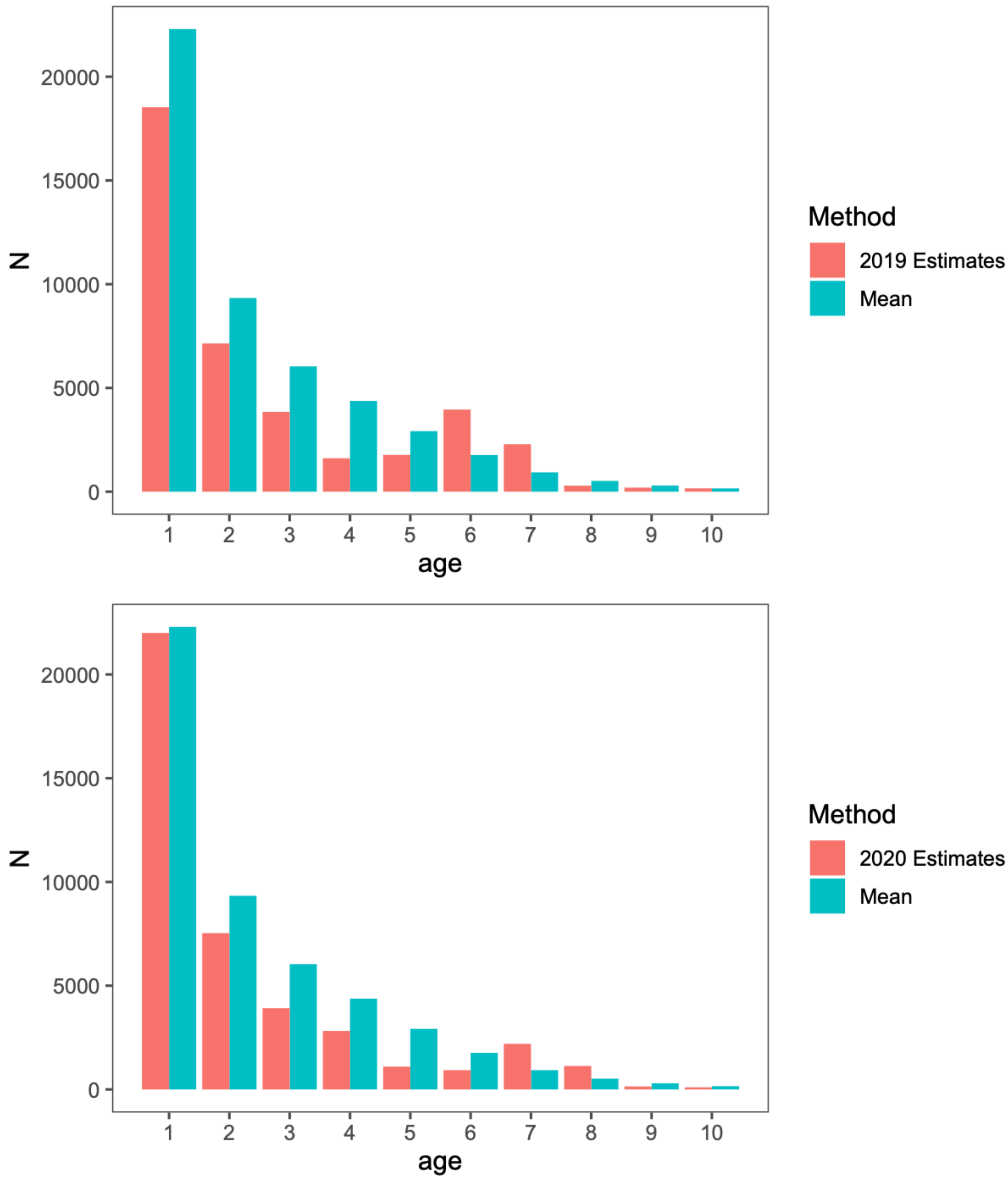


Figure 47: Numbers-at-age estimates for 2019 (top) and 2020 (bottom) cmpared to the mean values since 1991.

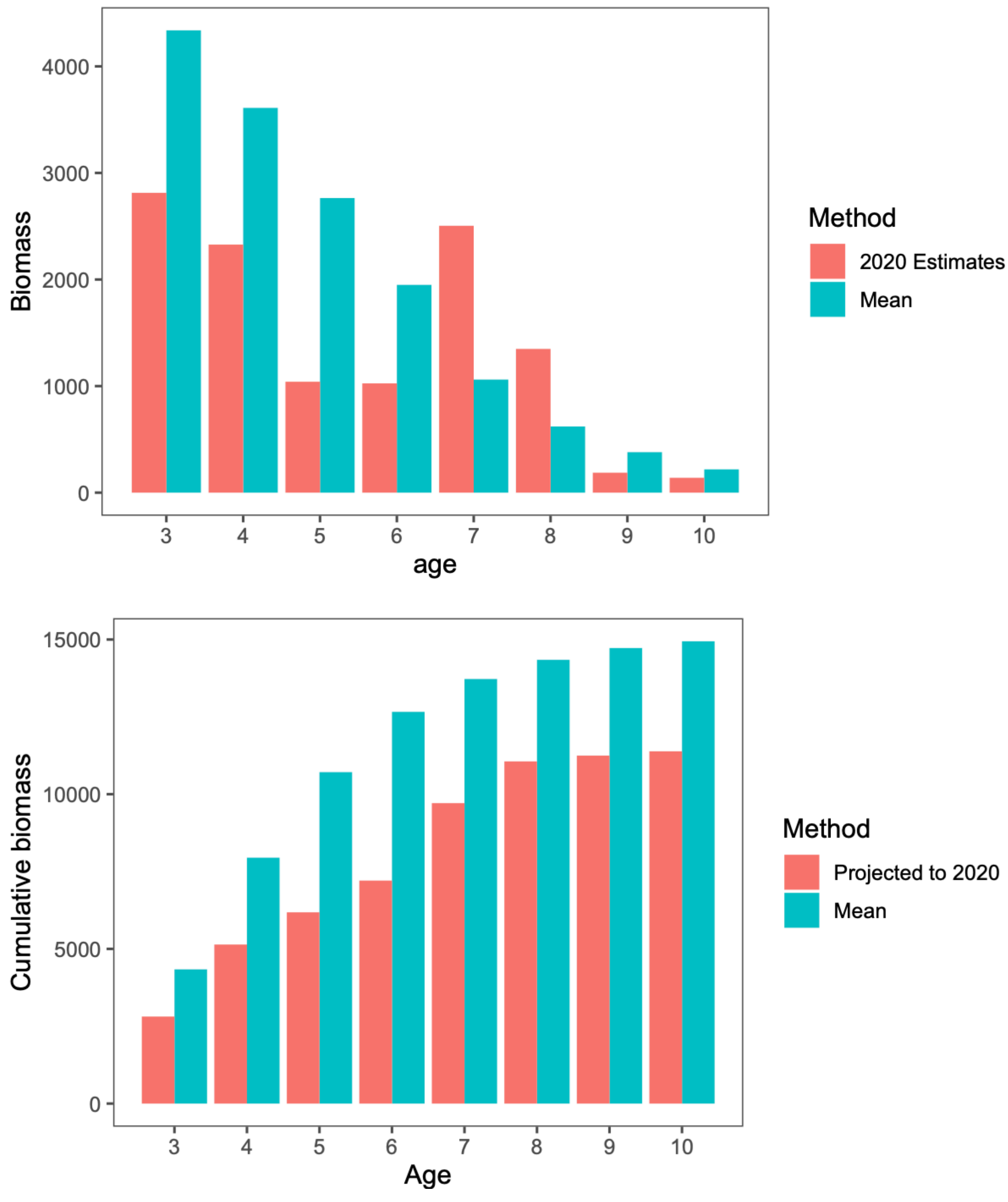


Figure 48: Numbers-at-age multiplied by weights-at-age estimates for 2020 (top) and accumulated (bottom).

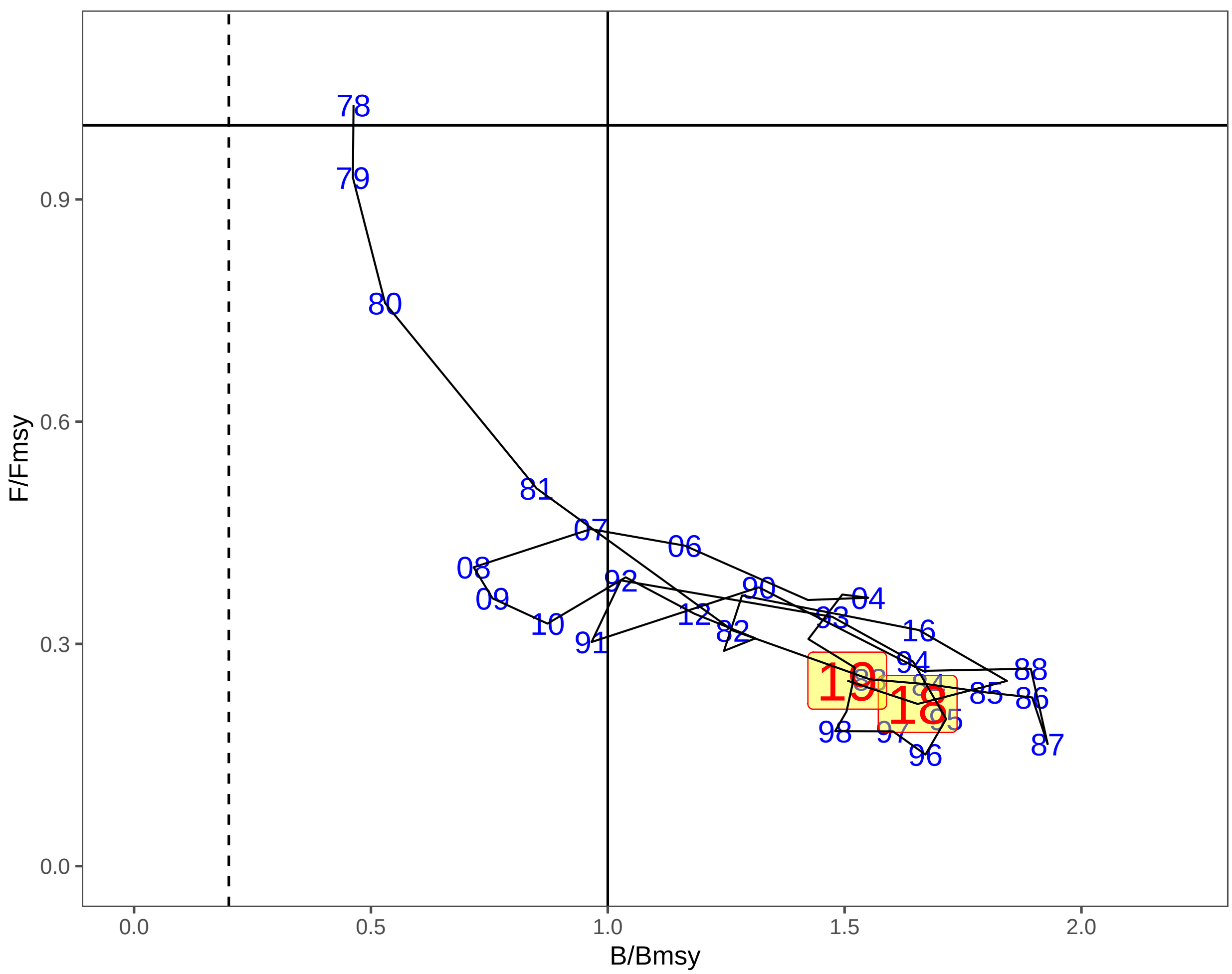


Figure 49: Estimated spawning biomass relative to annually estimated F_{MSY} values and fishing mortality rates for EBS pollock. Most recent two years are shaded in yellow

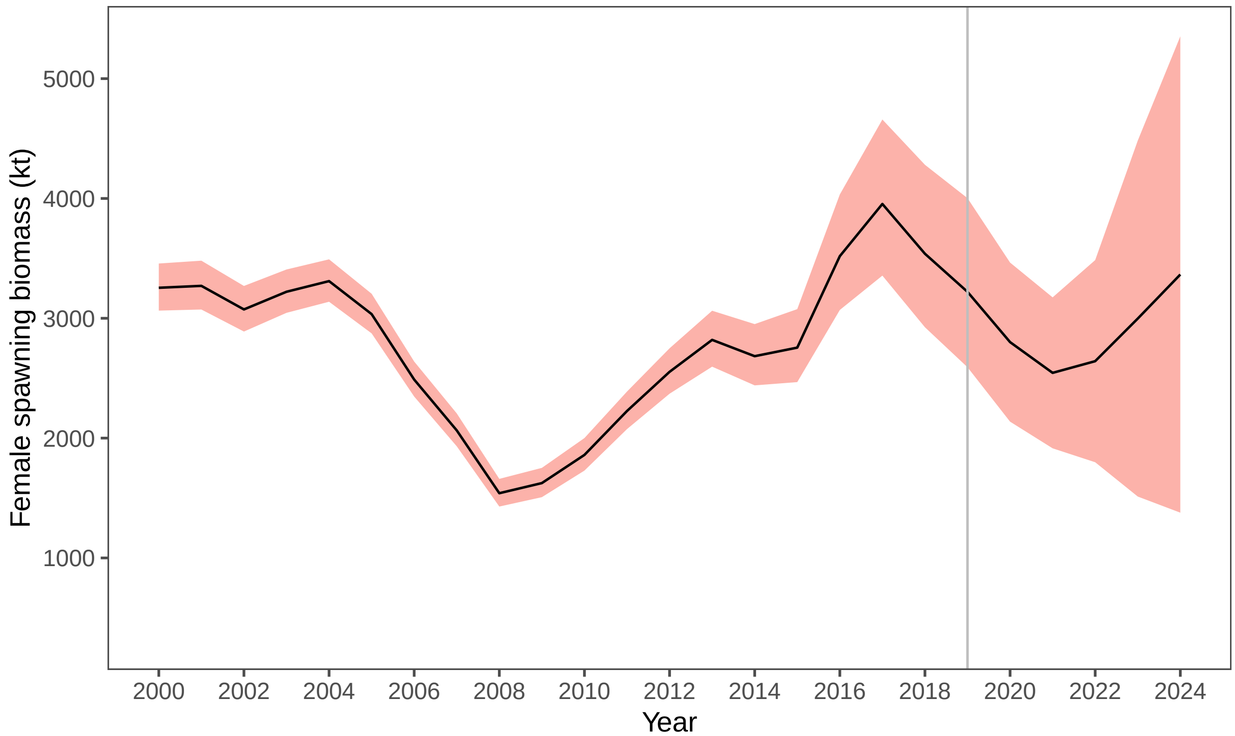


Figure 50: The estimated EBS pollock spawning stock biomass for model 16.1 with projections equal to the estimated fishing mortality from 2019.

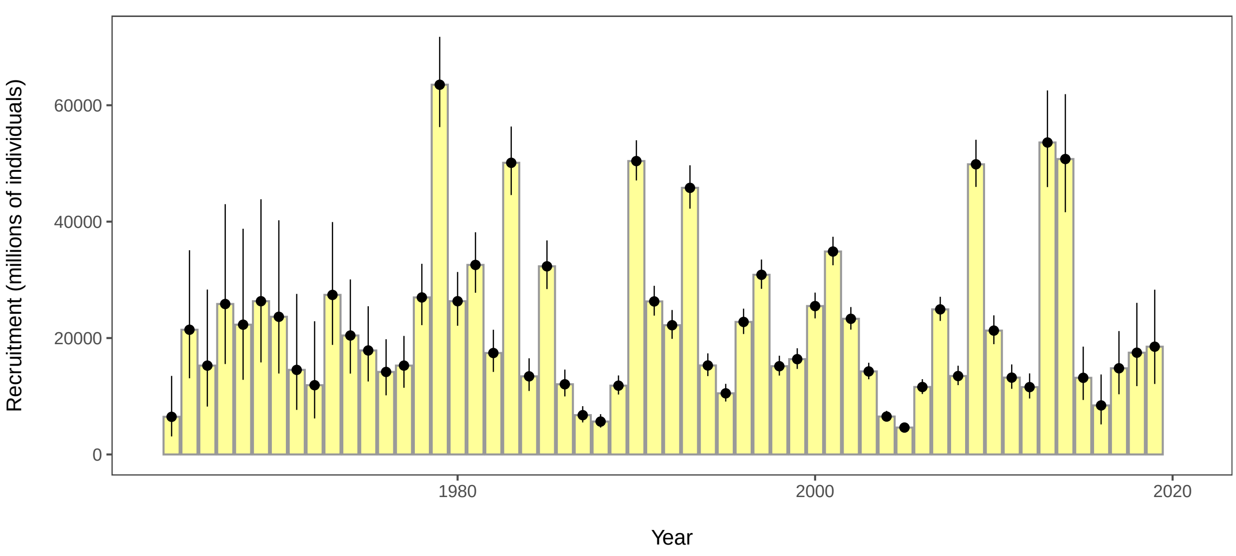


Figure 51: Recruitment estimates (age-1 recruits) for EBS pollock for all years since 1964 (1963–2017 year classes) for Model 16.1. Error bars reflect 90% credible intervals based on model estimates of uncertainty.

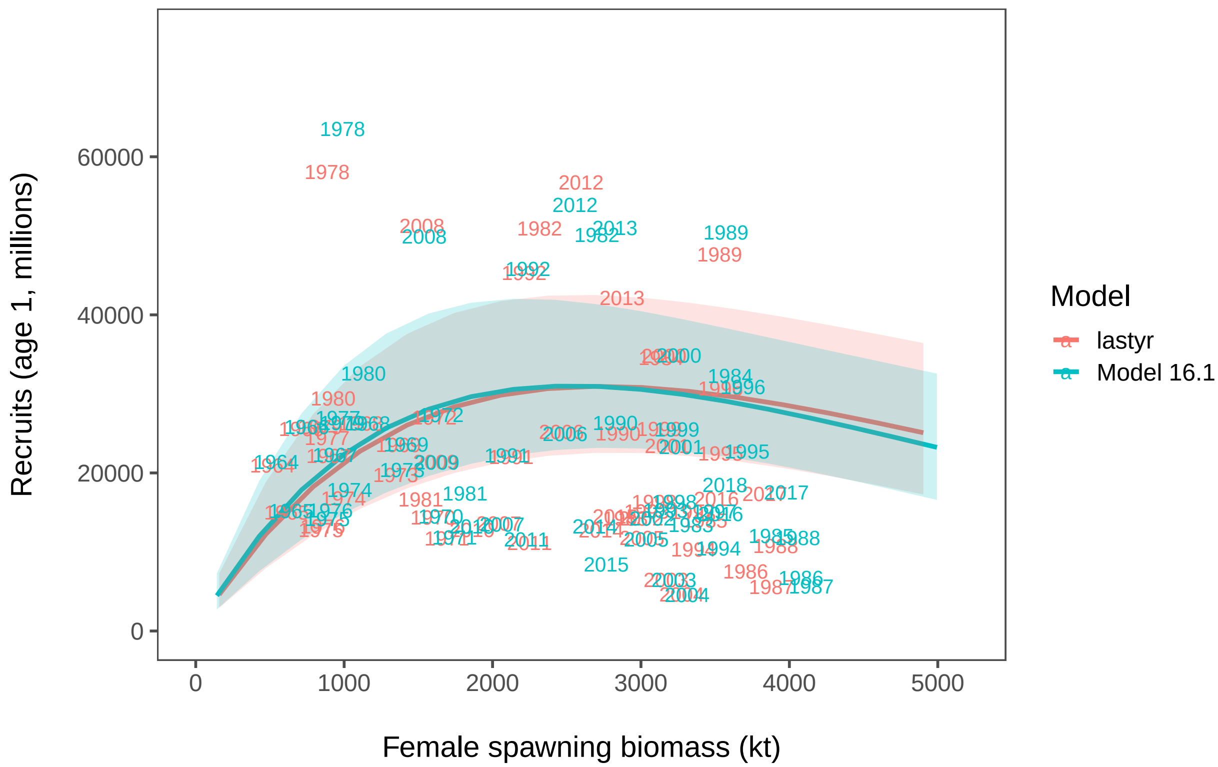


Figure 52: Stock-recruitment estimates (shaded represnts structural uncertainty) and age-1 EBS pollock estimates labeled by year-classes

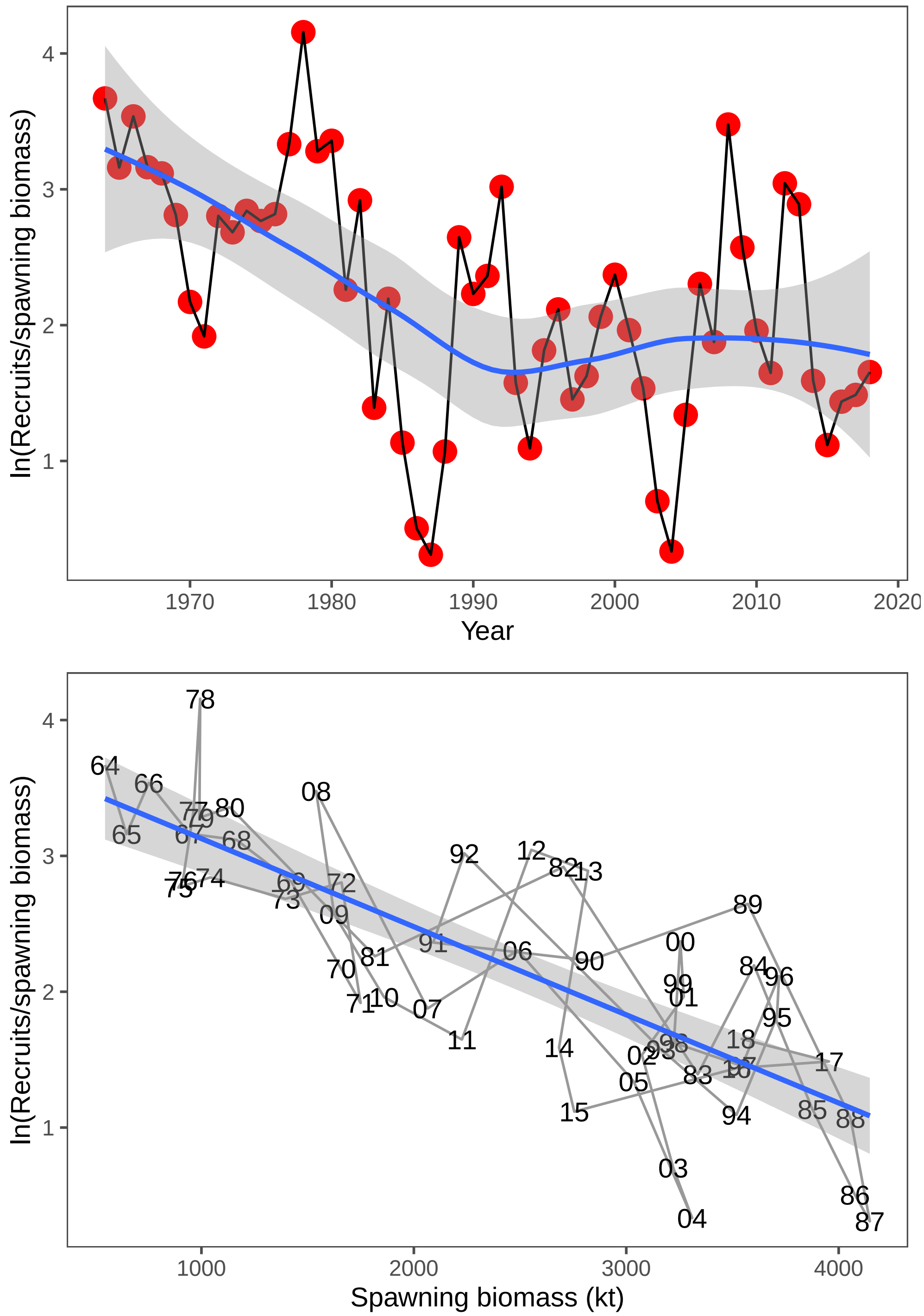


Figure 53: EBS pollock productivity as measured by logged recruits per spawning biomass, log(R/S), as a function of spawning biomass with a linear fit (bottom) and over time, 1964–2018 (top).

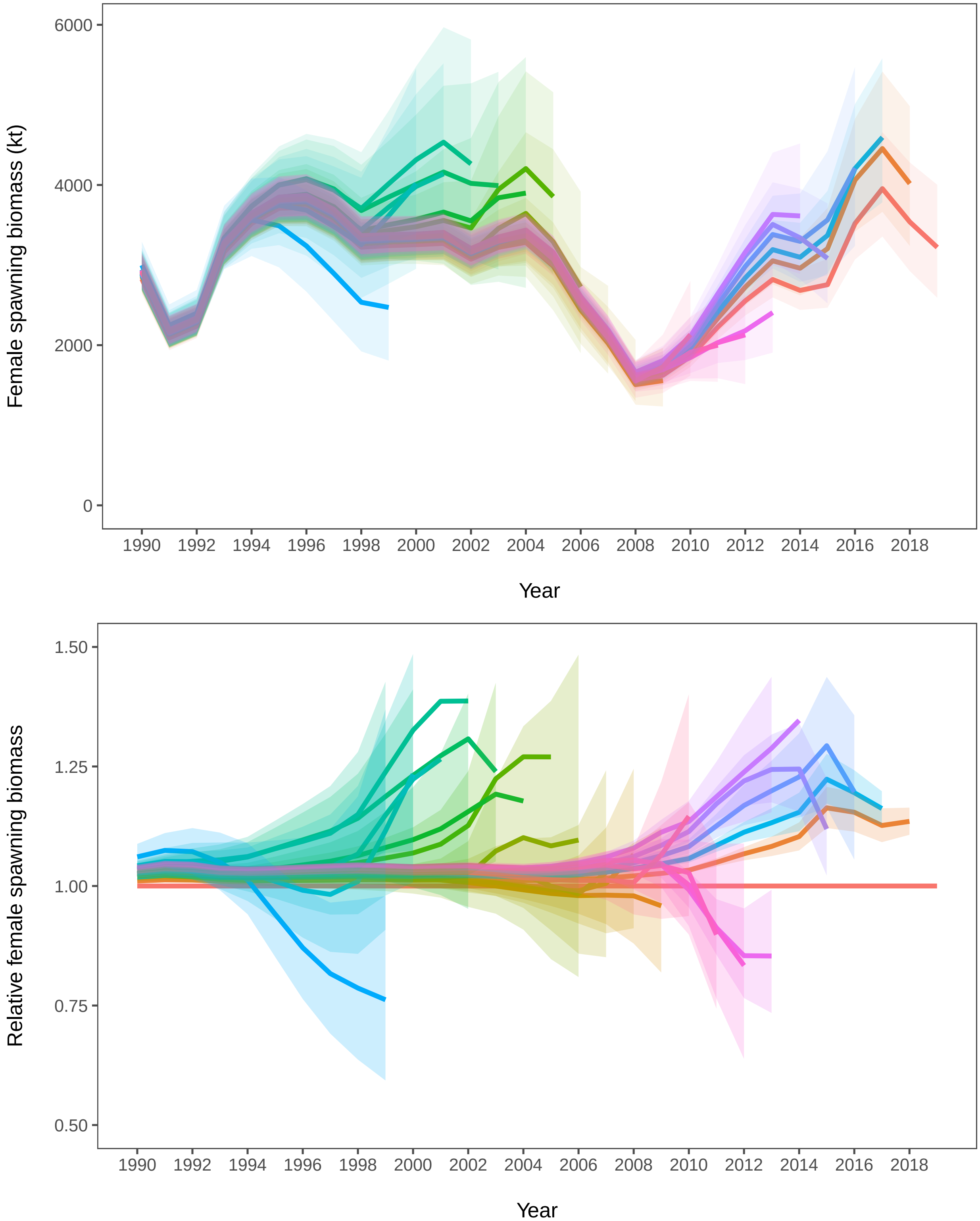


Figure 54: Retrospective patterns for EBS pollock spawning biomass showing the point estimates relative to the terminal year (top panel) and approximate confidence bounds on absolute scale (+2 standard deviations).

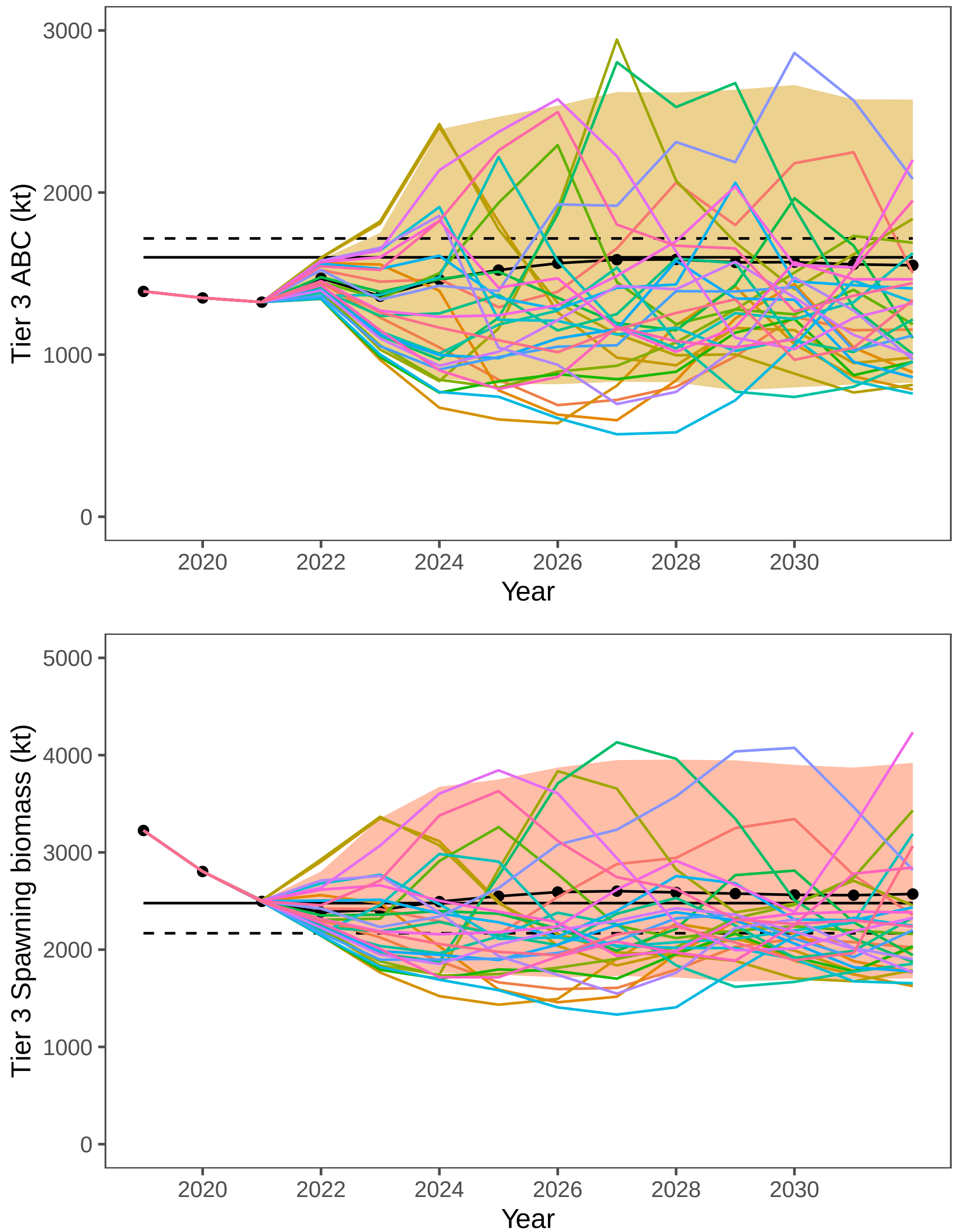


Figure 55: Projected EBS Tier 3 pollock yield (top) and female spawning biomass (bottom) relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines). $B_{40\%}$ is computed from average recruitment from 1978–2017. Future harvest rates follow the guidelines specified under Tier 3 Scenario 1.

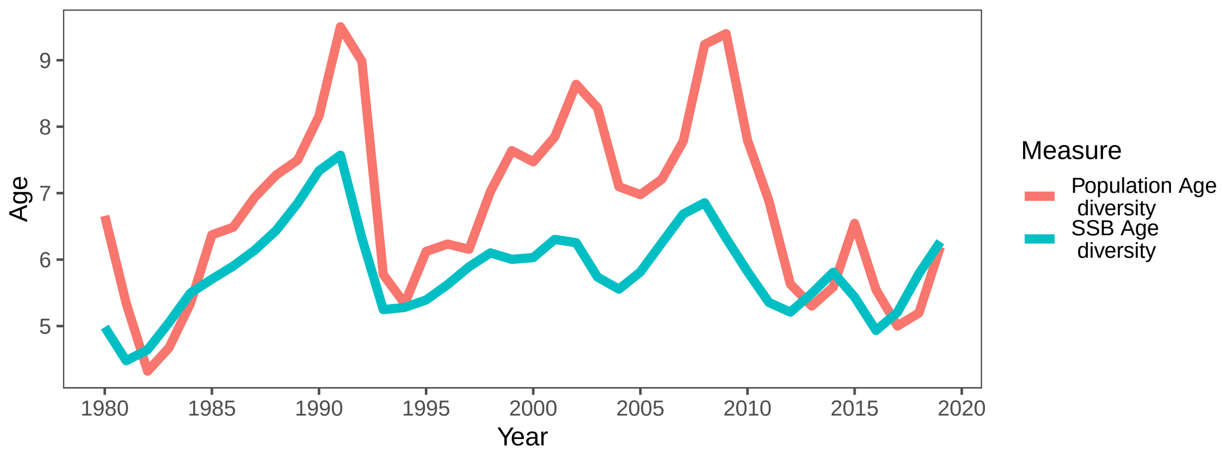


Figure 56: For the mature component of the EBS pollock stock, time series of estimated average age and diversity of ages (using the Shannon-Wiener H statistic), 1980–2018.

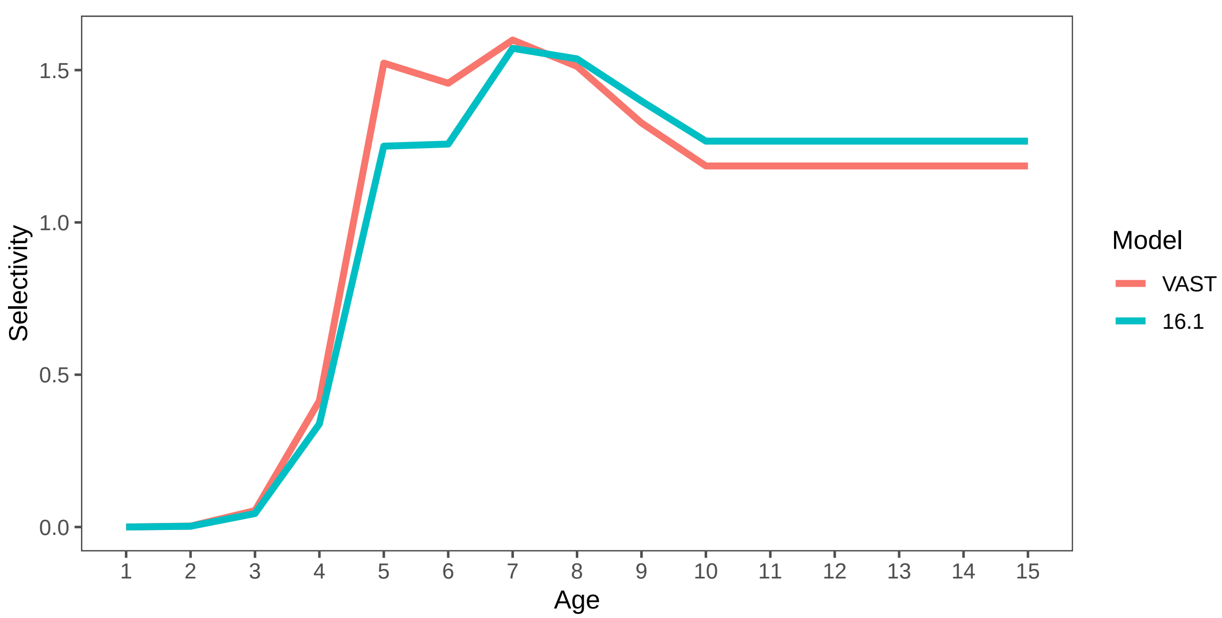


Figure 57: Comparison of the selectivity estimates between Model 16.1 and the implementation with the VAST treatment of the survey (including the NBS).

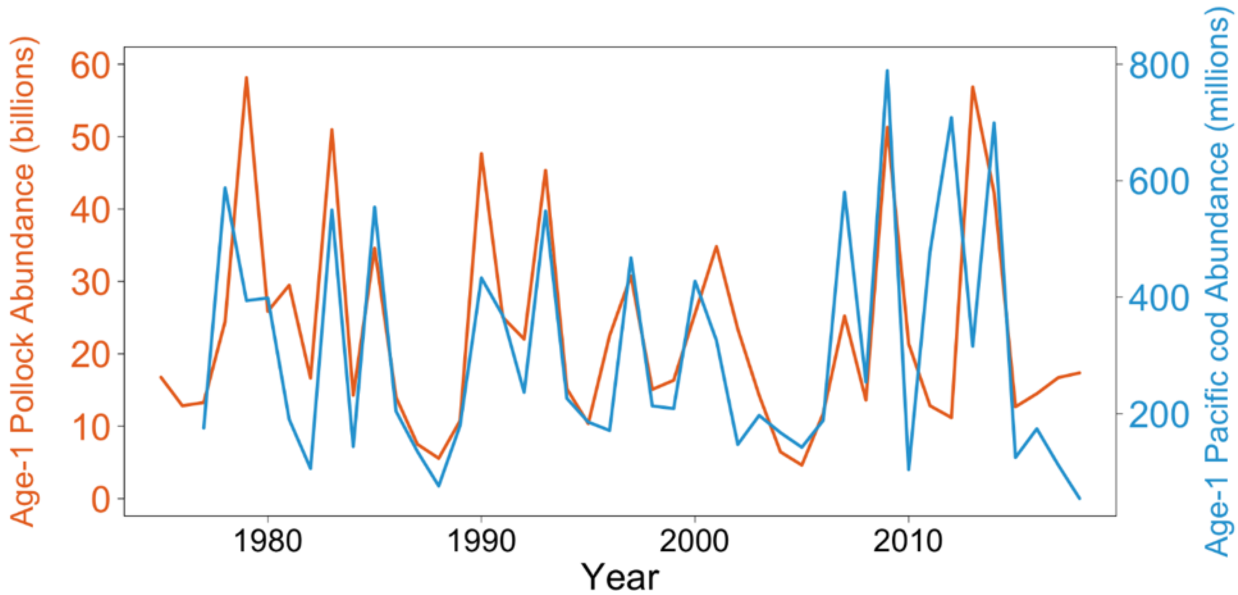


Figure 58: Plot of age-1 abundance for walleye pollock (orange; in millions) and Pacific cod (blue; in 1000s) as estimated in the 2018 stock assessments (Ianelli et al. 2018; Thompson 2018).

EBS Pollock Model Description

Dynamics

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

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

where

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

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

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

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

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

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

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

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

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

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

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

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

$$\tag{16}$$

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

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

The parameters to be estimated in this part of the model are thus for t=1982 through to 2019. The variance terms for these process error parameters were specified to be 0.04.

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

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

$$\tag{20}$$

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

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

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

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

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

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, "Bholt", 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):

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

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

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

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

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:

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

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

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

where

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

and (40)

$$\tau_t^2 = 1/n_t \quad (41)$$

which gives the variance for p_{ta}

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

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:

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

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:

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

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

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

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

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

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

(47)

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

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

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

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

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

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

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

Uncertainty in mean body mass

The approach we use to solve for F_{MSY} and related quantities (e.g., B_{MSY} MSY) within a general integrated model context was shown in Ianelli et al. (2001). In 2007 this was modified to include uncertainty in weight-at-age as an explicit part of the uncertainty for F_{MSY} calculations. This involved estimating a vector of parameters (w_{ta}^{future}) on current (2019) 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 1991-2018. The values of based on available data and (if this option is selected) estimates the parameters subject to the natural constraint:

$$w_{ta}^{future} \sim \mathcal{N}(\bar{w}_a, \sigma_{w_a}^2)$$

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:

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

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

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

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

$$(54)$$

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

Tier 1 projections

Tier 1 projections were calculated two ways. First, for 2020 and 2021 ABC and OFL levels, the harmonic mean F_{MSY} value was computed and the analogous harvest rate ($u_{\bar{H}M}$) applied to the estimated geometric mean fishable biomass at B_{MSY} :

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

$$B_{GM,t}^f = e^{\ln \hat{B}_t^f - 0.5\sigma_{B^f}^2} \qquad (56)$$

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

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

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

where $\hat{B}_t^f$ 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 bottom-trawl survey data

Overview

This application of `VAST` was configured to model a subset of NMFS/AFSC bottom trawl survey data. Specifically, the station-specific CPUE (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., `?Data_Fn` for explanation of data inputs, or `?Param_Fn` for explanation of parameters. 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.

Settings and configurations are available here (link to come…).

Spatio-temporal treatment of survey age composition data

To date, assessments using spatio-temporal indices have kept age-composition data unchanged (i.e., the estimates were based on the original design-based approach). Here we develop a spatio-temporal approach to obtain age composition estimates. We found that design-based and model-based inputs provided stock-assessment parameter estimates consistent with previous approaches (Fig. 17).

Diagnostic plots

Encounter-probability component

One can check to ensure that observed encounter frequencies for either low or high probability samples are within the 95% predictive interval for predicted encounter probability (Figure 60. Diagnostics for positive-catch-rate component was evaluated using a standard Q-Q plot. Qualitatively, the fits to pollock data are reasonable (Figures 61 and 62).

Pearson residuals

Spatially the residual pattern can be evaluated over time. Results for pollock data shows that consistent positive or negative residuals accross or within years is limited for the encounter probability component of the model and for the positive catch rate component (Figures 63 and 64, respectively).

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; (Figure 65). Index values and error terms (based on diagonal of covariance matrix over time) are shown in Figure 66

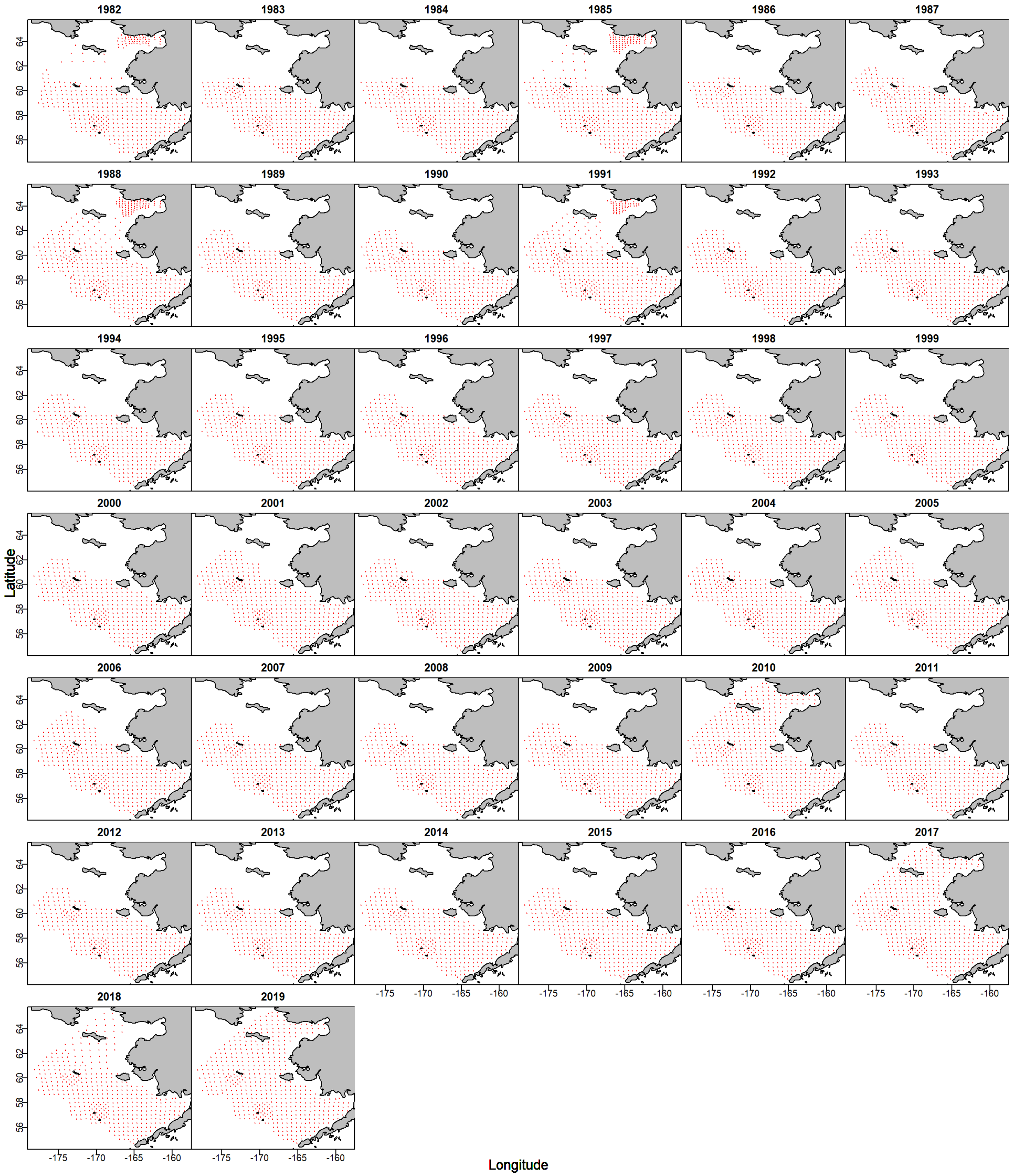


Figure 59: Numbers-at-age estimates for 2019 (top) and 2020 (bottom) cmpared to the mean values since 1991.

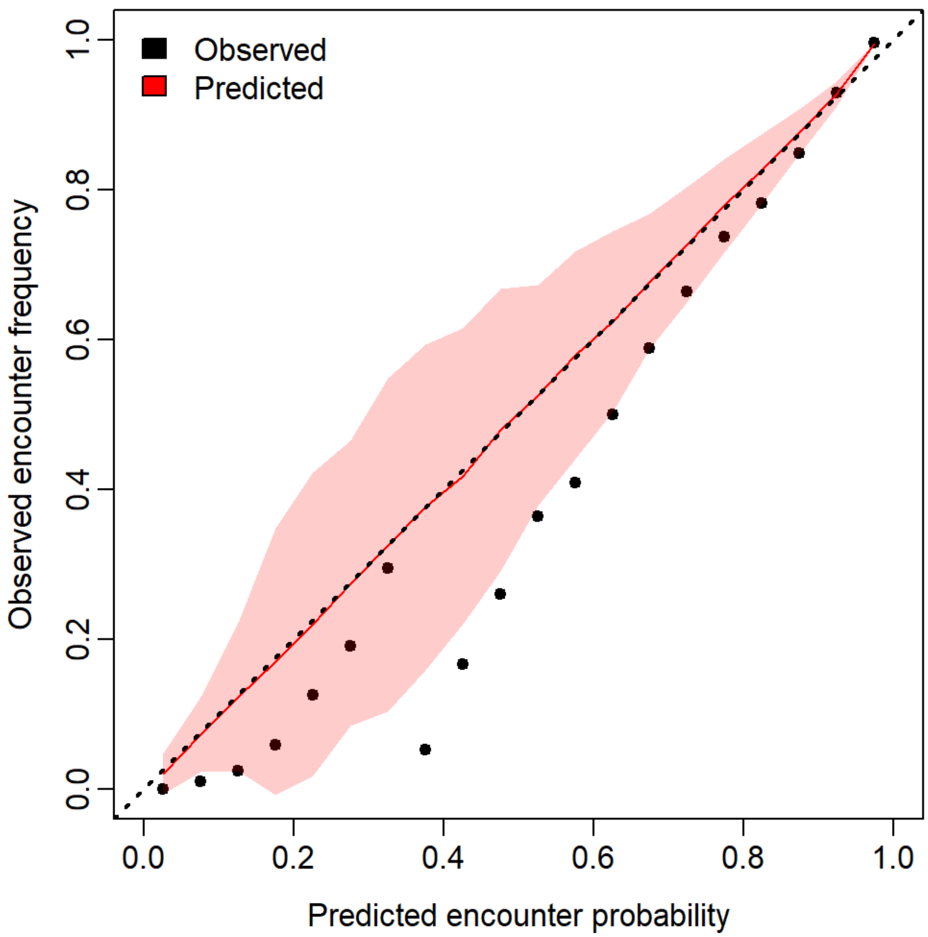


Figure 60: Observed encounter rates and predicted probabilities for pollock in the combined survey area.

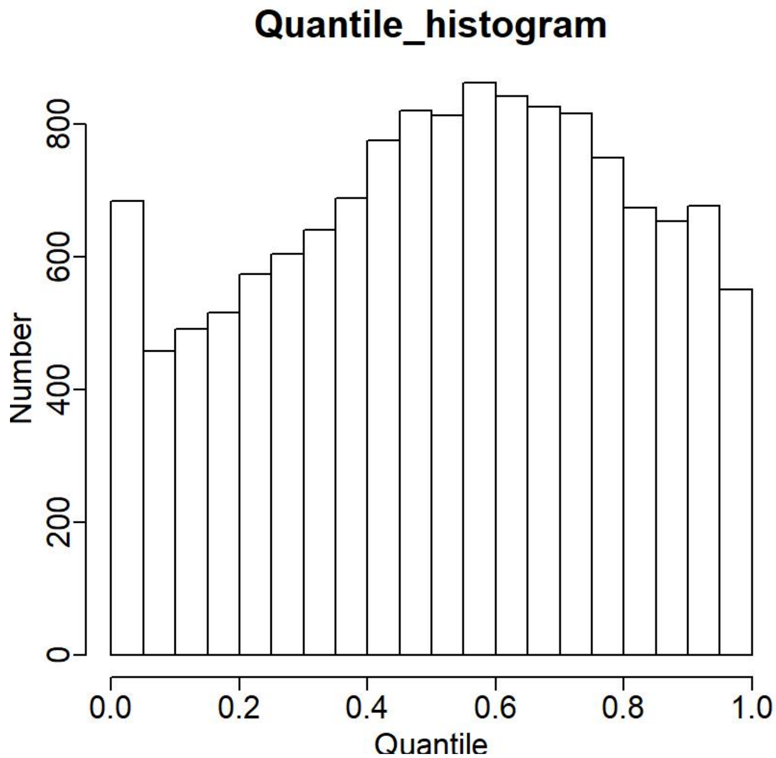


Figure 61: Plot indicating distribution of quantiles for “positive catch rate” component.

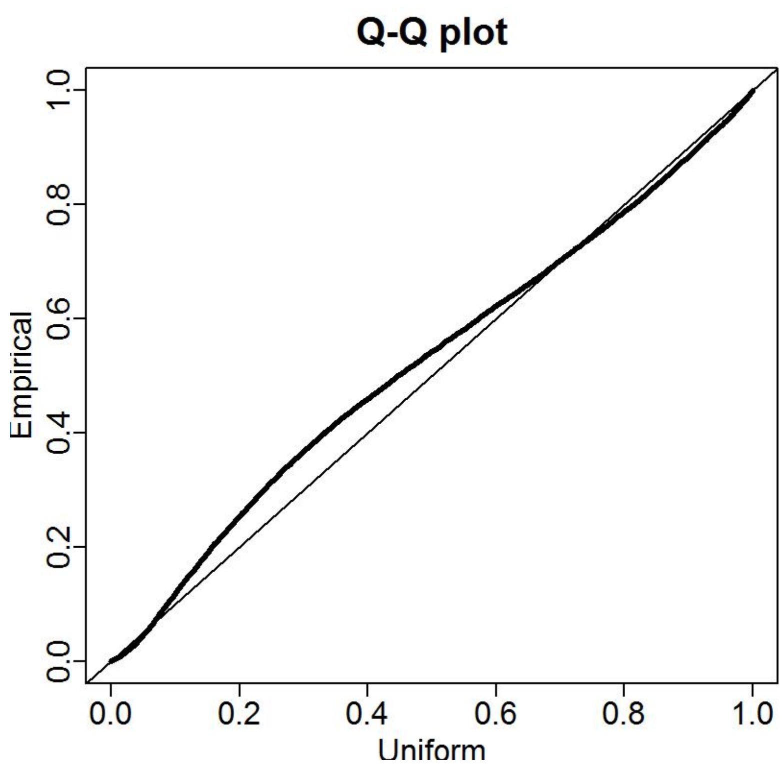


Figure 62: Quantile-quantile plot of residuals for “positive catch rate” component.

Figure 63: Pearson residuals of the encounter probability component for the combined survey area, 1982-2018.

Figure 64: Pearson residuals of the positive catch rate component for the combined survey area, 1982-2018.

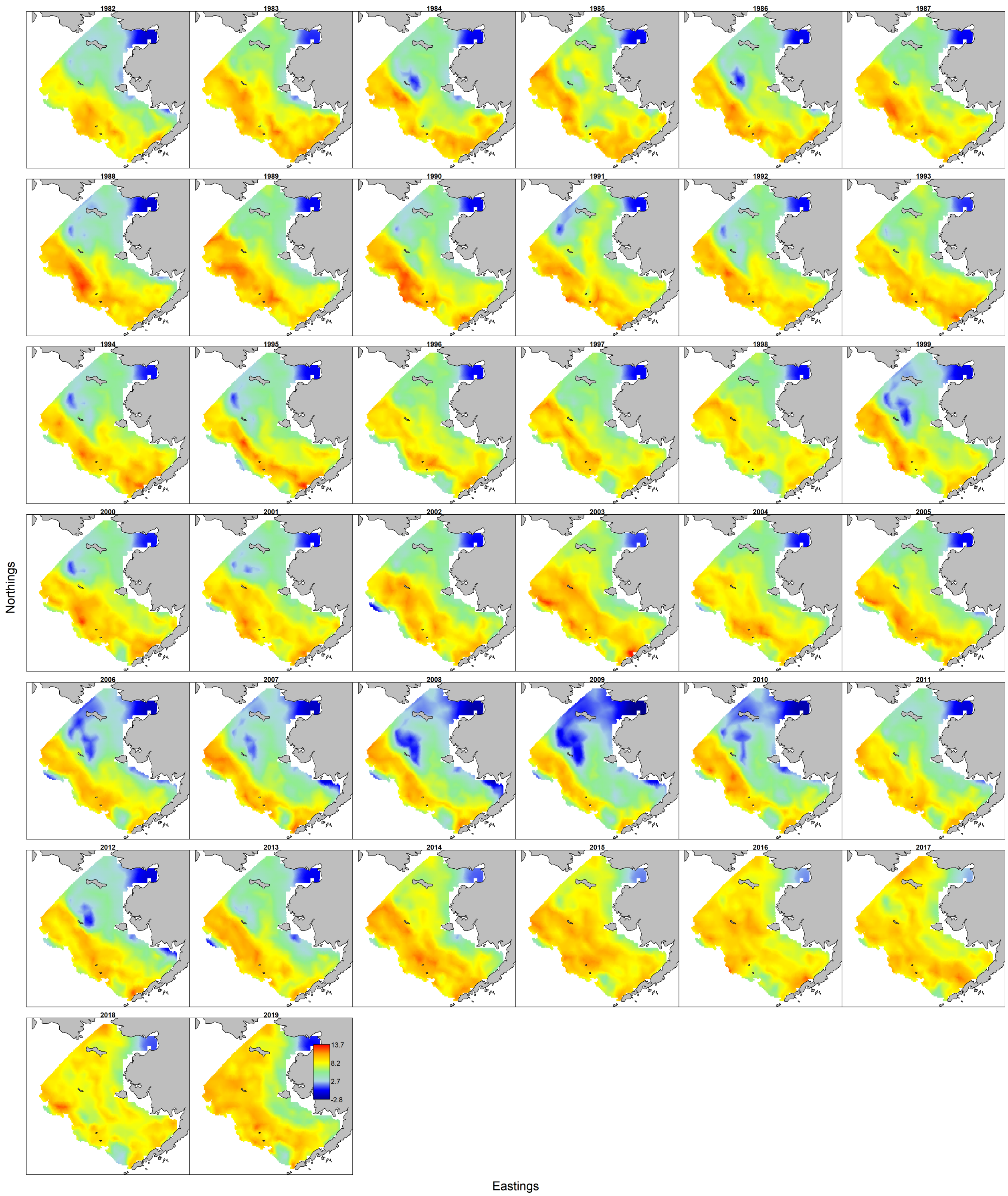


Figure 65: Pollock density maps using the VAST model approach, 1982-2019.

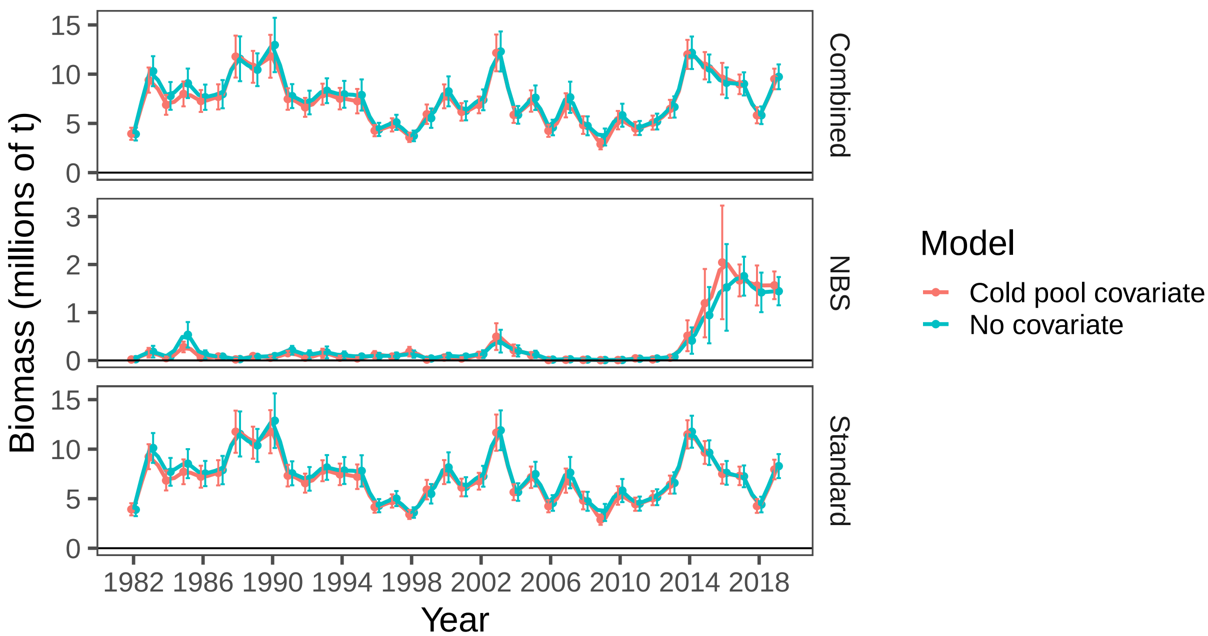


Figure 66: Pollock index values for the standard survey region, the NBS, and combined based on the VAST application to density-dependent corrected CPUE values from the BTS data, 1982–2019. The different lines are smoothed trends for with and without including the cold-pool extent as a covariate.

Summary tables for alternative models and/or Tiers

Tier 3, Model 16.1

Quantity	As estimated or *specified* *last* year for: 2019	2020	As estimated or *recommended* *this* year for: 2020	2021
M (natural mortality rate, ages 3+)	0.3	0.3	0.3	0.3
Tier	1a	1a	3a	3a
Projected total (age 3+) biomass (t)	9,110,000 t	8,156,000 t	8,580,000 t	7,990,000 t
Projected female spawning biomass (t)	3,107,000 t	2,725,000 t	2,781,000 t	2,476,000 t
$B_0 or B_{100}$	5,866,000 t	5,866,000 t	6,165,000 t	6,165,000 t
B_{msy}	2,280,000 t	2,280,000 t	2,158,000 t	2,158,000 t
F_{OFL}	0.645	0.645	0.314	0.321
$maxF_{ABC}$	0.510	0.51	0.253	0.262
F_{ABC}	0.356	0.375	0.253	0.262
OFL	3,913,000 t	3,082,000 t	2,539,000 t	2,098,000 t
$maxABC$	3,096,000 t	2,437,000 t	2,045,000 t	1,716,000 t
ABC	2,163,000 t	1,792,000 t	2,045,000 t	1,716,000 t
Status	2017	2018	2018	2019
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Tier 1, Model 16.2 (VAST bottom trawl survey data, full time series, include NBS)

Quantity	As estimated or *specified last* year for: 2019	2020	As estimated or *recommended this* year for: 2020	2021
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)	9,110,000 t	8,156,000 t	9,128,000 t	8,494,000 t
Projected female spawning biomass (t)	3,107,000 t	2,725,000 t	2,991,000 t	2,674,000 t
B_0	5,866,000 t	5,866,000 t	5,777,000 t	5,777,000 t
B_{msy}	2,280,000 t	2,280,000 t	2,148,000 t	2,148,000 t
F_{OFL}	0.645	0.645	0.449	0.449
$maxF_{ABC}$	0.510	0.51	0.383	0.383
F_{ABC}	0.356	0.375	0.225	0.235
OFL	3,913,000 t	3,082,000 t	4,085,000 t	3,385,000 t
$maxABC$	3,096,000 t	2,437,000 t	3,485,000 t	2,888,000 t
ABC	2,163,000 t	1,792,000 t	2,043,000 t	1,767,000 t
Status	2017	2018	2018	2019
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Tier 3, Model 16.2 (VAST bottom trawl survey data, full time series, include NBS)

Quantity	As estimated or *specified last* year for: 2019	2020	As estimated or *recommended this* year for: 2020	2021
M (natural mortality rate, ages 3+)	0.3	0.3	0.3	0.3
Tier	1a	1a	3a	3a
Projected total (age 3+) biomass (t)	9,110,000 t	8,156,000 t	9,128,000 t	8,494,000 t
Projected female spawning biomass (t)	3,107,000 t	2,725,000 t	2,991,000 t	2,674,000 t
$B_0 or B_{100}$	5,866,000 t	5,866,000 t	6,256,000 t	6,256,000 t
B_{msy}	2,280,000 t	2,280,000 t	2,190,000 t	2,190,000 t
F_{OFL}	0.645	0.645	0.277	0.29
$maxF_{ABC}$	0.510	0.51	0.225	0.235
F_{ABC}	0.356	0.375	0.225	0.235
OFL	3,913,000 t	3,082,000 t	2,523,000 t	2,188,000 t
$maxABC$	3,096,000 t	2,437,000 t	2,043,000 t	1,767,000 t
ABC	2,163,000 t	1,792,000 t	2,043,000 t	1,767,000 t
Status	2017	2018	2018	2019
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

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