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 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).

We contineud 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.

Summary of EBS pollock results

	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)	10,965,000 t	10,117,000 t	6,017,000 t	5,381,000 t
Projected female spawning biomass (t)	3,678,000 t	3,365,000 t	1,882,000 t	1,604,000 t
B_0	5,394,000 t	5,394,000 t	5,142,000 t	5,142,000 t
B_{msy}	2,042,000 t	2,042,000 t	1,970,000 t	1,970,000 t
F_{OFL}	0.621	0.621	0.494	0.494
$maxF_{ABC}$	0.466	0.466	0.395	0.395
F_{ABC}	0.336	0.336		
OFL	4,797,000 t	4,592,000 t	2,335,000 t	1,440,000 t
$maxABC$	3,603,000 t	3,448,000 t	1,869,000 t	1,153,000 t
ABC	2,592,000 t	2,467,000 t	1,589,000 t	980,000 t
Status	2016	2017	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

In the November 2017 Plan Team minutes: ”The Team recommends that more NBS surveys be conducted in the near future, as a time series of such data may be essential for understanding changes in the abundance of some individual stocks as well as the overall ecosystem. Some species, such as pollock and Pacific cod, exhibited enormous changes in NBS survey biomass between 2010 and 2017, both in absolute terms and relative to the NBS+EBS total, while others, such as Alaska plaice, exhibited very little change. The Team also recommends that assessment authors evaluate data from the NBS survey to determine if they should be included in their respective assessment models, particularly if more surveys are conducted, recognizing that it may be appropriate to include these data in some assessments but not others, and that the methods used to include these data may vary between assessments.”

In this assessment, a complete time series approach using a spatio temporal model for survey observations outside the standard area was developed and applied. This approach used the spatio-temporal model's estimated covariance matrix over time to fit the survey data (similar to the way the current, density-dependent correction is applied for survey data from the standard bottom trawl survey area).

Relative to the ecosystem status report… the Team recommends that assessment authors be more fully integrated into the prioritization of AFSC ecosystem research, in order to: 1) develop methods and approaches (where appropriate) of linking ecosystem indicators to individual species; 2) identify species-specific ecosystem "red-flags;" and 3) track indicator performance retrospectively, as is done for some of the pollock recruitment indicators.

A more formal qualitative risk table as developed by the Plan Team and a working group was used and is presented below in discussing ABC considerations

Comments specific to this assessment

SSC and Plan Team 2017 minutes:

…request that the authors develop a better prior for steepness, or at least a better rationale, and perhaps consider a meta-analytic approach.

A method outlined in a new meta-analytic paper on steepness using life history characteristics was evaluated using a Beverton-Holt stock recruitment relationship. This is presented as a model alternative.

The Team requests that the "year class diversity" index that had been reported in previous assessments be included in future assessments.

This is standard output from the assessment model and a time series of the estimate is provided.

The Team recommends that the authors compare fishery CPUE and survey CPUE in the core fishery area.

A more fully developed evaluation of fishery CPUE has yet to begin.

The Team recommends that next year's assessment include additional projections based on fixed levels of catch rather than fixed levels of fishing mortality, with the number of additional projections and the levels of fixed catch to be chosen by the author.

An array of fixed future catches has been included as part of the decision table.

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 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 second, 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. **??**). 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. **??**). The 2018 A-season fishery spatial pattern had relatively high concentrations of fishing on the shelf north of Unimak Island, especially compared to the pattern observed in 2016 when the fishing activity extended farther north (Fig. **??**). The 2018 A-season catch rates continued to be high improving even on the good conditions observed in 2016 and 2017 A (and B) seasons (Fig. **??**). 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. **??**).

The fishing in summer-fall 2018 was again concentrated in the south eastern area near the shelf break but also showed more catches in the northwestern part compared to 2016 and 2017 (Fig. ??). The 2018 summer and fall (B-season) catch per hour fished was lower than the last few years and fishing began slowly and improved to be about average (since 2011; Fig. ??). 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.

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 1995XX–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 2018 annual value was 54% but was quite high in the A-season (63%; 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. **??**).

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. **??**). 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 2017

Alaska pollock is the dominant species in terms of catch in the Bering Sea & Aleutian Island (BSAI) region. In 2017 pollock accounted for 70% of the BSAI's FMP groundfish harvest and 88% of the total pollock harvest in Alaska. Retained catch of pollock increased 0.5% to 1.36 million t in 2017. BSAI pollock first-wholesale value was $1.355 billion 2017, which was roughly equal to the value in 2016 and above the 2005–2007 average of $1.25 billion. The higher revenue in recent years is largely the result of increased catch and production levels as the average first-wholesale price of pollock products have declined since peaking in 2008–2010 and since 2013 have been close to the 2005–2007 average, though this varies across products types. The marginal increases in the average first-wholesale price of pollock products in 2016 and 2017 are largely due to increases the price of surimi products.

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] 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. 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.

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

[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%).

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. 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.[3] Additionally, pollock more broadly competes with other whitefish that, to varying degrees, can serve as substitutes depending on the product.

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%. With the U.S. supply reduction in 2008–2010, surimi production from pollock came under increased pressure as U.S. pollock prices rose and markets sought cheaper sources of raw materials (see Guenneugues and Ianelli 2013 for a global review of surimi resources and market). This contributed to a growth in surimi from warm-water fish of southeast Asia. Surimi prices spiked in 2008–2010 and have since tapered off as production from warm-water species increased (as has pollock). 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% increase to 710 kt. The value of these deliveries (shore-based ex-vessel value) totaled $205.1 million in 2017, which was down 1.8% from the ex-vessel value in 2016, as the increased catch was offset by a decrease in the ex-vessel price (Table 6). The first-wholesale value of pollock products was $841 million for the at-sea sector and $513 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 2017 increased for the at-sea sector and decreased for the shore-based sectors. The increase in the at-sea sector revenues was largely due to an increase in surimi prices, an increase which was not observed for the shore-based processors. Fillet product prices declined in 2017 while roe prices increased, however both 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%, 35%, and 10% of first-wholesale value (Table 7). The price of products

[3] 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.

produced at-sea tend to be higher than comparable products produced 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 35% 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 $0.20 per pound between 2011–2016, in part, because the shore-based sector increased their relative share of surimi production.[4] The at-sea price first wholesale premium increased to $0.37 in 2017 because of the difference in surimi prices between sectors.

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 increased to 37% in 2017. Total fillet production decreased 2.7% to 157 kt in 2016, 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 decreased 8% to $1.30 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 low throughout much of the year. High inventories, particularly early in the year, were cited as contributing factors. Low H&G prices incentivize Russia producers to upgrade their fillet production capacity in the near future, though fillets are a small portion of their primary production. Much of the Russian catch already 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% 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).[5] As fillet 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 has put upward pressure on pollock prices, however, U.S.-China trade policy uncertainty could negatively affect the market.

Surimi seafood

Surimi production continued an increasing trend through 2017, but at a rate of 3.1% to 196.7 kt which is above the 2005–2007 average. Prices have increased since 2013 to $1.35 per pound in the BSAI in 2017 (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 it yields a higher value than fillets. Additionally, the supply of raw surimi material in Japan has been limited (and is expected to be the case through

[4]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.

[5]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.

2018). Increasing Atka mackerel prices (another source of raw material for surimi) could also increase demand for pollock based surimi.

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 20 kt annually, production averaged 27 kt in 2005–2007 and was 18.4 kt in 2017, which is up 29% from 2016 (Fig. **??**). 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 has varied. The average roe price in the BSAI was up 2.2% in 2017 to $2.91 per pound, with a 32% increase in value to $118 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 10). 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.

Data

The following lists the data used in this assessment:

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. **??**; Table 11). The sampling effort for age determinations, weight-length measurements, and length frequencies is shown in Tables 12, 13, and 14. 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 15). 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 16; Fig. **??**). 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 C; Fig. **??**).

Beginning in 1987 NMFS expanded the standard survey area farther to the northwest. The pollock biomass levels found in the two northern strata were highly variable, ranging from 1% to 22% of the total biomass; whereas the 2014 estimate was 12%, 2015 was 7%, and in the past two years is slightly below the average (5%) at 4% and 3%–4% (Table 16). 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 these strata seem to improve coverage over the range of the exploited pollock stock.

The 2018 bottom-trawl survey biomass estimate (design-based, area swept) was 3.11 million t, below the average for this survey (4.7 million t). Particularly unusual this year was the complete lack of cold water on the bottom throughout the survey area (Fig. **??**). Pollock appeared to be distributed more northerly in 2018 again (as was the case in 2017 (Fig. **??**). These figures also show that the highest densities of pollock were at stations near Zhemchug Canyon.

The BTS abundance-at-age estimates show variability in year-class strengths with substantial consistency over time (Fig. **??**). 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 2018 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 17). 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 18 and contains the values used for the index which accounts for density-dependence in bottom trawl tows (Kotwicki et al. 2014). Mean body mass at ages from the survey are shown in (Table 19).

The bottom trawl survey has extended to the north in 2010, 2017, and again this year (but was limited to 49 stations). 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 20). 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 21). Estimated pollock biomass (to 3m from bottom) for the shelf was above 4 million tons in the early years of the time series (Table 20). 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 20 and 22).

The 2018 AT survey began on 6 June. Unfortunately, permission to extend the AT survey into the Russian Cape Navarin area was denied. Instead, the survey plan was to extend several tracklines north of the normal ('core') survey area between approximately 170°W and west of St. Matthew Island, based on 2016 and 2017 observations of more pollock than usual in that area. Due to an unforeseen ship failure mid-way through the survey the planned northern extension was reduced (trackline spacing increased). Due to another failure at the end of the survey, the final 3 transects of the AT survey core area were missed. (red transects in Fig. **??**). The survey ended about 2 weeks later than planned on 26 August. About 6.1% (~6,016 nmi^2) of the normal core survey area was unsampled.

Estimates of pollock by length and age for the surveyed area in 2018 were made using routine AT survey methods (e.g., Honkalehto and McCarthy, 2015). Estimates for pollock from the midwater layer between the surface and 3m were combined with those from the bottom layer between 0.5 and 3m depth, as adopted in 2016. The pollock biomass estimate to within 0.5 m of the seafloor was 2.321 million t for the sampled 'core' area, which encompassed 92,283 nmi^2 in 2018 was 2.321 million t. The pollock biomass estimate was 237,722 t for the northern extension area, which encompassed 6,900 nmi^2 outside of the traditional AT survey area, pollock biomass was estimated to be 237,722 t. A spatial comparison of these AT survey biomass estimates with the BTS biomass is shown in Fig. **??**.

The amount of pollock in the vicinity of the three unsampled transects at the survey end was estimated using acoustic data collected in that area by the RACE BTS vessels (see Honkalehto et al., 2011 for details, and McCarthy et al. in prep.) and AT survey trawl data. That is, BTS backscatter data in the unsampled area and the AT survey trawl data from the two adjacent transects surveyed by the RV Oscar Dyson were used to estimate pollock abundance and biomass by length and age in that area. The deeper shelf break portion (> 200 m) of the unsampled area normally covered by the AT survey was omitted as this relatively small area was not occupied by the BTS vessels. The estimates for the unsampled area (16m from sea surface to 0.5 m above sea floor) were 616 million pollock with a biomass of 178,194 t. These estimates represent 7.1% of the total biomass and 11.1% of total abundance for the entire core AT survey area (i.e. the traditional survey area excluding the northern extension).

The combined biomass estimates (sampled plus unsampled areas to within 0.5 m of seafloor, excluding northern extension area) for the 2018 AT survey is 2.50 million t. This is below average for the time series since 1994 (Table 22).

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 22; 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.

The 2018 EBS acoustic-trawl survey estimates of population numbers at age were developed based primarily on the BT survey age samples, and supplemented with a small set of juvenile samples from the AT survey. These samples were used to develop age-length keys, which were applied to the population size composition estimates from the AT survey (Fig. **??**). Interestingly, the 2018 data support the observation in 2016 that the 2013 year class was relatively abundant (along with the 2012 year class; Table 23).

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). This index was updated this year and shows acoustic- trawl survey in the EBS. This biomass series shows a steady decrease since 2015 (Table 24).

A spatial comparison between the BTS data and AVO survey transects in 2018 suggests differences in the locales and densities of pollock (Fig. **??**). This figure also shows that the AVO survey detected densities that were less apparent in the BTS data.

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 and biomass were added
- 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 developed this year relate primarily to alternative data treatment and a separate re-evaluation of the steepness prior and stock recruitment relationship. The two model alternatives (treated as sensitivities) includes one which incorporates a spatio-temporal model fit to BTS CPUE data *including stations from the NBS*. This survey data model applies the VAST (Thorson 2018) approach and due to allowing for spatial and temporal correlation, is well suited to having missing stations in some areas and years (and adjusts uncertainty accordingly). The second data treatment simply increased the weight on the final two survey data points (by reducing the CVs by a factor of 2). This was done because initial model runs indicated relatively poor fits to these data and by adding some constraint, it was hoped that structural aspects (and/or data conflicts) could be revealed. Finally, the fourth model involved revisiting prior distribution on steepness for the stock recruitment relationship (a response to Plan Team and SSC requests). This included comparing a Beverton-Holt model with some recent meta-analyses on priors for the steepness parameter based on Thorson et al. (2018) approach.

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 28). 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:

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

In the supplemental multi-species assessment model alternative values of age and time-varying natural mortality are presented. Those estimates indicate higher values than used 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., 2017 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 26). 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. **??**). 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 26). The changes in weight-at-age in the fishery are substantial, especially for the apparent abundant year-classes (e.g., the 4–9 year-olds from 2012–2017 representing the 2008 year class; Fig. **??**).) 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. **??**). Breaking this further by year and strata for recent years shows variability in the relative body mass at age between strata and years (Fig. **??**). In summary, these figures support that accounting for year and cohort effects is important in projecting body mass-at-age forward.

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. **??**). As the summer/fall progresses, fish were at their heaviest given length (Fig. ??). 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. ?? and ??). Differences in seasons were most apparent. The A-season data indicated that most pollock were below the global mean except for a few years whereas in the southeast the B-season were mostly above average in all years. Computing just the mean standardized value for each strata and year shows this pattern more clearly (Fig. ??). Of particular concern is that in the A-season, which is primarily focused on pre-spawning fish, the condition of pollock appears to have been the skinniest (given length) for the past four years in a row (Fig. ??).

Parameters estimated within the assessment model

For the selected model, 953 parameters were estimated conditioned on data and model assumptions. Initial age composition, subsequent recruitment, and stock- recruitment parameters account for 78 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. **??**; 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 28).

- 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 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). The extent that such relationships affect the stock-recruitment estimates (and future productivity) is a continuing area of research.

Results

Model evaluation

A sequential sensitivity of available new data showed that adding the 2017 fishery catch-at-age data and the 2018 catch biomass information resulted in an increase in spawning biomass estimates (Fig. **??**). As survey data were added to the model, the results become more similar to last year's estimate (for 2017 spawning biomass) and shows a lower biomass estimate for 2018 (Fig. **??**). Additional models for evaluations were

0. Last year's model ("Model 16.1") without any data update

1. The same as last year but with all data time series updated through the most recently available information

2. 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)
   - The rationale for considering this is the likelihood that pollock in the NBS are related and contribute to the EBS fishery

3. The same as Model 16.1 but with the coefficient of variations reduced by half in the terminal year
   - This was done as a sensitivity since three observations indicated a decline yet the structural aspects of the model seem to constrain the extent of the decline given past trends in the indices.

4. The same as Model 16.1 but with a Beverton-Holt stock recruitment relationship and steepness from a meta-analysis.
   - This was brought forward as a sensitivity in trying alternative prior distributions for steepness.

The reference model (Model 16.1) when compared to the two with different data treatments showed different patterns but ended up with similar model predictions for 2018 (Fig. **??**). The spawning biomass estimates and age compositions indicates a slight shift in the scale of spawning biomass estimates relative to last year (Fig. **??**). 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. **??**). Diagnostics of model fits between the set evaluated are given in Table **??**.

The model with a prior distribution based on meta-analysis (see section below on model description for details) using the Beverton-Holt stock recruitment estimation had very minor impact on the historical biomass and numbers at age, but did influence the shape of the stock-recruitment curve (Fig. **??**). Also, it affected management quantities (Table **??**).

The fit to the early Japanese fishery CPUE data (Low and Ikeda 1980) is consistent with the estimated population trends for this period (Fig. **??**). The model fits the fishery- independent index from the 2006–2018 AVO data well indicating a downward trend since 2016 (Fig. **??**). The fits to the bottom-trawl survey biomass (the density-dependent corrected series) appear to be reasonable (Fig. **??**). Similarly, the fits to the acoustic-trawl survey biomass series is consistent with the specified observation uncertainty (Fig. **??**).

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

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

Bottom-trawl survey selectivity (Fig. **??**) and fits to the numbers of age 2 and older pollock indicate that the model predicts fewer pollock than observed in the 2014 and 2015 survey but slightly more than observed in the 2012, 2013 and in 2016–17 (Fig. **??**). 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. **??**). 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 numbers of age 2 and older pollock in the AT 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. **??**). The AT age compositions consistently track large year classes through the population and the model fits these patterns reasonably well (Fig. **??**).

As in past assessments, an evaluation of the multivariate posterior distribution was performed by running a chain of 3 million Monte-Carlo Markov chain (MCMC) simulations and saving every 600th iteration (final posterior draws totaled 5,000). A pairwise comparison for some key parameters could be evaluated (along with their marginal distributions; Fig. **??**). To compare the point estimates (highest posterior density) with the mean of the posterior marginal distribution, overplotting the former on the latter for the 2018 spawning biomass estimate were similar (Fig. **??**).

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 **??**). 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 4.6 million t. The estimate for 2018 is trending downward and is at just over 10 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. **??**). 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 2016 was below 20% due to the reductions in TACs relative to the maximum permissible ABC values and increased 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 2016 is estimated at about 0.16. 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. **??**). The estimates of age 3+ pollock biomass were mostly higher than the estimates from previous years (Fig. **??**, Table **??**).

Estimated numbers-at-age are presented in (Table 29) and estimated catch-at-age values are presented in (Table 30). Estimated summary biomass (age 3+), female spawning biomass, and age-1 recruitment are given in (Table 32).

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. **??**).

Recruitment

Model estimates indicate that both the 2008 and 2012 year classes are well above average (Fig. **??**). 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. **??**). 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. **??**).

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 1997) results in a fair amount of variability in both spawning biomass and recruitment (Fig. **??**) Although the variability is high, the average bias appears to be low with Mohn's ρ equal to 0.025 for the 10 year retrospective and 0.05 if extended back 20-years.

Harvest recommendations

Status summary

The estimate of B_{MSY} is 1,970 kt (with a CV of 25%) which is less than the projected 2020 spawning biomass of 1,900 kt; (Table 33). For 2019, the Tier 1 levels of yield are 1,869,000 t from a fishable biomass estimated at around 4,969 kt (Table 34; about 95% 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 53% of the predicted value had no fishing occurred since 1978 (Table 33). This compares with the 45% of $B_{100}\%$ (based on the SPR expansion using mean recruitment from 1978–2016) and 117% of B_0 (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 $B_{40\%}$ (1,900 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}	= 1,970 kt female spawning biomass
B_0	= 5,142 kt female spawning biomass
$B_{100\%}$	= 5,118 kt female spawning biomass
$B_{40\%}$	= 2,047 kt female spawning biomass
$B_{35\%}$	= 1,791 kt female spawning biomass

Specification of OFL and Maximum Permissible ABC

Assuming the stock-recruit relationship the 2020 spawning biomass is estimated to be 1,882,000 t (at the time of spawning, assuming the stock is fished at about recent catch levels). This is above the B_{MSY} value of 1,970,000 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 (1,970 kt) and the $B_{40\%}$ value (2,047 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	1,869,000	2,335,000
1a	2021	1,153,000	1,440,000
3a	2020	1,792,000	2,208,000
3a	2021	1,521,000	1,861,000

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 2018, 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 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 38). 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. **??**).

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 35 through 38). 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 38). Based on this, the EBS pollock stock is being fished below the overfishing level and the stock size is estimated to be above, abd 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 (2,310 kt) which is about 117% of B_{MSY} (1,970 kt). The replacement yield—defined as the catch next year that is expected to achieve a 2020 spawning biomass estimate equal to that from 2019—is estimated to be about 220 t. Note that the negative value for replacement yield suggests that the stock will decline even in the absence of any fishing. This follows a period of increases from 2008–2017 and is expected. The extent that the stock will exhibit declines into the future depends on future recruitment, which is always uncertain. Some issues to consider in the medium-term are that

1. The conditions in summer 2018 were exceptional in the complete absence of a "cold pool" and being a second consecutive year with significant abundances found outside of the standard survey area.
2. There were relatively few juvenile pollock observed in the surveys during the summers of 2016–2018.
3. The recent BTS data continue to show low abundances of pollock aged 10 and older (Table 18). Historically there had been good representation of older fish in data from this survey. This is somewhat expected given the poor year-classes observed during the period 2000–2005.
4. The multispecies model suggests that the B_{MSY} level is around 2.9 million t instead of the 2 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. Finally, given the same estimated aggregate fishing effort in 2018, the estimated stock trend is downwards except at low catch levels (a replacement yield of 220 kt is the amount that would maintain the spawning stock constant). Being a negative value means that even without any fishing,the stock is projected to decline. Furthermore, the ability to catch roughly the same amount as in 2019 through to 2022 will require about *75% more effort* (effectively) with a decline in spawning biomass of about 30% compared to the current level (based on expected average recruitment; Fig. **??**).

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. This was implemented for this year's recommendation.

	Considerations		
	Assessment-related	**Population dynamics**	**Environmental & ecosystem**
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
Level 2 Substantially increased concerns	Substantially increased assessment uncertainty unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing an adverse signals but the pattern is inconsistent across all indicators.
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)
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

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.

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. It seems likely that recruitment in the near term will be below average yet the population dynamics, being data driven, projects recruitment to be average. Additional age-specific aspects of the spawning population indicates that the stock is at a low diversity of ages and the mean age of the spawning stock (weighted by spawning output) are both at relatively low levels (Fig. **??**). **We therefore rated the population-dynamic concern as level 2, a substantially increased concern.**

Environmental/Ecosystem considerations 2018 was unprecedented (for the period of our observations) with near- complete lack of sea ice in the Northern Bering Sea and complete lack of sea ice (and resulting cold pool) over the southeastern Bering Sea shelf. The ecosystem responses indicate potential concerns for pollock, as both prey resources and predator dynamics were impacted. Over the southern shelf, a weak, delayed bloom provided reduced phytoplankton biomass which likely impacted the zooplankton prey base.

Small copepod production in the spring of 2018 was apparently above average, but decreased nauplii survival is predicted based on reduced phytoplankton. Both acoustic and RZA (rapid zooplankton assessment) estimates indicate low euphausiid abundance; both indicators suggest this high-quality prey has become less available since 2012. Over the northern shelf, large copepods were an order of magnitude less abundant than a previous survey conducted in 2007; euphausiids were also several orders of magnitude lower. Larval pollock production appears high (comparable to 2014 and 2016), which is expected in warm years, but larval survival is expected to be low due to degraded prey resources and reduced energy transfer.

Fish condition (based on weight/length residuals) show that adult pollock condition was negative in both the SEBS and NBS, which continues a declining trend since 2012. The biomass of the pelagic forager guild, which includes pollock, remains below the long-term mean with pollock declining 59% since 2014 and 38% since 2017. Total CPUE of groundfish estimated from the bottom trawl survey showed a sharp decline in 2018, primarily due to a decrease in pollock, Pacific cod, and several flatfish species.

A seabird die-off event, unprecedented in terms of spatial and temporal scale, combined with broad reproductive failures and/or late breeding success indicate, in part, a lack of sufficient prey resources (emaciation and starvation are the only identified causes of mortality to date). In addition to several of these species preying on juvenile pollock, they also rely on the same zooplankton as pollock for survival. The die-offs may be indicative of poor juvenile pollock survival and/or available prey for juvenile pollock. Some outstanding ecosystem questions are whether Pacific cod and pollock remained in the NBS over winter 2017–2018. Given the warm water temperatures (and lack of sea ice), over-winter feeding to meet their metabolic demands may have reduced the prey base and shifted the food-web balance in the NBS.

There were also unusual observations of adult pollock behavior in Bristol Bay and these may be indicative of (i) a distribution shift in response to warm temperatures (although temperatures SEBS shelf were similar to a 'typical' warm year), (ii) looking for adequate prey (although stomachs were not empty and contents were 'typical'), or (iii) potential harmful algal bloom event (samples still being processed).

In summary,

- Unprecedented warm conditions in 2018 resulted in reduced primary and secondary production
- The cold pool prediction for summer 2019 is for continued warm conditions and reduced cold pool extent
- Weak, delayed phytoplankton bloom, reduced biomass, and reduced energy transfer to upper trophic levels (i.e., zooplankton prey base and juvenile pollock)
- Zooplankton prey base reduced (small, lipid-poor taxa, few euphausiids)
- Adult pollock condition index is negative in both SEBS and NBS and has been trending downwards in SEBS since 2010.
- Unprecedented seabird die-off event and broad reproductive failures indicate, in part, a lack of sufficient prey resources

We therefore rated the Ecosystem concern as Level 2, substantially increased concern. These results are summarized as:

	Considerations		
Assessment-related	Population dynamics	Environmental or ecosystem	Score (max of individual)
Level 1: No concern	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 $0.85 \times \text{ABC}_{max} = 1{,}588$ 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 again this year, (i.e., ABC = 1,792 kt) which implies a buffer of 4%.

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 2019 catch values. These indicators and rationale for including them are summarized in Table 44). Model 16.1 results for these indicators are provided in Table 45. Each column of this table uses a fixed 2019 catch and assumes the same effort for the four additional projection years (2020–2023). 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 2018 value, more fishing effort will likely be required and there is an good chance that the proportion of the stock less than age 6 will be greater than the historical average. In terms of catch advice, aiming for a catch between 1.25 and 1.374 million t results in a roughly even chance that the stock in 2020 will be equal to the long term mean.

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) will require careful monitoring and evaluation.

A brief summary of these two perspectives (ecosystem effects on pollock stock and pollock fishery effects on ecosystem) is given in (Table 42). 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 41). Jellyfish represent the largest component of the bycatch of non-target species and had averaged around 5–6 kt per year but more than doubled in 2014 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 39). 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 40).

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 42). 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 42). Ianelli and Stram (2014) provided estimates of the bycatch impact on Chinook salmon runs to the coastal west Alaska region and found that the peak bycatch levels exceeded 7% of the total run return. Since 2011, the impact has been estimated to be below 2%. Updated estimates given new genetic information and these levels of PSC 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:

- 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 availble samples) and apply high resolution genetic tools for stock structure analyses.

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References

Alaska Fisheries Science Center (AFSC). 2016. Wholesale market profiles for Alaska groundfish and crab fisheries. 134 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 San Point Way NE, Seattle WA 98115.

Aydin, K. Y., et al.2002. A comparison of the Eastern Bering and western Bering Sea shelf and slope ecosystems through the use of mass-balance food web models. U.S. Department of Commerce, Seattle, WA. (NOAA Technical Memorandum NMFS-AFSC-130) 78p.

Bacheler, N.M., L. Ciannelli, K.M. Bailey, and J.T. Duffy-Anderson. 2010. Spatial and temporal patterns of walleye pollock (*Theragra chalcogramma*) spawning in the eastern Bering Sea inferred from egg and larval distributions. Fish. Oceanogr. 19:2. 107-120.

Bailey, K.M., T.J. Quinn, P. Bentzen, and W.S. Grant. 1999. Population structure and dynamics of walleye pollock, *Theragra chalcogramma*. Advances in Mar. Biol. 37:179-255.

Bailey, K. M. 2000. Shifting control of recruitment of walleye pollock *Theragra chalcogramma* after a major climatic and ecosystem change. Mar. Ecol. Prog. Ser., 198, 215–224. link

Barbeaux, S. J., S. Gaichas, J. N. Ianelli, and M. W. Dorn. 2005. Evaluation of biological sampling protocols for at-sea groundfish observers in Alaska. Alaska Fisheries Research Bulletin 11(2):82-101.

Barbeaux, S.J., Horne, J., Ianelli, J. 2014. A novel approach for estimating location and scale specific fishing exploitation rate of eastern Bering Sea walleye pollock (*Theragra chalcogramma*). Fish. Res. 153 p. 69 – 82.

Brodeur, R.D.; Wilson, M.T.; Ciannelli, L.; Doyle, M. and Napp, J.M. (2002). Interannual and regional variability in distribution and ecology of juvenile pollock and their prey in frontal structures of the Bering Sea. Deep-Sea Research II. 49: 6051-6067.

Butterworth, D.S., J.N. Ianelli, and R. Hilborn. 2003. A statistical model for stock assessment of southern bluefin tuna with temporal changes in selectivity. Afr. J. mar. Sci. 25: 331-361.

Buckley, T.W., Greig, A., Boldt, J.L., 2009. Describing summer pelagic habitat over the continental shelf in the eastern Bering Sea, 1982–2006. United States Depart- ment of Commerce, NOAA Technical Memorandum. NMFS-AFSC-196. pp. 49.

Buckley, T. W., Ortiz, I., Kotwicki, S., & Aydin, K. (2015). Summer diet composition of walleye pollock and predator-prey relationships with copepods and euphausiids in the eastern Bering Sea, 1987-2011. Deep-Sea Research Part II: Topical Studies in Oceanography, 134, 302–311. link.

Canino, M.F., P.T. O'Reilly, L. Hauser, and P. Bentzen. 2005. Genetic differentiation in walleye pollock (*Theragra chalcogramma*) in response to selection at the pantophysin (Pan I) locus. Can. J. Fish. Aquat. Sci. 62:2519-2529.

Ciannelli, L., B.W. Robson, R.C. Francis, K. Aydin, and R.D. Brodeur 2004a. Boundaries of open marine ecosystems: an application to the Pribilof Archipelago, southeast Bering Sea. Ecological Applications, Volume 14, No. 3. pp. 942-953.

Ciannelli, L.; Brodeur, R.D., and Napp, J.M. 2004b. Foraging impact on zooplankton by age-0 walleye pollock (*Theragra chalcogramma*) around a front in the southeast Bering Sea. Marine Biology. 144: 515-525.

Clark, W.G. 1999. Effects of an erroneous natural mortality rate on a simple age-structured model. Can. J. Fish. Aquat. Sci. 56:1721-1731.

Cooper, D. W., Duffy-Anderson, J. T., Norcross, B. L., Holladay, B. A., & Stabeno, P. J. (2014). Nursery areas of juvenile northern rock sole (*Lepidopsetta polyxystra*) in the eastern Bering Sea in relation to hydrography and thermal regimes. ICES Journal of Marine Science, 71(7), 1683–1695. doi:10.1093/icesjms/fst210

Cotter, A.J.R., L. Burt, C.G.M Paxton, C. Fernandez, S.T. Buckland, and J.X Pan. 2004. Are stock assessment methods too complicated? Fish and Fisheries, 5:235-254.

Cotter, A. J. R., Mesnil, B., and Piet, G. J. 2007. Estimating stock parameters from trawl cpue-at-age series using year-class curves. – ICES Journal of Marine Science, 64: 234–247.

Coyle, K. O., Eisner, L. B., Mueter, F. J., Pinchuk, A. I., Janout, M. A., Cieciel, K. D., … Andrews, A. G. (2011). Climate change in the southeastern Bering Sea: impacts on pollock stocks and implications for the oscillating control hypothesis. Fisheries Oceanography, 20(2), 139–156. doi:10.1111/j.1365-2419.2011.00574.x

De Robertis, A., and K. Williams. 2008. Weight-length relationships in fisheries studies: the standard allometric model should be applied with caution. Trans. Am. Fish. Soc. 137:707-719.

De Robertis, A., McKelvey, D.R., and Ressler, P.H. 2010. Development and application of empirical multi-frequency methods for backscatter classification in the North Pacific. Can. J. Fish. Aquat. Sci. 67: 1459-1474.

De Robertis, A., Taylor, K., Wilson, C., and Farley, E. 2017. Abundance and Distribution of Arctic cod (Boreogadus saida) and other Pelagic Fishes over the U.S. Continental Shelf of the Northern Bering and Chukchi Seas Deep-Sea Research II, 135: 51-65.

Dorn, M.W. 1992. Detecting environmental covariates of Pacific whiting Merluccius productus growth using a growth-increment regression model. Fish. Bull. 90:260-275.

Duffy-Anderson, J. T., Barbeaux, S. J., Farley, E., Heintz, R., Horne, J. K., Parker-Stetter, S. L.,

… Smart, T. I. (2016). The critical first year of life of walleye pollock (Gadus chalcogrammus) in the eastern Bering Sea: Implications for recruitment and future research. Deep-Sea Research Part II: Topical Studies in Oceanography, 134, 283–301. link.

Fissel, B., M. Dalton, R. Felthoven, B. Garber-Yonts, A. Haynie, A. Himes-Cornell, S. Kasperski, J. Lee, D. Lew, and C. Seung. 2014. Stock assessment and fishery evaluation report for the Groundfish fisheries of the Gulf of Alaska and Bering Sea/Aleutian Islands area: Economic status of the groundfish fisheries off Alaska, 2013.

Fournier, D.A. and C.P. Archibald. 1982. A general theory for analyzing catch-at-age data. Can. J. Fish. Aquat. Sci. 39:1195-1207.

Fournier, D.A., J.R. Sibert, J. Majkowski, and J. Hampton. 1990. MULTIFAN a likelihood-based method for estimating growth parameters and age composition from multiple length frequency samples with an application to southern bluefin tuna (Thunnus maccoyii). Can. J. Fish. Aquat. Sci. 47:301-317.

Francis, R.I.C.C., and Shotton, R. 1997. Risk in fisheries management: a review. Can. J. Fish. Aquat. Sci.54: 1699–1715.

Francis, R.I.C.C. 1992. Use of risk analysis to assess fishery management strategies: a case study using orange roughy (Hoplostethus atlanticus) on the Chatham Rise, New Zealand. Can. J. Fish. Aquat. Sci. 49: 922-930.

Francis, R I C C 2011. Data weighting in statistical fisheries stock assessment models. Can. Journ. Fish. Aquat. Sci. 1138: 1124-1138.

Gann, J. C., Eisner, L. B., Porter, S., Watson, J. T., Cieciel, K. D., Mordy, C. W., Farley, E. V. (2015). Possible mechanism linking ocean conditions to low body weight and poor recruitment of age-0 walleye pollock (*Gadus chalcogrammus*) in the southeast Bering Sea during 2007. Deep Sea Research Part II: Topical Studies in Oceanography, 134, 1–13. link.

Gislason, H., Daan, N., Rice, J. C., & Pope, J. G. (2010). Size, growth, temperature and the natural mortality of marine fish. Fish and Fisheries, 11(2), 149–158. doi:10.1111/j.1467-2979.2009.00350.

Grant, W. S., Spies, I., and Canino, M. F. 2010. Shifting-balance stock structure in North Pacific walleye pollock (*Gadus chalcogrammus*). – ICES Journal of Marine Science, 67:1686-1696.

Greiwank, A., and G.F. Corliss (eds.) 1991. Automatic differentiation of algorithms: theory, implementation and application. Proceedings of the SIAM Workshop on the Automatic Differentiation of Algorithms, held Jan. 6-8, Breckenridge, CO. Soc. Indust. And Applied Mathematics, Philadelphia.

Guenneugues, P., & Ianelli, J. (2013). Surimi Resources and Market. In Surimi and Surimi Seafood, Third Edition (pp. 25–54). CRC Press. link.

Haynie, A. C. (2014). Changing usage and value in the Western Alaska Community Development Quota (CDQ) program. Fisheries Science, 80(2), 181–191. link.

Heintz, R. a., Siddon, E. C., Farley, E. V., & Napp, J. M. (2013). Correlation between recruitment and fall condition of age-0 pollock (*Theragra chalcogramma*) from the eastern Bering Sea under varying climate conditions. Deep Sea Research Part II: Topical Studies in Oceanography, 94, 150–156. link.

Hinckley, S. 1987. The reproductive biology of walleye pollock, *Theragra chalcogramma*, in the Bering Sea, with reference to spawning stock structure. Fish. Bull. 85:481-498.

Hollowed, A. B., J. N. Ianelli, and P. A. Livingston. 2000. Including predation mortality in stock assessments: A case study involving Gulf of Alaska walleye pollock. ICES Journal of Marine Science, 57, pp. 279-293.

Hollowed, A. B., Aydin, K. Y., Essington, T. E., Ianelli, J. N., Megrey, B. a, Punt, A. E., & Smith, A. D. M. (2011). Experience with quantitative ecosystem assessment tools in the northeast Pacific. Fish and Fisheries, 12(2), 189–208. doi:10.1111/j.1467-2979.2011.00413.

Hollowed, A. B., Barbeaux, S. J., Cokelet, E. D., Farley, E., Kotwicki, S., Ressler, P. H., … Wilson, C. D. 2012. Effects of climate variations on pelagic ocean habitats and their role in structuring forage fish distributions in the Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography, 65-70, 230–250. doi:10.1016/j.dsr2.2012.02.008

Honkalehto, T., Ressler, P.H., Towler, R.H., Wilson, C.D., 2011. Using acoustic data from fishing vessels to estimate walleye pollock (*Theragra chalcogramma*) abundance in the eastern Bering Sea. 2011. Can. J. Fish. Aquat. Sci. 68: 1231–1242

Honkalehto, T., D. McKelvey, and N. Williamson. 2005. Results of the echo integration-trawl survey of walleye pollock (*Theragra chalcogramma*) on the U.S. and Russian Bering Sea shelf in June and July 2004. AFSC Processed Rep. 2005-02, 43 p.

Honkalehto, T, A. McCarthy, P. Ressler, K. Williams, and D. Jones. 2012. Results of the Acoustic-Trawl Survey of Walleye Pollock (*Theragra chalcogramma*) on the U.S. and Russian Bering Sea Shelf in June - August 2010. AFSC Processed Rep. 2012-01, 57 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Honkalehto, T., A. McCarthy, P. Ressler, and D. Jones, 2013. Results of the acoustic-trawl survey of walleye pollock (*Theragra chalcogramma*) on the U.S., and Russian Bering Sea shelf in June–August 2012 (DY1207). AFSC Processed Rep. 2013-02, 60 p. Alaska Fish. Sci. Cent. NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115. Available

Honkalehto, T, P. H. Ressler, S. C. Stienessen, Z. Berkowitz, R. H. Towler, a. L. Mccarthy, and R. R. Lauth. 2014. Acoustic Vessel-of-Opportunity (AVO) index for midwater Bering Sea walleye pollock, 2012-2013. AFSC Processed Rep. 2014-04, 19 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115. Available

Honkalehto, T, and A. McCarthy. 2015. Results of the Acoustic-Trawl Survey of Walleye Pollock (*Gaddus chalcogrammus*) on the U.S. and Russian Bering Sea Shelf in June - August 2014. AFSC Processed Rep. 2015-07, 62 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115. Available

Hulson, P.-J.F., Miller, S.E., Ianelli, J.N., and Quinn, T.J., II. 2011. Including mark–recapture data into a spatial age-structured model: walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea. Can. J. Fish. Aquat. Sci. 68(9): 1625–1634. doi:10.1139/f2011-060.

Hulson, P. F., Quinn, T. J., Hanselman, D. H., Ianelli, J. N. (2013). Spatial modeling of Bering Sea walleye pollock with integrated age-structured assessment models in a changing environment. Canadian Journal of Fisheries & Aquatic Sciences, 70(9), 1402-1416. doi:10.1139/cjfas-2013-0020.

Hunt Jr., G.L., Coyle, K.O., Eisner, L.B., Farley, E.V., Heintz, R.A., Mueter, F., Napp, J.M., Overland, J.E., Ressler, P.H., Salo, S., Stabeno, P.J., 2011. Climate impacts on eastern Bering Sea foodwebs: a synthesis of new data and an assessment of the Oscillating Control Hypothesis. ICES J. Mar. Sci. 68 (6), 1230–1243. link.

Ianelli, J.N. 2005. Assessment and Fisheries Management of Eastern Bering Sea Walleye Pollock: is Sustainability Luck Bulletin of Marine Science, Volume 76, Number 2, April 2005 , pp. 321-336(16)

Ianelli, J.N. and D.A. Fournier. 1998. Alternative age-structured analyses of the NRC simulated stock assessment data. In Restrepo, V.R. [ed.]. Analyses of simulated data sets in support of the NRC study on stock assessment methods. NOAA Tech. Memo. NMFS-F/SPO-30. 96 p.

Ianelli, J.N., L. Fritz, T. Honkalehto, N. Williamson and G. Walters 1998. Bering Sea-Aleutian Islands Walleye Pollock Assessment for 1999. In: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pac. Fish. Mgmt. Council, Anchorage, AK, section 1:1-79.

Ianelli, J.N., S. Barbeaux, T. Honkalehto, N. Williamson and G. Walters. 2003. Bering Sea-Aleutian Islands Walleye Pollock Assessment for 2003. In: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pac. Fish. Mgmt. Council, Anchorage, AK, section 1:1-101.

Ianelli, J.N., S. Barbeaux, T. Honkalehto, S. Kotwicki, K. Aydin and N. Williamson. 2011. Assessment of the walleye pollock stock in the Eastern Bering Sea. In Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pac. Fish. Mgmt. Council, Anchorage, AK, section 1:58-157.

Ianelli, J.N., T. Honkalehto, S. Barbeaux, S. Kotwicki, K. Aydin, and N. Williamson, 2013. Assessment of the walleye pollock stock in the Eastern Bering Sea, pp. 51-156. In Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions for 2014. North Pacific Fishery Management Council, Anchorage, AK. Available

Ianelli, J.N., T. Honkalehto, S. Barbeaux, S. Kotwicki, B. Fissel, and K. Holsman, 2016. Assessment of the walleye pollock stock in the Eastern Bering Sea, pp. 51-156. In Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions for 2017. North Pacific Fishery Management Council, Anchorage, AK. Available

Ianelli, J.N., A.B. Hollowed, A.C. Haynie, F.J. Mueter, and N.A. Bond. 2011. Evaluating management strategies for eastern Bering Sea walleye pollock (*Theragra chalcogramma*) in a changing environment. ICES Journal of Marine Science, doi:10.1093/icesjms/fsr010.

Ianelli, J.N. and D.L. Stram. 2014. Estimating impacts of the pollock fishery bycatch on western Alaska Chinook salmon. ICES Journal of Marine Science. doi:10.1093/icesjms/fsu173

Jensen, A. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Canadian Journal of Fisheries and Aquatic Sciences 53, 820–822.

Johnson, K. F., Monnahan, C. C., McGilliard, C. R., Vert-pre, K. A., Anderson, S. C., Cunningham, C. J., … Punt, A. E. (2015). Time-varying natural mortality in fisheries stock assessment models: identifying a default approach. ICES Journal of Marine Science, 72(1), 137–150. link.

Jurado-Molina J., P. A. Livingston and J. N. Ianelli. 2005. Incorporating predation interactions to a statistical catch-at-age model for a predator-prey system in the eastern Bering Sea. Canadian Journal of Fisheries and Aquatic Sciences. 62(8): 1865-1873.

Kastelle, C. R., and Kimura, D. K. 2006. Age validation of walleye pollock (*Theragra chalcogramma*) from the Gulf of Alaska using the disequilibrium of Pb-210 and Ra-226. e ICES Journal of Marine Science, 63: 1520e1529.

Kimura, D.K. 1989. Variability in estimating catch-in-numbers-at-age and its impact on cohort analysis. In R.J. Beamish and G.A. McFarlane (eds.), Effects on ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Can. Spec. Publ. Fish. Aq. Sci. 108:57-66.

Kimura, D.K., J.J. Lyons, S.E. MacLellan, and B.J. Goetz. 1992. Effects of year-class strength on age determination. Aust. J. Mar. Freshwater Res. 43:1221-8.

Kimura, D.K., C.R. Kastelle , B.J. Goetz, C.M. Gburski, and A.V. Buslov. 2006. Corroborating ages of walleye pollock (*Theragra chalcogramma*), Australian J. of Marine and Freshwater Research 57:323-332.

Kotenev, B.N. and A.I. Glubokov. 2007. Walleye pollock *Theregra chalcogramma* from the Navarin Region and adjacent waters of the Bering Sea: ecology, biology, and stock structure. Moscow VNIRO publishing. 180p.

Kotwicki, S., T.W. Buckley, T. Honkalehto, and G. Walters. 2004. Comparison of walleye pollock data collected on the Eastern Bering Sea shelf by bottom trawl and echo integration trawl surveys. (poster presentation available at: ftp://ftp.afsc.noaa.gov/posters/pKotwicki01 pollock.pdf).

Kotwicki, S., T.W. Buckley, T. Honkalehto, and G. Walters. 2005. Variation in the distribution of walleye pollock (*Theragra chalcogramma*) with temperature and implications for seasonal migration. Fish. Bull 103:574–587.

Kotwicki, S., A. DeRobertis, P. vonSzalay, and R. Towler. 2009. The effect of light intensity on the availability of walleye pollock (*Theragra chalcogramma*) to bottom trawl and acoustic surveys. Can. J. Fisheries and Aquatic Science. 66(6): 983–994.

Kotwicki, S. and Lauth R.R. 2013. Detecting temporal trends and environmentally-driven changes in the spatial distribution of groundfishes and crabs on the eastern Bering Sea shelf. Deep-Sea Research Part II: Topical Studies in Oceanography. 94:231-243.

Kotwicki, S., Ianelli, J. N., & Punt, A. E. 2014. Correcting density-dependent effects in abundance estimates from bottom-trawl surveys. ICES Journal of Marine Science, 71(5), 1107–1116.

Lang, G.M., Livingston, P.A., Dodd, K.A., 2005. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1997 through 2001. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-158, 230p. URL

Lang, G.M., R.D. Brodeur, J.M. Napp, and R. Schabetsberger. (2000). Variation in groundfish predation on juvenile walleye pollock relative to hydrographic structure near the Pribilof Islands, Alaska. ICES Journal of Marine Science. 57:265-271.

Lauffenberger, N., De Robertis, A., and Kotwicki, S. 2017. Combining bottom trawls and acoustics in a diverse semipelagic environment: What is the contribution of walleye pollock (Gadus chalcogrammus) to near-bottom acoustic backscatter? Can J. Fish. Aquat. Sci., 74: 256-264.

Lauth, R.R., J.N. Ianelli, and W.W. Wakefield. 2004. Estimating the size selectivity and catching efficiency of a survey bottom trawl for thornyheads, Sebastolobus spp. using a towed video camera sled. Fisheries Research. 70:39-48.

Lehodey, P., I. Senina, and R. Murtugudde. 2008. A spatial ecosystem and populations dynamics model (SEAPODYM) – Modeling of tuna and tuna-like populations. Progress in Oceanography 78: 304–318.

Livingston, P. A., and Methot, R. D. (1998). Incorporation of predation into a population assessment model of Eastern Bering Sea walleye pollock. In Fishery Stock Assessment Models. NOAA Technical Report 126, NMFS F/NWC-54, Alaska Sea Grant Program, 304 Eielson Building, University of Alaska Fairbanks, Fairbanks, AK 99775. pp. 663-678.

Livingston, P.A. (1991). Walleye pollock. Pages 9-30 in: P.A. Livingston (ed.). Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea, 1984-1986. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-207, 240 p.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. J. Fish. Biol. 49:627-647.

Lorenzen, K. 2000. Allometry of natural mortality as a basis for assessing optimal release size in fish-stocking programmes. Canadian Journal of Fisheries and Aquatic Sciences 57, 2374-2381.

Low, L.L., and Ikeda. 1980. Average density index of walleye pollock in the Bering Sea. NOAA Tech. Memo. SFRF743.

Mace, P., L. Botsford, J. Collie, W. Gabriel, P. Goodyear J. Powers, V. Restrepo, A. Rosenberg, M. Sissenwine, G. Thompson, J. Witzig. 1996. Scientific review of definitions of overfishing in U.S. Fishery Management Plans. NOAA Tech. Memo. NMFS-F/SPO-21. 20 p.

MacLennan, D. N., Fernandes, P. G., and Dalen, J. 2002. A consistent approach to definitions and symbols in fisheries acoustics. ICES J. Mar Sci, 59: 365-369.

Martell, S., & Stewart, I. (2013). Towards defining good practices for modeling time-varying selectivity. Fisheries Research, 1–12. [URL](link

Martinson, E.C., H.H. Stokes and D.L. Scarnecchia. 2012. Use of juvenile salmon growth and temperature change indices to predict groundfish post age-0 yr class strengths in the Gulf of Alaska and eastern Bering Sea. Fisheries Oceanography 21:307-319.

McAllister, M.K. and Ianelli, J.N. 1997. Bayesian stock assessment using catch-age data and the sampling-importance resampling algorithm. Can. J. Fish. Aquat. Sci. 54:284-300.

Merritt, M.F. and T.J. Quinn II. 2000. Using perceptions of data accuracy and empirical weighting of information: assessment of a recreational fish population. Canadian Journal of Fisheries and Aquatic Sciences. 57: 1459-1469.

Methot, R.D. 1990. Synthesis model: an adaptable framework for analysis of diverse stock assessment data. In Proceedings of the symposium on applications of stock assessment techniques to Gadids. L. Low [ed.]. Int. North Pac. Fish. Comm. Bull. 50: 259-277.

Miller, T.J. 2005. Estimation of catch parameters from a fishery observer program with multiple objectives. PhD Dissertation. Univ. of Washington. 419p.

Mohn, R. 1999. The retrospective problem in sequential population analysis: An investigation using cod fishery and simulated data. Ices J. Mar Sci. 56, 473-488.

Moss, J.H., E.V. Farley, Jr., A.M. Feldmann, and J.N. Ianelli. (in review). Spatial distribution, energetic status, and food habits of eastern Bering Sea age-0 walleye pollock. Transactions of the American Fisheries Society.

Mueter, F. J., and M. Litzow. 2008. Sea ice retreat alters the biogeography of the Bering Sea continental shelf. Ecological Applications 18:309–320.

Mueter, F. J., C. Ladd, M. C. Palmer, and B. L. Norcross. 2006. Bottom-up and top-down controls of walleye pollock (*Theragra chalcogramma*) on the Eastern Bering Sea shelf. Progress in Oceanography 68:152-183.

Mueter, F. J., N.A. Bond, J.N. Ianelli, and A.B. Hollowed. 2011. Expected declines in recruitment of walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea under future climate change. ICES Journal of Marine Science.

O'Reilly, P.T., M.F. Canino, K.M. Bailey and P. Bentzen. 2004. Inverse relationship between FST and microsatellite polymorphism in the marine fish, walleye pollock (*Theragra chalcogramma*): implications for resolving weak population structure. Molecular Ecology (2004) 13, 1799–1814

Parma, A.M. 1993. Retrospective catch-at-age analysis of Pacfic halibut: implications on assessment of harvesting policies. In Proceedings of the International Symposium on Management Strategies of Exploited Fish Populations. Alaska Sea Grant Rep. No. 93-02. Univ. Alaska

Fairbanks.

Petitgas, P. 1993. Geostatistics for fish stock assessments: a review and an acoustic application. ICES J. Mar. Sci. 50: 285-298.

Petrik, C. M., Duffy-Anderson, J. T., Mueter, F., Hedstrom, K., & Curchitser, E. N. 2014. Biophysical transport model suggests climate variability determines distribution of Walleye Pollock early life stages in the eastern Bering Sea through effects on spawning. Progress in Oceanography, 138, 459–474. link.

Powers, J. E. 2014. Age-specific natural mortality rates in stock assessments: size-based vs. density-dependent. ICES Journal of Marine Science, 71(7), 1629–1637.

Press, W.H., S.A. Teukolsky, W.T. Vetterling, B.P. Flannery. 1992. Numerical Recipes in C. Second Ed. Cambridge University Press. 994 p.

Punt, A.E., Smith, D.C., KrusicGolub, K. and Robertson, S. 2008. Quantifying age-reading error for use in fisheries stock assessments, with application to species in Australia's Southern and Eastern Scalefish and Shark Fishery. Can. J. Fish. Aquat. Sci. 65:1991-2005.

Ressler, P.H., De Robertis, A., Warren, J.D., Smith, J.N., and Kotwicki, S. (2012). Using an acoustic index of euphausiid abundance to understand trophic interactions in the Bering Sea ecosystem. Deep-Sea Res. II. 0967-0645,

Restrepo, V.R., G.G. Thompson, P.M Mace, W.L Gabriel, L.L. Low, A.D. MacCall, R.D. Methot, J.E. Powers, B.L. Taylor, P.R. Wade, and J.F. Witzig. 1998. Technical guidance on the use of precautionary approaches to implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. NOAA Tech. Memo. NMFS-F/SPO-31. 54 p.

Schnute, J.T. 1994. A general framework for developing sequential fisheries models. Can. J. Fish. Aquat. Sci. 51:1676-1688.

Schnute, J.T. and Richards, L.J. 1995. The influence of error on population estimates from catch-age models. Can. J. Fish. Aquat. Sci. 52:2063-2077.

Seung, C., & Ianelli, J. (2016). Regional economic impacts of climate change: a computable general equilibrium analysis for an Alaskan fishery. Natural Resource Modeling, 29(2), 289–333. link.

Siddon, E. C., Heintz, R. a., & Mueter, F. J. (2013). Conceptual model of energy allocation in walleye pollock (*Theragra chalcogramma*) from age-0 to age-1 in the southeastern Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography, 94, 140–149. link.

Smart, T. I., Siddon, E. C., & Duffy-Anderson, J. T. (2013). Vertical distributions of the early life stages of walleye pollock (*Theragra chalcogramma*) in the Southeastern Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography, 94, 201–210. link.

Smith, G.B. 1981. The biology of walleye pollock. In Hood, D.W. and J.A. Calder, The Eastern Bering Sea Shelf: Oceanography and Resources. Vol. I. U.S. Dep. Comm., NOAA/OMP 527-551.

Stahl, J. 2004. Maturation of walleye pollock, *Theragra chalcogramma*, in the Eastern Bering Sea in relation to temporal and spatial factors. Masters thesis. School of Fisheries and Ocean Sciences, Univ. Alaska Fairbanks, Juneau. 000p.

Stahl, J., and G. Kruse. 2008a. Spatial and temporal variability in size at maturity of walleye pollock in the eastern Bering Sea. Transactions of the American Fisheries Society 137:1543–1557.

Stahl, J., and G. Kruse. 2008b. Classification of Ovarian Stages of Walleye Pollock (*Theragra chalcogramma*). In Resiliency of Gadid Stocks to Fishing and Climate Change. Alaska Sea

Grant College Program • AK-SG-08-01.

Sterling, J. T. and R. R. Ream 2004. At-sea behavior of juvenile male northern fur seals (Callorhinus ursinus). Canadian Journal of Zoology 82: 1621-1637.

Stewart, I. J., & Martell, S. J. D. (2015). Reconciling stock assessment paradigms to better inform fisheries management. ICES Journal of Marine Science: Journal Du Conseil, 72(8), 2187–2196. link.

Strong, J. W., & Criddle, K. R. (2014). A Market Model of Eastern Bering Sea Alaska Pollock: Sensitivity to Fluctuations in Catch and Some Consequences of the American Fisheries Act. North American Journal of Fisheries Management, 34(6), 1078–1094. link.

Stram, D. L., and Ianelli, J. N. 2014. Evaluating the efficacy of salmon bycatch measures using fishery-dependent data. ICES Journal of Marine Science, 3(2). doi:10.1093/icesjms/fsu168

Szuwalski, C.S, Ianelli, J.N, and Punt, A.E. 2018. Reducing retrospective patterns in stock assessment and impacts on management performance, ICES Journal of Marine Science, Volume 75, Issue 2, 1 March 2018, Pages 596–609, https://doi.org/10.1093/icesjms/fsx159

Swartzman, G.L., A.G. Winter, K.O. Coyle, R.D. Brodeur, T. Buckley, L. Ciannelli, G.L. Hunt, Jr., J. Ianelli, and S.A. Macklin (2005). Relationship of age-0 pollock abundance and distribution around the Pribilof Islands with other shelf regions of the Eastern Bering Sea. Fisheries Research, Vol. 74, pp. 273-287.

Takahashi, Y, and Yamaguchi, H. 1972. Stock of the Alaska pollock in the eastern Bering Sea. Bull. Jpn. Soc. Sci. Fish. 38:418-419.

Thompson, G.G. 1996. Risk-averse optimal harvesting in a biomass dynamic model. Unpubl. Manuscr., 54 p. Alaska Fisheries Science Center, 7600 Sand Pt. Way NE, Seattle WA, 98115. Distributed as Appendix B to the Environmental Analysis Regulatory Impact Review of Ammendments 44/44 to the Fishery Management Plans for the Groundfish Fisheries of the Bering Sea and Aleutian Islands Area and the Gulf of Alaska.

Thorson, J. T., & Taylor, I. G. (2014). A comparison of parametric, semi-parametric, and nonparametric approaches to selectivity in age-structured assessment models. Fisheries Research, 158, 74–83. link.

Thorson, J.T., Ianelli, J.N., Larsen, E., Ries, L., Scheuerell, M.D., Szuwalski, C., and Zipkin, E. 2016. Joint dynamic species distribution models: a tool for community ordination and spatiotemporal monitoring. Glob.Ecol. Biogeogr. 25(9): 1144-1158. doi:10.1111/geb.12464. url: http://onlinelibrary.wiley.com/doi/10.1111/geb.12464/abstract

Thorson, J.T., Shelton, A.O., Ward, E.J., Skaug, H.J., 2015. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. ICES J. Mar. Sci. J.Cons. 72(5), 1297-1310. doi:10.1093/icesjms/fsu243. URL: http://icesjms.oxfordjournals.org/content/72/5/1297

Thorson, J.T., and Kristensen, K. 2016. Implementing a generic method for bias correction in statisticalmodels using random effects, with spatial and population dynamics examples. Fish. Res. 175: 66-74.doi:10.1016/j.fishres.2015.11.016. url: http://www.sciencedirect.com/science/article/pii/S016578361

Thorson, J.T., Rindorf, A., Gao, J., Hanselman, D.H., and Winker, H. 2016. Density-dependent changes in effective area occupied for sea-bottom-associated marine fishes. Proc R Soc B 283(1840): 20161853.doi:10.1098/rspb.2016.1853. URL: http://rspb.royalsocietypublishing.org/content/283/18 see these entries in BibTeX format, use 'print(, bibtex=TRUE)', 'toBibtex(.)', or set 'options(citation.bibtex.max=999)'.10

Thorson, J.T. 2018a, *In Press*. Predicting recruitment density dependence and intrinsic growth rate for all fishes worldwide using a data-integrated life-history model. Fish and Fisheries.

Thorson, J..T. 2018b. Guidance for decisions using the Vector Autoregressive Spatio-Temporal (VAST) package in stock, ecosystem, habitat and climate assessments, Fisheries Research, Volume 210, 2019, Pages 143-161, ISSN 0165-7836, https://doi.org/10.1016/j.fishres.2018.10.013.(http://www.scien

von Szalay PG, Somerton DA, Kotwicki S. 2007. Correlating trawl and acoustic data in the Eastern Bering Sea: A first step toward improving biomass estimates of walleye pollock (*Theragra chalcogramma*) and Pacific cod (Gadus macrocephalus)? Fisheries Research 86(1) 77-83.

Walline, P. D. 2007. Geostatistical simulations of eastern Bering Sea walleye pollock spatial distributions, to estimate sampling precision. ICES J. Mar. Sci. 64:559-569.

Walters, C. J., and J. F. Kitchell. 2001. Cultivation/depensation effects on juvenile survival and recruitment. Can. J. Fish. Aquat. Sci. 58:39-50.

Wespestad, V. G. and J. M. Terry. 1984. Biological and economic yields for Eastern Bering Sea walleye pollock under differing fishing regimes. N. Amer. J. Fish. Manage., 4:204-215.

Wespestad, V. G., J. Ianelli, L. Fritz, T. Honkalehto, G. Walters. 1996. Bering Sea-Aleutian Islands Walleye Pollock Assessment for 1997. In: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pac. Fish. Mgmt. Council, Anchorage, AK, section 1:1-73.

Wespestad, V. G., L. W. Fritz, W. J. Ingraham, and B. A. Megrey. 2000. On relationships between cannibalism, climate variability, physical transport, and recruitment success of Bering Sea walleye pollock (*Theragra chalcogramma*). ICES Journal of Marine Science 57:272-278.

Williamson, N., and J. Traynor. 1996. Application of a one-dimensional geostatistical procedure to fisheries acoustic surveys of Alaskan pollock. ICES J. Mar. Sci. 53:423-428.

Winter, A.G., G.L. Swartzman, and L. Ciannelli (2005). Early- to late-summer population growth and prey consumption by age-0 pollock (*Theragra chalcogramma*), in two years of contrasting pollock abundance near the Pribilof Islands, Bering Sea. /Fisheries Oceanography/, Vol. 14, No. 4, pp. 307-320.

Yasumiishi, E. M., K. R. Criddle, N. Hillgruber, F. J. Mueter, and J. H. Helle. 2015. Chum salmon (Oncorhynchus keta) growth and temperature indices as indicators of the year–class strength of age-1 walleye pollock (*Gadus chalcogrammus*) in the eastern Bering Sea. Fish. Oceanogr. 24:242-256.

Zeppelin, T. K. and R.R. Ream. 2006. Foraging habitats based on the diet of female northern fur seals (Callorhinus ursinus) on the Pribilof Islands, Alaska. Journal of Zoology 270(4): 565-576.

Tables

Table 1: Catch from the Eastern Bering Sea by area, the Aleutian Islands, the Donut Hole, and the Bogoslof Island area, 1979–2018 (2018 values through October 15th 2018). The southeast area refers to the EBS region east of 170W; the Northwest is west of 170W. Note: 1979–1989 data are from Pacfin, 1990–2018 data are from NMFS Alaska Regional Office, and include discards. The 2018 EBS catch estimates are preliminary.

	Eastern Bering Sea					
Year	Southeast	Northwest	Total	Aleutians	Donut Hole	Bogoslof I.
1979	368,848	566,866	935,714	9,446		
1980	437,253	521,027	958,280	58,157		
1981	714,584	258,918	973,502	55,517		
1982	713,912	242,052	955,964	57,753		
1983	687,504	293,946	981,450	59,021		
1984	442,733	649,322	1,092,055	77,595	181,200	
1985	604,465	535,211	1,139,676	58,147	363,400	
1986	594,997	546,996	1,141,993	45,439	1,039,800	
1987	529,461	329,955	859,416	28,471	1,326,300	377,436
1988	931,812	296,909	1,228,721	41,203	1,395,900	87,813
1989	904,201	325,399	1,229,600	10,569	1,447,600	36,073
1990	640,511	814,682	1,455,193	79,025	917,400	151,672
1991	653,555	542,109	1,195,664	98,604	293,400	316,038
1992	830,559	559,741	1,390,299	52,362	10,000	241
1993	1,094,429	232,173	1,326,602	57,138	1,957	886
1994	1,152,575	176,777	1,329,352	58,659		556
1995	1,172,306	91,941	1,264,247	64,925		334
1996	1,086,843	105,939	1,192,781	29,062		499
1997	819,889	304,544	1,124,433	25,940		163
1998	971,388	132,515	1,103,903	22,054		8
1999	782,983	206,698	989,680	1,010		29
2000	839,177	293,532	1,132,710	1,244		29
2001	961,977	425,220	1,387,197	825		258
2002	1,160,334	320,442	1,480,776	1,177		1,042
2003	933,191	557,588	1,490,779	1,649		24
2004	1,090,008	390,544	1,480,552	1,158		0
2005	802,154	680,868	1,483,022	1,621		0
2006	827,207	660,824	1,488,031	1,745		0
2007	728,249	626,253	1,354,502	2,519		0
2008	482,698	507,880	990,578	1,278		9
2009	358,252	452,532	810,784	1,662		73
2010	255,132	555,075	810,207	1,285		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	2,964		57
2014	858,240	439,180	1,297,419	2,375		427
2015	696,249	625,331	1,321,581	915		733
2016	1,167,088	185,571	1,352,659	1,257		1,005
2017	1,178,112	181,162	1,359,274	1,507		186
2018	1,020,904	325,711	1,346,615	1,778		133
Avg.	788,905	414,351	1,203,256	25,481	697,696	30,505

Table 2: Time series of 1964–1976 catch (left) and ABC, TAC, and catch for EBS pollock, 1977–2018 in t. Source: compiled from NMFS Regional office web site and various NPFMC reports. Note that the 2018 value is based on catch reported to October 25th 2018 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	1,34xxxxx
		2019	2,163,000	1,397,000	1,34xxxxx
1977–2017 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, 1991–2018. SE represents the EBS east of 170W, NW is the EBS west of 170W, source: NMFS Blend and catch-accounting system database. 2018 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	19 (2%)	138 (19%)	2,419 (tr)	7,062 (1%)	9,638 (1%)	915	733	625,331	696,249	1,323,228
2016	59 (5%)	7 (1%)	998 (1%)	8,145 (1%)	9,209 (1%)	1,257	1,005	185,571	1,167,088	1,354,921
2017	17 (1%)	2 (1%)	1,357 (1%)	6,944 (1%)	8,321 (1%)	1,384	186	181,162	1,178,112	1,360,844
2018		2 (21%)	1,779 (1%)	8,261 (1%)	10,042 (1%)		9	328,722	1,045,138	1,373,868

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), 1998–2018. The 2018 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 (54%)

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 08-10	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 08-10	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 08-10	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 08-10	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: 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 2014–2017.

sector	Avg 05–07	Avg 08–10	Avg 11–13	2014	2015	2016	2017
All Sectors	1.25	2.03	1.76	2.19	1.84	2.06	1.92
Shoreside	2.07	2.58	2.00	2.42	1.94	2.28	2.09
At Sea	0.30	1.41	1.50	1.94	1.72	1.82	1.74

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 11: Eastern Bering Sea pollock catch at age estimates based on observer data, 1979–2017. Units are in millions of fish.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14+	Total
1979	101.4	543.0	719.8	420.1	392.5	215.5	56.3	25.7	35.9	27.5	17.6	7.9	3.0	1.1	2,567
1980	9.8	462.2	822.9	443.3	252.1	210.9	83.7	37.6	21.7	23.9	25.4	15.9	7.7	3.7	2,421
1981	0.6	72.2	1,012.7	637.9	227.0	102.9	51.7	29.6	16.1	9.3	7.5	4.6	1.5	1.0	2,175
1982	4.7	25.3	161.4	1,172.2	422.3	103.7	36.0	36.0	21.5	9.1	5.4	3.2	1.9	1.0	2,004
1983	5.1	118.6	157.8	312.9	816.8	218.2	41.4	24.7	19.8	11.1	7.6	4.9	3.5	2.1	1,745
1984	2.1	45.8	88.6	430.4	491.4	653.6	133.7	35.5	25.1	15.6	7.1	2.5	2.9	3.7	1,938
1985	2.6	55.2	381.2	121.7	365.7	321.5	443.2	112.5	36.6	25.8	24.8	10.7	9.4	9.1	1,920
1986	3.1	86.0	92.3	748.6	214.1	378.1	221.9	214.3	59.7	15.2	3.3	2.6	0.3	1.2	2,041
1987	-	19.8	111.5	77.6	413.4	138.8	122.4	90.6	247.2	54.1	38.7	21.4	28.9	14.1	1,379
1988	-	10.7	454.0	421.6	252.1	544.3	224.8	104.9	39.2	96.8	18.2	10.2	3.8	11.7	2,192
1989	-	4.8	55.1	149.0	451.1	166.7	572.2	96.3	103.8	32.4	129.0	10.9	4.0	8.5	1,784
1990	1.3	33.0	57.0	219.5	200.7	477.7	129.2	368.4	65.7	101.9	9.0	60.1	8.5	13.9	1,746
1991	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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
2017	0.0	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
Avg.	6.5	54.5	206.0	379.9	390.0	320.8	206.3	114.3	65.5	33.5	23.4	11.9	8.1	11.7	1,829

Table 12: Numbers of pollock NMFS observer samples measured for fishery catch length frequency (by sex and strata), 1977–2017.

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

Table 13: 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	12,421	11,318	12,374	7,809	7,977	7,738	59,637
2001	14,882	14,369	10,778	10,378	8,777	9,079	68,263
2002	14,004	13,541	12,883	12,942	7,202	7,648	68,220
2003	14,780	15,495	9,401	10,092	9,994	10,261	70,023
2004	7,690	7,890	6,819	6,847	4,603	4,321	38,170
2005	7,390	7,033	5,109	4,115	6,927	6,424	36,998
2006	7,324	6,989	5,085	4,068	6,842	6,356	36,664
2007	6,681	6,635	4,278	3,203	7,745	7,094	35,636
2008	4,256	4,787	2,056	2,563	5,950	6,316	25,928
2009	4,470	4,199	2,273	2,034	5,004	5,187	23,167
2010	4,536	5,272	2,261	2,749	4,125	4,618	23,561
2011	6,772	6,388	6,906	6,455	5,809	4,634	36,964
2012	5,500	5,981	4,508	4,774	4,928	5,348	31,039
2013	6,525	5,690	4,313	3,613	4,920	4,849	29,910
2014	5,675	5,871	4,753	5,180	4,785	4,652	30,916
2015	5,310	5,323	4,645	4,188	4,337	4,011	27,766
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

Table 14: Numbers of pollock fishery samples used for age determination estimates by sex and strata, 1977–2017, 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	666	626	843	584	253	293	3,265
2001	598	560	724	688	178	205	2,951
2002	651	670	834	886	201	247	3,489
2003	583	644	652	680	260	274	3,092
2004	560	547	599	697	244	221	2,867
2005	611	597	613	489	419	421	3,149
2006	608	599	590	457	397	398	3,048
2007	639	627	586	482	583	570	3,485
2008	492	491	313	356	541	647	2,838
2009	488	416	285	325	400	434	2,346
2010	624	545	504	419	465	414	2,971
2011	581	808	579	659	404	396	3,427
2012	517	571	480	533	485	579	3,165
2013	703	666	517	402	568	526	3,381
2014	609	629	475	553	413	407	3,086
2015	653	642	502	509	511	491	3,308
2016	488	599	929	969	157	125	3,267
2017	604	778	777	753	179	163	3,254

Table 15: NMFS total pollock research catch by year in t, 1964–2018.

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	

Table 16: Survey biomass estimates (age 1+, t) of Eastern Bering Sea pollock based on design-based area-swept expansion methods from NMFS bottom trawl surveys 1982–2018.

	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%
Average	4,484,154	224,241	4,708,394	5%

Table 17: Sampling effort for pollock in the EBS from the NMFS bottom trawl survey 1982–2018.

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

Table 18: 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	1,281	2,986	3,356	4,377	1,505	206	143	68	43	27	17	10	3	1	0	14,024
1983	1,810	681	1,655	2,980	6,690	2,042	371	198	89	77	58	20	8	7	2	16,688
1984	431	348	537	1,535	1,905	4,451	853	189	88	31	21	8	5	6	3	10,411
1985	5,919	959	3,844	1,222	4,031	2,455	1,678	331	84	69	23	8	9	1	0	20,634
1986	2,690	428	499	1,875	1,135	1,889	1,653	1,501	470	72	33	15	1	4	-	12,266
1987	379	779	1,082	817	4,956	1,371	1,313	519	1,640	253	74	29	5	2	2	13,222
1988	1,225	715	1,943	3,692	1,606	5,209	1,544	1,169	673	1,596	150	89	18	24	10	19,662
1989	917	342	672	2,218	4,981	989	3,761	571	686	266	836	144	126	63	83	16,656
1990	2,335	354	120	924	1,847	6,193	1,243	3,058	310	549	84	789	68	51	67	17,992
1991	3,161	885	319	94	639	600	1,986	746	1,606	420	568	116	352	49	40	11,580
1992	1,512	416	2,361	398	445	745	655	939	418	798	280	349	149	118	93	9,675
1993	2,417	338	898	3,844	833	667	345	474	643	396	347	252	198	109	128	11,890
1994	1,404	508	552	1,631	4,413	774	201	173	192	366	220	309	113	109	165	11,129
1995	1,571	137	426	1,995	2,654	4,322	1,834	483	294	184	347	137	255	100	137	14,877
1996	1,552	369	175	348	964	1,363	1,245	424	105	113	76	143	47	84	110	7,119
1997	2,490	383	201	259	3,109	1,383	828	997	169	84	64	70	114	37	127	10,314
1998	727	639	336	240	468	2,674	680	429	332	83	37	13	28	31	73	6,789
1999	1,109	1,018	967	1,050	599	1,069	2,691	725	350	326	119	50	19	28	96	10,217
2000	1,120	410	535	1,825	1,814	932	783	2,564	999	523	221	150	46	20	86	12,027
2001	1,829	1,052	571	546	1,381	1,444	621	308	918	659	252	201	80	28	77	9,967
2002	811	408	851	1,231	1,272	1,656	862	417	565	1,060	528	234	137	42	45	10,118
2003	549	165	1,045	1,752	2,078	1,908	2,555	1,445	660	860	1,752	758	285	148	108	16,068
2004	395	286	182	1,372	1,338	1,018	598	648	321	200	200	361	154	37	28	7,137
2005	397	151	247	1,073	3,008	2,023	1,055	479	364	268	72	152	248	96	98	9,732
2006	872	45	61	381	1,016	1,298	831	400	228	196	94	59	85	114	111	5,790
2007	2,353	45	118	445	1,501	1,767	1,275	920	388	174	161	140	63	80	152	9,582
2008	516	97	85	169	548	1,131	889	618	392	154	128	98	44	24	152	5,045
2009	798	219	431	444	248	393	558	443	323	155	103	34	34	18	71	4,271
2010	511	130	249	2,966	1,332	416	359	380	399	272	234	85	50	29	63	7,475
2011	1,115	119	268	360	1,855	908	266	151	237	236	197	151	63	30	80	6,036
2012	1,170	235	442	3,254	761	1,228	421	168	127	176	144	127	106	38	67	8,465
2013	1,227	104	217	974	5,002	1,161	725	254	86	78	102	77	71	39	51	10,167
2014	2,256	580	272	366	1,705	6,257	3,255	693	381	139	53	75	76	36	93	16,237
2015	1,183	809	2,296	583	1,221	2,276	4,433	1,292	305	145	17	16	29	17	36	14,659
2016	749	437	630	3,323	1,364	922	1,301	1,919	376	147	48	10	11	3	5	11,244
2017	586	289	460	2,367	2,863	1,247	861	774	919	262	93	32	4	1	5	10,763
2018	978	456	195	394	2,741	1,487	491	359	362	279	87	14	2	0	5	9,869
Avg	1,415	495	786	1,441	2,049	1,834	1,221	736	447	316	212	144	84	44	69	11,346

Table 19: Mean EBS pollock body mass (kg) at age as observed in the summer NMFS bottom trawl survey, 1982–2018.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1982	0.032	0.075	0.168	0.349	0.425	0.644	0.999	1.086	1.166	1.354	1.552	1.610	1.806	1.703	2.557
1983	0.017	0.141	0.242	0.360	0.490	0.572	0.714	1.057	1.101	0.990	1.075	1.084	1.494	1.074	1.721
1984	0.014	0.072	0.251	0.362	0.489	0.623	0.759	1.000	1.192	1.389	1.482	1.675	1.328	1.446	2.072
1985	0.014	0.104	0.235	0.394	0.486	0.616	0.752	0.869	1.400	1.092	1.246	1.744	1.615	1.600	2.562
1986	0.012	0.102	0.195	0.345	0.453	0.636	0.716	0.845	0.995	1.237	1.275	1.093	2.164	2.123	2.342
1987	0.017	0.110	0.271	0.356	0.435	0.525	0.696	0.777	0.869	0.956	1.134	1.369	1.680	2.007	2.122
1988	0.018	0.108	0.300	0.347	0.446	0.513	0.589	0.740	0.839	0.978	1.171	1.190	1.645	0.892	1.579
1989	0.016	0.092	0.177	0.363	0.432	0.514	0.617	0.655	0.894	0.889	1.006	1.027	1.069	1.118	1.133
1990	0.013	0.102	0.160	0.385	0.503	0.568	0.605	0.714	0.776	1.024	1.038	1.088	1.019	1.205	1.271
1991	0.019	0.108	0.156	0.371	0.492	0.581	0.689	0.731	0.859	0.890	1.055	1.145	1.216	1.325	1.816
1992	0.014	0.113	0.284	0.385	0.550	0.647	0.784	0.828	0.880	0.964	1.067	1.200	1.301	1.279	1.248
1993	0.012	0.072	0.323	0.448	0.493	0.540	0.644	0.778	0.963	1.017	1.130	1.235	1.342	1.493	1.597
1994	0.015	0.086	0.242	0.479	0.570	0.630	0.707	0.944	1.121	1.075	1.152	1.277	1.337	1.422	1.501
1995	0.013	0.088	0.170	0.371	0.474	0.627	0.652	0.784	0.900	1.099	1.045	1.221	1.220	1.338	1.544
1996	0.017	0.081	0.154	0.327	0.496	0.576	0.696	0.779	0.939	1.021	1.271	1.377	1.414	1.550	1.638
1997	0.016	0.053	0.237	0.337	0.406	0.537	0.677	0.769	0.937	1.013	1.123	1.269	1.227	1.462	1.569
1998	0.016	0.070	0.184	0.343	0.467	0.509	0.660	0.804	0.894	0.958	1.057	1.348	1.345	1.764	1.810
1999	0.014	0.080	0.216	0.354	0.417	0.557	0.631	0.762	0.961	0.986	1.075	1.162	1.519	1.725	1.869
2000	0.010	0.063	0.240	0.375	0.447	0.518	0.643	0.701	0.769	0.944	1.127	1.189	1.300	1.436	1.810
2001	0.016	0.069	0.166	0.376	0.502	0.598	0.670	0.764	0.852	0.906	1.093	1.193	1.402	1.384	1.680
2002	0.011	0.097	0.256	0.379	0.512	0.634	0.663	0.798	0.891	0.928	0.939	1.100	1.195	1.401	1.864
2003	0.021	0.106	0.341	0.431	0.568	0.688	0.745	0.849	0.904	0.964	0.969	1.019	1.025	1.120	1.187
2004	0.019	0.099	0.305	0.480	0.554	0.676	0.752	0.783	0.934	0.941	1.028	1.035	1.107	1.320	1.376
2005	0.018	0.079	0.241	0.391	0.510	0.583	0.688	0.792	0.862	0.901	1.006	1.058	1.090	1.187	1.317
2006	0.009	0.081	0.149	0.375	0.515	0.605	0.717	0.803	0.896	1.027	1.070	1.153	1.255	1.231	1.329
2007	0.012	0.095	0.312	0.443	0.548	0.668	0.771	0.838	0.915	1.060	1.108	1.089	1.276	1.267	1.373
2008	0.014	0.054	0.229	0.427	0.530	0.643	0.757	0.858	0.919	1.060	1.205	1.187	1.344	1.506	1.534
2009	0.010	0.113	0.222	0.411	0.563	0.687	0.845	0.915	0.956	1.166	1.165	1.432	1.431	1.529	1.761
2010	0.018	0.078	0.244	0.403	0.541	0.670	0.893	0.978	1.016	1.113	1.146	1.259	1.424	1.527	1.935
2011	0.015	0.112	0.233	0.426	0.548	0.641	0.795	0.995	1.094	1.140	1.229	1.279	1.400	1.447	1.617
2012	0.013	0.080	0.207	0.361	0.535	0.663	0.794	0.916	1.191	1.216	1.272	1.318	1.406	1.642	1.899
2013	0.017	0.069	0.225	0.424	0.492	0.617	0.824	0.970	1.079	1.212	1.288	1.335	1.450	1.603	1.707
2014	0.016	0.100	0.219	0.360	0.477	0.601	0.653	0.881	0.966	1.105	1.288	1.301	1.356	1.455	1.624
2015	0.019	0.093	0.288	0.392	0.518	0.595	0.718	0.803	1.037	1.069	1.305	1.575	1.343	1.557	1.756
2016	0.023	0.083	0.242	0.434	0.508	0.603	0.690	0.775	0.837	0.916	1.062	0.968	1.334	1.577	1.584
2017	0.022	0.098	0.198	0.398	0.528	0.595	0.686	0.737	0.818	0.819	0.947	0.816	1.183	1.319	1.578
2018	0.020	0.073	0.206	0.374	0.495	0.603	0.697	0.744	0.839	0.878	0.959	0.935	1.018	1.069	1.121
Avg	0.016	0.089	0.229	0.387	0.498	0.603	0.719	0.833	0.958	1.035	1.139	1.226	1.353	1.435	1.676

Table 20: Biomass (age 1+) of Eastern Bering Sea pollock as estimated by surveys 1979–2018 (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. AT survey data prior to 1994 represent estimates from the surface to 3m off bottom.

	Bottom trawl survey			AT	
Year	DDC	VAST	VAST + NBS	Survey	age 3+
1979				7.458	22%
1980					
1981					
1982	4.069	3.802	3.819	4.901	95%
1983	8.409	9.601	9.825		
1984	6.409	6.927	6.986		
1985	8.25	7.828	8.199	4.799	97%
1986	6.826	7.275	7.399		
1987	7.892	7.708	7.787		
1988	11.088	10.901	10.922	4.675	97%
1989	9.796	10.34	10.482		
1990	11.9	11.615	11.674		
1991	7.39	7.336	7.515	1.454	46%
1992	6.211	6.625	6.699		
1993	7.089	7.777	7.937		
1994	7.1	7.348	7.432	3.640	85%
1995	9.107	6.481	6.544		
1996	4.08	3.916	4.067	2.955	97%
1997	5.019	4.834	5.031	3.591	70%
1998	3.51	3.648	4.038		
1999	5.455	5.129	5.185	4.202	95%
2000	7.355	7.937	8.024	3.614	95%
2001	5.44	6.035	6.106		
2002	6.771	6.842	7.028	4.330	82%
2003	13.508	10.846	11.468		
2004	5.106	5.423	5.743	4.016	99%
2005	6.696	6.905	7.018		
2006	3.886	4.004	4.016	1.887	98%
2007	6.145	6.411	6.438	2.288	89%
2008	3.994	4.246	4.258	1.407	76%
2009	2.99	2.929	2.934	1.323	78%
2010	5.132	5.174	5.183	2.651	65%
2011	3.949	4.539	4.604		
2012	4.614	4.729	4.771	2.299	71%
2013	6.115	6.096	6.166		
2014	10.331	11.889	12.508	4.727	65%
2015	8.587	9.604	10.878		
2016	6.608	7.216	9.776	4.829	97%
2017	6.256	6.941	8.694		
2018	4.187	4.002	5.596	2.499	
Avg	6.683	6.780	7.101	3.141	

Table 21: 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 22: 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 23: AT survey estimates of EBS pollock abundance-at-age (millions), 1979–2018. 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	424	535	314	570	2,338	843	199	134	103	107	5,145	5,568
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 24: 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	1.560 (4%)	0.555 9%	26%
2007	1.769 (4%)	0.638 14%	44%
2008	0.997 (8%)	0.316 20%	33%
2009	0.924 (9%)	0.285 42%	62%
2010	2.323 (6%)	0.679 13%	44%
2011	$-no\,survey-$	0.543 11%	29%
2012	1.843 (4%)	0.661 9%	32%
2013	$-no\,survey-$	0.694 6%	20%
2014	3.439 (5%)	0.897 5%	22%
2015	$-no\,survey-$	0.953 5%	23%
2016	4.063 (2%)	0.776 5%	19%
2017	$-no\,survey-$	0.730 5%	18%
2018	2.499 (2%)	0.672 5%	17%

Table 25: Pollock sample sizes assumed for the age-composition data likelihoods from the fishery, bottom-trawl survey, and AT surveys, 1964–2018. 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 26: Mean weight-at-age (kg) estimates from the fishery (1991–2017; plus projections 2018–2020) showing the between-year variability (middle row) and sampling error (bottom panel) based on bootstrap resampling of observer data.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1964–90	0.007	0.170	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	0.150	0.286	0.476	0.604	0.728	0.839	0.873	1.014	1.127	1.129	1.251	1.240	1.308	1.249
1992	0.007	0.179	0.394	0.462	0.647	0.701	0.812	0.982	1.031	1.210	1.226	1.272	1.199	1.340	1.430
1993	0.007	0.331	0.497	0.610	0.650	0.754	0.904	1.039	1.211	1.232	1.391	1.538	1.610	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	0.840	0.856	0.986	1.220	1.315	1.388	1.477	1.390	1.297	1.341
1996	0.007	0.293	0.323	0.427	0.679	0.794	0.949	0.953	1.020	1.096	1.362	1.500	1.520	1.710	1.598
1997	0.007	0.187	0.315	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	1.250	1.248	1.431	0.990	0.516	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	1.101	1.165	1.466
2001	0.007	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	1.467
2002	0.007	0.231	0.386	0.509	0.666	0.795	0.910	1.029	1.104	1.095	1.288	1.448	1.597	1.343	1.683
2003	0.007	0.276	0.489	0.547	0.649	0.767	0.862	0.953	1.081	1.200	1.200	1.206	1.362	1.377	1.699
2004	0.007	0.135	0.409	0.583	0.640	0.758	0.889	0.924	1.035	1.162	1.110	1.160	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	1.500	1.738	1.520
2008	0.007	0.208	0.330	0.520	0.652	0.774	0.903	1.049	1.119	1.282	1.421	1.524	1.553	1.921	1.660
2009	0.007	0.136	0.340	0.526	0.704	0.879	1.002	1.125	1.399	1.490	1.563	1.614	1.814	1.996	2.230
2010	0.050	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	0.290	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	0.270	0.410	0.643	0.824	0.974	1.172	1.306	1.519	1.614	1.644	1.717	2.040	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	1.960	2.187	2.207
2014	0.014	0.193	0.316	0.455	0.617	0.751	0.894	1.154	1.310	1.370	1.692	1.815	1.733	1.658	2.236
2015	0.025	0.181	0.403	0.463	0.571	0.690	0.786	0.887	1.145	1.201	1.378	1.892	1.452	1.603	2.627
2016	0.025	0.181	0.407	0.531	0.557	0.648	0.732	0.801	0.943	1.047	1.201	0.637	1.088	1.870	1.638
2017	0.025	0.191	0.404	0.498	0.651	0.694	0.751	0.827	0.894	0.912	1.019	1.097	1.278	1.460	1.657
Avg	0.016	0.199	0.360	0.506	0.640	0.762	0.888	1.021	1.158	1.263	1.370	1.453	1.493	1.542	1.687
CV	NA	25%	16%	11%	7%	8%	12%	13%	13%	14%	13%	18%	19%	23%	24%
2018	0.025	0.191	0.363	0.507	0.656	0.804	0.851	0.930	1.050	1.157	1.321	1.491	1.629	1.786	1.888
2019	0.025	0.191	0.399	0.490	0.636	0.784	0.927	0.969	1.040	1.152	1.250	1.406	1.568	1.698	1.847
2020	0.025	0.191	0.399	0.526	0.620	0.764	0.907	1.045	1.079	1.141	1.245	1.335	1.482	1.637	1.760
Sampling CV (from bootstrap), ages 1 and 2 were excluded															
1991			2%	2%	2%	2%	1%	4%	2%	7%	3%	7%	4%	7%	5%
1992			1%	2%	3%	2%	2%	2%	4%	3%	4%	5%	14%	8%	9%
1993			1%	0%	2%	3%	3%	4%	3%	5%	6%	10%	11%	16%	12%
1994			3%	1%	1%	2%	5%	13%	7%	7%	6%	7%	8%	15%	8%
1995			2%	2%	1%	1%	2%	4%	7%	8%	7%	14%	8%	53%	9%
1996			2%	4%	2%	1%	1%	2%	4%	6%	18%	11%	9%	12%	13%
1997			3%	1%	1%	1%	2%	2%	4%	8%	14%	14%	23%	9%	9%
1998			2%	3%	2%	1%	2%	3%	2%	6%	11%	13%	18%	24%	22%
1999			0%	1%	1%	1%	1%	2%	3%	5%	15%	27%	43%	57%	27%
2000			1%	1%	1%	2%	1%	1%	3%	6%	6%	13%	52%	76%	70%
2001			2%	1%	1%	1%	3%	3%	2%	5%	7%	9%	13%	14%	47%
2002			1%	1%	1%	1%	1%	3%	3%	3%	6%	7%	11%	34%	35%
2003			1%	1%	1%	1%	1%	2%	4%	6%	5%	7%	14%	36%	22%
2004			2%	1%	1%	2%	2%	2%	3%	8%	6%	6%	14%	18%	11%
2005			2%	1%	0%	1%	2%	3%	3%	5%	8%	8%	25%	37%	28%
2006			1%	1%	1%	1%	1%	3%	4%	4%	9%	14%	12%	19%	11%
2007			1%	1%	1%	1%	1%	2%	4%	5%	7%	13%	14%	12%	10%
2008			1%	1%	1%	1%	1%	2%	3%	6%	7%	7%	8%	22%	8%
2009			1%	1%	3%	2%	2%	3%	4%	6%	10%	12%	9%	30%	16%
2010			2%	0%	1%	3%	3%	4%	4%	5%	7%	10%	15%	13%	11%
2011			1%	1%	0%	1%	3%	4%	5%	5%	6%	9%	29%	16%	21%
2012			1%	0%	1%	1%	2%	5%	8%	11%	9%	10%	13%	21%	45%
2013			1%	0%	0%	2%	3%	4%	8%	9%	10%	12%	13%	18%	16%
2014			2%	1%	1%	1%	2%	3%	6%	14%	16%	19%	16%	22%	17%
2015			2%	1%	1%	0%	2%	3%	5%	13%	16%	20%	15%	23%	16%
2016			2%	1%	1%	0%	2%	3%	5%	13%	16%	20%	15%	23%	16%
2017			1%	1%	1%	1%	2%	2%	5%	8%	14%	1%	22%	11%	15%

```
## Error in modlst[[ii]]: subscript out of bounds
## Error in names(df) <- c("Component", mod_names[mod_scen]): 'names' attribute [4] must be the
## Error in `align<-.xtable`(`*tmp*`, value = switch(1 + is.null(align), : "align" must have le
```

```
## Error in modlst[[ii]]: subscript out of bounds
## Error in names(df) <- c("Component", mod_names[mod_scen]): 'names' attribute [5] must be the
## Error in `align<-.xtable`(`*tmp*`, value = switch(1 + is.null(align), : "align" must have le
```

Table 27: Pollock sample sizes assumed for the age-composition data likelihoods from the fishery, bottom-trawl survey, and AT surveys, 1964–2018. 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 28: Pollock sample sizes assumed for the age-composition data likelihoods from the fishery, bottom-trawl survey, and AT surveys, 1964–2018. 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 29: Estimated billions of EBS pollock at age (columns 2–11) from the 2018 assessment model.

Year	1	2	3	4	5	6	7	8	9	10+
1964	6.37	3.46	2.18	0.47	0.20	0.39	0.18	0.06	0.04	0.22
1965	21.10	2.58	2.17	1.54	0.29	0.13	0.24	0.11	0.04	0.16
1966	15.10	8.56	1.62	1.53	0.96	0.18	0.08	0.16	0.07	0.13
1967	25.64	6.13	5.38	1.14	0.96	0.61	0.12	0.05	0.10	0.13
1968	22.18	10.39	3.80	3.51	0.66	0.56	0.35	0.07	0.03	0.13
1969	26.22	8.98	6.41	2.47	2.03	0.38	0.33	0.21	0.04	0.10
1970	23.55	10.61	5.52	4.06	1.45	1.20	0.23	0.19	0.12	0.08
1971	14.44	9.49	6.37	3.29	2.32	0.80	0.67	0.12	0.10	0.10
1972	11.80	5.80	5.56	3.57	1.72	1.15	0.40	0.33	0.06	0.09
1973	27.07	4.74	3.29	2.90	1.73	0.82	0.54	0.19	0.14	0.06
1974	19.90	10.89	2.61	1.59	1.29	0.76	0.36	0.24	0.08	0.08
1975	17.11	8.02	5.79	1.12	0.67	0.54	0.32	0.15	0.09	0.06
1976	13.39	6.91	4.53	2.61	0.51	0.31	0.25	0.15	0.07	0.06
1977	14.33	5.42	3.99	2.25	1.22	0.24	0.15	0.12	0.07	0.06
1978	25.52	5.81	3.17	2.19	1.15	0.61	0.12	0.07	0.06	0.06
1979	62.85	10.35	3.43	1.74	1.11	0.55	0.29	0.06	0.04	0.06
1980	26.99	25.50	6.26	1.99	0.91	0.53	0.26	0.14	0.03	0.04
1981	32.75	10.96	15.82	3.94	1.08	0.45	0.25	0.12	0.07	0.03
1982	16.27	13.30	6.89	10.80	2.36	0.58	0.24	0.13	0.07	0.05
1983	48.57	6.61	8.41	4.91	7.05	1.42	0.35	0.14	0.08	0.07
1984	13.50	19.74	4.18	6.05	3.32	4.48	0.88	0.22	0.09	0.09
1985	33.01	5.49	12.51	3.01	4.15	2.09	2.78	0.54	0.13	0.11
1986	12.37	13.42	3.48	8.98	2.08	2.71	1.27	1.70	0.33	0.15
1987	6.89	5.03	8.51	2.50	6.15	1.37	1.69	0.78	1.06	0.30
1988	5.66	2.80	3.20	6.14	1.76	4.18	0.90	1.11	0.50	0.88
1989	11.74	2.30	1.78	2.24	4.22	1.13	2.63	0.54	0.68	0.85
1990	50.11	4.77	1.46	1.27	1.51	2.70	0.70	1.56	0.33	0.95
1991	25.81	20.37	3.03	1.04	0.82	0.86	1.53	0.38	0.85	0.72
1992	21.56	10.49	12.91	2.19	0.71	0.50	0.50	0.78	0.21	0.78
1993	44.57	8.76	6.63	8.98	1.48	0.44	0.27	0.23	0.34	0.40
1994	14.91	18.12	5.57	4.72	5.69	0.97	0.26	0.14	0.12	0.39
1995	10.28	6.06	11.53	4.07	3.20	3.33	0.58	0.15	0.08	0.29
1996	22.51	4.18	3.86	8.46	2.89	2.02	1.80	0.33	0.08	0.22
1997	30.82	9.15	2.65	2.82	6.15	1.98	1.17	0.89	0.16	0.16
1998	15.18	12.53	5.79	1.93	2.00	4.16	1.22	0.64	0.47	0.16
1999	16.37	6.17	7.96	4.20	1.36	1.35	2.50	0.73	0.36	0.34
2000	25.44	6.66	3.93	5.66	2.92	0.92	0.87	1.46	0.43	0.41
2001	34.67	10.34	4.23	2.84	3.83	1.87	0.59	0.50	0.80	0.49
2002	23.18	14.10	6.58	3.08	1.96	2.32	1.02	0.32	0.27	0.73
2003	14.19	9.43	8.96	4.77	2.10	1.20	1.18	0.52	0.16	0.55
2004	6.46	5.77	6.00	6.32	3.23	1.24	0.62	0.58	0.26	0.39
2005	4.59	2.62	3.67	4.35	3.97	1.96	0.70	0.32	0.30	0.36
2006	11.62	1.87	1.67	2.66	2.87	2.19	1.05	0.38	0.18	0.38
2007	24.83	4.72	1.19	1.18	1.73	1.61	1.09	0.53	0.20	0.30
2008	13.10	10.10	3.00	0.84	0.76	0.96	0.78	0.54	0.27	0.26
2009	48.62	5.33	6.42	2.17	0.55	0.43	0.45	0.37	0.26	0.27
2010	20.78	19.76	3.39	4.61	1.42	0.33	0.22	0.23	0.19	0.27
2011	12.67	8.45	12.58	2.48	2.94	0.86	0.19	0.12	0.12	0.25
2012	11.01	5.15	5.37	9.15	1.71	1.44	0.41	0.09	0.06	0.18
2013	51.36	4.48	3.28	3.88	5.97	1.10	0.67	0.19	0.04	0.11
2014	49.81	20.88	2.85	2.37	2.58	3.58	0.65	0.35	0.09	0.07
2015	13.55	20.25	13.29	2.07	1.60	1.56	1.99	0.33	0.17	0.08
2016	9.19	5.51	12.90	9.33	1.35	0.98	0.83	1.01	0.16	0.12
2017	15.60	3.74	3.51	9.45	5.72	0.85	0.57	0.46	0.54	0.15
2018	17.42	6.34	2.38	2.58	6.50	3.44	0.46	0.30	0.25	0.38
2019	18.51	7.08	4.04	1.75	1.81	3.82	2.08	0.25	0.17	0.36

Table 30: Estimated millions of EBS pollock caught at age (columns 2–11) from the 2018 assessment model.

Year	1	2	3	4	5	6	7	8	9	10+
1964	8.83	37.81	85.23	62.33	27.25	52.61	22.95	7.08	4.32	25.21
1965	28.82	29.09	98.55	214.84	39.55	16.30	30.52	13.39	4.21	18.42
1966	20.66	101.17	79.04	194.22	119.33	21.77	9.13	17.36	7.74	13.62
1967	65.07	139.49	556.59	214.19	183.48	113.37	21.55	9.27	18.06	23.00
1968	64.20	263.20	395.65	663.04	121.65	100.56	63.23	12.16	5.31	24.02
1969	91.29	256.37	810.99	447.81	361.41	67.22	57.36	38.15	7.49	18.42
1970	141.00	490.34	938.35	810.67	317.47	262.02	52.17	48.78	31.95	22.00
1971	121.30	619.18	1349.47	839.25	670.16	229.96	193.49	41.09	35.81	38.75
1972	88.81	511.19	1438.57	1075.30	540.89	359.27	126.99	116.92	21.73	35.75
1973	180.79	523.08	1002.13	1005.00	621.98	295.21	196.18	74.59	60.28	25.71
1974	115.94	1465.51	966.36	596.60	491.55	287.50	135.22	96.85	33.46	34.44
1975	66.02	744.08	1991.10	375.08	221.85	177.93	104.25	51.56	34.93	21.91
1976	37.22	524.73	1300.28	837.13	159.53	95.22	76.77	46.01	22.70	22.17
1977	28.51	362.59	905.08	614.40	350.85	68.88	41.90	34.13	21.43	18.69
1978	41.88	352.65	711.54	600.40	349.70	183.55	36.86	22.67	19.79	20.85
1979	82.69	428.74	645.04	444.46	350.94	179.41	94.42	18.91	12.27	19.47
1980	24.48	554.03	812.17	465.10	271.03	166.00	79.98	42.54	8.69	13.36
1981	16.92	126.90	1080.00	661.66	252.53	107.91	59.92	29.53	16.05	8.07
1982	4.55	87.19	228.60	1115.86	380.08	97.74	39.84	22.65	11.31	9.10
1983	9.44	39.04	209.23	369.37	862.21	208.23	50.36	20.74	11.89	10.69
1984	2.13	93.56	103.72	396.61	427.27	631.84	126.13	30.66	12.79	13.67
1985	4.33	26.33	342.11	181.32	419.89	328.03	420.22	80.34	19.48	16.58
1986	1.27	57.11	93.89	581.24	196.50	374.48	190.98	235.34	46.33	20.90
1987	0.43	14.44	187.62	110.33	437.08	138.46	170.69	91.38	120.59	32.43
1988	0.40	9.97	153.72	392.85	194.60	549.00	139.92	162.10	73.01	120.20
1989	0.70	7.62	57.27	171.04	491.48	160.06	460.40	87.90	99.70	120.20
1990	3.53	21.40	44.72	134.97	301.37	553.60	162.77	360.00	72.41	192.42
1991	1.69	94.86	62.26	77.63	127.33	167.06	414.06	86.88	243.21	204.89
1992	1.72	71.78	686.67	166.09	99.01	123.68	165.77	278.58	84.31	305.88
1993	1.94	19.95	231.34	1120.91	142.37	76.34	69.25	58.59	91.85	101.74
1994	0.47	32.09	69.60	339.10	1043.35	165.27	53.15	27.53	23.00	73.92
1995	0.27	9.69	89.15	143.74	409.40	780.44	116.95	29.25	14.75	52.19
1996	0.69	14.48	48.12	141.68	194.58	391.68	526.71	100.91	22.48	50.99
1997	0.96	59.29	40.95	99.51	467.37	288.30	264.30	219.76	48.08	44.03
1998	0.37	43.14	100.47	76.13	154.63	682.29	205.30	137.60	114.13	37.07
1999	0.30	11.75	267.21	219.93	103.88	157.77	452.39	127.09	61.24	57.53
2000	0.47	11.71	81.83	423.33	350.07	114.64	166.24	335.95	82.49	72.22
2001	0.68	15.98	62.60	168.84	612.60	422.21	131.78	111.83	166.06	96.83
2002	0.51	32.65	124.91	215.54	298.10	631.47	282.19	88.01	69.40	161.87
2003	0.32	17.00	372.93	349.38	369.63	309.16	349.66	152.16	43.00	124.32
2004	0.12	7.73	111.48	831.43	511.21	257.76	164.78	150.11	59.74	78.83
2005	0.08	3.66	65.21	404.69	885.06	478.67	161.43	70.13	62.51	66.02
2006	0.23	3.82	65.48	288.68	608.94	631.64	288.82	102.09	44.31	86.59
2007	0.49	10.96	48.21	135.54	378.25	492.63	315.63	141.84	49.86	74.04
2008	0.25	21.50	70.06	84.91	155.22	307.80	238.84	157.44	76.93	70.00
2009	0.81	7.67	168.02	210.71	91.18	119.47	124.69	101.20	70.56	74.87
2010	0.28	25.16	39.01	564.23	226.34	61.74	47.05	55.48	46.25	64.31
2011	0.22	13.97	204.44	147.26	859.83	274.76	59.08	37.18	36.42	73.30
2012	0.19	10.02	113.41	946.18	196.29	469.09	129.74	29.22	18.12	54.96
2013	0.77	6.09	64.98	351.46	982.76	193.69	180.22	59.79	13.41	35.39
2014	0.69	28.12	50.84	182.03	404.95	785.45	182.53	97.34	25.59	22.46
2015	0.20	19.20	605.24	207.88	238.69	386.39	548.07	91.75	52.07	26.56
2016	0.10	2.97	120.88	1392.64	174.12	181.46	176.65	244.65	38.05	28.22
2017	0.16	1.78	29.21	580.02	939.67	201.91	140.71	113.42	121.70	34.57
2018	0.14	2.00	13.32	113.76	1175.81	545.27	102.25	65.85	49.39	67.20
2019	0.22	3.39	34.19	115.79	469.64	874.70	653.23	78.06	48.34	92.88

Table 31: Estimated EBS pollock age 3+ biomass, female spawning biomass, and age 1 recruitment for 1964–2018. 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	526	27	6,367	38	1,773	22
1965	623	23	21,100	25	2,158	20
1966	724	22	15,098	32	2,314	20
1967	911	20	25,641	26	3,549	17
1968	1,129	19	22,184	28	4,060	17
1969	1,382	19	26,223	26	5,154	16
1970	1,615	18	23,548	27	5,802	15
1971	1,707	17	14,439	33	6,247	13
1972	1,619	17	11,804	34	5,933	13
1973	1,357	19	27,069	19	4,759	14
1974	1,004	22	19,903	19	3,504	16
1975	852	20	17,106	18	3,617	12
1976	865	16	13,391	17	3,556	10
1977	900	13	14,334	14	3,492	9
1978	912	12	25,520	10	3,359	8
1979	886	11	62,850	6	3,275	8
1980	1,003	9	26,991	8	4,126	7
1981	1,663	6	32,745	7	7,945	5
1982	2,549	5	16,267	10	9,177	5
1983	3,201	5	48,572	6	10,509	4
1984	3,478	5	13,504	10	10,300	4
1985	3,737	4	33,007	6	12,202	4
1986	3,922	4	12,373	10	11,433	3
1987	4,006	4	6,892	10	11,891	3
1988	3,949	3	5,664	10	11,060	3
1989	3,498	3	11,740	7	9,246	3
1990	2,778	3	50,107	3	7,345	3
1991	2,061	4	25,807	5	5,815	3
1992	2,206	3	21,558	6	9,261	3
1993	3,120	3	44,569	4	11,539	3
1994	3,462	3	14,911	6	11,227	3
1995	3,628	3	10,276	7	12,668	3
1996	3,596	3	22,506	5	10,854	3
1997	3,389	3	30,819	4	9,466	3
1998	3,115	3	15,180	6	9,469	3
1999	3,138	3	16,371	5	10,427	3
2000	3,166	3	25,444	4	9,615	3
2001	3,190	3	34,673	3	9,366	3
2002	3,008	3	23,183	4	9,711	3
2003	3,168	3	14,186	5	11,638	2
2004	3,265	3	6,455	7	10,954	2
2005	2,993	3	4,594	8	9,152	2
2006	2,450	3	11,621	5	6,998	3
2007	2,026	3	24,833	4	5,645	3
2008	1,508	4	13,101	6	4,605	3
2009	1,593	4	48,615	4	5,758	3
2010	1,826	4	20,775	6	6,059	3
2011	2,179	3	12,669	7	8,467	3
2012	2,483	4	11,014	9	8,362	3
2013	2,727	4	51,357	7	8,168	4
2014	2,577	5	49,805	9	7,482	4
2015	2,622	5	13,550	17	10,479	5
2016	3,346	6	9,191	25	13,300	6
2017	3,769	7	15,600	18	11,879	7
2018	3,380	9	17,418	20	9,603	8
2019	2,308	10	18,506	21	6,841	9

```
## Error in data.frame(..., check.names = FALSE): arguments imply differing number of rows: 55

## Error in names(t3) <- c("Year", "Current", "CV", "2017", "CV", "2016", : object 't3' not fou

## Error in seq.default(2, length(t3[1, ]), 2): object 't3' not found

## Error in xtable(t3, caption = cap, label = paste0("tab:", tablab[32]), : object 't3' not fou
```

Table 32: Estimated EBS pollock age 3+ biomass, female spawning biomass, and age 1 recruitment for 1964–2018. 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	526	27	6,367	38	1,773	22
1965	623	23	21,100	25	2,158	20
1966	724	22	15,098	32	2,314	20
1967	911	20	25,641	26	3,549	17
1968	1,129	19	22,184	28	4,060	17
1969	1,382	19	26,223	26	5,154	16
1970	1,615	18	23,548	27	5,802	15
1971	1,707	17	14,439	33	6,247	13
1972	1,619	17	11,804	34	5,933	13
1973	1,357	19	27,069	19	4,759	14
1974	1,004	22	19,903	19	3,504	16
1975	852	20	17,106	18	3,617	12
1976	865	16	13,391	17	3,556	10
1977	900	13	14,334	14	3,492	9
1978	912	12	25,520	10	3,359	8
1979	886	11	62,850	6	3,275	8
1980	1,003	9	26,991	8	4,126	7
1981	1,663	6	32,745	7	7,945	5
1982	2,549	5	16,267	10	9,177	5
1983	3,201	5	48,572	6	10,509	4
1984	3,478	5	13,504	10	10,300	4
1985	3,737	4	33,007	6	12,202	4
1986	3,922	4	12,373	10	11,433	3
1987	4,006	4	6,892	10	11,891	3
1988	3,949	3	5,664	10	11,060	3
1989	3,498	3	11,740	7	9,246	3
1990	2,778	3	50,107	3	7,345	3
1991	2,061	4	25,807	5	5,815	3
1992	2,206	3	21,558	6	9,261	3
1993	3,120	3	44,569	4	11,539	3
1994	3,462	3	14,911	6	11,227	3
1995	3,628	3	10,276	7	12,668	3
1996	3,596	3	22,506	5	10,854	3
1997	3,389	3	30,819	4	9,466	3
1998	3,115	3	15,180	6	9,469	3
1999	3,138	3	16,371	5	10,427	3
2000	3,166	3	25,444	4	9,615	3
2001	3,190	3	34,673	3	9,366	3
2002	3,008	3	23,183	4	9,711	3
2003	3,168	3	14,186	5	11,638	2
2004	3,265	3	6,455	7	10,954	2
2005	2,993	3	4,594	8	9,152	2
2006	2,450	3	11,621	5	6,998	3
2007	2,026	3	24,833	4	5,645	3
2008	1,508	4	13,101	6	4,605	3
2009	1,593	4	48,615	4	5,758	3
2010	1,826	4	20,775	6	6,059	3
2011	2,179	3	12,669	7	8,467	3
2012	2,483	4	11,014	9	8,362	3
2013	2,727	4	51,357	7	8,168	4
2014	2,577	5	49,805	9	7,482	4
2015	2,622	5	13,550	17	10,479	5
2016	3,346	6	9,191	25	13,300	6
2017	3,769	7	15,600	18	11,879	7
2018	3,380	9	17,418	20	9,603	8
2019	2,308	10	18,506	21	6,841	9

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

Component	base
B_{2020}	1,900
$CV_{B_{2020}}$	0.13
B_{MSY}	1,970
$CV_{B_{MSY}}$	0.25
B_{2020}/B_{MSY}	95%
B_0	5,142
$B_{35\%}$	1,791
SPR rate at F_{MSY}	31%
Steepness	0.63
Est. $B_{2018}/B_{2018,nofishing}$	0.53
B_{2018}/B_{MSY}	117%

Table 34: Summary results of Tier 1 2018 yield projections for EBS pollock.

Component	base
2020 fishable biomass (GM)	4,969,000
Equilibrium fishable biomass at MSY	3,813,000
MSY R (HM)	0.395
2020 Tier 1 ABC	1,869,000
2020 Tier 1 F_{OFL}	0.494
2020 Tier 1 OFL	2,335,000
MSY R (HM)	0.336
Recommended ABC	1,589,000

Table 35: 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
2018	1,350	1,350	1,350	1,350	1,350	1,350	1,350
2019	2,163	1,350	1,403	976	0	2,659	2,163
2020	1,534	1,350	1,148	855	0	1,589	1,534
2021	1,170	1,527	1,023	795	0	1,203	1,434
2022	1,182	1,322	1,020	808	0	1,262	1,337
2023	1,265	1,320	1,061	847	0	1,371	1,394
2024	1,358	1,382	1,127	904	0	1,470	1,477
2025	1,401	1,411	1,164	940	0	1,505	1,508
2026	1,423	1,428	1,190	966	0	1,520	1,521
2027	1,417	1,418	1,196	976	0	1,505	1,506
2028	1,416	1,417	1,201	984	0	1,501	1,501
2029	1,399	1,400	1,193	981	0	1,480	1,480
2030	1,393	1,393	1,191	981	0	1,475	1,475
2031	1,399	1,399	1,195	985	0	1,483	1,483

Table 36: Tier 3 projections of EBS pollock ABC (given catches in Table 35) for the 7 scenarios.

ABC	Scenario.1	Scenario.2	Scenario.3	Scenario.4	Scenario.5	Scenario.6	Scenario.7
2018	2,310	2,310	1,490	1,033	0	2,853	2,853
2019	2,163	2,163	1,403	976	0	2,659	2,659
2020	1,534	1,791	1,148	855	0	1,589	1,859
2021	1,170	1,527	1,023	795	0	1,203	1,434
2022	1,182	1,322	1,020	808	0	1,262	1,337
2023	1,265	1,320	1,061	847	0	1,371	1,394
2024	1,358	1,382	1,127	904	0	1,470	1,477
2025	1,401	1,412	1,164	940	0	1,505	1,508
2026	1,423	1,428	1,190	966	0	1,520	1,521
2027	1,417	1,419	1,196	976	0	1,505	1,506
2028	1,416	1,417	1,201	984	0	1,501	1,501
2029	1,399	1,400	1,193	981	0	1,480	1,480
2030	1,393	1,393	1,191	981	0	1,475	1,475
2031	1,399	1,399	1,195	985	0	1,483	1,483

Table 37: 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
2018	0.251	0.251	0.251	0.251	0.251	0.251	0.251
2019	0.465	0.268	0.280	0.188	0.000	0.603	0.465
2020	0.458	0.333	0.280	0.188	0.000	0.537	0.458
2021	0.414	0.460	0.280	0.188	0.000	0.487	0.527
2022	0.412	0.429	0.280	0.188	0.000	0.496	0.509
2023	0.418	0.424	0.280	0.188	0.000	0.510	0.514
2024	0.423	0.426	0.280	0.188	0.000	0.520	0.521
2025	0.426	0.427	0.280	0.188	0.000	0.524	0.524
2026	0.426	0.427	0.280	0.188	0.000	0.523	0.523
2027	0.426	0.426	0.280	0.188	0.000	0.521	0.521
2028	0.426	0.426	0.280	0.188	0.000	0.520	0.520
2029	0.424	0.424	0.280	0.188	0.000	0.518	0.518
2030	0.424	0.424	0.280	0.188	0.000	0.517	0.517
2031	0.424	0.424	0.280	0.188	0.000	0.516	0.516

Table 38: Tier 3 projections of EBS pollock spawning biomass (kt) for the 7 scenarios.

SSB	Scenario.1	Scenario.2	Scenario.3	Scenario.4	Scenario.5	Scenario.6	Scenario.7
2018	3,559	3,559	3,559	3,559	3,559	3,559	3,559
2019	3,004	3,126	3,119	3,178	3,302	2,922	3,004
2020	2,346	2,708	2,715	2,931	3,445	2,134	2,346
2021	2,149	2,455	2,594	2,897	3,701	1,950	2,110
2022	2,225	2,357	2,666	3,020	4,055	2,037	2,093
2023	2,345	2,403	2,793	3,186	4,422	2,148	2,167
2024	2,429	2,456	2,902	3,329	4,755	2,213	2,220
2025	2,475	2,488	2,976	3,432	5,028	2,244	2,246
2026	2,490	2,496	3,015	3,494	5,240	2,249	2,250
2027	2,482	2,484	3,024	3,523	5,401	2,235	2,235
2028	2,470	2,471	3,022	3,534	5,517	2,222	2,222
2029	2,455	2,455	3,012	3,533	5,599	2,208	2,208
2030	2,455	2,455	3,013	3,541	5,678	2,210	2,210
2031	2,464	2,464	3,022	3,554	5,748	2,220	2,220

Table 39: Bycatch estimates (t) of FMP species caught in the BSAI directed pollock fishery, 1997–2018 based on then NMFS Alaska Regional Office reports from observers (2018 data are preliminary).

Year	Pacific.Cod	Flathead.Sole	Rock.Sole	Yellowfin.Sole	Arrowtooth.Flounder	Pacific.Ocean.Perch	Atka.Mackerel	Sablefish	Greenland.Turbot	Alaska.Plaice	Skates	Squid	Sharks	Sculpin	All.other	Total
1997	8,263	2,350	1,523	606	985	428	83	2	124	0	NA	1,369	NA	NA	1,693	17,426
1998	6,255	2,048	770	1,745	1,713	617	10	2	174	0	NA	544	NA	NA	1,732	15,609
1999	3,220	1,885	1,059	350	273	121	158	7	30	0	NA	419	NA	NA	1,428	8,950
2000	3,433	2,510	2,688	1,466	979	21	2	12	52	0	NA	355	NA	NA	5,999	17,518
2001	3,879	2,199	1,673	594	530	574	41	21	68	0	NA	1,730	NA	NA	3,880	15,191
2002	5,883	1,844	1,886	768	607	542	221	34	70	0	NA	1,312	NA	NA	2,298	15,466
2003	5,968	1,500	1,418	210	618	935	762	48	40	6	571	788	294	81	1,020	14,258
2004	6,437	2,104	2,554	841	557	394	1,053	17	18	8	841	977	187	150	469	16,605
2005	7,413	2,352	1,125	63	651	652	678	11	31	45	732	1,150	169	131	502	15,704
2006	7,291	2,862	1,361	256	1,089	736	789	9	65	11	1,308	1,399	512	169	630	18,486
2007	5,630	4,226	510	86	2,795	625	315	12	107	3	1,287	1,169	245	190	731	17,929
2008	6,971	4,315	2,150	552	1,715	336	15	5	85	58	2,756	1,452	144	281	442	21,277
2009	7,875	4,666	7,591	271	2,202	114	25	3	44	173	3,856	209	100	292	294	27,716
2010	6,965	4,358	2,242	1,056	1,466	231	57	2	26	119	1,886	277	26	258	296	19,264
2011	10,040	4,886	8,481	1,083	1,589	660	894	1	25	74	2,352	177	66	315	544	31,186
2012	10,061	3,968	6,701	1,496	745	712	263	1	53	137	2,018	495	55	286	507	27,502
2013	8,958	3,147	6,319	2,087	965	611	70	0	21	148	1,751	117	43	219	241	24,697
2014	5,212	2,554	4,359	1,954	737	1,299	117	0	29	318	809	1,477	75	190	422	19,552
2015	8,303	2,260	1,709	863	403	2,516	192	0	41	99	824	2,206	52	187	342	19,995
2016	4,975	1,628	1,142	882	282	3,272	69	19	29	39	461	1,164	58	124	517	14,663
2017	5,951	956	1,825	608	208	4,818	64	102	18	46	509	1,887	93	81	323	17,489
2018	4,264	1,038	1,145	788	263	4,091	546	447	30	104	583	1,644	63	58	322	15,384

Table 40: Bycatch estimates (t) of pollock caught in the other non-pollock EBS directed fisheries, 1997–2018 based on then NMFS Alaska Regional Office reports from observers.

Year	Pacific.Cod	Yellowfin.Sole	Rock.Sole	Flathead.Sole	Other.flatfish	Other.fisheries	Total
1997	33,658	24,100	9,123	2,983	75	14	69,955
1998	10,468	15,339	3,960	2,369	342	941	33,421
1999	21,131	8,701	5,207	4,040	406	1,197	40,684
2000	14,508	13,425	5,480	6,467	228	520	40,631
2001	11,570	16,502	4,577	4,337	270	488	37,748
2002	15,255	14,489	9,942	1,934	210	51	41,884
2003	15,926	11,578	4,924	2,983	381	260	36,055
2004	18,650	10,383	8,975	5,162	625	198	43,996
2005	14,109	10,312	7,235	3,662	1,133	220	36,674
2006	15,168	5,966	6,986	2,663	1,109	144	32,038
2007	20,319	4,020	3,245	3,417	616	276	31,895
2008	9,533	9,827	4,930	4,102	713	17	29,124
2009	7,875	7,036	6,171	3,160	324	13	24,582
2010	6,409	5,156	6,097	2,997	316	85	21,062
2011	8,987	8,673	6,931	1,473	704	306	27,077
2012	8,381	11,199	6,703	903	824	413	28,425
2013	9,096	20,171	7,327	2,010	1,948	238	40,792
2014	11,508	24,700	11,270	4,106	1,986	202	53,775
2015	9,076	21,281	9,381	2,632	1,615	429	44,417
2016	9,093	22,323	11,848	1,666	1,274	450	46,657
2017	8,345	23,433	5,617	1,956	1,315	512	41,180
2018	6,262	20,371	5,182	2,608	668	117	35,210

Table 41: Bycatch estimates (t) of non-target species caught in the BSAI directed pollock fishery, 2003–2018, based on observer data as processed through the catch accounting system (NMFS Regional Office, Juneau, Alaska).

Year	Scypho.jellies	Misc.fish	Eulachon.Osmerid	Sea.star	Eelpouts	Grenadier	Sea.pen	Lanternfish	Snails	All.other
2003	5,591	98	9	88	1	20	0	0	0	1
2004	6,490	87	20	7	0	14	0	0	0	1
2005	5,084	146	12	9	1	14	1	0	6	2
2006	2,657	147	92	8	20	15	1	9	0	6
2007	2,150	198	136	4	118	27	3	5	0	6
2008	3,711	103	4	6	7	27	1	0	0	6
2009	3,703	58	4	4	2	3	1	0	0	1
2010	2,153	116	0	4	0	1	1	0	0	1
2011	6,571	216	2	18	0	1	2	0	0	1
2012	2,454	124	1	3	0	0	2	0	0	1
2013	4,734	101	0	2	0	0	1	0	0	2
2014	11,036	40	2	5	2	0	3	0	0	4
2015	4,748	87	21	28	9	1	2	0	0	2
2016	2,185	70	5	48	22	3	1	0	0	2
2017	5,776	46	3	4	18	2	0	0	0	0

Table 42: Bycatch estimates of prohibited species caught in the BSAI directed pollock fishery, 1997–2018 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 2018 are preliminary.

Year	Bairdi.Crab.	Blue.King.Crab	Chinook.Salmon	Golden.King.Crab	Halibut.catch	Herring	Non.Chin..salmon	Opilio.Crab	Other.King.Crab	Red.King.Crab.
1991	249,836	0	31,702	0	525	3,095	23,304	1,681,668	14,937	535
1992	1,042,484	0	28,760	0	1,651	630	39,741	3,558,922	12,675	7,885
1993	387,357	0	32,533	0	634	519	239,384	215,733	394	9,342
1994	149,066	0	29,816	0	611	1,528	84,718	302,281	34	666
1995	46,286	0	8,800	0	157	798	14,509	59,936	521	2,013
1996	18,554	0	50,282	0	229	1,168	74,423	42,329	198	2,572
1997	6,525	0	43,329	0	160	1,088	61,504	88,589	156	0
1998	38,100	0	50,835	0	200	749	59,570	55,197	1,836	9,560
1999	1,077	0	10,331	0	84	784	44,586	12,783	2	0
2000	173	0	3,967	0	91	481	56,715	1,807	103	0
2001	86	0	30,118	0	195	224	52,857	2,179	5,136	38
2002	651	0	32,249	0	151	108	77,101	1,669	81	5
2003	723	8	42,146	0	86	947	178,224	607	0	52
2004	1,078	4	48,171	1	93	1,064	439,122	633	0	8
2005	592	0	64,018	1	100	421	695,006	1,913	0	0
2006	964	0	77,883	0	119	219	290,862	2,547	0	25
2007	826	0	104,078	3	274	345	82,410	2,713	0	7
2008	798	8	18,507	3	253	124	13,161	4,322	0	27
2009	849	0	8,163	0	254	64	41,833	2,999	0	34
2010	838	28	7,320	0	135	189	12,731	4,337	0	16
2011	2,929	25	24,100	0	258	345	185,279	4,405	0	3
2012	1,137	0	9,850	0	313	2,166	20,115	2,851	0	2
2013	1,576	6	11,454	4	129	958	123,792	3,746	0	0
2014	885	0	14,425	0	134	151	218,067	3,330	0	7
2015	1,179	0	17,583	0	117	1,387	236,185	2,942	0	0
2016	468	0	21,222	0	98	1,425	338,818	833	0	6
2017	327	0	29,517	0	76	957	466,484	288	0	22
2018	898	0	13,503	0	48	304	280,424	276	0	14

Table 43: Ecosystem considerations for BSAI pollock and the pollock fishery.

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

Table 44: Details and explanation of the decision table factors selected in response to the Plan Team requests (as originally proposed in the 2012 assessment).

Term	Description	Rationale
$P\left[F_{2019} > F_{MSY}\right]$	Probability that the fishing mortality in 2019 exceeds F_{MSY}	OFL definition is based on F_{MSY}
$P\left[B_{2020} < B_{MSY}\right]$	Probability that the spawning biomass in 2020 is less than B_{MSY}	B_{MSY} is a reference point target and biomass in 2020 provides an indication of the impact of 2019 fishing
$P\left[B_{2021} < B_{MSY}\right]$	Probability that the spawning biomass in 2021 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 2019 and 2020
$P\left[B_{2020} < \bar{B}\right]$	Probability that the spawning biomass in 2020 is less than the 1978–2018 mean	To provide some perspective of what the stock condition might be relative to historical estimates after fishing in 2019.
$P\left[B_{2023} < \bar{B}\right]$	Probability that the spawning biomass in 2023 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 2019.
$P\left[B_{2023} < B_{2019}\right]$	Probability that the spawning biomass in 2023 is less than that estimated for 2019	To provide a medium term expectation of stock status relative to 2019 levels
$P\left[B_{2021} < B_{20\%}\right]$	Probability that the spawning biomass in 2021 is less than $B_{20\%}$	$B_{20\%}$ had been selected as a Steller Sea Lion lower limit for allowing directed fishing
$P\left[p_{a_5,2021} > \bar{p}_{a_5}\right]$	Probability that in 2023 the proportion of age 1–5 pollock in the population exceeds the long-term mean	To provide some relative indication of the age composition of the population relative to the long term mean.
$P\left[D_{2020} < D_{1994}\right]$	Probability that the diversity of ages represented in the spawning biomass (by weight) in 2020 is less than the value estimated for 1994	To provide a relative index on the abundance of different age classes in the 2020 population relative to 1994 (a year identified as having low age composition diversity)
$P\left[D_{2023} < D_{1994}\right]$	Probability that the diversity of ages represented in the spawning biomass (by weight) in 2023 is less than the value estimated for 1994	To provide a medium-term relative index on the abundance of different age classes in the population relative to 1994 (a year identified as having low age composition diversity)
$P\left[E_{2019} > E_{2018}\right]$	Probability that the theoretical fishing effort in 2019 will be greater than that estimated in 2018.	To provide the relative effort that is expected (and hence some idea of costs).

Table 45: Outcomes of decision (expressed as chances out of 100) given different 2019 catches (first row, in kt). Note that for the 2017 and later year-classes average values were assumed. Constant Fs based on the 2019 catches were used for subsequent years.

	10	500	1000	1250	1387	1500	1750	2000
$P\left[F_{2019} > F_{MSY}\right]$	1	0	0	0	24	0	0	1
$P\left[B_{2020} < B_{MSY}\right]$	60	47	49	51	79	53	56	58
$P\left[B_{2021} < B_{MSY}\right]$	53	37	39	42	77	45	48	50
$P\left[B_{2020} < \bar{B}\right]$	100	100	100	100	100	100	100	100
$P\left[B_{2023} < \bar{B}\right]$	72	52	56	59	89	63	66	69
$P\left[B_{2023} < B_{2019}\right]$	26	14	16	18	43	20	22	24
$P\left[B_{2021} < B_{20\%}\right]$	3	1	2	2	8	2	2	2
$P\left[p_{a_5,2021} > \bar{p}_{a_5}\right]$	75	61	64	67	85	69	71	73
$P\left[D_{2020} < D_{1994}\right]$	0	0	0	0	0	0	0	0
$P\left[D_{2023} < D_{1994}\right]$	6	2	2	3	26	3	4	5
$P\left[E_{2019} > E_{2018}\right]$	9	0	0	0	83	0	1	4

#{r child = 'figs.Rmd'} #

EBS Pollock Model Description

Dynamics

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

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

where

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

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

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

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

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

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

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

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

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

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

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

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

$$\alpha_t^{\mu} - \alpha_{t+1}^{\mu} \sim \mathcal{N}(0,\, \sigma_{\alpha^{\mu}}^2) \tag{16}$$

$$\beta_t^{\mu} - \beta_{t+1}^{\mu} \sim \mathcal{N}(0,\, \sigma_{\beta^{\mu}}^2) \tag{17}$$

The parameters to be estimated in this part of the model are thus for t=1982, 1983, 2016. The variance terms for these process error parameters were specified to be 0.04.

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

$$\nu = \mathrm{var}\left(r_t^a \sqrt{\frac{N_t}{\kappa_t}}\right)^{-1} \tag{18}$$

$$r_t^a = \bar{a}_t - \hat{\bar{a}}_t \tag{19}$$

$$\kappa_t = \left[\sum_a^A \bar{a}_t - \hat{\bar{a}}_t\right]^{0.5} \tag{20}$$

where r_t^a is the residual of mean age and

$$\hat{\bar{a}}_t = \sum_a^A a\hat{p}_{ta} \tag{21}$$

$$\bar{a}_t = \sum_a^A a p_{ta} \tag{22}$$

For this assessment, we use 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.

$$R_t = f\left(B_{t-1}\right) \tag{23}$$

with mature spawning biomass during year t was defined as:

$$B_t = \sum_{a=1}^A w_{t,a}\phi_a N_{t,a} \tag{24}$$

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:

$$R_t = \frac{B_{t-1}e^{\varepsilon_t}}{\alpha + \beta B_{t-1}} \tag{25}$$

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:

$$\alpha = \tilde{B}_0 \frac{1-h}{4h} \tag{26}$$

$$\beta = \frac{5h-1}{4hR_0} \tag{27}$$

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):

$$R_t = \frac{B_{t-1} e^{\alpha\left(1 - B_{t-1}\frac{R_0}{\psi_0}\right)}}{\psi_0} \tag{28}$$

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

$$h = \frac{e^{\alpha}}{e^{\alpha} + 4} \tag{29}$$

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):

$$nll(i) = n \sum_{t,a} p_{ta} \ln \hat{p}_{ta} \tag{30}$$

$$p_{ta} = \frac{O_{ta}}{\sum_a O_{ta}} \qquad \hat{p}_{ta} = \frac{\hat{C}_{ta}}{\sum_a \hat{C}_{ta}} \tag{31}$$

$$\mathbf{C} = \mathbf{CE} \tag{32}$$

$$\mathbf{E} = \begin{matrix} b_{1,1} & b_{1,2} & \dots & b_{1,15} \\ b_{2,1} & b_{2,2} & & b_{2,15} \\ \vdots & & \ddots & \vdots \\ b_{15,1} & b_{15,2} & \dots & b_{15,15} \end{matrix} \tag{33}$$

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:

$$\prod_{a=1}^{A} \prod_{t=1}^{T} \left[\left(\exp\left(-\frac{(p_{ta} - \hat{p}_{ta})^2}{2\left(\eta_{ta} + 0.1/A\right)\tau_t^2} \right) + 0.01 \right) \times \frac{1}{\sqrt{2\pi\left(\eta_{ta} + 0.1/A\right)\tau_t}} \right] \tag{34}$$

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

$$nll(i) = -0.5 \sum_{a=1}^{A} \sum_{t=1}^{T} \ln 2\pi \left(\eta_{ta} + 0.1/A\right) - \sum_{t}^{T} A \ln \tau_t + \sum_{a=1}^{A} \sum_{t=1}^{T} \ln \left\{ \exp\left(-\frac{\left(p_{ta} - \hat{p}_{ta}\right)^2}{\left(2\eta_{ta} + 0.1/A\right) \tau_t^2} \right) + 0.01 \right\} \tag{35}$$

where

$$\eta_{ta} = p_{ta}(1 - p_{ta}) \tag{36}$$

$$\text{and} \tag{37}$$

$$\tau_t^2 = 1/n_t \tag{38}$$

which gives the variance for p_{ta}

$$(\eta_{ta} + 0.1/A)\tau_t^2 \tag{39}$$

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:

$$\hat{N}_{ta}^{s} = e^{-0.5 Z_{ta}} N_{ta} q_t^s s_{ta}^S \tag{40}$$

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:

$$\hat{N}_{ta}^{s} = e^{-0.5 Z_{ta}} w_{ta} N_{ta} q_t^s s_{ta}^S \tag{41}$$

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:

$$nll(i) = \sum_{t} \frac{\ln(u_t^s / \hat{N}_t^s)^2}{2\sigma_{s,t}^2} \tag{42}$$

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:

$$nll(i) = \sum_t \frac{(u_t^s - \hat{N}_t^s)^2}{2\sigma_{s,t}^2}. \tag{43}$$

$$\tag{44}$$

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

$$nll_i = 0.5\mathbf{X}\Sigma^{-1}\mathbf{X}' \tag{45}$$

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.

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

$$nll_i = 0.5 \sum_t \frac{\ln(C_b^{obs}/\hat{C}_b)^2}{2\sigma_{C_b,t}^2} \tag{46}$$

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 (2017) 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 1991-2017. 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:

$$\hat{w}_{ta} = \bar{w}_a e_t^{\upsilon} \qquad a = 1,\ t \geq 1964 \tag{47}$$

$$\hat{w}_{ta} = \hat{w}_{t-1,a-1} + \Delta_a e_t^{\psi} \qquad a > 1,\ t > 1964 \tag{48}$$

$$\Delta_a = \bar{w}_{a+1} - \bar{w}_a \qquad a < A \tag{49}$$

$$\bar{w}_a = \alpha \left\{ L_1 + (L_2 - L_1) \left(\frac{1 - K^{a-1}}{1 - K^{A-1}} \right) \right\}^3 \tag{50}$$

$$\tag{51}$$

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 2017 and 2018 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} :

$$ABC_t = B^f_{GM,t} \hat{u}_{HM} \zeta_t \tag{52}$$

$$B^f_{GM,t} = e^{\ln \hat{B}^f_t - 0.5\sigma^2_{Bf}} \tag{53}$$

$$u^f_{HM,t} = e^{\ln \hat{u}_{MSY,t} - 0.5\sigma^2_{u_{MSY}}} \tag{54}$$

$$\zeta_t = \frac{B_t / B_{MSY} - 0.05}{1 - 0.05} \qquad B_t < B_{MSY} \tag{55}$$

$$\zeta_t = 1.0 \qquad B_t \geq B_{MSY} \tag{56}$$

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

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