2A. Assessment of the Pacific Cod Stock in the Aleutian Islands

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EXECUTIVE SUMMARY

Summary of Changes in Assessment Inputs

Relative to the November edition of last year's BSAI SAFE report, the following substantive changes have been made in the Aleutian Islands (AI) Pacific cod stock assessment.

Changes in the Input Data

Catch data for 1991-2018 were updated, and preliminary catch data for 2019 were included.

Changes in the Assessment Methodology

There are no changes in the assessment methodology that is proposed for use in setting the 2020-2021 harvest specifications. However, Appendix 2A.4 describes an age-structured model that has potential for use in next year's specifications process.

Summary of Results

The principal results of the present assessment, based on the authors' recommended model, are listed in the table below (biomass and catch figures are in units of t) and compared with the corresponding quantities from last year's assessment as specified by the SSC:

Quantity	As estimated or *specified last* year for: 2019	2020	As estimated or *recommended this* year for: 2020	2021
M (natural mortality rate)	0.34	0.34	0.34	0.34
Tier	5	5	5	5
Biomass (t)	80,700	80,700	80,700	80,700
F_{OFL}	0.34	0.34	0.34	0.34
$maxF_{ABC}$	0.255	0.255	0.255	0.255
F_{ABC}	0.255	0.255	0.255	0.255
OFL (t)	27,400	27,400	27,400	27,400
maxABC (t)	20,600	20,600	20,600	20,600
ABC (t)	20,600	20,600	20,600	20,600
Status	As determined *this* year for: 2017	2018	As determined *this* year for: 2018	2019
Overfishing	No	n/a	No	n/a

Responses to SSC and Plan Team Comments on Assessments in General

Since last year's assessment was completed, the SSC has made the following comments on assessments in general:

Comments from the December 2018 SSC meeting

SSC1: "The SSC requests that all authors fill out the risk table in 2019, and that the PTs provide comment on the author's results in any cases where a reduction to the ABC may be warranted (concern levels 2-4). The author and PT do not have to recommend a specific ABC reduction, but should provide a complete evaluation to allow for the SSC to come up with a recommendation if they should choose not to do so." *Response*: The risk table is included here (see "Risk Table" subsection in the "Harvest Recommendations" section). No specific ABC reduction is recommended, but a complete evaluation is provided in order to allow the SSC to come up with a reduction if it chooses to do so.

Comments from the October 2019 SSC meeting

SSC2: "The SSC recommends the authors complete the risk table and note important concerns or issues associated with completing the table." *Response*: As noted in response to SSC1, the risk table is included here. Some concerns and issues associated with completing the table are noted in the subsection where the table appears.

Responses to SSC and Plan Team Comments Specific to this Assessment

Since last year's assessment was completed, the Team and SSC have made the following comments specific to this assessment.

Comments from the November 2018 Team meeting

BPT1: "The Team recommends investigating natural mortality to determine if there is a more appropriate value of M for this Tier 5 stock assessment. Potential sources of information are the GOA P. cod assessment, the prior for *M* currently developed for P. cod, and a prior for M using various approaches for estimating *M* (i.e., http://barefootecologist.com.au/shiny_m.html)." *Response:* Appendix 2A.4 contains an investigation of the natural mortality rate for this stock, including the value that was estimated in last year's GOA Pacific cod assessment (Barbeaux et al. 2018), the prior distribution that was used in last year's EBS Pacific cod assessment (Thompson 2018) and the "Shiny" app recommended by the Team. See also response to comment SSC3.

BPT2: "Given the continued concerns of the EBS Pcod assessment, the Team recommends continued focus on the EBS P. cod assessment and giving a lower priority to developing an age-structured AI P. cod model. Progress on the EBS and GOA P. cod assessments may provide useful insights into developing an age-structured assessment for AI P. cod." *Response:* See response to comment SSC5.

Comments from the December 2018 SSC meeting

SSC3: "The SSC agreed with the PT's recommendation to revisit the sources of information determining natural mortality in this assessment since genetic studies do not suggest that cod in the AI are similar to the BS, which is the source of the current value for natural mortality. Further, the general priors developed for both the BS and GOA Pacific cod stocks suggest a much higher value of *M*." *Response:* Given the SSC's view that the estimate of *M* for the EBS stock may not be a good estimator of *M* for the AI stock, the practice of setting *M* for the AI stock equal to the estimate from the current year's EBS assessment has been discontinued (i.e., the value of *M* has not been updated here), pending development of a more suitable estimator. See also response to comment BPT1.

SSC4: "The SSC encouraged the author to explore the VAST model as an alternative for future apportionment calculations, noting potential issues with estimating spatial processes around a chain of islands." *Response:* Use of the VAST model will be explored for this assessment once the AFSC survey group feels that it is ready for use in the context of the AI bottom trawl survey.

SSC5: "The SSC disagreed with the PT recommendation to continue to delay new modelling efforts for the AI, and instead requests that an age-structured model be developed." *Response:* Age-structured models are presented in Appendix 2A.4.

Comments from the September 2019 Team meeting

Five Team comments on the preliminary draft of Appendix 2A.4 are addressed in the version of Appendix 2A.4 presented here.

Comments from the October 2019 SSC meeting

Four SSC comments on the preliminary draft of Appendix 2A.x are addressed in the version of Appendix 2A.4 presented here.

INTRODUCTION

General

Pacific cod (*Gadus macrocephalus*) is a transoceanic species, ranging from Santa Monica Bay, California, northward along the North American coast; across the Gulf of Alaska and Bering Sea north to Norton Sound; and southward along the Asian coast from the Gulf of Anadyr to the northern Yellow Sea; and occurring at depths from shoreline to 500 m (Ketchen 1961, Bakkala et al. 1984). The southern limit of the species' distribution is about 34° N latitude, with a northern limit of about 65° N latitude (Lauth 2011). Pacific cod is distributed widely over the eastern Bering Sea (EBS) as well as in the Aleutian Islands (AI) area. Tagging studies (e.g., Shimada and Kimura 1994) have demonstrated significant migration both within and between the EBS, AI, and Gulf of Alaska (GOA). However, recent research indicates the existence of discrete stocks in the EBS and AI (Canino et al. 2005, Cunningham et al. 2009, Canino et al. 2010, Spies 2012). Research conducted in 2018 indicates that the genetic samples from the NBS survey in 2017 are very similar to those from the EBS survey area, and quite distinct from samples collected in the Aleutian Islands and the Gulf of Alaska (Spies et al. 2019).

Although the resource in the combined EBS and AI (BSAI) region had been managed as a single unit from 1977 through 2013, separate harvest specifications have been set for the two areas since the 2014 season.

Pacific cod are not known to exhibit any special life history characteristics that would require it to be assessed or managed differently from other groundfish stocks in the BSAI.

Review of Life History

Spawning, eggs, and larvae

Pacific cod in the EBS form large spawning aggregations, and typically spawn once per year (Sakurai and Hattori 1996, Stark 2007), from late February or early March through early to mid-April (Neidetcher et al. 2014). Shimada and Kimura (1994) identified major spawning areas between Unalaska and Unimak Islands, and seaward of the Pribilof Islands along the shelf edge. Neidetcher et al. (2014) identified spawning concentrations north of Unimak Island, in the vicinity of the Pribilof Islands, at the shelf break near Zhemchug Canyon, and adjacent to islands in the central and western Aleutian Islands along the continental shelf. In their tagging study, Shimada and Kimura observed a few travel distances in excess of 500 nmi, with a large number of travel distances in excess of 100 nmi, which they inferred to be part of an annual migration between summer feeding grounds and winter spawning grounds. Shimada and Kimura and Neidetcher et al. speculated that variations in spawning time may be temperature-related.

In a laboratory study, eggs hatched between 16-28 days after spawning, with peak hatching occurring on day 21 (Abookire et al. 2007). Settlement in the Gulf of Alaska is reported to occur from July onward (Blackburn and Jackson 1982, Abookire et al. 2007, Laurel et al. 2007), which, given a mean spawning date of mid-March (Neidetcher et al. 2014), and assuming that settlement occurs immediately after transformation, and subtracting about 20 days for the egg stage, implies that the larval life stage might last about 90 days. In the laboratory study by Hurst et al. (2010), postflexion larvae were all younger than 106 days post-hatching, and juveniles were all older than 131 days post-hatching, so it might be inferred that transformation typically takes place between 106 and 131 days after hatching.

Several studies have demonstrated an impact of temperature on survival and hatching of eggs and development of embryos and larvae (e.g., Laurel et al. 2008, Hurst et al. 2010, Laurel et al. 2011, Laurel et al. 2012, Bian et al. 2014, Bian et al. 2016). Temperature has been (negatively) related to recruitment of Pacific cod (e.g., Doyle et al. 2009, Hurst et al. 2012).

Pacific cod eggs are demersal (Thomson 1963), but Pacific cod larvae move quickly to surface waters after hatching (Rugen and Matarese 1988, Hurst et al. 2009), and appear to be capable of traveling considerable distances. Rugen and Materese concluded that larval Pacific cod were transported from waters near the Kenai peninsula and Kodiak Island to locations as far as Unimak Island. In the Gulf of Alaska, it is thought that movement of larvae has a significant shoreward component (Rugen and Materese, Abookire et al. 2001 and 2007, Laurel et al. 2007), but it is not obvious that this is always the case elsewhere in the species' range (Hurst et al. 2012), although Hurst et al. (2015) found that age 0 Pacific cod in the EBS were most abundant in waters along the Alaska peninsula to depths of 50 m.

Laurel et al. (2011) investigated the match-mismatch hypothesis for Pacific cod in the Gulf of Alaska. Their results showed that cold environments allow Pacific cod larvae to bridge gaps in prey availability (i.e., timing and magnitude), but negatively impact survival over longer periods. Under warmer conditions, mismatches in prey significantly impacted growth and survival. However, both yolk reserves and compensatory growth mechanisms reduced the severity of mismatches occurring in the first 3 weeks of development.

Doyle et al. (2009) found that larval retention of Pacific cod during the month of April was key to late spring abundance in the Gulf of Alaska, but it is unknown whether this result holds elsewhere in the species' range. Neidetcher et al. (2014) speculated that spawning locations in the EBS are the product of "an accumulation of conditions beneficial to Pacific cod productivity," with no consistent basis in topography, current structure, or water column hydrology.

Juveniles

Juveniles usually tend to settle near the seafloor (Abookire et al. 2007, Laurel et al. 2007).

Some studies of Pacific cod in the Gulf of Alaska, and also some studies of Atlantic cod, suggest that young-of-the-year cod are dependent on eelgrass, but this may not be the case elsewhere in the species' range. In contrast to other parts of the range of Pacific cod, where sheltered embayments are key nursery grounds, Hurst et al. (2015) found that habitat use of age 0 Pacific cod in the EBS occurs along a gradient from coastal-demersal (bottom depths < 50 m) to shelf-pelagic (bottom depths 60-80 m), with densities near the coastal waters of the Alaska peninsula much higher than elsewhere. Hurst et al. (2012) and Parker-Stetter et al. (2013) also observed age 0 Pacific cod in the shelf-pelagic zone. Hurst et al. (2012) found evidence of density-dependent habitat selection at the local scale, but no consistent shift in distribution of juvenile Pacific cod in response to interannual climate variability. Hurst et al. (2015) state, "The ability to utilize a mosaic of habitats as nursery areas may contribute to the persistence of the Pacific cod population in the Bering Sea,"

Hurst et al. (2015) suggested that habitat use by age 0 Pacific cod in the EBS is related to temperature and the distribution of large-bodied demersal predators. Gotceitas et al. (1997) found that the habitat distribution of age 0 Atlantic cod was influenced by predators.

Leslie matrix analysis of a Pacific cod stock occurring off Korea estimated the instantaneous natural mortality rate of 0-year-olds at 2.49% per day (Jung et al. 2009). This may be compared to a mean estimate for age 0 Atlantic cod (*Gadus morhua*) in Newfoundland of 4.17% per day, with a 95% confidence interval ranging from about 3.31% to 5.03% (Robert Gregory, DFO, *pers. commun.*); and age 0 Greenland cod (*Gadus ogac*) of 2.12% per day, with a 95% confidence interval ranging from about 1.56% to 2.68% (Robert Gregory and Corey Morris, DFO, *pers. commun.*).

Adults

Adult Pacific cod in the EBS are strongly associated with the seafloor (Nichol et al. 2007), suggesting that fishing activity has the potential to disturb habitat. Nichol et al. (2013) observed frequent diel vertical migration. Patterns varied significantly by location, bottom depth, and time of year, with daily depth changes averaging 8 m.

Although little is known about the likelihood of age-dependent natural mortality in adult Pacific cod, it has been suggested that Atlantic cod may exhibit increasing natural mortality with age (Greer-Walker 1970).

At least one study (Ueda et al. 2006) indicates that age 2 Pacific cod may congregate more, relative to age 1 Pacific cod, in areas where trawling efficiency is reduced (e.g., areas of rough substrate), causing their selectivity to decrease. Also, Atlantic cod have been shown to dive in response to a passing vessel (Ona and Godø 1990, Handegard and Tjøstheim 2005), which may complicate attempts to estimate catchability (*Q*) or selectivity. It is not known whether Pacific cod exhibit a similar response.

As noted above, Pacific cod are known to undertake seasonal migrations, the timing and duration of which may be variable (Savin 2008).

FISHERY

Description of the Directed Fishery

During the early 1960s, Japanese vessels began harvesting Pacific cod in the AI. However, these catches were not particularly large, and by the time that the Magnuson Fishery Conservation and Management Act went into effect in 1977, foreign catches of Pacific cod in the AI had never exceeded 4,200 t. Joint venture fisheries began operations in the AI in 1981, and peaked in 1987, with catches totaling over 10,000 t. Foreign fishing for AI Pacific cod ended in 1986, followed by an end to joint venture fishing in 1990. Domestic fishing for AI Pacific cod began in 1981, with a peak catch of over 43,000 t in 1992.

Presently, the Pacific cod stock is exploited by a multiple-gear fishery, including primarily trawl and longline components (Figure 2A.1). Pot gear accounted for 8% of the catch on average from 1991 through 2014 (peaking at 32% in 2014), then there were no catches taken by pot gear in either 2015 or 2016, but from 2017 through 2019 (as of October 27, 2019), pot gear accounted for 30% of the catch. Jig gear also contributes some of the catch, although the amounts are very small in comparison to the other three main gear types, with an average annual catch of 28 t since 1991. The breakdown of catch by gear during the most recent complete year (2018) is as follows: trawl gear accounted for 50% of the catch, longline gear accounted for 16%, and pot gear accounted for 34% of the catch.

Historically, Pacific cod were caught throughout the AI. For the last five years prior to enactment of additional Steller sea lion (*Eumetopias jubatus*) protective regulations in 2011, the proportions of Pacific cod catch in statistical areas 541 (Eastern AI), 542 (Central AI), and 543 (Western AI) averaged 58%, 19%, and 23%, respectively. For the period 2011-2014, the average distribution has was 84%, 16%, and 0%, respectively. In 2015, area 543 was reopened to limited fishing for Pacific cod (see "Management History" below). The average catch distribution for 2017-2019 (through October 27, 2019) was 62% (EAI), 24% (CAI), and 14% (WAI), respectively.

Catches of Pacific cod taken in the AI for the periods 1964-1980, 1981-1990, and 1991-2019 are shown in Tables 2A.1a, 2A.1b, and 2A.1c, respectively. The catches in Tables 2A.1a and 2A.1b are broken down by fleet sector (foreign, joint venture, domestic annual processing). The catches in Table 2A.1b are also broken down by gear to the extent possible. The catches in Table 2A.1c are broken down by gear. Table 2A.1d breaks down catches from 1994-2019 by 3-digit statistical area (area breakdowns not available prior to 1994), both in absolute terms and as proportions of the yearly totals.

Appendix 2A.1 contains an economic performance report on the BSAI Pacific cod fishery.

Effort and CPUE

Gear-specific time series of fishery catch per unit effort (CPUE) are plotted, scaled relative to the respective gear-specific long-term average, in Figure 2A.2. Year-to-date CPUEs for 2019 are 40% below and 6% above their long-term averages for trawl and longline gear. Although trawl CPUE has trended downward for the last three years, there is little indication of significant long-term trends for either gear.

Discards

The catches shown in Tables 2A.1b and 2A.1c include estimated discards. Discard amounts and rates of Pacific cod in the AI Pacific cod fisheries are shown for each year 1991-2019 in Table 2A.2. Amendment 49, which mandated increased retention and utilization of Pacific cod, was implemented in 1998. From 1991-1998, discard rates in the Pacific cod fishery averaged about 5.6%. Since then, they have averaged about 1.0%.

Management History

Table 2A.3 lists all implemented amendments to the BSAI Groundfish FMP that reference Pacific cod explicitly. In addition to those already implemented, Amendments 120/108, if approved by the Secretary of Commerce, will soon be added to the list. Those amendments would require that a C/P acting as a mothership receiving deliveries of BSAI non-CDQ Pacific cod from CVs engaged in directed fishing with trawl gear be designated on a groundfish LLP license with a "BSAI Pacific cod trawl mothership endorsement." Passage of the amendment was motivated by an increase in mothership activity since 2016 in the BSAI non-CDQ Pacific cod trawl CV directed fishery, which was linked to trawl CVs delivering to C/Ps operating as motherships, thereby decreasing Pacific cod landings at BSAI shoreside processing facilities. Only two groundfish LLP licenses will currently qualify for the BSAI Pacific cod trawl mothership endorsement. The proposed rule for Amendments 120/108 has already been published (84 FR 51092, September 27, 2019), and the final rule is expected to be published in time to be implemented for the 2020 A season trawl catcher vessel Pacific cod fishery in the BSAI (https://www.federalregister.gov/documents/2019/09/27/2019-20552/fisheries-of-the-exclusive-economic-zone-off-alaska-pacific-cod-management-in-the-groundfish).

History with Respect to the EBS Stock

Prior to 2014, the AI and EBS Pacific cod stocks were managed jointly, with a single TAC, ABC, and OFL. Beginning with the 2014 fishery, the two stocks have since been managed separately.

The history of acceptable biological catch (ABC), overfishing level (OFL), and total allowable catch (TAC) levels is summarized and compared with the time series of aggregate (i.e., all-gear, combined area) commercial catches in Table 2A.4. Note that, prior to 2014, this time series pertains to the combined BSAI region, so the catch time series differs from that shown in Table 2A.1, which pertains to the AI only. Total catch has been less than OFL in every year since 1993. Instances where catch exceeds TAC can typically be attributed to the fact that the catches listed in Table 2A.4 are *total* catches (i.e., Federal plus State), whereas the TAC applies only to the Federal catch. In the five years that AI Pacific cod have been managed separately from EBS Pacific cod, the ratio of Federal catch to TAC has ranged from 0.78 to 0.96 (2019 data are complete through October 27). See also "History with Respect to the State Fishery" below.

ABCs were first specified in 1980. Prior to separate management of the AI and EBS stocks in 2014, TAC averaged about 83% of ABC, and aggregate commercial catch averaged about 92% of TAC (since 1980). In 10 of the 34 years between 1980 and 2013, TAC equaled ABC exactly.

Changes in ABC over time are typically attributable to three factors: 1) changes in resource abundance, 2) changes in management strategy, and 3) changes in the stock assessment model. Because ABC for all years through 2013 were based on the EBS assessment model (with an expansion factor for the AI), readers are referred to Chapter 2 for a history of changes in that model. During the period of separate AI and EBS management, the assessment of the AI stock has been based on a simple, random effects (Tier 5) model.

History with Respect to the State Fishery

Beginning with the 2006 fishery, the State of Alaska managed a fishery for AI Pacific cod inside State waters, with a guideline harvest level (GHL) equal to 3% of the BSAI ABC. Beginning with the 2014 fishery, this practice was modified by establishing two separate GHL fisheries, one for the AI and one for the EBS. The table below shows the formulas that have been used to set the State GHL for the AI:

Year	Formula
2014	0.03 × (EBS ABC + AI ABC)
2015	0.03 × (EBS ABC + AI ABC)
2016	0.27 × AI ABC
2017	0.27 × AI ABC
2018	0.27 × AI ABC
2019	0.31 × AI ABC
2020	0.35 × AI ABC or 6,804 t, whichever is less

For 2020, if the 2020 ABC remains at the value that was specified last year (20,600 t), the above formula would result in a GHL of 6,804 t.

During the period in which a State fishery has existed: 1) TAC has been reduced so that the sum of the TAC and GHL would not exceed the ABC, 2) catch in the Federal fishery has been kept below TAC, and 3) total catch (Federal+State) has been kept below ABC.

History with Respect to Steller Sea Lion Protection Measures

The National Marine Fisheries Service (NMFS) listed the western distinct population segment of Steller sea lions as endangered under the ESA in 1997. Since then, protection measures designed to protect potential Steller sea lion prey from the potential effects of groundfish fishing have been revised several times. One such revision was implemented in 2011, remaining in effect through 2014. This revision prohibited the retention of Pacific cod in Area 543. The latest revision, implemented in 2015, replaced this prohibition with a "harvest limit" for Area 543 determined by subtracting the State GHL from the AI Pacific cod ABC, then multiplying the result by the proportion of the AI Pacific cod biomass in Area 543 (see "Area Allocation of ABC," under "Harvest Recommendations," in the "Results" section).

DATA

This section describes data used in the model presented in this stock assessment, and does not attempt to summarize all available data pertaining to Pacific cod in the AI.

Trawl Survey Biomass

The time series of NMFS bottom trawl survey biomass is shown for Areas 541-543 (Eastern, Central, and Western AI, respectively), together with their respective coefficients of variation, in Table 2A.5. These estimates pertain to the Aleutian *management* area, and so are smaller than the estimates pertaining to the Aleutian *survey* area that were reported in BSAI Pacific cod stock assessments prior to 2013.

Over the long term, the biomass data indicate a decline. Simple linear regression on the time series estimates a negative slope coefficient that is statistically significant at the 1% level. However, the trend since 2010 has been largely positive.

ANALYTIC APPROACH

Model Structure (General)

The history of models presented in previous AI Pacific cod assessments is described in Appendix 2A.2. From 2012 through the preliminary 2016 draft, a total of 22 unique age-structured models were fully vetted in the assessments of AI Pacific cod. However, none of them were accepted by either the Team or SSC for the purpose of recommending harvest specifications. Given that there were so many outstanding issues with respect to the assessments of Pacific cod in both the EBS and AI as of September/October 2016, the Team and SSC recommended suspending efforts to develop an age-structured model of the AI stock until such time as the issues with respect to the EBS assessment had been resolved. In December 2018, the SSC requested that an age-structured model be developed for the AI stock (comment SSC5). In response, an age-structured model was presented in this year's preliminary assessment, and has been updated here (Appendix 2A.4). However, the age-structured model should still be viewed as preliminary at this point.

Ever since the final 2015 assessment, model numbering has followed the protocol given by Option A in the SAFE chapter guidelines. The goal of this protocol is to make it easy to distinguish between major and minor changes in models and to identify the years in which major model changes were introduced. Names of models constituting *major* changes get linked to the year that they are introduced (e.g., Model 13.4 is one of four models introduced in 2013, the first year that the SSC accepted a model for separate management of the AI stock), while names of models constituting *minor* changes get linked to the model that they modify (e.g., a hypothetical "Model 13.4a" would refer to a model that constituted a minor change from Model 13.4).

Model 13.4 is the Tier 5 random effects model recommended by the Survey Averaging Working Group (http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/2013/Sept/SAWG_2013_draft.pdf), which has been accepted by the Plan Team and SSC since the 2013 assessment for the purpose of setting AI Pacific cod harvest specifications. The Tier 5 random effects model is programmed using the ADMB software package (Fournier et al. 2012).

The Tier 5 random effects model is a very simple, state-space model of the "random walk" variety. The only parameter in Model 13.4 is the log of the log-scale process error standard deviation.

When used to implement the Tier 5 harvest control rules, the Tier 5 models also require an estimate of the natural mortality rate.

The Tier 5 random effects model assumes that the observation error variances are equal to the sampling variances estimated from the haul-by-haul survey data. The log-scale process errors and observations are both assumed to be normally distributed.

Parameters Estimates

Natural Mortality

A value of 0.34 was used for the natural mortality rate M in all BSAI Pacific cod stock assessments from 2007 (Thompson et al. 2007) through 2015. This value was based on Equation 7 of Jensen (1996) and an age at maturity of 4.9 years (Stark 2007). In response to a request from the SSC, the 2008 assessment included a discussion of alternative values and a justification for the value chosen (Thompson et al. 2008). However, it should be emphasized that, even if Jensen's Equation 7 is exactly right, variability in the estimate of the age at maturity implies that the point of estimate of 0.34 is accompanied by some level of uncertainty. Using the variance for the age at 50% maturity published by Stark (0.0663), the 95% confidence interval for *M* extends from about 0.30 to 0.38.

The value of 0.34 adopted in 2007 replaced the value of 0.37 that had been used in all BSAI Pacific cod stock assessments from 1993 through 2006.

In the 2016 assessment (Thompson and Palsson 2016), the authors recommended changing the value of *M* from 0.34 to 0.36, based on the new recommended model for the EBS Pacific cod stock (Thompson 2016). In the 2018 EBS assessment (Thompson 2018), another new model was recommended for the EBS Pacific cod stock, which estimated *M* at a value of 0.34, and the value of *M* for the AI stock was updated accordingly (Thompson and Palsson 2018). Although another new estimate of M (0.35) is available from this year's EBS assessment (chapter 2, this volume), given the Team's and SSC's concerns that the practice of equating the AI estimate of *M* with the EBS estimate (see comments BPT1 and SSC3), this has been discontinued (i.e., the value of *M* has not been updated here), pending development of a more suitable estimator.

RESULTS

Model Output

Model 13.4 estimates the log-scale process error standard deviation at a value of 0.16 with a coefficient of variation equal to 0.36.

The time series of biomass estimated by the model, with 95% confidence intervals, is shown in Table 2A.6, along with the corresponding estimates from the 2017 assessment (Thompson and Palsson 2017), which comprised the most recent previous update of the time series.

The model's fit to the survey biomass time series is shown in Figure 2A.3. The root-mean-squared-error is 0.105, compared to an average log-scale standard error of 0.180. The mean normalized residual is 0.054, the standard deviation of normalized residuals is 0.633, and the correlation between the survey biomass data and the model's estimates is 0.972.

Harvest Recommendations

Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines the "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), 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.

The following formulae apply under Tier 5:

$$F_{OFL} = M$$

$$F_{ABC} \leq 0.75 \times M$$

The estimates needed for harvest specifications are as follow:

Quantity	2020	2021
Biomass (t)	80,700	80,700
M	0.34	0.34

The 95% confidence interval for the above biomass estimate extends from 58,500-108,000 t.

Specification of OFL and Maximum Permissible ABC

Estimates of OFL, maximum permissible ABC, and the associated fishing mortality rates for 2019 and 2020 are shown below:

Quantity	2020	2021
OFL (t)	27,400	27,400
maxABC (t)	20,600	20,600
F_{OFL}	0.34	0.34
$maxF_{ABC}$	0.255	0.255

Risk Table

Should the ABC be Reduced Below the Maximum Permissible ABC?

The SSC, in its December 2018 minutes, recommended that all assessment authors use the risk table when determining whether to recommend an ABC lower than the maximum permissible. The SSC also requested the addition of a fourth column on fishery performance, which has been included in the table below.

	Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment.	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental/ecosystem concerns	No apparent fishery/resource-use performance and/or behavior concerns
Level 2: Substantially increased concerns	Substantially increased assessment uncertainty/ unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing an adverse signals relevant to the stock but the pattern is not consistent across all indicators.	Some indicators showing adverse signals but the pattern is not consistent 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 as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock)	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types
Level 4: Extreme concern	Severe problems with the stock assessment; severe retrospective bias. Assessment considered unreliable.	Stock trends are unprecedented; More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; Potential for cascading effects on other ecosystem components	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

The table is applied by evaluating the severity of four types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. These considerations are stock assessment considerations, population dynamics considerations, environmental/ecosystem considerations, and fishery performance. Examples of the types of concerns that might be relevant include the following:

1. Assessment considerations—data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data; model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs; model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds; estimation uncertainty: poorly-estimated but influential year classes; retrospective bias in biomass estimates.

2. Population dynamics considerations—decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.

3. Environmental/ecosystem considerations—adverse trends in environmental/ecosystem indicators, ecosystem model results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.

4. Fishery performance—fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings.

Assessment Considerations

This stock been assessed using Tier 5 methodology since 2013. The standard Tier 5 random effects model fits the survey data quite well. Appendix 2A.4 presents a new age-structured model that is very similar to some of the age-structured models for the Aleutian Islands stock of Pacific cod that were developed between 2012 and 2016. One feature of that model is a positive retrospective pattern (ρ=0.206), meaning that, on average over the past 10 assessment years, the model's estimates of female spawning biomass in the terminal year would have exceeded the model's current estimate of female spawning biomass in that year by about 20%. This may suggest that the model could benefit from further development, although it should also be noted that Hurtado-Ferro et al. (2015) determined that this level of retrospective bias does not rise to the level that should be cause for concern. Assessment considerations were rated as level 1 (normal).

Population Dynamics Considerations

Although the long-term (1991-2018) survey biomass trend is downward, the trend since 2010 has been largely positive. The model presented in Appendix 2A.4 projects female spawning biomass to be above $B_{40\%}$ by approximately 2%, and at $B_{40\%}$ in 2021. Population dynamics considerations were rated as level 1 (normal).

Environmental/Ecosystem Considerations

Appendix 2.6 provides a detailed look at environmental/ecosystem considerations. These may be summarized as follows:

- Pacific cod are a large component of the apex predator guild in the Aleutian Islands ecosystem.
- In 2018, the condition of Pacific cod (length/weight residuals) were strongly negative, continuing a trend since 2010.
- In 2018, the biomass of the apex predator foraging guild in the western Aleutian Islands reached its lowest level of the time series, driven by Pacific cod declines.
- In 2018, the biomass of the apex predator foraging guild in the central Aleutian Islands decreased only slightly from 2016, but both years were below the long-term mean.
- In 2018, the biomass of the apex predator foraging guild in the eastern Aleutian Islands increased from a low in 2012, driven by Pacific cod.
- Parakeet and Least auklet reproductive success suggests zooplankton availability was sufficient to support chick rearing.
- Murre and puffin reproductive success suggest that forage fish prey were insufficient to support chick rearing at Buldir with mixed results at Aiktak.
- Indicators of crustacean zooplankton abundance were low during the previous heatwave (2014-2016).
- Steller sea lion population trends continued relatively steep declines in the western Aleutian Islands, a less steep decline in the central Aleutian Islands, and improvement in the eastern Aleutian Islands.
- The abundance of jellyfish peaked during the previous heatwave; jellyfish may act as both a predator and competitor, particularly for pre-settlement and juvenile Pacific cod.

Environmental/ecosystem considerations were rated as level 2 (substantially increased concern).

Fishery Performance Considerations

Since 1991, fishery CPUE shows less of a long-term trend than survey biomass, although since about the early 2000s both time series are essentially trendless. Trawl fishery CPUE has declined markedly since 2016, while survey biomass in 2018 was nearly unchanged from 2016. There does not appear to have been any unusual spatial patterns of fishing, or changes in the percent of TAC taken. The winter fishery targets spawning populations of Pacific cod. Pacific cod aggregate to spawn, implying that a reduction in stock size is unlikely to cause lower CPUE. Rather, hyper-aggregation may exist, in which higher CPUE is observed under low stock sizes. Fishery performance considerations were rated as level 1 (normal).

Risk Summary

The ratings of the four categories are summarized below:

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ ecosystem considerations*	*Fishery Performance considerations*	*Overall score (highest of the individual scores)*
Level 1: Normal	Level 1: Normal	Level 2: Substantially increased concerns	Level 1: Normal	Level 2: Substantially increased concerns

Because the overall score is greater than level 1, ABC may need to be reduced from the maximum permissible value. However, it should be noted that the overall score of level 2 is due entirely to the identification of "some indicators showing adverse signals" even though "the pattern is not consistent across all indicators." It seems likely that, given sufficient effort, it would almost always be possible to identify one or more indicators showing adverse signals, and it is not obvious how this is to be reconciled with the SSC's stated intent that "reductions from the maximum ABC are intended to be an infrequent action to respond to substantial unquantified risk" (SSC minutes, December 2018). Rather than having each assessment author determine the appropriate reduction in isolation, the SSC has volunteered to take responsibility for determining those reductions. This seems a preferable course of action, as it should tend to increase consistency across assessments. Therefore, no reduction is recommended here.

ABC Recommendation

The authors' recommended ABCs for 2020 and 2021 are the maximum permissible values: 20,600 t in both years (but see paragraph immediately above).

Area Allocation of Harvests

As noted in the "Management History" subsection of the "Fishery" section, the current Steller sea lion protection measures require an estimate of the proportion of the AI Pacific cod stock residing in Area 543, which will be used to set the harvest limit in 543 after subtraction of the State GHL from the overall AI ABC. The Area 543 proportion could be computed on the basis of the survey observations themselves, or by running Model 13.4 once for Area 543 and again for the entire AI, then computing the ratios of the resulting estimates. More specifically, some possible estimators of this proportion are: 1) the 1991-2018 average proportion from the raw survey data (25.1%), 2) the most recent proportion from the raw survey data (14.1%), 3) the 1991-2018 average proportion from Model 13.4 (24.5%), and 4) the most recent proportion from Model 13.4 (15.7%). If Model 13.4 is used to set the 2019 and 2020 ABCs based on the model's most recent estimate of biomass, it seems reasonable to estimate the biomass proportion in Area 543 accordingly, by using the most recent estimate from Model 13.4 (15.7%). This was the percentage adopted last year for setting the 2019 specifications.

Status Determination

Under the MSFCMA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing. This report involves the answers to three questions: 1) Is the stock being subjected to overfishing? 2) Is the stock currently overfished? 3) Is the stock approaching an overfished condition?

Is the stock being subjected to overfishing? The official AI catch estimate for the most recent complete year (2018) is 20,414 t. This is less than the 2018 AI OFL of 28,700 t. Therefore, the AI Pacific cod stock is not being subjected to overfishing.

Is the stock overfished? Because this stock is managed under Tier 5, no determination can be made with respect to overfished status.

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the Stock

A primary ecosystem phenomenon affecting the Pacific cod stock seems to be the occurrence of periodic "regime shifts," in which central tendencies of key variables in the physical environment change on a scale spanning several years to a few decades (Zador, 2011). One well-documented example of such a regime shift occurred in 1977, and shifts occurring in 1989 and 1999 have also been suggested (e.g., Hare and Mantua 2000). Because the data time series in the models presented in this assessment do not begin until 1991, the 1977 regime shift should not be a factor in any of the quantities presented here, although it may indeed have had an impact on the stock.

The prey and predators of Pacific cod have been described or reviewed by Albers and Anderson (1985), Livingston (1989, 1991), Lang et al. (2003), Westrheim (1996), and Yang (2004). The composition of Pacific cod prey varies to some extent by time and area. In terms of percent occurrence, some of the most important items in the diet of Pacific cod in the BSAI and GOA have been polychaetes, amphipods, and crangonid shrimp. In terms of numbers of individual organisms consumed, some of the most important dietary items have been euphausids, miscellaneous fishes, and amphipods. In terms of weight of organisms consumed, some of the most important dietary items have been walleye pollock, fishery offal, yellowfin sole, and crustaceans. Small Pacific cod feed mostly on invertebrates, while large Pacific cod are mainly piscivorous. Predators of Pacific cod include Pacific cod, halibut, salmon shark, northern fur seals, Steller sea lions, harbor porpoises, various whale species, and tufted puffin. Major trends in the most important prey or predator species could be expected to affect the dynamics of Pacific cod to some extent.

Fishery Effects on the Ecosystem

Potentially, fisheries for Pacific cod can have effects on other species in the ecosystem through a variety of mechanisms, for example by relieving predation pressure on shared prey species (i.e., species which serve as prey for both Pacific cod and other species), by reducing prey availability for predators of Pacific cod, by altering habitat, by imposing bycatch mortality, or by "ghost fishing" caused by lost fishing gear.

Incidental Catch Taken in the Pacific Cod Fisheries

Incidental catches taken in the Pacific cod target fisheries, expressed as proportions of total incidental EBS catches (i.e., across all targets) for the respective species, are summarized in Tables 2A.7-2A.10. For the purpose of generating these tables, Pacific cod targets were those identified as such in the AKFIN database. Catches for 2019 in each of these tables are incomplete. Table 2A.7 shows incidental catch of FMP species taken from 1991-2019 by trawl gear and fixed gear. Table 2A.8 shows incidental catch of certain species of squid and members of the former "other species" complex taken from 1991-2019, aggregated across gear types. Table 2A.9 shows incidental catch of prohibited species and discard mortality of halibut taken from 1991-2019, aggregated across gear types. Table 2A.10 shows incidental catch of non-target species groups taken from 2003-2019, aggregated across gear types.

Steller Sea Lions

Sinclair and Zeppelin (2002) showed that Pacific cod was one of the four most important prey items of Steller sea lions in terms of frequency of occurrence averaged over years, seasons, and sites, and was especially important in winter. Pitcher (1981) and Calkins (1998) also showed Pacific cod to be an important winter prey item in the GOA and BSAI, respectively. Furthermore, the size ranges of Pacific cod harvested by the fisheries and consumed by Steller sea lions overlap, and the fishery operates to some extent in the same geographic areas used by Steller sea lion as foraging grounds (Livingston (ed.), 2002).

One of the main research emphases of the AFSC Fisheries Interaction Team (now disbanded) was to determine the effectiveness of management measures designed to mitigate the impacts of the Pacific cod fisheries (among others) on Steller sea lions. A study conducted in 2002-2005 using pot fishing gear demonstrated that the local concentration of cod in the Unimak Pass area is very dynamic, so that fishery removals did not create a measurable decline in fish abundance (Conners and Munro 2008). A preliminary tagging study in 2003–2004 showed some cod remaining in the vicinity of the release area in the southeast Bering Sea for several months, while other fish moved distances of 150 km or more north-northwest along the shelf, some within a matter of two weeks (Rand et al. 2015).

Seabirds

The following is a summary of information provided by Livingston (ed., 2002): In both the BSAI and GOA, the northern fulmar (*Fulmarus glacialis*) comprises the majority of seabird bycatch, which occurs primarily in the longline fisheries, including the fixed gear fishery for Pacific cod. Shearwater (*Puffinus* spp.) distribution overlaps with the Pacific cod longline fishery in the Bering Sea, and with trawl fisheries in general in both the Bering Sea and GOA. Black-footed albatross (*Phoebastria nigripes*) is taken in much greater numbers in the GOA longline fisheries than the Bering Sea longline fisheries, but is not taken in the trawl fisheries. The distribution of Laysan albatross (*Phoebastria immutabilis*) appears to overlap with the longline fisheries in the central and western Aleutians. The distribution of short-tailed albatross (*Phoebastria albatrus*) also overlaps with the Pacific cod longline fishery along the Aleutian chain, although the majority of the bycatch has taken place along the northern portion of the Bering Sea shelf edge (in contrast, only two takes have been recorded in the GOA). Some success has been obtained in devising measures to mitigate fishery-seabird interactions. For example, on vessels larger than 60 ft. LOA, paired streamer lines of specified performance and material standards have been found to reduce seabird incidental take significantly.

Fishery Usage of Habitat

The following is a summary of information provided by Livingston (ed., 2002): The longline and trawl fisheries for Pacific cod each comprise an important component of the combined fisheries associated with the respective gear type in each of the three major management regions (EBS, AI, and GOA). Looking at each gear type in each region as a whole (i.e., aggregating across all target species) during the period 1998-2001, the total number of observed sets was as follows:

Gear	EBS	AI	GOA
Trawl	240,347	43,585	68,436
Longline	65,286	13,462	7,139

In the EBS, both longline and trawl effort was concentrated north of False Pass (Unimak Island) and along the shelf edge represented by the boundary of areas 513, 517 (in addition, longline effort was concentrated along the shelf edge represented by the boundary of areas 521-533). In the AI, both longline and trawl effort were dispersed over a wide area along the shelf edge. The catcher vessel longline fishery in the AI occurred primarily over mud bottoms. Longline catcher-processors in the AI tended to fish more over rocky bottoms

Impacts of the Pacific cod fisheries on essential fish habitat were further analyzed in an environmental impact statement by NMFS (2005), followed by "5-year reviews" in 2010 and 2017 (NMFS 2010 and 2017, respectively).

DATA GAPS AND RESEARCH PRIORITIES

Significant improvements in the quality of this assessment could be made if future research were directed toward closing certain data gaps. At this point, the most critical needs pertain to trawl survey catchability and selectivity, specifically: 1) to understand the factors determining these characteristics, 2) to understand whether/how these characteristics change over time, and 3) to obtain accurate estimates of these characteristics. Ageing also continues to be an issue, as assessment models of the EBS stock since 2009 have estimated a positive ageing bias, at least for otoliths aged prior to 2008. Longer-term research needs include improved understanding of: 1) the ecology of Pacific cod in the AI, including spatial dynamics, trophic and other interspecific relationships, and the relationship between climate and recruitment; 2) ecology of species taken as bycatch in the Pacific cod fisheries, including estimation of biomass, carrying capacity, and resilience; and 3) ecology of species that interact with Pacific cod, including estimation of interaction strengths, biomass, carrying capacity, and resilience.

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TABLES

Table 2A.1a—Summary of 1964-1980 catches (t) of Pacific cod in the AI by fleet sector. "For." = foreign, "JV" = joint venture processing, "Dom." = domestic annual processing. Catches by gear are not available for these years. Catches may not always include discards.

	Aleutian Islands			
Year	For.	JV	Dom.	Total
1964	241	0	0	241
1965	451	0	0	451
1966	154	0	0	154
1967	293	0	0	293
1968	289	0	0	289
1969	220	0	0	220
1970	283	0	0	283
1971	2,078	0	0	2,078
1972	435	0	0	435
1973	977	0	0	977
1974	1,379	0	0	1,379
1975	2,838	0	0	2,838
1976	4,190	0	0	4,190
1977	3,262	0	0	3,262
1978	3,295	0	0	3,295
1979	5,593	0	0	5,593
1980	5,788	0	0	5,788

Table 2A.1b—Summary of 1981-1990 catches (t) of Pacific cod in the AI by area, fleet sector, and gear type. All catches include discards. "LLine" = longline, "Subt." = sector subtotal. Breakdown of domestic annual processing by gear is not available prior to 1988.

	Foreign			Joint Venture		Domestic Annual Processing			
Year	Trawl	LLine	Subt.	Trawl	Subt.	Trawl	LL+pot	Subt.	Total
1981	2,680	235	2,915	1,749	1,749	n/a	n/a	2,770	7,434
1982	1,520	476	1,996	4,280	4,280	n/a	n/a	2,121	8,397
1983	1,869	402	2,271	4,700	4,700	n/a	n/a	1,459	8,430
1984	473	804	1,277	6,390	6,390	n/a	n/a	314	7,981
1985	10	829	839	5,638	5,638	n/a	n/a	460	6,937
1986	5	0	5	6,115	6,115	n/a	n/a	786	6,906
1987	0	0	0	10,435	10,435	n/a	n/a	2,772	13,207
1988	0	0	0	3,300	3,300	1,698	167	1,865	5,165
1989	0	0	0	6	6	4,233	303	4,536	4,542
1990	0	0	0	0	0	6,932	609	7,541	7,541

Table 2A.1c—Summary of 1991-2019 catches (t) of Pacific cod in the AI. To avoid confidentiality problems, longline and pot catches have been combined. The small catches taken by "other" gear types have been merged proportionally with the catches of the gear types shown. Catches for 2019 are through October 27.

	Federal			State	
Year	Trawl	LL+pot	Subtotal	Subtotal	Total
1991	3,414	6,383	9,798		9,798
1992	14,587	28,481	43,068		43,068
1993	17,328	16,876	34,205		34,205
1994	14,383	7,156	21,539		21,539
1995	10,574	5,960	16,534		16,534
1996	21,179	10,430	31,609		31,609
1997	17,411	7,753	25,164		25,164
1998	20,531	14,196	34,726		34,726
1999	16,478	11,653	28,130		28,130
2000	20,379	19,306	39,685		39,685
2001	15,836	18,372	34,207		34,207
2002	27,929	2,872	30,801		30,801
2003	31,478	978	32,457		32,457
2004	25,770	3,103	28,873		28,873
2005	19,624	3,069	22,694		22,694
2006	16,956	3,535	20,490	3,721	24,211
2007	25,714	4,495	30,208	4,146	34,355
2008	19,404	7,506	26,910	4,319	31,229
2009	20,277	6,245	26,522	2,060	28,582
2010	16,759	8,280	25,039	3,967	29,006
2011	9,359	1,263	10,623	266	10,889
2012	9,786	3,201	12,988	5,232	18,220
2013	7,001	1,811	8,812	4,793	13,606
2014	5,716	439	6,155	4,451	10,605
2015	5,968	3,087	9,056	161	9,217
2016	10,654	1,710	12,364	882	13,245
2017	8,530	3,728	12,258	2,946	15,204
2018	9,261	5,458	14,719	5,695	20,414
2019	9,564	3,120	12,684	6,215	18,899

Table 2A.1d—Summary of 1994-2019 catches (t) of Pacific cod in the AI, by NMFS 3-digit statistical area (area breakdowns not available prior to 1994). Catches for 2018 are through October 27.

	Amount			Proportion		
Year	Western	Central	Eastern	Western	Central	Eastern
1994	2,059	7,441	12,039	0.096	0.345	0.559
1995	1,713	5,086	9,735	0.104	0.308	0.589
1996	4,023	4,509	23,077	0.127	0.143	0.730
1997	894	4,440	19,830	0.036	0.176	0.788
1998	3,487	9,299	21,940	0.100	0.268	0.632
1999	2,322	5,276	20,532	0.083	0.188	0.730
2000	9,073	8,799	21,812	0.229	0.222	0.550
2001	12,767	7,358	14,082	0.373	0.215	0.412
2002	2,259	7,133	21,408	0.073	0.232	0.695
2003	2,997	6,707	22,752	0.092	0.207	0.701
2004	3,649	6,833	18,391	0.126	0.237	0.637
2005	4,239	3,582	14,873	0.187	0.158	0.655
2006	4,570	4,675	14,967	0.189	0.193	0.618
2007	4,974	4,692	24,689	0.145	0.137	0.719
2008	7,319	5,555	18,355	0.234	0.178	0.588
2009	7,929	6,899	13,754	0.277	0.241	0.481
2010	8,213	6,292	14,501	0.283	0.217	0.500
2011	24	1,770	9,095	0.002	0.163	0.835
2012	29	2,816	15,374	0.002	0.155	0.844
2013	50	2,874	10,681	0.004	0.211	0.785
2014	30	1,044	9,532	0.003	0.098	0.899
2015	3,170	2,365	3,681	0.344	0.257	0.399
2016	2,551	1,609	9,085	0.193	0.121	0.686
2017	3,373	3,774	8,058	0.222	0.248	0.530
2018	2,694	4,065	13,654	0.132	0.199	0.669
2019	1,343	5,294	12,262	0.071	0.280	0.649

Table 2A.2—Discards (t) and discard rates of Pacific cod in the AI Pacific cod fishery for the period 1991-2019 (2019 data are current through October 27). Note that Amendment 49, which mandated increased retention and utilization, was implemented in 1998.

Year	Discards	Total	Rate
1991	105	5,385	0.020
1992	1,085	38,788	0.028
1993	3,527	29,193	0.121
1994	1,302	14,295	0.091
1995	460	10,822	0.042
1996	859	22,436	0.038
1997	1,220	22,804	0.053
1998	613	30,836	0.020
1999	420	25,471	0.016
2000	605	37,308	0.016
2001	455	31,920	0.014
2002	604	29,369	0.021
2003	216	30,182	0.007
2004	238	26,538	0.009
2005	139	20,215	0.007
2006	214	22,470	0.010
2007	483	32,422	0.015
2008	143	29,901	0.005
2009	149	26,437	0.006
2010	187	27,242	0.007
2011	26	9,094	0.003
2012	41	16,789	0.002
2013	54	11,951	0.004
2014	25	9,233	0.003
2015	41	6,313	0.007
2016	48	10,080	0.005
2017	70	10,510	0.007
2018	209	16,510	0.013
2019	45	15,949	0.003

Table 2A.3 (page 1 of 2)—Amendments to the BSAI Fishery Management Plan (FMP) that reference Pacific cod explicitly (excerpted from Appendix A of the FMP, except that Amendment 113, which is listed in Appendix A of the FMP, is omitted here, due to the fact that the final rule implementing that amendment was vacated by the U.S. District Court for the District of Columbia on March 21, 2019).

Amendment 2, implemented January 12, 1982:

For Pacific cod, decreased maximum sustainable yield to 55,000 t from 58,700 t, increased equilibrium yield to 160,000 t from 58,700 t, increased acceptable biological catch to 160,000 t from 58,700 t, increased optimum yield to 78,700 t from 58,700 t, increased reserves to 3,935 t from 2,935 t, increased domestic annual processing (DAP) to 26,000 t from 7,000 t, and increased DAH to 43,265 t from 24,265 t.

Amendment 4, implemented May 9, 1983, supersedes Amendment 2:

For Pacific Cod, increased equilibrium yield and acceptable biological catch to 168,000 t from 160,000 t, increased optimum yield to 120,000 t from 78,700 t, increased reserves to 6,000 t from 3,935 t, and increased TALFF to 70,735 t from 31,500 t.

Amendment 10, implemented March 16, 1987:

Established Bycatch Limitation Zones for domestic and foreign fisheries for yellowfin sole and other flatfish (including rock sole); an area closed to all trawling within Zone 1; red king crab, C. bairdi Tanner crab, and Pacific halibut PSC limits for DAH yellowfin sole and other flatfish fisheries; a C. bairdi PSC limit for foreign fisheries; and a red king crab PSC limit and scientific data collection requirement for U.S. vessels fishing for Pacific cod in Zone 1 waters shallower than 25 fathoms.

Amendment 24, implemented February 28, 1994, and effective through December 31, 1996:

1. Established the following gear allocations of BSAI Pacific cod TAC as follows: 2 percent to vessels using jig gear; 44.1 percent to vessels using hook-and-line or pot gear, and 53.9 percent to vessels using trawl gear.
2. Authorized the seasonal apportionment of the amount of Pacific cod allocated to gear groups. Criteria for seasonal apportionments and the seasons authorized to receive separate apportionments will be set forth in regulations.

Amendment 46, implemented January 1, 1997, superseded Amendment 24:

Replaced the three year Pacific cod allocation established with Amendment 24, with the following gear allocations in BSAI Pacific cod: 2 percent to vessels using jig gear; 51 percent to vessels using hook-and-line or pot gear; and 47 percent to vessels using trawl gear. The trawl apportionment will be divided 50 percent to catcher vessels and 50 percent to catcher processors. These allocations as well as the seasonal apportionment authority established in Amendment 24 will remain in effect until amended.

Amendment 49, implemented January 3, 1998:

Implemented an Increased Retention/Increased Utilization Program for pollock and Pacific cod beginning January 1, 1998 and rock sole and yellowfin sole beginning January 1, 2003.

Amendment 64, implemented September 1, 2000, revised Amendment 46:

Allocated the Pacific cod Total Allowable Catch to the jig gear (2 percent), fixed gear (51 percent), and trawl gear (47 percent) sectors.

Amendment 67, implemented May 15, 2002, revised Amendment 39:

Established participation and harvest requirements to qualify for a BSAI Pacific cod fishery endorsement for fixed gear vessels.

Amendment 77, implemented January 1, 2004, revised Amendment 64:

Implemented a Pacific cod fixed gear allocation between hook and line catcher processors (80%), hook and line catcher vessels (0.3%), pot catcher processors (3.3%), pot catcher vessels (15%), and catcher vessels (pot or hook and line) less than 60 feet (1.4%).

(Continued on next page.)

Table 2.5 (page 2 of 2)—Amendments to the BSAI Fishery Management Plan (FMP) that reference Pacific cod explicitly (excerpted from Appendix A of the FMP).

Amendment 85, partially implemented March 5, 2007, superseded Amendments 46 and 77:

Implemented a gear allocation among all non-CDQ fishery sectors participating in the directed fishery for Pacific cod. After deduction of the CDQ allocation, the Pacific cod TAC is apportioned to vessels using jig gear (1.4 percent); catcher processors using trawl gear listed in Section 208(e)(1)-(20) of the AFA (2.3 percent); catcher processors using trawl gear as defined in Section 219(a)(7) of the Consolidated Appropriations Act, 2005 (Public Law 108-447) (13.4 percent); catcher vessels using trawl gear (22.1 percent); catcher processors using hook-and-line gear (48.7 percent); catcher vessels ≥60’ LOA using hook-and-line gear (0.2 percent); catcher processors using pot gear (1.5 percent); catcher vessels ≥60’ LOA using pot gear (8.4 percent); and catcher vessels <60’ LOA that use either hook-and-line gear or pot gear (2.0 percent).

Amendment 99, implemented January 6, 2014 (effective February 6, 2014):

Allows holders of license limitation program (LLP) licenses endorsed to catch and process Pacific cod in the Bering Sea/Aleutian Islands hook-and-line fisheries to use their LLP license on larger newly built or existing vessels by:

1. Increasing the maximum vessel length limits of the LLP license, and
2. Waiving vessel length, weight, and horsepower limits of the American Fisheries Act.

Amendment 103, implemented November 14, 2014:

Revise the Pribilof Islands Habitat Conservation Zone to close to fishing for Pacific cod with pot gear (in addition to the closure to all trawling).

Amendment 109, implemented May 4, 2016:

Revised provisions regarding the Western Alaska CDQ Program to update information and to facilitate increased participation in the groundfish CDQ fisheries (primarily Pacific cod) by:

1. Exempting CDQ group-authorized catcher vessels greater than 32 ft LOA and less than or equal to 46 ft LOA using hook-and-line gear from License Limitation Program license requirements while groundfish CDQ fishing,
2. Modifying observer coverage category language to allow for the placement of catcher vessels less than or equal to 46 ft LOA using hook-and-line gear into the partial observer coverage category while groundfish CDQ fishing, and
3. Updating CDQ community population information, and making other miscellaneous editorial revisions to CDQ Program-related text in the FMP.

Table 2A.4—History of **BSAI** Pacific cod catch, TAC, ABC, and OFL (t) through 2013, and **AI** catch and specifications for 2014-2019. Catch for 2019 is through October 27. Note that specifications through 2013 were for the combined BSAI region, so BSAI catch is shown rather than the AI catches from Table 2A.1 for the period 1977-2013. Source for historical specifications: NPFMC staff.

Year	Catch	TAC	ABC	OFL
1977	36,597	58,000	-	-
1978	45,838	70,500	-	-
1979	39,354	70,500	-	-
1980	51,649	70,700	148,000	-
1981	63,941	78,700	160,000	-
1982	69,501	78,700	168,000	-
1983	103,231	120,000	298,200	-
1984	133,084	210,000	291,300	-
1985	150,384	220,000	347,400	-
1986	142,511	229,000	249,300	-
1987	163,110	280,000	400,000	-
1988	208,236	200,000	385,300	-
1989	182,865	230,681	370,600	-
1990	179,608	227,000	417,000	-
1991	220,038	229,000	229,000	-
1992	207,278	182,000	182,000	188,000
1993	167,391	164,500	164,500	192,000
1994	193,802	191,000	191,000	228,000
1995	245,033	250,000	328,000	390,000
1996	240,676	270,000	305,000	420,000
1997	257,765	270,000	306,000	418,000
1998	193,256	210,000	210,000	336,000
1999	173,998	177,000	177,000	264,000
2000	191,060	193,000	193,000	240,000
2001	176,749	188,000	188,000	248,000
2002	197,356	200,000	223,000	294,000
2003	207,907	207,500	223,000	324,000
2004	212,618	215,500	223,000	350,000
2005	205,635	206,000	206,000	265,000
2006	193,025	194,000	194,000	230,000
2007	174,486	170,720	176,000	207,000
2008	171,277	170,720	176,000	207,000
2009	175,756	176,540	182,000	212,000
2010	171,875	168,780	174,000	205,000
2011	220,109	227,950	235,000	272,000
2012	251,055	261,000	314,000	369,000
2013	250,274	260,000	307,000	359,000
2014	10,605	6,997	15,100	20,100
2015	9,217	9,422	17,600	23,400
2016	13,245	12,839	17,600	23,400
2017	15,204	15,695	21,500	28,700
2018	20,414	15,695	21,500	28,700
2019	18,899	14,214	20,600	27,400

Table 2A.5— Total biomass (absolute and relative), with coefficients of variation, as estimated by AI shelf bottom trawl surveys, 1991-2018.

	Biomass (t)			
Year	Western	Central	Eastern	All
1991	75,514	39,729	64,926	180,170
1994	23,797	51,538	78,081	153,416
1997	14,357	30,252	28,239	72,848
2000	43,298	36,456	47,117	126,870
2002	23,623	24,687	25,241	73,551
2004	9,637	20,731	51,851	82,219
2006	19,480	22,033	43,348	84,861
2010	21,341	11,207	23,277	55,826
2012	13,514	14,804	30,592	58,911
2014	18,088	8,488	47,032	73,608
2016	19,775	19,496	45,138	84,409
2018	11,425	20,596	49,251	81,272

	Biomass proportions			
Year	Western	Central	Eastern	All
1991	0.419	0.221	0.360	1.000
1994	0.155	0.336	0.509	1.000
1997	0.197	0.415	0.388	1.000
2000	0.341	0.287	0.371	1.000
2002	0.321	0.336	0.343	1.000
2004	0.117	0.252	0.631	1.000
2006	0.230	0.260	0.511	1.000
2010	0.382	0.201	0.417	1.000
2012	0.229	0.251	0.519	1.000
2014	0.246	0.115	0.639	1.000
2016	0.234	0.231	0.535	1.000
2018	0.141	0.253	0.606	1.000

	Biomass coefficient of variation			
Year	Western	Central	Eastern	All
1991	0.092	0.112	0.370	0.141
1994	0.292	0.390	0.301	0.206
1997	0.261	0.208	0.230	0.134
2000	0.429	0.270	0.222	0.185
2002	0.245	0.264	0.329	0.164
2004	0.169	0.207	0.304	0.200
2006	0.233	0.188	0.545	0.288
2010	0.409	0.257	0.223	0.189
2012	0.264	0.203	0.241	0.148
2014	0.236	0.276	0.275	0.187
2016	0.375	0.496	0.212	0.184
2018	0.175	0.217	0.242	0.159

Table 2A.6—Comparison of biomass (t) estimated by Model 13.4 in the 2016-2017 and 2018-2019 assessments, with lower and upper 95% confidence bounds. Color scale: red = low, green = high.

	2016-2017 assessments			2018 assessment		
Year	Mean	L95%CI	U95%CI	Mean	L95%CI	U95%CI
1991	171,063	131,250	222,952	169,637	130,170	221,069
1992	158,448	111,091	225,993	157,122	111,801	220,817
1993	146,763	101,715	211,762	145,531	102,563	206,500
1994	135,940	99,846	185,083	134,795	99,856	181,959
1995	115,740	81,146	165,082	115,523	82,458	161,848
1996	98,541	70,100	138,522	99,006	71,632	136,841
1997	83,898	65,034	108,235	84,851	65,996	109,092
1998	89,858	64,296	125,581	90,024	65,500	123,730
1999	96,241	68,098	136,015	95,513	68,835	132,530
2000	103,077	76,655	138,607	101,336	76,156	134,843
2001	91,613	66,687	125,855	90,981	67,215	123,150
2002	81,424	63,142	104,999	81,684	63,728	104,699
2003	80,916	58,753	111,438	80,983	59,665	109,918
2004	80,411	60,488	106,895	80,289	60,846	105,944
2005	78,602	55,126	112,074	78,401	55,873	110,013
2006	76,833	54,117	109,084	76,558	54,637	107,274
2007	72,422	48,243	108,718	72,371	49,236	106,376
2008	68,263	45,047	103,446	68,412	46,179	101,350
2009	64,344	43,905	94,297	64,670	44,962	93,018
2010	60,650	45,318	81,169	61,133	45,966	81,304
2011	61,233	44,463	84,327	61,661	45,384	83,775
2012	61,822	48,618	78,611	62,193	49,091	78,792
2013	66,577	48,817	90,799	66,775	49,723	89,675
2014	71,699	54,757	93,882	71,694	55,354	92,859
2015	75,524	54,100	105,432	75,519	55,680	102,427
2016	79,553	58,520	108,145	79,548	61,159	103,467
2017				80,120	58,878	109,026
2018				80,696	61,744	105,465

Table 2A.7a (page 1 of 2)— Incidental catch (t) of FMP species taken in the AI trawl fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all FMP AI fisheries, 1991-2019 (2019 data current through October 27). Color shading: red = row minimum, green = row maximum (minima and maxima computed across both pages of the table).

Species group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Alaska Plaice												conf		conf	conf
Arrowtooth Flounder	0.00	0.08	0.08	0.05	0.01	0.06	0.05	0.14	0.14	0.15	0.13	0.27	0.30	0.29	0.26
Atka Mackerel	0.01	0.23	0.18	0.02	0.01	0.03	0.01	0.07	0.09	0.06	0.07	0.01	0.06	0.04	0.07
Flathead Sole					0.45	0.42	0.68	0.88	0.95	0.91	0.73	0.96	0.82	0.91	0.73
Flounder	conf	0.61	0.46	0.37											
Greenland Turbot	0.00	0.00	0.00	0.01	conf	conf	conf	0.17	0.01	0.03	0.02	0.02	0.04	0.04	0.04
Kamchatka Flounder															
Northern Rockfish												0.03	0.04	0.03	0.06
Octopus															
Other	0.07	0.15	0.09	0.06	0.05	0.07	0.10	0.13	0.14	0.12	0.05	0.17			
Other Flatfish						0.01	0.05	0.81	0.62	0.71	0.27	0.63	0.47	0.28	0.45
Other Rockfish	0.00	0.08	0.04	0.04	0.04	0.05	0.42	0.20	0.07	0.07	0.03	0.06	0.06	0.06	0.07
Other Species													0.25	0.18	0.14
Pacific Cod	0.04	0.28	0.23	0.31	0.04	0.11	0.27	0.22	0.44	0.20	0.45	0.72	0.56	0.57	0.21
Pacific Ocean Perch	0.01	0.08	0.07	0.04	0.01	0.02	0.03	0.16	0.03	0.11	0.05	0.03	0.07	0.05	0.07
Pollock	0.00	0.02	0.03	0.07	0.01	0.01	0.12	0.75	0.82	0.80	0.55	0.89	0.58	0.44	0.82
Rock Sole	0.03	0.73	0.56	0.58	0.56	0.52	0.76	0.89	0.94	0.96	0.86	0.94	0.88	0.85	0.86
Rougheye Rockfish														0.00	0.11
Sablefish		conf	conf	conf		conf	conf	0.19	conf	conf	conf	0.02	0.06	0.01	0.01
Sculpin															
Shark															
Sharpchin/Northern Rockfish		0.14	0.05	0.03	0.01	0.03	0.05	0.05	0.04	0.06	0.03				
Shortraker Rockfish														0.00	conf
Shortraker/Rougheye Rockfish		0.01	0.02	0.00	conf	0.01	0.01	0.01	0.01	0.00	0.02	0.00	0.06		
Short/Rough/Sharp/North	0.09	conf													
Skate															
Squid	conf	0.01	0.02	0.00	conf	conf	0.02	0.05	0.02	0.05	0.16	0.05	0.10	0.11	0.07
Yellowfin Sole				conf		conf		conf	conf	conf	conf	conf	0.71	1.00	conf

Table 2A.7a (page 2 of 2)—Incidental catch (t) of FMP species taken in the AI trawl fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all FMP AI fisheries, 1991-2019 (2019 data current through October 27). Color shading: red = row minimum, green = row maximum (minima and maxima computed across both pages of the table).

Species group	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Alaska Plaice	conf	0.22	1.00	conf	conf		conf	conf	conf		conf			conf
Arrowtooth Flounder	0.19	0.27	0.09	0.05	0.03	0.06	0.11	0.06	0.03	conf	0.07	0.11	0.06	0.17
Atka Mackerel	0.14	0.02	0.01	0.01	0.00	0.00	0.00	conf	conf	conf	conf	conf	0.00	conf
Flathead Sole	0.84	0.77	0.70	0.52	0.66	0.52	0.85	0.78	0.53	conf	0.84	0.53	0.19	0.79
Flounder														
Greenland Turbot	conf	0.09	0.00	0.00	conf		conf	conf						
Kamchatka Flounder						0.02	0.02	0.00	conf	conf	0.00	0.01	0.01	conf
Northern Rockfish	0.04	0.03	0.03	0.03	0.02	0.02	0.01	0.06	0.15	conf	0.12	0.02	0.02	0.04
Octopus						conf	0.17	conf	conf	conf	conf	conf	conf	conf
Other														
Other Flatfish	0.51	0.39	0.81	0.07	0.09	0.01	0.22	0.08	0.25	conf	0.08	conf	0.19	0.23
Other Rockfish	0.03	0.04	0.07	0.04	0.03	0.01	0.03	0.02	0.01	conf	0.02	conf	0.01	0.04
Other Species	0.15	0.19	0.07	0.08	0.04									
Pacific Cod	0.32	0.64	0.15	0.16	0.16	0.01	0.11	0.11	0.14	conf	0.29	0.09	0.22	0.13
Pacific Ocean Perch	0.04	0.03	0.09	0.01	0.01	0.00	0.01	0.00	0.00	conf	0.02	0.00	0.00	0.00
Pollock	0.89	0.58	0.47	0.06	0.02	0.01	0.65	0.16	0.04	conf	0.12	0.33	0.01	0.09
Rock Sole	0.85	0.75	0.91	0.84	0.86	0.75	0.88	0.82	0.79	conf	0.79	0.42	0.59	0.81
Rougheye Rockfish	0.02	0.01	0.00	conf	0.01	0.04	conf	conf				conf	conf	
Sablefish	0.03	0.02		conf			conf		conf			conf		conf
Sculpin						0.05	0.05	0.04	0.02	conf	0.05	conf	0.01	0.00
Shark						conf			conf	conf	conf			conf
Sharpchin/Northern Rockfish														
Shortraker Rockfish	0.00	0.00	conf		conf		conf	conf			conf	conf		
Shortraker/Rougheye Rockfish														
Short/Rough/Sharp/North														
Skate						0.01	0.03	0.02	0.01	conf	0.02	0.01	0.01	conf
Squid	0.07	0.02	0.00	0.00	0.00	conf	0.00	0.00	conf	conf	conf	conf		
Yellowfin Sole	0.79	0.05	0.41	conf	conf	conf	conf	conf	conf				conf	conf

Table 2A.7b (page 1 of 2)— Incidental catch (t) of FMP species taken in the AI fixed gear fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all FMP AI fisheries, 1991-2019 (2019 data current through October 27). Color shading: red = row minimum, green = row maximum (minima and maxima computed across both pages of the table).

Species group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Arrowtooth Flounder	0.01	0.14	0.05	0.03	0.02	0.02	0.05	0.12	0.09	0.24	0.23	0.04	0.01	0.03	0.08
Atka Mackerel	conf	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.05	0.03	0.01	0.00	0.00	0.01
Flathead Sole					0.03	0.11	0.05	0.10	0.01	0.06	0.17	0.01	0.00	0.01	0.01
Flounder	conf	0.08	0.07	0.02											
Greenland Turbot	0.09	0.05	0.03	0.01	0.00	0.02	0.03	0.05	0.15	0.04	0.04	0.02	0.00	0.02	conf
Kamchatka Flounder															
Northern Rockfish												0.01	0.00	0.01	0.01
Octopus															
Other	0.17	0.64	0.55	0.30	0.30	0.28	0.44	0.58	0.55	0.65	0.75	0.25			
Other Flatfish					conf	0.01	0.30	0.06	0.09	0.20	0.48	0.02		0.38	conf
Other Rockfish	0.07	0.15	0.17	0.37	0.04	0.16	0.21	0.30	0.15	0.27	0.24	0.11	0.04	0.32	0.12
Other Species													0.11	0.28	0.36
Pacific Cod	0.16	0.20	0.37	0.06	0.11	0.16	0.30	0.74	0.38	0.67	0.52	0.11	0.09	0.18	0.08
Pacific Ocean Perch	conf	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Pollock	0.00	0.00	0.02	0.00	0.01	0.01	0.03	0.05	0.01	0.02	0.06	0.00	0.00	0.01	0.00
Rock Sole	0.01	0.02	0.02	0.03	0.02	0.05	0.02	0.03	0.00	0.01	0.02	0.00	0.00	0.00	0.01
Rougheye Rockfish														0.26	0.27
Sablefish	0.30	0.19	0.26	0.03	0.02	0.34	0.21	0.17	0.04	0.13	0.32	0.06	0.08	0.00	conf
Sculpin															
Shark															
Sharpchin/Northern Rockfish		0.03	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.02	0.02				
Shortraker Rockfish														0.06	0.22
Shortraker/Rougheye Rockfish		0.62	0.34	0.19	0.06	0.23	0.19	0.77	0.49	0.54	0.49	0.18	0.14		
Short/Rough/Sharp/North	0.02	conf													
Skate															
Squid		conf				conf	conf	conf	conf		conf			conf	
Yellowfin Sole		conf		conf	conf	conf	conf	conf	conf	conf	conf				

Table 2A.7b (page 2 of 2)— Incidental catch (t) of FMP species taken in the AI fixed gear fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all FMP AI fisheries, 1991-2019 (2019 data current through October 27). Color shading: red = row minimum, green = row maximum (minima and maxima computed across both pages of the table).

Species group	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Arrowtooth Flounder	0.05	0.06	0.14	0.05	0.04	0.02	0.04	0.00	conf	0.06	conf	0.12	0.24	0.13
Atka Mackerel	0.01	0.01	0.04	0.03	0.01	conf	0.01	0.03	conf	0.02	conf	0.06	0.04	0.02
Flathead Sole	0.03	0.12	0.21	0.23	0.16	conf	0.12	conf	conf	conf	conf	0.18	0.37	0.02
Flounder														
Greenland Turbot	0.01	0.02	0.01	0.00	0.02	0.00	0.03	conf	conf	conf		conf	conf	conf
Kamchatka Flounder						conf	0.01	0.01	conf	0.01	conf	0.04	0.12	0.07
Northern Rockfish	0.00	0.01	0.03	0.04	0.06	conf	0.02	0.18	conf	0.07	conf	0.08	0.04	0.03
Octopus						0.79	0.50	0.89	conf	0.73	conf	0.66	0.78	0.84
Other														
Other Flatfish	0.01	0.01	0.04	0.52	0.15	conf	conf	conf	conf	conf		conf	conf	0.01
Other Rockfish	0.09	0.17	0.33	0.46	0.52	0.08	0.12	0.06	conf	0.28	conf	0.17	0.06	0.01
Other Species	0.28	0.26	0.30	0.41	0.51									
Pacific Cod	0.37	0.24	0.56	0.56	0.76	0.27	0.48	0.11	conf	0.41	conf	0.28	0.54	0.17
Pacific Ocean Perch	0.00	0.00	0.01	0.00	0.00	conf	0.00	conf	conf	0.00	conf	0.00	0.00	0.00
Pollock	0.01	0.00	0.01	0.01	0.05	0.02	0.01	0.00	conf	0.02	conf	0.02	0.00	0.00
Rock Sole	0.01	0.01	0.01	0.01	0.01	conf	0.01	0.01	conf	0.02	conf	0.01	0.01	0.00
Rougheye Rockfish	0.08	0.28	0.73	0.35	0.41	conf	0.52	conf	conf	0.84	conf	0.74	0.43	0.16
Sablefish	0.15	0.01	0.10	0.12	0.10	0.00	0.33	0.04	conf	conf		conf	conf	conf
Sculpin						0.17	0.39	0.43	conf	0.40	conf	0.32	0.32	0.31
Shark						0.02	0.12	conf	conf	0.24	conf	0.06	0.03	0.01
Sharpchin/Northern Rockfish														
Shortraker Rockfish	0.08	0.06	0.18	0.09	0.59	0.02	0.10	0.18	conf	0.18	conf	0.18	0.12	0.71
Shortraker/Rougheye Rockfish														
Short/Rough/Sharp/North														
Skate						0.09	0.36	0.17	conf	0.24	conf	0.30	0.22	0.19
Squid														
Yellowfin Sole	conf	conf	conf	conf				conf	conf				conf	0.94

Table 2A.8— Incidental catch (t) of selected members of the former "Other Species" complex taken in the AI fisheries for Pacific cod (all gears), expressed as a proportion of the incidental catch of that species taken in all FMP AI fisheries, 1991-2019 (2019 data current through October 27). Color shading: red = row minimum, green = row maximum (minima and maxima computed across both panels of the table).

Species	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
octopus, North Pacific									1.00	conf	conf	conf	0.73	0.72	0.96
Pacific sleeper shark										conf		conf	0.00	0.30	conf
shark, other														conf	
shark, salmon										conf					
shark, spiny dogfish													0.71	0.96	1.00
skate, Alaskan															
skate, big														1.00	conf
skate, longnose														0.56	conf
skate, other									0.99	conf	conf	0.34	0.28	0.49	0.59
squid, majestic	conf	0.01	0.02	conf	conf	conf	0.02	0.05	0.02	0.05	0.16	0.05	0.10	0.11	0.07

Species	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
octopus, North Pacific	0.94	0.77	0.89	0.97	0.97	0.93	0.67	0.89	0.30	0.75	conf	0.70	0.78	0.86
Pacific sleeper shark	conf	conf	conf	conf	0.08				conf	conf		conf		
shark, other														
shark, salmon				conf		conf				conf	conf			
shark, spiny dogfish	0.75	0.87	0.55	0.84	0.95	0.94	0.66	conf	conf	0.85	conf	0.14	0.78	0.99
skate, Alaskan					0.68									
skate, big	0.26	conf	conf	0.01	0.99									
skate, longnose	conf		conf	1.00	conf									
skate, other	0.42	0.54	0.34	0.62	0.60	0.10	0.39	0.19	0.02	0.25	0.27	0.31	0.23	0.20
squid, majestic	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	conf	0.00	conf		

Table 2A.9—Incidental catch (herring and halibut in t, salmon and crab in number of individuals) of prohibited species and discard mortality of halibut taken in the AI fisheries for Pacific cod (all gears), expressed as a proportion of the total for that species taken in all FMP AI fisheries, 1991-2019 (2019 data current through October 27). Color shading: red = row minimum, green = row maximum (minima and maxima computed across both panels of the respective table).

Incidental catch

Species	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Bairdi Tanner Crab	0.30	0.57	0.70	0.96	0.87	0.91	0.94	1.00	1.00	1.00	0.86	0.99	0.95	1.00	0.98
Blue King Crab													0.02		0.30
Chinook Salmon	0.01	0.02	0.15	0.03	0.23	0.17	0.46	0.71	0.90	1.00	0.46	0.68	0.80	0.73	0.80
Golden (Brown) King Crab													0.00	0.00	0.01
Halibut	0.52	0.81	0.42	0.44	0.46	0.57	0.53	0.82	0.57	0.48	0.74	0.28	0.16	0.35	0.07
Herring			conf							conf			0.01		1.00
Non-Chinook Salmon	conf	0.22			0.00	conf	0.07	0.03	conf	0.11	0.22	0.76	0.18	0.44	0.12
Opilio Tanner (Snow) Crab	0.40	0.30	0.51	0.02	0.01	0.19	0.25	0.52	0.30	0.26	conf	0.69	0.82	1.00	0.85
Other King Crab	0.08	0.24	0.04	0.05	0.04	0.10	0.00	0.06	0.23	0.07	0.13	0.03			
Red King Crab	0.21	0.08	0.33	0.14	0.11	0.05	conf	0.83	conf	0.43	0.94	0.97	0.84	0.97	0.84

Species	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Bairdi Tanner Crab	1.00	1.00	1.00	1.00	0.98	0.45	1.00	0.98	0.98	0.00	0.00	0.97	0.99	1.00
Blue King Crab	1.00	1.00	0.78	0.92	1.00	1.00	1.00	1.00		0.00	0.00	0.99	0.98	0.98
Chinook Salmon	0.87	0.72	0.83	0.82	0.76	0.55	0.65	0.94	0.62	0.44	0.57	0.21	0.06	0.06
Golden (Brown) King Crab	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.24	0.06	0.09
Halibut	0.34	0.67	0.36	0.60	0.47	0.36	0.34	0.16	0.18	0.41	0.27	0.44	0.44	0.61
Herring	0.05	0.19	0.25	0.07	0.00		0.00	1.00	1.00			0.00	0.00	0.40
Non-Chinook Salmon	0.34	0.56	0.21	0.17	0.02	0.36	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.02
Opilio Tanner (Snow) Crab	0.99	1.00	1.00	1.00	1.00	0.98	0.99	0.91	0.81	0.00	0.00	0.99	0.98	0.98
Other King Crab														
Red King Crab	0.06	0.84	0.77	0.34	0.22	0.32	0.20	0.91	0.16	0.00	0.00	0.61	0.97	0.72

Discard mortality

Species	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Halibut				0.20	0.37	0.42	0.44	0.72	0.38	0.29	0.59	0.26	0.36	0.46	0.62

Species	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Halibut	0.46	0.56	0.44	0.37	0.19	0.12	0.15	0.09	0.11	0.14	0.11	0.12	0.09	0.23

Table 2A.10a (page 1 of 2)—Incidental catch (t) of non-target species groups—other than birds—taken in the AI trawl fisheries for Pacific cod, expressed as a proportion of the incidental catch of that species group taken in all FMP AI fisheries, 2003-2019 (2019 data are current through October 27). Color shading: red = row minimum, green = row maximum.

Species group	2003	2004	2005	2006	2007	2008	2009	2010	2011
Benthic urochordata	0.05	0.16	0.35	0.12	0.05	conf	conf	conf	0.00
Bivalves	0.99	0.91	0.78	0.99	0.94	0.93	0.59	0.09	0.32
Brittle star Unid.	0.00	0.05	conf	0.19	0.64	0.00	0.00	0.00	conf
Capelin	0.00			0.00	conf	conf	0.00		
Corals Bryozoans - Corals Bryozoans Unid.	0.40	0.33	0.24	0.31	0.41	0.26	0.14	0.04	0.00
Corals Bryozoans - Red Tree Coral	0.00	0.01	0.49	0.00	0.91	0.00	0.00	0.00	0.00
Dark Rockfish						conf	0.00		
Deep sea smelts (bathylagidae)									
Eelpouts	0.08	0.51	conf	0.01	0.06	0.00	0.01	0.00	0.00
Eulachon			conf	0.01	conf	conf	0.00		
Giant Grenadier	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Greenlings	0.65	0.05	conf	0.05	0.13	0.10	0.01	conf	conf
Grenadier - Pacific Grenadier		0.00		0.00	0.00		0.00	0.00	0.00
Grenadier - Ratail Grenadier Unid.	0.00	conf	conf	0.00	0.00	0.00	0.00		
Grenadier - Rattail Grenadier Unid.								0.00	0.00
Gunnels			0.00			0.00			
Hermit crab Unid.	0.80	0.98	0.09	0.63	0.67	0.11	0.21	0.03	conf
Invertebrate Unid.	0.09	0.00	0.02	0.62	0.15	0.04	0.01	conf	0.01
Lanternfishes (myctophidae)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Sculpins	0.37	0.22	0.17	0.25	0.24				
Large Sculpins - Bigmouth Sculpin						0.08	0.10		
Large Sculpins - Brown Irish Lord									
Large Sculpins - Great Sculpin						0.61	0.68		
Large Sculpins - Hemilepidotus Unid.						0.00	0.00		
Large Sculpins - Myoxocephalus Unid.						0.09	0.00		
Large Sculpins - Plain Sculpin						conf	0.00		
Large Sculpins - Red Irish Lord						0.00	0.00		
Large Sculpins - Warty Sculpin						conf	conf		
Large Sculpins - Yellow Irish Lord						0.14	0.09		
Misc crabs	0.73	0.55	0.51	0.46	0.10	0.17	0.07	0.01	0.01
Misc crustaceans	0.99	0.29	0.98	0.93	0.33	conf	conf	0.16	conf
Misc deep fish	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Misc fish	0.23	0.10	0.12	0.06	0.09	0.05	0.07	0.06	0.04
Misc inverts (worms etc)	0.00	conf	conf	1.00	conf	0.00	0.00	0.00	0.00
Other osmerids	0.00		0.00	0.00	conf	0.00	0.00	0.00	0.00
Other Sculpins	0.31	0.01	0.04	0.07	0.05	0.01	0.03		
Pacific Sand lance	conf		conf		conf	conf		conf	
Pacific Sandfish									
Pandalid shrimp	0.06	0.01	0.03	0.00	0.06	0.00	conf	0.00	conf
Polychaete Unid.	0.00	conf	conf		0.15	conf	conf	0.00	0.00
Scypho jellies	0.17	0.48	conf	0.10	0.04	0.01	conf	0.20	conf
Sea anemone Unid.	0.61	0.31	0.22	0.17	0.10	0.05	0.01	conf	conf
Sea pens whips	0.34	0.91	0.04	0.07	0.11	conf	0.02	conf	conf
Sea star	0.49	0.26	0.14	0.24	0.14	0.04	0.02	0.01	0.02
Snails	0.52	0.49	0.15	0.26	0.25	0.05	0.06	0.03	conf
Sponge Unid.	0.30	0.13	0.28	0.21	0.08	0.02	0.05	0.01	0.02
Squid									
State-managed Rockfish								conf	0.00
Stichaeidae	0.00	0.00	conf	0.08	conf	0.00	conf	0.00	0.00
Surf smelt					0.00				
Urchins dollars cucumbers	0.40	0.42	0.15	0.16	0.32	0.03	0.16	0.01	0.00

Table 2A.10a (page 2 of 2)—Incidental catch (t) of non-target species groups—other than birds—taken in the AI trawl fisheries for Pacific cod, expressed as a proportion of the incidental catch of that species group taken in all FMP AI fisheries, 2003-2019 (2019 data are current through October 27). Color shading: red = row minimum, green = row maximum.

Species group	2012	2013	2014	2015	2016	2017	2018	2019
Benthic urochordata	0.00	0.14	conf	conf	conf	0.00	0.00	0.00
Bivalves	0.26	0.04	conf	conf	conf	conf	0.00	0.02
Brittle star Unid.	0.00	0.00	conf	conf	0.00	conf	0.00	0.00
Capelin	conf	0.10	1.00					
Corals Bryozoans - Corals Bryozoans Unid.	0.00	0.02	conf	conf	0.05	conf	0.02	0.00
Corals Bryozoans - Red Tree Coral	0.00	0.00	0.00				0.00	
Dark Rockfish								
Deep sea smelts (bathylagidae)		0.00		0.00				0.00
Eelpouts	0.01	0.00	conf	conf	0.00	0.00	0.00	0.00
Eulachon	1.00							
Giant Grenadier	0.00	conf	0.00	0.00	0.00	0.00	0.00	0.00
Greenlings	0.22		conf	0.00	0.00	0.00	0.00	0.00
Grenadier - Pacific Grenadier								
Grenadier - Ratail Grenadier Unid.								
Grenadier - Rattail Grenadier Unid.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gunnels		0.00		0.00		0.00		
Hermit crab Unid.	0.42	0.11	conf	0.00	conf	0.00	0.00	0.00
Invertebrate Unid.	0.00	0.00	conf	0.00	conf	0.00	0.00	0.00
Lanternfishes (myctophidae)	0.00	0.00	0.00	conf	0.00	0.00	0.00	0.00
Large Sculpins								
Large Sculpins - Bigmouth Sculpin								
Large Sculpins - Brown Irish Lord								
Large Sculpins - Great Sculpin								
Large Sculpins - Hemilepidotus Unid.								
Large Sculpins - Myoxocephalus Unid.								
Large Sculpins - Plain Sculpin								
Large Sculpins - Red Irish Lord								
Large Sculpins - Warty Sculpin								
Large Sculpins - Yellow Irish Lord								
Misc crabs	0.01	0.01	conf	conf	conf	0.00	0.00	0.01
Misc crustaceans	0.00	0.00	conf	conf	0.00	0.00	0.00	0.00
Misc deep fish	0.00	0.00	0.00	0.00	0.00		0.00	0.00
Misc fish	0.02	0.03	0.03	conf	0.01	0.00	0.00	0.00
Misc inverts (worms etc)	conf	0.00	conf	0.00	0.00	0.00	0.00	0.00
Other osmerids	conf	1.00					0.00	
Other Sculpins								
Pacific Sand lance				conf			1.00	1.00
Pacific Sandfish			0.00				1.00	
Pandalid shrimp	0.00	0.00	conf	conf	conf	conf	0.00	conf
Polychaete Unid.	0.00	1.00	conf		0.00	0.00	0.00	0.00
Scypho jellies	0.06	0.17	conf	conf	0.05	0.00	0.49	0.09
Sea anemone Unid.	0.01	0.00	conf	conf	conf	conf	0.01	0.00
Sea pens whips	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
Sea star	0.02	0.03	0.02	conf	0.02	0.03	0.01	0.02
Snails	0.01	0.01	conf	conf	conf	conf	0.00	0.00
Sponge Unid.	0.01	0.00	0.00	conf	0.01	conf	0.00	0.00
Squid								0.00
State-managed Rockfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stichaeidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Surf smelt								
Urchins dollars cucumbers	0.01	0.01	0.01	conf	0.01	0.01	0.01	0.00

Table 2A.10b (page 1 of 2)—Incidental catch (t) of non-target species groups—other than birds—taken in the AI fixed gear fisheries for Pacific cod, expressed as a proportion of the incidental catch of that species group taken in all FMP AI fisheries, 2003-2019 (2019 data are current through October 27). Color shading: red = row minimum, green = row maximum.

Species group	2003	2004	2005	2006	2007	2008	2009	2010	2011
Benthic urochordata	0.09	conf	0.07	0.01	0.01	0.03	0.01	0.07	0.01
Bivalves	0.00	0.02	0.21	0.01	0.04	0.03	0.19	0.71	0.22
Brittle star Unid.	0.00	0.00	0.02	0.20	0.00	0.20	0.01	0.01	0.00
Capelin	0.00			0.00	0.00	0.00	0.00		
Corals Bryozoans - Corals Bryozoans Unid.	0.01	0.04	0.01	0.02	0.07	0.02	0.24	0.23	0.08
Corals Bryozoans - Red Tree Coral	0.72	conf	0.00	0.01	0.00	0.14	0.88	0.00	0.00
Dark Rockfish						0.64	0.53		
Deep sea smelts (bathylagidae)									
Eelpouts	0.01	conf	0.13	0.02	0.09	0.02	0.00	0.02	0.01
Eulachon			0.00	0.00	0.00	0.00	0.00		
Giant Grenadier	0.30	conf	0.00	0.08	0.02	0.01	0.00	0.06	0.01
Greenlings	0.08	0.15	0.03	0.83	0.11	0.54	0.38	0.49	0.72
Grenadier - Pacific Grenadier		conf		0.00	0.00		0.00	conf	0.00
Grenadier - Ratail Grenadier Unid.	0.02	0.01	0.00	0.03	0.21	0.01	0.01		
Grenadier - Rattail Grenadier Unid.								0.20	0.00
Gunnels		conf	0.01			0.00			
Hermit crab Unid.	0.01	0.00	0.02	0.05	0.14	0.74	0.64	0.41	0.10
Invertebrate Unid.	0.00	0.12	0.03	0.00	0.02	0.05	0.00	0.22	0.03
Lanternfishes (myctophidae)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Sculpins	0.14	0.18	0.22	0.19	0.21				
Large Sculpins - Bigmouth Sculpin						0.04	0.04		
Large Sculpins - Brown Irish Lord									
Large Sculpins - Great Sculpin						0.33	0.27		
Large Sculpins - Hemilepidotus Unid.						0.96	0.98		
Large Sculpins - Myoxocephalus Unid.						0.79	1.00		
Large Sculpins - Plain Sculpin						0.98	0.97		
Large Sculpins - Red Irish Lord						0.12	0.32		
Large Sculpins - Warty Sculpin						0.96	0.92		
Large Sculpins - Yellow Irish Lord						0.20	0.10		
Misc crabs	0.00	0.01	0.01	0.04	0.55	0.31	0.40	0.38	0.02
Misc crustaceans	0.00	conf	0.00	0.00	0.01	0.01	0.00	0.22	conf
Misc deep fish	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Misc fish	0.01	0.02	0.00	0.00	0.00	0.02	0.01	0.03	0.01
Misc inverts (worms etc)	0.00	conf	0.75	0.00	0.00	0.00	0.00	0.00	0.00
Other osmerids	0.00		0.07	0.00	0.00	0.00	0.00	0.00	0.00
Other Sculpins	0.08	0.40	0.04	0.24	0.12	0.10	0.24		
Pacific Sand lance	0.00		0.00			0.00		0.00	
Pacific Sandfish									
Pandalid shrimp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	conf	0.00
Polychaete Unid.	1.00	conf	0.50		0.00	0.00	0.00	conf	conf
Scypho jellies	0.01	conf	0.00	0.08	0.02	0.21	0.11	0.16	0.20
Sea anemone Unid.	0.24	0.22	0.72	0.61	0.28	0.26	0.46	0.39	0.07
Sea pens whips	0.46	conf	0.92	0.89	0.62	0.36	0.62	0.94	0.93
Sea star	0.10	0.46	0.35	0.33	0.43	0.57	0.50	0.63	0.09
Snails	0.01	0.03	0.11	0.35	0.23	0.57	0.68	0.33	0.45
Sponge Unid.	0.02	0.03	0.05	0.01	0.02	0.01	0.07	0.09	0.01
Squid									
State-managed Rockfish								0.61	0.13
Stichaeidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Surf smelt					0.00				
Urchins dollars cucumbers	0.02	0.10	0.02	0.12	0.10	0.08	0.03	0.10	0.01

Table 2A.10b (page 2 of 2)—Incidental catch (t) of non-target species groups—other than birds—taken in the AI fixed gear fisheries for Pacific cod, expressed as a proportion of the incidental catch of that species group taken in all FMP AI fisheries, 2003-2019 (2019 data are current through October 27). Color shading: red = row minimum, green = row maximum.

Species group	2012	2013	2014	2015	2016	2017	2018	2019
Benthic urochordata	0.03	conf	0.00	conf	conf	0.00	0.04	0.00
Bivalves	0.50	0.09	0.09	0.18	conf	0.03	0.20	0.02
Brittle star Unid.	0.00	0.04	0.00	conf	0.00	0.12	0.00	0.00
Capelin	0.00	0.00	0.00					
Corals Bryozoans - Corals Bryozoans Unid.	0.09	0.06	conf	0.06	conf	0.12	0.23	0.06
Corals Bryozoans - Red Tree Coral	0.00	0.00	0.00				0.00	
Dark Rockfish								
Deep sea smelts (bathylagidae)		0.00		0.00				0.00
Eelpouts	0.00	conf	0.00	conf	0.00	0.06	0.01	conf
Eulachon	0.00							
Giant Grenadier	0.01	conf	conf	conf	0.00	conf	0.00	0.00
Greenlings	0.24		0.62	1.00	conf	0.47	0.47	0.24
Grenadier - Pacific Grenadier								
Grenadier - Ratail Grenadier Unid.								
Grenadier - Rattail Grenadier Unid.	0.01	conf	0.00	0.00	0.00	0.00	0.00	0.00
Gunnels		0.00		0.00		0.00		
Hermit crab Unid.	0.12	0.27	0.10	conf	0.00	0.78	0.54	0.85
Invertebrate Unid.	0.00	0.00	conf	conf	conf	conf	0.00	0.00
Lanternfishes (myctophidae)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Sculpins								
Large Sculpins - Bigmouth Sculpin								
Large Sculpins - Brown Irish Lord								
Large Sculpins - Great Sculpin								
Large Sculpins - Hemilepidotus Unid.								
Large Sculpins - Myoxocephalus Unid.								
Large Sculpins - Plain Sculpin								
Large Sculpins - Red Irish Lord								
Large Sculpins - Warty Sculpin								
Large Sculpins - Yellow Irish Lord								
Misc crabs	0.09	0.57	0.19	conf	conf	0.59	0.61	0.31
Misc crustaceans	conf	0.00	conf	conf	0.00	0.00	conf	conf
Misc deep fish	0.00	0.00	0.00	0.00	0.00		0.00	0.00
Misc fish	0.02	0.02	0.01	0.00	conf	0.00	0.01	0.00
Misc inverts (worms etc)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other osmerids	0.00	0.00					0.00	
Other Sculpins								
Pacific Sand lance				0.00			0.00	0.00
Pacific Sandfish			1.00				0.00	
Pandalid shrimp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polychaete Unid.	conf	0.00	0.00		0.00	0.00	0.00	0.00
Scypho jellies	0.77	0.81	0.61	0.00	0.00	0.85	0.38	0.30
Sea anemone Unid.	0.13	0.03	0.01	0.03	conf	0.05	0.13	0.04
Sea pens whips	1.00	conf	0.00	0.33	conf	0.53	0.42	0.26
Sea star	0.31	0.19	0.21	0.13	conf	0.29	0.20	0.39
Snails	0.27	0.29	0.14	0.04	conf	0.66	0.51	0.65
Sponge Unid.	0.04	0.01	0.00	0.02	conf	0.03	0.05	0.01
Squid								0.00
State-managed Rockfish	0.09	0.21	0.01	0.18	0.00	0.15	0.51	conf
Stichaeidae	0.00	0.00	0.00	0.00	0.00	0.00	0.05	
Surf smelt								
Urchins dollars cucumbers	0.03	0.01	0.02	0.02	conf	0.05	0.03	0.03

Table 2A.10c— Incidental catch (t) of bird species groups taken in the AI fisheries for Pacific cod, expressed as a proportion of the incidental catch of that species group taken in all FMP AI fisheries, 2003-2019 (2019 data are current through October 27).

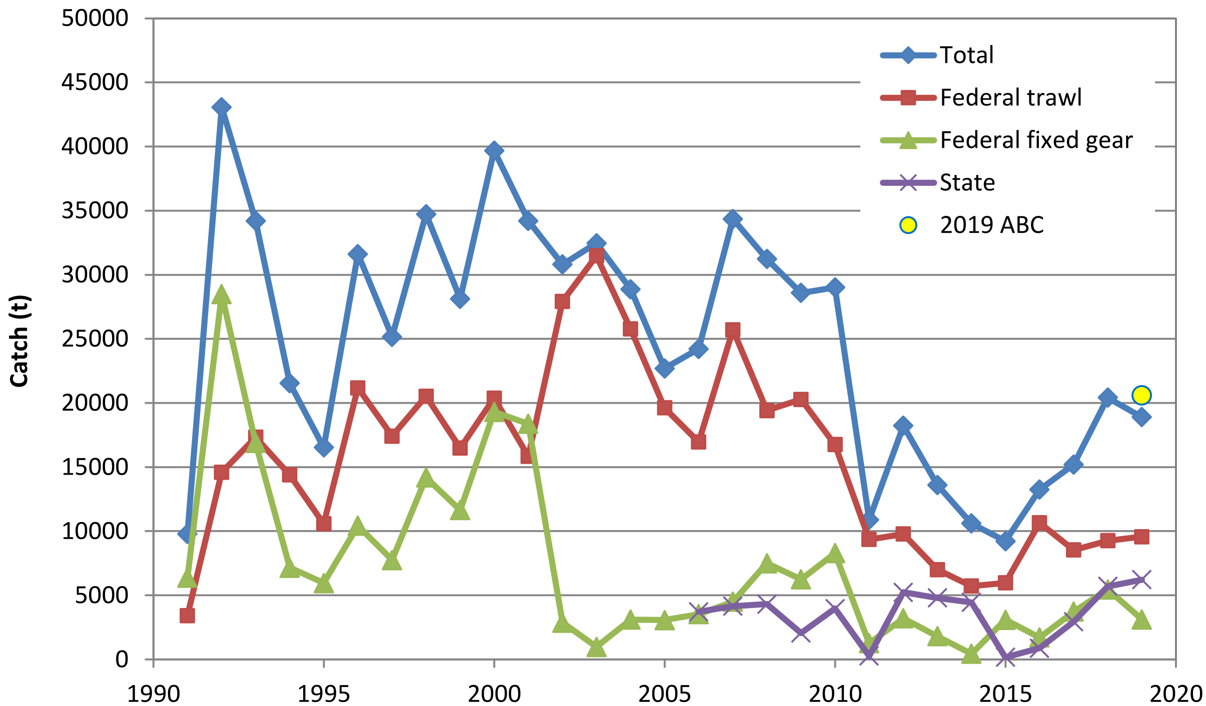
Trawl gear:

Species group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Birds - Auklets	conf									0.00		0.00			0.00	0.00	
Birds - Black-footed Albatross	0.00			0.00				0.00	0.00		0.00	0.00	0.00				
Birds - Cormorant																	
Birds - Gull	conf	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00		0.00	0.00
Birds - Kittiwake	0.00		0.00						0.00	0.00	0.00					0.00	
Birds - Laysan Albatross	0.35	0.00	conf	0.00	0.00	0.00	conf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Birds - Murre	0.00		0.00							0.00							
Birds - Northern Fulmar	0.00	0.04	0.63	0.10	0.00	0.49	conf	0.37	0.00	0.00	0.00	0.00	0.00	conf	0.00	0.00	0.00
Birds - Other	0.00																
Birds - Other Alcid																0.00	
Birds - Puffin								0.00									
Birds - Shearwaters	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Birds - Short-tailed Albatross								0.00	0.00								
Birds - Storm Petrels	0.00			0.00		0.00										0.00	
Birds - Unid.	0.00	0.00	0.00	0.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00				0.00	0.00	0.00
Birds - Unid. Albatross				1.00								0.00					

Longline gear:

Species group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Birds - Auklets	0.00									1.00		1.00			1.00	0.00	
Birds - Black-footed Albatross	1.00	conf		0.00				conf	0.00		0.00	0.00	0.00				
Birds - Cormorant																	
Birds - Gull	0.01	0.11	0.59	0.46	0.42	1.00	0.59	0.53	0.08	0.06	conf		conf	0.00		1.00	1.00
Birds - Kittiwake	1.00	conf	1.00						1.00	1.00	conf					1.00	
Birds - Laysan Albatross	0.04	conf	0.17	0.45	0.23	0.40	0.12	0.30	0.00	0.00	conf	0.00	conf	0.00	0.00	0.00	conf
Birds - Murre	1.00	conf	0.36							1.00							
Birds - Northern Fulmar	0.01	0.23	0.25	0.73	0.83	0.26	0.29	0.21	0.10	0.46	0.24	0.03	conf	0.00	0.27	0.02	0.05
Birds - Other	1.00																
Birds - Other Alcid		conf														1.00	
Birds - Puffin								conf									
Birds - Shearwaters	0.10	1.00	0.89	0.00	0.07	1.00	0.21	conf	0.26	0.26	conf	0.00	0.00	0.00	0.11	0.00	0.19
Birds - Short-tailed Albatross								conf	1.00								
Birds - Storm Petrels	1.00			1.00		0.00										0.00	
Birds - Unid.	1.00	1.00	1.00	0.00	0.27	1.00	0.10	0.62	1.00	1.00	conf				0.00	1.00	conf
Birds - Unid. Albatross				0.00								0.00					

FIGURES



Figue 2A.1. Catch history, with Federal catches are broken down by gear type.

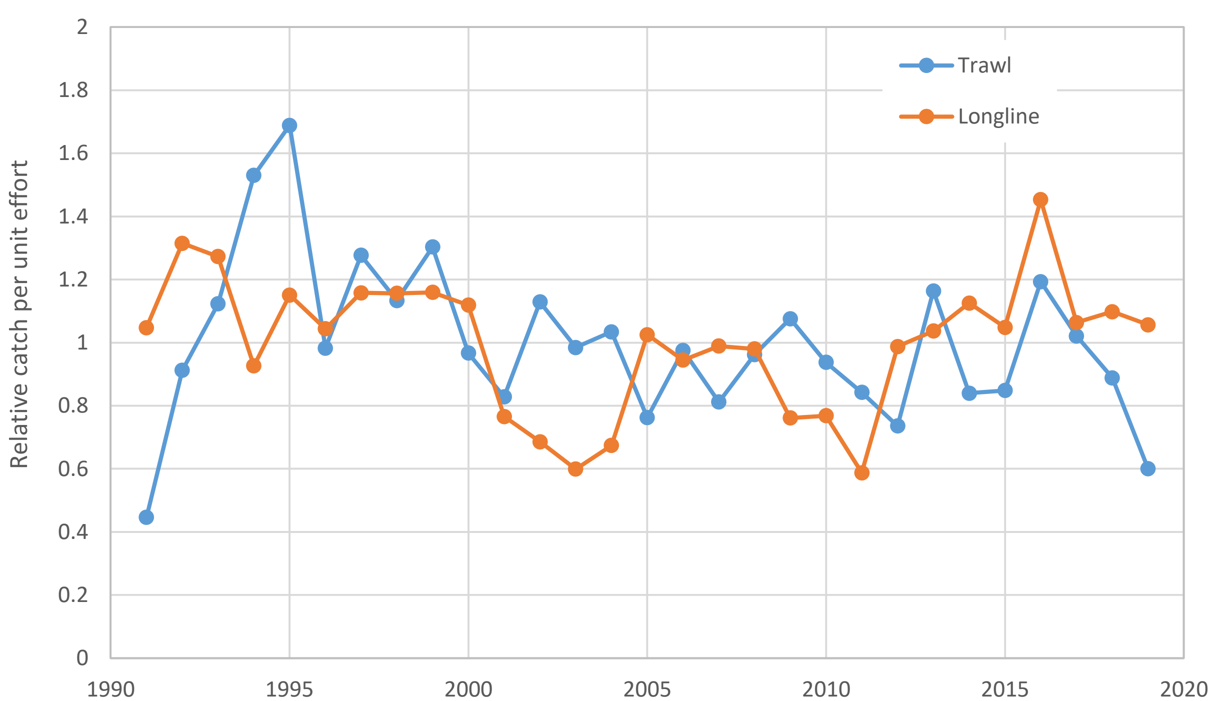


Figure 2A.2—Catch per unit effort for the trawl and longline fisheries, 1991-2018 (2018 data are partial).

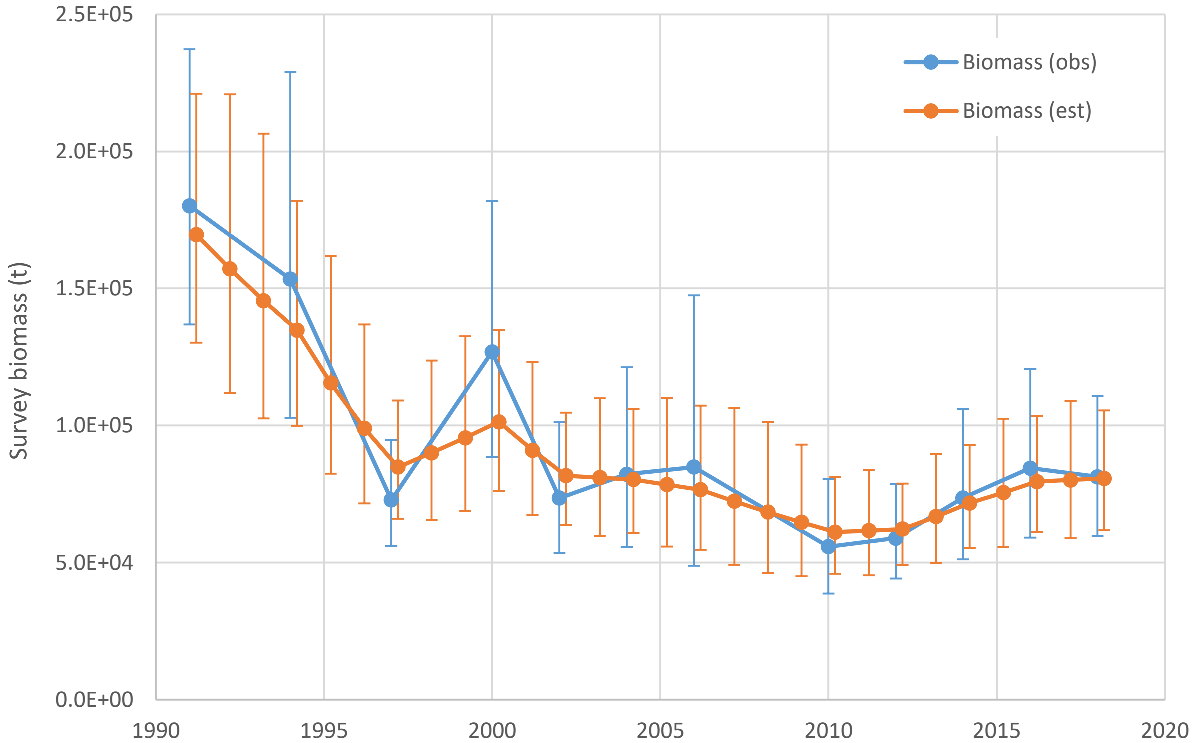


Figure 2A.3—Fit of Model 13.4 to survey biomass time series, with 95% confidence intervals for the observations and the estimates.

APPENDIX 2A.1--BSAI PACIFIC COD ECONOMIC PERFORMANCE REPORT FOR 2018

Ben Fissel

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Pacific cod is the second largest species in terms of catch in the Bering Sea & Aleutian Island (BSAI) region. Pacific cod accounted for 11% of the BSAI's FMP groundfish harvest and 94% of the total Pacific cod harvest in Alaska. Retained catch of Pacific cod decreased 13% to 218 thousand t in 2018 and was higher than the 2009-2013 average (Table 1). The products made from BSAI Pacific cod had a first-wholesale value of $461 million in 2018, which was up from $435 million in 2017 and above the 2009-2013 average of $303 million (Table 2). The higher revenue is the result of increased first-wholesale prices for fillet and headed-and-gutted (H&G) Pacific cod products.

Cod is an iconic fishery with a long history of production across much of the globe. Global catch was consistently over 2 million t through the 1980s, but began to taper off in the 1990s as cod stocks began to collapse in the northwest Atlantic Ocean. Over roughly the same period, the U.S. catch of Pacific cod (caught in Alaska) grew to approximately 250 thousand tons where it remained throughout the early to mid-2000s. European catch of Atlantic cod in the Barents Sea (conducted mostly by Russia, Norway, and Iceland) slowed and global catch hit a low in 2007 at 1.13 million t. U.S. Pacific cod's share of global catch was at a high at just over 20% in the early 2000s. Since 2007 global catch has grown to roughly 1.8 million t in recent years as catch in the Barents Sea has rebounded and U.S. catch has remained strong at over 300 thousand t since 2011 (Table 3). European Atlantic cod and U.S. Pacific cod remain the two major sources supplying the cod market over the past decade accounting for roughly 75% and 20%, respectively. Atlantic cod and Pacific cod are substitutes in the global market. Because of cod's long history global demand is present in a number of geographical regions, but Europe, China, Japan, and the U.S. are the primary markets for many Pacific cod products. The market for cod is also indirectly affected by activity in the pollock fisheries which experienced a similar period of decline in 2008-2010 before rebounding. Cod and pollock are commonly used to produce breaded fish portions. Alaska caught Pacific cod in the BSAI became certified by the Marine Stewardship Council (MSC) in 2010, a NGO based third-party sustainability certification, which some buyers seek.

The Pacific cod total allowable catch (TAC) is allocated to multiple sectors (fleets). CDQ entities receive 10% of the total BSAI quota. The largest sectoral allocation goes to the Freezer longline CPs which receive roughly 44% of the total BSAI cod quota (48.7% non-CDQ quota). While not an official catch share program, the Freezer longline CPs have formed a voluntary cooperative that allows them to form private contracts among members to distribute the sectoral allocation. The remaining large sectors are the trawl CPs, trawl CVs, the pot gear CVs and some smaller sideboard limits to cover the catch of Pacific cod while targeting other species. The CVs (collectively referred to as the inshore sector) make deliveries to shore-based processors, and catcher/processors process catch at-sea before going directly to the wholesale markets. Among the at-sea CPs, catch is distributed approximately three-quarters to the hook-and-line and one quarter to trawl. Prior to 2016 the inshore sector accounted for 25-30% of the total BSAI Pacific cod retained catch. Since 2016 this share has increased to 33-38%. Since 2016, approximately half of the retained catch is harvested by the trawl sector and half by the pot gear sector. The retained catch of the inshore sectors decreased 6% to 82.5 thousand t. The value of these deliveries (shoreside ex-vessel value) totaled $65.1 million in 2018, which was up 20% from 2017, as ex-vessel prices also increased 26% to $0.40 per pound. Changes in ex-vessel prices over time generally reflect changes in the corresponding wholesale prices. Catch from the fixed gear vessels (which includes hook-and-line and pot gear) typically receive a slightly higher price from processors because they incur less damage when caught. The fixed gear price premium has varied over time but recently has been about $0.03 per pound.

The first-wholesale value of Pacific cod products was up 6% to $461 million in 2018, and revenues in recent years have remained high as result of increased prices as catch and production saw marginal decreases in 2017 and 2018 (Table 2). The average price of Pacific cod products in 2018 increased 18% to $1.95. Head and gut (H&G) production is the focus of the BSAI processors but a significant amount of fillets are produced as well. H&G typically constitutes approximately 70%-80% of value and fillets approximately 10%-20% of value. Shoreside processors produce the majority of the fillets. Almost all of the at-sea sector's catch is processed into H&G. Other product types are not produced in significant quantities. At-sea head and gut prices tend to be about 20%-30% higher, in part because of the shorter period of time between catch and freezing, and in part because the at-sea sector is disproportionately caught by hook-and-line which yields a better price. Head & gut prices bottomed out at $1.05 per pound in 2013, a year in which Barents Sea cod catch increased roughly 240 thousand t (an increase that is approximately the size of Alaska's cod total catch) but rebounded to $1.37 in 2015. The H&G price was up 19% to $1.87 per pound in 2018. Fillet prices steady declined from over $3 in 2011 to $2.67 in 2015. Fillet prices have rebounded since then and increased 13% in 2018 to $4.19 from 2017. Changes in global catch and production account for much the trends in the cod markets. In particular, average first-wholesale prices peaked at over $1.80 per pound in 2007-2008 and subsequent declined precipitously in 2009 to $1.20 per pound as markets priced in consecutive years of approximately 100 thousand t increases in the Barents Sea cod catch in 2009-2011; coupled with reduced demand from the recession. Average first-wholesale prices since have fluctuated between approximately $1.20 and $1.55 per pound up to 2016. Since 2016 reductions in global supply have put upward pressure on prices resulting in significant year over year price increases in 2017 and 2018. Available information on 2019 prices indicate that prices may be leveling off as reflected in the highly exported H&G product type where the price through June of 2019 fell 2%.

U.S. exports of cod are roughly proportional to U.S. cod production. More than 90% of the exports are H&G, much of which goes to China for secondary processing and re-export (Table 3). China's rise as re-processor is fairly recent. Between 2001 and 2011 exports to China have increased nearly 10 fold and continued to increase up to 2016. Since 2017 China's share of exports has declined slightly going from 55% in 2016 to 47% in 2018. The cod industry has largely avoided U.S. tariffs that would have a significant negative impact on them in the U.S.-China trade war. However, Chinese tariffs on U.S. products could inhibit growth in that market. Japan and Europe (mostly Germany and the Netherlands) are also important export destinations. Japan and Europe accounted for 15% and 16% of the export volume respectively. Approximately 35% of Alaska's cod production is estimated to remain in the U.S.. Because U.S. cod production is approximately 20% of global production and the BSAI is approximately 90% of U.S. production, the BSAI Pacific cod is a significant component of the broader global cod market. Strong demand and tight supply in 2017-2018 from the U.S. and globally have contributed to increasing prices. The Barents Sea quota was reduced by 13% 2018 and the global cod supply will remain constrained. Groundfish forum estimates for 2019 indicate global catches of Atlantic and Pacific cod will be reduced by approximately 100 thousand t. Markets may have incorporated these supply adjustments as export prices in 2019 have leveled off, decreasing slightly by 2% (Table 3). A portion of the Russian catch of Pacific cod became MSC certified in Oct. 2019 which could put further downward pressure on prices going forward.

Table 2A.1.1. Bering Sea & Aleutian Islands Pacific cod catch and ex-vessel data. Total and retained catch (thousand metric tons), number of vessel, catcher/processor (CP) hook-and-line (H&L) share of catch, CP trawl share of catch, Shoreside retained catch (thousand metric tons), shoreside number of vessel, shoreside pot gear share of catch, shoreside trawl share of catch, shoreside ex-vessel value and price (million US$), and fixed gear to trawl price premium (US$ per pound); 2009-2013 average and 2014-2018.

	Avg 09-13	2014	2015	2016	2017	2018
Total catch K mt	213.82	249.3	242.1	260.9	253.1	220.3
Retained catch K mt	209.8	244.5	239.0	257.7	250.1	218.0
Vessels #	171.2	156	149	162	170	190
CP H&L share of BSAI catch	53%	50%	54%	49%	50%	46%
CP trawl share of BSAI catch	16%	14%	15%	14%	13%	14%
Shoreside retained catch K mt	60.1	79.1	68.4	86.0	88.0	82.5
Shoreside catcher vessels #	117.2	109	100	110	125	141
CV pot gear share of BSAI catch	10%	14%	13%	15%	17%	19%
CV trawl share of BSAI catch	18%	17%	16%	18%	18%	18%
Shoreside ex-vessel value M $	$33.1	$44.8	$34.1	$44.6	$54.1	$65.1
Shoreside ex-vessel price lb $	$0.250	$0.274	$0.248	$0.264	$0.316	$0.399
Shoreside fixed gear ex-vessel price premium	$0.05	$0.03	$0.03	$0.03	$0.04	$0.03

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 2A.1.2. Bering Sea & Aleutian Islands Pacific cod first-wholesale market data. First-wholesale production (thousand metric tons), value (million US$), price (US$ per pound); fillet and head and gut volume (thousand metric tons), value share, and price (US$ per pound); At-sea share of value and at-sea shoreside price difference (US$ per pound); 2009-2013 average and 2014-2018.

		Avg 09-13	2014	2015	2016	2017	2018
All products	**volume K mt**	103.11	123.51	120.47	126.40	119.54	107.36
All products	**Value M $**	$ 302.5	$ 352.5	$ 365.0	$ 388.3	$ 434.7	$ 461.0
All products	**price lb $**	$ 1.33	$ 1.29	$ 1.37	$ 1.39	$ 1.65	$ 1.95
Fillets	**volume K mt**	6.49	8.42	6.28	10.03	10.01	10.36
Fillets	**value share**	14%	14%	10%	19%	19%	21%
Fillets	**price lb $**	$ 2.88	$ 2.68	$ 2.67	$ 3.37	$ 3.70	$ 4.19
Head & Gut	**volume K mt**	84.48	100.56	100.82	98.68	92.38	78.99
Head & Gut	**value share**	79%	79%	83%	72%	74%	70%
Head & Gut	**price lb $**	$ 1.29	$ 1.25	$ 1.36	$ 1.29	$ 1.57	$ 1.87
At-sea	**value share**	74%	69%	76%	69%	70%	63%
At-sea	**price premium ($/lb)**	-$0.08	-$0.02	$0.07	-$0.32	-$0.33	-$0.53

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 2A.1.3. Cod U.S. trade and global market data. Global production (thousand metric tons), U.S. share of global production, and Europe's share of global production; U.S. export volume (thousand metric tons), value (million US$), and price (US$ per pound); U.S. cod consumption (estimated), and share of domestic production remaining in the U.S. (estimated); and the share of U.S. export volume and value for head and gut (H&G), fillets, China, Japan, and Germany and Netherlands; 2009-2013 average and 2014-2019.

		Avg 09-13	2014	2015	2016	2017	2018	2019 (thru June)
Global cod catch K mt		1,506	1,852	1,762	1,792	1,759	-	-
U.S. P. cod share of global catch		18.6%	17.6%	18.0%	17.9%	17.0%	-	-
Europe share of global catch		74.2%	75.9%	74.8%	74.8%	75.7%	-	-
Pacific cod share of U.S. catch		97.8%	99.3%	99.5%	99.5%	99.7%	-	-
U.S. cod consumption K mt (est.)		88	115	108	114	119	113	-
Share of U.S. cod not exported		27%	31%	26%	29%	32%	35%	-
Export volume K mt		98.3	107.3	113.2	105.3	92.8	73.2	39.4
Export value M US$		$309.9	$314.2	$335.0	$312.0	$295.5	$253.6	$133.6
Export price lb US$		$1.429	$1.328	$1.342	$1.344	$1.445	$1.570	$1.539
Frozen (H&G)	volume Share	74%	92%	91%	94%	94%	91%	90%
	value share	74%	91%	90%	92%	92%	90%	89%
Fillets	volume Share	10%	2%	3%	3%	4%	5%	6%
	value share	12%	4%	4%	4%	5%	6%	6%
China	volume Share	39%	54%	53%	55%	52%	47%	47%
	value share	37%	51%	51%	52%	50%	46%	45%
Japan	volume Share	17%	16%	13%	14%	16%	15%	7%
	value share	18%	16%	14%	15%	18%	17%	8%
Europe*	volume Share	30%	20%	19%	17%	17%	16%	20%
	value share	32%	22%	19%	18%	18%	18%	21%

Notes: Pacific cod in this table is for all U.S. Unless noted, `cod' in this table refers to Atlantic and Pacific cod. Russia, Norway, and Iceland account for the majority of Europe's cod catch which is largely focused in the Barents Sea.

*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

APPENDIX 2A.2--HISTORY OF PREVIOUS AI PACIFIC COD MODEL STRUCTURES DEVELOPED UNDER STOCK SYNTHESIS

For 2013 and beyond, the SSC's accepted model from the final assessment is shown in **bold red**.

Pre-2011

The AI Pacific cod stock was managed jointly with the EBS stock, with a single OFL and ABC. Prior to the 2004 assessment, results from the EBS model were inflated into BSAI-wide equivalents based on simple ratios of survey biomasses from the two regions.

Beginning with the 2004 assessment, the simple ratios were replaced by a random-walk Kalman filter.

2011

Preliminary assessment

A Tier 5 model based on the same Kalman filter approach that had been used to inflate EBS model results into BSAI-wide equivalents since 2004 was applied to the AI stock as a stand-alone model.

Final assessment

Because no new survey data had become available since the preliminary assessment, the Tier 5 Kalman filter model was not updated. The SSC did not accept the Tier 5 Kalman filter model, so the AI stock continued to be managed jointly with the EBS stock.

2012

Preliminary assessment

Two models were included:

- Model 1 was similar to the final 2011 EBS model except:
  - Only one season
  - Only one fishery
  - AI-specific weight-length parameters used
  - Length bins (1 cm each) extended out to 150 cm instead of 120 cm
  - Fishery selectivity forced asymptotic
  - Fishery selectivity constant over time
  - Survey samples age 1 fish at true age 1.5
  - Ageing bias not estimated (no age data available)
  - *Q* tuned to match the value from the archival tagging data relevant to the GOA/AI survey net
- Model 2 was identical to Model 1 except with time-varying *L1* and *Linf*
- Six other models considered in a factorial design in order to determine which growth parameters would be time-varying in Model 2, but only partial results presented

The SSC gave notice that it would not accept any model for this stock prior to the 2013 assessment.

Final assessment

Four models were included:

- Model 1 was identical to Model 1 from the preliminary assessment
- Model 2 was identical to Model 2 from the preliminary assessment
- Model 3 was identical to Model 1 except that input *N* values were multiplied by 1/3
- Model 4 was identical to Model 1 except:
    - Survey data from years prior to 1991 were omitted
    - Q was allowed to vary randomly around a base value
    - Survey selectivity was forced asymptotic
    - Fishery selectivity was allowed to be domed
    - Input N values for sizecomp data were estimated iteratively by setting the root-mean-squared-standardized-residual of the survey abundance time series equal to unity
    - All fishery selectivity parameters except *initial_selectivity* and the *ascending_width* survey selectivity parameters were allowed (initially) to vary randomly, with the input standard deviations estimated iteratively by matching the respective standard deviations of the estimated *dev*s
    - Input standard deviation for log-scale recruitment *dev*s was estimated internally (i.e., as a free parameter)

None of the models was accepted by the SSC, so the AI stock continued to be managed jointly with the EBS stock.

2013

Preliminary assessment

Three models were included:

- Model 1 was identical to Model 1 from the 2012 assessment except:
    - Fishery selectivity was not forced asymptotic
    - Selectivity was estimated as a random walk with respect to age instead of the double normal, with normal priors tuned so that the prior mean is consistent with logistic selectivity and the prior standard deviation is consistent with apparent departures from logistic selectivity
    - Potentially, length and age composition input sample sizes could be tuned so that the harmonic mean effective sample size is at least as large as the arithmetic mean input sample size (if it turned out that the initial average *N* of 300 already satisfied this criterion, no tuning was done)
    - Potentially, each selectivity parameter could be time-varying with annual additive *dev*s, where the sigma term is tuned to match the standard deviation of the estimated *dev*s (if this tuning resulted in a sigma that was essentially equal to zero, time variability was turned off)
- Model 2 was identical to Model 1 except that *Q* was estimated with an informative prior developed from a meta-analysis of other AI assessments
- Model 3 was identical to Model 1 except that both *M* and *Q* were estimated freely

Final assessment

Four models were included:

- Tier 3 Model 1 was identical to Model 1 from the preliminary assessment, except with *Q* fixed at 1.0
- Tier 3 Model 2 was identical to Tier 3 Model 1 except:
    - *Q* was estimated with the same prior as in Model 2 from the preliminary assessment
    - Survey selectivity was forced asymptotic

- Tier 5 Model 1 was the Kalman filter model that had been used since 2004 to estimate the expansion factor for converting results from the EBS model into BSAI equivalents
- **Tier 5 Model 2** was the random effects model recommended by the Survey Averaging Working Group

2014

Preliminary assessment

Three models were included:

- Model 1 was identical to Model 2 from the final 2013 assessment, except that survey selectivity was not forced to be asymptotic, each selectivity was allowed (potentially) to vary with time, a normal prior distribution for each selectivity parameter was tuned using the same method as Model 6 from the preliminary assessment 2014 EBS assessment, prior distributions and standard deviations for the annual selectivity deviations were estimated iteratively, and the 1976-1977 "recruitment offset" parameter was fixed at zero
- Model 2 was identical to Model 1, except that the recruitment offset was estimated freely
- Model 3 was identical to Model 2, except that survey selectivity first-differences were forced to equal zero after the age at which survey selectivity peaked in Model 2, and the lower bound on survey selectivity first-differences at all earlier ages was set at 0 (the combination of these two changes forced survey selectivity to increase monotonically until the age at which it peaked in Model 2, after which survey selectivity was constant at unity)

Final assessment

Three models were included:

- **Model 1** was identical to Tier 5 Model 2 from the final 2013 assessment
- Model 2 was identical to Model 1 from the preliminary assessment
- Model 3 was identical to Model 1 from the preliminary assessment, except that the prior distributions for survey selectivity parameters were tightened so that the resulting selectivity curve was less dome-shaped

2015

Preliminary assessment

New features or methods examined in the preliminary assessment included the following (these were based on experience with the preliminary assessment of the EBS Pacific cod stock):

1. The standard deviation of log-scale age 0 recruitment (σ_R) was estimated iteratively instead of being estimated internally.
2. Richards growth was assumed instead of von Bertalanffy growth (a special case of Richards).
3. 20 age groups were estimated in the initial numbers-at-age vector instead of 10.
4. Survey catchability was allowed to vary annually if the root-mean-squared-standardized residual exceeded unity (this resulted in time-varying Q for Model 5 but not for Model 3).
5. Selectivity at ages 8+ was constrained to equal selectivity at age 7 for the fishery, and selectivity at ages 9+ was constrained to equal selectivity at age 8 for the survey.
6. A superfluous selectivity parameter was fixed at the mean of the prior (in Models 3 and 4, the estimate of this parameter automatically went to the mean of the prior).

7. Composition data were given a weight of unity if the harmonic mean of the effective sample size was greater than the mean input sample size of 300; otherwise, composition data were weighted by tuning the mean input sample size to the harmonic mean of the effective sample size.
8. All iterative tunings were conducted simultaneously rather than sequentially.
9. The method of Thompson (in prep.) was used for iterative tuning of the sigma parameters for selectivity and recruitment.
10. Iterative tuning of the sigma parameter for time-varying catchability involved adjusting sigma until the root-mean-squared-standardized-residual for survey abundance equaled unity.

Four of the models spanned a 2×2 factorial design. The factors were:

- The new features or methods listed above (use or not use)
- Historic fishery time series data from 1977-1990 (use or not use)

Five models were included in all (there was no model numbered "1," per SSC request):

- Model 0 was identical to Model 1 from the final 2014 assessment (Tier 5 random effects)
- Model 2 used the new features/methods; did not use the historic fishery data
- Model 3 not use the new features/methods; did use the historic fishery data
- Model 4 did not use the new features/methods; did not use the historic fishery data
- Model 5 used the new features/methods; did not use the historic fishery data

Note that Model 4 was identical to Model 2 from the 2014 final assessment

Final assessment

Three models were included:

- **Model 13.4** (new name for the Tier 5 random effects model)
- Model 15.6 was also a random effects model, but with the IPHC longline survey CPUE added as a second time series
- Model 15.7 was the same as Model 3 from the preliminary assessment (now renamed Model 15.3), but with both fishery and survey selectivity held constant (with respect to age) above age 8, as opposed to being free at all ages (1-20) in Model 15.3

2016

Preliminary assessment

Six models were presented in the preliminary assessment. Model 13.4 was the standard Tier 5 "random effects" model, which has been the accepted model since 2013. The other five models (Models 16.1-16.5) wre all Tier 3 models, and are variants of Model 15.7, which was introduced in last year's final assessment as a modification of Model 15.3 from last year's preliminary assessment (where it was labeled "Model 3"). The distinguishing features of Models 16.1-16.5 were as follow:

- Model 16.1: Like AI Model 15.7, but simplified as follows:
    - Weight abundance indices more heavily than sizecomps.
    - Use the simplest selectivity form that gives a reasonable fit.
    - Do not allow survey selectivity to vary with time.
    - Do not allow survey catchability to vary with time.
    - Do not allow strange selectivity patterns.
    - Estimate trawl survey catchability internally with a fairly non-informative prior.
- Model 16.2: Like AI Model 15.7, but including the IPHC longline survey data and other features, specifically:

- Do now allow strange selectivity patterns.
- Estimate trawl survey catchability internally with a fairly non-informative prior.
- Estimate catchability of new surveys internally with non-restrictive priors.
- Include additional data sets to increase confidence in model results.
- Include IPHC longline survey, with "extra SD."

- Model 16.3: Like Model 3 above, but including the NMFS longline survey instead of the IPHC longline survey.
- Model 16.4: Like Models 3 and 4 above, but including both the IPHC and NMFS longline survey data.
- Model 16.5: Like AI Model 15.7, except:
    - Use the post-1994 AI time series (instead of the post-1986 time series).
    - Do not allow strange selectivity patterns.
    - Estimate trawl survey catchability internally with a fairly non-informative prior.

Final assessment

The Team and SSC felt that the authors' time was better spent on developing new models for the EBS stock than the AI stock, so **Model 13.4** was the only model presented in the final assessment.

2017

Preliminary assessment

The BSAI Team Pacific cod models subcommittee recommended suspending work on age-structured modeling of the AI stock, so no preliminary assessment was conducted.

Final assessment

As in 2016, Team and SSC felt that the authors' time was better spent on developing new models for the EBS stock than the AI stock, so **Model 13.4** was the only model presented in the final assessment.

2018

Preliminary assessment

The BSAI Team Pacific cod models subcommittee recommended suspending work on age-structured modeling of the AI stock, so no preliminary assessment was conducted.

Final assessment

As in 2016 and 2017, Team and SSC felt that the authors' time was better spent on developing new models for the EBS stock than the AI stock, so **Model 13.4** was the only model presented in the final assessment.

APPENDIX 2A.3--SUPPLEMENTAL CATCH DATA

NMFS Alaska Region has made substantial progress in developing a database documenting many of the removals of FMP species that have resulted from activities outside of fisheries prosecuted under the BSAI Groundfish FMP, including removals resulting from scientific research, subsistence fishing, personal use, recreational fishing, exempted fishing permit activities, and commercial fisheries other than those managed under the BSAI groundfish FMP. Estimates for AI Pacific cod from this dataset are shown in Table 2A.3.1.

Although many sources of removal are documented in Table 2A.3.1, the time series is highly incomplete for many of these. Cells shaded gray represent data contained in the NMFS database. Other entries represent extrapolations for years in which the respective activity was known or presumed to have taken place, where each extrapolated value consists of the time series average of the official data for the corresponding activity. In the case of surveys, years with missing values were identified from the literature or by contacting individuals knowledgeable about the survey (the NMFS database contains names of contact persons for most activities); in the case of fisheries, it was assumed that the activity occurred every year.

In the 2012 analysis of the combined BSAI Pacific cod stock (Attachment 2.4 of Thompson and Lauth 2012), the supplemental catch data were used to provide estimates of potential impacts of these data in the event that they were included in the catch time series used in the assessment model. The results of that analysis indicated that $F_{40\%}$ increased by about 0.01 and that the one-year-ahead catch corresponding to harvesting at $F_{40\%}$ decreased by about 4,000 t. Note that this is a separate issue from the effects of taking other removals "off the top" when specifying an ABC for the groundfish fishery; the former accounts for the impact on reference points, while the latter accounts for the fact that "other" removals will continue to occur.

The average of the total removals in Table 2A.3.1 for the last three complete years (2016-2018) is 55 t.

It should be emphasized that these calculations are provided purely for purposes of comparison and discussion, as NMFS and the Council continue to refine policy pertaining to treatment of removals from sources other than the directed groundfish fishery.

Reference

Thompson, G. G., and R. R. Lauth. 2012. Assessment of the Pacific cod stock in the Eastern Bering Sea and Aleutian Islands Area. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 245-544. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Table 2A.3.1—Total removals of Pacific cod (t) from activities not related to directed fishing. Cells shaded gray represent data contained in the NMFS database. Other entries represent extrapolations for years in which the respective activity was known or presumed to have taken place.

Activity	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
AFSC Annual Longline Survey			20	20	20	20	20	20	20	20	20	20	20	20
Aleutian Island Bottom Trawl Survey				15			15			15				
Aleutian Islands Cooperative Acoustic Survey														
Atka Tagging Survey														
Bait for Crab Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IPHC Annual Longline Survey														
Sport Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subsistence Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Activity	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
AFSC Annual Longline Survey	20	20	20	20		17		27		25		19		13
Aleutian Island Bottom Trawl Survey	15			15			15			15		15		15
Aleutian Islands Cooperative Acoustic Survey														
Atka Tagging Survey										100	100	100	100	100
Bait for Crab Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IPHC Annual Longline Survey								19	19	19	19	19	19	19
Sport Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subsistence Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Activity	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2918
AFSC Annual Longline Survey		25		13		16		18		19		20		24
Aleutian Island Bottom Trawl Survey		15				12		12		16		17		17
Aleutian Islands Cooperative Acoustic Survey				1										
Atka Tagging Survey		100	100				100	100		100	100			
Bait for Crab Fishery	0	0	0	0	0	0	0	0	0	1	0	0	1	0
IPHC Annual Longline Survey	19	19	19	19	19	9	23	9	13	15	21	15	28	41
Sport Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subsistence Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 2A.4: Preliminary age structured assessment model of the Pacific cod stock in the Aleutian Islands

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Executive summary

Harvest specifications for Aleutian Islands (AI) Pacific cod have been based on Tier 5 methodology since the AI and eastern Bering Sea (EBS) stocks were first managed separately in 2014. Several age-structured models of this stock have been explored in assessments from 2012-2016. This document presents an age structured model for the Aleutian Islands Pacific cod stock using complete data through 2019. A preliminary version of this document was presented to the BSAI Plan Team in September, 2019 and to the SSC in October, 2019.

Summary of changes in assessment inputs

The following changes have been made in the Aleutian Islands Pacific cod age structured assessment relative to the September 2019 preliminary report.

Changes in the data

1. Survey age data were included from the 2018 NMFS Aleutian Islands bottom-trawl survey.
2. The model contains data for and extends through 2019.
3. SSC and Plan Team comments were incorporated and discussed below.

Changes in the assessment methods

The September, 2019 preliminary model considered a new estimate for natural mortality, M, and a new method for calculating maturity at age. These parameterizations are discussed in this document. A value of M was selected in this model for consistency with previous Aleutian Islands assessments and the Bering Sea assessment.

1. The September preliminary model considered a higher value of M, 0.40, but the model presented here used M=0.34, which is consistent with the value of M used in the past several Aleutian Island assessments.
2. In the September model, the maturity ogive was based on maturity records from observers. This value was used in the current assessment, and a version of the model using maturity based on a study by Stark (2007) was presented.
3. In light of discussion with the Plan Team and SSC in September, four models are presented in this assessment, and described here.

- Model 19.0: Base model with M=0.34, maturity ogive derived from observer collections of maturity values from Aleutian Islands cod.
- Model 19.0a: Base model except M=0.40.
- Model 19.0b: Base model except Stark (2007) maturity ogive.
- Model 19.0c: Base model with no fishery length data likelihood.

Summary of results

The model projections for spawning biomass were based on annual catches of 19,191 t for 2019 and the ABC for 2020. The catch of Pacific cod in the Aleutian Islands as of October 22, 2019, was 18,999 t. Typically 99% of the annual catch occurs by this date, as estimated by catch statistics in 2014-2018. Therefore, the total catch for 2019 was extrapolated to 19,191 t.

The projected age 1+ total biomass for 2020 is 127,146 t, and is predicted to decrease to 119,180 t in 2021. The projected female spawning biomass for 2020 is 42,009 t, and is predicted to decline to 36,743 t in 2021. The model estimates for $B_{40\%}$ and $B_{35\%}$ are 41,332 t and 36,165 t; therefore the projection of the 2020 female spawning biomass of 42,009 t is above $B_{35\%}$=36,165 t, and is 101.64% of $B_{40\%}$.

The recommended 2020 ABC is 26,957 t based on an $F_{40\%}$ =0.605 harvest level. The 2020 overfishing level is 33,008 t based on a $F_{35\%}$ =0.787 harvest level. The OFL in 2021 is 25,419 t and the ABC is 20,781 t.

	As estimated or *specified* *last* year for:		As estimated or *recommended* *this* year for:	
Quantity	2019	2020	2020	2021
M (natural mortality rate)	0.34	0.34	0.34	0.34
Tier	5	5	3a	3b
Projected total (age 1+) biomass (t)	80,700	80,700	127,146 t	119,180 t
Projected female spawning biomass (t)	-	-	42,009 t	36,743 t
$B_{100\%}$	-	-	103,330 t	103,330 t
$B_{40\%}$	-	-	41,332 t	41,332 t
$B_{35\%}$	-	-	36,165 t	36,165 t
F_{OFL}	-	-	0.787	0.787
$maxF_{ABC}$	-	-	0.605	0.605
F_{ABC}	-	-	0.605	0.605
OFL	27,400	27,400	33,008 t	25,419 t
$maxABC$	20,600	20,600	26,957 t	20,781 t
ABC	20,600	20,600	26,957 t	20,781 t
Status	2017	2018	2018	2019
Overfishing	No	n/a	No	n/a
Overfished	-	-	n/a	No
Approaching overfished	-	-	n/a	No

Note: This model was not presented last year. Projections were based on annual catches of 19,191 t for 2019 and the ABC for 2020.

Responses to SSC and Plan Team Comments on Assessments in General

See the main body of this assessent.

Responses to SSC and Plan Team Comments Specific to this Assessment

BSAI Plan Team Comments, September 2019

1. The Team recommends that the authors report the fit of the maturity curve.

Authors' response

The fit to the observer data maturity curve is presented in Figure 2A.4.1 and the ogives are shown in Table 2A.4.1 and Figure 2A.4.2. This maturity curve was used in this assessment, and results are also shown using the Stark (2007) maturity curve.

2. The Team recommends that the authors report an exploration of how different reasonable M values impact reference points.

Authors' response

The reference points associated with different values of natural mortality, M=0.4 and M=0.34, are presented in Table 2A.4.2. Higher M increases biomass and reference points.

3. The Team recommends that the authors report the general results of an existing model that was run without fishery lengths.

Authors' response

The reference points that would result from a model without fishery lengths is shown in Table 2A.4.2 and the likelihood values are presented in Table 2A.4.3.

4. The Team recommends that the authors report quantitative goodness of fit statistics.

Authors' response

The CV of the root mean squared error (RMSE) was reported for biomass estimates.

$$CV(RMSE) = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}}{\bar{Y}_i}$$

The root sum of squared error was used for age composition data, and the standard deviation of normalized residuals (SDNRs) were reported for the biomass indices.

5. The Team recommends that the authors communicate with Cindy Tribuzio of AFSC to obtain IPHC survey indices and cod lengths for possible inclusion in future years.

Authors' response

These indices have been obtained and will be considered for future years.

SSC Comments, October 2019

1. The SSC endorses the PT recommendations.
2. Specifically, the PT noted differences in the fishery length compositions, with fishery lengths being larger on average than those observed in the survey. The author highlighted the methods used to collect the fishery length information were inconsistent across the time series. The SSC requests that the assessment provide detail about how the length information was combined in the model, whether temporal trends in length compositions are apparent, and identify important changes in the length measurement methods.

Authors' response

There may have been a misunderstanding, as length sampling methods have not changed.

It is true that the fishery catches larger fish on average than those observed in the survey. This could result from different selectivity and catchability between the fishery and the survey. Selectivity and catchability are estimated for the fishery and survey within the model.

There was also discussion in the Plan Team meeting that fishery length data were from several fisheries and taken throughout the year. This results in variation in lengths throughout each year, and potential differences due to gear selectivity. A model without fishery length data was considered, Table 2A.4.2 and Table 2A.4.3.

3. In addition, the SSC noted the wide variety of otolith sampling strategies that have been employed over time. The SSC requests that the authors elaborate on how different otolith sampling strategies were combined into one length-at-age curve.

Authors' response

Typically the age data is corrected for using survey length frequencies. Here the length frequency distribution did not match the observed lengths in the fishery, and resulted in an unrealistic growth curve. Therefore, no correction was made for different otolith sampling strategies. Future models could consider other sources for length frequency distributions of the Aleutian Islands cod stock.

4. Finally, retrospective analysis should have peels annually, not every two years, which is likely to result in a lower Mohn's rho value.

Authors' response The retrospective analyses have been revised, annually for 10 years.

Introduction

This document presents a new age-structured model for the assessment of the Pacific cod (*Gadus macrocephalus*) stock in the Aleutian Islands (AI). The most recent age-structured models for Aleutian Islands Pacific cod were presented in the 2016 preliminary (September) stock assessment. A recent Center for Independent Experts (CIE) commmittee reviewed the Aleutian Islands Pacific cod assessment. A preliminary version of this model was presented in September, 2019 to the BSAI Plan Team and in October, 2019 to the SSC.

Aleutian Islands Pacific cod were managed together with the eastern Bering Sea stock through the assessment year 2012. Starting in 2013, the assessment has been based on Tier 5 methodology, although age structured models have been presented from 2012-2016. The Aleutian Islands stock was determined to be distinct from the Bering Sea stock due to genetic, movement, and growth differences, which are summarized briefly here. There is evidence for isolation-by-distance stock structure in Pacific cod (Cunningham et al. 2009, Spies 2012, Drinan et al. 2018). The Bering Sea and Aleutian Islands have been shown to be genetically distinct (Spies 2012). Within the Aleutian Islands there may be some evidence for additional sub-structure at the level of the spawning stock but this remains to be confirmed (Spies 2012).

Tagging studies provide evidence for a closed system of annual migration in Pacific cod to spawning areas in winter return followed by movement to summer feeding areas (Shimada and Kimura 1994; Rand et al. 2014). Fish captured in the same three month period within the same season in different years showed only random movement, but little directional movement. In contrast, strong inter-seasonal movements between fall-winter and winter-spring tag recaptures were observed, as cod moved from feeding to spawning areas. Seasonal migrations outside of spawning season may be triggered by a combination of avoidance of temperature extremes and food availability.

Pacific cod range from the coast of Washington State, U.S.A, including the inland waters of Puget Sound, along the west coast of Canada, the Gulf of Alaska, the Bering Sea, Aleutian Islands, and along the Pacific rim as far as Korea. Pacific cod larvae can survive within a thermal window of 0-8°C (Laurel et al. 2008), and adults are seldom observed in the cold pool, water below 2°C (Stevenson and Lauth 2019). Temperature avoidance in the ocean may be achieved vertically or horizontally (Yang et al. 2019). Coastal stocks may achieve this by moving deeper to avoid warm water, but the bathymetry of the Bering Sea may necessitate long range movement (Shimada and Kimura 1994).

Further information on Pacific cod fishery, survey, and life history are available in the main portion of the 2019 Aleutian Islands stock assessment.

Data

The data used in this preliminary age structured model include fishery catch and size compositions, survey biomass and standard error, and age compositions from survey data. Data sources and years are shown in the following table.

Source	Type	Years
Fishery	Catch biomass	1990-2019*
Fishery	Size composition	1990-2019
AI bottom trawl survey	Biomass estimate	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018
AI bottom trawl survey	Age composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018

*Partial catch information for 2019 was available and was extrapolated to estimate the catch for the full year. The catch of Pacific cod in the Aleutian Islands as of October 22, 2019, was 18,999 t. Typically 99% of the annual catch occurs by this date, as estimated by catch statistics in 2014-2018. Therefore, the total catch for 2019 was extrapolated to 19,191 t.

Fishery

There are three predominant gear types in the Pacific cod fishery; pot, trawl, and longline (Figure 2A.4.3). The data in Figure 2A.4.3 is based on 816,676 observer records from 1990-2019. Approximately 57% of cod fishing in the Aleutian Islands takes place with longline gear, 13% with trawl gear, and 13% with pot gear.

Cod fisheries that operate during the feeding season, typically rely on longline gear, while cod are targeted primarily using trawl nets during spawning season because they aggregate. Pot gear is the least common gear type, and is used throughout the year. Catch data is used in the model by area and gear combined; there is a single catch biomass (Table 2A.4.4) and vector of length frequencies in each year from the fishery. The number of length observations from catch data by year is shown in Table 2A.4.5.

Fishery lengths are taken throughout the year by observers during commercial fishing operations (Figure 2A.4.3). The length frequency composition ranges from approximately 40-120 cm and varies over time (Figure 2A.4.4).

Survey

The National Marine Fisheries Service (NMFS) conducts biennial daytime summer trawl surveys in the Aleutian Islands. Survey biomass is estimated by extrapolating the weight from individual trawls with the measured path of the trawl area to the total area surveyed. The net used in the Aleutian Islands survey is a high-rise poly-Noreastern 4 seam bottom trawl (27.2 m headrope, 36.8 m footrope) (Nichol et al. 2007). Survey biomass estimates and standard error for Pacific cod are available for the survey years 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, and 2018 (Table 2A.4.6). Aleutian Islands surveys prior to 1991 were not used in the model because they were not standardized to current survey methodology; therefore, data from the 1980, 1983, and 1987 surveys were excluded. Survey data includes NMFS areas 541, 542, and 543. The Aleutian Islands bottom trawl survey does include NMFS areas 518 and 519, but these are part of the Bering Sea management area and were not included in data for this model.

Age data from the survey is available, and was used in the model, Figure 2A.4.5. The number of aged fish from each year of the survey is shown below. Length data from the surveys is available but was not used in the model because age data was available for those years (Figure 2A.4.6).

Year	Number aged
1991	919
1994	1,174
1997	845
2000	828
2002	1,270
2004	775
2006	754
2010	673
2012	598
2014	557
2016	681
2018	575

Survey estimates of biomass indicate a decline in biomass in the three NMFS areas in the Aleutian Islands, 543, 542, and 541 between the 1980s and 1990s, with the greatest declinein the central Aleutians (542). Downward trends have generally stabilized since the year 2000 (Figure 2A.4.7)

Other data used in the assessment

Length-at-age and weight-at-length were used outside the model to configure a length-age conversion matrix and vonBertalanffy growth curve.

Analytic Approach

General Model Structure

The Aleutian Islands stock of Pacific cod was managed jointly with the eastern Bering Sea stock through 2012. An age structured model for AI cod was first presented to the SSC in 2012 and age structured models were presented in 2013-2015. The development of these models is presented in the Appendix.

The initial age structured model presented by Grant Thompson in 2012 included:

- a single season,
- one fishery,
- AI-specific weight-length parameters,
- 1 cm length bins to 150cm,
- forced asymptotic fishery selectivity,
- fishery selectivity constant over time,
- survey samples age 1 fish at true age 1.5,
- ageing bias not estimated,
- q (catchability) tuned to match value from archival tagging data relevant to GOA/AI survey net.

In 2013 the SSC supported a model with the development of two models 1. fixed M fixed and q fixed at 1 and freely estimated selectivity. 2. M fixed, q estimated with a prior, and asymptotic survey selectivity.

In 2014 the Plan Team recommended only data from 1991 onward.

In 2015 the Plan Team did not consider any of the age structured models credible but encouraged further work on an age-structured model.

The model presented here is very similar to previously developed models, with the following differences:

- logistic fishery (and survey) selectivity,
- fishery (and survey) selectivity constant over time,
- ageing bias was estimated,
- survey catchability (q) freely estimated (bounds 0.5 to 1) and fishery q fixed at 1.

The age-structured statistical model was implemented in the Automatic Differentiation Model Builder (ADMB) framework (Fournier et al. 2012). This framework uses automatic differentiation and allows estimation of highly-parameterized and non-linear models. The age-structured population dynamics model was fit to survey abundance estimates, survey age data, fishery catch, and fishery length composition data. The model was fit to the data by minimizing the objective function, analogous to maximizing the likelihood function. The model implementation language provides the ability to estimate the variance-covariance matrix for all parameters of interest. The model incorporated ages 1-10, where 10 is considered a "plus group" including all ages 10 and above, and estimated selectivity using an increasing logistic equation for the fishery and the survey. A Markov chain Monte Carlo (MCMC) was performed in ADMB to capture variability in recruitment, female spawning biomass, and total (age 1+) biomass. The MCMC was run with 1,000,000 iterations, and thinning every 1000. A projection model was implemented to generate estimates of spawning stock biomass and reference points into the future. In this model, spawning month was set to February, which is typically the peak of spawning in the Aleutian Islands. As a result, estimates of spawning biomass for 2018 onward from the projection model are slightly lower than the age structured model results because they take into account two months of mortality (January, February).

Model features:

- One fishery, one gear type, one season per year.

- Single sex model, 1:1 male female ratio.
- Logistic age-based selectivity for both the fishery and survey.
- External estimation of a single growth curve (vonBertalanffy) for length at age, weight at age.
- An ageing error matrix for ages 1 through 10+.
- All parameters constant over time except for recruitment and fishing mortality.
- Internal estimation of fishing mortality, catchability, and selectivity parameters.
- Recruitment estimated as a mean with lognormally distributed deviations
- Natural mortality was fixed in the model using M=0.34 for consistency with previous Aleutian Islands Pacific cod assessments.
- Survey catchability was estimated within the model as a constant multiplier on survey selectivity.
- Maturity at age was estimated using observer data. This is consistent with the Gulf of Alaska Pacific cod assessment.

Data Weighting

Data weighting for age composition data was important because there was some conflict between the survey biomass estimates and the age composition data. Higher age composition likelihood weights decreased survey catchability and reduced biomass estimates. Data weighting was performed on age composition data using the methods of McAllister and Ianelli (2007: Appendix 2, Equations 2.5 and 2.6). The weight factor converged to 94 after 3 iterations. Statistical data weighting for fishery length likelihoods resulted in unreasonably high weights. The likelihood weight for fishery length composition data was set to 10 for all years, because it consists of lengths taken throughout the year from several gear types.

Parameters Estimated Outside the Assessment Model

Maturity

The maturity-at-age is governed by the relationship:

$$Maturity_{age} = \frac{1}{1 + e^{-(A+B*age)}},$$

where A and B are parameters in the relationship.

A study based on a collection of 129 female fish in February, 2003, from the Unimak Pass area, NMFS area 509, found that 50% of female fish become mature at approximately 4.88 years ($L_{50\%}$) and 58.0 cm, A=-4.7143, B=0.9654 (i.e. Tables 2 and 4 in Stark 2007). This maturity ogive is used in the Bering Sea Pacific cod assessment but was not used in this assessment, because the fish in the sample were not from the Aleutian Islands.

An alternative maturity curve was developed based on observer records of maturity from the Aleutian Islands. This model may be advantageous because it is based on more records that were taken from Aleutian Islands cod, and this was used in the model presented here. Observers routinely collect maturity at length from Pacific cod. There are 2,098 records from the Aleutian Islands (see table below) during the months January – March since 2008. These were used to estimate a maturity ogive by length using the R package *sizeMat*, which estimates the length of fish at gonad maturity. Maturity was considered a binomial response varable and variables were fitted to the logistic function above for maturity, and the length at which 50% of cod are mature is $L_{50\%} = -A/B$.

Year	Number of records
2008	1185
2009	35
2010	156
2011	80
2012	151
2013	61
2014	128
2015	78
2016	79
2017	42
2018	26
2019	77

The fit using this method is shown in Figure 2A.4.1, and the resulting parameters were A=-7.881832 and B=0.1464385. This ogive provided maturity at length which was converted to maturity at age using the length age conversion matrix, and was used in the assessment. The resulting ogive had $L_{50\%}$, slightly lower than the Stark (2007) estimate. $L_{50\%}$ was estimated to be 53.8 cm (age 4). Maturity parameters for the Stark (2007) data and the ogive using observer data are shown in Figure 2A.4.2 and Table 2A.4.1.

Length at Age

Pacific cod do not exhibit sexually dimorphic growth; males and females grow at the same rate. Therefore, the model did not distinguish between males and females. Growth was estimated from length and age data from AI surveys from 1991 to 2016 (Figure 2A.4.8). All data used in the model was aged after 2007, as there was a shift in our understanding of the first two checks deposited at early ages in Pacific cod. Prior to 2007 they were thought to be true annuli, but subsequently determined not to be. Length at age is typically adjusted for survey length frequencies for which there is more data and is assumed to be a better representation of the length frequencies in the population than the lengths of the aged fish. The correction is based on Bayes Theorem, and follows (Dorn 1992). The stratified age collections consist of the probability of length given age $P(Length|Age)$. These are often corrected for the length frequencies in the population by dividing by length frequencies from survey data from the same years,

$$P(Age|Length) = P(Length|Age) * P(Age)/P(Length).$$

Fish were historically collected in length stratified collections and there were 69,119 lengths collected on Aleutian Islands surveys and 512,613 total length observations from the fishery 1991-2019 Table 2A.4.5.

A von Bertalanffy individual growth model was applied to the corrected and uncorrected length at age data, using the R package *fishmethods*, resulting in the following parameter estimates.

Input data	L_{inf}	K	t_0
Corrected Length at age	106.3310	0.18587	-0.07247
Uncorrected length at age	124.93646	0.15883	-0.09981

The growth curve was fit to the vonBertalanffy growth equation:

$$Length_{age} = L_{inf}(1 - e^{-(K(age-t_0))}).$$

The correction downweights lengths for which there are fewer observations in the population as a whole, and the fewest length observations typically occur at very large and very small sizes. The correction operates under the assumption that the survey length frequencies are representative of the Aleutian Islands population as a whole. However, this may not be the case, as larger fish are observed in the fishery than the survey

(Figure 2A.4.9). For example the largest fish recorded in the fishery was 143 cm, while the largest fish from the survey was 116 cm. Correcting for survey length frequencies reduced the expected length at age in the population as compared to lengths of aged fish from a stratified collection (Figure 2A.4.10). When the correction was implemented, the asymptotic size L_{inf} was was 106 cm, but without the correction, L_{inf} was 124 cm (Figure 2A.4.10). Therefore, the growth curve and the length at age conversion matrix were calculated without correcting for survey length frequencies.

A length-age conversion matrix was compiled using average length-at-age based on the uncorrected lengths at age shown above. The coefficient of variation (CV) typically decreases with age. The CV of length at age was fitted using linear regression (Figure 2A.4.11), with the parameters shown in the figure. When a monotonically decreasing CV is converted to variance, the height of the distribution of length at each age becomes inversely dome shaped, with lower variance at middle ages (Figure 2A.4.12).

The length-age conversion matrix was generated by simulating $10x10^6$ data points for mean length at ages 1-10+ based on estimates of mean length at age and variance at each age. The simulations were generated from a normal distribution, with the mean length at age determined by the von Bertalanffy parameters fit to the length-age data and the variance for length at age determined by the parameters of the linear models (Figure 2A.4.10). The length-age conversion matrix is shown in Figure 2A.4.12, and mean length at age is compared with raw data in Figure 2A.4.10 (red line).

Length at age was converted to weight at age with the weight-at-length relationship described in the next section. The expected length at age was used as input into the weight at length equation for an estimate of weight at age.

Weight-at-length

The weight-length relationship for Aleutian Islands Pacific cod was evaluated to be:

$$Weight_{age} = 1.284x10^{-6} * Length_{age}^{3.319},$$

for both sexes combined, where weight is in kilograms and length in millimeters (Figure 2A.4.13). Analysis was performed using nonlinear least squares fit to all weight and length data, 9,213 individuals. The nonlinear least squares (nls) method was implemented from the R package *stats* R Core Team (2019).

Natural mortality

A natural mortality estimate of 0.34 been used in the most recent Aleutian Islands Pacific cod assessment, as well as the BSAI cod assessment (Thompson et al. 2018). This value was based on Equation 7 of Jensen (1996) and an age at maturity of 4.9 years (Stark 2007). The value of 0.34 adopted in 2007 replaced the value of 0.37 that had been used in all BSAI Pacific cod stock assessments from 1993 through 2006. In response to a request from the SSC, the 2008 assessment included a discussion of alternative values and a justification for the value chosen (Thompson et al. 2008). Using the variance for the age at 50% maturity published by Stark (0.0663), the 95% confidence interval for M extends from about 0.30 to 0.38. Recent estimates of natural mortality indicates that estimates have ranged from 0.20 to 0.96 for Pacific cod (Table 2A.4.7). The mean is presented three ways, but ranged from 0.45-0.58, and the mode was 0.40.

In the 2016 Aleutian Islands Pacific cod assessment (Thompson and Palsson 2016), the authors recommended changing the value of M from 0.34 to 0.36, based on the new recommended model for the EBS Pacific cod stock (Thompson 2016). In 2018, another new model was recommended for the EBS Pacific cod stock (see Chapter 2 of this volume), which estimated M at 0.34. To be consistent, a value of 0.34 was recommended for the AI Pacific cod stock also for 2018.

For the Gulf of Alaska, a natural mortality of 0.49 was used in the most recent assessment (Barbeaux et al. 2018).

A likelihood profile was performed in this 2019 age structured Aleutian Islands cod model on natural mortality values from 0.1 to 0.9.

The natural mortality likelihood profile showed some contrast in the results; the fishery length likelihood indicated that the lowest likelihood occurred at $M = 0.3$, whereas the other likelihood components (survey age, survey biomass, and recruitment) were minimized at $M = 0.8$ (Table 2A.4.8). However, these likelihoods decreased quickly until $M = 0.3$ and remained shallow thereafter (Figure 2A.4.14). To balance the different likelihood components and consider the values for M used in other assessments, the value $M = 0.4$ was considered a good starting point. This value also represents the mode of previous estimates (Table 2A.4.7). However, this value was not used in the current assessment, but it was explored as an alternative, Table 2A.4.2, Table 2A.4.3.

A tool for estimating natural mortality is available online (http://barefootecologist.com.au/shiny_m.html) that uses life history parameters, and provides a composite estimate of M. The estimate for Pacific cod was 0.36 (Figure 2A.4.15).

Given the long standing use of M=0.34 in the EBS and AI cod assessments, the effect of these values on reference points was calculated (Table 2A.4.2). For consistency with previous Aleutian Islands cod assessments, the value of 0.34 was selected for natural mortality.

Parameters Estimated Inside the Assessment Model

Catchability

Literature and previous studies can inform choices for catchability. Somerton (2004) found no evidence for herding in Pacific cod. This experiment took place using the 83-112 Eastern Trawl trawl net in the eastern Bering Sea and the Poly Noreastern trawl net in the Bering Sea (Somerton et al. 2004). Another study estimated that 47.3% of cod in the water column to be available to the trawl used on the eastern Bering Sea trawl survey and 91.6% are available to the trawl used on the Gulf of Alaska and Aleutian Islands surveys (Nichol et al. 2007). This study was based on results showing that 95% of cod were found within 10 m of the seafloor, based on 286 archival tagged cod off Kodiak Island in the Gulf of Alaska and off Unimak Pass in the eastern Bering Sea, Alaska (Nichol et al. 2007).

Survey catchability (q) was estimated within the model as a constant multiplier on the survey selectivity. Fishery catchability was assumed to be 1.

Selectivity

Selectivity for the fishery and the survey were fit (separately) using a two parameter logistic growth curve:

$$Selectivity_{age} = \frac{1}{1 + e^{-(slope*age - a_{50})}},$$

where the two parameters estimated were *slope* and a_{50}. Selectivity curves are presented in Figure 2A.4.16.

Figure 2A.4.17 supports the use of monotonically increasing selectivity for the survey and the fishery, because the fishery and the survey catch fish from the same length distributions. It also indicates that the use of dome-shaped selectivity is not warranted. Dome-shaped selectivity would be appropriate if larger cod resided in untrawlable habitat or left the region entirely, which is not supported by Figure 2A.4.17. The data for this figure was taken during the summer only, to be consistent with data from summer surveys. The fishery operates primarily in the winter, so the survey and fishery represent inherently fishing different distributions. Furthermore, the fishery and the survey often operate in different locations, even in the summer. The majority of fishing during the summer takes place near the Islands of the Four Mountains and Seguam Pass, in slightly different areas than NMFS survey tows (Figure 2A.4.18).

In the Bering Sea, the maximum length of Pacific cod taken during the summer is exactly the same for fishery and survey. In the Aleutian Islands the maximum length during the summer is a slightly higher for the fishery but most of the summer fishery lengths come from TWO areas that have never been within the spatial coverage of the NMFS Aleutian Islands survey.

Other parameters

The model contained a total of 67 parameters.

Catchability	Mean log recruitment	Log avg. fmort.	Selectivity	Fishing mortality	Recruitment	Total
1	1	1	4	30	30	67

Likelihood values for survey age composition, survey biomass, fishery length composition and recruitment are presented in Table 2A.4.3.

Final parameter estimates generated within the model are listed in Table 2A.4.9, with confidence bounds. Selectivity for the fishery and the survey are shown in Figure 2A.4.16 and the fit to age frequency from survey data is shown in Figure 2A.4.19.

Results

Model Evaluation

Four models are presented in this assessment:

- Model 19.0: M=0.34, observer-based maturity curve.
- Model 19.0a: base model with M=0.4.
- Model 19.0b: base model with Stark maturity curve.
- Model 19.0c: base model with no fishery length likelihood.

Likelihood components for the four models are shown in Table 2A.4.3 for recruitment, survey age, survey biomass, catch, fishery length, and total likelihood. Likelihoods were similar regardless of maturity curve. The model with the lowest likelihood was Model 19.0a, with improvements primarily in the survey biomass and fishery lengths. However, Model 19.0a was not selected in order to maintain natural mortality consistent with previous years of the Aleutian Islands assessment. Model 19.0c was not intended for an assessment, simply to consider how the models would change when the fishery length frequencies were not used. The reference points resulting from the four models are also compared in Table 2A.4.2. The ABCs for 2020 ranged from 20,591 t (Model 19.0c) to 38,482 t (Model 19.0a).

Several statistical goodness of fit tests were used to examine the four models. The root mean squared deviation (RMSD) was calculated for biomass, and the fit to length and age composition data was measured using the square root of the sum of squared differences (SSD). The RMSD is a measure of the average difference between the observed and predicted total biomass of Pacific cod in the Aleutian Islands, and is similar to a standard deviation. The standard deviation of normalized residuals (SDNRs) was calculated for biomass data (Table 2A.4.10). Model results did not differ significantly, but the CV of RMSD for biomass was lowest under Model 19.0a and SSD for survey age was lowest for Model 19.0. SDNR was not considered a diagnostic statistic, but values close to 1 are considered better, and plots of the fit to biomass are considered important diagnostic tools as well (Figure 2A.4.20).

Retrospective analysis

A retrospective analysis was performed extending back 10 years to evaluate the model, with data from 2009-2019. For example, the 2018 run was created by dropping all data except through 2018, the 2014 run included all data through 2014, etc. The spawning biomass estimates and error bars showed a negative retrospective bias (Figure 2A.4.21). Relative differences in spawning biomass were generally negative (Figure 2A.4.22). The value for Rho is -0.232.

There are no guidelines regarding how large Rho (absolute value) should be before an assessment is declared to exhibit an important retrospective bias. However, -0.232 is in the range of values exhibited by many other Alaska groundfish species, and recent values for EBS Pacific cod were in the range of 0.4 and GOA cod were 0.3. The positive retrospective bias indicates that the model may be slightly overestimating spawning biomass for the current year. The spawning biomass of Pacific cod has decreased and increased over the past 10 years and -0.232 represents an average in the differences between adjacent years.

Time Series Results

Total biomass (defined as age 1 and older) declined from approximately 190,000 t in 1990 to a low of 89,787 t in 2013 (Figure 2A.4.23). A similar table of time series results based on MCMC output that includes 95% credible intervals is also presented in Table 2A.4.11. Since 2013, the biomass has increased to an estimate of 127,882 t (Table 2A.4.12), Figure 2A.4.23. Female spawning biomass has followed a similar trajectory, with a peak of t in 1992, declining to t in 2011, and then increasing to its current level of t in 2019. A phase plane plot (Figure 2A.4.24) shows that spawning biomass was above $B_{40\%}$ from 1990 until approximately 2009. From 2007-2010, fishing was above F_{ABC} and declined starting in 2011. Spawning biomass fell below $B_{35\%}$ from 2009-2015. Since 2016, biomass has been above $B_{35\%}$ but it is projected to be below $B_{35\%}$ in 2020 and 2021. Estimates of total biomass, female spawning biomass, and recruitment with 95% MCMC credible intervals are presented in Figure 2A.4.25 and Table 2A.4.11. A second plot of recruitment that shows individual data points and the mean value over time is shown in Figure 2A.4.26. Most recent estimates of recruitment (2006 onward) are below the long term mean since 1990, with the exception of 2015. The model estimates of numbers at age for ages 1 to 10+ indicate lower recruitment and abundance of younger fish since 2002 than during the period 1990-2001, although the 2015 year class was stronger than average Table 2A.4.13 and Figure 2A.4.27.

Harvest Recommendations

Projected catch and abundance

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2019 numbers at age estimated in the assessment (Table 2A.4.14). This vector is then projected forward to the beginning of 2032 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch 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. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. 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, fishing mortality rates, and catches.

- Scenario 1: In all future years, F is set equal to max F_{ABC} . (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
- Scenario 2: In all future years, F is set equal to a constant fraction of max F_{ABC} , where this fraction is equal to the ratio of the F_{ABC} value for the assessment two years ago recommended in the assessment to the max F_{ABC} for the current year. (Rationale: When F_{ABC} is set at a value below max F_{ABC}, it is often set at the value recommended in the stock assessment.)
- Scenario 3: In all future years, the upper bound on F_{ABC} is set at $F_{60\%}$. (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 4: In all future years, F is set equal to the average of the five most recent years. (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 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.) Two other 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. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):
- 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 above ½ of its MSY level in the current year and above its MSY level in 25 years under this scenario, then the stock is not overfished.)

- Scenario 7: In the next two years, F is set equal to max F_{ABC}, 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 expected to be above its MSY level in 25 years under this scenario, then the stock is not approaching an overfished condition.)

Projected catch and abundance were estimated using $F_{40\%}$, F equal to the average F from 2014 to 2019 (F=0.391), F equal to one half $F_{40\%}$, and $F = 0$ from 2019 to 2032 (Table 2A.4.14). Under scenario 6 above, the year 2020 female spawning biomass is 33,009 t and the year 2032 spawning biomass is 24,505 t, above the $B_{35\%}$ level of 33,008 t. For scenario 7 above, the year 2032 spawning biomass is 24,505 t, also above $B_{35\%}$. Fishing at $F_{40\%}$, female spawning biomass would still be above $B_{40\%}$ (26,957 t) in year 2032 (23,829 t). Female spawning biomass would be expected to decrease to 18,297 over the next 12 years, if fishing continues at the last 5-year average fishing mortality (0.029) (Table 2A.4.14, Scenario 4).

ABC and OFL for 2020 and 2021

The Aleutian Islands Pacific cod stock is predicted to be above $B_{35\%}$ in 2020 and 2021. The 2020 biomass is estimated at 127,146 t and the spawning biomass is 42,009 t. The reference fishing mortality rate for Aleutian Islands Pacific cod is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands), and this model used Tier 3a methodology. Equilibrium female spawning biomass was calculated by applying the female spawning biomass per recruit resulting from a constant $F_{40\%}$ harvest to an estimate of average equilibrium recruitment. Year classes spawned in 1990-2014 were used to calculate the average equilibrium recruitment. This results in an estimate of $B_{40\%}$ = 41,332 t for 2020. Projected 2020 female spawning biomass is compared to $B_{40\%}$ to determine the Tier level. The stock assessment model estimates the 2020 level of female spawning biomass at 42,009 t. Since reliable estimates of B, $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist, Pacific cod reference fishing mortality is defined in Tier 3a. $B > B_{35\%}$ for all models evaluated (Table 2A.4.2). Therefore, Aleutian Islands Pacific cod reference fishing mortality is defined in Tier 3a.

The 2019 catch was estimated at 19,191 t and the total catch in 2020 was estimated to be the same as the 2020 ABC, 26,957 t.

The stock is being not subjected to overfishing and not overfished. If fishing continues at its average rate for the past 5 years, female spawning biomass is predicted to be above $B_{35\%}$ by all four models (Table 2A.4.2,Figure 2A.4.28).

Acknowledgements

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Tables

Table 2A.4.1: Maturity at age ogives based on Stark (2007) and observer maturity at length data.

Age	Stark 2007	Observer data
1	0.0230021	0.0083508
2	0.0582223	0.0861430
3	0.1396620	0.3217268
4	0.2988668	0.6259211
5	0.5281452	0.8466659
6	0.7461343	0.9453637
7	0.8852892	0.9799796
8	0.9529746	0.9916185
9	0.9815542	0.9956556
10	0.9928941	0.9977102

Table 2A.4.2: Comparison of reference points using the base model (M=0.34, observer-based maturity curve, and fishery length likelihood based on fishery length frequency data), with a model M=0.40, a model with no fishery length frequency likelihood, and a maturity curve based on Stark (2007).

	Model 19.0a, $M = 0.40$		Model 19.0, Base model	
Quantity	2020	2021	2020	2021
M (natural mortality rate)	0.40	0.40	0.34	0.34
Tier	3b	3b	3b	3b
Projected total (age 1+) biomass (t)	152,919	133,219	127,146 t	119,180 t
Projected female spawning biomass (t)	47,907	37,065	42,009 t	36,743 t
$B_{100\%}$	99,221	99,221	103,330 t	103,330 t
$B_{40\%}$	39,688	39,688	41,332 t	41,332 t
$B_{35\%}$	34,727	34,727	36,165 t	36,165 t
F_{OFL}	1.155	1.155	0.787	0.787
$maxF_{ABC}$	0.863	0.863	0.605	0.605
F_{ABC}	0.863	0.863	0.605	0.605
OFL	47,159	32,143	33,008 t	25,419 t
$maxABC$	38,482	26,278	26,957 t	20,781 t
ABC	38,482	26,278	26,957 t	20,781 t
Status	2018	2019	2018	2019
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

	Model 19.0b, Stark (2007) maturity		Model 19.0c, No Fishery lengths	
Quantity	2020	2021	2020	2021
M (natural mortality rate)	0.34	0.34	0.34	0.34
Tier	3b	3b	3b	3b
Projected total (age 1+) biomass (t)	127,152	125,482	116,010 t	115,421 t
Projected female spawning biomass (t)	34,328	32,647	37,310 t	35,341 t
$B_{100\%}$	91,688	91,688	101,934 t	101,934 t
$B_{40\%}$	36,675	36,675	40,773 t	40,773 t
$B_{35\%}$	32,091	32,091	35,677 t	35,677 t
F_{OFL}	0.609	0.609	0.651	0.651
$maxF_{ABC}$	0.483	0.483	0.511	0.511
F_{ABC}	0.483	0.483	0.511	0.511
OFL	25,458	22,825	24,942 t	22,344 t
$maxABC$	21,134	18,926	20,591 t	18,404 t
ABC	21,134	18,926	20,591 t	18,404 t
Status	2018	2019	2018	2019
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Projections were based on annual catches of 19,191 t for 2019 and the ABC for 2020.

Table 2A.4.3: Comparison of likelihood values for recruitment, survey age, survey biomass, catch, fishery length, and total likelihood for the base model and several alternatives.

	Model 19.0	Model 19.0a	Model 19.0b	Model 19.0c
Likelihood Component	Base Model	M=0.40	Stark (2007) maturity	No fishery lengths
Recruitment	5.994	5.587	5.994	5.494
Survey age	0.66	0.653	0.66	0.639
Survey biomass	14.558	12.911	14.557	13.061
Catch	0.001	0.001	0.001	0.001
Fishery length	20.93	20.299	20.93	-
Total	42.143	39.45	42.142	52.476

Table 2A.4.4: Fishery catch in metric tons by year, total allowable catch (TAC), acceptable biological catch (ABC), and overfishing limit (OFL), 1990-2019. Note that specifications were combined for the Bering Sea and Aleutian Islands cod stocks through 2013 and are shown for the Aleutian Islands alone for 2013 onwards. Catch for the current year is through October 22. ABC and OFL for the current year are based on the current year's model output.

Year	Catch (t)	TAC	ABC	OFL
1990	7,541	179,608	417,000	-
1991	9,798	220,038	229,000	-
1992	43,068	207,278	182,000	188,000
1993	34,205	167,391	164,500	192,000
1994	21,539	193,802	191,000	228,000
1995	16,534	245,033	328,000	390,000
1996	31,609	240,676	305,000	420,000
1997	25,164	257,765	306,000	418,000
1998	34,726	193,256	210,000	336,000
1999	28,130	173,998	177,000	264,000
2000	39,685	191,060	193,000	240,000
2001	34,207	176,749	188,000	248,000
2002	30,801	197,356	223,000	294,000
2003	32,457	207,907	223,000	324,000
2004	28,873	212,618	223,000	350,000
2005	22,694	205,635	206,000	365,000
2006	24,211	193,025	194,000	230,000
2007	34,355	174,486	176,000	207,000
2008	31,229	171,277	176,000	207,000
2009	28,582	175,756	182,000	212,000
2010	29,006	171,875	174,000	205,000
2011	10,889	220,109	235,000	272,000
2012	18,220	251,055	314,000	369,000
2013	13,606	250,274	307,000	359,000
2014	10,605	10,605	15,100	20,100
2015	9,217	9,217	17,600	23,400
2016	13,245	13,245	17,600	23,400
2017	15,204	15,204	21,500	28,700
2018	20,414	19,558	21,500	28,700
2019	18,899	-	26,957	33,008

Table 2A.4.5: The number of length observations available for the fishery length composition data, by year.

Year	Number of Lengths
1990	0
1991	0
1992	0
1993	0
1994	0
1995	0
1996	0
1997	0
1998	0
1999	0
2000	0
2001	0
2002	0
2003	0
2004	0
2005	0
2006	0
2007	0
2008	0
2009	0
2010	0
2011	0
2012	0
2013	0
2014	0
2015	0
2016	0
2017	0
2018	0
2019	0

Table 2A.4.6: Aleutian Islands bottom trawl survey biomass estimates and standard error for Pacific cod, for all years used in the model.

Year	Biomass (t)	Standard error
1991	180,170	16,302
1994	153,416	31,676
1997	72,848	9,790
2000	126,870	23,494
2002	73,551	12,051
2004	82,218	16,443
2006	84,861	24,406
2010	55,825	10,550
2012	58,910	8,733
2014	73,608	13,798
2016	84,409	15,500
2018	81,272	12,894

Table 2A.4.7: Estimates of natural mortality, M, for Pacific cod throughout their range. Values marked with asterisks * have been used in stock assessments, and statistics are provided to summarize the estimates. The value mu represents the mean of the log values and sigma is the standard deviation.

Region	Reference Author	Year	M estimate
EBS*	Low	1974	0.375
EBS	Wespestad et al.	1982	0.700
EBS	Bakkala and Wespestad	1985	0.450
EBS	Thompson and Shimada	1990	0.290
EBS	Thompson and Methot	1993	0.370
EBS*	Shimada and Kimura	1994	0.960
EBS*	Shi et al.	2007	0.450
EBS	Thompson et al.	2007	0.340
EBS	Thompson	2016	0.360
GOA	Thompson and Zenger	1993	0.270
GOA	Thompson and Zenger	1995	0.500
GOA	Thompson et al.	2007	0.380
GOA*	Barbeaux et al.	2016	0.470
BC*	Ketchen	1964	0.595
BC*	Fournier	1983	0.650
Korea*	Jung et al.	2009	0.820
Japan*	Ueda et al.	2004	0.200

Statistic	Value
mu:	-0.6666309
sigma:	0.4929505
Arithmetic:	0.5797660
Geometric:	0.5134355
Harmonic:	0.4546938
Mode:	0.4026727
L95%:	0.1953790
U95%:	1.3492544

Table 2A.4.8: Likelihood values for recruitment, survey age, survey biomass, fishery lengths likelihood components for various values of natural mortality, M. The total includes all likelihood components except the fishery.

Natural Mortality	Recruitment	Survey Age	Survey Biomass	Fishery	Total (excluding Fishery)
0.11	11.77	125.30	50.89	118.09	187.95
0.12	11.24	124.32	47.56	115.99	183.12
0.13	10.75	123.33	44.40	113.95	178.48
0.14	10.30	122.32	41.40	111.98	174.01
0.16	9.47	120.27	35.92	108.26	165.66
0.17	9.11	119.23	33.44	106.52	161.78
0.18	8.77	118.19	31.15	104.86	158.11
0.27	6.93	109.69	19.19	93.92	135.81
0.28	6.84	108.97	18.85	93.16	134.67
0.29	6.77	108.33	18.71	92.51	133.82
0.34	6.35	107.13	17.57	109.34	131.05
0.35	6.23	107.11	17.32	111.66	130.66
0.37	5.99	107.12	16.81	114.89	129.92
0.39	5.79	107.12	16.32	119.17	129.22
0.40	5.70	107.11	16.08	121.82	128.88
0.41	5.62	107.09	15.85	124.89	128.56
0.42	5.54	107.06	15.63	128.44	128.23
0.44	5.42	107.00	15.20	137.32	127.62
0.45	5.37	106.95	15.00	142.87	127.32
0.46	5.32	106.91	14.80	149.31	127.03
0.47	5.28	106.86	14.61	156.79	126.75
0.48	5.25	106.80	14.43	165.47	126.48
0.49	5.22	106.74	14.25	175.49	126.21
0.50	5.20	106.68	14.08	187.03	125.96
0.51	5.18	106.61	13.92	200.25	125.71
0.52	5.16	106.54	13.77	215.30	125.47
0.53	5.15	106.47	13.62	232.28	125.24
0.54	5.14	106.40	13.49	251.26	125.02
0.55	5.13	106.33	13.36	272.28	124.82
0.56	5.12	106.26	13.23	295.29	124.62
0.57	5.12	106.19	13.12	320.23	124.43
0.58	5.12	106.12	13.01	346.96	124.25
0.59	5.11	106.06	12.91	375.34	124.08
0.60	5.11	106.00	12.81	405.17	123.92
0.61	5.11	105.94	12.72	436.24	123.78
0.62	5.11	105.89	12.64	468.34	123.64
0.63	5.11	105.84	12.56	501.22	123.52
0.64	5.11	105.80	12.49	534.62	123.40
0.65	5.11	105.76	12.42	568.23	123.29
0.66	5.11	105.73	12.35	601.67	123.19
0.67	5.11	105.71	12.29	634.48	123.10
0.68	5.09	105.69	12.22	666.30	122.99
0.69	5.02	105.47	12.14	685.62	122.63
0.70	5.02	105.27	12.11	711.52	122.40
0.71	5.03	105.08	12.07	736.84	122.18
0.72	5.03	104.91	12.04	761.66	121.98
0.73	5.04	104.76	12.01	786.05	121.81
0.74	5.05	104.62	11.98	810.06	121.66
0.75	5.07	104.50	11.96	833.73	121.53

0.76	5.08	104.41	11.93	857.09	121.42
0.78	5.12	104.27	11.89	902.96	121.27
0.79	5.14	104.23	11.87	925.50	121.23
0.80	5.16	104.20	11.85	947.80	121.21
0.82	5.21	104.22	11.81	991.71	121.25
0.83	5.24	104.26	11.80	1013.35	121.30
0.84	5.27	104.32	11.78	1034.80	121.38
0.85	5.31	104.40	11.77	1056.06	121.48
0.86	5.34	104.50	11.76	1077.15	121.60
0.87	5.38	104.62	11.75	1098.08	121.75
0.88	5.42	104.76	11.73	1118.85	121.91
0.89	5.46	104.92	11.72	1139.48	122.10
0.90	5.50	105.10	11.71	1159.98	122.32

Table 2A.4.9: Parameter values for Model 19.0 and their 95% confidence intervals, estimated within the model. Parameters include catchability (q), the mean log(recruitment), the log of the average fishing mortality, and two selectivity parameters for the fishery and the survey, *slope* and a_{50}.

	Value	Lower Confidence Interval	Upper Confidence Interval
Catchability	0.80728	0.6940155	0.9205445
Mean log recruitment	10.19400	10.0941106	10.2938894
Log average fishing mortality	-0.73494	-1.0071644	-0.4627156
Survey selectivity slope	1.24040	1.1253715	1.3554285
Survey selectivity a50	3.00000	2.9999113	3.0000887
Fishery selectivity slope	1.63090	1.2540116	2.0077884
Fishery selectivity a50	5.34650	4.8769624	5.8160376

Table 2A.4.10: Goodness of fit tests for the four models, the coefficient of variation for the RMSD (root mean squared deviation) for fit to biomass, the square root of the sum of squared differences (SSD) for survey ages, and fishery lengths, the standard deviation of normalized residuals for biomass, as well as survey catchability estimated by the four models, Model 19.0, 19.0a, 19.0b, and 19.0c.

Test statistic	Model 19.0	Model 19.0a	Model 19.0b	Model 19.0c
CV of RMSD for biomass	0.285	0.273	0.285	0.266
SSD for survey age	0.402	0.404	0.402	0.392
SSD for fishery lengths	0.203	0.2	0.203	0.251
SDNR	1.661	1.594	1.661	1.68
Survey catchability	0.807277	0.69573	0.807267	0.966926

Table 2A.4.11: MCMC posterior estimates of female spawning biomass, FSB, (t), total biomass, (t), and recruitment (number of age 1 individuals). Mean values with 95% MCMC credible intervals are presented. Lower 95% credible intervals (LCI) and upper 95% credible intervals (UCI) are shown to the right of the statistic they refer to. The 2019 and 2020 values come from the project model, and confidence intervals were estimated from the variance of the 2018 values.

Year	FSB	LCI	UCI	Tot. biomass	LCI	UCI	Recruitment	LCI	UCI
1990	43526	37,213	50,568	163542	149,426	179,241	54,910	46,938	63,376
1991	50815	45,175	57,053	185375	171,614	200,510	16,359	12,199	20,960
1992	58231	52,874	64,118	198971	185,080	213,974	20,974	16,225	26,299
1993	49533	44,324	55,189	171046	157,355	185,756	26,704	21,354	32,436
1994	44864	39,724	50,446	155600	142,572	169,756	57,844	49,933	66,218
1995	45085	39,928	50,658	159166	146,761	172,832	25,604	19,920	31,806
1996	46164	41,106	51,674	168606	156,699	181,298	49,018	41,649	57,190
1997	40712	36,124	45,630	166394	155,323	178,122	53,699	46,173	61,706
1998	42189	37,881	46,734	177164	166,440	188,302	30,318	24,762	36,306
1999	41404	37,376	45,675	174427	164,211	185,458	29,341	24,133	34,948
2000	44117	40,143	48,332	177341	167,239	188,214	48,098	41,774	54,711
2001	41942	38,126	45,993	169085	158,979	179,794	48,041	41,526	54,953
2002	40995	37,177	45,091	167133	157,130	177,784	27,046	22,320	32,158
2003	40466	36,645	44,547	165420	155,034	176,191	20,665	16,241	25,474
2004	39837	36,159	43,766	157449	147,325	168,072	22,997	18,009	28,452
2005	41168	37,312	45,261	148539	138,685	158,866	12,828	8,985	17,218
2006	42852	38,841	47,103	141635	132,317	151,206	35,136	29,595	40,948
2007	40425	36,576	44,407	133569	125,413	141,837	29,296	24,710	34,275
2008	31324	28,035	34,792	116281	109,460	123,426	24,429	20,672	28,420
2009	24145	21,658	26,829	103664	97,768	110,031	17,830	14,835	21,083
2010	20202	18,300	22,269	93022	87,226	99,413	11,715	9,379	14,365
2011	17350	15,587	19,336	77624	71,717	84,382	13,566	10,887	16,560
2012	21056	18,929	23,511	80428	73,718	88,131	15,936	12,830	19,454
2013	19796	17,382	22,662	73835	66,359	82,590	24,195	19,452	29,520
2014	19128	16,423	22,284	74720	66,063	84,981	28,063	22,245	34,851
2015	19507	16,463	23,089	82688	71,836	95,493	33,362	25,484	42,514
2016	21518	18,037	25,603	95179	81,154	111,685	16,921	11,859	23,097
2017	23387	19,064	28,512	102340	84,698	123,098	20,571	13,117	29,933
2018	25958	20,261	32,674	105526	83,844	131,014	13,427	6,815	22,390
2019	26521	19,144	35,291	101029	75,805	130,302	29,919	28,795	31,156
2020	42,009	36,312	31046.4377	127,146	105,464	97,498	-	-	-
2021	36,743	47,706	42440.4377	119,180	148,828	140,862	-	-	-

Table 2A.4.12: Model estimates for total biomass (metric tons, age 1+), recruitment (number of age 1 individuals), and spawning biomass (t), 1990-2019.

Year	Biomass (t)	Spawning biomass (t)	Recruitment
1990	188,038	63,949	54,736
1991	209,152	73,752	17,021
1992	220,832	81,659	20,785
1993	190,125	71,060	25,762
1994	171,550	64,066	54,823
1995	171,645	61,184	24,948
1996	177,574	60,793	48,558
1997	172,364	55,327	54,235
1998	180,992	56,889	30,388
1999	177,190	55,372	29,472
2000	179,590	58,961	48,339
2001	171,165	55,650	48,488
2002	169,318	53,091	27,850
2003	167,743	52,959	21,490
2004	159,995	53,476	23,642
2005	151,543	54,248	14,235
2006	145,442	54,192	36,508
2007	138,175	49,982	30,879
2008	121,662	39,657	26,432
2009	110,085	33,009	19,707
2010	100,730	30,363	13,469
2011	87,103	27,388	15,803
2012	91,819	31,810	18,287
2013	87,190	30,020	27,407
2014	90,074	29,330	32,014
2015	100,316	30,629	38,002
2016	115,235	34,577	19,773
2017	124,732	38,989	23,752
2018	130,274	43,869	17,209
2019	127,882	45,134	30,896

Table 2A.4.13: Model 19.0 estimates of the numbers of cod by age 1-10+ in the Aleutian Islands (x 1,000) from 1990-2019.

	1	2	3	4	5	6	7	8	9	10+
1990	54,736	19,455	20,042	16,592	7,621	4,089	2,669	1,580	1,139	871
1991	17,021	38,956	13,841	14,234	11,690	5,227	2,697	1,726	1,017	1,292
1992	20,785	12,114	27,715	9,828	10,016	7,982	3,417	1,724	1,097	1,465
1993	25,762	14,788	8,604	19,515	6,650	5,936	3,901	1,515	745	1,101
1994	54,823	18,330	10,505	6,063	13,257	3,998	2,988	1,795	681	825
1995	24,948	39,011	13,030	7,428	4,186	8,447	2,267	1,597	945	790
1996	48,558	17,754	27,741	9,230	5,171	2,748	5,093	1,309	912	988
1997	54,235	34,548	12,611	19,542	6,258	3,087	1,363	2,301	577	833
1998	30,388	38,588	24,542	8,887	13,275	3,762	1,553	627	1,034	630
1999	29,472	21,617	27,385	17,211	5,899	7,340	1,595	576	224	591
2000	48,339	20,968	15,350	19,258	11,575	3,420	3,430	668	234	330
2001	48,488	34,382	14,872	10,733	12,610	6,091	1,310	1,118	209	175
2002	27,850	34,492	24,398	10,425	7,111	6,926	2,547	477	393	134
2003	21,490	19,812	24,486	17,137	6,971	4,037	3,099	1,010	183	201
2004	23,642	15,287	14,059	17,167	11,362	3,838	1,696	1,136	357	135
2005	14,235	16,818	10,851	9,872	11,464	6,420	1,701	665	431	185
2006	36,508	10,129	11,949	7,653	6,730	6,980	3,316	808	309	285
2007	30,879	25,976	7,197	8,430	5,227	4,125	3,654	1,603	383	280
2008	26,432	21,966	18,437	5,050	5,610	2,917	1,782	1,387	588	241
2009	19,707	18,800	15,578	12,885	3,298	2,925	1,096	567	423	251
2010	13,469	14,013	13,315	10,814	8,152	1,533	868	259	126	148
2011	15,803	9,574	9,908	9,164	6,572	3,275	337	141	39	40
2012	18,287	11,243	6,801	6,978	6,207	3,910	1,614	151	62	34
2013	27,407	13,009	7,981	4,774	4,657	3,500	1,725	629	57	36
2014	32,014	19,500	9,242	5,627	3,250	2,820	1,787	808	288	42
2015	38,002	22,780	13,860	6,531	3,873	2,048	1,564	929	413	168
2016	19,773	27,043	16,195	9,806	4,519	2,488	1,181	854	500	312
2017	23,752	14,069	19,216	11,430	6,708	2,787	1,319	580	411	389
2018	17,209	16,900	9,996	13,553	7,794	4,089	1,443	629	271	372
2019	30,896	12,244	12,002	7,037	9,163	4,606	1,987	635	270	274

Table 2A.4.14: Projections of Aleutian Islands Pacific cod female spawning biomass (FSB), future catch, and full selection fishing mortality rates (F) for seven future harvest scenarios. Estimates of FSB and catch are in metric tons (t).

Scenarios 1 and 2 Maximum ABC harvest permissible			
Year	FSB	Catch	F
2019	42,926	19,191	0.430
2020	42,009	26,957	0.605
2021	36,743	20,782	0.535
2022	35,416	18,244	0.514
2023	37,194	18,901	0.540
2024	39,720	21,159	0.562
2025	41,323	22,764	0.569
2026	42,077	23,473	0.572
2027	42,474	23,779	0.573
2028	42,661	23,998	0.574
2029	42,632	24,033	0.574
2030	42,521	23,953	0.573
2031	42,441	23,882	0.573
2032	42,465	23,829	0.573

Scenario 3, Maximum Tier 3 ABC harvest permissible set at F60			
Year	FSB	Catch	F
2019	42,926	19,191	0.430
2020	42,009	26,957	0.605
2021	37,033	15,977	0.391
2022	37,969	15,759	0.391
2023	40,766	16,200	0.391
2024	44,322	17,841	0.391
2025	47,180	19,502	0.391
2026	49,034	20,574	0.391
2027	50,198	21,202	0.391
2028	50,872	21,620	0.391
2029	51,129	21,826	0.391
2030	51,157	21,864	0.391
2031	51,124	21,855	0.391
2032	51,151	21,819	0.391

Scenario 4 Harvest at average F over past 5 years			
Year	FSB	Catch	F
2019	42,926	19,191	0.430
2020	42,009	26,957	0.605
2021	37,333	10,485	0.243
2022	40,972	11,323	0.243
2023	45,666	12,295	0.243
2024	50,612	13,862	0.243
2025	54,713	15,421	0.243
2026	57,672	16,553	0.243
2027	59,701	17,300	0.243
2028	61,005	17,816	0.243
2029	61,674	18,113	0.243
2030	61,959	18,239	0.243
2031	62,070	18,291	0.243
2032	62,172	18,297	0.243

Scenario 5 No fishing			
Year	FSB	Catch	F
2019	42,926	19,191	0.430
2020	42,009	26,957	0.605
2021	37,836	0	0.000
2022	46,818	0	0.000
2023	56,612	0	0.000
2024	66,259	0	0.000
2025	74,925	0	0.000
2026	82,278	0	0.000
2027	88,229	0	0.000
2028	92,871	0	0.000
2029	96,131	0	0.000
2030	98,378	0	0.000
2031	99,936	0	0.000
2032	101,083	0	0.000

Alternative 6, Determination of whether Pacific cod are currently overfished			
Year	FSB	Catch	F
2019	42,926	19,191	0.430
2020	41,587	33,009	0.787
2021	33,658	21,414	0.633
2022	32,306	18,467	0.606
2023	34,280	19,536	0.645
2024	36,748	22,467	0.686
2025	37,931	24,109	0.699
2026	38,267	24,535	0.702
2027	38,426	24,637	0.703
2028	38,502	24,764	0.703
2029	38,427	24,751	0.702
2030	38,307	24,624	0.701
2031	38,242	24,583	0.701
2032	38,270	24,505	0.701

Scenario 7, Determination of whether stock is approaching an overfished condition			
Year	FSB	Catch	F
2019	42,926	19,191	0.430
2020	42,009	26,958	0.605
2021	36,743	20,781	0.535
2022	35,150	22,395	0.663
2023	35,023	20,608	0.660
2024	36,853	22,640	0.688
2025	37,905	24,081	0.698
2026	38,242	24,503	0.702
2027	38,416	24,623	0.703
2028	38,500	24,760	0.703
2029	38,427	24,751	0.702
2030	38,307	24,624	0.701
2031	38,242	24,583	0.701
2032	38,270	24,505	0.701

Figures

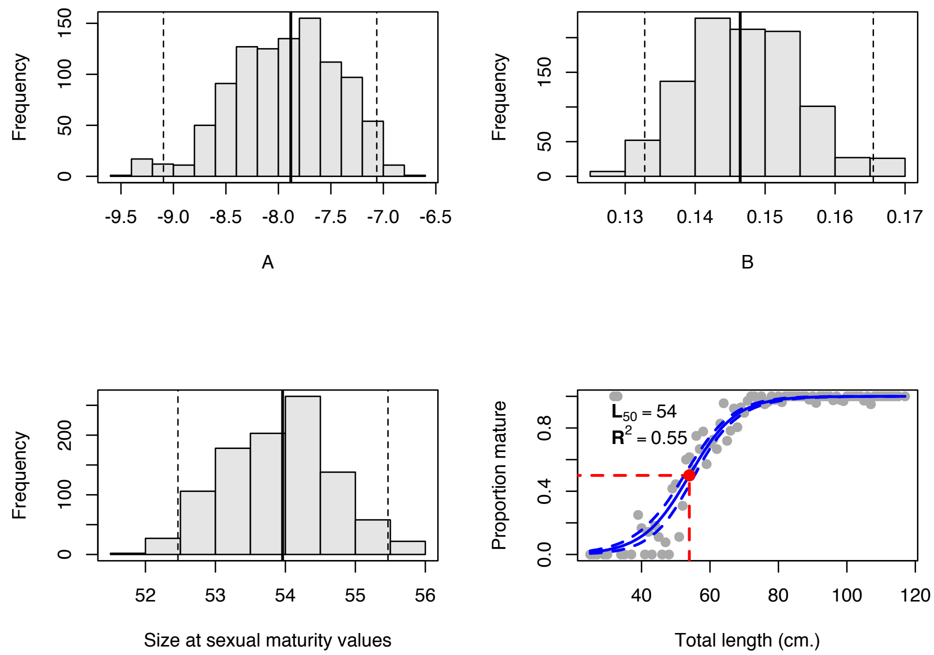


Figure 2A.4.1: Parameter estimation for A and B, size at maturity, and fit to the data for the proportion of Aleutian Islands cod mature by length, during January-March, 2008-2019. This is the maturity curve used in this assessment.

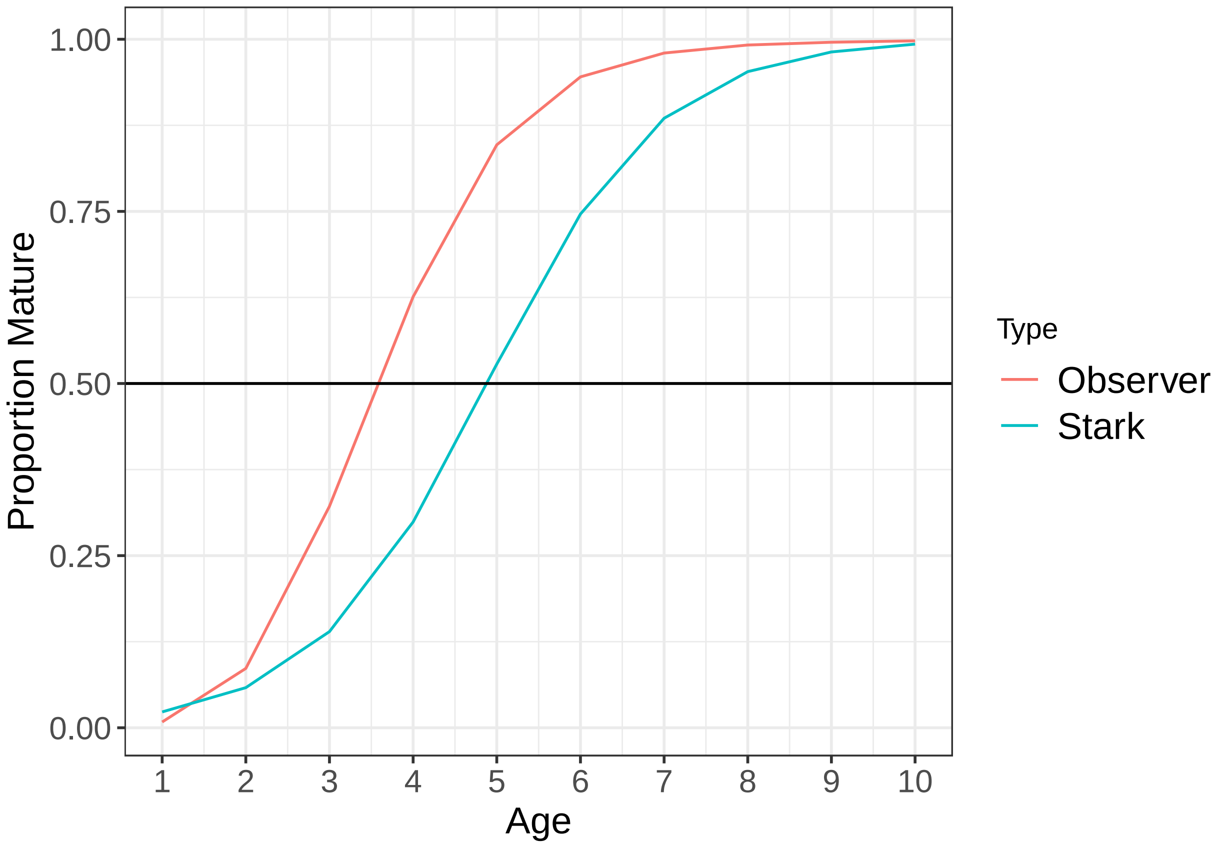


Figure 2A.4.2: Proportion mature by age, as measured using Stark (2007) parameters and observer maturity at length data.

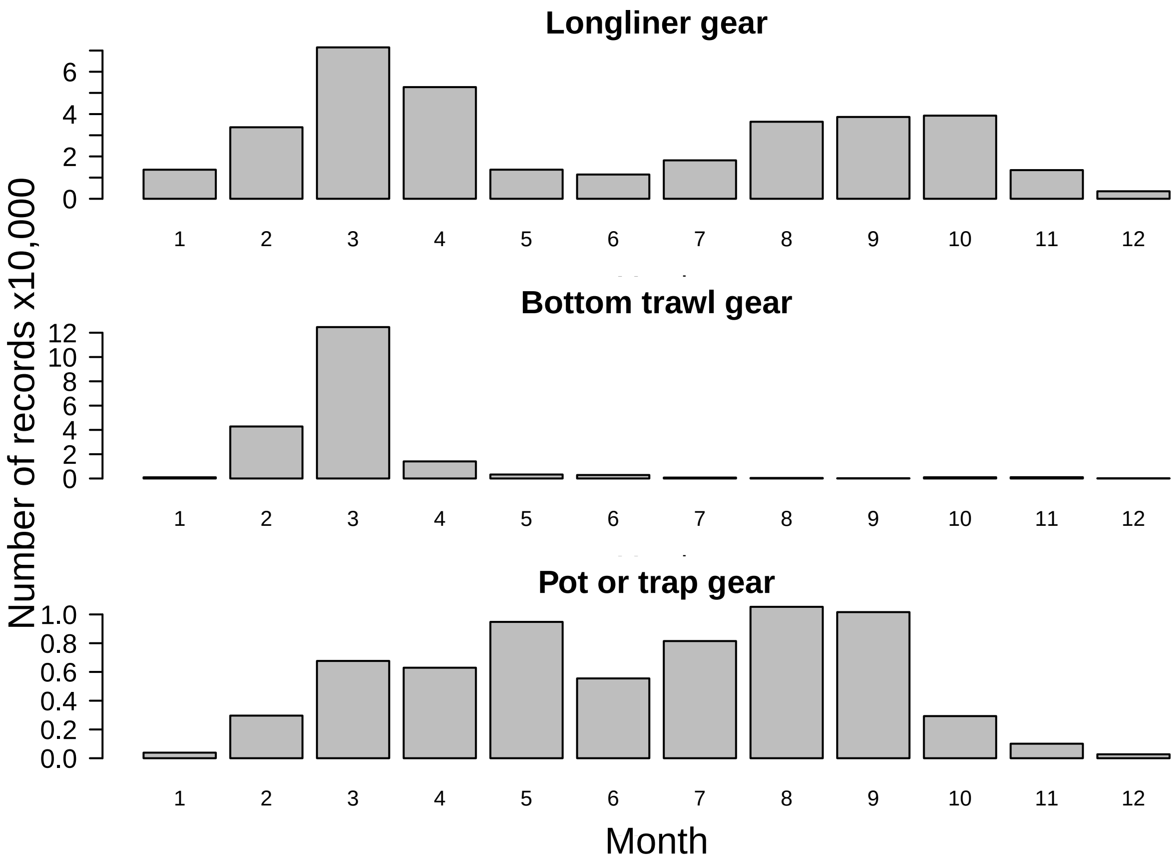


Figure 2A.4.3: Proportion of fishery lengths taken by month for each gear type, with year of the month listed as a number from 1 (January) to 12 (December), 1990-2018, based on 816,676 records.

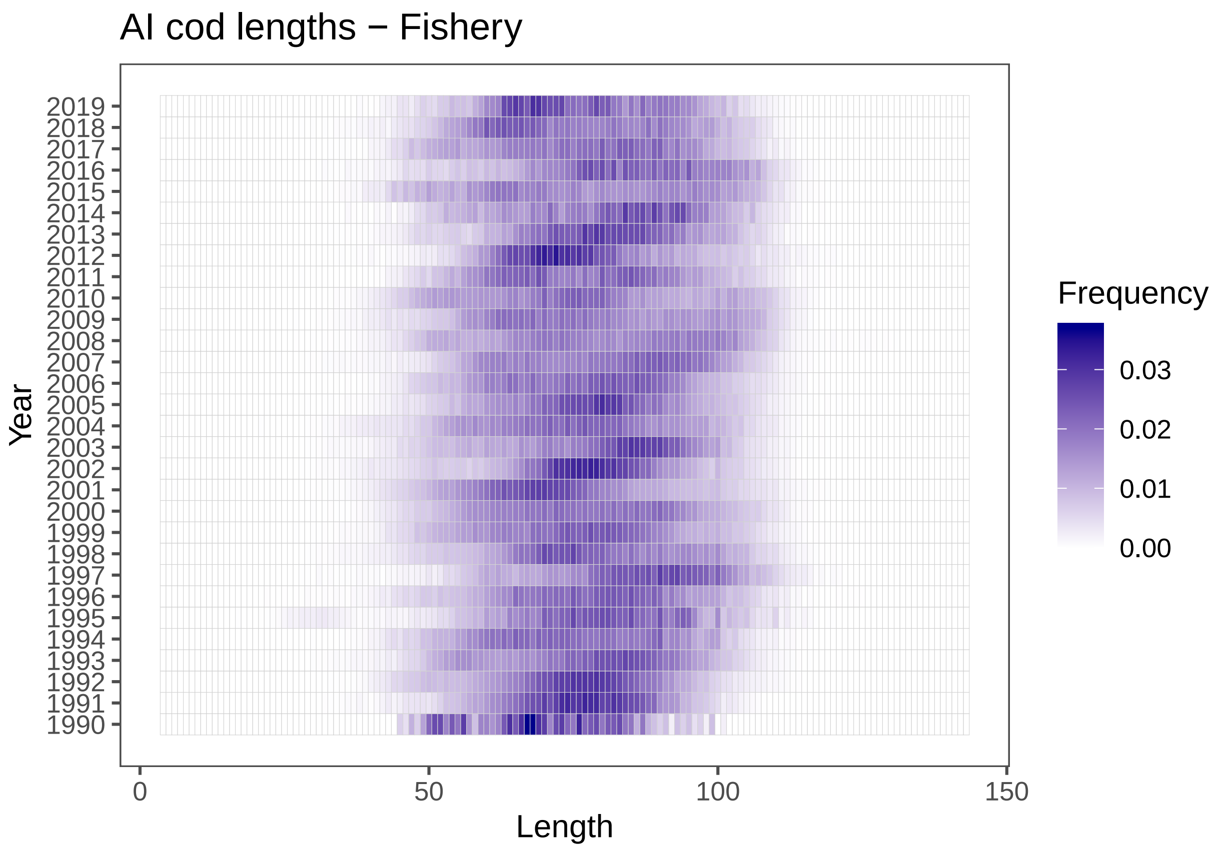


Figure 2A.4.4: Length compositions from the Aleutian Islands Pacific cod fishery, 1990-2019. Length is in centimeters (cm).

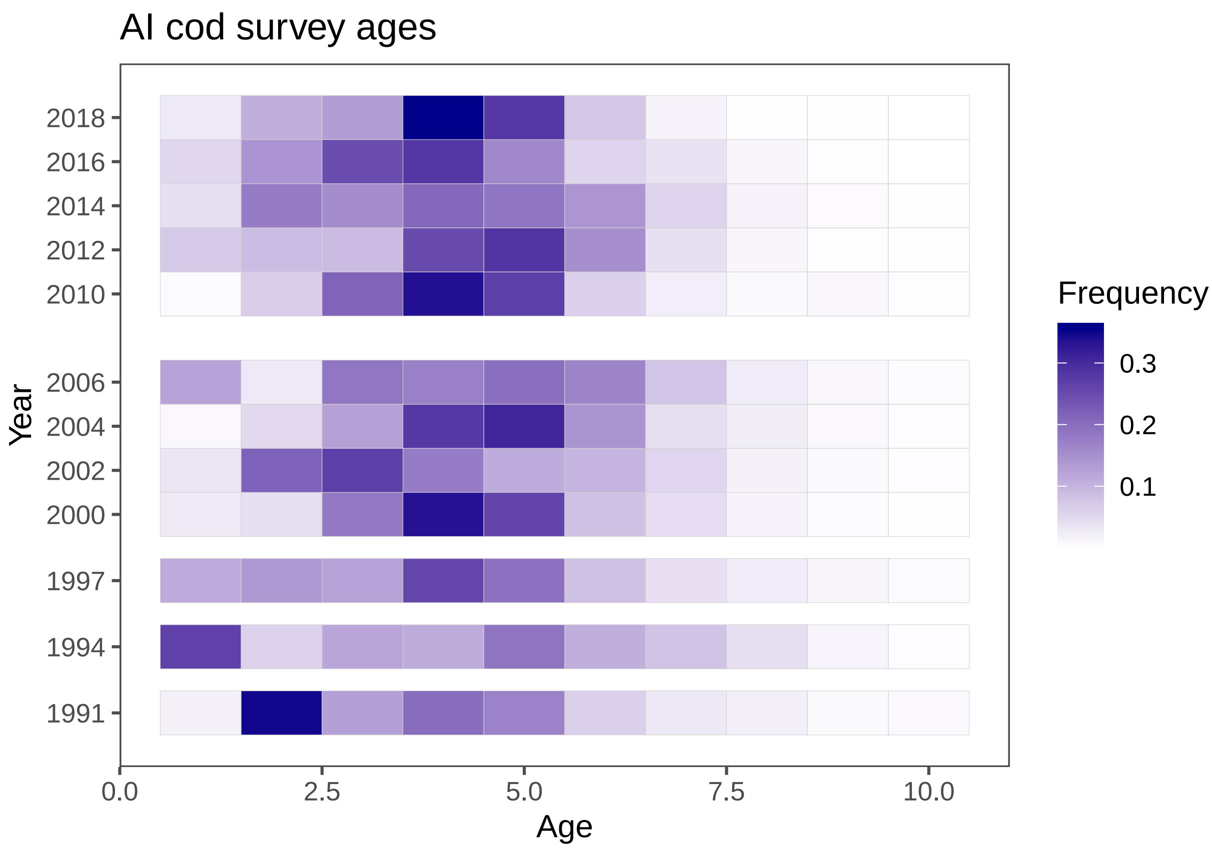


Figure 2A.4.5: Age composition from the NMFS Aleutian Islands surveys, 1991-2018.

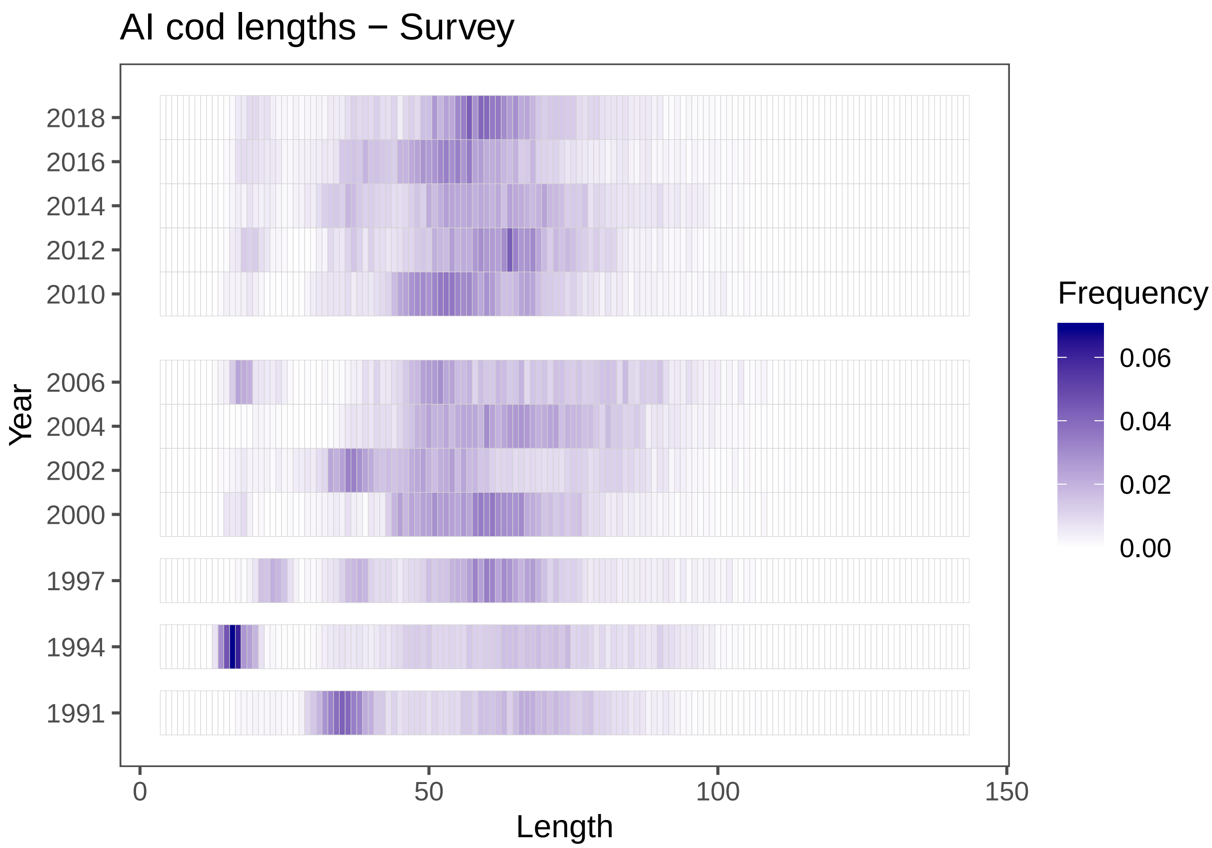


Figure 2A.4.6: Length compositions from the NMFS Aleutian Islands surveys, 1991-2018. Length is in centimeters (cm).

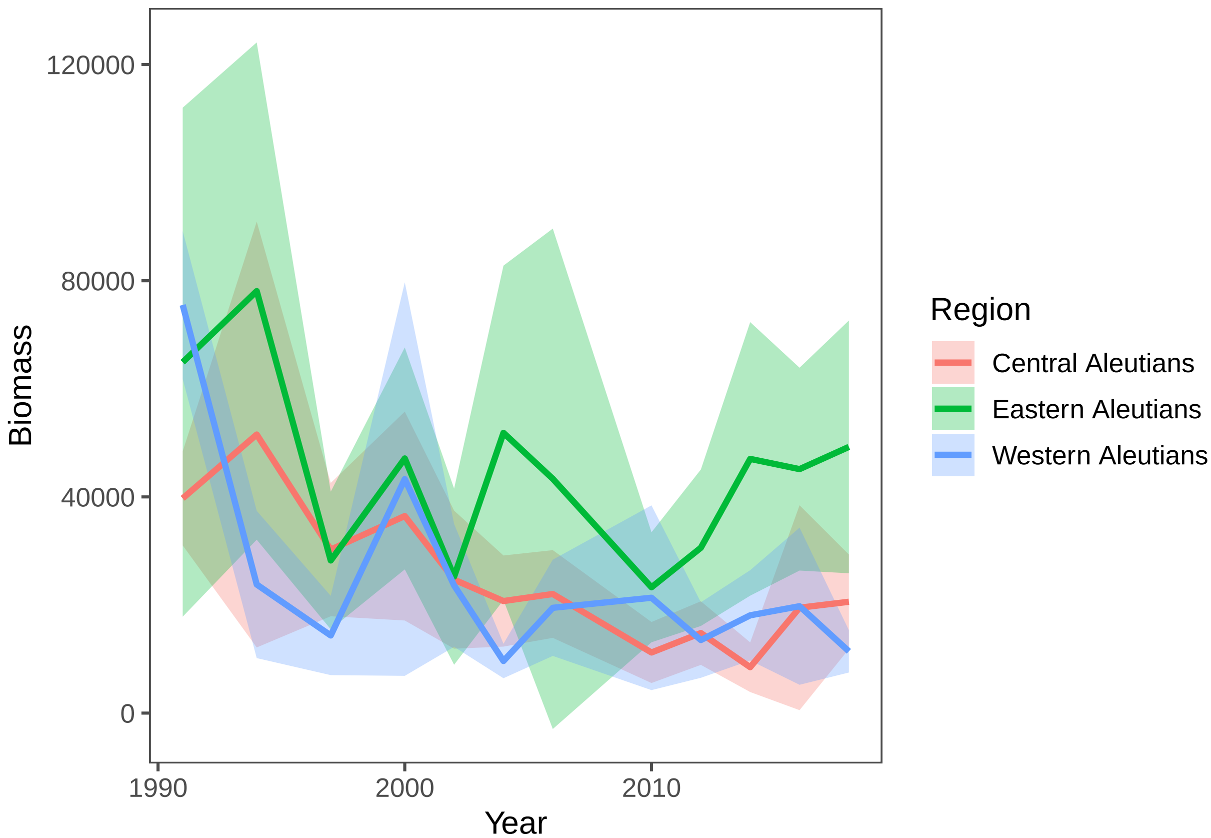


Figure 2A.4.7: Survey estimates of biomass in metric tons and 95% confidence intervals in the three NMFS areas of the Aleutian Islands, 543 (Western), 542 (Central), and 541 (Eastern), 1990-2018. Note that surveys prior to 1990 weren not performed under current standard, and were not used in this assessment.

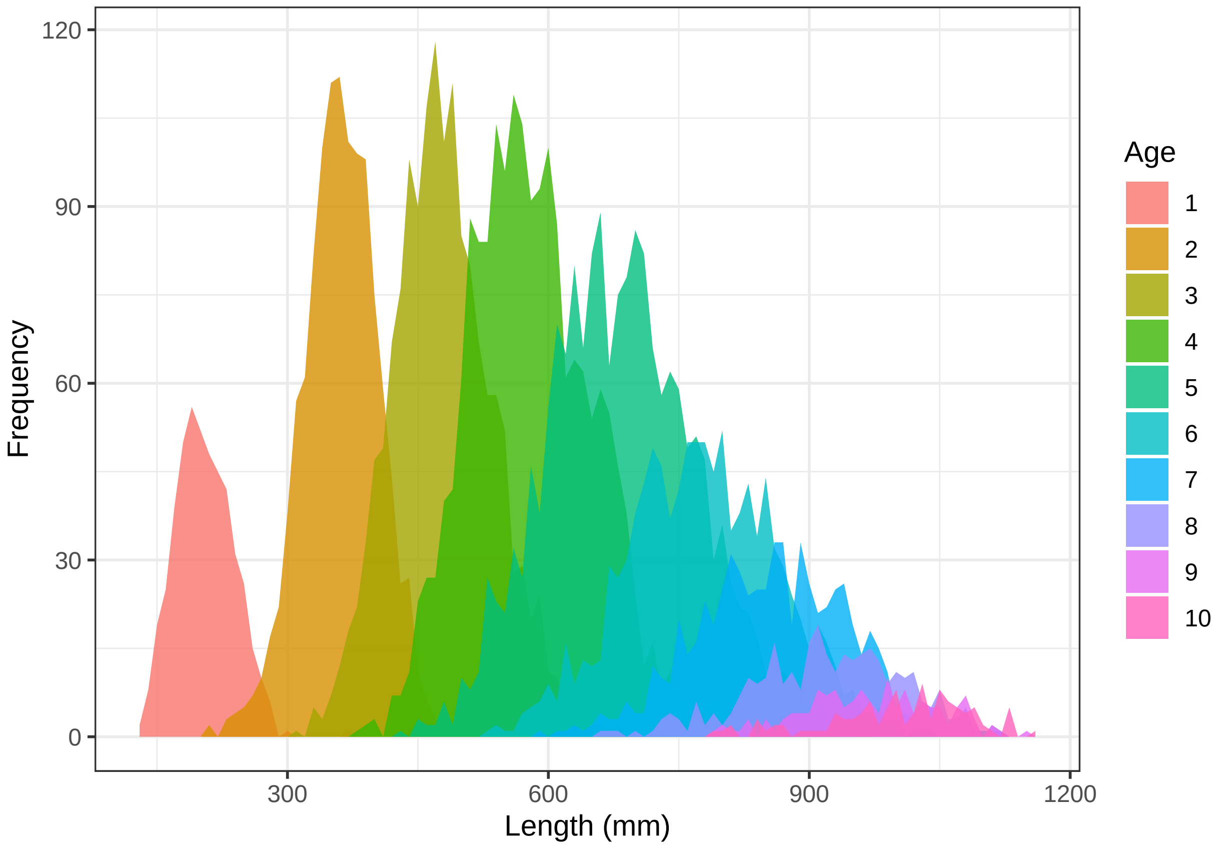


Figure 2A.4.8: Length frequency by age of cod collected from surveys from 1990-2018.

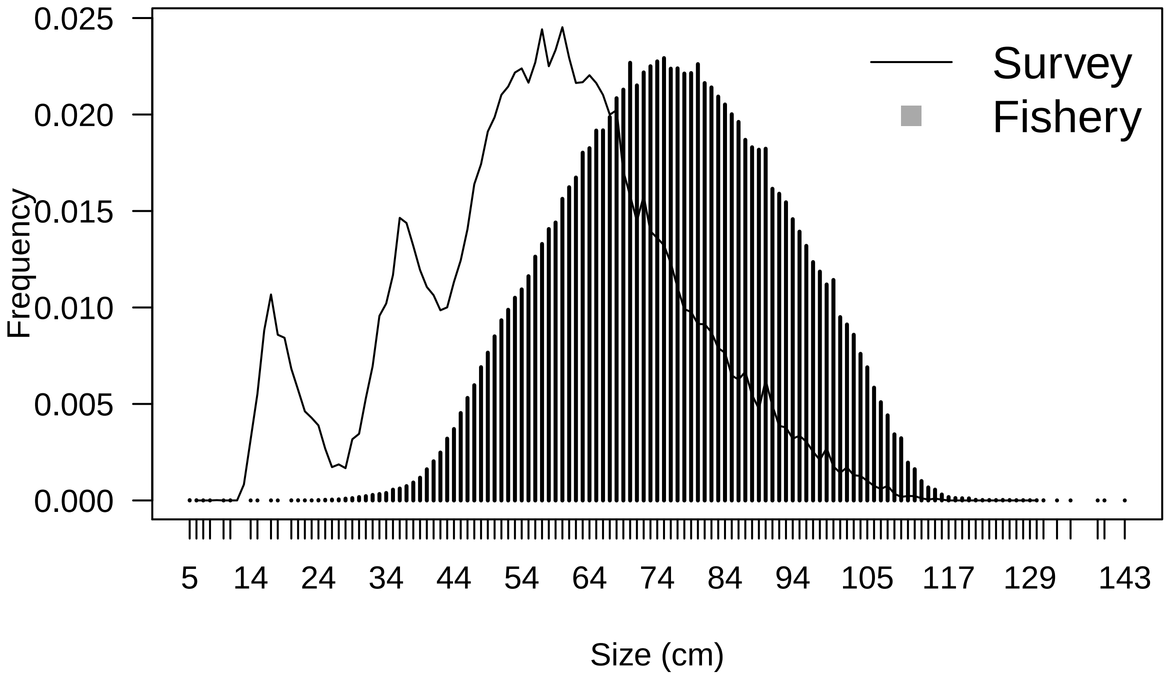


Figure 2A.4.9: Length frequencies for Pacific cod caught in the Aleutian Islands by the fishery (1990-2019) and the survey, 1991-2018.

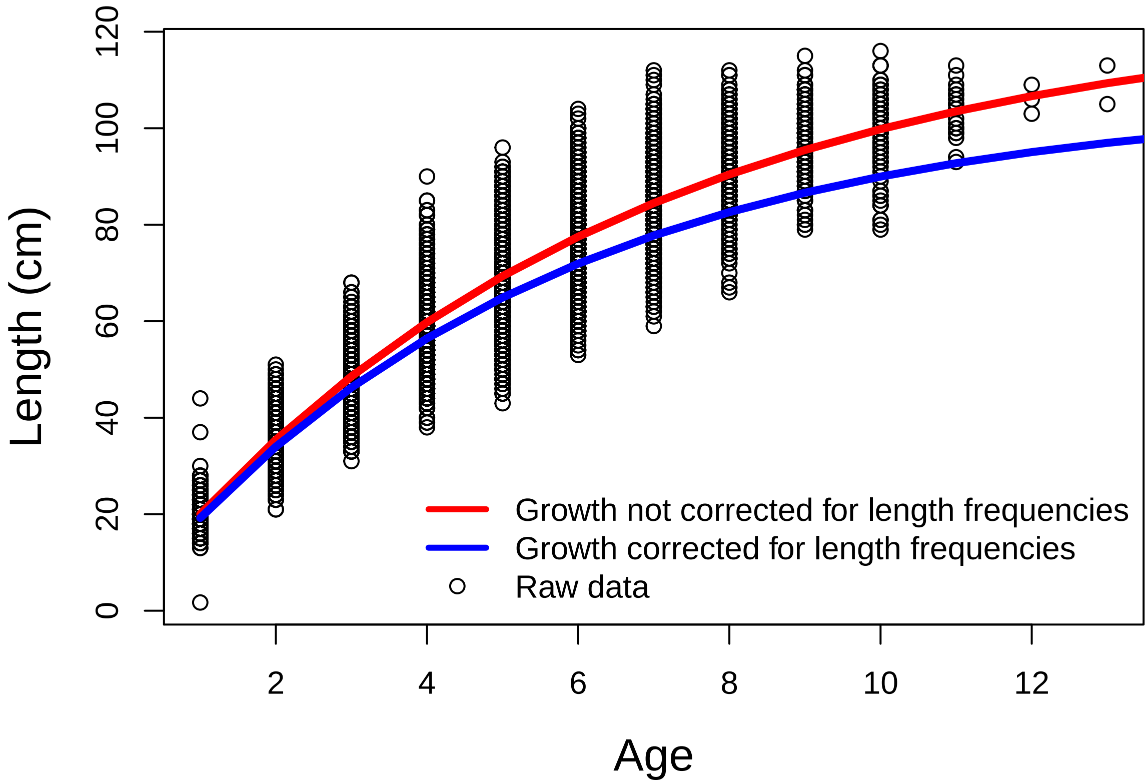


Figure 2A.4.10: Raw lengths at age and vonBertalanffy growth curves, corrected vs. not corrected for population length frequencies.

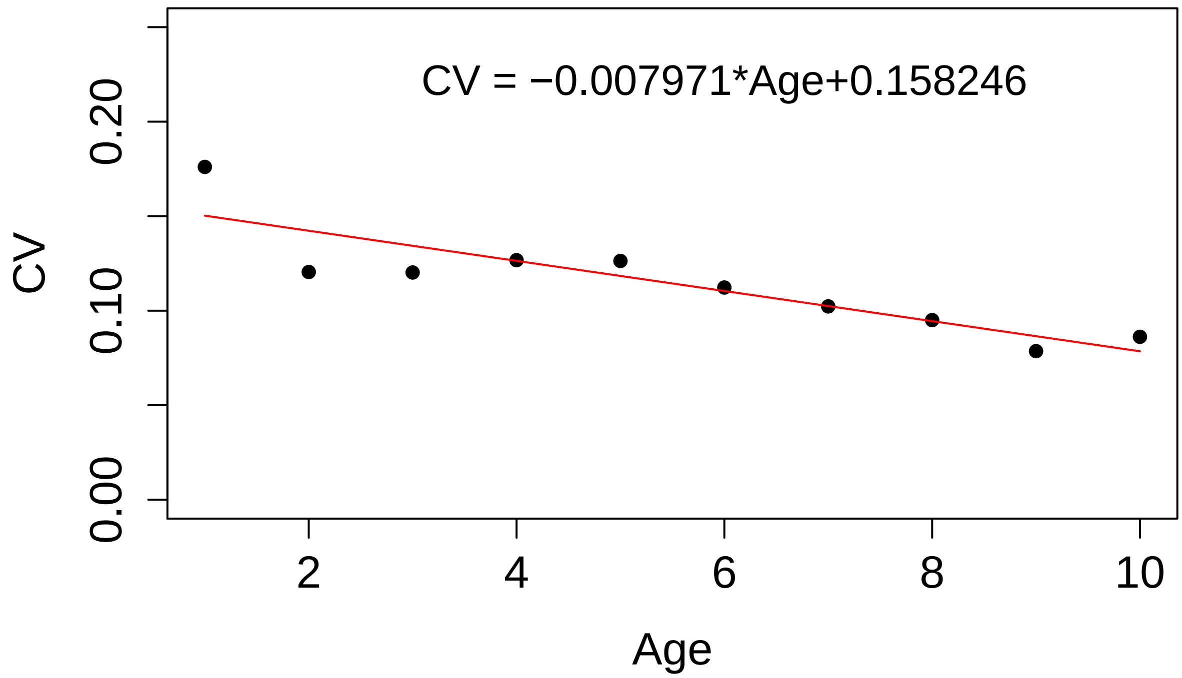


Figure 2A.4.11: Coefficient of variation (CV) fitted to age, based on raw data (black points.

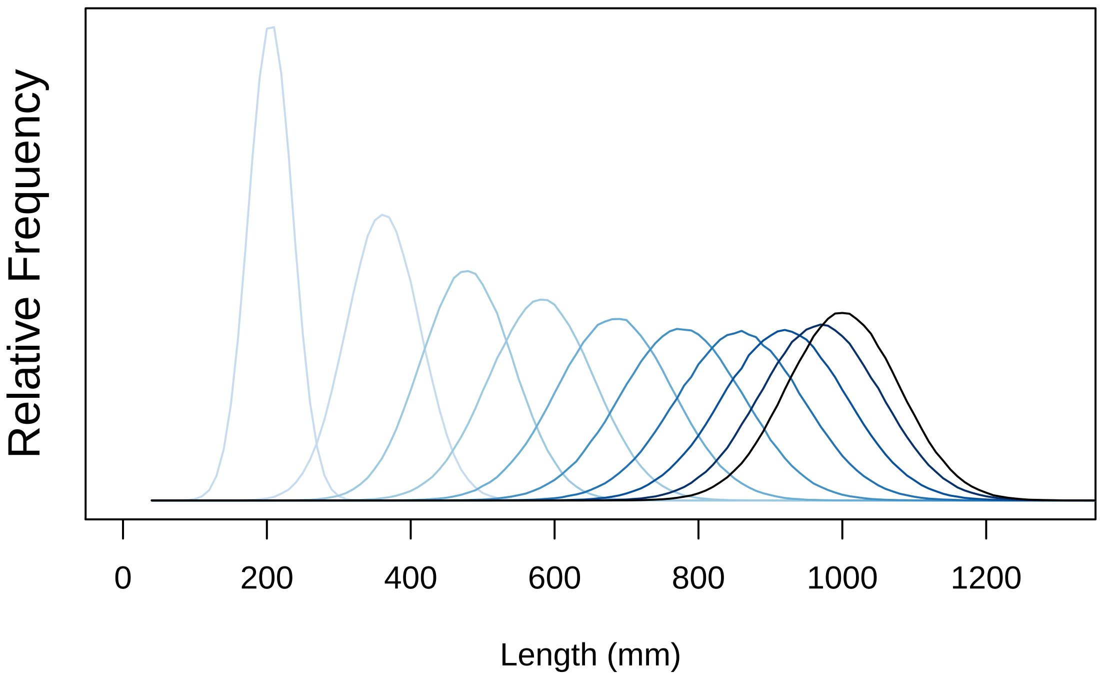


Figure 2A.4.12: Length age conversion matrix for Aleutian Islands Pacific cod, ages 1-10, where 10 represents ages 10 and higher.

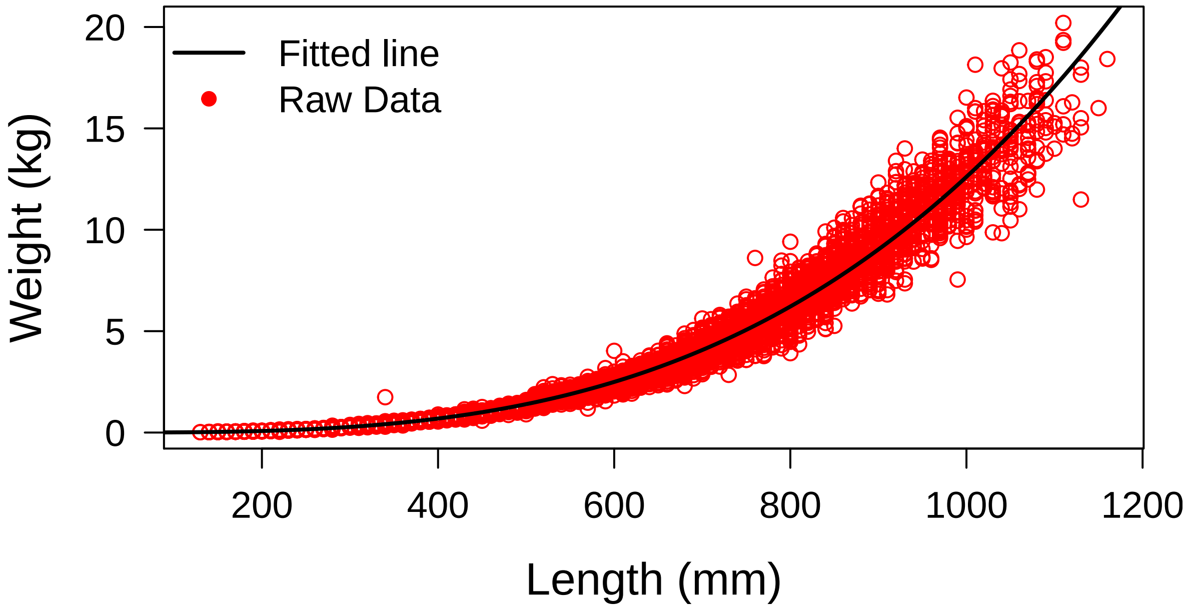


Figure 2A.4.13: Length-weight relationship for Aleutian Islands Pacific cod, males and females combined. The fit to weight-at-length is shown as a black line. Data is from surveys 1990-2018.

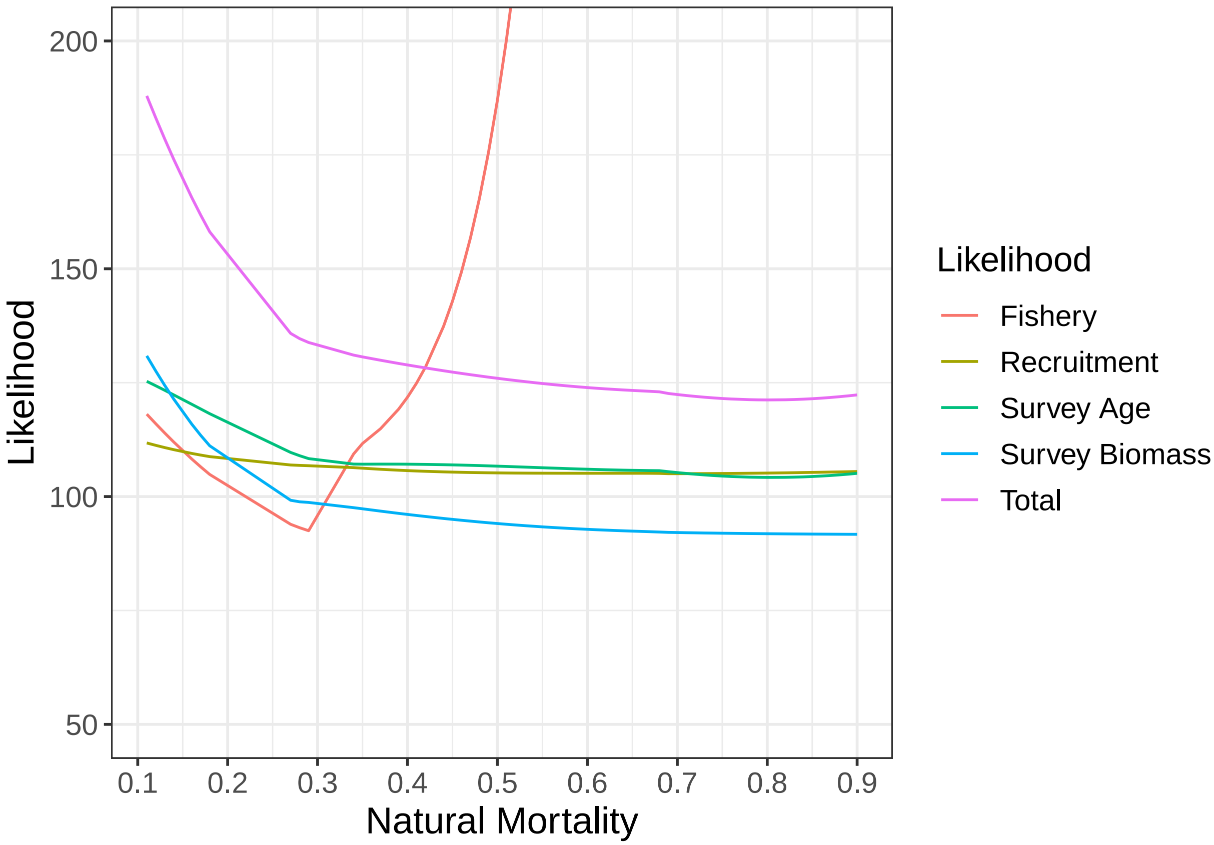


Figure 2A.4.14: Likelihood profile for natural mortality, showing age, fishery length, recruitment, survey biomass likelihood components. The total likelihood does not include the fishery likelihood component.

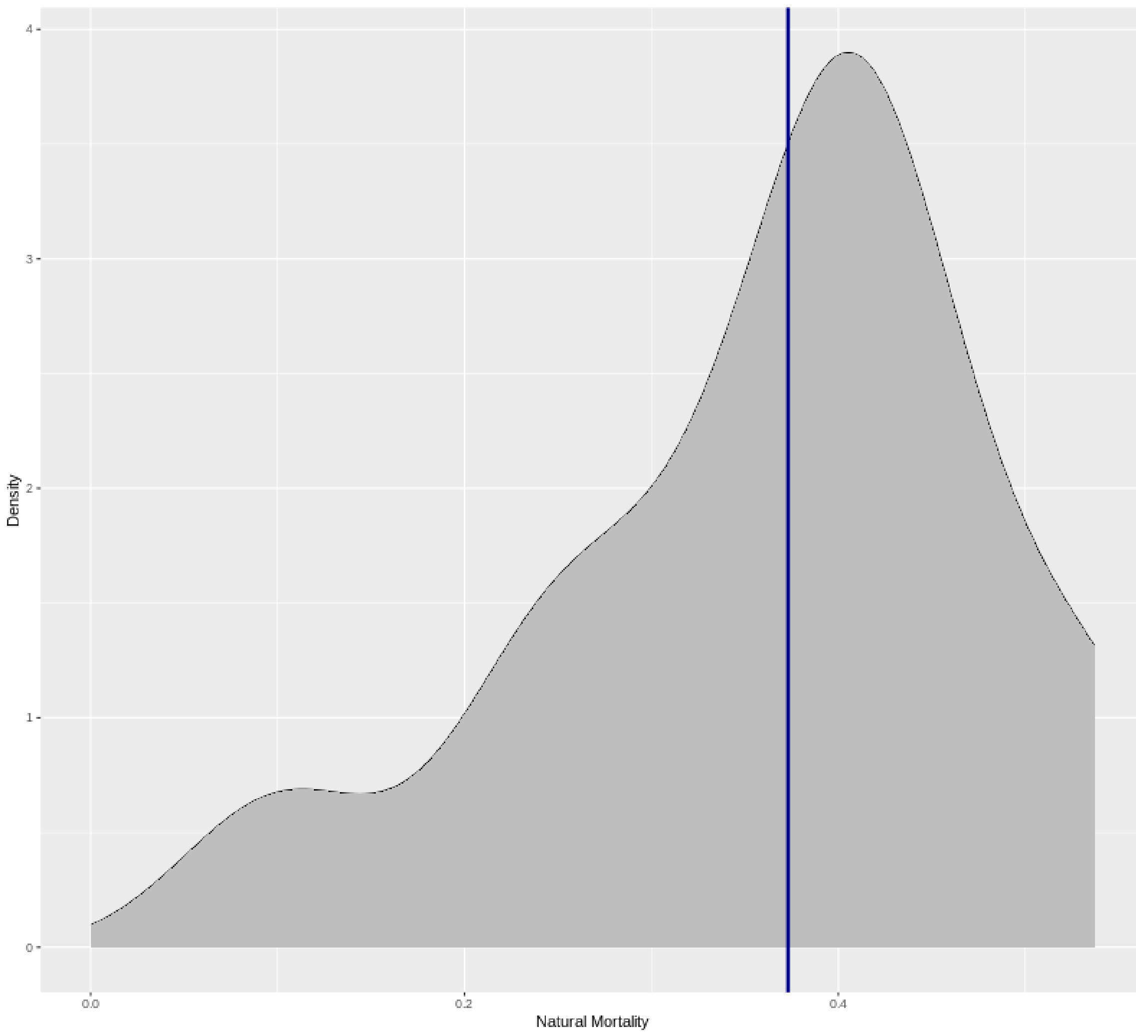


Figure 2A.4.15: Median value for natural mortality for Aleutian Islands Pacific cod (M=0.36) estimated using a composite method by Jason Cope (http://barefootecologist.com.au/shiny_m.html).

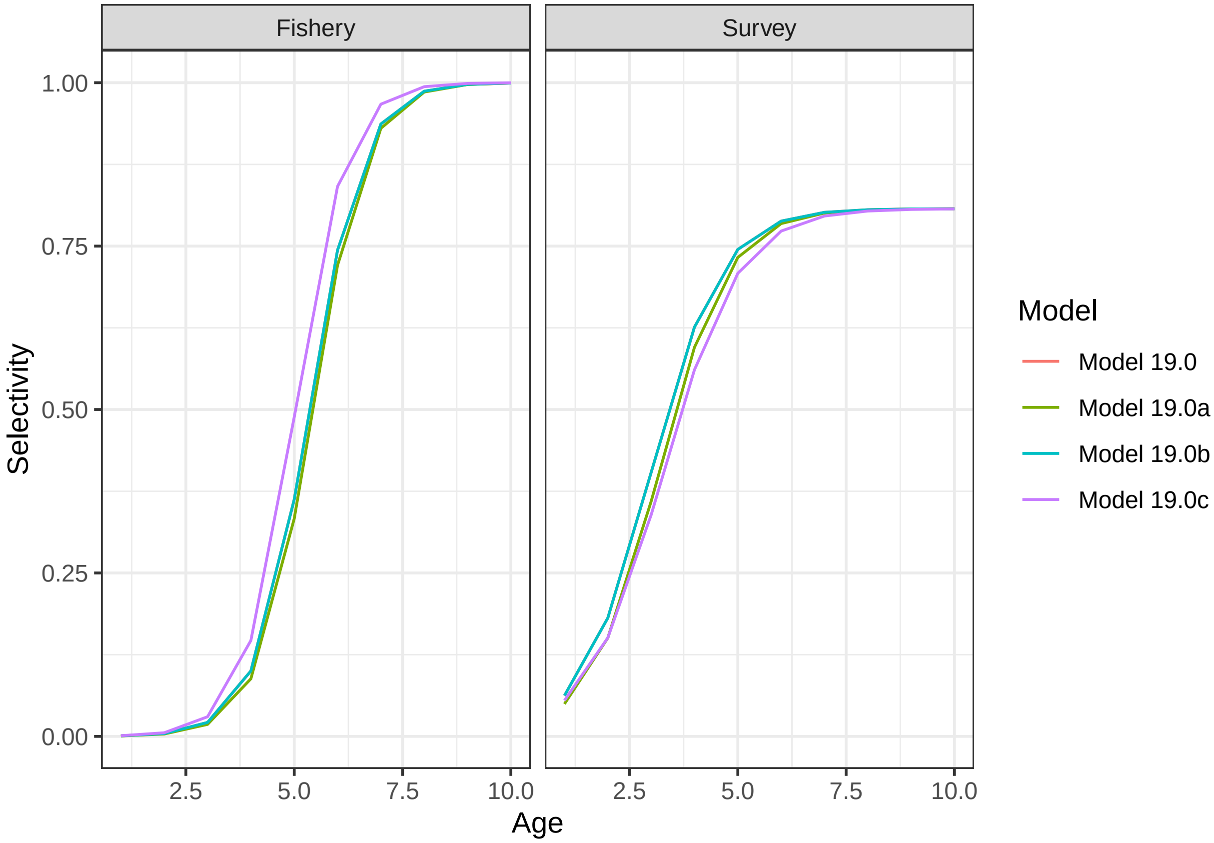


Figure 2A.4.16: Model estimates for selectivity for the survey and the fishery. The survey selectivity curve is the product of survey catchability and survey selectivity. Note: Model 19.0 and Model 19.0b have identical values.

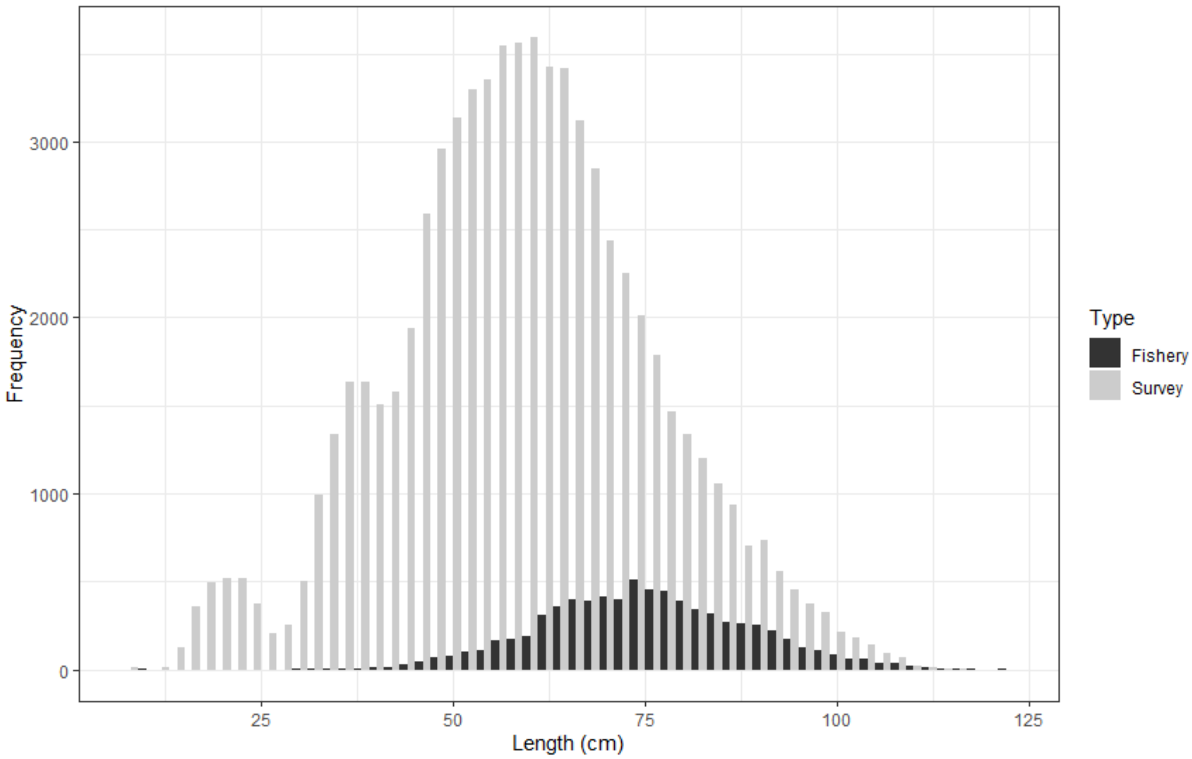


Figure 2A.4.17: Length frequency data for Pacific cod caught during summer daytime hours (May-August) in the Aleutian Islands by the fishery and the survey, from 1990-2018.

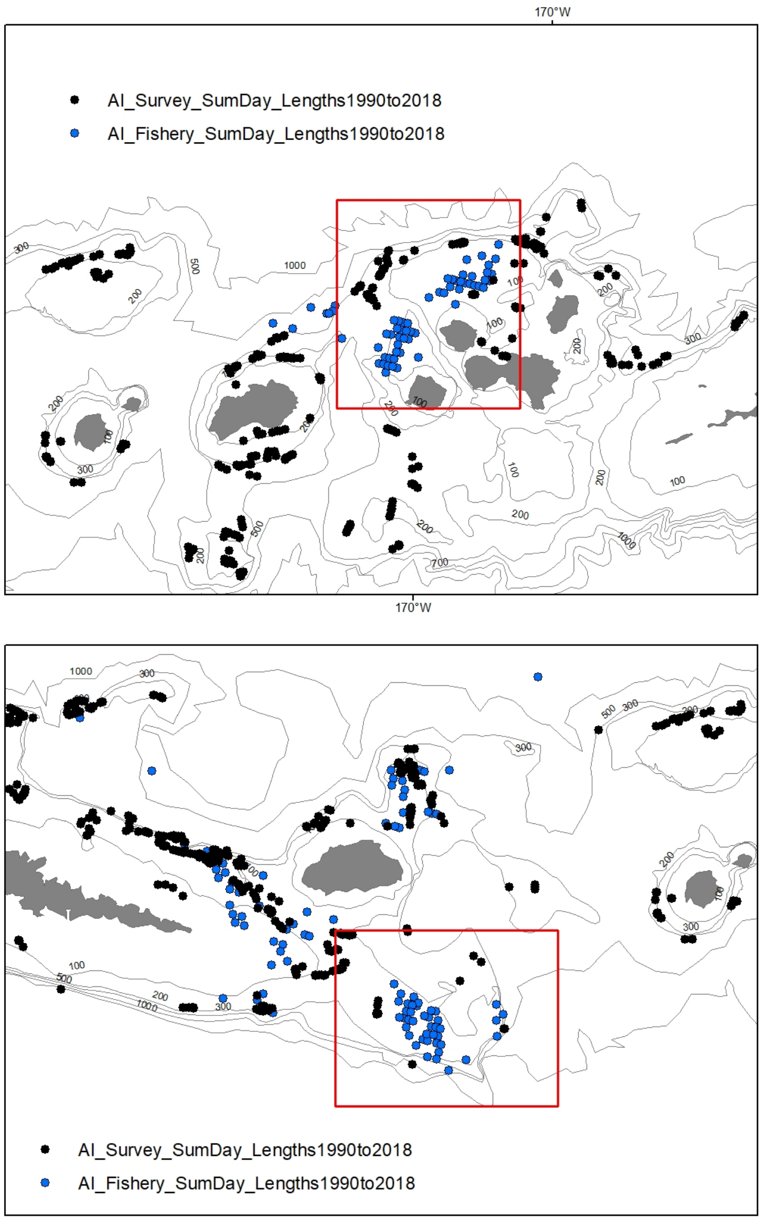


Figure 2A.4.18: Locations in which most summer fishing in the Aleutian Islands takes place, and proximate distribution of NMFS survey tows, 1990-2018. The upper plot is from the Islands of the Four Mountains and the lower plot is from Seguam Pass.

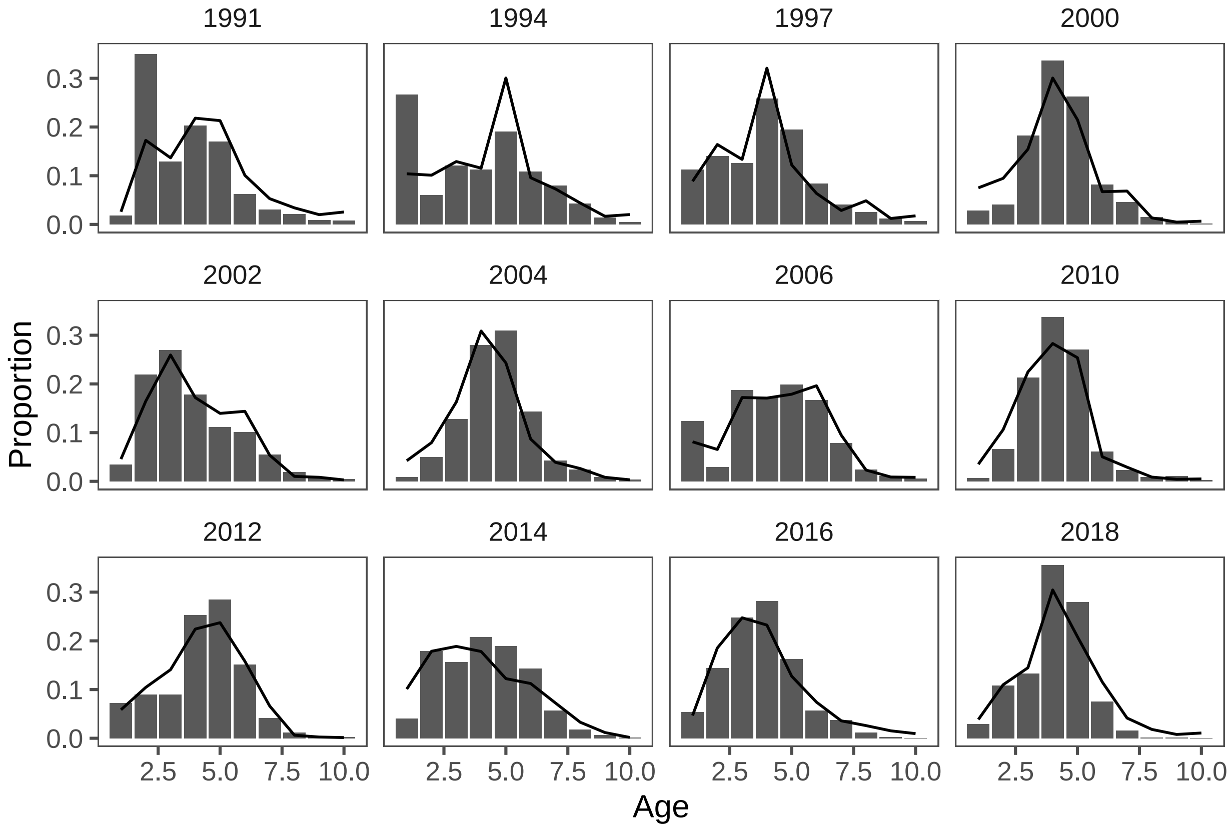


Figure 2A.4.19: Survey age frequency fit to model 19.0, solid line is predicted.

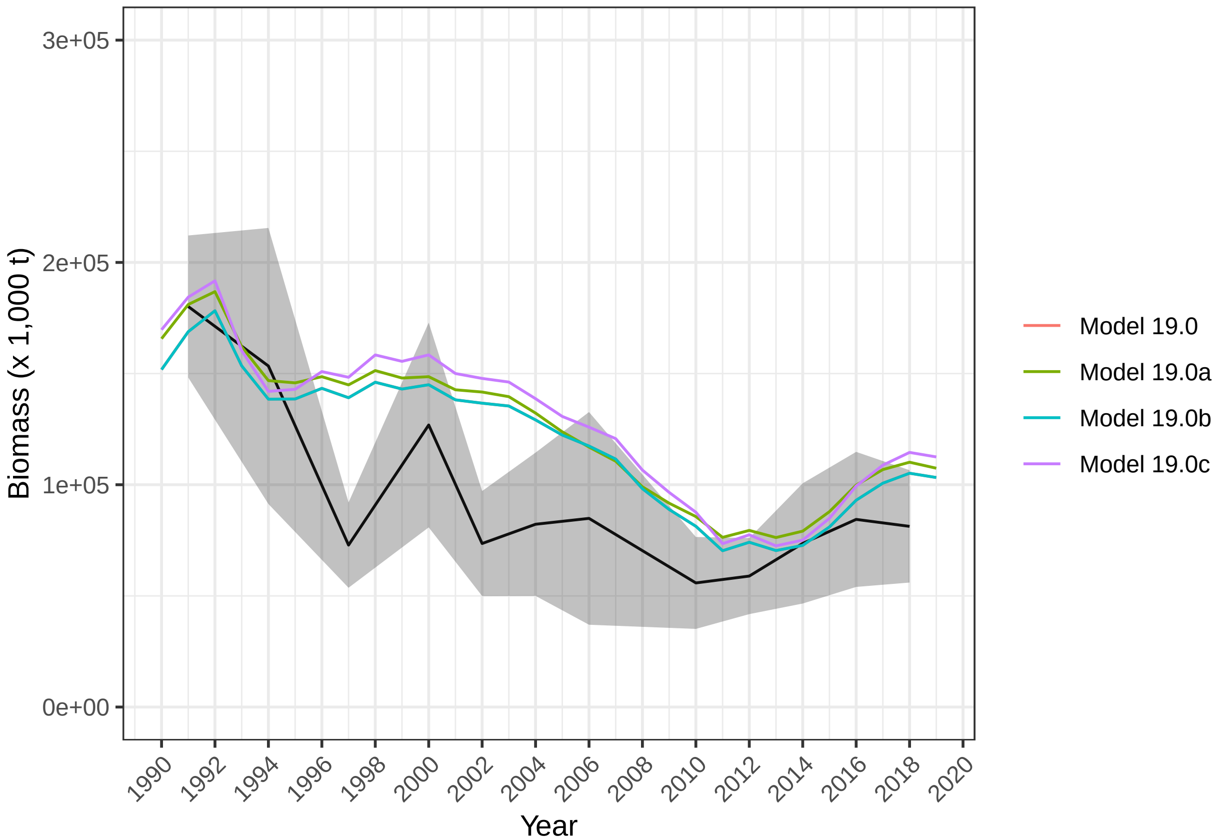


Figure 2A.4.20: NMFS Aleutian Islands survey biomass estimates, with 95% confidence intervals and the four model estimates of survey biomass, scaled down by their estimate of survey catchability, from 1990-2019. Note: Model 19.0b and Model 19.0 have the same biomass estimate.

Figure 2A.4.21: Retrospective plot of female spawning biomass. The preferred model with data through 2019 is shown, and data was sequentially removed through 2009.

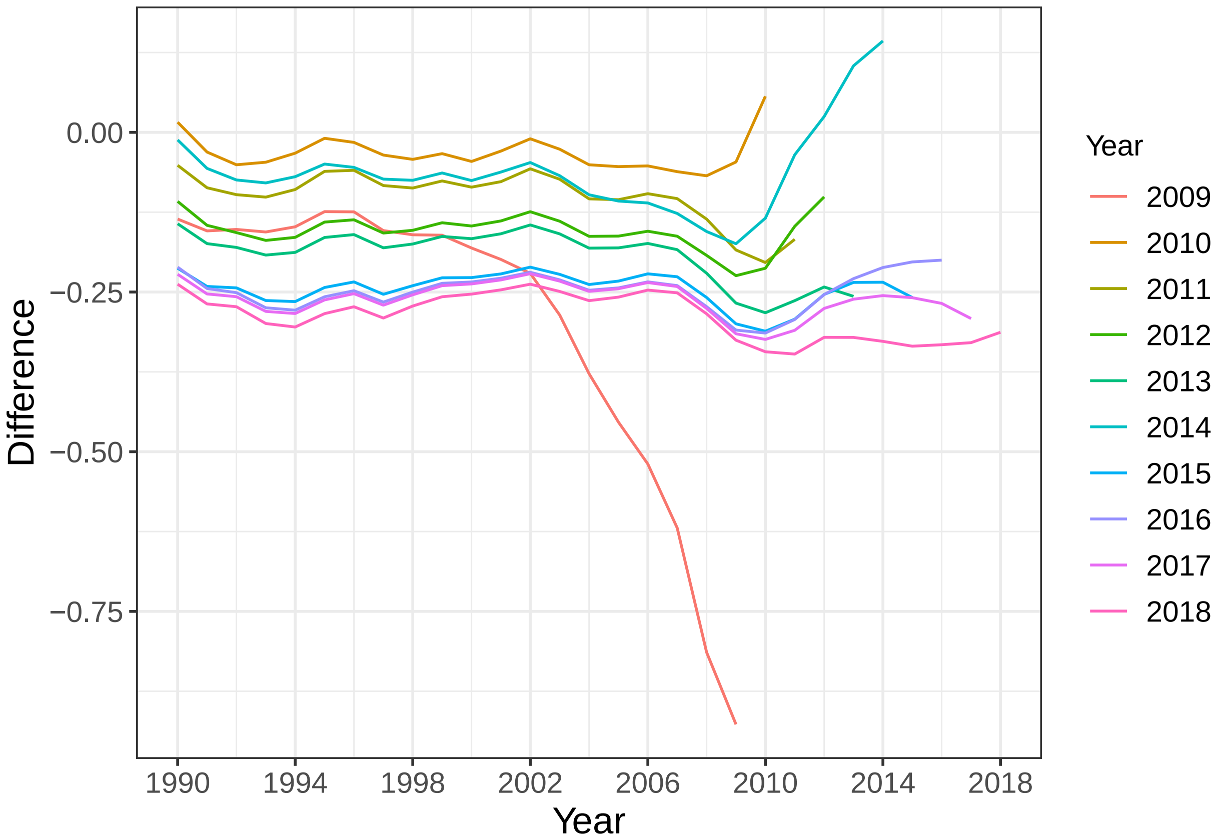


Figure 2A.4.22: Relative differences in estimates of spawning biomass between the 2019 model and the retrospective model run for years 2018 through 2009.

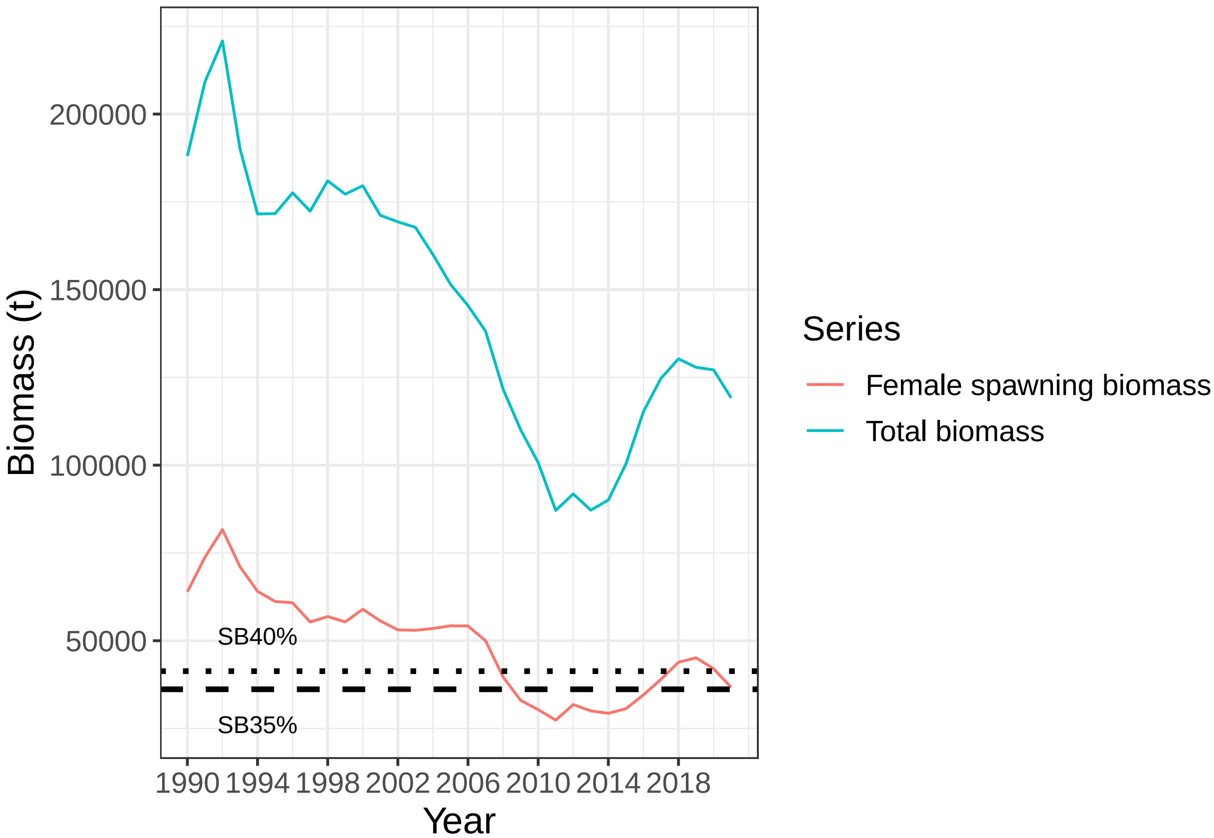


Figure 2A.4.23: Model estimates for total (age 1+) biomass and female spawning biomass from 1990-2019, plus projection model estimates for 2020 and 2021. Reference points SB40% and SB35% are shown as horizontal lines.

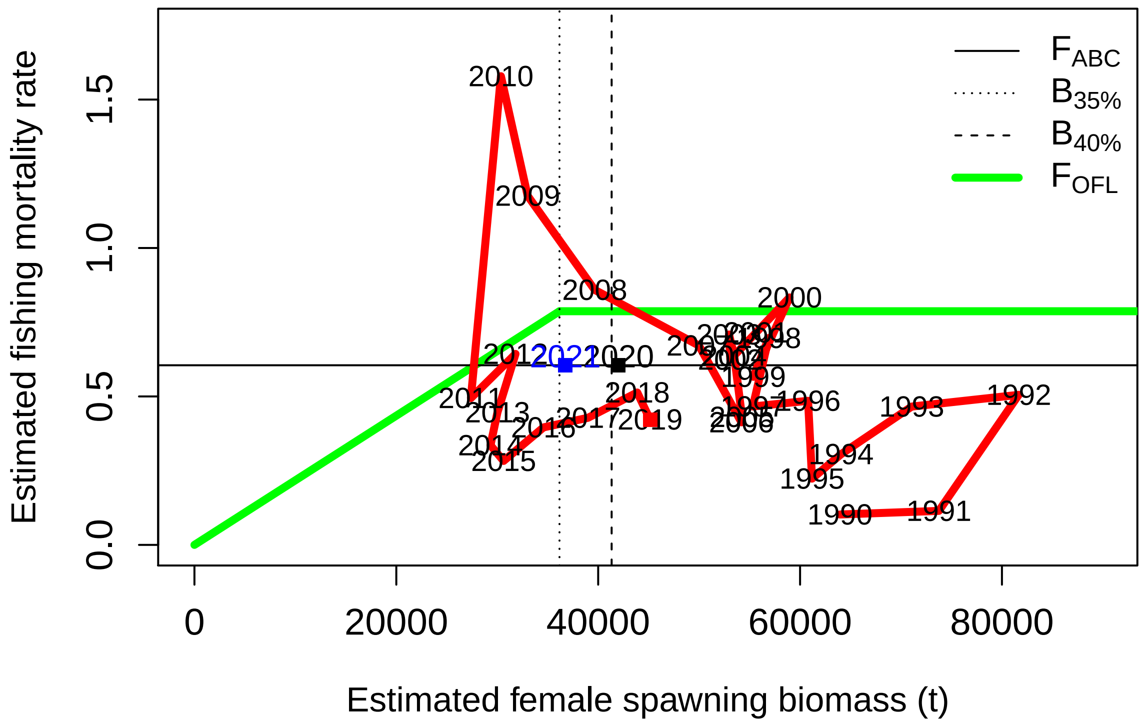
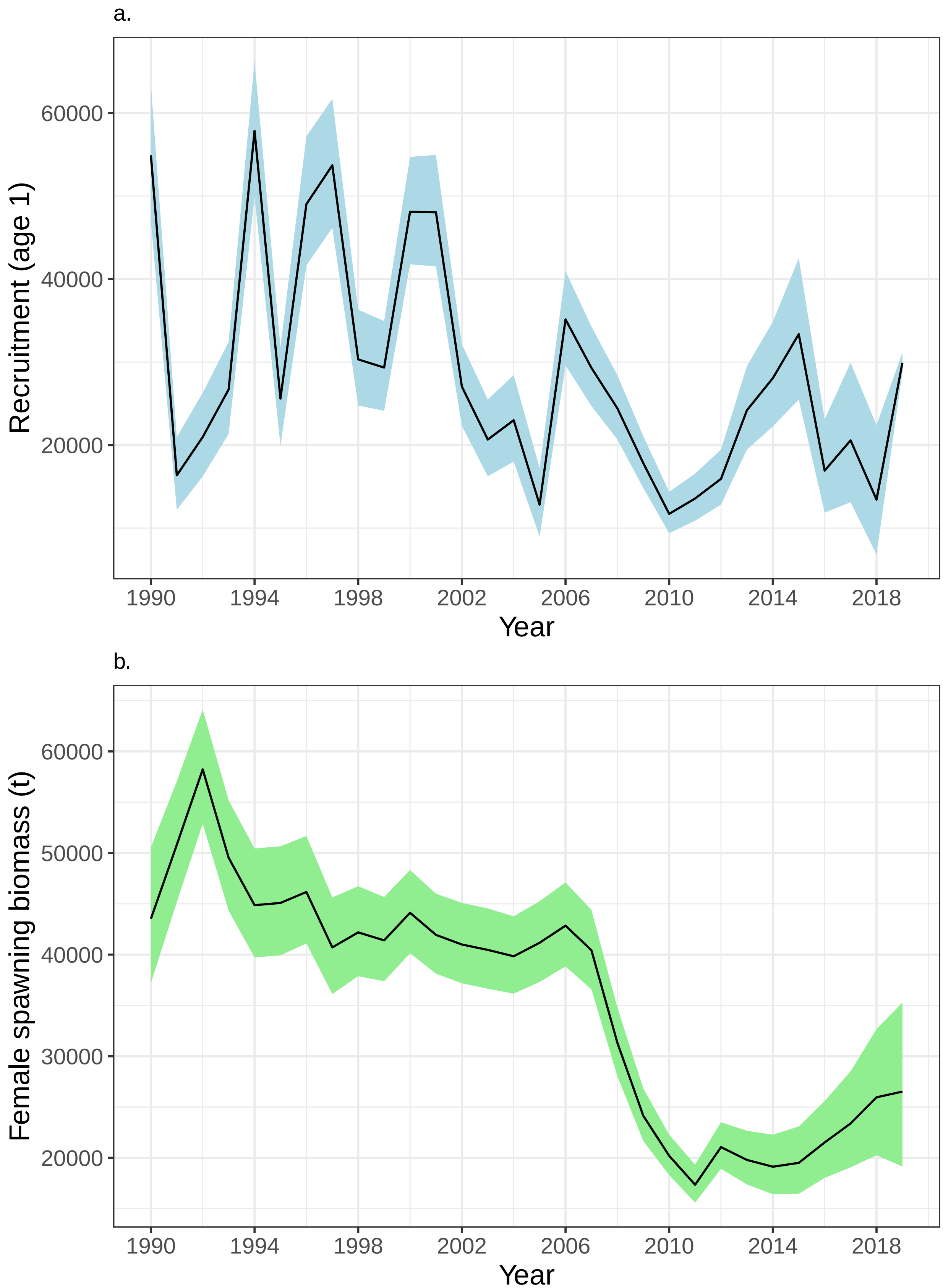


Figure 2A.4.24: Phase plane diagram showing the time-series of stock assessment model estimates of female spawning biomass relative to the harvest control rule, with assessment model results for 1990-2019 and projection model results for 2020 (black square) and 2021 (blue square).


a.
Recruitment (age 1)
60000
40000
20000
1990
1994
1998
2002
2006
2010
2014
2018
Year
b.
Female spawning biomass (t)
60000
50000
40000
30000
20000
1990
1994
1998
2002
2006
2010
2014
2018
Year

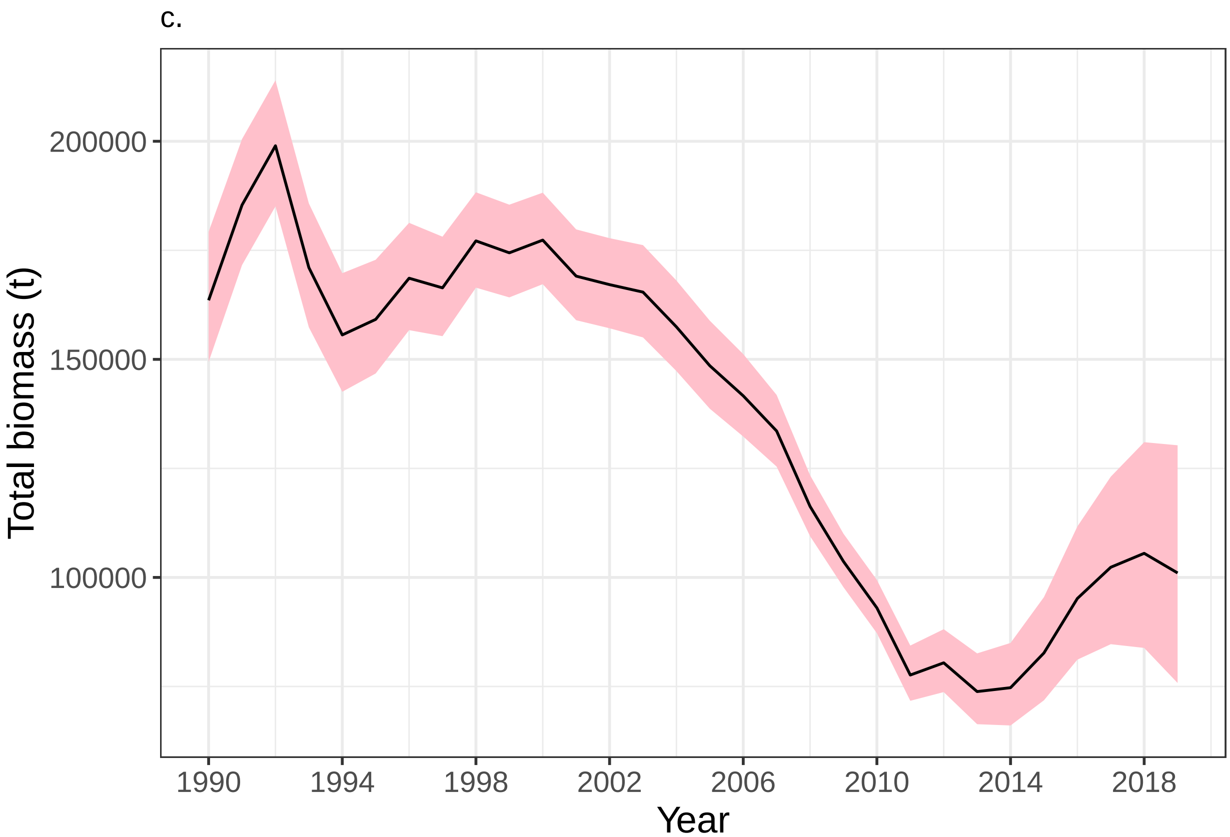


Figure 2A.4.25: Mean and 95% credible intervals for age 1 recruitment (panel a.), female spawning biomass (t) (Panel b.), and total biomass (t) (Panel c.).

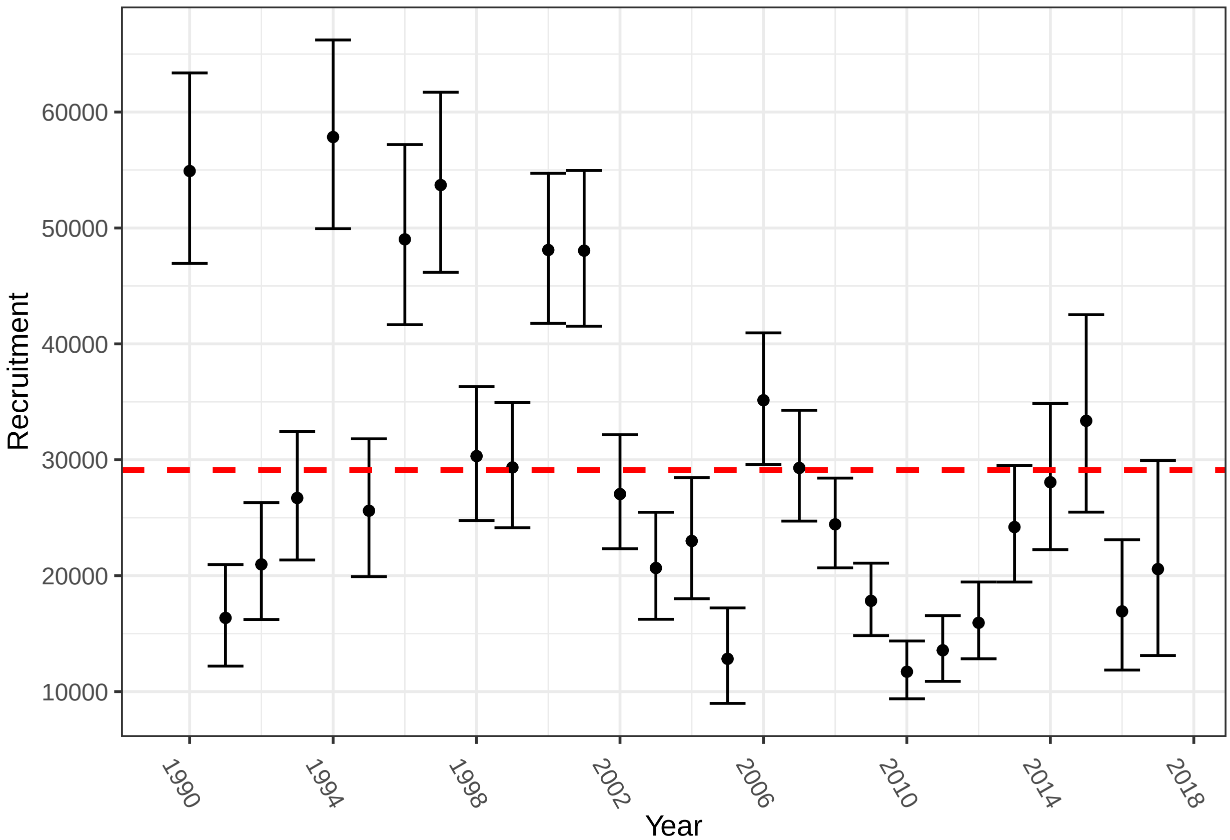


Figure 2A.4.26: Age 1 estimated recruitments (male plus female) in numbers from 1990 to 2017, with approximate 5% and 95% credible intervals. Data was generated using 1e+06 MCMC iterations, and thinning every 100 iterations. The horizontal line represents the average recruitment over this period. The dashed horizontal line indicates mean recruitment from 1990-2017, 2.863e+04.

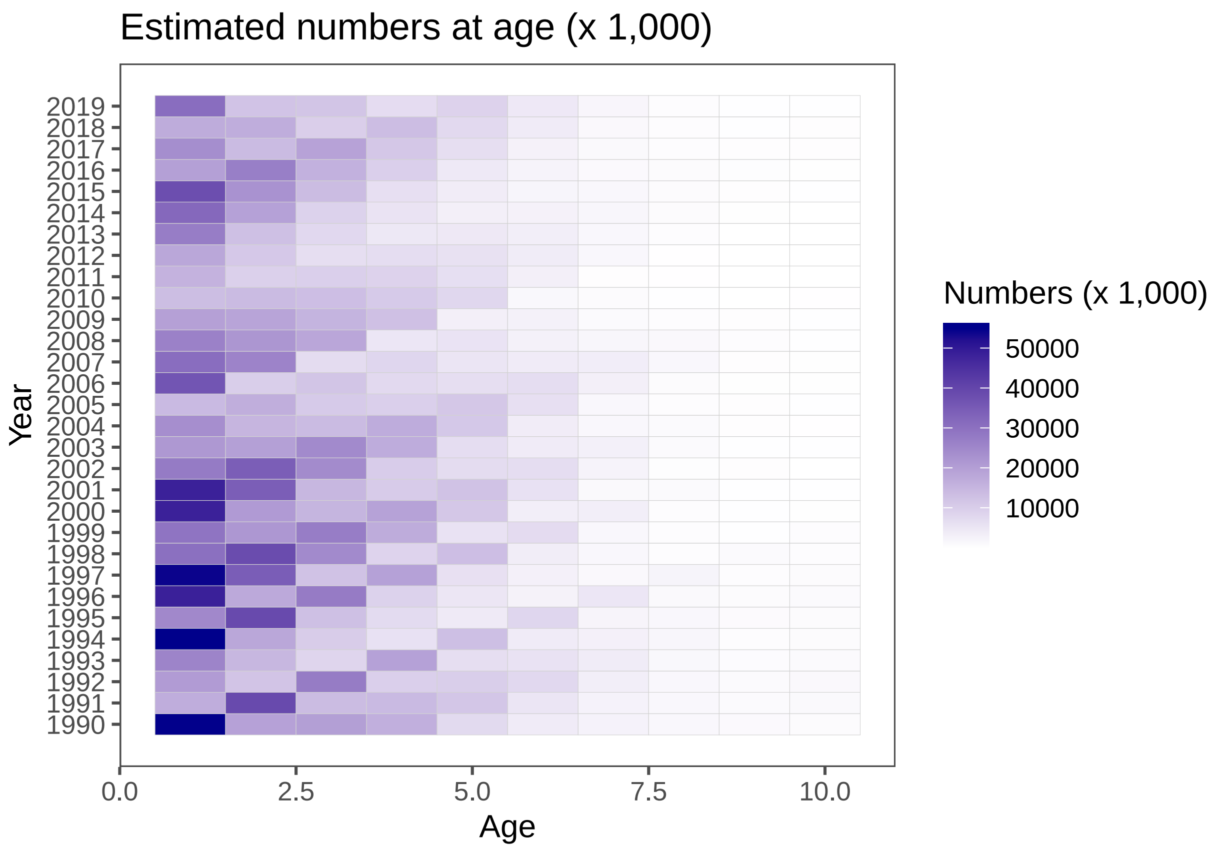


Figure 2A.4.27: Estimated numbers at age of Aleutian Islands cod (x 1,000), based on Model 19.0.

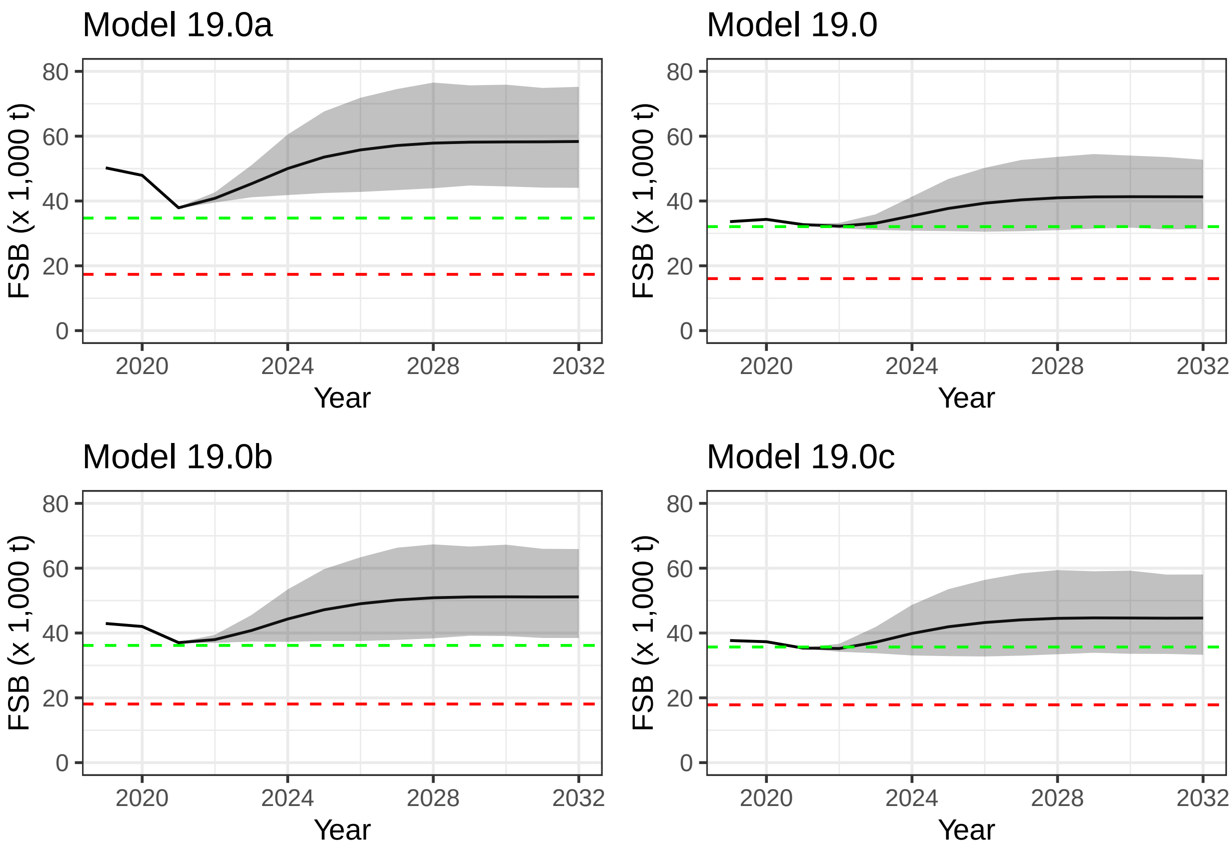


Figure 2A.4.28: Projected female spawning biomass (FSB x1,000 t) for 2019 to 2032 with 95% confidence intervals, and fishing at the 5-year (2014-2018) average fishing mortality rate. Green horizontal lines indicate B35% and red lines half of B35%.

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APPENDIX 2A.5--RISK TABLE INFORMATION FOR "ENVIRONMENTAL/ECOSYSTEM CONSIDERATIONS"

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The status of the Aleutian Island region was assessed in 2018 (no surveys in 2019), therefore the considerations noted here reflect 2018 conditions and/or conditions that prevailed during the previous marine heatwave in the Gulf of Alaska (2014-2016). The Gulf of Alaska is currently experiencing a new marine heatwave (since September 2018), and due to current flow, conditions in the Aleutian Islands reflect the broader conditions in the Gulf of Alaska.

Both Pacific cod and Arrowtooth flounder continue to be the largest component of the apex predator guild in the Aleutian Islands ecosystem. In 2018, the condition of Pacific cod (as measured by length/weight residuals) were strongly negative, continuing a trend since 2010.

In the western Aleutian Islands, the biomass of the apex predator foraging guild (including Pacific cod) continued its long term decline to the lowest level of the time series in 2018. Within the guild, the largest declines were noted for Pacific cod. The apex predator guild biomass was also low in 2016, therefore continued downward trends are expected under new marine heatwave conditions. However, the trend across the Aleutian Islands was balanced by increases in the eastern and central Aleutian Islands ecoregions.

In the central Aleutian Islands, the fish apex predator foraging guild biomass decreased only slightly from 2016 to 2018, but both years were below the long term mean. Pacific cod represent the largest portion of survey biomass in this region.

In the eastern Aleutian Islands, the fish apex predator foraging guild biomass increased from a low in 2012 and Pacific cod largely contributed to the increase. The biomass of this guild was below the long term in 2016, but increased to above the long term mean in 2018.

Prey: Pacific cod feed approximately equal parts on crustacean zooplankton and fish and are able to switch between prey resources based on availability. Indicators of Pacific cod prey abundance, both zooplankton and forage fish, are inferred from indirect indices. For zooplankton, auklet reproductive success can be used as an indicator for availability of zooplankton. Both Parakeet and Least auklet reproductive success were above at or, respectively, their long term mean at Buldir (western Aleutian Islands) in 2018. This suggests that zooplankton availability was sufficient to support chick-rearing at both colonies. For forage fish abundance, murre and puffin reproductive success indicate availability of forage fish. At Buldir, reproductive success was below the long term mean for both species; at Aiktak (eastern Aleutian Islands), murre reproductive success was down, but puffin success was well above average. This suggests that forage fish prey were insufficient to support chick-rearing at Buldir with mixed results at Aiktak. Other indirect indices of lower trophic dynamics include: (i) large diatoms, (ii) copepod size, and (iii) mesozooplankton available from the Continuous Plankton Recorder. Large diatoms reflect hard-shelled phytoplankton while the mean copepod community size is an indicator of community composition. All three metrics were low during the previous heatwave (2014-2016) and suggest reduced energy available for trophic transfer to apex predators such as Pacific cod.

Predators: Pacific cod are a prey source to other fish and marine mammals, including Steller sea lions, so fluctuations in its biomass affect both prey and predator populations. The western Aleutian Island Steller sea lion adult population decreased rapidly at approximately 7% per year and sub-area population trends improved to the east through the western Gulf of Alaska, where the annual trend increased approximately 4% per year. Regional trends in pup production are similar to trends in non-pup counts, with continued relatively steep declines in the western Aleutian Islands, a less steep decline in the central Aleutian Islands, and improvement in the eastern Aleutian Islands. Additionally, the abundance of jellyfish peaked during the previous heatwave (i.e., 2016) and therefore might be expected to increase under current heatwave conditions. Jellyfish may act as both a predator and competitor, particularly for pre-settlement and juvenile Pacific cod.