Assessment 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 since 2012. This document presents three age structured models for the Aleutian Islands Pacific cod stock using data from 1991 through 2021 and a Tier 5 status determination. A preliminary version of this document was presented to the BSAI Plan Team in September, 2021 and to the SSC in September, 2021.

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 2021 preliminary report. In this assessment, a Tier 5 model and three age-structured models are presented.

Changes in the input data

- Age structured models: Age structured model were last presented for AI cod in 2019. Updated catch data was included for the full 2019 and 2020 fishing seasons, and through October 1, 2021. Fishery length frequency data was added for 2019 through 2021. There have been no Aleutian Islands surveys since 2018.
- Tier 5 model (Model 13.4): No new data was available for the Tier 5 model, as there has not been an Aleutian Islands survey since 2018.

Changes in the assessment methods The September, 2021 preliminary models considered two estimates for natural mortality, M, and several methods for calculating natural mortality. These parameterizations are discussed in this document.

1. The September preliminary model considered M=0.34, which is consistent with the value of M used in the past several Aleutian Island assessments, and a higher value of M, 0.40.
2. In the September model, the preferred 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, three models are presented in this assessment, and described here.

- Model 19.0: Base age structured model with M=0.34, maturity ogive derived from observer collections of maturity values from Aleutian Islands cod.
- Model 19.0a: Base age structured model except Stark (2007) maturity ogive.

- Model 19.0b: Base age structured model except M=0.40. This is the authors' preferred model.
- 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.

Summary of Results

The principal results of the present assessment, based on the authors' recommended model, are listed in the tables below. Two tables are provided, the first is based on the preferred Tier 3 model (Model 19.0b), and the second is based on a Tier 5 model. The Tier 3 ABCs and OFLs are higher than the Tier 5 assessment. Biomass and catch figures are in units of metric tons (t) and compared with the corresponding quantities from last year's assessment. Spawning biomass estimated by the Tier 3 Model 19.0b was 1.7 * $B_{35\%}$. Therefore, Aleutian Island cod qualifies under Tier 3a.

Catch of Pacific cod as of October 1, 2021 was 12,882 t. Over the past 5 years (2016 - 2020), 96.5% of the catch has taken place by this date. Therefore, the full year's estimate of catch in 2021 was extrapolated to be 13,351 t. This is lower than the average catch over the past five years of 16,484 t. The Tier 3 projected estimate of total biomass for 2022 was 179,370 t and the model projection of spawning biomass for 2022, assuming catch for 2021 as described above, was 59,722 t. The 2022 and 2023 ABCs using Model 19.0b were higher than the Tier 5 estimates: 42,402 t (2022) and 43,211 t (2023).

Despite evaluation by multiple Tier 3 age structured models, the lack of survey data since 2018 increases uncertainty in the age structured models. A risk table is included in this assessment describes uncertainty involved in providing management quantities for Aleutian Islands Pacific cod. We recommend the Tier 5 ABC (20,600 t), citing an apparent decline in CPUE, lack of NMFS trawl survey since 2018, and climate-related concerns.

Tier 3

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2021	2022	2022	2023
M (natural mortality rate)	0.34	0.34	0.4	0.4
Tier	5	5	3a	3a
Projected total (age 1+) biomass (t)	80,700	80,700	179,370 t	182,203 t
Projected female spawning biomass (t)	-	-	59,722 t	58,993 t
$B_{100\%}$	-	-	100,508 t	100,508 t
$B_{40\%}$	-	-	40,203 t	40,203 t
$B_{35\%}$	-	-	35,177 t	35,177 t
F_{OFL}	-	-	0.892	0.892
$maxF_{ABC}$	-	-	0.679	0.679
F_{ABC}	-	-	0.287	0.294
OFL	27,400	27,400	51,913 t	52,900 t
$maxABC$	20,600	20,600	42,402 t	43,211 t
ABC	20,600	20,600	20,600 t	20,600 t
Status	2019	2020	2020	2021
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Note: Last year's assessment incorporated a Tier 5 model. Projections were based on annual catches of 13,351 t for 2021 and the mean of the past 5 years, 2017-2021 for 2022 (16,484 t).

Tier 5

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2021	2022	2022	2023
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	27,400	27,400	27,400	27,400
$maxABC$	20,600	20,600	20,600	20,600
ABC	20,600	20,600	20,600	20,600
Status	2019	2020	2020	2021
Overfishing	No	n/a	No	n/a

Responses to SSC and Plan Team Comments on Assessments in General

SSC December 2020 As suggested for a number of species in December 2019 (e.g., GOA Pacific cod, AI Pacific cod, GOA Pacific ocean perch), the SSC recommends exploring VAST apportionment for those species that use a VAST estimator for surveys.

Authors' response: No VAST models have been developed for Aleutian Islands Pacific cod.

Responses to SSC and Plan Team Comments Specific to this Assessment

Plan Team, September 2019 The estimated growth curve when corrected for observed lengths in the population did not fit the observed length-at-age data. The Team recommended one potential solution of using a three-parameter Richards growth curve, which with its increased flexibility may better model Pacific cod growth.

Authors' response: In the 2019 model, there was an issue with the age-length Bayesian correction. The issue has been resolved in the current assessment model. Nonetheless, we evaluated several growth curves (Richards, Von Bertalanffy, Logistic, and Gompertz) to determine the best choice for the Pacific cod data, as this is an important consideration. The results are described in the section "Parameters Estimated Outside the Assessment Model". The Von Bertalanffy model was determined to be the best growth curve, based on several factors, including the lowest AIC score.

SSC Comments, December 2019

1. The SSC noted that there may be other apportionment methods (aside from the random effects model) if smoother outcomes are desirable such as multiple survey averaging or the use of a VAST model.

Authors' response: Noted. This was not addressed in the current assessment.

2. In addition to those recommendations the authors should consider fitting the two maturity curves inside the model similar to some of the GOA rockfish assessments.

Authors' response: Fitting the maturity curve outside the model allows for a maturity curve fit without any confounding factors such as ageing error. The authors are open to more feedback if the SSC feels strongly about fitting the maturity curve within the model.

3. There was a Risk Table overall score based on ecosystem concerns of 2 [in 2020]. Unlike the EBS, the condition factor for the AI is quite low and continues to be low. However, given the Tier 5 estimates are more conservative than what was estimated for all of the Tier 3 models presented, the SSC concluded that no ABC reduction was necessary.

Authors' response: This year is similar to 2019, as some components of the Risk Table have a score of 2. Authors recommend the Tier 5 ABC, as it is more conservative than Tier 3 ABCs.

The SSC also recommends exploring the "Barefoot Ecologist" online tool for developing an appropriate prior distribution when estimating natural mortality in next year's age-structured model.

Authors' response: This tool was used for exploring estimates of natural mortality.

SSC Comments, December 2020

1. The BSAI GPT recommended presentation of an age-structured assessment at the BSAI GPT meeting in September 2021. This stock is scheduled for an ESP. The SSC looks forward to an age-structured assessment and ESP for this stock.

Authors' response:

The AI Pcod ESP will be revisited after 2022. Kalei Shotwell is implementing a new ESP schedule next year (starts January 2022) and is postponing new ESPs for next year until the schedule is implemented. Age structured assessment models are presented in this assessment.

Plan Team November 2019

1. The online tool to estimate natural mortality (http://barefootecologist.com.au/shiny_m.html) provided an estimate of 0.36. The Team noted that this tool uses multiple estimators, some of which are similar, and recommended that it would be useful to receive more information on the different components used and how they are related.

Authors' response: Natural mortality was examined using the barefoot ecologist tool and reported in this document.

2. Two maturity curves were estimated, one from visual observations collected by observers and the other from a histological study reported by Stark (2007). The observer data have the benefit of a large sample size (over 2000 samples) collected in January through March since 2008, while Stark (2007) histologically analyzed 129 samples collected from Unimak pass in February 2003. The Team supported the authors' recommendation that the observer data are more representative, but look forward to verifying the visual samples with histological studies. The Team recommended that model runs with both maturity curves be reported in the future until an appropriate curve can be identified.

Authors' response: Noted. We present models with both maturity curves and will revisit verification with histological studies when they are available.

3. The Risk Table issues for AI Pacific cod were the same as those identified for EBS Pacific cod. The Team agreed with the author's recommendation of an overall risk level of 2 and recommended that the SSC determine if a reduction is necessary.

Authors' response: Noted.

SSC Comments, September 2021

1. The author of the assessment requested input from the BSAI GPT on data weighting and the BSAI GPT noted that all stock assessment authors would benefit from additional guidance on data weighting. See the General Comments section under C6 BSAI and GOA Groundfish for the SSC's recommendation regarding data weighting. General Comment: In response to the AI Pacific cod author's and BSAI GPT teams request for guidance on data weighting, the SSC encourages the Plan Teams and stock assessment authors, perhaps through a working group, to build on previous efforts to develop standard practices for data weighting in stock assessments.

Authors' response: Noted. No further data weighting was explored in the models presented in this assessment.

2. The Aleutian Island Pacific cod stock has been managed under Tier 5 since the stock was first separated from the EBS in 2013. The SSC has been looking forward to the development of an age-structured assessment model for consideration to move the stock to Tier 3. The SSC concurs with the BSAI GPT to bring forward results from age-structured assessment models 19.0, 19.0a and 19.0b, in addition to a Tier 5 assessment, for consideration in November. The SSC agrees with the BSAI GPT that model 19.0c should be used for a sensitivity analysis only to assess the influence of the fishery length

information on model fits. This might help reconcile differences between survey and fishery data to support the use of the fishery length data.

Authors' response: Noted. The model with no fishery length data has been used for sensitivity analysis only and is not presented as a full model in this assessment.

3. The SSC appreciates the thorough exploration of natural mortality and agrees that a model with a natural mortality of M=0.4, corresponding to the mode of previous estimates of M across a range of Pacific cod stocks, is a reasonable starting point for Model 19.0b.

Authors' response: Natural mortality of M=0.4 was implemented in Model 19.0b.

Introduction

Pacific cod (*Gadus macrocephalus*) ranges across the northern Pacific Ocean from Santa Monica Bay, California, northward along the North American coast, Gulf of Alaska, Aleutian Islands, and Bering Sea north to Norton Sound; and southward along the Asian coast from the Gulf of Anadyr to the northern Yellow Sea. Cod occurs 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 (Stevenson and Lauth 2019). Pacific cod is distributed widely over the eastern Bering Sea (EBS) as well as in the Aleutian Islands (AI) area. In 2017, large scale movement was noted into the northern Bering Sea (NBS) by Eastern Bering Sea stocks (Spies et al. 2020). Tagging studies (e.g., Shimada and Kimura 1994) have demonstrated significant migration both within and between the EBS, AI, and Gulf of Alaska (GOA). Genetics research indicates the existence of discrete spawning stocks in the EBS and AI (Cunningham et al. 2009, Canino et al. 2010, Spies 2012). Pacific cod likely return to their natal origin to spawn during winter months (January - April) but perform feeding migrations during other months. High assignment success (>80%) was demonstrated among five spawning populations of Pacific cod throughout their range off Alaska using 6,425 single-nucleotide polymorphism (SNP) loci (Drinan et al. 2018). The three spawning groups examined in the Gulf of Alaska, Hecate Strait, Kodiak Island, and Prince William Sound, were all genetically distinct and could be assigned to their population of origin with 80-90% accuracy (Fig. 2.4; Drinan et al. 2018).

Separate harvest specifications for Pacific cod have been set for the Bering Sea and Aleutian Islands regions since the 2014 season. Pacific cod were managed in the combined EBS and AI (BSAI) region from 1977 through 2013.

Life history

Pacific cod in the EBS form large spawning aggregations, and typically spawn once per year (Sakurai and Hattori 1996, Stark 2007), from February through 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. Pacific cod are known to undertake seasonal migrations as part of an annual migration between summer feeding grounds and winter spawning grounds, the timing and duration of which may be variable (Savin 2008). Travel distances have been observed in excess of 500 nautical miles (nmi), with a large number of travel distances in excess of 100 nmi (Shimada and Kimura 1994).

Eggs hatched between 16-28 days after spawning in a laboratory study, with peak hatching 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). Recruitment of Pacific cod has been shown to be influenced by temperature (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). For example, 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.

Cold environments allow Pacific cod larvae to bridge gaps in prey availability (i.e., timing and magnitude), but negatively impact survival over longer periods (Laurel et al. 2011). 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 (Laurel et al. 2011). Larval retention of Pacific cod during the month of April appears to be important to late spring abundance in the Gulf of Alaska, but it is unknown whether this result holds elsewhere in the species' range (Doyle et al. 2009).

Juvenile Pacific cod typically 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. Key nursery habitat for age-0 Pacific cod across most of its range typically consists of sheltered embayments. Age-0 Pacific cod have also been observed in the shelf-pelagic zone (Hurst et al. 2012, Parker-Stetter et al. 2013). 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. 2015). 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. Habitat use by age-0 Pacific cod in the EBS may be related to temperature and the distribution of large-bodied demersal predators (Hurst et al. 2015). Similarly, the habitat distribution of age-0 Atlantic cod is influenced by predators (Gotceitas et al. 1997).

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.).

There was strong evidence for selective differentiation in the putative ZP3 locus in Pacific cod, in which a distinct set of haplotypes have been observed in spawning cod from Kodiak Island westward vs. Prince William Sound and samples to the east (Spies et al. 2021). Results were consistent with directional selection in the Bering Sea (Bering Sea, Aleutian Islands, Shumagin Islands, and Kodiak Island), and large regional differences among ZP3 haplotype frequencies between the Bering Sea group and other spawning locations in the Gulf of Alaska and further south, including Prince William Sound and Hecate Strait. Results were also indicative of selection currently acting on northern collections, as may indicate local adaptation driven by differences in ZP3 (Spies et al. 2021).

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. Diel vertical migration has also been observed (Nichol et al. 2013). 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.

Fishery

Description of the directed fishery

During the early 1960s, Japanese vessels began harvesting Pacific cod in the Aleutian Islands. However, these catches were not large, and by the time the Magnuson Fishery Conservation and Management Act went into effect in 1977, foreign catches of Pacific cod in the AI had not exceeded 4,200 t (Table 2A.1). 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 (Table 2A.2). Domestic fishing for AI Pacific cod began in 1981, with a peak catch of over 43,000 t in 1992 (Table 2A.3).

Presently, the Pacific cod stock is exploited by a multiple-gear fishery, including pot, trawl and longline components (Figure 2A.1). Pacific cod in the Aleutian Islands are exploited in the federal and state fisheries. The management quantities in this document pertain to the federal fishery; however, a proportion of the federal quota is allocated to the state fishery. In 2021 (as of October 30, 2021), the federal fishery consisted of 15% pot gear, `100*LLprop`% longline gear, and 44% trawl gear. In 2021, `100*State_prop`% of the catch was taken in the State fishery (Figure 2A.2).

Historically, Pacific cod were caught throughout the Aleutian Islands. 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 2017-2021 (through October 31, 2021) was 60% from the eastern Aleutian Islands (NMFS area 541), 26% from the central Aleutian Islands (NMFS area 542), and 13% from the western Aleutian Islands (NMFS area 543).

Catches of Pacific cod taken in the AI for the periods 1964-1980, 1981-1990, and 1991-2021 are shown in Table 2A.1, Table 2A.2, and Table 2A.3, respectively. The catches in Table 2A.1 and Table 2A.2 are broken down by fleet sector (foreign, joint venture, domestic annual processing). The catches in Table 2A.2 are also broken down by gear to the extent possible. The catches in Table 2A.3 are broken down by gear. Table 2A.4 breaks down catches from 1994-2021 by statistical area (area breakdowns not available prior to 1994), both in absolute terms and as proportions of the yearly totals.

Effort and CPUE

CPUE aggregated over gear types for the number and weight of fish show similar trends, indicating that there has been no large shifts in the weight of individual fish (Figure 2A.3). CPUE has decreased by all metrics since approximately 2015, including seasonally by trawl gear and for longline gear (Figure 2A.4). Recent declines in CPUE may be attributed to the timing of the fishery relative to spawning season or other factors such as hyperaggregation during spawning in the trawl fishery (Rose and Kulka 1999). Standardized surveys are needed to understand whether declines in fishery CPUE represent declines in Aleutian Islands Pacific cod stock size.

Discards

The catches shown in Table 2A.2 and Table 2A.3 include estimated discards. Discard amounts and rates of Pacific cod in the AI Pacific cod fisheries are shown for each year 1993-2021 in Table 2A.5. 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 1998, they have averaged about 1.0%.

Management History

Appendix 1 lists all implemented amendments to the BSAI Groundfish FMP that reference Pacific cod explicitly. The most recent is Amendment 120/108, which was finalized January 20, 2020.

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.6. 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, Table 2A.2, and Table 2A.3, which pertain to the AI only. Total catch has been less than the 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.6 are total catches (i.e., Federal plus State), whereas the TAC applies only to the Federal catch.

In the 8 years that AI Pacific cod have been managed separately from EBS Pacific cod, the ratio of Federal catch to TAC has ranged from 0.45 to 0.96. The catch/TAC ratio in 2021 (complete through October 30) was 0.45, which is the lowest ratio observed since 2014, .

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). 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 the Eastern Bering Sea Pacific cod stock assessment 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
2021	0.39*AI ABC or 6,804 t, whichever is less

The Aleutian Islands GHL increases 4% if 90% of the GHL is harvested by November 15 of the preceding year. The GHL cannot exceed 39% or 6,804 t. If the 2022 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 in 2022, which is the maximum allowed (39%) of the ABC. During the period in which a State fishery has existed: 1) TAC has been set 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 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.

The data used in the 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	1991-2021*
Fishery	Size composition	1991-2021
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 2021 was available and was extrapolated to estimate the catch for the full year. The catch of Pacific cod in the Aleutian Islands as of the end of October, 2021, was 12,882 t. On average, 96.5 % of the annual catch occurs by this date, as estimated by catch statistics in 2016-2020. Therefore, the total catch for 2021 was extrapolated to 13,351 t.

The data used in the Tier 5 Model included the same 12 years of biomass estimate and associated error for the NMFS Aleutian Island research surveys, 1991-2018.

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.7). 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.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.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

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.8. 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 survey 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 Figure 2A.7. Estimates since 2018 are associated with increased uncertainty Figure 2A.7.

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 decline in the central Aleutians (542). Downward trends have generally stabilized since the year 2000 (Figure 2A.8).

In addition to the NMFS Aleutian Islands trawl survey, the relative population numbers (RPN) and relative population weight (RPW) estimated from the NMFS Longline survey were included for comparison Figure 2A.9. In the longline survey, estimated weights and numbers appear to track eachother. Although 2021 data was not available, there appeared to be a peak in RPN and RPW in 2019 followed by a decline in both in 2020. The longline survey is not currently incorporated into the Aleutian Islands age structured or Tier 5 model.

Fishery

There are three predominant gear types in the Pacific cod fishery; pot, trawl, and longline (Figure 2A.10). The data in Figure 2A.10 is based on 832,658 observer records from 1991-2021. Approximately 58% 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 non-winter (feeding) season typically rely on longline gear, while cod are targeted primarily using trawl nets during spawning season because they aggregate during spawning. Pot gear is the least common gear type, and is used throughout the year. Catch data is used in the age-structured model by area and gear combined; there is a single catch biomass (Table 2A.9) 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.10.

Fishery lengths are taken throughout the year by observers during commercial fishing operations (Figure 2A.10). The length frequency composition ranges from approximately 40-120 cm and varies over time (Figure 2A.11), and also varies by season, with larger fish typically caught during winter (January - April) (Figure 2A.12). The number of observer length records taken during summer/non-spawning (May-December) and during winter/spawning (January-April) have declined continuously throughout the time series (Figure 2A.13). Most lengths by fisheries observers have been collected on longline and trawl vessels (Figure 2A.14).

Length frequencies from the fishery

Most of the cod lengths in the Aleutian Islands came from longline vessels; therefore the use of cod excluders is not an issue and are not considered to bias the results.

Other data used in the assessment

Age data from NMFS surveys 1991-2018 and survey length frequency data were used outside the model to configure a length-age conversion matrix and a Von Bertalanffy growth curve. These were updated in the current assessment with 2018 survey age data that was not available for the age-structured models presented in 2019. Details are described in the Analytic Approach section.

Analytic Approach

Model Structure (General)

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 age-structured statistical model presented in this assessment 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 (Von Bertalanffy) 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.
- Fishery length frequencies were weighted by the relative catch by year in the three NMFS areas (541, 542, and 543).

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 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.

Data Weighting

The AFSC/NMFS survey catches smaller, younger fish than the fishery (Figure 2A.15), and the fishery takes place primarily during spawning season. The majority, 81%, of fishery catch between 1991-2021 took place during January – April, whereas the survey occurs during summer months. Data weighting was performed for survey age and fishery length composition data to mitigate the effects of sample imbalance. Weighting age composition data was explored using the methods of McAllister and Ianelli (2007). Statistical data weighting for fishery length likelihoods resulted in unreasonably high weights. Higher age composition likelihood weights decreased survey catchability and reduced biomass estimates. Rather than weight likelihoods, weights associated with sample collections were used to inform compositional data weighting, following Stewart and Monnahan (2017). Weights for survey age composition data were set to the number of hauls from which aged collections were taken in each year.

Better fit to fishery length data achieved by higher weighting of that data component resulted in poorer fit to survey biomass estimates and poorer convergence criteria in the model. Fishery length frequency data weighted so that the mean was 20 resulted in Objective function value (OFV) = 113.5 and Maximum gradient component = 0.01997. At a mean weight of 20, the model appeared to converge, and no parameters were on their bounds. Lower weighting of fishery length values (10) also allowed the model to converge but resulted in poorer fit to fishery length data. Higher weighting (100) improved the fit to fishery lengths but resulted in poor convergence, OFV = 255 and MGC = 46. Therefore, the annual fishery length composition sample sizes were set to the number of fish lengthed annually, to retain the variability in sample size, and weighted so that the mean was 20. The fit is shown for Model 19.0 (Figure 2A.16) and Model 19.0b (Figure 2A.17).

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 1,331 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 $L_{50\%} = -A/B$. The formula used to fit proportion mature by length was

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

Year	Number of records
2008	545
2009	35
2010	116
2011	56
2012	129
2013	61
2014	94
2015	78
2016	79
2017	42
2018	26
2019	57
2020	13

The fit using this method is shown in Figure 2A.18, and the resulting parameters were A=-8.0847 and B=0.1472. 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 54.9 cm (age 4). Maturity parameters for the Stark (2007) data and the ogive using observer data are shown in Figure 2A.19 and Table 2A.11.

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.20). 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. 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.10.

Several growth curves were fit to raw data to explore which best fit growth patterns of Pacific cod from the Aleutian Islands. The growth curves were Von Bertalanffy, Gompertz, logistic, and Richards. The first three curves had three parameters, and the Richards had four parameters. The Gompertz growth function described growth as slowest at the start and end of a given time period. This model avoids the extra parameter used in the Richards growth curve while allowing for non-symmetric growth at the beginning and maximum ages. In the Gompertz growth equation, the point of inflection is always at about 36.8% of the asymptotic size. In cod the growth inflection point occurs later, age 8, which is approximately 2/3 of the asymptotic size. The logistic growth function approaches the early life stage growth and the maximum age growth asymptotes symmetrically. The Richards growth curve adds an additional parameter to the logistic growth curve to account for non-symmetrical growth at early ages and maximum ages Table 2A.12, (Figure 2A.21). The four growth curves were evaluated based on the sum of squared residuals (SSR), number of parameters, and Akaike Information Criterion, AIC (Akaike, 1974). The SSR was evaluated in two ways. First it was evaluated by comparing the fitted vs. observed lengths for each of the 9,075 length at age records in the raw dataset. Second, it was compared using the fitted vs. observed lengths for each age 1-13 based on mean length at age in the dataset (SSRmean).

We ruled out the Richards growth curve because a. the fourth parameter increases the AIC significantly and does not make up for the improvement to the fit; b. the Gompertz equation has an inflection point at 36.8% of the asymptotic size, and c. the logistic model has symmetrical growth at early and maximum ages. Therefore, Von Bertalanffy was the equation of choice.

There is a single length-age conversion matrix that is used to fit length composition data in an assessment from the model estimate of age compositions to observed lengths. A correction based on Bayes Theorem is applied to the raw length at age data, to determine the probability of fish being a certain age given its length, as follows (Dorn 1992). The stratified age collections consist of P(Length|Age). These are corrected for the length frequencies in the population by dividing by length frequencies from survey data from the same years.

$$P(Age|Length) = P(Length|Age)P(Age)/P(Length),$$

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	123.8012	0.1645	-0.1020
Uncorrected length at age	124.9502	0.1587	-0.1045

The growth curve was fit to the Von Bertalanffy 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. Larger fish are observed in the fishery than the survey, but the age length conversion matrix accounted for the size differences between the survey and the fishery (Figure 2A.15), spanning lengths from 4 - 143 cm. The largest fish recorded in the fishery was 143 cm. Correcting for survey length frequencies did not change the expected length at age in the population significantly (Figure 2A.22).

A length-age conversion matrix was compiled by fitting a Von Bertalanffy growth curve to the corrected age-length data. The variance of length at each age was calculated, as well as the CV, the square root of the variance divided by the fitted length at each age. The proportions at age were calculated by multiplying survey length frequency by the proportion of age at length. The proportion of ages 10 and older were used to calculate a mean length for the plus group.

The coefficient of variation (CV) typically decreases with age. The CV of length at age was fitted using linear regression (Figure 2A.23), 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 U-shaped, with lower variance at middle ages (Figure 2A.24).

The length-age conversion matrix was generated by simulating 10^7 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.22). The length-age conversion matrix is shown in Figure 2A.24, and mean length at age is compared with raw data in Figure 2A.22 (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:

$$Weight_{age} = 0.005611 * Length_{age}^{3.176},$$

for both sexes combined, where weight is in kilograms and length in centimeters (Figure 2A.25). 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-base.

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.13).

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 proposed models for 2021, EBS natural mortality ranges from 0.309 (Model 21.1) to 0.348 (Model 19.12a). For the Gulf of Alaska, a base natural mortality of 0.47 (SD = 0.41) was proposed for the 2021 model.

A likelihood profile was performed in the 2021 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 $M = 0.8$. However, these likelihoods decreased quickly until $M = 0.3$ and remained shallow thereafter (Figure 2A.26). 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.13). However, this value was not used in the current assessment, but it was explored as an alternative, Table 2A.14, Table 2A.15.

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.27).

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.14). For consistency with previous Aleutian Islands cod assessments, the value of 0.34 was selected for natural mortality in Model 19.0, and M=0.4 was used in Model 19.0b. The estimate of M=0.4 for Model 19.0b was supported by the SSC (September/October, 2021).

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.28.

Figure 2A.29 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.29. 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.

Other parameters

The model contained a total of 69 parameters.

Catchability	Mean log recruitment	Log avg. fmort.	Selectivity	Fishing mortality	Recruitment	Total
1	1	1	4	31	31	69

Likelihood values for survey age composition, survey biomass, fishery length composition and recruitment are presented in Table 2A.15.

Final parameter estimates generated within Model 19.0 are listed in Table 2A.16, and within Model 19.0b in Table 2A.17, with confidence bounds. Selectivity for the fishery and the survey for all models are shown in Figure 2A.28 and the fit to age frequency from survey data is shown in Figure 2A.30.

Results

Model 13.4 Model Evaluation

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.18, along with the corresponding estimates from the 2019 assessment (Thompson and Palsson 2019), which comprised the most recent previous update of the time series. The estimates were the same and based on the same time series of survey biomass, except for wider 95% confidence intervals in the most recent year.

The model's fit to the survey biomass time series is shown in Figure 2A.7. 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.

Model Evaluation

Four models were presented in this assessment:

- Model 19.0: M=0.34, observer-based maturity curve.
- Model 19.0a: base model with Stark maturity curve.
- Model 19.0b: base model with M=0.4.
- Model 13.4: Tier 5 random effects model.

Likelihood components for the three models are shown in Table 2A.15 for recruitment, survey age, survey biomass, catch, fishery length, and total likelihood. The likelihoods are comparable, as they are very similar with only adjustments to natural mortality and maturity. The likelihoods were similar regardless of maturity curve (Model 19.0 and 19.0a). The model with the lowest likelihood was Model 19.0b, in which the selection of M=0.4 appeared to result in the best fit to the data, with specific improvements in the survey biomass and fishery lengths. The reference points resulting from the four models are also compared in Table 2A.14. The age structured model ABCs for 2021 ranged from 22,617 t (Model 19.0a) to 42,402 t (Model 19.0b). Model 19.0b produced the highest ABCs and overall stock size, due to the higher estimate of M.

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.19). The CV of RMSD for biomass was lowest under Model 19.0a and SSD for survey age was lowest for Model 19.0 and Model 19.0a. SDNR was not considered a diagnostic statistic, but values close to 1 are considered better, and was lowest for Model 19.0b. Plots of the fit to biomass are considered important diagnostic tools as well (Figure 2A.31). The three models appeared to fit the survey estimates of biomass equally well.

Retrospective analysis

A retrospective analysis was performed extending back 10 years to evaluate the model, with data from 2011-2021. The spawning biomass estimates and error bars showed a positive retrospective bias for Model 19.0 (Figure 2A.32), and less so for Model 19.0b (Figure 2A.33). Relative differences in spawning biomass were generally positive for both Model 19.0 (Figure 2A.34) and Model 19.0b (Figure 2A.35). Mohn's ρ was evaluated for all models as a diagnostic tool to quantify retrospective bias. For Model 19.0, Mohn's ρ was 0.225. For Model 19.0b, Mohn's ρ was 0.154, which represents a large improvement over Model 19.0. Mohn's ρ for Model 19.0a was 0.255Recent Mohn's ρ values for EBS Pacific cod from 2016 - 2020 are 0.147, 0.243, 0.207, -0.061, and -0.021. The positive retrospective bias indicates that the model may be overestimating spawning biomass for the current year. The retrospective bias estimated by Mohn's ρ 0.225 represents an average in the differences between adjacent years over the past 10 years.

Hurtado-Ferro (2015) provides some guidance on the range of acceptable values for Mohn's ρ. For a flatfish-like species with M = 0.2, the lower and upper bounds were given as -0.15 and 0.2. For a sardine-like species with M = 0.4, the lower and upper bounds were given to be -0.22 and 0.3. If Mohn's ρ were entirely dependent on M (likely an oversimplification), then an equation for the lower and upper limits could be developed from these guidelines as follows: $Rho_{lowerbound} = -0.8 - 0.35 * M$ $Rho_{upperbound} = 0.10 + 0.50 * M$. This results in a lower and upper bound for Model 19.0, in which M = 0.34, of -0.199 and 0.27. For Model 19.0b, with M = 0.40, the lower and upper bounds on Mohn's ρ would be similar to that of the sardine-like species, -0.22 and 0.3. The estimates of Mohn's ρ for Models 19.0 and 19.0b do not surpass these confidence intervals, but they are still considerable.

Overall, the likelihood values (Table 2A.15) and retrospective analyses indicate that Model 19.0b is the best model, due to a more realistic selection of natural mortality. Age structured models provide a more thorough interpretation of the population dynamics of the Aleutian Islands cod stock than Tier 5 models due to the incorporation of more data sources (e.g. maturity at age, survey age compositions, fishery length compositions, catch). Furthermore, careful reanalysis of natural mortality for the Aleutian Islands cod stock is provided in Model 19.0b. We acknowledge that a major shortcoming of all these models is a lack of NMFS trawl survey data since 2018. Future models could explore an additional likelihood component for the AFSC longline survey, for which length composition data is available. We recommend Model 19.0b as the best age structured model. Given a positive retrospective bias of 0.154, and Risk Table considerations, reference points could be reduced by a value equal to or greater than 15.4%, the mean retrospective bias.

Time Series Results

Based on Model 19.0b, total biomass (defined as age 1 and older) declined from approximately 281,161 t in 1992 to a low of formatC(min(AI_M4$pred_bio),big.mark=",",format="d") t in 2013 (Figure 2A.36). A similar table of time series results based on MCMC output that includes 95% credible intervals is also presented in Table 2A.20. Since 2013, the biomass estimate has increased to an estimate of 172,761 t. Biomass and Female spawning biomass estimated by Models 19.0 and 19.0b are shown in Table 2A.21 and Table 2A.22, as well as Figure 2A.36, Figure 2A.36, and Figure 2A.37. Female spawning biomass has followed a similar trajectory, with a peak of 1.041e+05 t in 1992, declining to 3.475e+04 t in 2014, and then increasing to its current estimate of 5.953e+04 t in 2021. It should be noted that the age structured models presented have not been informed by survey data since 2018; therefore, recruitment is moving towards the mean value over the time series. Nonetheless, the age structured models presented here are intended to be available for use in 2022 when new trawl survey data is available. A phase plane plot for Model 19.0 (Figure 2A.38) shows that spawning biomass was above $B_{40\%}$ from 1991 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 $B_{35\%}$. The phase plane plot for Model 19.0b (Figure 2A.39) shows that spawning biomass was above $B_{40\%}$ from 1991 until approximately 2009. In 2010, fishing was above F_{ABC} and declined starting in 2011. Estimates of total biomass, female spawning biomass, and recruitment with 95% MCMC credible intervals are presented for Model 19.0 in Figure 2A.40 and for 19.0b in Figure 2A.41. A table showing the mcmc generated estimates for Model 19.0 is shwn in Table 2A.20 and in Table 2A.23 for Model 19.0b. A second plot of recruitment that shows individual data points and the mean value over time for Model 19.0 is shown in Figure 2A.42, and for Model 19.0b in Figure 2A.43. Most recent estimates of recruitment (2006 onward) are below the long term mean since 1990, with the exception of 2015. Model 19.0b estimates of numbers at age for ages 1 to 10+ indicate lower recruitment and abundance of younger fish since 2002 than during the period 1991-2001, although the 2015 year class was stronger than average (Table 2A.24 and Figure 2A.44).

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 (FOFL), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater.

Under Tier 5, F_{OFL} is set equal to the natural mortality, F_{OFL} = M, and the fishing mortality rate to achieve the acceptable biological catch is 75% of M, $F_{ABC} \leq 0.75\times$M.

The following tables include estimates needed for harvest specifications, estimates of OFL, maximum permissible ABC, and the associated fishing mortality rates for 2022 and 2023 for the Tier 3 (Model 19.0b) and Tier 5 reference points. Note that the 95% confidence interval for the estimate of biomass estimate is 48,234 t - 134,998 t. The confidence intervals are larger in the current year than in 2020 due to the lack of survey data since 2018. The values are the same as for 2020 because the random effects model provides the same biomass estimates when the same survey data is used, and there is no new survey data.

Tier 3a

Quantity	2022	2023
Biomass (t)	179,370	182,203 t
M	0.4	0.4 t
F_{OFL}	0.892	0.892
maxF_{ABC}	0.679	0.679
OFL (t)	51,913	52,900
maxABC (t)	42,402	43,211

Tier 5

Quantity	2022	2023
Biomass (t)	80,694	80,694 t
M	0.34	0.34 t
F_{OFL}	0.34	0.34
maxF_{ABC}	0.255	0.255
OFL (t)	27,436	27,436
maxABC (t)	20,577	20,577

Age Structured model(s) - 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 2021 numbers at age estimated in the assessment, for Model 19.0 (Table 2A.25) and Model 19.0b (Table 2A.26). This vector is then projected forward to the beginning of 2034 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2021. 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 1) above its MSY level in 2021 or 2) above 1/2 of its MSY level in 2021 and expected to be above its MSY level in 2031 under this scenario, then the stock is not overfished.)
- Scenario 7: In 2022 , 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 1) above its MSY level in 2023 or 2) above 1/2 of its MSY level in 2023 and expected to be above its MSY level in 2033 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 2016 to 2021 (F=0.338), F equal to one half $F_{40\%}$, and $F = 0$ from 2021 to 2034 (Table 2A.25). Under scenario 6 above, the year 2022 female spawning biomass is 51,913 t and the year 2034 spawning biomass is 26,770 t, above the $B_{35\%}$ level of 34,674 t. For scenario 7 above, the year 2034 spawning biomass is 26,770 t, also above $B_{35\%}$. Fishing at $F_{40\%}$, female spawning biomass would still be above $B_{40\%}$ (28,451 t) in year 2034 (25,832 t). Female spawning biomass would be expected to decrease to 19,530 over the next 12 years, if fishing continues at the last 5-year average fishing mortality (0.029) (Table 2A.25, Scenario 4).

ABC and OFL for 2022 and 2023

Based on the Tier 3 Model 19.0b, the Aleutian Islands Pacific cod stock is predicted to be above $B_{35\%}$ in 2022 and 2023. The 2022 biomass is estimated at 179,370 t and the spawning biomass is 59,722 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 $B_{40\%} = 40{,}203$ t for 2022. Projected 2022 female spawning biomass is compared to $B_{40\%}$ to determine the Tier level. The stock assessment model estimates the 2022 level of female spawning biomass at 49,099 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.14). Therefore, Aleutian Islands Pacific cod reference fishing mortality is defined in Tier 3a.

The 2021 catch was estimated at 13,351 t and the total catch in 2022 was estimated to be the same as the mean of the past 5 years, 16,484 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 $B_{35\%}$ (Table 2A.14, Figure 2A.45).

Risk Table

Assessment Considerations

This stock been assessed using Tier 5 methodology since 2013. The standard Tier 5 random effects model fits the survey data well; however, there has not been a NMFS trawl survey since 2018. While the age structured models presented here incorporate more data sources than the Tier 5 model, they still are limited by a lack of recent survey data. One feature of Model 19.0 is a positive retrospective pattern ($\rho = 0.225$), 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 22%. 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. Model 19.0b has a significantly lower ρ, 0.154, and is a better alternative to Model 19.0.

Assessment considerations were rated as level 2 due to lack of survey data the relatively recent development of age-structured models (substantially increased concern).

Population Dynamics Considerations

Although the long-term (1991-2018) survey biomass trend is downward, the trend between 2010-2018 has been largely positive. The AFSC longline survey RPW shows a stable trend since approximately 2010, although the longline survey does not always track the AFSC bottom trawl survey in the Aleutian Islands.

Interpretation of population dynamics using fishery CPUE can be complicated, and there is not necessarily a clear relationship between the two. Fishery length frequencies also provide information on the relative size of fish encountered, and in 2021 the fish appeared to be smaller than average, but larger than fish encountered in 2020.

Population dynamics considerations were rated as level 1.

Environmental/Ecosystem Considerations

Due to lack of 2020 surveys and fieldwork and the fact that this is a non-bottom trawl survey year for the Aleutians, several indicators have not been updated. Thus, much of the ecosystem information for 2021 is derived from remote sensing and seabird data. Pacific cod are typically found between 3.5–5.7°C in the Aleutian Islands survey. Mid-depth (100-300m) and water column temperature (surface to bottom) from the longline survey and bottom trawl survey, respectively show waters seem to have remained warmer since 2013. Likewise, sea surface temperature (SST) has been above the mean since 2013 and the number of days per season where SST have been above the heatwave threshold has been higher since 2013–2014. However for this year, the longline survey sampled the eastern Aleutians from 164°W to 170°W, where temperatures are cooler than in 2019 and similar to those in 2020. SST throughout the Aleutians was slightly above average overall with noticeably increased temperatures during August - September when the warmest temperatures on the satellite SST time series were recorded but the number of heatwave days is lower so far in 2021 (less than 50 days) compared to 2020 (~150 days) and 2019 (>300 days), which was a record warm year in the eastern AI. The pattern of heatwave years differs from that in the adjacent Gulf of Alaska.

In general, higher ambient temperatures incur bioenergetic costs for ectothermic fish such that, all else being equal, consumption must increase to maintain fish condition. Pacific cod are particularly sensitive to the impacts of increased temperatures due to a combination of their energetic demands and diet, as was seen in the Gulf of Alaska during the 2014–2016 heatwave (Barbeaux et al. 2020). Thus, the persistent higher temperatures are considered a negative indicator for Pacific cod.

Recent examinations of Pacific cod diets in the Aleutian Islands have shown changes in diet type and potentially, quality. Pacific cod stomachs collected in the bottom trawl survey in the western and central Aleutians (areas 543, 542) have shown decreases in Atka mackerel, previously one of their primary prey items, over the past few years. This has coincided with the declining biomass and body condition of Atka mackerel in these areas according to survey estimates (Laman and Rohan, AI ESR), potentially reflecting scarcer and lower quality prey available for Pacific cod. The reverse has happened in area 541, where Atka mackerel was not generally a common prey in earlier years, but has now increased to over 20% of Pacific cod diet by biomass since 2014, replacing sculpins.

In addition to the lower prey quality, availability may have also decreased given that the combined proportion of pelagic predators is now dominated by rockfish (POP and Northern Rockfish), where Atka mackerel and walleye pollock used to comprise the larger proportion of this group across the entire Aleutians. As a generalist, Pacific cod is able to offset the lower availability of any one type of prey, having the ability to easily switch between fish and benthic crustacean prey. However, the declining trend of Atka mackerel biomass is of concern. The observed body condition of Pacific cod in the AI bottom trawl survey (Laman and Rohan, AI ESR) has been lower than the survey mean from 2012–2018 in the entire Aleutians, with mean or slightly lower body condition since 2000 in the southern Bering Sea survey area, suggesting that Pacific cod have not been able to meet their energetic demands sufficiently. This year, however, piscivorous murres and piscivorous/cephalopod-eating tufted puffins had mostly above average reproductive success at Buldir and above average at Aiktak (eastern Aleutians) indicating that forage fish to support chick-rearing was available this year. Seabird success suggests broad availability of prey, particularly in the eastern Aleutians where at least half the Pacific cod stock is typically distributed.

Taken together, the cooler temperatures and seabird data suggest that conditions are potentially better for Pacific cod than in the past couple years. However, there is not enough updated data to confirm that this would reverse the negative trend in fish condition, nor that bioenergetic needs would decrease significantly, as the temperatures still remain above those before 2012. Considering both this year's and past trends in indicators suggests there are some adverse signals relevant to the stock, but the pattern is not consistent across all areas.

Environmental/ecosystem considerations were rated as level 2 (some indicators showing an adverse signal relevant to the stock but the pattern is not consistent across all indicators).

Fishery Performance Considerations

Trends in CPUE can be examined for evidence of population trends, although other factors can affect CPUE besides population dynamics. The trends in CPUE are available from fishery data through 2021, and consistently indicate a downward trend (Figure 2A.3, Figure 2A.4).

However, the fishery reports that lack of CV trawl effort in the Aleutian Islands is not due to lack of interest. The AI fishery often gets pre-empted by the BS fishery given the later timing of aggregation in the AI and the lack of an AI set-aside of the CV sector appointment. For the trawl CVs, for the A season the catch rates in the BS are often better, which is easier to access than the Aleutians.

In some years (e.g. 2020) the BSAI CV trawl fleet takes a large portion or all of their A season quota in the Bering Sea before the AI cod aggregate (for spawning). The Adak processor was closed in 2020 and 2021, so it was unable to take P. cod deliveries. This results in fewer smaller pot and hook-and-line vessels unless a floating processor or tender is available to assist.

Fishery performance considerations were rated as level 1.

Risk Summary

The ratings of the four categories are summarized below:

Assessment consideration	Population dynamics	Environmental ecosystem	Fishery performance
Level 2: Substantially increased concern	Level 1: Normal	Level 2: Substantially increased concern	Level 1: Normal

Because some components of the Risk Table are greater than level 1, ABC may need to be reduced from the maximum permissible value. In 2020 the risk table score was also 2 and the SSC concluded that no ABC reduction was necessary because Tier 5 estimates are more conservative than Tier 3 models. While the authors request consideration of the age structured models presented here, the recommended ABC is the Tier 5 ABC. This ABC is recommended for the reasons outlined in the Risk Table, particularly the lack of new survey data and the decline in Pacific cod stocks in other regions.

Area Allocation of ABC

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 2022 and 2023 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 2021 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? The official AI catch estimate for the most recent complete year (2020) is 14,250 t. This is less than the 2019 AI OFL of 27,400 t (and also the AI ABC of 20,600). Therefore, the AI Pacific cod stock is not being subjected to overfishing. Because this stock is managed under Tier 5, no determination can be made with respect to overfished status. If the status changes to Tier 3, it would not be considered subjected to overfishing.

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 common 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 common dietary items have been euphausids, miscellaneous fishes, and amphipods. In terms of weight of organisms consumed, common dietary items include 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 several tables. For the purpose of generating these tables, Pacific cod targets were those identified as such in the AKFIN database (https://akfin.psmfc.org/). Catches for 2021 in each of these tables are incomplete, through the end of

October 2021. The Pacific cod fishery using trawl gear Table 2A.27 and fixed gear Table 2A.28 take a small proportion of the incidental catch of FMP species (1991-2021). During some years from 1991-2021, the proportional catch of octopus and longnose skate was high in the Pacific cod trawl (Table 2A.29) and longline (Table 2A.30) fisheries, although incidental catch of squid and members of the former "other species" complex taken by trawl gear was lower. Similarly, the Pacific cod fishery accounts for a large proportion of several crab species bycatch (Table 2A.31). Discard mortality of halibut taken in the Pacific cod fishery from 1991-2021, aggregated across gear types, has declined during this time period. The proportion of incidental catch of non-target species groups taken from 2003-2021, excluding bird species, aggregated across gear types Table 2A.32 varies from very little to almost all of the bycatch in a given year.

Steller Sea Lions

Pacific cod is 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 is especially important in winter in the GOA and BSAI (Pitcher 1981, Calkins 1998, Sinclair and Zeppelin 2002). 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). 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 two weeks (Rand et al. 2015).

Seabirds

In the BSAI and GOA, the northern fulmar (*Fulmarus glacialis*) comprises the majority of seabird bycatch, primarily in the longline fisheries, including the fixed gear fishery for Pacific cod (Livingston (ed.) 2002). 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 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 significantly reduce seabird incidental take. Typically bycatch of bird species in the Pacific cod trawl and longline fisheries is low, although in some years a large proportion of certain species were taken in the Pacific cod fisheries (Table 2A.33.

Fishery Usage of Habitat

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 (Livingston (ed.) 2002). During the period 1998-2001, the total number of observed sets by gear type 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.1: Catch of Pacific cod in the Aleutian Islands by foreign, domestic, and joint venture fisheries, 1964-1980. Note that joint venture fisheries did not commence until 1981, and domestic catch information is not available prior to 1988.

Year	Foreign	Joint Venture	Domestic	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.2: Summary of catches of Pacific cod (t) in the Aleutian Islands by gear type. All catches include discards. Domestic annual catch by gear is not available prior to 1988.

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

Table 2A.3: Federal and state fishery catch in metric tons by year, 1991-2021. To avoid confidentiality problems, federal 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 2021 are through October 30.

Year	Federal		State	Total
	Trawl	Longline+Pot	Total	
1	1991	3,414	6,383	9,798
2	1992	14,559	28,425	43,068
3	1993	17,312	16,860	34,205
4	1994	14,383	7,156	21,539
5	1995	10,574	5,960	16,534
6	1996	21,179	10,430	31,609
7	1997	17,349	7,726	25,164
8	1998	20,531	14,196	34,726
9	1999	16,437	11,624	28,130
10	2000	20,362	19,290	39,685
11	2001	15,827	18,362	34,207
12	2002	27,929	2,872	30,801
13	2003	31,478	978	32,457
14	2004	25,770	3,103	28,873
15	2005	19,613	3,068	22,694
16	2006	20,062	4,141	24,211
17	2007	28,631	5,716	34,355
18	2008	21,826	9,193	31,229
19	2009	20,822	7,740	28,582
20	2010	18,872	10,134	29,006
21	2011	9,382	1,506	10,889
22	2012	12,139	6,059	18,220
23	2013	8,123	5,489	13,612
24	2014	6,766	3,818	10,583
25	2015	6,129	3,080	9,210
26	2016	11,535	1,696	13,232
27	2017	8,537	6,633	15,170
28	2018	10,119	10,240	20,414
29	2019	10,294	8,752	19,187
30	2020	4,316	9,929	14,250
31	2021	3,216	9,666	12,882

Table 2A.4: Summary of 1994-2021 catches (t) of Pacific cod in the AI, by NMFS statistical area (area breakdowns not available prior to 1994). Catches for 2021 are through October 30.

Year	Total Catch			Proportions		
	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	47	2,884	10,682	0.003	0.212	0.785
2014	29	1,039	9,514	0.003	0.098	0.899
2015	3,170	2,364	3,676	0.344	0.257	0.399
2016	2,550	1,607	9,074	0.193	0.121	0.686
2017	3,371	3,768	8,031	0.222	0.248	0.529
2018	2,695	4,066	13,654	0.132	0.199	0.669
2019	1,339	5,293	12,555	0.070	0.276	0.654
2020	1,972	5,127	7,151	0.138	0.360	0.502
2021	1,464	3,287	8,131	0.114	0.255	0.631

Table 2A.5: Discards (t) and discard rates for the Aleutian Islands Pacific cod fishery, for the period 1993-October 30, 2021 . Note that Amendment 49, which mandated increased retention and utilization, was implemented in 1998.

Year	Discards (t)	Total catch (t)	Proportion discarded
1993	1,508	4,208	0.358
1994	3,484	21,539	0.162
1995	3,180	16,534	0.192
1996	3,137	31,609	0.099
1997	2,107	25,164	0.084
1998	638	34,726	0.018
1999	514	28,130	0.018
2000	692	39,685	0.017
2001	471	34,207	0.014
2002	734	30,801	0.024
2003	332	32,457	0.010
2004	317	28,873	0.011
2005	489	22,694	0.022
2006	310	24,211	0.013
2007	554	34,355	0.016
2008	204	31,229	0.007
2009	208	28,582	0.007
2010	203	29,006	0.007
2011	91	10,889	0.008
2012	70	18,220	0.004
2013	253	13,612	0.019
2014	122	10,583	0.012
2015	95	9,210	0.010
2016	104	13,232	0.008
2017	150	15,170	0.010
2018	273	20,414	0.013
2019	137	19,187	0.007
2020	131	14,250	0.009
2021	171	12,882	0.013

Table 2A.6: Fishery catch in metric tons by year, total allowable catch (TAC), acceptable biological catch (ABC), and overfishing limit (OFL), 1991-2021. 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 2021 is through October 31. ABC and OFL for 2021 are based on this year's model output. TAC from 2021 is based on harvest specifications from 2020.

Year	Catch (t)	ABC	TAC	OFL
1991	9,797	229,000	229,000	-
1992	43,067	182,000	182,000	188,000
1993	34,204	164,500	164,500	192,000
1994	21,539	191,000	191,000	228,000
1995	16,534	328,000	250,000	390,000
1996	31,609	305,000	270,000	420,000
1997	25,164	306,000	270,000	418,000
1998	34,726	210,000	210,000	336,000
1999	28,130	177,000	177,000	264,000
2000	39,684	193,000	193,000	240,000
2001	34,207	188,000	188,000	248,000
2002	30,800	223,000	200,000	294,000
2003	32,456	223,000	207,500	324,000
2004	28,873	223,000	215,500	350,000
2005	22,693	206,000	206,000	365,000
2006	24,211	194,000	189,768	230,000
2007	34,354	176,000	170,720	207,000
2008	31,228	176,000	170,720	207,000
2009	28,581	182,000	176,540	212,000
2010	29,006	174,000	168,780	205,000
2011	10,888	235,000	227,950	272,000
2012	18,220	314,000	261,000	369,000
2013	13,608	307,000	260,000	359,000
2014	10,603	15,100	6,997	20,100
2015	9,216	17,600	9,422	23,400
2016	13,245	17,600	12,839	23,400
2017	15,202	21,500	15,695	28,700
2018	20,414	21,500	15,695	28,700
2019	19,200	20,600	14,214	27,400
2020	14,250	20,600	13,796	27,400
2021	12,882	20,600	13,796	27,400

Table 2A.7: 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.8: Aleutian Islands bottom trawl survey biomass estimates and standard error for Pacific cod, for all years used in the model.

Biomass (t)				
Year	Western	Central	Eastern	Total
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

Proportion by area				
Year	Western	Central	Eastern	Total
1991	0.419	0.221	0.360	1
1994	0.155	0.336	0.509	1
1997	0.197	0.415	0.388	1
2000	0.341	0.287	0.371	1
2002	0.321	0.336	0.343	1
2004	0.117	0.252	0.631	1
2006	0.230	0.260	0.511	1
2010	0.382	0.201	0.417	1
2012	0.229	0.251	0.519	1
2014	0.246	0.115	0.639	1
2016	0.234	0.231	0.535	1
2018	0.141	0.253	0.606	1

Biomass coefficient of variation				
Year	Western	Central	Eastern	Total
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.9: Fishery catch in metric tons by year, total allowable catch (TAC), acceptable biological catch (ABC), and overfishing limit (OFL), 1990-2021. 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
1991	9,797	229,000	229,000	-
1992	43,067	182,000	182,000	188,000
1993	34,204	164,500	164,500	192,000
1994	21,539	191,000	191,000	228,000
1995	16,534	250,000	328,000	390,000
1996	31,609	270,000	305,000	420,000
1997	25,164	270,000	306,000	418,000
1998	34,726	210,000	210,000	336,000
1999	28,130	177,000	177,000	264,000
2000	39,684	193,000	193,000	240,000
2001	34,207	188,000	188,000	248,000
2002	30,800	200,000	223,000	294,000
2003	32,456	207,500	223,000	324,000
2004	28,873	215,500	223,000	350,000
2005	22,693	206,000	206,000	265,000
2006	24,211	189,768	194,000	230,000
2007	34,354	170,720	176,000	207,000
2008	31,228	170,720	176,000	207,000
2009	28,581	176,540	182,000	212,000
2010	29,006	168,780	174,000	205,000
2011	10,888	227,950	235,000	272,000
2012	18,220	261,000	314,000	369,000
2013	13,608	260,000	307,000	359,000
2014	10,603	6,997	15,100	20,100
2015	9,216	9,422	17,600	23,400
2016	13,245	12,839	17,600	23,400
2017	15,202	15,695	21,500	28,700
2018	20,414	15,695	21,500	28,700
2019	19,200	14,214	20,600	27,400
2020	14,249	13,796	20,600	27,400
2021	12,025	13,796	28,451	34,674

Table 2A.10: The number of length observations available for the fishery length composition data, by year.

Year	Number of Lengths
1991	22,653
1992	102,653
1993	46,775
1994	29,716
1995	30,870
1996	42,610
1997	23,762
1998	74,286
1999	34,027
2000	52,435
2001	57,750
2002	23,442
2003	23,690
2004	23,990
2005	20,754
2006	20,446
2007	27,543
2008	26,262
2009	21,954
2010	34,330
2011	8,879
2012	11,789
2013	8,590
2014	4,276
2015	8,891
2016	6,740
2017	11,034
2018	11,994
2019	8,205
2020	8,008
2021	98

Table 2A.11: Maturity at age ogives based on Stark (2007) and observer maturity at length data from 2008-2021. The Stark (2007) maturity curve was used in Model 19.0b and the observer data-derived maturity curve was used in Model 19.0a.

Age	Stark 2007	Observer data
1	0.0230021	0.0069392
2	0.0582223	0.0739067
3	0.1396620	0.2914285
4	0.2988668	0.5947725
5	0.5281452	0.8288139
6	0.7461343	0.9378730
7	0.8852892	0.9771243
8	0.9529746	0.9904192
9	0.9815542	0.9951047
10	0.9928941	0.9973929

Table 2A.12: Comparison of the Richards, Von Bertalanffy, Gompertz, and Logistic growth curves fit to raw length at age data for Pacific cod. The sum of squared residuals were fit to each individual data point (SSR) and the mean of the data at each age (SSRmean). The Akaike Information criterion, AIC (Akaike, 1974) and the number of parameters are presented for each model.

	Richards	Von Bertalanffy	Gompertz	Logistic
SSR	696.649853	700.963949	700.664739	713.820945
SSRmean	6.673260	3.603178	4.135476	7.188336
Number of parameters	4.000000	3.000000	3.000000	3.000000
AIC	-5.092566	-7.104913	-7.104059	-7.141264

Table 2A.13: 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

Table 2A.14: Comparison of reference points using Model 19.0 (M=0.34, observer-based maturity curve), Model 19.0a (maturity curve based on Stark (2007)), and Model 19.0b (M=0.40).

	Model 19.0b, $M = 0.40$		Model 19.0	
Quantity	2022	2023	2022	2023
M (natural mortality rate)	0.40	0.40	0.34	0.34
Tier	3a	3a	3a	3a
Projected total (age 1+) biomass (t)	179,370	182,203	143,502 t	147,565 t
Projected female spawning biomass (t)	59,722	58,993	49,099 t	49,749 t
$B_{100\%}$	100,508	100,508	103,498 t	103,498 t
$B_{40\%}$	40,203	40,203	41,399 t	41,399 t
$B_{35\%}$	35,177	35,177	36,224 t	36,224 t
F_{OFL}	0.892	0.892	0.632	0.632
$maxF_{ABC}$	0.679	0.679	0.493	0.493
F_{ABC}	0.679	0.679	0.493	0.493
OFL	51,913	52,900	34,674 t	35,781 t
$maxABC$	42,402	43,211	28,451 t	29,363 t
ABC	42,402	43,211	28,451 t	29,363 t
Status	2020	2021	2020	2021
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

	Model 19.0a, Stark (2007) maturity	
Quantity	2022	2023
M (natural mortality rate)	0.34	0.34
Tier	3a	3a
Projected total (age 1+) biomass (t)	143,501	147,565
Projected female spawning biomass (t)	37,371	38,356
$B_{100\%}$	88,745	88,745
$B_{40\%}$	35,498	35,498
$B_{35\%}$	31,060	31,060
F_{OFL}	0.464	0.464
$maxF_{ABC}$	0.376	0.376
F_{ABC}	0.376	0.376
OFL	27,052	27,919
$maxABC$	22,617	23,343
ABC	22,617	23,343
Status	2020	2021
Overfishing	No	n/a
Overfished	n/a	No
Approaching overfished	n/a	No

Projections were based on annual catches of 13,351 t for 2021 and the last 5 years (2017-2021) for 2022 (16,484 t).

Table 2A.15: Comparison of likelihood values for recruitment, survey age, survey biomass, catch, fishery length, and total likelihood for the base model and several alternatives. Likelihood components for Models 19.0 and 19.0a are identical.

	Model 19.0	Model 19.0a	Model 19.0b
Likelihood Component	Base Model	Stark (2007) maturity	M=0.40
Recruitment	5.91	5.91	5.424
Survey age	56.055	56.055	56.228
Survey biomass	16.309	16.309	13.932
Catch	0.002	0.002	0.001
Fishery length	47.231	47.231	46.768
Total	125.507	125.507	122.354

Table 2A.16: 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
Survey catchability	0.83204	0.6841815	0.9798985
Mean log recruitment	10.19400	10.0773663	10.3106337
Log average fishing mortality	-0.91703	-1.1634020	-0.6706580
Survey selectivity slope	1.25320	1.0788560	1.4275440
Survey selectivity a50	3.15040	2.8547732	3.4460268
Fishery selectivity slope	1.83560	1.4883860	2.1828140
Fishery selectivity a50	4.73130	4.4005108	5.0620892

Table 2A.17: Parameter values for Model 19.0b 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
Survey catchability	0.70097	0.5626077	0.8393323
Mean log recruitment	10.61600	10.4862500	10.7457500
Log average fishing mortality	-1.06600	-1.3310508	-0.8009492
Survey selectivity slope	1.28100	1.1177163	1.4442837
Survey selectivity a50	3.28880	3.0034240	3.5741760
Fishery selectivity slope	1.85480	1.5160728	2.1935272
Fishery selectivity a50	4.78320	4.4504508	5.1159492

Table 2A.18: Comparison of biomass (t) estimated by Model 13.4 in the 2016-2017 and 2018-2019 assessments, with lower and upper 95% confidence bounds.

Year	2021 Model 19.0			2021 Model 13.4		
Year	Biomass	LCI	UCI	Biomass	LCI	UCI
1991	214,120	184,929	243,310	169,669	130,207	221,090
1992	228,030	199,055	257,004	157,157	111,812	220,891
1993	197,860	169,920	225,799	145,567	102,580	206,568
1994	177,910	151,665	204,154	134,832	99,904	181,971
1995	176,280	151,952	200,607	115,515	82,448	161,844
1996	182,990	160,500	205,479	98,965	71,605	136,781
1997	177,800	157,071	198,528	84,787	65,982	108,952
1998	185,360	165,770	204,949	89,988	65,473	123,683
1999	182,390	163,477	201,302	95,509	68,821	132,547
2000	184,700	166,175	203,224	101,368	76,177	134,890
2001	174,870	156,842	192,897	90,998	67,212	123,201
2002	173,420	155,699	191,140	81,688	63,719	104,726
2003	174,160	156,521	191,798	80,987	59,651	109,954
2004	166,870	149,660	184,079	80,291	60,838	105,964
2005	156,590	140,257	172,922	78,401	55,854	110,049
2006	148,390	133,449	163,330	76,555	54,615	107,310
2007	139,120	125,886	152,353	72,365	49,211	106,414
2008	122,160	110,400	133,919	68,405	46,155	101,381
2009	110,940	99,459	122,420	64,661	44,942	93,033
2010	100,880	88,817	112,942	61,123	45,955	81,296
2011	85,649	72,796	98,501	61,649	45,371	83,768
2012	88,045	74,205	101,884	62,180	49,091	78,760
2013	81,230	66,366	96,093	66,768	49,715	89,670
2014	82,618	65,982	99,253	71,695	55,363	92,843
2015	92,589	72,487	112,690	75,517	55,666	102,449
2016	108,060	82,593	133,526	79,544	61,132	103,502
2017	119,230	87,042	151,417	80,117	58,848	109,073
2018	127,270	87,287	167,252	80,694	61,710	105,518
2019	127,950	79,804	176,095	80,694	53,535	121,632
2020	129,390	73,032	185,747	80,694	48,234	134,998
2021	136,030	71,314	200,745	80,694	44,240	147,187

Table 2A.19: 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 and Mohn's *ho* 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
CV of RMSD for biomass	0.315	0.305	0.312
SSD for survey age	0.413	0.413	0.417
SSD for fishery lengths	0.248	0.248	0.247
SDNR	1.745	1.745	1.649
Survey catchability	0.832041	0.832042	0.700969
Mohn's ρ	0.225	0.255	0.154

Table 2A.20: MCMC posterior estimates of female spawning biomass, FSB, (t), total biomass, (t), and recruitment (number of age 1 individuals), based on Model 19.0. 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 2021 and 2022 values come from the project model, and confidence intervals were estimated from the variance of the 2020 values.

Year	FSB	LCI	UCI	Tot. biomass	LCI	UCI	Recruitment	LCI	UCI
1991	77915	67,511	89,582	214349	190,919	240,623	20,124	12,758	28,848
1992	86755	76,452	98,150	228248	205,067	253,935	23,362	15,759	31,757
1993	76010	65,966	87,110	198086	175,838	222,693	26,647	19,042	35,380
1994	68036	58,422	78,655	178178	157,398	201,289	50,424	40,325	61,051
1995	64842	55,885	74,824	176597	157,349	198,183	24,989	17,485	33,537
1996	65405	57,145	74,688	183329	165,359	203,447	46,324	36,569	56,804
1997	60829	53,335	69,165	178149	161,553	196,298	53,018	43,290	63,529
1998	62008	54,993	69,651	185764	169,938	202,924	31,053	23,507	39,336
1999	60409	53,735	67,678	182854	167,670	199,752	29,989	23,248	37,352
2000	63728	57,214	70,897	185195	170,346	201,845	48,385	40,067	57,365
2001	59519	53,138	66,656	175385	160,895	191,469	48,949	40,589	58,018
2002	56737	50,475	63,800	173848	159,487	189,687	27,823	21,527	34,571
2003	57731	51,520	64,614	174575	160,250	190,253	21,160	15,454	27,540
2004	58767	52,605	65,606	167283	153,295	182,764	24,362	17,914	31,240
2005	58505	52,265	65,326	156994	143,687	171,590	13,574	8,604	19,485
2006	57061	51,124	63,533	148795	136,587	162,155	35,828	28,606	43,792
2007	52033	46,648	57,923	139531	128,758	151,425	28,745	22,590	35,367
2008	41764	37,224	46,833	122580	113,182	133,201	24,995	19,803	30,666
2009	35624	31,796	39,984	111224	102,132	121,599	18,436	14,173	23,285
2010	32837	29,079	37,109	101043	91,533	111,861	12,222	8,773	16,154
2011	28772	24,761	33,453	85662	75,799	97,220	14,103	10,287	18,621
2012	31877	27,508	36,989	87955	77,277	100,225	16,962	12,561	21,986
2013	28889	24,262	34,280	81017	69,637	94,190	24,736	18,813	31,694
2014	27504	22,634	33,102	82284	69,626	96,933	30,920	23,229	40,020
2015	28786	23,486	34,920	92138	77,044	110,042	34,755	25,280	46,097
2016	33198	27,004	40,534	107445	88,049	130,380	19,137	12,346	27,835
2017	38037	30,058	47,546	118409	93,841	147,043	31,209	18,482	47,536
2018	42702	32,320	54,910	126290	95,670	162,173	23,216	10,622	41,162
2019	43661	30,614	58,881	127205	90,090	171,211	32,874	8,555	76,233
2020	44425	28,449	63,148	130028	85,852	182,461	28,803	7,366	69,836
2021	47959	29,165	70,207	139121	87,972	201,314	28,968	27,164	31,025
2022	49,099	30,306	30,955	143,502	92,353	96,417	-	-	-
2023	49,749	67,894	68,543	147,565	194,651	198,715	-	-	-

Table 2A.21: Model 19.0 estimates for total biomass (metric tons, age 1+), recruitment (number of age 1 individuals), and spawning biomass (t), 1991-2021.

Year	Biomass (t)	Spawning biomass (t)	Recruitment
1991	214,116	77,829	20,059
1992	228,035	86,725	23,368
1993	197,859	75,964	26,616
1994	177,915	67,948	50,309
1995	176,275	64,719	25,017
1996	182,986	65,274	46,186
1997	177,803	60,713	52,722
1998	185,355	61,891	31,153
1999	182,387	60,266	29,872
2000	184,701	63,547	48,402
2001	174,874	59,308	48,885
2002	173,425	56,558	27,807
2003	174,164	57,559	21,079
2004	166,871	58,605	24,242
2005	156,591	58,359	13,549
2006	148,385	56,914	35,772
2007	139,119	51,871	28,874
2008	122,158	41,563	25,103
2009	110,941	35,452	18,496
2010	100,884	32,708	12,322
2011	85,649	28,714	14,112
2012	88,045	31,873	17,059
2013	81,230	28,947	24,876
2014	82,618	27,607	31,029
2015	92,589	28,925	35,047
2016	108,057	33,386	19,305
2017	119,229	38,307	31,292
2018	127,270	43,068	23,160
2019	127,948	44,118	28,888
2020	129,387	44,888	24,819
2021	136,032	48,018	28,984

Table 2A.22: Model 19.0b estimates for total biomass (metric tons, age 1+), recruitment (number of age 1 individuals), and spawning biomass (t), 1991-2021.

Year	Biomass (t)	Spawning biomass (t)	Recruitment
1991	270,768	95,573	30,445
1992	281,161	104,064	35,196
1993	245,663	92,397	39,508
1994	221,476	82,888	73,366
1995	217,330	77,814	36,444
1996	221,941	77,006	67,042
1997	216,192	71,752	75,797
1998	224,096	72,541	44,815
1999	220,478	71,021	43,002
2000	221,314	74,366	69,934
2001	211,270	69,680	70,653
2002	210,565	66,655	40,006
2003	210,439	67,925	30,027
2004	200,149	69,078	34,496
2005	185,577	68,009	19,444
2006	173,021	64,961	51,582
2007	161,309	58,182	42,415
2008	144,177	46,961	37,558
2009	133,966	41,138	27,960
2010	124,579	39,239	18,874
2011	109,311	36,021	21,818
2012	111,162	39,411	26,368
2013	104,308	36,237	38,304
2014	107,329	34,748	47,637
2015	120,689	36,398	53,605
2016	139,794	41,769	29,607
2017	153,433	47,985	48,514
2018	163,004	53,753	35,526
2019	164,479	55,307	44,129
2020	166,345	56,360	37,718
2021	172,761	59,532	42,756

Table 2A.23: MCMC posterior estimates of female spawning biomass, FSB, (t), total biomass, (t), and recruitment (number of age 1 individuals), based on Model 19.0b. 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 2021 and 2022 values come from the project model, and confidence intervals were estimated from the variance of the 2020 values.

Year	FSB	LCI	UCI	Tot. biomass	LCI	UCI	Recruitment	LCI	UCI
1991	77915	67,511	89,582	214349	190,919	240,623	20,124	12,758	28,848
1992	86755	76,452	98,150	228248	205,067	253,935	23,362	15,759	31,757
1993	76010	65,966	87,110	198086	175,838	222,693	26,647	19,042	35,380
1994	68036	58,422	78,655	178178	157,398	201,289	50,424	40,325	61,051
1995	64842	55,885	74,824	176597	157,349	198,183	24,989	17,485	33,537
1996	65405	57,145	74,688	183329	165,359	203,447	46,324	36,569	56,804
1997	60829	53,335	69,165	178149	161,553	196,298	53,018	43,290	63,529
1998	62008	54,993	69,651	185764	169,938	202,924	31,053	23,507	39,336
1999	60409	53,735	67,678	182854	167,670	199,752	29,989	23,248	37,352
2000	63728	57,214	70,897	185195	170,346	201,845	48,385	40,067	57,365
2001	59519	53,138	66,656	175385	160,895	191,469	48,949	40,589	58,018
2002	56737	50,475	63,800	173848	159,487	189,687	27,823	21,527	34,571
2003	57731	51,520	64,614	174575	160,250	190,253	21,160	15,454	27,540
2004	58767	52,605	65,606	167283	153,295	182,764	24,362	17,914	31,240
2005	58505	52,265	65,326	156994	143,687	171,590	13,574	8,604	19,485
2006	57061	51,124	63,533	148795	136,587	162,155	35,828	28,606	43,792
2007	52033	46,648	57,923	139531	128,758	151,425	28,745	22,590	35,367
2008	41764	37,224	46,833	122580	113,182	133,201	24,995	19,803	30,666
2009	35624	31,796	39,984	111224	102,132	121,599	18,436	14,173	23,285
2010	32837	29,079	37,109	101043	91,533	111,861	12,222	8,773	16,154
2011	28772	24,761	33,453	85662	75,799	97,220	14,103	10,287	18,621
2012	31877	27,508	36,989	87955	77,277	100,225	16,962	12,561	21,986
2013	28889	24,262	34,280	81017	69,637	94,190	24,736	18,813	31,694
2014	27504	22,634	33,102	82284	69,626	96,933	30,920	23,229	40,020
2015	28786	23,486	34,920	92138	77,044	110,042	34,755	25,280	46,097
2016	33198	27,004	40,534	107445	88,049	130,380	19,137	12,346	27,835
2017	38037	30,058	47,546	118409	93,841	147,043	31,209	18,482	47,536
2018	42702	32,320	54,910	126290	95,670	162,173	23,216	10,622	41,162
2019	43661	30,614	58,881	127205	90,090	171,211	32,874	8,555	76,233
2020	44425	28,449	63,148	130028	85,852	182,461	28,803	7,366	69,836
2021	47959	29,165	70,207	139121	87,972	201,314	28,968	27,164	31,025
2022	49,099	30,306	30,955	143,502	92,353	96,417	-	-	-
2023	49,749	67,894	68,543	147,565	194,651	198,715	-	-	-

Table 2A.24: Model 19.0b estimates of the numbers of cod by age 1-10+ in the Aleutian Islands (x 1,000) from 1990-2021.

	1	2	3	4	5	6	7	8	9	10+
1991	30,445	52,026	19,886	18,850	15,656	6,519	2,995	1,833	1,117	863
1992	35,196	20,406	34,858	13,291	12,437	9,981	4,051	1,849	1,130	1,221
1993	39,508	23,585	13,651	23,070	8,320	6,716	4,827	1,904	865	1,099
1994	73,366	26,475	15,780	9,046	14,544	4,594	3,359	2,354	924	953
1995	36,444	49,169	17,726	10,500	5,827	8,597	2,547	1,832	1,280	1,020
1996	67,042	24,425	32,928	11,812	6,821	3,537	4,960	1,450	1,041	1,306
1997	75,797	44,925	16,339	21,792	7,392	3,680	1,708	2,328	677	1,095
1998	44,815	50,794	30,059	10,828	13,740	4,083	1,841	833	1,131	860
1999	43,002	30,028	33,960	19,826	6,656	7,004	1,810	787	354	845
2000	69,934	28,815	20,084	22,455	12,350	3,538	3,307	829	359	546
2001	70,653	46,855	19,254	13,202	13,552	5,942	1,437	1,286	320	349
2002	40,006	47,340	31,323	12,692	8,089	6,839	2,594	604	537	279
2003	30,027	26,806	31,653	20,673	7,827	4,166	3,078	1,128	261	353
2004	34,496	20,119	17,919	20,853	12,626	3,910	1,791	1,273	463	252
2005	19,444	23,115	13,454	11,837	12,924	6,605	1,802	799	565	317
2006	51,582	13,031	15,469	8,927	7,509	7,279	3,404	908	401	442
2007	42,415	34,567	8,719	10,257	5,644	4,186	3,692	1,685	448	415
2008	37,558	28,418	23,101	5,737	6,221	2,758	1,740	1,472	667	341
2009	27,960	25,161	18,978	15,129	3,394	2,810	1,019	610	512	350
2010	18,874	18,728	16,787	12,357	8,678	1,390	895	304	180	254
2011	21,818	12,641	12,488	10,893	6,959	3,354	406	243	82	116
2012	26,368	14,621	8,459	8,283	6,898	3,897	1,713	202	121	98
2013	38,304	17,668	9,777	5,584	5,114	3,566	1,764	750	88	95
2014	47,637	25,668	11,821	6,479	3,519	2,820	1,779	858	363	89
2015	53,605	31,925	17,180	7,850	4,130	2,013	1,487	919	442	232
2016	29,607	35,925	21,372	11,423	5,038	2,413	1,096	796	490	359
2017	48,514	19,841	24,038	14,168	7,216	2,800	1,218	540	390	416
2018	35,526	32,510	13,275	15,932	8,938	3,992	1,404	596	263	393
2019	44,129	23,806	21,746	8,783	9,952	4,794	1,911	653	276	303
2020	37,718	29,572	15,929	14,415	5,544	5,519	2,413	938	319	283
2021	42,756	25,278	19,798	10,594	9,265	3,255	3,027	1,301	504	323

Table 2A.25: Projections of Aleutian Islands Pacific cod female spawning biomass (FSB), future catch, and full selection fishing mortality rates (F) for seven future harvest scenarios, based on Model 19.0. Estimates of FSB and catch are in metric tons (t).

Scenarios 1 and 2 Maximum ABC harvest permissible			
Year	FSB	Catch	F
2021	56,949	13,351	0.191
2022	59,723	16,484	0.224
2023	58,994	43,212	0.679
2024	47,804	32,990	0.679
2025	43,114	28,320	0.673
2026	41,522	26,250	0.650
2027	41,147	25,752	0.643
2028	41,218	25,696	0.643
2029	41,419	25,878	0.645
2030	41,470	26,037	0.645
2031	41,365	25,937	0.644
2032	41,283	25,860	0.643
2033	41,282	25,819	0.643
2034	41,375	25,832	0.643

Scenario 3, Maximum Tier 3 ABC harvest permissible set at F60			
Year	FSB	Catch	F
2021	56,949	13,351	0.191
2022	59,723	16,484	0.224
2023	60,397	20,558	0.280
2024	59,353	19,986	0.280
2025	58,986	19,681	0.280
2026	59,098	19,746	0.280
2027	59,144	19,783	0.280
2028	59,333	19,805	0.280
2029	59,561	19,874	0.280
2030	59,709	19,990	0.280
2031	59,697	19,999	0.280
2032	59,626	19,978	0.280
2033	59,604	19,949	0.280
2034	59,672	19,940	0.280

Scenario 4 Harvest at average F over past 5 years			
Year	FSB	Catch	F
2021	56,949	13,351	0.191
2022	59,470	21,202	0.296
2023	58,222	18,827	0.267
2024	58,317	18,722	0.267
2025	58,763	18,759	0.267
2026	59,398	19,037	0.267
2027	59,770	19,208	0.267
2028	60,152	19,308	0.267
2029	60,485	19,418	0.267
2030	60,692	19,553	0.267
2031	60,712	19,576	0.267
2032	60,658	19,563	0.267
2033	60,644	19,538	0.267
2034	60,715	19,530	0.267

Scenario 5 No fishing			
Year	FSB	Catch	F
2021	56,949	13,351	0.191
2022	59,470	21,202	0.296
2023	59,141	0	0.000
2024	68,322	0	0.000
2025	76,322	0	0.000
2026	83,099	0	0.000
2027	88,211	0	0.000
2028	92,241	0	0.000
2029	95,112	0	0.000
2030	97,184	0	0.000
2031	98,525	0	0.000
2032	99,360	0	0.000
2033	99,933	0	0.000
2034	100,393	0	0.000

Alternative 6, Determination of whether Pacific cod are currently overfished			
Year	FSB	Catch	F
2021	56,949	13,351	0.191
2022	57,430	51,913	0.892
2023	42,587	35,830	0.892
2024	37,124	27,426	0.820
2025	36,543	26,003	0.799
2026	36,888	26,433	0.795
2027	37,014	26,610	0.794
2028	37,159	26,670	0.796
2029	37,349	26,880	0.798
2030	37,362	27,024	0.798
2031	37,234	26,839	0.795
2032	37,169	26,802	0.796
2033	37,170	26,742	0.796
2034	37,272	26,770	0.795

Scenario 7, Determination of whether stock is approaching an overfished condition			
Year	FSB	Catch	F
2021	56,949	13,351	0.191
2022	58,151	42,403	0.679
2023	47,282	32,839	0.679
2024	41,932	34,578	0.892
2025	37,640	27,694	0.818
2026	37,034	26,645	0.796
2027	37,006	26,598	0.793
2028	37,146	26,650	0.796
2029	37,344	26,871	0.798
2030	37,360	27,022	0.798
2031	37,234	26,839	0.795
2032	37,169	26,803	0.796
2033	37,170	26,742	0.796
2034	37,272	26,770	0.795

Table 2A.26: Projections of Aleutian Islands Pacific cod female spawning biomass (FSB), future catch, and full selection fishing mortality rates (F) for seven future harvest scenarios, based on Model 19.0b. Estimates of FSB and catch are in metric tons (t).

Scenarios 1 and 2 Maximum ABC harvest permissible			
Year	FSB	Catch	F
2021	56,949	13,351	0.191
2022	59,723	16,484	0.224
2023	58,994	43,212	0.679
2024	47,804	32,990	0.679
2025	43,114	28,320	0.673
2026	41,522	26,250	0.650
2027	41,147	25,752	0.643
2028	41,218	25,696	0.643
2029	41,419	25,878	0.645
2030	41,470	26,037	0.645
2031	41,365	25,937	0.644
2032	41,283	25,860	0.643
2033	41,282	25,819	0.643
2034	41,375	25,832	0.643

Scenario 3, Maximum Tier 3 ABC harvest permissible set at F60			
Year	FSB	Catch	F
2021	56,949	13,351	0.191
2022	59,723	16,484	0.224
2023	60,397	20,558	0.280
2024	59,353	19,986	0.280
2025	58,986	19,681	0.280
2026	59,098	19,746	0.280
2027	59,144	19,783	0.280
2028	59,333	19,805	0.280
2029	59,561	19,874	0.280
2030	59,709	19,990	0.280
2031	59,697	19,999	0.280
2032	59,626	19,978	0.280
2033	59,604	19,949	0.280
2034	59,672	19,940	0.280

Scenario 4 Harvest at average F over past 5 years			
Year	FSB	Catch	F
2021	56,949	13,351	0.191
2022	59,470	21,202	0.296
2023	58,222	18,827	0.267
2024	58,317	18,722	0.267
2025	58,763	18,759	0.267
2026	59,398	19,037	0.267
2027	59,770	19,208	0.267
2028	60,152	19,308	0.267
2029	60,485	19,418	0.267
2030	60,692	19,553	0.267
2031	60,712	19,576	0.267
2032	60,658	19,563	0.267
2033	60,644	19,538	0.267
2034	60,715	19,530	0.267

Scenario 5 No fishing			
Year	FSB	Catch	F
2021	56,949	13,351	0.191
2022	59,470	21,202	0.296
2023	59,141	0	0.000
2024	68,322	0	0.000
2025	76,322	0	0.000
2026	83,099	0	0.000
2027	88,211	0	0.000
2028	92,241	0	0.000
2029	95,112	0	0.000
2030	97,184	0	0.000
2031	98,525	0	0.000
2032	99,360	0	0.000
2033	99,933	0	0.000
2034	100,393	0	0.000

Alternative 6, Determination of whether Pacific cod are currently overfished			
Year	FSB	Catch	F
2021	56,949	13,351	0.191
2022	57,430	51,913	0.892
2023	42,587	35,830	0.892
2024	37,124	27,426	0.820
2025	36,543	26,003	0.799
2026	36,888	26,433	0.795
2027	37,014	26,610	0.794
2028	37,159	26,670	0.796
2029	37,349	26,880	0.798
2030	37,362	27,024	0.798
2031	37,234	26,839	0.795
2032	37,169	26,802	0.796
2033	37,170	26,742	0.796
2034	37,272	26,770	0.795

Scenario 7, Determination of whether stock is approaching an overfished condition			
Year	FSB	Catch	F
2021	56,949	13,351	0.191
2022	58,151	42,403	0.679
2023	47,282	32,839	0.679
2024	41,932	34,578	0.892
2025	37,640	27,694	0.818
2026	37,034	26,645	0.796
2027	37,006	26,598	0.793
2028	37,146	26,650	0.796
2029	37,344	26,871	0.798
2030	37,360	27,022	0.798
2031	37,234	26,839	0.795
2032	37,169	26,803	0.796
2033	37,170	26,742	0.796
2034	37,272	26,770	0.795

Table 2A.27: Incidental catch of FMP species taken by trawl gear in the Aleutian Islands target fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all AI FMP fisheries, 1991-2021 (2021 data current through October 30). Note: RE=rougheye, NR=northern, SR=shortraker, SC=sharpchin.

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Alaska Plaice												0.75		1.00	1.00
Other Flatfish					0.00	0.01	0.03	0.80	0.47	0.48	0.19	0.53	0.29	0.29	0.25
RE Rockfish														0.01	0.04
SR Rockfish														0.03	0.02
Skate															
Squid	0.00	0.01	0.02	0.00	0.00	0.00	0.01	0.03	0.01	0.05	0.33	0.05	0.10	0.11	0.07
Demersal Shelf Rockfish			0.77												
Flathead Sole		0.00			0.42	0.41	0.66	0.88	0.92	0.88	0.69	0.95	0.80	0.90	0.72
Flounder	0.01	0.59	0.45	0.35											
Greenland Turbot	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Non TAC Species									0.02	0.00	0.02	0.01			
Northern Rockfish												0.03	0.04	0.03	0.05
Octopus													0.00		
Other Rockfish	0.00	0.03	0.01	0.01	0.01	0.04	0.25	0.13	0.04	0.03	0.02	0.03	0.03	0.04	0.03
Other Species													0.23	0.16	0.13
Pacific Cod	0.08	0.24	0.36	0.33	0.35	0.38	0.60	0.48	0.49	0.46	0.40	0.86	0.90	0.81	0.77
Pacific Ocean Perch	0.01	0.02	0.03	0.01	0.00	0.00	0.01	0.03	0.00	0.01	0.01	0.01	0.01	0.01	0.02
Pollock	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.48	0.63	0.38	0.61	0.48	0.46	0.41
Rock Sole	0.13	0.68	0.56	0.38	0.52	0.55	0.74	0.86	0.93	0.95	0.88	0.93	0.82	0.85	0.80
Sablefish	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	0.00	0.00
Sculpin															
Shallow Water Flatfish		0.24													
Shark															
SC/NR Rockfish		0.13	0.07	0.03	0.01	0.02	0.04	0.04	0.03	0.05	0.03				
SR/RE Rockfish		0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02		
Shortraker/Rougheye/Sharpchin/Northern Rockfish	0.02	0.65	0.00		0.00		0.00								
Slope Rockfish		0.16													
Yellowfin Sole		0.00		0.05	0.00	0.36	0.00	0.00	0.20	0.90	0.97	1.00	0.72	1.00	1.00

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Alaska Plaice	1.00	0.27	1.00	0.24	0.00		1.00	1.00	1.00		1.00	0.00	0.00	0.98	1.00	
Other Flatfish	0.29	0.37	0.28	0.06	0.04	0.01	0.16	0.05	0.16	0.00	0.03	0.01	0.10	0.07	0.09	0.00
RE Rockfish	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SR Rockfish	0.01	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
Skate						0.01	0.02	0.01	0.00	0.00	0.02	0.01	0.00	0.01	0.01	0.00
Squid	0.07	0.02	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
Demersal Shelf Rockfish																
Flathead Sole	0.86	0.76	0.55	0.61	0.58	0.46	0.73	0.49	0.26	0.31	0.53	0.23	0.19	0.45	0.07	0.24
Flounder																
Greenland Turbot	0.00	0.01	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
Non TAC Species																
Northern Rockfish	0.05	0.02	0.02	0.02	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Octopus						0.14	0.16	0.00	0.00	0.02	0.04	0.01	0.00	0.01	0.00	0.00
Other Rockfish	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00
Other Species	0.14	0.16	0.06	0.07	0.03											
Pacific Cod	0.76	0.78	0.66	0.65	0.58	0.70	0.59	0.49	0.52	0.35	0.64	0.26	0.31	0.37	0.09	0.08
Pacific Ocean Perch	0.01	0.01	0.01	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
Pollock	0.18	0.16	0.04	0.03	0.01	0.05	0.08	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.03
Rock Sole	0.78	0.77	0.75	0.76	0.73	0.70	0.67	0.70	0.65	0.26	0.71	0.59	0.40	0.58	0.01	0.03
Sablefish	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
Sculpin						0.05	0.06	0.04	0.02	0.01	0.05	0.01	0.01	0.00	0.01	
Shallow Water Flatfish																
Shark						0.06	0.00	0.00	0.00	0.11	0.01	0.00	0.00	0.00	0.00	0.00
SC/NR Rockfish																
SR/RE Rockfish																
Shortraker/Rougheye/Sharpchin/Northern Rockfish																
Slope Rockfish																
Yellowfin Sole	0.79	0.05	0.23	0.03	0.09	0.00	0.11	0.08	0.01	0.00	0.00	0.00	0.05	0.03	0.15	0.00

Table 2A.28: Incidental catch of FMP species taken by longline gear in the Aleutian Islands target fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all AI FMP fisheries, 1993-2021 (2021 data current through October 30). Note: RE=rougheye, NR=northern, SR=shortraker, SC=sharpchin.

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Other Flatfish					0.00	0.01	0.22	0.06	0.06	0.13	0.29	0.01	0.00	0.32	0.00
RE Rockfish														0.14	0.02
SR Rockfish														0.03	0.09
Skate															
Flathead Sole		0.00			0.03	0.08	0.06	0.10	0.01	0.06	0.14	0.01	0.00	0.01	0.01
Flounder	0.00	0.08	0.07	0.02											
Greenland Turbot	0.02	0.06	0.03	0.01	0.01	0.01	0.03	0.04	0.06	0.03	0.02	0.01	0.02	0.01	0.00
Non TAC Species									0.04	0.06	0.08	0.00			
Northern Rockfish												0.01	0.00	0.01	0.00
Octopus													0.00		
Other Rockfish	0.10	0.29	0.07	0.11	0.02	0.08	0.12	0.25	0.09	0.11	0.16	0.06	0.03	0.16	0.04
Other Species													0.13	0.33	0.37
Pacific Cod	0.22	0.51	0.49	0.32	0.24	0.18	0.28	0.40	0.28	0.40	0.52	0.09	0.03	0.10	0.12
Pacific Ocean Perch	0.00	0.01	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
Pollock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.09	0.00	0.01	0.01	0.00
Rock Sole	0.00	0.01	0.02	0.02	0.01	0.04	0.02	0.03	0.00	0.01	0.01	0.00	0.00	0.00	0.01
Sablefish	0.04	0.05	0.03	0.04	0.01	0.09	0.04	0.02	0.02	0.02	0.03	0.06	0.01	0.00	0.00
Sculpin															
Shark															
SC/NR Rockfish		0.03	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02				
SR/RE Rockfish		0.31	0.17	0.11	0.02	0.12	0.06	0.30	0.21	0.31	0.23	0.08	0.04		
Shortraker/Rougheye/Sharpchin/Northern Rockfish	0.21	0.01	0.00		0.00		0.00								
Slope Rockfish		0.01													
Yellowfin Sole		0.00		0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Other Flatfish	0.01	0.00	0.01	0.35	0.05	0.05	0.13	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
RE Rockfish	0.01	0.18	0.27	0.12	0.14	0.01	0.16	0.05	0.01	0.11	0.04	0.34	0.12	0.06	0.12	0.09
SR Rockfish	0.05	0.06	0.06	0.05	0.17	0.01	0.03	0.04	0.00	0.04	0.00	0.05	0.08	0.32	0.04	0.12
Skate						0.12	0.29	0.17	0.03	0.24	0.16	0.23	0.22	0.22	0.36	0.44
Flathead Sole	0.02	0.08	0.13	0.14	0.09	0.01	0.09	0.00	0.00	0.01	0.01	0.06	0.20	0.01	0.12	0.12
Flounder																
Greenland Turbot	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non TAC Species																
Northern Rockfish	0.00	0.01	0.02	0.02	0.03	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00
Octopus						0.79	0.50	0.43	0.37	0.78	0.45	0.20	0.04	0.15	0.06	0.18
Other Rockfish	0.05	0.12	0.12	0.19	0.16	0.02	0.03	0.02	0.00	0.05	0.00	0.03	0.02	0.01	0.05	0.07
Other Species	0.26	0.36	0.34	0.43	0.50											
Pacific Cod	0.14	0.14	0.18	0.20	0.27	0.11	0.18	0.12	0.03	0.33	0.12	0.24	0.16	0.12	0.25	0.19
Pacific Ocean Perch	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
Pollock	0.00	0.00	0.01	0.02	0.04	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.01
Rock Sole	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00
Sablefish	0.03	0.02	0.03	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
Sculpin						0.17	0.39	0.38	0.12	0.40	0.14	0.32	0.23	0.26	0.32	
Shark						0.02	0.12	0.01	0.01	0.24	0.00	0.06	0.03	0.01	0.02	0.01
SC/NR Rockfish																
SR/RE Rockfish																
Shortraker/Rougheye/Sharpchin/Northern Rockfish																
Slope Rockfish																
Yellowfin Sole	0.00	0.00	0.23	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00

Table 2A.29: Incidental catch of selected “Other Species” complex species taken in the AI Pacific cod trawl fisheries, 1991-2021 (2021 data current through October 30), expressed as a ratio of bycatch in all fisheries and gears.

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
octopus, North Pacific									1.00	1.00	1.00	0.76	0.30	0.31	0.65
Pacific sleeper shark										0.06		1.00	0.00	0.30	0.62
shark, other													0.00	0.00	
shark, salmon										1.00			0.00		0.00
shark, spiny dogfish												0.00	0.26	0.00	0.00
skate, Alaskan															
skate, Aleutian															
skate, big														1.00	1.00
skate, longnose														0.01	0.49
skate, other									0.98	1.00	1.00	0.29	0.14	0.10	0.10
skate, Whiteblotched															
squid, majestic	0	0.01	0.02	0	0	0	0.01	0.03	0.01	0.05	0.33	0.05	0.10	0.11	0.07

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
octopus, North Pacific	0.07	0.14	0.18	0.07	0.02	0.14	0.16	0.00	0.00	0.02	0.04	0.01	0.00	0.01	0.00	0
Pacific sleeper shark	0.00	0.01	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0
shark, other				0.00									0.00			0
shark, salmon	0.00	0.00		0.29	0.00	0.39	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0
shark, spiny dogfish	0.09	0.00	0.00	0.00	0.02	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0
skate, Alaskan					0.06	0.11	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0
skate, Aleutian						0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
skate, big	0.22	0.02	0.25	0.01	0.00		1.00			0.00				1.00	0.00	
skate, longnose	0.00		0.00	0.76	0.00		0.00			0.00					0.00	
skate, other	0.10	0.10	0.03	0.04	0.01	0.01	0.03	0.02	0.01	0.00	0.02	0.01	0.01	0.01	0.01	0
skate, Whiteblotched						0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0
squid, majestic	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			

Table 2A.30: Incidental catch of selected "Other Species" complex species taken in the AI Pacific cod longline fisheries, 1991-2021 (2021 data current through October 30), expressed as a ratio of bycatch in all fisheries and gears.

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
octopus, North Pacific									0	0	0	0.14	0.43	0.42	0.32
Pacific sleeper shark										0		0.00	0.00	0.00	0.02
shark, other													0.00	1.00	
shark, salmon										0			0.00		0.00
shark, spiny dogfish												0.00	0.45	0.96	1.00
skate, Alaskan															
skate, Aleutian															
skate, big														0.00	0.00
skate, longnose														0.02	0.51
skate, other									0	0	0	0.04	0.16	0.46	0.48
skate, Whiteblotched															
squid, majestic	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
octopus, North Pacific	0.27	0.45	0.23	0.50	0.47	0.79	0.50	0.43	0.37	0.78	0.45	0.20	0.04	0.15	0.06	0.18
Pacific sleeper shark	0.38	0.01	0.04	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
shark, other				0.00									0.00			0.00
shark, salmon	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.84	0.00	0.00	0.00	0.00	0.00	0.00
shark, spiny dogfish	0.66	0.87	0.55	0.84	0.92	0.43	0.66	0.21	0.05	0.86	0.03	0.17	0.79	0.35	0.34	0.74
skate, Alaskan					0.52	0.11	0.08	0.10	0.07	0.17	0.03	0.07	0.19	0.29	0.52	0.23
skate, Aleutian						0.23	0.24	0.07	0.04	0.13	0.01	0.03	0.04	0.13	0.06	0.04
skate, big	0.11	0.00	0.00	0.00	0.55		0.00			0.59				0.00	1.00	
skate, longnose	1.00		1.00	0.24	1.00		0.00			1.00					0.82	
skate, other	0.34	0.54	0.38	0.58	0.58	0.12	0.41	0.22	0.03	0.32	0.27	0.34	0.30	0.30	0.45	0.52
skate, Whiteblotched						0.00	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.01
squid, majestic	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			

Table 2A.31: Incidental catch (herring and halibut in tons, 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, 1991-2020 (through November 4).

	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		
Herring	0.00	0.00	1.00	0.00	0.00		0.00			1.00			0.01		1.00
Non-Chinook Salmon	0.01	0.22	0.00	0.00	0.00	0.03	0.07	0.03	0.04	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	0.34	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	0.89	0.83	0.98	0.43	0.94	0.97	0.84	0.97	0.84

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Bairdi Tanner Crab	1.00	1.00	1.00	1.00	0.94	0.45	1.00	0.98	0.98	0.00	0.00	0.97	0.99	0.99	1.00	0.99
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	0.99	0.00	0.12
Chinook Salmon	0.87	0.72	0.83	0.82	0.75	0.55	0.65	0.94	0.62	0.41	0.57	0.21	0.05	0.04	0.00	0.00
Golden (Brown) King Crab	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.24	0.06	0.05	0.08	0.22
Halibut					0.19	0.04	0.28	0.16	0.18	0.41	0.26	0.36	0.30	0.41	0.39	0.65
Herring	0.05	0.19	0.25	0.07	0.00		0.00	1.00	1.00			0.00	0.00	0.01	0.98	0.00
Non-Chinook Salmon	0.34	0.56	0.21	0.17	0.02	0.38	0.00	0.02	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00
Opilio Tanner (Snow) Crab	0.99	1.00	1.00	1.00	0.99	0.98	0.99	0.91	0.81	0.00	0.00	0.99	0.98	0.95	0.99	0.99
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	0.69	0.92	0.99

Table 2A.32: Bycatch of Nontarget and Ecosystem Species for the Aleutian Islands Pacific cod fishery (all gear types), divided by the bycatch in all fisheries and gears in the same region. Bird bycatch is not included in this table. Data is from 1993-2021, and current through October 30 of the final year. Continued on next page.

	2003	2004	2005	2006	2007	2008	2009	2010	2011
Benthic urochordata	0.14	0.16	0.42	0.13	0.06	0.03	0.05	0.06	0.01
Bivalves	0.99	0.94	0.99	0.99	0.97	0.96	0.78	0.64	0.53
Brittle star unidentified	0.00	0.06	0.03	0.39	0.64	0.20	0.01	0.01	0.00
Capelin	0.00			0.00	0.00	1.00	0.00		
Bryozoan Corals	0.41	0.38	0.24	0.33	0.47	0.29	0.38	0.27	0.08
Bryozoan Red Tree Coral	0.72	0.01	0.49	0.01	0.91	0.14	0.88	0.00	0.00
Dark Rockfish						0.65	0.53		
Eelpouts	0.09	0.51	0.14	0.04	0.15	0.02	0.02	0.02	0.00
Eulachon			0.68	0.01	0.00	0.05	0.00	0.00	
Giant Grenadier	0.30	0.00	0.00	0.08	0.02	0.01	0.00	0.06	0.00
Greenlings	0.74	0.20	0.04	0.88	0.24	0.64	0.39	0.50	0.75
Grenadier - Pacific Grenadier		1.00		0.00	0.00		0.00	0.40	0.00
Rattail Grenadier Unid.	0.02	0.01	0.00	0.03	0.21	0.01	0.01	0.10	0.00
Gunnels			0.01			0.00			
Hermit crab unidentified	0.80	0.98	0.11	0.68	0.81	0.86	0.85	0.42	0.24
Invertebrate unidentified	0.09	0.13	0.05	0.62	0.18	0.09	0.01	0.22	0.04
Large Sculpins	0.51	0.40	0.39	0.45	0.44				
Large Sculpins - Bigmouth Sculpin						0.12	0.14		
Large Sculpins - Great Sculpin						0.94	0.95		
Large Sculpins - Hemilepidotus Unidentified						0.96	0.98		
Lg. Sculpins - Myoxocephalus Unid.						0.88	1.00		
Large Sculpins - Plain Sculpin						1.00	0.97		
Large Sculpins - Red Irish Lord						0.12	0.32		
Large Sculpins - Warty Sculpin						1.00	1.00		
Large Sculpins - Yellow Irish Lord						0.34	0.20		
Misc crabs	0.73	0.56	0.52	0.50	0.65	0.48	0.47	0.38	0.01
Misc crustaceans	0.99	0.29	0.98	0.93	0.33	0.88	0.13	0.38	0.06
Misc fish	0.23	0.11	0.12	0.06	0.09	0.06	0.08	0.09	0.05
Misc inverts (worms etc)	0.00	0.28	1.00	1.00	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	0.39	0.40	0.08	0.31	0.17	0.11	0.26		
Pacific Sand lance	1.00		1.00			1.00		0.01	
Pacific Sandfish									
Pandalid shrimp	0.06	0.01	0.03	0.00	0.06	0.00	0.00	0.00	0.00
Polychaete unidentified	1.00	0.13	1.00		0.15	0.76	0.11	0.00	0.98
Saffron Cod									
Sculpin									
Scypho jellies	0.17	0.48	0.45	0.19	0.06	0.22	0.11	0.21	0.25
Sea anemone unidentified	0.85	0.53	0.93	0.78	0.37	0.32	0.47	0.38	0.08
Sea pens whips	0.80	1.00	0.96	0.96	0.73	0.36	0.64	0.94	0.94
Sea star	0.59	0.73	0.49	0.57	0.57	0.61	0.52	0.63	0.11
Snails	0.53	0.52	0.25	0.60	0.48	0.62	0.74	0.35	0.45
Sponge unidentified	0.32	0.16	0.33	0.22	0.09	0.03	0.12	0.09	0.03
State-managed Rockfish								0.61	0.13
Stichaeidae	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00
urchins dollars cucumbers	0.42	0.53	0.17	0.28	0.42	0.11	0.18	0.11	0.01

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Benthic urochordata	0.04	0.15	0.01	0.01	0.04	0.00	0.03	0.00	0.00	0.10
Bivalves	0.76	0.14	0.11	0.32	0.33	0.04	0.21	0.05	0.68	0.32
Brittle star unidentified	0.00	0.04	0.01	0.00	0.00	0.12	0.00	0.00	0.10	0.01
Capelin	1.00	0.11	1.00						0.00	
Bryozoan Corals	0.09	0.08	0.02	0.10	0.08	0.13	0.25	0.05	0.40	0.36
Bryozoan Red Tree Coral	0.00	0.00	0.00				0.00			
Dark Rockfish										
Eelpouts	0.01	0.00	0.00	0.00	0.00	0.05	0.01	0.02	0.00	0.01
Eulachon	1.00								0.00	
Giant Grenadier	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Greenlings	0.46	1.00	0.68	1.00	0.67	0.48	0.47	0.20	0.10	0.15
Grenadier - Pacific Grenadier										
Rattail Grenadier Unid.	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.04
Gunnels		0.00		0.00		0.00			1.00	0.00
Hermit crab unidentified	0.54	0.38	0.10	0.00	0.15	0.78	0.54	0.78	0.71	0.95
Invertebrate unidentified	0.00	0.00	0.01	0.76	0.00	0.51	0.00	0.01	0.01	0.00
Large Sculpins										
Large Sculpins - Bigmouth Sculpin										
Large Sculpins - Great Sculpin										
Large Sculpins - Hemilepidotus Unidentified										
Lg. Sculpins - Myoxocephalus Unid.										
Large Sculpins - Plain Sculpin										
Large Sculpins - Red Irish Lord										
Large Sculpins - Warty Sculpin										
Large Sculpins - Yellow Irish Lord										
Misc crabs	0.10	0.57	0.19	0.00	0.04	0.59	0.61	0.45	0.72	0.45
Misc crustaceans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Misc fish	0.04	0.05	0.04	0.01	0.01	0.01	0.01	0.01	0.02	0.02
Misc inverts (worms etc)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Other osmerids	1.00	1.00					0.00	0.00	0.00	0.00
Other Sculpins										
Pacific Sand lance				1.00					0.00	
Pacific Sandfish			1.00						0.00	
Pandalid shrimp	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
Polychaete unidentified	0.26	1.00	0.00		0.00	0.00	0.00	0.00	0.01	0.00
Saffron Cod	1.00	1.00						0.00	0.00	
Sculpin										0.39
Scypho jellies	0.83	0.97	0.65	0.00	0.05	0.85	0.70	0.30	0.31	0.41
Sea anemone unidentified	0.14	0.03	0.01	0.03	0.08	0.05	0.15	0.02	0.28	0.11
Sea pens whips	1.00	0.03	0.00	0.34	0.01	0.55	0.30	0.20	0.30	0.57
Sea star	0.33	0.22	0.23	0.15	0.10	0.33	0.19	0.26	0.41	0.62
Snails	0.28	0.29	0.16	0.06	0.10	0.67	0.52	0.43	0.56	0.91
Sponge unidentified	0.05	0.01	0.00	0.02	0.10	0.03	0.06	0.01	0.06	0.03
State-managed Rockfish	0.09	0.21	0.01	0.18	0.00	0.15	0.49	0.02	0.29	0.32
Stichaeidae	0.00	0.00	0.00	0.00	0.00	0.00	0.06		0.00	
urchins dollars cucumbers	0.04	0.02	0.03	0.02	0.07	0.06	0.04	0.02	0.11	0.07

Table 2A.33: Bycatch of Nontarget and Ecosystem bird species for the Aleutian Islands Pacific cod fishery, expressed as a proportion of the incidental catch of that species group taken in the longline, trawl, and pot gear FMP AI fisheries 2003-2021 (through October 30).

	Longline																		
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Auklets	0.00									1.00		0			0.00	0.00			
Black-footed Albatross	1.00			0.00				1.00	0.00		0.00	0	0.00						
Gull	0.01	0.11	0.59	0.46	0.42	1.00	0.59	0.53	0.08	0.06	0.17		0.08	0		1.00	1.00	1.00	0.34
Kittiwake	1.00		1.00						1.00	1.00	1.00					1.00		0.89	
Laysan Albatross	0.04	0.00	0.17	0.45	0.23	0.40	0.12	0.30	0.00	0.00	0.00	0	0.22	0	0.00	0.00		0.00	
Murre	1.00		0.36							1.00								1.00	
Northern Fulmar	0.01	0.23	0.25	0.72	0.76	0.26	0.26	0.21	0.10	0.46	0.13	0	0.82	0	0.07	0.01	0.00	0.01	0.00
Other	1.00																	1.00	
Other Alcid																1.00			
Puffin								1.00											
Shearwaters	0.10	1.00	0.89	0.00	0.07	1.00	0.21	0.08	0.26	0.26	1.00	0	0.00	0	0.11	0.00	0.14	0.00	0.13
Short-tailed Albatross								1.00	1.00									1.00	
Storm Petrels	1.00			0.00		0.00										0.00			
Unidentified	1.00	1.00	1.00	0.00	0.27	1.00	0.10	0.62	1.00	0.11	0.00				0.00	1.00		1.00	0.00

	Non Pelagic Trawl																		
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Auklets	1.00									0		0			0	0			
Gull	0.99	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0	0	0		0	0.00		0	0	0	0
Laysan Albatross	0.35	0.00	0.43	0.00	0.00	0.00	0.26	0.00	0	0	0	0	0	0.00	0	0		0	
Northern Fulmar	0.00	0.04	0.63	0.10	0.00	0.49	0.05	0.37	0	0	0	0	0	0.81	0	0	0	0	0
Unidentified	0.00	0.00	0.00	0.95	0.00	0.00	0.00	0.00	0	0	0				0	0		0	0
Unidentified Albatross				1.00								0							

	Pot Gear																		
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Auklets	0									0.00		51.23			6.68	0.00			
Northern Fulmar	0	0	0	0.07	0.02	0.07	0.17	0.17	0	0.00	0.23	2.97	0	0	0.11	2.99	3.29	1.9	0
Shearwaters	0	0	0	0.51	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0	0.00	0.00	0.00	0.0	0
Storm Petrels	0			2.97		0.00										0.00			
Unidentified	0	0	0	0.00	0.00	0.00	0.00	0.00	0	0.79	0.00				0.00	0.00		0.0	0

Figures

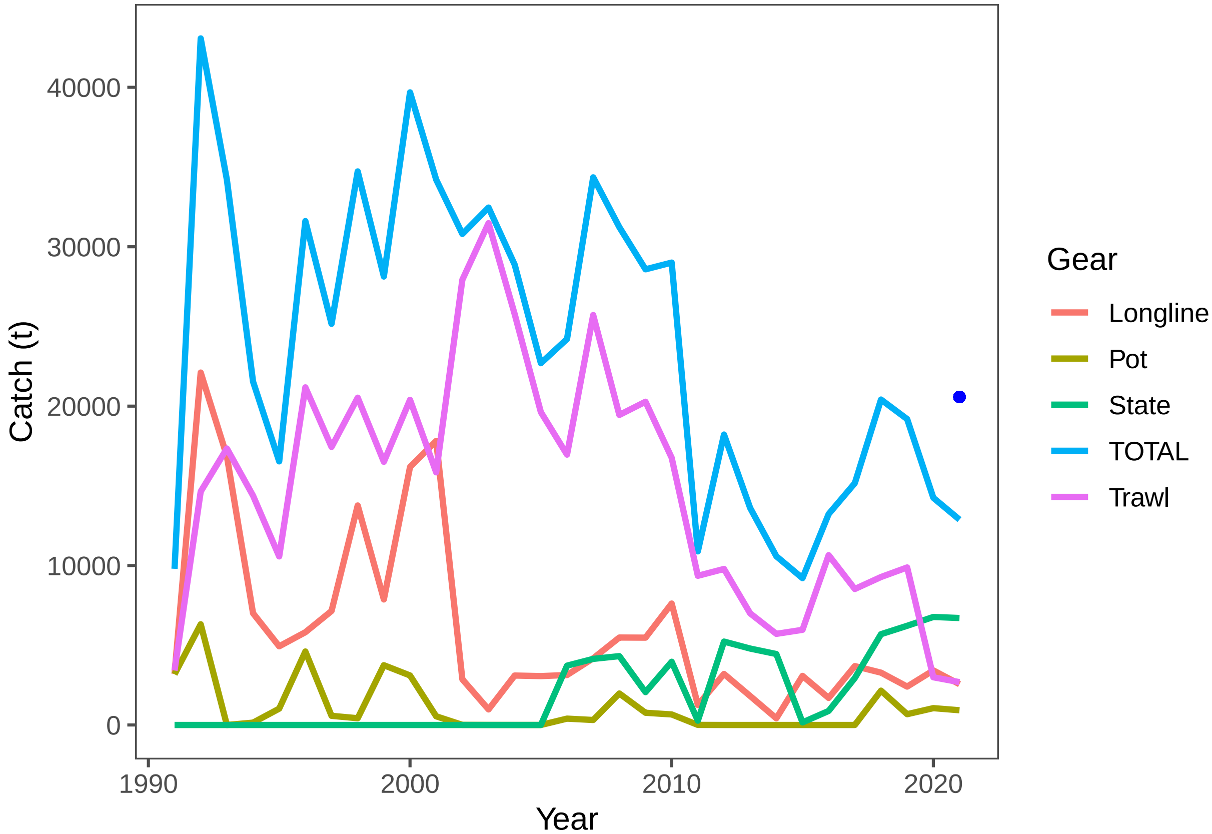


Figure 2A.1: Aleutian Islands Pacific cod catch history, with Federal catches broken down by gear type, from 1991-2021 (through October 30). The blue dot represents the ABC for 2021 based the Tier 5 Model.

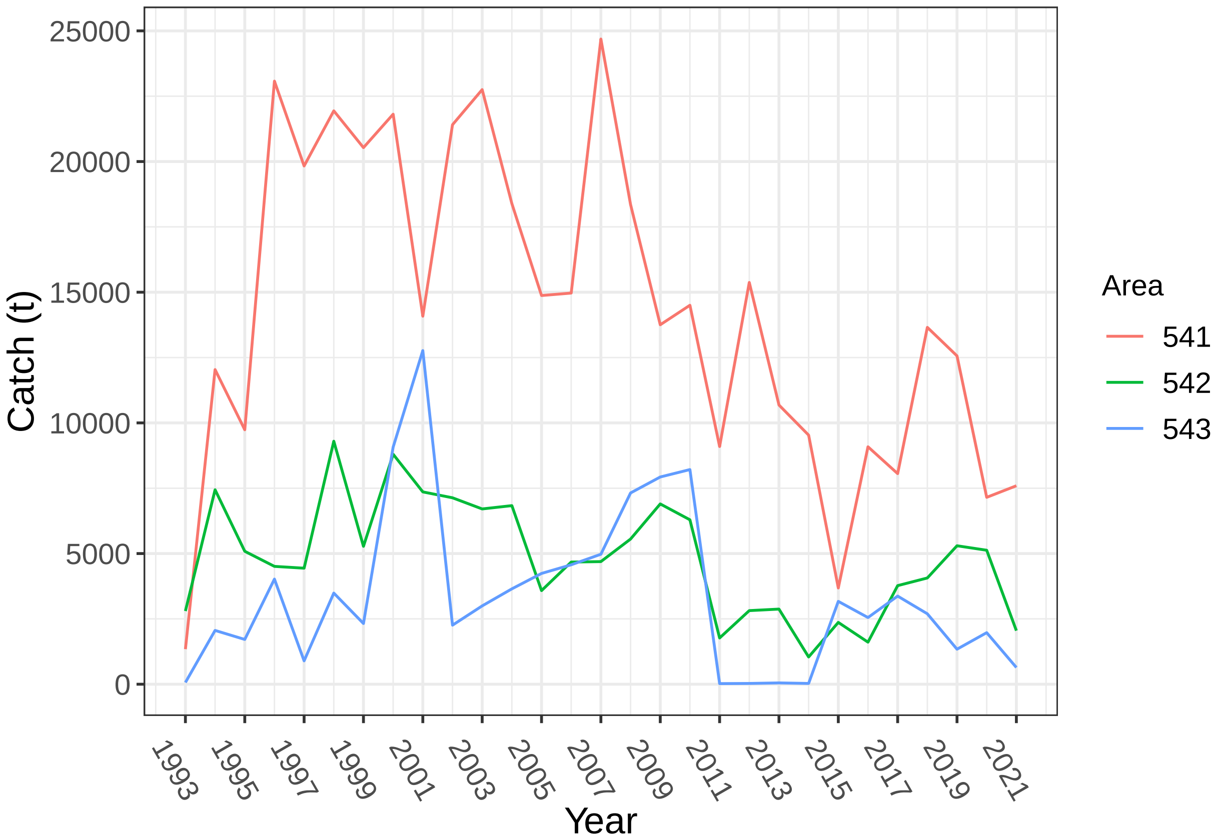


Figure 2A.2: Aleutian Islands Pacific cod catch in tons by area, from 1993-2021 (through October 30).

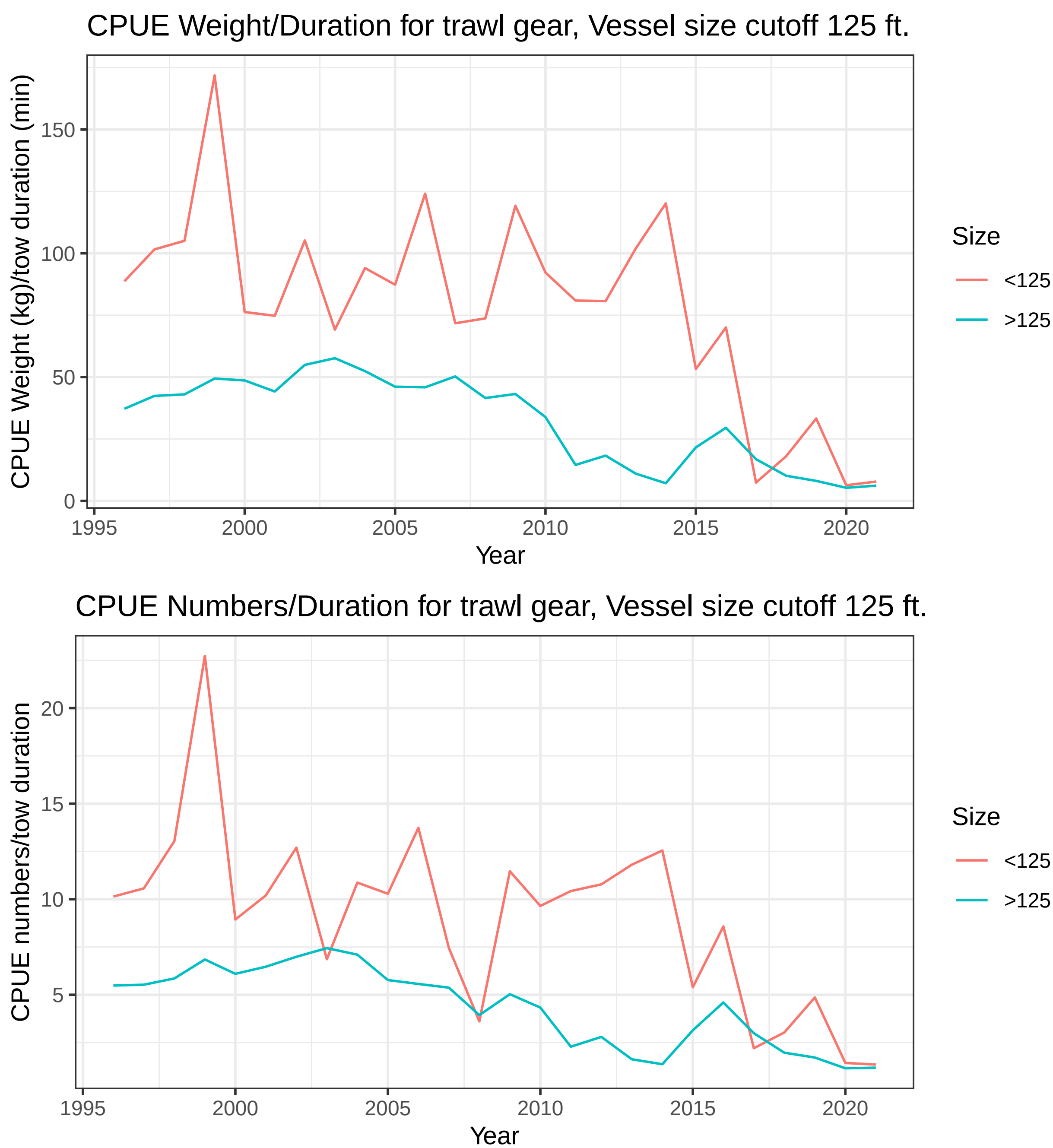


Figure 2A.3: Catch per unit effort for AI cod fisheries, 1996-2021. The upper plot represents CPUE weight (kg)/trawl duration (min) for vessels greater and less than 125 ft. The lower panel represents CPUE numbers/trawl duration for the same vessel sizes. Only tows with duration > 0 and < the 90th percentile of tow duration (915 minutes) are included. Estimates of relative CPUE are complete through October 31, 2021.

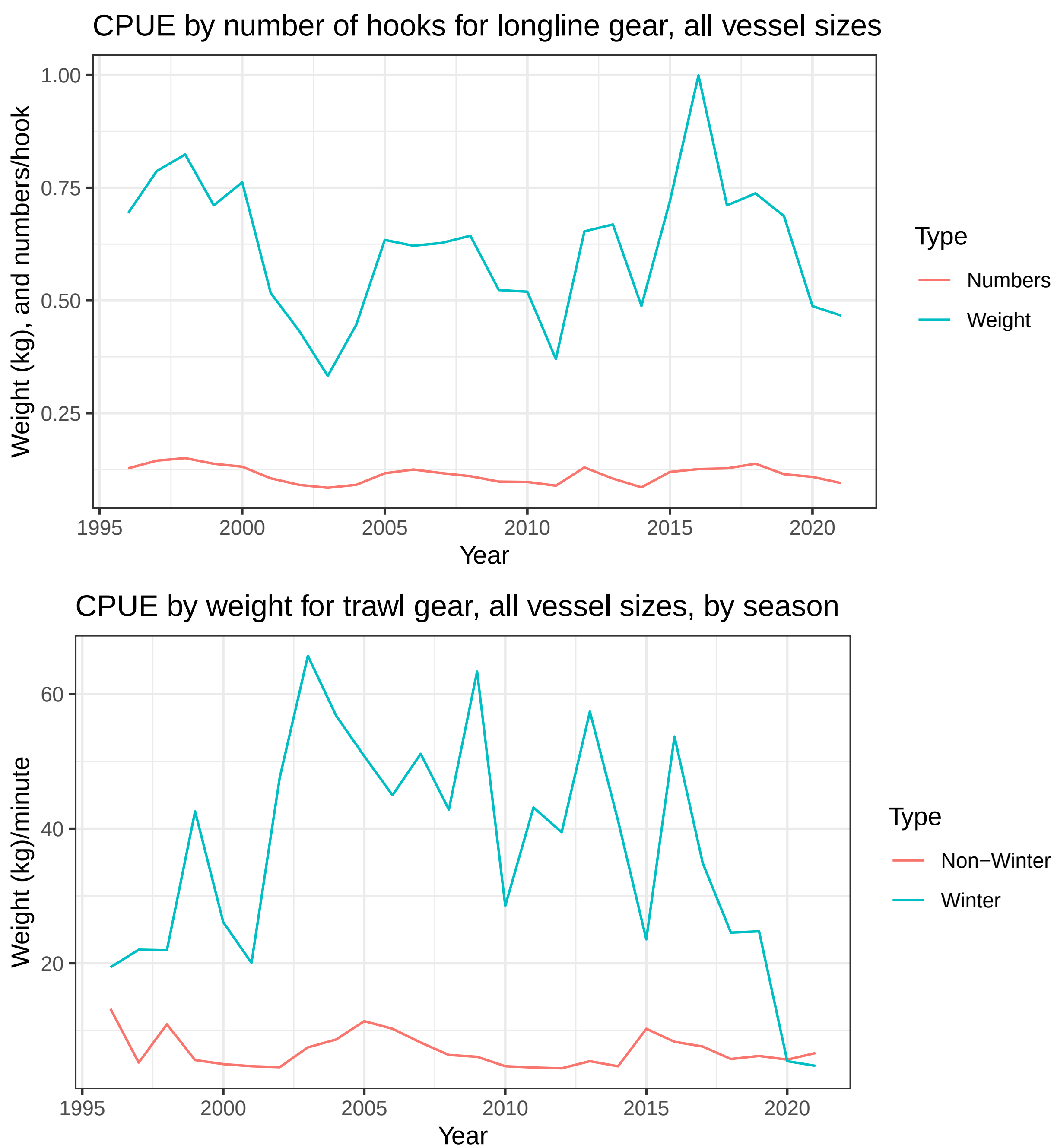


Figure 2A.4: Catch per unit effort for AI cod fisheries, 1996-2021. The upper plot represents longline CPUE weight (kg)/number of hooks for vessels of all sizes. The lower panel represents CPUE weight/trawl duration (kg/min) for trawl vessels by season (winter and non-winter). Estimates of relative CPUE were complete through October 31, 2021.

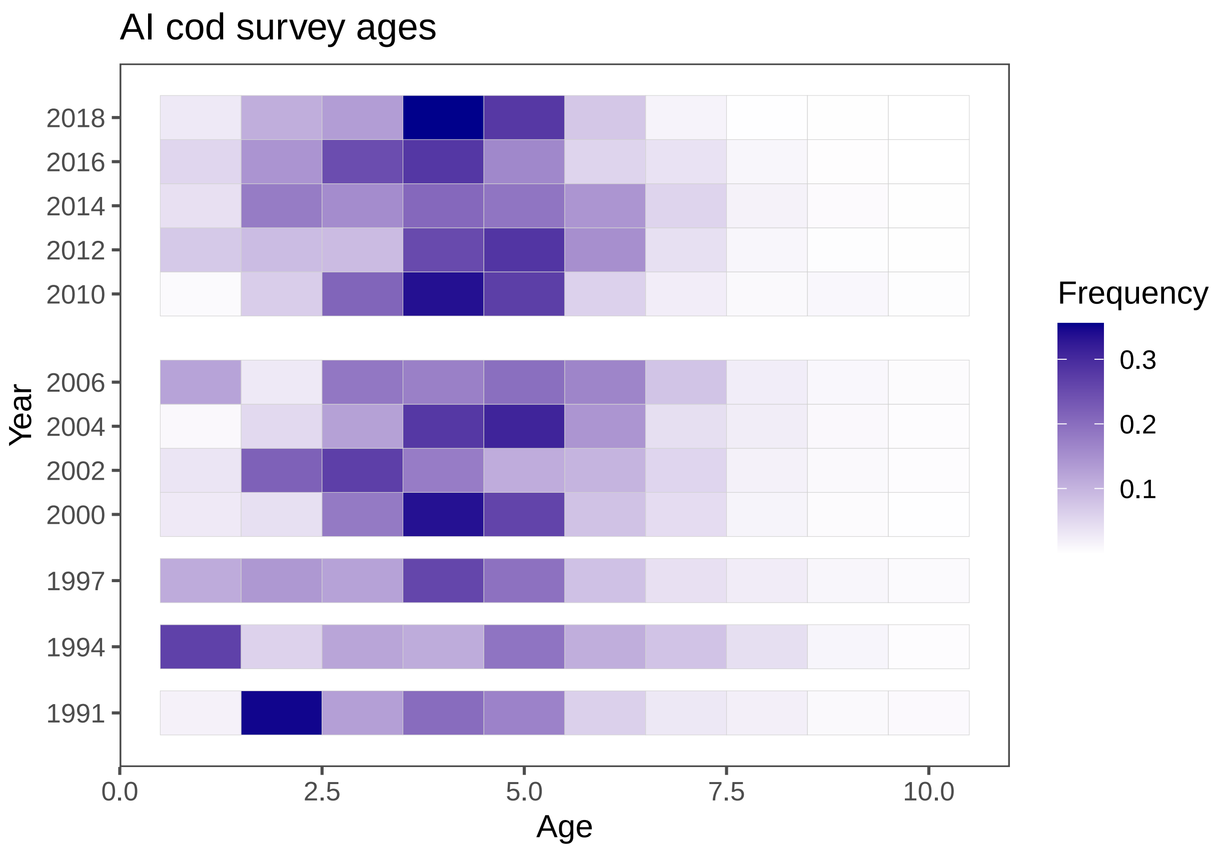


Figure 2A.5: Age composition from the NMFS Aleutian Islands surveys, 1991-2018.

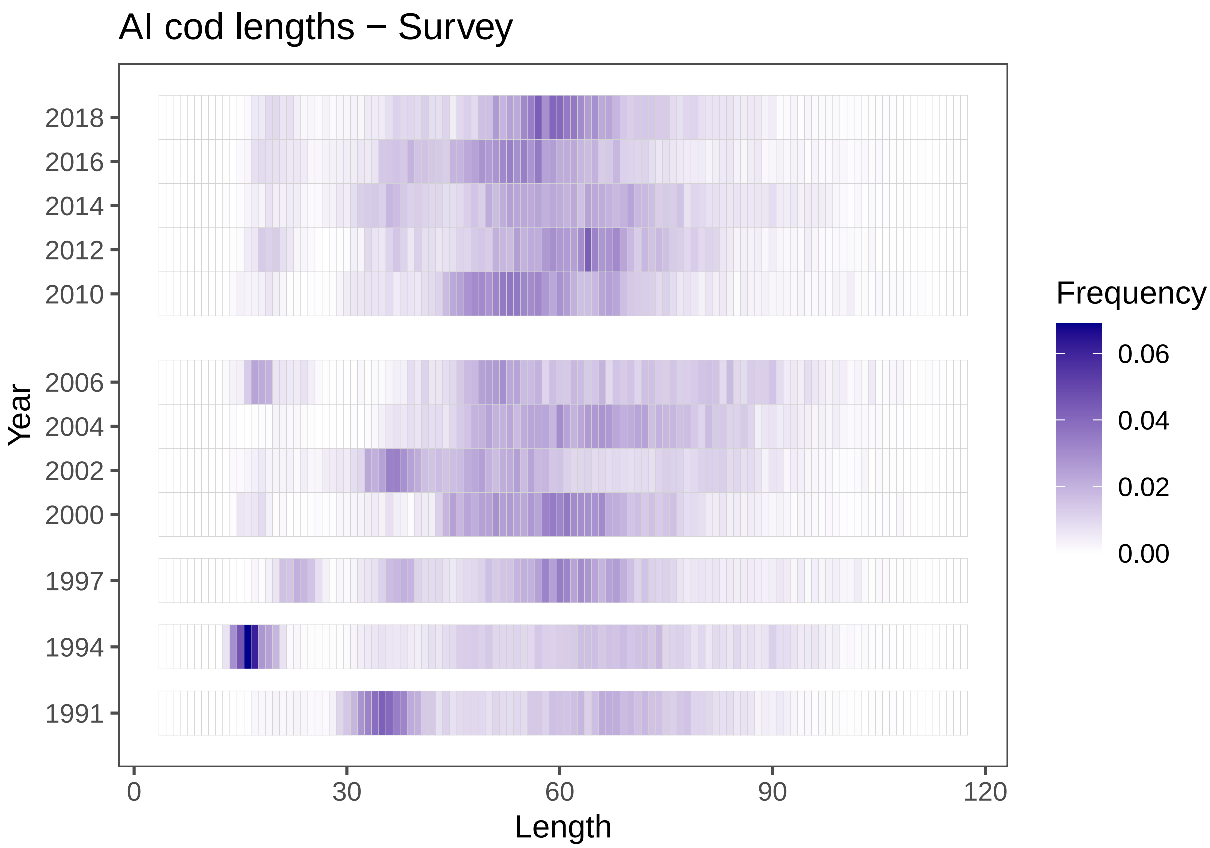


Figure 2A.6: Length compositions from the NMFS Aleutian Islands surveys, 1991-2018. Length is in centimeters (cm).

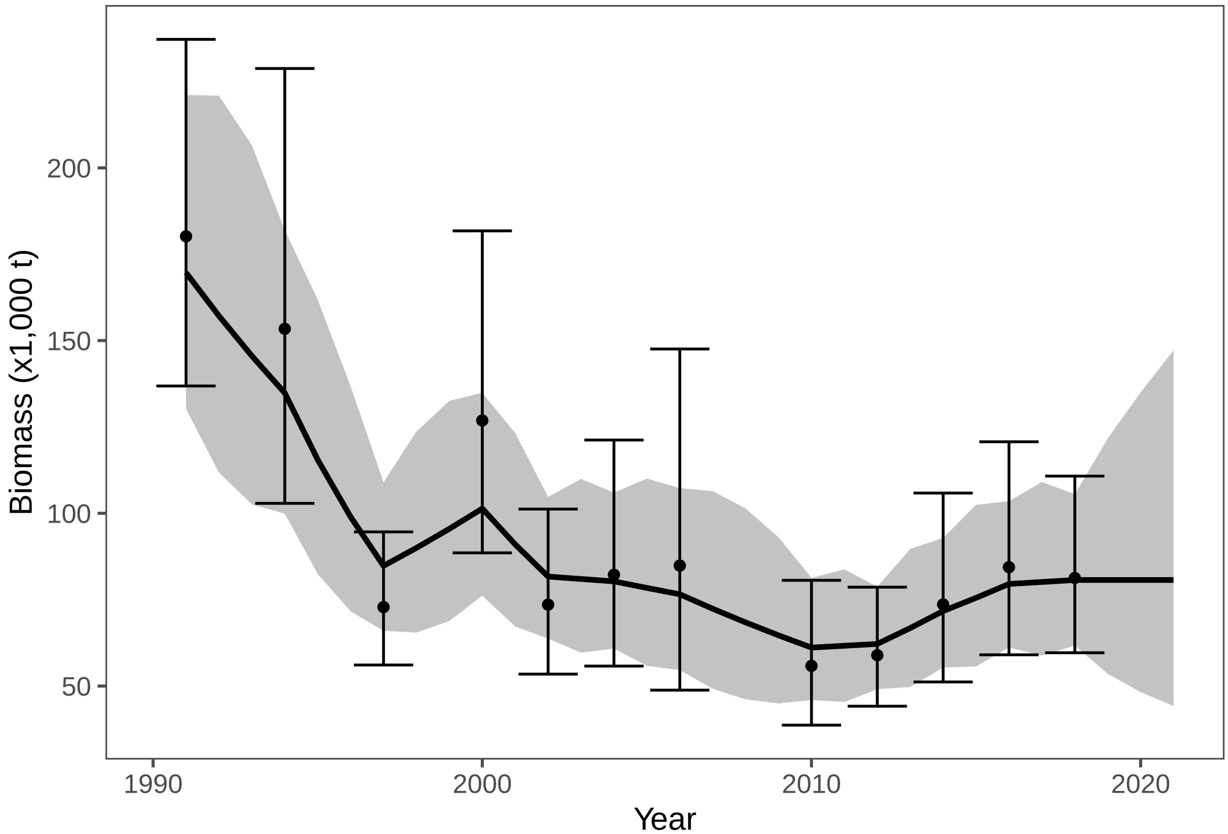


Figure 2A.7: Fit of Model 13.4 to survey biomass time series, with 95% confidence intervals for the observations and the estimates. Dots indicate survey estimates and black line represents the model estimate.

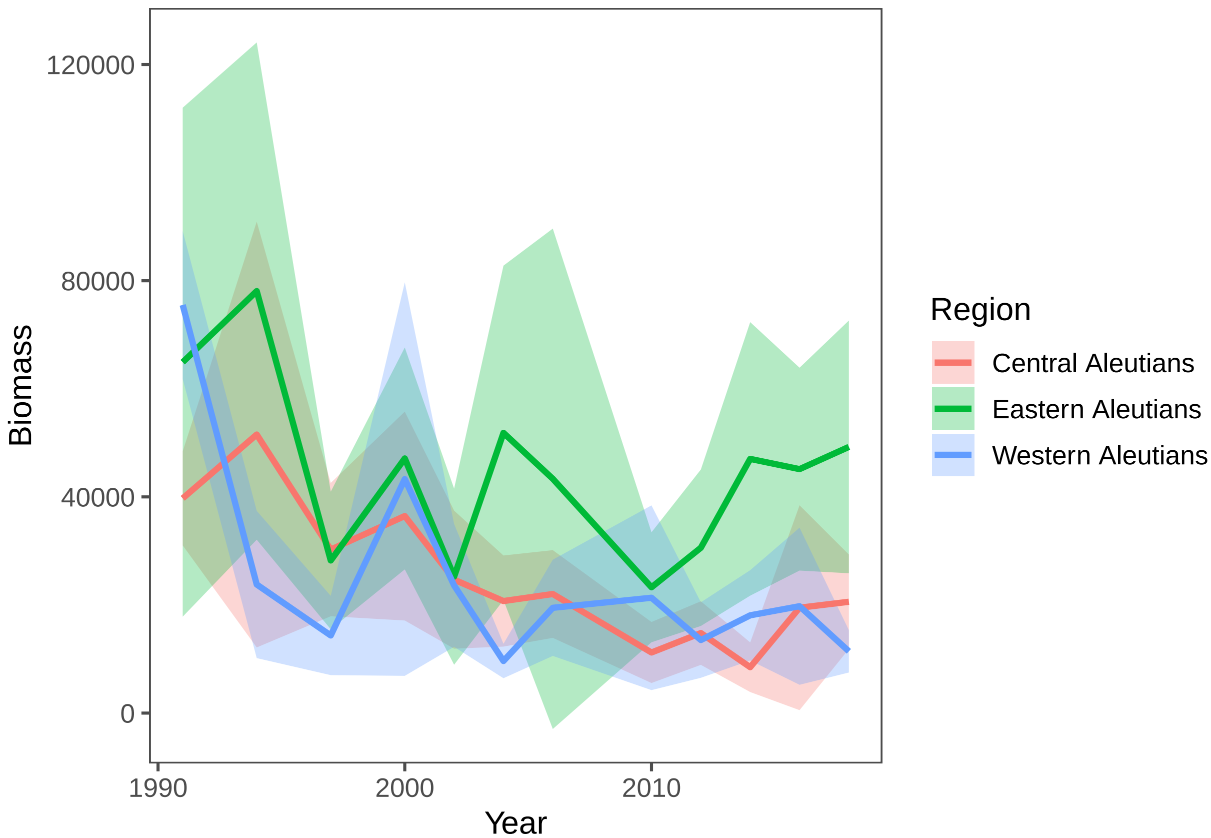


Figure 2A.8: Survey estimates of biomass in metric tons and 95% confidence intervals in the three NMFS areas of the Aleutian Islands, 543 (Western), 542 (Central), and 541 (Eastern), 1990-2018. Note that surveys prior to 1990 weren not performed using current standard methodology, and were not used in this assessment.

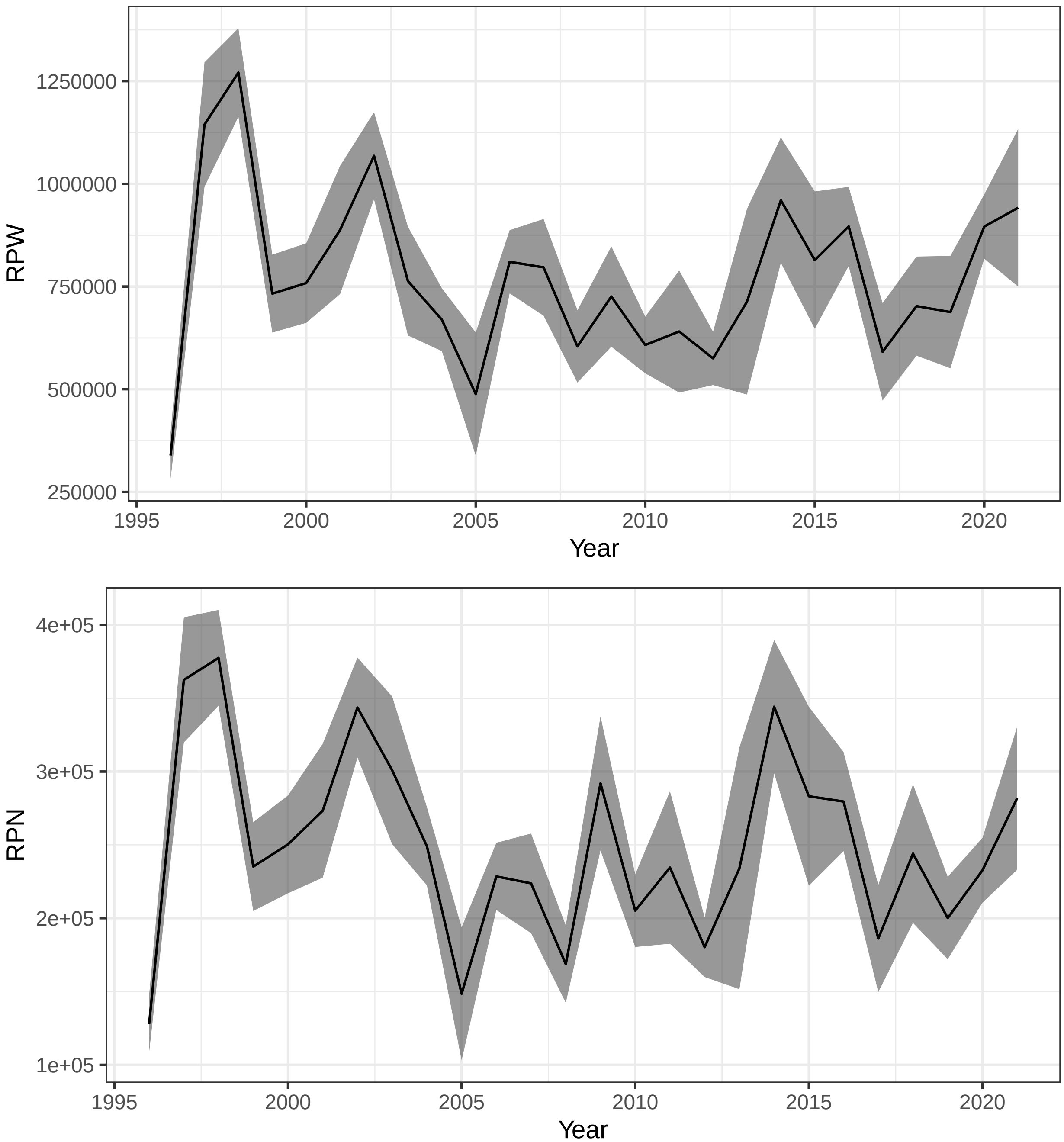


Figure 2A.9: Relative population numbers (RPN) and relative population weight (RPW) from the NMFS longline survey in the Aleutian Islands, 1982-2021.

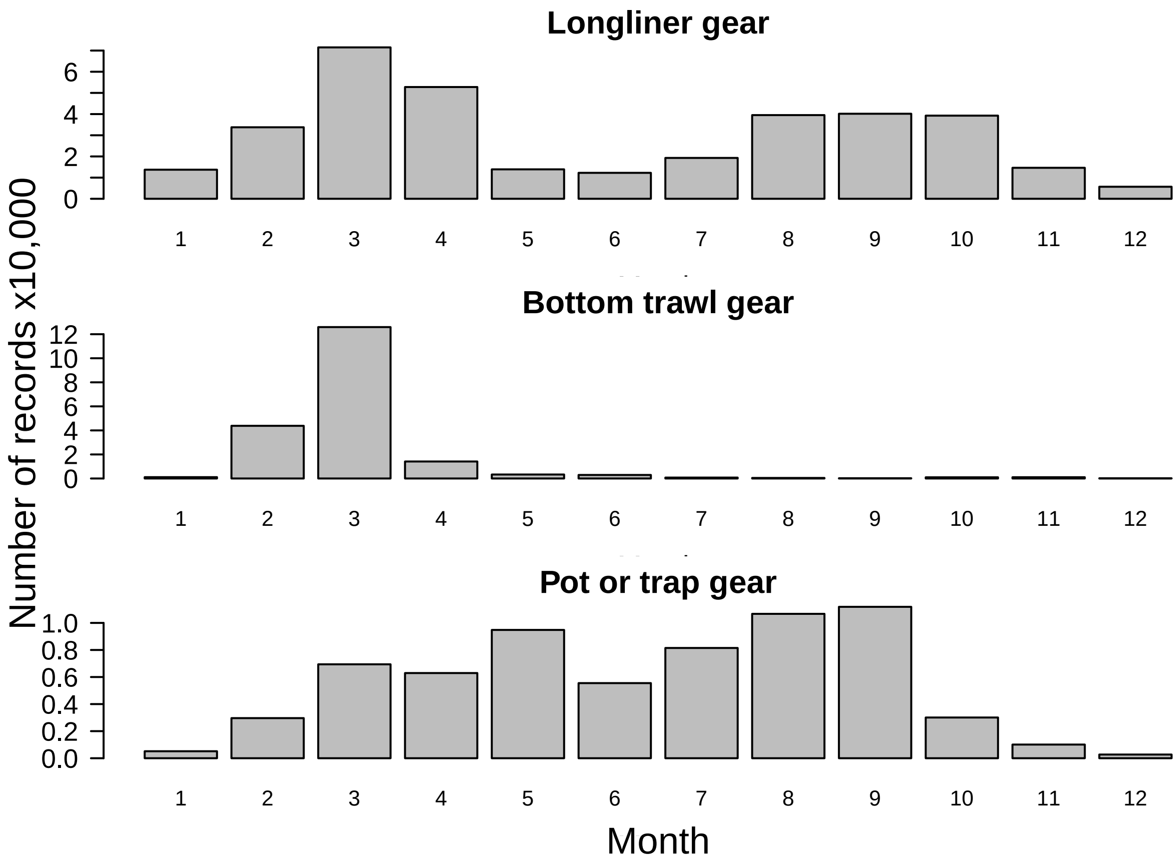


Figure 2A.10: Proportion of fishery lengths taken by month for each gear type, with year of the month listed as a number from 1 (January) to 12 (December), 1990-2021, based on 832,658 records.

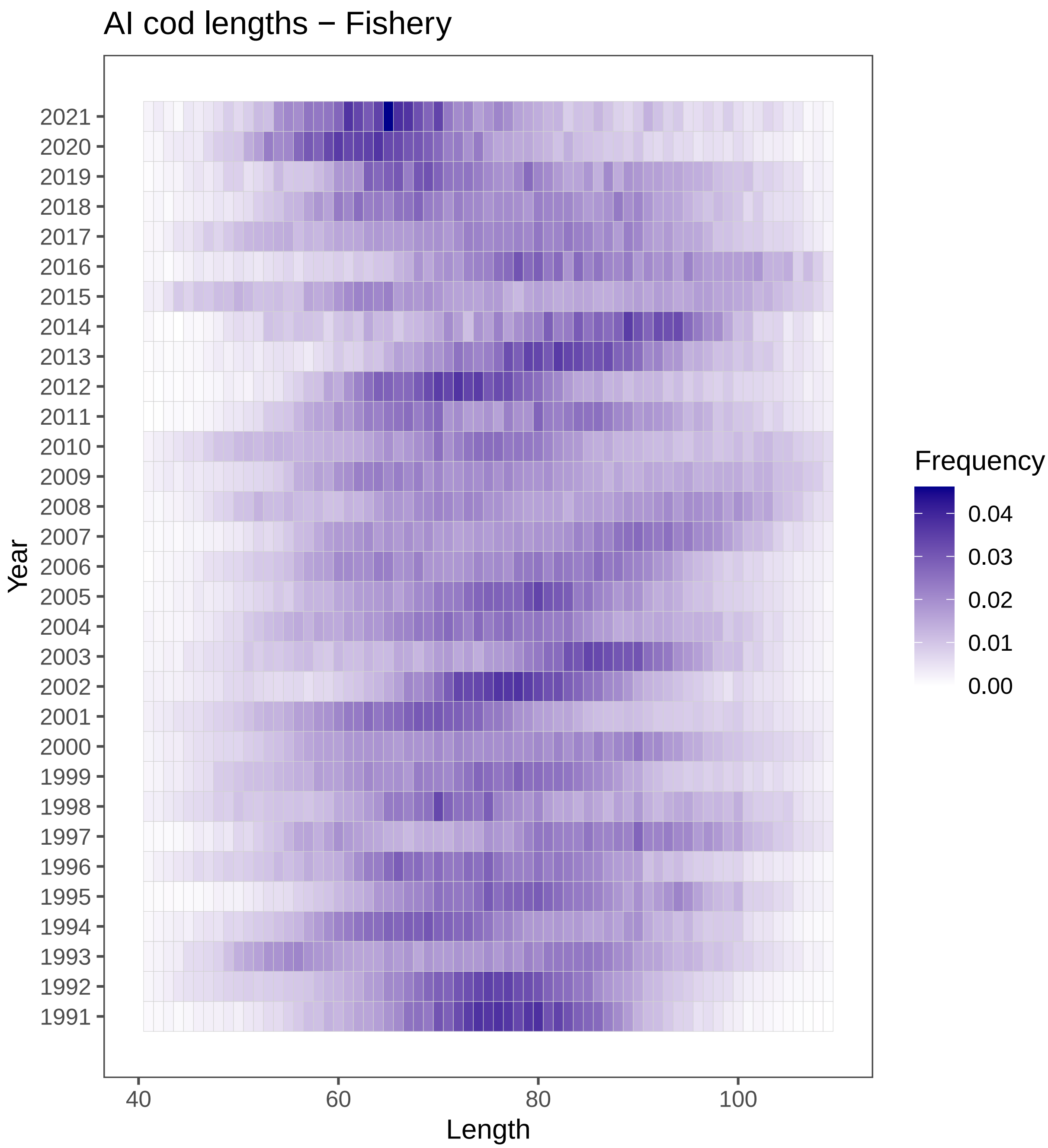


Figure 2A.11: Length compositions from the Aleutian Islands Pacific cod fishery, 1991-2021. Length is in centimeters (cm).

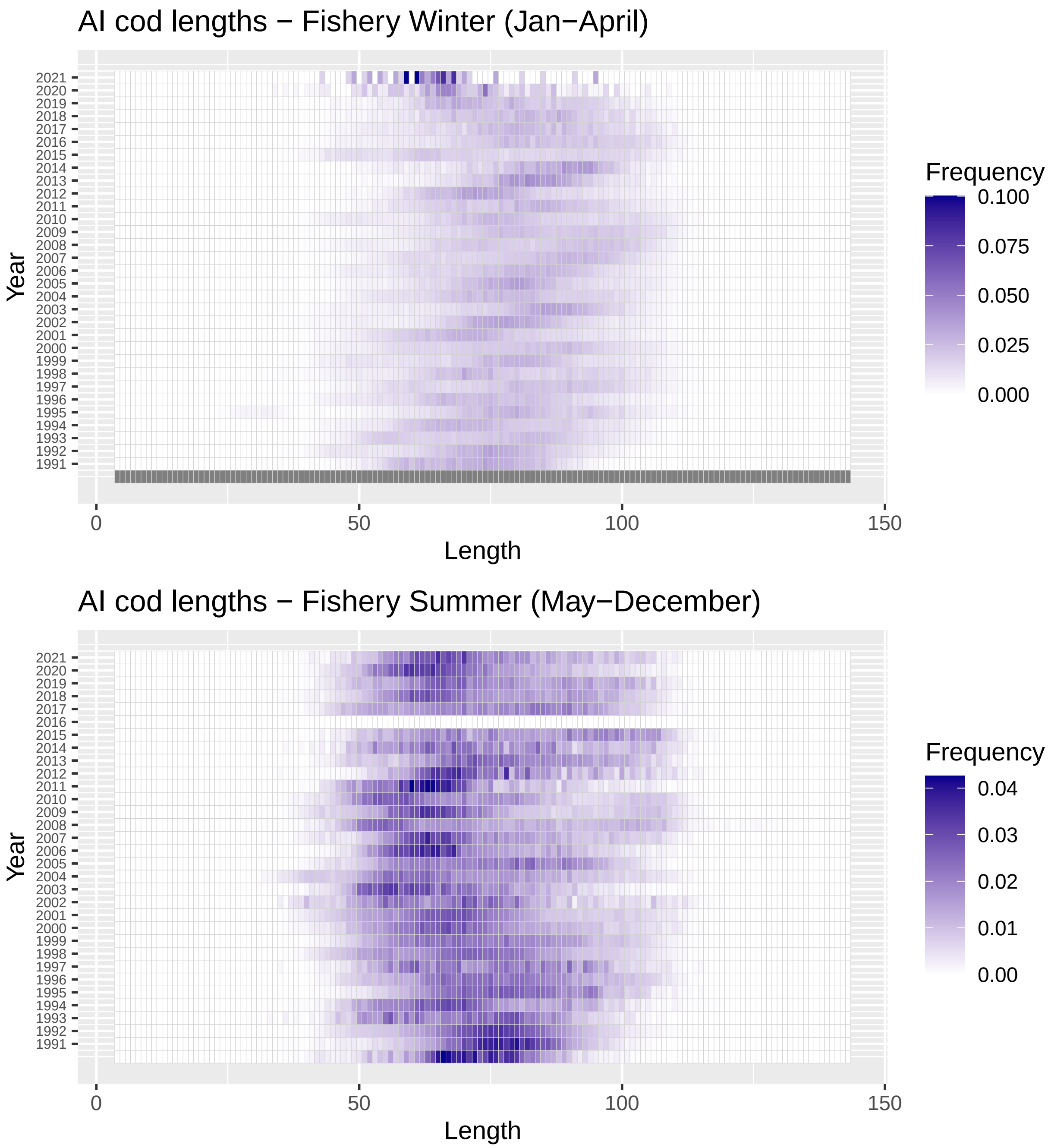


Figure 2A.12: Length compositions from the Aleutian Islands Pacific cod fishery, 1991-2020, by season. Seasons are defined as non-spawning (May - December) and spawning (January-April). Length is in centimeters (cm). There were too few lengths taken in 2021 (98) to use in the age-structured model.

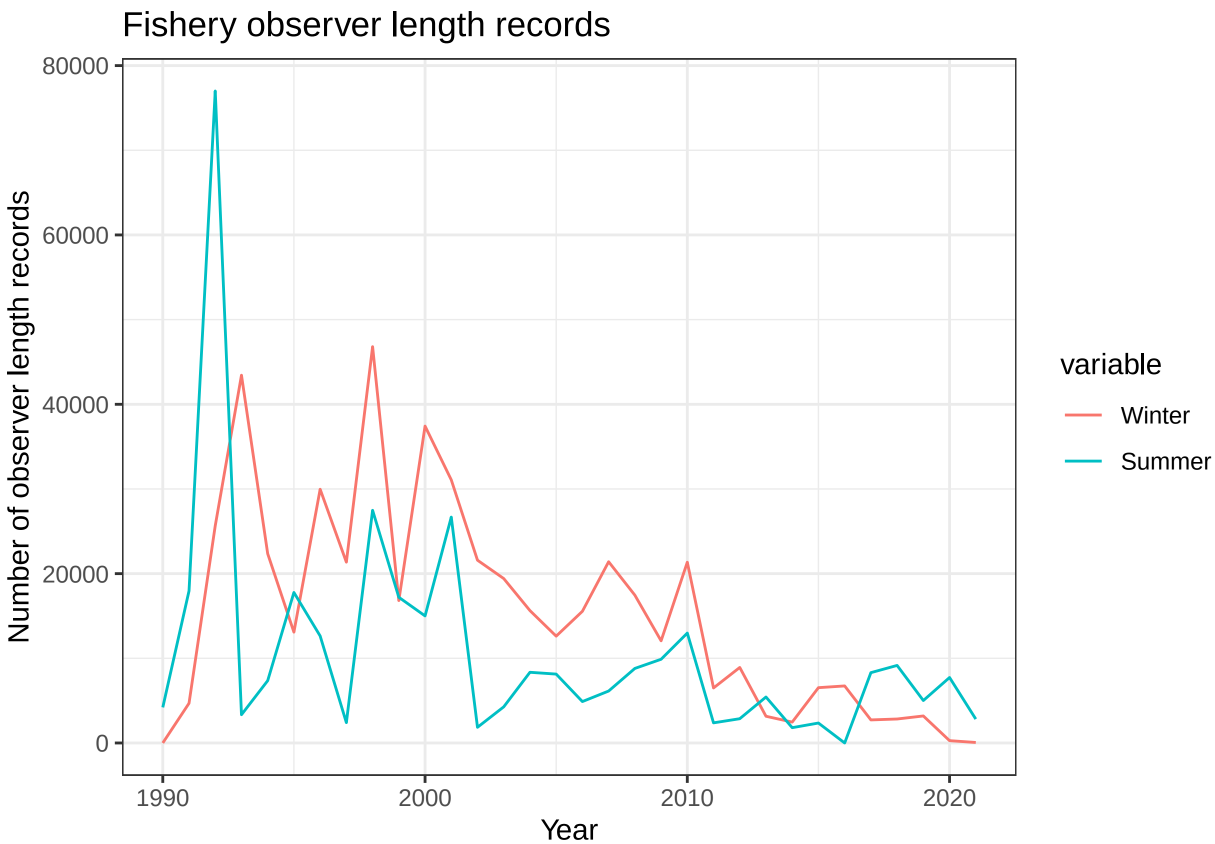


Figure 2A.13: The number of observer length records for Pacific cod taken in the Aleutian Islands from 1991-2021.

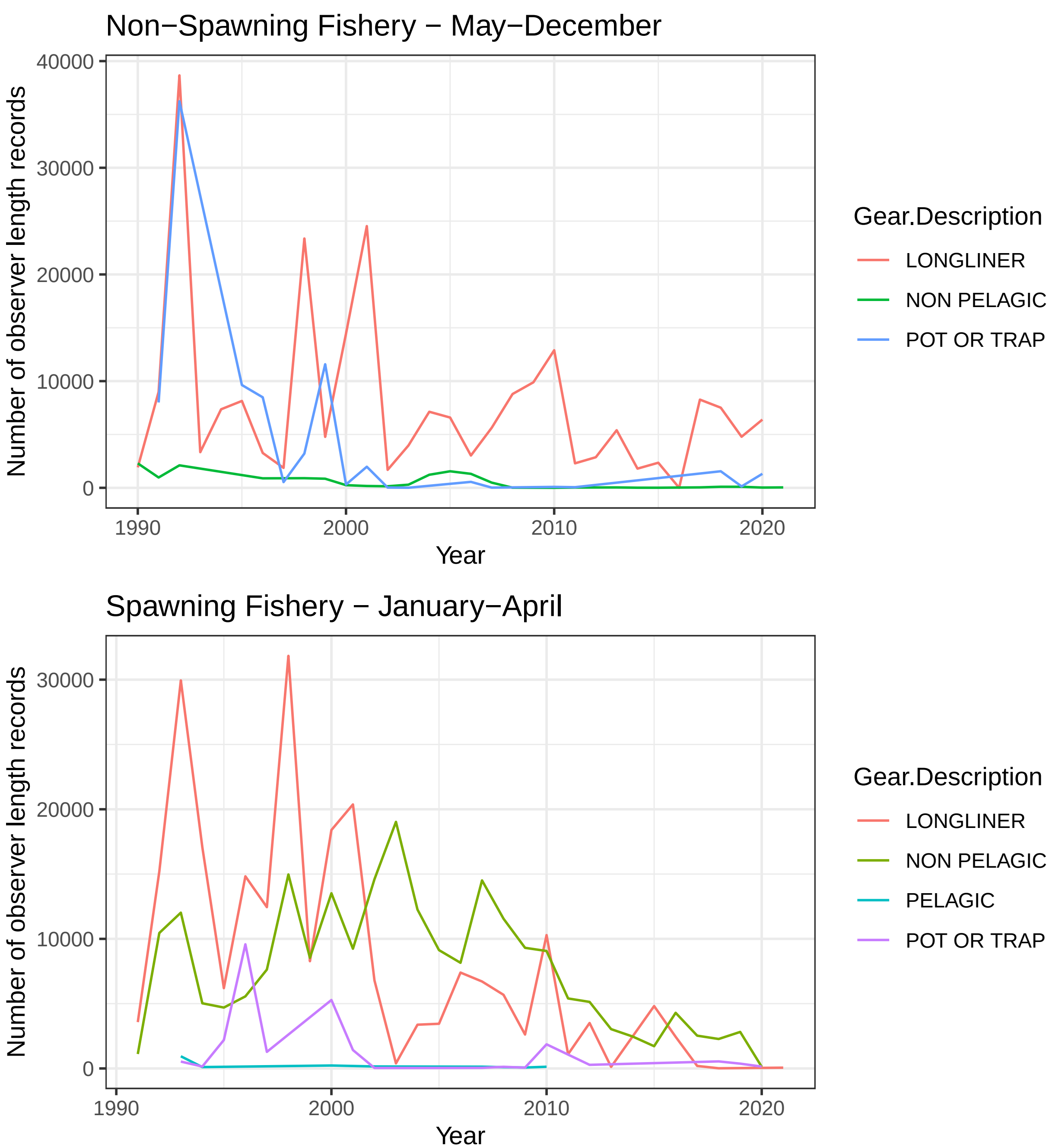


Figure 2A.14: The number of observer length records for Pacific cod taken in the Aleutian Islands by gear type during spawning (January-April) and non-spawning (May - December) seasons from 1991-2021.

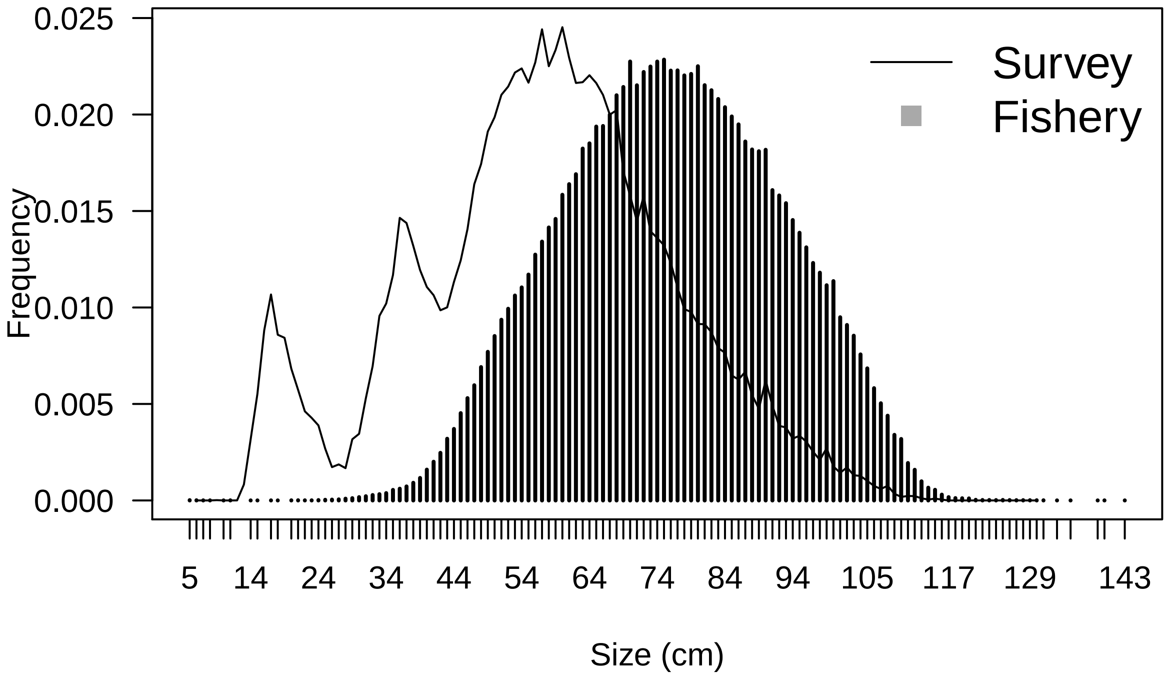


Figure 2A.15: Length frequencies for Pacific cod caught in the Aleutian Islands by the fishery (1990-2021) and the survey, 1991-2018.

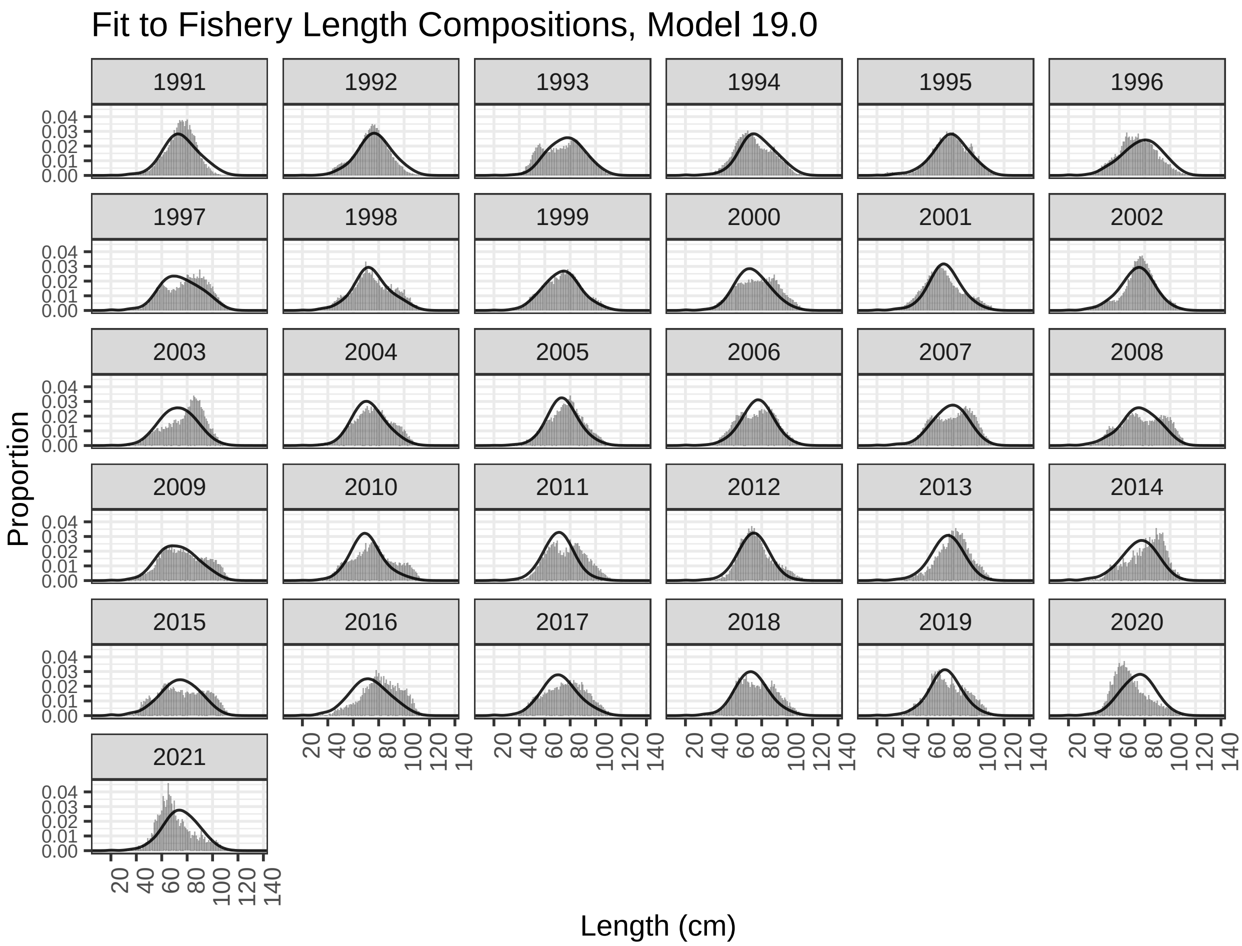


Figure 2A.16: Fishery length frequency fit to model 19.0, solid line is predicted.

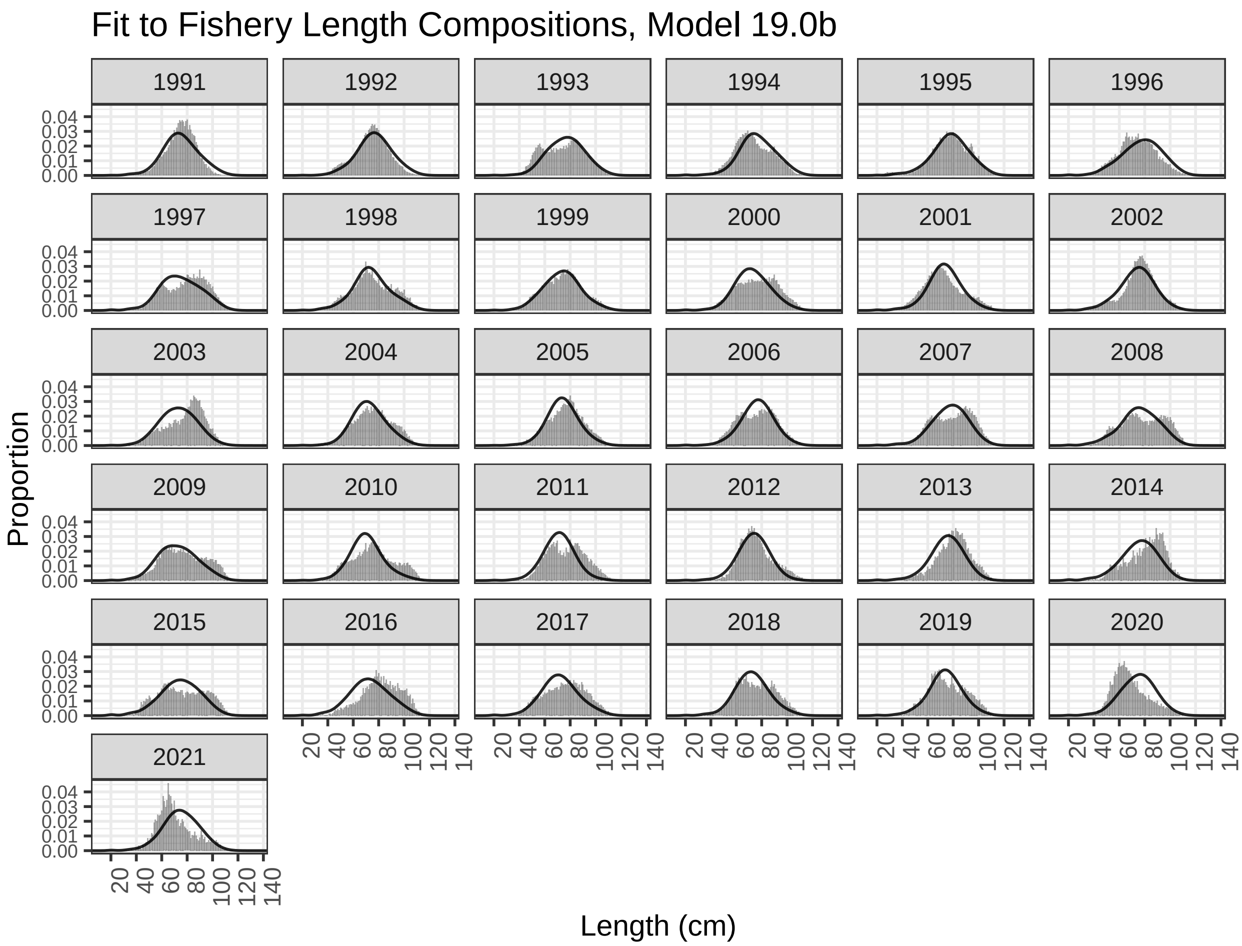


Figure 2A.17: Fishery length frequency fit to model 19.0b, solid line is predicted.

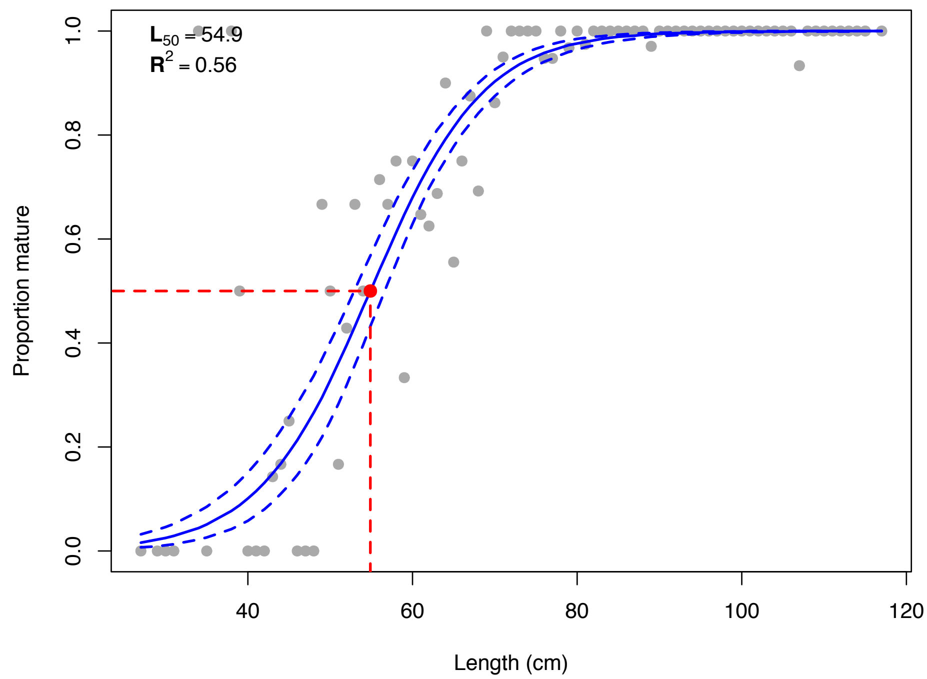


Figure 2A.18: Parameter estimation for A and B, size at maturity, and fit to the data for the proportion of Aleutian Islands cod mature by length, during January-March, 2008-2021. This is the maturity curve used in this assessment.

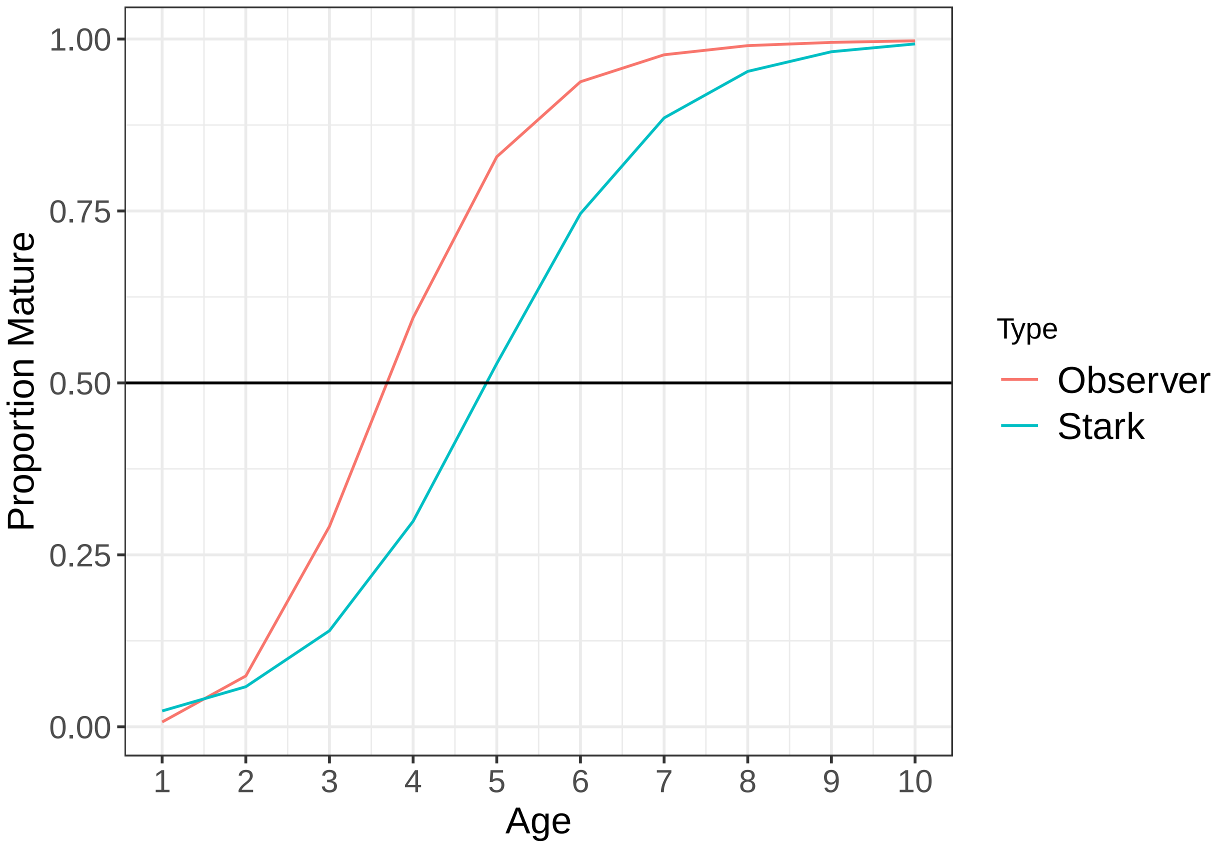


Figure 2A.19: Proportion mature by age, as measured using Stark (2007) parameters and observer maturity at length data.

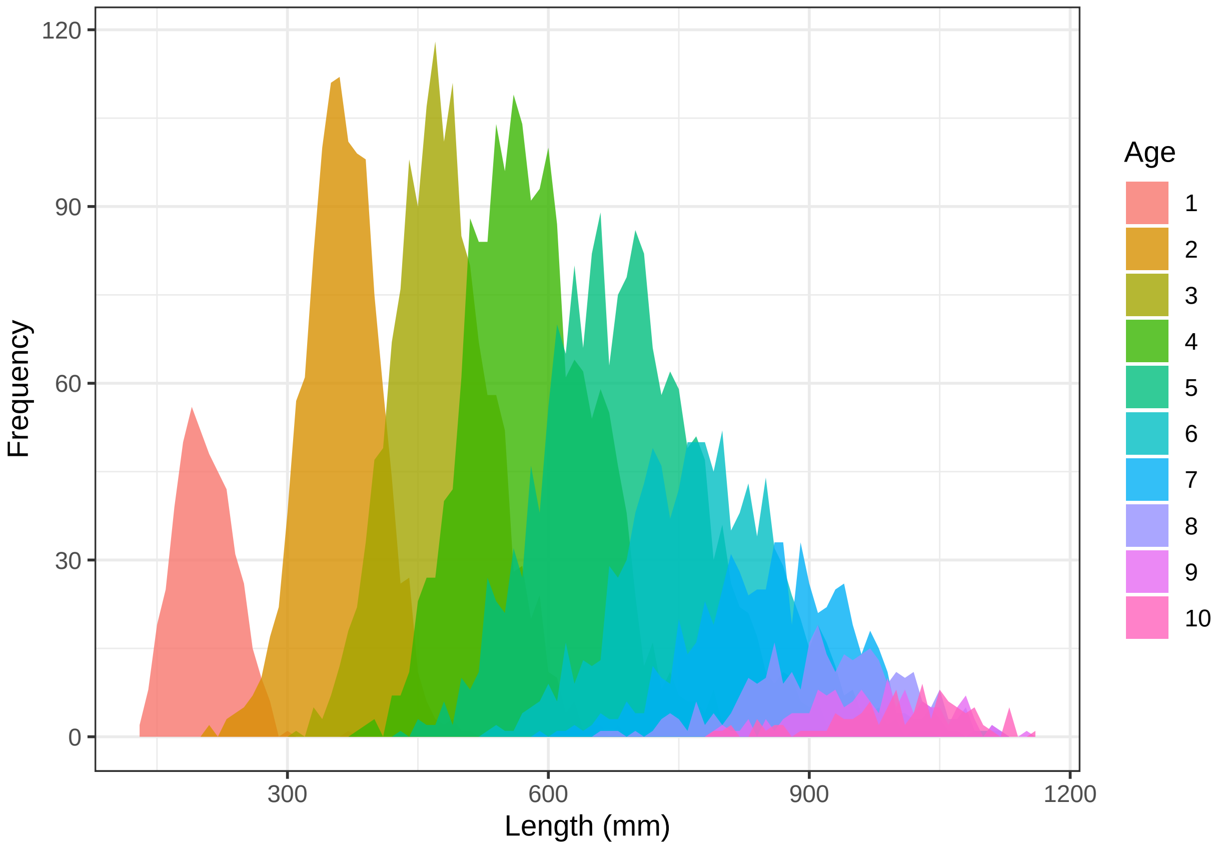


Figure 2A.20: Length frequency by age of cod collected from surveys from 1990-2018.

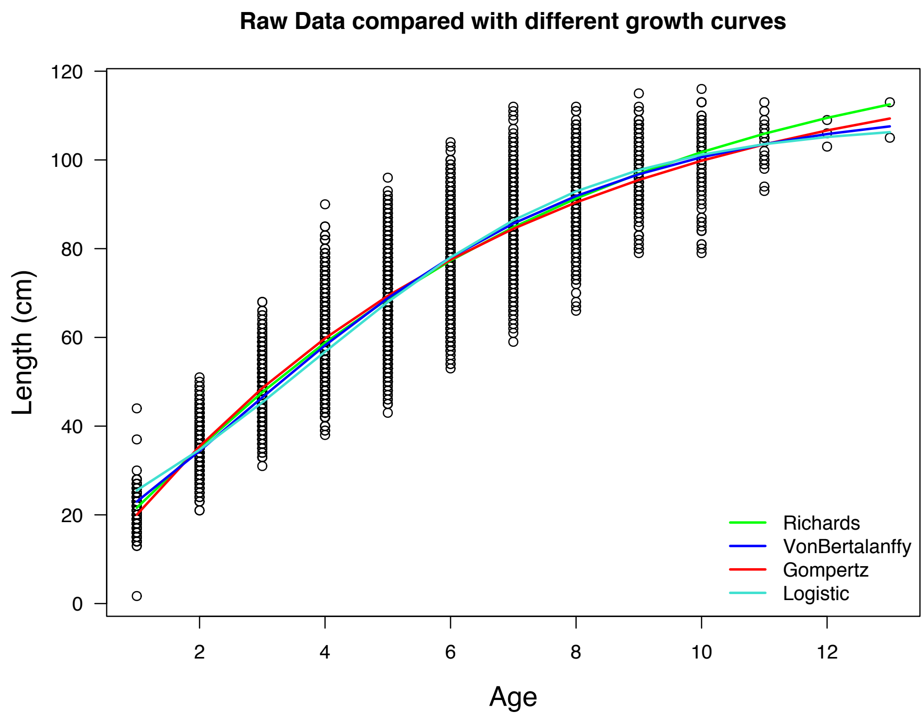


Figure 2A.21: Four models fit to length at age data for Aleutian Islands Pacific cod, Richards, Von Bertalanffy, Gompertz, and Logistic.

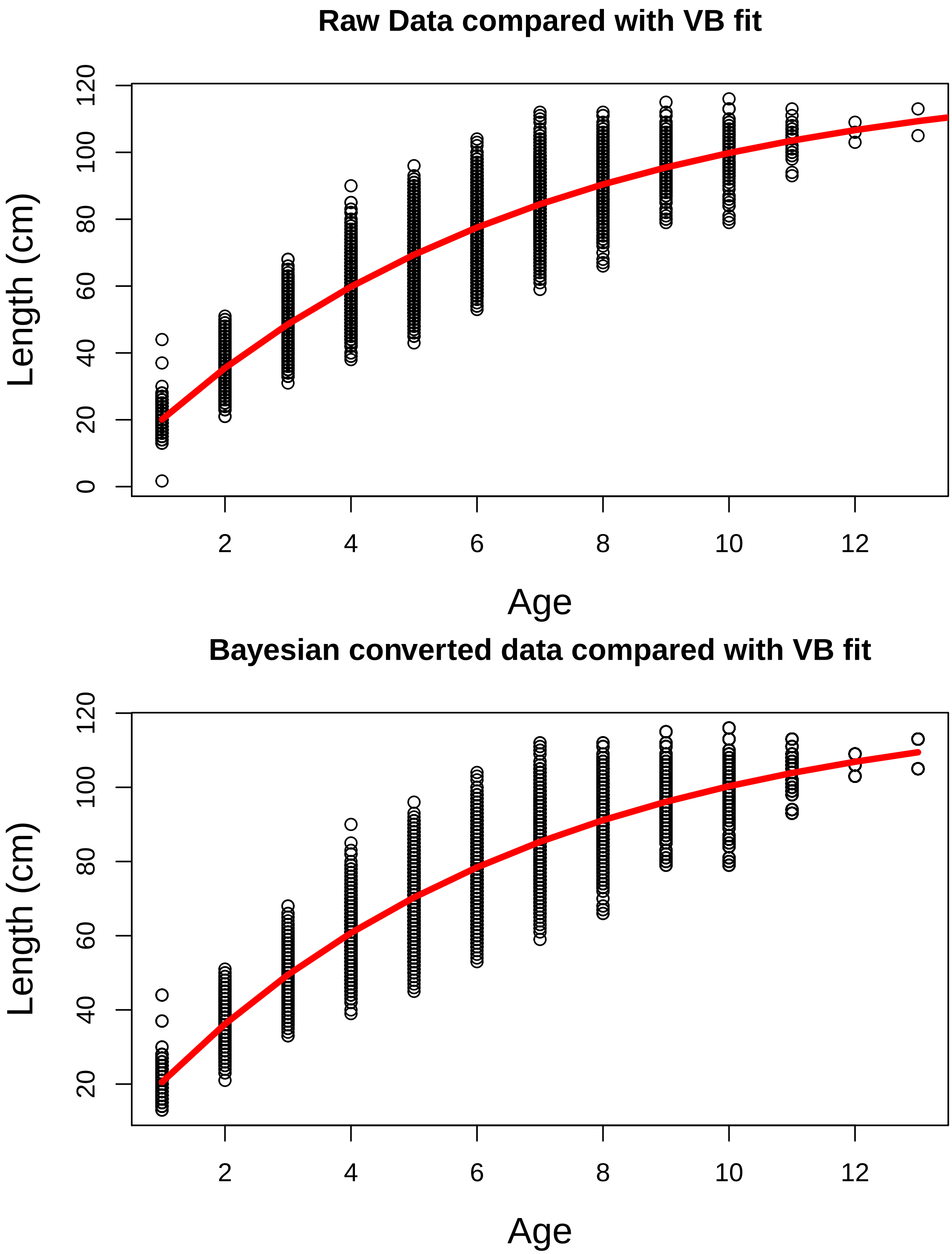


Figure 2A.22: Raw lengths at age and Von Bertalanffy growth curves, corrected vs. not corrected for population length frequencies.

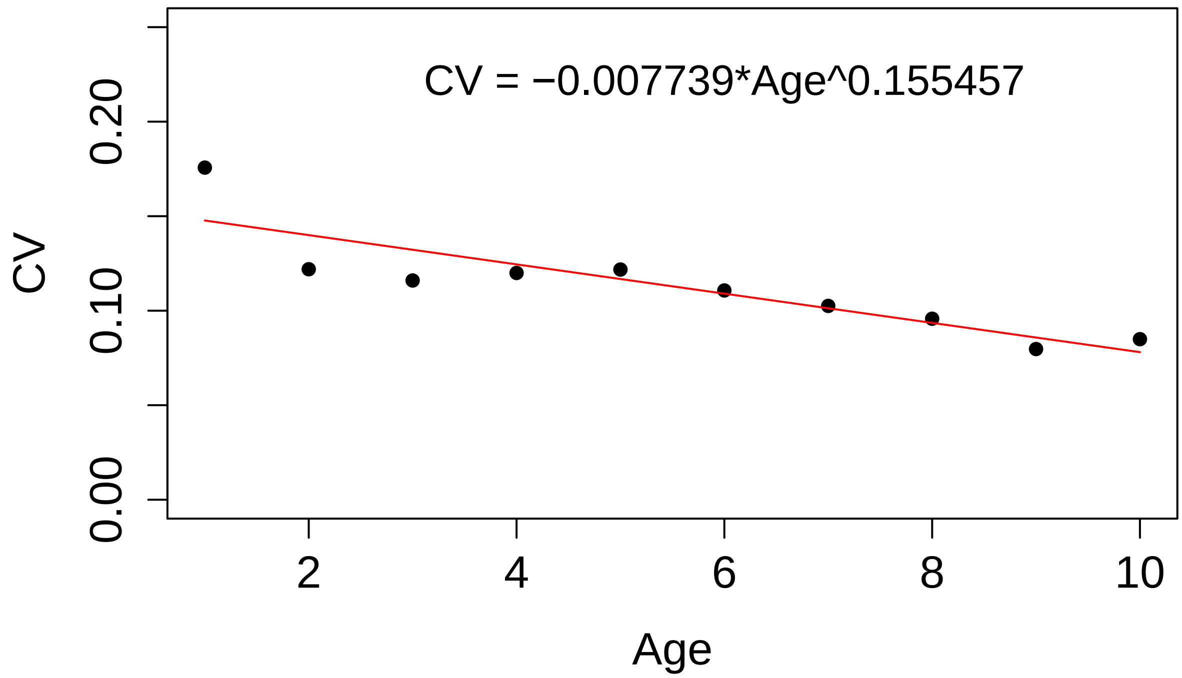


Figure 2A.23: Coefficient of variation (CV) fitted to age (red line), based on raw data (black points).

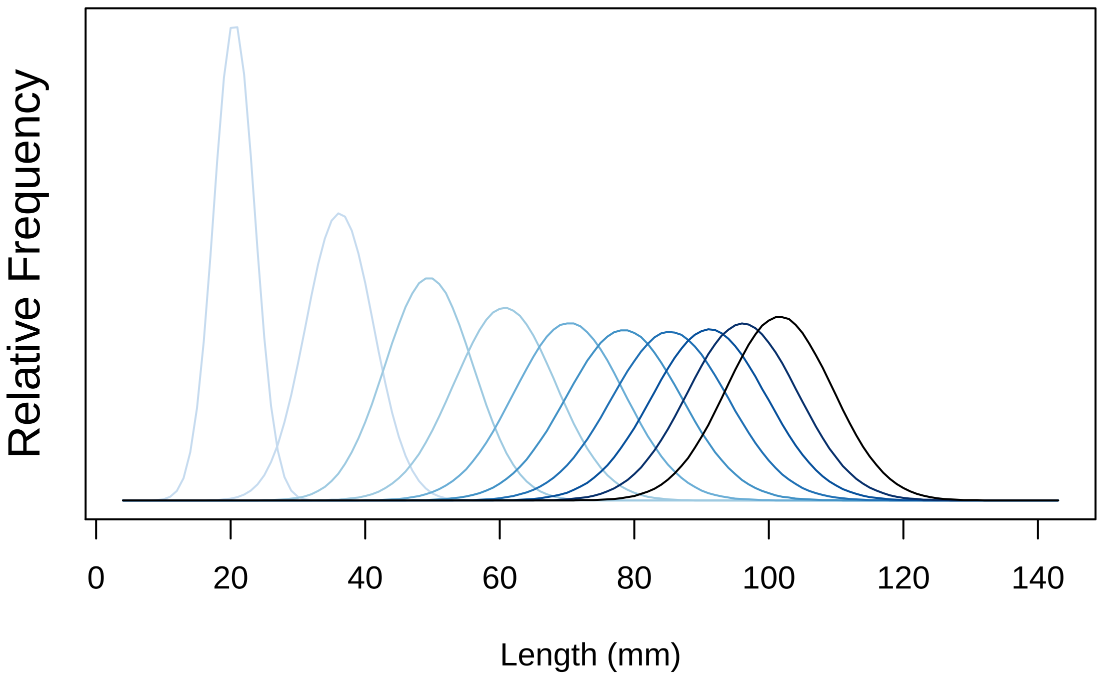


Figure 2A.24: Length age conversion matrix for Aleutian Islands Pacific cod, ages 1-10, where 10 represents the age 10+ group.

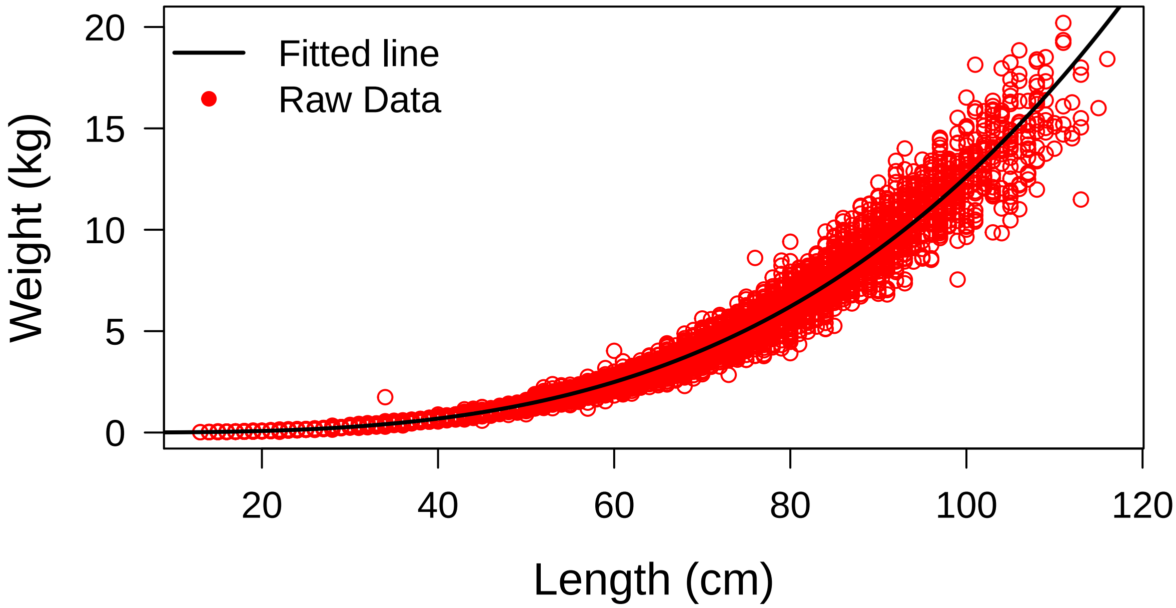


Figure 2A.25: Length-weight relationship for Aleutian Islands Pacific cod, males and females combined. The fit to weight-at-length is shown as a black line, Weight (g) = 0.005611*Length^3.176. Data is from surveys 1990-2018.

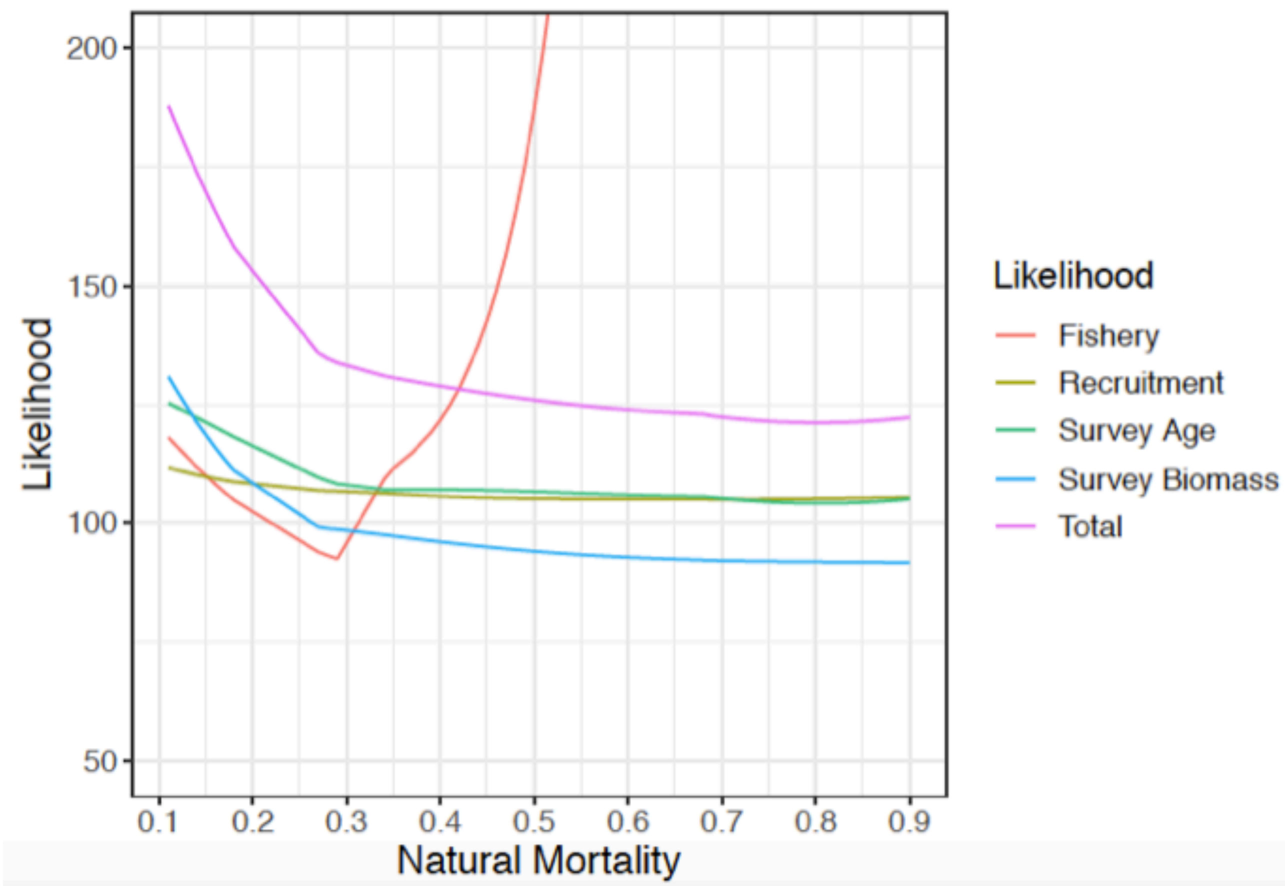


Figure 2A.26: Likelihood profile for natural mortality, showing age, fishery length, recruitment, survey biomass likelihood components. The total likelihood does not include the fishery likelihood component.

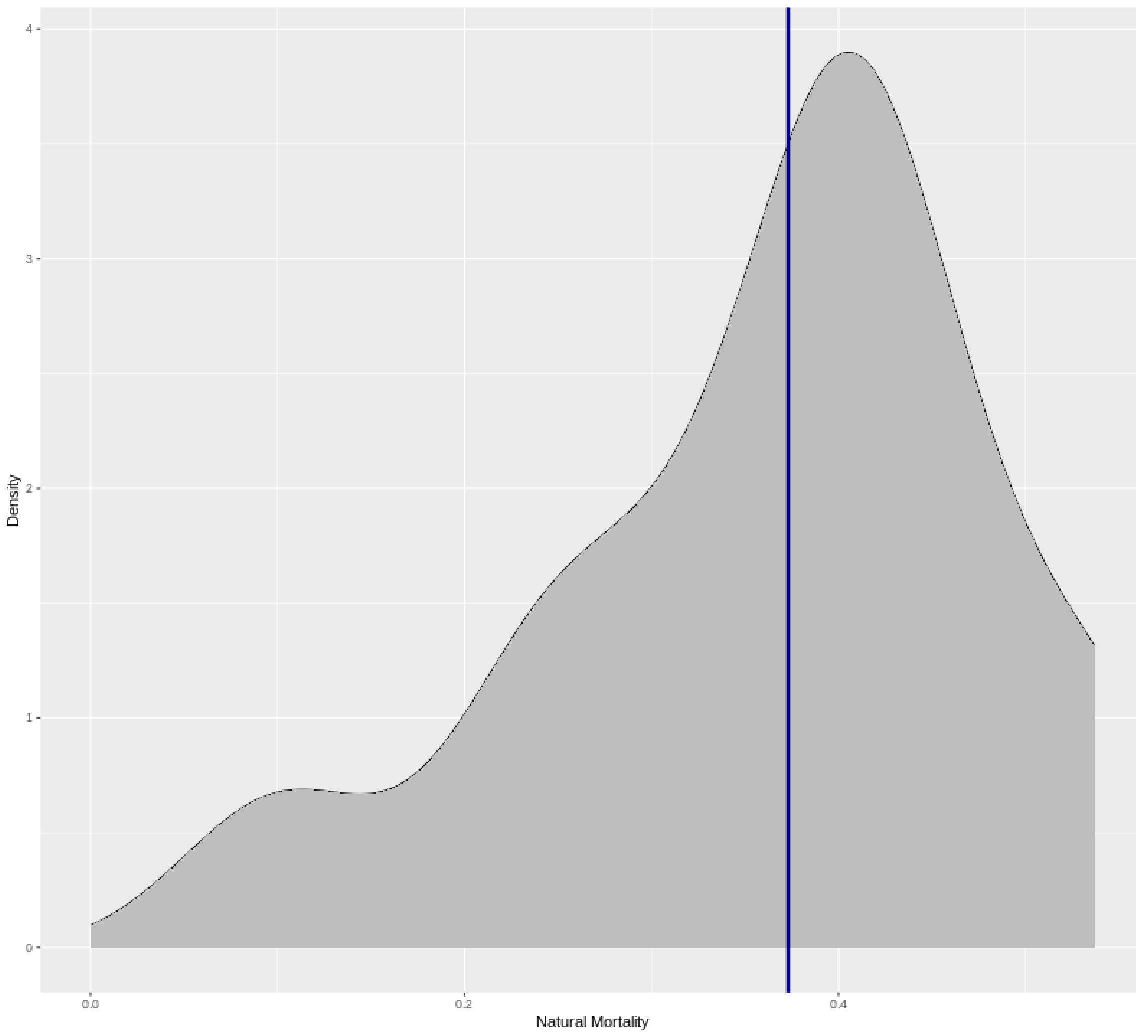


Figure 2A.27: Median value for natural mortality for Aleutian Islands Pacific cod (M=0.36) estimated using a composite method by Jason Cope (http://barefootecologist.com.au/shiny_m.html).

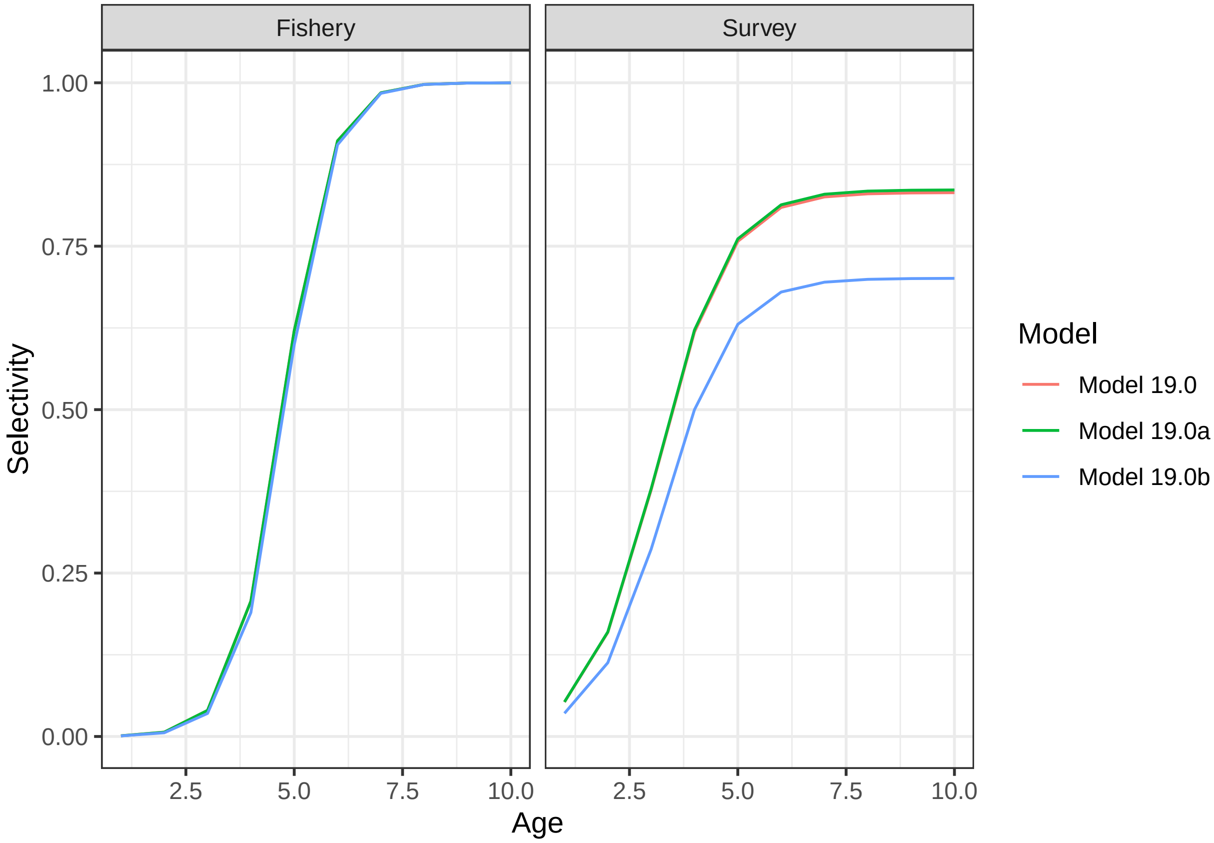


Figure 2A.28: Model estimates for selectivity for the survey and the fishery. The survey selectivity curve is the product of survey catchability and survey selectivity. Note: Model 19.0 and Model 19.0a have identical values.

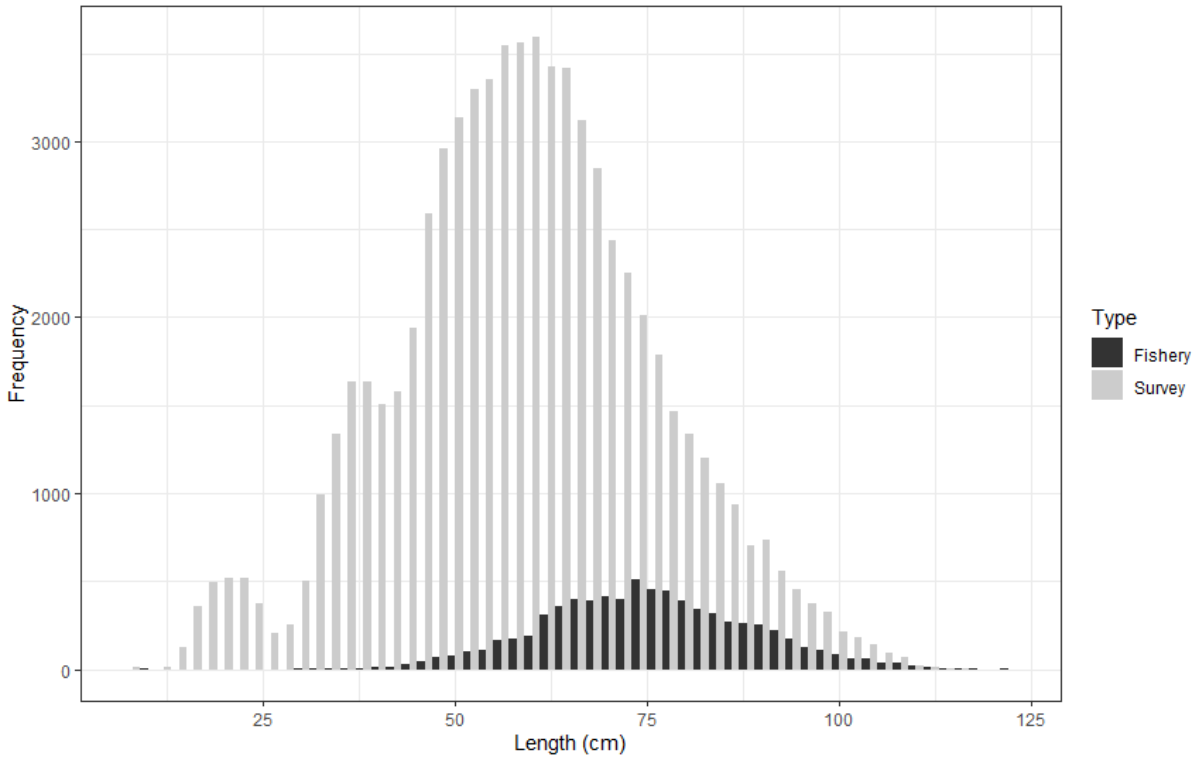


Figure 2A.29: Length frequency data for Pacific cod caught during summer daytime hours (May-August) in the Aleutian Islands by the fishery and the survey, from 1990-2018.

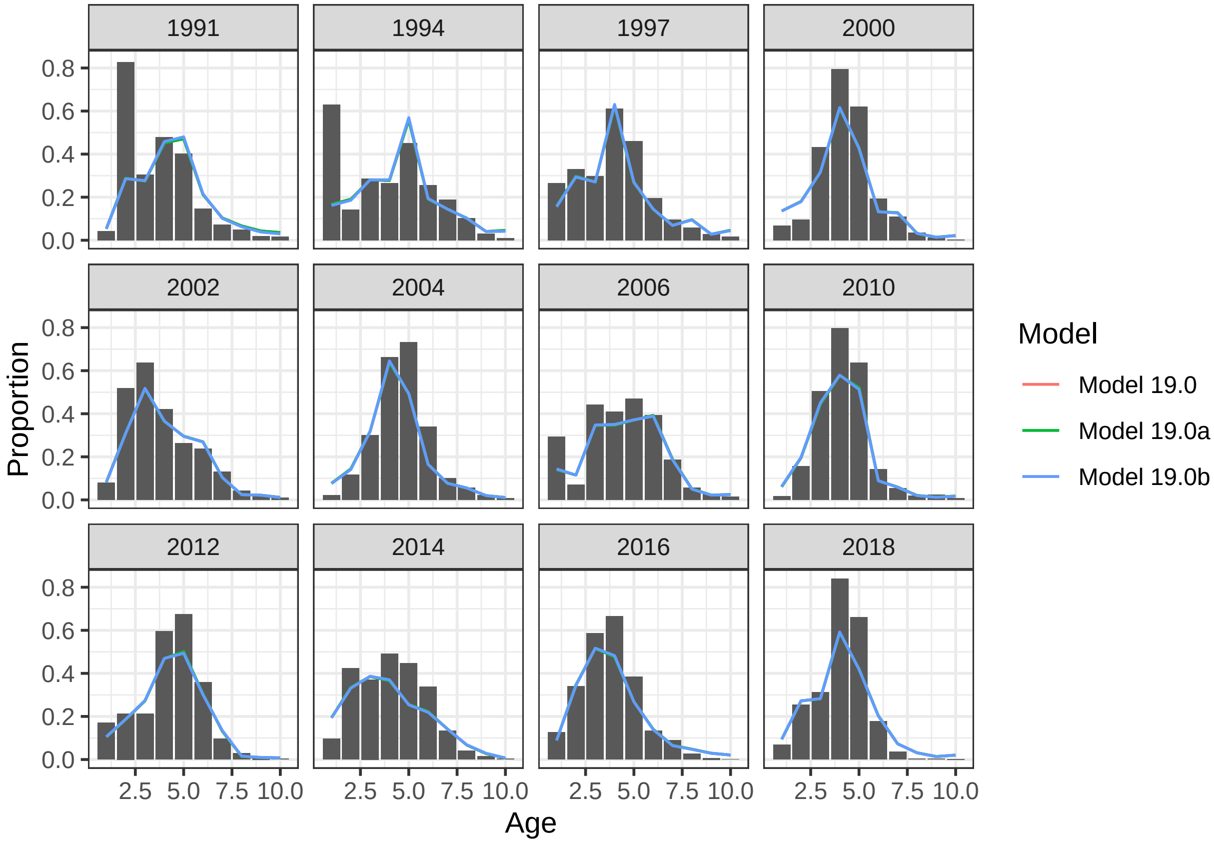


Figure 2A.30: Survey age frequency fit to model 19.0, 19.0a, and 19.0b, solid line is predicted.

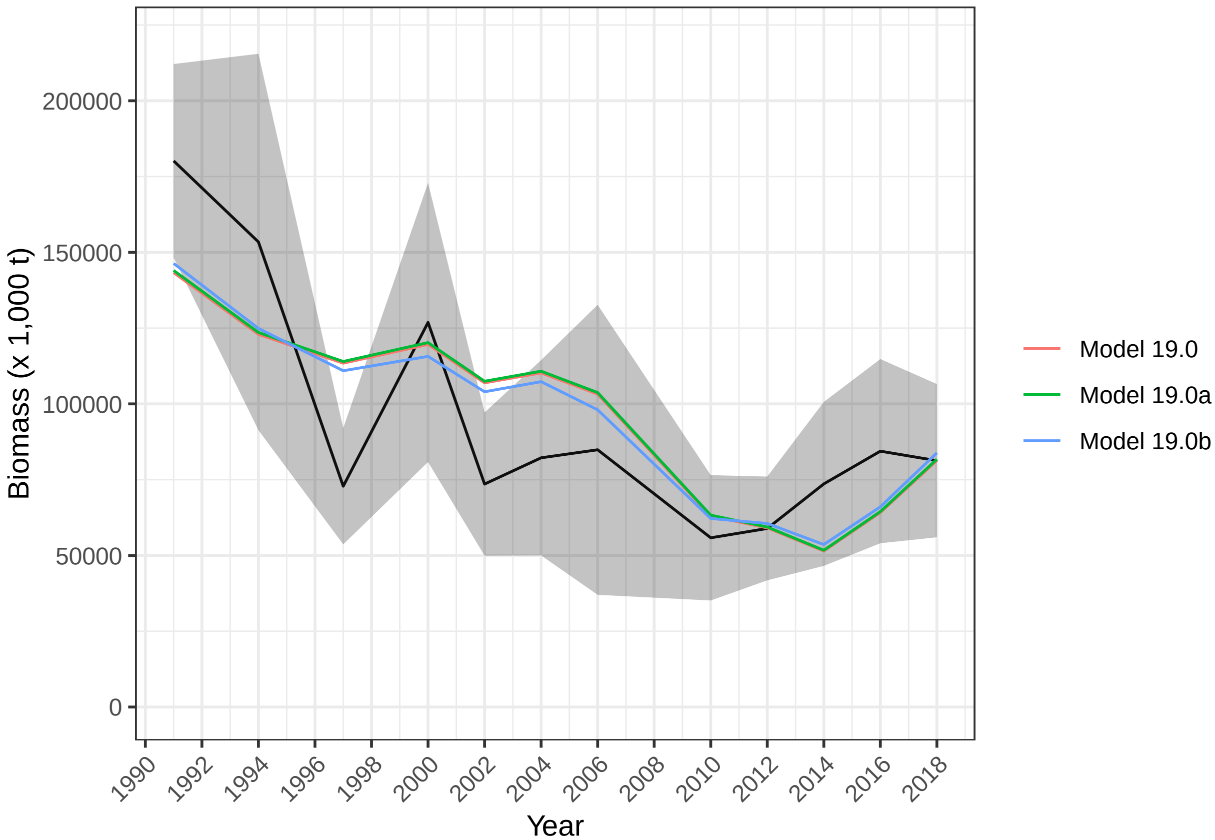


Figure 2A.31: NMFS Aleutian Islands survey biomass estimates, with 95% confidence intervals and the four model estimates of survey biomass, scaled down by their estimate of survey catchability, from 1991-2021. Note: Model 19.0a and Model 19.0 have very similar biomass estimates.

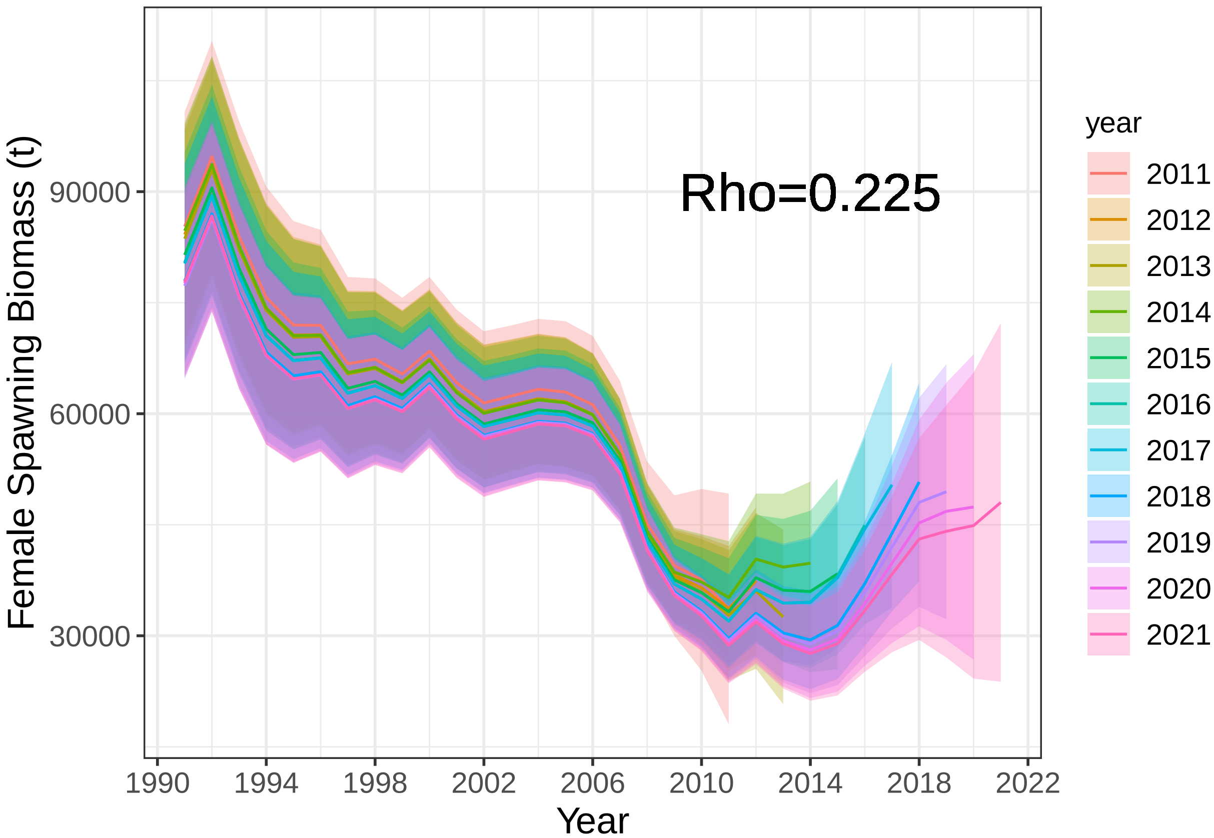


Figure 2A.32: Retrospective plot of female spawning biomass. Model 19.0 with data through 2021 is shown, and data was sequentially removed through 2011.

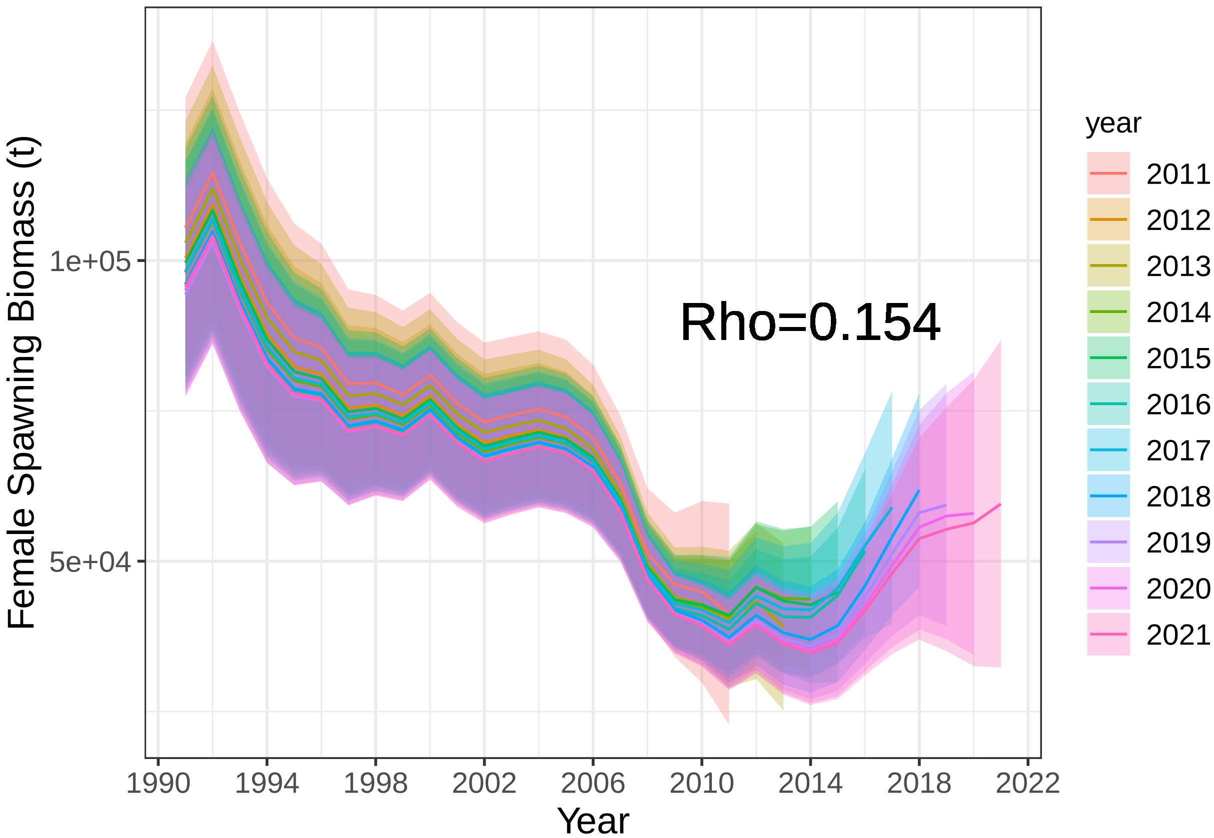


Figure 2A.33: Retrospective plot of female spawning biomass. Model 19.0b with data through 2021 is shown, and data was sequentially removed through 2011.

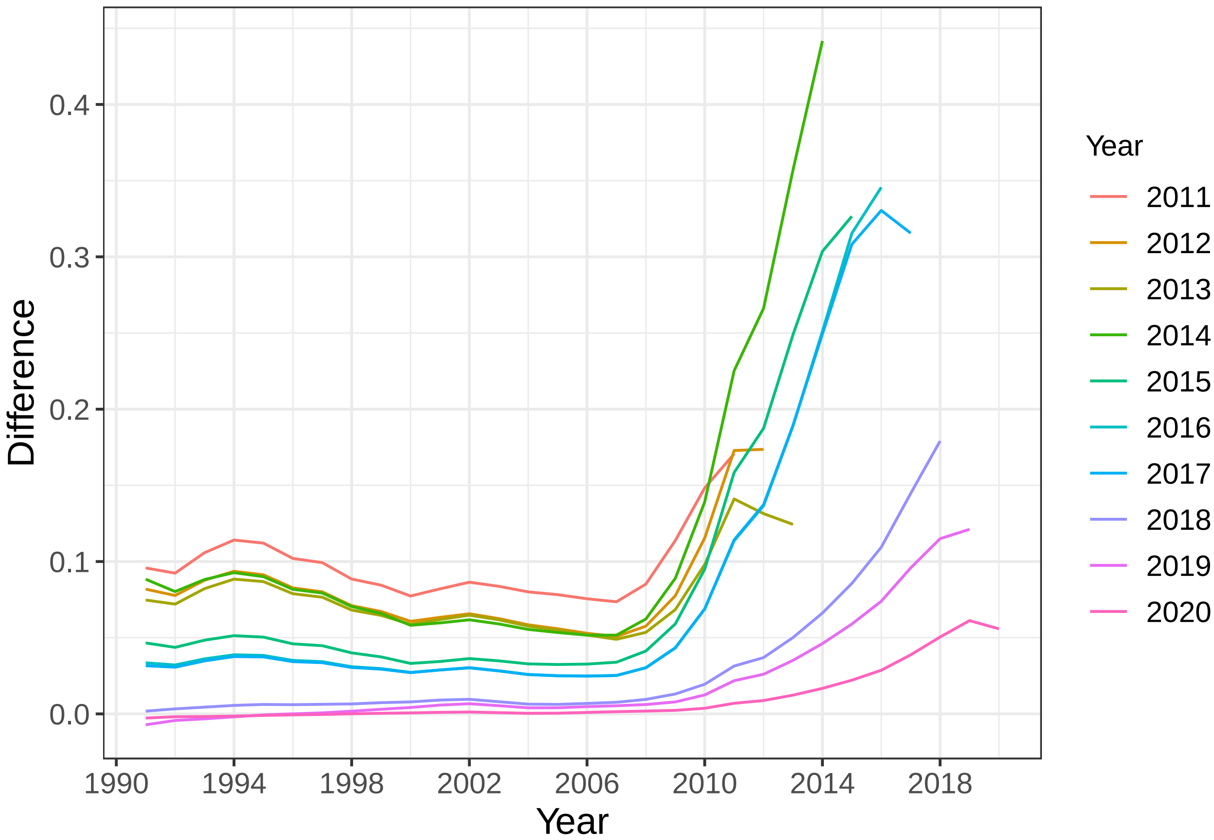


Figure 2A.34: Relative differences in estimates of spawning biomass between the 2021 model and the retrospective model run for years 2020 through 2011, for Model 19.0.

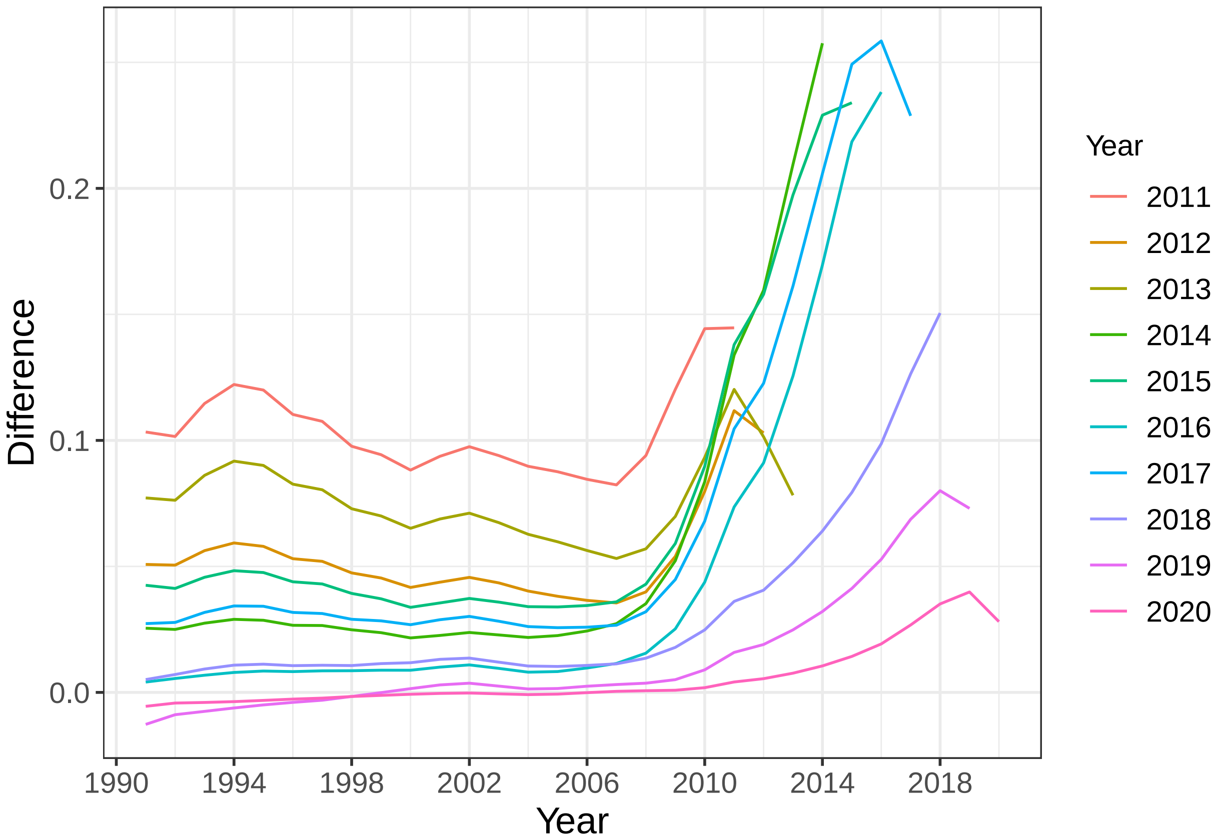


Figure 2A.35: Relative differences in estimates of spawning biomass between the 2021 model and the retrospective model run for years 2020 through 2011, for Model 19.0b.

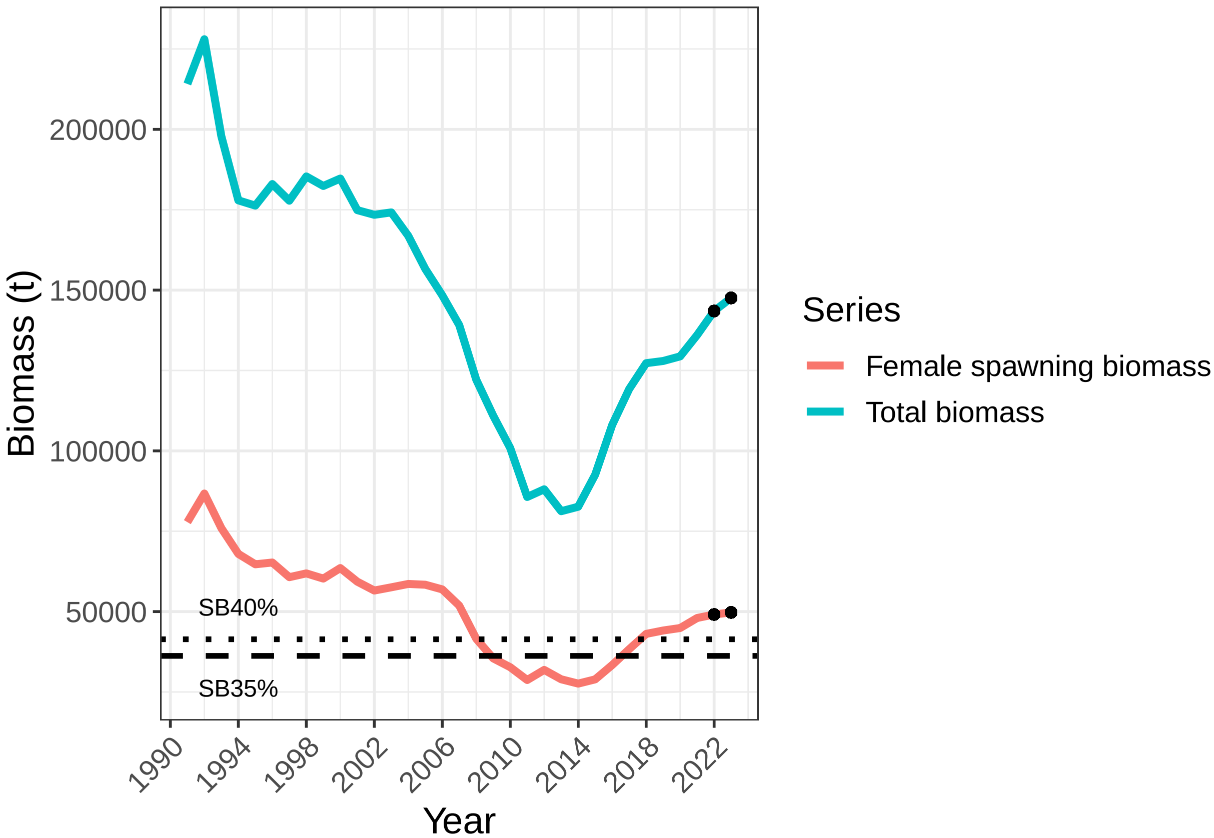


Figure 2A.36: Model 19.0 estimates for total (age 1+) biomass and female spawning biomass from 1991-2021, and projection model estimates for 2022 and 2023. Reference points SB40% and SB35% are shown as horizontal lines.

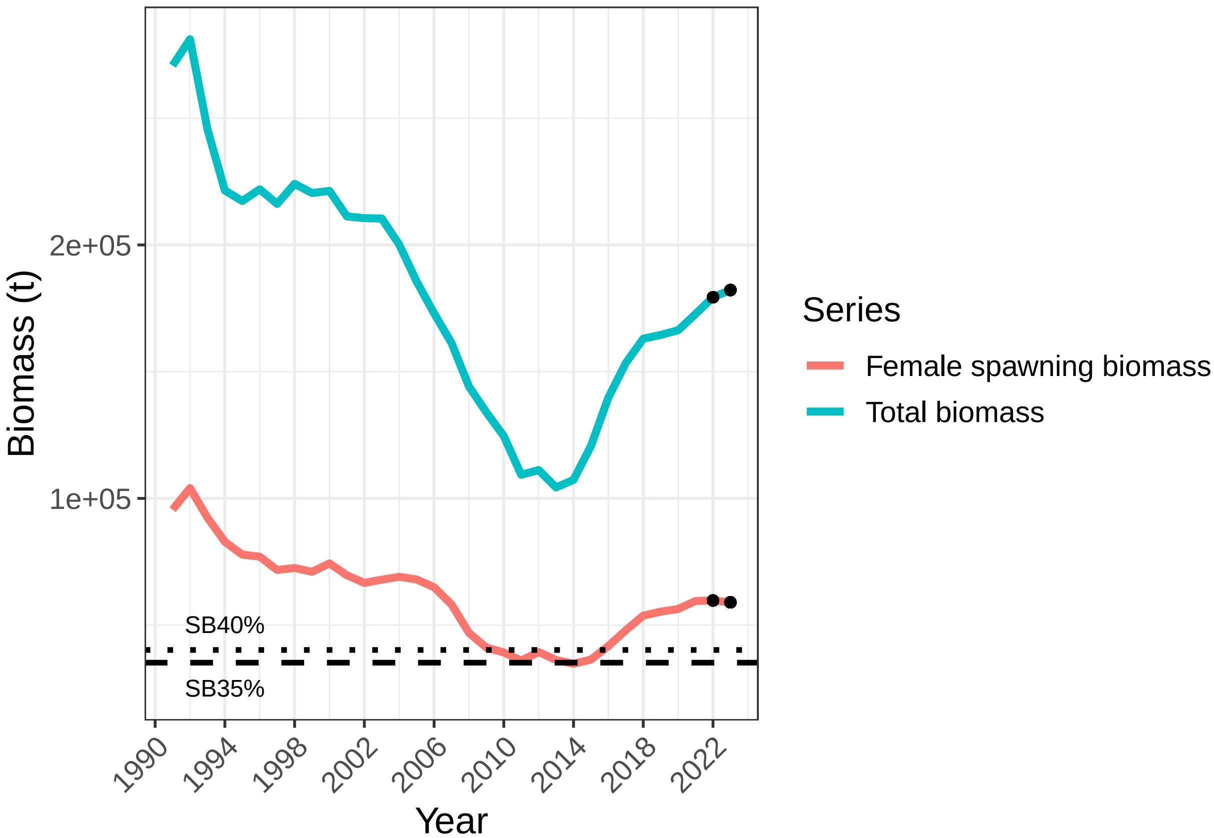


Figure 2A.37: Model 19.0b estimates for total (age 1+) biomass and female spawning biomass from 1991-2021, and projection model estimates for 2022 and 2023. Reference points SB40% and SB35% are shown as horizontal lines.

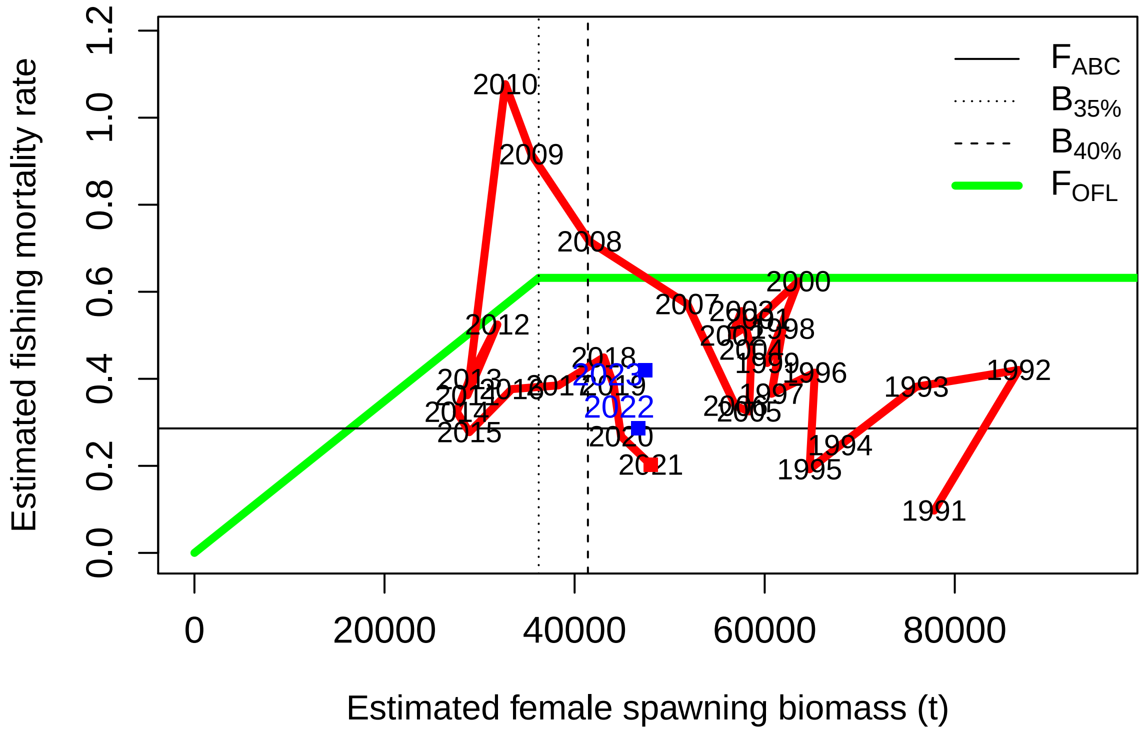


Figure 2A.38: Model 19.0 phase plane diagram showing the time-series of stock assessment model estimates of female spawning biomass relative to the harvest control rule, with assessment model results for 1991-2021 and projection model results for 2022 and 2023 (blue squares). Alternative 3 projections (fishing at the average fishing mortality rate for the past 5 years) were used for the 2022 and 2023 values.

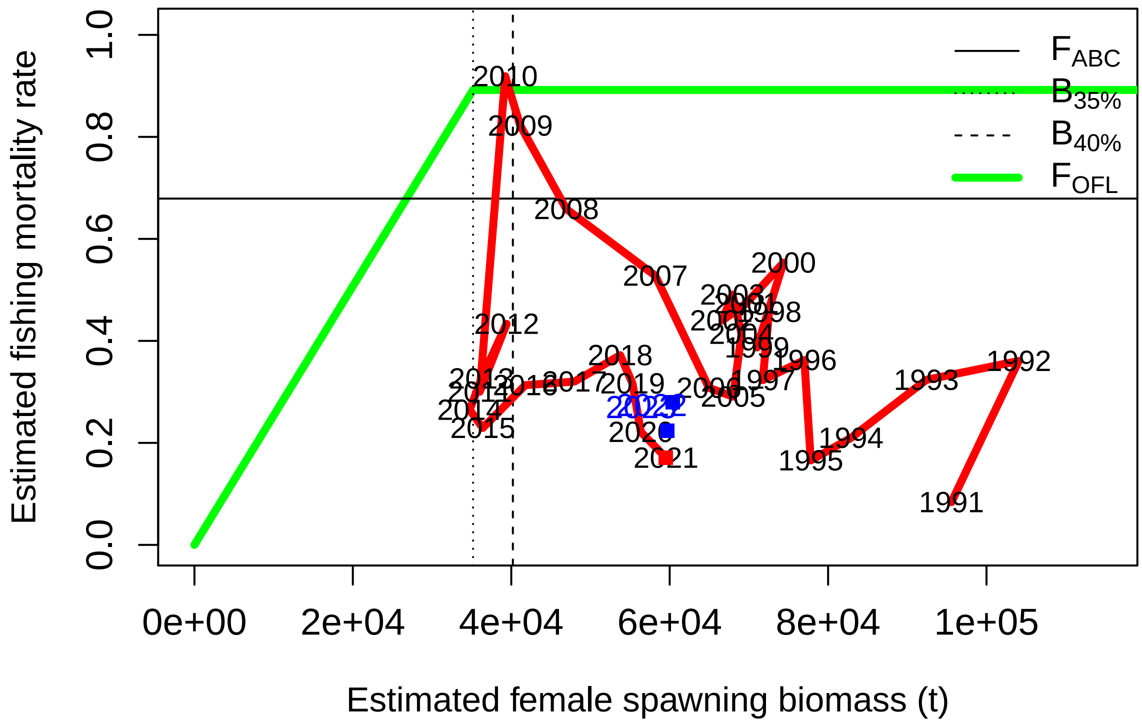
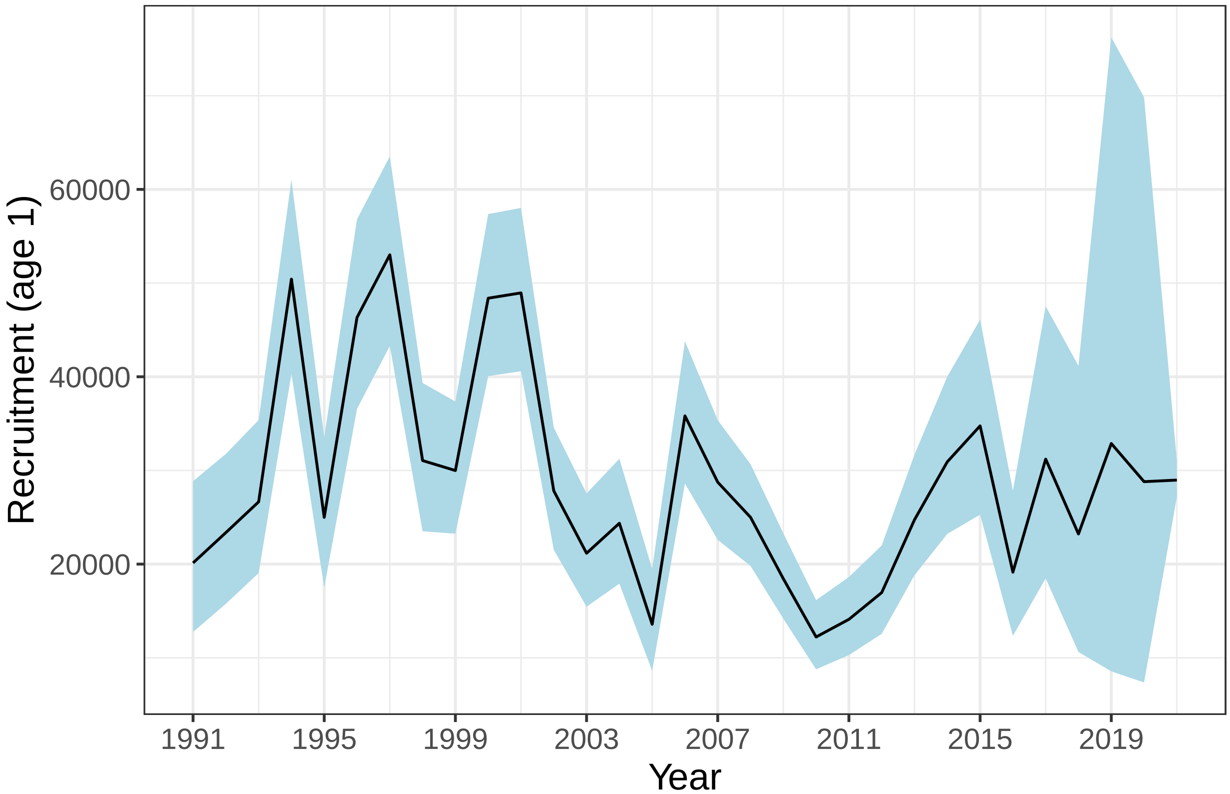
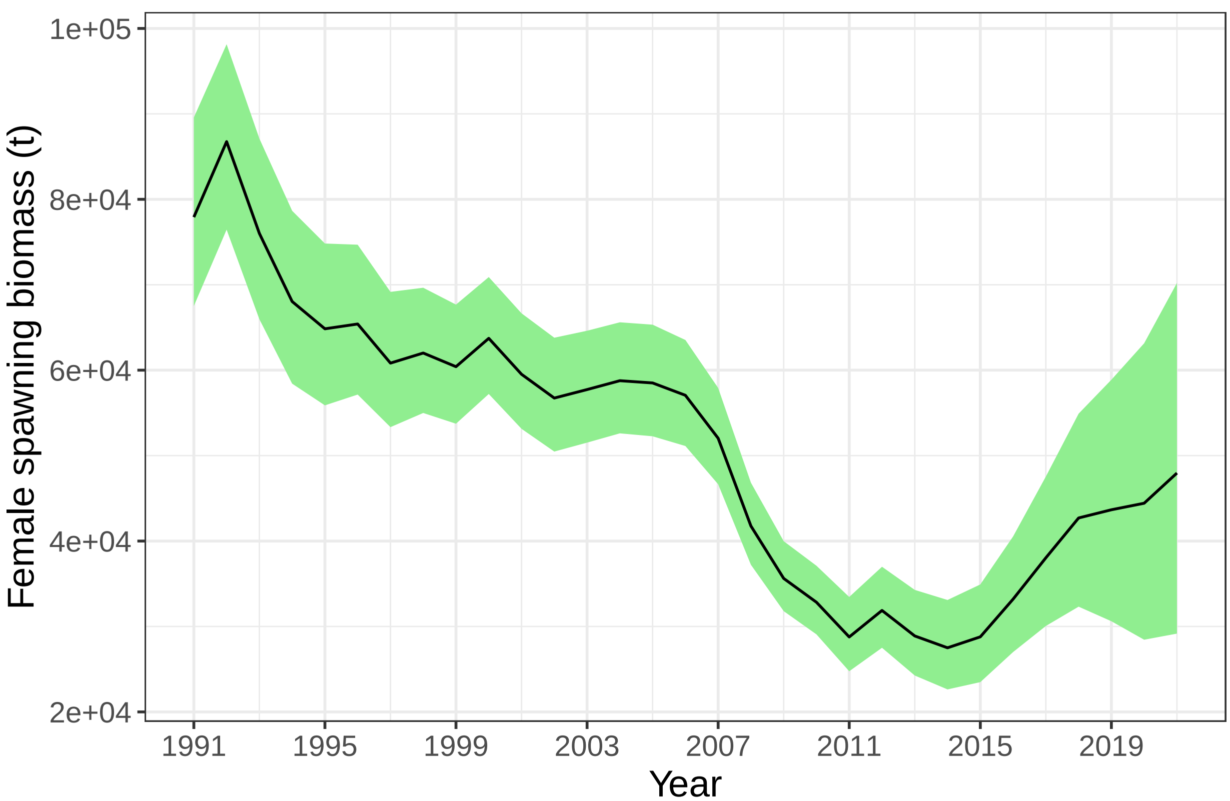


Figure 2A.39: Model 19.0b phase plane diagram showing the time-series of stock assessment model estimates of female spawning biomass relative to the harvest control rule, with assessment model results for 1991-2021 and projection model results for 2022 and 2023 (blue squares). Alternative 3 projections (fishing at the average fishing mortality rate for the past 5 years) were used for the 2022 and 2023 values.

a.


Recruitment (age 1)
60000
40000
20000
1991
1995
1999
2003
2007
2011
2015
2019
Year

b.


Female spawning biomass (t)
1e+05
8e+04
6e+04
4e+04
2e+04
1991
1995
1999
2003
2007
2011
2015
2019
Year

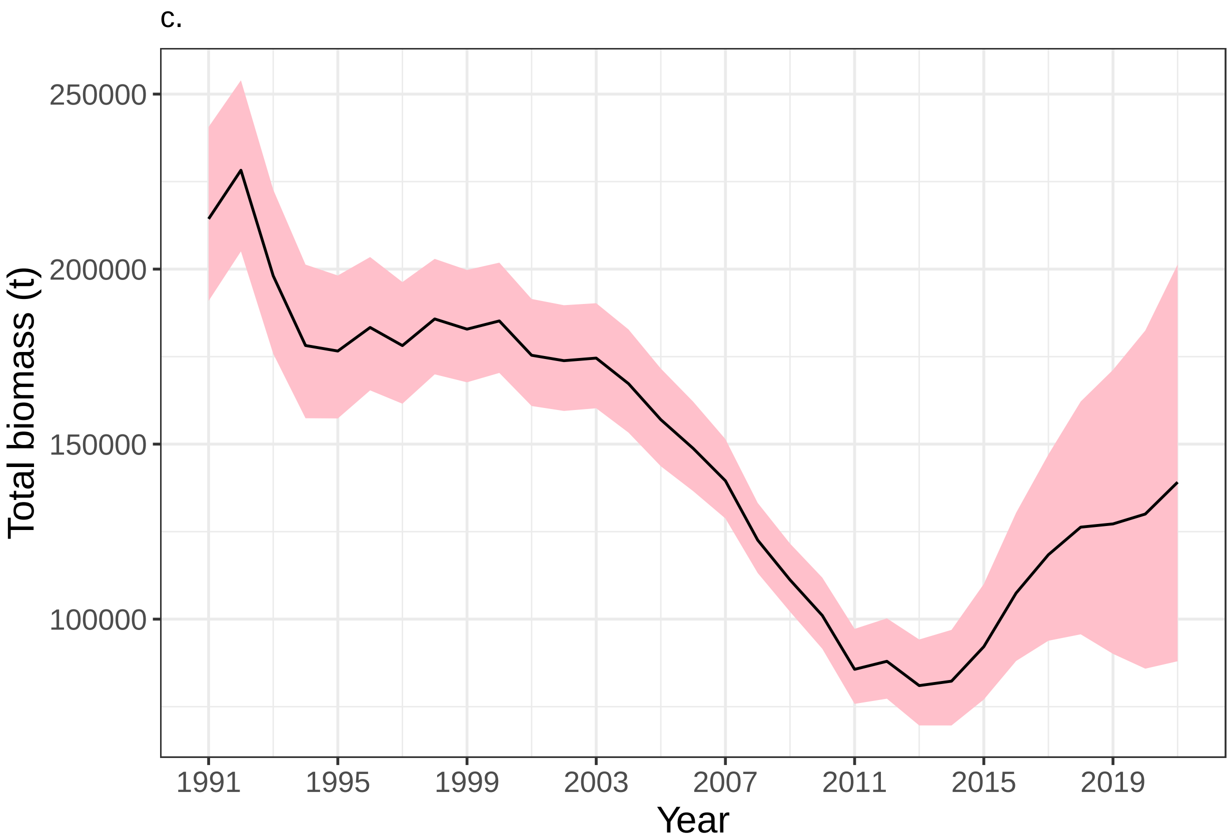
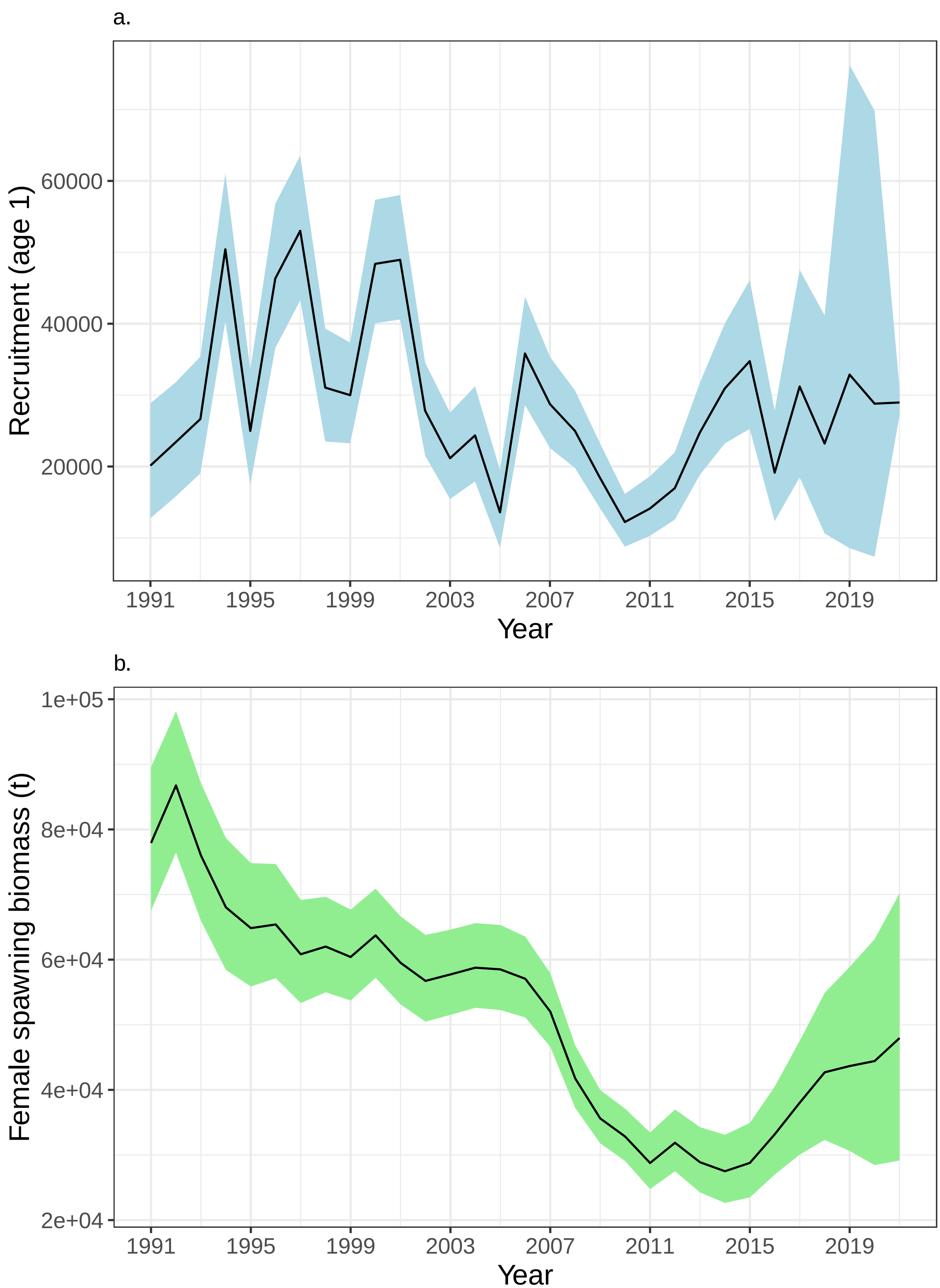


Figure 2A.40: MCMC estimates based on Model 19.0 mean and 95% credible intervals for age 1 recruitment (Panel a.), female spawning biomass (t) (Panel b.), and total biomass (t) (Panel c.).


a.
Recruitment (age 1)
60000
40000
20000
1991
1995
1999
2003
2007
2011
2015
2019
Year
b.
Female spawning biomass (t)
1e+05
8e+04
6e+04
4e+04
2e+04
1991
1995
1999
2003
2007
2011
2015
2019
Year

c.

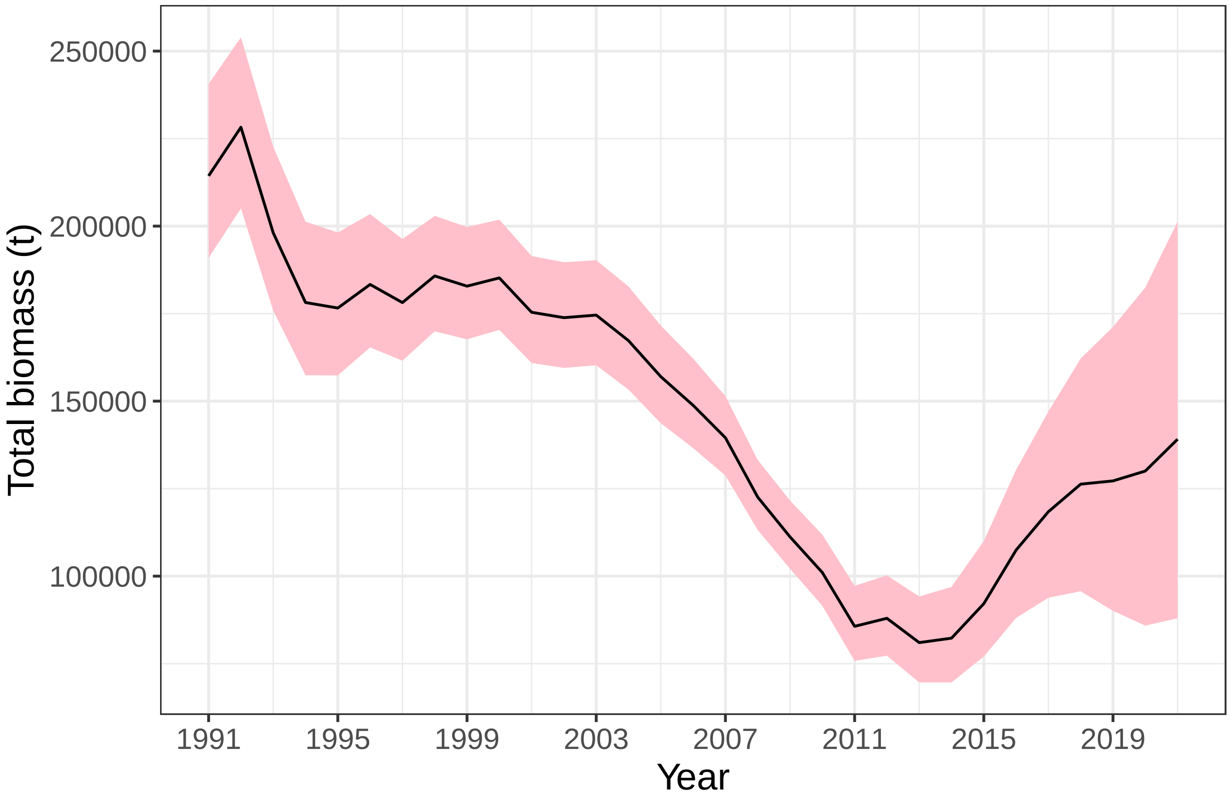


Figure 2A.41: MCMC estimates based on Model 19.0b mean and 95% credible intervals for age 1 recruitment (Panel a.), female spawning biomass (t) (Panel b.), and total biomass (t) (Panel c.).

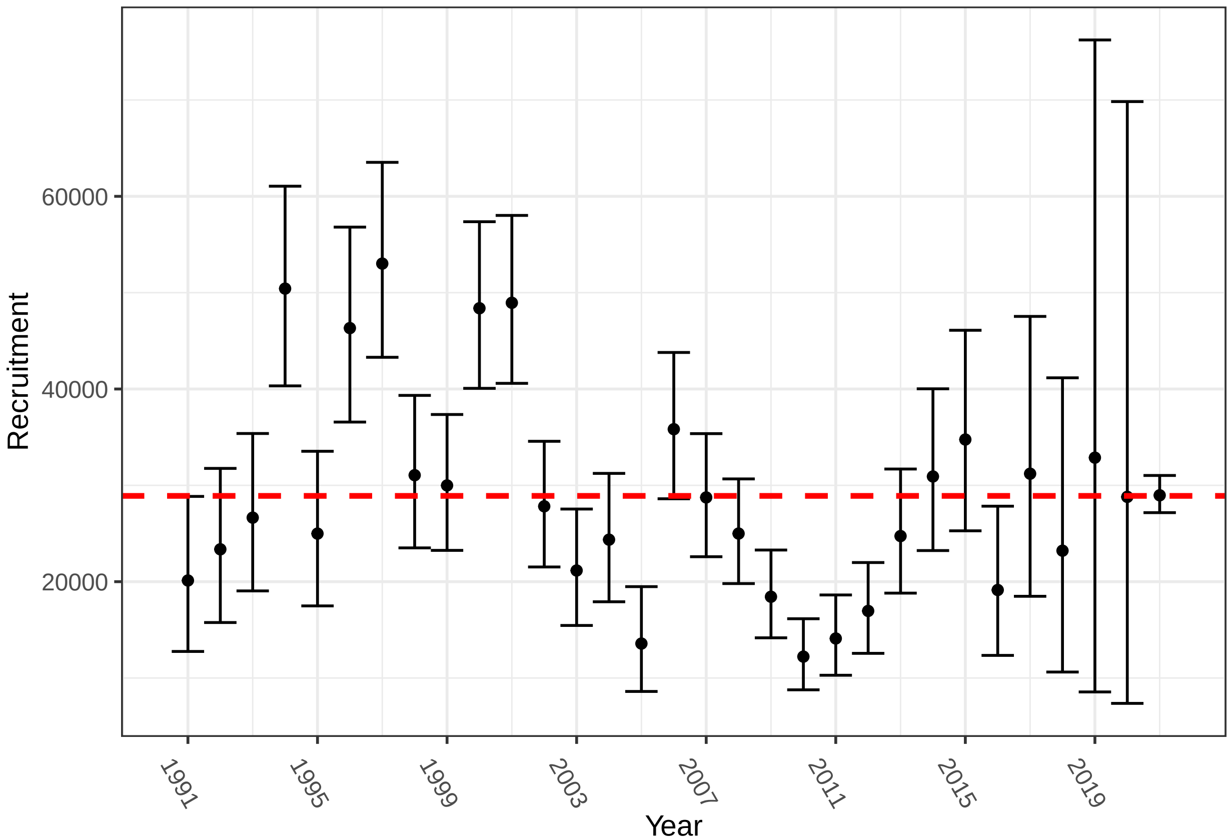


Figure 2A.42: Model 19.0 Age 1 estimated recruitments (male plus female) in numbers from 1991 to 2019, with approximate 5% and 95% credible intervals. Data was generated using 1e+06 MCMC iterations, and thinning every 100 iterations. The horizontal line represents the average recruitment over this period. The dashed horizontal line indicates mean recruitment from 1991-2019, 28,906.

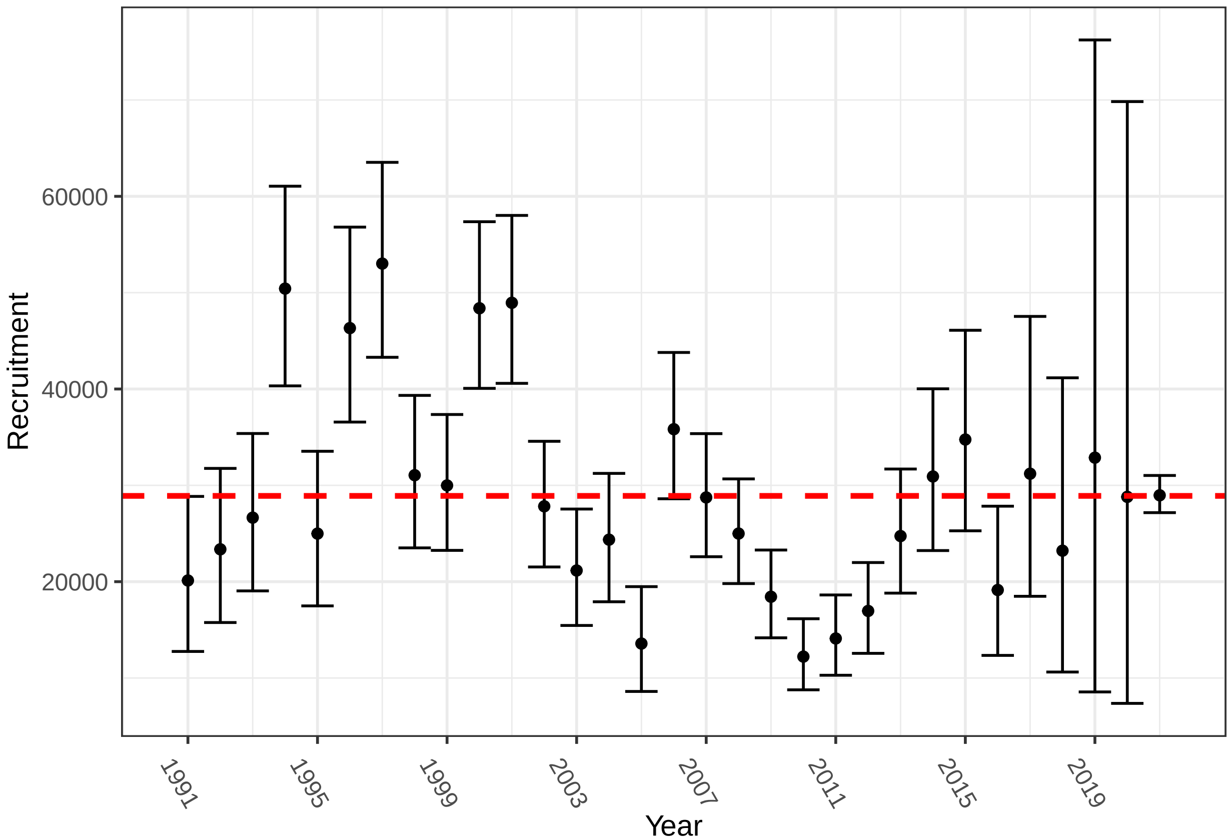


Figure 2A.43: Model 19.0b Age 1 estimated recruitments (male plus female) in numbers from 1991 to 2019, with approximate 5% and 95% credible intervals. Data was generated using 1e+06 MCMC iterations, and thinning every 100 iterations. The horizontal line represents the average recruitment over this period. The dashed horizontal line indicates mean recruitment from 1991-2019, 28,906.

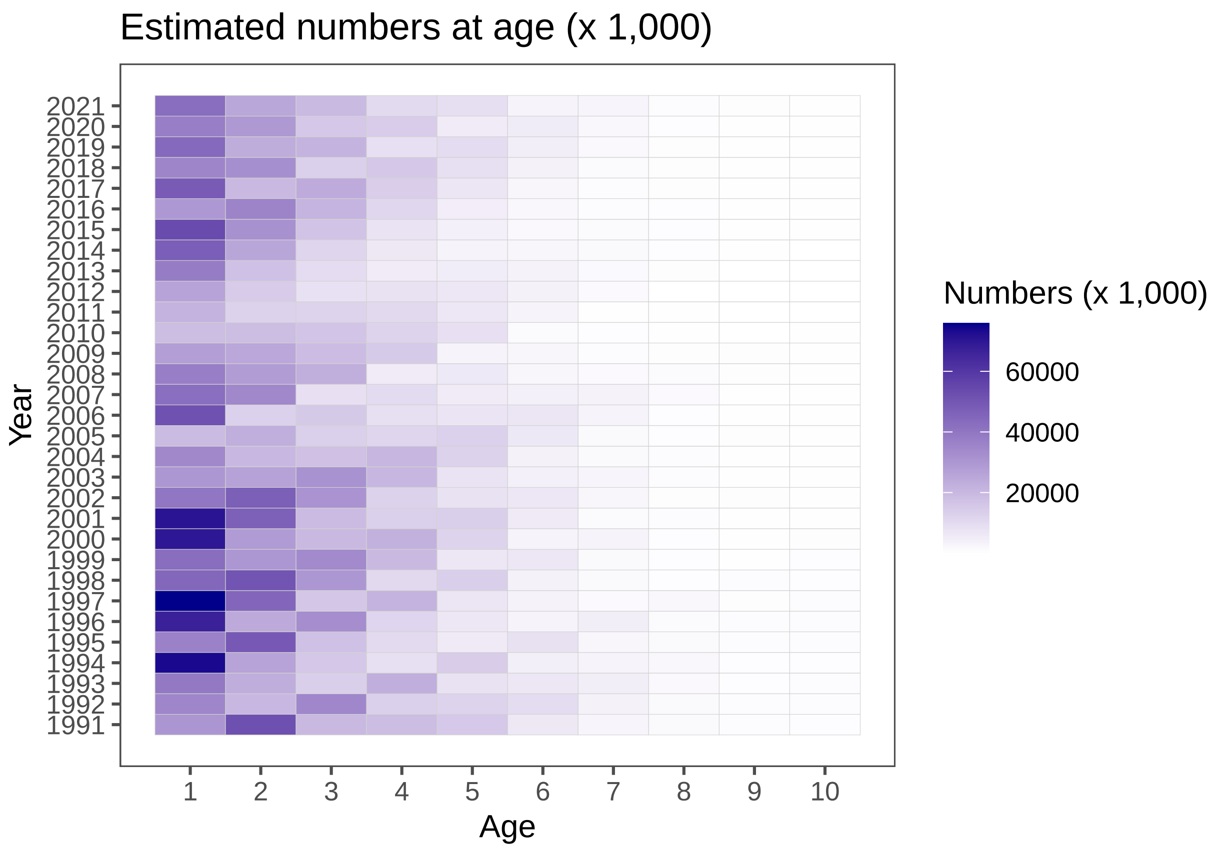


Figure 2A.44: Estimated numbers at age of Aleutian Islands cod (x 1,000), based on Model 19.0b.

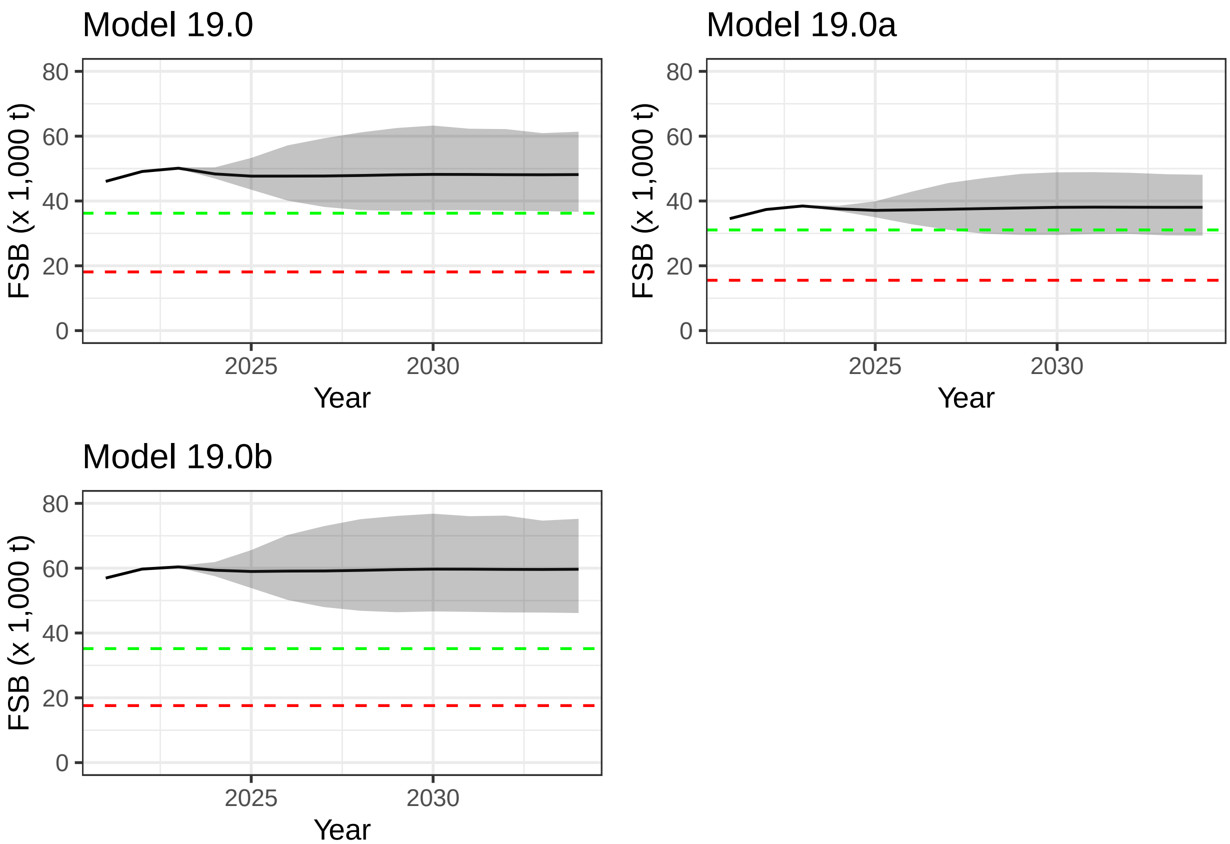


Figure 2A.45: Projected female spawning biomass (FSB x1,000 t) for 2021 to 2034 with 95% confidence intervals, and fishing at the 5-year (2017-2021) average fishing mortality rate for Models 19.0, 19.0a, and 19.0b. Green horizontal lines indicate B35% and red lines half of B35%.

Appendix 1: 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%).

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 greater than or equal to 60' LOA using hook-and-line gear (0.2 percent); catcher processors using pot gear (1.5 percent); catcher vessels greater than or equal to 60' LOA using pot gear (8.4 percent); and catcher vessels less than 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.

Amendments 120/108, implemented January 20, 2020.

A C/P acting as a mothership receiving deliveries of BSAI non-CDQ Pacific cod from CVs engaged in directed fishing with trawl gear must 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.