6. Assessment of the arrowtooth flounder stock in the Eastern Bering Sea and Aleutian Islands

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Executive Summary

Summary of Changes in Assessment Inputs

Changes in the input data:

1. Estimates of catch through October 25, 2020.
2. Fishery size compositions for 2018 (updated) and 2019.
3. Biomass point-estimates and standard errors from the 2019 Eastern Bering Sea shelf survey.
4. Age data from the 2018-2019 eastern Bering Sea shelf and the 2018 Aleutian Islands surveys.
5. Length compositions from the 2019 eastern Bering Sea shelf survey.
6. The recommended model did not include eastern Bering Sea shelf survey data for 1982-1991.

Changes in the assessment methodology:

There were no changes in the assessment methodology as we continue to use the 2018 assessment model (18.9). Please see Spies et al. (2018) for more details on the 2018 assessment methodology (available online at: https://apps-afsc.fisheries.noaa.gov/REFM/Docs/2018/BSAI/BSAIatf.pdf).

Summary of Results

The summarized results of the risk table for arrowtooth flounder are in the table below. All scores of Level 1 suggests no need to set the ABC below the maximum permissible. Further details for each category of this risk table are provided in the *Harvest Recommendations* section.

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ ecosystem considerations*	*Fishery Performance considerations*
Level 1: Normal	**Level 1:** Normal	**Level 1:** Normal	**Level 1:** Normal

Reference values for arrowtooth flounder are summarized in the following table. The stock is not being subject to overfishing, is not currently overfished, nor is it approaching a condition of being overfished.

Quantity	As estimate or specified last year for: 2020	2021	As estimated or recommended this year for: 2021	2022
M (natural mortality – Male, Female)	0.35, 0.2	0.35, 0.2	0.35, 0.2	0.35, 0.2
Specified/recommended Tier	3a	3a	3a	3a
Projected total (age 1+) biomass (t)	891,959	934,008	923,646	921,074
Female spawning biomass (t) Projected	481,845	478,260	497,556	509,208
$B_{100\%}$	606,237	606,237	558,826	558,826
$B_{40\%}$	242,495	242,495	223,530	223,530
$B_{35\%}$	212,183	212,183	195,589	195,589
F_{OFL}	0.161	0.161	0.160	0.160
$maxF_{ABC}$ (maximum allowable = $F_{40\%}$)	0.136	0.136	0.135	0.135
Specified/recommended F_{ABC}	0.136	0.136	0.135	0.135
Specified/recommended OFL (t)	82,860	84,057	90,873	94,368
*max*ABC (t)	70,606	71,618	77,349	80,323
Specified/recommended ABC (t)	70,606	71,618	77,349	80,323
Status	As determined *last* year for: 2018	2019	As determined *this* year for: 2019	2020
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

*Projections are based on estimated catches of 10,879 t and 9,109 t used in place of maximum permissible ABC for 2020 and 2021 in response to a Plan Team request to obtain more accurate two-year projections. Please see section on Specified Catch Estimation subsection in the Harvest Recommendations section for more details regarding these calculations.

The 2019 eastern Bering Sea trawl survey estimate increased 13% from the 2018 estimate and is now 27% above average. No 2020 surveys were conducted in the eastern Bering Sea and the Aleutian Islands this year due to Covid-19. Catch for arrowtooth flounder is generally low and has been between 10-18% of the acceptable biological catch (ABC) since 2011 when speciation began in the catch accounting system for this stock. Current catch as of October 25, 2020 is at 13.8% of ABC. The total allowable catches (TACs) for arrowtooth flounder are generally set well below ABC and have been between 11-27% since 2011. The 2020 ratio of TAC to ABC was 14%.

For the 2021 fishery, we recommend the maximum allowable ABC of 77,349 t from the 2018 accepted model (Model 18.9). This is an 8% increase from last year's ABC of 71,618 t. The projected female spawning biomass for 2021 is 497,556 t and the projected age 1+ total biomass for 2021 is 923,646 t. Female spawning biomass is well above B40%, and projected to be stable.

Summaries for Plan Team

Species	Year	Biomass[1]	OFL	ABC	TAC	Catch[2]
Arrowtooth Flounder	2019	892,591	82,939	70,673	8,000	10,048
	2020	934,008	84,057	71,618	10,000	10,040
	2021	923,646	90,873	77,349	n/a	n/a
	2022	921,074	94,368	80,323	n/a	n/a

[1]Total biomass (ages 1+) from the age-structured model

[2]Current as of October 25, 2020. Source: NMFS Alaska Regional Office Catch Accounting System via the AKFIN database (http://www.akfin.org).

Responses to SSC and Plan Team Comments on Assessments in General

"*The SSC considers the risk table approach an efficient method to organize and report this information and worthy of further investigation…The SSC recommends that one additional column be added to include concerns related to fishery/resource-use performance and behavior, considering commercial as well as local/traditional knowledge for a broader set of observations. This additional column should not include socio-economic considerations, but rather indications of concern such as inability to catch the TAC, or dramatic changes in spatial or temporal distribution that could indicate anomalous biological conditions. The SSC requests that all authors fill out the risk table in 2019, and that the PTs provide comment on the author's results in any cases where a reduction to the ABC may be warranted (concern levels 2-4).*" (SSC, December 2018)

"*Given that the risk table and ESP are clearly in development and are likely to evolve in important ways, the SSC suspends its requests for "OK-ness" and "inference of impending decline" for individual stock authors of all assessments…The SSC would like to see how these new processes and products develop to determine if they are able to provide the type of information needed to provide an early detection of ecosystem change. In addition, risk tables only need to be produced for groundfish assessments that are in a "full" year in the cycle.*" (SSC, June 2019)

"*The SSC recommends the authors complete the risk table and note important concerns or issues associated with completing the table.*" (SSC, October 2019)

"*The Teams recommended that authors continue to fill out the risk tables for full assessments.*

The Teams recommended that adjustment of ABC in response to levels of concern should be left to the discretion of the author, the Team(s), and/or the SSC, but should not be mandated by the inclusion of a >1 level in any particular category. The Teams request clarification and guidance from the SSC regarding the previously noted issues associated with completing the risk table, along with any issues noted by the assessment authors." (Joint Groundfish Plan Team, November 2019)

"*The SSC recommends dropping the overall risk scores in the tables as these provided no additional information relative to ABC-setting and seemed to cause confusion. They simply report the maximum value of risk for the four factors, which is redundant information.*

The SSC noted that the table ranking descriptions (e.g., description of what the scores mean) were not included in all the SAFE reports. The SSC requests that the table explanations be included in all the assessments which include a risk table for completeness.

The SSC notes that the risk tables provide important information beyond ABC-setting which may be useful for both the AP and the Council and welcomes feedback to improve this tool going forward."

(SSC, December 2019)

The comments that pertain to the risk table have been grouped together. Since this is a full assessment year for BSAI arrowtooth flounder, we provide a risk table as recommended by the SSC without the overall risk score in the table and the table ranking descriptions for completeness. Following the completion of this exercise, the highest score for this stock is a Level 1 and the authors do not recommend that the ABC be reduced below maximum permissible ABC. Please see the *Harvest Recommendations* section for further details for each category of this risk table.

"*The SSC recommends thinking beyond the current (2020) situation to develop methods for making stock assessment analyses more robust to possible future survey reductions/loss. These may include:*

- *Renewed investigation of data conflicts in the assessment models, perhaps addressed through data weighting and/or identification of un-modelled processes, or occasional anomalous data points.*
- *Model-based survey time series (e.g., vector-autoregressive spatio-temporal (VAST) models) that can accommodate incomplete data, changes in survey design, or alternative survey platforms and still produce indices of abundance with statistical variance estimates. These may be particularly helpful for stocks (e.g., Tier 4 crab and Tier 5 groundfish) where harvest levels are informed directly by trends in survey data rather than solely by the results of the stock assessment.*
- *Exploration of harvest control rules that are explicitly linked to survey and assessment uncertainty and the lag between surveys and assessments.*"

(SSC, October 2020)

We plan to explore the utility of model-based survey time series (e.g., VAST model) as a way to integrate the three surveys used in the BSAI arrowtooth flounder model in the future.

Responses to SSC and Plan Team Comments Specific to this Assessment

"*The CIE review requested investigation of other ways to integrate the three surveys. Ingrid presented two models (not included in the assessment document) that addressed this. Model 18.7 applied to the EBS shelf and slope only, and Model 18.8 applied to the AI only. These models indicated changes in proportions among the areas, with a large increase in the Aleutian Islands and lowered proportions in the EBS shelf and slope compared to the base model.*

The Plan Team recommends more investigation of Models 18.7 and 18.8, but not for November 2018. An ageing error matrix should be included." (BSAI Plan Team, September 2018)

"*The Team re-iterated a previous recommendation that Models 18.7 and 18.8 from this year's. September document be evaluated in a future year.*" (BSAI Plan Team, November 2018)

We plan to explore the utility of model-based survey time series (e.g., VAST model) as a way to integrate the three surveys used in the BSAI arrowtooth flounder model in the future.

"*The SSC has several recommendations regarding speciation of the survey and catch data being used in the assessment model. The SSC notes that the reliability of species composition information for survey data prior to 1991 may also be an issue for the non-slope surveys, and the SSC requests additional information on this topic. In addition, the SSC notes the observer program began speciating Kamchatka/arrowtooth flounder in 1995, and requests the author investigate whether observer data could be used to speciate the catch data.*" (SSC, December 2018)

We investigated the species identification confidence for the bottom trawl survey data used in this assessment (Stevenson and Hoff, 2009; Orr et al., 2014). Based on these studies, at least moderate confidence was attained for arrowtooth flounder species identification starting in 1980 for the Aleutian Islands bottom trawl survey and 1992 for the eastern Bering Sea bottom trawl survey. We, therefore, use information starting from 1992 for the eastern Bering Sea shelf expanded survey and continue with the current index time period for the Aleutian Islands bottom trawl survey. Please see the Survey Data subsection for more information. We also provide a comparison of the total and spawning biomass estimates for the last 20 years from Model 18.9 using the uncorrected eastern Bering Sea shelf index (1982-2019) with the corrected index (1992-2019). The average difference in biomass (ADSB) was about 2% for both spawning and total biomass (Figure 6.9). Based on this, we determined this change was a minor data correction and did not require a separate model evaluation.

We also investigated the methods used to inform the assumptions about species compositions of arrowtooth flounder and Kamchatka flounder in the North Pacific Groundfish and Halibut Observer Program (Observer Program). Sparse amounts of arrowtooth and Kamchatka flounder were identified to species since the early 1990s and recorded in the Observer Program database (NORPAC). In 2008, the observer program increased their subsampling protocol and also increased the identification of the two species in the catch samples. Their sampling has indicated that the proportion of Kamchatka flounder has been steadily increasing due to the development of a foreign market for Kamchatka flounder (Bryan et al., 2020). Speciation routines within the catch accounting system (CAS) for arrowtooth and Kamchatka flounder began in 2011. Therefore, we use the proportions of arrowtooth and Kamchatka flounder reported in the observer database to derive the catch for arrowtooth flounder from 2008 to 2010. Please see the Fishery Data subsection for more information regarding the method used to derive these values and when speciation began in the catch accounting system.

Introduction

Arrowtooth flounder (*Atheresthes stomias*) are relatively large flatfish that range from central California to the eastern Bering Sea (EBS), and as far west as the Kuril Islands (Orlov 2004). Arrowtooth flounder occur in waters from about 20m to 800m, although catch per unit effort (CPUE) from survey data is highest between 100m and 300m. Spawning occurs in deep water (>400 meters) in the Gulf of Alaska and along the shelf break in the eastern Bering Sea (Doyle et al. 2018). Migration patterns are not well known for arrowtooth flounder; however, there is some indication that arrowtooth flounder move into deeper water as they grow, similar to other flatfish, such as Alaska plaice and Greenland turbot (Barbeaux and Hollowed 2018). This is particularly relevant in the Bering Sea, where there is a separate research survey conducted on the EBS shelf and slope (<200m depth). Fisheries data off Washington suggest that larger fish may migrate to deeper water in winter and shallower water in summer (Rickey 1995).

The survey abundance of arrowtooth flounder is approximately eight times higher in the eastern Bering Sea than in the Aleutian Islands region (Figure 6.1, Table 6.1). The distribution of ages appears to vary by region and sex; male arrowtooth as old as 37 years have been observed in the Aleutian Islands are not commonly observed older than age 10 on the Bering Sea shelf, while the female length and weight relationships do not vary significantly between the two regions. Arrowtooth flounder begin to recruit to the eastern Bering Sea slope at about age 4. Recruitment to the slope gradually increases at older ages and reaches a maximum at age 9, based on age data from the 1982 U.S.-Japan cooperative survey. However, greater than 50% of age groups 9 and older continue to occupy continental shelf waters. The low proportion of the overall biomass on the slope during the 1988, 1991, and 2016 surveys, relative to that of earlier surveys, indicates that the proportion of the population occupying slope waters may vary considerably from year to year depending on the age structure of the population.

Arrowtooth flounder are batch spawners, spawning from fall to winter off Washington State at depths greater than 366m (Rickey 1995). Spawning females have been found at 400m and males at ≥450m in the Gulf of Alaska, and larvae have been found at depths greater than 200 m (Blood et al. 2007; De Forest et al. 2014). The age composition of the species shows fewer males relative to females as fish increase in age, which suggests higher natural mortality (*M*) for males (Wilderbuer and Turnock 2009). To account for this process, natural mortality was fixed at 0.2 for females and 0.35 for males in the model.

The arrowtooth flounder resource in the EBS and the Aleutians is managed as a single stock although little is known about stock structure. There has been no research on this topic for this species.

Fishery

Arrowtooth flounder were managed with Greenland turbot as a species complex until 1985 because of similarities in their life history characteristics, distribution and exploitation. Greenland turbot were the target species and arrowtooth flounder were caught as bycatch. Management of Greenland turbot and the *Atheresthes* complex was performed separately starting in 1986 due to considerable differences in their stock condition. Two species of *Atheresthes* occur in the Bering Sea, arrowtooth flounder (*Atheresthes stomias*) and Kamchatka flounder (*A. evermanni*). These two species are very similar in appearance and were not consistently distinguished in the commercial catches until 2008. Likewise, these species were not consistently distinguished in trawl survey catches until 1992 (Figure 6.1). The species complex was split and separate assessments began in 2010 due to the emergence of a directed fishery for Kamchatka flounder in the Bering Sea Aleutian Islands (BSAI) management area. Before 2010, the ABC for the species complex was determined by the large amount (~90%) of arrowtooth flounder relative to Kamchatka flounder in the species complex; overharvest of Kamchatka flounder could occur as the ABC for the species complex exceeded the Kamchatka flounder biomass.

Catch records for arrowtooth flounder and Greenland turbot were combined during the 1960s. The fisheries for Greenland turbot intensified during the 1970s and the bycatch of arrowtooth flounder is assumed to have also increased. In 1974-76, total catches of arrowtooth flounder reached peak levels ranging from 19,000 to 25,000 t (Table 6.2a). Catches decreased after implementation of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1976. The decline after 1976 resulted from catch restrictions placed on the fishery for Greenland turbot and phasing out of the foreign fishery in the U.S. EEZ. The estimated proportion of Kamchatka flounder in the combined catch of arrowtooth and Kamchatka are shown in Table 6.2b through 2007. Catches in Table 6.2b are for arrowtooth flounder and Kamchatka flounder combined until 2008. In 2011, the NMFS Alaska Regional Office (AKRO) started providing separate catch statistics using speciation protocols for arrowtooth and Kamchatka flounder. Arrowtooth flounder has remained lightly exploited with catches (extrapolated for arrowtooth only) averaging 13,137 t from 1991-2019 and 14,228 t from 2011-2019. Total catch reported through October 25, 2020 is 10,040 t. The NMFS AKRO BLEND/Catch Accounting System reports indicate that bottom trawling accounted for 94% of the 2020 catch (3% by pelagic trawl and 3% by hook and line).

Although much research has been conducted on their commercial utilization (e.g. Greene and Babbit 1990, Wasson et al. 1992, Porter et al. 1993, Reppond et al. 1993, Cullenberg 1995) and some targeting occurs in the Gulf of Alaska and the Bering Sea, arrowtooth flounder continue to be captured primarily in pursuit of higher value species and historically have been mostly discarded in the Bering Sea and the Aleutian Islands. The catch information in Table 6.2 reports the past annual total catch tonnage for the foreign and JV fisheries and the current domestic fisheries. The proportions of retained and discarded arrowtooth flounder in Bering Sea fisheries are estimated from observer at-sea sampling for 1985-2020 are shown in Table 6.3, and include Kamchatka flounder as well as arrowtooth flounder through 2007. With the implementation of Amendment 80 in 2008, the percentage of arrowtooth flounder retained in catches increased to 88% in 2014, and has remained high in 2019 (89%) and 2020 (93%). The largest catches, as well as discard amounts, occur in the flatfish fisheries. The trend of high retention is expected to continue in the near future due to the recent changes in fishing practices.

Data

New data used in this assessment include estimates of total catch, trawl survey biomass estimates and standard errors from the eastern Bering Sea shelf, sex-specific trawl survey age and length frequencies and fishery length-frequencies from observer sampling (Table 6.4). Length composition data are available from each survey; however, length data are only used in the model for each year when age composition data are not available. Age composition data are available for each survey, but not for each year of the survey (Table 6.4).

Fishery:

Fishery catch data from 1976 – October 25, 2020 (Table 6.2) and fishery length-frequency data from 1978-2019 are used in the assessment (Table 6.5). Arrowtooth flounder catch is available from observer at-sea sampling applied to the Alaska Regional Office blend estimates for 1991-2020. For 1976-2007 the annual arrowtooth flounder catch was calculated as 90% of the combined arrowtooth flounder-Kamchatka flounder catch on record, based on their average annual proportions in trawl surveys since 1992 (the first year of reliable identification by species). These proportions were applied to the catch totals in Table 6.2, under “ATF est”.

Sparse amounts of arrowtooth and Kamchatka flounder were identified to species since the early 1990s and recorded in the Observer Program database (NORPAC). In 2008, the observer program increased their subsampling protocol and also increased the identification of the two species in the catch samples. However, speciation routines within the NMFS Alaska Regional Office catch accounting system (CAS) for arrowtooth and Kamchatka flounder did not begin until 2011. Therefore, we use the proportions of arrowtooth and Kamchatka flounder reported in NORPAC to derive the catch for arrowtooth flounder from 2008 to 2010.

The proportions applied to the total combined catch for 2008-2010 were derived from the extrapolated weights for arrowtooth and Kamchatka flounder from the NORPAC Catch Report Table on AKFIN. The estimate of the proportion is as follows:

$$P_y = \frac{\sum_h ATF_{h,y}}{\sum_h ATF_{h,y} + Kam_{h,y}},$$

where Py is the proportion of arrowtooth in year y, $ATF_{h,y}$ is the extrapolated weight of arrowtooth flounder in haul h in year y, and $Kam_{h,y}$ is the extrapolated weight of Kamchatka flounder. These 2008-2010 proportions are similar to the proportions of arrowtooth from 2011 to present based on the current speciation practices used by AKRO (Table 6.2b).

Catch from sources other than those that are included in the Alaska Region's official estimate of catch from fisheries managed under the FMPs (e.g., removals due to scientific surveys, subsistence fishing, recreational fishing) is shown in the Appendix Table 6.A1.1

Survey:

Biomass estimates (t) for arrowtooth flounder from the standard survey area in the eastern Bering Sea and Aleutian Islands region are shown in Table 6.6. Although the standard sampling trawl for the EBS shelf started in 1982, the survey was expanded in 1987 to include two more strata in the northwest area and the expanded survey area has been the standard sampling area to present. An analysis of species identification confidence for the eastern Bering Sea shelf bottom trawl survey and the Aleutian Islands survey data (Stevenson and Hoff, 2009; Orr et al., 2014) indicates that a moderate level of confidence was attained for arrowtooth flounder starting in 1980 for the Aleutian Islands survey and in 1992 for the eastern Bering Sea shelf survey. We, therefore, use information starting from 1992 for the eastern Bering Sea shelf expanded survey and continue with the current index time period for the Aleutian Islands bottom trawl survey. This year, we also provided a comparison of the total and spawning biomass estimates for the last 20 years from Model 18.9 using the uncorrected eastern Bering Sea shelf index (1982-2019) with the corrected index (1992-2019). The average difference in biomass (ADSB) was about 2% for both spawning and total biomass (Figure 6.9). We, therefore, use survey estimates starting from 1992 for the eastern Bering Sea shelf expanded survey. Biomass estimates from AFSC surveys on the continental shelf have shown a somewhat cyclic pattern since 1992 that leveled off for a period of years from 2012-2018 and then increased in 2019. The peak of the time series occurred in 2005 at 662,711 t. The 2019 shelf survey estimate was an increase of 13 % from the 2018 and 27% from the long term time series mean.

Trawl surveys were intermittently conducted over the continental slope (1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010, 2012, and 2016). Only the surveys conducted since 2002 are considered part of a standard time series of biomass. These surveys sampled depths ranging from 200 - 1,200 meters and the Poly Nor' Eastern bottom trawl net with mud sweep ground gear was the standard sampling net. The slope surveys conducted in 1988 and 1991 sampled depths from 200-800 m and used a polyethylene Nor' Eastern trawl with bobbin roller gear. Slope surveys conducted between 1979 and 1985 sampled depths ranging from 200-1000 m and used different gear altogether. These surveys show that arrowtooth flounder biomass increased significantly from 1979 to 1985. The biomass estimate in 1988 and 1991 were lower. Based on slope surveys conducted between 1979 and 1985, 67% to 100% of the arrowtooth flounder biomass on the slope was found at depths less than 800 m. These data suggest that less than 20% of the total EBS population occupied slope waters in 1988 and 1991. Surveys conducted during periods of low and increasing arrowtooth abundance (1979-85) indicate that 27% to 51% of the population weight occupied slope waters. Although the 2002-2004 surveys were deeper than earlier slope surveys, over 90% of the estimated arrowtooth biomass was located in waters less than 800 meters. The 2016 EBS slope survey estimate of 45,525 t was the lowest since 2002, and may reflect movement of arrowtooth onto the shelf (Figure 6.2).

Trawl surveys have been conducted in the Aleutian Islands since 1980 on a triennial and then biennial schedule starting in 2000. This survey generally occurs on even years but was cancelled in 2008. An analysis of species identification confidence for the Aleutian Islands bottom trawl survey data (Orr et al., 2014) indicates that a moderate level of confidence was attained for arrowtooth flounder in the early part of the survey and then a high level of confidence attained in 1990. We, therefore, use survey estimates starting at the beginning of the available time series but may consider only using estimates from 1990 to present to allow for the higher confidence in species identification. Biomass estimates from this survey show an increasing trend overall, with a peak in 1986 and an all series peak in 2006 at 110,384 t and 181,062 t, respectively.

Length frequencies for the shelf (Figure 6.3), slope (Figure 6.4), and Aleutian Islands (Figure 6.5) males and females indicate that a strong year class that originated from strong recruitment since 2010 is present, and that 2018 showed evidence for another large year class.

Error estimates in the survey biomass estimates are due to sampling variability. Arrowtooth flounder absolute abundance estimates are based on "area-swept" bottom trawl survey methods. These methods require several assumptions that can add to the uncertainty of the estimates. For example, it is assumed that the sampling plan covers the distribution of the species and that all fish in the path of the trawl are captured (no losses due to escape or gains due to herding).

The relative abundance of arrowtooth flounder increased substantially on the continental shelf from 1992 to 1990; the CPUE from AFSC shelf surveys increased steadily from 1.6 to 9.9 kg/ha (Figure 6.6). The overall shelf catch rate decreased slightly to 7.1 kg/ha in 1991. The CPUE continued to increase through 1997 to 15.0 kg/ha. These increases in CPUE were also observed on the slope from 1981 to 1986 as CPUE from the Japanese land-based fishery increased from 1.5 to 21.0 t/hr (Bakkala and Wilderbuer 1990). From 1999 to 2005 the shelf survey CPUE increased at a high rate each year. Survey estimates are consistently high from 2003-2011 (between 8-11 kg/ha), and the 2005 CPUE of 15.4 kg/ha was the highest ever estimated from the shelf survey. Since that time, CPUE has decreased to a mean of approximately 5,000 kg/ha (Figure 6.6).

Analytic Approach

Model Structure

We present model results for the arrowtooth flounder stock based on an age-structured model using AD Model Builder software (Fournier et al. 2012). This consists of an assessment model, which uses survey and fishery data to generate a historical time series of population estimates, and a projection model which uses results from the assessment model to predict future population estimates and recommended harvest levels. This model does not attempt to fit a stock-recruitment relationship but estimates a mean recruitment, which is adjusted by estimated recruitment deviations for each year.

This age-structured population dynamics model is fit to survey abundance data, survey age data, and survey and fishery length composition data. The model is 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. A “generalized model” has been used in the Gulf of Alaska and the Bering Sea and Aleutian Islands arrowtooth flounder stock assessments since 2015. The model incorporates ages 1-21+ and estimates selectivity up to age 15 for the survey and 10 for the fishery. 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 20,000,000 iterations, and thinning every 4000.

Recruitment is calculated as an average value, $\overline{\log R}$, with an estimated lognormal deviation in each year of the model with the exception of the final year, in which the mean value is chosen. Recruitment is informed by subsequent year class strengths and there is little information to inform recruitment in the final few years because selectivity is low for younger arrowtooth flounder. Equilibrium age structure in the unfished population is based on mean recruitment that is subject to a vector of instantaneous rates of natural mortality, M_{sex}, in each subsequent year, and a plus group (x) that includes all ages 21 and older. Natural mortality is subscripted for sex, as males appear to have higher natural mortality than females in this species (Wilderbuer and Turnock 2009).

$$(1) \qquad \tilde{N}_{sex,\,a} = \begin{cases} e^{\overline{\log R}} & \text{if a=0} \\ \tilde{N}_{sex,\,a-1} e^{-M_{sex,a-1}} & \text{if } 1 \le \text{a} \le \text{x-1} \\ \tilde{N}_{sex,\,x} e^{-M_{sex,x-1}} / (1 - e^{-M_{sex,x-1}}) & \text{if a=x.} \end{cases} ,$$

where a represents age, N is numbers of fish by sex and age, and M represents natural mortality.

The numbers-at-age for all years in the model are computed allowing for fishery selectivity, and fishing and natural mortality.

$$(2) \qquad N_{sex,y+1,a} = \begin{cases} e^{\overline{\log R} + rec\_dev_y} & \text{if a = 0} \\ N_{sex,y,a-1} e^{-(S_{sex,a-1} F_{sex,y} + M_{sex,a-1})} & \text{if } 1 \le \text{a} \le \text{x-1} \\ N_{sex,y,x-1} e^{-(S_{sex,x-1} F_{sex,y} + M_{sex,x-1})} + N_{sex,y,x} e^{-(S_{sex,x} F_{sex,y} + M_{sex,x})} & \text{if a=x,} \end{cases}$$

where $N_{sex,y+1,a}$ is the number of fish of each sex at age a at the start of year y, $S_{sex,a}$ is the selectivity-at-age for the fishery for each sex, F_y is the instantaneous fully-selected fishing mortality rate during year y and is calculated from the log of the mean fishing mortality and a vector of fishing mortality deviations (fmort_devs) for each year of the model, $F_y = e^{\overline{\log F} + fmort\_dev_y}$.

There were 151 parameters estimated by the model examined in the current assessment (Table 6.9). Observation errors for age and length compositions were assumed to be multinomial distributed, while recruitment deviations, and catch and biomass observation errors were assumed to be lognormally distributed. Individual log-likelihood components are as follows:

$$(3) \quad recruitmentL = 0.5 \sum_{y=Styr}^{Endyr} \left(\frac{rec\_dev_y}{\sqrt{0.5}} \right)^2$$

$$(4) \qquad biomassL = 0.5 \sum_{y=Styr}^{Endyr} \left(\frac{\log(Biomass_{obs,y}) - \log(Biomass_{pred,y})}{BiomassSD_{obs,y} / Biomass_{obs,y}} \right)^2 ,$$

where the observed CV is an estimate of standard deviation.

(5) $$catchL = 0.5\sum_{y=Styr}^{Endyr}\left(\frac{\log(Catch_{obs,y}+d)-\log(Catch_{pred,y}+d)}{\sqrt{0.5}}\right)^2$$, where d is a small value needed in the case of zero catches.

(6) $$LengthL = \sum_{y=Styr}^{Endyr}\sum_{sex}\sum_{length} Nhauls_{sex,y}(obs\_prop_{sex,length,age}+\delta)\log(pred\_prop_{sex,length,age}+\delta)$$.

Length composition for the fishery and the survey are calculated as in Equation 6. Delta (d) is a small number less than 1 added to account for the possibility of zero observations in a length (or age category). Length compositions reflect the number of effective hauls and sample sizes are set to 200 for survey data and 25 for the fishery. The proportions of males and females sum to 1 in each year of the model. This also allows for the model to fit the observed skewed sex ratio (Figure 6.7), approximately 69% females and 31% males based on the fishery length composition data. Length composition data is only used in the model in years in which there is no age data.

The likelihood for survey ages assumes that observation error is distributed multinomially. The negative log-likelihood is similar to equation (6):

(7) $$AgeL = \sum_{y=Styr}^{Endyr}\sum_{sex}\sum_{length} Nhauls_{sex,y}(obs\_prop_{sex,length,age}+\delta)\log(pred\_prop_{sex,length,age}+\delta)$$.

Age data exist for the 1993, 1994, 1996, 1998, 2004, 2010, 2012, 2014-2019 EBS shelf surveys, the 2012 slope survey, and the 2010-2018 Aleutian Islands surveys. For the age composition, the number of hauls was assumed to be 200 for each year of data. Detailed cruise information for each survey from which age data were taken to construct the age-length curve is shown in Table 6.8.

Catch, in units of fish, is estimated in the model using the standard equation:

(8) $$Catch_{year,age} = \frac{F_{year,age}}{Z_{year,age}}(1-e^{-Z_{year,age}})N_{year,age},$$

where Z represents total mortality and is the sum of natural and fishery mortality.

Female spawning biomass is calculated as the product of the weight of mature females in each year.

(9) $FSB_{year} = \sum_{age} wt_{age}\phi_{age}N_{age,year}$, where ϕ_{age} is the proportion of mature females at each age from Stark (2011), $N_{age,year}$ is the number of females in the population, and wt_{age} is the weight at age for females.

Yield is the sum of the weight of the catch,

(10) $$Y_{year} = \sum_{age} wt_{year,age}Catch_{year,age}$$

Fishing mortality is calculated from the expected mean fishing mortality and an "fmort_dev" deviation for each year,

(11) $$F_{year,age,sex} = s_{year,age,sex}E_{year}e^{\varepsilon_{year}},\ \varepsilon_{year}\sim N(0,\sigma_f^2)$$, where s represents fishery selectivity.

The 10 selectivity parameters estimated in the model for the smooth fishery selectivity functions were constrained so that the number of effectively free parameters would be less than 10. There were 43 fishing mortality deviates in the model, plus one mean fishing mortality parameter, to fit the observed catch closely. Twenty-one initial recruitment deviations were estimated to start the population in 1976. Recruitments deviations from 1976 to 2019 account for 44 parameters, plus one parameter for the mean recruitment. Survey selectivity was estimated separately for males and females (4 parameters total). The instantaneous natural mortality rate, catchability for the survey and the von Bertalanffy growth parameters were fixed in the model. No spawner-recruit curve was used in the model. Recruitments were freely estimated, but with a modest penalty on extreme deviations from the mean value. Age at recruitment was set at one in the model.

A retrospective analysis was performed extending back 8 years, with data from 2012-2020. Eight runs were performed; the 2019 run was created by dropping the 2020 data, the 2018 run was created by dropping the 2019 data, etc. We only were able to extend the retrospective analysis back 8 years due to convergence issues when the slope age data dropped out of the model. This will be resolved in the next full assessment.

Description of Model

We use the base model from the last full assessment (Model 18.9) with updated and new data since the last full assessment. Model 18.9 is the same as Model 15.1b with the addition of a smoothed length-age conversion matrix, an ageing error matrix to account for known error rates in age reading, and removing the early years of the EBS slope survey (1979-1991). The removal of the slope survey years was motivated because those surveys did not use a standardized net or standardized survey depths. Also, arrowtooth flounder and Kamchatka flounder were not distinguished for all years. Please see Spies et al. (2018) for more details regarding this reference model. A summary of model results is shown in Table 6.9 comparing Model 18.9 (2020) with Model 18.9 from the last full assessments. Due to the increase in data in the current model, the likelihoods cannot be directly compared but are there for reference as are spawning and total biomass estimates.

Parameters Estimated Outside the Assessment Model

Natural mortality

Natural mortality (*M*) rates for Gulf of Alaska arrowtooth flounder were estimated using the methods of Wilderbuer and Turnock (2009). A higher natural mortality for males than females was used to fit the age and size composition data, which are about 70% females (Figure 6.7). A value of M=0.35 for males was chosen so that the survey selectivities for males and females both reached a maximum selectivity close to 1.0. A likelihood profile on male natural mortality resulted in a mean and mode of 0.354 with 95% confidence intervals of 0.32 to 0.38 (Turnock et al. 2002, Figure 10.14). Model runs examining the effect of different natural mortality values for male arrowtooth flounder can be found in the Appendix of the 2000 SAFE (https://www.afsc.noaa.gov/REFM/stocks/Historic_Assess.htm). Differential natural mortality by sex can be a factor that needs consideration in management of targeted fish stocks, however, since BSAI arrowtooth flounder is currently exploited at low levels, this effect is not a concern for this stock (Wilderbuer and Turnock 2009).

Data used to calculate length at age and weight at length

The data consisted of age data from the 1982-2017 EBS groundfish surveys. There were 7,790 such data points, each associated with age and length for each fish; 5,243 females and 2,547 females. Details of these cruises are shown in Table 6.8.

Length at Age

Growth was estimated from length and age data from BSAI surveys from 1982 to 2017 and incorporated in the assessment using a length-age conversion matrix. There is a single length-age conversion matrix that converts length frequencies from all years of data to age in the model. Length adjusted for survey length frequencies for which there is more data (489,000 observations from 1980-2017, Table 6.10) was converted to weight with the weight-at-length relationship described below. This correction is based on Bayes Theorem, and follows (Dorn 1992). The stratified age collections consist of the probability of length given age P(Length|Age). These are corrected for the length frequencies in the population by dividing by length frequencies from survey data from the same years, 1980-2017.

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

Correcting for survey length frequencies reduced the expected length at age in the population as compared to lengths of aged fish from a stratified collection (Figure 6.10).

A von Bertalanffy individual growth model was applied to the corrected length at age data, separately for males and females, using the R package 'fishmethods', resulting in the following parameter estimates.

For the remainder of the models the following parameters were used. Note lengths were in mm.

	Sample size	Age range	L_{inf}	K	t_0
Male	2,547	1-37	527.02	0.2084	-0.3870
Female	5,243	1-34	848.27	0.0992	-0.9504

The fitted equation was: $Length = S_{\infty}(1 - e^{-(K(age - t_0))})$.

The plus group contains all ages 21 and above, and was calculated as a weighted average of the von Bertalanffy mean length and the proportion estimated to be in each of those upper age categories based on *M*=0.2 for females and *M*=0.35 for males.

The coefficient of variation (CV) typically decreases with age. The CV of length at age was fitted using linear regression (Figure 6.11), with the parameters shown in the legend. When a monotonically decreasing CV is converted to variance, it becomes dome shaped, with higher variance at middle ages, e.g. ages 5-18 (Figure 6.12).

The length-age conversion matrix was generated by simulating 10,000 data points for mean length at ages 1-21+ 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 male and female von Bertalanffy parameters fit to the length-age data and the variance for length at age determined by the parameters of the linear models presented in Figure 6.10. These data were binned into 25 length categories bounded by the ranges shown below. These length categories were used for all length composition data in the model. The length-age conversion matrix is shown as Figure 6.13.

Range (cm)	100-160	160-180	180-200	200-220	220-240	240-260	260-280	280-300	300-320	320-340	340-360	360-380
Midpts	130	170	190	210	230	250	270	290	310	330	350	370

Range (cm)	400-430	430-460	460-490	490-520	520-550	550-580	580-610	610-640	640-670	670-700	700-750	>750
Midpts	415	445	475	505	535	565	595	625	655	685	725	850

Weight at Length

The weight-length relationship for arrowtooth flounder was evaluated to be:
Weight = 1.284×10^{-6}*Length$^{3.319}$, for both sexes combined, where weight is in grams and length in millimeters. Analysis was performed using nonlinear least squares fit to all weight and length data from the RACE Eastern Bering Sea surveys from 1982 to 2017, 3,852 females and 1,904 males. The nonlinear least squares (nls) method was implemented from the R package stats (Bates and Chambers 1992). The length-weight relationship was the same for male and females (Figure 6.14).

A previous estimate of weight at length was based on 282 observations from an AFSC survey conducted in 1976. The length (mm)-weight (gm) relationship for arrowtooth flounder (sexes combined) is described by the equation:

$W = 5.682 \times 10^{-6} * L^{3.1028}$. This estimate is also shown in Figure 6.14, as the previous estimate.

Weight at age

Weight at age used in the model is based on length at age corrected by survey length frequencies. Mean length at age from the length age conversion matrix was converted to weight at age based on the relationship in Figure 6.14. Weight at age is presented in Table 6.7.

Maturity

Maturity information from a histological examination of arrowtooth flounder in the Gulf of Alaska (Zimmerman 1997) indicates that 50% of male and female fish become mature at 46.9 and 42.2 cm, respectively. A similar study in the Bering Sea based on female samples only, found that 50% of female fish become mature at approximately 46 cm and 7 years (Stark 2011). The maturity-at-age is governed by the relationship:

$$Q_a = \frac{1}{1 + e^{-(A+aB)}},$$

where *A* and *B* are parameters in the relationship (i.e. Tables 1 and 2; Stark 2011) and *a* represents age. The parameters *A* and *B* are based on a February, 2008 collection of 175 female fish (Stark 2011). The weight-at-age and maturity-at age ogives used in the model are shown in Table 6.7.

Catchability

Attempts to estimate catchability by profiling over fixed *q* values in a previous assessment (Wilderbuer and Sample 1995) were unsuccessful as estimated values always reached the upper bounds placed on the parameter. The results indicated *q* values as high as 2.0 which suggests that more fish are caught in the survey trawl than are present in the "effective" fishing width of the trawl (i.e. some herding occurs or the "effective" fishing width of the trawl may be the distance between where the sweep lines contact the seafloor instead of between the wingtips of the survey trawl). Results from two herding experiments conducted in 1994 to discern the herding characteristics of the standard shelf survey trawl, indicated a trawl catch of flatfish was composed of fish which were directly in the trawl path as well as those which moved into the trawl path because of the mud cloud disturbance caused by the bridle contact with the seafloor (Somerton and Munro 2001). Thus the “area-swept” technique of estimation would overestimate the abundance when herding occurred. Further research on the whole gear efficiency, the proportion of fish passing between the otter doors of a bottom trawl net that are subsequently captured, included arrowtooth flounder. Results indicated that arrowtooth have high efficiency (the proportion of fish passing between the otter doors of a bottom trawl that are subsequently captured), varying by fish length, similar to other flatfish, approximately 40-50% (Somerton et al. 2007).

In this assessment, catchability for the three survey regions is estimated by biomass from each of the three regions using a random effects model estimate of the Aleutian Islands survey biomass from 1980-2018, the slope survey data from 2002-2016, and the Bering Sea 1982-2018 (Table 6.1). The relative proportions sum to 1. The 2018 estimates of q are 0.82 for the Bering Sea shelf, 0.08 for the Bering Sea slope, and 0.10 for the Aleutian Islands. The estimate of q in the Bering Sea is parameterized to covary with bottom water temperature.

Examination of Bering Sea shelf survey biomass estimates indicate that some of the annual variability seemed to positively co-vary with bottom water temperature. Variations in CPUE (Figure 6.6) were particularly evident during the coldest year (1999), and the previous warmest year (2003), although the relationship does not hold true in 2016 or 2018, the warmest and most recent years of anomalously warm temperatures. The relationship between average annual bottom water temperature collected during the survey and annual survey biomass estimates can be better understood by modeling survey catchability as:

$$q = e^{-\propto+\beta T_t}$$

where q is catchability, $\alpha$and β are a parameters estimated by the model, and T_t is the annual bottom water temperature anomaly. The catchability equation has two parts. The e^{α} term is a constant or time-independent estimate of q. The model estimate of α = -0.29 indicates that $q > 1$ suggesting that arrowtooth flounder are herded into the trawl path of the net which is consistent with the experimental results for other flatfish species. The second term, $e^{\beta T}$ is a time-varying (annual) q which relates to the metabolic aspect of herding or distribution (availability) which can vary annually with bottom water temperature. From 2014-2019, the temperature anomaly was positive, following two years of low temperatures; resulting in an increase in the catchability estimate (Figure 6.15).

Ageing error matrix

Ageing error in arrowtooth flounder is relatively high compared to walleye pollock and Pacific cod. Therefore, we implemented an ageing error transition matrix to convert population numbers at age to expected survey numbers at age. An ageing error matrix was constructed using data from two age reader comparisons of 1,701 arrowtooth flounder from the Bering Sea and Aleutian Islands (Jon Short, NMFS, report generated September 24, 2018). A matrix of reader agreement between the first and second reader was calculated from this data. Percent agreement was predicted by the sum probability that both readers are correct, that both readers are off by one year in the same direction, and the probability that both age readers are off by two years in the same direction (Methot 2000). The true age is unknown, therefore the variance in reader agreement was calculated from the data and expressed theoretically using estimates of the standard deviation in ageing error by age of the fish. Ageing agreement was 60-87% at ages 1-3 and declined to 20-30% for ages 14-17 (Figure 6.16). There was higher variation in the percent agreement at older ages. The model incorporated a linear increase in the standard deviation of ageing error and assumed that ageing error is normally distributed (Dorn et al. 2003, Methot 2000).

The variance in reader agreement, $\hat{P}$, was calculated from the data as follows:

$\hat{P}$=P(readers 1 and 2 agree)^2+2*P(reader1 off by 1 year)*P(reader 2 off by 1 year)+2* P(reader 1 off by 2 years)*P(reader 2 off by 2 years).

This value can be calculated using the cumulative distribution and the standard variation in reader agreement, if it is known, as shown below with R code.

P_calc=(pnorm(age+.5,age,sigma$_{age}$)-pnorm(age-.5,age, sigma$_{age}$))^2+2*(Pnorm(age-.5,age, sigma$_{age}$)-pnorm(age-1.5,age, sigma$_{age}$))+ 2*(Pnorm(age-1.5,age, sigma$_{age}$)-pnorm(age-2.5,age, sigma$_{age}$))

The standard deviation in ageing error (sigma) is expected to increase linearly by age.

The values of sigma were calculated by minimizing the difference between the Pcalc and $\hat{P}$ by adjusting the slope of the standard deviation, which was constrained to increase linearly by age.

Parameters Estimated Inside the Assessment Model

The suite of parameters estimated by the base model are classified by the following likelihood components:

Data Component	Distribution assumption
Trawl fishery size composition	Multinomial
Shelf survey population size composition	Multinomial
Slope survey population size composition	Multinomial
Shelf survey age composition	Multinomial
Aleutian survey age composition	Multinomial
Trawl survey biomass estimates and S.E.	Log normal

There were 20 parameters estimated for the fishery selectivity; 10 for each sex for the smooth selectivity function. Each survey selectivity had 4 parameters for the two sexes, two parameters for increasing logistic selectivity, as well as 4 additional parameters for the decreasing arm of the shelf survey selectivity. Two parameters, alpha and beta, were estimated for the temperature-dependent shelf survey catchability (q-shelf). There were 65 recruitment deviations, 21 for the starting conditions, and 44 additional for each year from 1976-2019 (recruitment was not estimated in the final year). There was a fishing mortality deviation for each year from 1976-2020 (45). Mean log recruitment and mean log fishing mortality were also estimated. The number of estimated parameters are given below.

Fishery Selectivity	Survey Selectivity	q-shelf	Recruitment deviations	Fishing mortality deviations	Mean log recruitment	Mean log fishing mortality	Total
20	17	2	65	45	1	1	151

Year class strengths

The population simulation specifies the number-at-age in the beginning year of the simulation, the number of recruits in subsequent years, and the survival rate for each cohort as it moves through the population calculated from the population dynamics equations.

Fishing Mortality

The fishing mortality rates (F) for each age and year are estimated to approximate the catch weight by solving for F while still allowing for observation error in catch measurement.

Selectivity

Separate fishery selectivities were estimated non-parametrically for each age, up to age 10, and the shape of the selectivity curve was constrained to not vary extremely between ages and constrained as to how much dome-shapedness can occur. Survey selectivities for the Bering Sea slope and Aleutian Islands surveys were modeled using a two parameter ascending logistic function. Selectivity for the Bering Sea shelf survey was estimated using a dome shaped curve based on a two parameter ascending logistic function and a two parameter descending logistic function. The selectivities by age were estimated separately for females and males. The differential natural mortality and selectivities by sex resulted in a predicted fraction female of about 0.70, which is close to the fraction of females in the fishery and survey length and age data.

Results

Model Evaluation

Model 18.9 was selected in the last full assessment as the authors' preferred model because it provided the best fit to the data and incorporated necessary changes to the model configuration. Final parameter estimates for Model 18.9 are shown in Table 6.A2.2.

Time Series Results

The current assessment model shows a recent trend of decreasing female spawning since 2012 that has since stabilized in the current spawning biomass estimates (Figure 6.8). The 2020 model estimates higher levels of total biomass than the 2018 assessment and a shift in trend to increasing. Since 2010, recruitment estimates have increased (Table 6.15, Figure 6.16) and a large cohort is evident in Bering Sea shelf length frequency data (Figure 6.3) as well as a large age 3 cohort in 2019.

Estimates indicate that arrowtooth flounder total biomass increased approximately three fold from 1976 to the 2009 (Figure 6.8, Table 6.13). Since 2009, estimates of biomass have decreased until 2016 when total biomass, and estimates have increased since the last full assessment in 2016 based on the current assessment model output (Table 6.13). Female spawning biomass has declined since 2010 to a 2018 but has stabilized since then (Figure 6.8, Table 6.13). The model estimates of population numbers by age, year, and sex are given in Table 6.14.

Slope and AI survey selectivities were estimated using a logistic fit to age, by sex (Figure 6.18). The shelf survey selectivity is assumed to be dome shaped, but male shelf selectivity was more similar to a logistic curve, likely due to lower asymptotic length of males.

The model fit to the fishery length data appears to track observed length frequency proportional to the number of observations (Figure 6.19). The model fit to the shelf survey tracks the trend of increasing abundance from 1992 to the high levels from 1993-97 and 2005-2006 (Figure 6.20). The model provides reasonable fits to the slope and Aleutian Island size composition time-series for males and females, which are shown in Figure 6.21 and Figure 6.22, except that it estimates more larger females than are observed. The model provides acceptable fits to the survey age compositions (Figures 6.23, 6.24, 6.25).

The model provides a close fit to the Bering Sea shelf and slope data (Figure 6.26). It does not fit an anomalously large abundance index from the Aleutian Island survey, although the uncertainty of that estimate is very high (Figure 6.26 lower left panel). The model estimate of total biomass and female spawning biomass are also presented in Figure 6.26. Estimates of female spawning biomass from the past two decades are well above $B_{40\%}$ and $B_{35\%}$. The posterior distribution of the 2018 female spawning biomass is higher than $B_{35\%}$ (Figure 6.27), and if fishing takes place as it has over the past five years, projected female spawning biomass is expected to remain above $B_{40\%}$ (Figure 6.28). The phase plane diagram indicates that the female spawning biomass is above $B_{40\%}$ and it is fished at lower rates than F_{ABC}, or $F_{40\%}$ (Figure 6.29).

Retrospective Analysis

Retrospective analysis is the examination of the consistency among successive estimates of the same parameters obtained as new data are added to a model. Retrospective analysis has been applied most commonly to age-structured assessments and can arise for many reasons, ranging from bias in the data (e.g., catch misreporting, non-random sampling) to different types of model misspecification (e.g., incorrect values of natural mortality, temporal trends in values set to be invariant). For this assessment, a within-model retrospective analysis of the preferred model was conducted for the last 10 years of the time-series by dropping data one year at a time from the current preferred model.

The retrospective female spawning biomass and the relative difference in female spawning biomass from the 2019 model are shown in Figure 6.30 and Figure 6.31, respectively. One common measure of the retrospective bias is Mohn's revised ρ ("rho") which indicates the size and direction of the bias (Hanselman et al. 2013). The revised Mohn's ρ statistic is small at 0.068 (compared to most AFSC assessments, Hanselman et al. 2013), indicating that the model estimates of spawning biomass increase relative to the terminal year estimates as data is removed from the assessment. Results do not indicate a strong pattern of change from the preferred model (Figure 6.30); however, the change is consistently upward for all years analyzed, indicating a small bias. Although there are no guidelines regarding how large rho (absolute value) should be before an assessment is declared to exhibit an important retrospective bias, 0.068 is very small compared with many other Alaska groundfish species. Additionally, the strange difference pattern in the earlier part of the time series has now disappeared (Figure 6.31), potentially due to the change in the Bering Sea shelf time series from 1982 to 1992.

Examining retrospective trends can show potential biases in the model, but may not identify what their source is. Other times a retrospective trend is merely a matter of the model having too much inertia in the age-structure and other historic data to respond to the most recent data. This retrospective pattern is likely to be considered mild, but an issue may be the "one-way" pattern in the retrospective time series. It is difficult to isolate the cause of this pattern but several possibilities exist. For example, hypotheses could include environmental changes in catchability, time-varying natural mortality, or changes in selectivity of the fishery or survey. It appears that the "loose" estimation of catchabilities of the model results in some shifts in scale that affect the retrospective bias in different assessments.

Harvest Recommendations

Amendment 56 Reference Points

Arrowtooth flounder have a wide-spread bathymetric distribution in the Bering Sea/Aleutian Islands region. The population is above $B_{40\%}$, and are subject to minimal commercial harvest. The estimate of projected 2021 total biomass from the stock assessment projection model is 923,646 t and the female spawning biomass is estimated at 497,556 t for the author recommended model.

The reference fishing mortality rate for arrowtooth flounder 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). Equilibrium female spawning biomass is 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 1976-2019 are used to calculate the average equilibrium recruitment. This results in an estimate of $B_{40\%}$ = 223,530 t for 2021. Projected 2021 female spawning biomass is compared to B40% to determine the Tier level. The stock assessment model estimates the 2021 level of female spawning biomass at 497,556 t. Since reliable estimates of B, $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and $B>B_{40\%}$, arrowtooth flounder reference fishing mortality is defined in Tier 3a. For 2021 the recommended $F_{ABC} = F_{40\%} = 0.135$ and $F_{OFL} = F_{3\%} = 0.160$ (full selection F values).

Specification of OFL and Maximum Permissible ABC

Acceptable biological catch is estimated for 2021 by applying the $F_{40\%}$ fishing mortality rate and age-specific fishery selectivities to the projected 2021 estimate of age-specific total biomass as follows:

$$ABC = \sum_{a=a_r}^{a_{nages}} \overline{w}_a n_a \left(1 - e^{-M - Fs_a}\right) \frac{Fs_a}{M + Fs_a}$$

where S_a is the selectivity at age, M is natural mortality, W_a is the mean weight at age, and n_a is the beginning of the year numbers at age. This results in a 2021 ABC of 77,349 t. There were no retrospective patterns to suggest that altering the ABC from this value is warranted. The overfishing level is estimated for 2021 by applying the $F_{35\%}$ fishing mortality rate and age-specific fishery selectivities to the projected 2020 estimate of age-specific total biomass. This results in a 2021 OFL of 90,873 t.

Population Projections

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 current year numbers at age estimated in the assessment. This vector is then projected forward to the beginning of the following year (current year +1) using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for the current year. 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.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for next year (current year +1), are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

> *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 next year's (current year +1) recommended in the assessment to the *max* F_{ABC} for next 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, F is set equal to 50% of max F_{ABC}. 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 most recent 5-year (current year -6 – current year -1) average F. Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.

> *Scenario 5*: In all future years, F is set equal to zero. Rationale: In extreme cases, TAC may be set at a level close to zero.

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

> *Scenario 6*: In all future years, F is set equal to F_{OFL}. Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above ½ of its MSY level in the current year and above its MSY level in 10 (current year +10) years under this scenario, then the stock is not overfished.

Scenario 7: In the next year and the following year (current year +1, current year +2), F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 13 years (current year +13) under this scenario, then the stock is not approaching an overfished condition.

Simulation results for the seven projection scenarios indicate that arrowtooth flounder are not currently overfished and the stock is not considered to be approaching an overfished condition (Table 6.16). The stock projection at the average exploitation rate for the past 5 years (Figure 6.28) indicates that the stock will remain above $B_{40\%}$ if fished at this rate for the next 12 years. A phase-plane diagram showing the time-series of female spawning biomass estimates relative to the harvest control rule (Figure 6.29) shows that the female spawning biomass is above $B_{40\%}$ and that the stock is lightly exploited relative to reference points, and that this trend is expected to continue through at least 2022. The ABC and TAC values that have been used to manage the combined stock since 1980 are presented in Table 6.17.

Status Determination

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2021, it does not provide the best estimate of OFL for 2022, because the mean 2021 catch under Scenario 6 is predicated on the 2021 catch being equal to the 2021 OFL, whereas the actual 2021 catch will likely be less than the 2021 OFL. The executive summary contains the appropriate one- and two-year ahead projections for both ABC and OFL.

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

Is the stock being subjected to overfishing? The official catch estimate for the most recent complete year (2019) is 10,048 t. This is less than the 2019 OFL of 82,939 t. Therefore, the stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be overfished. Any stock that is expected to fall below its MSST in the next two years is defined to be approaching an overfished condition. Harvest Scenarios #6 and #7 are used in these determinations as follows:

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2020:

a) If spawning biomass for 2020 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b) If spawning biomass for 2020 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c) If spawning biomass for 2020 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 6.16). If the mean spawning biomass for 2030 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario #7:

a) If the mean spawning biomass for 2022 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.
b) If the mean spawning biomass for 2022 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c) If the mean spawning biomass for 2022 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2032. If the mean spawning biomass for 2032 is

below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

Based on the above criteria and Table 6.16, the stock is not currently overfished, and is not approaching an overfished condition. The tests for evaluating these two statements on status determination require examining the current model projections of spawning biomass relative to B35% for 2020 and 2022. The estimates of spawning biomass for 2020 and 2022 from the current year (2020) projection model are 494,307 t and 451,894 t, respectively. Both estimates are well above the estimate of B35% at 195,589 t and, therefore, the stock is not currently overfished nor approaching an overfished condition. The *F* from the author's recommended model that would have produced a catch for last year equal to last year's *OFL* was *F*=0.152.

Specified Catch Estimation

In response to Plan Team recommendations, we have established a consistent methodology for estimating current-year and future year catches in order to provide more accurate two-year projections of ABC and OFL to management. In the past, two standard approaches in flatfish models have been employed; assume the full TAC will be taken, or use a certain date prior to publication of assessments as a final estimate of catch for that year. Both methods have disadvantages. If the author assumes the full TAC is taken every year, but it rarely is, the ABC will consistently be underestimated. Conversely, if the author assumes that the catch taken by around October is the final catch, and substantial catch is taken thereafter, ABC will consistently be overestimated.

Therefore, going forward in the arrowtooth flounder assessment, for current year catch, we are using an expansion factor to the catch in October by the 5-year average of catch taken between October 25 and December 31 in the last five complete catch years (e.g. 2015-2019 for this year. The 2020 catch through October 25, 2020 was 10,040 t. The total catch in 2020 was estimated to be 10,879 t based on the proportion caught through this date for the past 5 years (94%). The total catch in 2021 was the average catch 2015-2019 at 9,109 t. High catches in 2010-2012 over 20,000 t were the result of bycatch in targeted Kamchatka flounder fishing, and such high catches are unlikely to occur again.

Overfishing Definition

Based on the definitions for overfishing in Amendment 44 in Tier 3a (i.e., F_{OFL} = F35%=0.160), overfishing is set equal to 90,873 t in 2020 and 94,368 t in 2021 for BSAI arrowtooth flounder.

Should the ABC be reduced below the maximum permissible ABC?

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

	Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment.	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental/ecosystem concerns	No apparent fishery/resource-use performance and/or behavior concerns
Level 2: Substantially increased concerns	Substantially increased assessment uncertainty/ unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing an adverse signals relevant to the stock but the pattern is not consistent across all indicators.	Some indicators showing adverse signals but the pattern is not consistent across all indicators
Level 3: Major Concern	Major problems with the stock assessment; very poor fits to data; high level of uncertainty; strong retrospective bias.	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns.	Multiple indicators showing consistent adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock)	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types
Level 4: Extreme concern	Severe problems with the stock assessment; severe retrospective bias. Assessment considered unreliable.	Stock trends are unprecedented; More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; Potential for cascading effects on other ecosystem components	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

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

1. Assessment considerations—data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data; model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs; model performance: poor model convergence, multiple

minima in the likelihood surface, parameters hitting bounds; estimation uncertainty: poorly-estimated but influential year classes; retrospective bias in biomass estimates.

2. Population dynamics considerations—decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.
3. Environmental/ecosystem considerations—adverse trends in environmental/ecosystem indicators, ecosystem model results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.
4. Fishery performance—fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings.

Assessment considerations

The BSAI Arrowtooth Flounder assessment is based on a time series of all standard AFSC groundfish surveys dating back to 1992 in the Bering Sea and Aleutian Islands region. Ages from AFSC surveys are available for many years, and in general there has been a shelf survey for each year. The model exhibits good fits to abundance and composition data. The retrospective pattern from the current assessment is good, and Mohn's rho was calculated to be 0.068 for Model 18.9, indicating that there is little effect due to retrospective bias.

The EBS shelf and Aleutian Islands bottom trawl surveys were not conducted in 2020 due to COVID-19 concerns; therefore, we do not have information from surveys for this year. Bryan et al. (2020) evaluated the impact of missing the most recent survey data from many Alaska stock assessments and found the direction and magnitude of retrospective bias was an important determinant in the level of expected uncertainty in those stock assessment results. Notably, EBS snow crab exhibited a large, positive retrospective bias and uncertainty was greatest in its stock assessment outcomes. The Kamchatka flounder assessment exhibits a moderate level of positive retrospective bias in comparison to EBS snow crab. We consider the results from Kamchatka flounder to likely be similar to what would happen with arrowtooth flounder. Uncertainty is expected to be larger than when we have survey data, but it is not a concern for this one year as we currently have alternating surveys in the Gulf of Alaska and Aleutian Islands and that is not considered a cause for extra concern.

Population dynamics considerations

Stock assessment model results that arrowtooth flounder biomass (age 1+) was at low levels during the 1970s and 1980s, although surveys used during that time period used unconventional methods. The population has steadily increased since the 1990's and reached a peak in the 2010's at which time biomass was estimated at approximately 0.9 million tons. Total biomass declined only slightly for a few years but has recently returned to near historic high levels. The spawning biomass is well above the reference points with evidence of a recent strong recruitment in 2016. Population dynamics are not a concern for this assessment.

Environmental/Ecosystem considerations

Arrowtooth flounder have similar distributions as Kamchatka flounder within the BSAI, but arrowtooth flounder are more abundant in the GOA and distributed farther south. Adults avoid the cold pool, and their distribution increases over the EBS shelf when the cold pool is reduced. In contrast to the previous 2 years, the 2020 cold pool on the shelf was modeled to be close to average in spatial extent, reflecting the sea ice that built up to mean extent before breaking up rapidly in mid-March. Winter sea surface temperatures in both the EBS and NBS were close to the mean during winter, but warmed to well above the mean during summer. Thus their distribution over the shelf was likely more restricted relative to 2018 and 2019, but there are no survey data to confirm this. Modeled wind-forcing on springtime drift patterns appears to be consistent with years when below average recruitment occurred for winter-spawning flatfish such as arrowtooth flounder.

Condition factors measured for arrowtooth flounder during summer 2019 showed strongly positive anomalies, suggesting that arrowtooth flounder were successfully meeting their foraging demands. Common prey items for adult arrowtooth flounder are juvenile walleye pollock and benthic prey such as eel pouts and shrimp. Bottom trawl surveys and the EBS walleye pollock stock assessment estimated more age-1 pollock in 2019 compared to 2015-2018, but still much less abundant than the 2012 and 2013 year class. Due to lack of surveys, estimates of age-1 pollock are unknown this year. Benthic infauna and other non-targets are not sampled well by the bottom trawl survey. Recent surveys have indicated catch rates of eelpouts near the survey mean. Juvenile arrowtooth flounder are zooplanktivores. The latest data available from the Rapid Zooplankton Assessment indicates moderate to low abundances of large copepods in 2018 that decreased in 2019. The most recent acoustic surveys for euphausiids estimated relatively low abundances in 2016 and 2018, especially relative to peak abundances in 2007-2010. Taken together these suggest prey abundance for arrowtooth flounder has been low to moderate in recent years, although the strongly positive condition factor in 2019 suggests sufficient prey availability.

Greenland turbot, Kamchatka flounder, and Pacific halibut can be considered competitors based on overlap in their ecological niches as large upper-trophic predatory flatfish. Recent assessments for the BSAI show a declining trend in greenland turbot; recent increases approaching peak biomass for Kamchatka flounder; and recent increases in Pacific halibut. Taken together these indicate that any competitive impact would likely be from halibut or Kamchatka flounder, although the latter are much less abundant that arrowtooth flounder.

Predators of adult arrowtooth flounder are not well known but likely include toothed whales. Predators of juveniles are also not well known but likely include fur seals, Pacific cod, skates, and sleeper sharks. Fur seal abundance has been steadily declining, and Pacific cod have been at low abundance in the past 3 years relative to recent peaks in 2014 and 2015. Trends in predator abundances that would indicate a change in predation impact on arrowtooth flounder are unknown.

Together, the most recent data available suggest there are no apparent ecosystem concerns.

Fishery performance

There is no concern regarding the ability of the fishery to catch arrowtooth flounder. At the current time, fishery CPUE is not showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, or changes in the percent of TAC taken, or changes in the duration of fishery openings.

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ ecosystem considerations*	*Fishery Performance considerations*
Level 1: Normal	**Level 1:** Normal	**Level 1:** Normal	**Level 1:** Normal

Ecosystem Considerations

Ecosystem Effects on the Stock

1) Prey availability/abundance trends

Arrowtooth flounder diet varies by life stage. Information on juvenile prey and its associated habitat is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) was based on sampling conducted in 1975 and 1976 and has not be re-sampled since. Information on pollock abundance is available in Chapter 1 of this SAFE report. It has been hypothesized that predators on pollock, such as adult arrowtooth flounder, may be important species which control (with other factors) the variation in year-class strength of juvenile pollock (Hunt et al. 2011). The populations of arrowtooth flounder which have occupied the outer shelf and slope areas of the Bering Sea over the past twenty years for summertime feeding do not appear food-limited. These populations have fluctuated due to the variability in recruitment success which suggests that the primary infaunal food source has been at an adequate level to sustain the arrowtooth flounder population.

2) Predator population trends

It is well-documented from studies in other parts of the world that larval and juvenile flatfish are prey for shrimp species in nearshore areas. This has not been reported for Bering Sea arrowtooth flounder due to a lack of juvenile sampling and collections in nearshore areas, but is thought to occur. Late juveniles they are found in stomachs of pollock and Pacific cod, which are mostly small arrowtooth flounder ranging from 5 to 15 cm standard length.

Past, present and projected future population trends of these predator species can be found in their respective SAFE chapters in this volume. Encounters between arrowtooth flounder and their predators may be limited as their distributions do not completely overlap in space and time.

3) Changes in habitat quality

Changes in the physical environment which may affect arrowtooth flounder distribution patterns, recruitment success, migration timing and patterns are described in the Ecosystem Considerations section of this SAFE report (citation). Habitat quality may be enhanced during years of favorable cross-shelf advection (juvenile survival) and warmer bottom water temperatures with reduced ice cover (higher metabolism with more active feeding).

Arrowtooth flounder are a high trophic level predator in the Bering Sea, feeding on both benthic and pelagic components of the food web (Figure 6.32). Unlike the Gulf of Alaska however, they are not at the top of the food chain on the eastern Bering Sea shelf. Arrowtooth flounder in the Bering Sea are an occasional prey in the diets of groundfish in the Bering Sea and are eaten by Pacific cod, walleye pollock, Alaska skates, and sleeper sharks. However, given the large biomass of these species as juveniles in the Bering Sea overall, these occasionally recorded events translate into considerable total mortality for the arrowtooth flounder population in the Bering Sea ecosystem. Using the year 1991 as a baseline, the top three predators on arrowtooth flounder >30 cm, by relative importance, are walleye pollock (29% of the total mortality), Alaska skate (21%) and sleeper shark (11%) (Figure 6.33). After these predators the next highest sources of mortality (1991) on arrowtooth flounder are four fisheries, the flatfish trawl (7%) pollock trawl (6%), Pacific cod trawl (4) and the Pacific cod longline fishery (2%). In the Aleutian Islands, sleeper sharks are the primary predators on arrowtooth flounder adults, while Pacific cod are the primary predator on arrowtooth flounder juveniles.

Most of the occurrences of arrowtooth flounder measured in groundfish stomachs were fish between 20-40cm fork length, and were found in larger individuals of the predator species. For juvenile arrowtooth flounder (<20cm fork length), 97% of the total mortality is unknown with the remaining 3% primarily attributed to arrowtooth flounder and a few other species (Figure 6.34).

The three major predators listed above do not depend on arrowtooth flounder in terms of their total consumption. Arrowtooth flounder only comprise approximately 2% of the diet of Bering Sea pollock, 3% of Alaska skate and 12% of the sleeper shark diet. Therefore it is not expected that a change in arrowtooth flounder would have a great effect on these species' prey availability, while decreases in the large adults of these species might reduce overall predation mortality experienced by arrowtooth flounder.

Fishery Effects on the Ecosystem

Arrowtoooth flounder are not pursued as a target fishery at this time and thus have no "fishery effect" on the ecosystem. In instances when arrowtooth flounder were caught in sufficient quantities in the catch that they could be classified as a target, their contribution to the total bycatch of prohibited species is summarized for 2006 and 2007 in Table 13 of the Economic SAFE (Appendix C) and is summarized for 2007 as follows:

Prohibited species	Arrowtooth flounder "fishery" % of total bycatch
Halibut mortality	<1
Herring	0
Red King crab	0
C. bairdi	<1
Other Tanner crab	<1
Salmon	<1

2) Relative to the predator needs in space and time, harvesting of arrowtooth flounder selects few fish between 5-15 cm and therefore has minimal overlap with removals from predation.

3) The catch is not perceived to have an effect on the amount of large size target fish in the population due to its history of very light exploitation (2%) over the past 30 years.

4) Arrowtooth flounder discards are presented in the Catch History section above.

5) It is unknown what effect the catch has had on arrowtooth flounder maturity-at-age and fecundity.

6) Analysis of the benthic disturbance from harvesting arrowtooth flounder is available in the Final Environmental Assessment for: Essential Fish Habitat (EFH) Environmental Assessment Omnibus Amendments (https://alaskafisheries.noaa.gov/sites/default/files/analyses/efh-omnibus-amendments-ea0618.pdf).

Arrowtooth flounder are an important ecosystem component as predators. This is particularly relevant as their abundance has increased in the eastern Bering Sea since 1976. Nearly half of the adult diet is comprised of juvenile pollock (47%) followed by adult pollock (19%) and euphausiids (9%). This is in marked contrast to their diet in the Gulf of Alaska, where pollock are a relatively small percentage of their forage base, which instead consists primarily of shrimp.

The balance of the arrowtooth flounder diet in the eastern Bering Sea includes eelpouts, shrimp, herring, eulachon and flathead sole juveniles (Figure 6.35). Diets of juvenile arrowtooth flounder are more similar to other Bering Sea shelf flatfish species than to arrowtooth flounder adults. Nonpandalid shrimp compose 42% of the total consumption, euphausiids 25%, juvenile pollock 22% and then polychaetes, sculpins and mysids accounting for another 10% (Figure 6.36). With the exception of juvenile pollock, juvenile arrowtooth flounder exhibit a stronger benthic pathway in their diet than adults. In the Aleutian Islands, arrowtooth flounder feed on the range of available forage fishes, including myctophids, Atka mackerel, and pollock. They are an important predator on Atka mackerel juveniles, making up 23% of the assumed natural mortality of this species.

In terms of the size of pollock consumed, arrowtooth flounder consume a greater number of pollock between the range of 15-25cm fork length than do Pacific cod or Pacific halibut, which consume primarily adult fish and fish smaller than 15cm (Figure 6.37).

Food web models for the Bering Sea have been constructed to discern what the effect of changes in key predators has as a source of mortality on species which are linked to them through consumption pathways. These models are 30 year realizations run 1,000 times and thus give a measure of the uncertainty in the food model parameters. A simulation analysis where arrowtooth flounder survival was decreased by 10% and the rest of the ecosystem was allowed to adjust to this decrease for 30 years (Figure 6.38), indicates that positive changes in biomass for affected species were only minimal with flathead sole showing the largest increase (~3%), probably due to competition for a variety of shared prey resources such as shrimp. As expected, the largest negative changes in biomass were for arrowtooth flounder (both adults and juveniles) themselves and a smaller negative change for sleeper sharks (<4%). All other effects were on the order of 1-2%. When juvenile arrowtooth flounder are decreased, again it is flathead sole biomass which is increased, but only by a small percentage change, even if the change in arrowtooth juveniles is as much as 60% (Figure 6.39). As in the first simulation, the changes are minor for all other species and fisheries. However, it’s important to note that this reflects a sensitivity analysis around conditions in the early 1990s; the increase of arrowtooth flounder in recent years suggests that this analysis should be re-performed with current conditions.

To evaluate the dependence of arrowtooth flounder adults and juveniles on a suite of species and fisheries which are dynamically related to them, a simulation analysis was conducted where survival of each species group/fishery on the X axis in Figure 6.40 was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. These model runs indicate that the biomass of arrowtooth juveniles is very sensitive to changes on the order of only 10% in key species, whereby their biomass may be reduced by 40-60%. The changes are primarily bottom-up, with few top-down or competitive effects. This supports the research of Wilderbuer et al. (2002) which suggests that the control of arrowtooth flounder production is primarily based on physical drivers, e.g. advection to nursery habitat. However, it’s important to note that the effect of decreasing pollock (adults or juveniles) is to increase arrowtooth flounder in the model rather than decrease it; suggesting that the role of pollock as a predator on arrowtooth flounder (potentially limiting their population growth) is greater than the importance of pollock as prey, at least for small perturbations of pollock. For adults, the pattern is similar although the percent change in biomass is less (30%). Arrowtooth flounder effects on the ecosystem and ecosystem effects on arrowtooth flounder are presented in the following table.

Ecosystem effects on arrowtooth flounder			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Benthic infauna	Stomach contents	Stable, data limited	Unknown
Predator population trends			
Fish (Pollock, Pacific cod)	Stable	Possible increases to arrowtooth mortality	
Changes in habitat quality			
Temperature regime	Cold years arrowtooth catchability and herding may decrease	Likely to affect surveyed stock	No concern (dealt with in model)
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability

***Arrowtooth flounder* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Minor contribution to mortality	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	No concern
HAPC biota	Low bycatch levels of (spp)	Bycatch levels small relative to HAPC biota	No concern
Marine mammals and birds	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Very low exploitation rate	Little detrimental effect	No concern
Fishery effects on amount of large size target fish	Very low exploitation rate	Natural fluctuation	No concern
Fishery contribution to discards and offal production	Stable trend	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	Unknown	NA	Possible concern

Data Gaps and Research Priorities

We recommend studies on genetic population structure of arrowtooth flounder, as stock structure has not been examined in this species. In addition, the relationship between male and female natural mortality and sex ratio should be further investigated. We plan to explore the utility of model-based survey time series (e.g., VAST model) as a way to integrate the three surveys used in the BSAI arrowtooth flounder model in the future.

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Tables

Table 6.1. Random effects model estimates of biomass and CV for the Aleutian Islands, Eastern Bering Sea shelf, and Eastern Bering Sea slope surveys. The random effects model was applied to all years of the slope survey and to only the most recent 6 years. The proportion of biomass in each of the three regions is presented at the bottom, with all data from the slope survey and just the last 6 years.

	Aleutian Islands		Shelf		Slope all years		Slope last 6 surveys	
Year	Biomass	CV	Biomass	CV	Biomass	CV	Biomass	CV
1979					36,385	0.10		
1980	19,024	0.26	-	-	35,144	0.17		
1981	20,915	0.28	-	-	33,945	0.10		
1982	22,993	0.25			29,702	0.14		
1983	25,277	0.13			37,427	0.20		
1984	30,717	0.26			47,162	0.21		
1985	37,328	0.31			59,430	0.16		
1986	45,361	0.34			48,346	0.21		
1987	39,907	0.35			39,329	0.20		
1988	35,109	0.34			31,994	0.10		
1989	30,887	0.31			30,889	0.19		
1990	27,173	0.25			29,822	0.19		
1991	23,906	0.12			28,792	0.09		
1992	31,549	0.22	387,984	0.11	29,892	0.22		
1993	41,635	0.23	435,726	0.08	31,034	0.29		
1994	54,945	0.13	463,360	0.08	32,220	0.33		
1995	60,239	0.23	465,715	0.09	33,452	0.35		
1996	66,043	0.22	485,244	0.08	34,730	0.36		
1997	72,406	0.11	436,565	0.09	36,057	0.36		
1998	70,617	0.22	366,155	0.09	37,435	0.35		
1999	68,872	0.22	335,807	0.12	38,865	0.33		
2000	67,170	0.10	340,349	0.10	40,350	0.29		
2001	76,462	0.20	363,998	0.07	41,892	0.23		
2002	87,039	0.12	357,487	0.08	43,493	0.12	45,803	0.12
2003	92,124	0.20	469,149	0.07	48,106	0.17	49,303	0.12
2004	97,506	0.12	526,979	0.06	53,208	0.10	53,069	0.09
2005	113,746	0.22	624,617	0.06	56,501	0.20	56,086	0.14
2006	132,690	0.22	590,495	0.06	59,997	0.23	59,273	0.15
2007	117,198	0.28	506,408	0.06	63,709	0.21	62,642	0.14
2008	103,515	0.29	507,598	0.07	67,652	0.12	66,203	0.11
2009	91,429	0.26	454,521	0.08	69,897	0.18	67,805	0.13
2010	80,754	0.16	506,609	0.07	72,217	0.13	69,445	0.12
2011	72,429	0.21	500,990	0.06	70,670	0.19	67,699	0.14
2012	64,963	0.15	432,452	0.08	69,157	0.15	65,997	0.13
2013	68,972	0.21	421,213	0.07	62,749	0.22	61,124	0.15
2014	73,229	0.13	450,701	0.06	56,935	0.24	56,610	0.16
2015	69,555	0.21	422,509	0.05	51,659	0.21	52,430	0.15
2016	66,066	0.16	466,591	0.04	46,873	0.12	48,559	0.12
2017	63,011	0.21	442,344	0.06	46,873	0.12	48,559	0.12
2018	60,098	0.11	507,392	0.06	46,873	0.12	48,559	0.12
2019	60,098	0.11	564,645	0.06	46,873	0.12	48,559	0.12

Table 6.2a. All nation total combined catch (t) of arrowtooth and Kamchatka flounder in the eastern Bering Sea and Aleutian Islands regions, 1970-1990. Totals for arrowtooth (ATF) and Kamchatka are under “Combined” total, extrapolated ATF only, is under “ATF est”. [a]Catches prior to 1991 are on file at the Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115. [b]Non-U.S. fisheries: Japan, U.S.S.R., Republic of Korea, Taiwan, Poland, and Federal Republic of Germany. [c]Joint ventures between U.S. fishing vessels and foreign processing vessels. [d]Domestic annual harvesting.

Year	Eastern Bering Sea				Aleutian Islands Region				Combined	ATF est.
	Non-U.S.[b]	U.S. J.V.[c]	U.S. DAH[d]	Total	Non-U.S.	U.S. J.V.	U.S. DAH	Total	Total	Total
1970	12,598			12,598	274			274	12,872	11,971
1971	18,792			18,792	581			581	19,373	18,017
1972	13,123			13,123	1,323			1,323	14,446	13,435
1973	9,217			9,217	3,705			3,705	12,922	12,017
1974	21,473			21,473	3,195			3,195	24,668	22,941
1975	20,832			20,832	784			784	21,616	20,103
1976	17,806			17,806	1,370			1,370	19,176	17,834
1977	9,454			9,454	2,035			2,035	11,489	10,685
1978	8,358			8,358	1,782			1,782	10,140	9,430
1979	7,921			7,921	6,436			6,436	14,357	13,352
1980	13,674	87		13,761	4,603			4,603	18,364	17,079
1981	13,468	5		13,473	3,624	16		3,640	17,113	15,915
1982	9,065	38		9,103	2,356	59		2,415	11,518	10,712
1983	10,180	36		10,216	3,700	53		3,753	13,969	12,991
1984	7,780	200		7,980	1,404	68		1,472	9,452	8,790
1985	6,840	448		7,288	11	59	89	159	7,447	6,926
1986	3,462	3,298	5	6,766		78	337	415	7,181	6,678
1987	2,789	1,561	158	4,508		114	237	351	4,859	4,519
1988		2,552	15,395	17,947		22	2,021	2,043	19,990	18,591
1989		2,264	4,000	6,264			1,042	1,042	7,306	6,795
1990		660	7,315	7,975			5,083	5,083	13,058	12,144

Table 6.2b. All nation total combined catch (t) of arrowtooth and Kamchatka flounder in the eastern Bering Sea and Aleutian Islands region, 1991-2020. Totals for arrowtooth (ATF) and Kamchatka are under "Combined" total, extrapolated ATF only is under "ATF est". *Catch information through October 25, 2021, source: AKFIN NMFS AKRO BLEND/Catch Accounting System.

Year	Combined Total	Proportion ATF	ATF estimate	Notes
1991	19,511	0.90	17,559	
1992	11,897	0.90	10,707	
1993	9,299	0.90	8,369	
1994	14,338	0.90	12,904	
1995	9,284	0.90	8,356	
1996	14,654	0.90	13,189	
1997	10,469	0.90	9,422	1991-2007 based on average proportion identified to species in the NMFS Bering Sea bottom trawl surveys
1998	15,237	0.90	13,713	
1999	11,378	0.90	10,240	
2000	13,230	0.90	11,907	
2001	14,058	0.90	12,652	
2002	11,855	0.90	10,670	
2003	13,253	0.90	11,928	
2004	18,185	0.90	16,367	
2005	14,243	0.90	12,819	
2006	13,442	0.90	12,098	
2007	11,916	0.90	10,724	
2008	21,370	0.66	14,105	2008-2010 based on proportion in FMA Observer database
2009	29,900	0.58	17,342	
2010	38,799	0.46	17,847	
2011	30,146	0.67	20,141	
2012	31,835	0.70	22,325	
2013	28,303	0.73	20,537	
2014	25,577	0.75	19,110	
2015	16,263	0.69	11,269	2011 – present based on speciation in Catch Accounting System (CAS)
2016	15,950	0.70	11,100	
2017	11,023	0.59	6,519	
2018	10,106	0.69	6,999	
2019	14,535	0.69	10,048	
2020*	17,306	0.58	10,040	

Table 6.3. Estimates of retained and discarded arrowtooth flounder catch. Beginning in 2007, when the two species were differentiated in commercial catches, catch is calculated based on values from the Observer database; prior to 2007, proportion was calculated as 0.10. Arrowtooth flounder were identified to species starting in 2008; therefore only arrowtooth flounder data is presented from this year onward.

Year	Retained	Discarded	Total (t)	% Retained
1985	17	72	89	19
1986	65	277	342	19
1987	75	320	395	19
1988	3,309	14,107	17,416	19
1989	958	4,084	5,042	19
1990*	2,356	10,042	12,398	19
1991	16,133	3,378	19,511	17.3
1992	10,987	910	11,897	7.6
1993	8,638	661	9,299	7.1
1994	13,683	631	14,314	4.4
1995	8,775	509	9,284	5.5
1996	13,282	1,372	14,654	9.4
1997	9,396	1,073	10,469	10.2
1998	12,483	2,753	15,237	18.1
1999	8,676	2,702	11,378	23.7
2000	7,986	5,244	13,230	39.6
2001	8,757	5,301	14,058	37.7
2002	7,812	4,043	11,855	34.1
2003	8,555	4,698	13,253	35.4
2004	14,338	3,847	18,185	21.2
2005	6,952	7,291	14,243	51.2
2006	7,339	6,103	13,442	45.4
2007	6,786	5,130	11,916	43.1
2008	5,457	15,913	21,370	74.5
2009	5,767	24,133	29,900	80.7
2010	6,869	31,930	38,799	82.3
2011	3,692	16,449	20,141	81.7
2012	2,828	19,496	22,325	87.3
2013	3,592	16,945	20,537	82.5
2014	2,345	16,766	19,110	87.7
2015	1,830	9,439	11,269	83.8
2016	2,101	8,999	11,100	81.1
2017	897	5,622	6,519	86.2
2018	1,089	5,910	6,999	84.4
2019	1,092	8,957	10,048	89.1
2020*	671	9,370	10,040	93.3

*1990 retained rate was applied to the 1985-89 reported catch. The 2020 catch is reported through October 25, 2020. Source: AKFIN NMFS AKRO BLEND/Catch Accounting System.

Table 6.4. Length composition data are available from each survey. It is used in the model for each year unless age composition data are available. Age composition data are also available for each survey. Bolded text represents new data added this assessment to the model.

Source	**Data**	**Years**
NMFS Bering Sea shelf survey	Survey biomass	1992-2018, **2019**
	Age Composition	1993, 1994, 1996, 1998, 2004, 2010, 2012, 2014, 2015, 2016, 2017, **2018**, **2019**
	Length composition	1992-2019
NMFS Bering Sea slope survey	Survey biomass	2002, 2004, 2008, 2010, 2012, 2016
	Age Composition	2012
	Length composition	2002, 2004, 2008, 2010, 2016
NMFS Aleutian Islands survey	Survey biomass	1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018
	Age composition	2010, 2012, 2014, 2016, **2018**
	Length composition	1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2016, 2018
Fishery	Catch Biomass	1970-**2019, 2020**
	Length composition	1978 – 1988, 1990-2017, **2018**, **2019**

Table 6.5. The number of fisheries length observations in each year 1978-2019. Source: AKFIN NMFS AKRO BLEND/Catch Accounting System.

Year	Number of length observations	Year	Number of length observations
1978	11,426	1999	986
1979	6,565	2000	1,407
1980	9,945	2001	2,701
1981	7,790	2002	2,385
1982	36,784	2003	3,501
1983	31,955	2004	4,356
1984	23,189	2005	2,649
1985	25,817	2006	2,128
1986	14,399	2007	575
1987	24,066	2008	1,417
1988	833	2009	555
1989	224	2010	921
1990	2,652	2011	885
1991	1,337	2012	521
1992	163	2013	642
1993	63	2014	245
1994	282	2015	16
1995	3,098	2016	128
1996	1,185	2017	50
1997	3,914	2018	7,290
1998	563	2019	10,345

Table 6.6. Estimated arrowtooth flounder biomass from trawl surveys conducted on the Eastern Bering Sea shelf, slope and the Aleutian Islands. The 1988 and 1991 slope estimates were from the depth ranges of 200-800 m while earlier slope estimates were from 200-1,000 m. The 2002 through 2016 slope

estimates were from sampling conducted from 200-1,200 m. The 1979-1991 slope survey estimates (underlined) were not included in the final model. The 1987-1991 shelf survey estimates (underlined) had low confidence in species identification for arrowtooth and so were not included in the model.

Year	EBS shelf survey		EBS slope survey		Aleutian Islands Survey	
	Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV
1979			36,700	0.11		
1980					16,463	0.32
1981			34,900	0.11		
1982			24,700	0.15		
1983					24,529	0.14
1984						
1985			74,400	0.15		
1986					110,384	0.44
1987	280,117	0.07				
1988	297,331	0.11	30,600	0.11		
1989	339,246	0.10				
1990	402,326	0.09				
1991	298,789	0.12	28,400	0.09	21,919	0.12
1992	345,562	0.14				
1993	446,816	0.09				
1994	476,355	0.10			58,230	0.14
1995	448,016	0.15				
1996	527,254	0.11				
1997	463,081	0.13			74,085	0.11
1998	345,172	0.11				
1999	239,708	0.26				
2000	314,694	0.17			65,191	0.11
2001	378,107	0.09				
2002	313,075	0.09	42,508	0.13	88,809	0.13
2003	498,041	0.09				
2004	519,129	0.07	53,745	0.11	95,041	0.13
2005	662,712	0.07				
2006	608,055	0.08			181,063	0.27
2007	482,359	0.08				
2008	530,127	0.09	68,317	0.13		
2009	406,855	0.10				
2010	528,667	0.08	74,065	0.15	80,049	0.19
2011	522,106	0.08				
2012	402,887	0.11	72,845	0.18	60,371	0.17
2013	405,509	0.09				
2014	465,616	0.07			75,958	0.15
2015	409,243	0.06				
2016	475,264	0.05	45,525	0.12	65,901	0.20
2017	424,194	0.07				
2018	511,192	0.07			59,493	0.12
2019	578,390	0.07				

Table 6.7. Arrowtooth flounder male and female weight-at-age (kg) used in the 2016 and 2018 assessments and proportion of females mature at age. Weight at age was recalculated using the 2018 length age conversion matrix.

Age	Female weight at age 2018	Male weight at age 2018	Female weight at age 2016	Male weight at age 2016	Female maturity at age (Stark 2011)
1	0.02	0.02	0.02	0.01	0.00
2	0.07	0.06	0.04	0.04	0.00
3	0.16	0.15	0.11	0.09	0.01
4	0.30	0.25	0.22	0.17	0.02
5	0.47	0.37	0.36	0.27	0.06
6	0.68	0.49	0.55	0.39	0.16
7	0.91	0.61	0.76	0.52	0.34
8	1.17	0.72	0.99	0.66	0.59
9	1.45	0.82	1.25	0.80	0.80
10	1.73	0.90	1.52	0.94	0.97
11	2.02	0.98	1.80	1.08	0.99
12	2.31	1.04	2.08	1.21	1
13	2.60	1.09	2.35	1.34	1
14	2.88	1.14	2.61	1.45	1
15	3.16	1.17	2.83	1.56	1
16	3.42	1.20	3.01	1.66	1
17	3.67	1.23	3.16	1.75	1
18	3.91	1.25	3.27	1.83	1
19	4.13	1.27	3.37	1.91	1
20	4.34	1.28	3.44	1.98	1
21+	4.97	1.30	3.53	2.04	1

Table 6.8. Cruise data used to construct arrowtooth flounder age-length growth curves. Longitude and latitude represent minimum values from which samples were taken. Count represents the number of fish for which age and length data are available.

Cruise	Survey Name	Latitude	Longitude	Count
198203	CRAB/GRFSH	55.00	-158.32	237
199110	EBS Triennial Survey	54.21	-165.81	187
199301	EBS Crab/Groundfish Bottom Trawl Survey	54.78	-159.54	209
199401	EBS Crab/Groundfish Bottom Trawl Survey	54.69	-158.31	125
199601	EBS Crab/Groundfish Bottom Trawl Survey	54.83	-176.96	211
199801	EBS Crab/Groundfish Bottom Trawl Survey	54.84	-178.15	275
200401	2004 Bering Sea Shelf Survey	54.66	-178.16	592
201001	2010 EBS Bottom Trawl Survey	54.71	-178.23	470
201201	2012 EBS Slope Survey	54.26	-179.50	765
201201	2012 EBS Bottom Trawl Survey	54.66	-177.45	328
201401	2014 EBS Bottom Trawl Survey	54.98	-178.19	388
201501	2015 EBS Bottom Trawl Survey	54.69	-178.18	611
201601	2016 EBS Bottom Trawl Survey	55	-178	1,683
201701	2017 EBS Bottom Trawl Survey	55	-178	523

Table 6.9. Results comparing model fits from the current assessment compared to the last full assessment.

	Model 18.9 (2018)	*Model 18.9 (2020)*
Total -log(Likelihood)		
Catch	0.008	0.006
Recruitment	40.4	40.9
EBS shelf survey biomass	30.08	17.87
EBS slope survey biomass	2.89	3.40
Aleutian survey biomass	41.25	36.14
EBS shelf survey age comp	255.68	250.26
EBS slope survey age comp	37.10	36.53
Aleutian survey age comp	125.52	141.10
Survey length comp	433.67	275.29
Fishery length comp	605.72	583.96
Priors/Penalties	1.31	1.25
Fishery selectivity	14.04	13.42
Number of parameters	153.00	151.00
Total Likelihood	1,587.62	1,400.09
Stock status (t)		
Spawning biomass	498,263	494,307
Total biomass	853,048	921,508

Table 6.10. The number of male, female, and total lengths measured on BSAI surveys used in the length age conversion matrix. The 2018 length data was not used in the calculations, because they were calculated prior to the completion of the 2018 surveys.

Year	Female	Male	Total
1980	3,321	1,798	5,319
1982	1,578	1,237	2,841
1983	6,953	4,375	11,356
1984	3,882	2,167	6,050
1985	3,445	2,103	5,550
1986	8,598	6,531	15,133
1987	5,116	2,768	7,885
1988	4,234	2,256	6,492
1989	5,201	3,001	8,261
1990	4,426	2,161	6,589
1991	7,756	4,514	12,279
1992	4,019	1,659	5,711
1993	5,299	2,064	7,367
1994	13,319	6,836	20,181
1995	4,427	1,348	5,782
1996	6,498	2,207	8,749
1997	12,388	6,277	19,359
1998	6,500	2,295	8,910
1999	4,671	1,682	6,390
2000	13,901	7,127	21,035
2001	6,233	2,430	8,663
2002	17,608	7,205	24,896
2003	10,654	4,159	14,829
2004	22,772	9,684	32,508
2005	10,268	4,185	14,734
2006	15,524	6,993	22,556
2007	7,092	3,084	10,354
2008	14,978	5,016	20,000
2009	6,998	2,545	9,611
2010	19,580	7,742	27,398
2011	8,505	3,055	11,640
2012	16,319	6,990	23,316
2013	6,040	2,178	8,282
2014	12,140	6,165	18,343
2015	8,548	2,719	11,440
2016	19,320	8,745	28,138
2017	8,170	3,244	11,437
Total	336,281	150,545	489,384

Table 6.11. Model estimates of arrowtooth flounder fishing mortality and exploitation rate (catch/total biomass). Full selection occurred at age 8 in males and age 9 in females.

Year	Full selection *F*	Exploitation rate
1976	0.112	0.054
1977	0.064	0.031
1978	0.051	0.027
1979	0.063	0.038
1980	0.074	0.050
1981	0.069	0.048
1982	0.049	0.034
1983	0.063	0.043
1984	0.044	0.030
1985	0.035	0.025
1986	0.035	0.024
1987	0.024	0.016
1988	0.109	0.057
1989	0.041	0.018
1990	0.070	0.028
1991	0.090	0.037
1992	0.045	0.020
1993	0.028	0.015
1994	0.036	0.021
1995	0.021	0.014
1996	0.031	0.021
1997	0.022	0.015
1998	0.031	0.021
1999	0.024	0.016
2000	0.028	0.017
2001	0.029	0.018
2002	0.024	0.014
2003	0.026	0.015
2004	0.034	0.020
2005	0.025	0.015
2006	0.023	0.014
2007	0.019	0.012
2008	0.024	0.015
2009	0.029	0.018
2010	0.029	0.019
2011	0.033	0.022
2012	0.037	0.025
2013	0.034	0.023
2014	0.032	0.022
2015	0.019	0.013
2016	0.019	0.013
2017	0.012	0.008
2018	0.012	0.008
2019	0.018	0.011
2020	0.017	0.011

Table 6.12. Model estimates of arrowtooth flounder age-specific fishery and survey selectivities, by sex.

	Fishery		EBS shelf survey		EBS slope survey		Aleutians survey	
Age	females	males	females	males	females	males	females	males
1	0.00	0.01	0.06	0.03	0.00	0.00	0.04	0.02
2	0.01	0.03	0.24	0.14	0.00	0.00	0.11	0.09
3	0.05	0.06	0.63	0.40	0.00	0.00	0.27	0.31
4	0.13	0.12	0.89	0.71	0.02	0.01	0.53	0.68
5	0.28	0.24	0.97	0.82	0.41	0.15	0.77	0.90
6	0.49	0.40	0.96	0.78	0.96	0.78	0.91	0.98
7	0.77	0.61	0.93	0.67	1.00	0.99	0.97	0.99
8	0.98	0.81	0.86	0.52	1.00	1.00	0.99	1.00
9	0.98	0.94	0.75	0.37	1.00	1.00	1.00	1.00
10	0.96	1.00	0.57	0.23	1.00	1.00	1.00	1.00
11	0.96	1.00	0.38	0.14	1.00	1.00	1.00	1.00
12	0.96	1.00	0.22	0.08	1.00	1.00	1.00	1.00
13	0.96	1.00	0.12	0.04	1.00	1.00	1.00	1.00
14	0.96	1.00	0.06	0.02	1.00	1.00	1.00	1.00
15	0.96	1.00	0.03	0.01	1.00	1.00	1.00	1.00
16	0.96	1.00	0.03	0.01	1.00	1.00	1.00	1.00
17	0.96	1.00	0.03	0.01	1.00	1.00	1.00	1.00
18	0.96	1.00	0.03	0.01	1.00	1.00	1.00	1.00
19	0.96	1.00	0.03	0.01	1.00	1.00	1.00	1.00
20	0.96	1.00	0.03	0.01	1.00	1.00	1.00	1.00
21+	0.96	1.00	0.03	0.01	1.00	1.00	1.00	1.00

Table 6.13. Model estimates of arrowtooth flounder 1+ total biomass, in tons, and female spawning biomass (FSB) in tons, from the 2018 and 2020 assessments. Lower 95% and upper 95% confidence intervals (CIs) are provided for the estimates of total biomass and female spawning biomass.

	2018 Assessment		2020 Assessment					
Year	**Total biomass**	**FSB**	**Total Biomass**	**Biomass lower CI**	**Biomass Upper CI**	**FSB**	**FSB Lower CI**	**FSB Upper CI**
1976	318,843	152,647	321,463	290,529	362,062	138,952	111,825	174,856
1977	306,325	146,983	328,582	298,756	366,349	129,345	105,347	161,430
1978	294,589	153,532	334,189	305,517	369,836	132,508	111,242	162,546
1979	280,137	165,889	336,336	307,872	370,570	146,303	126,022	174,246
1980	262,107	172,532	330,452	302,826	363,155	165,709	145,549	191,998
1981	246,440	167,280	319,255	292,110	351,180	182,196	162,348	206,863
1982	239,708	154,347	305,970	279,090	336,285	188,369	168,568	211,580
1983	245,051	141,231	294,437	267,812	324,119	186,585	167,217	209,064
1984	255,318	125,401	279,275	253,155	307,716	176,989	158,617	198,553
1985	275,301	116,355	269,424	243,934	297,011	170,705	152,808	191,072
1986	303,277	115,817	268,338	243,311	294,836	167,896	150,267	187,284
1987	339,649	123,643	281,622	257,209	307,101	164,530	146,834	183,271
1988	387,906	139,585	316,174	292,454	340,750	160,361	143,359	178,568
1989	431,691	148,870	355,848	332,113	380,370	143,409	126,654	161,037
1990	494,098	168,273	419,940	396,044	443,800	139,437	123,273	156,289
1991	548,332	188,799	479,361	455,579	503,395	139,692	124,072	155,751
1992	589,693	211,411	525,884	500,824	550,265	149,692	134,472	165,359
1993	625,598	244,022	568,130	542,043	593,235	180,782	165,397	196,163
1994	651,743	285,652	600,723	573,902	626,260	228,477	212,677	244,199
1995	662,015	327,982	616,268	588,823	642,040	279,378	263,164	295,706
1996	671,228	369,260	631,047	603,342	656,721	328,925	312,043	345,986
1997	671,884	395,735	637,606	609,600	663,558	361,717	344,017	379,326
1998	676,515	411,591	648,454	620,571	674,324	381,854	363,422	399,623
1999	681,530	412,757	660,092	631,502	686,245	386,765	368,040	404,572
2000	697,736	409,895	681,486	652,188	708,469	386,919	367,983	404,274
2001	720,593	403,436	707,888	677,491	736,452	383,406	364,876	400,625
2002	749,885	397,511	739,390	707,127	769,499	381,287	363,339	397,901
2003	786,132	398,055	776,662	742,747	808,184	386,143	367,930	403,076
2004	824,573	404,346	814,772	779,322	847,755	396,156	377,339	413,655
2005	855,712	413,866	845,848	809,108	880,714	409,127	389,699	427,532
2006	887,244	434,285	877,995	839,831	914,130	432,104	411,549	451,519
2007	914,427	461,726	905,789	865,675	943,032	460,049	438,151	480,973
2008	935,734	491,841	928,359	887,702	966,158	489,342	466,196	511,284
2009	943,717	517,458	939,126	897,918	978,146	514,075	489,854	537,186
2010	939,969	537,972	937,008	895,041	976,035	532,570	507,176	556,380
2011	925,548	551,362	925,871	884,148	965,060	545,274	519,208	569,822
2012	901,347	556,003	906,046	864,542	944,616	550,307	523,964	575,408
2013	872,920	553,163	882,402	841,582	919,918	548,686	521,983	574,075
2014	848,196	546,149	862,465	822,156	899,834	543,696	516,766	569,311
2015	827,152	533,753	846,929	806,803	884,758	534,094	507,409	559,224
2016	816,183	523,000	844,473	804,244	882,413	526,693	500,029	551,655
2017	822,634	508,431	855,942	813,972	895,680	515,737	489,931	539,826
2018	849,621	497,583	880,407	836,535	923,532	508,517	483,362	532,118
2019			907,398	858,079	956,163	504,837	479,854	528,232
2020			921,508	866,524	978,051	503,360	478,339	527,036

Table 6.14. Model estimates of arrowtooth flounder population numbers-at-age, by sex, 1976-2020.

Females	Numbers at age (1,000s)									
Year	1	2	3	4	5	6	7	8	9	10
1976	28,513	46,718	177,495	116,195	41,925	21,400	13,953	10,033	7,723	6,259
1977	22,483	23,335	38,189	144,537	93,737	33,270	16,580	10,487	7,366	5,667
1978	31,820	18,403	19,088	31,169	117,334	75,377	26,387	12,922	8,063	5,662
1979	124,425	26,047	15,057	15,589	25,349	94,715	60,188	20,782	10,069	6,282
1980	59,759	101,846	21,307	12,290	12,658	20,391	75,166	46,956	15,999	7,750
1981	34,354	48,913	83,297	17,382	9,964	10,151	16,094	58,145	35,760	12,181
1982	25,842	28,120	40,008	67,972	14,102	8,002	8,033	12,502	44,517	27,372
1983	32,596	21,154	23,006	32,678	55,293	11,390	6,396	6,336	9,760	34,748
1984	62,319	26,681	17,304	18,779	26,534	44,482	9,040	4,991	4,879	7,514
1985	89,346	51,014	21,831	14,137	15,285	21,456	35,629	7,154	3,913	3,825
1986	182,086	73,141	41,745	17,843	11,520	12,391	17,261	28,388	5,658	3,094
1987	300,445	149,060	59,853	34,120	14,541	9,340	9,971	13,759	22,462	4,476
1988	329,655	245,960	121,997	48,945	27,845	11,824	7,555	8,011	10,998	17,954
1989	297,972	269,787	201,065	99,358	39,500	22,114	9,174	5,691	5,898	8,094
1990	201,582	243,921	220,755	164,291	80,907	31,971	17,742	7,278	4,476	4,639
1991	127,551	164,998	199,509	180,130	133,277	64,963	25,289	13,771	5,567	3,423
1992	132,717	104,394	134,917	162,634	145,734	106,407	50,874	19,327	10,327	4,174
1993	108,065	108,641	85,416	110,218	132,357	117,813	85,187	40,231	15,138	8,088
1994	112,133	88,467	88,912	69,837	89,901	107,509	95,115	68,247	32,039	12,055
1995	119,582	91,794	72,393	72,667	56,904	72,863	86,458	75,742	53,934	25,316
1996	198,229	97,898	75,132	59,211	59,332	46,319	59,046	69,669	60,767	43,268
1997	167,595	162,277	80,117	61,422	48,281	48,161	37,351	47,218	55,354	48,276
1998	175,322	137,204	132,820	65,526	50,144	39,290	39,011	30,077	37,849	44,368
1999	289,086	143,524	112,283	108,579	53,425	40,695	31,672	31,179	23,881	30,048
2000	266,549	236,662	117,468	91,824	88,619	43,453	32,931	25,466	24,945	19,104
2001	228,996	218,209	193,687	96,046	74,905	71,997	35,093	26,397	20,294	19,878
2002	278,448	187,465	178,580	158,352	78,331	60,826	58,096	28,093	21,001	16,145
2003	267,472	227,953	153,431	146,039	129,236	63,702	49,211	46,697	22,467	16,794
2004	243,609	218,966	186,564	125,462	119,159	105,048	51,493	39,501	37,280	17,935
2005	197,757	199,424	179,188	152,495	102,259	96,637	84,574	41,077	31,286	29,524
2006	242,514	161,894	163,216	146,525	124,432	83,127	78,128	67,903	32,803	24,983
2007	207,900	198,536	132,505	133,481	119,600	101,223	67,289	62,849	54,360	26,259
2008	173,823	170,202	162,503	108,385	109,008	97,397	82,093	54,289	50,502	43,678
2009	170,517	142,301	139,301	132,890	88,454	88,644	78,790	65,972	43,406	40,375
2010	137,995	139,592	116,459	113,892	108,388	71,839	71,551	63,102	52,518	34,550
2011	133,855	112,968	114,241	95,214	92,888	88,020	57,975	57,287	50,214	41,787
2012	159,474	109,578	92,448	93,384	77,616	75,353	70,902	46,285	45,420	39,807
2013	214,516	130,548	89,668	75,556	76,088	62,901	60,590	56,448	36,567	35,879
2014	197,848	175,609	106,832	73,294	61,583	61,706	50,641	48,332	44,707	28,958
2015	182,007	161,964	143,710	87,329	59,751	49,964	49,716	40,443	38,336	35,457
2016	226,607	149,004	132,569	117,550	71,316	48,655	40,517	40,105	32,491	30,797
2017	487,692	185,516	121,960	108,436	95,995	58,073	39,456	32,684	32,220	26,101
2018	197,590	399,271	151,863	99,797	88,644	78,340	47,275	32,019	26,459	26,082
2019	74,148	161,765	326,838	124,260	81,573	72,324	63,747	38,339	25,899	21,401
2020	104,812	60,703	132,409	267,363	101,497	66,456	58,698	51,488	30,851	20,839

Table 6.14 (cont'd). Model estimates of arrowtooth flounder population numbers-at-age, by sex, 1976-2018.

Females	Numbers at age (1,000s)									
Year	11	12	13	14	15	16	17	18	19	20	21+
1976	5,304	4,503	3,877	3,398	2,935	2,552	2,205	1,927	1,681	1,461	3,386
1977	4,604	3,902	3,312	2,852	2,499	2,159	1,877	1,622	1,417	1,236	3,565
1978	4,363	3,544	3,003	2,550	2,195	1,924	1,662	1,445	1,248	1,091	3,696
1979	4,416	3,403	2,764	2,342	1,989	1,712	1,501	1,296	1,127	974	3,734
1980	4,842	3,404	2,622	2,130	1,805	1,533	1,319	1,156	999	869	3,628
1981	5,910	3,692	2,595	\2,000	1,624	1,377	1,169	1,006	882	762	3,429
1982	9,338	4,530	2,830	1,990	1,533	1,245	1,055	896	771	676	3,212
1983	21,388	7,296	3,540	2,211	1,555	1,198	973	825	700	603	3,038
1984	26,787	16,488	5,624	2,729	1,705	1,198	923	750	636	540	2,807
1985	5,896	21,018	12,937	4,413	2,141	1,338	940	724	589	499	2,626
1986	3,027	4,665	16,632	10,237	3,492	1,694	1,058	744	573	466	2,472
1987	2,450	2,396	3,694	13,168	8,105	2,765	1,341	838	589	454	2,326
1988	3,580	1,959	1,916	2,954	10,531	6,482	2,211	1,073	670	471	2,223
1989	13,243	2,640	1,445	1,414	2,179	7,768	4,781	1,631	791	494	1,987
1990	6,371	10,424	2,078	1,137	1,113	1,715	6,114	3,763	1,284	623	1,953
1991	3,552	4,879	7,983	1,592	871	852	1,313	4,682	2,882	983	1,973
1992	2,571	2,668	3,665	5,996	1,195	654	640	986	3,517	2,165	2,220
1993	3,272	2,015	2,092	2,873	4,700	937	513	502	773	2,757	3,437
1994	6,444	2,607	1,606	1,666	2,289	3,745	747	409	400	616	4,935
1995	9,532	5,096	2,061	1,270	1,318	1,810	2,961	590	323	316	4,390
1996	20,318	7,651	4,090	1,654	1,019	1,058	1,453	2,377	474	259	3,777
1997	34,396	16,152	6,082	3,251	1,315	810	841	1,155	1,889	377	3,209
1998	38,712	27,582	12,952	4,877	2,607	1,055	650	674	926	1,515	2,875
1999	35,246	30,754	21,911	10,289	3,874	2,071	838	516	536	736	3,488
2000	24,050	28,210	24,615	17,537	8,235	3,101	1,658	671	413	429	3,380
2001	15,232	19,176	22,493	19,626	13,983	6,566	2,472	1,322	535	329	3,037
2002	15,823	12,125	15,264	17,904	15,622	11,130	5,227	1,968	1,052	426	2,680
2003	12,917	12,659	9,700	12,212	14,324	12,499	8,905	4,182	1,575	842	2,484
2004	13,413	10,316	10,111	7,748	9,754	11,441	9,983	7,112	3,340	1,258	2,656
2005	14,213	10,630	8,176	8,013	6,140	7,730	9,067	7,911	5,637	2,647	3,102
2006	23,588	11,355	8,493	6,532	6,402	4,906	6,176	7,244	6,321	4,503	4,593
2007	20,008	18,891	9,094	6,802	5,231	5,127	3,929	4,946	5,802	5,062	7,285
2008	21,107	16,083	15,185	7,310	5,467	4,205	4,121	3,158	3,976	4,663	9,925
2009	34,937	16,883	12,864	12,146	5,847	4,373	3,363	3,296	2,526	3,180	11,669
2010	32,157	27,826	13,447	10,246	9,674	4,657	3,483	2,679	2,625	2,012	11,826
2011	27,508	25,602	22,154	10,706	8,157	7,702	3,708	2,773	2,133	2,090	11,017
2012	33,150	21,822	20,310	17,575	8,493	6,471	6,110	2,941	2,200	1,692	10,398
2013	31,469	26,206	17,251	16,056	13,894	6,714	5,116	4,830	2,325	1,739	9,558
2014	28,433	24,939	20,768	13,671	12,724	11,010	5,321	4,054	3,828	1,843	8,953
2015	22,982	22,566	19,792	16,482	10,850	10,098	8,738	4,223	3,217	3,038	8,568
2016	28,495	18,470	18,135	15,906	13,246	8,720	8,116	7,023	3,394	2,586	9,327
2017	24,750	22,900	14,843	14,574	12,783	10,645	7,008	6,522	5,644	2,727	9,574
2018	21,134	20,040	18,543	12,019	11,801	10,351	8,620	5,674	5,281	4,570	9,960
2019	21,101	17,098	16,213	15,002	9,723	9,547	8,374	6,973	4,590	4,272	11,755
2020	17,226	16,985	13,763	13,051	12,075	7,827	7,685	6,741	5,613	3,695	12,901

Table 6.14 (cont'd). Model estimates of arrowtooth flounder population numbers-at-age, by sex, 1976-2018.

Males	Numbers at age (1,000s)									
Year	1	2	3	4	5	6	7	8	9	10
1976	28,513	40,211	131,491	74,089	23,009	10,109	5,673	3,511	2,326	1,623
1977	22,483	20,068	28,254	92,056	51,494	15,793	6,811	3,736	2,261	1,475
1978	31,820	15,832	14,118	19,835	64,357	35,742	10,845	4,616	2,500	1,500
1979	124,425	22,411	11,142	9,919	13,891	44,814	24,680	7,411	3,123	1,679
1980	59,759	87,619	15,767	7,823	6,936	9,644	30,790	16,739	4,964	2,074
1981	34,354	42,077	61,626	11,062	5,462	4,803	6,597	20,743	11,112	3,262
1982	25,842	24,190	29,598	43,252	7,730	3,788	3,293	4,459	13,831	7,339
1983	32,596	18,201	17,025	20,798	30,297	5,385	2,617	2,253	3,021	9,309
1984	62,319	22,954	12,805	11,953	14,543	21,036	3,700	1,775	1,509	2,007
1985	89,346	43,893	16,157	9,000	8,377	10,142	14,562	2,538	1,207	1,020
1986	182,086	62,936	30,903	11,362	6,315	5,854	7,046	10,043	1,738	823
1987	300,445	128,264	44,310	21,732	7,972	4,413	4,068	4,861	6,881	1,185
1988	329,655	211,662	90,329	31,180	15,268	5,586	3,080	2,824	3,358	4,738
1989	297,972	232,022	148,736	63,249	21,679	10,487	3,768	2,031	1,823	2,136
1990	201,582	209,881	163,329	104,560	44,345	15,130	7,269	2,590	1,385	1,236
1991	127,551	141,942	147,634	114,627	73,051	30,741	10,368	4,910	1,725	914
1992	132,717	89,793	99,792	103,489	79,884	50,399	20,894	6,918	3,219	1,117
1993	108,065	93,477	63,202	70,136	72,520	55,695	34,875	14,324	4,700	2,173
1994	112,133	76,128	65,824	44,464	49,251	50,764	38,803	24,156	9,866	3,225
1995	119,582	78,987	53,596	46,287	31,193	34,412	35,256	26,749	16,533	6,719
1996	198,229	84,249	55,631	37,723	32,534	21,874	24,048	24,533	18,537	11,425
1997	167,595	139,641	59,322	39,132	26,482	22,761	15,225	16,633	16,866	12,690
1998	175,322	118,073	98,349	41,750	27,502	18,567	15,900	10,589	11,518	11,645
1999	289,086	123,504	83,137	69,177	29,307	19,237	12,919	10,993	7,275	7,880
2000	266,549	203,662	86,978	58,505	48,606	20,538	13,428	8,974	7,601	5,014
2001	228,996	187,776	143,415	61,193	41,087	34,030	14,313	9,305	6,185	5,218
2002	278,448	161,318	132,223	100,889	42,966	28,754	23,699	9,908	6,404	4,239
2003	267,472	196,166	113,608	93,045	70,885	30,107	20,068	16,459	6,848	4,412
2004	243,609	188,430	138,144	79,937	65,359	49,649	20,997	13,922	11,359	4,710
2005	197,757	171,603	132,667	97,155	56,095	45,691	34,513	14,494	9,546	7,753
2006	242,514	139,318	120,847	93,349	68,248	39,293	31,869	23,947	10,006	6,567
2007	207,900	170,852	98,117	85,044	65,596	47,834	27,434	22,147	16,565	6,900
2008	173,823	146,473	120,338	69,064	59,788	46,016	33,449	19,109	15,367	11,464
2009	170,517	122,458	103,153	84,680	48,523	41,892	32,112	23,226	13,205	10,584
2010	137,995	120,123	86,230	72,568	59,461	33,963	29,181	22,237	15,993	9,056
2011	133,855	97,212	84,585	60,662	50,954	41,615	23,654	20,203	15,307	10,964
2012	159,474	94,292	68,446	59,491	42,574	35,630	28,940	16,339	13,865	10,457
2013	214,516	112,333	66,383	48,130	41,734	29,745	24,742	19,947	11,180	9,439
2014	197,848	151,110	79,090	46,686	33,774	29,175	20,676	17,079	13,677	7,630
2015	182,007	139,370	106,396	55,628	32,768	23,619	20,293	14,286	11,725	9,347
2016	226,607	128,230	98,163	74,891	39,107	22,986	16,515	14,133	9,911	8,113
2017	487,692	159,652	90,317	69,096	52,648	27,433	16,072	11,502	9,805	6,858
2018	197,590	343,627	112,471	63,602	48,622	37,000	19,242	11,247	8,030	6,835
2019	74,148	139,220	242,072	79,200	44,751	34,163	25,944	13,458	7,847	5,593
2020	104,812	52,241	98,062	170,408	55,689	31,404	23,904	18,087	9,349	5,438

Table 6.14 (cont'd). Estimates of arrowtooth flounder population number-at-age, by sex, 1976-2018.

Males				Numbers at age (1,000s)							
Year	11	12	13	14	15	16	17	18	19	20	21
1976	1,184	865	641	483	359	269	200	150	113	85	103
1977	1,023	746	545	404	305	227	170	126	95	71	118
1978	975	676	493	360	267	201	150	112	83	63	125
1979	1,005	653	453	330	241	179	135	100	75	56	126
1980	1,111	665	432	300	219	160	118	89	66	50	120
1981	1,357	727	435	283	196	143	104	77	58	43	111
1982	2,146	893	478	286	186	129	94	69	51	38	102
1983	4,926	1,441	599	321	192	125	87	63	46	34	94
1984	6,161	3,260	953	397	213	127	83	57	42	31	85
1985	1,353	4,153	2,198	643	267	143	86	56	39	28	78
1986	694	920	2,825	1,495	437	182	97	58	38	26	72
1987	560	472	626	1,922	1,017	297	124	66	40	26	67
1988	815	385	325	431	1,322	699	205	85	46	27	64
1989	2,995	515	243	205	272	836	442	129	54	29	58
1990	1,445	2,026	348	165	139	184	565	299	87	36	58
1991	812	950	1,331	229	108	91	121	371	197	57	62
1992	589	523	612	858	148	70	59	78	239	127	77
1993	752	396	352	412	578	99	47	40	52	161	137
1994	1,489	515	272	241	282	396	68	32	27	36	204
1995	2,192	1,012	350	185	164	192	269	46	22	18	163
1996	4,637	1,513	698	242	127	113	132	186	32	15	125
1997	7,807	3,169	1,034	477	165	87	77	90	127	22	96
1998	8,751	5,384	2,185	713	329	114	60	53	62	87	81
1999	7,952	5,976	3,677	1,492	487	225	78	41	36	43	115
2000	5,423	5,473	4,113	2,530	1,027	335	155	54	28	25	109
2001	3,437	3,718	3,752	2,819	1,735	704	230	106	37	19	92
2002	3,571	2,352	2,544	2,567	1,929	1,187	482	157	73	25	76
2003	2,917	2,457	1,618	1,750	1,766	1,327	817	331	108	50	70
2004	3,030	2,003	1,687	1,111	1,202	1,213	911	561	228	74	82
2005	3,208	2,064	1,364	1,149	757	819	826	621	382	155	106
2006	5,326	2,204	1,418	937	789	520	562	568	427	262	180
2007	4,522	3,668	1,518	976	645	544	358	387	391	294	304
2008	4,770	3,126	2,536	1,049	675	446	376	248	268	270	414
2009	7,885	3,281	2,150	1,744	722	464	307	259	170	184	470
2010	7,247	5,399	2,246	1,472	1,194	494	318	210	177	117	448
2011	6,199	4,960	3,695	1,538	1,008	817	338	218	144	121	387
2012	7,476	4,227	3,382	2,520	1,048	687	557	231	148	98	346
2013	7,105	5,080	2,872	2,298	1,712	712	467	379	157	101	302
2014	6,430	4,839	3,460	1,956	1,565	1,166	485	318	258	107	274
2015	5,205	4,386	3,301	2,360	1,334	1,068	796	331	217	176	260
2016	6,461	3,598	3,032	2,282	1,631	922	738	550	229	150	301
2017	5,607	4,465	2,487	2,095	1,577	1,128	638	510	380	158	312
2018	4,777	3,906	3,111	1,732	1,460	1,099	786	444	355	265	327
2019	4,757	3,325	2,719	2,165	1,206	1,016	765	547	309	247	412
2020	3,872	3,293	2,302	1,882	1,499	835	703	529	379	214	457

Table 6.15. Estimated age 1 recruitment of arrowtooth flounder (1,000s of fish) from the 2018 and 2020 stock assessments. The 95% credible intervals (CI) are based on MCMC runs from Model 18.9 (2020). Mean recruitment over the entire time interval 1976-2019 is 339,099,004 fish.

Year class	2018 Assessment	2020 Assessment	Lower CI	Upper CI
1976	32,093	57,027	20,200	119,000
1977	23,942	44,967	17,500	88,003
1978	32,621	63,640	22,200	132,000
1979	86,362	248,850	134,975	357,025
1980	198,894	119,519	43,995	222,000
1981	321,828	68,708	26,700	127,000
1982	204,240	51,685	20,298	97,300
1983	149,173	65,193	28,500	111,000
1984	387,670	124,637	70,598	186,000
1985	304,454	178,692	118,000	247,000
1986	290,725	364,172	281,000	454,000
1987	557,107	600,889	499,000	711,000
1988	589,214	659,310	554,000	764,000
1989	530,891	595,945	508,000	690,000
1990	430,325	403,164	330,000	478,000
1991	266,347	255,102	201,000	316,000
1992	270,672	265,434	211,000	322,000
1993	214,595	216,130	168,000	267,000
1994	221,077	224,265	178,000	274,000
1995	233,495	239,165	189,000	296,000
1996	381,055	396,457	324,000	468,000
1997	311,199	335,189	259,000	416,000
1998	335,016	350,643	268,000	444,000
1999	570,401	578,172	478,975	684,000
2000	547,328	533,098	442,000	628,000
2001	477,408	457,991	374,000	544,000
2002	583,747	556,896	470,000	644,000
2003	539,119	534,943	455,000	616,000
2004	484,238	487,217	419,975	558,000
2005	396,394	395,515	342,000	453,000
2006	481,216	485,027	431,000	540,025
2007	402,866	415,800	365,000	465,000
2008	328,054	347,647	305,000	393,000
2009	317,298	341,034	298,000	383,000
2010	254,065	275,990	238,000	315,000
2011	239,809	267,711	230,000	306,000
2012	293,817	318,947	277,000	363,000
2013	408,756	429,033	376,975	483,000
2014	372,122	395,695	342,000	451,000
2015	294,759	364,014	302,000	426,000
2016	292,494	453,213	372,000	539,000
2017	1,202,835	975,385	797,000	1,160,000
2018		395,180	241,975	589,025
2019		148,296	46,398	375,000

Table 6.16 Set of projections of spawning biomass (SB) and yield for arrowtooth flounder. Seven harvest scenarios designed to satisfy the requirements of Amendment 56, NEPA, and MSFCMA. For a description of scenarios see *Harvest Recommendations* section. Spawning biomass and yield are in t. $B_{40\%}$ = 223,530 t, $B_{35\%}$ = 195,589 t, $F_{40\%}$ = 0.135 and $F_{35\%}$ = 0.160.

Year	Maximum permissible F	Author's F*	Half maximum F	5-year average F	No fishing	Overfished	Approaching overfished
			Spawning Biomass (t)				
2020	494,307	494,307	494,307	494,307	494,307	494,307	494,307
2021	492,834	497,556	495,487	497,534	498,154	491,844	492,834
2022	451,894	509,208	483,279	508,907	516,924	440,690	451,894
2023	423,421	523,316	479,288	527,516	543,054	404,288	422,575
2024	401,299	487,854	478,915	549,462	572,837	375,741	391,285
2025	373,676	446,694	469,388	561,403	592,639	343,261	356,119
2026	339,777	399,602	447,557	557,725	595,940	306,629	316,947
2027	307,481	355,292	420,707	545,024	588,832	273,522	281,591
2028	282,849	320,383	396,587	532,609	580,868	249,131	255,325
2029	265,756	294,861	378,048	523,713	575,673	232,731	237,394
2030	253,491	275,785	364,460	516,622	571,607	222,104	225,360
2031	244,939	261,647	354,655	511,161	568,666	215,699	217,881
2032	239,128	251,295	349,491	506,795	566,393	211,944	213,350
2033	235,550	244,237	343,517	503,676	565,038	210,117	210,988
			Fishing Mortality				
2020	0.018	0.018	0.018	0.018	0.018	0.018	0.018
2021	0.135	0.015	0.067	0.016	-	0.160	0.160
2022	0.135	0.015	0.067	0.016	-	0.160	0.160
2023	0.135	0.135	0.067	0.016	-	0.160	0.160
2024	0.135	0.135	0.067	0.016	-	0.160	0.160
2025	0.135	0.135	0.067	0.016	-	0.160	0.160
2026	0.135	0.135	0.067	0.016	-	0.160	0.160
2027	0.135	0.135	0.067	0.016	-	0.160	0.160
2028	0.135	0.135	0.067	0.016	-	0.160	0.160
2029	0.135	0.135	0.067	0.016	-	0.155	0.155
2030	0.133	0.135	0.067	0.016	-	0.149	0.149
2031	0.131	0.133	0.067	0.016	-	0.146	0.146
2032	0.129	0.131	0.067	0.016	-	0.144	0.144
2033	0.128	0.130	0.067	0.016	-	0.143	0.143
			Yield (t)				
2020	10,879	10,879	10,879	10,879	10,879	10,879	10,879
2021	77,349	77,349	39,784	9,437	-	90,873	77,349
2022	72,900	80,323	39,589	9,795	-	83,933	72,900
2023	69,240	83,345	39,520	10,167	-	78,273	81,335
2024	64,461	76,236	38,621	10,325	-	71,592	74,100
2025	57,843	67,318	36,312	10,081	-	63,177	65,152
2026	52,047	59,525	33,968	9,749	-	56,104	57,628
2027	48,322	54,166	32,413	9,548	-	51,662	52,826
2028	46,005	50,529	31,429	9,445	-	48,947	49,841
2029	44,271	47,751	30,641	9,359	-	45,884	46,866
2030	42,611	45,573	29,974	9,274	-	43,259	44,003
2031	41,120	43,696	29,453	9,205	-	41,686	42,193
2032	40,102	42,080	29,049	9,148	-	40,910	41,231
2033	39,566	40,998	28,787	9,117	-	40,634	40,826

*Projections are based on estimated catches of 10,879 t and 9,109 t used in place of maximum permissible ABC for 2020 and 2021 in response to a Plan Team request to obtain more accurate two-year projections.

Table 6.17. Catch, OFL, TAC, and ABC used to manage the BSAI arrowtooth flounder complex since 1980. **Catch information through October 25, 2020, source: AKFIN NMFS AKRO BLEND/Catch Accounting System.

Year	Catch	OFL	TAC	ABC
1980	16,528			20,000
1981	15,402			16,500
1982	10,366			16,500
1983	12,572			20,000
1984	8,507			20,000
1985	6,702			20,000
1986	6,463		20,000	20,000
1987	4,373		9,795	30,900
1988	17,991		5,531	99,500
1989	6,575		6,000	163,700
1990	11,752		10,000	106,500
1991	17,559		20,000	116,400
1992	10,707	114,000	10,000	82,300
1993	8,369	96,000	10,000	72,000
1994	12,904	130,000	10,000	93,400
1995	8,356	138,000	10,227	113,000
1996	13,189	162,000	9,000	129,000
1997	9,422	167,000	20,760	108,000
1998	13,713	230,000	16,000	147,000
1999	10,240	219,000	134,354	140,000
2000	11,907	160,000	131,000	131,000
2001	12,652	141,500	22,015	117,000
2002	10,670	137,000	16,000	113,000
2003	11,928	139,000	12,000	112,000
2004	16,367	142,000	12,000	115,000
2005	12,819	132,000	12,000	108,000
2006	12,098	166,000	13,000	136,000
2007	10,724	193,000	20,000	158,000
2008	14,104	297,000	75,000	244,000
2009	17,342	190,000	75,000	156,000
2010	17,847	191,000	75,000	156,000
2011	20,141	186,000	25,900	153,000
2012	22,325	181,000	25,900	157,000
2013	20,537	186,000	25,000	152,000
2014	19,110	125,642	25,000	106,599
2015	11,269	93,856	22,000	80,547
2016	11,099	94,035	14,000	80,701
2017	6,519	76,100	14,000	65,371
2018	6,998	76,757	13,621	65,932
2019	10,048	82,939	8,000	70,673
2020	10,040	84,057	10,000	71,618

Figures

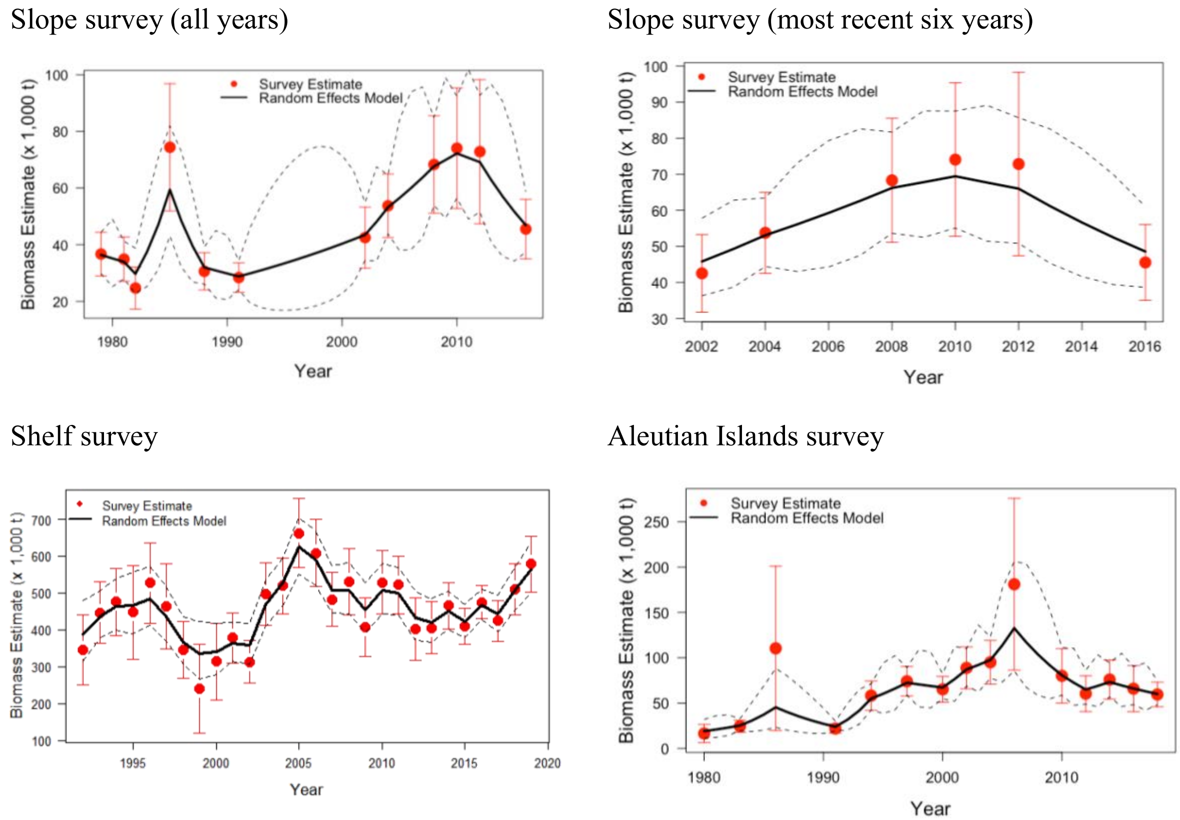


Figure 6.1. Survey estimates for the Bering Sea shelf, slope and the Aleutian Islands arrowtooth flounder biomass, with fitted linear model predictions. Predictions based on the random effect model applied to survey data indicate 11% in the Aleutians, 79% on the Bering Sea shelf, and 10% on the Bering Sea slope. Proportions do not change when the 1979-1991 slope survey data is excluded (Table 6.6).

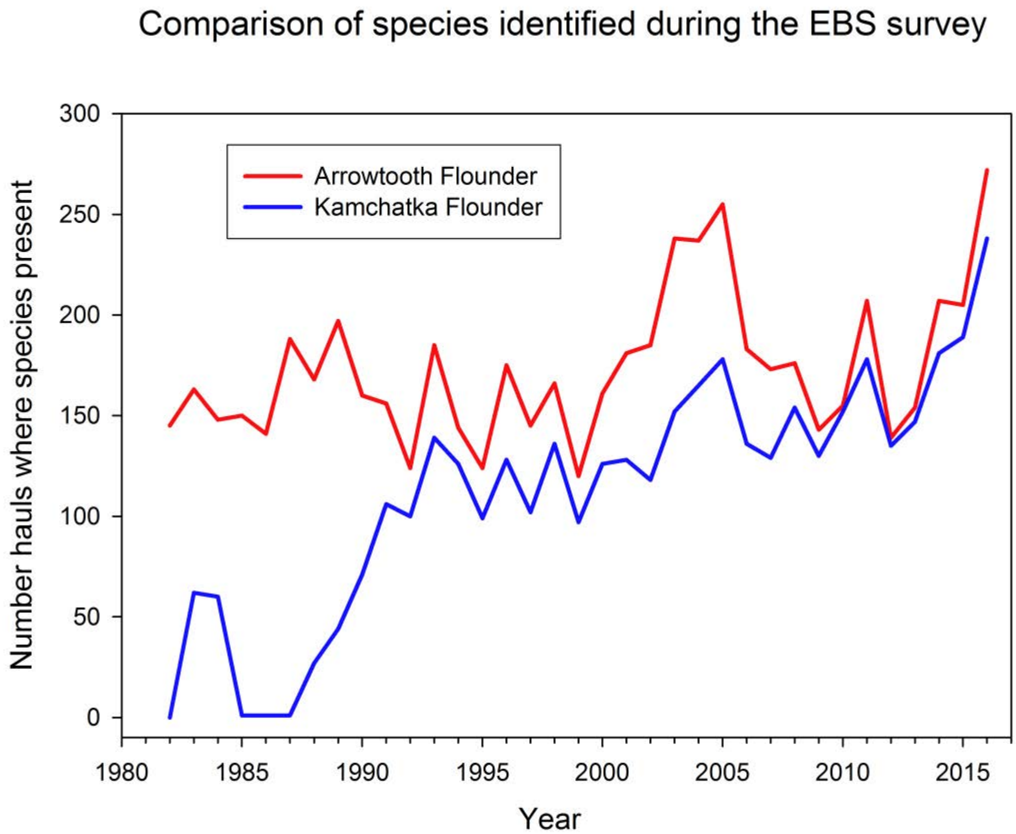


Figure 6.2. Numbers of hauls where arrowtooth flounder and Kamchatka flounder were identified during the annual Bering Sea shelf surveys, 1982-2017, within the standard survey area.

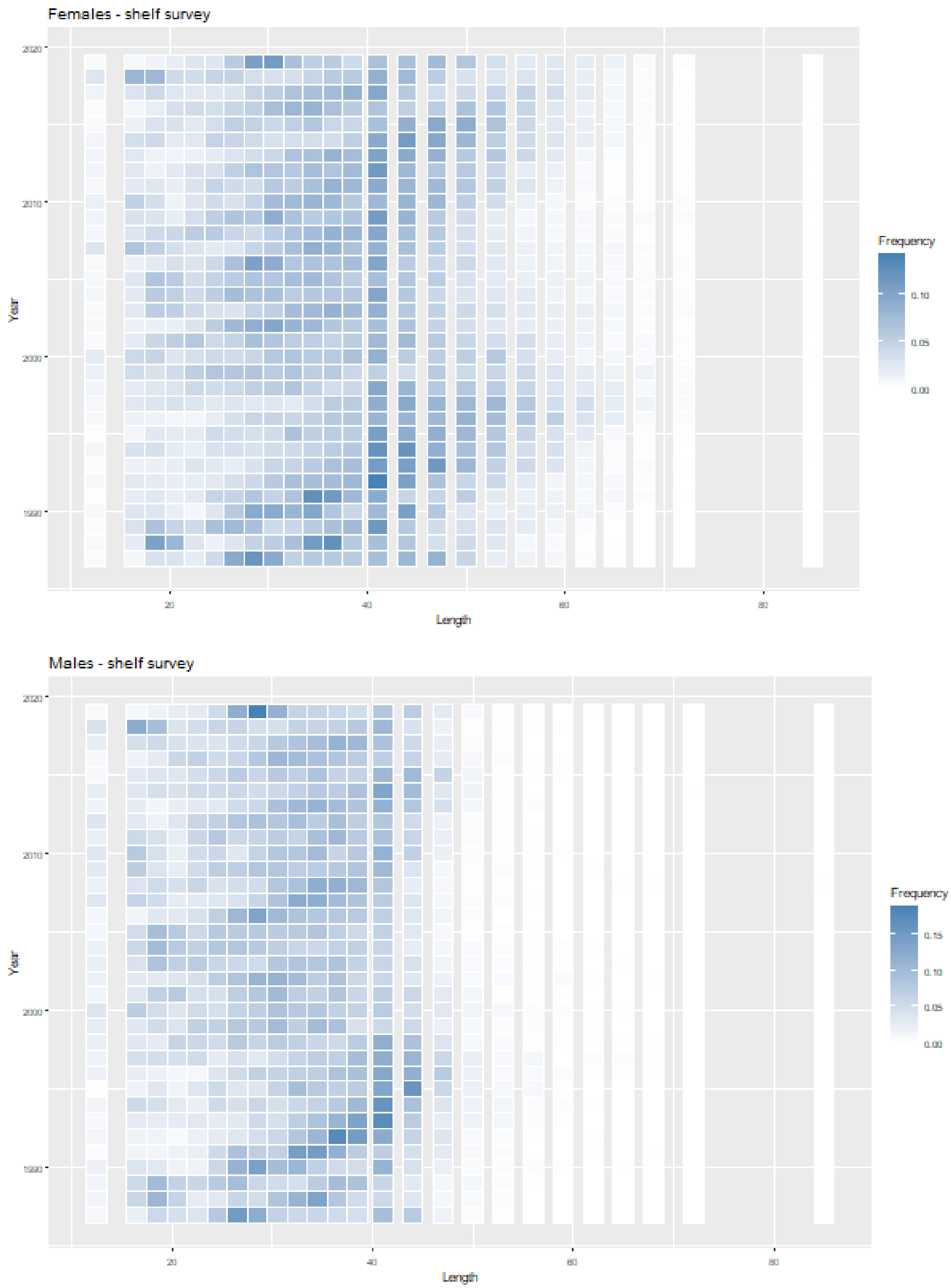


Figure 6.3. Length frequency data from female (upper panel) and male (lower panel) Bering Sea shelf survey arrowtooth flounder from 1987-2019.

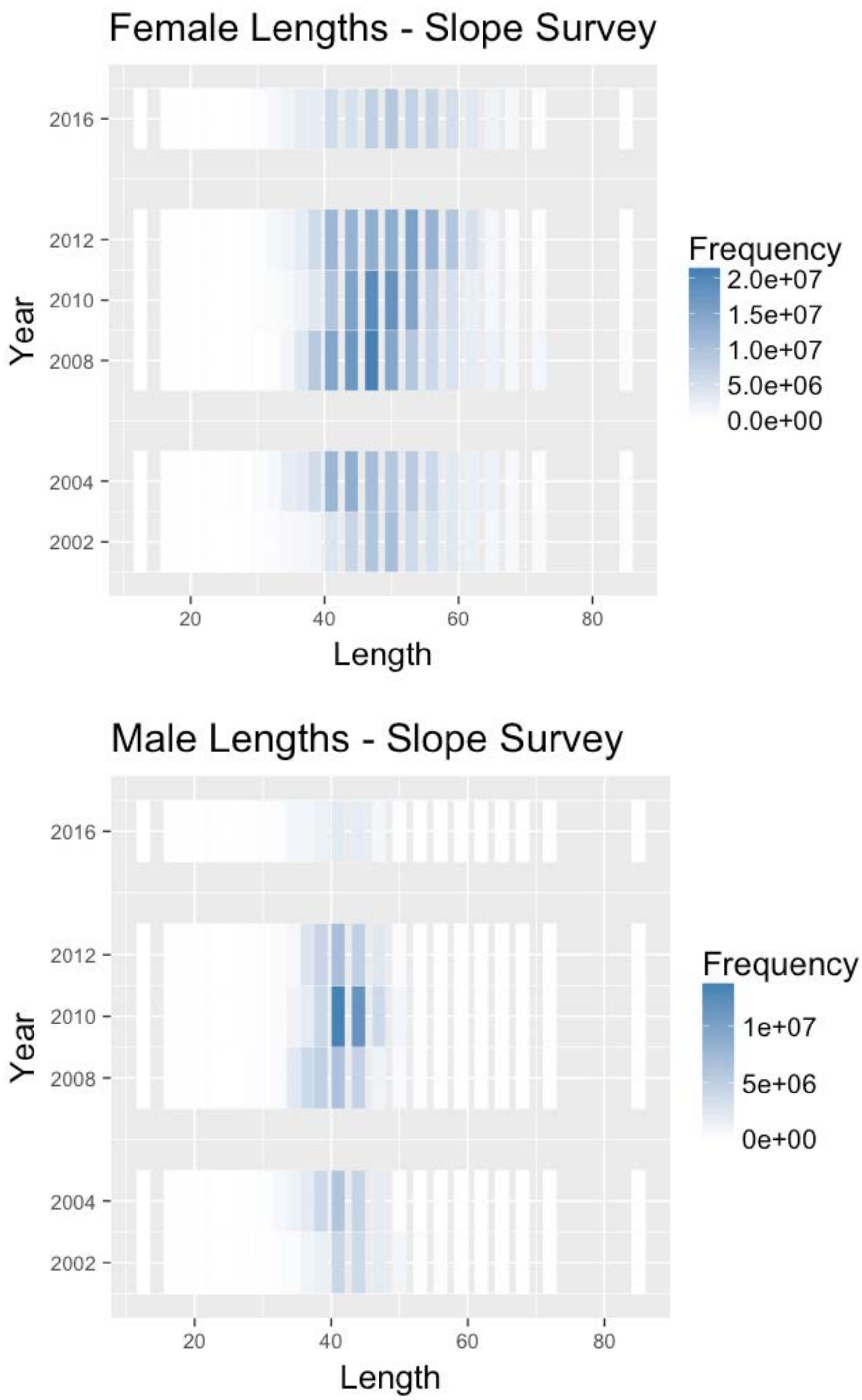


Figure 6.4. Length frequency data from female (upper panel) and male (lower panel) Bering Sea slope survey arrowtooth flounder from 2002-2016.

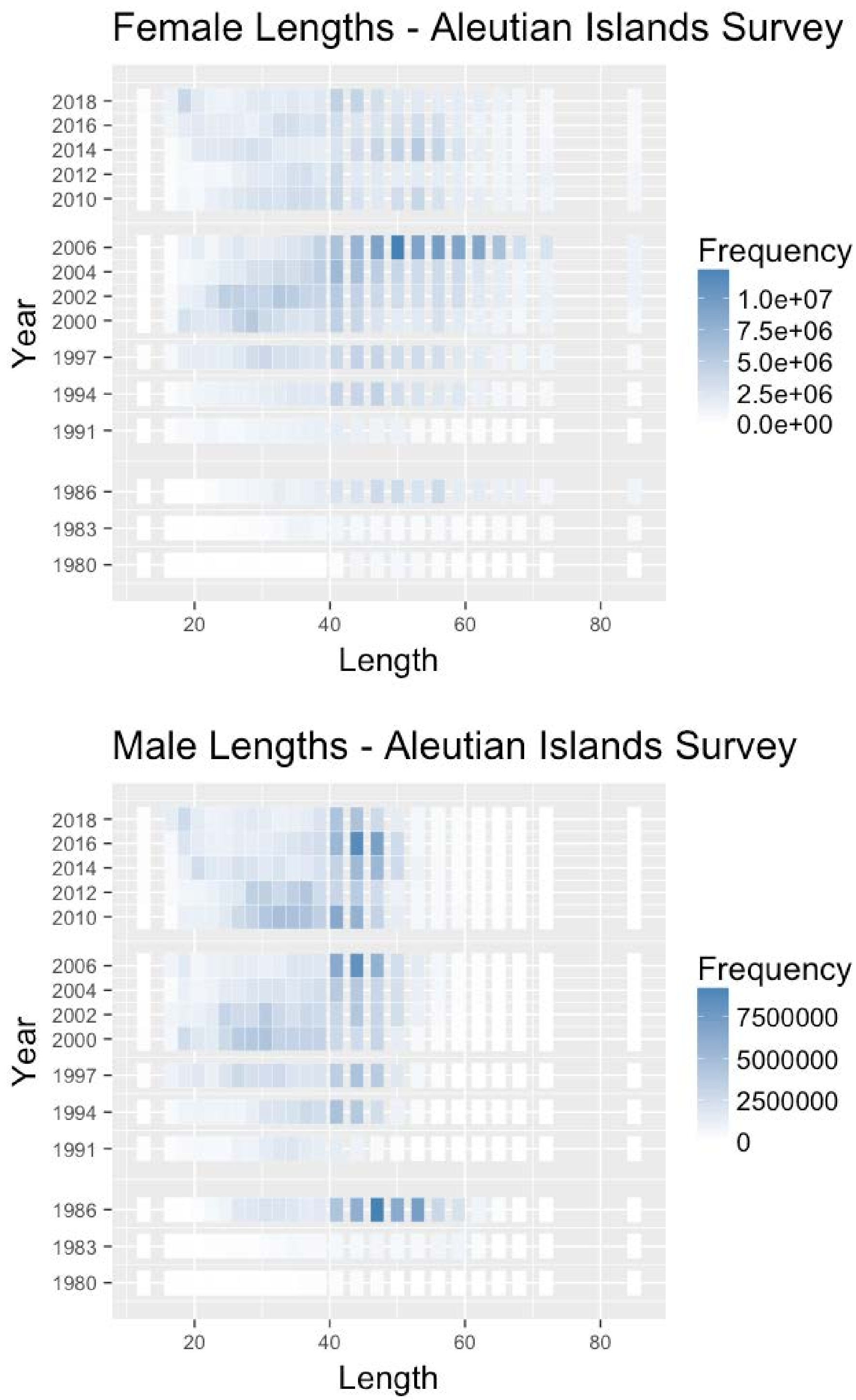


Figure 6.5. Length frequency data from female (upper panel) and male (lower panel) Aleutian Islands survey arrowtooth flounder from 1980-2018.

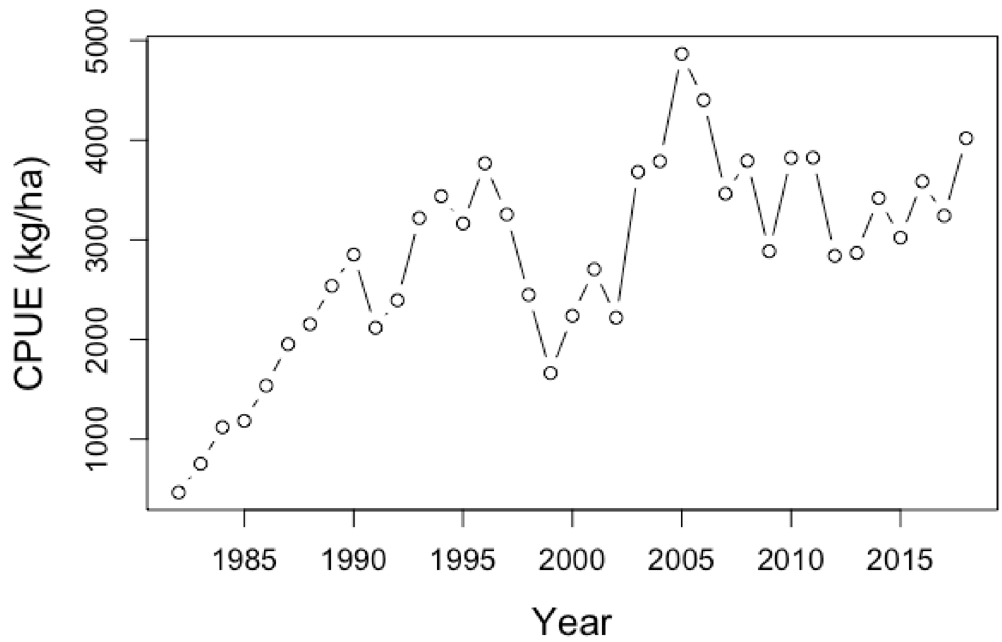


Figure 6.6 Arrowtooth flounder CPUE (kg/ha) from the standard shelf survey area (1982-1992) and standard shelf survey area including Northwestern stratum 82 and 90 (1993-2018).

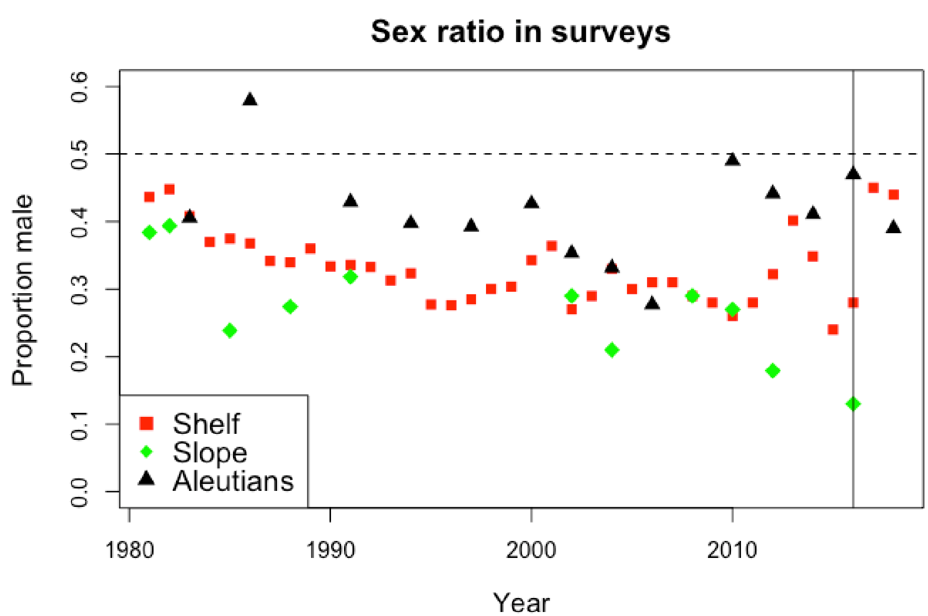


Figure 6.7. Proportion of the estimated male population from Bering Sea and Aleutian Islands trawl surveys on the continental shelf and slope.

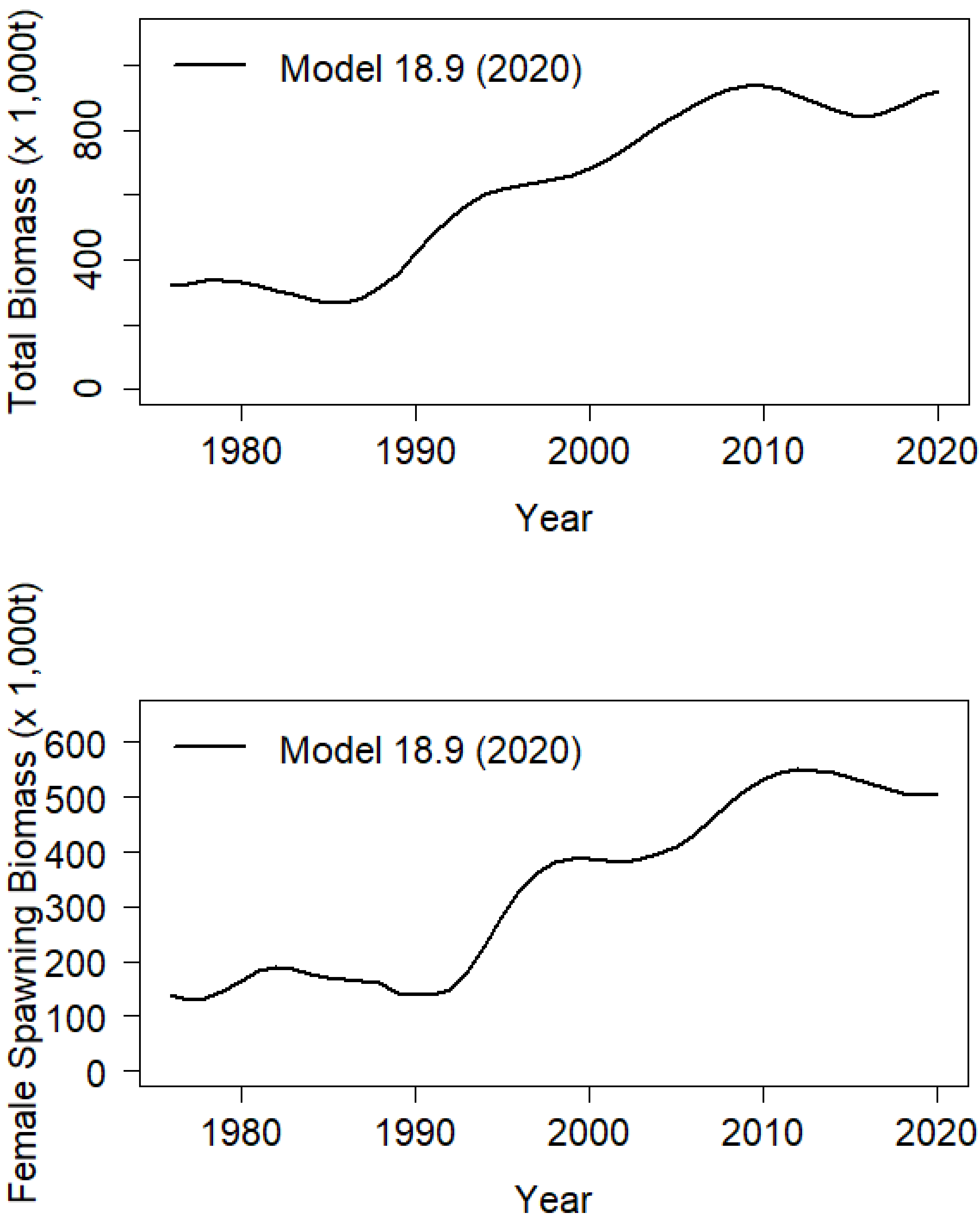
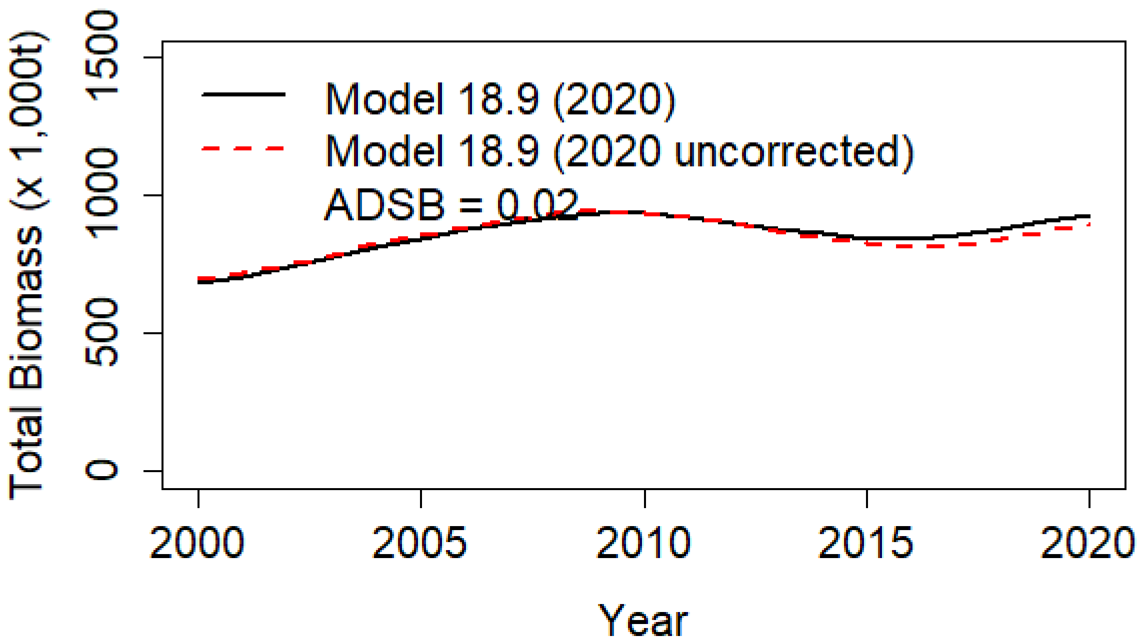


Figure 6.8. Total biomass and female spawning biomass for the different model configurations presented in this assessment.



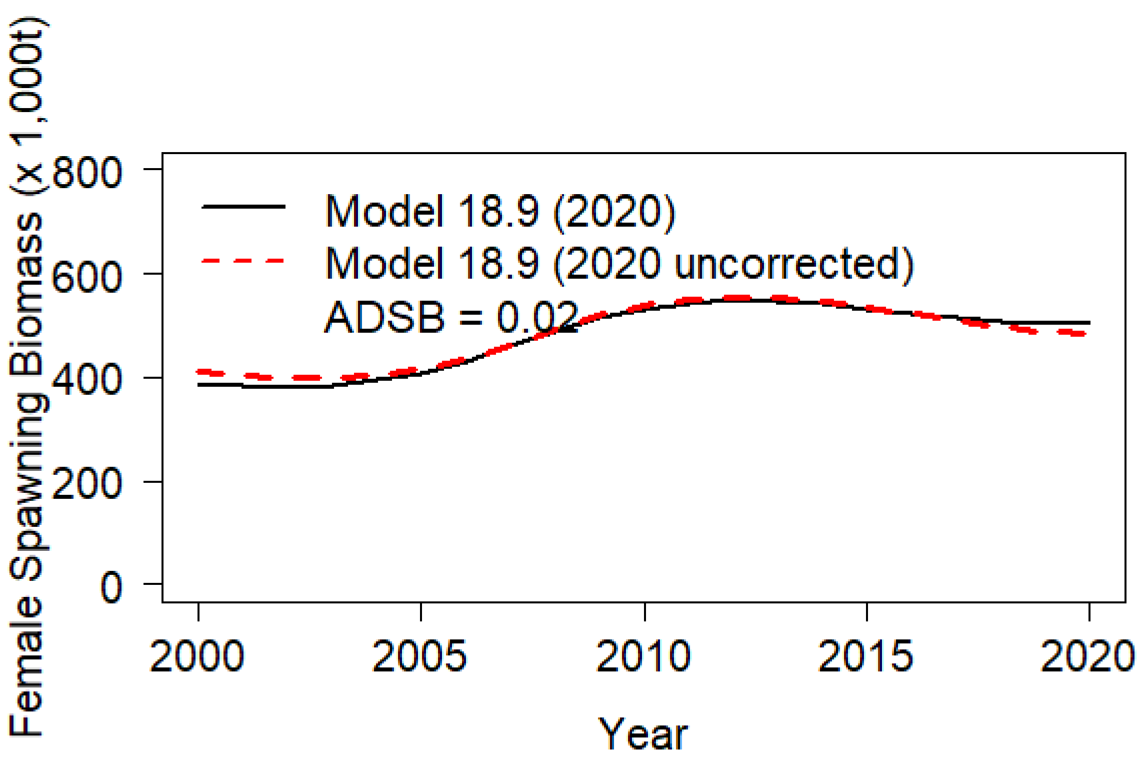


Figure 6.9. Total biomass and female spawning biomass for the corrected model compared to the uncorrected model (using eastern Bering Sea shelf survey data from the 2018 assessment). ADSB is average difference of biomass. This plot is provided only as a sensitivity check and is not part of the main assessment results (see Responses to SSC and Plan Team Comments Specific to this Assessment)

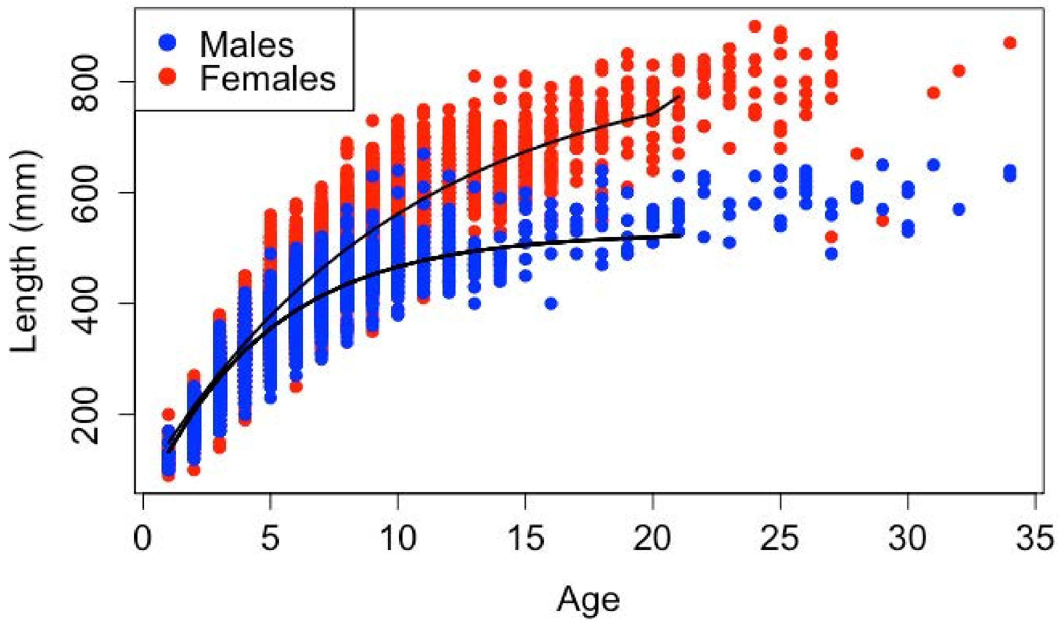


Figure 6.10. Fit to age data based on length at age data and length frequency data from surveys (black lines, females are larger than males). Blue circles represent males and red circles are females. The plus group is estimated length at age for ages 21+, and is based on a weighted average of those ages.

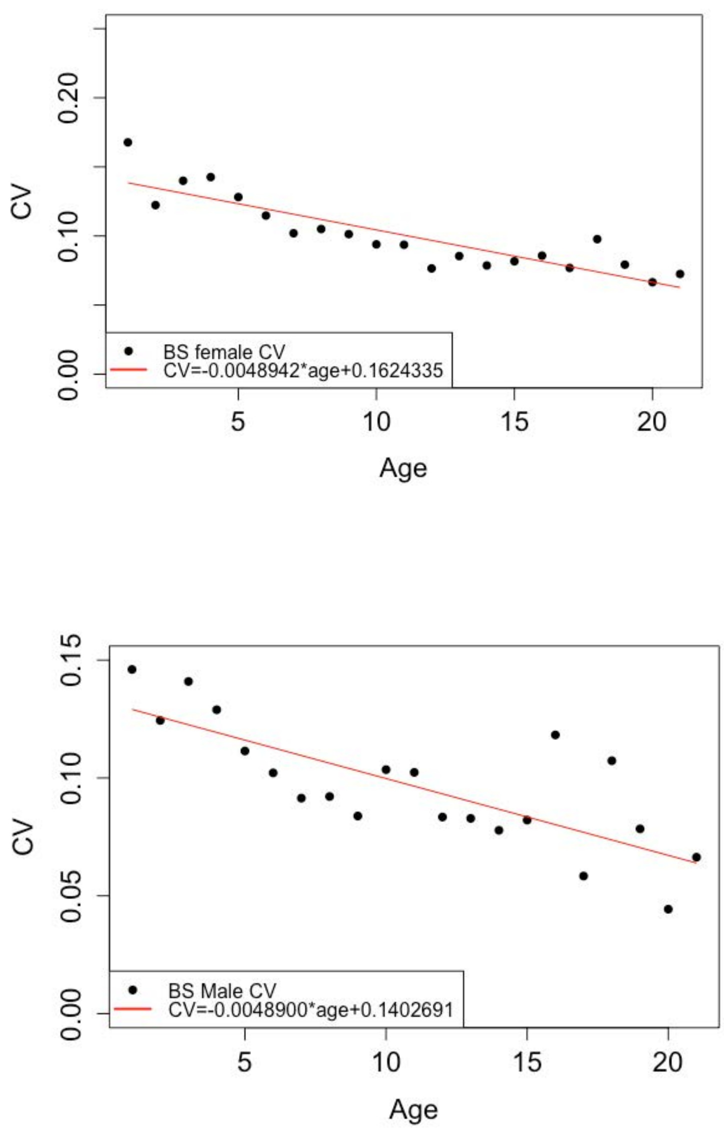


Figure 6.11. The CV of length at age for each age from 1-21+ for females (upper panel) and males (lower panel). The CV is fit to a linear model with respect to age, which is shown in the legend in each panel.

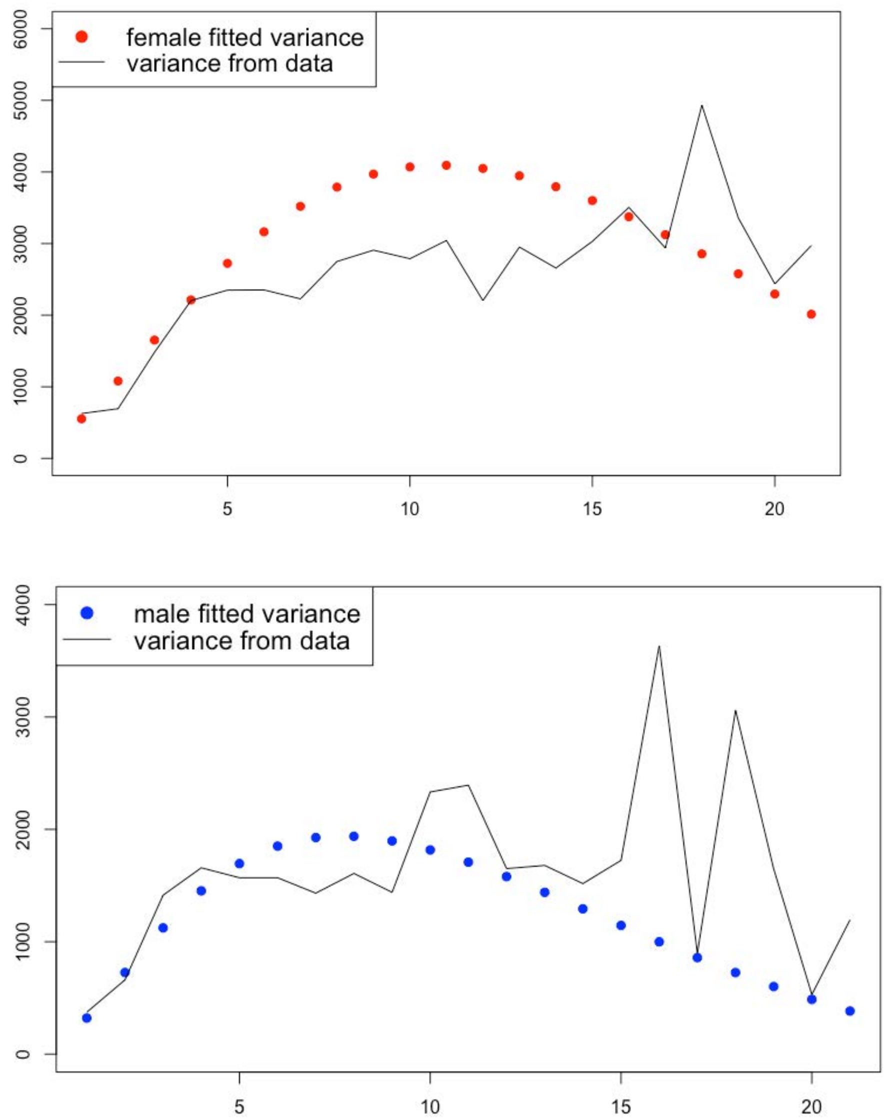


Figure 6.12. The variance of length at age for each age from 1-21+ for females (upper panel) and males (lower panel), as red (female) and blue (male) points. Data values are shown as a black line.

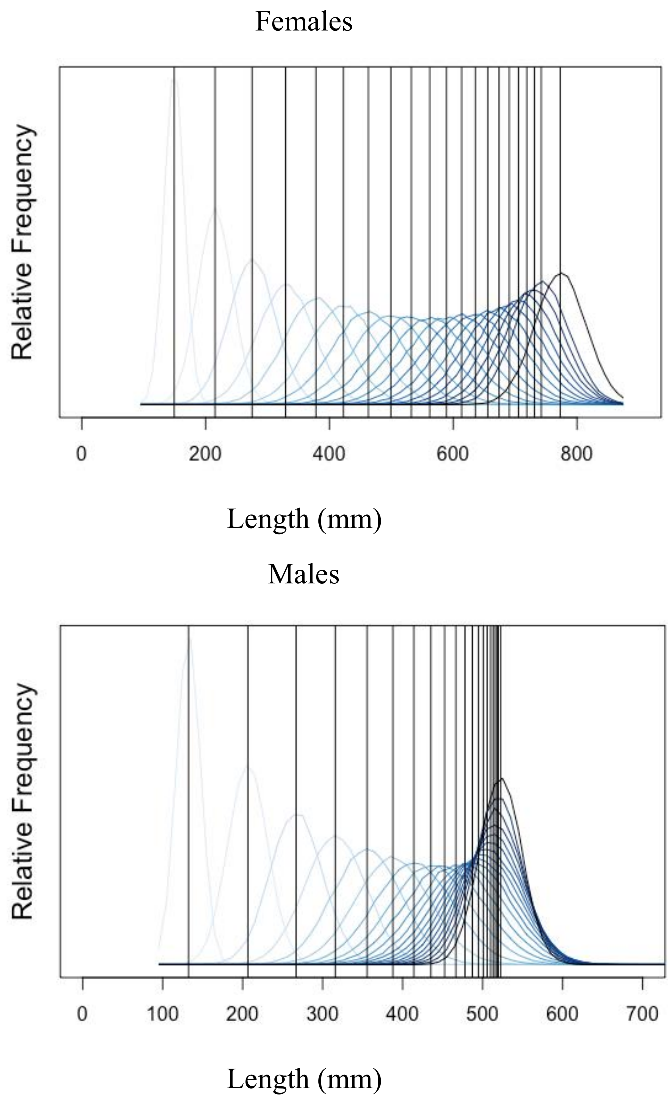


Figure 6.13. Length-age conversion matrix for females (upper panel) and males (lower panel), with length in mm.

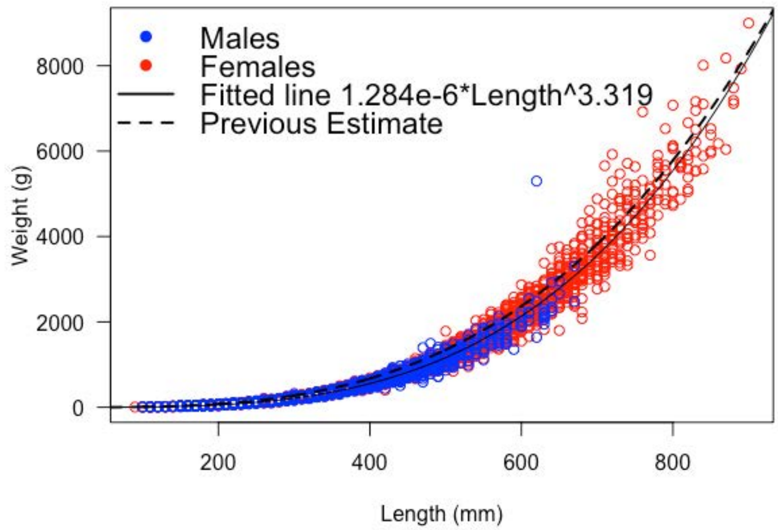


Figure 6.14. Length-weight relationship of arrowtooth flounder. Males and females grow at the same trajectory. The fits to the weight-at-length data is shown as a black line. Data from BSAI surveys 1980-2017.

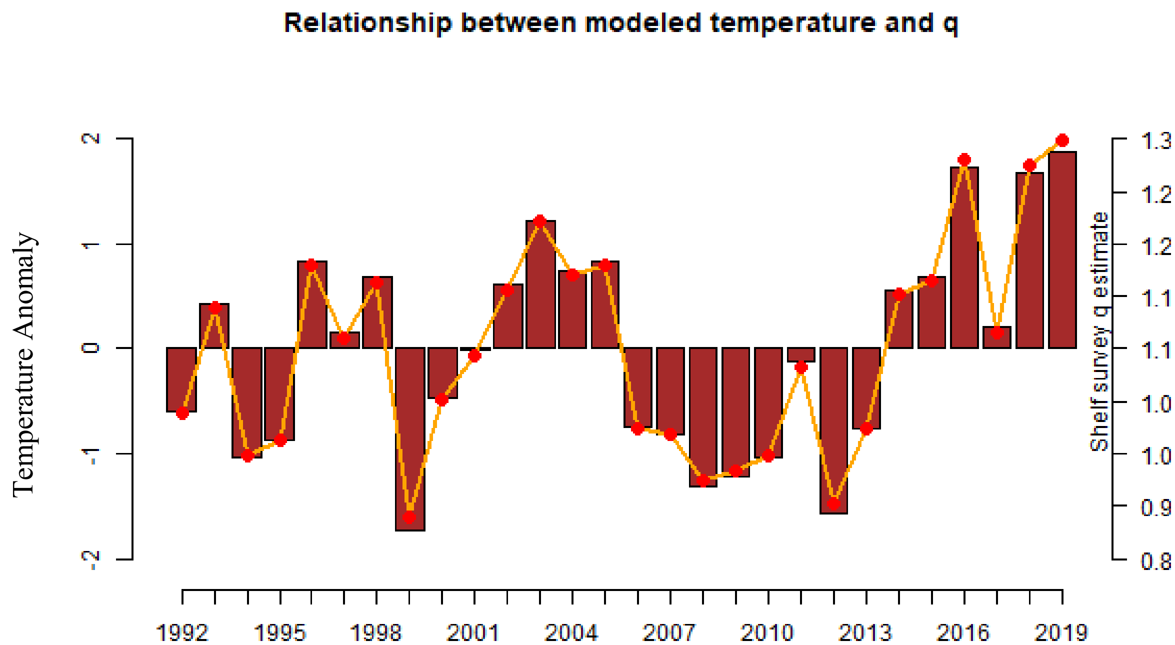


Figure 6.15. Shelf survey annual average bottom temperature anomalies (bars), model estimate of annual shelf survey q due to effect of water temperature (circles with lines).

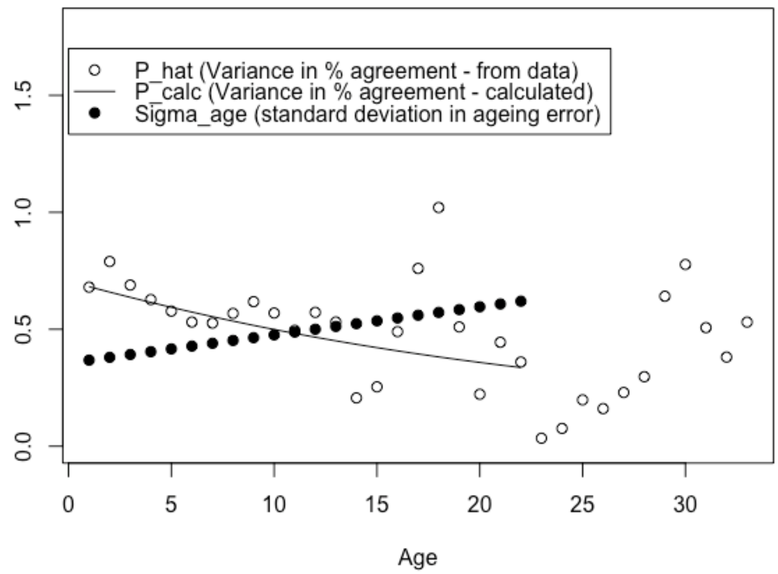


Figure 6.16. Ageing error; the variance in percent agreement from the data (p_hat, open circles), calculated variance in percent agreement (p_calc), and standard deviation in ageing error, by age.

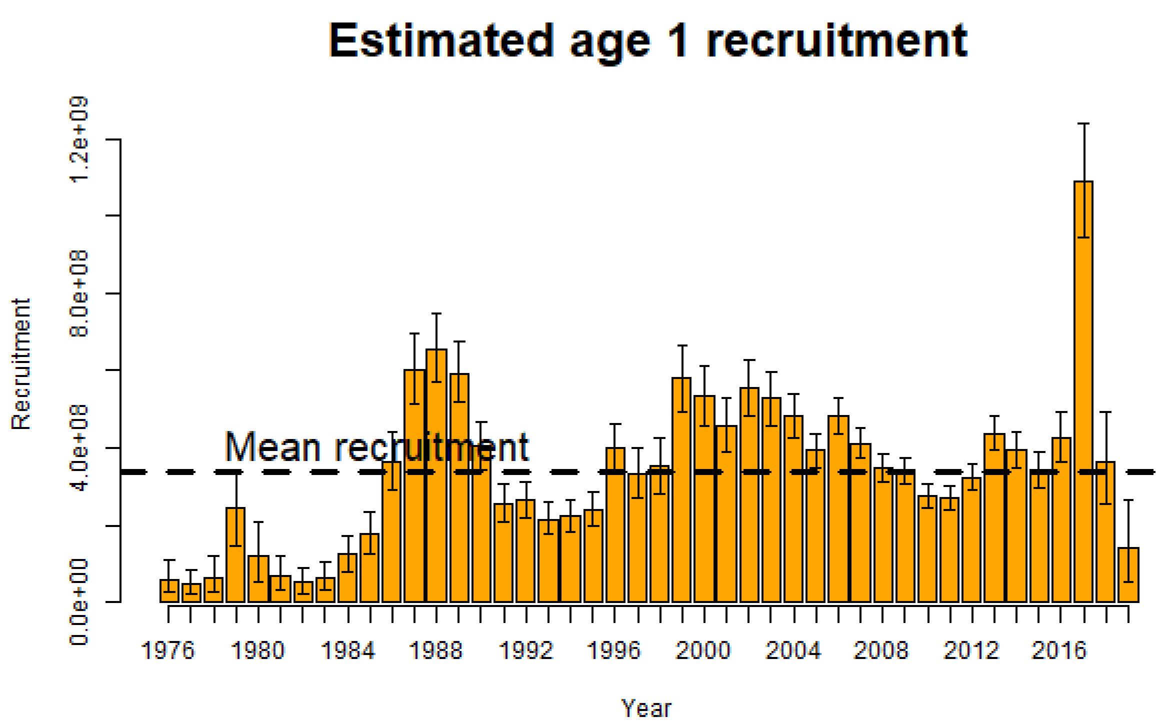


Figure 6.17. Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model 18.9 (2020) MCMC output, with 5% and 95% credible intervals. Mean recruitment is shown over all years from 1976-2019.

Model 18.9

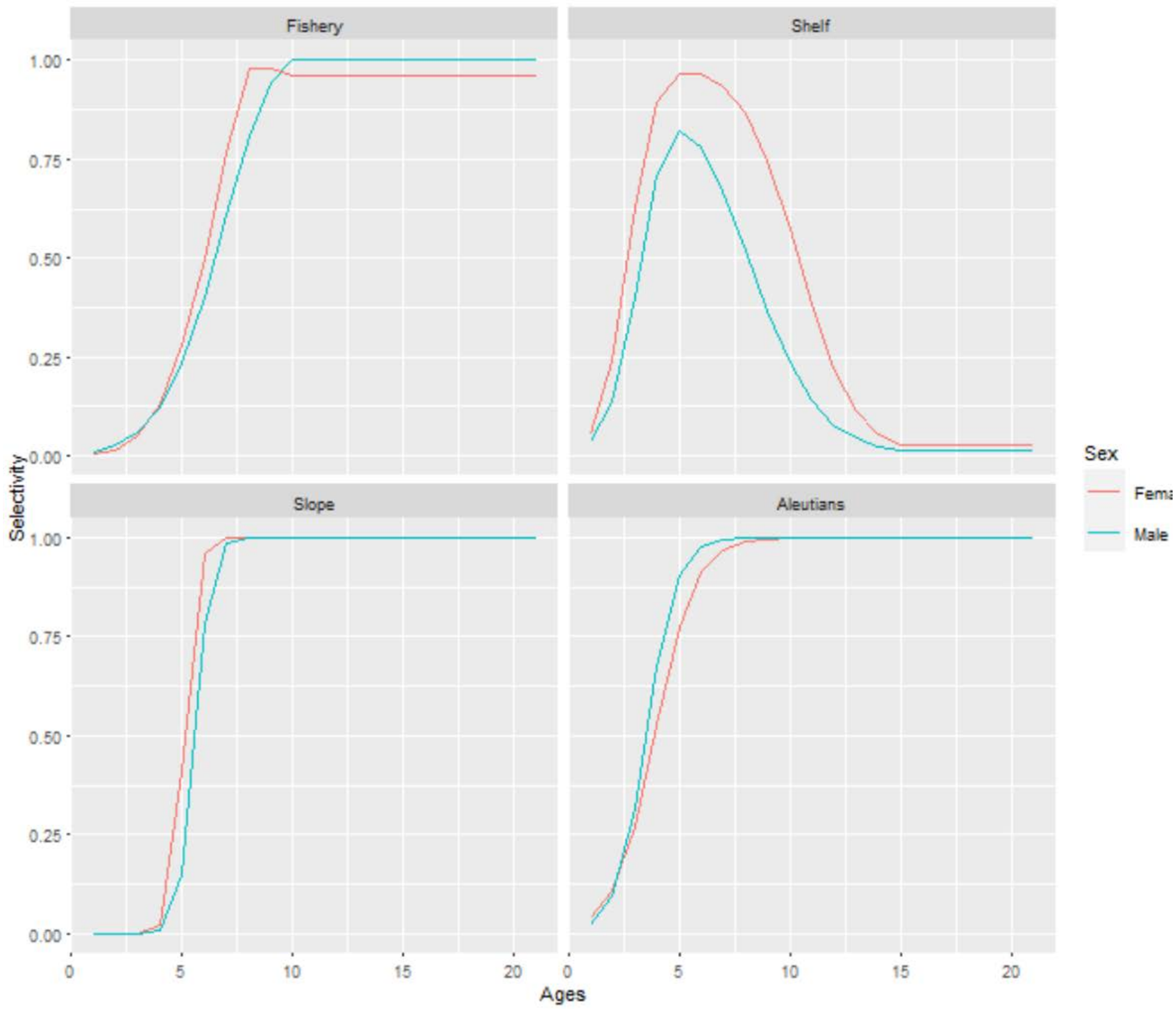


Figure 6.18. Age-specific fishery selectivity (top left), shelf survey selectivity (top right) slope survey selectivity (bottom left) and Aleutian Islands survey selectivity (bottom right), by sex, estimated in model 18.9 (2020).

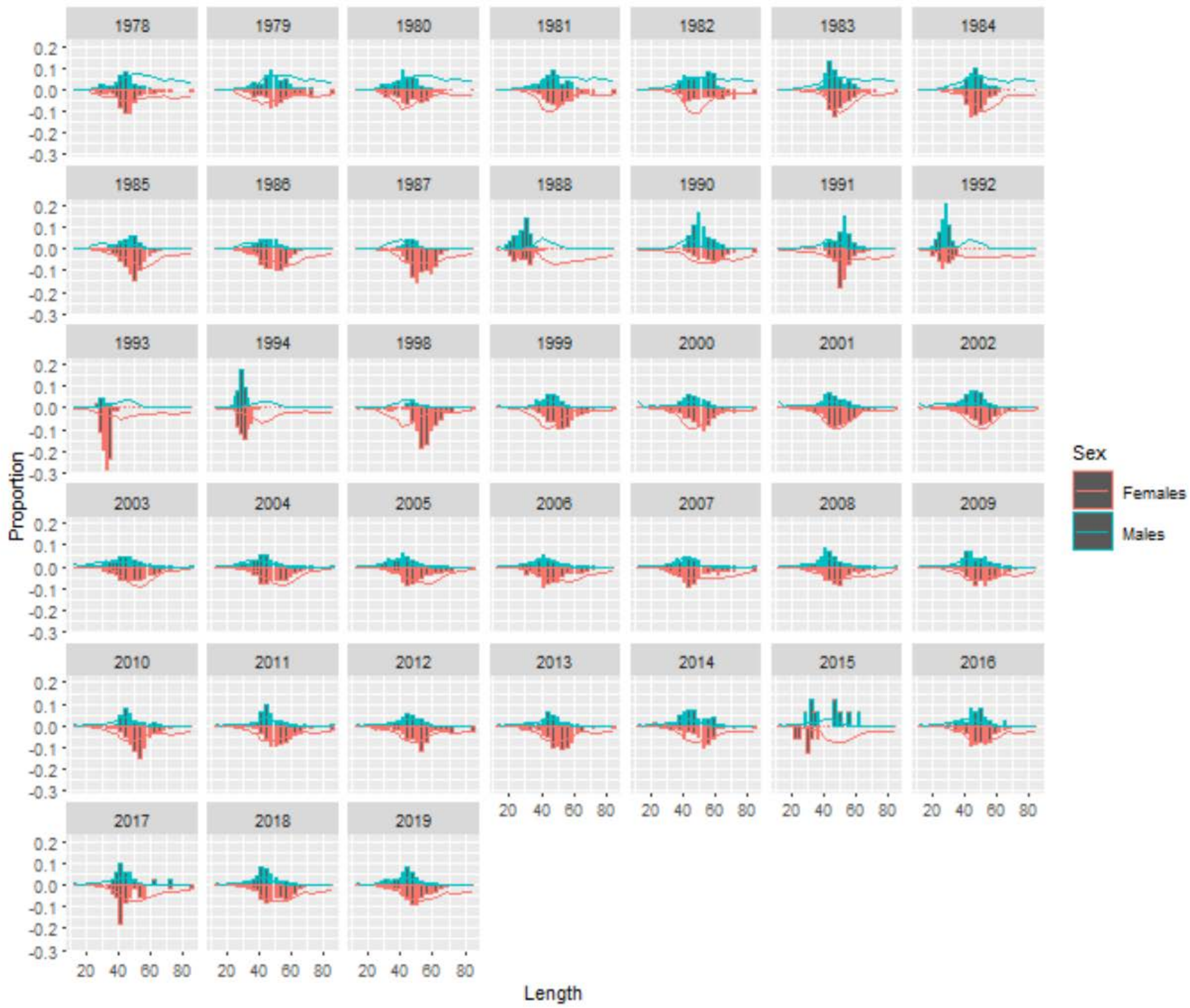


Figure 6.19. Model fit to observed fishery length composition (bar plots) and predicted (lines), with males in blue, females in red.

Figure 6.20. Model fit to Bering Sea shelf survey observed length composition (bar plots) and predicted (lines), with males in blue, females in red.

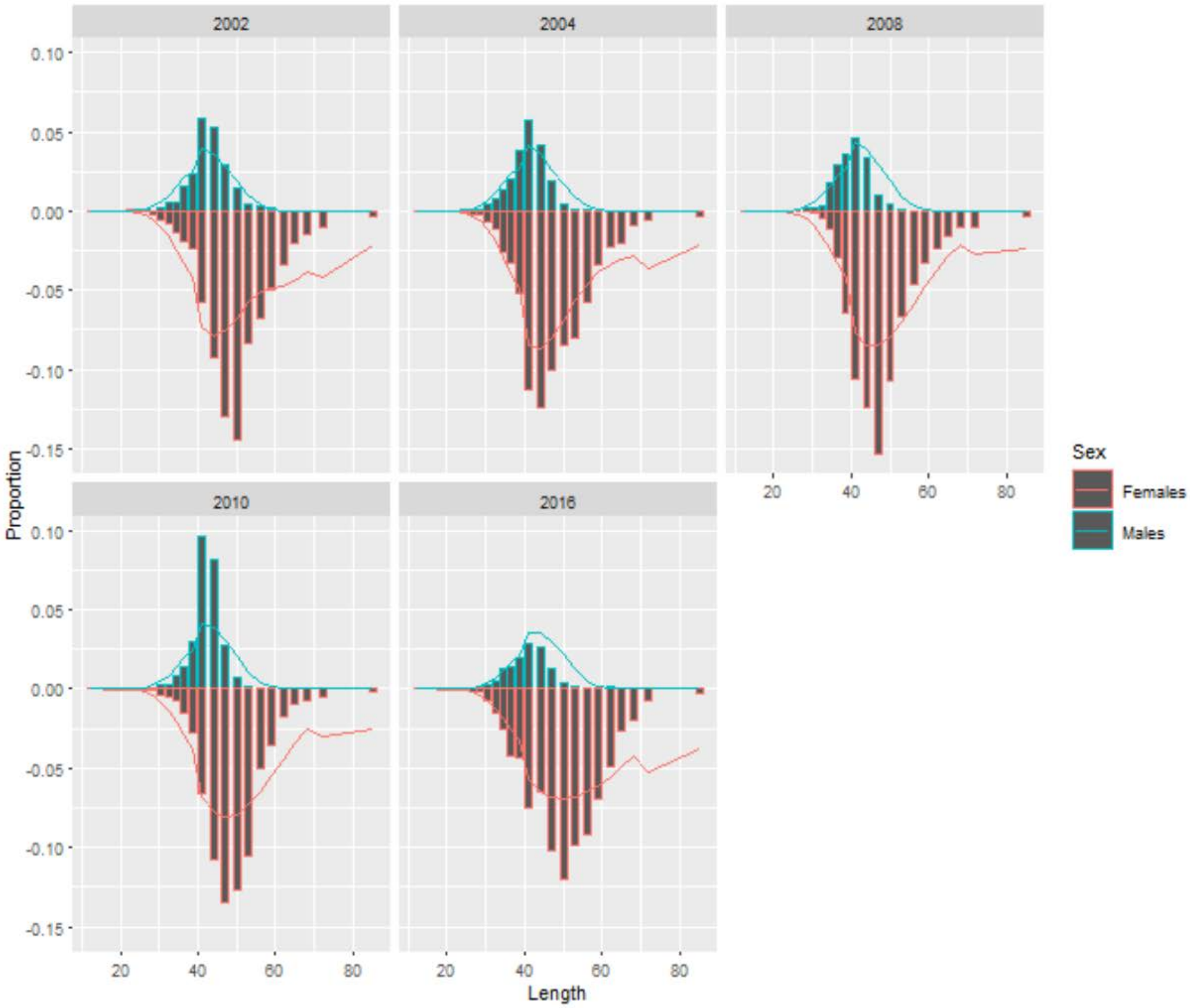


Figure 6.21. Model fit to Bering Sea slope survey observed length composition (bar plots) and predicted (lines), with males in blue, females in red.

Figure 6.22. Model fit to Aleutian Island survey observed length composition (bar plots) and predicted (lines), with males in blue, females in red.

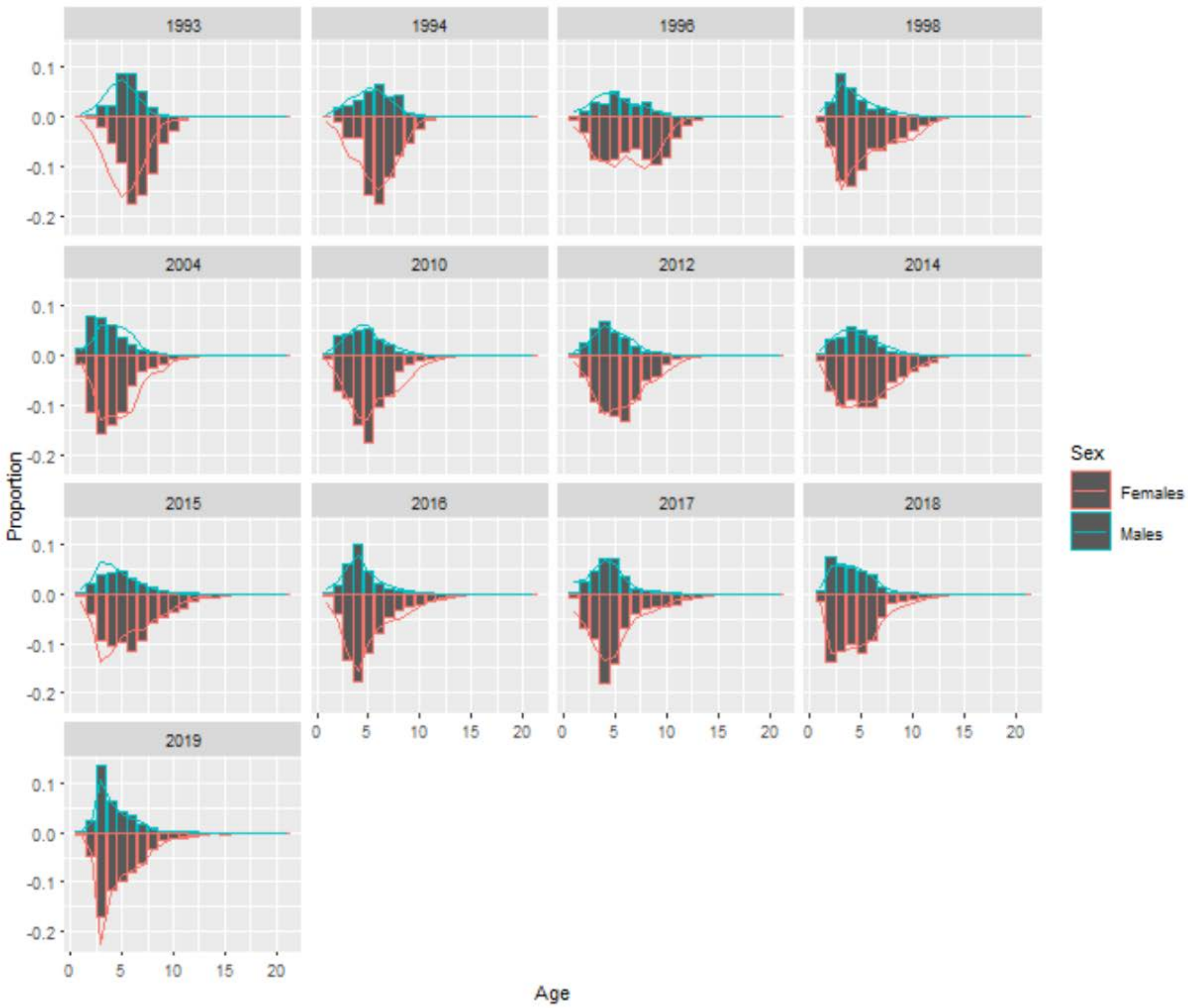


Figure 6.23. Model fit to Bering Sea shelf survey observed age composition (bar plots) and predicted (lines), with males in blue, females in red.

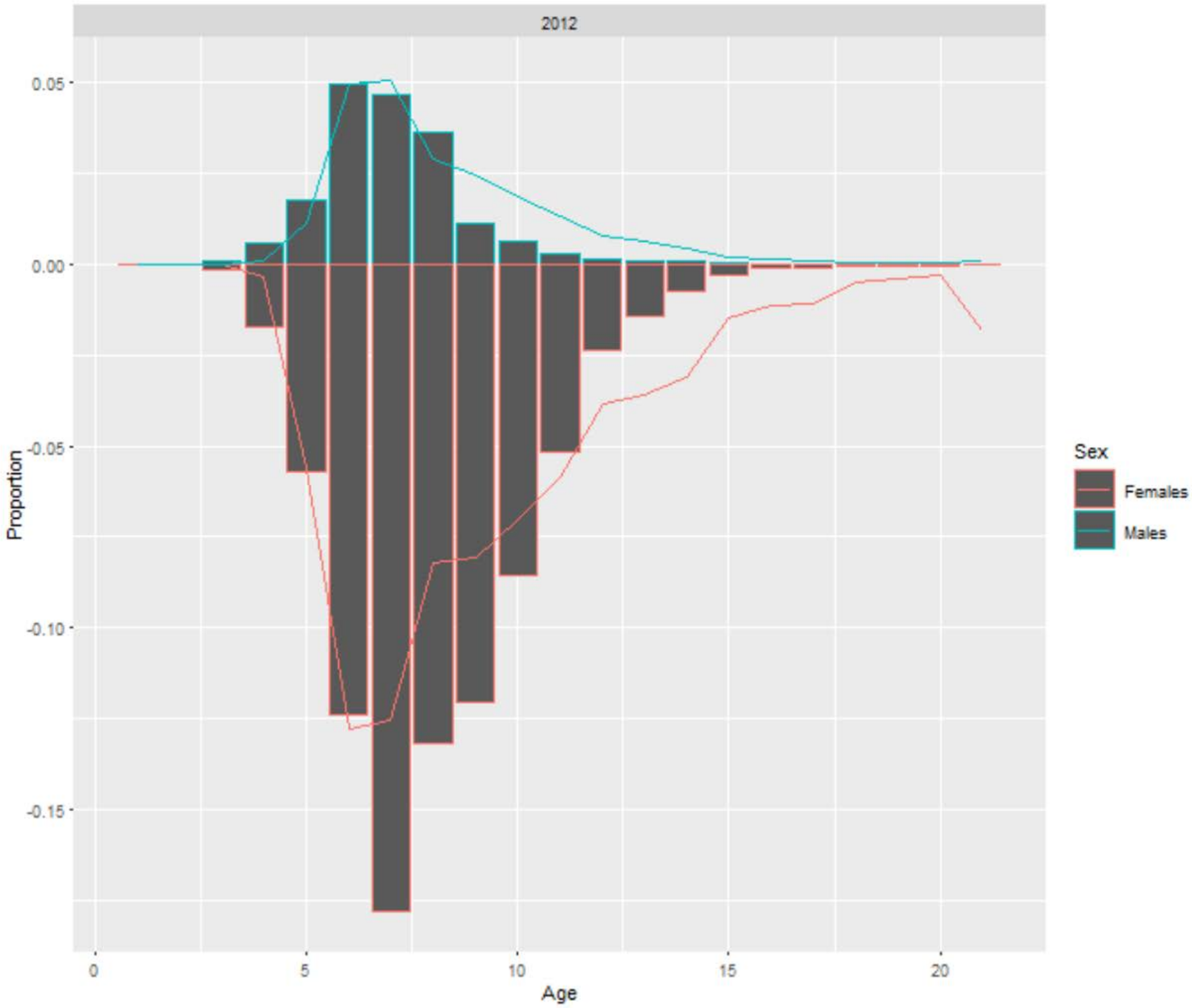


Figure 6.24. Model fit to Bering Sea slope survey observed age composition (bar plots) and predicted (lines), with males in blue, females in red (only one year of age data).

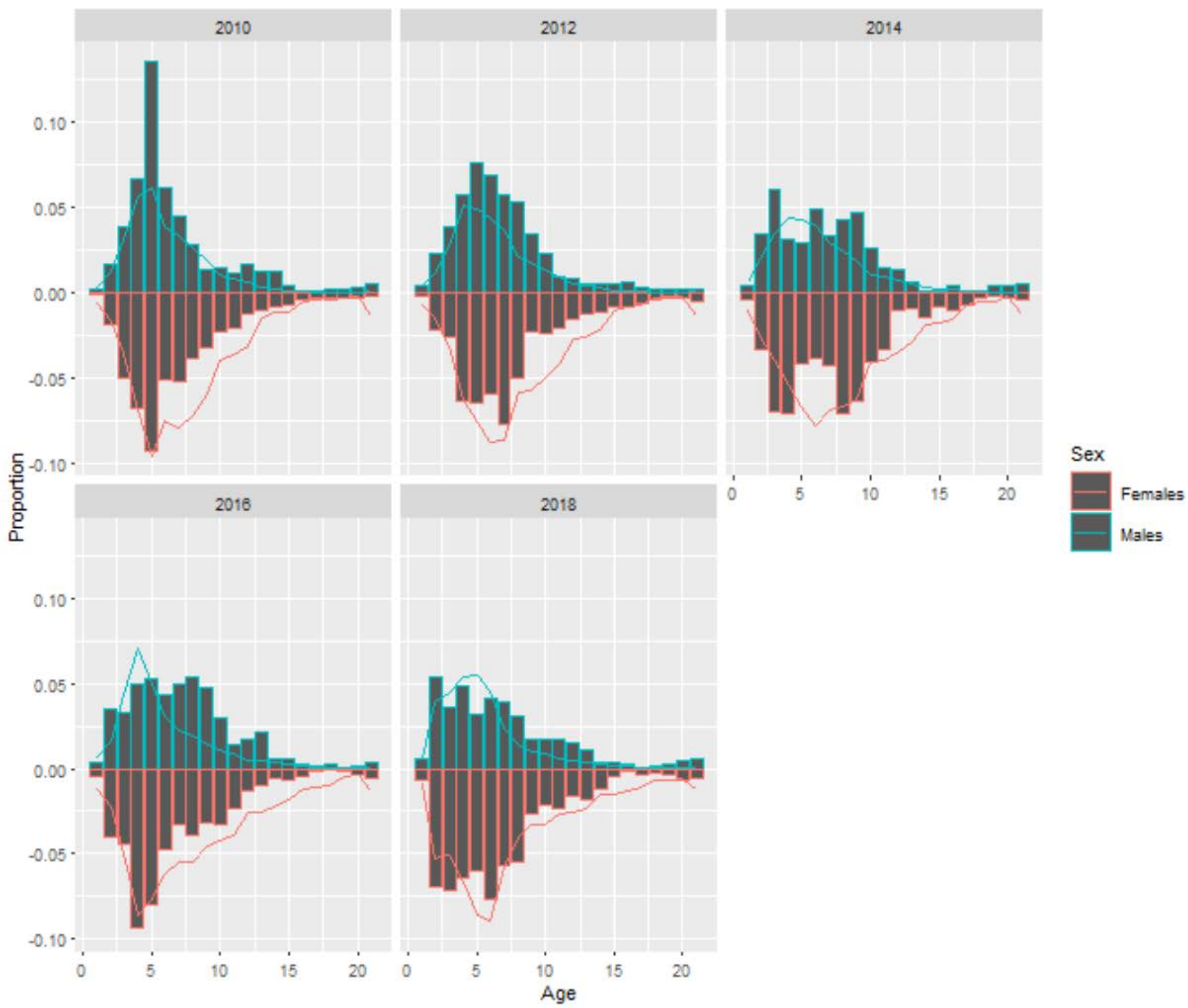


Figure 6.25. Model fit to Aleutian Island survey observed age composition (bar plots) and predicted (lines), with males in blue, females in red.

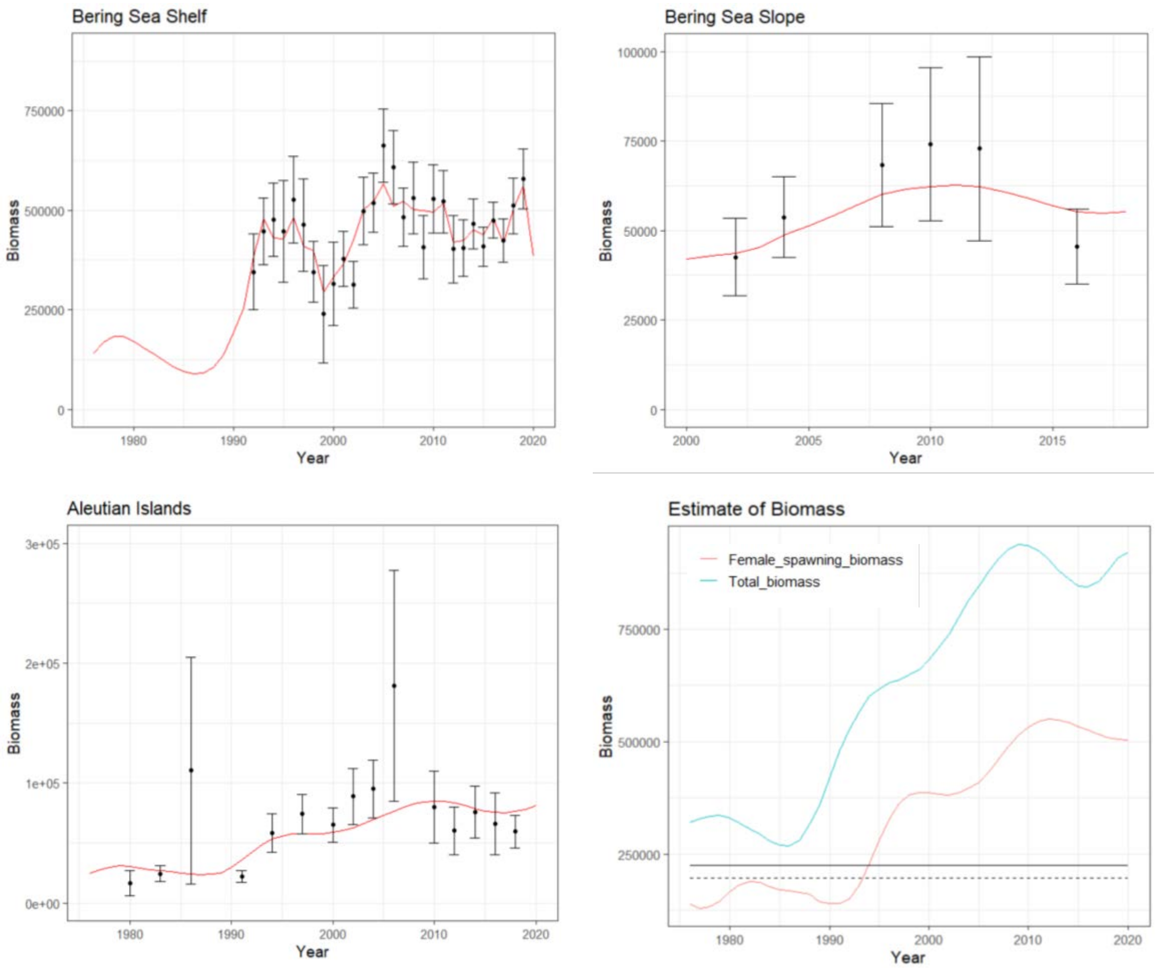


Figure 6.26. Model 18.9 results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), the fit to the Aleutian Islands survey (bottom left panel), and the estimate of female spawning biomass with $B_{35\%}$ (dashed lines) and $B_{40\%}$ (solid lines) indicated (bottom right panel). The 95% confidence intervals for survey estimates are represented as black vertical lines associated with survey biomass mean estimates (black points).

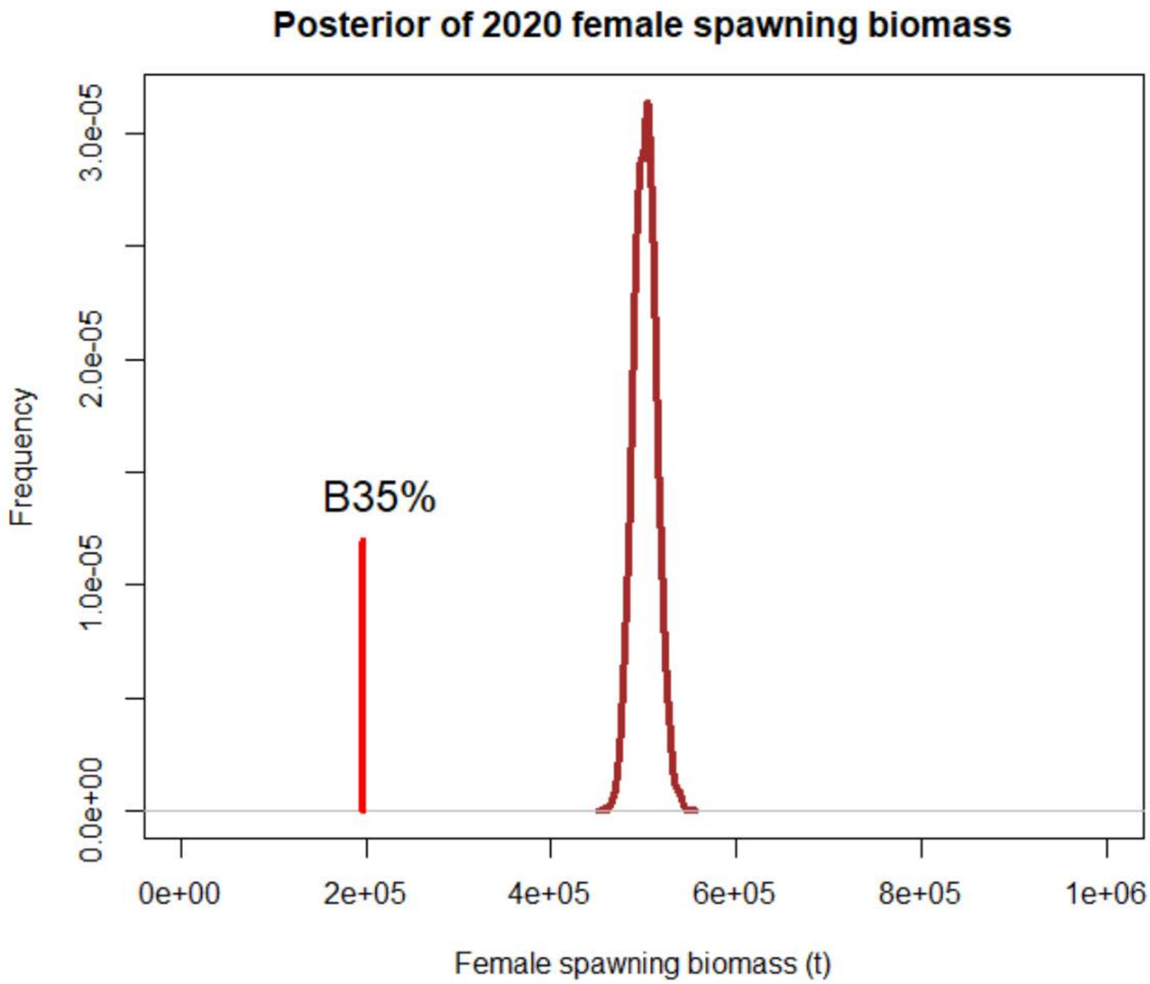


Figure 6.27. Posterior distribution of the estimate of female spawning biomass (t) from the preferred stock assessment model run (Model 18.9 (2020)), compared with the model estimate of $B_{35\%}$ or 195,589 t.

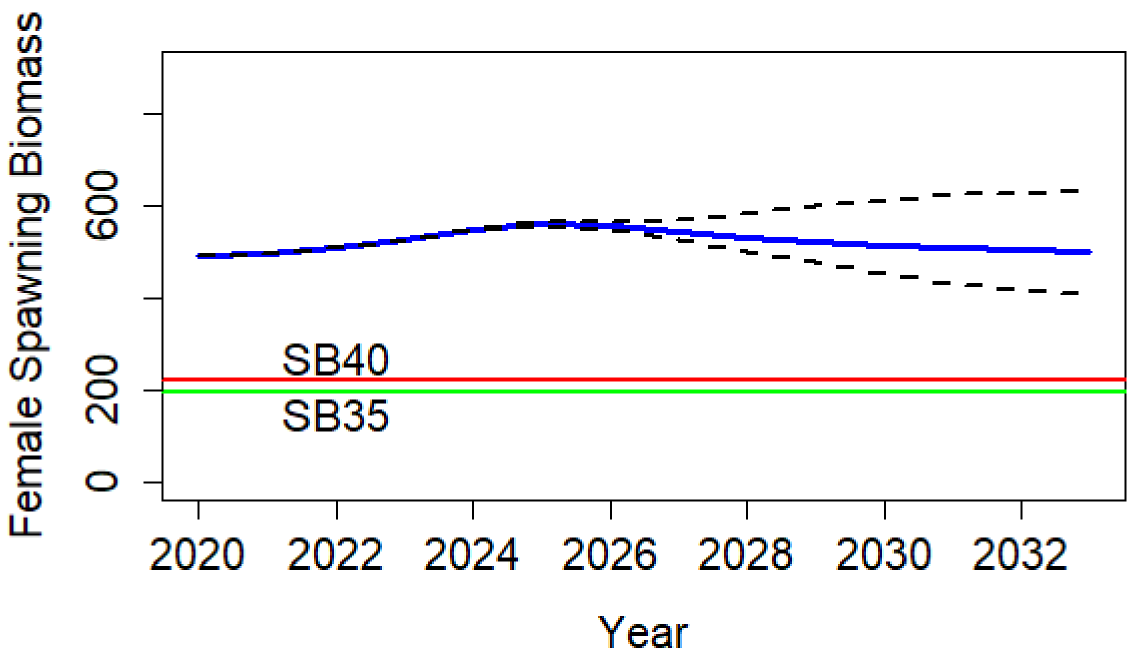


Figure 6.28. Projected female spawning biomass (1,000s t) of arrowtooth flounder if future harvest is at the same fishing mortality rate as the past five years (Alternative 4, Table 6.16).

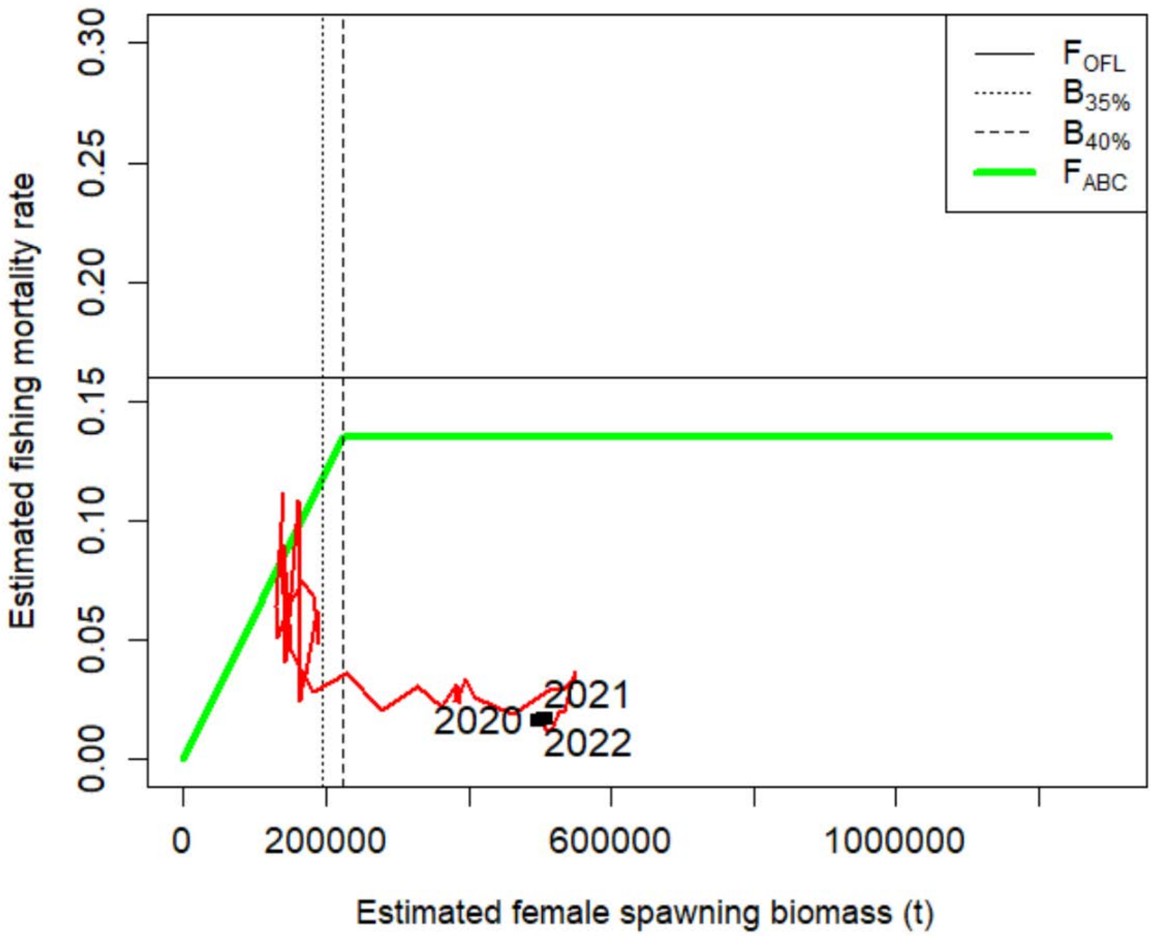


Figure 6.29. Phase plane diagram showing the time-series of stock assessment model estimates of female spawning biomass relative to the harvest control rule, with assessment model results for 2020 and projection model results for 2021 and 2022.

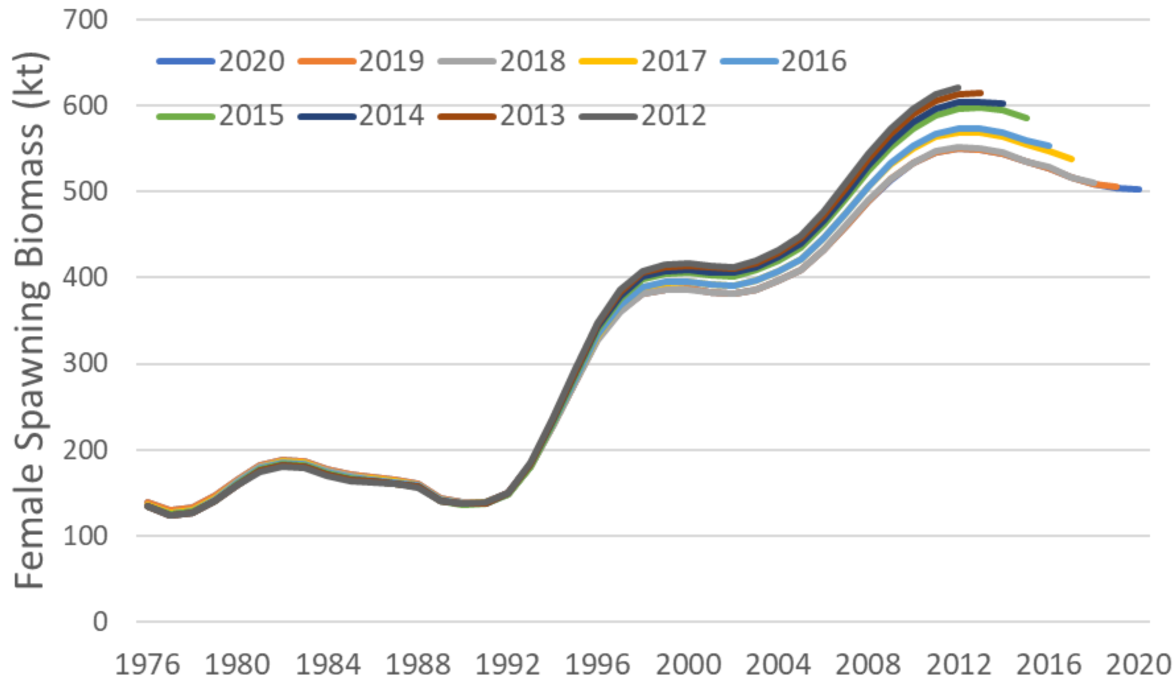


Figure 6.30. Retrospective plot of female spawning biomass. The preferred model (Model 18.9 (2020)) with data through 2020 is the longest time series. Retrospective runs were obtained by removing one year of data at a time through 2012.

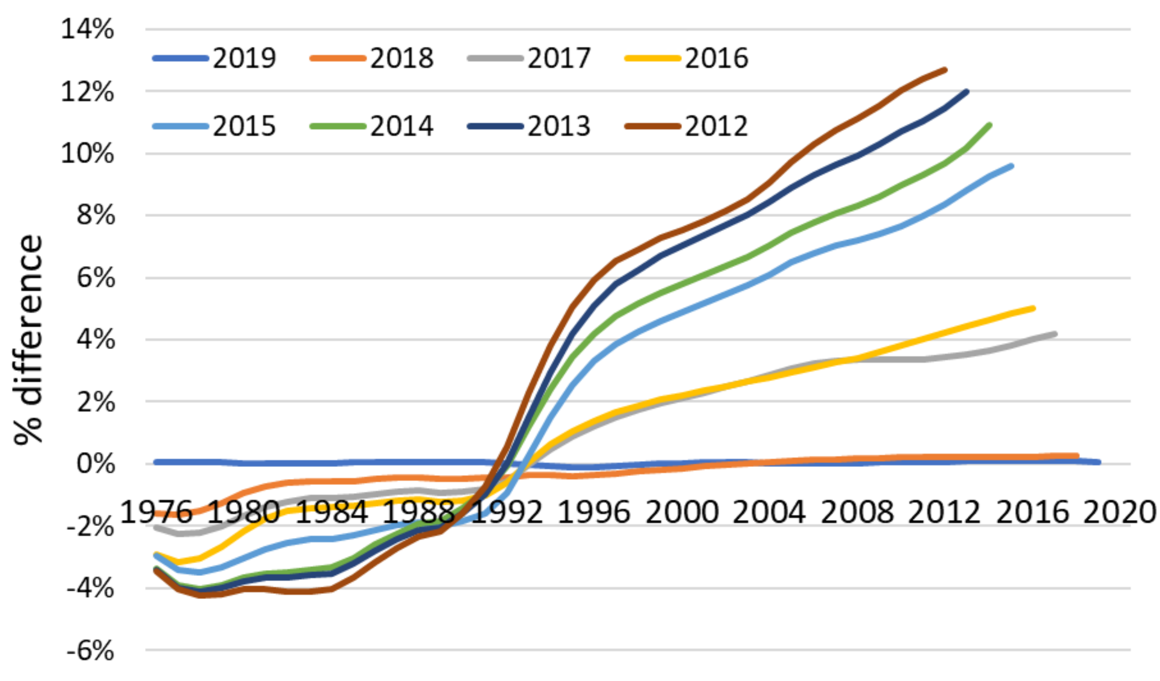


Figure 6.31. Relative differences in estimates of spawning biomass between the 2020 preferred model (Model 18.9 (2020)) and the retrospective model run for years 2020 through 2012.

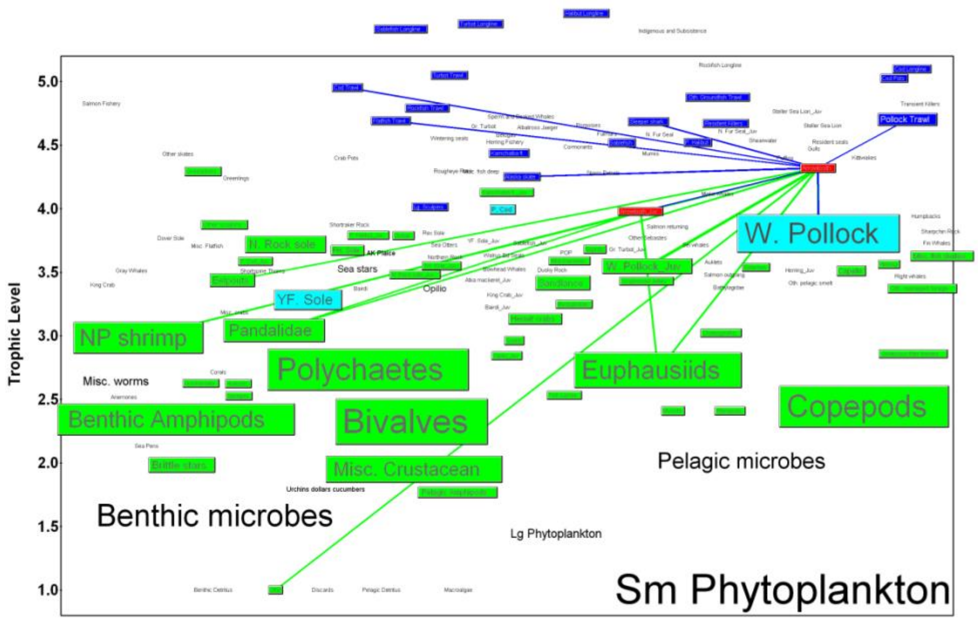


Figure 6.32. Adult and juvenile arrowtooth flounder in the EBS food web. Box size is proportional to biomass, and lines between boxes represent the most significant energy flows. Predators of arrowtooth are dark blue, prey of arrowtooth are green, and species that are both predators and prey of arrowtooth are light blue.

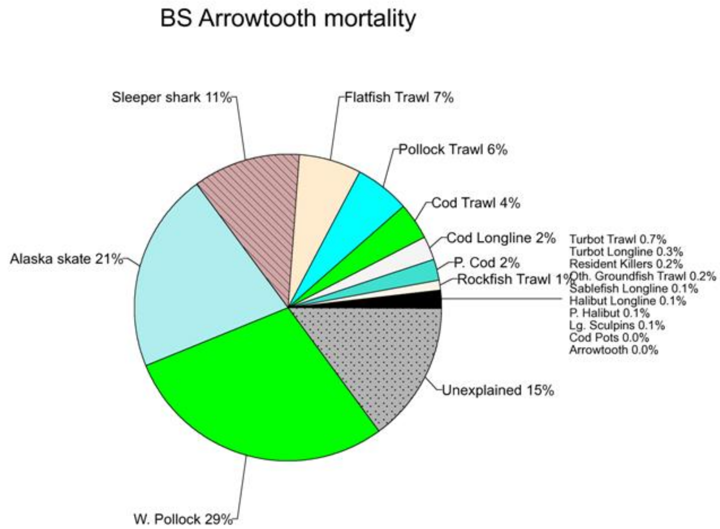


Figure 6.33. Mortality of Bering Sea arrowtooth flounder >20cm fork length by predator or fishery from predator ration and diet estimates and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter (citation). “Unexplained” mortality is the difference between the stock assessment mortality and total predation; high unexplained mortality may indicate a top predator in an ecosystem. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good diet coverage within the time period and region; striped hatching indicates limited data from literature sources; cross-hatching indicates estimate derived from ecosystem model (poor data quality).

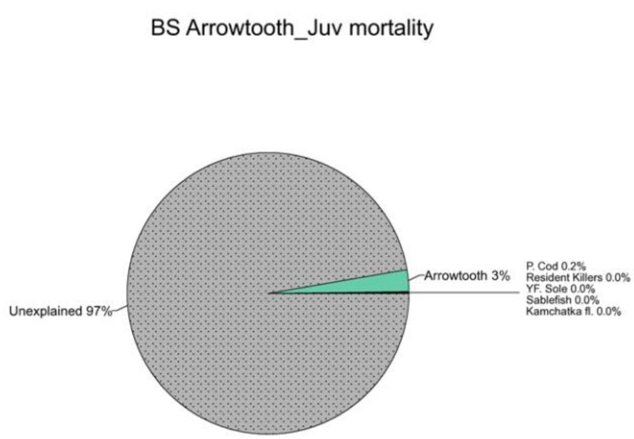


Figure 6.34. Mortality of Bering Sea arrowtooth flounder <20cm fork length by predator or fishery from predator ration and diet estimates and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter (citation). “Unexplained” mortality is the difference between the stock assessment mortality and total predation; high unexplained mortality may indicate a top predator in an ecosystem. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good diet coverage within the time period and region; striped hatching indicates limited data from literature sources; cross-hatching indicates estimate derived from ecosystem model (poor data quality).

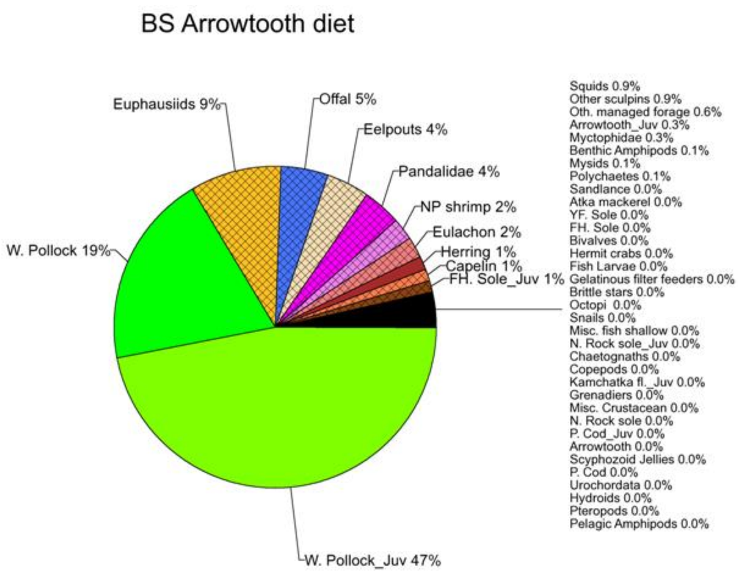


Figure 6.35. Diet of Bering Sea arrowtooth flounder >20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter (citation). Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good diet coverage within the time period and region; striped hatching indicates limited data from literature sources; cross-hatching indicates estimate derived from ecosystem model (poor data quality).

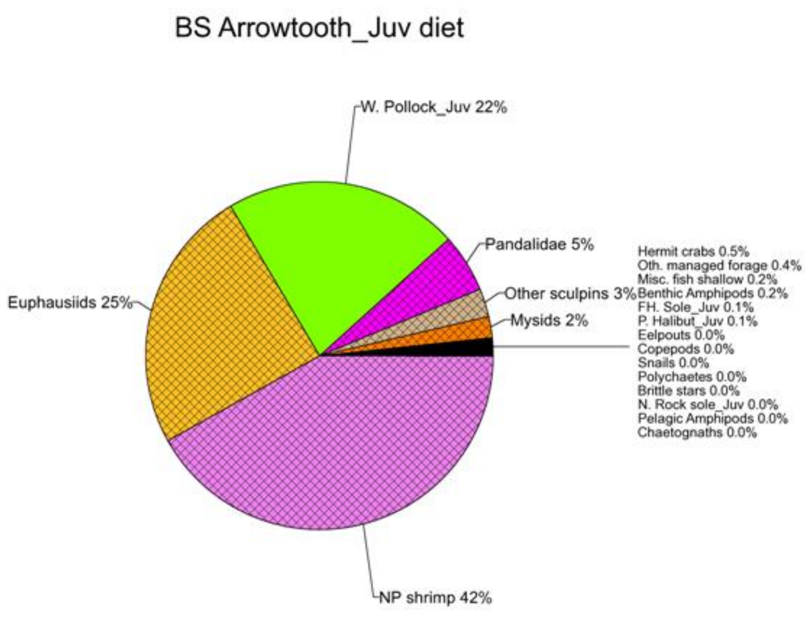


Figure 6.36. Diet of Bering Sea arrowtooth flounder <20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter (citation). Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good diet coverage within the time period and region; striped hatching indicates limited data from literature sources; cross-hatching indicates estimate derived from ecosystem model (poor data quality).

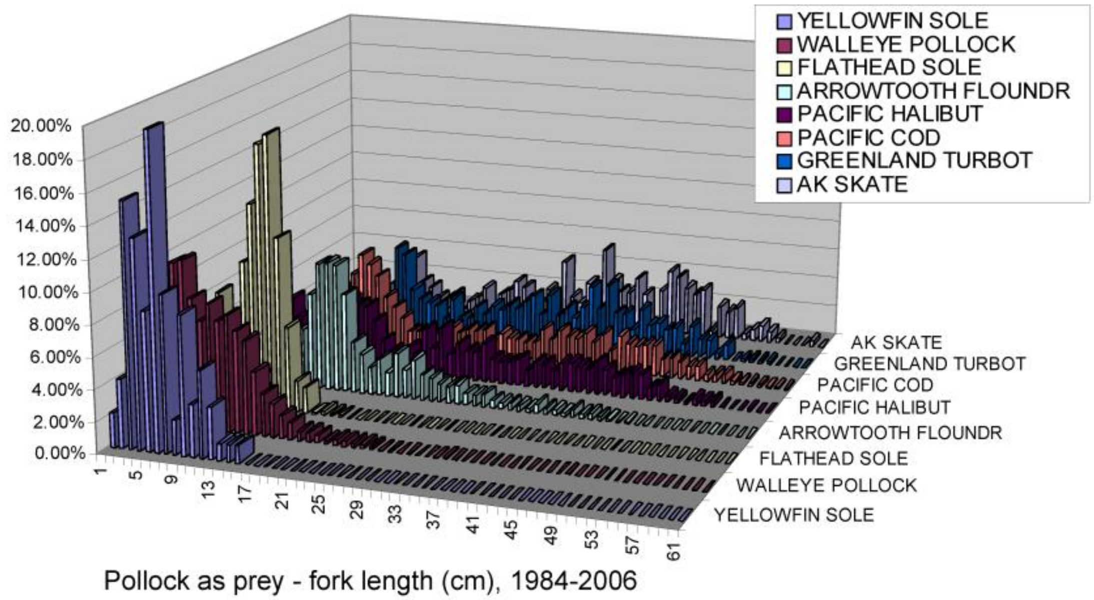


Figure 6.37. Length frequency of pollock found in stomachs, from groundfish food habits collected from 1984-2006 on AFSC summer trawl surveys in the eastern Berng Sea. Predators are sorted by median prey length of pollock in their stomachs. All lengths of predators are combined.

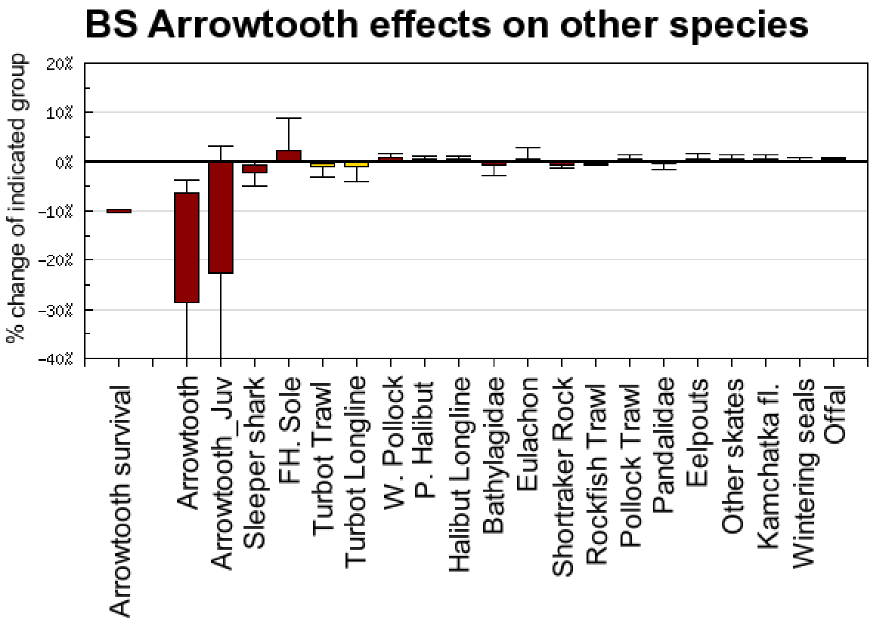


Figure 6.38. Effect of changing arrowtooth >20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting percent change in the biomass of each species on the x-axis after 30 years for 50% of feasible ecosystems, error bars show results for 95% of feasible ecosystems (see Aydin et al. in press for detailed methods).

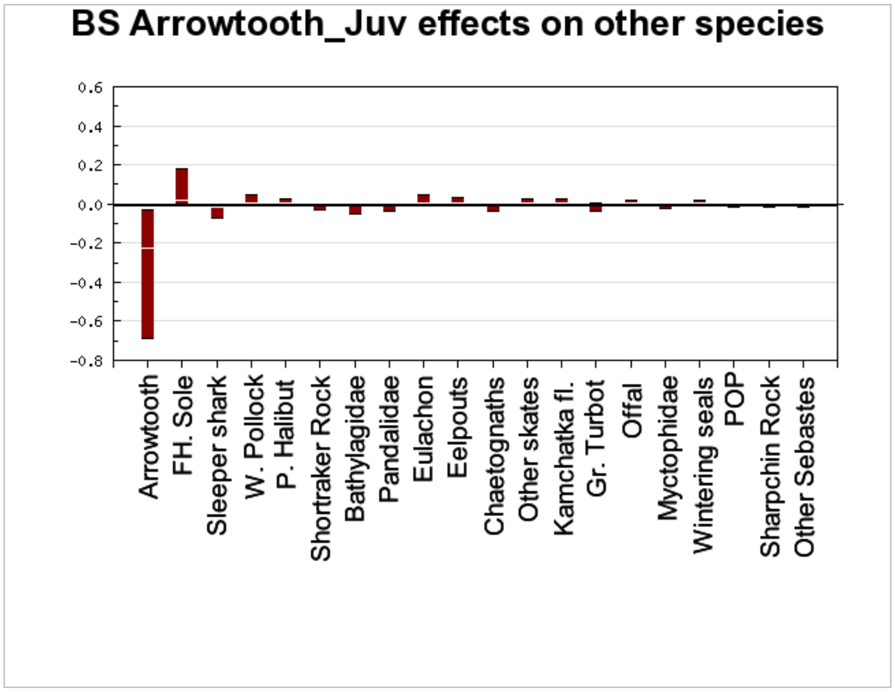


Figure 6.39. Effect of changing arrowtooth < 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting percent change in the biomass of each species on the x axis after 30 years for 50% of feasible ecosystems, error bars show results for 95% of feasible ecosystems (see Aydin et al. in press for detailed methods).

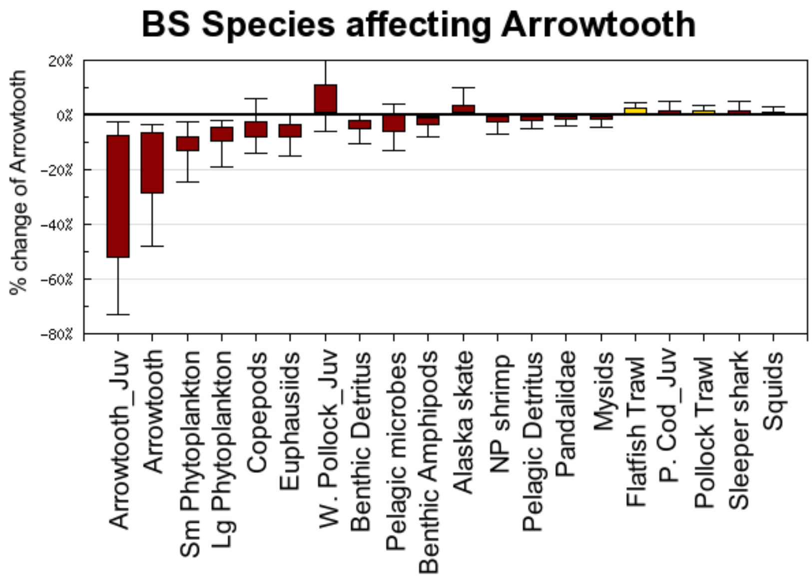


Figure 6.40. Effect of reducing fisheries catch (yellow) and other species survival (dark red) on arrowtooth > 20 cm biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting percent change in the biomass of adult arrowtooth after 30 years for 50% of feasible ecosystems, error bars show results for 95% of feasible ecosystems (see Aydin et al. in press for detailed methods).

Appendix 1

Table 6.A1.1. Total tonnage of the research catches for arrowtooth flounder and Kamchatka flounder through 2007, and for arrowtooth only from 2008 onwards. Data for 1991-2019 is from AKFIN Noncommercial Fishery Catch, and represents only arrowtooth flounder.

Year	Research catch (t)
1977	1
1978	3.7
1979	22.5
1980	63.6
1981	48.4
1982	46.6
1983	21.8
1984	6.1
1985	194.1
1986	57.7
1987	9.4
1988	33.7
1989	22.8
1990	21.9
1991	21.5
1992	23.6
1993	32.1
1994	22.5
1995	38.9
1996	27.5
1997	47.6
1998	43
1999	68.8
2000	48.3
2001	49.3
2002	24.8
2003	38.7
2004	22.6
2005	38
2006	27.6
2007	38.5
2008	22.3
2009	31.3
2010	62.6
2011	42.4
2012	50.4
2013	27.4
2014	38.3
2015	27.4
2016	46.2
2017	31.4
2018	41.9
2019	36.1

Appendix 2

Table 6.A2.2 Parameters estimated in Model 18.9 and standard deviation

Parameter name	Value	Standard deviation
srv_params_f[1]	1.67E+00	1.11E-01
srv_params_f[2]	2.69E+00	8.36E-02
srv_params_f[3]	3.51E+00	5.23E-01
srv_params_f[4]	5.10E+00	8.17E-02
srv_params_f[5]	1.12E+00	8.70E-02
srv_params_f[6]	3.90E+00	1.38E-01
srv_params_m[1]	1.49E+00	9.56E-02
srv_params_m[2]	3.23E+00	9.62E-02
srv_params_m[3]	3.03E+00	7.34E-01
srv_params_m[4]	5.58E+00	1.49E-01
srv_params_m[5]	1.51E+00	1.10E-01
srv_params_m[6]	3.51E+00	1.09E-01
srv1desc_params_f[1]	7.79E-01	7.17E-02
srv1desc_params_f[2]	1.04E+01	1.98E-01
srv1desc_params_m[1]	6.35E-01	1.09E-01
srv1desc_params_m[2]	8.13E+00	2.61E-01
alpha	-2.89E-01	2.97E-02
beta	1.01E-01	8.11E-03
mean_log_rec	1.85E+01	3.43E-02
rec_dev	-1.14E+00	4.71E-01
rec_dev	-4.73E-01	5.75E-01
rec_dev	-5.33E-01	5.63E-01
rec_dev	-5.96E-01	5.51E-01
rec_dev	-6.61E-01	5.39E-01
rec_dev	-7.15E-01	5.30E-01
rec_dev	-7.75E-01	5.20E-01
rec_dev	-8.29E-01	5.11E-01
rec_dev	-8.97E-01	5.03E-01
rec_dev	-9.47E-01	4.96E-01
rec_dev	-9.84E-01	4.90E-01
rec_dev	-1.02E+00	4.86E-01
rec_dev	-1.01E+00	4.86E-01
rec_dev	-9.46E-01	4.91E-01
rec_dev	-8.16E-01	5.05E-01
rec_dev	-5.89E-01	5.34E-01
rec_dev	-1.16E-01	6.17E-01
rec_dev	7.03E-01	5.83E-01
rec_dev	9.27E-01	3.87E-01
rec_dev	-6.08E-01	5.26E-01
rec_dev	-1.30E+00	4.38E-01
rec_dev	-1.54E+00	4.18E-01
rec_dev	-1.19E+00	4.41E-01

rec_dev	1.72E-01	2.40E-01
rec_dev	-5.62E-01	4.01E-01
rec_dev	-1.12E+00	3.93E-01
rec_dev	-1.40E+00	3.92E-01
rec_dev	-1.17E+00	3.41E-01
rec_dev	-5.20E-01	2.39E-01
rec_dev	-1.60E-01	1.91E-01
rec_dev	5.52E-01	1.29E-01
rec_dev	1.05E+00	9.71E-02
rec_dev	1.15E+00	8.73E-02
rec_dev	1.04E+00	8.60E-02
rec_dev	6.54E-01	9.82E-02
rec_dev	1.96E-01	1.17E-01
rec_dev	2.36E-01	1.12E-01
rec_dev	3.06E-02	1.20E-01
rec_dev	6.75E-02	1.14E-01
rec_dev	1.32E-01	1.17E-01
rec_dev	6.37E-01	9.70E-02
rec_dev	4.69E-01	1.23E-01
rec_dev	5.14E-01	1.31E-01
rec_dev	1.01E+00	9.38E-02
rec_dev	9.33E-01	9.57E-02
rec_dev	7.82E-01	9.89E-02
rec_dev	9.77E-01	8.61E-02
rec_dev	9.37E-01	8.35E-02
rec_dev	8.43E-01	7.84E-02
rec_dev	6.35E-01	7.66E-02
rec_dev	8.39E-01	6.43E-02
rec_dev	6.85E-01	6.61E-02
rec_dev	5.06E-01	7.01E-02
rec_dev	4.87E-01	7.01E-02
rec_dev	2.75E-01	7.65E-02
rec_dev	2.45E-01	7.72E-02
rec_dev	4.20E-01	7.30E-02
rec_dev	7.16E-01	6.79E-02
rec_dev	6.35E-01	7.55E-02
rec_dev	5.52E-01	8.84E-02
rec_dev	7.71E-01	9.77E-02
rec_dev	1.54E+00	9.94E-02
rec_dev	6.34E-01	2.21E-01
rec_dev	-3.46E-01	5.32E-01
log_avg_fmort	-3.39E+00	3.73E-02
fmort_dev	1.20E+00	1.07E-01
fmort_dev	6.46E-01	9.83E-02
fmort_dev	4.07E-01	8.96E-02
fmort_dev	6.26E-01	8.49E-02

fmort_dev	7.88E-01	8.06E-02
fmort_dev	7.12E-01	7.48E-02
fmort_dev	3.69E-01	7.31E-02
fmort_dev	6.22E-01	7.39E-02
fmort_dev	2.75E-01	7.29E-02
fmort_dev	5.25E-02	7.18E-02
fmort_dev	3.68E-02	7.28E-02
fmort_dev	-3.18E-01	7.37E-02
fmort_dev	1.17E+00	7.58E-02
fmort_dev	1.98E-01	7.48E-02
fmort_dev	7.26E-01	7.24E-02
fmort_dev	9.82E-01	7.09E-02
fmort_dev	2.97E-01	7.08E-02
fmort_dev	-1.73E-01	7.09E-02
fmort_dev	7.27E-02	6.94E-02
fmort_dev	-4.84E-01	6.62E-02
fmort_dev	-9.19E-02	6.40E-02
fmort_dev	-4.42E-01	6.37E-02
fmort_dev	-6.90E-02	6.41E-02
fmort_dev	-3.54E-01	6.42E-02
fmort_dev	-1.98E-01	6.43E-02
fmort_dev	-1.38E-01	6.41E-02
fmort_dev	-3.37E-01	6.35E-02
fmort_dev	-2.66E-01	6.34E-02
fmort_dev	7.79E-03	6.36E-02
fmort_dev	-2.78E-01	6.40E-02
fmort_dev	-3.82E-01	6.46E-02
fmort_dev	-5.64E-01	6.43E-02
fmort_dev	-3.27E-01	6.46E-02
fmort_dev	-1.58E-01	6.46E-02
fmort_dev	-1.45E-01	6.49E-02
fmort_dev	-2.37E-02	6.52E-02
fmort_dev	8.10E-02	6.53E-02
fmort_dev	8.77E-03	6.53E-02
fmort_dev	-3.70E-02	6.58E-02
fmort_dev	-5.54E-01	6.56E-02
fmort_dev	-5.53E-01	6.56E-02
fmort_dev	-1.07E+00	6.55E-02
fmort_dev	-9.98E-01	6.52E-02
fmort_dev	-6.43E-01	6.50E-02
fmort_dev	-6.79E-01	6.51E-02
log_selcoffs_fish	-4.81E+00	8.50E-01
log_selcoffs_fish	-3.49E+00	7.66E-01
log_selcoffs_fish	-2.26E+00	7.35E-01
log_selcoffs_fish	-1.26E+00	7.24E-01
log_selcoffs_fish	-5.09E-01	7.18E-01

log_selcoffs_fish	6.05E-02	7.16E-01
log_selcoffs_fish	4.98E-01	7.14E-01
log_selcoffs_fish	7.41E-01	7.12E-01
log_selcoffs_fish	7.45E-01	7.10E-01
log_selcoffs_fish	7.23E-01	7.10E-01
log_selcoffs_fish	-3.63E+00	7.50E-01
log_selcoffs_fish	-2.79E+00	7.30E-01
log_selcoffs_fish	-1.97E+00	7.20E-01
log_selcoffs_fish	-1.23E+00	7.15E-01
log_selcoffs_fish	-5.81E-01	7.12E-01
log_selcoffs_fish	-4.69E-02	7.11E-01
log_selcoffs_fish	3.66E-01	7.09E-01
log_selcoffs_fish	6.48E-01	7.08E-01
log_selcoffs_fish	8.07E-01	7.08E-01
log_selcoffs_fish	8.64E-01	7.09E-01
F40	1.39E-01	2.43E-02
F35	1.66E-01	2.98E-02