6. Assessment of the arrowtooth flounder stock in the 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 14, 2022 for Bering Sea Aleutian Islands (BSAI).
2. Fishery size compositions for 2020 and 2021.
3. Biomass point-estimates and standard errors from the 2021 and 2022 eastern Bering Sea (EBS) shelf bottom trawl survey (BTS) and 2022 Aleutian Islands (AI) BTS.
4. Age data from the 2021 eastern Bering Sea shelf.
5. The recommended model did not include fishery size compositions prior to the start of the Observer Program (pre-1991), or fishery size compositions with fewer than 300 samples, or Aleutian Islands survey data prior to the standardization of the survey (pre-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). We do provide a sensitivity analysis to the data cleaning exercise as requested by the BSAI Plan Team and the SSC and present this in the Response to SSC and Plan Team Comments Specific to this Stock section. 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 suggest 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.

	As estimated or *specified last* year for:		*As estimated or *recommended this* year for:	
Quantity	2022	2023	2023	2024
M (natural mortality rate)**	0.2, 0.35	0.2, 0.35	0.2, 0.35	0.2, 0.35
Tier	3a	3a	3a	3a
Projected total (age 1+) biomass (t)	921,690	914,915	929,274	919,797
Projected Female spawning	509,672	528,725	514,577	537,999
$B_{100\%}$	558,826	558,826	561,219	561,219
$B_{40\%}$	223,530	223,530	224,487	224,487
$B_{35\%}$	195,589	195,589	196,427	196,427
F_{OFL}	0.160	0.160	0.174	0.174
$maxF_{ABC}$	0.135	0.135	0.146	0.146
F_{ABC}	0.135	0.135	0.146	0.146
OFL (t)	94,445	97,944	98,787	103,070
maxABC (t)	80,389	83,389	83,852	87,511
ABC (t)	80,389	83,389	**83,852**	**87,511**
	As determined *last* year for:		As determined *this* year for:	
Status	2020	2021	2021	2022
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 8,048 t for 2022, 8,507 t for 2023, and 7,977 t for 2024 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.
**Natural mortality rate is 0.2 for females, 0.35 for males.

The 2021 eastern Bering Sea (EBS) bottom trawl survey estimate decreased 21% from the 2019 survey and the 2022 EBS bottom trawl survey increased 14% from the 2021 estimate. The 2022 EBS estimate is now 14% above average. The 2022 Aleutian Islands (AI) bottom trawl survey estimate decreased 3% from the 2018 estimate and is now 18% below average. 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 14, 2022 is at 9% of ABC. The total allowable catches (TACs) for arrowtooth flounder are generally set well below ABC and have been between 11-27% of ABC. The 2022 ratio of TAC to ABC was 25%.

For the 2023 fishery, we recommend the maximum allowable ABC of 83,852 t from the 2018 accepted model (Model 18.9). This is a 4% increase from last year's ABC of 80,389 t. The projected female spawning biomass for 2023 is 514,577 t and the projected age 1+ total biomass for 2023 is 929,274 t. Female spawning biomass is well above $B_{40\%}$, and projected to be stable.

Summaries for Plan Team

Species	Year	Biomass[1]	OFL	ABC	TAC	Catch[2]
Arrowtooth Flounder	2021	923,646	90,873	77,349	15,000	9,014
	2022	921,690	94,445	80,389	20,000	7,107
	2023	929,274	98,787	83,852	n/a	n/a
	2024	919,797	103,070	87,511	n/a	n/a

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

[2]Current as of October 14, 2022. 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 Teams recommend that, for ESPs in general, when a fishery performance indicator may have ambiguous interpretations, no traffic light color coding should be assigned, but the scoring (which is indicative of a trend, but not the relationship of the indicator to stock health) should be maintained.*" (Joint Plan Team, November 2021)

An ecosystem and socioeconomic profile or ESP has not been created for this stock at this time. If an ESP is generated in the future we will use the standardized format which no longer includes a traffic light color coding for fishery performance indicators. This was instituted in the 2022 ESPs for several groundfish stocks and allows for the scoring to be maintained without the ambiguous color interpretations.

"*The Team recommends that the AFSC prioritize research on best practices for specifying the selectivity schedules used in projections for Tier 1-3 stocks in general.*" (BSAI Plan Team, November 2021)

Since BSAI ATF does not use time-varying fishery selectivity, selectivity is the same for projections as in the assessment model.

"*The Team recommends all GOA authors evaluate any bottom trawl survey information used in their assessment prior to 1990 including the 1984 and 1987 surveys and conduct sensitivity analyses to evaluate their usefulness to the assessment. This may apply for Aleutian Islands surveys but this was only raised during GOA assessment considerations.*" (GOA Plan Team, November 2021)

This is not a GOA stock but we did consult the Groundfish Assessment Program (GAP) regarding the appropriate starting year for arrowtooth flounder biomass estimates from the Aleutian Islands bottom trawl survey (AI BTS). The time series for the AI BTS began in 1980 but gear was not standardized until the 1991 survey when the Poly'Noreastern (PNE) bottom trawl was uniformly implemented. We now start the AI BTS biomass time series, length compositions, and age compositions in 1991 based on recommendations from the GAP program to use the standardized time series estimates. Please see the Survey Data subsection for more information. We also provide a comparison of the spawning biomass estimates for full time series from Model 18.9 using the full AI BTS time series (1980-2022) with the standardized index (1991-2022). The average difference in biomass (ADSB) was about 0.5% (Figure 6.11). Based on this result, we determined this change was a minor data correction and did not require a separate model evaluation.

"*With respect to Risk Tables, the SSC would like to highlight that "risk" is the risk of the ABC exceeding the true (but unknown) OFL, as noted in the October 2021 SSC Risk Table workshop report. Therefore, for all stocks with a risk table, assessment authors should evaluate the risk of the ABC exceeding the true (but unknown) OFL and whether a reduction from maximum ABC is warranted, even if past TACs or exploitation rates are low.*" (SSC, December 2021)

Since this is a full assessment year for BSAI arrowtooth flounder, we provide a risk table with formatting as recommended by the SSC and the table ranking descriptions for completeness. We evaluated the four

risk categories as they relate to the arrowtooth flounder stock assessment, population dynamics and fishery performance as presented in this SAFE report and also consulted with the Ecosystem Status Report or ESR editors regarding the environmental/ecosystems considerations. 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 that groundfish, crab and scallop assessment authors do not change recommendations in documents between the Plan Team and the SSC meetings, because it makes it more difficult to understand the context of the Plan Team's rationale and seems counter to the public process without seeing a revision history of the document."*

"The SSC recommends a working group be formed to explore options for altering the timing of reviews of select crab and groundfish assessments to address this timing issue"

(SSC, December 2021)

We do not plan to change the recommendations in this SAFE document between the Plan Team and the SSC meetings and did not change the SAFE document from the last full assessment between meetings.

In reference to the lack of recent EBS slope survey information: "*The SSC recommends that assessment authors continue to highlight instances where the lack of these data may degrade stock assessment performance.*" (SSC, October 2022)

In the September Plan Team meeting we discussed the importance of the EBS slope survey information during several of the presentations to the BSAI Plan Team. We also continue to use the EBS slope survey in the arrowtooth flounder assessment which highlights the importance of this survey. The BSAI Plan Team minutes also reflect the importance of the slope survey information and highlight the need for continued monitoring of the slope environment. It is possible that the AFSC longline survey may be used in the future to substitute for information previously provided by the EBS slope trawl survey.

"*The Teams recommended that stock assessment authors transition from the ADMB random-effects survey smoother to this package which implements the same model with several improvements.*" (Joint Plan Team, September 2022)

"*The SSC supports the JGPT's recommendation that stock assessment authors transition from the ADMB RE variants to the rema framework, which implements the same model variants in a single framework with several improvements.*" (SSC, October 2022)

We use the rema R package to estimate the proportion of arrowtooth flounder in each survey.

Responses to SSC and Plan Team Comments Specific to this Assessment

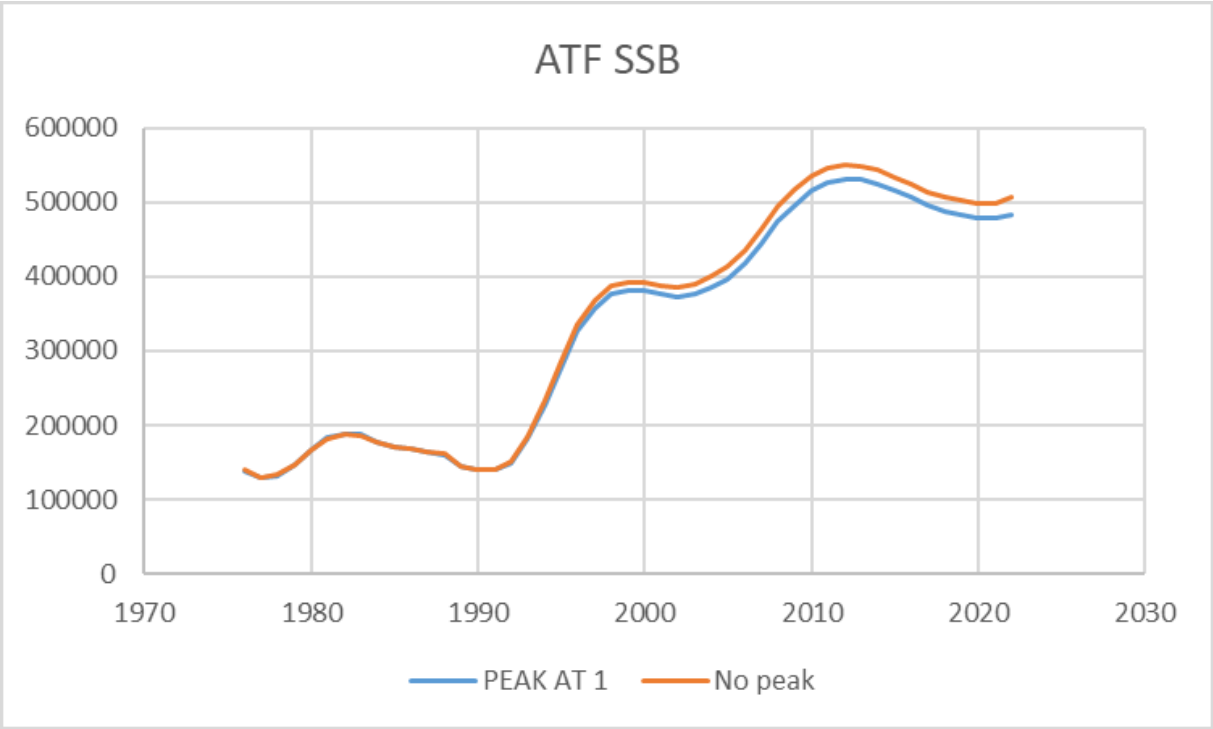
"The SSC notes that model fits to the female fishery composition data are poor and this may still be related to the amount of sex-specific data available for certain years and issues with speciation. The authors are planning to investigate data quality issues as they relate to sample size and speciation issues associated with the compositional information. The SSC looks forward to this additional information in the next assessment." (SSC, December 2022)

While inspecting the poor fits to the fishery length composition data, we found that the poorest fits were often in the more historical data (70s and early 80s). We consulted with the Observer Program on the appropriate starting point for using data from the observer database for this stock. Joint venture started in the late 1970s and the U.S. domestic program was phased in starting in 1987 and was completely domestic by 1990. Reliable cruise and vessel records started in 1991 and so the recommendation from the Observer

Program was to start using data at that time. After limiting the data to post-1990, we also inspected the sample sizes and found that there were several years with very low sample sizes that were used in the size compositions (<300 was our guideline). Along with removing pre-1991 data, we also removed years with low sample size (1992-1997, 2014-2017). Please see the Fishery Data subsection for more information. We also provide a comparison of the spawning biomass estimates for the full time series from Model 18.9 using the full set of fishery size compositions from the base model (1978-2021) with the cleaned fishery size composition index (1991-2022, removing low sample size years). The average difference in biomass (ADSB) was about 0.2% (Figure 6.11). Based on this result, we determined this change was a minor data correction and did not require a separate model evaluation.

"The SSC recommends that the authors check the parameterization for selectivity and the estimated selectivity curves for the shelf survey to verify that the peaks of the domed shape failing to reach a value of 1.0 does not create any unexpected artifacts in the calculations or change the interpretation of catchability or other model results. In addition, the SSC requests the authors bring forward historical information on the rationale used for the selectivity parameterizations used in the assessment." (SSC, December 2020)

The double logistic selectivities do not necessarily peak at 1 as they are the product of two curves with asymptotes at each end of the ages. The female selectivity does peak at 1 and is constrained to do so, the male selectivity is not. There may or may not be a biological rationale for this, but as currently estimated implies that males are a little less vulnerable than females to the shelf survey gear. We will do a literature review to find out the background for why the shelf is assumed to be both dome shaped and not reach a peak of 1 for males. We ran a sensitivity analysis to this assumption and forced males to also peak at 1 and it resulted in approximately 5% less female spawning biomass in the terminal year.



Regarding selectivities used in the model, the fishery uses the non-parametric smoothing function with ages after 10 set to be equal, while the EBS shelf survey uses a 4 parameter double logistic to allow for a descending limb and the AI and EBS slope surveys use a regular asymptotic logistic.

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 but 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 14,681 t from 1991-2021 and 12,790 t from 2011-2021. Total catch reported through October 14, 2022 is 7,107 t. The NMFS AKRO BLEND/Catch Accounting System reports indicate that bottom trawling accounted for 94% of the 2021 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 joint venture 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 1985-2022 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 85% in 2014, and has remained high through 2021 (89%). 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 (EBS) shelf, EBS slope, and Aleutian Islands (AI) bottom trawl survey (BTS), sex-specific BTS 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 are available from 1976 – October 14, 2022 (Table 6.2) and fishery length-frequency data from 1978-2021. Underlined values are used in the assessment (Table 6.5). Joint venture fisheries started in the late 1970s and the U.S. domestic Observer Program was phased in starting in 1987 and was completely domestic by 1990. Reliable cruise and vessel records started in 1991. Arrowtooth flounder catch is available from observer at-sea sampling applied to the Alaska Regional Office blend estimates for 1991-2022. 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 in the EBS BTS survey). These proportions were applied to the catch totals in Table 6.2, under “ATF estimate”.

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, species identification 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).

Arrowtooth flounder catch was relatively steady from 1991-2007 and were primarily caught in various Bering Sea flatfish fisheries and in the Pacific cod fisheries. In 2008, catch increased to a peak in 2010 and has been declining since. There was a large catch of arrowtooth flounder in the eastern AI NMFS region 541 in 2010 that added to the near average catch in the Bering Sea to create the peak in the time series. After this peak, catch has steadily been decreasing to current levels. Fishing has occurred in various NMFS areas over time, but often in area 517 and 521 near the slope area, and 509 and more recently in 513 in the middle shelf area. These fishing distributions overall match the spatial distribution of the stock on the EBS shelf as generally spread out along the outer shelf domain (Figure 6.3), but the peak in 2010 in the AI does not match the peak in the survey that occurred in 2006 (Figure 6.1).

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.

Detailed tables on the economic performance of flatfish fisheries in the BSAI are provided in Appendix Table 6.A1.2 for the first-wholesale market and Table 6.A1.3 for the U.S. trade and global market (A. Ableman, *pers. commun.*).

Fishery Age and Length Compositions

Otoliths have been collected sporadically in the fishery since 1982 but sample sizes are generally low following the initiation of the Observer Program (Table 6.5). Not all of these otoliths have been aged. It may be possible to age some of these otoliths during years when the samples were higher (>100) through the AFSC Age and Growth prioritization system; however, the ageing request would need to be evaluated within the scope of the AFSC Age and Growth available staff time and resources (J. Short and B. Matta, *pers. commun*.). Also, the years when otolith sample sizes were higher are fairly sporadic, and aging of these otoliths may not be worth the extra effort given the number of otoliths aged by the AFSC Age and Growth program each year.

The number of fisheries length observations taken by fisheries observers by year from 1978-2021 are presented in Table 6.5. Sample sizes (number of individual fish) for the fishery length data were generally above 5,000 from the late 1970s through 1987 (Table 6.5). Sample sizes were considerably lower from 1988 until 2018. The data prior to 1989 is referred to as "foreign" data, but the fishing of the latter years was done predominately by joint venture vessels which eventually replaced the foreign fishers (Table 6.2a). The number of male and female lengths used in the model as length composition data, by year, are shown in Figure 6.2. We restricted the start year to 1991 as that is when reliable length composition data were available since the start of the domestic Observer Program. We also restricted the analysis to years

when greater than 300 lengths were collected. There do not appear to be any long-term trends in the length composition data from the fishery (Figure 6.2), but there is variation over time.

Survey:

Biomass estimates (t) for arrowtooth flounder from the standard survey area in the eastern Bering Sea (EBS) and Aleutian Islands (AI) region are shown in Table 6.6. Biomass estimates for arrowtooth flounder were produced from cooperative U.S.-Japan bottom trawl surveys (BTS) from 1979-1985 on the EBS slope, and from 1980-1986 in the AI. U.S domestic bottom trawl surveys were conducted from 1982-2022 on the EBS shelf BTS, in 1988, 1991, 2002, 2004, 2008, 2010, 2012, and 2016 on the EBS slope, and in 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018, and 2022 on the AI BTS (Table 6.6). The 2008 AI survey and 2006, 2010, and 2018 EBS slope surveys were canceled. The 2020 EBS shelf, AI, and EBS slope BTS were canceled due to the COVID-19 pandemic. The spatial distribution of the BTS strata are provided in Figure 6.2.

AFSC Eastern Bering Sea Shelf Survey Biomass Estimates

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. The expanded survey area has been the standard sampling area to the present time. 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) indicated 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. The spatial distribution of arrowtooth flounder catch-per-unit-effort from 1991 to present is provided in Figure 6.3 and shows the majority of the arrowtooth flounder distribution on the mid to outer shelf with concentration shifting northwest along the slope, sometimes following the cold pool (red polygon) extent. Large concentrations tended to exist in the southern corner of the area during the earlier part of the time series, but the population has spread out more since the marine heatwaves began in 2014 (Figure 6.3). Biomass estimates from EBS shelf BTS 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 660,315 t. The 2021 shelf survey estimate was a decrease of 20% from the 2019 survey, while the 2022 shelf survey estimate was an increase of 14% from the 2021 estimate and is now 14% above the long-term time series mean.

AFSC Eastern Bering Sea Shelf Survey Age and Length Compositions

Arrowtooth flounder otolith samples from AFSC BTS have been collected from 1979 to the present. Otolith samples from most years have been aged and are summarized in Table 6.7. All the available age composition data collected from 1992 to present with adequate sample sizes (>100) are used in the model for the EBS shelf BTS survey (Table 6.7). Differences in ageing methodology exist but are not expected to bias results (D. Anderl, *pers. commun.*). Age frequency data for males and females indicate some recent recruitment events and that the population consists of more old females and more young males (Figure 6.4). Length composition data are not used when age data are available or anticipated to be available in the following assessment year. Length frequency data from the EBS shelf BTS indicate slightly smaller sizes in females since the 1990s, and that females are larger than males overall (Figure 6.5). The number of lengths collected from AFSC BTS are shown in Table 6.7.

AFSC Eastern Bering Sea Slope Survey Biomass Estimates

Trawl surveys were intermittently conducted over the continental slope of the eastern Bering Sea (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 used the Poly Nor' Eastern bottom trawl net with mud sweep ground gear as 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 200-1,000 m and did not use standard sampling gear. These surveys show that arrowtooth flounder biomass increased significantly from 1979 to 1985. The biomass estimates 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 (1979-1985) 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.

AFSC Eastern Bering Sea Shelf Survey Age and Length Compositions

Otoliths samples only exist for one year, 2012, of the EBS slope BTS and this age composition is used in the model as sample sizes were sufficient (Table 6.7). Length composition data are not used when age data are available so we do not use the 2012 slope survey length data. Length frequency data from the EBS slope BTS indicate no long-term trends and that females are larger than males (Figure 6.6). The number of lengths collected from AFSC surveys are shown in Table 6.7.

AFSC Aleutian Islands Survey Biomass Estimates

The AI BTS is a multi-species survey and biomass estimates are based on a stratified random design of habitat stratified by management area, sub-region, and depth zones (0-100 m, 101-200 m, 201-300 m and 301-500 m). However, the AI BTS is based on a stratified random design of previously successful stations and is therefore an index survey. Design-based biomass estimates may be more appropriately viewed as weighted mean catch-per-unit-effort expanded by strata over the survey area. The AI BTS time series began in 1980 but gear was not standardized until the 1991 survey when the Poly'Noreastern (PNE) bottom trawl was uniformly implemented. Before then, a mix of large, fortified nets and a similar net to the PNE were used. Also haul duration was generally 30 minutes prior to 1997 when haul duration was reduced to 15 minutes. Based on recommendations from the Groundfish Assessment Program (GAP), we start the AI BTS biomass time series in 1991 for this assessment. 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. Therefore, using survey estimates at the start of the standardized time series also allows for higher confidence in species identification for arrowtooth flounder. The spatial distribution of arrowtooth flounder catch-per-unit-effort from 1991 to present is provided in Figure 6.7 and shows a relatively even distribution of catches over time with a few larger catches from single tows in the eastern AI in some years (figure 6.7). Biomass estimates from this survey show an increasing trend overall, with an all series peak in 2006 at 181,062 t. The 2022 AI survey estimate was a decrease of 3% from the 2018 survey and is now 18% below the long-term time series mean.

AFSC Aleutian Islands Survey Age and Length Compositions

Arrowtooth flounder otolith samples have been collected on the AFSC AI trawl surveys since 1980 but have not been aged for all survey years (Table 6.7). Age composition data that are available are all used in the model for the AI BTS survey since 1991 and where there were enough samples (>100) to age (Table 6.7). There are several years of historical age data that are available from the AI survey and these may be useful to age for future assessments to compare with the age distribution on the EBS shelf. Age frequency data for males and females show evidence of strong recruitment events in 2010 and 2018 and that females are older than males (Figure 6.8). Length composition data are not used when age data are available or anticipated to be available in the following assessment year. Length frequency data from the AI BTS indicate a more spread out size distribution since 2010 for females, and that females are larger than males

overall (Figure 6.9). The 2018 year class also seems to be present in the 2018 length compositions for both males and females. The number of lengths collected from AFSC surveys are shown in Table 6.7.

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).

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 parametric selectivities for the survey and a non-parametric selectivity up to age 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, the first 20% removed for burn-in, and a thinned sample of 4000 from the remaining chain.

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 153 parameters estimated by the model examined in the current assessment (Table 6.8). 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.

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

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

Length composition for the fishery and the survey are calculated as in Equation 6. Delta (δ) 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 6.10), approximately 69% females and 31% males over all survey years and areas. Length composition data is only used in the model in years in which there are no age data.

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

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

Age data exist for the 1993, 1994, 1996, 1998, 2004, 2010, 2012, 2014-2021 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 6.9.

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 (20 total for males and females) were constrained so that the number of effectively free parameters would be less than 10. There were 47 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 2021 account for 46 parameters, plus one parameter for the mean recruitment. Survey selectivity was estimated separately for males and females (16 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 10 years, with data from 2012-2022. Ten runs were performed; the 2021 run was created by dropping the 2022 data, the 2020 run was created by dropping the 2021 data, etc.

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 a series of data cleaning exercises over the last several assessments to remove data that was non-standard, low sample size, or low confidence in species identification. Specifically, these actions were 1) removing the non-standardized early years of the EBS slope survey (1979-1991) in the 2018 assessment (Spies et al., 2018), 2) updating the ratio of arrowtooth flounder and Kamchatka flounder in the catch estimates, using

the expanded survey area for the EBS shelf survey that has been the standard sampling area to present, and removing the survey years where there was low confidence in species identification for arrowtooth flounder in the EBS shelf survey (1982-1991) in the 2020 assessment (Shotwell et al., 2020), and 3) removing the foreign fleet data from the fishery length compositions that were pre-Observer Program, removing low sample size (<300 lengths) fishery length compositions, and removing the early non-standardized years of the AI survey (1980-1990) in the 2022 assessment (Shotwell et al., 2022).

A summary of model results is shown in Table 6.8 comparing Model 18.9 (2022 version) with Model 18.9 (2020 version) from the last full assessment. Due to the change in data observations in the current model, the likelihoods cannot be directly compared but are there for reference as are spawning and total biomass estimates. We also provide a sensitivity analysis for these data changes in each of the assessments. We first compared the spawning biomass estimates from Model 18.9 using the full set of fishery size compositions from the base model (1978-2021) with the cleaned fishery size composition index (1991-2022, removing low sample size years). The average difference in spawning biomass (ADSB) was about 0.2% (Figure 6.11). We then compared the spawning biomass estimates from Model 18.9 with cleaned fishery size composition index but using the full AI BTS time series (1980-2022) with Model 18.9 using the standardized AI index years (1991-2022). The ADSB for this change was about 0.5% (Figure 6.11). Based on this result, we determined these data cleaning changes were minor data corrections and did not require separate model evaluations.

Parameters Estimated Outside the Assessment Model

Natural mortality

Natural mortality (*M*) rates for BSAI 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 6.10). 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). Female natural mortality continued to use the traditional value of M=0.2. 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 at this time (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 6.9.

Length at Age

Growth was estimated from length and age data from BSAI surveys from 1982 to 2017 (Table 6.11) and incorporated in the assessment using a length-age conversion matrix. There is a single length-age conversion matrix that uses age data to predict lengths. Length-at-age data collected from stratified sampling were 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 6.12).

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: $Length = S_{\square}(1 - e^{-(K(age - t_0))})$.

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 6.13), 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 6.14).

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 6.12. 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 6.15.

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 = $1.284 \times 10^{-6} * \text{Length}^{3.319}$, 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 AFSC EBS 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 6.16).

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 6.16, labelled 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 6.16. Weight at age is presented in Table 6.10.

Maturity

Maturity information from a histological examination of arrowtooth flounder in the Gulf of Alaska (Zimmerman 1997) indicating 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, 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 6.10.

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 that were directly in the trawl path as well as those that 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 1991-2022, the slope survey data from 2002-2016, and the Bering Sea 1992-2022 (Table 6.1). The relative proportions sum to 1. The 2022 estimates of q are 0.825 for the Bering Sea shelf, 0.08 for the Bering Sea slope, and 0.095 for the Aleutian Islands. The estimate of q in the Bering Sea is parameterized to co-vary 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 6.17) were particularly evident during the coldest year (1999), which had a large cold pool extent (Figure 6.3), and the next warmest year (2005), which had a very small cold pool extent (Figure 6.3). This relationship held for the earlier part of the time series until about 2005 but then degraded for the next decade until just recently with the onset of the marine heatwave in 2014. 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, α and β are 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 is negative which indicates that q is generally greater than the base value of q estimated by the ration above. The second term, $e^{\beta T}$ is a time-varying (annual) q, which relates to the metabolic aspect of herding or distribution (availability) and can vary annually with bottom water temperature. The estimate of β is positive so positive temperature anomalies result in higher catchability. From 2014-2022, the temperature anomaly was positive, following several years of low temperatures; resulting in an increase in the catchability estimate (Figure 6.18).

Ageing error matrix

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 6.19). 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 (16 total parameters). Two parameters, alpha and beta, were estimated for the temperature-dependent shelf survey catchability (*q*-shelf). There were 66 recruitment deviations, 21 for the starting conditions, and 46 additional for each year from 1976-2021 (recruitment was not estimated in the final year). There was a fishing mortality deviation for each year from 1976-2022 (47). 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	16	2	66	47	1	1	153

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 (Figure 6.20). The differential natural mortality and selectivities by sex resulted in a fraction proportion male of 40% in the terminal year numbers at age estimates, which is similar to the recent fraction seen in the survey data (Figure 6.10).

Results

Model Evaluation

There were no recommended changes to this year's assessment model compared to the model used in the last full assessment except for the data cleaning exercises. Since the sensitivity analysis using the ADSB was <0.1 (Figure 6.11), we determined these data cleaning changes were minor data corrections and did not require separate model evaluations.

Negative log-likelihood and estimates of key parameters for last year's full assessment (Model 18.9 2020) and this year's updated model (Model 18.9 2022) are provided in Table 6.8 for comparison. Due to the change in data in the current model, the likelihoods cannot be directly compared, but the likelihoods are relatively close where data did not change (e.g., slope survey, AI age compositions), implying some

consistency in model fit. Model estimates of age-specific fishery and survey selectivities by sex are provided in Table 6.12. Slope and AI survey selectivities were estimated using a logistic fit to age, by sex (Figure 6.20). The shelf survey selectivity is assumed to be dome shaped for both males and females, with the dome for the males occurring below one, potentially indicating some difference in catchability between sexes.

Observed and model predictions for the age and size composition data are provided in Figures 6.21, 6.22, 6.23, 6.24, 6.25, 6.26, and 6.27.

The model fits the male fishery size compositions relatively well but misses the peak in most years and there is a consistent lack of fit in most years for large females as the model is estimating more large females than were observed (Figure 6.21). This may be due to the limitations imposed by the penalties on the non-parametric fishery selectivity curve. Fit to the EBS shelf BTS size compositions are generally good with some overestimation of larger females from 2006-2009 (Figure 6.22). Fit to the EBS slope and AI BTS size compositions are variable, with good fits for males in most years and generally estimating more large females than are observed (similar to the fishery size compositions), and with an underestimation of the peaks in most years (Figure 6.23 and 6.24). This may be due to the limitations of the logistic selectivity function for these two surveys. Fits to the age compositions were generally better than the size compositions and fit the estimates of the two abundant cohorts of 2016 and 2018 well. The fits to the EBS shelf BTS age compositions were generally good with some underestimation of the peaks for females in several years (Figure 6.25). The new 2021 EBS shelf BTS age compositions also show evidence of both the 2016 and 2018 year classes. The model provides reasonable fits to the EBS slope and AI age composition time-series for males and females (Figure 6.26 and 6.27), except that it estimates more old females and fewer old males than are observed. The AI BTS age compositions in 2018 fit the 2016 year class well, suggesting some permanence of the large 2016 cohort (Figure 6.27).

The consistent patterns of positive and negative residuals in the fishery and survey size compositions on the EBS slope and AI BTS could be due to a variety of confounding issues between selectivity and growth. Potentially the selectivity for the fishery could be dome-shaped as this is a non-target fishery and catch occurs while targeting other high value species at depths shallower than inhabited by larger females. Arrowtooth flounder may exhibit different spatial distributions on the EBS slope and in the AI than in the EBS shelf environment. There is only one growth curve estimated for the entire BSAI region and it primarily uses data from the EBS shelf survey. There may be area-specific differences in growth due to forage or thermal conditions that could influence the fit to the size composition data. In the future we may consider applying different shaped selectivity curves for the fishery, EBS slope BTS, and AI BTS size compositions and update the growth curve with more recent data to explore area-specific growth differences. Another factor that could influence the model's expectation of more large females could be related to the assumed value of female *M*.

We continue to recommend model 18.9 to update management quantities for 2023 and 2024 because it uses the best available data and provides a good fit to the EBS shelf survey data where the majority of the population resides (79% on average, Table 6.1). We discuss results of this model in the following section and final parameter estimates for Model 18.9 are shown in Table 6.A2.1.

Time Series Results

The current assessment model shows a recent trend of decreasing female spawning biomass since 2012 that has stabilized since 2020. The 2022 model estimates very similar levels of total biomass to the 2020 assessment and continues to increase slightly (Table 6.13, Figure 6.28). Since 2010, recruitment estimates have steadily increased (Table 6.14, Figure 6.29) and two large year classes of 2016 and 2018 are more prevalent in the age composition data for the EBS shelf and AI BTS (Figures 6.25 and 6.27). The 2018 year class was not estimated in the 2020 assessment (Table 6.14) but is now supported by the new 2021 age composition data on the EBS shelf BTS (Figure 6.25).

Estimates indicate that arrowtooth flounder total biomass increased approximately three-fold from 1976 to 2009 (Figure 6.8, Table 6.13). Since 2009, estimates of biomass have decreased until 2016 and then increased to current values that are just slightly below the all-time peak of the time series (Table 6.13). Model estimates of fishing mortality and exploitation rate suggest a very steady and lightly exploited population over time (Table 6.15). The model estimates of population numbers by age, year, and sex are given in Table 6.16.

The model fit to the EBS shelf survey tracks the trend of increasing abundance from 1992 to the high levels from 1993-97 and 2005-2006 (Figure 6.28). The model also provides a close fit to the EBS shelf data and to most of the EBS slope data (Figure 6.28). It does not fit an anomalously large abundance estimate (2006) from the Aleutian Island survey, although the uncertainty of that estimate is very high (Figure 6.28 lower left panel) and it does not fit several of the recent AI estimates, particularly the 2022 estimate. This may be due to the existence of many more precise estimates from the EBS shelf that overwhelms the information from the AI survey during years when both estimates exist. The model estimates of total biomass and female spawning biomass are also presented in Figure 6.28. 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 6.30), 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 6.31). 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 6.32).

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 patterns 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 2022 model are shown in Figure 6.33 and Figure 6.34, 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 0.055 (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 6.33); however, the change is consistently positive for all years analyzed, indicating a small overestimate in each year. Although there are no guidelines regarding how large rho (absolute value) should be before an assessment is declared to exhibit an important retrospective bias, 0.055 is very small compared with many other Alaska groundfish species.

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 2022 total biomass from the stock assessment projection model is 929,274 t and the female spawning biomass is estimated at 514,577 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 1976-2021 are used to calculate the average equilibrium recruitment. This results in an estimate of $B_{40\%}$ = 224,487 t for 2022. Projected 2023 female spawning biomass is compared to B40% to determine the Tier level. The stock assessment model estimates the 2023 level of female spawning biomass at 514,577 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 2023 the recommended $F_{ABC} = F_{40\%} = 0.146$ and $F_{OFL} = F_{3\%} = 0.174$ (full selection F values).

Specification of OFL and Maximum Permissible ABC

Acceptable biological catch is estimated for 2023 by applying the $F_{40\%}$ fishing mortality rate and age-specific fishery selectivities to the projected 2023 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 2023 ABC of 83,852 t. There were no retrospective patterns to suggest that altering the ABC from this value is warranted. The overfishing level is estimated for 2023 by applying the $F_{35\%}$ fishing mortality rate and age-specific fishery selectivities to the projected 2022 estimate of age-specific total biomass. This results in a 2023 OFL of 98,787 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 6.17). The stock projection at the average exploitation rate for the past 5 years (Figure 6.31) 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 6.32) 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 2024. The ABC and TAC values that have been used to manage the combined stock since 1980 are presented in Table 6.18.

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 2023, it does not provide the best estimate of OFL for 2024, because the mean 2023 catch under Scenario 6 is predicated on the 2023 catch being equal to the 2023

OFL, whereas the actual 2023 catch will likely be less than the 2023 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 (2021) is 9,014 t. This is less than the 2021 OFL of 90,873 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 2022:

a) If spawning biomass for 2022 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b) If spawning biomass for 2022 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c) If spawning biomass for 2022 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 2032 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 2024 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.
b) If the mean spawning biomass for 2024 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c) If the mean spawning biomass for 2024 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2034. If the mean spawning biomass for 2034 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 6.17, 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 2022 and 2024. The estimates of spawning biomass for 2022 and 2024 from the current year (2022) projection model are 498,352 t and 537,999 t, respectively. Both estimates are well above the estimate of B35% at 196,427 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*=0.176.

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 14 and December 31 in the last five complete catch years (e.g. 2017-2021) for this year. The 2022 catch through October 14, 2022 was 7,107 t. The total catch in 2022 was estimated to be 8,048 t based on the proportion caught through this date for the past 5 years (94%). The total catch in 2023 was based on the percentage of catch to ABC in the most recent years. 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%=0.174), overfishing is set equal to 98,787 t in 2023 and 103,070 t in 2024 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 1991 in the 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 relatively good fits to abundance and age composition data for the EBS shelf where the majority of the population resides (79% on average). The retrospective pattern from the current assessment is good, and Mohn's rho was calculated to be 0.055 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 two new surveys in 2022 from both the EBS and the AI areas and this is not considered a cause for extra concern. We rate the assessment considerations as Level 1 – Normal.

Population dynamics considerations

Stock assessment model results show that arrowtooth flounder biomass (age 1+) was at low levels during the 1970s and 1980s, although surveys during that time period used unconventional methods. The population has steadily increased since the 1990s and reached a peak in the 2009 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 and again in 2018 based on new age composition data for 2021. Population dynamics are not a concern for this assessment and we rate this section as Level 1 – Normal.

Environmental/Ecosystem considerations

Environmental processes: The extended warm phase experienced in the eastern Bering Sea (EBS) that began in approximately 2014 has largely relaxed to normal conditions over the past year (August 2021 - August 2022). Sea surface temperature (SST) was within one standard deviation of the long term average and marine heatwaves were relatively weak and short-lived compared to recent years. Estimates of bottom temperature derived from the ROMS model suggest that bottom temperatures in the northern Bering Sea (NBS) over the past year were within normal ranges while the southeastern Bering Sea (SEBS) was significantly cooler than average. The Bering Sea ice extent was generally higher than average throughout much of the 2021-2022 winter. Ice advanced rapidly in November, though there was an abrupt springtime retreat beginning in mid-April. These cool-to-normal winter conditions were favorable to cold pool formation, though not to the areal extent in the years preceding 2014 (Hennon et al., 2022).

Arrowtooth flounder have similar distributions as Kamchatka flounder within the BSAI. Historically, adult arrowtooth flounder distributions tended to avoid the cold pool, with contractions in years with larger cold pool spatial extent over the shelf and expansions in years with smaller cold pool extent. This relationship somewhat decoupled after 2005 but has recently returned since the onset of the marine heatwave in 2014. Drastically reduced cold pool extents were observed in 2018, 2019, and 2021. The 2020 cold pool on the shelf was modeled (i.e., ROMS output) to be close to average in spatial extent and the 2022 cold pool (observed and modeled) was near the historical average and resembled other average-to-cool years, most similar to 2017 (Hennon et al., 2022).

Arrowtooth flounder is a winter-spawning flatfish; increased young-of-the-year recruitment is correlated to years with onshore winds during the larval period (Bond et al., 2020). The along- and cross-slope wind components along the Bering shelf break may be informative to understanding the larval dispersal in the upper ocean. Cross-slope winds will be parallel to the shelf break, and in Jan-Apr 2022 may have enhanced transport to the northwest, while Jul-Sep 2022 winds may have inhibited transport (winds to the southeast). Along-shelf winds were variable from month to month in 2022, but favored onshelf Ekman transport in April and June which overlaps with the arrowtooth flounder larval period (Hennon et al., 2022).

Prey: Juvenile arrowtooth flounder are zooplanktivores. Zooplankton abundances (copepods and euphausiids) over the southeastern Bering Sea shelf were surveyed in spring and late-summer 2022. Spring trends are likely more important for small life stages of arrowtooth flounder, as by late-summer the fish have settled out of the pelagic environment. Relative to the last cold period which ended in 2012, large copepod abundances were reduced, though abundances were increased from 2021. Small copepod numbers remained elevated compared to abundances during the cold period from 2006-2012 and were

also increased from 2021. Euphausiid estimates remained low, as is common during the spring, and were decreased from 2021 (Kimmel et al., 2022).

Common prey items for adult arrowtooth flounder are juvenile walleye pollock and benthic prey such as eel pouts and shrimp. The 2022 age-0 pollock relative biomass estimates from the BASIS survey in the northeastern and southeastern regions of the Bering Sea are lower than estimates during the recent warm period (2014-2018), and are slightly greater than the cold period from 2007-2013 (Andrews et al., 2022). Benthic infauna and other non-targets are not sampled well by the bottom trawl survey. The 2022 relative CPUE estimate for eelpouts showed a modest increase from 2021 to just above the average of the estimates over the last 10 years. Eelpouts have important roles in the energy flow within benthic communities, including as prey of arrowtooth flounder, but it is not known at present whether these changes in CPUE are related to changes in energy flow (Buser, 2022).

The condition of arrowtooth flounder (as measured by length-weight residuals) was slightly below-average in 2022, but increased from 2021 (Rohan et al., 2022), mirroring overall trends in prey availability and indicating sufficient prey is available over the southern shelf.

Competitors: Greenland turbot, Kamchatka flounder, and Pacific halibut can be considered competitors based on overlap in their ecological niches as large upper-trophic predatory flatfish. These species are included within the apex predator guild. The biomass of the apex predator guild increased from 2021 to 2022 and is nearly equal to their long term mean. The trend in this guild is largely driven by Pacific cod and arrowtooth flounder, both of whom have increased from 2021 (Whitehouse, 2022). Taken together, and given that arrowtooth flounder biomass greatly exceeds the biomass of these other species, competition for habitat or prey resources is unlikely to impact arrowtooth flounder in the EBS. In the Aleutian Islands, all apex predators (which include all the large flatfish) decreased compared to 2018, except for large sculpins.

Predators: Predators of juvenile arrowtooth flounder are not well known, but likely include fur seals, Pacific cod, skates, and sleeper sharks. Predators of adult arrowtooth flounder are also not well known, but likely include toothed whales. Fur seal abundance has been steadily declining, as measured by pup counts at St. Paul Island through 2021 (Siddon, 2022). Pacific cod abundance increased over the southern shelf from 2021 to 2022 (Whitehouse, 2022). Indirect evidence of killer whale presence in the Bering Sea is available based on depredation noted during the NOAA AFSC longline survey. While rates of depredation increased from 1997-2009, depredation interactions remained relatively consistent between 2009-2021 (Siwicke, pers. comm.). Taken together, trends in predator abundances would indicate no increased predation concern for arrowtooth flounder.

Summary for Environmental/Ecosystem considerations:

- Environment: The extended warm phase experienced by the eastern Bering Sea (EBS) that began in approximately 2014 has largely relaxed to normal conditions over the past year (August 2021 - August 2022).
- Winds: Along-shelf winds were variable in 2022, but favored onshelf Ekman transport in April and June that supported transport to suitable nursery habitat.
- Juvenile prey: Small copepod abundance remained elevated and increased from 2021; large copepod abundance was reduced (compared to cold year levels) but increased from 2021; euphausiid abundance was low, which is typical for spring, but decreased from 2021.
- The condition of arrowtooth flounder was slightly below-average in 2022, but increased from 2021, mirroring overall trends in prey availability and indicating sufficient prey is available over the southern shelf.
- Competition: arrowtooth flounder biomass greatly exceeds the biomass of competitive species (e.g., Kamchatka flounder), therefore competition for habitat or prey resources is unlikely to impact arrowtooth flounder.

- Predation: Trends in predator abundances would indicate no increased predation concern for arrowtooth flounder.

Together, the most recent data available suggest an ecosystem risk Level 1 – Normal: "No apparent environmental/ecosystem concerns."

Fishery performance

Total catch has been decreasing steadily since the time series peak in 2010, but as arrowtooth flounder is a non-target stock, this decline is unlikely to be related to the arrowtooth flounder population. As stated previously, fishery selectivity may be too restrictive for the model to fit the fishery size compositions and an alternative selectivity function could be explored in the future. At the current time, fishery CPUE is not showing an unusual spatial pattern of fishing, or changes in the percent of TAC taken, or changes in the duration of fishery openings. Therefore, we rate the fishery performance section as Level 1 – Normal.

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 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 6.35). 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 >20 cm, by relative importance, are walleye pollock (29% of the total mortality), Alaska skate (21%) and sleeper shark (11%) (Figure 6.36). 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 6.37).

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 6.38). 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 6.39). 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 6.40).

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 6.41), 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 6.42). 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 6.43 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

Due to the relatively poor fits to the fishery size compositions and the EBS slope and AI BTS size compositions, we plan to investigate different selectivity curves for these three data sources. The growth curve has also not been updated since 2017 and contains primarily EBS shelf BTS data. We intend to update the growth curve and to also explore area-specific estimates of growth to determine if the EBS slope and AI environment may have a lower growth potential for arrowtooth flounder. We also recommend studies on genetic population structure of arrowtooth flounder, as stock structure has not been examined in this species and may explain some of the differences between the three areas. In addition, the relationship between male and female natural mortality and sex ratio should be further investigated. The female natural mortality is much lower than the male natural mortality estimate and so the model would expect the females to live longer and grow larger than the males. This could also explain the lack of fit for the EBS slope and AI BTS size compositions. The sex ratio in the EBS shelf is very consistent and has a slight decreasing pattern until about 2015 just after the onset of the marine heatwave and then males begin to steadily increase. This could be due to changes in the prey base that may support the increase of males in the population as they are generally smaller than females.

We plan to explore the utility of model-based survey time series (e.g., vector autoregressive spatio-temporal or VAST model) as a way to integrate the three surveys used in the BSAI arrowtooth flounder model in the future. Spatial metrics such as area occupied and center of gravity can be generated from the VAST estimates and could help understand any inherent differences between the three areas. Also the condition of the fish can be estimated through VAST and would be a useful comparison with the current condition estimates from the design-based survey.

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Tables

Table 6.1. Proportion of biomass by strata from the random effects model estimates for the Aleutian Islands, eastern Bering Sea shelf, and eastern Bering Sea slope bottom trawl surveys.

Year	Aleutian Islands	EBS Shelf	EBS Slope
1991	0.052	0.848	0.100
1992	0.067	0.834	0.099
1993	0.079	0.833	0.088
1994	0.096	0.822	0.082
1995	0.104	0.815	0.081
1996	0.110	0.812	0.077
1997	0.130	0.786	0.083
1998	0.146	0.759	0.095
1999	0.153	0.745	0.102
2000	0.149	0.750	0.101
2001	0.158	0.748	0.095
2002	0.177	0.730	0.094
2003	0.151	0.768	0.081
2004	0.144	0.777	0.079
2005	0.140	0.788	0.071
2006	0.162	0.761	0.077
2007	0.165	0.743	0.092
2008	0.150	0.751	0.099
2009	0.147	0.742	0.111
2010	0.124	0.770	0.106
2011	0.114	0.780	0.106
2012	0.117	0.765	0.117
2013	0.126	0.763	0.111
2014	0.126	0.776	0.098
2015	0.128	0.776	0.097
2016	0.114	0.802	0.084
2017	0.114	0.798	0.088
2018	0.098	0.823	0.079
2019	0.090	0.837	0.073
2020	0.095	0.827	0.078
2021	0.100	0.817	0.083
2022	0.095	0.825	0.080

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-present. Totals for arrowtooth (ATF) and Kamchatka are under "Combined" total, extrapolated ATF only is under "ATF estimate". *Catch information through October 14, 2022, 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	30,627	0.67	20,575	
2012	32,236	0.70	22,641	
2013	28,843	0.73	21,007	
2014	26,194	0.75	19,626	
2015	16,793	0.70	11,721	2011 – present based on speciation in Catch Accounting System (CAS)
2016	16,409	0.70	11,485	
2017	11,515	0.60	6,934	
2018	10,409	0.70	7,243	
2019	14,955	0.69	10,374	
2020	18,353	0.59	10,874	
2021	15,681	0.57	9,014	
2022	15,393	0.46	7,107	

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. *1990 retained rate was applied to the 1985-89 reported catch. The 2022 catch is reported through October 14, 2022. Source: AKFIN NMFS AKRO BLEND/Catch Accounting System.

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	3,378	16,133	19,511	17.3
1992	910	10,987	11,897	7.6
1993	661	8,638	9,299	7.1
1994	655	13,683	14,338	4.6
1995	509	8,775	9,284	5.5
1996	1,373	13,282	14,654	9.4
1997	1,073	9,396	10,469	10.2
1998	2,753	12,483	15,237	18.1
1999	2,702	8,676	11,378	23.7
2000	5,244	7,986	13,230	39.6
2001	5,301	8,757	14,058	37.7
2002	4,043	7,812	11,855	34.1
2003	4,698	8,555	13,253	35.4
2004	3,847	14,338	18,185	21.2
2005	7,291	6,952	14,243	51.2
2006	6,103	7,339	13,442	45.4
2007	5,130	6,786	11,916	43.1
2008	15,913	5,457	21,370	74.5
2009	24,133	5,767	29,900	80.7
2010	31,930	6,885	38,815	82.3
2011	16,504	4,071	20,575	80.2
2012	19,554	3,087	22,641	86.4
2013	17,006	4,001	21,007	81.0
2014	16,816	2,810	19,626	85.7
2015	9,478	2,244	11,721	80.9
2016	9,014	2,471	11,485	78.5
2017	5,737	1,197	6,934	82.7
2018	5,964	1,279	7,243	82.3
2019	9,100	1,274	10,374	87.7
2020	9,946	928	10,874	91.5
2021	8,029	984	9,014	89.1
2022	6,176	931	7,107	86.9

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 year to the model.

Source	Data	Years
NMFS Bering Sea shelf survey	Survey biomass	1992-2019, **2021, 2022**
	Age Composition	1993, 1994, 1996, 1998, 2004, 2010, 2012, 2014, 2015, 2016, 2017, 2018, 2019, **2021**
	Length composition	1992, 1995, 1997, 1999, 2000, 2001, 2002, 2003, 2005, 2006, 2007, 2008, 2009, 2011, 2013
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	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018, **2022**
	Age composition	2010, 2012, 2014, 2016, 2018
	Length composition	1991, 1994, 1997, 2000, 2002, 2004, 2006
Fishery	Catch Biomass	1970-**2021, 2022**
	Length composition	1991, 1998-2013, 2018-**2020**, **2021**

Table 6.5. The number of fisheries length and otolith (for age) samples in each year 1978-2021. Underlined values are used in the assessment. Source: AKFIN NMFS AKRO BLEND/Catch Accounting System.

Year	Number of lengths	Year	Number of otoliths
1978	11,426		
1979	6,565		
1980	9,945		
1981	7,790		
1982	36,784	1982	1926
1983	31,955	1983	1213
1984	23,189	1984	1355
1985	25,817	1985	1784
1986	14,399	1986	626
1987	24,066	1987	302
1988	833		
1989	224		
1990	2,652		
1991	1,337	1991	0
1992	163		
1993	63		
1994	282		
1998	563		
1999	986	1999	35
2000	1407	2000	19
2001	2701	2001	27
2002	2385	2002	22
2003	3501	2003	93
2004	4355	2004	5
2005	2649	2005	5
2006	2128	2006	30
2007	574	2007	11
2008	1417	2008	27
2009	555		
2010	921	2010	0
2011	885	2011	5
2012	521	2012	4
2013	641		
2014	245		
2015	16		
2016	128		
2017	50		
2018	7291	2018	529
2019	10345	2019	538
2020	13771	2020	692
2021	12509	2021	283

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. Underlined values were used in the assessment.

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	342,758	0.14				
1993	444,330	0.10				
1994	473,657	0.10			58,230	0.14
1995	445,071	0.15				
1996	524,049	0.11				
1997	459,633	0.13			74,085	0.11
1998	343,423	0.11				
1999	237,388	0.26				
2000	312,691	0.17			65,028	0.11
2001	375,950	0.09				
2002	311,321	0.10	42,508	0.13	88,809	0.13
2003	496,523	0.09				
2004	516,845	0.07	53,745	0.11	95,041	0.13
2005	660,315	0.07				
2006	604,951	0.08			181,063	0.27
2007	479,428	0.08				
2008	526,836	0.09	68,317	0.13		
2009	403,585	0.10				
2010	525,732	0.08	74,065	0.15	80,049	0.19
2011	519,361	0.08				
2012	400,282	0.11	72,845	0.18	60,371	0.17
2013	402,453	0.09				
2014	463,305	0.07			75,958	0.15
2015	407,519	0.06				
2016	473,809	0.05	45,525	0.12	65,900	0.20
2017	422,368	0.07				
2018	509,638	0.07			59,493	0.12
2019	576,230	0.07				
2020						
2021	457,569	0.08				
2022	521,615	0.12			57,993	0.12

Table 6.7. The number of survey length and otolith samples in each year, 1979-2022 from bottom trawl surveys conducted on the Eastern Bering Sea shelf, slope and the Aleutian Islands. Underlined values are used in the assessment.

Year	EBS shelf survey		EBS slope survey		Aleutian Islands Survey	
	#lengths	#otoliths	#lengths	#otoliths	#lengths	#otoliths
1979		133				
1980		459			5319	1084
1981		104				
1982	2841	350			5207	
1983	6149					325
1984	6050					
1985	5550	129			9321	
1986	5812					328
1987	7885					
1988	6492					
1989	8261					
1990	6589					
1991	5720	187			6559	605
1992	5711	97				
1993	7367	211				
1994	7193	125			12988	602
1995	5782					
1996	8749	218				
1997	7193				12166	773
1998	8910	280				
1999	6390					
2000	8212				12823	780
2001	8663					
2002	8574	487	3565		12757	1609
2003	14829					
2004	13495	595	7433		11580	765
2005	14734	554				
2006	12923	604			9633	568
2007	10354					
2008	12472	795	7528			
2009	9611	691				
2010	10602	1482	6662		10134	726
2011	11640	709				
2012	9033	620	5897	473	8386	402
2013	8282					
2014	8131	392			10212	315
2015	11440	913				
2016	15513	1214	3459		9166	483
2017	11437	530				
2018	18744	804			10225	594
2019	14276	709				
2020						
2021	13909	607				
2022	10165				10011	

Table 6.8. Results comparing model fits from the current assessment compared to the last full assessment.

	Model 18.9 (2020)	*Model 18.9 (2022)*
Total -log(Likelihood)		
Catch	0.006	0.007
Recruitment	40.9	26.72
EBS shelf survey biomass	17.87	21.69
EBS slope survey biomass	3.40	3.12
Aleutian survey biomass	36.14	32.01
EBS shelf survey age comp	250.26	252.40
EBS slope survey age comp	36.53	36.18
Aleutian survey age comp	141.10	139.91
Survey length comp	275.29	272.61
Fishery length comp	583.96	151.35
Priors/Penalties	1.25	1.55
Fishery selectivity	13.42	15.41
Number of parameters	151	153
Total Likelihood	1,400.09	1,570.74
Stock status (t)		
Spawning biomass	494,307	514,577
Total biomass	921,508	929,274

Table 6.9. 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 6.10. Arrowtooth flounder male and female weight-at-age (kg) used in the 2018-2022 assessments and proportion of females mature at age. Weight at age was calculated using the 2018 length age conversion matrix.

Age	Female weight at age	Male weight at age	Female maturity at age (Stark 2011)
1	0.02	0.02	0.00
2	0.07	0.06	0.00
3	0.16	0.15	0.01
4	0.30	0.25	0.02
5	0.47	0.37	0.06
6	0.68	0.49	0.16
7	0.91	0.61	0.34
8	1.17	0.72	0.59
9	1.45	0.82	0.80
10	1.73	0.90	0.97
11	2.02	0.98	0.99
12	2.31	1.04	1
13	2.60	1.09	1
14	2.88	1.14	1
15	3.16	1.17	1
16	3.42	1.20	1
17	3.67	1.23	1
18	3.91	1.25	1
19	4.13	1.27	1
20	4.34	1.28	1
21+	4.97	1.30	1

Table 6.11. The number of male, female, and total lengths measured on BSAI surveys used in the length age conversion matrix.

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 6.12. 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	0.05	0.03	0.00	0.00	0.06	0.03
2	0.00	0.02	0.27	0.15	0.00	0.00	0.14	0.12
3	0.02	0.03	0.72	0.47	0.00	0.00	0.29	0.35
4	0.05	0.08	0.94	0.79	0.02	0.01	0.51	0.69
5	0.16	0.16	0.98	0.89	0.41	0.15	0.72	0.90
6	0.41	0.30	0.98	0.85	0.96	0.77	0.87	0.97
7	0.78	0.51	0.96	0.74	1.00	0.99	0.94	0.99
8	0.99	0.73	0.91	0.58	1.00	1.00	0.98	1.00
9	0.98	0.91	0.82	0.40	1.00	1.00	0.99	1.00
10	0.95	1.00	0.67	0.25	1.00	1.00	1.00	1.00
11	0.95	1.00	0.47	0.14	1.00	1.00	1.00	1.00
12	0.95	1.00	0.28	0.07	1.00	1.00	1.00	1.00
13	0.95	1.00	0.15	0.04	1.00	1.00	1.00	1.00
14	0.95	1.00	0.07	0.02	1.00	1.00	1.00	1.00
15	0.95	1.00	0.03	0.01	1.00	1.00	1.00	1.00
16	0.95	1.00	0.03	0.01	1.00	1.00	1.00	1.00
17	0.95	1.00	0.03	0.01	1.00	1.00	1.00	1.00
18	0.95	1.00	0.03	0.01	1.00	1.00	1.00	1.00
19	0.95	1.00	0.03	0.01	1.00	1.00	1.00	1.00
20	0.95	1.00	0.03	0.01	1.00	1.00	1.00	1.00
21+	0.95	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 2020 and 2022 assessments. Lower 95% and upper 95% confidence intervals (CIs) are provided for the estimates of total biomass and female spawning biomass.

	2020 Assessment		2022 Assessment					
Year	Total biomass	FSB	Total Biomass	Biomass lower CI	Biomass Upper CI	FSB	FSB Lower CI	FSB Upper CI
1976	321,463	138,952	362,114	302,507	490,940	251,143	201,098	361,401
1977	328,582	129,345	333,519	278,303	450,592	229,822	183,302	330,672
1978	334,189	132,508	313,468	262,769	420,565	214,775	171,946	308,198
1979	336,336	146,303	295,711	249,024	392,626	201,147	162,032	285,972
1980	330,452	165,709	275,218	232,476	362,740	184,763	149,044	261,794
1981	319,255	182,196	252,654	213,360	330,210	166,114	133,316	235,901
1982	305,970	188,369	233,170	196,498	303,631	149,611	118,545	212,411
1983	294,437	186,585	220,715	186,411	283,581	138,647	109,846	195,265
1984	279,275	176,989	208,999	177,072	265,162	126,820	100,202	177,556
1985	269,424	170,705	207,039	178,017	257,262	119,526	94,584	165,000
1986	268,338	167,896	217,479	190,642	261,198	114,676	91,335	155,409
1987	281,622	164,530	244,915	220,604	282,787	110,885	89,361	147,815
1988	316,174	160,361	294,588	271,639	327,765	110,039	89,943	143,522
1989	355,848	143,409	347,208	325,098	376,735	100,476	82,229	129,930
1990	419,940	139,437	420,553	398,754	447,923	105,607	88,874	131,232
1991	479,361	139,692	484,989	462,902	510,938	116,658	101,290	139,036
1992	525,884	149,692	533,209	511,115	557,882	138,012	124,034	157,076
1993	568,130	180,782	575,127	552,676	599,052	179,170	165,408	196,544
1994	600,723	228,477	606,650	583,709	630,420	234,710	220,540	251,365
1995	616,268	279,378	622,065	598,757	645,724	290,535	275,651	306,715
1996	631,047	328,925	636,697	612,964	660,134	340,888	325,518	356,856
1997	637,606	361,717	643,191	619,129	666,049	371,457	355,840	387,405
1998	648,454	381,854	654,270	630,013	677,494	388,700	372,803	404,557
1999	660,092	386,765	665,966	641,269	689,433	390,873	374,744	406,603
2000	681,486	386,919	687,980	662,859	711,325	389,827	373,583	405,425
2001	707,888	383,406	715,143	689,278	739,194	385,910	369,988	401,112
2002	739,390	381,287	747,385	720,444	772,287	383,877	368,074	399,018
2003	776,662	386,143	785,730	757,291	811,536	389,168	373,360	404,079
2004	814,772	396,156	825,187	794,919	851,681	399,809	383,762	414,671
2005	845,848	409,127	857,842	826,294	886,182	413,442	396,720	428,594
2006	877,995	432,104	891,371	858,564	920,702	437,118	419,542	453,136
2007	905,789	460,049	920,085	885,743	950,818	465,632	447,085	482,493
2008	928,359	489,342	943,106	907,695	974,457	495,618	475,868	512,986
2009	939,126	514,075	951,363	915,199	982,670	519,203	498,625	537,349
2010	937,008	532,570	946,535	910,053	978,241	536,649	515,009	555,493
2011	925,871	545,274	931,832	895,397	963,617	547,603	525,095	567,286
2012	906,046	550,307	911,072	875,526	942,725	552,852	529,789	573,095
2013	882,402	548,686	886,098	851,081	917,351	551,347	527,892	572,142
2014	862,465	543,696	864,102	829,714	894,722	546,184	522,682	566,986
2015	846,929	534,094	845,967	811,808	876,331	536,228	512,797	557,241
2016	844,473	526,693	840,045	805,721	869,997	528,398	505,642	549,197
2017	855,942	515,737	844,527	810,297	874,774	516,700	494,481	536,726
2018	880,407	508,517	861,555	827,429	892,093	508,313	486,389	527,684
2019	907,398	504,837	889,827	855,094	920,677	502,961	481,673	521,903
2020	921,508	503,360	913,124	877,649	944,017	499,087	477,830	517,819
2021			928,203	890,910	959,987	499,394	478,036	518,352
2022			933,466	893,299	968,430	507,275	485,751	526,420

Table 6.14. Estimated age 1 recruitment of arrowtooth flounder (1,000s of fish) from the 2020 and 2022 stock assessments. The 95% credible intervals (CI) are based on MCMC runs from Model 18.9 (2022). Mean recruitment over the entire time interval 1976-2021 is 344,669,053 fish.

Year	2020 Assessment	2022 Assessment	Lower CI	Upper CI
1976	57,027	94,617	34,795	185,000
1977	44,967	92,257	35,695	177,000
1978	63,640	90,099	34,100	177,000
1979	248,850	89,604	35,895	171,050
1980	119,519	89,370	35,495	170,000
1981	68,708	88,477	34,600	168,000
1982	51,685	85,525	34,300	157,000
1983	65,193	92,275	40,300	163,000
1984	124,637	172,538	98,190	250,000
1985	178,692	252,296	176,000	337,000
1986	364,172	440,250	349,000	533,050
1987	600,889	652,222	554,000	748,000
1988	659,310	680,680	589,000	771,000
1989	595,945	551,669	479,000	628,050
1990	403,164	357,258	300,000	415,000
1991	255,102	233,472	190,000	279,000
1992	265,434	254,800	210,000	302,000
1993	216,130	221,105	181,000	264,000
1994	224,265	225,137	186,000	269,000
1995	239,165	244,915	200,000	291,000
1996	396,457	400,313	341,950	461,000
1997	335,189	340,943	275,000	408,000
1998	350,643	363,651	288,000	439,000
1999	578,172	580,145	495,000	665,000
2000	533,098	531,604	452,000	613,000
2001	457,991	466,251	395,000	539,000
2002	556,896	562,891	488,000	641,000
2003	534,943	555,584	481,000	624,000
2004	487,217	495,216	435,000	555,000
2005	395,515	398,094	352,000	446,000
2006	485,027	487,446	440,000	535,050
2007	415,800	418,332	375,000	459,000
2008	347,647	348,467	312,000	385,000
2009	341,034	340,911	303,000	376,000
2010	275,990	273,096	241,000	305,000
2011	267,711	262,401	231,000	294,000
2012	318,947	307,236	273,000	341,050
2013	429,033	413,892	372,000	456,000
2014	395,695	383,063	339,000	428,000
2015	364,014	346,533	302,000	391,000
2016	453,213	406,834	353,000	462,000
2017	975,385	806,251	718,000	893,000
2018	395,180	456,613	370,000	546,000
2019	148,296	601,883	471,000	748,000
2020		256,253	135,000	406,000
2021		150,272	53,295	332,050

Table 6.15. 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	0.067	0.048
1977	0.043	0.031
1978	0.041	0.029
1979	0.062	0.044
1980	0.087	0.060
1981	0.090	0.061
1982	0.066	0.044
1983	0.086	0.057
1984	0.063	0.041
1985	0.051	0.032
1986	0.051	0.030
1987	0.035	0.018
1988	0.151	0.061
1989	0.054	0.019
1990	0.086	0.028
1991	0.103	0.036
1992	0.048	0.020
1993	0.029	0.015
1994	0.036	0.021
1995	0.020	0.013
1996	0.030	0.021
1997	0.021	0.015
1998	0.031	0.021
1999	0.024	0.015
2000	0.028	0.017
2001	0.030	0.018
2002	0.024	0.014
2003	0.026	0.015
2004	0.034	0.020
2005	0.026	0.015
2006	0.023	0.014
2007	0.019	0.012
2008	0.028	0.017
2009	0.033	0.021
2010	0.034	0.022
2011	0.034	0.022
2012	0.037	0.025
2013	0.035	0.024
2014	0.033	0.023
2015	0.020	0.014
2016	0.020	0.014
2017	0.012	0.008
2018	0.013	0.008
2019	0.019	0.012
2020	0.020	0.012
2021	0.016	0.010
2022	0.014	0.009

Table 6.16. Model estimates of arrowtooth flounder population numbers-at-age, by sex, 1976-2022.

Females	Numbers at age (1,000s)									
Year	1	2	3	4	5	6	7	8	9	10
1976	47,308	40,054	34,009	29,144	25,025	21,037	18,314	15,847	13,651	11,771
1977	46,129	38,729	32,783	27,813	23,774	20,266	16,747	14,212	12,118	10,449
1978	45,050	37,765	31,702	26,821	22,718	19,327	16,294	13,243	11,132	9,498
1979	44,802	36,881	30,913	25,938	21,911	18,476	15,555	12,911	10,400	8,747
1980	44,685	36,678	30,187	25,283	21,164	17,757	14,737	12,115	9,919	7,997
1981	44,239	36,581	30,016	24,679	20,602	17,082	14,014	11,249	9,072	7,437
1982	42,762	36,215	29,937	24,539	20,107	16,621	13,466	10,674	8,399	6,783
1983	46,138	35,008	29,641	24,483	20,019	16,285	13,236	10,457	8,169	6,435
1984	86,269	37,770	28,650	24,233	19,951	16,159	12,857	10,110	7,837	6,130
1985	126,148	70,625	30,914	23,432	19,773	16,168	12,887	10,011	7,765	6,024
1986	220,125	103,274	57,808	25,288	19,131	16,053	12,954	10,124	7,776	6,036
1987	326,111	180,210	84,533	47,289	20,647	15,532	12,863	10,178	7,866	6,046
1988	340,340	266,984	147,518	69,169	38,643	16,807	12,530	10,238	8,039	6,216
1989	275,835	278,588	218,428	120,475	56,167	30,865	12,914	9,087	7,182	5,652
1990	178,629	225,817	228,028	178,672	98,346	45,579	24,700	10,122	7,038	5,567
1991	116,736	146,232	184,807	186,428	145,605	79,398	35,999	18,880	7,593	5,286
1992	127,400	95,561	119,665	151,049	151,785	117,224	62,262	27,143	13,918	5,606
1993	110,552	104,299	78,221	97,895	123,345	123,294	94,051	49,041	21,154	10,855
1994	112,569	90,509	85,381	64,011	80,025	100,515	99,739	75,256	38,996	16,828
1995	122,457	92,159	74,090	69,863	52,307	65,138	81,072	79,358	59,411	30,801
1996	200,157	100,257	75,446	60,639	57,136	42,683	52,878	65,304	63,640	47,658
1997	170,471	163,867	82,071	61,739	49,566	46,548	34,505	42,255	51,840	50,541
1998	181,826	139,566	134,149	67,170	50,489	40,438	37,768	27,768	33,845	41,535
1999	290,073	148,860	114,249	109,775	54,901	41,125	32,675	30,154	22,018	26,848
2000	265,802	237,483	121,862	93,503	89,760	44,775	33,337	26,248	24,097	17,601
2001	233,125	217,612	194,409	99,726	76,438	73,156	36,232	26,691	20,888	19,184
2002	281,446	190,859	178,140	159,090	81,517	62,279	59,153	28,967	21,200	16,598
2003	277,792	230,420	156,244	145,790	130,080	66,476	50,472	47,495	23,134	16,938
2004	247,608	227,429	188,628	127,866	119,193	106,045	53,831	40,464	37,860	18,448
2005	199,047	202,715	186,172	154,348	104,492	97,039	85,577	42,873	31,985	29,941
2006	243,723	162,960	165,948	152,359	126,193	85,192	78,596	68,635	34,192	25,518
2007	209,166	199,537	133,405	135,815	124,585	102,928	69,075	63,167	54,882	27,350
2008	174,233	171,246	163,352	109,188	111,079	101,681	83,592	55,688	50,710	44,072
2009	170,455	142,645	140,185	133,679	89,259	90,525	82,268	66,907	44,298	40,354
2010	136,548	139,551	116,769	114,712	109,252	72,689	73,105	65,612	52,980	35,093
2011	131,201	111,791	114,235	95,548	93,743	88,947	58,661	58,227	51,867	41,902
2012	153,618	107,413	91,512	93,476	78,085	76,327	71,798	46,744	46,055	41,045
2013	206,946	125,765	87,926	74,877	76,377	63,542	61,523	57,056	36,844	36,321
2014	191,532	169,425	102,950	71,946	61,188	62,176	51,268	48,983	45,080	29,125
2015	173,266	156,806	138,691	84,242	58,798	49,824	50,197	40,866	38,759	35,688
2016	203,417	141,855	128,369	113,512	68,896	47,981	40,448	40,439	32,776	31,095
2017	403,126	166,539	116,129	105,065	92,835	56,222	38,953	32,586	32,435	26,297
2018	228,306	330,046	136,342	95,059	85,961	75,852	45,791	31,576	26,343	26,225
2019	300,942	186,918	270,201	111,603	77,772	70,229	61,762	37,099	25,509	21,285
2020	128,127	246,384	153,022	221,153	91,280	63,479	57,047	49,810	29,796	20,493
2021	75,136	104,898	201,703	125,243	180,872	74,494	51,547	45,978	39,973	23,919
2022	118,352	61,515	85,877	165,097	102,451	147,700	60,585	41,667	37,036	32,207

Table 6.16 (cont'd). Model estimates of arrowtooth flounder population numbers-at-age, by sex, 1976-2022.

Females	Numbers at age (1,000s)										
Year	11	12	13	14	15	16	17	18	19	20	21+
1976	10,131	8,699	7,449	6,359	5,415	4,595	3,888	3,280	2,760	2,315	7,636
1977	9,032	7,773	6,675	5,716	4,879	4,155	3,526	2,983	2,517	2,118	7,635
1978	8,203	7,090	6,102	5,240	4,487	3,830	3,261	2,768	2,342	1,976	7,656
1979	7,474	6,455	5,579	4,802	4,123	3,531	3,014	2,566	2,178	1,843	7,579
1980	6,741	5,760	4,975	4,300	3,701	3,178	2,721	2,323	1,978	1,678	7,262
1981	6,015	5,070	4,332	3,741	3,234	2,783	2,390	2,047	1,747	1,488	6,724
1982	5,578	4,512	3,803	3,250	2,806	2,426	2,088	1,793	1,535	1,310	6,159
1983	5,208	4,283	3,464	2,920	2,495	2,155	1,863	1,603	1,377	1,179	5,736
1984	4,843	3,921	3,224	2,608	2,198	1,878	1,622	1,402	1,207	1,036	5,205
1985	4,723	3,732	3,021	2,484	2,009	1,694	1,447	1,250	1,080	930	4,808
1986	4,691	3,678	2,906	2,352	1,935	1,565	1,319	1,127	973	841	4,468
1987	4,701	3,654	2,865	2,264	1,832	1,507	1,219	1,027	878	758	4,136
1988	4,784	3,720	2,891	2,267	1,791	1,450	1,192	964	813	695	3,872
1989	4,394	3,382	2,629	2,044	1,602	1,266	1,025	843	682	575	3,228
1990	4,390	3,412	2,626	2,042	1,587	1,244	983	796	655	529	2,953
1991	4,194	3,307	2,571	1,979	1,538	1,196	938	741	600	493	2,624
1992	3,917	3,108	2,450	1,905	1,466	1,140	886	695	549	444	2,310
1993	4,380	3,060	2,428	1,914	1,488	1,145	891	692	543	429	2,151
1994	8,644	3,487	2,437	1,933	1,524	1,185	912	709	551	432	2,055
1995	13,309	6,836	2,758	1,927	1,529	1,206	937	721	561	436	1,967
1996	24,726	10,683	5,488	2,214	1,547	1,227	968	752	579	450	1,929
1997	37,890	19,658	8,494	4,363	1,760	1,230	976	769	598	460	1,891
1998	40,525	30,381	15,762	6,810	3,498	1,411	986	782	617	480	1,886
1999	32,986	32,184	24,127	12,518	5,409	2,778	1,121	783	621	490	1,878
2000	21,481	26,392	25,750	19,304	10,015	4,327	2,223	897	627	497	1,895
2001	14,026	17,118	21,031	20,520	15,383	7,981	3,448	1,771	715	499	1,906
2002	15,260	11,157	13,617	16,730	16,323	12,237	6,349	2,743	1,409	568	1,914
2003	13,272	12,202	8,922	10,888	13,377	13,052	9,785	5,076	2,193	1,127	1,985
2004	13,519	10,594	9,740	7,121	8,691	10,678	10,418	7,810	4,052	1,751	2,483
2005	14,608	10,705	8,388	7,712	5,639	6,882	8,455	8,249	6,184	3,208	3,353
2006	23,909	11,665	8,548	6,698	6,158	4,503	5,495	6,751	6,587	4,938	5,239
2007	20,428	19,141	9,338	6,843	5,362	4,930	3,605	4,399	5,405	5,273	8,148
2008	21,978	16,416	15,381	7,504	5,499	4,309	3,962	2,897	3,535	4,343	10,785
2009	35,107	17,507	13,077	12,252	5,977	4,380	3,432	3,156	2,307	2,816	12,051
2010	32,007	27,844	13,885	10,372	9,718	4,741	3,474	2,722	2,503	1,830	11,791
2011	27,789	25,345	22,049	10,996	8,213	7,695	3,754	2,751	2,156	1,982	10,786
2012	33,199	22,018	20,081	17,470	8,712	6,507	6,097	2,974	2,180	1,708	10,116
2013	32,412	26,217	17,387	15,858	13,795	6,879	5,138	4,815	2,349	1,721	9,338
2014	28,747	25,654	20,750	13,761	12,551	10,919	5,445	4,067	3,811	1,859	8,753
2015	23,085	22,785	20,333	16,446	10,907	9,948	8,654	4,316	3,224	3,020	8,411
2016	28,652	18,533	18,293	16,325	13,204	8,757	7,987	6,948	3,465	2,588	9,178
2017	24,966	23,004	14,880	14,687	13,107	10,601	7,031	6,412	5,579	2,782	9,447
2018	21,271	20,195	18,608	12,037	11,881	10,602	8,575	5,687	5,187	4,512	9,892
2019	21,200	17,195	16,325	15,043	9,730	9,604	8,571	6,932	4,597	4,193	11,644
2020	17,112	17,043	13,824	13,124	12,093	7,822	7,721	6,890	5,573	3,696	12,732
2021	16,462	13,746	13,691	11,105	10,543	9,714	6,284	6,202	5,535	4,477	13,196
2022	19,283	13,271	11,081	11,037	8,952	8,499	7,831	5,066	5,000	4,462	14,248

Table 6.16 (cont'd). Model estimates of arrowtooth flounder population numbers-at-age, by sex, 1976-2022.

Males	Numbers at age (1,000s)									
Year	1	2	3	4	5	6	7	8	9	10
1976	47,308	34,475	25,194	18,583	13,734	9,937	7,446	5,545	4,112	3,052
1977	46,129	33,322	24,268	17,712	13,026	9,573	6,858	5,067	3,716	2,721
1978	45,050	32,497	23,466	17,075	12,439	9,115	6,656	4,725	3,456	2,514
1979	44,802	31,737	22,885	16,512	11,994	8,707	6,342	4,592	3,229	2,344
1980	44,685	31,558	22,343	16,091	11,579	8,366	6,018	4,327	3,087	2,147
1981	44,239	31,470	22,208	15,695	11,261	8,043	5,738	4,052	2,855	2,004
1982	42,762	31,155	22,145	15,599	10,982	7,819	5,511	3,858	2,668	1,849
1983	46,138	30,120	21,931	15,568	10,935	7,656	5,398	3,753	2,587	1,767
1984	86,269	32,493	21,196	15,407	10,896	7,598	5,252	3,636	2,478	1,681
1985	126,148	60,766	22,875	14,903	10,804	7,600	5,251	3,582	2,445	1,646
1986	220,125	88,863	42,786	16,090	10,460	7,549	5,271	3,602	2,428	1,641
1987	326,111	155,064	62,570	30,095	11,293	7,309	5,236	3,616	2,442	1,631
1988	340,340	229,750	109,211	44,037	21,149	7,912	5,095	3,623	2,482	1,665
1989	275,835	239,580	161,514	76,543	30,665	14,539	5,319	3,318	2,278	1,518
1990	178,629	194,304	168,684	113,595	53,709	21,418	10,074	3,644	2,244	1,525
1991	116,736	125,803	136,737	118,505	79,511	37,321	14,696	6,789	2,407	1,460
1992	127,400	82,203	88,507	96,003	82,836	55,096	25,473	9,817	4,428	1,541
1993	110,552	89,747	57,883	62,262	67,396	57,915	38,248	17,505	6,671	2,982
1994	112,569	77,889	63,215	40,748	43,777	47,271	40,451	26,554	12,073	4,577
1995	122,457	79,306	54,857	44,490	28,634	30,669	32,944	27,981	18,217	8,228
1996	200,157	86,282	55,868	38,629	31,301	20,111	21,476	22,971	19,418	12,595
1997	170,471	141,018	60,773	39,327	27,156	21,949	14,040	14,898	15,823	13,301
1998	181,826	120,111	99,340	42,793	27,666	19,070	15,364	9,783	10,330	10,928
1999	290,073	128,102	84,599	69,925	30,081	19,396	13,308	10,652	6,733	7,068
2000	265,802	204,377	90,238	59,565	49,183	21,116	13,568	9,263	7,373	4,641
2001	233,125	187,271	143,958	63,526	41,883	34,501	14,752	9,424	6,392	5,062
2002	281,446	164,247	131,905	101,338	44,662	29,371	24,090	10,236	6,494	4,381
2003	277,792	198,298	115,698	92,871	71,275	31,348	20,542	16,762	7,082	4,473
2004	247,608	195,721	139,680	81,454	65,310	50,012	21,911	14,280	11,581	4,870
2005	199,047	174,445	137,847	98,309	57,245	45,765	34,868	15,166	9,805	7,902
2006	243,723	140,241	122,879	97,050	69,137	40,170	31,993	24,244	10,483	6,745
2007	209,166	171,721	98,790	86,520	68,265	48,536	28,105	22,275	16,790	7,229
2008	174,233	147,377	120,973	69,568	60,877	47,955	33,999	19,608	15,472	11,620
2009	170,455	122,756	103,808	85,162	48,915	42,702	33,498	23,609	13,527	10,618
2010	136,548	120,090	86,460	73,067	59,858	34,286	29,787	23,207	16,232	9,244
2011	131,201	96,201	84,580	60,852	51,350	41,945	23,904	20,618	15,936	11,076
2012	153,618	92,434	67,755	59,531	42,768	35,986	29,249	16,551	14,165	10,880
2013	206,946	108,225	65,098	47,683	41,828	29,955	25,068	20,216	11,341	9,639
2014	191,532	145,797	76,222	45,817	33,509	29,308	20,882	17,347	13,877	7,735
2015	173,266	134,939	102,687	53,649	32,202	23,485	20,440	14,461	11,921	9,478
2016	203,417	122,082	95,059	72,310	37,746	22,617	16,446	14,253	10,037	8,243
2017	403,126	143,325	86,002	66,939	50,875	26,511	15,839	11,469	9,893	6,941
2018	228,306	284,053	100,980	60,578	47,125	35,778	18,610	11,089	8,006	6,891
2019	300,942	160,870	200,127	71,126	42,644	33,137	25,110	13,025	7,738	5,573
2020	128,127	212,042	113,329	140,932	50,047	29,959	23,215	17,522	9,050	5,358
2021	75,136	90,277	149,377	79,806	99,160	35,155	20,983	16,194	12,167	6,261
2022	118,352	52,942	63,601	105,204	56,168	69,695	24,651	14,665	11,275	8,447

Table 6.16 (cont'd). Estimates of arrowtooth flounder population number-at-age, by sex, 1976-2022.

Males	Numbers at age (1,000s)										
Year	11	12	13	14	15	16	17	18	19	20	21
1976	2,261	1,671	1,231	905	663	484	353	256	185	134	233
1977	2,008	1,487	1,099	810	595	436	319	232	169	122	242
1978	1,834	1,353	1,002	741	546	401	294	215	156	114	245
1979	1,699	1,240	915	677	501	369	271	199	145	106	242
1980	1,550	1,123	819	605	448	331	244	179	131	96	230
1981	1,383	998	724	528	389	288	213	157	115	85	210
1982	1,288	888	641	465	339	250	185	137	101	74	189
1983	1,217	848	585	422	306	223	165	122	90	66	173
1984	1,140	785	547	377	272	197	144	106	79	58	155
1985	1,111	753	519	361	249	180	130	95	70	52	141
1986	1,100	742	503	347	241	167	120	87	64	47	129
1987	1,097	736	496	336	232	161	111	80	58	43	117
1988	1,108	746	500	337	229	158	110	76	55	40	109
1989	1,005	669	450	302	203	138	95	66	46	33	89
1990	1,011	669	446	300	201	136	92	63	44	30	82
1991	984	653	432	288	194	130	88	59	41	28	72
1992	926	624	414	274	182	123	82	56	38	26	64
1993	1,033	621	419	278	184	122	82	55	37	25	60
1994	2,041	707	425	286	190	126	84	56	38	25	58
1995	3,109	1,386	480	289	195	129	85	57	38	26	57
1996	5,679	2,146	957	332	199	134	89	59	39	26	57
1997	8,604	3,879	1,466	654	226	136	92	61	40	27	57
1998	9,169	5,931	2,674	1,010	451	156	94	63	42	28	58
1999	7,457	6,256	4,047	1,825	689	307	107	64	43	29	58
2000	4,861	5,128	4,303	2,783	1,255	474	211	73	44	30	60
2001	3,178	3,329	3,512	2,947	1,906	859	325	145	50	30	61
2002	3,460	2,172	2,276	2,401	2,014	1,303	587	222	99	34	63
2003	3,011	2,378	1,493	1,564	1,650	1,384	895	404	153	68	67
2004	3,068	2,065	1,631	1,024	1,073	1,132	950	614	277	105	92
2005	3,313	2,087	1,405	1,110	697	730	770	646	418	188	134
2006	5,423	2,273	1,433	964	762	478	501	528	443	287	221
2007	4,642	3,732	1,565	986	664	524	329	345	364	305	350
2008	4,994	3,207	2,579	1,081	681	458	362	227	238	251	452
2009	7,954	3,419	2,195	1,765	740	466	314	248	156	163	482
2010	7,235	5,420	2,330	1,496	1,203	504	318	214	169	106	439
2011	6,289	4,922	3,687	1,585	1,018	818	343	216	145	115	371
2012	7,539	4,280	3,350	2,510	1,079	693	557	233	147	99	331
2013	7,380	5,114	2,903	2,272	1,702	732	470	378	158	100	291
2014	6,554	5,017	3,477	1,974	1,545	1,157	497	319	257	108	266
2015	5,267	4,463	3,417	2,368	1,344	1,052	788	339	218	175	254
2016	6,542	3,636	3,080	2,358	1,634	928	726	544	234	150	296
2017	5,690	4,516	2,510	2,126	1,628	1,128	640	501	376	161	308
2018	4,829	3,959	3,142	1,746	1,479	1,133	785	446	349	261	327
2019	4,791	3,358	2,752	2,184	1,214	1,029	787	546	310	242	409
2020	3,852	3,312	2,321	1,903	1,510	839	711	544	377	214	450
2021	3,700	2,661	2,287	1,603	1,314	1,043	580	491	376	260	459
2022	4,341	2,565	1,844	1,586	1,111	911	723	402	340	261	499

Table 6.17 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. $B_{40\%}$ = 224,487 t, $B_{35\%}$ = 196,427 t, $F_{40\%}$ = 0.146 and $F_{35\%}$ = 0.174.

Year	Maximum permissible F	Author's F*	Half maximum F	5-year average F	No fishing	Overfished	Approaching overfished
			Spawning Biomass (t)				
2022	498,352	498,352	498,352	498,352	498,352	498,352	498,352
2023	509,362	514,577	512,240	514,470	515,134	508,262	509,362
2024	473,339	537,999	508,011	536,538	545,315	460,698	473,339
2025	439,726	554,429	502,174	556,717	574,043	417,969	438,764
2026	403,435	501,260	488,669	567,451	593,267	375,019	392,346
2027	362,668	443,237	464,283	563,942	597,524	330,144	344,081
2028	322,542	387,068	433,399	549,296	589,322	288,346	299,241
2029	290,204	340,891	404,259	532,335	577,415	256,029	264,378
2030	267,885	307,095	381,630	518,941	567,992	234,539	240,813
2031	253,622	283,640	364,710	510,575	562,943	221,675	226,098
2032	244,275	266,958	354,728	505,059	560,210	214,653	217,590
2033	238,510	255,147	347,750	501,633	559,175	211,156	213,039
2034	234,912	246,753	341,223	498,957	558,456	209,503	210,658
2035	232,968	241,220	339,731	497,017	558,095	209,112	209,788
			Fishing Mortality				
2022	0.014	0.014	0.014	0.014	0.014	0.014	0.014
2023	0.146	0.014	0.073	0.017	-	0.174	0.174
2024	0.146	0.013	0.073	0.017	-	0.174	0.174
2025	0.146	0.146	0.073	0.017	-	0.174	0.174
2026	0.146	0.146	0.073	0.017	-	0.174	0.174
2027	0.146	0.146	0.073	0.017	-	0.174	0.174
2028	0.146	0.146	0.073	0.017	-	0.174	0.174
2029	0.146	0.146	0.073	0.017	-	0.174	0.174
2030	0.146	0.146	0.073	0.017	-	0.171	0.171
2031	0.145	0.146	0.073	0.017	-	0.164	0.164
2032	0.143	0.145	0.073	0.017	-	0.159	0.159
2033	0.140	0.144	0.073	0.017	-	0.157	0.157
2034	0.139	0.142	0.073	0.017	-	0.156	0.156
2035	0.139	0.141	0.073	0.017	-	0.155	0.155
			Yield (t)				
2022	8,048	8,048	8,048	8,048	8,048	8,048	8,048
2023	83,852	83,852	43,219	10,124	-	98,787	83,852
2024	78,621	87,511	43,017	10,556	-	90,539	78,621
2025	71,963	88,707	41,633	10,675	-	81,147	84,749
2026	64,043	77,549	39,097	10,463	-	70,782	73,621
2027	56,071	66,732	35,977	10,028	-	60,860	63,046
2028	50,213	58,520	33,470	9,649	-	53,814	55,474
2029	46,975	53,393	32,054	9,471	-	50,025	51,276
2030	45,113	50,028	31,218	9,393	-	47,417	48,676
2031	43,657	47,493	30,562	9,328	-	44,403	45,473
2032	42,101	45,533	30,038	9,272	-	42,595	43,315
2033	40,985	43,787	29,642	9,232	-	41,693	42,149
2034	40,373	42,394	29,347	9,200	-	41,410	41,679
2035	40,149	41,580	29,193	9,190	-	41,521	41,676

*Projections are based on estimated catches of 8,048 t and 8,507 t used in place of maximum permissible ABC for 2022 and 2023 in response to a Plan Team request to obtain more accurate two-year projections.

Table 6.18. Catch, OFL, TAC, and ABC used to manage the BSAI arrowtooth flounder complex since 1980. **Catch information through October 14, 2022, 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	16,306	297,000	75,000	244,000
2009	19,644	190,000	75,000	156,000
2010	20,874	191,000	75,000	156,000
2011	20,575	186,000	25,900	153,000
2012	22,641	181,000	25,900	157,000
2013	21,007	186,000	25,000	152,000
2014	19,626	125,642	25,000	106,599
2015	11,721	93,856	22,000	80,547
2016	11,485	94,035	14,000	80,701
2017	6,934	76,100	14,000	65,371
2018	7,243	76,757	13,621	65,932
2019	10,374	82,939	8,000	70,673
2020	10,874	84,057	10,000	71,618
2021	9,014	90,873	15,000	77,349
2022	7,107	94,445	20,000	80,389

Figures

Bottom trawl survey (BTS) biomass (t) by region

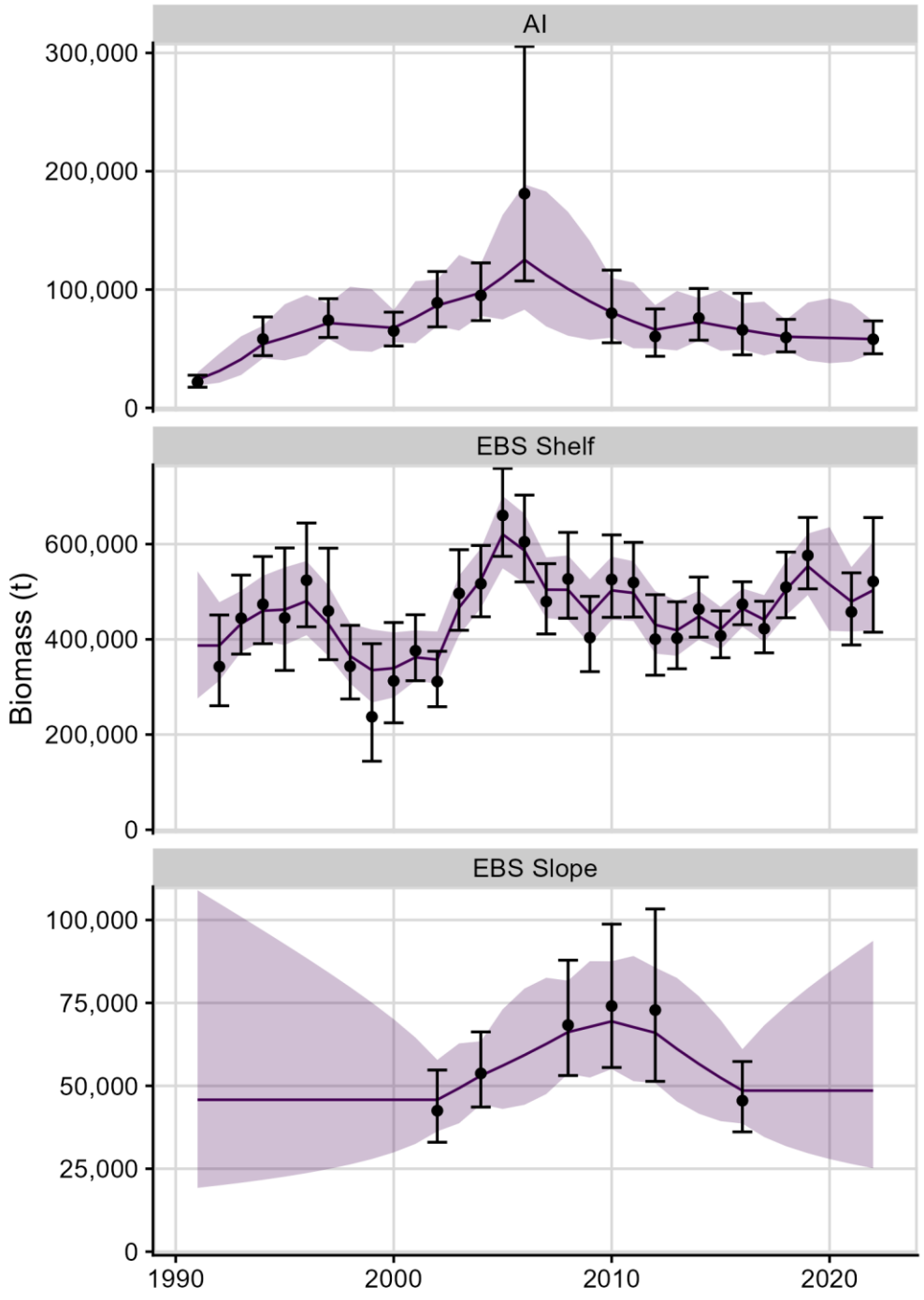

Figure 6.1. Survey estimates for the EBS shelf, slope and the AI arrowtooth flounder biomass, with fitted linear model predictions.

Figure 6.2 Number of fishery lengths by year, males above, females below for sample sizes >300 lengths.

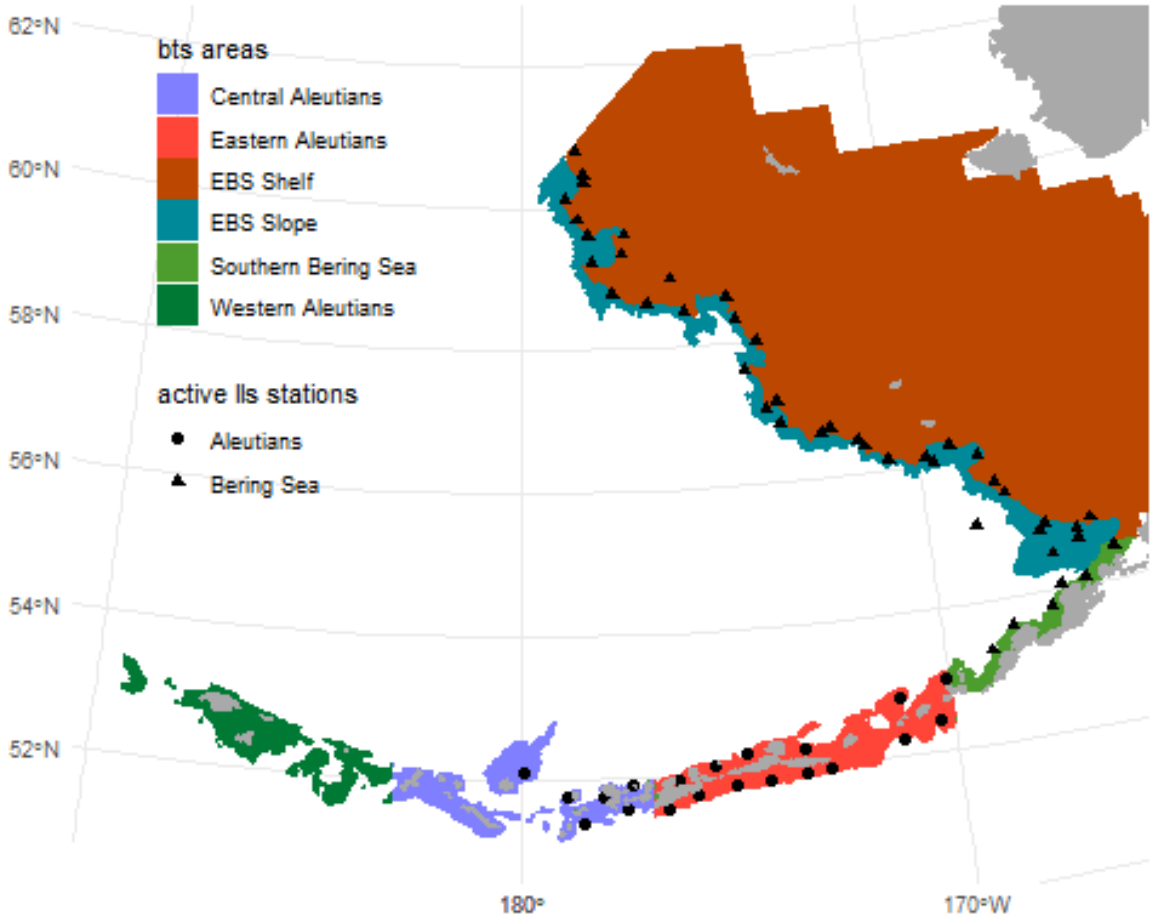

Figure 6.2 Bottom trawl surveys (BTS) strata and active longline survey (LLS) stations in the Aleutian Islands and eastern Bering Sea.

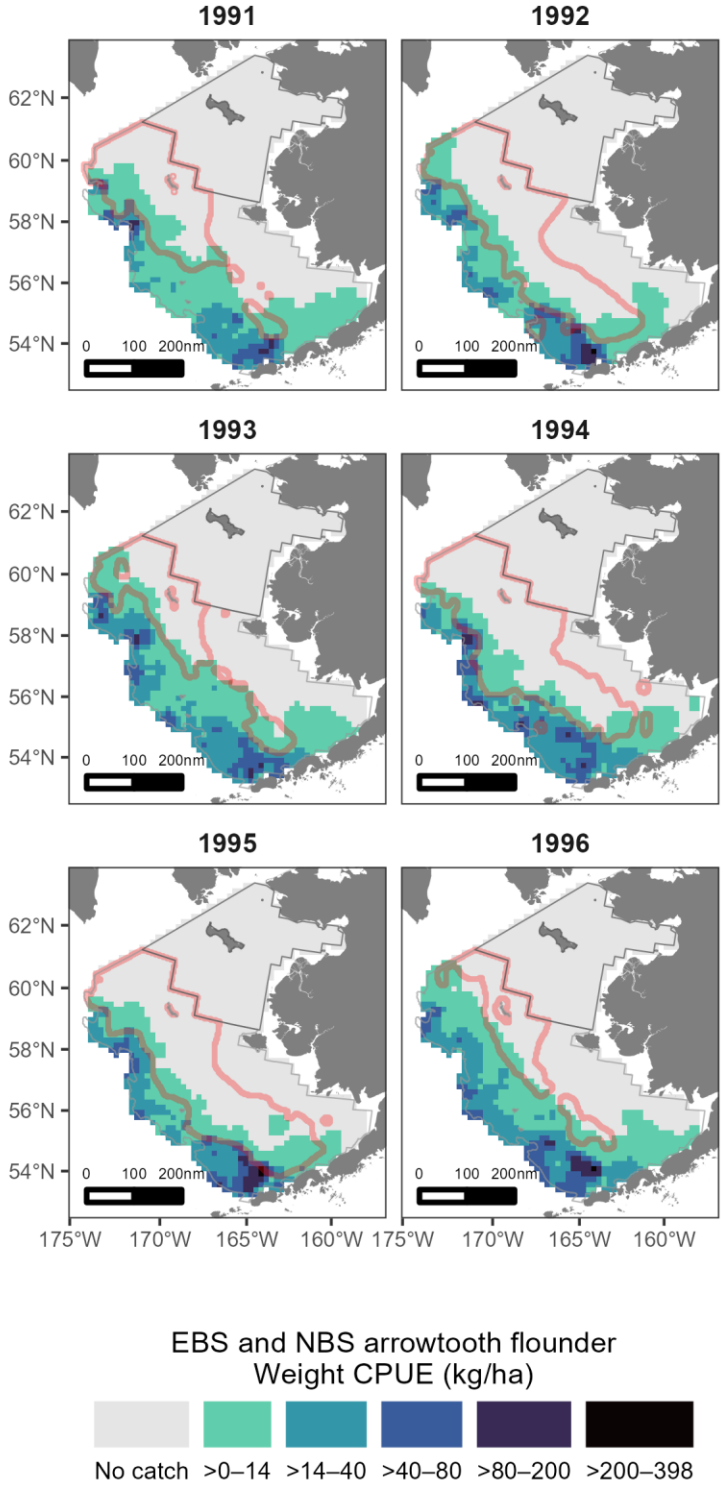

Figure 6.3. Spatial distribution map of catch-per-unit-effort (CPUE) in kg/ha of arrowtooth flounder on the eastern Bering Sea bottom trawl survey from 1991 to present. Red polygon outlines the extent of the cold pool.

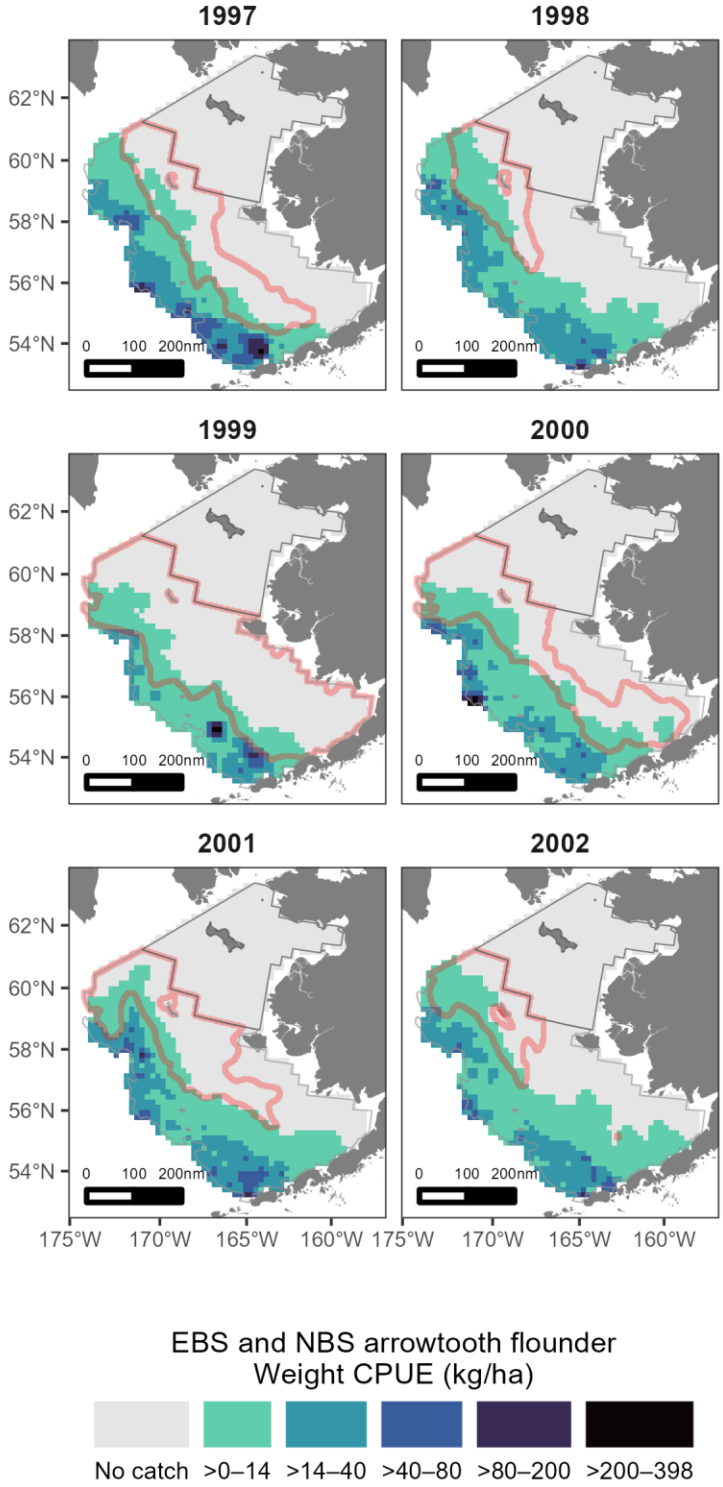

Figure 6.3 (cont.). Spatial distribution map of catch-per-unit-effort (CPUE) in kg/ha of arrowtooth flounder on the eastern Bering Sea bottom trawl survey from 1991 to present. Red polygon outlines the extent of the cold pool.

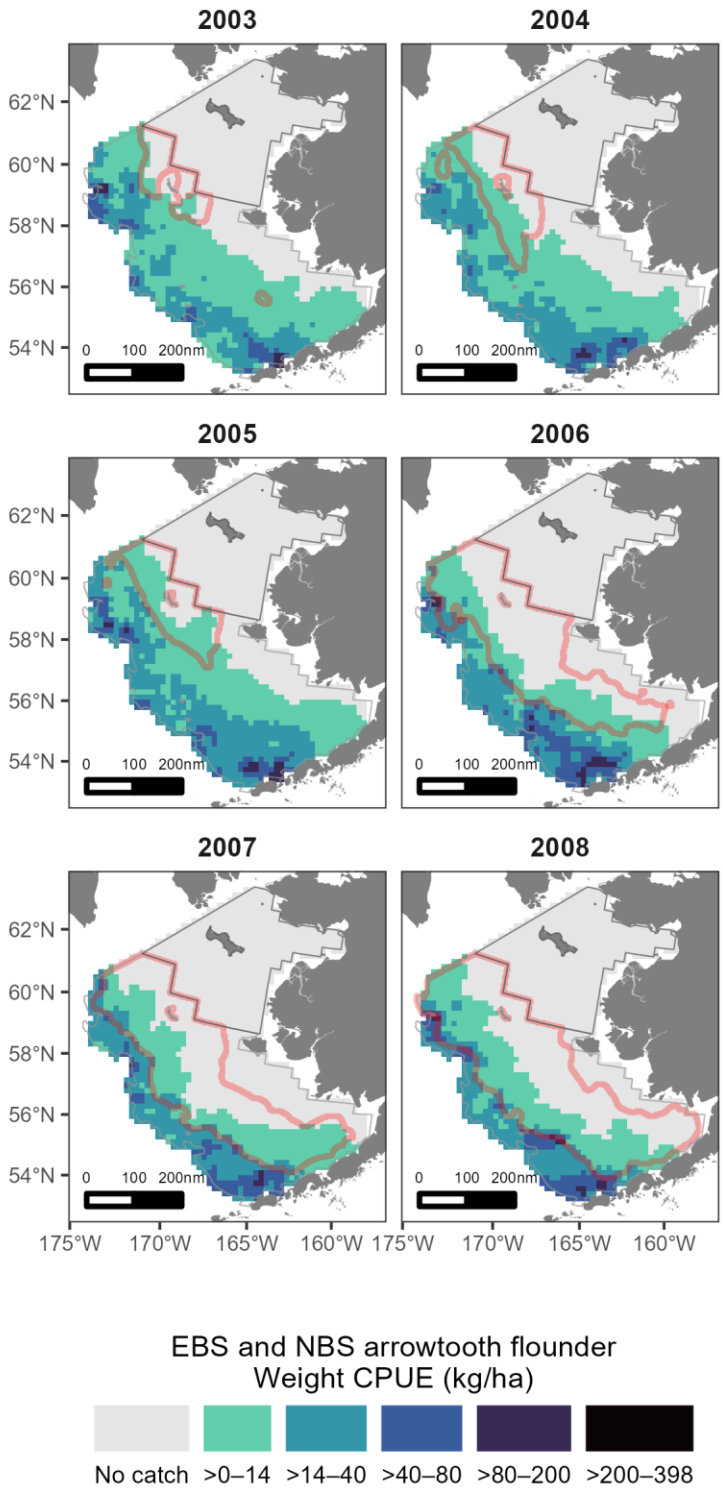

Figure 6.3 (cont.). Spatial distribution map of catch-per-unit-effort (CPUE) in kg/ha of arrowtooth flounder on the eastern Bering Sea bottom trawl survey from 1991 to present. Red polygon outlines the extent of the cold pool.

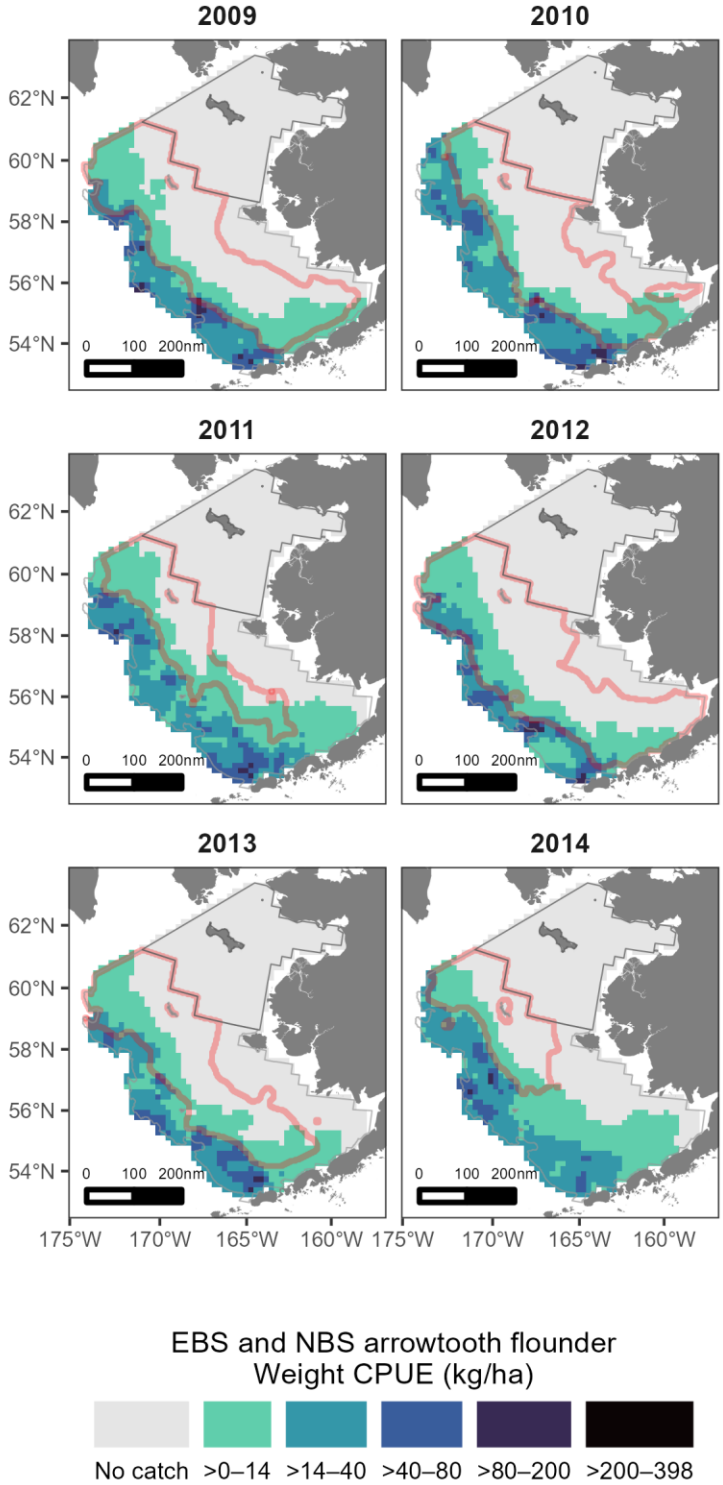

Figure 6.3 (cont.). Spatial distribution map of catch-per-unit-effort (CPUE) in kg/ha of arrowtooth flounder on the eastern Bering Sea bottom trawl survey from 1991 to present. Red polygon outlines the extent of the cold pool.

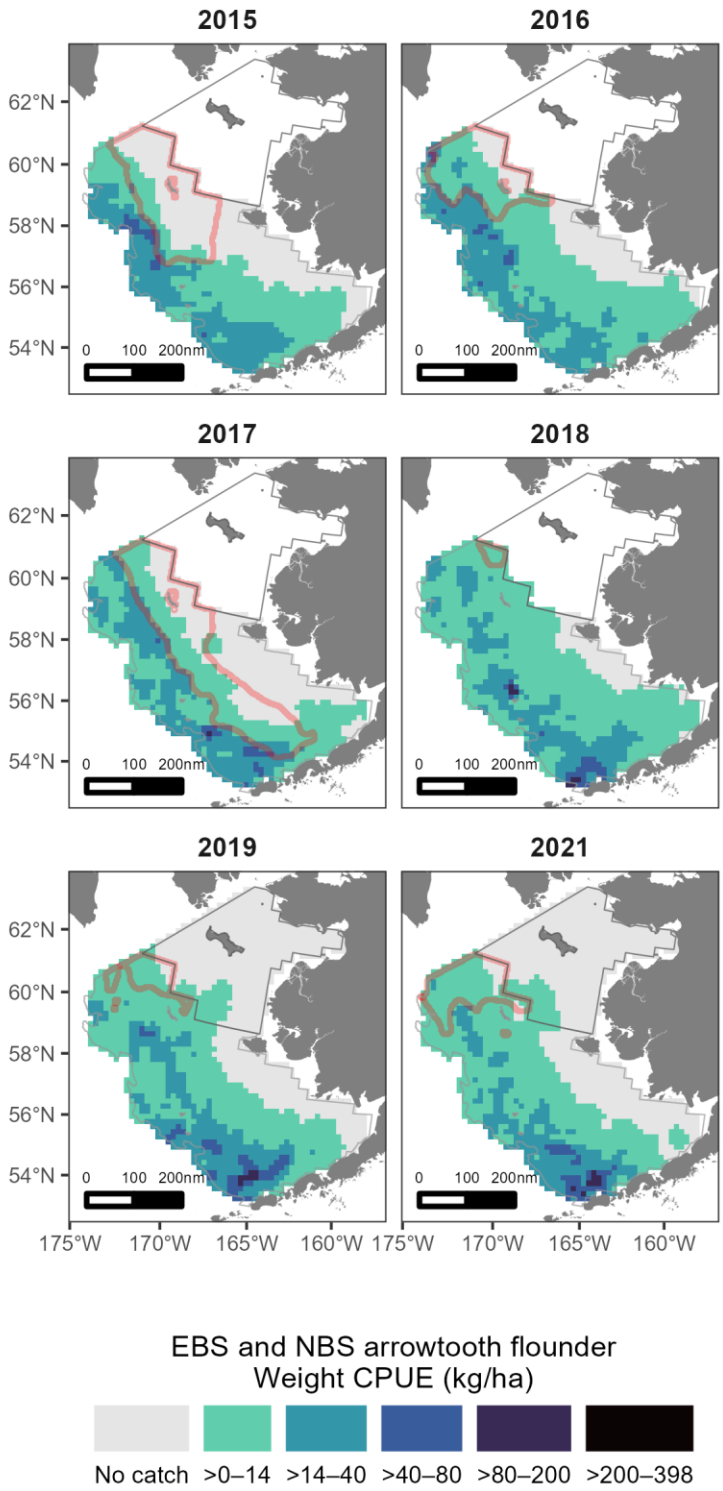

Figure 6.3 (cont.). Spatial distribution map of catch-per-unit-effort (CPUE) in kg/ha of arrowtooth flounder on the eastern Bering Sea bottom trawl survey from 1991 to present. Red polygon outlines the extent of the cold pool.

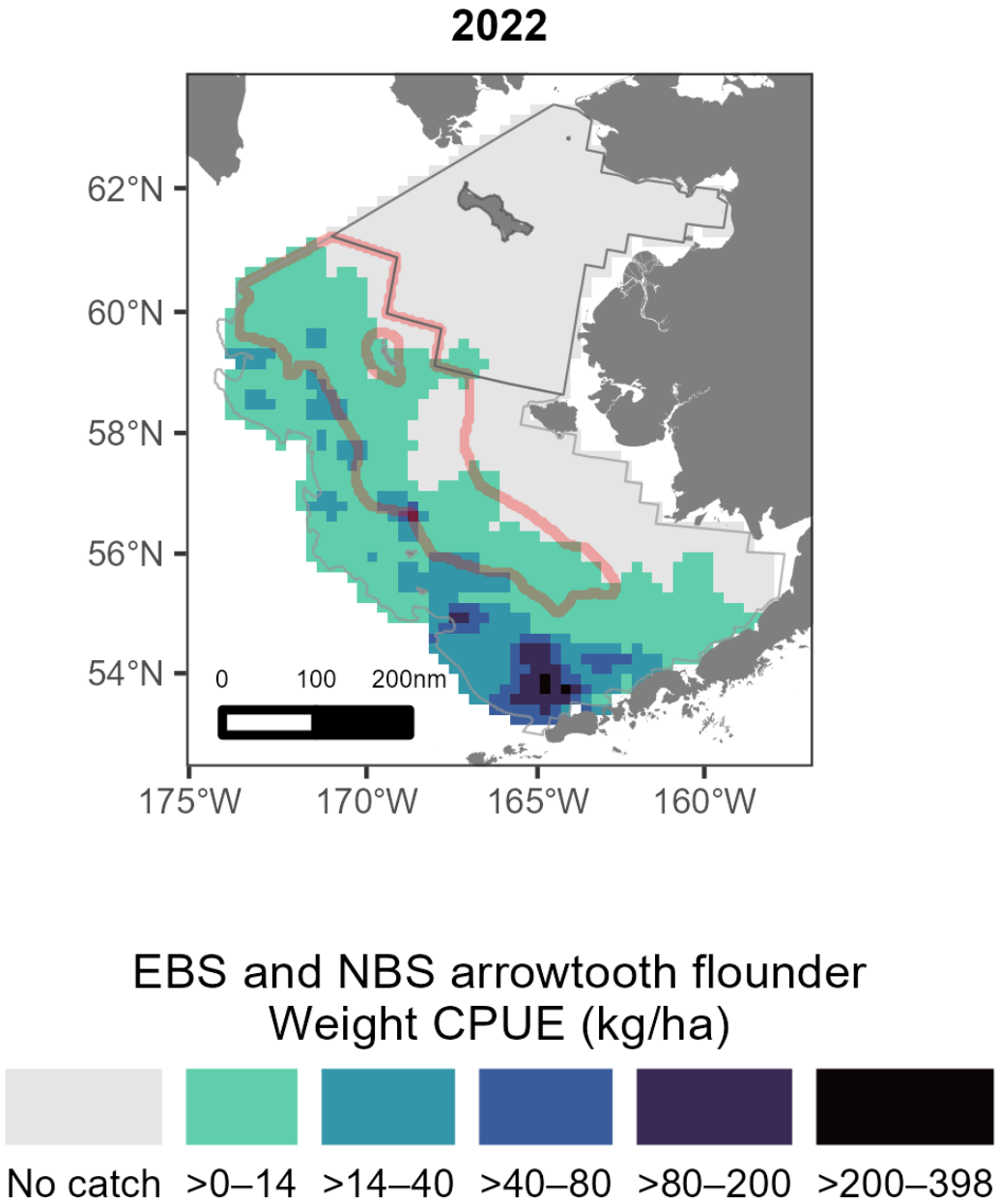

Figure 6.3 (cont.). Spatial distribution map of catch-per-unit-effort (CPUE) in kg/ha of arrowtooth flounder on the eastern Bering Sea bottom trawl survey from 1991 to present. Red polygon outlines the extent of the cold pool.

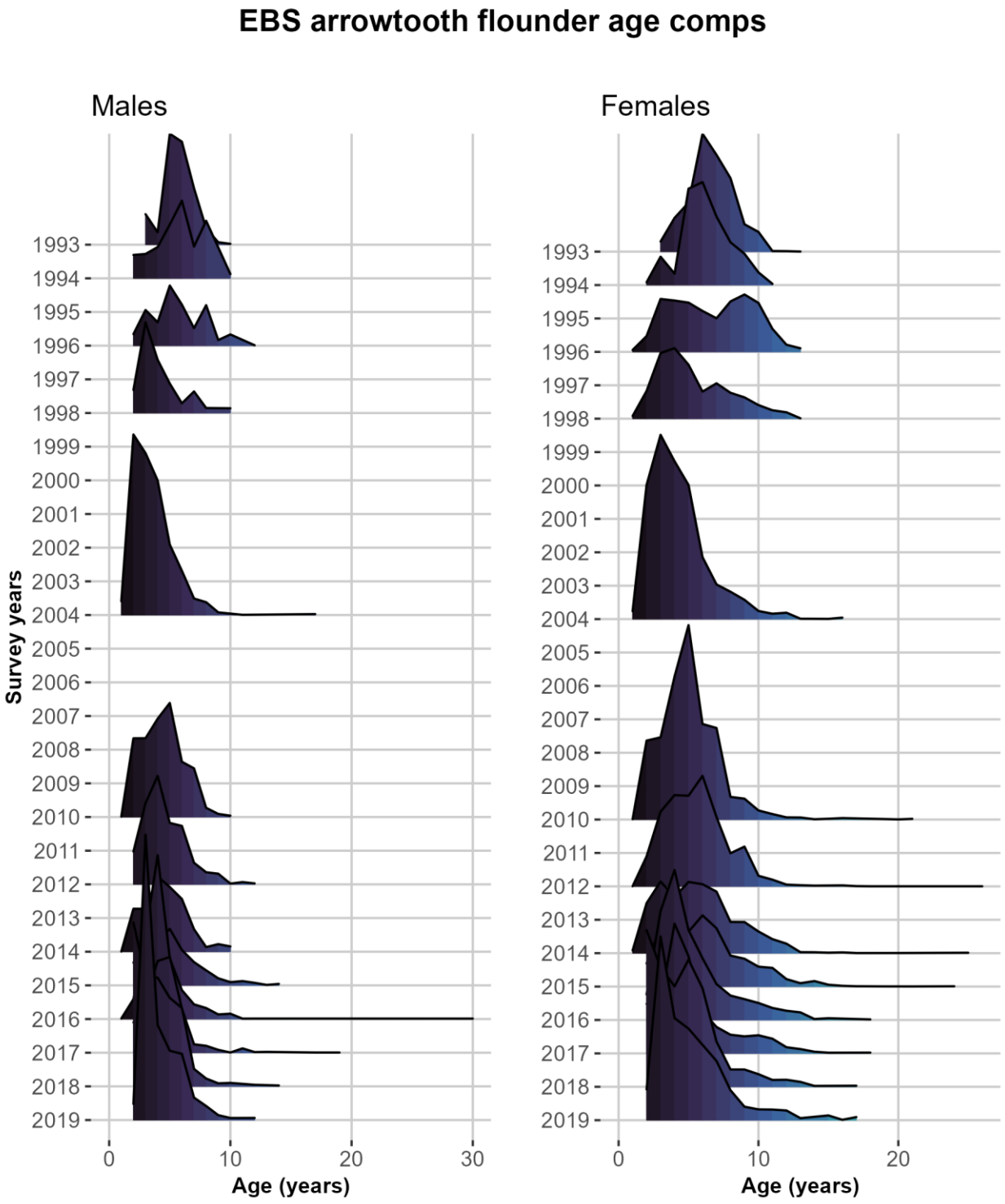

Figure 6.4. Age frequency data from male (left panel) and female (right panel) arrowtooth flounder in the eastern Bering Sea shelf bottom trawl survey from 1991-2022.

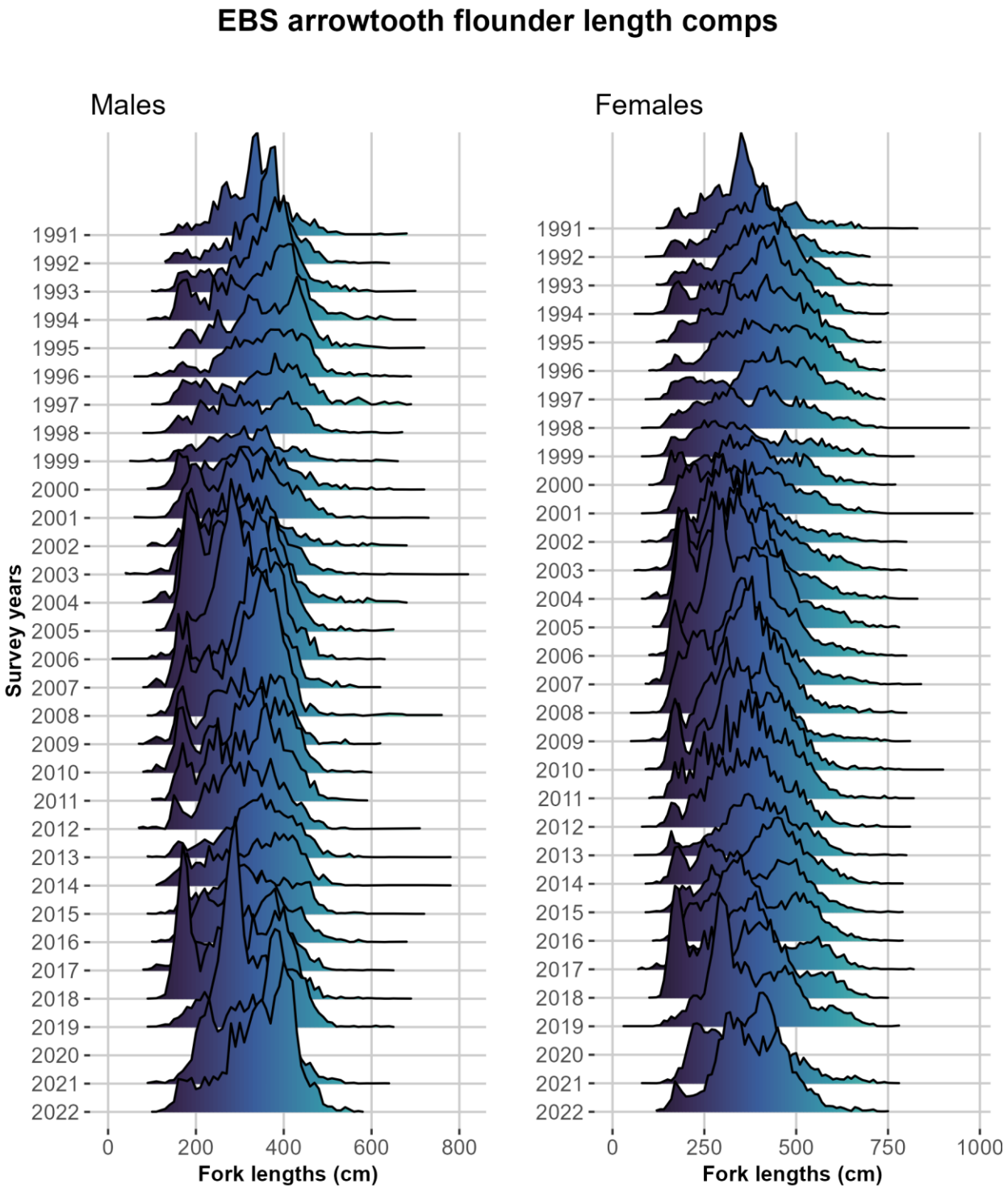

Figure 6.5. Length frequency data from male (left panel) and female (right panel) arrowtooth flounder on the EBS shelf survey from 1991-2022.

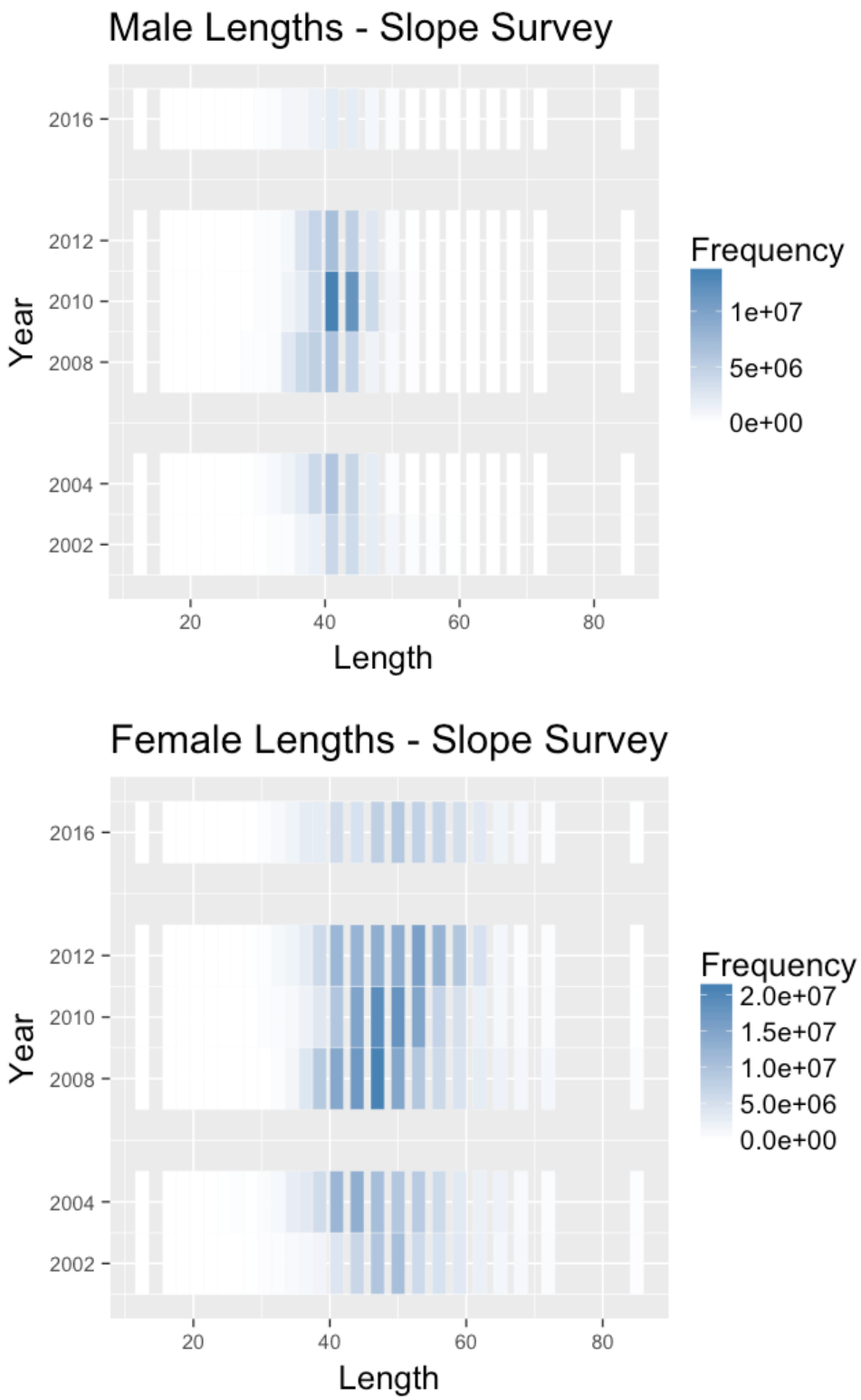

Figure 6.6: Length frequency data from female (upper panel) and male (lower panel) Bering Sea slope survey arrowtooth flounder from 2002-2016.

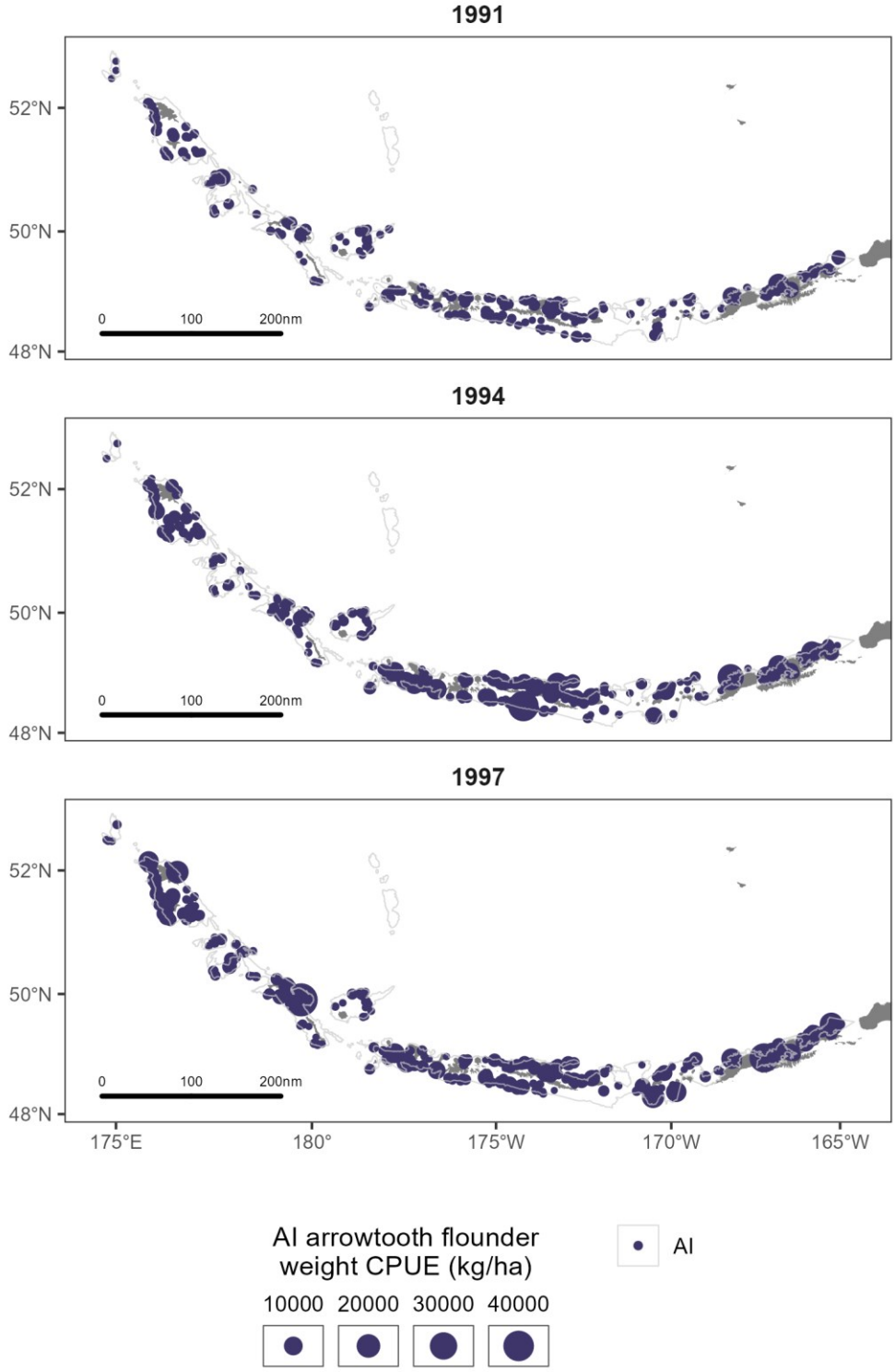

Figure 6.7. Spatial distribution map of catch-per-unit-effort (CPUE) in kg/ha of arrowtooth flounder on the Aleutian Islands bottom trawl survey from 1991 to present.

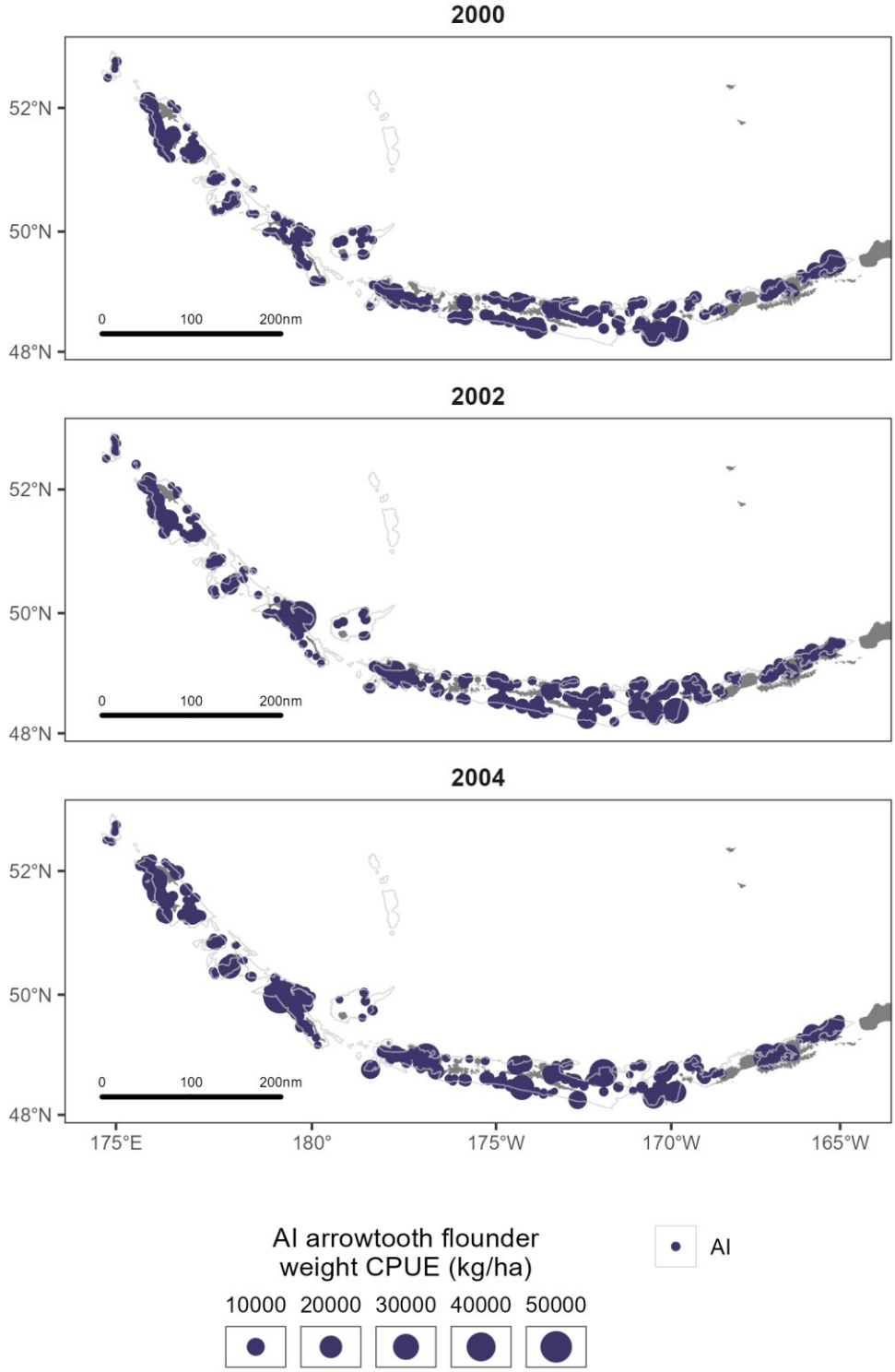

Figure 6.7 (cont.). Spatial distribution map of catch-per-unit-effort (CPUE) in kg/ha of arrowtooth flounder on the Aleutian Islands bottom trawl survey from 1991 to present.

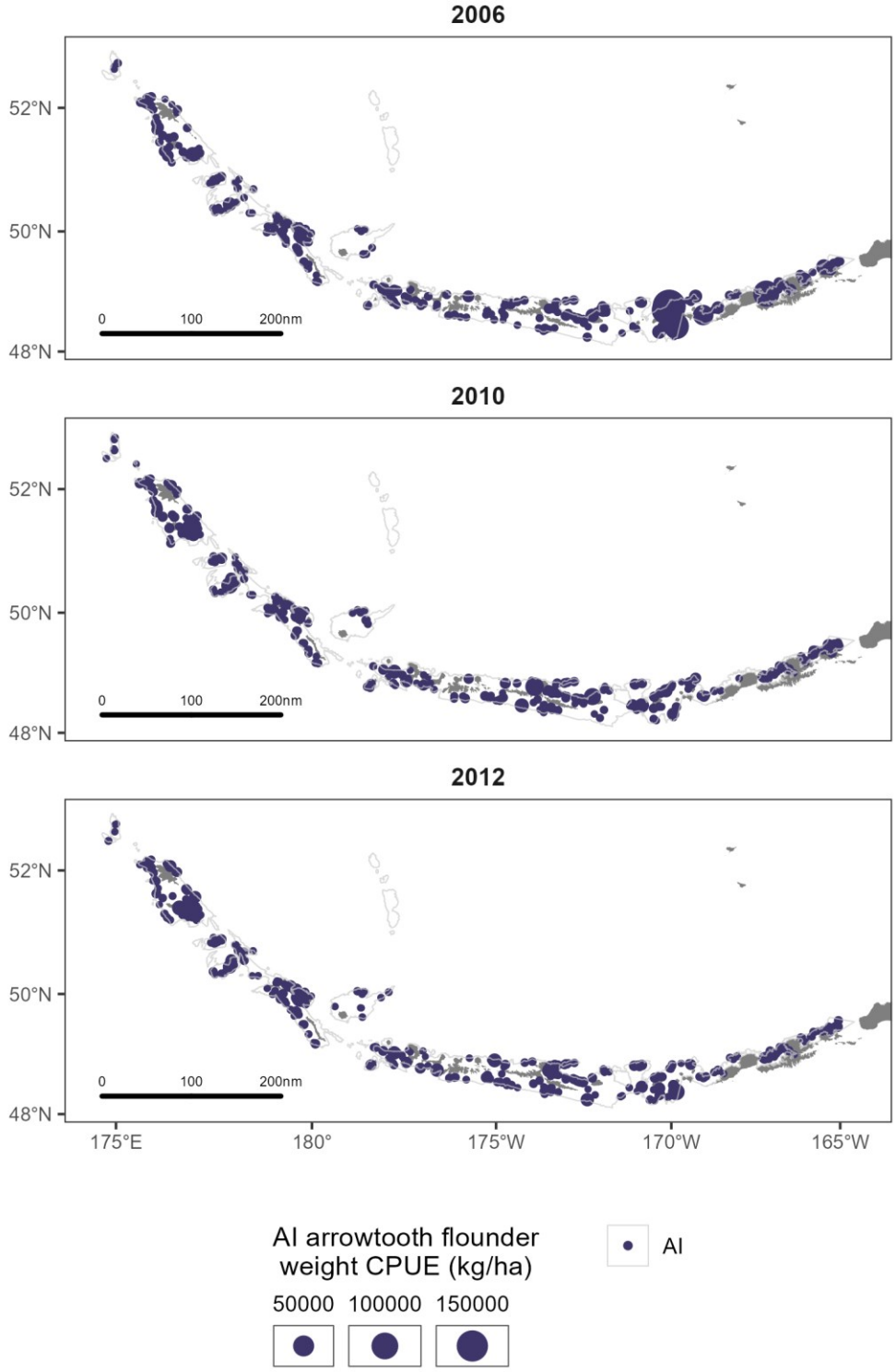

Figure 6.7 (cont.). Spatial distribution map of catch-per-unit-effort (CPUE) in kg/ha of arrowtooth flounder on the Aleutian Islands bottom trawl survey from 1991 to present.

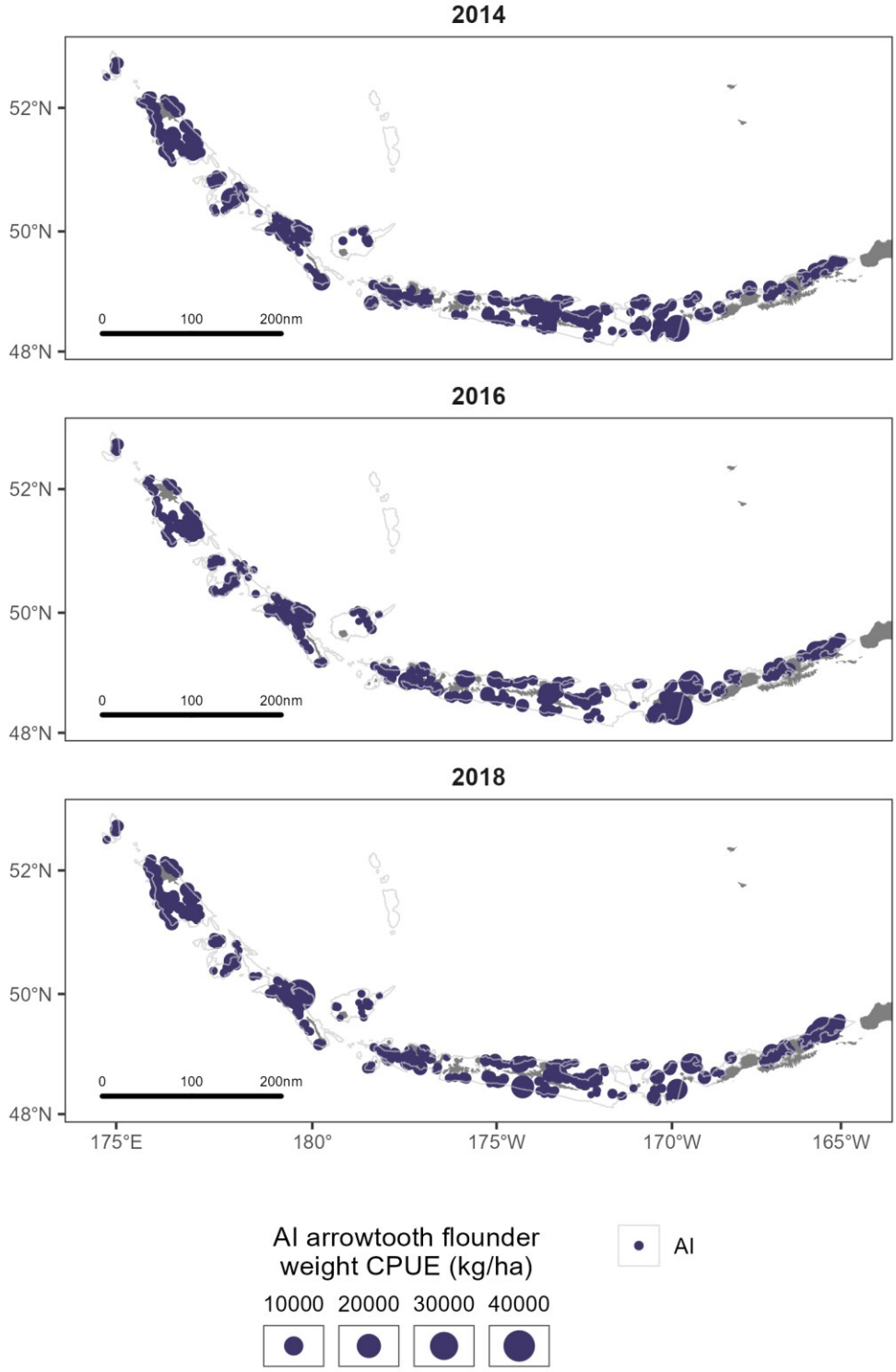

Figure 6.7 (cont.). Spatial distribution map of catch-per-unit-effort (CPUE) in kg/ha of arrowtooth flounder on the Aleutian Islands bottom trawl survey from 1991 to present.

2022

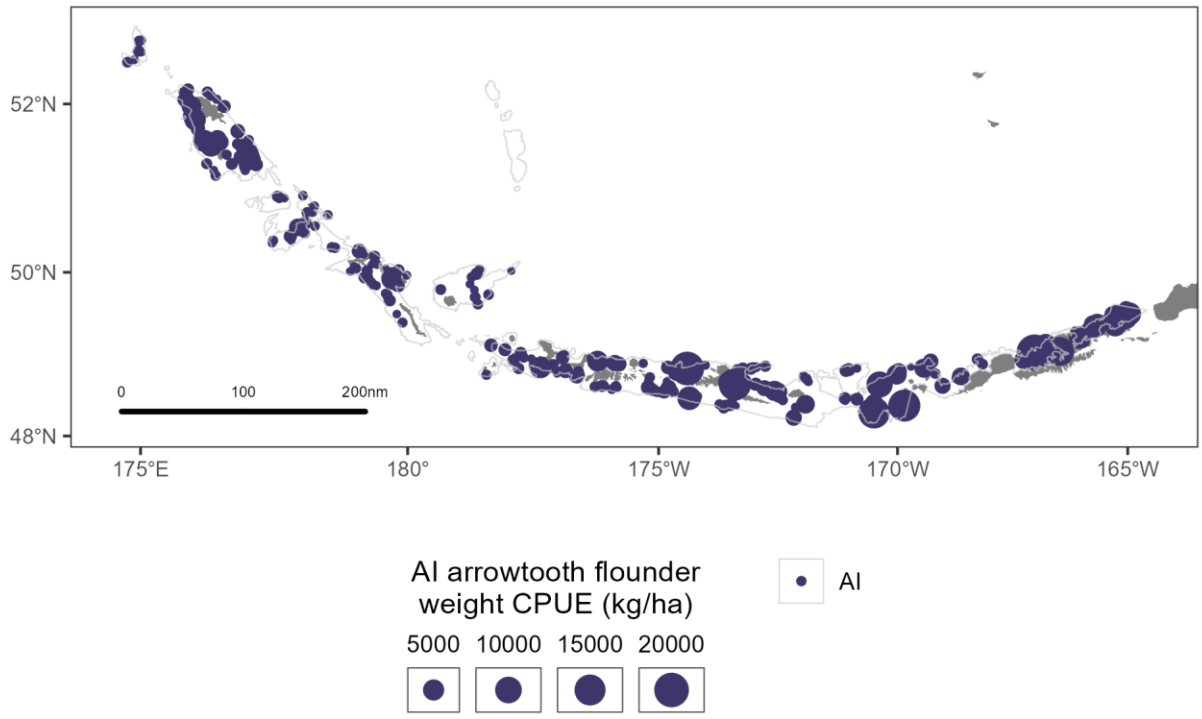

Figure 6.7 (cont.). Spatial distribution map of catch-per-unit-effort (CPUE) in kg/ha of arrowtooth flounder on the Aleutian Islands bottom trawl survey from 1991 to present.

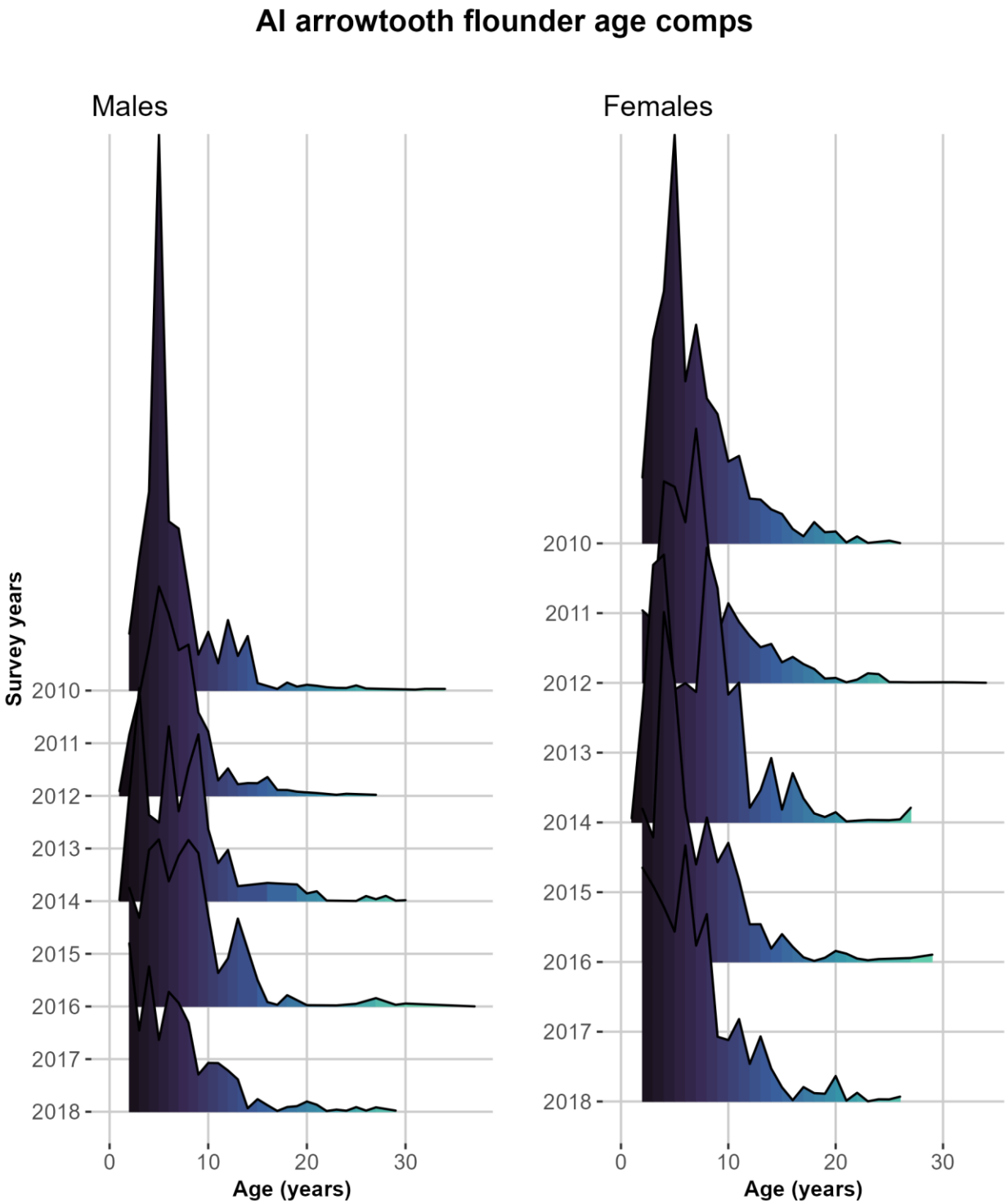

Figure 6.8. Age frequency data from male (left panel) and female (right panel) arrowtooth flounder in the AI bottom trawl survey from 1991-2022.

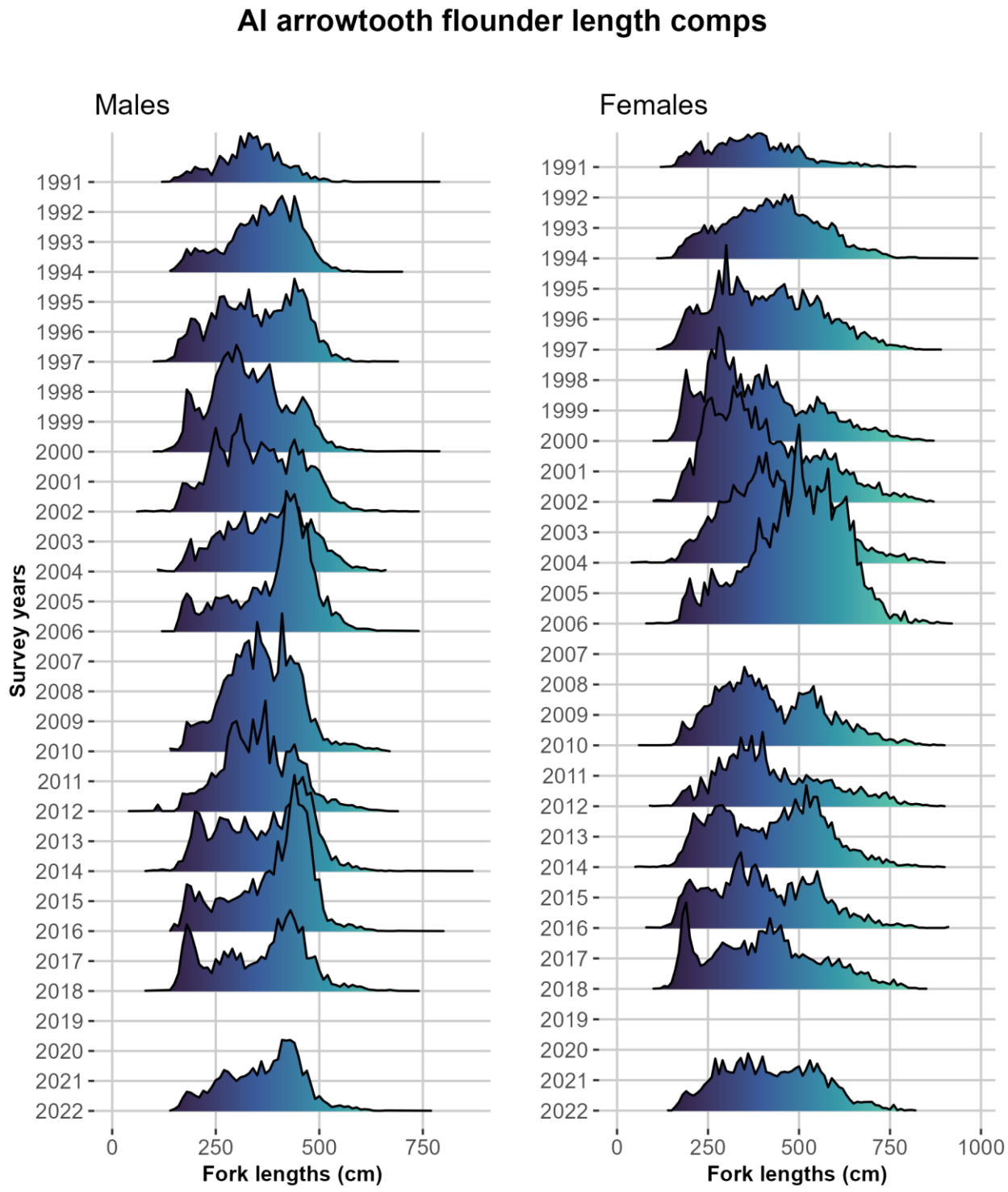

Figure 6.9. Length frequency data from male (left panel) and female (right panel) arrowtooth flounder in the AI bottom trawl survey from 1991-2022.

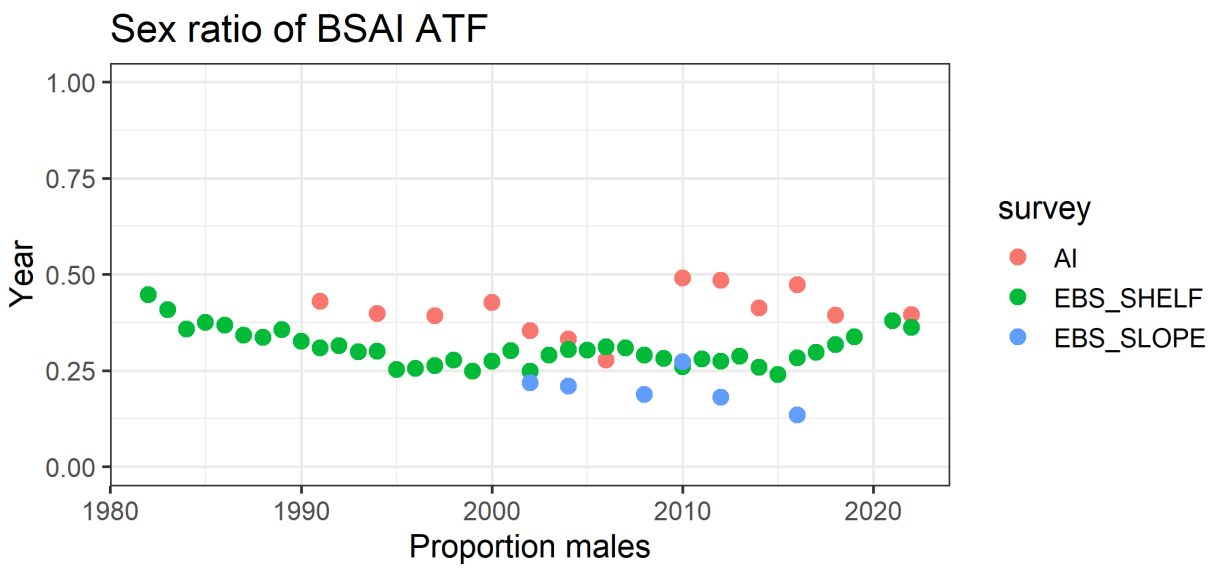

Figure 6.10. Proportion of the estimated male population from Bering Sea and Aleutian Islands trawl surveys on the continental shelf and slope.

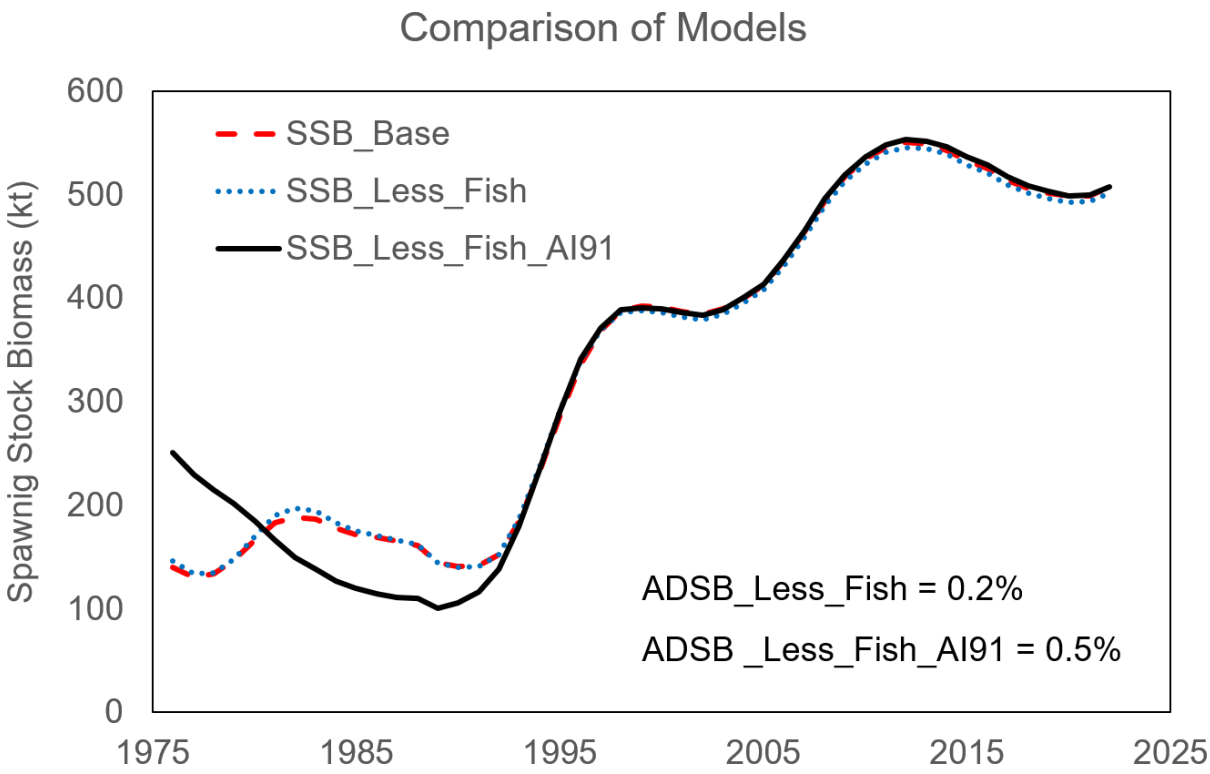

Figure 6.11. Female spawning biomass for the base model (SSB_Base) compared to the corrected model with fewer fishery size compositions (SSB_Less_Fish) and the further corrected model with no Aleutian Islands survey data prior to the standardized survey year of 1991 (SSB_Less_Fish_AI91). ADSB is average difference of biomass and should be less than 0.1 for minor model change. 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).

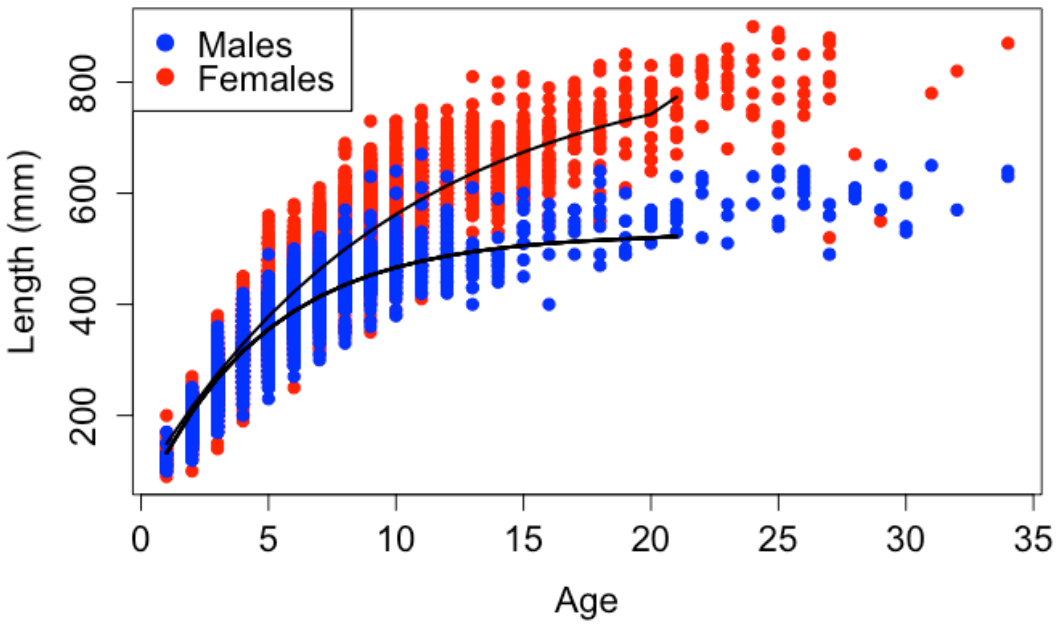

Figure 6.12. Fit to age data based on length at age data and length frequency data from surveys (black lines, females are larger than males). Blue circles represent males and red circles are females. The plus group is estimated length at age for ages 21+, and is based on a weighted average of those ages.

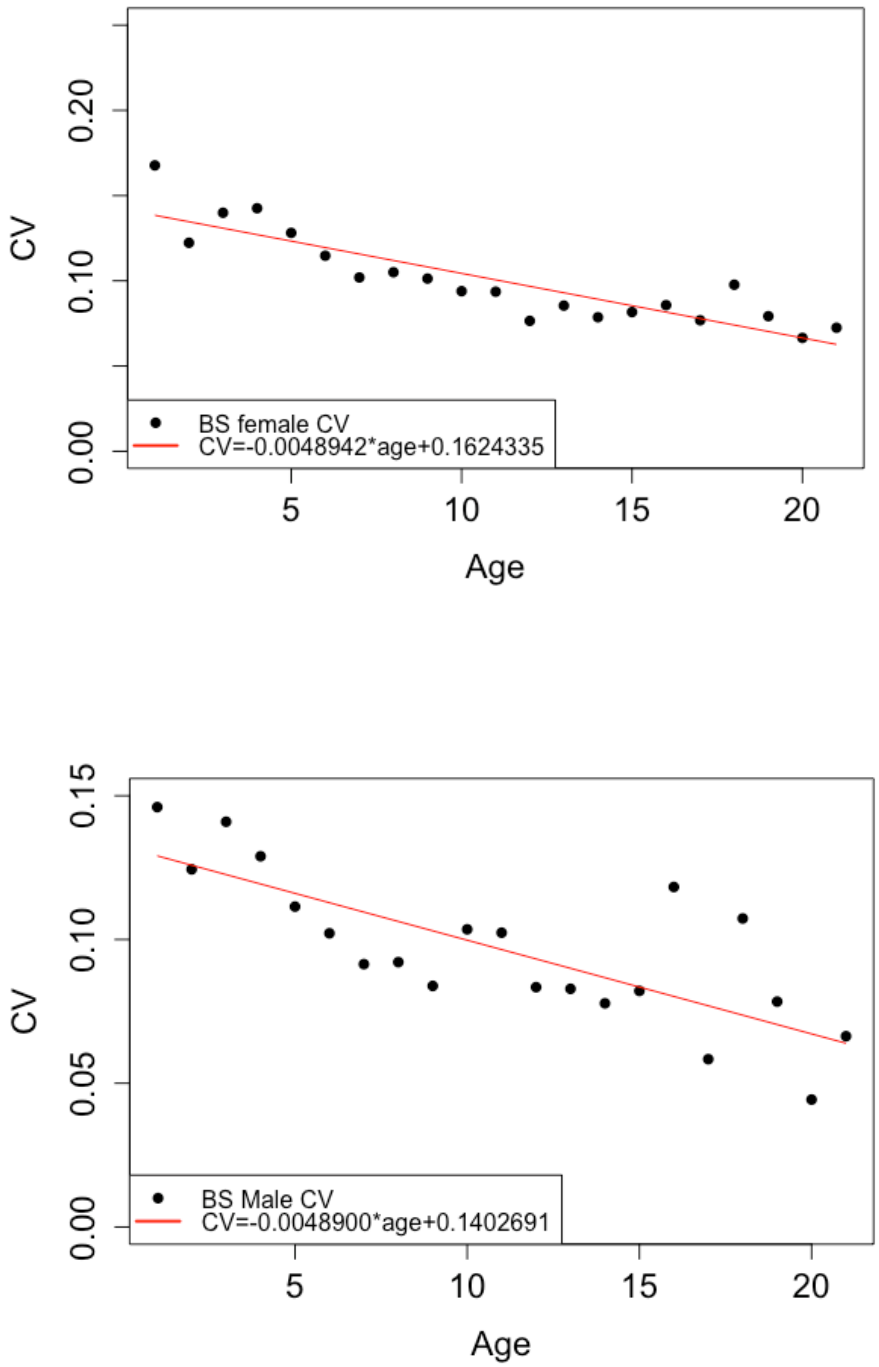

Figure 6.13. The CV of length at age for each age from 1-21+ for females (upper panel) and males (lower panel). The CV is fit to a linear model with respect to age, which is shown in the legend in each panel.

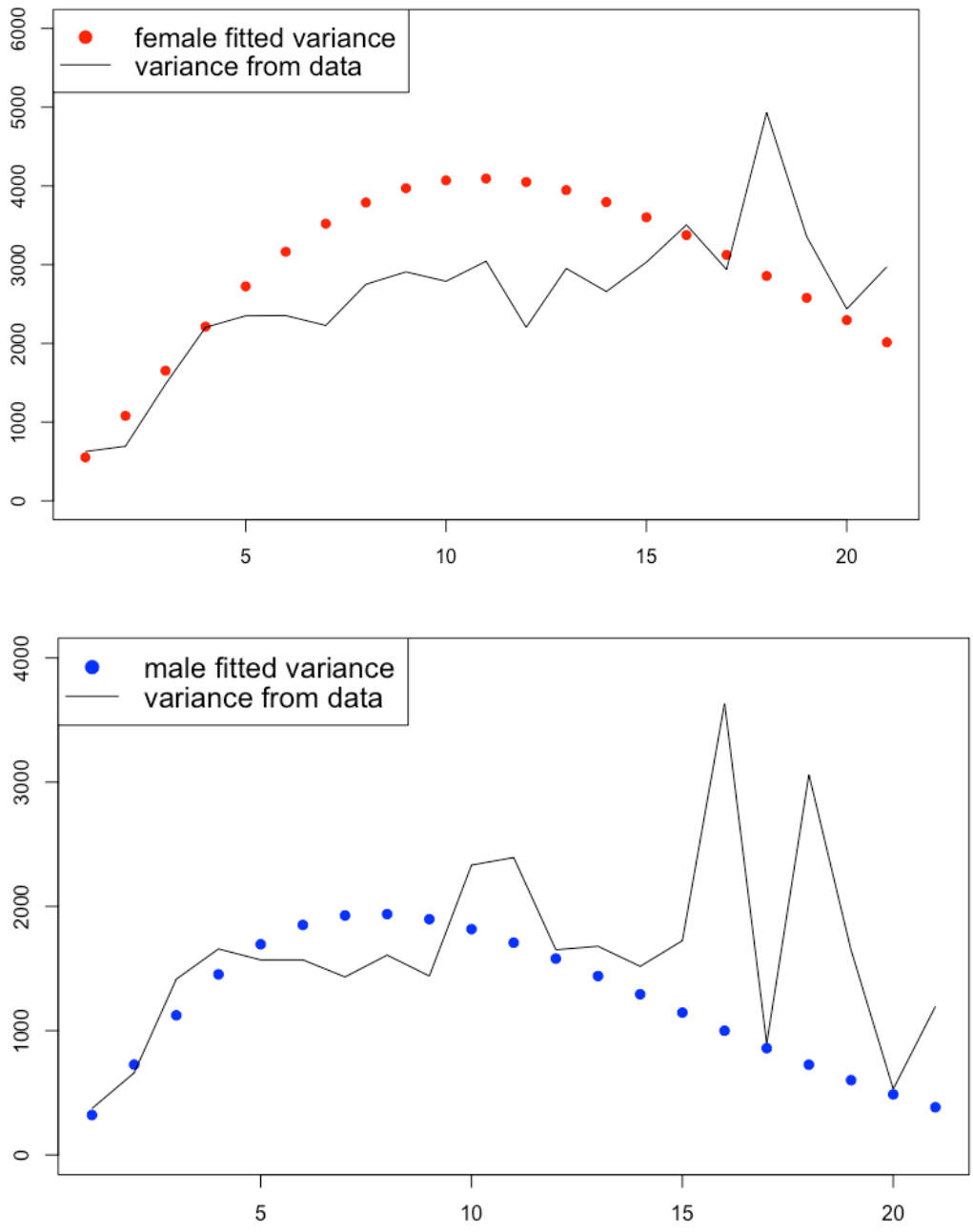

Figure 6.14. The variance of length at age for each age from 1-21+ for females (upper panel) and males (lower panel), as red (female) and blue (male) points. Data values are shown as a black line.

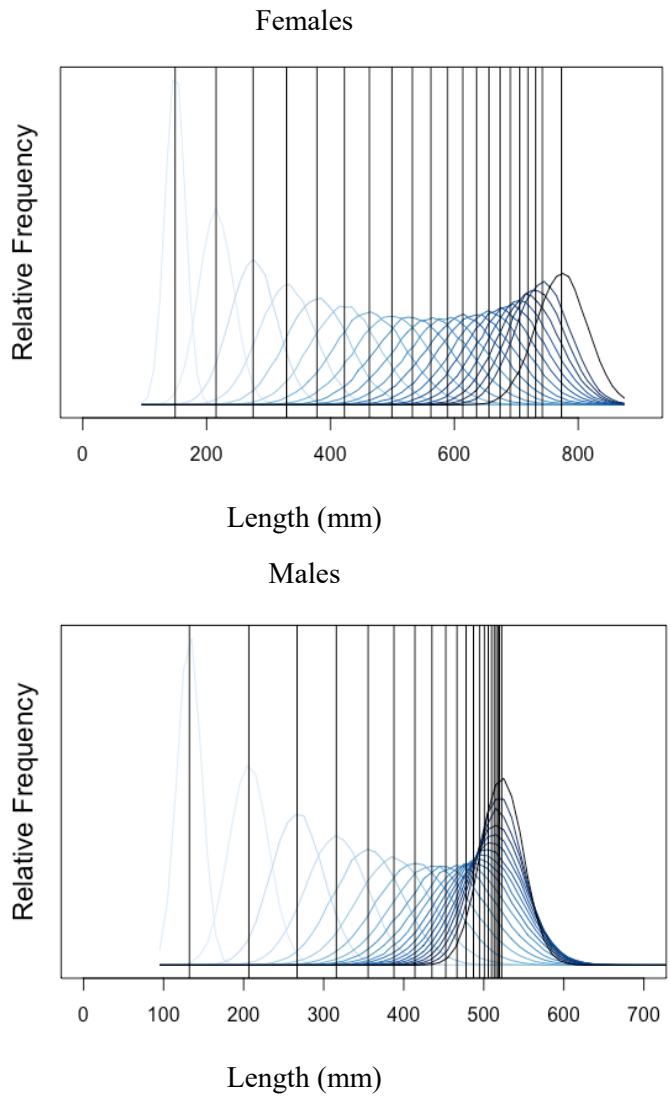

Figure 6.15. Length-age conversion matrix for females (upper panel) and males (lower panel), with length in mm.

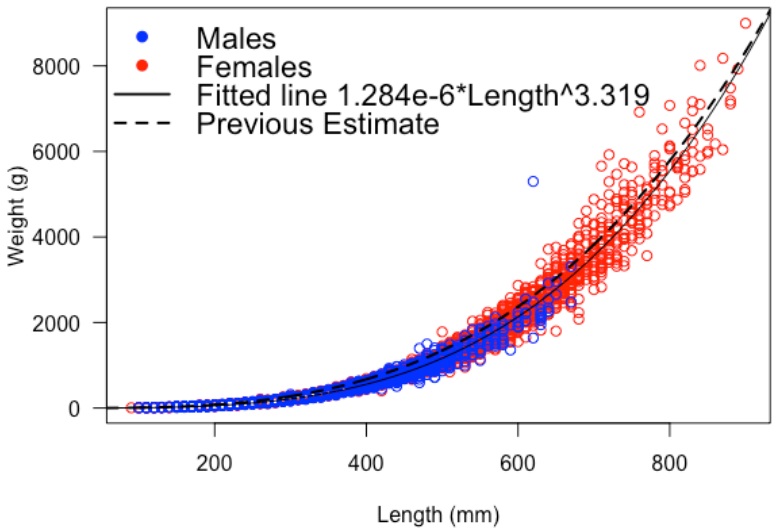

Figure 6.16. Length-weight relationship of arrowtooth flounder. Males and females grow at the same trajectory. The fits to the weight-at-length data is shown as a black line. Data from BSAI surveys 1980-2017.

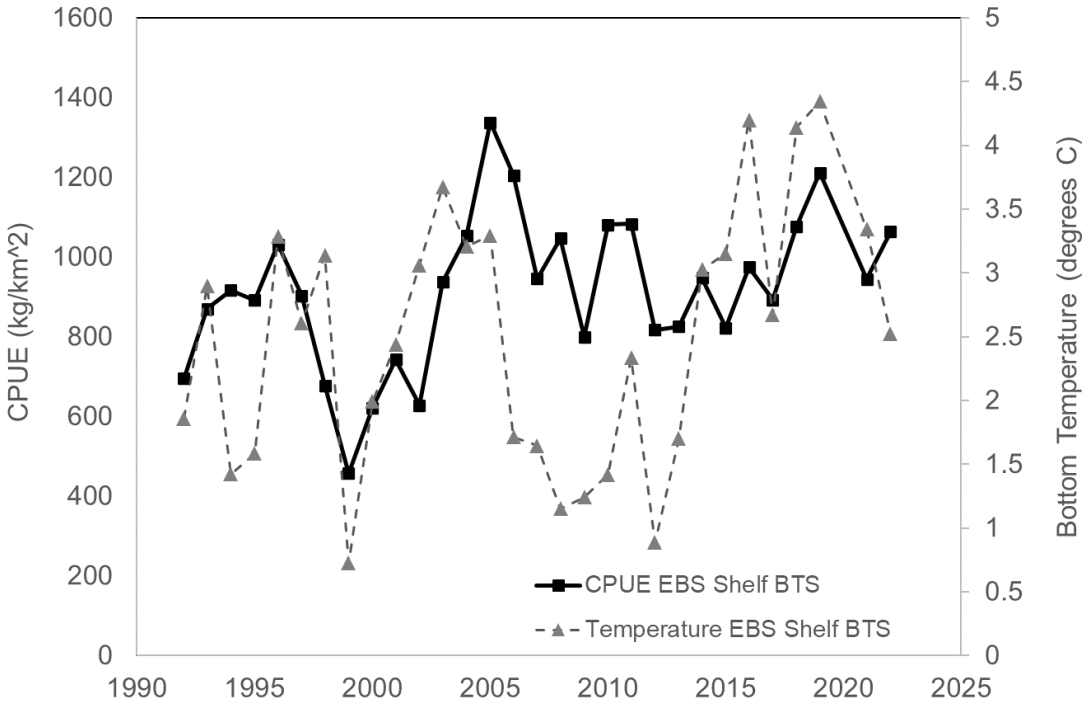

Figure 6.17: Arrowtooth flounder CPUE (kg/km^2) and bottom temperature (degrees C) from the EBS shelf survey area including Northwestern stratum 82 and 90 (1992-2022).

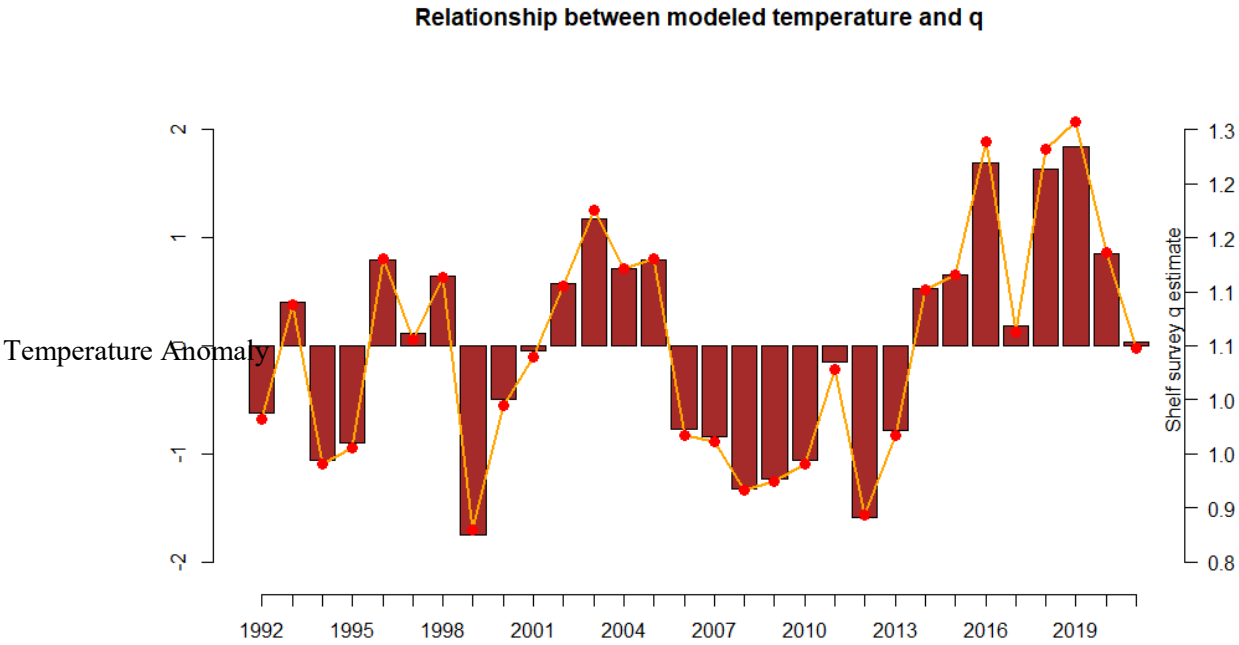

Figure 6.18. Shelf survey annual average bottom temperature anomalies (bars), model estimate of annual shelf survey *q* due to effect of water temperature (red circles with lines).

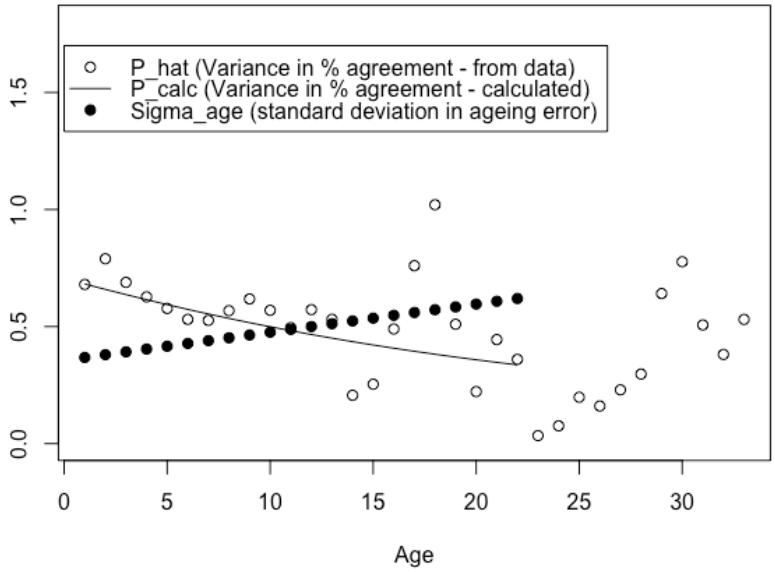

Figure 6.19. Ageing error; the variance in percent agreement from the data (p_hat, open circles), calculated variance in percent agreement (p_calc), and standard deviation in ageing error, by age.

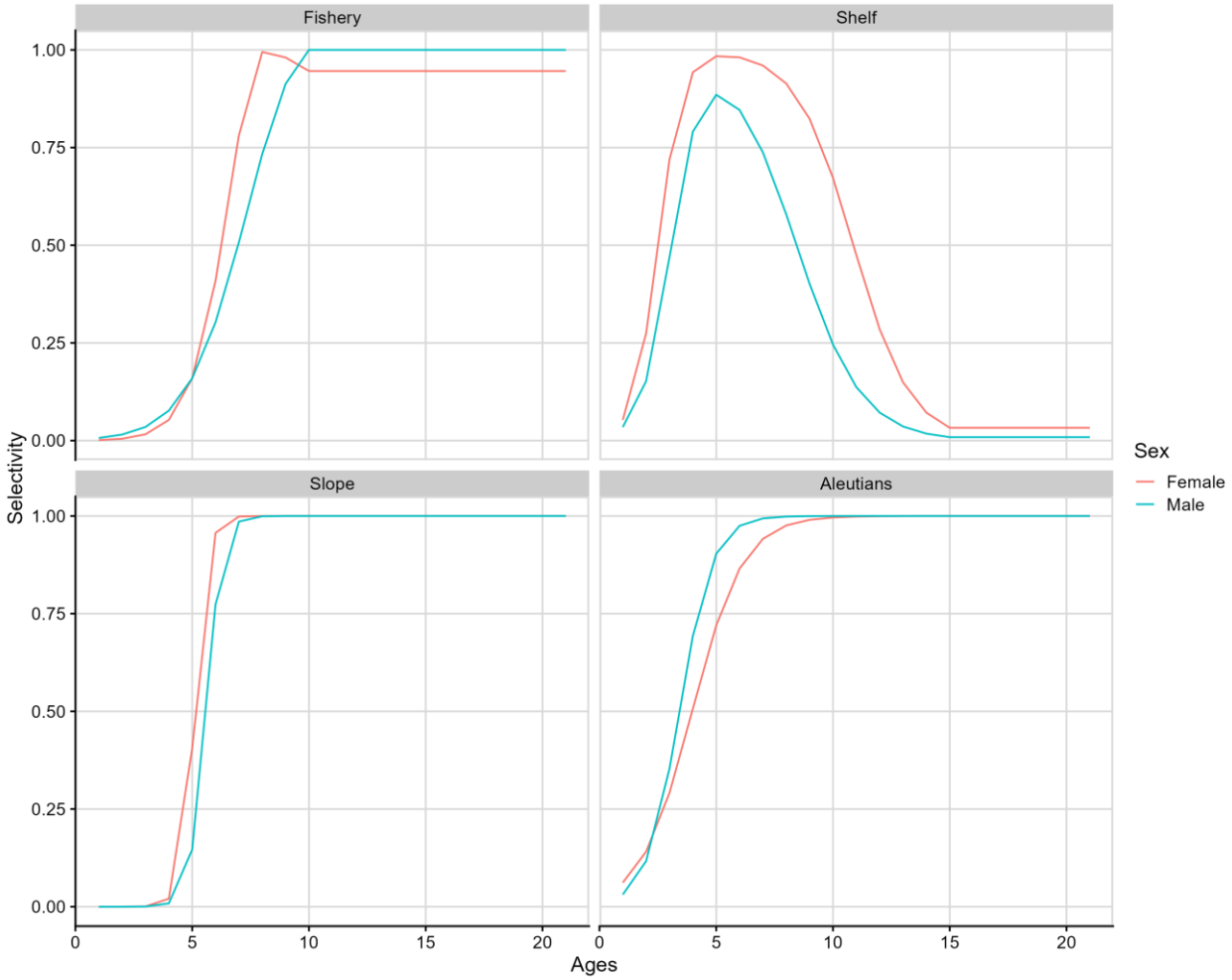

Figure 6.20. Age-specific fishery selectivity (top left), shelf survey selectivity (top right) slope survey selectivity (bottom left) and Aleutian Islands survey selectivity (bottom right), by sex, estimated in model 18.9 (2022).

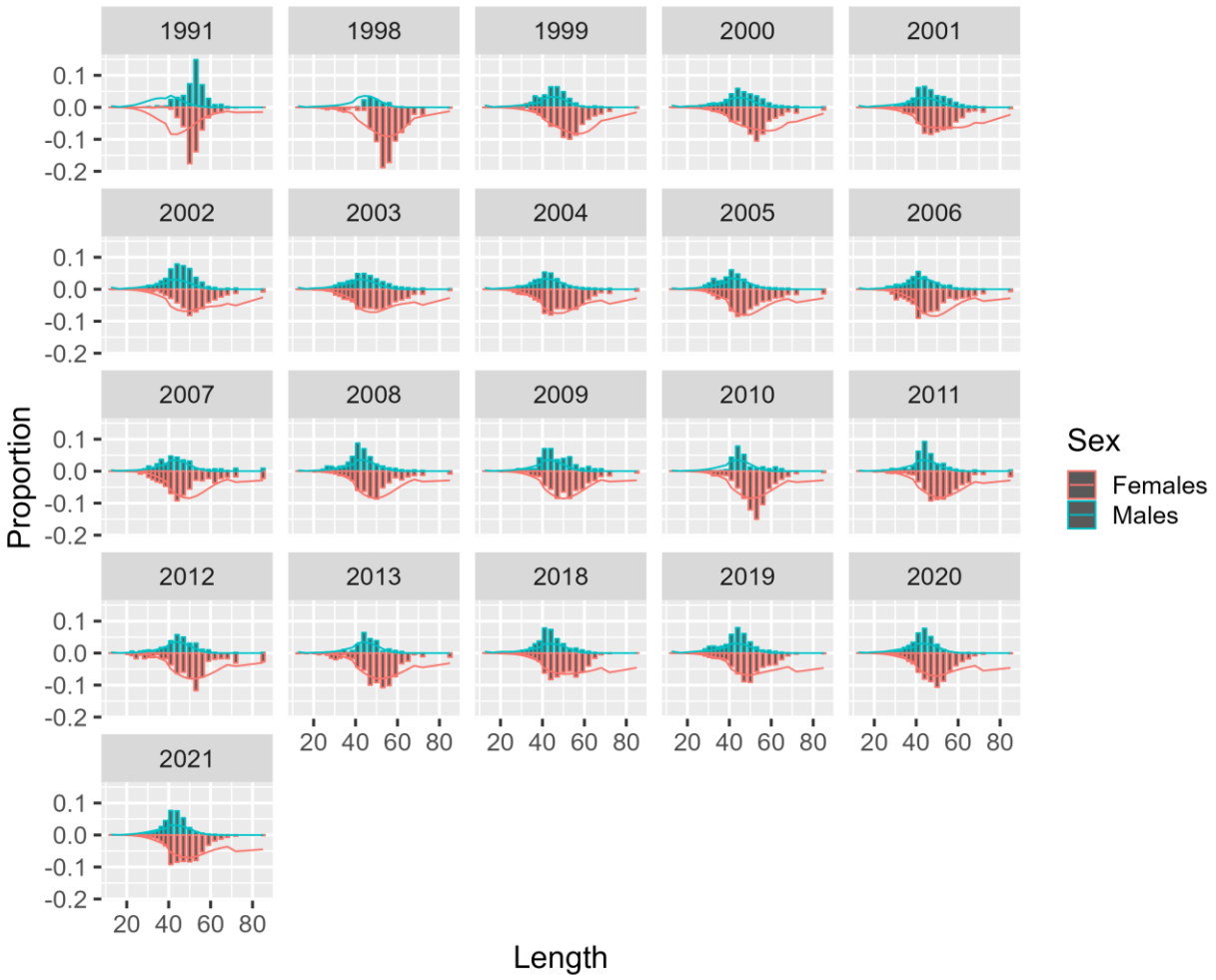

Figure 6.21. Model fit to observed fishery length composition (bar plots) and predicted (lines), with males in blue, females in red.

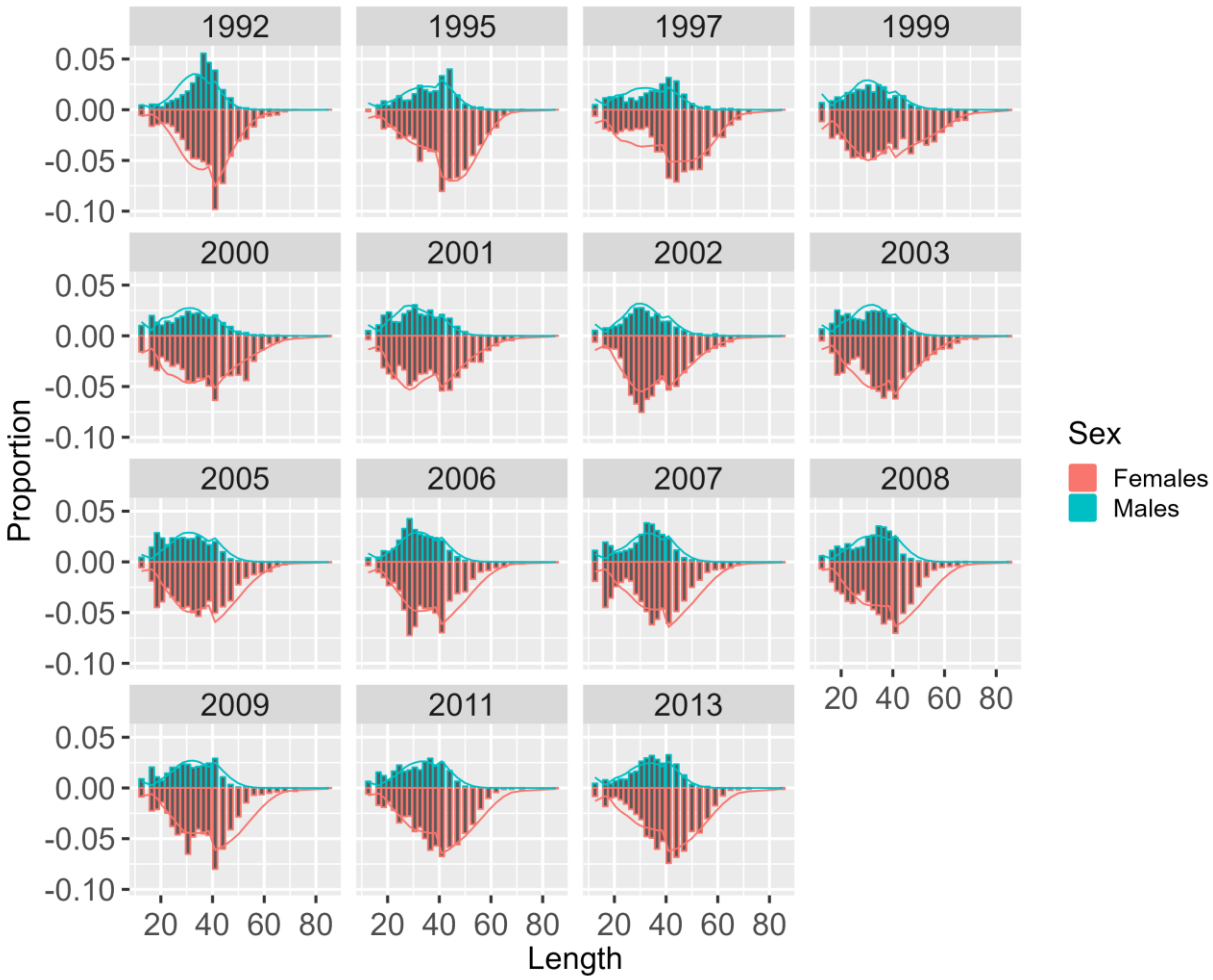

Figure 6.22. Model fit to eastern Bering Sea shelf survey observed length composition (bar plots) and predicted (lines), with males in blue, females in red.

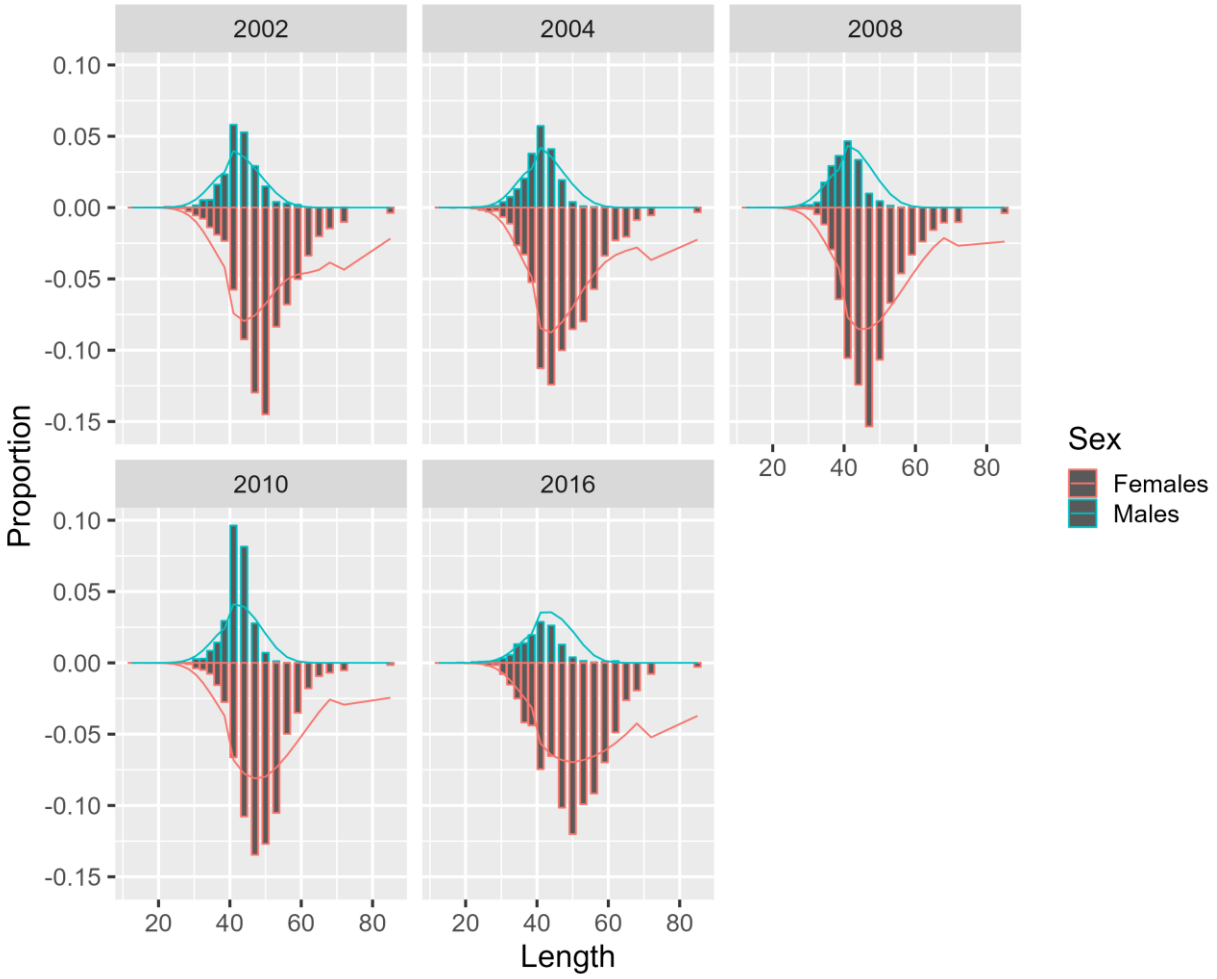

Figure 6.23. Model fit to Bering Sea slope survey observed length composition (bar plots) and predicted (lines), with males in blue, females in red.

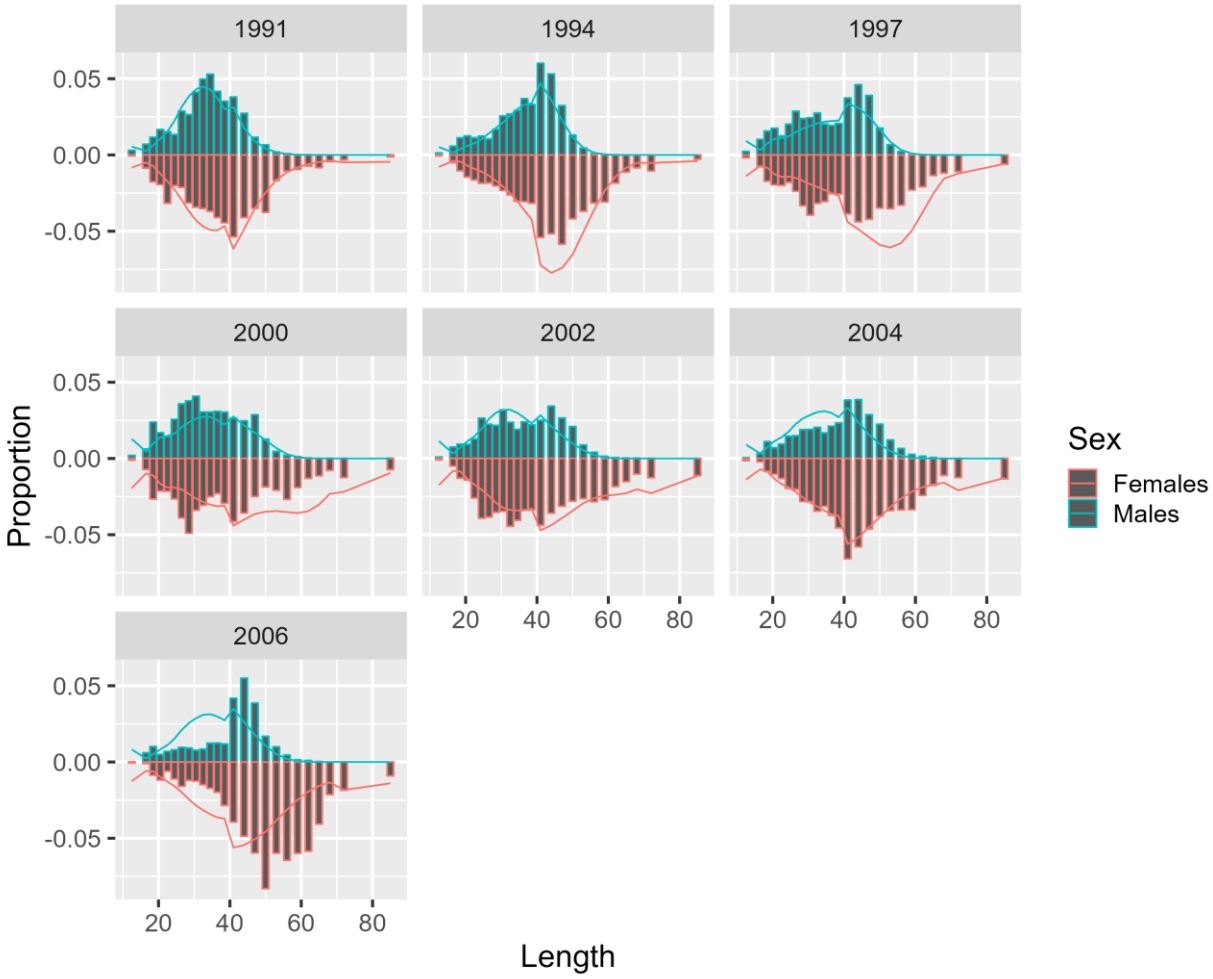

Figure 6.24. Model fit to Aleutian Island survey observed length composition (bar plots) and predicted (lines), with males in blue, females in red.

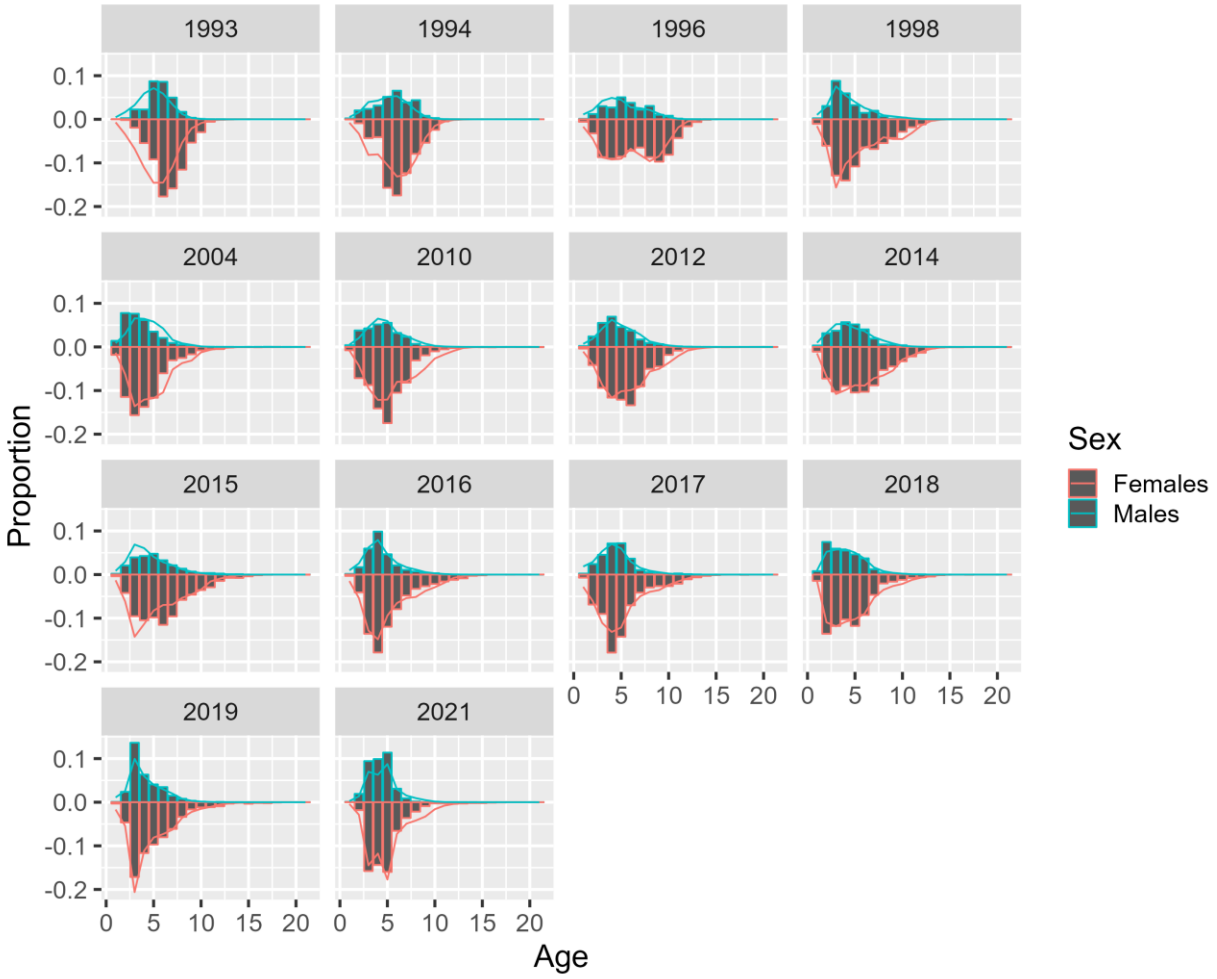

Figure 6.25. Model fit to Bering Sea shelf survey observed age composition (bar plots) and predicted (lines), with males in blue, females in red.

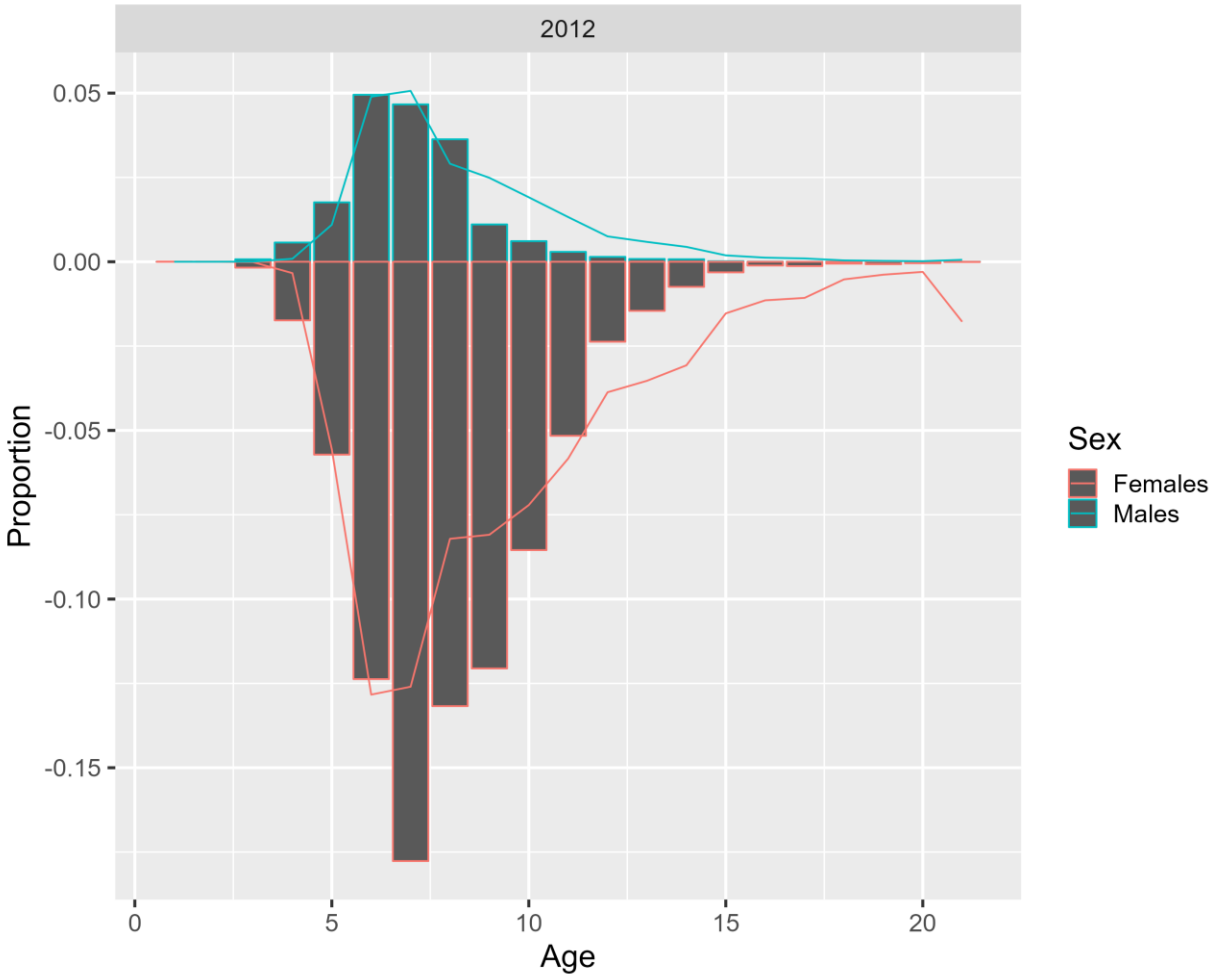

Figure 6.26. Model fit to Bering Sea slope survey observed age composition (bar plots) and predicted (lines), with males in blue, females in red (only one year of age data).

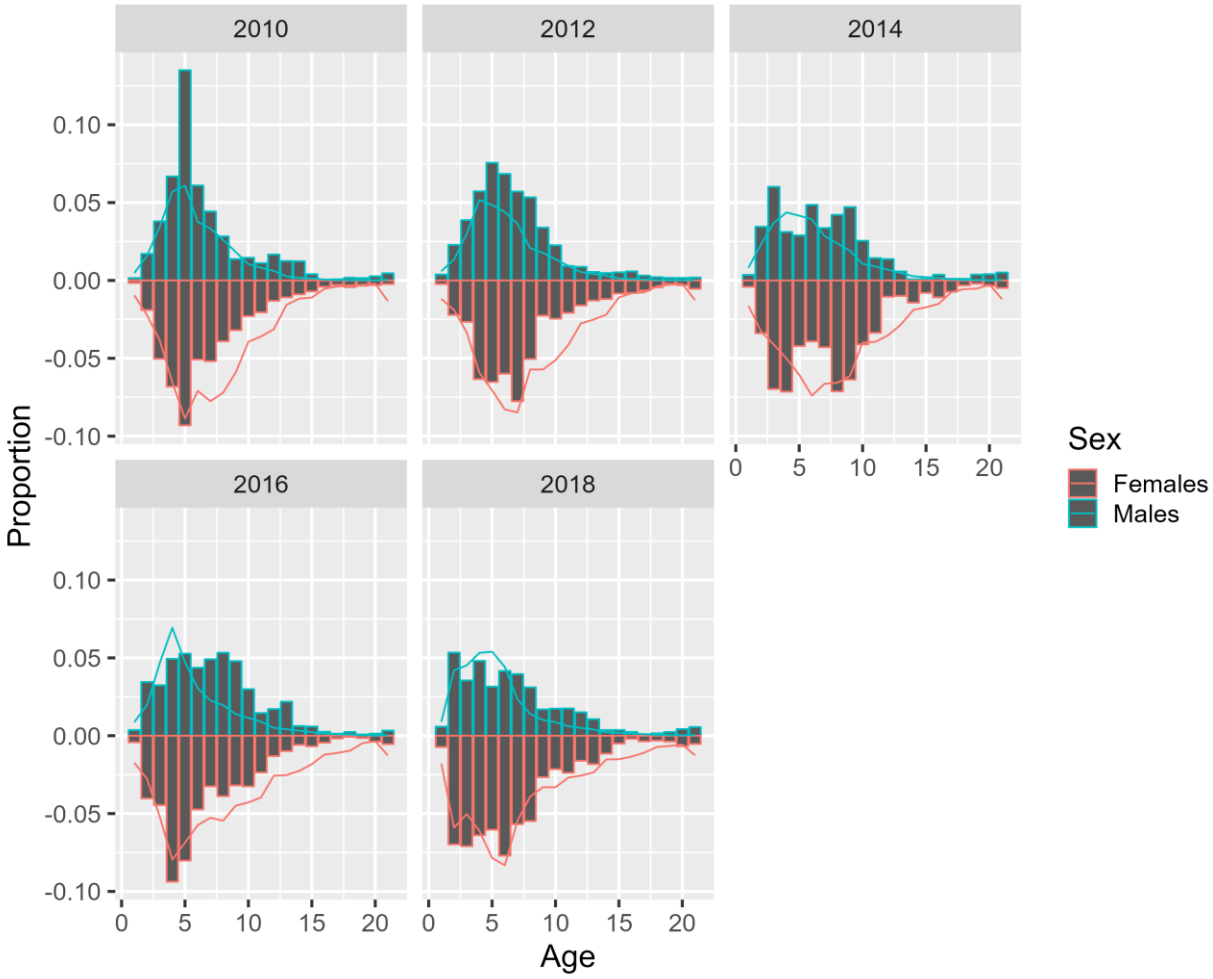

Figure 6.27. Model fit to Aleutian Island survey observed age composition (bar plots) and predicted (lines), with males in blue, females in red.

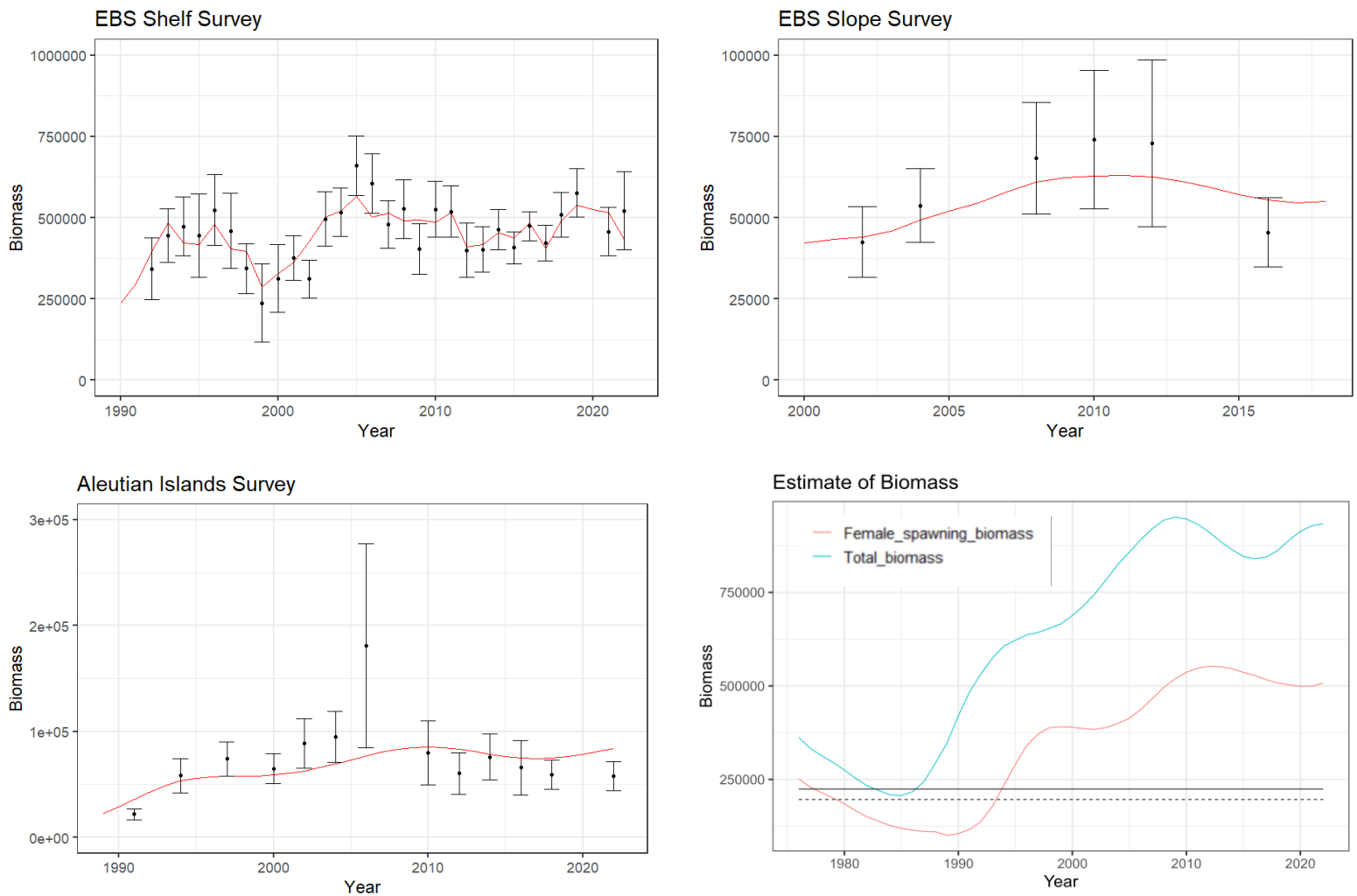

Figure 6.28 Model 18.9 results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), the fit to the Aleutian Islands survey (bottom left panel), and the estimate of female spawning biomass with $B_{35\%}$ (dashed lines) and $B_{40\%}$ (solid 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).

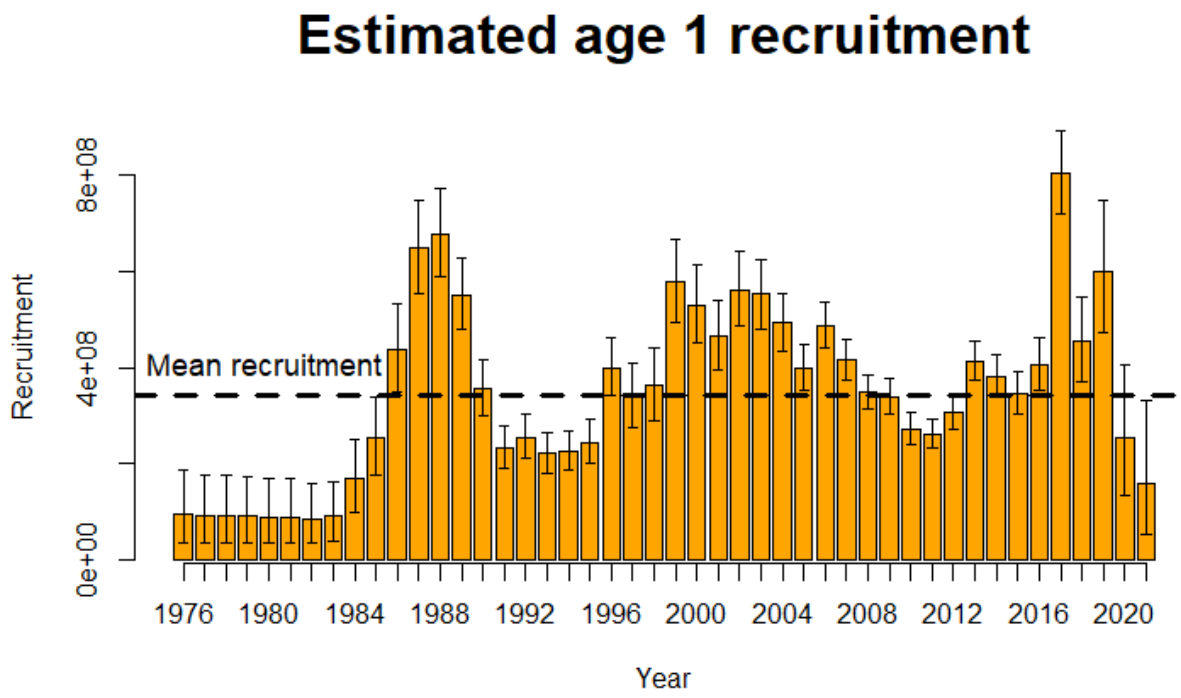

Figure 6.29. Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model 18.9 (2022) MCMC output, with 5% and 95% credible intervals. Mean recruitment is shown overall years from 1976-2021.

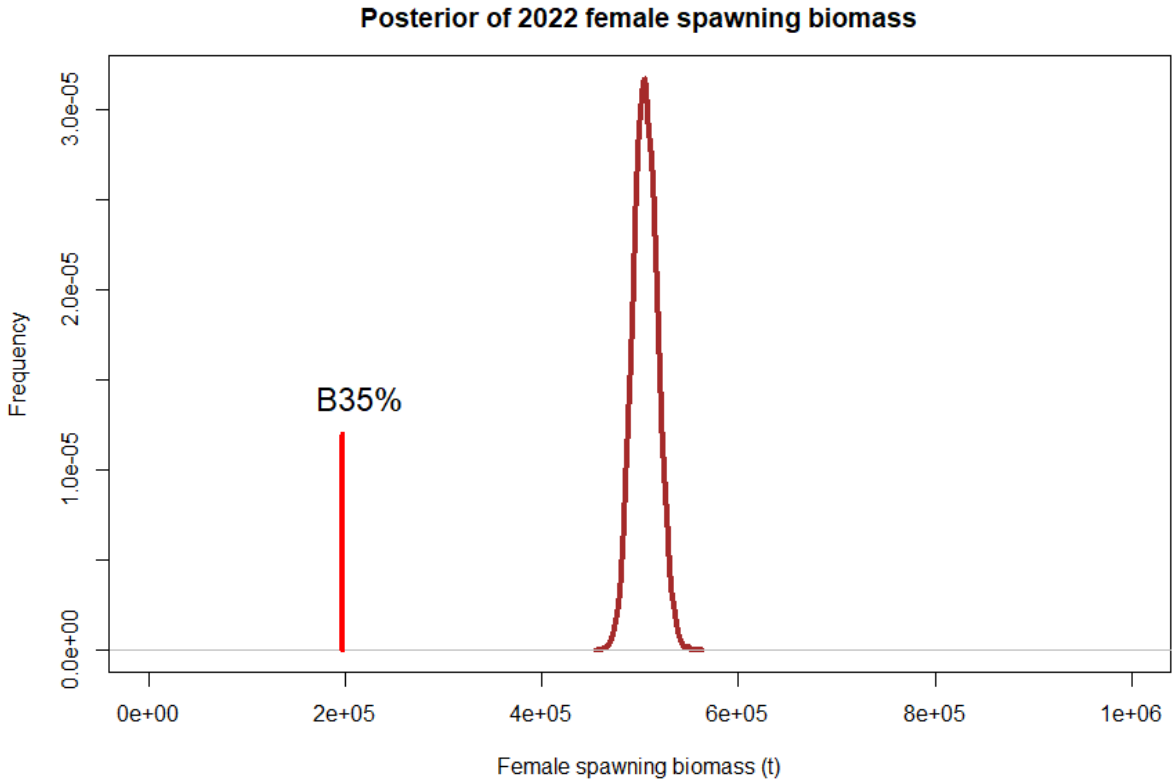

Figure 6.30. Posterior distribution of the estimate of female spawning biomass (t) from the preferred stock assessment model run (Model 18.9 (2022), compared with the model estimate of $B_{35\%}$ or 196,427 t.

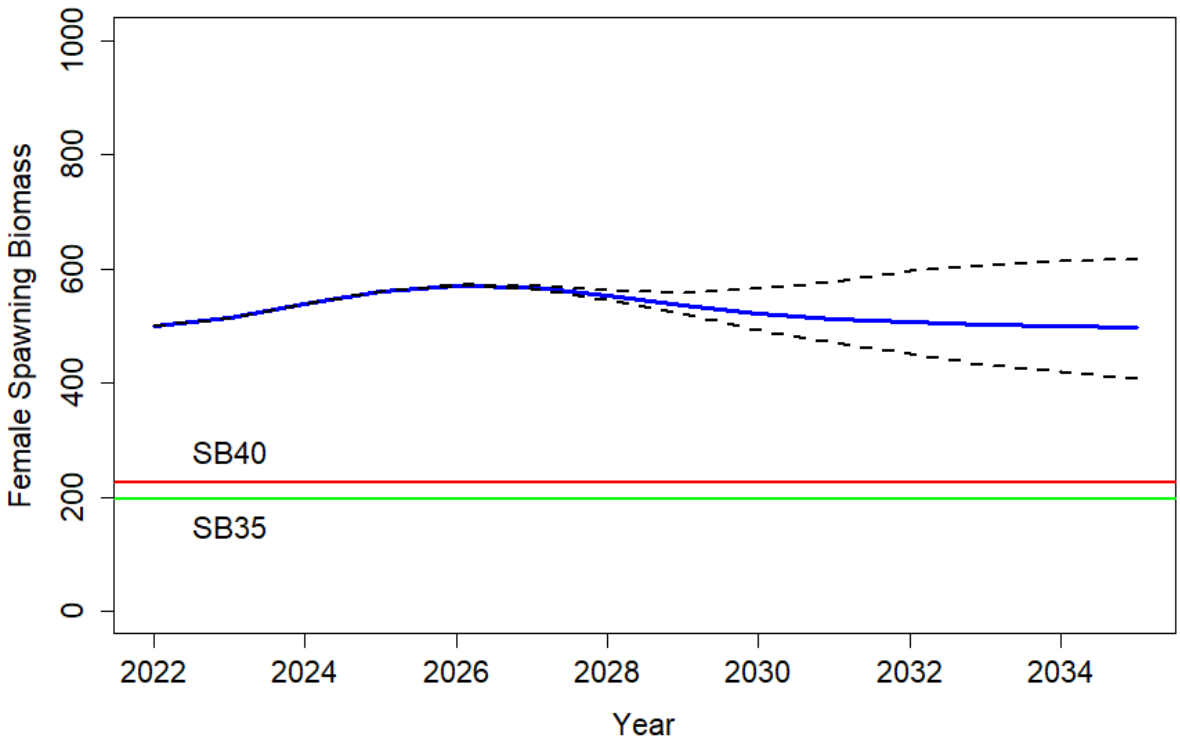

Figure 6.31. Projected female spawning biomass (1,000s t) of arrowtooth flounder if future harvest is at the same fishing mortality rate as the past five years (Alternative 4, Table 6.16).

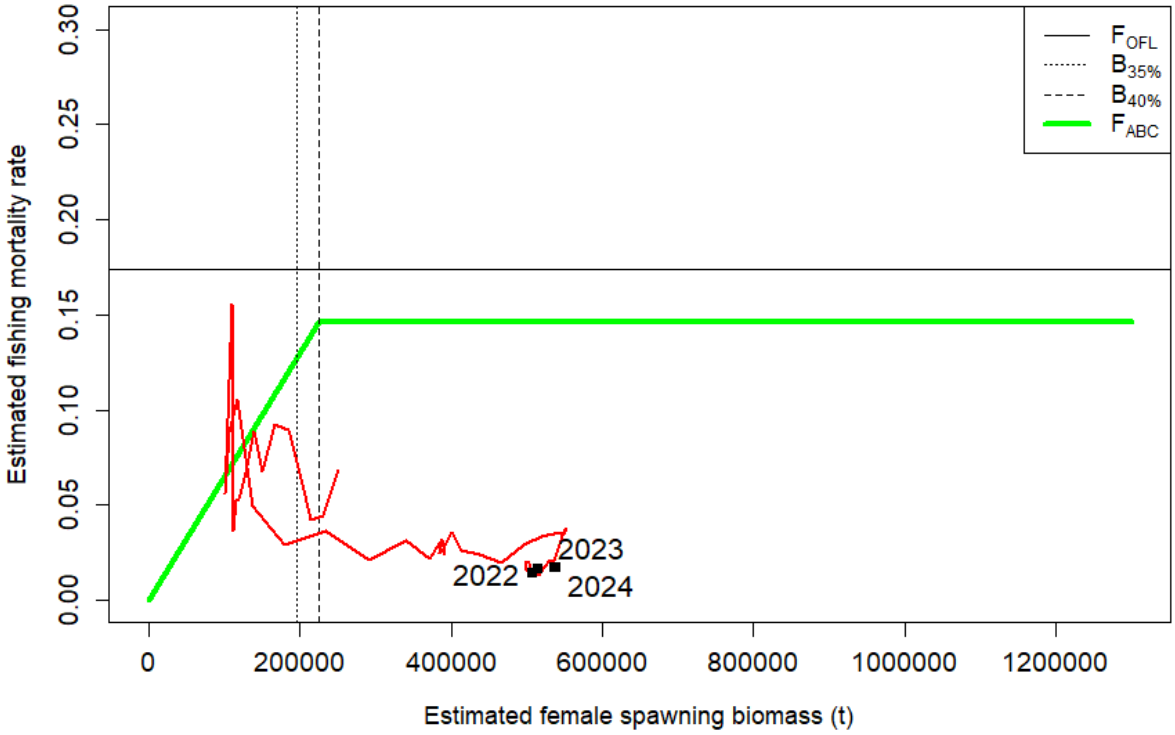

Figure 6.32. Phase plane diagram showing the time-series of stock assessment model estimates of female spawning biomass relative to the harvest control rule, with assessment model results for 2022 and projection model results for 2023 and 2024.

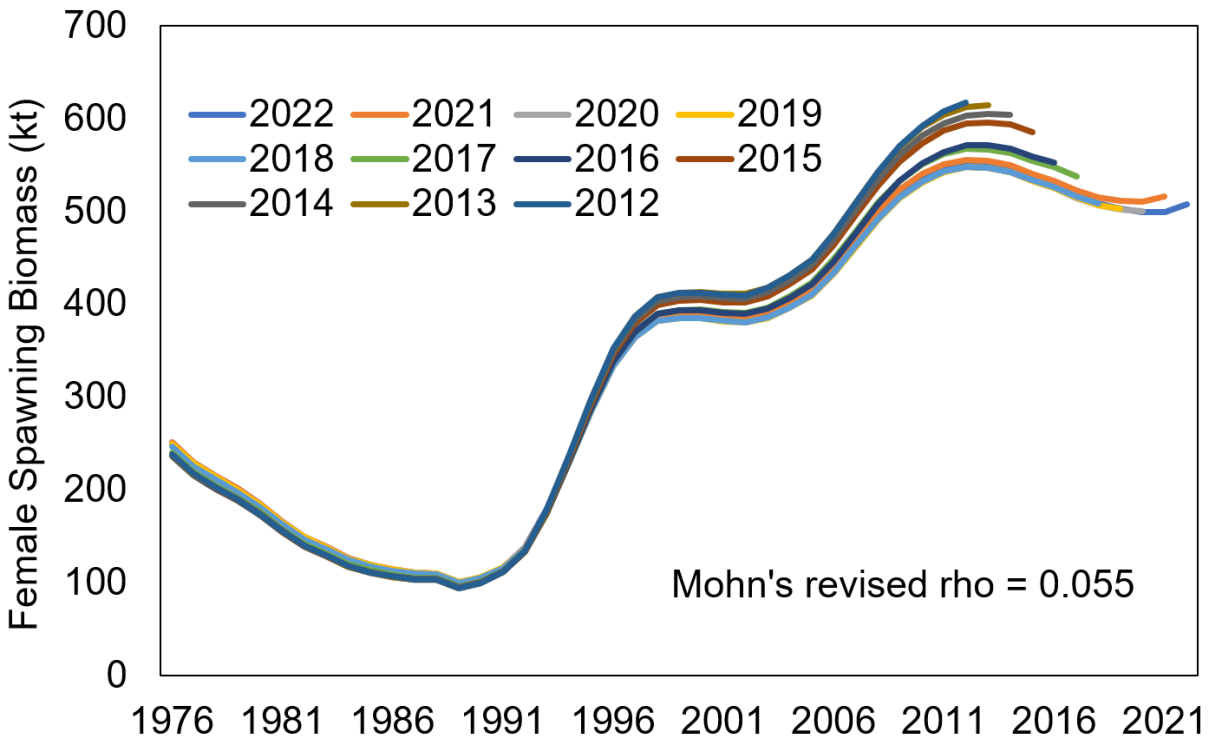

Figure 6.33. Retrospective plot of female spawning biomass with data through 2022 in the longest time series. Retrospective runs were obtained by removing one year of data at a time through 2012.

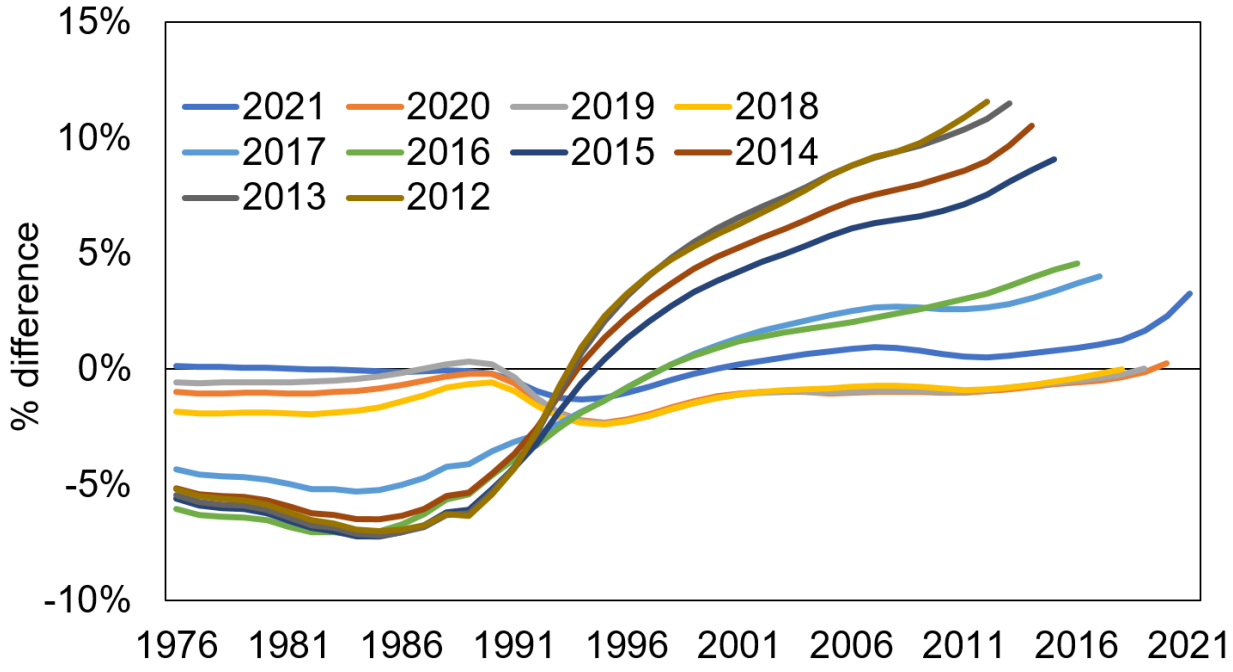

Figure 6.34. Relative differences in estimates of spawning biomass between the 2022 preferred model and the retrospective model run for years 2022 through 2012.

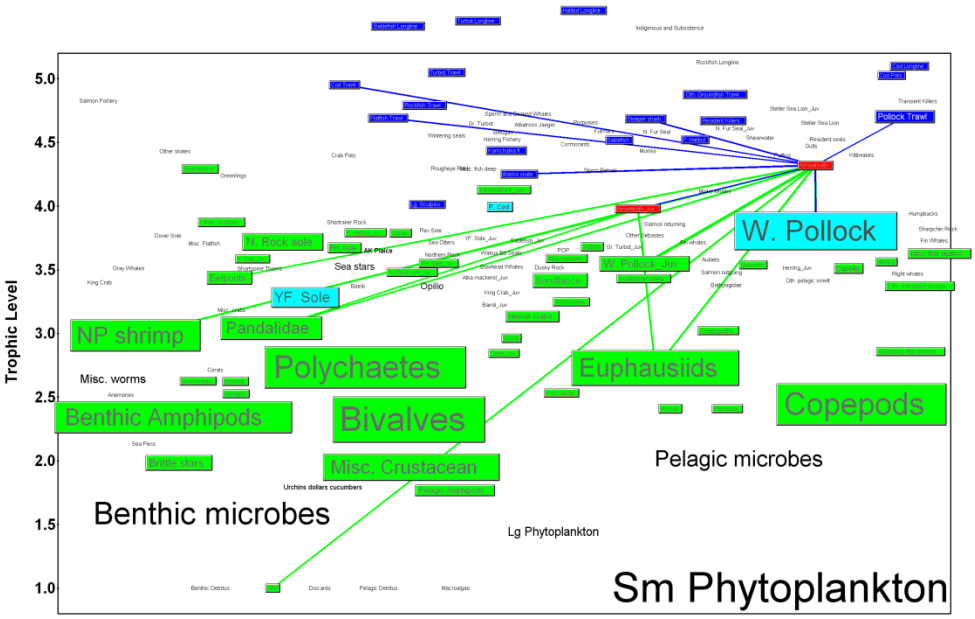

Figure 6.35. Adult and juvenile arrowtooth flounder in the EBS food web. Box size is proportional to biomass, and lines between boxes represent the most significant energy flows. Predators of arrowtooth are dark blue, prey of arrowtooth are green, and species that are both predators and prey of arrowtooth are light blue.

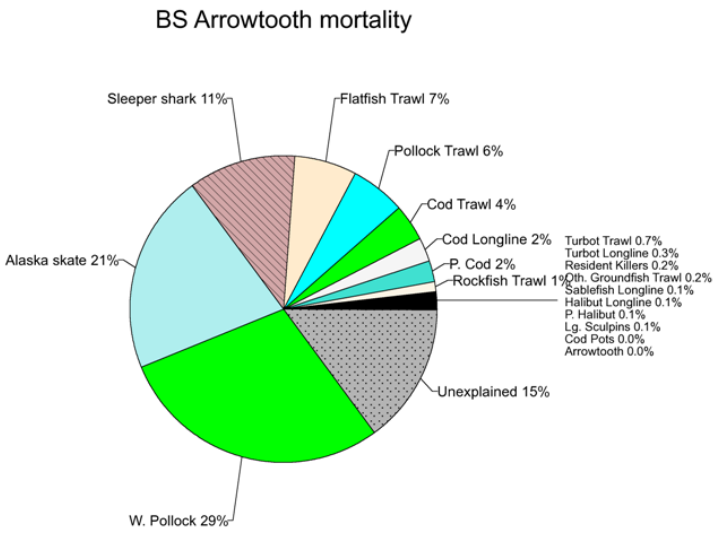

Figure 6.36. Mortality of Bering Sea arrowtooth flounder >20cm fork length by predator or fishery from predator ration and diet estimates and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter (citation). "Unexplained" mortality is the difference between 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).

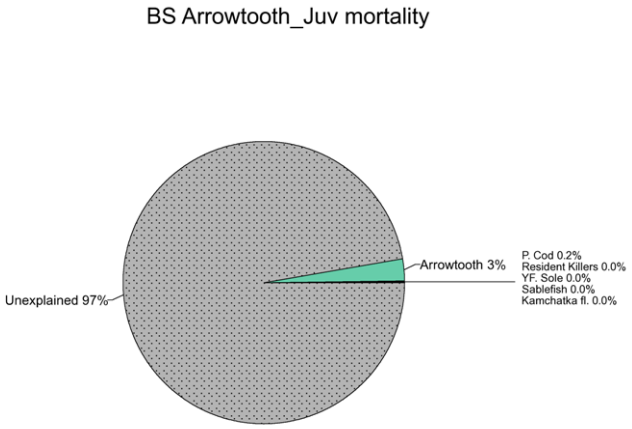

Figure 6.37. Mortality of Bering Sea arrowtooth flounder <20cm fork length by predator or fishery from predator ration and diet estimates and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter (citation). "Unexplained" mortality is the difference between 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).

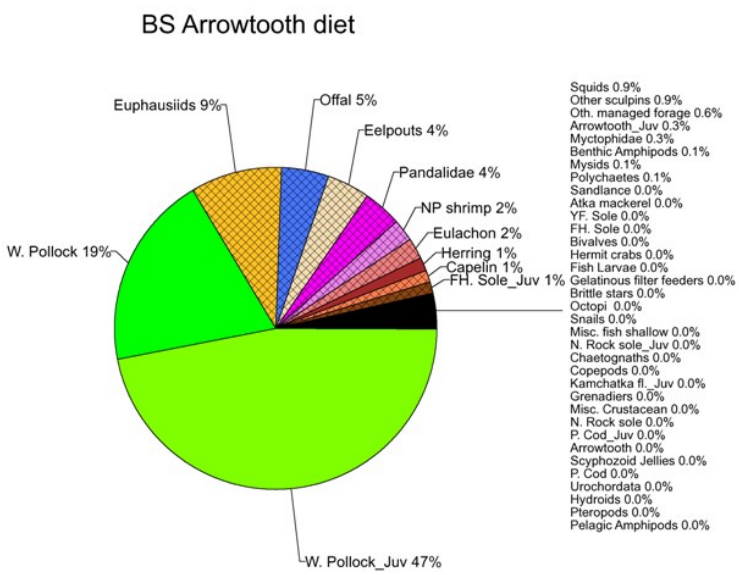

Figure 6.38. Diet of Bering Sea arrowtooth flounder >20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter (citation). Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species 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).

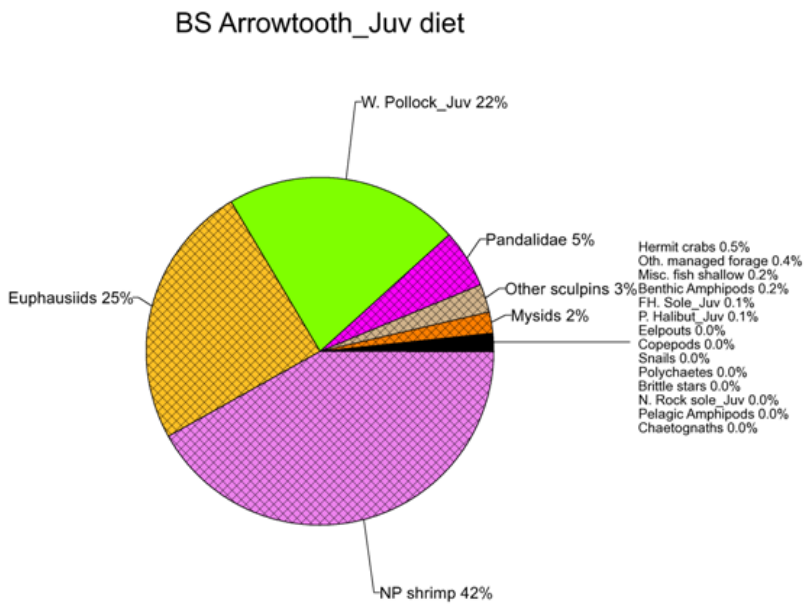

Figure 6.39. Diet of Bering Sea arrowtooth flounder <20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter (citation). Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species 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).

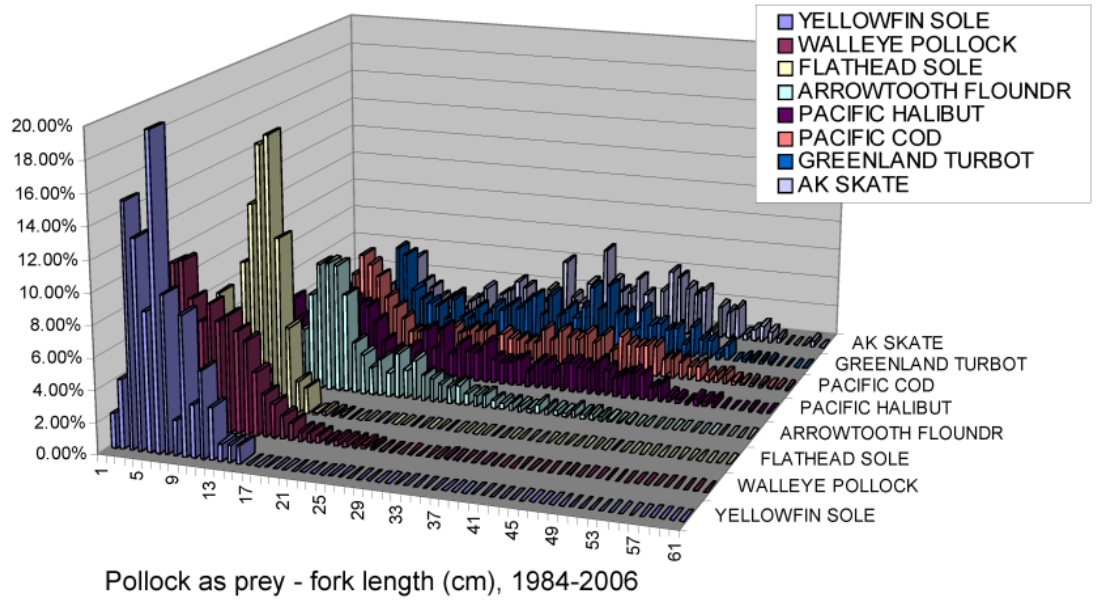

Figure 6.40. Length frequency of pollock found in stomachs, from groundfish food habits collected from 1984-2006 on AFSC summer trawl surveys in the eastern Berng Sea. Predators are sorted by median prey length of pollock in their stomachs. All lengths of predators are combined.

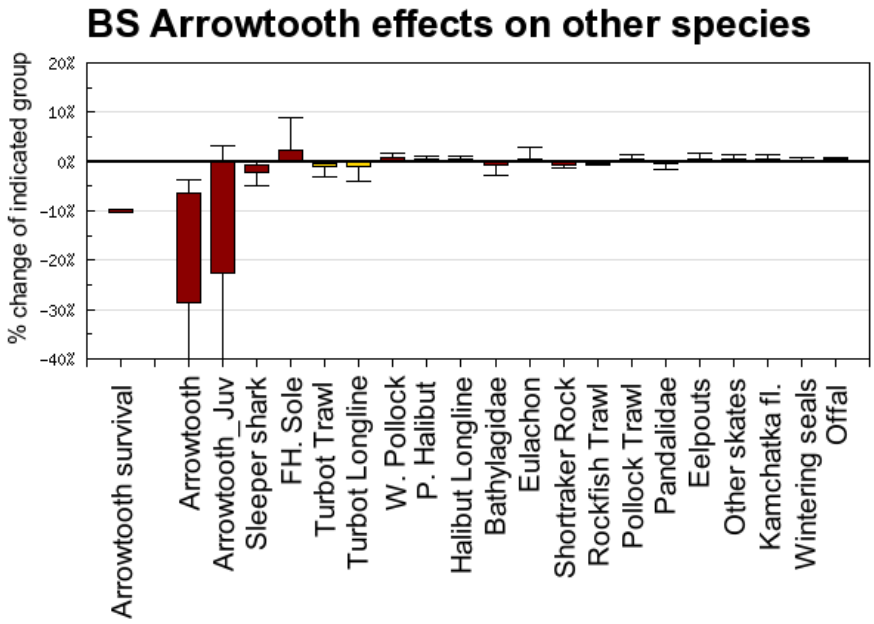

Figure 6.41. Effect of changing arrowtooth >20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting 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).

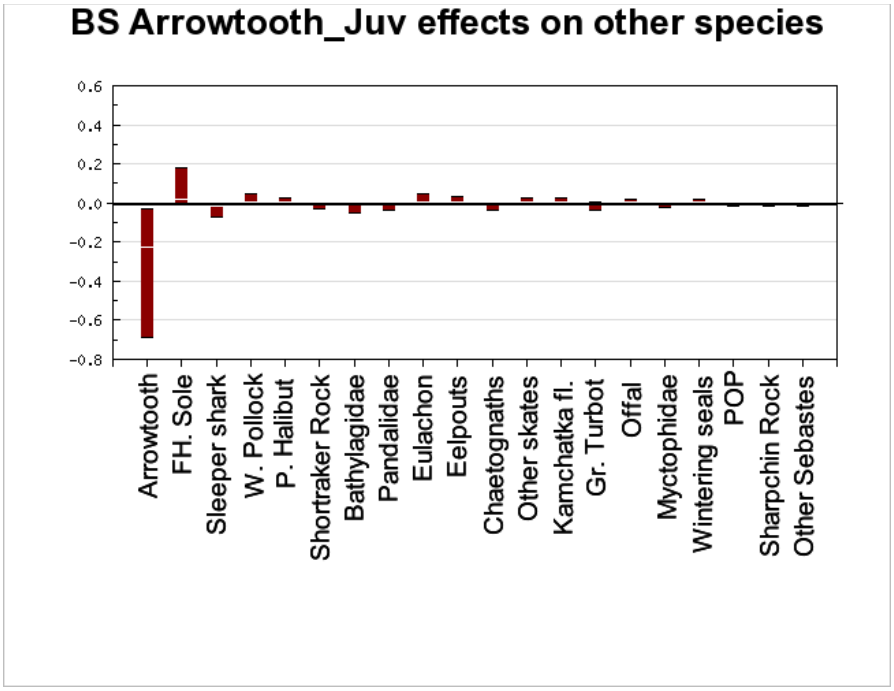

Figure 6.42. Effect of changing arrowtooth < 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting 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).

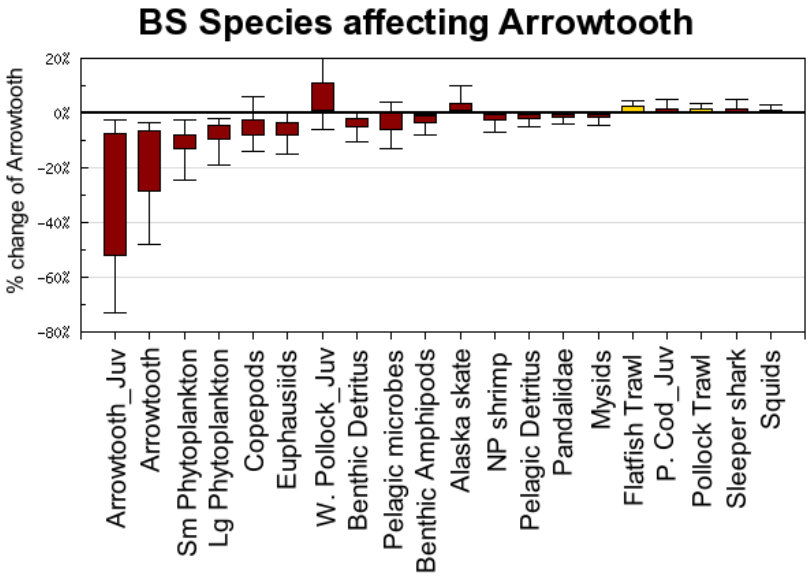

Figure 6.43. Effect of reducing fisheries catch (yellow) and other species survival (dark red) on arrowtooth > 20 cm biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting 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 1991-2021 is from AKFIN Noncommercial Fishery Catch, and represents only arrowtooth flounder. Majority of catch in 2021 was from EBS shelf BTS (66%), the ADF&G large mesh trawl survey (26%), and AFSC longline survey (6%).

Year	Research catch (t)	Year	Research catch (t)
1977	1	2010	62.6
1978	3.7	2011	42.4
1979	22.5	2012	50.4
1980	63.6	2013	27.4
1981	48.4	2014	38.3
1982	46.6	2015	27.4
1983	21.8	2016	46.2
1984	6.1	2017	31.4
1985	194.1	2018	41.9
1986	57.7	2019	36.2
1987	9.4	2020	1.6
1988	33.7	2021	25.3
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		

Table 6.A1.2. BSAI flatfish catch and first-wholesale market data. Total and retained catch (thousand metric tons), number of vessels, first-wholesale production (thousand metric tons), value (million US$), price (US$ per pound), and head and gut share of production; 2011-2015 average and 2016-2020.

	2012-2016 Average	2017	2018	2019	2020	2021
Total catch K mt	262.22	211.4	212.2	208.6	214.1	169.2
Retained catch K mt	238.152	198.71	197.47	198.22	203.52	160.99
Yellowfin sole share of retained	57.35%	64.73%	64.48%	63.62%	64.68%	66.28%
Rock sole share of retained	22.14%	17.08%	13.75%	12.3%	12.12%	8.31%
Flathead sole share of retained	4.96%	4.07%	5.15%	7.52%	4.07%	5.89%
Arrowtooth and Kamchatka flounder share of retained	8.62%	4.95%	4.48%	6.7%	8.36%	8.96%
Vessels #	37.2	35	35	35	33	28
Total flatfish first-wholesale production K mt	142.45	116.9	115.11	116.18	121.32	91.69
Total flatfish first-wholesale value M US$	$192.83	$192.37	$211.65	$209.83	$174.56	$118.38
Total flatfish first-wholesale price/lb US$	$0.61	$0.75	$0.83	$0.82	$0.65	$0.59
Yellowfin sole share of value	53.04%	57.57%	64.55%	61.41%	61.73%	63.76%
Yellowfin sole price/lb US$	$0.54	$0.65	$0.81	$0.78	$0.6	$0.55
Rock sole share of value	22.65%	15.75%	13.76%	11.63%	12.01%	6.84%
Rock sole price/lb US$	$0.66	$0.72	$0.89	$0.83	$0.72	$0.55
Flathead sole share of value	5.33%	4.17%	5.63%	7.28%	3.36%	5.05%
Flathead sole price/lb US$	$0.78	$0.86	$0.96	$0.85	$0.63	$0.58
Arrowtooth and Kamchatka flounder share of value	9.9%	8.64%	4.54%	6.74%	9.45%	12.04%
Arrowtooth and Kamchatka flounder price/lb US$	$0.77	$1.36	$1	$0.91	$0.79	$0.82
H&G share of value	86.32%	89.68%	93.04%	93.95%	92.83%	96.44%

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; NMFS Alaska Region At-sea Production Reports; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

Table 6.A1.3. Flatfish U.S. trade and global market data. Global production (thousand metric tons), U.S. share of global production, BSAI share of U.S. production. U.S. yellowfin sole and rock sole export volume (thousand metric tons), U.S. export value (million US$), U.S. export price (US$ per pound), the share of U.S. export value from China, and the Euro/U.S. Dollar exchange rate; 2011-2015 average and 2016-2020.

	2012-2016 Average	2017	2018	2019	2020	2021
Global production of flounder, halibut, and sole K mt	1011.47	977.32	994.28	954.56	934.23	-
US share global production	30%	27%	25%	27%	27%	-
BSAI FMP flatfish share of U.S. [1]	85.16%	80.79%	85.52%	81.79%	83.62%	-
Export quantity of yellowfin sole and rock sole K mt	84.61	81.36	72	76.7	80.75	48.54
Export value of yellowfin sole and rock sole M US$	$119.93	$115.26	$107.06	$118.43	$118.12	$71.69
Export price/lb of yellowfin sole and rock sole US$	$0.64	$0.64	$0.67	$0.7	$0.66	$0.67
China's share of yellowfin sole and rock sole export value	82.69%	81.67%	78.63%	70.6%	79.6%	73.59%
Exchange rate, Euro/Dollar	0.82	0.89	0.85	0.89	0.88	0.845

Source: FAO Fisheries & Aquaculture Dept. Statistics http://www.fao.org/fishery/statistics/en. NOAA Fisheries, Fisheries Statistics Division, Foreign Trade Division of the U.S. Census Bureau, http://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/index. U.S. Department of Agriculture http://www.ers.usda.gov/data-products/agricultural-exchange-rate-data-set.aspx.

[1] - The BSAI FMP share of U.S. production is calculated as the BSAI retained catch divided by the FAO's U.S. production of flounder, halibut and sole.

Appendix 2

Table 6.A2.1 Parameters estimated in Model 18.9 (2022) and standard deviation

Parameter name	Value	Standard deviation
srv_params_f[1]	1.92E+00	1.31E-01
srv_params_f[2]	2.51E+00	6.96E-02
srv_params_f[3]	3.48E+00	5.21E-01
srv_params_f[4]	5.11E+00	8.22E-02
srv_params_f[5]	9.17E-01	8.77E-02
srv_params_f[6]	3.97E+00	1.82E-01
srv_params_m[1]	1.62E+00	9.89E-02
srv_params_m[2]	3.05E+00	7.95E-02
srv_params_m[3]	3.00E+00	7.20E-01
srv_params_m[4]	5.59E+00	1.50E-01
srv_params_m[5]	1.42E+00	1.16E-01
srv_params_m[6]	3.43E+00	1.23E-01
srv1desc_params_f[1]	8.21E-01	7.60E-02
srv1desc_params_f[2]	1.09E+01	1.69E-01
srv1desc_params_m[1]	7.21E-01	1.24E-01
srv1desc_params_m[2]	8.44E+00	2.43E-01
alpha	-2.10E-01	2.56E-02
beta	1.14E-01	7.65E-03
mean_log_rec	1.86E+01	4.41E-02
rec_dev	-4.49E-01	5.85E-01
rec_dev	-1.34E-01	6.59E-01
rec_dev	-1.58E-01	6.52E-01
rec_dev	-1.86E-01	6.44E-01
rec_dev	-2.16E-01	6.36E-01
rec_dev	-2.49E-01	6.28E-01
rec_dev	-2.85E-01	6.19E-01
rec_dev	-3.24E-01	6.09E-01
rec_dev	-3.66E-01	6.00E-01
rec_dev	-4.10E-01	5.90E-01
rec_dev	-4.58E-01	5.80E-01
rec_dev	-5.08E-01	5.70E-01
rec_dev	-5.60E-01	5.60E-01
rec_dev	-6.11E-01	5.50E-01
rec_dev	-6.66E-01	5.40E-01
rec_dev	-7.27E-01	5.30E-01
rec_dev	-7.54E-01	5.26E-01
rec_dev	-8.01E-01	5.19E-01
rec_dev	-8.47E-01	5.12E-01
rec_dev	-8.83E-01	5.06E-01
rec_dev	-9.17E-01	5.01E-01
rec_dev	-9.42E-01	4.97E-01
rec_dev	-9.66E-01	4.92E-01
rec_dev	-9.71E-01	4.89E-01
rec_dev	-9.74E-01	4.85E-01
rec_dev	-9.84E-01	4.79E-01

rec_dev	-1.02E+00	4.67E-01
rec_dev	-9.42E-01	4.20E-01
rec_dev	-3.16E-01	2.84E-01
rec_dev	6.38E-02	2.03E-01
rec_dev	6.21E-01	1.37E-01
rec_dev	1.01E+00	1.03E-01
rec_dev	1.06E+00	9.26E-02
rec_dev	8.46E-01	9.24E-02
rec_dev	4.12E-01	1.04E-01
rec_dev	-1.38E-02	1.22E-01
rec_dev	7.37E-02	1.16E-01
rec_dev	-6.82E-02	1.22E-01
rec_dev	-5.01E-02	1.18E-01
rec_dev	3.41E-02	1.20E-01
rec_dev	5.25E-01	1.02E-01
rec_dev	3.65E-01	1.26E-01
rec_dev	4.29E-01	1.33E-01
rec_dev	8.96E-01	9.83E-02
rec_dev	8.09E-01	1.00E-01
rec_dev	6.78E-01	1.03E-01
rec_dev	8.66E-01	9.09E-02
rec_dev	8.53E-01	8.77E-02
rec_dev	7.38E-01	8.34E-02
rec_dev	5.20E-01	8.17E-02
rec_dev	7.22E-01	7.05E-02
rec_dev	5.69E-01	7.22E-02
rec_dev	3.87E-01	7.60E-02
rec_dev	3.65E-01	7.61E-02
rec_dev	1.43E-01	8.21E-02
rec_dev	1.03E-01	8.27E-02
rec_dev	2.61E-01	7.90E-02
rec_dev	5.59E-01	7.41E-02
rec_dev	4.81E-01	8.03E-02
rec_dev	3.81E-01	9.02E-02
rec_dev	5.42E-01	9.31E-02
rec_dev	1.23E+00	8.03E-02
rec_dev	6.57E-01	1.21E-01
rec_dev	9.33E-01	1.44E-01
rec_dev	7.94E-02	3.27E-01
rec_dev	-4.54E-01	5.60E-01
log_avg_fmort	-3.33E+00	5.44E-02
fmort_dev	6.49E-01	1.50E-01
fmort_dev	2.15E-01	1.47E-01
fmort_dev	1.55E-01	1.43E-01
fmort_dev	5.77E-01	1.40E-01
fmort_dev	9.17E-01	1.40E-01
fmort_dev	9.48E-01	1.42E-01
fmort_dev	6.36E-01	1.41E-01
fmort_dev	9.07E-01	1.39E-01

fmort_dev	5.83E-01	1.36E-01
fmort_dev	3.89E-01	1.31E-01
fmort_dev	3.84E-01	1.24E-01
fmort_dev	6.86E-03	1.16E-01
fmort_dev	1.47E+00	1.11E-01
fmort_dev	4.42E-01	1.02E-01
fmort_dev	8.97E-01	8.96E-02
fmort_dev	1.08E+00	8.42E-02
fmort_dev	3.23E-01	8.25E-02
fmort_dev	-2.00E-01	8.02E-02
fmort_dev	2.01E-02	7.73E-02
fmort_dev	-5.43E-01	7.52E-02
fmort_dev	-1.44E-01	7.46E-02
fmort_dev	-4.86E-01	7.48E-02
fmort_dev	-1.08E-01	7.52E-02
fmort_dev	-3.88E-01	7.55E-02
fmort_dev	-2.27E-01	7.57E-02
fmort_dev	-1.63E-01	7.59E-02
fmort_dev	-3.62E-01	7.58E-02
fmort_dev	-2.89E-01	7.59E-02
fmort_dev	-1.49E-02	7.63E-02
fmort_dev	-3.07E-01	7.67E-02
fmort_dev	-4.13E-01	7.71E-02
fmort_dev	-5.97E-01	7.69E-02
fmort_dev	-2.13E-01	7.73E-02
fmort_dev	-6.62E-02	7.72E-02
fmort_dev	-1.71E-02	7.75E-02
fmort_dev	-3.35E-02	7.76E-02
fmort_dev	6.26E-02	7.76E-02
fmort_dev	-2.47E-03	7.76E-02
fmort_dev	-4.52E-02	7.78E-02
fmort_dev	-5.50E-01	7.74E-02
fmort_dev	-5.52E-01	7.74E-02
fmort_dev	-1.03E+00	7.72E-02
fmort_dev	-9.82E-01	7.71E-02
fmort_dev	-6.20E-01	7.72E-02
fmort_dev	-5.78E-01	7.73E-02
fmort_dev	-7.86E-01	7.71E-02
fmort_dev	-9.37E-01	7.71E-02
log_selcoffs_fish	-5.76E+00	1.07E+00
log_selcoffs_fish	-4.52E+00	8.93E-01
log_selcoffs_fish	-3.29E+00	7.93E-01
log_selcoffs_fish	-2.11E+00	7.47E-01
log_selcoffs_fish	-1.00E+00	7.28E-01
log_selcoffs_fish	-6.09E-02	7.20E-01
log_selcoffs_fish	5.86E-01	7.13E-01
log_selcoffs_fish	8.28E-01	7.09E-01
log_selcoffs_fish	8.14E-01	7.09E-01
log_selcoffs_fish	7.78E-01	7.09E-01

log_selcoffs_fish	-4.01E+00	7.88E-01
log_selcoffs_fish	-3.19E+00	7.54E-01
log_selcoffs_fish	-2.37E+00	7.34E-01
log_selcoffs_fish	-1.59E+00	7.23E-01
log_selcoffs_fish	-8.56E-01	7.17E-01
log_selcoffs_fish	-2.14E-01	7.13E-01
log_selcoffs_fish	3.02E-01	7.10E-01
log_selcoffs_fish	6.71E-01	7.08E-01
log_selcoffs_fish	8.90E-01	7.08E-01
log_selcoffs_fish	9.81E-01	7.10E-01
F40	1.49E-01	2.63E-02
F35	1.77E-01	3.25E-02