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

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Executive Summary

Summary of Changes in Assessment Inputs

Changes in the input data:

1. Length compositions from the 2017 and 2018 Eastern Bering Sea shelf survey, and 2018 Aleutian Islands survey.
2. Biomass point-estimates and standard errors from the 2017 and 2018 Eastern Bering Sea shelf surveys, and 2018 Aleutian Islands survey.
3. Fishery size compositions for 2017 and 2018.
4. Estimates of catch through October 19, 2018.
5. Estimated total catch of 6,387 t for 2018 and 10,878 t for 2020.
6. Age data from the 2016 and 2017 Bering Sea shelf and the 2012 and 2016 Aleutian Islands surveys.
7. The final model did not include Bering Sea slope survey data for 1979-1991.

Changes in the assessment methodology:

The age-structured assessment model is similar to the model used for the 2016 and 2017 assessments. The 2018 model implemented the following changes based on Plan Team and SSC comments and authors' recommendations:

1. The model uses a smoothed length-age conversion matrix that corrects for stratified sampling.
2. The model uses an ageing error matrix to account for error in age reading.
3. Eastern Bering Sea slope data from 1979-1991 was excluded based on concerns about methodology and species identification (Figure 6.1).

Summary of Results

1. The projected age 1+ total biomass for 2019 is 892,591 t.
2. The projected female spawning biomass for 2019 is 482,174 t.
3. The recommended 2019 ABC is 70,673 t based on an $F_{40\%}$=0.136 harvest level.
4. The 2019 overfishing level is 82,939 t based on a $F_{35\%}$=0.161 harvest level.

Quantity/Status	Last year 2018	2019	This year 2019	2020
M (natural mortality – Male, Female)	0.35, 0.2	0.35, 0.2	0.35, 0.2	0.35, 0.2
Specified/recommended Tier	3a	3a	3a	3a
Projected biomass (ages 1+)	785,141	782,840	892,591	932,024
Female spawning biomass (t) Projected	490,663	472,562	482,174	472,507
$B_{100\%}$	530,135	530,135	606,237	606,237
$B_{40\%}$	212,054	212,054	242,495	242,495
$B_{35\%}$	185,547	185,547	212,183	212,183
F_{OFL}	0.151	0.151	0.161	0.161
$maxF_{ABC}$ (maximum allowable = $F_{40\%}$)	0.129	0.129	0.136	0.136
Specified/recommended F_{ABC}	0.129	0.129	0.136	0.136
Specified/recommended OFL (t)	76,757	75,084	82,939	83,814
Specified/recommended ABC (t)	65,932	64,494	70,673	71,411
Status	As determined *last* year for: 2015	2016	As determined *this* year for: 2016	2017
Is the stock being subjected to overfishing?	no	na	no	na
Is the stock currently overfished?	na	no	na	no
Is the stock approaching a condition of being overfished?	na	no	na	no

*Projections are based on estimated catches of 6,387 t and 10,878 t used in place of maximum permissible ABC for 2018 and 2019.

Responses to SSC and Plan Team Comments on Assessments in General

Comments from the SSC 2017:

1. The SSC recommends that authors balance the desire to improve model fit with increased risk of model misspecification.

Authors' response:

The authors have considered model complexity in this assessment and made efforts to reduce unnecessary complexity.

2. The SSC recommends that the metric (or metrics) used to describe fish condition be consistent among assessments and the Ecosystem Status Report where possible.

Authors' response:

Noted.

3. The SSC recommends that authors investigate alternative methods for projection that incorporate uncertainty in model parameters in addition to recruitment deviations, with consideration of a two-step approach including a projection using F to find the catch associated with that F and then a second projection using that fixed catch. More specifically: step 1 would

consist of using the target F for each forecast year to obtain a distribution of catch levels due to parameter and model uncertainty; and step 2 would consist of running a new set of projections conditional on each year's catch being fixed at the mean or median of the corresponding distribution computed in step 1, so as to obtain a distribution of F for each forecast year.

Authors' response:

This will be investigated in future assessments.

4. The SSC recommends that, for those sets of environmental and fisheries observations that support the inference of an impending severe decline in stock biomass, the issue of concern be brought to the SSC along with an integrated analysis of the indices. These integrated analyses are to be produced by the respective assessment author(s) and presented at the October Council meeting.

Authors' response:

This recommendation will be followed.

Responses to SSC and Plan Team Comments Specific to this Assessment

Comments from the 2016 November Plan Team

The Team recommended the authors consider smoothing the age length conversion matrix and ensure that selectivity parameters are not on bounds without reason.

Authors' response:

These recommendations have been included in the 2018 assessment.

Comments from 2016 December SSC

Some additional work is indicated for the preferred model for next year's assessment. For instance, the authors were concerned that some selectivity parameters may be at or near their boundaries. They suggested investigating this by considering alternatives for the degree of dome-shaped selectivity curves for the EBS survey. In addition, the PT recommended that the authors consider smoothing the age-length conversion matrix. The SSC supports these explorations.

Authors' response:

These recommendations have been followed in the 2018 assessment.

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

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

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

Fishery

Arrowtooth flounder were managed with Greenland turbot as a species complex until 1985 because of similarities in their life history characteristics, distribution and exploitation. Greenland turbot were the target species and arrowtooth flounder were caught as bycatch. Management of Greenland turbot and the *Atheresthes* complex was performed separately starting in 1986 due to considerable differences in their stock condition. Two species of *Atheresthes* occur in the Bering Sea, arrowtooth flounder (*Atheresthes stomias*) and Kamchatka flounder (*A. evermanni*). These two species are very similar in appearance and were not routinely distinguished in the commercial catches until 2007. 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, the year in which the NMFS Alaska Regional Office (AKRO) started providing separate catch statistics for arrowtooth and Kamchatka flounder. Arrowtooth flounder has remained lightly exploited with catches (extrapolated for arrowtooth only) averaging 13,031 t from 1970-2017 and 16,059 t from 2010-2017. Total catch reported through October 19, 2018 is 6,004 t. The NMFS AKRO BLEND/Catch Accounting System reports indicate that bottom trawling accounted for 92% of the 2018 catch (3% by pelagic trawl and 4% by hook and line).

Although much research has been conducted on their commercial utilization (e.g. Greene and Babbit 1990, Wasson et al. 1992, Porter et al. 1993, Reppond et al. 1993, Cullenberg 1995) and some targeting occurs in the Gulf of Alaska and the Bering Sea, arrowtooth flounder continue to be captured primarily in pursuit of higher value species and historically have been mostly discarded in the Bering Sea and the Aleutian Islands. The catch information in Table 6.2 reports the past annual total catch tonnage for the foreign and JV fisheries and the current domestic fisheries. The proportions of retained and discarded arrowtooth flounder in Bering Sea fisheries are estimated from observer at-sea sampling for 1985-2018 are shown in Table 6.3, and include Kamchatka flounder as well as arrowtooth flounder through 2007. With the implementation of Amendment 80 in 2008, the percentage of arrowtooth flounder retained in catches increased to 88% in 2014, and has remained high in 2017 (86%) and 2018 (86%). The largest catches, as well as discard amounts, occur in the flatfish fisheries. The trend of high retention is expected to continue in the near future due to the recent changes in fishing practices.

Data

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

Fishery:

Fishery catch data from 1976 – October 19, 2018 (Table 6.2) and fishery length-frequency data from 1978-2018 are used in the assessment (Table 6.5). Arrowtooth flounder catch is available from observer at-sea sampling applied to the Alaska Regional Office blend estimates for 2007-2018. For 1976-2006 the annual arrowtooth flounder catch was calculated as 90% of the combined arrowtooth flounder-Kamchatka flounder catch on record, based on their average annual proportions in trawl surveys since 1992 (the first year of reliable identification by species). These corrections were been applied to the catch totals in Table 6.2, under “ATF est”.

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.A2.1

Survey:

Biomass estimates (t) for arrowtooth flounder from the standard survey area in the eastern Bering Sea and Aleutian Islands region are shown in Table 6.6. Although the standard sampling trawl for the EBS shelf changed in 1982 to the more efficient trawl 83/112 trawl which may have caused an overestimate of the biomass increase in the pre-1982 part of the time-series, biomass estimates from AFSC surveys on the continental shelf have shown a consistent increasing trend since 1975 that has leveled off since 2010. Since 1982, biomass point estimates indicate that arrowtooth abundance has increased eight-fold to a high of 772,988 t in 2005. In 2006 - 2007 the estimates declined slightly but remained at high levels, between 547,496-670,132 t. Survey biomass estimates have declined since 2005 and have remained in the range of 400,000-500,000 t. The 2016 EBS slope survey estimate of 45,525 t was the lowest since 2002, and may reflect movement of arrowtooth onto the shelf (Figure 6.2). Length frequencies for the shelf (Figure 6.3), slope (Figure 6.4), and Aleutian Islands (Figure 6.5) males and females indicate that a strong year class that originated from strong recruitment since 2010 is present, and that 2018 showed evidence for another large year class.

Trawl surveys were intermittently conducted over the continental slope (1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010, 2012, and 2016). Only the surveys conducted since 2002 are considered part of a standard time series of biomass. These surveys sampled depths ranging from 200 - 1,200 meters and the Poly Nor' Eastern bottom trawl net with mud sweep ground gear was the standard sampling net. The slope surveys conducted in 1988 and 1991 sampled depths from 200-800 m and used a polyethylene Nor' Eastern trawl with bobbin roller gear. Slope surveys conducted between 1979 and 1985 sampled depths ranging from 200-1000 m and used different gear altogether. These surveys show that arrowtooth flounder biomass increased significantly from 1979 to 1985. The biomass estimate in 1988 and 1991 were lower. Based on slope surveys conducted between 1979 and 1985, 67% to 100% of the arrowtooth flounder biomass on the slope was found at depths less than 800 m. These data suggest that less than 20% of the total EBS population occupied slope waters in 1988 and 1991, a period of high arrowtooth flounder abundance. Surveys conducted during periods of low and increasing arrowtooth abundance (1979-85) indicate that 27% to 51% of the population weight occupied slope waters. Although the 2002-2004 surveys were deeper than earlier slope surveys, over 90% of the estimated arrowtooth biomass was located in waters less than 800 meters.

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

The relative abundance of arrowtooth flounder increased substantially on the continental shelf from 1982 to 1990; the CPUE from AFSC shelf surveys increased steadily from 1.6 to 9.9 kg/ha (Figure 6.3). The overall shelf catch rate decreased slightly to 7.1 kg/ha in 1991. The CPUE continued to increase through 1997 to 15.0 kg/ha. These increases in CPUE were also observed on the slope from 1981 to 1986 as CPUE from the Japanese land-based fishery increased from 1.5 to 21.0 t/hr (Bakkala and Wilderbuer 1990). From 1999 to 2005 the shelf survey CPUE increased at a high rate each year. Survey estimates are consistently high from 2003-2011 (between 8-11 kg/ha), and the 2005 CPUE of 15.4 kg/ha was the highest ever estimated from the shelf survey. Since that time, CPUE has decreased to a mean of approximately 5,000 kg/ha (Figure 6.6).

Analytic Approach

Model Structure

The assessment is based on an age-structured statistical model implemented in the Automatic Differentiation Model Builder (ADMB) framework (Fournier et al. 2012). This framework uses automatic differentiation and allows estimation of highly-parameterized and non-linear models. This age-structured population dynamics model is fit to survey abundance data, survey age data, and survey and fishery length composition data with a harvest control rule to model the status and productivity of these stocks and set quotas. The model is fit to the data by minimizing the objective function, analogous to maximizing the likelihood function. The model implementation language provides the ability to estimate the variance-covariance matrix for all parameters of interest. A "generalized model" has been used in the Gulf of Alaska and the Bering Sea and Aleutian Islands arrowtooth flounder stock assessments since 2015. The model incorporates ages 1-21+ and estimates selectivity up to age 15 for the survey and 10 for the fishery. A Markov chain Monte Carlo (MCMC) was performed in ADMB to capture variability in recruitment, female spawning biomass, and total (age 1+) biomass. The MCMC was run with 1,000,000 iterations, and thinning every 1000.

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).

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

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.

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

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 145-153 parameters estimated by models examined in the current assessment (Table 6.9). Several likelihood equations contributed to the final likelihood: recruitment, fishery and survey length compositions, age composition from the survey and survey biomass. 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.

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

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

where the observed CV is an estimate of standard deviation.

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

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

Length composition for the fishery and the survey are calculated as in Equation 5. 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 6.7), approximately 69% females and 31% males based on the fishery length composition data. Length composition data is only used in the model in years in which there is no age data.

The likelihood for survey ages assumes that observation error is distributed multinomially. The likelihood is similar to equation (5):

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

Age data exist for the 1993, 1994, 1996, 1998, 2004, 2010, 2012, 2014, 2015, 2016, and 2017 EBS shelf surveys, the 2012 slope survey, and the 2010-2016 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 is shown in Table 6.8.

For the multinomial likelihoods, an offset was calculated which was a constant that is added to the likelihood. The offset decreases as the number of samples increases, and when observations are less frequent than 0.5, and is calculated as follows:

(7) $$offset = \sum_{y=Styr}^{Endyr}\sum_{length/age} Nhauls_y(obs\_prop_{length/age})\log(obs\_prop_{length/age}).$$

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

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

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

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

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

Yield is the sum of the weight of the catch,

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

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

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

The 10 selectivity parameters estimated in the model for the smooth fishery selectivity functions were constrained so that the number of effectively free parameters would be less than 10. There were 43 fishing mortality deviates in the model, plus one mean fishing mortality parameter, to fit the observed catch closely. Twenty-one initial recruitment deviations were estimated to start the population in 1976. Recruitments deviations from 1976 to 2018 account for 43 parameters, plus one parameter for the mean recruitment. Survey selectivity was estimated separately for males and females (4 parameters total). The instantaneous natural mortality rate, catchability for the survey and the von Bertalanffy growth parameters were fixed in the model. No spawner-recruit curve was used in the model. Recruitments were freely estimated, but with a modest penalty on extreme deviations from the mean value. Age at recruitment was set at one in the model. Table 6.A1 shows parameters estimated inside the model.

A retrospective analysis was performed extending back 10 years, with data from 2009-2018. Ten runs were performed; the 2017 run was created by dropping the 2018 data, the 2016 run was created by dropping all data except through 2016, etc.

Description of Alternative Models

Five models were evaluated in this assessment. The base model, Model 15.1b is the same as the final model in the 2016 BSAI assessment (Spies et al. 2016), except length, age, and survey data were updated through 2018. Model 15.1c is the same as the base model except it incorporates a smoothed length-age conversion matrix. Model 18.3 is the same as Model 15.1c but it also incorporates an ageing error matrix to account for known error rates in age reading. Model 18.6 explores an alternative to age-based survey selectivity; it uses length-based survey selectivity (fishery selectivity remains non-parametric). The length-based selectivity retains the increasing logistic form for the Aleutian Island and the Bering Sea slope survey data, and the dome shaped form for the Eastern Bering Sea. The parameters for the logistic function are determined by length; therefore only two parameters are required for the selectivity curve for each survey (rather than four if selectivity is by sex). Logistic selectivity is then converted back to selectivity by age using the length age conversion matrix, separately for each sex. Finally, Model 18.9 improves on

Model 18.3 by removing early years of the EBS slope survey (1979-1991). This change was motivated because those surveys did not use a standardized net or standardized survey depths. Also, arrowtooth flounder and Kamchatka flounder were not distinguished for all years. A summary of model results is shown in Table 6.9, and stock size estimates for the various models is presented in Figure 6.8. A more comprehensive description of the alternative models presented to the September 2018 Plan Team is provided in Appendix 2.

Name	Model configuration
15.1b	Base model – same as 2015 model.
15.1c	Base model with smoothed length age conversion matrix and updated weight at age
18.3	Model 15.1c with an ageing error matrix.
18.6	Model 15.1c with length-based survey selectivity.
18.9	Model 18.3 with early years of slope survey removed (1979-1991).

Parameters Estimated Outside the Assessment Model

Natural mortality

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

Data used to calculate length at age and weight at length

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

Length at Age

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

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

Correcting for survey length frequencies reduced the expected length at age in the population as compared to lengths of aged fish from a stratified collection (Figure 6.9).

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

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

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

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

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

The coefficient of variation (CV) typically decreases with age. The CV of length at age was fitted using linear regression (Figure 6.10), 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 6.11).

The length-age conversion matrix was generated by simulating 10,000 data points for mean length at ages 1-21+ based on estimates of mean length at age and variance at each age. The simulations were generated from a normal distribution, with the mean length at age determined by the male and female von Bertalanffy parameters fit to the length-age data and the variance for length at age determined by the parameters of the linear models presented in Figure 6.10. These data were binned into 25 length categories bounded by the ranges shown below. These length categories were used for all length composition data in the model. The length-age conversion matrix is shown as Figure 6.12. The length age conversion matrix is compared with the length-age relationship used in the 2016 BSAI arrowtooth flounder assessment in Figure 6.13.

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

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

Weight at Length

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

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

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

Weight at age

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

Maturity

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

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

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

Catchability

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

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

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

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

where q is catchability, $\alpha$and β are a parameters estimated by the model, and T_t is the annual bottom water temperature anomaly. The catchability equation has two parts. The e^{α} term is a constant or time-independent estimate of q. The model estimate of α = -0.49 indicates that $q > 1$ suggesting that arrowtooth flounder are herded into the trawl path of the net which is consistent with the experimental results for other flatfish species. The second term, $e^{\beta T}$ is a time-varying (annual) q which relates to the metabolic aspect of herding or distribution (availability) which can vary annually with bottom water temperature. From 2014-2018, the temperature anomaly was positive, following two years of low temperatures; resulting in an increase in the catchability estimate (Figure 6.15).

Ageing error matrix

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

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

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

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

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

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

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

Parameters Estimated Inside the Assessment Model

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

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

There were 24 parameters estimated for the fishery selectivity; 10 for each sex for the smooth selectivity function and two additional for each sex for the two parameter selectivity functions. Each survey selectivity had 4 parameters for the two sexes, two parameters for increasing logistic selectivity, as well as 4 additional parameters for the decreasing arm of the shelf survey selectivity. Two parameters, alpha and beta, were estimated for the temperature-dependent shelf survey catchability (*q*-shelf). There were 63 recruitment deviations, 21 for the starting conditions, and 42 additional for each year from 1976-2017 (recruitment was not estimated in the final year). There was a fishing mortality deviation for each year from 1976-2018 (43). 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
24	16	2	63	43	1	1	150

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 calculated 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 be a smooth function. Survey selectivities for the Bering Sea slope and Aleutian Islands surveys were modeled using a two parameter ascending logistic function. Selectivity for the Bering Sea shelf survey was estimated using a dome shaped curve based on a two parameter ascending logistic function and a two parameter descending logistic function. The selectivities by age were estimated separately for females and males. The differential natural mortality and selectivities by sex resulted in a predicted fraction female of about 0.70, which is close to the fraction of females in the fishery and survey length and age data. Selectivity was estimated up to age 15 in the model for the survey, for males and females separately.

Table 6.A1.2 shows parameters estimated inside the model and their standard deviation.

Results

Model Evaluation

In September 2018, the BSAI Plan Team recommended that the arrowtooth flounder assessment investigate three models, the base model (Model 15.1b), as well as a model that uses a smoothed age-length conversion matrix (Model 15.1c), an ageing error matrix (Model 18.3), length-based survey selectivity (Model 18.6). In addition, further work included a model that did not include early slope survey data (1979-1991), Model 18.9 (Table 6.9).

Important likelihood components of all models are shown in Table 6.9, but the list is not comprehensive. The total objective function value is provided as an indication of overall model fit. Model 15.1c did not result in a lower objective function value, or a better fit, but it was a necessary change because it incorporated a smoothed length age conversion matrix and updated weight at age. Model 18.3 incorporated an ageing error matrix which did improve the fit to the data, particularly a better fit to the Aleutian Island biomass estimates, the slope and Aleutian Island age compositions, and the fishery length compositions. Model 18.6 estimated selectivity by length rather than age, and reduced the number of parameters estimated by the ADMB model by 8 (two fewer parameters for each survey logistic curve, and 4 for the shelf selectivity curve). Model 18.9 builds upon Model 18.3 by removing the early years of the slope survey (1979-2002). This provides an improved fit to the model in terms of a better fit to the shelf and Aleutian Islands survey biomass, and a much better fit to the slope survey biomass.

Model 18.9 was selected as the authors' preferred model because it provided the best fit to the data and incorporated necessary changes to the model configuration. Model 18.9 had the lowest negative log likelihood score (objective function value) (Table 6.9). The objective function value for Model 18.9 was 2,690, and the next smallest objective function value occurred in Model 18.3 (3,315). Model 18.3 differed from Model 18.9 only in the exclusion of the early years of the Bering Sea slope survey. The negative log likelihood for Model 18.9 was also the lowest for the Bering Sea slope biomass likelihood component. Final parameter estimates for Model 18.9 are shown in Table 6.A2.2.

Time Series Results

The current assessment model shows a recent trend of decreasing female spawning and total biomass (Figure 6.8). The 2018 model estimates higher levels of total biomass than the 2017 assessment. Since 2010, recruitment estimates have increased (Table 6.15, Figure 6.17) and a large cohort is evident in Bering Sea shelf length frequency data (Figure 6.3) as well as a large age 2 cohort in 2018.

Estimates indicate that arrowtooth flounder total biomass increased approximately three fold from 1976 to the 2009 value of 944,739 t (Figure 6.5, Table 6.13). Since 2009, estimates of biomass have decreased until 2016 when total biomass was estimated to be 817,349 t, and estimates have increased since the last full assessment in 2016, to 853,048 based on the assessment model output (Table 6.13). Female spawning biomass has declined since 2010 to a 2018 estimate of 498,263 (Table 6.13). The model estimates of population numbers by age, year, and sex are given in Table 6.14.

Selectivity was estimated using a logistic fit to age, by sex, for all models except Model 18.6 (Figure 6.18). The other models (Model 15.1b, 15.1c, 18.3, and 18.9) all estimated similar selectivity curves. The shelf survey selectivity is assumed to be dome shaped, but male shelf selectivity was more similar to a logistic curve, likely due to lower asymptotic length of males.

The model fit to the fishery length data appears to track observed length frequency proportional to the number of observations (Figure16.19). The model fit to the shelf survey tracks the trend of increasing abundance from 1982 to the high levels from 1993-97 and 2005-2006 (Figure 6.20). The model provides reasonable fits to the slope survey size composition time-series for males and females, which are shown in Figure 6.21, except that it estimates more larger females than are observed. The model provides acceptable fits to the survey age compositions (Figures 6.22, 6.23, 6.24).

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

Results of the retrospective analysis obtained by removing one year of data at a time from the preferred model does not indicate a strong pattern of change from the preferred model (Figure 6.30). However, the change is consistently upward for all years analyzed, indicating a small bias. The change in spawning biomass relative to Model 18.9 for each of the retrospective runs was highest in years 1980-1990, indicating that the least amount of certainty in the model results is for the early period of the analysis rather than more recent years (Figure 6.31). Mohn's rho is 0.029. Although there are no guidelines regarding how large rho (absolute value) should be before an assessment is declared to exhibit an important retrospective bias, 0.029 is very small compared with many other Alaska groundfish species.

Harvest Recommendations

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 2019 total biomass from the stock assessment projection model is 1,041,250 t and the female spawning biomass is estimated at 561,174 t for Model 18.9.

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 1976-2011 are used to calculate the average equilibrium recruitment. This results in an estimate of $B_{40\%}$ = 242,495 t for 2019. Projected 2019 female spawning biomass is compared to B40% to determine the Tier level. The stock assessment model estimates the 2019 level of female spawning biomass at 561,174 t. Since reliable estimates of B, $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and B>$B_{40\%}$ (561,174>> 242,495), arrowtooth flounder reference fishing mortality is defined in Tier 3a. For 2019 the recommended F_{ABC} □ $F_{40\%}$ = 0.131 and F_{OFL}= $F_{3\%}$ = 0.155 (full selection F values).

Acceptable biological catch is estimated for 2019 by applying the $F_{40\%}$ fishing mortality rate and age-specific fishery selectivities to the projected 2019 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 2019 ABC of 70,673 t. There were no retrospective patterns to suggest that altering the ABC from this value is warranted. The overfishing level is estimated for 2019 by applying the $F_{35\%}$ fishing mortality rate and age-specific fishery selectivities to the projected 2018 estimate of age-specific total biomass. This results in a 2019 OFL of 82,939 t. The 2020 recommended ABC is 71,411 t and the 2020 OFL is 83,814 t.

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

For each scenario, the projections begin with the vector of current year numbers at age estimated in the assessment. This vector is then projected forward to the beginning of the following year (current year +1) using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for the current year. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

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

> *Scenario 1*: In all future years, F is set equal to *max* F_{ABC}. Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.
>
> *Scenario 2*: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for next year's (current year +1) recommended in the assessment to the *max* F_{ABC} for next year. Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.
>
> *Scenario 3*: In all future years, F is set equal to 50% of max F_{ABC}. Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.
>
> *Scenario 4*: In all future years, F is set equal to the most recent 5-year (current year -6 – current year -1) average F. Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.
>
> *Scenario 5*: In all future years, F is set equal to zero. Rationale: In extreme cases, TAC may be set at a level close to zero.

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

> *Scenario 6*: In all future years, F is set equal to F_{OFL}. Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above ½ of its MSY level in the current year and above its MSY level in 10 (current year +10) years under this scenario, then the stock is not overfished.
>
> *Scenario 7*: In the next year and the following year (current year +1, current year +2), F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 13 years (current year +13) under this scenario, then the stock is not approaching an overfished condition.

Simulation results for the seven projection scenarios indicate that arrowtooth flounder are not currently overfished and the stock is not considered to be approaching an overfished condition (Table 6.16). The stock projection at the average exploitation rate for the past 5 years (Figure 6.28) indicates that the stock will remain above $B_{40\%}$ if fished at this rate for the next 12 years. A phase-plane diagram showing the time-series of female spawning biomass estimates relative to the harvest control rule (Figure 6.29) shows that the female spawning biomass is above $B_{40\%}$ and that the stock is lightly exploited relative to reference points, and that this trend is expected to continue through at least 2020. The ABC and TAC values that have been used to manage the combined stock since 1980 are presented in Table 6.17.

The 2018 catch through October 19, 2018 was 6,004 t. The total catch in 2018 was estimated to be 6,387 t based on the proportion caught through this date for the past 5 years (94%). The total catch in 2020 was the average catch 2014-2018, with the estimate of 6,387 t used for 2018. 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.

Ecosystem Considerations

Ecosystem Effects on the Stock

1) Prey availability/abundance trends

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

2) Predator population trends

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

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

3) Changes in habitat quality

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

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

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

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

Fishery Effects on the Ecosystem

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Data Gaps and Research Priorities

We recommend studies on genetic population structure of arrowtooth flounder, as stock structure has not been examined in this species. In addition, the relationship between male and female natural mortality and sex ratio should be further investigated.

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Tables

Table 6.1. Random effects model estimates of biomass and CV for the Aleutian Islands, Eastern Bering Sea shelf, and Eastern Bering Sea slope surveys. The random effects model was applied to all years of the slope survey and to only the most recent 6 years. The proportion of biomass in

each of the three regions is presented at the bottom, with all data from the slope survey and just the last 6 years.

	Aleutian Islands		Shelf		Slope all years		Slope last 6 surveys	
Year	Biomass	CV	Biomass	CV	Biomass	CV	Biomass	CV
1979					36,385	0.10		
1980	19,024	0.26	-	-	35,144	0.17		
1981	20,915	0.28	-	-	33,945	0.10		
1982	22,993	0.25	78,013	0.10	29,702	0.14		
1983	25,277	0.13	109,523	0.08	37,427	0.20		
1984	30,717	0.26	147,139	0.10	47,162	0.21		
1985	37,328	0.31	169,197	0.08	59,430	0.16		
1986	45,361	0.34	226,651	0.08	48,346	0.21		
1987	39,907	0.35	288,795	0.06	39,329	0.20		
1988	35,109	0.34	317,427	0.09	31,994	0.10		
1989	30,887	0.31	370,569	0.08	30,889	0.19		
1990	27,173	0.25	415,150	0.08	29,822	0.19		
1991	23,906	0.12	370,641	0.09	28,792	0.09		
1992	31,549	0.22	430,341	0.09	29,892	0.22		
1993	41,635	0.23	526,604	0.07	31,034	0.29		
1994	54,945	0.13	553,468	0.08	32,220	0.33		
1995	60,239	0.23	506,833	0.10	33,452	0.35		
1996	66,043	0.22	527,546	0.09	34,730	0.36		
1997	72,406	0.11	466,326	0.10	36,057	0.36		
1998	70,617	0.22	379,069	0.09	37,435	0.35		
1999	68,872	0.22	335,908	0.13	38,865	0.33		
2000	67,170	0.10	352,561	0.11	40,350	0.29		
2001	76,462	0.20	396,887	0.08	41,892	0.23		
2002	87,039	0.12	384,056	0.08	43,493	0.12	45,803	0.12
2003	92,124	0.20	520,722	0.07	48,106	0.17	49,303	0.12
2004	97,506	0.12	563,419	0.06	53,208	0.10	53,069	0.09
2005	113,746	0.22	739,415	0.06	56,501	0.20	56,086	0.14
2006	132,690	0.22	664,399	0.06	59,997	0.23	59,273	0.15
2007	117,198	0.28	561,623	0.06	63,709	0.21	62,642	0.14
2008	103,515	0.29	571,316	0.07	67,652	0.12	66,203	0.11
2009	91,429	0.26	489,444	0.08	69,897	0.18	67,805	0.13
2010	80,754	0.16	570,513	0.07	72,217	0.13	69,445	0.12
2011	72,429	0.21	555,249	0.06	70,670	0.19	67,699	0.14
2012	64,963	0.15	458,072	0.08	69,157	0.15	65,997	0.13
2013	68,972	0.21	420,212	0.08	62,749	0.22	61,124	0.15
2014	73,229	0.13	455,599	0.06	56,935	0.24	56,610	0.16
2015	69,555	0.21	417,865	0.06	51,659	0.21	52,430	0.15
2016	66,066	0.16	469,469	0.05	46,873	0.12	48,559	0.12
2017	63,011	0.21	435,105	0.06	46,873	0.12	48,559	0.12
2018	60,098	0.11	501,802	0.07	46,873	0.12	48,559	0.12
Proportion	9.87%		82.43%		7.70%			
Proportion	9.85%		82.20%				7.95%	

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 1990 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 regiona, 1991-2018. Totals for arrowtooth (ATF) and Kamchatka are under “Combined” total, extrapolated ATF only is under “ATF est”. *Species-specific estimates of catch available starting in 2008.**Catch information through October 19, 2018, source: AKFIN NMFS AKRO BLEND/Catch Accounting System.

Year	Combined Total	ATF estimate
1991	22,052	17,559
1992	10,382	10,707
1993	9,338	8,369
1994	14,366	12,904
1995	9,280	8,356
1996	14,652	13,189
1997	10,054	9,422
1998	15,241	13,713
1999	10,573	10,240
2000	12,929	11,907
2001	13,908	12,652
2002	11,540	10,670
2003	12,834	11,928
2004	17,809	16,367
2005	13,685	12,819
2006	13,309	12,098
2007	11,913	10,724
2008		14,745
2009		16,445
2010		17,467
2011		20,141
2012		22,325
2013		20,537
2014		19,110
2015		11,269
2016		11,104
2017		6,518
2018**		6,004**

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 Interface Database; prior to 2007, proportion was calculated as 0.10. Arrowtooth flounder were identified to species starting in 2008; therefore only arrowtooth flounder data is presented from this year onward.

Year	Retained	Discarded	Total (t)	% Retained
1985	17	72	89	19
1986	65	277	342	19
1987	75	320	395	19
1988	3,309	14,107	17,416	19
1989	958	4,084	5,042	19
1990*	2,356	10,042	12,398	19
1991	3,211	18,841	22,052	15
1992	675	9,707	10,382	7
1993	403	6,775	7,178	6
1994	626	13,641	14,267	4
1995	509	8,772	9,281	5
1996	1,372	13,280	14,652	9
1997	1,029	9,024	10,054	10
1998	2,896	12,345	15,241	19
1999	2,538	8,035	10,573	24
2000	5,124	7,805	12,929	60
2001	4,271	6,959	11,230	62
2002	4,039	7,501	11,540	35
2003	4,024	8,810	12,834	31
2004	3,747	14,062	17,809	21
2005	7,010	6,675	13,685	51
2006	6,104	7,205	13,309	46
2007	5,067	6,603	11,670	43
2008	15,913	5,457	21,370	74.46
2009	24,133	5,767	29,900	80.71
2010	31,929	6,886	38,815	82.26
2011	16,449	3,692	20,141	81.67
2012	19,493	2,831	22,325	87.32
2013	16,939	3,598	20,537	82.48
2014	16,765	2,345	19,110	87.73
2015	9,437	1,832	11,269	83.74
2016	8,998	2,106	11,104	81.03
2017	5,622	896	6,518	86.26
2018*	5,153	851	6,004	85.83

*1990 retained rate was applied to the 1985-89 reported catch. The 2018 catch is reported through October 19, 2018. Source: AKFIN NMFS AKRO BLEND/Catch Accounting System.

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

Source	Data	Years
NMFS Bering Sea shelf survey	Survey biomass	1982-2016, **2017, 2018**
	Age Composition	1993, 1994, 1996, 1998, 2004, 2010, 2012, 2014, 2015, **2016, 2017**
	Length composition	1987-2016, **2017, 2018**
NMFS Bering Sea slope survey	Survey biomass	1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010, 2012, 2016
	Age Composition	2012
	Length composition	1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010, 2016
NMFS Aleutian Islands survey	Survey biomass	1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, **2018**
	Age composition	2010, 2012, **2014, 2016**
	Length composition	1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2016, **2018**
Fishery	Catch length composition	1978 – 1988, 1990 -2016, **2017, 2018**

Table 6.5. The number of fisheries length observations in each year 1978-2018. Source: AKFIN NMFS AKRO BLEND/Catch Accounting System.

Year	Number of length observations	Year	Number of length observations
1978	11,426	1999	3,974
1979	6,565	2000	1,415
1980	9,945	2001	2,984
1981	7,790	2002	2,404
1982	36,784	2003	3,565
1983	31,955	2004	4,367
1984	23,189	2005	2,689
1985	25,817	2006	2,143
1986	14,399	2007	601
1987	24,066	2008	1,422
1988	833	2009	557
1989	224	2010	922
1990	3,831	2011	887
1991	10,179	2012	529
1992	816	2013	643
1993	1,570	2014	156
1994	410	2015	16
1995	3,098	2016	128
1996	1,185	2017	49
1997	3,914	2018	3,237

1998	3,819

Table 6.6. Estimated arrowtooth flounder biomass from trawl surveys conducted on the Eastern Bering Sea shelf, slope and the Aleutian Islands. The 1988 and 1991 slope estimates were from the depth ranges of 200-800 m while earlier slope estimates were from 200-1,000 m. The 2002 through 2016 slope estimates were from sampling conducted from 200-1,200 m. The 1979-1991 slope survey estimates (underlined) were not included in the final model. Slope survey estimates from 1979-2002 were not included in the assessment model.

Year	EBS shelf survey		EBS slope survey		Aleutian Islands Survey	
	Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV
1979			36,700	(0.11)		
1980					16,463	(0.32)
1981			34,900	(0.11)		
1982	69,990	(0.11)	24,700	(0.15)		
1983	110,643	(0.09)			24,529	(0.14)
1984	160,396	(0.14)				
1985	163,637	(0.09)	74,400	(0.15)		
1986	229,865	(0.10)			110,384	(0.44)
1987	294,710	(0.07)				
1988	310,933	(0.11)	30,600	(0.11)		
1989	374,317	(0.10)				
1990	435,211	(0.09)				
1991	336,457	(0.12)	28,400	(0.09)	21,919	(0.12)
1992	421,985	(0.12)				
1993	542,827	(0.09)				
1994	570,835	(0.09)			58,230	(0.14)
1995	475,339	(0.14)				
1996	552,269	(0.10)				
1997	482,684	(0.12)			74,085	(0.11)
1998	369,118	(0.11)				
1999	258,809	(0.24)				
2000	336,163	(0.16)			65,191	(0.11)
2001	409,306	(0.09)				
2002	356,665	(0.09)	42,508	(0.13)	88,809	(0.13)
2003	543,569	(0.08)				
2004	549,338	(0.07)	53,745	(0.11)	95,041	(0.13)
2005	772,988	(0.07)				
2006	670,132	(0.07)			181,063	(0.27)
2007	547,496	(0.07)				
2008	588,342	(0.08)	68,317	(0.13)		
2009	456,371	(0.09)				
2010	586,954	(0.08)	74,065	(0.15)	80,049	(0.19)
2011	568,200	(0.07)				
2012	445,736	(0.10)	72,845	(0.18)	60,371	(0.17)
2013	405,509	(0.09)				
2014	465,616	(0.07)			75,958	(0.15)
2015	409,243	(0.06)				
2016	475,264	(0.05)	45,525	(0.12)	65,901	(0.20)
2017	424,194	(0.07)				
2018	511,192	(0.07)			59,493	(0.12)

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

Age	Female weight at age 2018	Male weight at age 2018	Female weight at age 2016	Male weight at age2016	Female maturity at age (Stark 2011)
1	0.02	0.02	0.02	0.01	0.00
2	0.07	0.06	0.04	0.04	0.00
3	0.16	0.15	0.11	0.09	0.01
4	0.30	0.25	0.22	0.17	0.02
5	0.47	0.37	0.36	0.27	0.06
6	0.68	0.49	0.55	0.39	0.16
7	0.91	0.61	0.76	0.52	0.34
8	1.17	0.72	0.99	0.66	0.59
9	1.45	0.82	1.25	0.80	0.80
10	1.73	0.90	1.52	0.94	0.97
11	2.02	0.98	1.80	1.08	0.99
12	2.31	1.04	2.08	1.21	1
13	2.60	1.09	2.35	1.34	1
14	2.88	1.14	2.61	1.45	1
15	3.16	1.17	2.83	1.56	1
16	3.42	1.20	3.01	1.66	1
17	3.67	1.23	3.16	1.75	1
18	3.91	1.25	3.27	1.83	1
19	4.13	1.27	3.37	1.91	1
20	4.34	1.28	3.44	1.98	1
21+	4.97	1.30	3.53	2.04	1

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

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

Table 6.9. Results comparing model fits and 2018 yield for different model configurations.

	Model 15.1b	*Model 15.1c*	*Model 18.3*	*Model 18.6*	*Model 18.9*
Total -log(Likelihood)					
Catch	0.012	0.014	0.011	0.015	0.008
Recruitment	52.27	32.55	45.30	28.97	40.35
EBS shelf survey biomass	31.12	34.59	34.79	40.36	30.08
EBS slope survey biomass	45.32	61.01	64.66	75.08	2.89
Aleutian survey biomass	44.63	43.99	42.47	43.65	41.25
EBS shelf survey age comp	347.32	317.65	274.06	317.96	255.68
EBS slope survey age comp	43.96	42.15	54.79	36.43	37.10
Aleutian survey age comp	160.74	163.43	130.08	134.88	125.52
Survey length comp	402.88	387.10	437.36	494.57	433.67
Fishery length comp	667.13	669.84	596.98	597.83	605.72
Priors/Penalties	0.83	0.95	1.09	1.12	1.31
Fishery selectivity	13.88	14.81	13.96	14.96	14.04
NumParams	153	153	153	145	153
TotLike	1,987.70	1,957.96	1,887.58	1,982.21	1,789.18
ADSB	-	0.12	0.09	0.12	0.19
ObjFun	3,567.92	3,629.12	3,315.00	3,620.89	2,690.25
Stock status (t)					
2018 Spawning biomass	494,638	534,625	554,216	547,940	853,048
2018 Total biomass	801,623	881,880	950,576	937,500	498,263

Brief model descriptions (see text for details):

Model 15.1b - Base model from 2016 assessment.
Model 15.1c - Model 15.1b with smoothed length at conversion matrix.
Model 18.3 - Model 15.1c with ageing error matrix.
Model 18.6 - Model 18.3 with length-based survey selectivity and non-parametric fishery selectivity.
Model 18.9 - Model 18.3 with slope survey years 1979-1991 removed.

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

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

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

Year	Full selection *F*	Exploitation rate
1976	0.086	0.054
1977	0.049	0.034
1978	0.040	0.031
1979	0.056	0.046
1980	0.075	0.063
1981	0.078	0.062
1982	0.058	0.043
1983	0.078	0.051
1984	0.056	0.033
1985	0.042	0.024
1986	0.038	0.021
1987	0.023	0.013
1988	0.085	0.046
1989	0.029	0.015
1990	0.046	0.024
1991	0.058	0.032
1992	0.031	0.018
1993	0.021	0.013
1994	0.028	0.020
1995	0.017	0.013
1996	0.025	0.020
1997	0.018	0.014
1998	0.027	0.020
1999	0.020	0.015
2000	0.024	0.017
2001	0.025	0.018
2002	0.021	0.014
2003	0.023	0.015
2004	0.030	0.020
2005	0.022	0.015
2006	0.020	0.014
2007	0.017	0.012
2008	0.022	0.016
2009	0.024	0.017
2010	0.025	0.019
2011	0.029	0.022
2012	0.032	0.025
2013	0.030	0.023
2014	0.029	0.023
2015	0.018	0.014
2016	0.018	0.014
2017	0.010	0.008
2018	0.008	0.005

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	0.04	0.02	0.06	0.04	0.01	0.00	0.04	0.00
2	0.10	0.08	0.21	0.15	0.02	0.00	0.10	0.00
3	0.25	0.29	0.56	0.42	0.06	0.00	0.25	0.00
4	0.50	0.65	0.89	0.79	0.12	0.02	0.50	0.01
5	0.76	0.89	1.00	1.00	0.23	0.42	0.75	0.15
6	0.90	0.97	1.00	0.98	0.40	0.96	0.90	0.79
7	0.97	0.99	0.94	0.82	0.60	1.00	0.97	0.99
8	0.99	1.00	0.82	0.59	0.80	1.00	0.99	1.00
9	1.00	1.00	0.63	0.36	0.94	1.00	1.00	1.00
10	1.00	1.00	0.41	0.19	1.00	1.00	1.00	1.00
11	1.00	1.00	0.23	0.09	1.00	1.00	1.00	1.00
12	1.00	1.00	0.12	0.04	1.00	1.00	1.00	1.00
13	1.00	1.00	0.05	0.02	1.00	1.00	1.00	1.00
14	1.00	1.00	0.02	0.01	1.00	1.00	1.00	1.00
15	1.00	1.00	0.01	0.00	1.00	1.00	1.00	1.00
16	1.00	1.00	0.01	0.00	1.00	1.00	1.00	1.00
17	1.00	1.00	0.01	0.00	1.00	1.00	1.00	1.00
18	1.00	1.00	0.01	0.00	1.00	1.00	1.00	1.00
19	1.00	1.00	0.01	0.00	1.00	1.00	1.00	1.00
20	1.00	1.00	0.01	0.00	1.00	1.00	1.00	1.00
21+	1.00	1.00	0.01	0.00	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 2016 and 2018 assessments. Lower 95% and upper 95% confidence intervals (CIs) are provided for the estimates of total biomass and female spawning biomass.

	2016 Assessment		2018 Assessment					
Year	**Total biomass**	**FSB**	**Total Biomass**	**Biomass lower CI**	**Biomass Upper CI**	**FSB**	**FSB Lower CI**	**FSB Upper CI**
1976	390,856	220,752	318,843	284,180	353,506	152,647	119,525	185,769
1977	370,529	222,374	306,325	274,600	338,050	146,983	117,632	176,334
1978	353,616	230,546	294,589	265,554	323,624	153,532	127,196	179,869
1979	337,621	234,225	280,137	253,538	306,736	165,889	141,456	190,322
1980	316,147	224,650	262,107	237,907	286,307	172,532	149,749	195,315
1981	294,020	204,088	246,440	224,576	268,304	167,280	146,726	187,835
1982	278,586	182,632	239,708	219,889	259,528	154,347	135,928	172,766
1983	275,086	168,333	245,051	226,954	263,148	141,231	124,694	157,768
1984	280,844	155,518	255,318	238,679	271,957	125,401	110,615	140,187
1985	294,173	147,059	275,301	259,781	290,821	116,355	103,302	129,408
1986	316,171	142,848	303,277	288,290	318,264	115,817	104,241	127,393
1987	346,003	145,414	339,649	324,553	354,745	123,643	113,156	134,130
1988	384,995	158,480	387,906	371,927	403,885	139,585	129,652	149,519
1989	417,692	167,959	431,691	414,066	449,316	148,870	139,288	158,452
1990	469,980	187,240	494,098	474,549	513,647	168,273	158,846	177,700
1991	516,793	206,192	548,332	526,835	569,829	188,799	179,065	198,533
1992	551,853	223,632	589,693	566,551	612,835	211,411	200,790	222,032
1993	590,261	253,621	625,598	601,282	649,914	244,022	232,374	255,670
1994	621,176	291,844	651,743	626,651	676,835	285,652	272,580	298,724
1995	636,732	330,313	662,015	636,484	687,546	327,982	313,269	342,695
1996	649,886	367,626	671,228	645,472	696,984	369,260	353,142	385,378
1997	651,189	390,281	671,884	646,020	697,748	395,735	378,710	412,760
1998	655,984	404,944	676,515	650,531	702,499	411,591	394,139	429,043
1999	658,794	407,468	681,530	655,303	707,757	412,757	395,243	430,271
2000	672,283	406,905	697,736	671,006	724,467	409,895	392,549	427,241
2001	690,899	400,347	720,593	692,955	748,231	403,436	386,281	420,591
2002	716,031	392,546	749,885	721,230	778,540	397,511	380,592	414,430
2003	749,117	390,974	786,132	756,315	815,950	398,055	381,180	414,930
2004	784,858	396,355	824,573	793,519	855,627	404,346	387,266	421,426
2005	815,630	407,748	855,712	823,507	887,917	413,866	396,321	431,411
2006	849,607	430,302	887,244	853,938	920,550	434,285	415,927	452,643
2007	876,395	457,121	914,427	880,100	948,754	461,726	442,359	481,093
2008	899,248	486,330	935,734	900,587	970,881	491,841	471,532	512,151
2009	904,125	507,179	943,717	908,023	979,411	517,458	496,272	538,644
2010	891,490	518,572	939,969	904,105	975,833	537,972	515,953	559,991
2011	860,724	515,407	925,548	889,886	961,210	551,362	528,644	574,080
2012	845,222	520,482	901,347	866,183	936,511	556,003	532,785	579,221
2013	822,562	518,416	872,920	838,373	907,467	553,163	529,643	576,683
2014	798,002	512,882	848,196	814,255	882,137	546,149	522,572	569,726
2015	773,399	503,052	827,152	793,648	860,656	533,753	510,394	557,112
2016	762,657	495,189	816,183	782,863	849,503	523,000	500,146	545,854
2017			822,634	787,750	857,518	508,431	486,279	530,583
2018			849,621	810,174	889,068	497,583	476,147	519,020
2019			892,571	844,430	940,713	482,174	461,235	503,113

Table 6.14. Model estimates of arrowtooth flounder population numbers-at-age, by sex, 1976-2018.

Females	Numbers at age (1,000s)									
Year	1	2	3	4	5	6	7	8	9	10
1976	15,846	23,883	38,490	62,945	100,344	29,482	16,798	11,417	8,530	6,709
1977	12,213	12,970	19,531	31,382	50,897	79,783	22,881	12,709	8,504	6,354
1978	16,396	9,997	10,612	15,953	25,512	40,982	63,364	17,911	9,860	6,598
1979	42,528	13,422	8,181	8,671	12,986	20,604	32,727	50,002	14,032	7,725
1980	100,172	34,812	10,981	6,680	7,043	10,433	16,299	25,467	38,522	10,811
1981	162,256	81,993	28,473	8,958	5,410	5,621	8,154	12,458	19,204	29,051
1982	99,066	132,808	67,060	23,224	7,252	4,313	4,385	6,215	9,363	14,435
1983	76,566	81,092	108,651	54,753	18,858	5,823	3,408	3,406	4,779	7,200
1984	194,685	62,670	66,324	88,625	44,330	15,039	4,544	2,600	2,562	3,595
1985	151,856	159,364	51,272	54,156	71,978	35,613	11,895	3,535	2,002	1,974
1986	145,412	124,311	130,402	41,892	44,068	58,087	28,401	9,368	2,763	1,565
1987	278,628	119,038	101,726	106,571	34,112	35,622	46,462	22,465	7,360	2,171
1988	295,014	228,103	97,431	83,196	86,969	27,716	28,760	37,263	17,945	5,879
1989	266,165	241,466	186,542	79,442	67,281	69,170	21,523	21,777	27,784	13,382
1990	214,996	217,897	197,621	152,520	64,777	54,560	55,650	17,172	17,287	22,056
1991	134,166	175,996	178,290	161,445	124,056	52,223	43,430	43,707	13,376	13,467
1992	135,595	109,824	143,982	145,566	131,082	99,596	41,253	33,726	33,589	10,281
1993	107,459	111,004	89,879	117,709	118,654	106,211	80,010	32,842	26,701	26,594
1994	111,138	87,974	90,857	73,514	96,085	96,467	85,853	64,280	26,287	21,373
1995	116,434	90,984	72,000	74,287	59,945	77,922	77,620	68,509	51,036	20,872
1996	190,504	95,322	74,474	58,901	60,675	48,802	63,142	62,588	55,076	41,029
1997	156,150	155,958	78,017	60,901	48,050	49,254	39,338	50,520	49,849	43,868
1998	167,497	127,837	127,657	63,820	49,733	39,102	39,882	31,684	40,560	40,023
1999	284,873	137,122	104,627	104,385	52,054	40,358	31,499	31,880	25,208	32,270
2000	273,744	233,219	112,236	85,580	85,219	42,332	32,638	25,325	25,539	20,195
2001	239,662	224,105	190,884	91,788	69,831	69,220	34,161	26,157	20,210	20,382
2002	292,954	196,202	183,420	156,094	74,879	56,689	55,801	27,336	20,836	16,100
2003	268,933	239,833	160,592	150,022	127,417	60,876	45,821	44,828	21,878	16,677
2004	243,075	220,167	196,300	131,339	122,429	103,527	49,151	36,751	35,808	17,477
2005	199,040	198,993	180,186	160,488	107,074	99,237	83,225	39,169	29,131	28,386
2006	241,532	162,947	162,873	147,366	130,974	87,004	80,134	66,762	31,295	23,276
2007	202,146	197,736	133,374	133,220	120,303	106,503	70,351	64,412	53,469	25,064
2008	164,381	165,494	161,856	109,110	108,808	97,938	86,299	56,724	51,778	42,983
2009	158,342	134,573	135,455	132,376	89,046	88,418	79,093	69,239	45,329	41,378
2010	127,428	129,629	110,145	110,774	108,010	72,321	71,335	63,367	55,235	36,162
2011	120,119	104,320	106,096	90,071	90,370	87,688	58,307	57,092	50,487	44,010
2012	147,285	98,336	85,378	86,744	73,438	73,270	70,526	46,498	45,293	40,055
2013	204,292	120,574	80,476	69,793	70,691	59,474	58,807	56,070	36,754	35,803
2014	186,338	167,243	98,678	65,793	56,895	57,291	47,798	46,845	44,424	29,121
2015	148,060	152,546	136,874	80,679	53,644	46,129	46,078	38,117	37,164	35,245
2016	147,038	121,214	124,865	111,969	65,889	43,662	37,365	37,133	30,622	29,856
2017	602,873	120,377	99,218	102,145	91,442	53,627	35,363	30,106	29,825	24,596
2018	335,024	493,573	98,543	81,192	83,503	74,600	43,621	28,676	24,367	24,140

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

Females	Numbers at age (1,000s)									
Year	11	12	13	14	15	16	17	18	19	20	21+
1976	5,642	4,800	4,151	3,730	3,201	2,766	2,378	2,067	1,795	1,554	3,705
1977	5,005	4,210	3,581	3,097	2,783	2,388	2,064	1,774	1,542	1,339	3,923
1978	4,935	3,887	3,269	2,781	2,405	2,161	1,855	1,603	1,378	1,198	4,086
1979	5,173	3,869	3,048	2,563	2,181	1,886	1,694	1,454	1,256	1,080	4,143
1980	5,958	3,990	2,984	2,350	1,977	1,682	1,454	1,307	1,121	969	4,028
1981	8,164	4,499	3,013	2,253	1,775	1,493	1,270	1,098	987	847	3,774
1982	21,867	6,145	3,386	2,268	1,696	1,336	1,124	956	827	743	3,478
1983	11,111	16,832	4,730	2,607	1,746	1,306	1,028	865	736	636	3,249
1984	5,424	8,370	12,680	3,563	1,964	1,315	983	775	652	554	2,927
1985	2,772	4,182	6,453	9,776	2,747	1,514	1,014	758	597	502	2,684
1986	1,544	2,168	3,271	5,048	7,646	2,149	1,184	793	593	467	2,492
1987	1,230	1,214	1,705	2,572	3,969	6,012	1,689	931	623	466	2,327
1988	1,735	983	970	1,362	2,055	3,171	4,804	1,350	744	498	2,232
1989	4,390	1,296	734	724	1,017	1,535	2,368	3,588	1,008	556	2,039
1990	10,628	3,487	1,029	583	575	808	1,219	1,881	2,850	801	2,061
1991	17,196	8,286	2,719	802	455	449	630	950	1,467	2,222	2,231
1992	10,361	13,230	6,375	2,092	617	350	345	485	731	1,128	3,426
1993	8,144	8,208	10,480	5,050	1,657	489	277	273	384	579	3,607
1994	21,295	6,521	6,572	8,392	4,044	1,327	392	222	219	307	3,352
1995	16,978	16,916	5,180	5,221	6,666	3,212	1,054	311	176	174	2,907
1996	16,784	13,653	13,603	4,166	4,198	5,361	2,583	848	250	142	2,478
1997	32,694	13,375	10,880	10,840	3,320	3,345	4,272	2,058	675	199	2,087
1998	35,231	26,258	10,742	8,738	8,706	2,666	2,687	3,431	1,653	542	1,836
1999	31,858	28,044	20,901	8,550	6,955	6,930	2,122	2,139	2,731	1,316	1,894
2000	25,862	25,531	22,475	16,750	6,852	5,574	5,554	1,701	1,714	2,189	2,572
2001	16,124	20,648	20,384	17,944	13,374	5,471	4,450	4,434	1,358	1,368	3,801
2002	16,244	12,850	16,456	16,246	14,301	10,658	4,360	3,547	3,534	1,082	4,120
2003	12,891	13,006	10,289	13,176	13,007	11,450	8,534	3,491	2,840	2,829	4,165
2004	13,327	10,302	10,394	8,222	10,530	10,395	9,150	6,820	2,790	2,269	5,590
2005	13,861	10,570	8,170	8,244	6,521	8,351	8,244	7,257	5,409	2,213	6,233
2006	22,689	11,079	8,449	6,531	6,589	5,212	6,675	6,590	5,801	4,323	6,751
2007	18,649	18,178	8,877	6,769	5,232	5,279	4,176	5,348	5,280	4,648	8,873
2008	20,155	14,996	14,618	7,138	5,443	4,207	4,245	3,358	4,301	4,246	10,872
2009	34,363	16,113	11,988	11,686	5,707	4,352	3,364	3,394	2,685	3,438	12,086
2010	33,024	27,426	12,860	9,568	9,327	4,554	3,473	2,685	2,709	2,143	12,390
2011	28,826	26,324	21,861	10,251	7,627	7,435	3,630	2,768	2,140	2,159	11,584
2012	34,934	22,881	20,896	17,353	8,137	6,054	5,901	2,882	2,198	1,699	10,909
2013	31,681	27,630	18,097	16,527	13,725	6,436	4,788	4,668	2,279	1,738	9,972
2014	28,383	25,115	21,904	14,346	13,102	10,880	5,102	3,796	3,700	1,807	9,283
2015	23,116	22,529	19,935	17,386	11,388	10,400	8,637	4,050	3,013	2,937	8,803
2016	28,323	18,576	18,105	16,020	13,972	9,151	8,357	6,940	3,254	2,421	9,434
2017	23,989	22,757	14,925	14,547	12,872	11,226	7,353	6,715	5,576	2,615	9,526
2018	19,911	19,420	18,422	12,083	11,776	10,420	9,088	5,952	5,436	4,514	9,828

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

Males	Numbers at age (1,000s)									
Year	1	2	3	4	5	6	7	8	9	10
1976	15,846	20,556	28,514	40,136	55,070	13,926	6,830	3,995	2,569	1,739
1977	12,213	11,155	14,452	19,985	27,957	37,944	9,440	4,538	2,603	1,651
1978	16,396	8,601	7,851	10,153	13,991	19,450	26,155	6,433	3,058	1,741
1979	42,528	11,549	6,055	5,518	7,116	9,756	13,461	17,932	4,371	2,065
1980	100,172	29,950	8,126	4,252	3,860	4,943	6,706	9,133	12,016	2,903
1981	162,256	70,529	21,062	5,699	2,966	2,667	3,367	4,489	6,012	7,816
1982	99,066	114,237	49,596	14,770	3,974	2,048	1,815	2,250	2,947	3,898
1983	76,566	69,765	80,377	34,825	10,328	2,759	1,407	1,230	1,505	1,954
1984	194,685	53,907	49,059	56,367	24,287	7,133	1,878	940	808	977
1985	151,856	137,104	37,930	34,451	39,425	16,867	4,902	1,274	630	536
1986	145,412	106,959	96,504	26,658	24,139	27,476	11,662	3,356	864	424
1987	278,628	102,426	75,296	67,846	18,691	16,844	19,037	8,009	2,285	585
1988	295,014	196,295	72,134	52,986	47,665	13,094	11,750	13,211	5,530	1,572
1989	266,165	207,689	138,006	50,562	36,912	32,850	8,880	7,812	8,616	3,558
1990	214,996	187,503	146,244	97,080	35,495	25,821	22,857	6,138	5,366	5,892
1991	134,166	151,426	131,968	102,764	67,995	24,718	17,828	15,615	4,151	3,603
1992	135,595	94,482	106,541	92,661	71,856	47,198	16,972	12,078	10,442	2,750
1993	107,459	95,518	66,525	74,934	65,029	50,234	32,806	11,713	8,278	7,122
1994	111,138	75,707	67,273	46,819	52,659	45,579	35,072	22,794	8,101	5,706
1995	116,434	78,293	53,310	47,323	32,869	36,838	31,717	24,246	15,659	5,540
1996	190,504	82,034	55,147	37,527	33,274	23,062	25,765	22,098	16,830	10,841
1997	156,150	134,207	57,769	38,800	26,356	23,294	16,069	17,848	15,221	11,546
1998	167,497	110,014	94,528	40,664	27,276	18,486	16,284	11,186	12,375	10,523
1999	284,873	117,997	77,471	66,504	28,554	19,091	12,875	11,272	7,698	8,481
2000	273,744	200,701	83,107	54,525	46,740	20,018	13,334	8,951	7,801	5,311
2001	239,662	192,853	141,342	58,479	38,303	32,737	13,959	9,247	6,175	5,362
2002	292,954	168,839	135,809	99,446	41,071	26,816	22,812	9,670	6,370	4,237
2003	268,933	206,392	118,912	95,579	69,884	28,786	18,722	15,849	6,688	4,391
2004	243,075	189,465	145,353	83,678	67,150	48,958	20,081	12,992	10,943	4,601
2005	199,040	171,234	133,407	102,240	58,733	46,957	34,046	13,869	8,913	7,473
2006	241,532	140,225	120,593	93,879	71,832	41,149	32,760	23,629	9,578	6,134
2007	202,146	170,166	98,761	84,874	65,977	50,354	28,736	22,771	16,350	6,606
2008	164,381	142,423	119,859	69,523	59,676	46,291	35,218	20,020	15,805	11,318
2009	158,342	115,808	100,303	84,346	48,846	41,811	32,298	24,446	13,828	10,878
2010	127,428	111,551	81,556	70,578	59,249	34,210	29,151	22,395	16,860	9,501
2011	120,119	89,772	78,556	57,382	49,570	41,482	23,839	20,197	15,430	11,571
2012	147,285	84,619	63,212	55,258	40,281	34,670	28,857	16,473	13,866	10,545
2013	204,292	103,752	59,578	44,455	38,772	28,149	24,082	19,895	11,275	9,443
2014	186,338	143,912	73,053	41,905	31,201	27,110	19,571	16,627	13,644	7,696
2015	148,060	131,267	101,334	51,387	29,416	21,823	18,858	13,523	11,415	9,324
2016	147,038	104,315	92,459	71,332	36,128	20,636	15,259	13,133	9,381	7,897
2017	602,873	103,595	73,475	65,084	50,149	25,343	14,428	10,626	9,109	6,489
2018	335,024	424,786	72,981	51,743	45,799	35,243	17,775	10,095	7,417	6,348

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

Males				Numbers at age (1,000s)							
Year	11	12	13	14	15	16	17	18	19	20	21
1976	1,259	922	686	531	392	292	216	161	121	90	113
1977	1,111	805	589	439	339	251	186	138	103	77	130
1978	1,101	741	536	393	292	226	167	124	92	69	138
1979	1,172	741	499	361	264	197	152	112	84	62	139
1980	1,366	776	490	330	239	175	130	101	74	55	133
1981	1,879	884	502	317	214	155	113	84	65	48	122
1982	5,042	1,212	570	324	205	138	100	73	54	42	110
1983	2,575	3,330	800	377	214	135	91	66	48	36	100
1984	1,261	1,662	2,149	517	243	138	87	59	43	31	88
1985	646	834	1,099	1,422	342	161	91	58	39	28	79
1986	360	434	560	738	955	230	108	61	39	26	72
1987	286	243	293	378	499	645	155	73	41	26	66
1988	402	197	167	201	260	343	443	106	50	28	63
1989	1,006	257	126	107	129	166	219	283	68	32	59
1990	2,428	687	175	86	73	88	114	150	193	47	62
1991	3,943	1,625	460	117	58	49	59	76	100	129	73
1992	2,378	2,603	1,073	303	77	38	32	39	50	66	133
1993	1,872	1,619	1,772	730	206	53	26	22	26	34	136
1994	4,903	1,289	1,114	1,220	503	142	36	18	15	18	117
1995	3,895	3,347	880	761	833	343	97	25	12	10	92
1996	3,831	2,694	2,314	608	526	576	237	67	17	8	71
1997	7,425	2,624	1,845	1,585	417	360	394	163	46	12	54
1998	7,973	5,127	1,812	1,274	1,095	288	249	272	112	32	46
1999	7,199	5,455	3,508	1,240	872	749	197	170	186	77	53
2000	5,843	4,960	3,758	2,417	854	601	516	136	117	128	89
2001	3,645	4,010	3,404	2,579	1,659	586	412	354	93	80	149
2002	3,673	2,497	2,747	2,332	1,767	1,136	402	282	243	64	157
2003	2,917	2,528	1,719	1,891	1,605	1,216	782	276	194	167	152
2004	3,016	2,004	1,737	1,181	1,299	1,103	835	537	190	133	219
2005	3,136	2,056	1,365	1,184	805	885	752	569	366	129	240
2006	5,135	2,155	1,413	938	813	553	608	516	391	252	254
2007	4,225	3,537	1,484	973	646	560	381	419	356	269	348
2008	4,568	2,921	2,446	1,026	673	447	387	263	290	246	427
2009	7,779	3,139	2,008	1,681	705	462	307	266	181	199	463
2010	7,463	5,336	2,154	1,377	1,153	484	317	211	183	124	454
2011	6,510	5,113	3,656	1,476	944	790	331	217	144	125	396
2012	7,893	4,440	3,488	2,494	1,006	644	539	226	148	98	356
2013	7,166	5,363	3,017	2,370	1,695	684	437	366	154	101	309
2014	6,432	4,881	3,653	2,055	1,614	1,154	466	298	249	105	279
2015	5,249	4,388	3,329	2,492	1,402	1,101	787	318	203	170	262
2016	6,443	3,627	3,032	2,301	1,722	969	761	544	220	140	298
2017	5,456	4,451	2,506	2,095	1,589	1,190	669	526	376	152	303
2018	4,519	3,799	3,100	1,745	1,459	1,107	828	466	366	262	317

Table 6.15. Estimated age 1 recruitment of arrowtooth flounder (1,000s of fish) from the 2016 and 2018 stock assessments. The 95% credible intervals (CI) are based on MCMC runs from Model 18.9. Mean recruitment over the entire time interval 1976-2017 is 353,803,000 fish.

Year class	2016 Assessment	2018 Assessment	Lower CI	Upper CI
1976	71,884	32,093	15,678	53,969
1977	282,532	23,942	11,193	40,586
1978	67,171	32,621	15,209	54,908
1979	50,648	86,362	41,643	139,844
1980	108,815	198,894	95,188	297,723
1981	408,312	321,828	170,536	454,526
1982	421,280	204,240	89,013	347,621
1983	74,881	149,173	62,961	256,316
1984	529,016	387,670	288,640	489,941
1985	322,280	304,454	231,121	382,552
1986	292,492	290,725	236,414	346,701
1987	664,810	557,107	492,112	625,712
1988	690,854	589,214	520,287	660,399
1989	583,820	530,891	467,252	597,463
1990	400,490	430,325	370,521	493,476
1991	284,192	266,347	218,748	316,175
1992	415,026	270,672	224,356	319,726
1993	280,914	214,595	174,695	256,445
1994	255,838	221,077	182,214	262,433
1995	251,052	233,495	191,264	278,098
1996	389,560	381,055	326,597	439,990
1997	372,168	311,199	249,907	376,739
1998	493,502	335,016	264,773	409,932
1999	687,566	570,401	489,228	654,974
2000	645,522	547,328	467,084	630,879
2001	539,010	477,408	406,331	552,990
2002	647,950	583,747	507,696	661,736
2003	690,176	539,119	470,477	611,931
2004	593,234	484,238	427,874	541,157
2005	387,078	396,394	350,936	443,646
2006	598,034	481,216	436,736	525,946
2007	456,668	402,866	364,512	442,870
2008	364,604	328,054	293,683	364,517
2009	425,010	317,298	284,998	351,589
2010	321,184	254,065	224,152	285,247
2011	294,236	239,809	211,192	270,477
2012	317,722	293,817	259,987	329,294
2013	425,728	408,756	364,855	454,532
2014	287,256	372,122	323,123	424,099
2015	265,542	294,759	237,996	357,206
2016		292,494	209,523	386,909
2017		1,202,835	936,623	1,494,257

Table 6.16. Projections of arrowtooth flounder female spawning biomass (t), future catch (t) and full selection fishing mortality rates for seven future harvest scenarios.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2018	489,069	6,387	0.012
2019	482,174	10,878	0.020
2020	472,507	71,411	0.136
2021	424,642	67,235	0.136
2022	391,415	66,268	0.136
2023	376,643	66,946	0.136
2024	376,325	66,482	0.136
2025	374,855	63,451	0.136
2026	363,835	59,713	0.136
2027	346,649	56,484	0.136
2028	328,504	53,792	0.136
2029	312,122	51,438	0.136
2030	297,958	49,214	0.134
2031	286,200	47,261	0.133

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2018	489,069	6,387	0.012
2019	480,442	35,336	0.066
2020	457,295	8,641	0.016
2021	459,113	8,973	0.016
2022	469,089	9,595	0.016
2023	493,360	10,394	0.016
2024	532,473	11,053	0.016
2025	571,187	11,289	0.016
2026	595,642	11,296	0.016
2027	605,904	11,253	0.016
2028	607,663	11,181	0.016
2029	605,362	11,086	0.016
2030	600,515	10,968	0.016
2031	594,390	10,843	0.016

Scenario 4
Harvest at average *F* over the past 5 years

Year	Female spawning biomass	catch	F
2018	489,069	6,387	0.012
2019	481,919	14,525	0.027
2020	472,082	36,775	0.069
2021	451,198	36,519	0.069
2022	440,030	37,578	0.069
2023	444,034	39,368	0.069
2024	461,947	40,522	0.069
2025	478,405	40,080	0.069
2026	482,248	38,938	0.069
2027	475,437	37,803	0.069
2028	463,750	36,746	0.069
2029	451,013	35,757	0.069
2030	438,334	34,828	0.069
2031	426,440	33,995	0.069

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2018	489,069	6,387	0.012
2019	482,925	0	0.000
2020	486,322	0	0.000
2021	494,070	0	0.000
2022	509,324	0	0.000
2023	538,444	0	0.000
2024	582,755	0	0.000
2025	627,256	0	0.000
2026	657,331	0	0.000
2027	672,358	0	0.000
2028	677,950	0	0.000
2029	678,725	0	0.000
2030	676,248	0	0.000
2031	671,942	0	0.000

Table 6.16 (continued).

Scenario 6
Determination of whether arrowtooth flounder are currently overfished
B35=212,183

Year	Female spawning biomass	catch	F
2018	489,069	6,387	0.012
2019	476,882	82,935	0.161
2020	414,557	74,670	0.161
2021	366,747	70,023	0.161
2022	335,221	69,288	0.161
2023	322,791	70,382	0.161
2024	324,149	69,983	0.161
2025	323,596	66,619	0.161
2026	313,642	62,514	0.161
2027	298,115	59,043	0.161
2028	282,044	55,866	0.160
2029	268,103	52,715	0.156
2030	256,822	50,027	0.153
2031	248,057	47,961	0.149

Scenario 7
Determination of whether arrowtooth flounder are approaching an overfished condition
B35=212,183

Year	Female spawning biomass	catch	F
2018	489,069	6,387	0.012
2019	477,825	70,671	0.136
2020	425,052	64,938	0.136
2021	383,451	72,686	0.161
2022	349,073	71,434	0.161
2023	334,074	72,089	0.161
2024	333,194	71,319	0.161
2025	330,719	67,645	0.161
2026	319,157	63,291	0.161
2027	302,317	59,630	0.161
2028	285,197	56,386	0.160
2029	270,388	53,141	0.157
2030	258,422	50,344	0.153
2031	249,143	48,183	0.150

Table 6.17. Catch, OFL, TAC, and ABC used to manage the BSAI arrowtooth flounder complex since 1980. **Catch information through October 19, 2018, source: AKFIN NMFS AKRO BLEND/Catch Accounting System.

Year	Catch	OFL	TAC	ABC
1980	17,079			20,000
1981	15,915			16,500
1982	10,712			16,500
1983	12,991			20,000
1984	8,790			20,000
1985	6,926			20,000
1986	6,678		20,000	20,000
1987	4,519		9,795	30,900
1988	18,591		5,531	99,500
1989	6,795		6,000	163,700
1990	12,144		10,000	106,500
1991	17,559		20,000	116,400
1992	10,707	114,000	10,000	82,300
1993	8,369	96,000	10,000	72,000
1994	12,904	130,000	10,000	93,400
1995	8,356	138,000	10,227	113,000
1996	13,189	162,000	9,000	129,000
1997	9,422	167,000	20,760	108,000
1998	13,713	230,000	16,000	147,000
1999	10,240	219,000	134,354	140,000
2000	11,907	160,000	131,000	131,000
2001	12,652	141,500	22,015	117,000
2002	10,670	137,000	16,000	113,000
2003	11,928	139,000	12,000	112,000
2004	16,367	142,000	12,000	115,000
2005	12,819	132,000	12,000	108,000
2006	12,098	166,000	13,000	136,000
2007	10,724	193,000	20,000	158,000
2008	14,745	297,000	75,000	244,000
2009	16,445	190,000	75,000	156,000
2010	17,467	191,000	75,000	156,000
2011	20,141	186,000	25,900	153,000
2012	22,325	181,000	25,900	157,000
2013	20,537	186,000	25,000	152,000
2014	19,110	125,642	25,000	106,599
2015	11,269	93,856	22,000	80,547
2016	11,104	94,035	14,000	80,701
2017	6,518	76,100	14,000	65,371
2018	6,004**	76,757	13,621	65,932

Figures

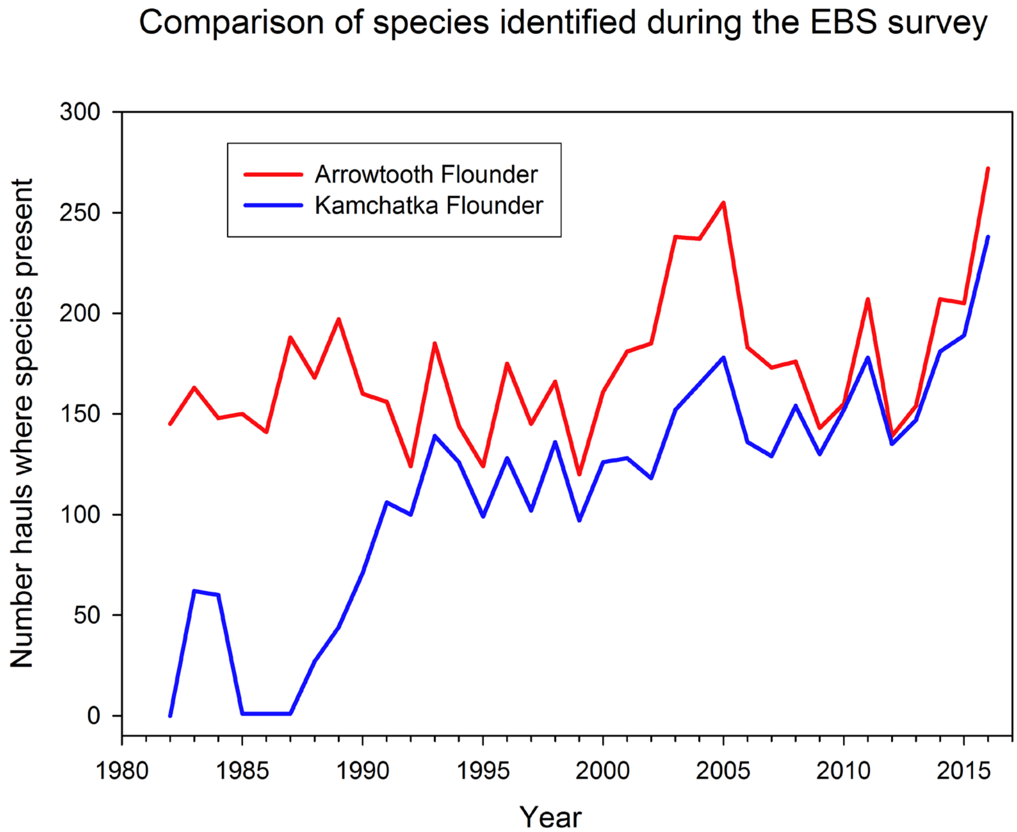


Figure 6.1. Numbers of hauls where arrowtooth flounder and Kamchatka flounder were identified during the annual Bering Sea shelf surveys, 1982-2017, within the standard survey area.

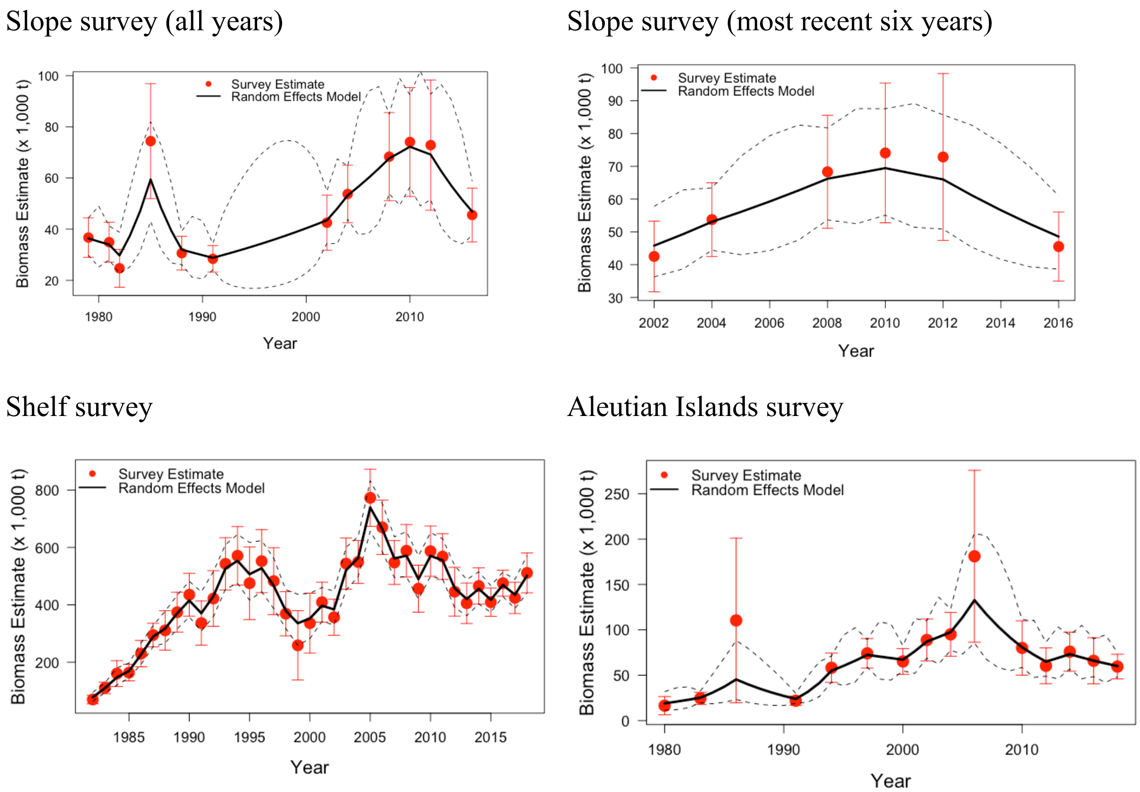


Figure 6.2. Survey estimates for the Bering Sea shelf, slope and the Aleutian Islands arrowtooth flounder biomass, with fitted linear model predictions. Predictions based on the random effect model applied to survey data indicate 10% in the Aleutians, 82% on the Bering Sea shelf, and 8% on the Bering Sea slope. Proportions do not change when the 1979-1991 slope survey data is excluded (Table 6.6).

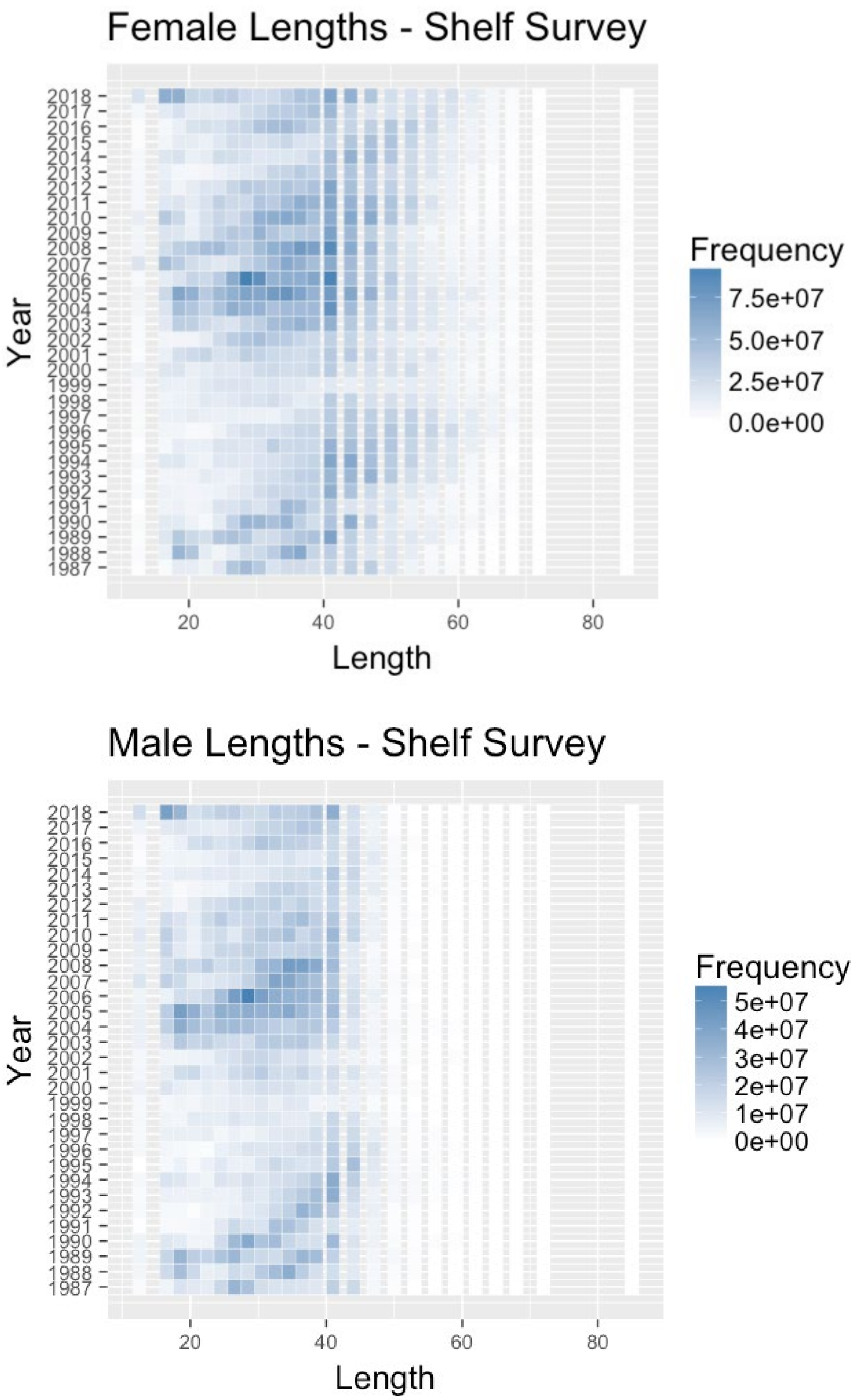


Figure 6.3. Length frequency data from male (upper panel) and female (lower panel) Bering Sea shelf survey arrowtooth flounder from 1987-2018.

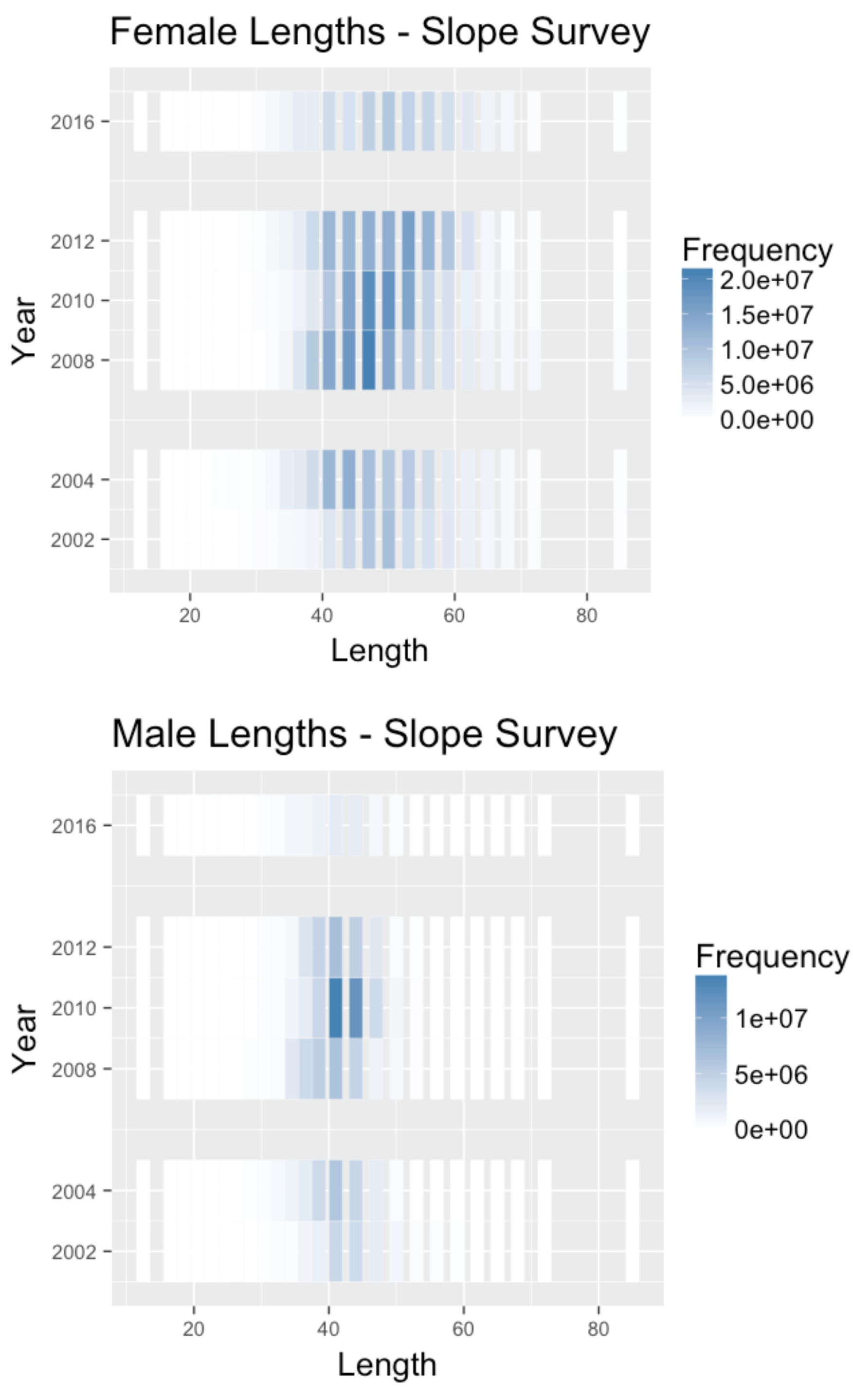


Figure 6.4. Length frequency data from female (upper panel) and male (lower panel) Bering Sea slope survey arrowtooth flounder from 2002-2016.

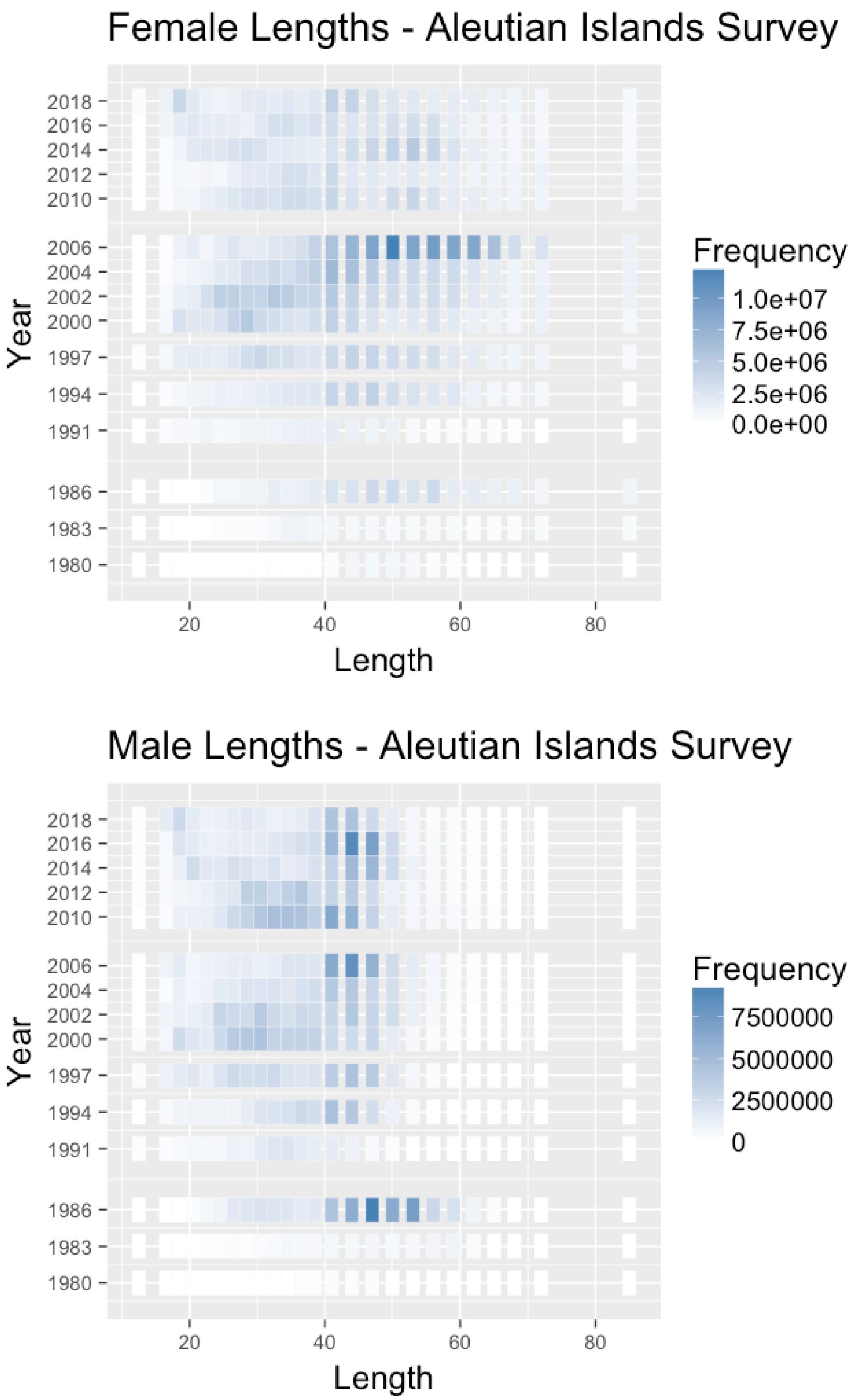


Figure 6.5. Length frequency data from female (upper panel) and male (lower panel) Aleutian Islands survey arrowtooth flounder from 1980-2018.

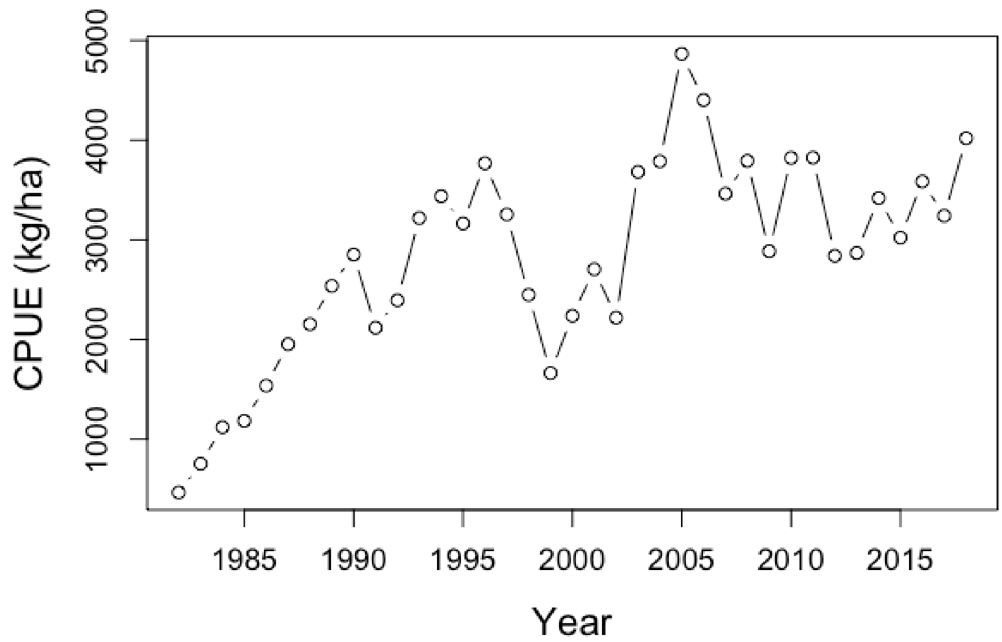


Figure 6.6 Arrowtooth flounder CPUE (kg/ha) from the standard shelf survey area (1982-1992) and standard shelf survey area including Northwestern stratum 82 and 90 (1993-2018).

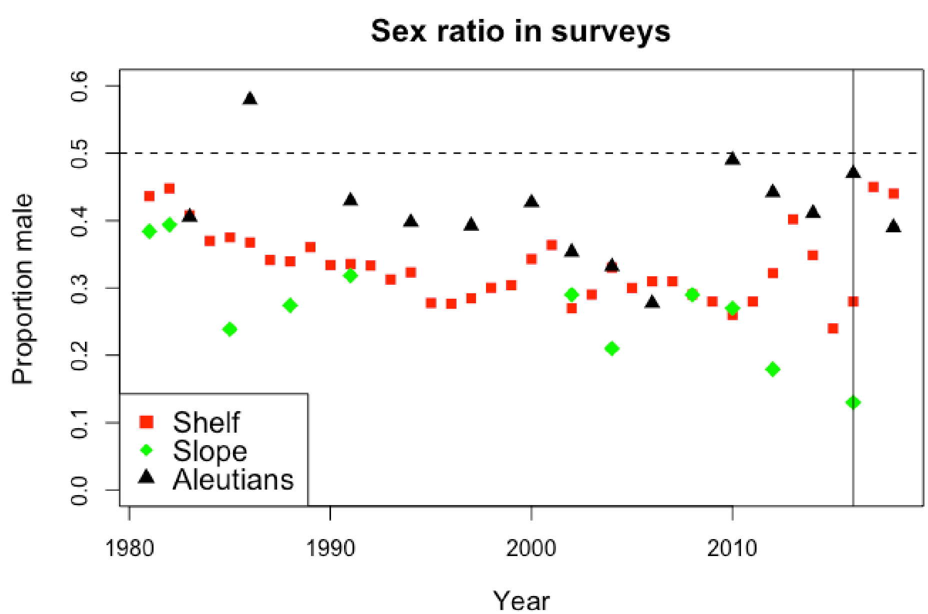
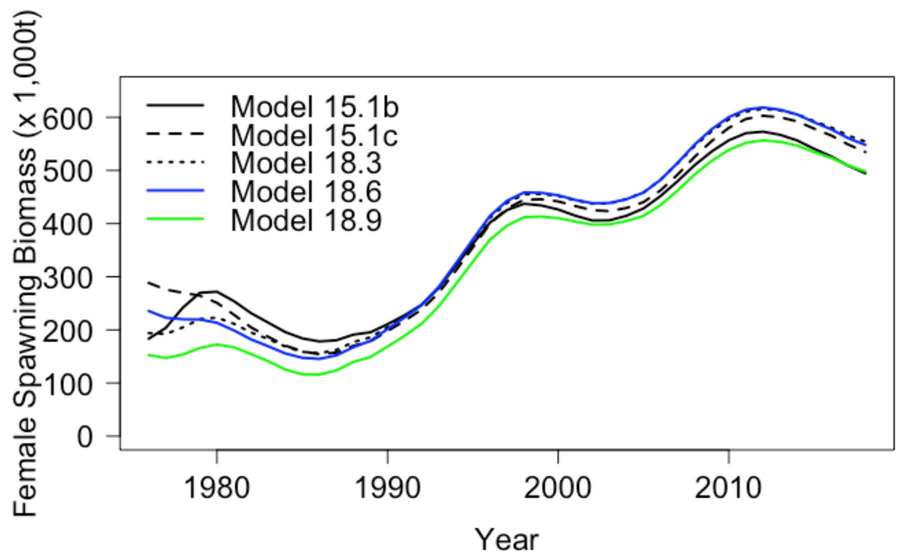


Figure 6.7. Proportion of the estimated male population from Bering Sea and Aleutian Islands trawl surveys on the continental shelf and slope.



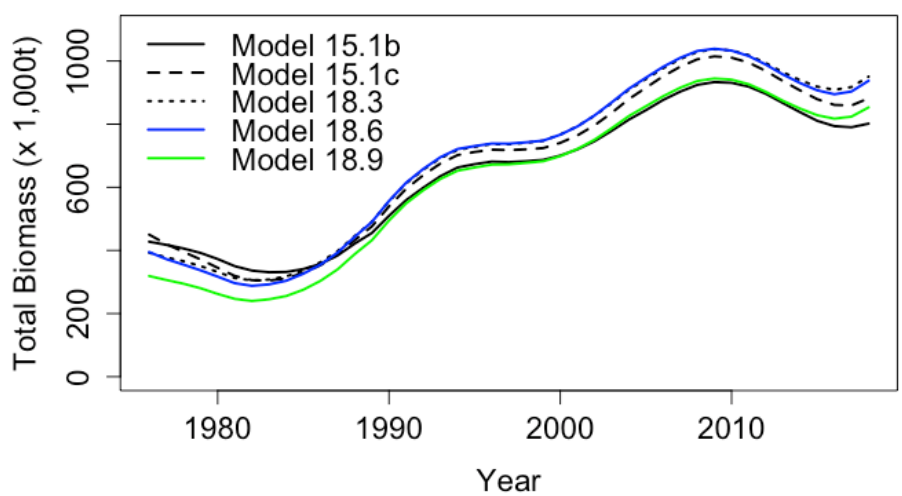


Figure 6.8. Total biomass and female spawning biomass for the different model configurations presented in this assessment.

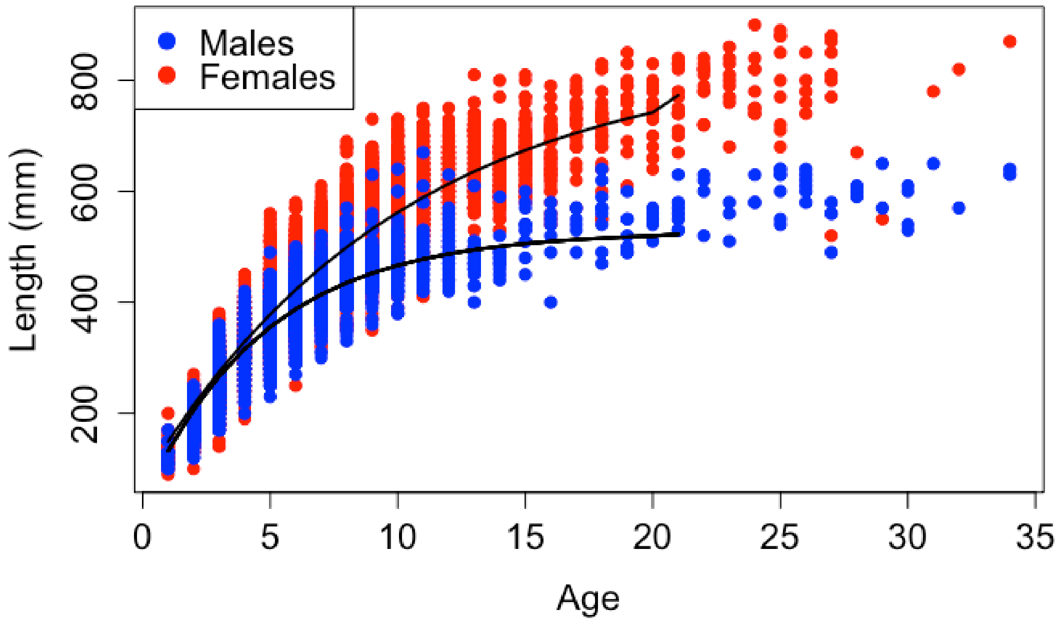


Figure 6.9. Fit to age data based on length at age data and length frequency data from surveys (black lines, females are larger than males). Blue circles represent males and red circles are females. The plus group is estimated length at age for ages 21+, and is based on a weighted average of those ages.

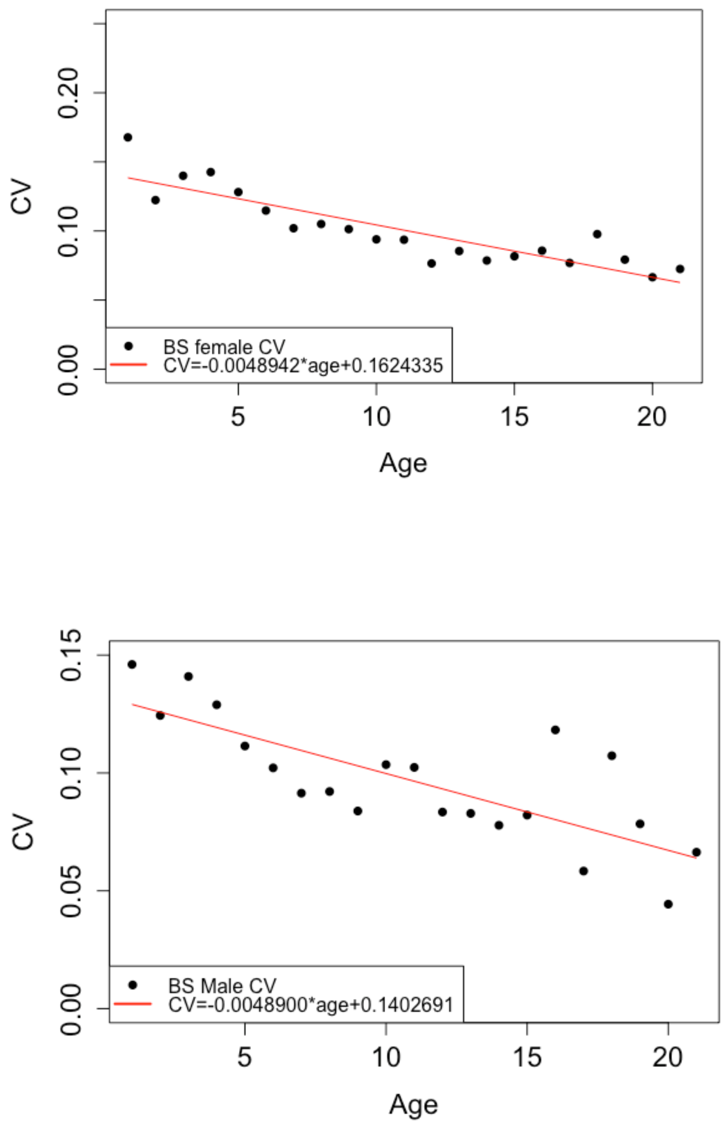


Figure 6.10. The CV of length at age for each age from 1-21+ for females (upper panel) and males (lower panel). The CV is fit to a linear model with respect to age, which is shown in the legend in each panel.

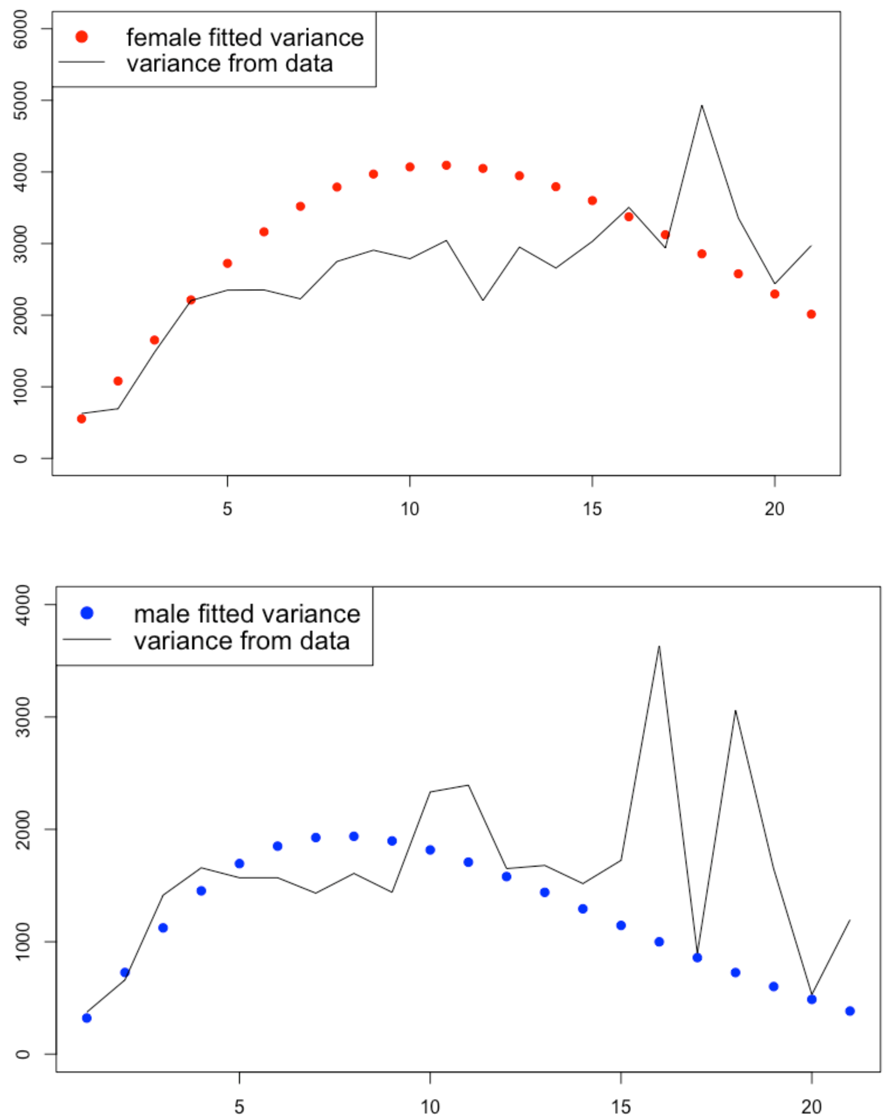


Figure 6.11. The variance of length at age for each age from 1-21+ for females (upper panel) and males (lower panel), as red (female) and blue (male) points. Data values are shown as a black line.

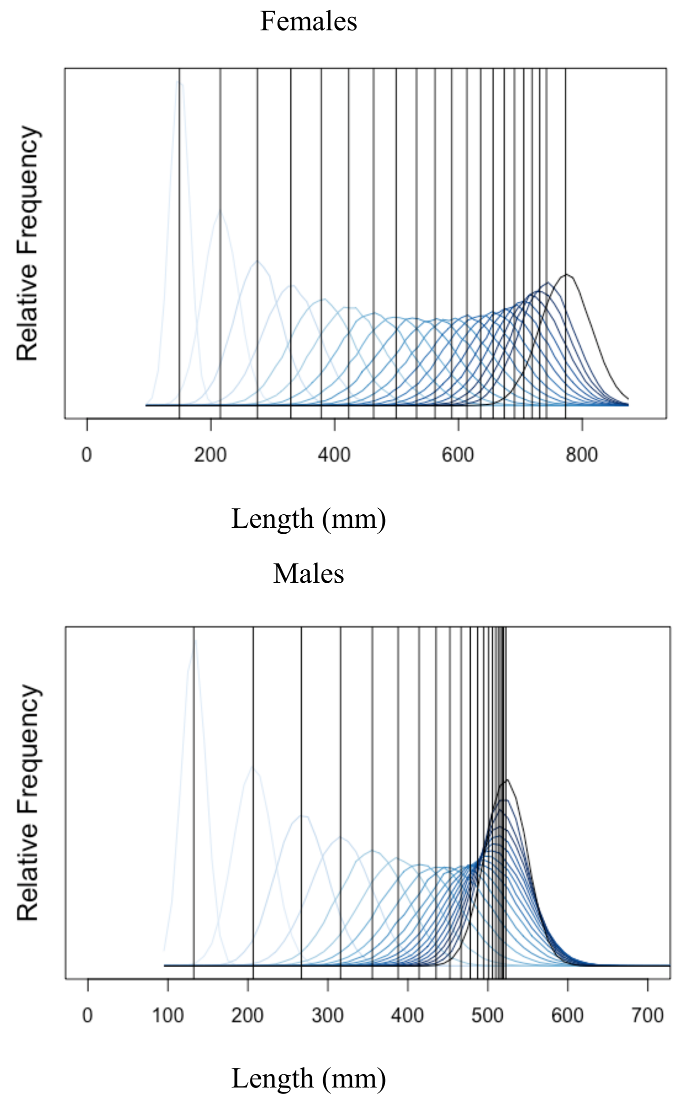
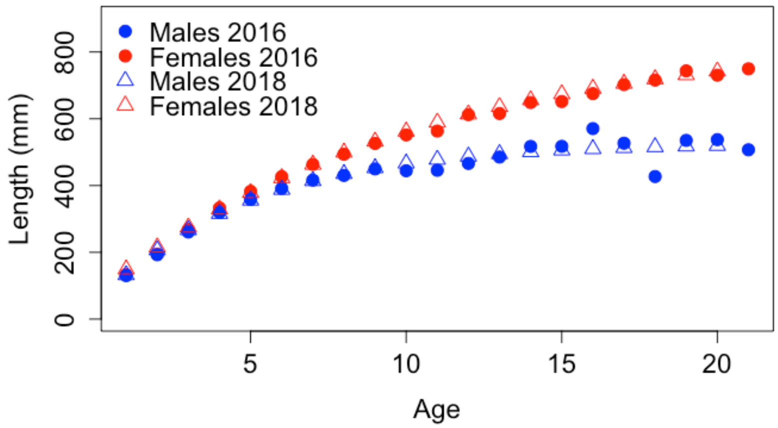


Figure 6.12. Length-age conversion matrix for females (upper panel) and males (lower panel), with length in mm.

a.



b.

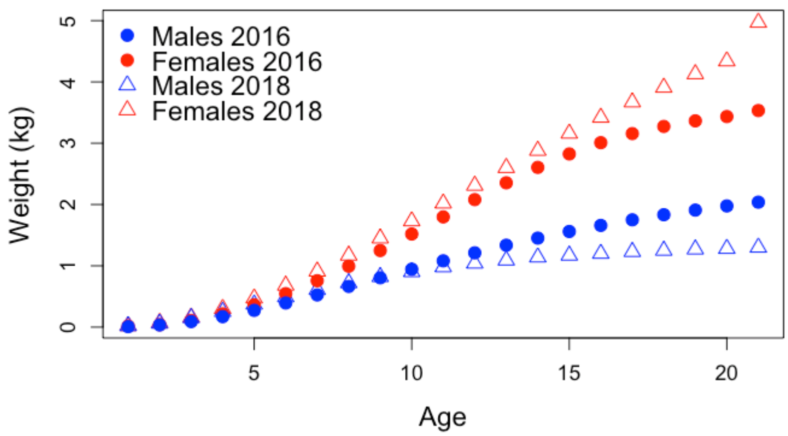


Figure 6.13. Mean length at age based on the smoothed length age conversion matrix, compared to the length age conversion matrix used in the 2016 BSAI ATF assessment (Panel a). Calculated weight at age (kg) for males and females used in the assessment model, compared to previous estimates (Panel b).

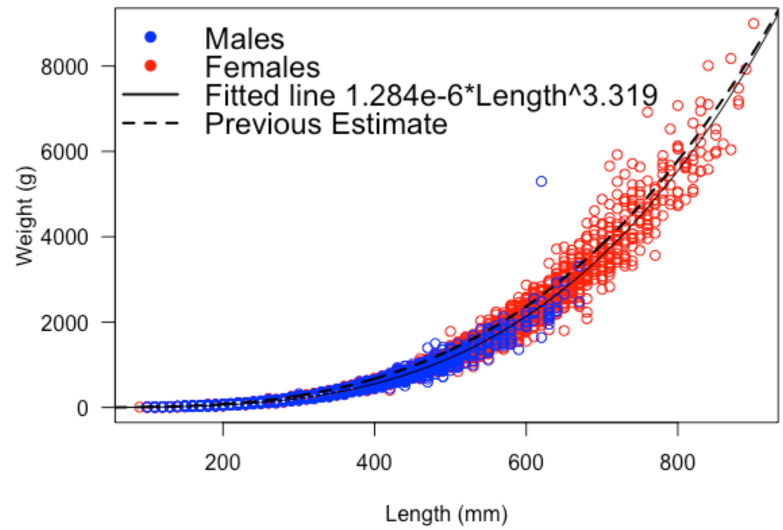


Figure 6.14. Length-weight relationship of arrowtooth flounder. Males and females grow at the same trajectory. The fit to weight-at-length is shown as a black line. Data from BSAI surveys 1980-2017.

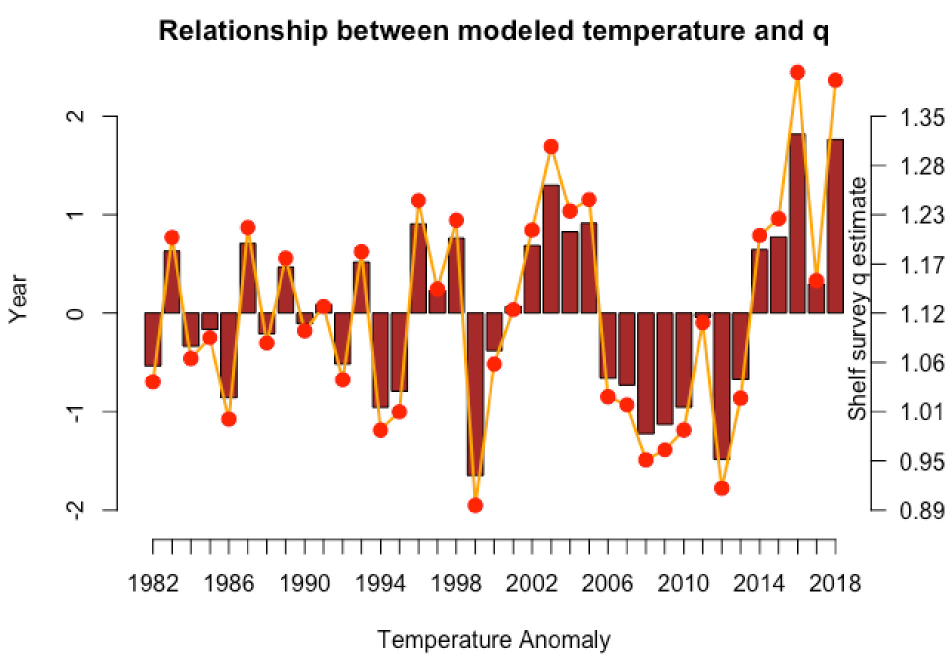


Figure 6.15. Shelf survey annual average bottom temperature anomalies (bars), model estimate of annual shelf survey *q* due to effect of water temperature (circles with lines).

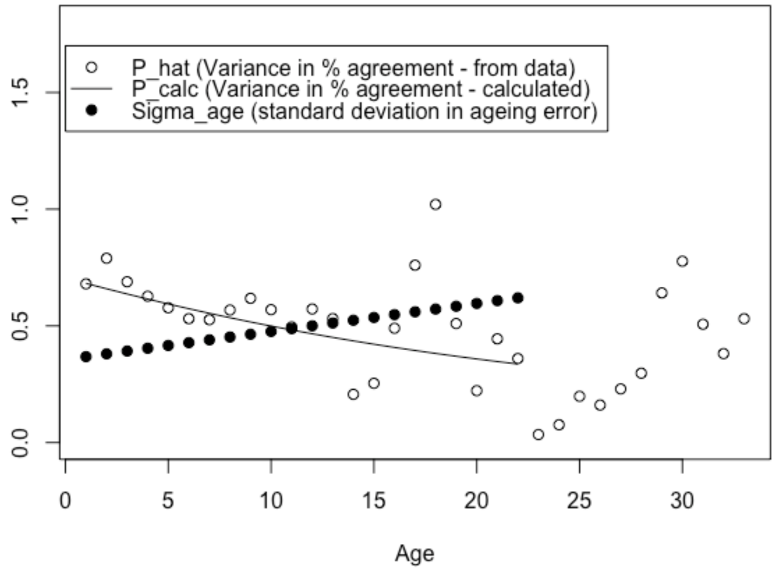


Figure 6.16. Ageing error; the variance in percent agreement from the data (p_hat, open circles), calculated variance in percent agreement (p_calc), and standard deviation in ageing error, by age.

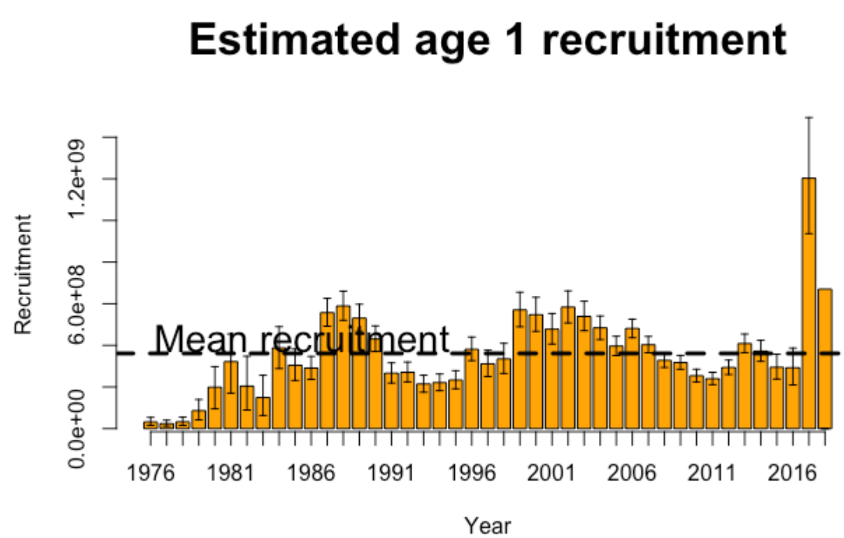
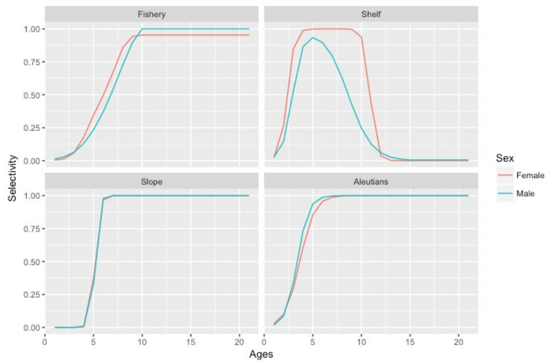
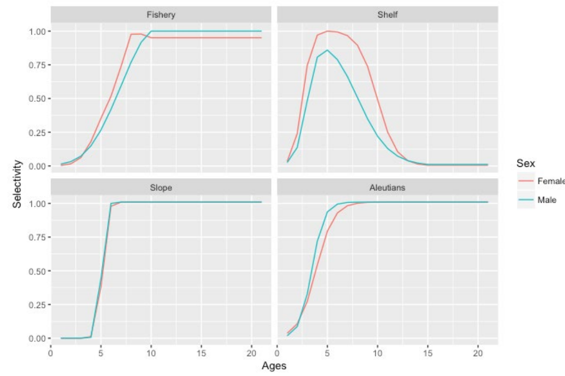


Figure 6.17. Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model 18.9 MCMC output, with 5% and 95% credible intervals. Mean recruitment is shown over all years from 1976-2018.

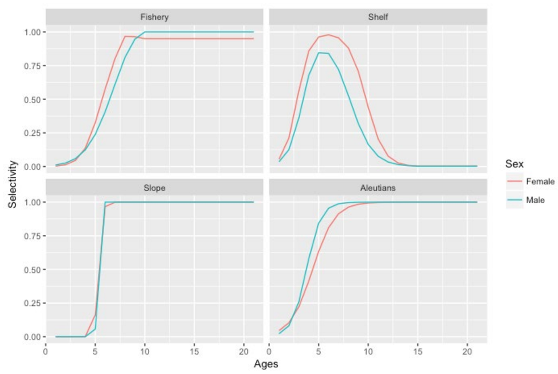
Model 15.1b



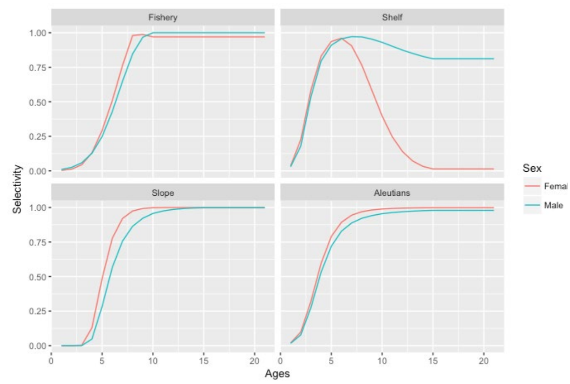
Model 15.1c



Model 18.3



Model 18.6



Model 18.9

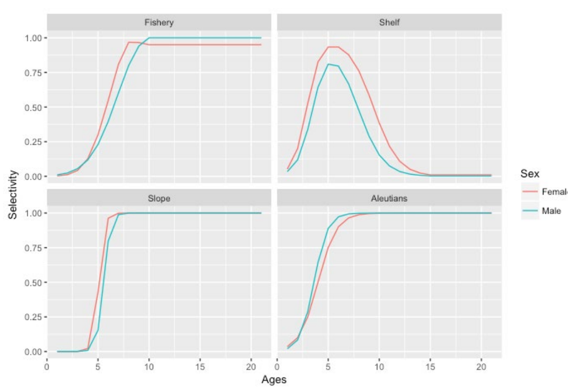


Figure 6.18. Within each panel: age-specific fishery selectivity (top left), shelf survey selectivity (top right) slope survey selectivity (bottom left) and Aleutian Islands survey selectivity (bottom right), by sex, estimated by the stock assessment model. Models 15.1b, 15.1c, 18.3, 18.6, and 18.9 are presented.

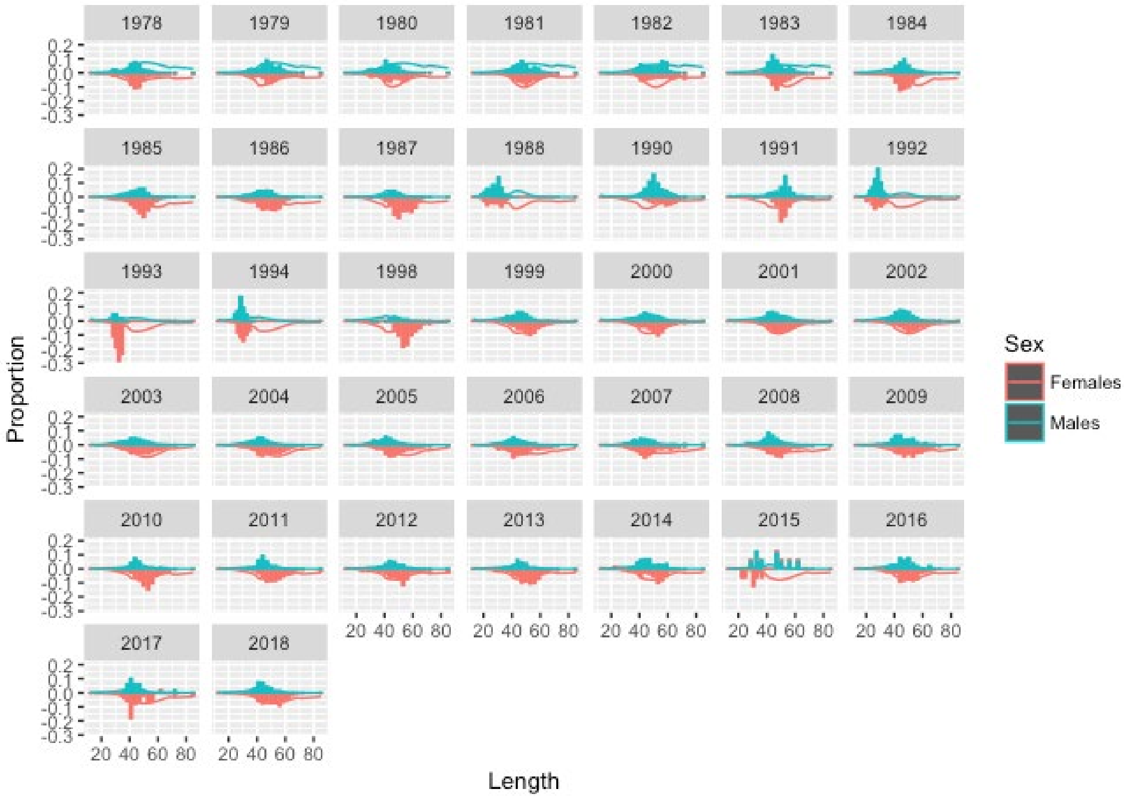


Figure 6.19. Model fit to observed fishery length composition (bar plots) and predicted (lines), with males in blue, females in red.

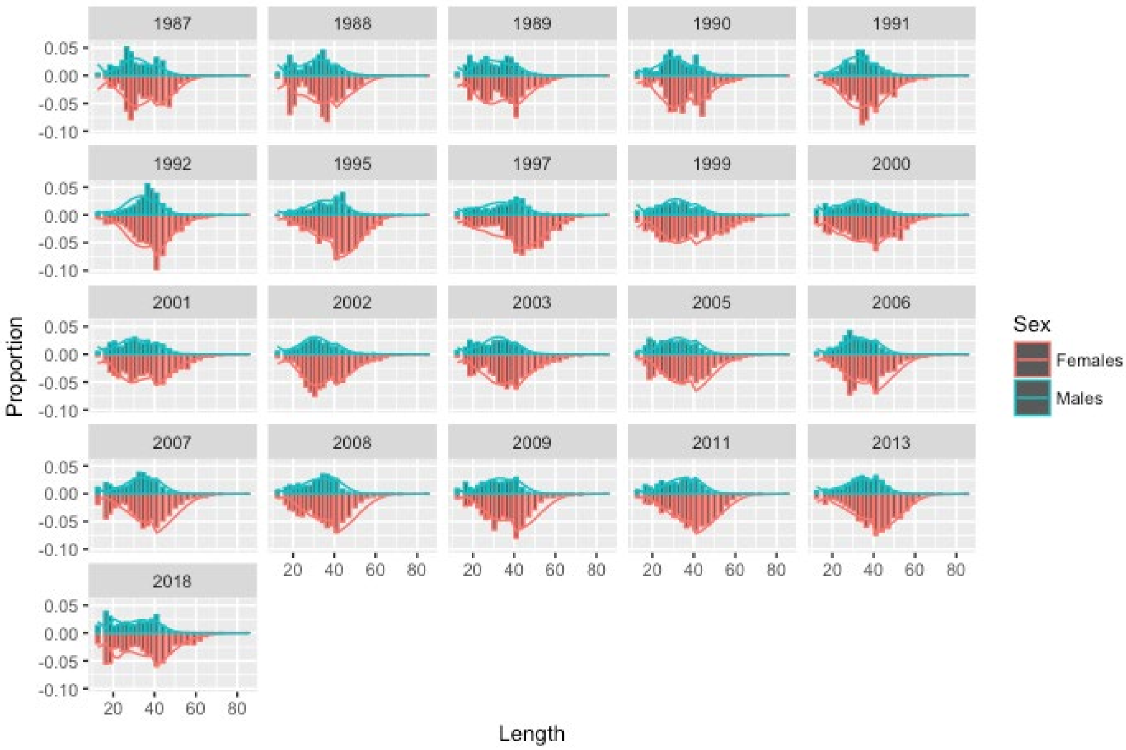


Figure 6.20. Model fit to Bering Sea shelf survey observed length composition (bar plots) and predicted (lines), with males in blue, females in red.

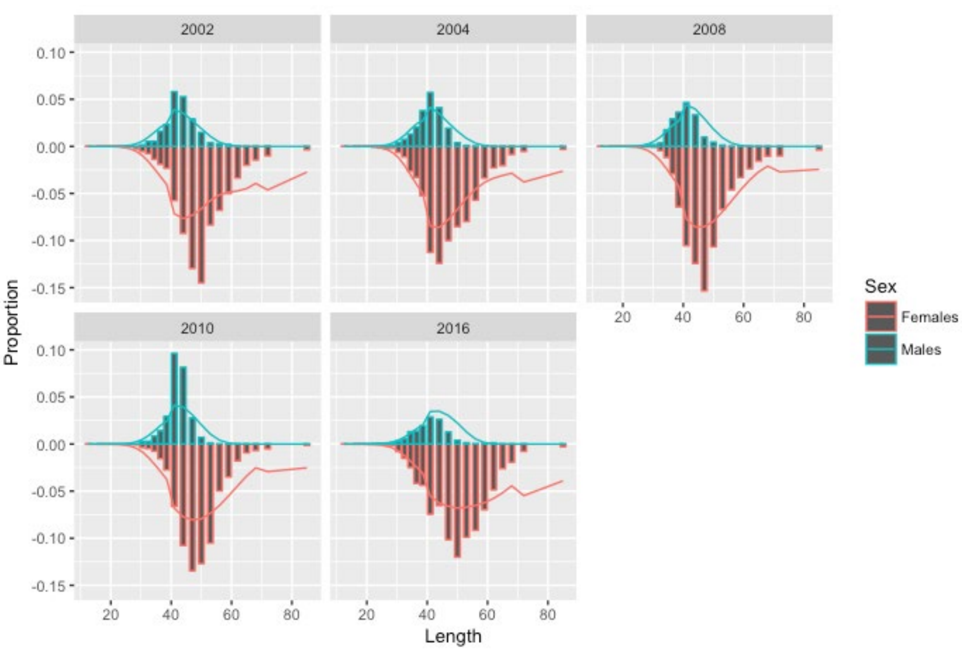


Figure 6.21. Model fit to Bering Sea slope survey observed length composition (bar plots) and predicted (lines), with males in blue, females in red.

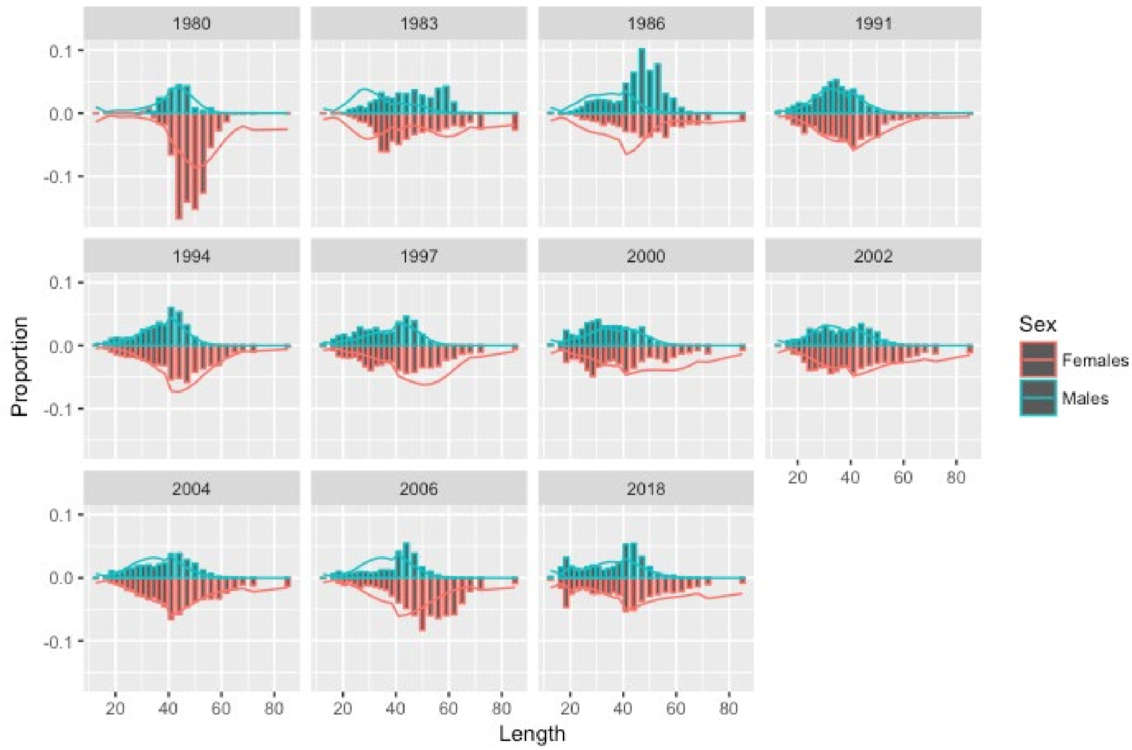


Figure 6.22. Model fit to Aleutian Island survey observed length composition (bar plots) and predicted (lines), with males in blue, females in red.

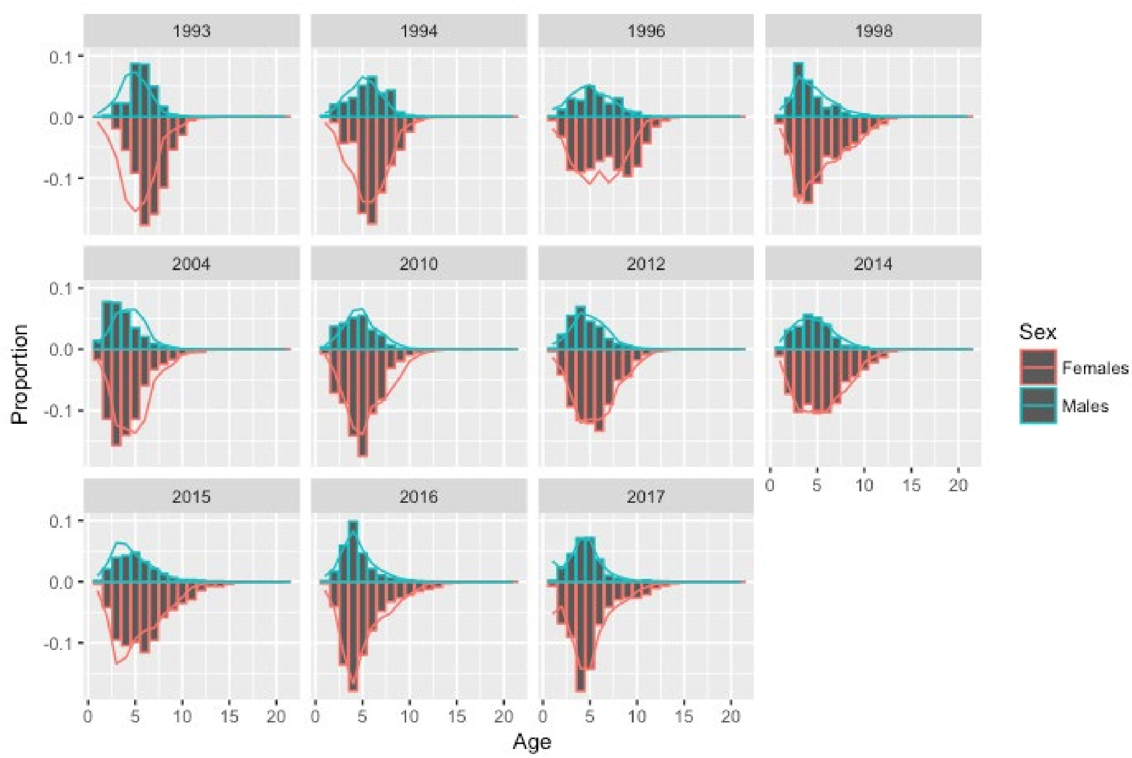


Figure 6.23. Model fit to Bering Sea shelf survey observed age composition (bar plots) and predicted (lines), with males in blue, females in red.

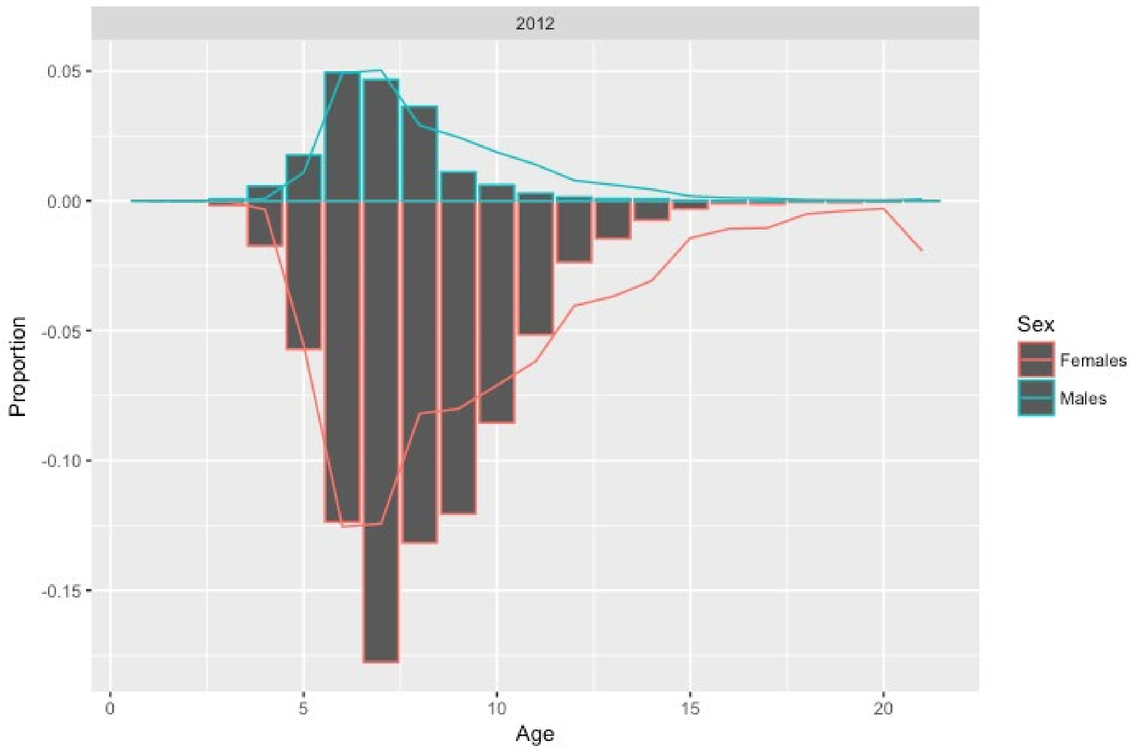


Figure 6.24. Model fit to Bering Sea slope survey observed age composition (bar plots) and predicted (lines), with males in blue, females in red.

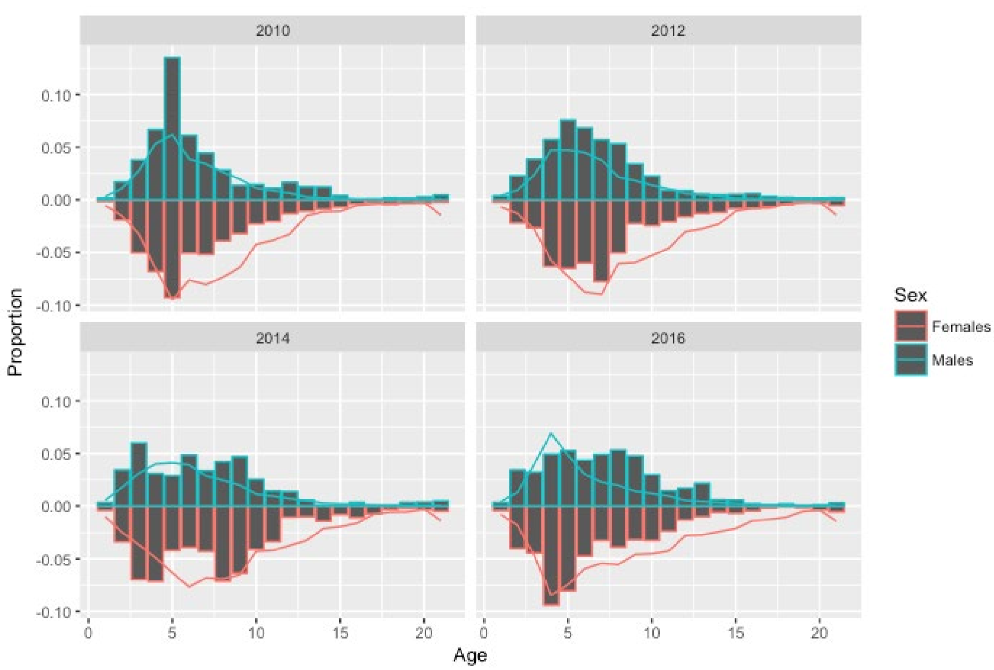


Figure 6.25. Model fit to Aleutian Island survey observed age composition (bar plots) and predicted (lines), with males in blue, females in red.

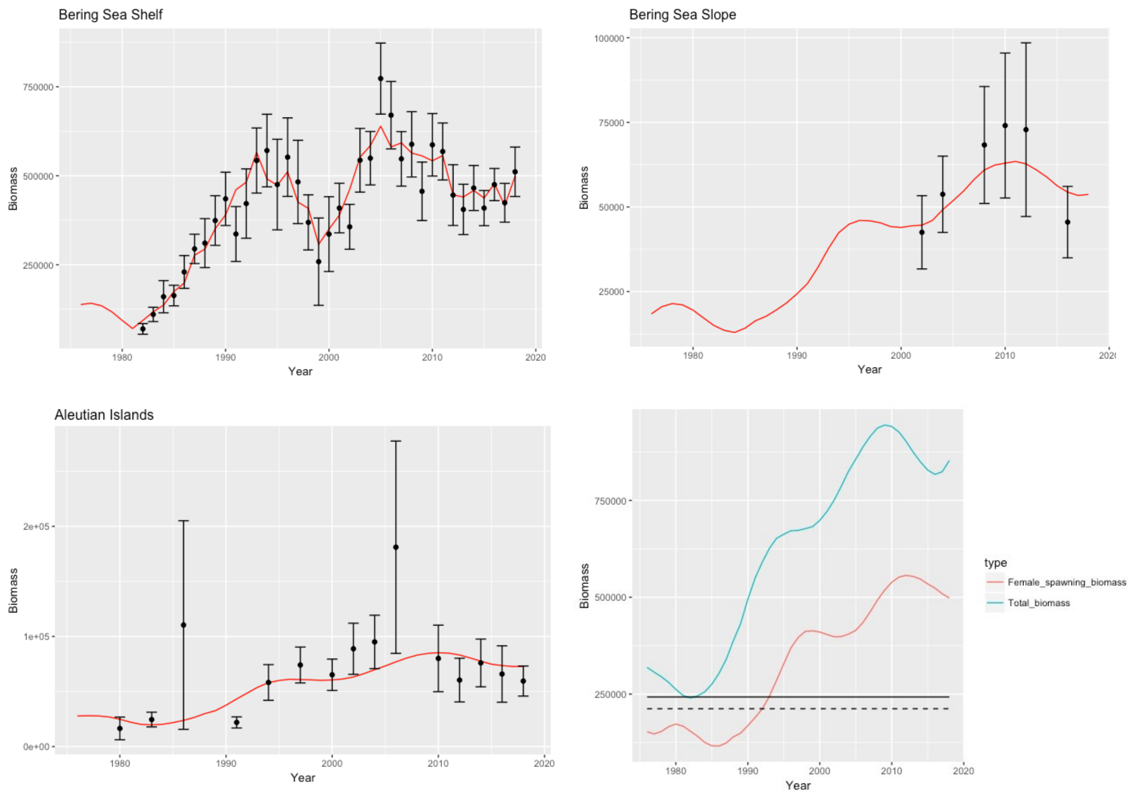


Figure 6.26. Model 18.9 results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), the fit to the Aleutian Islands survey (bottom left panel), and the estimate of female spawning biomass with $B_{35\%}$ (dashed lines) and $B_{40\%}$ (solid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

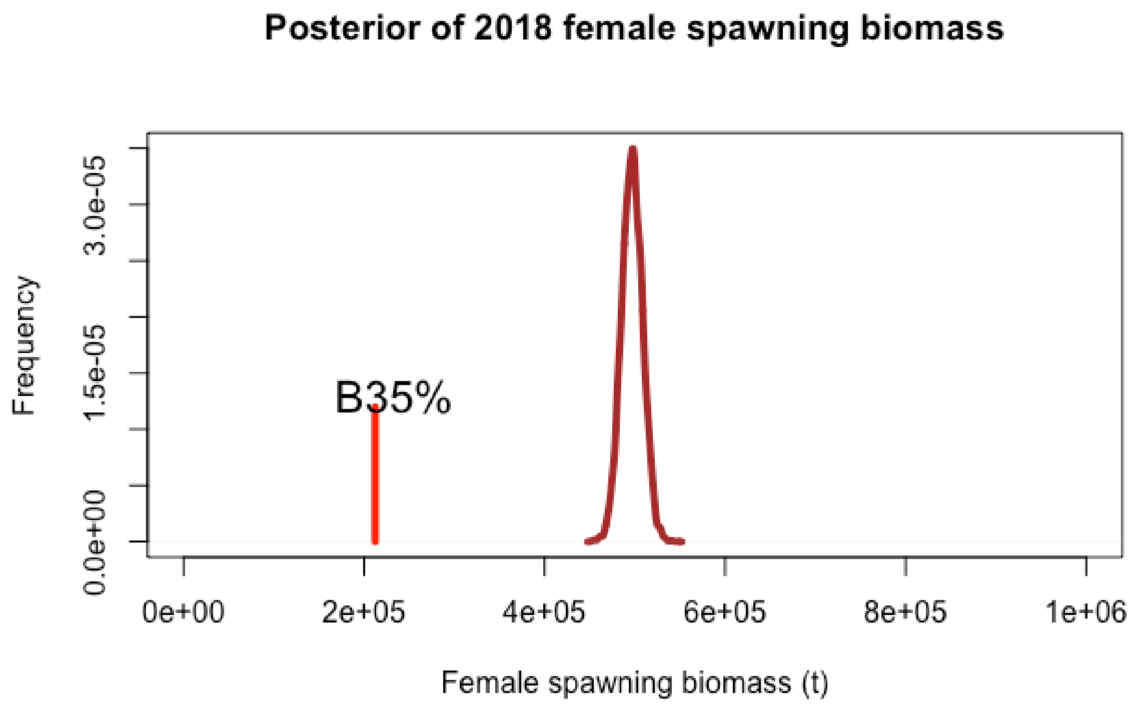


Figure 6.27. Posterior distribution of the estimate of female spawning biomass (t) from the preferred stock assessment model run (Model 18.9), compared with the model estimate of $B_{35\%}$ or 212,183 t.

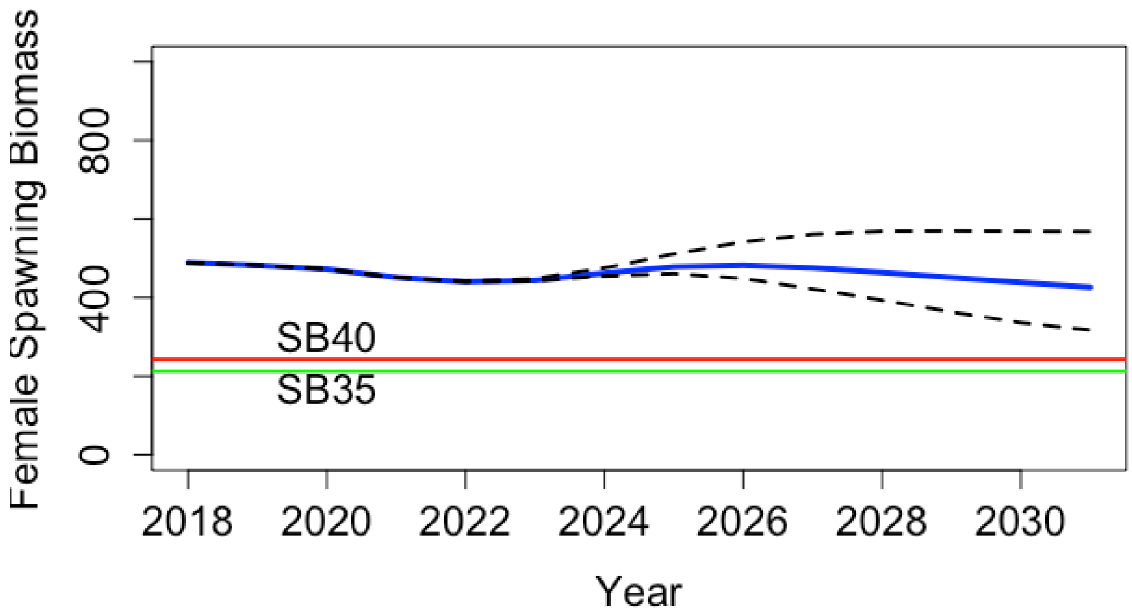


Figure 6.28. Projected female spawning biomass (1,000s t) of arrowtooth flounder if future harvest is at the same fishing mortality rate as the past five years (Alternative 4, Table 6.16).

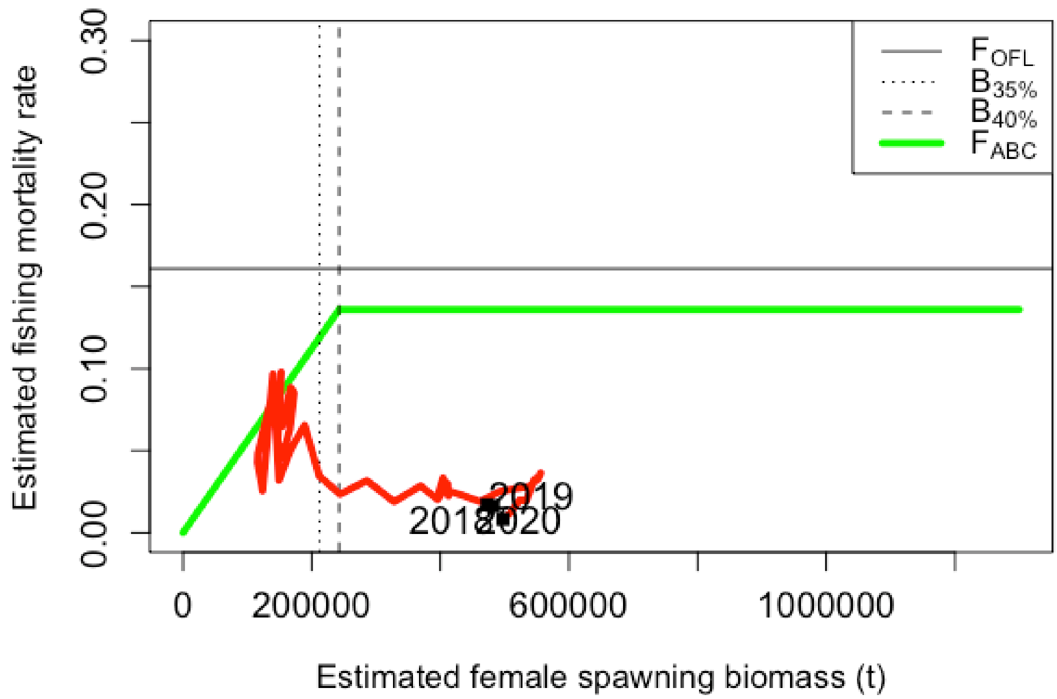


Figure 6.29. Phase plane diagram showing the time-series of stock assessment model estimates of female spawning biomass relative to the harvest control rule, with assessment model results for 2018 and projection model results for 2019 and 2020.

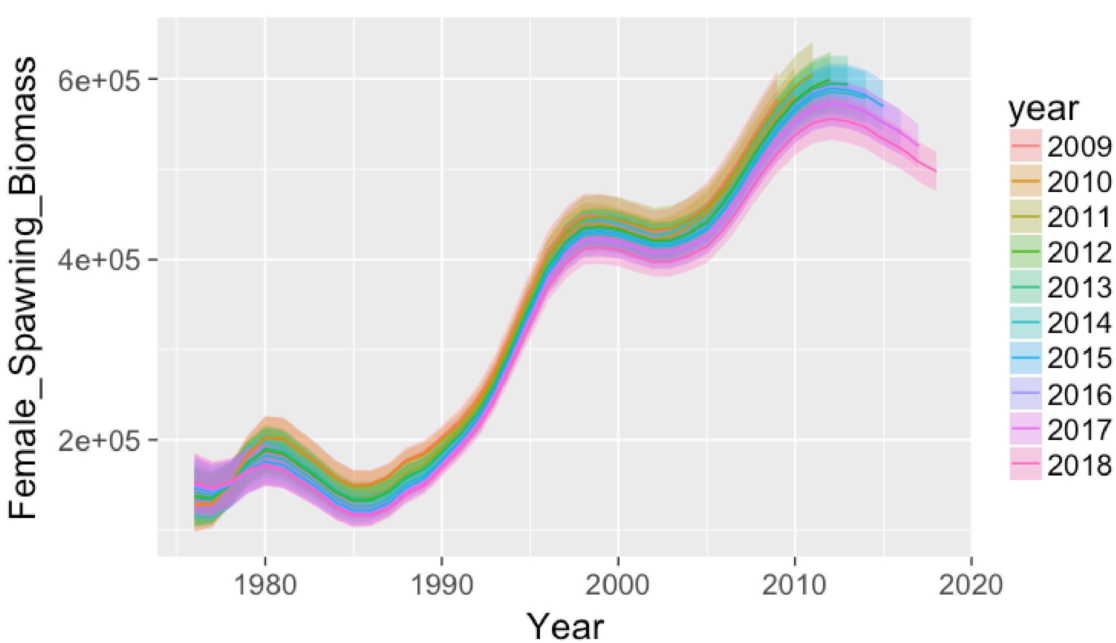


Figure 6.30. Retrospective plot of female spawning biomass. The preferred model (Model 18.9) with data through 2018 is the longest time series. Retrospective runs were obtained by removing one year of data at a time through 2009.

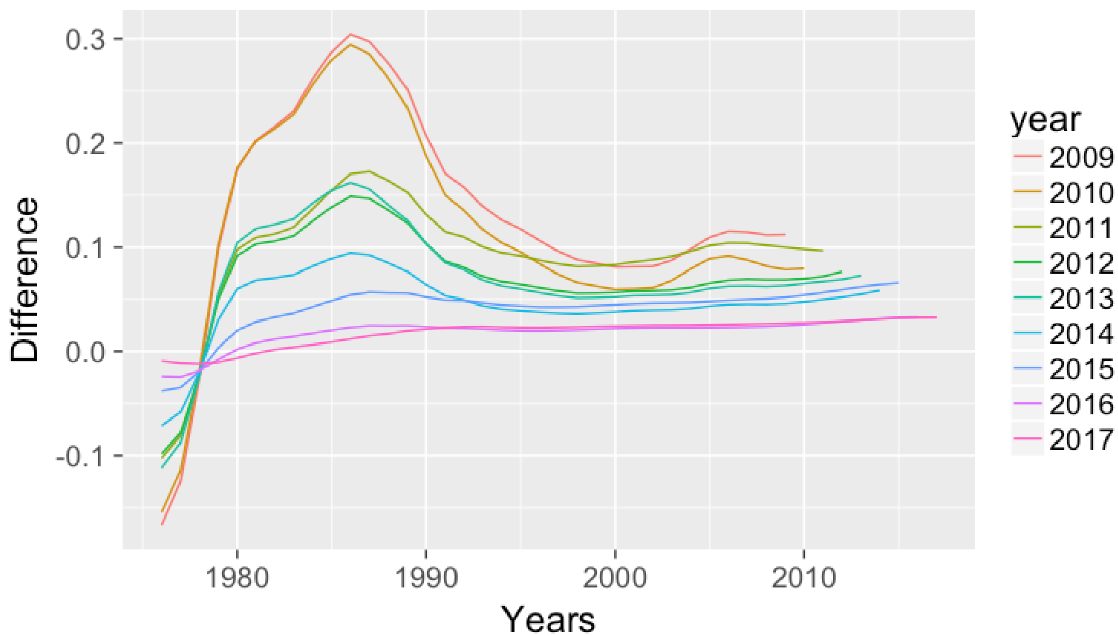


Figure 6.31. Relative differences in estimates of spawning biomass between the 2018 preferred model (Model 18.9) and the retrospective model run for years 2017 through 2009.

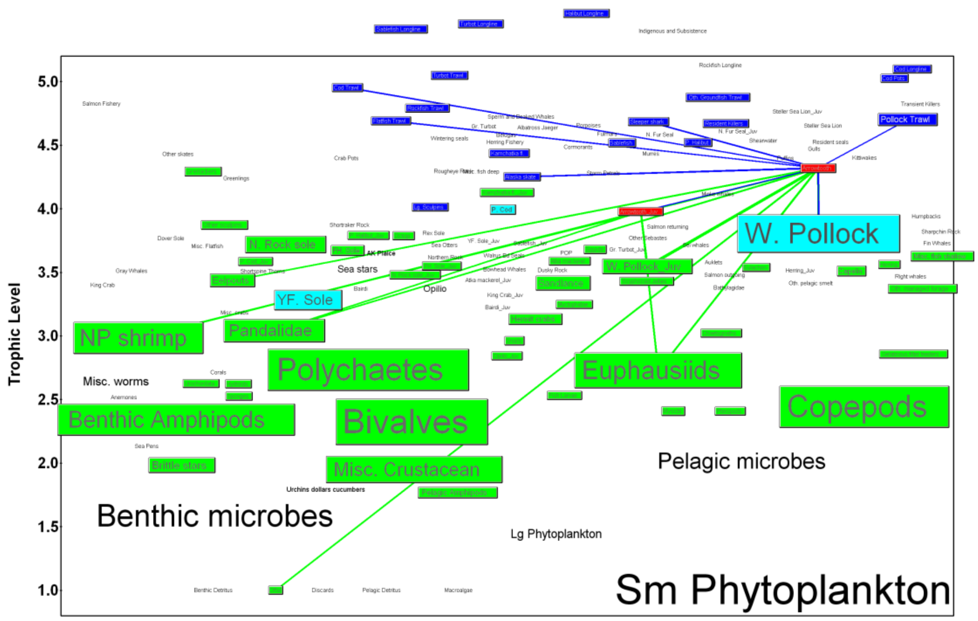


Figure 6.32. Adult and juvenile arrowtooth flounder in the EBS food web. Box size is proportional to biomass, and lines between boxes represent the most significant energy flows. Predators of arrowtooth are dark blue, prey of arrowtooth are green, and species that are both predators and prey of arrowtooth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

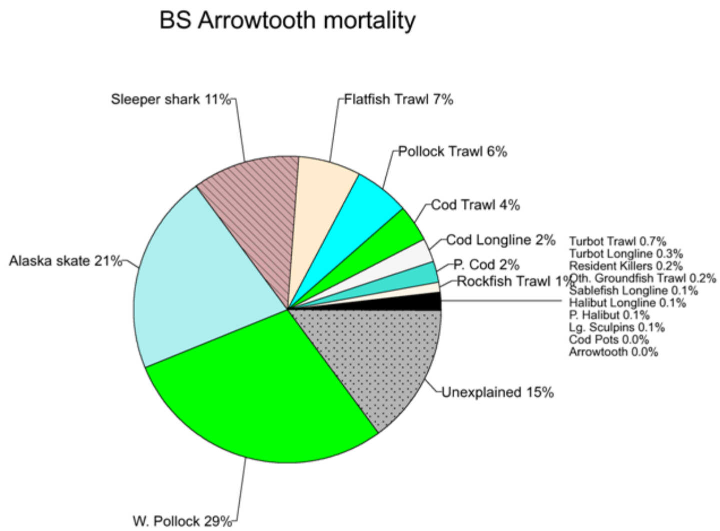


Figure 6.33. Mortality of Bering Sea arrowtooth flounder >20cm fork length by predator or fishery from predator ration and diet estimates and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter (citation). "Unexplained" mortality is the difference between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

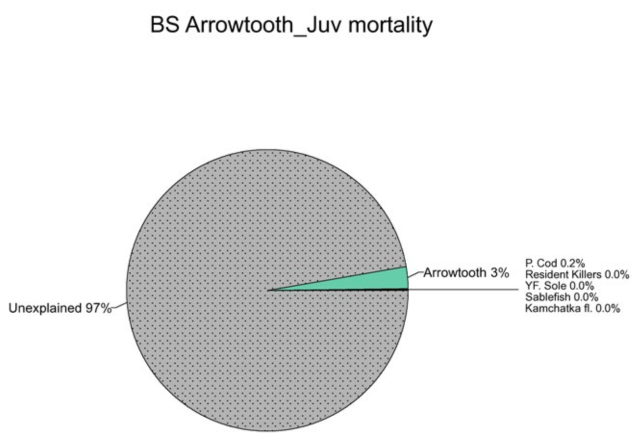


Figure 6.34. Mortality of Bering Sea arrowtooth flounder <20cm fork length by predator or fishery from predator ration and diet estimates and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter (citation). "Unexplained" mortality is the difference between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

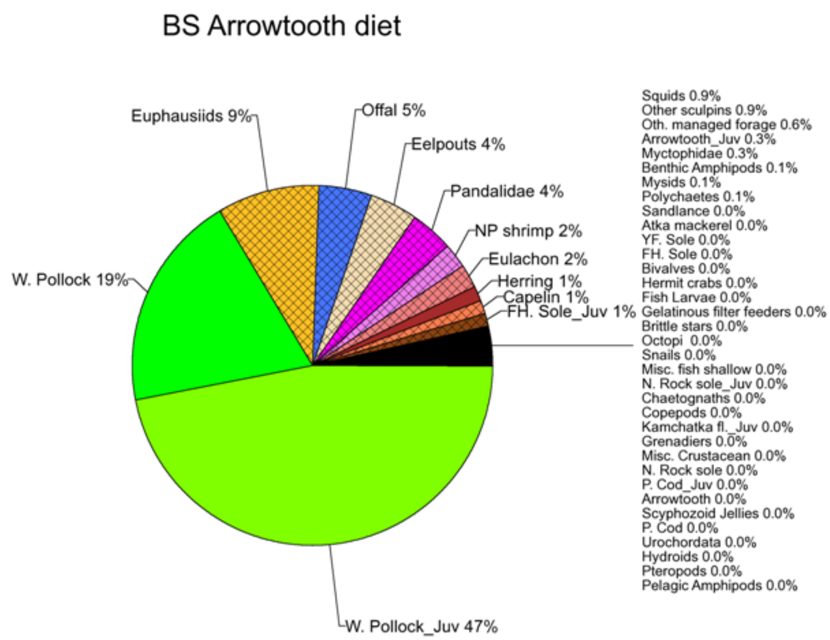


Figure 6.35. Diet of Bering Sea arrowtooth flounder >20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter (citation). Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species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

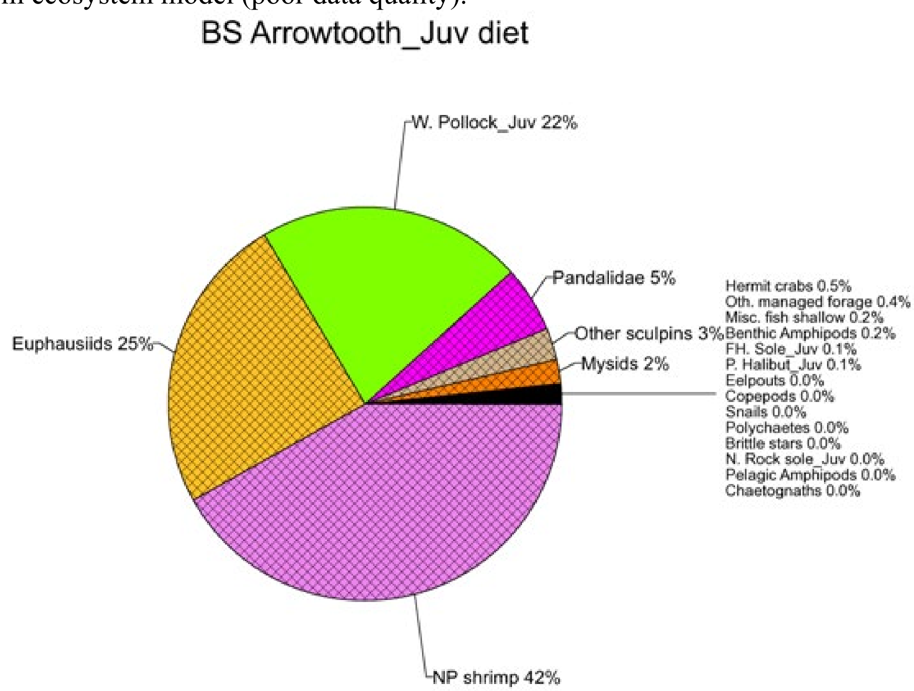


Figure 6.36. Diet of Bering Sea arrowtooth flounder <20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter (citation). Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species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

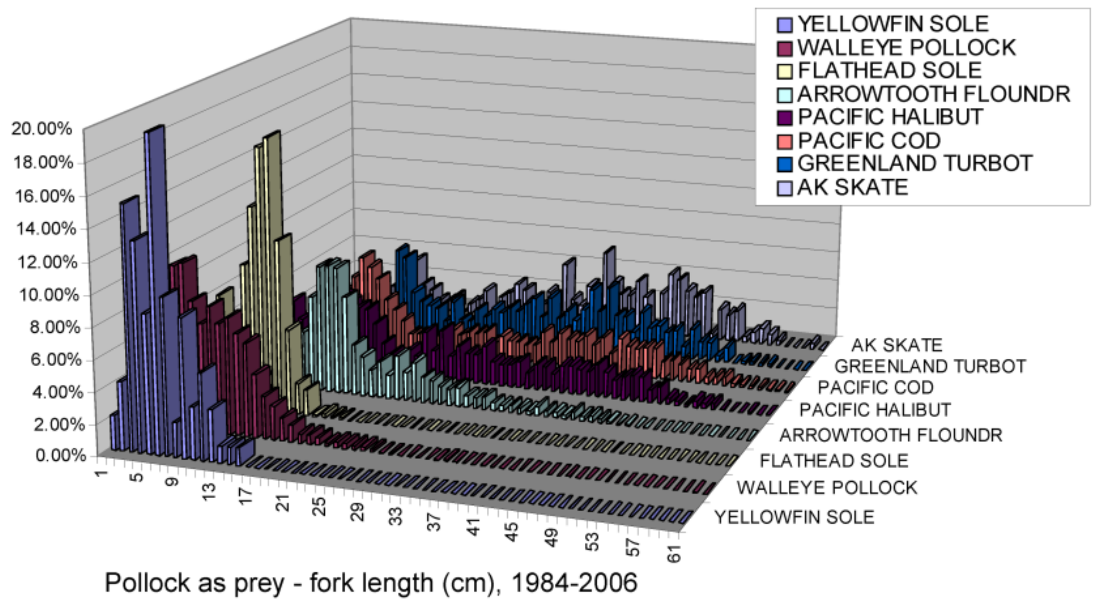


Figure 6.37. Length frequency of pollock found in stomachs, from groundfish food habits collected from 1984-2006 on AFSC summer trawl surveys in the eastern Berng Sea. Predators are sorted by median prey length of pollock in their stomachs. All lengths of predators are combined.

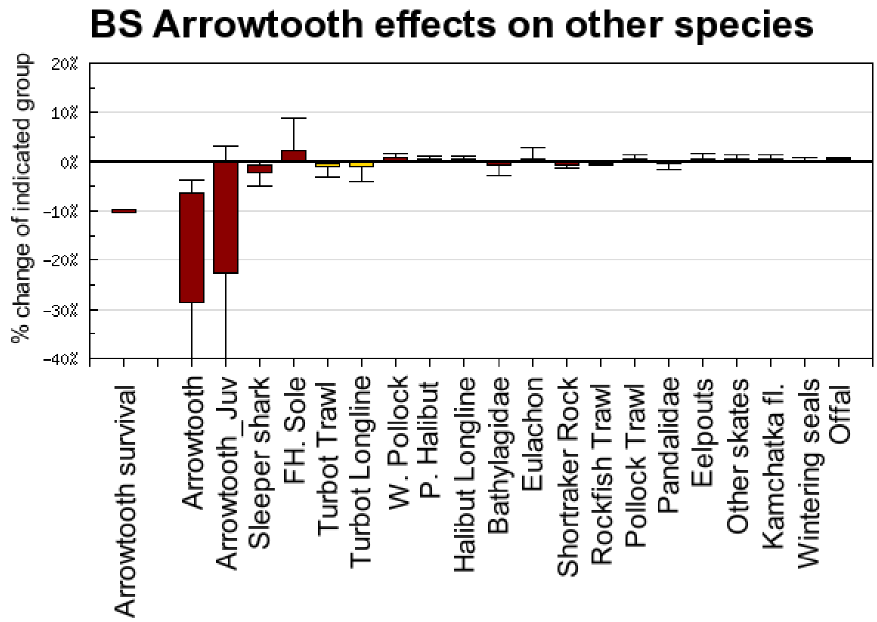


Figure 6.38. Effect of changing arrowtooth >20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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

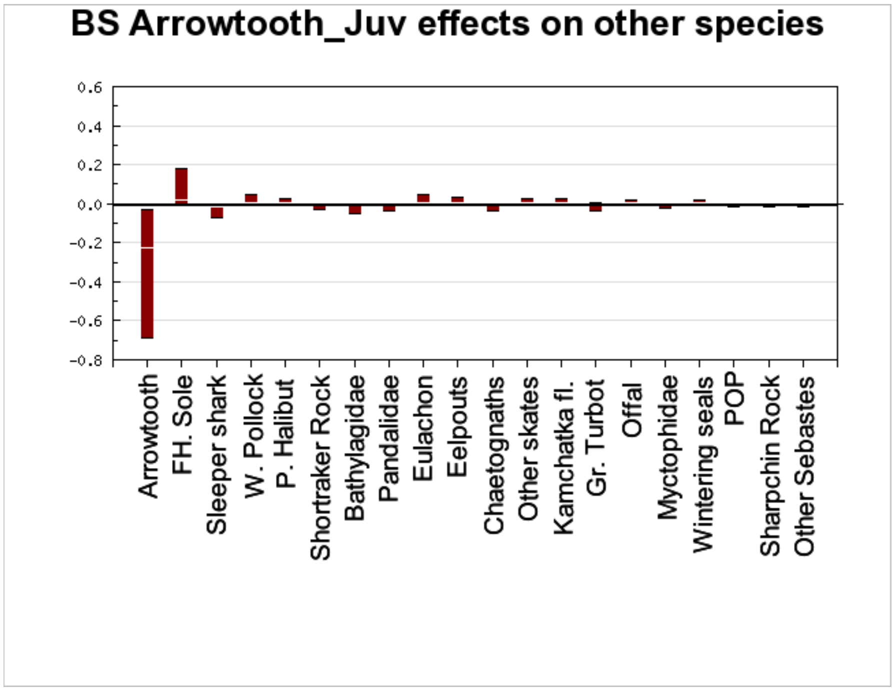


Figure 6.39. Effect of changing arrowtooth < 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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

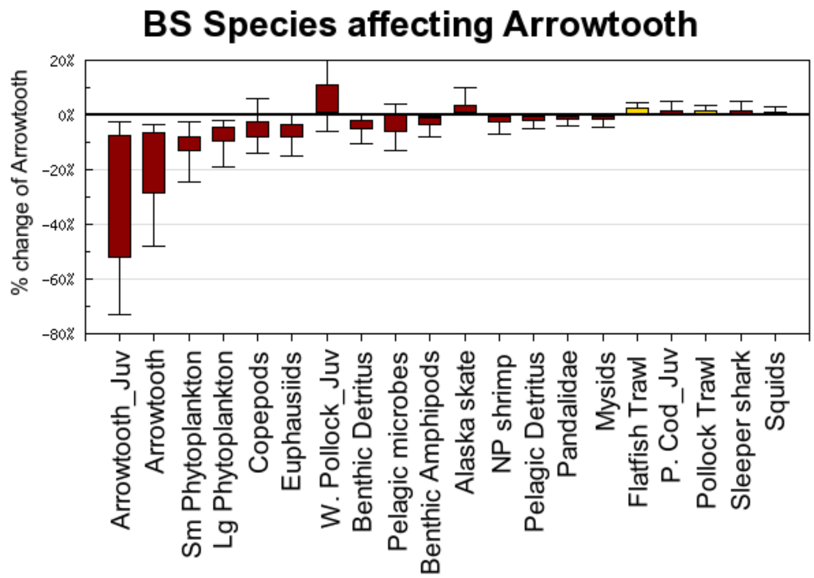


Figure 6.40. Effect of reducing fisheries catch (yellow) and other species survival (dark red) on arrowtooth > 20 cm biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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

Appendix 1

Preliminary assessment of the arrowtooth flounder stock in the Bering Sea and Aleutian Islands

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Introduction

This document was presented to the September 2018 Plan Team and represents an effort to respond to comments made by the 2017 Flatfish CIE Review committee, the Bering Sea and Aleutian Islands (BSAI) Plan Team and the Scientific and Statistical Committee (SSC) of the North Pacific Fishery Management Council (NPFMC) regarding the arrowtooth flounder (*Atheresthes stomias*) stock assessment for the BSAI. The comments are provided below, followed by responses and methodology to apply suggestions to the arrowtooth flounder assessment model.

Comments from the 2017 CIE Review

The CIE review committee noted that the arrowtooth assessment model is able to make use of both biomass, age and length composition data in a unified framework. There is also a fairly well established statistical framework in which to estimate the parameters, and the model is supported by comprehensive survey biomass estimates, which should provide high quality estimates of biomass trends.

The reviewers provided several suggestions to improve the model. In particular, they felt that the model would be improved with fewer parameters and more age data. They suggested exploring alternatives for male and female natural mortality. In addition, they suggested examining alternatives for integrating the three research surveys that provide biomass estimates for the Aleutian Islands, Bering Sea slope, and Eastern Bering Sea shelf. The committee questioned whether the temperature relationship with catchability on the EBS shelf was significant. They also emphasized the need to understand the stock dynamics immediately preceding the assessment period; one reviewer considered this a major weakness of the assessment.

Comments from the 2016 November Plan Team

The Team recommended the authors consider smoothing the age length conversion matrix and ensure that selectivity parameters are not on bounds without reason.

Comments from 2016 December SSC

Some additional work is indicated for the preferred model for next year's assessment. For instance, the authors were concerned that some selectivity parameters may be at or near their boundaries. They suggested investigating this by considering alternatives for the degree of dome-shaped selectivity curves for the EBS survey. In addition, the PT recommended that the authors consider smoothing the age-length conversion matrix. The SSC supports these explorations.

Seven new models are presented here, to respond to CIE Review, Plan Team, and SSC comments, and general model improvements. The new proposed models include explorations of length-based rather than age-based selectivity for the survey and the fishery, inclusion of an ageing error matrix, and two alternatives to fixed male and female natural mortality. New models are compared to the base model from 2016 (Model 15.1c). All models include a smoothed length age conversion matrix.

Currently the arrowtooth flounder stock assessment has fixed constant natural mortality for males (0.35) and females (0.2). 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). Different options have been explored in the current assessment, which consider natural mortality as a function of the size of the fish (Gislason et al. 2010, Lorenzen 1996). The distribution of ages appears to vary by region and sex; male arrowtooth as old as 36 years have been observed in the Aleutian Islands, but are not commonly observed older than age 10 on the Bering Sea shelf. Males older than age 20 were not observed prior to 2005 in the Gulf of Alaska; however, males age 21 have been observed in every survey since that time. The sex ratio of arrowtooth flounder also varies by region. In the Gulf of Alaska, the observed ratio from fishery observer length frequency collections is 69% female, 31% male. Survey length compositions from the Bering Sea indicate that the proportion female is 70% on the Bering Sea shelf, 72% on the Bering Sea slope, and 62% in the Aleutian Islands. In British Columbia catches have been over 70% female since 1996 and the stock is assessed solely based on female numbers (DFO 2015).

Several models investigate consolidating male and female selectivity curves. This is most feasible if selectivity is determined by length, since male and female arrowtooth flounder grow at different rates (females grow larger than males). Length-based selectivity is converted to selectivity at age for age-based calculations in the model, such as numbers at age.

Ageing error in arrowtooth flounder is relatively high compared to walleye pollock and Pacific cod. Therefore, an ageing error transition matrix was incorporated to convert population numbers at age to expected survey numbers at age. The matrix was computed using the estimated percent agreement among two age readers. We used the percent agreement for ages from 1987-2015. The model incorporates a linear increase in the standard deviation of ageing error and assumes that ageing error is normally distributed (Dorn et al. 2003, Methot 2000). Percent agreement is 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).

Data

Data in all models was identical to data used in the last full BSAI arrowtooth flounder stock assessment in 2016.

Model structures

The assessment is an age-structured statistical model implemented in the Automatic Differentiation Model Builder (ADMB) framework (Fournier et al. 2012). This framework uses automatic differentiation and allows estimation of highly-parameterized and non-linear models. This age-structured population dynamics model is fit to survey abundance data, survey age data, and survey and fishery length composition data with a harvest control rule to model the status and productivity of these stocks and set quotas. 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.

Each model was given a different decimal number for consistency, because some of the models discussed here resulted in an average difference in spawning biomass that was greater than 0.2, but some did not.

Base model

Model 15.1b was adopted during the last BSAI arrowtooth flounder stock assessment cycle in 2016. Its main features are as follows:

- Male and female natural mortality are fixed at 0.35 and 0.2, respectively.
- The model estimates male and female parameters separately.
- For years in which there is no age data, length data is converted to age via a length-age conversion matrix.
- The model incorporates data from three surveys: the Aleutian Islands, Eastern Bering Sea, and Bering Sea slope.
- Age-based fishery selectivity is estimated non-parametrically and constrained to be monotonically increasing, separately by sex.
- Age-based selectivity for the Aleutian Island and Bering Sea slope surveys is estimated using a two-parameter ascending logistic curve, separately by sex.
- Age-based selectivity for the Eastern Bering Sea survey is estimated using dome shaped selectivity via a two-parameter ascending and a two-parameter descending logistic curve, separately by sex.

In this document, Model 15.1b is run using a smoothed version of the length age conversion matrix, and renamed Model 15.1c. All further models are run using this improved length age conversion matrix, as suggested by the BSAI Plan Team and SSC.

Alternative models

Model 15.1c: Base model with smoothed length age conversion matrix (all models considered here use the same smoothed length age conversion matrix).

Model 18.0: This model incorporates survey selectivity at length (rather than at age) for the three surveys. It retains the increasing logistic form for the Aleutian Island and the Bering Sea slope survey data, and the dome shaped form for the Eastern Bering Sea. The parameters for the logistic function are determined by length; therefore only two parameters are required for the selectivity curve for each survey (rather than four if selectivity is by sex). Logistic selectivity is then converted back to selectivity by age using the length age conversion matrix, separately for each sex.

Model 18.1: This model is the same as Model 18.0, except it also incorporates two-parameter logistic selectivity by sex and age for the fishery. It does not incorporate non-parametric fishery selectivity.

Model 18.2: This model is the same as Model 18.0, except it also incorporates survey and fishery selectivity at length (rather than at age). This represents a change from the non-parametric fishery selectivity previously used.

Model 18.3: This model is the same as the base model, except it includes an ageing error matrix.

Model 18.4: This model includes Lorenzen natural mortalities using parameters specified for marine fish species (Lorenzen, K. 1996). The natural mortality for ages 1-5 are set to the natural mortality for age 6 fish.

The Lorenzen (1996) natural mortality equation is as follows:

(1) $M_{age} = aWt_{age}^{b}$, where a and b are estimated parameters, and Wt_{age} is based on emprirical data.

Model 18.5: Gislason natural mortality; the natural mortality equation of Gislason et al. (2010) is as follows:

(2) $\ln(M_{age}) = 0.55 - 1.61\ln(L_{age}) + 1.44\ln(L_{\infty}) + \ln(K)$, where L_{age} is length at age, and L_{∞} and K are parameters from the sex-specific von-Bertalanffy fit to length at age. The mortality in equation 2 is multiplied by W=3 to match the natural mortalities previously established for ATF.

Model 18.6: This model is similar to Model 18.0, with length-based survey selectivity and non-parametric fishery selectivity. It also incorporates the ageing error matrix.

Typically the proportion of arrowtooth flounder in the Aleutians, EBS shelf and slope is estimated by applying the random effects model to survey estimates of biomass. Models 18.7 and 18.8 examine alternatives to this method.

Model 18.7: This model estimated catchability for the EBS shelf and slope within the model, and only included the EBS shelf and slope survey data. It used logistic (not nonparameteric) fishery selectivity.

Model 18.8 only incorporated Aleutian Islands survey data. It also used logistic (not nonparameteric) fishery selectivity. Only length data was used because the model did not converge with just two years of age data.

Model evaluation

Models were evaluated using several criteria (Table A1.1), including survey selectivity likelihood values for the fishery and the three surveys (EBS shelf, Bering Sea slope, and Aleutian Islands), fishery length likelihood, survey length likelihood, survey age likelihood, catch likelihood, and recruitment likelihood. The total likelihood and the objective function value from the ADMB model output are also presented, as well as the AIC value calculated as described below.

Calculating AIC from the hessian and objective function value (ADMB output)

The hessian, the matrix of second mixed derivatives in transformed space, is created as output from each ADMB model run. The hessian was transformed back into the original parameter space ($Hess_T$) by taking the log of the determinant of the hessian, and the marginal likelihood ($Likelihood_{MAR}$) was estimated (Thorson et al. 2014) as follows, where OFV is the objective function value from the ADMB .par file:

$\text{likelihood}_{MAR} = -0.5\,Hess_T - OFV$. Note: log(2pi) not necessary…

The marginal likelihood can be used to calculate AIC, as follows:

$AIC = 2k - 2 * likelihood_{MAR}$, where k is the number of parameters used in the model.

Results

Models 18.0, 18.1, 18.2:

These models incorporated changes in selectivity, by reducing the number of parameters and incorporating selectivity based on length rather than age (Figure A1.1). These models did not improve the overall likelihood or reduce the AIC, but they did reduce the number of parameters from 167 in the base model. Model 18.0 reduced the number of parameters by 8, 18.1 by 46 and 18.2 by 48. These models did not improve the survey biomass likelihoods, but they did improve the survey age and length likelihoods, as well as the recruitment likelihood.

Recruitment, biomass, and female spawning biomass for these three models are very similar to the base model (Figures A1.2, A1.3, A1.4).

Model 18.3:

This model was the same as the base model, except it incorporated the ageing error matrix. This resulted in the lowest AIC over all models. In particular, it resulted in the lowest fishery length likelihood and lower survey age and recruitment likelihood. Recruitment, biomass, and female spawning biomass are similar to the base model. Fit to age data was better than the base model (Figure A1.5).

Models 18.4 and 18.5:

The natural mortality at age for Models 18.4 (Lorenzen), and 18.5 (Gislason) are shown in Figure A1.6. The first 5 ages were fixed to be the same as the natural mortality at the sixth age for the Lorenzen method, because extremely large natural mortalities in younger fish resulted in much higher recruitment. These estimates for natural mortality conform to observations that there are more females than males in the population (Figure A1.7).

These models do not currently converge given the parameters provided. Recruitment for the Lorenzen natural mortality appears to be similar to other models, but the Gislason has not converged (Figure A1.2). Biomass estimates using the Lorenzen, and particularly the Gislason natural mortality are higher than other models (Figure A1.3). Estimates of female spawning biomass are lowest for these models out of all models considered (Figure A1.3). These models resulted in a poor fit to age data for the EBS shelf survey (Figure A1.5).

Models 18.7 and 18.8

The difference among the proportions in the three surveys changed slightly with Models 18.7 and 18.8. Fishery selectivity was estimated logistically, as was survey biomass (Figure A1.8). The proportion of female spawing biomass in the Aleutians, EBS shelf, and slope differed slightly with Model 18.1 vs. 18.7 and 18.8 (Figure A1.9). The last year of estimated biomass was used to estimate the proportion of the biomass in the three regions: Aleutians, EBS shelf, and slope (Table A1.2). Model 18.7 estimated that catchability in the EBS slope was 0.91 and the slope was 0.14, which normalized to 0.87 and 0.13 (Table A1.3). The 2016 estimate of biomass in the BSAI using Model 18.1 was 728,768 t. This was lower than the total estimate with Models 18.7 and 18.8 combined, 907,526 t, primarily due to an increase in the estimated biomass in the Aleutian Islands. Initial values used for the EBS shelf, slope, and AI in 2016 were based on the random effect model applied to survey biomass: 0.79 0.09 0.13.

Conclusions

Models presented here represented an effort to improve the BSAI arrowtooth stock assessment. Overall, the ageing error matrix (Model 18.3) appears to be the best model, considering the lowest AIC and objective function value. The other models that examined selectivity changes (Models 18.0, 18.1, and 18.2) did improve aspects of the model; with lower survey age, survey length, and recruitment likelihoods. Arrowtooth flounder likely move off the Eastern Bering Sea shelf when they attain a certain age, or maturity, rather than a particular length. The EBS shelf survey selectivity curve is specified to be domed shaped for this reason. If selectivity is based on length, it will predict that fewer males will move off the shelf that is biologically likely, since it will only predict movement by only large males.

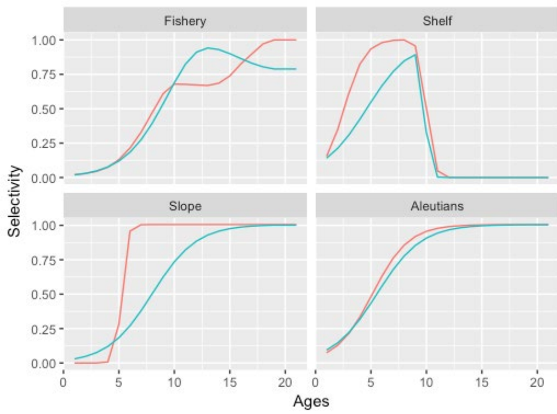
Differences in the abundance of male and female arrowtooth flounder has been a point of discussion for some time (Wilderbuer and Turnock 2009), and Plan Team, SSC, and CIE reviewers have suggested exploring alternatives for a fixed M that is higher for females than males. Genetic theory indicates that it is unlikely for a natural population to exhibit a skewed sex ratio, as is observed in the arrowtooth flounder. Fisher's principle states that the sex ratio of most species is approximately 1:1 because parents will invest equally in reproduction when competition for mates takes place equally among the entire population. Non-Fisherian populations are those that appear to violate Fisher's principle and have a skewed sex ratio. In species in which individuals undergo sex change throughout their lifetimes, skewed sex ratio is typical (Charnov 1982). However, it is unlikely that arrowtooth flounder change sex in ages 2 or greater because intermediate sexes have not been observed. Flounder of the genus Paralichthys exhibit a mode of sex determination in which male-skewed sex ratios are induced by temperatures lower and higher than average (Luckenbach et al. 2009). High and low temperatures also induce sex reversal in juvenile southern flounder, such that there are 96% males at high temperature and 78% males at low temperature (Luckenbach et al. 2003). Such a mechanism is unlikely in arrowtooth flounder because they have a female skewed sex ratio. The skewed sex ratio in arrowtooth flounder is consistent with research by Beverton (1992) who suggests that natural mortality for male flatfish is approximately 50% higher than that of females. Efforts to improve estimates of natural mortality did not converge with recommended parameters, and different parameterization may improve these models.

Models 18.7 and 18.8 investigated questions from the CIE review on integrating surveys. Model 18.7 did successfully allow the model to estimate catchability between the EBS shelf and slope, likely because it is a simpler model. The EBS is a contiguous area and ATF move to deeper water as they age. Therefore, the Model 18.7 makes sense in that it is more likely to cover a single stock than a three survey model. A separate assessment was run for the Aleutian Islands. This provided a higher estimate of biomass in the Aleutian Islands than typically provided by the BSAI model.

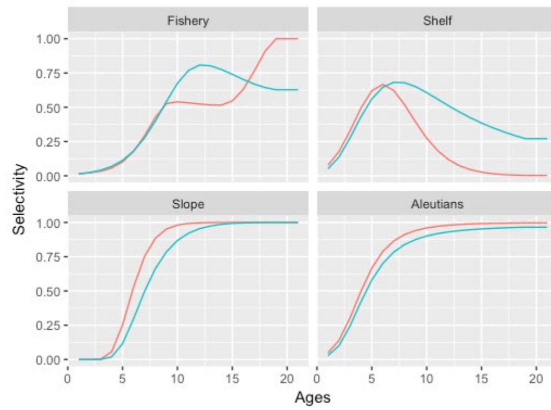
Figures and Tables

Figure A1.1a. Selectivity for the base model (15.1c, and Models 18.0, 18.1, n18.2). In all panels, red is female, blue is male).

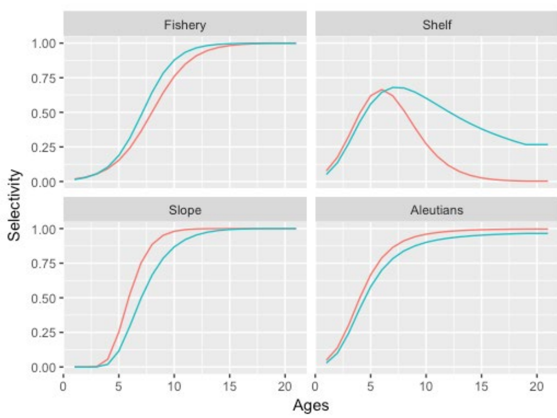
Model 15.1c



Model 18.0



Model 18.1



Model 18.2

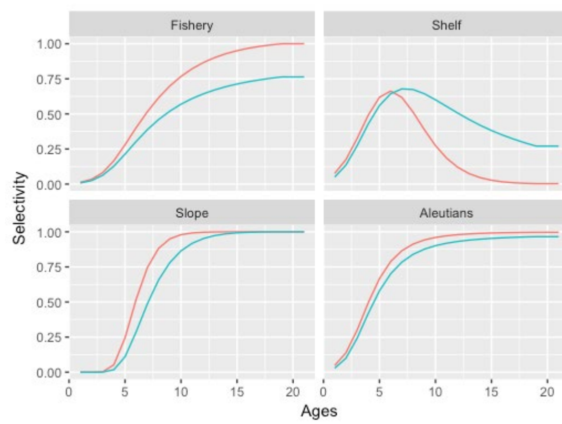
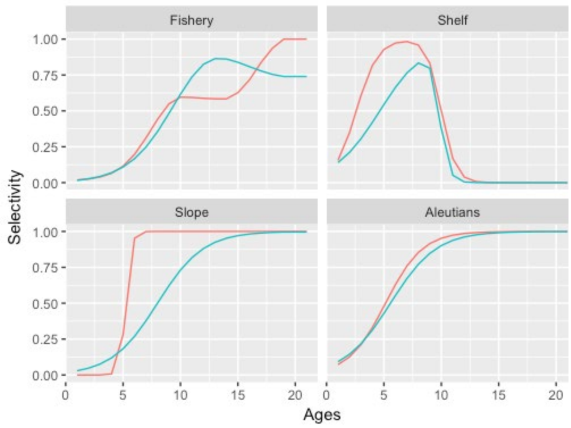
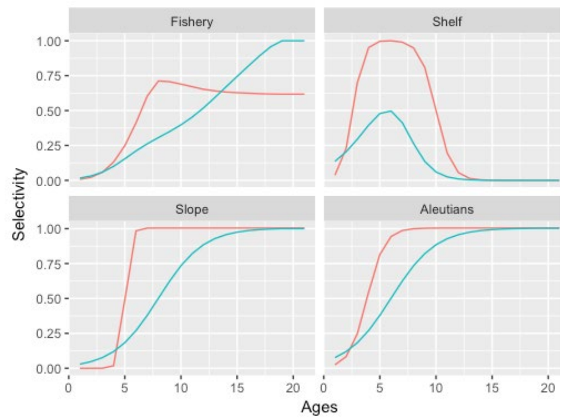


Figure A1.1b. Selectivity for Models 18.3, 18.4, 18.5, 18.6. In all panels, red is female, blue is male).

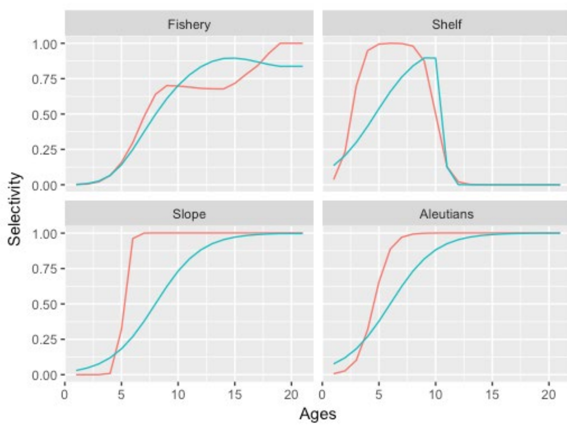
Model 18.3



Model 18.4



Model 18.5



Model 18.6

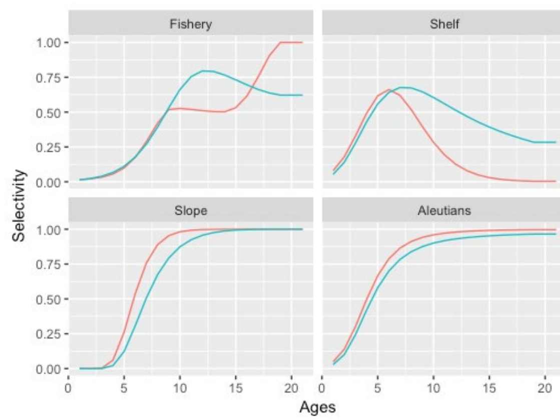


Figure A1.2. Recruitment estimates from 1976-2011 (5 years prior to the last year of the model) for all models.

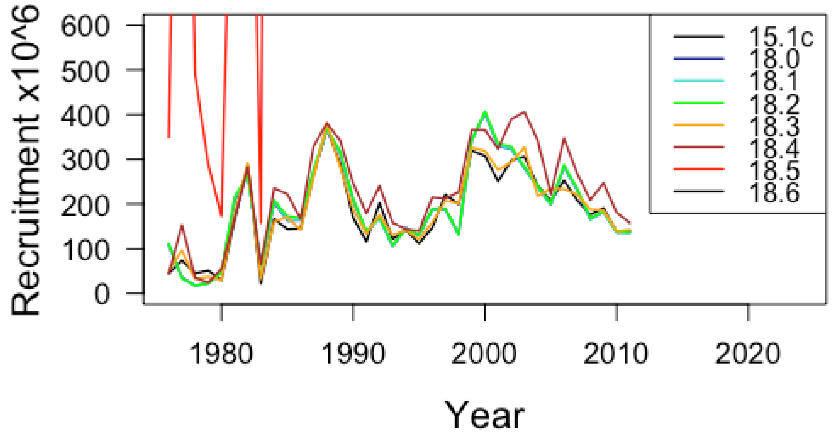


Figure A1.3. Biomass estimates for 1976-2016 for all models.

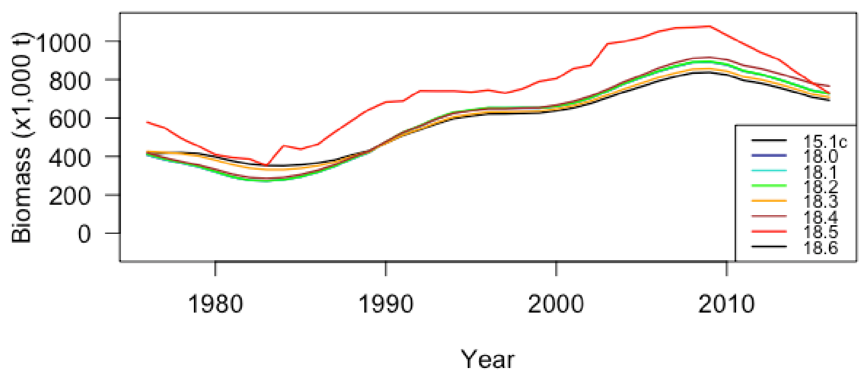


Figure A1.4. Female spawning biomass estimates for all models.

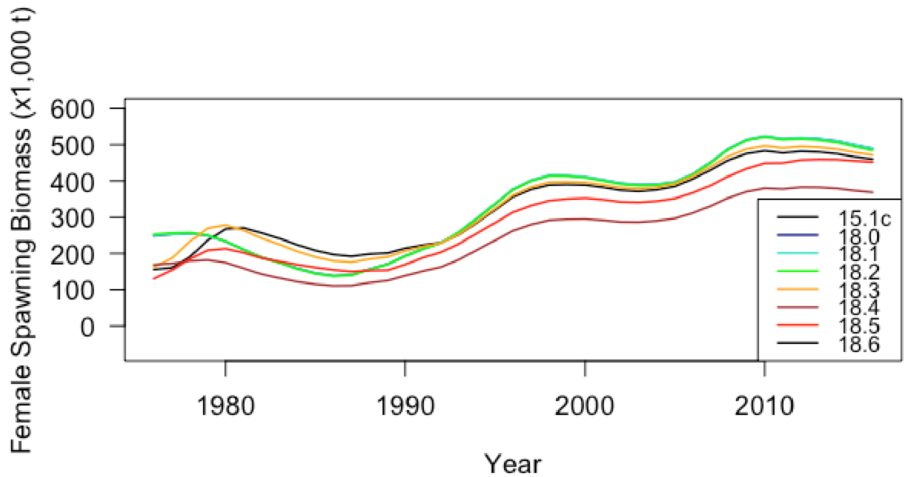


Figure A1.5. Fit to EBS shelf age data, for Models 15.1c, 18.4, 18.5, and 18.6. Females are red, males are blue.

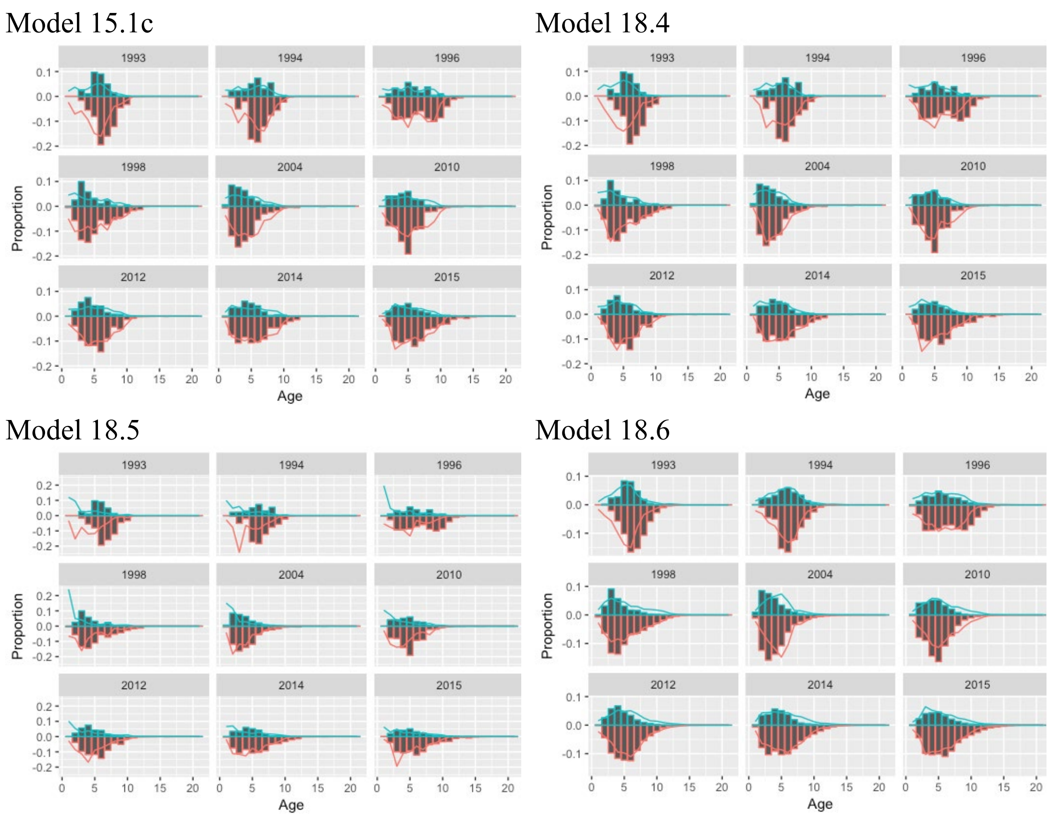


Figure A1.6. Natural mortality at age for the constant M, Lorenzen, and Gislason natural mortality. In all cases, females are represented by a solid line and males by a dotted line.

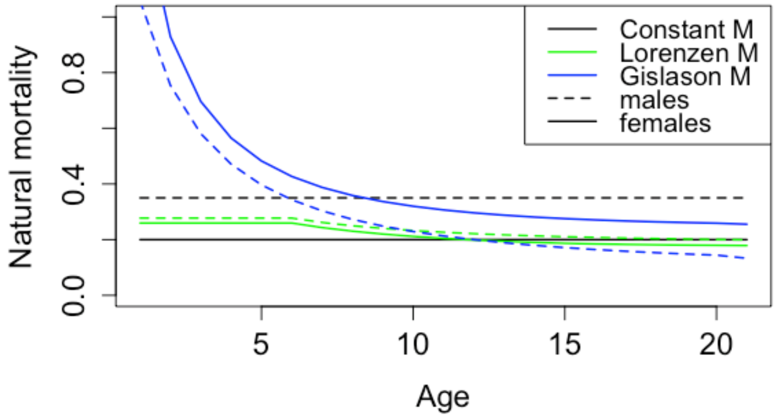


Figure A1.7. Relative numbers at age for the constant M, Lorenzen, and Gislason natural mortality. In all cases, females are represented by a solid line and males by a dotted line.

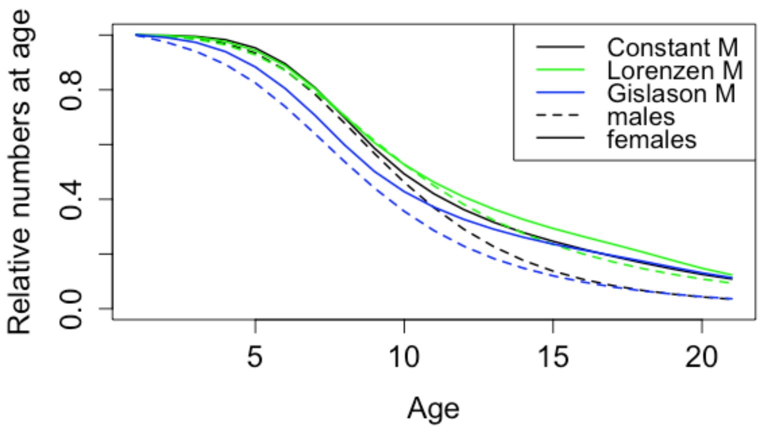
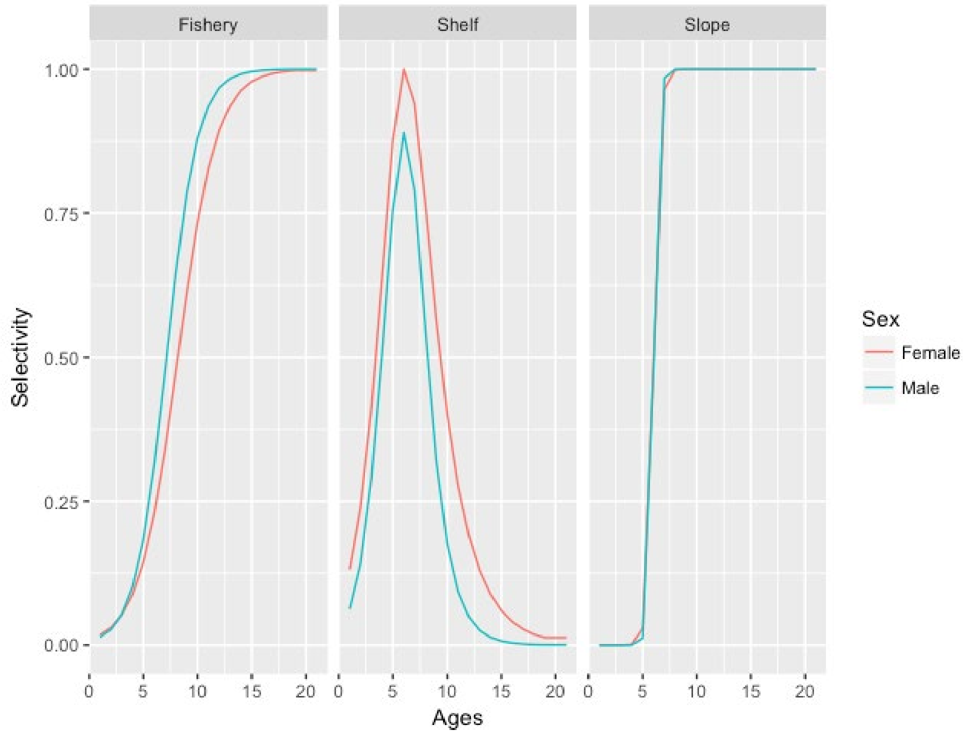


Figure A1.8. Selectivity for the fishery and the survey(s) for Models 18.7 and 18.8 (b).

a.



b.

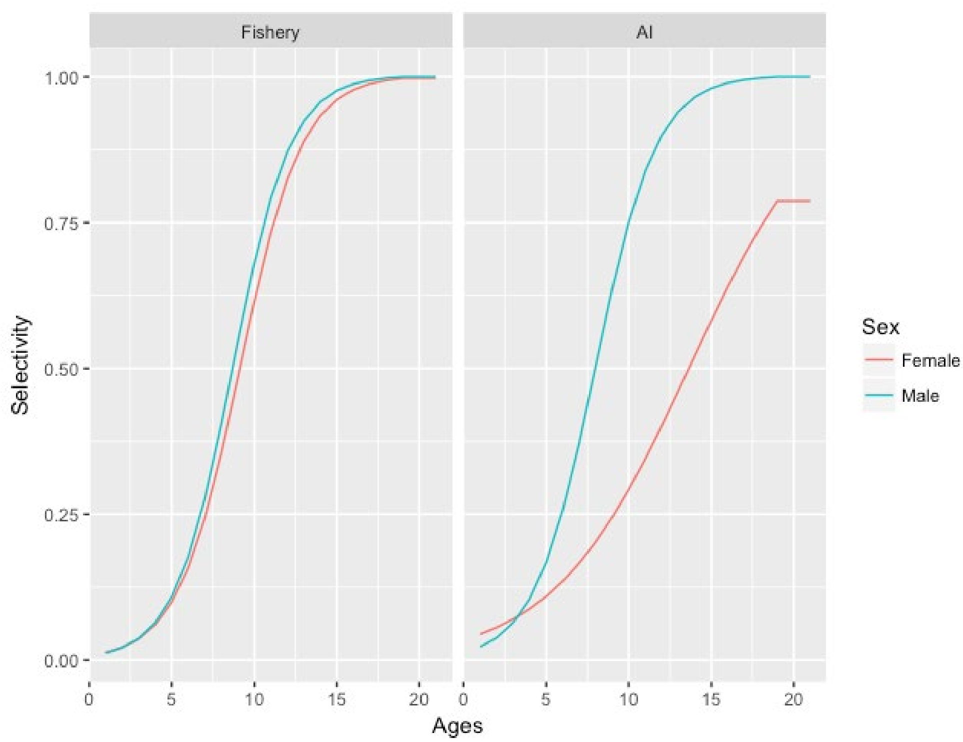
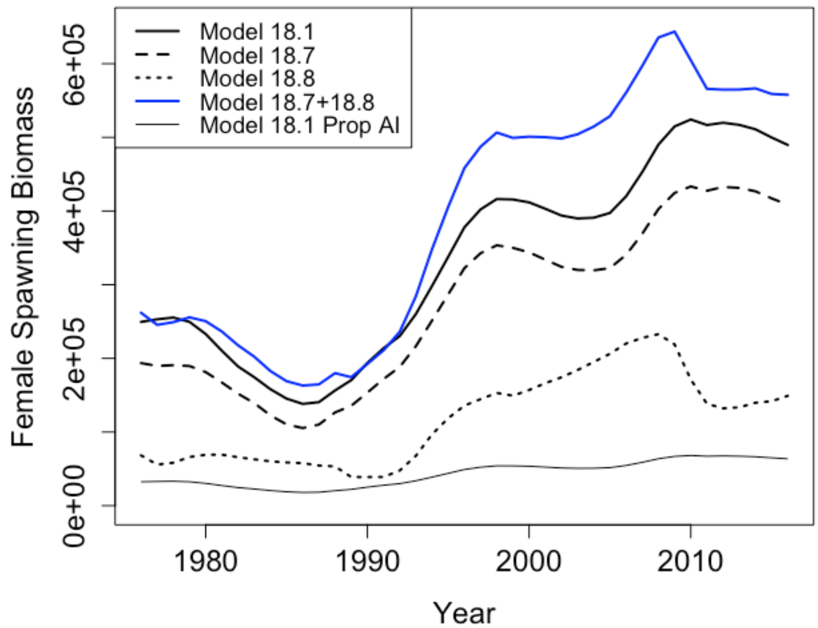


Figure A1.9. Female spawning biomass (a) and Total Biomass for Models 18.2, 18.7, and 18.8.

a.



b.

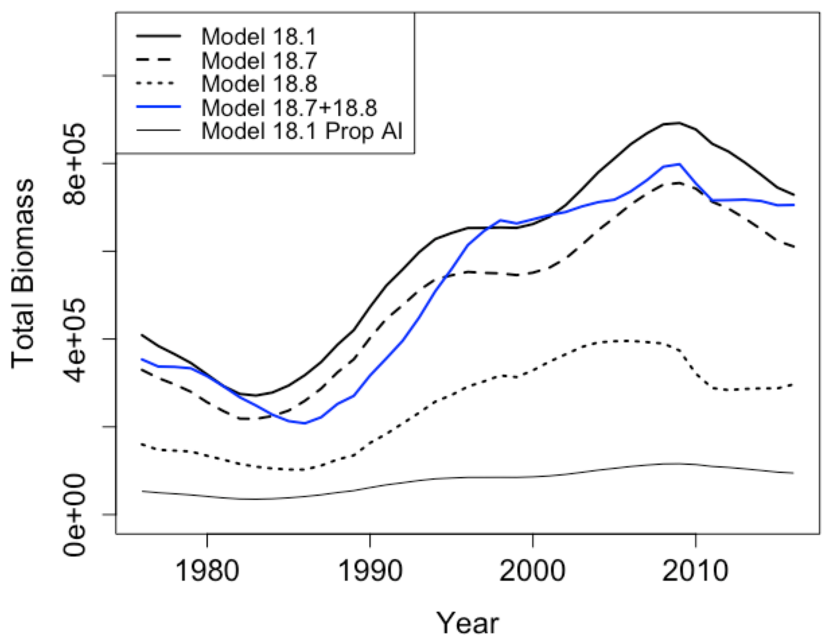


Figure A1.10. Observed and predicted survey biomass for Aleutian Islands model (18.8).

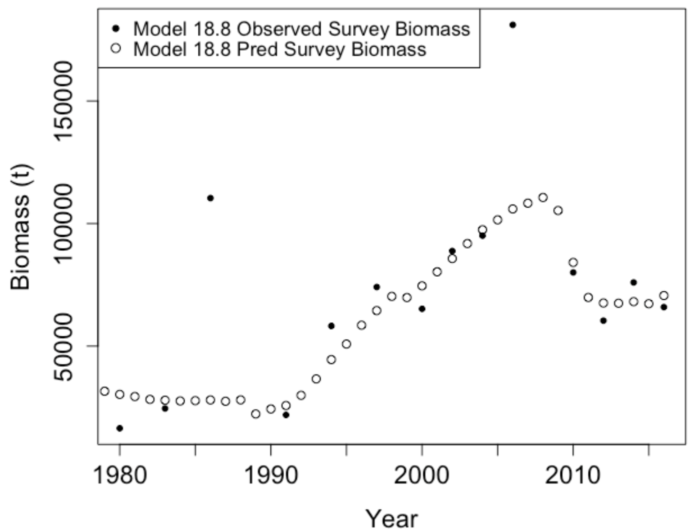


Table A1.1. Statistics used to evaluate models. Likelihood (Like.) values are shown for the Eastern Bering Sea survey biomass (EBS Surv. Biom.), the Bering Sea slope survey biomass (Slope Surv. Biom. Like), Aleutian Islands survey biomass (AI Surv. Biom.), Fishery length (Fish. Length), Survey length, Survey age, catch, recruitment (Rec.), fishery selectivity (Fish sel.), Survey selectivity (Surv. Sel.), the number of parameters. The total likelihood and the objective function value from the ADMB model output are also presented, as well as the Akaike Information Criterion (AIC).

Model Number	EBS. Surv. Biom. Like.	Slope Surv. Biom. Like.	AI Surv. Biom. Like.	Fish. Length Like.	Surv. Length Like.	Surv. Age Like.	Rec. Like.	Fish. sel. Like.	Surv. sel. Like.	Number of Parameters	Total Like.	ADSB	Obj. fun.	AIC*
15.1c	24.4	34.8	45.7	479.9	593.8	444.6	50.8	0.83	3.96	167	1674.8	-	3824.5	8078.4
18.0	34.9	71.3	45.9	493.2	544.8	341.0	29.9	1.43	5.53	159	1562.5	0.193	3831.7	8406.3
18.1	35.0	71.4	46.0	498.1	544.9	339.7	29.7	0.00	0.00	121	1564.9	0.194	3831.5	8384.0
18.2	35.1	71.7	46.3	546.9	548.0	343.4	29.8	0.00	0.00	119	1621.2	0.198	3876.1	8459.2
18.3	32.5	62.7	45.6	437.5	538.2	368.5	20.4	2.32	5.93	167	1507.7	0.062	3801.6	7817.8
18.4	37.3	48.7	50.8	498.1	1623.5	898.0	43.9	3.48	17.51	167	3203.7	0.290	6473.3	-Inf
18.5	35.6	71.4	46.0	498.5	532.4	270.3	28.7	0.00	0.00	121	1482.9	0.145	3730.2	-Inf
18.6	35.5	71.2	45.9	493.9	532.2	271.6	28.9	1.47	5.45	159	1480.8	0.196	3730.3	8208.4

Table A1.2. Model estimates for total biomass, Models 18.1, 18.7, and 18.8. The proportion of biomass in the Aleutian Islands, EBS shelf and EBS slope were obtained from the estimated proportions from random effects model estimates (based on survey biomass) of 0.13, 0.79, and 0.09 (Table 3). The proportion in the EBS shelf and slope are based on catchability estimated by Model 18.7 (0.87 and 0.13).

	Model 18.1	Model 18.7	Model 18.8
Aleutian Islands	94,740 t		296,778 t
EBS shelf	517,425 t	531,351 t	
EBS slope	65,589 t	79,397 t	
Total	728,768 t	907,526 t	

Table A1.3. Estimated proportions in the Aleutian Islands, EBS shelf, and slope, based on Model 18.1 (random effect model estimate) and Models 18.7 and 18.8.

	Model 18.1	Model 18.7 + 18.8
Aleutian Islands	0.13	0.33
EBS shelf	0.79	0.59
EBS slope	0.09	0.09

Literature Cited

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Appendix 2

Table 6.A2.1. Total tonnage of the research catches for arrowtooth flounder and Kamchatka flounder through 2007, and for arrowtooth only from 2008 onwards. Data for 1991-2017 is from AKFIN Noncommercial Fishery Catch, and represents only arrowtooth flounder (accessed October 25, 2018).

Year	Research catch (t)
1977	1
1978	3.7
1979	22.5
1980	63.6
1981	48.4
1982	46.6
1983	21.8
1984	6.1
1985	194.1
1986	57.7
1987	9.4
1988	33.7
1989	22.8
1990	21.9
1991	21.5
1992	23.6
1993	32.1
1994	22.5
1995	38.9
1996	27.5
1997	47.6
1998	43
1999	68.8
2000	48.3
2001	49.3
2002	24.8
2003	38.7
2004	22.6
2005	38
2006	27.6
2007	38.5
2008	22.3
2009	31.3
2010	196.1
2011	242.7
2012	50.4
2013	14.8
2014	38.5
2015	27.3
2016	17.2
2017	31.3

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

Parameter name	Year	Value	Standard deviation
fishsel_params_f[1]		0.41	919.41
fishsel_params_f[2]		5.01	15,134.00
fishsel_params_m[1]		0.11	71.16
fishsel_params_m[2]		8.01	34,371.00
srv_params_f[1]		1.51	0.10
srv_params_f[2]		2.92	0.10
srv_params_f[3]		3.55	0.53
srv_params_f[4]		5.07	0.08
srv_params_f[5]		1.10	0.08
srv_params_f[6]		4.00	0.14
srv_params_m[1]		1.35	0.08
srv_params_m[2]		3.48	0.10
srv_params_m[3]		30.00	6.45
srv_params_m[4]		5.07	0.02
srv_params_m[5]		1.49	0.10
srv_params_m[6]		3.61	0.10
srv1desc_params_f[1]		0.82	0.07
srv1desc_params_f[2]		9.42	0.21
srv1desc_params_m[1]		0.81	0.14
srv1desc_params_m[2]		7.89	0.24
alpha		-0.49	0.03
beta		0.10	0.01
mean_log_rec		18.48	0.03
rec_dev	age1	-1.07	0.48
rec_dev	age2	-0.43	0.58
rec_dev	age3	-0.48	0.57
rec_dev	age4	-0.54	0.56
rec_dev	age5	-0.60	0.55
rec_dev	age6	-0.65	0.54
rec_dev	age7	-0.70	0.53
rec_dev	age8	-0.75	0.52
rec_dev	age9	-0.84	0.51
rec_dev	age10	-0.90	0.50
rec_dev	age11	-0.94	0.50
rec_dev	age12	-0.96	0.49
rec_dev	age13	-0.92	0.50
rec_dev	age14	-0.83	0.51
rec_dev	age15	-0.65	0.53
rec_dev	age16	-0.28	0.60
rec_dev	age17	0.74	0.46
rec_dev	age18	0.07	0.60
rec_dev	age19	-0.62	0.47
rec_dev	age20	-1.29	0.41
rec_dev	1976	-1.90	0.38
rec_dev	1977	-2.17	0.37
rec_dev	1978	-1.87	0.38
rec_dev	1979	-0.92	0.36
rec_dev	1980	-0.06	0.31
rec_dev	1981	0.42	0.27
rec_dev	1982	-0.07	0.41
rec_dev	1983	-0.33	0.40
rec_dev	1984	0.60	0.17
rec_dev	1985	0.36	0.15

Parameter name	Year	Value	Standard deviation
rec_dev	1986	0.31	0.12
rec_dev	1987	0.96	0.08
rec_dev	1988	1.02	0.08
rec_dev	1989	0.92	0.08
rec_dev	1990	0.70	0.09
rec_dev	1991	0.23	0.11
rec_dev	1992	0.24	0.11
rec_dev	1993	0.01	0.12
rec_dev	1994	0.04	0.11
rec_dev	1995	0.09	0.12
rec_dev	1996	0.58	0.10
rec_dev	1997	0.38	0.12
rec_dev	1998	0.45	0.13
rec_dev	1999	0.98	0.09
rec_dev	2000	0.94	0.09
rec_dev	2001	0.81	0.10
rec_dev	2002	1.01	0.08
rec_dev	2003	0.93	0.08
rec_dev	2004	0.83	0.08
rec_dev	2005	0.63	0.08
rec_dev	2006	0.82	0.06
rec_dev	2007	0.64	0.07
rec_dev	2008	0.43	0.07
rec_dev	2009	0.40	0.07
rec_dev	2010	0.18	0.08
rec_dev	2011	0.12	0.08
rec_dev	2012	0.32	0.08
rec_dev	2013	0.65	0.07
rec_dev	2014	0.56	0.09
rec_dev	2015	0.33	0.12
rec_dev	2016	0.32	0.18
rec_dev	2017	1.73	0.14
rec_dev	2018	0.00	0.70
log_avg_fmort		-3.38	0.04
fmort_dev	1976	1.06	0.10
fmort_dev	1977	0.49	0.09
fmort_dev	1978	0.30	0.08
fmort_dev	1979	0.62	0.08
fmort_dev	1980	0.92	0.07
fmort_dev	1981	0.96	0.07
fmort_dev	1982	0.65	0.07
fmort_dev	1983	0.95	0.07
fmort_dev	1984	0.62	0.07
fmort_dev	1985	0.35	0.07
fmort_dev	1986	0.23	0.07
fmort_dev	1987	-0.29	0.06
fmort_dev	1988	1.05	0.06
fmort_dev	1989	-0.06	0.06
fmort_dev	1990	0.42	0.06
fmort_dev	1991	0.66	0.06
fmort_dev	1992	0.02	0.06
fmort_dev	1993	-0.37	0.06
fmort_dev	1994	-0.07	0.06
fmort_dev	1995	-0.59	0.06
fmort_dev	1996	-0.17	0.06

Parameter name	Year	Value	Standard deviation
fmort_dev	1997	-0.52	0.06
fmort_dev	1998	-0.14	0.06
fmort_dev	1999	-0.41	0.06
fmort_dev	2000	-0.25	0.06
fmort_dev	2001	-0.18	0.06
fmort_dev	2002	-0.37	0.06
fmort_dev	2003	-0.29	0.06
fmort_dev	2004	-0.02	0.06
fmort_dev	2005	-0.30	0.06
fmort_dev	2006	-0.40	0.06
fmort_dev	2007	-0.58	0.06
fmort_dev	2008	-0.30	0.06
fmort_dev	2009	-0.23	0.06
fmort_dev	2010	-0.19	0.06
fmort_dev	2011	-0.04	0.06
fmort_dev	2012	0.07	0.06
fmort_dev	2013	0.00	0.06
fmort_dev	2014	-0.04	0.06
fmort_dev	2015	-0.55	0.06
fmort_dev	2016	-0.54	0.06
fmort_dev	2017	-1.05	0.06
fmort_dev	2018	-1.41	0.06
log_selcoffs_fish		-5.05	0.86
log_selcoffs_fish		-3.69	0.77
log_selcoffs_fish		-2.41	0.74
log_selcoffs_fish		-1.31	0.72
log_selcoffs_fish		-0.45	0.72
log_selcoffs_fish		0.15	0.72
log_selcoffs_fish		0.54	0.71
log_selcoffs_fish		0.72	0.71
log_selcoffs_fish		0.72	0.71
log_selcoffs_fish		0.70	0.71
log_selcoffs_fish		-3.72	0.75
log_selcoffs_fish		-2.86	0.73
log_selcoffs_fish		-2.02	0.72
log_selcoffs_fish		-1.26	0.72
log_selcoffs_fish		-0.60	0.71
log_selcoffs_fish		-0.05	0.71
log_selcoffs_fish		0.37	0.71
log_selcoffs_fish		0.65	0.71
log_selcoffs_fish		0.81	0.71
log_selcoffs_fish		0.87	0.71
F40		0.14	0.02
F35		0.16	0.03
F30		0.24	247.42
fspbio	1976	152,650	16,899
fspbio	1977	146,980	14,975
fspbio	1978	153,530	13,437
fspbio	1979	165,890	12,466
fspbio	1980	172,530	11,624
fspbio	1981	167,280	10,487
fspbio	1982	154,350	9,398
fspbio	1983	141,230	8,437
fspbio	1984	125,400	7,544
fspbio	1985	116,350	6,660

Parameter name	Year	Value	Standard deviation
fspbio	1986	115,820	5,906
fspbio	1987	123,640	5,351
fspbio	1988	139,590	5,068
fspbio	1989	148,870	4,889
fspbio	1990	168,270	4,810
fspbio	1991	188,800	4,967
fspbio	1992	211,410	5,419
fspbio	1993	244,020	5,943
fspbio	1994	285,650	6,669
fspbio	1995	327,980	7,507
fspbio	1996	369,260	8,224
fspbio	1997	395,730	8,686
fspbio	1998	411,590	8,904
fspbio	1999	412,760	8,936
fspbio	2000	409,900	8,850
fspbio	2001	403,440	8,752
fspbio	2002	397,510	8,632
fspbio	2003	398,050	8,610
fspbio	2004	404,350	8,714
fspbio	2005	413,870	8,951
fspbio	2006	434,290	9,366
fspbio	2007	461,730	9,881
fspbio	2008	491,840	10,362
fspbio	2009	517,460	10,809
fspbio	2010	537,970	11,234
fspbio	2011	551,360	11,591
fspbio	2012	556,000	11,846
fspbio	2013	553,160	12,000
fspbio	2014	546,150	12,029
fspbio	2015	533,750	11,918
fspbio	2016	523,000	11,660
fspbio	2017	508,430	11,302
fspbio	2018	497,580	10,937
totalbiomass	1976	318,840	17,685
totalbiomass	1977	306,320	16,186
totalbiomass	1978	294,590	14,814
totalbiomass	1979	280,140	13,571
totalbiomass	1980	262,110	12,347
totalbiomass	1981	246,440	11,155
totalbiomass	1982	239,710	10,112
totalbiomass	1983	245,050	9,233
totalbiomass	1984	255,320	8,489
totalbiomass	1985	275,300	7,918
totalbiomass	1986	303,280	7,646
totalbiomass	1987	339,650	7,702
totalbiomass	1988	387,910	8,153
totalbiomass	1989	431,690	8,992
totalbiomass	1990	494,100	9,974
totalbiomass	1991	548,330	10,968
totalbiomass	1992	589,690	11,807
totalbiomass	1993	625,600	12,406
totalbiomass	1994	651,740	12,802
totalbiomass	1995	662,020	13,026
totalbiomass	1996	671,230	13,141
totalbiomass	1997	671,880	13,196

Parameter name	Year	Value	Standard deviation
totalbiomass	1998	676,520	13,257
totalbiomass	1999	681,530	13,381
totalbiomass	2000	697,740	13,638
totalbiomass	2001	720,590	14,101
totalbiomass	2002	749,890	14,620
totalbiomass	2003	786,130	15,213
totalbiomass	2004	824,570	15,844
totalbiomass	2005	855,710	16,431
totalbiomass	2006	887,240	16,993
totalbiomass	2007	914,430	17,514
totalbiomass	2008	935,730	17,932
totalbiomass	2009	943,720	18,211
totalbiomass	2010	939,970	18,298
totalbiomass	2011	925,550	18,195
totalbiomass	2012	901,350	17,941
totalbiomass	2013	872,920	17,626
totalbiomass	2014	848,200	17,317
totalbiomass	2015	827,150	17,094
totalbiomass	2016	816,180	17,000
totalbiomass	2017	822,630	17,798
totalbiomass	2018	849,620	20,126