7. Assessment of the Arrowtooth Flounder Stock in the Gulf of Alaska

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Executive Summary

Summary of Changes in Assessment Inputs

Changes in the input data

The following new data was included in the model:

1. The 2017 NOAA Resource Assessment and Conservation Engineering (RACE) Gulf of Alaska (GOA) survey biomass estimate and standard error were added to the model.
2. Catch for 2015 and 2016 were updated and preliminary 2017 catch (to September 26, 2017) were added.
3. Fishery length data were updated for 2016 and 2017.
4. Survey age data were added for 2015.
5. Survey length frequency data were added for 2017.

Changes in assessment methodology

1. The length-age conversion matrix was modified using age length data from 1984-2013 based on suggestions from the 2015 Plan Team.
2. Weight at age was recalculated for males and females, using 1977-2013 age data, based on lengths at age obtained from the updated length-age conversion matrix by fitting the length data to weight at age.
3. An ageing error matrix was added to account for age reading error.
4. Additions to the model included data weighting (fishery and survey length compositions, survey age composition) using the Francis (2011) method.
5. Alternatives to fixed M for males and females were explored but not used in the final model, and are presented in the Model Evaluation section.

Summary of Results

Arrowtooth flounder biomass estimates in the current model have changed relative to the projection model estimates in 2016. The model projection of spawning biomass for 2018, assuming fishing mortality equal to the recent 5-year average, was 873,789 t, 24% lower than the projected 2018 biomass from the 2016 assessment of 1,154,310 t. The 2018 ABC (estimated in 2017) using $F_{40\%}$ was 170,510 t. The 2018 and 2019 ABCs using $F_{40\%}$ were lower, 150,945 t and 145,234 t, The projected estimate of total biomass for 2018 was down by 32% from the 2016 assessment of 2,079,029 t, to 1,421,306 t. The 2018 and 2019 OFLs estimated using the projection model were 180,697 t and 173,872 t. The arrowtooth flounder stock in the Gulf of Alaska is not being subjected to overfishing and is not approaching a condition of being overfished.

Quantity	As estimated or *specified last* year for: 2017	2018	*As estimated or *recommended this* year for: 2018	2019
M (natural mortality rate)**	0.35, 0.2	0.35, 0.2	0.35, 0.2	0.35, 0.2
Tier	3a	3a	3a	3a
Projected total (age 1+) biomass (t)	2,103,090	2,079,029	1,421,306	1,384,292
Projected Female spawning	1,174,400	1,154,310	873,789	835,009
$B_{100\%}$	992,272	992,272	924,644	924,644
$B_{40\%}$	396,909	396,909	369,858	369,858
$B_{35\%}$	347,295	347,295	323,625	323,625
F_{OFL}	0.204	0.204	0.238	0.238
$maxF_{ABC}$	0.171	0.171	0.196	0.196
F_{ABC}	0.171	0.171	0.196	0.196
OFL (t)	219,327	196,635	180,697	173,872
maxABC (t)	186,093	170,510	150,945	145,234
ABC (t)	186,093	170,510	150,945	145,234
Status	As determined *this* year for: 2015	2016	2016	2017
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

*Projections are based on estimated catches of 21,080 t for 2016 and 23,720 t for 2017.
**Natural mortality rate is 0.35 for males, 0.2 for males.

Area Apportionment

Arrowtooth flounder is managed as a single stock in the Gulf of Alaska. However, the ABC by management area using $F_{40\%}$ was estimated by calculating the fraction of the survey biomass in each area and applying that fraction to the ABC. The **Western** region is NMFS reporting area 610 (Shumagin), **Central** is 620 and 630 (Chirikof and Kodiak), and **West Yakutat** and **East Yakutat/SE Alaska** result from the combined NMFS areas 640 and 650 redistributed such that the West Yakutat area is between 147°W and 140°W and the East Yakutat/SE is the portion east of 140°W. Proportions in the four areas are determined by applying a time series of survey biomass estimates and their coefficients of variation (CV's) to the random effects model (Appendix A).

Arrowtooth ABC by INPFC area

	Western	Central	West Yakutat	East Yakutat/SE	Total
2015 survey biomass percent by area	14.34%	54.88%	19.14%	11.64%	100%
ABC 2016	26,699	102,180	35,636	21,672	186,188
ABC 2017	27,150	103,905	36,238	22,038	189,332
2017 survey biomass percent by area	24.68%	48.68%	10.91%	15.73%	100%
ABC 2018	37,253	73,480	16,468	23,744	150,945
ABC 2019	35,844	70,700	15,845	22,845	145,234

Summaries for Plan Team

Year	Biomass[1]	OFL	ABC*	TAC	Catch[2]
2016	2,103,860	219,430	186,188	103,300	19,828
2017	2,103,090	219,327	186,083	103,300	20,283
2018	1,421,306	180,697	150,945		
2019	1,384,292	173,872	145,234		

	2017			2018		2019	
Area	OFL	ABC[3]	TAC	OFL	ABC	OFL	ABC
Western	-	28,100	14,500	-	37,253	-	35,844
Central	-	107,934	75,000	-	73,480	-	70,700
W. Yakutat	-	37,405	6,900	-	16,468	-	15,845
E. Yak./SE	-	12,654	6,900	-	23,744	-	22,845
Total	219,327	186,093	103,000	180,697	150,945	173,872	145,234

[1]Total biomass (ages 1+) from the projection model based on parameters from the age-structured model.

[2]Current as of September 21, 2017. Source: NMFS Alaska Regional Office Catch Accounting System via the AKFIN database (http://www.akfin.org).

[3]Source: Alaska Regional Office Final Harvest Specifications for 2017-2018.

Responses to SSC and Plan Team Comments on Assessments in General

SSC October 2017

The SSC also recommends explicit consideration and documentation of ecosystem and stock assessment status for each stock, perhaps following the framework suggested below, during the December Council meeting to aid in identifying areas of concern.

Authors' response: This was done in the current assessment.

Responses to SSC and Plan Team Comments Specific to this Assessment

December 2015 SSC

The SSC supports the PT's recommendations that future arrowtooth flounder assessments consider the following:

1. Fit growth curves and age-length transition matrix such that the effect of length-stratified otolith sampling on estimated size at age is removed. It was noted that weight-at-age appears to be decreasing over time for most male and females between 1 and 10.

   Authors' response:

   The age-length transition matrix was adjusted by the survey length frequencies to remove the effect of length-stratified otolith sampling. Growth curves were adjusted accordingly. Mean length at age was adjusted to remove the effect of length-stratified otolith sampling using survey length frequencies. Then weight at age was calculated using adjusted length at age applied to a non-linear model fit to age and weight data.

2. Evaluate models which allow time-varying size at age.

   Authors' response:

   Size at age was evaluated for all years. No clear trend exists and not enough age data exists to fit growth annually. This is discussed in the assessment.

3. Evaluate additional variance components as the design-based variances may be underestimates.

   Authors' response:

   Methods presented in Francis (2011) were explored which allow tuning of the survey biomass based on the standard deviation of normalized residuals, as well as the composition variance components.

4. Investigate if the IPHC longline survey data could be used as an additional tuning index.

   Authors' response:

   This was investigated and presented in the September 2017 Plan Team meeting. This survey uses size 6 hooks which are too large to catch the size range of arrowtooth flounder. Survey data exists from a short time series, 2007-2016.

5. Examine potential for iteratively reweighting age and length composition data, potentially with one of the methods described in Francis (2011).

   Authors' response:

   Iterative reweighting was applied to fishery and survey length composition likelihoods and the survey age composition likelihood.

6. Re-evaluate sex ratios and sex-specific natural mortality rates. The natural mortality for one sex could be fixed and the other estimated. The hypothesis that males are in deeper water and thus less available to the survey and fishery should be re-examined.

   Authors' response:

   Two new methods were evaluated for calculating natural mortality, Lorenzen (1996) and Gislason et al. (2010). These were not selected for the final model.

7. The Team recommends evaluation of standardizing the surveys from the 1960 and 1970 with the more recent NMFS trawl survey estimates or, alternatively, removing the older surveys from the model. The trawl survey biomass estimates are obtained from several sources, including IPHC surveys in the 1960s and exploratory NMFS surveys in the 1970s. The estimated variances for several survey biomass estimates appear to be small.

   Authors' response:

   The model was run with and without the two earliest surveys and the validity of those surveys was considered. Authors retained those surveys in the current assessment because removal changed early trajectories of arrowtooth flounder biomass significantly.

Introduction

Arrowtooth flounder (*Atheresthes stomias*) range from central California to the Gulf of Alaska (GOA), Aleutian Islands, and northern Bering Sea. Arrowtooth flounder (ATF) has been considered the most abundant groundfish species in the Gulf of Alaska for the past several years, but its abundance measured by biomass may have shifted to less than that of Pacific Ocean Perch, based on the 2017 Gulf of Alaska groundfish survey. Projections for 2016 from the 2015 GOA assessments estimated Pacific Ocean Perch at 457,768 t and ATF at 2,103,860 t. However, survey biomass estimates of Pacific Ocean Perch in the 2017 survey were higher than arrowtooth (over 1.5 million t vs. 1,053,695 t).

Arrowtooth flounder occur in waters from about 20m to 800m, but catch per unit effort (CPUE) from survey data is highest between 100m and 300m. 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 (Zimmerman and Goddard 1996). Fisheries data off Washington suggest that larger fish may migrate to deeper water in winter and shallower water in summer (Rickey 1995). Arrowtooth flounder spawn in deep waters (>400m) along the continental shelf break in winter (Blood et al. 2007). They are batch spawners, spawning from fall to winter off Washington State at depths greater than 366m (Rickey 1995).

Trophic studies (Yang 1993, Hollowed, et al. 1995, Hollowed et al. 2000) suggest they are an important component in the dynamics of the Gulf of Alaska benthic ecosystem. The majority of the prey by weight of arrowtooth larger than 40 cm was pollock, the remainder consisting of herring, capelin, euphausids, shrimp and cephalopods (Yang 1993). The percent of pollock in the diet of arrowtooth flounder increases for sizes greater than 40 cm. Arrowtooth flounder 15 cm to 30 cm consume mostly shrimp, capelin, euphausiids and herring, with small amounts of pollock and other miscellaneous fish. Groundfish predators include Pacific cod and halibut (see Ecosystem Considerations section).

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 has typically been fixed at 0.2 for females and 0.35 for males in the model. 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 were not observed older than age 20 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).

Information concerning the genetic stock structure of ATF is not currently available, although efforts are underway to initiate research, given the importance of this stock to the Alaska ecosystem.

Fishery

Management of the arrowtooth flounder stock in the GOA has changed over time. Prior to 1990, flatfish catch in the Gulf of Alaska was reported as an aggregate of all flatfish species. The bottom trawl fishery in the Gulf of Alaska primarily targets rock, rex and Dover sole. The North Pacific Fisheries Management Council divided the flatfish assemblage into four categories for management in 1990; "shallow flatfish" and "deep flatfish", flathead sole and arrowtooth flounder. Arrowtooth flounder was separated from the group and managed under a separate acceptable biological catch (ABC) because of its present high abundance and low commercial value. In the Gulf of Alaska, arrowtooth flounder were first managed under a separate assessment in 2001. They are currently managed as a single stock but the ABC is specified separately for the Western (NMFS area 610), Central (620, 630), West Yakutat, and East Yakutat/Southeast outside.

The area of highest abundance of arrowtooth flounder in the GOA is in the central and western gulf (Figure 7.1). The directed fishery takes place throughout the GOA, but is primarily in the central GOA (NMFS area 630). Arrowtooth flounder are typically caught with bottom trawl nets. Outside of the directed fishery, they are primarily caught as bycatch in the Other Flatfish fisheries. Table 7.2 presents discard rates since 1991, which were calculated from observed at-sea sampling and industry reported retained catch. Under current fishing practices, the percent retained has increased from below 10% in the early 1990's to over 70% from 2010-2013, and 90% or greater since that time.

Viable products were developed for arrowtooth flounder around 2008, which prevented the muscle from degrading rapidly when heated. Until that time it was not targeted as a commercial fishery. Several methods exist to neutralize the enzymes that cause the flesh to degrade, including chilling to near zero or immediate processing and freezing. The arrowtooth flounder currently caught, processed, and sold each year from the Gulf of Alaska are typically sold in Asian markets. They are eaten as less expensive fillets, used raw in sashimi, or used to manufacture surimi.

The catches for arrowtooth flounder remain below the TAC (Tables 7.3a, 7.3b); approximately 20,000-30,000 t for the past 10 years, averaging 24,697 t, and catch/TAC averaged 39% from 2008-2017. Catches were below 10,000 t, on average, prior to 1990, and increased to an average of approximately 16,000 t in the 1990's and 24,000 t in the 2000's. The highest recorded catch was 34,327 t in 2014. Catch as of September 21, 2017 was 20,283 t, and the projected total for 2017 is 20,803 t, based on the average proportion caught by that date for the past 8 years (2009-2016). Total allowable catch for 2017 was 14,500 t for the Western GOA, 6,900 t for the W. Yakutat, 75,000 t for the Central GOA, and 6,900 t for the SE outside region (103,300 t total). TAC increased from 43,000 t in 2011 to 103,300 t in 2012-2017 (Table 7.3b). Specified TAC, ABC, and OFL since the 1990s are shown in Table 7.3b.

Data

The model simulates the dynamics of the population and compares the expected values of the population characteristics to those observed from surveys and fishery sampling programs.

The following data sources (and years of availability) were used in the model:

Data component	**Years**
Fishery catch	1961-2017
IPHC trawl survey biomass and S.E. *	1961-1962
NMFS exploratory research trawl survey biomass, S.E.*	1973-1976
NMFS trawl survey biomass and S.E.	1984,1987,1990,1993,1996,1999,2001,2003, 2005,2007,2009, 2011, 2013, 2015, 2017
Fishery size compositions	1977-1993,1995-2017
NMFS survey size compositions	1975, 1985, 1986, 1989, 2017
NMFS triennial trawl survey age composition data	1984,1987,1990,1993,1996,1999,2001, 2003,2005,2007,2009, 2011, 2013, 2015

* The data from the 1961 and 1962 IPHC surveys were combined to provide total coverage of the GOA area. The NMFS surveys in 1973 to 1976 were also combined to provide total coverage of the survey area.

**Fishery size composition data is available for all years from which NMFS trawl surveys occurred. For years in which age compositions are available, length composition is not used directly in the model. Length composition data from 1984-2013 were used to construct the length age conversion matrix.

Fishery:

Catch

The estimate of annual arrowtooth catch between 1960 and 1993 was calculated by multiplying the proportion of arrowtooth in observer sampled flatfish catches (nearly 50%) by the reported flatfish catch (1960-1977 from Murai et al. 1981 and 1978-1993 from Wilderbuer and Brown 1993) (Tables 7.3a, 7.3b).

Removals from sources other than those that are included in the Alaska Region's official estimate of catch (e.g., removals due to scientific surveys, subsistence fishing, recreational fishing, fisheries managed under other FMPs) are presented in Appendix C.

Age and size composition

The number of fisheries length observations taken by fisheries observers, and the number of hauls from which those samples were taken, by year, 1975-2017 are presented in Table 7.4. Table 7.5 contains incidental catches from halibut fisheries by area and year (2003-2017). Sample sizes for the fishery length data were generally at least 1,000 for the 1970s through 1984 (Table 7.4). Sample sizes were under 800 between 1985-1990, 1992, 1994, 1998, and were not taken in 1989. Fishery length data was updated in the current assessment, and the following years of data were added: 1982, 1983, 1984, 2014, 2015. Domestic data was downloaded from the OBSINT debriefed_length table. The data prior to 1989 is referred to as "foreign" data, but the fishing of the latter years was done predominately by joint venture vessels which eventually replaced the foreign fishers (Figure 7.2). Length frequencies from the fishery are presented in Figure 7.3.

There is no age data from the fishery but otoliths will be collected by observers starting in 2018 for this purpose.

Survey:

Biomass estimates

The survey biomass estimates used in this assessment are from International Pacific Halibut Commission (IPHC) trawl surveys, and NMFS groundfish surveys (Table 7.6). Biomass estimates from the surveys in the 1960's and 1970's were analyzed using the same strata and methods as the triennial survey (Brown 1986). The data from the 1961 and 1962 IPHC surveys were combined to provide total coverage of the GOA area. The NMFS surveys in 1973 to 1976 were also combined to provide total coverage of the survey area. However, sample sizes were lower in the 1970's surveys (403 hauls, Table 7.6) than for other years, and some strata had less than 3 hauls. The IPHC and NMFS 1970's surveys used a 400 mesh Eastern trawl, while the triennial surveys used a noreastern trawl. The trawl used in the early surveys had no bobbin or roller gear, which would cause the gear to be more in contact with the bottom than current trawl gear. Also the locations of trawl sites may have been restricted to smooth bottoms in the earlier surveys because the trawl could not be used on rough bottoms. Selectivity of the different surveys is assumed to be equal. There is limited size composition data for the 1970's surveys and none for the 1960's surveys.

The 400 mesh eastern trawl used in the 1960's and 1970's surveys was estimated to be 1.61 times as efficient at catching arrowtooth flounder than the noreastern trawl used in the NMFS triennial surveys (Brown, unpub.). The 1960's and 1970's survey abundance estimates have been lowered by dividing by 1.61. A coefficient of variation (cv) of 0.2 for the efficiency estimate was assumed since variance estimates were unavailable. Even the uncorrected estimates would be much lower than more recent survey estimates. Without dividing by 1.61, the 1960's biomass estimate would be lower than standard survey estimates from 1984-2017, 454,078 t and the 1970's estimate would be 233,190 t.

The survey catchability coefficient (q) in the assessment model was assumed to be 1.0. NMFS has conducted studies to estimate the escapement under the triennial survey net and herding of fish into the net. The percent of arrowtooth flounder caught that were in the path of the net varies by size from about 80% at 27 cm (about age 3) to about 96% at greater than 45cm (equal to or greater than age 7 for females and age 10 for males) (Somerton et al. 2007). Somerton et al. (2007) estimated the effect of herding combined with escapement under the net to be an effective multiplier of about 1.3 on survey catch for arrowtooth flounder. The combination of escapement under the net and herding into the net indicates that abundance would be about 23% less than the estimated survey abundance.

Survey abundance estimates were low in the 1960's and 1970's, and increased from about 146,000 t in the early 1970's to a high of 2,819,095 t in 2003. Survey biomass has generally been in decline since 2003, and the 2017 estimate of 1,053,695 t was the lowest estimate since 1987. The 1984, 1987, 1999, 2005, 2007, 2009 and 2011, and 2015 surveys covered depths to 1000m, the 1990, 1993, 1996, and 2001 surveys to 500m and the 2003, 2013 and 2017 surveys covered depths to 700m. The 2001 survey excluded the eastern Gulf of Alaska. The average biomass estimated for the 1993 to 1999 surveys was used to estimate the biomass in the eastern Gulf for 2001 (Table 7.6). The eastern Gulf biomass was between 14% and 22% of the total biomass for the 1993-1999 surveys. Biomass by area is shown in Table 7.7. Survey biomass estimates, standard error, number of hauls, and maximum depth are shown in Table 7.6.

Recently, VAST, an R package for implementing a spatial delta-generalized linear mixed model for size and age classes (Thorson et al. 2015) has been considered as an alternative to design-based methods to develop indices from survey biomass data. Alternative analysis of GOA surveys using the VAST packages has been performed for all the standardized survey years 1984-2015 (C. Cunningham AFSC, pers. comm.). The VAST method estimates approximately 50% more biomass than design-based methods for the period 1990-2000, and approximately 25% more for the period 2005-2015 (Figure 7.4).

Effort on CPUE data since 1984 is available from the NMFS GOA trawl survey (Figure 7.1). CPUE by haul indicates that the highest abundance occurs between about 149 and 156 degrees longitude, to the southwest and to the northeast of Kodiak Island (Figure 7.1). Results show that CPUE is typically highest in the Chirikof region of the central GOA, NMFS area 620. Between 2011 and 2015, the peak CPUE appears to have shifted east from approximately 155W to 150W. There were no locations with CPUE as high as high points from 2015 in the 2017 GOA survey.

Survey age and length compositions

Otoliths from the 1984 to 2015 NMFS trawl surveys have been aged and are used in the model (Table 7.8). Length composition data from 1975, 1985, 1986, 1989, and 2017 are used in the model since age data are not yet available for 2017 and only length data are available for 1975, 1985, 1986, and 1989. Length and age frequency data used in the model from NMFS surveys are shown in Figures 7.4 and 7.6, respectively, and Table 7.9.

Other time series data used in the assessment:

No other data was used in the assessment.

Analytic approach

General Model Structure

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. In November 2015, a new generalized model was accepted by the GOA Plan Team, which can be used to assess the status of arrowtooth flounder stocks in the Bering Sea and Aleutian Islands (BSAI) and Gulf of Alaska (GOA) management areas. This "generalized model" was used in the 2015 and the current assessment, and incorporates ages 1-21+ and estimates selectivity up to age 19, similar to the BSAI assessment model. 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, particularly because 50% maturity occurs at age 7 in 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).

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

The numbers-at-age for years Styr=1961 through Endyr=2017 are computed allowing for fishery selectivity, fishing and natural mortality, and the same plus group.

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

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 189 parameters estimated all models examined in 2017. Four of these parameters were not estimated but were included in the final count. These were 2 female and 2 male slope and $a_{50\%}$ for a descending arm of a dome shaped survey selectivity pattern that were not used in this version of the model.

Parameters were estimating by minimizing the objective function. Several likelihood equations contributed to the final likelihood: recruitment, fishery and survey length compositions, age composition from the survey, and 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). The weights ("Nhauls") applied to the fishery length comps are shown in Table 7.4. Lower weights are applied to length compositions in the years prior to 1989 because the number of hauls are not known. Length comps reflect the number of hauls from 1990-1998 and are generally 200 from then through 2017. The proportion 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, 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 use length data. These years are 1975, 1985, 1986, 1989, and 2017.

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 all standard GOA surveys. For the age composition, the number of hauls was assumed to be 200 for each year of data. The numbers of fish aged in each year are shown in Table 7.8, but only years 1984-2015 were applied to the model. Detailed cruise information for each survey from which age data were taken is shown in Table 7.10.

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 (Stark 2008), $N_{age,year}$ 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 18 selectivity parameters estimated in the model for the smooth selectivity functions were constrained so that the number of effectively free parameters would be less than 18. There were 57 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 1961. Recruitments deviations from 1961 to 2017 account for 57 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 7.A1 shows parameters estimated inside the model.

Description of Alternative Models

Model 15.0: This is the 2015 model with 2015 data.

Model 15.0a: This is the 2015 model with 2017 data. New data is listed below.

1. The 2017 RACE GOA survey biomass estimate and standard error.
2. Catch for 2015 was updated and 2016 and preliminary 2017 catch (to September 26, 2017).

3. Fishery length data was updated for 2016 and 2017.
4. Survey age data was added for 2015.
5. Survey length frequency data was added for 2017.

Model 15.0b: Same as 15.0 but removed a modest penalty on the fishing mortality rate that penalized large values.

Model 17.0: Same model as 15.0a but the length-age conversion matrix was modified using age length data from 1984-2013 based on suggestions from the 2015 Plan Team.

Model 17.0a: Same model as 17.1 but weight at age was recalculated for males and females, using 1977-2013 age data, based on lengths at age obtained from the updated length-age conversion matrix by fitting the length data to weight at age.

Model 17.0b: Same model as 17.1a but an ageing error matrix was added.

Model 17.0c: Same model as 17.0b but fishery length composition data was iteratively reweighted (Francis 2011).

Model 17.0d: Same model as 17.0c but survey length composition data was iteratively reweighted (Francis 2011).

Model 17.0e: Same model as 17.0d but survey age composition data was iteratively reweighted (Francis 2011). This is the authors' preferred model.

Model 17.0f: Same model as 17.0e but biomass variance was iteratively reweighted using the standard deviation of normalized residuals, SDNR.

Model 17.0g: Same model as 17.0f but removed the 1961 and 1975 survey biomass estimates and removed the SDNR adjustment to survey biomass.

Model 17.0h: Lorenzen natural mortalities (a = 0.23, b = -0.8), 1961 and 1975 surveys included (Lorenzen, K. 1996). The natural mortality for ages 1-5 are set to the natural mortality for age 6 fish. No SDNR adjustment.

Model 17.0i: Gislason natural mortality, 1961 and 1975 surveys included. The Gislason natural mortality is multiplied by W=3 to match the natural mortalities previously established for ATF as closely as possible. No SDNR adjustment.

Reviewers from the 2017 Flatfish CIE review suggested using the Lorenzen (1996) natural mortality equation:

(12) $M_{age} = aWt_{age}^{b}$, where a and b are estimated parameters.

In addition, we explored the natural mortality equations of Gislason et al. (2010),

(13) $\ln(M_{age}) = 0.55 - 1.61\ln(L_{age}) + 1.44\ln(L_{\infty}) + \ln(K)$, 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 13 is multiplied by W=3 to match the natural mortalities previously established for ATF.

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% female. 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. Differential natural mortality by sex can be a factor that needs consideration in management of targeted fish stocks, however, since GOA 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 1984-2013 GOA RACE groundfish surveys. There were 9,686 such data points, each associated with age, length, and weight for each fish and 12,308 that had age and length (Table 7.8). Ageing methods have changed throughout the time series but this is not expected to cause bias over time or errors in the earlier datasets (D. Anderl, AFSC Age and Growth, pers. comm.).

Weight at Length

The weight-length relationship for arrowtooth flounder was evaluated to be:

Weight = 0.004312 $\text{Length}^{3.186}$, for both sexes combined, where weight is in grams and length in centimeters. Analysis was performed using nonlinear least squares fit to all weight and length data from the RACE Gulf of Alaska surveys from 1984 to 2013. The nonlinear least squares (nls) method was implemented from the R package stats (Bates and Chambers 1992). The length-weight relationship was the same among male and females (Figure 7.7).

Growth

Growth was estimated from length and age data from RACE Gulf of Alaska surveys from 1984 to 2013 and incorporated in the assessment using a length-age conversion matrix. Length (adjusted for survey length frequencies) was converted to weight with the weight-at-length relationship described above. Length frequencies from stratified sampling for age data was corrected using length frequencies from surveys for which there is more data, averaging 17,000 male and 36,000 females lengths per survey (Table 7.11).

Length at Age

There is a single length-age conversion matrix that converts length frequencies from all years of data to age in the model. This correction is based on Bayes Theorem, as follows (Dorn 1992). The stratified age collections consist of P(Length|Age). These are corrected for the length frequencies in the population by dividing by length frequencies from survey data from the same years, 1984-2013.

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

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 7.8).

A vonBertalanffy 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 (Figure 7.9). The plus group contains all ages 21 and above, and was calculated as a weighted average of the vonBertalanffy 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.

	S_{inf}	K	t_0
Females	837.61404	0.07587	-2.57872
Males	524.1389	0.1672	-1.4684

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

The coefficient of variation (CV) typically decreases with age. This was not the case with the GOA ATF data (Figure 7.10), although Bering Sea females data did fit this pattern. Therefore, female CV of length at age was fitted to a straight line and adjusted slightly so that a normal distribution around the vonBertalanffy estimate of length at age did not reach out of the range of lengths observed. Male variance was also fitted to a linear model, but not adjusted. Parameters of the linear models are shown in the legend in Figure 7.10.

The length-age conversion matrix was generated by simulating 1000 data points for each length observed from survey lengths of arrowtooth flounder, from 90 to 880mm. The simulations were generated from a normal distribution, with the mean length at age determined by the male and female vonBertalanffy fit to the length-age data and the CV for each length determined by the parameters of the linear models presented in Figure 7.10. These data were binned into 26 length categories bounded by the range shown below. These length categories were used for all length composition data in the model. The length-age conversion matrix is shown as Figure 7.11.

Range (cm)	<100	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	90	130	170	190	210	230	250	270	290	310	330	350	370

Range (cm)	380-400	400-430	430-460	460-490	490-520	520-550	550-580	580-610	610-640	640-670	670-700	700-750	>750
Midpts	390	415	445	475	505	535	565	595	625	655	685	725	850

Weight at age

Weight at age used in the model is based on length at age corrected as shown in Figure 7.8 by survey length frequencies. The corrected lengths were applied to the weight at age relationship determined by aged fish shown in Figure 7.7. Weight at age of females determined by this method is slightly lower than weight at age determined by a weight-at-age vonBertalanffy relationship determined from the stratified age collection. Differences in male weight at age were not as significant as differences in female weight at age (Figure 7.12).

Maturity

Maturity at age estimates in the model was based on a maturity-at-length study by Zimmerman (1997) through 2013. Length at 50% maturity was estimated at 47 cm with a logistic slope of -0.3429 from arrowtooth flounder sampled in hauls that occurred in September from the 1993 bottom trawl survey (Zimmerman 1997). Elsewhere in their range, length at 50% maturity was 36.8 cm for females and 28.0 cm for males from survey data in 1992 off Washington, with logistic slopes of -0.54 and -0.893

respectively (Rickey 1995). Arrowtooth flounder had length at 50% maturity of 44 cm for females and 29 cm for males of the coast of Oregon (Rickey 1995). Spawning fish were found in depths from 108m to 360m in March to August in the Gulf of Alaska (Hirshberger and Smith 1983) from analysis of trawl surveys from 1975 to 1981. Most observations of spawning fish have been in the northeastern Gulf, off Prince William Sound, off Cape St. Elias, and Icy Bay.

A newer study was conducted in 2008 that examined maturity-at-age, and is considered a better estimate of maturity because it estimates age at maturity rather than length at maturity (Stark 2008). In this study, a sample of 301 fish was taken in February 2002 and a separate collection (226 fish) was taken in July 2003, both form the central GOA. Parameter estimates based on the February sample were used in the current study because arrowtooth flounder spawn during winter months. The estimate of logistic 50% maturity was 7 years, the logistic slope (B) was 1.3817 and the *y* intercept was -9.6183. Fish matured at a slightly younger age in the 2008 study compared to the 1997 study (Figure 7.13). The maturity ogive from Stark (2008) has been used in the model since 2015.

$$Maturity_{age} = 1/(1+\exp^{-A+B \bullet ages})$$

Likelihood weights

Likelihood weights were adjusted using the methodology of Francis (2011) and are described in more detail in the Model Evaluation section. The parameter s1 in Table 7.12 is

$s1 = [\chi^2_{0.95,m-1}/(m-1)]^{0.5}$, where $\chi^2_{0.95,m-1}$ is the 95[th] percentile of a chi-squared distribution with m-1 degrees of freedom and m is the number of observations (Francis 2011).

Population dynamics

Several aspects of the arrowtooth flounder population dynamics that were not used directly in the model are presented here. Differences in growth show up around the age at maturity at age 6 (Figure 7.14). Age at 50% maturity is age 7 in females, and is 20% in age 6 fish.

There have been some trends in the age data collected for arrowtooth flounder (Figure 7.15). Mean age at length increased throughout the data collection (upper panel) and max age for each year of data also increased (lower panel).

The mean age observed and the maximum age in each year increased throughout the collection (Figure 7.15), even though the number of fish collected did not increase (Table 7.8). The differences in ageing methodology are considered an unlikely cause of this trend (D. Anderl, REFM Age and Growth, pers. comm.). It is not known whether the increase in age is the sign of an increase in population size or due to differences in collecting or ageing otoliths over time.

Whether trends exist in length at age was explored in Figure 7.16. The average length of aged male and female arrowtooth from 1977-2013 is shown for ages 1-16. The line at the bottom of the plot is age 1 (black), followed by age 2 above it (red), etc. The length at age is distinct until around age 9 for females and 7-8 for males. For the years 1977-2013. A linear model was fit to length at each age and whether a significant downward trend over time was observed was measured by the significance of the slope parameter. The average length at age of females declined significantly at younger ages (1,2,3) and of males (2,3,5), but ages greater than 4 did not change significantly. When early years were excluded, so data consisted of 1987-2013, these results changed. There was a significant downward trend in length at age of females age 2, 5, 6, 9, 10, 11, 12, 14 and males age 2, 3, 4, 5, 6, 11. The discrepancy of the results when different years of data were analyzed led to some uncertainty in the overall trends. It appears that there has been some decline in size at age of arrowtooth flounder, but for what ages this applies is uncertain. In addition, there is too little data to estimate annual growth for arrowtooth flounder, and the model is constrained by the length-age conversion matrix. Multiple matrices would be needed if length at age were expected to change over time. This may be a change that can be implemented at a later date.

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. 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). Ageing agreement is 88% at age 1 and declines to 50% at age 5 and 12% at age 15 (Figure 7.17). There is higher variation in the percent agreement at older ages, which could be due to a sampling effect; there are fewer older fish and therefore lower probability of selecting an older fish for double-reading.

Parameters Estimated Inside the Assessment Model

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 19, and the shape of the selectivity curve was constrained to be a smooth function (Figure 7.8). Survey selectivities were modeled using a two parameter ascending 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 female in the fishery and survey length and age data. Selectivity was estimated up to age 19 in the model for both fishery and survey, males and females. The previous model estimated selectivity up to age 11. The increase in maximum selectivity parameters estimated improved the overall fit to the data.

Table 7.A2 shows parameters estimated outside the model.

Results

Response to 2017 Flatfish CIE review

In April 2017 the Alaska Fisheries Science Center hosted an external review of BSAI flatfish. The GOA arrowtooth flounder model is the same as the BSAI arrowtooth flounder model; therefore, some of the comments were applied to the current assessment. Reviewers suggested that alternatives to the fixed natural mortality of 0.35 for males and 0.2 for females be explored. Models Model 17.0h and Model 17.0i examined natural mortality options suggested by CIE reviewers.

Model evaluation

Several new models were introduced this year to respond to Plan Team and SSC comments.

Figure 7.18a shows the predicted survey biomass for Model 15.0 through Model 17.0e. These models all use the standard survey biomass estimates as well as the two earliest biomass estimates from the early 1960s and 1970s and there was no adjustment on the uncertainty of the estimates. The largest change was that trajectory of predicted biomass decreased with the addition of 2017 data, whereas it increased in the 2015 model. Figure 7.18b shows Model 17.0f, which adjusted the CV of survey biomass so that the SDNR was 1.26, which is more favorable than 2.56 in Model 17.03 (Francis 2011, Table 7.12). The parameter *s1* in Table 7.12 is a guideline for the optimal size of the SDNR. Figure 7.18c shows In Model 17.0g the first two survey biomass points were removed, and the result was average biomass for the early period through the 1980s. Models with different values for natural mortality, Lorenzen (1996) Model 17.0h, and Gislason et al. (2010) Model 17.0i follow similar trajectories of spawning and total biomass as the previous models (Figure 7.18d). Predicted female spawning biomass for all models roughly follows the estimates of total biomass (Figure 7.19). All models with the exception of Model 15.0 indicate a decline in total and female spawning biomass since 2010.

Model 17.0b removed a modest penalty on fishing mortality that penalized the likelihood for high fishing mortality values. Removal of this penalty resulted in slightly lower fishing mortality in the early years of the time series, which is reasonable considering that fishing was likely low at that time (Figure 7.21). Overall the overall difference without the fishing mortality penalty was very small.

Model 17.0 incorporated a new length-age transition matrix. This resulted in small changes to the overall estimate of biomass and female spawning biomass (Figures 7.17 and 7.19) but did improve the fit to survey length compositions by providing a more accurate length at age (Figure 7.22). Addition of the updated weight at age (Model 17.0a) decreased weight at age (primarily for females) and had the effect of increasing numbers at age, which was most apparent for younger ages (Figure 7.23).

Model 17.0b added an ageing error matrix, which smoothed the fit to age composition data. The error matrix allowed less specificity in fitting predicted age compositions. A comparison before and after the addition of the ageing error matrix; Model 17.0a vs. Model 17.0b. is shown in Figure 7.24.

Models 17.0c, 17.0d, and 17.0e weighted fishery length compositions, survey length compositions, and survey age compositions (respectively). Weighting resulted in lower weights than the initial weight of 1. The weights for the three compositions were 0.11, 0.12, and 0.12, respectively.

Model 17.0f addressed comments by the Plan Teams and SSC such as: Evaluate additional variance components as the design-based variances may be underestimates. The result of adjusting the multiplier of the survey biomass likelihood was a decrease in the variance on those estimates, which is contrary to the Plan Team comments. Changes in survey biomass and female spawning biomass resulting from adjusting the survey biomass variance are shown in Figures 7.17 and 7.19. The result (Figure 7.18b) is that the trend in biomass in the 1960's and 1970s shows a larger population at that time, although the gradual increase remains. This is in contrast to Model 17.0g in which the two early surveys are removed.

Removal of the first two survey biomass estimates changed the estimates of biomass and female spawning biomass in the 1960-1980 period significantly. However, removal of these points did not change these estimates for the more recent years. Our understanding of the population dynamics of arrowtooth flounder over the past few several decades rests heavily on the biomass estimates in the 1960s and 1970s. These surveys were performed with similar gear as the standard GOA surveys, the biomass estimates are calculated using the same methodology, and the CV is increased to 20% to account for uncertainty, even before SDNR correction (Table 7.6). There is some additional information that suggests that the population has increased in size. Fishery length frequency data (Figure 7.3), survey length frequencies (Figure 7.5), and age frequency data (Figure 7.6) do not show a clear shift in the length distribution in the population. However, if the population was smaller prior to the 1980's it may have retained similar age/length frequencies as it does today. There is a clear increase in maximum and average age in the arrowtooth flounder age collection that includes ages from 1984-2015 (Figure 7.10), but this may be due to extrinsic factors rather than a true change in the age frequency in the population. In addition, the Bering Sea and Aleutian Islands assessment indicates an increase in the arrowtooth flounder population since the 1970s. Therefore, the authors felt that it is important to leave these two biomass estimates in the current assessment.

Model 17.0e was chosen as the authors' preferred model because it incorporated many improvements to the model suggested by the Plan Team, SSC, and CIE reviewers. The model added an improved length age conversion matrix and updated weight at age that takes into account population lengths. It added an ageing error matrix to account for ageing error in the model. It weighted all composition data: length compositions from the survey and fishery as well as the age compositions from the survey. It includes early survey estimates because there did not seem to be a reasonable cause to remove these points. Without these points, the historical trajectory of arrowtooth flounder growth in the Gulf of Alaska would contradict our current paradigm that arrowtooth flounder biomass has increased since the period before the standardized survey began in 1984.

Model 17.0f adjusted the multiplier on the survey biomass likelihood (which was 1 by default). A factor of 2.556 reduced the SDNR to 1.26 from 2.56 (Table 7.12). This had the effect of dividing the standard deviation of the survey biomass estimate by the square root of 2.556, which was contrary to Plan Team comments indicating that the variance of survey biomass appeared too low.

Model 17.0g removed the SDNR correction and also removed the 1961 and 1975 surveys from the time series of survey biomass estimates.

Models 17.0h and 17.0i were an attempt to model natural mortality differently than is currently assumed. This 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.

An alternative explanation for the skewed sex ratio is that the prevalence of females in the survey and fishery data is the result of lower availability for males. If lower availability is assumed, then the 3+ biomass and ABC will be higher, even though the $F_{40\%}$ and female spawning biomass will remain unchanged. However, if males became unavailable to the gear at a fairly constant rate as they age, the same effect could explain the data. Three pieces of evidence indicate the process is linked to natural mortality rather than catchability. First, the survey and fishery data in both the Bering Sea and GOA have about 70% female in the catches, which also points towards a higher M for males. Second, most of the abundance of arrowtooth flounder from survey data occurs at depths less than 300 meters. The fraction female is fairly constant at about 65% to 74% for depths up to 500 meters. In the deepest areas, covered in the 1999 and 1987 surveys, the proportion female was variable, being about 50% in 1987 and 83% in 1999. The data by depth do not indicate that males in any depth strata are less available than in other depth strata. Third, analysis of arrowtooth flounder age data in the Bering Sea show the same phenomena.

The natural mortality at age for Models 17.0e (fixed M), 17.0h (Lorenzen), and 17.0i (Gislason) are shown in Figure 7.25. 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 (Figure 7.26). The trajectory of biomass for Models 17.0h and 17.0i was similar to the preferred model in more recent years but started the population at a smaller size in the 1960's (Figures 7.18, 7.19). Smaller populations consist of younger fish, and the natural mortality at age models incorporate higher natural mortality for those younger ages. The biggest drawback of the Gislason and Lorenzen natural mortality models was a degraded fit to age data (Figure 7.24).

Many of the changes to the model did not result in significant changes (Table 7.12), particularly as measured by average difference in spawning biomass, ADSB, although this may not be the most accurate measure of model changes. All models with 2017 data estimated 189 parameters. The objective function value, which is a proxy for the likelihood function, decreased with model tuning, although this is not a good measure of model fit since the fitting procedure lowers various likelihood components.

Several additional aspects of the final model are highlighted here. The selectivity for fishery and survey are presented in Figure 7.20. Recruitment is shown in Figure 7.26, and indicates patterns that we expect for arrowtooth flounder, which is high recruitment in the 2000's followed by lower recruitment since then and before then. The fit to fishery length compositions is shown in Figure 7.27, and fit to survey length compositions are in Figure 7.28.

Time series results

Female spawning biomass was increased throughout 2007-2015 in the 2015 assessment (Figure 7.19, Model 15.0). However, the addition of the 2017 data resulted in a decreasing trend in female spawning biomass since 2010, for all models explored in this assessment (Figure 7.19). Female spawning biomass in 2017 was estimated (in the current assessment) at 923,548 t, a 24% decrease from the model estimate of female spawning biomass in 2015 (1,221,500 t, from the 2015 assessment, Table 7.1). The 2015 model estimate of age 1+ biomass increased from a low of 390,626 t in 1970 to a high of 2,109,820 in 2009 and slight decrease to 2,093,010 t in 2015 (Table 7.1). The 2017 model estimated higher biomass in 1970, 660,454 t, to a high of 2,076,580 in 2006 and a decrease since that time to 1,463,110 t in 2017. This is due to the removal of the penalty on fishing mortality, which had the effect of reducing fishing mortality in the 1960-1970's. In addition, reweighting the age compositions essentially increased the variance on age frequency resulted in a slightly higher biomass estimate in the 1960s and 1970s, a higher peak of biomass in the 2000's, and a slightly stronger decline since that time.

Age 1 recruitment estimates from the MCMC simulation are shown in Figure 7.29. Recruitment peaked in 2000 at 1.8×10^9, and again in 2004 and 2005 over 1.0×10^9, then a smaller peak just over 7.5×10^9 t in 2012.

Reference fishing mortality rates and yields

Reliable estimates of biomass, $B_{35\%}$, $F_{35\%}$ and $F_{40\%}$, are available for arrowtooth flounder. The current projection model estimate of female spawning biomass is greater than $B_{40\%}$. It is 873,789 t, which is 95% of the unfished biomass estimate of 924,644 t from the current assessment. Therefore, the arrowtooth flounder stock in the Gulf of Alaska is in Tier 3a of the ABC and overfishing definitions. Under this definition, $F_{OFL}= F_{35\%}$, and F_{ABC} is less than or equal to $F_{40\%}$.

Reference points for the 2017 assessment are summarized in Table 7.13. ABC for 2018 using $F_{40\%} =$ 0.196 (2015 assessment $F_{40\%} = 0.171$) was estimated at 150,945 t (2015 ABC was 186,188 t). OFL for 2018 at $F_{35\%} = 0.238$ (2015 assessment $F_{35\%} = 0.204$) was estimated at 180,697 t. Model estimates of fishing mortality have been well below target rates (Figure 7.30). The highest fishing mortality was estimated to be 0.036 in 2014 (Table 7.1), which corresponds with the highest catch on record in 2014 (Table 7.3b).

Maximum sustainable yield

Since there is no estimate of the spawner-recruit relationship for arrowtooth flounder, no attempt has been made to estimate MSY. However, using the projection model described in the next section, spawning biomass with F=0 was estimated at 906,682 t in 2017 (Table 7.14). The equilibrium spawning biomass with fishing at $F_{35\%}$, $B_{35\%}$ was estimated at 342,008 t and $B_{40\%}$ was 323,625 t.

Retrospective analysis

A retrospective analysis was performed, in which data were sequentially removed from the preferred model through 2015, 2013, 2011, 2009, and 2007, and spawning biomass was estimated (Figure 7.33). In each retrospective year, the estimate for spawning biomass was higher than the current model during the respective terminal year. The difference between the current model and the retrospective years shows that the difference between the current model estimate of spawning biomass increases as data is removed and is highest for the 2007 retrospective year (Table 7.34), indicating a potential retrospective bias. Mohn's rho was calculated to be 0.092, which is in the range of other Alaska groundfish assessment models, indicating that the effect of the bias is small.

Harvest Recommendations

Projected catch and abundance

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

For each scenario, the projections begin with the vector of 2017 numbers at age estimated in the assessment (Table 7.14). This vector is then projected forward to the beginning of 2018 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2017. 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 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches. Catch as of September 21, 2017 is extrapolated to be 97.5% of the catch for the year, based on catch for the past 10 years (2009-2016), for a prediction of 20,803 t total catch for 2017 (20,324 t). The 2018 predicted catch of 23,471 t is based on the average of the past 5 years of ATF catches in the GOA (2012-2016).

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 2018, are as follows ("*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 the assessment two years ago recommended in the assessment to the *max* F_{ABC} for the current year. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)
> *Scenario* 3: In all future years, F is set equal to the average of the five most recent years. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
> *Scenario* 4: In all future years, the upper bound on F_{ABC} is set at $F_{60\%}$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)
> *Scenario 5*: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

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

> *Scenario 6*: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above ½ of its MSY level in the current year and above its MSY level in 25 years under this scenario, then the stock is not overfished.)
> *Scenario 7*: In the next two years, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 25 years under this scenario, then the stock is not approaching an overfished condition.)

Projected catch and abundance were estimated using $F_{40\%}$, F equal to the average F from 2012 to 2017 (F=0.024), F equal to one half $F_{40\%}$, and F=0 from 2017 to 2030 (Table 7.14). Under scenario 6 above, the year 2018 female spawning biomass is 860,706 t and the year 2030 spawning biomass is 341,945 t, above the $B_{35\%}$ level of 323,625 t. For scenario 7 above, the year 2030 spawning biomass is 342,008 t, also above $B_{35\%}$. Fishing at $F_{40\%}$, female spawning biomass would still be above $B_{40\%}$ (369,858 t) in year 2030 (376,537 t, Figure 7.31). Female spawning biomass would be expected to decrease by about 40% over the next 12 years, if fishing continues at the last 5-year average fishing mortality (0.024) (Table 7.14, Figure 7.32, Scenario 4).

ABC and OFL for 2018 and 2019

ABC for 2018 using $F_{40\%}$ = 0.196 was estimated at 150,945 t. The projection model was used to estimate the 2019 ABC using an estimated 2018 catch of 23,471 t at 145,234 t. In the 2016 update assessment, the 2018 ABC using $F_{40\%}$ = 0.171 was estimated at 170,510 t. (http://www.afsc.noaa.gov/REFM/Stocks/assessments.htm). An ABC of 150,945 t and an OFL of

180,697 t is recommended for 2018 and an ABC of 145,234 t and an OFL of 173,872 t is recommended for 2019. The stock is not currently being subjected to overfishing, as determined by comparing the complete 2015 and 2016 catch to the specified OFL for that year (Table 7.3b). The stock is not overfished, and is not approaching a condition of being overfished (Figures 7.31 and 7.32).

Ecosystem Considerations

See Appendix B.

Data gaps and research priorities

Analysis of the herding and escapement studies for arrowtooth would result in improved estimates of selectivities and catchability. Otoliths have been aged through the 2009 survey, but continued aging will allow monitoring of growth trends. A correlation between bottom temperatures and catchability has been observed in arrowtooth flounder and other flatfish; whether a similar relationship exists for GOA ATF would provide helpful information for the estimation of catchability. In addition, an examination of catchability may benefit the model. Examination of genetic stock structure of arrowtooth flounder throughout its range is important to delineate stock boundaries and may lead to insight on the migratory behavior and skewed sex ratio of this species.

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Tables

Table 7.1. Estimated total (age 1+) biomass (t), female spawning biomass (FSB) (t) and age 1 recruitment (1,000's), and estimated fishing mortality (*F*), from the current and the 2015 assessment.

Year	1+ biomass 2017	1+ biomass 2015	FSB 2017 assessment	FSB 2015 assessment	Age 1 Recruits 2017 (x1,000)	Age 1 Recruits 2015 (x1,000)	2017 *F*	2015 *F*
1961	660,454	421,726	402,550	286,489	320,780	170,067	0.001	0.002
1962	658,200	415,135	396,491	277,722	312,024	169,265	0.001	0.002
1963	655,709	409,843	390,732	269,440	300,480	165,289	0.001	0.002
1964	652,626	405,378	386,077	262,314	290,452	169,845	0.001	0.002
1965	648,666	401,810	383,055	256,714	280,740	175,320	0.001	0.002
1966	643,784	399,127	381,550	252,571	273,907	186,403	0.007	0.011
1967	636,185	395,981	379,158	247,901	270,558	179,951	0.006	0.01
1968	628,931	394,160	376,980	244,135	278,044	160,770	0.005	0.008
1969	623,424	393,039	374,776	241,375	296,148	129,226	0.004	0.006
1970	621,070	390,626	372,125	239,584	331,903	466,273	0.005	0.009
1971	623,051	406,022	368,226	238,254	387,381	300,667	0.003	0.005
1972	633,921	424,045	364,438	238,422	475,981	566,353	0.013	0.02
1973	654,689	466,379	357,812	236,487	621,190	832,731	0.030	0.044
1974	681,364	532,107	347,543	231,192	662,023	474,029	0.015	0.021
1975	718,011	606,912	344,308	235,161	582,640	342,835	0.008	0.011
1976	765,672	682,328	346,894	253,472	693,426	405,358	0.009	0.011
1977	820,927	744,378	355,237	285,454	763,684	448,124	0.027	0.027
1978	880,015	788,488	366,698	328,185	877,758	500,825	0.023	0.021
1979	951,243	832,184	388,751	385,082	967,783	668,668	0.020	0.017
1980	1,025,080	887,070	418,502	437,470	877,651	673,641	0.019	0.016
1981	1,091,640	948,508	450,683	471,790	735,070	556,769	0.016	0.014
1982	1,149,270	1,009,880	485,924	496,345	680,684	693,984	0.009	0.009
1983	1,201,440	1,078,370	528,837	523,650	697,269	757,709	0.012	0.011
1984	1,253,130	1,145,360	576,575	555,804	884,335	896,677	0.006	0.006
1985	1,321,280	1,227,350	630,045	598,683	1,170,890	974,717	0.002	0.002
1986	1,389,530	1,323,860	681,291	647,268	988,394	666,379	0.002	0.002
1987	1,459,610	1,410,050	722,317	693,396	1,023,300	735,275	0.007	0.007
1988	1,532,820	1,487,500	749,876	736,291	1,179,170	916,511	0.007	0.007
1989	1,600,730	1,559,090	773,795	785,333	1,028,930	736,206	0.003	0.003
1990	1,660,800	1,621,360	805,744	846,525	904,012	686,125	0.010	0.009
1991	1,713,780	1,667,580	843,895	903,970	1,047,170	875,032	0.012	0.011
1992	1,755,040	1,710,410	884,842	950,486	944,598	755,378	0.019	0.016
1993	1,773,450	1,736,810	920,130	982,362	750,150	574,496	0.017	0.016
1994	1,782,690	1,746,870	954,911	1,008,600	800,289	614,004	0.026	0.023
1995	1,776,230	1,736,300	978,182	1,022,980	829,797	683,821	0.020	0.018
1996	1,770,270	1,723,440	997,972	1,034,910	823,725	619,970	0.024	0.022
1997	1,769,730	1,700,170	1,008,190	1,041,290	1,077,690	768,352	0.017	0.016
1998	1,793,380	1,692,380	1,017,650	1,048,020	1,297,600	938,817	0.013	0.013
1999	1,835,310	1,703,410	1,020,210	1,046,640	1,346,420	943,918	0.017	0.016
2000	1,906,500	1,725,840	1,012,410	1,034,220	1,766,770	1,640,110	0.025	0.025
2001	1,957,130	1,794,460	996,990	1,014,920	1,122,680	926,252	0.021	0.021
2002	2,004,400	1,858,460	991,159	1,005,260	1,047,080	950,466	0.022	0.022
2003	2,035,310	1,931,650	997,947	1,006,340	938,466	903,072	0.031	0.03
2004	2,048,680	1,970,000	1,016,940	1,019,770	1,013,960	978,029	0.015	0.015
2005	2,069,910	2,010,430	1,065,750	1,065,840	1,024,700	1,120,920	0.019	0.018
2006	2,076,580	2,040,080	1,118,770	1,124,890	990,331	1,335,910	0.026	0.025
2007	2,054,040	2,073,070	1,155,680	1,172,450	698,779	816,526	0.023	0.022
2008	2,020,760	2,090,960	1,173,220	1,198,700	693,510	1,107,220	0.026	0.025
2009	1,962,540	2,109,820	1,170,930	1,206,030	503,745	701,888	0.022	0.021
2010	1,895,200	2,098,620	1,164,890	1,214,950	495,688	604,712	0.022	0.02
2011	1,826,620	2,070,550	1,156,880	1,231,940	624,089	919,316	0.028	0.026
2012	1,756,300	2,028,960	1,136,320	1,245,960	753,172	1,627,620	0.019	0.017
2013	1,701,770	2,033,570	1,112,380	1,256,950	735,744	1,622,170	0.021	0.018
2014	1,647,660	2,073,910	1,074,570	1,252,250	638,226	748,601	0.036	0.031
2015	1,571,460	2,093,010	1,014,240	1,221,500	431,167	436,000	0.020	0.014
2016	1,520,290		966,248		614,957		0.022	
2017	1,463,110		923,548		436,000		0.024	

Table 7.2. Percent of the Gulf of Alaska stock of arrowtooth flounder retained by commercial fishing operations 1991-2017.

Year	Percent retained
1991	10%
1992	2%
1993	6%
1994	2%
1995	12%
1996	24%
1997	18%
1998	15.8%
1999	26.3%
2000	43.2%
2001	33.2%
2002	49.2%
2003	57.3%
2004	56.5%
2005	60.0%
2006	57.8%
2007	59.2%
2008	69.3%
2009	54.1%
2010	72.8%
2011	76.8%
2012	74.3%
2013	71.4%
2014	90.5%
2015	89.7%
2016	91.2%
2017[1]	93.5%

[1]Data obtained October 29, 2017. Source: AKFIN database (https://akfinbi.psmfc.org/analytics/).

Table 7.3a. Catch, ABC, OFL and TAC for arrowtooth flounder in the Gulf of Alaska from 1964 to 1992. Values are in metric tons.

Year	Catch	ABC	OFL	TAC
1964	514			
1965	514			
1966	2,469			
1967	2,276			
1968	1,697			
1969	1,315			
1970	1,886			
1971	1,185			
1972	4,477			
1973	10,007			
1974	4,883			
1975	2,776			
1976	3,045			
1977	9,449			
1978	8,409			
1979	7,579			
1980	7,848			
1981	7,433			
1982	4,639			
1983	6,331			
1984	3,457			
1985	1,539			
1986	1,221			
1987	4,963			
1988	5,138			
1989	2,584			
1990	7,706	343,300		
1991	10,034	340,100		20,000
1992	15,970	303,889	427,220	25,000

Table 7.3b. Catch, ABC, OFL and TAC for arrowtooth flounder in the Gulf of Alaska from 1993 to September 21, 2017. Values are in metric tons. Arrowtooth flounder ABC was separated from Flatfish ABC after 1990.

Year	Catch	ABC	OFL	TAC
1993	15,559	321,287	451,690	30,000
1994	23,560	236,240	275,930	30,000
1995	18,428	198,130	231,420	35,000
1996	22,583	198,130	231,420	35,000
1997	16,319	197,840	280,800	35,000
1998	12,975	208,337	295,970	35,000
1999	16,207	217,106	308,875	35,000
2000	24,252	145,361	173,915	35,000
2001	19,964	148,151	173,546	38,000
2002	21,231	146,264	171,057	38,000
2003	29,994	155,139	181,394	38,000
2004	15,304	194,900	228,134	38,000
2005	19,770	194,900	228,134	38,000
2006	27,653	177,800	207,700	38,000
2007	25,494	184,008	214,828	43,000
2008	29,293	226,470	266,914	43,000
2009	24,937	221,512	261,022	43,000
2010	24,268	215,882	254,271	43,000
2011	30,903	213,150	251,068	43,000
2012	20,565	212,882	250,100	103,300
2013	21,612	210,451	247,196	103,300
2014	36,294	195,358	229,248	103,300
2015	19,054	189,556	222,160	103,300
2016	19,828	186,188	219,430	103,300
2017	20,283*	186,083	219,327	103,300

*Catch as of September 21, 2017 is extrapolated to be 97.5% of the catch for the year, based on catch for the past 10 years (2009-2016), for a prediction of 20,803 t total catch for 2017.

Table 7.4. The number of fisheries length observations taken by fisheries observers, and the number of hauls from which those samples were taken, by year, 1975-2017 (source: RACE obsint database). Historical foreign and current domestic data were downloaded for this stock assessment (downloaded October 21, 2017).

Year	Number of observations	Number of hauls	Weights applied to fishery length comps	
1975	121			
1976	0			
1977	868		20	20
1978	5,491		20	20
1979	9,499		20	20
1980	4,500		20	20
1981	2,062		20	20
1982	19,139		20	20
1983	14,963		20	20
1984	7,149		20	20
1985	671		20	20
1986	194		20	20
1987	763		20	20
1988	211		20	20
1989	0			
1990	217	7	7	7
1991	5,892	89	95	89
1992	198	2	2	2
1993	1,223	12	12	12
1994	121			
1995	2,628	10	10	10
1996	889	15	15	15
1997	2,999	14	14	14
1998	472	4	6	4
1999	2,642	122	129	122
2000	6,351	293	200	200
2001	6,266	290	200	200
2002	8,275	396	200	200
2003	15,052	730	200	200
2004	4,961	187	200	200
2005	7,073	285	200	200
2006	8,413	309	200	200
2007	10,004	397	200	200
2008	9,271	390	200	200
2009	8,406	306	200	200
2010	7,600	264	200	200
2011	11,282	426	200	200
2012	9,583	403	200	200
2013	8,186	409	200	200
2014	16,346	678	200	200
2015	10,568	547	200	200
2016	8,368	567	200	200
2017	8,198	545	172	160

Table 7.5. Catch (t) of arrowtooth in targeted halibut fisheries by area and year (2003-2017). Source Source: NMFS AKRO BLEND/Catch Accounting System. Downloaded October 30, 2017.

	WGOA Shumagin (610)	CGOA Chirikof (620)	CGOA Kodiak/PWS (630)	EGOA-Yakutat (640)	EGOA-Southeast (650)	Total
2003	11.68	3.11	17.58	1.07	16.57	50.01
2004	13.55	5.9	14.65	3.41	9.96	47.47
2005	10.31	13.34	22.39	5.96	9.32	61.32
2006	4.84	3.85	14.12	5.55	7.16	35.52
2007	10.53	8.17	30.76	12.7	18.11	80.27
2008	6.76	3.92	10.85	2	5.89	29.42
2009	5.94	10.16	25.73	10.44	7.07	59.34
2010	4.08	7.13	27.67	4.55	8.6	52.03
2011	1.34	2.29	9.65	1.99	2.87	18.14
2012	0.58	0.88	2.58	0.26	0.64	4.94
2013	4	25.72	55.7	10.13	11.3	106.85
2014	1.89	15.93	13.76	6.56	4.95	43.09
2015	5.19	5.91	10.71	6.87	5.43	34.11
2016	0.85	1.5	9.85	2.55	2.17	16.92
2017	4.35	5.16	18.85	2.58	2.26	33.2

Table 7.6. Biomass estimates and standard errors from bottom trawl surveys, 1961-2017.

Survey	Biomass(t)	Standard Error	Coefficient of variance (CV)	No. hauls	Maximum Depth(m)
IPHC 1961-1962	283,799	61,515	0.22	1,172	
NMFS groundfish 1973-1976	145,744	33,531	0.23	403	
NMFS triennial 1984	1,112,215	71,209	0.06	930	1,000
NMFS triennial 1987	931,598	74,673	0.08	783	1,000
NMFS triennial 1990	1,907,177	239,150	0.13	708	500
NMFS triennial 1993	1,551,657	101,160	0.07	776	500
NMFS triennial 1996	1,639,632	114,792	0.07	804	500
NMFS triennial 1999	1,262,151	99,329	0.08	764	1,000
NMFS 2001	1,621,892*	178,408	0.11	489	500
NMFS 2003	2,819,095	372,326	0.13	809	700
NMFS 2005	1,899,778	125,788	0.07	839	1,000
NMFS 2007	1,939,055	150,059	0.08	820	1,000
NMFS 2009	1,772,029	159,402	0.09	823	1,000
NMFS 2011	1,747,339	179,801	0.10	670	1,000
NMFS 2013	1,290,727	130,348	0.10	548	700
NMFS 2015	1,659,128	133,986	0.08	772	1,000
NMFS 2017	1,053,695	76,190	0.07	536	700

*The 2001 survey biomass for the eastern gulf was estimated by using the average of the 1993 to 1999 biomass estimates in the eastern gulf.

Table 7.7. Survey biomass estimates (t) for 1993 to 2017 by area; Western (NMFS area 610), Central (areas 620 and 630), and Eastern (areas 640, 650, 649, 659). *The 2001 survey biomass for the eastern gulf was estimated by using the average of the 1993 to 1999 biomass estimates in the eastern gulf.

Year	Western	Central	Eastern
1993	212,332	1,117,361	222,015
1996	202,594	1,176,714	260,324
1999	143,374	845,176	273,490
2001	188,100	1,181,848	251,943*
2003	341,620	2,198,829	282,379
2005	215,287	1,441,111	243,381
2007	263,856	1,437,886	237,313
2009	285,427	1,201,756	284,846
2011	225,683	1,175,072	346,584
2013	205,752	763,845	321,130
2015	237,919	910,561	510,649
2017	311,318	519,312	223,065

Table 7.8. The number of fished aged for collection years from 1977-2015. The methods of otolith reading are as follows: 1. No method specified, 3. Otolith surface reading, 4. Break and burn, 5. Thin section, 6. Break burn toasted, 7. Break no burn, 9. Oven bake flame burn. Note: fish collected from the 2017 GOA survey have not been aged yet. The ageing collection includes 14,098, but only 12,308 fish collected from 1984-2013 were used in the length age conversion matrix.

	Ageing method (percentage)						
Year	1	3	4	6	7	9	Total
1977	100						285
1978	100						888
1984	100						1,293
1987		23	41	28	9		1,534
1990			100				325
1993			100				1,043
1996			100				706
1999			100				931
2001			100				1,384
2003			100				1,034
2005		32		62	3	4	729
2007		5		92	3		786
2009		26	72	2			822
2011		9	6	82	3		899
2013		31		67	2		822
2015		29		69	2		617
Total							14,098

Table 7.9. Length data (cm) from NMFS GOA surveys in 1984 through 2017. The numbers are percentages, where the numbers add to 100 within a year for each sex.

Female	10	16	18	20	22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58	61	64	67	70	75	75+
1984	0.00	0.12	0.23	0.53	1.19	1.62	2.12	2.36	3.17	4.73	4.26	4.72	5.45	7.03	13.25	11.28	7.60	6.73	5.38	3.99	3.32	3.21	3.43	2.70	1.38	0.21
1985	0.00	0.30	0.03	0.51	1.89	2.59	1.58	1.01	1.69	3.18	3.18	4.04	4.81	5.25	9.45	13.59	12.29	7.35	6.06	4.26	3.53	3.14	3.56	3.75	2.58	0.36
1986	0.00	0.00	0.00	0.00	0.13	0.67	1.33	3.47	4.00	6.93	9.07	9.33	7.73	6.27	7.47	9.33	7.07	9.73	5.33	2.00	1.33	2.13	3.07	2.00	1.33	0.27
1987	0.00	0.03	0.12	0.42	1.30	1.56	1.57	2.88	5.84	5.91	4.94	5.50	5.78	5.09	6.92	7.96	10.15	11.36	7.99	3.91	2.26	2.01	1.89	2.39	1.86	0.36
1989	0.00	0.08	0.21	0.53	1.12	2.08	2.59	2.56	3.02	3.04	3.73	4.14	4.86	5.97	11.15	10.53	8.80	10.18	9.39	7.17	3.84	1.74	1.15	0.61	0.93	0.56
1990	0.00	0.13	0.21	0.86	1.62	2.10	2.87	3.44	4.08	5.05	4.72	4.81	5.27	5.55	9.36	9.53	8.92	7.75	7.49	5.92	3.64	2.17	1.36	0.90	1.44	0.80
1993	0.00	0.14	0.28	1.29	2.50	2.85	2.77	2.88	3.15	3.49	3.59	3.93	3.98	4.41	7.35	8.16	8.75	10.17	10.84	8.16	4.40	2.42	1.59	1.23	1.11	0.56
1996	0.01	0.21	0.57	1.89	3.37	4.38	3.39	2.52	2.82	3.41	3.51	3.71	4.32	4.74	7.45	7.35	7.37	9.47	10.94	7.69	3.99	2.36	1.60	1.10	1.26	0.60
1999	0.02	0.21	0.54	2.57	4.11	3.29	2.82	4.08	4.70	4.62	4.60	4.83	4.72	4.25	5.77	5.23	6.20	7.40	8.98	8.55	5.17	2.90	1.78	1.25	0.95	0.44
2001	0.02	0.18	0.55	3.04	7.10	8.20	4.74	2.90	3.53	4.24	4.08	3.90	4.22	4.06	6.08	6.33	6.28	6.32	6.37	5.95	4.38	2.61	1.73	1.32	1.36	0.53
2003	0.01	0.59	0.81	2.29	5.06	5.14	4.43	4.53	5.24	6.07	6.46	6.33	6.25	5.02	5.67	4.97	4.75	5.53	6.39	5.79	3.66	2.07	1.00	0.66	0.83	0.45
2005	0.01	0.57	0.75	1.43	2.23	2.39	3.25	4.22	4.72	4.66	5.00	5.58	5.97	6.56	9.65	8.60	7.45	6.24	6.06	5.50	3.90	2.23	1.23	0.72	0.70	0.40
2007	0.02	0.13	0.64	2.85	4.95	3.79	3.02	4.04	5.15	5.07	3.98	3.30	3.20	3.64	6.05	6.94	9.00	11.49	9.22	5.45	3.34	1.96	1.10	0.71	0.55	0.40
2009	0.01	0.24	0.77	3.66	4.99	3.64	2.97	4.02	5.20	5.46	4.83	4.59	4.42	4.53	5.84	4.96	5.72	9.39	11.03	6.57	3.31	1.65	0.89	0.55	0.51	0.25
2011	0.02	0.19	0.17	0.58	1.85	2.91	2.84	2.64	3.58	4.24	4.10	4.65	5.16	5.24	8.38	8.18	8.52	9.28	10.52	7.97	4.34	2.00	1.08	0.65	0.64	0.26
2013	0.04	0.68	0.30	0.69	2.40	4.68	5.05	3.36	3.35	3.69	3.50	2.77	3.11	3.54	6.72	7.96	10.59	11.95	9.98	7.70	4.39	1.80	0.74	0.38	0.43	0.22
2015	0.01	0.24	0.33	0.57	1.68	3.61	4.72	6.11	7.18	8.76	7.18	4.63	3.87	3.72	4.99	5.16	6.76	8.91	9.32	6.40	3.38	1.33	0.59	0.27	0.20	0.08
2017	0.01	0.2	0.35	1.47	2.34	3.33	3.67	3.33	4.34	4.71	5.47	6.32	7.2	7.99	9.77	7.91	6.94	7.09	6.29	4.56	3.09	2.02	0.89	0.4	0.22	0.09
Male	10	16	18	20	22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58	61	64	67	70	75	75+
1984	0.00	0.38	0.49	1.37	2.43	3.45	4.09	5.18	7.22	8.39	7.70	8.55	11.98	13.84	14.03	6.23	2.39	1.07	0.37	0.24	0.16	0.12	0.16	0.13	0.03	0.02
1985	0.00	0.40	0.02	0.80	4.52	5.58	2.80	2.18	4.81	8.03	10.48	11.59	11.01	11.68	14.45	7.52	3.11	0.62	0.20	0.07	0.07	0.04	0.04	0.00	0.00	0.00
1986	0.00	0.22	0.22	0.00	0.65	2.17	3.04	4.12	4.99	18.66	16.27	10.85	11.93	7.81	9.11	5.21	2.82	1.52	0.22	0.00	0.00	0.00	0.22	0.00	0.00	0.00
1987	0.00	0.19	0.26	0.85	1.85	2.48	2.61	5.17	9.69	9.29	9.49	11.47	9.46	8.96	13.20	9.48	3.54	1.10	0.44	0.20	0.11	0.04	0.06	0.03	0.01	0.01
1989	0.00	0.10	0.40	0.64	0.94	2.38	3.32	3.85	4.49	4.82	5.73	5.43	6.13	10.21	22.84	17.82	8.67	1.84	0.30	0.03	0.03	0.00	0.00	0.00	0.00	0.03
1990	0.00	0.20	0.31	1.35	2.53	2.62	3.75	4.81	5.95	7.18	7.21	7.47	7.79	8.79	16.12	14.41	6.89	1.74	0.51	0.17	0.05	0.05	0.04	0.04	0.01	0.00
1993	0.00	0.23	0.57	2.42	3.85	3.63	3.31	4.19	4.59	4.73	5.06	5.37	6.41	7.80	15.83	16.61	11.29	3.10	0.53	0.21	0.12	0.05	0.06	0.03	0.02	0.00
1996	0.01	0.57	0.99	2.68	5.64	6.07	4.35	3.18	3.67	4.52	5.14	5.41	5.94	6.83	11.99	16.26	11.72	3.94	0.72	0.13	0.11	0.08	0.02	0.02	0.01	0.00
1999	0.05	0.50	1.05	4.33	6.51	4.81	4.11	5.57	6.11	5.70	5.79	5.99	5.74	5.84	9.85	11.93	10.58	4.45	0.77	0.16	0.10	0.02	0.01	0.02	0.01	0.01
2001	0.02	0.40	1.01	5.59	11.92	10.80	5.67	4.34	5.62	5.72	5.37	5.19	5.42	4.74	8.93	8.31	6.73	3.66	0.53	0.02	0.01	0.00	0.00	0.00	0.00	0.00
2003	0.00	1.47	1.15	3.83	7.18	7.49	5.67	5.34	6.81	8.04	8.45	8.01	7.33	5.58	8.37	7.45	4.86	2.18	0.57	0.13	0.04	0.00	0.03	0.00	0.01	0.00
2005	0.02	1.29	1.64	2.71	4.00	4.27	5.54	6.39	6.34	6.08	6.34	6.69	8.39	9.80	14.09	8.56	4.69	2.22	0.67	0.15	0.06	0.04	0.00	0.02	0.01	0.00
2007	0.02	0.22	1.15	4.34	7.04	4.82	4.28	6.17	7.31	6.67	4.74	3.86	4.28	6.39	16.16	14.15	5.43	2.07	0.70	0.12	0.03	0.04	0.02	0.02	0.00	0.00
2009	0.03	0.52	1.60	5.82	6.60	5.16	3.94	5.44	6.70	6.42	5.42	5.26	5.89	6.26	12.29	13.35	6.30	2.23	0.58	0.13	0.02	0.01	0.01	0.00	0.01	0.00
2011	0.01	0.32	0.60	1.14	3.47	4.90	4.03	4.51	6.28	5.82	5.64	6.16	6.96	8.02	15.40	15.15	8.19	2.63	0.61	0.11	0.03	0.01	0.00	0.01	0.01	0.00
2013	0.02	0.48	0.34	1.13	4.11	6.10	5.27	4.71	5.21	5.42	4.05	4.17	5.68	7.20	15.31	17.01	9.48	3.51	0.59	0.15	0.03	0.02	0.01	0.01	0.00	0.00
2015	0.01	0.26	0.42	0.79	2.74	4.46	6.55	7.81	9.68	9.72	5.87	4.86	5.56	5.76	10.75	12.87	8.24	2.95	0.54	0.12	0.02	0.01	0.00	0.01	0.00	0.00
2017	0.02	0.27	0.56	2	3.38	4.68	5.46	6.51	6.17	7.03	7.72	9.54	9.8	9.14	10.61	9.31	5.95	1.62	0.13	0.05	0.02	0.00	0.01	0.00	0.00	0.00

Table 7.10. Cruise information from which age data is available for ATF from 1984-2015 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	Start Date
1984-01	Gulf of Alaska Bottom Trawl Survey	52.43	-145.56	1293	Jul. -Oct
1987-01	Gulf of Alaska Bottom Trawl Survey	53.20	-166.92	1373	May-Jul.
1987-02	Gulf of Alaska Bottom Trawl Survey	52.40	-149.47	161	Aug. 5
1990-01	Gulf of Alaska Bottom Trawl Survey	52.45	-144.97	325	Jun. 4
1993-01	Gulf of Alaska Bottom Trawl Survey	52.61	-144.57	660	Jun. 6
1993-09	Gulf of Alaska Bottom Trawl Survey	54.80	-144.09	383	Jul. 23
1996-01	Gulf of Alaska Bottom Trawl Survey	52.64	-169.82	706	May 22
1999-01	Gulf of Alaska Bottom Trawl Survey	52.51	-169.91	931	May 16
2001-01	Gulf of Alaska Bottom Trawl Survey	52.64	-169.78	1384	May 20
2003-01	Gulf of Alaska Bottom Trawl Survey	52.54	-169.69	1034	May 20
2005-01	Gulf of Alaska Bottom Trawl Survey	52.48	-169.78	729	May 20
2007-01	Gulf of Alaska Bottom Trawl Survey	52.57	-169.91	786	May 25
2009-01	Gulf of Alaska Bottom Trawl Survey	52.46	-169.92	822	May 18
2011-01	Gulf of Alaska Bottom Trawl Survey	52.46	-169.87	899	May 18
2013-01	Gulf of Alaska Bottom Trawl Survey	52.60	-169.67	822	May 24
2015-01	Gulf of Alaska Bottom Trawl Survey			617	May 27

Table 7.11. The number of male and female arrowtooth flounder lengths recorded on NMFS GOA surveys, 1984-2017.

Year	Male	Female
1984	17,858	28,308
1987	19,828	45,979
1990	16,829	37,574
1993	19,311	46,558
1996	17,822	38,306
1999	16,653	36,828
2001	10,357	24,383
2003	22,878	49,979
2005	19,647	45,362
2007	19,891	42,763
2009	19,959	42,695
2011	15,626	31,708
2013	10,870	19,735
2015	20,605	36,822
2017	12,740	22,427

Table 7.12. Likelihood components for all models presented in this assessment. For each model number likelihood (L.) values are given in this order: survey biomass likelihood, fishery length composition likelihood, survey length composition likelihood, survey age composition likelihood, catch likelihood, recruitment likelihood, fishery selectivity likelihood, survey selectivity likelihood, S1 (the maximum SDNR value expected given the number of biomass estimates, Francis 2011), standard deviation of normalized residuals (SDNR), the number of parameters estimated in the model, the average deviation of spawning biomass from one model to the previous model, and the objective function value. *Preferred model.

Model Number	Surv. Biom. L.	Fish. Len. L.	Surv. Len. L.	Surv. Age L.	Catch L.	Rec. L.	Fish sel. L.	Surv. sel. L.	S1	SDNR	#Params	ADSB	Obj. Fun.
Model 15.0	51.95	1392.64	191.71	404.62	0.00	40.58	9.94	13.12			185	-	
Model_15.0a	58.35	1314.38	161.50	380.93	6.84E-07	42.22	11.19	13.44	1.27	2.71	189	-	1053.02
Model_15.0b	62.42	1272.22	164.66	386.95	1.70E-07	33.00	11.05	13.40	1.27	2.81	189	0.02	1007.53
Model_17.0	68.58	1311.25	136.53	373.28	2.03E-07	27.00	4.02	9.25	1.27	2.94	189	0.09	964.48
Model_17.0a	69.28	1398.86	134.36	368.17	2.13E-07	27.03	4.03	9.24	1.27	2.96	189	0.04	979.83
Model_17.0b	69.94	1400.88	132.43	283.50	1.97E-07	24.72	3.89	9.27	1.27	2.97	189	0.01	891.97
Model_17.0c	63.03	676.98	137.20	292.75	1.44E-07	27.16	1.25	4.67	1.27	2.82	189	0.04	615.87
Model_17.0d	58.33	714.80	154.90	328.32	1.02E-07	22.85	1.22	4.64	1.27	2.71	189	0.04	527.36
Model_17.0e*	51.93	714.34	134.99	298.92	2.16E-08	20.78	1.23	5.13	1.27	2.56	189	0.02	224.20
Model_17.0f	11.69	674.20	128.83	295.41	1.01E-08	9.56	1.23	5.16	1.27	1.26	189	0.16	185.56
Model_17.0g	6.87	720.43	134.32	296.49	1.18E-08	3.79	1.24	5.18	1.29	1.00	189	0.00	171.66
Model 17.0h	8.75	568.16	150.82	414.92	1.33E-04	5.22	8.12	9.84	1.29	1.12	189	0.06	375.85
Model 17.0i	8.60	680.87	237.57	687.22	4.11E-05	4.68	3.29	9.63	1.29	1.11	189	0.03	210.98

<u>Brief model descriptions (each model builds on previous one):</u>
Model 15.0: 2015 model with 2015 data.
Model 15.0a: 2015 model with 2017 data added.
Model 15.0b: Removed penalty on fishing mortality.
Model 17.0: Added new length age conversion matrix.
Model 17.0a: Added adjusted weight at age.
Model 17.0b: Added ageing error matrix.
Model 17.0c: Weighted fishery length comps.
Model 17.0d: Weighted survey length comps.
Model 17.0e: Weighted age comps (survey).
Model 17.0f: Biomass likelihood weighting (SDNR).
Model 17.0g: Removed 1961,1975 surveys, adjusted SDNR.
Model 17.0h: Included early surveys, Lorenzen (1996) natural mortality.
Model 17.0i: Included early surveys, Gislason et al (2010) natural mortality.

Table 7.13. Summary of results of arrowtooth flounder assessment in the Gulf of Alaska.

Natural Mortality		0.2 females 0.35 males
Age of full (95%) fishery selection		11 females, 10 males
Reference fishing mortalities		
	F_{OFL}	0.238
	F_{ABC}	0.196
Biomass at MSY		N/A
Equilibrium unfished Female Spawning biomass		924,644
$B_{40\%}$ Female Spawning biomass fishing at $F_{40\%}$		369,858
$B_{35\%}$ Female Spawning biomass fishing at $F_{35\%}$		323,625
2017 ABC		150,945
2017 OFL		180,697
Projected 2017 biomass		
	Total(age 1+)	1,421,306
	Spawning	873,789

Table 7.14. Projections of arrowtooth flounder female spawning biomass (1,000s t), future catch (1,000s 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
2017	906,682	906,682	0.024
2018	873,789	873,789	0.028
2019	835,009	835,009	0.196
2020	705,523	705,523	0.196
2021	596,706	596,706	0.196
2022	510,307	510,307	0.196
2023	446,744	446,744	0.196
2024	406,707	406,707	0.196
2025	386,348	386,348	0.192
2026	377,668	377,668	0.188
2027	374,946	374,946	0.187
2028	375,041	375,041	0.186
2029	375,531	375,531	0.186
2030	375,864	375,864	0.186

Scenario 3
F set to average of 5 most recent years

Year	Female spawning biomass	catch	F
2017	906,682	20,803	0.024
2018	873,789	23,470	0.028
2019	845,296	19,273	0.024
2020	820,247	18,697	0.024
2021	788,775	18,105	0.024
2022	757,410	17,539	0.024
2023	731,217	17,067	0.024
2024	715,936	16,780	0.024
2025	712,415	16,705	0.024
2026	715,359	16,800	0.024
2027	720,709	16,989	0.024
2028	727,850	17,203	0.024
2029	734,566	17,397	0.024
2030	740,895	17,577	0.024

Scenario 4
Upper bound of F set to $F_{60\%}$

Year	Female spawning biomass	catch	F
2017	906,682	20,803	0.024
2018	873,789	23,470	0.028
2019	841,218	71,100	0.092
2020	772,729	65,393	0.092
2021	705,886	60,289	0.092
2022	646,601	55,912	0.092
2023	599,057	52,454	0.092
2024	567,636	50,132	0.092
2025	551,663	48,892	0.092
2026	544,624	48,463	0.092
2027	541,871	48,492	0.092
2028	541,826	48,671	0.092
2029	542,277	48,858	0.092
2030	542,886	49,041	0.092

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2017	908,278	0	0.000
2018	893,254	0	0.000
2019	882,896	0	0.000
2020	871,114	0	0.000
2021	850,758	0	0.000
2022	828,560	0	0.000
2023	809,737	0	0.000
2024	800,383	0	0.000
2025	801,724	0	0.000
2026	808,797	0	0.000
2027	817,626	0	0.000
2028	828,031	0	0.000
2029	837,691	0	0.000
2030	846,847	0	0.000

Table 7.14. (continued).

Scenario 6
Determination of whether arrowtooth flounder are currently overfished
B35=323,625

Year	Female spawning biomass	catch	F
2017	906,682	20,802	0.024
2018	860,706	195,893	0.238
2019	702,599	162,059	0.238
2020	582,528	137,249	0.238
2021	485,944	118,116	0.238
2022	412,352	103,386	0.238
2023	361,085	92,578	0.232
2024	333,555	82,468	0.213
2025	326,859	75,802	0.207
2026	328,814	74,067	0.208
2027	333,131	74,393	0.210
2028	337,471	75,275	0.211
2029	340,378	75,966	0.213
2030	341,945	76,439	0.214

Scenario 7
Determination of whether arrowtooth flounder are approaching an overfished condition
B35=323,625

Year	Female spawning biomass	catch	F
2017	906,682	20,803	0.024
2018	863,341	150,941	0.196
2019	729,233	127,398	0.196
2020	621,443	131,069	0.238
2021	514,910	110,464	0.238
2022	433,563	95,246	0.238
2023	376,255	84,765	0.238
2024	342,944	73,092	0.219
2025	332,258	69,050	0.211
2026	331,813	69,043	0.209
2027	334,687	70,388	0.210
2028	338,200	71,697	0.212
2029	340,661	72,633	0.213
2030	342,008	73,269	0.214

Figures

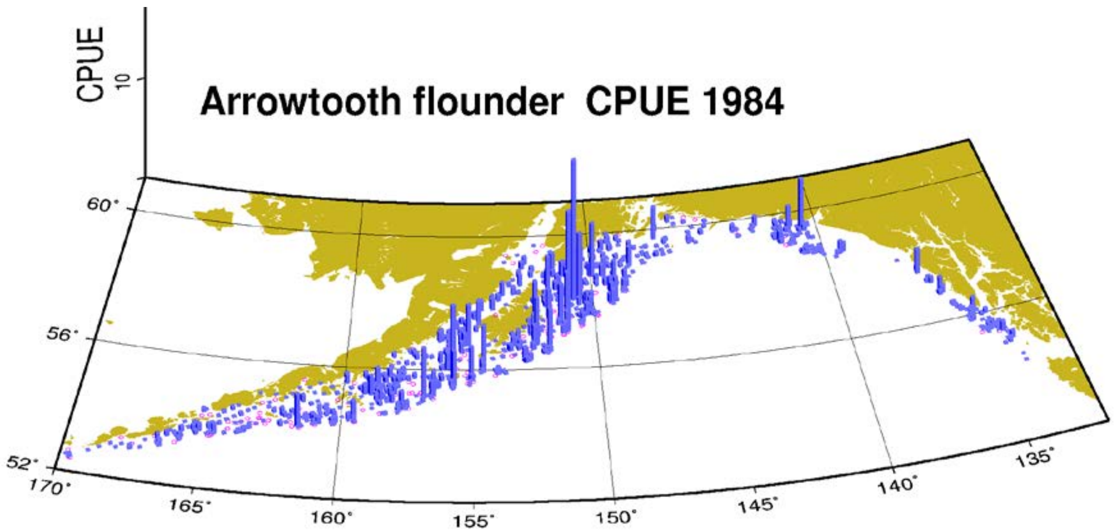


Figure 7.1a. Arrowtooth flounder 1984 survey cpue by tow.

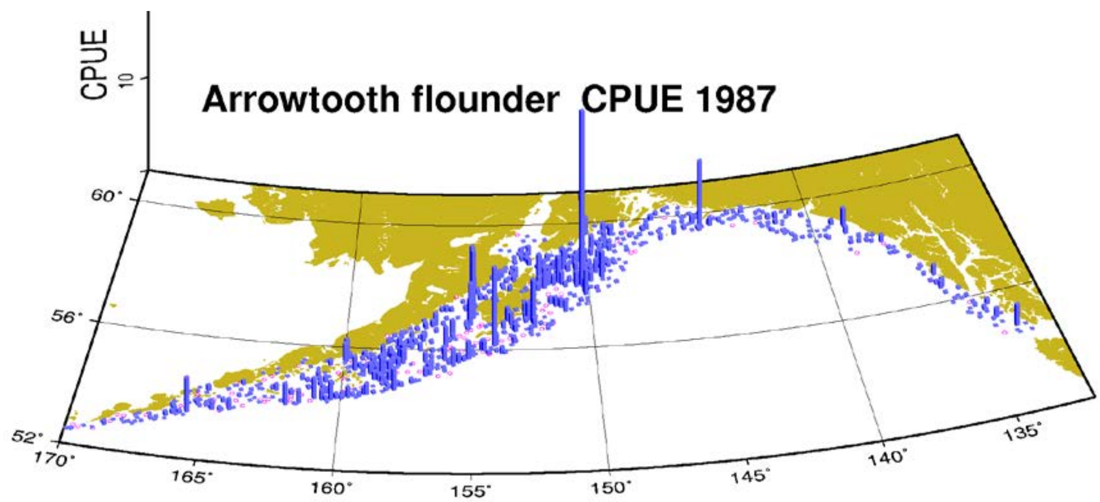


Figure 7.1b. Arrowtooth flounder 1987 survey cpue by tow.

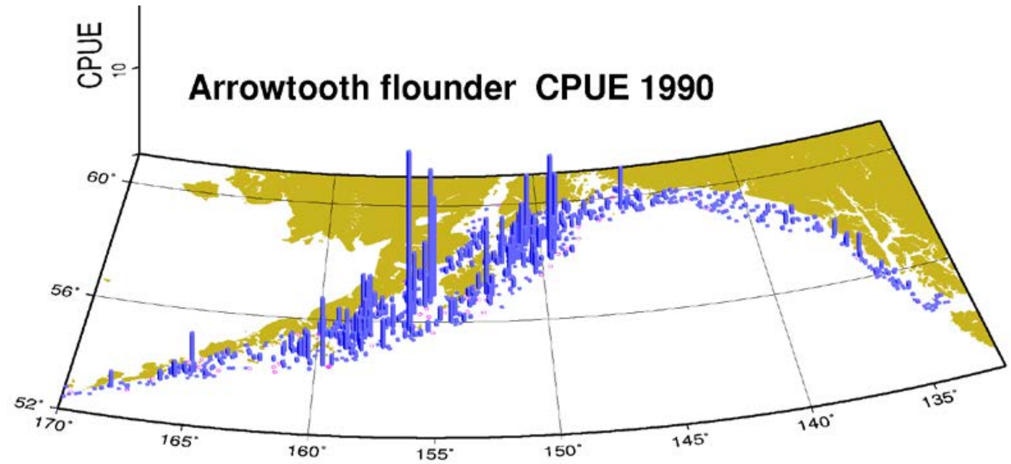


Figure 7.1c. Arrowtooth flounder 1990 survey cpue by tow.

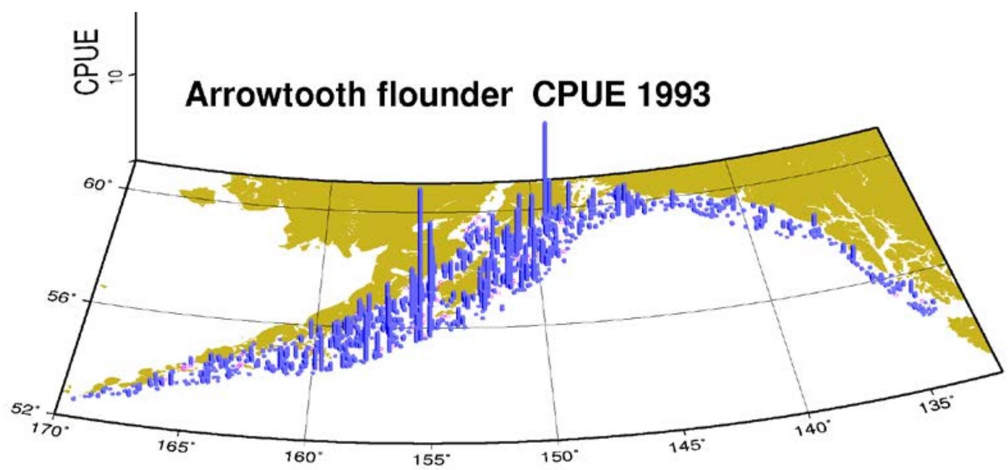


Figure 7.1d. Arrowtooth flounder 1993 survey cpue by tow.

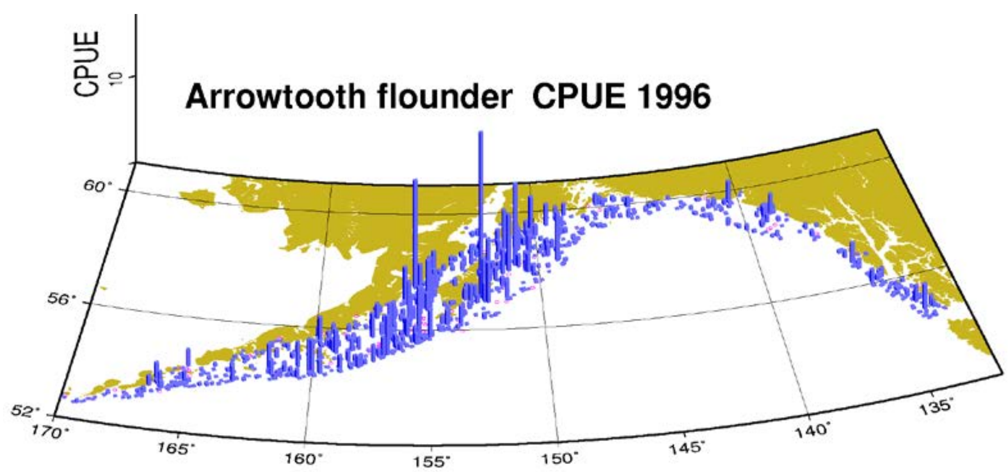


Figure 7.1e. Arrowtooth flounder 1996 survey cpue by tow.

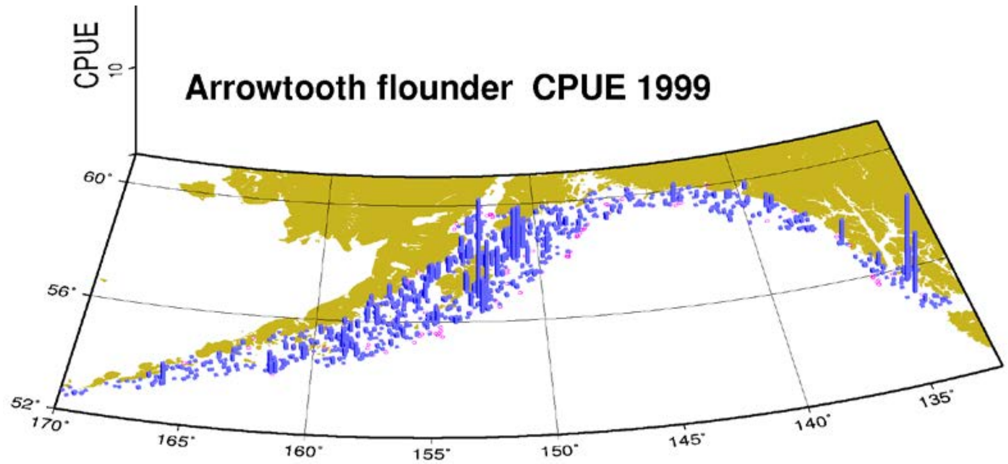


Figure 7.1f. Arrowtooth flounder 1999 survey cpue by tow.

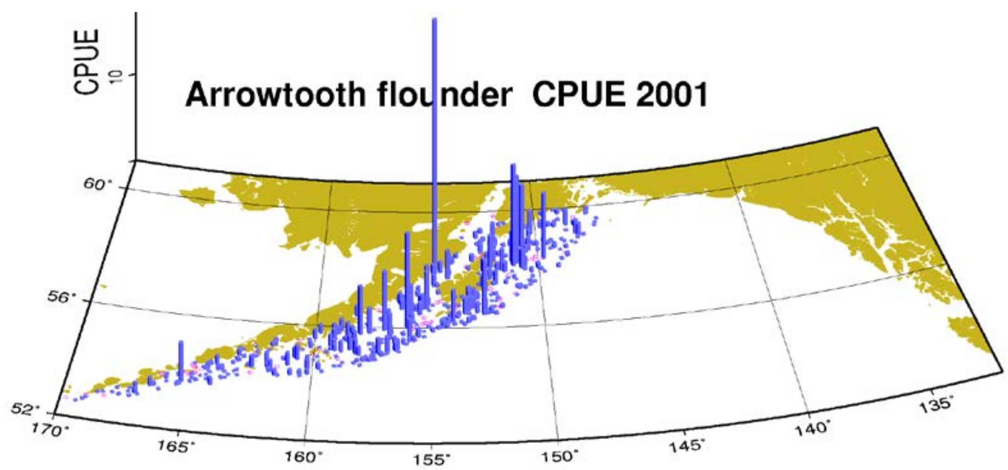


Figure 7.1g. Arrowtooth flounder 2001 survey cpue by tow.

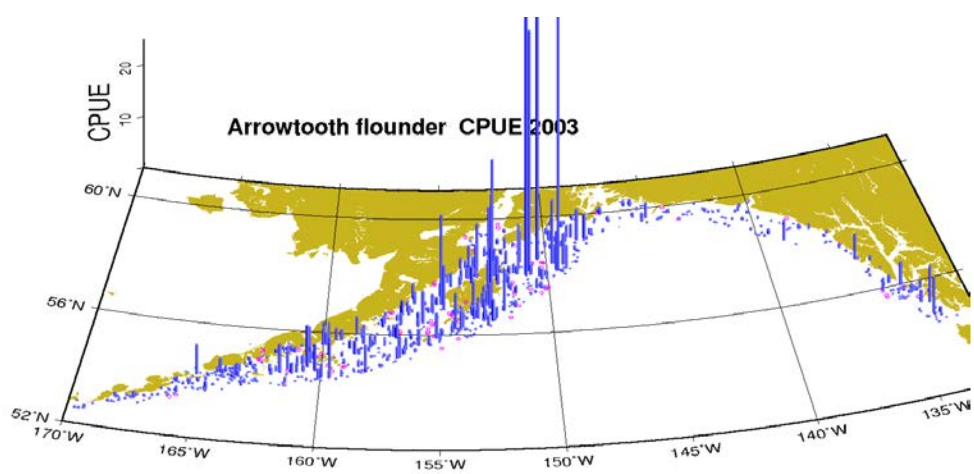


Figure 7.1h. Arrowtooth flounder 2003 survey cpue by tow.

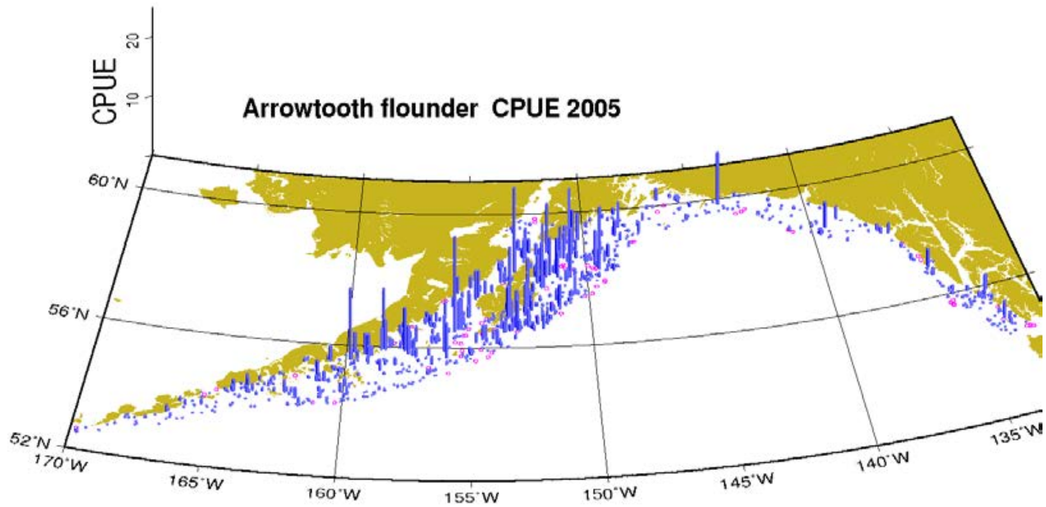


Figure 7.1i. Arrowtooth flounder 2005 survey cpue by tow.

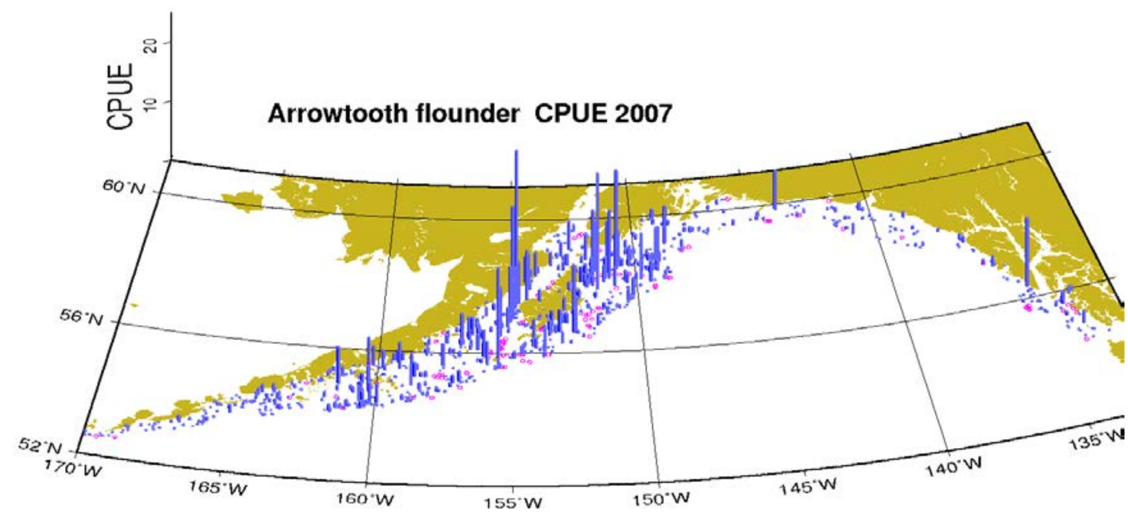


Figure 7.1j. Arrowtooth flounder 2007 survey cpue by tow.

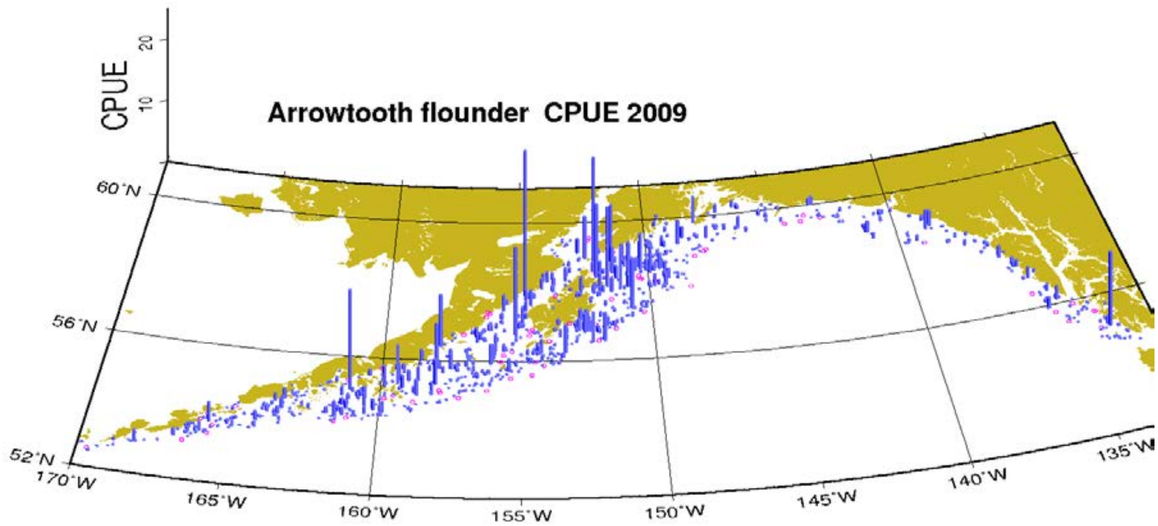


Figure 7.1k. Arrowtooth flounder 2009 survey cpue by tow.

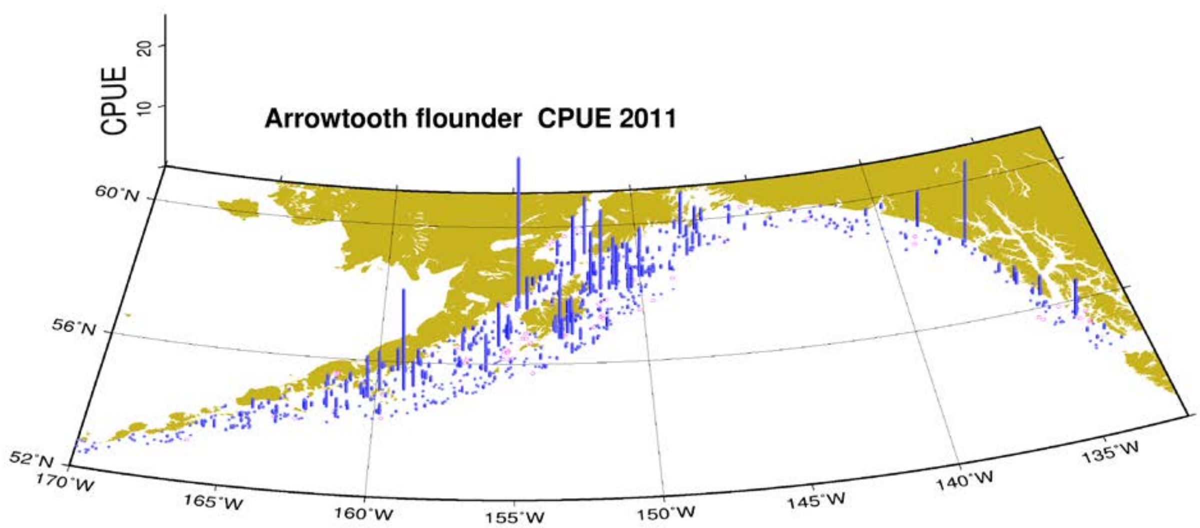


Figure 7.1l. Arrowtooth flounder 2011 survey cpue by tow.

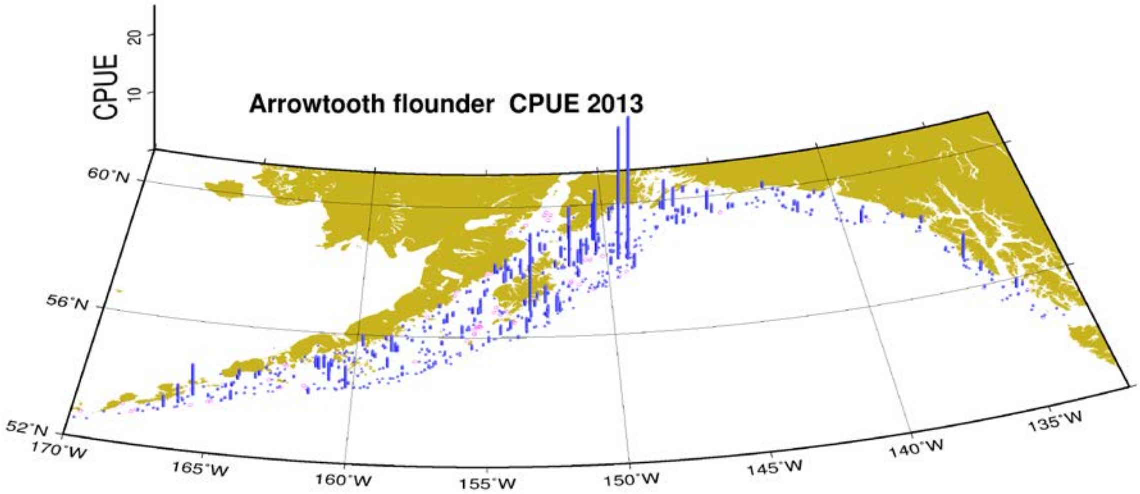


Figure 7.1m. Arrowtooth flounder 2013 survey cpue by tow.

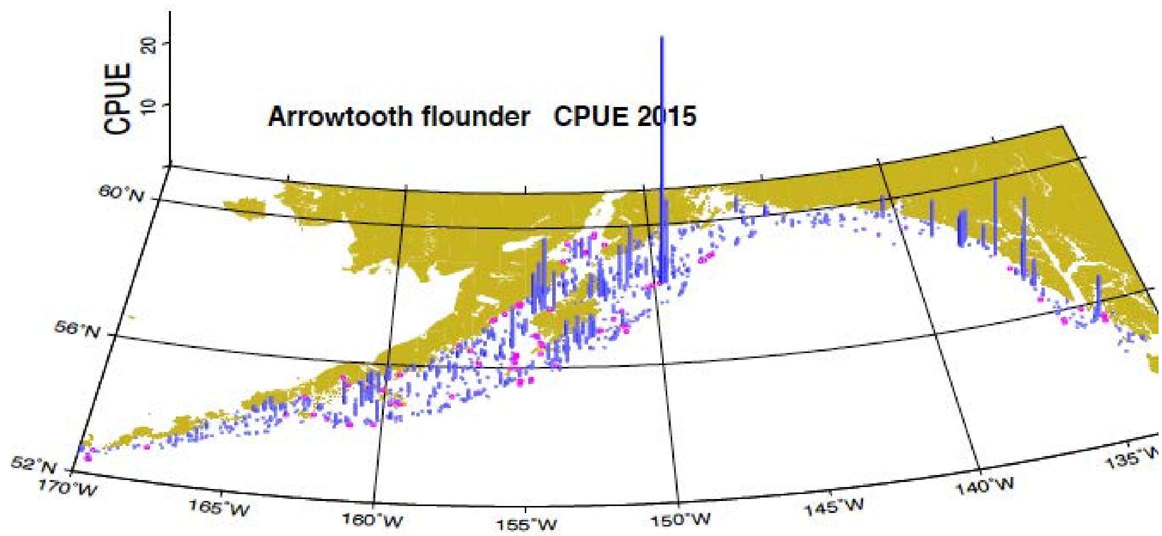


Figure 7.1n. Arrowtooth flounder 2015 survey cpue by tow.

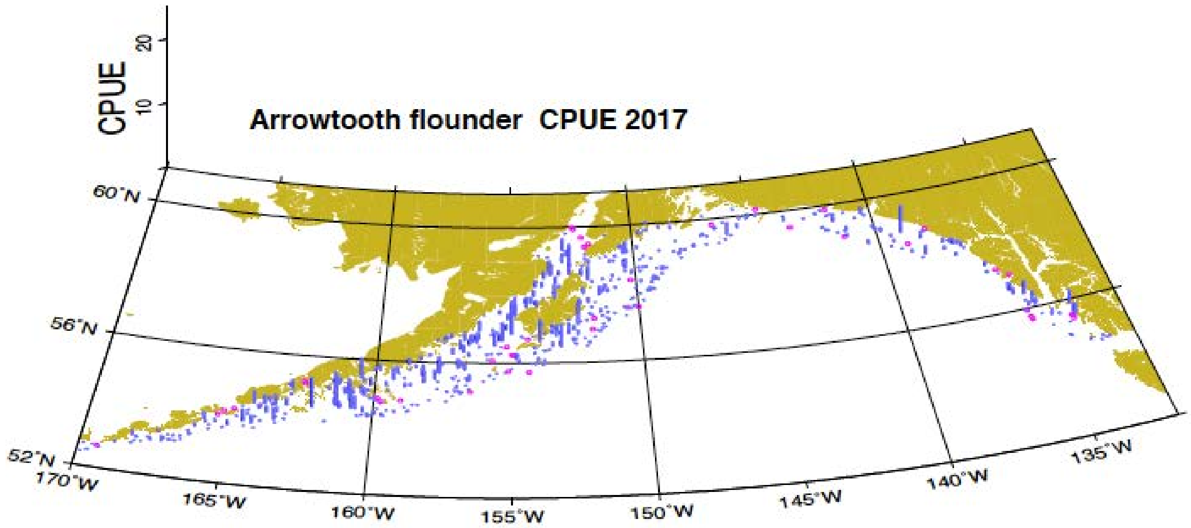


Figure 7.1o. Arrowtooth flounder 2017 survey cpue by tow.

Figure 7.2. Length frequency data was re-downloaded for the 2015 assessment, green bars for historical data, prior to 1990 and yellow bars for 1990 and later. Blue bars show the number of length frequency observations for the 2013 assessment.

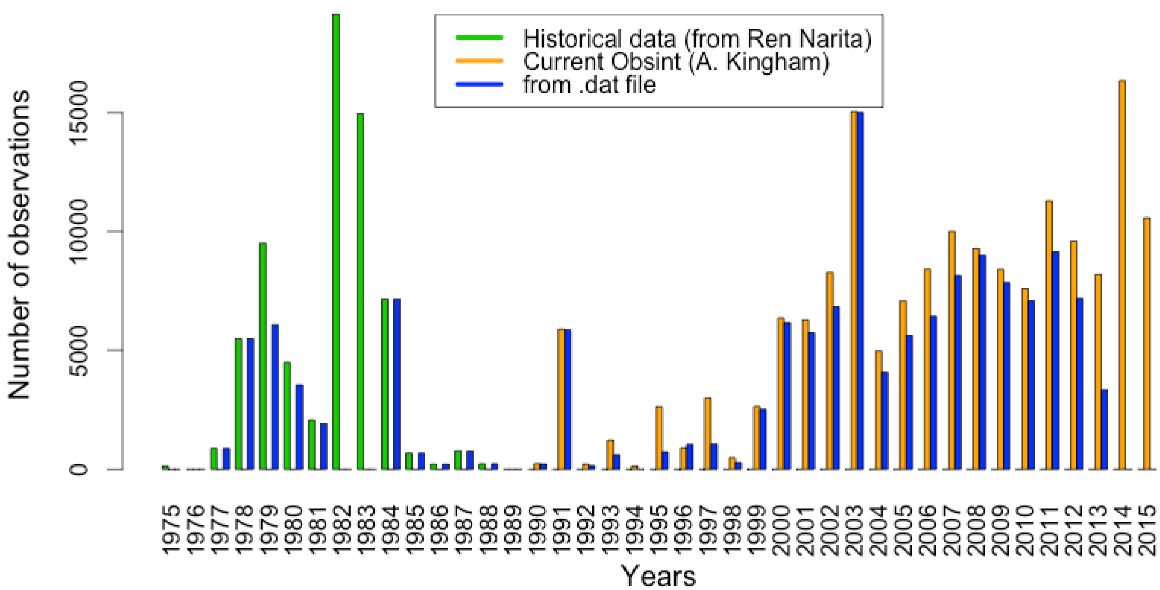
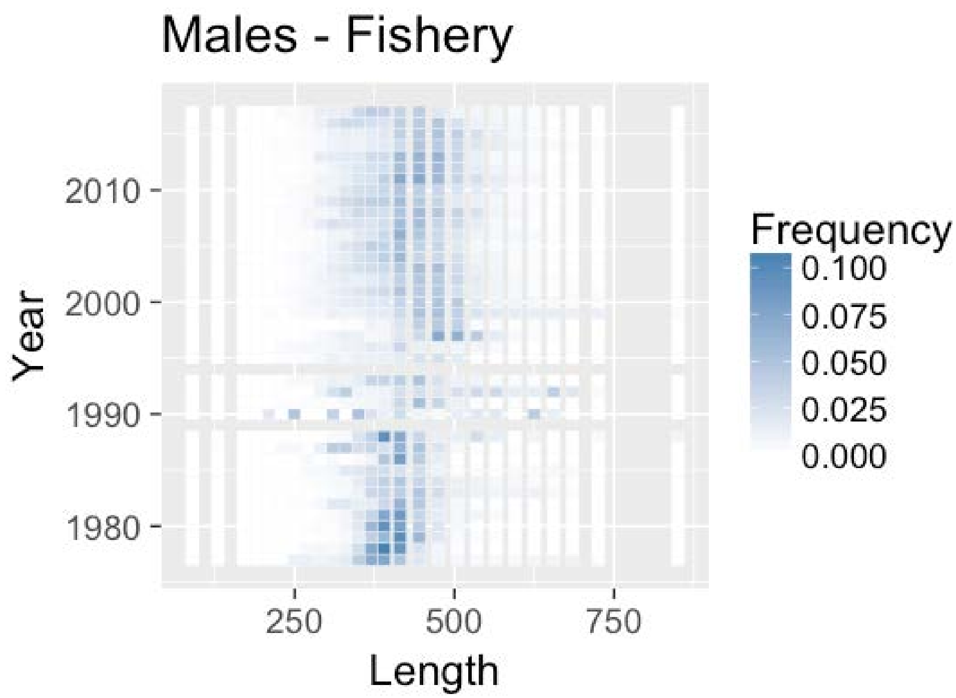


Figure 7.3. Length frequency data for fishery data, females above, males below.



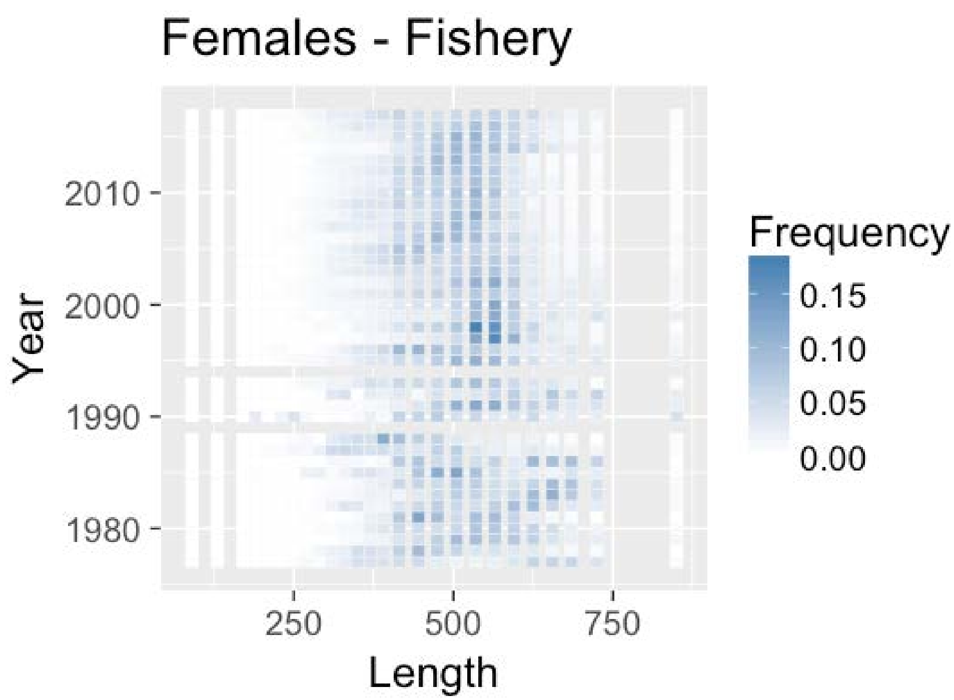


Figure 7.4. VAST model estimates of survey biomass from standard GOA survey data, 1984-2015, compared with design-based estimates.

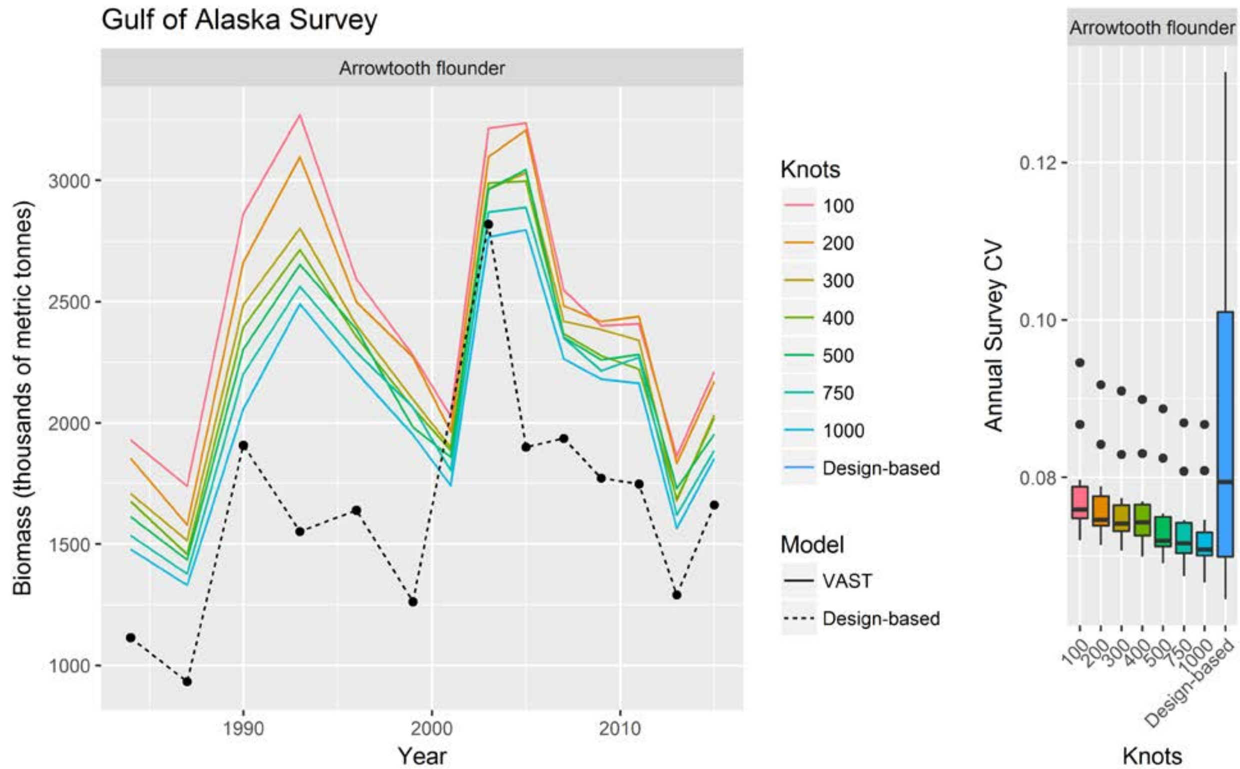
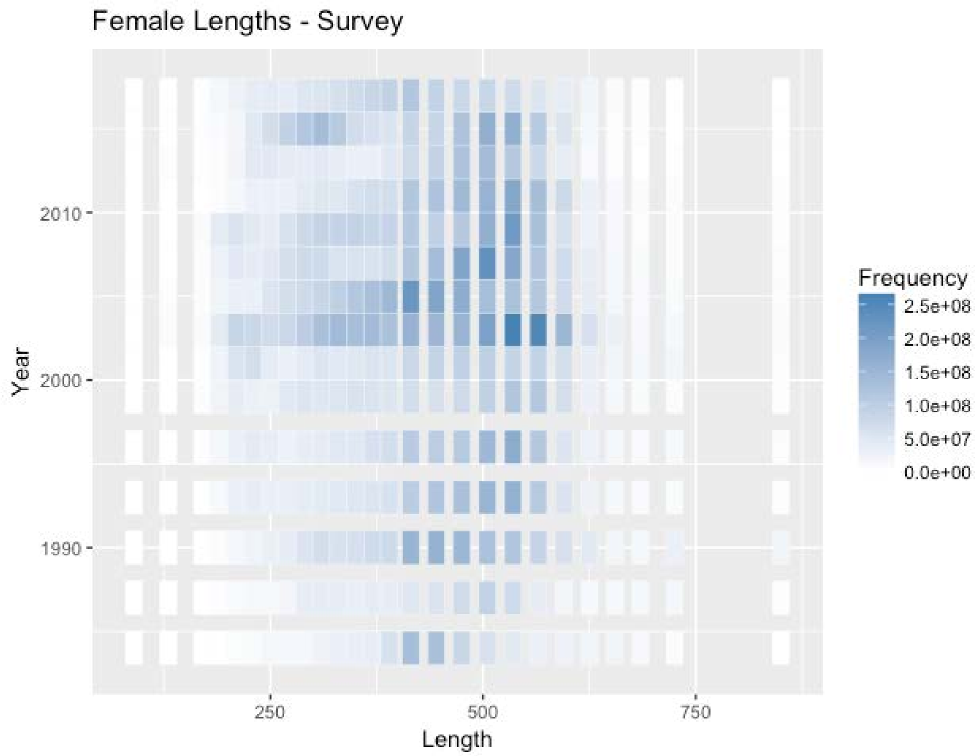


Figure 7.5. Length frequency data for all survey data, females above, males below. Note that only length composition data from 1975, 1985, 1986, 1989, and 2017 are used in the model since age data are not yet available for 2017 and only length data are available for 1975, 1985, 1986, and 1989.



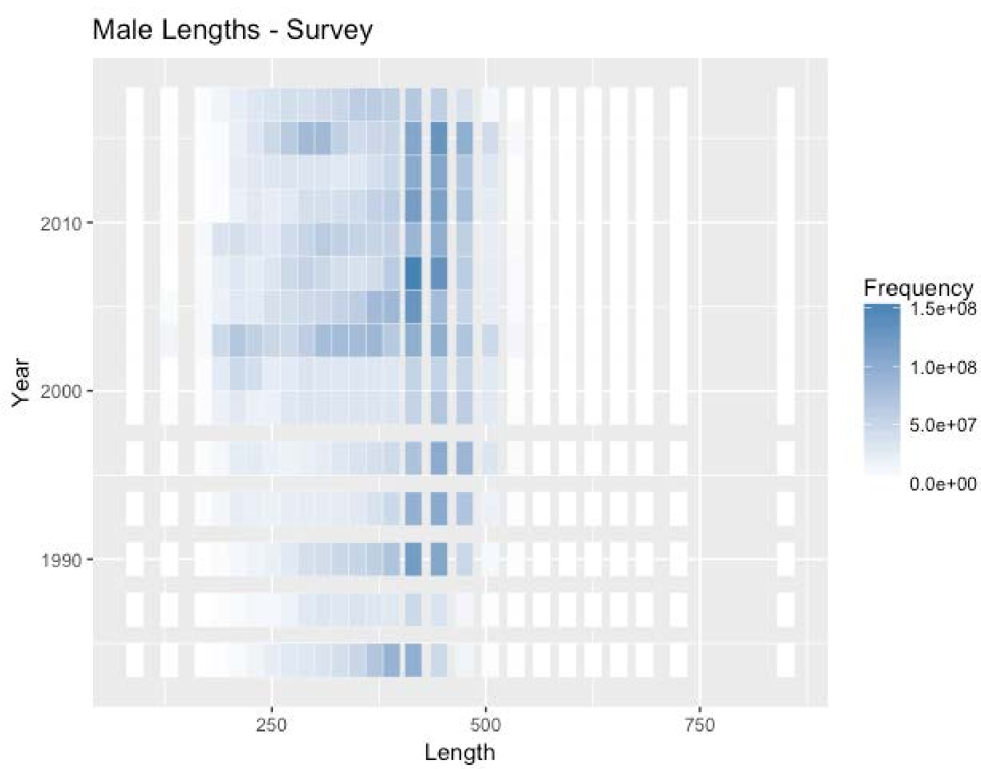
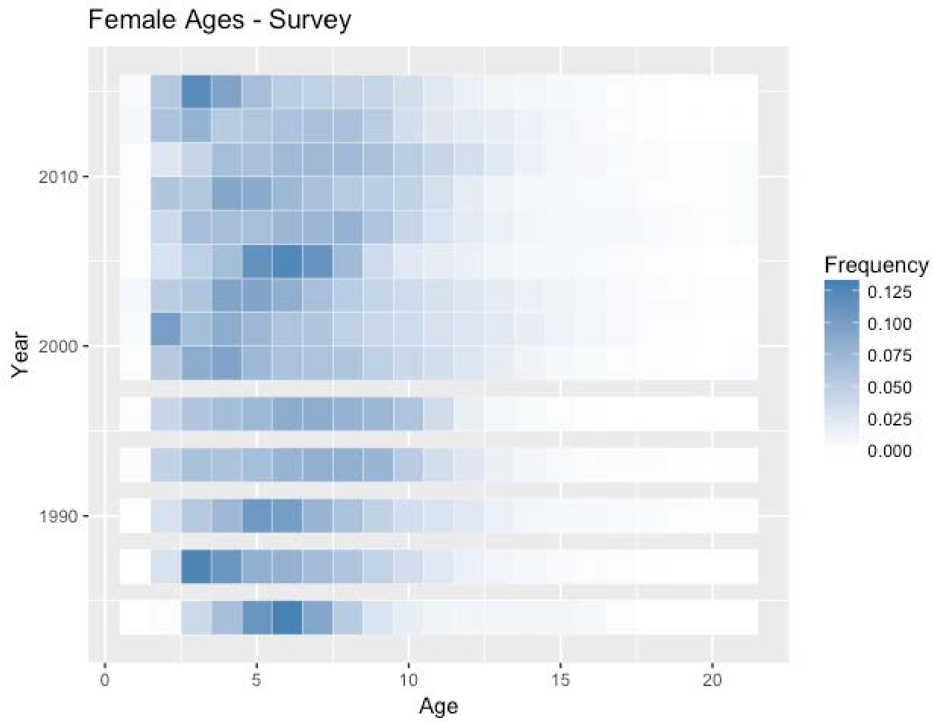


Figure 7.6. Age data from 1984-2015 used in the assessment (females above, males below).



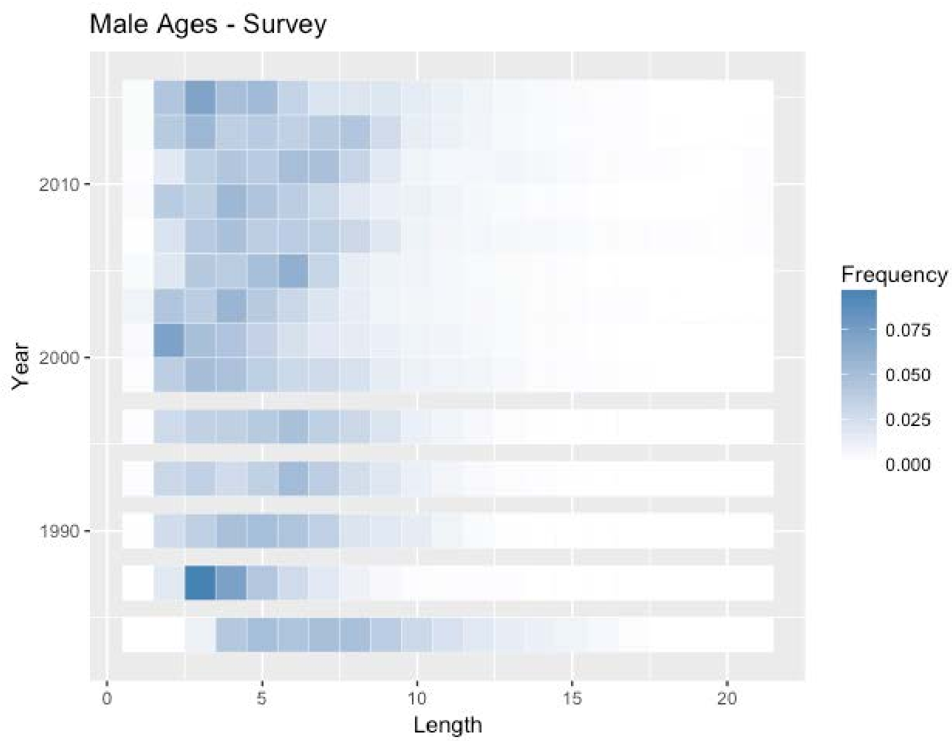


Figure 7.7. Length-weight relationship of arrowtooth flounder. Males and females grow at the same trajectory. The fit to weight-at-length is shown as a black line. Data from GOA surveys 1984-2013.

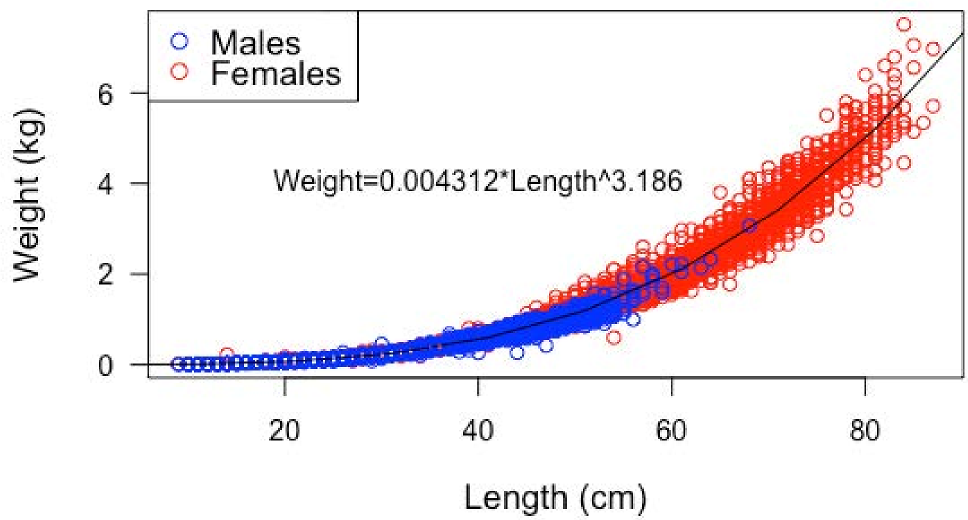


Figure 7.8. The correction for length frequencies (dividing length at age from the stratified age data by survey length frequency proportions) shifts the expected lengths at age in the population to lower values than in the length stratified age collection.

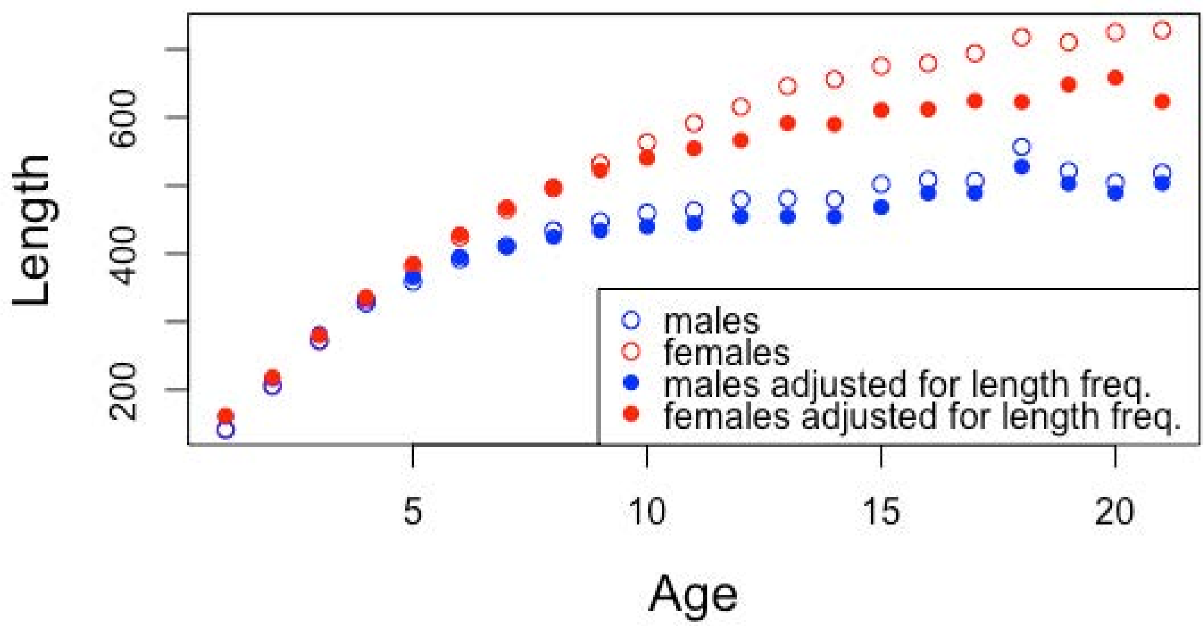


Figure 7.9. VonBertalanffy fit to age data, with the plus group (estimated length at age for ages 21+) shown as a red circle, for males and females.

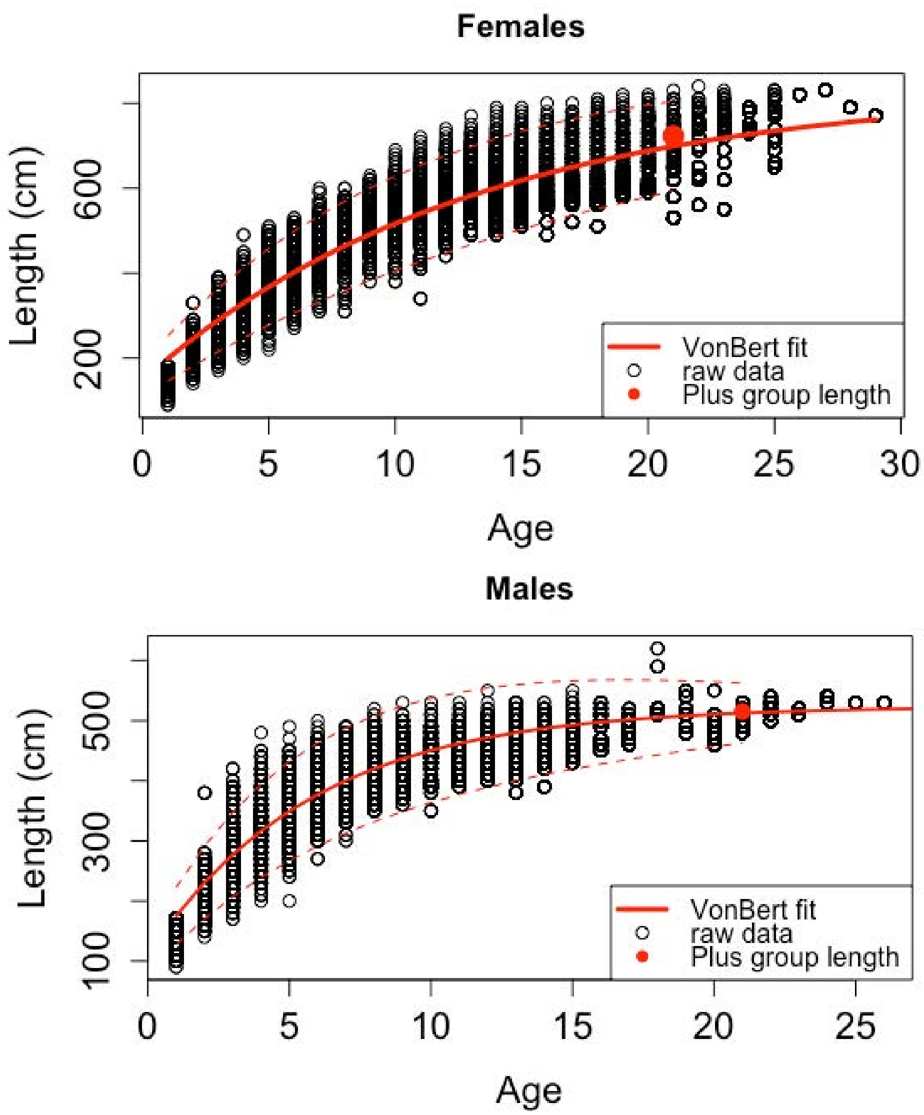
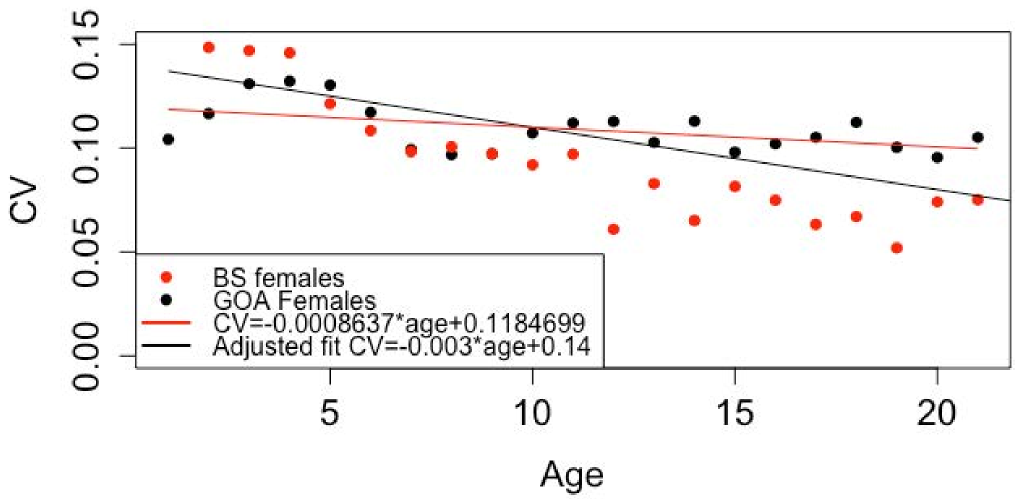


Figure 7.10. The CV of length at age for females (upper panel) and males (lower panel). Bering Sea values are shown in black for comparison. Linear models fit to GOA data are shown, and the parameters are presented in the legend. The linear model of the GOA female CV is drawn in red in the upper plot. The black line represents an adjusted relationship based on the assumption that CV will decrease with age. The adjusted CV was used in the length-age conversion matrix.



Males

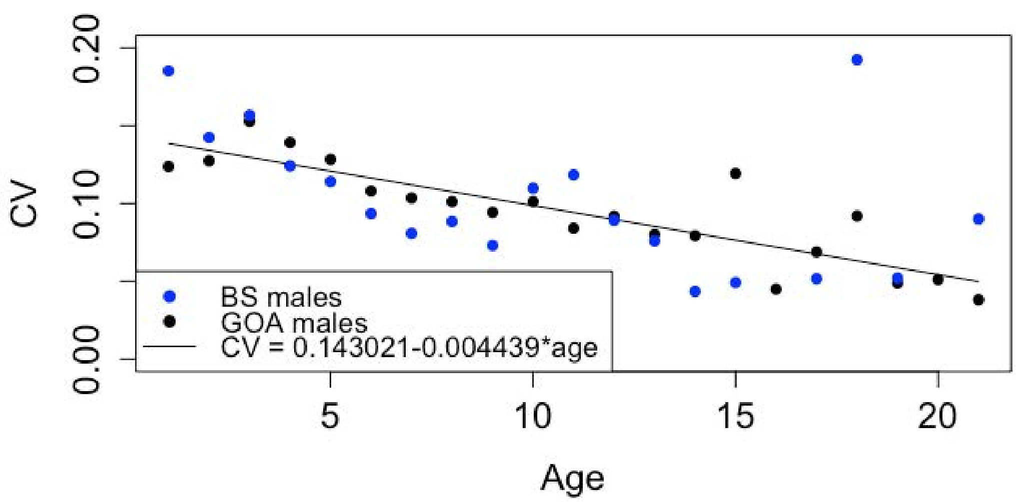


Figure 7.11. Visual representation of the length age conversion matrix used in the model, females above, males below.

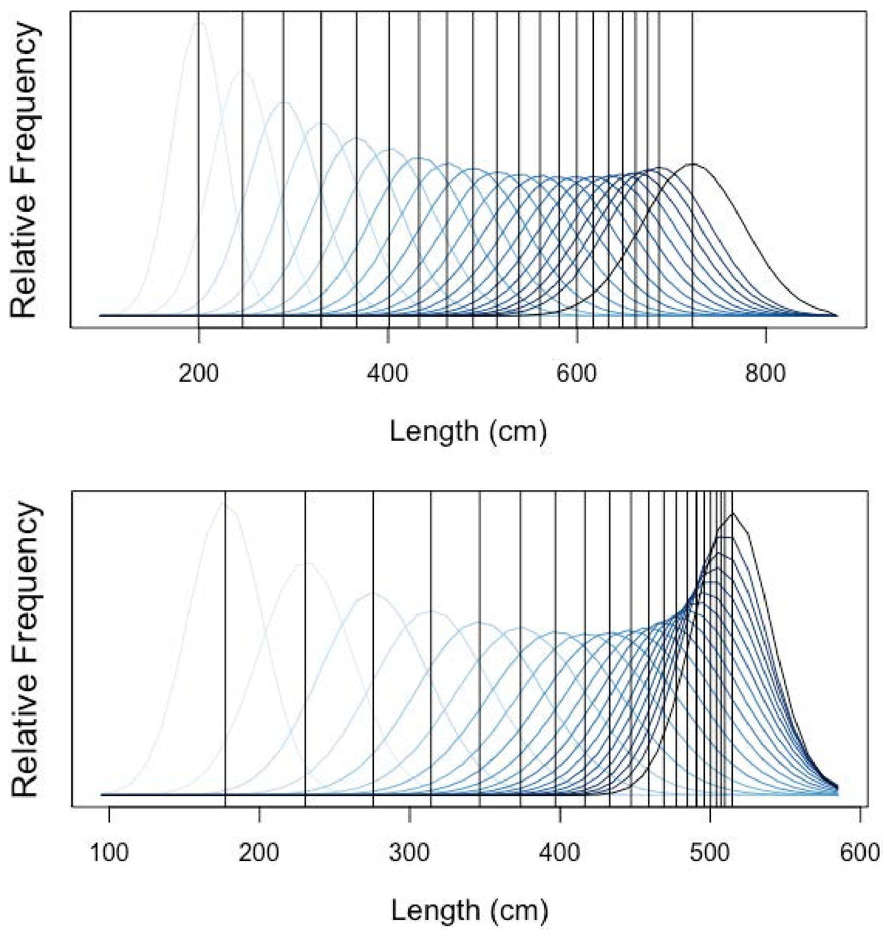


Figure 7.12. Weight at age used in the model is based on length at age corrected as shown in Figure 7.8 by survey length frequencies. The corrected lengths were applied to the weight at age relationship determined by aged fish shown in Figure 7.7. Weight at age of females determined by this method is slightly lower than weight at age determined by a weight-at-age vonBertalanffy relationship determined from the stratified age collection. Differences in male weight at age were not as significant as differences in female weight at age.

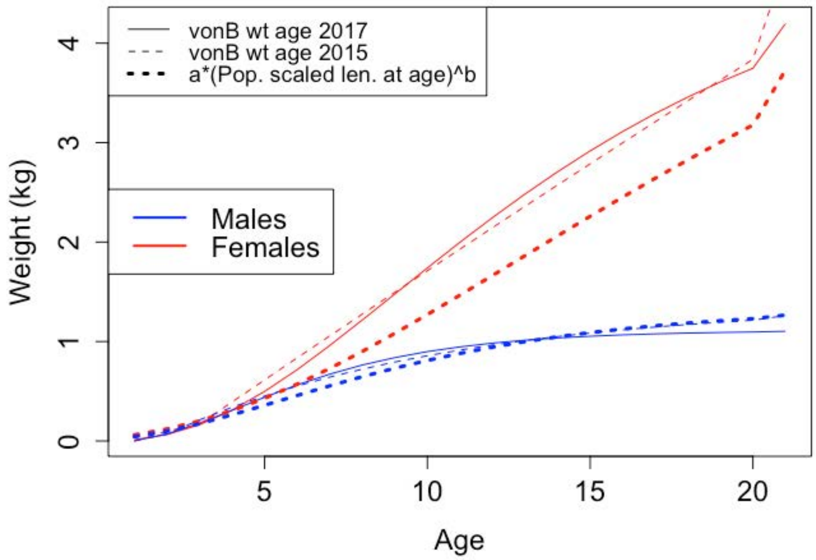


Figure 7.13. Maturity ogive used in the previous assessment (Zimmerman, 1997), and the maturity estimate used in the current assessment (Stark, 2008).

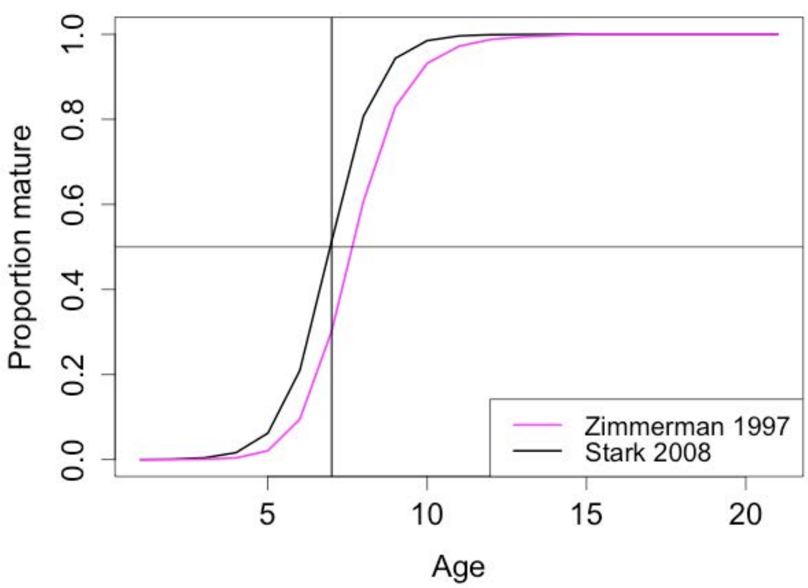


Figure 7.14. Growth differences among males and females start to appear around age 6. Age at 50% maturity is age 7 in females, and is 20% in age 6 fish.

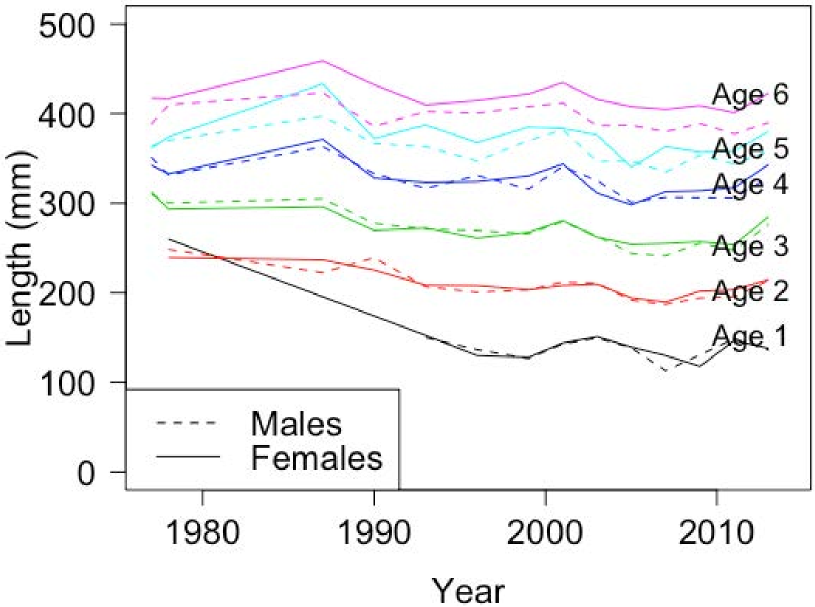


Figure 7.15. Mean age at length increased throughout the data collection (upper panel) and max age for each year of data also increased (lower panel).

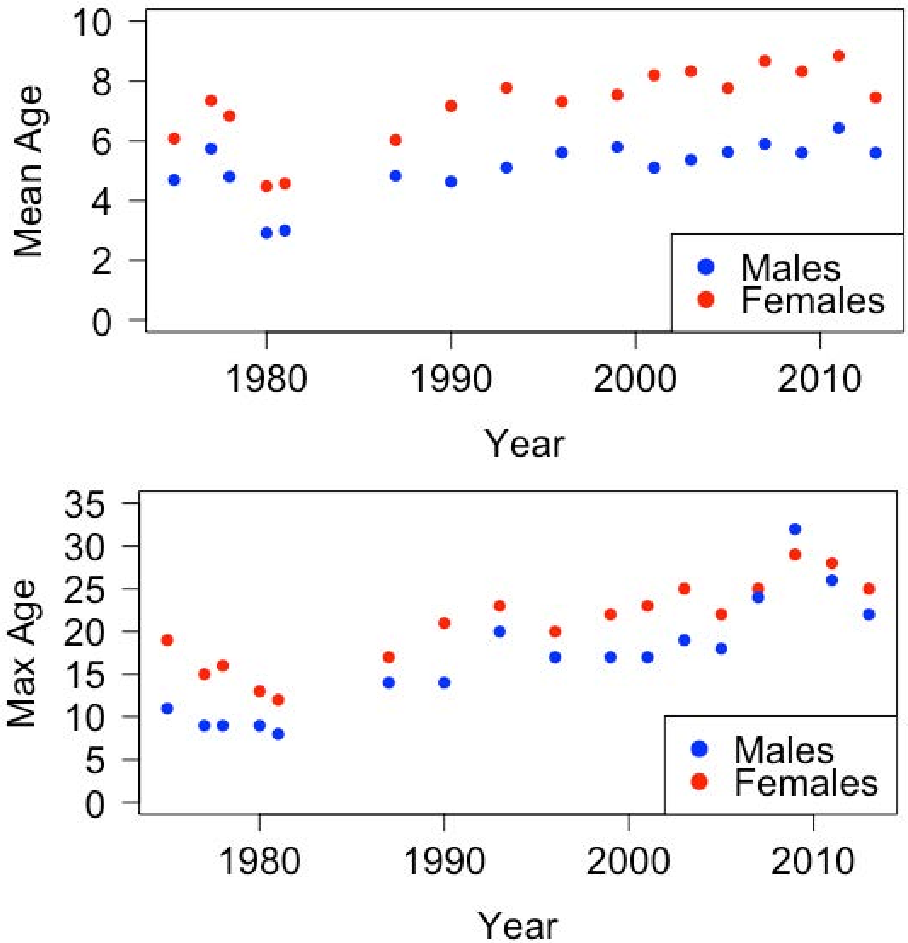
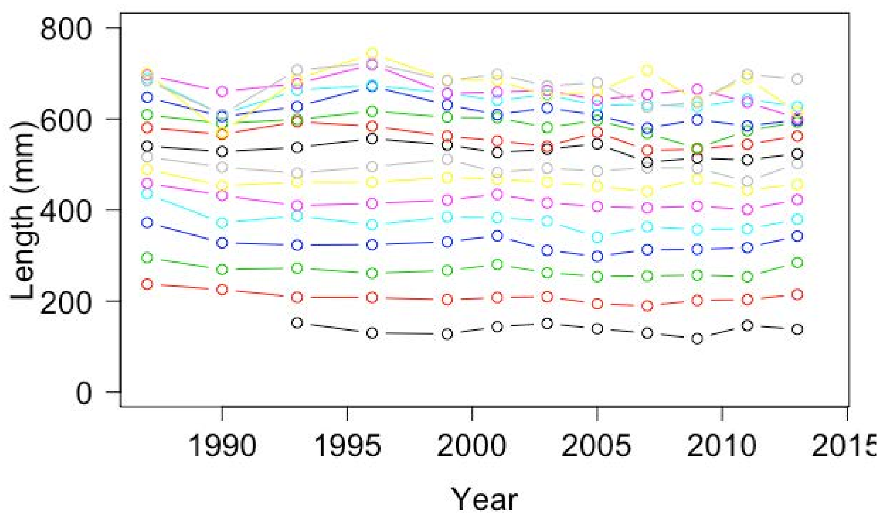


Figure 7.16. Average length of a. female and b. male arrowtooth flounder sampled in the Gulf of Alaska from 1977-2013 (1977, 1978, 1987, 1990, 1993, 1996, 1999, 2001, 2003, 2005, 2007, 2009, 2011, 2013) for ages 1-16 presented here. The line at the bottom of the plot is age 1 (black), followed by age 2 above it (red), etc. The length at age is distinct until around age 9 for females and 7-8 for males. The average length at age of females declined significantly age these ages (1,2,3) and of males (2,3,5) but ages greater than 4 did not change significantly.

a. Females



b. Males

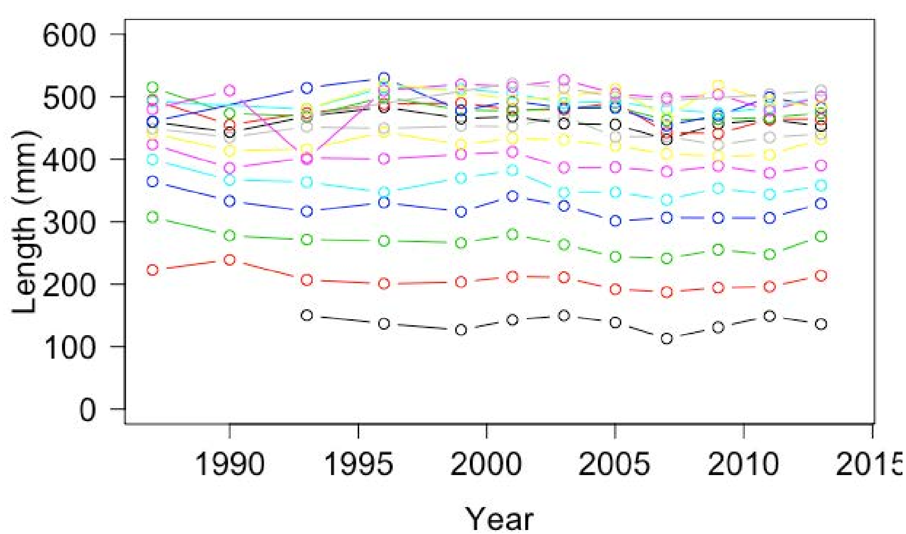


Figure 7.17. Trends in percent agreement in reader-tester evaluations for arrowtooth flounder (sample size 3,173 fish aged by two readers.

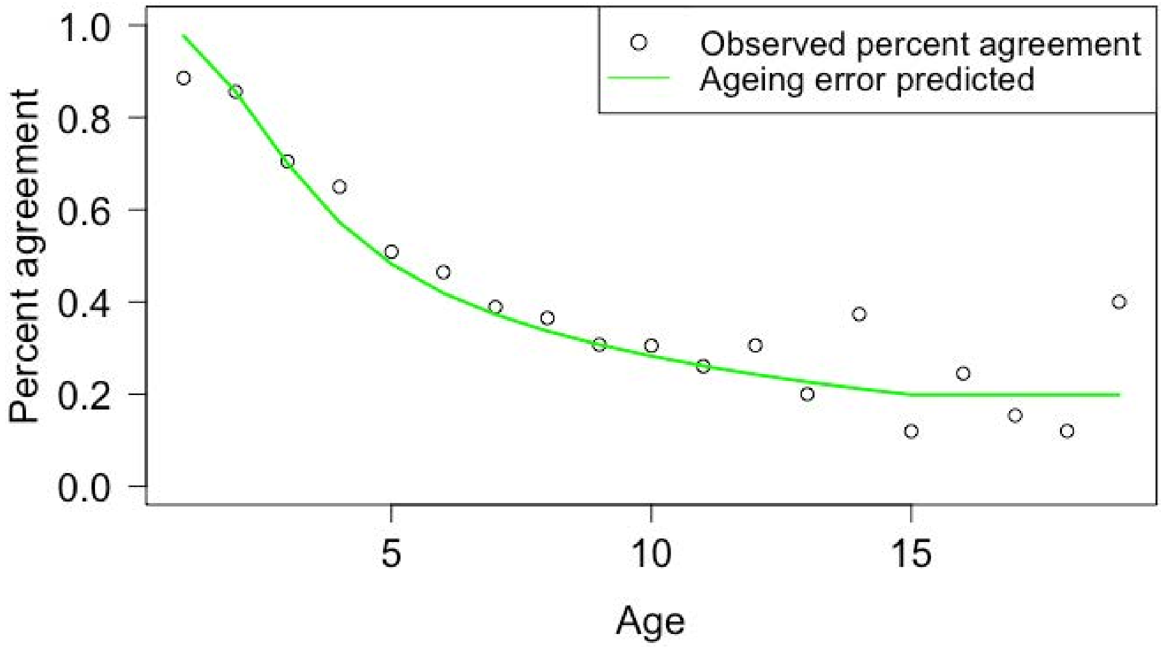
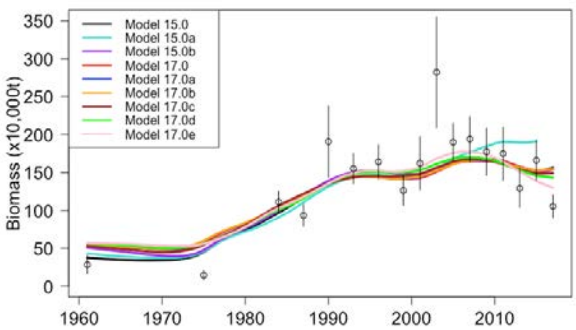
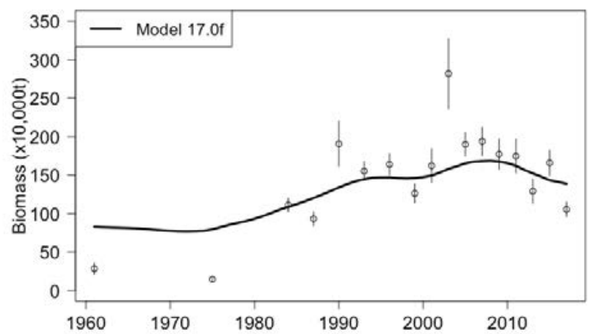


Figure 7.18. Predicted and observed survey biomass for all models explored in this assessment. Panel a: Model 15.0 through Model 17.0e. These models all use the standard survey biomass estimates as well as the two earliest biomass estimates from the early 1960s and 1970s. 95% Confidence intervals are shown (vertical lines) with the survey biomass estimates (open circles). Panel b. The variance of the biomass estimates were reweighted using the standard deviation of normalized residuals (SDNR) method of Francis (2011). Panel c. Model 15.0g: the two earliest survey biomass estimates were removed. Panel d. Different natural mortalities were explored. Lorenzen (1996) (Model 15.0h) and Gislason et al. (2010) (Model 15.0i).

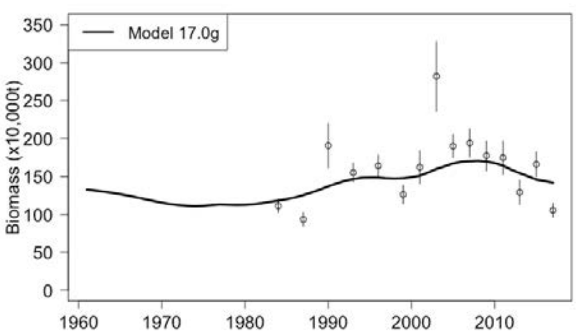
a.



b.



c.



d.

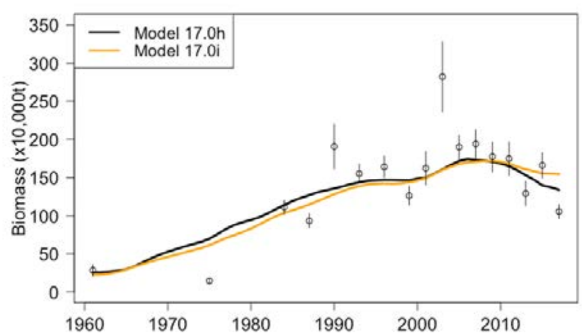
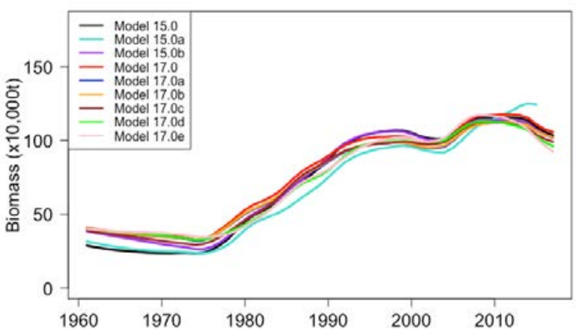
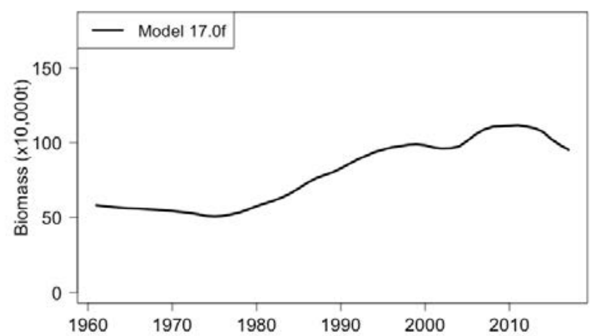


Figure 7.19. Predicted female spawning biomass for all models explored in this assessment. Panel a: Model 15.0 through Model 17.0e. These models all use the standard survey biomass estimates as well as the two earliest biomass estimates from the early 1960s and 1970s. Panel b. The variance of the biomass estimates were reweighted using the standard deviation of normalized residuals (SDNR) method of Francis (2011). Panel c. Model 15.0g: the two earliest survey biomass estimates were removed. Panel d. Different natural mortalities were explored. Lorenzen (1996) (Model 15.0h) and Gislason et al. (2010) (Model 15.0i).

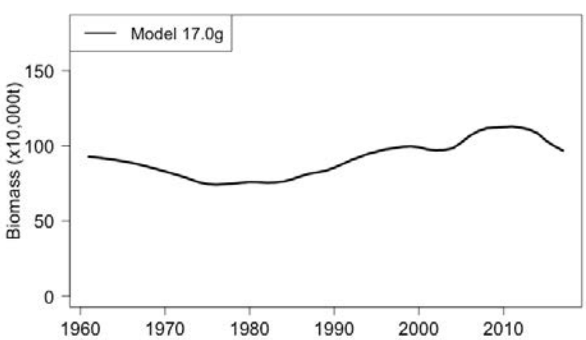
a.



b.



c.



d.

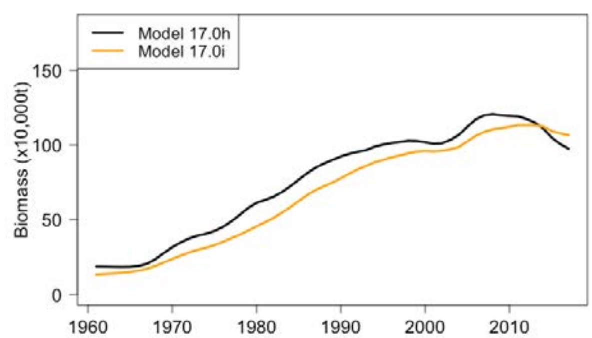
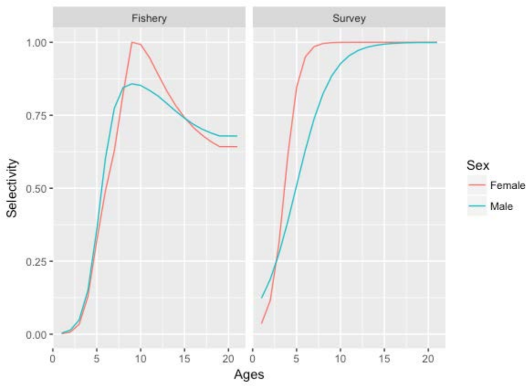
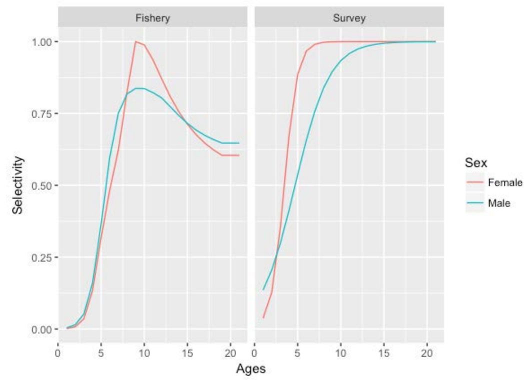


Figure 7.20. Selectivities for fishery and survey for models 15.0, 15.0a, 17.0e, 17.0f, 17.0h, and 17.0i.

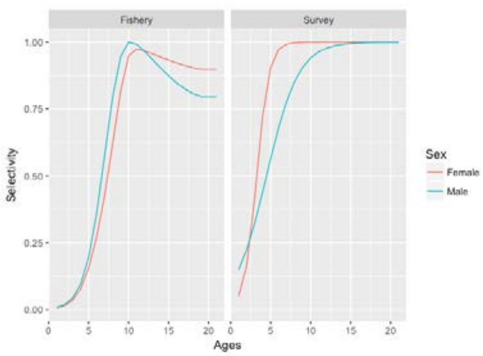
Model 15.0



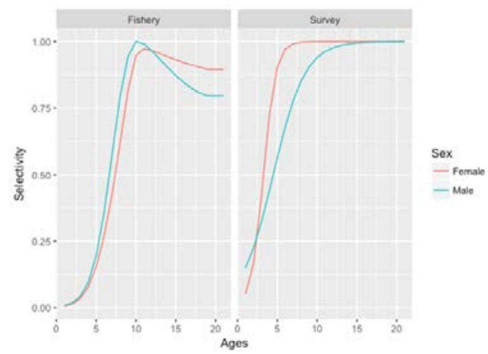
Model 15.0a



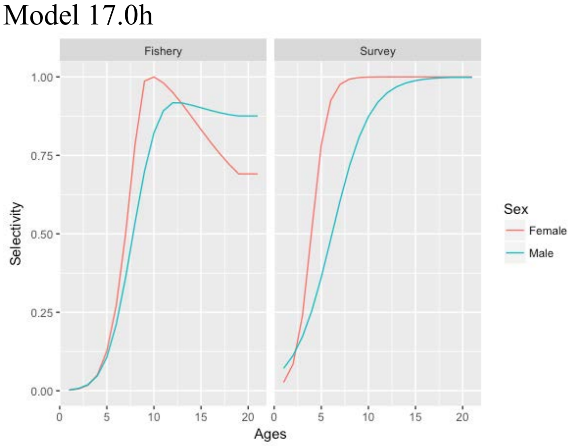
Model 17.0e



Model 17.0f



Model 17.0h



Model 17.0i

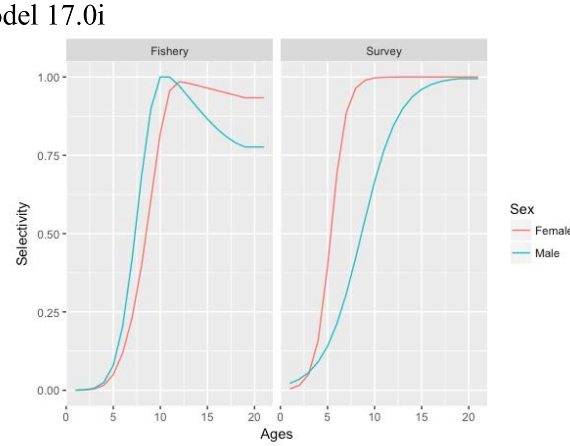


Figure 7.21. Change to fishing mortality when the penalty on fishing mortality was removed (Model 15.0, Model 15.0a).

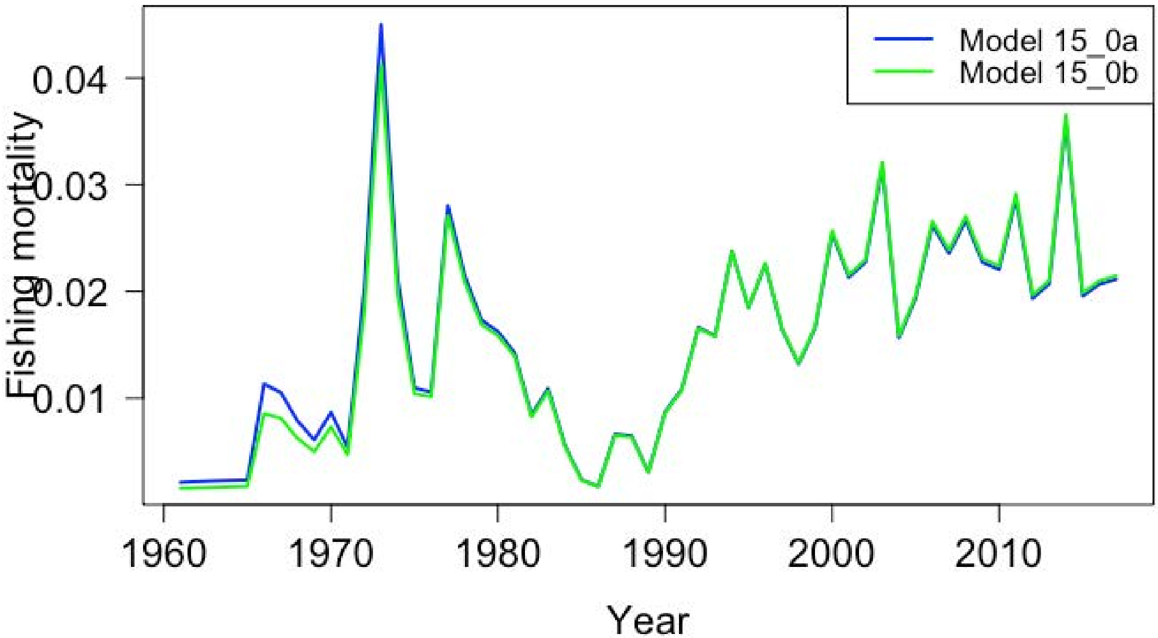
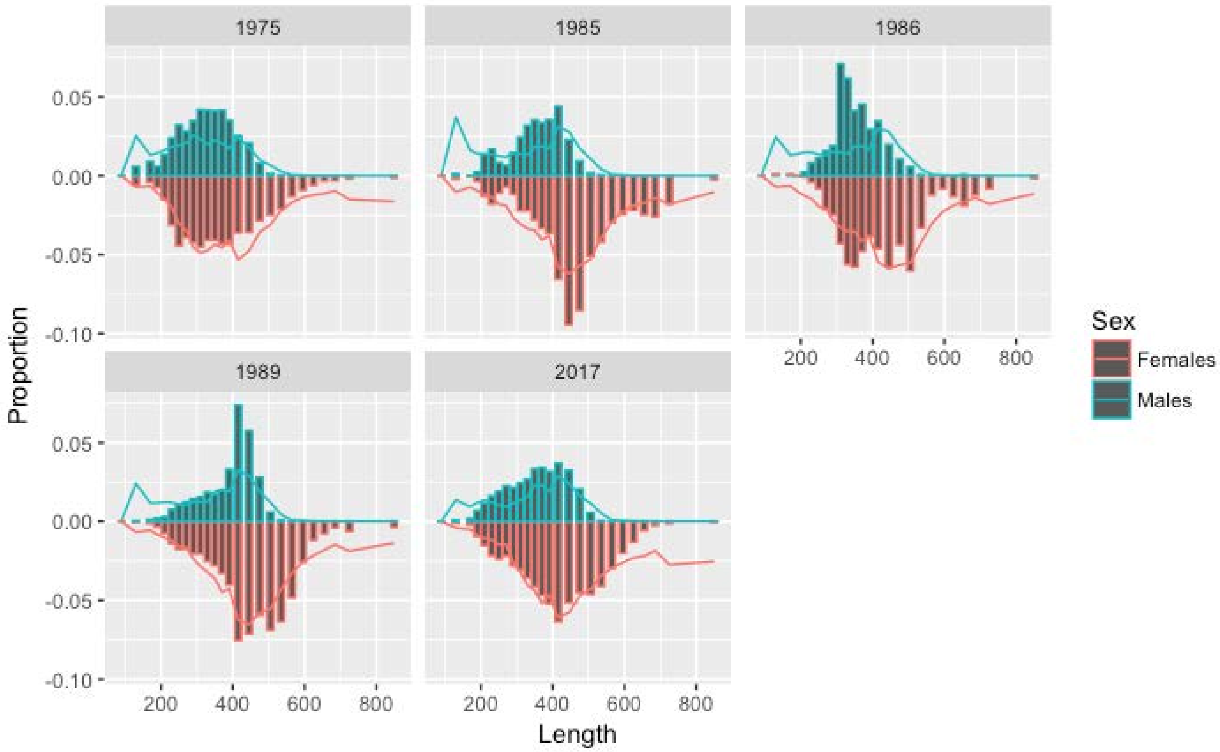


Figure 7.22. Survey length frequency fit to model Models 15.0a and Model 17.0.

Model 15.0a



Model 17.0

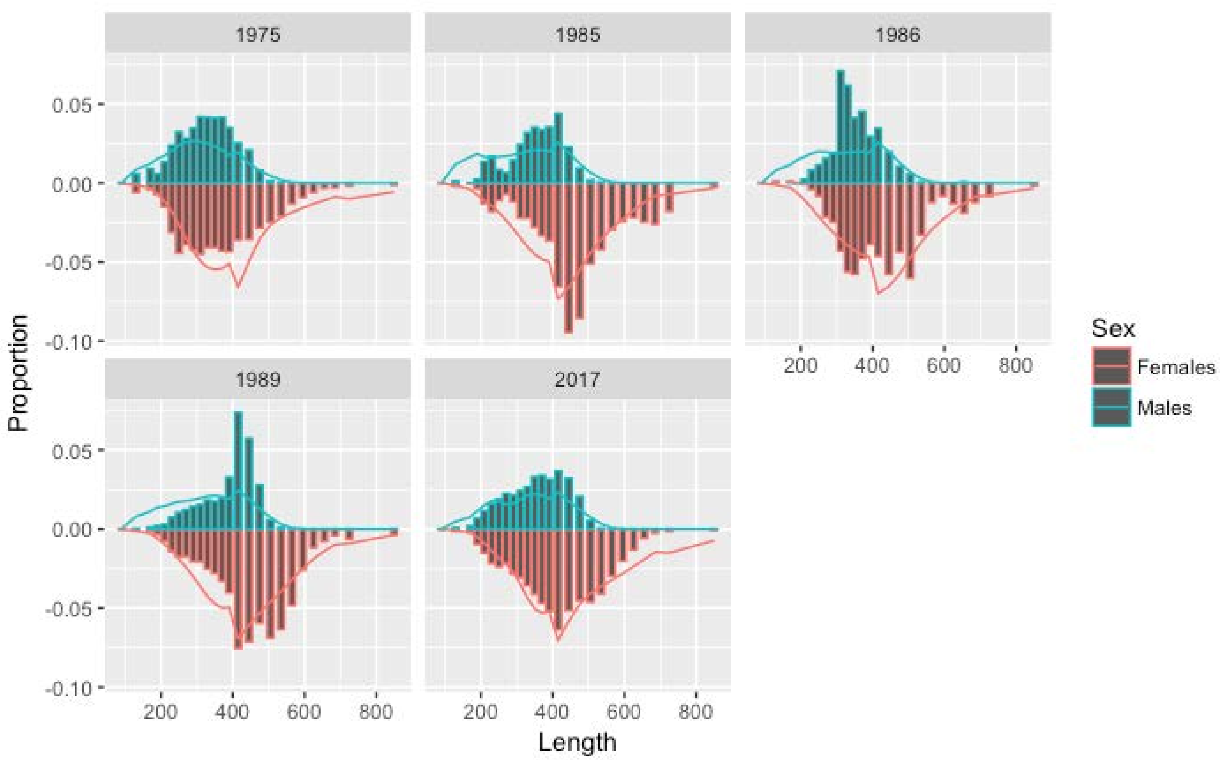
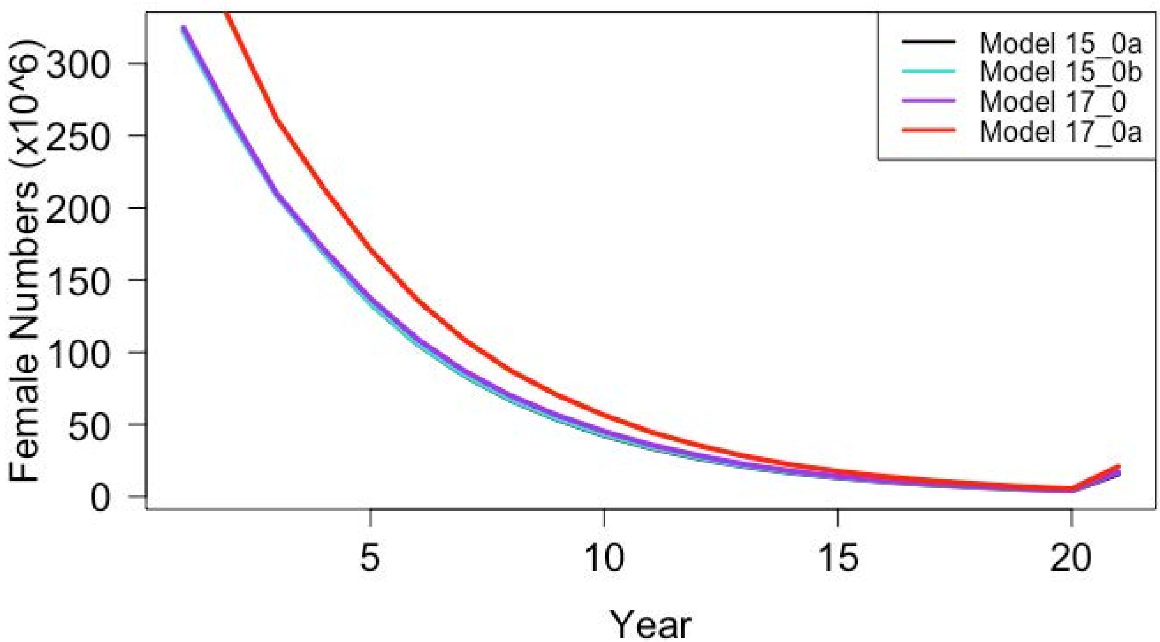


Figure 7.23. Predicted female (upper panel) and male (lower panel) numbers at age for Models 15.0a, 15.0b, 17.0, and 17.0a.

Females



Males

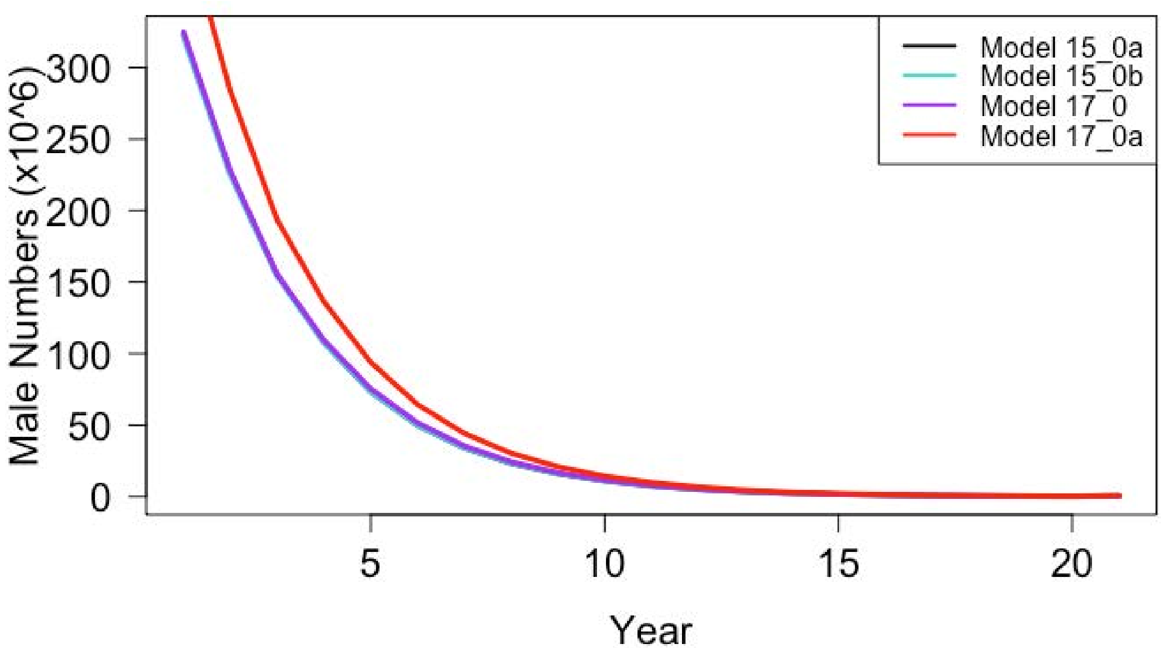
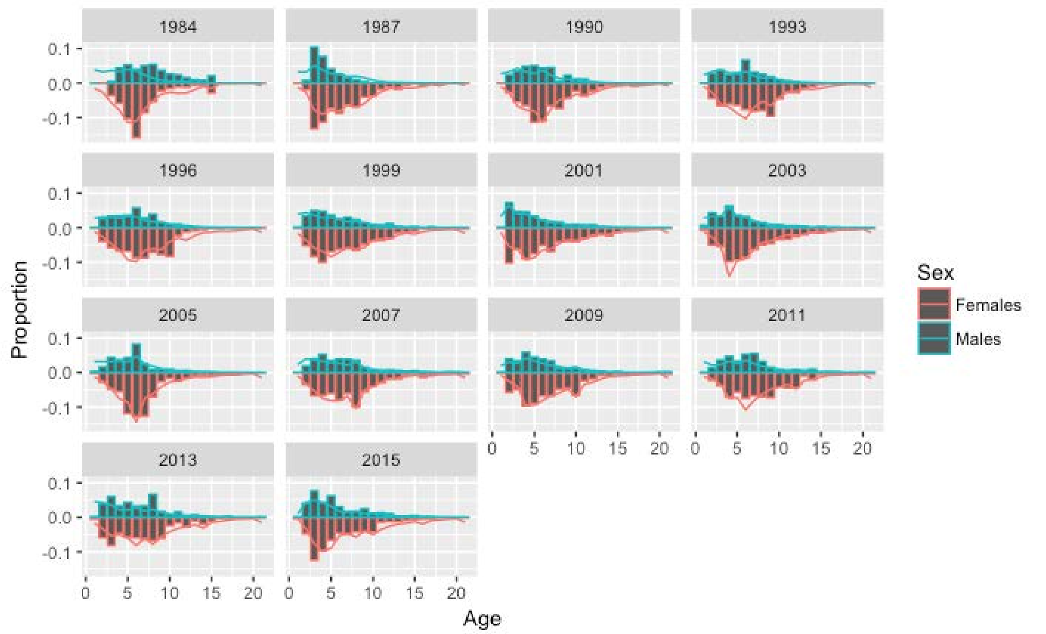
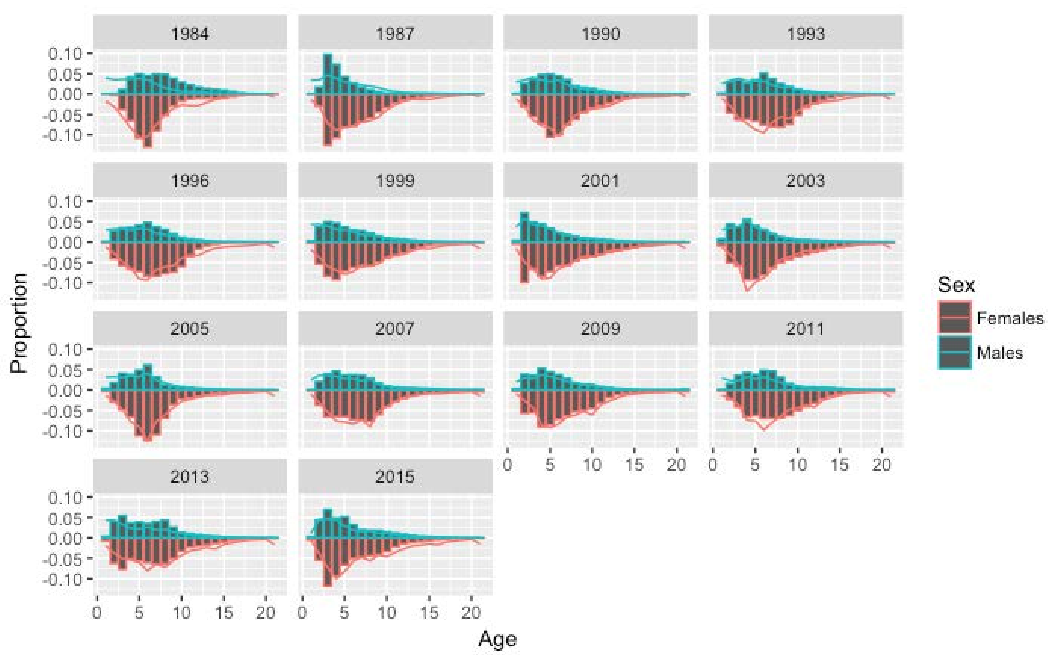


Figure 7.24. Fit to age frequency data in Model 17.0a (prior to ageing error matrix) Model 17.0b (with ageing error matrix), Model 17.0e (preferred model), Model 17.0h (Lorenzen natural mortality), and Model 17.0i (Gislason natural mortality).

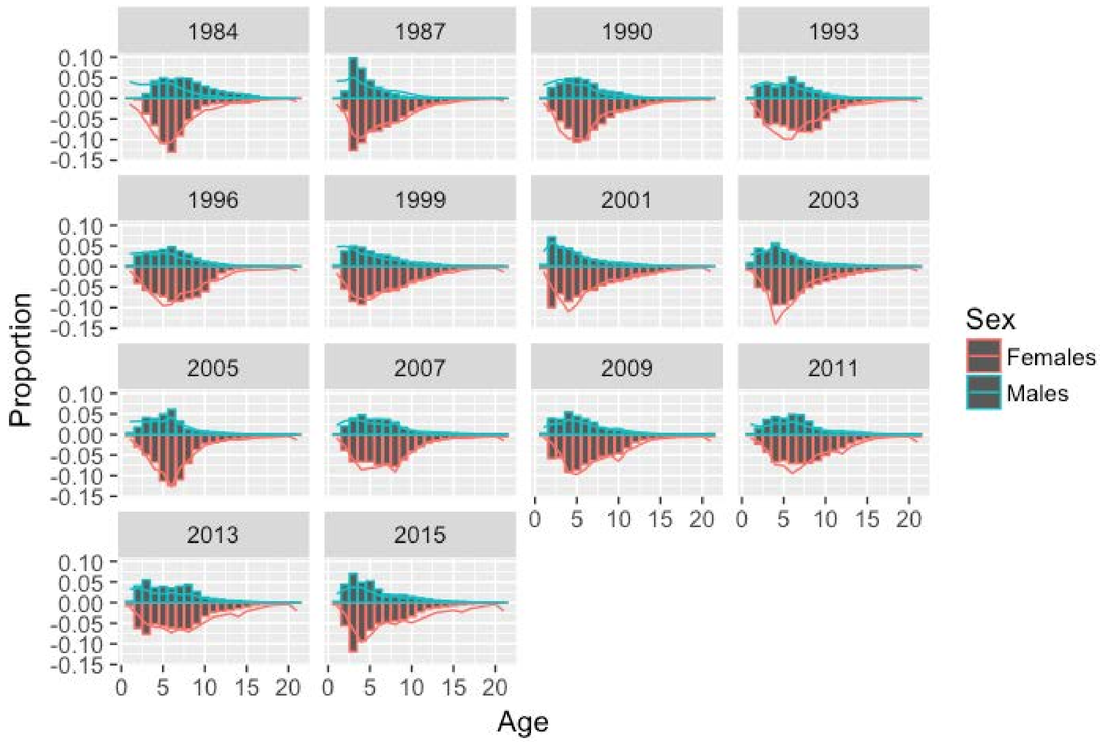
Model 17.0a



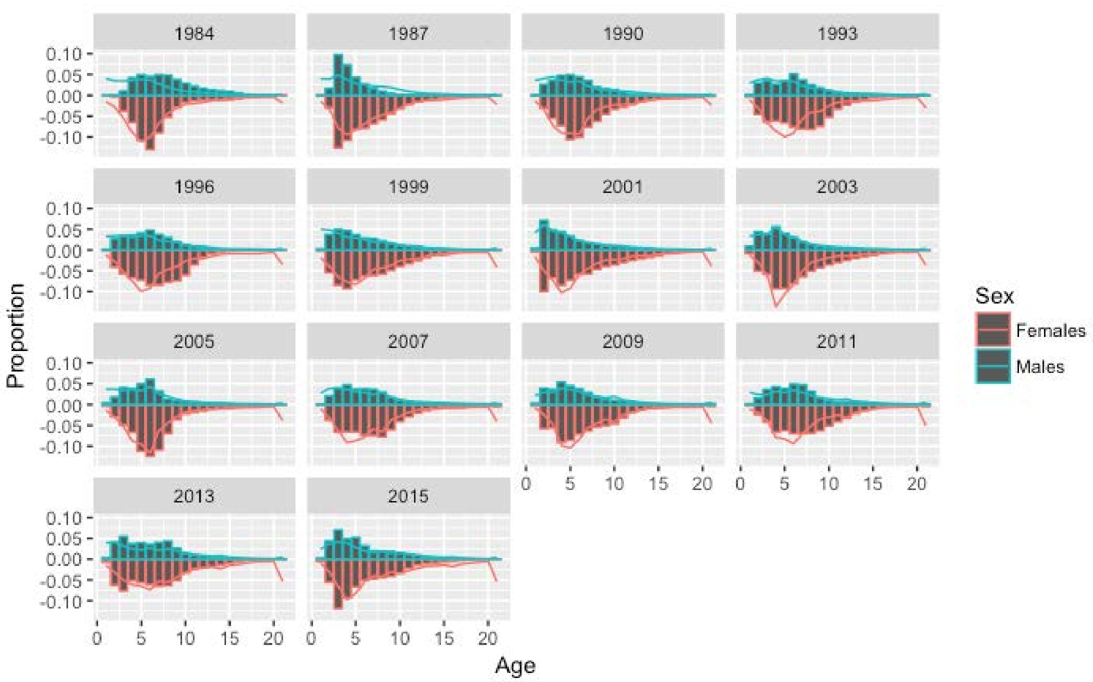
Model 17.0b



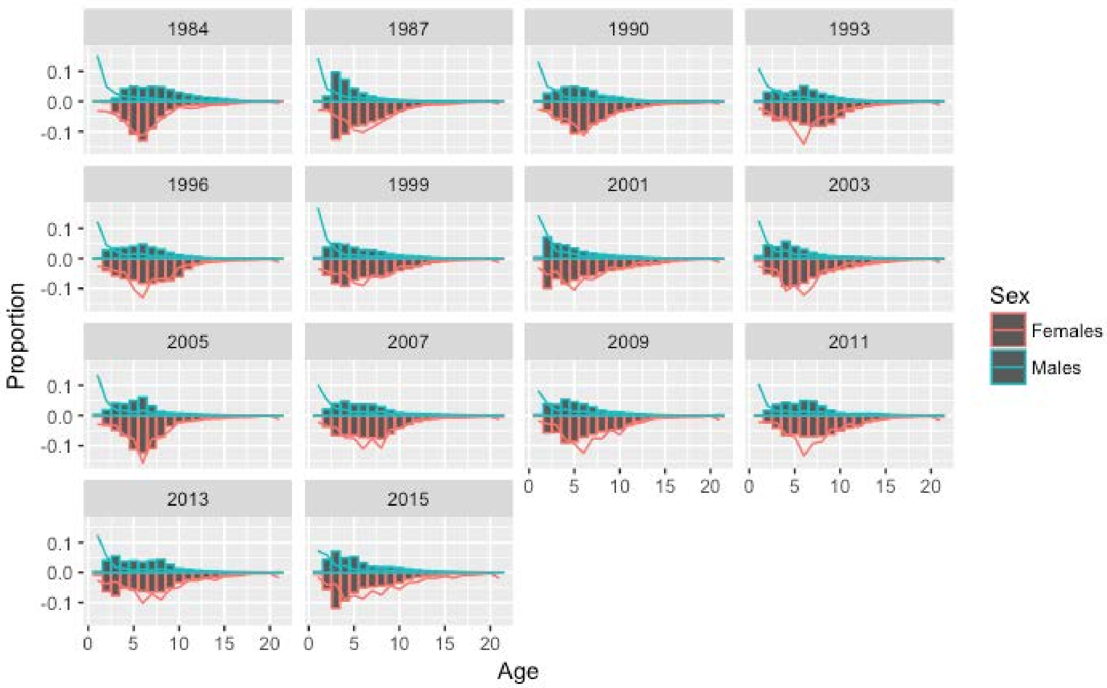
Model 17.0e



Model 17.0h



Model 17.0i



1984
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1996
1999
2001
2003
2005
2007
2009
2011
2013
2015
0.1
0.0
-0.1
0
5
10
15
20
Proportion
Age
Sex
Females
Males

Figure 7.25. Natural mortality at age for the preferred model and all other models with the exception of these models: Lorenzen mortality (17.0h), and Gislason mortality (17.0i).

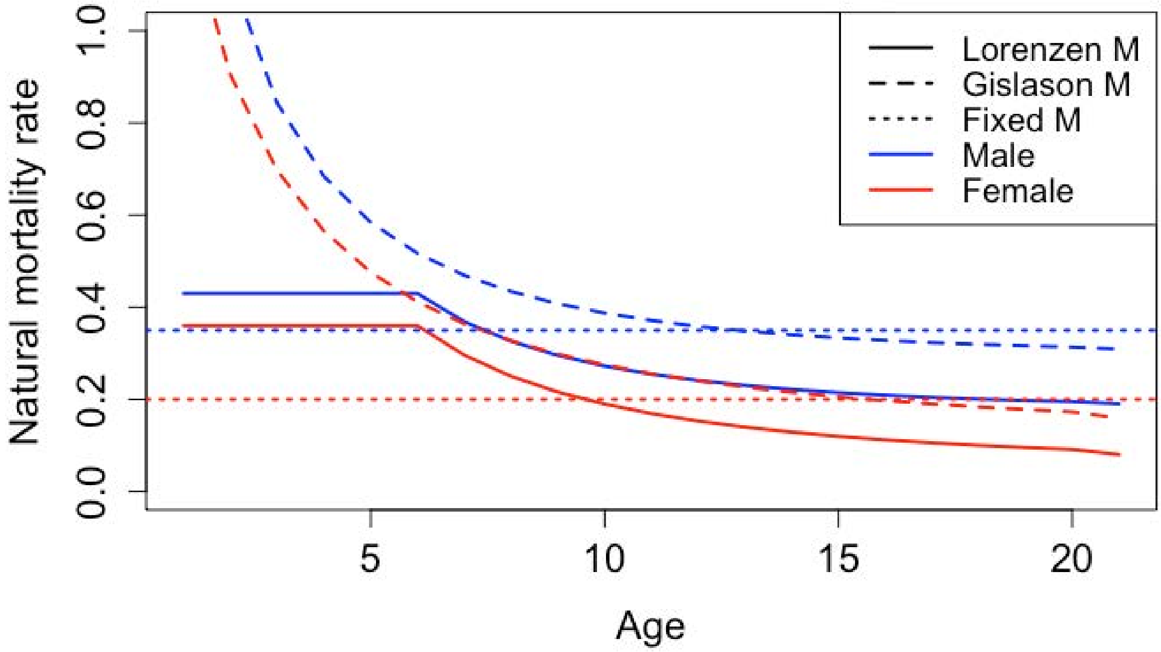


Figure 7.26. Recruitment for Models 17.0e, 17.0h, 17.0i (upper panel) and Model 17.0e (preferred model) scaled to fit for comparison (lower panel).

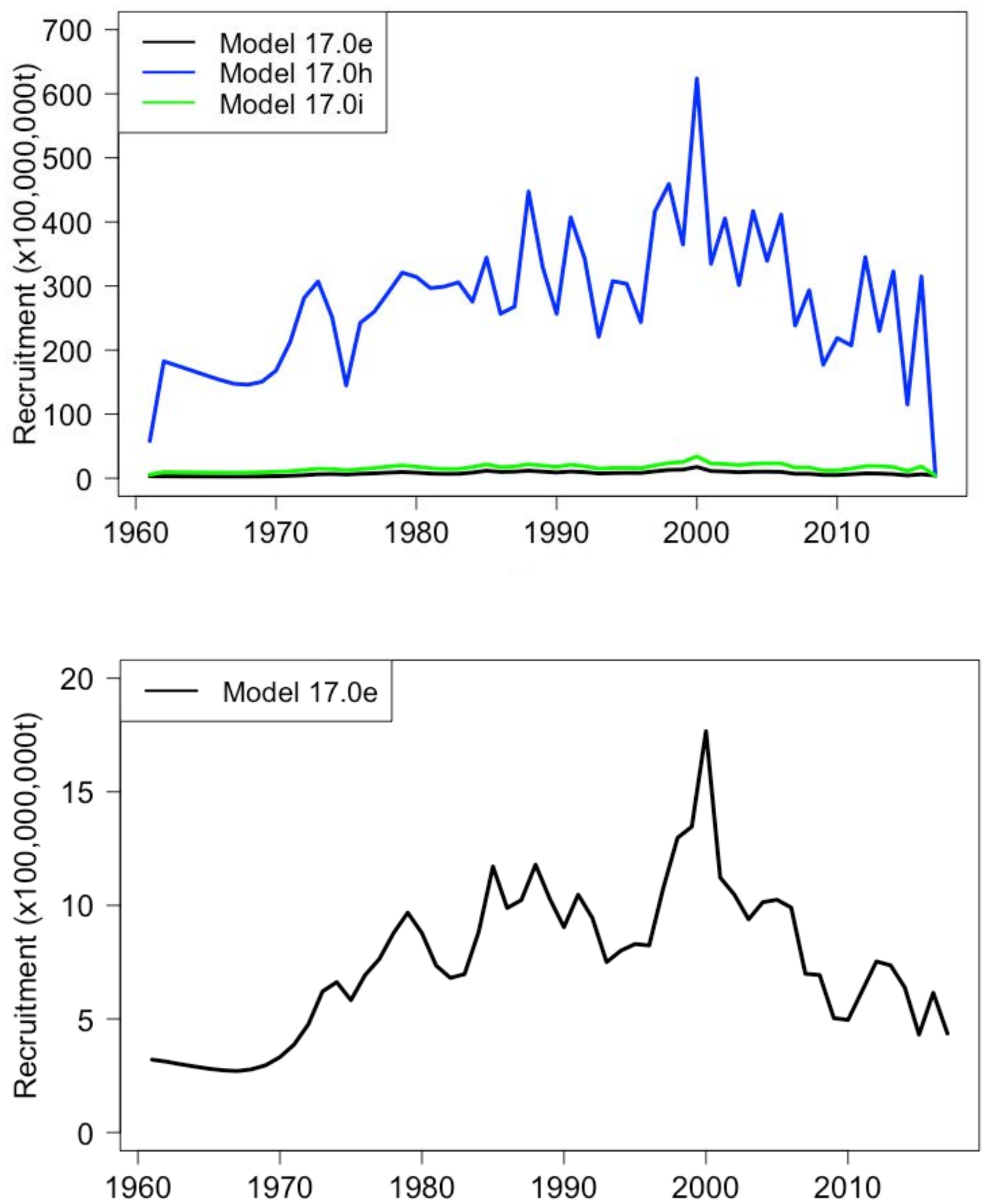


Figure 7.27. Fit to the male and female fishery length composition data, Model 17.0e, 1977-2017. Solid line is predicted.

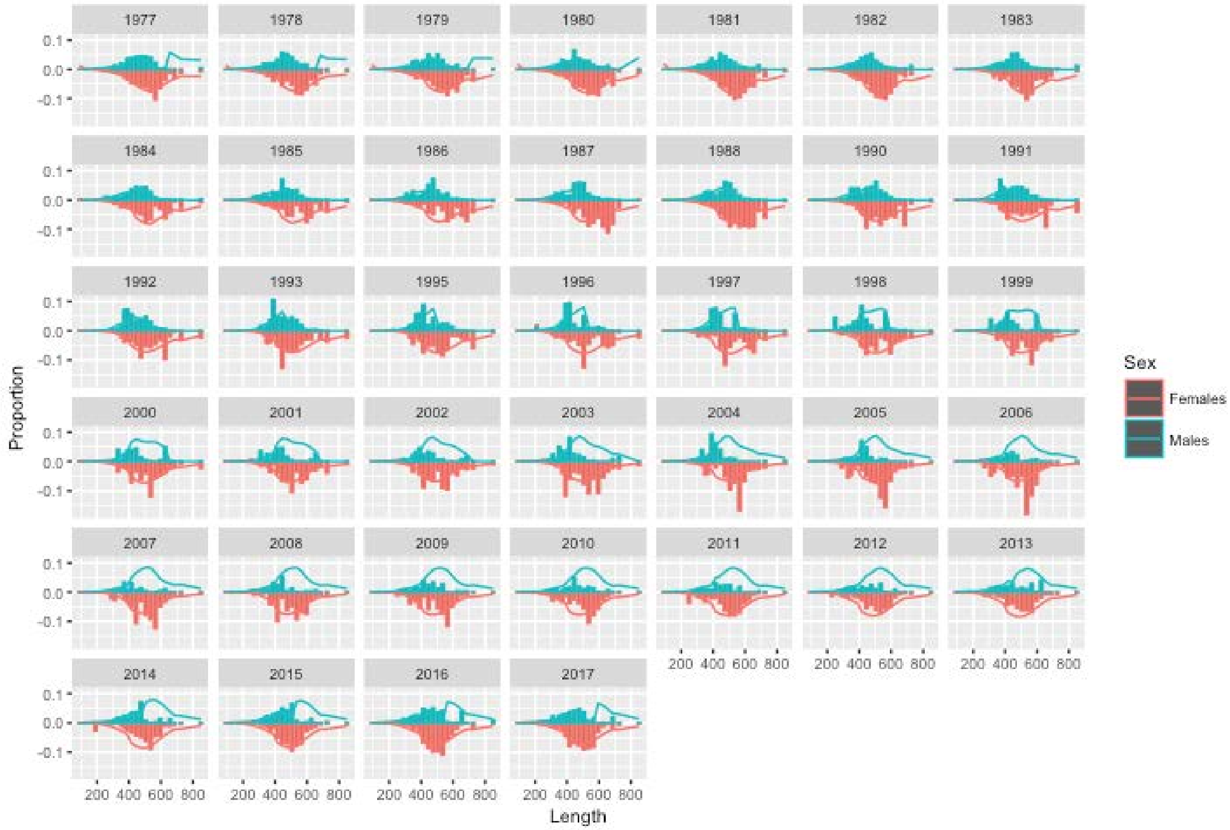


Figure 7.28. Fit to the male and female survey length data for 1975, 1985, 1986, 1989, and 2017, Model 17.0e.

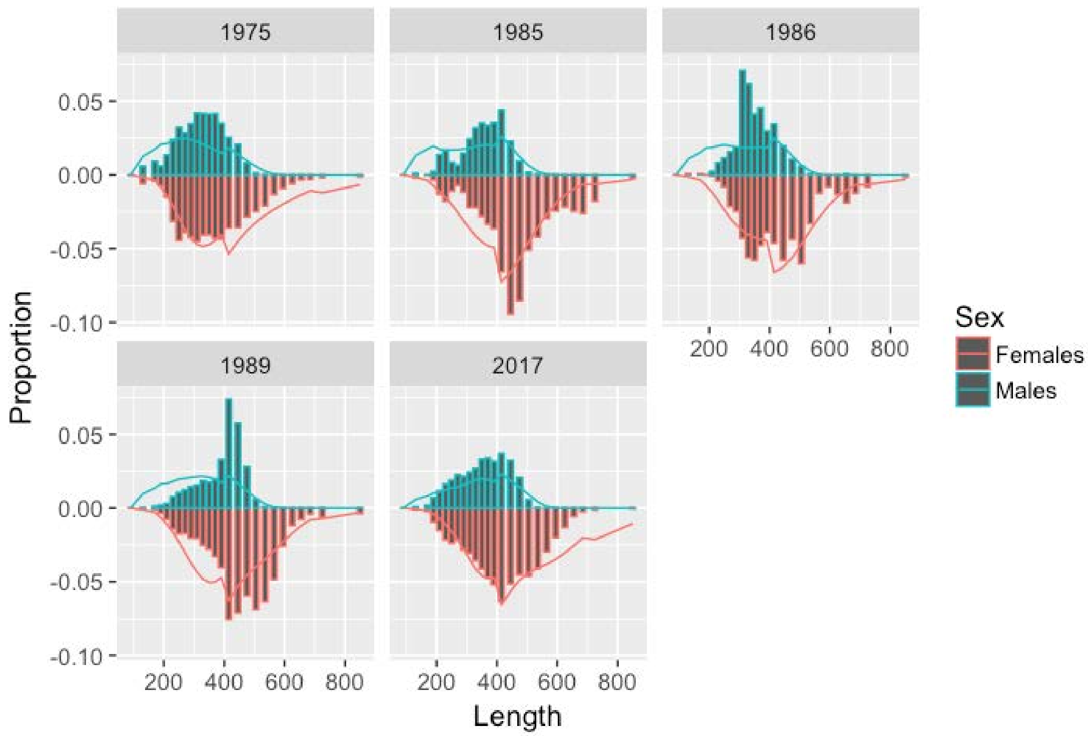


Figure 7.29. Age 1 estimated recruitments (male plus female) in numbers from 1961 to 2017, with approximate 5% and 95% credible intervals. Data was generated using out of 10^6 mcmc iterations, and thinning every 100 iterations. The horizontal line represents the average recruitment over this period.

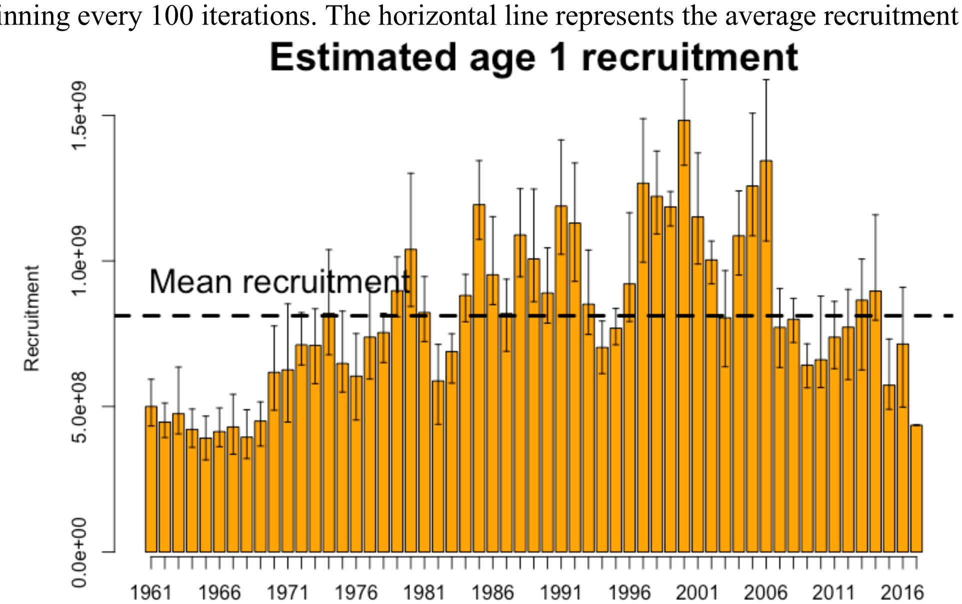


Figure 7.30. Fishing mortality rate and female spawning biomass from 1961 to 2017 compared to the $F_{35\%}$ and $F_{40\%}$ control rules. Vertical lines are $B_{35\%}$ and $B_{40\%}$.

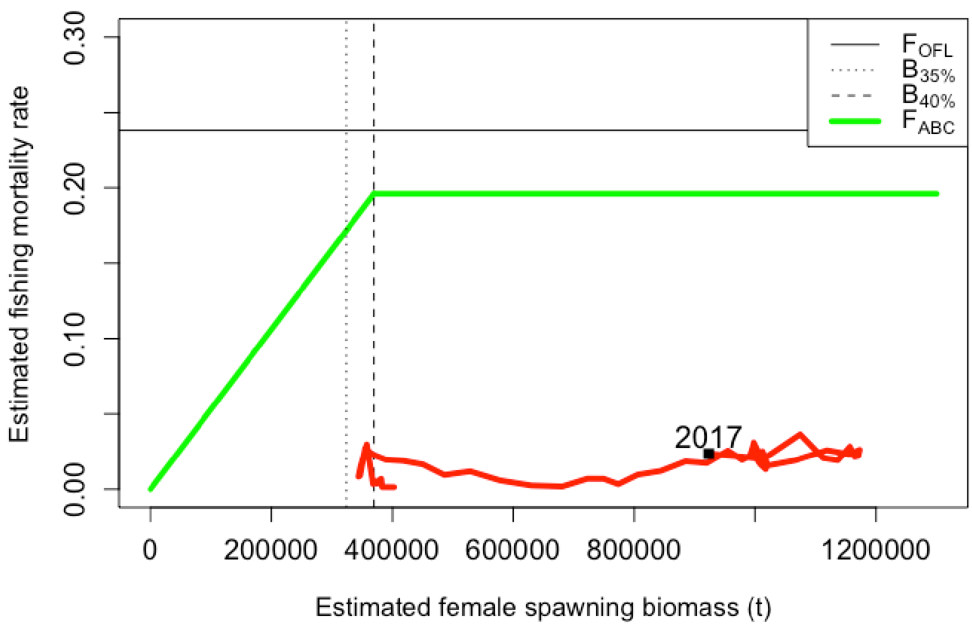


Figure 7.31. Projected female spawning biomass for 2017 to 2030 (blue line), with 5% and 95% confidence intervals, fishing at the maximum F_{ABC}=F40%.

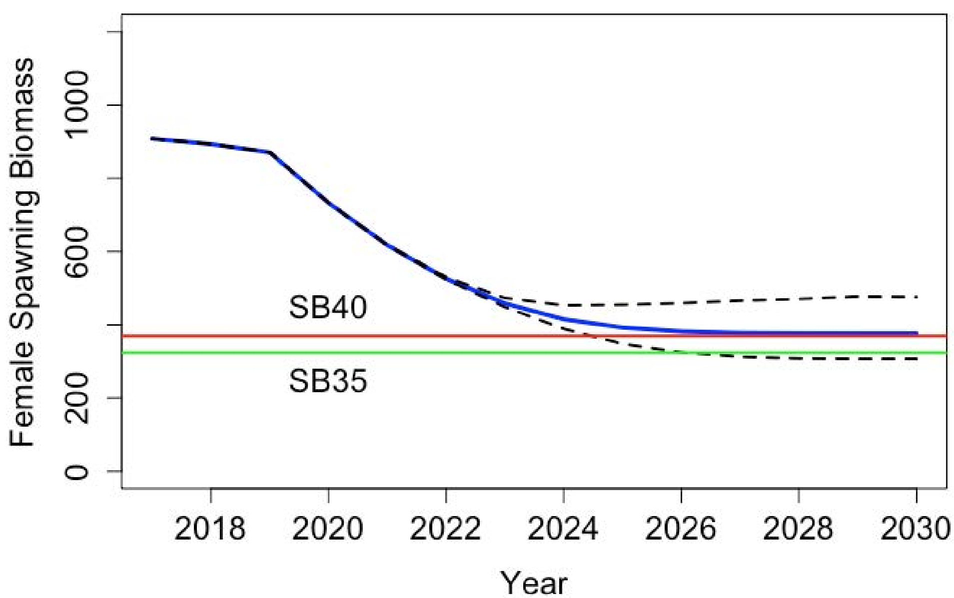


Figure 7.32. Projected female spawning biomass for 2015 to 2028 (blue line), with 5% and 95% confidence intervals, and fishing at the 5-year (2012-2017) average fishing mortality rate, *F*.

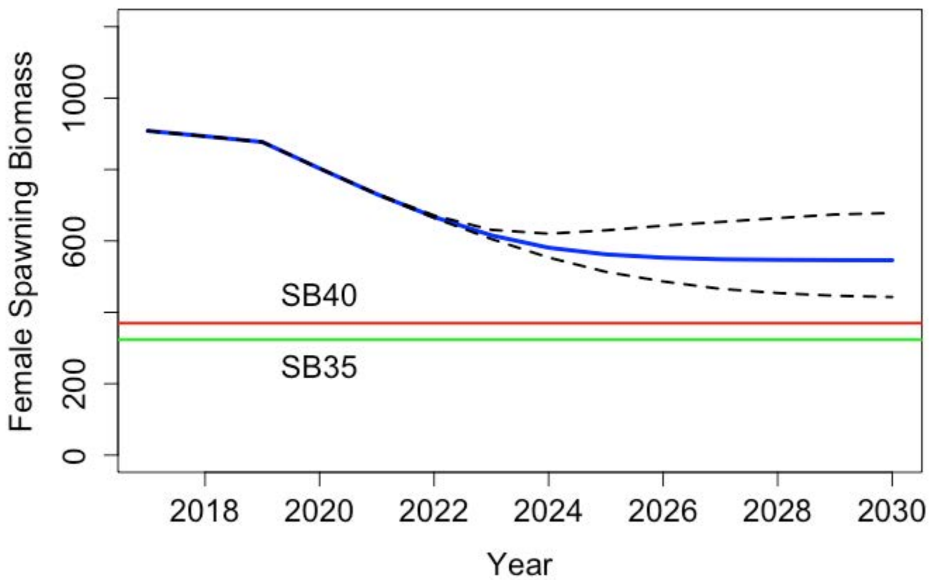


Figure 7.33. Retrospective plots of female spawning biomass. The preferred model with data through 2017 is shown, and data was sequentially removed through 2015, 2013, 2011, 2009, and 2007.

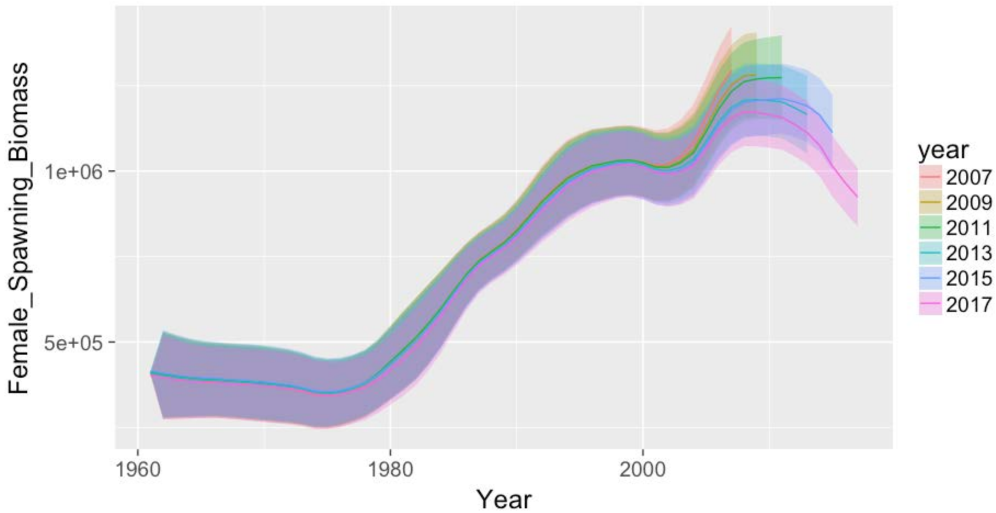
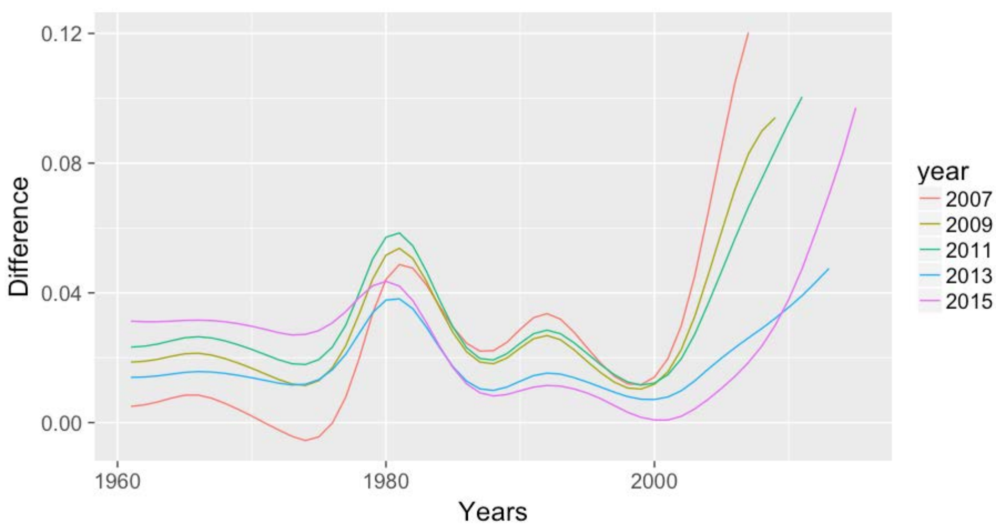


Figure 7.34. Relative differences in estimates of spawning biomass between the 2017 preferred model and the retrospective model run for years 2015, 2013, 2011, 2009, and 2007.



Appendix A.

Table 7.A1. Random effects model applied to survey biomass estimates in the four Gulf of Alaska regulatory areas, Western GOA (NMFS area 610), Central GOA (620 and 630), West Yakutat, and East Yakutat/SE Alaska.

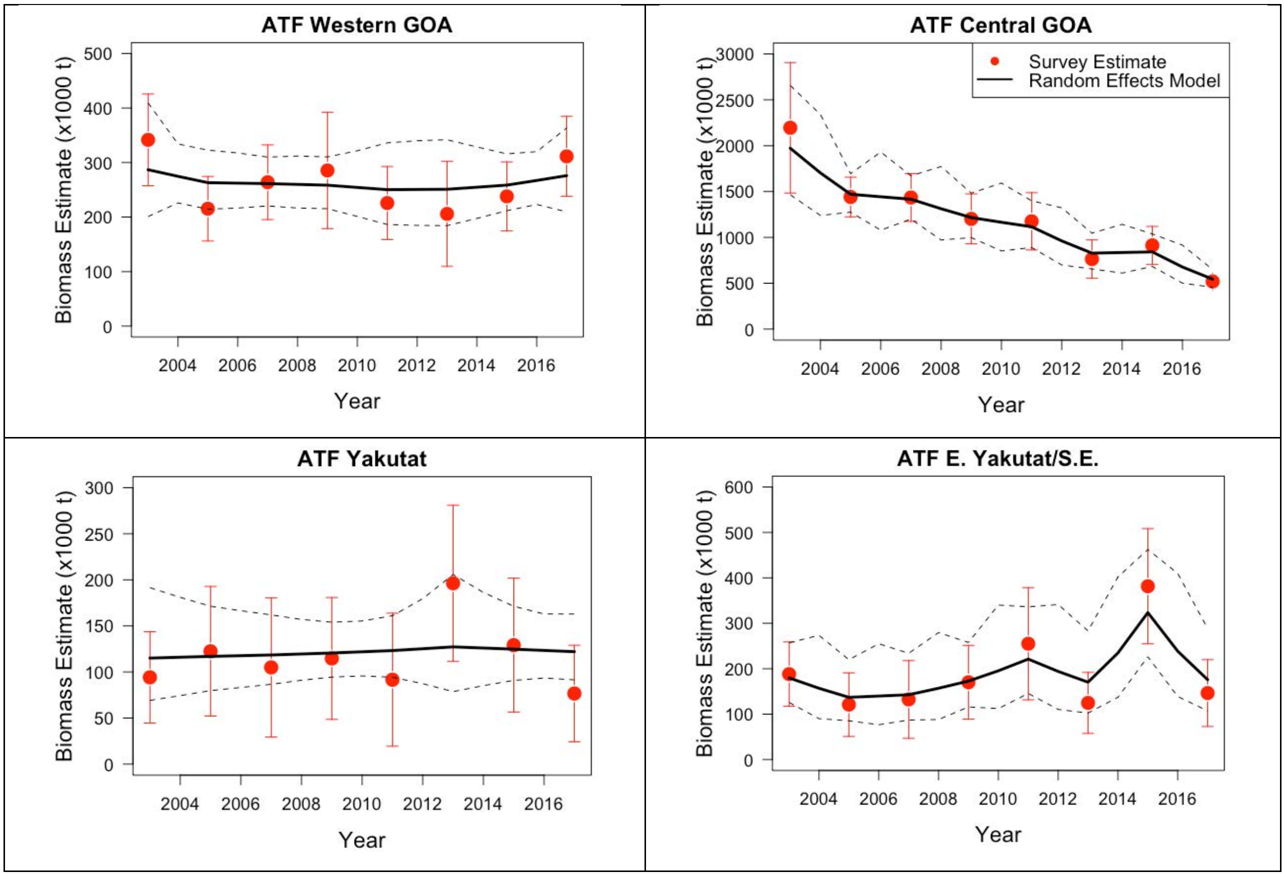


Table 7.A1. Random effects biomass estimates based on the GOA survey biomass estimates.

Year	Western GOA	Central GOA	Yakutat	Eyak/SE
2003	286,812	1,972,030	115,050	179,779
2004	274,691	1,702,680	115,976	156,953
2005	263,082	1,470,110	116,910	137,025
2006	262,201	1,442,880	117,668	139,825
2007	261,322	1,416,140	118,431	142,683
2008	259,890	1,312,280	119,508	157,006
2009	258,465	1,216,040	120,594	172,767
2010	254,322	1,164,780	121,896	195,469
2011	250,246	1,115,690	123,211	221,155
2012	250,597	961,304	125,202	194,091
2013	250,949	828,284	127,226	170,339
2014	254,736	835,050	125,978	234,763
2015	258,580	841,871	124,743	323,553
2016	267,133	676,919	123,372	238,543
2017	275,969	544,287	122,017	175,869

Appendix B. Ecosystem Considerations

Arrowtooth flounder are important predators of other groundfish in Alaskan ecosystems. In this section, we give an overview of diet data and ecosystem model results for arrowtooth flounder in the Gulf of Alaska (GOA). While arrowtooth flounder are present in the Aleutian Islands (AI) and Eastern Bering Sea (EBS or BS in figures), the density of arrowtooth flounder as measured in survey-estimated tons per square kilometer is by far the greatest in the GOA (Fig. B.1, left). Although the density of arrowtooth differs between ecosystems, the relative effects of fishing and predation mortality as estimated within food web models constructed for each ecosystem (Aydin et al. in press) are similar between the AI, EBS, and GOA. Here, sources of mortality are compared against the total production of arrowtooth as estimated in the BSAI and GOA arrowtooth stock assessment models (see Background, "Production rates," for detailed methods). The "unknown" mortality in Figure B.1 (right) represents the difference between the stock assessment estimated arrowtooth production and the known sources of fishing and predation mortality. Nearly half of arrowtooth production as estimated by the stock assessment appears to be "unused" in the AI and GOA, which is consistent with results for other predator species such as Pacific cod and halibut. In the EBS, considerably more mortality is accounted for; please see the discussion of arrowtooth mortality rates in the EBS in the BSAI arrowtooth assessment (Wilderbuer et al. 2007). Of the accounted sources of mortality, fishing mortality is generally lower for arrowtooth flounder than predation mortality in all three ecosystems (Fig. B.1, right). This is consistent with the currently low fishing effort directed at this species.

To explore ecosystem relationships of arrowtooth flounder in more detail, we first examine the diet data collected for arrowtooth. Diet data are collected aboard NMFS bottom trawl surveys in the GOA during the summer (May – August); this comparison uses diet data collected in the early 1990s. In the GOA a total of 1704 arrowtooth stomachs were collected between the 1990 and 1993 bottom trawl surveys (n=654 and 1050, respectively) and used in this analysis and to build the GOA food web model. The diet compositions reported here reflect the size and spatial distribution of arrowtooth in each survey (see Appendix A, "Diet calculations" for detailed methods). While the diet compositions summarized here most accurately reflect early 1990's conditions in the GOA, we also examine changes in arrowtooth diets over time below.

Arrowtooth flounder have a varied diet comprised of zooplankton, fish, and benthic invertebrates as both juveniles (0-20 cm TL fish) and adults (>20 cm TL; Fig. B.2). Capelin, euphausiids, adult and juvenile pollock, Pandalid shrimp, herring, and other forage fish comprise the majority of adult arrowtooth flounder diet, but none of these prey account for more than 22% of diet. As juveniles, arrowtooth prey mainly on euphausiids, which make up nearly 60% of diet, followed by capelin at 24% (Fig. B.2). When the uncertainty in food web model parameters is included (see Aydin et al in press for Ecosense methods), we estimate fairly high annual consumption of these prey by arrowtooth flounder. For example, estimated consumption of all forage fish (capelin, sandlance, eulachon, etc.) by adult arrowtooth ranges from 300,000 to 1.2 million metric tons, and estimated consumption of pollock by adult arrowtooth ranges from 400,000 to 800,000 metric tons annually (Fig. B.3, upper panel). Consumption of euphausiids by adult arrowtooth is estimated to range from 100,000 to 800,000 tons annually, with another 60,000 to 490,000 tons consumed annually by juvenile arrowtooth flounder (Fig. B.3, upper and lower).

Using diet data for all predators of arrowtooth flounder and consumption estimates for those predators, as well as fishery catch data, we next estimate the sources of arrowtooth mortality in the GOA (see detailed methods in Background section). As described above, sources of mortality are compared against the total production of arrowtooth as estimated in the GOA stock assessment model for the early 1990s. There are few sources of mortality for arrowtooth flounder in the GOA as both adults and juveniles, as indicated by the large proportion of unexplained mortality (76% for adults, 88% for juveniles) in Figure B.4. Predators explain more mortality than fisheries for arrowtooth flounder (at least in this model based on early 1990s data where the fishery for arrowtooth flounder was extremely limited). Pacific halibut, Steller sea lions, and Pacific cod together explain about 10% of adult arrowtooth mortality, while the flatfish trawl fishery accounts for 2% (Fig. B.4, upper panel). Juvenile arrowtooth flounder mortality is caused by adult arrowtooth flounder, and both adult and juvenile pollock in the GOA, but the total of these mortality sources is less than 7% of juvenile arrowtooth production (Fig. B.4, lower panel). The total tonnage consumed by predators of arrowtooth flounder is low relative to their biomass for both adults and juveniles: the most important predators of arrowtooth, pinnipeds and halibut, are each estimated to consume between 13,000 and 30,000 or 20,000 tons of arrowtooth annually, respectively (Fig. B.5, upper panel). Adult arrowtooth flounder are estimated to consume 4,000 to 12,000 tons of juvenile arrowtooth flounder annually, with pollock consuming nearly the same small amount (Fig. B.5, lower panel). Few mortality sources for arrowtooth flounder are consistent with an increasing population, which has been observed in the Gulf of Alaska since the 1960s.

After comparing the different diet compositions and mortality sources of arrowtooth flounder, we shift focus slightly to view them within the context of the larger GOA food webs (Fig. B.6). Arrowtooth flounder occupy a relatively high trophic level in the GOA, and represent the highest biomass single species group at that high trophic level. The green boxes represent direct prey of arrowtooth, the dark blue boxes the direct predators of arrowtooth, and light blue boxes represent groups that are both predators and prey of arrowtooth. Visually, it is apparent that arrowtooth's direct trophic relationships in each ecosystem include a majority of species groups. In the GOA, the significant predators of arrowtooth (blue boxes joined by blue lines) include the halibut, sea lions, sharks, and fisheries. Significant prey of arrowtooth (green boxes joined by green lines) include several fish groups, Euphausiids, and Pandalid shrimp. The most interesting interaction may be with pollock, which are both prey of adult arrowtooth, and predators on juvenile arrowtooth. This situation is also observed in the EBS, but there the biomass of pollock overwhelms that of arrowtooth so the impact of this interaction on the two populations is very different between ecosystems.

We next use the diet and mortality results integrated with information on uncertainty in the food web using the Sense routines (Aydin et al. in press) and a perturbation analysis with each model food web to explore the ecosystem relationships of arrowtooth flounder further. Two questions are important in determining the ecosystem role of arrowtooth flounder: which species groups are arrowtooth important to, and which species groups are important to arrowtooth? First, the importance of arrowtooth to other groups within the GOA ecosystem was assessed using a model simulation analysis where arrowtooth survival was decreased (mortality was increased) by a small amount, 10%, over 30 years to determine the potential effects on other living groups. This analysis also incorporated the uncertainty in model parameters using the Sense routines, resulting in ranges of possible outcomes which are portrayed as 50% confidence intervals (boxes in Figure B.7) and 95% confidence intervals (error bars in Figure B.7). Species showing the largest median changes from baseline conditions are presented in descending order from left to right. Therefore, the largest change resulting from a 10% decrease in arrowtooth survival is a highly uncertain increase in herring biomass, and an accompanying increase in herring catches in the fishery (Fig. B.7). A more certain outcome of the perturbation is the expected direct effect, a decrease in adult arrowtooth biomass, which has a smaller median change than the herring change. Similarly, sleeper sharks decrease with some certainty, while sablefish and pollock are predicted to increase but with nearly as much uncertainty as herring. In general, the effects of a small change in arrowtooth survival result in a large amount of uncertainty in the ecosystem, with potentially large effects on multiple species due to arrowtooth's ecosystem interactions.

To determine which groups were most important to arrowtooth in each ecosystem, we conducted the inverse of the analysis presented above. In this simulation, each species group in the ecosystem had survival reduced by 10% and the system was allowed to adjust over 30 years. The strongest median effects on GOA arrowtooth are presented in Figure B.8. Here the largest impacts on arrowtooth biomass are the direct effects through changes in arrowtooth survival and juvenile arrowtooth survival, but the next largest impacts are more interesting ecologically. Arrowtooth biomass appears strongly influenced by changes in bottom up production, with decreases in survival for large and small phytoplankton and euphausiids having similar biomass effects as direct effects from arrowtooth and juvenile arrowtooth (Fig. B.8). While euphausiids are direct prey of arrowtooth, phytoplankton are not. Smaller effects on arrowtooth biomass are seen due to decreased survival of capelin (direct prey), but these are uncertain compared with those due to phytoplankton and euphausiids. There are more unequivocal bottom up effects related to arrowtooth flounder in these simulations than top down effects of arrowtooth on other species.

Finally, we summarize the available food habits collections for arrowtooth flounder in the GOA in Table 1, and make preliminary consumption estimates from this data in Figures B.9 and B.10 for juvenile and adult arrowtooth. In general, while changes in the amount of consumption have been noted, the arrowtooth diet remains diverse and focused on euphausiids, pollock, capelin, and other fish throughout the time series (Fig. B.9). Further analysis of this data will be presented in an upcoming assessment.

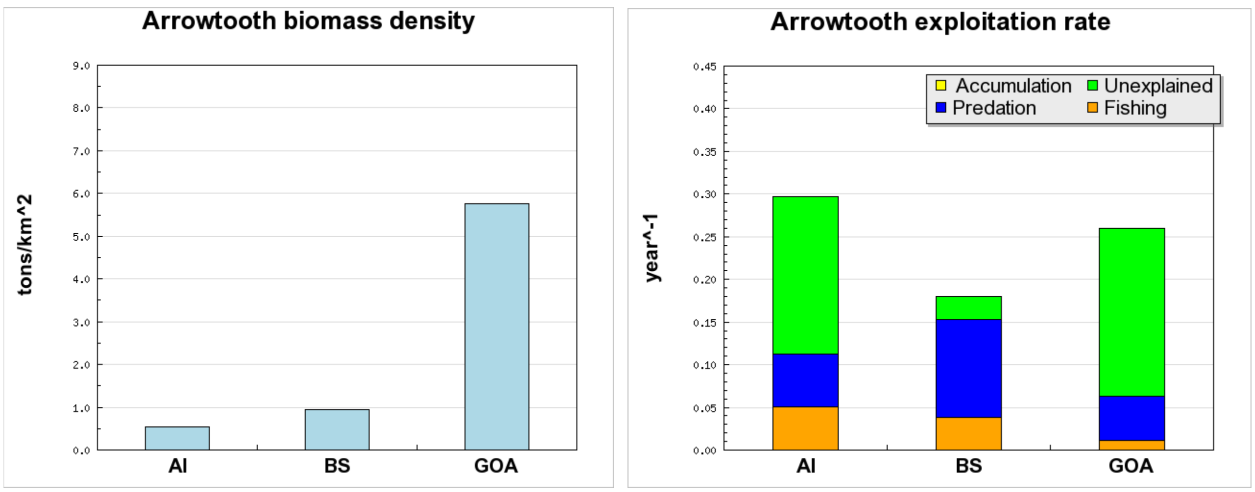


Figure B.1. Comparative biomass density (left) and mortality sources (right) for Arrowtooth flounder in the AI, EBS, and GOA ecosystems. Biomass density (left) is the average biomass from early 1990s NMFS bottom trawl surveys divided by the total area surveyed. Total arrowtooth production (right) is derived from stock assessments for the early 1990's, and partitioned according to fishery catch data and predation mortality estimated from cod predator diet data (Aydin et al. in press). See Background section for detailed methods.

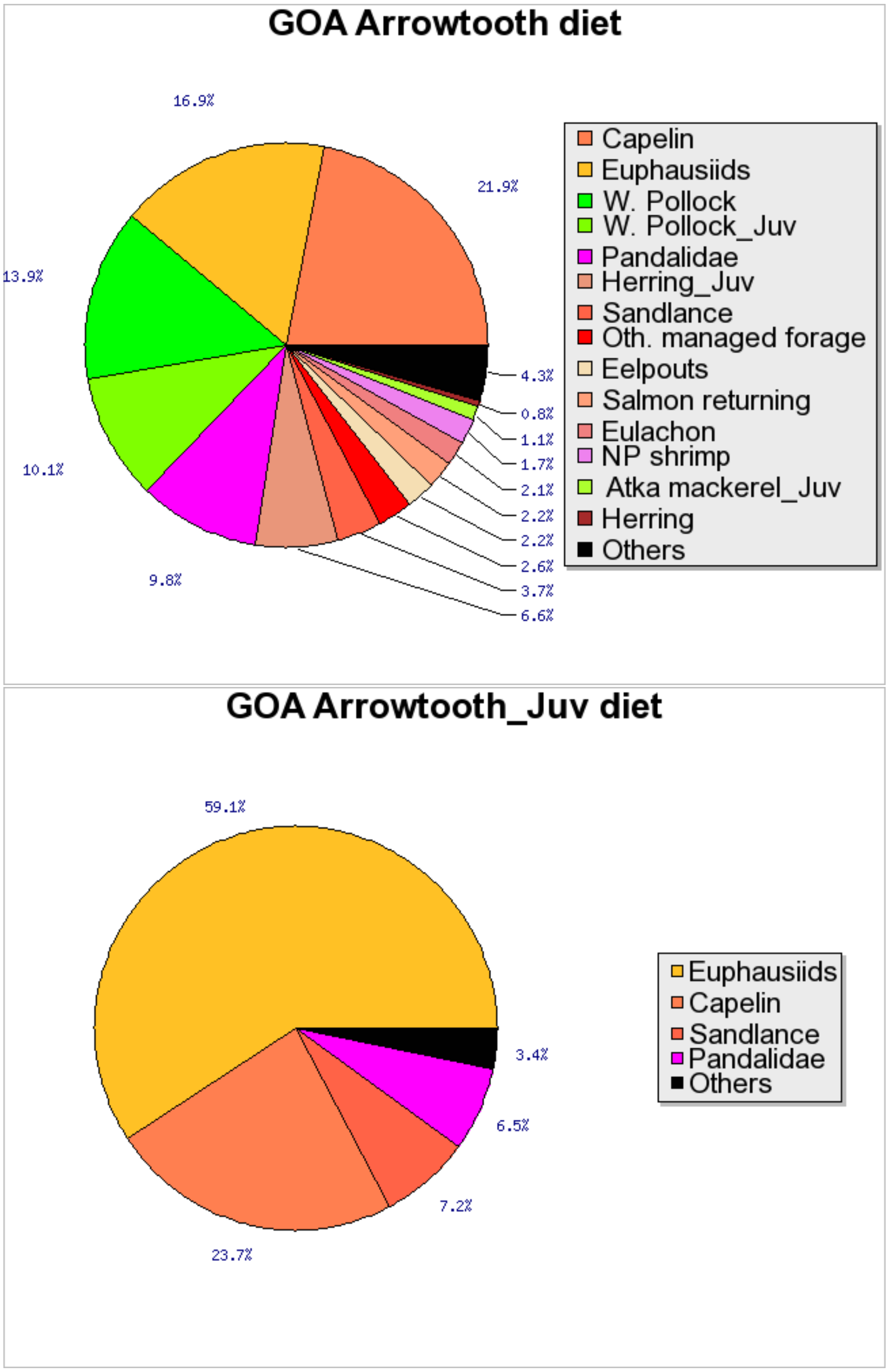


Figure B.2. Arrowtooth flounder diet compositions for the GOA ecosystem, for adults > 20cm (top) and juveniles 0-20 cm in length (bottom). Diets are estimated from stomach collections taken aboard NMFS bottom trawl surveys in 1990-1993. See Background section for detailed methods.

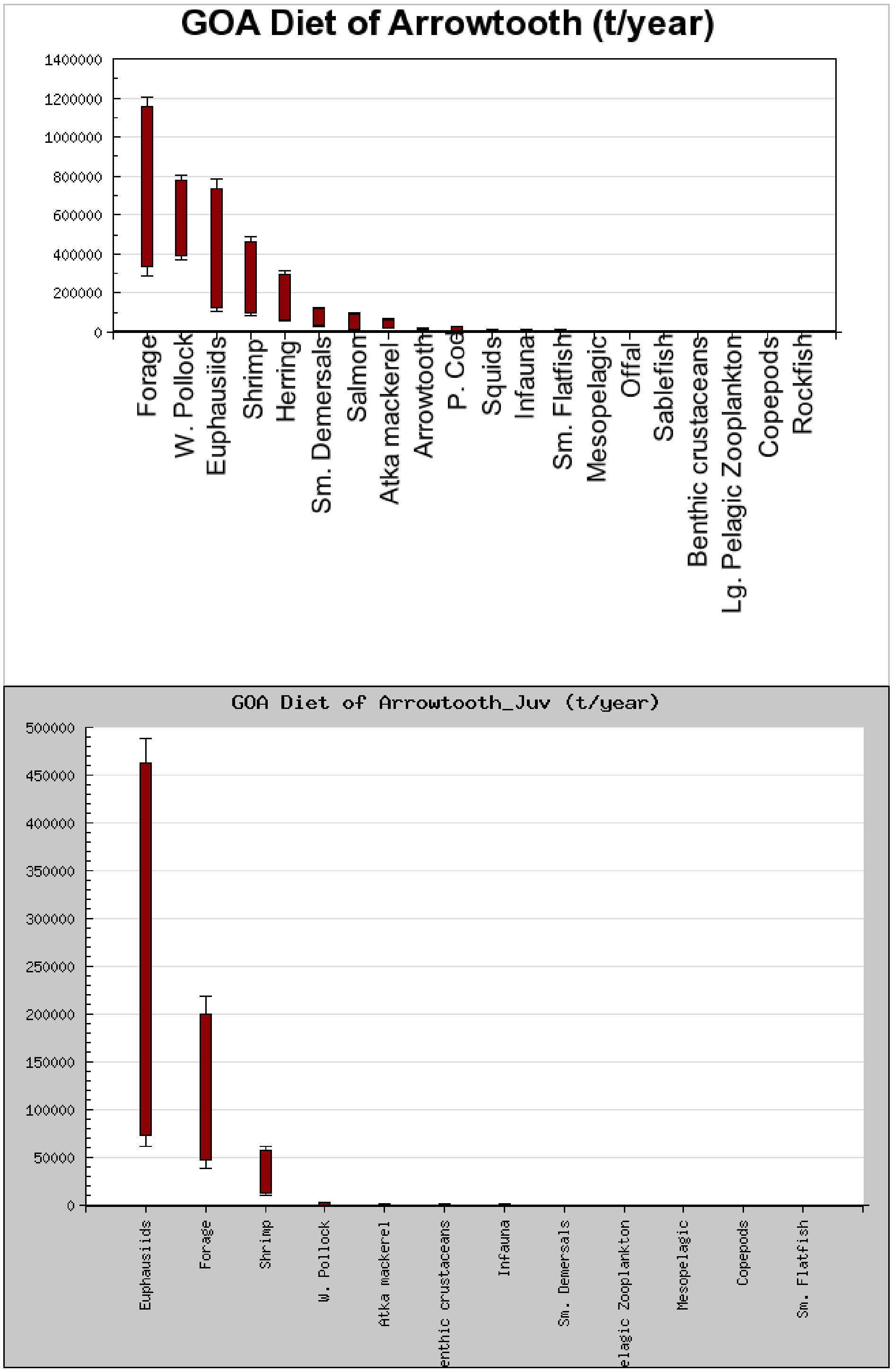
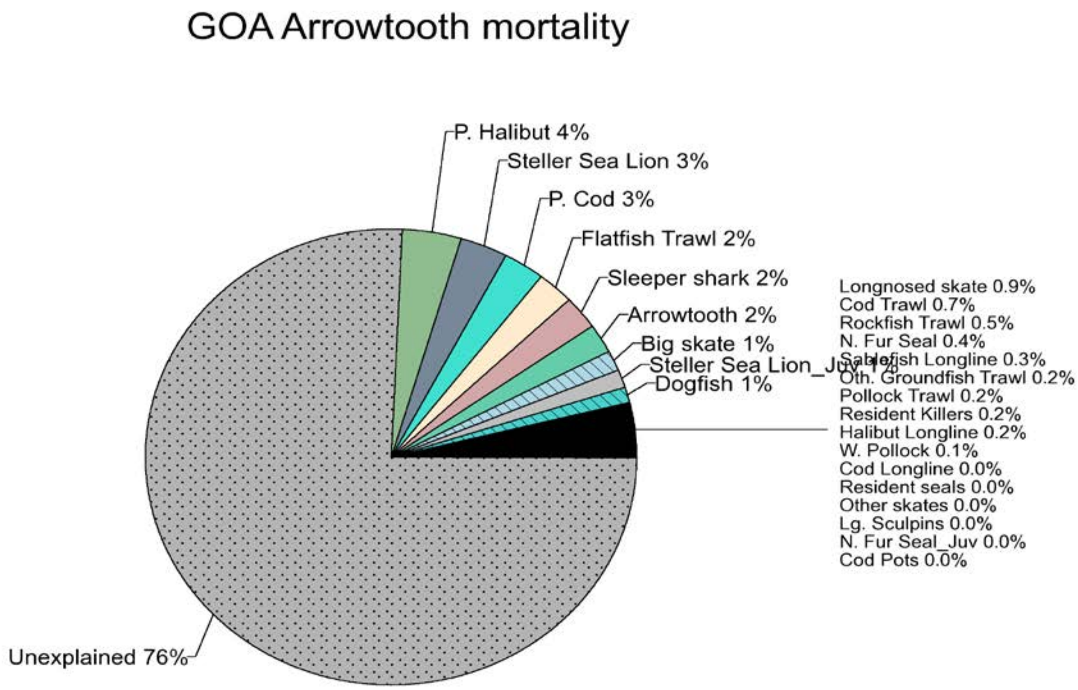


Figure B.3. Estimated annual tons of each prey type consumed by GOA Arrowtooth flounder adults >20 cm (top) and juveniles 0-20 cm (bottom), based on diets in Fig. B.2. “Forage” is all forage fish together, including capelin, sand lance, eulachon, and other managed forage.



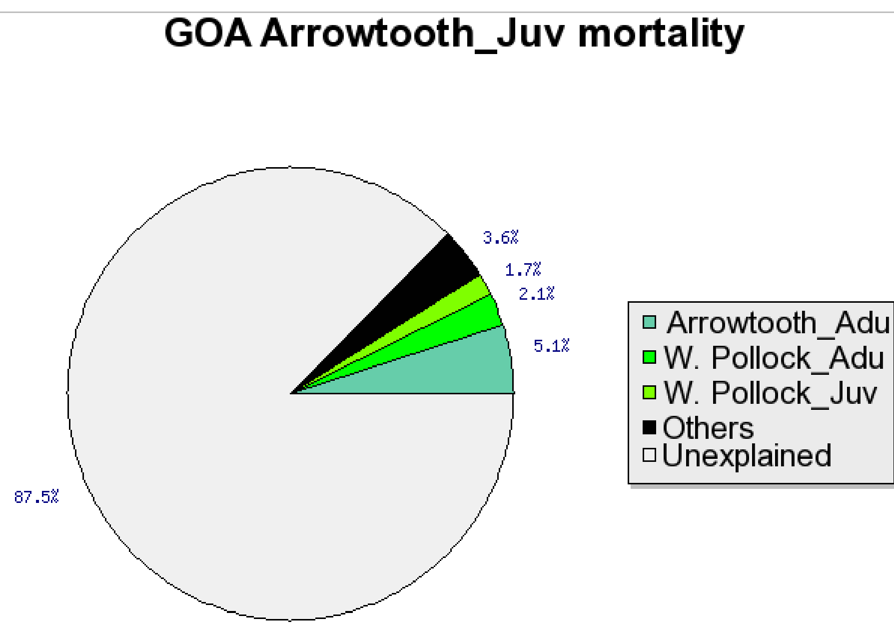


Figure B.4. Arrowtooth flounder mortality sources for the GOA ecosystem, for adults > 20cm (top) and juveniles 0-20 cm in length (bottom). Mortality sources reflect arrowtooth flounder predator diets estimated from stomach collections taken aboard NMFS bottom trawl surveys in 1990-1993, arrowtooth predator consumption rates estimated from stock assessments and other studies, and catch of arrowtooth by all fisheries in the same time periods (Aydin et al. in press). See Background section for detailed methods.

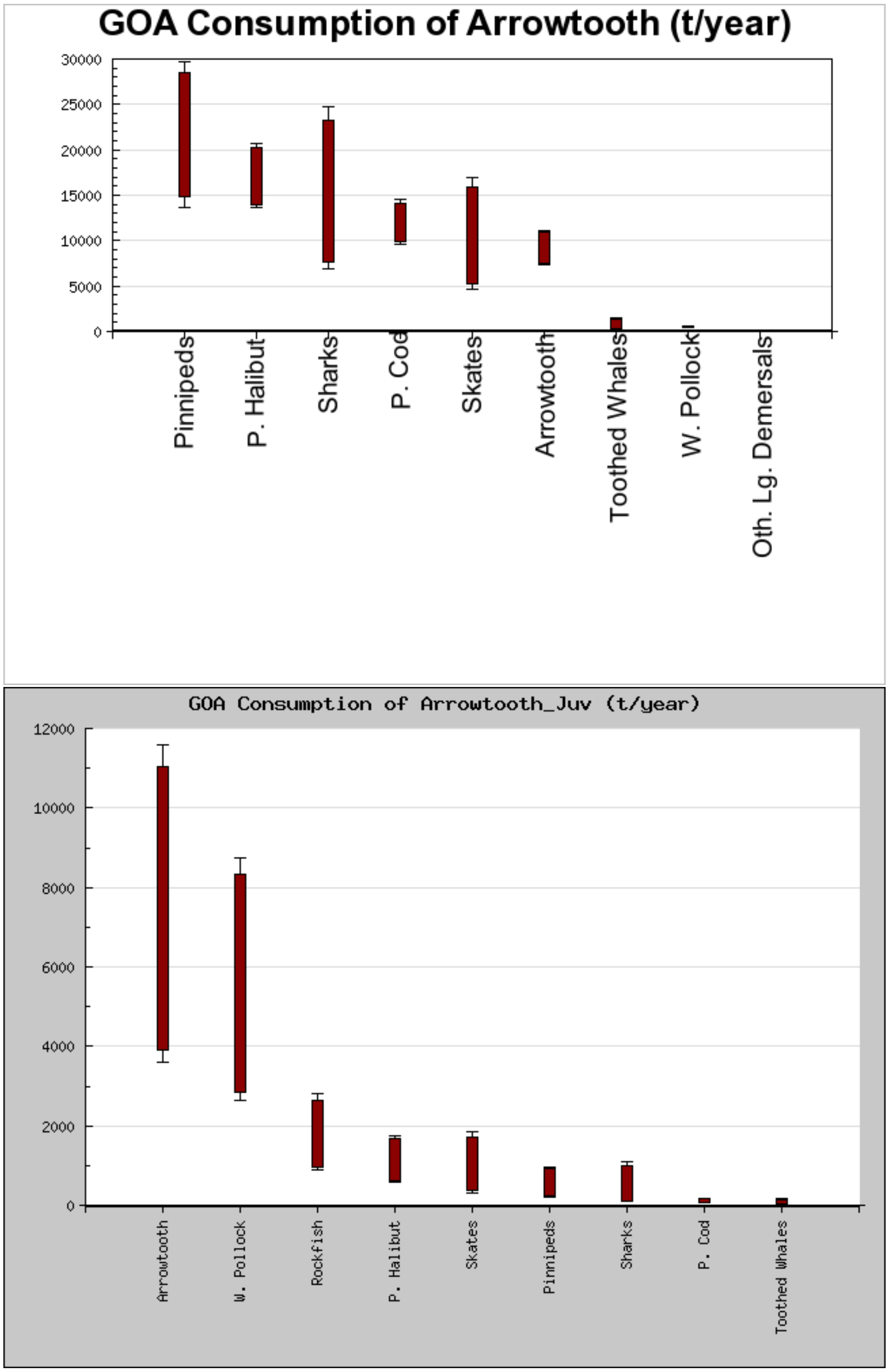


Figure B.5. Estimated annual tons of arrowtooth flounder consumed by predators in the GOA. Consumption of adult arrowtooth 20 cm (top) and juveniles 0-20 cm (bottom), based on mortality estimates in Fig. B.4. “Forage” is all forage fish together, including capelin, sand lance, eulachon, and other managed forage.

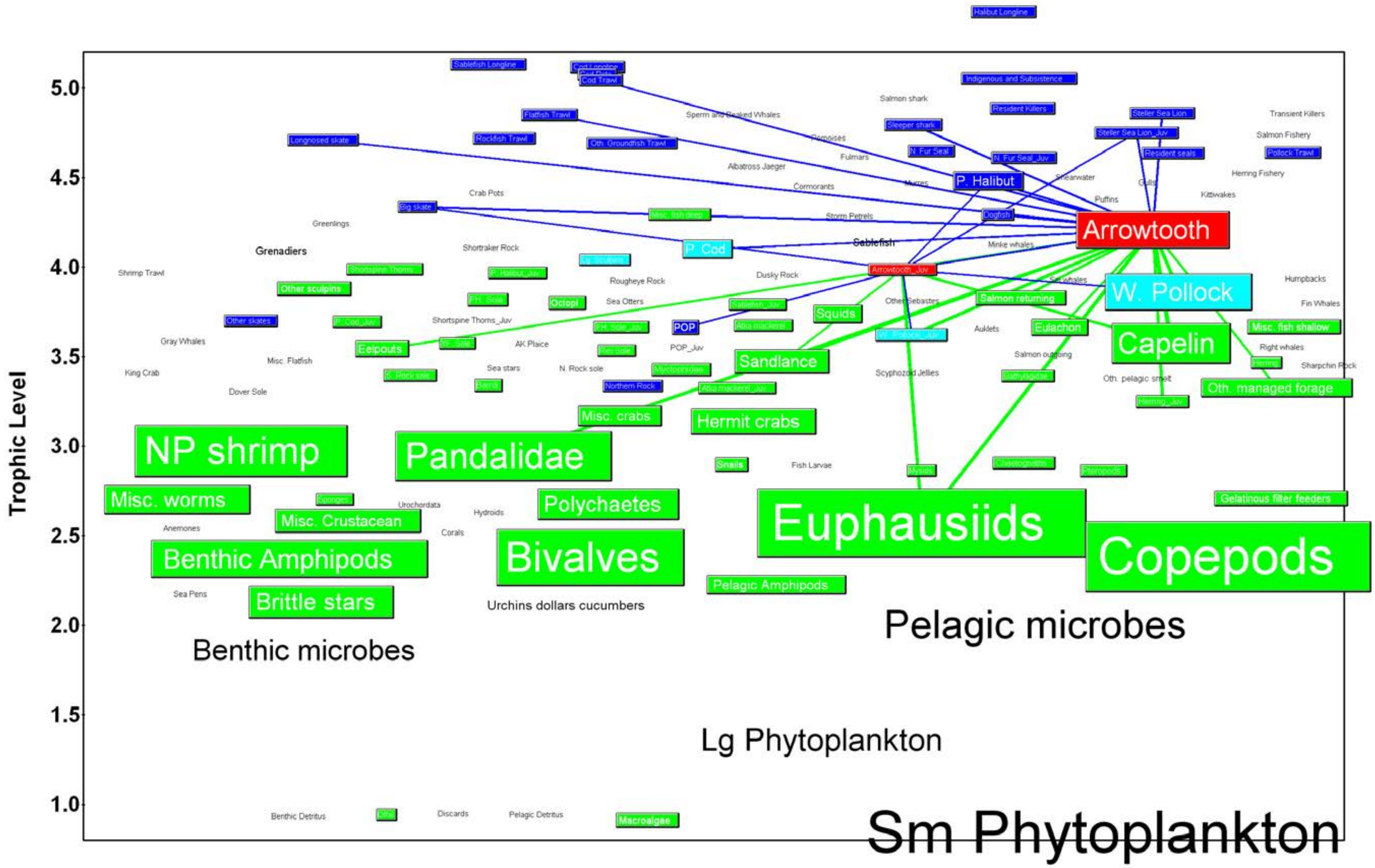


Figure B.6. Adult and juvenile arrowtooth flounder in the GOA food web. Box size is proportional to biomass, and lines between boxes represent the most significant energy flows. Predators of arrowtooth are dark blue, prey of arrowtooth are green, and species that are both predators and prey of arrowtooth are light blue.

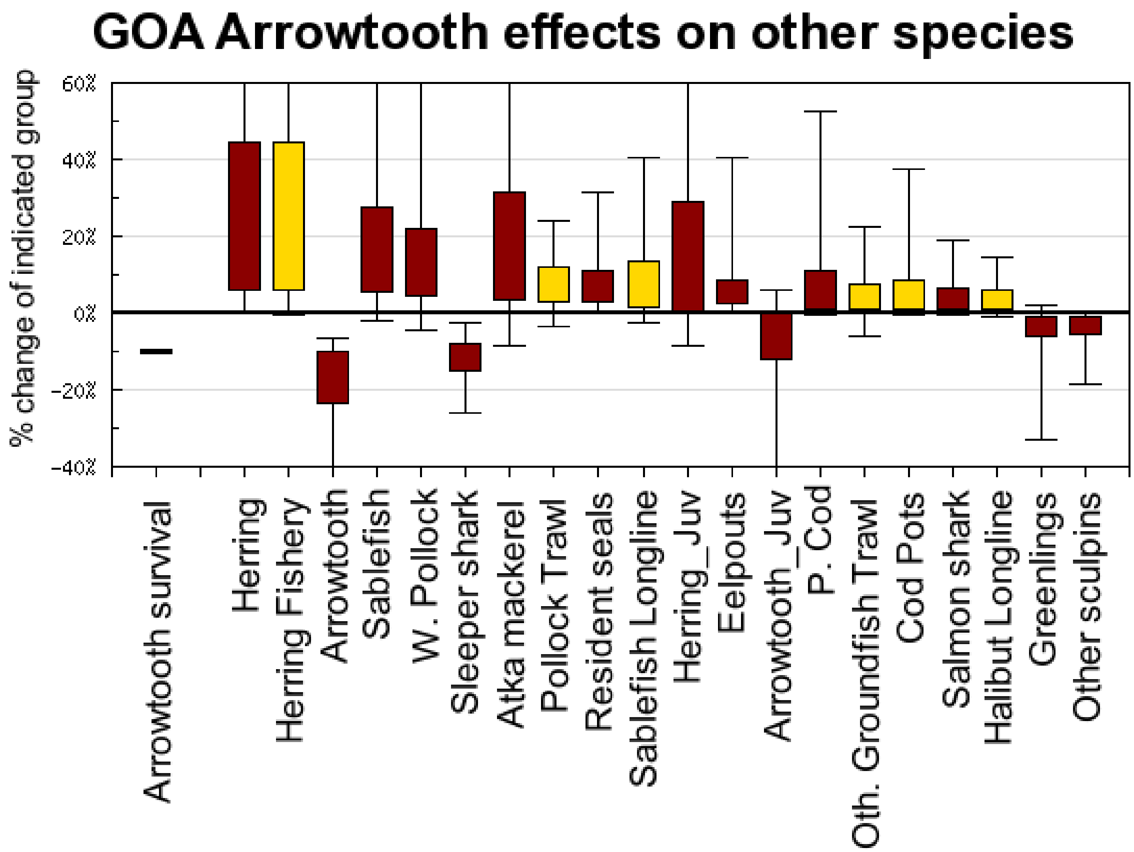


Figure B.7. Effect of changing arrowtooth > 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the GOA, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting 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 Sense methods).

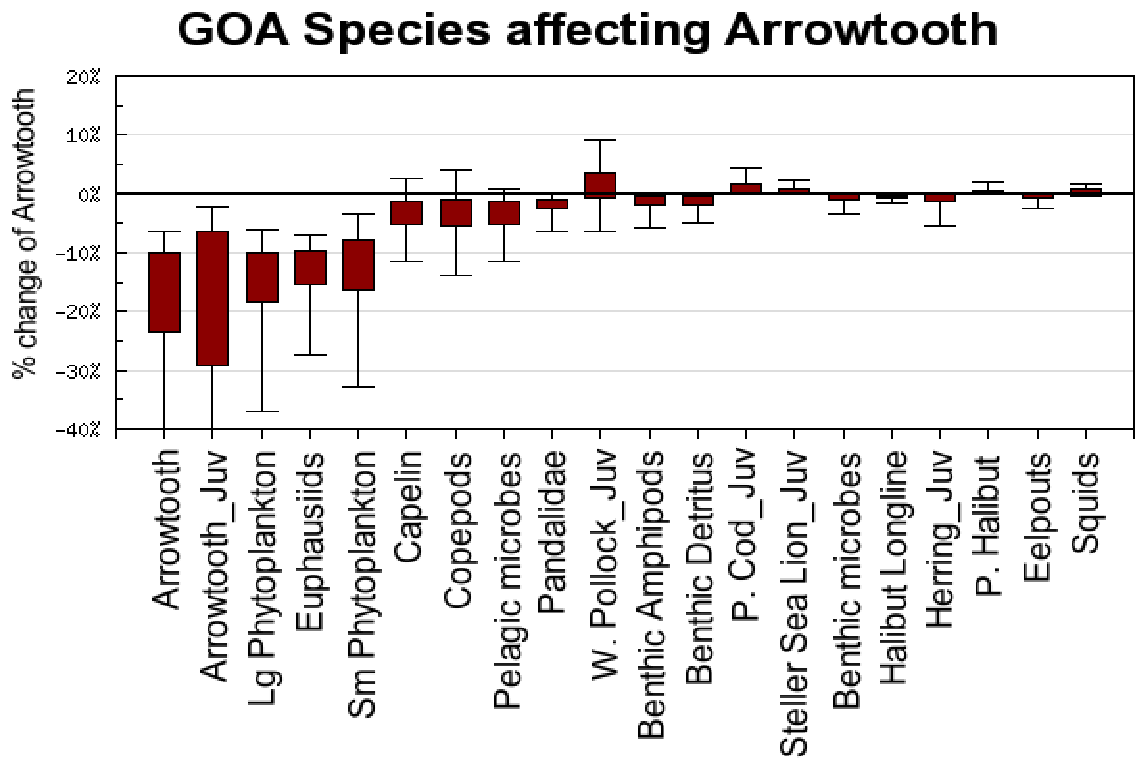


Figure B.8. Effect of reducing fisheries catch (yellow) and other species survival (dark red) on arrowtooth > 20 cm biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting 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 Sense methods).

Following Page: Table B.1 of sample sizes for GOA arrowtooth flounder stomach collections. Season 3 is May-September and Season 1 is the rest of the year (October-April). HAULCOUNT is the number of hauls sampled in a given regional stratum/arrowtooth size cell. PREDCOUNT is the number of arrowtooth stomachs in the same cell. When we calculate diets, our sample unit is the haul, not the individual fish; all fish collected in a given haul have diets combined based on the assumption that foraging in a given area will be sampling the same prey field. (This assumption may not be correct if fish move very far and digest very slowly). See the full diet calculations in Background section. Regional strata include area and depth: West is NMFS area 610, Central is 620-630, East is 640, and Southeast is 650. Shelf is waters 0-200 m, slope is offshore waters 200 m -1000 m (although not all surveys went that deep), and gully is inshore waters ranging from 100-500 m (gullies are defined according to GOA survey strata). NA did not map to these strata (may have taken samples for diet from "bad" trawl survey hauls that did not go into official biomass estimates). Divisions under each region are three arrowtooth size classes: 0 cm to 19.9 cm, 20 cm to 39.9 cm, and 40 cm and up. Therefore, the first size class represents our juveniles in the ecosystem model, and the second and third size classes are combined to give us our "adult" group of fish 20 cm and larger. Note that 2007 samples are not yet complete, there are still buckets to be analyzed for this past summer so these numbers will increase.

Year	Season	Data	Westshelf			Westgully			Westslope			Centralshelf			Centralgully			Centralslope			Eastshelf			Eastgully			Eastslope			Southeastshelf			Southeastgully			NA		
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1985	1	HAULCOUNT									1																											
		PREDCOUNT									2																											
1986	1	HAULCOUNT		1	2																																	
		PREDCOUNT		3	10																																	
1987	1	HAULCOUNT		2	2					1	2																											
		PREDCOUNT		5	9					2	7																											
	3	HAULCOUNT											4	7		2	3																					
		PREDCOUNT											11	28		2	9																					
1990	3	HAULCOUNT		2	1		2	1				3	34	35	2	27	29		1	2		2	2						1									
		PREDCOUNT		8	11		10	5				4	150	212	7	80	131		1	5		14	10						6									
1991	3	HAULCOUNT												3						2																		
		PREDCOUNT												12						6																		
1992	1	HAULCOUNT												1		2	3																					
		PREDCOUNT												6		2	10																					
1993	3	HAULCOUNT	5	12	10		3	3				12	36	45	12	34	46			5	2	7	8															
		PREDCOUNT	16	52	32		6	6				44	146	253	22	158	228			14	16	22	35															
1994	1	HAULCOUNT												1		1	7																					
		PREDCOUNT												2		5	22																					
1995	1	HAULCOUNT		1	1								1				2																					
		PREDCOUNT		4	1								1				11																					
	3	HAULCOUNT	1	8	7		1	1					3	3																								
		PREDCOUNT	1	35	14		1	5					16	15																								
1996	1	HAULCOUNT												1		1	3																					
		PREDCOUNT												1		1	19																					
	3	HAULCOUNT	21	48	38	2	10	10	1	1	9	16	67	88	3	34	52		1	11			1															
		PREDCOUNT	36	177	150	3	33	35	1	1	23	32	256	429	3	100	308		1	25			2															
1997	1	HAULCOUNT																																			2	10
		PREDCOUNT																																			2	31
1998	1	HAULCOUNT										1	9	7	2	7	7																					
		PREDCOUNT										4	44	51	9	32	19																					
	3	HAULCOUNT										4	8	9		4	4																					
		PREDCOUNT										26	31	43		15	17																					
1999	1	HAULCOUNT										8	14	13	5	5	6																					
		PREDCOUNT										21	56	55	7	24	28																					
	3	HAULCOUNT	5	9	10	2	3	3			2	8	34	33	1	23	25			4																		
		PREDCOUNT	18	26	27	3	21	6			3	8	138	146	1	70	100			9																		
2000	1	HAULCOUNT																																			1	3
		PREDCOUNT																																			1	3
	3	HAULCOUNT																																				1
		PREDCOUNT																																				2
2001	1	HAULCOUNT																																		14	28	30
		PREDCOUNT																																		33	102	103
	3	HAULCOUNT	11	20	14	1	5	4		1	2	24	58	48	11	26	27		3	8																		8
		PREDCOUNT	78	98	59	3	30	22		2	4	56	354	292	20	166	144		4	31																		28
2002	1	HAULCOUNT																																				1
		PREDCOUNT																																				3
	3	HAULCOUNT																																				2
		PREDCOUNT																																				4
2003	1	HAULCOUNT																																				3
		PREDCOUNT																																				5
	3	HAULCOUNT	5	11	12							5	16	16		1	1				2	5	5			1					3	3					5	8
		PREDCOUNT	8	73	65							9	139	91		8	5				3	25	8			6					12	5					11	20
2004	1	HAULCOUNT																													2	2					1	7
		PREDCOUNT																													2	4					2	11
	3	HAULCOUNT																													1	2					1	8
		PREDCOUNT																													1	4					1	24
2005	3	HAULCOUNT	3	7	6		1	2		1	1	2	6	15		6	8			6	2	5	10		1			1		1	4	5			3			
		PREDCOUNT	5	13	10		2	2		2	1	7	16	40		21	24			8	2	16	26		3			7		1	7	13			8			
2007	3	HAULCOUNT	3	9	11		2			1	1	2	13	17		10	11				1	6	7			1					1	1		1	1			
		PREDCOUNT	12	27	33		2			1	1	2	31	47		17	19				1	7	14			3					5	7		1	1			

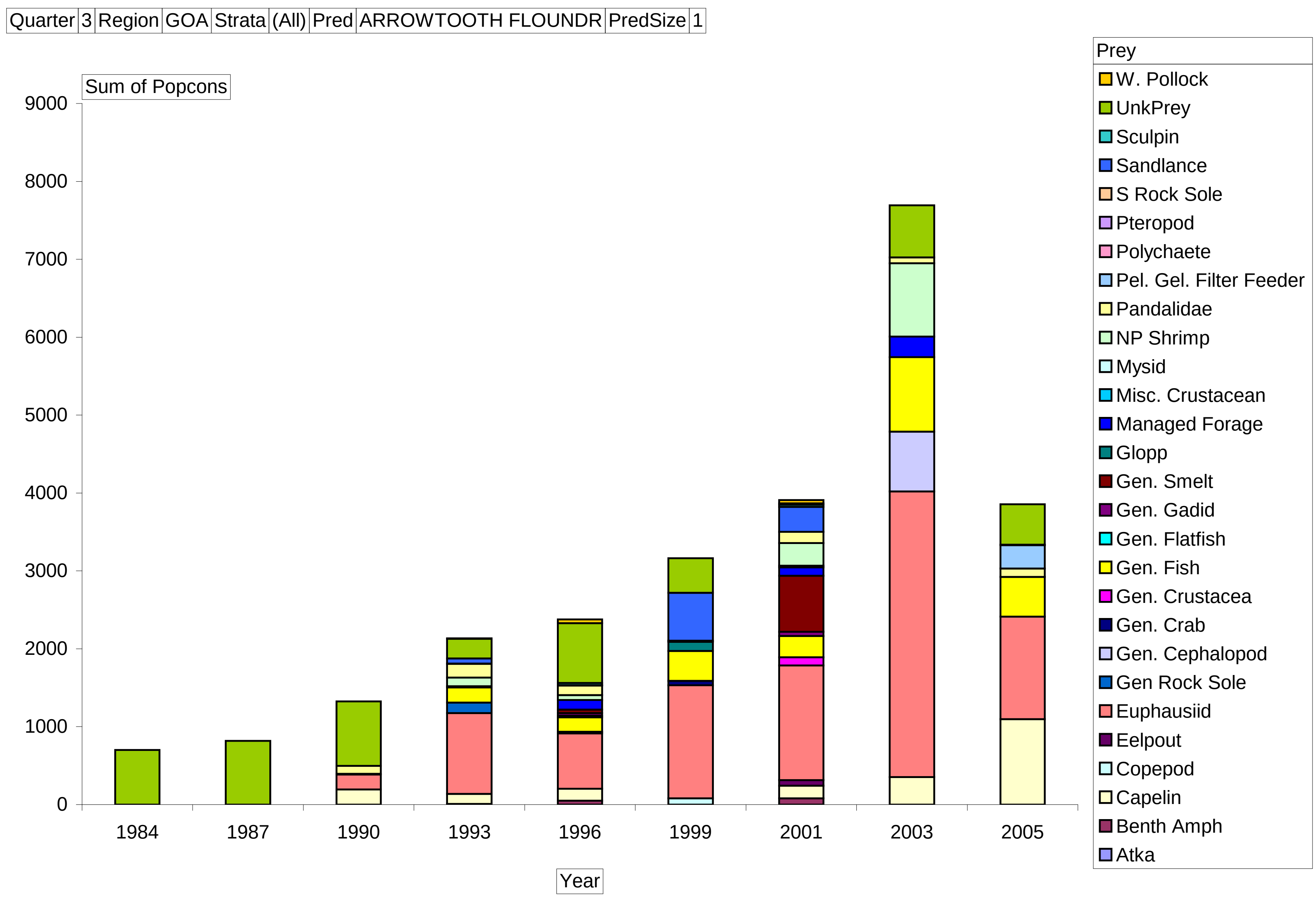


Figure B.9. Juvenile (<20 cm) arrowtooth estimated consumption of prey by survey year in the GOA.

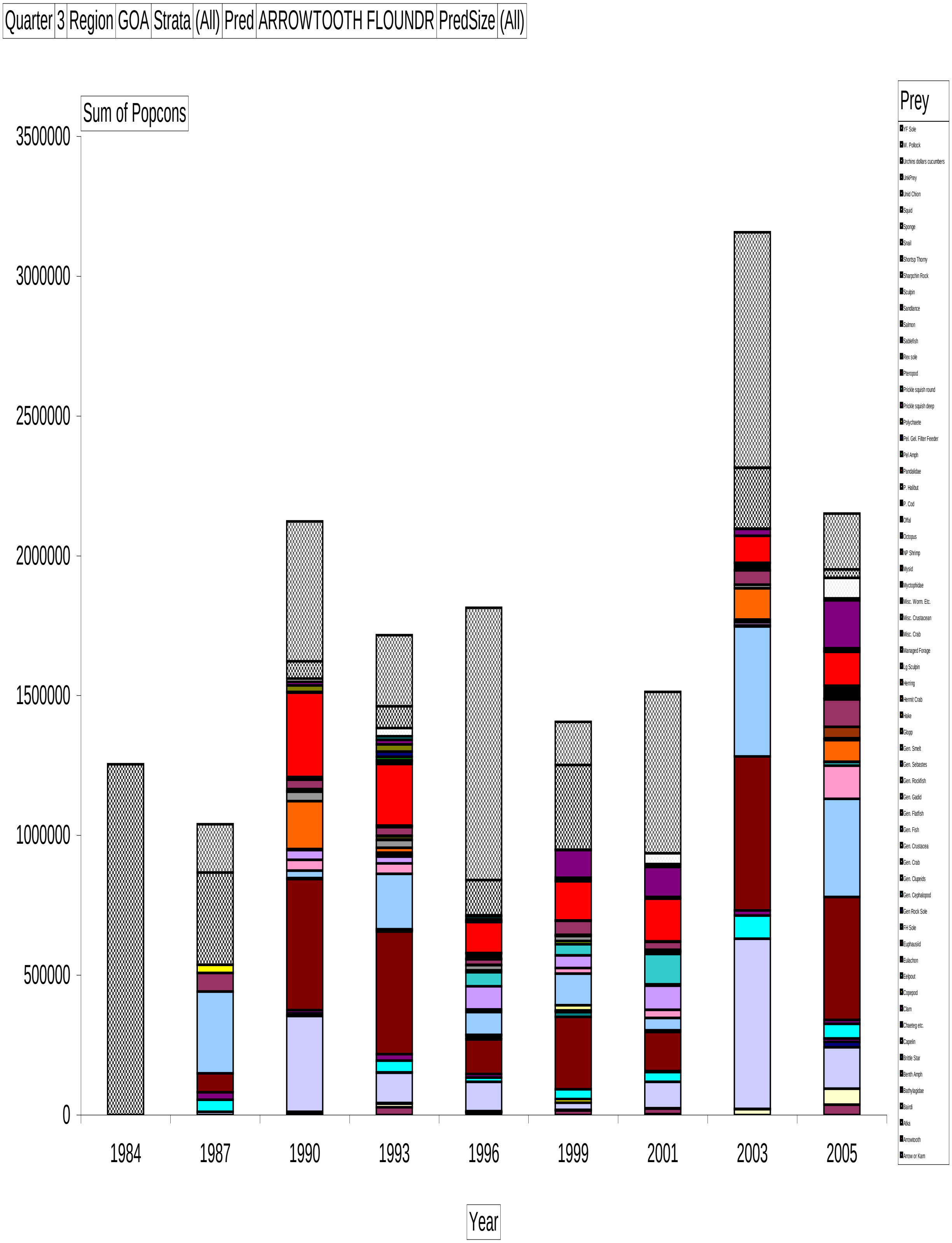


Figure B.10. Adult (20+ cm) arrowtooth estimated consumption of prey by survey year in the GOA.

BACKGROUND INFO ON MODEL PARAMETERS: REPRINTED FROM Aydin, et al., TECH MEMO

Arrowtooth flounder (*Atherestes stomias*) are relatively large, piscivorous flatfish in the family Pleuronectidae (right-eyed flounders) which range from Kamchatka, Russia in the Bering Sea through the Gulf of Alaska to Santa Barbara, CA on the U.S. west coast. It is found in benthic habitats from less than 10m to over 1000 m depth (Love et al. 2005). Arrowtooth flounder are currently the most abundant groundfish in the GOA (Turnock et al. 2003a). They exhibit differential growth by sex, with females reaching a maximum size of 1 m and age of 23, and males growing to 54 cm and 20 years. Females reach 50% maturity at 47 cm in the GOA, and display exponentially increasing fecundity with length, with large females producing over 2 million eggs annually (Zimmerman 1997). Until recently, arrowtooth flounder were not a desirable commercial species because their flesh quality was considered poor; however recently developed processing techniques have allowed a moderate commercial fishery to develop around Kodiak Island (AFSC website http://www.afsc.noaa.gov/species/Arrowtooth_flounder.php).

Adult arrowtooth flounder

In the EBS model, adult arrowtooth biomass is the NMFS bottom trawl survey estimate from 1991. GOA adult biomass is the average of 1990 and 1993 GOA NMFS bottom trawl survey estimates. In the AI biomass is the average of 1991 and 1994 estimates from the AI bottom trawl survey. The biomass was proportioned across the subareas according to survey estimates in each one.

In the EBS, the P/B ratio of 0.18 was estimated from the 1991 age structure in the EBS arrowtooth/Kamchatka flounder stock assessment (Wilderbuer and Sample 2003), and weight at age data collected on NMFS bottom trawl surveys for the EBS (see Appendix B for methods). The EBS Q/B ratio of 1.16 was estimated using weight at age data fit a generalized von Bertalanffy growth function (Essington et al. 2001) and scaled to the 1991 age structure from the EBS stock assessment. The GOA P/B ratio of 0.26 and Q/B ratio of 1.44 were estimated using the same methods as in the EBS from the 1990-1993 age structure in the GOA arrowtooth flounder stock assessment (Turnock et al. 2003a) and weight at age data collected on NMFS bottom trawl surveys. Values for the AI P/B and Q/B ratios of 0.297 and 2.61 were estimated using the age structure for 1991 in the BSAI stock assessment for arrowtooth/ Kamchatka flounder (Wilderbuer and Sample 2003), and weight at age data collected on NMFS bottom trawl surveys for the Gulf of Alaska.

Adult arrowtooth diet composition was estimated from food habits collections made during bottom trawl surveys in each ecosystem. The EBS diet was derived from 1991 collections, the GOA diet was derived from the 1990 and 1993 bottom trawl surveys of the GOA, and in the AI it comes from stomachs collected in 1991 and 1994 as part of the bottom trawl surveys.

The adult arrowtooth biomass data pedigree was 2 for the EBS and AI models (data is a direct estimate from surveys in AI and EBS but the assessment is conducted for the combined area), and 1 for the GOA model (direct estimate from surveys which agrees with the GOA assessment). P/B and Q/B parameters were rated differently by system: 3 in the GOA model (proxy with known and consistent bias), 4 in the EBS model (proxy for combined BSAI with some species mixing), and 5 in the AI model (proxy for combined BSAI with some species mixing plus weight at age from adjacent area). Diet composition data rated 1 in all systems (data established and substantial, with resolution on multiple spatial scales).

Arrowtooth flounder adults have a significantly higher density in the GOA (5.7 t/km^2) than in either the EBS or AI (<1 t/km^2). They are preyed upon by pollock, Alaska skates and sleeper sharks which jointly account for 60% of the total mortality in the EBS, but have relatively few predators in the AI; sleeper sharks are the only significant ones (16% of total mortality). In the GOA, there are no major predators on arrowtooth, as sleeper sharks, cod, pollock and cannibalism barely account for 11% of the total mortality. The fisheries in aggregate cause 15%-17% of the mortality in the EBS and AI respectively, while only 4% in the GOA. In all three systems adult arrowtooth flounder eat primarily pelagic prey. In the GOA they eat mostly capelin (22% of diet) and euphausiids (17%), followed by adult pollock (14%), and juvenile pollock (10%). In the EBS, arrowtooth flounder eat primarily juvenile pollock (47% of diet), followed by adult pollock (20%) and euphausiids (10%). In the AI, arrowtooth mostly prey on myctophids (27%), juvenile Atka mackerel (16%), and pandalid shrimp (16%).

Juvenile arrowtooth flounder

In all three models, juveniles were defined as fish less than 20 cm in length, which roughly corresponds to 0 through 1 year old arrowtooth. In the AI, juvenile arrowtooth biomass is based on an EE of 0.8. In the EBS and GOA models, initial attempts at estimating juvenile biomass using top-down methods were not successful because there are apparently few predators of juvenile arrowtooth flounder in either ecosystem. Therefore, in the EBS juvenile arrowtooth flounder biomass in each model stratum was assumed to be 10% of adult arrowtooth biomass in that stratum. In the GOA, we estimated juvenile arrowtooth mortality to be 0.5, a rate comparable to those estimated by MSVPA model runs in the EBS (Jurado-Molina 2001). This mortality rate was used to estimate juvenile biomass given the numbers and weight at age estimated for those years.

In the EBS, the P/B ratio of 1.58 was estimated by the same methods as described above for adults. In the GOA, the estimated juvenile mortality rate of 0.5 was used to estimate the P/B ratio to 0.90 for 1990-1993 based on stock assessment age structure. The juvenile arrowtooth P/B in the AI was estimated using the same method as that described above for adults, resulting in a value of 1.01. In all three ecosystems, Q/B ratios were estimated by the same method and using the same information as for adults. The EBS juvenile arrowtooth Q/B was therefore 3.31, the GOA juvenile arrowtooth Q/B was 2.45, and the AI Q/B ratio was 3.77.

Juvenile arrowtooth flounder diet composition was estimated from food habits collections made during bottom trawl surveys in each ecosystem. The EBS diet was derived from 1991 collections, the GOA diet was derived from the 1990 and 1993 bottom trawl surveys of the GOA, and in the AI it comes from stomachs collected in 1991 and 1994 as part of the bottom trawl surveys.

The juvenile arrowtooth biomass data pedigree was 8 for the EBS and AI models (no estimate available, top down balance), and 4 for the GOA (proxy with limited confidence). P/B and Q/B parameters were rated differently by system: 4 in the GOA model (proxy with limited confidence), 5 in the EBS model (downgraded from adult rating of 4), and 6 in the AI model (downgraded from adult rating of 5). Diet composition data rated 1 in all systems (data established and substantial, with resolution on multiple spatial scales).

Arrowtooth flounder juveniles have a low fraction of total mortality due to predation in the EBS and GOA, so the assumption of an EE=0.8 in the AI model to top down balance this group might be re-examined in revisions to that model. The major source of mortality in the EBS and GOA are adult arrowtooth (3-5%, respectively), but they are preyed upon mostly by Pacific cod (20%) in the AI. Juvenile arrowtooth flounder appear to eat from different sections of the food web in each system. They eat primarily benthic invertebrates (pandalids and benthic amphipods) in the AI, show approximately equal feeding from benthic and pelagic groups (non pandalids and juvenile pollock) in the EBS, but feed predominantly on pelagic euphausiids and capelin in the GOA.

[*NOTE: Parameter estimation methods below are reprinted from tech memo*]

Fish Production rates

Production/biomass (P/B) and consumption/biomass (Q/B) for a given population depend heavily on the age structure, and thus mortality rate of that population. For a population with an equilibrium age structure, assuming exponential mortality and Von Bertalanffy growth, P/B is in fact equal to total mortality Z (Allen 1971) and Q/B is equal to (Z+3K)/A, where K is Von Bertalanffy's K, and A is a scaling factor for indigestible proportions of prey (Aydin 2004). If a population is not in equilibrium, P/B may differ substantially from Z although it will still be a function of mortality.

For the Bering Sea, Aleutian Islands, and Gulf of Alaska ECOPATH models, P/B and Q/B values depend on available mortality rates, which were taken from estimates or literature values used in single-species models of the region. It is noted that the single-species model assumptions of constant natural mortality are violated by definition in multispecies modeling; therefore, these estimates should be seen as "priors" to be input into the ECOPATH balancing procedures or other parameter-fitting (e.g. Bayesian) techniques.

Several methods were used to calculate P/B, depending on the level of data available. Proceeding from most data to least data, the following methods were used:

1. If a population is not in equilibrium, total production P for a given age class over the course of a year can be approximated as ($N_{at} \cdot \Delta W_{at}$), where N_{at} is the number of fish of a given age class in a given year, exponentially averaged to account for mortality throughout the year, and ΔW_{at} is the change in body weight of that age class over that year. For a particular stock, if weight-at-age data existed for multiple years, and stock-assessment reconstructed numbers-at-age were also available, production was calculated by summing this equation over all assessed age classes. Walleye pollock P/B for both the EBS and GOA were calculated using this method: examining the components of this sum over the years showed that numbers-at-age variation was responsible for considerably more variability in overall P/B than was weight-at-age variation.
2. If stock assessment numbers-at-age were available, but a time series of weight-at-age was not available and some weight-at-age data was available, the equation in (1), above, was used, however, the change in body weight over time was estimated using fits to the generalized Von Bertalanffy equations described in the consumption section, below.
3. If no stock assessment of numbers-at-age was available, the population was assumed to be in equilibrium, so that P/B was taken to equal Z. In cases for many nontarget species, estimates of Z were not available so estimates of M were taken from conspecifics with little assumed fishing mortality for this particular calculation.

Fish Consumption rates

There are multiple methods for estimating the consumption rates (Q/B, consumption per unit biomass) for fish. Four methods were considered in the construction of these models: bioenergetics models (based on laboratory and field experiments), allometric fitting to weight-at-age data (e.g. Essington et al. 2001), evacuation rate calculation from field stomach contents data (e.g. MAXIMS, Jarre et al. 1991) and empirical methods based on morphological characteristics (Pauly 1986). One goal in selecting methods was to choose options which could be used consistently in all three ecosystem models and thus provide reasonable bases for comparison.

It was determined that insufficient data existed for the application of bioenergetics models or evacuation rate calculations; while models existed for a very limited number species, input data such as foraging rates and water temperature specific to the Alaska region were not consistently available, and lack of these data could result in extremely broad error ranges or bias in estimates. Pauly's (1986) empirical methods have an order-of-magnitude error range and thus were considered as a worst-case solution only.

While bioenergetics data was limited, weight-at-age data existed for many species throughout the region: the method of fitting the generalized Von Bertalanffy growth equations to these data (Essington et al. 2001) was thus selected. (The solution for Q/B given above, (Z+3K)/A, is a solution for a specialized case of the equations, as described below).

The generalized Von Bertalanffy growth equation assumes that both consumption and respiration scale allometrically with body weight, and change in body weight over time (dW/dT) is calculated as follows (Paloheimo and Dickie 1965):

$$\frac{dW_t}{dt} = H \cdot W_t^d - k \cdot W_t^n \qquad (1)$$

Here, W_t is body mass, t is the age of the fish (in years), and H, d, k, and n are allometric parameters. The term $H \cdot W_t^d$ is an allometric term for "useable" consumption over a year, in other words, the consumption (in wet weight) by the predator after indigestible portions of the prey have been removed and assuming constant caloric density between predator and prey. Total consumption (Q) is calculated as $(1/A) \cdot H \cdot W_t^d$, where A is a scaling fraction between predator and prey wet weights that accounts for indigestible portions of the prey and differences in caloric density. The term $k \cdot W_t^n$ is an allometric term for the amount of biomass lost yearly as respiration.

Based on an analysis performed across a range of fish species, Essington et al. (2001) suggested that it is reasonable to assume that the respiration exponent n is equal to 1 (respiration linearly proportional to body weight). In this case, the differential equation above can be integrated to give the following solution for weight-at-age:

$$W_t = W_\infty \cdot \left(1 - e^{-k(1-d)(t-t_0)}\right)^{\frac{1}{1-d}} \qquad (2)$$

Where W_∞ (asymptotic body mass) is equal to $(H/k)^{\frac{1}{1-d}}$, and t_0 is the weight of the organism at time=0. If the consumption exponent d is set equal to 2/3, this equation simplifies into the "specialized" von Bertalanffy length-at-age equation most used in fisheries management, with the "traditional" von Bertalanffy K parameter being equal to the k parameter from the above equations divided by 3.

From measurements of body weight and age, equation 2 can be used to fit four parameters (W_∞, d, k, and t_0) and the relationship between W_∞ and the H, k, and d parameters can then be used to determine the consumption rate $H \cdot W_t^d$ for any given age class of fish. For these calculations, weight-at-age data available and specific to the modeled regions were fit by minimizing the difference between log(observed) and log(predicted) body weights as calculated by minimizing negative log likelihood: observation error was assumed to be in weight but not aging. A process-error model was also examined but did not give significantly different results.

Initial fitting of 4-parameter models showed, in many cases, poor convergence to unique minima and shallow sum-of-squares surfaces: the fits suffered especially from lack of data at the younger age classes that would allow fitting to body weights near t=0 or during juvenile, rapidly growing life stages. To counter this, the following multiple models were tested for goodness-of-fit:

1. All four parameters estimated by minimization;
2. d fixed at 2/3 (specialized von Bertalanffy assumption)
3. d fixed at 0.8 (median value based on metaanalysis by Essington et al. 2001).
4. t_0 fixed at 0.
5. d fixed at 2/3 with t_0 fixed at 0, and d fixed at 0.8 with t_0 fixed at 0.

The multiple models were evaluated using Aikeike's Information Criterion, AIC (Anderson and Burnham 2002). In general, the different methods resulted in a twofold range of consumption rate estimates; consistently, model #3, *d* fixed at 0.8 while the other three parameters were free, gave the most consistently good results using the AIC. In some cases model #1 was marginally better, but in some cases, model #1 failed to converge. The poorest fits were almost always obtained by assuming that d was fixed at 2/3.

To obtain absolute consumption (*Q*) for a given age class, the additional parameter *A* is required to account for indigestible and otherwise unassimilated portions of prey. We noted that the range of indigestible percentage for a wide range of North Pacific zooplankton and fish summarized in Davis (2003) was between 5-30%, with major zooplankton (copepods and euphasiids), as well as many forage fish, having a narrower range of indigestible percentages, generally between 10-20%. Further, bioenergetics models, for example for walleye pollock (Buckley and Livingston 1994), indicate that nitrogenous waste (excretion) and egestion resulted in an additional 20-30% loss of consumed biomass. As specific bioenergetics models were not available for most species, we made a uniform assumption of a total non-respirative loss of 40% (from a range of 25-60%) for all fish species, with a corresponding *A* value of 0.6.

Finally, consumption for a given age class was scaled to population-level consumption using the available numbers-at-age data from stock assessments, or using mortality rates and the assumption of an equilibrium age structure in cases where numbers-at-age reconstructions were not available.

Diet queries for fish

The most central parameter set for food web models are the diet composition matrices, obtainable through stomach sampling or other analyses. In particular, the elaboration of our food web models with respect to fished species depends heavily on the analysis of 250,000+ stomachs collected by the Resource Ecology and Ecosystem Management (REEM) program. Continuation of this collection will allow for a regular update and improvement of these models. Due to the high resolution and coverage of this diet data, we were able to model functional groups at a relatively high resolution: over 120 functional groups are specifically and separately accounted with survey strata-level resolution (rough depth and location), with specific juvenile and adult accounting for several of the commercial groundfish, crab, and pinniped species. Diets estimated directly from stomach samples collected in the same area that a model covers are considered "direct".

The diet composition for a species is calculated from stomach sampling beginning at the level of the individual survey haul (1), combining across hauls within a survey stratum (2), weighting stratum diet compositions by stratum biomass (3), and finally combining across predator size classes by weighting according to size-specific ration (consumption rate) estimates and biomass from stock assessment estimated age structure (4). Consumption rate calculations are described in detail above.

Notation:

DC = diet composition
W = weight in stomach
n = prey
p = predator
s = predator size class
h = survey haul
r = survey stratum
B = biomass estimate
v = survey
a = assessment
R = Q/B = ration estimate

Diet composition (DC) of prey n in predator p of size s in haul h is the total weight of prey n in all of the stomachs of predator p of size s in the haul divided by the sum over all prey in all of the stomachs for that predator size class in that haul:

$$DC_{n,p,s,h} = W_{n,p,s,h} \Big/ \sum_{n} W_{n,p,s,h} \qquad (1)$$

Diet composition of prey n in predator p of size s in survey stratum r is the average of the diet compositions across hauls within that stratum:

$$DC_{n,p,s,r} = \sum_{h} DC_{n,p,s,h} \Big/ h \qquad (2)$$

Diet composition of prey n in predator p of size s for the entire area t is the sum over all strata of the diet composition in stratum r weighted by the survey biomass proportion of predator p of size s in stratum r:

$$DC_{n,p,s,t} = \sum_{r} DC_{n,p,s,r} * B^{v}_{p,s,r} \Big/ \sum_{r} B^{v}_{p,s,r} \qquad (3)$$

Diet composition of prey n in predator p for the entire area t is the sum over all predator sizes of the diet composition for predator p of size s as weighted by the relative stock assessment biomass of predator size s times the ration of predator p of size s:

$$DC_{n,p,t} = \sum_{s} DC_{n,p,s,t} * B^{a}_{p,s} * R_{p,s} \Big/ \sum_{s} B^{a}_{p,s} * R_{p,s} \qquad (4)$$

Diets for fish and shellfish not included in the REEM database were taken from published literature sources or the nearest survey samples. For example, diets estimated from stomachs collected in the EBS may be used as surrogates in the AI and GOA if these last systems lack specific diet information. However these diets would be considered "general" for the AI and GOA in the sense that they are not from stomach samples taken as part of the REEM program and are neither weighted by depth nor location (but they would be for the EBS); in these cases prey items were assigned fixed percentages.

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Appendix C.

Table 7.C1. Removals of arrowtooth flounder from the Gulf of Alaska (GOA) from sources other than those that are included in the Alaska Region's official estimate of catch, 1990-2015. Source NMFS Alaska Region: AKR.V_NONCOMMERCIAL_FISHERY_CATCH table, October 23, 2017. Abbreviations: IPHC (International Pacific Halibut Commission), EIT (Echo Integration trawl survey), PWS (Prince William Sound), Surv. (survey).

Source of removals	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Annual Longline Survey	21.92	21.45	23.60	31.99	22.51	38.91	25.80	27.00	33.28	41.08	35.67
Golden King Crab Pot Surv.											
GOA Bottom Trawl Surv.											
IPHC Annual Longline Surv.											
Large-Mesh Trawl Survey									4.49	16.61	7.33
PWS Sablefish Tagging											
Sablefish Longline Survey									0.24	0.29	0.52
Salmon EFP 13-01											
Scallop Dredge Survey									22.00		
Shelikof Acoustic Survey											
Shelikof and Chirikof EIT											

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Annual Longline Survey	26.04	16.48	13.79	13.13	11.23	16.64	17.06	16.16	14.92	15.81	14.25
Golden King Crab Pot Surv.				0.04	0.02	0.03					
GOA Bottom Trawl Surv.											87.64
IPHC Annual Longline Surv.										11.05	8.11
Large-Mesh Trawl Survey	13.26	4.63	14.17	4.76	13.14	4.65	8.34	0.84	6.63	96.65	86.79
PWS Sablefish Tagging											
Sablefish Longline Survey	0.31	0.38	0.32	0.21	0.03	0.13					
Salmon EFP 13-01											
Scallop Dredge Survey		0.00	0.00	1.00	0.05	0.00	0.01	0.00	0.06	0.00	0.02
Shelikof Acoustic Survey										0.10	
Shelikof and Chirikof EIT											

	2012	2013	2014	2015
Annual Longline Survey	7.41	9.27	11.86	10.21
Golden King Crab Pot Surv.				
GOA Bottom Trawl Surv.		59.21		107.49
IPHC Annual Longline Surv.	8.42	6.06	9.20	5.54
Large-Mesh Trawl Survey	77.48	45.10	59.04	113.99
PWS Sablefish Tagging		0.09		0.03
Sablefish Longline Survey				
Salmon EFP 13-01		8.52	4.99	
Scallop Dredge Survey	0.00	0.06		0.01
Shelikof Acoustic Survey				
Shelikof and Chirikof EIT	0.04			

Appendix D.

Table 7.D1. Estimated parameters for the model. There were 189 total parameters estimated in the model (but 4 were included in the final count and not actually estimated).

Parameter	N	Description
mean_log_rec	1	log of the geometric mean value of age 1 recruitment
rec_dev$_y$ 1961≤y≤2017-1,	56	Recruitment deviation in year t (not estimated in final year)
rec_dev$_y$ 1940≤y≤1960	21	Recruitment deviation for initial age composition
log_avg_fmort	1	log of geometric mean value of fishing mortality
fmort_dev$_y$ 1961≤y≤2017	57	deviations in fishing mortality rate in year t
Slope and a50% selectivity parameters	8	Slope and $a_{50\%}$ parameters for male and female, fishery and survey.
Nonparameteric estimates of fishery selectivity	38	19 male and 19 female fishery selectivity parameters, total of 38
$F_{40\%}$, $F_{30\%}$, $F_{35\%}$	3	
Parameters for descending arm of survey selectivity	4	Male and female slope and $a_{50\%}$. This is an option that is not used in this model. Parameters are not estimated but are included in the final count.

Table 7.A.2. Fixed parameters in the model.

Parameter	Description
M = 0.2 females , M=0.35 males	Natural mortality*
Q = 1.0	Survey catchability
Weight at age for males and females.	Length at age derived from the length-age conversion matrix was converted to weight based on a von Bertalanffy relationship from 1977-2013 survey data.

*Note: Model 17.0h used Lorenzen (1996) natural mortality and Model 17.0i used Gislason et al. (2010) natural mortality ogives.