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

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Executive Summary

Summary of Changes in Assessment Inputs

Changes in the input data:

1. Survey size compositions from the 2015 and 2016 Eastern Bering Sea shelf survey, 2016 Eastern Bering Sea slope survey, and 2016 Aleutian Islands survey.
2. Biomass point-estimates and standard errors from the 2015 and 2016 Eastern Bering Sea shelf surveys, 2016 Eastern Bering Sea slope survey, and 2016 Aleutian Islands survey.
3. Fishery size compositions for 2015 and 2016.
4. Estimates of catch through October 26, 2016.
5. Age data from the 1993, 1994, 2012, 2014, and 2015 Bering Sea shelf and 2014 Aleutian Islands surveys, as well as the 2012 Eastern Bering Sea slope survey.

Changes in the assessment methodology:

The age-structured assessment model is similar to the model used for the 2014 and 2015 assessments, and was developed using AD Model Builder (a C++ software language extension and automatic differentiation library). The 2016 model implemented the following changes based on Plan Team and SSC comments:

1. Multiplicative weights were set on an *ad hoc* basis for the survey index data and fixed at 1.0 for the size composition data.
2. A likelihood component was added to incorporate the 2012 slope survey age data.
3. The model uses an improved length-age conversion matrix that corrects for stratified sampling.

Summary of Results

1. The projected age 1+ total biomass for 2017 is 779,195 t.
2. The projected female spawning biomass for 2017 is 485,802 t.
3. The recommended 2017 ABC is 65,371 t based on an $F_{0.40}$=0.129 harvest level.
4. The 2017 overfishing level is 76,100 t based on a F_{OFL}=0.151 harvest level.

Quantity/Status	Last year 2016	2017	This year 2017	2018
M (natural mortality – Male, Female)	0.35, 0.2	0.35, 0.2	0.35, 0.2	0.35, 0.2
Specified/recommended Tier	3a	3a	3a	3a
Projected biomass (ages 1+)	910,012	920,920	779,195	772,153
Female spawning biomass (t)	535,350	534,347	485,802	464,066
Projected				
$B_{100\%}$	555,049	555,049	530,135	530,135
$B_{40\%}$	222,019	222,019	212,054	212,054
$B_{35\%}$	194,267	194,267	185,547	185,547
F_{OFL}	0.180	0.180	0.151	0.151
$maxF_{ABC}$ (maximum allowable = $F_{40\%}$)	0.153	0.153	0.129	0.129
Specified/recommended F_{ABC}	0.153	0.153	0.129	0.129
Specified/recommended OFL (t)	94,035	84,156	76,100	67,023
Specified/recommended ABC (t)	80,701	72,216	65,371	58,633
Status	As determined *last* year for: 2014	2015	As determined *this* year for: 2015	2016
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 11,267 t and 17,045 t used in place of maximum permissible ABC for 2017 and 2018.

Responses to SSC and Plan Team Comments on Assessments in General

October 2015 SSC

The Team Procedures document clarifies that the proposed development and testing of a naming convention should focus on tracking the modeling configurations used for a particular stock assessment. The rationale for this request is two-fold. First, it will help us understand how long it has been since a benchmark change in model configuration has occurred; second, it will help the reviewers and public to track model changes. Of the options presented in the Joint Plan Teams minutes, the SSC agrees that Option 4 has several advantages and recommends that this Option be advanced next year.

Authors' response: New naming conventions were incorporated. See table in "Analytic Approach".

December 2015 SSC

Many assessments are currently exploring ways to improve model performance by re-weighting historic survey data. The SSC encourages the authors and PTs to refer to the forthcoming CAPAM data-weighting workshop report.

October 2016 SSC

The SSC recommends that the Gulf of Alaska Groundfish Plan Team (GOA GPT), BSAI GPT, and CPT encourage the continued use of multiple approaches to data weighting (not just the Francis (2011) method, but also including the harmonic mean and others).

Authors' response to previous two comments: We explored the Francis (2011) methodology for data weighting, and results were presented to the September 2016 Plan Team meeting. Future assessments will explore other data weighting approaches as well as the findings of the CAPAM data-weighting workshop.

December 2015 SSC

The SSC recommends that assessment authors work with AFSC's survey program scientists to develop some objective criteria to inform the best approaches for calculating Q with respect to information provided by previous survey trawl performance studies (e.g. Somerton and Munro 2001), and fish-temperature relationships which may impact Q.

Authors' response: Catchability is modeled as a temperature dependent parameter in the Bering Sea shelf survey data component of the BSAI ATF assessment model. Authors will continue to evaluate Q with respect to trawl performance studies.

October 2016 SSC

The SSC reminds groundfish and crab stock assessment authors to follow their respective guidelines for SAFE preparation.

Authors' response: Noted.

October 2016 SSC

The SSC found the model numbering in the Eastern Bering Sea (EBS) Pacific cod model extremely helpful and looks forward to having more standardized model numbering across all stock assessment documents.

Authors' response: We incorporated the suggested naming convention.

October 2016 SSC

The SSC requests that stock assessment authors bookmark their assessment documents and commends those that have already adopted this practice.

Authors' response: Noted.

October 2016 SSC

Some assessment authors have started to explore geostatistical approaches to estimating survey abundance or biomass and the SSC is encouraged by this development. The SSC re-iterates its support of the GOA GPT recommendation to form a study group to explore criteria necessary for adopting a geostatistical generalized linear mixed model approach (see December 2015 minutes).

Authors' response: Authors will consider this approach for future assessments.

Responses to SSC and Plan Team Comments Specific to this Assessment

September 2016 Plan Team

Ingrid Spies presented recent arrowtooth flounder model developments, which included data weighting and an improved length-age conversion matrix. As the BSAI arrowtooth flounder model is based on the BS shelf survey, BS slope survey, and AI survey, all of which have different sampling frequencies and numbers of hauls, she explored methods to weight the survey index data and the size composition data. In the current model, sizecomp data are weighted the same for all survey and fishery years, with a multinomial sample size of 200 for the survey sizecomp data and 25 for the fishery sizecomp data, and all likelihood components are assigned a multiplicative weight (“lambda,” or “emphasis”) of 1.0.

The exploration of data weighting was conducted according to the two-step process described by Francis (2011), where step 1 involves using information about the data by themselves (e.g., number of samples, number of hauls from which data were taken, etc.), and step 2 involves tuning the weights based on the model’s fits to the data. Final multiplicative weights are the product of the respective step 1 and step 2 multiplicative weights.

Five weighting approaches were explored:
● Model A: step 1 multinomial sample sizes and multiplicative weights were left as in the current model; step 2 multiplicative weights were set on an *ad hoc* basis for the survey index data and fixed at 1.0 for the sizecomp data.
● Model B: step 1 was the same as in Model A; step 2 multiplicative weights were set at 1.0 for all data components.
● Model C: step 1 multinomial sample sizes were set equal to the number of hauls from which data were taken and multiplicative weights were set at 1.0 for all data components; step 2 multiplicative weights were set on an ad hoc basis for the survey index data and set at 1.0 for all sizecomp data components.
● Model D: step 1 was the same as in Model C; step 2 multiplicative weights for the index data set by tuning the standard deviations of normalized residuals and multiplicative weights for the sizecomp data set by Equation TA1.8 of Francis (2011).
● Model E: step 1 was the same as Models C and D; step 2 was the same as in Model D, except that the multiplicative weight for the fishery sizecomp data was multiplied by 0.1.

The following table shows the resulting step 2 multiplicative weights for all models and data components:

	Biomass data			Size composition data			
Model	Shelf	Slope	AI	Shelf	Slope	AI	Fishery
A	12	3	5	1	1	1	1
B	1	1	1	1	1	1	1
C	12	3	5	1	1	1	1
D	3.3	1.3	2.4	0.46	0.28	0.16	0.11
E	3.3	1.3	2.4	0.46	0.28	0.16	0.011

Model A is Ingrid’s preferred model. Although the standard deviations of normalized residuals for the survey index data are all somewhat high, she felt that they were reasonable, and the smaller sizecomp weights from Models D and E did not improve the fits to the index data appreciably. She noted that the Francis paper suggests that ad hoc weighting in step 2 (as in Model A) can be an acceptable method in some cases.

The Team recommends examining the length at age data to determine if they came from a length stratified or a random sample. If two different sampling methods were used, the results are not directly comparable. For November, the Team recommends that the length-age conversion matrix be corrected if needed. The Team recommends bringing forward the original (2014) model and Model A with the new weightings in November.

Authors' response: The current assessment contains model 15.0 (The original 2014 model), as well as Model 15.0a with new weightings (referred to as Model A above), as recommended by the Plan Team. The final model 15.1b also incorporates the suggested weightings.

Introduction

Arrowtooth flounder (*Atheresthes stomias*) are relatively large flatfish that range from central California to the eastern Bering Sea and are currently the most abundant groundfish species in the Gulf of Alaska. Arrowtooth flounder occur from central California to the Bering Sea, in waters from about 20m to 800m, although catch per unit effort (CPUE) from survey data is highest between 100m and 300m. Spawning occurs in deep water in the Gulf of Alaska and along the shelf break in the eastern Bering Sea. 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).

In the Bering Sea and Aleutian Islands management area, their abundance is approximately six times higher in the eastern Bering Sea than in the Aleutian Islands region. 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 are not commonly observed older than age 10 on the Bering Sea shelf, while the female length and weight relationships do not vary significantly between the two regions. Arrowtooth flounder begin to recruit to the eastern Bering Sea slope at about age 4. Based on age data from the 1982 U.S.-Japan cooperative survey, recruitment to the slope gradually increases at older ages and reaches a maximum at age 9. However, greater than 50% of age groups 9 and older continue to occupy continental shelf waters. The low proportion of the overall biomass on the slope during the 1988, 1991, and 2016 surveys, relative to that of earlier surveys, indicates that the proportion of the population occupying slope waters may vary considerably from year to year depending on the age structure of the population.

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

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

Fishery

Arrowtooth flounder were managed with Greenland turbot as a species complex until 1985 because of similarities in their life history characteristics, distribution and exploitation. Greenland turbot were the target species and arrowtooth flounder were caught as bycatch. Management of Greenland turbot and the *Atheresthes* complex was performed separately starting in 1986 due to considerable differences in their stock condition. Two species of *Atheresthes* occur in the Bering Sea, arrowtooth flounder (*Atheresthes stomias*) and Kamchatka flounder (*A. evermanni*). These two species are very similar in appearance and were not routinely distinguished in the commercial catches until 2007 (Figure 6.1). Likewise, these species were not consistently distinguished in trawl survey catches until 1992. The species complex was split and separate assessments begun in 2010 due to the emergence of a directed fishery for Kamchatka flounder in the BSAI management area. Before 2010, the ABC for the species complex was determined by the large amount (~93%) of arrowtooth flounder relative to Kamchatka flounder in the species complex; overharvest of Kamchatka flounder could occur as the ABC for the species complex exceeded the Kamchatka flounder biomass. Separate management of arrowtooth flounder and Kamchatka flounder began in the 2011 fishing season.

Catch records of arrowtooth flounder and Greenland turbot were combined during the 1960s. The fisheries for Greenland turbot intensified during the 1970s and the bycatch of arrowtooth flounder is assumed to have also increased. In 1974-76, total catches of arrowtooth flounder reached peak levels ranging from 19,000 to 25,000 t (Table 6.1). Catches decreased after implementation of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1976. The decline after 1976 resulted from catch restrictions placed on the fishery for Greenland turbot and phasing out of the foreign fishery in the U.S. EEZ. Catches in Table 6.2 are for arrowtooth flounder and Kamchatka flounder combined until 2008, the year in which the NMFS Alaska Regional Office (AKRO) started providing separate catch statistics for arrowtooth and Kamchatka flounder. Arrowtooth flounder has remained lightly exploited with catches (extrapolated for arrowtooth only) averaging 14,155 t from 1976-2015. The estimated proportion of Kamchatka flounder in the combined catch of arrowtooth and Kamchatka are shown in Table 6.1 through 2007. Total catch reported through October 26, 2016 is 9,712 t (below the 2016 TAC of 14,000 t). The NMFS AKRO BLEND/Catch Accounting System reports indicate that bottom trawling accounted for 94% of the 2016 catch (4% by pelagic trawl and 2% by hook and line).

Although much research has been conducted on their commercial utilization (e.g. Greene and Babbit 1990, Wasson et al. 1992, Porter et al. 1993, Reppond et al. 1993, Cullenberg 1995) and some targeting occurs in the Gulf of Alaska and the Bering Sea, arrowtooth flounder continue to be captured primarily in pursuit of higher value species and historically have been mostly discarded in the Bering Sea and the Aleutian Islands. The catch information in Table 6.1 reports the past annual total catch tonnage for the foreign and JV fisheries and the current domestic fisheries. The proportions of retained and discarded arrowtooth flounder in Bering Sea fisheries are estimated from observer at-sea sampling for 1985-2016 are shown in Table 6.2, and include Kamchatka flounder as well as arrowtooth flounder through 2007. With the implementation of Amendment 80 in 2008, the percentage of arrowtooth flounder retained in catches has increased to 88% in 2014, and has remained high in 2015 (84%) and 2016 (83%). The largest catches, as well as discard amounts, occur in the flatfish fisheries. The increasing trend of retention is expected to continue in the near future due to the recent changes in fishing practices.

Data

The data used in this assessment include estimates of total catch, trawl survey biomass estimates and standard error from the eastern Bering Sea shelf, eastern Bering Sea slope and Aleutian Islands surveys, sex-specific trawl survey length frequencies and fishery length-frequencies from observer sampling. Length composition data is available from each survey. It is used in the model for each year unless age composition data is available. Age composition data is also available for each survey. Bolded text represents new data added this assessment.

Source	Data	Years
NMFS Bering Sea shelf survey	Survey biomass	1982-2014, **2015, 2016**
	Age Composition	**1993, 1994,** 1996, 1998, 2004, 2010, **2012, 2014, 2015**
	Length composition	1987-2013, **2016**
NMFS Bering Sea slope survey	Survey biomass	1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010, 2012, **2016**
	Age Composition	**2012**
	Length composition	1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010, **2016**
NMFS Aleutian Islands survey	Survey biomass	1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, **2016**
	Age composition	2010, **2014**
	Length composition	1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, **2016**
Fishery	Catch length composition	1978 – 1988, 1990 -2014, **2015, 2016**

Fishery:

Fishery catch data from 1976 - October 26, 2016 (Table 6.1) and fishery length-frequency data from 1978-2016 are used in the assessment. Actual arrowtooth flounder catch is available from observer at-sea sampling applied to the Alaska regional office blend estimates for 2007-2016. For 1976-2006 the annual arrowtooth flounder catch was calculated as 93% of the combined arrowtooth flounder-Kamchatka flounder catch on record, based on their average annual proportions in trawl surveys since 1992 (the first year of reliable identification by species). These corrections were been applied to the catch totals in Table 6.1, under “ATF est”. New fishery length-at-age data is incorporated in this assessment, and is shown in Figure 6.2. The number of fisheries length observations in each year is shown below.

Year	Number of length observations	Year	Number of length observations
1978	11,426	1998	3,819
1979	6,565	1999	3,974
1980	9,945	2000	1,415
1981	7,790	2001	2,984
1982	36,784	2002	2,404
1983	31,955	2003	3,565
1984	23,189	2004	4,367
1985	25,817	2005	2,689
1986	14,399	2006	2,143
1987	24,066	2007	601
1988	833	2008	1,422
1989	224	2009	557
1990	3,831	2010	922
1991	10,179	2011	887
1992	816	2012	529
1993	1,570	2013	643
1994	410	2014	156
1995	3,098	2015	16

1996	1,185	2016	128
1997	3,914		

Catch 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 is shown in the Appendix Table A1.

Survey:

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

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

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

The relative abundance of arrowtooth flounder increased substantially on the continental shelf from 1982 to 1990; the CPUE from AFSC shelf surveys increased steadily from 1.6 to 9.9 kg/ha (Figure 6.4). The overall shelf catch rate decreased slightly to 7.1 kg/ha in 1991. The CPUE continued to increase through 1997 to 15.0 kg/ha. These increases in CPUE were also observed on the slope from 1981 to 1986 as CPUE from the Japanese land-based fishery increased from 1.5 to 21.0 t/hr (Bakkala and Wilderbuer 1990). From 1999 to 2005 the shelf survey CPUE increased at a high rate each year. Survey estimates are consistently high from 2003-2011 (between 8-11 kg/ha), and the 2005 CPUE of 15.4 kg/ha was the highest ever estimated from the shelf survey.

Analytic Approach

Model Structure

This stock assessment utilizes AD Model Builder software (a C++ software language extension and automatic differentiation library) to model the population dynamics of Bering Sea and Aleutian Islands arrowtooth flounder. The model is parameterized in terms of numbers at age. Survey and fishery length composition observations are fit using a length-age conversion matrix. In 2010 there were two years of age data incorporated into the model, and numbers-at-age were primarily fit to length composition data. The number of age data collections has increased to 12 in the current assessment. The model simulates the dynamics of the population and matches observed biomass estimates and length and age compositions from surveys and fishery sampling programs as closely as possible. This is accomplished by the simultaneous estimation of the parameters in the model using the maximum likelihood estimation procedure. The fit of the simulation values to the observed characteristics is optimized by maximizing the likelihood function given some distributional assumptions about the observed data (see Table 6.4).

A retrospective analysis was performed extending back 10 years, with data from 2007-2016. Ten runs were performed; the 2015 run was created by dropping the 2016 data, the 2014 run was created by dropping all data except through 2014, etc (Figure 6.5).

Description of Alternative Models

The age-structured assessment model is similar to the model used for the 2014 and 2015 assessments. The 2015 model (Model 15.0) was similar to the 2014 model but was adapted to incorporate data from a varying number of surveys and could therefore be used to run Gulf of Alaska or BSAI arrowtooth flounder stock assessments. There were no changes to the configuration of the BSAI assessment model from previous years. Weights were applied to the three survey indices, shelf, Aleutian Islands, and slope (weight values were 12, 3, 5) in Model 15.0a, and the data was current through 2014. Data was current through 2016 in Model 15.0b, with length composition and survey estimates of biomass for each of the three surveys, as well as updated age data from the shelf and AI data. Slope age data was added to the data in Model 15.1. A new likelihood component was added for slope age likelihood because this was the first time that age data from the slope survey was incorporated into the model. The length-age conversion matrix was added in Model 15.1a, based on age data from Table 6.5. The length-age matrix was corrected for stratified sample design using methods in Dorn (1992). Finally, survey index weights were added in Model 15.1b, but due to new data, the weights were adjusted from Model 15.0a (weight values were 4, 2, 3). A summary of model results is shown in Table 6.6, and stock size estimates for the various models is shown in Figure 6.6.

Name	New data	Weights	Model configuration change
15.0	No	No	No change – same as 2015 model.
15.0a	No	Yes	No other changes.
15.0b	Yes – updated AI, shelf, ages and lengths for all surveys. Also updated temperature anomalies.	No	No.
15.1	Yes – all new data added (AI, shelf, slope ages and lengths). Also updated temperature anomalies.	No	Yes - Added new likelihood component for slope ages.
15.1a	Yes – all new data added (AI, shelf, slope ages and lengths). Also updated	No	Yes - Added new likelihood component for slope ages. Also new age-length conversion matrix (after Dorn 2002).

	temperature anomalies.		
15.1b	Yes – all new data added (AI, shelf, slope ages and lengths). Also updated temperature anomalies.	Yes	Yes - Added new likelihood component for slope ages. New length-age conversion matrix (after Dorn 2002).

Parameters Estimated Outside the Assessment Model

Parameters of the von Bertalanffy growth curve for arrowtooth flounder from age data collected during the 1982 U.S.-Japan cooperative survey and the 1991 slope survey (Zimmermann and Goddard 1996) are as follows:

	Sample size	Age range	L_{inf}	k	t_0
1982 age sample					
Male	528	2-14	45.9	0.23	-0.70
Female	706	2-14	73.8	0.14	-0.20
Sexes combined	1,234	2-14	59.0	0.17	-0.50
1991 age sample					
Male	53	3-9	57.9	0.17	-2.17
Female	134	4-12	85.0	0.16	-0.81

Based on 282 observations during an AFSC survey in 1976, the length (mm)-weight (gm) relationship for arrowtooth flounder (sexes combined) is described by the equation:

$$W = 5.682 \times 10^{-6} * L^{3.1028}.$$

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

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

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

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

Examination of Bering Sea shelf survey biomass estimates indicate that some of the annual variability seemed to positively co-vary with bottom water temperature. Variations in CPUE (Figure 6.4) were particularly evident during the coldest year (1999) and the warmest year (2003). The relationship between average annual bottom water temperature collected during the survey and annual survey biomass estimates can be better understood by modeling survey catchability as:

$$q = e^{-\alpha + \beta T}$$

where q is catchability, α and β are a parameters estimated by the model, and T_t is the average annual bottom water temperature. The catchability equation has two parts. The e^{α} term is a constant or time-independent estimate of q. The model estimate of $\alpha = -0.52$ indicates that $q > 1$ suggesting that arrowtooth flounder are herded into the trawl path of the net which is consistent with the experimental results for other flatfish species. The second term, $e^{\beta T}$ is a time-varying (annual) q which relates to the metabolic aspect of herding or distribution (availability) which can vary annually with bottom water temperature. In 2014, the temperature anomaly was positive, following two years of low temperatures; resulting in an increase in the catchability estimate (Figure 6.8).

Parameter Estimates

Parameters Estimated Inside the Assessment Model

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

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

The total log likelihood is the sum of the log likelihoods for each data component. The model allows for the individual likelihood components to be weighted by an emphasis factor. The number of parameters estimated by the base model are presented below:

Fishing mortality (avg. and devs)	Selectivity	Temp-q	Year class strength	Total
42	58	5	61	166

The recruitment parameters are comprised of 21 initial ages in 1976 and 41 subsequent age sex-specific recruitment estimates from 1976-2016. The difference in the number of parameters estimated in this assessment compared to last year can be accounted for by additional years of survey data, estimates of more years of recruitment and fishing mortality. Five more parameters, alpha, beta, and a proportion attributed to each survey, are estimated in a later stage to estimate the annual relationship between bottom water temperature (to 200 m) and shelf survey catchability and the overall value of catchability which relates to the capture process and availability of the stock (discussed in the next section). In addition, two parameters per sex are estimated for increasing logistic selectivity for the three surveys, and 19 parameters per sex for the fishery selectivity.

It was assumed that the shelf and slope surveys measure non-overlapping segments of the arrowtooth flounder stock. Biomass was apportioned between the three areas by a linear fit to the 3 survey time-series and the averages of the annual proportions were estimated from the linear regressions (Fig 6.3). The resulting proportions are 79% shelf, 9% slope and 13% in the Aleutian Islands. Equal emphasis was placed on fitting all data components for this assessment. The relationship between annual bottom water temperature and shelf survey catchability was modeled to improve the fit to the shelf survey biomass estimates. Results are closely linked to fitting the general trend of increasing shelf survey biomass estimates during the 1980s to the present high level, and to fitting the male and female size compositions (Fig 6.10) and sex ratios from the shelf, slope and Aleutian Islands surveys.

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 (see Table 6.4 and Table 6.8).

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 (Table 6.9). No additional weighting were placed on the catch, age, or length likelihood components. Selectivities for fishery and the three surveys are shown in Table 6.10.

Survey results indicate that fish less than about 4 years old (< 30 cm) are found only on the Bering Sea shelf. Males from 30-50 cm and females 30-70 cm are found in shelf and slope waters, and males > 50 cm and females > 70 cm are mainly found on the slope. Sex specific "domed-shaped" selectivity was estimated for males and females in the shelf survey, using an ascending and descending logistic curve. We assumed an asymptotic selectivity pattern for both sexes in the slope surveys and the Aleutian Islands surveys (Figure 6.9).

Past estimates of the natural mortality of arrowtooth flounder were assumed to be 0.20. This estimate was used because it is similar to that of other species of flatfish with approximately the same age range as arrowtooth flounder and is the same estimate used by Okada et al. (1980). However, examination of shelf and slope survey population estimates indicated that females are consistently estimated to be in higher abundance than males (Figure 6.7). This difference was also evident in the Gulf of Alaska from triennial surveys conducted from 1984-2007 (Turnock et al. 2007). Possible reasons for the higher estimates of females in the survey observations may be: 1) there is a spatial separation of males and females where males are less available to the survey trawl, 2) there is a higher natural mortality for males than females, or 3) there are some sampling problems.

Since there is a current lack of evidence that male arrowtooth flounder are less available to the Bering Sea shelf survey sampling trawl than females, differential sex-specific natural mortality has been investigated as an alternative model in past assessments as an explanation of the observed differences in survey catch sex ratio (Figure 6.7; Wilderbuer and Sample 2002). For this assessment, model runs were again made with female natural mortality fixed at 0.2 for a range of values for males. Model runs were evaluated with respect to the estimate of male and female selectivity for the shelf survey, the estimated sex ratio and the overall model fit. Also, a constraint was placed on fitting the sex ratio estimated from the trawl surveys, as follows:

$$SRlike = 0.5\left[\frac{\sum\left(S\overline{R}_{obs} - SR_{pred} \right)^2}{\sigma_{obs}}\right]$$

where SRlike is the sex ratio likelihood component, SR_{obs} is the observed sex ratio in shelf survey trawl surveys from 1982-2014, SR_{pred} is the model predicted sex ratio in the estimated population, and σ_{obs} is the standard error of the observed population sex ratio.

Results

Model Evaluation

In September 2016, the BSAI Plan Team recommended that the arrowtooth flounder assessment bring forward the 2015 combined model (Model 15.0), as well as a model that includes weights for the three survey indices. They also recommended that the length-age conversion matrix be corrected for stratified age sampling designs. The length-age conversion matrix was added in Model 15.1a, based on age data from Table 6.5, and was corrected for stratified sample design using methods in Dorn (1992). The final model (Model 15.1b) includes adjusted weights for the three survey indices (4, 2, 3). This adjustment was necessary after addition of new data for the model to converge. It also includes the corrected length-age conversion matrix, and new data. These three models (15.0, 15.0a, and 15.1b) are compared in Table 6.6 and Figure 6.6.

Results of the retrospective analysis are shown in Figure 6.5. The upper panel shows the spawning biomass time series from the current version of 15_1b with 10 retrospective runs (2006-2015) obtained by dropping one year of data at a time. The lower panel shows the change in spawning biomass relative to the current version of model 15_1b for each of the 10 retrospective runs. Mohn's rho is 0.246. The plots of spawning biomass are all higher than the base model (Model 15_1b using data through 2016) as data is removed sequentially for each retrospective run. Retrospective runs for 2015 and 2014 show sequentially higher spawning biomass but the remaining retrospective runs remain relatively constant. Although there are no guidelines regarding how large rho (absolute value) should be before an assessment is declared to exhibit an important retrospective bias, 0.246 is not out of the range observed for other Alaska groundfish species.

Final parameter estimates for Model 15_1b are shown in Table A2.

Time Series Results

This year's model shows a recent trend of increasing female spawning biomass, but a decrease in total biomass (Figure 6.10). The 2016 model estimates lower levels of total biomass than the 2014 assessment, and a downward shift in historical biomass.

Estimates indicate that arrowtooth flounder total biomass increased almost four fold from 1976 to the 2009 value of 907,756 t (Figure 6.10, Table 6.11). After a rapid increase from 1985-94, the population increase slowed to a lower rate from 1992-1999 before increasing at a higher rate to the highest level estimated in 2009 (Figure 6.10), largely from the influence of the largest shelf survey biomass estimates ever recorded of 772,998 t in 2005 (Table 6.3) and consecutive years of good recruitment. Biomass estimates from surveys have declined for the Bering Sea shelf since 2005 and the slope since 2008. The most recent year of Aleutian Islands data is also lower than the highest estimate in 2006 (Table 6.3). Female spawning biomass in 2016 is estimated at 427,240 t, which represents approximately 25% decrease from estimates for 2014 (Table 6.11). The model estimates of population numbers by age, year, and sex are given in Table 6.12.

The model fit to the shelf survey tracks the trend of increasing abundance from 1982 to the high levels from 1993-97 and 2005-2006 (Figure 6.10). It does not fit the extremely high values in 2005 or the lower values in recent years. Consideration of the relationship between annual bottom water temperature and catchability improves the fit to the shelf survey biomass. Figure 6.10 shows that the data weighting in

Model 15_1b provides a better fit to the data than Model 15_1a, which does not have survey biomass index data weighting.

The model provides reasonable fits to the survey size composition time-series for males and females, which are shown in Figure 6.11. The shelf survey has the best fit, due to the fact that there are more years of data for that survey. The model provides better fits to the survey age compositions, Bering Sea shelf, as well as the Aleutian Islands survey (Figure 6.11).

Increases in abundance from 1983-95 were the result of strong year-classes spawned in 1981, 1984, 1987, 1988, and 1989 (Figure 6.12, Table 6.13). From 1989-1993 recruitment was below average and stock abundance leveled-off. Recent leveling off in arrowtooth flounder biomass can be attributed to below-average year classes in 2006 and 2010, as well as lower estimates of survey biomass in recent years.

The conclusion from the CAPAM workshop was that both the McAllister & Ianelli and Francis data weighting methods should be considered, and alternative likelihoods should be coded in the future. This assessment incorporated methods from Francis (2011). Alternative methods will be examined in the future.

Harvest Recommendations

Arrowtooth flounder have a wide-spread bathymetric distribution in the Bering Sea/Aleutian Islands region and are above $B_{40\%}$, and are subject to minimal commercial harvest. The estimate of projected 2017 total biomass from the stock assessment projection model is 779,195 t and the female spawning biomass is estimated at 485,802 t.

The reference fishing mortality rate for arrowtooth flounder is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Equilibrium female spawning biomass is calculated by applying the female spawning biomass per recruit resulting from a constant $F_{0.40}$ harvest to an estimate of average equilibrium recruitment. Year classes spawned in 1976-2011 are used to calculate the average equilibrium recruitment. This results in an estimate of $B_{0.40}$ = 212,054 t for 2017. The stock assessment model estimates the 2016 level of female spawning biomass at 495,189 t. Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and $B > B_{0.40}$ (495,189 >> 212,054), arrowtooth flounder reference fishing mortality is defined in tier 3a. For the 2017 harvest: F_{ABC} □ $F_{0.40}$ = 0.129 and $F_{OFL} = F_{0.35}$ = 0.151 (full selection F values).

Acceptable biological catch is estimated for 2017 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2017 estimate of age-specific total biomass as follows:

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

where S_a is the selectivity at age, M is natural mortality, W_a is the mean weight at age, and n_a is the beginning of the year numbers at age. This results in a 2017 ABC of 65,371 t.

The overfishing level is estimated for 2017 by applying the $F_{35\%}$ fishing mortality rate and age-specific fishery selectivities to the projected 2016 estimate of age-specific total biomass. This results in a 2017 OFL of 76,100 t.

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of

Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of current year numbers at age estimated in the assessment. This vector is then projected forward to the beginning of the following year (current year +1) using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for the current year. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

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

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for next year's (current year +1) recommended in the assessment to the *max* F_{ABC} for next year. Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.

Scenario 4: In all future years, F is set equal to the most recent 5-year (current year -6 – current year -1) average F. Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.

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

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

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

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

Simulation results (Table 6.14) indicate that arrowtooth flounder are not currently overfished and the stock is not considered to be approaching an overfished condition. The stock projection at the average exploitation rate for the past 5 years is shown in Figure 6.15 and a phase-plane diagram showing the time-series of FSB estimates relative to the harvest control rule is shown in Figure 6.16. The ABC and TAC values that have been used to manage the combined stock since 1980 are listed in Table 6.15.

The 2016 catch through October 26, 2016 was 9,712 t. The total catch in 2016 was estimated to be the same as the 2015 total catch, 11,267 t. The 2017, and 2018 catches were estimated to be mean of the last three years (2013, 2014, 2015) catches, 16,964 t. Arrowtooth flounder catches have ranged from 11,267-38,881 for the past six full years, between 2011 and 2015, with the highest catch in 2011 and the lowest in 2015, indicating a possible declining trend. High catches in 2011 were the result of bycatch in targeted Kamchatka flounder fishing, and such high catches are unlikely to occur again. Therefore, the most recent full years catch of 11,267 t in 2015 is a good estimate of future catch.

Ecosystem Considerations

Ecosystem Effects on the Stock

1) Prey availability/abundance trends

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

2) Predator population trends

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

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

3) Changes in habitat quality

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

Arrowtooth flounder are a high trophic level predator in the Bering Sea, feeding on both benthic and pelagic components of the food web (Figure 6.17). Unlike the Gulf of Alaska however, they are not at the top of the food chain on the eastern Bering Sea shelf. Arrowtooth flounder in the Bering Sea are an occasional prey in the diets of groundfish in the Bering Sea and are eaten by Pacific cod, walleye pollock, Alaska skates, and sleeper sharks. However, given the large biomass of these species as juveniles in the Bering Sea overall, these occasionally recorded events translate into considerable total mortality for the arrowtooth flounder population in the Bering Sea ecosystem. Using the year 1991 as a baseline, the top three predators on arrowtooth flounder >30 cm, by relative importance, are walleye pollock (29% of the total mortality), Alaska skate (21%) and sleeper shark (11%) (Figure 6.18). After these predators the next highest sources of mortality (1991) on arrowtooth flounder are four fisheries, the flatfish trawl (7%) pollock trawl (6%), cod trawl (4) and the cod longline fishery (2%). In the Aleutian Islands, sleeper sharks are the primary predators on arrowtooth flounder adults, while Pacific cod are the primary predator on arrowtooth flounder juveniles.

Most of the occurrences of arrowtooth flounder measured in groundfish stomachs was of fish between 20-40cm fork length, and were found in larger individuals of the predator species. For juvenile arrowtooth flounder (<20cm fork length), 97% of the total mortality is unknown with the remaining 3% primarily attributed to arrowtooth flounder and a few other species (Figure 6.19).

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

Fishery Effects on the Ecosystem

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

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

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

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

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

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

6) Analysis of the benthic disturbance from harvesting arrowtooth flounder is available in the Preliminary draft of the Essential Fish Habitat Environmental Impact.

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

The balance of the arrowtooth flounder diet in the eastern Bering Sea includes eelpouts, shrimp, herring, eulachon and flathead sole juveniles (Figure 6.20). Diets of juvenile arrowtooth flounder are more similar to other Bering Sea shelf flatfish species than to arrowtooth flounder adults. Nonpandalid shrimp compose 42% of the total consumption, euphausiids 25%, juvenile Pollock 22% and then polychaetes, sculpins and mysids accounting for another 10% (Figure 6.21). With the exception of juvenile pollock, juvenile arrowtooth flounder exhibit a stronger benthic pathway in their diet than adults. In the Aleutian Islands, arrowtooth flounder feed on the range of available forage fishes, including myctophids, Atka mackerel, and pollock. They are an important predator on Atka mackerel juveniles, making up 23% of the assumed natural mortality of this species.

In terms of the size of pollock consumed, arrowtooth flounder consume a greater number of pollock between the range of 15-25cm fork length than do Pacific cod or Pacific halibut, which consume primarily adult fish and fish smaller than 15cm (Figure 6.22).

Food web models for the Bering Sea have been constructed to discern what the effect of changes in key predators has as a source of mortality on species which are linked to them through consumption pathways. These models are 30 year realizations run 1,000 times and thus give a measure of the uncertainty in the food model parameters. A simulation analysis where arrowtooth flounder survival was decreased by 10% and the rest of the ecosystem was allowed to adjust to this decrease for 30 years (Figure 6.23) indicates that positive changes in biomass for affected species were only minimal with flathead sole showing the largest increase (~3%), probably due to competition for a variety of shared prey resources such as shrimp. As expected the largest negative changes in biomass were for arrowtooth flounder (both adults and juveniles) themselves and a smaller negative change for sleeper sharks (<4%). All other effects were on the order of 1-2%. When juvenile arrowtooth flounder are decreased, again it is flathead sole biomass which is increased, but only by a small percentage change, even if the change in arrowtooth juveniles is as much as 60% (Figure 6.24). As in the first simulation, the changes are minor for all other species and fisheries. However, it’s important to note that this reflects a sensitivity analysis around conditions in the early 1990s; the increase of arrowtooth flounder in recent years suggests that this analysis should be re-performed with current conditions.

To evaluate the dependence of arrowtooth flounder adults and juveniles on a suite of species and fisheries which are dynamically related to them, a simulation analysis was conducted where survival of each species group/fishery on the X axis in Figure 6.25 was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. These model runs indicate that the biomass of arrowtooth juveniles is very sensitive to changes on the order of only 10% in key species, whereby their biomass may be reduced by 40-60%. The changes are primarily bottom-up, with few top-down or competitive effects. This supports the research of Wilderbuer et al. (2002) which suggests that the control of arrowtooth flounder production is primarily based on physical drivers, e.g. advection to nursery habitat. However, it’s important to note that the effect of decreasing pollock (adults or juveniles) is to increase arrowtooth flounder in the model rather than decrease it; this suggests that the role of pollock as a predator on arrowtooth flounder (potentially limiting their population growth) is greater than the importance of pollock as prey, at least for small perturbations of pollock. For adults, the pattern is similar although the percent change in biomass is less (30%).

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

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

Data Gaps and Research Priorities

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

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Tables

Table 6.1a. All nation total combined catch (t) of arrowtooth and Kamchatka flounder in the eastern Bering Sea and Aleutian Islands region[a], 1970-1990. Totals for arrowtooth (ATF) and Kamchatka are under “Combined” total, extrapolated ATF only is under “ATF est”. [a]Catches prior to 1990 are on file at the Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115. [b]Non-U.S. fisheries: Japan, U.S.S.R., Republic of Korea, Taiwan, Poland, and Federal Republic of Germany. [c]Joint ventures between U.S. fishing vessels and foreign processing vessels. [d]Domestic annual harvesting.

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

Table 6.1b. All nation total combined catch (t) of arrowtooth and Kamchatka flounder in the eastern Bering Sea and Aleutian Islands regiona, 1991-2016. Totals for arrowtooth (ATF) and Kamchatka are under "Combined" total, extrapolated ATF only is under "ATF est". *Species-specific estimates of catch available starting in 2008.**Catch information through 26 October, 2016 (NMFS regional office).

Year	Eastern Bering Sea				Aleutian Islands Region			Combined	ATF est.
Year	Non-U.S.[b]	U.S. J.V.[c]	U.S. DAH[d]	Total	Non-U.S.	U.S. J.V.	U.S. DAH	Total	Total
1991								22,052	20,508
1992								10,382	9,655
1993								9,338	8,684
1994								14,366	13,360
1995								9,280	8,631
1996								14,652	13,626
1997								10,054	9,350
1998								15,241	14,174
1999								10,573	9,833
2000								12,929	12,024
2001								13,908	12,934
2002								11,540	10,732
2003								12,834	11,936
2014								17,809	16,562
2005								13,685	12,727
2006								13,309	12,377
2007								11,913	10,722
2008*									21,368
2009									29,900
2010									38,881
2011									20,095
2012									22,333
2013									20,538
2014									19,088
2015									11,267
2016**									9,712

Table 6.2. Estimates of retained and discarded arrowtooth flounder catch, and the proportion of arrowtooth flounder in the total catch of 1985-2016. Beginning in 2007, when the two species were differentiated in commercial catches, catch is calculated based on values from the Observer Interface Database; prior to 2007, proportion was calculated as 0.07. Arrowtooth flounder were identified to species starting in 2008; therefore only arrowtooth flounder data is presented from this year onward.

Year	Retained	Discarded	Total (t)	% Retained	Proportion ATF in catch
1985	17	72	89	19	0.07
1986	65	277	342	19	0.07
1987	75	320	395	19	0.07
1988	3,309	14,107	17,416	19	0.07
1989	958	4,084	5,042	19	0.07
1990*	2,356	10,042	12,398	19	0.07
1991	3,211	18,841	22,052	15	0.07
1992	675	9,707	10,382	7	0.07
1993	403	6,775	7,178	6	0.07
1994	626	13,641	14,267	4	0.07
1995	509	8,772	9,281	5	0.07
1996	1,372	13,280	14,652	9	0.07
1997	1,029	9,024	10,054	10	0.07
1998	2,896	12,345	15,241	19	0.07
1999	2,538	8,035	10,573	24	0.07
2000	5,124	7,805	12,929	60	0.07
2001	4,271	6,959	11,230	62	0.07
2002	4,039	7,501	11,540	35	0.07
2003	4,024	8,810	12,834	31	0.07
2004	4,987	12,822	17,809	28	0.07
2005	8,211	5,474	13,685	60	0.07
2006	6,921	6,388	13,309	52	0.07
2007	6,910	5,003	11,913	58	0.10
2008	14,316	7,051	21,368	67	-
2009	21,827	8,073	29,900	73	-
2010	27,994	10,887	38,881	72	-
2011	16,560	3,635	20,195	82	-
2012	19,470	2,909	22,379	87	-
2013	17,015	3,485	20,501	83	-
2014	16,765	2,323	19,088	88	-
2015	9,437	1,829	11,267	84	
2016	8,205	1,733	9,938	83	

*1990 retained rate was applied to the 1985-89 reported catch. The 2016 catch is through 10/26/2016.
Source: NMFS AKRO BLEND/Catch Accounting System.

Table 6.3. Estimated arrowtooth flounder biomass from trawl surveys conducted on the Eastern Bering Sea shelf, slope and the Aleutian Islands. The 1988 and 1991 slope estimates were from the depth ranges of 200-800 m while earlier slope estimates were from 200-1,000 m. The 2002 through 2016 slope estimates were from sampling conducted from 200-1,200 m.

Year	shelf survey	slope survey	Aleutian Islands
1979		36,700	
1980			16,500
1981		34,900	
1982	69,990	24,700	
1983	110,643		24,465
1984	160,396		
1985	163,637	74,400	
1986	229,865		110,476
1987	294,670		
1988	297,210	30,600	
1989	355,844		
1990	402,326		
1991	298,670	28,400	21,897
1992	370,517		
1993	497,085		
1994	514,336		58,191
1995	446,826		
1996	527,249		
1997	463,081		73,893
1998	345,130		
1999	239,708		
2000	314,694		65,028
2001	378,107		
2002	331,345	42,508	88,750
2003	543,569		
2004	549,338	53,745	94,998
2005	772,988		
2006	670,132		183,836
2007	547,496		
2008	588,342	68,317	
2009	456,371		
2010	586,954	74,065	80,060
2011	568,200		
2012	445,736	72,845	60,371
2013	405,509		
2014	465,616		75,958
2015	409,243		
2016	475,264	45,525	65,901

Table 6.4. Key equations used in the population dynamics model.

$N_{t,1} = R_t = R_0 e^{\tau_t}$, $\tau_t \sim N(0,\delta^2{}_R)$	Recruitment 1956-75
$N_{t,1} = R_t = R_\gamma e^{\tau_t}$, $\tau_t \sim N(0,\delta^2{}_R)$	Recruitment 1976-2005
$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}\left(1 - e^{-z_{t,a}}\right)N_{t,a}$	Catch in year *t* for age *a* fish
$N_{t+1,a+1} = N_{t,a}e^{-z_{t,a}}$	Numbers of fish in year *t+1* at age *a*
$N_{t+1,A} = N_{t,A-1}e^{-z_{t,A-1}} + N_{t,A}e^{-z_{t,A}}$	Numbers of fish in the "plus group"
$S_t = \sum N_{t,a}W_{t,a}\phi_a$	Spawning biomass
$Z_{t,a} = F_{t,a} + M$	Total mortality in year *t* at age *a*
$F_{t,a} = s_a \mu^F \exp^{\varepsilon^F{}_t}$, $\varepsilon^F{}_t \sim N(o,\sigma^2{}_F)$	Fishing mortality
$s_a = \frac{1}{1+\left(e^{-\alpha+\beta a}\right)}$	Age-specific fishing selectivity
$C_t = \sum C_{t,a}$	Total catch in numbers
$P_{t,a} = {C_{t,a}}/{C_t}$	Proportion at age in catch
$SurB_t = q\sum N_{t,a}W_{t,a}v_a$	Survey biomass
$reclike = \lambda(\sum_{i=1965}^{endyear} \bar{R} - R_i)^2 + \sum_{a=1}^{20}(\bar{R}_{init} - R_{init,a})^2$	recruitment likelihood
$catchlike = \lambda \sum_{i=startyear}^{endyear}(\ln C_{obs,i} - \ln C_{est,i})^2$	catch likelihood

$$surveylike = \lambda \frac{(\ln B - \ln \hat{B})^2}{2\sigma^2}$$ survey biomass likelihood

$$SurvAgelike = \sum_{t,a} n_t P_{t,a} (\ln \hat{P}_{t,a} + 0.001) - \sum_{t,a} n_t P_{t,a} (\ln P_{t,a} + 0.001)$$ survey age comp likelihood

$$SurvLengthlike = \sum_{t,a} n_t P_{t,a} (\ln \hat{P}_{t,a} + 0.001) - \sum_{t,a} n_t P_{t,a} (\ln P_{t,a} + 0.001)$$ survey length comp likelihood

$$Sexratiolike = \frac{\sum_{i=1982}^{lastsurvey} (\bar{SR}_{obs} - SR_i)^2}{\sigma_{SR}}$$ sex ratio likelihood

Table 6.5. Cruise data from which age data is available for arrowtooth flounder. 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
198001	Aleutian Islands Bottom Trawl Survey	51.32	-165.11	70
198301	Aleutian Islands Bottom Trawl Survey	51.23	-167.27	55
198601	Aleutian Islands Bottom Trawl Survey	51.19	-165.02	328
199101	Aleutian Islands Bottom Trawl Survey	51.25	-165.14	605
199701	Aleutian Islands Bottom Trawl Survey	51.19	-179.96	773
200001	Aleutian Islands Bottom Trawl Survey	51.20	-179.95	780
200201	Aleutian Islands Bottom Trawl Survey	51.25	-179.95	1050
201001	Aleutian Island Bottom Trawl Survey	51.20	-179.96	477
201401	Aleutian Island Bottom Trawl Survey	51.25	-179.97	314
197601	EBS Crab/Groundfish Bottom Trawl Survey	54.85	-159.15	282
198106	Marine Mammal Feeding Study	53.79	-163.42	91
198203	CRAB/GRFSH	55.00	-158.32	237
198402	EBS Crab/Groundfish Bottom Trawl Survey	54.98	-158.31	576
198501	Winter Groundfish Trawl Survey	54.98	-159.57	78
198701	US-Japan Cooperative Longline Survey	51.32	-133.92	1771
199110	EBS Triennial Survey	54.21	-165.81	187
199201	EBS Crab/Groundfish Bottom Trawl Survey	54.68	-158.31	97
199301	EBS Crab/Groundfish Bottom Trawl Survey	54.78	-159.54	209
199401	EBS Crab/Groundfish Bottom Trawl Survey	54.69	-158.31	125
199601	EBS Crab/Groundfish Bottom Trawl Survey	54.83	-176.96	211
199801	EBS Crab/Groundfish Bottom Trawl Survey	54.84	-178.15	275
200401	2004 Bering Sea Shelf Survey	54.66	-178.16	592
200501	EBS Crab/Groundfish Bottom Trawl Survey	54.99	-176.76	554
200601	EBS Crab/Groundfish Bottom Trawl Survey	54.98	-178.18	604
200801	EBS Crab/Groundfish Bottom Trawl Survey	54.68	-178.20	795
200901	EBS Crab/Groundfish Bottom Trawl Survey	54.68	-178.18	691
201001	2010 EBS Bottom Trawl Survey	54.71	-178.23	470
201201	2012 EBS Slope Survey	54.26	-179.50	765
201201	2012 EBS Bottom Trawl Survey	54.66	-177.45	328
201401	2014 EBS Bottom Trawl Survey	54.98	-178.19	388
201501	2015 EBS Bottom Trawl Survey	54.69	-178.18	611

Table 6.6. Results comparing model fits and 2017 yield for different model configurations.

	Model 15.0	*Model 15.0a*	*Model 15.0b*	*Model 15.1*	*Model 15.1a*	*Model 15.1b*
Total log(Likelihood)						
Catch	0.01	0.02	0.02	0.02	0.01	0.03
Recruitment	26.80	28.30	26.30	26.90	21.20	26.90
EBS shelf survey biomass	145.40	32.20	187.70	185.00	185.00	88.10
EBS slope survey biomass	61.50	51.90	54.40	50.60	38.00	59.00
Aleutian survey biomass	45.40	32.50	45.20	47.00	49.70	44.00
EBS shelf survey age comp	147.00	200.70	636.30	310.00	300.00	306.40
EBS slope survey age comp	-	-	-	47.40	43.70	49.00
Aleutian survey age comp	119.80	134.50	476.80	284.70	287.60	313.90
EBS shelf survey length comp	849.70	900.70	1777.8	613.30	619.60	637.00
EBS slope survey length comp						735.60
Aleutian survey length comp						893.80
Fishery length comp	385.00	406.20	609.00	442.50	538.70	516.40
Priors/Penalties	0.92	0.96	0.86	0.79	0.69	0.79
Stock status (t)						
2017 Spawning biomass	530,121	618,340	452,585	447,755	427,240	427,240
2017 Total biomass	896,812	976,238	752,296	734,214	694,508	694,508

Model descriptions (see text for details):

Model 15.0—last year’s base model with 2014 data.

Model 15.0a—base model with weights on survey indices.

Model 15.0b—base model with updated length composition and bottom temperature data, plus age data from the Aleutians and shelf surveys.

Model 15.1— Model 15.0b with slope age data and slope likelihood component for age.

Model 15.1a—model 15.1 with updated length-age conversion matrix.

Model 15.1b—model 15.1a with survey index weights.

Table 6.7. Arrowtooth flounder male and female weight-at-age (kg) and proportion of females mature at age.

Age	Female weight at age	Male wt at age	Female maturity at age (Zimmerman 2007)	Female maturity at age (Stark 2011)
1	0.02	0.01	0	0.00
2	0.04	0.04	0	0.00
3	0.11	0.09	0	0.01
4	0.22	0.17	0.02	0.02
5	0.36	0.27	0.39	0.06
6	0.55	0.39	0.84	0.16
7	0.76	0.52	0.97	0.34
8	0.99	0.66	1.00	0.59
9	1.25	0.80	1.00	0.80
10	1.52	0.94	1	0.97
11	1.80	1.08	1	0.99
12	2.08	1.21	1	1
13	2.35	1.34	1	1
14	2.61	1.45	1	1
15	2.83	1.56	1	1
16	3.01	1.66	1	1
17	3.16	1.75	1	1
18	3.27	1.83	1	1
19	3.37	1.91	1	1
20	3.44	1.98	1	1
21	3.53	2.04	1	1

Table 6.8. Variables used in the population dynamics model.

Variables	
R_t	Age 1 recruitment in year *t*
R_0	Geometric mean value of age 1 recruitment, 1956-75
R_γ	Geometric mean value of age 1 recruitment, 1976-96
τ_t	Recruitment deviation in year *t*
$N_{t,a}$	Number of fish in year *t* at age *a*
$C_{t,a}$	Catch numbers of fish in year *t* at age *a*
$P_{t,a}$	Proportion of the numbers of fish age *a* in year *t*
C_t	Total catch numbers in year *t*
$W_{t,a}$	Mean body weight (kg) of fish age *a* in year *t*
φ_a	Proportion of mature females at age *a*
$F_{t,a}$	Instantaneous annual fishing mortality of age *a* fish in year *t*
M	Instantaneous natural mortality, assumed constant over all ages and years
$Z_{t,a}$	Instantaneous total mortality for age *a* fish in year *t*
s_a	Age-specific fishing gear selectivity
μ^f	Median year-effect of fishing mortality
ε_t^f	The residual year-effect of fishing mortality
ν_a	Age-specific survey selectivity
α	Slope parameter in the logistic selectivity equation
β	Age at 50% selectivity parameter in the logistic selectivity equation
σ_t	Standard error of the survey biomass in year *t*

Table 6.9. Model estimates of arrowtooth flounder fishing mortality and exploitation rate (catch/total biomass). Full selection occurred at age 21 in males and age 8 in females.

Year	Full selection F	Exploitation rate
1976	0.070	0.046
1977	0.041	0.029
1978	0.038	0.027
1979	0.058	0.040
1980	0.082	0.054
1981	0.085	0.054
1982	0.059	0.038
1983	0.072	0.047
1984	0.053	0.031
1985	0.042	0.024
1986	0.038	0.021
1987	0.023	0.013
1988	0.089	0.048
1989	0.030	0.016
1990	0.050	0.026
1991	0.073	0.040
1992	0.031	0.017
1993	0.024	0.015
1994	0.034	0.022
1995	0.021	0.014
1996	0.032	0.021
1997	0.022	0.014
1998	0.033	0.022
1999	0.023	0.015
2000	0.029	0.018
2001	0.031	0.019
2002	0.025	0.015
2003	0.027	0.016
2004	0.035	0.021
2005	0.026	0.016
2006	0.027	0.016
2007	0.022	0.014
2008	0.039	0.024
2009	0.053	0.033
2010	0.071	0.044
2011	0.037	0.023
2012	0.041	0.026
2013	0.038	0.025
2014	0.037	0.024
2015	0.022	0.015
2016	0.019	0.013

Table 6.10. Model estimates of arrowtooth flounder age-specific fishery and survey selectivities, by sex.

	Fishery		shelf survey		slope survey		Aleutians survey	
Age	females	males	females	males	females	males	females	males
1	0.01	0.02	0.04	0.19	0.00	0.03	0.05	0.09
2	0.04	0.05	0.23	0.28	0.00	0.05	0.10	0.14
3	0.10	0.09	0.70	0.41	0.00	0.08	0.18	0.21
4	0.22	0.16	0.95	0.57	0.01	0.12	0.31	0.31
5	0.43	0.26	1.00	0.74	0.28	0.19	0.48	0.42
6	0.71	0.37	1.00	0.89	0.95	0.27	0.65	0.55
7	0.96	0.48	0.99	1.00	1.00	0.38	0.79	0.67
8	1.00	0.58	0.95	0.95	1.00	0.51	0.88	0.77
9	0.98	0.65	0.81	0.60	1.00	0.63	0.94	0.85
10	0.94	0.72	0.50	0.21	1.00	0.74	0.97	0.90
11	0.91	0.78	0.20	0.05	1.00	0.82	0.98	0.94
12	0.88	0.83	0.06	0.01	1.00	0.89	0.99	0.96
13	0.87	0.88	0.01	0.00	1.00	0.93	1.00	0.98
14	0.86	0.93	0.00	0.00	1.00	0.96	1.00	0.99
15	0.86	0.97	0.00	0.00	1.00	0.98	1.00	0.99
16	0.87	0.99	0.00	0.00	1.00	0.99	1.00	1.00
17	0.87	1.00	0.00	0.00	1.00	0.99	1.00	1.00
18	0.88	1.00	0.00	0.00	1.00	1.00	1.00	1.00
19	0.90	1.00	0.00	0.00	1.00	1.00	1.00	1.00
20	0.90	1.00	0.00	0.00	1.00	1.00	1.00	1.00
21	0.90	1.00	0.00	0.00	1.00	1.00	1.00	1.00

Table 6.11. Model estimates of arrowtooth flounder 1+ total biomass (t) and female spawning biomass (t) from the 2016 and 2014 assessments.

	2016 Assessment		2014 Assessment	
	Total biomass	Female Spawning biomass	Total biomass	Female Spawning biomass
1976	390,856	220,752	269,581	137,913
1977	370,529	222,374	267,323	127,605
1978	353,616	230,546	273,114	128,654
1979	337,621	234,225	281,156	136,179
1980	316,147	224,650	284,669	142,697
1981	294,020	204,088	287,394	144,561
1982	278,586	182,632	291,738	144,598
1983	275,086	168,333	304,652	148,601
1984	280,844	155,518	317,146	152,209
1985	294,173	147,059	333,697	159,777
1986	316,171	142,848	353,901	170,170
1987	346,003	145,414	381,113	182,853
1988	384,995	158,480	412,852	199,211
1989	417,692	167,959	437,638	204,155
1990	469,980	187,240	477,253	216,960
1991	516,793	206,192	510,536	228,980
1992	551,853	223,632	531,547	239,547
1993	590,261	253,621	559,302	263,221
1994	621,176	291,844	583,417	293,761
1995	636,732	330,313	598,051	320,825
1996	649,886	367,626	616,089	345,783
1997	651,189	390,281	627,504	359,496
1998	655,984	404,944	645,562	371,083
1999	658,794	407,468	661,463	375,655
2000	672,283	406,905	683,861	381,405
2001	690,899	400,347	707,317	385,656
2002	716,031	392,546	731,488	391,757
2003	749,117	390,974	761,140	403,703
2004	784,858	396,355	791,072	418,167
2005	815,630	407,748	816,099	431,908
2006	849,607	430,302	845,881	450,913
2007	876,395	457,121	870,942	470,156
2008	899,248	486,330	895,262	491,018
2009	904,125	507,179	907,756	505,908
2010	891,490	518,572	905,159	513,829
2011	860,724	515,407	889,634	510,566
2012	845,222	520,482	888,498	517,672
2013	822,562	518,416	881,413	522,331
2014	798,002	512,882	877,781	527,622
2015	773,399	503,052		
2016	762,657	495,189		

Table 6.12. Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2016.

females	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	35,942	18,918	11,144	25,451	55,906	90,306	48,497	12,562	27,053	12,401
1977	141,266	29,400	15,449	9,064	20,533	44,485	70,551	37,243	9,624	20,758
1978	33,585	115,597	24,034	12,599	7,356	16,530	35,424	55,612	29,316	7,583
1979	25,324	27,484	94,512	19,608	10,234	5,931	13,197	28,022	43,937	23,181
1980	54,407	20,718	22,454	76,958	15,860	8,184	4,672	10,249	21,720	34,099
1981	204,156	44,498	16,912	18,242	61,932	12,558	6,343	3,549	7,763	16,482
1982	210,640	166,964	36,317	13,734	14,668	48,965	9,708	4,801	2,678	5,870
1983	37,441	172,326	136,403	29,569	11,106	11,725	38,539	7,531	3,717	2,076
1984	264,508	30,625	140,714	110,915	23,843	8,829	9,145	29,531	5,757	2,846
1985	161,140	216,414	25,026	114,637	89,814	19,109	6,979	7,137	23,004	4,490
1986	146,246	131,859	176,914	20,408	93,038	72,295	15,214	5,500	5,616	18,121
1987	332,405	119,677	107,806	144,323	16,576	74,999	57,698	12,029	4,343	4,439
1988	345,427	272,068	97,899	88,069	117,583	13,442	60,451	46,240	9,633	3,480
1989	291,910	282,486	222,022	79,479	70,766	92,834	10,368	45,614	34,786	7,261
1990	200,245	238,902	231,023	181,256	64,660	57,229	74,482	8,257	36,289	27,694
1991	142,096	163,842	195,240	188,258	146,859	51,878	45,322	58,270	6,449	28,374
1992	207,513	116,229	133,783	158,747	151,784	116,710	40,445	34,706	44,512	4,934
1993	140,457	169,829	95,052	109,214	129,134	122,723	93,607	32,195	27,598	35,420
1994	127,919	114,960	138,921	77,644	88,962	104,686	98,858	74,956	25,759	22,093
1995	125,526	104,685	94,004	113,372	63,116	71,832	83,776	78,453	59,417	20,435
1996	194,780	102,744	85,644	76,814	92,420	51,242	58,003	67,306	62,986	47,724
1997	186,084	159,407	84,022	69,908	62,470	74,691	41,068	46,124	53,465	50,068
1998	246,751	152,310	130,407	68,650	56,976	50,696	60,269	32,962	36,993	42,901
1999	343,783	201,937	124,550	106,436	55,819	46,027	40,602	47,881	26,158	29,379
2000	322,761	281,381	165,192	101,751	86,721	45,273	37,106	32,548	38,353	20,963
2001	269,505	264,157	230,134	134,883	82,808	70,181	36,365	29,597	25,936	30,582
2002	323,975	220,563	216,026	187,864	109,713	66,943	56,273	28,937	23,526	20,631
2003	345,088	265,162	180,416	176,449	153,004	88,915	53,898	45,031	23,136	18,821
2004	296,617	282,437	216,883	147,339	143,655	123,912	71,506	43,062	35,945	18,479
2005	193,539	242,740	230,945	176,986	119,753	115,962	99,117	56,712	34,113	28,497
2006	299,017	158,403	198,549	188,616	144,114	97,012	93,302	79,241	45,300	27,264
2007	228,334	244,730	129,563	162,149	153,565	116,719	78,024	74,552	63,261	36,186
2008	182,302	186,891	200,205	105,855	132,141	124,600	94,155	62,600	59,770	50,742
2009	212,505	149,181	152,794	163,311	85,960	106,484	99,386	74,387	49,392	47,200
2010	160,592	173,866	121,904	124,477	132,239	68,888	84,167	77,550	57,942	38,517
2011	147,118	131,360	141,977	99,135	100,397	105,167	53,769	64,556	59,338	44,404
2012	158,931	120,393	107,402	115,834	80,535	80,965	83,992	42,554	51,026	46,941
2013	213,320	130,052	98,419	87,589	94,014	64,832	64,474	66,207	33,497	40,203
2014	144,026	174,565	106,328	80,286	71,135	75,776	51,731	50,963	52,265	26,465
2015	133,229	117,863	142,730	86,753	65,229	57,379	60,539	40,960	40,302	41,365
2016	419,018	109,048	96,421	116,618	70,704	52,936	46,301	48,591	32,852	32,340

Table 6.12 (cont'd). Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2016.

	females			numbers at age (1,000s)							
	11	12	13	14	15	16	17	18	19	20	21
1976	10,343	8,638	7,512	6,783	4,551	4,178	3,276	2,754	2,330	1,984	4,724
1977	9,537	7,971	6,669	5,805	5,245	3,519	3,230	2,532	2,127	1,797	5,175
1978	16,377	7,534	6,303	5,276	4,595	4,151	2,785	2,555	2,003	1,681	5,510
1979	6,003	12,980	5,977	5,003	4,189	3,648	3,296	2,211	2,027	1,588	5,702
1980	18,024	4,676	10,125	4,666	3,908	3,272	2,849	2,573	1,724	1,580	5,683
1981	25,946	13,748	3,574	7,747	3,573	2,992	2,505	2,180	1,967	1,317	5,546
1982	12,499	19,725	10,474	2,726	5,914	2,727	2,283	1,911	1,661	1,497	5,224
1983	4,560	9,726	15,371	8,169	2,127	4,615	2,128	1,781	1,489	1,294	5,234
1984	1,594	3,507	7,494	11,855	6,304	1,642	3,560	1,641	1,372	1,146	5,025
1985	2,223	1,247	2,748	5,875	9,299	4,945	1,287	2,792	1,286	1,075	4,833
1986	3,541	1,756	986	2,174	4,649	7,359	3,913	1,019	2,207	1,016	4,668
1987	14,339	2,806	1,392	782	1,725	3,690	5,839	3,104	808	1,749	4,505
1988	3,559	11,505	2,252	1,118	628	1,386	2,964	4,690	2,492	648	5,020
1989	2,631	2,698	8,740	1,713	851	478	1,054	2,255	3,563	1,892	4,302
1990	5,786	2,098	2,153	6,980	1,368	680	382	842	1,800	2,843	4,942
1991	21,689	4,538	1,648	1,692	5,487	1,076	534	300	661	1,413	6,111
1992	21,762	16,670	3,495	1,270	1,305	4,233	830	412	231	509	5,788
1993	3,930	17,350	13,301	2,790	1,014	1,042	3,379	662	329	184	5,023
1994	28,377	3,151	13,919	10,674	2,239	814	836	2,712	531	264	4,176
1995	17,546	22,559	2,507	11,080	8,499	1,783	648	666	2,158	423	3,531
1996	16,424	14,111	18,152	2,018	8,920	6,843	1,435	522	536	1,736	3,181
1997	37,976	13,082	11,248	14,476	1,610	7,115	5,457	1,145	416	427	3,918
1998	40,205	30,514	10,517	9,046	11,644	1,295	5,723	4,389	920	334	3,492
1999	34,107	31,994	24,303	8,380	7,210	9,281	1,032	4,560	3,496	733	3,046
2000	23,562	27,373	25,693	19,523	6,733	5,793	7,456	829	3,662	2,806	3,034
2001	16,731	18,821	21,881	20,546	15,616	5,386	4,633	5,963	663	2,926	4,667
2002	24,351	13,335	15,012	17,460	16,399	12,464	4,298	3,697	4,756	528	6,055
2003	16,518	19,511	10,691	12,040	14,007	13,156	9,998	3,447	2,964	3,812	5,276
2004	15,045	13,215	15,620	8,562	9,645	11,220	10,537	8,007	2,760	2,372	7,274
2005	14,666	11,954	10,509	12,427	6,814	7,676	8,928	8,384	6,368	2,194	7,668
2006	22,795	11,741	9,576	8,421	9,960	5,462	6,152	7,155	6,716	5,099	7,897
2007	21,798	18,239	9,401	7,670	6,746	7,980	4,375	4,927	5,729	5,376	10,403
2008	29,046	17,508	14,658	7,557	6,167	5,425	6,416	3,517	3,960	4,603	12,677
2009	40,122	22,993	13,874	11,621	5,994	4,891	4,301	5,087	2,787	3,137	13,687
2010	36,871	31,391	18,014	10,877	9,115	4,701	3,835	3,373	3,985	2,182	13,172
2011	29,587	28,383	24,208	13,905	8,401	7,041	3,630	2,961	2,601	3,071	11,831
2012	35,170	23,460	22,526	19,222	11,045	6,673	5,592	2,883	2,350	2,063	11,822
2013	37,034	27,782	18,551	17,823	15,214	8,742	5,281	4,425	2,280	1,857	10,975
2014	31,804	29,331	22,024	14,714	14,141	12,072	6,935	4,189	3,508	1,806	10,168
2015	20,971	25,229	23,288	17,496	11,692	11,238	9,591	5,510	3,326	2,784	9,504
2016	33,217	16,851	20,283	18,729	14,073	9,405	9,038	7,714	4,430	2,673	9,877

Table 6.12 (cont'd). Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2016.

males	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	35,942	16,283	8,256	16,228	30,682	42,658	19,717	4,396	8,148	3,215
1977	141,266	25,284	11,435	5,779	11,301	21,213	29,253	13,416	2,971	5,475
1978	33,585	99,447	17,781	8,027	4,044	7,874	14,709	20,190	9,222	2,035
1979	25,324	23,645	69,950	12,486	5,620	2,821	5,468	10,172	13,912	6,335
1980	54,407	17,820	16,616	49,024	8,713	3,899	1,944	3,744	6,925	9,426
1981	204,156	38,263	12,507	11,618	34,071	6,004	2,661	1,314	2,512	4,616
1982	210,640	143,564	26,850	8,742	8,069	23,455	4,092	1,796	880	1,670
1983	37,441	148,221	100,876	18,816	6,100	5,596	16,154	2,800	1,222	596
1984	264,508	26,337	104,079	70,600	13,098	4,214	3,834	10,978	1,890	820
1985	161,140	186,156	18,512	72,980	49,311	9,099	2,910	2,632	7,497	1,285
1986	146,246	113,437	130,914	12,994	51,066	34,357	6,309	2,008	1,809	5,136
1987	332,405	102,961	79,789	91,921	9,098	35,614	23,854	4,362	1,383	1,242
1988	345,427	234,107	72,472	56,102	64,520	6,370	24,870	16,614	3,031	959
1989	291,910	242,886	164,252	50,641	38,942	44,376	4,336	16,759	11,099	2,010
1990	200,245	205,553	170,905	115,416	35,504	27,217	30,905	3,010	11,598	7,663
1991	142,096	140,938	144,498	119,869	80,651	24,683	18,812	21,243	2,059	7,902
1992	207,513	99,954	98,962	101,124	83,431	55,714	16,906	12,780	14,329	1,380
1993	140,457	146,121	70,330	69,535	70,891	58,303	38,794	11,731	8,842	9,889
1994	127,919	98,919	102,847	49,447	48,799	49,627	40,700	27,007	8,148	6,129
1995	125,526	90,068	69,591	72,242	34,644	34,071	34,511	28,195	18,648	5,610
1996	194,780	88,412	63,405	48,944	50,730	24,276	23,817	24,069	19,624	12,958
1997	186,084	137,152	62,205	44,546	34,305	35,440	16,897	16,518	16,641	13,533
1998	246,751	131,061	96,546	43,745	31,276	24,032	24,764	11,778	11,490	11,555
1999	343,783	173,742	92,208	67,824	30,656	21,844	16,719	17,166	8,138	7,918
2000	322,761	242,122	122,296	64,836	47,608	21,467	15,255	11,646	11,931	5,646
2001	269,505	227,287	170,382	85,948	45,469	33,289	14,961	10,598	8,068	8,246
2002	323,975	189,772	159,922	119,713	60,248	31,771	23,176	10,379	7,330	5,567
2003	345,088	228,161	133,566	112,428	84,004	42,168	22,172	16,128	7,206	5,078
2004	296,617	243,020	160,572	93,884	78,869	58,767	29,408	15,416	11,185	4,986
2005	193,539	208,844	170,961	112,781	65,771	55,055	40,856	20,366	10,640	7,698
2006	299,017	136,298	146,982	120,178	79,126	46,021	38,406	28,418	14,130	7,367
2007	228,334	210,576	95,922	103,316	84,308	55,357	32,097	26,706	19,710	9,779
2008	182,302	160,817	148,229	67,454	72,533	59,054	38,675	22,368	18,572	13,682
2009	212,505	128,343	113,109	104,071	47,221	50,574	40,988	26,727	15,400	12,745
2010	160,592	149,557	90,209	79,311	72,688	32,804	34,918	28,133	18,251	10,471
2011	147,118	112,969	105,022	63,142	55,218	50,237	22,484	23,742	18,997	12,253
2012	158,931	103,578	79,463	73,749	44,216	38,521	34,894	15,552	16,363	13,054
2013	213,320	111,883	72,842	55,778	51,606	30,809	26,711	24,084	10,691	11,211
2014	144,026	150,182	78,694	51,144	39,051	35,988	21,389	18,464	16,586	7,340
2015	133,229	101,402	105,642	55,263	35,818	27,246	25,002	14,798	12,730	11,401
2016	419,018	93,835	71,381	74,292	38,800	25,092	19,039	17,428	10,294	8,839

Table 6.12 (cont'd). Estimates of arrowtooth flounder population number-at-age, by sex, 1976-2016.

males	numbers at age (1,000s)									
	11	12	13	14	15	16	17	18	19	20	21
1976	2,308	1,659	1,242	965	557	440	297	215	157	115	144
1977	2,150	1,537	1,101	821	636	366	289	195	141	103	170
1978	3,741	1,465	1,045	747	556	430	247	195	131	95	184
1979	1,395	2,557	1,000	712	508	377	291	167	132	89	189
1980	4,276	938	1,715	668	474	337	250	193	111	88	185
1981	6,248	2,820	616	1,121	435	308	218	162	125	72	176
1982	3,051	4,108	1,846	401	727	281	198	141	104	81	160
1983	1,126	2,050	2,752	1,233	267	483	187	132	93	69	159
1984	398	749	1,357	1,815	810	175	316	122	86	61	149
1985	556	269	504	912	1,216	541	117	211	81	57	140
1986	878	379	183	342	617	822	365	79	142	55	133
1987	3,517	600	258	124	232	419	557	248	53	96	128
1988	860	2,432	414	178	86	160	288	383	170	37	154
1989	632	564	1,587	269	115	55	103	185	246	109	123
1990	1,385	435	387	1,088	184	79	38	70	126	168	158
1991	5,203	938	294	261	731	123	53	25	47	84	218
1992	5,273	3,456	620	194	171	478	81	34	16	31	198
1993	951	3,624	2,372	425	132	117	327	55	23	11	156
1994	6,843	657	2,501	1,635	293	91	80	224	38	16	115
1995	4,210	4,692	450	1,709	1,115	199	62	55	153	26	89
1996	3,893	2,918	3,248	311	1,180	769	137	43	38	105	79
1997	8,916	2,674	2,000	2,223	212	805	525	94	29	26	126
1998	9,383	6,174	1,849	1,382	1,534	146	555	361	65	20	104
1999	7,945	6,439	4,229	1,265	944	1,046	100	378	246	44	85
2000	5,484	5,495	4,448	2,918	872	650	720	69	260	169	89
2001	3,894	3,777	3,778	3,054	2,001	597	444	492	47	178	176
2002	5,677	2,676	2,591	2,588	2,088	1,366	407	303	336	32	242
2003	3,850	3,921	1,846	1,785	1,780	1,435	938	280	208	231	188
2004	3,508	2,655	2,700	1,269	1,226	1,221	984	643	192	143	287
2005	3,424	2,404	1,816	1,843	865	834	830	669	437	130	292
2006	5,320	2,363	1,656	1,250	1,267	594	572	569	459	300	290
2007	5,089	3,670	1,627	1,139	858	869	407	392	390	314	404
2008	6,778	3,523	2,537	1,124	786	591	599	280	270	269	495
2009	9,365	4,628	2,400	1,725	763	532	400	405	190	183	517
2010	8,636	6,325	3,117	1,612	1,156	510	355	267	270	127	467
2011	6,996	5,745	4,191	2,058	1,061	758	334	233	175	177	388
2012	8,399	4,785	3,921	2,855	1,399	720	514	226	158	119	383
2013	8,918	5,724	3,253	2,660	1,933	946	486	347	153	106	339
2014	7,677	6,093	3,902	2,214	1,807	1,311	641	329	235	103	301
2015	5,033	5,252	4,160	2,659	1,506	1,227	889	435	223	159	275
2016	7,905	3,485	3,633	2,874	1,835	1,038	846	613	299	154	299

Table 6.13. Estimated age 1 recruitment of arrowtooth flounder (thousands of fish) from the 2016 and 2014 stock assessments. Average from 1976-2011, from the 2016 assessment = 402,411,100 t.

Year class	2016 Assessment	2014 Assessment
1976	71,884	148,166
1977	282,532	318,730
1978	67,171	165,953
1979	50,648	212,560
1980	108,815	207,590
1981	408,312	457,928
1982	421,280	179,162
1983	74,881	162,072
1984	529,016	411,610
1985	322,280	310,242
1986	292,492	286,798
1987	664,810	739,482
1988	690,854	442,634
1989	583,820	457,740
1990	400,490	322,520
1991	284,192	339,574
1992	415,026	392,778
1993	280,914	316,026
1994	255,838	322,154
1995	251,052	402,700
1996	389,560	521,000
1997	372,168	433,762
1998	493,502	472,252
1999	687,566	638,174
2000	645,522	472,150
2001	539,010	504,390
2002	647,950	601,246
2003	690,176	735,422
2004	593,234	519,780
2005	387,078	366,568
2006	598,034	689,512
2007	456,668	585,760
2008	364,604	491,166
2009	425,010	652,230
2010	321,184	
2011	294,236	

Table 6.14. Projections of arrowtooth flounder female spawning biomass (t), future catch (t) and full selection fishing mortality rates for seven future harvest scenarios.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2016	497,979	11,267	0.018
2017	485,802	17,045	0.028
2018	464,066	63,450	0.131
2019	410,282	57,473	0.131
2020	365,411	53,120	0.131
2021	330,106	50,640	0.131
2022	306,101	49,189	0.131
2023	291,597	47,129	0.131
2024	280,393	45,162	0.131
2025	269,184	43,471	0.131
2026	258,733	42,067	0.131
2027	249,790	40,704	0.131
2028	242,452	39,427	0.130
2029	236,473	38,401	0.129

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2016	497,979	11,267	0.018
2017	484,700	32,684	0.064
2018	454,866	16,830	0.034
2019	437,916	16,492	0.034
2020	424,058	16,357	0.034
2021	414,509	16,555	0.034
2022	412,319	16,945	0.034
2023	417,913	17,048	0.034
2024	425,010	17,040	0.034
2025	428,853	16,984	0.034
2026	430,003	16,918	0.034
2027	429,704	16,831	0.034
2028	428,532	16,731	0.034
2029	426,599	16,632	0.034

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2016	497,979	11,267	0.018
2017	485,325	23,853	0.038
2018	460,792	33,282	0.068
2019	430,680	31,724	0.068
2020	405,031	30,682	0.068
2021	385,044	30,383	0.068
2022	373,488	30,503	0.068
2023	370,107	30,135	0.068
2024	368,717	29,642	0.068
2025	365,205	29,143	0.068
2026	360,325	28,698	0.068
2027	355,209	28,278	0.068
2028	350,254	27,888	0.068
2029	345,435	27,547	0.068

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2016	497,979	11,266	0.018
2017	486,974	0	0
2018	482,238	0	0
2019	477,839	0	0
2020	475,331	0	0
2021	475,832	0	0
2022	482,683	0	0
2023	497,145	0	0
2024	512,938	0	0
2025	524,593	0	0
2026	532,395	0	0
2027	537,620	0	0
2028	540,981	0	0
2029	542,684	0	0

Table 6.14 (continued).

Scenario 6
Determination of whether arrowtooth flounder are currently overfished
B35=185,547

Year	Female spawning biomass	catch	F
2016	497,979	11,267	0.018
2017	481,501	76,100	0.154
2018	416,637	67,023	0.154
2019	361,957	60,112	0.154
2020	317,814	55,299	0.154
2021	284,380	52,732	0.154
2022	262,705	51,313	0.154
2023	250,269	49,175	0.154
2024	240,829	47,144	0.154
2025	231,352	45,108	0.154
2026	222,839	42,994	0.153
2027	216,186	41,235	0.150
2028	211,224	39,937	0.147
2029	207,486	39,025	0.144

Scenario 7
Determination of whether arrowtooth flounder are approaching an overfished condition
B35=185,547

Year	Female spawning biomass	catch	F
2016	497,979	11,267	0.018
2017	482,312	65,371	0.131
2018	425,796	58,633	0.131
2019	376,569	62,241	0.154
2020	330,122	57,028	0.154
2021	294,550	54,114	0.154
2022	270,947	52,403	0.154
2023	256,833	50,021	0.154
2024	245,969	47,792	0.154
2025	235,303	45,734	0.154
2026	225,740	43,533	0.153
2027	218,221	41,630	0.151
2028	212,596	40,206	0.148
2029	208,371	39,196	0.145

Table 6.15. TAC and ABC used to manage the BSAI arrowtooth flounder complex since 1980.

year	TAC	ABC
1980		20,000
1981		16,500
1982		16,500
1983		20,000
1984		20,000
1985		20,000
1986	20,000	20,000
1987	9,795	30,900
1988	5,531	99,500
1989	6,000	163,700
1990	10,000	106,500
1991	20,000	116,400
1992	10,000	82,300
1993	10,000	72,000
1994	10,000	93,400
1995	10,227	113,000
1996	9,000	129,000
1997	20,760	108,000
1998	16,000	147,000
1999	134,354	140,000
2000	131,000	131,000
2001	22,015	117,000
2002	16,000	113,000
2003	12,000	112,000
2004	12,000	115,000
2005	12,000	108,000
2006	13,000	136,000
2007	20,000	158,000
2008	75,000	244,000
2009	75,000	156,000
2010	75,000	156,000
2011	25,900	153,000
2012	25,900	157,000
2013	25,000	152,000
2014	25,000	106,599
2015	22,000	80,547
2016	14,000	80,701

Figures

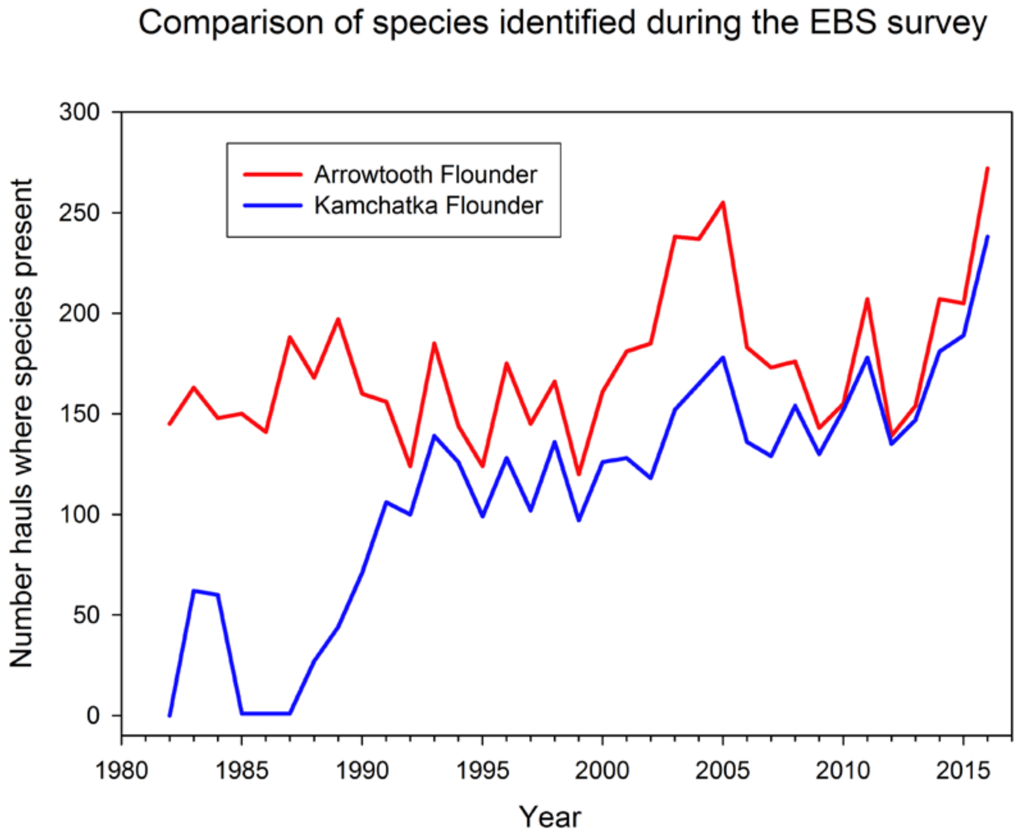

Figure 6.1. Number of hauls where arrowtooth flounder and Kamchatka flounder were identified during the annual Bering Sea shelf surveys, 1982-2016, within the standard survey area.

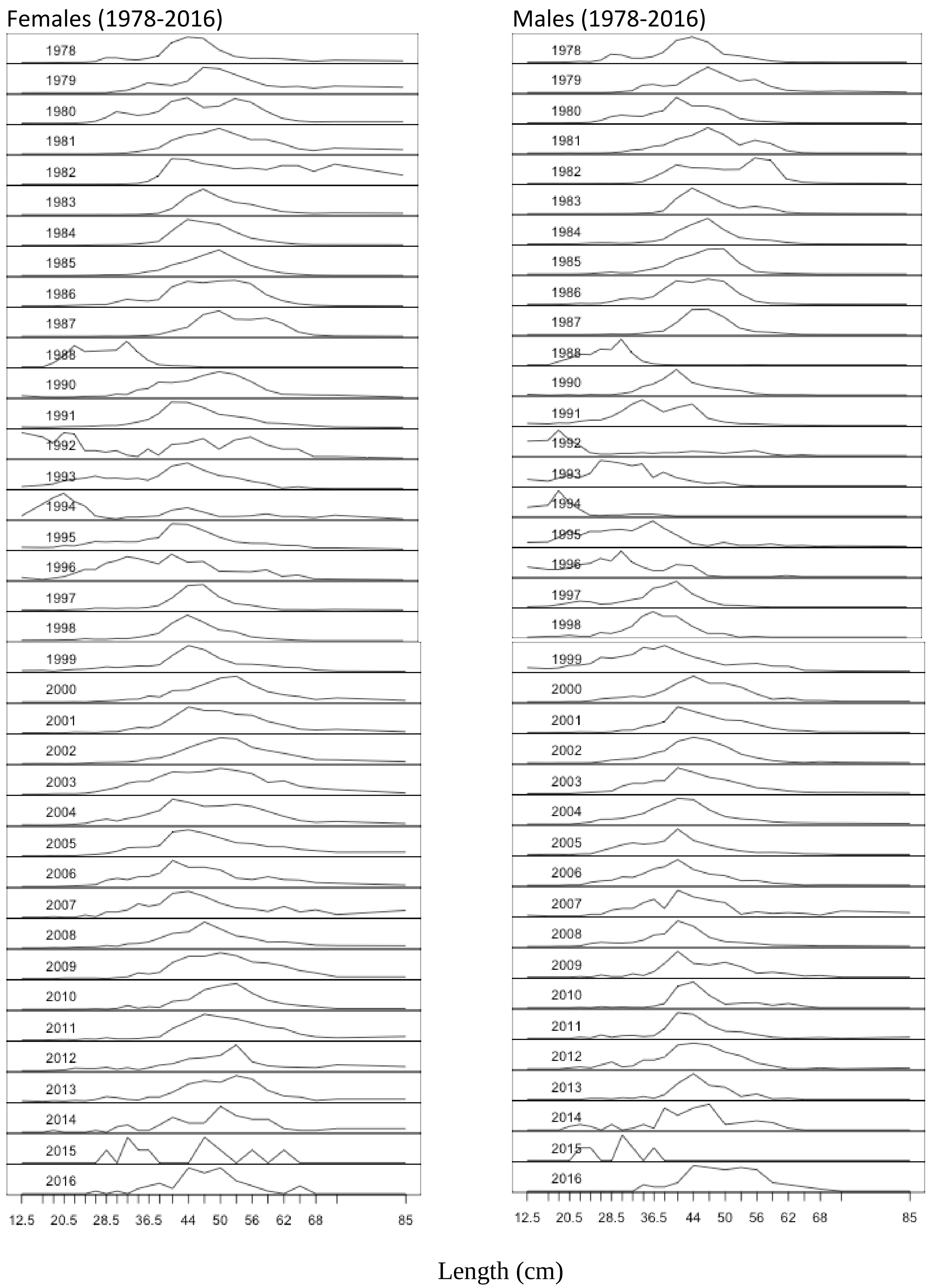

Figure 6.2. Size composition of arrowtooth flounder from the fishery data 1976-2016.

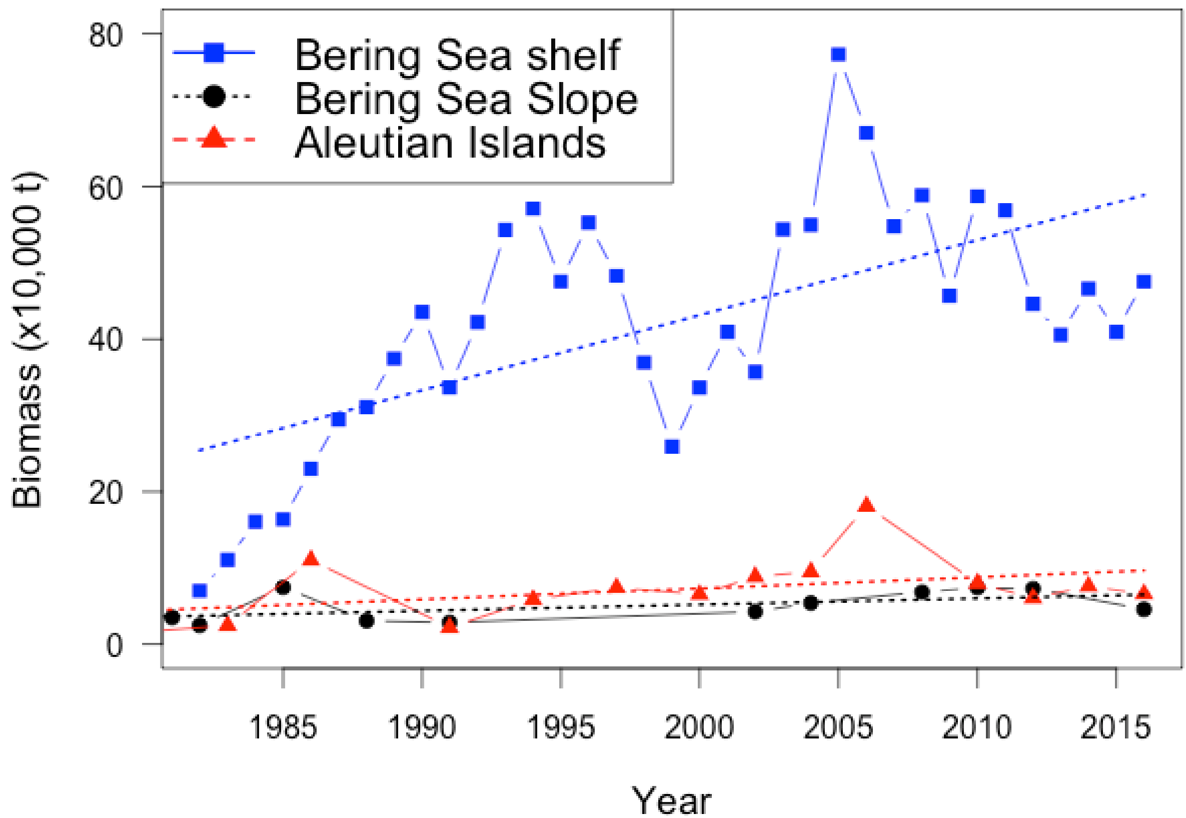

Figure 6.3. Survey estimates for the Bering Sea shelf, slope and the Aleutian Islands arrowtooth flounder biomass, with fitted linear model predictions. Predictions based on linear models of survey data indicate 750,179 t in the BSAI, with 13% in the Aleutians, 78% on the Bering Sea shelf, and 9% on the Bering Sea slope.

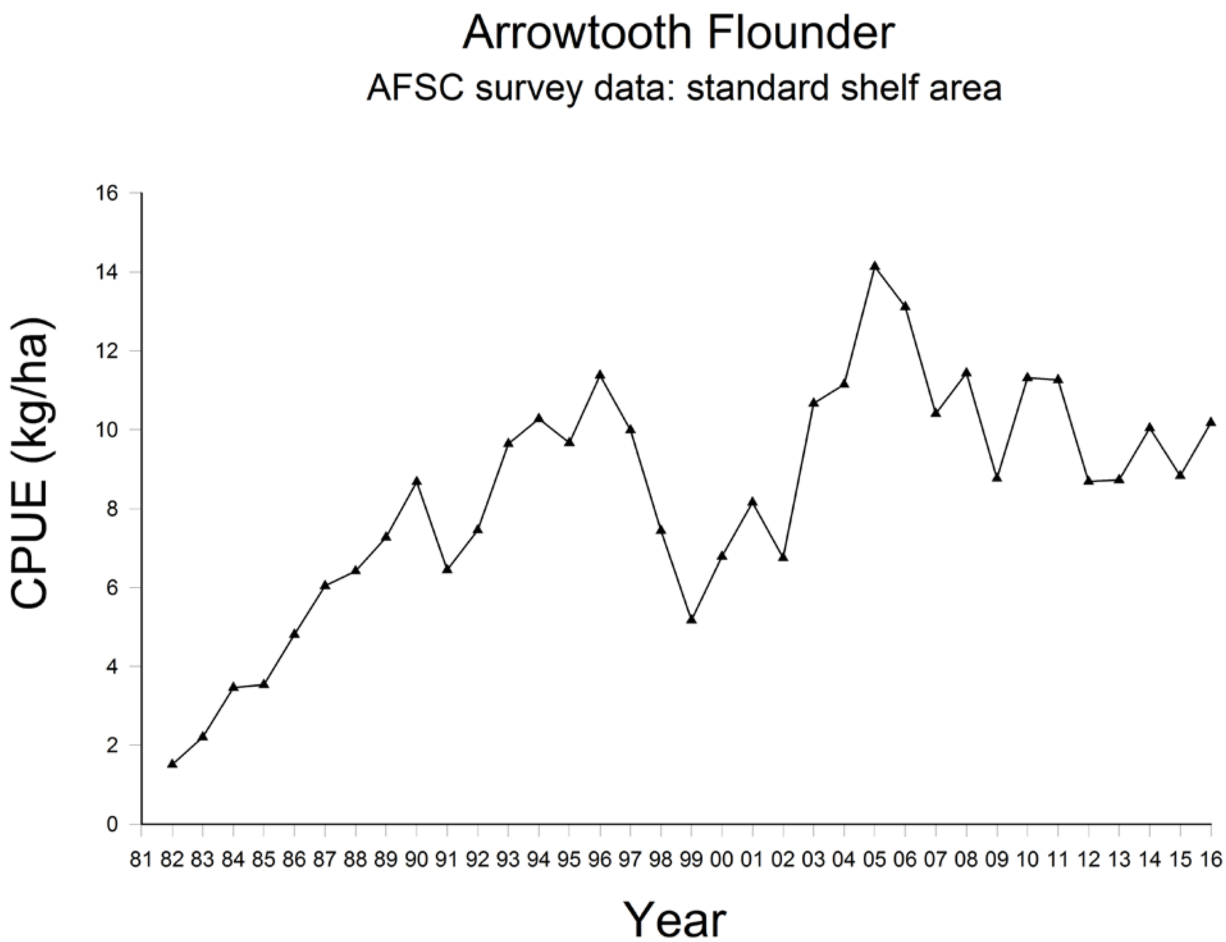

Figure 6.4. Arrowtooth flounder CPUE (kg/ha) from the standard shelf survey area (1982-1992) and standard shelf survey area including Northwestern stratum 82 and 90 (1993-2016).

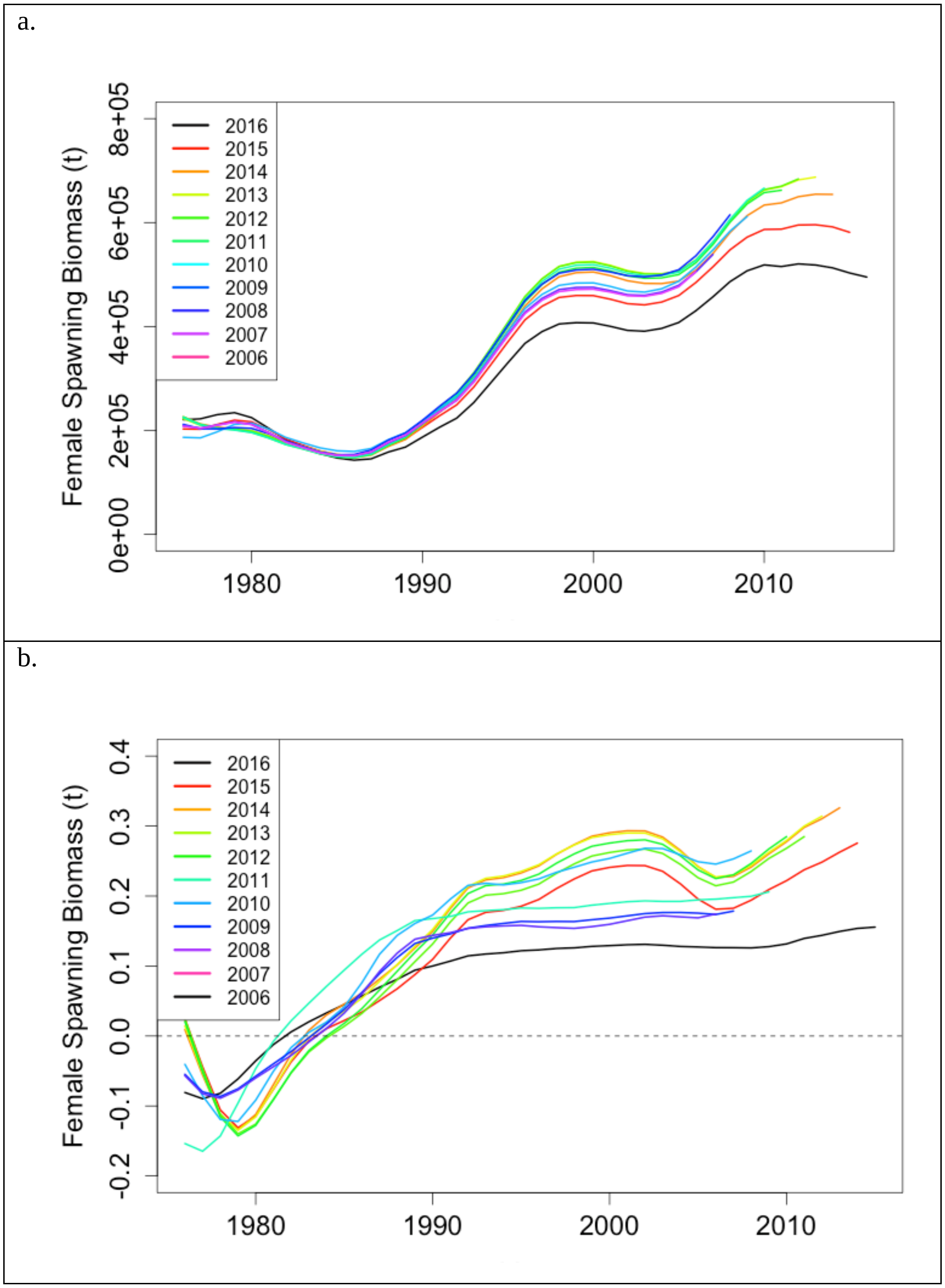

Figure 6.5. Retrospective analysis of spawning biomass estimates from model 15_1b. The top panel shows the spawning biomass time series from the current version of 15_1b with 10 retrospective runs (2006-2015) obtained by dropping one year of data at a time. The bottom panel shows the change in spawning biomass relative to the current version of model 15_1b for each of the 10 retrospective runs.

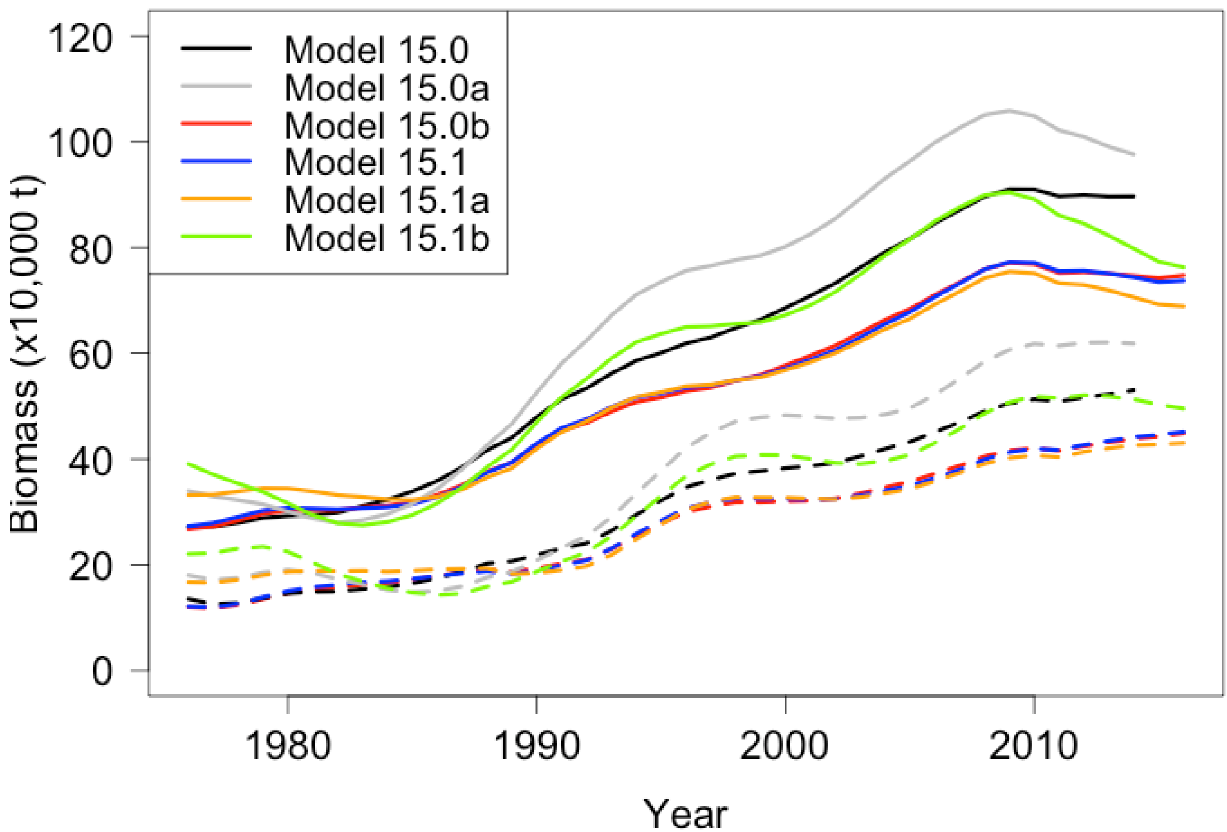

Figure 6.6. Total biomass and female spawning biomass for the different model configurations presented in this assessment.

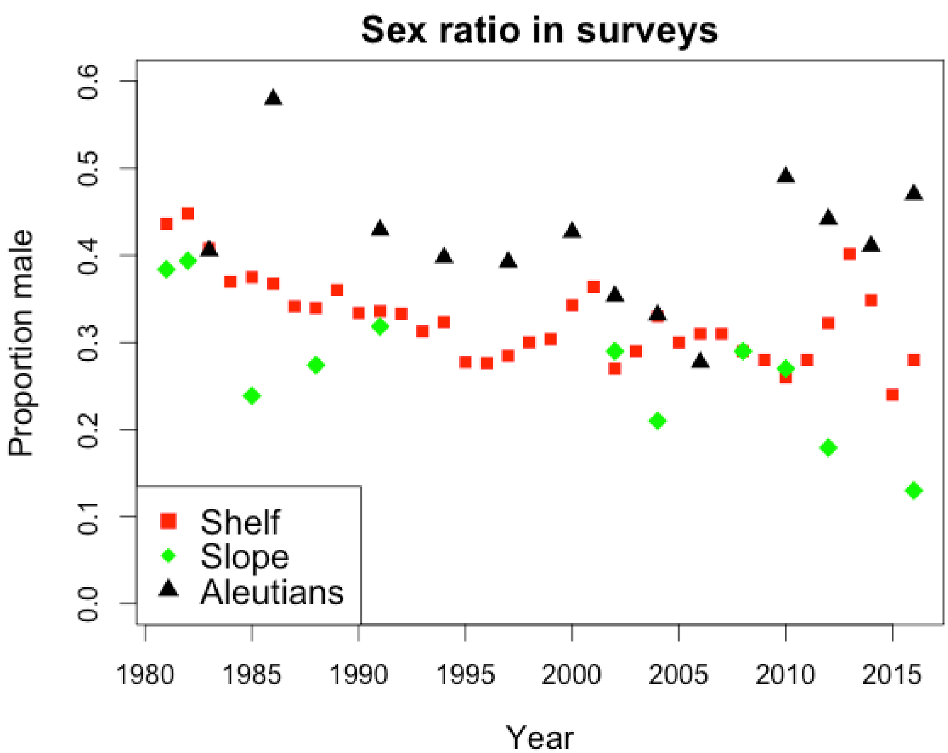

Figure 6.7. Proportion of the estimated male population from Bering Sea and Aleutian Islands trawl surveys on the continental shelf and slope.

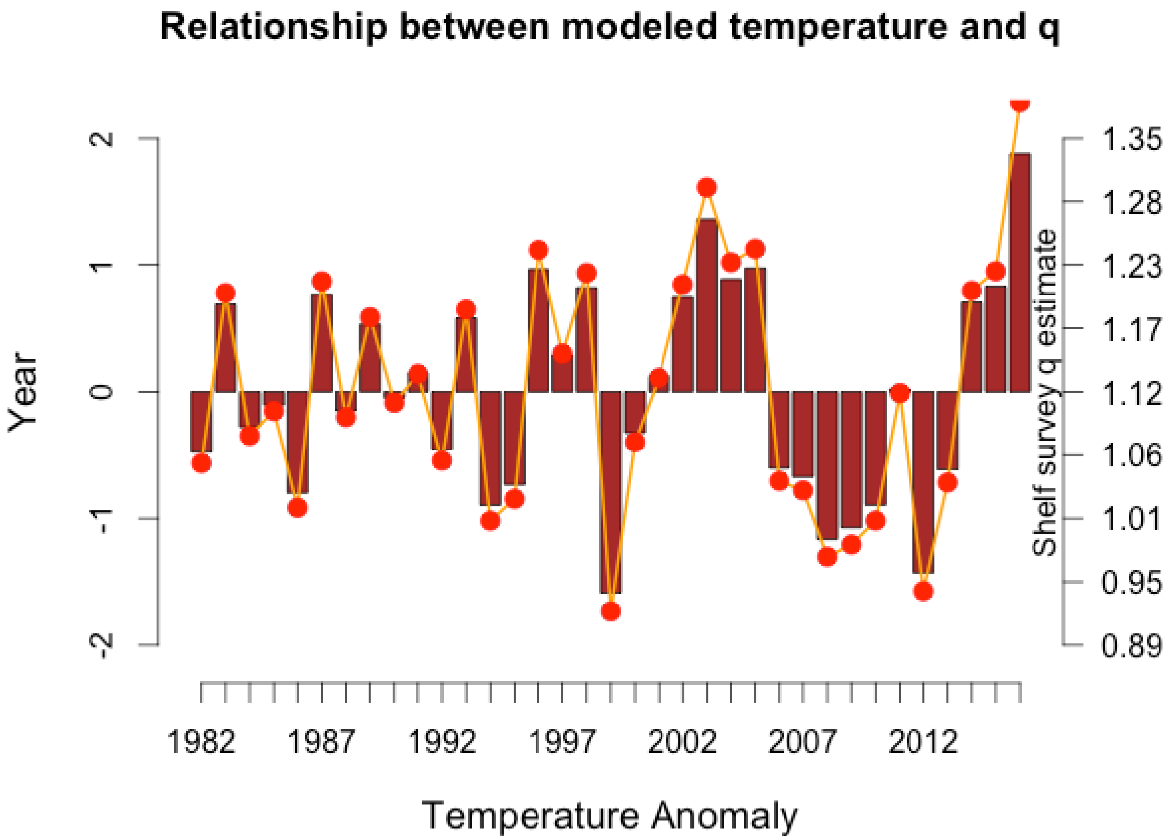

Figure 6.8. Shelf survey annual avg. bottom temperature anomalies (bars), model estimate of annual shelf survey q due to effect of water temperature (circles with lines).

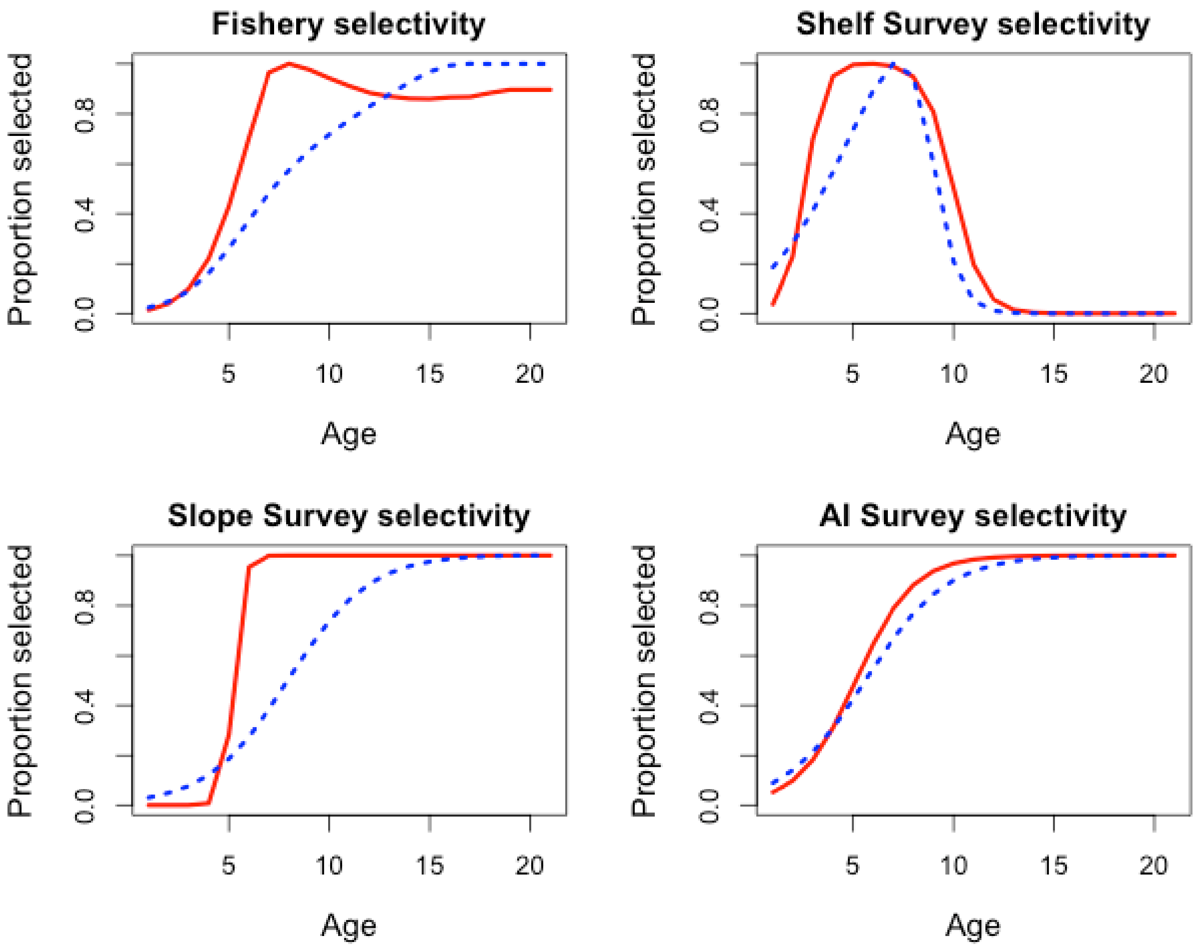

Figure 6.9. Age-specific fishery selectivity (top left panel), shelf survey selectivity (top right panel) slope survey selectivity (bottom left panel) and Aleutian Islands survey selectivity (bottom right panel), by sex, estimated from the stock assessment model.

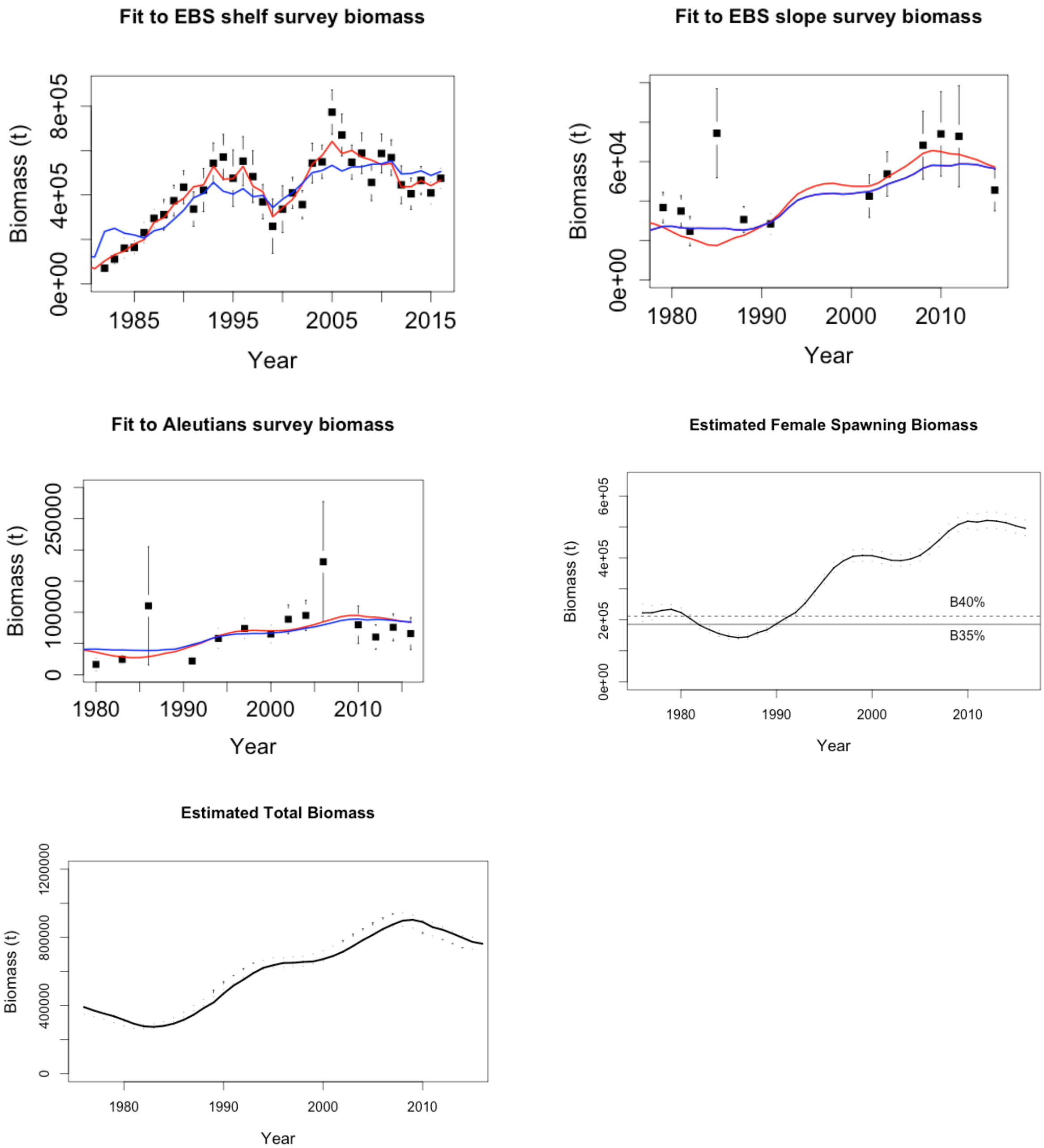

Figure 6.10. Stock assessment model results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), estimate of female spawning biomass with $B_{35\%}$ and $B_{40\%}$ indicated (middle right panel), the fit to the Aleutian Islands survey (middle left panel) and the estimate of total biomass (bottom panel). Credible intervals on model estimates of female spawning biomass and total biomass are from 5% and 95% quantiles of MCMC posterior values. Red lines in the fit to survey data show the results of the final model, and the blue lines show Model 15_1a, the same as the preferred model without data weighting.

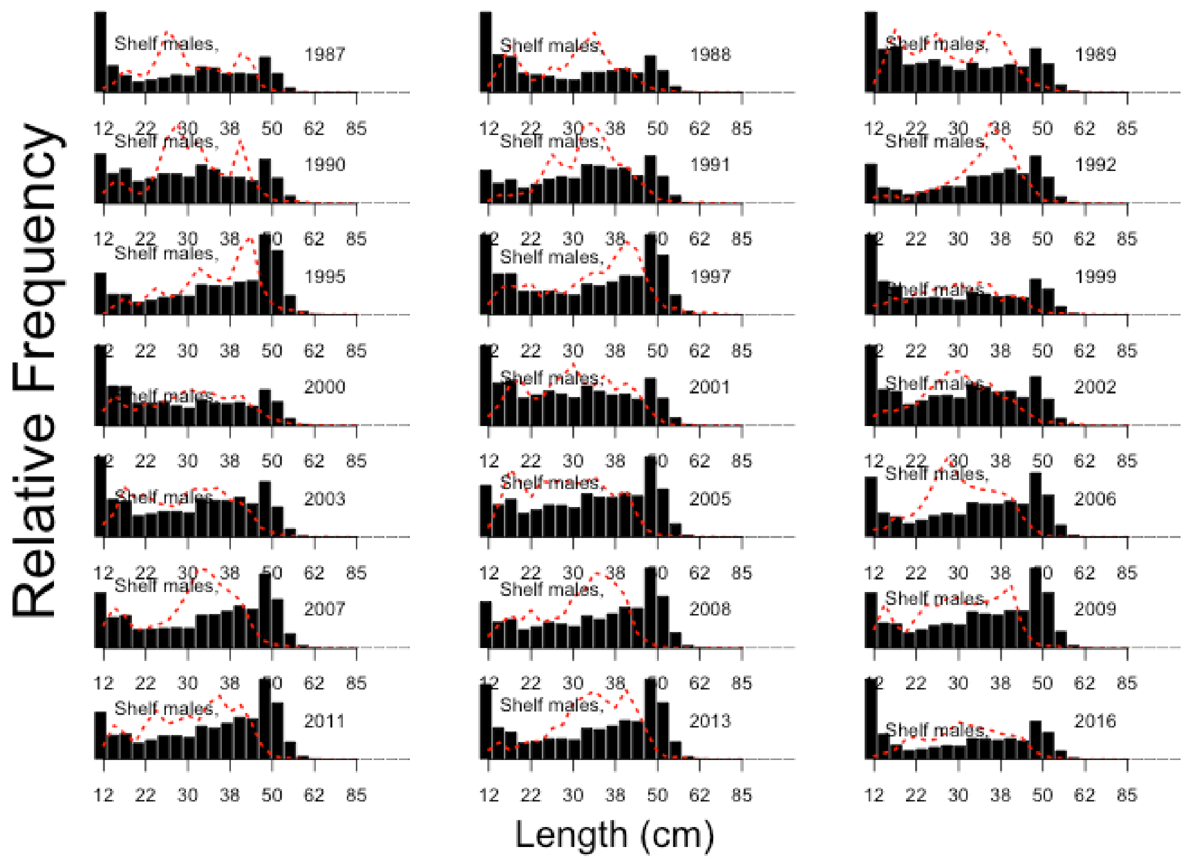

Figure 6.11. Model fit (dotted lines) to Bering Sea shelf survey male observed length composition (bar plots).

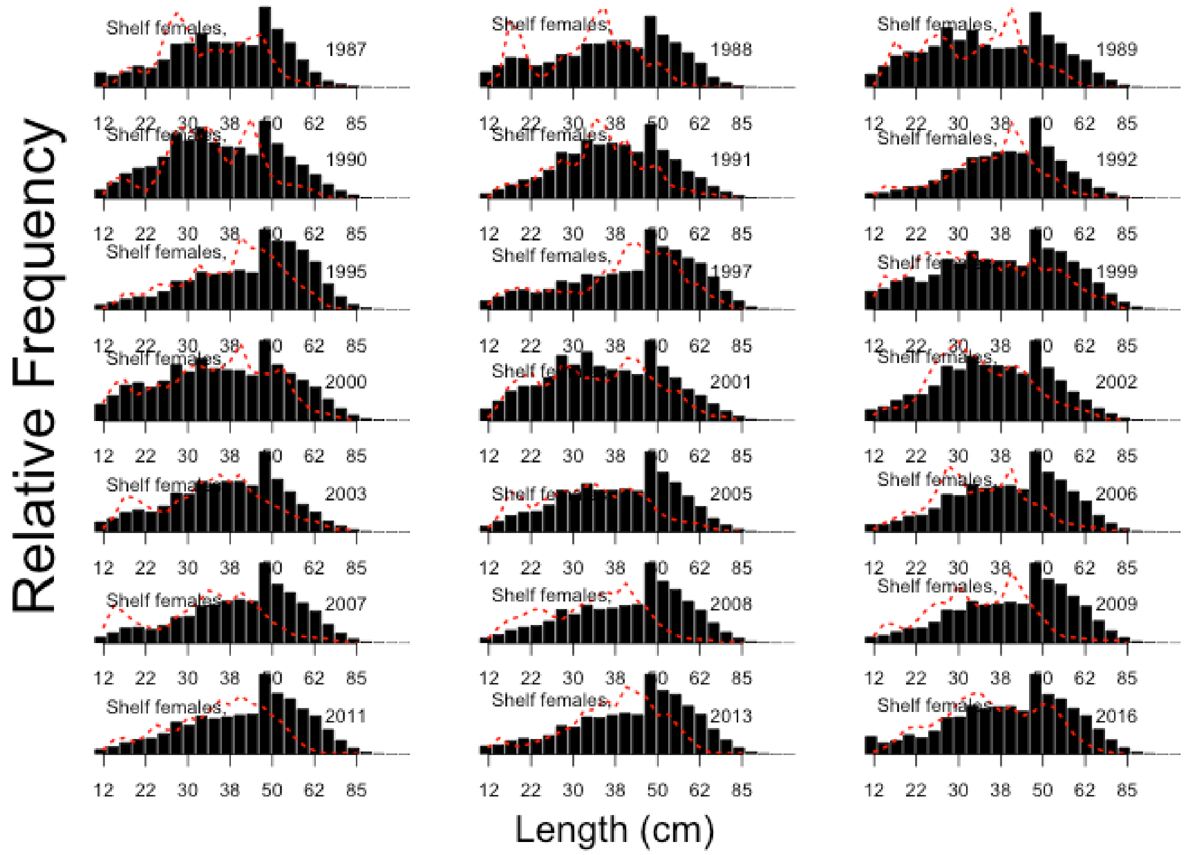

Figure 6.11 (continued). Model fit (dotted lines) to Bering Sea shelf survey female observed length composition (bar plots).

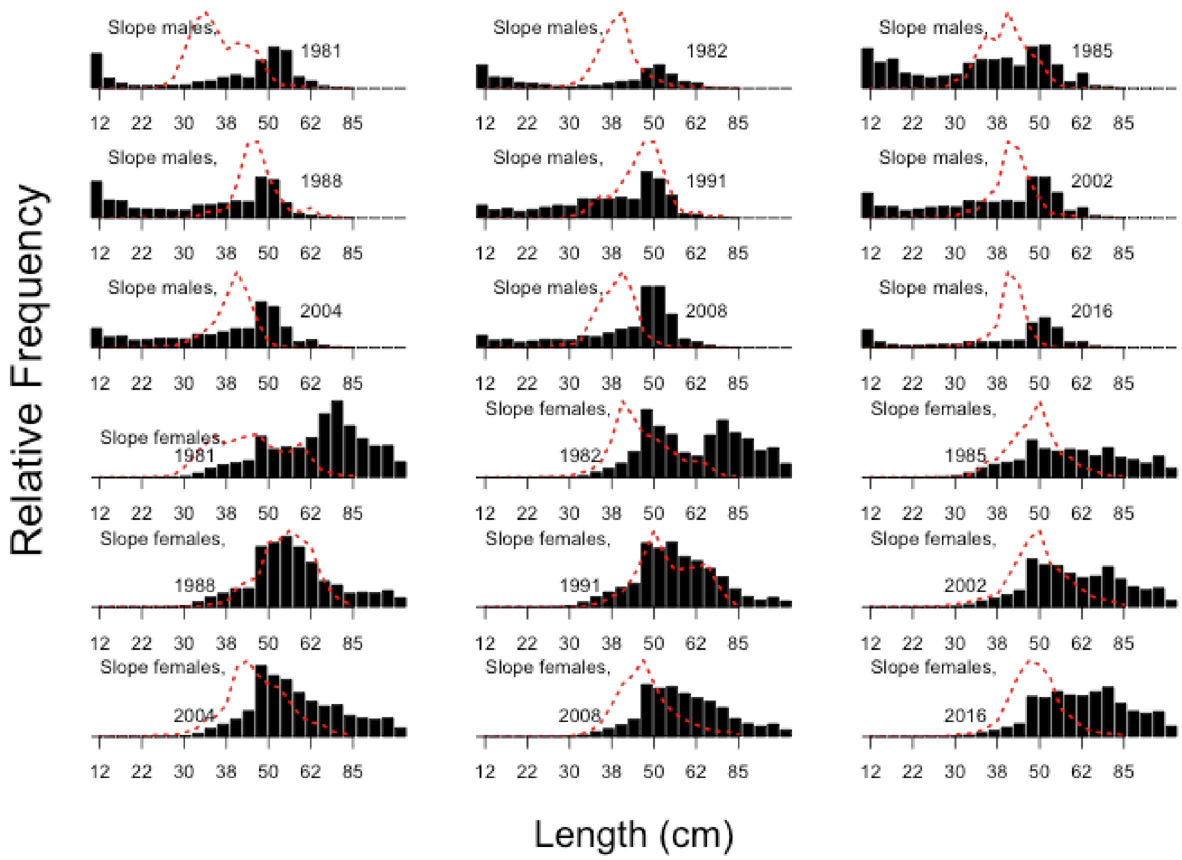

Figure 6.11 (continued). Model fit (dotted lines) to Bering Sea slope survey male and female observed length composition (bar plots).

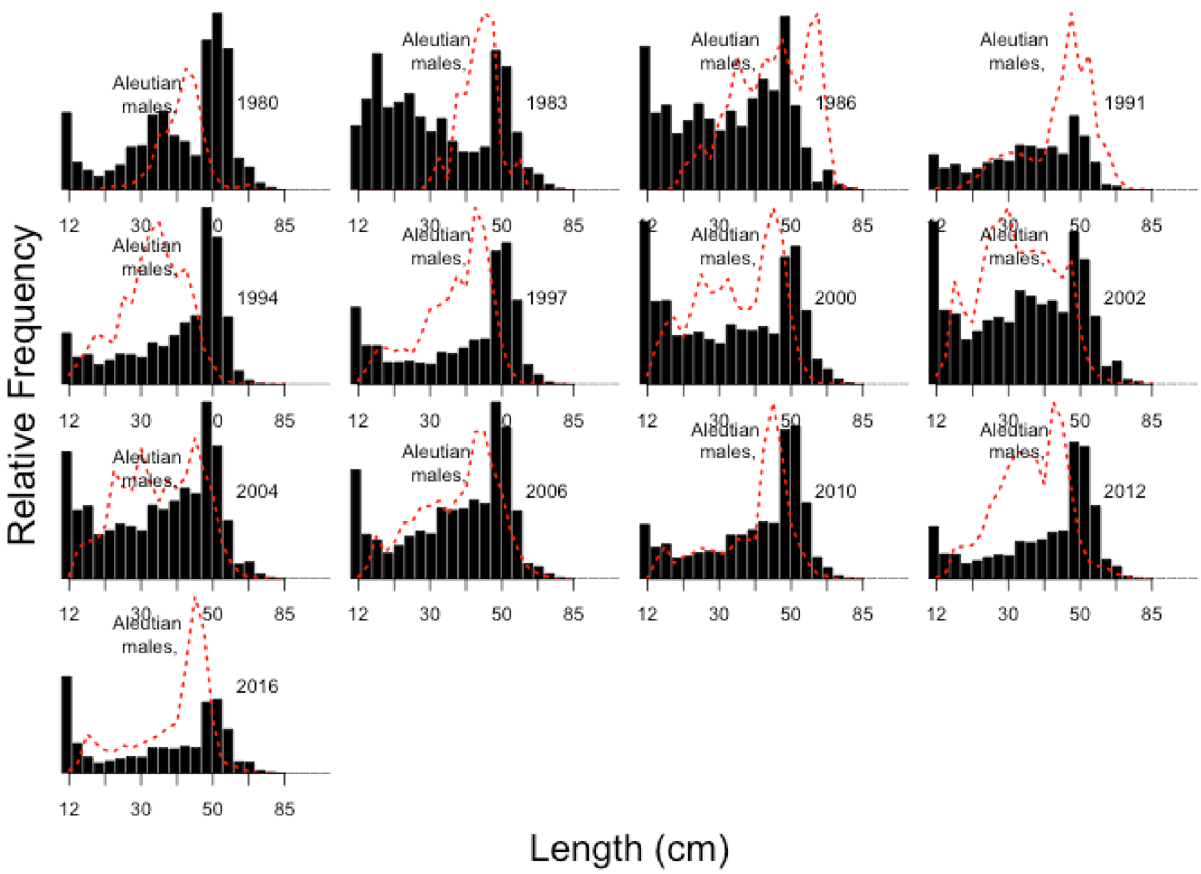

Figure 6.11 (continued). Model fit (dotted lines) to Aleutian Islands survey observed male length composition (bar plots).

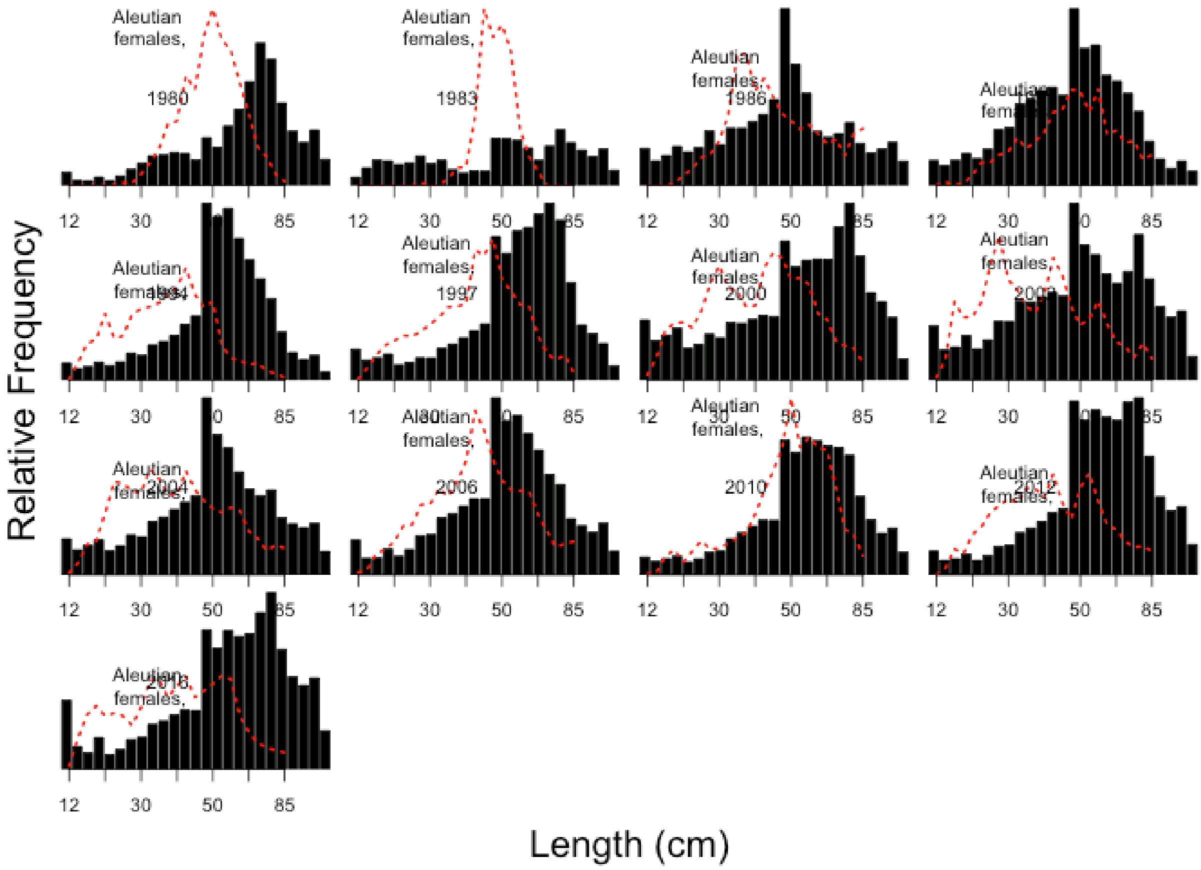

Figure 6.11 (continued). Model fit (dotted lines) to Aleutian Islands survey female observed length composition (bar plots).

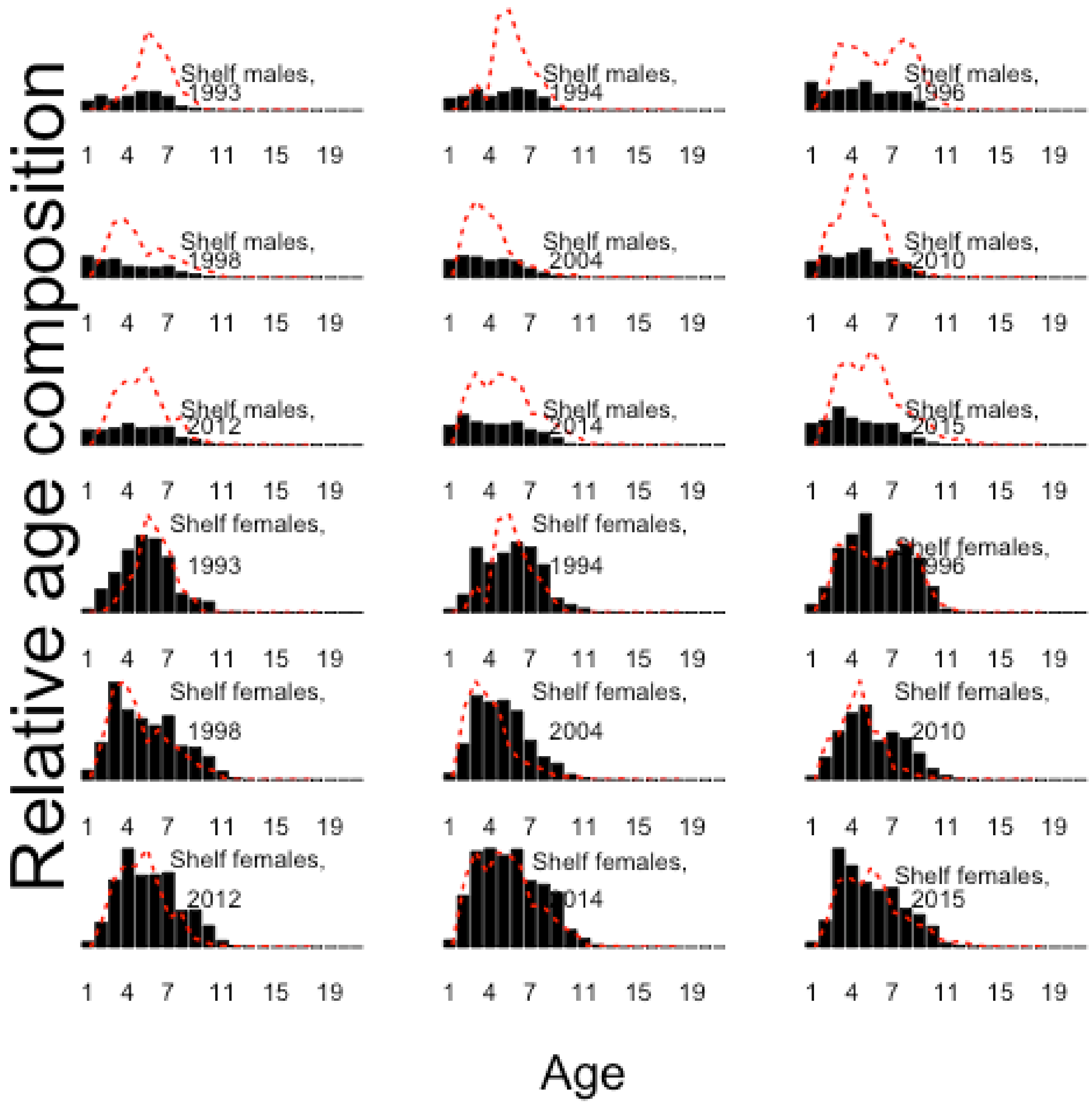

Figure 6.11 (continued). Model fit (dotted lines) to Bering Sea shelf survey male and female observed age composition (bar plots).

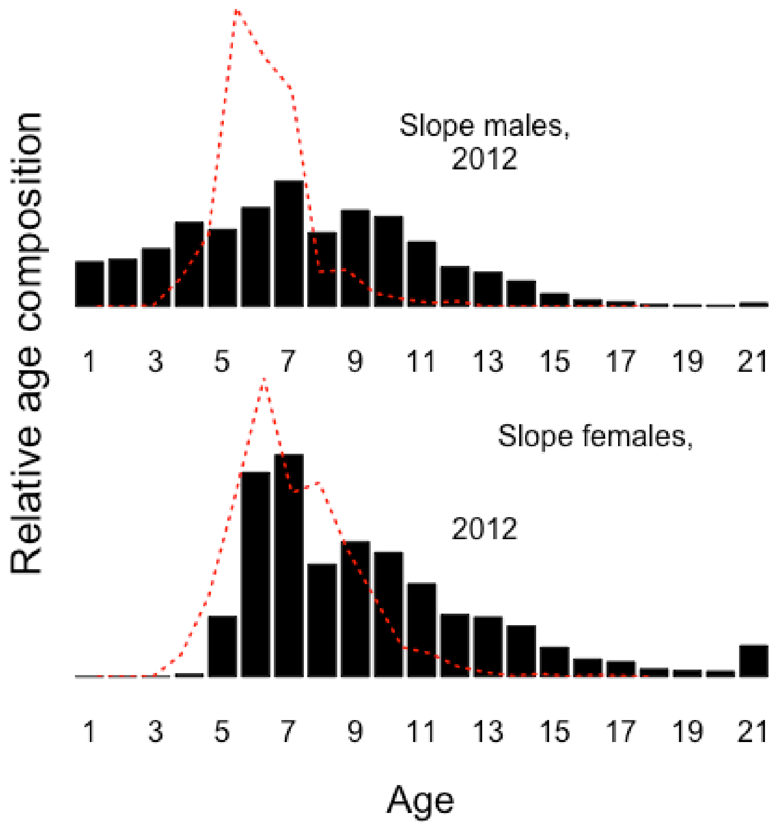

Figure 6.11 (continued). Model fit (dotted lines) to Bering Sea slope male and female survey observed age composition (bar plots).

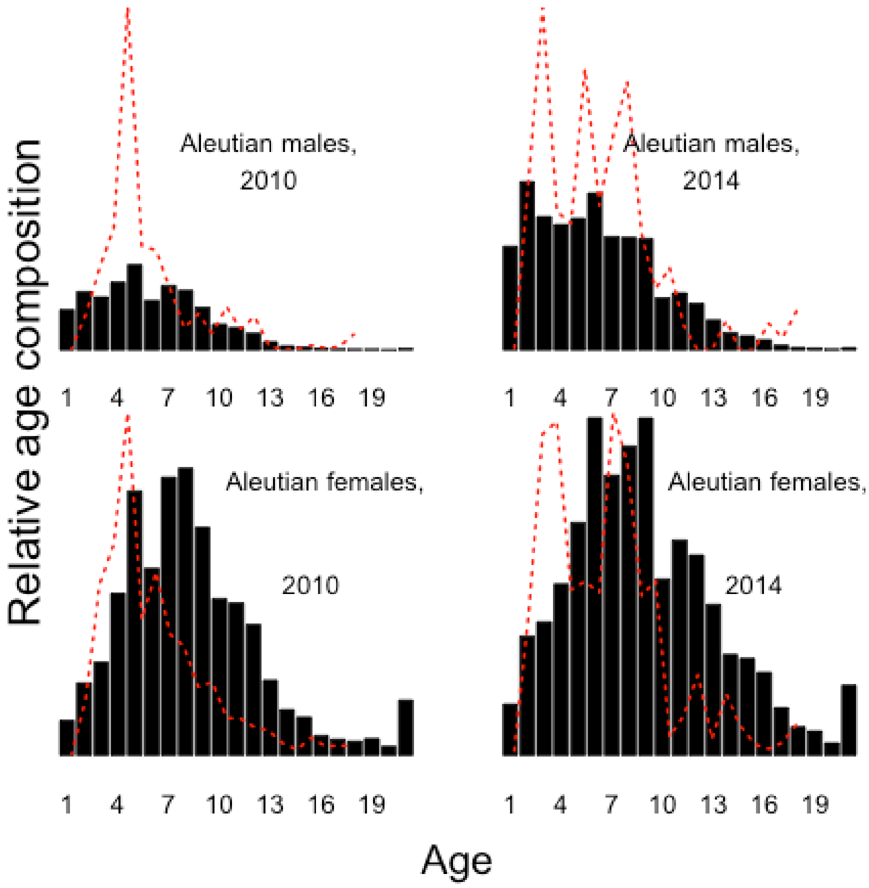

Figure 6.11 (continued). Model fit (dotted lines) to Aleutian Islands survey male and female observed age composition (bar plots).

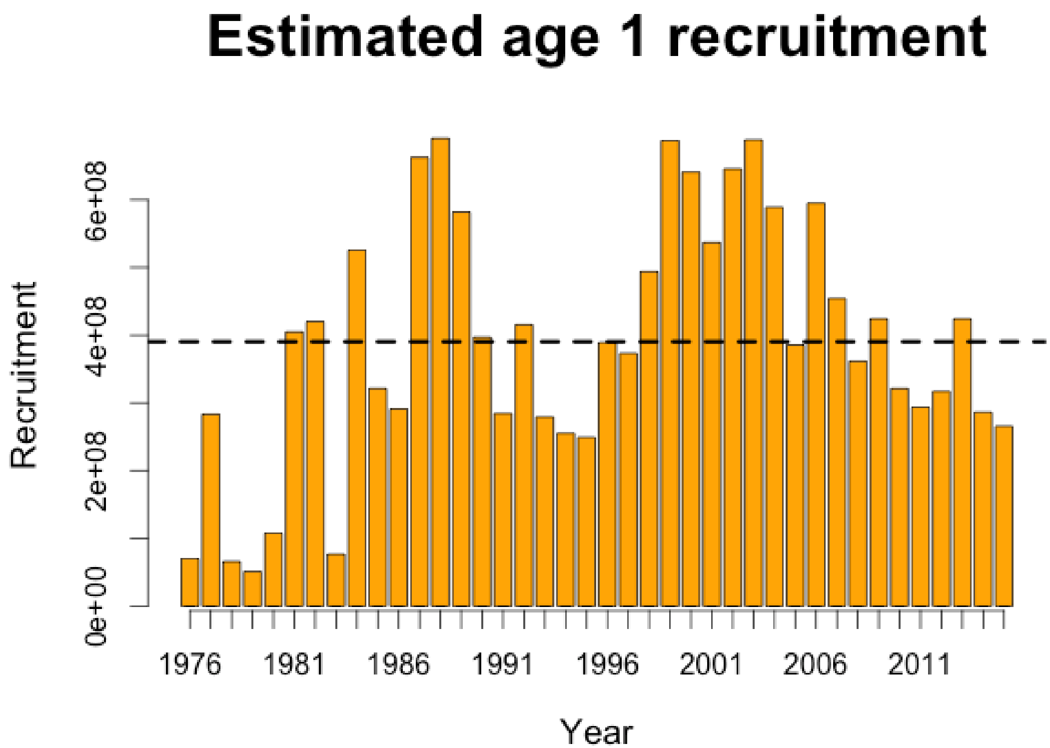

Figure 6.12. Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model mcmc output, with 5% and 95% credible intervals.

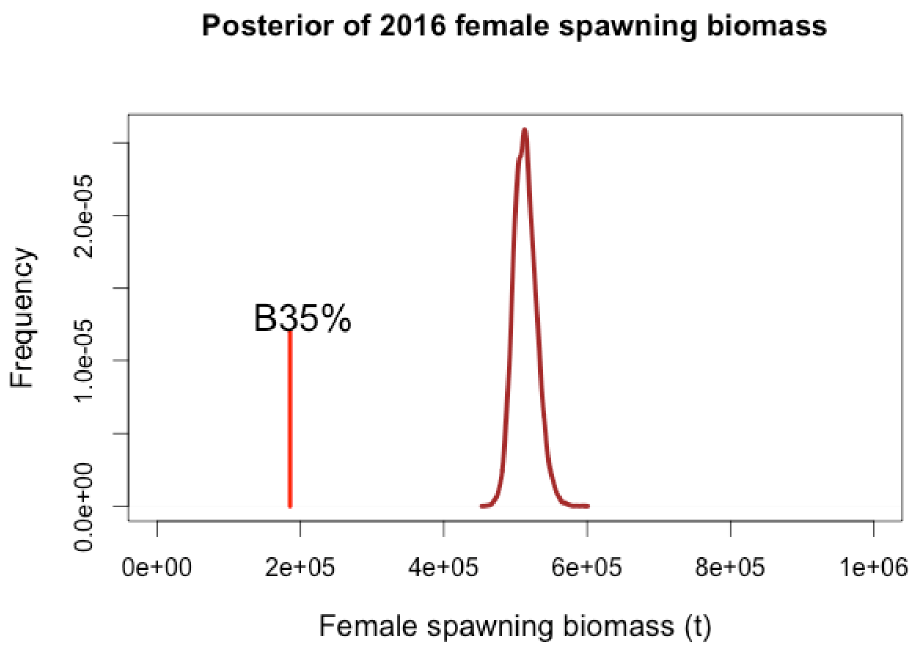

Figure 6.13. Posterior distribution of the estimate of female spawning biomass (t) from the preferred stock assessment model run, compared with the model estimate of $B_{35\%}$, 210,622 t.

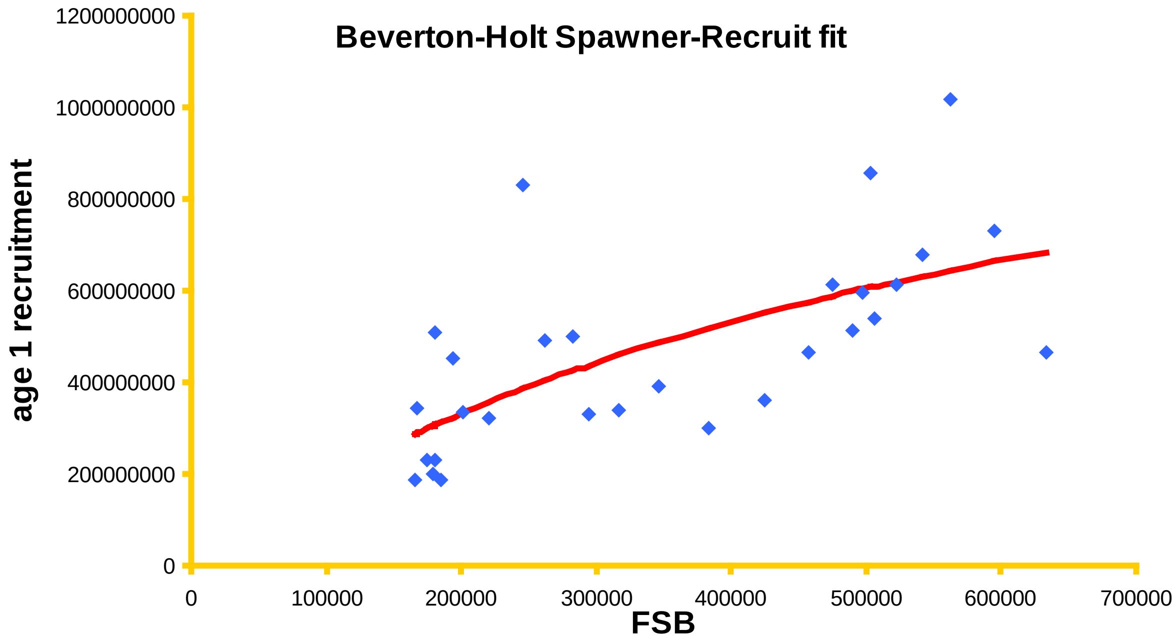

Figure 6.14. Beverton and Holt spawner recruit model fit to the age 1 recruitment data for Bering Sea arrowtooth flounder.

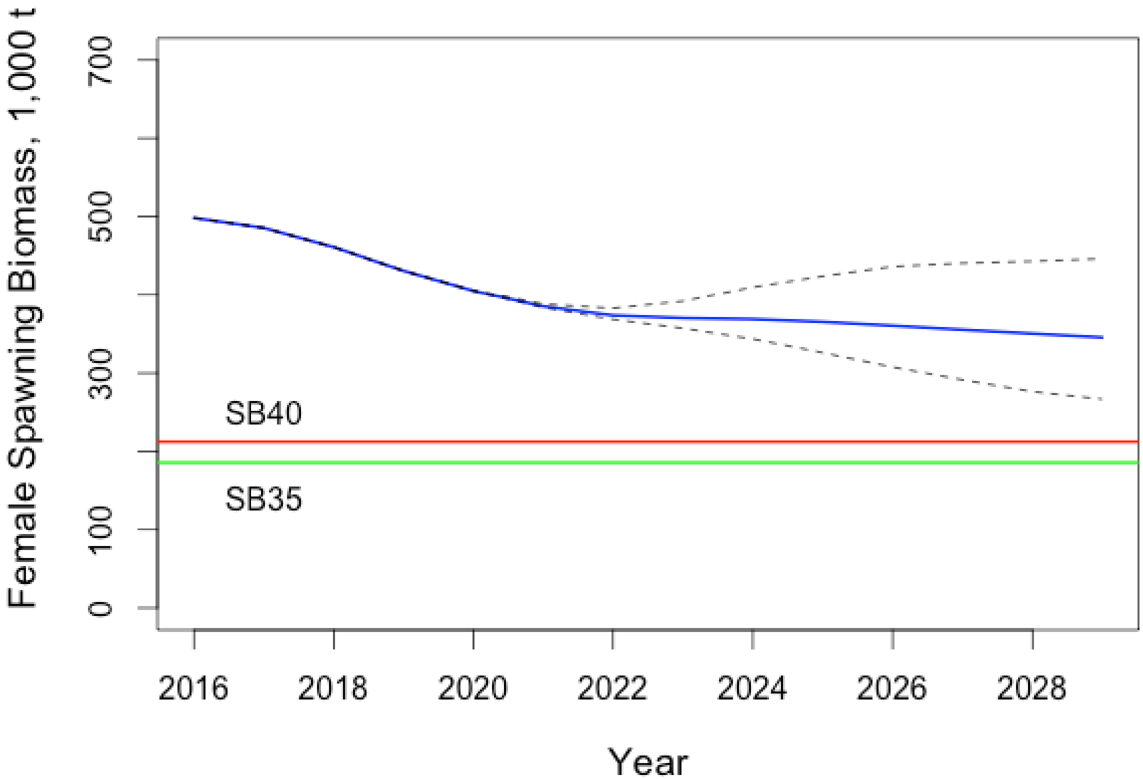

Figure 6.15. Projected female spawning biomass (1,000s t) of arrowtooth flounder if future harvest is at the same fishing mortality rate as the past five years.

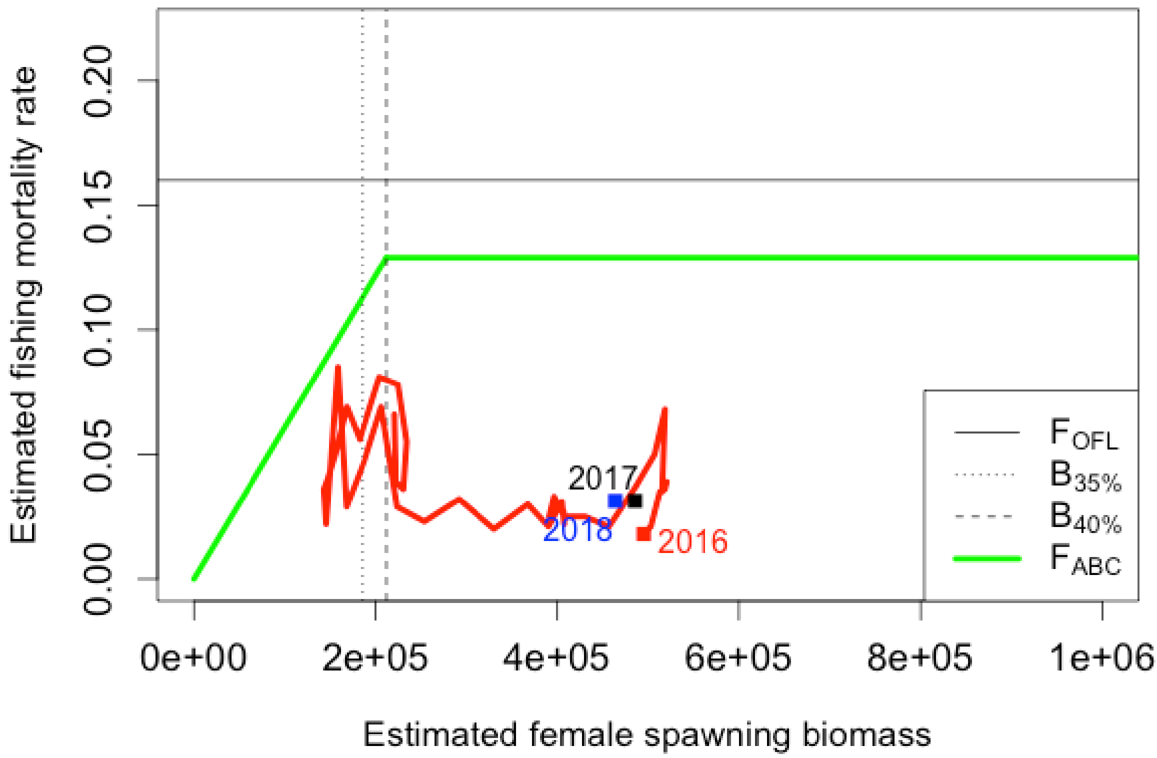

Figure 6.16. Phase plane diagram showing the time-series of stock assessment model estimates of female spawning biomass relative to the harvest control rule, with projection model results for 2017 and 2018.

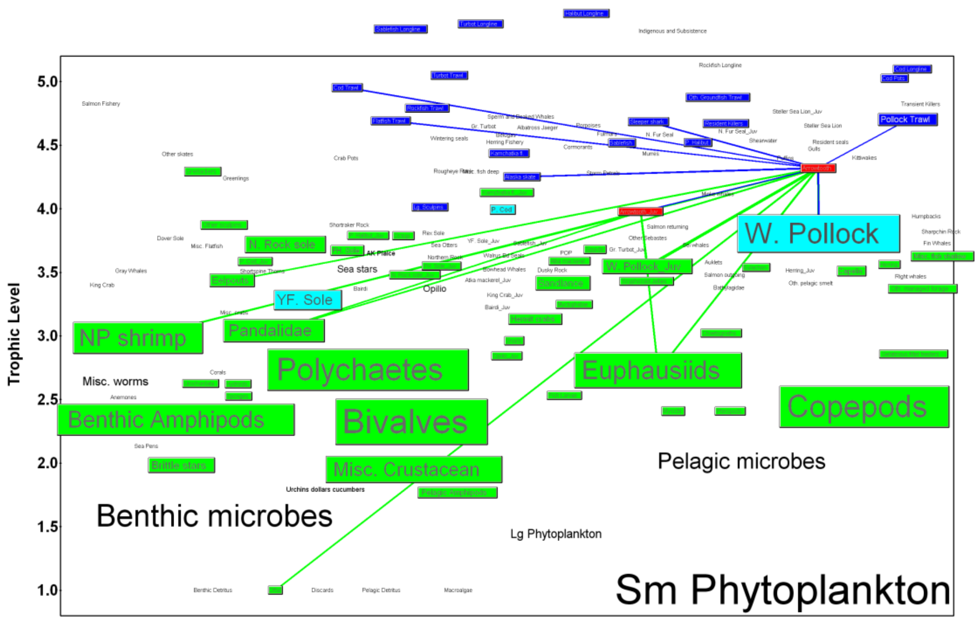

Figure 6.17. Adult and juvenile arrowtooth flounder in the EBS food web. Box size is proportional to biomass, and lines between boxes represent the most significant energy flows. Predators of arrowtooth are dark blue, prey of arrowtooth are green, and species that are both predators and prey of arrowtooth are light blue.

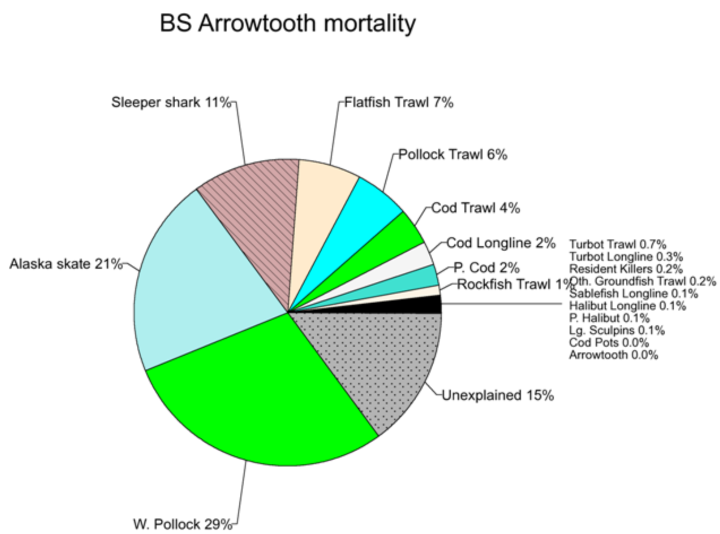

Figure 6.18. Mortality of Bering Sea arrowtooth flounder >20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. "Unexplained" mortality is the difference between the stock assessment mortality and total predation; high unexplained mortality may indicate a top predator in an ecosystem. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good diet coverage within the time period and region; striped hatching indicates limited data from literature sources; cross-hatching indicates estimate derived from ecosystem model (poor data quality).

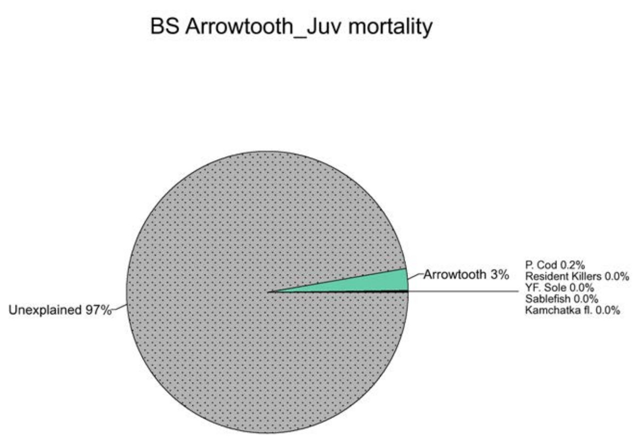

Figure 6.19. Mortality of Bering Sea arrowtooth flounder <20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. "Unexplained" mortality is the difference between the stock assessment mortality and total predation; high unexplained mortality may indicate a top predator in an ecosystem. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good diet coverage within the time period and region; striped hatching indicates limited data from literature sources; cross-hatching indicates estimate derived from ecosystem model (poor data quality).

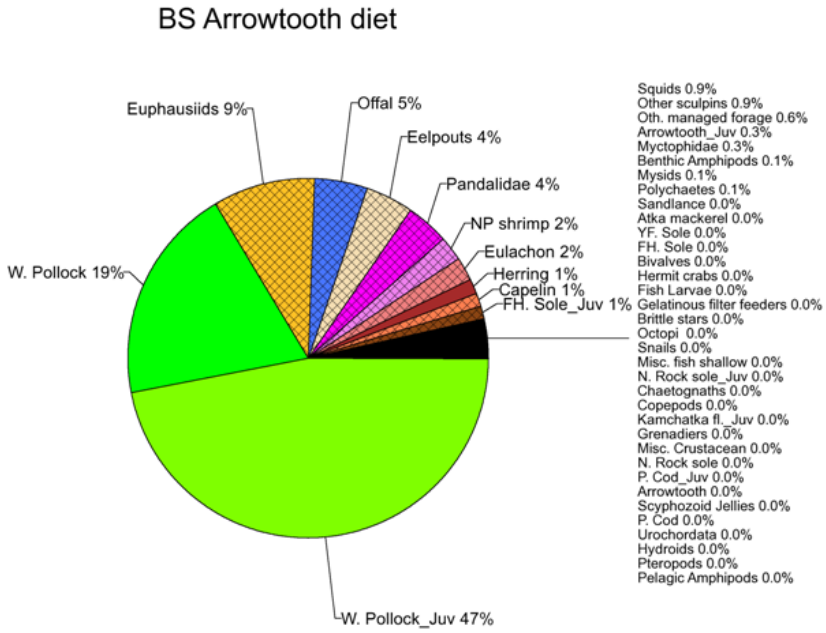

Figure 6.20. Diet of Bering Sea arrowtooth flounder >20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good diet coverage within the time period and region; striped hatching indicates limited data from literature sources; cross-hatching indicates estimate derived from ecosystem model (poor data quality).

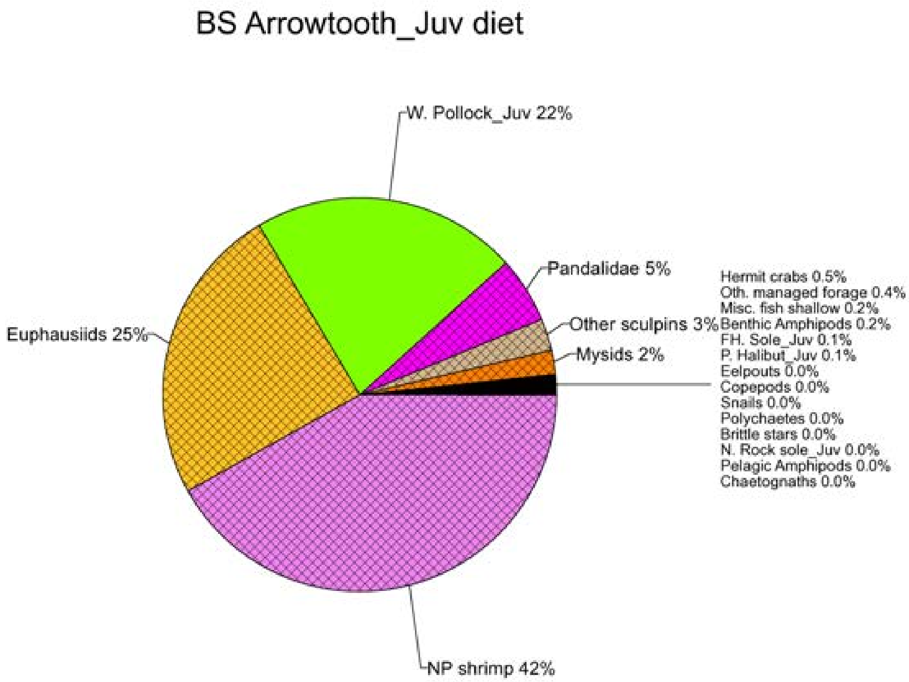

Figure 6.21. Diet of Bering Sea arrowtooth flounder <20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good diet coverage within the time period and region; striped hatching indicates limited data from literature sources; cross-hatching indicates estimate derived from ecosystem model (poor data quality).

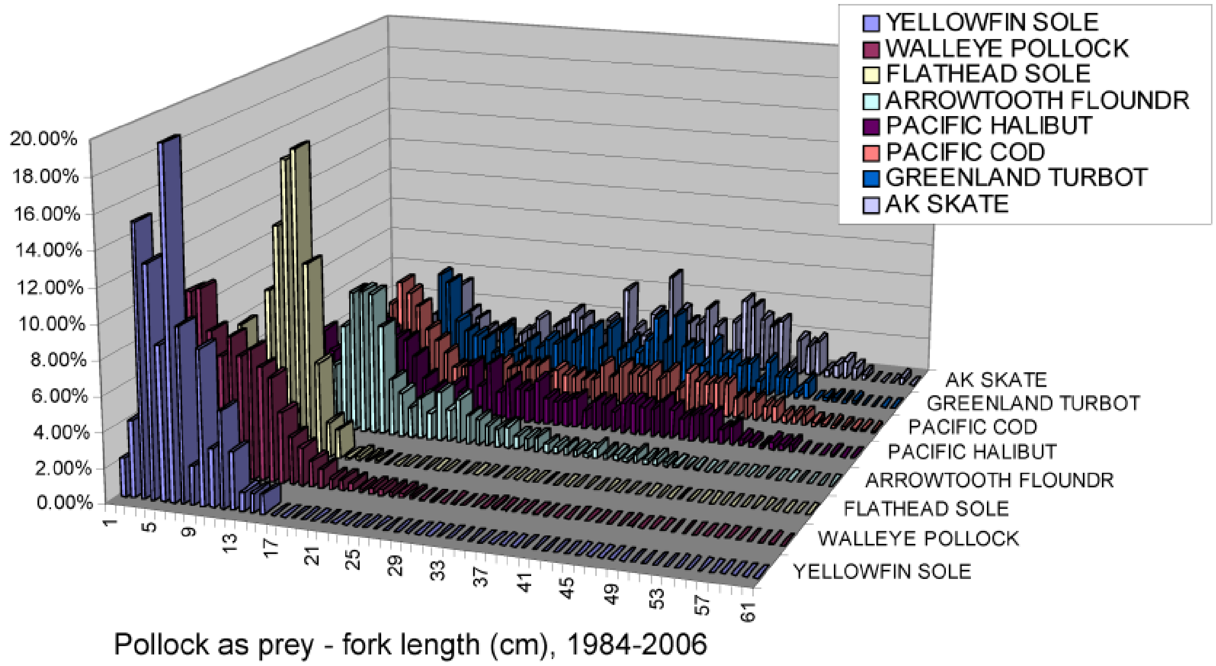

Figure 6.22. Length frequency of pollock found in stomachs, from groundfish food habits collected from 1984-2006 on AFSC summer trawl surveys in the eastern Berng Sea. Predators are sorted by median prey length of pollock in their stomachs. All lengths of predators are combined.

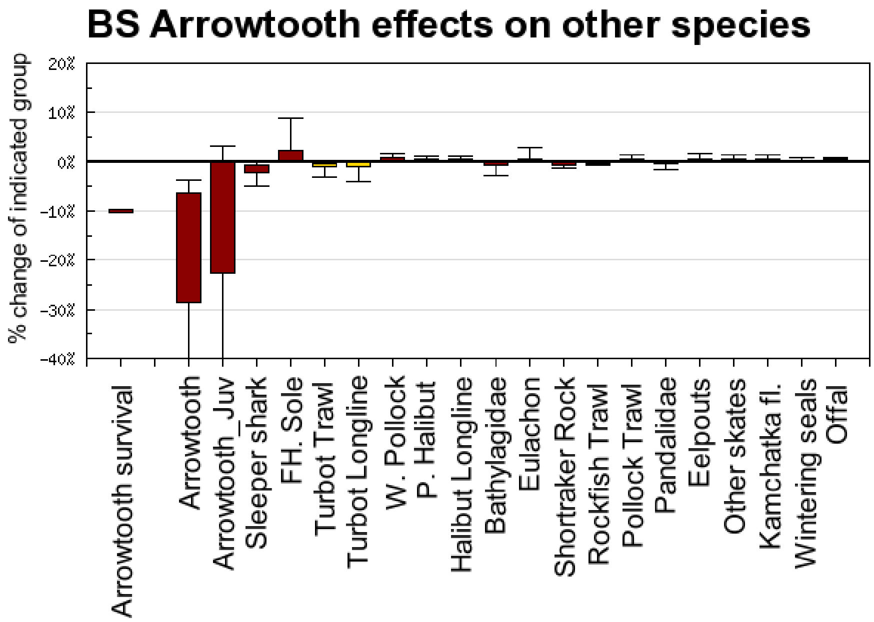

Figure 6.23. Effect of changing arrowtooth > 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting percent change in the biomass of each species on the x axis after 30 years for 50% of feasible ecosystems, error bars show results for 95% of feasible ecosystems (see Aydin et al. in press for detailed Sense methods).

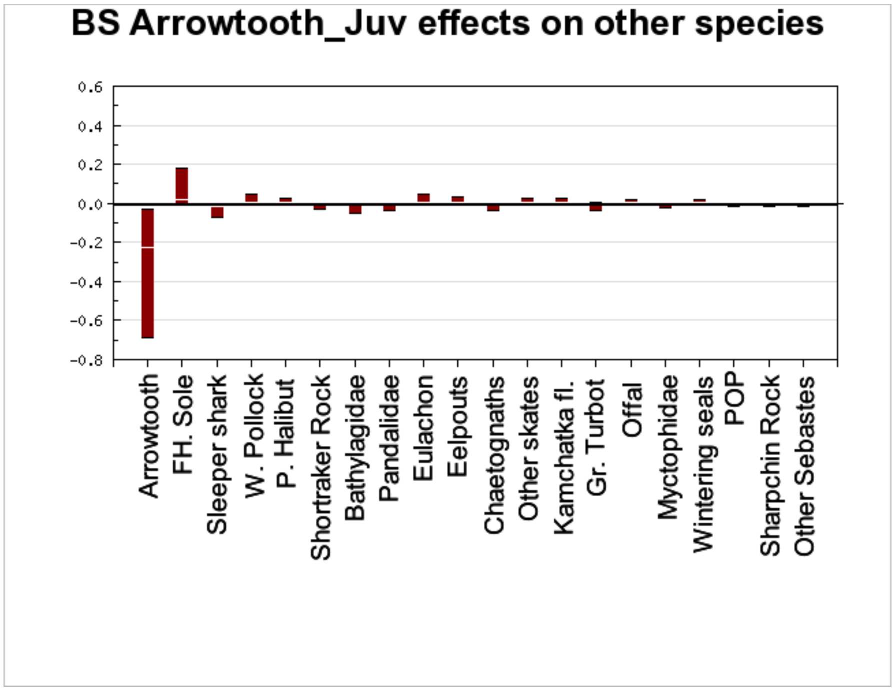

Figure 6.24. Effect of changing arrowtooth < 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting percent change in the biomass of each species on the x axis after 30 years for 50% of feasible ecosystems, error bars show results for 95% of feasible ecosystems (see Aydin et al. in press for detailed Sense methods).

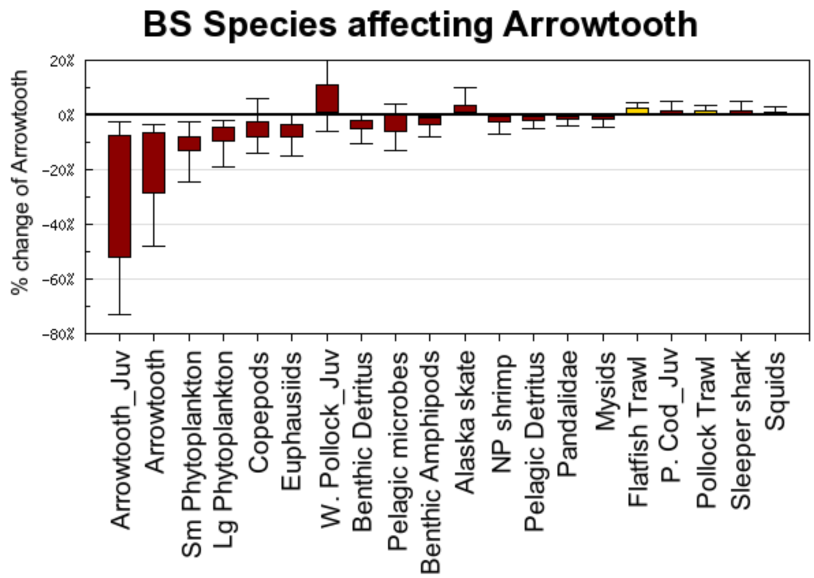

Figure 6.25. Effect of reducing fisheries catch (yellow) and other species survival (dark red) on arrowtooth > 20 cm biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting 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).

Appendix

Table A1. Total tonnage of the research catch for arrowtooth flounder and Kamchatka flounder through 2007, and for arrowtooth only from 2008 onwards. Data for 1991-2015 is from AKFIN, Noncommercial Fishery Catch and represents only arrowtooth flounder (accessed October 27, 2016). Data for 2016 are incomplete, but include catch from the 2016 EBS shelf survey.

Year	Research catch (t)
1977	1
1978	3.7
1979	22.5
1980	63.6
1981	48.4
1982	46.6
1983	21.8
1984	6.1
1985	194.1
1986	57.7
1987	9.4

1988	33.7
1989	22.8
1990	21.9
1991	21.5
1992	23.6
1993	32.1
1994	22.5
1995	38.9
1996	27.5
1997	47.6
1998	43
1999	68.8
2000	48.3
2001	49.3
2002	24.8
2003	38.7
2004	22.6
2005	38
2006	27.6
2007	38.5
2008	22.3
2009	31.3
2010	196.1
2011	242.7
2012	50.4
2013	14.8
2014	38.5
2015	27.3
2016	17.2

Table A2. Parameters estimated in the model, and standard deviation.

Parameter name	Year	value	std.dev
fishsel_params_f[1]		1.12420	2,536
fishsel_params_f[2]		13.59200	6,699
fishsel_params_m[1]		0.42326	230
fishsel_params_m[2]		3.18460	13,758
srv_params_f[1]		2.04850	0.134
srv_params_f[2]		2.59860	0.061
srv_params_f[3]		3.95830	0.594
srv_params_f[4]		5.23510	0.057
srv_params_f[5]		0.70245	0.074
srv_params_f[6]		5.13660	0.288
srv_params_m[1]		0.50000	0.000
srv_params_m[2]		4.69850	0.099
srv_params_m[3]		0.50000	0.000
srv_params_m[4]		7.95140	0.145
srv_params_m[5]		0.50000	0.000
srv_params_m[6]		5.61060	0.154
srv1desc_params_f[1]		1.41540	0.131
srv1desc_params_f[2]		10.00000	0.000

srv1desc_params_m[1]		1.59620	0.273
srv1desc_params_m[2]		8.97600	0.183
alpha		-0.55531	0.024
beta		0.10101	0.007
mean_log_rec		18.66400	0.030
F40		0.14201	0.028
F35		0.16693	0.034
F30		0.44144	343
fspbio		220,750	17,569
fspbio	1976	222,370	14,493
fspbio	1977	230,550	11,622
fspbio	1978	234,220	9,523
fspbio	1979	224,650	8,269
fspbio	1980	204,090	7,406
fspbio	1981	182,630	6,676
fspbio	1982	168,330	6,004
fspbio	1983	155,520	5,388
fspbio	1984	147,060	4,849
fspbio	1985	142,850	4,386
fspbio	1986	145,410	4,082
fspbio	1987	158,480	4,075
fspbio	1988	167,960	4,276
fspbio	1989	187,240	4,586
fspbio	1990	206,190	5,103
fspbio	1991	223,630	5,824
fspbio	1992	253,620	6,651
fspbio	1993	291,840	7,645
fspbio	1994	330,310	8,712
fspbio	1995	367,630	9,626
fspbio	1996	390,280	10,234
fspbio	1997	404,940	10,548
fspbio	1998	407,470	10,663
fspbio	1999	406,900	10,638
fspbio	2000	400,350	10,521
fspbio	2001	392,550	10,376
fspbio	2002	390,970	10,317
fspbio	2003	396,360	10,430
fspbio	2004	407,750	10,768
fspbio	2005	430,300	11,313
fspbio	2006	457,120	11,951
fspbio	2007	486,330	12,562
fspbio	2008	507,180	13,138
fspbio	2009	518,570	13,652
fspbio	2010	515,410	14,114
fspbio	2011	520,480	14,389
fspbio	2012	518,420	14,538
fspbio	2013	512,880	14,537
fspbio	2014	503,050	14,371
fspbio	2015	495,190	14,040
totalbiomass	1976	390,860	14,851
totalbiomass	1977	370,530	12,834
totalbiomass	1978	353,620	11,305
totalbiomass	1979	337,620	10,095
totalbiomass	1980	316,150	9,097
totalbiomass	1981	294,020	8,242
totalbiomass	1982	278,590	7,524

totalbiomass	1983	275,090	6,995
totalbiomass	1984	280,840	6,645
totalbiomass	1985	294,170	6,513
totalbiomass	1986	316,170	6,682
totalbiomass	1987	346,000	7,209
totalbiomass	1988	384,990	8,038
totalbiomass	1989	417,690	9,183
totalbiomass	1990	469,980	10,485
totalbiomass	1991	516,790	11,801
totalbiomass	1992	551,850	12,998
totalbiomass	1993	590,260	13,960
totalbiomass	1994	621,180	14,697
totalbiomass	1995	636,730	15,204
totalbiomass	1996	649,890	15,532
totalbiomass	1997	651,190	15,698
totalbiomass	1998	655,980	15,842
totalbiomass	1999	658,790	16,005
totalbiomass	2000	672,280	16,308
totalbiomass	2001	690,900	16,761
totalbiomass	2002	716,030	17,349
totalbiomass	2003	749,120	18,017
totalbiomass	2004	784,860	18,725
totalbiomass	2005	815,630	19,404
totalbiomass	2006	849,610	20,090
totalbiomass	2007	876,390	20,696
totalbiomass	2008	899,250	21,204
totalbiomass	2009	904,120	21,588
totalbiomass	2010	891,490	21,745
totalbiomass	2011	860,720	21,749
totalbiomass	2012	845,220	21,548
totalbiomass	2013	822,560	21,225
totalbiomass	2014	798,000	20,790
totalbiomass	2015	773,400	20,392
totalbiomass	2016	762,660	20,019

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