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

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Executive Summary

The following changes have been made to this assessment relative to the November 2013 SAFE.

Summary of changes in assessment model input data

The following new data was included in the model:

1) Survey size compositions from the 2013 and 2014 Eastern Bering Sea shelf survey, and 2014 Aleutian Islands survey.
2) Biomass point-estimates and standard errors from the 2013 and 2014 Eastern Bering Sea shelf survey, and 2014 Aleutian Islands survey.
3) Fishery size compositions for 2012, 2013, and 2014. Fishery size composition data was also added for 1992-1999 that had not previously been included.
4) Estimates of catch through October 10, 2014.
5) Age data from the 2010 Bering Sea shelf and 2010 Aleutian Islands surveys, as well as the 2004 shelf survey, which was not previously included.

Summary of changes to the assessment model methodology

The age-structured assessment model is similar to the model used for the 2012 and 2013 assessments, and was developed using AD Model Builder (a C++ software language extension and automatic differentiation library). The 2014 model implemented the following changes based on Plan Team and SSC comments:

1) Fishery selectivity is estimated non-parametrically rather than using a 2-parameter logistic function.
2) An additional likelihood component was added to incorporate new Aleutian Islands age data that had not been included in the past.

Summary of results

1) The projected age 1+ total biomass for 2015 is 908,379 t.

2) The projected female spawning biomass for 2015 is 533,731 t.

3) The recommended 2015 ABC is 80,547 t based on an $F_{0.40}$=0.153 harvest level.

4) The 2015 overfishing level is 93,856 t based on a F_{OFL}=0.180 harvest level.

Quantity/Status	Last year 2014	2015	This year 2015	2016
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+)	1,023,440	995,494	908,379	911,652
Female spawning biomass (t)				
Projected	626,319	632,319	533,731	528,020
$B_{100\%}$	577,538	577,538	555,049	555,049
$B_{40\%}$	231,015	231,015	222,019	222,019
$B_{35\%}$	202,138	202,138	194,267	194,267
F_{OFL}	0.186	0.186	0.180	0.180
$maxF_{ABC}$ (maximum allowable = $F_{40\%}$)	0.156	0.156	0.153	0.153
Specified/recommended F_{ABC}	0.156	0.156	0.153	0.153
Specified/recommended OFL (t)	125,642	125,025	93,856	91,663
Specified/recommended ABC (t)	106,599	106,089	80,547	78,661
Is the stock being subjected to overfishing?	no	no	no	no
Is the stock currently overfished?	no	no	no	no
Is the stock approaching a condition of being overfished?	no	no	no	no

Responses to SSC and Plan Team Comments on Assessments in General

In December 2013 the SSC noted that different stock assessment scientists often use different methods for catch estimation to estimate catches between late October and December 31 of the current assessment year, as well as catches to be taken during the following two years for use in the catch specification process. The SSC understands that Dana Hanselman will compile the various methods in use. The SSC looks forward to Plan Team advice on the merits of the various alternatives.

Authors' response: The best method for catch projections appears to be species-specific. The 2014 catch of arrowtooth flounder through October 13, 2014 was 18,119 t. The total catch in 2014 and 2015 was estimated to be the same as the 2013 catch of 20,501 t. This choice is discussed further under Projected Biomass.

Responses to SSC and Plan Team Comments on Assessments Specific to this Assessment

In December 2013 the SSC accepted the author's and Plan Team's recommended ABCs and OFLs for 2014 and 2015 under Tier 3a using the current model updated with female maturity information based on research by Stark (2011). The SSC looks forward to a full analysis of the model results with the old and new data in next year's stock assessment. The assessment should compare the alternative maturity curves, along with their uncertainty.

Authors' response: Assessment results using Stark (2011) and Zimmerman (1997) maturity values are presented in the Appendix.

In September 2014, the BSAI Plan Team recommended that the arrowtooth flounder assessment bring forward a model that explores selectivity shapes for both the survey and the fishery, including a model with non-parametric selectivity-by-age as an alternative to the logistic model. For the selectivity-by-age model, the weightings used in the smoothing penalties should also be explored.

Authors' response: The 2014 BSAI arrowtooth assessment is based on the author's preferred model, which incorporates non-parametric fisheries selectivity as an alternative to the logistic model, as well as the Stark (2011) female maturity values. The logistic model is compared with the non-parametric fishery selectivity model and results of the logistic model are included in the Appendix. Weightings used in the smoothing penalties are also explored in Appendix.

Introduction

Arrowtooth flounder (*Atheresthes stomias*) is a relatively large flatfish that is found throughout the BSAI management area. Their abundance is approximately six times higher in the eastern Bering Sea than in the Aleutian Islands region. Spawning occurs in deep water in the Gulf of Alaska and along the shelf break in the eastern Bering Sea. 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 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 (Figure 6.1)

Arrowtooth flounder begin to recruit to the continental 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 and 1991 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.

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 in 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 6.2). Until about 1992, these species were not consistently separated in trawl survey catches and were combined in the arrowtooth flounder stock assessment. The species complex was split 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 and separate assessments began in 2010.

Arrowtooth flounder has remained lightly exploited with catches (extrapolated for arrowtooth only) averaging 14,447 t from 1976-2014. 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. The estimated proportion of Kamchatka flounder in the combined catch of arrowtooth and Kamchatka are shown in Table 6.2 through 2007, while Table 6.1 provides catch estimates for arrowtooth only. Total catch reported through October 13, 2014 is 18,119 t (below the 2014 TAC of 25,000 t). The NMFS AKRO BLEND/Catch Accounting System reports indicate that bottom trawling accounted for 95% of the 2014 catch (3% 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 1985-2014 are shown in Table 6.2, and include Kamchatka flounder as well as arrowtooth flounder through 2007. With the implementation Amendment 80 in 2008, the percentage of arrowtooth flounder retained in catches has increased to 89% in 2014. The largest discard amounts occur in the Pacific cod fishery and the various 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 Bering Sea shelf, 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 NFMS survey. It is used in the model for each year unless age composition data is available.

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

Fishery:
Fishery catch data from 1976 - October 13, 2014 (Table 6.1) and fishery length-frequency data from 1978-2014 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 2007-2014. For 1976-2006 the annual arrowtooth flounder catch is 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 have 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 6.3. 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	1997	3,914
1979	6,565	1998	3,819
1980	9,945	1999	3,974
1981	7,790	2000	1,415
1982	36,784	2001	2,984
1983	31,955	2002	2,404
1984	23,189	2003	3,565
1985	25,817	2004	4,367
1986	14,399	2005	2,689
1987	24,066	2006	2,143
1988	833	2007	601
1989	224	2008	1,422
1990	3,831	2009	557
1991	10,179	2010	922
1992	816	2011	887
1993	1,570	2012	529
1994	410	2013	643
1995	3,098	2014	156
1996	1,185		

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 Table 6.3.

Survey:
The relative abundance of arrowtooth flounder increased substantially on the continental shelf from 1982 to 1990 as the CPUE from AFSC shelf surveys increased steadily from 1.6 to 9.9 kg/ha (Figure 6.1). 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 fairly consistent from 2003-2014 (between 8-11 kg/ha), although the 2005 CPUE of 15.39 kg/ha was the highest ever estimated from the shelf survey. The 2014 survey estimates for the shelf and Aleutian Islands survey are slightly up from 2012 estimates (Figure 6.4).

Biomass estimates (t) for arrowtooth flounder from the standard survey area in the eastern Bering Sea and Aleutian Islands region are shown in Table 6.4. Table 6.3 lists the total research catch of these species. 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. Since 1982, biomass point estimates indicate that arrowtooth abundance has increased eight-fold to a high of 570,600 t in 1994. The population biomass remained at a high level from 1992-97. Results from the 1997-2000 bottom trawl surveys indicate the Bering Sea shelf population biomass had declined to 340,000 t, 60% of the peak 1994 biomass point estimate. Beginning in 2002 the shelf survey estimate increased again and peaked in 2005 at a biomass of 722,209 t. In 2006 - 2007 the estimates declined slightly but remained at high levels, between 400,000 t – 550,000 t through 2014. Survey biomass estimates were all lower in 2012 than in previous years. The 2012 shelf survey estimate of 445,736 t (s.e. 43,514) was the lowest since 2002. Similarly, the 2012 Aleutian Islands survey estimate of 60,371 t (s.e. 10,118) was the lowest since 1994, and the slope survey estimate of 73,676 t (s.e. 8199) was the lowest since 2004. The 2014 estimates of biomass on the EBS shelf and Aleutian Islands were slightly higher, 465,616 t (s.e. 32,255) for the shelf and 75,958 t (s.e. = 11,055) for the Aleutians (Figure 6.4).

Trawl surveys were intermittently conducted over the continental slope (1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010 and 2012). 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).

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 a length-based approach where survey and fishery length composition observations are used to calculate estimates of population numbers-at-age by the use of a length-age (growth) matrix. The model simulates the dynamics of the population and compares the expected values of the population characteristics to those observed from surveys and fishery sampling programs. 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 6.5).

The age-structured assessment model is similar to the model used for the 2012 and 2013 assessments. The 2014 model implemented two changes based on Plan Team and SSC comments. First, fishery selectivity is estimated non-parametrically rather than using a 2-parameter logistic function as was done in past models. Separate fishery selectivities were estimated non-parametrically for each age, and the shape of the selectivity curve was constrained to be a monotonic, smooth function. The non-parametric method for estimating fishery selectivity results in a lower Akaike information criterion (AIC) when applied to the BSAI model, and is therefore the preferred model. The Appendix to this stock assessment provides details on the model when logistic fishery selectivity is applied, and provides a comparison between the two methods. The second change was the addition of a likelihood component for Aleutian Islands age data that had not been included in the past.

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:

Sex	Sample size	Age range	L_{inf}	k	t_o
<u>1982 age sample</u>					
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
<u>1991 age sample</u>					
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 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 6.6.

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, 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 6.1) 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 6.5).

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	Selectivity	Temp-q	Year class strength	Total
40	58	5	59	162

The recruitment parameters are comprised of 21 initial ages in 1976 and 39 subsequent age sex-specific recruitment estimates from 1976-2014. Recruitment in 2014 was set at the average from 1976-2009. 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 76% shelf, 10% slope and 14% 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.

Parameters Estimated Conditionally

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 6.5 and Table 6.7).

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 6.8). A large emphasis (300) was placed on the catch likelihood component.

Selectivity and sex ratio

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 freely estimated for males and females in the shelf survey. We assumed an asymptotic selectivity pattern for both sexes in the slope surveys and the Aleutian Islands surveys.

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 6.6). 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

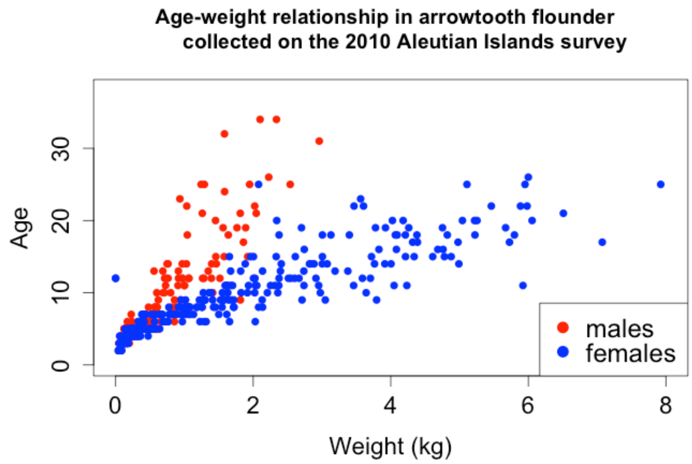
In September 2014, the BSAI Plan Team recommended that the arrowtooth flounder assessment bring forward a model that explores selectivity shapes for both the survey and the fishery, including a model with non-parametric selectivity-by-age as an alternative to the logistic model. For the selectivity-by-age model, the weightings used in the smoothing penalties should also be explored. Both types of fishery selectivity were explored, and the criterion to determine the best model was the Akaike Information Criterion (AIC; Akaike 1974). The method used to calculate AIC is described in the Appendix.

The non-parametric method for estimating fishery selectivity adds 38 new parameters to the model, but results in a lower AIC, 9,818 for the non-parametric model vs. 9,990 for the logistic method (Table A2). However, the effective number of parameters may be smaller than 38 due to the non-parametric method applied. If this were the case, the AIC would still be lower with the non-parametric method; therefore, the authors prefer the non-parametric model. Logistic fisheries selectivity results are presented in the Appendix. Parameter estimates of selectivity using the non-parametric method are shown in Table 6.9 and Figure 6.8. Age-specific selectivity estimated by the model (Table 6.9, Figure 6.8) indicate that arrowtooth flounder are 50% selected by the fishery at about 6 years for females and 6.5 years for females. Selectivity increases to its highest level of 100% for males at age 9 and age 8 for females, before declining to 69% for females and 67% for females at age 21.

In this year's assessment, model runs were made using the shelf and slope surveys and Aleutian Islands survey data with female natural mortality fixed at 0.2 and male natural mortality fixed at 0.35. The BSAI data analyzed with the current model configuration indicates that male M most likely ranges between 0.27 and 0.36. Lower values in this range do not provide estimates of maximum selectivity and sex ratio which would be expected with the differential sex-specific natural mortality hypothesis. The run with male M = 0.35 is the preferred run since it provides a reasonable fit to all the data components and is consistent with the hypothesis that differences in sex ratios observed from trawl surveys are the result of differential sex-specific natural mortality and not availability. These male and female natural mortality values are also used in the Gulf of Alaska stock assessment, an assessment with age data from eight surveys, which may provide more precise estimates.

As in past years, it is important to evaluate the value of the maximum male selectivity on the shelf because estimates of this value at a level well less than 1.0 indicate that the sex ratio observed in the surveys are a result of a difference in male and female capture behavior or availability to the survey trawls and not the result of differential sex-specific natural mortality. The current year estimate of maximum male shelf selectivity was approximately 0.8, compared to 1.0 for females (Figure 6.8). This is lower than in past years, and may suggest low male selectivity rather than high natural morality.

In the past, age data from the Gulf of Alaska and the Bering Sea shelf indicated that the maximum age of males was lower than females. This result is what would be expected in age compositions from a population with a higher M for males than females (Turnock et al. 2007; Wilderbuer and Turnock 2009). This stock assessment incorporates the first aged sample of Aleutian Island arrowtooth flounder. The sample was collected on the 2010 Aleutian Islands survey, and consisted of 294 females and 183 males. The maximum age of males observed was 34 and females were only observed as old as 26. A similar pattern is seen in Pacific halibut (*hippoglossus stenolepis*); older males are observed in the Western Aleutian Islands but not in the Gulf of Alaska or the Bering Sea shelf (Figure 20 in Stewart et al. 2012). This may suggest either that the males in the Aleutian Islands consist of a distinct stock as arrowtooth from other regions, or that sex-specific mortality is not as discrepant as previously suspected. The issue of sex-specific natural mortality and the discrepancy in age frequencies will be addressed in the next full BSAI arrowtooth flounder assessment.



Time Series Results

This year's model shows a recent trend of increasing female spawning biomass, but a decrease in total biomass (Figure 6.9). The 2014 model estimates similar levels of total biomass as the 2012 assessment through 2004, but indicate slightly lower total biomass subsequent to 2004. This is the first year that the assessment model suggested that total biomass in BSAI arrowtooth flounder may not be increasing.

Estimates indicate that arrowtooth flounder total biomass increased almost four fold from 1976 to the 2009 value of 907,756 t (Figure 6.9, Table 6.10). 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 6.9), largely from the influence of the largest shelf survey biomass estimates ever recorded of 772,998 t in 2005 (Table 6.4) 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 6.4). Female spawning biomass in 2014 is estimated at 527,622 t, which is similar to estimates for the past 5 years (Table 6.10). The model estimates of population numbers by age, year, and sex are given in Table 6.11.

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 6.9). 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. The model indicates an increasing biomass trend on the slope and provides good fits to the 2002, 2004, 2008, 2010, and 2012 trend in survey estimates, but is slightly lower than survey estimates (Figure 6.9). The slope biomass represents a smaller fraction of the total stock and does not fit the 1985 slope survey. The Aleutian Islands survey estimates in 1986 and 2006 were highly variable and were not fit very well by the model but the general trend in this index was fit well.

The model provides reasonable fits to the survey size composition time-series for males and females, which are shown in Figure 6.10. 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 in 1996, 1998, 2004, 2010, as well as the 2010 Aleutian Islands survey (Figure 6.10).

Increases in abundance from 1983-95 were the result of strong year-classes spawned in 1981, 1984, 1987, 1988, and 1989 (Figure 6.11, Table 6.12). 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 posterior distribution of the female spawning biomass estimate for 2014 (Figure 6.12), calculated from mcmc integration of the preferred model run indicates the spawning stock is at a high level and that the estimate is highly certain. A Beverton-Holt fit curve to the estimated spawning biomass-age 1 recruitment estimates was done outside the stock assessment model and is shown in Figure 6.13.

Harvest Recommendations

Arrowtooth flounder have a wide-spread bathymetric distribution in the Bering Sea/Aleutian Islands region and are believed to be at a high level, primarily due to increasing recruitment since 1976-1992 and minimal commercial harvest. **The estimate of projected 2015 total biomass from the stock assessment projection model is 908,379 t (95% CI: 835,653, 981,105) and the female spawning biomass is estimated at 533,731 t (95% CI: 490,186 – 577,276 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 2000-2009 are used to calculate the average equilibrium recruitment. Using the time-series of age 1 recruitment from 1974-2009 from the stock assessment model results in an estimate of $B_{0.40}$ = 231,015 t for 2014. The stock assessment model estimates the 2014 level of female spawning biomass at 632,319 t. Since reliable estimates of *B*, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and $B > B_{0.40}$ (632,319 > 231,015), arrowtooth flounder reference fishing mortality is defined in tier 3a. For the 2014 harvest: F_{ABC} □ $F_{0.40}$ = 0.153 and $F_{OFL} = F_{0.35}$ = 0.180 (full selection F values).

Acceptable biological catch is estimated for 2014 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2014 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 2015 ABC of 80,547 t.**

The overfishing level is estimated for 2015 by applying the $F_{35\%}$ fishing mortality rate and age-specific fishery selectivities to the projected 2013 estimate of age-specific total biomass. **This results in a 2015 OFL of 93,856 t.**

The potential yield of arrowtooth flounder in 2015 is summarized as follows:

F level	Exploitation rate	Potential yield
F_{OFL}	0.180	163,508 t
$F_{0.40}$	0.153	138,982 t

Projected Biomass

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 6.13) 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 6.14 and a phase-plane diagram showing the time-series of FSB estimates relative to the harvest control rule is shown in Figure 6.15. The ABC and TAC values that have been used to manage the combined stock since 1980 are listed in Table 6.14.

Scenario Projections and Two-Year Ahead Overfishing Level

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While

Scenario 6 gives the best estimate of OFL for 2015, it does not provide the best estimate of OFL for 2016, because the mean 2016 catch under Scenario 6 is predicated on the 2015 catch being equal to the 2015 OFL, whereas the actual 2015 catch will likely be less than the 2015 ABC. Therefore, the projection model was re-run with the 2015 and 2016 catch fixed equal to the 2014 catch estimate to calculate the 2016 ABC and OFL.

The 2014 catch through October 13, 2014 was 18,119 t. The total catch in 2014, 2015, and 2016 was estimated to be the same as the 2013 catch of 20,501. Arrowtooth flounder catches have ranged from 20,195-22,379 for the past six full years, between 2008 and 2013, with exception of the high catches of 29,900 t in 2009 and 38,881 t in 2010. These high catches 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 20,501 t in 2013 is a good estimate of future catch.

Year	Catch	ABC	OFL
2015	20,501	80,547	93,856
2016	20,501	78,661	91,663

Ecosystem Considerations

Predators of arrowtooth flounder

Arrowtooth flounder are a high trophic level predator in the Bering Sea, feeding on both benthic and pelagic components of the food web (Figure 6.16). 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 6.17). 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 6.18).

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.

Arrowtooth flounder predation

Arrowtooth flounder are an important ecosystem component as predators. This is particularly relevant as this stock assessment indicates that they are now increasing rapidly in abundance in the eastern Bering Sea. 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 6.19). 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 6.20). 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 6.21).

Analysis of role in the ecosystem

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 6.22) 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 6.23). 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 6.24 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 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).

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 Statement.

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

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Literature cited

Akaike, H. 1974. A new look at the statistical model identification, IEEE Transactions on Automatic Control. 19(6): 716-723 doi:10.1109/TAC.1974.1100705, MR 0423716.

Blood, D., Matarese, A., and Busby, M. 2007. Spawning, egg development, and early life history dynamics of arrowtooth flounder (*Atheresthes stomias*) in the Gulf of Alaska. NOAA Professional Paper NMFS 7, 28 p.

Cullenberg, P. 1995. Commercialization of arrowtooth flounder. The Next Step. Proceedings of the International Symposium on North Pacific Flatfish (1994: Anchorage, Alaska). pp623-630.

De Forest, L., Duffy-Anderson, J. , Heintz, R., Matarese, A., Siddon, E., Smart, T., and Spies, I. Ecology and taxonomy of the early life stages of arrowtooth flounder (*Atheresthes stomias)* and Kamchatka flounder (*A. evermanni)* in the eastern Bering Sea, Bering Sea 3rd Special Volume (BSIERP project).

Greene, D. H. and J. K. Babbit. 1990. Control of muscle softening and protease-parasite interactions in arrowtooth flounder, *Atheresthes stomias*. J. Food Sce. 55(2): 579-580.

Haflinger, K. 1981. A survey of benthic infaunal communities of the Southeastern Bering Sea shelf. *In* Hood and Calder (editors) The Eastern Bering Sea Shelf: Oceanography and Resources, Vol. 2. P. 1091-1104. Office Mar. Pol. Assess., NOAA. Univ. Wash. Press, Seattle, Wa 98105.

Hunt, G. L., Jr., Coyle, K., Eisner, L., Farley, E., Heintz, R., Mueter, F., Napp, J,. Overland., J., Ressler, P,. Salo. S., Stabeno, P. 2011. Climate impacts on eastern Bering Sea foodwebs: a synthesis of new data and an assessment of the Oscillating Control Hypothesis. ICES Journal of Marine Science, 68(6): 1230-1243, doi:10.1093/icesjms/fsr036.

Okada K., H. Yamaguchi, T. Sasaki, and K. Wakabayashi. 1980. Trends of groundfish stocks in the Bering Sea and the northeastern Pacific based on additional preliminary statistical data in 1979. Unpubl. Manuscr., 37 p. Far Seas Fish. Res. Lab., Japan Fish. Agency.

Porter, R. W., B. J. Kouri and G. Kudo, 1993. Inhibition of protease activity in muscle extracts and surimi from Pacific Whiting, Merluccius productus, and arrowtooth flounder, *Atheresthes stomias*. Mar. Fish. Rev. 55(3):10-15.

Reppond, R. W., D. H. Wasson, and J. K. Babbitt. 1993. Properties of gels produced from blends of arrowtooth flounder and Alaska pollock surimi. J. Aquat. Food Prod. Technol., vol. 2(1): 83-98.

Somerton, D. A., and P. Munro. 2001. Bridle efficiency of a survey trawl for flatfish. Fish. Bull. 99:641-652(2001).

Somerton, D., Munro, P., and Weinberg, K. 2007. Whole gear efficiency of a benthic survey trawl for flatfish. Fish. Bull. 105: 278-291.

Stark, J. 2011. Female maturity, reproductive potential, relative distribution, and growth compared between arrowtooth flounder (*Atheresthes stomias*) and Kamchatka flounder (*A. evermanni*) indicating concerns for management. Journal of Applied Ichthyology. 28(2) 226-230. doi: 10.1111/j.1439-0426.2011.01885.x.

Stewart, I., Leaman, B., Martell, S., Webster, R. 2012. Assessment of the Pacific halibut stock at the end of 2012. IPHC Report of Assessment and Research Activities. http://www.iphc.int/publications/rara/2012/rara2012093_assessment.pdf.

Turnock, B. J., T. K. Wilderbuer and E. S. Brown. 2007. Arrowtooth flounder. In Stock Assessment and Fishery Evaluation Report for the 2007 Gulf of Alaska Groundfish Fishery. Gulf of Alaska

Groundfish Plan Team, North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, AK 99510.

Wasson, D. H., K. D. Reppond, J. K. Babbitt and J. S. French. 1992. Effects of additives on proteolytic and functional properties of arrowtooth flounder surimi. J. Aquat. Food Prod. Technol., vol. 1(3/4):147-165.

Wilderbuer, T. K., and T. M. Sample. 1995. Arrowtooth flounder. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 1991, p.129-141. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage Alaska 99510.

Wilderbuer, T. K., and T. M. Sample. 2002. Arrowtooth flounder. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 2003, p.283-320. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage Alaska 99510.

Wilderbuer, T. K., A. B. Hollowed, W. J. Ingraham, Jr., P. D. Spencer, M. E. Conners, N. A. Bond, and G. E. Walters. Flatfish recruitment response to decadal climate variability and ocean conditions in the eastern Bering Sea. Progress Oceanography 55 (2002) 235-247.

Wilderbuer, T. K., and B. J. Turnock. 2009. Sex-specific natural mortality of arrowtooth flounder in Alaska: Implications of a skewed sex ratio on exploitation and management. NAJFM 29:306-322.

Zimmermann, M., and Pamela G. 1996. Biology and distribution of arrowtooth (*Atheresthes stomias*) and Kamachatka (*A. evermanni*) flounders in Alaskan waters. Fishery Bulletin 94: 358-370.

Zimmermann, Mark. 1997. Maturity and fecundity of arrowtooth flounder, *Atheresthes stomias*, from the Gulf of Alaska. Fish Bull. 95:598-611.

Tables

Table 6.1. All nation total combined catch (t) of arrowtooth and Kamchatka flounder in the eastern Bering Sea and Aleutian Islands region[a], 1970-2014. Totals for arrowtooth (ATF) and Kamchatka are under "Combined" total, extrapolated ATF only is under "ATF est".

	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	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
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										20,195
2012										22,379
2013										20,501
2014**										18,119

[a]Catches from data prior to 1990 are on file 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. *Species-specific estimates of catch available starting in 2008.**Catch information through 13 October, 2014 (NMFS regional office).

Table 6.2. Estimates of retained and discarded arrowtooth flounder catch, and the proportion of arrowtooth flounder in the total catch of 1985-2014. 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	16,126	1,993	18,119	89	-

*1990 retained rate was applied to the 1985-89 reported catch. The 2014 catch is through 10/13/2014.
Source: NMFS AKRO BLEND/Catch Accounting System.

Table 6.3. Total tonnage of the research catch for arrowtooth flounder and Kamchatka flounder through 2007, and for arrowtooth only from 2008 onwards. Data for 1991-2012 is from AKFIN, Noncommercial Fishery Catch (accessed October 15, 2014). Data for 2013, 2014 are incomplete.

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	0

Table 6.4. 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 and 2004 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	61,153	88,750
2003	543,569		
2004	549,338	68,568	94,998
2005	772,988		
2006	670,132		183,836
2007	547,496		
2008	588,342	96,248	
2009	456,371		
2010	586,954	74,065	80,060
2011	568,200		
2012	445,736	73,676	60,371
2013	405,509		
2014	465,616		75,958

Table 6.5. 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

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

Table 6.6. 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 6.7. 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 6.8. Model estimates of arrowtooth flounder fishing mortality and exploitation rate (catch/total biomass).

year	Full selection F	Exploitation rate
1976	0.092	0.066
1977	0.053	0.040
1978	0.043	0.035
1979	0.057	0.047
1980	0.074	0.060
1981	0.070	0.055
1982	0.046	0.037
1983	0.053	0.043
1984	0.035	0.028
1985	0.026	0.021
1986	0.024	0.019
1987	0.015	0.012
1988	0.057	0.045
1989	0.021	0.016
1990	0.034	0.025
1991	0.053	0.040
1992	0.023	0.018
1993	0.019	0.016
1994	0.026	0.023
1995	0.016	0.014
1996	0.025	0.022
1997	0.017	0.015
1998	0.026	0.022
1999	0.018	0.015
2000	0.021	0.018
2001	0.022	0.018
2002	0.018	0.015
2003	0.019	0.016
2004	0.026	0.021
2005	0.019	0.016
2006	0.019	0.016
2007	0.016	0.014
2008	0.028	0.024
2009	0.038	0.033
2010	0.050	0.043
2011	0.027	0.023
2012	0.029	0.025
2013	0.026	0.023
2014	0.026	0.023

Table 6.9. 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	0.01	0.05	0.11	0.00	0.03	0.04	0.08
2	0.02	0.02	0.15	0.17	0.00	0.05	0.08	0.13
3	0.06	0.05	0.41	0.27	0.00	0.08	0.15	0.20
4	0.13	0.11	0.79	0.39	0.00	0.12	0.27	0.29
5	0.26	0.21	1.00	0.55	0.06	0.18	0.43	0.40
6	0.51	0.40	0.96	0.71	0.91	0.27	0.61	0.52
7	0.85	0.67	0.81	0.82	1.00	0.38	0.77	0.64
8	0.95	0.90	0.66	0.84	1.00	0.50	0.87	0.75
9	0.93	1.00	0.52	0.77	1.00	0.63	0.93	0.83
10	0.89	0.99	0.41	0.62	1.00	0.73	0.97	0.89
11	0.84	0.94	0.32	0.46	1.00	0.82	0.98	0.93
12	0.81	0.89	0.24	0.32	1.00	0.88	0.99	0.96
13	0.77	0.84	0.18	0.21	1.00	0.93	1.00	0.97
14	0.75	0.80	0.14	0.14	1.00	0.95	1.00	0.98
15	0.73	0.76	0.10	0.09	1.00	0.97	1.00	0.99
16	0.72	0.73	0.08	0.05	1.00	0.98	1.00	0.99
17	0.71	0.70	0.06	0.03	1.00	0.99	1.00	1.00
18	0.70	0.68	0.04	0.02	1.00	0.99	1.00	1.00
19	0.69	0.67	0.03	0.01	1.00	1.00	1.00	1.00
20	0.69	0.67	0.02	0.01	1.00	1.00	1.00	1.00
21	0.69	0.67	0.02	0.00	1.00	1.00	1.00	1.00

Table 6.10. Model estimates of arrowtooth flounder 1+ total biomass (t) and female spawning biomass (t) from the 2012 and 2014 assessments.

	2012 Assessment		2014 Assessment	
	Total biomass	**Female Spawning biomass**	**Total biomass**	**Female Spawning biomass**
1976	261,843	145,079	269,581	137,913
1977	259,394	135,957	267,323	127,605
1978	265,437	140,201	273,114	128,654
1979	274,039	149,543	281,156	136,179
1980	278,544	155,185	284,669	142,697
1981	282,838	154,787	287,394	144,561
1982	289,105	154,463	291,738	144,598
1983	304,256	160,634	304,652	148,601
1984	319,243	165,944	317,146	152,209
1985	338,135	176,108	333,697	159,777
1986	360,542	190,169	353,901	170,170
1987	389,916	207,577	381,113	182,853
1988	423,607	226,675	412,852	199,211
1989	450,671	231,305	437,638	204,155
1990	491,982	248,134	477,253	216,960
1991	526,128	264,652	510,536	228,980
1992	546,661	279,076	531,547	239,547
1993	571,926	310,864	559,302	263,221
1994	592,011	346,248	583,417	293,761
1995	601,598	371,401	598,051	320,825
1996	614,404	391,549	616,089	345,783
1997	621,046	398,706	627,504	359,496
1998	635,335	404,618	645,562	371,083
1999	649,181	402,715	661,463	375,655
2000	670,513	404,531	683,861	381,405
2001	695,086	407,830	707,317	385,656
2002	721,321	415,548	731,488	391,757
2003	755,958	430,045	761,140	403,703
2004	792,770	448,107	791,072	418,167
2005	827,972	467,148	816,099	431,908
2006	869,734	491,079	845,881	450,913
2007	909,359	516,763	870,942	470,156
2008	948,231	548,056	895,262	491,018
2009	980,823	580,548	907,756	505,908
2010	1,002,620	608,551	905,159	513,829
2011	1,017,650	630,021	889,634	510,566
2012	1,023,890	652,156	888,498	517,672
2013			881,413	522,331
2014			877,781	527,622

Table 6.11. Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

females				**numbers at age (1,000s)**						
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1976	99,854	36,124	88,697	69,612	75,583	29,045	16,248	11,126	8,530	6,963
1977	134,535	81,656	29,478	72,014	56,006	59,784	22,216	11,868	8,018	6,166
1978	97,794	110,071	66,725	24,017	58,363	44,942	47,045	17,019	9,020	6,105
1979	104,931	80,022	89,979	54,416	19,503	47,016	35,638	36,506	13,123	6,965
1980	102,024	85,846	65,381	73,284	44,067	15,627	36,889	27,166	27,593	9,938
1981	233,579	83,451	70,099	53,173	59,168	35,100	12,118	27,571	20,086	20,454
1982	90,140	191,065	68,152	57,029	42,960	47,191	27,291	9,098	20,488	14,961
1983	73,116	73,756	156,172	55,565	46,285	34,572	37,344	21,104	6,988	15,761
1984	215,759	59,820	60,270	127,243	45,033	37,143	27,208	28,612	16,042	5,322
1985	155,957	176,569	48,916	49,190	103,492	36,393	29,639	21,336	22,323	12,531
1986	125,630	127,644	144,428	39,954	40,075	83,913	29,230	23,498	16,851	17,646
1987	390,774	102,826	104,418	117,998	32,568	32,526	67,533	23,252	18,629	13,370
1988	215,315	319,879	84,143	85,379	96,346	26,522	26,350	54,316	18,662	14,958
1989	222,861	176,154	261,356	68,534	69,148	77,209	20,815	20,096	41,078	14,142
1990	159,389	182,415	144,118	213,588	55,896	56,186	62,276	16,620	15,998	32,724
1991	167,744	130,440	149,168	117,634	173,757	45,190	44,872	48,904	12,987	12,515
1992	197,292	137,243	106,591	121,540	95,343	139,455	35,573	34,394	37,192	9,895
1993	158,123	161,480	112,272	87,087	99,075	77,390	112,252	28,306	27,275	29,518
1994	161,020	129,429	132,122	91,768	71,054	80,562	62,511	89,842	22,594	21,785
1995	200,538	131,788	105,869	107,918	74,764	57,612	64,706	49,560	70,958	17,861
1996	261,783	164,153	107,837	86,552	88,088	60,846	46,615	51,938	39,687	56,853
1997	210,862	214,261	134,277	88,091	70,531	71,455	48,914	37,011	41,088	31,423
1998	243,482	172,602	175,316	109,769	71,893	57,384	57,780	39,221	29,604	32,884
1999	321,293	199,281	141,186	143,207	89,441	58,306	46,112	45,845	31,004	23,422
2000	236,170	262,993	163,055	115,410	116,860	72,750	47,125	36,944	36,637	24,792
2001	251,240	193,307	215,157	133,242	94,112	94,924	58,642	37,586	29,375	29,152
2002	298,720	205,639	158,140	175,801	108,632	76,416	76,455	46,711	29,842	23,340
2003	362,206	244,515	168,256	129,266	143,451	88,353	61,751	61,238	37,316	23,855
2004	270,734	296,476	200,056	137,520	105,455	116,619	71,334	49,386	48,840	29,781
2005	186,261	221,586	242,514	163,418	112,055	85,529	93,720	56,608	39,046	38,648
2006	333,811	152,461	181,298	198,220	133,325	91,108	69,073	74,988	45,171	31,177
2007	274,448	273,234	124,740	148,180	161,709	108,389	73,560	55,244	59,809	36,050
2008	234,999	224,652	223,576	101,979	120,949	131,599	87,691	59,034	44,231	47,912
2009	316,645	192,331	183,745	182,585	83,052	97,996	105,546	69,354	46,499	34,872
2010	160,354	259,118	157,251	149,916	148,406	67,030	77,995	82,410	53,848	36,150
2011	173,447	131,201	211,764	128,160	121,574	119,238	52,878	59,997	62,926	41,188
2012	198,602	141,958	107,317	172,966	104,408	98,565	95,752	41,909	47,369	49,726
2013	306,064	162,541	116,105	87,635	140,844	84,568	79,006	75,656	32,974	37,307
2014	409,222	250,499	132,953	94,834	71,395	114,191	67,916	62,625	59,740	26,061

Table 6.11 (cont'd). Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

	females				numbers at age (1,000s)						
	11	12	13	14	15	16	17	18	19	20	21
1976	5,879	5,078	4,432	3,893	3,438	3,042	2,685	2,374	2,076	1,810	4,180
1977	5,060	4,297	3,730	3,269	2,881	2,550	2,261	1,998	1,769	1,548	4,467
1978	4,710	3,878	3,302	2,874	2,524	2,227	1,974	1,751	1,549	1,371	4,664
1979	4,726	3,655	3,017	2,574	2,244	1,973	1,742	1,545	1,372	1,214	4,730
1980	5,293	3,604	2,796	2,314	1,979	1,727	1,520	1,344	1,192	1,059	4,590
1981	7,398	3,958	2,706	2,107	1,748	1,497	1,309	1,153	1,020	906	4,293
1982	15,297	5,557	2,984	2,047	1,597	1,328	1,139	997	879	778	3,965
1983	11,541	11,832	4,309	2,319	1,593	1,245	1,036	889	778	687	3,706
1984	12,040	8,845	9,095	3,320	1,790	1,232	963	802	689	604	3,407
1985	4,165	9,444	6,951	7,159	2,617	1,412	972	761	634	545	3,170
1986	9,921	3,303	7,499	5,526	5,697	2,084	1,125	775	607	505	2,962
1987	14,019	7,893	2,631	5,980	4,410	4,549	1,665	899	619	485	2,773
1988	10,744	11,277	6,354	2,119	4,820	3,556	3,669	1,343	725	500	2,629
1989	11,373	8,197	8,631	4,875	1,630	3,711	2,741	2,831	1,037	560	2,417
1990	11,279	9,082	6,553	6,906	3,904	1,306	2,975	2,198	2,270	832	2,388
1991	25,650	8,859	7,146	5,165	5,449	3,083	1,032	2,352	1,738	1,796	2,548
1992	9,565	19,667	6,812	5,509	3,989	4,214	2,387	799	1,824	1,349	3,370
1993	7,863	7,612	15,671	5,434	4,398	3,186	3,368	1,908	639	1,459	3,774
1994	23,601	6,294	6,099	12,567	4,360	3,531	2,559	2,706	1,533	514	4,205
1995	17,247	18,714	4,998	4,849	10,000	3,472	2,813	2,039	2,157	1,223	3,763
1996	14,324	13,845	15,036	4,019	3,901	8,049	2,795	2,265	1,643	1,738	4,017
1997	45,079	11,374	11,009	11,970	3,202	3,110	6,420	2,231	1,808	1,312	4,595
1998	25,173	36,150	9,130	8,844	9,621	2,575	2,502	5,166	1,795	1,455	4,754
1999	26,055	19,976	28,728	7,264	7,042	7,666	2,053	1,995	4,121	1,433	4,955
2000	18,748	20,877	16,022	23,059	5,834	5,659	6,163	1,651	1,605	3,315	5,138
2001	19,751	14,955	16,673	12,808	18,447	4,670	4,531	4,936	1,322	1,286	6,774
2002	23,193	15,734	11,928	13,312	10,234	14,749	3,735	3,626	3,951	1,059	6,452
2003	18,677	18,578	12,616	9,572	10,690	8,222	11,853	3,003	2,915	3,177	6,040
2004	19,058	14,938	14,876	10,111	7,676	8,576	6,599	9,516	2,411	2,341	7,403
2005	23,600	15,126	11,873	11,836	8,052	6,117	6,838	5,264	7,593	1,924	7,777
2006	30,892	18,886	12,117	9,519	9,496	6,463	4,912	5,492	4,228	6,101	7,795
2007	24,910	24,710	15,122	9,711	7,634	7,619	5,187	3,944	4,411	3,396	11,161
2008	28,906	19,993	19,850	12,157	7,811	6,143	6,133	4,177	3,176	3,553	11,725
2009	37,836	22,866	15,839	15,746	9,653	6,207	4,884	4,878	3,323	2,528	12,160
2010	27,171	29,548	17,895	12,418	12,362	7,586	4,881	3,843	3,840	2,617	11,567
2011	27,732	20,907	22,800	13,840	9,621	9,590	5,891	3,794	2,989	2,988	11,036
2012	32,597	21,983	16,597	18,121	11,010	7,659	7,638	4,694	3,024	2,383	11,181
2013	39,228	25,760	17,400	13,154	14,377	8,742	6,084	6,071	3,732	2,405	10,786
2014	29,529	31,100	20,452	13,831	10,465	11,446	6,963	4,849	4,839	2,976	10,518

Table 6.11 (cont'd). Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

males	numbers at age (1,000s)								
	1	2	3	4	5	6	7	8	9	10
1976	99,854	31,092	65,708	44,386	41,481	13,720	6,606	3,894	2,569	1,805
1977	134,535	70,267	21,841	45,984	30,829	28,399	9,158	4,255	2,431	1,582
1978	97,794	94,728	49,425	15,329	32,132	21,363	19,390	6,125	2,794	1,584
1979	104,931	68,869	66,654	34,716	10,729	22,338	14,676	13,100	4,077	1,848
1980	102,024	73,878	48,435	46,767	24,244	7,425	15,216	9,776	8,557	2,641
1981	233,579	71,814	51,930	33,943	32,578	16,695	5,011	9,981	6,254	5,416
1982	90,140	164,425	50,485	36,402	23,658	22,459	11,290	3,298	6,415	3,979
1983	73,116	63,476	115,685	35,453	25,467	16,432	15,404	7,607	2,188	4,227
1984	215,759	51,482	44,648	81,194	24,774	17,648	11,221	10,302	4,996	1,426
1985	155,957	151,962	36,235	31,381	56,904	17,269	12,184	7,643	6,935	3,346
1986	125,630	109,857	106,990	25,485	22,024	39,775	11,985	8,371	5,205	4,705
1987	390,774	88,498	77,353	75,263	17,893	15,407	27,648	8,256	5,722	3,546
1988	215,315	275,313	62,333	54,451	52,918	12,553	10,766	19,212	5,709	3,948
1989	222,861	151,597	193,628	43,736	38,028	36,627	8,553	7,175	12,557	3,700
1990	159,389	156,999	106,755	136,240	30,723	26,628	25,505	5,909	4,923	8,591
1991	167,744	112,262	110,507	75,038	95,500	21,423	18,397	17,393	3,984	3,303
1992	197,292	118,112	78,965	77,562	52,439	66,185	14,631	12,308	11,428	2,597
1993	158,123	138,980	83,166	55,549	54,460	36,687	46,012	10,082	8,415	7,787
1994	161,020	111,396	97,876	58,525	39,033	38,157	25,576	31,850	6,935	5,773
1995	200,538	113,424	78,430	68,838	41,074	27,283	26,482	17,573	21,692	4,705
1996	261,783	141,283	79,885	55,202	48,387	28,800	19,046	18,373	12,126	14,933
1997	210,862	184,406	99,475	56,189	38,749	33,834	20,001	13,101	12,532	8,241
1998	243,482	148,554	129,873	70,010	39,491	27,162	23,608	13,865	9,030	8,617
1999	321,293	171,512	104,593	91,346	49,140	27,609	18,858	16,230	9,451	6,132
2000	236,170	226,351	120,790	73,608	64,194	34,439	19,257	13,065	11,178	6,492
2001	251,240	166,373	159,391	84,984	51,700	44,938	23,969	13,294	8,954	7,637
2002	298,720	176,986	117,151	112,134	59,679	36,180	31,257	16,530	9,099	6,109
2003	362,206	210,448	124,644	82,445	78,800	41,822	25,231	21,650	11,380	6,248
2004	270,734	255,169	148,203	87,710	57,926	55,201	29,146	17,455	14,881	7,801
2005	186,261	190,710	179,658	104,239	61,564	40,498	38,327	20,040	11,900	10,108
2006	333,811	131,219	134,305	126,427	73,243	43,132	28,229	26,525	13,782	8,161
2007	274,448	235,165	92,408	94,509	88,828	51,309	30,059	19,530	18,233	9,448
2008	234,999	193,352	165,626	65,040	66,431	62,280	35,815	20,852	13,474	12,550
2009	316,645	165,531	136,122	116,470	45,633	46,405	43,173	24,561	14,164	9,115
2010	160,354	223,005	116,494	95,648	81,583	31,773	31,973	29,309	16,458	9,438
2011	173,447	112,913	156,877	81,782	66,872	56,591	21,737	21,452	19,331	10,776
2012	198,602	122,177	79,496	110,332	57,394	46,738	39,269	14,931	14,605	13,111
2013	306,064	139,891	86,012	55,899	77,400	40,082	32,384	26,908	10,132	9,869
2014	409,222	215,594	98,491	60,492	39,230	54,098	27,815	22,247	18,322	6,873

Table 6.11 (cont'd). Estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

males				numbers at age (1,000s)							
	11	12	13	14	15	16	17	18	19	20	21
1976	1,312	975	733	554	421	321	244	185	140	105	128
1977	1,114	814	609	461	351	268	205	156	119	90	150
1978	1,032	729	535	402	305	233	178	137	104	80	160
1979	1,048	685	485	357	269	205	157	120	92	71	162
1980	1,199	682	448	319	235	178	136	104	80	61	155
1981	1,674	763	437	288	206	153	116	89	68	52	142
1982	3,450	1,071	491	282	187	134	100	76	58	45	128
1983	2,624	2,281	711	327	189	125	90	67	51	39	116
1984	2,757	1,717	1,499	469	216	125	83	60	45	34	104
1985	955	1,852	1,156	1,012	317	147	85	57	41	31	94
1986	2,271	650	1,261	789	692	217	101	58	39	28	86
1987	3,206	1,550	444	864	541	475	149	69	40	27	79
1988	2,447	2,215	1,072	307	599	375	330	104	48	28	73
1989	2,562	1,594	1,449	704	203	396	249	219	69	32	67
1990	2,532	1,755	1,094	996	484	140	273	172	151	48	69
1991	5,767	1,704	1,184	739	675	329	95	186	117	103	79
1992	2,155	3,776	1,120	781	490	448	219	63	124	78	122
1993	1,770	1,471	2,582	767	536	336	308	151	44	86	138
1994	5,344	1,217	1,012	1,779	529	370	232	213	104	30	155
1995	3,919	3,634	829	691	1,216	362	254	160	146	72	127
1996	3,240	2,701	2,508	573	478	842	251	176	111	102	138
1997	10,153	2,207	1,843	1,714	392	328	578	172	121	76	165
1998	5,668	6,991	1,521	1,272	1,184	271	227	400	120	84	167
1999	5,854	3,857	4,766	1,039	870	811	186	156	275	82	172
2000	4,214	4,027	2,657	3,287	717	602	561	129	108	191	176
2001	4,438	2,884	2,761	1,824	2,260	494	414	387	89	74	253
2002	5,213	3,033	1,974	1,893	1,253	1,554	340	286	267	61	226
2003	4,196	3,584	2,088	1,361	1,307	865	1,075	235	198	185	199
2004	4,284	2,881	2,464	1,438	938	902	598	743	163	137	266
2005	5,301	2,916	1,964	1,683	984	643	619	411	510	112	277
2006	6,935	3,641	2,006	1,353	1,161	679	444	428	284	353	269
2007	5,597	4,761	2,503	1,381	933	801	469	307	296	196	430
2008	6,504	3,857	3,285	1,729	955	646	555	325	213	205	435
2009	8,494	4,410	2,621	2,237	1,180	652	442	380	223	146	439
2010	6,078	5,678	2,956	1,762	1,507	797	441	299	258	151	397
2011	6,185	3,996	3,747	1,958	1,171	1,004	532	295	201	173	368
2012	7,311	4,204	2,721	2,556	1,338	801	688	365	203	138	372
2013	8,864	4,952	2,853	1,851	1,742	913	548	471	250	139	349
2014	6,697	6,025	3,373	1,947	1,265	1,192	626	376	323	172	335

Table 6.12. Estimated age 2 recruitment of arrowtooth flounder (thousands of fish) from the 2012 and 2014 stock assessments. Average over all years from 2014 assessment = 312,040.

Year class	2012 Assessment	2014 Assessment
1974	230,069	67,217
1975	297,213	151,923
1976	245,370	204,799
1977	260,994	148,890
1978	466,116	159,724
1979	278,861	155,265
1980	279,797	355,490
1981	295,261	137,232
1982	261,457	111,302
1983	512,622	328,531
1984	300,425	237,501
1985	424,330	191,324
1986	454,913	595,192
1987	228,364	327,751
1988	469,933	339,414
1989	570,669	242,702
1990	346,025	255,355
1991	608,477	300,460
1992	709,081	240,825
1993	533,246	245,212
1994	590,261	305,436
1995	484,687	398,667
1996	422,013	321,156
1997	461,524	370,793
1998	440,673	489,344
1999	501,638	359,680
2000	439,534	382,625
2001	375,534	454,963
2002	369,206	551,645
2003	381,796	412,296
2004	327,427	283,680
2005	322,479	508,399
2006	346,488	418,004
2007	389,187	357,862
2008		482,123
2009		244,114

Table 6.13. 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
2014	530,889	20,501	0.04
2015	529,660	80,547	0.15
2016	481,674	72,088	0.15
2017	434,751	65,261	0.15
2018	393,679	61,202	0.15
2019	363,823	59,752	0.15
2020	345,632	58,859	0.15
2021	333,040	56,342	0.15
2022	319,430	53,281	0.15
2023	303,991	50,558	0.15
2024	288,928	48,317	0.15
2025	275,621	46,516	0.15
2026	264,416	45,092	0.15
2027	255,232	43,929	0.15

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2014	530,889	20,501	0.04
2015	532,426	40,274	0.07
2016	516,863	16,421	0.03
2017	512,701	16,157	0.03
2018	506,844	16,215	0.03
2019	505,637	16,682	0.03
2020	512,311	17,212	0.03
2021	522,832	17,288	0.03
2022	529,326	17,076	0.03
2023	529,092	16,783	0.03
2024	524,371	16,476	0.03
2025	517,530	16,181	0.03
2026	509,885	15,918	0.03
2027	501,982	15,689	0.03

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2014	530,889	20,501	0.04
2015	533,135	29,601	0.05
2016	523,538	41,138	0.08
2017	500,033	39,036	0.08
2018	476,545	37,953	0.08
2019	459,612	38,022	0.08
2020	451,787	38,306	0.08
2021	448,433	37,586	0.08
2022	442,331	36,347	0.08
2023	431,756	35,092	0.08
2024	419,113	33,957	0.08
2025	406,455	32,969	0.08
2026	394,710	32,152	0.08
2027	384,140	31,485	0.08

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2014	530,889	20,501	0.04
2015	535,049	0	0
2016	549,429	0	0
2017	558,020	0	0
2018	563,313	0	0
2019	571,716	0	0
2020	587,151	0	0
2021	606,195	0	0
2022	620,630	0	0
2023	627,061	0	0
2024	627,533	0	0
2025	624,574	0	0
2026	619,717	0	0
2027	613,636	0	0

Table 6.13 (continued).

Scenario 6
Determination of whether arrowtooth flounder are currently overfished
B35=194,267

Year	Female spawning biomass	catch	F
2014	530,889	20,501	0.04
2015	528,711	93,856	0.18
2016	470,597	82,316	0.18
2017	416,041	73,232	0.18
2018	369,729	67,770	0.18
2019	336,388	65,546	0.18
2020	315,620	64,041	0.18
2021	300,848	60,765	0.18
2022	285,649	57,029	0.18
2023	269,447	53,818	0.18
2024	254,310	51,231	0.18
2025	241,395	48,907	0.18
2026	231,059	46,835	0.18
2027	223,233	45,190	0.17

Scenario 7
Determination of whether arrowtooth flounder are approaching an overfished condition
B35=194,267

Year	Female spawning biomass	catch	F
2014	530,889	20,501	0.04
2015	529,660	80,547	0.15
2016	481,673	72,088	0.15
2017	433,982	76,071	0.18
2018	384,850	70,023	0.18
2019	348,817	67,309	0.18
2020	325,635	65,401	0.18
2021	308,778	61,798	0.18
2022	291,825	57,804	0.18
2023	274,186	54,395	0.18
2024	257,898	51,667	0.18
2025	244,075	49,305	0.18
2026	232,990	47,176	0.18
2027	224,564	45,448	0.17

Table 6.14. TAC and ABC used to manage the BSAI arrowtooth flounder complex since 1980.

	arowtooth flounder	
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

Figures

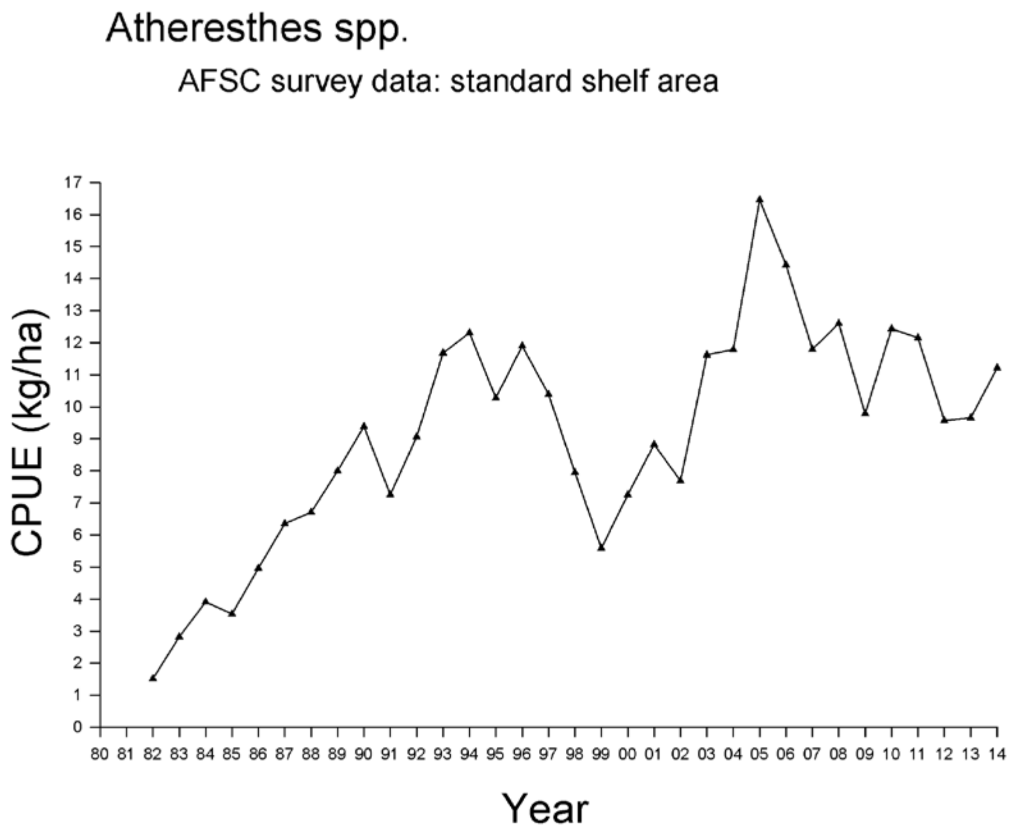

Figure 6.1. Arrowtooth flounder CPUE (kg/ha) from the standard shelf survey area (1982-1992) and standard shelf survey area including Northwestern stratum 82 and 90 (1993-2012).

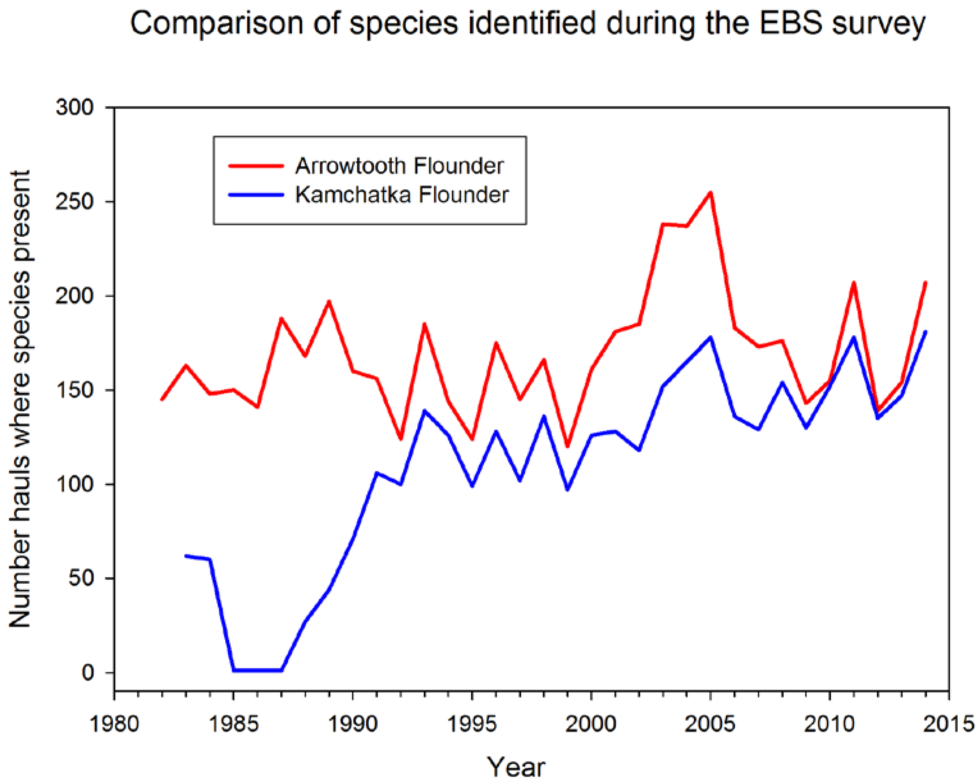

Figure 6.2. Number of hauls where arrowtooth flounder and Kamchatka flounder were identified during the annual Bering Sea shelf surveys, 1982-2014, within the standard survey area.

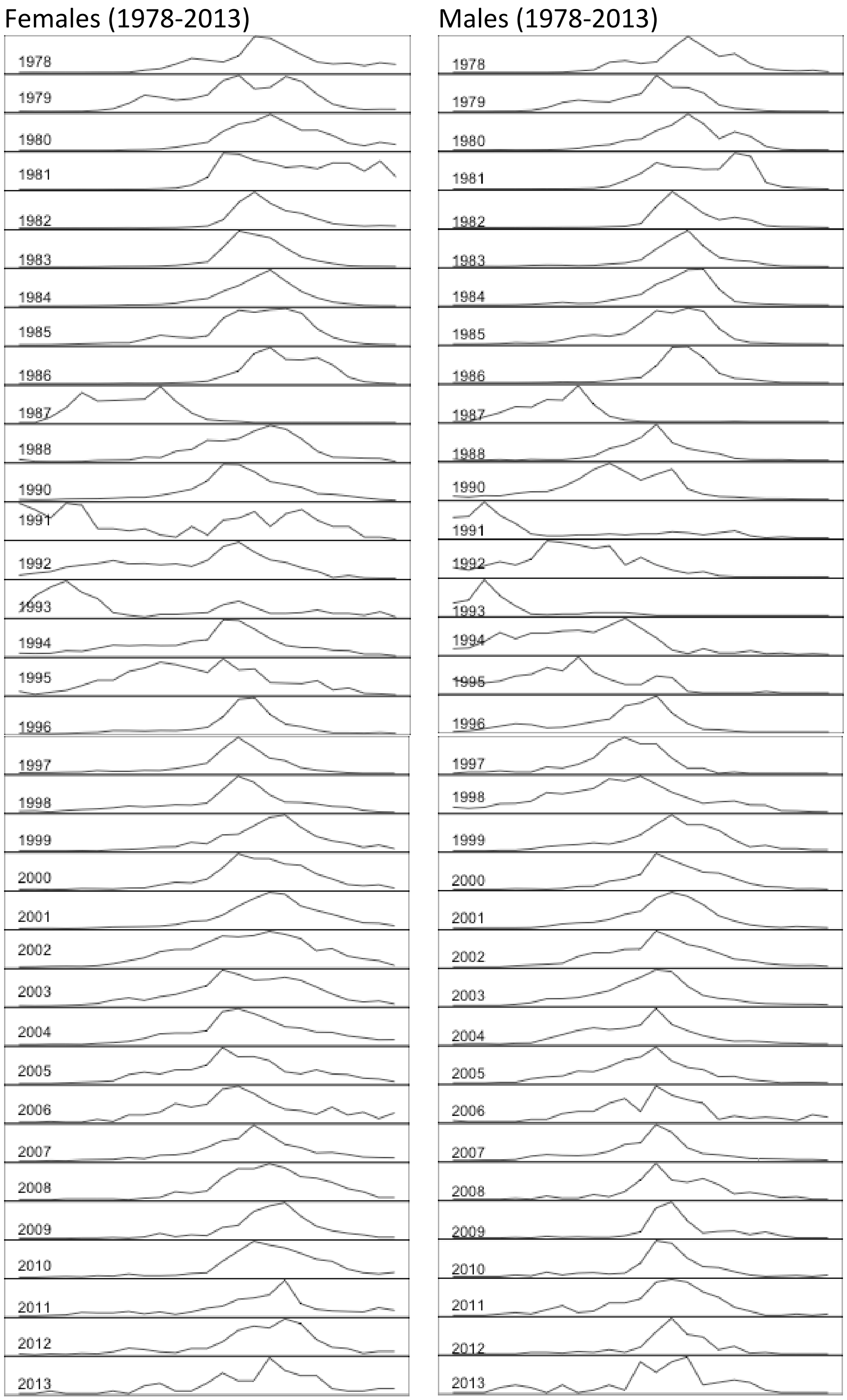

Figure 6.3. Size composition of arrowtooth flounder from the fishery data 1976-2013.

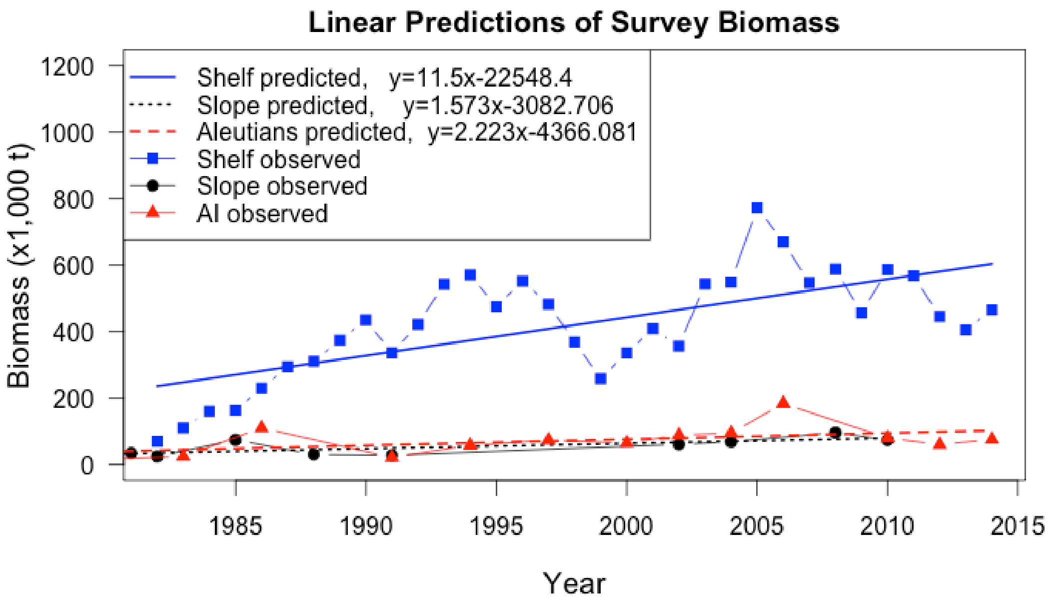

Figure 6.4. Linear regressions of trawl survey estimates for the Bering Sea shelf, slope and the Aleutian Islands used to estimate the proportion of biomass in each area.

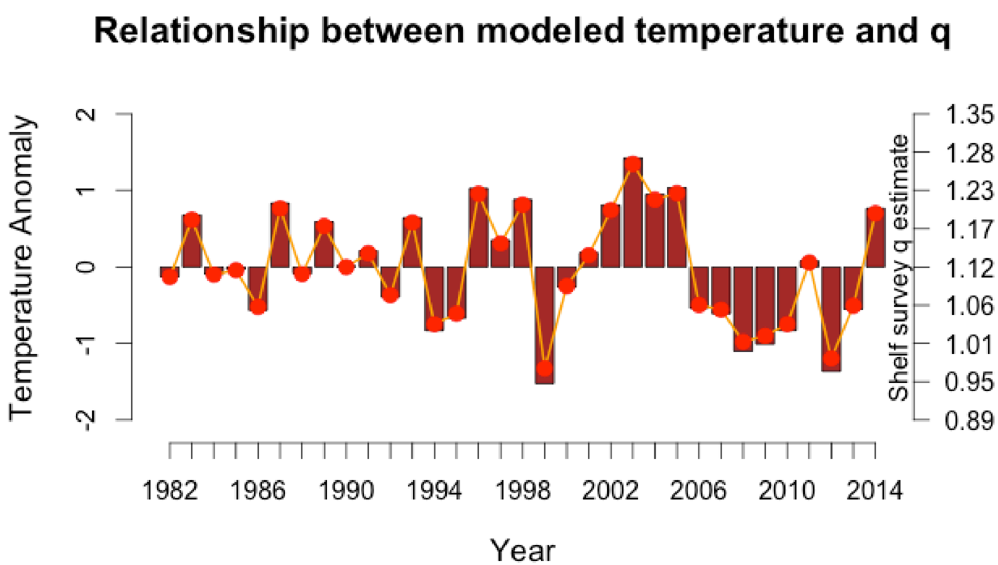

Figure 6.5. Shelf survey annual avg. bottom temperature anomalies (bars), model estimate of annual shelf survey q due to effect of water temperature (circles with lines).

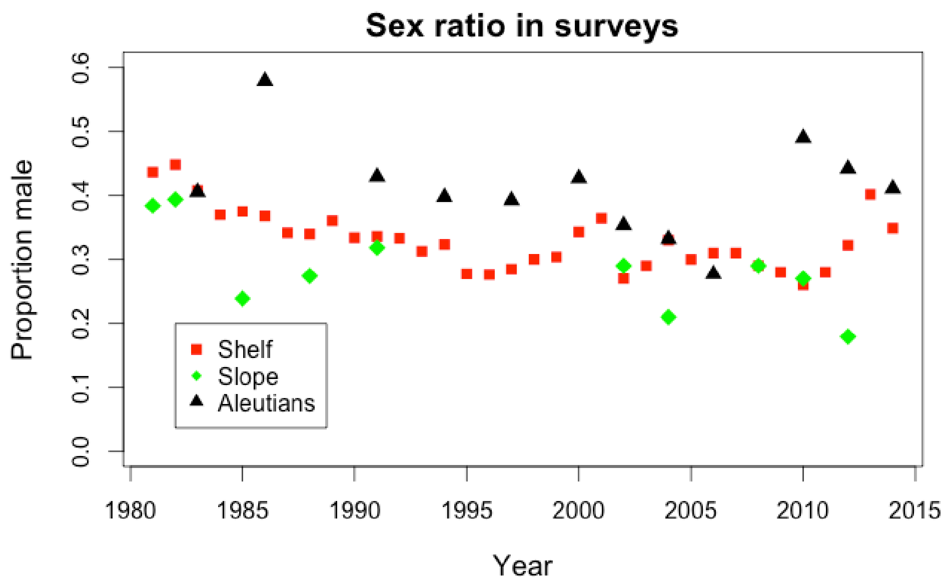

Figure 6.6. Proportion of the estimated male population from Bering Sea and Aleutian Islands trawl surveys on the continental shelf and slope.

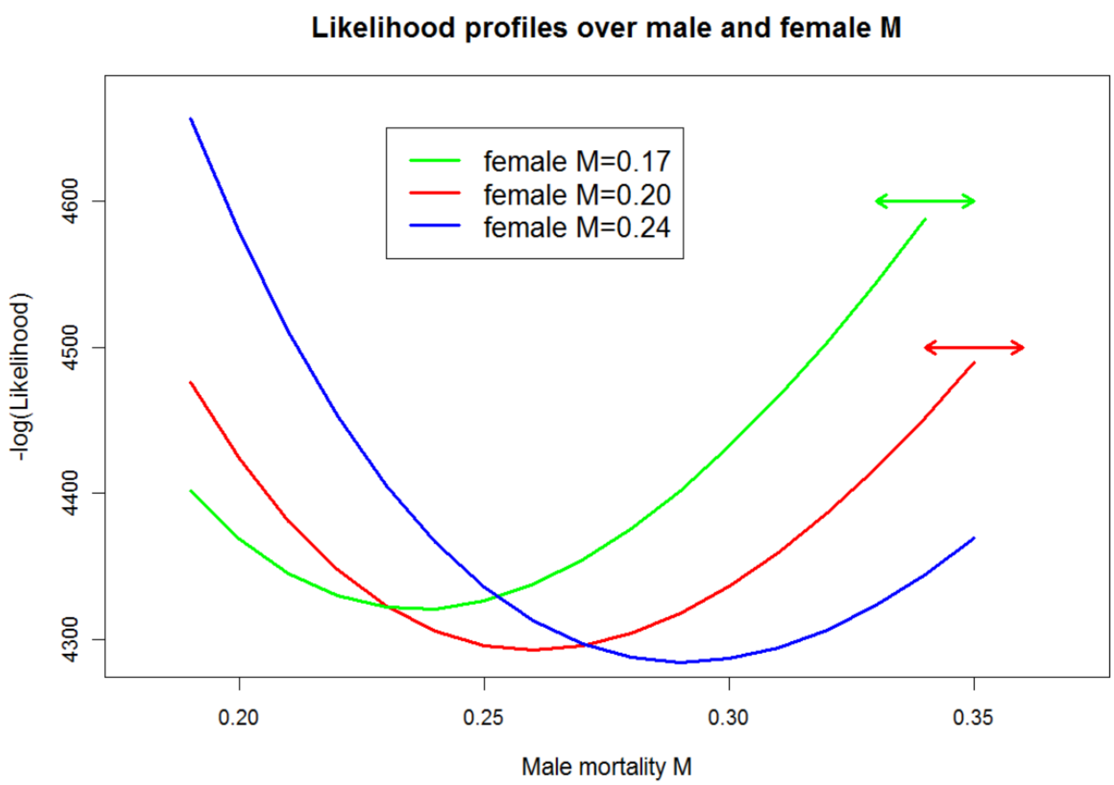

Figure 6.7. Fit to the stock assessment model in terms of –log(likelihood) when profiling over male natural mortality (x axis) for three different levels of female natural mortality. Arrows indicate the values of male natural mortality where the model estimates that maximum male selectivity is close to 1.0 for a given combination of male and female natural mortality.

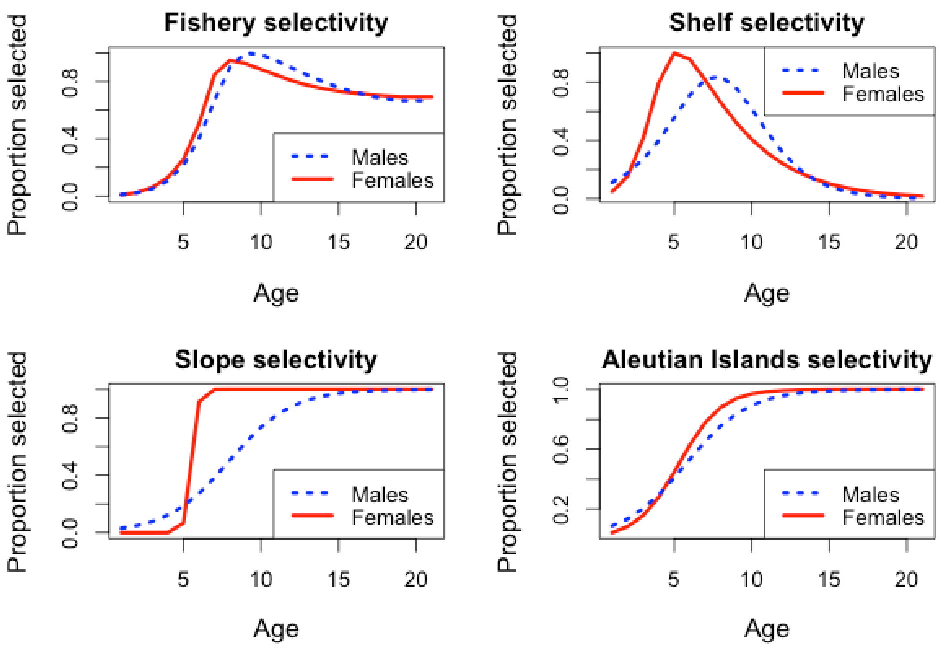

Figure 6.8. Age-specific fishery selectivity (top left panel), shelf survey selectivity (top right panel) slope survey selectivity (bottom left panel) and Aleutian Islands survey selectivity (bottom right panel), by sex, estimated from the stock assessment model.

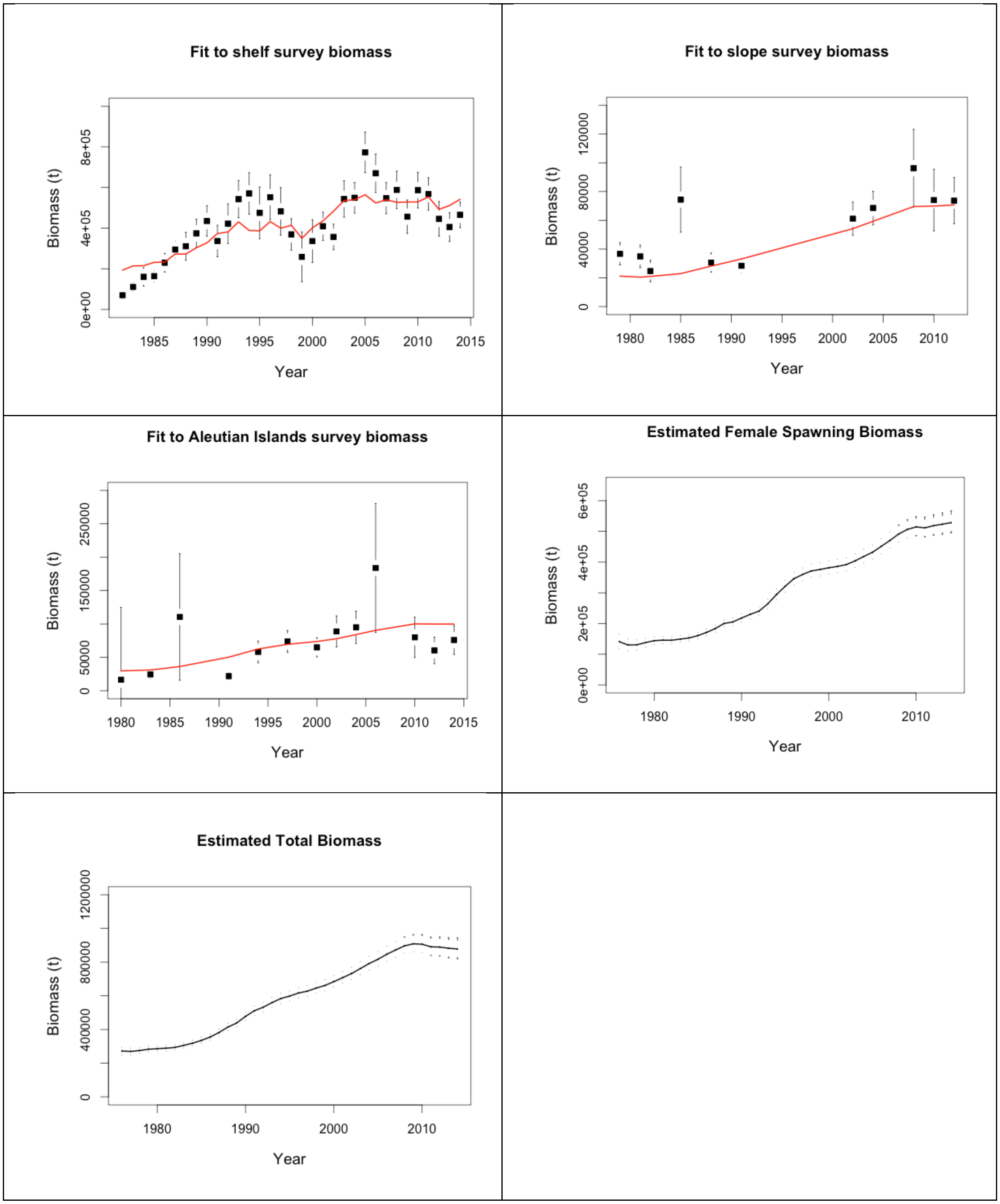

Figure 6.9. Stock assessment model results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), estimate of female spawning biomass with $B_{35\%}$ and $B_{40\%}$ indicated (middle right panel), the fit to the Aleutian Islands survey (middle 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.

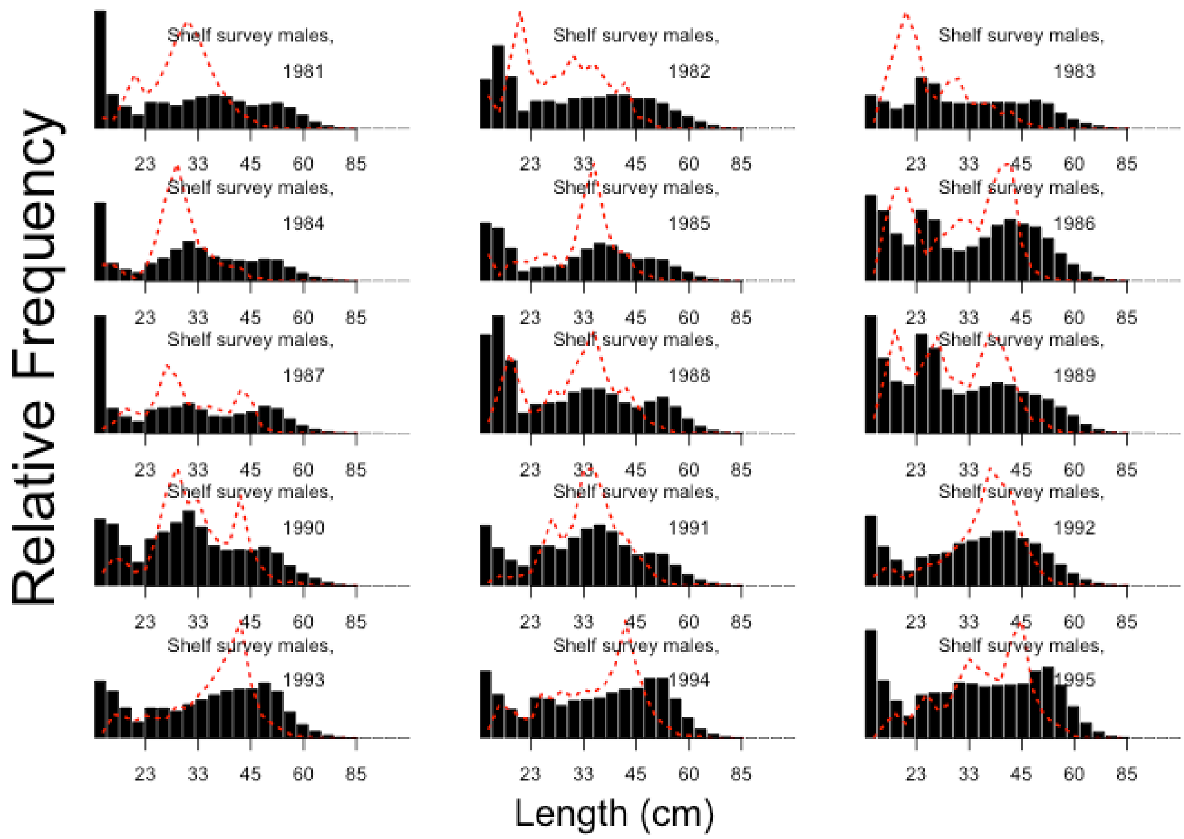

Figure 6.10. Model fit (dotted lines) to Bering Sea shelf survey observed length composition (bar plots).

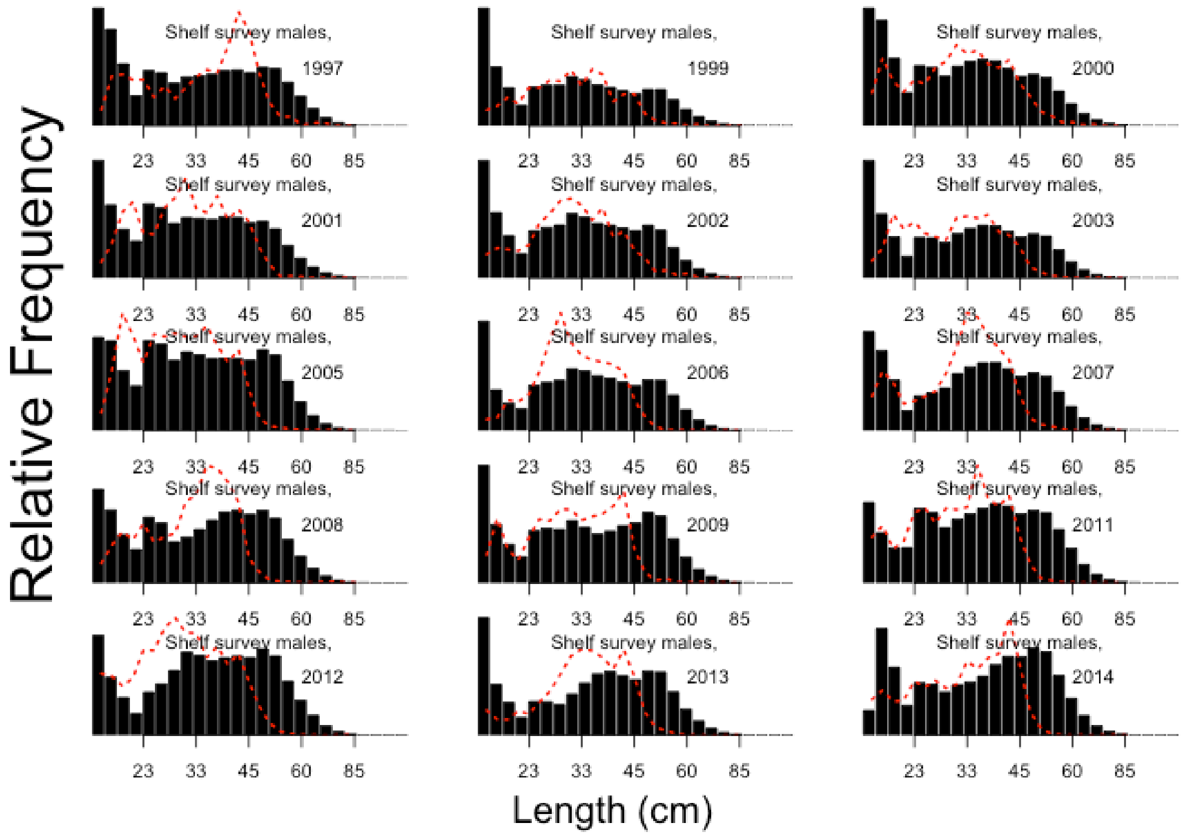

Figure 6.10 (cont'd). Model fit (dotted lines) to Bering Sea shelf survey observed length composition (bar plots).

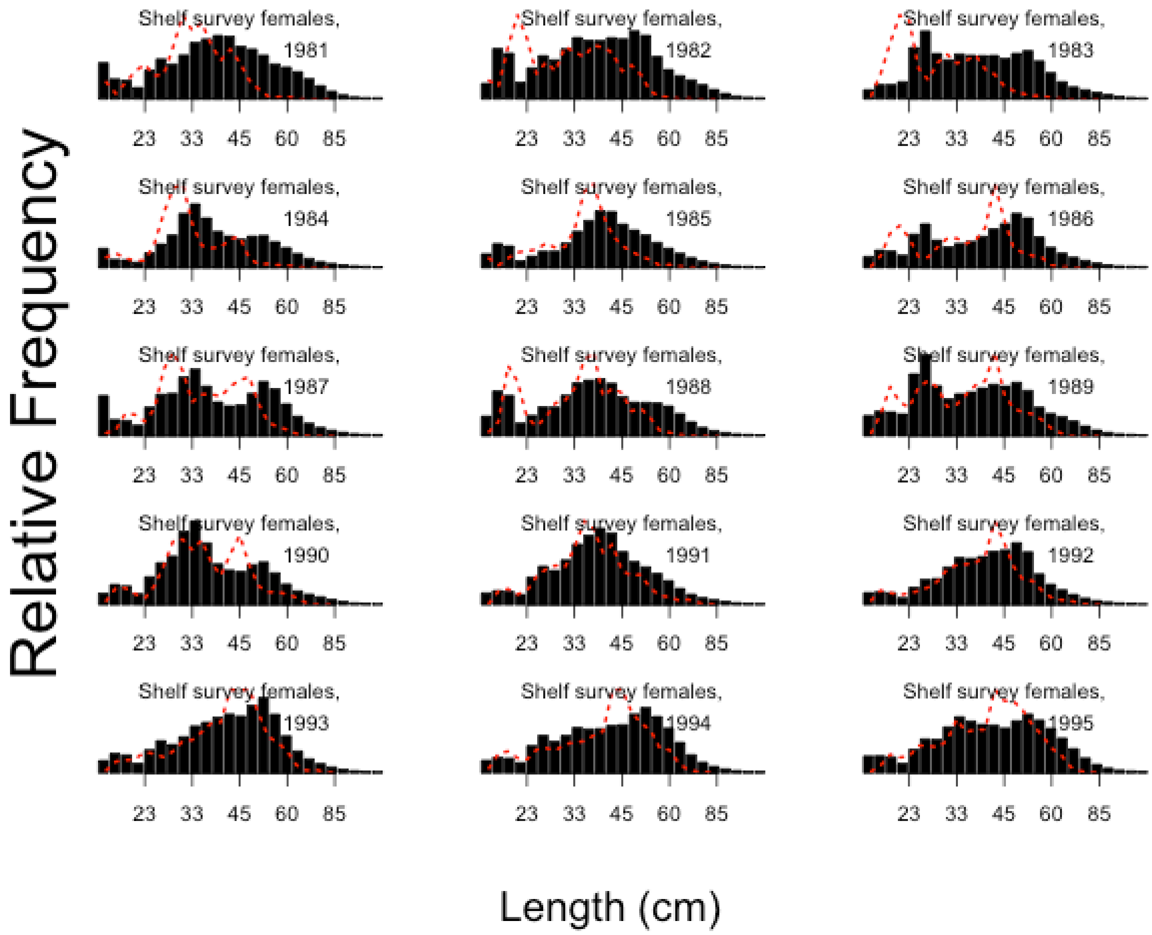

Figure 6.10 (cont'd). Model fit (dotted lines) to Bering Sea shelf survey observed length composition (bar plots).

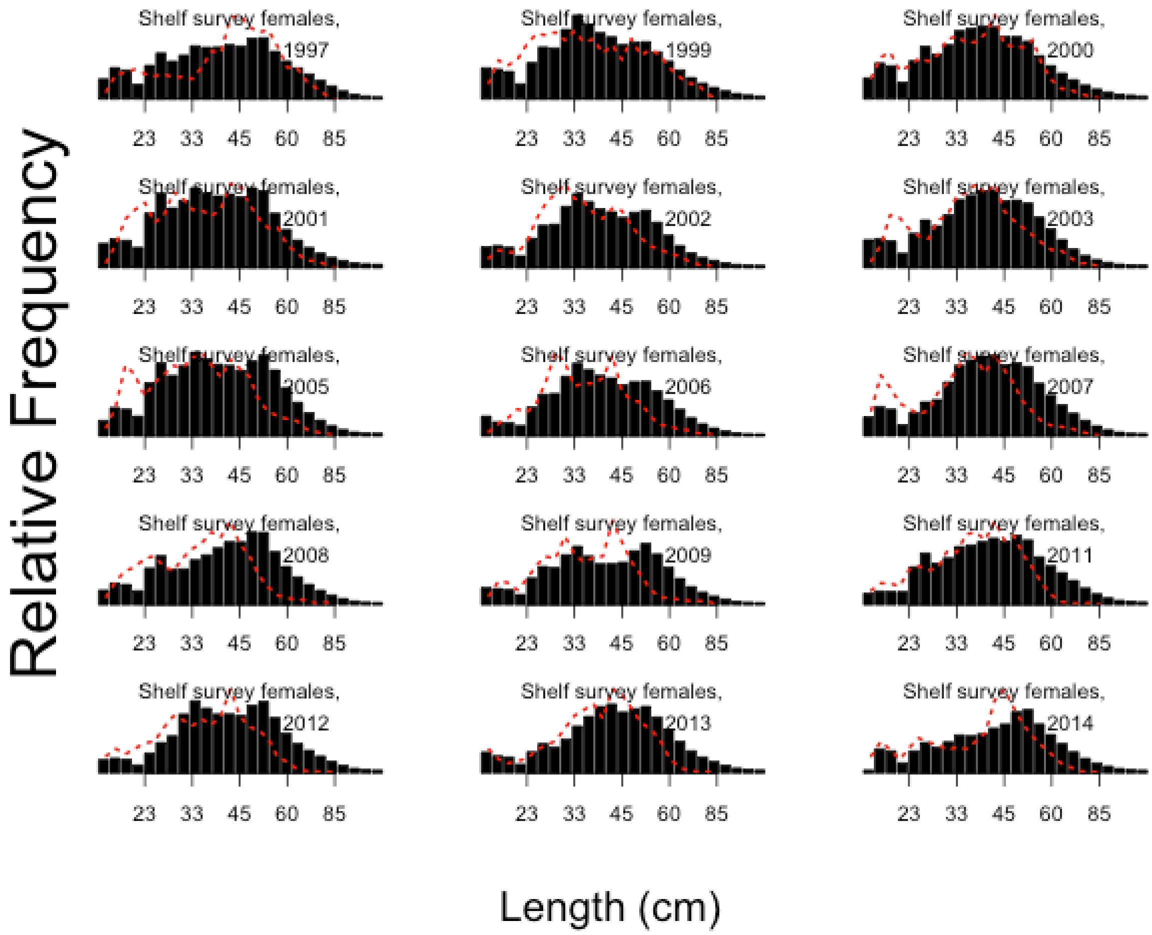

Figure 6.10 (cont'd). Model fit (dotted lines) to Bering Sea shelf survey observed length composition (bar plots).

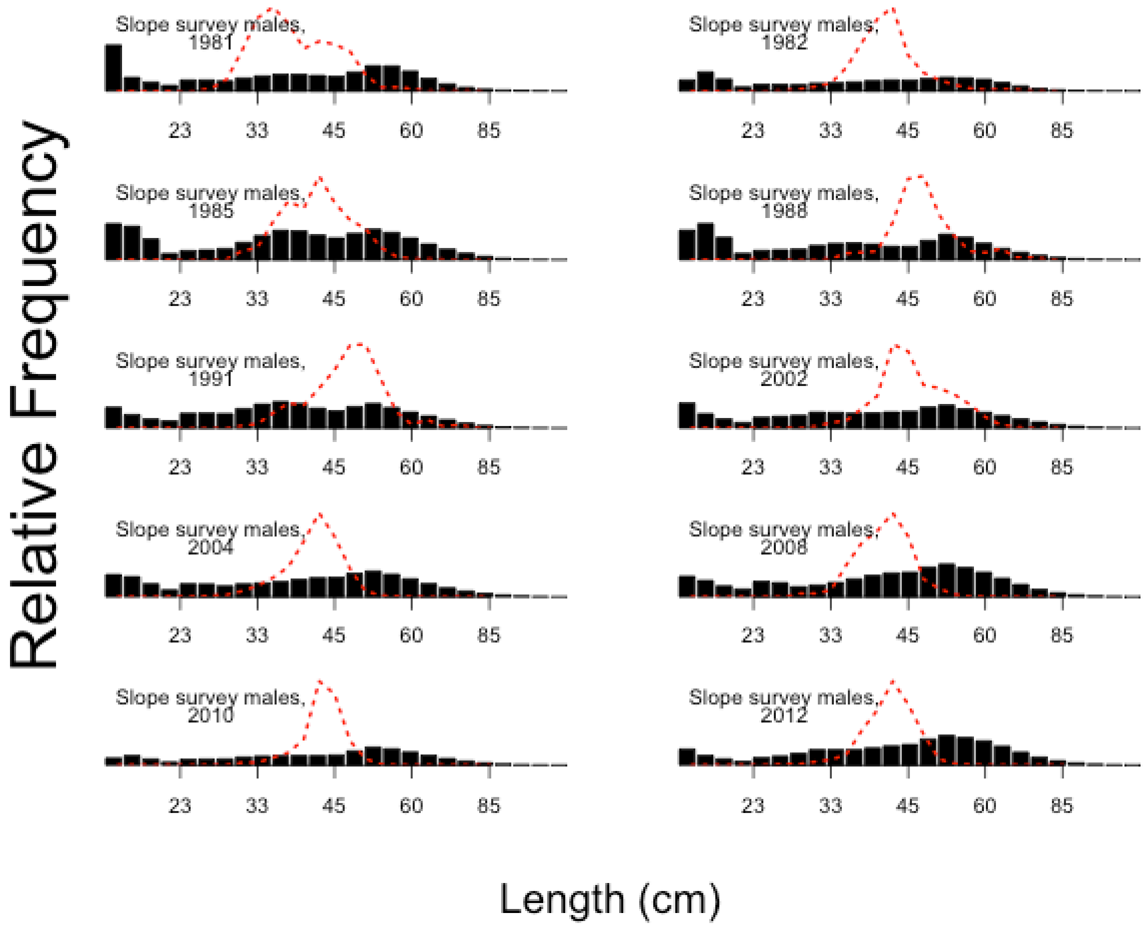

Figure 6.10 (cont'd). Model fit (dotted lines) to Bering Sea slope survey observed length composition (bar plots).

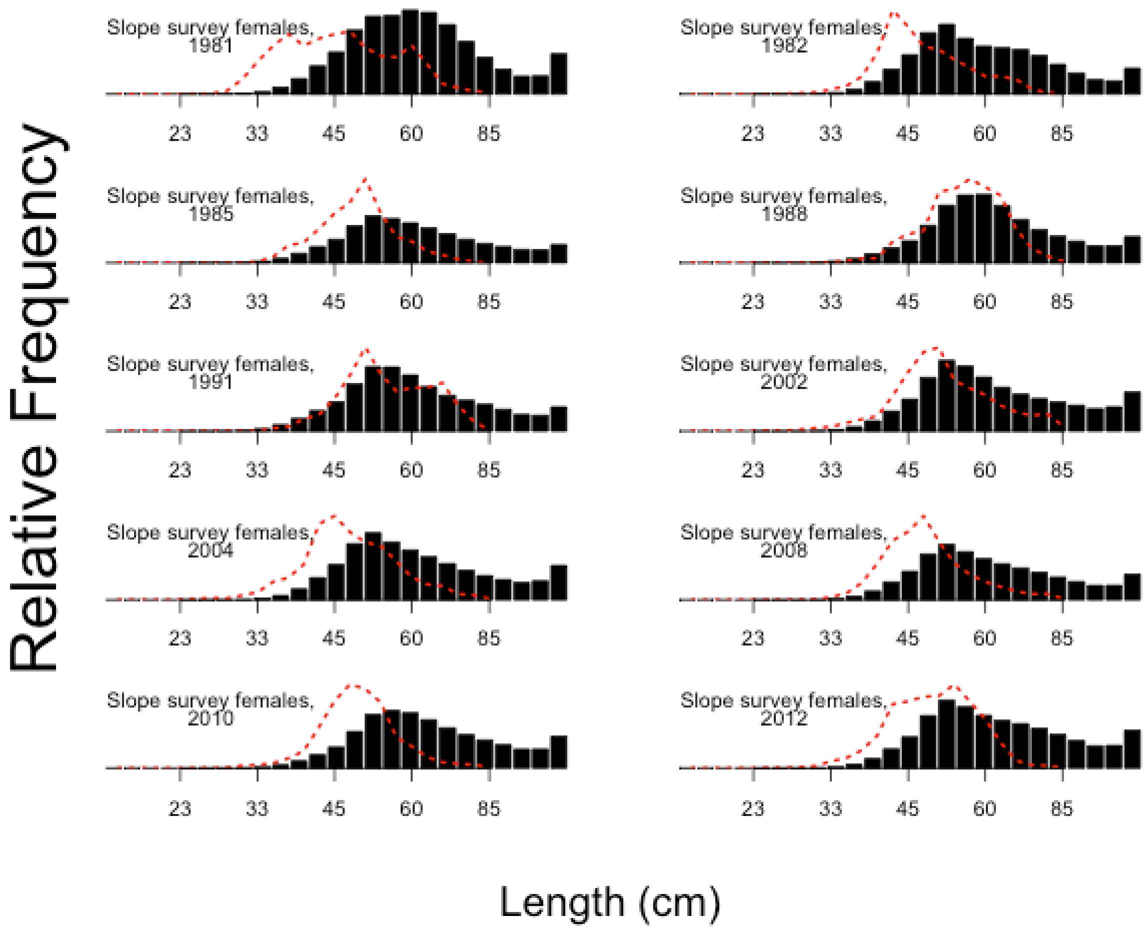

Figure 6.10 (cont'd). Model fit (dotted lines) to Bering Sea slope survey observed length composition (bar plots).

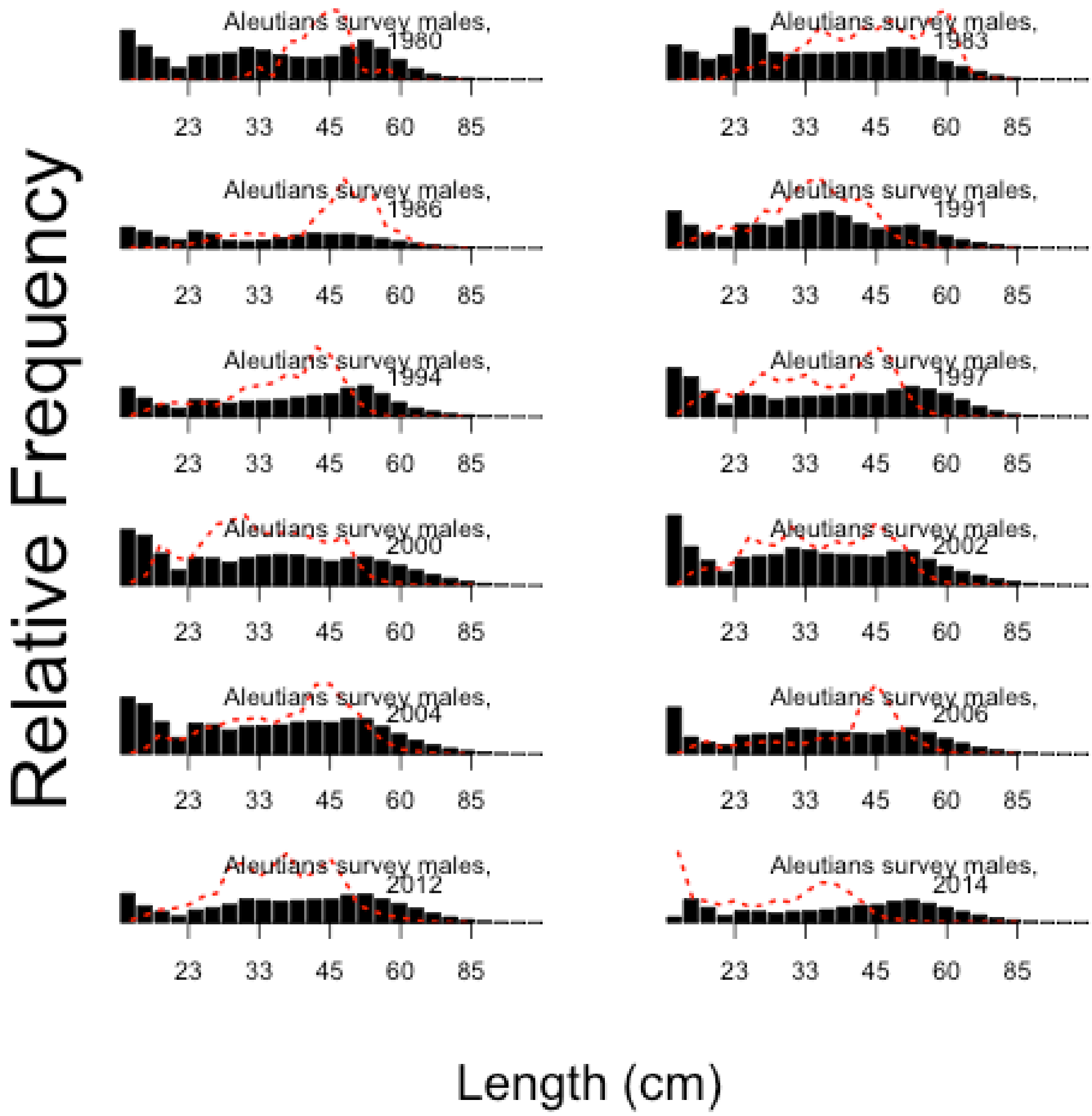

Figure 6.10 (cont'd). Model fit (dotted lines) to Aleutian Islands survey observed length composition (bar plots).

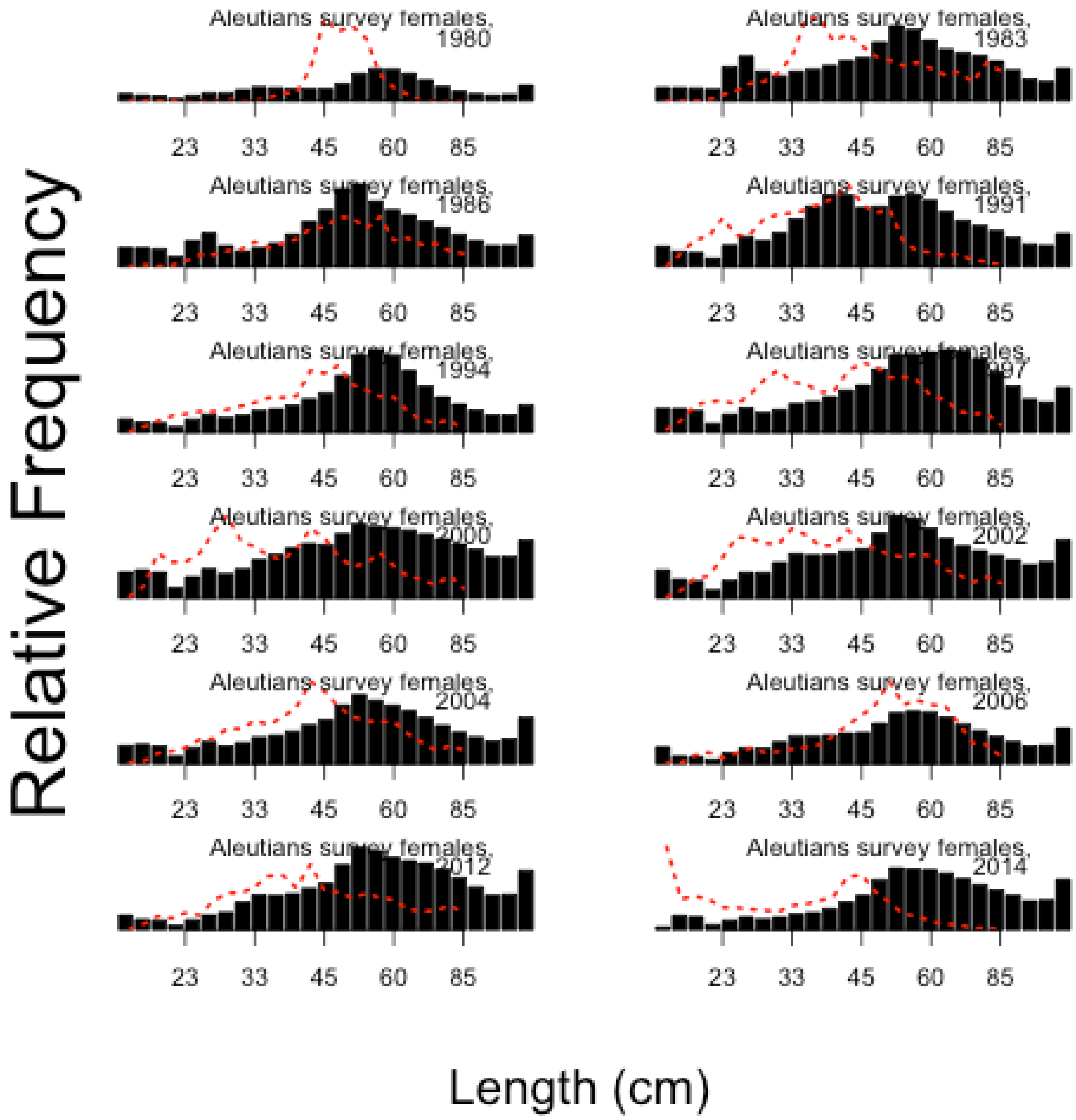

Figure 6.10 (cont'd). Model fit (dotted lines) to Aleutian Islands survey observed length composition (bar plots).

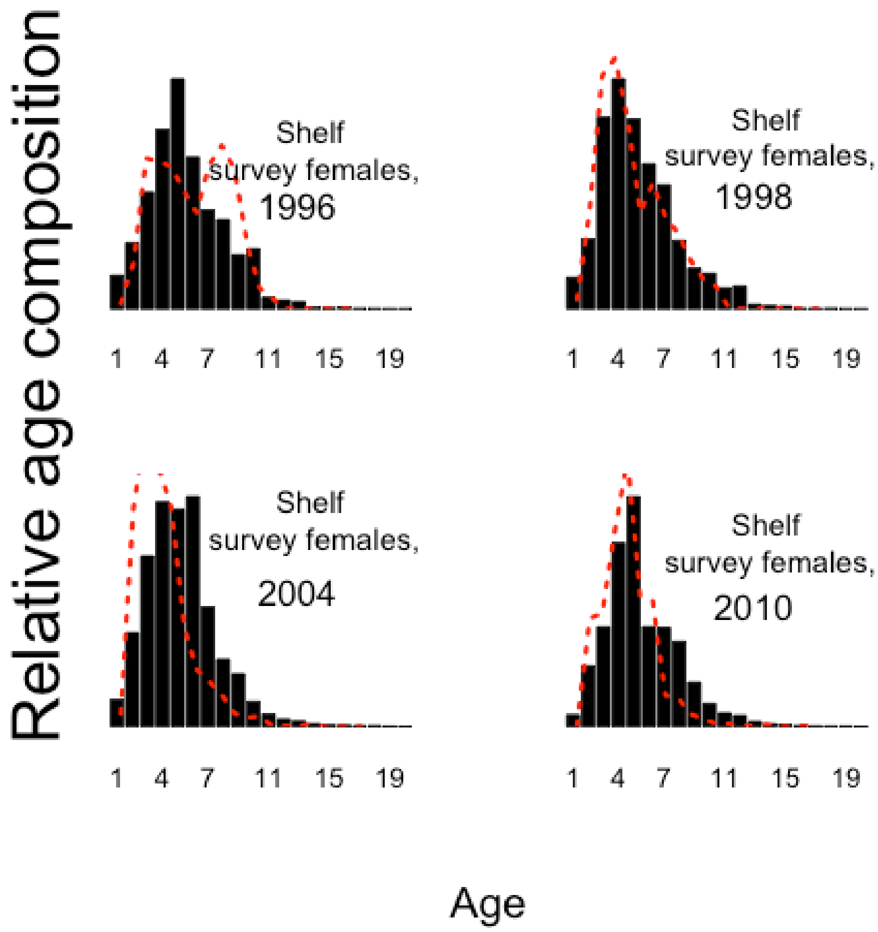

Figure 6.10 (cont'd). Model fit (dotted lines) to Bering Sea shelf survey observed age composition (bar plots).

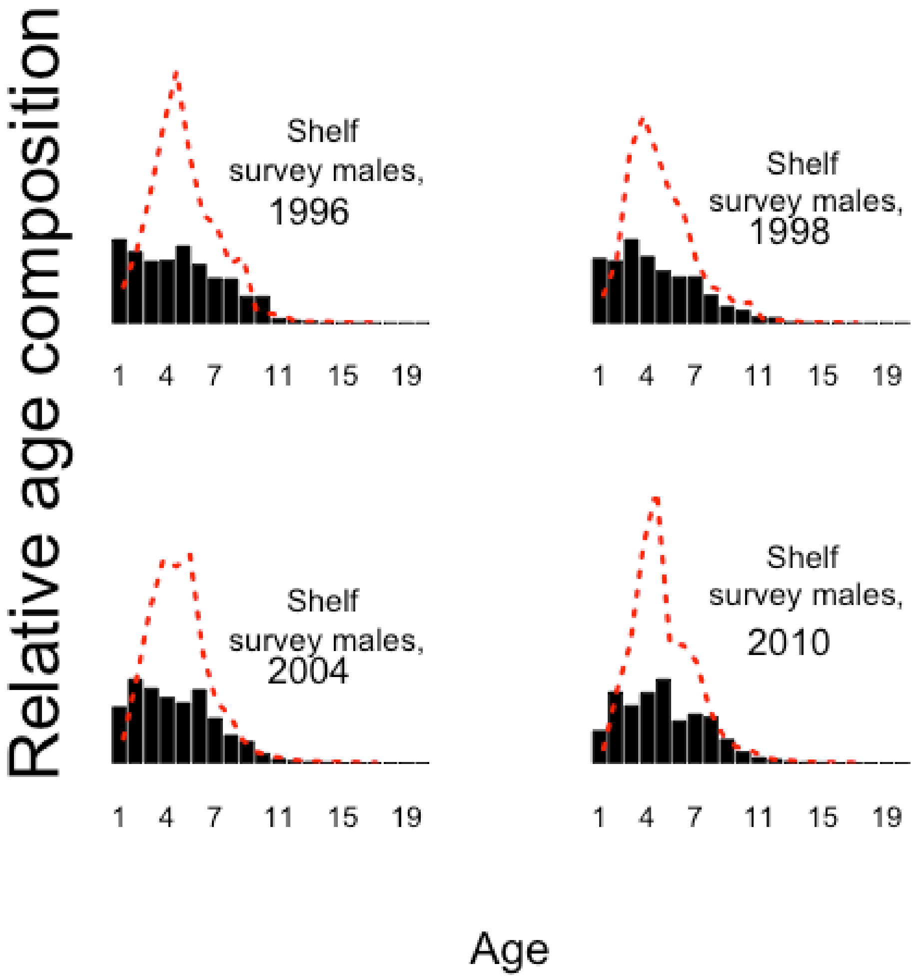

Figure 6.10 (cont'd). Model fit (dotted lines) to Bering Sea shelf survey observed age composition (bar plots).

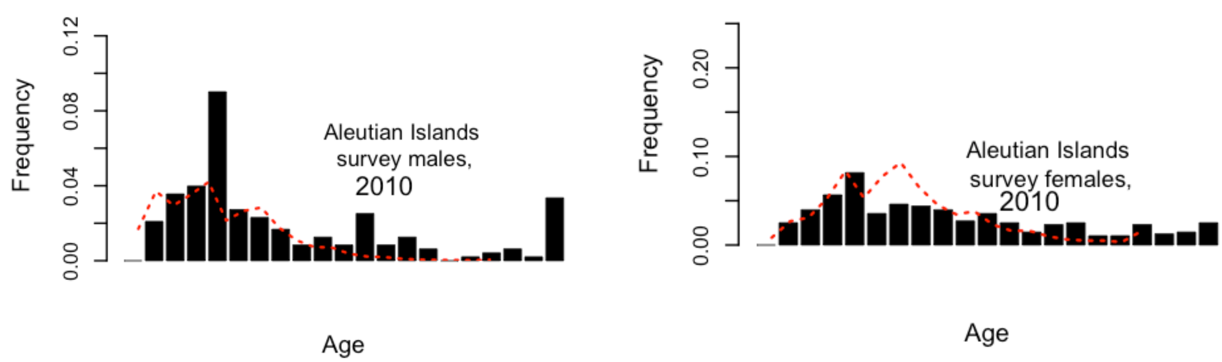

Figure 6.10 (cont'd). Model fit (dotted lines) to Aleutian Islands survey observed age composition (bar plots), males (left) and females (right).

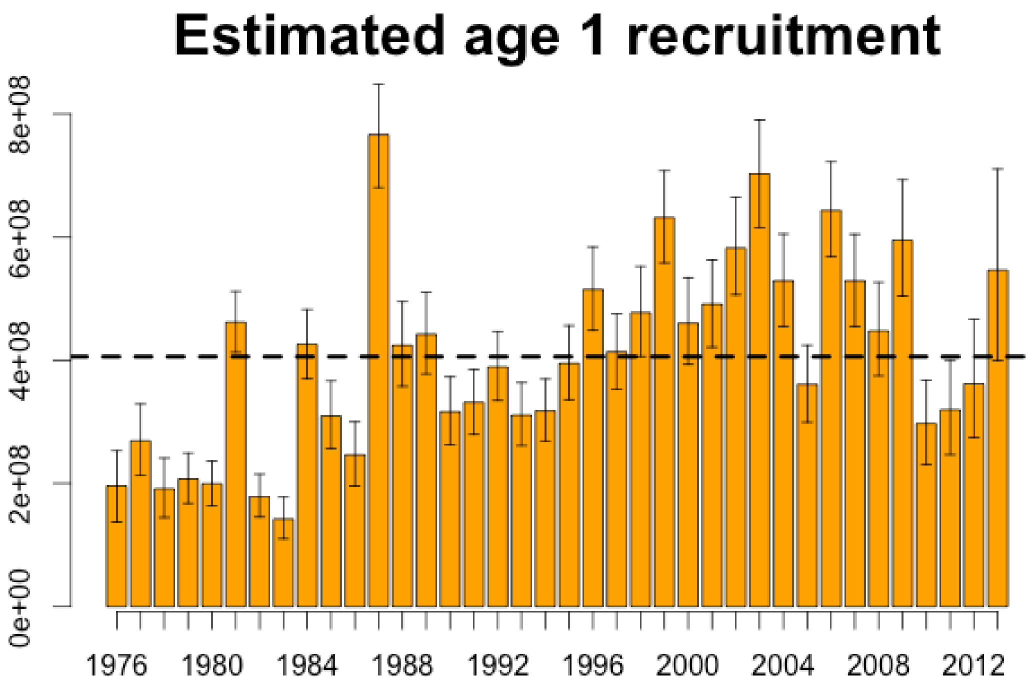

Figure 6.11. Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model.

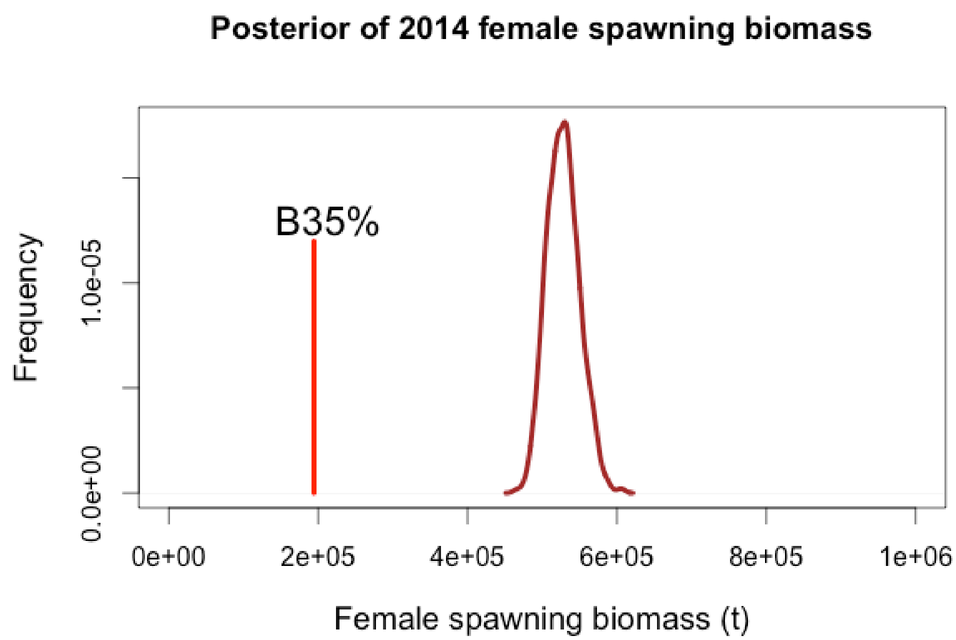

Figure 6.12. Posterior distribution of the estimate of female spawning biomass (t) from the preferred stock assessment model run, compared with the model estimate of $B_{35\%}$, 244,616 t.

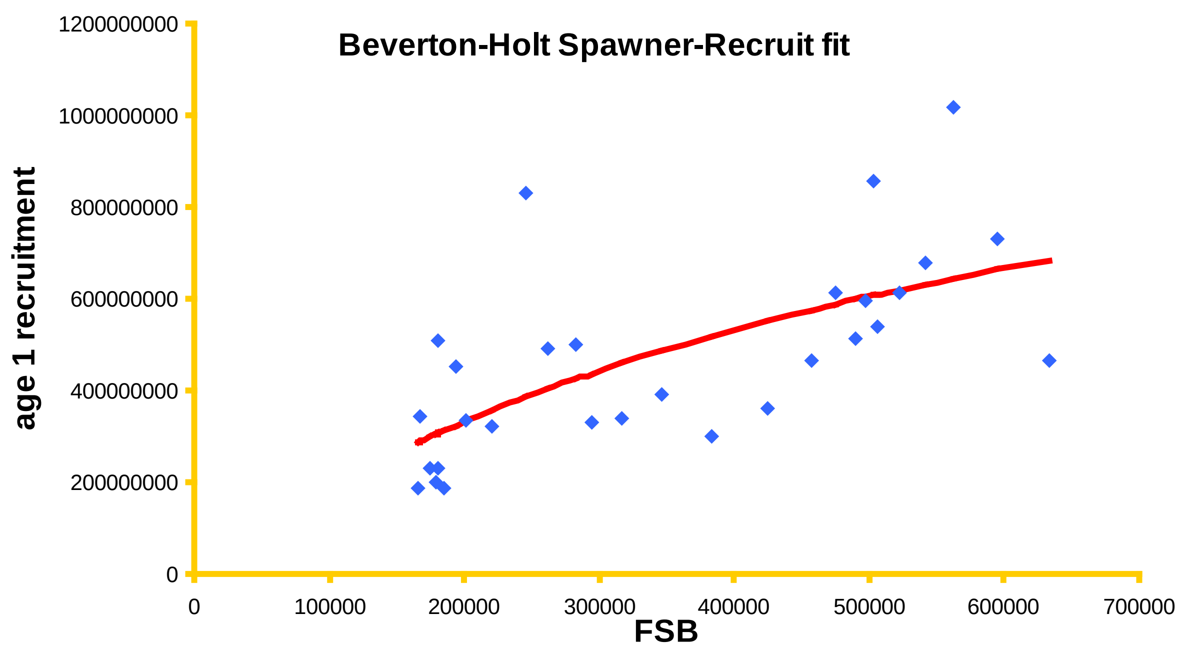

Figure 6.13. Beverton and Holt spawner recruit model fit to the age 1 recruitment data for Bering Sea arrowtooth flounder.

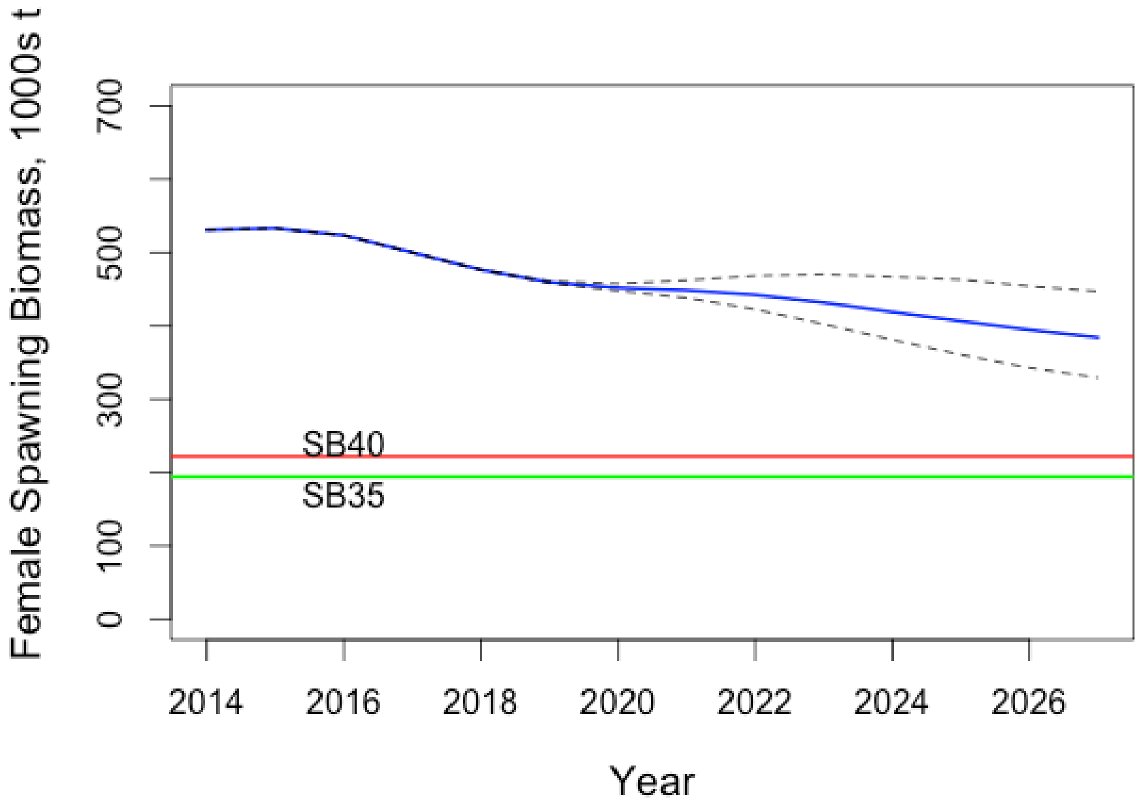

Figure 6.14. Projected female spawning biomass (1,000s t) of arrowtooth flounder if future harvest is at the same fishing mortality rate as the past five years.

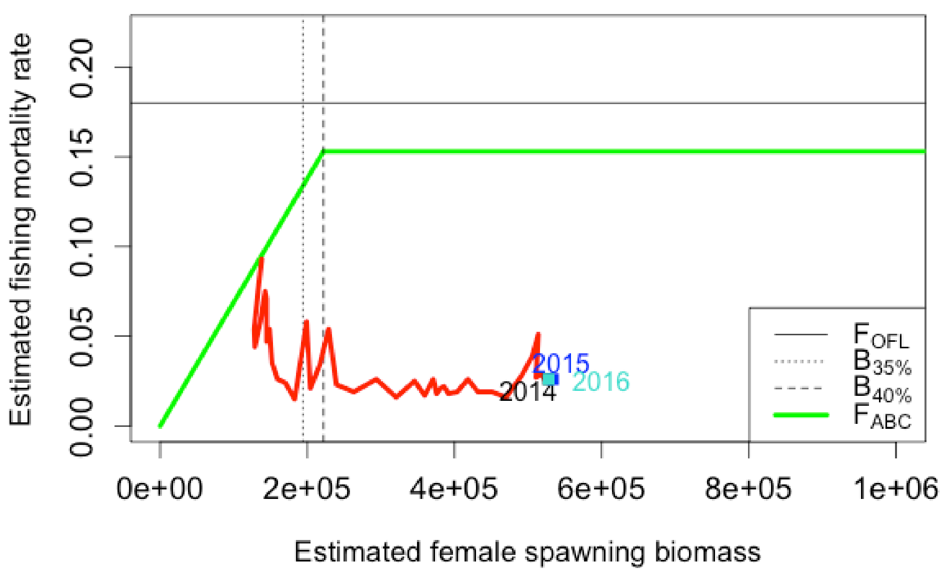

Figure 6.15. Phase plane diagram showing the time-series of stock assessment model estimates of female spawning biomass relative to the harvest control rule, with projection model results for 2015 and 2016.

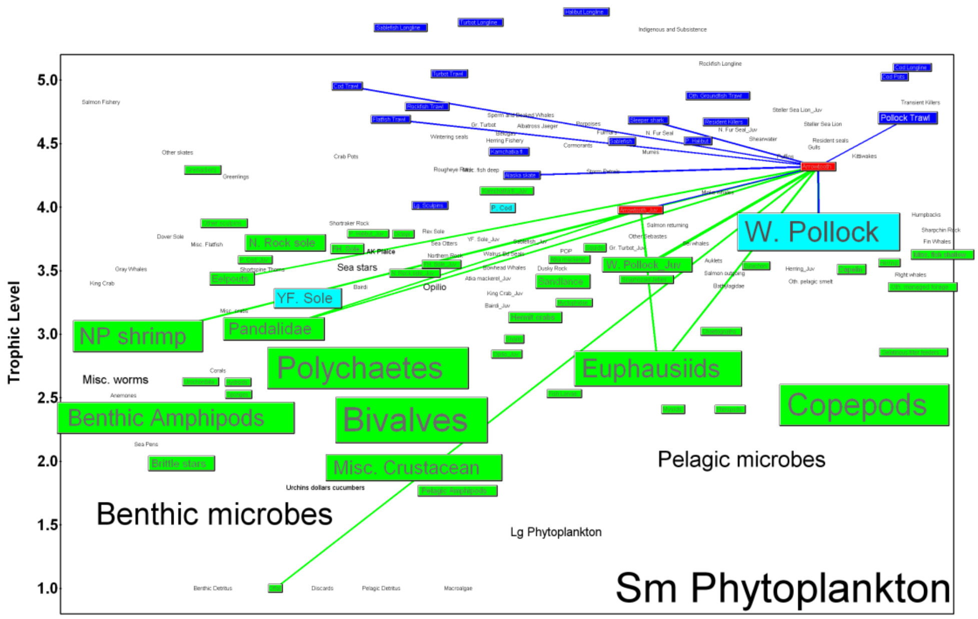

Figure 6.16. Adult and juvenile arrowtooth flounder in the EBS food web. Box size is proportional to biomass, and lines between boxes represent the most significant energy flows. Predators of arrowtooth are dark blue, prey of arrowtooth are green, and species that are both predators and prey of arrowtooth are light blue.

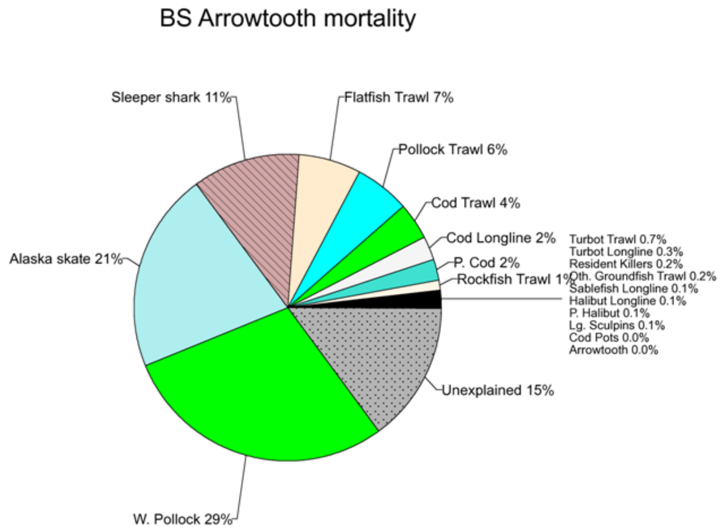

Figure 6.17. Mortality of Bering Sea arrowtooth flounder >20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. "Unexplained" mortality is the difference between the stock 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).

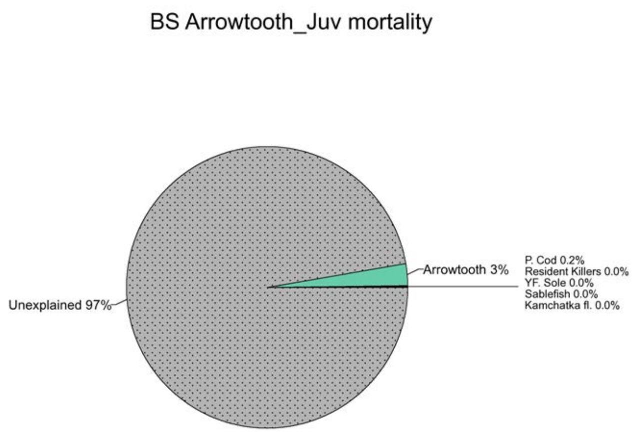

Figure 6.18. Mortality of Bering Sea arrowtooth flounder <20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. "Unexplained" mortality is the difference between the stock 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).

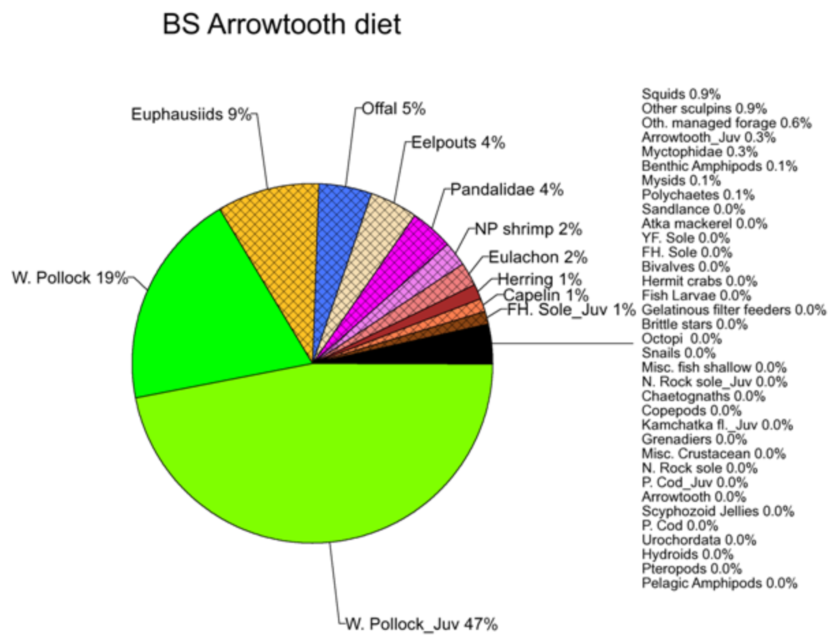

Figure 6.19. Diet of Bering Sea arrowtooth flounder >20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good 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).

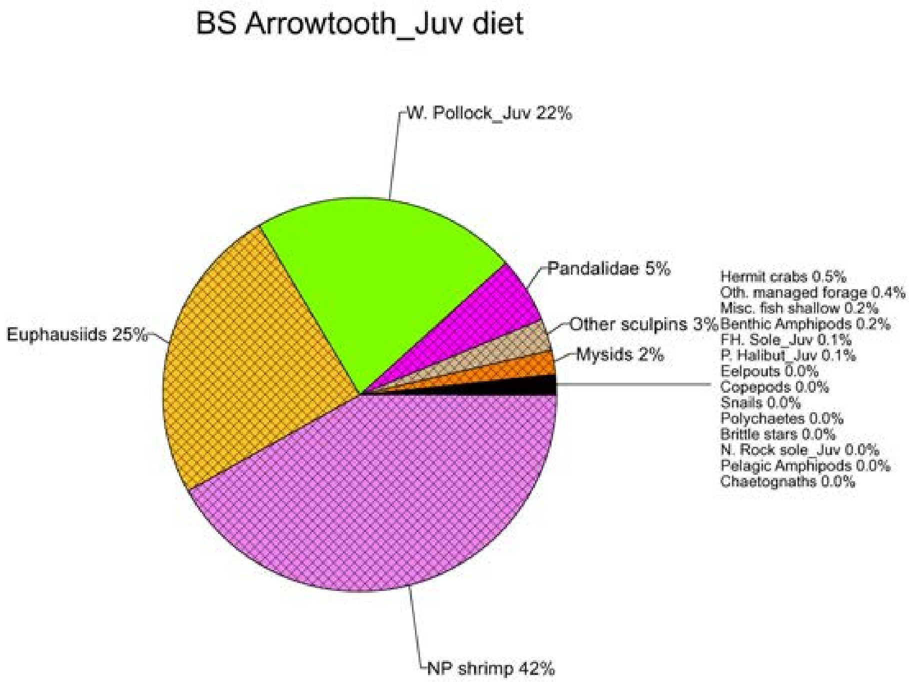

Figure 6.20. Diet of Bering Sea arrowtooth flounder <20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good 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).

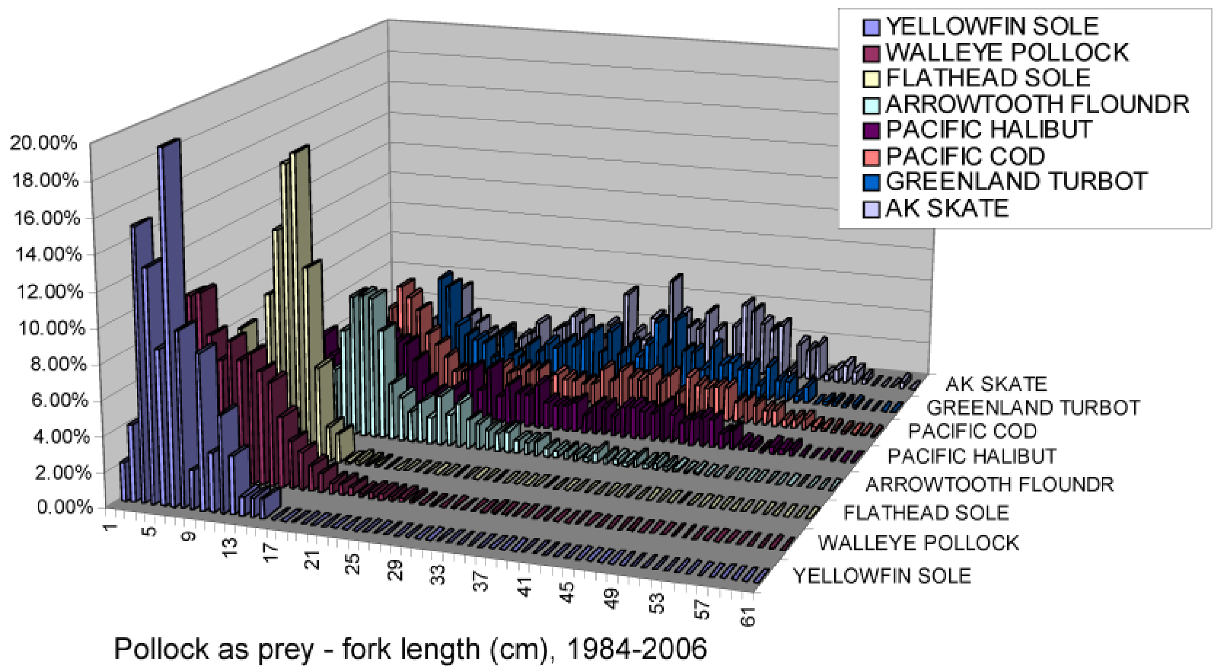

Figure 6.21. Length frequency of pollock found in stomachs, from groundfish food habits collected from 1984-2006 on AFSC summer trawl surveys in the eastern Berng Sea. Predators are sorted by median prey length of pollock in their stomachs. All lengths of predators are combined.

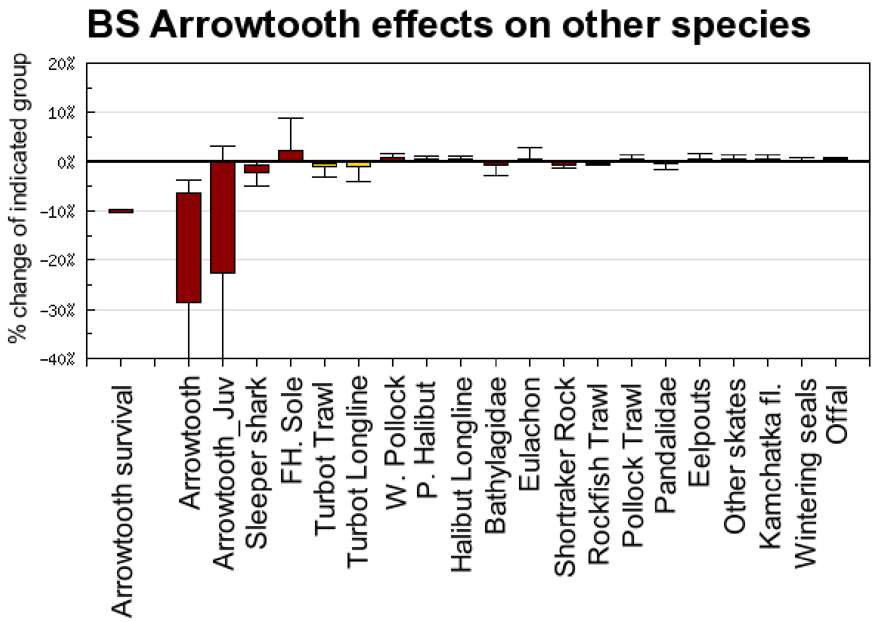

Figure 6.22. Effect of changing arrowtooth > 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting 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).

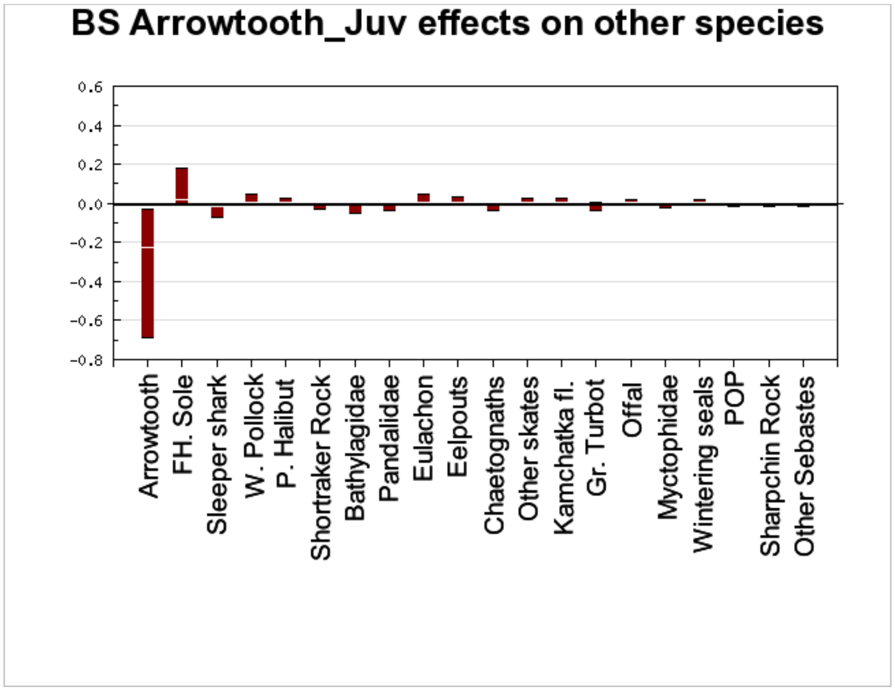

Figure 6.23. Effect of changing arrowtooth < 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting 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).

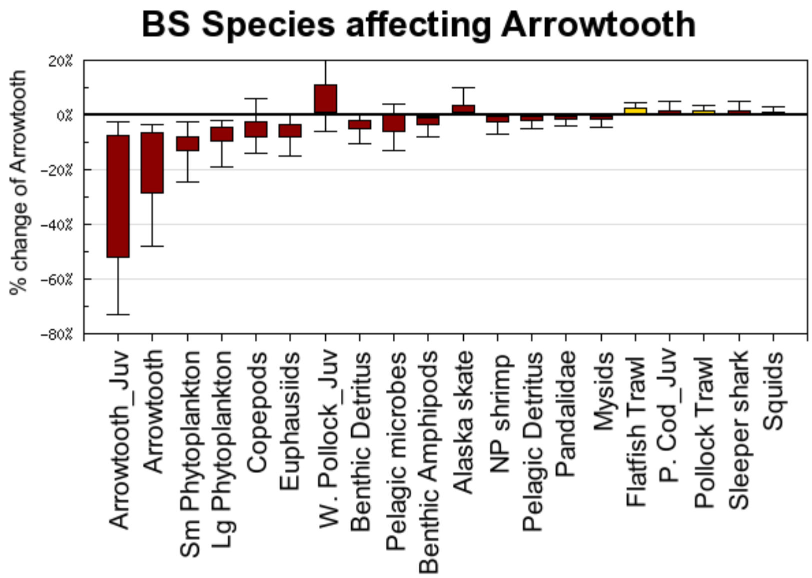

Figure 6.24. Effect of reducing fisheries catch (yellow) and other species survival (dark red) on arrowtooth > 20 cm biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting 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:

An exploration of alternative assessment models for arrowtooth flounder in the Bering Sea and Aleutian Islands

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Alaska Fisheries Science Center
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Introduction

This document presents responses to comments made by the BSAI Plan team and the SSC with regard to the 2013 BSAI arrowtooth assessment. The SSC requested that the 2014 assessment compare alternative maturity curves (Zimmerman 1997 and Stark 2011), along with their uncertainty. This year an attempt was made to standardize the GOA and BSAI arrowtooth models, and the discrepancy between the methods for estimating selectivity in the fishery was noted. The September 2014 meeting of the BSAI plan team suggested that both methods for estimating fishery selectivity be explored in the 2014 BSAI arrrowtooth flounder assessment, as well as likelihood weights for the non-parametric fishery selectivity model. In the BSAI arrowtooth flounder model, sex-specific "domed-shaped" selectivity has been assumed for males and females in the shelf survey due to age distributions observed there. In addition, an asymptotic selectivity pattern has been assumed for both sexes for the fishery, the slope surveys, and the Aleutian Islands surveys, through 2013. In the GOA model, fishery selectivity has been estimated non-parametrically for each age, and the shape of the selectivity curve has been constrained to be a smooth, monotonic function.

The author's preferred BSAI model incorporated non-parametric fishery selectivity. This appendix includes model results that incorporate logistic fishery selectivity, compared with non-parametric fishery selectivity. In addition, alternatives to the current likelihood weighting system on monotonicity and smoothness of these selectivity values are explored. Finally, assessment results comparing maturity values based on the Stark (2011) and Zimmerman (1997) analysis are presented.

In December 2013 the SSC accepted the author's and Plan Team's recommended ABCs and OFLs for 2014 and 2015 under Tier 3a using the current model updated with female maturity information based on research by Stark (2011). The SSC looks forward to a full analysis of the model results with the old and new data in next year's stock assessment. The assessment should compare the alternative maturity curves, along with their uncertainty.

In September 2014, the BSAI Plan Team recommended that the arrowtooth flounder assessment bring forward a model that explores selectivity shapes for both the survey and the fishery, including a model with non-parametric selectivity-by-age as an alternative to the logistic model. For the selectivity-by-age model, the weightings used in the smoothing penalties should also be explored.

Author's response: The 2014 BSAI arrowtooth assessment is based on the author's preferred model, which incorporates non-parametric fisheries selectivity as an alternative to the logistic model, as well as the Stark (2011) female maturity values. The logistic model is compared with the non-parametric fishery selectivity model and results of the logistic model are included in this Appendix. Weightings used in the smoothing penalties are also explored in this Appendix. Assessment results using old maturity values are considered here as well.

Data and Analytic Approach

Model Structures

Three models are considered here:

Model 1: Logistic fishery selectivity. This model is the same as the 2013 accepted model (Spies et al. 2013). The same weightings were used in the smoothing penalties as those used in the GOA model (Table A1). This model uses Stark (2011) maturity values (Table A2).

Model 2: Non-parametric fishery selectivity with equal weights for the monotonic and smoothness likelihood components. This is the same as the 2014 preferred model, with logistic weights as shown in Table A1. This model uses Stark (2011) maturity values (Table A2).

Model 3: The author's preferred model with Zimmerman (1997) female maturity values, rather than Stark (2011) maturity-at-age (Table A2).

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

The hessian, the matrix of second mixed derivatives in transformed space, is created as output from each ADMB model run. Transformed parameters (bounded parameters estimated using a logit transform) were back-transformed by taking the log of the determinant of the hessian, and the marginal likelihood ($Likelihood_{MAR}$) was estimated as in Thorson et al. (2014), where OFV is the objective function value from the ADMB .par file:

$$Likelihood_{MAR} \approx -0.5 Hess_T - OFV.$$

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

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

Results

Models 1 and 2:

The non-parametric method for estimating fishery selectivity (Model 2) resulted in a lower Akaike information criterion (AIC) when applied to the BSAI model; and is therefore the preferred model. The non-parametric method (Model 2) for estimating fishery selectivity adds 38 new parameters to the model, but results in a lower AIC, 9,818 for the non-parametric model vs. 9,990 for the logistic method (Model 1; Table A3). However, the effective number of parameters may be smaller than 38 due to the non-parametric method applied. If this were the case, the AIC would still be lower with the non-parametric method; therefore, the non-parametric model (Model 2) is preferred by the authors and is presented in the main document. The most notable improvement in the new method for estimating fishery selectivity is in the fit to fishery lengths (Table A3).

Model 1 reference values are summarized in Table A4. Reference values are very similar to those using Model 2,the non-parametric fishery selectivity.

Selectivity curves estimated by the two models are shown in Figures A1 (Model 1) and A2 (Model 2). The survey selectivity curves are not affected by changes to fishery selectivity. The non-parametric selectivity estimates are dome shaped for both sexes, and descend more steeply for males.

Tables 6.8, 6.9, 6.10, 6.11, and 6.12 and from the assessment were recreated using model output with logistic fishery selectivity and are presented in Tables A5, A6, A7, A8, and A9. In addition, Figures A3 and A4 are provided for comparison with Figures 6.9 and 6.11 respectively. Both are similar to the results for the preferred model.

When equal weightings were applied to the smoothness and monotonicity likelihood components for male and female fishery selectivity in Model 2, the model estimates for fishery selectivity changed. Fishery selectivity was not smooth for either sex (Figure A5). However, results did not change significantly; male selectivity peaked at a higher level than female selectivity and declined more quickly for older ages in males. Although this was not a thorough analysis of alternatives for likelihood weights, the original weightings in Table A1 were used in all further analyses.

Model 3:
In 2011 a study was published which estimated maturity-at-age of arrowtooth flounder in the Bering Sea (Stark 2011). The Bering Sea and Aleutian Islands (BSAI) stock assessment uses parameters from Zimmerman (1997), which estimated maturity-at-length (Figure A6). In 2012 the BSAI Plan Team requested an analysis of the different maturity-at-age and length parameters in order to determine the best parameters to use in the BSAI ATF stock assessment. The 2011 maturity-at-age parameters are recommended to replace Zimmerman (1997) parameters in the BSAI ATF stock assessment because maturity-at-age is less variable than maturity-at-length and the sample is taken in the Bering Sea rather than the Gulf of Alaska.

Estimates of female spawning biomass and total biomass with both maturity estimates are shown in Figure A7. The Model 3 2014 estimate of total biomass is 877,781 t (95% CI: 807,366, 948,196) and female spawning biomass is 656,643 t (95% CI: 613,098, 700,188).

Literature Cited

Akaike, H. 1974. A new look at the statistical model identification, IEEE Transactions on Automatic Control. 19(6): 716-723 doi:10.1109/TAC.1974.1100705, MR 0423716.

Spies, I. Wilderbuer, T., Nichol, D., and Aydin, K. 2013. Assessment of the arrowtooth flounder stock in the Eastern Bering Sea and Aleutian Islands. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage Alaska 99510.

Stark, J. 2011. Female maturity, reproductive potential, relative distribution, and growth compared between arrowtooth flounder (*Atheresthes stomias*) and Kamchatka flounder (*A. evermanni*) indicating concerns for management. Journal of Applied Ichthyology. 28(2) 226-230. doi: 10.1111/j.1439-0426.2011.01885.x.

Thorson, J., Hicks, A.C., and Methot, R. 2014. Random effect estimation of time-varying factors in Stock Synthesis. ICES Journal of Marine Science; doi: 10.1093/icesjms/fst211.

Wilderbuer, T., and Turnock, J. 2009. Sex-specific natural mortality of arrowtooth flounder in Alaska: Implications of a skewed sex ratio on exploitation and management. North American Journal of Fisheries Management 29: 306-322.

Zimmermann, Mark. 1997. Maturity and fecundity of arrowtooth flounder, *Atheresthes stomias*, from the Gulf of Alaska. Fish Bull. 95:598-611.

Tables

Table A1. Weightings used in the smoothing and monotonicity penalties in the GOA model. Values in parentheses were tested.

	Fishery female	Fishery male
Smooth selectivity likelihoods	10 (1)	40 (1)
Monotonicity constraint	200 (1)	100 (1)

Table A2. Arrowtooth flounder female female maturity at age, based on Zimmerman (2007) and Stark (2011).

age	female maturity at age (Zimmerman 2007)	female maturity at age (Stark 2011)
1	0	0.00
2	0	0.00
3	0	0.01
4	0.02	0.02
5	0.39	0.06
6	0.84	0.16
7	0.97	0.34
8	1.00	0.59
9	1.00	0.80
10	1	0.97
11	1	0.99
12	1	1
13	1	1
14	1	1
15	1	1
16	1	1
17	1	1
18	1	1
19	1	1
20	1	1
21	1	1

Table A3. Likelihood components for the Bering Sea and Aleutian Islands arrowtooth flounder model run with two configurations: fishery selectivity estimated separately (non-parametrically) for each age (Model 1), and fishery selectivity estimated as an increasing logistic function (Model 2). Lower values indicate a better fit; green is the lower value and red is higher, for each row of the table.

	Non-parametric selectivity (Model 1)	Logistic fishery selectivity (Model 2)
Shelf survey biomass	133.9	134.4
Slope survey biomass	62.6	64.0
AI biomass	47.6	47.2
Shelf survey lengths	1852.0	1854.1
Slope survey lengths	1046.0	1042.5
AI survey lengths	1087.3	1083.0
Fishery lengths	280.114	301.2
Recruitment	27.4	27.8
Catch	0.001106	0.001257
Sex ratio	46.6	46.7
Shelf survey ages	140.4	140.4
Total Obj. Fun. value	4753.54	4759.74
Number of Parameters	158	120
AIC	9818.488	9990.455

Table A4. Summary of results if the fishery selectivity were modeled as logistic.

	Last year		This year*	
Quantity/Status	2014	2015	2015	2016
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+)	1,023,440	995,494	908,644	912,220
Female spawning biomass (t)				
Projected	626,319	632,319	533,246	527,257
$B_{100\%}$	577,538	577,538	551,587	551,587
$B_{40\%}$	231,015	231,015	220,635	220,635
$B_{35\%}$	202,138	202,138	193,055	193,055
F_{OFL}	0.186	0.186	0.163	0.163
$maxF_{ABC}$ (maximum allowable = F40%)	0.156	0.156	0.138	0.138
Specified/recommended F_{ABC}	0.156	0.156	0.138	0.138
Specified/recommended OFL (t)	125,642	125,025	97,286	98,757
Specified/recommended ABC (t)	106,599	106,089	84,300	83,043
Is the stock being subjected to overfishing?	no	no	no	no
Is the stock currently overfished?	no	no	no	no
Is the stock approaching a condition of being overfished?	no	no	no	no

*Using logistic fishery selectivity.

Table A5 (Table 6.8 with logistic fishery selectivity). Model estimates of arrowtooth flounder fishing mortality and exploitation rate (catch/total biomass).

year	Full selection F	Exploitation rate
1976	0.115	0.068
1977	0.068	0.041
1978	0.057	0.035
1979	0.077	0.048
1980	0.099	0.061
1981	0.092	0.056
1982	0.060	0.037
1983	0.070	0.043
1984	0.046	0.028
1985	0.034	0.021
1986	0.030	0.019
1987	0.019	0.012
1988	0.075	0.045
1989	0.026	0.016
1990	0.044	0.026
1991	0.069	0.040
1992	0.030	0.018
1993	0.024	0.016
1994	0.035	0.023
1995	0.021	0.015
1996	0.032	0.022
1997	0.022	0.015
1998	0.032	0.022
1999	0.022	0.015
2000	0.027	0.018
2001	0.028	0.018
2002	0.022	0.015
2003	0.024	0.016
2004	0.032	0.021
2005	0.024	0.016
2006	0.024	0.016
2007	0.021	0.014
2008	0.036	0.024
2009	0.049	0.033
2010	0.064	0.043
2011	0.033	0.023
2012	0.036	0.025
2013	0.033	0.023
2014	0.033	0.023

Table A6 (Table 6.9 with logistic fishery selectivity). 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	0.01	0.05	0.11	0.00	0.03	0.03	0.07
2	0.02	0.03	0.16	0.18	0.00	0.05	0.06	0.12
3	0.06	0.06	0.42	0.27	0.00	0.08	0.13	0.18
4	0.15	0.13	0.80	0.40	0.00	0.12	0.24	0.26
5	0.32	0.25	1.00	0.56	0.06	0.19	0.41	0.37
6	0.57	0.43	0.95	0.71	0.91	0.27	0.61	0.49
7	0.78	0.63	0.81	0.82	1.00	0.38	0.77	0.62
8	0.91	0.79	0.65	0.83	1.00	0.51	0.88	0.73
9	0.96	0.89	0.52	0.75	1.00	0.63	0.94	0.81
10	0.99	0.95	0.40	0.60	1.00	0.74	0.97	0.88
11	1.00	0.98	0.31	0.44	1.00	0.82	0.99	0.92
12	1.00	0.99	0.23	0.31	1.00	0.88	0.99	0.95
13	1.00	1.00	0.18	0.20	1.00	0.93	1.00	0.97
14	1.00	1.00	0.13	0.13	1.00	0.95	1.00	0.98
15	1.00	1.00	0.10	0.08	1.00	0.97	1.00	0.99
16	1.00	1.00	0.07	0.05	1.00	0.98	1.00	0.99
17	1.00	1.00	0.06	0.03	1.00	0.99	1.00	1.00
18	1.00	1.00	0.04	0.02	1.00	0.99	1.00	1.00
19	1.00	1.00	0.03	0.01	1.00	1.00	1.00	1.00
20	1.00	1.00	0.02	0.01	1.00	1.00	1.00	1.00
21	1.00	1.00	0.02	0.00	1.00	1.00	1.00	1.00

Table A7 (Table 6.10 with logistic (Model 1) and non-parametric fishery selectivity (preferred model), and Zimmerman (1997) maturity at age (Model 3)). Model estimates of arrowtooth flounder 1+ total biomass (t) and female spawning biomass (FSB, t) from the 2012 and 2014 assessments.

	Assessment – Year and specifications							
	2012		**2014 - logistic fishery selectivity (Model 1)**		**2014 – non-parametric fishery selectivity (preferred model)**		**2014 – Zimmerman (1997) maturity (Model 3)**	
	Total biomass	**FSB**	**Total biomass**	**FSB**	**Total biomass**	**FSB**	**Total biomass**	**FSB**
1976	261,843	145,079	264,056	133,980	269,581	137,913	269,581	173,333
1977	259,394	135,957	262,121	123,565	267,323	127,605	267,323	175,020
1978	265,437	140,201	268,235	124,872	273,114	128,654	273,114	184,953
1979	274,039	149,543	276,615	132,758	281,156	136,179	281,156	192,187
1980	278,544	155,185	280,479	139,542	284,669	142,697	284,669	190,820
1981	282,838	154,787	283,547	141,544	287,394	144,561	287,394	189,593
1982	289,105	154,463	288,163	141,810	291,738	144,598	291,738	191,786
1983	304,256	160,634	301,258	146,066	304,652	148,601	304,652	197,742
1984	319,243	165,944	313,872	149,797	317,146	152,209	317,146	201,440
1985	338,135	176,108	330,491	157,560	333,697	159,777	333,697	215,974
1986	360,542	190,169	350,689	168,113	353,901	170,170	353,901	236,432
1987	389,916	207,577	377,811	180,864	381,113	182,853	381,113	247,589
1988	423,607	226,675	409,441	197,255	412,852	199,211	412,852	262,481
1989	450,671	231,305	434,105	201,979	437,638	204,155	437,638	271,692
1990	491,982	248,134	473,581	214,875	477,253	216,960	477,253	289,596
1991	526,128	264,652	506,758	226,742	510,536	228,980	510,536	314,053
1992	546,661	279,076	527,758	237,127	531,547	239,547	531,547	345,015
1993	571,926	310,864	555,514	260,883	559,302	263,221	559,302	379,741
1994	592,011	346,248	579,651	291,359	583,417	293,761	583,417	408,124
1995	601,598	371,401	594,349	318,281	598,051	320,825	598,051	423,307
1996	614,404	391,549	612,430	343,276	616,089	345,783	616,089	440,068
1997	621,046	398,706	623,890	356,942	627,504	359,496	627,504	449,474
1998	635,335	404,618	641,961	368,595	645,562	371,083	645,562	457,834
1999	649,181	402,715	657,897	373,112	661,463	375,655	661,463	460,931
2000	670,513	404,531	680,318	378,959	683,861	381,405	683,861	473,362
2001	695,086	407,830	703,805	383,243	707,317	385,656	707,317	487,465
2002	721,321	415,548	728,041	389,353	731,488	391,757	731,488	500,318
2003	755,958	430,045	757,761	401,379	761,140	403,703	761,140	521,503
2004	792,770	448,107	787,765	415,913	791,072	418,167	791,072	545,164
2005	827,972	467,148	812,922	429,639	816,099	431,908	816,099	560,603
2006	869,734	491,079	842,848	448,765	845,881	450,913	845,881	581,116
2007	909,359	516,763	868,078	468,126	870,942	470,156	870,942	608,386
2008	948,231	548,056	892,574	489,122	895,262	491,018	895,262	638,824
2009	980,823	580,548	905,333	503,901	907,756	505,908	907,756	648,982
2010	1,002,620	608,551	903,157	511,655	905,159	513,829	905,159	646,995
2011	1,017,650	630,021	888,164	508,374	889,634	510,566	889,634	641,469
2012	1,023,890	652,156	887,486	516,069	888,498	517,672	888,498	649,475
2013			880,840	521,099	881,413	522,331	881,413	654,377
2014			877,625	526,780	877,781	527,622	877,781	656,643

Table A8 (Table 6.11 with logistic fishery selectivity). Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

females	**numbers at age (1,000s)**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1976	98,634	36,674	84,221	70,500	76,130	28,181	15,765	10,915	8,387	6,829
1977	133,932	80,679	29,950	68,492	56,758	60,075	21,622	11,799	8,051	6,147
1978	96,310	109,593	65,955	24,423	55,520	45,466	47,328	16,785	9,081	6,173
1979	103,831	78,816	89,615	53,820	19,831	44,637	36,050	37,068	13,052	7,039
1980	101,050	84,956	64,419	73,039	43,569	15,839	34,985	27,787	28,295	9,920
1981	231,602	82,666	69,405	52,438	58,942	34,560	12,264	26,517	20,801	21,063
1982	89,429	189,477	67,543	56,518	42,357	46,851	26,858	9,343	19,966	15,580
1983	71,989	73,182	154,924	55,105	45,867	34,015	37,074	20,978	7,242	15,424
1984	213,283	58,906	59,824	126,320	44,654	36,715	26,764	28,730	16,113	5,540
1985	155,023	174,557	48,180	48,849	102,734	36,029	29,295	21,145	22,568	12,625
1986	124,957	126,887	142,808	39,368	39,797	83,205	28,940	23,359	16,789	17,885
1987	387,187	102,281	103,817	116,714	32,089	32,268	66,967	23,140	18,607	13,350
1988	214,014	316,953	83,706	84,903	95,292	26,113	26,136	54,018	18,621	14,957
1989	221,331	175,113	259,067	68,230	68,751	76,156	20,488	20,175	41,303	14,177
1990	158,440	181,172	143,287	211,780	55,648	55,817	61,434	16,434	16,129	32,971
1991	166,372	129,674	148,187	117,012	172,280	44,924	44,578	48,600	12,929	12,658
1992	196,123	136,137	106,005	120,833	94,834	137,950	35,367	34,573	37,364	9,901
1993	156,911	160,533	111,386	86,638	98,498	76,902	111,049	28,286	27,547	29,720
1994	159,906	128,442	131,363	91,065	70,680	80,016	62,101	89,205	22,652	22,030
1995	198,983	130,883	105,079	107,332	74,180	57,228	64,239	49,484	70,770	17,936
1996	260,327	162,885	107,108	85,924	87,604	60,322	46,296	51,730	39,741	56,768
1997	209,614	213,082	133,264	87,526	70,016	70,983	48,491	36,956	41,126	31,537
1998	241,870	171,587	174,373	108,969	71,433	56,927	57,408	39,034	29,668	32,974
1999	319,782	197,974	140,383	142,494	88,794	57,880	45,763	45,827	31,033	23,543
2000	234,968	261,768	162,008	114,787	116,287	72,184	46,799	36,825	36,773	24,871
2001	249,945	192,334	214,192	132,435	93,615	94,400	58,219	37,529	29,431	29,346
2002	297,076	204,591	157,373	175,079	107,987	75,962	76,079	46,637	29,957	23,456
2003	360,419	243,181	167,422	128,677	142,873	87,778	61,409	61,205	37,413	24,002
2004	269,641	295,029	198,994	136,881	104,982	116,076	70,897	49,342	49,030	29,930
2005	185,492	220,706	241,378	162,616	111,543	85,071	93,326	56,607	39,237	38,918
2006	332,646	151,838	180,604	197,348	132,676	90,630	68,720	75,001	45,356	31,396
2007	273,741	272,293	124,248	147,656	161,004	107,786	73,193	55,209	60,071	36,278
2008	234,419	224,083	222,834	101,603	120,527	130,951	87,226	58,968	44,364	48,215
2009	315,252	191,870	183,319	182,059	82,752	97,556	105,072	69,450	46,740	35,093
2010	159,547	258,003	156,919	149,657	147,988	66,691	77,681	82,779	54,376	36,493
2011	172,736	130,557	210,935	127,990	121,379	118,685	52,650	60,477	63,924	41,838
2012	198,124	141,386	106,813	172,363	104,282	98,324	95,364	42,001	48,044	50,687
2013	305,145	162,163	115,664	87,265	140,371	84,390	78,865	75,893	33,273	37,981
2014	409,222	249,764	132,671	94,515	71,102	113,717	67,816	62,926	60,302	26,388

Table A8 (cont'd). Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

	females				**numbers at age (1,000s)**						
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
1976	5,748	4,947	4,305	3,772	3,325	2,940	2,594	2,295	2,010	1,756	4,012
1977	4,991	4,197	3,611	3,142	2,753	2,427	2,146	1,894	1,675	1,467	4,210
1978	4,705	3,819	3,211	2,762	2,403	2,106	1,856	1,641	1,448	1,281	4,342
1979	4,779	3,641	2,955	2,484	2,137	1,859	1,629	1,436	1,270	1,120	4,350
1980	5,340	3,623	2,760	2,239	1,883	1,619	1,409	1,235	1,088	962	4,146
1981	7,368	3,963	2,688	2,047	1,661	1,396	1,201	1,045	916	807	3,789
1982	15,745	5,503	2,960	2,007	1,529	1,240	1,043	897	780	684	3,432
1983	12,020	12,141	4,243	2,281	1,547	1,178	956	804	691	602	3,173
1984	11,782	9,176	9,266	3,238	1,741	1,181	899	730	613	528	2,880
1985	4,337	9,218	7,178	7,248	2,533	1,362	924	703	571	480	2,666
1986	9,997	3,433	7,297	5,682	5,737	2,005	1,078	731	557	452	2,490
1987	14,212	7,942	2,727	5,796	4,513	4,557	1,592	856	581	442	2,336
1988	10,727	11,418	6,380	2,191	4,656	3,626	3,661	1,279	688	466	2,232
1989	11,368	8,148	8,671	4,845	1,664	3,536	2,753	2,780	971	522	2,049
1990	11,311	9,068	6,499	6,915	3,864	1,327	2,820	2,196	2,217	775	2,051
1991	25,850	8,864	7,106	5,092	5,419	3,028	1,040	2,209	1,720	1,737	2,214
1992	9,678	19,753	6,772	5,428	3,890	4,139	2,313	794	1,688	1,314	3,018
1993	7,870	7,691	15,696	5,381	4,313	3,091	3,289	1,838	631	1,341	3,442
1994	23,755	6,289	6,146	12,542	4,300	3,446	2,470	2,628	1,468	504	3,822
1995	17,430	18,789	4,974	4,860	9,919	3,400	2,725	1,953	2,078	1,161	3,421
1996	14,381	13,972	15,061	3,987	3,896	7,950	2,726	2,185	1,566	1,666	3,673
1997	45,016	11,400	11,075	11,938	3,160	3,088	6,302	2,160	1,732	1,241	4,232
1998	25,274	36,069	9,134	8,873	9,564	2,532	2,474	5,049	1,731	1,387	4,385
1999	26,148	20,036	28,592	7,240	7,034	7,581	2,007	1,961	4,002	1,372	4,575
2000	18,859	20,942	16,046	22,897	5,798	5,632	6,071	1,607	1,570	3,205	4,762
2001	19,836	15,038	16,697	12,793	18,255	4,623	4,491	4,840	1,281	1,252	6,352
2002	23,374	15,795	11,974	13,294	10,186	14,535	3,681	3,575	3,854	1,020	6,054
2003	18,784	18,714	12,646	9,586	10,643	8,155	11,636	2,947	2,862	3,085	5,664
2004	19,191	15,016	14,959	10,108	7,662	8,507	6,518	9,301	2,355	2,288	6,993
2005	23,740	15,218	11,906	11,861	8,014	6,075	6,745	5,168	7,374	1,867	7,358
2006	31,124	18,982	12,167	9,519	9,482	6,407	4,857	5,392	4,132	5,896	7,376
2007	25,098	24,876	15,170	9,723	7,607	7,578	5,120	3,881	4,309	3,302	10,606
2008	29,104	20,132	19,952	12,167	7,799	6,101	6,078	4,107	3,113	3,456	11,154
2009	38,108	22,996	15,906	15,763	9,613	6,161	4,820	4,802	3,244	2,459	11,543
2010	27,370	29,710	17,926	12,398	12,286	7,492	4,802	3,757	3,742	2,529	10,913
2011	28,038	21,017	22,809	13,761	9,517	9,432	5,751	3,686	2,884	2,873	10,319
2012	33,149	22,209	16,646	18,065	10,899	7,537	7,470	4,555	2,920	2,284	10,448
2013	40,038	26,177	17,536	13,143	14,263	8,605	5,951	5,898	3,596	2,305	10,052
2014	30,100	31,722	20,738	13,892	10,412	11,299	6,817	4,714	4,672	2,849	9,789

Table A8 (cont'd). Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

males	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	98,634	31,566	62,393	44,953	41,781	13,312	6,410	3,819	2,526	1,770
1977	133,932	69,398	22,168	43,647	31,203	28,603	8,930	4,204	2,459	1,607
1978	96,310	94,293	48,806	15,554	30,484	21,615	19,577	6,031	2,808	1,630
1979	103,831	67,816	66,336	34,269	10,880	21,177	14,866	13,315	4,064	1,881
1980	101,050	73,092	47,680	46,517	23,905	7,519	14,438	9,983	8,830	2,673
1981	231,602	71,113	51,357	33,390	32,358	16,432	5,079	9,566	6,509	5,698
1982	89,429	163,004	49,976	35,979	23,246	22,279	11,131	3,379	6,269	4,224
1983	71,989	62,968	114,662	35,083	25,154	16,135	15,300	7,554	2,271	4,186
1984	213,283	50,682	44,280	80,440	24,495	17,415	11,032	10,318	5,036	1,503
1985	155,023	150,205	35,666	31,114	56,347	17,064	12,035	7,556	7,014	3,408
1986	124,957	109,193	105,742	25,080	21,828	39,371	11,852	8,303	5,185	4,796
1987	387,187	88,020	76,878	74,372	17,603	15,265	27,387	8,196	5,714	3,556
1988	214,014	272,776	61,992	54,109	52,278	12,346	10,670	19,071	5,689	3,958
1989	221,331	150,660	191,793	43,476	37,755	36,148	8,424	7,173	12,665	3,749
1990	158,440	155,914	106,086	134,929	30,532	26,430	25,188	5,840	4,952	8,718
1991	166,372	111,585	109,728	74,549	94,536	21,279	18,278	17,269	3,975	3,355
1992	196,123	117,130	78,471	76,984	52,058	65,466	14,556	12,334	11,523	2,633
1993	156,911	138,150	82,467	55,192	54,037	36,409	45,545	10,068	8,489	7,906
1994	159,906	110,537	97,282	58,024	38,769	37,846	25,391	31,610	6,960	5,854
1995	198,983	112,631	77,814	68,403	40,703	27,083	26,277	17,509	21,675	4,755
1996	260,327	140,181	79,320	54,760	48,068	28,530	18,912	18,273	12,134	14,988
1997	209,614	183,369	98,689	55,781	38,425	33,598	19,828	13,060	12,552	8,307
1998	241,870	147,669	129,135	69,449	39,196	26,930	23,457	13,784	9,048	8,676
1999	319,782	170,368	103,961	90,813	48,732	27,397	18,716	16,199	9,469	6,194
2000	234,968	225,279	119,978	73,157	63,809	34,150	19,124	13,008	11,218	6,542
2001	249,945	165,520	158,627	84,404	51,373	44,666	23,793	13,255	8,977	7,720
2002	297,076	176,067	116,543	111,584	59,261	35,949	31,102	16,477	9,137	6,170
2003	360,419	209,282	123,990	82,010	78,401	41,525	25,090	21,612	11,408	6,311
2004	269,641	253,901	147,374	87,241	57,609	54,915	28,963	17,418	14,944	7,868
2005	185,492	189,931	178,751	103,641	61,219	40,270	38,169	20,004	11,967	10,234
2006	332,646	130,672	133,748	125,773	72,806	42,882	28,090	26,501	13,835	8,256
2007	273,741	234,335	92,017	94,105	88,350	50,994	29,907	19,498	18,322	9,541
2008	234,419	192,849	165,032	64,758	66,136	61,937	35,620	20,806	13,519	12,676
2009	315,252	165,112	135,754	116,032	45,421	46,188	42,984	24,547	14,255	9,228
2010	159,547	222,007	116,183	95,366	81,240	31,614	31,870	29,373	16,640	9,614
2011	172,736	112,333	156,147	81,538	66,637	56,328	21,672	21,572	19,675	11,072
2012	198,124	121,670	79,082	109,803	57,209	46,567	39,133	14,958	14,809	13,460
2013	305,145	139,547	85,648	55,599	77,009	39,948	32,309	26,958	10,244	10,103
2014	409,222	214,936	98,241	60,228	39,011	53,818	27,756	22,303	18,510	7,009

Table A8 (cont'd). Estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

males	numbers at age (1,000s)										
	11	12	13	14	15	16	17	18	19	20	21
1976	1,282	950	712	537	407	310	235	179	135	102	123
1977	1,119	808	598	447	337	256	195	148	113	85	141
1978	1,061	738	532	393	294	222	168	128	97	74	149
1979	1,089	708	491	354	262	196	148	112	85	65	148
1980	1,232	712	462	321	231	171	128	96	73	56	139
1981	1,716	788	455	295	205	148	109	82	62	47	124
1982	3,679	1,105	507	292	190	132	95	70	52	40	110
1983	2,812	2,444	734	337	194	126	87	63	47	35	99
1984	2,760	1,850	1,607	482	221	127	83	57	41	31	88
1985	1,014	1,860	1,246	1,082	325	149	86	56	39	28	80
1986	2,326	692	1,268	849	737	221	101	58	38	26	73
1987	3,284	1,591	473	867	581	504	151	69	40	26	68
1988	2,461	2,272	1,100	327	599	401	349	105	48	28	65
1989	2,597	1,612	1,486	719	214	392	262	228	68	31	61
1990	2,577	1,784	1,107	1,020	494	147	269	180	156	47	63
1991	5,893	1,740	1,204	746	688	333	99	181	121	105	74
1992	2,214	3,881	1,145	792	491	452	219	65	119	80	118
1993	1,804	1,515	2,655	783	541	336	309	150	45	82	135
1994	5,444	1,241	1,042	1,826	538	372	231	213	103	31	149
1995	3,992	3,709	845	710	1,243	367	253	157	145	70	122
1996	3,284	2,755	2,559	583	490	858	253	175	108	100	133
1997	10,242	2,242	1,880	1,746	398	334	585	173	119	74	159
1998	5,735	7,067	1,547	1,297	1,204	274	230	404	119	82	160
1999	5,929	3,916	4,823	1,055	885	822	187	157	275	81	166
2000	4,274	4,089	2,699	3,324	727	610	566	129	108	190	170
2001	4,496	2,935	2,807	1,853	2,281	499	418	389	89	74	247
2002	5,298	3,083	2,012	1,924	1,270	1,564	342	287	266	61	220
2003	4,257	3,653	2,125	1,386	1,326	875	1,077	236	198	184	194
2004	4,347	2,930	2,514	1,462	954	912	602	741	162	136	259
2005	5,378	2,969	2,000	1,716	998	651	622	411	506	111	270
2006	7,051	3,703	2,044	1,377	1,181	687	448	428	283	348	262
2007	5,686	4,852	2,548	1,406	947	812	472	308	295	194	419
2008	6,594	3,927	3,351	1,759	971	654	561	326	213	203	424
2009	8,635	4,487	2,671	2,279	1,196	660	444	381	222	145	426
2010	6,206	5,800	3,012	1,793	1,529	802	443	298	256	149	383
2011	6,373	4,107	3,835	1,991	1,185	1,010	530	293	197	169	351
2012	7,560	4,348	2,801	2,615	1,357	807	689	361	199	134	355
2013	9,164	5,142	2,956	1,904	1,777	922	549	468	246	136	332
2014	6,900	6,253	3,507	2,016	1,298	1,212	629	374	319	167	319

Table A9 (Table 6.12 with logistic fishery selectivity). Estimated age 2 recruitment of arrowtooth flounder (thousands of fish) from the 2012 and 2014 stock assessments. Average over all years from 2014 assessment = 310,216.

Year class	2012 Assessment	2014 Assessment
1974	230,069	68,240
1975	297,213	150,077
1976	245,370	203,886
1977	260,994	146,632
1978	466,116	158,049
1979	278,861	153,779
1980	279,797	352,481
1981	295,261	136,150
1982	261,457	109,587
1983	512,622	324,762
1984	300,425	236,080
1985	424,330	190,301
1986	454,913	589,729
1987	228,364	325,773
1988	469,933	337,086
1989	570,669	241,259
1990	346,025	253,267
1991	608,477	298,683
1992	709,081	238,979
1993	533,246	243,514
1994	590,261	303,066
1995	484,687	396,451
1996	422,013	319,256
1997	461,524	368,342
1998	440,673	487,047
1999	501,638	357,854
2000	439,534	380,658
2001	375,534	452,463
2002	369,206	548,930
2003	381,796	410,637
2004	327,427	282,510
2005	322,479	506,628
2006	346,488	416,932
2007	389,187	356,982
2008		480,010
2009		242,890

Figures

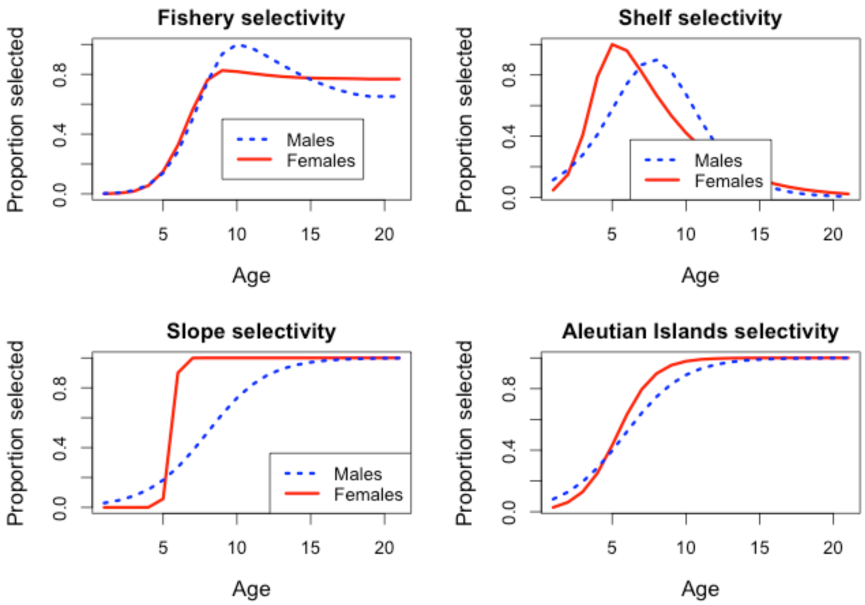

Figure A1. Age-specific fishery selectivity (top left panel), shelf survey selectivity (top right panel) slope survey selectivity (bottom left panel) and Aleutian Islands survey selectivity (bottom right panel), by sex, estimated within the stock assessment model. Fishery selectivity estimated non-parametrically for all ages.

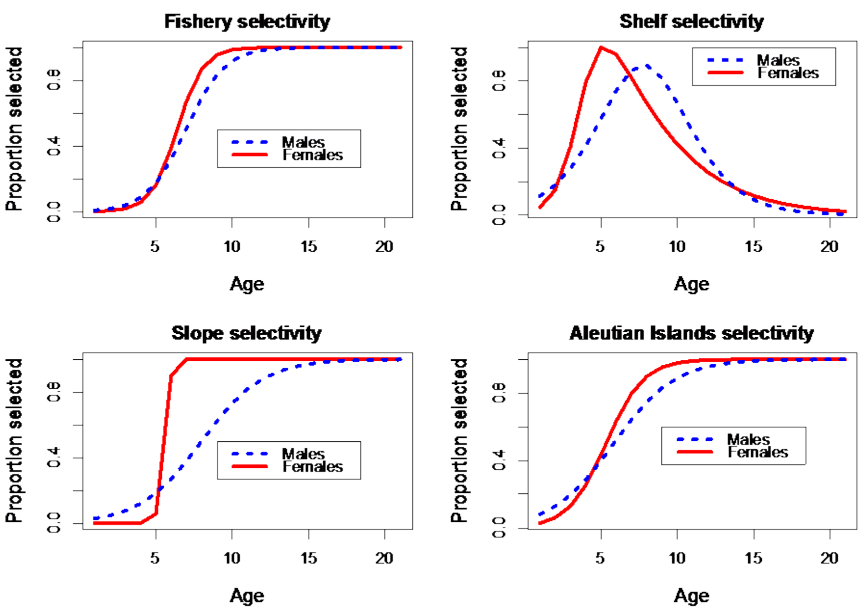

Figure A2. (Figure 6.8 with logistic fishery selectivity) Age and sex-specific fishery selectivity (top left panel), shelf survey selectivity (top right panel) slope survey selectivity (bottom left panel) and Aleutian Islands survey selectivity (bottom right panel), by sex, estimated within the stock assessment model. Selectivity is estimated using a two parameter ascending logistic function.

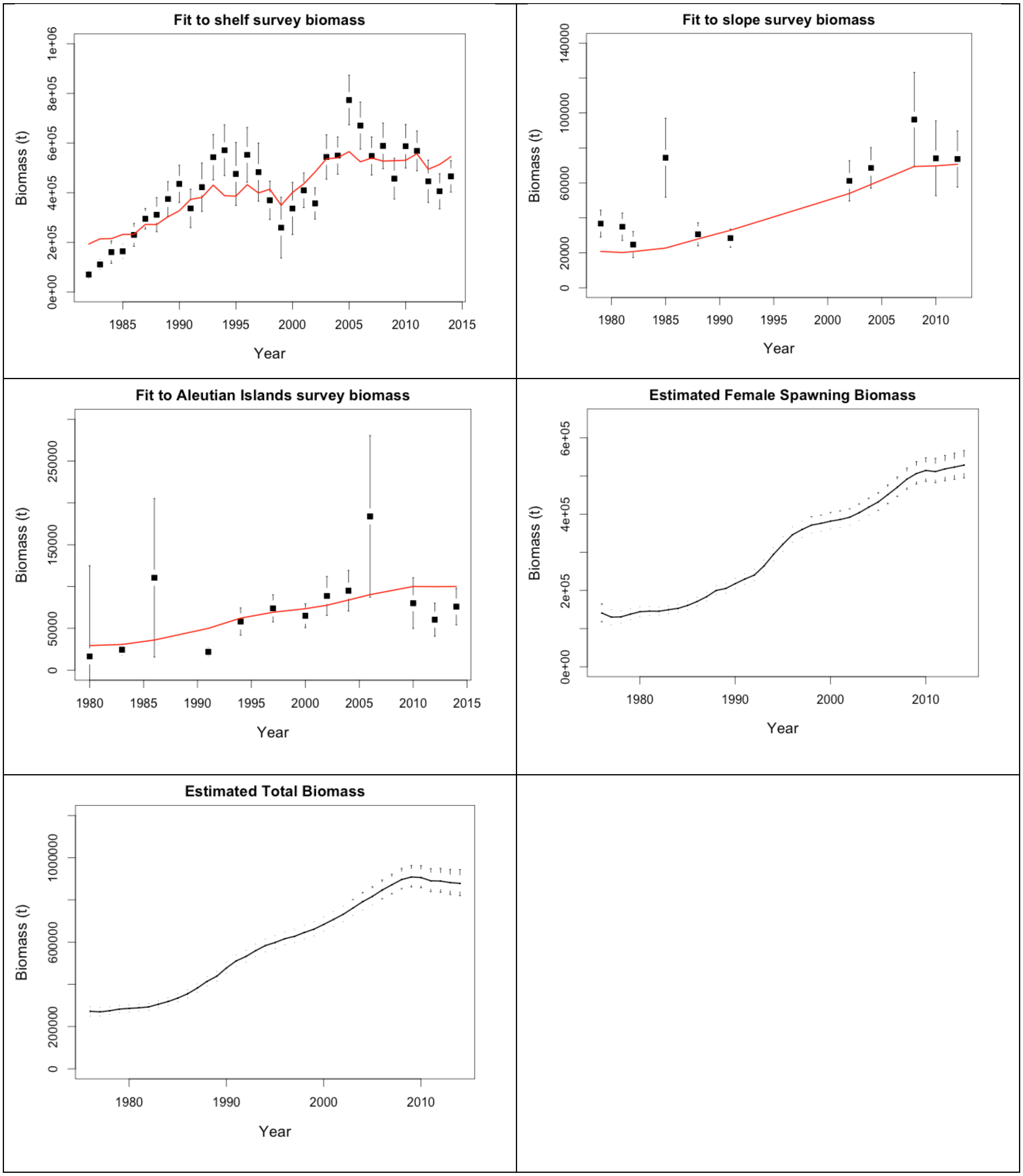

Figure A3 (Figure 6.9 with logistic fishery selectivity). Stock assessment model results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), estimate of female spawning biomass with $B_{35\%}$ and $B_{40\%}$ indicated (middle right panel), 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.

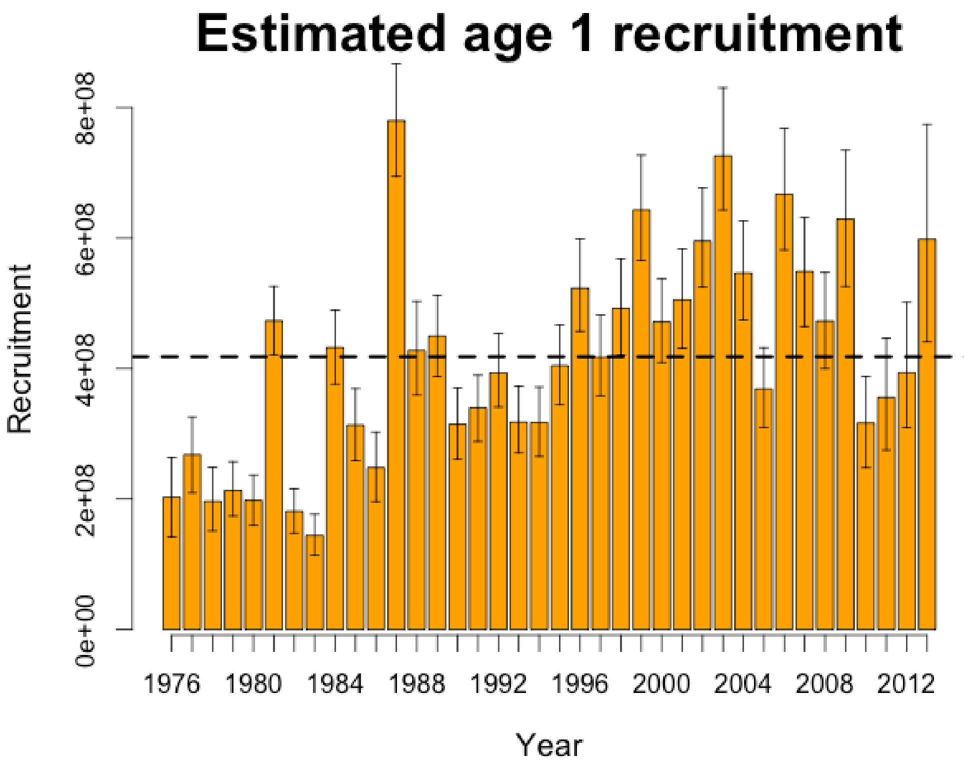

Figure A4 (Figure 6.11 using logistic fishing selectivity). Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model.

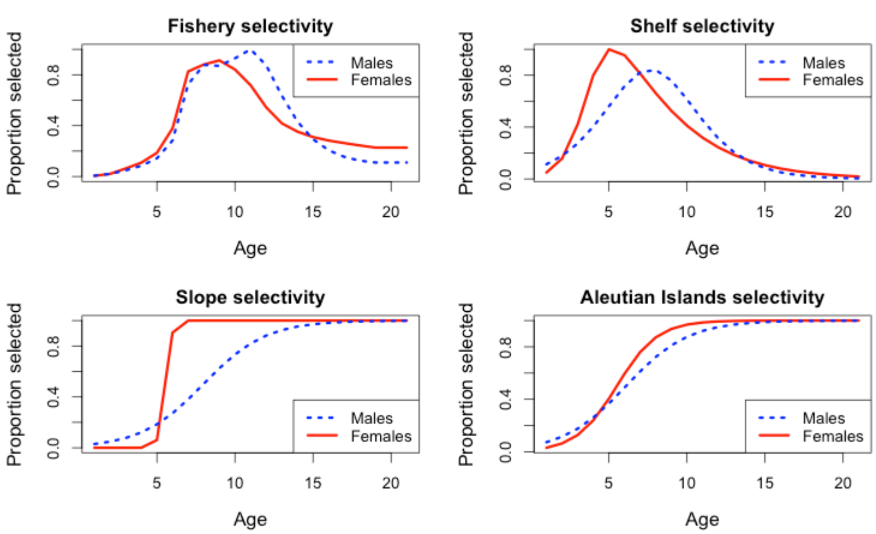

Figure A5 (Figure 6.8 with non-parametric fishery selectivity and equal weights on smoothing likelihood components). Selectivity estimated by the model when non-parametric selectivity was used, and all weights were equal to 1.

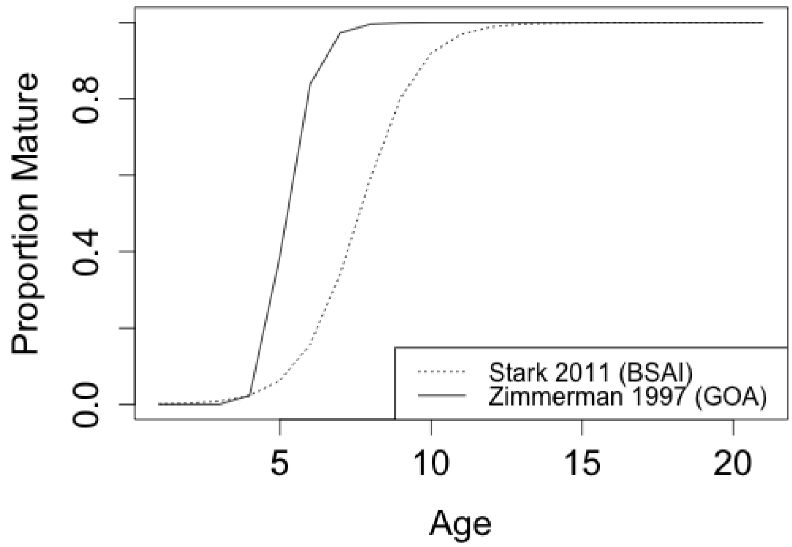

Figure A6. Stark (2011) parameters indicate that ATF mature at a younger age than estimates from the Zimmermann (1997) study.

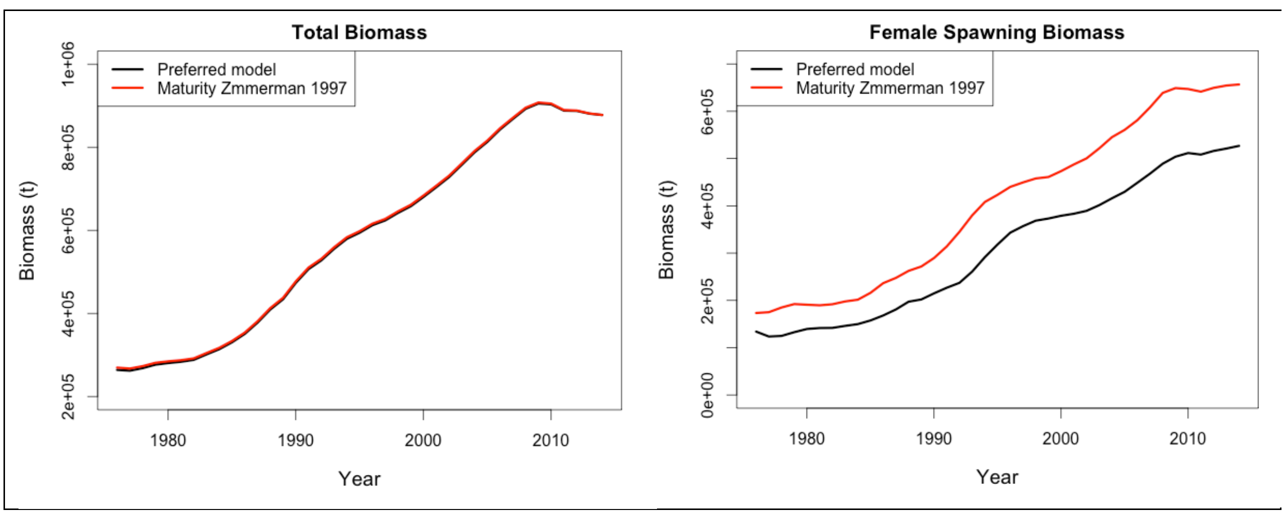

Figure A7. Total biomass (left) and female spawning biomass (right) for maturity estimated by Stark (2011) as in the preferred model, and by Zimmerman (1997).