Chapter 6. Arrowtooth Flounder

By

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Executive Summary

The following changes have been made to this assessment relative to the November 2011 SAFE.

Changes to the input data

1) Since the 2010 SAFE, input data includes arrowtooth flounder only as this assessment is no longer for the *Atheresthes* complex.

2) The following new data was included in the model:

- Size compositions from the 2012 Eastern Bering Sea shelf survey, 2012 Aleutian Islands survey, and 2012 Eastern Bering Sea slope survey.
- Biomass point-estimates and standard errors for the 2012 Eastern Bering Sea shelf survey, 2012 Aleutian Islands survey, and 2012 Eastern Bering Sea slope survey.
- Fishery size composition for 2010 and 2011 (2010: n = 3402 females and n=1467 males, 2011: n=1004 females, n = 820 males).
- Estimates of catch and discard rate through October 15, 2012.
- Estimates of the retained and discarded portion of the 2011 and 2012 catch through October 15, 2012.
- Female natural mortality was changed to values in Stark 2008.

3) Age data is currently being prepared from the 2012 shelf, slope, and Aleutian Islands surveys to be incorporated in the next assessment.

Assessment results

1) The projected age 1+ total biomass for 2013 is 1,021,060 t.

2) The projected female spawning biomass for 2013 is 638,377 t.

3) The recommended 2013 ABC is 111,204 t based on an $F_{0.40}$ (0.17) harvest level.

4) The 2013 overfishing level is 131,985 t based on a $F_{0.35}$ (0.21) harvest level.

Quantity/Status	Last year 2012	2013	This year 2013	2014
M (natural mortality)	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+)	1,127,050	1,129,760	1,021,060	1,014,250
Female spawning biomass (t)				
Projected	818,286	811,932	638,377	642,518
$B_{100\%}$	702,721	--	616,191	--
$B_{40\%}$	281,088	--	246,476	--
$B_{35\%}$	245,852	--	215,667	--
F_{OFL}	0.27	0.27	0.21	0.21
$maxF_{ABC}$ (maximum allowable = F40%)	0.22	0.22	0.17	0.17
Specified/recommended F_{ABC}	0.22	0.22	0.17	0.17
Specified/recommended OFL (t)	181,000	186,000	131,985	134,443
Specified/recommended ABC (t)	150,000	152,000	111,204	112,484
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 Comments from the Plan Teams and SSC

In 2011, the SSC and Plan Team recommended examining a model that estimated male natural mortality internally. This model was implemented and resulted in a higher likelihood. However, the original model was retained because the AIC value was higher for the test model. Further, the original model with male M=0.35 provided 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 mortality and not availability.

Introduction

The arrowtooth flounder (*Atheresthes stomias*) is a relatively large flatfish which occupies continental shelf waters almost exclusively until age 4, but at older ages occupies both shelf and slope waters. Two species of *Atheresthes* occur in the Bering Sea. Arrowtooth flounder and Kamchatka flounder (*A. evermanni*) are very similar in appearance and were not routinely distinguished in the commercial catches until 2007 (Fig. 6.1). Until about 1992, these species were not consistently separated in trawl survey catches and were combined in the arrowtooth flounder stock assessment. However, managing the two species as a complex became undesirable in 2010 due to the emergence of a directed fishery for Kamchatka flounder in the BSAI management area. Since the ABC was determined by the large amount (~93%) of arrowtooth flounder relative to Kamchatka flounder in the species complex, the possibility arose of an overharvest of Kamchatka flounder as the complex ABC exceeded the Kamchatka flounder biomass. Separate management of arrowtooth flounder and Kamchatka flounder began in the 2011fishing season, and they were assessed separately starting in 2010 (see Chapter 6.5).

Arrowtooth flounder are found throughout the BSAI management area; however, their abundance in the Aleutian Islands region is lower than in the eastern Bering Sea. The resource in the EBS and the Aleutians are managed as a single stock although the stock structure has not been studied.

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 of the fisheries whereas arrowtooth flounder were caught as bycatch. Starting in 1986, management has been by accomplished individually for Greenland turbot and arrowtooth flounder due to considerable differences in their stock condition.

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.

Catch History

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) and the resource has remained lightly exploited with catches (extrapolated for arrowtooth only) averaging 12,382 t from 1976-2012. This decline 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. The regional office started providing separate catch statistics for arrowtooth and Kamchatka flounder in 2011. Estimated proportion of Kamchatka flounder in the combined catch of arrowtooth and Kamchatka are shown in Table 6.2, and Table 6.1 provides catch estimates for arrowtooth only. Total catch reported through October 15, 2012 is 21,189 t (well below the 2012 ABC of 149,683 t). The NMFS AKRO BLEND/Catch Accounting System reports indicate that bottom trawling accounted for 90% of the 2012 catch (3% by pelagic trawl and 4% by hook and line).

Although research has been conducted on their commercial utilization (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 1985-2011 are shown in Table 6.2, and include Kamchatka flounder as well as arrowtooth flounder. With the advent of Amendment 80 fishing practices in 2008 the percentage of arrowtooth flounder retained in catches has increased to 92%. 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 size composition and fishery length-frequencies from observer sampling. Age data from the 1996 and 1998 shelf surveys are included as well.

Fishery Catch and Catch-at-Age

Fishery catch data from 1976 – October 15, 2012 (Table 6.1) and fishery length-frequency data from 1978-91 and 2000-2011 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 2007-2012. 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”.

Survey CPUE

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 (Fig. 6.2). 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 2003-2012 (between 8-11 kg/ha), although the 2005 CPUE of 15.39 kg/ha was the highest ever estimated from the shelf survey. The 2012 survey estimates for all three surveys (shelf, slope, and Aleutian Islands) are all down from previous estimates (Figure 6.3).

Absolute Abundance from Trawl Surveys

Biomass estimates (t) for arrowtooth flounder from the standard survey area in the eastern Bering Sea and Aleutian Islands region are shown in Table 6.3. Table 6.5 lists the total research catch of these species. Although the standard sampling trawl 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 further and peaked in 2005 at a biomass of 722,209 t. In 2006 - 2007 the estimates declined slightly but were still at high levels. Slope survey biomass has remained between 400,000 t – 550,000 t through 2012. 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) is the lowest since 2002. Similarly, the 2012 Aleutian Islands survey estimate of 60,371 t (s.e. 10,118) is the lowest since 1994, and the slope survey estimate of 73,676 t (s.e. 8199) is the lowest since 2004.

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).

Trawl surveys were intermittently conducted over the continental slope in 1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010 and 2012. The eastern Bering Sea continental slope was surveyed in 2002 and 2004, 2008, 2010, and 2012 at depths ranging from 200 - 1,200 meters. 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 polyethelene Nor' Eastern trawl with bobbin roller gear. Slope surveys conducted between 1979 and 1985 sampled depths ranging from 200-1000 m. These surveys show that arrowtooth flounder biomass increased significantly from 1979 to 1985. The biomass estimate in 1988 and 1991 were lower. However, sampling in 1988 and 1991 (200-800 m) was not as deep as in 1985 and earlier years (200-1,000 m), and used different gear altogether. 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. The 2012 slope survey estimate of 74,065 t is slightly less than the 2012 estimate of 74,065 t (Figure 6.3).

The arrowtooth flounder abundance estimated from the 2012 Aleutian Islands trawl survey is 60,371 t, and is well below the record high 2006 estimate, which was a record high. Results from trawl surveys in the three areas indicate that approximately 14% of the arrowtooth flounder biomass is located in the Aleutian Islands in any year. In this assessment all 11 surveys conducted in the Aleutian Islands are included in the base model (Figure 6.3).

Weight-at-age, Length-at-age and Maturity-at-age

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 1995) are as follows:

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

Based on 282 observations during a 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 2008). 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 (Table 3) and *a* represents age. The parameters A and B are weighted averages of two separate analyses performed at different times of the year (February, n=301, and July, n=226; Stark 2008). The weight-at-age and maturity-at age schedules used in the model are shown in Table 6.4.

Analytic Approach

Model Structure

This stock assessment utilizes AD Model Builder software 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 6.6).

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 (1996 and 1998)	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
37	25	2	56	120

The recruitment parameters are comprised of 21 initial ages in 1976 and 37 subsequent age sex-specific recruitment estimates from 1976-2012. Recruitment in 2012 was set at the average from 1976-2012. The difference in the number of parameters estimated in this assessment compared to last year can be accounted for by an additional year (2012) of shelf survey data, slope survey data, Aleutian Islands survey data, and fishery catch and the estimate of one more year of recruitment. In addition, two more parameters 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).

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 Independently

Catchability

Attempts to estimate catchability by profiling over fixed q values in a previous assessment (Wilderbuer and Sample 1995) were unsuccessful as estimated values always reached the upper bounds placed on the parameter. The results indicated q values as high as 2.0 which suggests that more fish are caught in the survey trawl than are present in the "effective" fishing width of the trawl (ie. 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. Although arrowtooth flounder were not one of the seven flatfish species considered in this experiment, it seems reasonable to assume that they also exhibit this same behavior, and should be included in the catchability model.

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 (Fig. 6.2) 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 2012, the temperature anomaly was the lowest it has been since 1999; resulting in a similarly low estimate of q (Fig. 6.5).

Parameters Estimated Conditionally

Year class strengths

The population simulation specifies the number-at-age in the beginning year of the simulation, the number of recruits in subsequent years, and the survival rate for each cohort as it moves through the population calculated from the population dynamics equations (see Table 6.6 and Table 6.7).

Fishing Mortality

The fishing mortality rates (F) for each age and year are calculated to approximate the catch weight by solving for F while still allowing for observation error in catch measurement. 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.

At the present time there is no directed fishery for arrowtooth flounder in the eastern Bering Sea. Length measurements collected from the fishery represent opportunistic samples of arrowtooth flounder taken as bycatch. This results in sample size problems which make estimates of fishery selectivity unreliable. Also, we felt that a directed fishery would likely target a different segment of the stock. Accordingly, the shape of the selectivity curve was fixed asymptotic for older fish in the fishery since a directed fishery would presumably target larger fish. This also allowed for a realistic calculation of exploitable biomass from the model estimate of total biomass and reasonable fishing mortality values.

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 (Fig. 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 (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 1982-2008, 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.

Model Evaluation

In this year's assessment, model runs were made using the shelf and slope surveys and Aleutian Islands surveys as described above with female natural mortality fixed at 0.2 and male natural mortality fixed at 0.35. As in past years, it is very 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. Although the hypothesis of lower availability for males cannot be ruled out without further research, age data from Gulf of Alaska trawl surveys indicate that males do not live past 17 years whereas many female arrowtooth flounder have been aged as high as 25 years. This result is what would be expected in age compositions from a population with a higher M for males than females and is the view supported by the authors in this assessment (and also in the Gulf of Alaska arrowtooth flounder assessment (Turnock et al. 2007).

In past years, male natural mortality was also profiled over a range of values for two alternative levels of female natural mortality to discover if our fits to some of the likelihood components could be improved by a consideration of alternative estimates of female (and male) natural mortality. For these model runs female natural mortality was fixed at 0.17 and 0.24 to bracket the value of 0.2 that has become the base model in the attempt to model differential sex-specific natural mortality. Results from these runs are evaluated in terms of the total –log(likelihood) of all the data components and are shown in Figure 6.7. Profiling over female natural mortality values of 0.17 returns comparable fits to the female M=0.2 model runs over the range of male M values of 0.21-0.26 but these runs did not estimate maximum male selectivity at values close to 1.0. When this value was obtained, in the runs where male M = 0.33-0.34, the fit to the total –log(likelihood) suffered a larger degradation in model fit than female M = 0.2 model evaluation. The runs with female M = 0.24 had better results in terms of total fit to the components but did not include estimates of maximum shelf selectivity which were close to 1.0. The run with female M set at 0.2 and male M set at 0.35 gave the best fit and satisfied the male selectivity requirement with a maximum of 0.93 at age 8 for shelf males. Likelihood values for all the data components are shown below for both models from runs made with male natural mortality rates ranging from 0.27 – 0.36 with equal emphasis placed on all data components.

female M = 0.2					**male natural mortality values**					
	0.27	**0.28**	**0.29**	**0.3**	**0.31**	**0.32**	**0.33**	**0.34**	**0.35**	**0.36**
Likelihood component										
shelf biomass	98.5	98.8	99.1	99.4	99.7	99.9	100.2	100.4	100.6	100.8
slope biomass	70.2	69.1	68.2	67.4	66.9	66.4	66.1	65.9	65.8	65.7
Aleutian biomass	64.0	63.5	62.9	62.3	61.7	61.1	60.5	59.8	59.2	58.6
shelf length comp	1680.3	1684.5	1688.8	1693.2	1697.7	1702.3	1707.0	1711.9	1716.9	1722.0
slope length comp	769.6	773.0	777.8	783.8	790.8	798.8	807.8	817.6	828.3	839.6
Aleutian length comp	816.0	823.1	831.7	841.6	852.9	865.3	878.8	893.4	908.8	925.1
recruitment	28.8	28.9	29.0	29.2	29.5	29.8	30.2	30.5	30.9	31.3
sex ratio	105.2	94.2	84.2	75.1	66.9	59.4	52.5	46.4	40.8	35.8
shelf age comps	135.6	136.2	136.8	137.4	137.9	138.5	139.0	139.6	140.1	140.6
total likelihood	3768.2	3771.4	3778.6	3789.6	3804.0	3821.6	3842.2	3865.5	3891.4	3919.6
male max shelf selectivity (age)										
	0.57 (7)	0.61 (7)	0.64 (7)	0.69 (7)	0.72 (7)	0.76 (8)	0.81 (8)	0.87 (8)	0.93 (8)	1 (8)

At increasing values of male M the estimated sex ratio more closely matches the observed sex ratio and maximum male selectivity for the shelf survey increases. By increasing the value of male M there is a trade-off between fitting the time series of survey length compositions and the observed sex ratio. Model runs with increasing emphasis placed on fitting the observed sex ratio provide the best fit to all the observed data components at higher values of male M (best fit M=0.3 at emphasis =15, M=0.31 at emphasis = 20, and M=0.32 at emphasis =30).

This year, natural mortality was also estimated within a separate model run while setting female natural mortality to be 0.2. The result was 0.41 ($\sigma^2 =$ 0.0302). Although that value was fairly close to the previously estimated value of 0.35, the AIC was higher for that model than for the original model. The Akaike Information Criterion (AIC) for the “M estimation model” was 224.95, versus 223.06 for the “original” model. Because the original model had a better fit to the data, the original model was used and male natural mortality was set at 0.35.

The natural mortality value for males is unknown but has been estimated to be higher than for females from a suite of natural mortality estimation methods (Wilderbuer and Turnock 2009). 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. For this run the maximum shelf selectivity occurs at 0.93 for age 8 fish. This value is close to 1.0 but still allows for some overlap with slope survey size composition observations where fish of this age are present in both shelf and slope surveys. 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.

Model Results

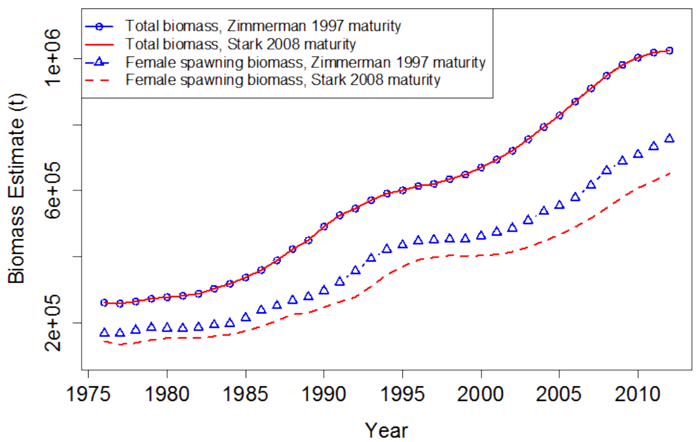
Fishing mortality and selectivity

The stock assessment model estimates of the annual fishing mortality on fully selected ages and the estimated annual exploitation rates (catch/total biomass) are given in Table 6.8. The average exploitation rate has been at a low level, less than 3%, from 1977-2011 due to the relative undesirability of arrowtooth flounder as a commercial product and the additional constraints of the halibut bycatch limits. Age-specific selectivity estimated by the model (Table 6.9, Fig. 6.8) indicate that arrowtooth flounder are 50% selected by the fishery at about 7- 8 years of age and are fully selected by ages 14 and 11, for males and females, respectively.

Abundance Trend

Although absolute estimated numbers for female spawning and total biomass are lower than last year’s model, this year’s model output shows a similar trend of increasing biomass. The absolute numbers of female spawning biomass and total biomass are lower in this year’s model due to the difference in maturity ogives; maturity from Stark 2008 was used rather than estimates from Zimmerman 1997 that been used previously (Table 6.4). Female spawning biomass-at-age is estimated at a significantly lower level than it was previously and total biomass is slightly lower. The change in maturity-at-age resulted in signficantly lower values of female spawning biomass (see figure below and Table 6.10). The change in maturity-at-age estimates was implemented because new values are based on more recent work and more samples (n=282 vs. n=527).

Estimates indicate that arrowtooth flounder total biomass increased approximately four fold from 1976 to the 2012 value of 1.02 million t (Fig. 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 the past few years to highest level estimated in 2012, largely from the influence of the largest shelf survey biomass estimates ever recorded in 2005 and 2006 (Table 6.3) and consecutive years of good recruitment. Female spawning biomass is also estimated to be at a high level, 652,156 t in 2012, also the highest level estimated from 1976 to the present in the current model (Table 6.10). 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 currently observed but underestimates the increase from 1993-97 and 2005-2006 and does not fit the low 2009 estimate (Fig. 6.9). Consideration of the relationship between annual bottom water temperature and catchability improved the fit to the shelf survey biomass and was modeled so that catchability would co-vary with water temperature. The model indicates an increasing biomass trend on the slope and provides good fits to the 2002, 2004, 2008 and 2010 trend in survey estimates (Fig. 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 increasing trend in this index was fit very well.

The model provides reasonable fits to the survey shelf size composition time-series since 1981 for males and females, which are shown in figure 6.10. Reasonable fits also resulted for slope survey and Aleutian Islands size composition observations and the 1996 and 1998 shelf survey age compositions (Fig. 6.10). The shelf survey has the best fit, due to the fact that there are more years of data for that survey.

Recruitment Trends

Increases in abundance from 1983-95 were the result of 5 strong year-classes spawned in 1980, 1983, 1986, 1987 and 1988 (Fig. 6.11, Table 6.12). From 1989-1993 recruitment was below average and stock abundance leveled-off. Recent increases in arrowtooth flounder biomass can be attributed to the strong 1995, 1997 and very strong 1998 year classes. Small fish present in the three shelf surveys from 2003-2005 (Fig. 6.11) indicate strong 2000 - 2005 year classes, as also estimated by the model as very strong in 2002 and 2005 (Fig. 6.4). These fish are now increasing the stock size further. Above average recruitment from 9 consecutive year classes (1995-2003) have caused the projected values for 2010-2013 to remain at a high level.

The posterior distribution of the female spawning biomass estimate for 2012 (Fig. 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.

Acceptable Biological Catch

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 as a result of a series of above average year-classes spawned from 1995-2003, and minimal commercial harvest. They are currently estimated to be at a high and increasing level. **The estimate of projected 2012 total biomass from the stock assessment projection model is 1,012,060 t and the female spawning biomass is estimated at 638,377 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 1997-2008 are used to calculate the average equilibrium recruitment. Using the time-series of age 1 recruitment from 1974-2007 from the stock assessment model results in an estimate of $B_{0.40}$ = 281,088 t. The stock assessment model estimates the 2012 level of female spawning biomass at 792,769 t (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and $B>B_{0.40}$ (792,769 > 281,088), arrowtooth flounder reference fishing mortality is defined in tier 3a. For the 2012 harvest: F_{ABC} □$F_{0.40}$ = 0.22 and $F_{overfishing} = F_{0.35}$ = 0.27 (full selection F values).

Acceptable biological catch is estimated for 2012 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2012 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 2013 ABC of 111,204 t.**

The overfishing level is estimated for 2013 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 2013 OFL of 131,985 t.**

The potential yield of arrowtooth flounder in 2013 is summarized as follows:

F level	Exploitation rate	Potential yield
$F_{overfishing}$	0.21	131,985 t
$F_{0.40}$	0.17	111,204 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 2012 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2013 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2012. 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 2013, 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 2013 recommended in the assessment to the *max* F_{ABC} for 2013. 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 2008-2012 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 2012 and above its MSY level in 2022 under this scenario, then the stock is not overfished.

Scenario 7: In 2012 and 2013, 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 2024 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 2013, it does not provide the best estimate of OFL for 2014, because the mean 2014 catch under Scenario 6 is predicated on the 2013 catch being equal to the 2013 OFL, whereas the actual 2013 catch will likely be less than the 2013 ABC. Therefore, the projection model was re-run with the 2013 and 2014 catch fixed equal to the 2012 catch to calculate the 2014 ABC and OFL.

Year	Catch	ABC	OFL
2013	21,189	111,203	131,985
2014	21,189	112,484	134,443

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 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%) (Fig. 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 (Fig 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 euphausids (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 (Fig 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, euphausids 25%, juvenile Pollock 22% and then polychaetes, sculpins and mysids accounting for another 10% (Fig 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 (Fig 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 (Fig. 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% (Fig 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 Fig 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. 2002). 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 Appendix 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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Table 6.1. All nation total combined catch (t) of arrowtooth and Kamchatka flounder in the eastern Bering Sea and Aleutian Islands region[a], 1970-2012. Catches since 1990 are not reported by area. Total catch of both arrowtooth and Kamchatka flounder are shown in the "combined" total, and the extrapolated total of arrowtooth only is under "ATF est".

	Eastern Bering Sea				Aleutian Islands Region				Combined	ATF est.
Year	Non-U.S. fisheries[b]	U.S. J.V.	U.S DAH	Total	Non-U.S. fisheries	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									21,912	14,243
2009									30,411	17,638
2010									39,416	17,737
2011									20,612	13,398
2012**									21,189	14,832

[a]Catches from data prior to 1990 are on file Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115. [b]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. **Catch information through 15 October, 2012 (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 1985-2012. 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.

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	14,681	7,231	21,912	67	0.35
2009	22,200	8,211	30,411	73	0.42
2010	28,380	11,036	39,416	72	0.55
2011	17,314	3,298	20,612	84	0.35
2012	19,494	1,695	21,189	92	0.30

1990 retained rate was applied to the 1985-89 reported catch
and 2012 catch is through 10/15/2012. Source: Observer Interface Dataset.

Table 6.3 Estimated arrowtooth flounder biomass from trawl surveys conducted on the Eastern Bering Sea shelf, slope and the Aleutian Islands. The 1988 and 1991 slope estimates were from the depth ranges of 200-800 m while earlier slope estimates were from 200-1,000 m. The 2002 and 2004 slope estimate was 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

Table 6.4—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 (previous)	female maturity at age (Stark 2008)
1	0.02	0.01	0	0
2	0.04	0.04	0	0.01
3	0.11	0.09	0	0.02
4	0.22	0.17	0.02	0.04
5	0.36	0.27	0.39	0.12
6	0.55	0.39	0.84	0.28
7	0.76	0.52	0.97	0.54
8	0.99	0.66	1.00	0.78
9	1.25	0.80	1.00	0.91
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 6.5—Total tonnage of the research catch for arrowtooth flounder and Kamchatka flounder. Data for 1991-2011 is from AKFIN, Noncommercial Fishery Catch (accessed October 15, 2012). Data for 2012 is 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	14.5

Table 6.6--Key equations used in the population dynamics model.

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

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

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

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

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

Table 6.7--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	0.124	0.068
1977	0.075	0.041
1978	0.063	0.036
1979	0.085	0.049
1980	0.107	0.061
1981	0.1	0.056
1982	0.066	0.037
1983	0.076	0.043
1984	0.049	0.028
1985	0.036	0.02
1986	0.032	0.019
1987	0.02	0.012
1988	0.078	0.044
1989	0.027	0.015
1990	0.046	0.025
1991	0.073	0.039
1992	0.032	0.018
1993	0.025	0.015
1994	0.036	0.023
1995	0.022	0.014
1996	0.033	0.022
1997	0.022	0.015
1998	0.034	0.022
1999	0.024	0.015
2000	0.029	0.018
2001	0.03	0.019
2002	0.025	0.015
2003	0.026	0.016
2004	0.035	0.021
2005	0.026	0.015
2006	0.024	0.014
2007	0.019	0.012
2008	0.024	0.015
2009	0.029	0.018
2010	0.028	0.018
2011	0.02	0.013
2012	0.022	0.014

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	0.00	0.01	0.05	0.11	0.00	0.03	0.03	0.08
2	0.01	0.02	0.15	0.18	0.00	0.05	0.06	0.13
3	0.02	0.04	0.41	0.28	0.00	0.08	0.13	0.20
4	0.06	0.09	0.79	0.41	0.00	0.12	0.25	0.29
5	0.16	0.17	1.00	0.57	0.06	0.18	0.43	0.40
6	0.39	0.32	0.96	0.74	0.90	0.27	0.63	0.52
7	0.67	0.51	0.82	0.86	1.00	0.38	0.80	0.64
8	0.87	0.70	0.67	0.89	1.00	0.50	0.90	0.75
9	0.96	0.84	0.53	0.82	1.00	0.62	0.95	0.83
10	0.99	0.92	0.42	0.67	1.00	0.73	0.98	0.89
11	1.00	0.96	0.33	0.50	1.00	0.82	0.99	0.93
12	1.00	0.98	0.26	0.35	1.00	0.88	1.00	0.96
13	1.00	0.99	0.20	0.23	1.00	0.92	1.00	0.97
14	1.00	1.00	0.15	0.15	1.00	0.95	1.00	0.98
15	1.00	1.00	0.12	0.09	1.00	0.97	1.00	0.99
16	1.00	1.00	0.09	0.06	1.00	0.98	1.00	0.99
17	1.00	1.00	0.07	0.04	1.00	0.99	1.00	1.00
18	1.00	1.00	0.05	0.02	1.00	0.99	1.00	1.00
19	1.00	1.00	0.04	0.01	1.00	1.00	1.00	1.00
20	1.00	1.00	0.03	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 6.10 Model estimates of arrowtooth flounder 1+ total biomass (t) and female spawning biomass (t) from the 2011 and 2012 assessments.

	2011 Assessment		2012 Assessment	
	Total biomass	Female Spawning biomass	Total biomass	Female Spawning biomass
1976	266,767	170,517	261,843	145,079
1977	264,346	170,816	259,394	135,957
1978	271,333	181,231	265,437	140,201
1979	281,218	188,931	274,039	149,543
1980	286,882	188,041	278,544	155,185
1981	292,363	187,596	282,838	154,787
1982	299,979	191,603	289,105	154,463
1983	317,110	200,237	304,256	160,634
1984	333,842	206,518	319,243	165,944
1985	354,523	225,000	338,135	176,108
1986	378,646	250,163	360,542	190,169
1987	409,553	265,060	389,916	207,577
1988	444,648	282,897	423,607	226,675
1989	471,856	293,647	450,671	231,305
1990	514,134	313,523	491,982	248,134
1991	548,659	339,579	526,128	264,652
1992	568,824	372,897	546,661	279,076
1993	594,574	410,549	571,926	310,864
1994	615,270	439,171	592,011	346,248
1995	625,219	452,140	601,598	371,401
1996	639,127	464,995	614,404	391,549
1997	646,850	468,487	621,046	398,706
1998	663,226	471,588	635,335	404,618
1999	679,546	471,227	649,181	402,715
2000	704,304	482,714	670,513	404,531
2001	732,908	496,726	695,086	407,830
2002	763,616	511,130	721,321	415,548
2003	803,571	538,098	755,958	430,045
2004	845,848	568,995	792,770	448,107
2005	886,113	590,143	827,972	467,148
2006	932,937	618,958	869,734	491,079
2007	976,040	661,292	909,359	516,763
2008	1,017,910	711,845	948,231	548,056
2009	1,048,900	743,233	980,823	580,548
2010	1,066,670	766,275	1,002,620	608,551
2011	1,081,290	792,769	1,017,650	630,021
2012			1,023,890	652,156

Table 6.11 Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2012.

females	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	98,778	33,952	85,275	68,395	71,458	27,898	15,728	10,926	8,407	6,855
1977	132,469	80,855	27,778	69,659	55,604	57,330	21,766	11,845	8,030	6,113
1978	99,496	108,442	66,170	22,712	56,789	44,967	45,583	16,939	9,082	6,117
1979	106,230	81,451	88,753	54,113	18,529	46,019	35,927	35,772	13,129	7,001
1980	104,920	86,961	66,655	72,553	44,092	14,961	36,458	27,784	27,207	9,913
1981	242,045	85,885	71,154	54,466	59,041	35,472	11,750	27,770	20,721	20,105
1982	93,953	198,135	70,277	58,150	44,340	47,552	27,932	8,991	20,835	15,413
1983	75,980	76,913	162,159	57,469	47,432	35,914	37,952	21,879	6,952	16,020
1984	222,514	62,199	62,944	132,580	46,848	38,352	28,545	29,514	16,761	5,291
1985	154,306	182,164	50,910	51,488	108,244	38,048	30,806	22,609	23,151	13,092
1986	126,804	126,327	149,112	41,654	42,068	88,098	30,715	24,612	17,934	18,307
1987	406,619	103,812	103,409	122,011	34,041	34,261	71,230	24,606	19,592	14,237
1988	221,804	332,900	84,985	84,633	99,781	27,780	27,834	57,540	19,799	15,738
1989	223,474	181,573	272,435	69,481	68,985	80,657	22,064	21,621	44,014	15,044
1990	146,206	182,956	148,636	222,940	56,798	56,229	65,340	17,736	17,286	35,108
1991	149,879	119,693	149,753	121,592	182,054	46,156	45,225	51,872	13,954	13,547
1992	171,916	122,695	97,956	122,445	99,141	147,292	36,737	35,258	39,866	10,657
1993	129,485	140,745	100,436	80,154	100,070	80,752	119,124	29,445	28,085	31,670
1994	153,376	106,009	115,216	82,192	65,530	81,591	65,466	95,878	23,582	22,443
1995	197,373	125,566	86,775	94,270	67,157	53,340	65,885	52,330	76,105	18,661
1996	255,014	161,589	102,792	71,018	77,087	54,790	43,306	53,162	42,045	61,034
1997	201,532	208,776	132,273	84,108	58,035	62,773	44,285	34,674	42,289	33,351
1998	251,355	164,994	170,910	108,252	68,775	47,342	50,949	35,715	27,841	33,891
1999	348,899	205,779	135,060	139,843	88,459	55,997	38,253	40,773	28,392	22,068
2000	220,140	285,642	168,455	110,530	114,341	72,146	45,429	30,827	32,705	22,728
2001	266,946	180,226	233,826	137,848	90,348	93,177	58,415	36,484	24,618	26,054
2002	314,721	218,545	147,531	191,335	112,666	73,604	75,392	46,858	29,091	19,578
2003	437,944	257,660	178,905	120,734	156,434	91,874	59,691	60,715	37,554	23,266
2004	302,518	358,541	210,923	146,405	98,702	127,528	74,457	48,014	48,587	29,984
2005	221,026	247,666	293,491	172,579	119,629	80,350	103,004	59,542	38,133	38,472
2006	370,964	180,952	202,742	240,178	141,091	97,534	65,133	82,890	47,674	30,465
2007	327,378	303,707	148,131	165,919	196,376	115,068	79,121	52,481	66,476	38,156
2008	253,478	268,025	248,627	121,237	135,693	160,268	93,500	63,935	42,245	53,422
2009	318,274	207,521	219,410	203,468	99,123	110,653	129,977	75,302	51,244	33,789
2010	212,657	260,568	169,876	179,544	166,315	80,775	89,592	104,382	60,133	40,821
2011	181,950	174,100	213,301	139,013	146,768	135,554	65,428	72,001	83,432	47,950
2012	41,296	148,963	142,525	174,572	113,684	119,769	110,118	52,847	57,926	67,006

Table 6.11 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2012.

	females				numbers at age (1,000s)						
	11	12	13	14	15	16	17	18	19	20	21
1976	5,779	4,981	4,340	3,806	3,356	2,968	2,619	2,316	2,027	1,770	4,081
1977	4,966	4,182	3,603	3,138	2,753	2,427	2,146	1,894	1,675	1,466	4,231
1978	4,646	3,771	3,175	2,735	2,383	2,090	1,843	1,630	1,438	1,271	4,326
1979	4,707	3,573	2,900	2,441	2,103	1,832	1,607	1,417	1,253	1,105	4,303
1980	5,273	3,542	2,688	2,181	1,836	1,582	1,378	1,209	1,066	942	4,068
1981	7,302	3,880	2,605	1,977	1,604	1,351	1,163	1,014	889	784	3,685
1982	14,909	5,410	2,874	1,929	1,464	1,188	1,000	862	751	658	3,310
1983	11,827	11,434	4,148	2,203	1,479	1,123	911	767	661	575	3,042
1984	12,164	8,974	8,674	3,146	1,671	1,122	851	691	582	501	2,744
1985	4,127	9,483	6,995	6,760	2,452	1,303	875	664	539	453	2,529
1986	10,342	3,259	7,487	5,523	5,337	1,936	1,028	690	524	425	2,355
1987	14,519	8,199	2,583	5,935	4,378	4,231	1,535	815	547	415	2,204
1988	11,429	11,653	6,580	2,073	4,763	3,514	3,396	1,232	654	439	2,102
1989	11,930	8,657	8,825	4,983	1,570	3,607	2,661	2,571	933	495	1,924
1990	11,990	9,505	6,897	7,031	3,970	1,251	2,874	2,120	2,048	743	1,928
1991	27,475	9,379	7,435	5,394	5,499	3,105	978	2,247	1,658	1,602	2,089
1992	10,324	20,924	7,141	5,660	4,107	4,186	2,364	745	1,711	1,262	2,810
1993	8,458	8,191	16,600	5,665	4,490	3,258	3,321	1,875	591	1,357	3,230
1994	25,288	6,752	6,538	13,250	4,522	3,584	2,601	2,651	1,497	472	3,662
1995	17,741	19,983	5,335	5,166	10,469	3,573	2,832	2,055	2,094	1,183	3,266
1996	14,956	14,216	16,011	4,275	4,139	8,388	2,863	2,269	1,646	1,678	3,564
1997	48,366	11,848	11,260	12,682	3,386	3,279	6,644	2,267	1,797	1,304	4,152
1998	26,710	38,726	9,486	9,015	10,154	2,711	2,625	5,319	1,815	1,439	4,368
1999	26,836	21,143	30,651	7,508	7,135	8,036	2,145	2,077	4,210	1,437	4,596
2000	17,653	21,462	16,908	24,511	6,004	5,706	6,426	1,716	1,661	3,367	4,824
2001	18,090	14,047	17,077	13,453	19,502	4,777	4,540	5,113	1,365	1,322	6,517
2002	20,702	14,370	11,157	13,563	10,684	15,489	3,794	3,606	4,061	1,084	6,226
2003	15,647	16,540	11,480	8,913	10,835	8,536	12,374	3,031	2,881	3,244	5,840
2004	18,562	12,480	13,191	9,156	7,109	8,641	6,807	9,869	2,417	2,297	7,245
2005	23,717	14,677	9,867	10,429	7,239	5,620	6,832	5,382	7,802	1,911	7,544
2006	30,712	18,929	11,713	7,874	8,323	5,777	4,485	5,452	4,295	6,226	7,545
2007	24,365	24,557	15,135	9,365	6,295	6,654	4,618	3,586	4,359	3,434	11,010
2008	30,645	19,566	19,719	12,152	7,519	5,055	5,343	3,708	2,879	3,500	11,598
2009	42,697	24,487	15,633	15,755	9,709	6,008	4,039	4,269	2,963	2,300	12,063
2010	26,893	33,974	19,482	12,437	12,534	7,725	4,780	3,213	3,396	2,357	11,427
2011	32,524	21,421	27,059	15,517	9,906	9,983	6,152	3,807	2,559	2,705	10,978
2012	38,487	26,100	17,189	21,712	12,451	7,948	8,010	4,937	3,055	2,053	10,980

Table 6.11 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2012.

males	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	98,778	29,223	63,173	43,611	39,217	13,178	6,395	3,823	2,532	1,777
1977	132,469	69,535	20,546	44,295	30,407	27,051	8,928	4,231	2,471	1,608
1978	99,496	93,290	48,932	14,434	31,013	21,151	18,612	6,055	2,829	1,635
1979	106,230	70,076	65,664	34,394	10,117	21,619	14,610	12,703	4,084	1,891
1980	104,920	74,806	49,304	46,115	24,062	7,026	14,831	9,862	8,439	2,681
1981	242,045	73,869	52,610	34,594	32,199	16,646	4,786	9,897	6,450	5,437
1982	93,953	170,422	51,958	36,924	24,170	22,301	11,363	3,205	6,503	4,179
1983	75,980	66,171	119,948	36,517	25,874	16,840	15,392	7,744	2,157	4,338
1984	222,514	53,508	46,564	84,266	25,565	17,994	11,583	10,434	5,175	1,426
1985	154,306	156,738	37,672	32,748	59,131	17,863	12,484	7,961	7,105	3,499
1986	126,804	108,704	110,377	26,508	23,005	41,409	12,444	8,637	5,470	4,857
1987	406,619	89,333	76,557	77,680	18,628	16,122	28,883	8,626	5,951	3,752
1988	221,804	286,492	62,929	53,905	54,647	13,082	11,289	20,149	5,995	4,124
1989	223,474	156,200	201,595	44,205	37,733	37,994	8,993	7,646	13,446	3,957
1990	146,206	157,443	110,016	141,905	31,078	26,465	26,543	6,250	5,286	9,262
1991	149,879	102,990	110,854	77,384	99,608	21,728	18,381	18,275	4,266	3,585
1992	171,916	105,553	72,478	77,889	54,193	69,318	14,963	12,483	12,242	2,829
1993	129,485	121,115	74,339	51,009	54,739	37,982	48,361	10,377	8,606	8,402
1994	153,376	91,227	85,308	52,332	35,868	38,406	26,551	33,643	7,184	5,937
1995	197,373	108,050	64,244	60,029	36,765	25,121	26,761	18,375	23,127	4,914
1996	255,014	139,061	76,111	45,233	42,224	25,812	17,581	18,652	12,755	16,006
1997	201,532	179,656	97,935	53,563	31,785	29,585	17,999	12,183	12,844	8,743
1998	251,355	141,991	126,549	68,951	37,673	22,312	20,701	12,541	8,452	8,883
1999	348,899	177,076	99,996	89,055	48,448	26,393	15,555	14,339	8,631	5,790
2000	220,140	245,816	124,729	70,399	62,630	34,003	18,461	10,831	9,940	5,964
2001	266,946	155,092	173,132	87,793	49,488	43,917	23,745	12,821	7,482	6,839
2002	314,721	188,066	109,230	121,854	61,706	34,691	30,651	16,477	8,846	5,140
2003	437,944	221,734	132,467	76,897	85,689	43,300	24,257	21,332	11,414	6,107
2004	302,518	308,545	156,177	93,249	54,067	60,111	30,260	16,868	14,760	7,869
2005	221,026	213,118	217,287	109,901	65,515	37,871	41,893	20,949	11,600	10,102
2006	370,964	155,720	150,110	152,961	77,276	45,964	26,472	29,140	14,501	8,001
2007	327,378	261,362	109,686	105,680	107,571	54,233	32,148	18,431	20,198	10,018
2008	253,478	230,662	184,112	77,234	74,347	75,550	37,982	22,431	12,813	14,003
2009	318,274	178,586	162,471	129,614	54,312	52,171	52,829	26,436	15,540	8,846
2010	212,657	224,230	125,780	114,359	91,113	38,084	36,432	36,690	18,260	10,691
2011	181,950	149,822	157,931	88,537	80,397	63,902	26,604	25,316	25,362	12,574
2012	41,296	128,196	105,538	111,202	62,284	56,459	44,744	18,557	17,591	17,574

Table 6.11 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2012.

males	numbers at age (1,000s)										
	11	12	13	14	15	16	17	18	19	20	21
1976	1,290	957	717	542	411	313	238	181	136	102	125
1977	1,117	806	597	447	337	256	195	148	113	85	141
1978	1,058	732	528	390	292	220	167	127	97	74	148
1979	1,087	701	485	349	258	193	146	111	84	64	146
1980	1,233	706	455	314	226	167	125	94	72	55	136
1981	1,712	784	448	288	199	143	106	79	60	45	121
1982	3,493	1,095	500	286	184	127	91	67	51	38	106
1983	2,772	2,311	724	330	189	121	84	60	45	33	95
1984	2,850	1,815	1,511	473	216	123	79	55	39	29	84
1985	961	1,915	1,219	1,014	317	145	83	53	37	26	76
1986	2,385	654	1,302	828	689	216	98	56	36	25	69
1987	3,322	1,629	446	889	565	470	147	67	38	25	64
1988	2,596	2,297	1,126	308	614	390	325	102	46	26	61
1989	2,705	1,697	1,499	734	201	400	255	212	66	30	57
1990	2,720	1,857	1,164	1,028	503	138	274	175	145	45	60
1991	6,258	1,834	1,251	784	692	339	93	185	117	98	71
1992	2,363	4,112	1,203	820	514	454	222	61	121	77	111
1993	1,937	1,616	2,809	822	560	351	310	152	42	83	128
1994	5,784	1,332	1,110	1,930	565	385	241	213	104	29	145
1995	4,049	3,939	906	755	1,313	384	262	164	145	71	118
1996	3,395	2,795	2,717	625	521	905	265	180	113	100	130
1997	10,941	2,317	1,906	1,853	426	355	617	181	123	77	157
1998	6,036	7,546	1,597	1,314	1,277	294	245	425	124	85	161
1999	6,068	4,117	5,143	1,088	895	870	200	167	290	85	167
2000	3,993	4,180	2,835	3,541	749	616	599	138	115	199	174
2001	4,093	2,737	2,864	1,942	2,425	513	422	410	94	79	255
2002	4,687	2,801	1,872	1,958	1,327	1,658	351	288	280	64	228
2003	3,541	3,226	1,927	1,288	1,347	913	1,140	241	198	193	201
2004	4,201	2,433	2,215	1,323	884	924	627	782	166	136	271
2005	5,370	2,862	1,657	1,508	900	602	629	426	532	113	277
2006	6,953	3,692	1,967	1,138	1,036	619	413	432	293	366	267
2007	5,517	4,789	2,542	1,354	783	713	426	284	297	202	436
2008	6,934	3,815	3,311	1,757	936	541	493	294	196	205	440
2009	9,649	4,773	2,625	2,277	1,208	643	372	339	202	135	444
2010	6,072	6,614	3,270	1,798	1,559	827	441	255	232	139	397
2011	7,345	4,167	4,536	2,242	1,233	1,069	567	302	175	159	367
2012	8,698	5,077	2,879	3,133	1,549	851	738	392	209	121	363

Table 6.12 Estimated age 2 recruitment of arrowtooth flounder (thousands of fish) from the 2011 and 2012 stock assessments. Average from 2012 = 323,729.

Year class	2012 Assessment	2011 Assessment
1974	63,176	65,163
1975	150,390	162,674
1976	201,732	214,337
1977	151,527	164,833
1978	161,767	172,810
1979	159,754	171,660
1980	368,557	394,349
1981	143,084	151,698
1982	115,706	122,602
1983	338,902	354,833
1984	235,031	242,306
1985	193,145	200,832
1986	619,392	637,772
1987	337,773	347,351
1988	340,399	351,494
1989	222,683	231,704
1990	228,248	239,491
1991	261,860	276,206
1992	197,236	209,186
1993	233,616	248,724
1994	300,650	320,649
1995	388,432	416,632
1996	306,985	331,010
1997	382,855	414,566
1998	531,458	576,770
1999	335,318	365,776
2000	406,611	443,328
2001	479,394	524,840
2002	667,086	725,377
2003	460,784	493,555
2004	336,672	352,244
2005	565,069	603,853
2006	498,687	490,641
2007	63,176	365,045
2008	150,390	

Table 6.13 Projections of arrowtooth flounder female spawning biomass (1,000s t), future catch (1,000s t) and full selection fishing mortality rates for seven future harvest scenarios.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2012	621.480	21.189	0.03
2013	631.367	111.203	0.17
2014	567.003	99.854	0.17
2015	507.764	89.290	0.17
2016	451.222	79.034	0.17
2017	396.086	69.051	0.17
2018	345.320	60.406	0.17
2019	306.476	54.411	0.17
2020	282.223	50.890	0.17
2021	267.906	48.502	0.17
2022	259.811	46.785	0.17
2023	255.313	45.817	0.17
2024	253.048	45.367	0.17
2025	252.131	45.227	0.17

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2012	621.480	21.189	0.03
2013	636.628	44.604	0.07
2014	629.115	29.362	0.04
2015	626.845	29.062	0.04
2016	615.051	28.272	0.04
2017	592.418	26.984	0.04
2018	562.108	25.499	0.04
2019	533.104	24.264	0.04
2020	511.717	23.414	0.04
2021	496.696	22.845	0.04
2022	486.164	22.443	0.04
2023	478.361	22.148	0.04
2024	472.744	21.932	0.04
2025	468.870	21.788	0.04

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2012	621.480	21.189	0.03
2013	635.789	55.602	0.08
2014	617.866	54.000	0.08
2015	595.019	51.729	0.08
2016	565.363	48.792	0.08
2017	528.181	45.223	0.08
2018	487.084	41.614	0.08
2019	451.017	38.777	0.08
2020	425.405	36.878	0.08
2021	407.980	35.637	0.08
2022	396.122	34.786	0.08
2023	387.669	34.184	0.08
2024	381.782	33.761	0.08
2025	377.827	33.485	0.08

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2011	623.010	21.189	0.03
2012	657.965	0	0
2013	686.836	0	0
2014	707.239	0	0
2015	715.644	0	0
2016	710.046	0	0
2017	692.949	0	0
2018	673.127	0	0
2019	657.624	0	0
2020	646.215	0	0
2021	637.842	0	0
2022	631.217	0	0
2023	626.157	0	0
2024	622.507	0	0

Table 6.13 (continued).

Scenario 6
Determination of whether arrowtooth flounder are currently overfished
B35=215,667

Year	Female spawning biomass	catch	F
2012	621.480	21.189	0.03
2013	629.631	131.985	0.21
2014	548.164	115.069	0.21
2015	477.193	100.194	0.21
2016	413.340	86.579	0.21
2017	354.482	74.017	0.21
2018	302.887	63.631	0.21
2019	265.275	56.772	0.21
2020	243.286	51.115	0.20
2021	232.688	47.865	0.19
2022	228.509	46.664	0.19
2023	227.134	46.359	0.19
2024	227.117	46.457	0.19
2025	227.711	46.729	0.19

Scenario 7
Determination of whether arrowtooth flounder are approaching an overfished condition
B35=215,667

Year	Female spawning biomass	catch	F
2012	621.480	21.189	0.03
2013	631.367	111.203	0.17
2014	567.002	99.853	0.17
2015	506.363	105.967	0.21
2016	436.071	91.014	0.21
2017	371.693	77.331	0.21
2018	315.602	66.054	0.21
2019	274.484	58.521	0.21
2020	249.790	53.005	0.20
2021	236.737	49.116	0.19
2022	230.872	47.378	0.19
2023	228.434	46.743	0.19
2024	227.771	46.639	0.19
2025	228.000	46.801	0.19

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

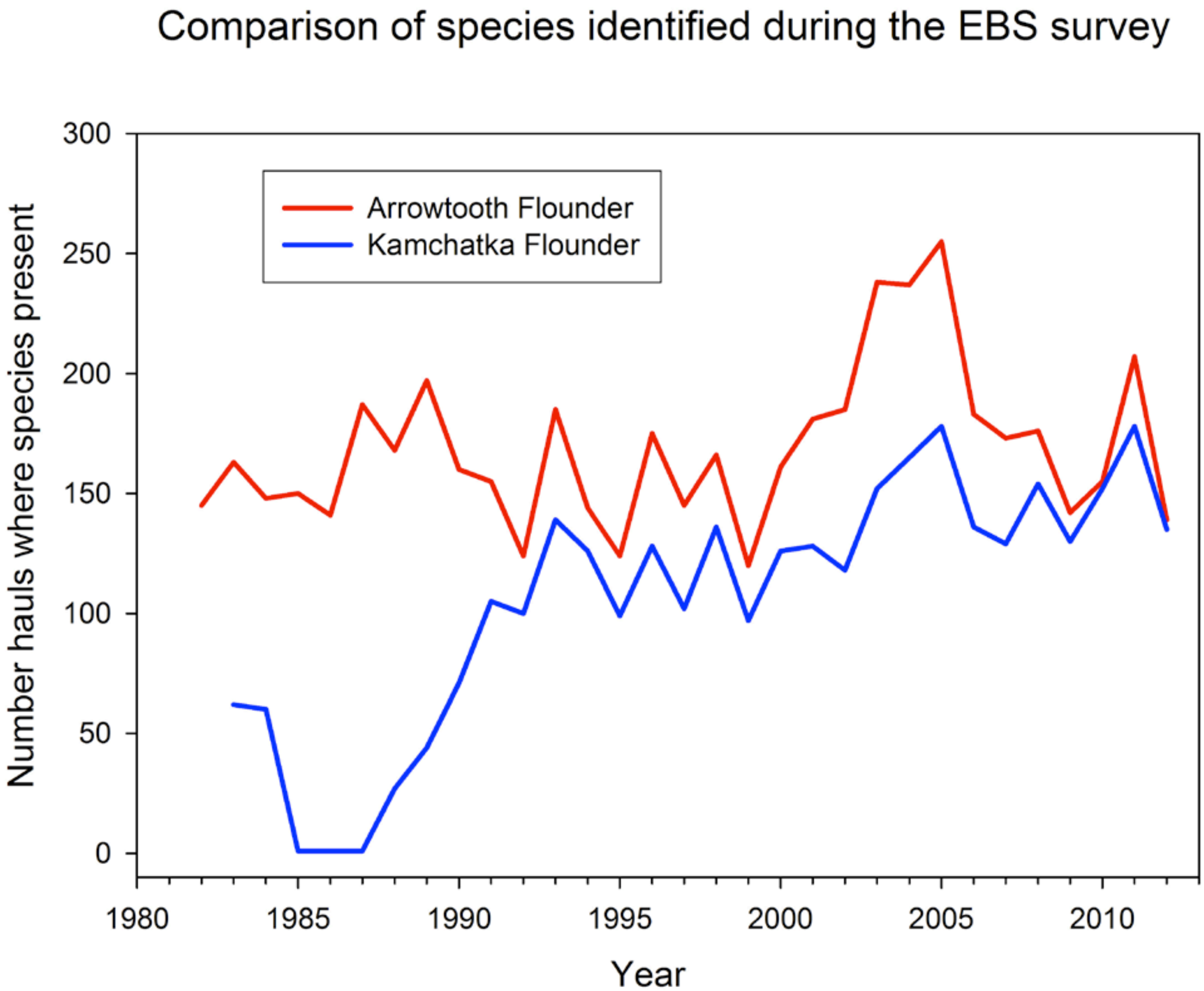


Figure 6.1—Number of hauls where arrowtooth flounder and Kamchatka flounder were identified during the annual Bering Sea shelf surveys, 1982-2012. Years 1982-1986 are the standard survey area and 1987-2012 include northwest strata 82 and 90.

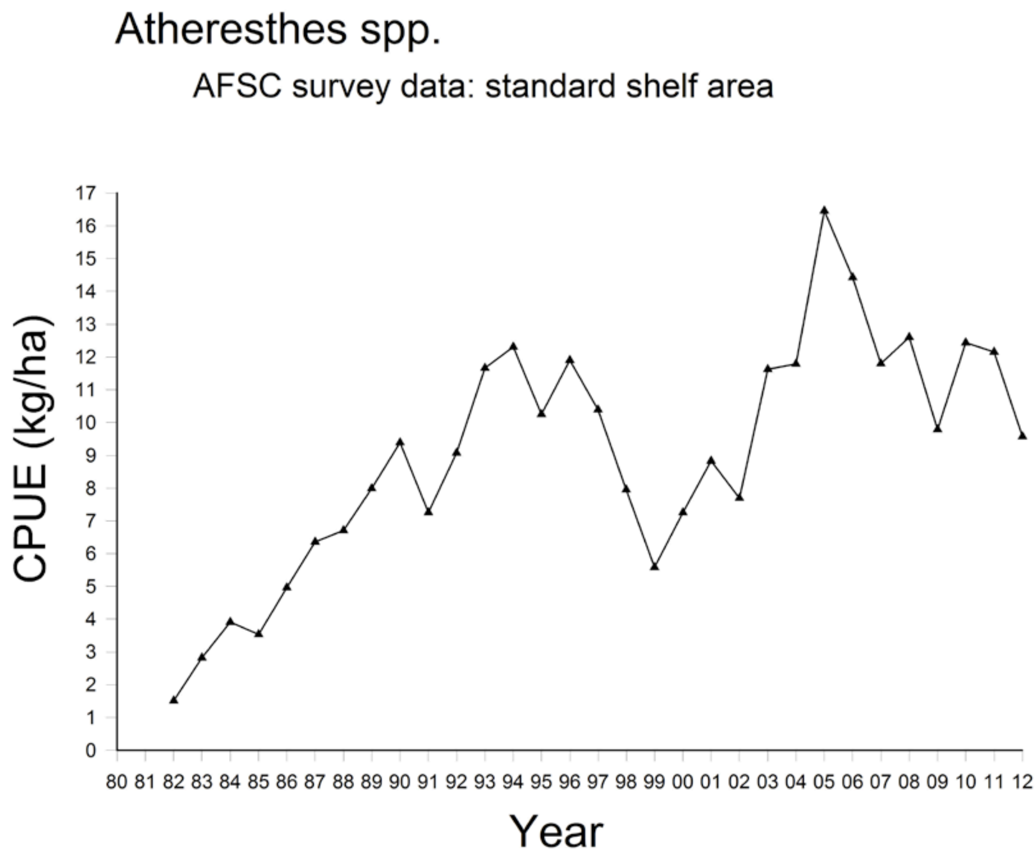


Figure 6.2 Arrowtooth flounder CPUE (kg/ha) from the standard shelf survey area (1982-1992) and standard shelf survey area including Northwestern stratum 82 and 90 (1993-2012).

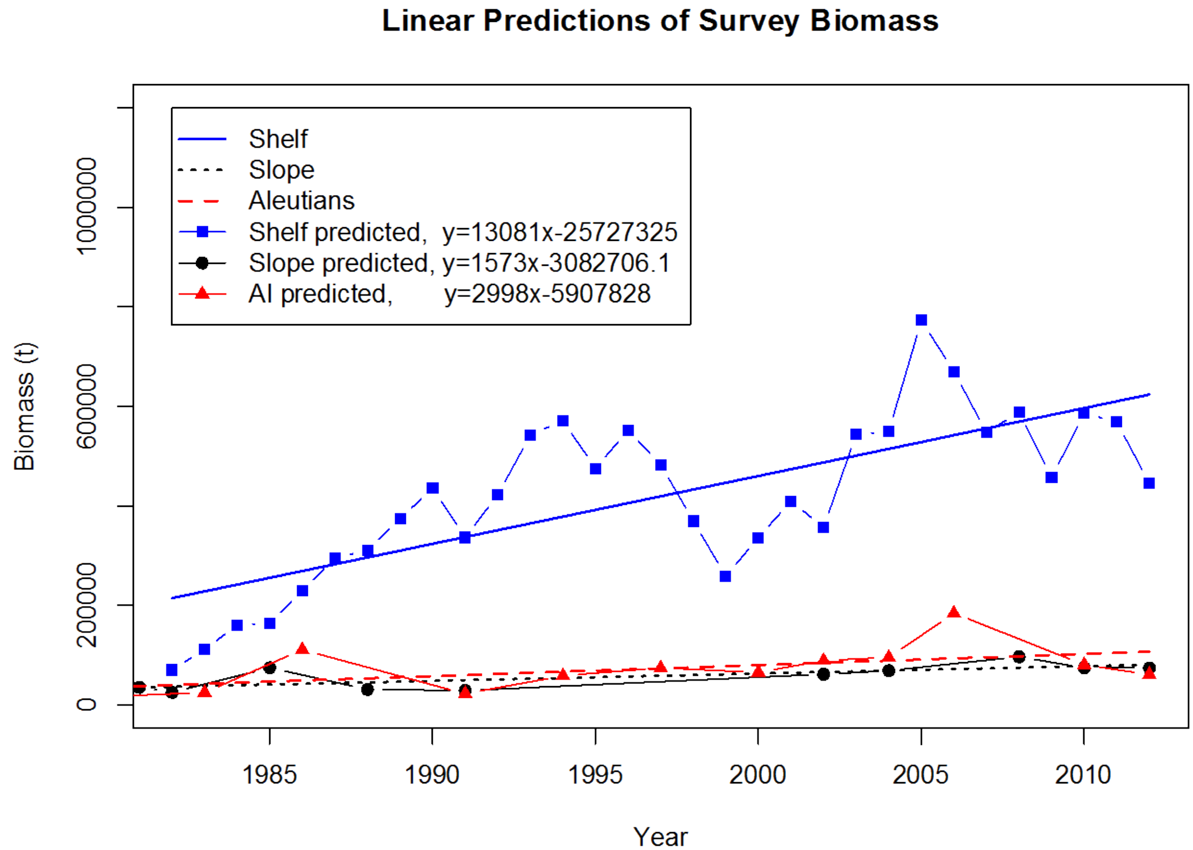


Figure 6.3—Linear regressions of trawl survey estimates for the Bering Sea shelf, slope and the Aleutian Islands used to estimate the proportion of biomass in each area.

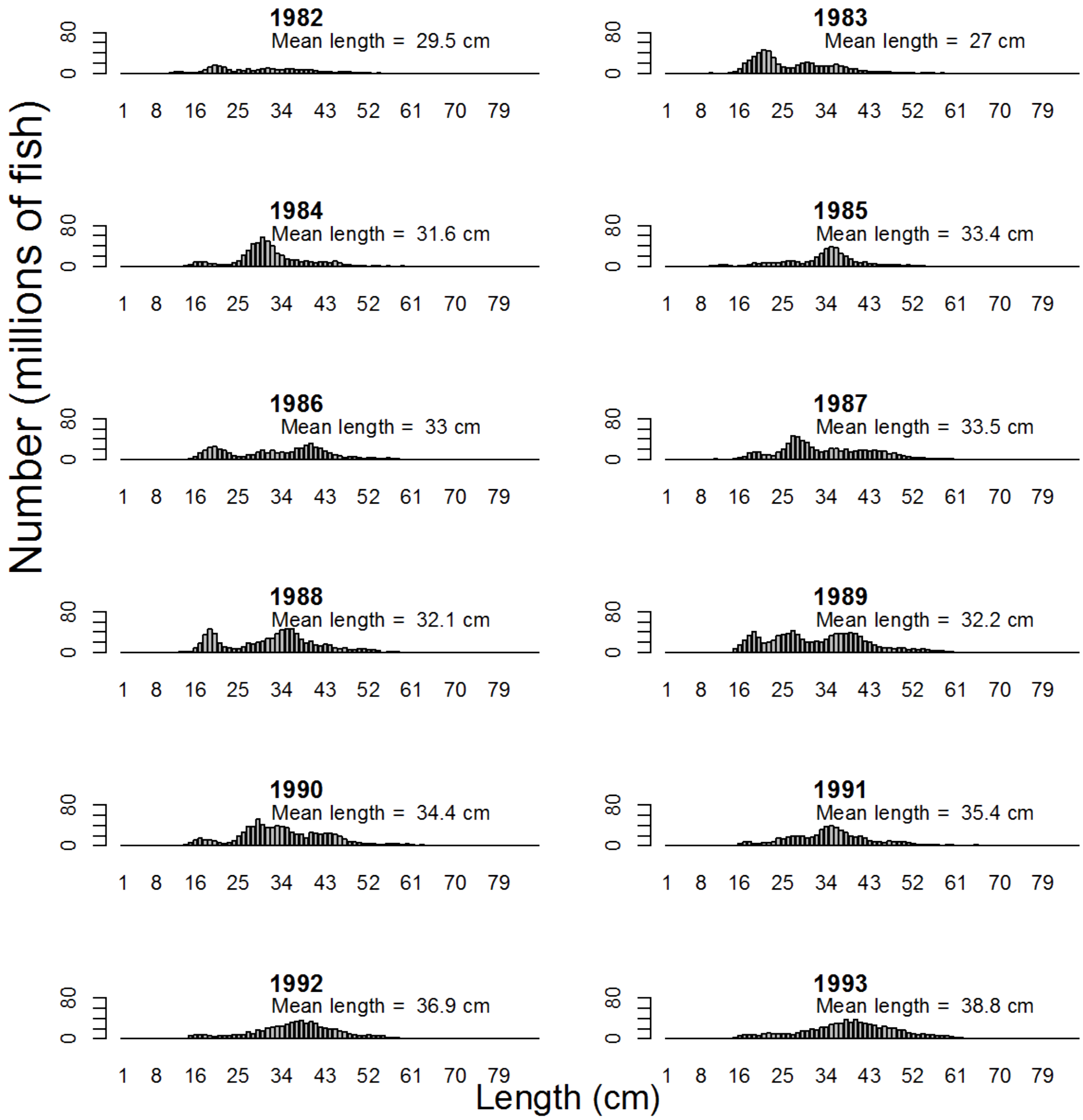


Figure 6.4. Size composition of arrowtooth flounder from the shelf trawl surveys.

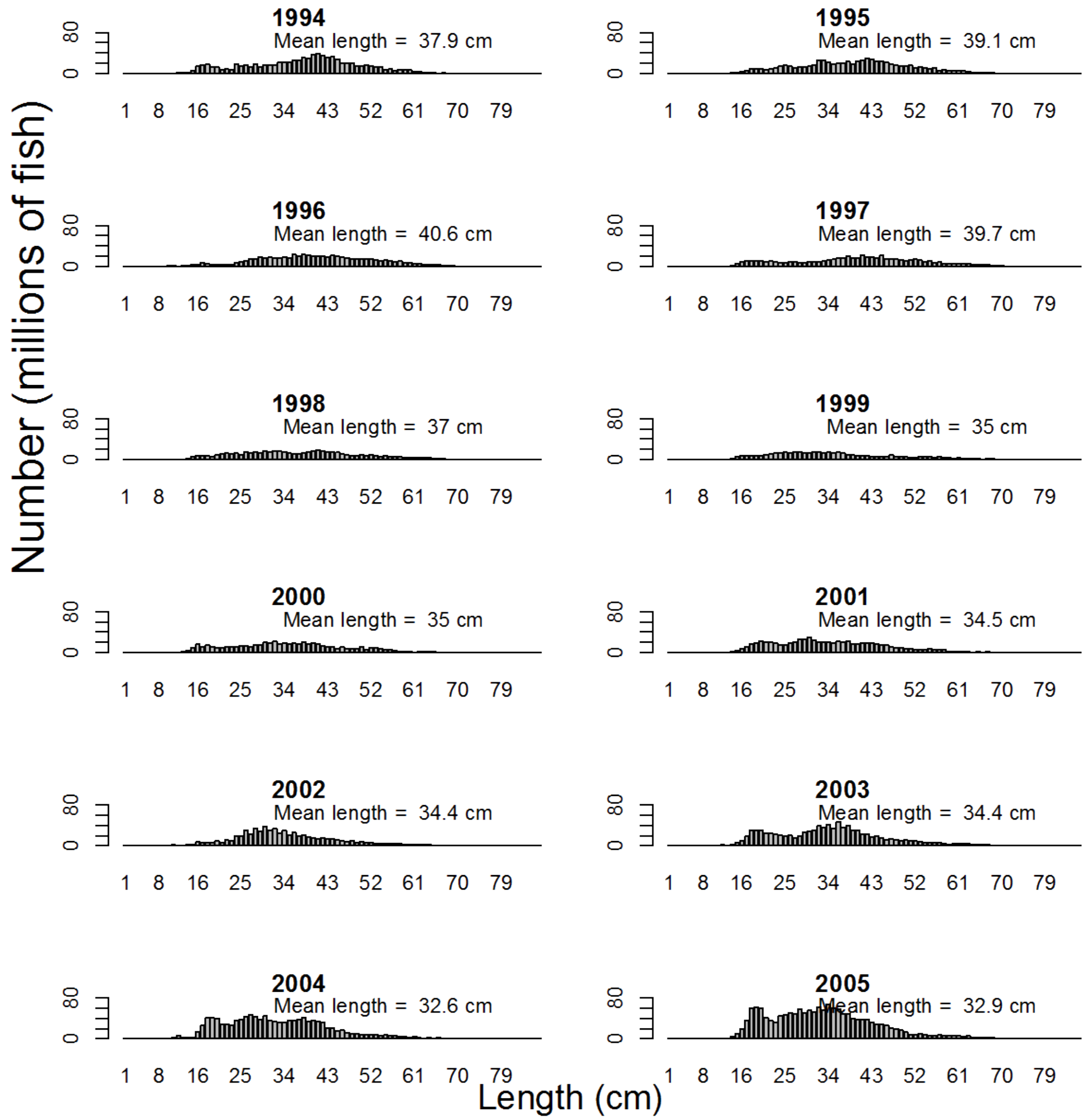


Figure 6.4. continued.

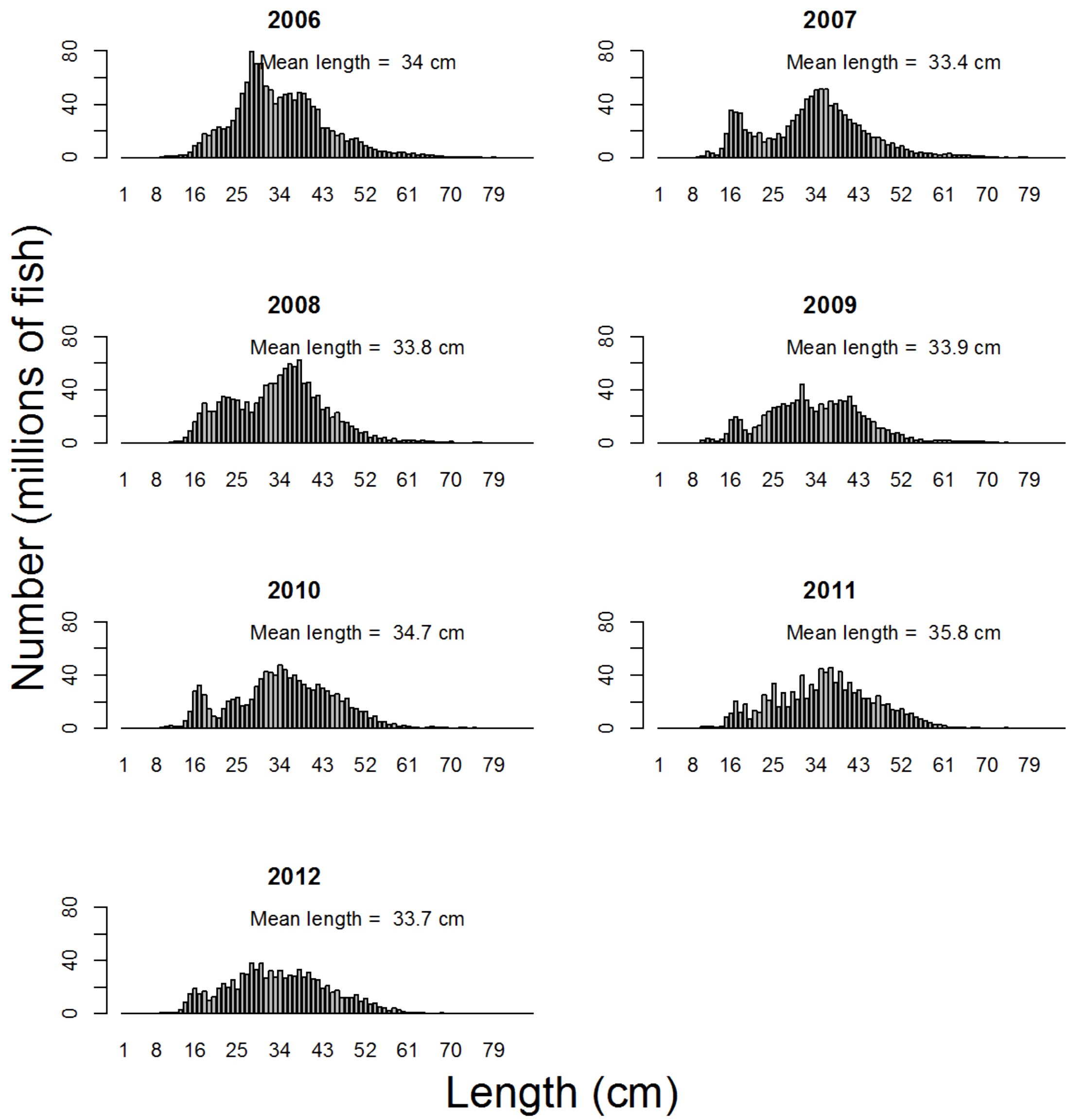


Figure 6.4. continued.

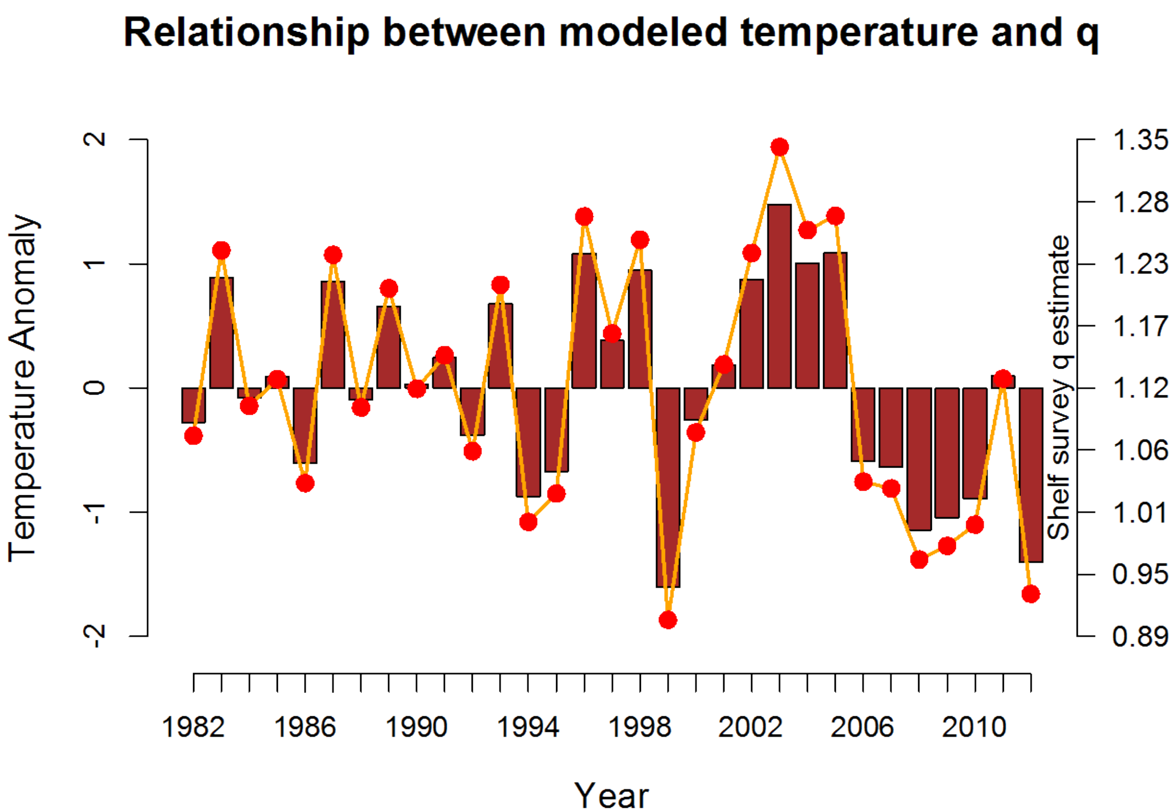


Figure 6.5--Shelf survey annual avg. bottom temperature anomalies (bars), model estimate of annual shelf survey q due to effect of water temperature (circles with lines).

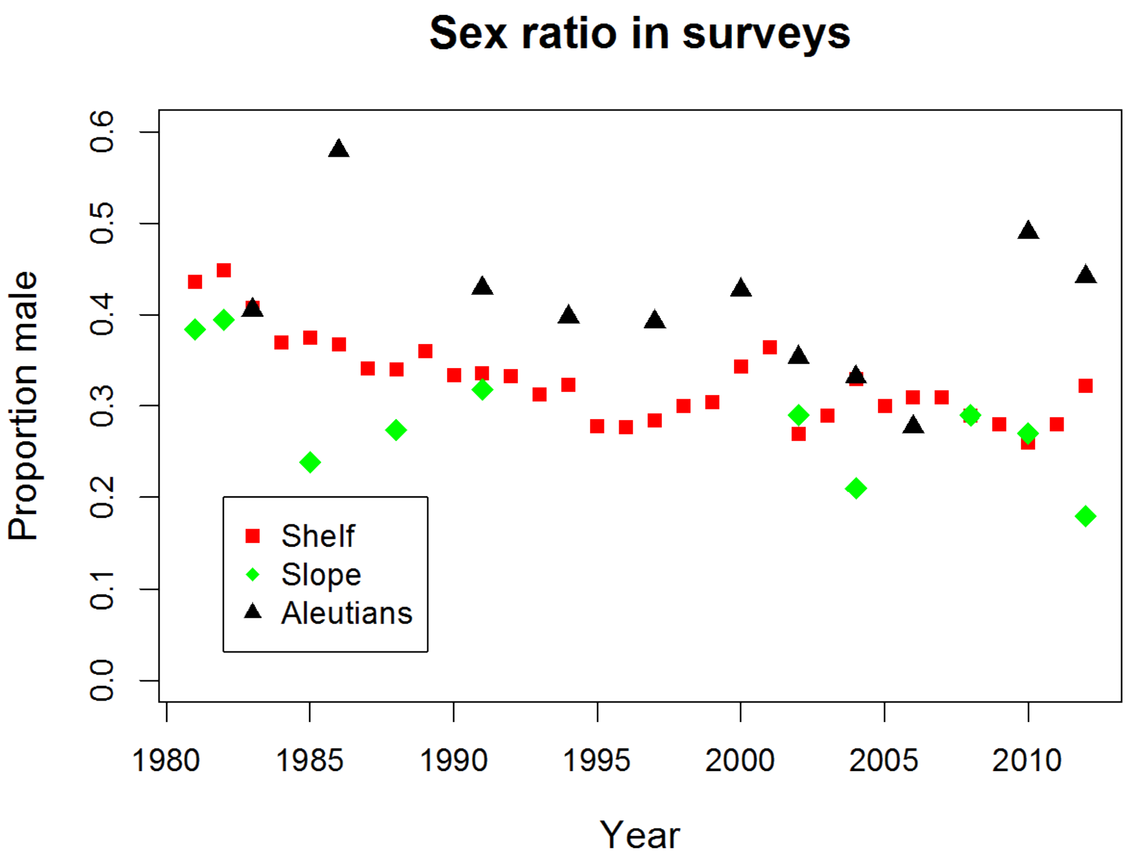


Figure 6.6--Proportion of the estimated male population from Bering Sea and Aleutian Islands trawl surveys on the continental shelf and slope.

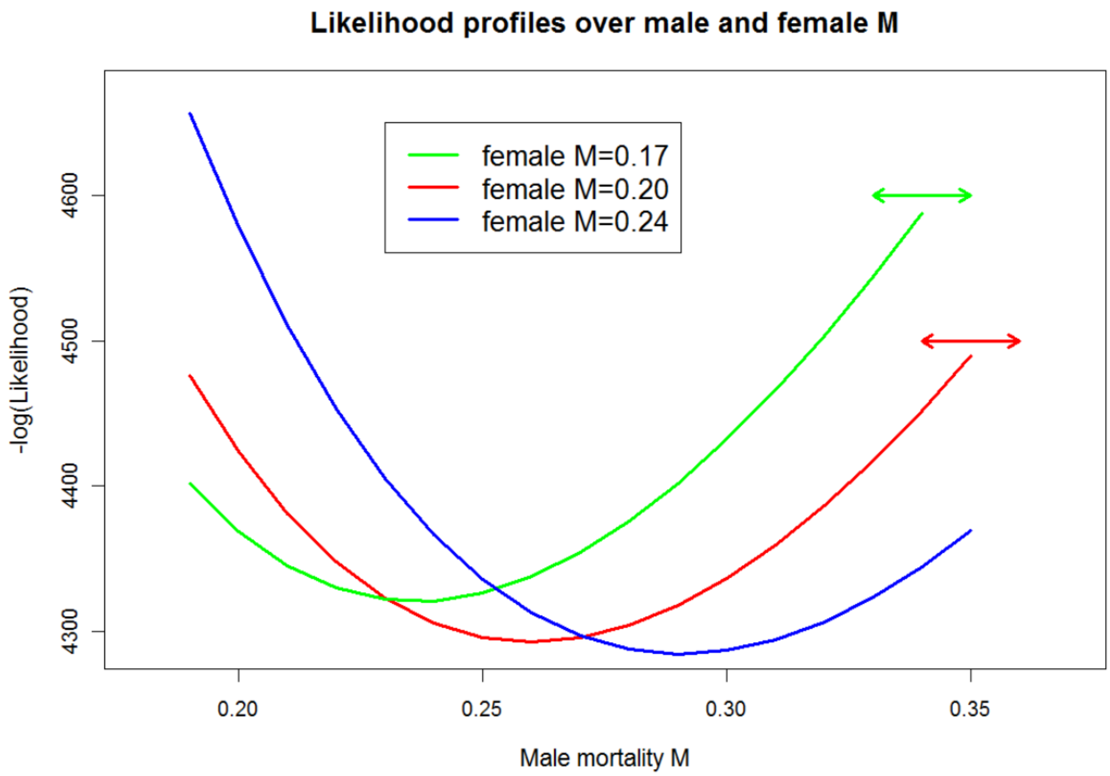


Figure 6.7—Fit to the stock assessment model in terms of –log(likelihood) when profiling over male natural mortality (x axis) for three different levels of female natural mortality. Arrows indicate the values of male natural mortality where the model estimates that maximum male selectivity is close to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

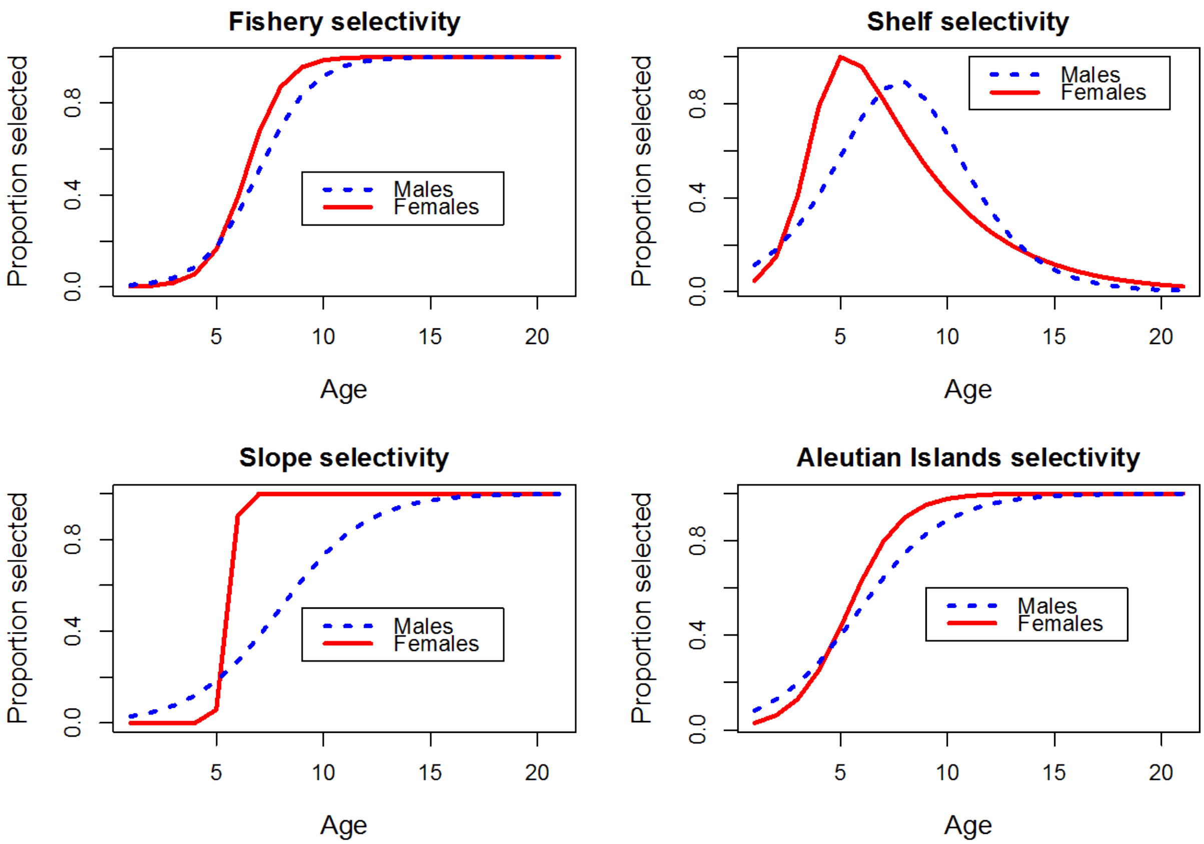


Figure 6.8--Age-specific fishery selectivity (top left panel), shelf survey selectivity (top right panel) slope survey selectivity (bottom left panel) and Aleutian Islands survey selectivity (bottom right panel), by sex, estimated from the stock assessment model.

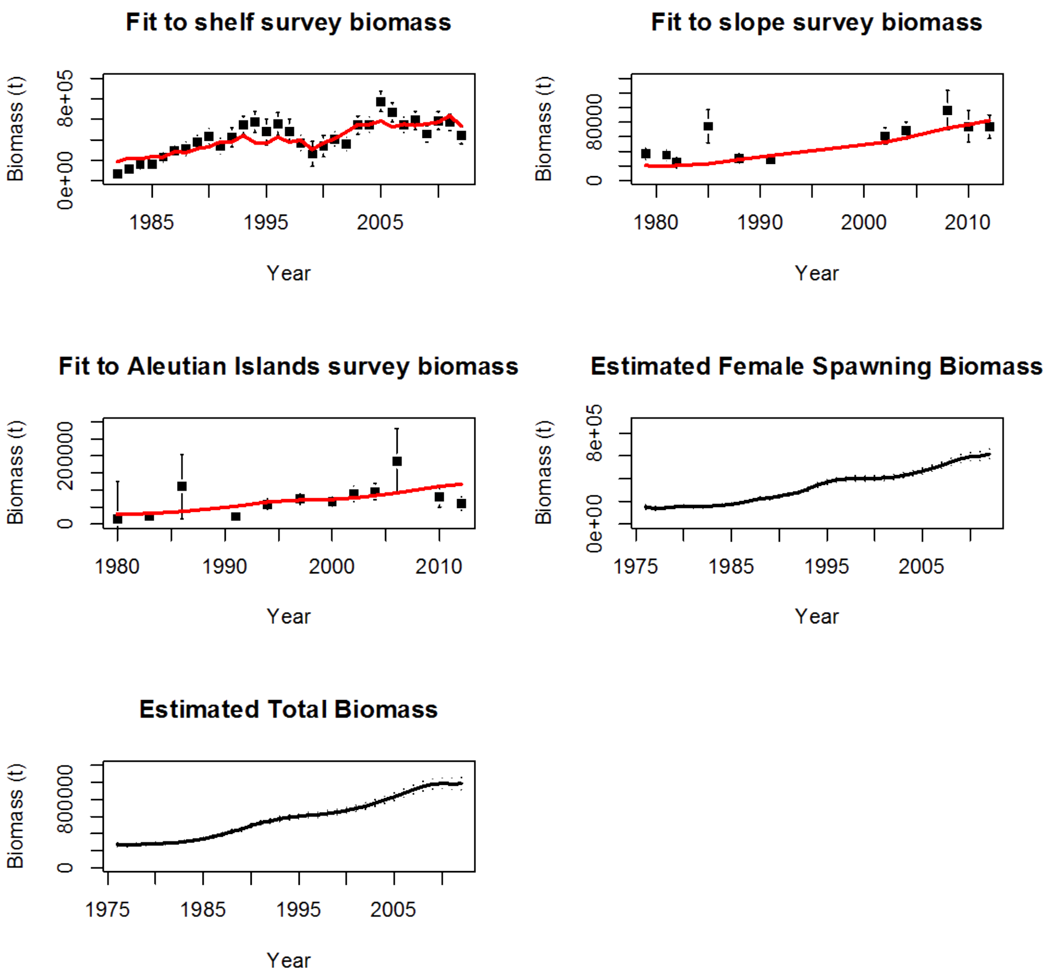


Figure 6.9--Stock assessment model results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), estimate of female spawning biomass with B35 and B40 indicated (middle right panel), the fit to the Aleutian Islands survey (middle left panel) and 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.

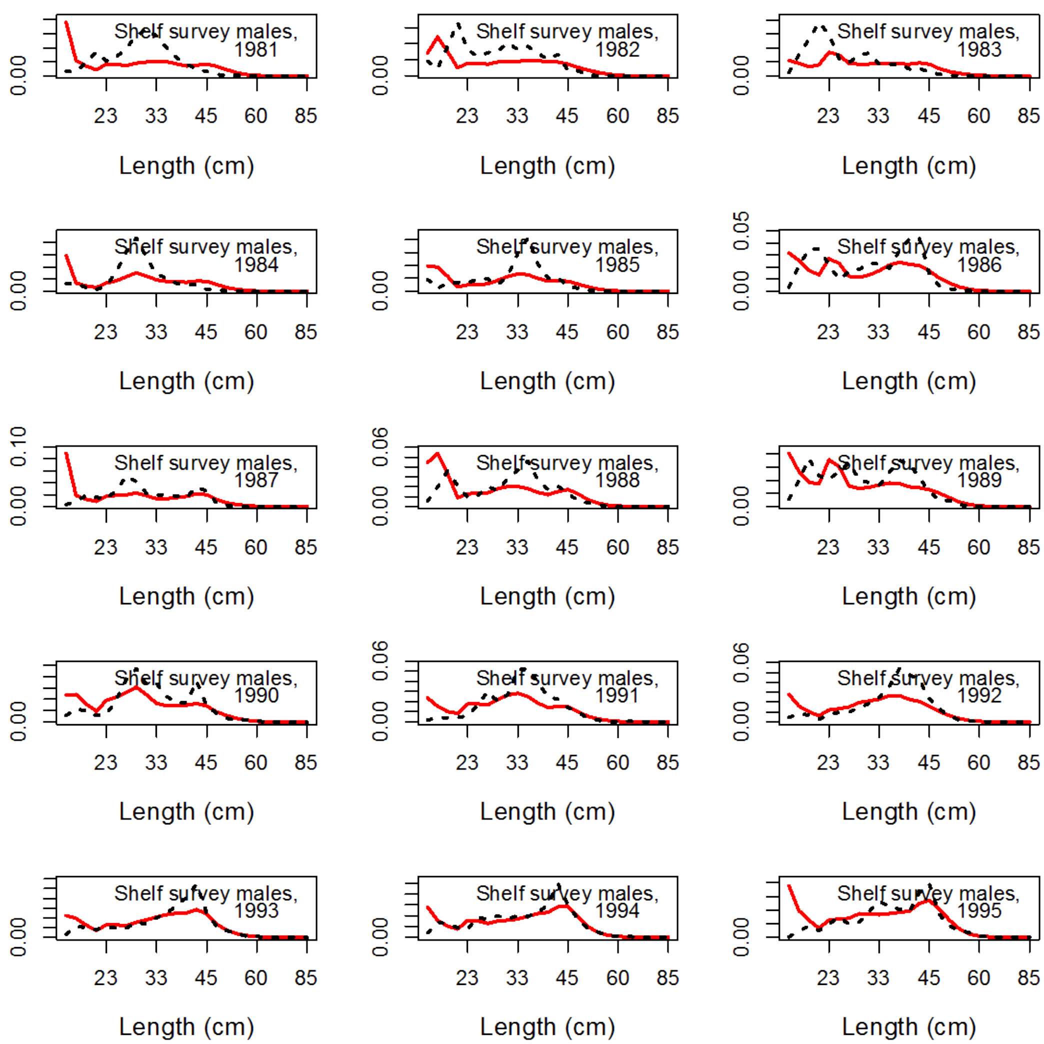


Figure 6.10—Length composition; model fit (dotted lines) to trawl survey size and age composition estimates (solid lines).

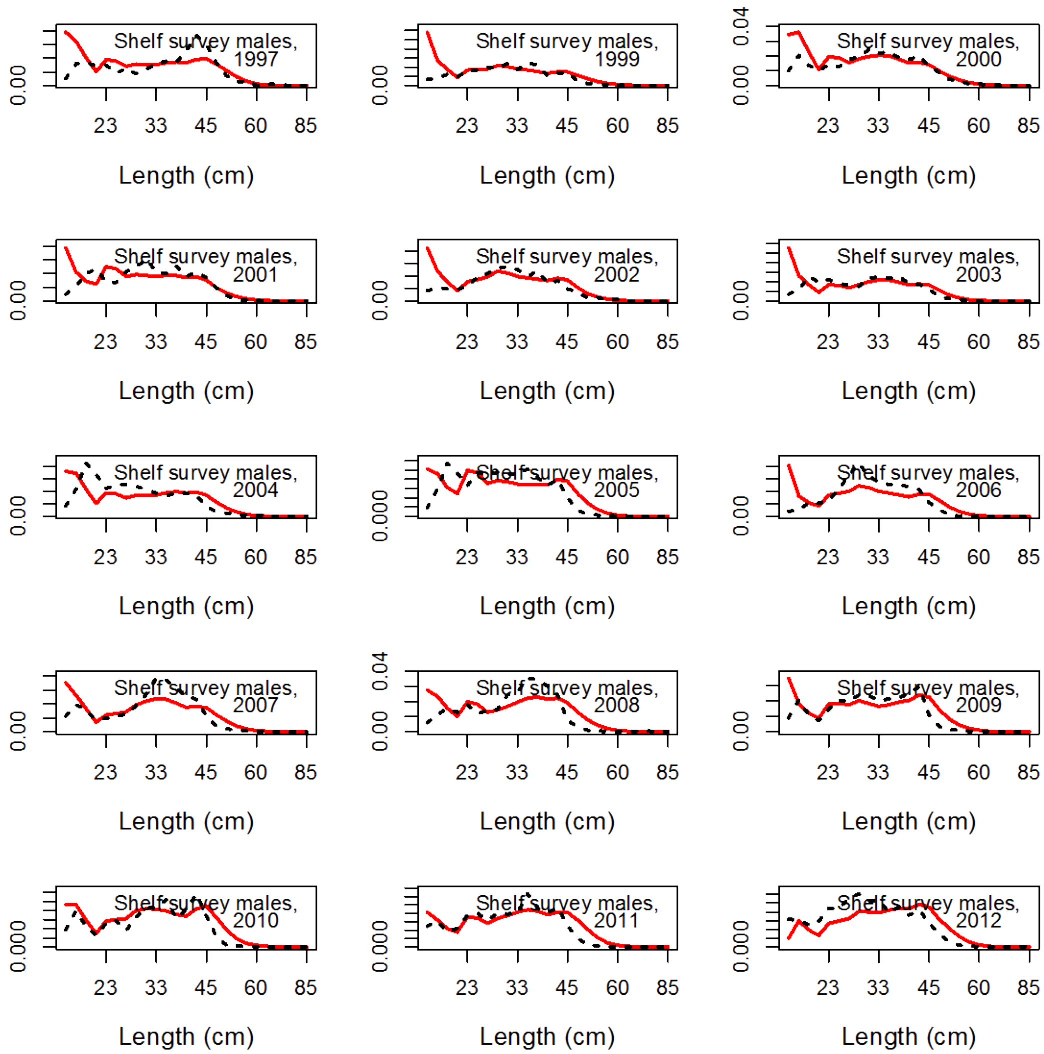


Figure 6.10—continued.

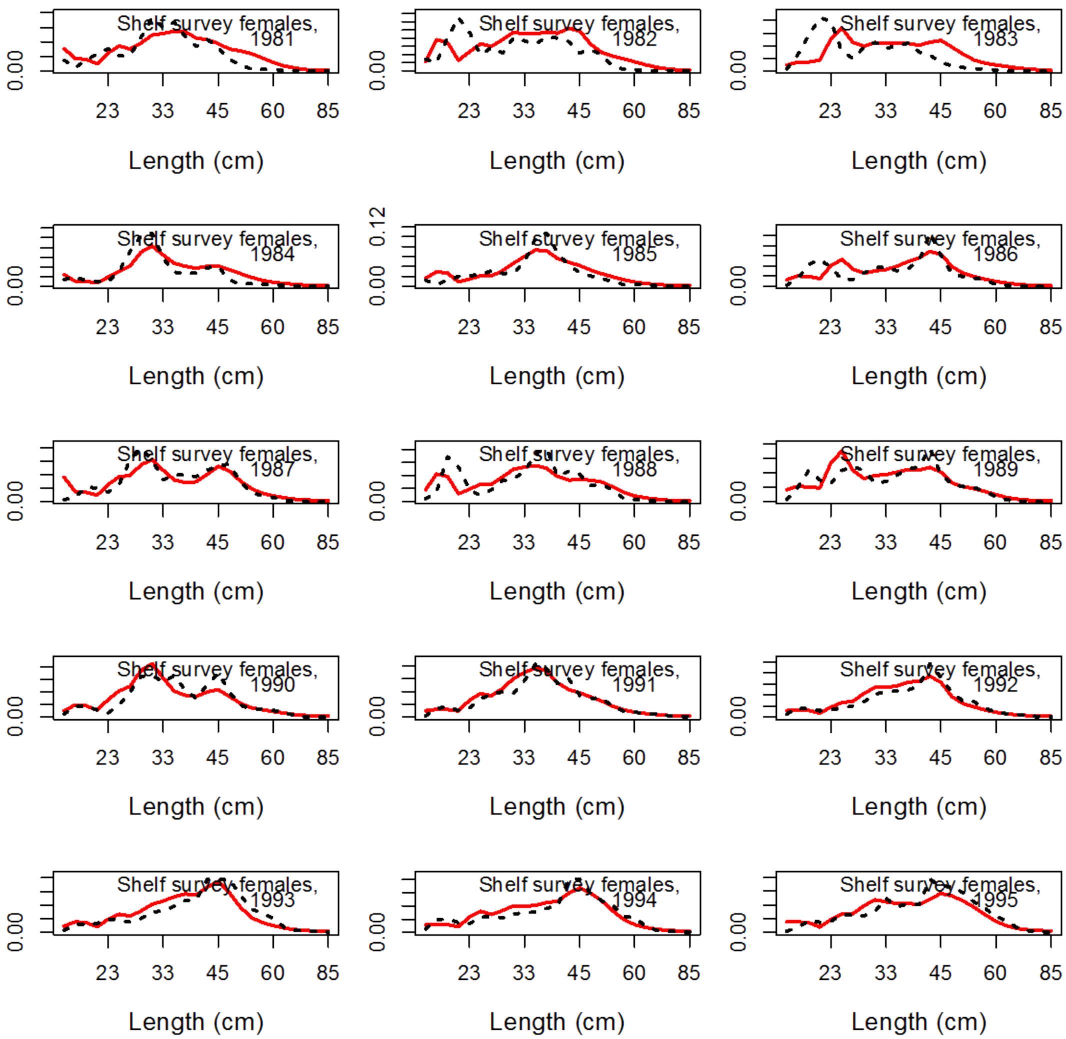


Figure 6.10—continued.

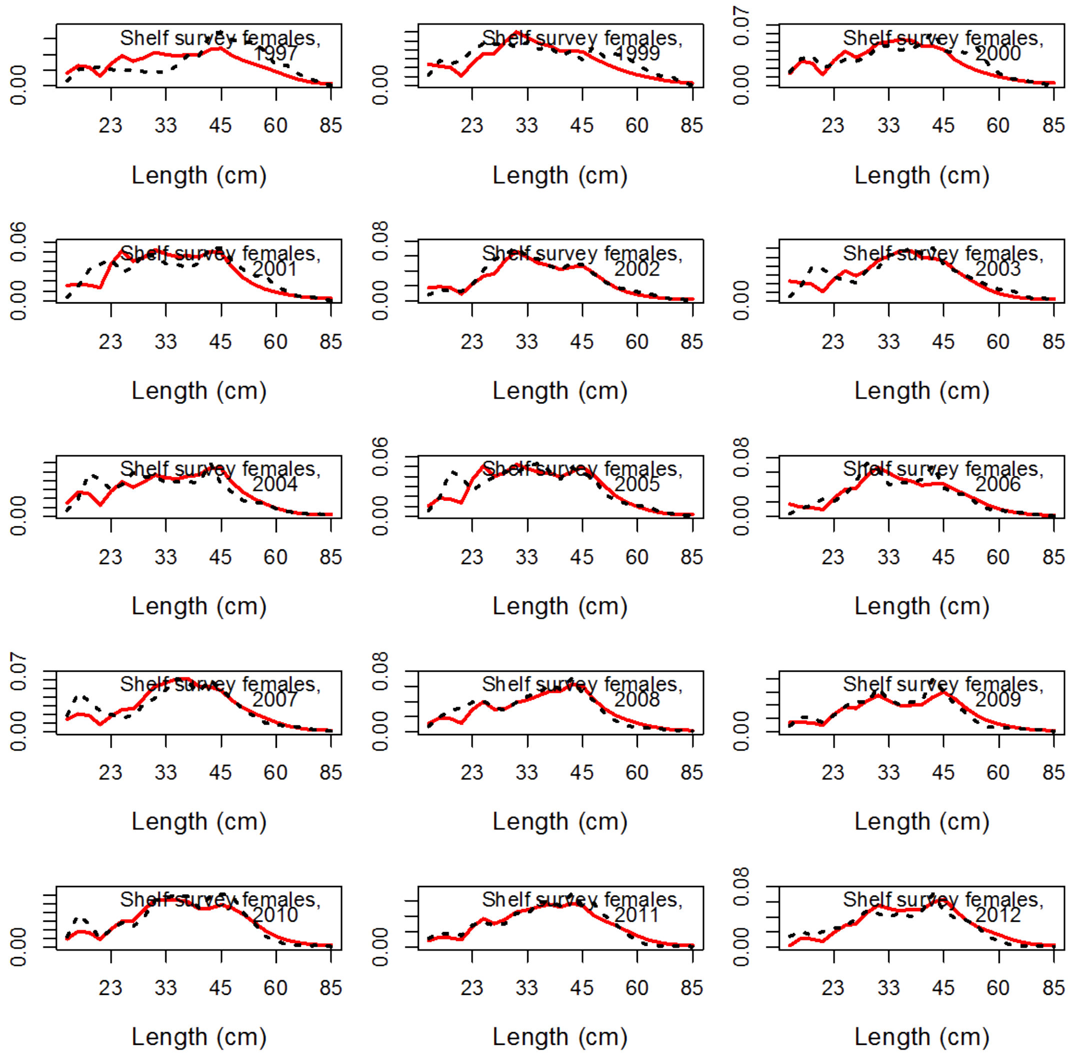
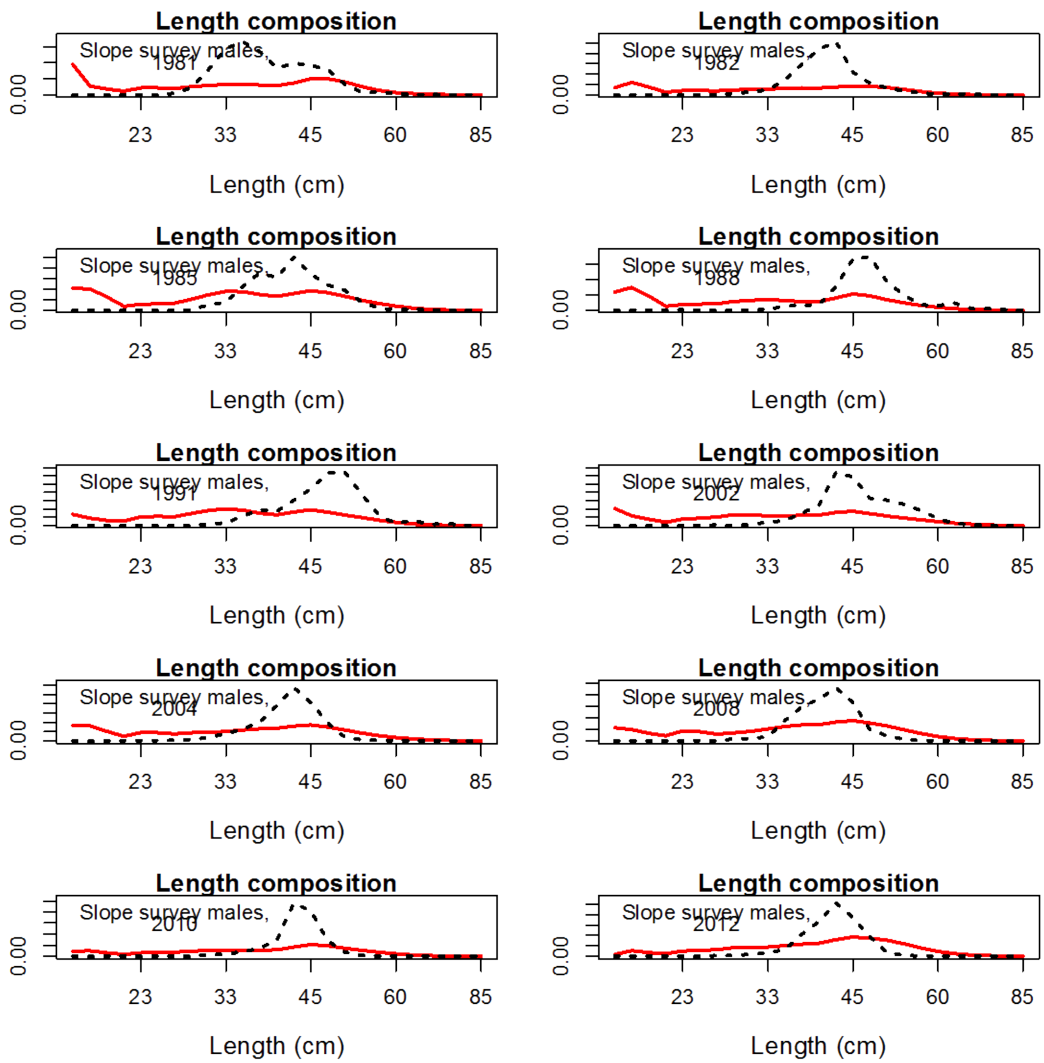


Figure 6.10—continued.



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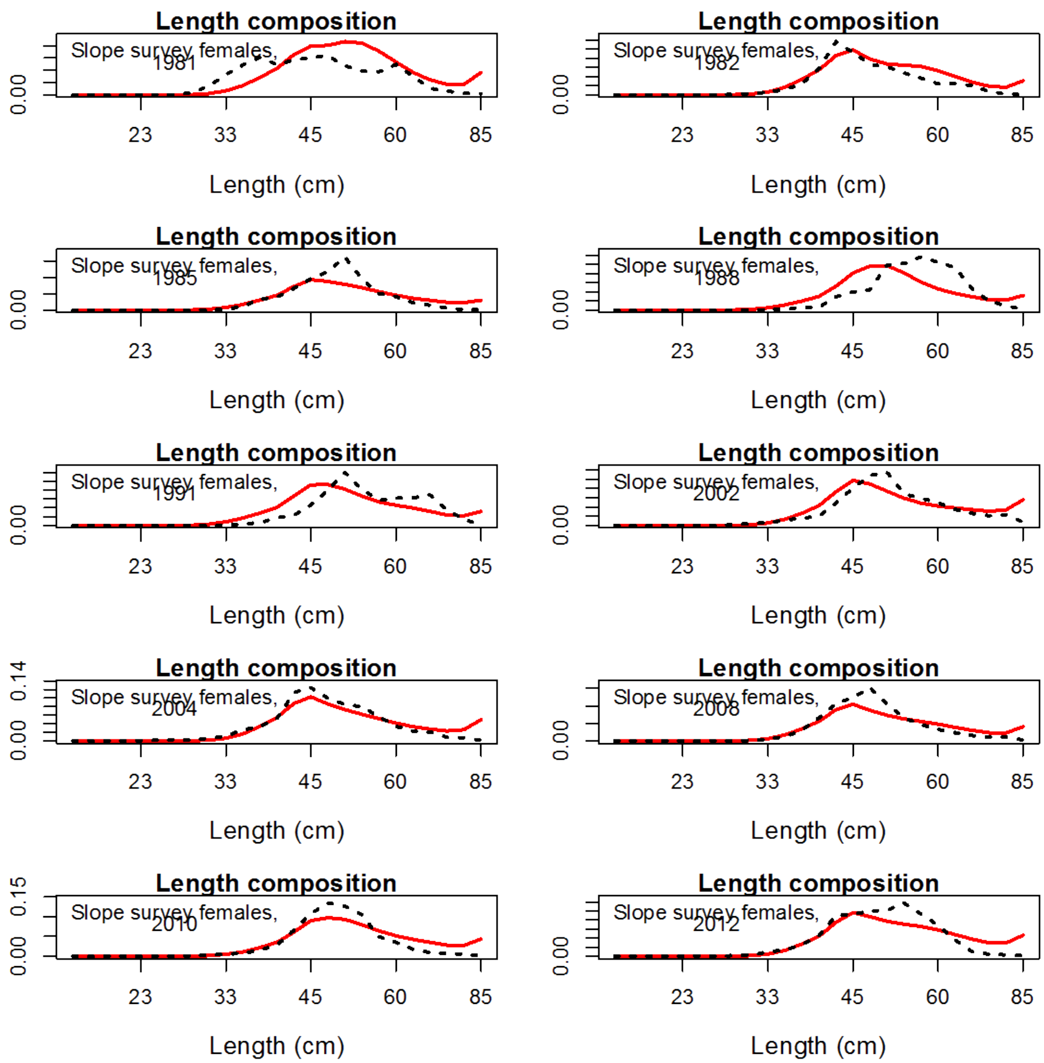

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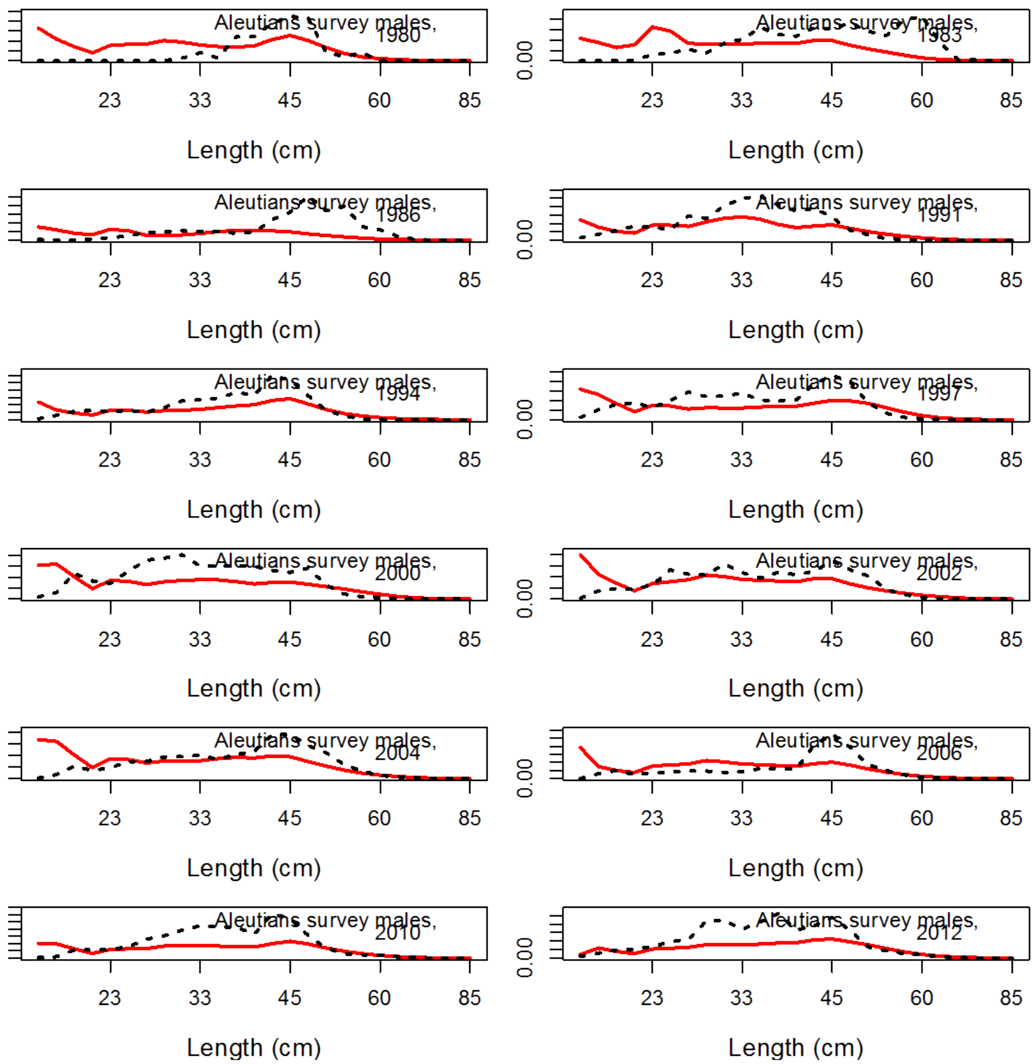

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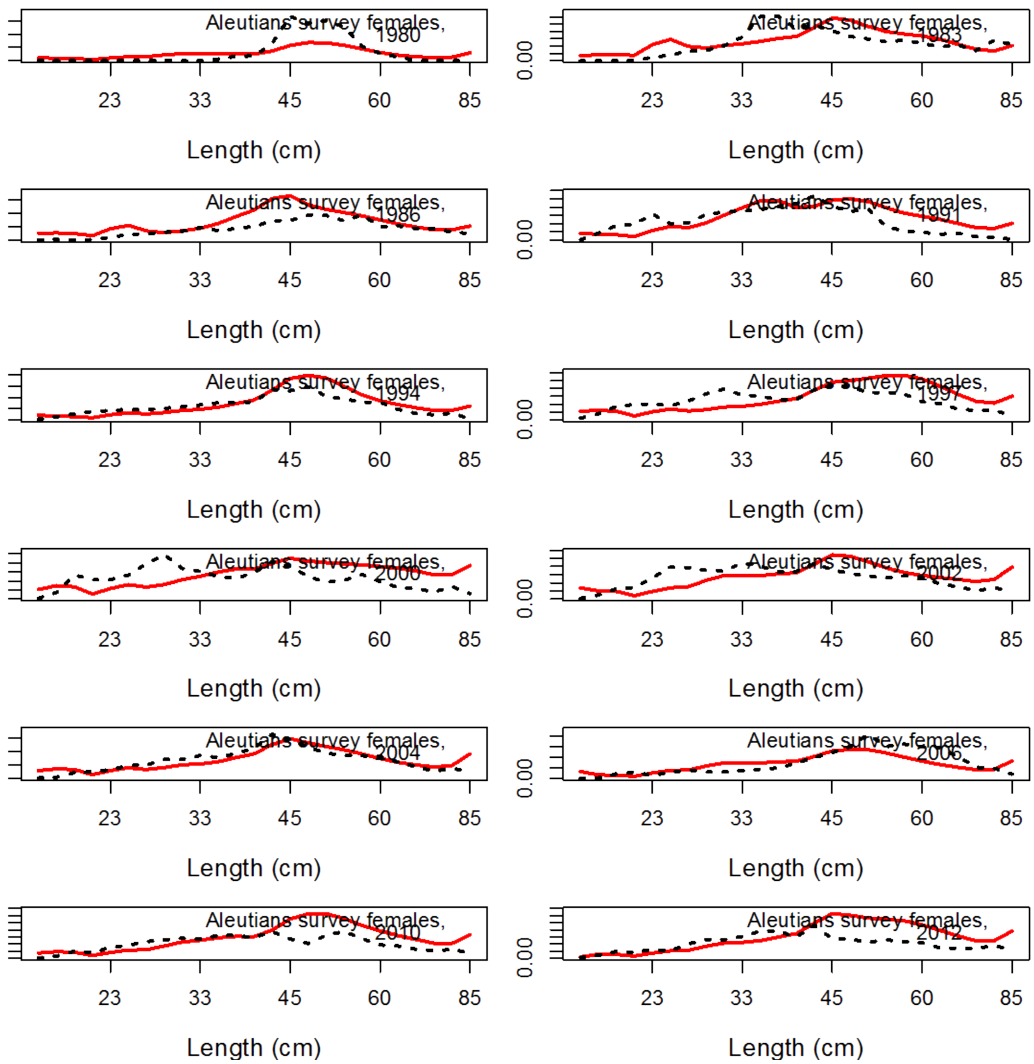

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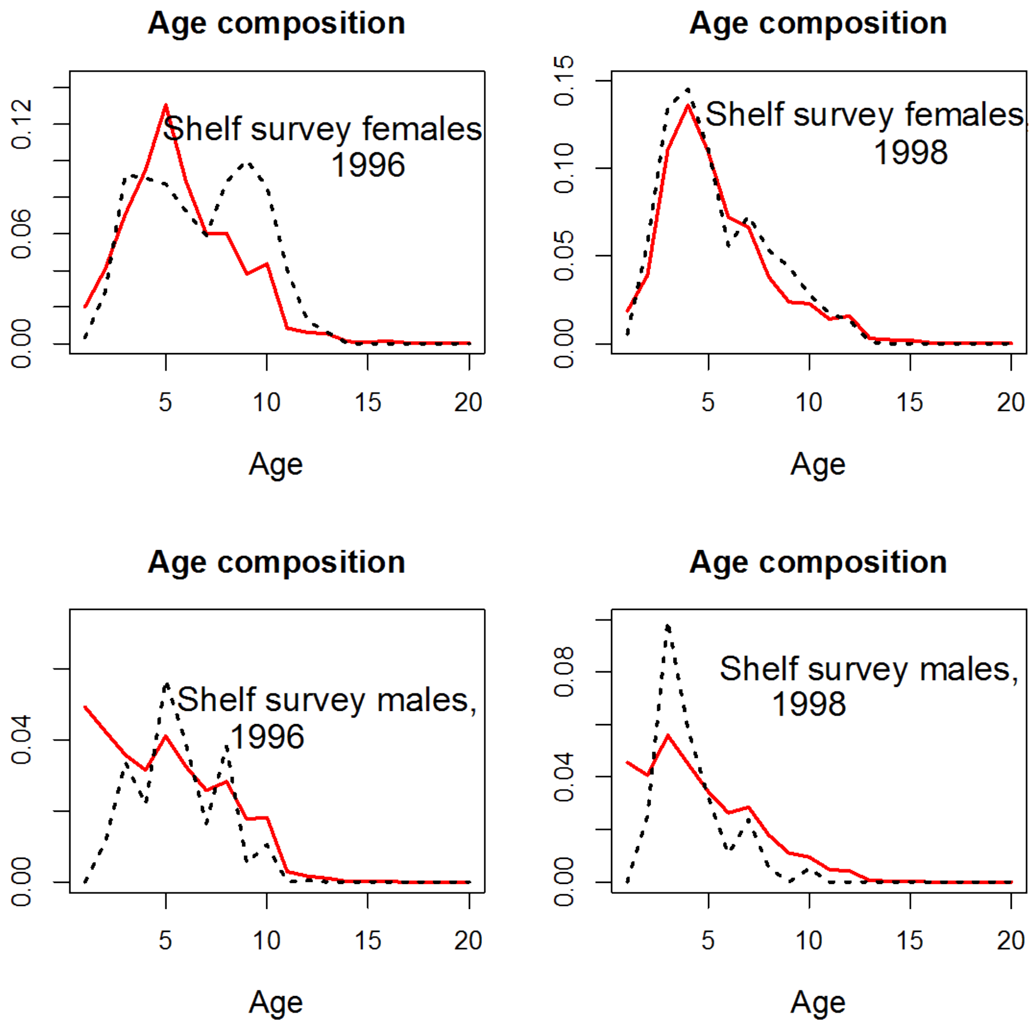

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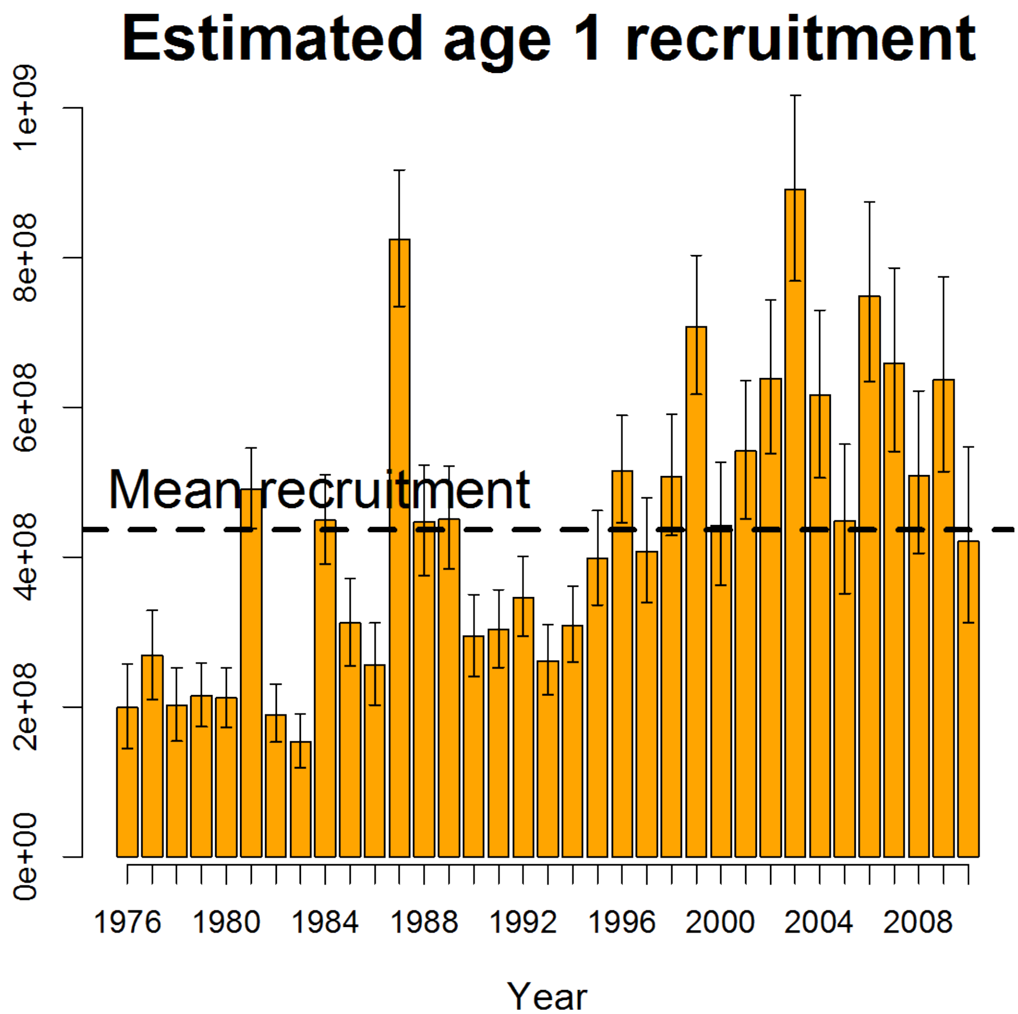

Figure 6.11--Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model.

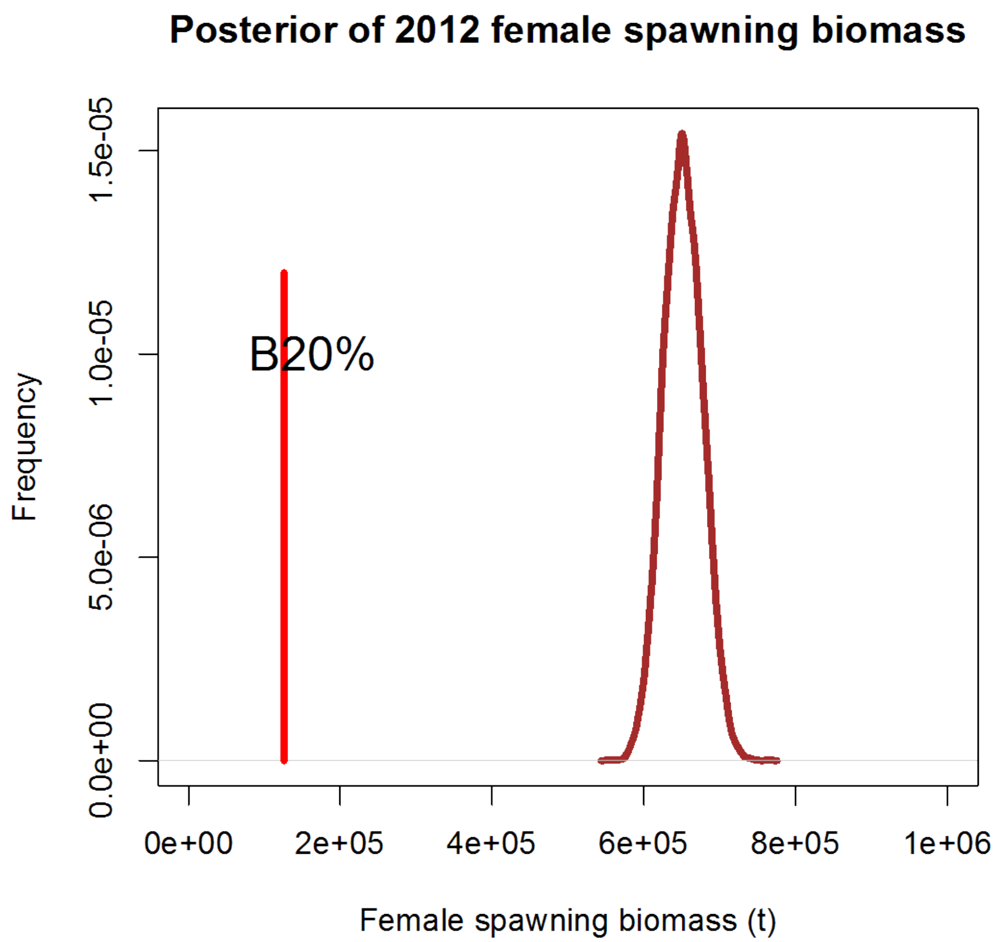

Figure 6.12—Posterior distribution of the estimate of female spawning biomass (t) from the preferred stock assessment model run.

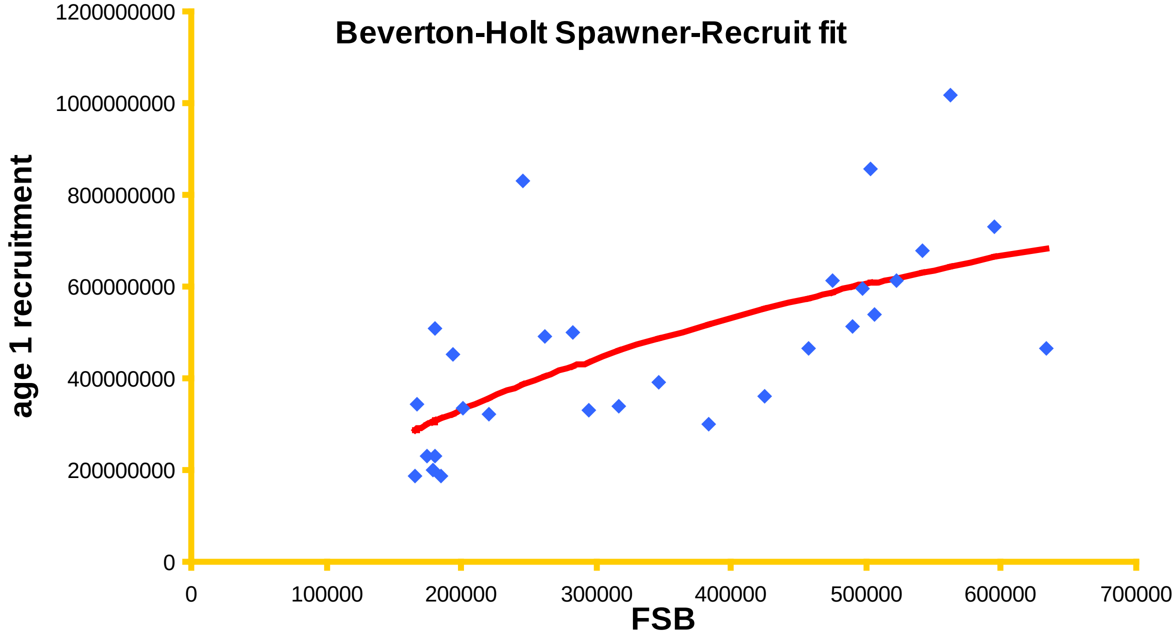

Figure 6.13—Beverton and Holt spawner recruit model fit to the age 1 recruitment data for Bering Sea arrowtooth flounder.

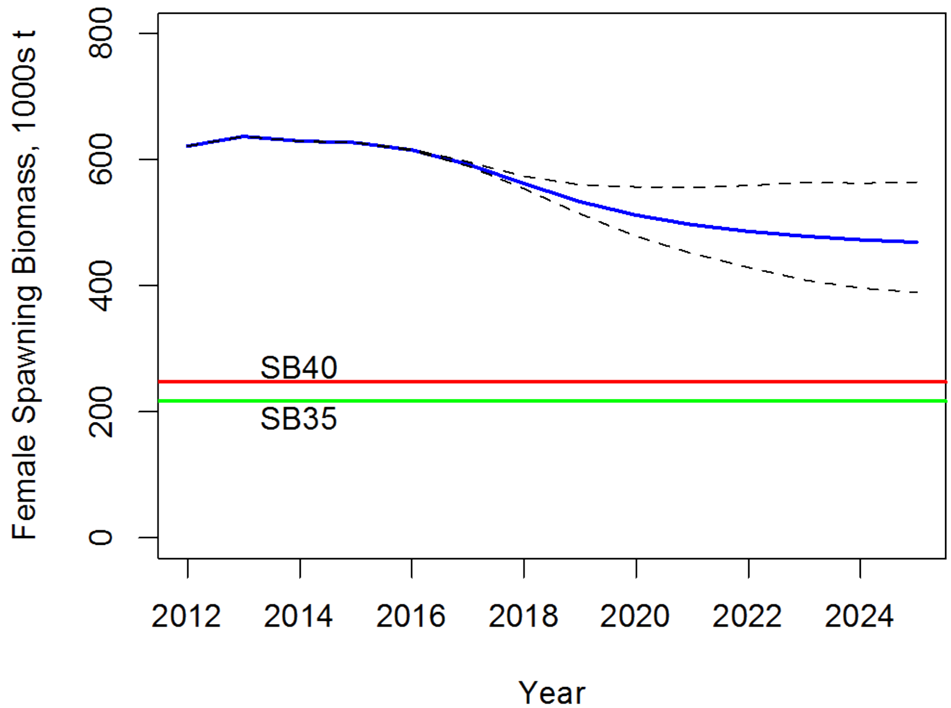

Figure 6.14--Projected female spawning biomass (1,000s t) of arrowtooth flounder if future harvest is at the same fishing mortality rate as the past five years.

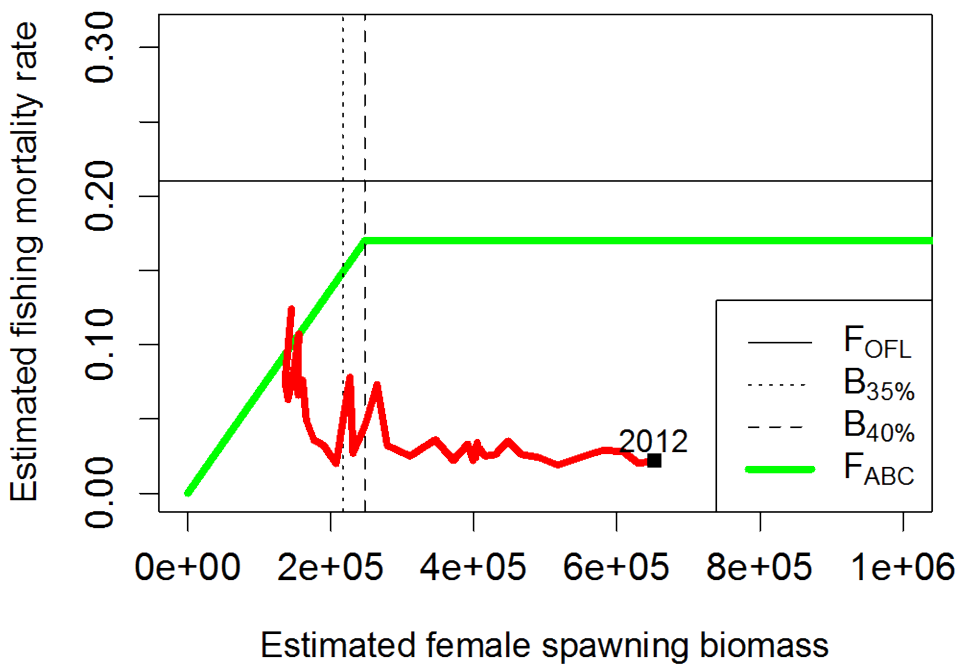

Figure 6.15—Phase plane diagram showing the time-series of stock assessment model estimates of female spawning biomass relative to the harvest control rule.

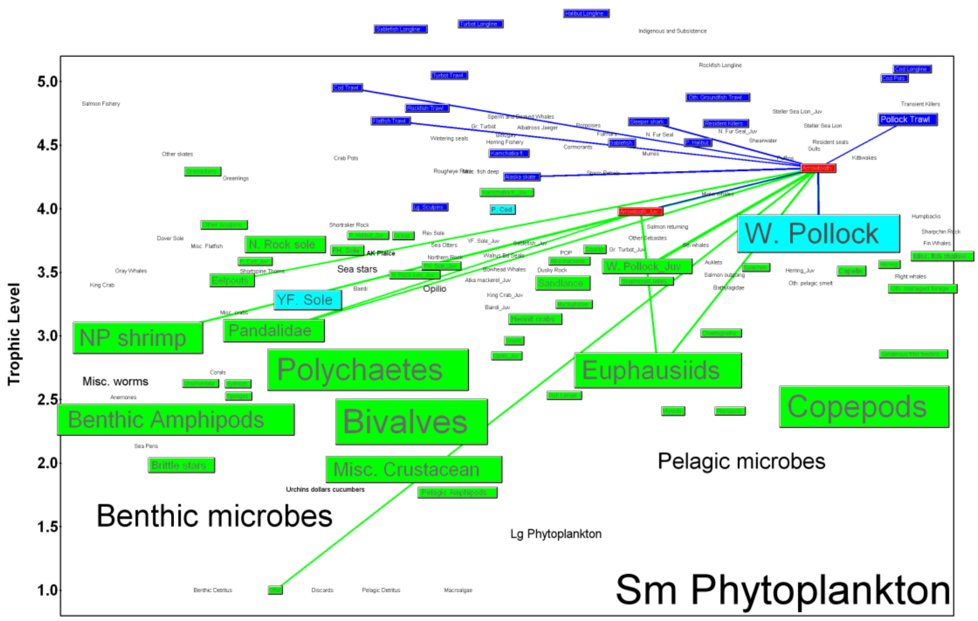

Figure 6.16. Adult and juvenile arrowtooth flounder in the EBS food web. Box size is proportional to biomass, and lines between boxes represent the most significant energy flows. Predators of arrowtooth are dark blue, prey of arrowtooth are green, and species that are both predators and prey of arrowtooth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

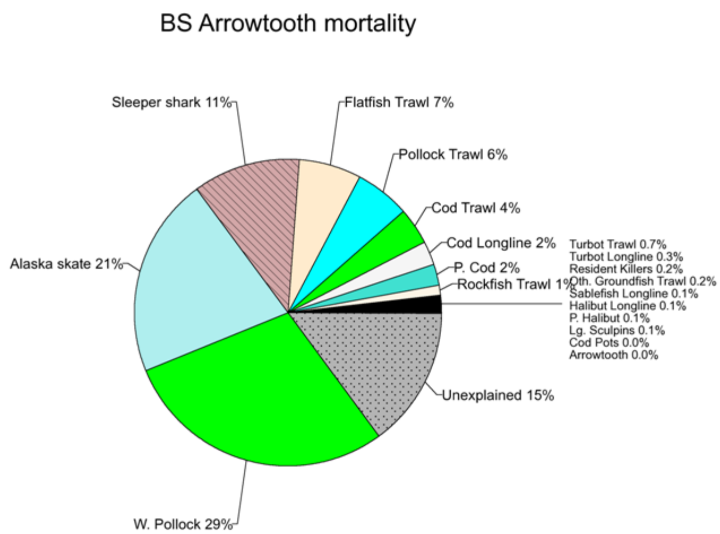

Figure 6.17. Mortality of Bering Sea arrowtooth flounder >20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. “Unexplained” mortality is the difference between the stock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

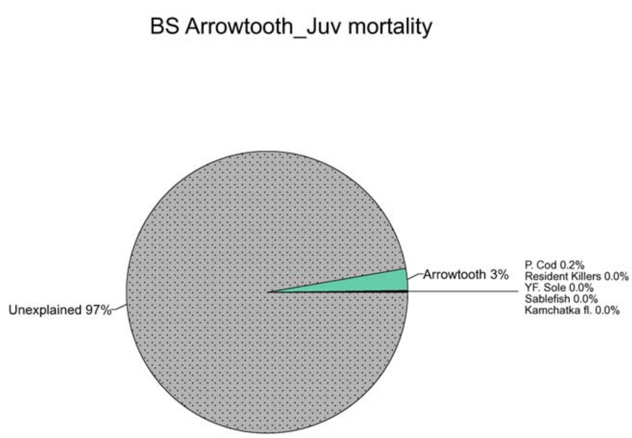

Figure 6.18. Mortality of Bering Sea arrowtooth flounder <20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. “Unexplained” mortality is the difference between the stock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

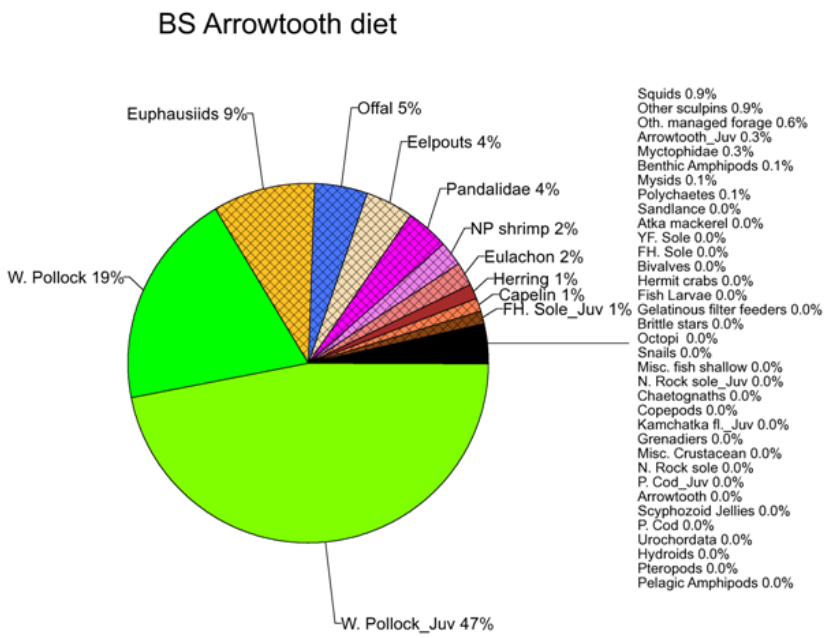

Figure 6.19. Diet of Bering Sea arrowtooth flounder >20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good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

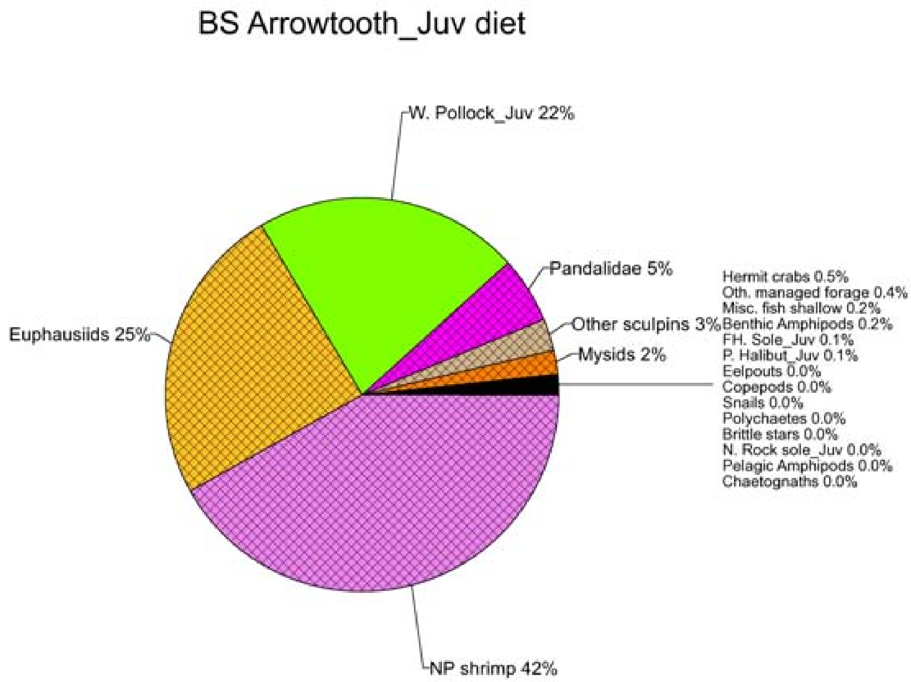

Figure 6.20. Diet of Bering Sea arrowtooth flounder <20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good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

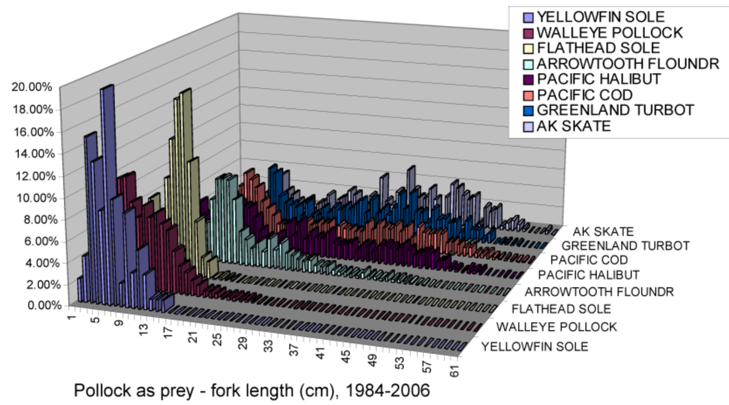

Figure 6.21. Length frequency of pollock found in stomachs, from groundfish food habits collected from 1984-2006 on AFSC summer trawl surveys in the eastern Berng Sea. Predators are sorted by median prey length of pollock in their stomachs. All lengths of predators are combined.

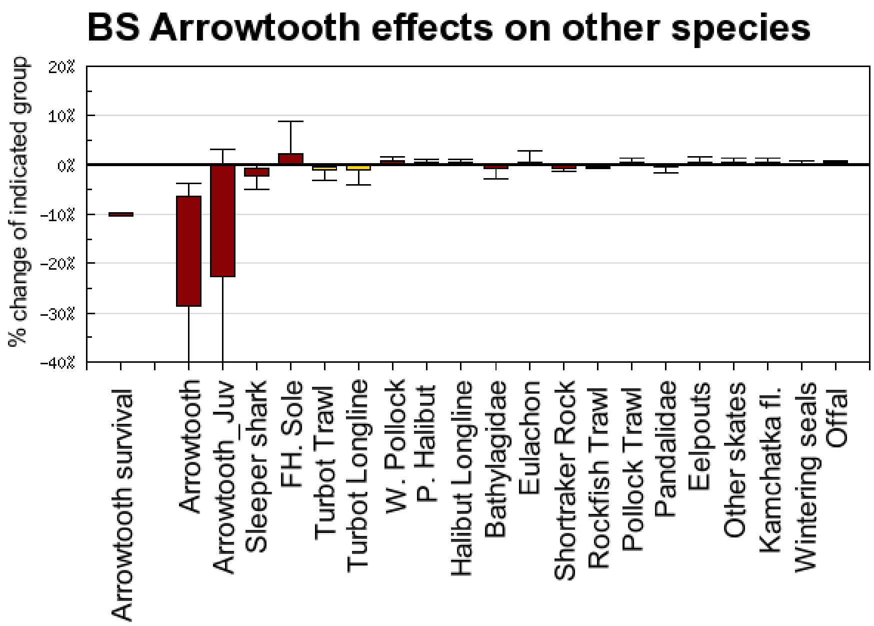

Figure 6.22. Effect of changing arrowtooth > 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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

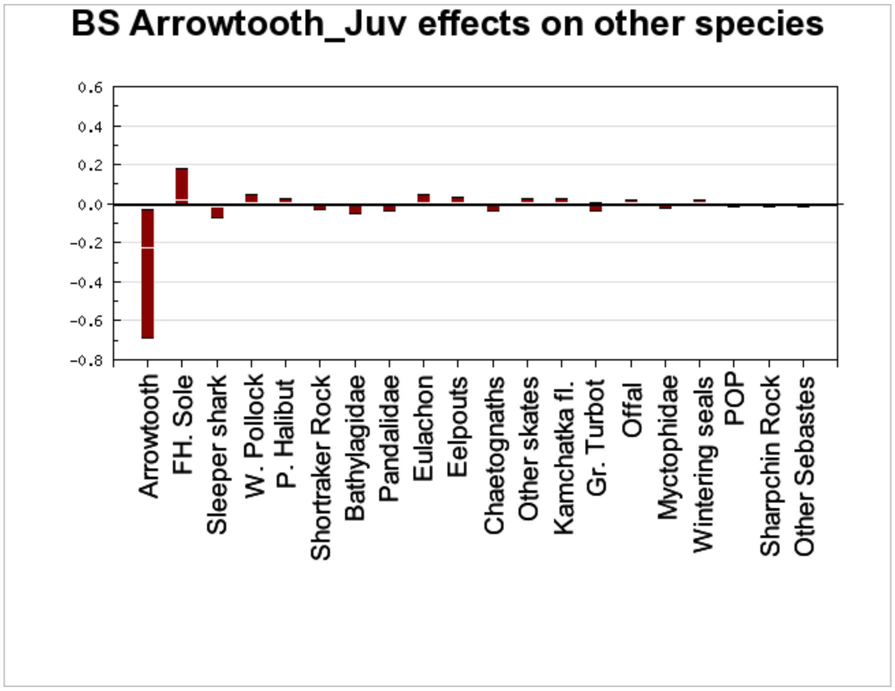

Figure 6.23. Effect of changing arrowtooth < 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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

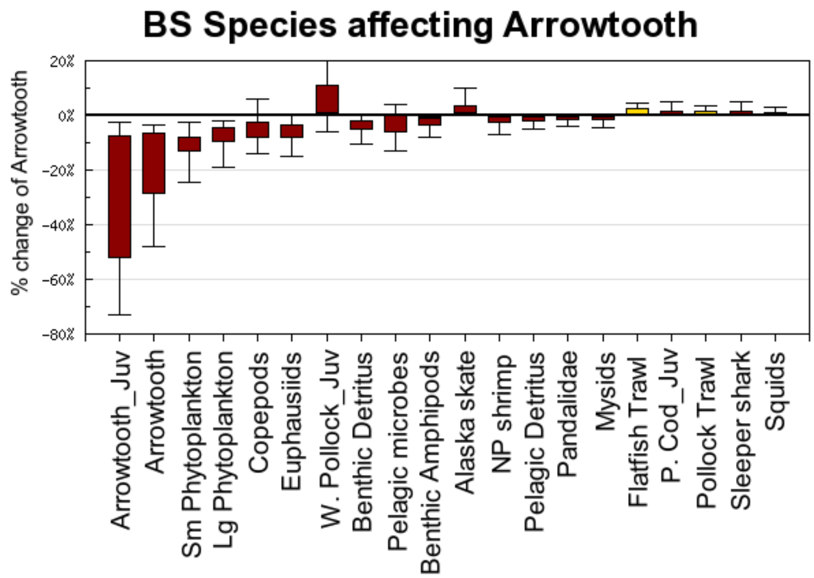

Figure 6.24. Effect of reducing fisheries catch (yellow) and other species survival (dark red) on arrowtooth > 20 cm biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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

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