Chapter 6. Assessment of the arrowtooth flounder stock in the Bering Sea/Aleutian Islands

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Executive Summary

The following changes have been made to this assessment relative to the November 2010 SAFE.

Summary of Changes in the Assessment Inputs

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) 2011 shelf survey size compositions.

3) 2011 shelf survey survey biomass point-estimates and standard error.

4) Estimate of catch and discards through 12, September 2011.

5) Estimate of retained and discarded portion of the 2010 catch.

Changes in the assessment methodology

1) This stock assessment is conducted for arrowtooth flounder only.

Summary of Assessment Results

1) The projected age 1+ total biomass for 2012 is 1,127,050 t.

2) The projected female spawning biomass for 2012 is 818,286 t.

3) The recommended 2012 ABC is 149,683 t based on an $F_{0.40\%}$ (0.22) harvest level.

4) The 2012 overfishing level is 180,939 t based on a $F_{0.35\%}$ (0.27) harvest level.

Quantity/Status	**Last year** 2011	2012	**This year** **2012**	2013
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+)	1,124,200	1,125,900	**1,127,050**	1,129,760
Female spawning biomass (t)				
Projected	806,100	811,600	**818,286**	811,932
$B_{100\%}$	669,000		**702,721**	--
$B_{40\%}$	279,600	--	**281,088**	--
$B_{35\%}$	244,650	--	**245,852**	--
F_{OFL}	0.29	0.29	**0.27**	0.27
$maxF_{ABC}$ (maximum allowable = F40%)	0.23	0.23	**0.22**	0.22
Specified/recommended F_{ABC}	0.23	0.23	**0.22**	0.22
Specified/recommended OFL (t)	186,400	191,000	**180,939**	186,123
Specified/recommended ABC (t)	153,200	157,100	**149,683**	151,941
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

*The first value is for males, the second value is for females.

Responses to SSC Comments

The 2010 SSC comments mention that in the future, it will be interesting to see if increasing biomass causes density dependence in the stock-recruit relationship. This will be examined in future assessments.

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 also 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 a concern 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. These species were assessed separately in 2010 (Wilderbuer et al. 2010a, Wilderbuer et al. 2010b), and separate management and harvest specifications of arrowtooth flounder and Kamchatka flounder were implemented for the 2011 fishing season.

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 historically managed with Greenland turbot as a species complex until 1985 because of similarities in their life history characteristics, distribution and exploitation. However, Greenland turbot were the target species of the fisheries whereas arrowtooth flounder were caught as bycatch. Starting in 1986, Greenland turbot and arrowtooth flounder have been managed separately 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 averaging 13,763 t from 1976-2011. 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 through 2006 are for arrowtooth flounder and Kamchatka flounder combined, catches thereafter are those estimated for arrowtooth flounder only. The NMFS Alaska Regional Office (AKRO) started providing separate catch statistics for arrowtooth and Kamchatka flounder in 2011. Total catch reported through 12 September, 2011 is 15,918 t (well below the 2011 ABC of 157,100 t). The AKRO reports indicate that bottom trawling accounted for 90% of the 2011 catch (4% by pelagic trawl and 6% 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 have historically 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 proportion 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 until 2011, values include Kamchatka flounder as well as arrowtooth flounder. With the advent of Amendment 80 in 2008 fishing practices changed and the percentage of arrowtooth flounder retained in catches has increased to 86%. Largest discard amounts still 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, slope and Aleutian Islands surveys, sex-specific trawl survey size composition and fishery length-frequencies from observer sampling.

Fishery Catch and Catch-at-Age

Fishery catch data from 1976 – September 13, 2011 (Table 6.1) and fishery length-frequency data from 1978-91 and 2000-2009 are used in the assessment. Actual arrowtooth flounder catch is available from observer at-sea sampling applied to the AKRO blend estimates for 2007-2011. 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.

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. The 2005 CPUE of 15.39 kg/ha was the highest ever estimated from the shelf survey. The 2006 - 2008 estimates are lower than the 2005 level but were still at high levels. The 2010 and 2011 estimates are at about the same levels estimated for 2006 through 2010 (between 8-11 kg/ha).

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 and the total research catch of these species is listed in Table 6.5. 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, and survey biomass has remained between 400,000 t – 550,000 t through 2011.

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). Due to sampling variability alone, the 95% confidence intervals for the 2011 point estimate are 442,548 – 601,664 t.

Trawl surveys were intermittently conducted over the continental slope in 1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008 and 2010. The eastern Bering Sea continental slope was surveyed in 2002 and 2004 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). 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 2010 slope survey estimate of 74,065 t is less than the 2008 estimate and is at about the levels estimated in 2002 and 2004.

The arrowtooth flounder abundance estimated from the 2010 Aleutian Islands trawl survey is 80,060 t, and is also at levels observed in the early part of the present decade but is well-below the record high 2006 estimate. 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.

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. 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 parameters estimated by the base model are classified by the following likelihood components:

Data Component	Distribution assumption
Trawl fishery size composition	Multinomial
Survey population size composition (shelf, slope, and Aleutians)	Multinomial
Survey biomass estimates and S.E. (shelf, slope, and Aleutians)	Log normal
Fishery catch composition	Log normal
Sex ratio composition	Log normal

The total log likelihood is the sum of the log likelihoods for each data component, as well as a penalty for fishing mortality deviations and a penalty for expected female spawning biomass. The model allows for the individual likelihood components to be weighted by an emphasis factor. Equal emphasis (1) was placed on fitting all data components for this assessment, except for the fishery catch likelihood which received additional emphasis (300). The number of parameters estimated by the base model are presented below:

Fishing mortality	Selectivity	Temp-q	Year class strength	Total
36	14	2	56	108

The recruitment parameters are comprised of 21 initial ages in 1976 and 33 subsequent age sex-specific recruitment estimates from 1976-2008. Recruitment in 2009 was set at the average from 1976-2008. The difference in the number of parameters estimated in this assessment compared to last year can be accounted for by an additional year (2011) of shelf 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. 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:

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

where q is catchability, α and β are a parameters estimated by the model, and T_t is the average annual bottom water temperature for year t. The catchability equation has two parts. The $e^{-\alpha}$ term is a constant or time-independent estimate of q. The model estimate of $\alpha = -0.45$ 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, $e^{\beta T_t}$, 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 (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 fishery 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 on 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, and a range of values for males (0.27-0.36). 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:

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

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 last year’s assessment initial model runs were made using the Eastern Bering Sea shelf and slope surveys and the Aleutian Islands surveys as described above with female natural mortality fixed at 0.2 and 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. It is important to evaluate the value of the maximum male selectivity on the shelf because estimates of this value at a level well less than 1.0 indicate that the sex ratio observed in the surveys are a result of a difference in male and female capture behavior or availability to the survey trawls, and not the result of differential sex-specific natural mortality. 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).

Male natural mortality was also profiled over a range of values for three 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, 0.2, 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. 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. 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. 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)

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

Model estimates indicate that arrowtooth flounder total biomass increased more than four fold from 1976 to the 2011 value of 1.08 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 observed in 2011, 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, 792,769 t in 2011, also the highest level estimated from 1976 to the present (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. 6.4) indicate large numbers from the 2002 - 2004 year classes; the model also estimated very strong recruitment in 2002 - 2004 and 2006 (Fig. 6.11). 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 2011 (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 spawner-recruit curve fit 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 abundance 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 1,127,050 t and the female spawning biomass is estimated at 818,286 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 $F_{40\%}$ 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 $B_{40\%}$ = 281,088 t. The stock assessment model estimates the 2012 level of female spawning biomass at 818,286 t (*B*). Since reliable estimates of *B*, $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and $B > B_{40\%}$ (818,286 > 281,088), arrowtooth flounder reference fishing mortality is defined in tier 3a. For the 2012 harvest recommendation: maximum permissible $F_{ABC} = F_{40\%} = 0.22$ and $F_{OFL} = F_{35\%} = 0.27$ (full selection F values).

Acceptable biological catch is estimated for 2012 by applying the $F_{40\%}$ 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 2012 ABC of 149,683 t.**

The overfishing level is estimated for 2012 by applying the $F_{35\%}$ fishing mortality rate and age-specific fishery selectivities to the projected 2012 estimate of age-specific total biomass. **This results in a 2012 OFL of 180,939 t.**

The potential yield of arrowtooth flounder in 2012 is summarized as follows:

F level	Fishing mortality rate	Potential yield
F_{OFL}	0.27	180,939 t
$F_{40\%}$	0.22	149,683 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 2011 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2012 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2011. 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 2011, 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 2012 recommended in the assessment to the *max* F_{ABC} for 2012. 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 2007-2011 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 2021 under this scenario, then the stock is not overfished.

Scenario 7: In 2011 and 2012, 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 2023 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 2012, it does not provide the best estimate of OFL for 2013, because the mean 2013 catch under Scenario 6 is predicated on the 2012 catch being equal to the 2012 OFL, whereas the actual 2012 catch will likely be less than the 2012 ABC. Therefore, the projection model was re-run with the 2012 and 2013 catch fixed equal to the 2011 catch to calculate the 2013 ABC and OFL.

Year	Catch	ABC	OFL
2012	15,918	149,683	180,939
2013	15,918	151,941	186,123

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 in the Bering Sea overall, these occasionally recorded events translate into considerable total mortality for the arrowtooth flounder population in the Bering Sea ecosystem. Using the year 1991 as a baseline, the top three predators on arrowtooth flounder >30 cm, by relative importance, are walleye pollock (29% of the total mortality), Alaska skate (21%) and sleeper shark (11%, Fig. 6.17). The next highest sources of mortality on arrowtooth flounder are four fisheries: the flatfish trawl (7%), pollock trawl (6%), Pacific cod trawl (4%), and the Pacific cod longline fishery (2%). In the Aleutian Islands, sleeper sharks are the primary predators on arrowtooth flounder adults, while Pacific cod are the primary predator on arrowtooth flounder juveniles.

Most of the occurrences of arrowtooth flounder measured in groundfish stomachs were fish between 20-40cm fork length, and were found in larger individuals of the predator species. For juvenile arrowtooth flounder (<20cm fork length), 97% of the total mortality is unknown with the remaining 3% primarily attributed to arrowtooth flounder and a few other species (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 abundance would have a great effect on these species' prey availability. However, decreases in the abundance of large adults of these species might reduce overall predation mortality experienced by arrowtooth flounder.

Arrowtooth flounder predation

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

The balance of the arrowtooth flounder diet in the eastern Bering Sea includes eelpouts, shrimp, herring, eulachon and flathead sole juveniles (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 of juveniles, euphausids 25%, juvenile pollock 22%, followed by 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, consuming more of their diet from benthic organisms, 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 was conducted assuming arrowtooth flounder survival decreased by 10%, and allowing the rest of the ecosystem to adjust to this decrease for 30 years (Fig. 6.22). This simulation 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, flathead sole biomass again increased, but only by a small percentage change. This effect on flathead sole biomass was observed 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 is 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 updated 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, whereas 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 is 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. Information on juvenile prey and their associated habitat is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) was based on samples collected in 1975 and 1976 and has not been 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

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

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

3) Changes in habitat quality

Changes in the physical environment which may affect arrowtooth flounder distribution patterns, recruitment success, migration timing and patterns are discussed 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) Arrowtooooth 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 the 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 Essential Fish Habitat Environmental Impact Statement (http://alaskafisheries.noaa.gov/habitat/seis/efheis.htm).

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], 1970-2011. Catches since 1990 are not reported by area. Beginning in 2007, when the two species were differentiated in commercial catches, catch is reported for arrowtooth flounder only in this table.

	Eastern Bering Sea				Aleutian Island Region				
Year	Non-U.S. fisheries[b]	U.S. J.V.[c]	U.S. DAH	Total	Non-U.S. fisheries	U.S. J.V.	U.S. DAH	Total	Total
1970	12,598			12,598	274			274	12,872
1971	18,792			18,792	581			581	19,373
1972	13,123			13,123	1,323			1,323	14,446
1973	9,217			9,217	3,705			3,705	12,922
1974	21,473			21,473	3,195			3,195	24,668
1975	20,832			20,832	784			784	21,616
1976	17,806			17,806	1,370			1,370	19,176
1977	9,454			9,454	2,035			2,035	11,489
1978	8,358			8,358	1,782			1,782	10,140
1979	7,921			7,921	6,436			6,436	14,357
1980	13,674	87		13,761	4,603			4,603	18,364
1981	13,468	5		13,473	3,624	16		3,640	17,113
1982	9,065	38		9,103	2,356	59		2,415	11,518
1983	10,180	36		10,216	3,700	53		3,753	13,969
1984	7,780	200		7,980	1,404	68		1,472	9,452
1985	6,840	448		7,288	11	59	89	159	7,447
1986	3,462	3,298	5	6,766		78	337	415	7,181
1987	2,789	1,561	158	4,508		114	237	351	4,859
1988		2,552	15,395	17,947		22	2,021	2,043	19,990
1989		2,264	4,000	6,264			1,042	1,042	7,306
1990		660	7,315	7,975			5,083	5,083	13,058
1991									22,052
1992									10,382
1993									9,338
1994									14,366
1995									9,280
1996									14,652
1997									10,054
1998									15,241
1999									10,573
2000									12,929
2001									13,908
2002									11,540
2003									12,834
2004									17,809
2005									13,685
2006									13,309
2007									10,503
2008									15,083
2009									16,702
2010									16,553
2011**									15,918

[a]Catches from data 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 12 September, 2011 (NMFS regional office).

Table 6.2 Estimates of retained and discarded arrowtooth flounder catch, 1985-2011.

Year	Retained	Discarded	Total	% retained
1985	17	72	89	19
1986	65	277	342	19
1987	75	320	395	19
1988	3,309	14,107	17,416	19
1989	958	4,084	5,042	19
1990*	2,356	10,042	12,398	19
1991	3,211	18,841	22,052	15
1992	675	9,707	10,382	7
1993	403	6,775	7,178	6
1994	626	13,641	14,267	4
1995	509	8,772	9,281	5
1996	1,372	13,280	14,652	9
1997	1,029	9,024	10,054	10
1998	2,896	12,345	15,241	19
1999	2,538	8,035	10,573	24
2000	5,124	7,805	12,929	60
2001	4,271	6,959	11,230	62
2002	4,039	7,501	11,540	35
2003	4,024	8,810	12,834	31
2004	3,747	14,062	17,809	21
2005	7,010	6,675	13,685	51
2006	6,104	7,205	13,309	46
2007	5,067	6,603	11,670	43
2008	15,956	5,904	21,860	73
2009	24,226	6,184	30,411	80
2010	32,064	7,349	39,412	81
2011	13,726	2,191	15,918	86

1990 retained rate was applied to the 1985-89 reported catch
and 2011 catch is through 9/12/2011. Source: AKFIN data base.

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	515,004		
2004	519,129	68,568	94,998
2005	722,209		
2006	608,488		183,836
2007	482,184		
2008	530,127	96,248	
2009	406,854		
2010	528,667	74,065	80,060
2011	522,110		

Table 6.4—Arrowtooth flounder male and female weight-at-age (kg) and proportion of females mature at age.

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

Table 6.5—Total tonnage of the research catch for arrowtooth flounder and Kamchatka flounder.

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	18.4
1991	27.5
1992	10.9
1993	16.3
1994	40.7
1995	18.2
1996	17.9
1997	32.3
1998	12.6
1999	9.8
2000	10.8
2002	11.2
2003	18
2004	19.4
2005	23.1
2006	20.3
2007	19.1
2008	20.8
2009	14.8
2010	19.6
2011	20.5

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	0.134	0.072
1977	0.082	0.043
1978	0.068	0.037
1979	0.092	0.051
1980	0.116	0.064
1981	0.108	0.059
1982	0.070	0.038
1983	0.081	0.044
1984	0.052	0.028
1985	0.038	0.021
1986	0.034	0.019
1987	0.021	0.012
1988	0.081	0.045
1989	0.028	0.015
1990	0.048	0.025
1991	0.076	0.040
1992	0.033	0.018
1993	0.027	0.016
1994	0.037	0.023
1995	0.023	0.015
1996	0.035	0.023
1997	0.023	0.016
1998	0.035	0.023
1999	0.025	0.016
2000	0.030	0.018
2001	0.032	0.019
2002	0.025	0.015
2003	0.027	0.016
2004	0.036	0.021
2005	0.026	0.015
2006	0.024	0.014
2007	0.018	0.011
2008	0.024	0.015
2009	0.025	0.016
2010	0.024	0.016
2011	0.022	0.015

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	0.07
2	0.01	0.02	0.15	0.18	0.00	0.05	0.06	0.11
3	0.02	0.04	0.41	0.28	0.00	0.08	0.12	0.18
4	0.06	0.08	0.80	0.41	0.00	0.12	0.23	0.26
5	0.15	0.16	1.00	0.58	0.05	0.18	0.40	0.37
6	0.37	0.30	0.95	0.75	0.89	0.27	0.60	0.49
7	0.64	0.49	0.82	0.87	1.00	0.38	0.77	0.61
8	0.85	0.68	0.67	0.91	1.00	0.50	0.88	0.72
9	0.95	0.82	0.54	0.83	1.00	0.62	0.94	0.81
10	0.98	0.91	0.44	0.69	1.00	0.73	0.97	0.88
11	0.99	0.96	0.34	0.51	1.00	0.82	0.99	0.92
12	1.00	0.98	0.27	0.36	1.00	0.88	0.99	0.95
13	1.00	0.99	0.21	0.24	1.00	0.92	1.00	0.97
14	1.00	1.00	0.17	0.15	1.00	0.95	1.00	0.98
15	1.00	1.00	0.13	0.10	1.00	0.97	1.00	0.99
16	1.00	1.00	0.10	0.06	1.00	0.98	1.00	0.99
17	1.00	1.00	0.08	0.04	1.00	0.99	1.00	1.00
18	1.00	1.00	0.06	0.02	1.00	0.99	1.00	1.00
19	1.00	1.00	0.05	0.01	1.00	1.00	1.00	1.00
20	1.00	1.00	0.04	0.01	1.00	1.00	1.00	1.00
21	1.00	1.00	0.03	0.01	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 2010 and 2011 assessments.

	2011 Assessment		2010 Assessment	
	Total biomass	Female Spawning biomass	Total biomass	Female Spawning biomass
1976	266,767	170,517	255,717	163,978
1977	264,346	170,816	253,858	164,188
1978	271,333	181,231	260,936	174,333
1979	281,218	188,931	270,883	181,949
1980	286,882	188,041	277,057	181,453
1981	292,363	187,596	283,407	181,614
1982	299,979	191,603	291,883	186,137
1983	317,110	200,237	309,456	195,050
1984	333,842	206,518	326,950	201,819
1985	354,523	225,000	348,221	220,450
1986	378,646	250,163	372,968	245,653
1987	409,553	265,060	404,737	260,865
1988	444,648	282,897	440,671	279,065
1989	471,856	293,647	470,078	291,282
1990	514,134	313,523	513,537	312,033
1991	548,659	339,579	549,601	339,517
1992	568,824	372,897	571,828	374,930
1993	594,574	410,549	598,503	413,802
1994	615,270	439,171	619,820	443,278
1995	625,219	452,140	630,620	457,119
1996	639,127	464,995	644,900	470,268
1997	646,850	468,487	653,403	474,218
1998	663,226	471,588	670,301	477,457
1999	679,546	471,227	687,752	477,584
2000	704,304	482,714	713,480	489,365
2001	732,908	496,726	743,340	503,966
2002	763,616	511,130	775,067	519,261
2003	803,571	538,098	815,384	547,408
2004	845,848	568,995	857,591	579,813
2005	886,113	590,143	897,662	602,300
2006	932,937	618,958	943,869	630,857
2007	976,040	661,292	986,129	671,768
2008	1,017,910	711,845	1,026,170	720,447
2009	1,048,900	743,233	1,054,380	750,570
2010	1,066,670	766,275	1,072,260	772,191
2011	1,081,290	792,769		

Table 6.11 Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2011.

females	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	106,848	35,021	88,373	72,895	73,652	28,389	15,952	11,058	8,490	6,908
1977	140,748	87,458	28,650	72,178	59,242	59,060	22,129	11,977	8,075	6,120
1978	108,233	115,217	71,570	23,422	58,828	47,891	46,925	17,184	9,145	6,117
1979	113,483	88,603	94,294	58,524	19,104	47,656	38,240	36,760	13,273	7,017
1980	112,740	92,896	72,503	77,073	47,674	15,420	37,730	29,510	27,836	9,962
1981	258,985	92,284	76,006	59,236	62,701	38,339	12,102	28,670	21,895	20,424
1982	99,609	211,997	75,508	62,106	48,211	50,485	30,174	9,242	21,413	16,184
1983	80,508	81,542	173,497	61,742	50,652	39,044	40,283	23,609	7,127	16,401
1984	232,974	65,905	66,730	141,837	50,324	40,951	31,029	31,296	18,036	5,402
1985	159,082	190,725	53,942	54,582	115,794	40,871	32,895	24,566	24,512	14,056
1986	131,850	130,236	156,117	44,133	44,594	94,245	32,998	26,277	19,470	19,355
1987	418,685	107,943	106,607	127,740	36,066	36,320	76,214	26,435	20,904	15,438
1988	228,093	342,777	88,366	87,250	104,465	29,434	29,511	61,569	21,264	16,782
1989	230,757	186,718	280,509	72,241	71,116	84,461	23,394	22,931	47,046	16,122
1990	152,128	188,918	152,847	229,543	59,054	57,970	68,439	18,807	18,328	37,500
1991	157,260	124,541	154,630	125,032	187,443	47,995	46,644	54,342	14,787	14,344
1992	181,334	128,736	101,920	126,426	101,942	151,675	38,221	36,368	41,713	11,268
1993	137,330	148,455	105,380	83,395	103,321	83,037	122,690	30,633	28,950	33,100
1994	163,295	112,431	121,525	86,236	68,178	84,244	67,326	98,739	24,518	23,112
1995	210,502	133,685	92,030	99,429	70,459	55,497	68,036	53,808	78,307	19,374
1996	273,528	172,337	109,438	75,317	81,304	57,484	45,061	54,893	43,211	62,748
1997	217,305	223,932	141,069	89,543	61,546	66,209	46,470	36,076	43,633	34,232
1998	272,173	177,906	183,315	115,448	73,217	50,207	53,744	37,475	28,952	34,938
1999	378,645	222,822	145,627	149,989	94,337	59,617	40,576	43,007	29,769	22,920
2000	240,135	309,994	182,405	119,176	122,634	76,942	48,373	32,698	34,481	23,811
2001	291,051	196,595	253,757	149,259	97,413	99,941	62,310	38,848	26,098	27,442
2002	344,554	238,278	160,929	207,639	121,990	79,365	80,882	49,984	30,961	20,736
2003	476,210	282,084	195,057	131,696	169,763	99,484	64,376	65,142	40,046	24,744
2004	324,032	389,868	230,914	159,620	107,663	138,407	80,646	51,792	52,115	31,954
2005	231,247	265,277	319,130	188,933	130,427	87,657	111,836	64,513	41,124	41,238
2006	396,424	189,320	217,157	261,157	154,462	106,351	71,082	90,026	51,651	32,842
2007	322,093	324,550	154,980	177,715	213,532	125,989	86,306	57,295	72,204	41,329
2008	239,649	263,698	265,691	126,845	145,357	174,339	102,475	69,846	46,196	58,116
2009	270,775	196,199	215,867	217,433	103,713	118,561	141,474	82,595	56,014	36,962
2010	143,323	221,681	160,610	176,656	177,771	84,580	96,173	113,950	66,179	44,772
2011	441,296	117,338	181,472	131,439	144,443	145,008	68,645	77,533	91,412	52,967

Table 6.11 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2011.

	females				numbers at age (1,000s)						
	11	12	13	14	15	16	17	18	19	20	21
1976	5,815	5,006	4,359	3,824	3,372	2,983	2,634	2,331	2,043	1,785	4,086
1977	4,956	4,166	3,584	3,121	2,737	2,414	2,135	1,885	1,668	1,462	4,203
1978	4,623	3,740	3,142	2,703	2,354	2,064	1,821	1,611	1,422	1,258	4,273
1979	4,682	3,536	2,860	2,402	2,067	1,800	1,578	1,392	1,231	1,087	4,229
1980	5,249	3,499	2,641	2,136	1,795	1,544	1,344	1,179	1,040	920	3,971
1981	7,280	3,831	2,552	1,926	1,558	1,309	1,126	980	860	758	3,566
1982	15,038	5,353	2,816	1,876	1,416	1,145	962	827	720	632	3,178
1983	12,365	11,480	4,086	2,149	1,432	1,080	874	734	631	550	2,908
1984	12,396	9,336	8,666	3,084	1,622	1,080	815	659	554	477	2,609
1985	4,202	9,637	7,257	6,735	2,397	1,260	840	634	512	431	2,398
1986	11,084	3,312	7,595	5,719	5,308	1,889	993	662	499	404	2,229
1987	15,330	8,775	2,622	6,012	4,527	4,201	1,495	786	524	395	2,084
1988	12,385	12,294	7,037	2,103	4,821	3,630	3,369	1,199	630	420	1,988
1989	12,687	9,354	9,283	5,313	1,587	3,639	2,740	2,543	905	476	1,818
1990	12,838	10,099	7,445	7,388	4,228	1,263	2,897	2,181	2,024	720	1,826
1991	29,300	10,025	7,885	5,812	5,768	3,301	986	2,261	1,703	1,580	1,988
1992	10,902	22,248	7,610	5,985	4,412	4,378	2,506	749	1,716	1,292	2,708
1993	8,931	8,637	17,624	6,028	4,741	3,495	3,468	1,985	593	1,360	3,169
1994	26,399	7,121	6,886	14,050	4,806	3,779	2,786	2,765	1,582	473	3,610
1995	18,239	20,824	5,616	5,431	11,081	3,790	2,981	2,197	2,180	1,248	3,220
1996	15,512	14,599	16,667	4,495	4,346	8,869	3,033	2,386	1,758	1,745	3,576
1997	49,649	12,269	11,545	13,180	3,555	3,437	7,013	2,399	1,886	1,391	4,207
1998	27,388	39,711	9,812	9,233	10,541	2,843	2,749	5,608	1,918	1,509	4,477
1999	27,625	21,646	31,381	7,754	7,296	8,329	2,246	2,172	4,432	1,516	4,730
2000	18,317	22,070	17,292	25,068	6,194	5,828	6,653	1,794	1,735	3,540	4,989
2001	18,931	14,558	17,538	13,741	19,920	4,922	4,631	5,287	1,426	1,379	6,777
2002	21,780	15,018	11,548	13,912	10,899	15,800	3,904	3,674	4,194	1,131	6,469
2003	16,558	17,386	11,987	9,217	11,104	8,699	12,611	3,116	2,932	3,347	6,066
2004	19,725	13,195	13,853	9,552	7,344	8,847	6,931	10,048	2,483	2,336	7,500
2005	25,253	15,582	10,422	10,941	7,544	5,800	6,987	5,474	7,936	1,961	7,769
2006	32,903	20,142	12,427	8,312	8,726	6,016	4,626	5,572	4,366	6,329	7,759
2007	26,257	26,297	16,097	9,931	6,642	6,973	4,808	3,697	4,453	3,489	11,259
2008	33,244	21,116	21,147	12,944	7,986	5,341	5,607	3,866	2,972	3,581	11,859
2009	46,459	26,568	16,874	16,898	10,343	6,381	4,268	4,481	3,089	2,375	12,338
2010	29,517	37,090	21,208	13,469	13,489	8,256	5,094	3,407	3,577	2,466	11,744
2011	35,803	23,597	29,649	16,953	10,767	10,782	6,600	4,072	2,723	2,859	11,359

Table 6.11 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2011.

males	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	106,848	30,143	65,468	46,480	40,421	13,410	6,485	3,870	2,557	1,791
1977	140,748	75,216	21,192	45,905	32,408	27,877	9,078	4,281	2,489	1,613
1978	108,233	99,120	52,930	14,889	32,139	22,538	19,169	6,147	2,854	1,639
1979	113,483	76,230	69,767	37,204	10,435	22,401	15,561	13,066	4,135	1,901
1980	112,740	79,914	53,635	48,997	26,028	7,246	15,359	10,487	8,652	2,702
1981	258,985	79,376	56,203	37,633	34,213	18,004	4,933	10,231	6,832	5,542
1982	99,609	182,352	55,832	39,447	26,294	23,695	12,285	3,298	6,700	4,405
1983	80,508	70,155	128,347	39,242	27,644	18,321	16,350	8,366	2,216	4,456
1984	232,974	56,698	49,369	90,171	27,476	19,227	12,601	11,075	5,579	1,460
1985	159,082	164,108	39,919	34,722	63,281	19,200	13,340	8,657	7,533	3,766
1986	131,850	112,070	115,570	28,090	24,395	44,321	13,377	9,228	5,945	5,144
1987	418,685	92,889	78,929	81,338	19,742	17,098	30,919	9,273	6,355	4,074
1988	228,093	294,995	65,435	55,577	57,224	13,866	11,974	21,569	6,443	4,402
1989	230,757	160,633	207,592	45,972	38,914	39,803	9,537	8,111	14,386	4,247
1990	152,128	162,576	113,142	146,134	32,324	27,298	27,813	6,629	5,607	9,904
1991	157,260	107,163	114,473	79,589	102,592	22,605	18,965	19,151	4,523	3,800
1992	181,334	110,755	75,419	80,441	55,750	71,421	15,573	12,881	12,820	2,994
1993	137,330	127,751	78,004	53,082	56,538	39,079	49,836	10,799	8,876	8,791
1994	163,295	96,755	89,984	54,914	37,327	39,671	27,320	34,666	7,474	6,119
1995	210,502	115,039	68,138	63,322	38,583	26,146	27,645	18,905	23,817	5,107
1996	273,528	148,312	81,035	47,976	44,542	27,090	18,301	19,267	13,118	16,472
1997	217,305	192,700	104,452	57,031	33,715	31,214	18,893	12,680	13,261	8,983
1998	272,173	153,104	135,739	73,542	40,114	23,669	21,842	13,162	8,794	9,166
1999	378,645	191,744	107,826	95,528	51,679	28,107	16,504	15,129	9,055	6,019
2000	240,135	266,776	135,063	75,914	67,186	36,274	19,662	11,492	10,484	6,253
2001	291,051	169,181	187,898	95,072	53,369	47,119	25,334	13,656	7,935	7,208
2002	344,554	205,050	119,156	132,254	66,828	37,418	32,892	17,580	9,418	5,448
2003	476,210	242,756	144,433	83,888	93,010	46,901	26,168	22,893	12,176	6,499
2004	324,032	335,509	170,988	101,678	58,988	65,258	32,784	18,198	15,838	8,390
2005	231,247	228,278	236,284	120,332	71,447	41,329	45,495	22,701	12,515	10,834
2006	396,424	162,924	160,793	166,344	84,620	50,136	28,896	31,653	15,715	8,630
2007	322,093	279,303	114,763	113,207	116,996	59,400	35,076	20,124	21,942	10,855
2008	239,649	226,943	196,761	80,818	79,662	82,208	41,634	24,502	14,009	15,234
2009	270,775	168,846	159,858	138,530	56,842	55,918	57,512	28,994	16,984	9,676
2010	143,323	190,774	118,932	112,544	97,425	39,893	39,108	40,031	20,083	11,721
2011	441,296	100,980	134,382	83,735	79,158	68,390	27,912	27,239	27,755	13,876

Table 6.11 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2011.

males	numbers at age (1,000s)									
	11	12	13	14	15	16	17	18	19	20	21
1976	1,297	961	721	544	413	314	239	182	137	103	125
1977	1,116	804	594	444	335	254	194	147	112	85	141
1978	1,055	727	523	386	289	218	165	126	96	73	146
1979	1,085	696	479	344	254	190	143	109	83	63	144
1980	1,232	700	448	308	221	163	122	92	70	53	133
1981	1,713	777	441	282	194	139	102	77	58	44	117
1982	3,539	1,088	492	279	178	122	88	65	48	37	102
1983	2,911	2,331	716	324	183	117	80	58	43	32	91
1984	2,915	1,897	1,517	465	210	119	76	52	38	28	80
1985	981	1,954	1,270	1,015	311	141	80	51	35	25	72
1986	2,563	667	1,326	862	689	211	95	54	35	24	66
1987	3,515	1,748	454	904	587	469	144	65	37	24	61
1988	2,817	2,428	1,207	314	624	405	324	99	45	25	58
1989	2,881	1,837	1,580	785	204	405	263	210	65	29	54
1990	2,916	1,976	1,259	1,083	538	140	278	180	144	44	57
1991	6,683	1,964	1,329	846	728	361	94	187	121	97	68
1992	2,499	4,379	1,285	869	553	475	236	61	122	79	108
1993	2,047	1,706	2,988	876	592	377	324	161	42	83	128
1994	6,046	1,406	1,171	2,050	601	406	259	222	110	29	145
1995	4,167	4,110	955	795	1,392	408	276	176	151	75	118
1996	3,525	2,873	2,833	658	548	959	281	190	121	104	133
1997	11,245	2,402	1,957	1,929	448	373	653	191	129	82	161
1998	6,196	7,748	1,654	1,347	1,328	308	257	449	132	89	168
1999	6,253	4,220	5,273	1,126	916	903	210	175	306	90	175
2000	4,147	4,304	2,903	3,626	774	630	621	144	120	210	182
2001	4,288	2,840	2,945	1,986	2,480	529	431	425	99	82	268
2002	4,935	2,931	1,940	2,011	1,356	1,694	361	294	290	67	239
2003	3,751	3,394	2,014	1,333	1,382	932	1,163	248	202	199	210
2004	4,468	2,575	2,329	1,382	914	948	639	798	170	139	281
2005	5,722	3,042	1,752	1,583	939	622	644	434	542	116	285
2006	7,454	3,932	2,089	1,203	1,087	645	427	442	298	372	275
2007	5,949	5,132	2,706	1,437	827	748	444	293	304	205	445
2008	7,525	4,120	3,553	1,873	995	573	518	307	203	211	450
2009	10,500	5,181	2,835	2,444	1,288	684	394	356	211	140	454
2010	6,663	7,221	3,561	1,948	1,680	885	470	271	245	145	408
2011	8,081	4,589	4,971	2,450	1,340	1,156	609	323	186	168	381

Table 6.12 Estimated age 1 recruitment of arrowtooth flounder (thousands of fish) from the 2010 and 2011 stock assessments. Average from 2011 = 441,356.

Year class	2010 Assessment	2011 Assessment
1975	207,702	213,696
1976	274,260	281,496
1977	210,932	216,466
1978	222,072	226,966
1979	221,362	225,480
1980	509,366	517,970
1981	196,852	199,218
1982	159,795	161,017
1983	465,852	465,948
1984	320,116	318,164
1985	265,472	263,700
1986	844,620	837,370
1987	458,688	456,186
1988	462,672	461,514
1989	303,430	304,256
1990	312,626	314,520
1991	359,594	362,668
1992	273,102	274,660
1993	325,920	326,590
1994	420,346	421,004
1995	546,526	547,056
1996	434,730	434,610
1997	544,086	544,346
1998	759,230	757,290
1999	482,964	480,270
2000	588,190	582,102
2001	703,844	689,108
2002	980,020	952,420
2003	663,492	648,064
2004	467,512	462,494
2005	799,072	792,848
2006	643,458	644,186
2007	487,974	479,298
2008	468,948	541,550

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
2011	800.493	15.918	0.02
2012	806.702	149.683	0.22
2013	693.439	129.063	0.22
2014	595.102	111.369	0.22
2015	522.226	96.820	0.22
2016	478.526	86.080	0.22
2017	438.548	78.872	0.22
2018	402.687	73.116	0.22
2019	373.042	67.836	0.22
2020	349.413	63.291	0.22
2021	331.019	59.503	0.21
2022	317.323	56.446	0.21
2023	307.508	54.179	0.21
2024	300.939	52.567	0.21

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2011	800.493	15.918	0.02
2012	813.424	74.842	0.10
2013	766.520	67.815	0.10
2014	717.716	64.018	0.10
2015	677.570	60.166	0.10
2016	653.740	56.862	0.10
2017	624.689	54.388	0.10
2018	593.972	52.136	0.10
2019	565.369	49.757	0.10
2020	539.668	47.430	0.10
2021	517.185	45.346	0.10
2022	498.148	43.557	0.10
2023	482.329	42.066	0.10
2024	469.596	40.849	0.10

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2011	800.493	15.918	0.02
2012	818.286	16.423	0.02
2013	823.672	17.616	0.02
2014	816.550	17.636	0.02
2015	810.753	17.480	0.02
2016	814.232	17.285	0.02
2017	806.300	17.145	0.02
2018	791.615	16.954	0.02
2019	774.648	16.639	0.02
2020	756.593	16.245	0.02
2021	738.484	15.833	0.02
2022	721.255	15.435	0.02
2023	705.327	15.066	0.02
2024	691.021	14.732	0.02

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2011	800.493	15.918	0.02
2012	819.598	0	0
2013	840.011	0	0
2014	847.908	0	0
2015	855.785	0	0
2016	871.341	0	0
2017	873.829	0	0
2018	868.002	0	0
2019	858.376	0	0
2020	846.132	0	0
2021	832.442	0	0
2022	818.414	0	0
2023	804.656	0	0
2024	791.621	0	0

Table 6.13 (continued).

Scenario 6
Determination of whether arrowtooth flounder are currently overfished
B35=244,664

Year	Female spawning biomass	catch	F
2011	800.493	15.918	0.02
2012	803.708	180.939	0.27
2013	663.332	149.602	0.27
2014	549.130	124.381	0.27
2015	468.418	104.866	0.27
2016	422.001	91.249	0.27
2017	382.114	82.585	0.27
2018	347.653	75.913	0.27
2019	320.129	69.788	0.27
2020	299.250	63.850	0.26
2021	284.540	59.200	0.25
2022	274.913	56.042	0.25
2023	268.902	53.983	0.24
2024	265.628	52.774	0.24

Scenario 7
Determination of whether arrowtooth flounder are approaching an overfished condition
B35=244,664

Year	Female spawning biomass	catch	F
2011	800.493	15.918	0.02
2012	806.702	149.683	0.22
2013	693.439	129.063	0.22
2014	592.886	134.633	0.27
2015	499.977	112.319	0.27
2016	444.297	96.525	0.27
2017	397.580	86.240	0.27
2018	358.212	78.400	0.27
2019	327.227	71.560	0.27
2020	303.858	65.195	0.26
2021	287.325	60.073	0.25
2022	276.500	56.551	0.25
2023	269.757	54.261	0.25
2024	266.056	52.912	0.24

Table 6.14—TAC and ABC used to manage the BSAI arrowtooth flounder complex for 1980-2010, and 2011 TAC and ABC for arrowtooth flounder only.

	arrowtooth 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

*Arrowtooth flounder only, previous years include Kamchatka flounder.

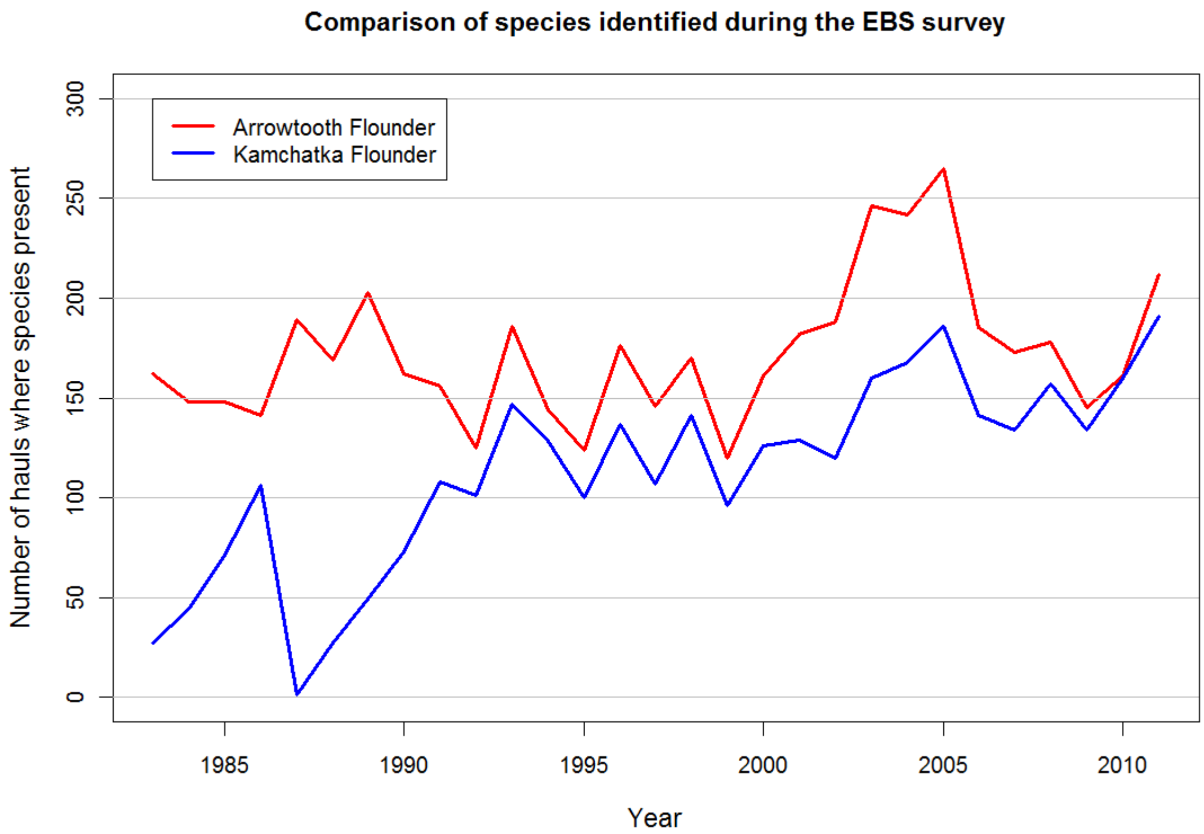


Figure 6.1—Number of hauls where arrowtooth flounder and Kamchatka flounder were identified during the annual Bering Sea shelf surveys, 1982-2011. Years 1982-1986 are the standard survey area and 1987-2011 include northwest strata 82 and 90.

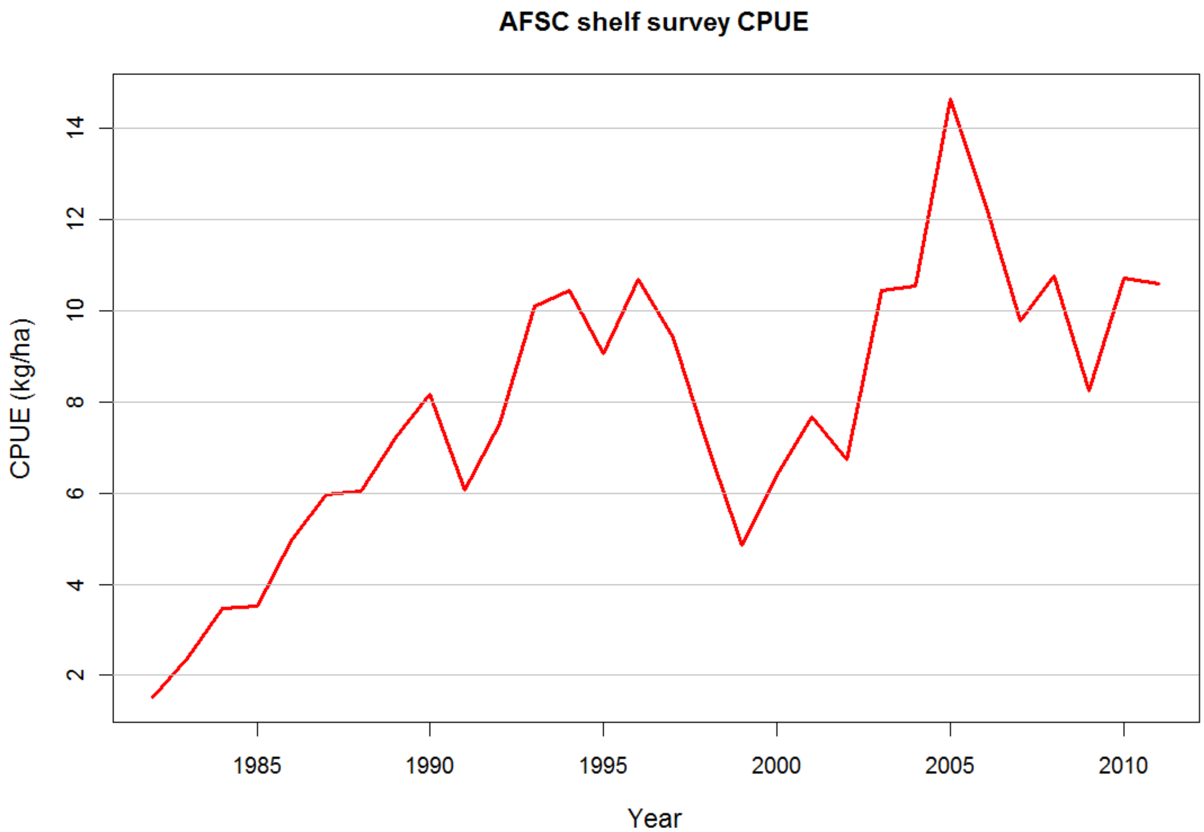


Figure 6.2 Arrowtooth flounder CPUE (kg/ha) from the standard shelf survey area (1982-1992) and standard shelf survey area including Northwestern stratum 82 and 90 (1993-2011).

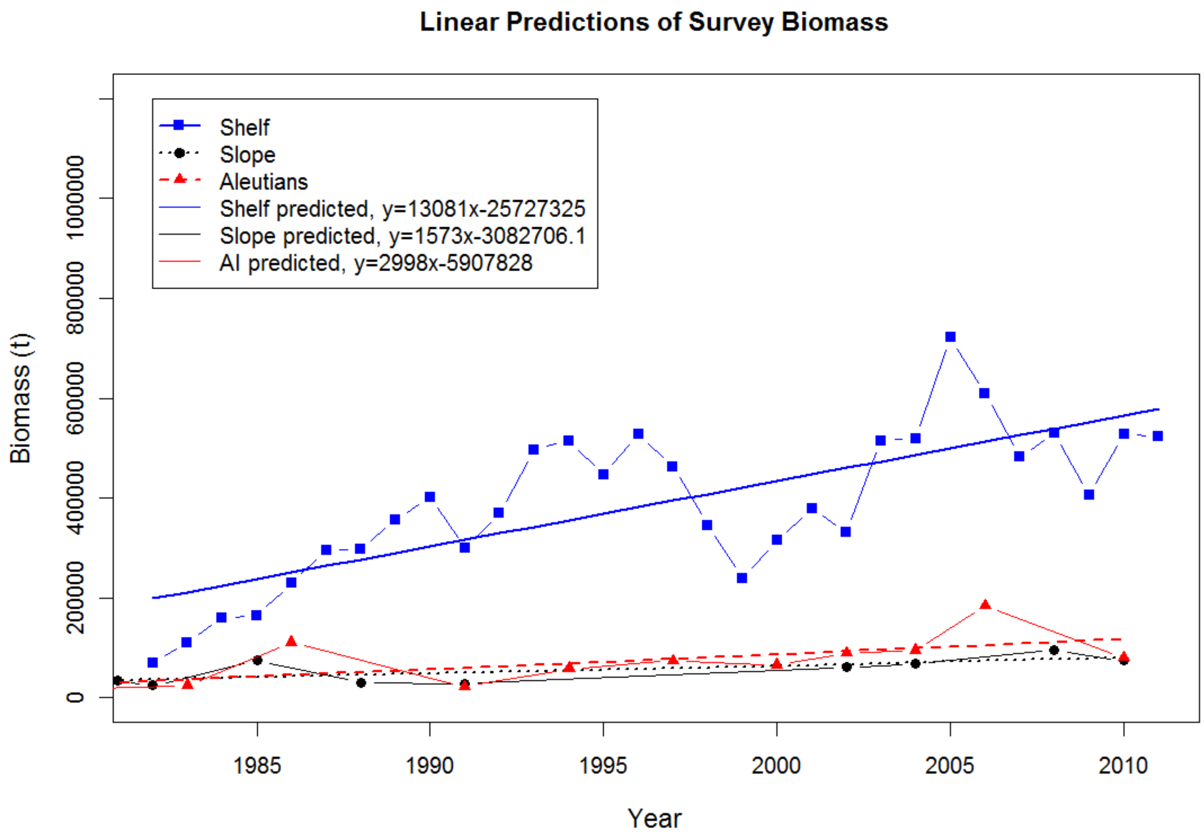


Figure 6.3—Linear regressions of trawl survey estimates for the Bering Sea shelf, slope and the Aleutian Islands used to estimate the proportion of biomass in each area.

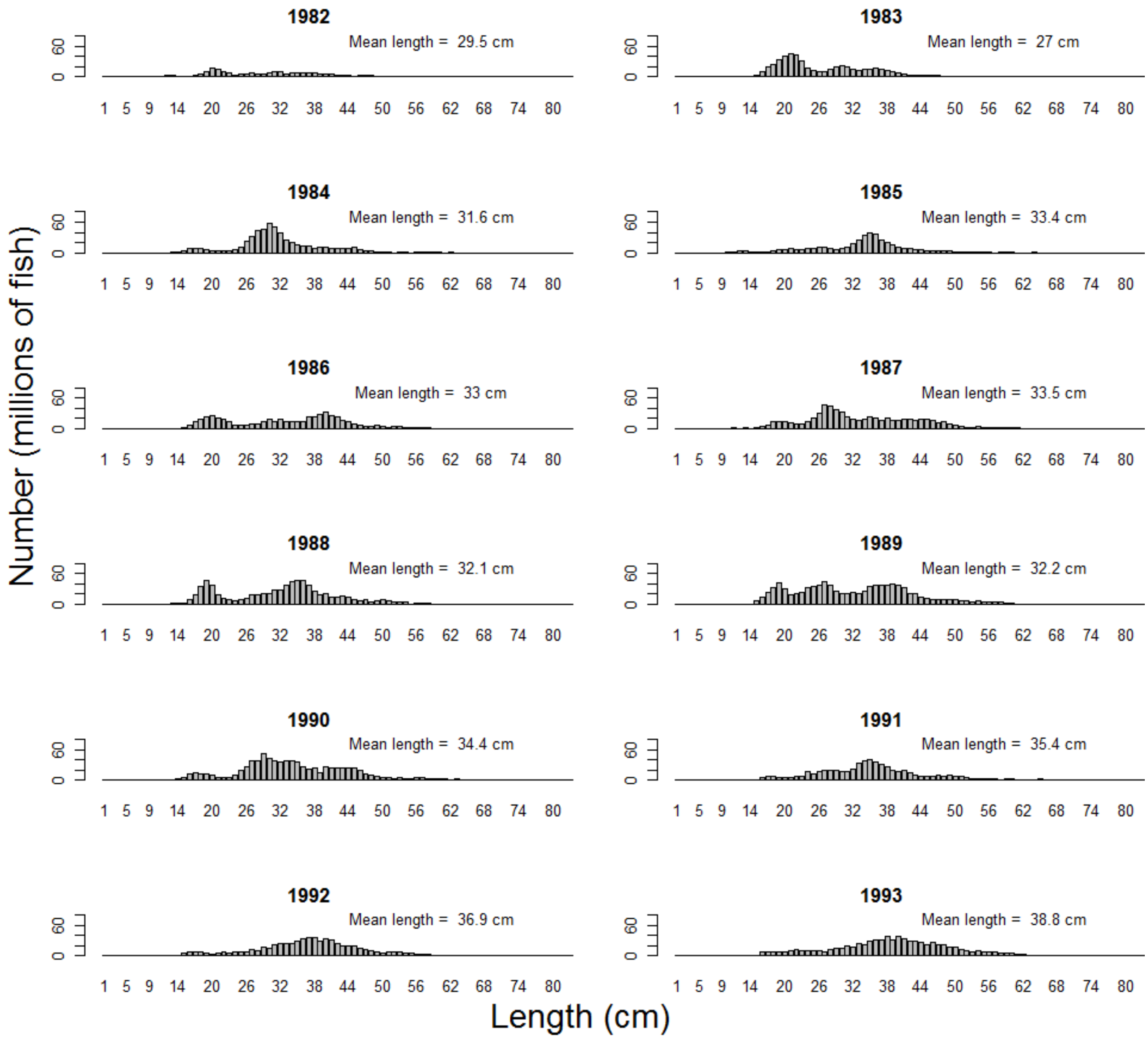


Figure 6.4. Size composition of arrowtooth flounder from the shelf trawl surveys.

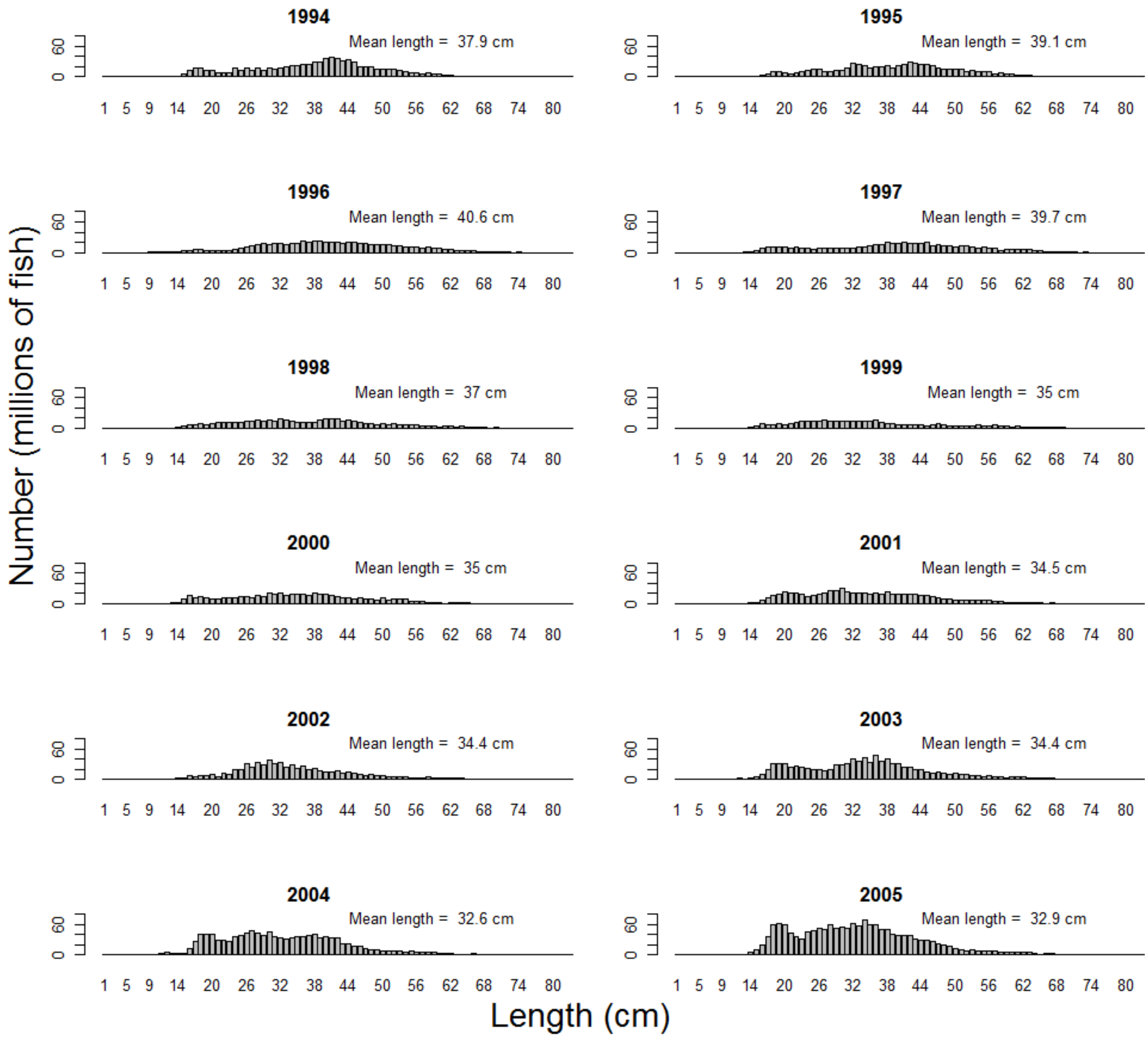


Figure 6.4. continued.

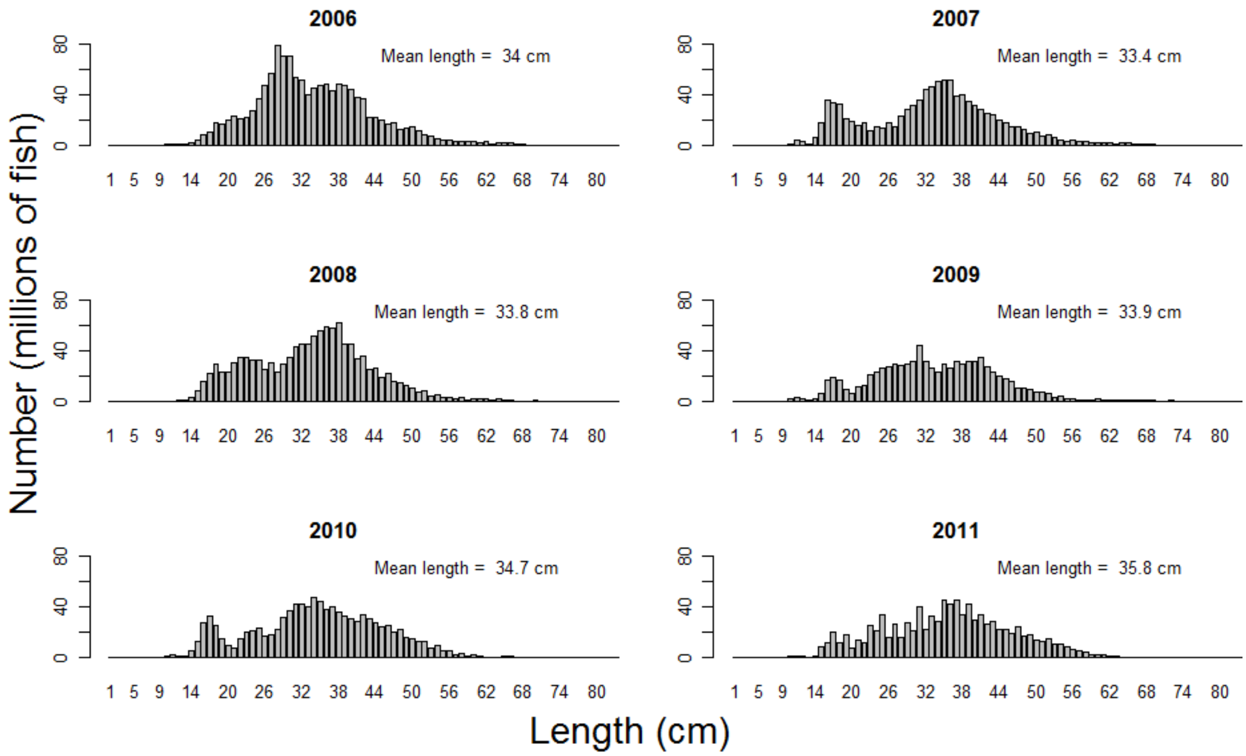


Figure 6.4. continued.

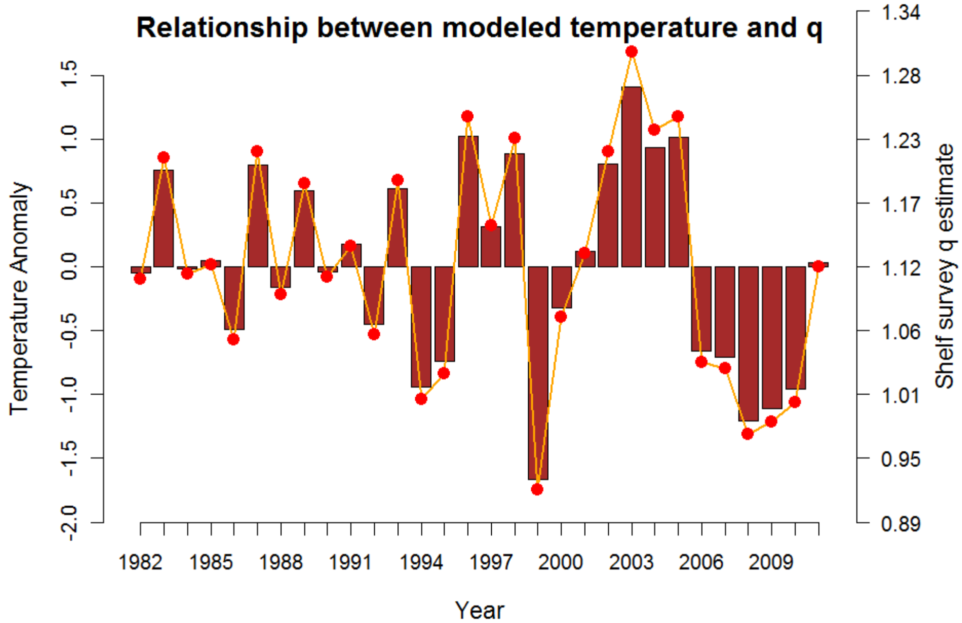


Figure 6.5--Shelf survey annual average bottom temperature anomalies (bars), and model estimates of annual shelf survey q due to effect of water temperature (circles with lines).

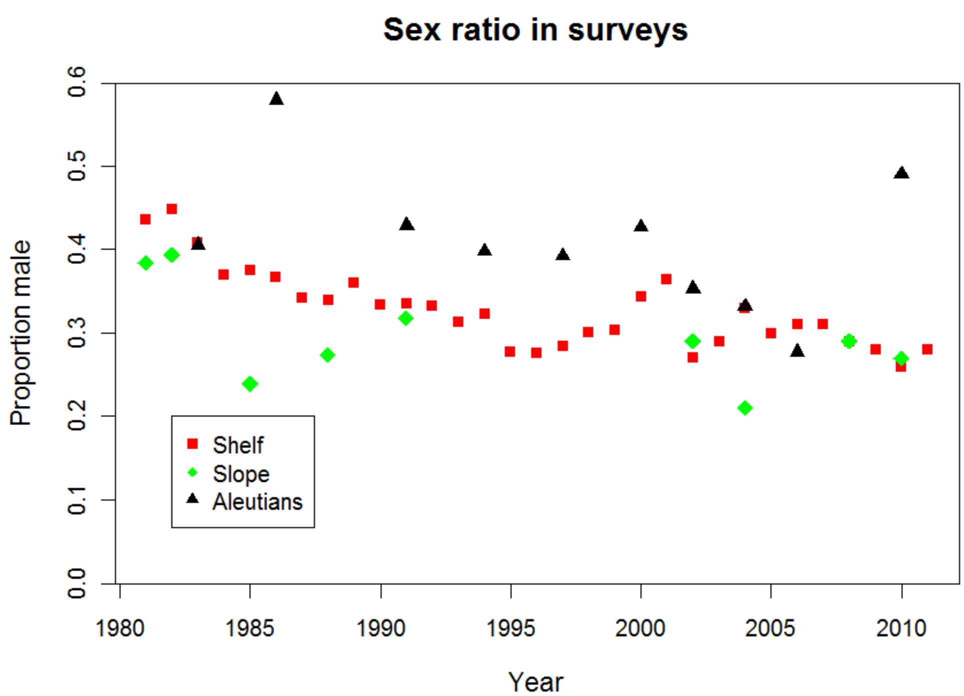


Figure 6.6--Proportion of the estimated male population from Bering Sea and Aleutian Islands trawl surveys on the continental shelf and slope.

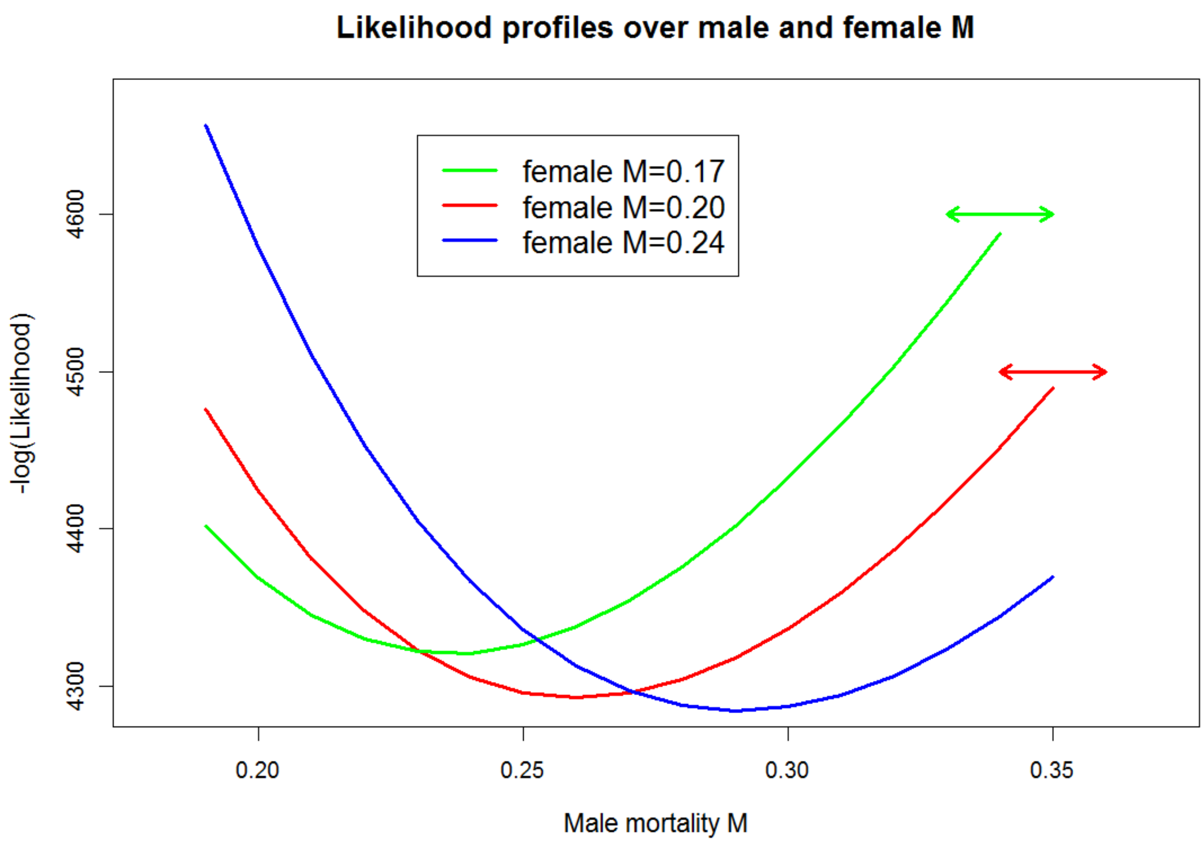


Figure 6.7—Fit to the stock assessment model in terms of –log(likelihood) when profiling over male natural mortality (x axis) for three different levels of female natural mortality. Arrows indicate the values of male natural mortality where the model estimates that maximum male selectivity is close to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

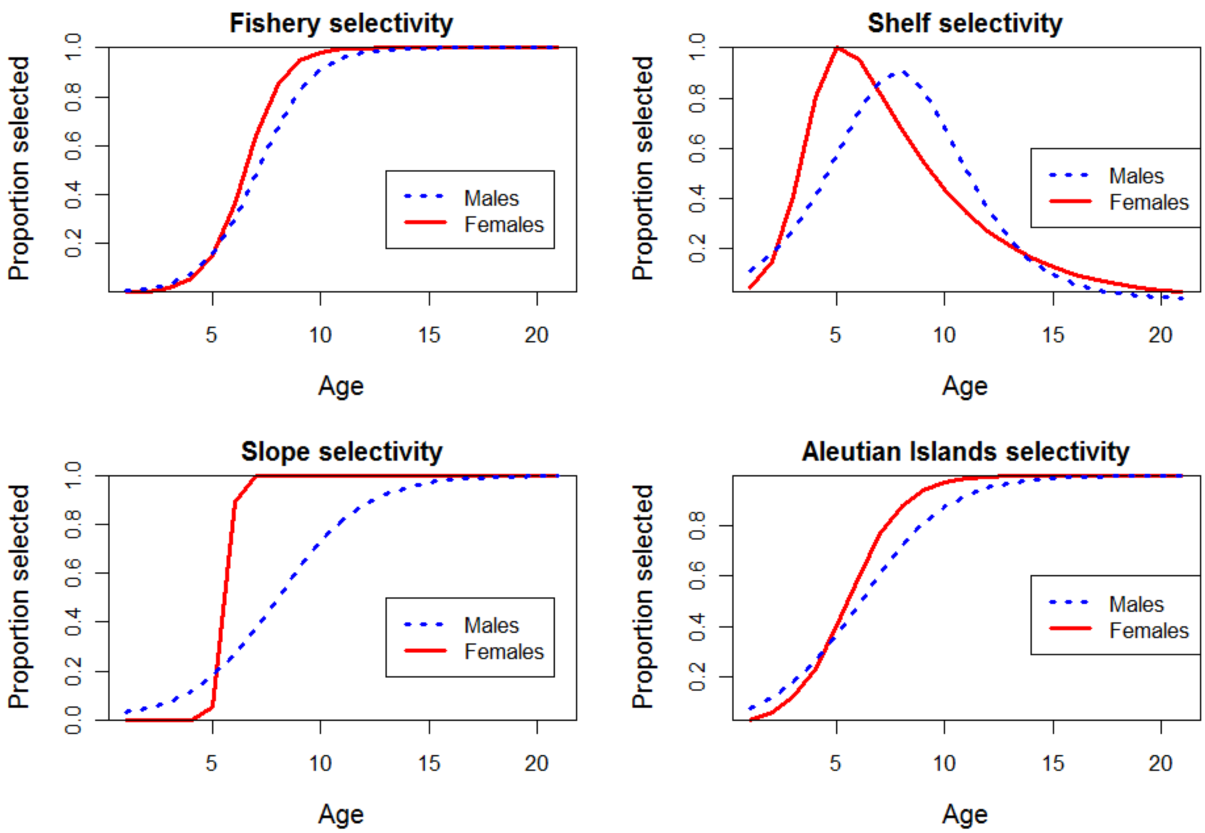


Figure 6.8--Age-specific fishery selectivity (top left panel), shelf survey selectivity (top right panel) slope survey selectivity (bottom left panel) and Aleutian Islands survey selectivity (bottom right panel), by sex, estimated from the stock assessment model.

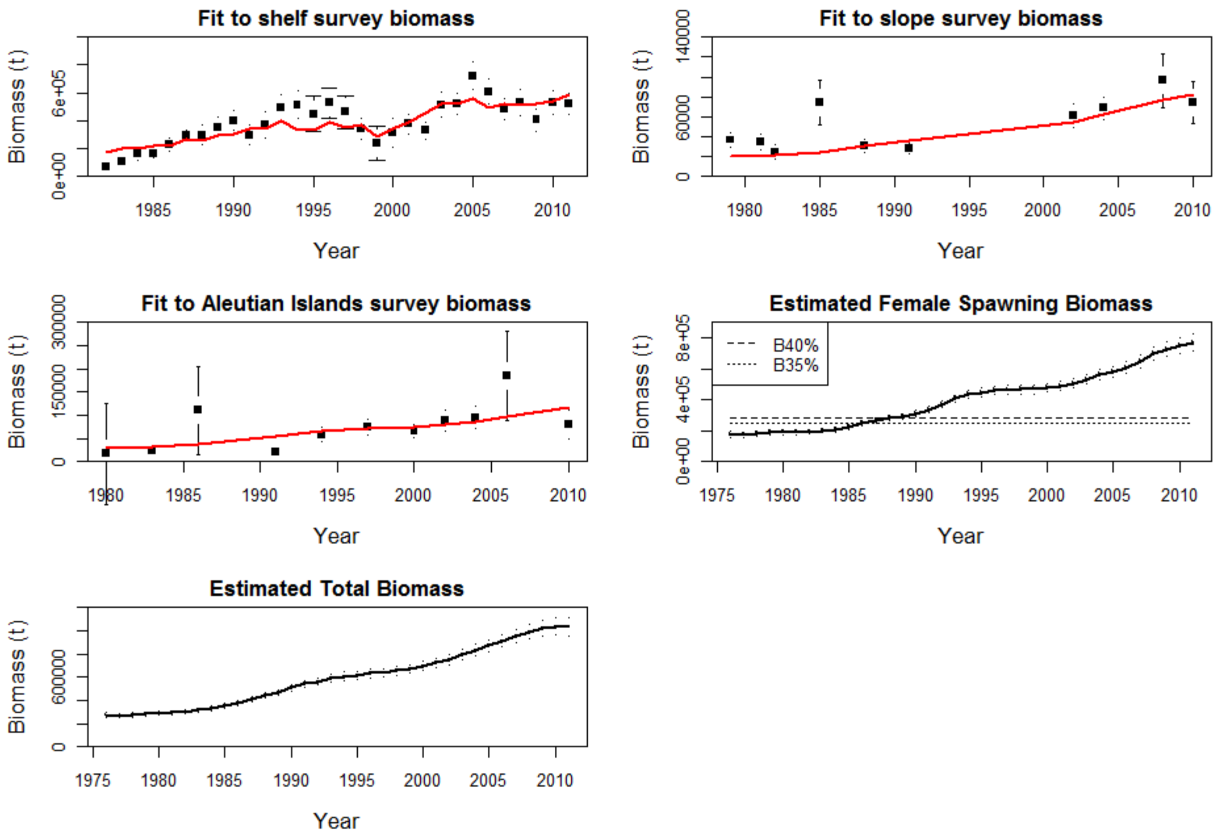


Figure 6.9--Stock assessment model results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), estimate of female spawning biomass with $B_{35\%}$ and $B_{40\%}$ indicated (middle right panel), the fit to the Aleutian Islands survey (middle left panel) and the estimate of total biomass (bottom panel). Intervals on model estimates of female spawning biomass and total biomass are from 5% and 95% quantiles of MCMC posterior values.

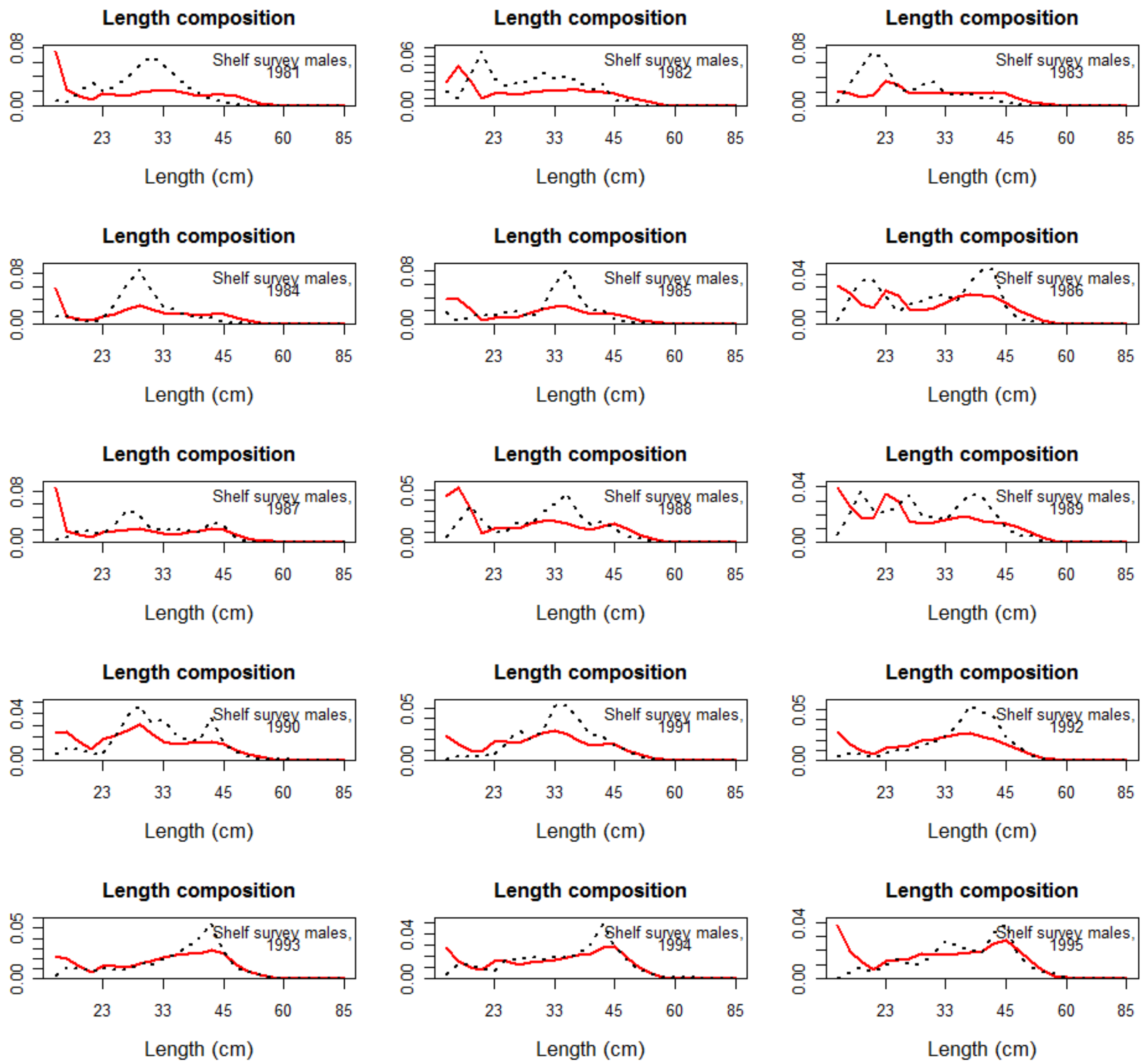


Figure 6.10—Model fit (dotted lines) to trawl survey size and age composition estimates (solid lines).

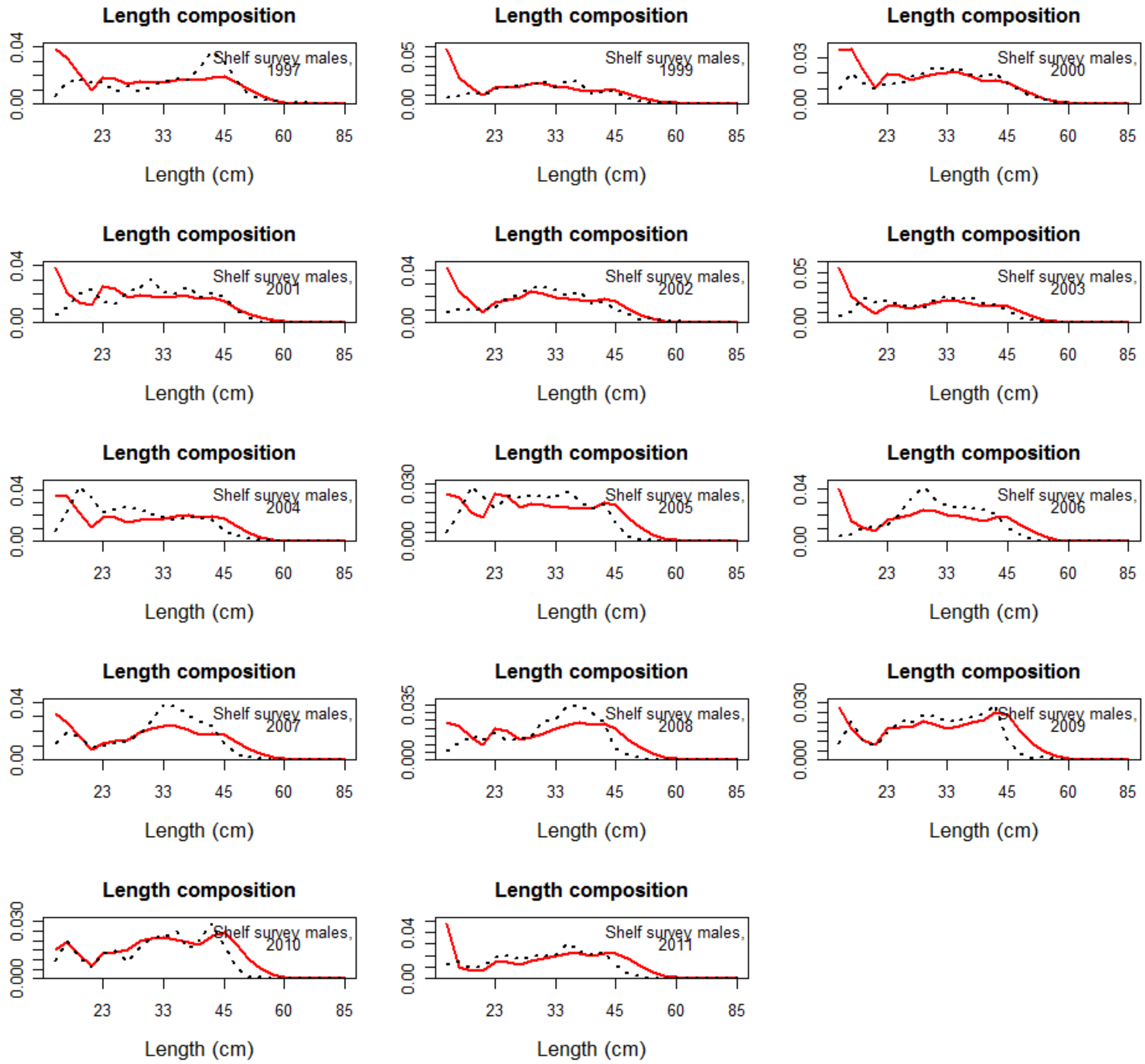
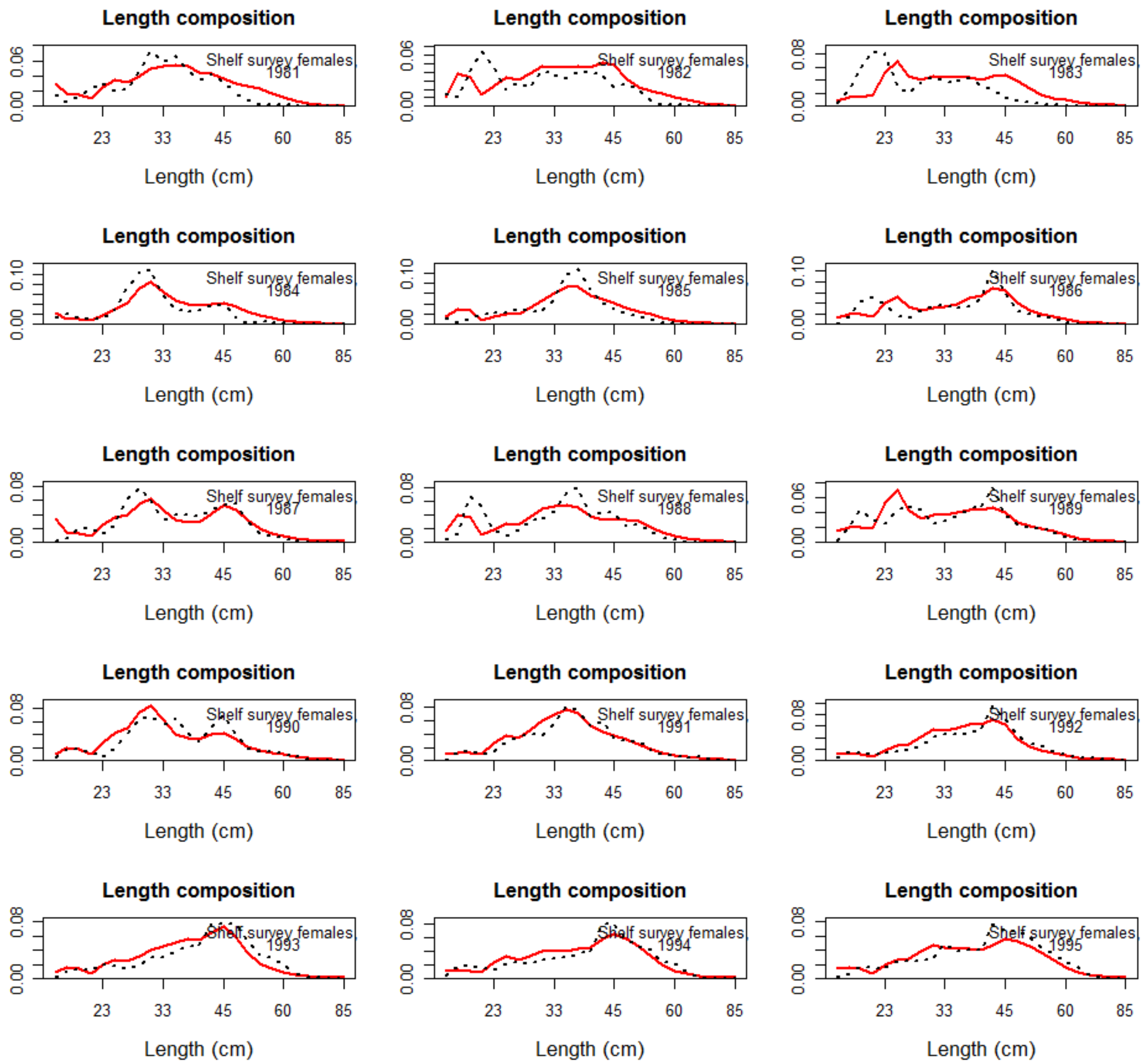


Figure 6.10—continued.



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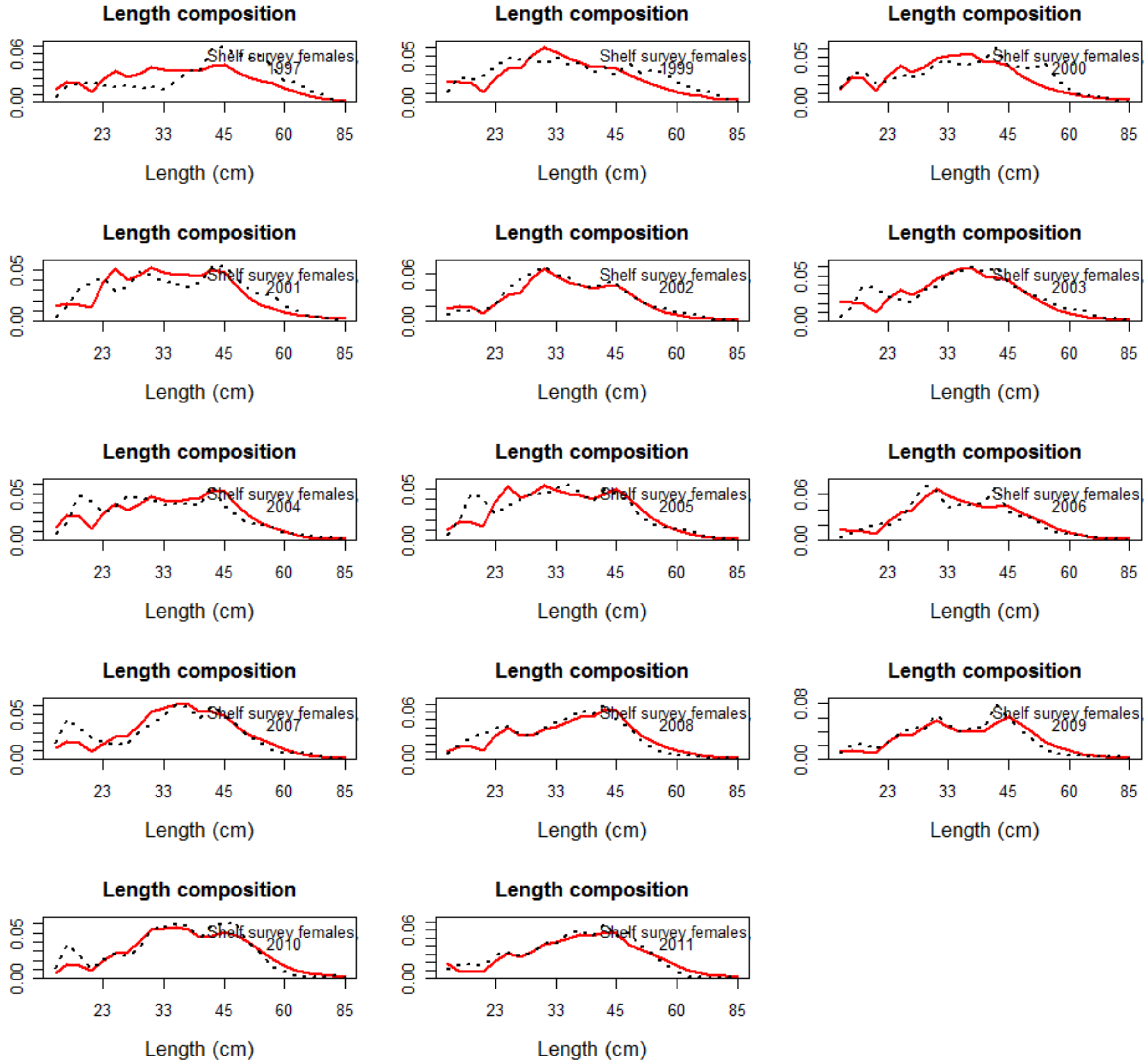

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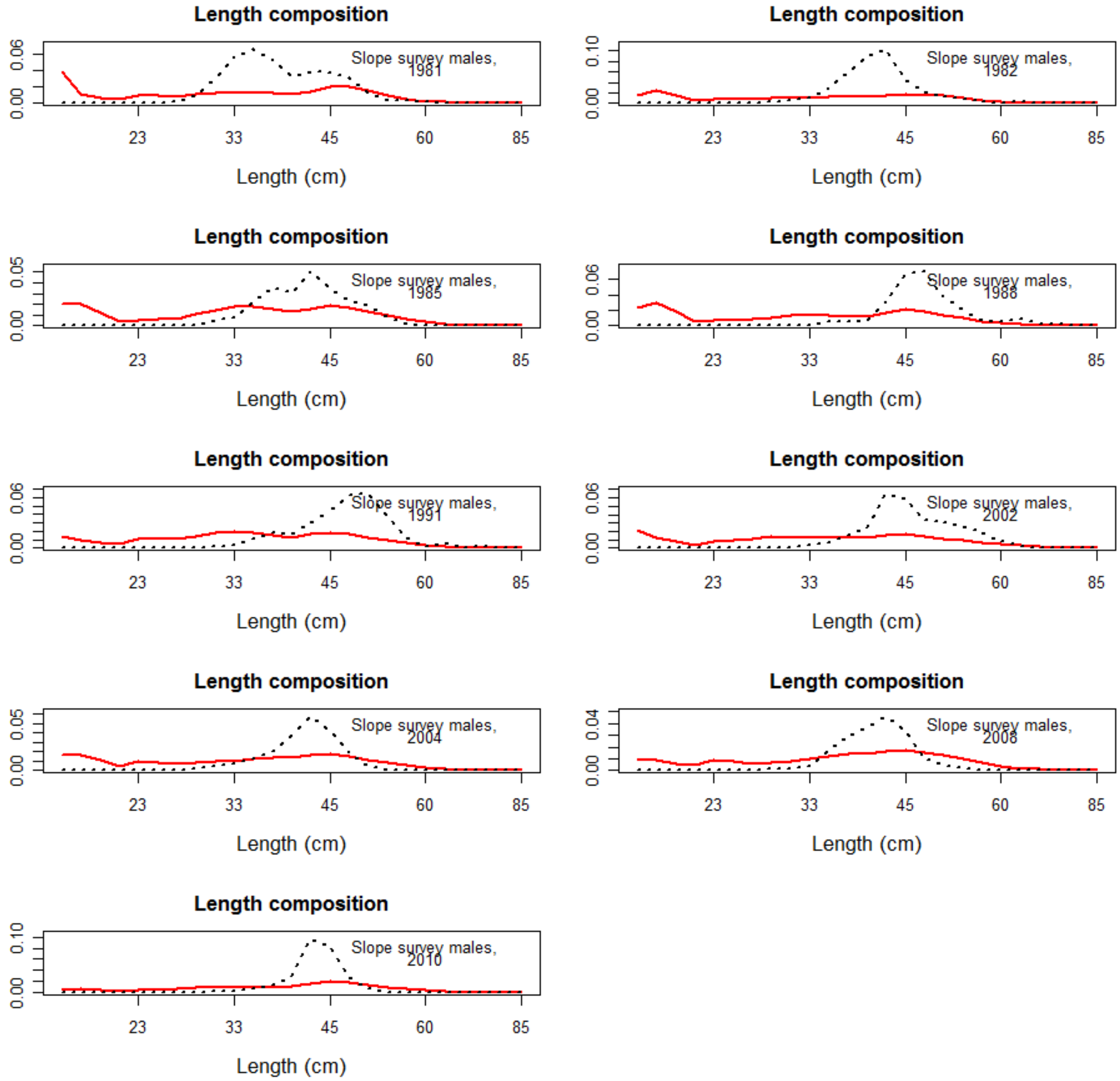

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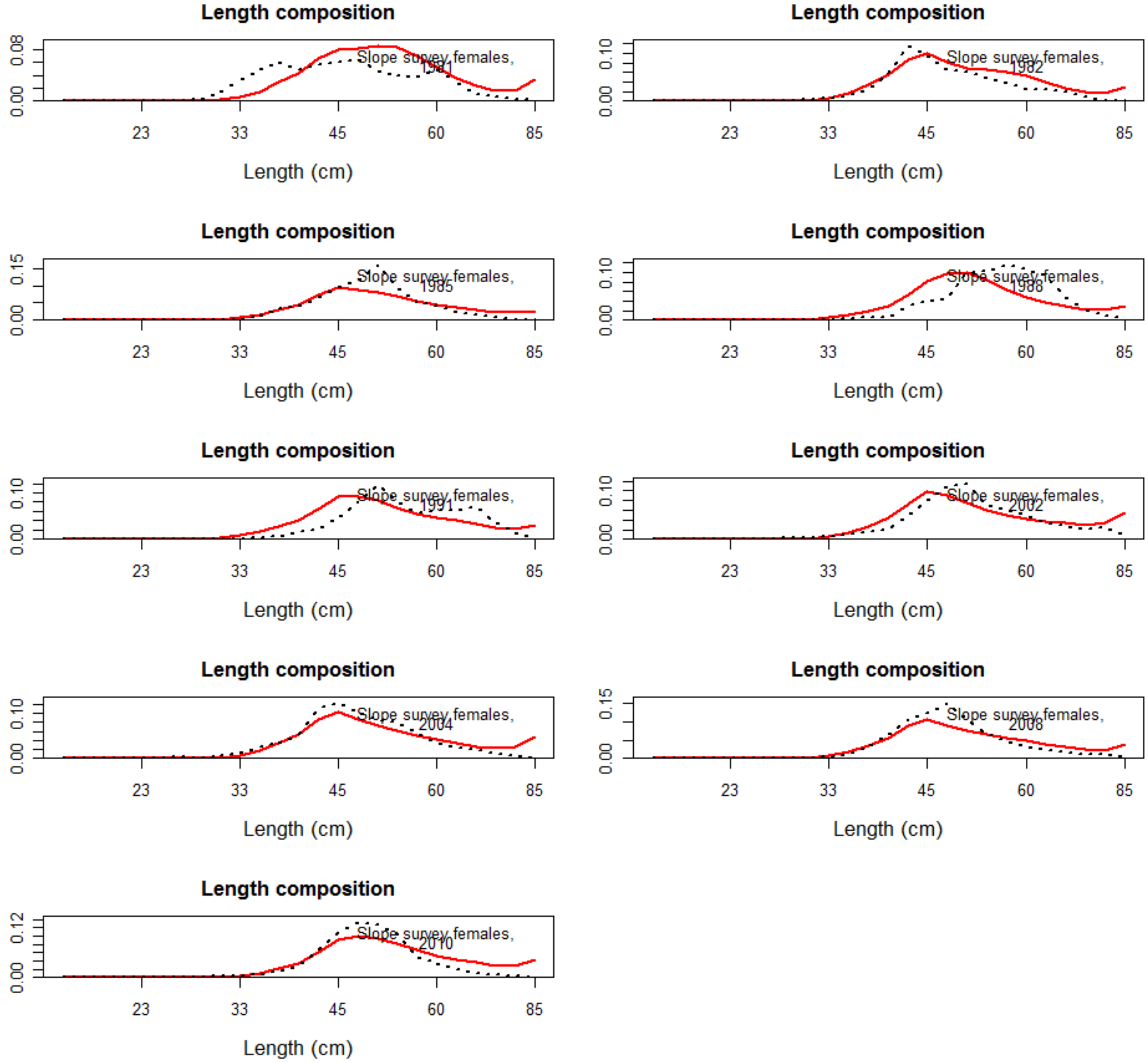

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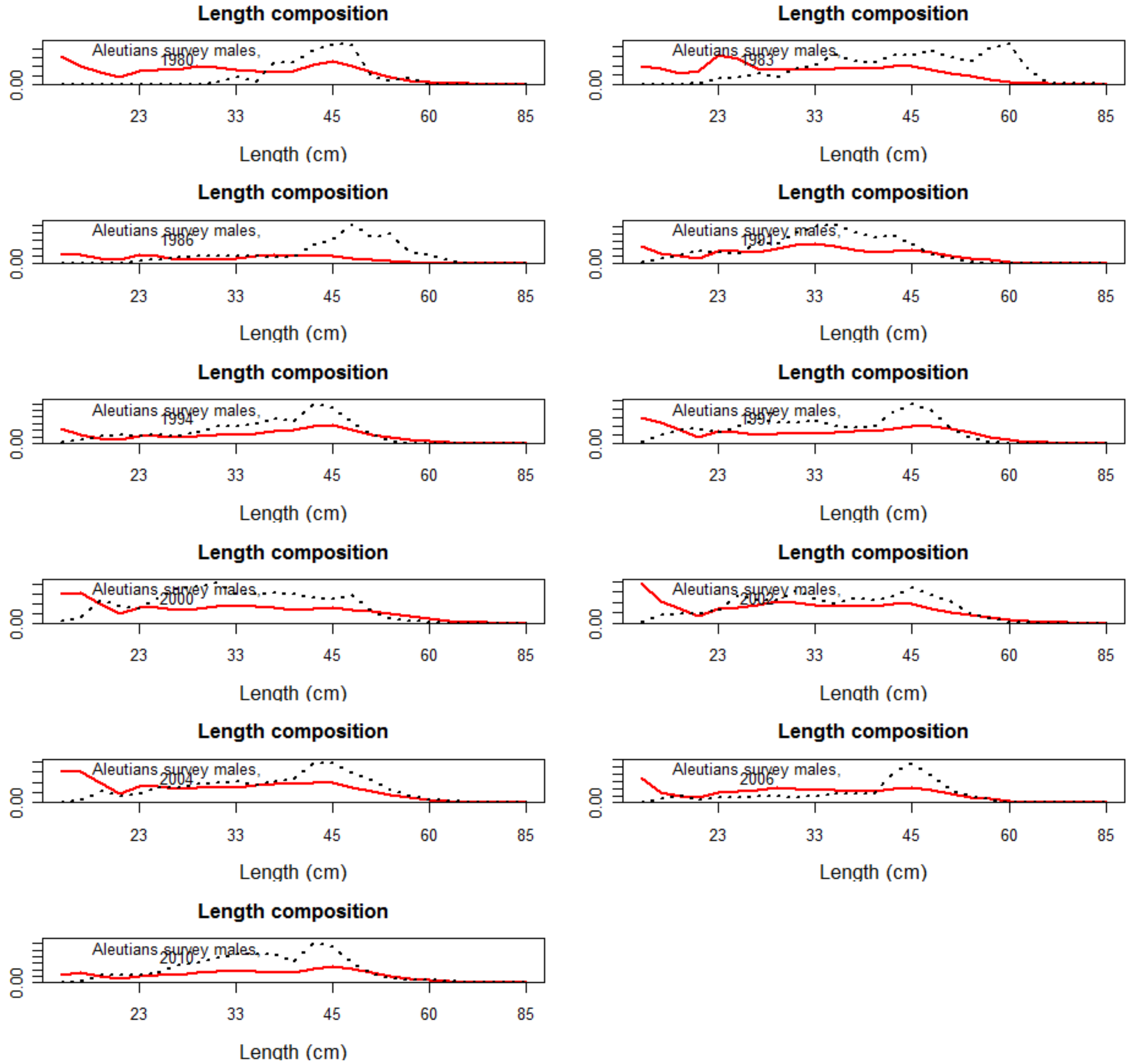

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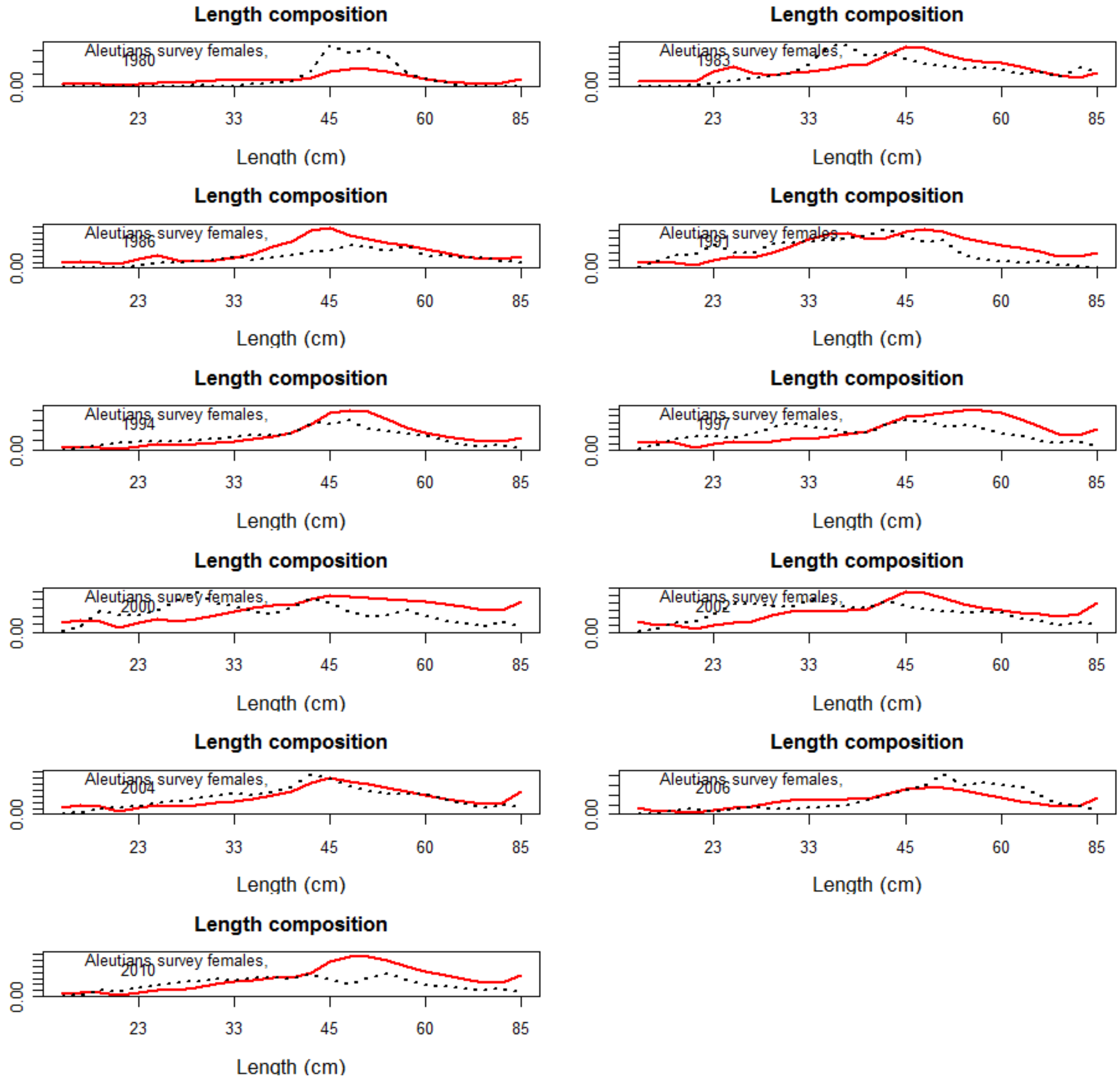

Figure 6.10—continued.

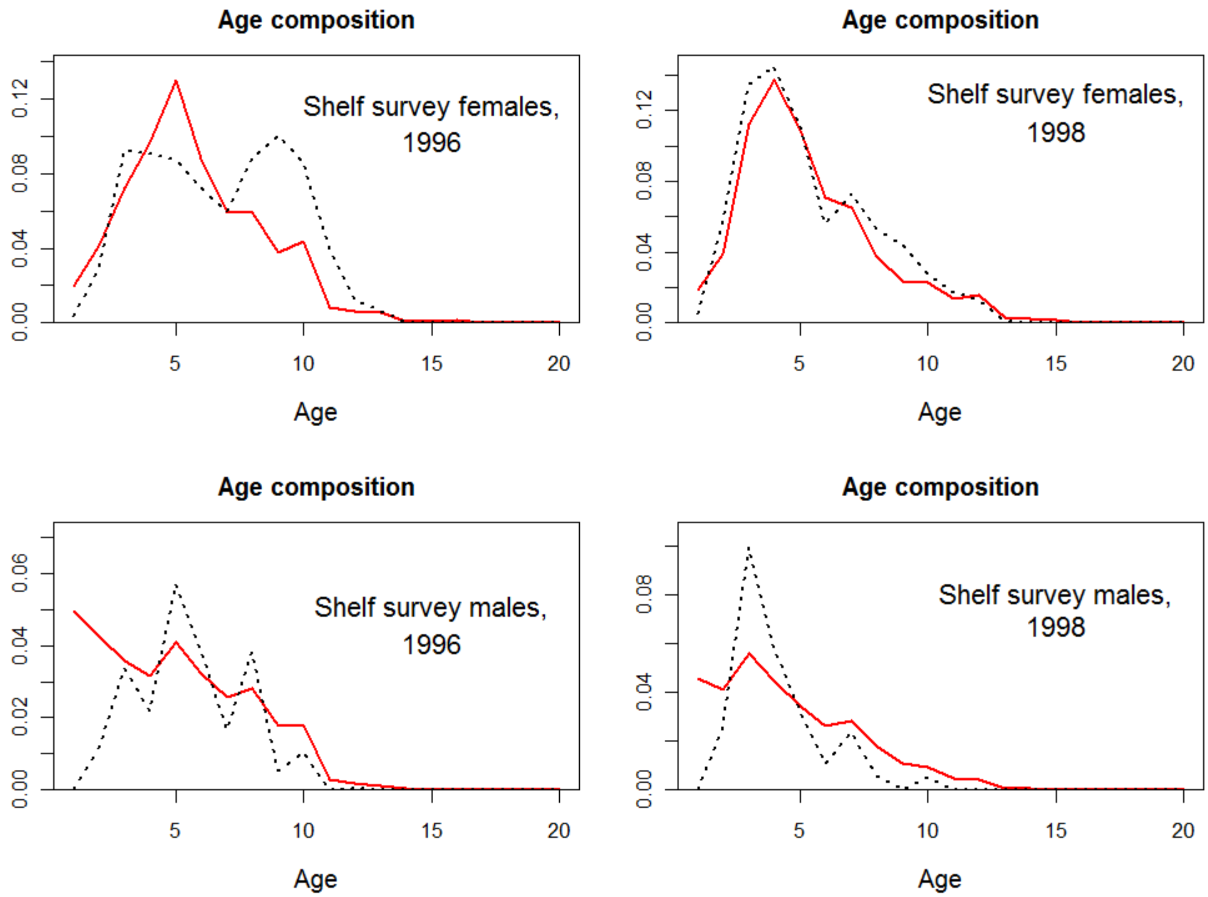

Figure 6.10—continued.

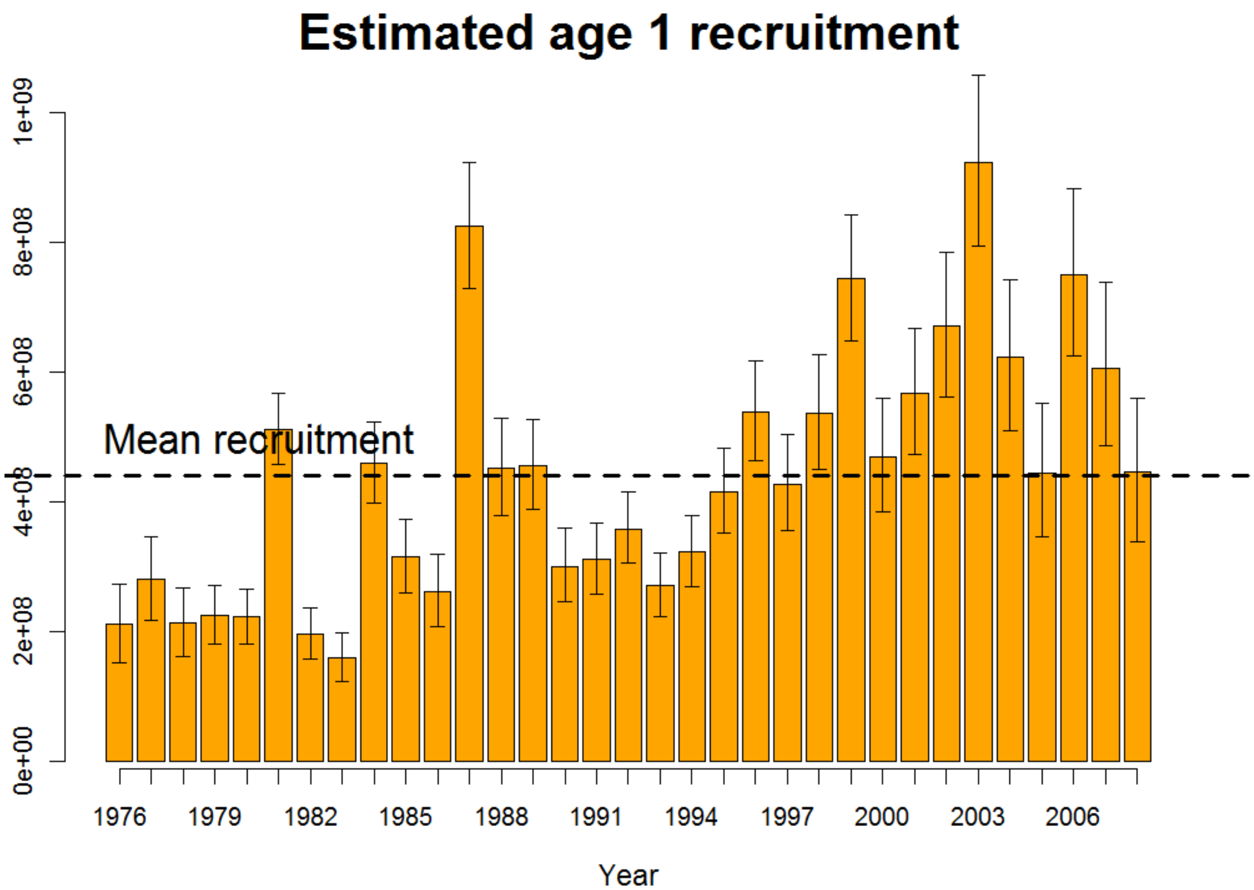

Figure 6.11--Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model.

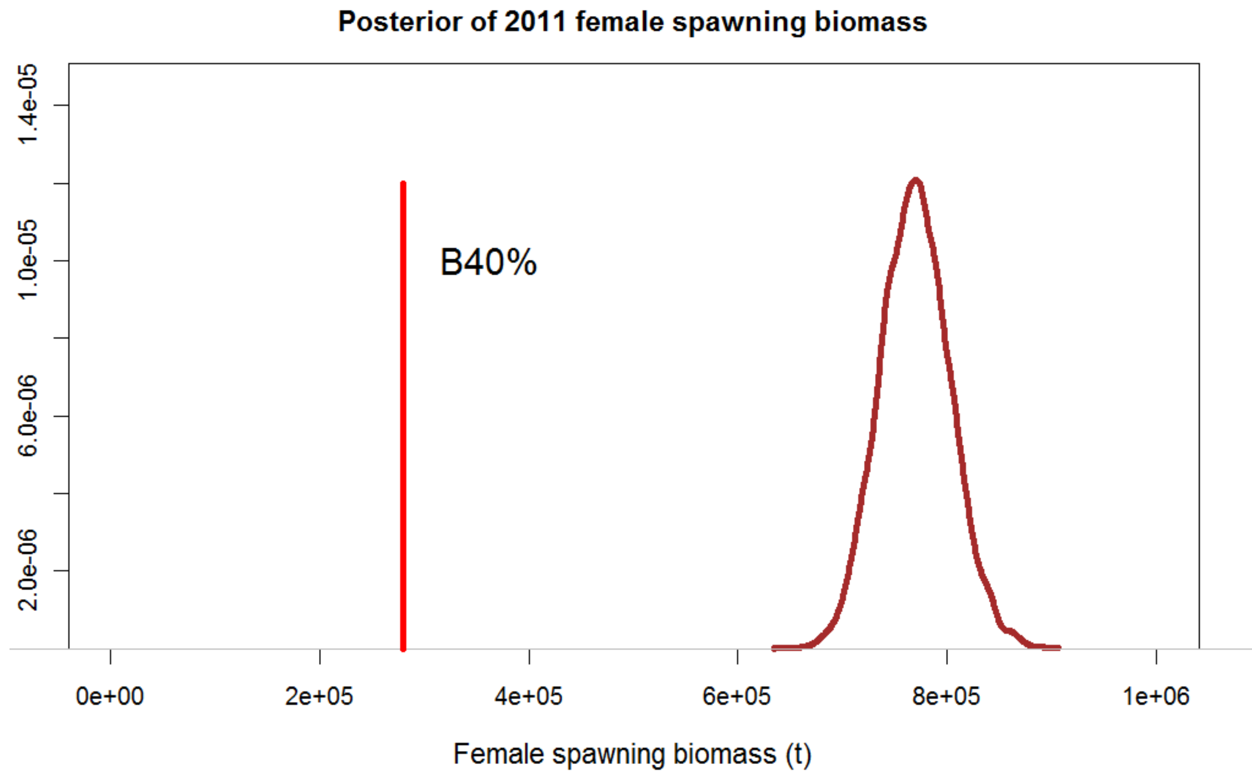

Figure 6.12—Posterior distribution of the estimate of female spawning biomass (t) from the preferred stock assessment model run.

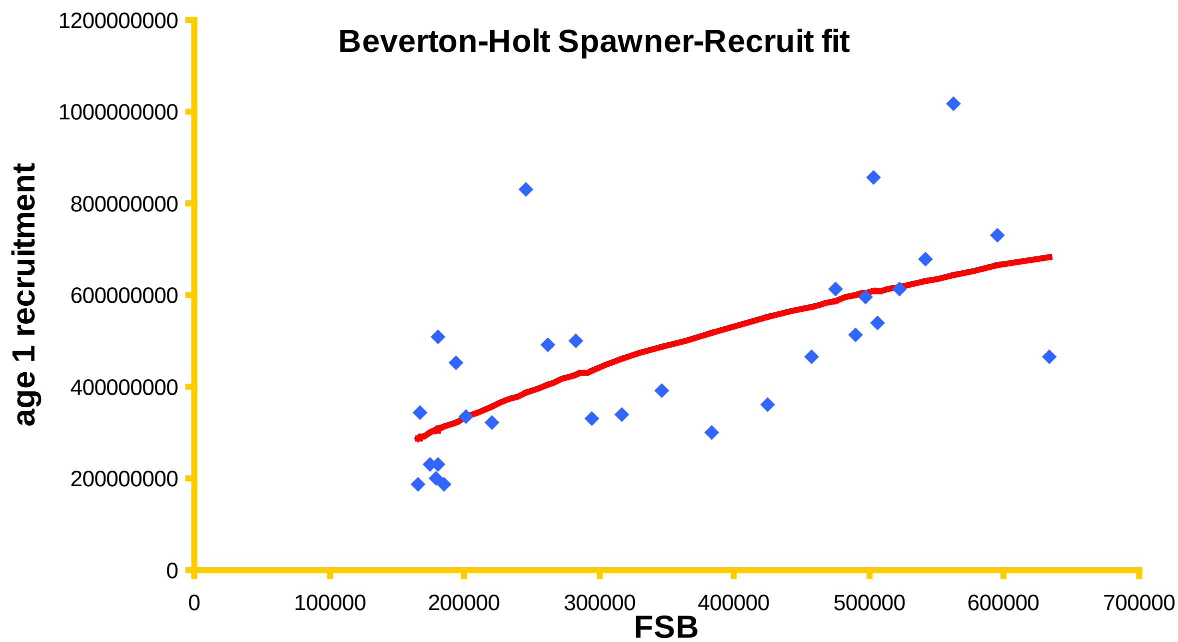

Figure 6.13—Beverton and Holt spawner recruit model fit to the age 1 recruitment data for Bering Sea arrowtooth flounder.

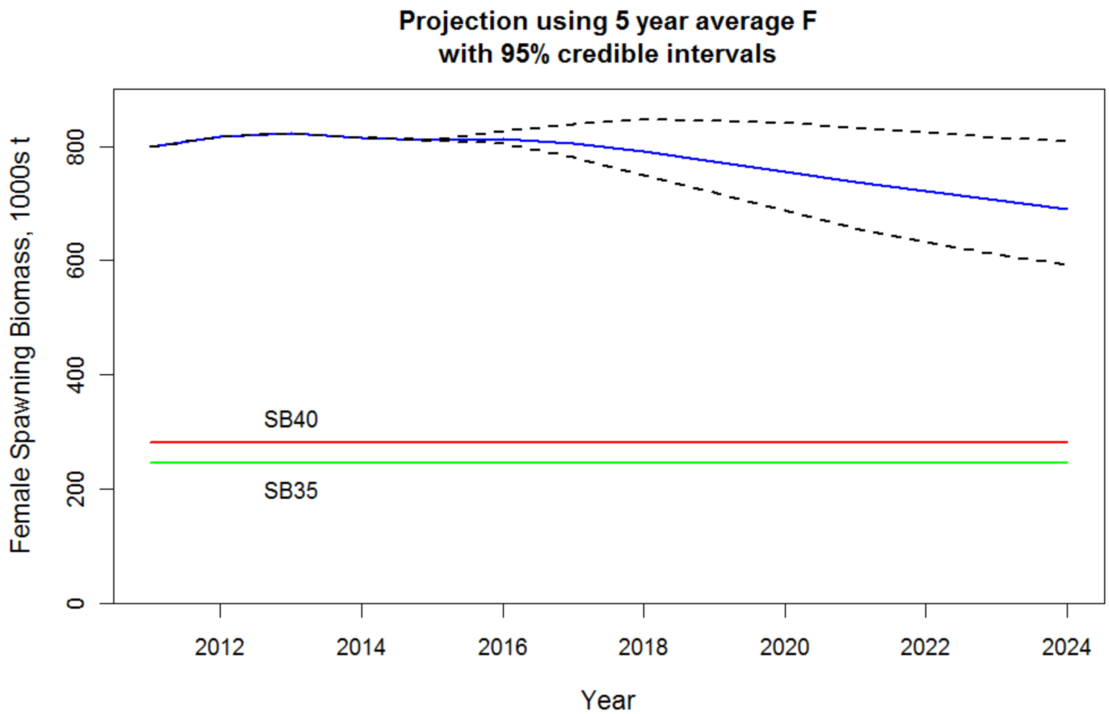

Figure 6.14--Projected female spawning biomass (1,000s t) of arrowtooth flounder if future harvest is at the same average fishing mortality rate over the past five years.

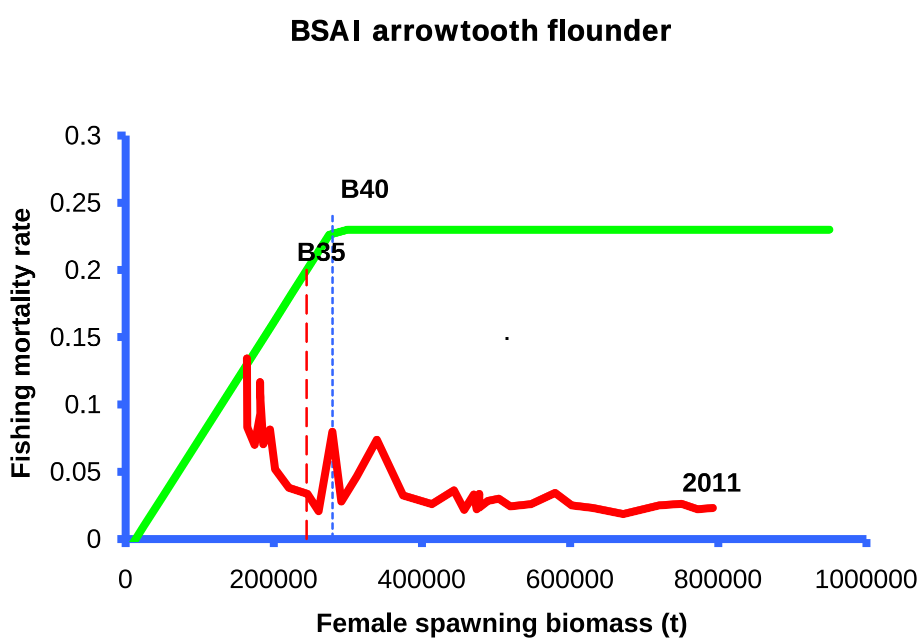

Figure 6.15—Phase plane diagram showing the time-series of stock assessment model estimates of female spawning biomass relative to the harvest control rule.

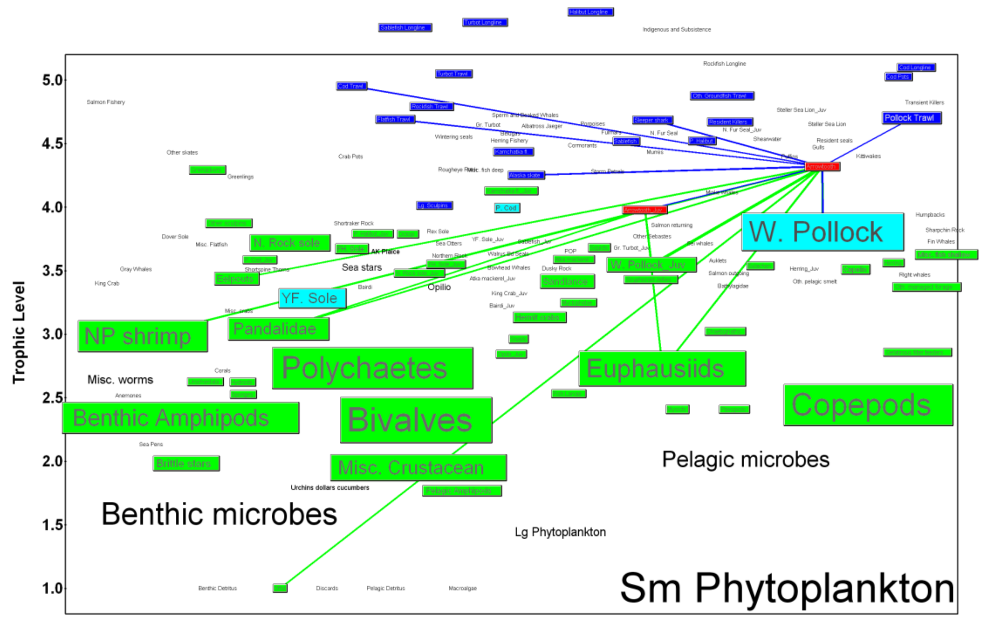

Figure 6.16. Adult and juvenile arrowtooth flounder in the EBS food web. Box size is proportional to biomass, and lines between boxes represent the most significant energy flows. Predators of arrowtooth are dark blue, prey of arrowtooth are green, and species that are both predators and prey of arrowtooth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

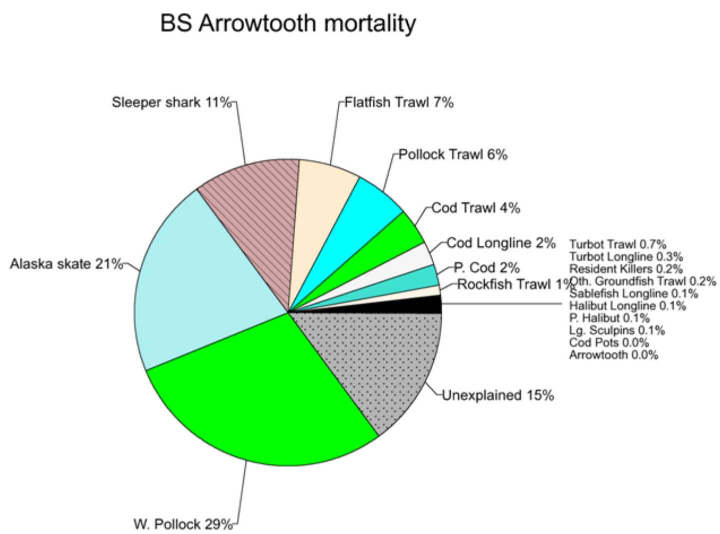

Figure 6.17. Mortality of Bering Sea arrowtooth flounder >20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. "Unexplained" mortality is the difference between the stock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

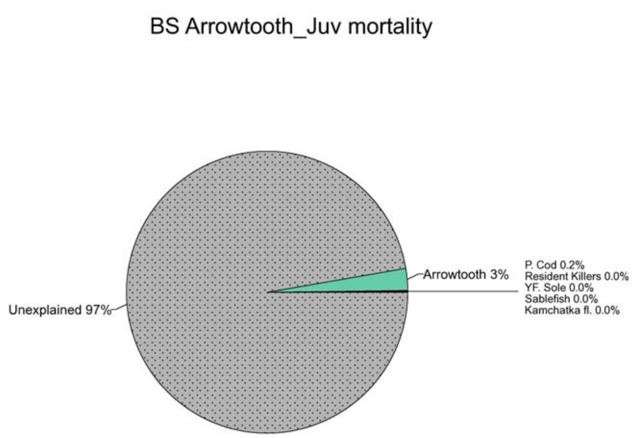

Figure 6.18. Mortality of Bering Sea arrowtooth flounder <20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. "Unexplained" mortality is the difference between the stock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

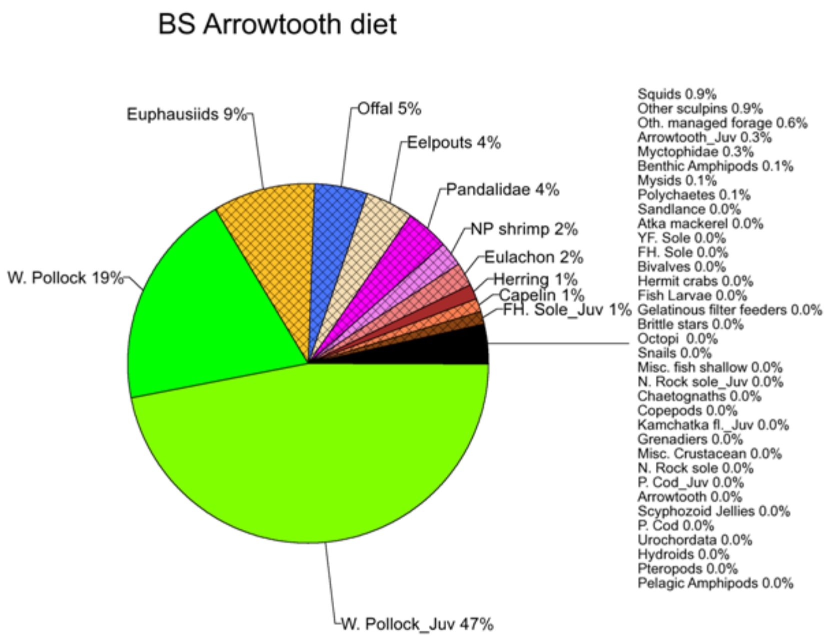

Figure 6.19. Diet of Bering Sea arrowtooth flounder >20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good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

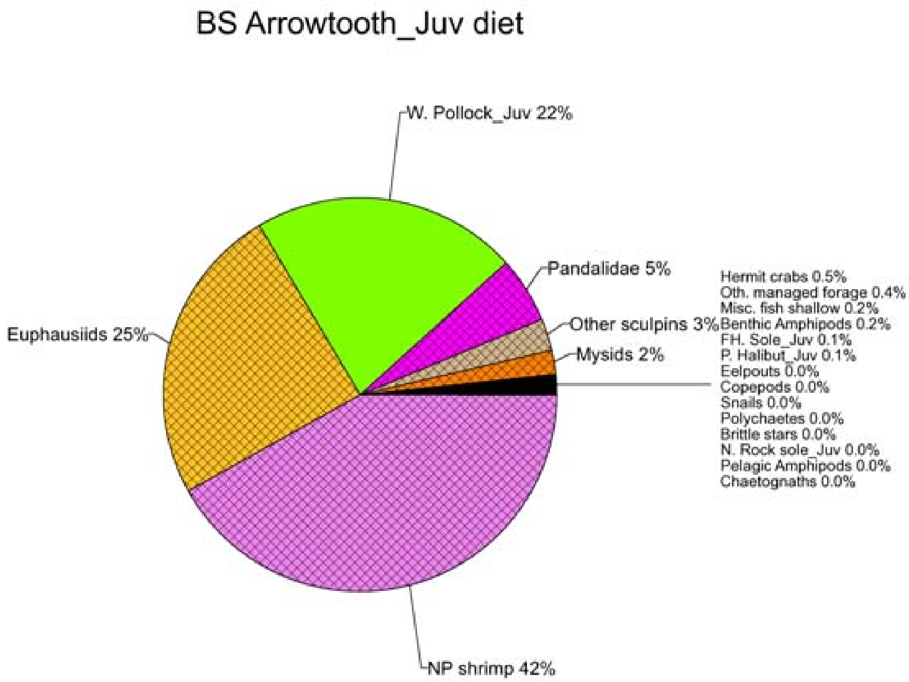

Figure 6.20. Diet of Bering Sea arrowtooth flounder <20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good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

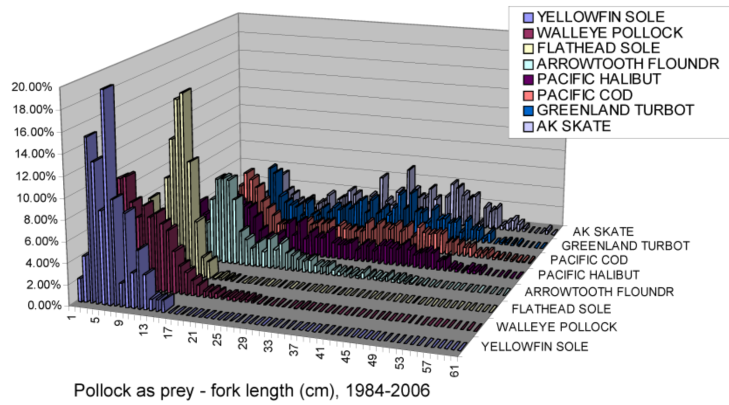

Figure 6.21. Length frequency of pollock found in stomachs, from groundfish food habits collected from 1984-2006 on AFSC summer trawl surveys in the eastern Berng Sea. Predators are sorted by median prey length of pollock in their stomachs. All lengths of predators are combined.

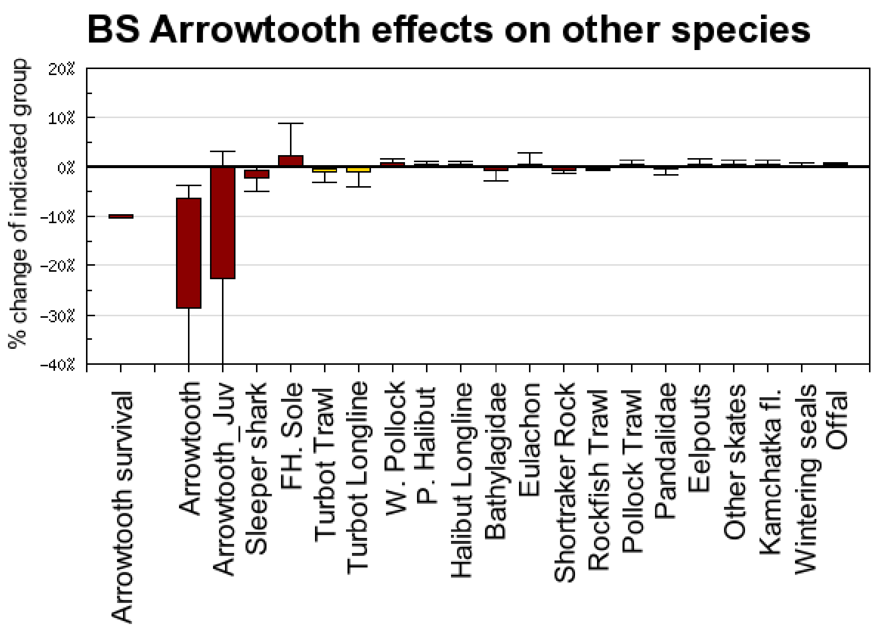

Figure 6.22. Effect of changing arrowtooth > 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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

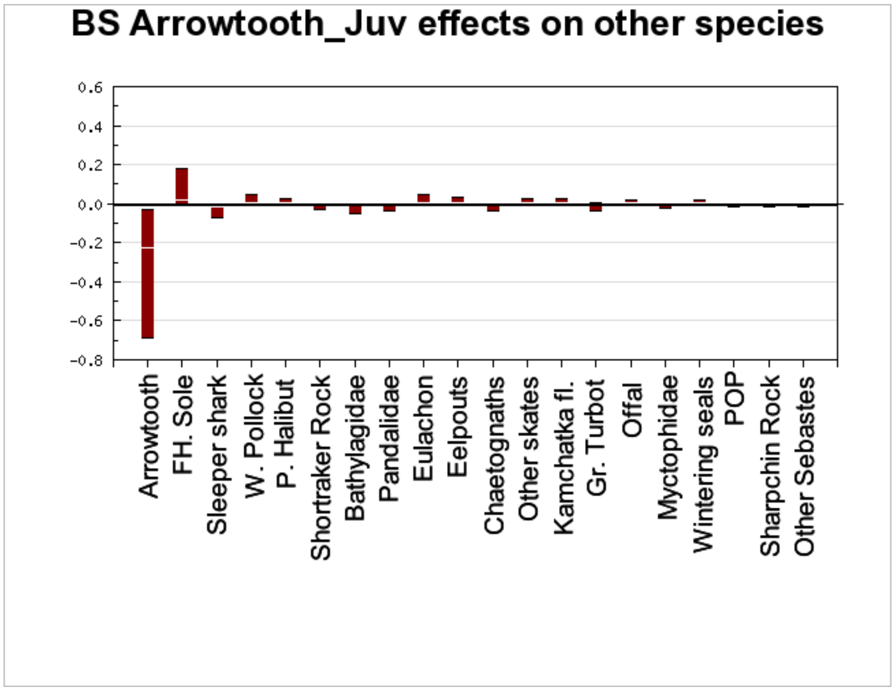

Figure 6.23. Effect of changing arrowtooth < 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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

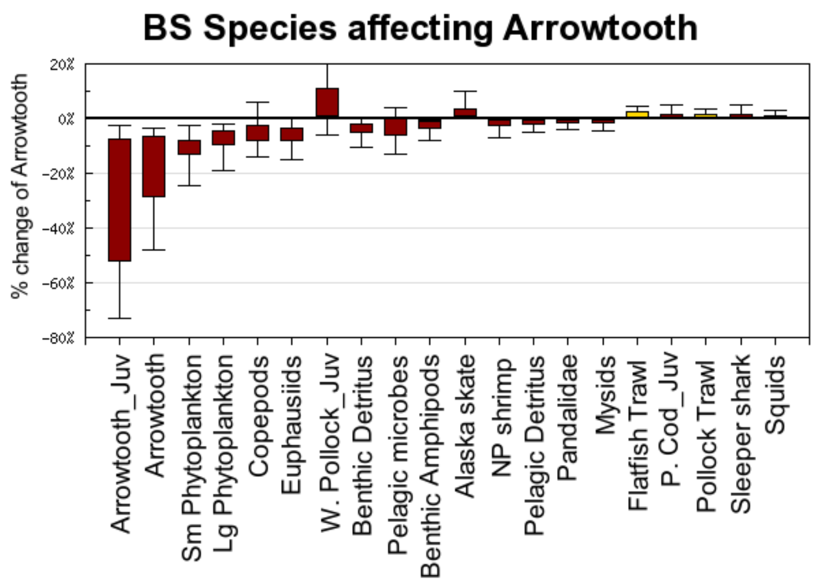

Figure 6.24. Effect of reducing fisheries catch (yellow) and other species survival (dark red) on arrowtooth > 20 cm biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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