Chapter 6. Arrowtooth Flounder

By

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Executive Summary

The following changes have been made to this assessment relative to the November 2009 SAFE.

Changes to the input data

1) Input data includes arrowtooth flounder only as this assessment is no longer for the Atheresthes complex.

2) 2010 shelf survey, slope survey and Aleutian Islands survey size compositions.

3) 2010 shelf survey, slope survey and Aleutian Islands survey biomass point-estimates and standard errors.

4) Estimate of catch and discards through 15, October 2010.

5) Estimate of retained and discarded portion of the 2009 catch.

Assessment results

1) The projected age 1+ total biomass for 2011 is 1,124,200 t.

2) The projected female spawning biomass for 2011 is 806,000 t.

3) The recommended 2011 ABC is 153,200 t based on an $F_{0.40}$ (0.23) harvest level.

4) The 2011 overfishing level is 186,400 t based on a $F_{0.35}$ (0.29) harvest level.

Quantity/Status	Last year 2010	2011	This year **2011**	2012
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 X+)	1,120,160	1,103,100	**1,124,200**	1,125,900
Female spawning biomass (t)				
Projected	807,100	807,200	**806,100**	811,600
$B_{100\%}$			**669,000**	--
$B_{40\%}$	296,800	--	**279,600**	--
$B_{35\%}$	259,700	--	**244,650**	--
F_{OFL}	0.295	0.295	**0.29**	0.29
$maxF_{ABC}$ (maximum allowable = F40%)	0.235	0.235	**0.23**	0.23
Specified/recommended F_{ABC}	0.235	0.235	**0.23**	0.23
Specified/recommended OFL (t)	190,800	191,300	**186,400**	191,000
Specified/recommended ABC (t)	156,300	157,100	**153,200**	157,100
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

No SSC comments regarding arrowtooth flounder from the 2009 assessment.

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 undesirable in 2010 due to the emergence of a directed fishery for Kamchatka flounder in the BSAI management area. Since the ABC was determined by the large amount of arrowtooth flounder relative to Kamchatka flounder (complex is about 93% arrowtooth flounder) the possibility arose of an overharvest of Kamchatka flounder as the complex ABC exceeded the Kamchatka flounder biomass. Beginning with the 2011 fishing season, arrowtooth flounder and Kamchatka flounder will be managed separately (see Chapter 6.5).

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

Arrowtooth flounder were managed with Greenland turbot as a species complex until 1985 because of similarities in their life history characteristics, distribution and exploitation. Greenland turbot were the target species of the fisheries whereas arrowtooth flounder were caught as bycatch. Starting in 1986, management has been by accomplished individually for Greenland turbot and arrowtooth flounder due to considerable differences in their stock condition.

Arrowtooth flounder begin to recruit to the continental slope at about age 4. Based on age data from the 1982 U.S.-Japan cooperative survey, recruitment to the slope gradually increases at older ages and reaches a maximum at age 9. However, greater than 50% of age groups 9 and older continue to occupy continental shelf waters. The low proportion of the overall biomass on the slope during the 1988 and 1991 surveys, relative to that of earlier surveys, indicates that the proportion of the population occupying slope waters may vary considerably from year to year depending on the age structure of the population.

Catch History

Catch records of arrowtooth flounder and Greenland turbot were combined during the 1960s. The fisheries for Greenland turbot intensified during the 1970s and the bycatch of arrowtooth flounder is assumed to have also increased. In 1974-76, total catches of arrowtooth flounder reached peak levels ranging from 19,000 to 25,000 t (Table 6.1). Catches decreased after implementation of the MFCMA and the resource has remained lightly exploited with catches averaging 12,831 t from 1977-2008. 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 6.1 through 2006 are for arrowtooth flounder and Kamchatka flounder combined, catches thereafter are those estimated for arrowtooth flounder only. Total catch reported through 15 October, 2010 is 14,855 t (well below the 2010 ABC of 156,000 t). NMFS Regional Office reports indicate that bottom trawling accounted for 92% of the 2010 catch (2% by pelagic trawl and 5% 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 1985-2009 are shown in Table 6.2. With the advent of Amendment 80 fishing practices in 2008 the percentage of arrowtooth flounder retained in catches has increased to 80%. 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 1970 – October 15, 2010 (Table 6.1) and fishery length-frequency data from 1978-91 and 2000-2005 are used in the assessment. Actual arrowtooth flounder catch is available from observer at-sea sampling applied to the Alaska regional office blend estimates for 2007-2010. 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).

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 16.35 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 estimate is at about the same levels estimated for 2003, 2004, 2007 and 2008. The 2010 CPUE in the Aleutian Islands is well below the record high 2006 estimate but remains at the levels estimated in 2003 and 2004.

Absolute Abundance from Trawl Surveys

Biomass estimates (t) for arrowtooth flounder from the standard survey area in the eastern Bering Sea and Aleutian Islands region are shown in Table 6.3. Table 6.5 lists the total research catch of these species. Although the standard sampling trawl changed in 1982 to the more efficient trawl 83/112 trawl which may have caused an overestimate of the biomass increase in the pre-1982 part of the time-series, biomass estimates from AFSC surveys on the continental shelf have shown a consistent increasing trend since 1975. Since 1982, biomass point -estimates indicate that arrowtooth abundance has increased eight-fold to a high of 570,600 t in 1994. The population biomass remained at a high level from 1992-97. Results from the 1997-2000 bottom trawl surveys indicate the Bering Sea shelf population biomass had declined to 340,000 t, 60% of the peak 1994 biomass point estimate. Beginning in 2002 the shelf survey estimate increased further and peaked in 2005 at a biomass of 757,685. In 2006 - 2008 the estimates declined slightly but were still at high levels. The 2009 survey point estimate was lower but the 2010 biomass estimate on the shelf increased to the former estimated level.

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 2010 point estimate are 437,230 – 611,570 t.

Trawl surveys were intermittently conducted over the continental slope in 1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004 and 2008. 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 were 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 74,000 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, 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
<u>1982 age sample</u>					
Male	528	2-14	45.9	0.23	-0.70
Female	706	2-14	73.8	0.14	-0.20
Sexes Combined	1,234	2-14	59.0	0.17	-0.50
<u>1991 age sample</u>					
Male	53	3-9	57.9	0.17	-2.17
Female	134	4-12	85.0	0.16	-0.81

Based on 282 observations during 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 the 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 log(likelihood) function given some distributional assumptions about the observed data (see Table 6.6).

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

Data Component	Distribution assumption
Trawl fishery size composition	Multinomial
Shelf survey population size composition	Multinomial
Slope survey population size composition	Multinomial
Shelf survey age composition (1996 and 1998)	Multinomial
Trawl survey biomass estimates and S.E.	Log normal

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

Fishing mortality	Selectivity	Temp-q	Year class strength	Total
35	14	2	55	106

The recruitment parameters are comprised of 21 initial ages in 1976 and 32 subsequent age sex-specific 1 recruitment estimates from 1976-2007. Recruitment in 2008 was set at the average from 1976-2007. The difference in the number of parameters estimated in this assessment compared to last year can be accounted for by an additional year (2010) 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 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 then calculating the average of the annual proportions estimated from the linear regressions (Fig 6.3). The resulting proportions are 76% shelf, 10% slope and 14% in the Aleutian Islands. Equal emphasis was placed on fitting all data components for this assessment and 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 6.3) and sex ratios from the shelf, slope and Aleutian Islands surveys.

Parameters Estimated Independently

Catchability

Attempts to estimate catchability by profiling over fixed q values in a previous assessment (Wilderbuer and Sample 1995) were unsuccessful as estimated values always reached the upper bounds placed on the parameter. The results indicated q values as high as 2.0 which suggests that more fish are caught in the survey trawl than are present in the "effective" fishing width of the trawl (ie. some herding occurs or the "effective" fishing width of the trawl may be the distance between where the sweep lines contact the seafloor instead of between the wingtips of the survey trawl). Results from two herding experiments conducted in 1994 to discern the herding characteristics of the standard shelf survey trawl indicated a trawl catch of flatfish was composed of fish which were directly in the trawl path as well as those which moved into the trawl path because of the mud cloud disturbance caused by the bridle contact with the seafloor (Somerton and Munro 2001). Thus the “area-swept” technique of estimation would overestimate the abundance when herding occurred. Although arrowtooth flounder were not one of the seven flatfish species considered in this experiment, it seems reasonable to assume that they also exhibit this same behavior, and should be included in the catchability model.

Examination of Bering Sea shelf survey biomass estimates indicate that some of the annual variability seemed to positively co-vary with bottom water temperature. Variations in CPUE (Fig. 6.2) were particularly evident during the coldest year (1999) and the warmest year (2003). The relationship between average annual bottom water temperature collected during the survey and annual survey biomass estimates can be better understood by modeling survey catchability as:

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

where q is catchability, α and β are a parameters estimated by the model, and T_t is the average annual bottom water temperature. The catchability equation has two parts. The e^{α} term is a constant or time-independent estimate of q. The model estimate of $\alpha = -0.45$ 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, $e^{\beta T}$ 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 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, 3) there are some sampling problems, or 4) there is a genetic predisposition to produce more females than males.

Since there is a current lack of evidence that male arrowtooth flounder are less available to the Bering Sea shelf survey sampling trawl than females, differential sex-specific natural mortality has been investigated as an alternative model in past assessments as an explanation of the observed differences in survey catch sex ratio (Wilderbuer and Sample 2002).

For this assessment, model runs were again made with female natural mortality fixed at 0.2 for a range of values for males. Model runs were evaluated with respect to the estimate of male and female selectivity for the shelf survey, the estimated sex ratio and the overall model fit. Also, a constraint was placed on fitting the sex ratio estimated from the trawl surveys, as follows:

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

where SRlike is the sex ratio likelihood component, SR_{obs} is the observed sex ratio in shelf survey trawl surveys from 1982-2008, SR_{pred} is the model predicted sex ratio in the estimated population, and σ_{obs} is the standard error of the observed population sex ratio.

Model Evaluation

In last year's assessment initial model runs were made using the shelf and slope surveys and Aleutian Islands surveys as described above with female natural mortality fixed at 0.2 for a range of values for males. As in past years, it is very important to evaluate the value of the maximum male selectivity on the shelf because estimates of this value at a level well less than 1.0 indicate that the sex ratio observed in the surveys are a result of a difference in male and female capture behavior or availability to the survey trawls and not the result of differential sex-specific natural mortality. Although the hypothesis of lower availability for males cannot be ruled out without further research, age data from Gulf of Alaska trawl surveys indicate that males do not live past 17 years whereas many female arrowtooth flounder have been aged as high as 25 years. This result is what would be expected in age compositions from a population with a higher M for males than females and is the view supported by the authors in this assessment (and also in the Gulf of Alaska arrowtooth flounder assessment, Turnock et al. 2007).

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

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

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

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 1977-2010 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 2010 value of 1.07 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 its highest level yet observed, largely from the influence of the largest shelf survey biomass estimates ever recorded in 2005 and 2006 and consecutive years of good recruitment. Female spawning biomass is also estimated to be at a high level, 772,000 t in 2010, 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. 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).

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 6.3) indicate strong 2000 - 2005 year classes, as also estimated by the model as very strong in 2002 and 2005 (Fig. 611). These fish are now increasing the stock size further. Above average recruitment from 9 consecutive year classes (1995-2003) cause the projected values for 2010-2013 to remain at a high level.

The posterior distribution of the female spawning biomass estimate for 2010 (Fig. 6.12), calculated from mcmc integration of the preferred model run indicates the spawning stock is at a high level and that the estimate is highly certain. A Beverton-Holt fit to the estimated spawning biomass-age 1 recruitment estimates was done outside the stock assessment model and is shown in figure 6.13.

Acceptable Biological Catch

Arrowtooth flounder have a wide-spread bathymetric distribution in the Bering Sea/Aleutian Islands region and are believed to be at a high level, primarily as a result of a series of above average year-classes spawned from 1995-2003, and minimal commercial harvest. They are currently estimated to be at a high and increasing level. **The estimate of projected 2011 total biomass from the stock assessment projection model is 1,124,170 t and the female spawning biomass is estimated at 806,000 t**.

The reference fishing mortality rate for arrowtooth flounder is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Equilibrium female spawning biomass is calculated by applying the female spawning biomass per recruit resulting from a constant $F_{0.40}$ harvest to an estimate of average equilibrium recruitment. Year classes spawned in 1977-2007 are used to calculate the average equilibrium recruitment. Using the time-series of age 1 recruitment from 1978-2006 from the stock assessment model results in an estimate of $B_{0.40}$ = 279,600 t. The stock assessment model estimates the 2011 level of female spawning biomass at 806,000 t (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and $B>B_{0.40}$ (806,000 > 279,600), arrowtooth flounder reference fishing mortality is defined in tier 3a. For the 2011 harvest: $F_{ABC} = F_{0.40} = 0.23$ and $F_{overfishing} = F_{0.35} = 0.29$ (full selection F values).

Acceptable biological catch is estimated for 2011 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2011 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 2011 ABC of 153,200 t.**

The overfishing level is estimated for 2011 by applying the $F_{35\%}$ fishing mortality rate and age-specific fishery selectivities to the projected 2011 estimate of age-specific total biomass. **This results in a 2011 OFL of 186,400 t.**

The potential yield of arrowtooth flounder in 2011is summarized as follows:

F level	Exploitation rate	Potential yield
$F_{overfishing}$	0.29	186,400 t
$F_{0.40}$	**0.23**	**153,200 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 2010 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2011 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2010. 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 2011 recommended in the assessment to the *max* F_{ABC} for 2011. (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 2006-2010 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 2010 and above its MSY level in 2020 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2010 and 2011, 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 2022 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 2011, it does not provide the best estimate of OFL for 2012, because the mean 2012 catch under Scenario 6 is predicated on the 2011 catch being equal to the 2011 OFL, whereas the actual 2011 catch will likely be less than the 2011 ABC. Therefore, the projection model was re-run with the 2011 and 2012 catch fixed equal to the 2010 catch to calculate the 2012 ABC and OFL.

Year	Catch	ABC	OFL
2011	14,855	153,200	186,400
2012	14,855	157,100	191,000

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 three predators on arrowtooth flounder >30 cm, by relative importance, are walleye pollock (29% of the total mortality), Alaska skate (21%) and sleeper shark (11%) (Fig. 6.17). After these predators the next highest sources of mortality (1991) on arrowtooth flounder are four fisheries, the flatfish trawl (7%) pollock trawl (6%), cod trawl (4) and the cod longline fishery (2%). In the Aleutian Islands, sleeper sharks are the primary predators on arrowtooth flounder adults, while Pacific cod are the primary predator on arrowtooth flounder juveniles.

Most of the occurrences of arrowtooth flounder measured in groundfish stomachs was of fish between 20-40cm fork length, and were found in larger individuals of the predator species. For juvenile arrowtooth flounder (<20cm fork length), 97% of the total mortality is unknown with the remaining 3 % primarily attributed to arrowtooth flounder and a few other species (Fig 6.18).

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

Arrowtooth flounder predation

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

The balance of the arrowtooth flounder diet in the eastern Bering Sea includes eelpouts, shrimp, herring, eulachon and flathead sole juveniles (Fig 6.19). Diets of juvenile arrowtooth flounder are more similar to other Bering Sea shelf flatfish species than to arrowtooth flounder adults. Nonpandalid shrimp compose 42% of the total consumption, euphausids 25%, juvenile Pollock 22% and then polychaetes, sculpins and mysids accounting for another 10% (Fig 6.20). With the exception of juvenile pollock, juvenile arrowtooth flounder exhibit a stronger benthic pathway in their diet than adults. In the Aleutian Islands, arrowtooth flounder feed on the range of available forage fishes, including myctophids, Atka mackerel, and pollock. They are an important predator on Atka mackerel juveniles, making up 23% of the assumed natural mortality of this species.

In terms of the size of pollock consumed, arrowtooth flounder consume a greater number of pollock between the range of 15-25cm fork length than do Pacific cod or Pacific halibut, which consume primarily adult fish and fish smaller than 15cm (Fig 6.21).

Analysis of role in the ecosystem

Food web models for the Bering Sea have been constructed to discern what the effect of changes in key predators has as a source of mortality on species which are linked to them through consumption pathways. These models are 30 year realizations run 1,000 times and thus give a measure of the uncertainty in the food model parameters. A simulation analysis where arrowtooth flounder survival was decreased by 10% and the rest of the ecosystem was allowed to adjust to this decrease for 30 years (Fig. 6.22) indicates that positive changes in biomass for affected species were only minimal with flathead sole showing the largest increase (~3%), probably due to competition for a variety of shared prey resources such as shrimp. As expected the largest negative changes in biomass were for arrowtooth flounder (both adults and juveniles) themselves and a smaller negative change for sleeper sharks (<4%). All other effects were on the order of 1-2%. When juvenile arrowtooth flounder are decreased, again it is flathead sole biomass which is increased, but only by a small percentage change, even if the change in arrowtooth juveniles is as much as 60% (Fig 6.23). As in the first simulation, the changes are minor for all other species and fisheries. However, it's important to note that this reflects a sensitivity analysis around conditions in the early 1990s; the increase of arrowtooth flounder in recent years suggests that this analysis should be re-performed with current conditions.

To evaluate the dependence of arrowtooth flounder adults and juveniles on a suite of species and fisheries which are dynamically related to them, a simulation analysis was conducted where survival of each species group/fishery on the X axis in Fig 6.24 was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. These model runs indicate that the biomass of arrowtooth juveniles is very sensitive to changes on the order of only 10% in key species, whereby their biomass may be reduced by 40-60%. The changes are primarily bottom-up, with few top-down or competitive effects. This supports the research of Wilderbuer et al. (2002) which suggests that the control of arrowtooth flounder production is primarily based on physical drivers, e.g. advection to nursery habitat. However, it's important to note that the effect of decreasing pollock (adults or juveniles) is to increase arrowtooth flounder in the model rather than decrease it; this suggests that the role of pollock as a predator on arrowtooth flounder (potentially limiting their population growth) is greater than the importance of pollock as prey, at least for small perturbations of pollock. For adults, the pattern is similar although the percent change in biomass is less (30%).

Ecosystem Effects on the stock

1) Prey availability/abundance trends

Arrowtooth flounder diet varies by life stage as indicated in the previous section. Regarding juvenile prey and its associated habitat, information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not be re-sampled since. Information on pollock abundance is available in Chapter 1 of this SAFE report. It has been hypothesized that predators on pollock, such as adult arrowtooth flounder, may be important species which control (with other factors) the variation in year-class strength of juvenile pollock (Hunt et al. 2002). The populations of arrowtooth flounder which have occupied the outer shelf and slope areas of the Bering Sea over the past twenty years for summertime feeding do not appear food-limited. These populations have fluctuated due to the variability in recruitment success which suggests that the primary infaunal food source has been at an adequate level to sustain the arrowtooth flounder population.

2) Predator population trends

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

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

3) Changes in habitat quality

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

Fishery Effects on the ecosystem

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

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

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

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

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

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

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

Ecosystem effects on arrowtooth flounder

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

***Arrowtooth flounder* effects on ecosystem**

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

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Table 6.1. All nation total combined catch (t) of arrowtooth and Kamchatka flounder in the eastern Bering Sea and Aleutian Islands region[a], 1970-2010. 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 **									14,855

[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 15 October, 2010 (NMFS regional office).

Table 6.2 Estimates of retained and discarded arrowtooth flounder catch, 1985-2009.

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	24,294	6,073	30,367	80

1990 retained rate was applied to the 1985-89 reported catch.

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	69,690	24,700	
1983	127,942		24,465
1984	181,091		
1985	163,668	74,400	
1986	229,865		110,476
1987	297,095		
1988	308,562	30,600	
1989	374,893		
1990	435,125		
1991	329,218	28,400	21,897
1992	420,598		
1993	538,805		
1994	570,604		58,191
1995	480,842		
1996	556,416		
1997	478,667		73,893
1998	368,604		
1999	263,115		
2000	340,365		65,028
2001	409,227		
2002	356,558	61,153	88,750
2003	546,672		
2004	550,984	68,568	94,998
2005	763,887		
2006	670,131		183,836
2007	546,483		
2008	583,918	96,248	
2009	453,559		
2010	528,667	74,065	80,060

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

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

Table 6.6-continued.

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

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

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

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

Table 6.7--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	0.070
1977	0.083	0.042
1978	0.070	0.036
1979	0.093	0.049
1980	0.116	0.062
1981	0.108	0.056
1982	0.070	0.037
1983	0.081	0.042
1984	0.052	0.027
1985	0.038	0.020
1986	0.034	0.018
1987	0.021	0.011
1988	0.080	0.042
1989	0.028	0.014
1990	0.046	0.024
1991	0.074	0.037
1992	0.032	0.017
1993	0.026	0.015
1994	0.036	0.022
1995	0.022	0.014
1996	0.033	0.021
1997	0.022	0.014
1998	0.033	0.021
1999	0.023	0.014
2000	0.028	0.017
2001	0.030	0.017
2002	0.024	0.014
2003	0.026	0.015
2004	0.034	0.019
2005	0.025	0.014
2006	0.023	0.013
2007	0.018	0.011
2008	0.025	0.015
2009	0.026	0.016
2010	0.022	0.014

Table 6.9 Model estimates of arrowtooth flounder age-specific fishery and survey selectivities, by sex.

	Fishery		shelf survey		slope survey		Aleutians survey	
Age	females	males	females	males	females	males	females	males
1	0.00	0.01	0.04	0.11	0.00	0.03	0.03	0.07
2	0.00	0.01	0.15	0.18	0.00	0.05	0.06	0.11
3	0.01	0.03	0.41	0.28	0.00	0.08	0.12	0.18
4	0.04	0.06	0.80	0.41	0.00	0.12	0.23	0.26
5	0.12	0.13	1.00	0.58	0.05	0.18	0.40	0.37
6	0.29	0.24	0.95	0.75	0.88	0.27	0.60	0.49
7	0.57	0.42	0.82	0.88	1.00	0.38	0.77	0.61
8	0.80	0.61	0.68	0.92	1.00	0.50	0.88	0.72
9	0.93	0.78	0.55	0.85	1.00	0.62	0.94	0.81
10	0.98	0.89	0.44	0.70	1.00	0.73	0.97	0.88
11	0.99	0.95	0.35	0.52	1.00	0.82	0.99	0.92
12	1.00	0.97	0.28	0.36	1.00	0.88	0.99	0.95
13	1.00	0.99	0.22	0.24	1.00	0.92	1.00	0.97
14	1.00	0.99	0.17	0.16	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 2008 and 2009 assessments.

	2010 Assessment age 1+ Total biomass	Female Spawning biomass	2009 Assessment age 1+ Total biomass	Female Spawning biomass
1976	255,717	163,978	251,268	159,544
1977	253,858	164,188	248,748	158,926
1978	260,936	174,333	256,061	169,154
1979	270,883	181,949	266,515	176,758
1980	277,057	181,453	273,050	176,083
1981	283,407	181,614	279,707	176,127
1982	291,883	186,137	288,716	180,832
1983	309,456	195,050	307,502	190,490
1984	326,950	201,819	326,251	197,861
1985	348,221	220,450	349,257	217,730
1986	372,968	245,653	376,150	244,545
1987	404,737	260,865	411,109	261,083
1988	440,671	279,065	451,048	280,966
1989	470,078	291,282	484,671	294,341
1990	513,537	312,033	534,051	317,283
1991	549,601	339,517	575,906	348,376
1992	571,828	374,930	603,188	389,137
1993	598,503	413,802	635,217	433,892
1994	619,820	443,278	661,418	468,567
1995	630,620	457,119	676,161	486,199
1996	644,900	470,268	694,556	502,919
1997	653,403	474,218	706,650	509,563
1998	670,301	477,457	727,833	515,192
1999	687,752	477,584	749,731	517,392
2000	713,480	489,365	780,623	532,252
2001	743,340	503,966	816,036	550,238
2002	775,067	519,261	853,148	569,025
2003	815,384	547,408	897,991	602,012
2004	857,591	579,813	942,279	639,742
2005	897,662	602,300	980,929	666,347
2006	943,869	630,857	1,021,360	698,350
2007	986,129	671,768	1,053,780	740,110
2008	1,026,170	720,447	1,079,470	783,938
2009	1,054,380	750,570	1,086,210	799,107
2010	1,072,260	772,191		

Table 6.11 Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2010.

females	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	103,116	33,062	84,872	70,406	68,788	27,013	15,187	10,563	8,133	6,634
1977	135,822	84,409	27,054	69,367	57,339	55,455	21,268	11,525	7,763	5,879
1978	105,025	111,190	69,085	22,126	56,607	46,498	44,317	16,614	8,826	5,884
1979	110,320	85,980	91,009	56,511	18,065	45,975	37,302	34,879	12,859	6,773
1980	110,195	90,312	70,367	74,422	46,097	14,633	36,631	28,972	26,493	9,655
1981	254,059	90,206	73,906	57,526	60,652	37,238	11,580	28,081	21,600	19,468
1982	98,371	207,977	73,822	60,425	46,897	49,044	29,544	8,920	21,079	15,998
1983	79,829	80,532	170,228	60,386	49,334	38,087	39,339	23,246	6,902	16,167
1984	232,536	65,351	65,912	139,225	49,281	40,015	30,453	30,762	17,828	5,240
1985	159,734	190,371	53,494	53,928	113,754	40,108	32,270	24,212	24,157	13,910
1986	132,717	130,773	155,839	43,776	44,086	92,728	32,476	25,860	19,227	19,093
1987	422,004	108,655	107,053	127,535	35,793	35,956	75,180	26,089	20,608	15,259
1988	228,729	345,498	88,952	87,624	104,332	29,235	29,262	60,842	21,010	16,554
1989	230,711	187,248	282,778	72,753	71,515	84,641	23,387	22,904	46,725	15,977
1990	151,393	188,884	153,288	231,436	59,500	58,366	68,742	18,851	18,340	37,286
1991	156,050	123,943	154,615	125,427	189,137	48,455	47,144	54,824	14,868	14,382
1992	179,720	127,751	101,445	126,468	102,392	153,542	38,827	37,021	42,299	11,367
1993	136,612	147,136	104,580	83,022	103,412	83,521	124,536	31,216	29,536	33,613
1994	163,265	111,845	120,452	85,594	67,903	84,415	67,868	100,481	25,031	23,608
1995	211,131	133,664	91,558	98,572	69,979	55,364	68,391	54,446	79,919	19,820
1996	275,340	172,855	109,425	74,940	80,635	57,151	45,043	55,313	43,807	64,130
1997	219,565	225,420	141,503	89,552	61,276	65,769	46,345	36,199	44,105	34,788
1998	276,629	179,760	184,542	115,819	73,255	50,041	53,501	37,473	29,115	35,376
1999	385,891	226,475	147,155	151,025	94,700	59,746	40,573	42,983	29,866	23,109
2000	244,626	315,931	185,404	120,444	123,535	77,327	48,586	32,786	34,541	23,932
2001	289,490	200,276	258,632	151,741	98,501	100,814	62,791	39,149	26,240	27,549
2002	332,494	237,005	163,952	211,669	124,088	80,368	81,821	50,545	31,288	20,893
2003	469,703	272,214	194,024	134,191	173,134	101,312	65,338	66,080	40,586	25,048
2004	328,086	384,547	222,847	158,801	109,754	141,330	82,326	52,719	52,991	32,442
2005	227,925	268,602	314,796	182,371	129,840	89,506	114,564	66,113	41,993	42,031
2006	394,153	186,603	219,890	257,651	149,166	106,000	72,752	92,488	53,057	33,596
2007	317,663	322,695	152,763	179,978	210,756	121,805	86,208	58,798	74,341	42,526
2008	240,472	260,075	264,181	125,042	147,247	172,188	99,194	69,853	47,435	59,837
2009	230,742	196,875	212,909	216,224	102,275	120,210	139,956	80,078	56,057	37,949
2010	252,000	188,909	161,171	174,257	176,847	83,485	97,675	112,911	64,203	44,798

Table 6.11 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2010.

	females				numbers at age (1,000s)						
	11	12	13	14	15	16	17	18	19	20	21
1976	5,597	4,828	4,212	3,700	3,266	2,892	2,555	2,263	1,984	1,735	3,957
1977	4,764	4,011	3,458	3,016	2,649	2,339	2,071	1,829	1,620	1,421	4,075
1978	4,438	3,592	3,023	2,606	2,272	1,996	1,762	1,560	1,378	1,221	4,141
1979	4,500	3,391	2,743	2,308	1,989	1,735	1,524	1,345	1,191	1,052	4,094
1980	5,063	3,359	2,529	2,046	1,722	1,484	1,294	1,137	1,003	888	3,838
1981	7,056	3,693	2,448	1,843	1,491	1,255	1,081	943	828	731	3,444
1982	14,345	5,190	2,715	1,800	1,355	1,096	922	795	693	609	3,069
1983	12,229	10,953	3,961	2,072	1,373	1,034	836	704	606	529	2,807
1984	12,227	9,237	8,269	2,990	1,564	1,037	780	631	531	458	2,518
1985	4,078	9,509	7,181	6,429	2,325	1,216	806	607	491	413	2,313
1986	10,974	3,216	7,496	5,661	5,067	1,832	958	635	478	387	2,149
1987	15,128	8,691	2,546	5,935	4,482	4,012	1,451	759	503	379	2,007
1988	12,245	12,136	6,971	2,042	4,760	3,595	3,218	1,164	609	403	1,914
1989	12,540	9,264	9,178	5,271	1,544	3,599	2,718	2,433	880	460	1,752
1990	12,732	9,989	7,379	7,310	4,198	1,230	2,866	2,165	1,938	701	1,762
1991	29,175	9,955	7,809	5,767	5,713	3,281	961	2,240	1,692	1,515	1,925
1992	10,957	22,200	7,572	5,939	4,386	4,345	2,495	731	1,704	1,287	2,616
1993	9,019	8,689	17,602	6,004	4,708	3,477	3,445	1,978	580	1,351	3,094
1994	26,834	7,197	6,933	14,044	4,790	3,756	2,774	2,748	1,578	462	3,546
1995	18,661	21,198	5,684	5,475	11,091	3,783	2,967	2,191	2,171	1,247	3,166
1996	15,888	14,954	16,985	4,554	4,387	8,886	3,031	2,377	1,756	1,739	3,535
1997	50,847	12,591	11,848	13,457	3,608	3,476	7,040	2,401	1,883	1,391	4,178
1998	27,873	40,726	10,083	9,488	10,777	2,890	2,783	5,638	1,923	1,508	4,460
1999	28,033	22,076	32,250	7,984	7,513	8,533	2,288	2,204	4,464	1,523	4,726
2000	18,497	22,430	17,661	25,800	6,387	6,010	6,826	1,830	1,763	3,571	4,998
2001	19,061	14,725	17,854	14,058	20,535	5,084	4,784	5,433	1,457	1,403	6,821
2002	21,904	15,148	11,701	14,186	11,170	16,316	4,039	3,801	4,317	1,158	6,534
2003	16,707	17,508	12,107	9,351	11,337	8,926	13,039	3,228	3,038	3,450	6,147
2004	19,998	13,333	13,970	9,660	7,461	9,046	7,122	10,404	2,576	2,424	7,658
2005	25,690	15,827	10,550	11,054	7,643	5,903	7,157	5,635	8,232	2,038	7,977
2006	33,586	20,521	12,641	8,426	8,828	6,104	4,715	5,716	4,501	6,574	7,998
2007	26,898	26,881	16,422	10,115	6,742	7,064	4,885	3,773	4,574	3,601	11,661
2008	34,199	21,625	21,609	13,201	8,131	5,420	5,679	3,926	3,033	3,677	12,268
2009	47,814	27,317	17,271	17,257	10,542	6,494	4,328	4,535	3,136	2,422	12,734
2010	30,290	38,148	21,791	13,777	13,766	8,409	5,180	3,453	3,617	2,501	12,089

Table 6.11 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2010.

males	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	103,116	28,457	62,875	44,893	37,752	12,760	6,174	3,696	2,450	1,720
1977	135,822	72,608	20,019	44,140	31,380	26,159	8,705	4,115	2,399	1,555
1978	105,025	95,666	51,111	14,074	30,949	21,884	18,067	5,926	2,756	1,585
1979	110,320	73,980	67,354	35,947	9,876	21,619	15,163	12,368	4,001	1,839
1980	110,195	77,699	52,071	47,340	25,189	6,879	14,895	10,279	8,232	2,622
1981	254,059	77,600	54,672	36,574	33,125	17,493	4,713	10,001	6,745	5,298
1982	98,371	178,920	54,608	38,410	25,605	23,029	12,010	3,175	6,597	4,370
1983	79,829	69,292	125,969	38,406	26,952	17,885	15,955	8,219	2,143	4,401
1984	232,536	56,228	48,779	88,566	26,931	18,800	12,358	10,870	5,511	1,418
1985	159,734	163,816	39,597	34,324	62,216	18,855	13,083	8,523	7,421	3,730
1986	132,717	112,538	115,383	27,874	24,132	43,635	13,166	9,075	5,868	5,077
1987	422,004	93,506	79,270	81,232	19,602	16,934	30,500	9,149	6,265	4,029
1988	228,729	297,345	65,875	55,828	57,172	13,778	11,874	21,311	6,367	4,345
1989	230,711	161,108	209,322	46,318	39,153	39,889	9,524	8,096	14,303	4,217
1990	151,393	162,553	113,490	147,392	32,585	27,495	27,922	6,635	5,609	9,865
1991	156,050	106,656	114,481	79,871	103,574	22,829	19,159	19,301	4,545	3,812
1992	179,720	109,920	75,088	80,506	56,033	72,315	15,803	13,094	13,000	3,024
1993	136,612	126,623	77,427	52,866	56,622	39,327	50,565	10,988	9,047	8,934
1994	163,265	96,255	89,200	54,522	37,196	39,771	27,541	35,252	7,622	6,248
1995	211,131	115,027	67,798	62,795	38,338	26,093	27,783	19,120	24,300	5,222
1996	275,340	148,763	81,036	47,748	44,193	26,943	18,292	19,404	13,296	16,838
1997	219,565	193,992	104,787	57,052	33,580	31,014	18,836	12,715	13,401	9,133
1998	276,629	154,705	136,665	73,796	40,150	23,598	21,739	13,152	8,840	9,282
1999	385,891	194,899	108,972	96,216	51,898	28,175	16,495	15,108	9,080	6,069
2000	244,626	271,896	137,302	76,741	67,707	36,466	19,744	11,513	10,496	6,284
2001	289,490	172,357	191,532	96,679	53,986	47,544	25,522	13,751	7,974	7,236
2002	332,494	203,965	121,411	134,857	68,005	37,901	33,261	17,763	9,514	5,489
2003	469,703	234,272	143,687	85,499	94,893	47,777	26,553	23,205	12,333	6,579
2004	328,086	330,944	165,034	101,181	60,156	66,654	33,459	18,512	16,096	8,518
2005	227,925	231,152	233,110	116,186	71,154	42,210	46,584	23,246	12,775	11,045
2006	394,153	160,593	162,838	164,155	81,752	49,985	29,567	32,490	16,133	8,830
2007	317,663	277,718	113,134	114,676	115,518	57,444	35,030	20,638	22,576	11,168
2008	240,472	223,830	195,658	79,683	80,721	81,217	40,301	24,498	14,381	15,684
2009	230,742	169,433	157,680	137,782	56,067	56,706	56,889	28,108	17,002	9,939
2010	252,000	162,577	119,358	111,034	96,940	39,381	39,709	39,658	19,494	11,740

Table 6.11 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2010.

males	numbers at age (1,000s)									
	11	12	13	14	15	16	17	18	19	20	21
1976	1,249	927	696	526	400	305	232	177	133	100	121
1977	1,076	775	573	430	325	247	188	143	109	82	136
1978	1,018	701	504	372	279	211	160	122	93	71	142
1979	1,050	672	461	331	245	183	138	105	80	61	140
1980	1,193	677	432	297	213	157	118	89	67	51	129
1981	1,667	753	426	271	186	134	99	74	56	42	113
1982	3,393	1,060	478	270	172	118	84	62	47	35	98
1983	2,893	2,237	698	314	177	113	77	55	41	31	88
1984	2,886	1,888	1,456	454	204	115	73	50	36	27	77
1985	954	1,936	1,265	975	304	137	77	49	34	24	69
1986	2,541	649	1,315	859	662	206	93	52	33	23	63
1987	3,473	1,735	442	896	585	451	140	63	36	23	59
1988	2,788	2,400	1,198	306	619	404	311	97	44	25	56
1989	2,853	1,822	1,565	781	199	403	263	203	63	28	53
1990	2,900	1,959	1,250	1,073	535	136	276	180	139	43	55
1991	6,671	1,956	1,319	841	722	360	92	186	121	93	66
1992	2,516	4,384	1,283	864	551	473	236	60	122	79	105
1993	2,071	1,720	2,994	875	590	376	323	161	41	83	126
1994	6,153	1,424	1,182	2,057	601	405	258	222	110	28	143
1995	4,265	4,191	969	804	1,398	409	275	175	151	75	116
1996	3,610	2,944	2,892	668	554	964	282	190	121	104	132
1997	11,524	2,466	2,009	1,973	456	378	658	192	129	83	161
1998	6,311	7,953	1,701	1,385	1,360	314	261	453	132	89	168
1999	6,350	4,309	5,425	1,160	944	927	214	178	309	90	175
2000	4,190	4,378	2,968	3,736	799	650	638	147	122	213	183
2001	4,319	2,875	3,001	2,034	2,560	547	445	437	101	84	271
2002	4,965	2,958	1,967	2,053	1,391	1,751	374	305	299	69	243
2003	3,786	3,420	2,036	1,354	1,412	957	1,204	257	210	206	214
2004	4,531	2,604	2,350	1,399	930	970	657	827	177	144	288
2005	5,824	3,092	1,775	1,601	953	633	661	448	563	120	294
2006	7,613	4,008	2,127	1,220	1,101	655	435	454	308	387	285
2007	6,097	5,250	2,762	1,465	841	758	451	300	313	212	463
2008	7,743	4,223	3,634	1,912	1,014	582	525	312	207	216	467
2009	10,811	5,329	2,904	2,499	1,314	697	400	361	215	143	470
2010	6,844	7,433	3,661	1,995	1,716	902	478	274	248	147	420

Table 6.12 Estimated age 2 recruitment of arrowtooth flounder (thousands of fish) from the 2009 and 2010 stock assessments. Average from 2010 = 332,489.

Year class	2009 Assessment	2010 Assessment
1974	60,686	61,518
1975	162,702	157,017
1976	210,351	206,856
1977	167,122	159,960
1978	172,234	168,011
1979	172,965	167,807
1980	400,314	386,897
1981	155,112	149,824
1982	126,265	121,579
1983	370,646	354,187
1984	256,997	243,311
1985	214,634	202,161
1986	705,098	642,843
1987	383,427	348,356
1988	388,566	351,437
1989	254,553	230,599
1990	262,193	237,671
1991	302,267	273,759
1992	229,607	208,100
1993	274,775	248,691
1994	355,446	321,618
1995	465,148	419,412
1996	371,564	334,465
1997	470,172	421,374
1998	655,155	587,827
1999	417,702	372,633
2000	487,492	440,970
2001	545,433	506,486
2002	713,349	715,491
2003	447,287	499,754
2004	308,576	347,196
2005	525,225	600413
2006	418,000	483905

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
2010	779.781	14.855	0.02
2011	794.780	**153.237**	0.23
2012	688.480	131.924	0.23
2013	596.112	114.613	0.23
2014	520.322	99.985	0.23
2015	460.720	87.770	0.23
2016	413.445	78.109	0.23
2017	377.157	70.660	0.23
2018	350.080	64.989	0.23
2019	330.006	60.627	0.23
2020	315.275	57.149	0.23
2021	305.040	54.619	0.23
2022	298.230	52.894	0.23
2023	294.142	51.775	0.22

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2010	779.781	14.855	0.02
2011	801.753	76.619	0.11
2012	763.515	68.553	0.10
2013	722.445	65.454	0.10
2014	680.884	62.014	0.10
2015	641.919	58.365	0.10
2016	604.977	54.865	0.10
2017	571.771	51.674	0.10
2018	543.059	48.849	0.10
2019	518.516	46.434	0.10
2020	497.689	44.412	0.10
2021	480.594	42.751	0.10
2022	466.879	41.410	0.10
2023	456.367	40.357	0.10

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2010	779.781	14.855	0.02
2011	805.955	26.784	0.04
2012	813.086	17.006	0.02
2013	815.485	17.267	0.02
2014	810.556	17.306	0.02
2015	801.167	17.135	0.02
2016	786.934	16.834	0.02
2017	770.212	16.460	0.02
2018	752.684	16.048	0.02
2019	734.986	15.632	0.02
2020	717.544	15.230	0.02
2021	701.360	14.857	0.02
2022	686.838	14.522	0.02
2023	674.443	14.231	0.02

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2010	779.781	14.855	0.02
2011	808.118	0	0
2012	838.835	0	0
2013	855.084	0	0
2014	862.838	0	0
2015	864.654	0	0
2016	859.933	0	0
2017	850.968	0	0
2018	839.523	0	0
2019	826.379	0	0
2020	812.122	0	0
2021	798.026	0	0
2022	784.718	0	0
2023	772.885	0	0

Table 6.13 (continued).

Scenario 6
Determination of whether arrowtooth flounder are currently overfished
B35=244,600

Year	Female spawning biomass	catch	F
2010	779.781	14.855	0.02
2011	791.539	**186.441**	0.29
2012	656.477	153.250	0.29
2013	547.721	127.961	0.29
2014	463.932	108.009	0.29
2015	401.844	92.423	0.29
2016	355.411	80.839	0.29
2017	321.688	72.374	0.29
2018	297.979	65.178	0.28
2019	282.294	59.765	0.28
2020	272.409	56.321	0.27
2021	266.517	54.289	0.27
2022	263.195	53.099	0.26
2023	261.765	52.489	0.26

Scenario 7
Determination of whether arrowtooth flounder are approaching an overfished condition
B35=244,600

Year	Female spawning biomass	catch	F
2010	779.781	14.855	0.02
2011	794.780	153.237	0.23
2012	688.480	131.923	0.23
2013	593.702	139.487	0.29
2014	496.404	116.248	0.29
2015	424.265	98.144	0.29
2016	370.599	84.716	0.29
2017	331.803	74.975	0.29
2018	304.565	67.243	0.29
2019	286.221	61.088	0.28
2020	274.608	57.076	0.27
2021	267.683	54.693	0.27
2022	263.773	53.296	0.26
2023	262.027	52.575	0.26

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

	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

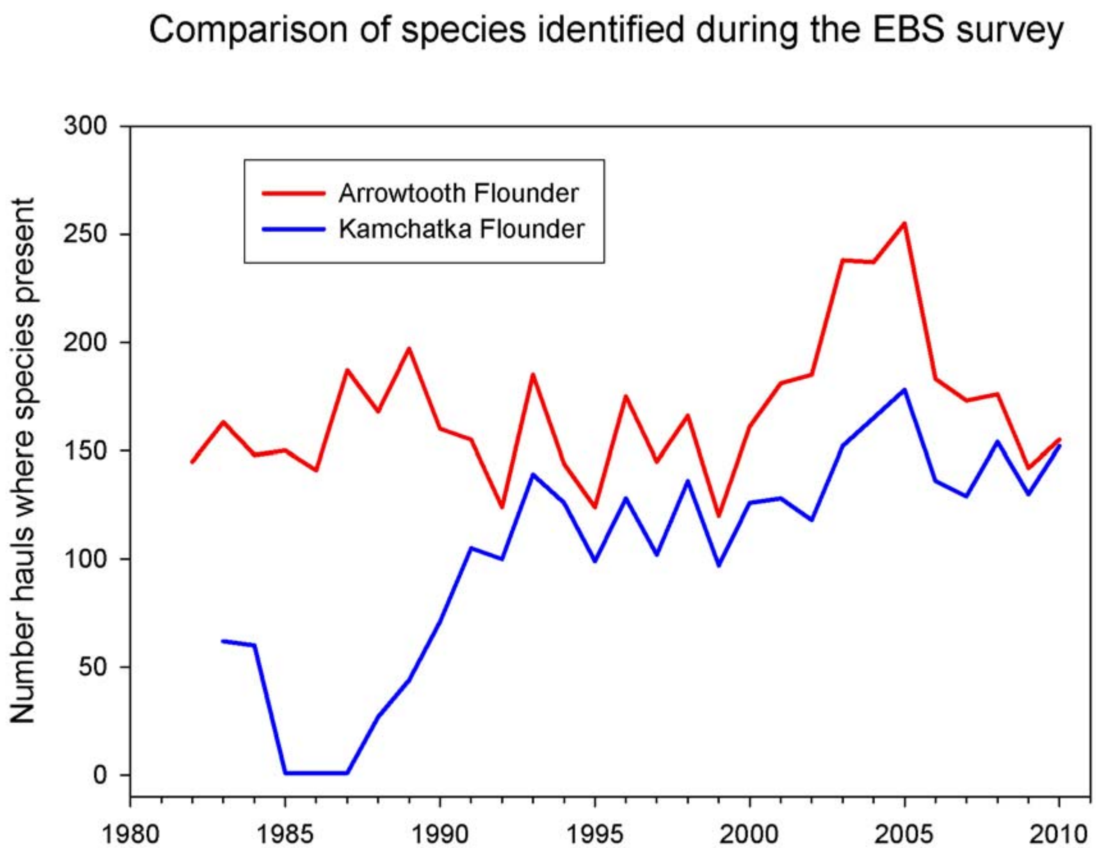

Figure 6.1—Number of hauls where arrowtooth flounder and Kamchatka flounder were identified during the annual Bering Sea shelf surveys, 1982-2010.

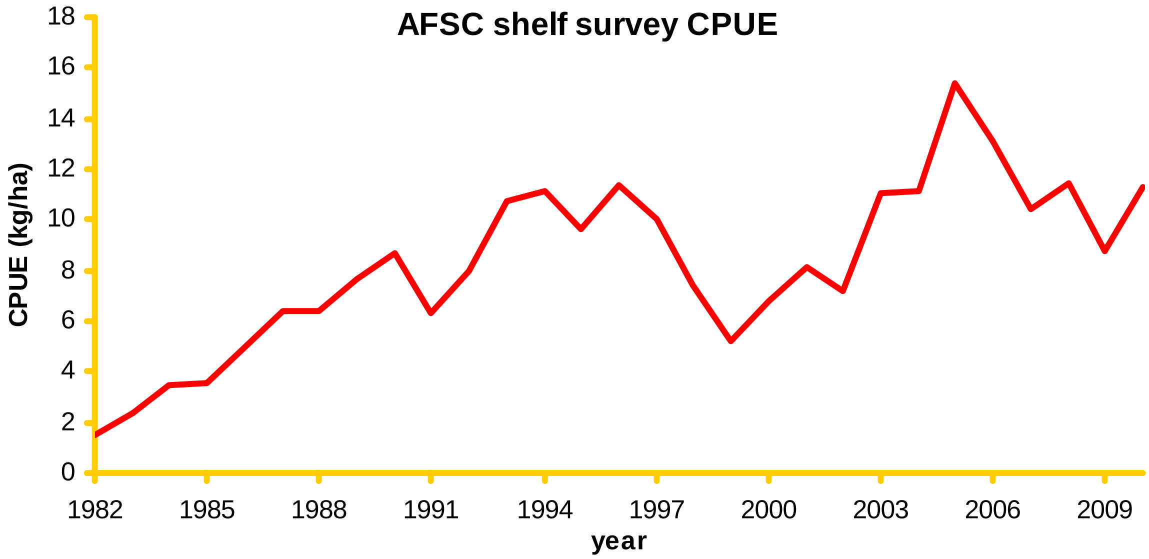

Figure 6.2 Arrowtooth flounder CPUE (kg/ha) from the standard shelf survey area.

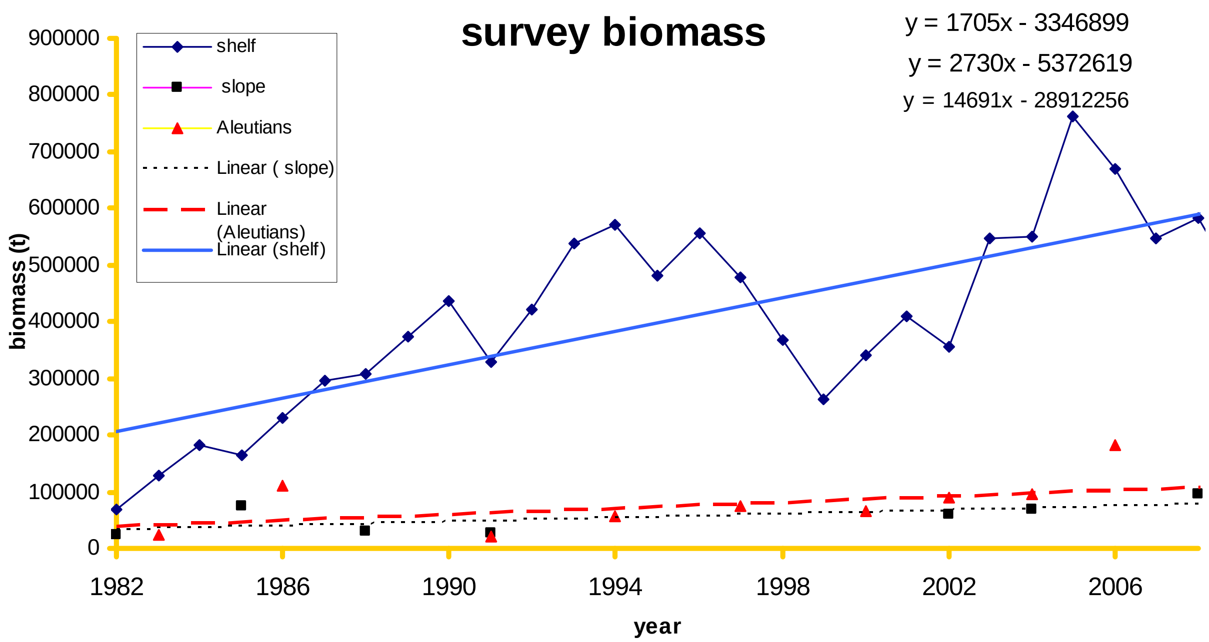

Figure 6.3—Linear regressions of trawl survey estimates for the Bering Sea shelf, slope and the Aleutian Islands used to estimate the proportion of biomass in each area.

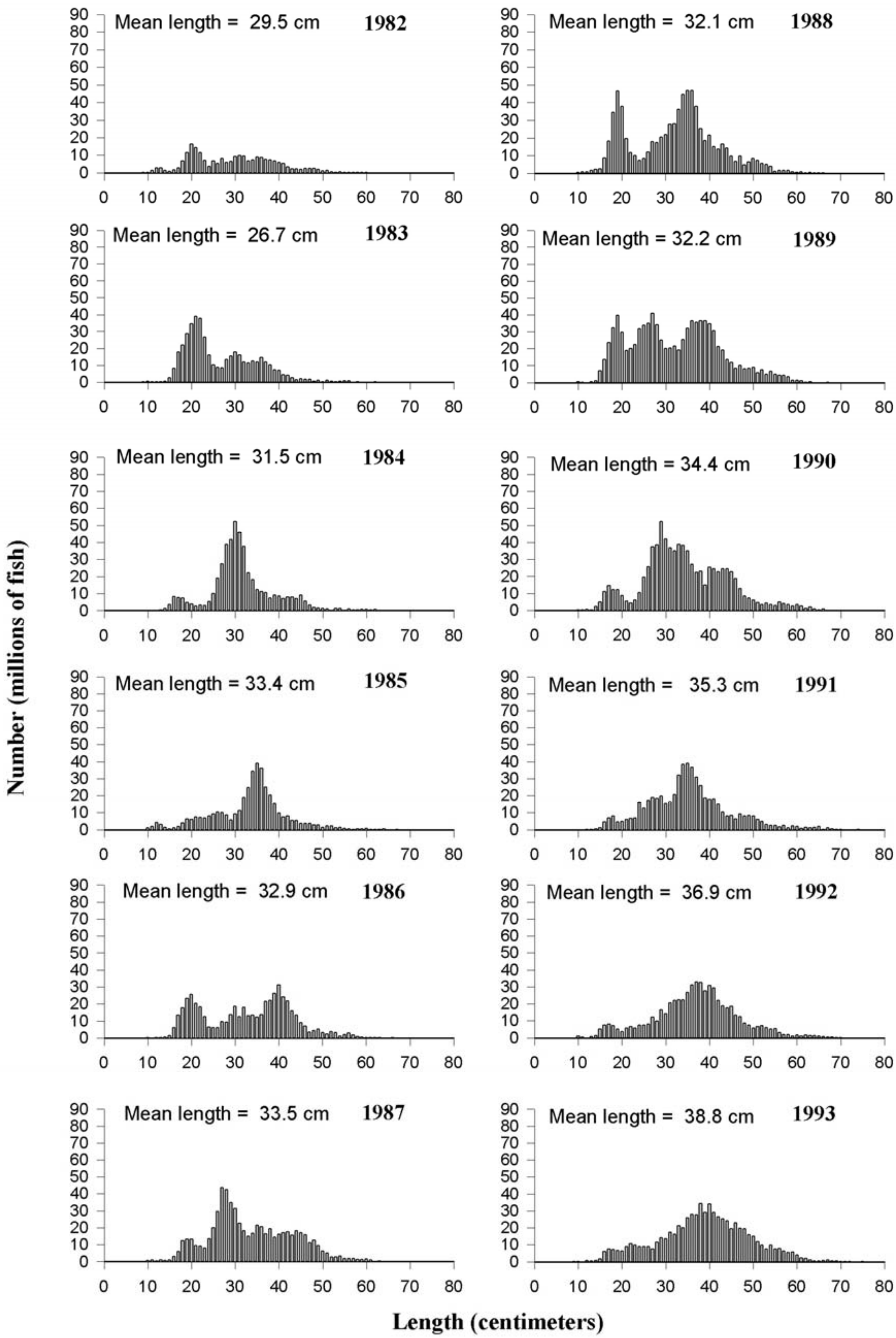

Figure 6.4. Size composition of arrowtooth flounder from the shelf trawl surveys.

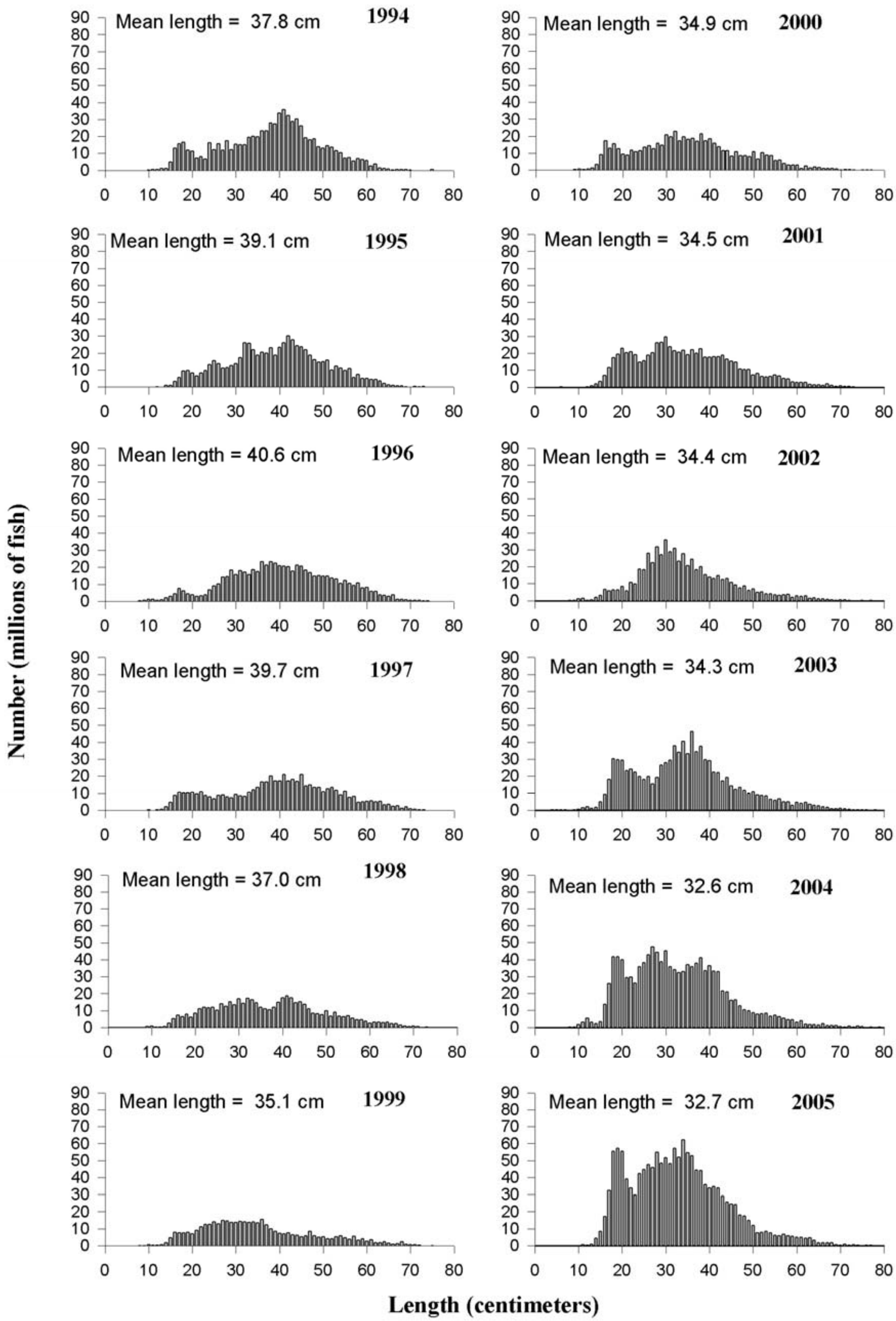

Figure 6.4. continued.

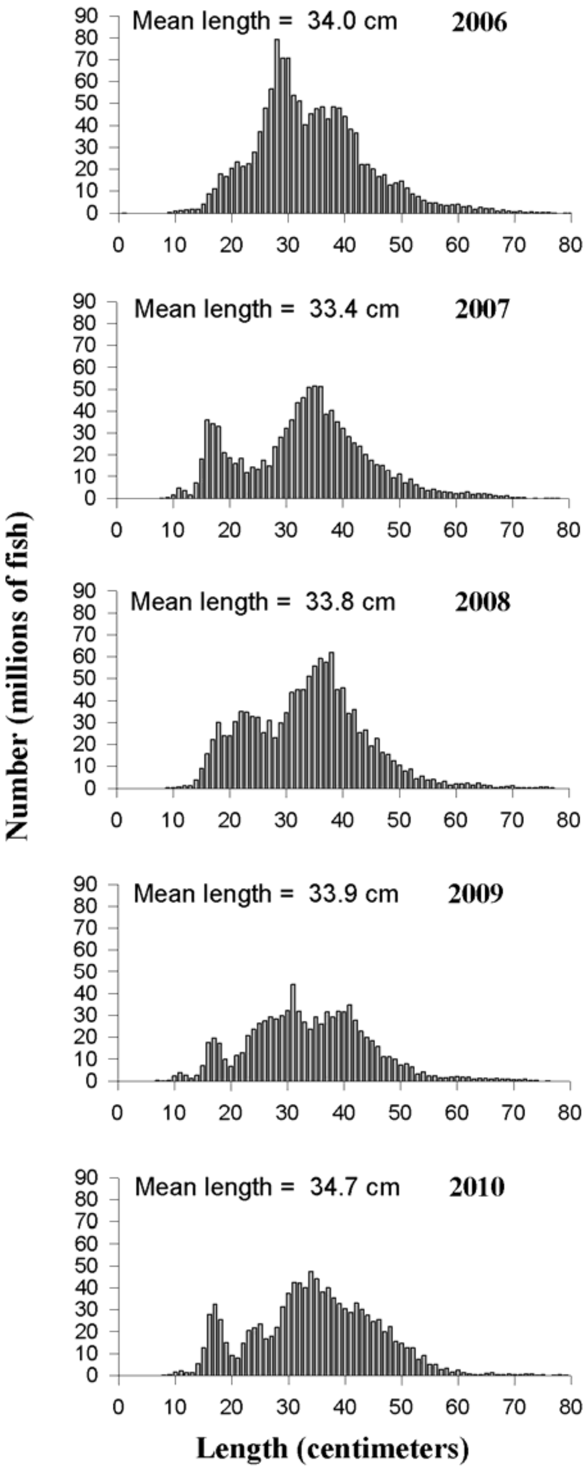

Figure 6.4. continued.

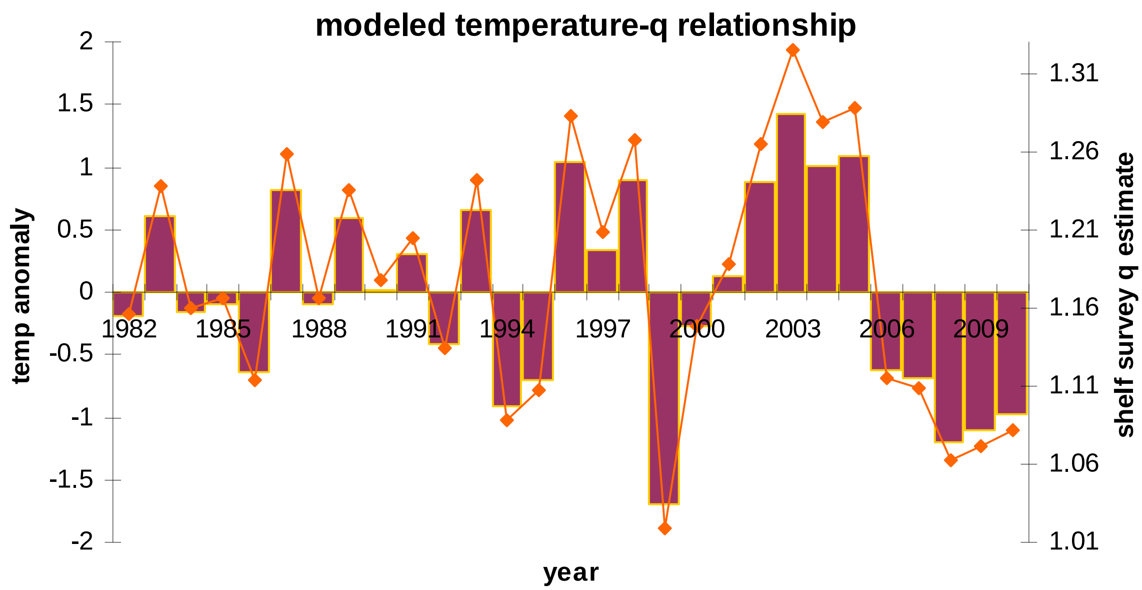

Figure 6.5--Shelf survey annual avg. bottom temperature anomalies (bars), model estimate of annual shelf survey q due to effect of water temperature (diamonds with lines).

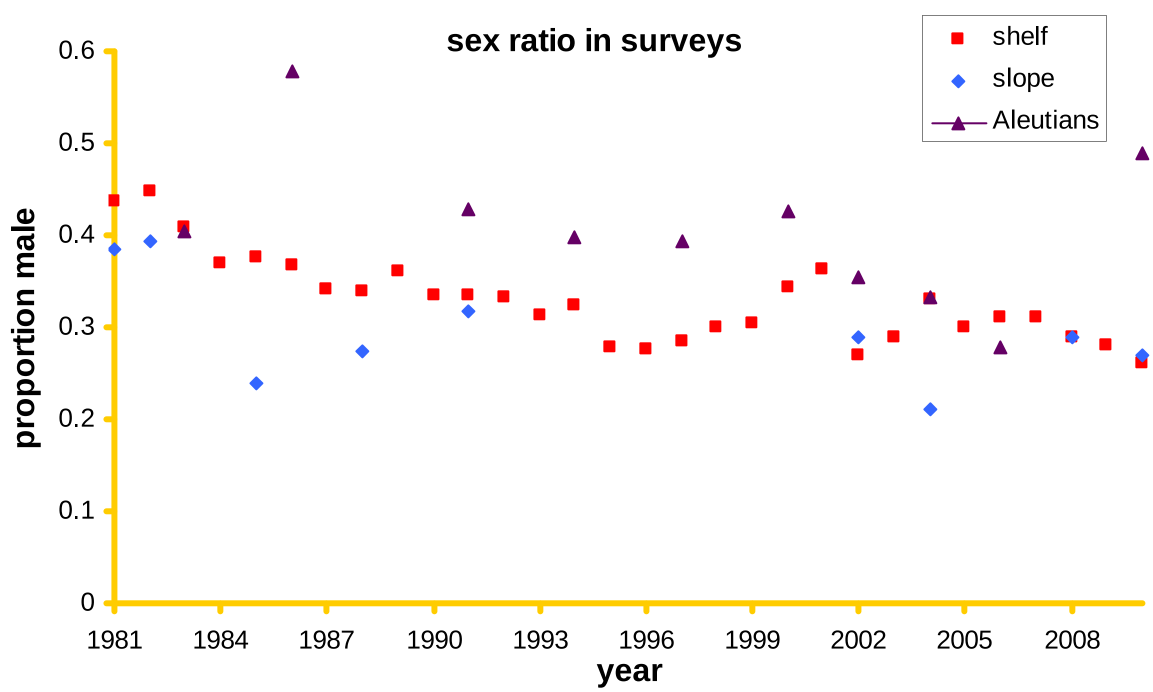

Figure 6.6--Proportion of the estimated male population from Bering Sea and Aleutian Islands trawl surveys on the continental shelf and slope.

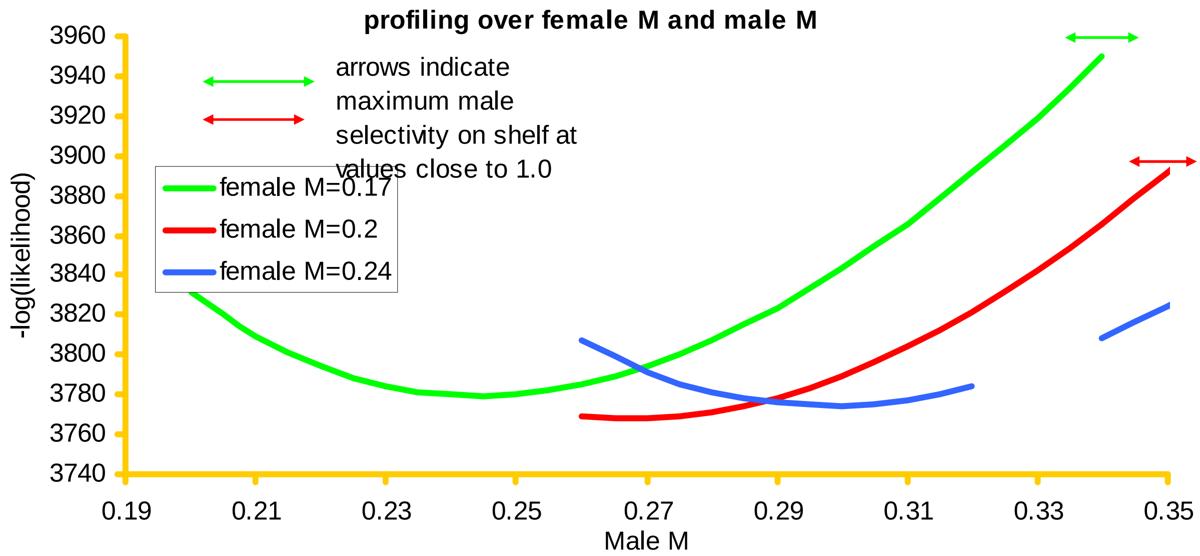

Figure 6.7—Fit to the stock assessment model in terms of –log(likelihood) when profiling over male natural mortality (x axis) for three different levels of female natural mortality. Arrows indicate the values of male natural mortality where the model estimates that maximum male selectivity is close to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

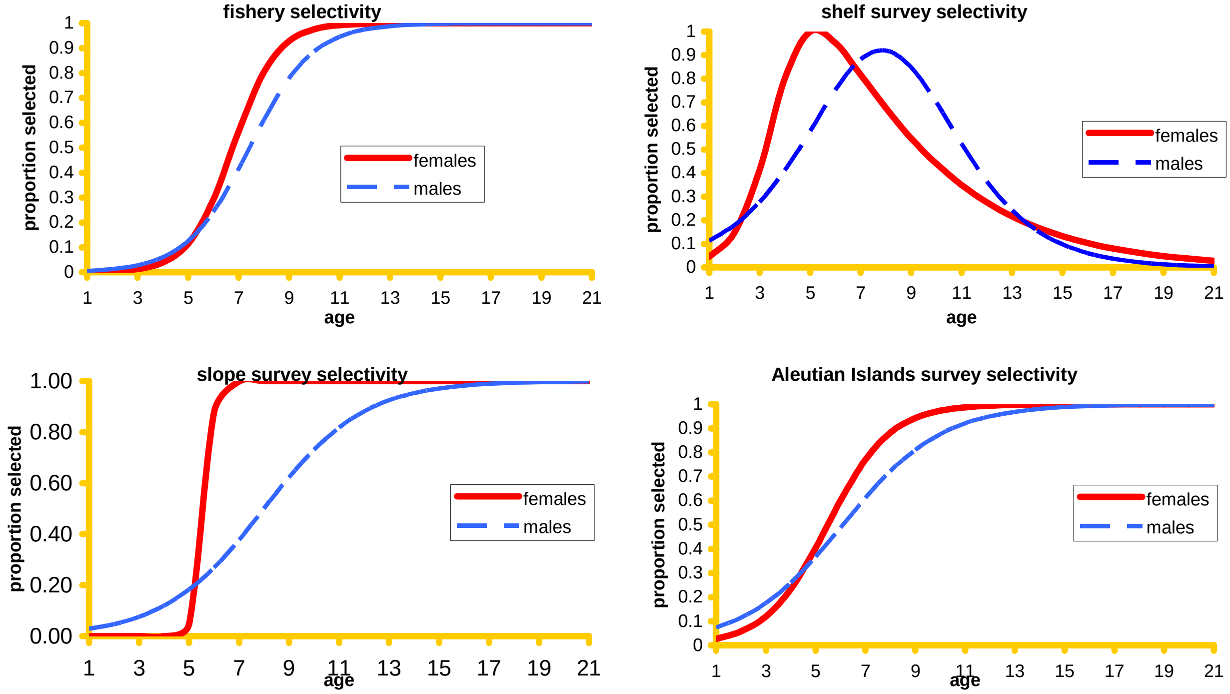

Figure 6.8--Age-specific fishery selectivity (top left panel), shelf survey selectivity (top right panel) slope survey selectivity (bottom left panel) and Aleutian Islands survey selectivity (bottom right panel), by sex, estimated from the stock assessment model.

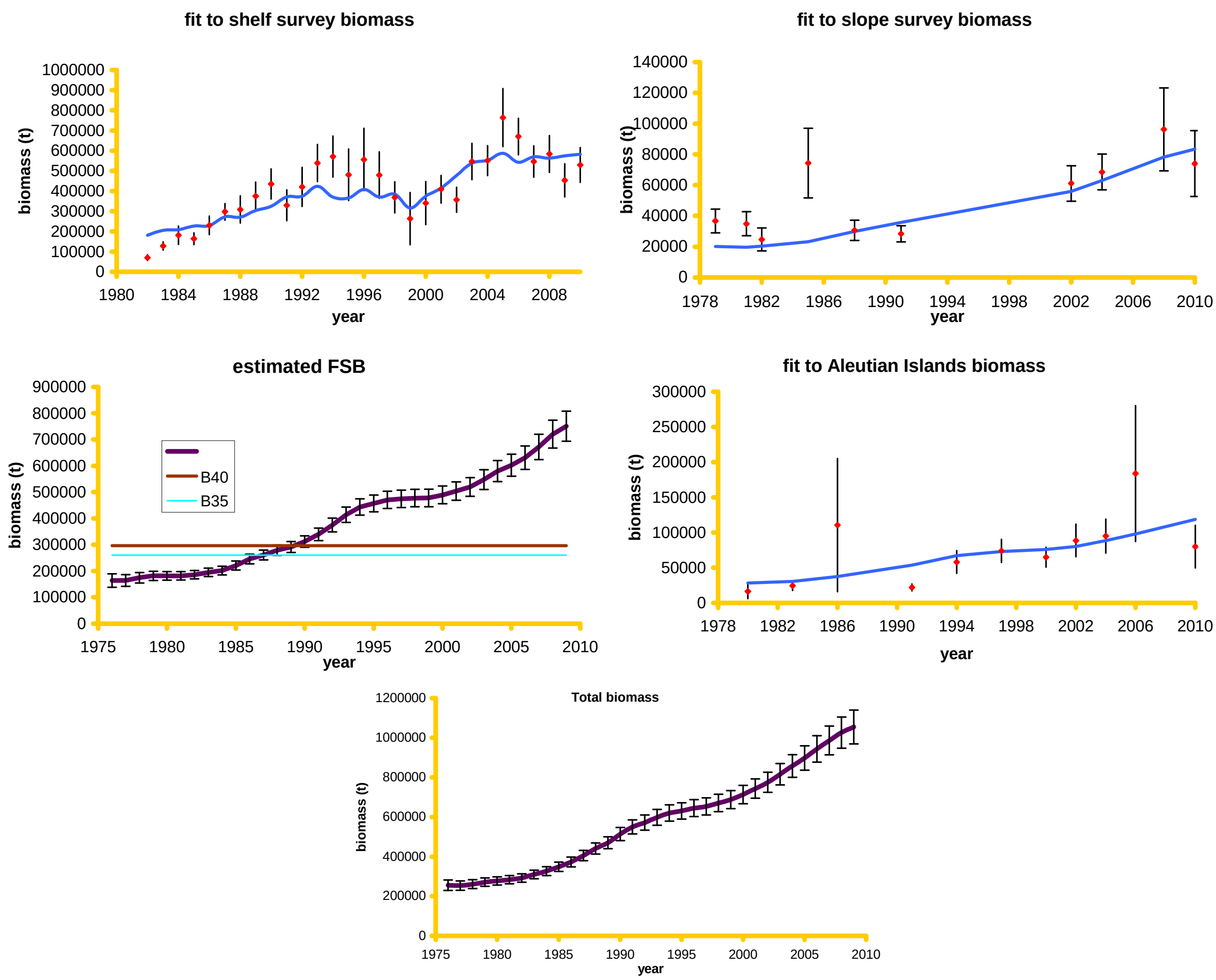

Figure 6.9--Stock assessment model results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), estimate of female spawning biomass with B35 and B40 indicated (middle left panel), the fit to the Aleutian Islands survey (middle right panel) and the estimate of total biomass (bottom panel). Confidence intervals on model estimates of female spawning biomass and total biomass are from mcmc integration.

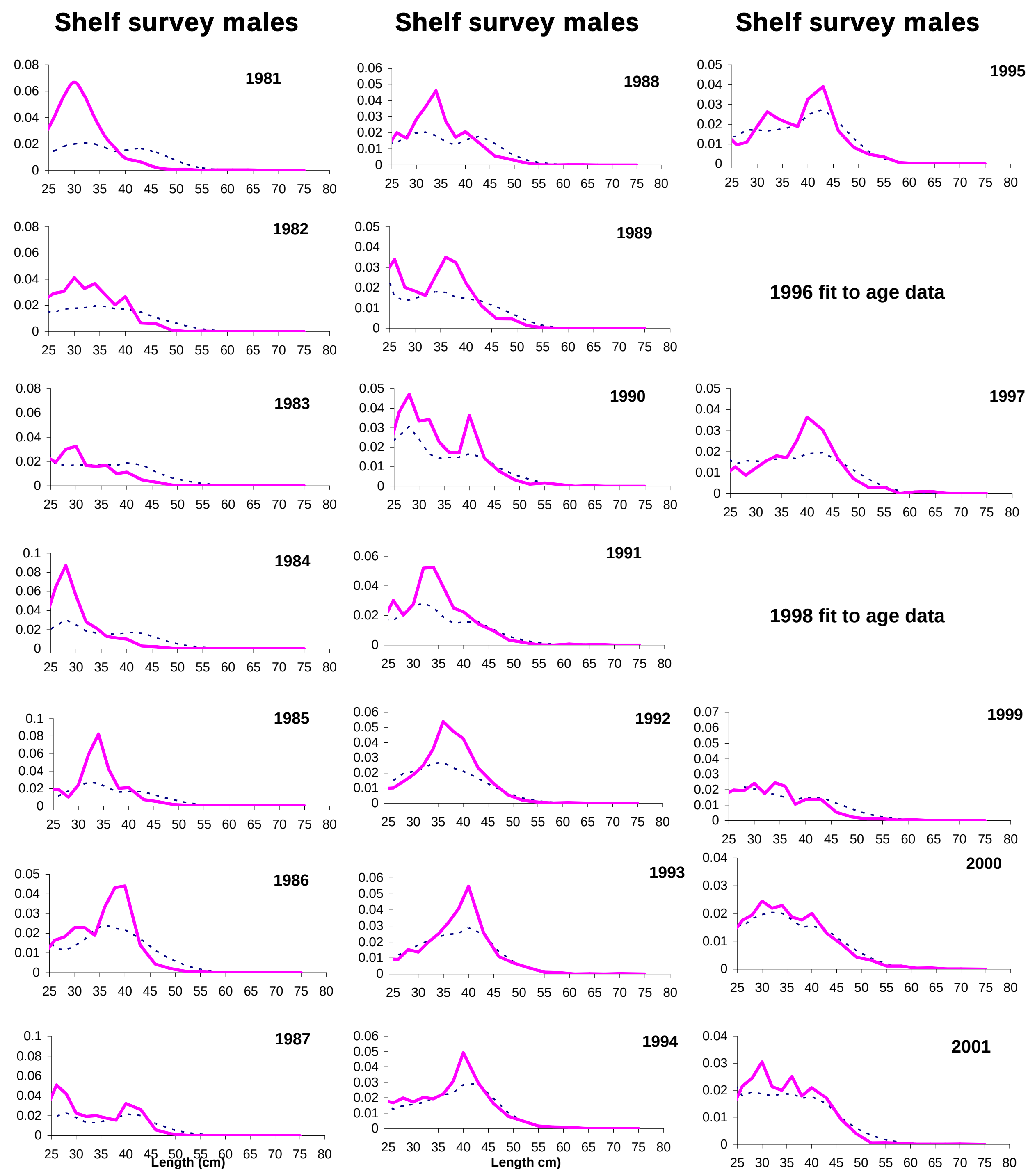

Figure 6.10—Model fit (dotted lines) to trawl survey size and age composition estimates (solid lines).

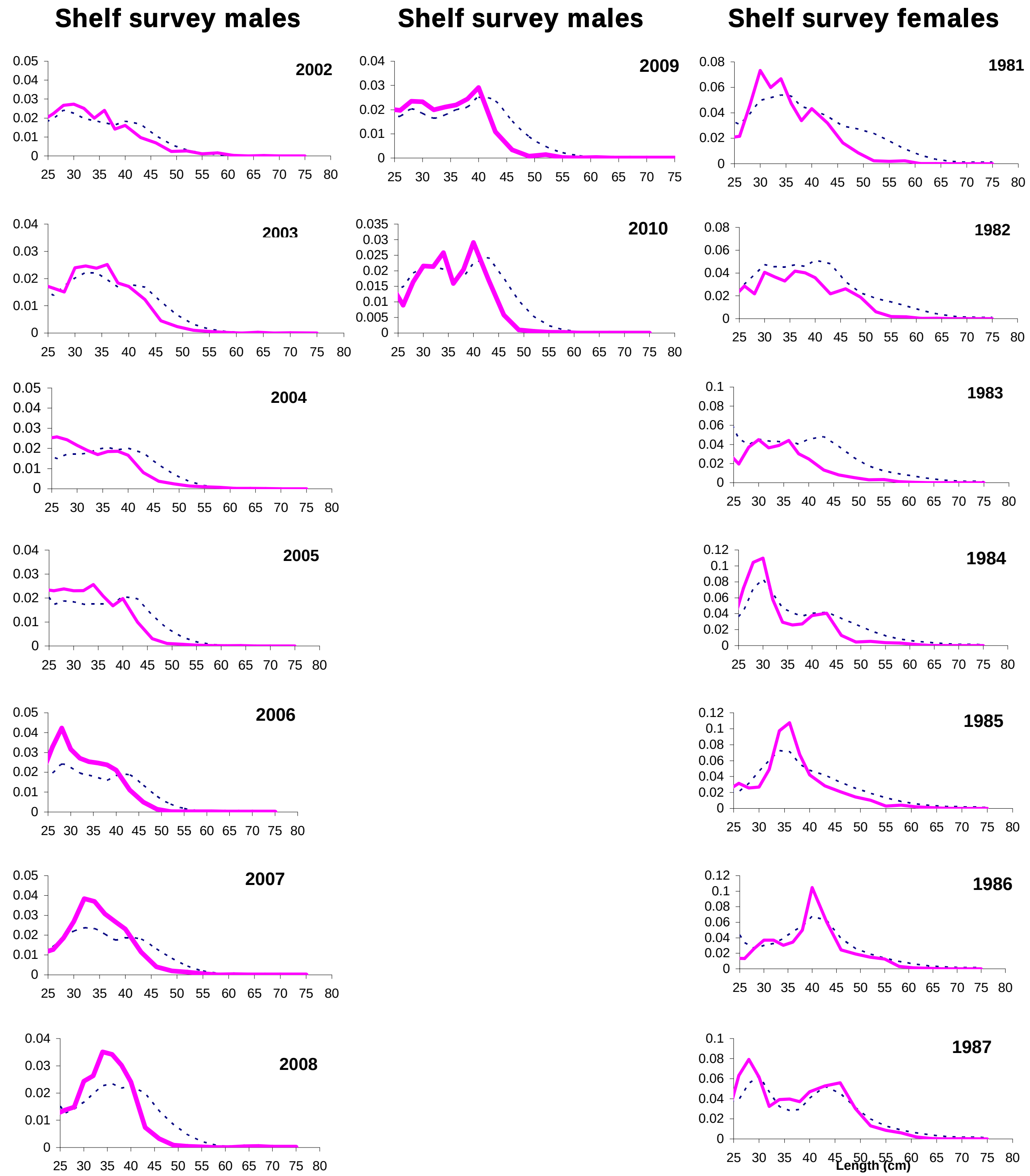

Figure 6.10—continued.

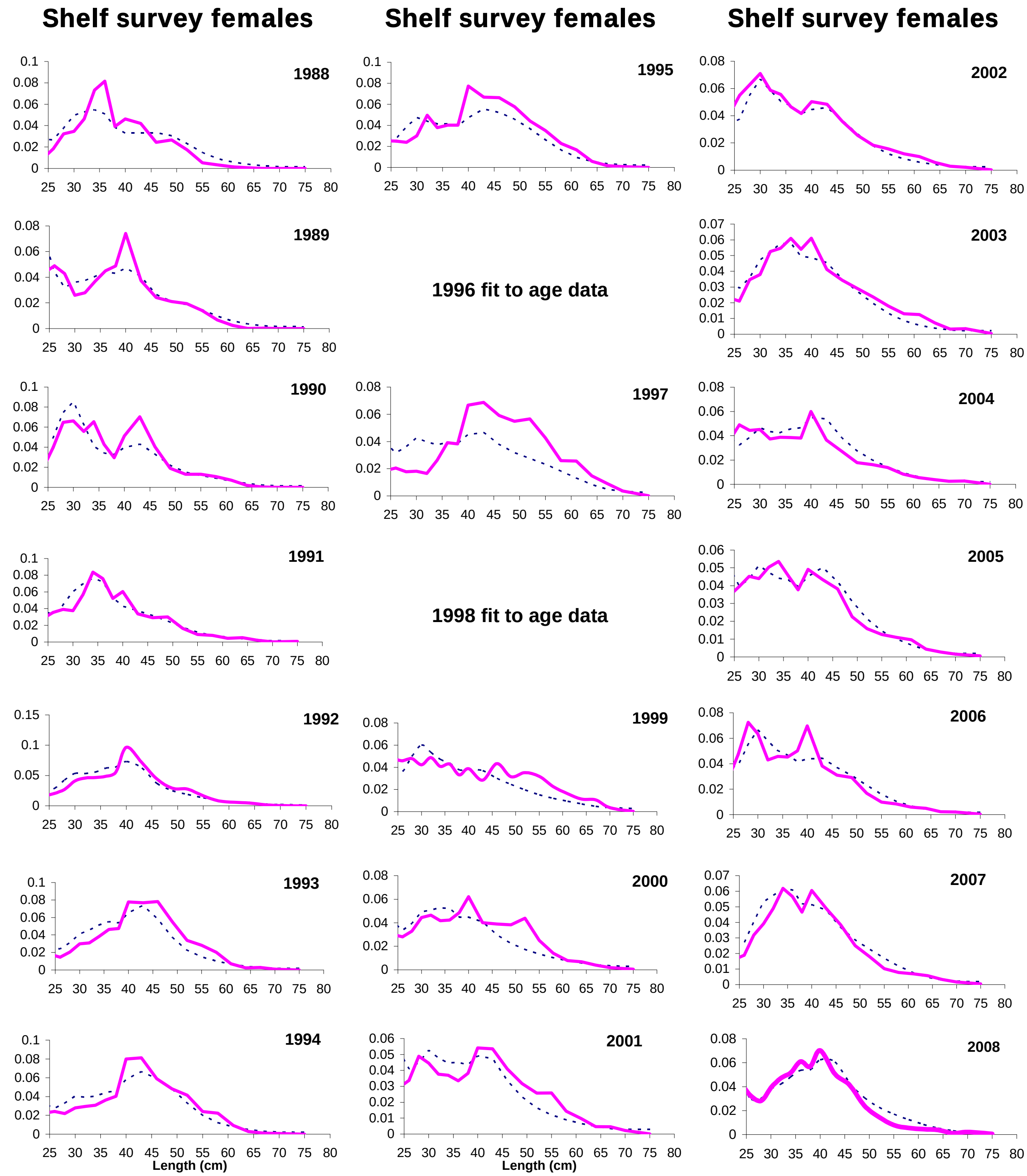

Figure 6.10—continued.

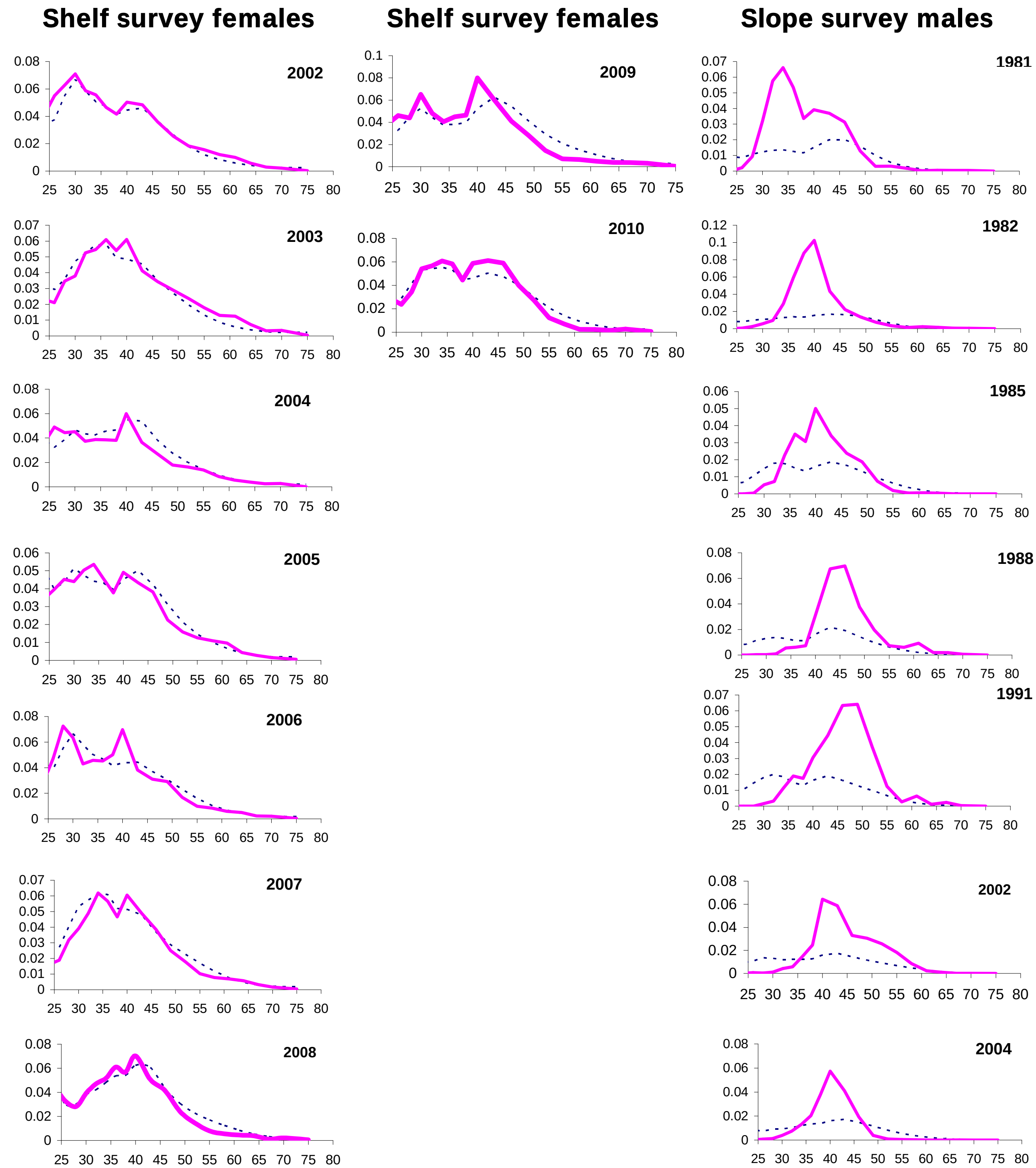

Figure 6.10—continued.

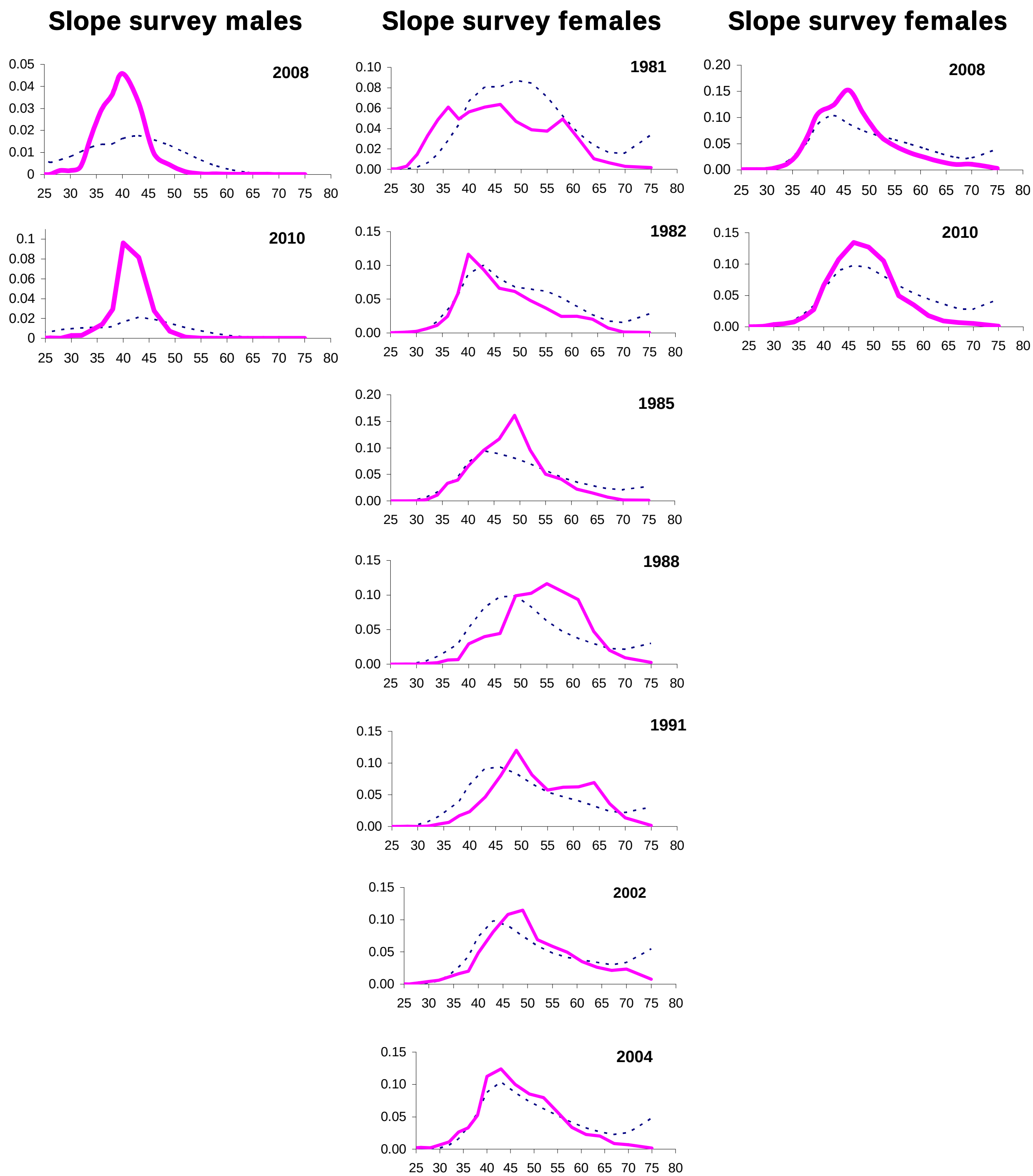

Figure 6.10—continued.

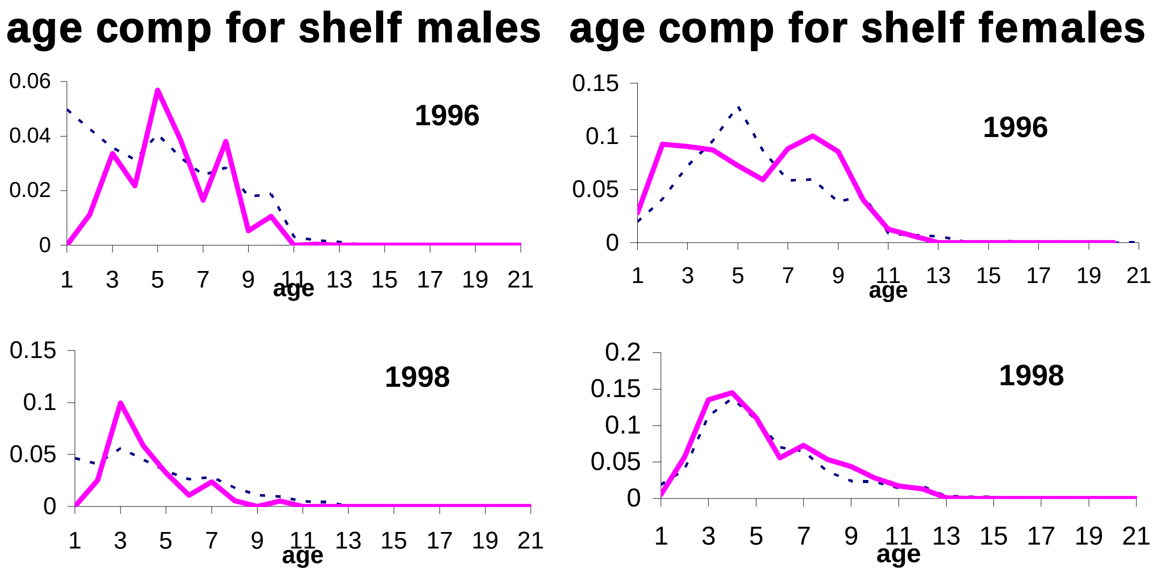

Figure 6.10 (continued).

Aleutian Islands survey length composition by year and sex.

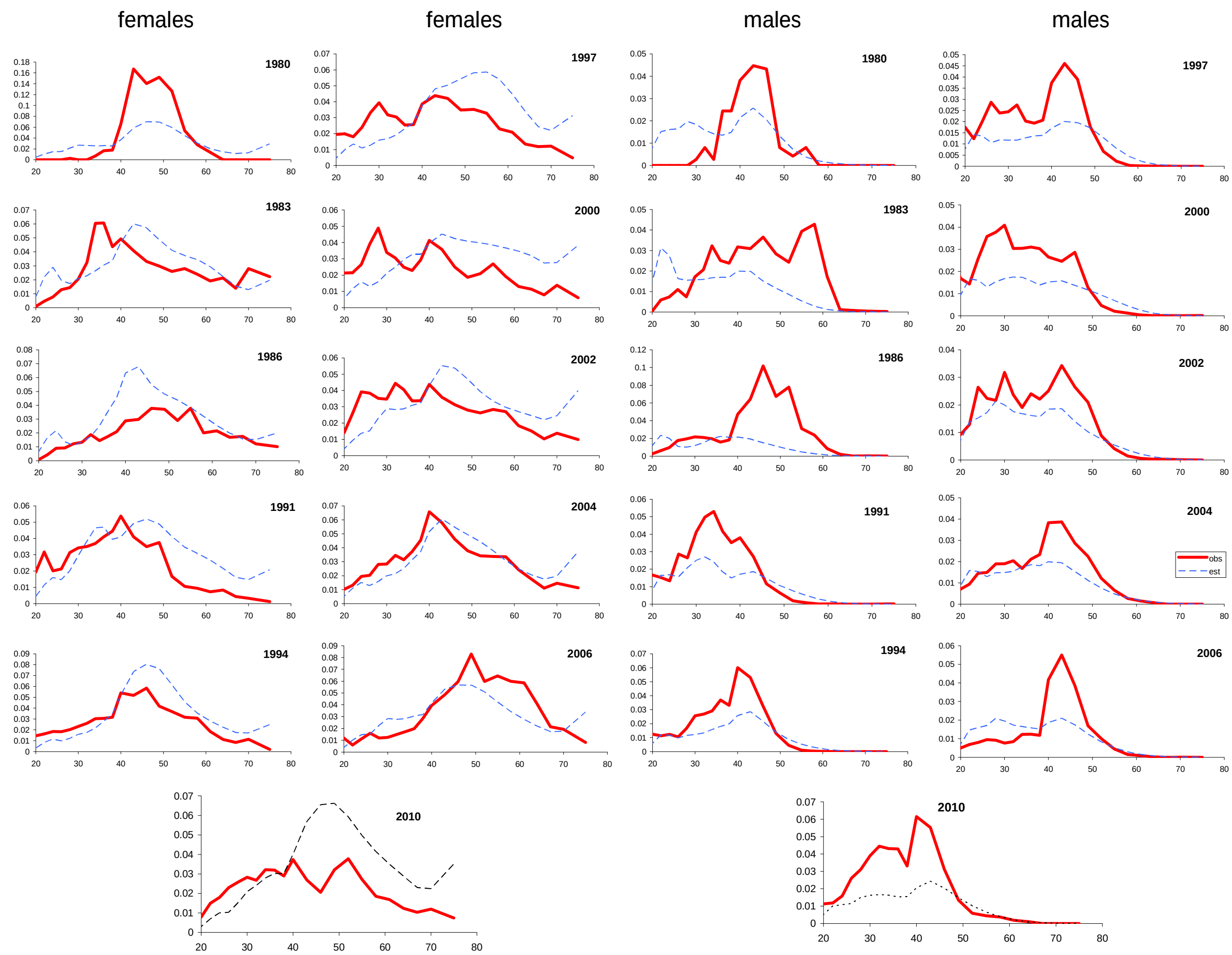

Figure 6.10—continued.

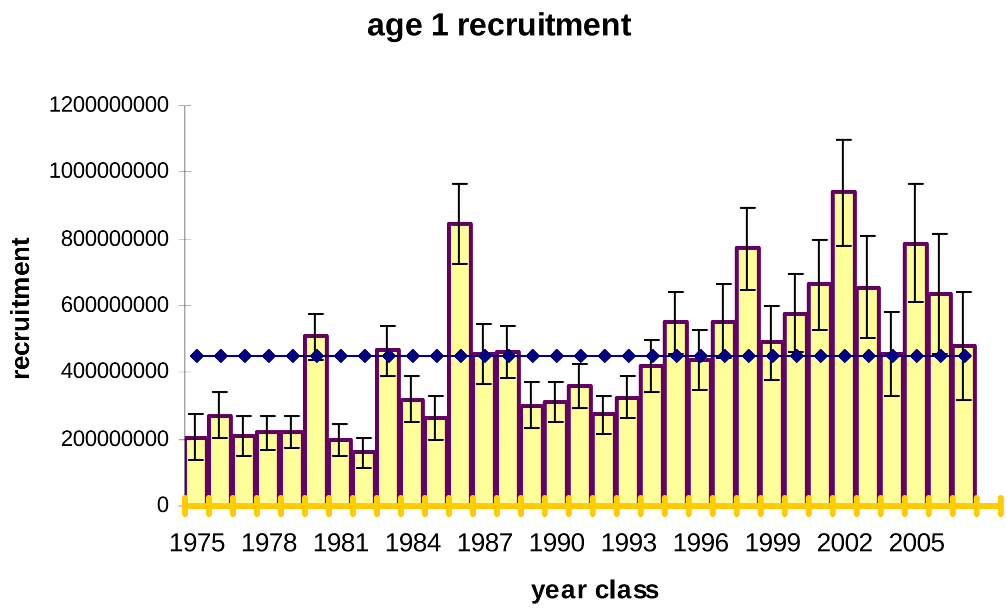

Figure 6.11--Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model.

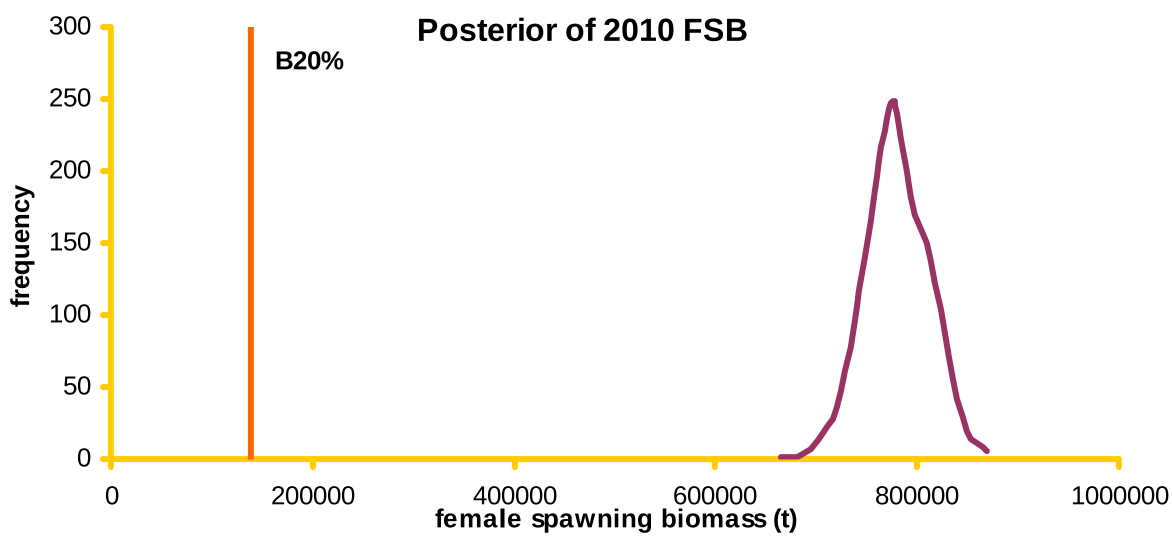

Figure 6.12—Posterior distribution of the estimate of female spawning biomass (t) from the preferred stock assessment model run.

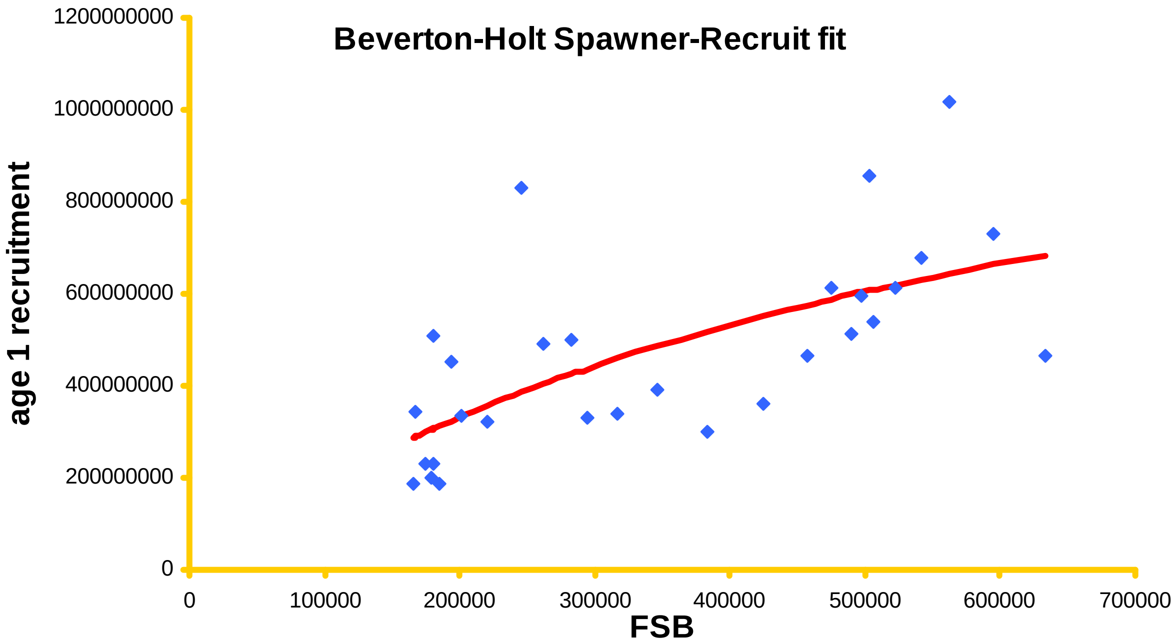

Figure 6.13—Beverton and Holt spawner recruit model fit to the age 1 recruitment data for Bering Sea arrowtooth flounder.

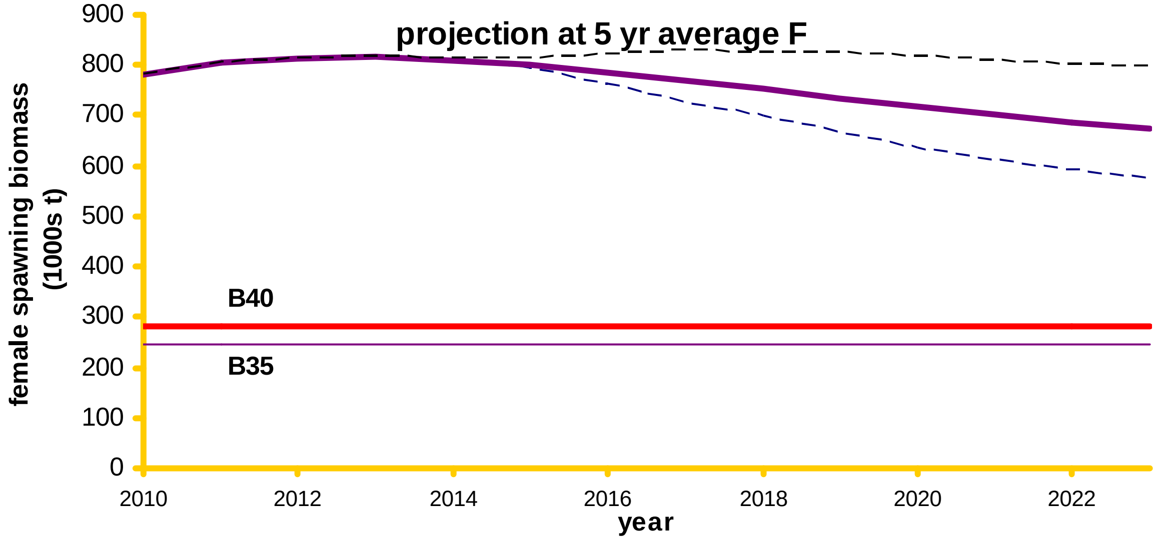

Figure 6.14--Projected female spawning biomass (1,000s t) of arrowtooth flounder if future harvest is at the same fishing mortality rate as the past five years.

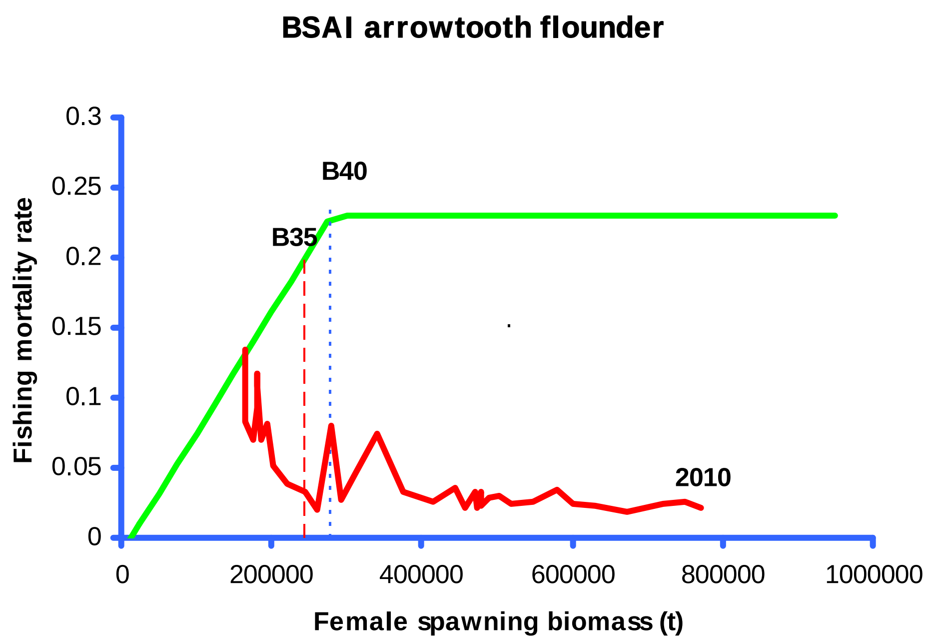

Figure 6.15—Phase plane diagram showing the time-series of stock assessment model estimates of female spawning biomss relative to the harvest control rule.

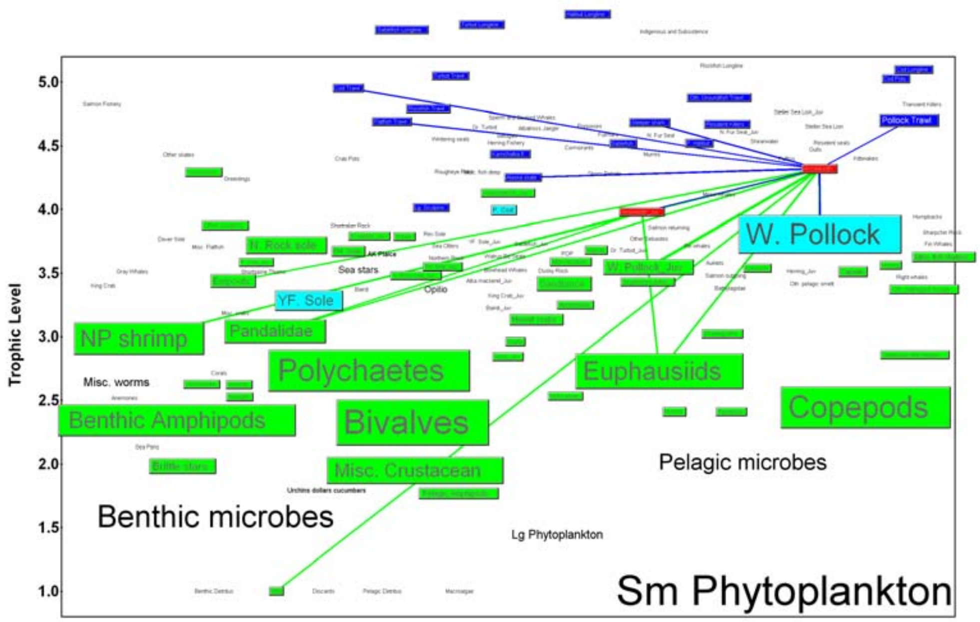

Figure 6.16. Adult and juvenile arrowtooth flounder in the EBS food web. Box size is proportional to biomass, and lines between boxes represent the most significant energy flows. Predators of arrowtooth are dark blue, prey of arrowtooth are green, and species that are both predators and prey of arrowtooth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

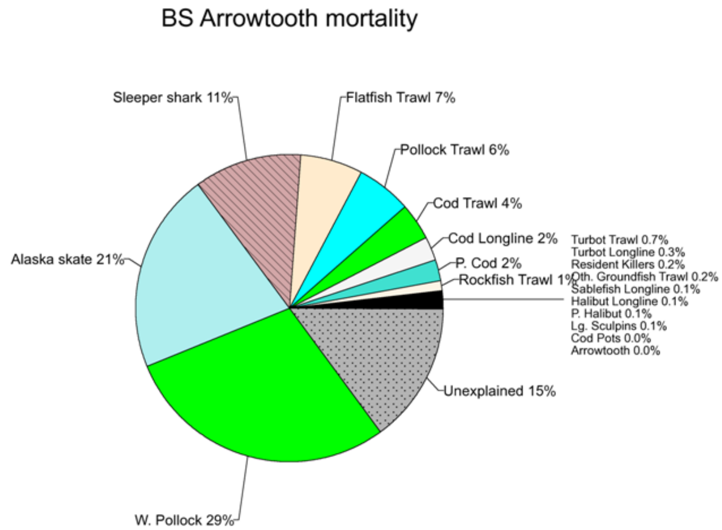

Figure 6.17. Mortality of Bering Sea arrowtooth flounder >20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. "Unexplained" mortality is the difference between the stock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

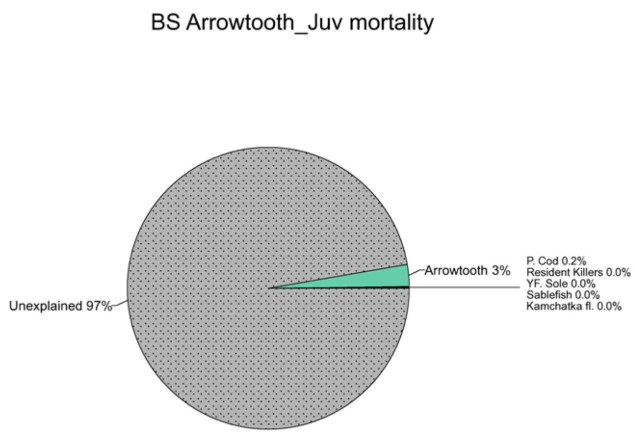

Figure 6.18. Mortality of Bering Sea arrowtooth flounder <20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. "Unexplained" mortality is the difference between the stock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

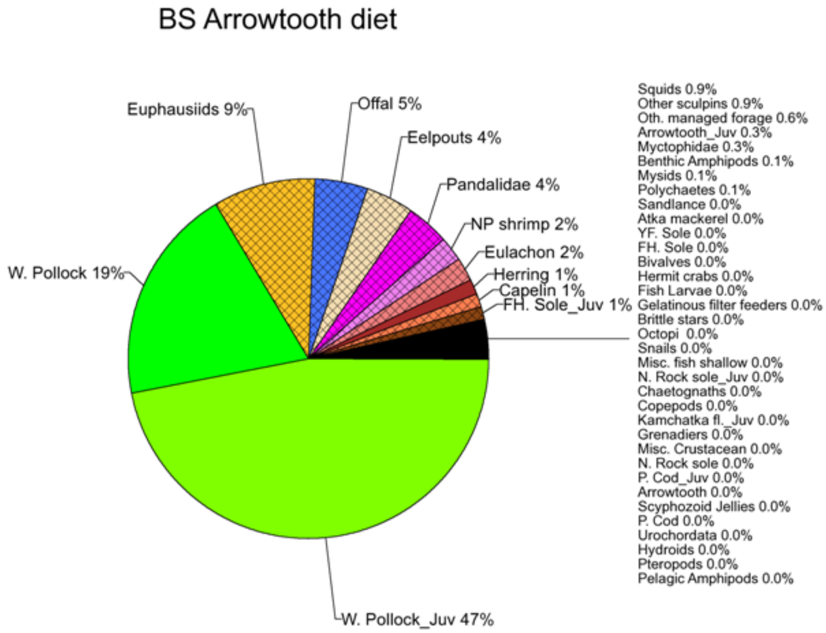

Figure 6.19. Diet of Bering Sea arrowtooth flounder >20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good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

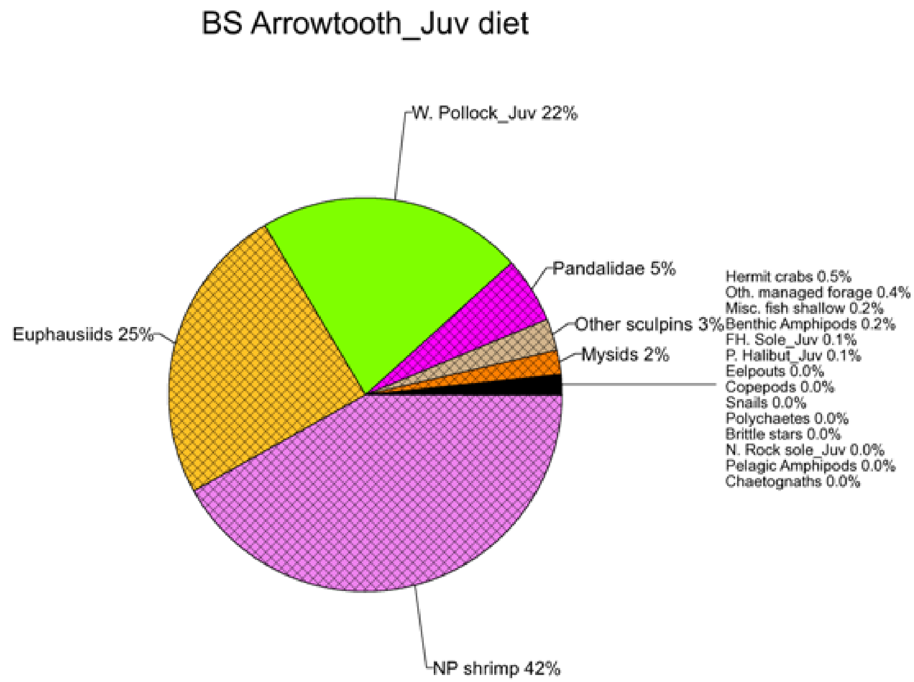

Figure 6.20. Diet of Bering Sea arrowtooth flounder <20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good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

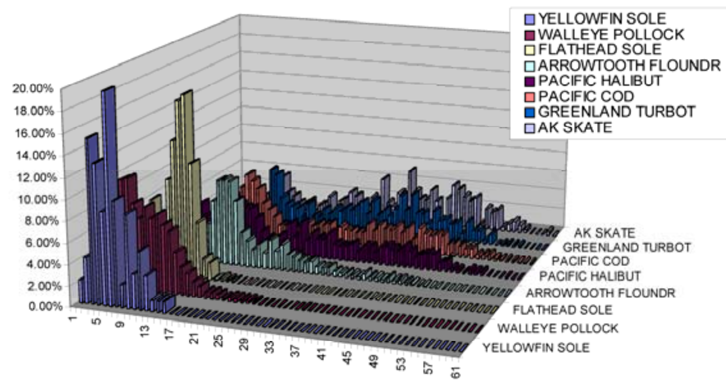

Figure 6.21. Length frequency of pollock found in stomachs, from groundfish food habits collected from 1984-2006 on AFSC summer trawl surveys in the eastern Berng Sea. Predators are sorted by median prey length of pollock in their stomachs. All lengths of predators are combined.

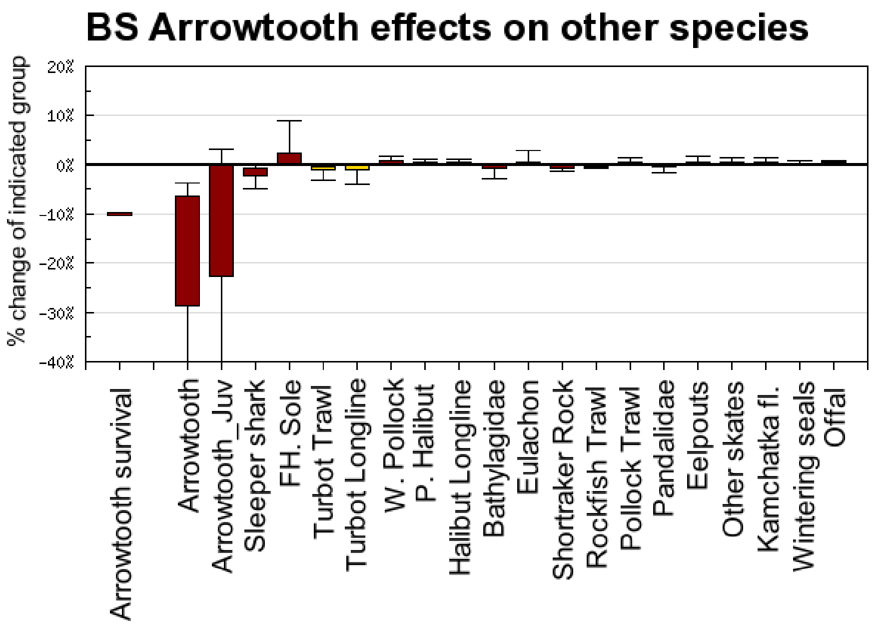

Figure 6.22. Effect of changing arrowtooth > 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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

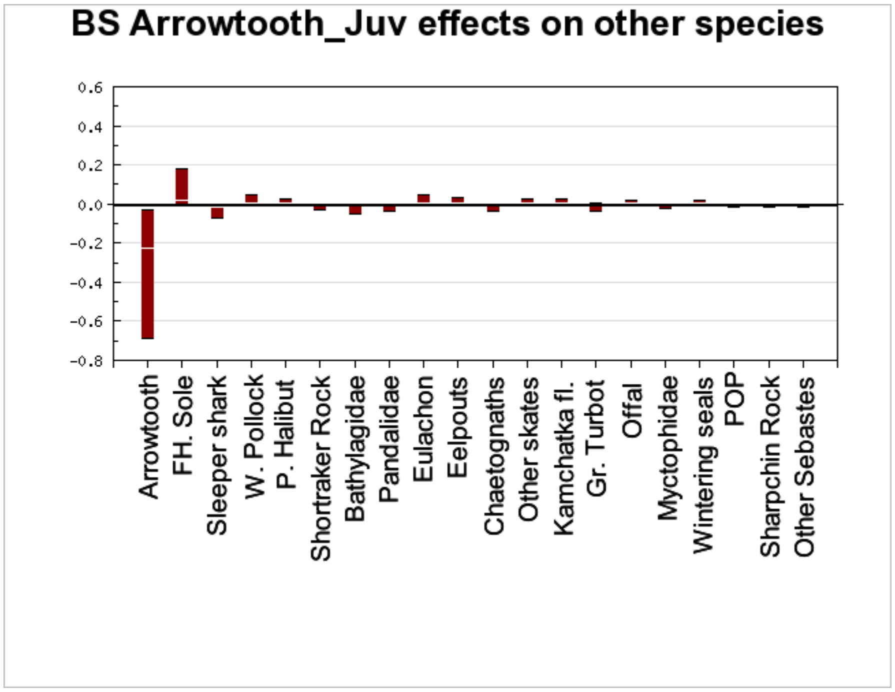

Figure 6.23. Effect of changing arrowtooth < 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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

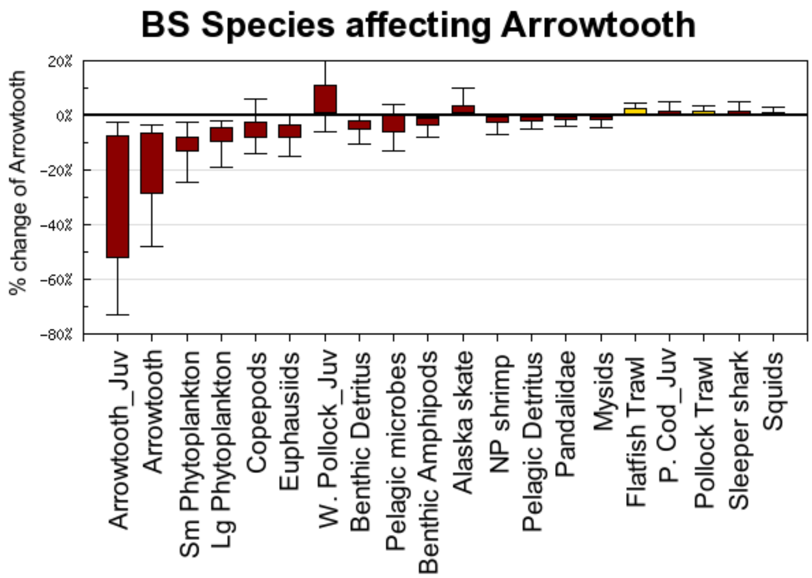

Figure 6.24. Effect of reducing fisheries catch (yellow) and other species survival (dark red) on arrowtooth > 20 cm biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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