Chapter 6. Arrowtooth Flounder

By

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Executive Summary

The following changes have been made to this assessment relative to the November 2008 SAFE.

Changes to the input data

1) 2009 shelf survey size composition.

2) 2009 shelf survey biomass point-estimates and standard errors.

3) Estimate of catch and discards through 3, October 2009.

4) Estimate of retained and discarded portion of the 2008 catch.

Assessment results

1) The projected age 1+ total biomass for 2010 is 1,120,160 t.

2) The projected female spawning biomass for 2010 is 807,100 t.

3) The recommended 2010 ABC is 156,300 t based on an $F_{0.40}$ (0.236) harvest level.

4) The 2010 overfishing level is 190,800 t based on a $F_{0.35}$ (0.295) harvest level.

Assessment Year	2008	2009	
Projections Year	2009	2010	2011
M (male, female)	0.34, 0.2	0.35, 0.2	0.35, 0.2
Tier	3a	3a	3a
B_{MSY} (t) ($B_{35\%}$)	255,300 t	259,700	--
$B_{40\%}$ (t)	292,200 t	296,800	--
Female spawning biomass (t)	802,130	807,100	807,200
Total Biomass (t)	1,136,600	1,120,160	1,103,100
Tier 3a $F_{overfishing}$ ($F_{35\%}$)	0.29	0.295	0.295
Tier 3a F_{ABC} ($F_{40\%}$)	0.235	0.236	0.236
Tier 3a ABC	156,300	156,300	157,100
Tier 3a overfishing	190,350	190,800	191,300

No SSC comments regarding arrowtooth flounder this time

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 are not always distinguished in the commercial catches. Until about 1992, these species were also not consistently separated in trawl survey catches (Fig. 6.1) and are combined in this assessment until their identification in commercial longline catches can be made with certainty, and to maintain the comparability of the trawl survey time series. 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 individual species due to considerable differences in 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. Total catch reported through 3 September, 2009 is 26,647 t (well below the 2009 ABC of 156,000 t). NMFS Regional Office reports indicate that bottom trawling accounted for 88% of the 2009 catch (6% by pelagic trawl and 6% 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, arrowtooth flounder continue to be captured primarily in pursuit of other high 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 1985-2008 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 73%. Largest discard amounts still occur in the Pacific cod fishery and the various flatfish fisheries. An increasing trend of retention is expected in the near future due to the recent change in fishing practices.

Data

The data used in this assessment include estimates of total catch, trawl survey biomass estimates and standard error from shelf and slope 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 3, 2009 (Table 6.1) and fishery length-frequency data from 1978-91 and 2000-2005 are used in the assessment.

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 2009 CPUE is in contrast to this trend and is about 78% of the 2008 value. The CPUE in the Aleutian Islands has also increased to the highest levels yet observed in the 2006 survey.

Absolute Abundance from Trawl Surveys

Biomass estimates (t) for arrowtooth and Kamchatka flounder from the standard survey area in the eastern Bering Sea and Aleutian Islands region are shown in Table 6.3 (combined) and Table 6.4 (by species). Table 6.5 lists the total research catch of these species. Although the standard sampling trawl changed in 1982 to a more efficient 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 is lower at 453,559 t.

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 2009 point estimate are 370,742 – 536,377 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 poly 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 increase in estimated biomass in the 2008 survey to 96,248 indicates that the arrowtooth-Kamchatka complex has increased throughout its range since 2004.

The combined arrowtooth/Kamchatka flounder abundance estimated from the 2006 Aleutian Islands trawl survey is 229,205 t, the highest estimate observed in the Aleutian Islands since surveys began in 1980. Results from trawl surveys in the three areas indicate that approximately 15-20% of the arrowtooth-Kamchatka flounder biomass is located in the Aleutian Islands in any year. Until last year the stock assessment model did not consider the Aleutian Islands portion of the biomass to model stock abundance and was therefore a conservative estimate of the stock size. In this assessment the 10 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.

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
34	14	2	53	103

The recruitment parameters are comprised of 21 initial ages in 1976 and 32 subsequent age 1 recruitment estimates from 1976-2007. Recruitment in 2007 was set at the average from 1976-2006. The difference in the number of parameters estimated in this assessment compared to last year can be accounted for by an additional year (2008) 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 value 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. The base model was configured with the assumption that the Bering Sea shelf area comprises 72% of the population, calculated from the average proportion of shelf, slope and Aleutian Islands biomass. 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 72% shelf, 9% slope and 18% 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 and slope 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 Monro 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 $\alpha = -0.42$ 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 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

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 1977-2009 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 2009 value of 1.09 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, 799,000 t in 2009, 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. 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 and 2008 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 - 2003 year classes which 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.

Otoliths for aging arrowtooth flounder have been routinely collected during AFSC surveys in the EBS, but they have been infrequently aged because of higher priority for aging other species. However, an examination of length-frequency data shows that modes formed by age groups 1 to 3 are reasonably well separated so that fish less than 25 cm can be used as a measure of recruitment for age 2 fish; some age 1 fish are also included, but they are poorly recruited to the survey trawls. Population estimates (in millions) for fish less than 25 cm are shown in Table 6.12

Over this 24 year period, population estimates for this size group have averaged 126 million. Above average recruitment been observed in surveys conducted in 1983, 1986, 1988, 1989, 2001 and 2003. Since the estimates primarily represent age 2 fish, the year-classes producing the strong recruitment are 1981, 1984, 1986, 1987, 1992, 1999 and 2001-2003. The stock assessment model estimates of age 2 recruitment are based on these data and show the same trends in recruitment (Fig. 6.11).

The posterior distribution of the female spawning biomass estimate for 2009 (Fig. 6.12), calculated from mcmc integration of the preferred model run indicates the spawning stock is at a high level with only a small dispersal around the estimate. 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 2010 total biomass from the stock assessment projection model is 1,120,160 t and the female spawning biomass is estimated at 807,100 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 1977-2004 are used to calculate the average equilibrium recruitment. Using the time-series of age 1 recruitment from 1978-2004 from the stock assessment model results in an estimate of $B_{0.40}$ = 296,800 t. The stock assessment model estimates the 2010 level of female spawning biomass at 807,100 t (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and B>$B_{0.40}$ (807,100 > 296,800), arrowtooth flounder reference fishing mortality is defined in tier 3a. For the 2010 harvest: $F_{ABC} = F_{0.40} = 0.236$ and $F_{overfishing} = F_{0.35} = 0.295$ (full selection F values).

Acceptable biological catch is estimated for 2010 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2010 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 2010 ABC of 156,280 t.**

The overfishing level is estimated for 2010 by applying the $F_{35\%}$ fishing mortality rate and age-specific fishery selectivities to the projected 2010 estimate of age-specific total biomass. **This results in a 2010 OFL of 190,800 t.**

The potential yield of arrowtooth flounder in 2010, at various levels of fishing mortality (full selection), are as follows:

F level	Exploitation rate	Potential yield
$F_{overfishing}$	0.295	190,800 t
$F_{0.40}$	**0.236**	**156,280 t**

This estimate of 2010 ABC is for the combined harvest of arrowtooth flounder and Kamchatka flounder. If future catches were separated by species, then this complex could be managed with Kamchatka flounder in the Tier 5 management category. Using 0.2 as a value for M (although it is unknown if sexual specific natural mortality exists for Kamchatka flounder) and the 2009 shelf survey biomass point estimate of 47,252 t (Table 6.4) would give an overfishing limit of 9,450 t. It is unlikely that the current level of catch is sufficient to warrant a conservation concern for this complex.

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 2009 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2010 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2009. 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 2010, 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 2010 recommended in the assessment to the *max* F_{ABC} for 2010. (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 2005-2009 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 2010, it does not provide the best estimate of OFL for 2011, because the mean 2011 catch under Scenario 6 is predicated on the 2010 catch being equal to the 2010 OFL, whereas the actual 2010 catch will likely be less than the 2010 ABC. Therefore, the projection model was re-run with the 2010 and 2011 catch fixed equal to the 2009 catch to calculate the 2011 ABC and OFL.

Year	Catch	ABC	OFL
2010	26,647	156,300	190,800
2011	26,647	157,100	191,300

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). However, as opposed to the Gulf of Alaska, 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, being 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 three 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 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. 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 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 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 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 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 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 (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 to mid 1990s; the increase of arrowtooth 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 resource.

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 near shore areas. This has not been reported for Bering Sea arrowtooth flounder due to a lack of juvenile sampling and collections in near shore areas, but is thought to occur. As late juveniles they are found in stomachs of pollock and Pacific cod, mostly on 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	2
Salmon	<1

2) Relative to the predator needs in space and time, any harvesting of arrowtooth flounder is not very selective for 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 catch (t) of arrowtooth flounder in the eastern Bering Sea and Aleutian Islands region[a], 1970-2009. Catches since 1990 are not reported by area.

	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									11,670
2008									21,860
2009**									26,647

[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 3 October, 2009 (NMFS regional office).

Table 6.2 Estimates of retained and discarded arrowtooth flounder catch, 1985-2008.

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

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

Table 6.3 Estimated combined arrowtooth flounder and Kamchatka flounder biomass from trawl surveys conducted on the Eastern Bering Sea shelf, slope and the Aleutian Islands.

Year	shelf survey	slope survey	shelf + slope	Aleutian Islands
1975	28,000	--	--	--
1979	35,000	36,700	71,700	--
1980	47,800	--	--	17,016
1981	49,500	34,900	84,400	--
1982	67,400	24,700	92,100	--
1983	149,300	--	--	25,499
1984	182,900	--	--	--
1985	159,900	74,400	234,300	--
1986	232,100	--	--	111,040
1987	290,600	--	--	--
1988	306,500	30,600*	337,100	--
1989	410,700	--	--	--
1990	459,200	--	--	--
1991	329,200	28,000*	357,200	38,152
1992	414,000	--	--	--
1993	543,600	--	--	--
1994	570,600	--	--	107,347
1995	480,800	--	--	--
1996	556,400	--	--	--
1997	478,600	--	--	111,557
1998	344,900	--	--	--
1999	243,800	--		
2000	340,400	--	--	95,563
2001	408,800	--	--	--
2002	355,100	61,200	416,300	137,785
2003	553,900	--	--	--
2004	547,400	68,500	615,900	134,217
2005	757,685			
2006	670,131			229,205
2007	546,483			
2008	583,918	96,248	680,166	
2009	453,559			

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.

Table 6.4—Estimated shelf survey biomass (t) for arrowtooth flounder and Kamchatka flounder, by species 1982-2009.

	Shelf survey biomass estimates (t)	
year	**Arrowtooth flounder**	**Kamchatka flounder**
1982	69,690	0
1983	110,643	17,299
1984	160,396	20,695
1985	163,637	31
1986	229,865	0
1987	296,964	40
1988	294,771	13,723
1989	355,347	17,108
1990	402,192	32,799
1991	292,066	37,152
1992	370,287	50,081
1993	500,385	38,376
1994	514,336	56,268
1995	452,449	28,393
1996	532,159	24,196
1997	460,348	18,282
1998	344,890	23,474
1999	244,141	18,974
2000	318,814	21,551
2001	378,071	31,120
2002	331,191	25,213
2003	515,363	27,531
2004	518,788	29,663
2005	709,047	46,084
2006	608,487	61,644
2007	481,292	65,191
2008	529,951	53,967
2009	406,307	47,252

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

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

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

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

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

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

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

Table 6.7--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	0.151	0.076
1977	0.094	0.046
1978	0.079	0.040
1979	0.106	0.054
1980	0.132	0.067
1981	0.122	0.061
1982	0.079	0.040
1983	0.091	0.045
1984	0.058	0.029
1985	0.042	0.021
1986	0.037	0.019
1987	0.022	0.012
1988	0.086	0.044
1989	0.030	0.015
1990	0.050	0.024
1991	0.078	0.038
1992	0.034	0.017
1993	0.027	0.015
1994	0.037	0.022
1995	0.022	0.014
1996	0.033	0.021
1997	0.022	0.014
1998	0.034	0.021
1999	0.023	0.014
2000	0.028	0.017
2001	0.030	0.017
2002	0.024	0.014
2003	0.025	0.014
2004	0.034	0.019
2005	0.024	0.014
2006	0.022	0.013
2007	0.019	0.011
2008	0.033	0.020
2009	0.039	0.025

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	0.12	0.00	0.03	0.03	0.06
2	0.00	0.01	0.15	0.18	0.00	0.05	0.05	0.10
3	0.01	0.03	0.42	0.28	0.00	0.07	0.11	0.16
4	0.04	0.06	0.82	0.42	0.00	0.11	0.21	0.23
5	0.11	0.12	1.00	0.59	0.05	0.18	0.36	0.33
6	0.28	0.23	0.95	0.76	0.88	0.26	0.55	0.45
7	0.55	0.40	0.81	0.89	1.00	0.37	0.72	0.58
8	0.79	0.60	0.68	0.93	1.00	0.49	0.85	0.69
9	0.92	0.77	0.55	0.86	1.00	0.61	0.92	0.79
10	0.97	0.88	0.45	0.71	1.00	0.72	0.96	0.86
11	0.99	0.94	0.36	0.53	1.00	0.81	0.98	0.91
12	1.00	0.97	0.29	0.37	1.00	0.88	0.99	0.94
13	1.00	0.99	0.23	0.24	1.00	0.92	1.00	0.96
14	1.00	0.99	0.18	0.16	1.00	0.95	1.00	0.98
15	1.00	1.00	0.14	0.10	1.00	0.97	1.00	0.99
16	1.00	1.00	0.11	0.06	1.00	0.98	1.00	0.99
17	1.00	1.00	0.09	0.04	1.00	0.99	1.00	1.00
18	1.00	1.00	0.07	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.

	2008 Assessment		2009 Assessment	
	age 1+ Total biomass	Female Spawning biomass	age 1+ Total biomass	Female Spawning biomass
1976	251,434	158,781	251,268	159,544
1977	248,550	157,687	248,748	158,926
1978	255,523	167,314	256,061	169,154
1979	265,676	174,482	266,515	176,758
1980	271,974	173,514	273,050	176,083
1981	278,414	173,256	279,707	176,127
1982	287,306	177,675	288,716	180,832
1983	306,042	187,094	307,502	190,490
1984	324,760	194,330	326,251	197,861
1985	347,781	213,962	349,257	217,730
1986	374,697	240,468	376,150	244,545
1987	409,525	256,850	411,109	261,083
1988	449,340	276,549	451,048	280,966
1989	482,729	289,764	484,671	294,341
1990	531,932	312,459	534,051	317,283
1991	573,663	343,049	575,906	348,376
1992	600,869	383,001	603,188	389,137
1993	632,893	426,976	635,217	433,892
1994	659,131	461,060	661,418	468,567
1995	673,945	478,406	676,161	486,199
1996	692,466	494,967	694,556	502,919
1997	704,798	501,634	706,650	509,563
1998	726,368	507,398	727,833	515,192
1999	748,908	509,864	749,731	517,392
2000	780,786	524,969	780,623	532,252
2001	817,676	543,316	816,036	550,238
2002	856,909	562,611	853,148	569,025
2003	904,521	596,293	897,991	602,012
2004	951,786	635,103	942,279	639,742
2005	993,348	663,351	980,929	666,347
2006	1,035,350	697,773	1,021,360	698,350
2007	1,067,480	742,608	1,053,780	740,110
2008	1,090,100	788,485	1,079,470	783,938
2009			1,086,210	799,107

Table 6.11 Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2009.

females	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	106,852	32,614	84,459	73,003	68,127	26,461	14,857	10,311	7,918	6,442
1977	138,120	87,467	26,686	69,021	59,430	54,863	20,772	11,198	7,492	5,642
1978	109,730	113,070	71,585	21,824	56,309	48,157	43,753	16,151	8,510	5,624
1979	113,096	89,830	92,545	58,552	17,814	45,703	38,565	34,298	12,419	6,476
1980	113,585	92,583	73,516	75,671	47,747	14,417	36,331	29,796	25,826	9,224
1981	262,877	92,980	75,761	60,092	61,646	38,531	11,377	27,670	21,977	18,725
1982	101,845	215,192	76,089	61,934	48,972	49,798	30,487	8,710	20,562	16,074
1983	82,907	83,375	176,129	62,235	50,555	39,747	39,876	23,894	6,696	15,644
1984	243,344	67,871	68,237	144,040	50,778	40,978	31,721	31,050	18,196	5,039
1985	168,720	199,219	55,555	55,828	117,672	41,310	33,011	25,158	24,281	14,123
1986	140,906	138,129	163,079	45,461	45,635	95,897	33,427	26,410	19,922	19,122
1987	462,873	115,359	113,074	133,457	37,169	37,212	77,708	26,818	20,999	15,765
1988	251,758	378,957	94,439	92,552	109,173	30,356	30,276	62,844	21,570	16,841
1989	255,086	206,100	310,158	77,238	75,528	88,538	24,260	23,639	48,045	16,306
1990	167,120	208,839	168,720	253,842	63,166	61,635	71,887	19,540	18,902	38,267
1991	172,151	136,818	170,949	138,051	207,437	51,433	49,764	57,266	15,378	14,779
1992	198,435	140,932	111,982	139,826	112,692	168,379	41,198	39,026	44,061	11,712
1993	150,731	162,458	115,369	91,645	114,333	91,921	136,555	33,107	31,104	34,961
1994	180,389	123,404	132,995	94,425	74,956	93,330	74,693	110,155	26,531	24,838
1995	233,338	147,683	101,020	108,837	77,200	61,118	75,622	59,917	87,567	20,989
1996	305,365	191,036	120,902	82,685	89,034	63,053	49,731	61,166	48,203	70,244
1997	243,919	250,001	156,386	98,945	67,612	72,628	51,144	39,978	48,773	38,269
1998	308,663	199,698	204,665	128,003	80,941	55,220	59,093	41,363	32,157	39,118
1999	430,087	252,701	163,477	167,496	104,667	66,025	44,789	47,499	32,977	25,525
2000	274,213	352,116	206,875	133,806	137,014	85,476	53,708	36,207	38,181	26,428
2001	320,029	224,498	288,256	169,317	109,435	111,832	69,435	43,299	28,991	30,460
2002	358,060	262,008	183,782	235,917	138,469	89,305	90,802	55,927	34,624	23,092
2003	468,293	293,146	214,494	150,424	192,978	113,071	72,630	73,372	44,929	27,729
2004	293,639	383,394	239,983	175,557	123,038	157,556	91,919	58,639	58,873	35,931
2005	202,571	240,401	313,855	196,400	143,552	100,364	127,792	73,882	46,749	46,731
2006	344,793	165,846	196,805	256,885	160,651	117,216	81,614	103,236	59,333	37,424
2007	274,399	282,284	135,771	161,086	210,142	131,207	95,370	66,003	83,037	47,584
2008	189,507	224,654	231,098	111,135	131,793	171,699	106,867	77,291	53,250	66,830
2009	252,000	155,149	183,907	189,130	90,876	107,511	139,280	85,918	61,640	42,284

Table 6.11 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2009.

	females				numbers at age (1,000s)						
	11	12	13	14	15	16	17	18	19	20	21
1976	5,426	4,674	4,076	3,581	3,165	2,806	2,482	2,203	1,936	1,696	3,812
1977	4,555	3,826	3,293	2,871	2,522	2,229	1,976	1,748	1,551	1,364	3,879
1978	4,215	3,397	2,852	2,455	2,140	1,880	1,661	1,473	1,303	1,156	3,907
1979	4,263	3,190	2,570	2,158	1,857	1,619	1,422	1,257	1,114	985	3,830
1980	4,784	3,144	2,351	1,894	1,590	1,368	1,193	1,048	926	821	3,548
1981	6,643	3,438	2,257	1,688	1,359	1,141	982	856	752	664	3,136
1982	13,610	4,818	2,492	1,636	1,223	985	827	711	620	545	2,753
1983	12,180	10,299	3,644	1,884	1,237	925	745	625	538	469	2,494
1984	11,718	9,108	7,698	2,723	1,408	924	691	557	467	402	2,214
1985	3,899	9,059	7,039	5,948	2,104	1,088	714	534	430	361	2,022
1986	11,098	3,062	7,112	5,526	4,670	1,652	854	561	419	338	1,870
1987	15,103	8,760	2,416	5,612	4,360	3,685	1,304	674	442	331	1,742
1988	12,628	12,094	7,014	1,935	4,493	3,491	2,950	1,044	540	354	1,660
1989	12,675	9,490	9,084	5,267	1,453	3,374	2,622	2,215	784	405	1,512
1990	12,968	10,075	7,542	7,219	4,186	1,154	2,681	2,083	1,760	623	1,524
1991	29,845	10,105	7,848	5,875	5,623	3,260	899	2,088	1,623	1,371	1,672
1992	11,211	22,609	7,651	5,942	4,448	4,257	2,468	681	1,581	1,228	2,304
1993	9,277	8,875	17,894	6,056	4,703	3,520	3,369	1,953	539	1,251	2,795
1994	27,881	7,394	7,073	14,261	4,826	3,748	2,805	2,685	1,557	429	3,225
1995	19,613	22,000	5,834	5,580	11,250	3,807	2,956	2,213	2,118	1,228	2,883
1996	16,818	15,709	17,619	4,672	4,468	9,009	3,049	2,367	1,772	1,696	3,292
1997	55,674	13,322	12,441	13,953	3,700	3,538	7,134	2,414	1,875	1,403	3,950
1998	30,658	44,584	10,667	9,961	11,172	2,962	2,833	5,712	1,933	1,501	4,286
1999	30,998	24,280	35,303	8,446	7,887	8,845	2,345	2,243	4,522	1,530	4,582
2000	20,432	24,803	19,425	28,242	6,756	6,309	7,076	1,876	1,794	3,618	4,890
2001	21,054	16,269	19,746	15,464	22,483	5,378	5,023	5,633	1,494	1,429	6,773
2002	24,226	16,736	12,931	15,693	12,290	17,868	4,274	3,992	4,477	1,187	6,518
2003	18,471	19,370	13,380	10,337	12,545	9,824	14,283	3,417	3,191	3,579	6,159
2004	22,147	14,746	15,461	10,679	8,251	10,013	7,841	11,400	2,727	2,547	7,772
2005	28,472	17,539	11,676	12,241	8,455	6,532	7,927	6,208	9,026	2,159	8,170
2006	37,363	22,754	14,015	9,329	9,781	6,756	5,219	6,334	4,961	7,212	8,253
2007	29,979	29,919	18,219	11,221	7,469	7,831	5,409	4,179	5,071	3,971	12,382
2008	38,261	24,098	24,046	14,642	9,018	6,003	6,294	4,347	3,358	4,076	13,143
2009	52,978	30,313	19,088	19,047	11,598	7,143	4,755	4,985	3,443	2,660	13,638

Table 6.11 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2009.

males	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	106,852	28,071	62,569	46,548	37,389	12,500	6,040	3,608	2,385	1,670
1977	138,120	75,235	19,745	43,915	32,520	25,878	8,506	4,007	2,323	1,497
1978	109,730	97,281	52,957	13,880	30,780	22,660	17,843	5,772	2,669	1,523
1979	113,096	77,292	68,487	37,240	9,736	21,486	15,678	12,180	3,879	1,770
1980	113,585	79,651	54,397	48,127	26,084	6,775	14,775	10,589	8,057	2,520
1981	262,877	79,984	56,040	38,198	33,659	18,094	4,631	9,875	6,896	5,131
1982	101,845	185,122	56,280	39,362	26,730	23,375	12,394	3,107	6,468	4,424
1983	82,907	71,737	130,327	39,576	27,612	18,658	16,171	8,460	2,088	4,288
1984	243,344	58,394	50,496	91,617	27,743	19,246	12,873	10,985	5,644	1,371
1985	168,720	171,427	41,121	35,529	64,347	19,415	13,382	8,863	7,477	3,804
1986	140,906	118,868	120,741	28,945	24,977	45,117	13,549	9,272	6,090	5,101
1987	462,873	99,275	83,727	85,001	20,354	17,523	31,523	9,407	6,391	4,171
1988	251,758	326,141	69,939	58,966	59,822	14,305	12,285	22,015	6,541	4,427
1989	255,086	177,327	229,586	49,171	41,347	41,723	9,880	8,361	14,730	4,313
1990	167,120	179,727	124,915	161,658	34,591	29,033	29,199	6,880	5,788	10,145
1991	172,151	117,735	126,574	87,909	113,593	24,231	20,224	20,168	4,705	3,925
1992	198,435	121,261	82,888	89,009	61,670	79,302	16,768	13,810	13,560	3,122
1993	150,731	139,809	85,416	58,357	62,602	43,282	55,445	11,656	9,536	9,310
1994	180,389	106,203	98,489	60,148	41,060	43,973	30,310	38,649	8,082	6,582
1995	233,338	127,092	74,806	69,336	42,295	28,806	30,721	21,042	26,636	5,535
1996	305,365	164,410	89,536	52,684	48,798	29,726	20,195	21,457	14,633	18,453
1997	243,919	215,147	115,811	63,039	37,055	34,251	20,786	14,042	14,821	10,051
1998	308,663	171,866	151,571	81,562	44,366	26,042	24,011	14,517	9,764	10,267
1999	430,087	217,471	121,062	106,715	57,365	31,139	18,210	16,694	10,027	6,705
2000	274,213	303,039	153,206	85,259	75,101	40,313	21,826	12,713	11,602	6,941
2001	320,029	193,204	213,475	107,882	59,984	52,745	28,224	15,208	8,809	8,001
2002	358,060	225,484	136,100	150,314	75,893	42,120	36,913	19,652	10,527	6,067
2003	468,293	252,287	158,850	95,847	105,779	53,329	29,517	25,764	13,652	7,283
2004	293,639	329,955	177,729	111,864	67,443	74,315	37,359	20,589	17,881	9,434
2005	202,571	206,886	232,420	125,131	78,677	47,336	51,963	25,974	14,220	12,279
2006	344,793	142,730	145,747	163,677	88,055	55,282	33,170	36,261	18,038	9,835
2007	274,399	242,941	100,553	102,645	115,193	61,886	38,755	23,165	25,212	12,495
2008	189,507	193,346	171,159	70,824	72,256	80,996	43,423	27,107	16,144	17,515
2009	252,000	133,519	136,194	120,507	49,814	50,717	56,640	30,195	18,727	11,090

Table 6.11 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2009.

males				numbers at age (1,000s)							
	11	12	13	14	15	16	17	18	19	20	21
1976	1,211	898	674	509	388	296	225	172	130	98	116
1977	1,031	740	546	409	309	235	179	136	104	79	130
1978	971	665	476	351	263	198	151	115	88	67	134
1979	1,001	635	434	310	229	171	129	98	75	57	131
1980	1,136	639	404	275	197	145	108	82	62	47	119
1981	1,582	707	396	250	170	122	90	67	51	38	103
1982	3,247	993	443	247	156	106	76	56	42	32	88
1983	2,907	2,123	648	288	161	102	69	49	36	27	78
1984	2,788	1,879	1,369	417	186	104	65	44	32	23	68
1985	918	1,860	1,252	911	278	123	69	43	30	21	61
1986	2,583	622	1,258	846	616	188	83	47	29	20	55
1987	3,480	1,758	423	855	575	418	127	57	32	20	51
1988	2,882	2,401	1,212	291	589	396	288	88	39	22	49
1989	2,891	1,872	1,555	784	188	381	256	186	57	25	46
1990	2,960	1,981	1,281	1,064	537	129	261	175	127	39	49
1991	6,842	1,990	1,330	860	714	360	86	175	117	85	59
1992	2,581	4,478	1,300	867	560	465	234	56	114	77	94
1993	2,135	1,762	3,053	886	591	382	317	160	38	78	116
1994	6,406	1,467	1,209	2,095	608	405	262	217	110	26	133
1995	4,489	4,359	997	821	1,423	413	275	178	148	74	108
1996	3,825	3,098	3,006	687	566	981	284	190	123	102	126
1997	12,627	2,612	2,113	2,050	469	386	668	194	129	84	155
1998	6,945	8,713	1,801	1,457	1,413	323	266	461	134	89	164
1999	7,024	4,742	5,943	1,228	993	963	220	181	314	91	173
2000	4,630	4,843	3,267	4,093	846	684	663	152	125	216	182
2001	4,772	3,177	3,321	2,239	2,805	579	468	454	104	86	273
2002	5,492	3,270	2,175	2,272	1,532	1,919	396	320	311	71	245
2003	4,187	3,784	2,251	1,497	1,564	1,054	1,320	273	220	214	217
2004	5,019	2,880	2,601	1,547	1,029	1,074	724	907	187	151	296
2005	6,454	3,427	1,964	1,773	1,054	701	732	493	618	128	305
2006	8,469	4,445	2,358	1,351	1,220	725	482	503	339	425	298
2007	6,795	5,844	3,065	1,625	931	841	500	332	347	234	498
2008	8,662	4,705	4,044	2,121	1,124	644	581	346	230	240	506
2009	11,988	5,916	3,211	2,758	1,446	767	439	396	236	157	509

Table 6.12 Estimated age 2 recruitment of arrowtooth flounder (thousands of fish) from the 2007 and 2008 stock assessments and also from estimates of fish less than 25 cm in the annual Bering Sea shelf trawl survey. Average from 2009 = 347,002.

Year class	2009 Assessment	2008 Assessment	shelf survey fish<25 cm
1974	60,686	59,884	
1975	162,702	160,107	
1976	210,351	207,800	
1977	167,122	165,452	
1978	172,234	170,973	
1979	172,965	171,913	
1980	400,314	396,963	86,100
1981	155,112	153,874	290,200
1982	126,265	125,470	57,900
1983	370,646	367,373	62,400
1984	256,997	254,766	150,300
1985	214,634	213,063	94,300
1986	705,098	695,504	200,600
1987	383,427	379,372	273,800
1988	388,566	384,142	105,200
1989	254,553	252,091	71,700
1990	262,193	260,564	79,400
1991	302,267	300,195	96,800
1992	229,607	228,495	126,600
1993	274,775	274,075	75,100
1994	355,446	354,391	55,600
1995	465,148	464,834	108,800
1996	371,564	372,549	93,600
1997	470,172	471,692	92,100
1998	655,155	661,181	126,300
1999	417,702	425,325	164,300
2000	487,492	500,643	108,800
2001	545,433	567,634	253,400
2002	713,349	734,155	406,700
2003	447,287	436,106	407,800
2004	308,576	296,806	335,800
2005	525,225		495,500
2006	418,000		217,200

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
2009	805.972	26.647	0.04
2010	795.816	156.638	0.24
2011	682.307	133.095	0.24
2012	587.806	113.820	0.24
2013	509.232	98.580	0.24
2014	450.114	86.258	0.24
2015	406.229	76.722	0.24
2016	374.473	69.835	0.24
2017	351.870	64.922	0.24
2018	335.765	61.084	0.23
2019	324.503	58.261	0.23
2020	316.995	56.360	0.23
2021	312.195	55.123	0.23
2022	309.541	54.363	0.23

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2009	805.972	26.647	0.04
2010	802.987	78.319	0.11
2011	759.003	69.176	0.10
2012	715.871	65.240	0.10
2013	670.465	61.424	0.10
2014	630.769	57.628	0.10
2015	596.147	54.095	0.10
2016	566.735	51.090	0.10
2017	542.262	48.617	0.10
2018	521.982	46.616	0.10
2019	505.231	45.006	0.10
2020	491.694	43.704	0.10
2021	481.071	42.669	0.10
2022	473.166	41.869	0.10

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2009	805.972	26.647	0.04
2010	807.102	29.837	0.04
2011	807.201	19.901	0.03
2012	805.384	19.933	0.03
2013	793.969	19.809	0.03
2014	781.219	19.504	0.03
2015	766.933	19.087	0.03
2016	752.041	18.652	0.03
2017	737.308	18.232	0.03
2018	723.092	17.842	0.03
2019	709.671	17.488	0.03
2020	697.427	17.165	0.03
2021	686.789	16.882	0.03
2022	678.035	16.640	0.03

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2009	805.972	26.65	0.04
2010	809.525	0	0
2011	835.985	0	0
2012	850.386	0	0
2013	853.548	0	0
2014	853.509	0	0
2015	849.902	0	0
2016	843.646	0	0
2017	835.656	0	0
2018	826.549	0	0
2019	816.873	0	0
2020	807.216	0	0
2021	798.308	0	0
2022	790.628	0	0

Table 6.13 (continued).

Scenario 6

Determination of whether arrowtooth flounder are currently overfished

B35=259,700

Year	Female spawning biomass	catch	F
2009	805.972	26.647	0.037767
2010	792.457	190.785	0.295099
2011	649.414	154.492	0.295099
2012	538.669	126.766	0.295099
2013	452.664	106.21	0.295099
2014	391.57	90.6092	0.295099
2015	348.897	79.2697	0.295099
2016	319.943	70.9881	0.292092
2017	301.207	64.2229	0.282003
2018	290.097	60.1531	0.274563
2019	283.511	57.8685	0.270145
2020	279.753	56.6017	0.267802
2021	277.76	55.8986	0.266575
2022	277.124	55.575	0.266096

Scenario 7

Determination of whether arrowtooth flounder are approaching an overfished condition

B35=259,700

Year	Female spawning biomass	catch	F
2009	805.972	26.647	0.037767
2010	795.816	156.638	0.236491
2011	682.307	133.095	0.236491
2012	585.383	138.666	0.295099
2013	485.382	114.626	0.295099
2014	413.996	96.4068	0.295099
2015	363.983	83.1715	0.295099
2016	329.891	73.9443	0.294034
2017	307.343	66.3118	0.284873
2018	293.585	61.3824	0.276561
2019	285.382	58.5252	0.271253
2020	280.701	56.9328	0.268377
2021	278.202	56.0495	0.266839
2022	277.305	55.6332	0.266196

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

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

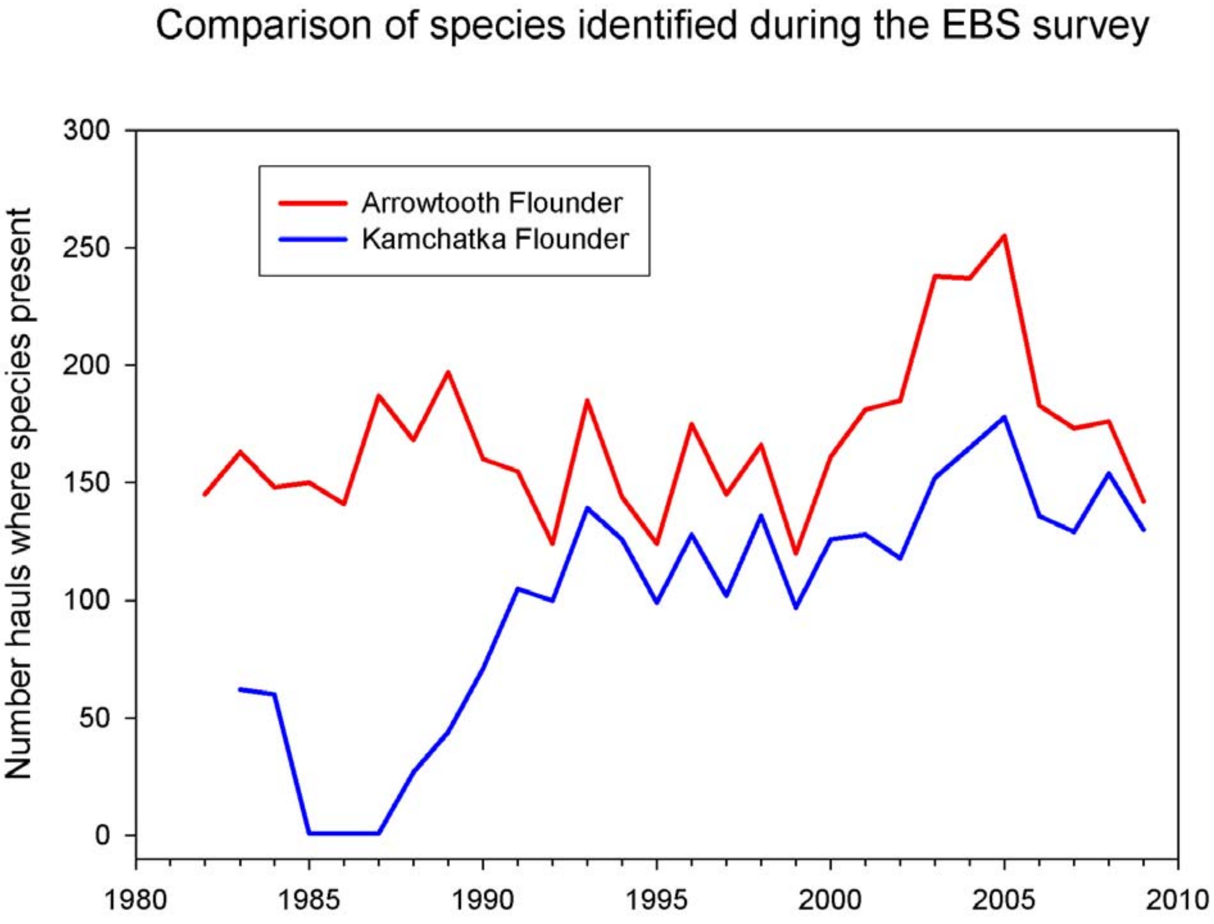

Figure 6.1—Number of hauls where arrowtooth flounder and Kamchatka flounder were identified during the annual Bering Sea shelf surveys, 1982-2009.

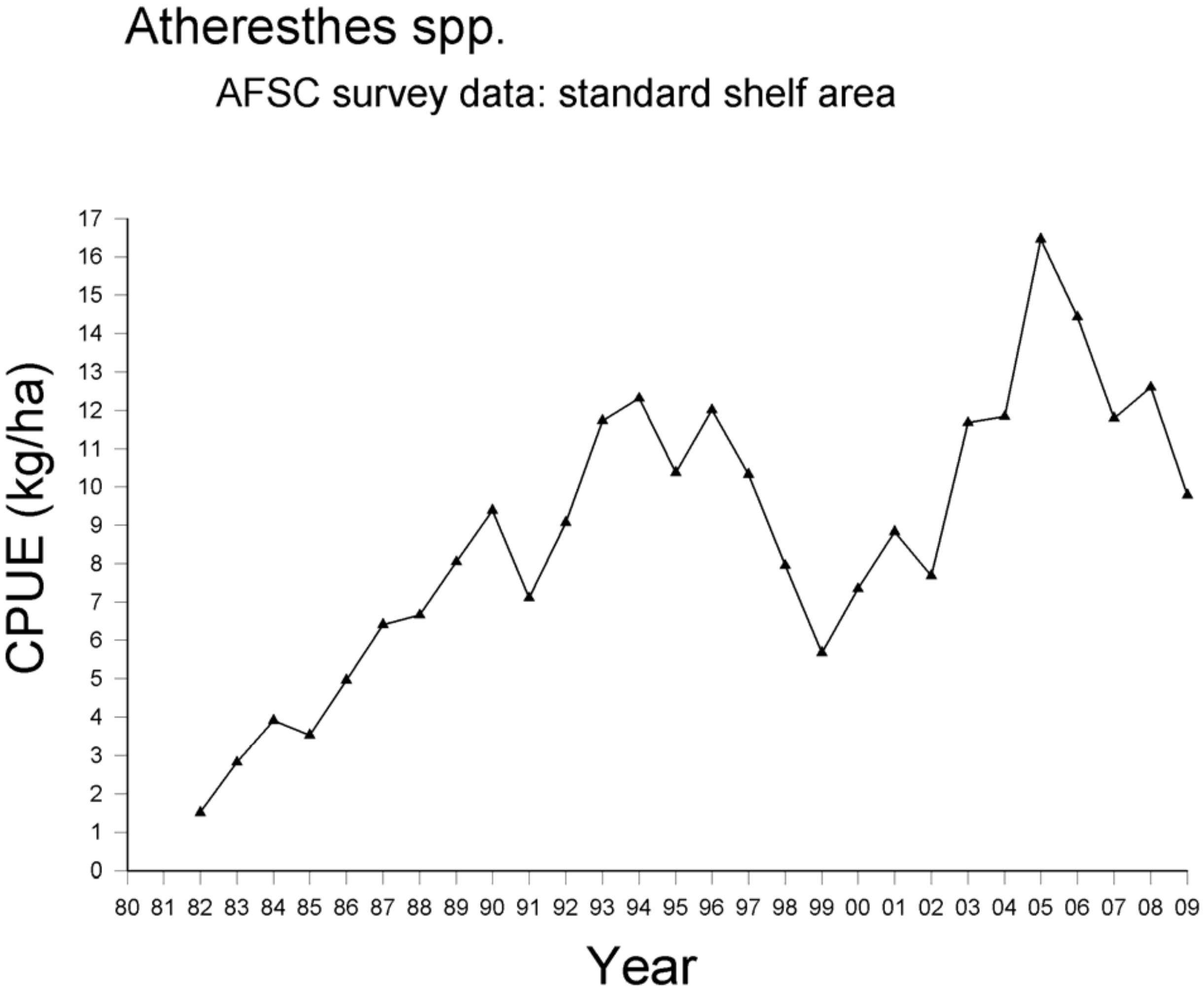

Figure 6.2 Atheresthes species combined CPUE (kg/ha) from the standard shelf survey area.

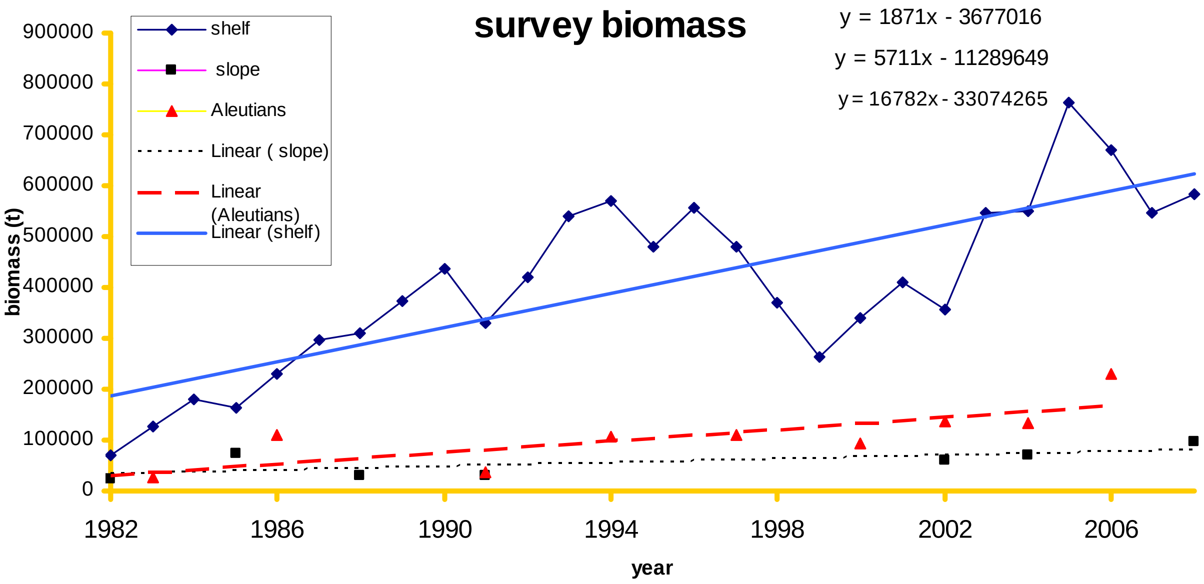

Figure 6.3—Linear regressions of trawl survey estimates for the Bering Sea shelf, slope and the Aleutian Islands used to estimate the proportion of biomass in each area.

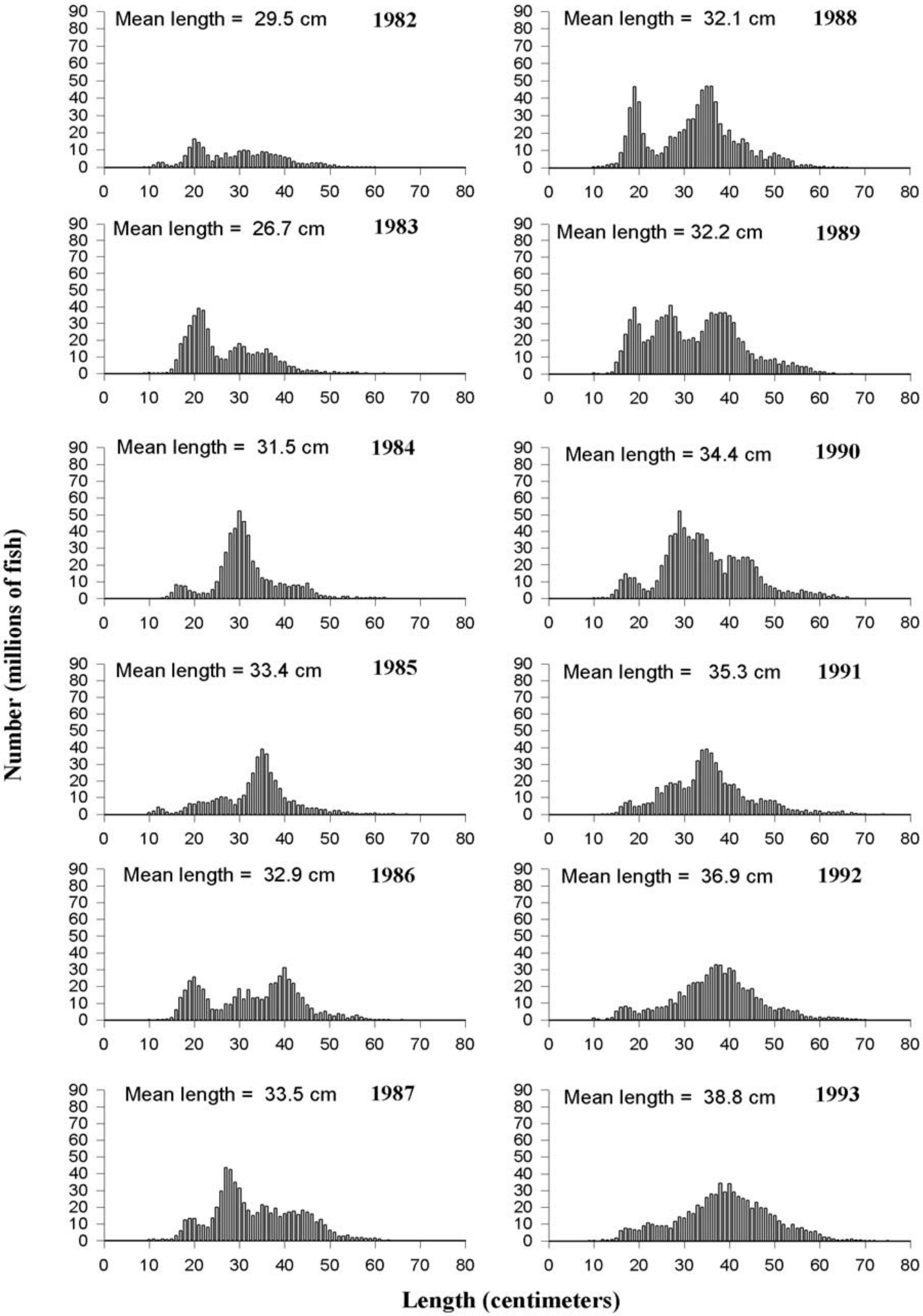

Figure 6.4. Size composition of arrowtooth flounder from the shelf trawl surveys.

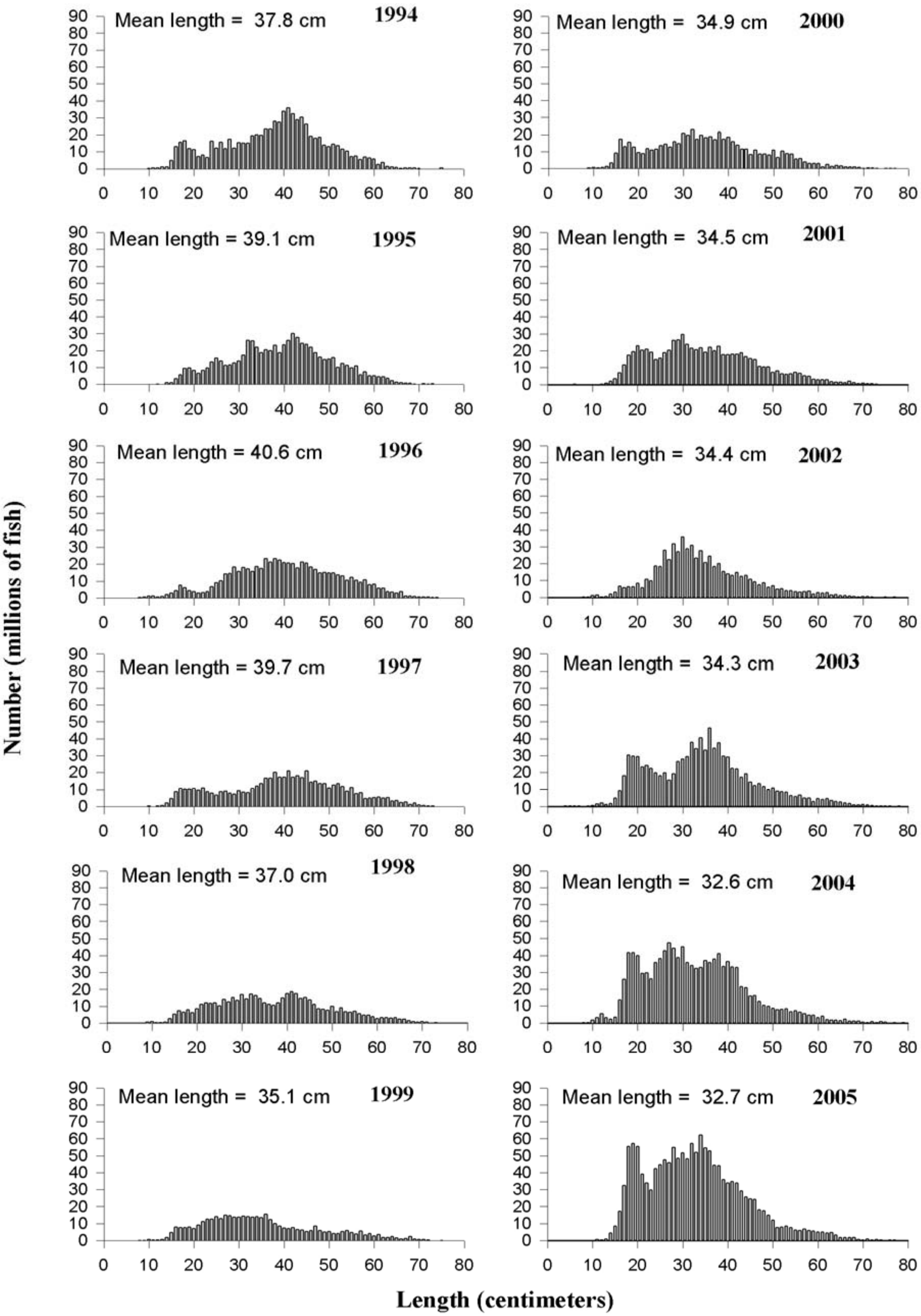

Figure 6.4. continued.

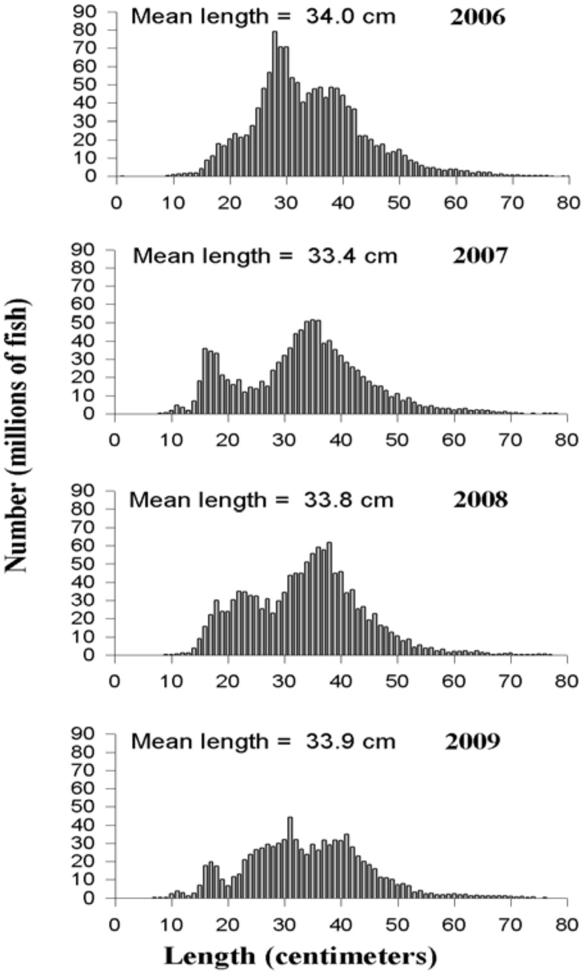

Figure 6.4. continued.

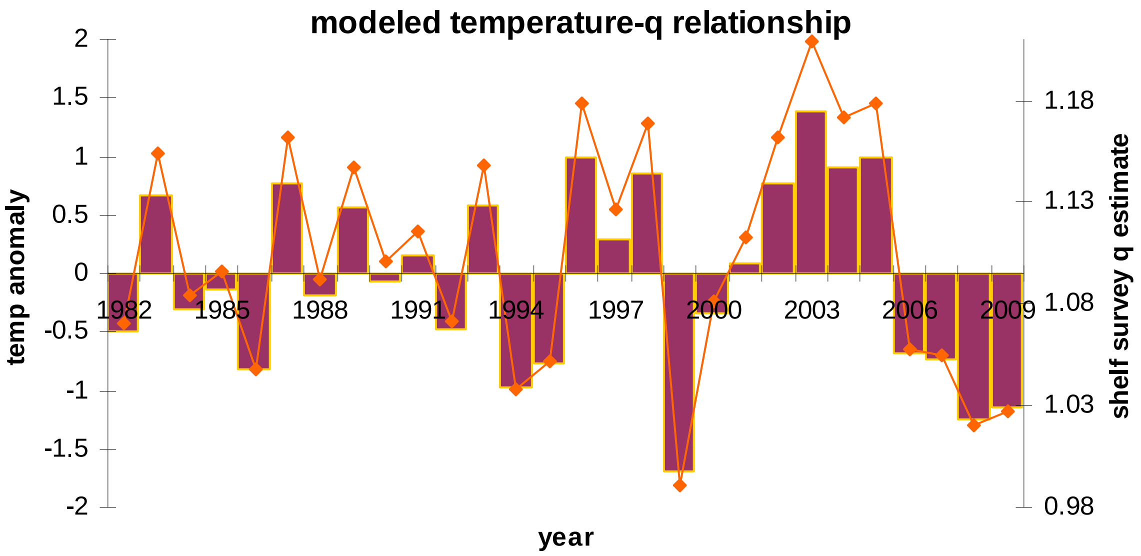

Figure 6.5--Shelf survey annual avg. bottom temperature anomalies (bars), model estimate of annual shelf survey q due to effect of water temperature (diamonds with lines).

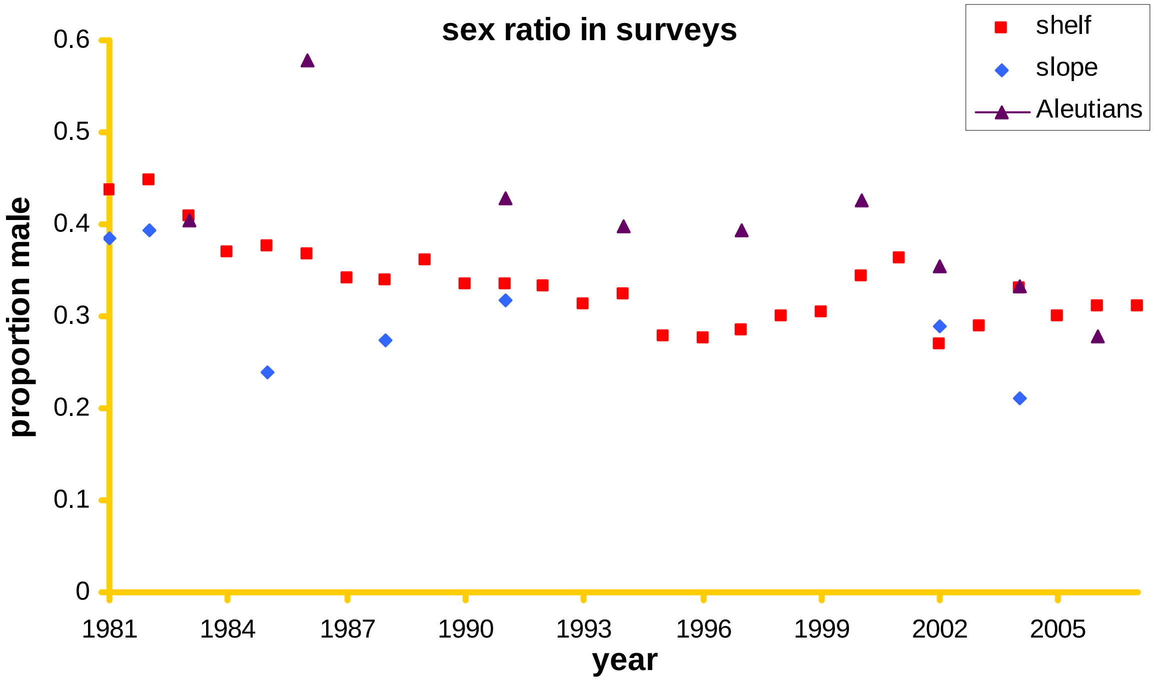

Figure 6.6--Proportion of the estimated male population from Bering Sea and Aleutian Islands trawl surveys on the continental shelf and slope.

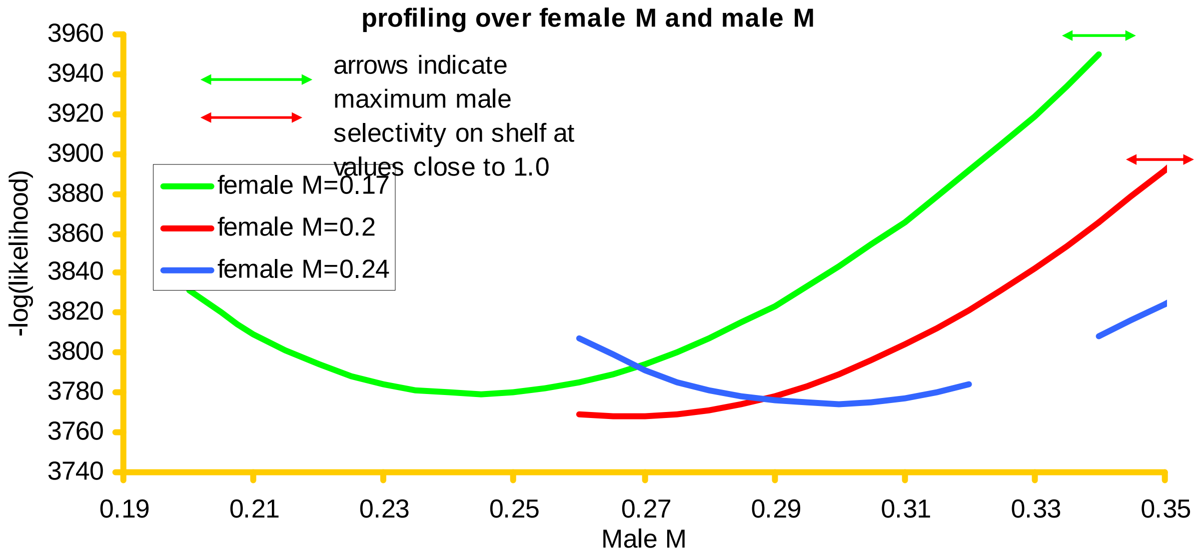

Figure 6.7—Fit to the stock assessment model in terms of –log(likelihood) when profiling over male natural mortality (x axis) for three different levels of female natural mortality. Arrows indicate the values of male natural mortality where the model estimates that maximum male selectivity is close to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

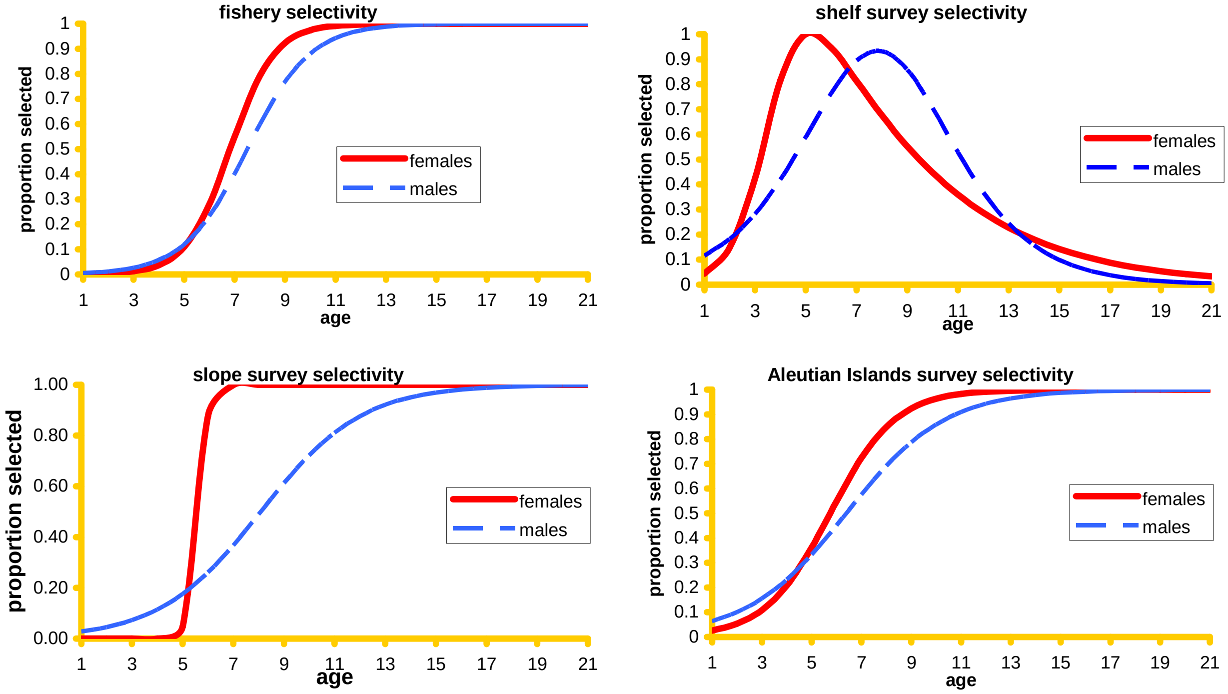

Figure 6.8--Age-specific fishery selectivity (top left panel), shelf survey selectivity (top right panel) slope survey selectivity (bottom left panel) and Aleutian Islands survey selectivity (bottom right panel), by sex, estimated from the stock assessment model.

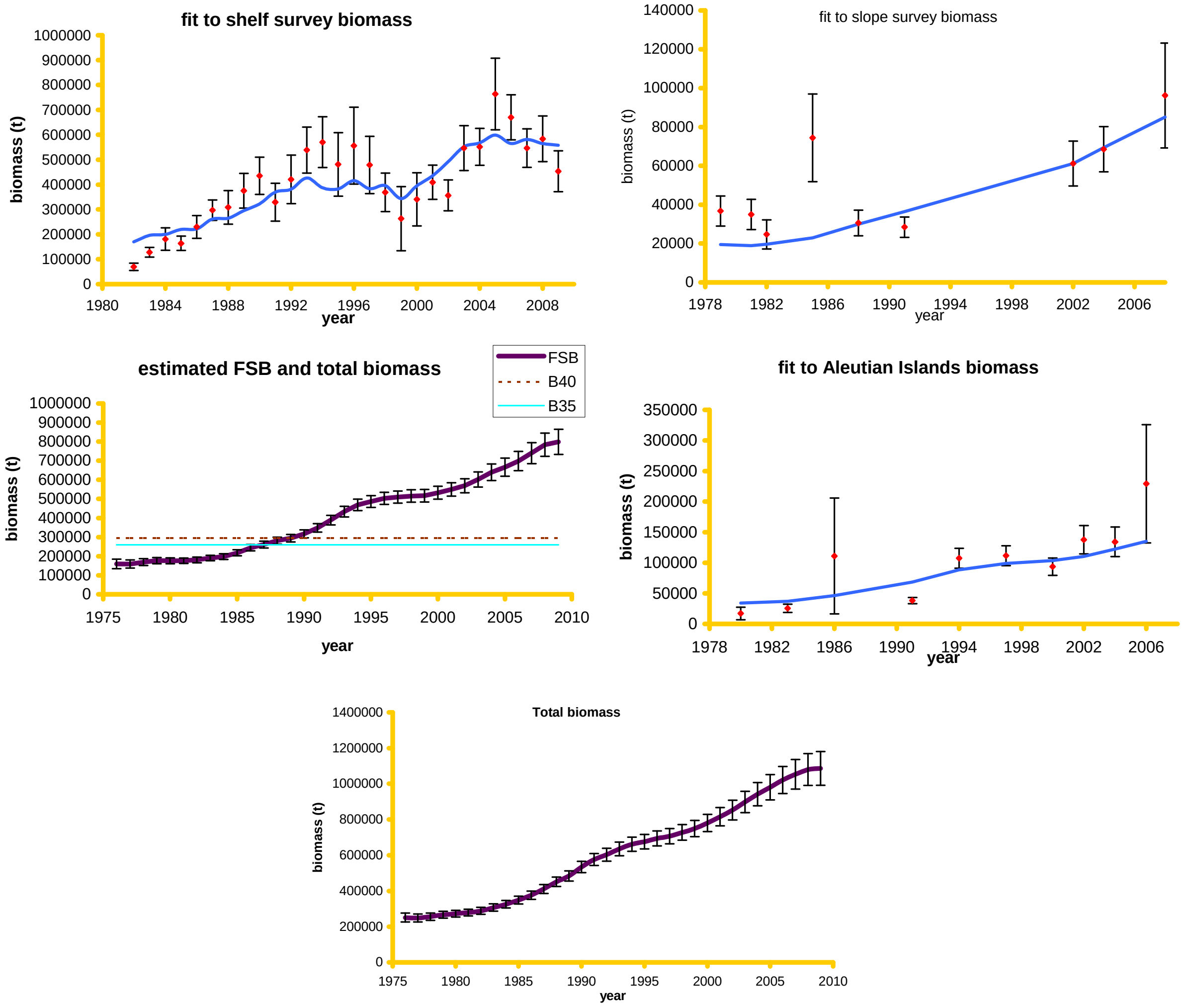

Figure 6.9--Stock assessment model results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), estimate of female spawning biomass with B35 and B40 indicated (middle left panel), the fit to the Aleutian Islands survey (middle right panel) and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

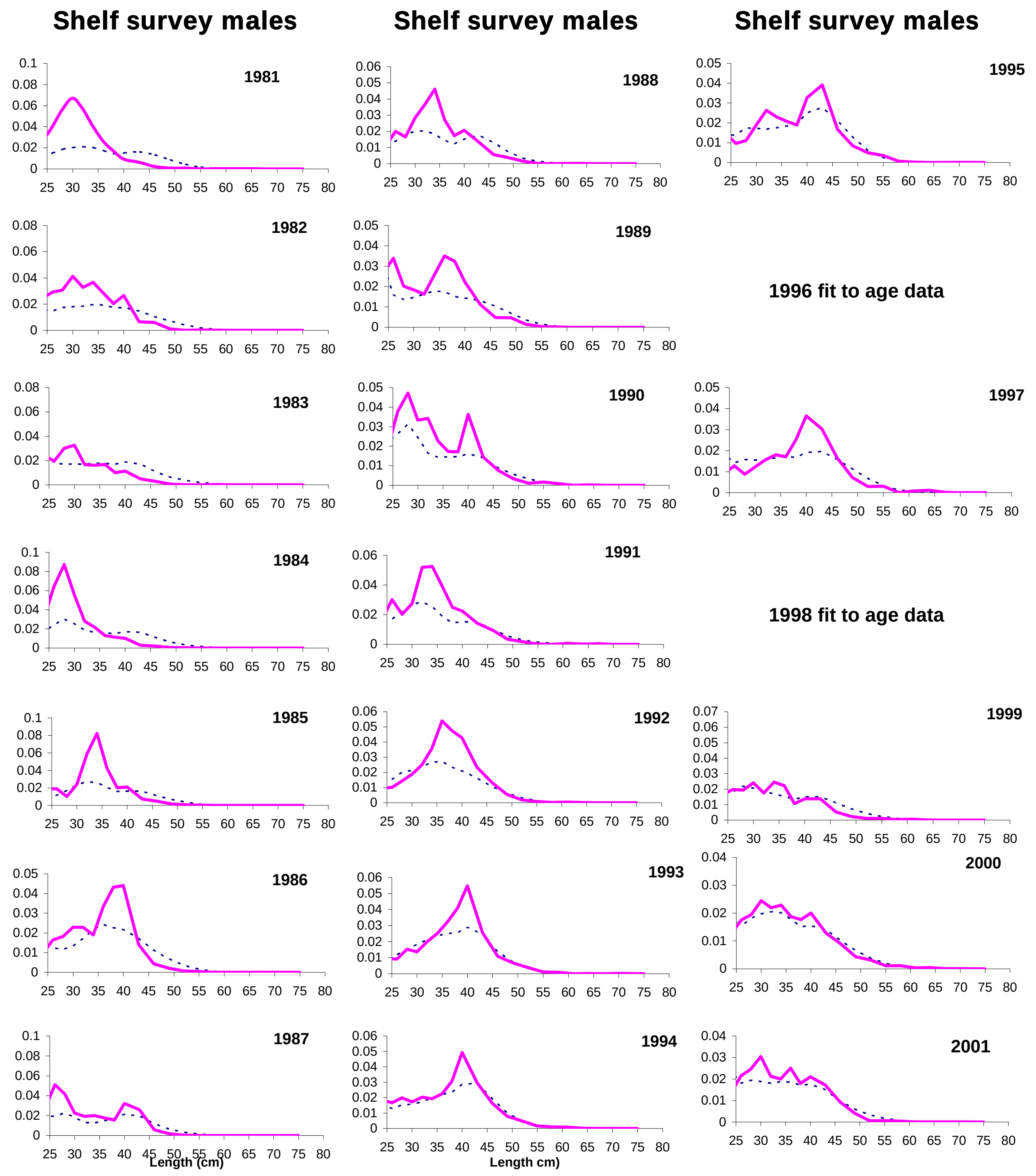

Figure 6.10—Model fit (dotted lines) to trawl survey size and age composition estimates (solid lines).

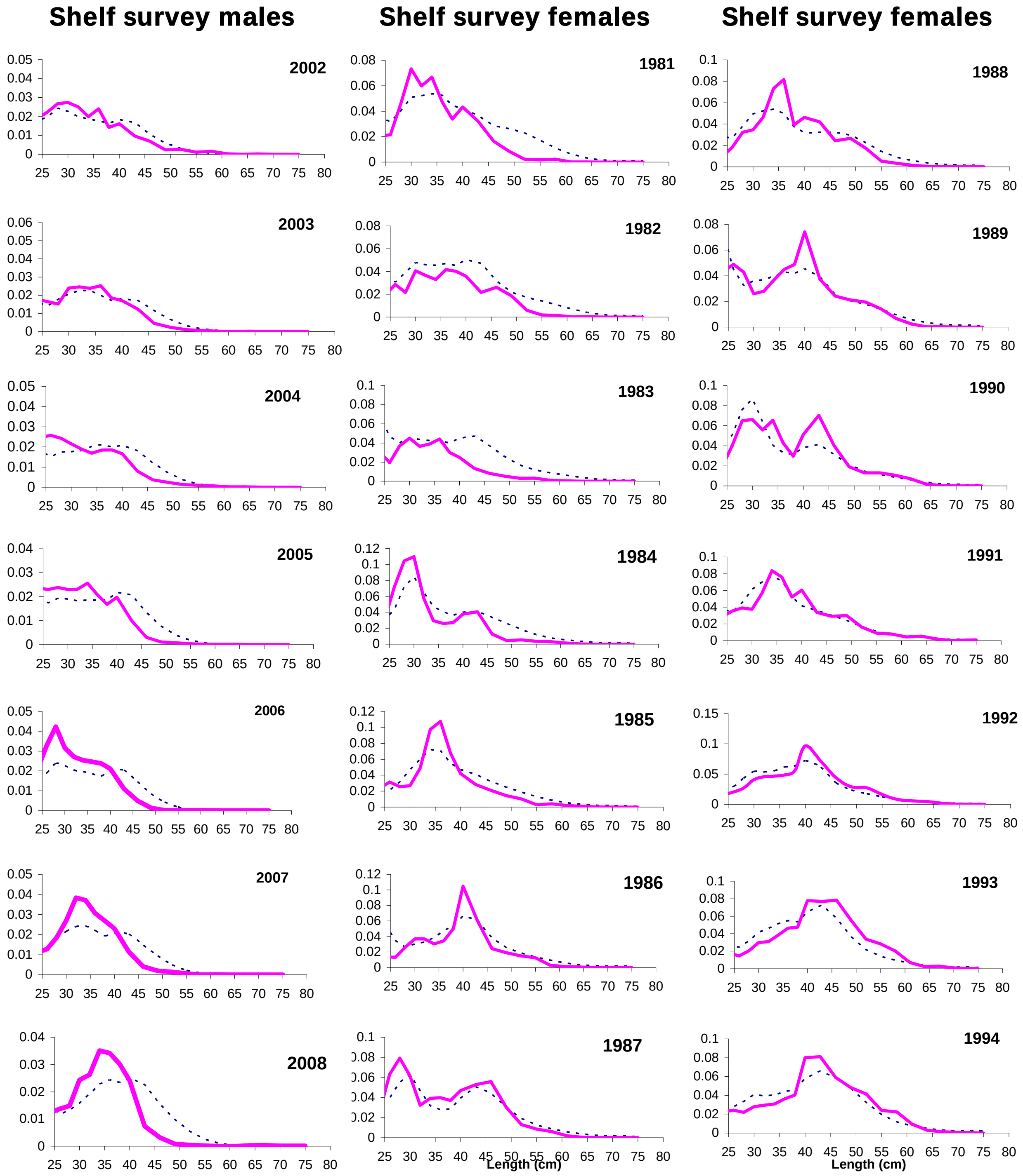

Figure 6.10—continued.

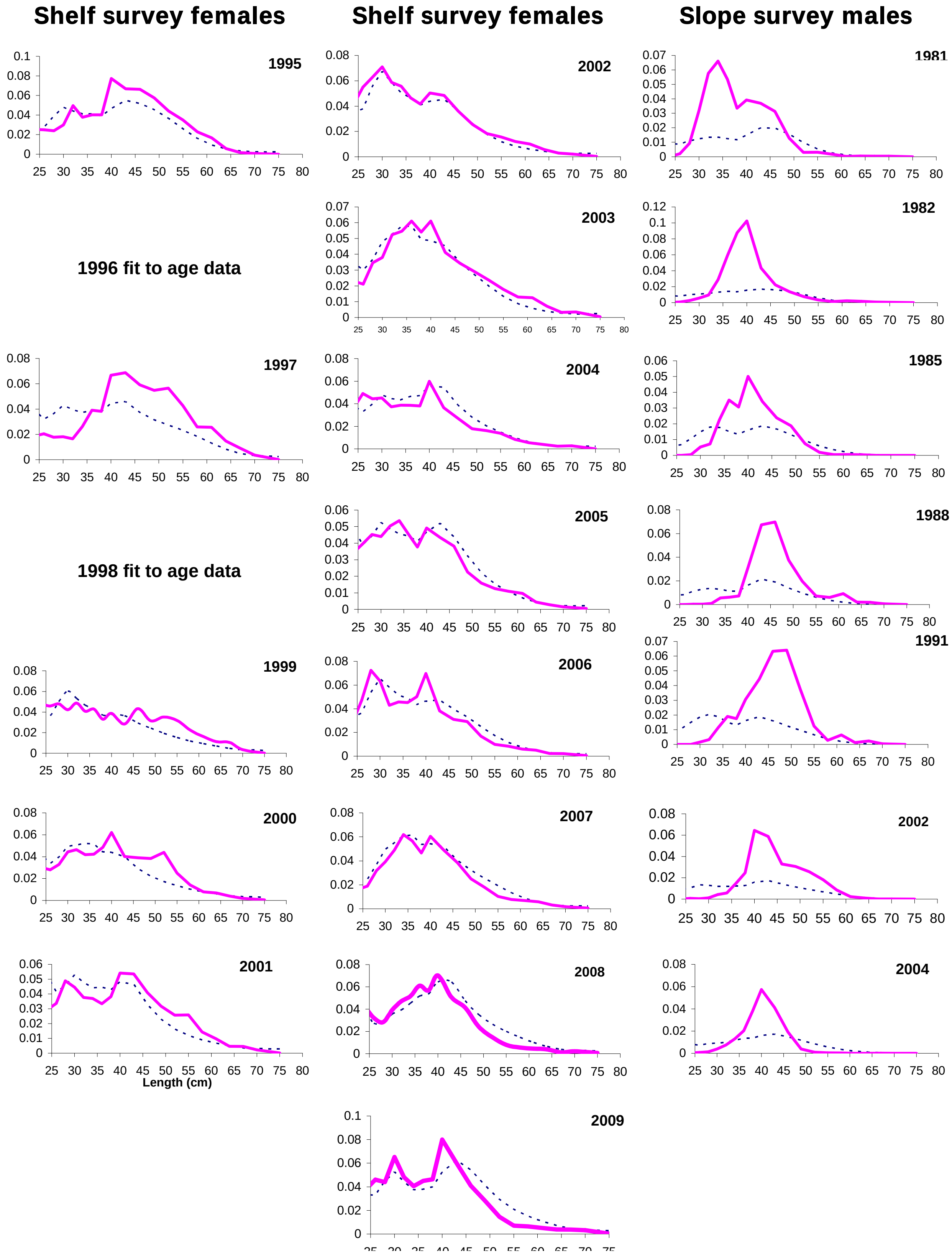

Figure 6.10—continued.

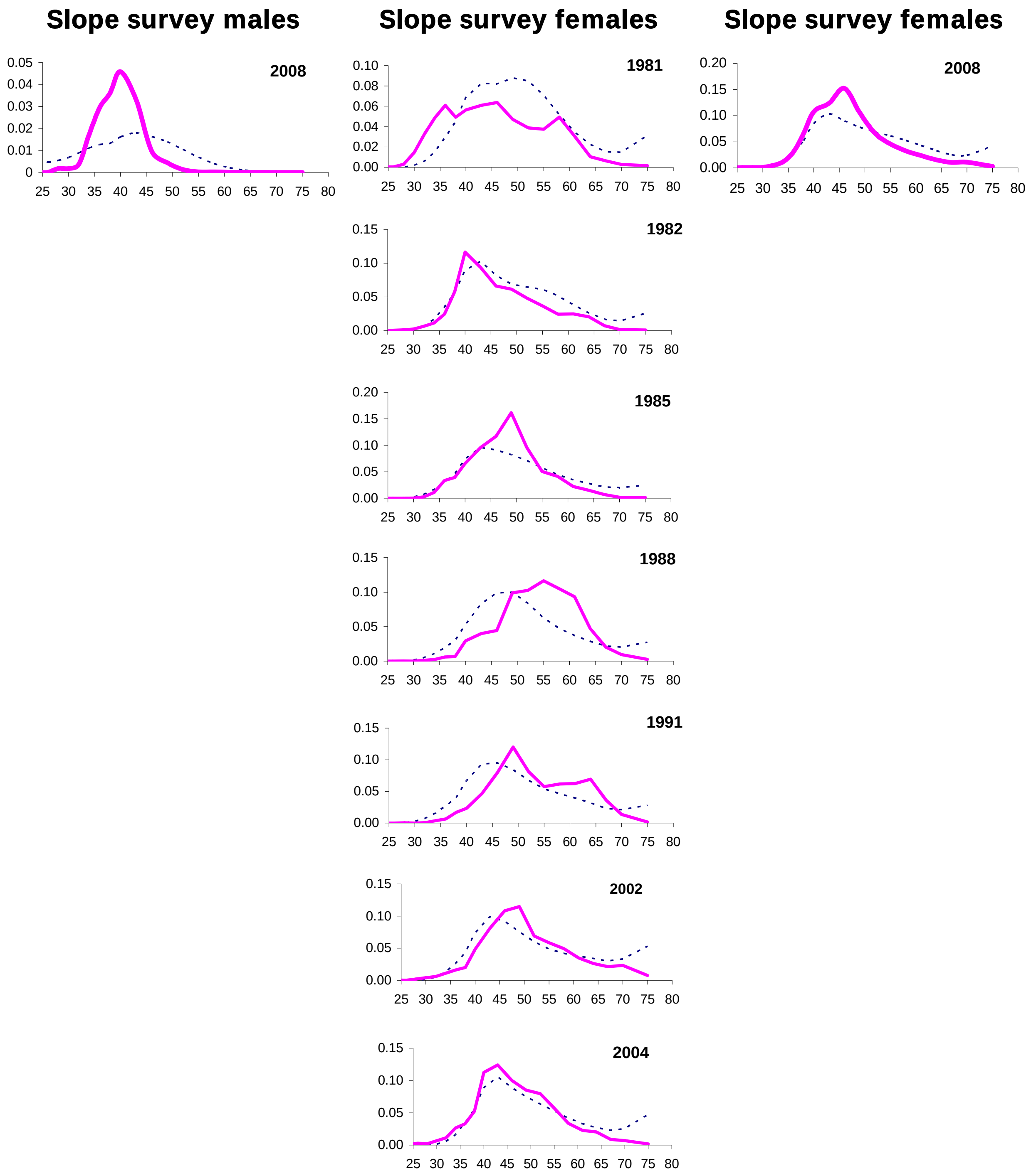

Figure 6.10—continued.

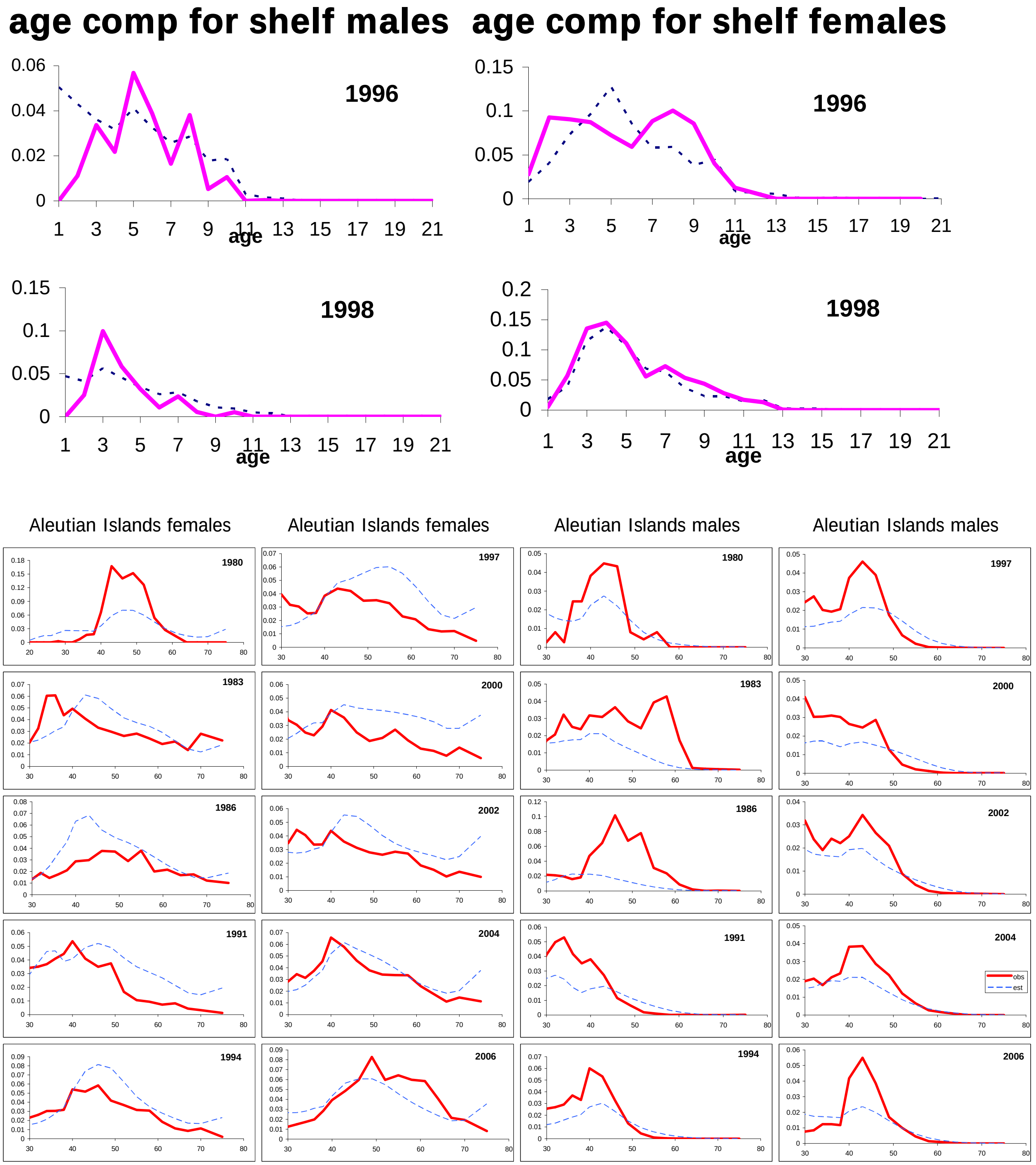

Figure 6.10—continued.

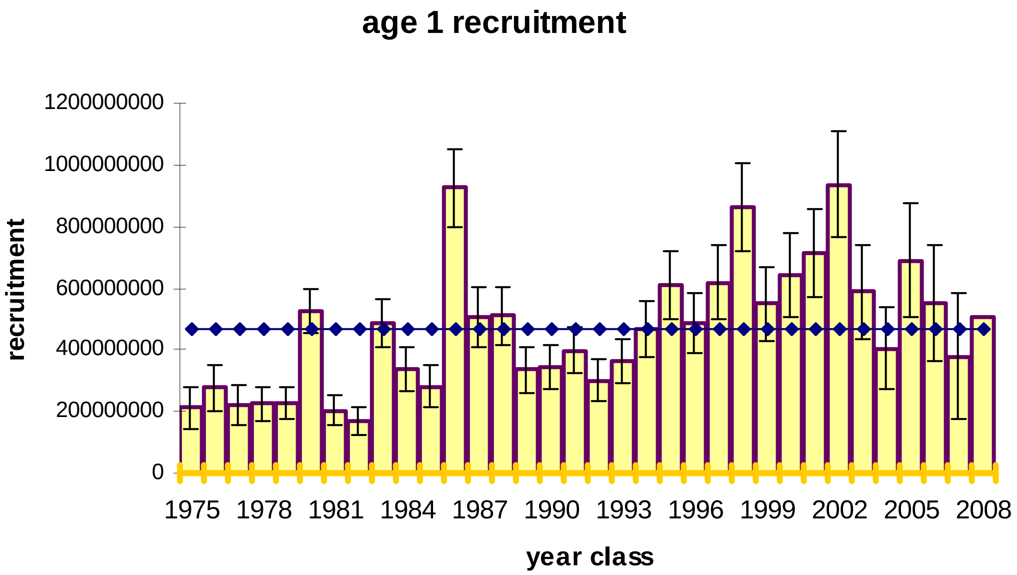

Figure 6.11--Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model.

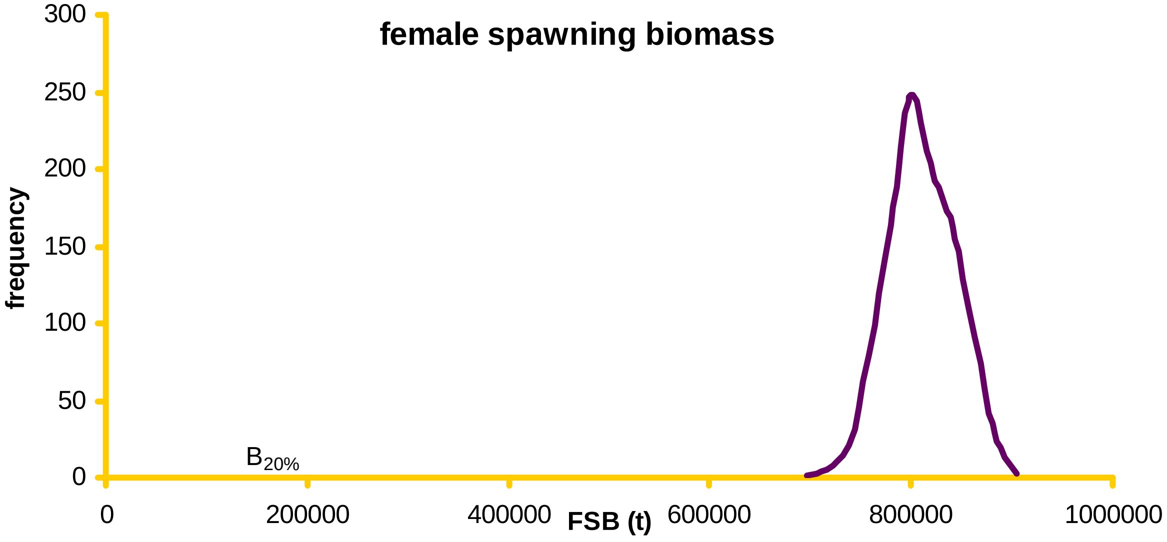

Figure 6.12—Posterior distribution of the estimate of female spawning biomass (t) from the preferred stock assessment model run.

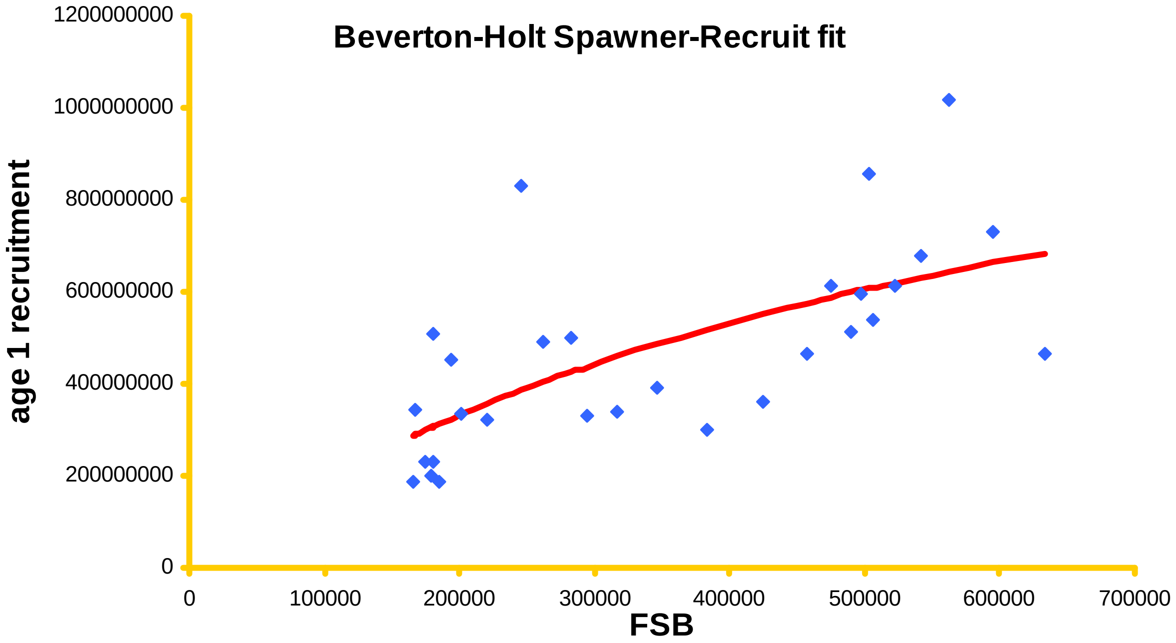

Figure 6.13—Beverton and Holt spawner recruit model fit to the age 1 recruitment data for Bering Sea arrowtooth flounder.

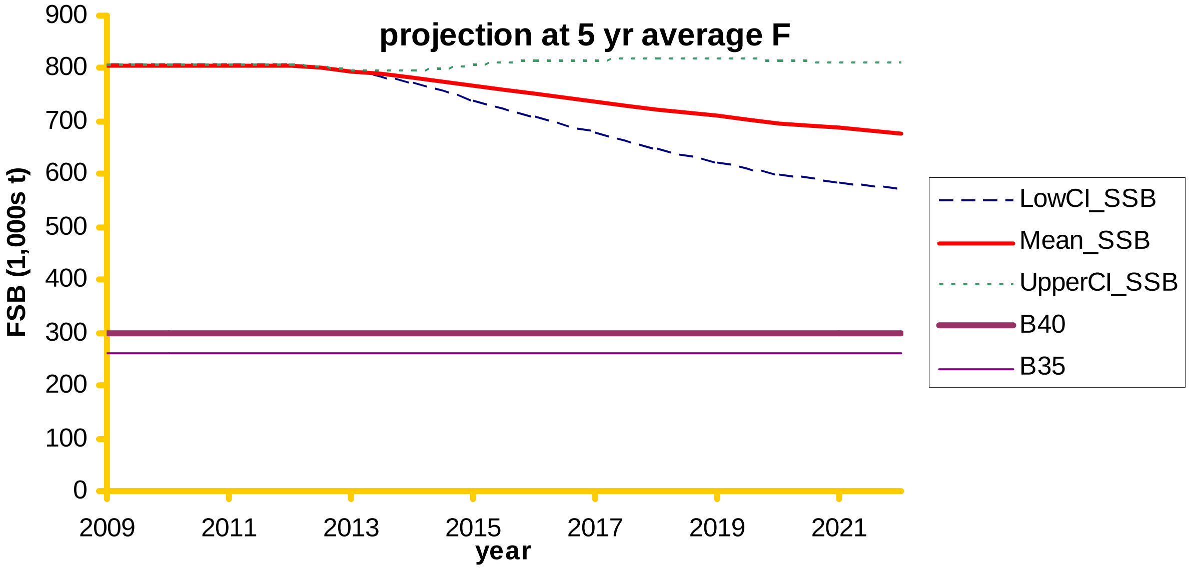

Figure 6.14--Projected female spawning biomass (1,000s t) of arrowtooth flounder if future harvest is at the same fishing mortality rate as the past five years.

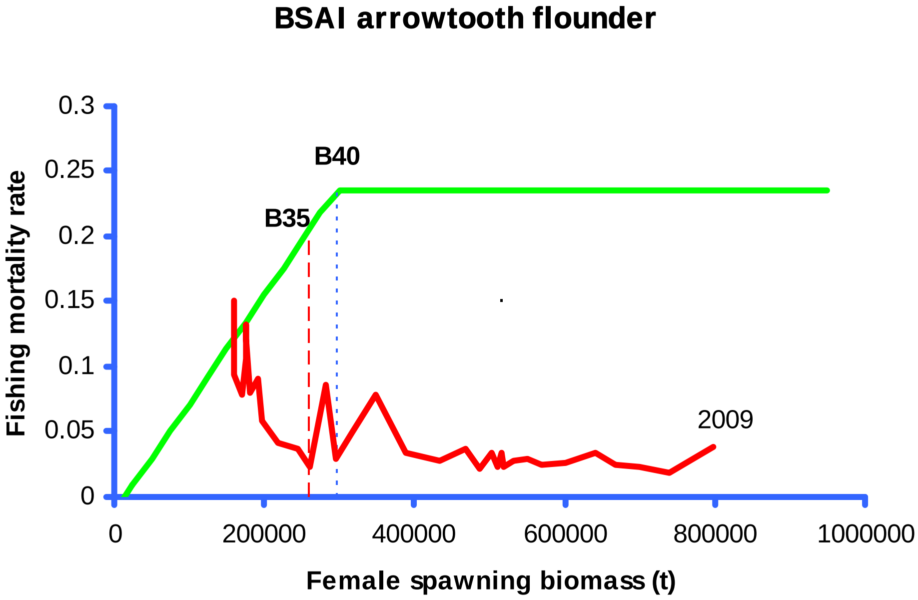

Figure 6.15—Phase plane diagram showing the time-series of stock assessment model estimates of female spawning biomss relative to the harvest control rule.

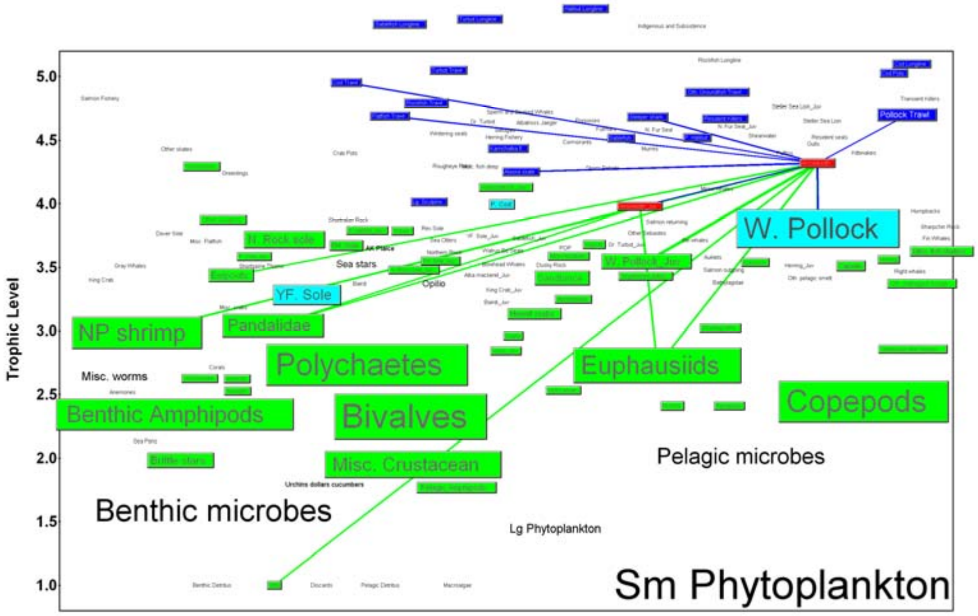

Figure 6.16. Adult and juvenile arrowtooth flounder in the EBS food web. Box size is proportional to biomass, and lines between boxes represent the most significant energy flows. Predators of arrowtooth are dark blue, prey of arrowtooth are green, and species that are both predators and prey of arrowtooth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

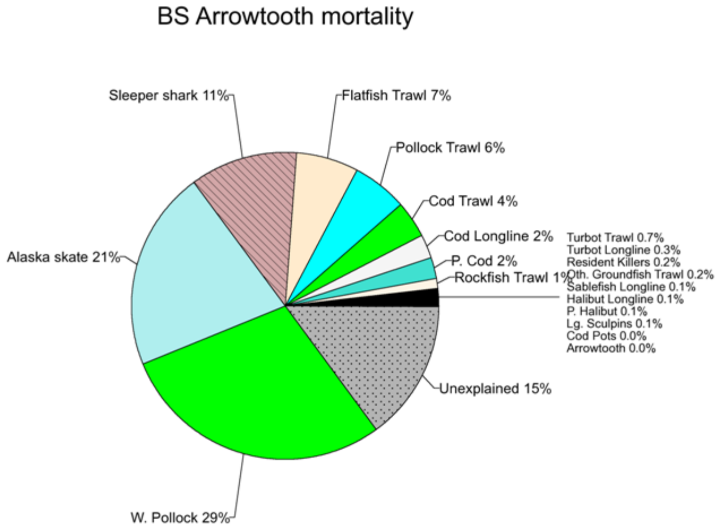

Figure 6.17. Mortality of Bering Sea arrowtooth flounder >20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. "Unexplained" mortality is the difference between the stock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

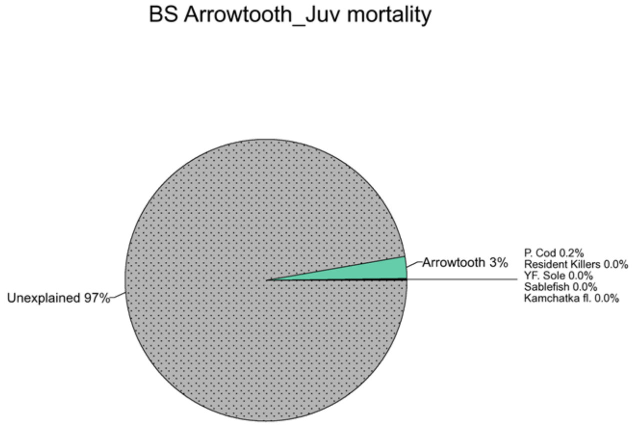

Figure 6.18. Mortality of Bering Sea arrowtooth flounder <20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. "Unexplained" mortality is the difference between the stock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

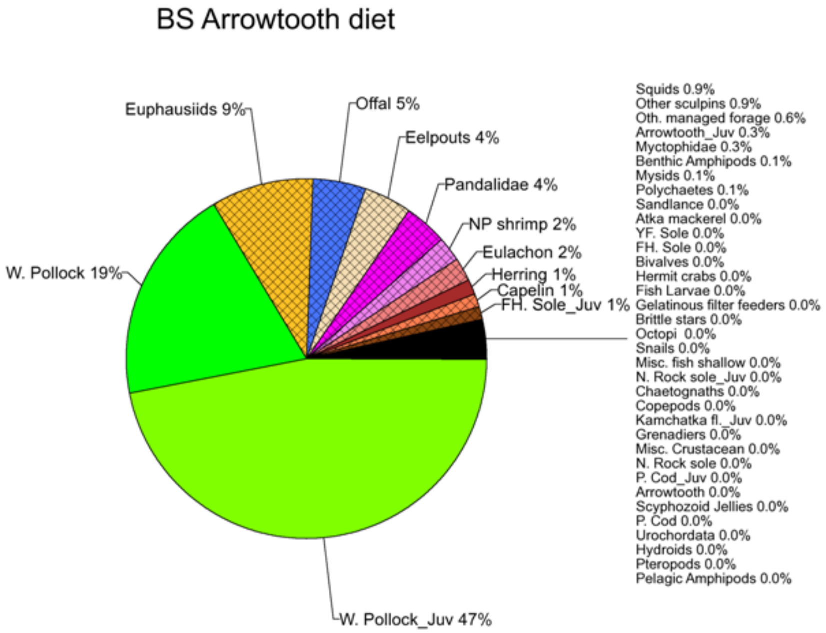

Figure 6.19. Diet of Bering Sea arrowtooth flounder >20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good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

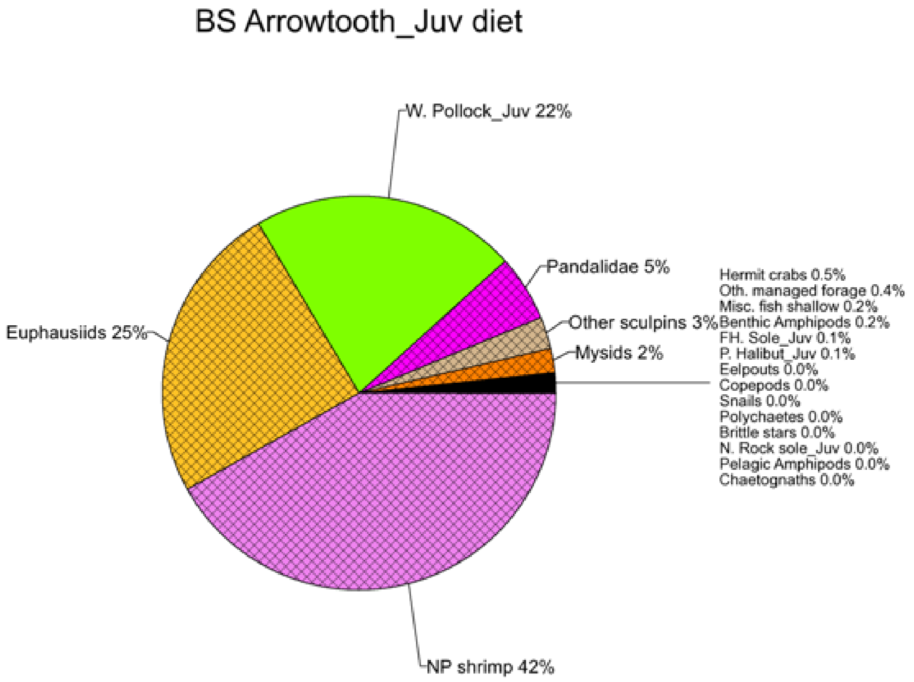

Figure 6.20. Diet of Bering Sea arrowtooth flounder <20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good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

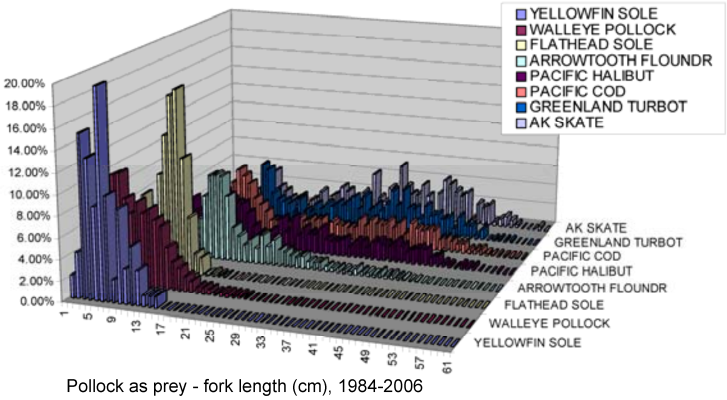

Figure 6.21. Length frequency of pollock found in stomachs, from groundfish food habits collected from 1984-2006 on AFSC summer trawl surveys in the eastern Berng Sea. Predators are sorted by median prey length of pollock in their stomachs. All lengths of predators are combined.

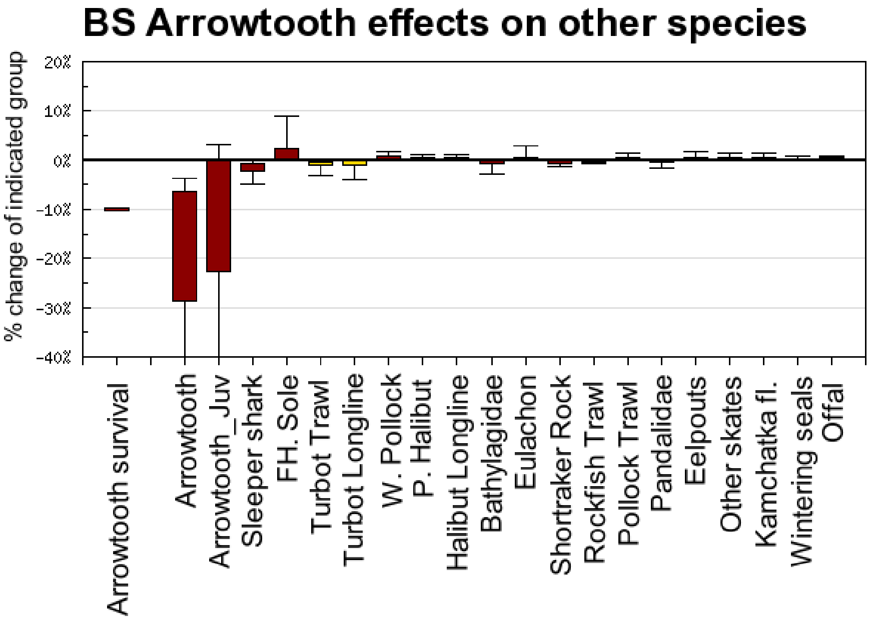

Figure 6.22. Effect of changing arrowtooth > 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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

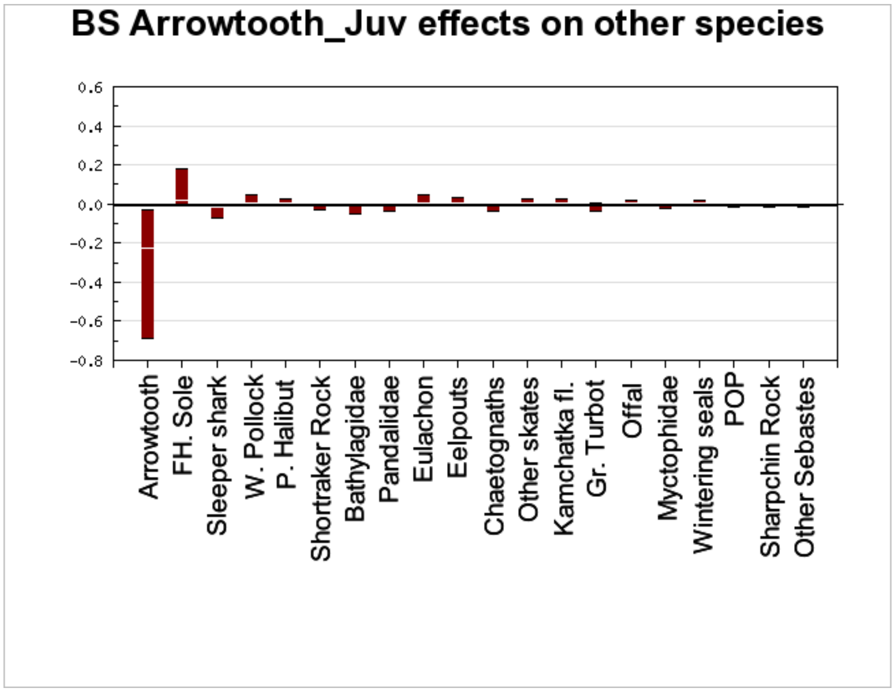

Figure 6.23. Effect of changing arrowtooth < 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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

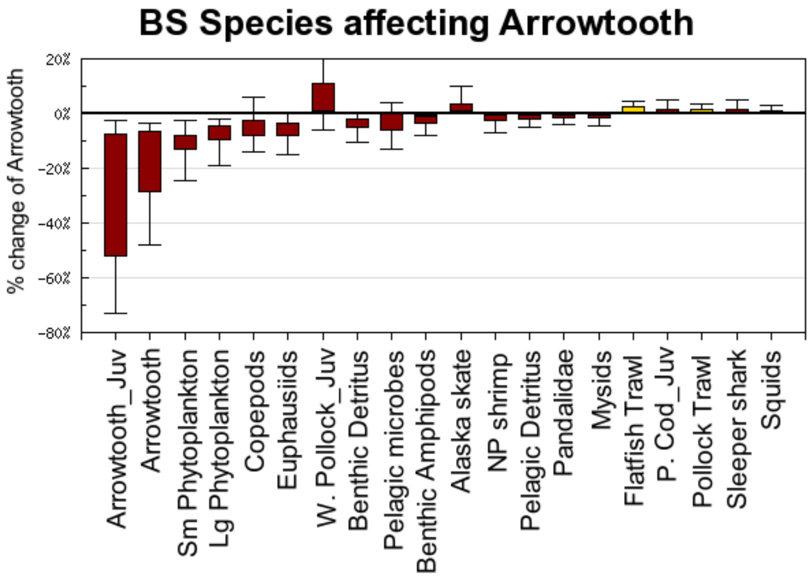

Figure 6.24. Effect of reducing fisheries catch (yellow) and other species survival (dark red) on arrowtooth > 20 cm biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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