Chapter 6. Arrowtooth Flounder

By

Thomas K. Wilderbuer, Daniel G. Nichol and Kerim Aydin

Alaska Fisheries Science Center
NMFS/NOAA 7600 Sand Point Way NE
Seattle WA 98115

Executive Summary

The following changes have been made to this assessment relative to the November 2007 SAFE.

Changes to the input data

1) 2008 shelf survey size composition.

2) 2008 shelf survey biomass point-estimates and standard errors.

3) Estimate of catch and discards through 18, September 2008.

4) Estimate of retained and discarded portion of the 2007 catch.

5) 2008 estimate of the slope survey biomass point-estimates and standard errors.

6) 2008 slope survey size composition.

Assessment results

1) The projected age 1+ total biomass for 2009 is 1,136,600 t.

2) The projected female spawning biomass for 2009 is 802,130 t.

3) The recommended 2009 ABC is 156,300 t based on an $F_{0.40}$ (0.235) harvest level.

4) The 2009 overfishing level is 190,350 t based on a $F_{0.35}$ (0.29) harvest level.

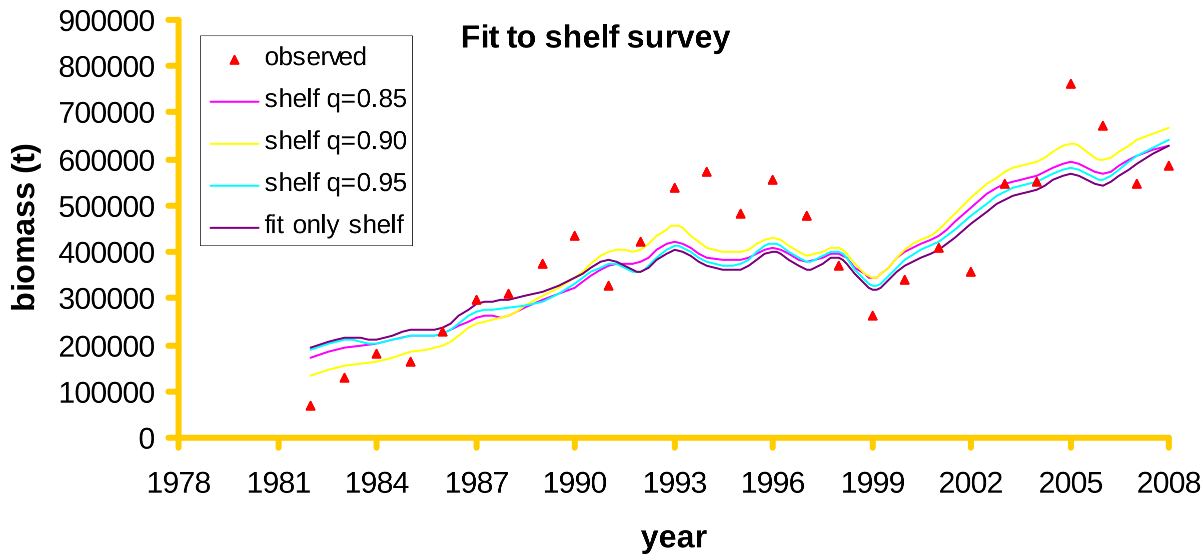
Assessment Year	2007	2008	
Projections Year	2008	2009	2010
M (male, female)	0.34, 0.2	0.34, 0.2	0.34, 0.2
Tier	3a	3a	3a
B_{MSY} (t) ($B_{35\%}$)	301,500 t	292,200	--
$B_{40\%}$ (t)	344,500 t	255,300	--
Female spawning biomass (t)	993,500	802,130	807,200
Total Biomass (t)	1,780,300	1,136,600	1,28,700
Tier 3a $F_{overfishing}$ ($F_{35\%}$)	0.30	0.29	0.29
Tier 3a F_{ABC} ($F_{40\%}$)	0.24	0.235	0.235

Tier 3a ABC	243,900	156,300	160,600
Tier 3a overfishing	297,200	190,350	195,500

SSC comments to the assessment authors:

The SSC looks forward to further development of the model along the lines suggested by the authors to resolve some of the structural uncertainties. In particular, reasons for the model consistently underfitting shelf survey biomass in the mid-1990s should be explored. For example, change in the relative proportions of arrowtooth flounder on the shelf and slope (in addition to those accounted for by a temperature effect) may account for a much more rapid increase in survey biomass estimates relative to the model.

As part of the model explorations for this assessment cycle, we varied the proportions of biomass available to the three components of the stock (shelf, slope and Aleutian Islands) with the aim to increase the proportion of biomass on the shelf (and decrease the others) in order to better fit the shelf survey estimates of the mid-1990s. Proportions on the shelf were allowed to vary from 85 to 95% of the total stock biomass (base model used 72% on the shelf) but still did not closely fit the survey biomass estimates in 1994-1998. The level of recruitment estimated for the late 1980s appears to have been enough to increase the stock from a low to a high and stable level, but not enough to bring the stock to the level indicated by those surveys. Subsequent recruitment in the early 2000s has brought the stock to a higher abundance level.



Time-series of observed shelf survey biomass and model fit under three different values of catchability.

Male natural mortality was also profiled over a range of values to assess the sensitivity of the model to three different levels of female natural mortality to discover if our fits to some of the likelihood components could be improved by doing better in our estimates of female natural mortality. This exercise indicated that departures from a female M of 0.2 degrade the fit to most likelihood components and result in a higher total likelihood (discussed in the model evaluation section).

As noted last year, an examination of the relationship between bottom temperature and q for all flatfish species would be useful to standardize the treatment of bottom temperatures in the assessments. The recent cold years should provide additional contrast for this analysis.

The catchability model used in this assessment was changed to standardize it with the other flatfish stock assessments for the Bering Sea, as shown in the section where the catchability model is presented. The estimates resulting from the two parameter catchability model used in this assessment results in the lower values of total biomass, female spawning biomass, ABC, and biomass reference points for 2009 relative to those used in last year's assessment (see previous page).

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 (see Appendix figure) 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 18 September, 2008 is 19,403 t (well below the 2008 ABC of 243,900 t). NMFS Regional Office reports indicate that bottom trawling accounted for 85% of the 2008 catch (6% by pelagic trawl and 8% 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 most often 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 1985-2007 are shown in Table 6.2. Forty-three percent of the arrowtooth flounder caught in 2007 were retained.

Substantial amounts of arrowtooth flounder are discarded overboard in the various trawl and longline target fisheries. Largest discard amounts occurred in the Pacific cod fishery and the various flatfish fisheries. Retention is expected to increase in the future due to enactment of improved retention/utilization regulations by the Council.

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 - September 18, 2008 (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. 6.1). The overall shelf catch rate decreased slightly to 7.1 kg/ha in 1991. The CPUE continued to increase through 1997 to 15.0 kg/ha. These increases in CPUE were also observed on the slope from 1981 to 1986 as CPUE from the Japanese land-based fishery increased from 1.5 to 21.0 t/hr (Bakkala and Wilderbuer 1990). From 1999 to 2005 the shelf survey CPUE increased at a high rate each year. 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 are still at high levels. The CPUE in the Aleutian Islands has also increased to the high 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. 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 remain at high levels.

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 2008 point estimate are 491,400 – 676,400 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 6.4).

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
33	14	2	52	101

The recruitment parameters are comprised of 21 initial ages in 1976 and 30 subsequent age 1 recruitment estimates from 1976-2004. 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 (2007) 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/shelf+slope biomass from the trawl survey time-series. In this assessment we also incorporate the Aleutian Islands survey biomass and size composition estimates into the stock assessment model. Biomass was apportioned between the three areas (shelf, slope and Aleutian Islands) 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 6.2). 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. 6.1) were particularly evident during the coldest year (1999) and the warmest year (2003). The relationship between average annual bottom water temperature collected during the survey and annual survey biomass estimates can be better understood by modeling survey catchability as:

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

where q is catchability, α and β are a parameters estimated by the model, and T_t is the average annual bottom water temperature. The catchability equation has two parts. The e^{α} term is a constant or time-independent estimate of q. The model estimate of $\alpha = -0.42$ 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 6.4) Modeling catchability in this way results in estimates of total biomass and female spawning biomass which are lower than the estimates from the 2007 assessment.

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 6.4 and Table 6.5).

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. 6.5). 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 we do not believe 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

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 6.6. 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 = 0.27-0.28, the fit to the total –log(likelihood) suffered a large degradation in fit. The runs with female M = 0.24 had worse results in terms of total fit to the components and also 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 0.34 gave the best fit and satisfied the male selectivity requirement with a maximum of 0.9 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 – 0.34 with equal emphasis placed on all data components.

female M = 0.2	**male natural mortality values**									
	0.26	**0.27**	**0.28**	**0.29**	**0.3**	**0.31**	**0.32**	**0.33**	**0.34**	**0.35**
Likelihood component										
shelf biomass	100.9	101.4	101.8	102.2	102.6	103.0	103.3	103.6	103.9	104.2
slope biomass	68.8	68.0	67.4	67.0	66.7	66.6	66.5	66.5	66.6	66.8
Aleutian biomass	65.8	65.5	65.1	64.7	64.2	63.7	63.1	62.6	62.0	61.4
shelf length comp	1637.4	1641.0	1644.7	1648.6	1652.6	1656.8	1661.1	1665.6	1670.2	1674.9
slope length comp	948.4	950.4	953.7	958.3	964.0	970.9	978.7	987.4	997.0	1007.4
Aleutian length comp	815.1	821.1	828.6	837.7	848.2	859.9	872.8	886.8	901.8	917.7
recruitment	31.3	31.1	31.1	31.1	31.2	31.4	31.6	31.8	32.1	221.3
sex ratio	112.5	101.2	90.9	81.5	73.0	65.1	58.0	51.5	45.6	40.2
shelf age comps	133.8	134.4	135.0	135.6	136.2	136.7	137.2	137.7	138.2	138.8
total likelihood	3913.9	3914.1	3918.5	3926.8	3938.7	3954.0	3972.3	3993.6	4017.4	4232.7
male max shelf selectivity (age)										
	0.55 (7)	0.58 (7)	0.62 (7)	0.65 (7)	0.69 (7)	0.73 (8)	0.79 (8)	0.84 (8)	0.90 (8)	0.96 (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 most likely ranges between 0.27 and 0.35. 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 = 0.34** 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 0.9 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. It may be that the rate of male natural mortality is even higher as it has been estimated at 0.35 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 6.6. The average exploitation rate has been at a low level, less than 3%, from 1977-2008 due to the relative undesirability of arrowtooth flounder as a commercial product and the additional constraints of the 2 million ton TAC and halibut bycatch limits. Age-specific selectivity estimated by the model (Table 6.7, Fig. 6.7) 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 2008 value of 1.09 million t (Fig. 6.8, Table 6.8). 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, 785,000 t in 2008, also the highest level estimated from 1976 to the present (Table 6.8). Model estimates of population numbers by age, year, and sex are given in Table 6.9.

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 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. 6.8). 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 the Appendix. Reasonable fits also resulted for slope survey and Aleutian Islands size composition observations and the 1996 and 1998 shelf survey age compositions.

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. 6.9, Table 6.10). 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 should increase the stock size even higher in the near future. Above average recruitment from 9 consecutive year classes (1995-2003) cause the projected values for 2009 to be much higher than 2008.

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 6.10

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. 6.9).

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 five above average year-classes spawned during the 1980s, very strong recent recruitment, and minimal commercial harvest. They are currently estimated to be at a high and increasing level. **The estimate of projected 2009 total biomass from the stock assessment projection model is 1,136,600 t and the female spawning biomass is estimated at 802,100 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 $B_{0.40}$ = 292,200 t. The stock assessment model estimates the 2009 level of female spawning biomass at 802,100 t (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and B>$B_{0.40}$ (802,100 > 292,200), arrowtooth flounder reference fishing mortality is defined in tier 3a. For the 2009 harvest: $F_{ABC} = F_{0.40} = 0.235$ and $F_{overfishing} = F_{0.35} = 0.29$ (full selection F values).

Acceptable biological catch is estimated for 2009 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2009 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 2009 ABC of 156,280 t.**

The overfishing level is estimated for 2008 by applying the $F_{35\%}$ fishing mortality rate and age-specific fishery selectivities to the projected 2008 estimate of age-specific total biomass. **This results in a 2009 OFL of 190,350 t.**

The potential yield of arrowtooth flounder in 2009, at various levels of fishing mortality (full selection), are as follows:

F level	Exploitation rate	Potential yield
$F_{overfishing}$	0.29	190,350 t
$F_{0.40}$	**0.235**	**156,280 t**

This estimate of 2009 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 54,000 t (Appendix table) would give an overfishing limit of 10,800 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 2008 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2009 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2008. 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 2009, 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 2009 recommended in the assessment to the *max* F_{ABC} for 2009. (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 2004-2008 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 2009 and above its MSY level in 2019 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2009 and 2010, 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 2021 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results (Table 6.11) 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 6.11.

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 2009, it does not provide the best estimate of OFL for 2010, because the mean 2010 catch under Scenario 6 is predicated on the 2009 catch being equal to the 2009 OFL, whereas the actual 2009 catch will likely be less than the 2009 ABC. Therefore, the projection model was re-run with the 2009 and 2010catch fixed equal to the 2008 catch to calculate the 2010 ABC and OFL.

Year	Catch	ABC	OFL
2009	19,403	156,300	190,400
2010	19,403	160,600	195,500

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 6.12). 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. 6.13). 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 6.14).

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 6.15). 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 6.16). 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 6.17).

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. 6.18) 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 6.19). 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 6.20 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 2005 and 2006 in Table 13 of the Economic SAFE (Appendix C) and is summarized for 2006 as follows:

Prohibited species	Arrowtooth flounder "fishery" % of total bycatch
Halibut mortality	2.9
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 28 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], 1970-2008. 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**									19,403

[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 18 September, 2008 (NMFS regional office).

Table 6.2 Estimates of retained and discarded arrowtooth flounder catch, 1985-2007.

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

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	

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--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 6.5--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 6.6 Model estimates of arrowtooth flounder fishing mortality and exploitation rate (catch/total biomass).

year	Full selection F	Exploitation rate
1976	0.149	0.076
1977	0.093	0.046
1978	0.079	0.040
1979	0.105	0.054
1980	0.132	0.068
1981	0.123	0.061
1982	0.080	0.040
1983	0.092	0.046
1984	0.058	0.029
1985	0.042	0.021
1986	0.037	0.019
1987	0.022	0.012
1988	0.087	0.044
1989	0.030	0.015
1990	0.050	0.025
1991	0.079	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	0.013
2003	0.025	0.014
2004	0.033	0.019
2005	0.024	0.014
2006	0.022	0.013
2007	0.018	0.011
2008	0.029	0.018

Table 6.7 Model estimates of arrowtooth flounder age-specific fishery and survey selectivities, by sex.

	Fishery		shelf survey		slope survey		Aleutians survey	
Age	**females**	**males**	**females**	**males**	**females**	**males**	**females**	**males**
1	0.00	0.01	0.04	0.11	0.00	0.03	0.03	0.06
2	0.00	0.01	0.15	0.18	0.00	0.04	0.05	0.10
3	0.01	0.03	0.42	0.28	0.00	0.07	0.11	0.15
4	0.04	0.06	0.82	0.41	0.00	0.11	0.21	0.23
5	0.11	0.12	1.00	0.58	0.05	0.17	0.37	0.33
6	0.28	0.23	0.95	0.74	0.88	0.25	0.56	0.45
7	0.56	0.40	0.82	0.86	1.00	0.36	0.74	0.57
8	0.80	0.59	0.69	0.89	1.00	0.48	0.86	0.69
9	0.93	0.77	0.57	0.81	1.00	0.60	0.93	0.78
10	0.98	0.88	0.46	0.66	1.00	0.72	0.97	0.86
11	0.99	0.94	0.38	0.49	1.00	0.81	0.98	0.91
12	1.00	0.97	0.30	0.34	1.00	0.87	0.99	0.94
13	1.00	0.99	0.24	0.23	1.00	0.92	1.00	0.96
14	1.00	0.99	0.19	0.15	1.00	0.95	1.00	0.98
15	1.00	1.00	0.15	0.09	1.00	0.97	1.00	0.99
16	1.00	1.00	0.12	0.06	1.00	0.98	1.00	0.99
17	1.00	1.00	0.10	0.03	1.00	0.99	1.00	0.99
18	1.00	1.00	0.08	0.02	1.00	0.99	1.00	1.00
19	1.00	1.00	0.06	0.01	1.00	1.00	1.00	1.00
20	1.00	1.00	0.05	0.01	1.00	1.00	1.00	1.00
21	1.00	1.00	0.04	0.00	1.00	1.00	1.00	1.00

Table 6.8 Model estimates of arrowtooth flounder 1+ total biomass (t) and female spawning biomass (t) from the 2007 and 2008 assessments.

	2008 Assessment		2007 Assessment	
	age 1+ Total biomass	Female Spawning biomass	age 1+ Total biomass	Female Spawning biomass
1976	251,434	158,781	257,242	159,296
1977	248,550	157,687	256,695	158,786
1978	255,523	167,314	266,771	169,692
1979	265,676	174,482	281,720	177,491
1980	271,974	173,514	293,738	178,260
1981	278,414	173,256	307,197	181,771
1982	287,306	177,675	323,450	192,024
1983	306,042	187,094	350,236	206,780
1984	324,760	194,330	377,028	219,370
1985	347,781	213,962	407,740	245,582
1986	374,697	240,468	442,521	279,119
1987	409,525	256,850	485,517	300,596
1988	449,340	276,549	533,677	325,331
1989	482,729	289,764	576,250	344,157
1990	531,932	312,459	634,434	372,218
1991	573,663	343,049	684,635	409,561
1992	600,869	383,001	719,144	456,976
1993	632,893	426,976	757,020	507,729
1994	659,131	461,060	787,937	547,633
1995	673,945	478,406	806,845	568,301
1996	692,466	494,967	829,689	586,699
1997	704,798	501,634	847,381	595,254
1998	726,368	507,398	876,280	603,044
1999	748,908	509,864	909,775	608,367
2000	780,786	524,969	955,234	628,255
2001	817,676	543,316	1,009,050	653,841
2002	856,909	562,611	1,065,870	682,863
2003	904,521	596,293	1,129,740	731,362
2004	951,786	635,103	1,191,300	788,038
2005	993,348	663,351	1,243,360	830,943
2006	1,035,350	697,773	1,291,400	876,441
2007	1,067,480	742,608	1,324,440	929,641
2008	1,090,100	788,485		

Table 6.9 Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2008.

females				numbers at age (1,000s)						
	1	2	3	4	5	6	7	8	9	10
1976	104,660	32,034	83,167	71,041	66,645	26,099	14,705	10,231	7,873	6,417
1977	135,813	85,673	26,212	67,966	57,835	53,667	20,482	11,079	7,434	5,613
1978	108,130	111,181	70,117	21,436	55,449	46,862	42,790	15,921	8,419	5,582
1979	111,748	88,521	91,000	57,352	17,498	45,002	37,520	33,532	12,240	6,408
1980	112,372	91,480	72,445	74,408	46,768	14,159	35,760	28,970	25,237	9,089
1981	259,469	91,987	74,859	59,217	60,616	37,734	11,167	27,208	21,348	18,288
1982	100,564	212,403	75,277	61,197	48,258	48,957	29,838	8,540	20,198	15,602
1983	82,004	82,327	173,846	61,571	49,952	39,161	39,186	23,369	6,560	15,358
1984	240,079	67,131	67,379	142,173	50,235	40,482	31,239	30,485	17,780	4,933
1985	166,481	196,546	54,950	55,126	116,144	40,864	32,602	24,761	23,825	13,793
1986	139,227	136,296	160,891	44,966	45,061	94,646	33,058	26,072	19,600	18,758
1987	454,461	113,985	111,574	131,667	36,763	36,741	76,679	26,513	20,723	15,506
1988	247,942	372,071	93,314	91,324	107,708	30,024	29,890	62,000	21,321	16,617
1989	251,015	202,976	304,522	76,318	74,524	87,338	23,985	23,320	47,365	16,109
1990	164,737	205,506	166,163	249,230	62,413	60,813	70,903	19,313	18,642	37,719
1991	170,290	134,867	168,221	135,959	203,666	50,816	49,088	56,458	15,193	14,572
1992	196,163	139,408	110,386	137,595	110,983	165,298	40,688	38,472	43,413	11,566
1993	149,307	160,598	114,122	90,339	112,508	90,522	134,036	32,688	30,654	34,441
1994	179,097	122,238	131,472	93,404	73,887	91,837	73,547	108,099	26,190	24,475
1995	231,569	146,625	100,065	107,591	76,365	60,244	74,399	58,979	85,907	20,715
1996	303,746	189,587	120,036	81,904	88,014	62,368	49,014	60,165	47,439	68,903
1997	243,434	248,676	155,201	98,237	66,972	71,792	50,581	39,389	47,960	37,655
1998	308,227	199,301	203,581	127,033	80,361	54,696	58,407	40,899	31,678	38,461
1999	432,034	252,345	163,153	166,609	103,873	65,549	44,356	46,933	32,598	25,140
2000	277,924	353,710	206,583	133,540	136,287	84,825	53,314	35,850	37,719	26,121
2001	327,141	227,537	289,561	169,078	109,216	111,234	68,896	42,972	28,698	30,086
2002	370,909	267,831	186,270	236,986	138,273	89,123	90,305	55,480	34,355	22,856
2003	479,722	303,666	219,261	152,460	193,851	112,908	72,475	72,958	44,564	27,511
2004	284,973	392,750	248,596	179,459	124,703	158,265	91,778	58,505	58,533	35,637
2005	193,942	233,307	321,515	203,449	146,743	101,720	128,354	73,757	46,637	46,462
2006	319,339	158,782	190,997	263,156	166,417	119,820	82,711	103,681	59,230	37,337
2007	241,237	261,446	129,988	156,333	215,272	135,916	97,486	66,889	83,397	47,508
2008	142,900	197,504	214,038	106,401	127,905	175,892	110,702	79,006	53,968	67,131

Table 6.9 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2008.

	females				numbers at age (1,000s)						
	11	12	13	14	15	16	17	18	19	20	21
1976	5,412	4,668	4,073	3,578	3,162	2,803	2,477	2,197	1,929	1,689	3,826
1977	4,541	3,821	3,293	2,872	2,523	2,230	1,976	1,747	1,549	1,360	3,889
1978	4,195	3,389	2,850	2,456	2,142	1,882	1,663	1,474	1,303	1,155	3,915
1979	4,232	3,177	2,565	2,157	1,858	1,621	1,424	1,258	1,115	986	3,837
1980	4,734	3,121	2,341	1,890	1,589	1,369	1,194	1,049	927	822	3,553
1981	6,544	3,401	2,241	1,680	1,357	1,141	983	857	753	665	3,140
1982	13,285	4,744	2,464	1,623	1,217	983	826	712	621	545	2,756
1983	11,817	10,049	3,587	1,863	1,227	920	743	624	538	469	2,496
1984	11,497	8,833	7,508	2,679	1,391	916	687	555	466	402	2,215
1985	3,816	8,885	6,824	5,799	2,070	1,075	708	531	429	360	2,021
1986	10,837	2,996	6,974	5,356	4,552	1,624	843	556	417	336	1,869
1987	14,812	8,552	2,364	5,502	4,226	3,591	1,282	665	438	329	1,740
1988	12,420	11,860	6,847	1,893	4,405	3,383	2,875	1,026	533	351	1,656
1989	12,502	9,330	8,906	5,140	1,421	3,307	2,540	2,158	770	400	1,507
1990	12,810	9,936	7,414	7,077	4,085	1,129	2,628	2,018	1,715	612	1,515
1991	29,412	9,980	7,739	5,775	5,511	3,181	879	2,047	1,572	1,336	1,657
1992	11,051	22,275	7,555	5,858	4,371	4,172	2,408	666	1,549	1,190	2,265
1993	9,160	8,747	17,629	5,979	4,636	3,459	3,301	1,905	527	1,226	2,734
1994	27,463	7,301	6,971	14,048	4,765	3,694	2,756	2,631	1,518	420	3,155
1995	19,323	21,668	5,760	5,498	11,081	3,758	2,914	2,174	2,075	1,198	2,820
1996	16,597	15,476	17,352	4,612	4,403	8,873	3,009	2,333	1,741	1,662	3,217
1997	54,602	13,145	12,255	13,740	3,652	3,486	7,026	2,383	1,848	1,378	3,863
1998	30,163	43,722	10,524	9,811	11,000	2,924	2,791	5,625	1,908	1,479	4,196
1999	30,472	23,885	34,616	8,332	7,767	8,708	2,315	2,210	4,453	1,510	4,493
2000	20,121	24,380	19,107	27,691	6,665	6,213	6,966	1,851	1,768	3,562	4,802
2001	20,806	16,020	19,408	15,210	22,042	5,305	4,946	5,545	1,474	1,407	6,658
2002	23,927	16,538	12,732	15,424	12,087	17,517	4,216	3,930	4,406	1,171	6,409
2003	18,282	19,130	13,221	10,178	12,330	9,662	14,002	3,370	3,142	3,522	6,059
2004	21,973	14,595	15,271	10,554	8,124	9,841	7,712	11,177	2,690	2,508	7,648
2005	28,241	17,403	11,558	12,092	8,356	6,433	7,793	6,107	8,850	2,130	8,042
2006	37,152	22,573	13,908	9,237	9,663	6,678	5,141	6,227	4,880	7,072	8,129
2007	29,915	29,756	18,077	11,138	7,397	7,738	5,348	4,117	4,987	3,908	12,173
2008	38,208	24,051	23,921	14,532	8,953	5,946	6,221	4,299	3,309	4,009	12,927

Table 6.9 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2008.

males	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	104,660	27,849	62,856	46,677	38,068	12,961	6,348	3,840	2,569	1,820
1977	135,813	74,434	19,787	44,565	32,945	26,625	8,915	4,258	2,501	1,631
1978	108,130	96,619	52,921	14,049	31,553	23,193	18,551	6,115	2,867	1,657
1979	111,748	76,931	68,706	37,590	9,956	22,252	16,214	12,797	4,153	1,921
1980	112,372	79,494	54,689	48,768	26,597	6,999	15,461	11,067	8,555	2,727
1981	259,469	79,926	56,492	38,792	34,455	18,640	4,834	10,444	7,284	5,505
1982	100,564	184,560	56,806	40,081	27,421	24,173	12,901	3,277	6,911	4,720
1983	82,004	71,548	131,240	40,348	28,400	19,335	16,895	8,896	2,224	4,627
1984	240,079	58,339	50,870	93,188	28,570	19,998	13,477	11,595	5,996	1,476
1985	166,481	170,827	41,495	36,153	66,111	20,197	14,046	9,373	7,972	4,082
1986	139,227	118,470	121,529	29,502	25,671	46,823	14,238	9,831	6,506	5,494
1987	454,461	99,078	84,286	86,417	20,955	18,193	33,046	9,986	6,845	4,501
1988	247,942	323,433	70,502	59,957	61,431	14,876	12,883	23,312	7,013	4,789
1989	251,015	176,396	229,972	50,068	42,467	43,282	10,381	8,859	15,759	4,671
1990	164,737	178,636	125,508	163,559	35,577	30,121	30,597	7,301	6,194	10,963
1991	170,290	117,224	127,072	89,216	116,089	25,174	21,196	21,350	5,045	4,244
1992	196,163	121,156	83,358	90,261	63,221	81,870	17,600	14,623	14,503	3,381
1993	149,307	139,597	86,200	59,279	64,122	44,819	57,821	12,359	10,200	10,057
1994	179,097	106,257	99,329	61,311	42,129	45,495	31,704	40,715	8,656	7,111
1995	231,569	127,450	75,597	70,631	43,548	29,855	32,107	22,235	28,345	5,988
1996	303,746	164,804	90,691	53,776	50,210	30,915	21,142	22,653	15,618	19,835
1997	243,434	216,158	117,256	64,495	38,204	35,598	21,837	14,850	15,806	10,836
1998	308,227	173,248	153,814	83,410	45,848	27,121	25,208	15,405	10,430	11,059
1999	432,034	219,347	123,263	109,384	59,257	32,504	19,156	17,704	10,748	7,235
2000	277,924	307,471	156,082	87,682	77,754	42,062	23,013	13,510	12,429	7,515
2001	327,141	197,788	218,775	111,012	62,310	55,161	29,747	16,198	9,456	8,658
2002	370,909	232,812	140,729	155,596	78,883	44,196	38,995	20,924	11,327	6,579
2003	479,722	263,968	165,661	100,104	110,599	55,989	31,286	27,493	14,683	7,916
2004	284,973	341,405	187,828	117,835	71,149	78,487	39,621	22,045	19,276	10,249
2005	193,942	202,799	242,905	133,573	83,713	50,444	55,440	27,829	15,382	13,373
2006	319,339	138,024	144,305	172,783	94,944	59,415	35,706	39,083	19,525	10,747
2007	241,237	227,269	98,216	102,652	122,828	67,403	42,077	25,192	27,454	13,663
2008	142,900	171,689	161,728	69,874	72,989	87,238	47,775	29,732	17,737	19,269

Table 6.9 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2008.

males				numbers at age (1,000s)							
	11	12	13	14	15	16	17	18	19	20	21
1976	1,335	1,001	759	580	445	343	264	203	155	118	146
1977	1,136	825	616	466	356	273	210	162	125	95	162
1978	1,069	741	536	400	302	231	177	136	105	81	167
1979	1,101	707	488	353	263	199	152	117	90	69	163
1980	1,247	709	454	313	226	169	127	97	75	57	149
1981	1,729	784	444	284	196	141	105	80	61	47	129
1982	3,518	1,096	495	280	179	123	89	66	50	38	110
1983	3,132	2,323	722	326	184	117	81	58	44	33	98
1984	3,038	2,045	1,512	469	212	120	76	53	38	28	85
1985	998	2,047	1,375	1,016	315	142	80	51	35	26	76
1986	2,799	683	1,399	939	693	215	97	55	35	24	69
1987	3,785	1,924	469	960	644	476	148	67	38	24	64
1988	3,141	2,638	1,340	326	668	448	331	103	46	26	61
1989	3,159	2,060	1,726	875	213	436	293	216	67	30	57
1990	3,239	2,186	1,425	1,192	605	147	301	202	149	46	60
1991	7,468	2,199	1,482	965	808	410	100	204	137	101	72
1992	2,819	4,936	1,450	976	635	531	270	66	134	90	114
1993	2,336	1,943	3,399	998	672	437	366	185	45	92	140
1994	6,990	1,621	1,347	2,356	692	465	303	253	128	31	161
1995	4,898	4,804	1,112	924	1,616	474	319	208	174	88	132
1996	4,180	3,414	3,346	775	643	1,125	330	222	145	121	153
1997	13,709	2,883	2,352	2,304	533	443	774	227	153	100	189
1998	7,562	9,554	2,008	1,638	1,604	371	308	539	158	106	201
1999	7,642	5,215	6,581	1,382	1,127	1,104	255	212	371	109	211
2000	5,046	5,322	3,629	4,578	961	784	768	178	148	258	223
2001	5,218	3,497	3,685	2,512	3,169	665	543	531	123	102	333
2002	6,003	3,611	2,418	2,547	1,736	2,189	460	375	367	85	300
2003	4,585	4,178	2,511	1,681	1,770	1,206	1,521	319	261	255	268
2004	5,510	3,186	2,901	1,743	1,167	1,229	837	1,056	222	181	363
2005	7,084	3,800	2,195	1,998	1,200	803	846	576	727	153	374
2006	9,318	4,928	2,642	1,526	1,388	834	558	588	400	505	366
2007	7,502	6,495	3,433	1,840	1,062	966	581	388	409	279	606
2008	9,570	5,248	4,542	2,400	1,286	742	675	406	271	286	618

Table 6.10 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 2008 = 338,948.

Year class	2007 Assessment	2008 Assessment	shelf survey fish<25 cm
1974	83,117	59,884	
1975	168,219	160,107	
1976	271,177	207,800	
1977	190,823	165,452	
1978	205,941	170,973	
1979	205,839	171,913	
1980	469,176	396,963	86,100
1981	178,084	153,874	290,200
1982	155,476	125,470	57,900
1983	425,395	367,373	62,400
1984	294,680	254,766	150,300
1985	269,357	213,063	94,300
1986	781,139	695,504	200,600
1987	432,562	379,372	273,800
1988	458,701	384,142	105,200
1989	293,467	252,091	71,700
1990	292,240	260,564	79,400
1991	348,334	300,195	96,800
1992	279,592	228,495	126,600
1993	330,379	274,075	75,100
1994	428,024	354,391	55,600
1995	561,995	464,834	108,800
1996	479,979	372,549	93,600
1997	599,679	471,692	92,100
1998	872,260	661,181	126,300
1999	549,027	425,325	164,300
2000	617,032	500,643	108,800
2001	663,439	567,634	253,400
2002	788,196	734,155	406,700
2003	249,560	436,106	407,800
2004		296,806	335,800
2005			495,500
2006			217,200

Table 6.11 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. 2009 ABC is highlighted.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2008	796.049	19.403	0.03
2009	802.128	**156.277**	0.24
2010	686.312	135.503	0.24
2011	594.757	116.555	0.24
2012	514.672	100.637	0.24
2013	445.923	87.598	0.24
2014	396.544	76.776	0.24
2015	362.971	68.649	0.24
2016	340.489	63.188	0.23
2017	325.308	59.283	0.23
2018	315.314	56.701	0.23
2019	309.082	55.121	0.23
2020	305.316	54.165	0.23
2021	303.377	53.620	0.22

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2008	796.049	19.403	0.03
2009	809.179	78.139	0.11
2010	762.368	70.276	0.10
2011	723.239	66.687	0.10
2012	677.456	62.706	0.10
2013	628.706	58.645	0.10
2014	588.612	54.542	0.10
2015	556.594	50.871	0.10
2016	530.876	48.002	0.10
2017	510.015	45.851	0.10
2018	493.218	44.218	0.10
2019	480.091	42.956	0.10
2020	469.969	41.979	0.10
2021	462.591	41.249	0.10

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2008	796.049	19.403	0.03
2009	814.277	16.839	0.02
2010	821.936	19.009	0.03
2011	825.038	19.169	0.03
2012	814.217	19.048	0.03
2013	792.990	18.718	0.03
2014	773.359	18.198	0.03
2015	755.332	17.613	0.03
2016	738.213	17.090	0.03
2017	721.888	16.646	0.03
2018	706.840	16.269	0.03
2019	693.639	15.944	0.03
2020	682.238	15.663	0.03
2021	673.028	15.433	0.03

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2008	796.049	19.403	0.03
2009	815.619	0	0
2010	838.686	0	0
2011	857.969	0	0
2012	862.035	0	0
2013	853.949	0	0
2014	845.469	0	0
2015	836.466	0	0
2016	826.325	0	0
2017	815.188	0	0
2018	803.882	0	0
2019	793.287	0	0
2020	783.573	0	0
2021	775.428	0	0

Table 6.11 (continued).

Scenario 6
Determination of whether arrowtooth flounder are currently overfished
B35=255,680

Year	Female spawning biomass	catch	F
2008	796.049	19.403	0.03
2009	798.831	**190.345**	0.29
2010	653.689	157.477	0.29
2011	545.400	129.928	0.29
2012	457.499	108.417	0.29
2013	386.666	91.908	0.29
2014	338.621	79.006	0.29
2015	308.319	68.872	0.29
2016	290.646	61.689	0.28
2017	281.197	58.044	0.27
2018	276.132	56.316	0.27
2019	273.593	55.511	0.26
2020	272.439	55.142	0.26
2021	272.269	55.028	0.26

Scenario 7
Determination of whether arrowtooth flounder are approaching an overfished condition
B35=255,680

Year	Female spawning biomass	catch	F
2008	796.049	19.403	0.03
2009	802.128	156.277	0.24
2010	686.312	135.503	0.24
2011	592.313	141.937	0.29
2012	490.543	116.965	0.29
2013	409.416	97.820	0.29
2014	353.989	82.998	0.29
2015	318.474	72.098	0.29
2016	296.782	63.833	0.28
2017	284.647	59.275	0.27
2018	277.967	56.966	0.27
2019	274.511	55.833	0.27
2020	272.859	55.284	0.26
2021	272.436	55.080	0.26

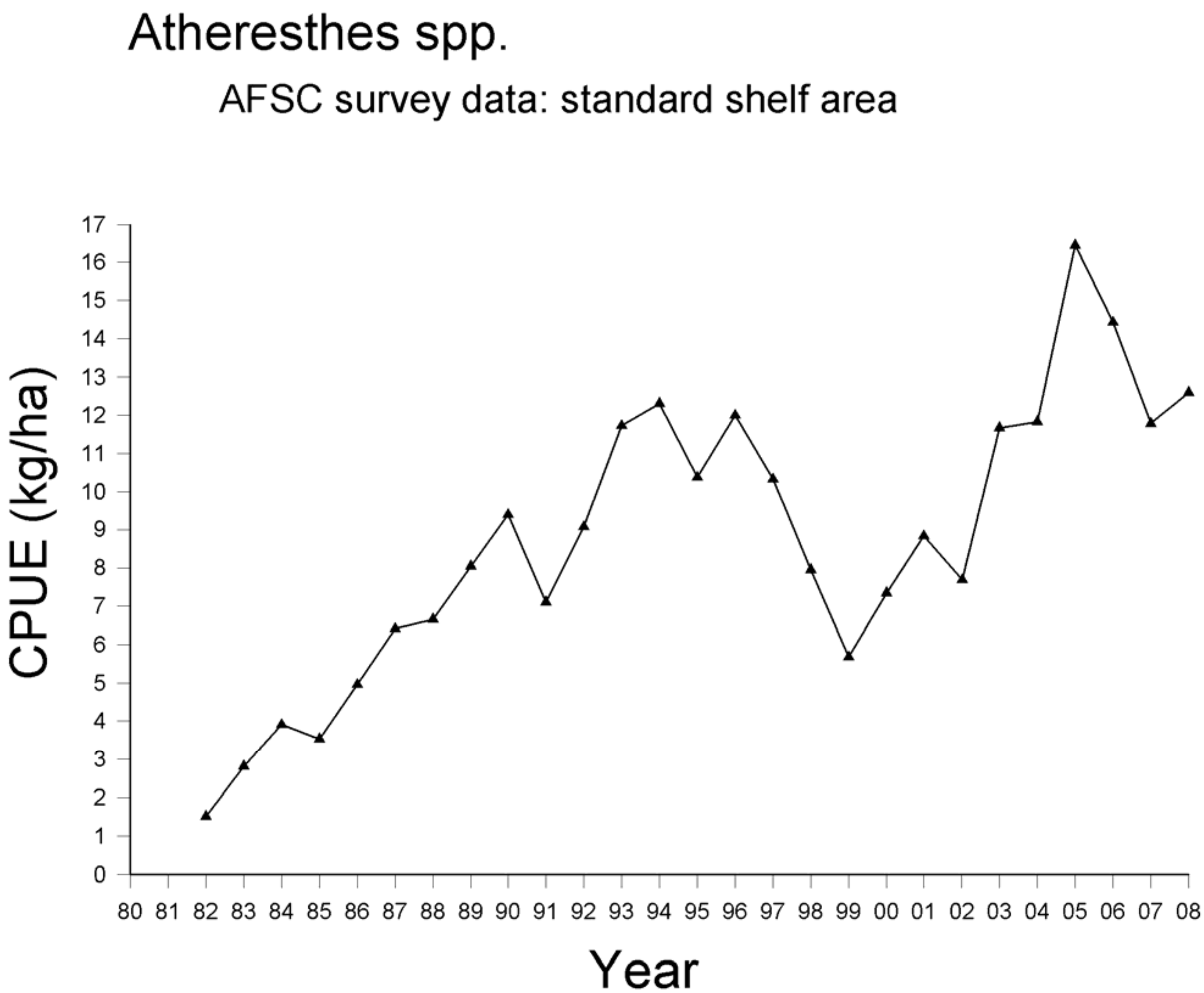


Figure 6.1 Atheresthes species combined CPUE (kg/ha) from the standard shelf survey area.

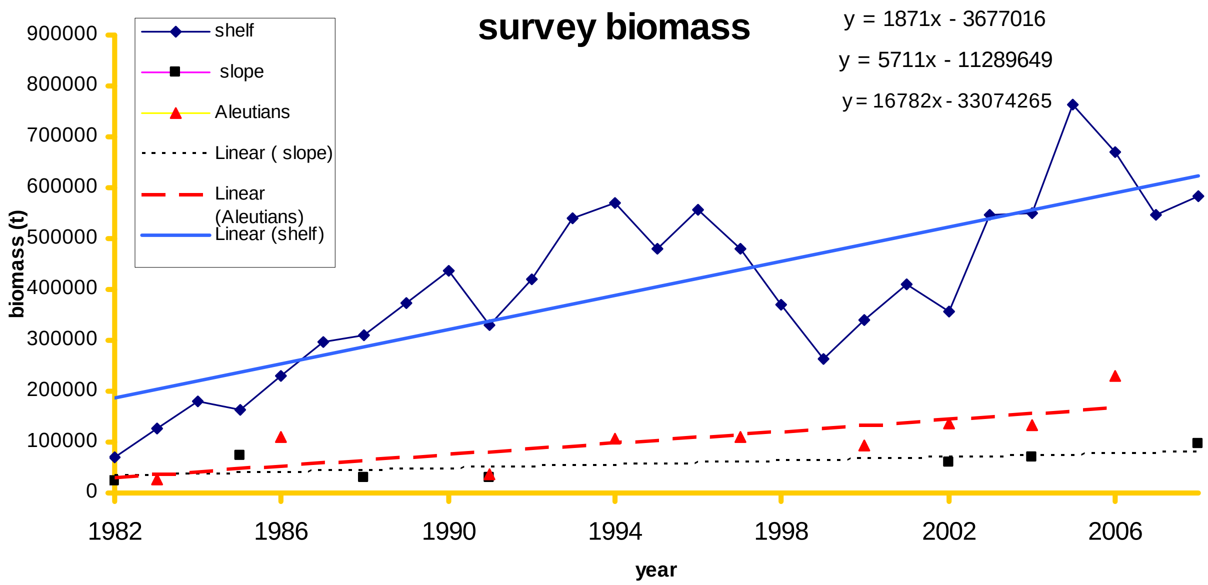


Figure 6.2—Linear regressions of trawl survey estimates for the Bering Sea shelf, slope and the Aleutian Islands used to estimate the proportion of biomass in each area.

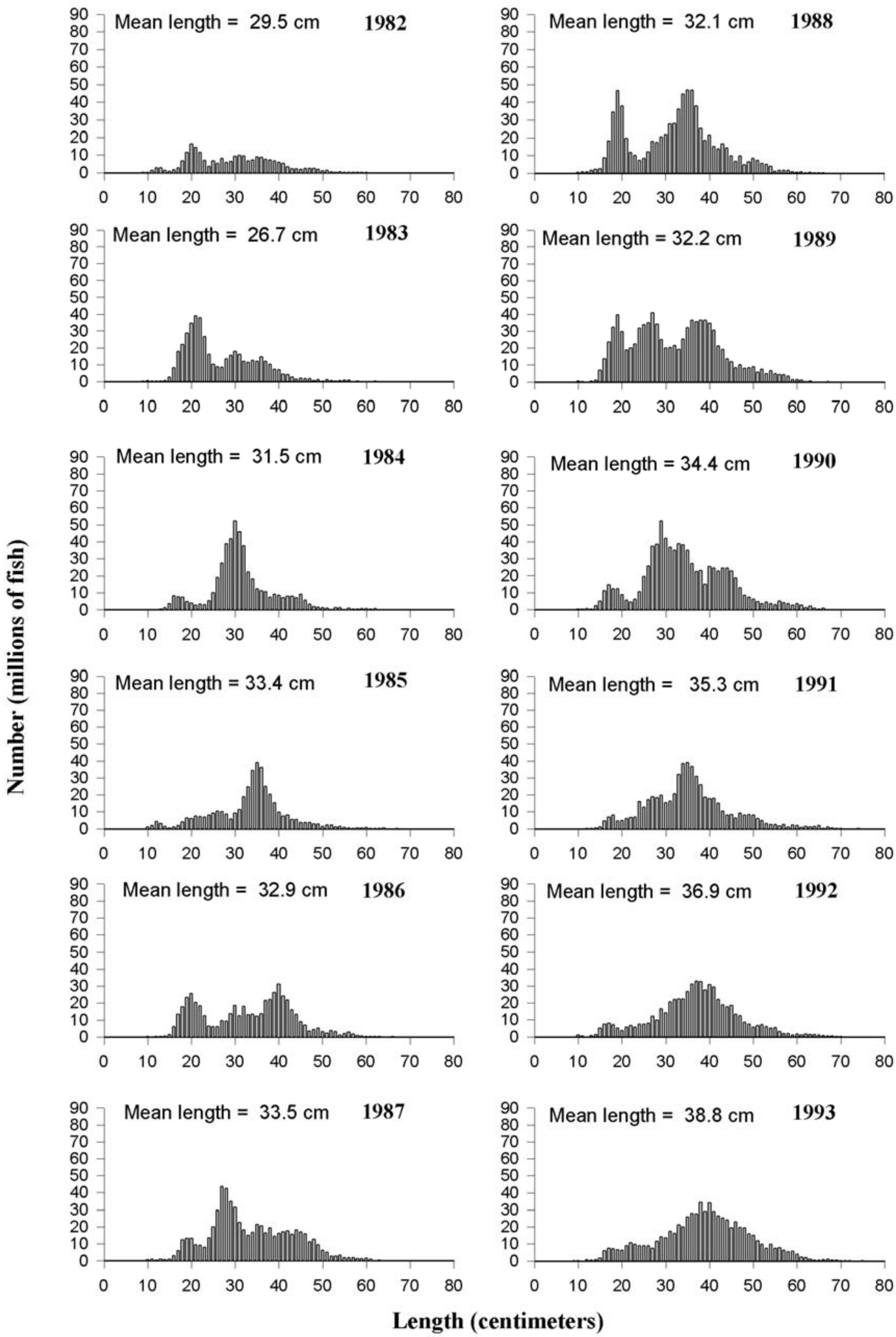


Figure 6.3. Size composition of arrowtooth flounder from the shelf trawl surveys.

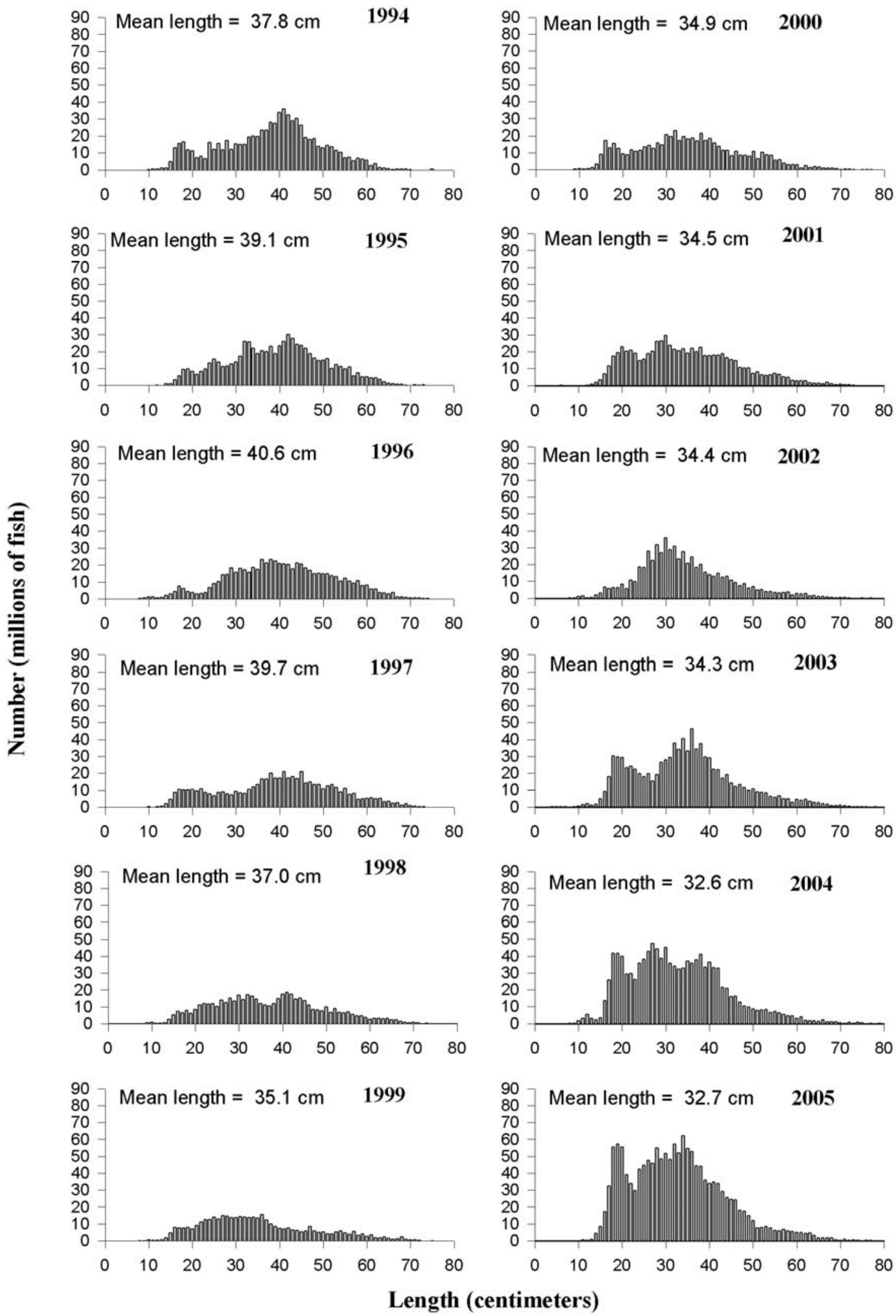


Figure 6.3. continued.

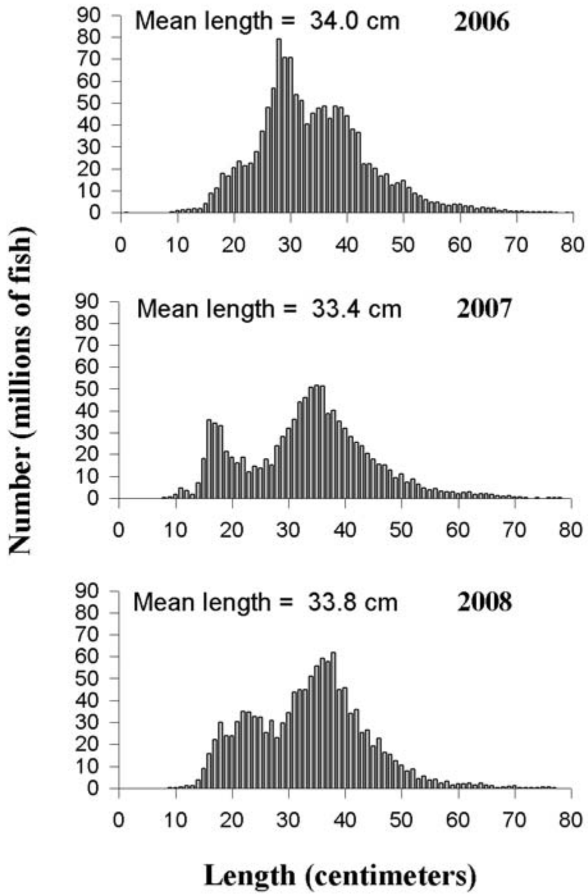


Figure 6.3. continued.

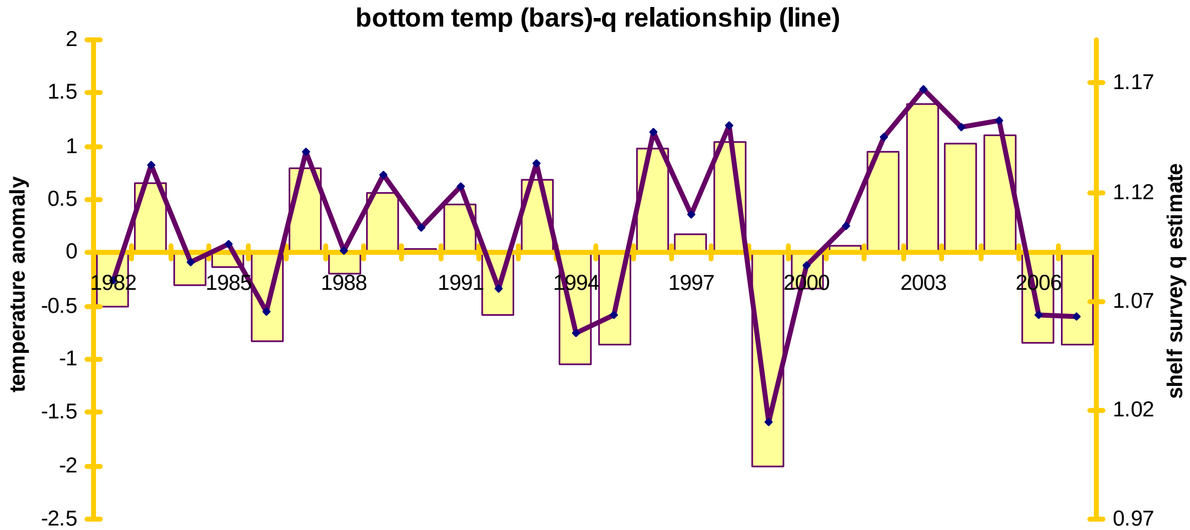


Figure 6.4--Shelf survey annual avg. bottom temperature anomalies (bars), model estimate of annual shelf survey q due to effect of water temperature (diamonds with lines).

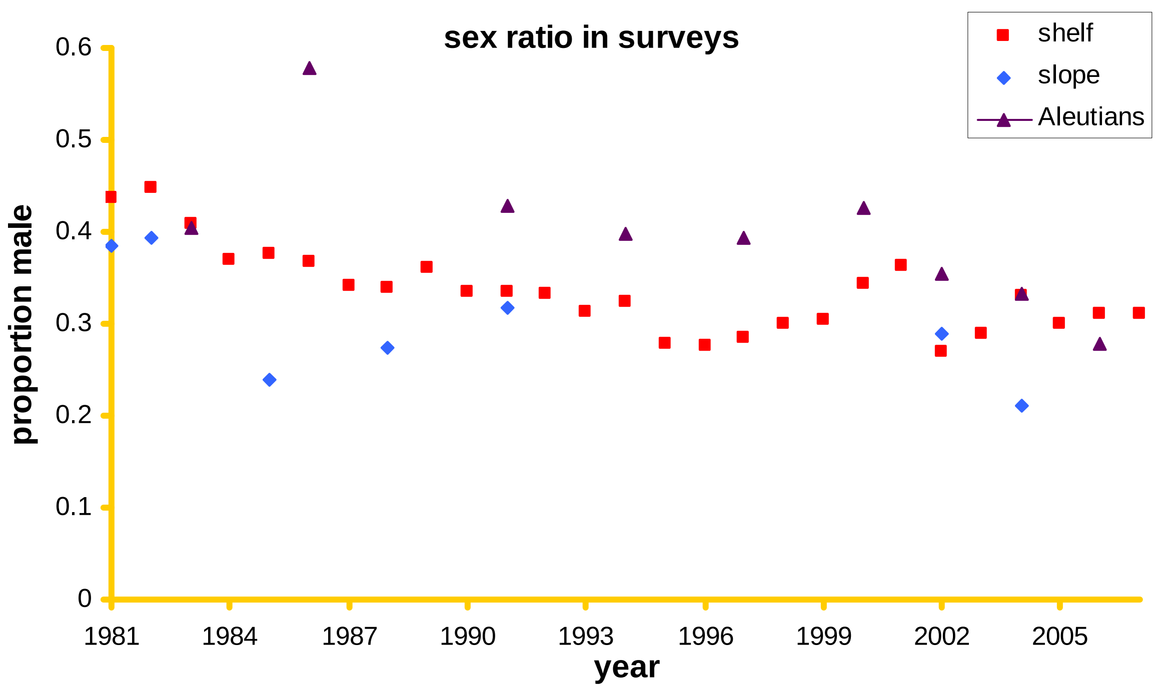


Figure 6.5--Proportion of the estimated male population from Bering Sea and Aleutian Islands trawl surveys on the continental shelf and slope.

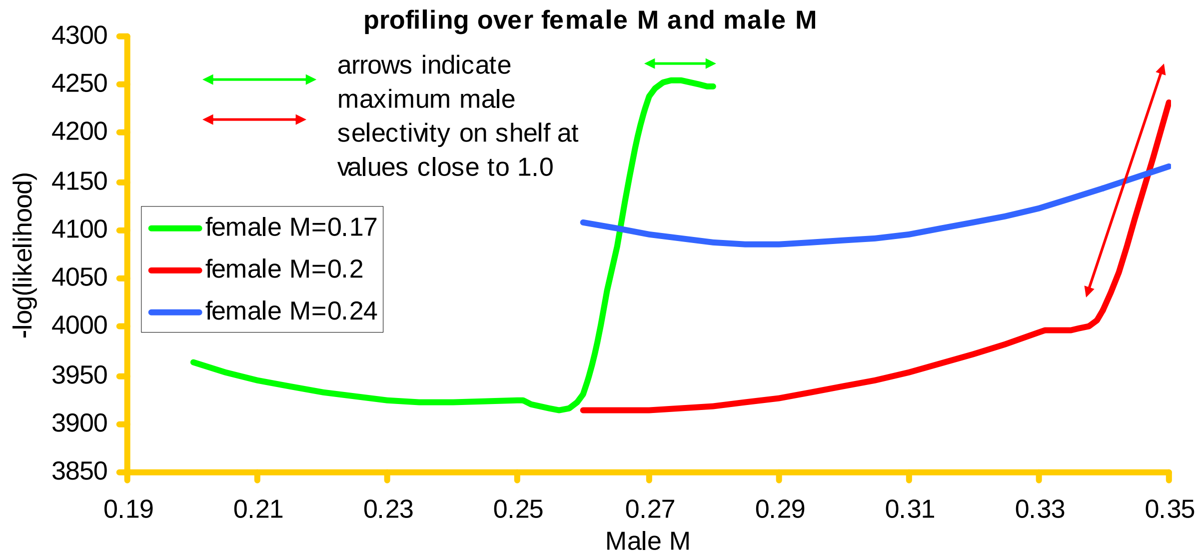


Figure 6.6—Fit to the stock assessment model in terms of –log(likelihood) when profiling over male natural mortality (x axis) for three different levels of female natural mortality. Arrows indicate the values of male natural mortality where the model estimates that maximum male selectivity is close to 1.0 for a given combination of male and female natural mortality.

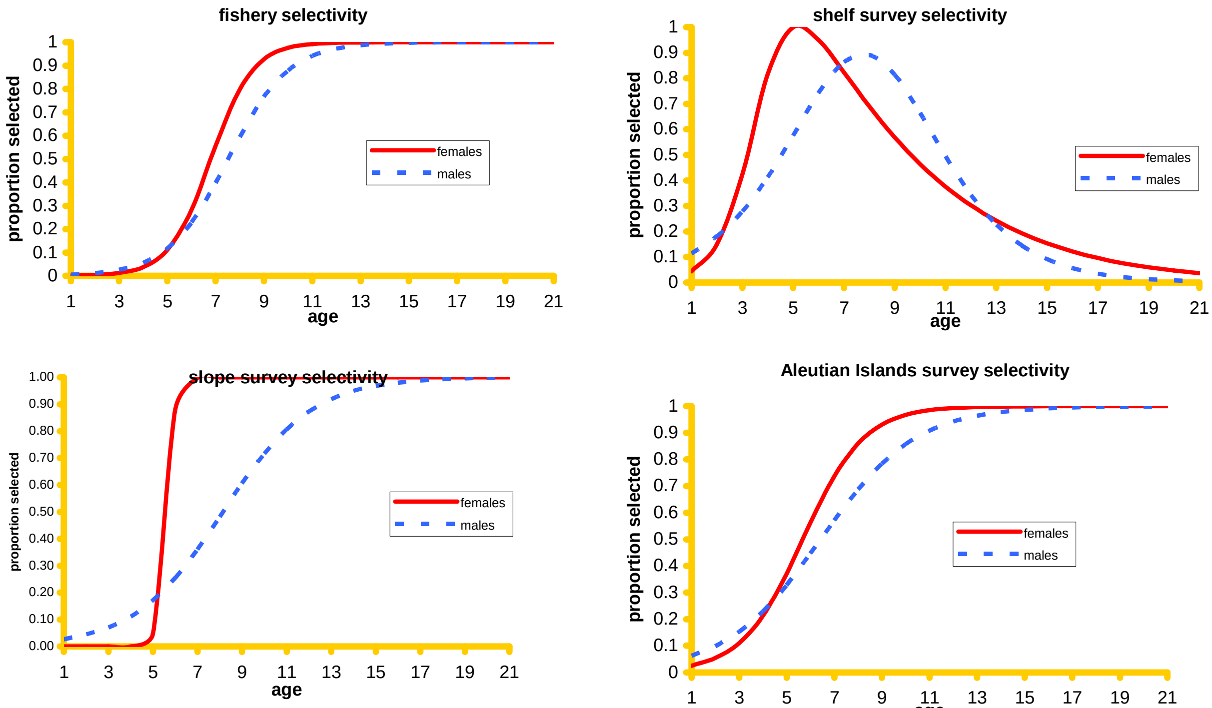


Figure 6.7--Age-specific fishery selectivity (top left panel), shelf survey selectivity (top right panel) slope survey selectivity (bottom left panel) and Aleutian Islands survey selectivity (bottom right panel), by sex, estimated from the stock assessment model.

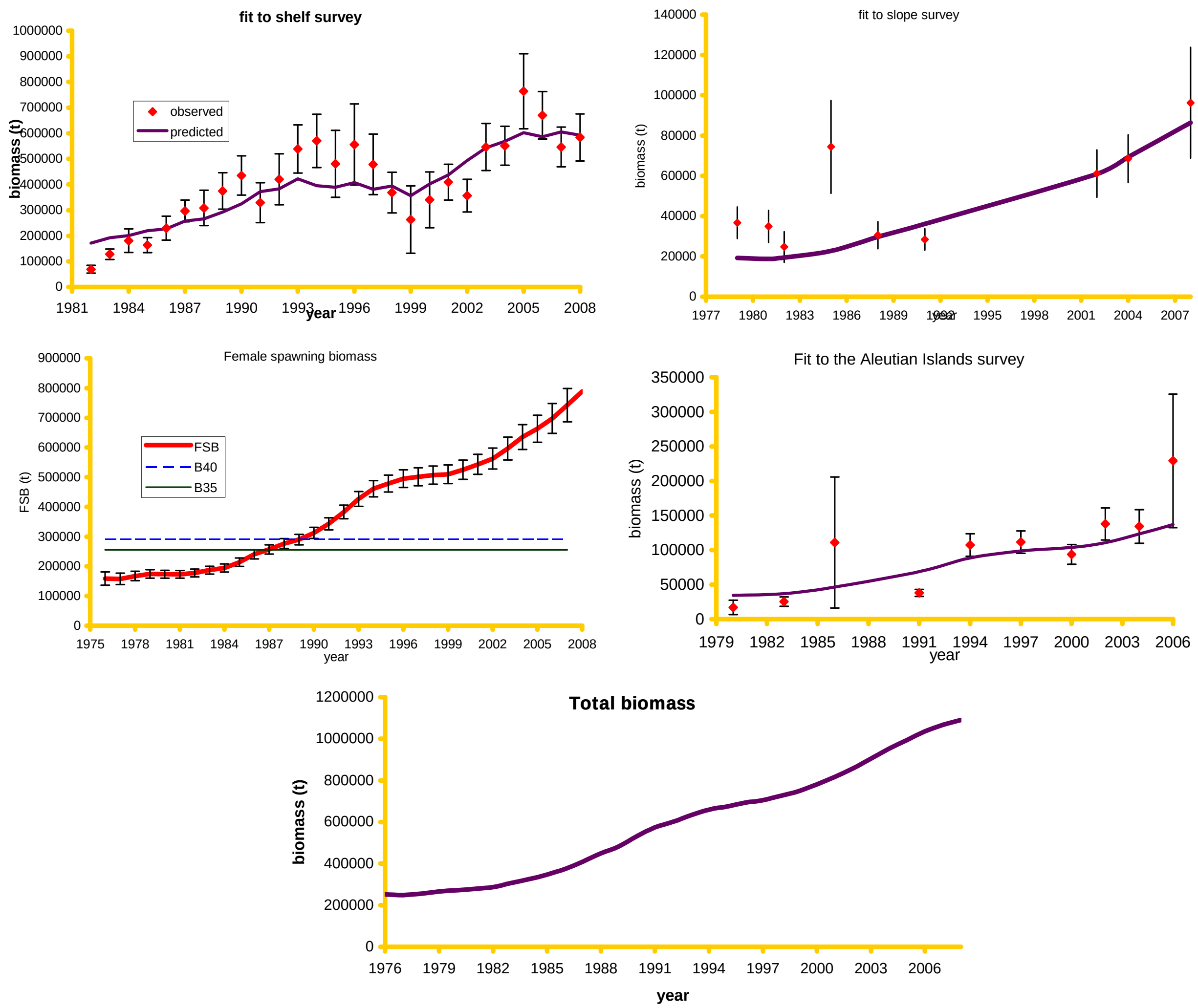


Figure 6.8--Stock assessment model results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), estimate of female spawning biomass with B35 and B40 indicated (middle left panel), the fit to the Aleutian Islands survey (middle right panel) and the estimate of total biomass (bottom panel).

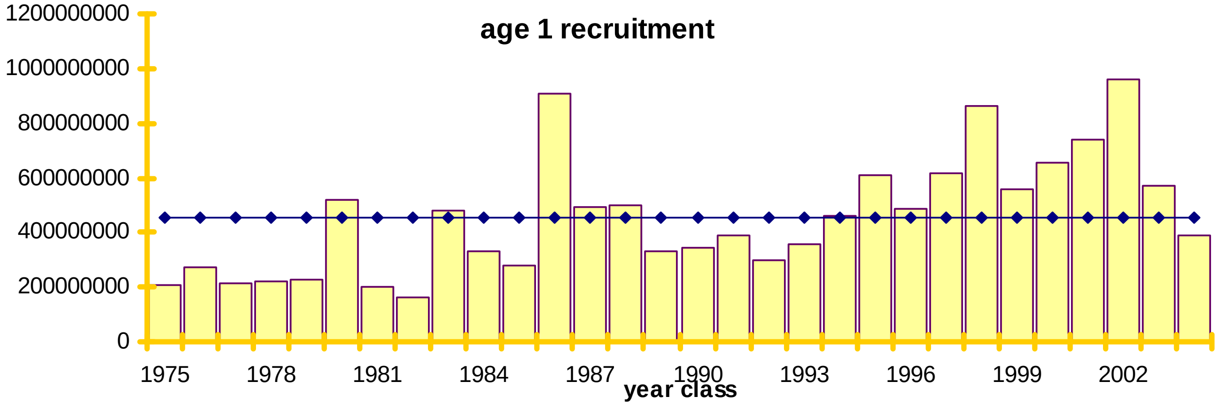


Figure 6.9--Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model.

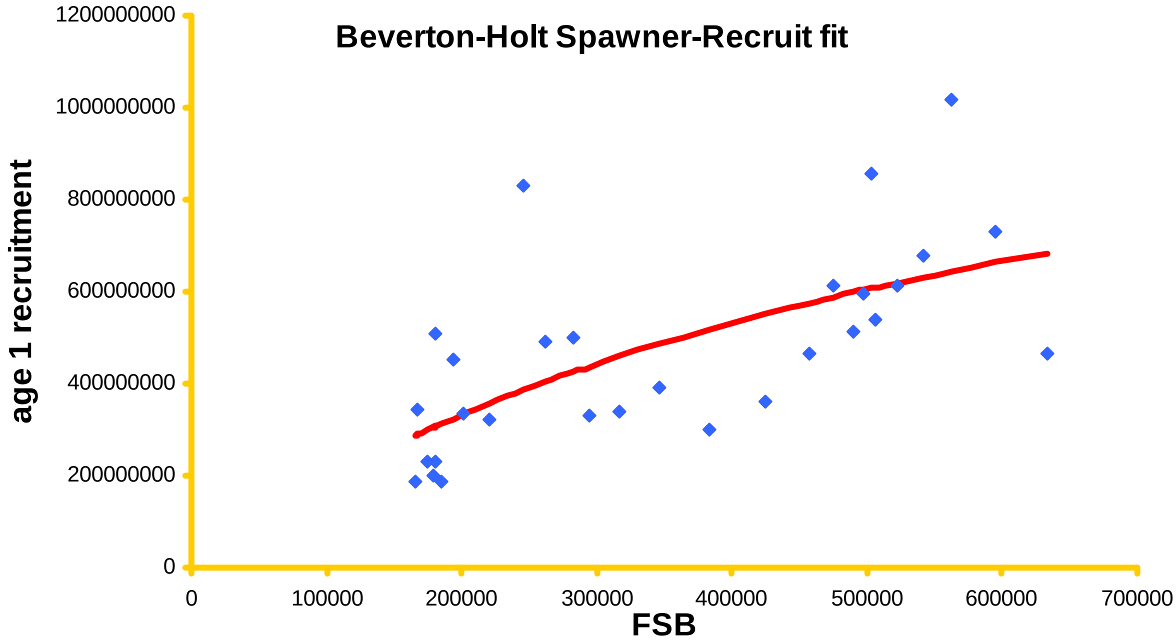


Figure 6.10—Beverton and Holt spawner recruit model fit to the age 1 recruitment data for Bering Sea arrowtooth flounder.

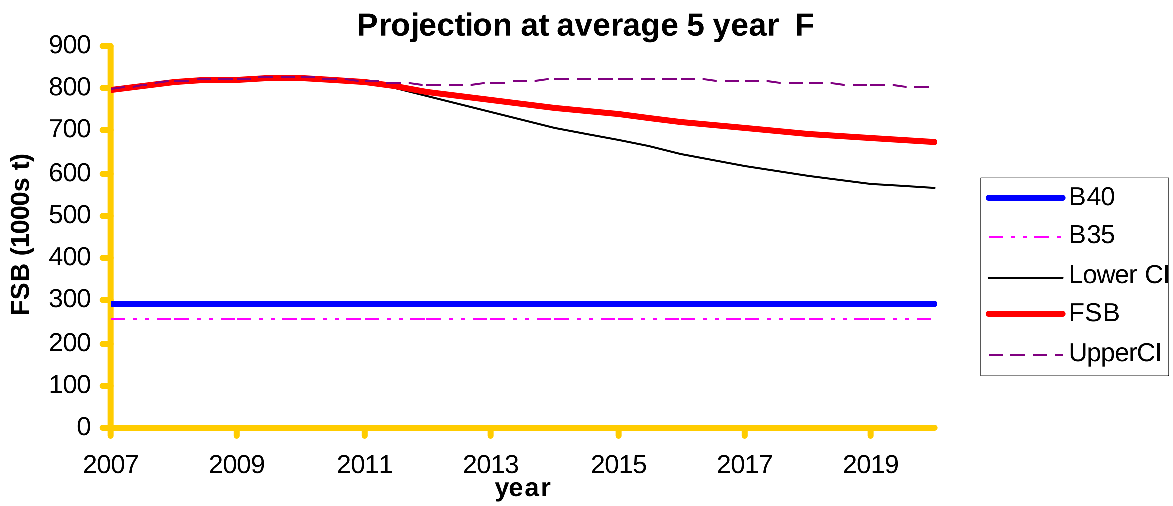


Figure 6.11--Projected female spawning biomass (1,000s t) of arrowtooth flounder if future harvest is at the same fishing mortality rate as the past five years.

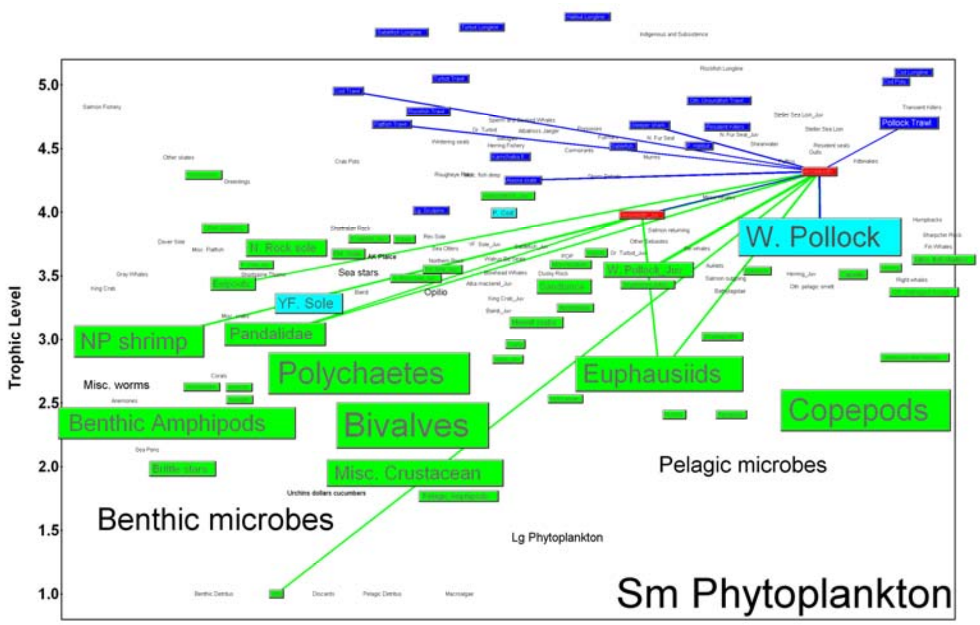


Figure 6.12. Adult and juvenile arrowtooth flounder in the EBS food web. Box size is proportional to biomass, and lines between boxes represent the most significant energy flows. Predators of arrowtooth are dark blue, prey of arrowtooth are green, and species that are both predators and prey of arrowtooth are light blue.

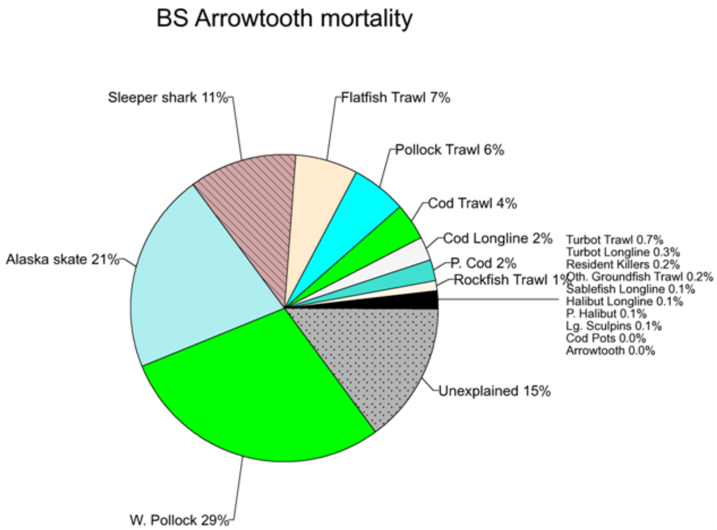


Figure 6.13. Mortality of Bering Sea arrowtooth flounder >20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. “Unexplained” mortality is the difference between the stock 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).

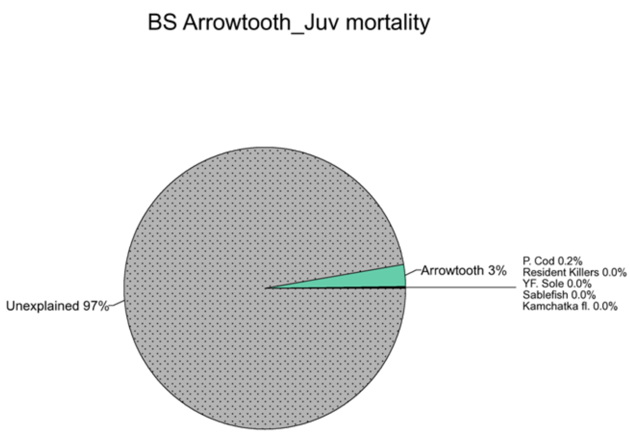


Figure 6.14. Mortality of Bering Sea arrowtooth flounder <20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. “Unexplained” mortality is the difference between the stock 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).

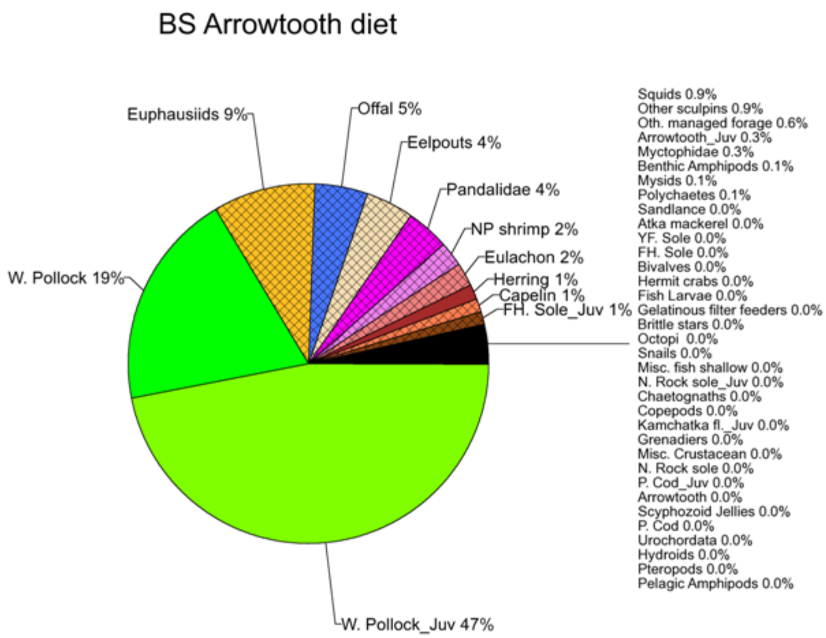


Figure 6.15. Diet of Bering Sea arrowtooth flounder >20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good 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).

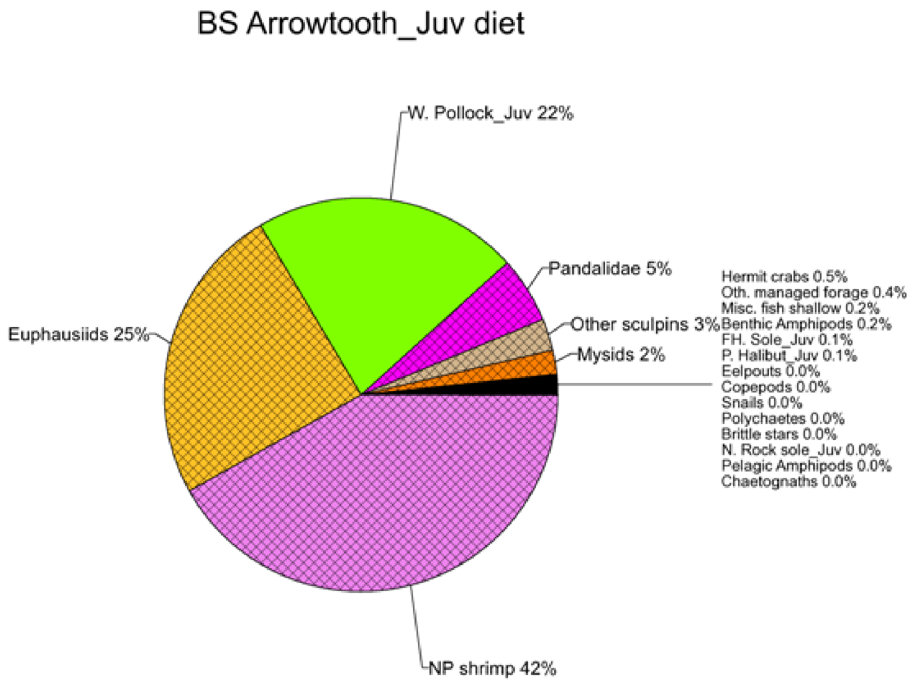


Figure 6.16. Diet of Bering Sea arrowtooth flounder <20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good 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).

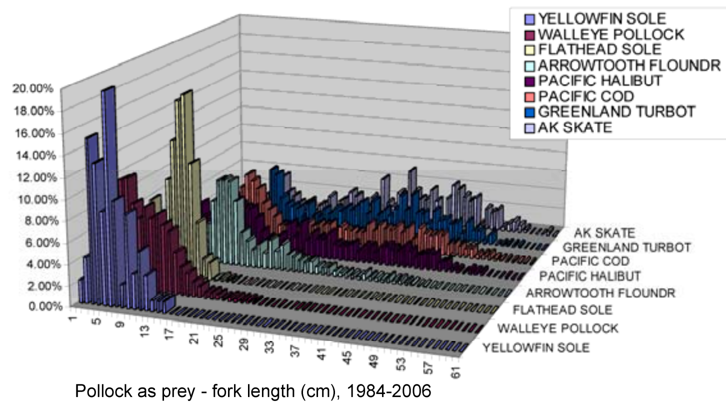


Figure 6.17. Length frequency of pollock found in stomachs, from groundfish food habits collected from 1984-2006 on AFSC summer trawl surveys in the eastern Berng Sea. Predators are sorted by median prey length of pollock in their stomachs. All lengths of predators are combined.

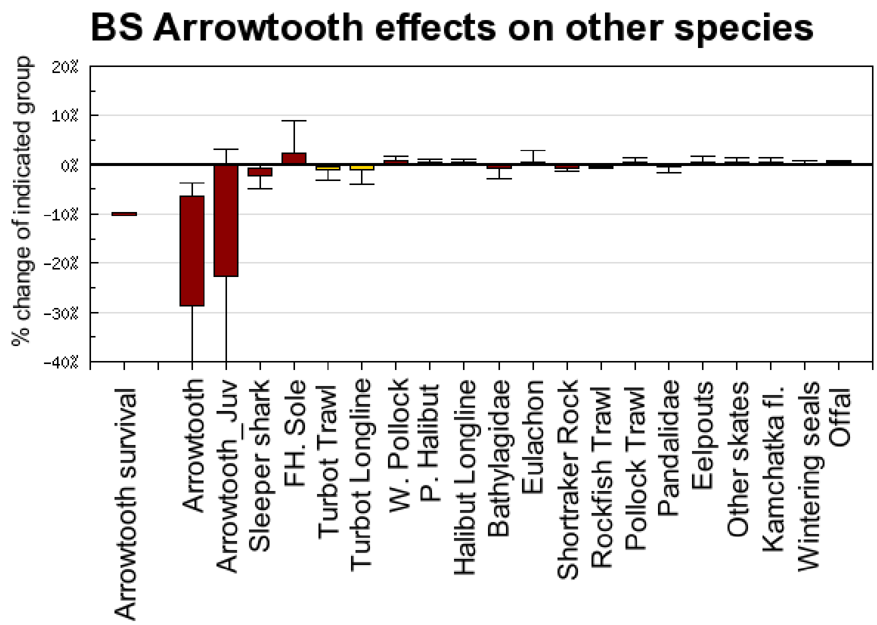


Figure 6.18. Effect of changing arrowtooth > 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting 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).

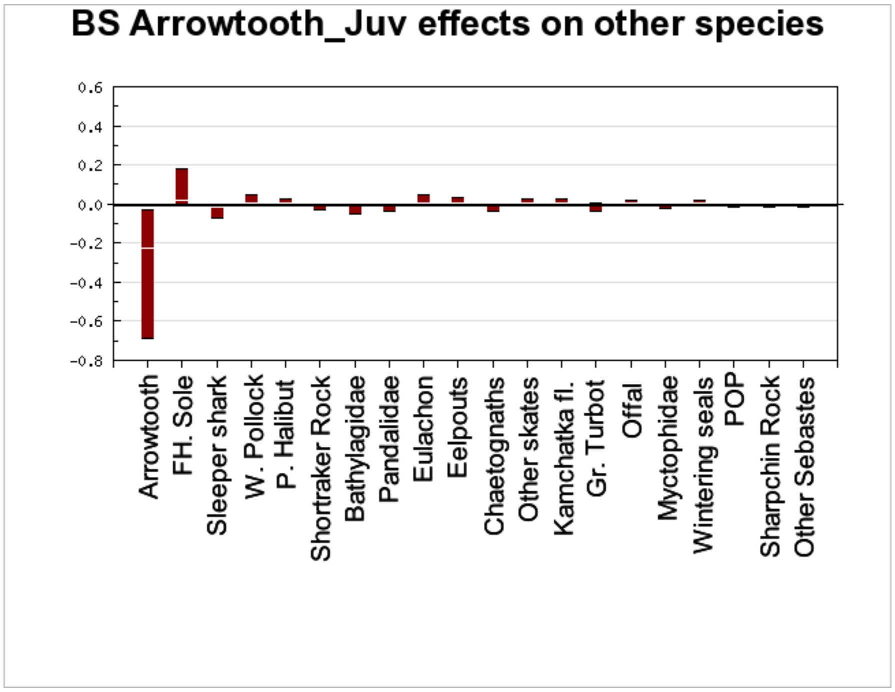


Figure 6.19. Effect of changing arrowtooth < 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting 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).

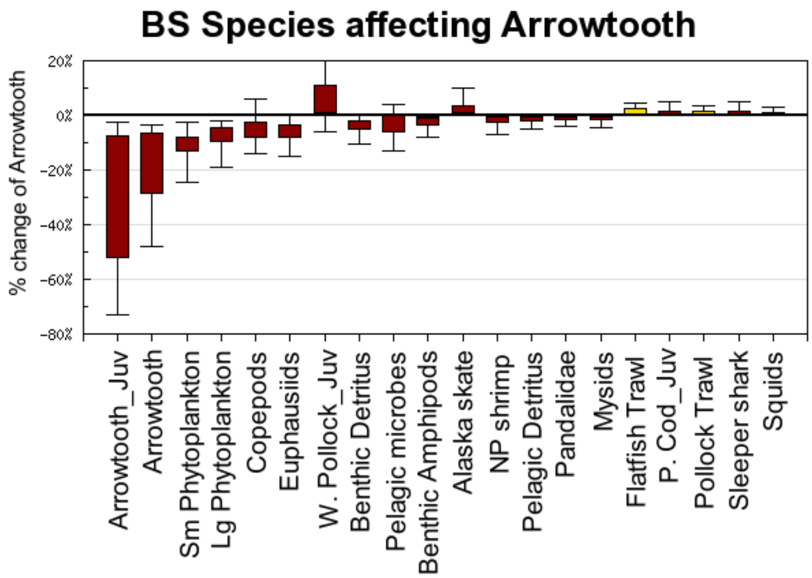


Figure 6.20. Effect of reducing fisheries catch (yellow) and other species survival (dark red) on arrowtooth > 20 cm biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting percent change in the biomass of adult arrowtooth after 30 years for 50% of feasible ecosystems, error bars show results for 95% of feasible ecosystems (see Aydin et al. in press for detailed Sense methods).

APPENDIX

Figures showing the fit of the stock assessment model to the time-series of shelf, slope and Aleutian Islands survey ,size composition data by sex (estimated values are the dotted lines) and the fishery size composition data from 1978-90.

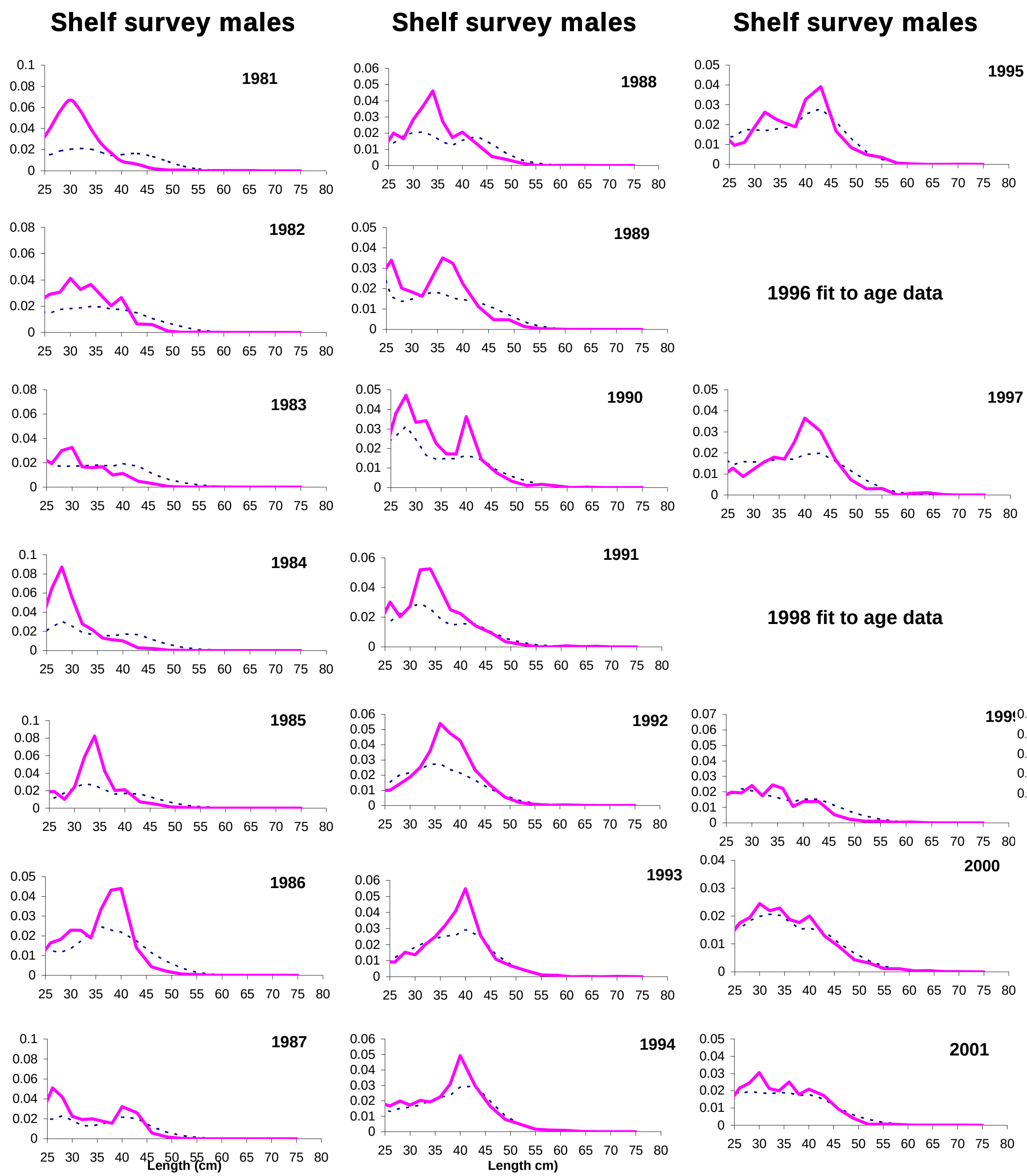
Table of arrowtooth flounder catch during research activities by the Alaska Fisheries Science Center, 1977-2008.

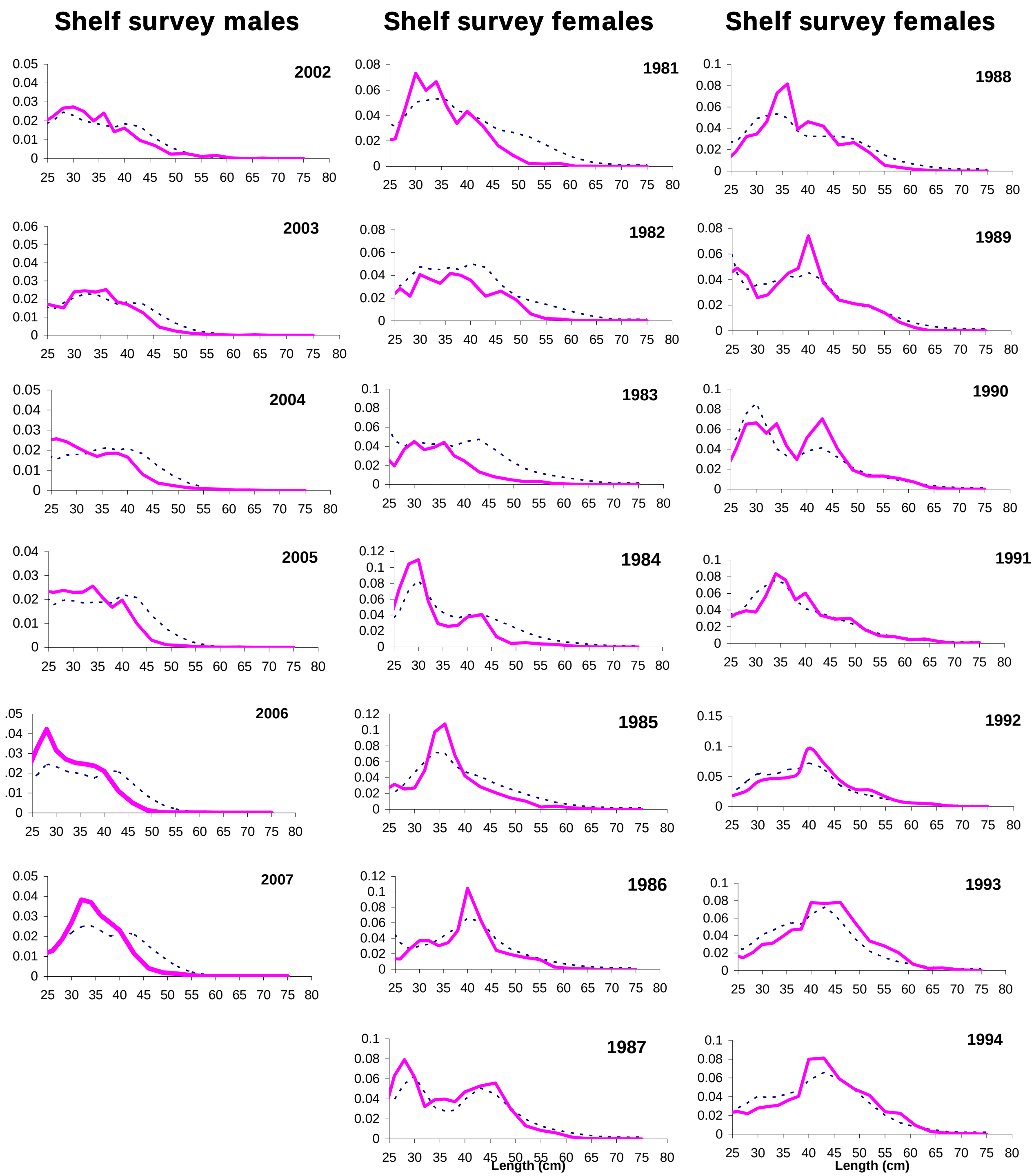
BSAI arrowtooth flounder TAC (1986-2008) and ABC (1982-2008)

Shelf survey biomass estimates for arrowtooth and Kamchatka flounder 1982-2008

Figure showing the number of hauls with arrowtooth flounder and Kamchatka flounder during Bering Sea shelf surveys

Phase-plane figure for BSAI arrowtooth flounder indicating the estimated FSB time-series relative to B40 and F40 estimates in from the 2008 assessment.


Shelf survey males
Shelf survey males
Shelf survey males
1981
1988
1995
1982
1989
1996 fit to age data
1983
1990
1997
1984
1991
1998 fit to age data
1985
1992
1999
1986
1993
2000
1987
1994
2001
Length (cm)
Length cm)


Shelf survey males
Shelf survey females
Shelf survey females
2002
2003
2004
2005
2006
2007
1981
1982
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1990
1991
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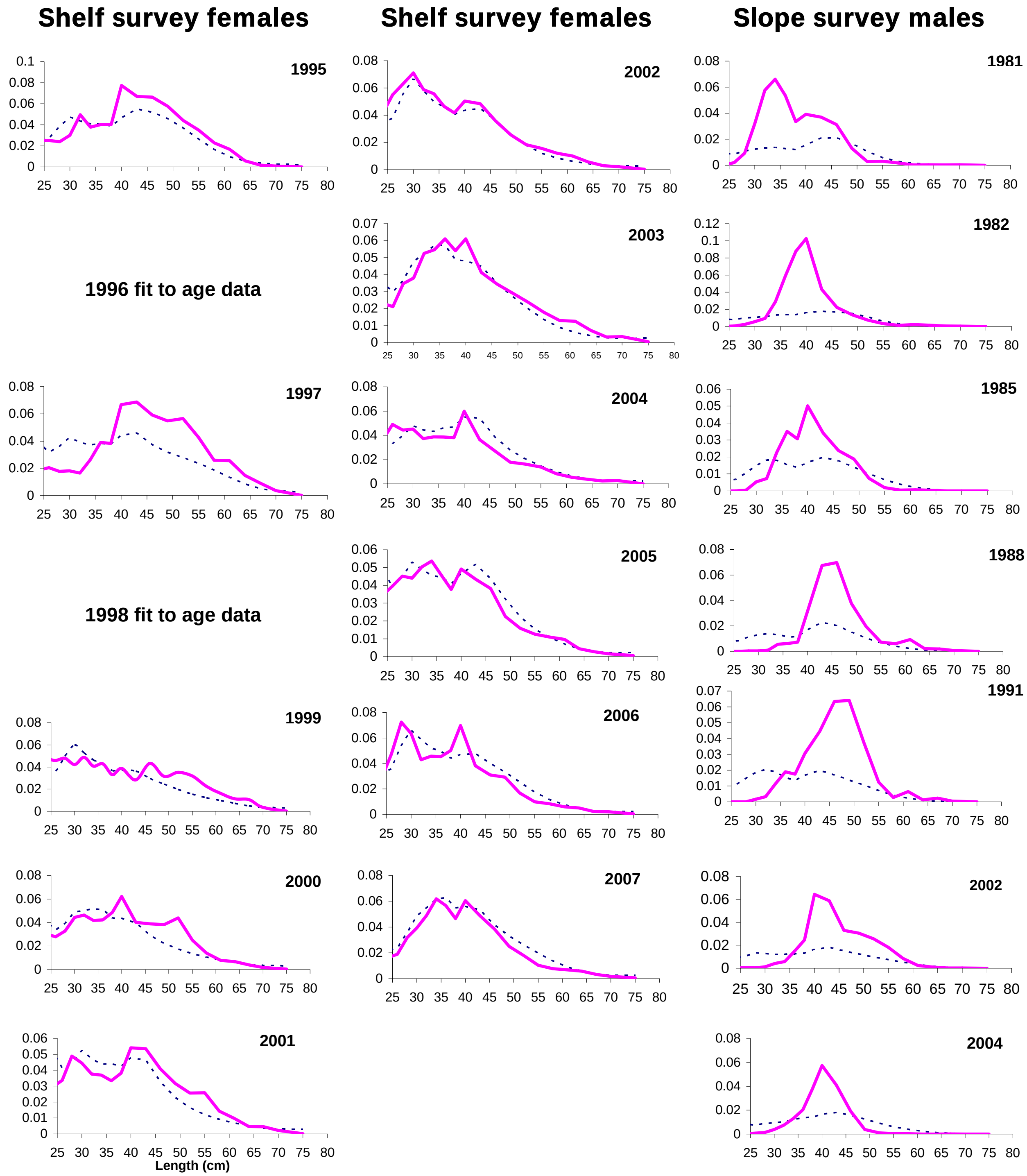
1994
Length (cm)
Length (cm)


Shelf survey females
Shelf survey females
Slope survey males
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1996 fit to age data
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1998 fit to age data
1999
2006
1991
2000
2007
2002
2001
2004
Length (cm)


Slope survey females
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age comp for shelf males
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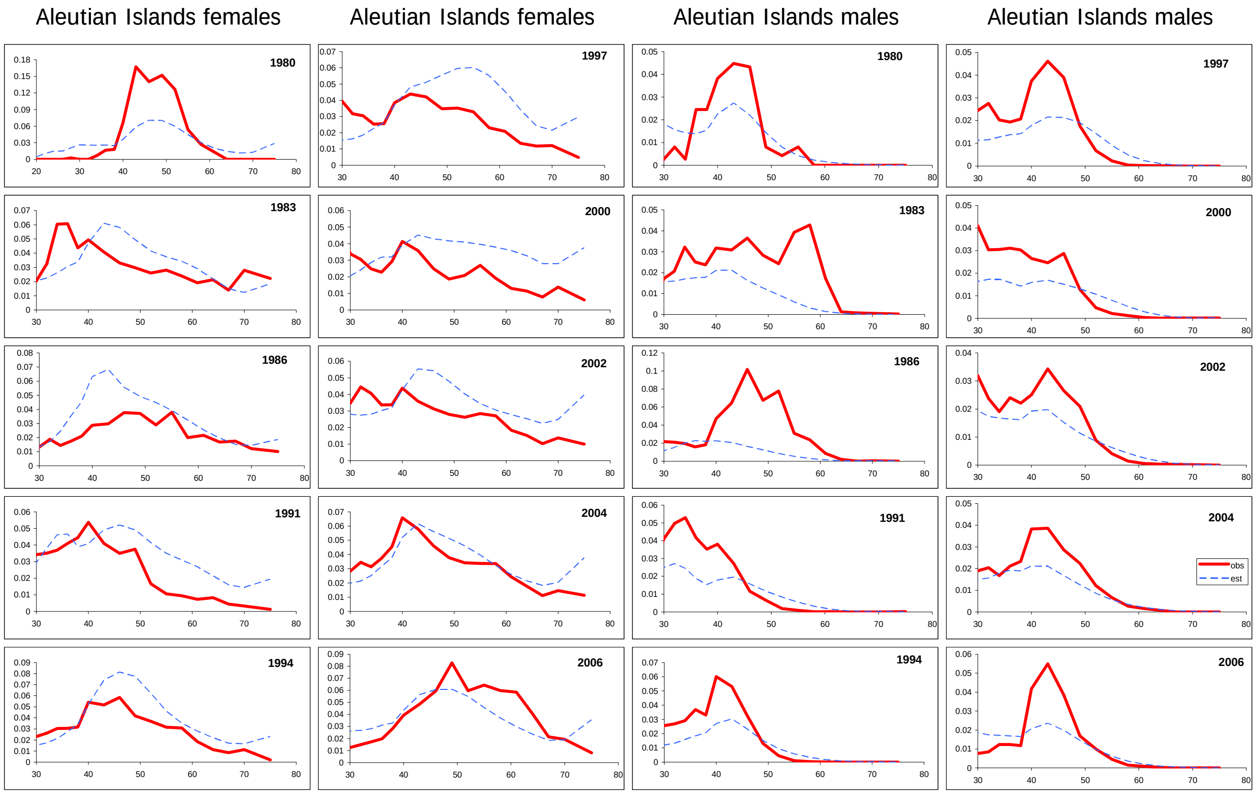
age


Aleutian Islands females
Aleutian Islands females
Aleutian Islands males
Aleutian Islands males
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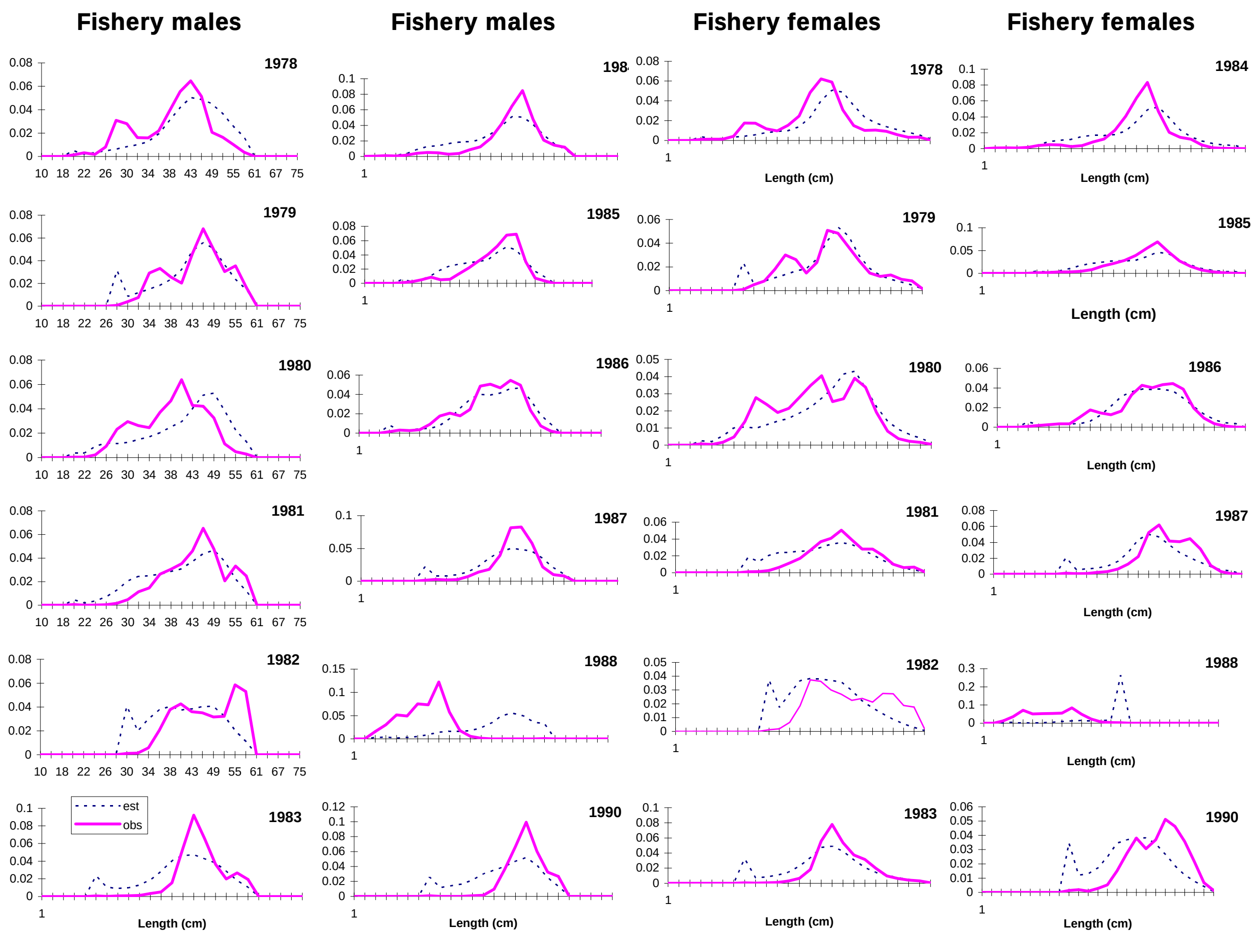
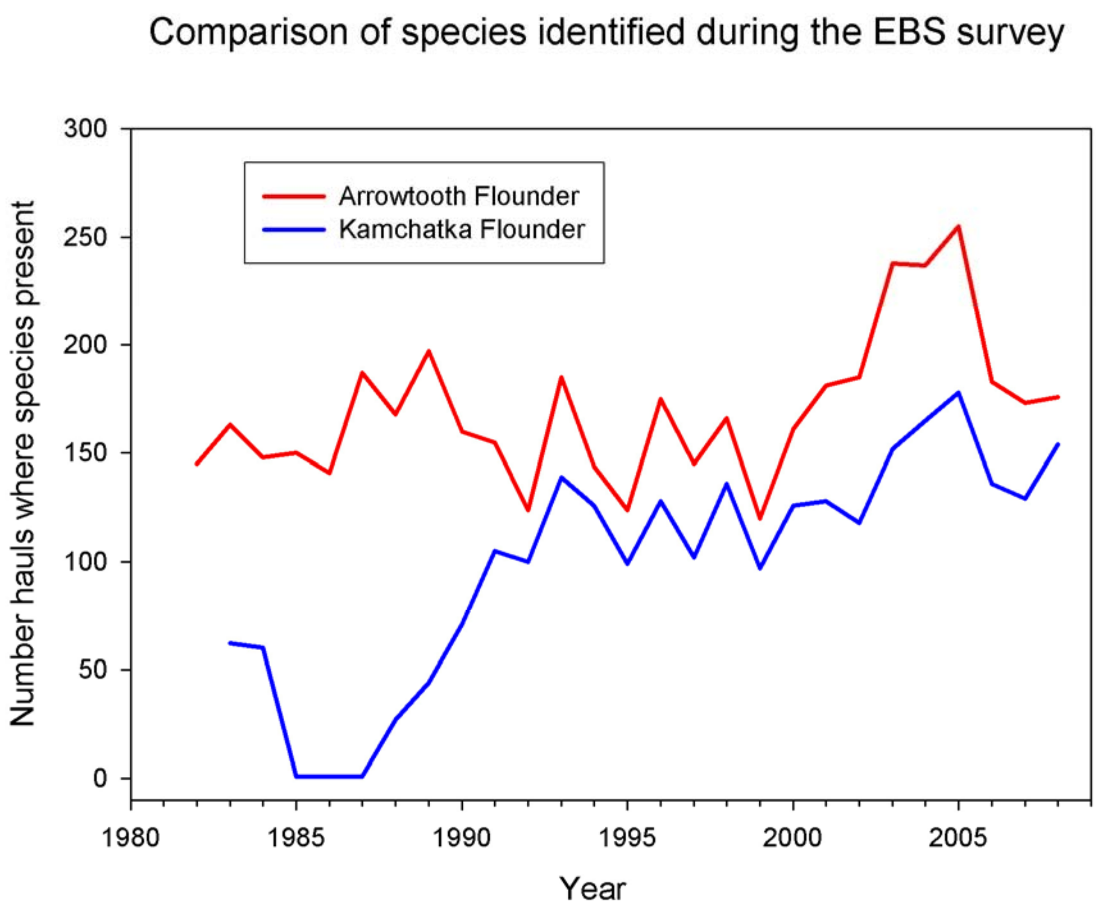

Fishery males
Fishery males
Fishery females
Fishery females
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1990
est
obs
Length (cm)

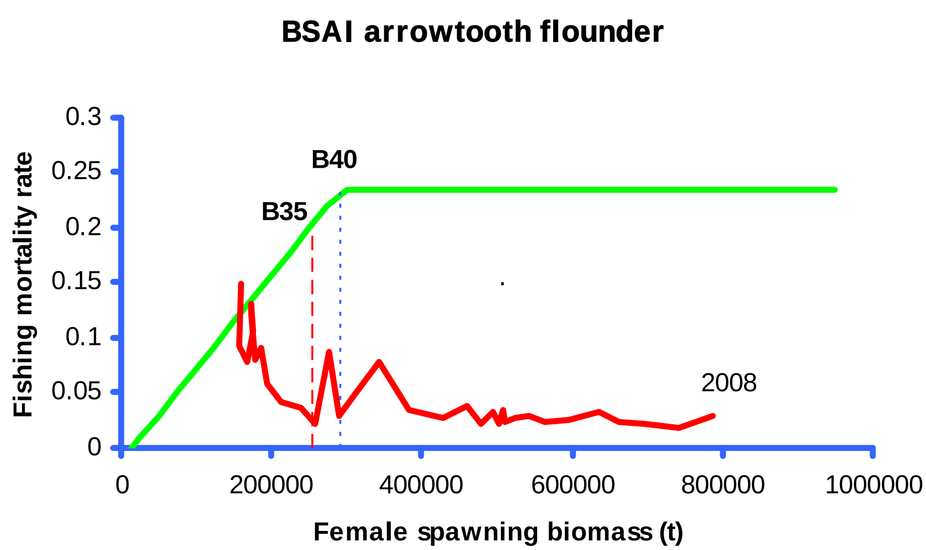
Total catch of arrowtooth flounder and Kamchatka flounder due to Alaska Fisheries Science Center research activity in the Bering Sea and Aleutian Islands

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

	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

	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


Comparison of species identified during the EBS survey
Arrowtooth Flounder
Kamchatka Flounder
Number hauls where species present
Year
0
50
100
150
200
250
300
1980
1985
1990
1995
2000
2005


BSAI arrowtooth flounder
B40
B35
2008
Fishing mortality rate
Female spawning biomass (t)
0
0.05
0.1
0.15
0.2
0.25
0.3
200000
400000
600000
800000
1000000

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