Chapter 6. Arrowtooth Flounder

By

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Executive Summary

The following changes have been made to this assessment relative to the November 2006 SAFE.

Changes to the input data

1) 2007 shelf survey size composition.

2) 2007 shelf survey biomass point-estimates and standard errors.

3) Estimate of catch and discards through 8, September 2007.

4) Estimate of retained and discarded portion of the 2006 catch.

5) Expanded the stock assessment to include the 10 Aleutian Islands surveys and the survey size compositions.

Assessment results

1) The projected age 1+ total biomass for 2008 is 1,780,300 t.

2) The projected female spawning biomass for 2008 is 993,500 t.

3) The recommended 2008 ABC is 243,900 t based on an $F_{0.40}$ (0.24) harvest level.

4) The 2008 overfishing level is 297,200 t based on a $F_{0.35}$ (0.30) harvest level.

	2007 Assessment recommendation for 2008 harvest	2006 Assessment recommendation for 2007 harvest
Total biomass	1,780,300 t	1,275,900 t
ABC	**243,900** t*	158,000 t
Overfishing	297,200 t	193,000 t
F_{ABC}	$F_{0.40} = 0.24$	$F_{0.40} = 0.24$
$F_{overfishing}$	$F_{0.35} = 0.30$	$F_{0.30} = 0.30$
B_{40}	344,500 t	324,500 t
B_{35}	301,500 t	283,900 t

* Based on a new model which incorporates the Aleutian Islands

<u>**SSC comments to the assessment authors:**</u>

Given the large and growing importance of arrowtooth flounder and likely impacts of this stock on other Council-managed species and the ecosystem in general, an expanded ecosystem section is warranted in future assessments. The SSC looks forward to the expanded discussion promised by the assessment author. The SSC also supports continued research into predator-prey dynamics involving arrowtooth flounder.
Please see enhanced ecosystem section included in the assessment.

Along those lines, the SSC encourages further development of this model, as arrowtooth flounder are becoming more important, and there are several lack of fit issues that could be improved. For example, the model consistently underfits shelf survey biomass in the mid-1990s, and poorly fits the slope survey throughout the range. In addition, the model fit to survey length compositions fits poorly for males in the shelf and the slope surveys, and also fits the fishery poorly for 1988 males.

The Aleutian Islands surveys were added as a further development of the stock assessment model, as per a previous comment in a past year. However, many of the issues mentioned above remain and are troublesome. Some explorations we have in mind are 1) modeling selectivity as a function of length instead of age, 2) re-examining the growth transition matrix (borrowed from the GOA arrowtooth assessment which has age data from 8 surveys), 3) profiling over male M with a different M for females than 0.2, 4) allowing proportions of the stock to change between areas on an annual basis, 5) re-explore the possibility of estimating q to allow for the herding behavior seen for other flatfish.

It would be useful to maintain and expand ancillary data in the assessment to monitor relative trends in Kamchatka flounder biomass.

We continue to provide individual estimates of biomass for both arrowtooth and Kamchatka flounders and to monitor their trends. We calculate a Tier 5 OFL for Kamchatka flounder in the ABC section to discern the level of harvest necessary to warrant a concern.

The SSC also requests that the authors include a figure showing the stock-recruitment curve, and to explore a Tier 1 analysis.

A stock-recruitment curve is presented. Given some of the lack of fit problems discussed above, the authors would prefer to concentrate on modifications to the structural model before exploring parameter uncertainty in a Tier 1 analysis.

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 usually distinguished in the commercial catches. Until about 1992, these species were not consistently separated in trawl survey catches (see Appendix figure) and are thus combined in this assessment to maintain the comparability of the trawl survey time series. Arrowtooth flounder ranges into the Aleutian Islands region where their abundance 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 was 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 12,538 t from 1977-2007. 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 8 September, 2007 is 9,441 t (well below the 2007 ABC of 158,000 t). NMFS Regional Office reports indicate that bottom trawling accounted for 65% of the 2007 catch (20% by pelagic trawl and 15% 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 annual total catch tonnage for the foreign, JV, and DAP fisheries. The proportion of retained and discarded arrowtooth flounder in Bering Sea fisheries are estimated from observer at-sea sampling for 1985-2006 are shown in Table 6.2. Forty-six percent of the arrowtooth flounder caught in 2006 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 available fishery length-frequencies from observer sampling.

Fishery Catch and Catch-at-Age

Fishery catch data from 1970 - September 8, 2007 (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 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 and 2007 estimates are lower at 13.12 and 11.79 kg/ha, respectively.

Absolute Abundance from Trawl Surveys

Biomass estimates (t) for arrowtooth flounder from the standard survey area in the eastern Bering Sea and Aleutian Islands region are shown in Table 6.3. 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. In 2006 and 2007 the estimates declined slightly. These recent increases have had a large effect on the model estimates in this assessment.

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 2006 point estimate are 516,000 – 700,340 t.

Trawl surveys were intermittently conducted over the continental slope in 1979, 1981, 1982, 1985, 1988, 1991, 2002 and 2004. 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 2002 slope point estimate was 61,200 t which increased to 68,600 t in 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. However, past assessment models did not consider the Aleutian Islands portion of the biomass to model stock abundance and were therefore conservative estimates of the stock size. In this assessment the 10 surveys conducted in the Aleutian Islands are included as an alternative model.

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

Parameters of the von Bertalanffy growth curve for arrowtooth flounder from age data collected during the 1982 U.S.-Japan cooperative survey and the 1991 slope survey (Zimmermann and Goddard 1995) are as follows:

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

Based on 282 observations during a AFSC survey in 1976, the length (mm)-weight (gm) relationship for arrowtooth flounder (sexes combined) is described by the equation:

$$W = 5.682 \times 10^{-6} * L^{3.1028}.$$

Maturity information from a histological examination of arrowtooth flounder in the Gulf of Alaska (Zimmerman 1997) indicate 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
32	14	1	51	98

The recruitment parameters are comprised of 21 initial ages in 1976 and 30 subsequent age 1 recruitment estimates from 1976-2004. Recruitment in 2006 was set at the average from 1976-2005. The difference in the number of parameters estimated in this assessment compared to last year can be accounted for by an additional year (2006) of shelf survey data and fishery catch and the estimate of one more year of recruitment. In addition, one more parameter is estimated in a later stage to estimate the relationship between bottom water temperature and shelf survey catchability (discussed later).

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 87% of the population, calculated from the average proportion of shelf/shelf+slope biomass from the trawl survey time-series. In this assessment we attempted to incorporate the Aleutian Islands survey biomass and size composition estimates as an alternative 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 73% shelf, 10% slope and 17% 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 6.2) 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 the doors instead of between the wingtips of the survey trawl). Given the present level of available information, it may not be possible to obtain reliable estimates of q for this stock. Catchability is therefore assumed to be 1.0 for the whole stock with the biomass partitioned between areas as discussed above.

Examination of Bering Sea shelf survey biomass estimates indicate that some of the annual variability seemed to positively covary with bottom water temperature. Variations in CPUE (Fig. 6.1) were particularly evident during the coldest year (1999) and the warmest year (2003) (Fig. 6.4). The relationship between average annual bottom water temperature collected during the survey and annual survey biomass estimates were modeled to provide an improved fit to the shelf survey biomass, as:

$$SurB_t = qe^{-\alpha T_t} \sum N_{t,a} W_{t,a} v_a$$

where $SurB_t$ is the model estimate of shelf survey biomass in year t, α is a parameter estimated by the model, T_t is the average annual bottom water temperature, $N_{t,a}$ is the number at age for each year and age estimated by the model, $W_{t,a}$ is the weight at age for fish in each year, and v_a is the selectivity at age estimated by the model. The value of q was fixed at 0.73 and the annual estimates of shelf survey q were allowed to vary about this average with the annual bottom temperature.

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 found exclusively 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 survey.

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 1982-2007, 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 just the shelf and slope surveys as in past years (base model) and also runs were made which incorporated the Aleutian Islands surveys. Both models gave similar results. Model runs configured as described above result in the best fit to all the data components at male M = 0.27 for the base model and at male M = 0.26 for the Alternative model. However, at these values, maximum male selectivity on the shelf is estimated at 0.65 and0.68 for age 7 in the base and alternative models which is inconsistent with the hypothesis that the observed sex ratio is the result of increased male natural mortality, not availability to the survey bottom trawl. 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). 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 (0.26- 0.34 for the Alternative model) with equal emphasis placed on all data components.

Base model results

Likelihood component	male natural mortality values							
	0.27	**0.28**	**0.29**	**0.30**	**0.31**	**0.32**	**0.33**	**0.34**
shelf biomass	71.45	72.45	73.37	74.25	75.09	75.89	76.66	77.41
slope biomass	92.98	91.30	89.85	88.61	87.56	86.68	85.94	85.33
shelf length comp	1541.47	1545.02	1548.76	1552.65	1556.69	1560.89	1565.24	1569.74
slope length comp	658.40	663.01	668.76	675.52	683.19	691.70	700.96	710.91
fishery length comp	182.02	186.13	190.77	195.90	201.48	207.49	213.89	220.65
recruitment	30.08	29.62	29.24	28.93	28.67	28.48	28.32	28.20
sex ratio	91.15	82.39	74.38	67.06	60.37	54.27	48.70	43.64
shelf age comps	130.17	130.74	131.23	131.68	132.12	132.55	132.98	133.42
total likelihood	2615.70	2614.53	2615.59	2618.69	2623.69	2630.45	2638.81	2648.64
male max shelf selectivity (age)	.61 (7)	.65 (7)	0.69 (7)	0.73 (8)	0.78 (8)	0.83 (8)	.89 (8)	0.95 (8)

Alternative model with Aleutian Islands

Likelihood component	male natural mortality values								
	0.26	**0.27**	**0.28**	**0.29**	**0.3**	**0.31**	**0.32**	**0.33**	**0.34**
shelf biomass	108.44	107.14	106.01	105.02	104.15	103.38	102.69	102.11	100.36
slope biomass	74.18	73.32	72.67	72.20	71.88	71.68	71.59	71.61	72.15
Aleutian biomass	75.87	73.55	71.37	69.32	67.39	65.57	63.87	62.36	59.78
shelf length comp	1613.36	1615.44	1617.71	1620.19	1622.90	1625.82	1628.94	1631.82	1639.22
slope length comp	658.51	662.13	666.89	672.70	679.48	687.17	695.68	705.07	716.42
Aleutian length comp	825.17	830.40	837.22	845.51	855.14	866.01	878.03	891.36	904.31
recruitment	35.29	34.91	34.67	34.53	34.49	34.52	34.61	34.78	214.32
sex ratio	100.56	90.87	81.98	73.83	66.36	59.53	53.29	47.61	42.63
shelf age comps	133.79	134.07	134.36	134.67	135.00	135.36	135.75	136.11	137.12
total likelihood	3625.17	3621.84	3622.89	3627.97	3636.79	3649.04	3664.46	3682.83	3706.70
male max shelf selectivity (age)	0.64 (7)	0.68 (7)	0.71 (7)	0.75 (7)	0.79 (7)	0.83 (8)	0.89 (8)	0.94 (8)	1.0 (8)

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 = 0.33 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 0.94 for age 8 fish in the Alternative model. 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. These analyses are consistent with our hypothesis that the differences in sex ratios observed in catches of arrowtooth flounder throughout the Bering Sea, Aleutian Islands and the Gulf of Alaska result from differential sex-specific survival rates and are not due to distributional or behavior differences. 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.

A comparison of model estimates between the base model and the Alternative model (with Aleutian Islands surveys) is shown in Figure 6.6. The primary difference in model results are the estimates of female spawning biomass since about 1999 and the fit to the shelf survey. Incorporation of the Aleutian Islands survey biomass gives a higher estimate of BSAI arrowtooth flounder abundance, especially since 1999 when there has been a large increase in the arrowtooth flounder Aleutian Islands survey estimates. The Alternative model includes fitting 2 more data series (Aleutian biomass and size composition) than the base model and thus has more trade offs in fitting the data components as evidenced by the fit to the shelf survey. Recruitment estimates are also higher after 1999 in the Alternative model to make up for the increased biomass from the Aleutians relative to the base model. Other model estimates such as the selectivity estimates and fits to the age and size compositions are very similar between models, as well as the results from profiling over male M as was discussed above.

Given these results, the model of choice for this assessment is the Alternative model. Arrowtooth flounder currently lack importance as a fishery target but are an important component of the Bering Sea and Aleutian Islands ecosystems and these results, which do not ignore the Aleutian Islands component of the stock, provide better estimates of their population dynamics and total abundance, useful for ecosystem modeling. It should be noted that ichthyoplankton surveys indicate that arrowtooth flounder release larvae in deep waters over the slope and in the Aleutian Islands. Preliminary simulations based on a coupled bio-physical model of the EBS and the Aleutain Islands suggest that larvae released in eastern Aleutian Islands be entrained there or drift onto the EBS shelf in years of strong cross – shelf transport. Since genetic studies are lacking for BSAI arrowtooth flounder, it is unknown if they are one stock.

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 1977-2007 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 five fold from 1976 to the 2007 value of 1.32 million t (Fig. 6.8, Table 6.8). After a rapid increase from 1985-94, the population increased slowed to a lower rate from 1995-2003 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, 929,600 t in 2007, 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 1987-97 and 2005-2006. The high 2005 and 2006 survey estimates are particularly not fit very well by the model but they do have a large influence on estimates of total biomass, female spawning biomass, overall abundance trend and the recent recruitment estimates by increasing all the estimated values. Consideration of the relationship between annual bottom water temperature and catchability improved the fit to the shelf survey biomass and indicated that catchability increases with water temperature, although the relationship does not hold in all years (Fig 6.4). The model indicates an increasing biomass trend on the slope and estimates a higher biomass than the 2002 and 2004 slope survey estimates (Fig. 6.8). The slope biomass represents a smaller fraction of the total stock and was considered to be poorly estimated by the 1991 survey which is an underestimate due to the reduction in sampling depth relative to earlier surveys. The Aleutian Islands survey estimates in 1986 and 2006 were not fit 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 2001 - 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 2008 to be much higher than 2007.

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, good recent recruitment, and minimal commercial harvest. They are currently estimated to be at a high and increasing level. **The estimate of projected 2008 total biomass from the stock assessment projection model is 1,780,300 t and the female spawning biomass is estimated at 993,500 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 $B_{0.40}$ = 344,500 t. The stock assessment model estimates the 2008 level of female spawning biomass at 929,600 t (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and $B > B_{0.40}$ (929,600 > 344,500), arrowtooth flounder reference fishing mortality is defined in tier 3a. For the 2008 harvest: F_{ABC} ◂ $F_{0.40}$ = 0.24 and $F_{overfishing} = F_{0.35}$ = 0.29 (full selection F values).

Acceptable biological catch is estimated for 2008 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2008 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 2008 ABC of 243,900 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 2008 OFL of 297,200 t.**

The potential yield of arrowtooth flounder in 2006, at various levels of fishing mortality (full selection), are as follows:

F level	Exploitation rate	Potential yield
$F_{overfishing}$	0.29	297,200 t
$F_{0.40}$	**0.24**	**243,900 t**

This estimate of 2008 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 2007 survey biomass point estimate of 65,312 t (Appendix table) would give an overfishing limit of 13,062 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 2007 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2008 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2007. 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 2008, 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 2008 recommended in the assessment to the *max* F_{ABC} for 2008. (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 2003-2007 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 2008 and above its MSY level in 2018 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2008 and 2009, 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 2020 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 2008, it does not provide the best estimate of OFL for 2009, because the mean 2009 catch under Scenario 6 is predicated on the 2008 catch being equal to the 2008 OFL, whereas the actual 2008 catch will likely be less than the 2008 ABC. Therefore, the projection model was re-run with the 2008 catch fixed equal to the 2007 catch and the 2009 fishing mortality rate fixed at F_{ABC}.

Year	Catch	ABC	OFL
2008	9,441	243,900	297,200
2009	9,441	246,400	299,900

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 2003 and 2004 in Table 13 of the Economic SAFE (Appendix C) and is summarized for 2004 as follows:

Prohibited species	Arrowtooth flounder “fishery” % of total bycatch
Halibut mortality	4.9
Herring	0
Red King crab	0
C. bairdi	<1
Other Tanner crab	<1
Salmon	<1

2) Relative to the predator needs in space and time, 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 rock sole 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

References

Cullenberg, P. 1995. Commercialization of arrowtooth flounder. The Next Step. Proceedings of the International Symposium on North Pacific Flatfish (1994: Anchorage, Alaska). pp623-630.

Greene, D. H. and J. K. Babbit. 1990. Control of muscle softening and protease-parasite interactions in arrowtooth flounder, Atheresthes stomias. J. Food Sce. 55(2): 579-580.

Haflinger, K. 1981. A survey of benthic infaunal communities of the Southeastern Bering Sea shelf. *In* Hood and Calder (editors) The Eastern Bering Sea Shelf: Oceanography and Resources, Vol. 2. P. 1091-1104. Office Mar. Pol. Assess., NOAA. Univ. Wash. Press, Seattle, Wa 98105.

Hunt, G. L., Jr., and P. J. Stabeno (2002). Climate change and the control of energy flow in the southeastern Bering Sea. Prog. Oceanogr., 55(1-2), 5-22.

Lang, Geoffrey M., P. A. Livingston, R. Pacunski, J. Parkhurst and M. S. Yang. 1991. Groundfish food habits and predation of commercially important prey species in the eastern Bering Sea from 1984-86. 240 p. NOAA Tech. Memo. NMFS F/NWC-207.

Livingston, Patricia A., A. Ward, G. M. Lang and M. S. Yang. 1993. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1987 to 1989.192 p. NOAA Tech. Memo. NMFS-AFSC-11.

Okada K., H. Yamaguchi, T. Sasaki, and K. Wakabayashi. 1980. Trends of groundfish stocks in the Bering Sea and the northeastern Pacific based on additional preliminary statistical data in 1979. Unpubl. Manuscr., 37 p. Far Seas Fish. Res. Lab., Japan Fish. Agency.

Plan Team for the Groundfish Fisheries of the Bering Sea, Aleutians and Gulf of Alaska. 1994. Ecosystem Considerations. 88 p. North Pacific Fisheries Management Council, P. O. Box 103136 Anchorage, AK 99519.

Porter, R. W., B. J. Kouri and G. Kudo, 1993. Inhibition of protease activity in muscle extracts and surimi from Pacific Whiting, Merluccius productus, and arrowtooth flounder, Atheresthes stomias,. Mar. Fish. Rev. 55(3):10-15.

Reppond, R. W., D. H. Wasson, and J. K. Babbitt. 1993. Properties of gels produced from blends of arrowtooth flounder and Alaska pollock surimi. J. Aquat. Food Prod. Technol., vol. 2(1):83-98.

Turnock, B. J., T. K. Wilderbuer and E. S. Brown. 2007. Arrowtooth flounder. In Stock Assessment and Fishery Evaluation Report for the 2007 Gulf of Alaska Groundfish Fishery. Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, AK 99510.

Wasson, D. H., K. D. Reppond, J. K. Babbitt and J. S. French. 1992. Effects of additives on proteolytic and functional properties of arrowtooth flounder surimi. J. Aquat. Food Prod. Technol., vol. 1(3/4):147-165.

Wilderbuer, T. K., and T. M. Sample. 1995. Arrowtooth flounder. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 1991, p.129-141. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage Alaska 99510.

Wilderbuer, T. K., and T. M. Sample. 2002. Arrowtooth flounder. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 2003, p.283-320. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage Alaska 99510.

Wilderbuer, T. K., A. B. Hollowed, W. J. Ingraham, Jr., P. D. Spencer, M. E. Conners, N. A. Bond, and G. E. Walters. Flatfish recruitment response to decadal climate variability and ocean conditions in the eastern Bering Sea. Progress Oceanography 55 (2002) 235-247.

Zimmermann, Mark, and Pamela Goddard 1995. Biology and distribution of arrowtooth (Atheresthes stomias) and Kamachatka (A. evermanni) flounders in Alaskan waters. 47 p. Submitted Fishery Bulletin.

Zimmermann, Mark. 1997. Maturity and fecundity of arrowtooth flounder, Atheresthes stomias, from the Gulf of Alaska. Fish Bull. 95:598-611.

Table 6.1. All nation total catch (t) of arrowtooth flounder in the eastern Bering Sea and Aleutian Islands region[a], 1970-2007. 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**									9,441

[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 8 September, 2007 (NMFS regional office).

Table 6.2 Estimates of retained and discarded arrowtooth flounder catch, 1985-2006.

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

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	68,600	616,000	134,217
2005	757,685			
2006	670,131			229,205
2007	546,483			

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.

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

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

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

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

$$Sexratiolike = \frac{\sum_{i=1982}^{lastsurvey} (S\bar{R}_{obs} - SR_i)^2}{\sigma_{SR}}$$ 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	0.147	0.075
1977	0.092	0.045
1978	0.077	0.038
1979	0.103	0.051
1980	0.127	0.063
1981	0.116	0.056
1982	0.074	0.036
1983	0.083	0.040
1984	0.051	0.025
1985	0.037	0.018
1986	0.032	0.016
1987	0.019	0.010
1988	0.073	0.037
1989	0.025	0.013
1990	0.041	0.021
1991	0.065	0.032
1992	0.028	0.014
1993	0.022	0.012
1994	0.031	0.018
1995	0.018	0.012
1996	0.028	0.018
1997	0.019	0.012
1998	0.028	0.017
1999	0.019	0.012
2000	0.023	0.014
2001	0.025	0.014
2002	0.020	0.011
2003	0.021	0.011
2004	0.027	0.015
2005	0.019	0.011
2006	0.015	0.010
2007	0.012	0.007

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	0.05	0.12	0.00	0.02	0.03	0.05
2	0.00	0.01	0.17	0.19	0.00	0.04	0.05	0.08
3	0.01	0.03	0.48	0.29	0.00	0.06	0.10	0.13
4	0.04	0.06	0.86	0.44	0.00	0.10	0.18	0.20
5	0.11	0.12	1.00	0.61	0.07	0.15	0.31	0.29
6	0.28	0.22	0.97	0.78	0.65	0.23	0.47	0.41
7	0.56	0.39	0.88	0.91	0.98	0.33	0.63	0.53
8	0.80	0.59	0.79	0.94	1.00	0.45	0.77	0.65
9	0.93	0.76	0.70	0.86	1.00	0.57	0.87	0.75
10	0.98	0.88	0.62	0.70	1.00	0.69	0.93	0.83
11	0.99	0.94	0.55	0.52	1.00	0.79	0.96	0.89
12	1.00	0.97	0.48	0.36	1.00	0.86	0.98	0.93
13	1.00	0.99	0.42	0.24	1.00	0.91	0.99	0.96
14	1.00	0.99	0.37	0.15	1.00	0.94	0.99	0.97
15	1.00	1.00	0.32	0.10	1.00	0.96	1.00	0.98
16	1.00	1.00	0.28	0.06	1.00	0.98	1.00	0.99
17	1.00	1.00	0.24	0.04	1.00	0.99	1.00	0.99
18	1.00	1.00	0.21	0.02	1.00	0.99	1.00	1.00
19	1.00	1.00	0.18	0.01	1.00	1.00	1.00	1.00
20	1.00	1.00	0.16	0.01	1.00	1.00	1.00	1.00
21	1.00	1.00	0.13	0.01	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 2006 and 2007 assessments.

	2007 Assessment		2006 Assessment	
	age 1+ Total biomass	Female Spawning biomass	age 1+ Total biomass	Female Spawning biomass
1976	257,242	159,296	256,799	188,233
1977	256,695	158,786	242,346	173,329
1978	266,771	169,692	241,173	164,447
1979	281,720	177,491	248,466	156,804
1980	293,738	178,260	256,175	150,274
1981	307,197	181,771	268,480	151,976
1982	323,450	192,024	286,215	162,318
1983	350,236	206,780	316,934	175,868
1984	377,028	219,370	349,684	188,506
1985	407,740	245,582	387,615	218,853
1986	442,521	279,119	431,114	258,822
1987	485,517	300,596	482,306	286,657
1988	533,677	325,331	538,038	318,441
1989	576,250	344,157	585,224	345,180
1990	634,434	372,218	644,789	380,757
1991	684,635	409,561	693,228	423,327
1992	719,144	456,976	722,711	471,102
1993	757,020	507,729	753,551	518,712
1994	787,937	547,633	775,196	552,569
1995	806,845	568,301	782,795	566,724
1996	829,689	586,699	792,358	577,885
1997	847,381	595,254	794,845	577,545
1998	876,280	603,044	806,168	575,216
1999	909,775	608,367	821,070	568,298
2000	955,234	628,255	847,056	574,240
2001	1,009,050	653,841	882,597	585,655
2002	1,065,870	682,863	925,437	598,762
2003	1,129,740	731,362	980,859	630,168
2004	1,191,300	788,038	1,042,920	673,219
2005	1,243,360	830,943	1,106,230	707,778
2006	1,291,400	876,441	1,168,600	753,323
2007	1,324,440	929,641		

Table 6.9 Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2007.

females	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	109,449	44,256	74,720	83,941	64,082	25,486	14,401	10,030	7,742	6,341
1977	176,407	89,594	36,214	61,071	68,358	51,635	20,019	10,861	7,298	5,531
1978	124,129	144,415	73,329	29,618	49,834	55,410	41,192	15,569	8,259	5,486
1979	133,974	101,620	118,204	59,983	24,181	40,459	44,386	32,297	11,979	6,293
1980	133,918	109,676	83,168	96,662	48,927	19,578	32,178	34,311	24,348	8,914
1981	305,234	109,627	89,754	67,992	78,774	39,508	15,463	24,536	25,362	17,712
1982	115,842	249,871	89,717	73,385	55,431	63,683	31,299	11,861	18,292	18,634
1983	101,138	94,835	204,522	73,391	59,920	45,018	51,056	24,582	9,149	13,978
1984	276,695	82,797	77,621	167,287	59,905	48,616	36,001	39,898	18,823	6,932
1985	191,664	226,526	67,776	63,513	136,707	48,773	39,229	28,639	31,343	14,692
1986	175,191	156,915	185,439	55,467	51,931	111,481	39,521	31,467	22,768	24,803
1987	508,036	143,429	128,456	151,769	45,360	42,371	90,462	31,790	25,117	18,101
1988	281,376	415,936	117,422	105,148	124,172	37,061	34,505	73,282	25,633	20,204
1989	298,335	230,352	340,450	96,056	85,860	100,864	29,727	27,126	56,597	19,617
1990	190,878	244,249	188,579	278,657	78,573	70,107	82,004	24,003	21,771	45,282
1991	190,094	156,270	199,944	154,322	227,802	64,042	56,733	65,604	19,010	17,153
1992	226,556	155,624	127,913	163,578	126,051	185,201	51,483	44,798	50,991	14,656
1993	181,843	185,482	127,401	104,693	133,790	102,888	150,438	41,498	35,863	40,679
1994	214,879	148,876	151,848	104,280	85,645	109,272	83,708	121,639	33,371	28,759
1995	278,377	175,922	121,876	124,278	85,282	69,885	88,687	67,360	97,148	26,549
1996	365,519	227,911	144,023	99,762	101,682	69,683	56,920	71,867	54,340	78,188
1997	312,168	299,253	186,579	117,878	81,596	82,999	56,605	45,883	57,539	43,355
1998	390,029	255,576	244,991	152,725	96,445	66,670	67,598	45,865	37,008	46,302
1999	567,301	319,319	209,227	200,517	124,913	78,723	54,155	54,485	36,716	29,523
2000	357,080	464,456	261,418	171,262	164,054	102,056	64,103	43,863	43,923	29,527
2001	401,311	292,345	380,233	213,973	140,099	133,976	83,009	51,804	35,247	35,192
2002	431,488	328,557	239,330	311,220	175,030	114,398	108,933	67,036	41,586	28,207
2003	512,629	353,264	268,980	195,903	254,624	142,998	93,145	88,218	54,029	33,435
2004	347,155	419,695	289,207	220,170	160,271	208,002	116,399	75,388	71,042	43,398
2005	233,056	284,218	343,584	236,709	180,084	130,838	169,015	93,883	60,410	56,736
2006	308,210	190,806	232,682	281,240	193,666	147,134	106,543	136,903	75,691	48,587
2007	142,900	252,337	156,211	190,471	230,137	158,308	119,966	86,519	110,777	61,134

Table 6.9 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2007.

	females				numbers at age (1,000s)						
	11	12	13	14	15	16	17	18	19	20	21
1976	5,383	4,673	4,105	3,631	3,229	2,876	2,554	2,276	2,007	1,765	3,882
1977	4,499	3,810	3,305	2,903	2,567	2,283	2,033	1,806	1,609	1,419	3,992
1978	4,139	3,362	2,846	2,468	2,168	1,918	1,705	1,519	1,349	1,202	4,042
1979	4,165	3,139	2,548	2,157	1,871	1,643	1,453	1,292	1,151	1,022	3,974
1980	4,661	3,080	2,320	1,883	1,594	1,382	1,214	1,074	955	850	3,691
1981	6,446	3,363	2,221	1,673	1,358	1,149	997	875	774	688	3,274
1982	12,942	4,701	2,452	1,619	1,219	989	837	726	638	564	2,888
1983	14,189	9,843	3,574	1,864	1,230	926	752	636	552	485	2,624
1984	10,550	10,695	7,416	2,693	1,404	927	698	567	479	416	2,342
1985	5,398	8,208	8,318	5,768	2,094	1,092	721	543	441	373	2,145
1986	11,606	4,262	6,479	6,566	4,553	1,653	862	569	428	348	1,987
1987	19,690	9,209	3,381	5,140	5,209	3,611	1,311	684	451	340	1,852
1988	14,548	15,820	7,398	2,716	4,129	4,184	2,901	1,053	549	363	1,761
1989	15,410	11,083	12,047	5,633	2,068	3,144	3,186	2,209	802	418	1,617
1990	15,677	12,310	8,852	9,622	4,499	1,652	2,511	2,545	1,764	641	1,625
1991	35,607	12,319	9,671	6,954	7,559	3,535	1,298	1,973	1,999	1,386	1,780
1992	13,184	27,340	9,456	7,423	5,337	5,801	2,713	996	1,514	1,534	2,430
1993	11,676	10,499	21,769	7,529	5,910	4,249	4,619	2,160	793	1,205	3,156
1994	32,586	9,350	8,406	17,430	6,028	4,732	3,402	3,698	1,729	635	3,492
1995	22,846	25,874	7,423	6,673	13,837	4,785	3,756	2,701	2,936	1,373	3,276
1996	21,349	18,366	20,798	5,967	5,364	11,122	3,846	3,019	2,171	2,360	3,737
1997	62,300	17,003	14,626	16,562	4,751	4,271	8,856	3,063	2,404	1,729	4,855
1998	34,857	50,074	13,665	11,754	13,310	3,818	3,433	7,117	2,461	1,932	5,291
1999	36,887	27,757	39,869	10,880	9,358	10,597	3,040	2,733	5,666	1,960	5,750
2000	23,720	29,629	22,293	32,020	8,738	7,516	8,510	2,441	2,195	4,551	6,192
2001	23,631	18,977	23,701	17,832	25,613	6,989	6,012	6,807	1,953	1,756	8,593
2002	28,130	18,882	15,162	18,935	14,246	20,462	5,584	4,803	5,438	1,560	8,268
2003	22,658	22,589	15,161	12,173	15,203	11,438	16,429	4,483	3,856	4,367	7,891
2004	26,830	18,175	18,119	12,161	9,764	12,194	9,174	13,177	3,596	3,093	9,831
2005	34,614	21,391	14,489	14,443	9,693	7,783	9,720	7,313	10,504	2,866	10,302
2006	45,590	27,806	17,182	11,638	11,601	7,786	6,251	7,807	5,874	8,437	10,577
2007	39,215	36,788	22,436	13,863	9,390	9,360	6,282	5,044	6,299	4,739	15,341

Table 6.9 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2007.

males	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	109,449	38,861	57,613	56,833	38,098	13,305	6,601	4,037	2,736	1,968
1977	176,407	78,625	27,890	41,264	40,529	26,931	9,255	4,481	2,662	1,759
1978	124,129	126,762	56,465	20,004	29,516	28,831	18,967	6,419	3,052	1,785
1979	133,974	89,203	91,050	40,514	14,320	21,032	20,371	13,229	4,409	2,069
1980	133,918	96,265	64,054	65,286	28,962	10,174	14,776	14,068	8,953	2,932
1981	305,234	96,212	69,105	45,900	46,608	20,519	7,109	10,107	9,384	5,843
1982	115,842	219,305	69,076	49,533	32,787	33,062	14,371	4,883	6,784	6,174
1983	101,138	83,249	157,527	49,566	35,465	23,371	23,376	10,036	3,360	4,609
1984	276,695	72,679	59,792	113,009	35,471	25,254	16,491	16,266	6,870	2,267
1985	191,664	198,869	52,219	42,929	81,015	25,350	17,947	11,620	11,346	4,749
1986	175,191	137,765	142,910	37,507	30,801	57,999	18,076	12,719	8,175	7,932
1987	508,036	125,928	99,006	102,659	26,917	22,063	41,402	12,835	8,975	5,738
1988	281,376	365,203	90,513	71,143	73,727	19,309	15,794	29,545	9,125	6,360
1989	298,335	202,210	262,331	64,951	50,942	52,563	13,658	11,037	20,352	6,208
1990	190,878	214,452	145,332	188,477	46,631	36,519	37,579	9,724	7,819	14,358
1991	190,094	137,197	154,100	104,372	135,192	33,365	26,012	26,583	6,823	5,448
1992	226,556	136,616	98,560	110,603	74,768	96,472	23,642	18,233	18,397	4,669
1993	181,843	162,852	98,185	70,806	79,393	53,580	68,923	16,812	12,895	12,948
1994	214,879	130,716	117,048	70,547	50,842	56,931	38,328	49,119	11,929	9,114
1995	278,377	154,457	93,941	84,082	50,632	36,422	40,647	27,224	34,677	8,376
1996	365,519	200,113	111,019	67,505	60,387	36,323	26,077	29,012	19,361	24,583
1997	312,168	262,742	143,819	79,757	48,456	43,275	25,951	18,544	20,519	13,627
1998	390,029	224,403	188,851	103,346	57,281	34,762	30,982	18,522	13,187	14,544
1999	567,301	280,360	161,276	135,672	74,183	41,048	24,835	22,031	13,098	9,280
2000	357,080	407,804	201,512	115,888	97,434	53,214	29,383	17,720	15,660	9,280
2001	401,311	256,682	293,101	144,786	83,208	69,861	38,058	20,933	12,566	11,061
2002	431,488	288,475	184,482	210,585	103,949	59,652	49,949	27,099	14,833	8,867
2003	512,629	310,175	207,344	132,562	151,232	74,564	42,698	35,636	19,259	10,507
2004	347,155	368,501	222,939	148,986	95,194	108,467	53,359	30,450	25,311	13,631
2005	233,056	249,542	264,842	160,166	106,952	68,227	77,513	37,961	21,549	17,830
2006	308,210	167,533	179,362	190,308	115,026	76,721	48,840	55,310	26,985	15,268
2007	142,900	221,563	120,423	128,899	136,706	82,556	54,976	34,912	39,422	19,186

Table 6.9 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2007.

males				numbers at age (1,000s)							
	11	12	13	14	15	16	17	18	19	20	21
1976	1,467	1,118	863	670	523	409	319	250	193	149	186
1977	1,244	919	697	537	416	325	254	198	155	120	208
1978	1,167	821	604	458	352	273	213	167	130	102	215
1979	1,199	780	547	402	305	234	182	142	111	86	211
1980	1,359	783	508	355	261	198	152	118	92	72	193
1981	1,885	867	497	322	225	165	125	96	75	58	168
1982	3,793	1,215	557	319	206	144	106	80	62	48	145
1983	4,159	2,543	813	372	213	138	96	71	53	41	128
1984	3,081	2,765	1,686	538	246	141	91	64	47	35	112
1985	1,558	2,110	1,891	1,152	368	168	96	62	43	32	101
1986	3,307	1,082	1,464	1,311	799	255	117	67	43	30	92
1987	5,547	2,308	755	1,020	913	556	177	81	46	30	85
1988	4,057	3,917	1,629	532	720	644	392	125	57	33	81
1989	4,291	2,724	2,624	1,090	356	481	431	262	84	38	76
1990	4,367	3,014	1,912	1,841	764	250	338	302	184	59	80
1991	9,955	3,020	2,081	1,320	1,270	527	172	233	208	127	96
1992	3,701	6,735	2,039	1,404	890	856	355	116	157	140	150
1993	3,276	2,591	4,712	1,426	982	622	599	249	81	110	203
1994	9,128	2,306	1,823	3,314	1,003	690	437	421	175	57	220
1995	6,377	6,375	1,609	1,271	2,310	699	481	305	293	122	193
1996	5,926	4,506	4,502	1,136	897	1,631	493	340	215	207	222
1997	17,248	4,150	3,153	3,149	794	628	1,140	345	237	150	300
1998	9,639	12,185	2,930	2,226	2,222	561	443	805	243	168	318
1999	10,203	6,750	8,525	2,049	1,556	1,554	392	310	563	170	339
2000	6,560	7,203	4,762	6,013	1,445	1,098	1,096	276	218	397	359
2001	6,537	4,614	5,063	3,346	4,224	1,015	771	770	194	153	531
2002	7,783	4,592	3,239	3,553	2,348	2,964	712	541	540	136	480
2003	6,267	5,493	3,239	2,284	2,505	1,655	2,089	502	381	381	435
2004	7,419	4,419	3,871	2,282	1,609	1,764	1,166	1,472	354	269	574
2005	9,573	5,201	3,095	2,711	1,598	1,126	1,235	816	1,030	248	590
2006	12,605	6,759	3,670	2,184	1,912	1,127	794	871	576	726	591
2007	10,837	8,938	4,791	2,601	1,547	1,355	798	563	617	408	933

Table 6.10 Estimated age 2 recruitment of arrowtooth flounder (thousands of fish) from the 2006 and 2007 stock assessments and also from estimates of fish less than 25 cm in the annual Bering Sea shelf trawl survey.

Year class	2007 Assessment	2006 Assessment	shelf survey fish<25 cm
1974	83,117	91,854	
1975	168,219	176,600	
1976	271,177	300,190	
1977	190,823	169,748	
1978	205,941	179,474	
1979	205,839	228,447	
1980	469,176	513,951	86,100
1981	178,084	196,556	290,200
1982	155,476	175,165	57,900
1983	425,395	467,733	62,400
1984	294,680	318,113	150,300
1985	269,357	314,178	94,300
1986	781,139	747,396	200,600
1987	432,562	411,643	273,800
1988	458,701	404,744	105,200
1989	293,467	250,297	71,700
1990	292,240	268,021	79,400
1991	348,334	289,462	96,800
1992	279,592	229,179	126,600
1993	330,379	260,227	75,100
1994	428,024	332,198	55,600
1995	561,995	473,639	108,800
1996	479,979	389,913	93,600
1997	599,679	452,206	92,100
1998	872,260	773,802	126,300
1999	549,027	479,174	164,300
2000	617,032	577,269	108,800
2001	663,439	722,270	253,400
2002	788,196	832,652	406,700
2003	249,560	660,527	407,800
2004			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. 2008 ABC is highlighted.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2007	939.731	9.44	0.01
2008	977.852	243.90	0.24
2009	846.419	204.98	0.24
2010	727.585	172.43	0.24
2011	623.599	144.25	0.24
2012	534.274	120.57	0.24
2013	471.189	101.62	0.24
2014	429.206	87.90	0.24
2015	401.63	78.88	0.23
2016	383.234	72.69	0.23
2017	371.203	68.73	0.23
2018	363.816	66.34	0.23
2019	359.467	64.93	0.22
2020	357.341	64.13	0.22

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2007	939.731	9.44	0.01
2008	986.372	121.65	0.11
2009	938.545	106.16	0.10
2010	883.862	98.42	0.10
2011	822.663	89.98	0.10
2012	758.11	81.37	0.10
2013	705.731	73.27	0.10
2014	664.509	66.41	0.10
2015	631.732	61.20	0.10
2016	605.276	57.38	0.10
2017	583.954	54.55	0.10
2018	567.39	52.43	0.10
2019	554.813	50.86	0.10
2020	545.676	49.71	0.10

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2007	939.731	9.44	0.01
2008	992.613	24.50	0.02
2009	1012.07	21.57	0.02
2010	1014	21.35	0.02
2011	1000.72	20.76	0.02
2012	974.315	19.89	0.02
2013	950.193	18.87	0.02
2014	928.162	17.88	0.02
2015	907.066	17.03	0.02
2016	886.691	16.34	0.02
2017	867.505	15.76	0.02
2018	850.546	15.29	0.02
2019	836.105	14.91	0.02
2020	824.21	14.59	0.02

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2007	939.731	9.44	0.01
2008	994.121	0	0
2009	1030.62	0	0
2010	1047.15	0	0
2011	1047.48	0	0
2012	1033.13	0	0
2013	1019.14	0	0
2014	1005.22	0	0
2015	990.285	0	0
2016	974.403	0	0
2017	958.332	0	0
2018	943.435	0	0
2019	930.282	0	0
2020	919.063	0	0

Table 6.11 (continued).

Scenario 6

Determination of whether arrowtooth flounder are currently overfished

B35=301,500

Year	Female spawning biomass	catch	F
2007	939.731	9.44	0.01
2008	973.869	297.22	0.29
2009	806.912	238.40	0.29
2010	667.471	192.43	0.29
2011	553.531	155.25	0.29
2012	461.62	125.90	0.29
2013	400.53	103.75	0.29
2014	363.033	87.25	0.29
2015	341.808	76.17	0.28
2016	330.719	70.59	0.27
2017	324.852	67.90	0.27
2018	322.015	66.61	0.26
2019	320.825	65.99	0.26
2020	320.813	65.79	0.26

Scenario 7

Determination of whether arrowtooth flounder are approaching an overfished condition

B35=301,500

Year	Female spawning biomass	catch	F
2007	939.731	9.44	0.01
2008	977.85	243.93	0.24
2009	846.397	204.98	0.24
2010	724.554	210.05	0.29
2011	593.799	167.56	0.29
2012	489.362	134.26	0.29
2013	419.274	109.30	0.29
2014	375.42	91.66	0.29
2015	349.273	79.03	0.28
2016	334.915	72.22	0.27
2017	327.085	68.76	0.27
2018	323.132	67.03	0.26
2019	321.338	66.18	0.26
2020	321.017	65.86	0.26

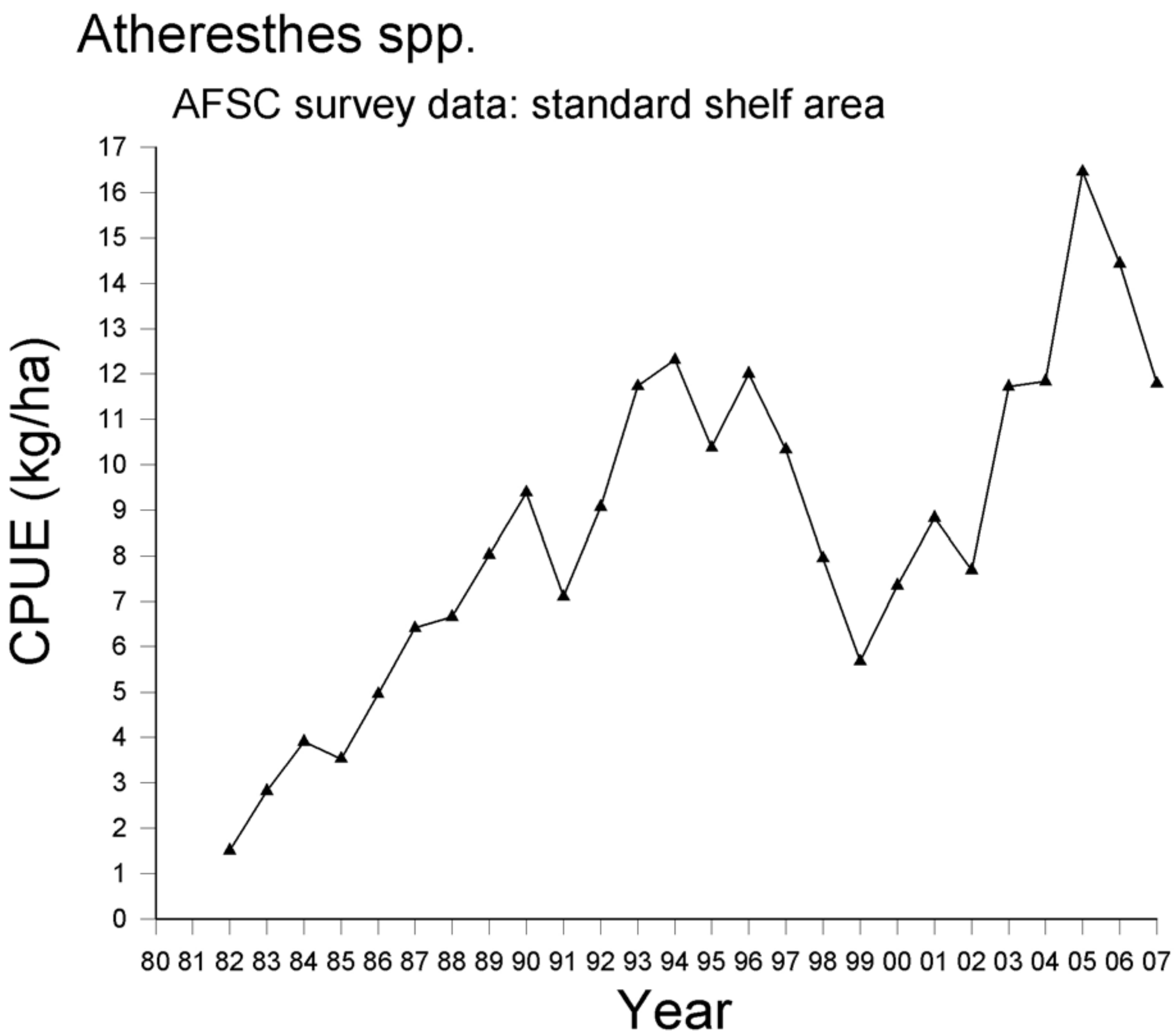


Figure 6.1 Atheresthes species combined CPUE (kg/ha) from the standard shelf survey area.

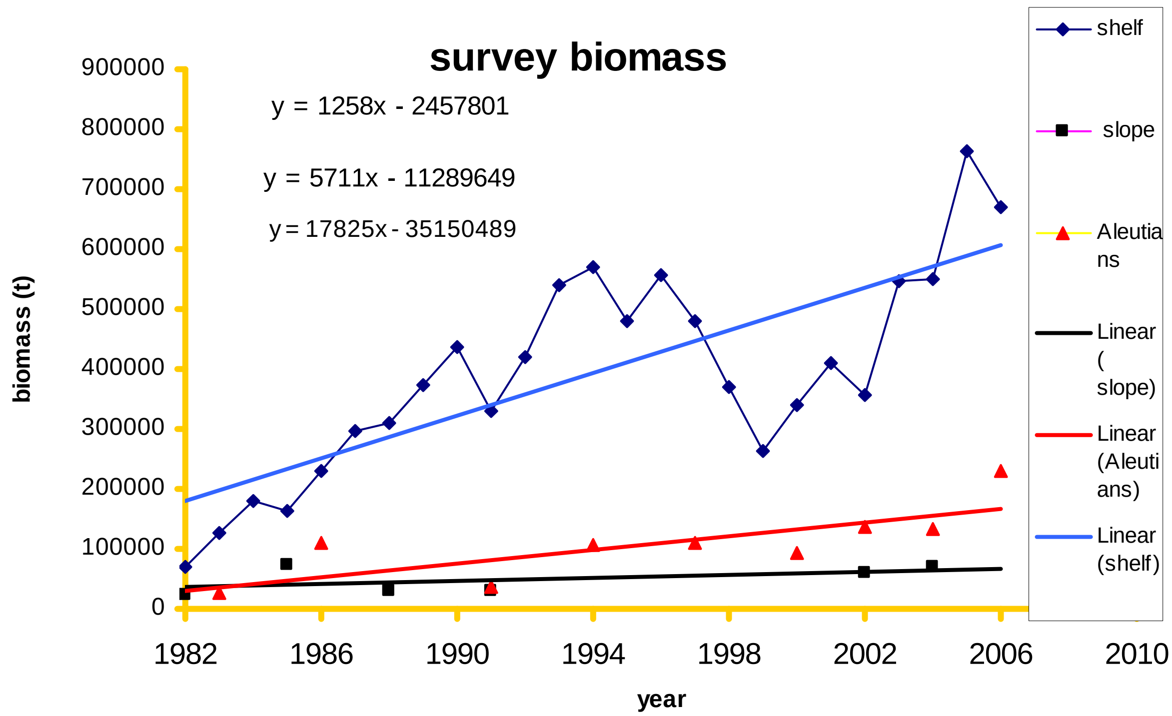


Figure 6.2—Linear regressions of trawl survey estimates for the Bering Sea shelf, slope and the Aleutian Islands used to estimate the proportion of biomass in each area.

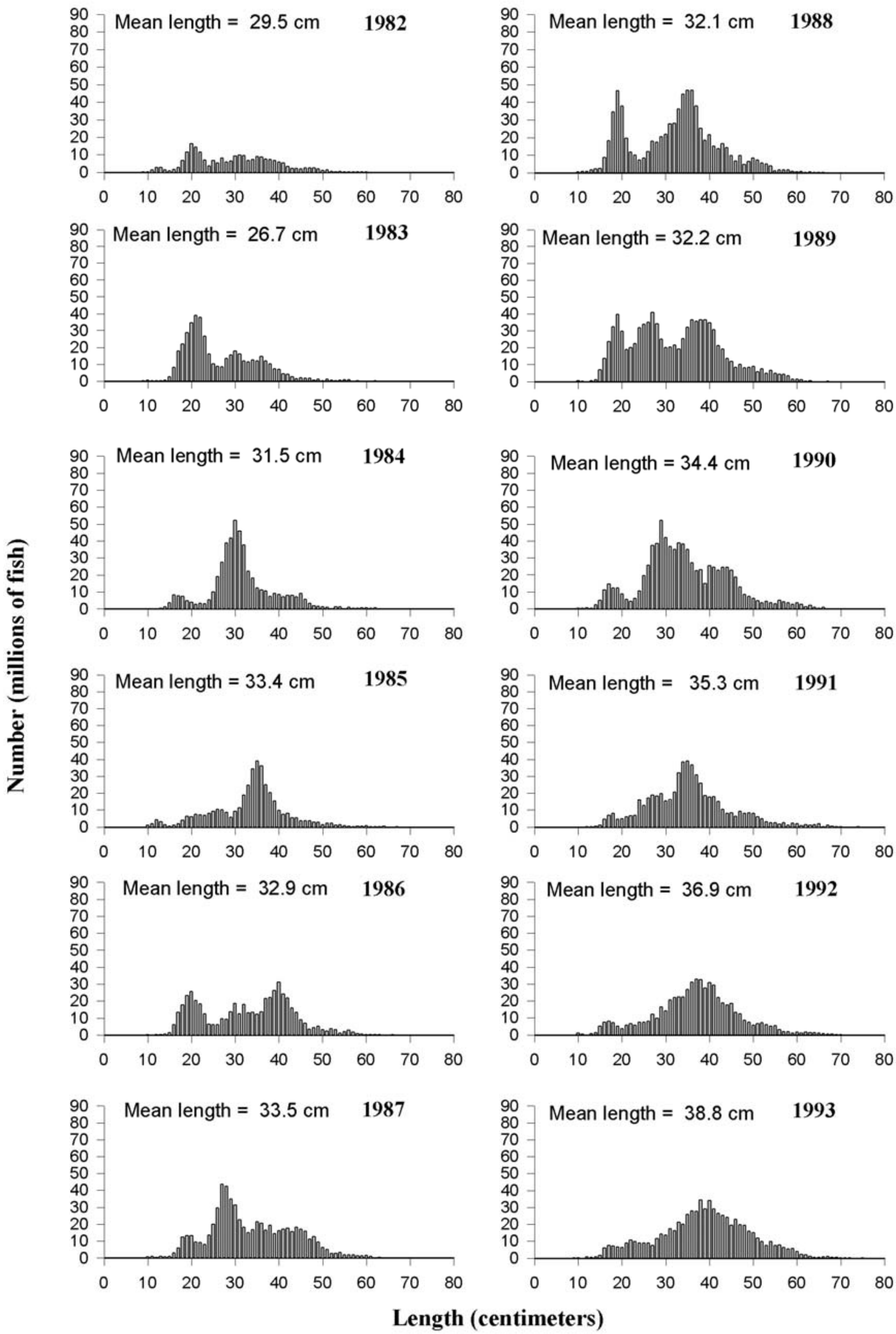


Figure 6.3. Size composition of arrowtooth flounder from the shelf trawl surveys.

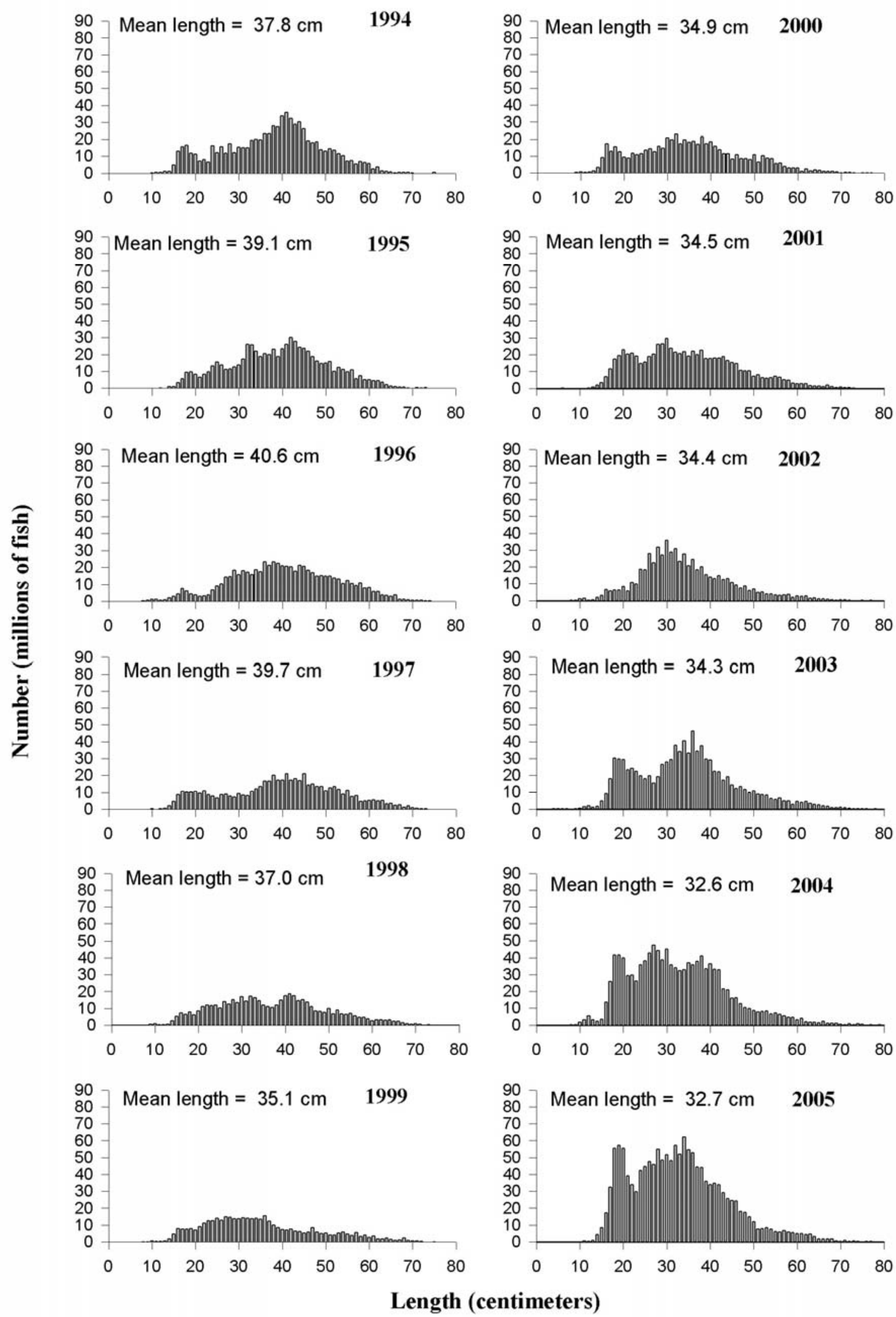


Figure 6.3. continued.

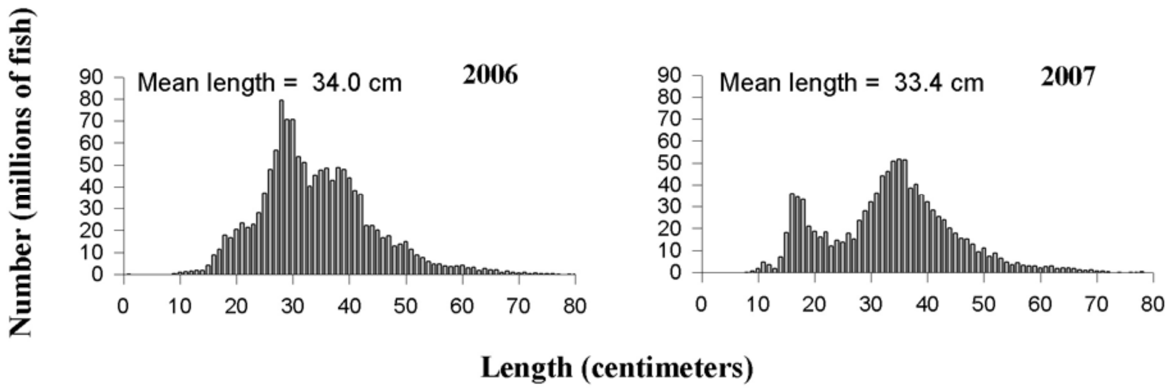


Figure 6.3. continued.

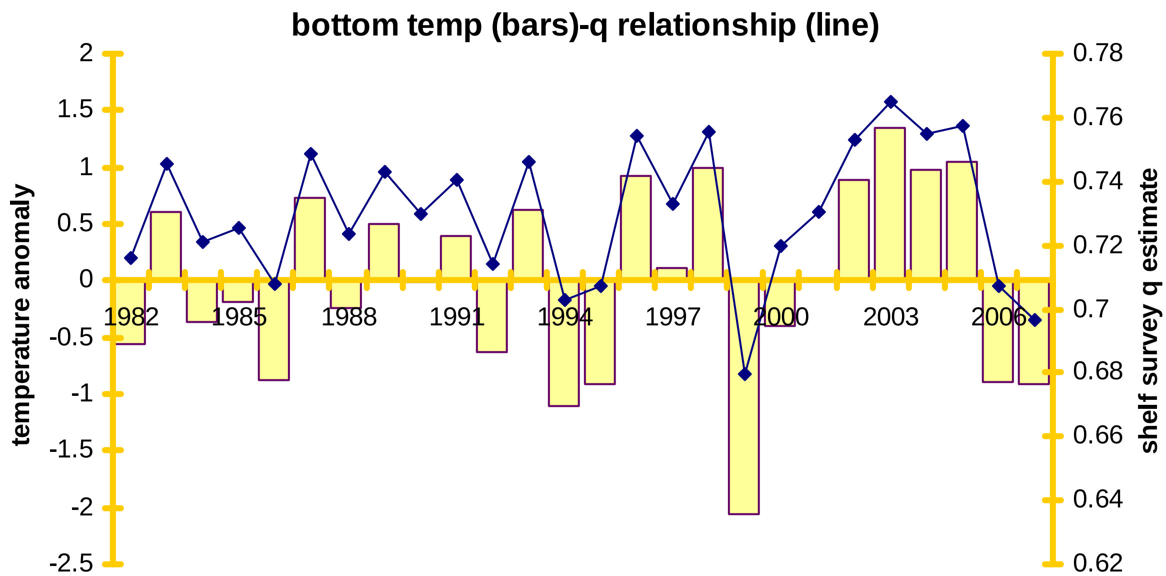


Figure 6.4--Shelf survey annual avg. bottom temperature anomalies (bars), model estimate of annual shelf survey q due to effect of water temperature (diamonds with lines), given the assumption that 73% of the biomass resides on the Bering Sea shelf.

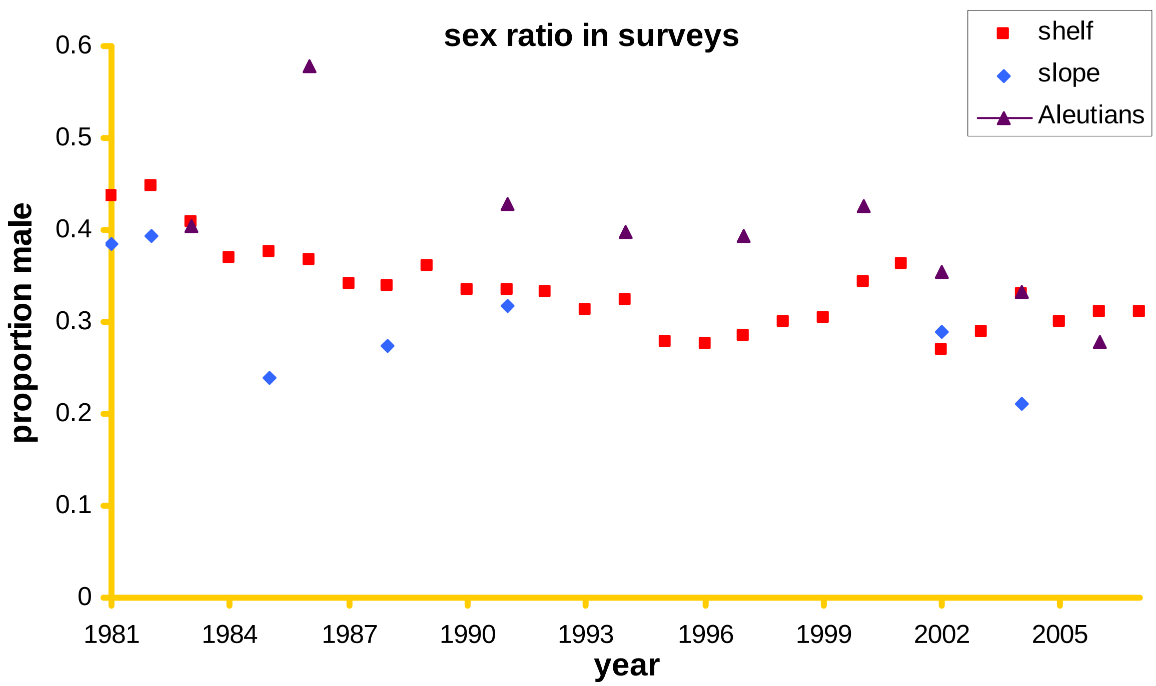


Figure 6.5--Proportion of the estimated male population from Bering Sea and Aleutian Islands trawl surveys on the continental shelf and slope.

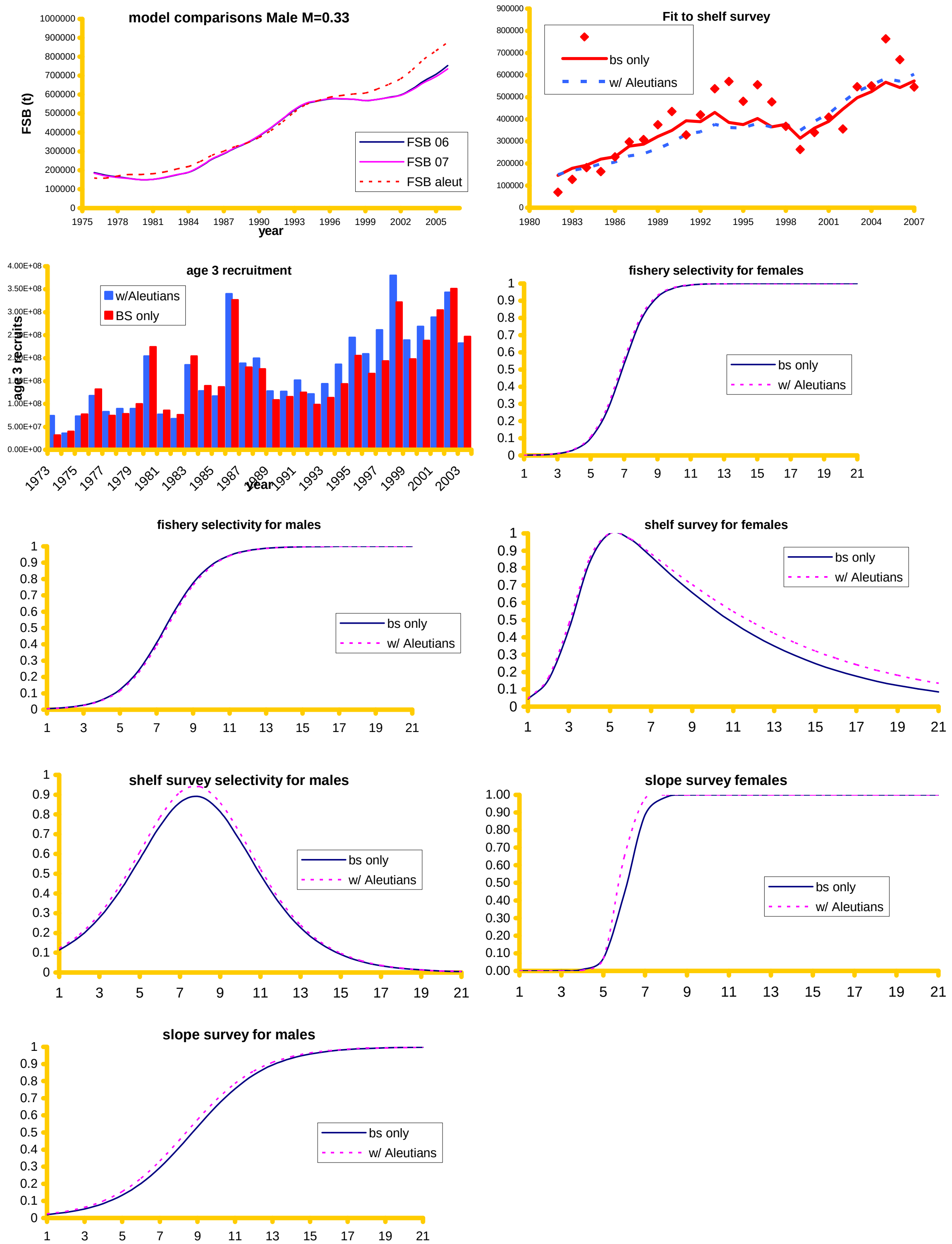


Figure 6.6—Comparison of some model output between the base model (Bering Sea shelf and slope surveys only) and the Alternative model which incorporates the Aleutian Islands survey and size composition estimates.

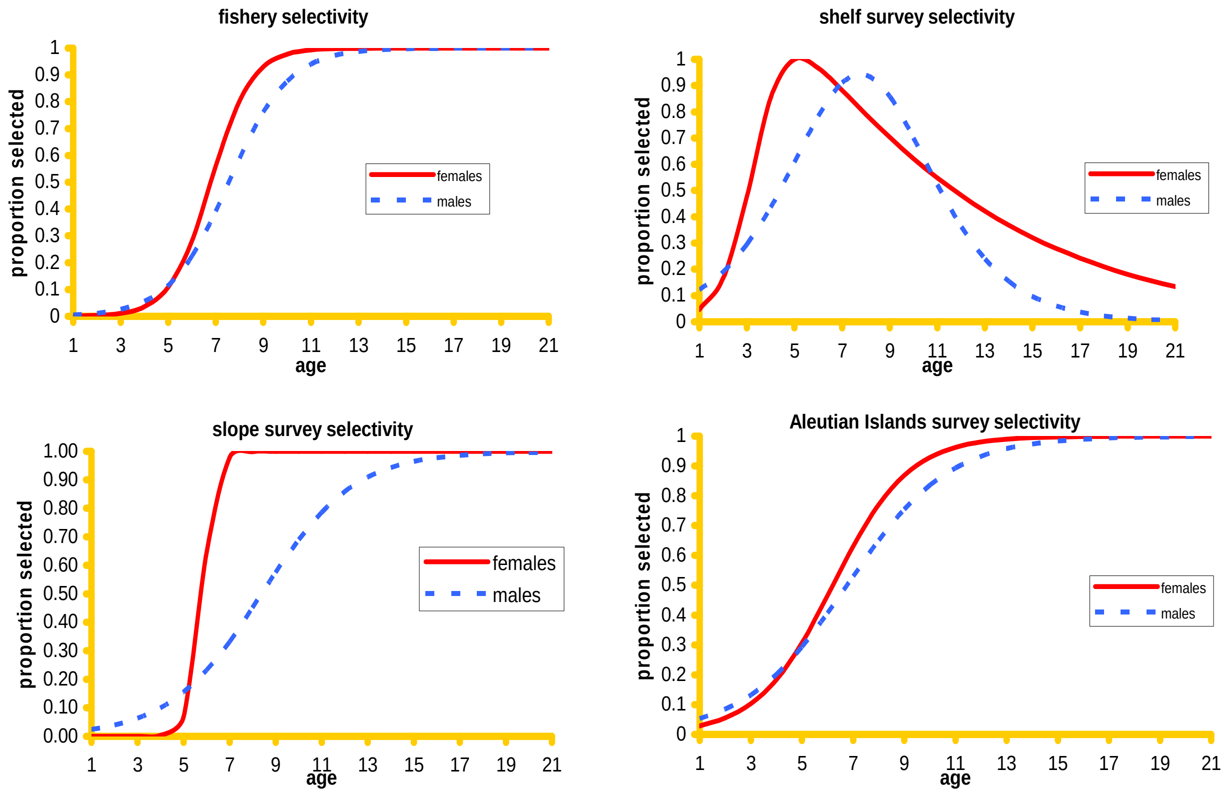


Figure 6.7--Age-specific fishery selectivity (top left panel), shelf survey selectivity (top right panel) slope survey selectivity (bottom left panel) and Aleutian Islands survey selectivity (bottom right panel), by sex, estimated from the stock assessment model.

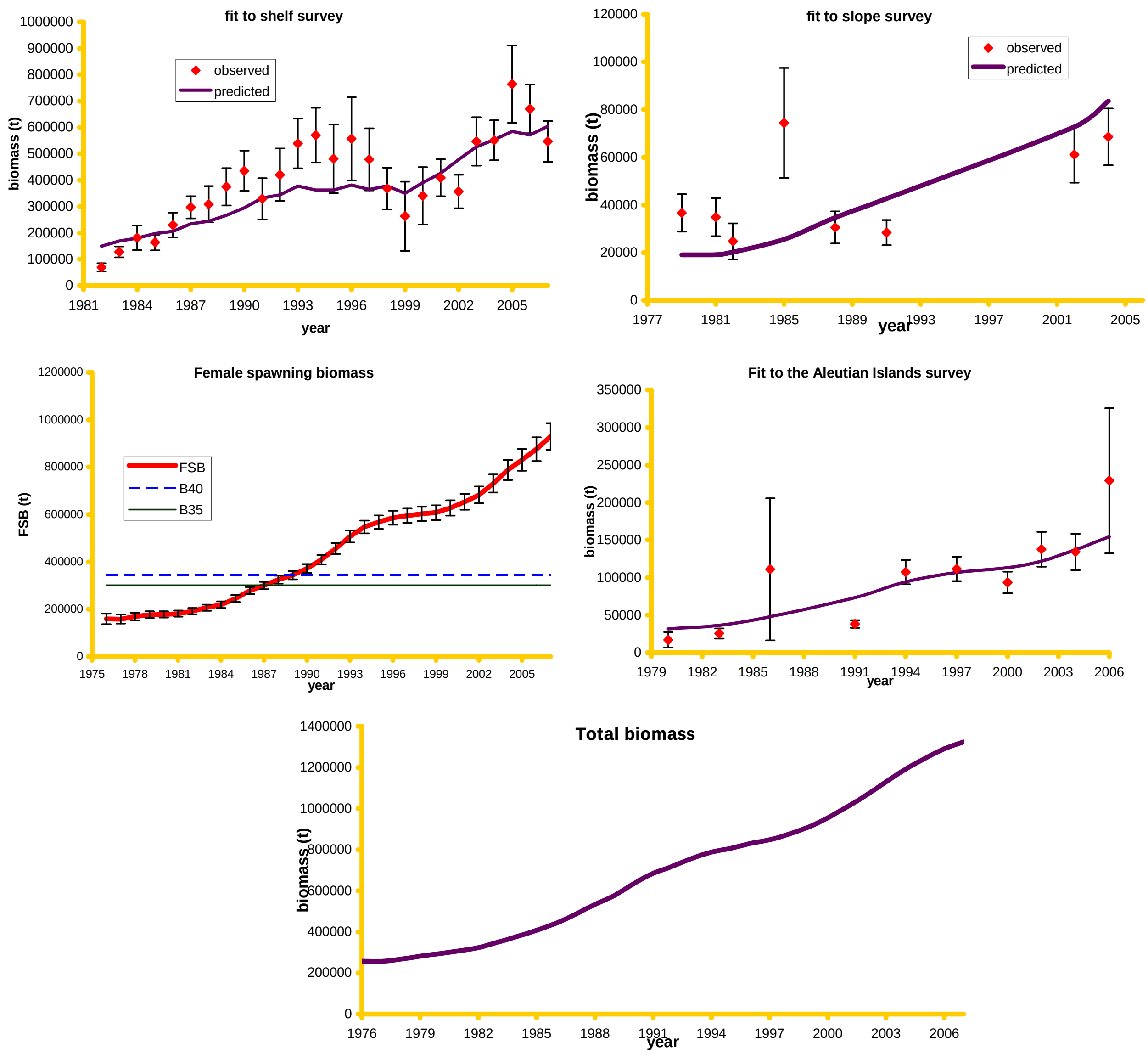


Figure 6.8--Stock assessment model results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), estimate of female spawning biomass with B35 and B40 indicated (middle left panel), the fit to the Aleutian Islands survey (middle right panel) and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

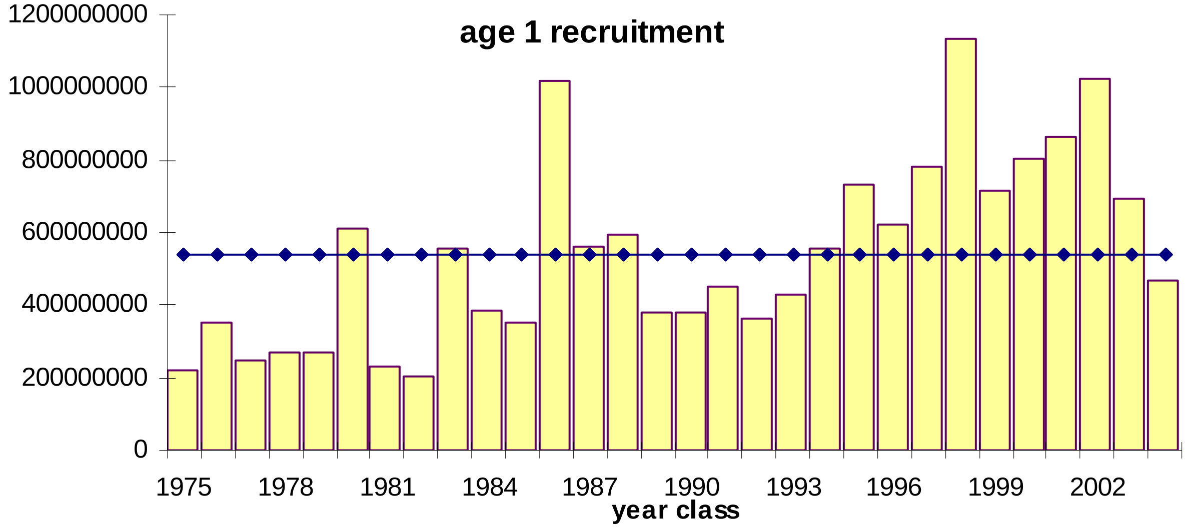


Figure 6.9--Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model.

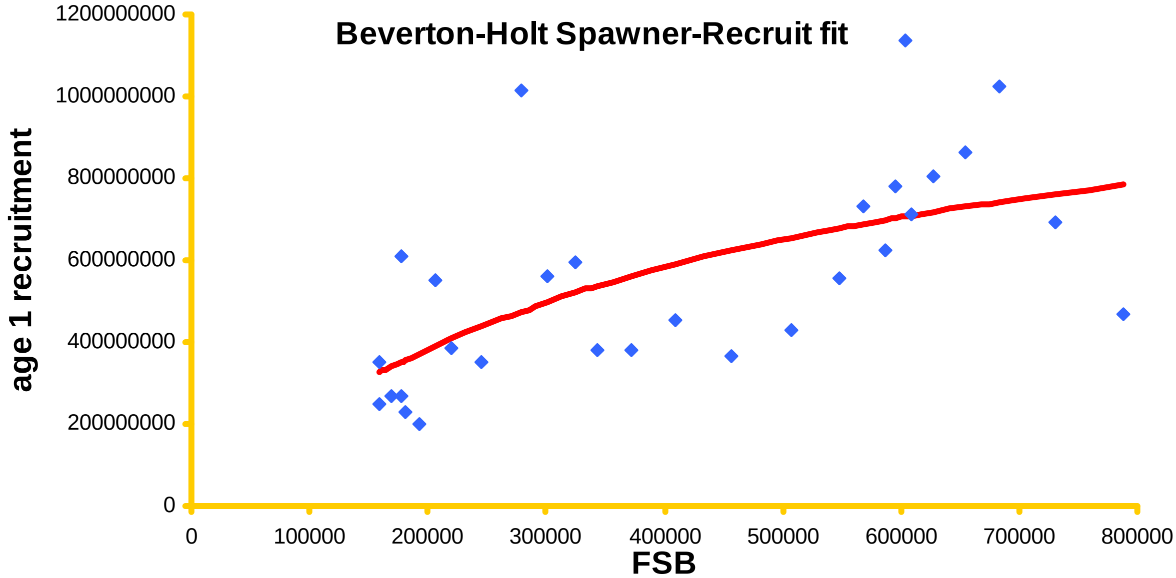


Figure 6.10—Beverton and Holt spawner recruit model fit to the age 1 recruitment data for Bering Sea arrowtooth flounder.

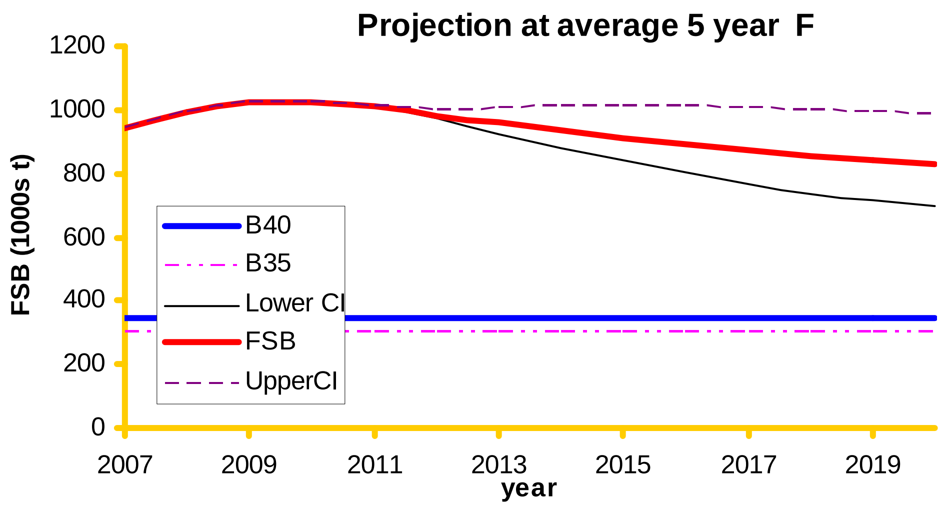


Figure 6.11--Projected female spawning biomass (1,000s t) of arrowtooth flounder if future harvest is at the same fishing mortality rate as the past five years.

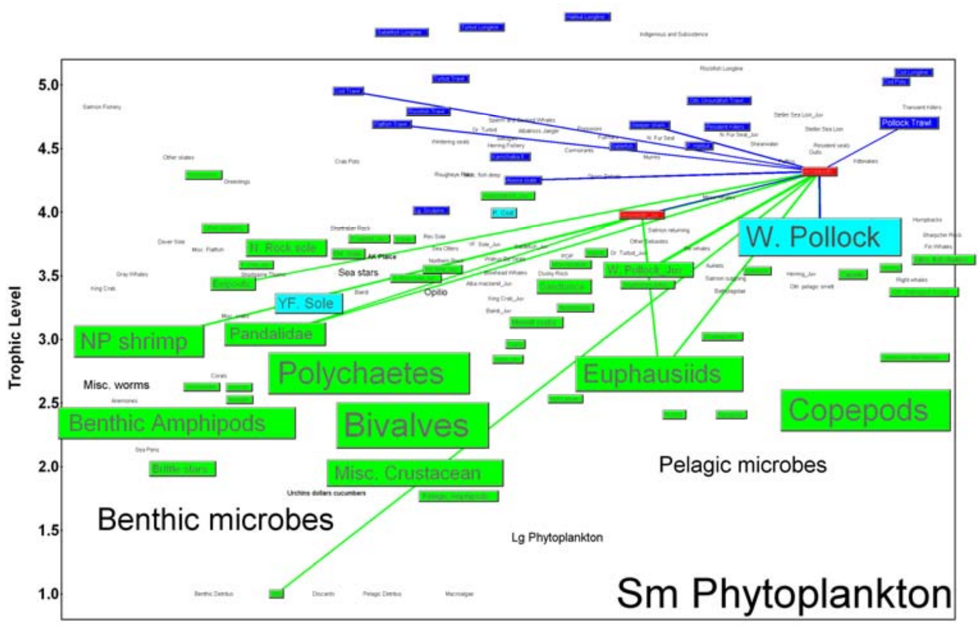


Figure 6.12. Adult and juvenile arrowtooth flounder in the EBS food web. Box size is proportional to biomass, and lines between boxes represent the most significant energy flows. Predators of arrowtooth are dark blue, prey of arrowtooth are green, and species that are both predators and prey of arrowtooth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

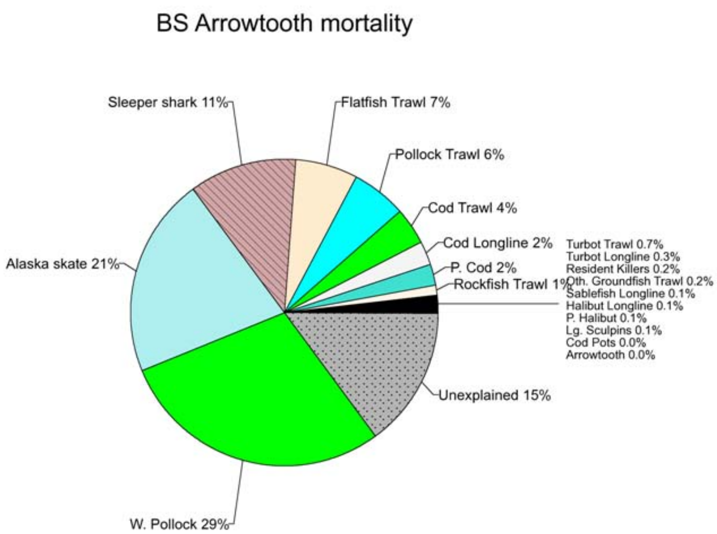


Figure 6.13. Mortality of Bering Sea arrowtooth flounder >20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. "Unexplained" mortality is the difference between the stock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

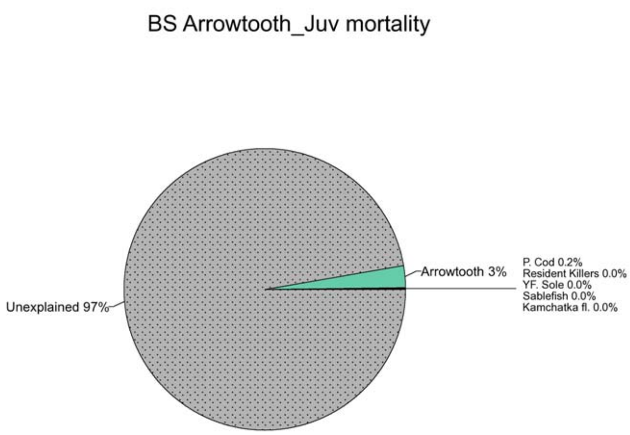


Figure 6.14. Mortality of Bering Sea arrowtooth flounder <20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. "Unexplained" mortality is the difference between the stock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

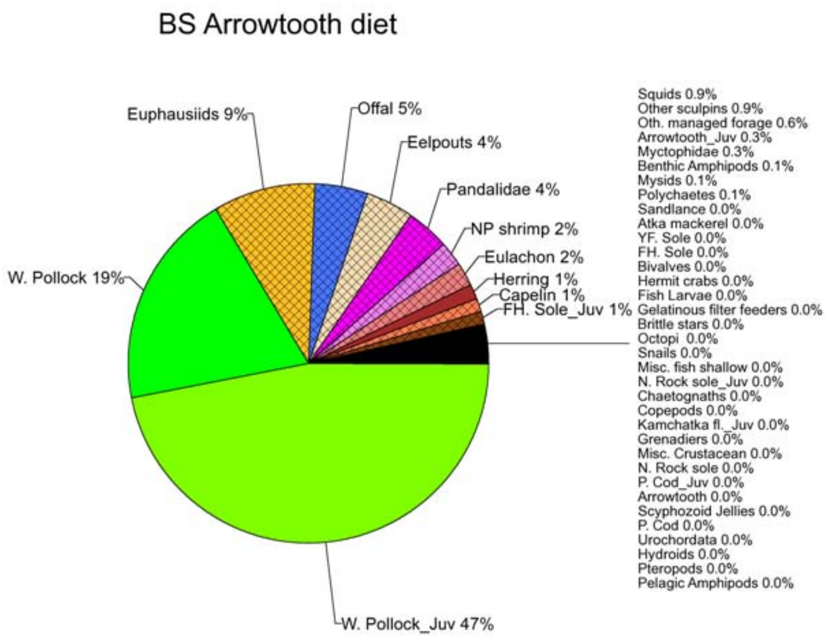


Figure 6.15. Diet of Bering Sea arrowtooth flounder >20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good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

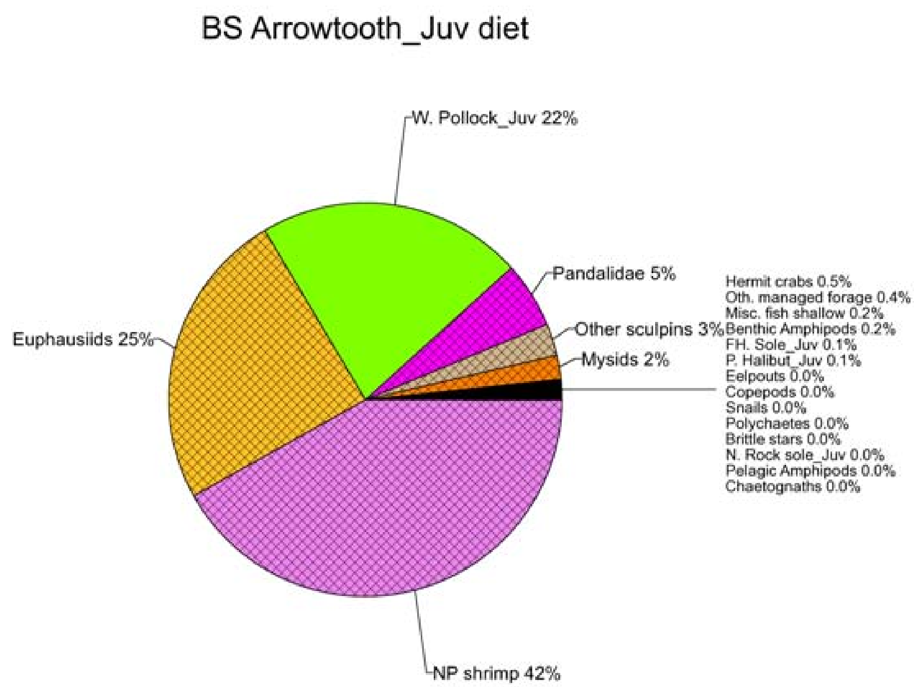


Figure 6.16. Diet of Bering Sea arrowtooth flounder <20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good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

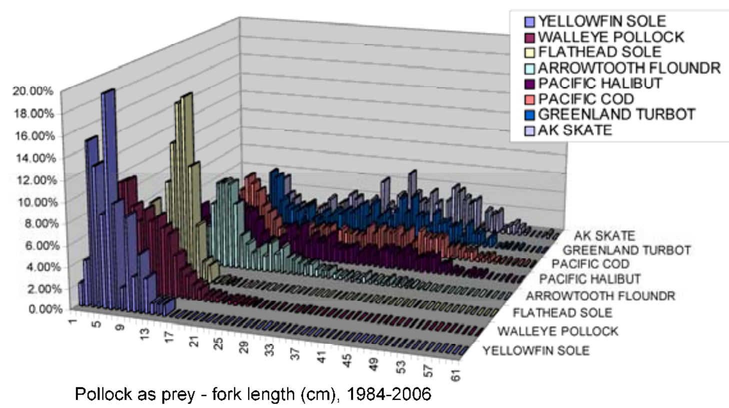


Figure 6.17. Length frequency of pollock found in stomachs, from groundfish food habits collected from 1984-2006 on AFSC summer trawl surveys in the eastern Berng Sea. Predators are sorted by median prey length of pollock in their stomachs. All lengths of predators are combined.

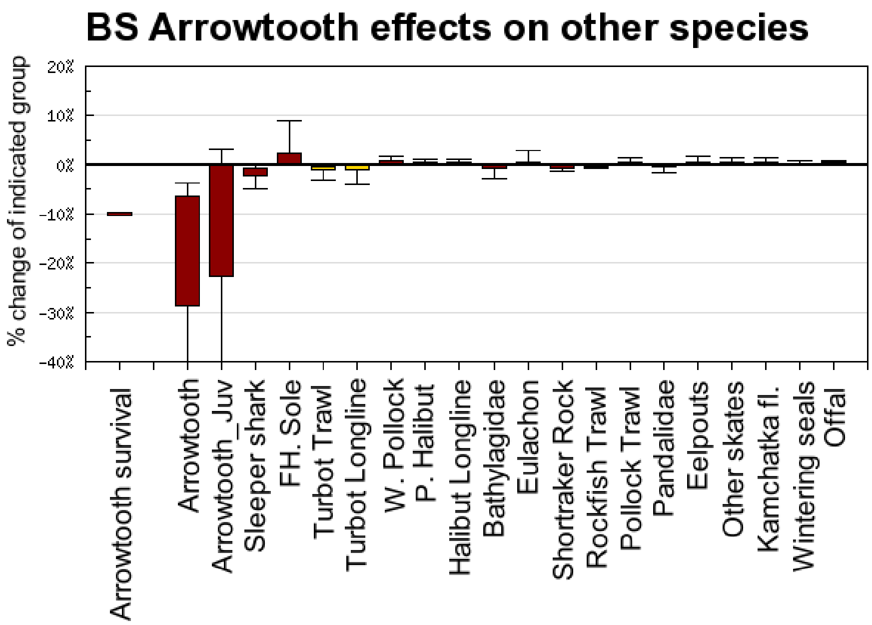


Figure 6.18. Effect of changing arrowtooth > 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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

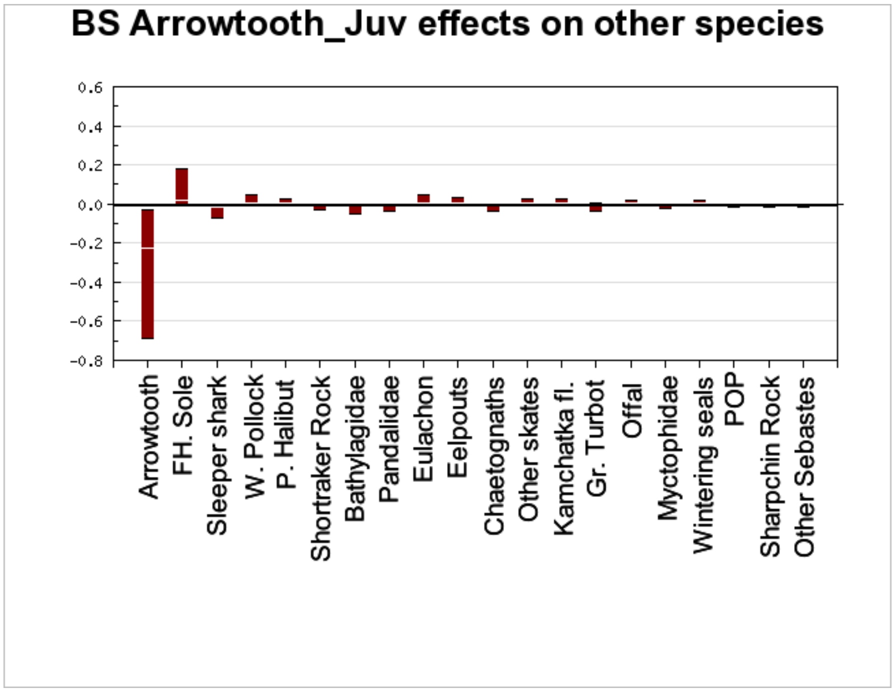


Figure 6.19. Effect of changing arrowtooth < 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting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

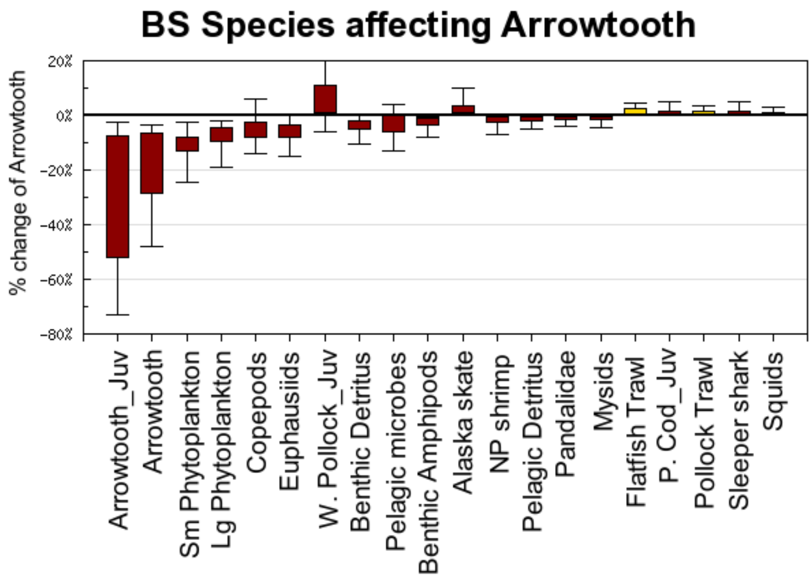


Figure 6.20. Effect of reducing fisheries catch (yellow) and other species survival (dark red) on arrowtooth > 20 cm biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting 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

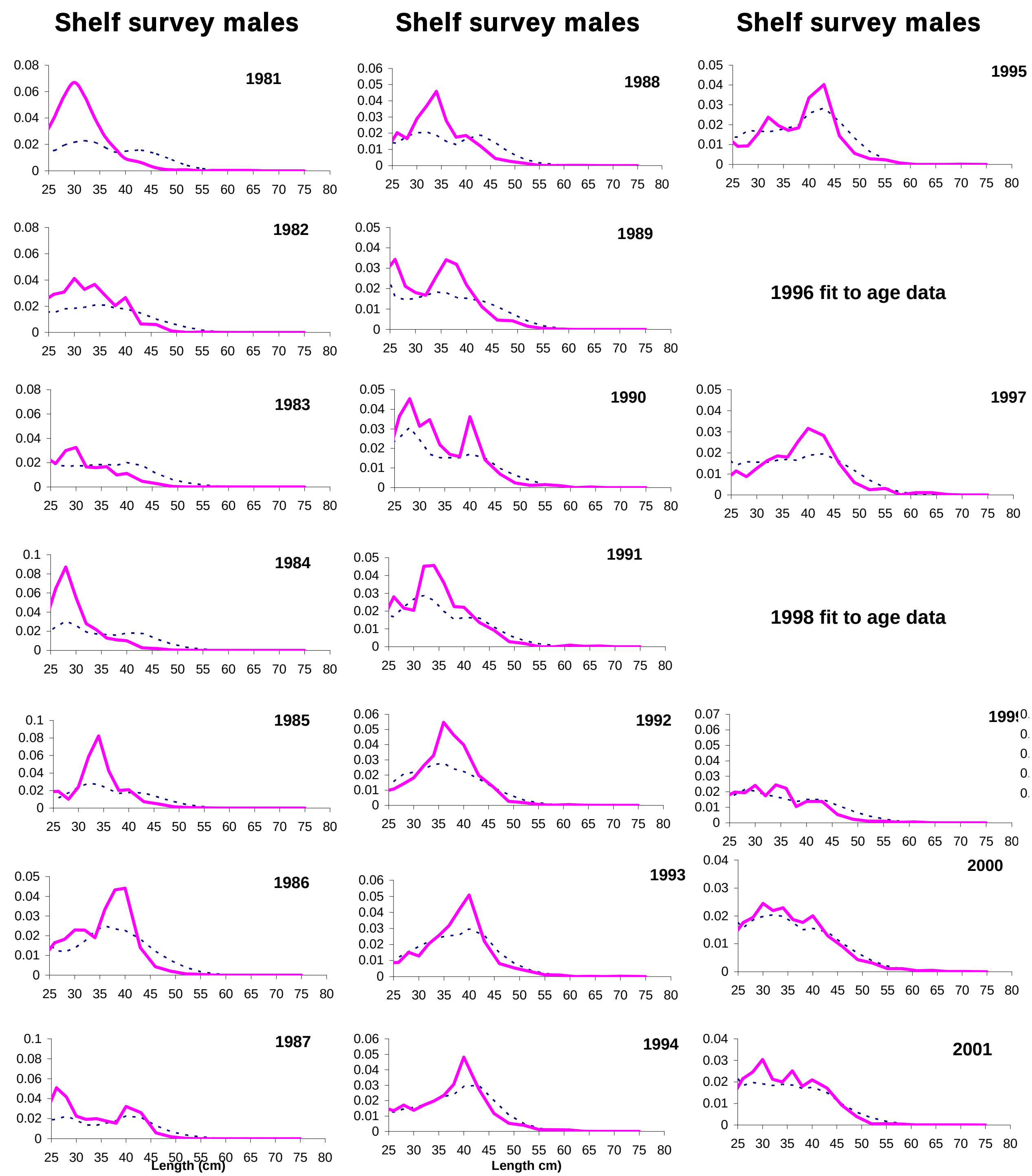
Figures showing the fit of the stock assessment model to the time-series of shelf, slope and Aleutian Islands survey ,size composition data by sex (estimated values are the dotted lines) and the fishery size composition data from 1978-90.

Table of arrowtooth flounder catch during research activities by the Alaska Fisheries Science Center, 1977-2005.

BSAI arrowtooth flounder TAC (1986-2007) and ABC (1982-2007)

Shelf survey biomass estimates for arrowtooth and Kamchatka flounder 1982-2007

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



Shelf survey males
Shelf survey males
Shelf survey males
1981
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1982
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1996 fit to age data
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1998 fit to age data
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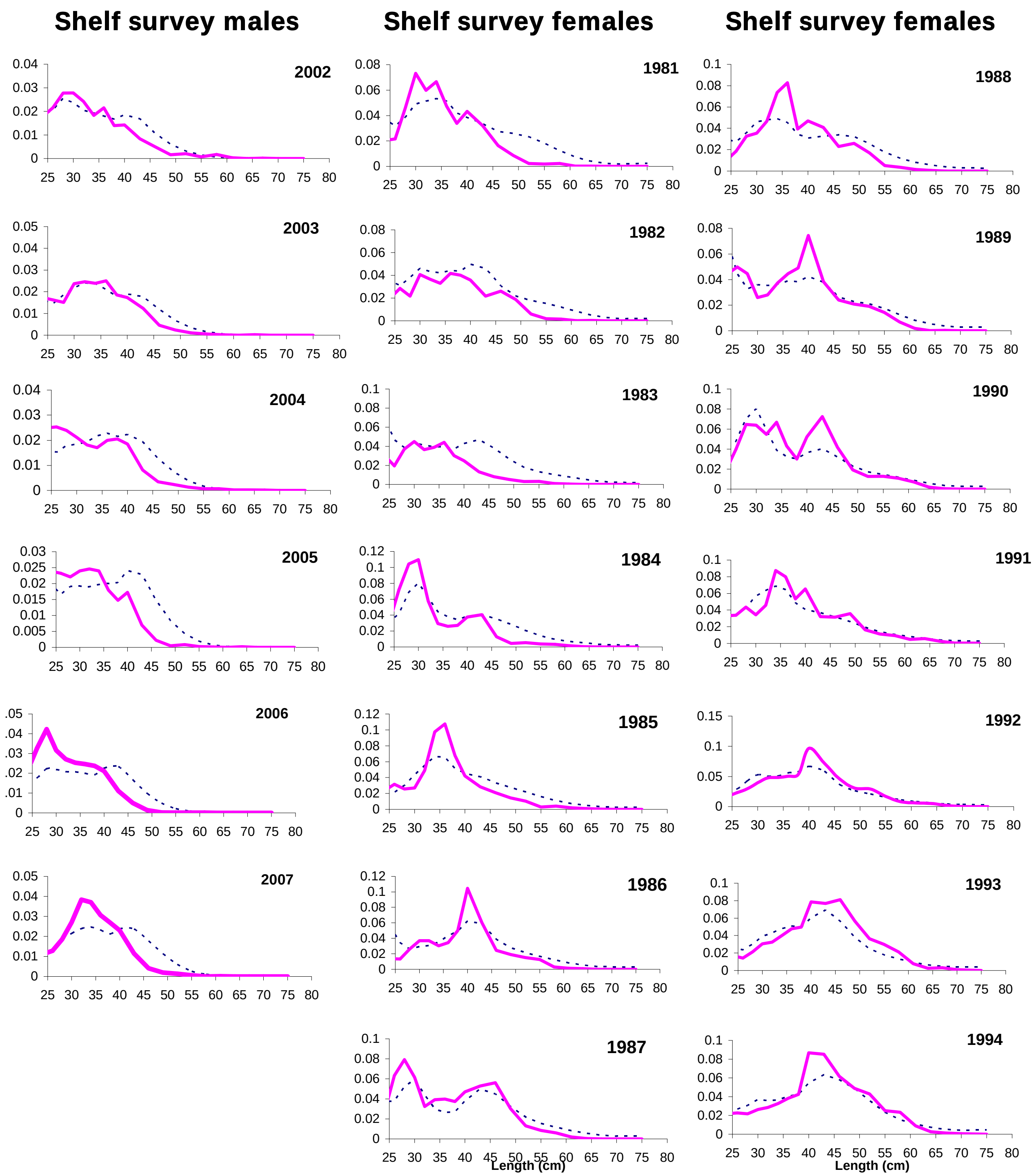
Length (cm)
Length cm)


Shelf survey males
Shelf survey females
Shelf survey females
2002
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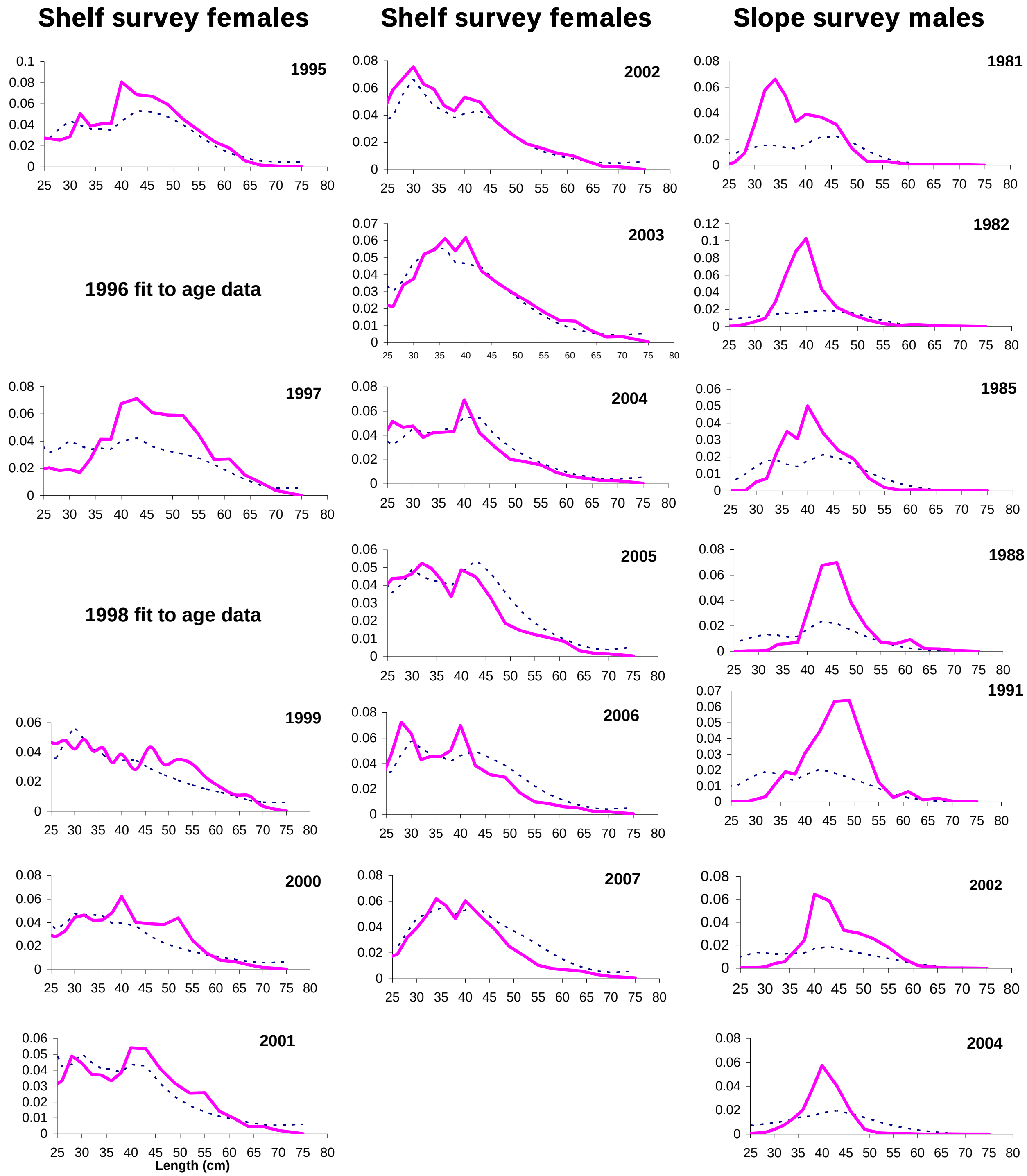
1993
1994
Length (cm)
Length (cm)


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
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1991
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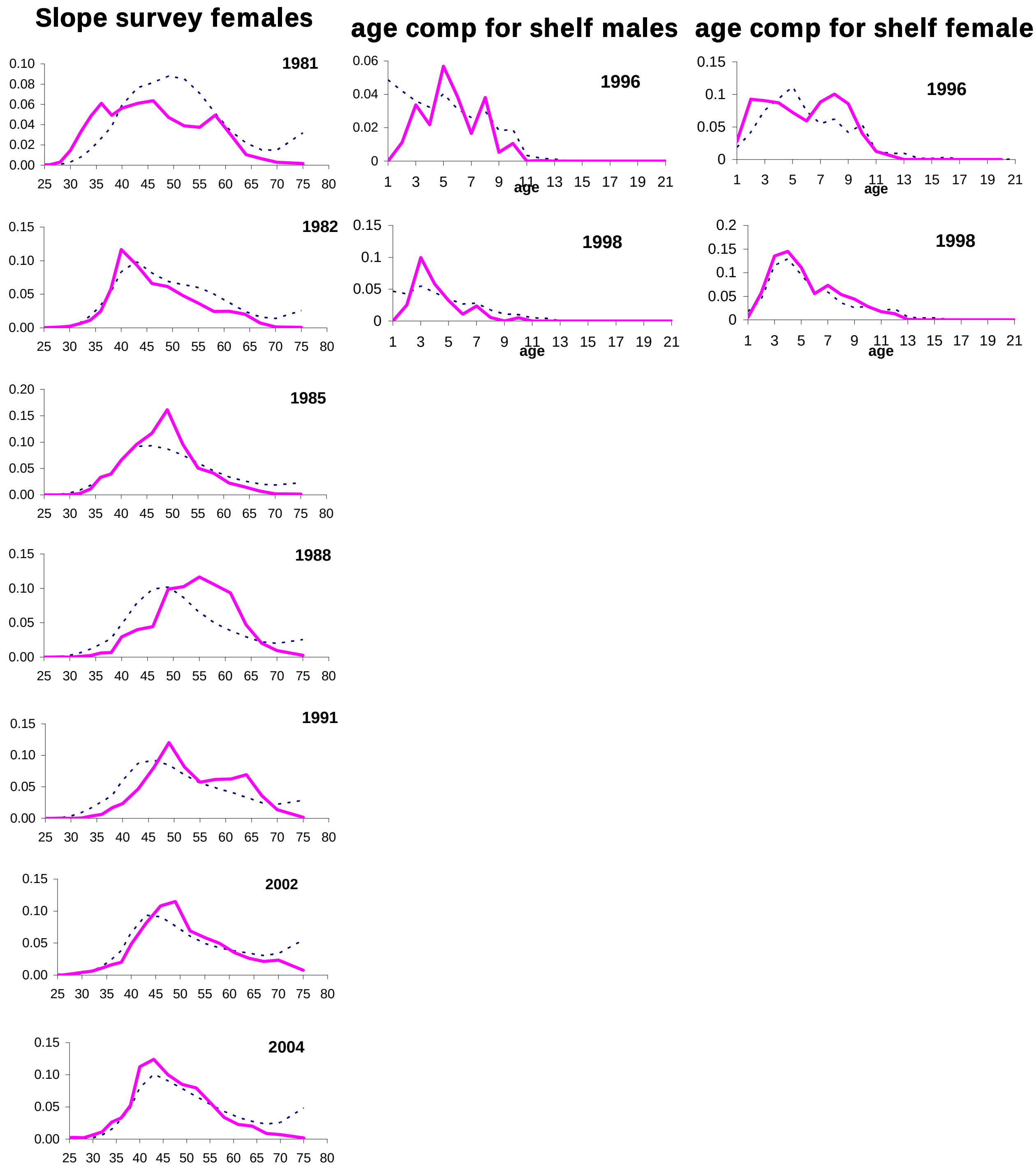
Length (cm)


Slope survey females
1981
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age comp for shelf males
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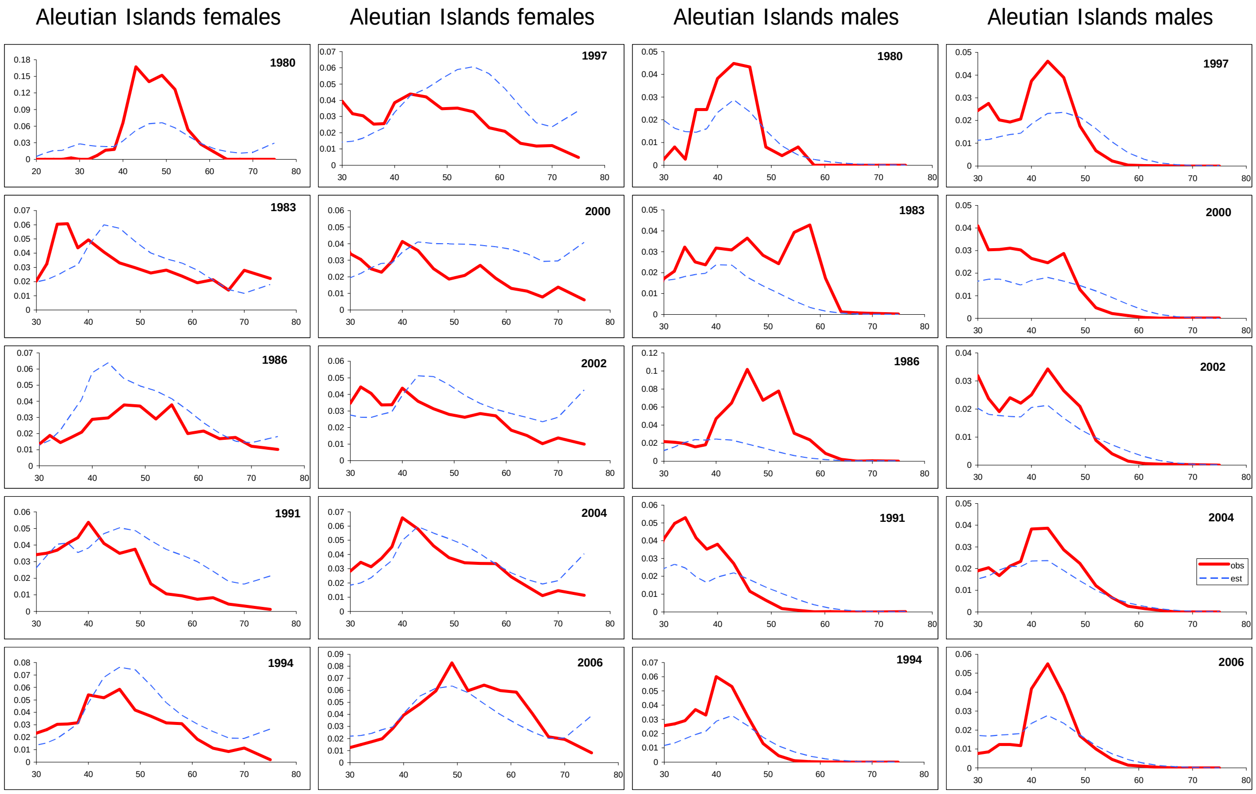
Aleutian Islands females
Aleutian Islands females
Aleutian Islands males
Aleutian Islands males
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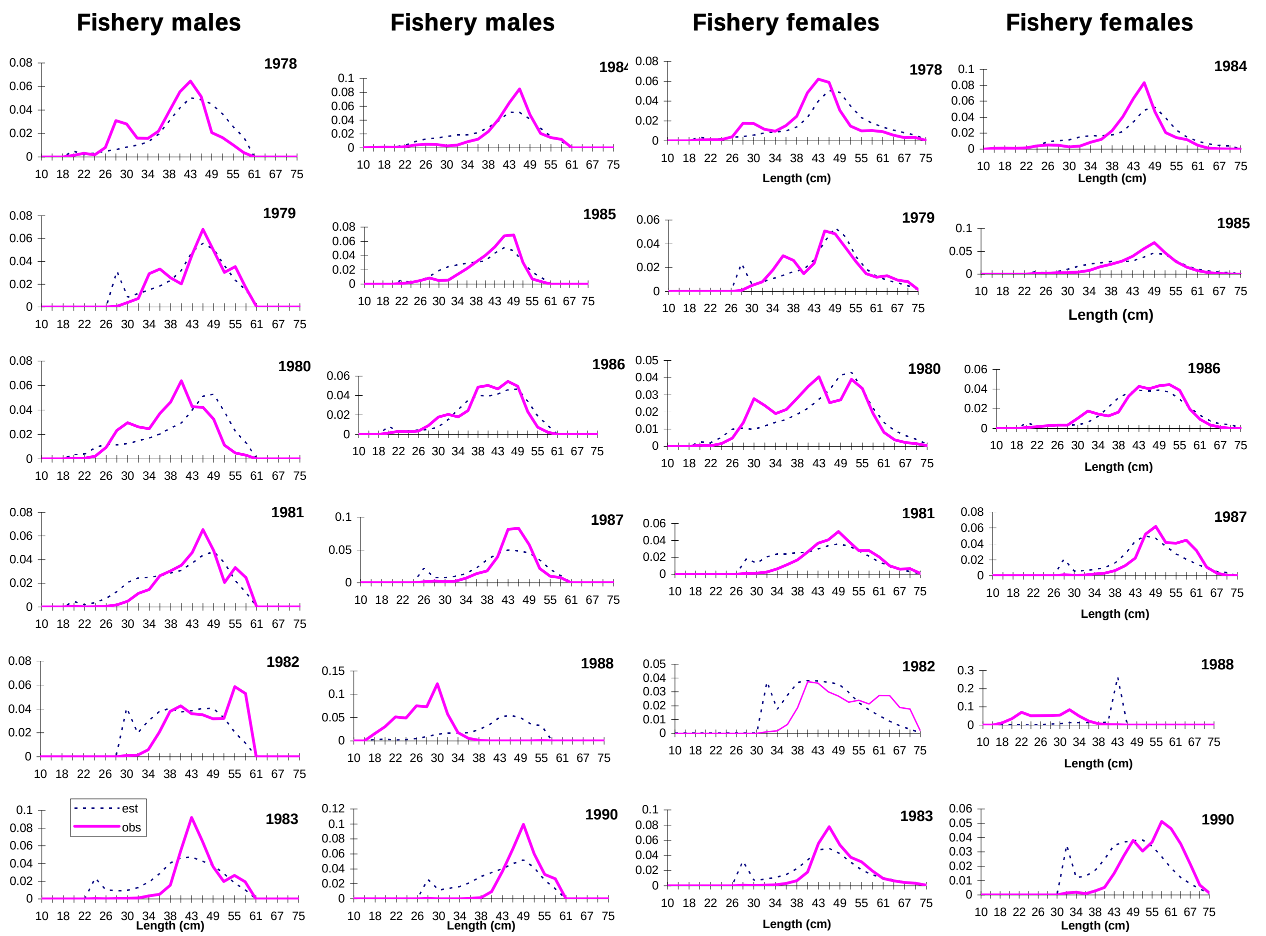
Fishery males
Fishery males
Fishery females
Fishery females
1978
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1979
1980
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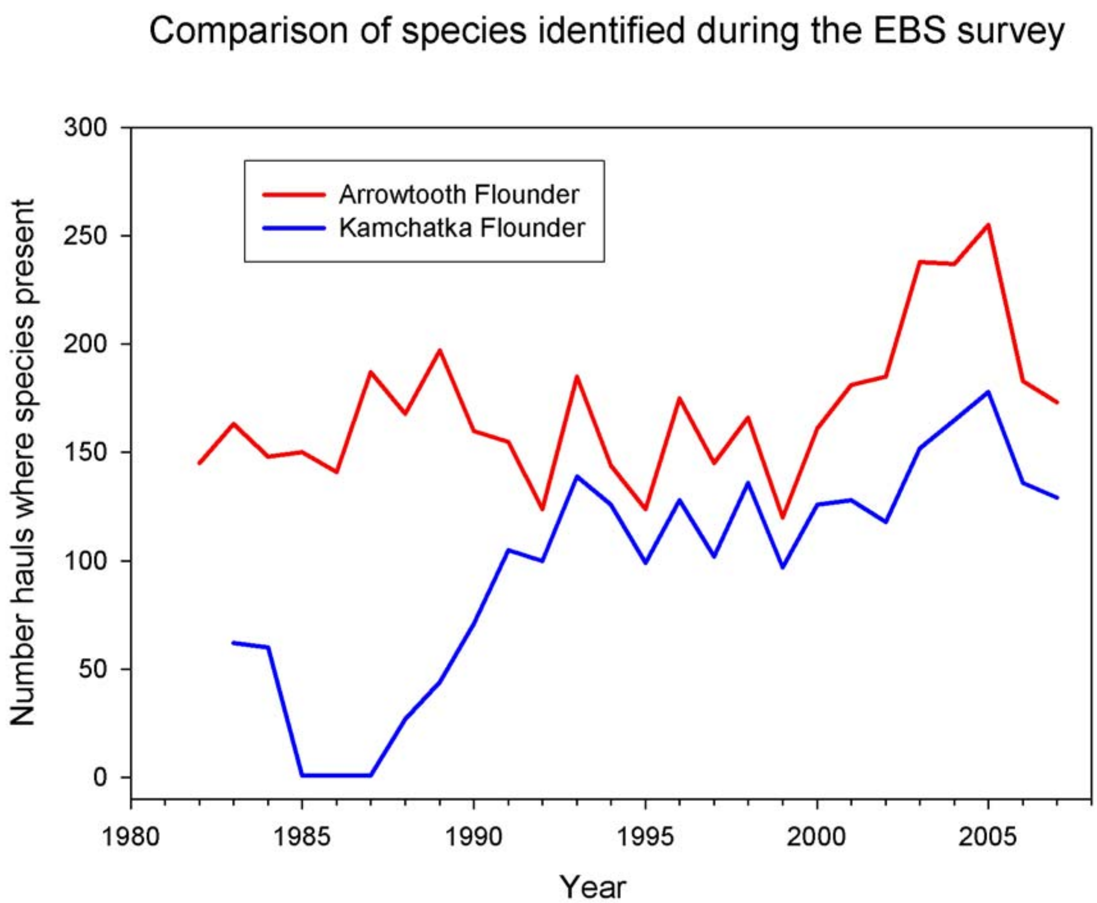
1990
est
obs
Length (cm)

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

	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

	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


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