Chapter 6. Arrowtooth Flounder

By

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Executive Summary

The following changes have been made to this assessment relative to the November 2005 SAFE.

Changes to the input data

1) 2006 shelf survey size composition.

2) 2006 shelf survey biomass point-estimates and standard errors.

3) Estimate of catch and discards through 6, September 2006.

4) Estimate of retained and discarded portion of the 2005 catch.

Assessment results

1) The projected age 1+ total biomass for 2007 is 1,275,900 t.

2) The projected female spawning biomass for 2007 is 824,400 t.

3) The recommended 2007 ABC is 158,000 t based on an $F_{0.40}$ (0.24) harvest level.

4) The 2007 overfishing level is 193,000 t based on a $F_{0.35}$ (0.30) harvest level.

	2006 Assessment recommendation for 2007 harvest	2005 Assessment recommendation for 2006 harvest
Total biomass	1,275,900 t	964,200 t
ABC	**158,000** t	135,500 t
Overfishing	193,000 t	166,100 t
F_{ABC}	$F_{0.40}$ = 0.24	$F_{0.40}$ = 0.26
$F_{overfishing}$	$F_{0.35}$ = 0.30	$F_{0.30}$ = 0.32
B_{40}	339,600 t	295,100 t
B_{35}	297,000 t	258,200 t

SSC comments to the assessment authors:

- **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.**

Work has begun on an expanded ecosystem section, primarily focusing on the arrowtooth flounder-pollock mortality relationship. A key part of this analysis is an updated bioenergetics model which is now in preparation. We anticipate providing the requested expanded analysis in next year's assessment.

Introduction

The arrowtooth flounder (Atheresthes stomias) is a relatively large flatfish which occupies continental shelf waters almost exclusively until age 4, but at older ages occupies both shelf and slope waters. Two species of Atheresthes occur in the Bering Sea. Arrowtooth flounder and Kamchatka flounder (A. evermanni) are very similar in appearance and 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 12,751 t from 1977-2006. 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 6 September, 2006 is 11,214 t (well below the 2006 ABC of 136,000 t). NMFS Regional Office reports indicate that bottom trawling accounted for 79% of the 2006 catch.

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 1985-2005 are shown in Table 6.2. Half of the arrowtooth flounder caught in 2005 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 6, 2006 (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). The 2005 CPUE of 16.35 kg/ha was the highest ever estimated from the shelf survey. The 2006 estimate is lower at 13.12 kg/ha.

Absolute Abundance from Trawl Surveys

Biomass estimates (t) for arrowtooth flounder from the standard survey area in the eastern Bering Sea and Aleutian Islands region are shown in Table 6.3. 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 the estimate declined slightly. The 2005 and 2006 biomass estimates 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. 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. Surveys conducted in 1988 and 1991 used a Nor' Eastern trawl with bobbin roller gear. Trawl surveys on the continental slope estimate 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.

Approximately 1.35 billion fish were estimated for the eastern Bering Sea in 2004 with most of the fish (1.3 billion) occupying shelf waters and 53.2 million located on the continental slope. The Aleutian Islands region accounted for an additional 132 million arrowtooth flounder. The assessment model described below does not use the Aleutian Islands portion of the biomass to model stock abundance and is thus a conservative estimate of the arrowtooth/Kamchatka flounder stock size.

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.

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

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

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

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

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

Maturity information from a histological examination of arrowtooth flounder in the Gulf of Alaska (Zimmerman 1997) 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 Modeler Builder software to model the population dynamics of Bering Sea 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 three likelihood components:

Data Component	Distribution assumption
Trawl fishery size composition	Multinomial
Shelf survey population size composition	Multinomial
Slope survey population size composition	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 in the initial stages by the model are presented below:

Fishing mortality	Selectivity	Year class strength	Total
31	14	49	94

The recruitment parameters are comprised of 21 initial ages in 1976 and 27 subsequent age 1 recruitment estimates from 1976-2004. Recruitment in 2006 was set at the average from 1976-2002. 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).

We assume that the shelf and slope surveys measure non-overlapping segments of the arrowtooth flounder stock. The 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 did not attempt to incorporate the Aleutian Islands biomass estimate. 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 and sex ratios from the shelf and slope surveys (Fig. 6.2).

Parameters Estimated Independently

Catchability

A past assessment (Wilderbuer and Sample 1995) analyzed the value of q or catchability of the research trawl by examining fits of the models' various likelihood components over a range of fixed q values. The results indicated q = 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).

Attempts to estimate q in previous assessments were unsuccessful as estimated values always reached the upper bounds placed on the parameter. It may not be possible to obtain reliable estimates of q for this stock given the present level of information available. Catchability is therefore assumed to be 1.0 for the whole stock with 87% on the shelf and 13% in slope waters (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. 6.3). 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 0.87 (as discussed above).

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 indicate that females are consistently estimated to be in higher abundance than males (Fig. 6.4). This difference was also evident in the Gulf of Alaska from triennial surveys conducted from 1984-96 (Turnock et al. 1998). 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:

$$SRlike = 0.5\left[\frac{SR_{obs} - SR_{pred}}{\sigma_{obs}}\right]^2$$

where SRlike is the sex ratio likelihood component, SR_{obs} is the observed sex ratio in shelf survey trawl surveys from 1982-2006, 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 runs with this configuration result in the best fit to all the data components (Fig. 6.5) at male M = 0.27. However, at this value, maximum male selectivity on the shelf is estimated at 0.65 for age 7 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 from runs made with male natural mortality rates ranging from 0.27 – 0.34 with equal emphasis placed on all data components.

	male natural mortality values							
	0.27	0.28	0.29	0.3	0.31	0.32	0.33	0.34
Likelihood component								
shelf biomass	66.31	67.46	68.48	69.44	70.34	71.20	72.02	72.80
slope biomass	92.70	91.03	89.59	88.35	87.31	86.44	85.72	85.12
shelf length comp	1497.21	1500.78	1504.57	1508.53	1512.64	1516.90	1521.32	1525.88
slope length comp	660.64	665.19	670.91	677.65	685.31	693.79	703.02	712.93
recruitment	30.43	29.94	29.52	29.17	28.89	28.67	28.48	28.34
sex ratio	81.44	72.68	64.72	57.50	50.97	45.06	39.73	34.93
shelf age comps	130.05	130.70	131.21	131.67	132.10	132.53	132.96	133.39
total likelihood	2558.78	2557.78	2559.00	2562.32	2567.56	2574.58	2583.24	2593.40
male max shelf selectivity (age)								
	0.61 (7)	.65 (7)	0.69 (7)	0.73 (8)	0.78 (8)	0.83 (8)	.89 (8)	0.96 (8)

The natural mortality value for males is unknown but most likely ranges between 0.28 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 good 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 0.89 for age 8 fish. This value is close to 1.0 but still allows for some overlap with slope survey size composition observations where fish of this age are present in both shelf and slope surveys. It may be that the rate of male natural mortality is even higher as it has been estimated at 0.35 in the Gulf of Alaska stock assessment, an assessment with age data from eight surveys which may provide more precise estimates. 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.

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 1977-2006 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. 6.5) 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 more than quadrupled from 1976 to the 2006 value of 1.17 million t (Fig. 6.6, Table 6.8). After a rapid increase from 1985-94, the population leveled-off from 1995-2003 before increasing again 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. Female spawning biomass is also estimated to be at a high level, 753,000 t in 2006, 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 since the mid 1990s, but does not fit the high biomass estimates of 1993-1997, and 2005-2006. The very high 2005 survey estimate is particularly not fit very well by the model but does 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 6.3). The model indicates an increasing biomass trend on the slope and estimates a higher biomass than the 2002 and 2004 slope survey estimates (Fig. 6.6). 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 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 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. 6.7, Table 6.10). From 1989-1994 recruitment was below average and stock abundance leveled-off. Recent increases in arrowtooth flounder biomass can be attributed to the strong 1995 and very strong 1998 year classes. Small fish present in the three shelf surveys from 2003-2005 (fig 6.2) indicate strong 2001 - 2003 year classes which should increase the stock size even higher than the present level in the near future.

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. 6.7).

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 stable and high level. **The estimate of projected 2007 total biomass from the stock assessment projection model is 1,275,900 t and the female spawning biomass is estimated at 824,400 t (not including the Aleutian Islands)**.

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 1977-2003 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 $B_{0.40}$ = 339,600 t. The stock assessment model estimates the 2007 level of female spawning biomass at 824,400 t (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and $B>B_{0.40}$ (824,400 > 339,600), arrowtooth flounder reference fishing mortality is defined in tier 3a. For the 2007 harvest: F_{ABC} ◂ $F_{0.40}$ = 0.24 and $F_{overfishing} = F_{0.35}$ = 0.30 (full selection F values).

Acceptable biological catch is estimated for 2007 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2007 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 2007 ABC of 158,000 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
$F_{overfishing}$	0.30	193,200 t
$F_{0.40}$	**0.24**	**158,000 t**

This estimate of 2007 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 2006 survey biomass point estimate of 61,644 t (Appendix table) would give an overfishing limit of 12,329 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 2006 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2007 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2006. 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 2007, 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 2007 recommended in the assessment to the *max* F_{ABC} for 2007. (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 2002-2006 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 2007 and above its MSY level in 2017 under this scenario, then the stock is not overfished.)

Scenario 7: In 2007 and 2008, *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 2019 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 6.8.

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 2007, it does not provide the best estimate of OFL for 2008, because the mean 2008 catch under Scenario 6 is predicated on the 2007 catch being equal to the 2007 OFL, whereas the actual 2007 catch will likely be less than the 2007 ABC. Therefore, the projection model was re-run with the 2007 catch fixed equal to the 2006 catch and the 2008 fishing mortality rate fixed at F_{ABC}.

Year	Catch	ABC	OFL
2007	11,214	158,000	193,000
2008	11,214	170,500	208,400

Ecosystem Considerations

Ecosystem Effects on the stock

1) Prey availability/abundance trends

Arrowtooth flounder diet varies by life stage as follows: Larvae consume plankton and algae, early juveniles consume zooplankton, late juvenile stage and adults prey includes polychaetes, crustaceans, brittle stars, shrimp, herring myctophids and other small fish. Adult arrowtooth larger than 30 cm are mainly piscivorus and consume pollock as a major portion of their diet. 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	2.1
Herring	0
Red King crab	0
C. bairdi	<1
Other Tanner crab	<1
Salmon	<1

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

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Table 6.1. All nation total catch (t) of arrowtooth flounder in the eastern Bering Sea and Aleutian Islands region[a], 1970-2006. 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**									11,214

[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 6 September, 2006 (NMFS regional office).

Table 6.2 Estimates of retained and discarded arrowtooth flounder catch, 1985-2005.

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

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

The 1988 and 1991 slope estimates were from the depth ranges of 200-800 m while earlier slope estimates were from 200-1,000 m.

The 2002 and 2004 slope estimate was from sampling conducted from 200-1,200 m.

Table 6.4--Key equations used in the population dynamics model.

$N_{t,1} = R_t = R_0 e^{\tau_t}$, $\tau_t \sim N(0, \delta^2{}_R)$	Recruitment 1956-75
$N_{t,1} = R_t = R_\gamma e^{\tau_t}$, $\tau_t \sim N(0, \delta^2{}_R)$	Recruitment 1976-2005
$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}\left(1 - e^{-z_{t,a}}\right)N_{t,a}$	Catch in year *t* for age *a* fish
$N_{t+1,a+1} = N_{t,a} e^{-z_{t,a}}$	Numbers of fish in year *t+1* at age *a*
$N_{t+1,A} = N_{t,A-1} e^{-z_{t,A-1}} + N_{t,A} e^{-z_{t,A}}$	Numbers of fish in the “plus group”
$S_t = \sum N_{t,a} W_{t,a} \phi_a$	Spawning biomass
$Z_{t,a} = F_{t,a} + M$	Total mortality in year *t* at age *a*
$F_{t,a} = s_a \mu^F \exp^{\varepsilon^F{}_t}$, $\varepsilon^F{}_t \sim N(o, \sigma^2{}_F)$	Fishing mortality
$s_a = \frac{1}{1 + \left(e^{-\alpha + \beta a}\right)}$	Age-specific fishing selectivity
$C_t = \sum C_{t,a}$	Total catch in numbers
$P_{t,a} = {C_{t,a}}/{C_t}$	Proportion at age in catch
$SurB_t = q \sum N_{t,a} W_{t,a} v_a$	Survey biomass
$L = \sum_{t,a} m_t p_{t,a} \ln \frac{\hat{p}_{t,a}}{p_{t,a}} + (-0.5) \sum_t \left[\left(\ln \frac{surB_t}{s\hat{u}rB_t} {1}/{\sigma_t} \right)^2 - \ln \sigma_t \right]$	Total log 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	0.119	0.075
1977	0.079	0.047
1978	0.073	0.042
1979	0.109	0.058
1980	0.150	0.072
1981	0.148	0.064
1982	0.095	0.040
1983	0.104	0.044
1984	0.062	0.027
1985	0.043	0.019
1986	0.036	0.017
1987	0.021	0.010
1988	0.076	0.037
1989	0.025	0.012
1990	0.041	0.020
1991	0.064	0.032
1992	0.027	0.014
1993	0.022	0.012
1994	0.030	0.019
1995	0.018	0.012
1996	0.028	0.018
1997	0.019	0.013
1998	0.029	0.019
1999	0.020	0.013
2000	0.025	0.015
2001	0.027	0.016
2002	0.022	0.012
2003	0.024	0.013
2004	0.032	0.017
2005	0.023	0.012
2006	0.017	0.010

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

	Fishery		shelf survey		slope survey	
Age	**females**	**males**	**females**	**males**	**females**	**males**
1	0.00	0.01	0.04	0.11	0.00	0.02
2	0.00	0.01	0.15	0.18	0.00	0.03
3	0.01	0.03	0.43	0.27	0.00	0.05
4	0.03	0.06	0.83	0.40	0.01	0.08
5	0.10	0.12	1.00	0.56	0.07	0.13
6	0.26	0.24	0.97	0.73	0.43	0.20
7	0.52	0.41	0.87	0.86	0.88	0.29
8	0.78	0.60	0.76	0.89	0.99	0.40
9	0.92	0.77	0.66	0.82	1.00	0.53
10	0.97	0.88	0.57	0.68	1.00	0.65
11	0.99	0.94	0.49	0.51	1.00	0.75
12	1.00	0.97	0.42	0.35	1.00	0.83
13	1.00	0.99	0.36	0.23	1.00	0.89
14	1.00	0.99	0.30	0.15	1.00	0.93
15	1.00	1.00	0.25	0.09	1.00	0.96
16	1.00	1.00	0.21	0.06	1.00	0.97
17	1.00	1.00	0.18	0.04	1.00	0.98
18	1.00	1.00	0.15	0.02	1.00	0.99
19	1.00	1.00	0.13	0.01	1.00	0.99
20	1.00	1.00	0.11	0.01	1.00	1.00
21	1.00	1.00	0.09	0.00	1.00	1.00

Table 6.8 Model estimates of arrowtooth flounder 1+ total biomass (t) and female spawning biomass (t) from the 2005 and 2006 assessments.

	2005 Assessment		2006 Assessment	
	age 2+ Total biomass	Female Spawning biomass	age 2+ Total biomass	Female Spawning biomass
1976	248,608	179,275	256,799	188,233
1977	235,767	166,195	242,346	173,329
1978	236,275	159,111	241,173	164,447
1979	244,946	152,849	248,466	156,804
1980	253,757	147,398	256,175	150,274
1981	266,858	150,041	268,480	151,976
1982	285,145	161,150	286,215	162,318
1983	316,173	175,316	316,934	175,868
1984	349,043	188,294	349,684	188,506
1985	386,948	218,733	387,615	218,853
1986	430,165	258,720	431,114	258,822
1987	481,305	286,525	482,306	286,657
1988	537,011	318,029	538,038	318,441
1989	584,155	344,425	585,224	345,180
1990	643,636	379,624	644,789	380,757
1991	691,603	422,354	693,228	423,327
1992	720,380	471,184	722,711	471,102
1993	750,290	518,645	753,551	518,712
1994	770,760	550,949	775,196	552,569
1995	776,741	564,174	782,795	566,724
1996	784,094	574,985	792,358	577,885
1997	783,604	573,642	794,845	577,545
1998	790,796	569,515	806,168	575,216
1999	798,875	560,489	821,070	568,298
2000	815,566	563,698	847,056	574,240
2001	837,169	571,182	882,597	585,655
2002	861,848	578,624	925,437	598,762
2003	893,464	599,767	980,859	630,168
2004	922,807	627,794	1,042,920	673,219
2005	946,736	646,631	1,106,230	707,778
2006			1,168,600	753,323

Table 6.9 Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2006.

females				numbers at age (1,000s)						
	1	2	3	4	5	6	7	8	9	10
1976	114,894	48,908	31,277	31,084	42,495	25,057	15,006	11,130	9,066	7,721
1977	195,275	94,055	40,026	25,575	25,349	34,387	19,896	11,544	8,308	6,656
1978	110,420	159,864	76,985	32,743	20,884	20,594	27,588	15,630	8,889	6,327
1979	116,760	90,397	130,853	62,981	26,743	16,977	16,548	21,743	12,094	6,809
1980	148,640	95,584	73,984	107,009	51,379	21,663	13,516	12,798	16,360	8,963
1981	334,401	121,676	78,218	60,476	87,177	41,451	17,065	10,231	9,328	11,677
1982	127,867	273,741	99,570	63,938	49,271	70,345	32,670	12,931	7,468	6,670
1983	113,955	104,678	224,048	81,438	52,182	39,962	56,194	25,442	9,829	5,601
1984	304,247	93,288	85,673	183,230	66,445	42,286	31,850	43,556	19,205	7,312
1985	206,910	249,079	76,361	70,096	149,705	54,067	34,068	25,236	33,970	14,848
1986	204,346	169,396	203,899	62,491	57,308	122,049	43,777	27,269	19,980	26,733
1987	486,095	167,298	138,673	166,874	51,102	46,754	99,004	35,173	21,711	15,828
1988	267,773	397,972	136,963	113,510	136,531	41,753	38,075	80,181	28,336	17,440
1989	263,243	219,216	325,748	112,044	92,700	110,950	33,523	29,957	61,883	21,640
1990	162,800	215,519	179,464	266,627	91,657	75,708	90,247	27,084	24,048	49,502
1991	174,341	133,283	176,428	146,868	217,998	74,739	61,331	72,312	21,477	18,960
1992	188,266	142,728	109,100	144,348	119,991	177,367	60,197	48,566	56,346	16,587
1993	149,055	154,134	116,845	89,297	118,076	97,977	144,200	48,585	38,928	44,993
1994	169,253	122,033	126,185	95,643	73,057	96,464	79,767	116,715	39,108	31,239
1995	216,054	138,568	99,902	103,278	78,226	59,635	78,361	64,272	93,321	31,136
1996	308,054	176,887	113,443	81,776	84,505	63,930	48,594	63,541	51,875	75,127
1997	253,592	252,206	144,809	92,851	66,890	68,996	51,964	39,204	50,898	41,391
1998	294,116	207,619	206,475	118,535	75,972	54,662	56,212	42,121	31,624	40,948
1999	503,268	240,794	169,967	168,995	96,954	62,022	44,419	45,324	33,712	25,208
2000	311,651	412,032	197,132	139,127	138,267	79,220	50,512	35,978	36,521	27,087
2001	375,455	255,152	337,314	161,354	113,811	112,921	64,437	40,809	28,881	29,213
2002	469,756	307,387	208,881	276,088	131,985	92,930	91,802	52,004	32,708	23,059
2003	541,549	384,594	251,648	170,976	225,874	107,823	75,648	74,286	41,845	26,236
2004	429,611	443,372	314,854	205,979	139,872	184,494	87,734	61,161	59,696	33,514
2005	394,240	351,724	362,963	257,693	168,464	114,160	149,821	70,646	48,854	47,474
2006	142,900	322,769	287,945	297,096	210,821	137,616	92,917	121,199	56,818	39,167

Table 6.9 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2006.

females				**numbers at age (1,000s)**							
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
1976	6,728	5,940	5,268	4,673	4,128	3,645	3,188	2,789	2,402	2,061	5,515
1977	5,631	4,897	4,320	3,831	3,398	3,002	2,650	2,318	2,028	1,747	5,508
1978	5,048	4,264	3,706	3,269	2,899	2,571	2,271	2,005	1,754	1,534	5,490
1979	4,827	3,846	3,247	2,822	2,489	2,207	1,958	1,729	1,527	1,335	5,348
1980	5,016	3,549	2,826	2,386	2,073	1,828	1,621	1,438	1,270	1,121	4,909
1981	6,345	3,541	2,503	1,992	1,682	1,461	1,289	1,143	1,014	896	4,252
1982	8,282	4,488	2,503	1,769	1,408	1,188	1,032	911	807	716	3,636
1983	4,976	6,169	3,341	1,863	1,316	1,047	884	768	678	601	3,239
1984	4,143	3,674	4,551	2,464	1,374	971	773	652	567	500	2,832
1985	5,634	3,189	2,826	3,501	1,896	1,057	747	594	502	436	2,563
1986	11,658	4,420	2,501	2,217	2,745	1,487	829	586	466	393	2,352
1987	21,136	9,211	3,491	1,975	1,751	2,168	1,174	655	463	368	2,168
1988	12,700	16,953	7,387	2,800	1,584	1,404	1,739	942	525	371	2,034
1989	13,263	9,645	12,868	5,606	2,125	1,202	1,066	1,320	715	398	1,825
1990	17,286	10,590	7,700	10,273	4,475	1,696	960	851	1,053	570	1,775
1991	38,941	13,588	8,322	6,050	8,072	3,517	1,333	754	668	828	1,843
1992	14,592	29,935	10,441	6,394	4,648	6,202	2,702	1,024	579	513	2,052
1993	13,225	11,629	23,852	8,319	5,094	3,704	4,941	2,153	816	462	2,044
1994	36,063	10,596	9,316	19,107	6,664	4,081	2,967	3,958	1,724	654	2,007
1995	24,830	28,648	8,416	7,399	15,174	5,292	3,241	2,356	3,143	1,369	2,113
1996	25,041	19,962	23,029	6,765	5,947	12,197	4,254	2,605	1,894	2,527	2,799
1997	59,852	19,939	15,892	18,333	5,385	4,734	9,710	3,386	2,074	1,508	4,240
1998	33,265	48,084	16,017	12,766	14,726	4,326	3,803	7,799	2,720	1,666	4,616
1999	32,588	26,459	38,240	12,737	10,152	11,710	3,440	3,024	6,202	2,163	4,996
2000	20,232	26,145	21,225	30,674	10,217	8,143	9,393	2,759	2,426	4,975	5,742
2001	21,637	16,153	20,871	16,943	24,485	8,155	6,500	7,498	2,202	1,936	8,555
2002	23,289	17,241	12,869	16,627	13,497	19,505	6,497	5,178	5,973	1,755	8,357
2003	18,474	18,651	13,805	10,304	13,313	10,807	15,617	5,202	4,146	4,782	8,096
2004	20,985	14,770	14,909	11,035	8,236	10,641	8,638	12,483	4,158	3,314	10,294
2005	26,606	16,650	11,716	11,826	8,753	6,533	8,440	6,852	9,901	3,298	10,794
2006	38,012	21,294	13,324	9,375	9,463	7,004	5,228	6,754	5,483	7,923	11,276

Table 6.9 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2006.

males				numbers at age (1,000s)						
	1	2	3	4	5	6	7	8	9	10
1976	114,894	42,946	24,116	21,046	25,264	13,081	6,879	4,480	3,204	2,396
1977	195,275	82,545	30,830	17,282	15,026	17,903	9,145	4,713	2,998	2,102
1978	110,420	140,326	59,286	22,117	12,367	10,700	12,635	6,368	3,231	2,028
1979	116,760	79,351	100,793	42,538	15,833	8,813	7,562	8,819	4,382	2,196
1980	148,640	83,890	56,971	72,249	30,388	11,234	6,176	5,202	5,938	2,897
1981	334,401	106,771	60,199	40,792	51,490	21,454	7,797	4,179	3,417	3,804
1982	127,867	240,210	76,620	43,106	29,075	36,361	14,898	5,280	2,748	2,192
1983	113,955	91,878	172,489	54,942	30,818	20,662	25,561	10,303	3,583	1,835
1984	304,247	81,877	65,968	123,656	39,259	21,877	14,494	17,613	6,955	2,377
1985	206,910	218,654	58,818	47,346	88,576	28,011	15,499	10,159	12,195	4,765
1986	204,346	148,717	157,112	42,236	33,952	63,347	19,935	10,949	7,116	8,480
1987	486,095	146,880	106,869	112,841	30,301	24,303	45,159	14,124	7,703	4,976
1988	267,773	349,424	105,568	76,787	81,026	21,729	17,387	32,194	10,028	5,450
1989	263,243	192,427	250,974	75,740	54,960	57,718	15,346	12,121	22,109	6,799
1990	162,800	189,225	138,297	180,307	54,371	39,391	41,249	10,920	8,582	15,587
1991	174,341	117,014	135,969	99,314	129,316	38,894	28,047	29,164	7,658	5,977
1992	188,266	125,293	84,058	97,583	71,135	92,254	27,547	19,649	20,177	5,242
1993	149,055	135,328	90,046	60,387	70,043	50,972	65,900	19,586	13,896	14,204
1994	169,253	107,146	97,264	64,698	43,358	50,222	36,457	46,959	13,897	9,823
1995	216,054	121,659	77,001	69,868	46,430	31,056	35,849	25,888	33,145	9,758
1996	308,054	155,311	87,444	55,330	50,176	33,305	22,231	25,581	18,406	23,493
1997	253,592	221,433	111,618	62,818	39,713	35,950	23,787	15,801	18,082	12,949
1998	294,116	182,294	159,156	80,203	45,111	28,485	25,730	16,969	11,230	12,809
1999	503,268	211,412	131,008	114,330	57,562	32,317	20,338	18,280	11,986	7,894
2000	311,651	361,770	151,951	94,132	82,097	41,280	23,122	14,501	12,980	8,482
2001	375,455	224,022	260,003	109,166	67,574	58,840	29,501	16,452	10,267	9,151
2002	469,756	269,882	161,000	186,784	78,357	48,419	42,030	20,974	11,634	7,226
2003	541,549	337,676	193,971	115,677	134,108	56,180	34,628	29,944	14,877	8,221
2004	429,611	389,280	242,692	139,360	83,046	96,134	40,162	24,653	21,218	10,499
2005	394,240	308,803	279,753	174,327	100,004	59,475	68,600	28,504	17,388	14,885
2006	142,900	283,392	221,943	200,996	125,160	71,696	42,528	48,861	20,211	12,282

Table 6.9 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2006.

males				numbers at age (1,000s)							
	11	12	13	14	15	16	17	18	19	20	21
1976	1,834	1,422	1,107	862	669	519	398	306	231	174	264
1977	1,551	1,178	910	708	551	427	331	254	195	148	280
1978	1,410	1,035	785	605	470	366	284	220	169	130	284
1979	1,368	946	693	525	405	315	245	190	147	113	277
1980	1,434	887	612	448	339	261	203	158	122	95	251
1981	1,825	896	552	380	277	210	162	126	98	76	214
1982	2,401	1,142	558	343	236	172	130	100	78	61	180
1983	1,449	1,577	748	365	224	154	113	85	66	51	157
1984	1,203	944	1,024	485	236	145	100	73	55	42	135
1985	1,617	816	638	692	328	160	98	67	49	37	120
1986	3,298	1,116	562	440	477	226	110	68	46	34	108
1987	5,906	2,292	775	390	305	331	156	76	47	32	98
1988	3,513	4,164	1,615	546	275	215	233	110	54	33	92
1989	3,664	2,351	2,780	1,077	364	183	143	155	73	36	83
1990	4,780	2,572	1,649	1,949	755	255	128	100	109	51	83
1991	10,807	3,306	1,777	1,138	1,345	521	176	89	69	75	93
1992	4,062	7,317	2,234	1,199	768	908	352	119	60	47	113
1993	3,679	2,846	5,122	1,563	839	537	635	246	83	42	112
1994	10,017	2,591	2,003	3,604	1,100	590	378	447	173	58	108
1995	6,875	6,997	1,808	1,398	2,514	767	412	264	312	121	116
1996	6,903	4,857	4,941	1,277	986	1,774	541	291	186	220	167
1997	16,476	4,833	3,398	3,455	892	690	1,240	378	203	130	271
1998	9,154	11,634	3,410	2,397	2,437	630	486	875	267	143	283
1999	8,975	6,402	8,130	2,382	1,674	1,702	440	340	611	186	297
2000	5,573	6,329	4,512	5,727	1,678	1,179	1,199	310	239	430	341
2001	5,963	3,912	4,439	3,163	4,015	1,176	827	840	217	168	540
2002	6,422	4,178	2,738	3,106	2,213	2,809	823	578	588	152	495
2003	5,094	4,521	2,939	1,926	2,184	1,556	1,975	579	407	413	455
2004	5,787	3,580	3,175	2,063	1,352	1,533	1,092	1,386	406	285	609
2005	7,340	4,038	2,496	2,212	1,437	942	1,068	761	965	283	623
2006	10,487	5,164	2,839	1,754	1,555	1,010	662	750	535	678	637

Table 6.10 Estimated age 2 recruitment of arrowtooth flounder (thousands of fish) from the 2005 and 2006 stock assessments and also from estimates of fish less than 25 cm in the annual Bering Sea shelf trawl survey.

Year class	2005 Assessment	2006 Assessment	shelf survey fish<25 cm
1974	90,202	91,854	
1975	179,026	176,600	
1976	299,862	300,190	
1977	171,830	169,748	
1978	178,454	179,474	
1979	226,701	228,447	
1980	511,851	513,951	86,100
1981	196,785	196,556	290,200
1982	172,697	175,165	57,900
1983	463,036	467,733	62,400
1984	317,925	318,113	150,300
1985	307,381	314,178	94,300
1986	763,287	747,396	200,600
1987	416,129	411,643	273,800
1988	379,073	404,744	105,200
1989	242,933	250,297	71,700
1990	272,594	268,021	79,400
1991	284,381	289,462	96,800
1992	212,340	229,179	126,600
1993	246,661	260,227	75,100
1994	316,190	332,198	55,600
1995	447,325	473,639	108,800
1996	353,281	389,913	93,600
1997	400,751	452,206	92,100
1998	639,346	773,802	126,300
1999	384,309	479,174	164,300
2000	425,284	577,269	108,800
2001	543,515	722,270	253,400
2002		832,652	406,700
2003		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. 2007 ABC is highlighted.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2006	760.788	11.214	0.02
2007	812.001	158.000	0.24
2008	751.244	143.333	0.24
2009	698.999	133.060	0.24
2010	637.350	124.111	0.24
2011	564.581	113.837	0.24
2012	501.926	101.835	0.24
2013	453.133	90.328	0.24
2014	416.818	81.411	0.24
2015	390.026	74.963	0.24
2016	370.441	70.026	0.24
2017	356.805	66.438	0.24
2018	347.780	64.020	0.24
2019	342.388	62.476	0.23

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2006	760.788	11.214	0.02
2007	818.946	79.000	0.12
2008	826.919	73.384	0.11
2009	831.264	74.305	0.11
2010	812.584	74.635	0.11
2011	770.841	73.272	0.11
2012	727.830	69.955	0.11
2013	688.109	65.641	0.11
2014	652.524	61.538	0.11
2015	621.073	58.050	0.11
2016	593.755	55.144	0.11
2017	570.721	52.734	0.11
2018	551.920	50.777	0.11
2019	537.331	49.240	0.11

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2006	760.788	11.214	0.02
2007	824.400	12.750	0.02
2008	890.672	9.932	0.01
2009	947.846	10.713	0.01
2010	978.191	11.388	0.01
2011	980.551	11.801	0.01
2012	975.004	11.887	0.01
2013	964.606	11.729	0.01
2014	949.934	11.475	0.01
2015	931.907	11.196	0.01
2016	911.856	10.911	0.01
2017	891.241	10.629	0.01
2018	871.423	10.362	0.01
2019	853.643	10.122	0.01

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2006	760.788	11.214	0.02
2007	825.286	0	0
2008	902.760	0	0
2009	968.155	0	0
2010	1006.740	0	0
2011	1017.120	0	0
2012	1019.010	0	0
2013	1015.100	0	0
2014	1005.760	0	0
2015	991.868	0	0
2016	974.843	0	0
2017	956.257	0	0
2018	937.656	0	0
2019	920.480	0	0

Table 6.9 (continued).

Scenario 6
Determination of whether arrowtooth flounder are currently overfished
B35=297,000

Year	Female spawning biomass	catch	F
2006	760.788	11.214	0.02
2007	808.682	193.181	0.30
2008	718.135	167.373	0.30
2009	647.308	149.848	0.30
2010	574.413	135.723	0.30
2011	494.236	121.215	0.30
2012	427.691	105.597	0.30
2013	379.238	91.533	0.30
2014	347.265	81.289	0.30
2015	324.024	74.041	0.30
2016	310.207	67.623	0.29
2017	304.259	64.330	0.28
2018	299.209	62.533	0.28
2019	297.042	61.997	0.28

Scenario 7
Determination of whether arrowtooth flounder are approaching an overfished condition
B35=297,000

Year	Female spawning biomass	catch	F
2006	760.788	11.214	0.02
2007	811.993	158.077	0.24
2008	751.177	143.319	0.24
2009	696.193	162.707	0.30
2010	609.244	145.099	0.30
2011	519.982	127.915	0.30
2012	448.055	110.473	0.30
2013	395.610	95.292	0.30
2014	359.382	83.720	0.30
2015	335.213	74.908	0.29
2016	320.119	69.303	0.28
2017	311.227	66.050	0.28
2018	306.290	64.184	0.28
2019	304.134	63.249	0.27

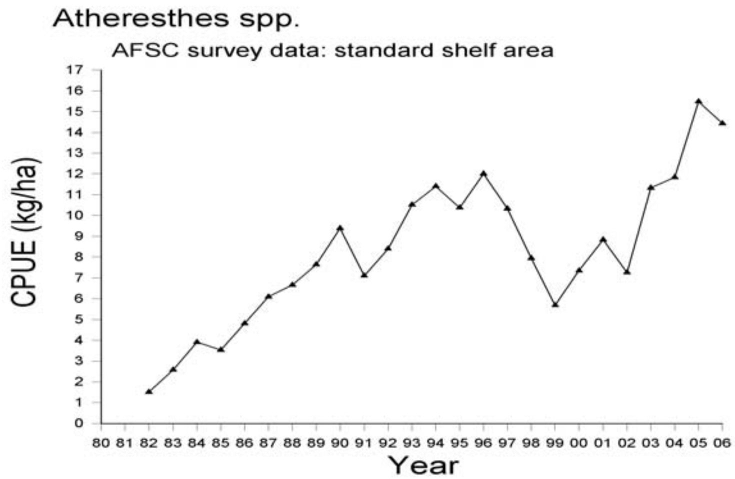


Figure 6.1 Atheresthes species combined CPUE (kg/ha) from the standard shelf survey area.

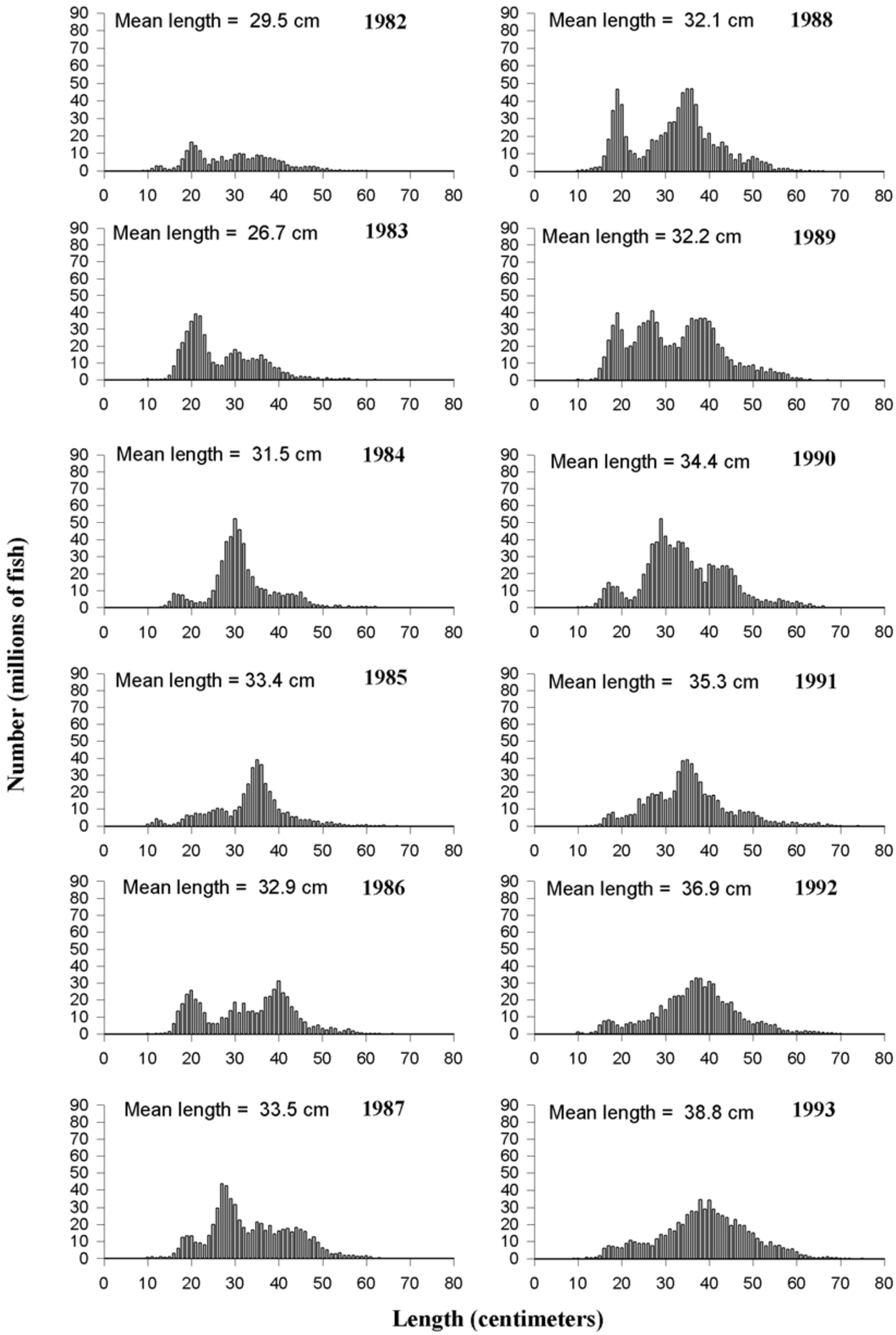


Figure 6.2. Size composition of arrowtooth flounder from the shelf trawl surveys.

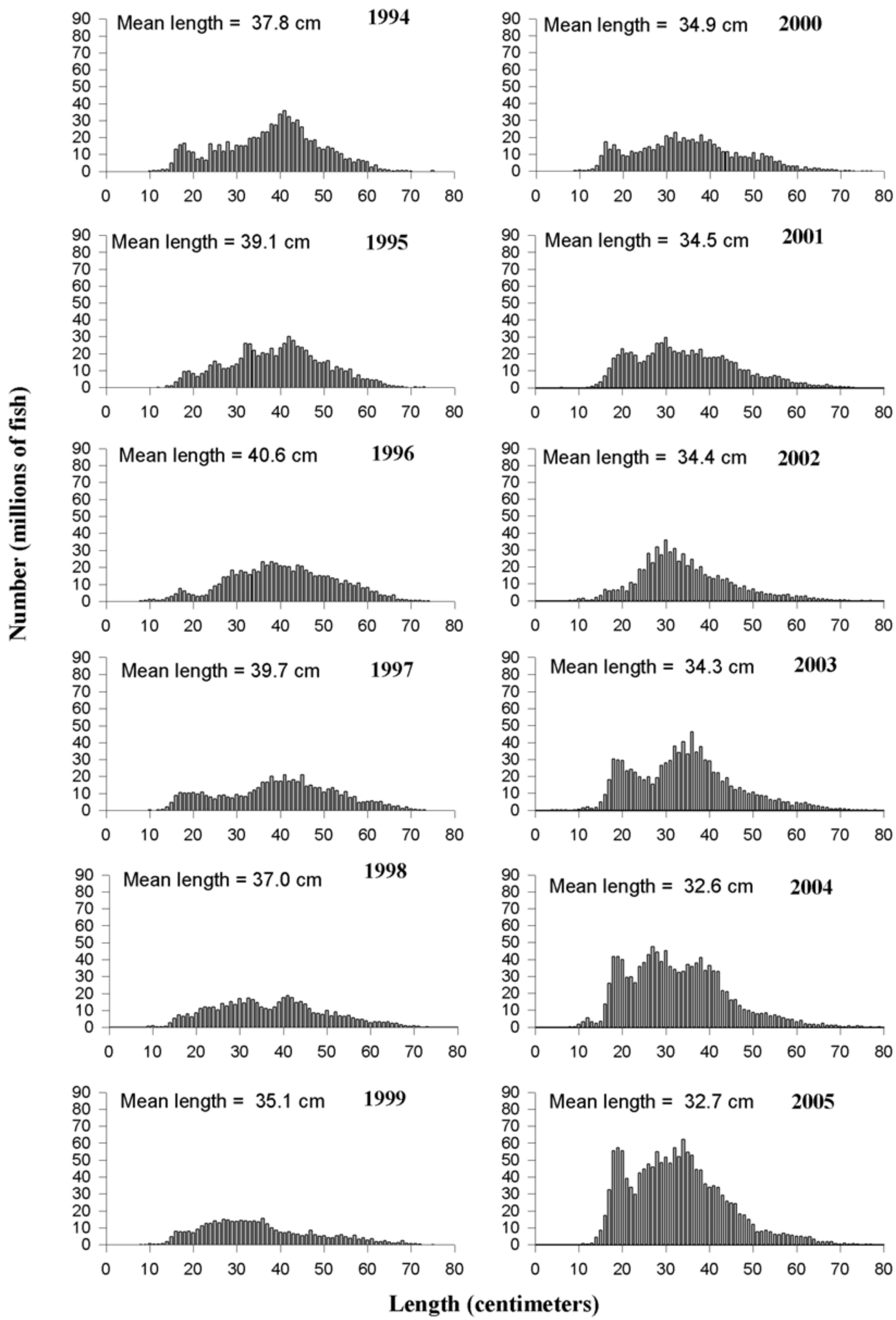


Figure 6.2. continued.

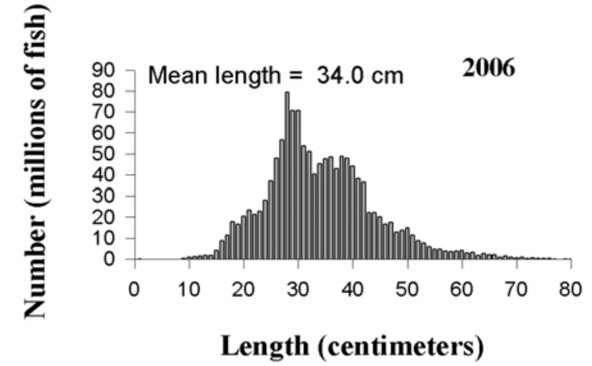


Figure 6.2. continued.

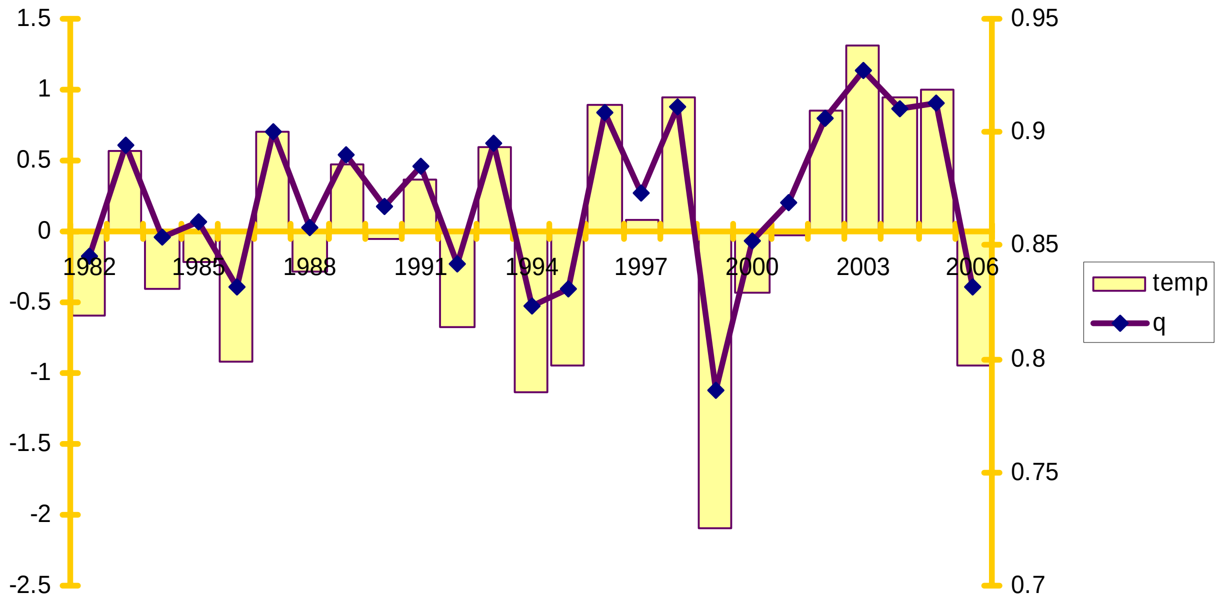


Figure 6.3--Shelf survey annual avg. bottom temperature anomalies (bars), model estimate of annual shelf survey q due to effect of water temperature (diamonds with lines), given the assumption that 87% of the biomass resides on the Bering Sea shelf.

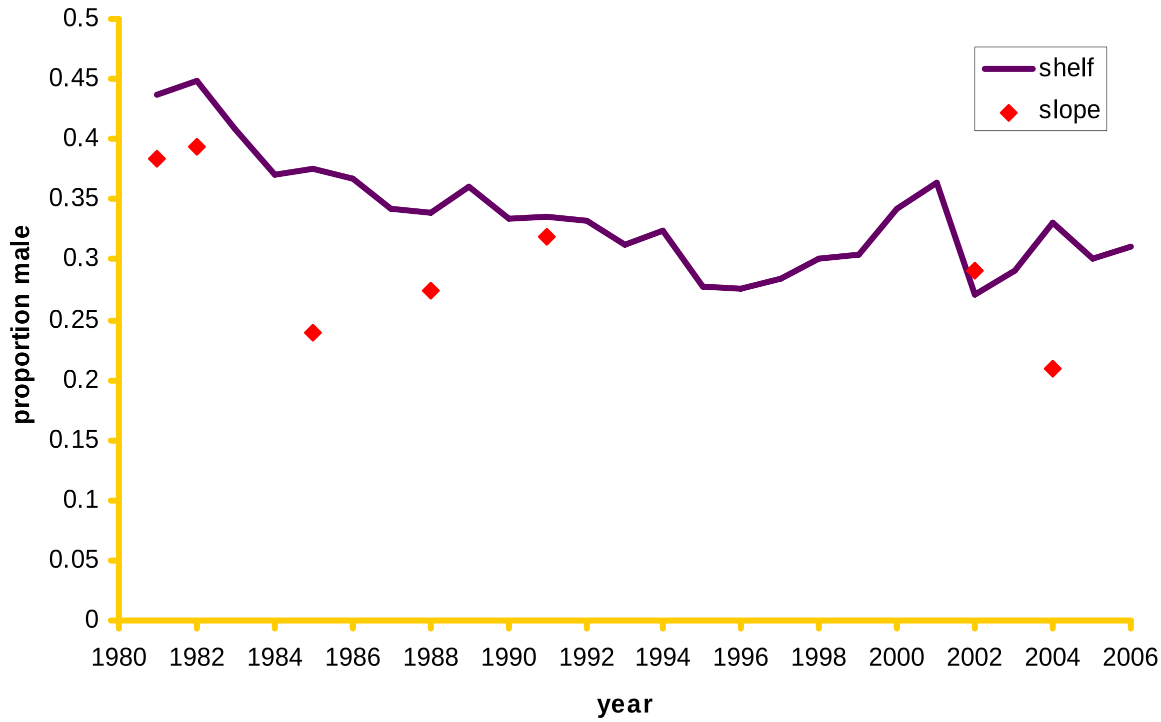
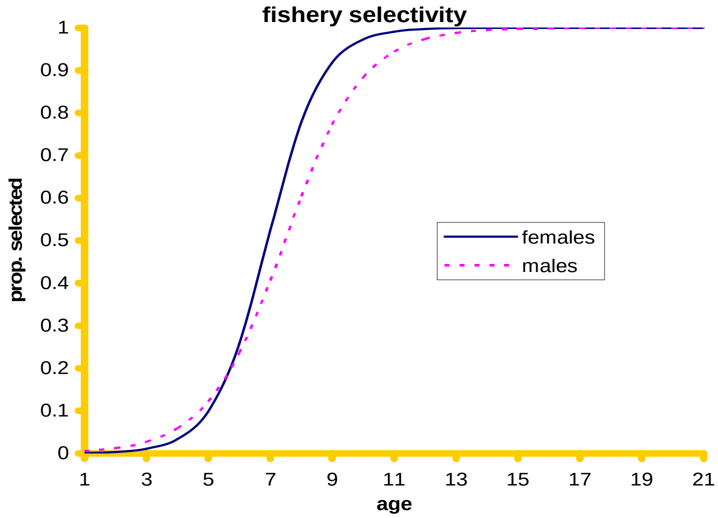


Figure 6.4--Proportion of the estimated male population from Bering Sea trawl surveys on the continental shelf and slope.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prop. selected
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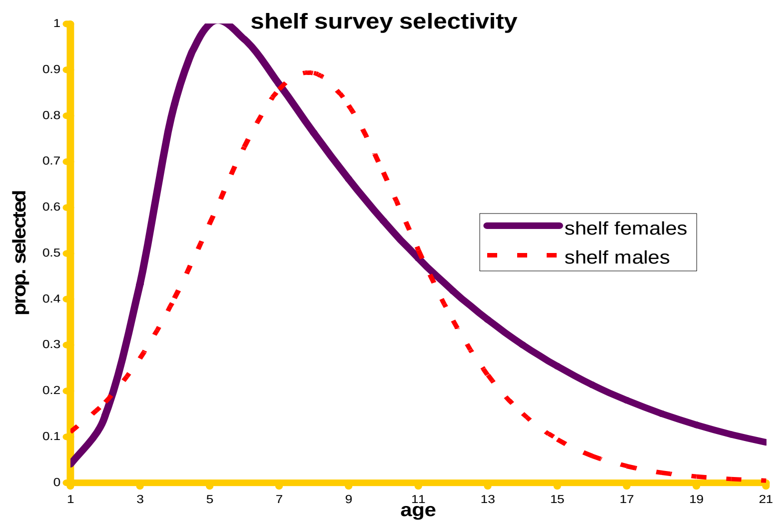
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 3 5 7 9 11 13 15 17 19 21
age
females
males


shelf survey selectivity
prop. selected
1
0.9
0.8
0.7
0.6
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0.4
0.3
0.2
0.1
0
1 3 5 7 9 11 13 15 17 19 21
age
shelf females
shelf males

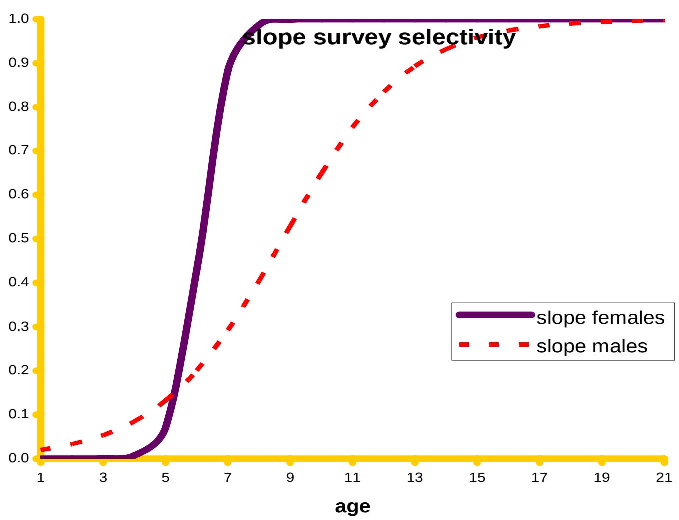

slope survey selectivity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1 3 5 7 9 11 13 15 17 19 21
age
slope females
slope males

Figure 6.5--Age-specific fishery selectivity (top panel), shelf survey selectivity (middle panel) and slope survey selectivity (bottom panel), by sex, estimated from the stock assessment model.

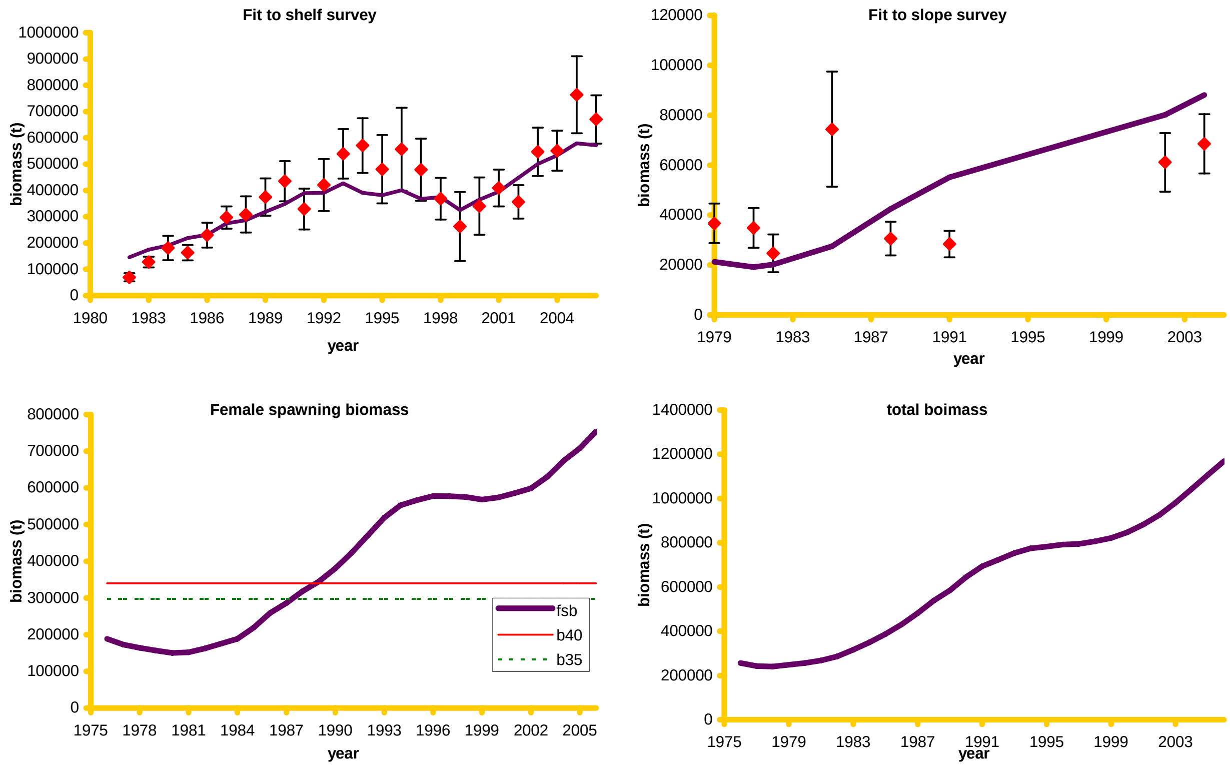


Figure 6.6--Stock assessment model results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), estimate of female spawning biomass with B35 and B40 indicated (bottom left panel) and the estimate of total biomass (bottom right panel).

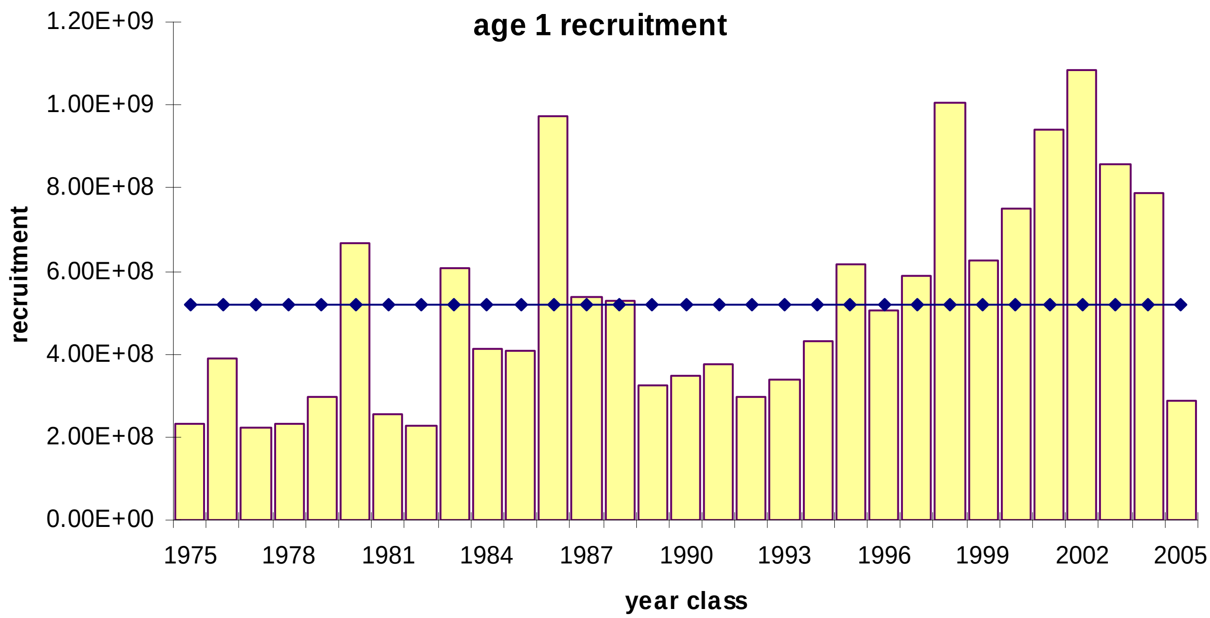


Figure 6.7--Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model.

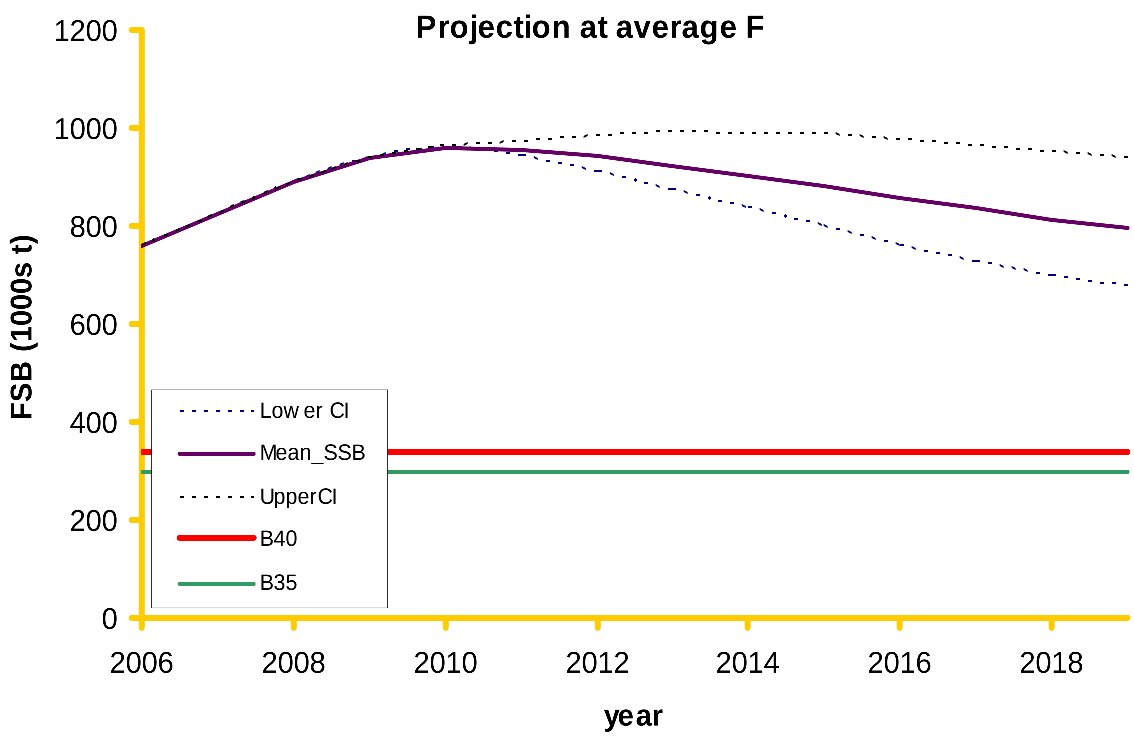


Figure 6.8--Projected female spawning biomass (1,000s t) of arrowtooth flounder if future harvest is at the same fishing mortality rate as the past five years.

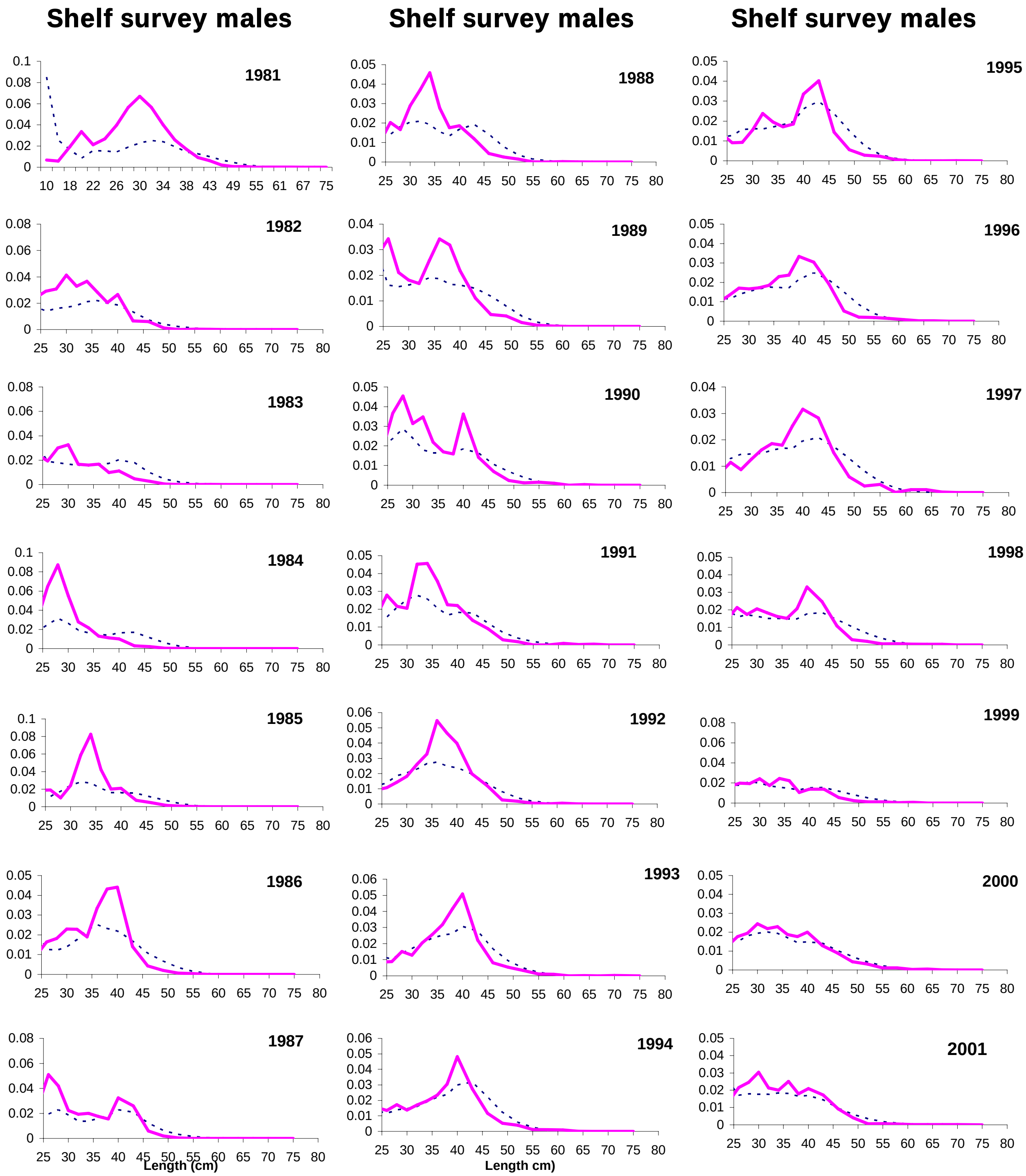
APPENDIX

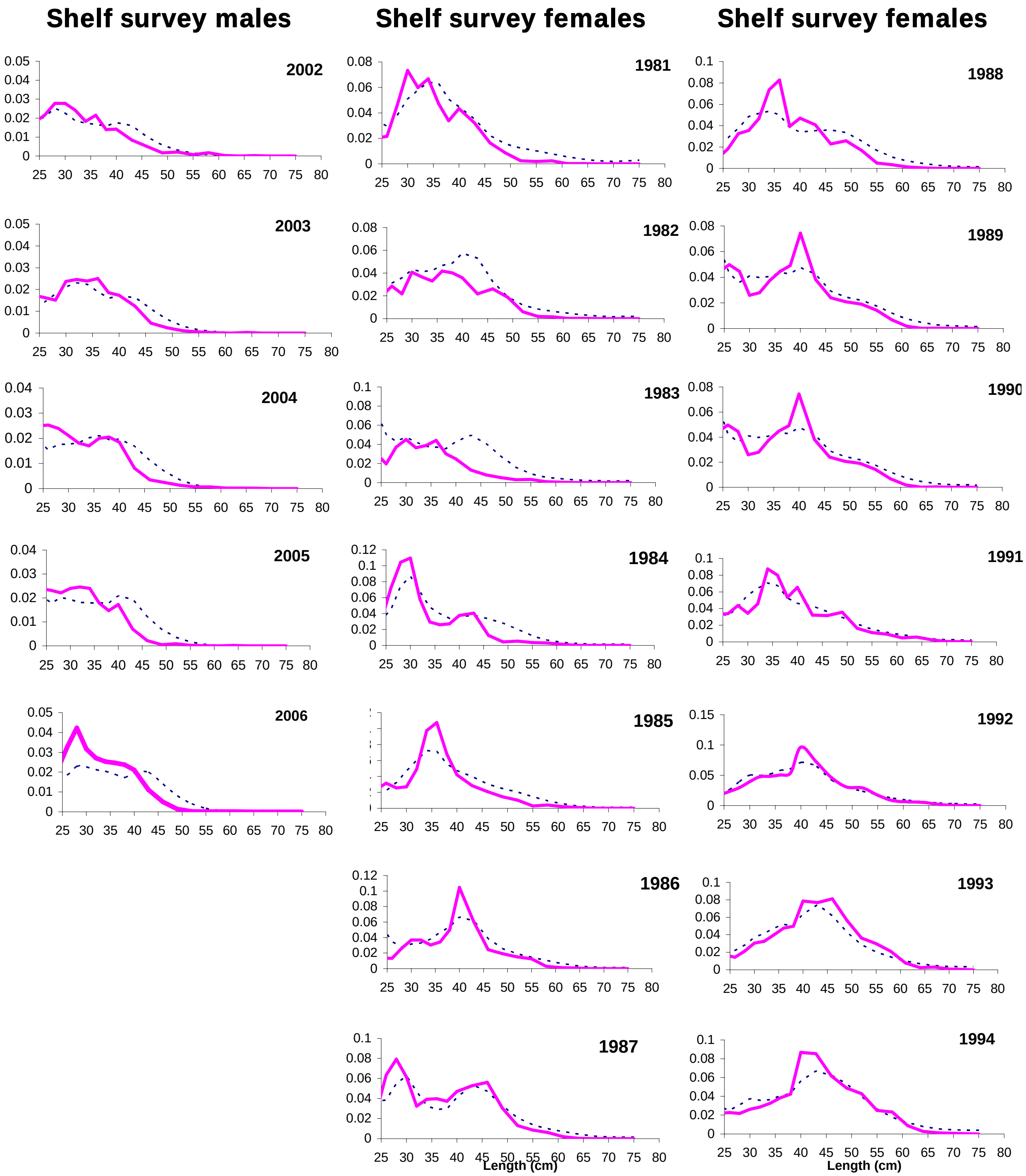
Figures showing the fit of the stock assessment model to the time-series of shelf and slope survey size composition data by sex (estimated values are the dotted lines) and the fishery size composition data from 1978-90.

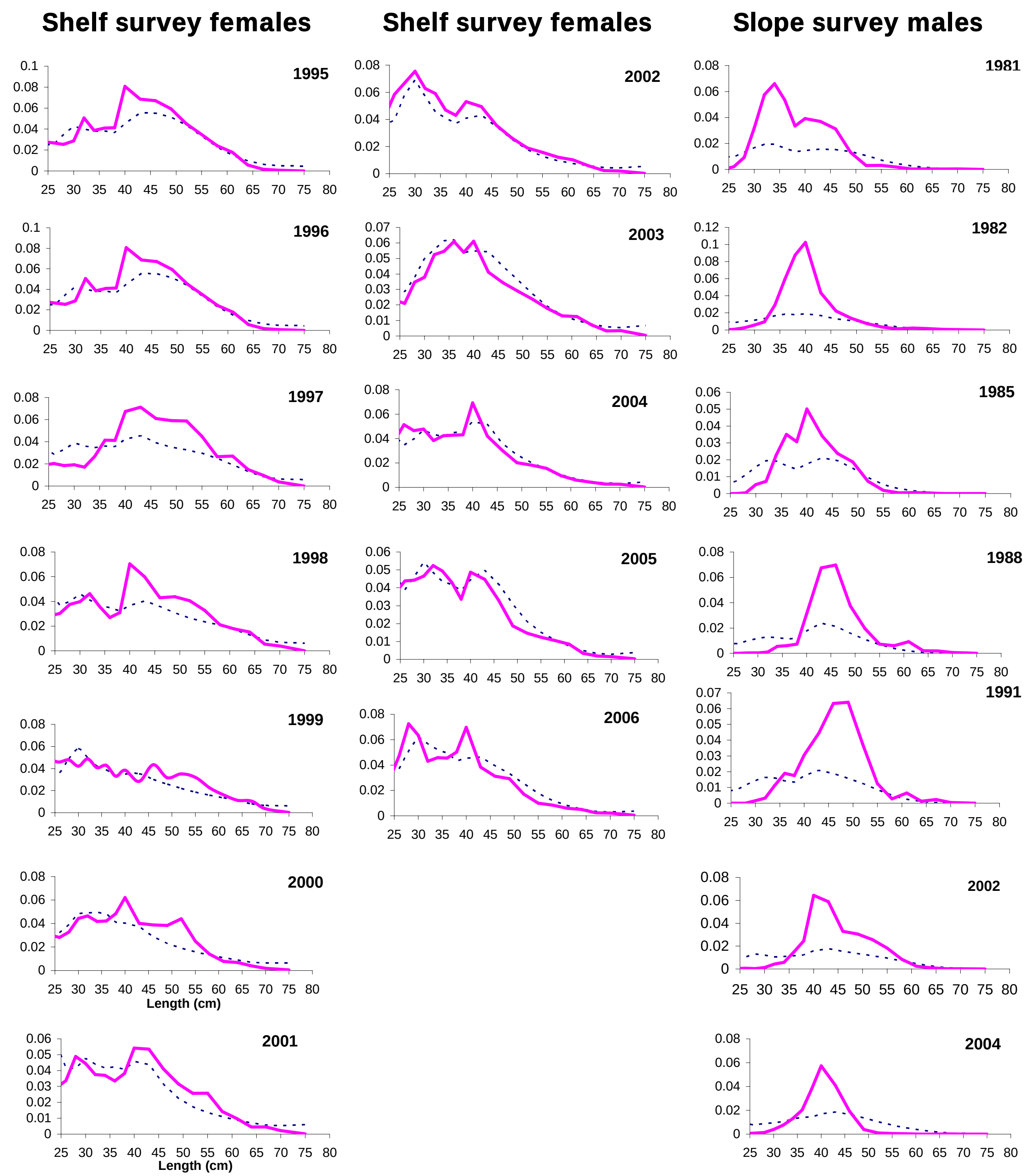
Table of arrowtooth flounder catch during research activities by the Alaska Fisheries Science Center, 1977-2005.

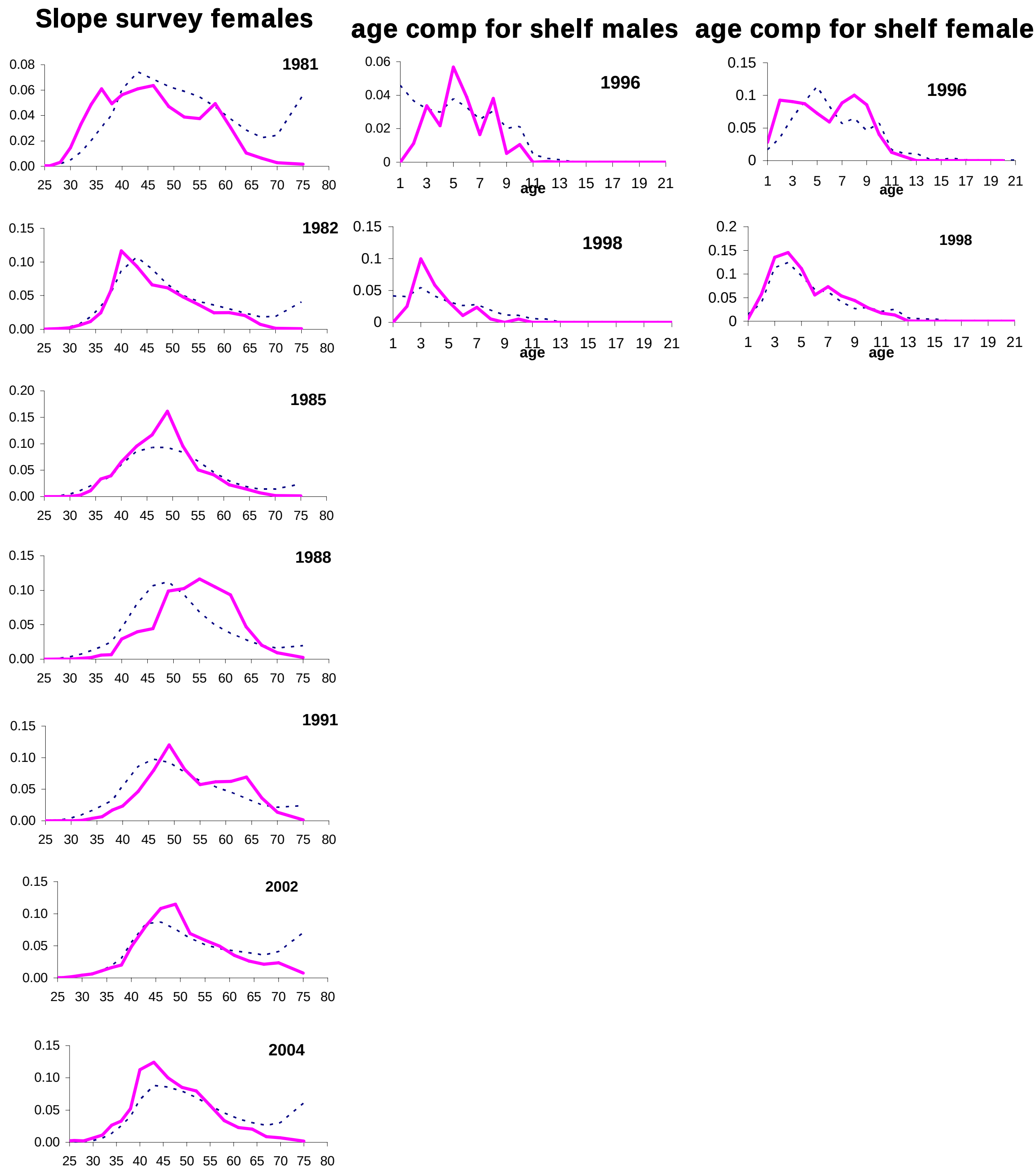
BSAI arrowtooth flounder TAC (1986-2006) and ABC (1982-2006)

Shelf survey biomass estimates for arrowtooth and Kamchatka flounder 1982-2006

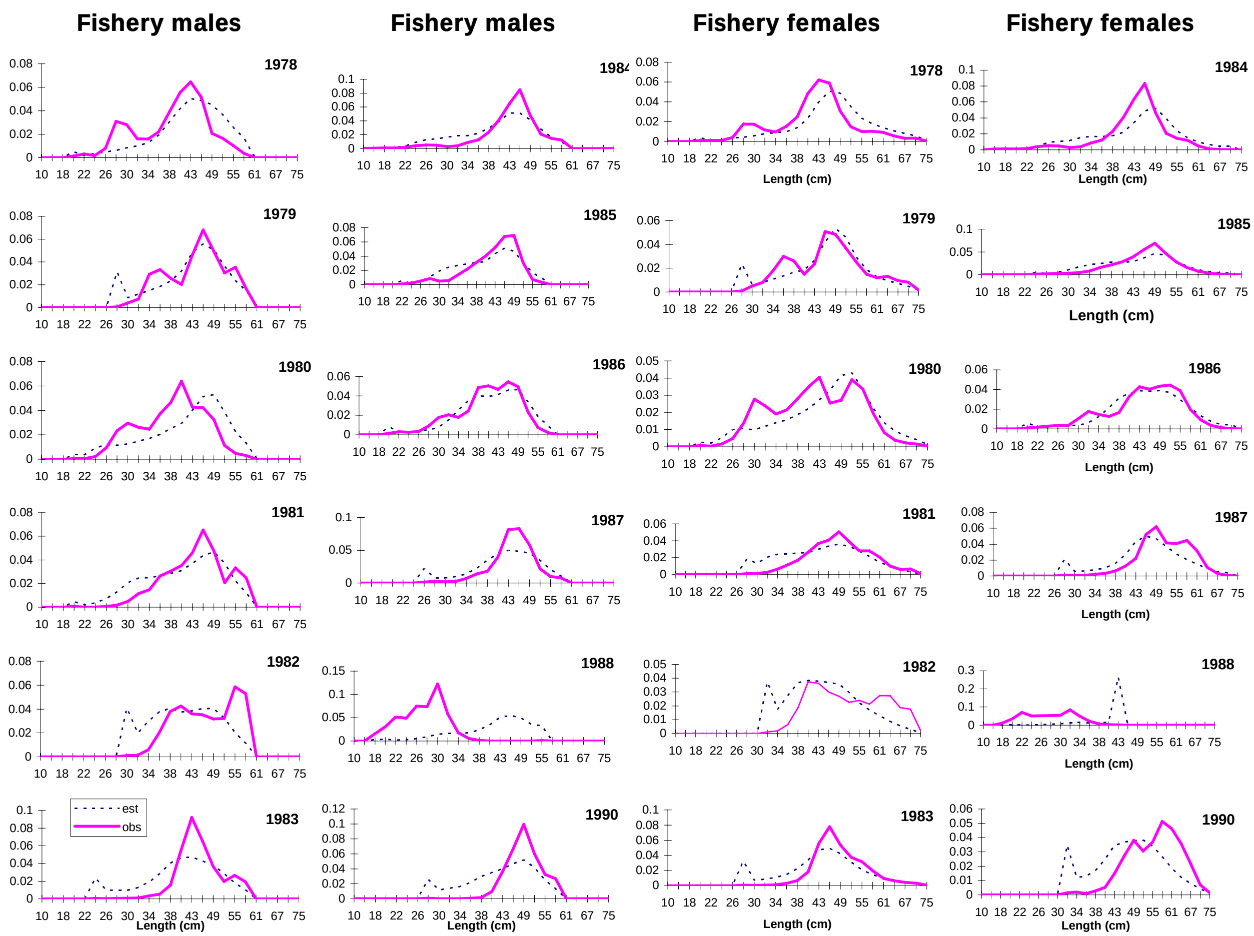

Shelf survey males
Shelf survey males
Shelf survey males
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Length (cm)
Length cm)


Shelf survey males
Shelf survey females
Shelf survey females
2002
2003
2004
2005
2006
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
Length (cm)
Length (cm)


Shelf survey females
Shelf survey females
Slope survey males
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
1981
1982
1985
1988
1991
2002
2004
Length (cm)
Length (cm)



Slope survey females
age comp for shelf males
age comp for shelf female
1981
1982
1985
1988
1991
2002
2004
1996
1998
1996
1998
age
age
age
age

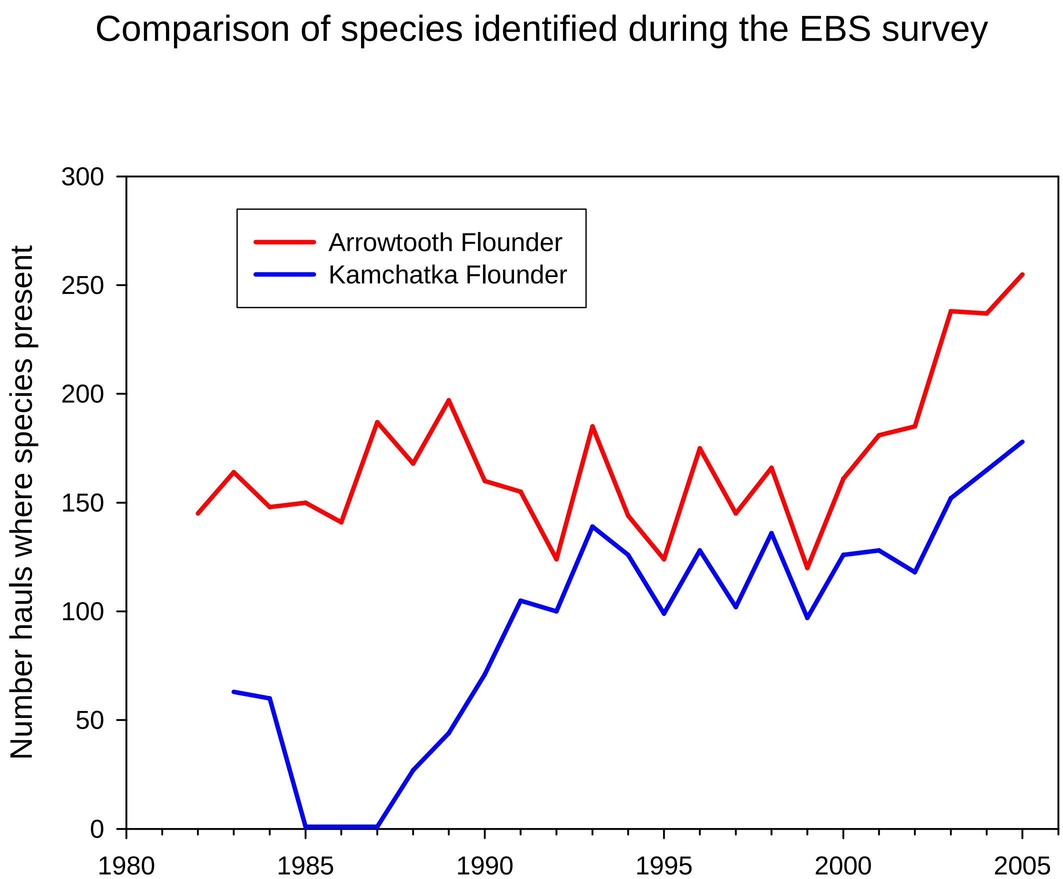

Fishery males
Fishery males
Fishery females
Fishery females
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1990
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1990
est
obs
Length (cm)

Total catch (t) of arrowtooth flounder due to Alaska Fisheries Science Center research activity in the Bering Sea and Aleutian Islands, 1977-2000 and 2002-2005.

year	Research catch (t)
1977	1.0
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	18.0
2004	19.4
2005	23.1

	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

	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


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

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