Chapter 6

Arrowtooth Flounder

By

Thomas K. Wilderbuer and Daniel G. Nichol

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

Executive Summary

The following changes have been made to this assessment relative to the November 2004 SAFE.

Changes to the input data

1) 2005 shelf survey size composition.
2) 2005 shelf survey biomass point-estimates and standard errors.
3) Estimate of catch and discards through 3, September 2005.
4) Estimate of retained and discarded portion of the 2004 catch.

Assessment results

1) The projected age 1+ total biomass for 2006 is 964,200 t.
2) The projected female spawning biomass for 2006 is 666,750 t.
3) The recommended 2006 ABC is 135,500 t based on an $F_{0.40}$ (0.26) harvest level.
4) The 2006 overfishing level is 163,700 t based on a $F_{0.35}$ (0.32) harvest level.

	2005 Assessment recommendation for 2006 harvest	2004 Assessment recommendation for 2005 harvest
Total biomass	964,200 t	683,700 t
ABC	135,500 t	107,700 t
Overfishing	166,100 t	132,200 t
F_{ABC}	$F_{0.40} = 0.26$	$F_{0.40} = 0.26$
$F_{overfishing}$	$F_{0.35} = 0.32$	$F_{0.30} = 0.33$
B_{40}	295,100 t	235,400 t
B_{35}	258,200 t	206,000 t

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. Because the stock condition of the two species have differed markedly in recent years, management since 1986 has been by individual species.

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 12,400 t from 1977-2005. This decline resulted from catch restrictions placed on the fishery for Greenland turbot and phasing out of the foreign fishery in the U.S. EEZ. Total catch reported through 3 September, 2005 is 12,237 t (well below the 2005 ABC of 108,000 t). NMFS Regional Office reports indicate that bottom trawling accounted for 85% of the 2005 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 1985-2004 are shown in Table 6.2.

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 3, 2005 (Table 6.1) and fishery length-frequency data from 1978-91 and 2000-2003 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 is the highest ever estimated from the shelf survey.

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. The 2002 shelf survey estimate was higher at 355,100 t and increased further to the high levels estimated in 2003 and 2004 (547,400 t in 2004), near the peak level estimated in 1994. The 2005 estimate is the highest ever estimated for the time series (200,000 t more than the previous high estimate of 1994) and has 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 2005 point estimate are 658,800 – 856,600 t.

Trawl surveys on the continental slope estimate that arrowtooth flounder biomass increased significantly from 1982 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.

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.

Although the latter 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 2004 Aleutian Islands trawl survey is 134,600 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
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 male and female fish become 50% 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
30	14	48	92

The recruitment parameters are comprised of 21 initial ages in 1976 and 26 subsequent age 1 recruitment estimates from 1976-2003. Recruitment in 2004 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 (2005) 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. In past assessments we placed an emphasis of 5.0 on fitting the shelf survey biomass trend since it was the most reliable source of data to discern arrowtooth flounder abundance. Although this is still true, we changed our modeling approach and placed equal emphasis on all data components for this assessment, and instead explored the relationship between annual bottom water temperature and shelf survey catchability to improve the fit to the shelf survey biomass estimates. As in past assessments, results are still closely linked to fitting the general trend of increasing shelf survey biomass estimates during the 1980s to a 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 for this assessment were again 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 1982-2005, 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 = 0.28. However, at this value, maximum male selectivity on the shelf is estimated at 0.68 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 0.25 – 0.34 with equal emphasis placed on all data components.

			male natural mortality values							
	0.25	**0.26**	**0.27**	**0.28**	**0.29**	**0.3**	**0.31**	**0.32**	**0.33**	**0.34**
shelf biomass	71.16	73.65	74.97	76.14	77.23	78.26	79.23	81.22	81.02	81.83
slope biomass	94.82	93.32	91.41	89.76	88.36	87.18	86.20	84.98	84.73	84.23
shelf length comp	1436.76	1437.85	1440.83	1444.04	1447.41	1450.93	1454.59	1472.45	1462.35	1466.36
slope length comp	653.24	653.71	656.89	661.34	666.90	673.46	680.94	688.60	698.31	708.15
recruit like	27.23	26.77	26.24	25.80	25.45	25.17	24.95	24.62	24.67	24.59
sex ratio	96.77	86.31	76.84	68.24	60.47	53.44	47.10	40.75	36.28	31.70
shelf ages	128.30	130.66	131.25	131.69	132.09	132.47	132.84	133.21	133.60	133.96
total likelihood	2508.53	2502.54	2498.68	2497.29	2498.19	2501.21	2506.16	2526.15	2521.28	2531.17
male max shelf selectivity	0.56 at age 7	0.60 at age 7	0.64 at age 7	0.68 at age7	0.72 at age 7	0.76 at age7	0.81at age8	0.86 at age 8	0.92 at age 8	0.99 at age 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 0.92 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 three 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 14-15 years whereas female arrowtooth flounder have been aged at over 20 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, 3%, from 1977-2005 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 increased more than 3.5 times from 1976 to the 2005 value of 946,700 t (Fig. 6.6, Table 6.8). After a rapid increase from 1985-95, the population leveled-off from 1996-2003 before increasing again the past few years to its highest level yet observed, largely from the influence of the record high 2005 shelf survey biomass estimate. Female spawning biomass is also estimated to be at high level, 646,600 t in 2005, 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 2003-2004. 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 1998 year classes. Small fish present in the past two shelf surveys indicate strong 2001 and 2002 year classes which should keep stock size at a high 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. Estimates of age 2 recruitment from the stock assessment model also indicate a period of favorable recruitment in the late 1980s and also since 1995 (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 2006 total biomass from the stock assessment model is 964,200 t and the female spawning biomass is estimated at 666,750 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 1977-2001 are used to calculate the average equilibrium recruitment. Using the time-series of age 1 recruitment from 1978-2002 from the stock assessment model results in an estimate of $B_{0.40}$ = 295,100 t. The stock assessment model estimates the 2006 level of female spawning biomass at 666,750 t (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and $B>B_{0.40}$ (666,750 > 295,100), arrowtooth flounder reference fishing mortality is defined in tier 3a. For the 2006 harvest: $F_{ABC} \leq F_{0.40} = 0.26$ and $F_{overfishing} = F_{0.35} = 0.32$ (full selection F values).

Acceptable biological catch is estimated for 2006 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2006 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 2006 ABC of 135,500 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
$F_{overfishing}$	0.32	166,100 t
$F_{0.40}$	**0.26**	**135,500 t**

This estimate of 2006 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 2005 survey biomass point estimate of 46,084 t (Appendix table) would give an overfishing limit of 9,217 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 2005 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2006 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2005. 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 2006, 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 2006 recommended in the assessment to the *max* F_{ABC} for 2006. (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 2001-2005 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 2006 and above its MSY level in 2016 under this scenario, then the stock is not overfished.)

Scenario 7: In 2006 and 2007, *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 2018 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 2006, it does not provide the best estimate of OFL for 2007, because the mean 2007 catch under Scenario 6 is predicated on the 2006 catch being equal to the 2006 OFL, whereas the actual 2006 catch will likely be less than the 2006 ABC. Therefore, the projection model was re-run with the 2006 catch fixed equal to the 2005 catch and the 2007 fishing mortality rate fixed at F_{ABC}.

Year	Catch	ABC	OFL
2006	12,000	135,500	166,100
2007	141,600	141,600	173,500

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], 1970-2005. 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**									12,237

[a]Catches from data on file Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115.
[b]Japan, U.S.S.R., Republic of Korea, Taiwan, Poland, and Federal Republic of Germany.
[c]Joint ventures between U.S. fishing vessels and foreign processing vessels.
**Catch information through 3 September, 2005 (NMFS regional office).

Table 6.2 Estimates of retained and discarded arrowtooth flounder catch, 1985-2004.

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

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	--	--	40,400
1981	49,500	34,900	84,400	--
1982	67,400	24,700	92,100	--
1983	149,300	--	--	45,100
1984	182,900	--	--	--
1985	159,900	74,400	234,300	--
1986	232,100	--	--	125,700
1987	290,600	--	--	--
1988	306,500	30,600*	337,100	--
1989	410,700	--	--	--
1990	459,200	--	--	--
1991	329,200	28,000*	357,200	37,294
1992	414,000	--	--	--
1993	543,600	--	--	--
1994	570,600	--	--	107,019
1995	480,800	--	--	--
1996	556,400	--	--	--
1997	478,600	--	--	111,557
1998	344,900	--	--	--
1999	243,800	--		
2000	340,400	--	--	93,515
2001	408,800	--	--	--
2002	355,100	61,200	416,300	88,700
2003	553,900	--	--	--
2004	547,400	68,600	616,000	134,600
2005	757,685			

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

$$L = \sum_{t,a} m_t\, p_{t,a} \ln\frac{\hat{p}_{t,a}}{p_{t,a}} + (-0.5)\sum_t \left[\left(\ln\frac{surB_t}{\hat{surB}_t}\ {1}/{\sigma_t}\right)^2 - \ln\sigma_t\right]$$

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	0.130	0.077
1977	0.084	0.049
1978	0.077	0.043
1979	0.114	0.059
1980	0.156	0.072
1981	0.153	0.064
1982	0.099	0.040
1983	0.108	0.044
1984	0.064	0.027
1985	0.044	0.019
1986	0.037	0.017
1987	0.021	0.010
1988	0.078	0.037
1989	0.026	0.013
1990	0.042	0.020
1991	0.065	0.032
1992	0.028	0.014
1993	0.022	0.012
1994	0.031	0.019
1995	0.019	0.012
1996	0.029	0.019
1997	0.019	0.013
1998	0.030	0.019
1999	0.021	0.013
2000	0.026	0.016
2001	0.028	0.017
2002	0.023	0.013
2003	0.025	0.014
2004	0.030	0.017
2005	0.022	0.013

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	0.12	0.00	0.02
2	0.00	0.01	0.16	0.19	0.00	0.03
3	0.01	0.03	0.46	0.29	0.00	0.06
4	0.03	0.05	0.85	0.43	0.01	0.09
5	0.09	0.11	1.00	0.60	0.07	0.14
6	0.23	0.22	0.96	0.77	0.46	0.21
7	0.48	0.39	0.86	0.90	0.91	0.30
8	0.74	0.58	0.75	0.93	0.99	0.42
9	0.90	0.76	0.65	0.85	1.00	0.54
10	0.96	0.87	0.56	0.69	1.00	0.66
11	0.99	0.94	0.48	0.52	1.00	0.76
12	1.00	0.97	0.41	0.36	1.00	0.84
13	1.00	0.99	0.35	0.24	1.00	0.90
14	1.00	0.99	0.30	0.15	1.00	0.94
15	1.00	1.00	0.25	0.10	1.00	0.96
16	1.00	1.00	0.21	0.06	1.00	0.98
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 2004 and 2005 assessments.

	2005 Assessment		2004 Assessment	
	age 2+ Total biomass	Female Spawning biomass	age 2+ Total biomass	Female Spawning biomass
1976	248,608	179,275	291,246	211,215
1977	235,767	166,195	275,943	197,064
1978	236,275	159,111	273,516	188,461
1979	244,946	152,849	279,254	180,912
1980	253,757	147,398	285,064	173,524
1981	266,858	150,041	295,164	173,525
1982	285,145	161,150	310,595	182,646
1983	316,173	175,316	338,798	194,656
1984	349,043	188,294	368,864	205,391
1985	386,948	218,733	403,855	233,423
1986	430,165	258,720	443,814	271,011
1987	481,305	286,525	491,514	296,206
1988	537,011	318,029	543,434	324,665
1989	584,155	344,425	586,786	348,457
1990	643,636	379,624	642,415	380,409
1991	691,603	422,354	686,546	419,497
1992	720,380	471,184	711,646	464,983
1993	750,290	518,645	737,911	508,771
1994	770,760	550,949	754,706	537,624
1995	776,741	564,174	756,828	547,954
1996	784,094	574,985	759,402	555,823
1997	783,604	573,642	752,934	551,846
1998	790,796	569,515	751,789	545,077
1999	798,875	560,489	747,127	532,803
2000	815,566	563,698	746,904	530,455
2001	837,169	571,182	744,761	529,776
2002	861,848	578,624	738,310	526,401
2003	893,464	599,767	728,128	529,433
2004	922,807	627,794	709,898	532,078
2005	946,736	646,631		

Table 6.9 Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2005.

Females — numbers at age (1,000s)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1976	116,473	48,029	32,085	32,244	44,415	26,279	15,251	11,031	8,834	7,430	6,408	5,603	4,929	4,346	3,826	3,373	2,955	2,593	2,245	1,938	4,888
1977	195,062	95,347	39,306	26,235	26,297	35,953	20,886	11,735	8,206	6,438	5,369	4,616	4,032	3,546	3,126	2,752	2,426	2,126	1,865	1,615	4,910
1978	111,774	159,689	78,042	32,154	21,425	21,371	28,872	16,422	9,026	6,228	4,859	4,044	3,474	3,034	2,668	2,352	2,070	1,825	1,599	1,403	4,909
1979	116,095	91,505	130,709	63,847	26,264	17,423	17,190	22,781	12,700	6,895	4,733	3,686	3,066	2,633	2,300	2,022	1,783	1,569	1,384	1,212	4,785
1980	147,502	95,039	74,890	106,894	52,094	21,289	13,897	13,326	17,142	9,386	5,057	3,462	2,694	2,240	1,924	1,680	1,477	1,302	1,146	1,011	4,381
1981	333,029	120,744	77,772	61,220	87,108	42,072	16,819	10,560	9,723	12,204	6,613	3,550	2,427	1,888	1,570	1,348	1,177	1,035	912	803	3,778
1982	128,016	272,618	98,808	63,577	49,892	70,365	33,256	12,795	7,719	6,937	8,618	4,653	2,495	1,705	1,326	1,102	947	827	727	641	3,217
1983	112,348	104,799	223,129	80,817	51,897	40,493	56,314	25,963	9,734	5,780	5,161	6,396	3,451	1,850	1,264	983	817	702	613	539	2,860
1984	301,189	91,973	85,772	182,485	65,952	42,088	32,340	43,773	19,619	7,230	4,263	3,796	4,701	2,535	1,359	929	722	600	516	450	2,497
1985	206,787	246,576	75,285	70,179	149,116	53,692	33,953	25,672	34,169	15,159	5,563	3,275	2,915	3,609	1,946	1,043	713	554	461	396	2,262
1986	199,925	169,295	201,850	61,611	57,381	121,612	43,515	27,214	20,340	26,883	11,891	4,359	2,565	2,283	2,826	1,524	817	558	434	361	2,082
1987	496,429	163,678	138,591	165,200	50,387	46,828	98,727	35,001	21,680	16,109	21,239	9,386	3,440	2,024	1,801	2,230	1,203	645	441	343	1,927
1988	270,689	406,432	133,999	113,444	135,167	41,176	38,152	80,008	28,208	17,413	12,920	17,026	7,523	2,757	1,622	1,444	1,787	964	517	353	1,819
1989	246,546	221,603	332,675	109,624	92,662	109,912	33,115	30,092	61,837	21,534	13,225	9,795	12,899	5,699	2,088	1,229	1,093	1,354	730	391	1,645
1990	158,009	201,849	181,418	272,301	89,683	75,693	89,455	26,778	24,169	49,462	17,195	10,553	7,814	10,290	4,546	1,666	980	872	1,080	582	1,625
1991	177,314	129,361	165,238	148,470	222,658	73,155	61,376	71,775	21,251	19,053	38,883	13,504	8,285	6,134	8,077	3,568	1,308	769	685	848	1,732
1992	184,960	145,162	105,889	135,197	121,318	181,255	59,004	48,703	55,993	16,408	14,647	29,845	10,360	6,355	4,705	6,195	2,737	1,003	590	525	1,979
1993	138,103	151,428	118,838	86,671	110,597	99,083	147,450	47,665	39,057	44,705	13,076	11,665	23,763	8,248	5,059	3,746	4,932	2,179	798	470	1,993
1994	160,429	113,066	123,970	97,275	70,912	90,371	80,706	119,431	38,382	31,339	35,818	10,471	9,339	19,024	6,603	4,050	2,999	3,949	1,744	639	1,972
1995	205,643	131,344	92,562	101,466	79,567	57,899	73,462	65,096	95,551	30,557	24,898	28,435	8,310	7,412	15,097	5,240	3,214	2,380	3,133	1,384	2,072
1996	290,939	168,363	107,528	75,769	83,027	65,037	47,200	59,607	52,561	76,923	24,569	20,010	22,849	6,677	5,955	12,131	4,210	2,583	1,912	2,518	2,777
1997	229,766	238,193	137,831	88,012	61,981	67,806	52,899	38,118	47,779	41,941	61,263	19,554	15,922	18,180	5,313	4,738	9,652	3,350	2,055	1,521	4,213
1998	260,648	188,113	195,004	112,825	72,016	50,659	55,268	42,908	30,762	38,441	33,700	49,203	15,702	12,785	14,598	4,266	3,805	7,750	2,690	1,650	4,604
1999	415,819	213,394	153,999	159,608	92,290	58,808	41,194	44,609	34,366	24,522	30,583	26,792	39,108	12,479	10,161	11,601	3,390	3,024	6,159	2,138	4,970
2000	249,951	340,436	174,700	126,057	130,594	75,422	47,917	33,390	35,961	27,612	19,675	24,526	21,482	31,355	10,005	8,146	9,301	2,718	2,424	4,938	5,699
2001	276,603	204,637	278,702	142,995	103,126	106,677	61,382	38,744	26,815	28,761	22,045	15,699	19,565	17,136	25,011	7,981	6,498	7,419	2,168	1,934	8,484
2002	353,495	226,457	167,527	228,117	116,974	84,222	86,773	49,577	31,062	21,402	22,912	17,550	12,495	15,571	13,637	19,904	6,351	5,171	5,904	1,725	8,291
2003	384,720	289,410	185,393	137,128	186,635	95,575	68,587	70,253	39,895	24,904	17,132	18,330	14,038	9,994	12,454	10,908	15,920	5,080	4,136	4,723	8,011
2004	142,900	314,974	236,930	151,748	112,185	152,464	77,795	55,475	56,447	31,926	19,896	13,679	14,633	11,205	7,977	9,941	8,706	12,707	4,055	3,301	10,164
2005	142,900	116,993	257,853	193,923	124,128	91,606	123,966	62,779	44,416	44,979	25,389	15,810	10,867	11,624	8,901	6,337	7,897	6,916	10,095	3,221	10,697

Table 6.9 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2005.

males				numbers at age (1,000s)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1976	116,473	42,174	24,739	21,831	26,406	13,719	6,991	4,440	3,122	2,306	1,746	1,341	1,036	802	620	480	369	284	216	164	234
1977	195,062	83,679	30,275	17,728	15,586	18,708	9,585	4,781	2,960	2,035	1,480	1,112	850	655	507	392	303	233	180	137	251
1978	111,774	140,173	60,101	21,719	12,687	11,099	13,202	6,670	3,272	1,996	1,359	983	736	562	433	335	259	200	154	119	256
1979	116,095	80,325	100,685	43,125	15,550	9,042	7,844	9,212	4,584	2,219	1,341	909	656	490	374	288	223	172	133	103	250
1980	147,502	83,414	57,672	72,179	30,813	11,036	6,339	5,396	6,196	3,023	1,444	866	585	421	315	240	185	143	110	86	226
1981	333,029	105,957	59,862	41,301	51,456	21,766	7,666	4,291	3,542	3,959	1,897	897	535	360	259	194	148	114	88	68	192
1982	128,016	239,233	76,042	42,871	29,447	36,358	15,128	5,194	2,821	2,268	2,489	1,181	555	331	223	160	120	91	70	54	160
1983	112,348	91,986	171,796	54,533	30,656	20,934	25,573	10,466	3,524	1,881	1,495	1,630	771	362	215	145	104	78	59	46	140
1984	301,189	80,725	66,050	123,173	38,976	21,772	14,695	17,630	7,063	2,334	1,230	971	1,055	498	234	139	93	67	50	38	119
1985	206,787	216,460	57,992	47,408	88,244	27,818	15,431	10,304	12,207	4,836	1,586	832	655	712	336	158	94	63	45	34	106
1986	199,925	148,630	155,539	41,646	34,001	63,124	19,804	10,905	7,219	8,486	3,344	1,094	573	451	490	231	108	64	43	31	96
1987	496,429	143,703	106,809	111,718	29,880	24,342	45,013	14,036	7,673	5,046	5,907	2,322	758	397	313	339	160	75	45	30	88
1988	270,689	356,855	103,287	76,746	80,224	21,430	17,418	32,095	9,965	5,428	3,561	4,162	1,635	534	280	220	239	113	53	31	83
1989	246,546	194,526	256,324	74,111	54,943	57,170	15,144	12,151	22,048	6,754	3,645	2,379	2,774	1,089	355	186	146	159	75	35	76
1990	158,009	177,224	139,808	184,158	53,205	39,384	40,866	10,779	8,604	15,543	4,747	2,557	1,668	1,944	763	249	130	102	111	52	78
1991	177,314	113,572	127,349	100,405	132,094	38,069	28,052	28,905	7,561	5,991	10,770	3,280	1,765	1,150	1,340	526	172	90	71	77	90
1992	184,960	127,432	81,589	91,405	71,930	94,268	26,977	19,665	20,003	5,173	4,068	7,282	2,213	1,190	775	903	354	116	60	48	112
1993	138,103	132,953	91,585	58,615	65,614	51,549	67,354	19,186	13,908	14,079	3,629	2,849	5,095	1,548	832	542	631	248	81	42	112
1994	160,429	99,274	95,559	65,805	42,089	47,052	36,877	48,004	13,614	9,830	9,925	2,555	2,004	3,582	1,088	585	381	444	174	57	108
1995	205,643	115,317	71,345	68,646	47,229	30,152	33,595	26,194	33,889	9,559	6,877	6,929	1,782	1,397	2,497	758	407	265	309	121	115
1996	290,939	147,827	82,887	51,268	49,301	33,882	21,587	23,977	18,626	24,019	6,760	4,858	4,892	1,257	986	1,762	535	287	187	218	167
1997	229,766	209,132	106,242	59,547	36,800	35,329	24,206	15,349	16,952	13,103	16,841	4,731	3,397	3,419	879	689	1,231	374	201	131	269
1998	260,648	165,168	150,316	76,343	42,764	26,399	25,290	17,272	10,910	12,009	9,261	11,888	3,338	2,395	2,411	620	486	868	264	142	282
1999	415,819	187,357	118,703	107,986	54,796	30,641	18,855	17,974	12,203	7,669	8,412	6,475	8,303	2,330	1,672	1,682	432	339	606	184	295
2000	249,951	298,910	134,663	85,293	77,546	39,301	21,927	13,446	12,765	8,635	5,413	5,930	4,561	5,847	1,641	1,177	1,184	304	239	426	338
2001	276,603	179,672	214,829	96,750	61,233	55,586	28,093	15,606	9,520	8,997	6,068	3,798	4,156	3,196	4,096	1,149	825	830	213	167	535
2002	353,495	198,827	129,128	154,336	69,449	43,881	39,712	19,976	11,035	6,699	6,310	4,248	2,656	2,906	2,234	2,863	803	576	580	149	491
2003	384,720	254,105	142,904	92,779	110,816	49,797	31,385	28,294	14,167	7,794	4,719	4,438	2,985	1,866	2,041	1,569	2,011	564	405	407	449
2004	142,900	276,548	182,629	102,671	66,610	79,440	35,600	22,343	20,041	9,991	5,480	3,312	3,113	2,093	1,308	1,431	1,100	1,409	395	284	600
2005	142,900	102,718	198,749	131,197	73,693	47,724	56,732	25,297	15,782	14,083	6,996	3,830	2,312	2,172	1,460	912	998	767	983	276	617

Table 6.10 Estimated age 2 recruitment of arrowtooth flounder (thousands of fish) from the 2004 and 2005 stock assessments and also from estimates of fish less than 25 cm in the annual Bering Sea shelf trawl survey.

Year class	2005 Assessment	2004 Assessment	shelf survey fish < 25 cm
1974	90,202	102,295	
1975	179,026	160,019	
1976	299,862	309,442	
1977	171,830	169,478	
1978	178,454	175,436	
1979	226,701	221,575	
1980	511,851	509,997	86,100
1981	196,785	192,115	290,200
1982	172,697	161,727	57,900
1983	463,036	452,273	62,400
1984	317,925	310,323	150,300
1985	307,381	284,846	94,300
1986	763,287	748,156	200,600
1987	416,129	397,530	273,800
1988	379,073	358,838	105,200
1989	242,933	227,905	71,700
1990	272,594	254,674	79,400
1991	284,381	264,061	96,800
1992	212,340	194,903	126,600
1993	246,661	222,931	75,100
1994	316,190	278,239	55,600
1995	447,325	377,119	108,800
1996	353,281	281,346	93,600
1997	400,751	297,358	92,100
1998	639,346	413,810	126,300
1999	384,309	213,890	164,300
2000	425,284	196,032	108,800
2001	543,515		253,400
2002			406,700
2003			407,800

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. 2006 ABC is highlighted.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2005	652.110	12.237	0.02
2006	666.750	**135.543**	0.25
2007	593.254	117.941	0.25
2008	533.099	104.706	0.25
2009	467.275	94.431	0.25
2010	408.671	84.472	0.25
2011	367.264	74.573	0.25
2012	340.314	66.796	0.25
2013	323.656	61.468	0.25
2014	313.671	58.263	0.25
2015	307.446	56.531	0.24
2016	303.568	55.594	0.24
2017	301.455	55.051	0.24
2018	300.805	54.785	0.24

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2005	652.110	12.237	0.02
2006	672.527	71.353	0.13
2007	654.130	68.550	0.13
2008	632.454	66.169	0.13
2009	592.641	63.950	0.13
2010	550.483	60.871	0.13
2011	517.498	56.835	0.13
2012	492.479	52.998	0.13
2013	473.602	50.149	0.13
2014	459.130	48.205	0.13
2015	447.587	46.843	0.13
2016	438.551	45.838	0.13
2017	431.908	45.072	0.13
2018	427.545	44.512	0.13

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2005	652.110	12.237	0.02
2006	677.163	15.209	0.03
2007	708.096	15.834	0.03
2008	729.292	16.408	0.03
2009	726.144	16.877	0.03
2010	714.525	17.030	0.03
2011	705.528	16.810	0.03
2012	697.719	16.433	0.03
2013	690.124	16.095	0.03
2014	682.504	15.835	0.03
2015	674.691	15.625	0.03
2016	667.270	15.443	0.03
2017	660.844	15.281	0.03
2018	655.948	15.146	0.03

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2005	652.110	0	0
2006	678.360	0	0
2007	722.823	0	0
2008	757.159	0	0
2009	766.534	0	0
2010	766.556	0	0
2011	767.931	0	0
2012	768.859	0	0
2013	768.290	0	0
2014	766.171	0	0
2015	762.565	0	0
2016	758.293	0	0
2017	754.152	0	0
2018	750.917	0	0

Table 6.9 (continued).

Scenario 6
Determination of whether arrowtooth flounder are currently overfished
B35=258,200

Year	Female spawning biomass	catch	F
2005	652.110	12.237	0.02
2006	663.789	166.132	0.32
2007	564.577	137.479	0.32
2008	489.894	117.194	0.32
2009	416.629	102.417	0.32
2010	355.124	89.170	0.32
2011	314.049	76.820	0.32
2012	289.861	65.251	0.30
2013	278.831	59.456	0.29
2014	274.343	57.336	0.29
2015	272.236	56.622	0.29
2016	271.215	56.393	0.29
2017	271.021	56.408	0.29
2018	271.551	56.550	0.29

Scenario 7
Determination of whether arrowtooth flounder are approaching an overfished condition
B35=258,200

Year	Female spawning biomass	catch	F
2005	652.110	12.237	0.02
2006	666.750	135.543	0.25
2007	593.254	117.941	0.25
2008	530.843	128.419	0.32
2009	444.965	110.324	0.32
2010	374.267	94.576	0.32
2011	326.706	80.537	0.32
2012	297.915	68.439	0.31
2013	283.242	61.228	0.30
2014	276.629	58.248	0.29
2015	273.348	57.059	0.29
2016	271.708	56.582	0.29
2017	271.207	56.473	0.29
2018	271.599	56.561	0.29

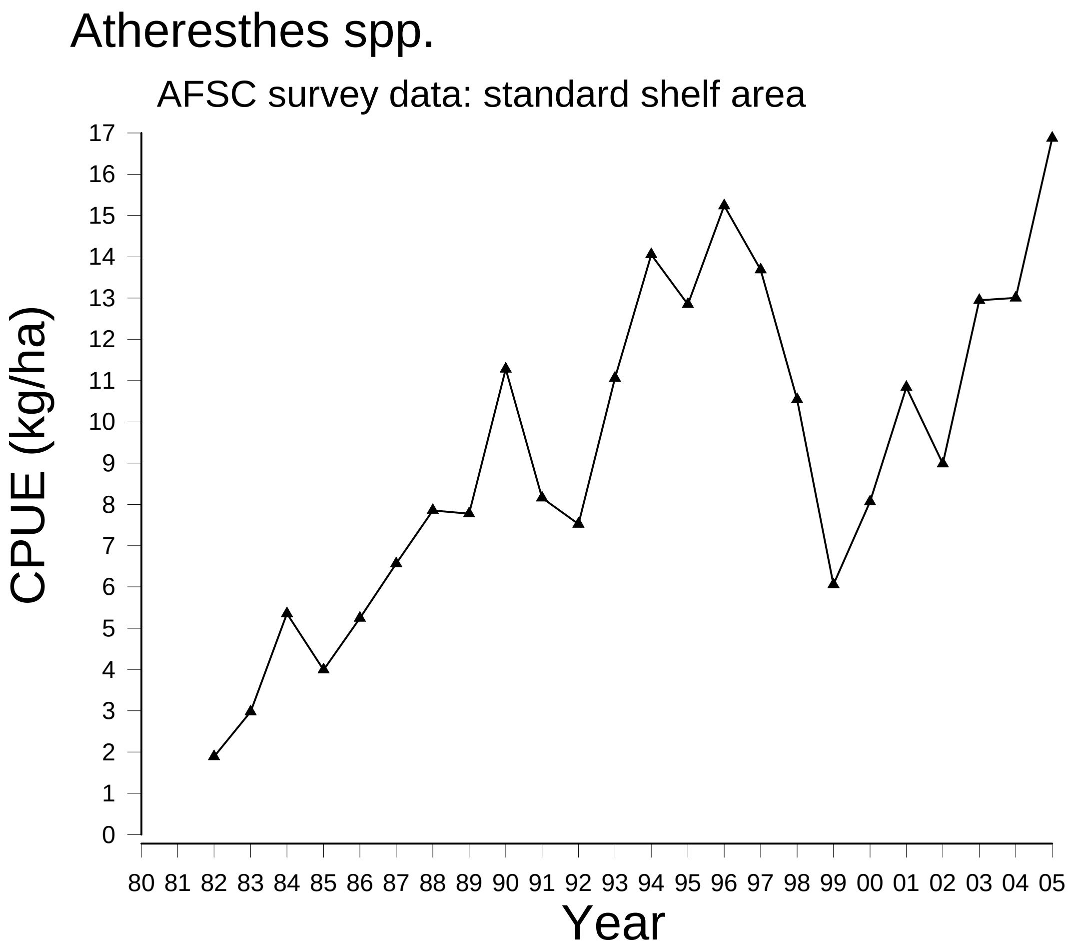


Figure 6.1--Catch per unit effort (CPUE) of Atheresthes spp. (arrowtooth flounder and Kamchatka flounder) on the eastern Bering Sea continental shelf as shown by Alaska Fisheries Science Center (AFSC) survey data.

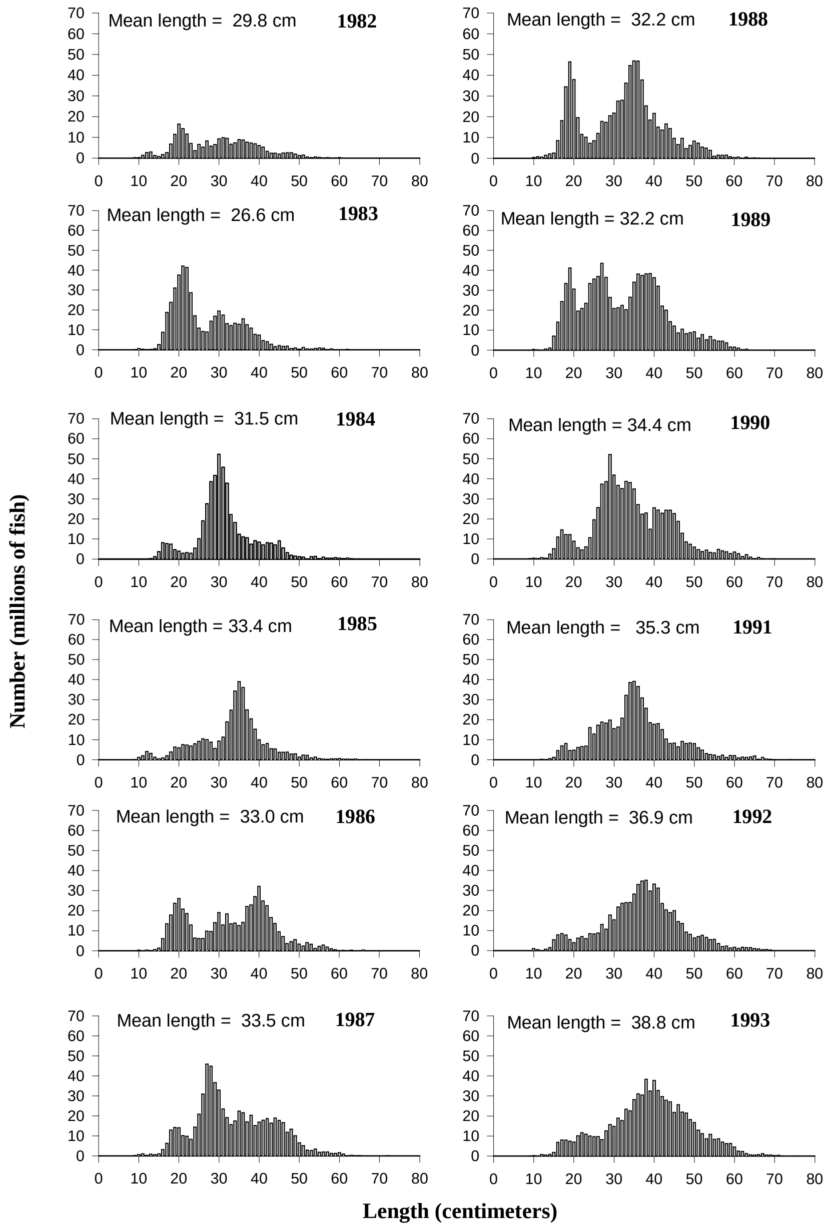


Figure 6.2-- Size composition (millions of fish) of arrowtooth flounder from the eastern Bering Sea bottom trawl surveys during 1982-2004.

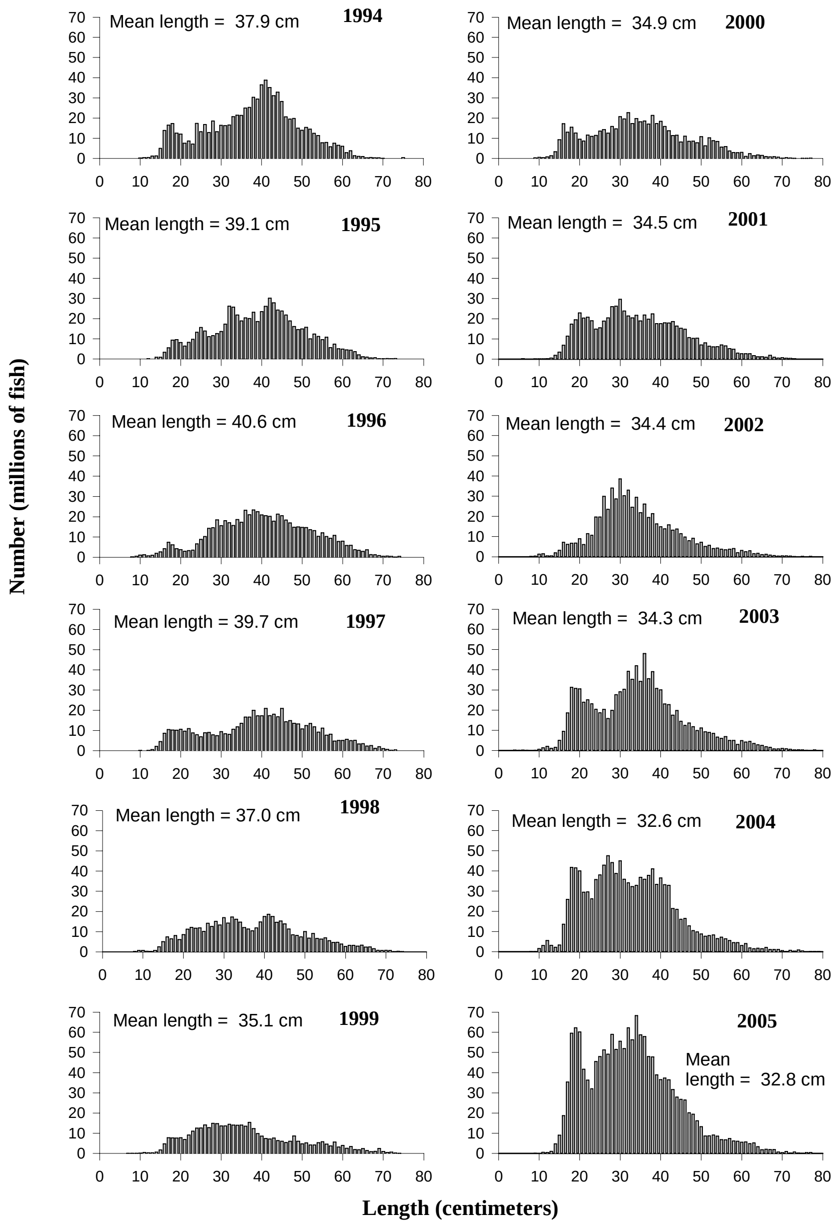


Figure 6.2-- Continued.

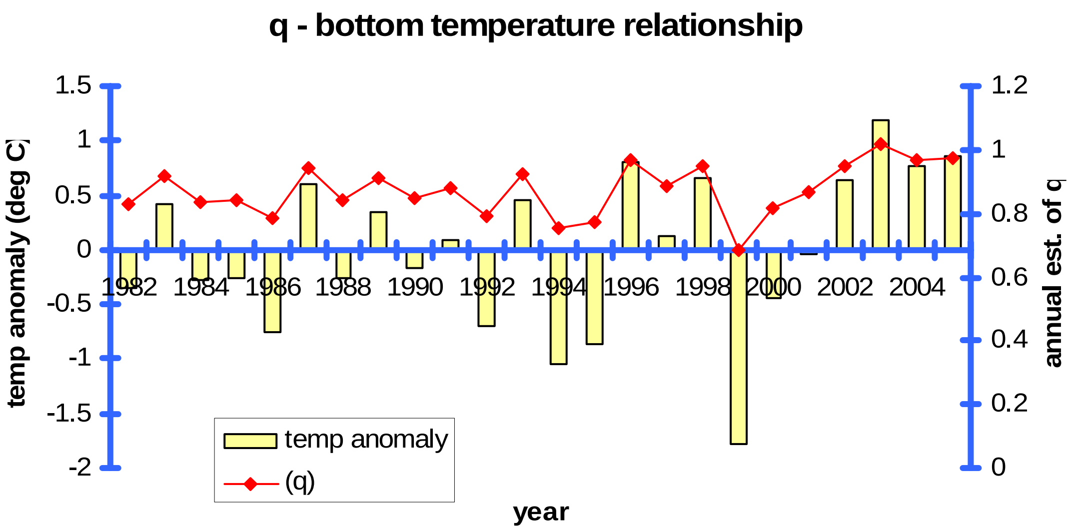


Figure 6.3--Shelf survey annual avg. bottom temperature anomalies (bars), model estimate of annual shelf survey q due to effect of water temperature (diamonds with lines), given the assumption that 87% of the biomass resides on the Bering Sea shelf.

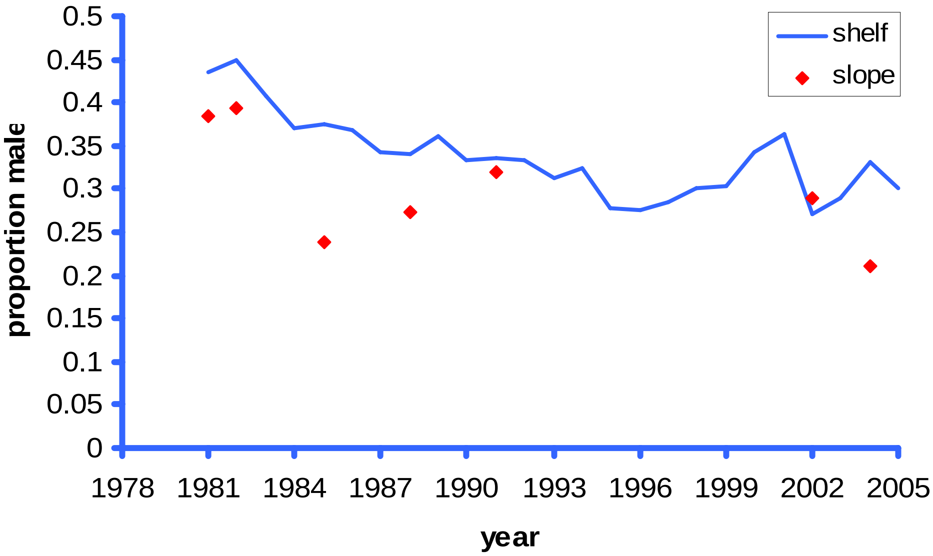


Figure 6.4--Proportion of the estimated male population from Bering Sea trawl surveys on the continental shelf and slope.

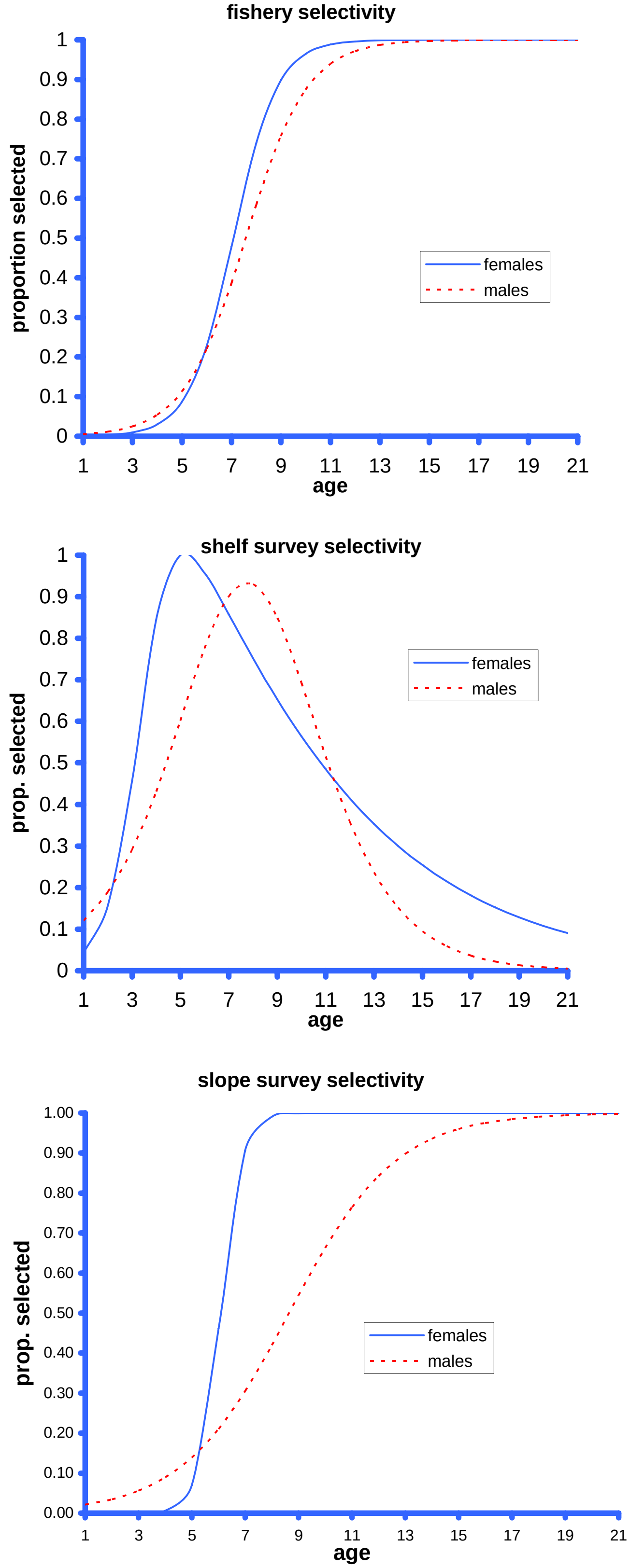


Figure 6.5--Age-specific fishery selectivity (top panel), shelf survey selectivity (middle panel) and slope survey selectivity (bottom panel), by sex, estimated from the stock assessment model.

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).

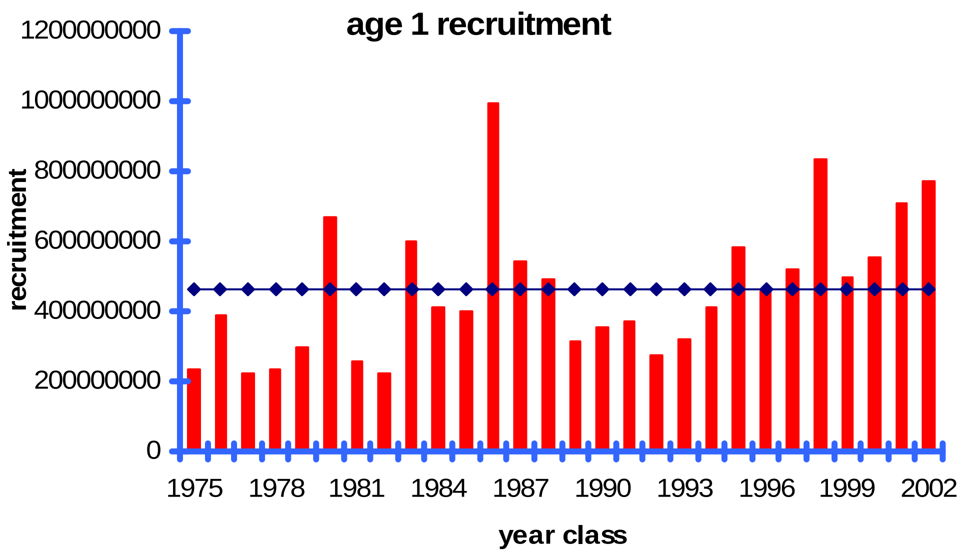


Figure 6.7--Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model.

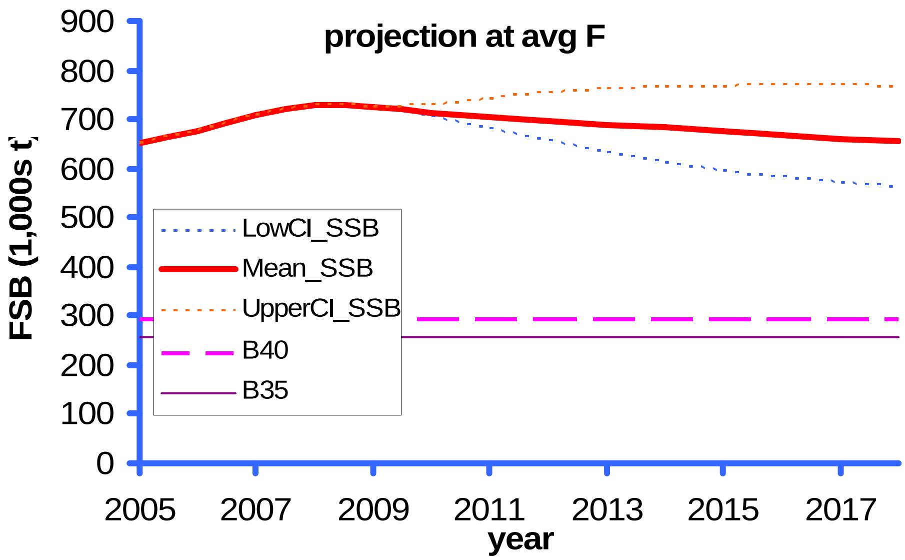


Figure 6.8--Projected female spawning biomass (1,000s t) of arrowtooth flounder if future harvest is at the same fishing mortality rate as the past five years.

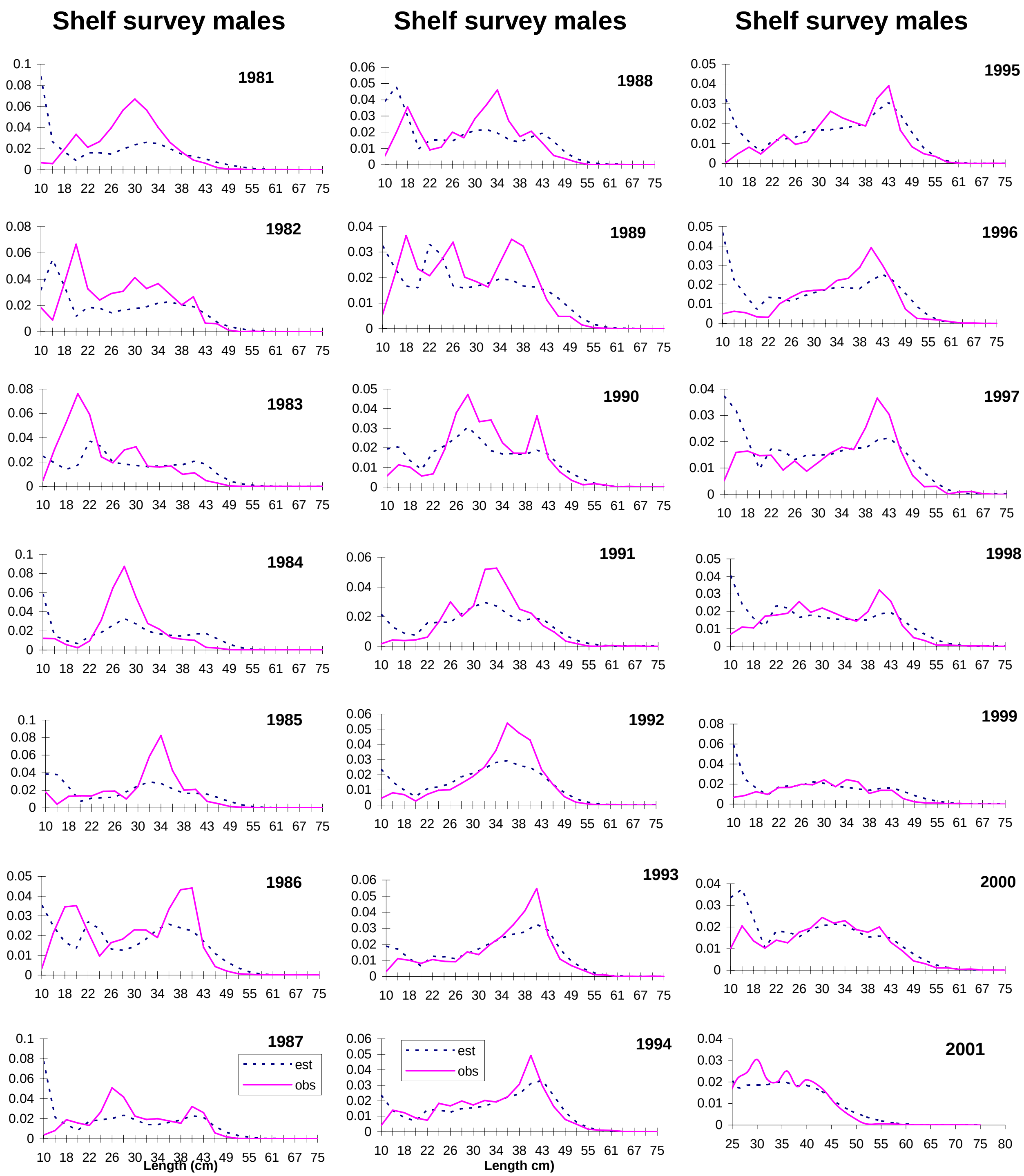
APPENDIX

Figures show 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, 1977-2003.

BSAI arrowtooth flounder TAC (1986-2004) and ABC (1982-2004)

Shelf survey biomass estimates for arrowtooth and Kamchatka flounder 1982-2005


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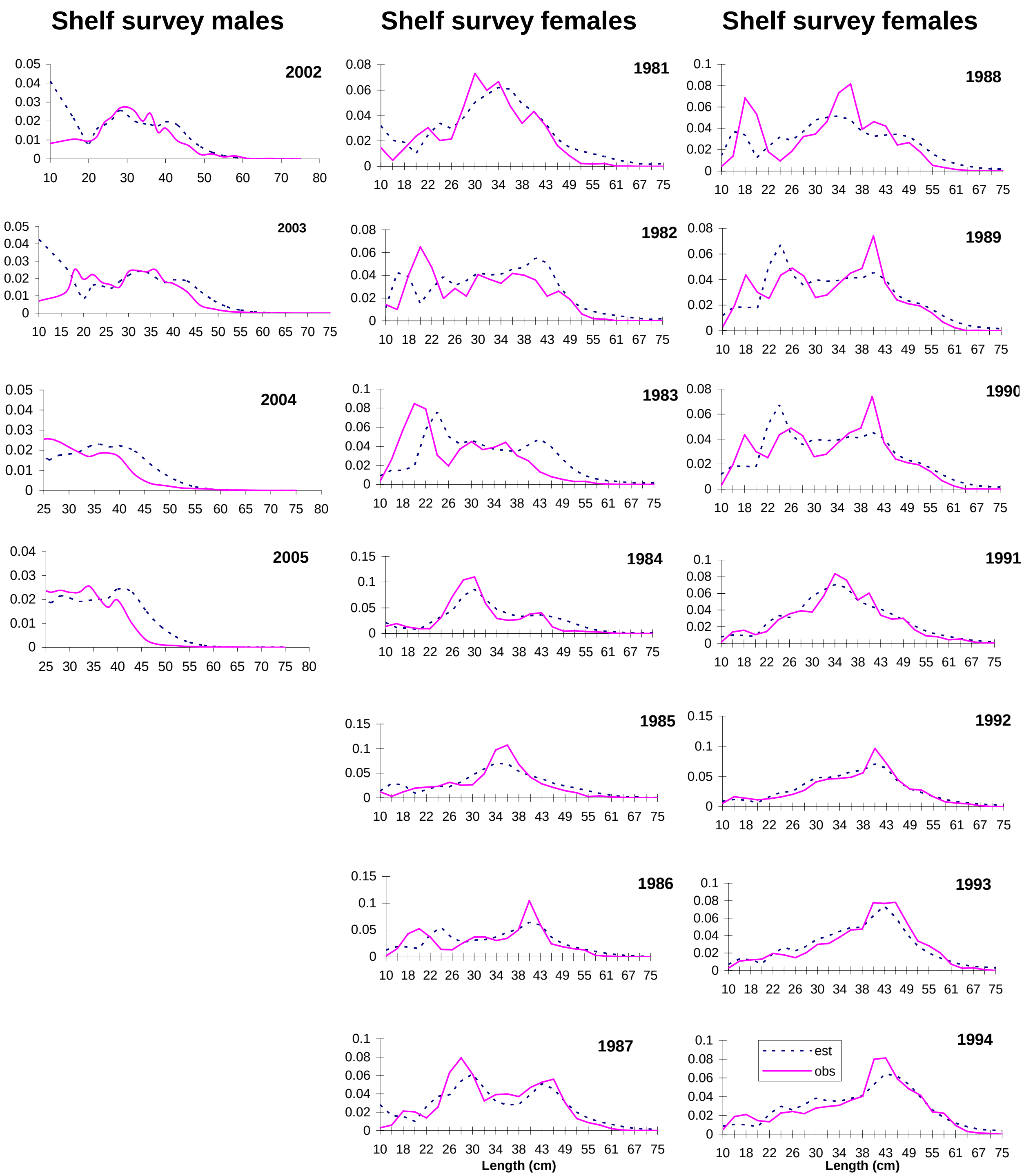
2001
est
obs
Length (cm)
Length cm)


Shelf survey males
Shelf survey females
Shelf survey females
2002
2003
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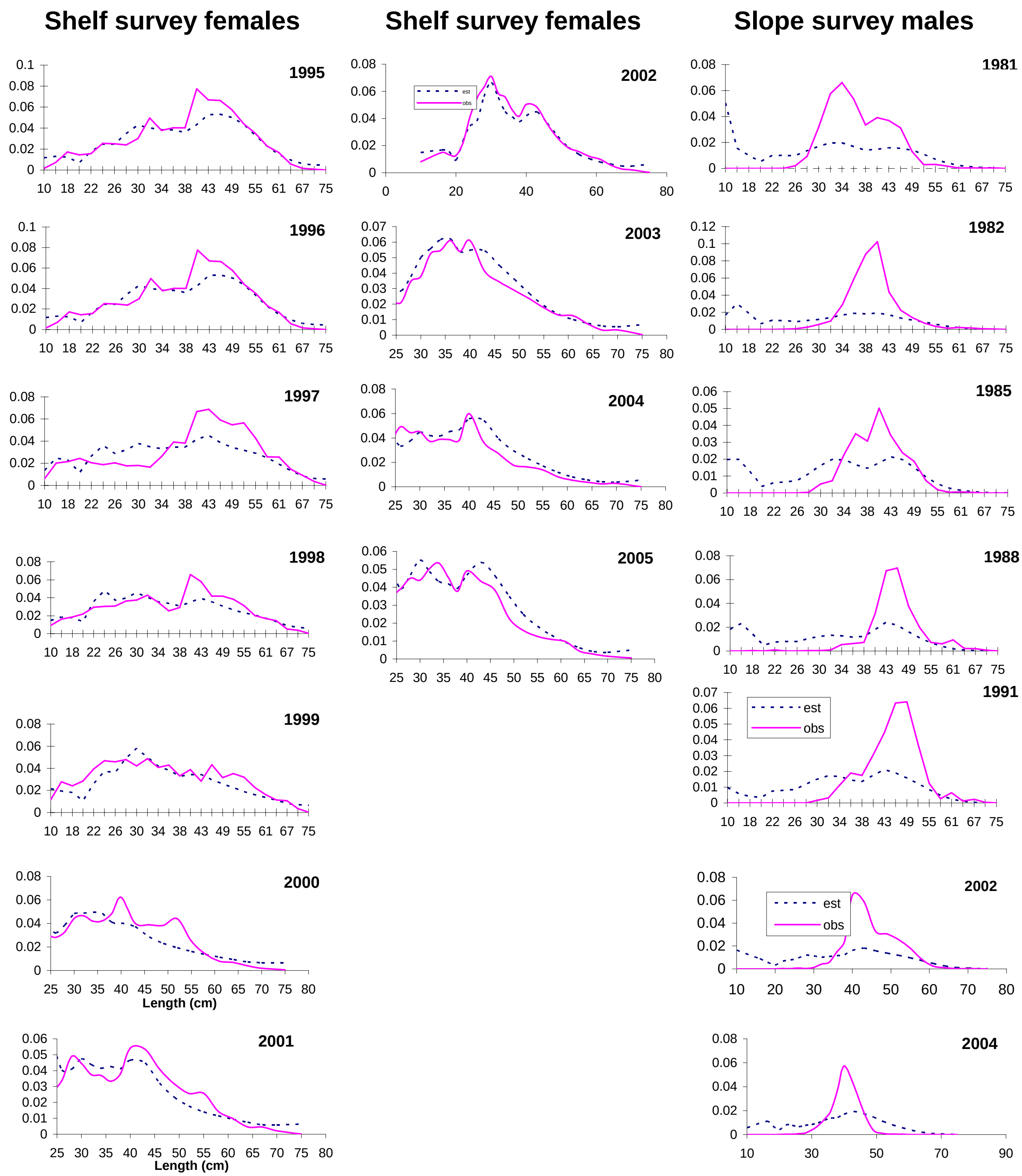
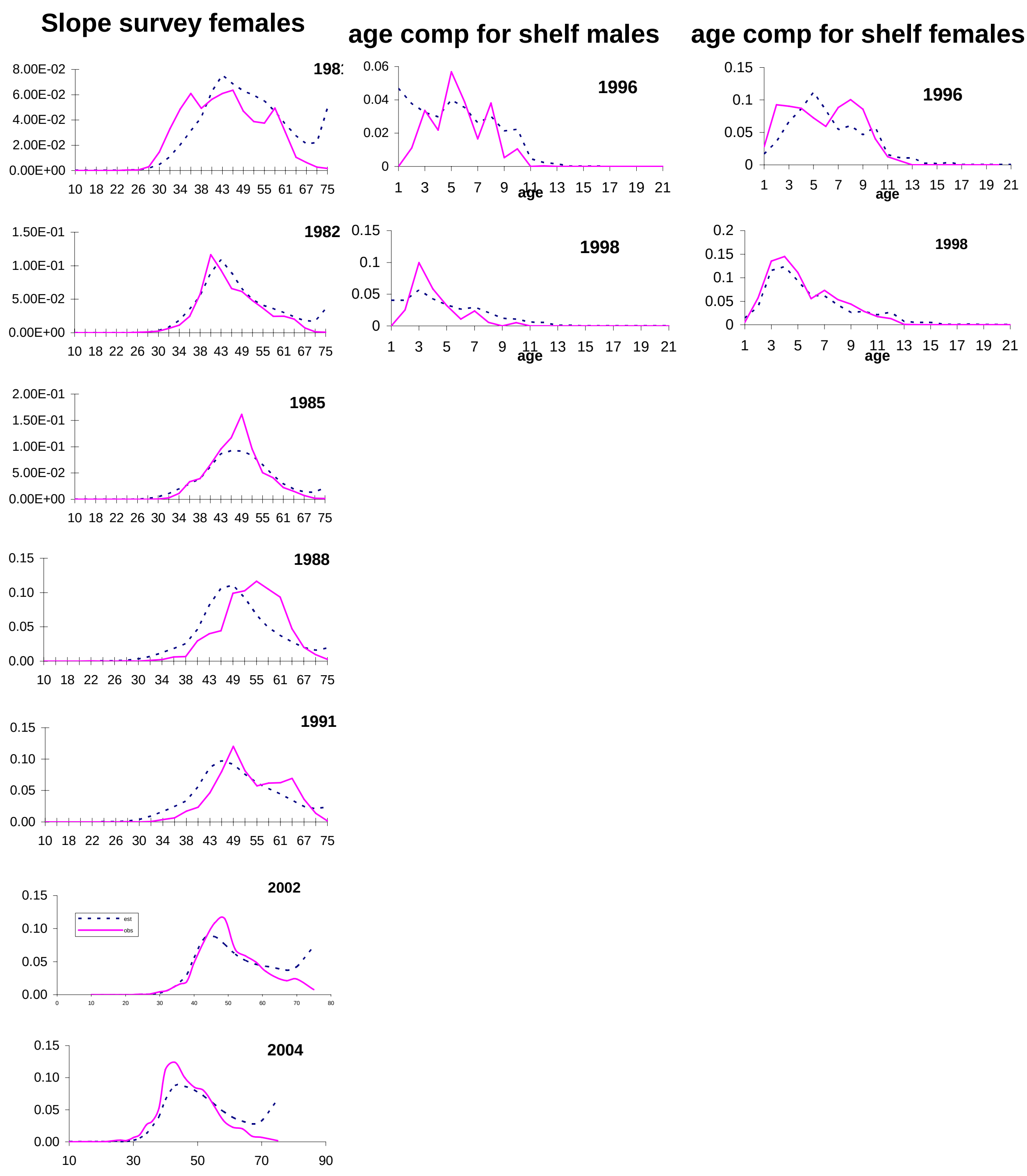
Length (cm)
Length (cm)


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

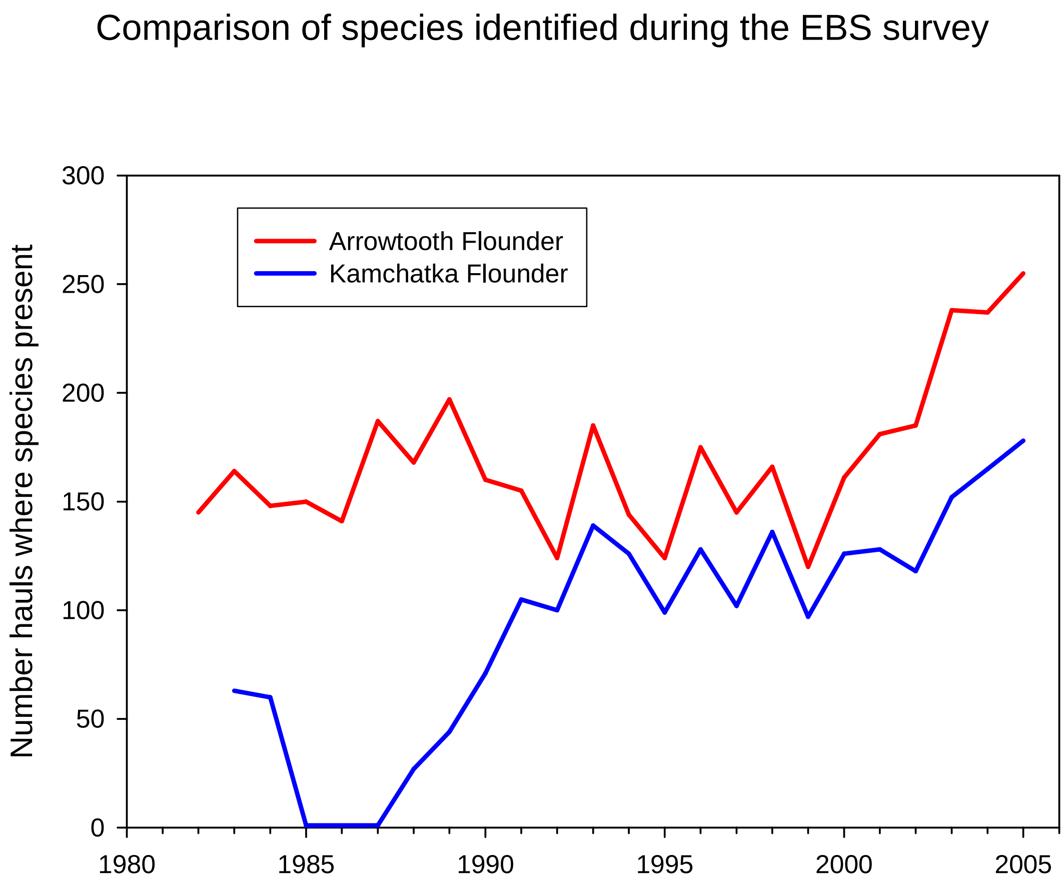

Slope survey females
age comp for shelf males
age comp for shelf females
1982
1985
1988
1991
2002
2004
1996
1998
age
est
obs

Total catch (t) of arrowtooth flounder due to Alaska Fisheries Science Center research activity in the Bering Sea and Aleutian Islands, 1977-2000 and 2002-2004.

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

	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

	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


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

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