Chapter 6

Arrowtooth Flounder

By

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Executive Summary

The following changes have been made to this assessment relative to the November 2003 SAFE.

Changes to the input data

1) 2004 shelf and slope survey size composition.

2) 2004 shelf and slope survey biomass point-estimates and standard errors.

3) Estimate of catch and discards through 4, September 2004.

4) Estimate of retained and discarded portion of the 2003 catch.

5) Revised estimates of shelf survey biomass and size composition for 2001-2003 from recalculation of the distance fished during the trawl survey.

6) 1996 and 1998 shelf survey age composition

Assessment results

1) The projected age 1+ total biomass for 2005 is 683,700 t.

2) The projected female spawning biomass for 2005 is 504,600 t.

3) The recommended 2005 ABC is 107,700 t based on an $F_{0.40}$ (0.26) harvest level.

4) The 2005 overfishing level is 132,200 t based on a $F_{0.35}$ (0.33) harvest level.

	2004 Assessment recommendation for 2005 harvest	2003 Assessment recommendation for 2004 harvest
Total biomass	683,700 t	696,400 t
ABC	107,700 t	114,600 t
Overfishing	132,200 t	141,500 t
F_{ABC}	$F_{0.40}$ = 0.26	$F_{0.40}$ = 0.28
$F_{overfishing}$	$F_{0.35}$ = 0.33	$F_{0.30}$ = 0.36

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. In past years, these species were not consistently separated in trawl survey catches and are 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 12,300 t from 1977-2003. 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 4 September, 2004 is 15,755 t (well below the 2004 ABC of 115,000 t). NMFS Regional Office reports indicate that bottom trawling accounted for 90% of the 2004 catch.

Although research has been conducted on their commercial utilization (Greene and Babbitt 1990, Wasson et al. 1992, Porter et al. 1993, Reppond et al. 1993, Cullenberg 1995) and some targeting occurs, arrowtooth flounder continue to have a low perceived commercial value as they are captured primarily in pursuit of other high value species and most are discarded.. 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 1985-2003, as follows:

Year*	Retained	Discarded	Total	% Retained
1985	17 t	72 t	89 t	19
1986	65 t	277 t	342 t	19
1987	75 t	320 t	395 t	19
1988	3,309 t	14,107 t	17,416 t	19
1989	958 t	4,084 t	5,042 t	19
1990	2,356 t	10,042 t	12,398 t	19
1991	3,211 t	18,841 t	22,052 t	15
1992	675 t	9,707 t	10,382 t	7
1993	403 t	6,775 t	7,178 t	6
1994	626 t	13,641 t	14,267 t	4
1995	509 t	8,772 t	9,281 t	5
1996	1,372 t	13,280 t	14,652 t	9
1997	1,029 t	9,024 t	10,054 t	10
1998	2,896 t	12,345 t	15,241 t	19
1999	2,538 t	8,035 t	10,573 t	24
2000	5,124 t	7,805 t	12,929 t	60
2001	4,271 t	6,959 t	11,230 t	62
2002	4,039 t	7,501 t	11,540 t	35
2003	4,024 t	8,810 t	12,834 t	31

*1990 % retained rate applied to the 1985-89 reported retained DAP catch.

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 4, 2004 and fishery length-frequency data from 1978-91 and 2000-2003are 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 surveys on the shelf 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 during 1991 but increased to 9.5 kg/ha during the 1992 bottom trawl survey. The CPUE continued to increase through 1996 to 12.0 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 CPUE declined from10.3 kg/ha in 1997 to 5.7 kg/ha in 1999 and has increased since that time to 7.7 kg/ha in 2002 and 11.4 kg/ha in 2003.

Absolute Abundance from Trawl Surveys

Biomass estimates (t) for arrowtooth flounder from U.S. and U.S.-Japanese cooperative surveys in the eastern Bering Sea and Aleutian Islands region are as follows:

	Eastern Bering Sea			Aleutian Islands
Year	Shelf	Slope	Shelf and Slope combined	
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

*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 slope estimate was from sampling conducted from 200-1,200 m.

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.

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 2004 point estimate are 471,600 – 623,200 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 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
<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 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 the 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.

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 (see Table 6-6). 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
29	14	47	90

The recruitment parameters are comprised of 21 initial ages in 1976 and 26 subsequent age 1 recruitment estimates from 1976-2002. Recruitment in 2003 and 2004 was set at the average from 1976-2000. The difference in the number of parameters estimated in this assessment compared to last year can be accounted for by an additional year (2004) 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 6-6).

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.

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 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. Since fishery length data were essentially from bycatch during the 1980s and were generally low in sample size, they were given a lower weight (0.25) 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 1982-2004, 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 0.73 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 survey biomass	83.24	86.18	88.75	90.91	92.64	93.99	94.97	95.65	96.07	96.20
slope survey biomass	74.97	72.15	69.99	68.30	66.94	65.86	65.01	64.42	64.05	64.44
shelf survey length	1409.4	1411.84	1414.49	1417.34	1420.34	1423.48	1426.76	1430.04	1433.49	1437.1
slope survey length	666.67	670.55	674.62	679.05	684.00	689.55	695.74	702.76	710.54	719.40
recruitment likelihood	18.02	17.09	16.31	15.71	15.29	15.03	14.92	14.92	15.02	15.31
catch likelihood	0.0008	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0008	0.0008
sex ratio	85.55	75.26	66.06	57.86	50.60	44.17	38.51	33.53	29.16	25.35
shelf survey age	131.04	131.17	131.33	131.52	131.75	132.01	132.31	132.55	132.8	132.46
total likelihood	2468.9	2464.24	2461.55	2460.70	2461.57	2464.10	2468.22	2473.89	2481.15	2490.3
male max shelf selectivity	0.61 at age 7	0.64 at age 7	0.68@ age 8	0.73@ age7	0.77@ age 7	0.81@ age 7	0.86@ age 8	0.91@ age 8	0.97@ age 8	1@ 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 are consistent with the differential sex-specific natural mortality hypothesis. The run with male M = 0.32 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 0.91 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 6.2. The average exploitation rate has been at a low level, 2%, from 1977-2004 due to the relative undesirability of arrowtooth flounder as a commercial product. Age-specific selectivity estimated by the model (Table 6.3, 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 15 and 14, for males and females, respectively.

Abundance Trend

Model estimates indicate that arrowtooth flounder total biomass increased more than 2.5 times from 1976 to the 1996 value of 759,400 t (Fig. 6.6, Table 6.4). The biomass has declined 7% since then to the 2004 estimate of 710,000 t. Female spawning biomass is also estimated to be at high level, 532,000 t in 2004, a 4% decline from the 1996 peak level (Table 6.4). Model estimates of population numbers by age, year, and sex are given in Table 5.5.

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, 1994, 1996 and 2003 and 2004. 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 (1989-99), which are shown in the Appendix. Reasonable fits also resulted for slope survey size composition observations. The fit to the 1996 and 1998 shelf survey age compositions are also shown in the Appendix.

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 6.6). Since 1989, recruitment is estimated to be at or below average from 1989-93 and then stronger in 1995 and 1998. The 2001 year class also appears strong from small fish observed in the 2003 survey.

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 as follows:

Year	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	
Population estimates	86.1	290.2	57.9	62.4	150.3	94.3	200.6	273.8	105.2	71.7	79.4	
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Population estimates	96.8	126.6	75.1	55.6	108.8	93.6	92.1	126.3	164.3	108.8	253.4	406.7

Over this 22 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. Estimates of age 2 recruitment from the stock assessment model fits this information in the population simulation and indicates average to above average recruitment for the four years following the large 1986 and 1987 year-classes (Fig. 6.7). Recruitment declined in the early 1990s causing a leveling in the population trend but above average year classes in 1998 and 2001 should contribute to a stable population level in the near future.

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 strong year-classes spawned during the 1980s and minimal commercial harvest. They are currently estimated to be at a stable and high level. **The estimate of projected 2005 total biomass from the stock assessment model is 683,700 t and the female spawning biomass is estimated at 504,600 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 1978-2001 from the stock assessment model results in an estimate of $B_{0.40}$ = 235,400 t. The stock assessment model estimates the 2005 level of female spawning biomass at 504,600 t (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and B>$B_{0.40}$ (504,600 > 235,400), arrowtooth flounder reference fishing mortality is defined in tier 3a. For the 2005 harvest: $F_{ABC} \leq F_{0.40} = 0.26$ and $F_{overfishing} = F_{0.35} = 0.33$ (full selection F values).

Acceptable biological catch is estimated for 2005 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2005 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 2005 ABC of 107,700 t.**

The potential yield of arrowtooth flounder in 2005 at various levels of fishing mortality (full selection) are as follows:

F level	Exploitation rate	Potential yield
$F_{overfishing}$	0.33	132,200 t
$F_{0.40}$	**0.26**	**107,700 t**

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 2004 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2005 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2004. 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 2005, 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 2005 recommended in the assessment to the *max* F_{ABC} for 2005. (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 2000-2004 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 2005 and above its MSY level in 2015 under this scenario, then the stock is not overfished.)

Scenario 7: In 2005 and 2006, 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 2017 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results (Table 6.7) 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.

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 2001 and 2002 in Table 14 of the Economic SAFE (Appendix C) and is summarized for 2002 as follows:

Prohibited species	Arrowtooth flounder "fishery" % of total bycatch
Halibut mortality	1.7
Herring	0
Red King crab	0
C. bairdi	<1
Other Tanner crab	2.3

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], 1970-2004. 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**									15,755

[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 4 September, 2004 (NMFS regional office).

Table 6.2 Model estimates of arrowtooth flounder fishing mortality and exploitation rate (catch/total biomass).

year	Full selection F	Exploitation rate
1976	0.107	0.066
1977	0.070	0.042
1978	0.064	0.037
1979	0.094	0.051
1980	0.128	0.064
1981	0.126	0.058
1982	0.083	0.037
1983	0.094	0.041
1984	0.057	0.026
1985	0.040	0.018
1986	0.034	0.016
1987	0.020	0.010
1988	0.075	0.037
1989	0.025	0.012
1990	0.041	0.020
1991	0.064	0.032
1992	0.028	0.015
1993	0.023	0.013
1994	0.032	0.019
1995	0.019	0.012
1996	0.029	0.019
1997	0.020	0.013
1998	0.031	0.020
1999	0.022	0.014
2000	0.027	0.017
2001	0.030	0.019
2002	0.025	0.016
2003	0.028	0.018
2004	0.034	0.022

Table 6.3 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	0.13	0.00	0.02
2	0.00	0.02	0.17	0.20	0.00	0.04
3	0.01	0.04	0.50	0.31	0.00	0.06
4	0.03	0.07	0.88	0.45	0.00	0.10
5	0.08	0.15	1.00	0.62	0.07	0.16
6	0.21	0.29	0.95	0.79	0.57	0.23
7	0.44	0.47	0.86	0.90	0.96	0.33
8	0.70	0.66	0.76	0.91	1.0	0.45
9	0.88	0.82	0.67	0.81	1.0	0.58
10	0.95	0.91	0.59	0.65	1.0	0.69
11	0.98	0.96	0.52	0.48	1.0	0.79
12	0.99	0.98	0.45	0.33	1.0	0.86
13	1.0	0.99	0.39	0.22	1.0	0.91
14	1.0	1.0	0.34	0.14	1.0	0.94
15	1.0	1.0	0.29	0.09	1.0	0.96
16	1.0	1.0	0.25	0.05	1.0	0.98
17	1.0	1.0	0.22	0.03	1.0	0.99
18	1.0	1.0	0.19	0.02	1.0	0.99
19	1.0	1.0	0.16	0.01	1.0	1.0
20	1.0	1.0	0.14	0.01	1.0	1.0
21	1.0	1.0	0.12	0.0	1.0	1.0

Table 6.4 Model estimates of arrowtooth flounder 1+ total biomass (t) and female spawning biomass (t) from the 2003 and 2004 assessments.

	2004 Assessment		2003 Assessment	
	age 2+ Total biomass	Female Spawning biomass	age 2+ Total biomass	Female Spawning biomass
1976	291,246	211,215	292,953	211,918
1977	275,943	197,064	278,791	198,411
1978	273,516	188,461	277,535	189,875
1979	279,254	180,912	284,965	182,705
1980	285,064	173,524	292,548	176,372
1981	295,164	173,525	304,751	177,952
1982	310,595	182,646	322,461	188,966
1983	338,798	194,656	353,321	202,221
1984	368,864	205,391	386,392	214,424
1985	403,855	233,423	424,821	244,553
1986	443,814	271,011	468,667	284,558
1987	491,514	296,206	521,727	311,998
1988	543,434	324,665	579,246	343,251
1989	586,786	348,457	629,303	370,729
1990	642,415	380,409	691,430	406,643
1991	686,546	419,497	741,748	451,675
1992	711,646	464,983	771,929	504,319
1993	737,911	508,771	803,002	552,460
1994	754,706	537,624	821,526	584,498
1995	756,828	547,954	823,910	598,516
1996	759,402	555,823	822,382	608,851
1997	752,934	551,846	809,062	605,743
1998	751,789	545,077	797,838	596,615
1999	747,127	532,803	780,431	576,890
2000	746,904	530,455	766,400	565,366
2001	744,761	529,776	749,564	553,529
2002	738,310	526,401	727,472	538,871
2003	728,128	529,433	703,141	529,199
2004	709,898	532,078		

Table 6.5 Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2004.

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	103,625	54,213	35,660	33,171	48,978	30,041	16,935	12,276	9,965	8,504	7,420	6,552	5,803	5,138	4,517	3,962	3,446	2,991	2,562	2,182	7,055
1977	200,358	84,830	44,369	29,164	27,071	39,742	24,042	13,221	9,322	7,428	6,286	5,467	4,822	4,270	3,780	3,323	2,914	2,535	2,200	1,884	6,794
1978	109,731	164,026	69,436	36,300	23,828	22,036	32,061	19,085	10,308	7,181	5,691	4,806	4,177	3,683	3,261	2,887	2,538	2,225	1,936	1,680	6,628
1979	113,603	89,834	134,263	56,812	29,664	19,405	17,799	25,517	14,941	7,982	5,533	4,377	3,694	3,209	2,830	2,505	2,218	1,949	1,710	1,487	6,383
1980	143,500	93,000	73,525	109,819	46,384	24,097	15,573	13,976	19,555	11,266	5,974	4,130	3,263	2,753	2,392	2,109	1,867	1,653	1,453	1,274	5,865
1981	330,289	117,470	76,108	60,118	89,569	37,571	19,199	12,045	10,457	14,313	8,163	4,312	2,977	2,351	1,983	1,723	1,519	1,345	1,190	1,046	5,143
1982	124,397	270,377	96,134	62,231	49,036	72,566	29,949	14,864	9,026	7,669	10,392	5,905	3,115	2,149	1,698	1,432	1,244	1,097	971	859	4,468
1983	104,725	101,838	221,302	78,641	50,824	39,869	58,370	23,630	11,478	6,871	5,800	7,840	4,451	2,347	1,619	1,279	1,079	937	826	731	4,014
1984	292,824	85,732	83,351	181,012	64,206	41,287	31,998	45,840	18,113	8,657	5,145	4,330	5,848	3,319	1,750	1,207	953	804	699	616	3,537
1985	200,905	239,728	70,178	68,202	147,947	52,316	33,393	25,539	36,048	14,104	6,711	3,981	3,349	4,521	2,566	1,353	933	737	622	540	3,211
1986	184,406	164,479	196,245	57,433	55,771	120,721	42,467	26,854	20,325	28,490	11,111	5,280	3,131	2,633	3,555	2,018	1,064	734	580	489	2,950
1987	484,321	150,973	134,648	160,615	46,974	45,531	98,118	34,242	21,462	16,147	22,573	8,795	4,178	2,477	2,083	2,813	1,596	842	581	459	2,720
1988	257,399	396,519	123,597	110,217	131,421	38,394	37,117	79,612	27,638	17,262	12,967	18,116	7,057	3,352	1,987	1,671	2,257	1,281	675	466	2,550
1989	232,299	210,722	324,557	101,115	90,037	106,928	30,939	29,397	61,845	21,196	13,161	9,864	13,770	5,362	2,547	1,510	1,270	1,715	973	513	2,292
1990	147,547	190,185	172,509	265,656	82,724	73,561	87,079	25,049	23,646	49,532	16,942	10,512	7,876	10,994	4,281	2,034	1,206	1,014	1,369	777	2,239
1991	164,894	120,796	155,688	141,179	217,233	67,495	59,701	69,999	19,922	18,673	38,988	13,319	8,260	6,189	8,638	3,364	1,598	947	797	1,075	2,369
1992	170,946	134,993	98,877	127,382	115,365	176,901	54,509	47,500	54,772	15,417	14,377	29,960	10,228	6,342	4,751	6,631	2,582	1,226	727	611	2,645
1993	126,172	139,954	110,512	80,930	104,205	94,233	143,977	44,078	38,134	43,762	12,290	11,452	23,858	8,144	5,049	3,783	5,280	2,056	976	579	2,592
1994	144,322	103,298	114,575	90,459	66,216	85,155	76,782	116,702	35,520	30,611	35,066	9,841	9,168	19,098	6,519	4,042	3,028	4,226	1,646	782	2,539
1995	180,118	118,156	84,564	93,776	73,992	54,070	69,252	61,988	93,449	28,288	24,318	27,831	7,808	7,273	15,150	5,171	3,206	2,402	3,353	1,305	2,634
1996	244,138	147,465	96,732	69,222	76,733	60,483	44,089	56,220	50,074	75,241	22,742	19,539	22,357	6,272	5,842	12,169	4,154	2,575	1,929	2,693	3,164
1997	182,130	199,876	120,722	79,173	56,624	62,671	49,212	35,631	45,092	39,962	59,908	18,092	15,539	17,778	4,987	4,645	9,676	3,303	2,048	1,534	4,657
1998	192,503	149,112	163,633	98,818	64,783	46,283	51,093	39,936	28,766	36,279	32,101	48,095	14,521	12,471	14,268	4,003	3,728	7,766	2,651	1,644	4,969
1999	267,882	157,603	122,069	133,929	80,832	52,904	37,647	41,266	32,000	22,929	28,847	25,502	38,195	11,531	9,903	11,329	3,178	2,960	6,166	2,105	5,250
2000	138,466	219,318	129,024	99,920	109,581	66,059	43,115	30,527	33,274	25,706	18,387	23,119	20,433	30,601	9,238	7,934	9,077	2,546	2,372	4,940	5,893
2001	126,907	113,363	179,545	105,607	81,741	89,514	53,773	34,875	24,520	26,601	20,507	14,657	18,423	16,281	24,382	7,361	6,321	7,232	2,029	1,890	8,631
2002	128,684	103,899	92,804	146,954	86,386	66,757	72,823	43,444	27,959	19,556	21,166	16,303	11,648	14,640	12,937	19,374	5,849	5,023	5,746	1,612	8,360
2003	42,900	105,355	85,058	75,962	120,226	70,579	54,365	58,962	34,948	22,394	15,633	16,908	13,019	9,301	11,690	10,330	15,470	4,670	4,011	4,588	7,962
2004	42,900	35,122	86,249	69,619	62,140	98,204	57,444	43,963	47,337	27,923	17,854	12,453	13,464	10,367	7,406	9,308	8,225	12,317	3,718	3,193	9,993

Table 6.5 (cont'd) Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2004.

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	103,625	48,083	28,051	23,142	30,307	16,487	8,243	5,300	3,816	2,888	2,235	1,750	1,375	1,080	842	655	505	389	295	223	424
1977	200,358	75,189	34,855	20,293	16,671	21,651	11,611	5,691	3,584	2,539	1,903	1,465	1,144	898	705	549	427	330	254	193	422
1978	109,731	145,416	54,537	25,249	14,660	11,978	15,413	8,160	3,946	2,459	1,731	1,293	994	776	608	477	372	289	223	172	416
1979	113,603	79,645	105,486	39,514	18,247	10,542	8,541	10,861	5,680	2,721	1,685	1,183	882	677	529	415	325	254	197	152	401
1980	143,500	82,436	57,747	76,347	28,492	13,062	7,452	5,933	7,409	3,820	1,814	1,119	783	584	448	349	274	215	168	130	365
1981	330,289	104,105	59,738	41,745	54,911	20,290	9,144	5,095	3,957	4,847	2,470	1,165	717	501	373	286	223	175	137	107	317
1982	124,397	239,620	75,444	43,188	30,030	39,117	14,213	6,258	3,403	2,593	3,140	1,590	748	459	321	239	183	143	112	88	271
1983	104,725	90,277	173,768	54,624	31,167	21,531	27,738	9,925	4,300	2,309	1,746	2,106	1,064	500	307	214	160	122	96	75	240
1984	292,824	75,994	65,456	125,768	39,389	22,311	15,222	19,272	6,772	2,893	1,540	1,159	1,395	704	331	203	142	106	81	63	208
1985	200,905	212,545	55,133	47,435	90,936	28,353	15,938	10,759	13,471	4,693	1,994	1,059	796	957	483	227	139	97	72	56	186
1986	184,406	145,844	154,240	39,978	34,342	65,629	20,353	11,356	7,606	9,466	3,285	1,393	739	555	668	337	158	97	68	50	169
1987	484,321	133,873	105,846	111,866	28,956	24,807	47,191	14,542	8,060	5,371	6,663	2,308	978	519	390	468	236	111	68	48	154
1988	257,399	351,637	97,180	76,806	81,109	20,961	17,910	33,942	10,418	5,757	3,829	4,745	1,643	696	369	277	333	168	79	48	143
1989	232,299	186,808	255,035	70,383	55,462	58,231	14,900	12,555	23,453	7,118	3,906	2,589	3,202	1,108	469	249	187	225	113	53	129
1990	147,547	168,653	135,596	185,031	51,012	40,120	41,981	10,692	8,966	16,685	5,052	2,769	1,834	2,268	785	332	176	132	159	80	129
1991	164,894	107,109	122,386	98,321	133,946	36,811	28,791	29,898	7,554	6,295	11,670	3,527	1,931	1,278	1,581	547	232	123	92	111	146
1992	170,946	119,681	77,697	88,670	71,053	96,315	26,243	20,282	20,801	5,205	4,312	7,968	2,404	1,316	871	1,076	372	158	84	63	175
1993	126,172	124,107	86,868	56,365	64,254	51,376	69,384	18,807	14,457	14,765	3,685	3,049	5,630	1,698	929	615	760	263	111	59	168
1994	144,322	91,605	90,087	63,029	40,860	46,498	37,067	49,851	13,454	10,307	10,504	2,619	2,165	3,998	1,206	660	436	540	187	79	161
1995	180,118	104,775	66,485	65,345	45,661	29,528	33,461	26,519	35,447	9,521	7,273	7,401	1,844	1,524	2,813	848	464	307	380	131	169
1996	244,138	130,774	76,059	48,246	47,382	33,060	21,325	24,080	19,014	25,342	6,795	5,186	5,274	1,314	1,086	2,004	604	331	219	270	214
1997	182,130	177,243	94,917	55,174	34,957	34,254	23,807	15,274	17,149	13,482	17,921	4,798	3,659	3,721	927	766	1,413	426	233	154	342
1998	192,503	132,234	128,663	68,876	40,005	25,307	24,732	17,126	10,945	12,252	9,614	12,767	3,417	2,605	2,649	660	545	1,006	303	166	353
1999	267,882	139,755	95,975	93,329	49,900	28,914	18,217	17,702	12,185	7,752	8,653	6,780	8,997	2,407	1,835	1,865	464	384	709	214	365
2000	138,466	194,492	101,448	69,639	67,661	36,115	20,866	13,093	12,670	8,693	5,519	6,154	4,819	6,394	1,710	1,304	1,325	330	273	503	412
2001	126,907	100,527	141,169	73,596	50,466	48,929	26,022	14,959	9,337	8,999	6,159	3,905	4,351	3,407	4,519	1,209	921	937	233	193	647
2002	128,684	92,133	72,963	102,402	53,322	36,479	35,227	18,631	10,649	6,617	6,359	4,346	2,753	3,067	2,401	3,185	852	649	660	164	591
2003	42,900	93,427	66,876	52,935	74,220	38,573	26,300	25,280	13,306	7,576	4,697	4,508	3,079	1,950	2,173	1,700	2,255	603	460	467	535
2004	42,900	31,146	67,812	48,514	38,359	53,667	27,787	18,849	18,020	9,445	5,364	3,321	3,186	2,175	1,378	1,534	1,201	1,593	426	325	708

Table 6.6 Estimated age 2 recruitment of arrowtooth flounder (thousands of fish) from the 2003 and 2004 stock assessments.

Year class	2004 Assessment	2003 Assessment
1974	102,295	117,282
1975	160,019	161,375
1976	309,442	333,942
1977	169,478	167,671
1978	175,436	184,830
1979	221,575	233,491
1980	509,997	532,924
1981	192,115	203,417
1982	161,727	179,982
1983	452,273	481,304
1984	310,323	342,166
1985	284,846	309,771
1986	748,156	836,081
1987	397,530	414,325
1988	358,838	378,220
1989	227,905	260,010
1990	254,674	301,816
1991	264,061	258,483
1992	194,903	241,242
1993	222,931	146,262
1994	278,239	267,266
1995	377,119	313,174
1996	281,346	246,405
1997	297,358	252,439
1998	413,810	332,391
1999	213,890	196,497
2000	196,032	174,464

Table 6.7 Projections of arrowtooth flounder female spawning biomass (t), future catch (t) and full selection fishing mortality rates for seven future harvest scenarios.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2004	522,025	15,756	0.03
2005	504,553	107,718	0.26
2006	411,668	88,439	0.26
2007	334,733	72,425	0.26
2008	267,613	59,045	0.26
2009	220,721	45,355	0.24
2010	202,118	35,350	0.22
2011	201,159	32,492	0.22
2012	207,193	33,452	0.22
2013	214,932	35,935	0.23
2014	221,881	38,435	0.24
2015	227,180	40,418	0.24
2016	231,161	41,848	0.24
2017	234,008	42,811	0.25

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2004	522,025	15,756	0.03
2005	509,154	56,836	0.13
2006	458,839	51,923	0.13
2007	408,809	46,917	0.13
2008	356,570	41,824	0.13
2009	315,405	36,930	0.13
2010	294,057	32,755	0.13
2011	285,591	30,095	0.13
2012	284,547	29,158	0.13
2013	287,605	29,355	0.13
2014	292,609	30,044	0.13
2015	298,168	30,873	0.13
2016	303,880	31,681	0.13
2017	309,245	32,398	0.13

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2004	522,025	15,756	0.03
2005	513,140	8,444	0.02
2006	504,319	8,466	0.02
2007	488,089	8,353	0.02
2008	461,971	8,090	0.02
2009	439,588	7,719	0.02
2010	430,397	7,320	0.02
2011	428,739	7,031	0.02
2012	431,017	6,930	0.02
2013	435,858	6,978	0.02
2014	442,480	7,107	0.02
2015	450,133	7,271	0.02
2016	458,652	7,447	0.02
2017	467,430	7,621	0.02

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2004	522,025	0	0
2005	513,801	0	0
2006	512,312	0	0
2007	502,822	0	0
2008	482,651	0	0
2009	465,268	0	0
2010	460,055	0	0
2011	461,397	0	0
2012	465,885	0	0
2013	472,420	0	0
2014	480,474	0	0
2015	489,457	0	0
2016	499,302	0	0
2017	509,427	0	0

Table 6.7 (continued).

Scenario 6
Determination of whether arrowtooth flounder are currently overfished
B35=206,000

Year	Female spawning biomass	catch	F
2004	522,025	15,756	0.03
2005	502,165	132,180	0.33
2006	389,248	102,702	0.33
2007	302,420	80,042	0.33
2008	231,997	61,677	0.32
2009	186,899	39,846	0.26
2010	176,067	32,517	0.24
2011	180,130	31,520	0.25
2012	189,197	33,980	0.26
2013	198,329	37,589	0.27
2014	205,409	40,782	0.28
2015	210,043	42,996	0.29
2016	213,039	44,400	0.29
2017	214,875	45,205	0.29

Scenario 7
Determination of whether arrowtooth flounder are approaching an overfished condition
B35=206,000

Year	Female spawning biomass	catch	F
2004	522,025	15,756	0.03
2005	504,553	107,718	0.26
2006	411,668	88,439	0.26
2007	333,129	88,855	0.33
2008	252,545	68,496	0.33
2009	199,614	45,664	0.27
2010	182,639	35,234	0.25
2011	183,574	32,912	0.25
2012	190,903	34,683	0.26
2013	199,073	37,899	0.27
2014	205,663	40,881	0.28
2015	210,079	43,000	0.29
2016	212,998	44,372	0.29
2017	214,819	45,173	0.29

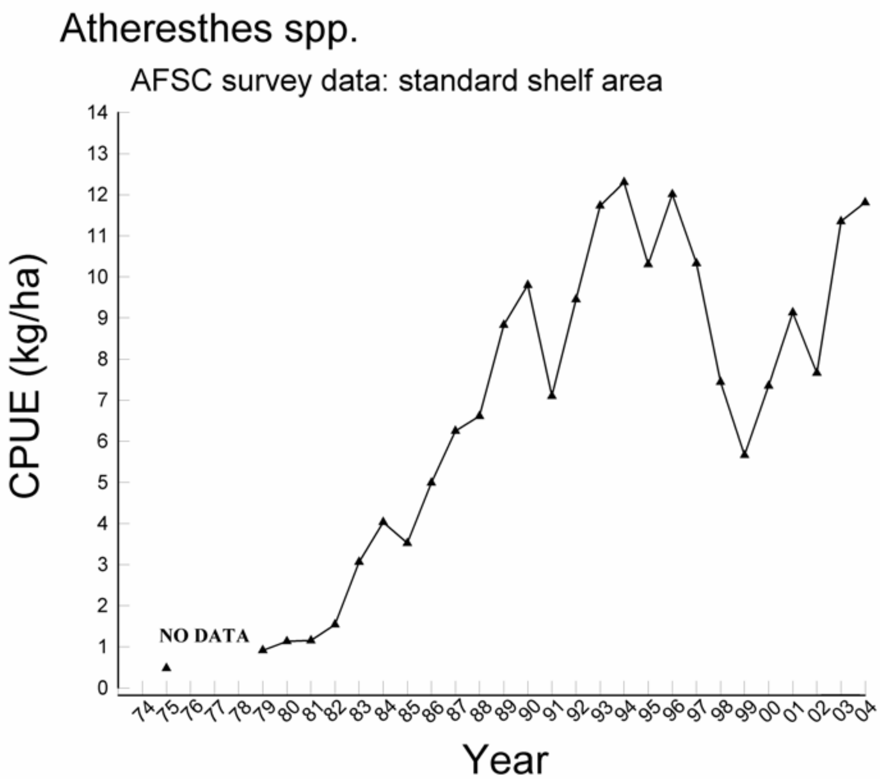


Figure 6.1--Catch per unit effort (CPUE) of Atheresthes spp. (arrowtooth flounder and Kamchatka flounder) on the eastern Bering Sea continental shelf as shown by Alaska Fisheries Science Center (AFSC) survey data.

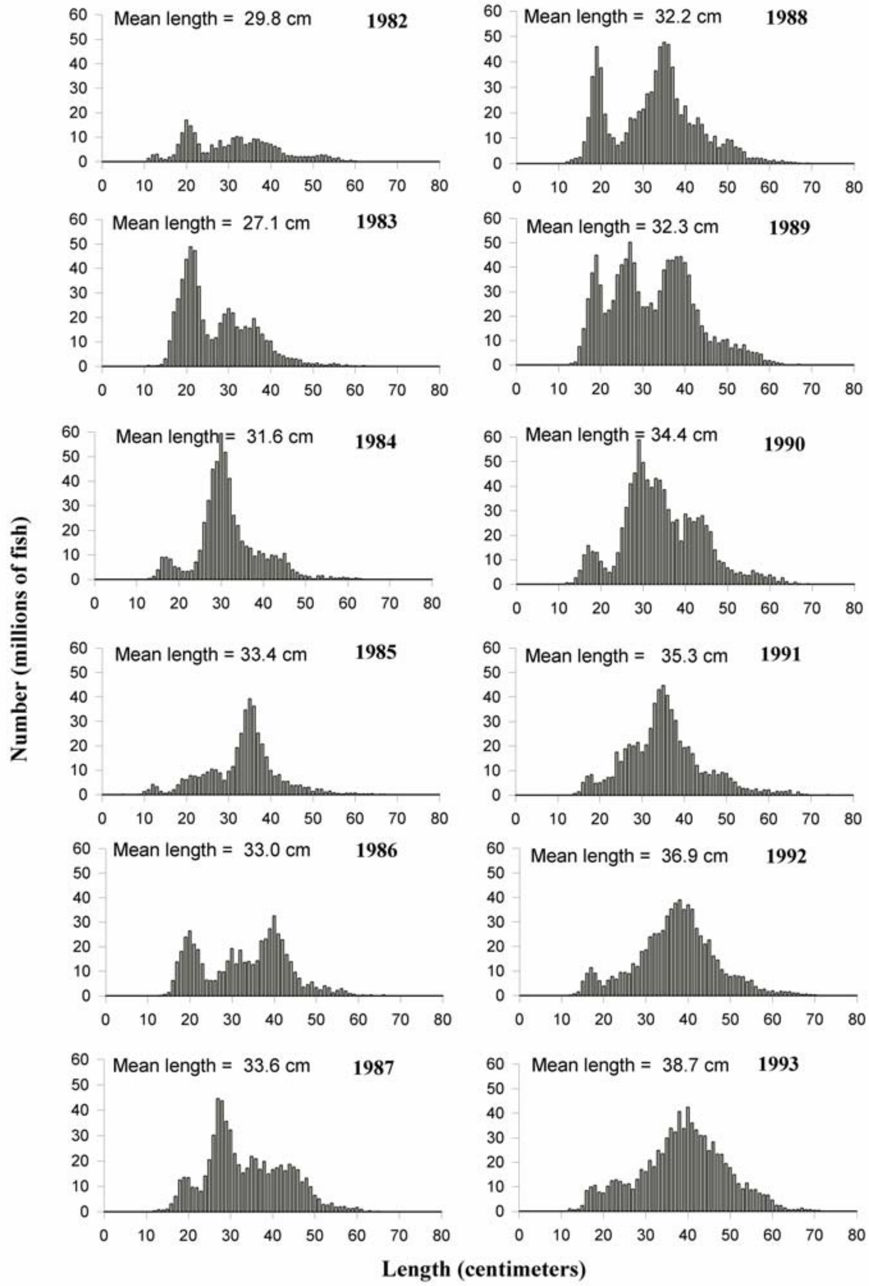


Figure 6.2-- Size composition (millions of fish) of arrowtooth flounder from the eastern Bering Sea bottom trawl surveys during 1982-2004.

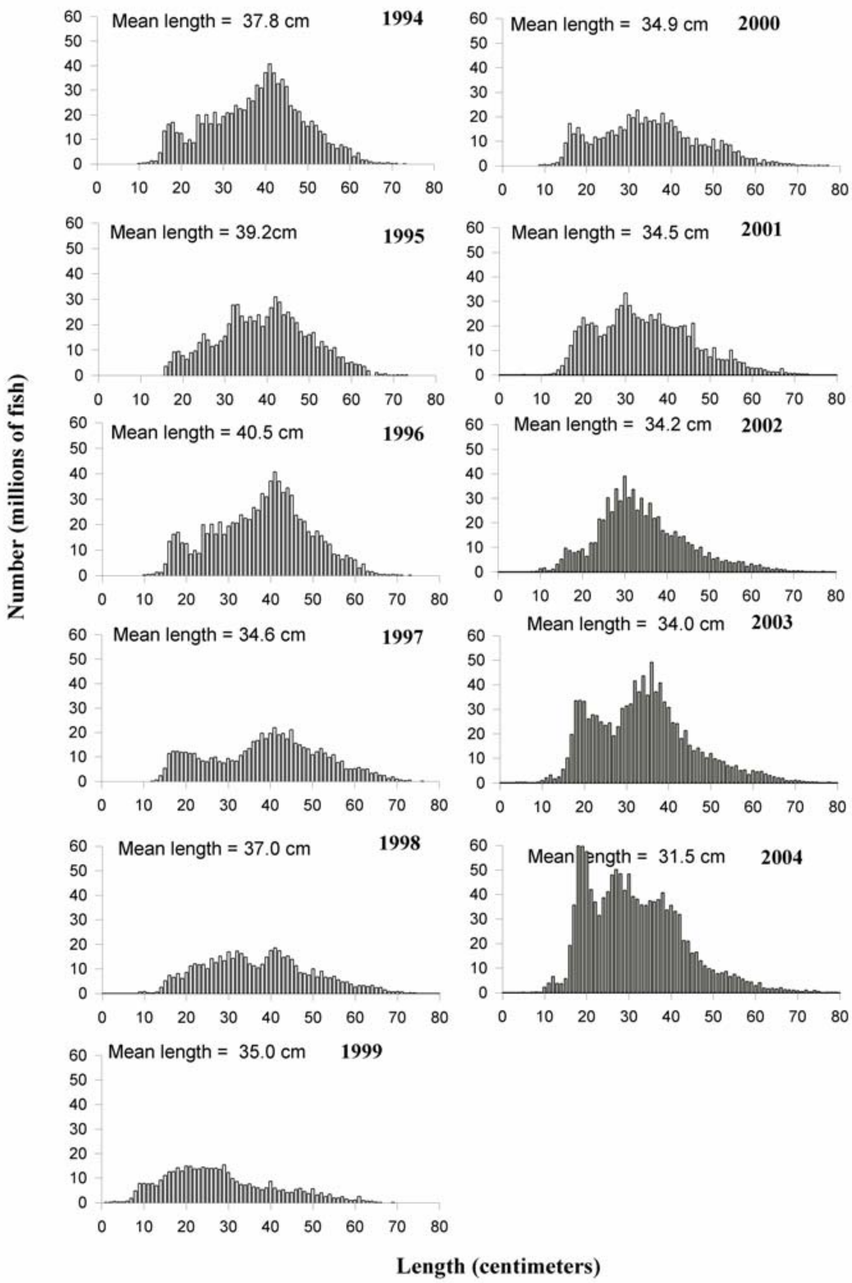


Figure 6.2-- Continued.

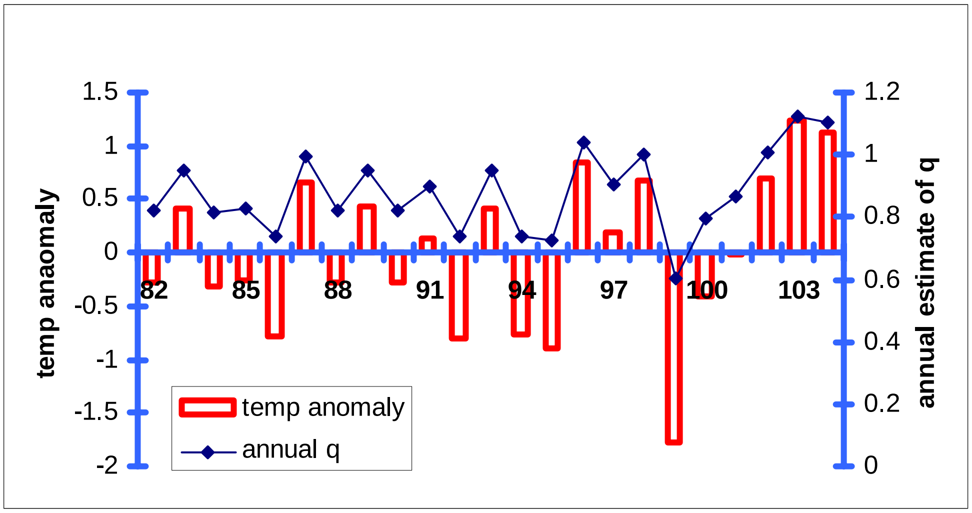


Figure 6.3--Shelf survey annual avg. bottom temperature anomalies (bars), model estimate of annual shelf survey q due to effect of water temperature (diamonds with lines), given the assumption that 87% of the biomass resides on the Bering Sea shelf.

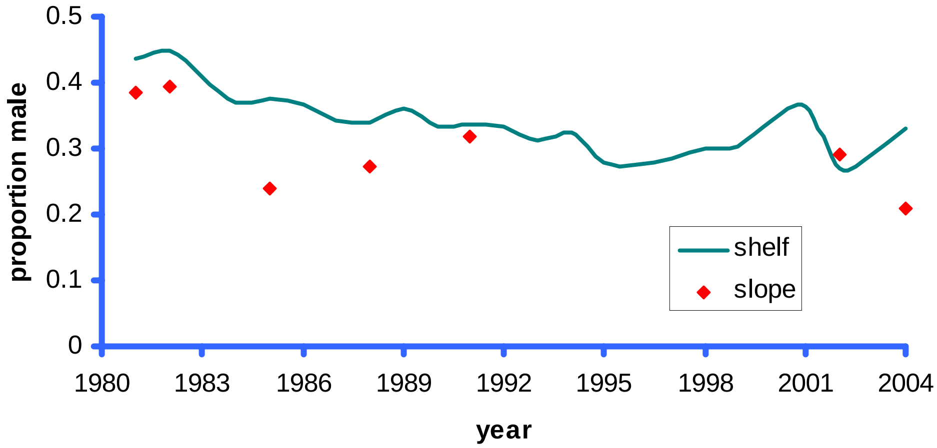


Figure 6.4--Proportion of the estimated male population from Bering Sea trawl surveys on the continental shelf and slope. Figure 6.5--Model fit in terms of total -log(likelihood) for a range of natural mortality values for males with females fixed at 0.2.

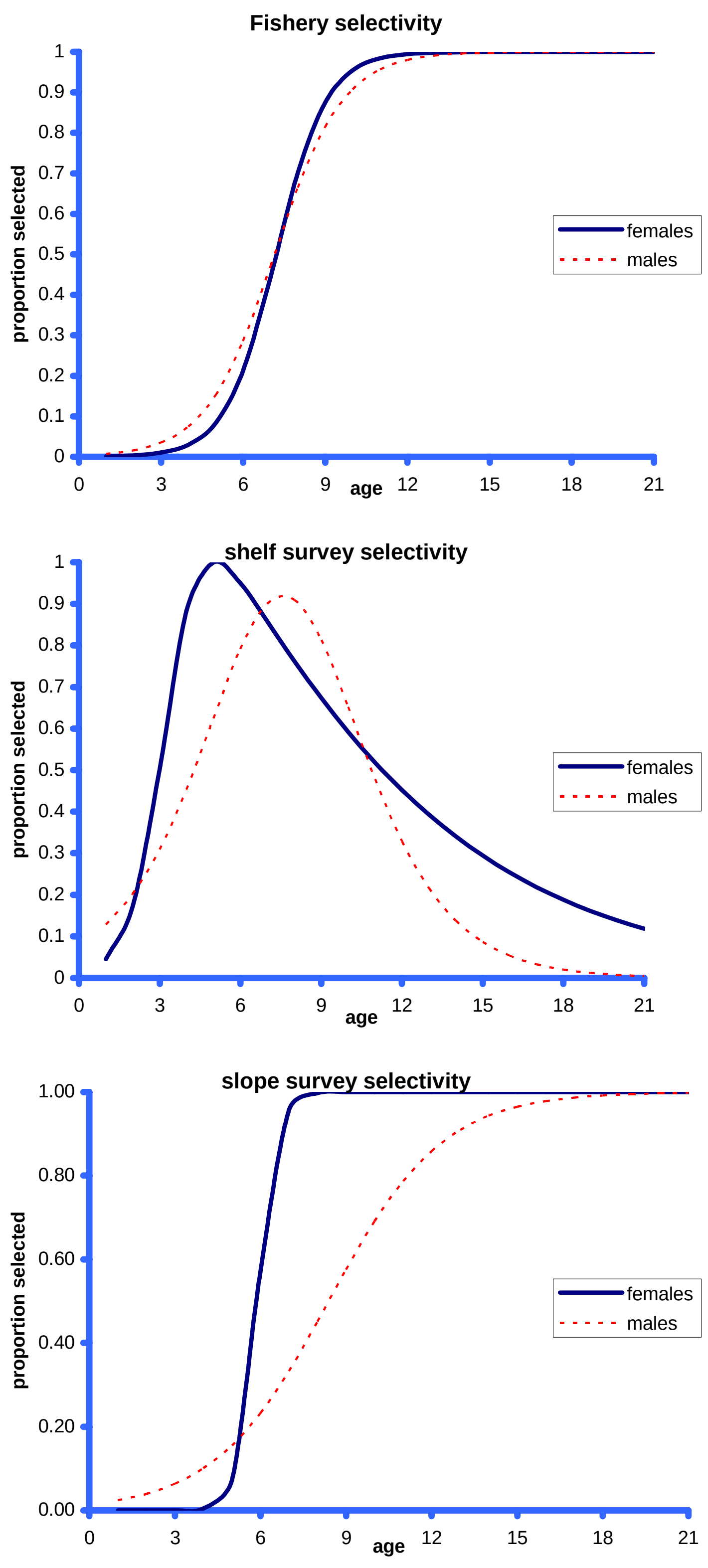


Figure 6.5--Age-specific fishery selectivity (top panel), shelf survey selectivity (middle panel) and slope survey selectivity (bottom panel), by sex, estimated from the stock assessment model.

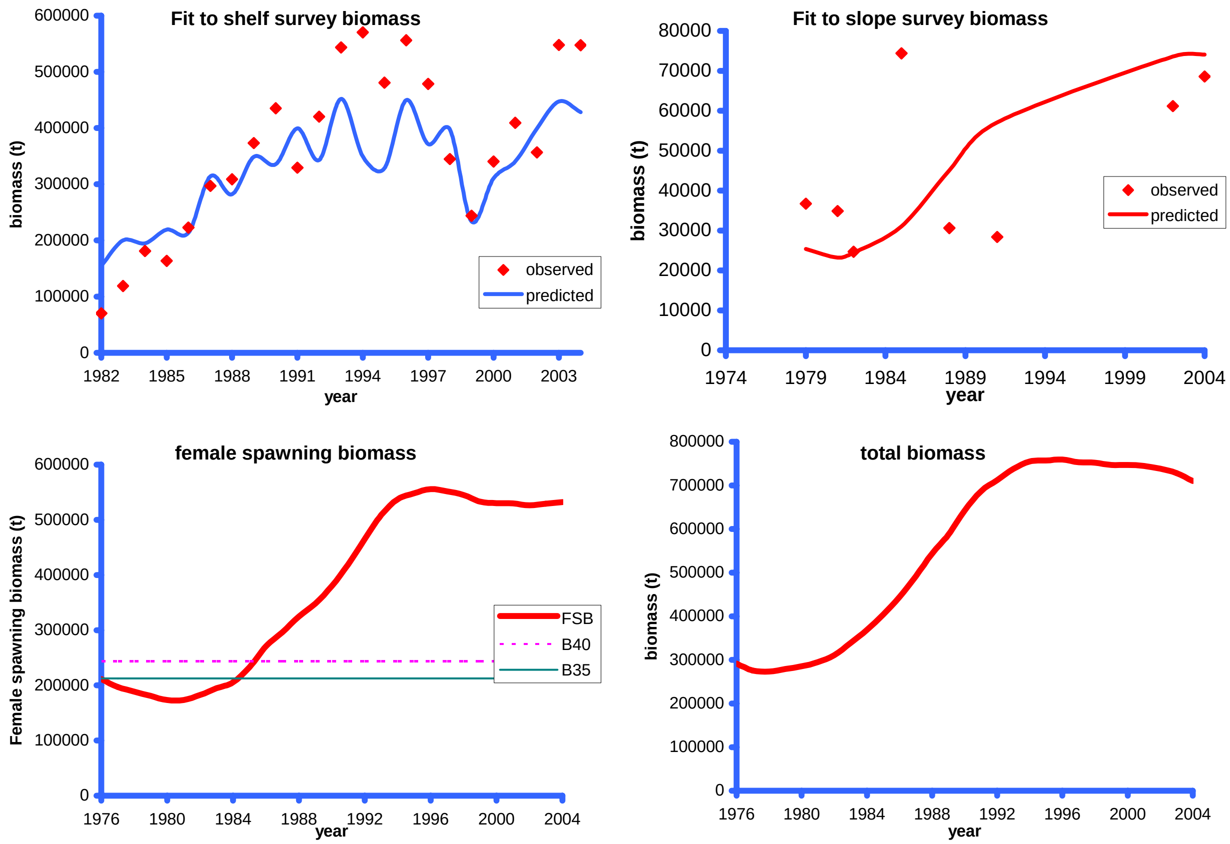


Figure 6.6--Stock assessment model results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), estimate of female spawning biomass with B35 and B40 indicated (bottom left panel) and the estimate of total biomass (bottom right panel).

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

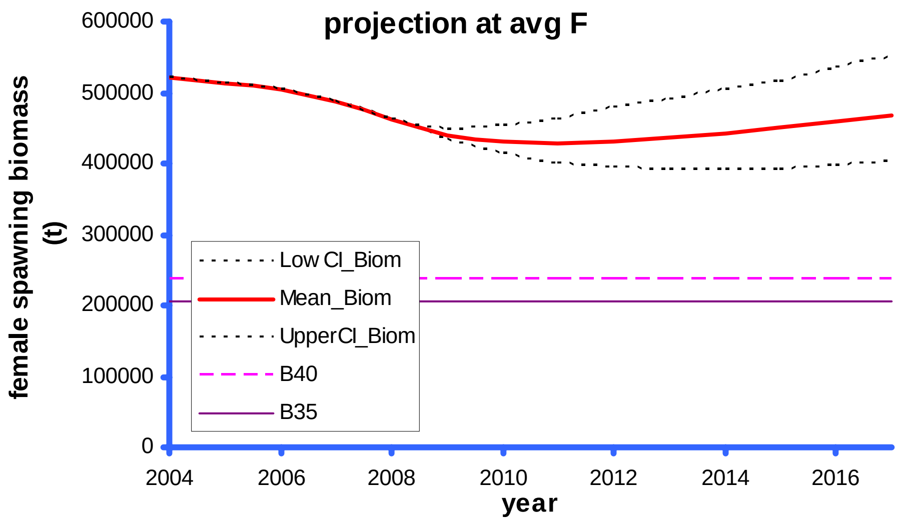
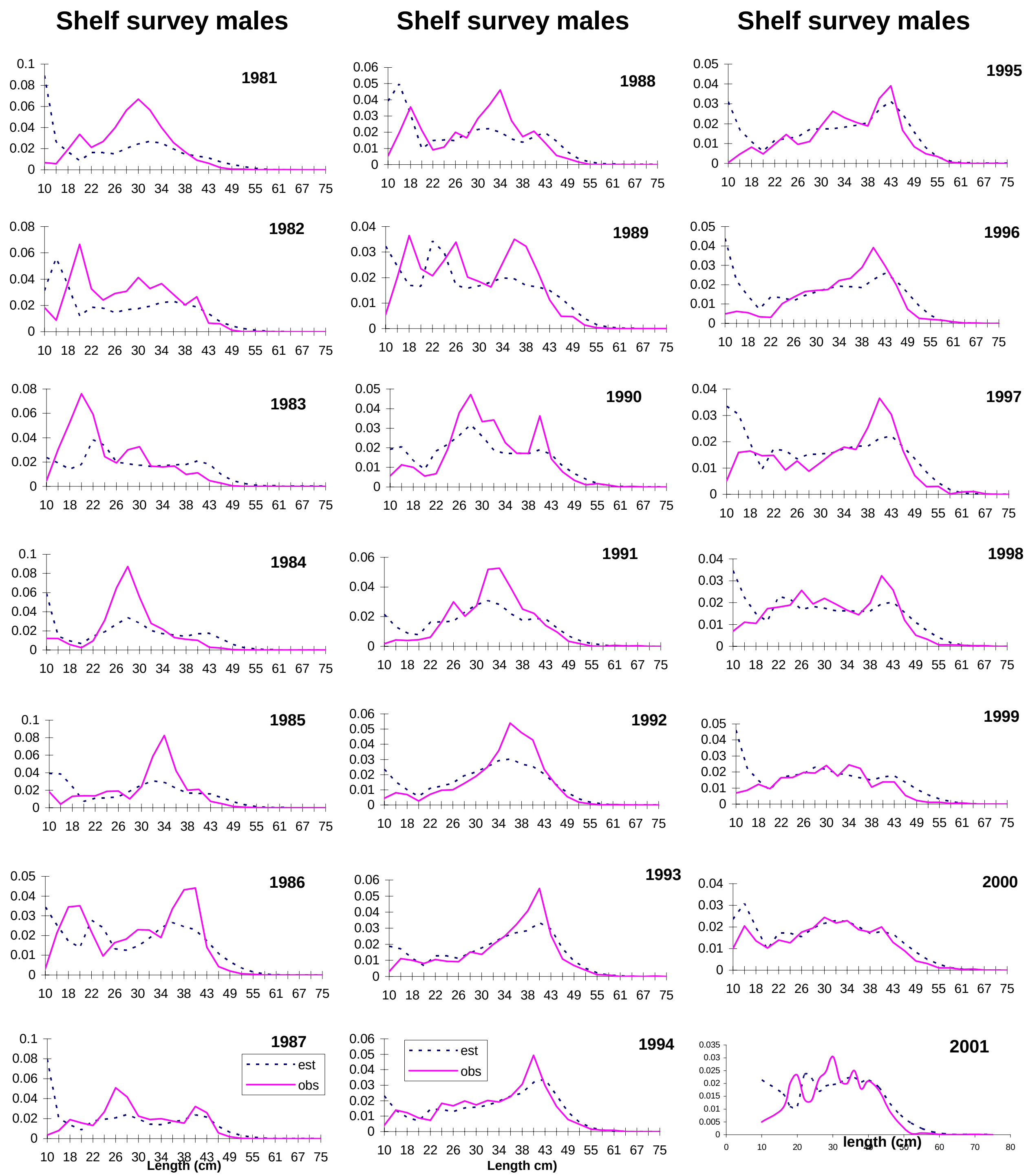


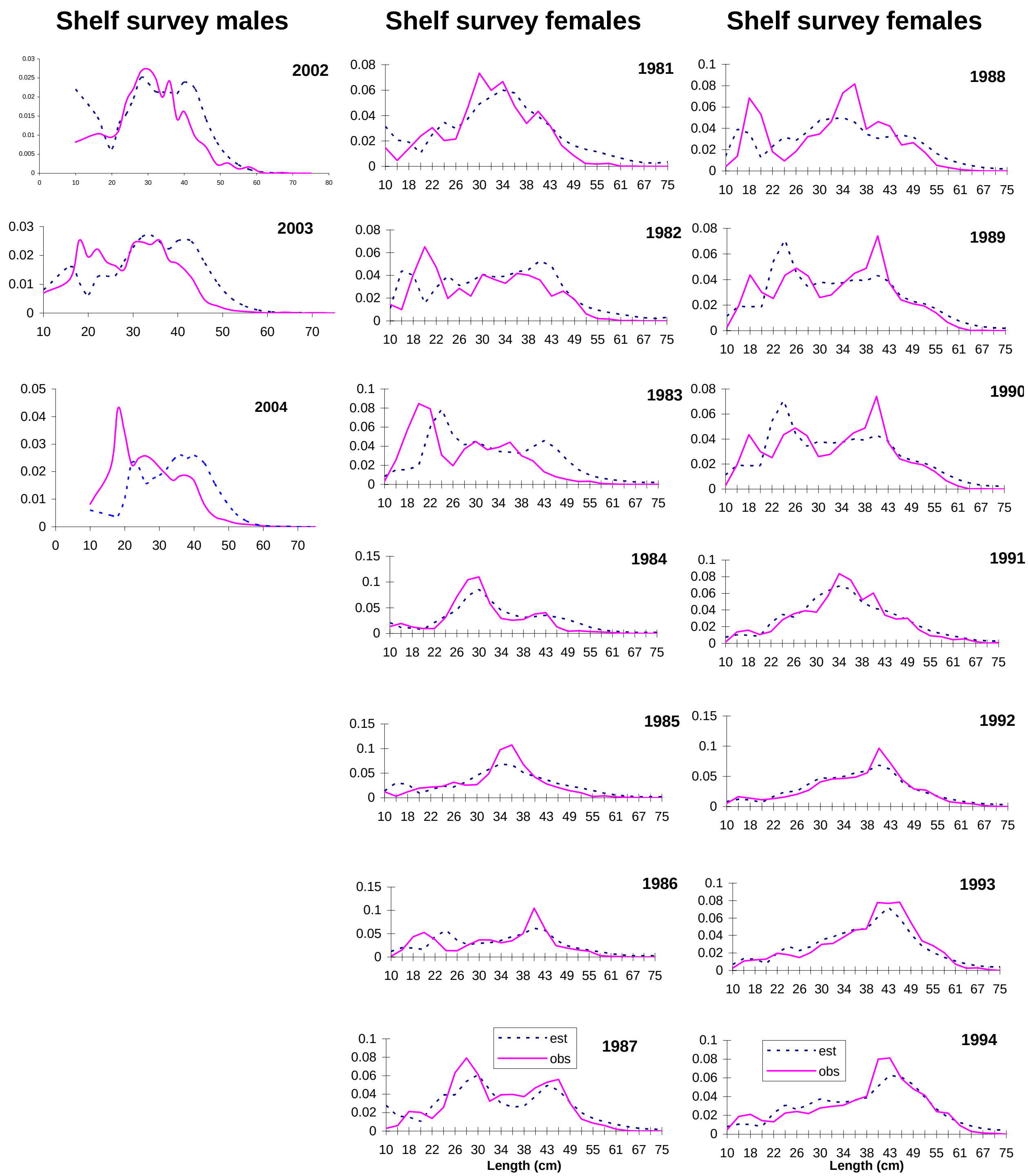
Figure 6.8--Projected female spawning biomass (t) of arrowtooth flounder if future harvest is at the same fishing mortality rate as the past five years.

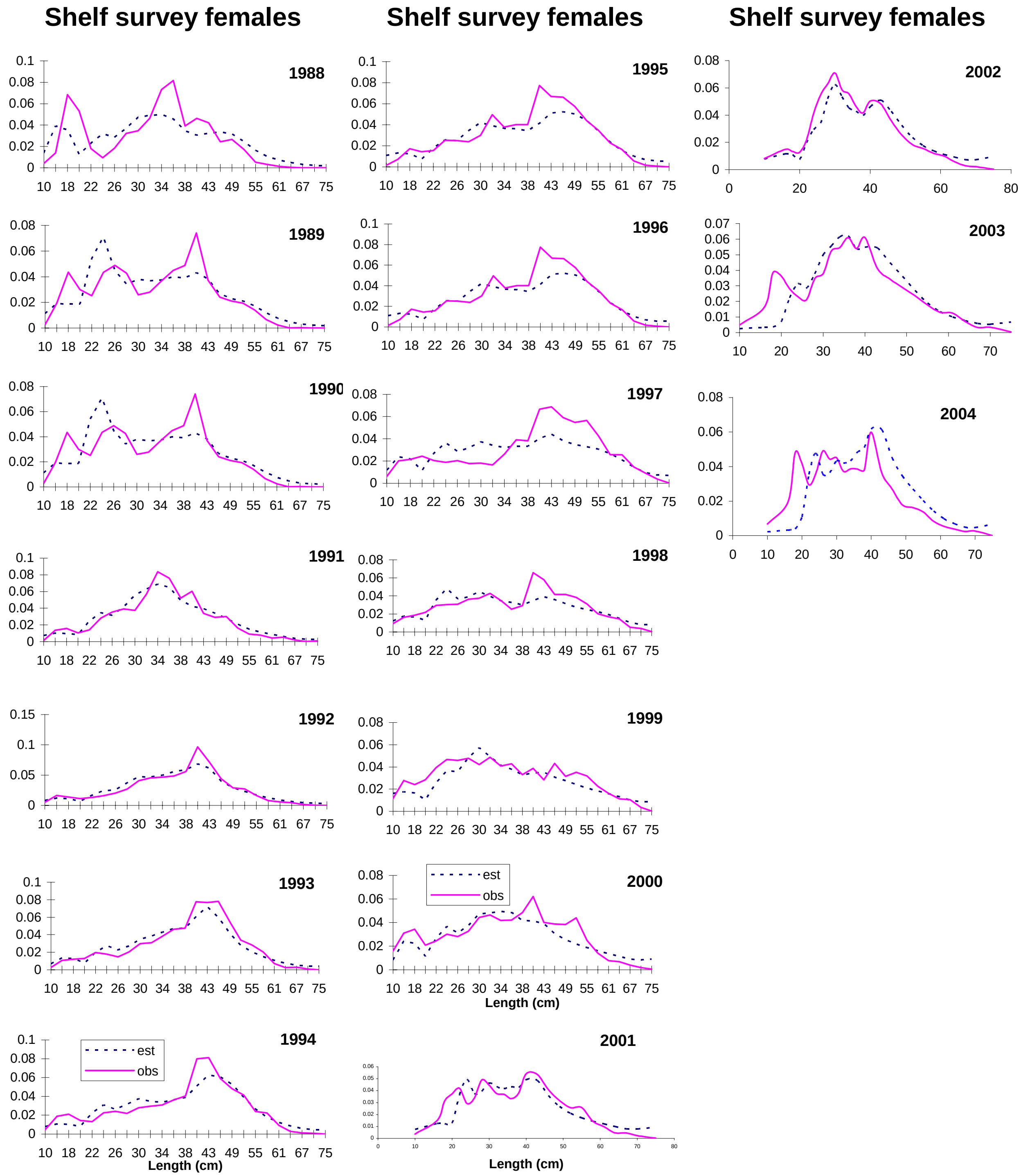
APPENDIX

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.


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
est
obs
Length (cm)
Length cm)
length (cm)


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


Shelf survey females
Shelf survey females
Shelf survey females
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
est
obs
Length (cm)

Slope survey females
age comp for shelf males
age comp for shelf females
1981
1982
1985
1988
1991
2002
2004
1996
199
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

year	arowtooth flounder 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