Section 5

ARROWTOOTH FLOUNDER

by
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EXECUTIVE SUMMARY

The following changes have been made to this assessment relative to the November 1998 SAFE.

Changes to the input data

1) 1999 survey size composition
2) 1999 survey biomass point-estimate and-standard error.
3) Estimate of catch and discards through 18, September 1999.
4) Estimate of retained and discarded portion of the 1998 catch.

Assessment results

1) The projected age 1+ total biomass for 2000 is 784,630 t.
2) The projected female spawning biomass for 2000 is 496,000 t.
3) The recommended 2000 ABC is 130,500 t based on an $F_{0.40}$ (0.22) harvest level.
4) The 2000 overfishing level is 160,200 t based on a $F_{0.35}$ (0.27) harvest level.

	1999 Assessment recommendation for 2000 harvest	1998 Assessment recommendation for 1999 harvest
Total biomass	784,630 t	819,250 t
ABC	130,500 t	140,000 t
Overfishing	160,200 t	219,100 t
F_{ABC}	$F_{0.40}$ = 0.22	$F_{0.40}$ = 0.23
$F_{overfishing}$	$F_{0.35}$ = 0.27	$F_{0.30}$ = 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 has been the target species of the fisheries whereas arrowtooth flounder are taken 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 199 1 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 arrow-tooth 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 arrow-tooth flounder reached peak levels ranging from 19,000 to 25,000 t (Table 5.1). Catches decreased after implementation of the MFCMA and the resource has remained lightly exploited with catches averaging 12,200 t from 1977-99. This decline resulted from catch restrictions placed on the fishery for Greenland turbot and phasing out of the foreign fishery in the U.S. EEZ. Total catch reported through 18 September, 1999 is 9,152 t (well below the ABC of 140,000 t). NMFS Regional Office reports indicate that bottom trawling accounted for 85% of the 1999 catch.

Although research is being conducted on their commercial utilization (Greene and Babbitt 1990, Wasson et al. 1992, Porter et al. 1993, Reppond et al. 1993, Cullenberg 1995), arrowtooth flounder currently 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 5.1 reports the annual total catch tonnage for the foreign, JV, and DAP fisheries. The proportion of retained and discarded arrow-tooth flounder in Bering Sea fisheries can be estimated from observer sampling applied to the 'blend' estimate of reported and observed retained catch 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

'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, rock sole, 'other flatfish' and Greenland turbot fisheries.

DATA

The data used in this assessment include estimates oftotal 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 observers.

Fishery Catch and Catch-at-Age

Fishery catch data are available from 1970 - September 18, 1999 and fishery length-frequency data from 1978-91.

Survey CPUE

The relative abundance of arrow-tooth 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. 5.1). The overall shelf catch rate decreased slightly to 7.1 kg/ha during 199 1 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 landbased fishery increased from 1.5 to 2 1 .O t/hr (Bakkala and Wilderbuer 1990). The CPUE declined in 1997 to 10.3 kg/ha and continued to decline over the next two years to 5.7 kg/ha in 1999.

Absolute Abundance from Trawl Surveys

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

Year	Eastern Bering Sea			Aleutian Islands
	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	43,500
1992	414,000	--	--	--
1993	543,600	--	--	--
1994	570,600	--	--	71,600
1995	480,800	--	--	--
1996	556,400	--	--	--
1997	478,600	--	--	94,118
1998	344,900	--	--	
1999	243,800			

*The 1988 and 199 1 slope estimates were from the depth ranges of 200-800 m while earlier slope estimates were from 200-1,000 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 of the 1998 and 1999 bottom trawl surveys indicate the Bering Sea shelf population biomass has since declined to 243,800 t, half of the 1997 biomass point estimate.

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 1999 point estimate are 112,200 - 375,400 t.

Trawl surveys on the continental slope estimate that arrow-tooth flounder biomass increased significantly from 1982 to 1985. The biomass estimate in 1988 and 1991 were lower. However, sampling in 1988 and 199 1 (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 199 1, a period of high arrowtooth flounder abundance. Surveys conducted during periods of low and increasing arrow-tooth abundance (1979-85) indicate that 27% to 5 1% of the population weight occupied slope waters.

The combined arrowtooth/Kamchatka flounder abundance estimated from the 1997 Aleutian Islands trawl survey is 94,100 t, which is a continuation of the increasing trend observed in the Aleutian Islands since 199 1.

Weight-at-age. Length-at-age and Maturitv-at-age

Parameters of the von Bertalanffy growth curve for arrow-tooth 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 arrow-tooth 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

The abundance, mortality, recruitment and selectivity of arrowtooth flounder were assessed with a split-sex, length-based version of the stock synthesis assessment model (Methot 1990). The model is a separable catch-age analysis that uses survey estimates of biomass and size composition estimates as auxiliary information. 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 model are classified by three likelihood components:

Data Component	Distribution assumption
Trawl fishery size composition	Multinomial
Trawl survey population size composition	Muitinomial
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 parameters estimated by the model are presented below:

Fishing mortality	Selectivity		Year class strength	Total
30	12	=	52	94

Natural mortality and survey catchability were estimated independently of the model. The increase in the number of parameters estimated in this assessment compared to last year can be accounted for by the input of another year of fishery catch data and the entry of another year class into the observed population.

We assume that the shelf and slope surveys measure non-overlapping segments of the arrowtooth flounder stock. The model was configured with the Bering Sea shelf comprising 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. For Bering Sea shelf flatfish, the accepted belief is that the trawl survey is a good indicator of the flatfish abundance level. Thus, it is desirable to obtain a reasonable fit to this data component and the model was configured with an emphasis of 5.0 was placed on fitting the shelf survey biomass trend. This resulted in a better fit to the abundance trend without degrading the fit to the other primary data components.

The most reliable and consistent data for modeling the arrowtooth flounder population are the shelf survey biomass and size composition time-series. Consequently, results are most closely linked to fitting the general trend of increasing shelf survey biomass estimates during the 1980s to its peak level in the mid- 1990s, and to fitting the male and female size compositions from the shelf survey (Fig. 5.2).

Parameters Estimated Independently

Natural mortality

The natural mortality of arrowtooth flounder is 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 arrow-tooth flounder and is the same estimate used by Okada et al. (1980).

Aging by both U.S. and Japanese scientists from samples collected in the EBS during U.S.-Japanese cooperative surveys has shown age 15 to be the maximum age of arrow-tooth flounder.

Catchability

A past assessment (Wilderbuer and Sample 1995) also 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 that 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 may occur or the "effective" fishing width of the trawl may be the distance between the doors instead of between the wingtips of the survey trawl).

In the case of the fit to the slope survey abundance estimates, Q is less than 1.0 as the fit to this likelihood component degrades with increasing Q. This is consistent with the Q profiling presented in the Greenland turbot assessment (Ianelli et al., section 4) and our belief that the Noreastem trawl is a poor sampling tool on the Bering Sea slope (Bakkala and Wilderbuer 1990).

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 year, and the survival rate for each cohort as it moves through the population calculated from the population dynamics equations (see Table 6-6).

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 the shelf survey; for the slope survey we assumed an asymptotic selectivity pattern.

At the present time there is no arrowtooth flounder directed fishery. 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.

Examination of the shelf and slope survey population estimates indicate that females are consistently estimated to be in higher abundance than males (Fig. 5.3). This difference was also evident in the Gulf of Alaska from triennial surveys conducted from 1984-96 (Tumock et al. 1998). This information was incorporated into last years' assessment by adjusting the size composition data input into the model by the sex ratio proportion observed in shelf and slope trawl surveys and fishery data. This resulted in unsatisfactory results as the mode1 gave low estimates of male selectivity which has the undesirable result ofartificially increasing population estimates. This assessment assumes an equal population sex composition.

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.

Growth

The length-based synthesis model allows flexibility on the relationship between length and age. The model was configured to estimate the L_{inf} and K parameters by sex as was described in a past asssessment (Wilderbuer and Sample 1995). These estimates of the growth parameters provided the best fit to the slope and shelf size compositions.

Fishing mortality

The fishing mortality rates (Fj for each age and year are calculated to exactly match the catch weight by solving for F as follows:

$$\sum_a [N_{ay}\hat{W}_a (\frac{f_y S_a}{f_y S_a + M}) 1 - \exp^{(-f_y S_a + M)}] - \sum_a C_{ay}\hat{W}_a = 0$$

where $F_{ay} = f_y S_a$, N_{ay} = numbers of fish age a in year y, $\hat{W}_a$ = average weight-at-age, M is the natural mortality rate, C_{ay} = catch weight of age a fish in year y, S, is the fishery selectivity at age and f_y is the fishing effort in year y.

MODEL RESULTS

Fishing mortality and selectivity

The stock synthesis model estimates of the annual fishing mortality on fully selected ages and the estimated annual exploitation rates (catch/total biomass) are given in Table 5.2. The exploitation rate has been at a low level, 4%, from 1977- 1999 due to the undesirability of arrowtooth flounder as a commercial product. Age-specific selectivity estimated by the model (Table 5.3, Fig. 5.4) indicate that arrow-tooth flounder are 50% selected by the fishery at about 8 and 7 years of age and are fully selected by ages 17 and 11, for males and females, respectively.

Abundance Trend

Model estimates indicate that arrow-tooth flounder total biomass increased more than 5 fold from 1980 to its' most abundant level in 1995 at 915,230 t (Fig. 5.5, Table 5.4). The biomass has declined 10% since then to the 1999 estimate of 823,435 t. Female spawning biomass is also estimated at a high level, projected at nearly 48 1,000 t in 2000 (Table 5.4). Model estimates of population numbers by age, year and sex and total biomass are given in Table 5.5.

The model fit to the shelf survey (emphasis 5.0) tracks the abundance trend well through 1990. The model estimate of survey biomass is less than the observed values from 1993-97 and does not provide a godd fit to the declining estimates from the 1998 and 1999 shelf surveys. The model indicates an increasing biomass trend on the slope which fits the slope survey estimates poorly (Fig. 5.5). The slope biomass represents a smaller fraction of the total stock and is not well estimated by the survey, particularly the 199 1 point estimate which is considered to be an underestimate of the slope survey biomass due to the reduction in sampling depth relative to earlier surveys.

The model provided a good fit to the survey shelf size compositions for the past 10 years for males and females (1989-99) and are shown in the Appendix. Reasonable fits also resulted for slope survey size composition observations.

Recruitment Trends

Increases in abundance from 1983-95 were the result of 5 strong year-classes spawned in 1981, 1984, 1986, 1987 and 1988 (Fig. 5.6, Table 5.6). Recruitment since 1990 is estimated to be near average in 1990-92, weak in 1993 and 1994, but stronger than average in 1995.

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
Population estimates	86.1	290.2	57.9	62.4	150.3	94.3	200.6	273.8	105.2
Year	1991	1992	1993	1994	1995	1996	1997	1998	1999
Population estimates	71.7	79.4	96.8	126.6	75.1	55.6	108.8	93.6	92.1

Over this period, population estimates for this size group have averaged 120 million. Above average recruitment has occurred in 1983, 1986, 1988, 1989 and 1994. Since the estimates primarily represent age 2 fish, the year-classes producing the strong recruitment are 198 1, 1984, 1986, 1987 and 1992 (Fig. 5.6). Estimates of age 2 recruitment from the synthesis model agree well with the trawl survey population estimates and also indicate average to above average recruitment for the four years following the large '1986 and 1987 year-classes. The past five surveys indicate recruitment below the 1982-99 average.

ACCEPTABLE BIOLOGICAL CATCH

Arrow-tooth 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 estimated to have declined 10% since a peak population biomass in 1995. **The estimate of 2000 total biomass from stock synthesis is 784,600 t and the female spawning biomass is estimated at 496,000 t.**

The reference fishing mortality rate for arrowtooth flounder is determined by the amount of reliable population information available (Amendment 44 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. For the 1999 assessment, the Alaska Fisheries Science Center policy is to use only year classes spawned in 1977 or later to calculate the average equilibrium recruitment. Using the time-series of recruitment from 1978-98 from the stock assessment model results in an estimate of $B_{0.40}$ = 194,600 t. The stock synthesis model estimates the 2000 level of female spawning biomass at 496,000 t (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and $B>B_{0.40}$ (496,000 > 194,600), arrowtooth flounder reference fishing mortality is defined in tier 3a. For the 2000 harvest: $F_{ABC} \le F_{0.40} = 0.22$ and $F_{overfishing} = F_{0.35} = 0.27$ (full selection F values).

Acceptable biological catch is estimated for 2000 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2000 estimate of age-specific total biomass as follows:

$$ABC = \sum_{a=a_r}^{a_{max}} \bar{w}_a n_a \left(\frac{Fs_a}{M + Fs_a} \right) \left(1 - e^{-M - Fs_a} \right)$$

where S, is the selectivity at age, M is natural mortality, W_a is the mean weight at age, and n, is the beginning of the year numbers at age. This results in a 2000 ABC of **130,500** t.

The potential yield of arrowtooth flounder for 2000 at various levels of fishing mortality (full selection) are as follows:

Fevel	Exploitation rate	Potential vield
$F_{overfishing}$	0.27	160,200 t
$F_{0.40}$	0.22	**130,500** t

Please note that these values are estimated assuming that the "area-swept" survey estimates of biomass are unbiased (ie. "Q" = 1 .O). Preliminary results suggest that "Q" > 1 .O which would result in lower biomass and ABC estimates (for the Bering Sea shelf and slope).

PROJECTED BIOMASS

This year, 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 1999 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2000 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 1999. 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 2000, 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 2000 recommended in the assessment to the max F_{ABC} for 2000. (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 1994-1998 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 2000 and above its MSY level in 20 10 under this scenario, then the stock is not overfished.)

Scenario 7: In 2000 and 200 1, *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 20 12 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results (Table 5.7) indicate that arrowtooth flounder are not currently overfished and the stock is not considered to be approaching an overfished condition.

OTHER CONSIDERATIONS

Arrow-tooth flounder are currently of limited economic importance as a fisheries product, however, trophic studies (Lang et al. 1991, Livingston et al. 1993) indicate they are an important predator and may be an important component in understanding the dynamics of the Bering Sea benthic ecosystem. This is particularly relevant as the Council begins to consider shifting emphasis from single species to multi-species fisheries management of the Bering Sea and Aleutian Islands (Ecosystem Considerations, 1994 SAFE). Trophic studies indicate that the main food item in the diet of arrowtooth flounder is fish, particularly for arrow-tooth larger than 30 cm. Pollock are a major component of the diet as well as other fish such as zoarcids. Invertebrates are also important and include cephalopods, euphausiids and pandalid and crangonid shrimp. Preadators of arrowtooth flounder include Pacific cod and large pollock, mostly on juvenile fish.

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Table 5.1.--All nation total catch (t) of arrowtooth flounder in the eastern Bering Sea and Aleutian Islands region[a], 1970-99. 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		13,361	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*									9,152

[a]Catches from data on file Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115.
[b]Japan, U.S.S.R., Republic of Korea, Taiwan, Poland, and Federal Republic of Germany.
[c]Joint ventures between U.S. fishing vessels and foreign processing vessels.
*Catch information through 18 September, 1999 (NMFS regional office).

Table 5.2 -Model estimates of arrowtooth flounder fishing mortality and exploitation rate (catch/summary biomass).

year	Full selection F	Exploitation rate
1970	0.0931	0.067
1971	0.1506	0.107
1972	0.1265	0.087
1973	0.123	0.083
1974	0.2521	0.165
1975	0.2649	0.160
1976	0.2769	0.153
1977	0.1873	0.095
1978	0.1626	0.080
1979	0.217	0.105
1980	0.2749	0.123
1981	0.2625	0.105
1982	0.1696	0.062
1983	0.1748	0.064
1984	0.0986	0.037
1985	0.0625	0.024
1986	0.0482	0.020
1987	0.026	0.011
1988	0.0854	0.039
1989	0.0268	0.012
1990	0.0404	0.019
1991	0.0583	0.029
1992	0.0239	0.013
1993	0.0184	0.011
1994	0.0247	0.016
1995	0.0145	0.010
1996	0.0214	0.016
1997	0.0143	0.011
1998	0.0215	0.017
1999	0.0131	0.010

Table 5.3--Model estimates of arrowtooth flounder age-specific fishery and survey selectivities, by sex.

Age	Fishery females	Fishery males	Survey females	Survey males
1	0.000	0.000	0.047	0.046
2	0.006	0.005	0.393	0.368
3	0.021	0.017	0.650	0.602
4	0.065	0.044	0.838	0.777
5	0.163	0.099	0.945	0.889
6	0.338	0.187	0.922	0.897
7	0.575	0.309	0.779	0.804
8	0.784	0.455	0.634	0.677
9	0.907	0.597	0.550	0.562
10	0.962	0.715	0.511	0.474
11	0.985	0.801	0.495	0.413
12	0.994	0.861	0.489	0.370
13	0.997	0.901	0.486	0.341
14	0.999	0.928	0.485	0.321
15	0.999	= 0.946	0.464	0.307
16	1.000	0.958	0.464	0.296
17	1.000	0.967	0.464	0.289
18	1.000	0.973	0.464	0.283
19	1.000	0.977	0.464	0.278
20	1.000	0.981	0.464	0.274
21	1.000	0.981	0.484	0.270

Table 5.4-Model estimates of arrowtooth flounder 2+ total biomass and female spawning biomass from the 1998 and 1999 assessments.

	1999 Assessment		1998 Assessment	
	age 2+ Total biomass	Female Spawning biomass	age 2+ Total biomass	Female Spawning biomass
1970	186,006	103,542	188,758	105,215
1971	174,677	96,547	177,317	98,089
1972	159,476	86,171	161,999	87,523
1973	152,082	79,725	154,498	80,968
1974	147,825	74,081	150,150	75,286
1975	134,478	61,153	136,616	62,232
1976	125,965	54,127	128,010	55,005
1977	122,167	52,505	124,374	53,189
1978	131,001	53,718	133,525	54,391
1979	145,605	54,614	148,467	55,349
1980	159,399	54,622	162,533	55,428
1981	175,678	55,190	179,219	56,137
1982	204,246	64,297	208,142	65,287
1983	244,820	78,938	248,905	80,044
1984	285,738	88,926	289,966	90,116
1985	340,004	109,249	344,409	110,648
1986	402,308	145,379	406,875	146,727
1987	474,461	179,579	479,429	180,879
1988	561,402	206,601	566,713	208,048
1989	639,767	238,940	644,791	240,061
1990	729,045	285,960	733,461	287,354
1991	801,388	332,417	804,664	333,872
1992	849,325	387,937	850,948	389,255
1993	891,353	444,838	891,398	445,733
1994	915,230	483,870	913,850	484,203
1995	915,230	504,089	912,723	503,861
1996	907,483	518,070	904,590	517,286
1997	885,180	520,490	882,194	519,285
1998	860,433	515,001	855,373	513,859
1999	823,435	496,004	819,244	498,729
2000	784,630	480,966		

Table 5.5-Model estimates of arrowtooth flounder population number-at-age, by sex, 1970-2000.

Cmalaa	numbers at age (1,000s)																				
	1	2	5	4	6	6	7	6	9	10	11	12	13	14	16	16	17	16	19	20	21
70	21922	27603	22762	18631	15243	12450	10159	6263	6705	5433	4400	3562	2663	2334	1889	1529	1238	1002	611	656	2760
71	24848	17948	22751	18597	15156	12282	9867	7662	6265	5023	4048	3270	2645	2141	1733	1402	1135	919	744	602	2557
72	70556	20190	14661	18583	15087	12085	9519	7356	5667	4427	3517	2624	2279	1842	1490	1208	976	790	639	516	2198
73	50015	57766	16510	11966	15067	12069	9456	7214	6422	4106	3165	2523	2024	1632	1319	1067	663	699	586	458	1044
74	15780	40948	47261	13460	9732	12077	9457	7165	5335	3946	2969	2295	1616	1456	1174	949	787	621	502	407	1727
75	47229	12919	33473	36485	10636	7610	6993	6567	4719	3385	2465	1643	1421	1123	900	728	586	474	384	311	1319
76	43953	38668	10560	27236	30901	6469	5642	6218	4283	2960	2089	1511	1127	866	666	549	443	356	289	234	995
77	71488	35986	31805	8581	21886	24070	6252	3881	4015	2665	1811	1269	916	662	525	415	332	266	216	175	743
76	142142	56529	29431	25772	6947	17352	18478	4584	2734	2763	1614	1226	859	619	481	355	280	225	181	146	821
79	51146	116376	47876	24014	20880	5539	13446	13776	3304	1932	1934	1266	655	596	431	321	247	195	156	126	534
60	76603	41676	95163	39015	19381	18468	4207	9690	8476	2212	1277	1273	631	561	392	263	210	162	126	103	433
61	185095	62661	34231	77442	31355	15140	12250	2920	6333	5060	1373	786	783	511	345	241	174	129	100	79	329
82	245575	151542	51406	27666	62316	24574	11325	8596	1938	4068	3764	864	494	491	320	216	151	109	61	62	255
63	54969	201058	123960	41943	22577	49682	18042	6442	6195	1369	2647	2639	602	344	342	223	150	105	76	56	221
64	139665	45004	164461	101135	33874	17990	36456	14170	6068	4363	955	1979	1632	417	239	237	154	104	73	52	192
65	354364	114348	36828	134390	62313	27402	14260	29870	10797	4572	3271	714	1479	1369	312	176	177	115	76	54	163
86	125891	290129	93590	30115	109616	66756	22001	11309	23369	6367	3540	2528	552	1143	1056	241	138	137	89	60	163
67	376676	103070	237479	76553	24565	89097	53640	17556	8941	18375	6576	2774	1981	432	895	828	189	108	107	70	191
88	345300	308561	84378	184333	62579	26050	72358	43477	14106	7163	14701	6280	2218	1684	346	718	662	151	86	86	209
69	206037	262707	252514	66962	156272	50558	15971	58532	33395	10728	5422	11109	3972	1674	1195	261	540	500	114	65	222
90	155663	168689	231429	208631	56369	129047	41042	12887	45374	26721	8571	4330	8869	3171	1336	954	206	431	399	Ql	229
91	137416	127626	136061	169324	188755	45862	104290	32866	10237	35674	21081	6757	3412	6988	2498	1053	752	164	340	314	252
92	156926	112506	104458	112918	154446	136907	38646	82679	25752	7986	27631	16334	5232	2642	5410	1934	815	582	127	263	436
93	118188	128482	92101	86483	92314	125982	111234	29775	68497	20866	6361	22262	13075	4188	2114	4330	1540	652	466	102	581
94	84781	96764	105162	75376	69908	75363	102534	90153	24044	53561	16626	5135	17926	10516	3369	1701	3483	1245	525	375	533
95	64042	69413	79213	66072	61819	57012	61204	82797	72436	19262	42868	13295	4105	14330	8406	2693	1360	2764	995	419	728
96	174098	52433	56926	64635	70405	50332	48453	49701	67036	58645	15556	34608	10732	3313	11567	6786	2174	1097	2247	803	924
97	79638	142538	42923	46504	53009	57442	40911	37567	40014	53829	46955	12470	27736	6601	2655	9270	5439	1742	879	1601	1365
96	66902	65202	118891	35132	36039	43296	46801	33219	30411	32335	43464	37901	10064	22366	6941	2143	7481	4389	1408	710	2571
99	27012	71149	53376	95494	26723	31032	35166	37636	28733	24408	25921	34824	30381	8062	17831	5560	1716	5992	3515	1128	2828
2000	26985	22115	56248	43666	76116	23465	25282	28567	30852	21622	19726	20842	26133	24526	6512	14464	4491	1366	4840	2840	3032

Table 5.5--Continued.

males	numbers al age (1,000s)																				
	1	2	3	4	5	6	7	0	9	10	11	12	13	14	15	16	17	18	19	20	21
70	21922	27003	22762	10631	15243	12450	10159	0263	6705	5433	4400	3562	2003	2334	1889	152B	1230	1002	011	656	2700
11	24646	17948	22761	10597	16150	12202	9007	7002	8265	5023	4040	3270	2045	2141	1733	1402	1135	919	744	602	2557
72	70556	20100	14001	10503	15067	12065	9519	7350	5661	4427	3517	2024	2279	1642	1490	1206	976	790	639	516	2198
73	60015	57766	16510	11966	15067	12089	9456	7214	5422	4100	3105	2523	2024	1632	1319	1067	663	699	566	450	1944
74	15760	40946	47201	13400	9732	12077	9457	7105	5335	3946	2969	2295	1616	1450	1174	949	767	621	502	407	1727
75	47229	12919	33473	36465	10630	7610	8993	6507	4719	3305	2465	1043	1421	1123	Boo	726	506	474	304	311	1319
76	43953	30660	10560	27230	30901	6450	5042	6216	4203	2960	2089	1511	1127	868	686	549	443	358	269	234	995
77	71466	35906	31605	8591	21060	24079	6252	3001	4015	2665	1611	1269	916	062	525	415	332	260	216	175	743
76	142142	50529	29431	25772	6947	17352	10470	4504	2734	2763	1014	1220	059	619	461	355	280	225	101	146	621
19	51148	116376	47016	24014	20000	5539	13440	13770	3304	1932	1934	1260	055	590	431	321	247	195	156	126	534
60	76003	41076	95163	39015	19301	16466	4207	9690	9478	2212	1277	1273	031	561	392	263	210	162	126	103	433
01	105095	62001	34231	17442	31355	16140	12250	2920	6333	5980	1313	700	763	511	345	241	174	129	100	79	329
62	245575	151542	51406	21660	62318	24574	11325	6590	1938	4068	3704	064	494	491	320	216	151	109	01	62	255
83	54969	201059	123960	41943	22617	40602	19042	0442	6195	1369	2047	2639	602	344	342	223	150	105	76	56	221
64	139665	45004	164461	101135	33874	17890	30450	14170	6068	4363	855	1979	1632	417	239	237	154	104	73	52	192
65	354364	114340	30020	134390	02313	27402	14200	29670	10797	4572	3271	714	1479	1369	312	176	177	115	70	54	163
86	125891	290129	93590	30115	109616	60756	22001	11309	23369	0301	3540	2529	552	1143	1050	241	130	137	09	60	103
61	376016	103070	237479	76553	24505	60097	53040	11556	0941	10315	6570	2774	1901	432	095	026	189	106	107	70	191
66	345300	300501	64376	194333	62579	20050	72350	43477	14106	7103	14701	5260	2210	1504	346	718	662	151	66	66	206
69	206037	202707	252514	68962	150272	50559	15971	56532	33395	10726	5422	11109	3972	1674	1195	261	540	500	114	65	222
90	155063	168689	231429	206631	56369	129047	41042	12007	45374	26721	6571	4330	8869	3171	1336	954	206	431	399	91	229
91	137416	127626	138081	109324	160155	45002	1042QO	32006	10237	35074	21061	6757,	3412	6988	2496	1053	752	164	340	314	252
92	156928	112506	104450	112916	154446	136907	36846	82679	25752	7966	27031	16334	5232	2642	5410	1934	015	502	127	263	438
93	110166	126402	92101	05403	92314	125802	111234	29775	66497	20655	6361	22262	13075	4106	2114	4330	1546	652	466	102	561
94	64761	96764	105162	75376	69908	76363	102534	QO153	24044	53501	16626	5135	17926	10016	3369	1701	3463	1245	525	375	533
95	64042	69413	79213	66012	61619	51012	61204	82797	72436	19262	42666	13295	4105	14330	6400	2693	1360	2164	995	419	726
96	174086	52433	56626	64035	70405	50332	46453	48701	67036	50545	15556	34600	10732	3313	11567	6706	2174	1097	2247	003	924
97	79638	142530	42023	46504	53009	57442	40911	37567	40014	53029	46955	12410	21730	6601	2655	9270	5438	1742	079	1001	1305
96	06902	65202	116691	35132	30039	43298	46001	33219	30411	32335	43464	37901	10064	22386	6941	2143	7461	4369	1406	710	2571
99	27012	71148	53376	95494	26723	31032	35100	37036	26733	24400	25921	34624	30361	6062	17931	5560	1716	5992	3515	1126	2626
2000	26985	22115	50240	43600	10116	23465	25292	20567	30652	21622	19726	20942	20133	24526	6512	14404	4491	1306	4040	2040	3032

Table 5.6--Estimated age 2 recruitment of arrowtooth flounder (thousands of fish) from the 1998 and 1999 assessments.

Year class	1999 Assessment	1998 Assessment
1968	55,606	56,418
1969	35,896	36,928
1970	40,360	42,372
1971	115,532	115,600
1972	81,896	81,058
1973	25,838	27,170
1974'	77,336	80,218
1975	71,972	72,484
1976	117,058	124,612
1977	232,752	230,706
1978	83,752	85,194
1979	125,762	127,988
1980	303,064	314,420
1981	402,118	391,692
1982	90,608	91,868
1983	228,696	235,552
1984	580,258	581,090
1985	206,140	206,388
1986	617,122	630,502
1987	565,414	553,862
1988	337,378	330,984
1989	255,252	248,266
1990	225,012	224,026
1991	256,964	248,774
1992	193,528	196,248
1993	138,826	137,278
1994	104,866	112,274
1995	285,076	291,080
1996	173,804	124,880

Table 5.7-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	catch	F
1999	496,094	9,153	0.01
2000	464,154	126,476	0.22
2001	375,488	101,483	0.22
2002	304,467	82,123	0.22
2003	246.041	67,228	0.22
2004	203,888	55,889	0.22
2005	183,959	44,562	0.21
2006	178,885	39,319	0.20
2007	179,842	38,139	0.19
2008	184,138	39,041	0.20
2009	189,236	40,716	0.20
2010	191,850	42,241	0.20
2011	193,407	43,461	0.20
2012	196,043	44,394	0.20

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning	catch	F
1999	496,094	9,152	0.01
2000	472,119	66,314	0.11
2001	419,924	58,566	0.11
2002	370,856	51,743	0.11
2003	323,997	45,784	0.11
2004	286,273	40,670	0.11
2005	265,885	36,589	0.11
2006	256,400	33,806	0.11
2007	252,489	32,453	0.11
2008	253,055	32,022	0.11
2009	256,109	32,208	0.11
2010	258,214	32,688	0.11
2011	260,281	33,267	0.11
2012	264,019	33,819	0.11

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning	catch	F
1999	496,094	9,152	0.01
2000	478,936	10,927	0.02
2001	461,771	10,470	0.02
2002	439,459	9,984	0.02
2003	412,054	9,477	0.02
2004	387,610	8,970	0.02
2005	375,613	8,515	0.02
2006	370,923	8,172	0.02
2007	369,849	8,011	0.02
2008	372,394	7,986	0.02
2009	377,302	8,049	0.02
2010	361,569	8,167	0.02
2011	386,192	8,310	0.02
2012	392,836	8,460	0.02

Scenario 5
No fishing

Year	Female spawning	catch	F
1999	496,094	0	0
2000	480,227	0	0
2001	470,127	0	0
2002	453,861	0	0
2003	431,449	0	0
2004	410,981	0	0
2005	402,046	0	0
2006	399,636	0	0
2007	400,323	0	0
2008	404297	0	0
2009	410,467	0	0
2010	415,944	0	0
2011	421,779	0	0
2012	429,656	0	0

Table 5.7—continued.

Scenario 6

Determination of whether arrowtooth flounder are currently overfished B35=170,314

Year	Female spawning	catch	F
1999	496,094	9,153	0.01
2000	460,441	152,924	027
2001	356,310	117.314	027
2002	277,883	91.167	027
2003	216.964	72.126	027
2004	175.911	52,962	025
2005	160,649	41,710	0.22
2006	159,661	38,322	0.22
2007	163,291	38,496	0.22
2008	166.619	40,496	023
2009	174,190	42,882	023
2010	176.461	44,719	024
2011	177,467	45,984	0.24
2012	179,505	46,793	024

Scenario 7

Determination of whether arrowtooth flounder ere approaching en overfished condition B35=170,314

Year	Female spewning	catda	F
1999	496.094	9.152	0.01
2000	4641154	126.476	0.22
2001	375,466	101,463	0.22
2002	302,110	99,334	027
2003	233.801	77,870	027
2004	167.027	59,766	026
2005	166.794	44,954	023
2006	163,090	40,022	0.22
2007	164.974	39,379	022
2008	169,629	40,931	023
2009	174.527	43,067	023
2010	176.562	44,780	024
2011	177,464	45,988	024
2012	179,465	46,776	0.24

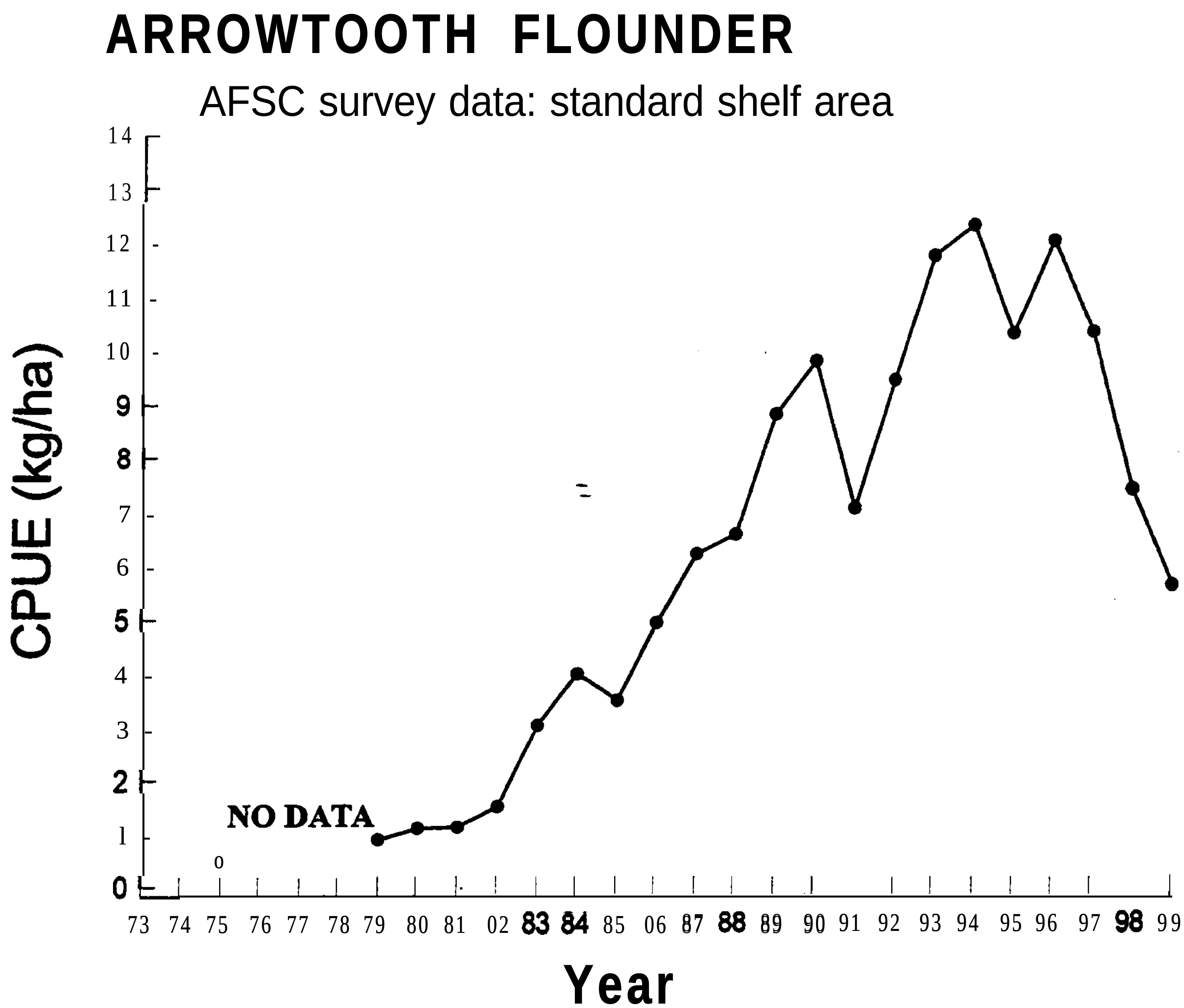


Figure **5.1--Catch** per unit effort (CPUE) of arrowtooth flounder on the eastern Bering Sea continental **shelf** as shown by Alaska Fisheries Science Center (AFSC) survey data.

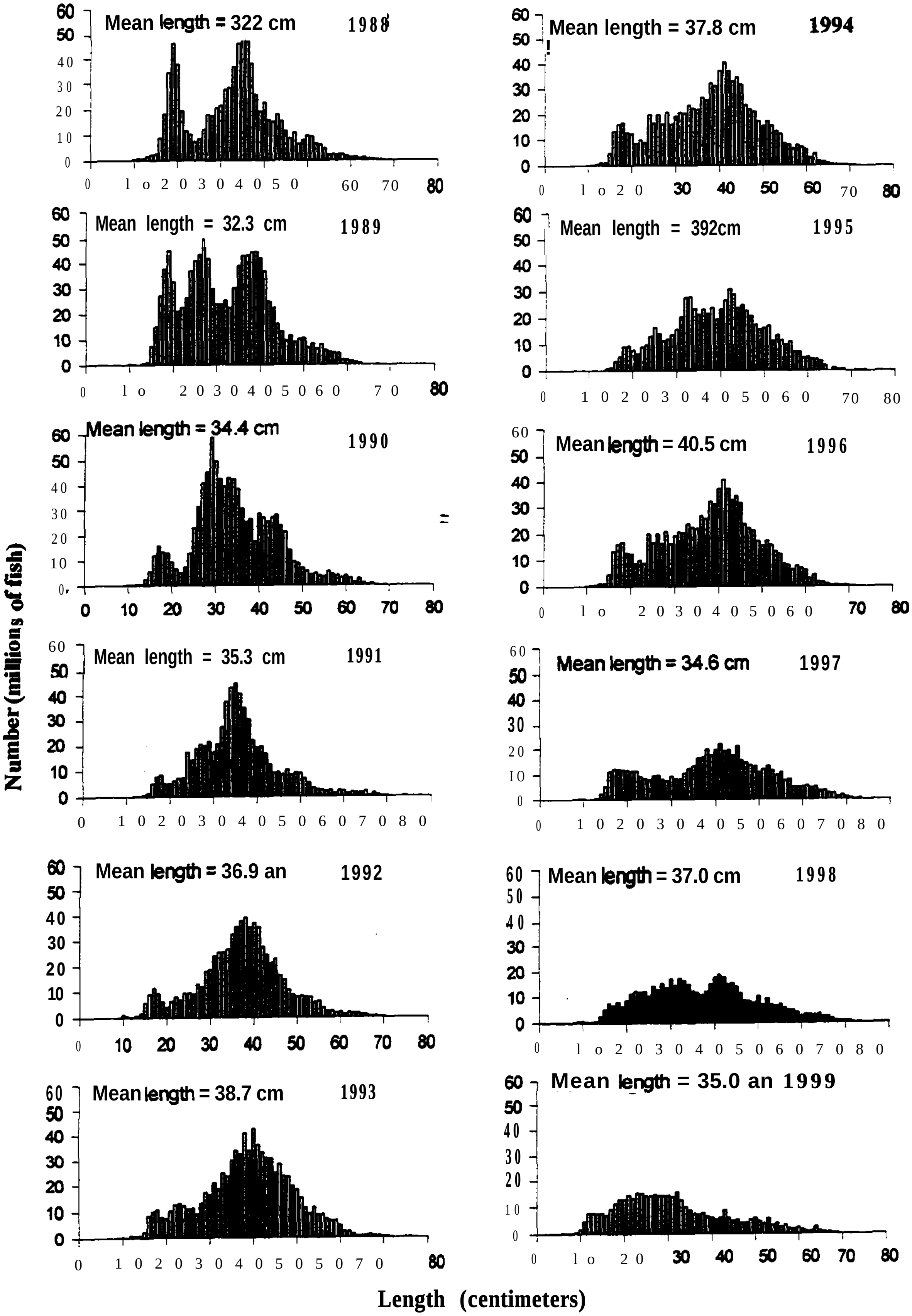


Figure 5.2-- Size composition (millions of fish) of arrowtooth flounder from the eastern Bering Sea bottom trawl surveys during 1988-1999.

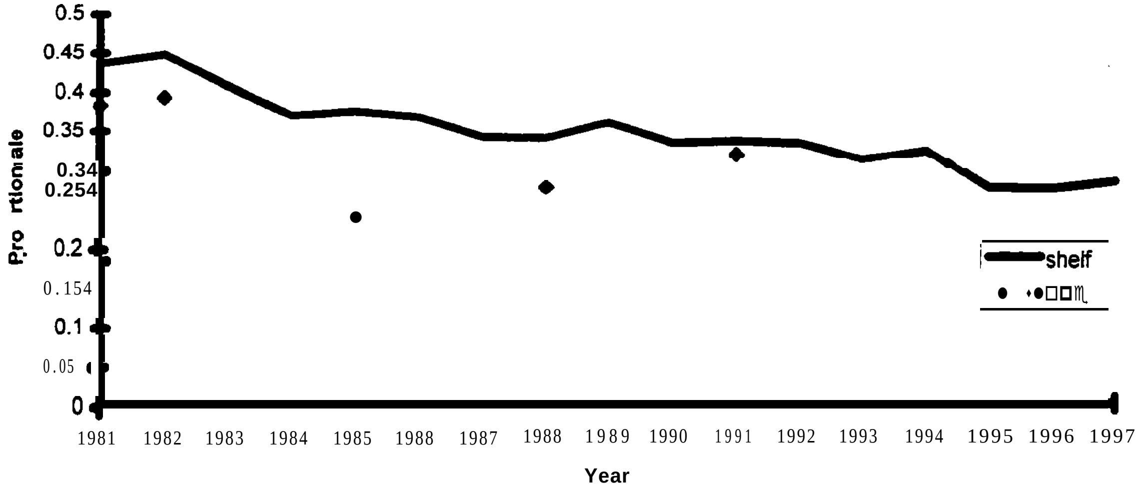


Figure **5.3--Proportion** of the estimated male population from Bering Sea bottom trawl surveys on the shelf and the continental slope.

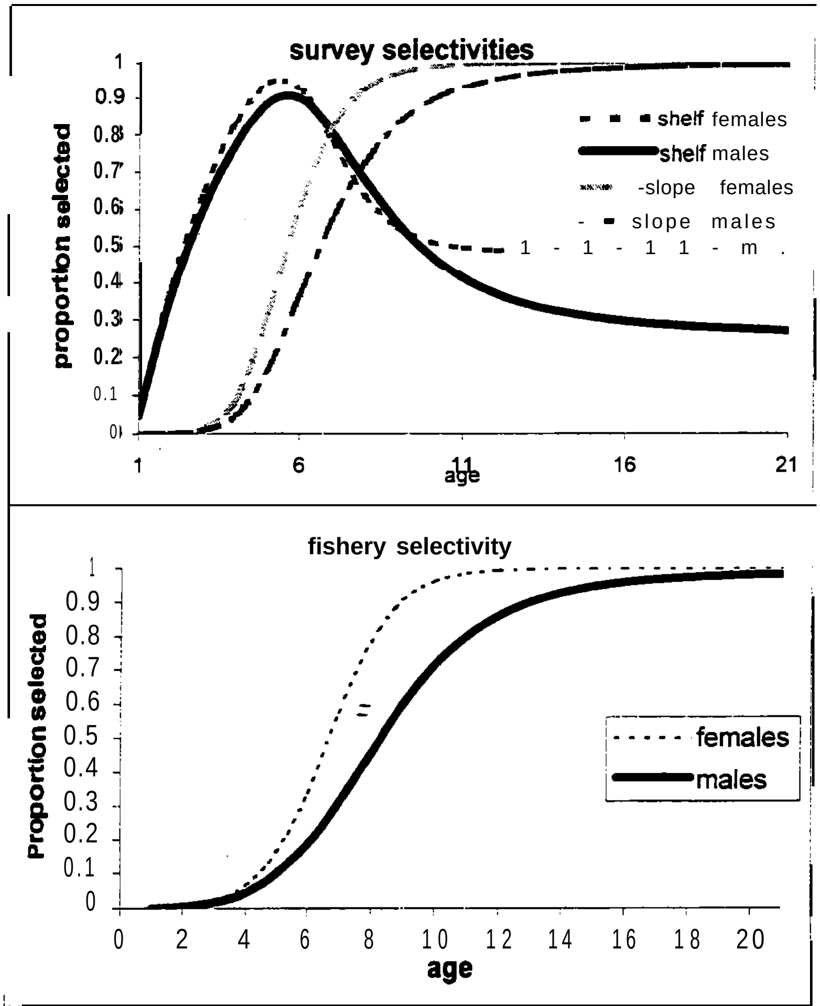


Figure 5.4--Age-specific shelf and slope survey selectivity (top panel) and fishery selectivity (bottom panel) by sex, estimated from the stock synthesis model.

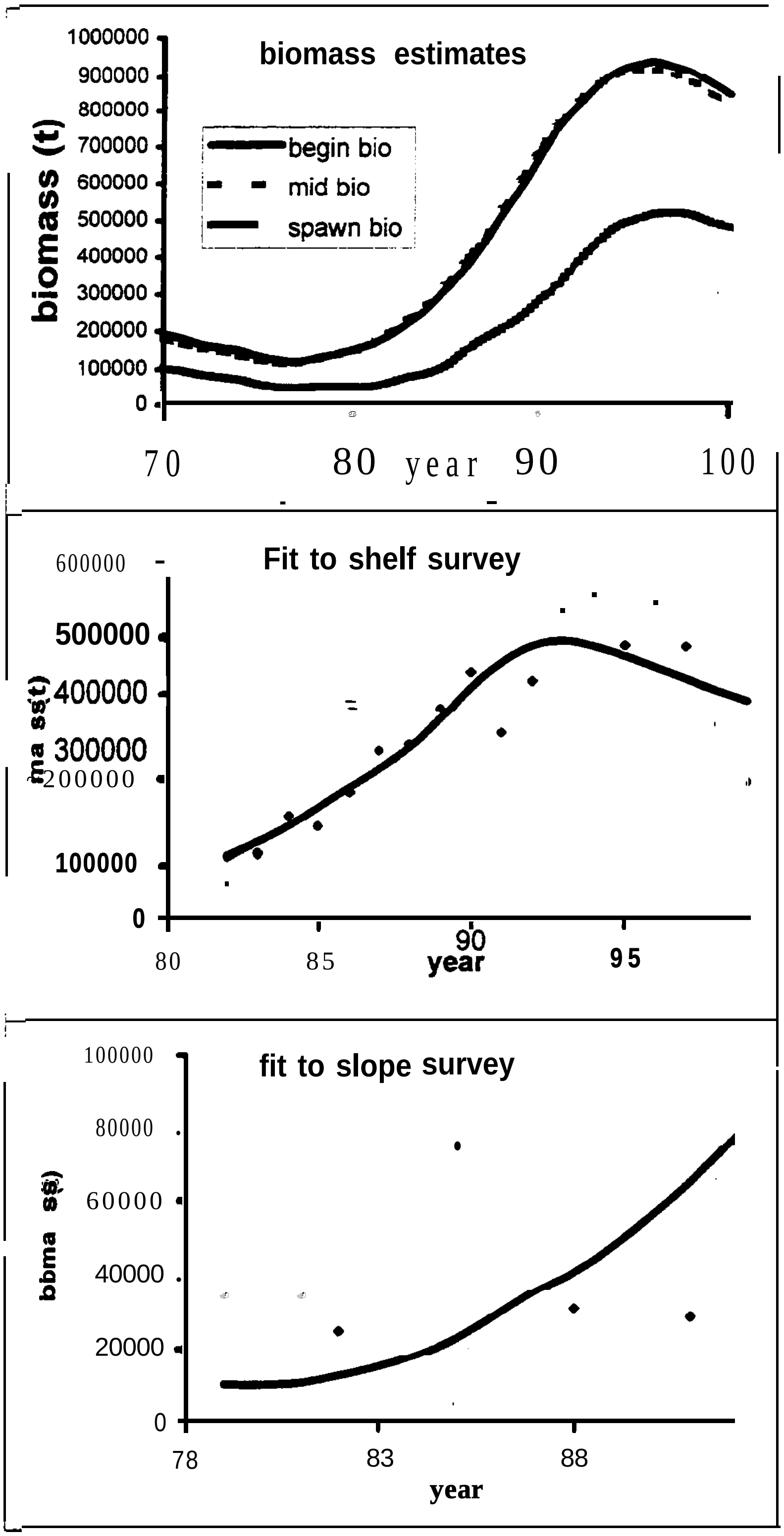


Figure 5.5--Stock synthesis model estimates of begin year biomass, mid-year biomass and spawning biomass (top panel), model fit to shelf survey biomass (middle panel) and model fit to the slope survey biomass (bottom panel).

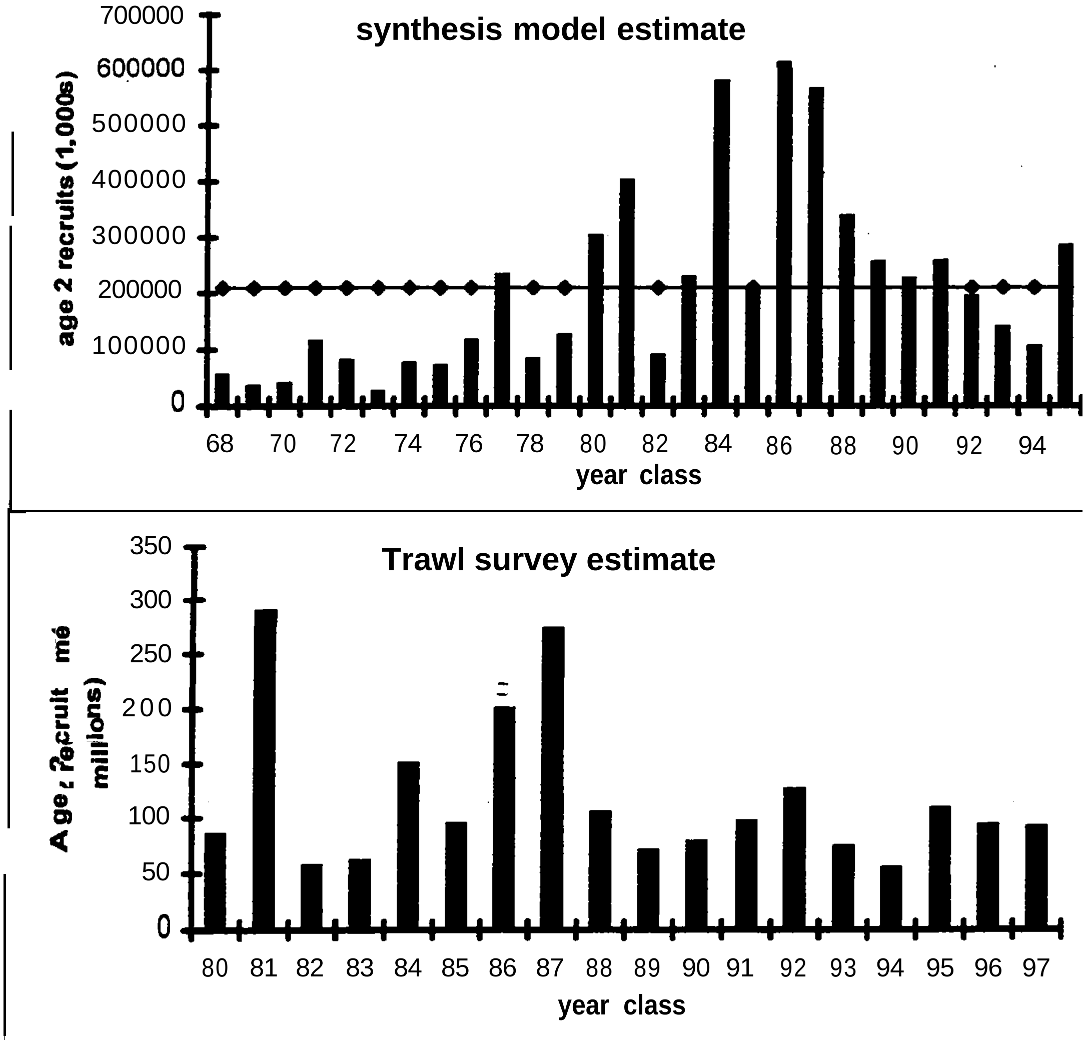


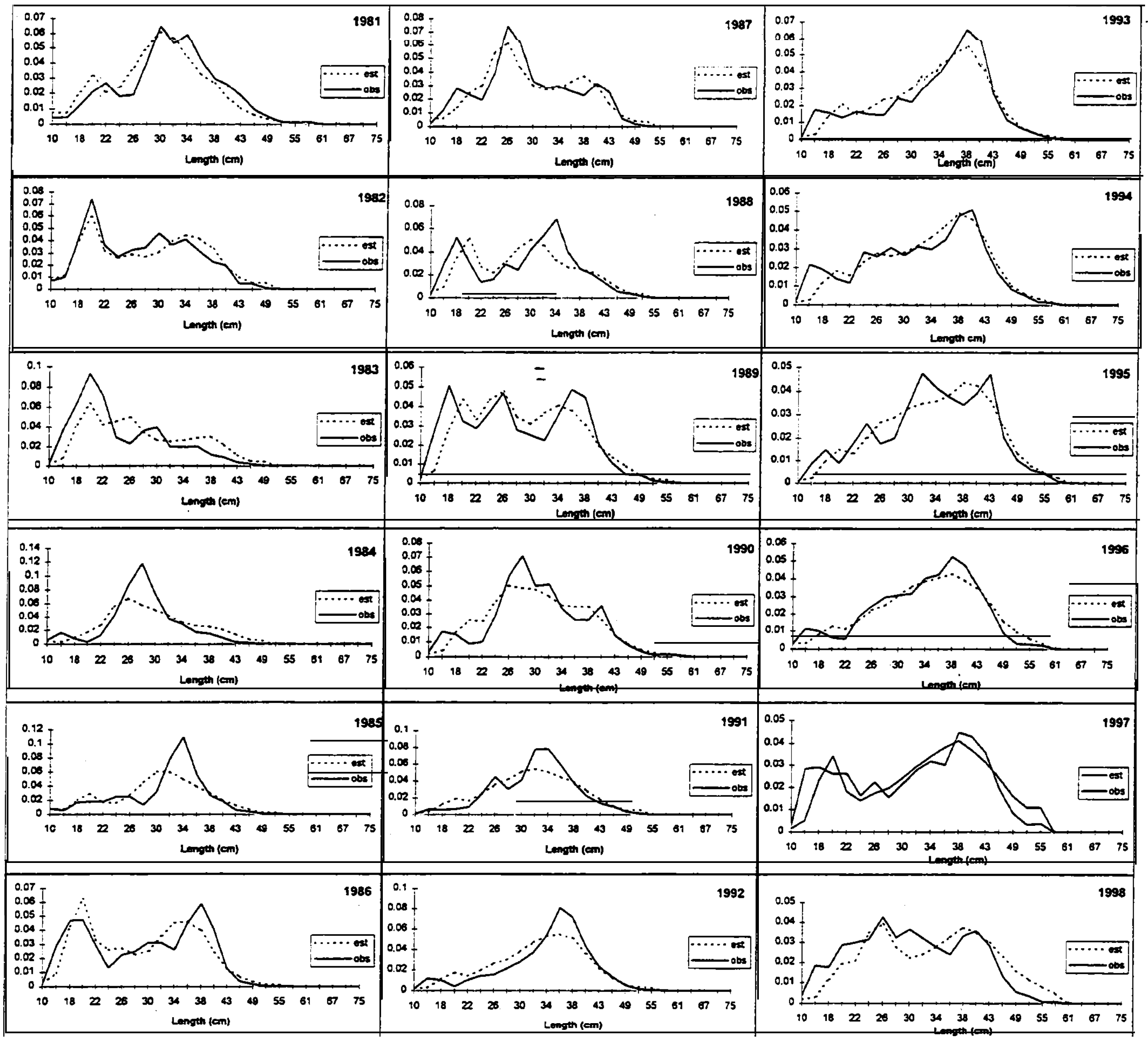
Figure 5-6--Estimates of arrowtooth flounder age 2 recruitment from the synthesis model (top panel) and from the shelf trawl survey (bottom panel).

APPENDIX

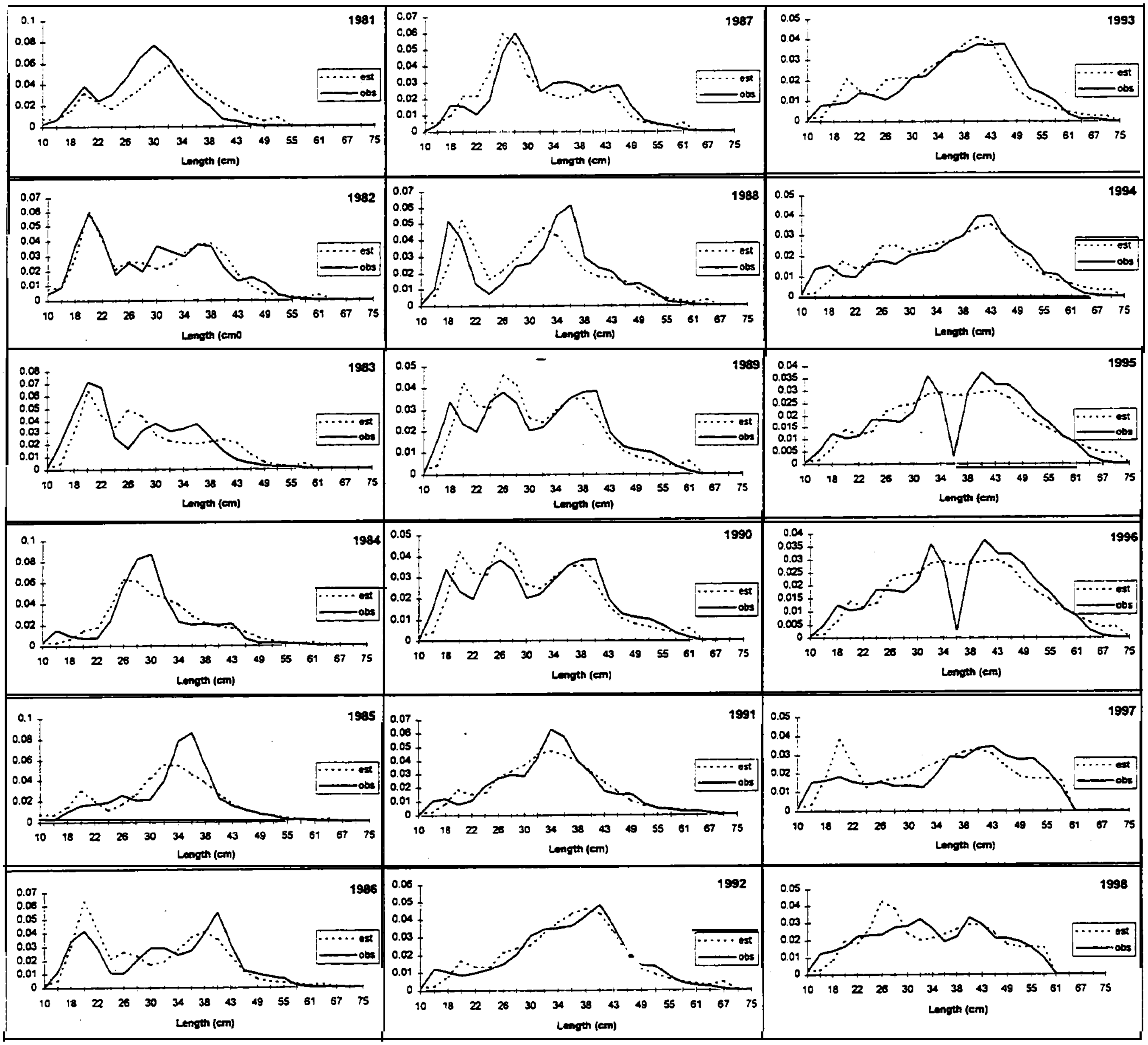
Figures show the fit of the stock synthesis model to the time-series of shelf and slope survey size composition data by sex (estimated values are the dotted lines) and the fishery size composition data from 1978-90.

Table of arrowtooth flounder catch during research activities by the Alaska Fisheries Science Center, 1977-99.

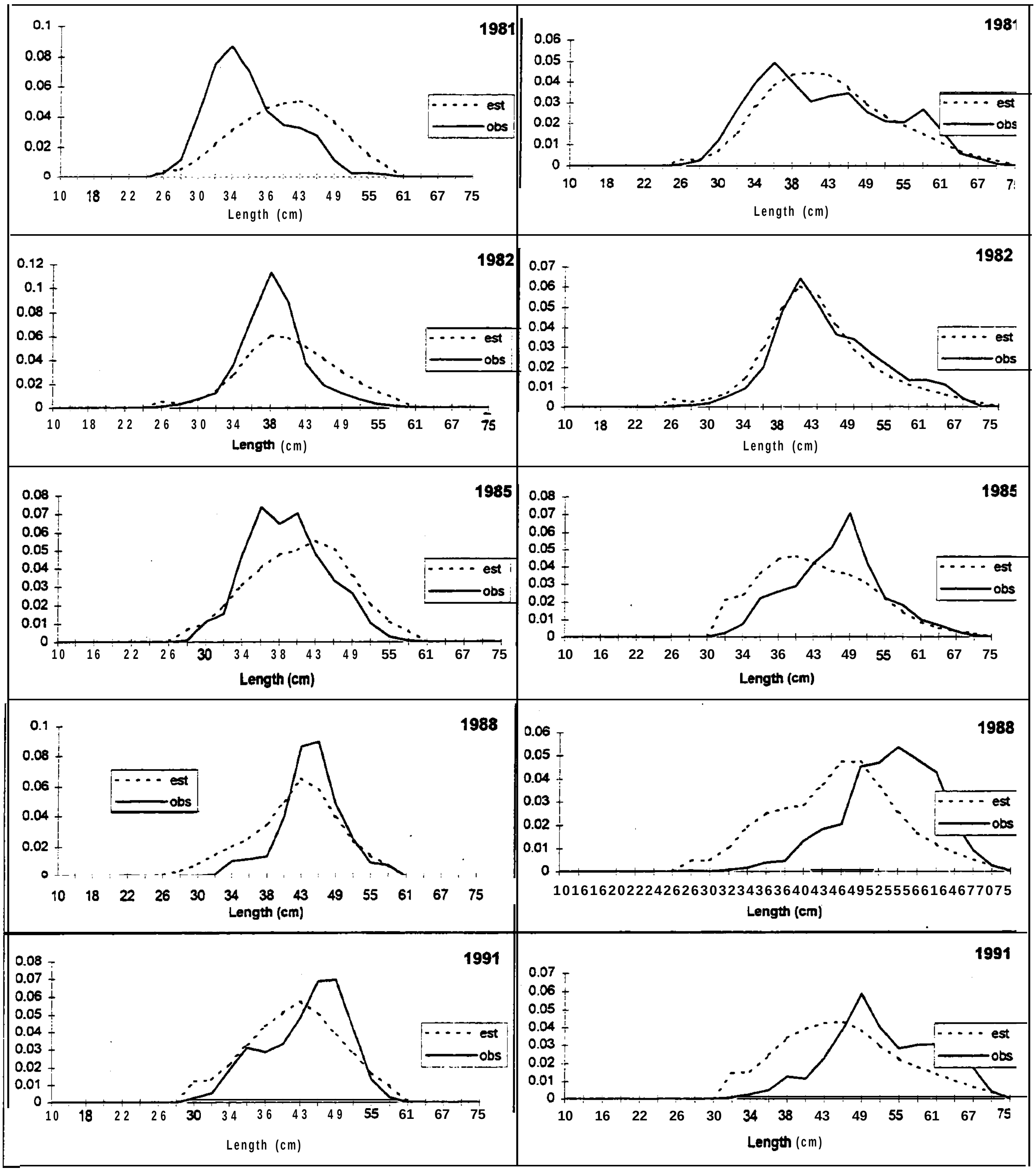
Shelf survey males | Shelf suwey males | Shelf survey males

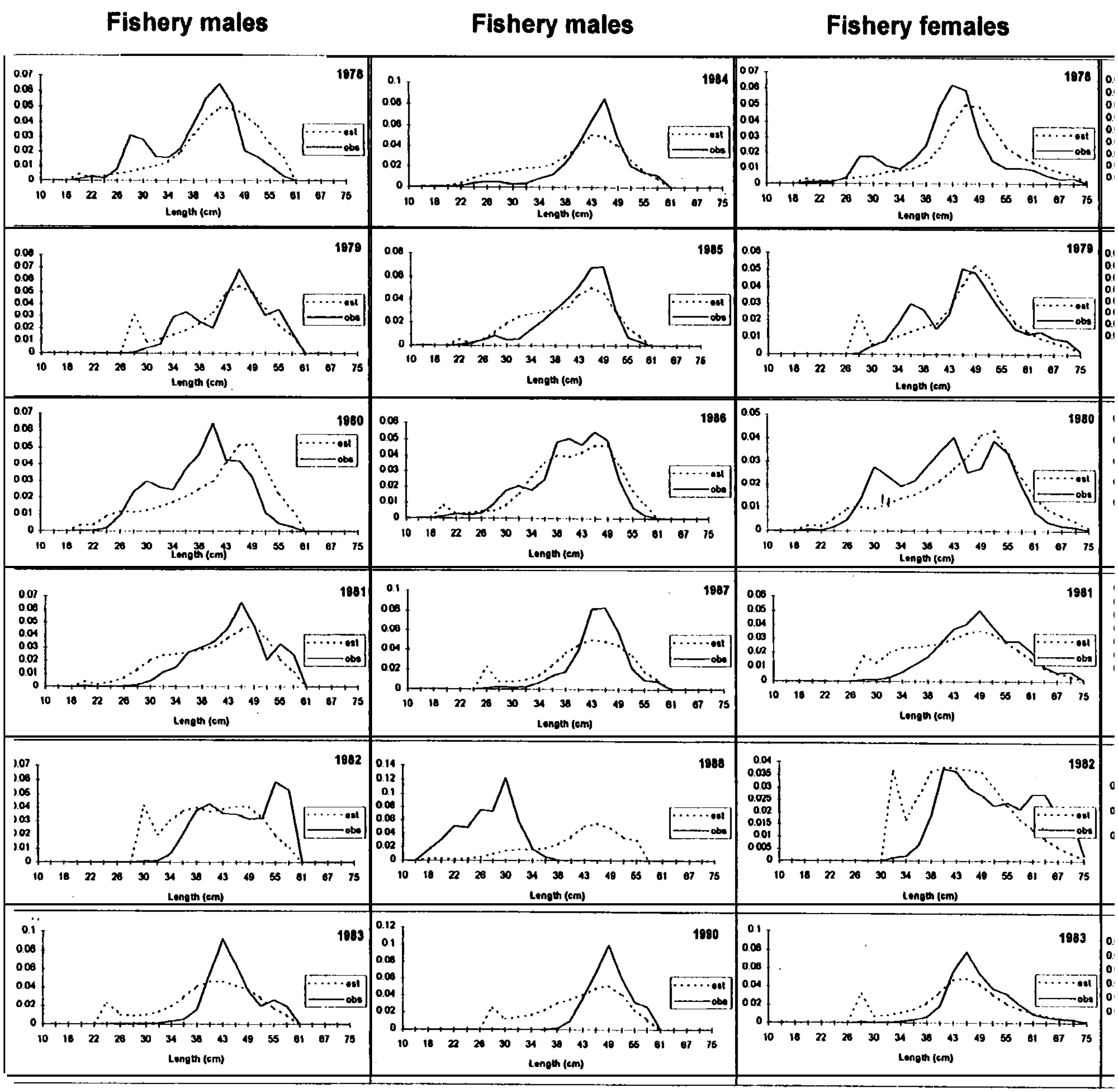


Shelf survey females Shelf survey females Shelf survey females



Slope survey males **Slope survey females**




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

Total catch (t) of arrowtooth flounder due to Alaska Fisheries Science Center research activity in the Bering Sea and Aleutian Islands, 1977-99.

year	Research catch (t)	Proportion of the commercial catch
1977	1.0	0.00009
1978	3.7	0.00037
1979	22.5	0.00157
1980	63.6	0.00346
1981	48.4	0.00283
1982	46.6	0.00404
1983	21.8	0.00156
1964	6.1	0.00065
1985	194.1	0.02606
1986	57.7	0.00804
1987	9.4	0.00193
1988	33.7	0.00168
1989	22.8	0.00312
1990	18.4	0.00141
1991	27.5	0.00125
1992	10.9	0.00105
1993	16.3	0.00175
1994	40.7	0.00284
1995	18.2	0.00196
1996	17.9	0.00122
1997	32.3	0.00321
1998	12.6	0.00082
1999	0.1	0.00001