

Gulf of Alaska Arrowtooth Flounder

Stock Assessment

by

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Executive Summary

Summary of major changes

Changes in the input data

The 2005 survey biomass and length data were added to the model. Catch and fishery length data for 2003 were updated and 2004 and 2005 catch and fishery length data were added to the model. Survey age data from the 1999, 2001 and 2003 surveys were also incorporated.

Changes in assessment methodology

An age-based model was used with the same configuration as the 2003 assessment.

Changes in assessment results

The estimated age 3+ biomass from the model increased from 330,944 t in 1961 to a high of 2,109,700 t in 2005. Female spawning biomass in 2005 was estimated at 1,095,690 t, a 20% decline from the projected 2005 biomass (fishing at the average 5 year F) of 1,374,820 t from the 2003 assessment. The 2006 ABC using F40% was 177,800 t, a decline from the 2004 and 2005 ABC of 194,900 t. The 2006 OFL using F35% was 207,700 t. The 2007 ABC using F40% was estimated at 185,400 t and the 2007 OFL was 216,500 t, using the projection model and catch in 2006 estimated using the recent 5 year average $F=0.012$.

The ABC by management area using $F_{40\%}$ was estimated by calculating the fraction of the 2005 survey biomass in each area and applying that fraction to the ABC:

Arrowtooth ABC by INPFC area

	Western	Central	West Yakutat	East Yakutat/SE	Total
2005 survey biomass	215,287	1,441,111	170,423	72,958	1,899,778
ABC 2006	20,154	134,907	15,954	6,830	177,844
ABC 2007	21,010	140,641	16,632	7,120	185,403

SSC comments specific to arrowtooth flounder assessment

There were no specific SSC comments on the GOA arrowtooth flounder assessment in 2003.

SSC comments on assessment in general

From the December, 2004 SSC minutes: *In its review of the SAFE chapter, the SSC noted that there is variation in the information presented. Several years ago, the SSC developed a list of items that should be included in the document. The SSC requests that stock assessment authors exert more effort to address each item contained in the list. Items contained in the list are considered critical to the SSC's ability to formulate advice to the Council. The SSC will review the contents of this list at its February meeting.*

Introduction

Arrowtooth flounder (*Atheresthes stomias*) range from central California to the eastern Bering Sea and are currently the most abundant groundfish species in the Gulf of Alaska. 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), however, arrowtooth flounder are currently of low value and most are discarded. In 1990, the North Pacific Fisheries Management Council separated arrowtooth flounder for management purposes from the flatfish assemblage, which at the time included all flatfish.

Although arrowtooth flounder are presently of limited economic importance as a fisheries product, trophic studies (Yang 1993, Hollowed, et al. 1995, Hollowed et al. 2000) suggest they are an important component in the dynamics of the Gulf of Alaska benthic ecosystem. The majority of the prey by weight of arrowtooth larger than 40 cm was pollock, the remainder consisting of herring, capelin, euphausiids, shrimp and cephalopods (Yang 1993). The percent of pollock in the diet of arrowtooth flounder increases for sizes greater than 40 cm. Arrowtooth flounder 15 cm to 30 cm consume mostly shrimp, capelin, euphausiids and herring, with small amounts of pollock and other miscellaneous fish. Groundfish predators include Pacific cod and Halibut.

Arrowtooth flounder occur from central California to the Bering Sea, in waters from about 20m to 800m, although CPUE from survey data is highest in 100m to 300m. Information concerning stock structure is not currently available. Migration patterns are not well known for arrowtooth flounder, however, there is some indication that arrowtooth flounder move into deeper water as they grow, similar to other flatfish (Zimmerman and Goddard 1996).

Catch History

Prior to 1990, flatfish catch in the Gulf of Alaska was reported as an aggregate of all flatfish species. The bottom trawl fishery in the Gulf of Alaska primarily targets on rock, rex and Dover sole. The best estimate of annual arrowtooth catch since 1960 was calculated by multiplying the proportion of arrowtooth in observer sampled flatfish catches in recent years (nearly 50%) by the reported flatfish catch (1960-1977 from Murai et al. 1981 and 1978-1993 from Wilderbuer and Brown 1993) (Table 5.1). Catch through 1 October 2005 was 18,098 t, an increase from the 2004 catch of 15,304. Total allowable catch for 2005 was 8,000 t for the Western GOA, 5,000 t for the Eastern GOA, and 25,000 t for the Central GOA. Table 5.2 documents annual research catches (1977 - 2002) from NMFS longline, trawl, and echo integration trawl surveys.

Substantial amounts of flatfish are discarded overboard in the various trawl target fisheries. The following estimates of retained and discarded catch (t) since 1991 were calculated from discard rates observed from at-sea sampling and industry reported retained catch. Under current fishing practices, the percent retained has increased from below 10% in the early 1990's to about 57% in 2004.

Rationalization in the Gulf of Alaska may change retention rates in the future as bycatch in trawl fisheries could be reduced, allowing more catch of arrowtooth and development of markets.

Year	Retained	Discards	Percent retained
1991	2,174	19,896	10%
1992	498	22,629	2%
1993	1,488	22,565	6%
1994	458	22,011	2%
1995	2,275	16,153	12%
1996	5,438	17,093	24%
1997	2,985	13,442	18%
1998	2,057	10,943	15.8%
1999	4,265	11,943	26.3%
2000	9,938	13,044	43.2%
2001	6619	13,345	33.2%
2002	10,032	10,381	49.2%
2003	17,325	12,890	57.3%
2004	8,660	6,665	56.5%

Abundance and exploitation trends

The survey biomass estimates used in this assessment are from International Pacific Halibut Commission (IPHC) trawl surveys, NMFS groundfish surveys, and NMFS triennial surveys (Table 5.3). Biomass estimates from the surveys in the 1960's and 1970's were analyzed using the same strata and methods as the triennial survey (Brown 1986). The IPHC surveys did not cover the whole Gulf of Alaska area in one year, but surveyed different regions each year. The data from the 1961 and 1962 IPHC surveys were combined to provide total coverage of the GOA area. The NMFS surveys in 1973 to 1976 also did not cover the entire GOA in any one year and were combined to provide total coverage of the survey area. However, sample sizes were lower in the 1970's surveys (403 hauls, Table 5.3) than for other years, and some strata had less than 3 hauls.

The IPHC and NMFS 1970's surveys used a 400 mesh Eastern trawl, while the triennial surveys used a noreastern trawl. The trawl used in the early surveys had no bobbin or roller gear, which would cause the gear to be more in contact with the bottom than current trawl gear. Also the locations of trawl sites may have been restricted to smooth bottoms in the earlier surveys because the trawl could not be used on rough bottoms. Selectivity of the different surveys is assumed to be equal. There is limited size composition data for the 1970's surveys but none for the 1960's surveys.

In the assessment modeling, the survey catchability coefficient (Q) was assumed to be 1.0. NMFS has conducted studies to estimate the escapement under the triennial survey net and herding of fish into the net. The percent of arrowtooth flounder caught that were in the path of the net varies by size from about 40% to 50% at 20-25 cm to about 95% at greater than 40cm (Peter Munro, pers. Comm.). This results in a Q that is close to 1.0. Although the analysis is not yet complete, the herding component results in an overall Q of about 1.3 (Somerton pers. comm.), which means that the survey potentially overestimates population biomass. The estimated escapement and herding catchability will be incorporated into the assessment model when results from these analyses are complete.

The 400 mesh eastern trawl used in the 1960's and 1970's surveys was estimated to be 1.61 times as efficient at catching arrowtooth flounder than the noreastern trawl used in the NMFS triennial surveys (Brown, in prep). The 1960's and 1970's survey abundance estimates have been lowered by dividing by 1.61. A coefficient of variation (cv) of 0.2 for the efficiency estimate was assumed since variance estimates were unavailable.

Survey abundance estimates were low in the 1960's and 1970's, increasing from about 146,000 t in the early 1970's to about 2,822,830 t in 2003. Survey biomass declined to 1,899,778 t in 2005. The 1984, 1987 and 1999 surveys covered depths to 1000m, the 1990, 1993, 1996 and 2001 surveys to 500m and the 2003 and 2005 surveys covered depths to 700m. The 2001 survey excluded the eastern Gulf of Alaska. The average biomass estimated for the 1993 to 1999 surveys was used to estimate the biomass in the eastern Gulf for 2001 (Table 5.4). The eastern gulf biomass was between 14% and 22% of the total biomass for the 1993-1999 surveys. CPUE by haul indicates that the highest abundance occurs between about 149 deg and 156 deg longitude, to the southwest and to the northeast of Kodiak Island (Figures 5.15 to 5.22). There were several large catches that occurred between about 149 deg and 151 deg longitude in the 2003 survey, however, CPUE was higher in most areas compared to the 2001 survey (Figures 5.21 and 5.22).

Data

The model simulates the dynamics of the population and compares the expected values of the population characteristics to those observed from surveys and fishery sampling programs.

The following data sources (and years of availability) were used in the model:

Data component	Years
Fishery catch	1960-2005
IPHC trawl survey biomass and S.E.	1961-1962
NMFS exploratory research trawl survey biomass and S.E.	1973-1976
NMFS triennial trawl survey biomass and S.E.	1984,1987,1990,1993, 1996,1999,2001,2003,2005
Fishery size compositions	1977-1981,1984-1993,1995-2005
NMFS survey size compositions	1975,2005
NMFS triennial trawl survey age composition data	1984,1987,1990,1993,1996,1999,2001, ,2003

Sample sizes for the fishery length data were adequate for the 1970's and 1980's. However, sample sizes in recent years have decreased. No length samples were collected in 1994. Otoliths from the 1984 to 2003 NMFS trawl surveys have been aged and used in the model (Table 5.5). Size composition data for the surveys are shown in Table 5.6.

Analytic approach

Model Structure

The model structure is developed following Fournier and Archibald's (1982) methods, with many similarities to Methot (1990). We implemented the model using automatic differentiation software developed as a set of libraries under C++ (ADModel Builder). ADModel Builder can estimate a large number of parameters in a non-linear model using automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries. This software provides the derivative calculations needed for finding the objective function via a quasi-Newton function minimization routine (e.g., Press et al. 1992). The model implementation language (ADModel Builder) gives simple and rapid access to these routines and provides the ability to estimate the variance-covariance matrix for all parameters of interest.

Details of the population dynamics and estimation equations, description of variables and likelihood equations are presented in Appendix A (Tables A.1, A.2 and A.3). There were a total of 126 parameters estimated in the model (Table A.4). The 22 selectivity parameters estimated in the model were constrained so that the number of effectively free parameters would be less than the total of 126. There were 43 fishing mortality deviates in the model which were constrained to be small, to fit the observed catch closely. The instantaneous natural mortality rate, catchability for the survey and the Von Bertalanffy growth parameters were fixed in the model (Table A.5).

Parameters Estimated Independently

Natural mortality, Age of recruitment, and Maximum Age

Natural mortality rates for Gulf of Alaska arrowtooth flounder were estimated using the methods of Alverson and Carney (1975), Pauly (1980), and Hoenig (1983) in the 1988 assessment (Wilderbuer and Brown 1989). The maximum age of female arrowtooth flounder otoliths collected was 23 years. Using Hoenig's empirical regression method (Hoenig 1983) M would be estimated at 0.18. There are fewer

males than females in the 15+ age group, with the maximum age for males varying between 14 and 20 years from different survey years. Natural Mortality with a maximum age of 14 years and 20 years was estimated at 0.30 and 0.21 respectively using Hoenig's method.

The age composition of males shows fewer males relative to females as fish increase in age, which would be the case for higher M for males. To account for this process, natural mortality was fixed at 0.2 for females and 0.35 for males. A higher natural mortality for males was used to fit the age and size composition data, which are about 70% female. A value of $M=0.35$ for males was chosen so that the survey selectivities for males and females both reached a maximum selectivity close to 1.0. A likelihood profile on male natural mortality resulted in a mean and mode of 0.354 with 95% confidence intervals of 0.32 to 0.38 (Turnock et al 2002, Figure 5.14). Model runs examining the effect of different natural mortality values for male arrowtooth flounder can be found in the Appendix of the 2000 SAFE.

An alternative explanation for the data is that the prevalence of females in the survey and fishery data are the result of lower availability for males. If lower availability is assumed, then the 3+ biomass and ABC will be higher, even though the F40% and female spawning biomass will remain unchanged. However, if males became unavailable to the gear at a fairly constant rate as they aged, the same effect could explain the data. Three pieces of evidence indicate the process is linked to natural mortality rather than catchability. First, the survey and fishery data in both the Bering Sea and GOA have about 70% female in the catches, which also points towards a higher M for males. Second, most of the abundance of arrowtooth flounder from survey data occurs at depths less than 300 meters. The fraction female is fairly constant at about 65% to 74% for depths up to 500 meters. In the deepest areas, covered in the 1999 and 1987 surveys, the fraction female was variable, being about 0.5 in 1987 and 0.83 in 1999. The data by depth do not indicate that males in any depth strata are less available than in other depth strata. Third, analysis of arrowtooth flounder age data in the Bering sea show the same phenomena.

Age at recruitment was set at three in the model due to the small number of fish caught at younger ages.

Weight at Length

The weight-length relationship for arrowtooth flounder is, $W = .003915 L^{3.2232}$, for both sexes combined where weight is in grams and length in centimeters.

Growth

In the growth equation shown below, L_{inf} was estimated as 101.5 cm for females and 54 cm for males (Figure 5.2). The length at age 2 (L_2) for both sexes was estimated at 20 cm and k was 0.077 for females and 0.22 for males from the survey age and length data in 1984 through 1996.

$$L_{age} = L_{inf} + (L_2 - L_{inf}) * \exp(-k(age - 2)).$$

The mean length at age data from the surveys show no trends from 1984 to 2003 for females (Table 5.8 and Figure 5.3). Males were smaller in 1984, however other years are similar (Table 5.7 and Figure 5.4).

Maturity

Length at 50% mature was estimated at 47 cm with a logistic slope of -0.3429 from arrowtooth sampled in hauls that occurred in September from the 1993 bottom trawl survey (Zimmerman in review). Arrowtooth flounder are batch spawners, spawning from fall to winter off Washington State at depths greater than 366 m (Rickey 1995). There was some indication of migration of larger fish to deeper water in winter and shallower water in summer from examination of fisheries data off Washington, however, discarding of fish may confound observations (Rickey 1995). Length at 50% mature from survey data in 1992 off Washington was 36.8 cm for females and 28.0 cm for males, with logistic slopes of -0.54 and -0.893 respectively (Rickey 1995). Oregon arrowtooth flounder had length at 50% mature of 44 cm for females and 29 cm for males (Rickey 1995). Spawning fish were found in depths from 108m to 360m in March to August in the Gulf of Alaska (Hirshberger and Smith 1983) from analysis of trawl surveys from

1975 to 1981. Most observations of spawning fish were found in the northeastern Gulf, off Prince William Sound, off Cape St. Elias, and Icy Bay.

Likelihood weights and other model structure

Weights used on the likelihood values were 1.0 for the survey length, survey age data and the survey biomass (simply implying that the variances and sample sizes specified for each data component were approximately correct). A weight of 0.25 was used for the fishery length data. The fishery length data is essentially from bycatch and in some years has low sample sizes. A lower weight on the fishery length data allows the model to fit the survey data components better. The estimated length at age relationship is used to convert population age compositions to estimated size compositions. The current model estimated size compositions using a fixed length-age transition matrix estimated from the 1984 through 1996 survey data combined. The distribution of lengths within ages was assumed to be normal with cv 's estimated from the length at age data of 0.06 for younger ages and 0.05 for older ages. Size bins were 2 cm starting at 24 cm, 3 cm bins from 40 cm to 69cm, one 5 cm bin from 70 cm to 74 cm, then a 75+cm bin. There were 13 age bins from 3 to 14 by 1 year interval, and ages over 15 accumulated in the last bin, 15+.

Parameters Estimated Conditionally

Recent recruitments

Recruitment in the last three years (2003, 2004 and 2005) of the model were conditioned to be close to the mean recruitment over the 22 year period from 1981 to 2002, due to the lack of data to estimate recruitments for recent years. This constraint was not used in the 2003 assessment.

Selectivity

Separate fishery selectivities were estimated for each age, however the shape of the selectivity curve was constrained to be a smooth function (Figure 5.1). Survey selectivities were modeled using a two parameter ascending logistic function. The selectivities by age were estimated separately for females and males. The differential natural mortality and selectivities by sex resulted in a predicted fraction female of about 0.70, which is close to the fraction female in the fishery and survey length and age data.

Results

Fits to the size composition data from the fishery are shown in Figure 5.5 for females and Figure 5.6 for males. The model overestimates large female fish for 1975 and 2005 surveys (Figure 5.7). The high recruitments in the 1980's and early 1990's and the low fishing mortalities resulted in more large older female fish in the estimated population than were found in the surveys. The survey length data for males is fit well (Figure 5.8). Age data are fit well for both females and males (Figure 5.9). The model estimates of survey biomass are higher than the survey for 1999, lower for 2003 and very close for 2001 and 2005 (Figure 5.13).

Model estimates of biomass

The model estimates of age 3+ biomass increased from a low of 330,994 t in 1961 to a high of 2,109,700 t in 2005 (Table 5.9 and Figure 5.11). The 2005 biomass estimate is lower than the projected 2005 biomass from the 2003 assessment due to the decline in survey biomass in 2005.

Model estimates of recruitment

The model estimates of age 3 recruits have an increasing trend in the 1970's, declined slightly from the late 1980's to the mid-1990's, and increased through 2002 (Table 5.9 and Figure 5.12). The 2003, 2004 and 2005 recruits were constrained to be near the long term harmonic mean.

Spawner-Recruit Relationship

No spawner-recruit curve was used in the model. Recruitments were freely estimated but with a modest penalty on extreme deviations from the mean value.

Reference fishing mortality rates and yields

Reliable estimates of biomass, $B_{35\%}$, $F_{35\%}$ and $F_{40\%}$, are available for arrowtooth flounder. Given that the current biomass is greater than $B_{40\%}$, arrowtooth flounder is in Tier 3a of the ABC and overfishing definitions. Under this definition, $F_{off} = F_{35\%}$, and F_{ABC} is less than or equal to $F_{40\%}$.

Yield for 2006 using $F_{40\%} = 0.142$ was estimated at 177,844 t. Yield at $F_{35\%} = 0.168$ was estimated at 207,678 t. Model estimates of fishing mortality have been well below target rates (Figure 5.14). Fishing mortality was estimated to be lower than about 0.03 since 1961 and was about 0.01 in 2005.

Maximum sustainable yield

Since there is no estimate of the spawner-recruit relationship for arrowtooth flounder, no attempt has been made to estimate MSY. However, using the projection model described in the next section, spawning biomass with $F=0$ was estimated at 1,364,820 t. $B_{35\%}$ (equilibrium spawning biomass with fishing at $F_{35\%}$) is estimated at 545,926 t.

Projected catch and abundance

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2005 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2006 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2005. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2006, are as follow ("*max F_{ABC}*" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max F_{ABC}*. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of $\max F_{ABC}$, where this fraction is equal to the ratio of the F_{ABC} value for 2006 recommended in the assessment to the $\max F_{ABC}$ for 2006. (Rationale: When F_{ABC} is set at a value below $\max F_{ABC}$, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of $\max F_{ABC}$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 1999-2003 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 $\frac{1}{2}$ of its MSY level in 2005 and above its MSY level in 2016 under this scenario, then the stock is not overfished.)

Scenario 7: In 2006 and 2007, F is set equal to $\max F_{ABC}$, and in all subsequent years, F is set equal to F_{OFL} . (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2018 under this scenario, then the stock is not approaching an overfished condition.)

Projected catch and abundance were estimated using $F_{40\%}$, F equal to the average F from 1999 to 2003, F equal to one half $F_{40\%}$, and $F=0$ from 2006 to 2010 (Table 5.10). Under scenario 6 above, the year 2006 female spawning biomass is 1,306,640 t and the year 2016 spawning biomass is 667,223 t, above the $B_{35\%}$ level of 542,794 t. For scenario 7 above, the year 2018 spawning biomass is 614,602 t also above $B_{35\%}$. Fishing at $F_{40\%}$, female spawning biomass would still be above $B_{40\%}$ in year 20168 (Figure 5.23). Female spawning biomass would be expected to increase if fishing continues at current fishing mortality values (Figure 5.24)(about 0.01).

Acceptable biological catch

ABC for 2006 using $F_{40\%} = 0.142$ was estimated at 177,844 t. The projection model was used to estimate the 2007 ABC using $F_{40\%}=0.142$ and the 2006 catch estimated using the average recent 5 year $F=0.012$. In the 2003 assessment the 2004 ABC using $F_{40\%} = 0.14$ was estimated at 194,934 t (Turnock et al. 2003).

The ABC by management area using $F_{40\%}$ was estimated by calculating the fraction of the 2005 survey biomass in each area and applying that fraction to the ABC:

Arrowtooth ABC by INPFC area

	Western	Central	West Yakutat	East Yakutat/SE	Total
2005 survey biomass	215,287	1,441,111	170,423	72,958	1,899,778
ABC 2006	20,154	134,907	15,954	6,830	177,844
ABC 2007	21,010	140,641	16,632	7,120	185,403

Overfishing level

Yield at $F_{35\%} = 0.168$ was estimated at 207,678 t.

Data gaps and research priorities

Analysis of the herding and escapement studies for arrowtooth, would result in improved estimates of selectivities and catchability. Otoliths have been aged through the 2003 survey, continued aging will allow monitoring of growth.

Summary

Table 5.11 shows a summary of model results.

Ecosystem Considerations

Ecosystem effects on the stock

Based on food habits studies, capelin, euphausiids and pollock were the most important prey (73% of the diet) for arrowtooth flounder in the Gulf of Alaska (Livingston and Goiney 1983, Yang 1993) (Figure 5.25). Trends in abundance are not available for important prey items, except Pollock. The abundance of walleye pollock has declined rather steadily since the early 1990's, but recent evidence suggests the stock may be starting to increase again (Dorn et al., 2004).

Important predators include Pacific halibut, Stellar sea lions, Pacific cod, sleeper shark, arrowtooth flounder, big skates and other groundfish (Figure 5.26). Arrowtooth flounder are currently the most abundant groundfish in the Gulf of Alaska, and have steadily increased in abundance since the early 1970's (Turnock et al., 2003). Pacific cod abundance in the Gulf of Alaska has been declining since 1990 (Thompson et al., 2004).

Fishery effects on ecosystem

Protected species such as halibut, salmon, and crab are taken in flatfish fisheries and result in closures of bottom trawl fisheries in the GOA.

The ecosystem effects of this spatial concentration of fishing activity are unknown.

Effects of discards and offal production on the ecosystem are unknown for the arrowtooth flounder fishery.

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Table 5.1. Catch of arrowtooth flounder in the Gulf of Alaska from 1964 to 1 October, 2005.

Year	Catch(t)
1964	514
1965	514
1966	2,469
1967	2,276
1968	1,697
1969	1,315
1970	1,886
1971	1,185
1972	4,477
1973	10,007
1974	4,883
1975	2,776
1976	3,045
1977	9,449
1978	8,409
1979	7,579
1980	7,848
1981	7,433
1982	4,639
1983	6,331
1984	3,457
1985	1,539
1986	1,221
1987	4,963
1988	5,138
1989	2,584
1990	7,706
1991	10,034
1992	15,970
1993	15,559
1994	23,560
1995	18,428
1996	22,583
1997	16,319
1998	12,975
1999	16,207
2000	24,252
2001	19,964
2002	21,231
2003	29,994
2004	15,304
2005	18,098

Table 5.2. Catches from NMFS research cruises from 1977 to 2002.

Year	Catch (t)
1977	29.3
1978	30.6
1979	38.9
1980	36.7
1981	151.5
1982	90.2
1983	61.4
1984	223.9
1985	149.4
1986	179.0
1987	297.4
1988	22.0
1989	64.1
1990	228.1
1991	27.7
1992	32.1
1993	255.4
1994	36.7
1995	173.5
1996	154.6
1997	40.6
1998	115.6
1999	101.5
2000	24.0
2001	83.9
2002	11.0

Table 5.3. Biomass estimates and standard errors from bottom trawl surveys.

Survey	Biomass(t)	Stand. Error	No. hauls	Maximum Depth(m)
IPHC 1961-1962	283,799	61,515	1,172	
NMFS groundfish 1973-1976	145,744	33,531	403	
NMFS triennial 1984	1,112,215	71,209	930	1,000
NMFS triennial 1987	931,598	74,673	783	1,000
NMFS triennial 1990	1,907,177	239,150	708	500
NMFS triennial 1993	1,551,657	101,160	776	500
NMFS triennial 1996	1,639,632	114,792	804	500
NMFS triennial 1999	1,262,151	99,329	764	1,000
NMFS 2001	1,621,892*	178,408	489	500
NMFS 2003	2,819,095	372,326	809	700
NMFS 2005	1,899,778	125,788	839	700

* A value for the eastern gulf survey biomass was estimated by using the average of the 1993 to 1999 biomass estimates in the eastern gulf, which was added to the 2001 survey biomass in the central and western gulf to obtain a survey biomass for the total area.

Table 5.4. Survey biomass estimates (t) for 1993 to 2005 by area. The 2001 survey biomass for the eastern gulf was estimated by using the average of the 1993 to 1999 biomass estimates in the eastern gulf.

Area	1993	1996	1999	2001	2003	2005
Western	212,332	202,594	143,374	188,100	341,620	215,287
Central	1,117,361	1,176,714	845,176	1,181,848	2,198,829	1,441,111
Eastern	222,015	260,324	273,490	251,943*	282,379	243,381

Table 5.6. Length data from triennial surveys in 1984 through 2005. The numbers are percentages, where the female plus the male numbers add to 100 within a year.

		Length(cm)																				
		22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58	61	64	67	70	75+
Female																						
	1975	4.99	4.38	4.77	5.07	4.59	4.58	4.83	4.89	4.05	4.02	3.21	2.79	2.37	1.49	1.04	0.67	0.38	0.34	0.21	0.14	0.01
	1999	1.90	1.78	2.89	3.34	3.18	3.35	3.68	3.56	3.25	4.30	3.98	4.81	5.92	7.46	7.26	4.11	1.84	1.06	0.69	0.53	0.33
	2001	4.10	2.51	2.00	2.66	3.21	2.89	3.04	3.47	3.29	5.06	5.53	5.99	6.14	5.63	5.76	4.18	2.32	1.39	1.00	1.29	0.36
	2003	2.22	2.48	3.10	3.99	4.34	4.07	4.29	3.93	4.87	4.60	4.75	6.01	8.18	7.82	4.66	1.97	0.92	0.42	0.51	0.03	2.22
	2005	1.46	2.41	3.13	3.39	3.80	4.44	5.14	5.91	6.59	6.68	5.49	5.33	3.94	3.83	3.43	2.22	1.10	0.56	0.34	0.19	0.06
Male																						
	1975	3.63	3.19	3.91	4.72	4.69	4.64	4.68	3.96	2.88	2.35	0.91	0.16	0.04	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00
	1999	1.22	1.14	1.83	1.98	1.93	1.91	2.00	1.95	2.04	3.31	4.34	3.76	1.76	0.24	0.05	0.03	0.00	0.00	0.00	0.00	0.00
	2001	2.46	1.36	1.55	2.00	1.87	1.82	1.87	1.88	1.84	3.31	3.27	3.02	1.62	0.28	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	2003	1.46	1.38	1.83	2.46	2.47	2.49	2.67	1.96	2.99	3.03	2.19	1.45	0.35	0.10	0.01	0.00	0.01	0.00	0.00	0.00	1.46
	2005	1.16	1.67	1.85	2.06	2.16	2.42	2.71	3.77	3.86	3.79	2.57	1.55	0.73	0.22	0.03	0.01	0.00	0.00	0.00	0.00	0.00

Table 5.7. Mean length (cm) at age for male arrowtooth flounder from triennial surveys 1984 through 1996.

	1984	1987	1990	1993	1996	1999	2001	2003
1	0.0	0.0	0.0	15.8	14.5	12.7	14.3	15.0
2	0.0	23.8	0.0	21.4	20.7	20.3	21.2	21.1
3	22.3	28.4	28.6	27.6	26.3	26.6	28.0	26.3
4	26.0	33.1	33.6	31.9	34.0	31.6	34.1	32.5
5	29.9	36.9	37.2	36.9	35.3	37.0	38.2	34.7
6	33.6	41.1	39.4	40.9	41.1	40.8	41.2	38.7
7	36.1	41.2	41.8	42.2	43.6	42.3	43.3	43.1
8	37.8	42.5	43.7	44.3	44.7	45.3	45.3	47.0
9	39.3	42.8	44.5	45.7	46.9	46.5	46.8	45.7
10	40.1	0.0	45.3	45.5	46.9	49.0	47.9	47.9
11	41.7	42.5	46.2	46.2	48.1	47.9	47.8	48.2
12	42.6	42.9	0.0	48.8	49.1	47.8	49.3	48.2
13	42.9	45.0	0.0	47.1	49.3	51.2	50.6	49.0
14	44.3	45.0	51.0	40.0	51.0	52.0	51.6	52.7
15	47.5	0.0	0.0	48.0	52.0	50.8	49.5	50.0
16	0.0	0.0	0.0	47.0	0.0	0.0	52.2	51.4
17	0.0	0.0	0.0	0.0	51.0	48.3	51.8	50.7
18	0.0	0.0	0.0	52.0	0.0	0.0	0.0	63.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	55.0
20	0.0	0.0	0.0	48.0	0.0	0.0	0.0	0.0

Table 5.8. Mean length (cm) at age for female arrowtooth flounder from triennial surveys 1984 through 1996.

	1984	1987	1990	1993	1996	1999	2001	2003
1	0.0	0.0	0.0	15.4	13.3	12.8	14.4	15.1
2	0.0	23.0	22.6	21.5	21.5	20.3	20.8	21.0
3	25.2	30.1	27.9	27.6	26.3	26.8	28.1	26.2
4	31.5	35.3	33.2	32.5	32.9	33.0	34.4	31.1
5	38.0	38.6	38.1	39.4	37.4	38.5	38.4	37.6
6	42.3	44.9	43.5	41.7	42.1	42.2	43.5	41.6
7	46.6	47.2	45.4	46.5	46.6	47.2	46.8	46.1
8	50.8	50.1	49.1	48.5	49.7	51.2	48.2	49.2
9	54.0	51.7	51.7	52.5	53.6	54.3	52.6	53.3
10	56.7	50.4	55.8	55.6	54.8	56.2	55.2	54.0
11	58.9	50.2	58.3	55.8	59.2	60.4	60.2	58.1
12	60.8	51.5	58.3	55.9	63.8	63.1	61.0	62.4
13	62.8	55.2	58.5	61.5	64.7	65.6	64.1	65.3
14	63.9	51.0	63.8	59.7	68.2	65.6	65.9	66.3
15	66.8	57.0	56.2	60.5	73.7	68.6	68.4	65.0
16	0.0	0.0	60.8	67.2	68.3	68.4	69.8	67.2
17	0.0	0.0	74.7	64.4	0.0	69.8	70.8	73.0
18	0.0	0.0	73.4	69.1	81.0	74.5	75.5	71.9
19	0.0	0.0	63.0	76.7	0.0	74.5	74.5	73.4
20	0.0	0.0	0.0	70.6	82.0	0.0	73.0	73.2
21	0.0	0.0	70.0	81.2	0.0	54.0	80.8	71.7
22	0.0	0.0	0.0	0.0	0.0	82.0	0.0	79.0
23	0.0	0.0	0.0	79.0	0.0	0.0	77.7	0.0

Table 5.9. Estimated age 3+ population biomass(t), female spawning biomass(t) and age 3 recruits(1,000's) from the current assessment and from the 2003 assessment.

Year	age 3+ biomass	Age 3+ biomass 2003 assessment	Female spawning biomass	Female spawning biomass 2003 assessment	Age 3 recruits (1,000's)	Age 3 recruits(1000's) 2003 assessment
1961	330,944	327,622	197,596	196,544	90,599	86,027
1962	341,711	336,979	207,848	206,436	86,840	80,874
1963	348,352	342,102	215,172	213,451	80,689	74,379
1964	353,003	344,904	220,512	218,426	84,811	76,591
1965	355,510	345,335	224,448	221,843	82,113	72,965
1966	357,411	344,803	227,194	223,852	86,871	75,877
1967	356,788	341,412	226,998	222,661	89,206	76,718
1968	357,070	338,537	225,999	220,469	95,233	80,869
1969	359,892	337,642	225,109	218,159	105,806	88,661
1970	366,335	339,830	224,639	215,999	121,288	101,918
1971	374,885	343,988	224,192	213,530	130,077	111,186
1972	393,940	358,793	225,255	212,233	184,593	167,220
1973	424,354	385,845	224,906	209,080	260,281	248,063
1974	469,316	431,809	222,115	203,124	355,750	368,866
1975	538,180	507,005	226,297	204,250	423,027	460,251
1976	600,286	566,705	238,003	213,073	304,725	270,183
1977	672,258	635,893	258,614	231,622	373,574	346,868
1978	731,447	691,135	287,916	260,619	321,110	293,084
1979	783,580	738,764	330,445	305,041	282,208	255,139
1980	836,231	786,046	380,547	357,274	309,716	280,067
1981	905,603	847,711	430,715	407,082	440,351	398,137
1982	978,300	914,745	478,963	452,711	439,947	415,870
1983	1,029,720	964,312	524,531	494,795	277,911	274,770
1984	1,077,710	1,013,150	567,546	533,887	303,405	307,513
1985	1,146,720	1,081,330	616,664	578,988	442,957	424,270
1986	1,226,600	1,165,780	673,636	633,556	478,848	484,840
1987	1,317,230	1,264,030	727,813	687,592	546,735	559,939
1988	1,382,430	1,328,190	758,101	714,092	481,990	471,785
1989	1,442,870	1,393,530	789,905	745,231	438,602	457,187
1990	1,502,310	1,461,060	824,031	780,054	487,506	516,520
1991	1,539,150	1,508,860	859,090	817,487	412,215	448,166
1992	1,565,410	1,560,740	898,809	860,652	379,976	503,896
1993	1,597,400	1,645,060	939,706	905,171	443,977	716,132
1994	1,613,490	1,712,660	971,505	944,273	382,260	571,969
1995	1,597,230	1,751,680	978,147	962,968	349,485	536,637
1996	1,586,100	1,799,990	986,746	990,193	348,867	558,549
1997	1,585,360	1,857,640	996,543	1,027,910	399,988	613,872
1998	1,607,640	1,933,180	1,007,040	1,078,650	515,137	686,158
1999	1,655,110	2,005,700	1,016,530	1,132,070	617,140	626,827
2000	1,721,130	2,062,320	1,010,980	1,168,280	762,127	633,556
2001	1,800,890	2,139,060	995,821	1,195,420	847,976	848,932
2002	1,932,880	2,287,200	996,178	1,232,860	1,050,490	1,214,090
2003	2,007,760	2,391,550	1,006,470	1,267,070	609,893	840,902
2004	2,056,920		1,031,120	1,306,640	563,901	
2005	2,109,700		1,095,690	1,374,820	519,528	

Table 5.10. Projected female spawning biomass and yield from 2006 to 2010.

Year	Female spawning biomass(t)	Yield(t)
F=F40%		
2006	1,173,030	177,844
2007	1,125,670	167,792
2008	1,063,960	155,322
2009	992,517	141,907
2010	920,381	129,408
F=0.012(avg F)		
2006	1,173,030	15,763
2007	1,254,030	16,431
2008	1,317,060	16,723
2009	1,359,070	16,695
2010	1,385,650	16,525
F=0.5 F40%		
2006	1,173,030	91,294
2007	1,194,000	90,958
2008	1,195,260	88,637
2009	1,177,810	84,938
2010	1,149,650	80,917
F=0		
2006	1,173,030	0
2007	1,266,750	0
2008	1,343,760	0
2009	1,401,260	0
2010	1,447,070	0

Table 5.11. Summary of results of arrowtooth flounder assessment in the Gulf of Alaska.

Natural Mortality	0.2 females 0.35 males
Age of full(95%) selection	9 females, 12 males
Reference fishing mortalities	
$F_{40\%}$	0.142
$F_{35\%}$	0.168
Biomass at MSY	N/A
Equilibrium unfished Female Spawning biomass	1,364,820
$B_{40\%}$ Female Spawning biomass fishing at $F_{40\%}$	545,926
$B_{35\%}$ Female Spawning biomass fishing at $F_{35\%}$	477,685
Projected 2006 biomass	
Total(age 3+)	2,140,170
Spawning	1,173,030
Overfishing level for 2006	207,678

Figures

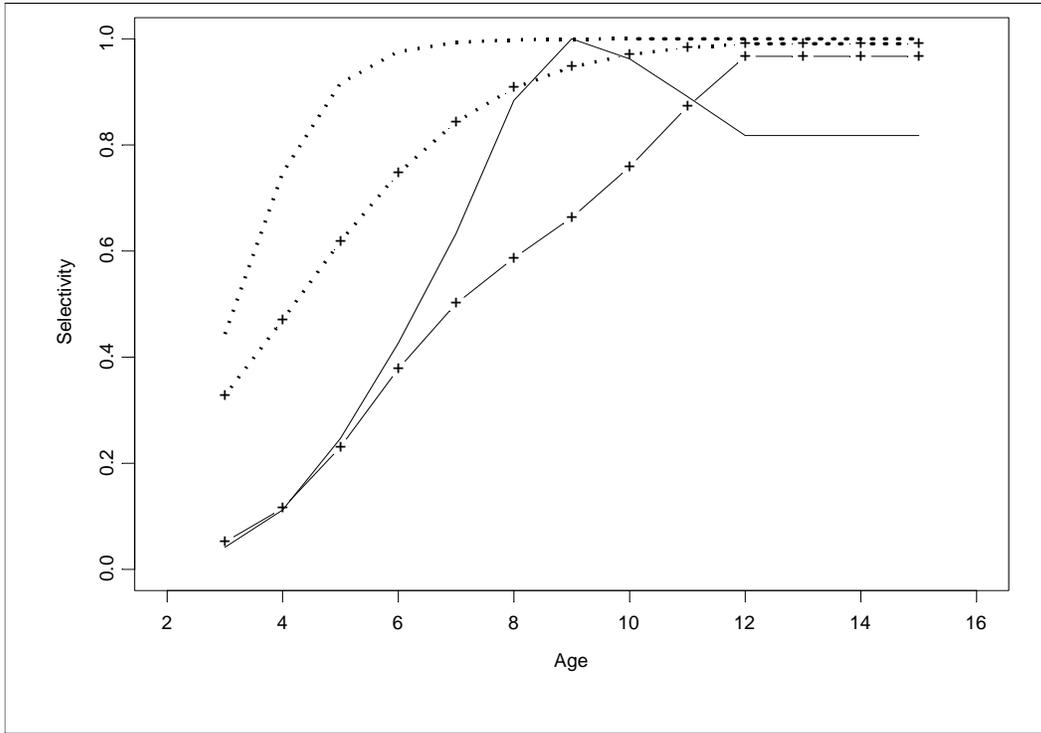


Figure 5.1. Selectivities for the fishery (solid line) and survey (dotted line). Males are the lines with the + symbol.

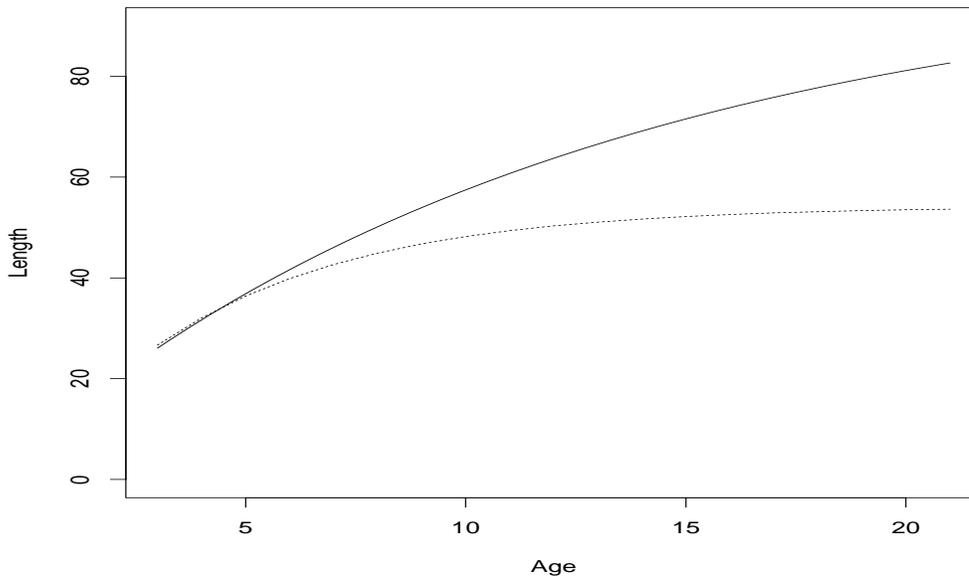


Figure 5.2. Mean length at age estimated from the 1984 through 1996 survey combined (females solid line, males dotted line), used to estimate the length-age transition matrix.

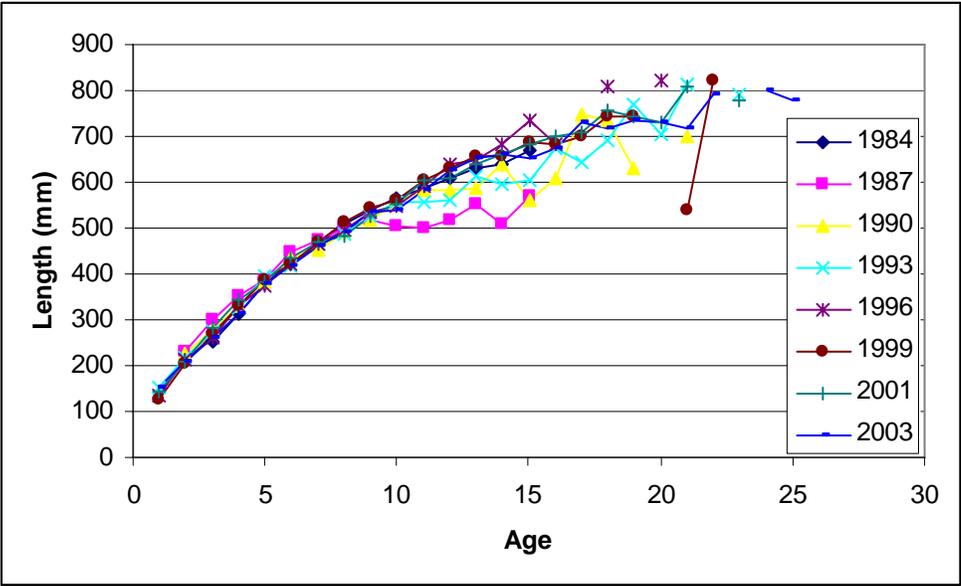


Figure 5.3. Mean length at age for female arrowtooth flounder from survey data 1984 to 2003.

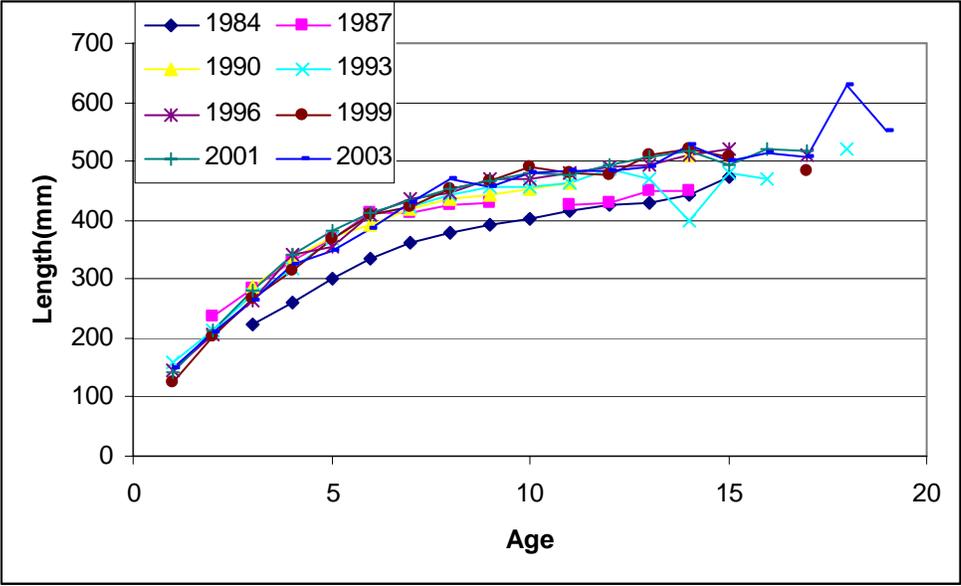


Figure 5.4. Mean length at age for male arrowtooth flounder from survey data 1984 to 2003.

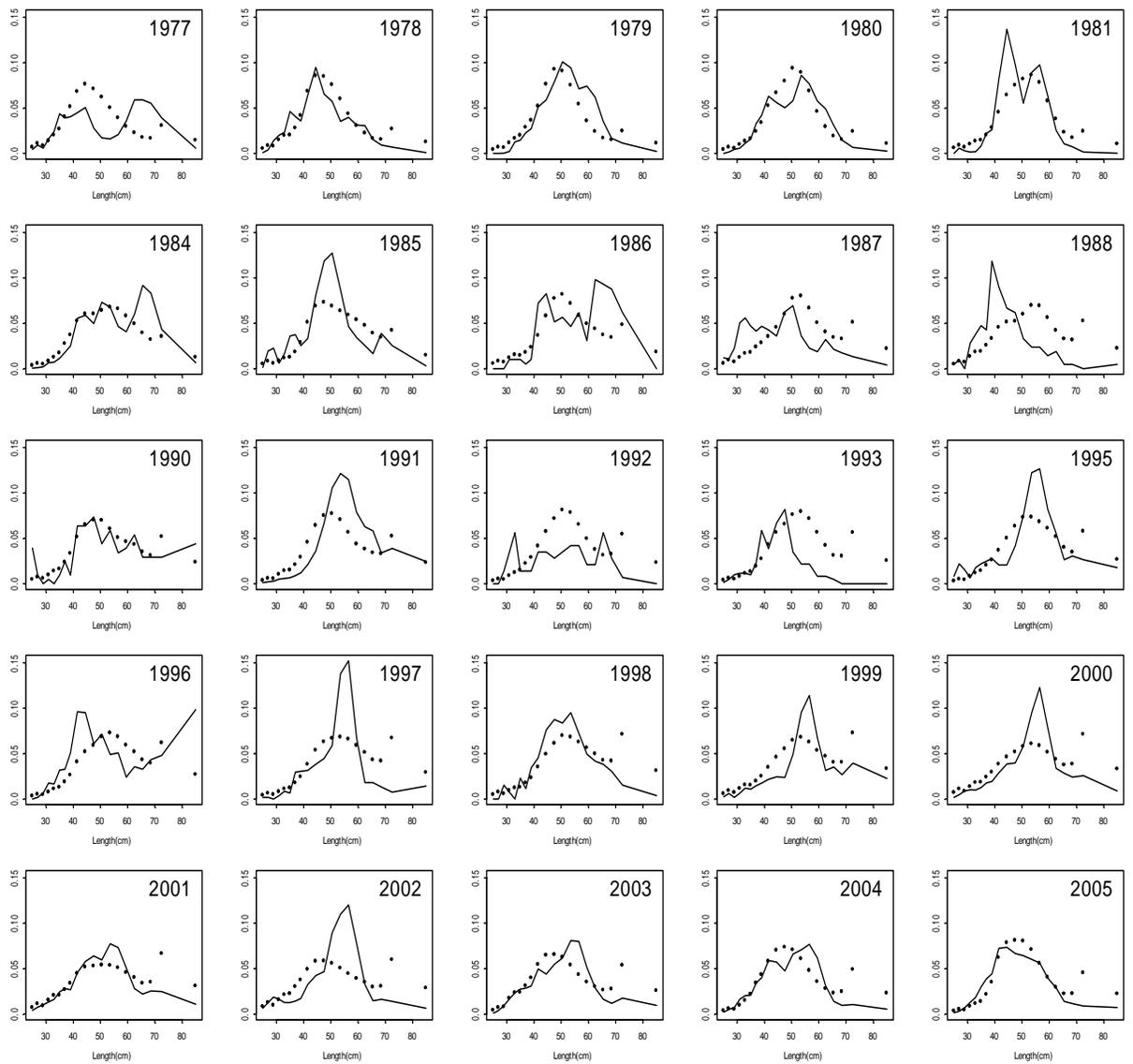


Figure 5.5. Fit to the female fishery length composition data. Dotted line is predicted.

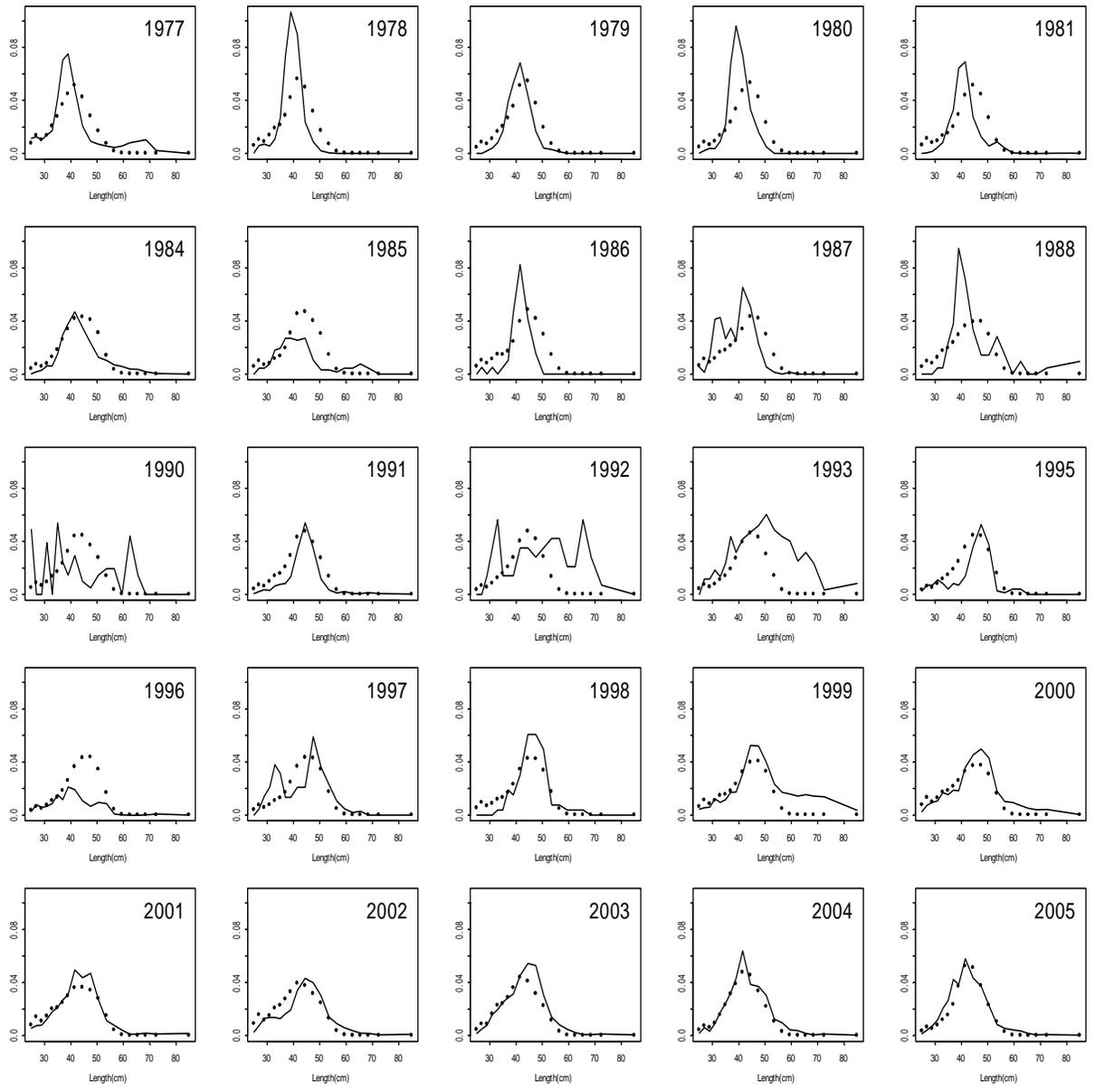


Figure 5.6. Fit to the male fishery length composition data. Dotted line is predicted.

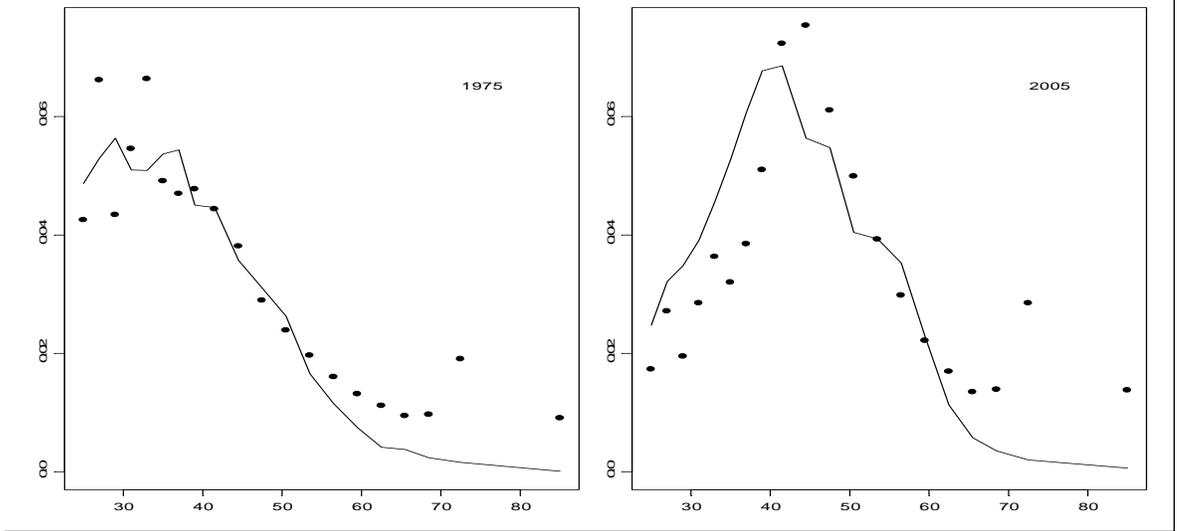


Figure 5.7. Fit to the female survey length data. Dotted line is predicted.

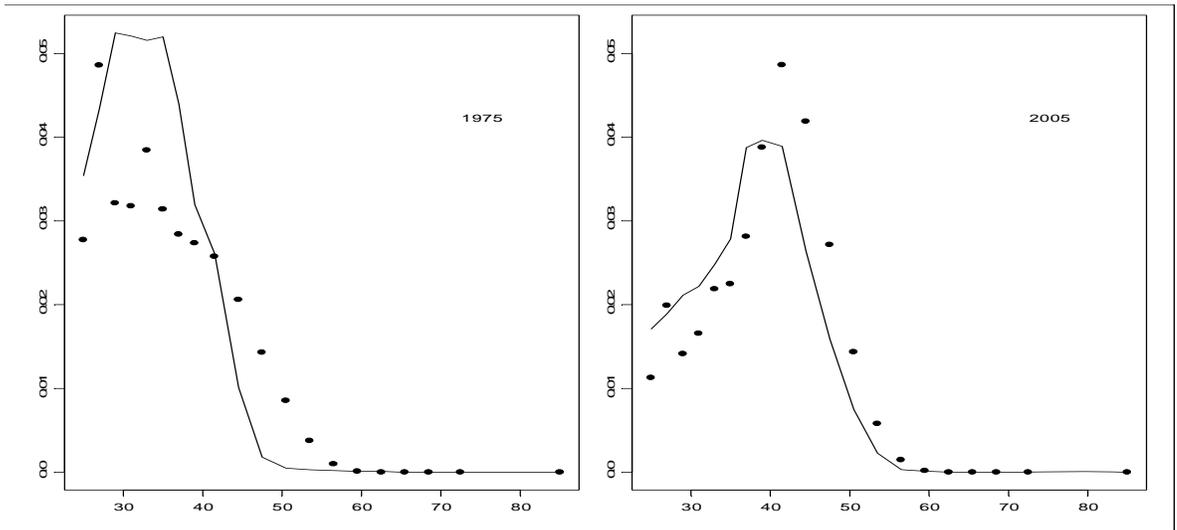


Figure 5.8. Fit to the male survey length data. Dotted line is predicted.

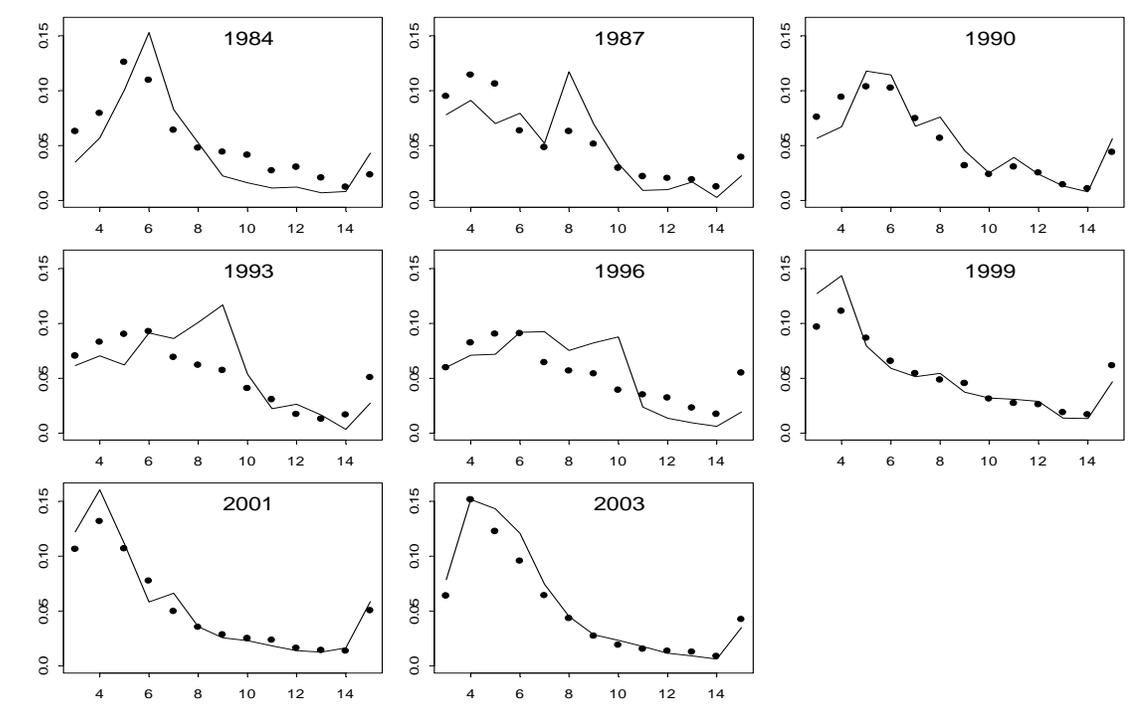


Figure 5.9. Fit to the female survey age data. The last age group is 15+. Dotted line is predicted.

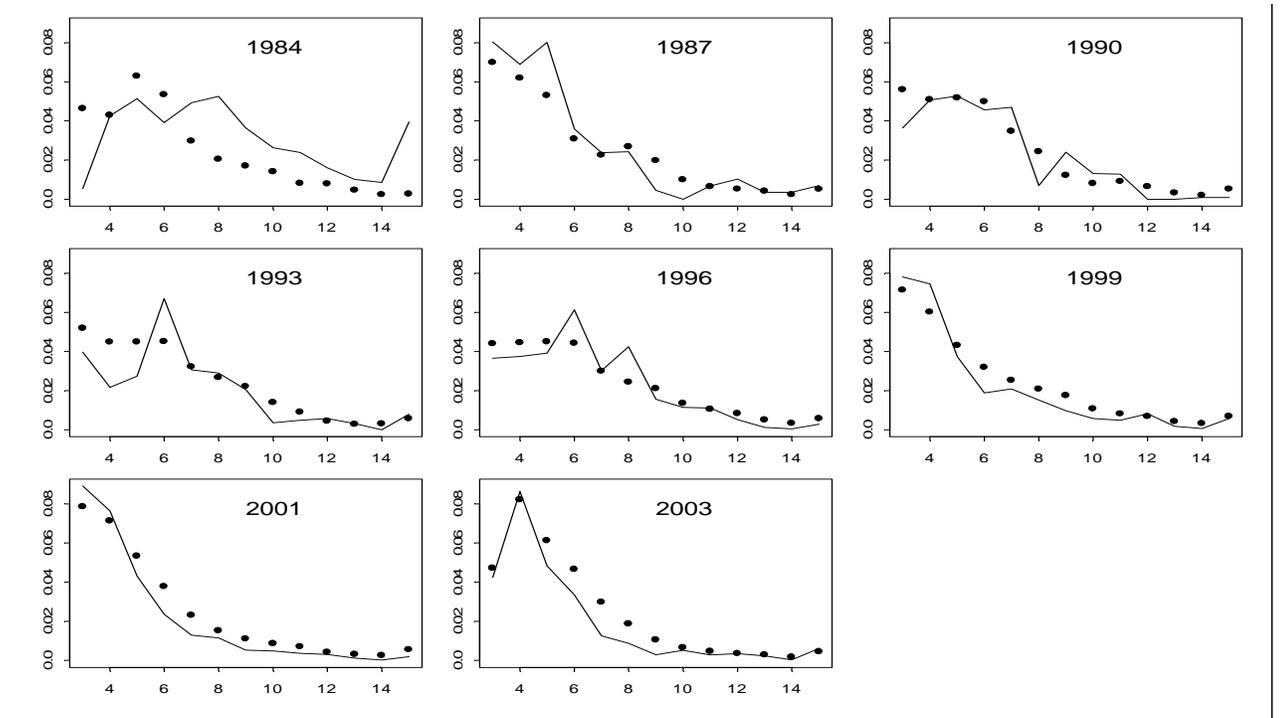


Figure 5.10. Fit to the male survey age data. The last age group is 15+. Dotted line is predicted.

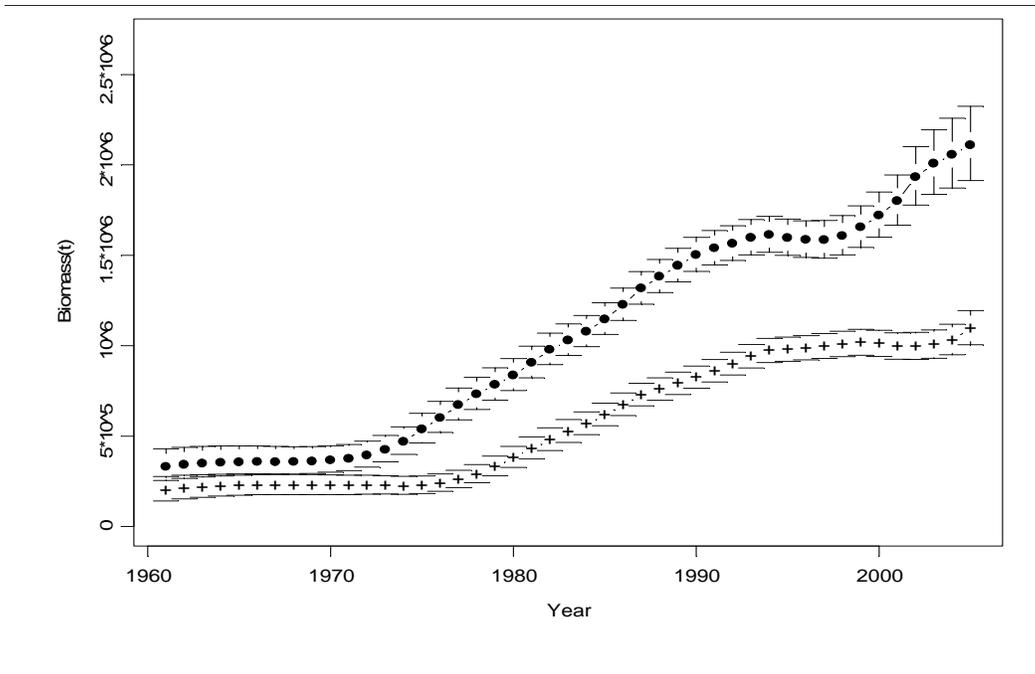


Figure 5.11. Age 3+ biomass (solid line) and female spawning biomass (line with +) from 1961 to 2005. The approximate lognormal 95% confidence intervals shown underestimate the uncertainty because variance in natural mortality and survey Q as well as other fixed parameters are not accounted for.

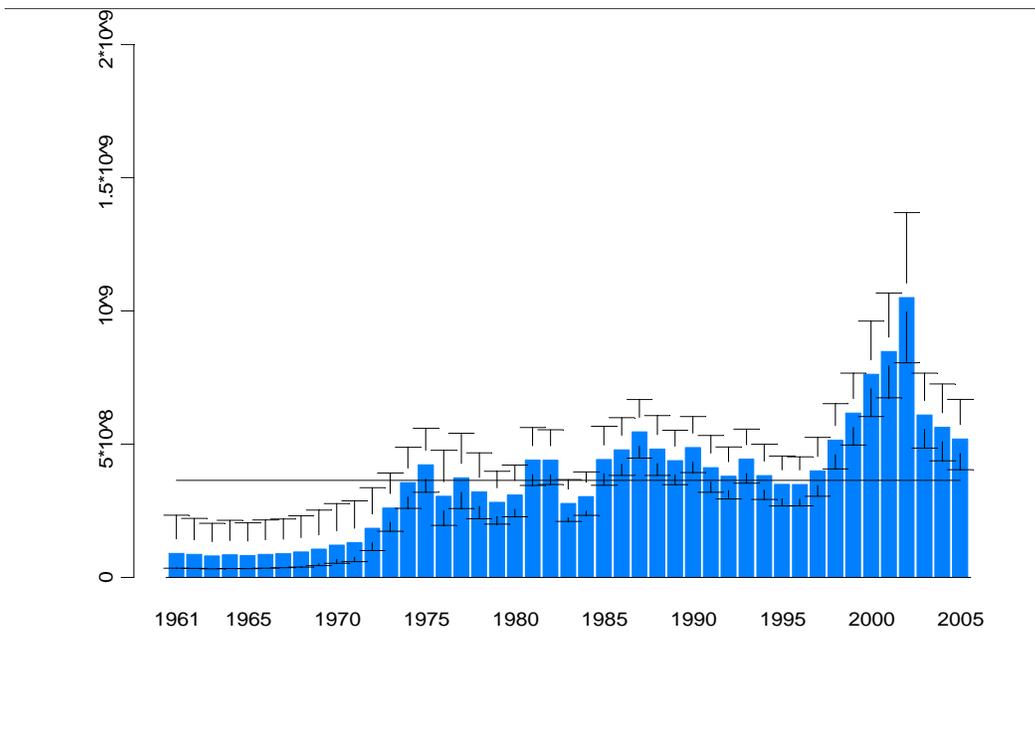


Figure 5.12. Age 3 estimated recruitments (male plus female) in numbers from 1961 to 2005, with approximate 95% confidence intervals. Horizontal line is average recruitment.

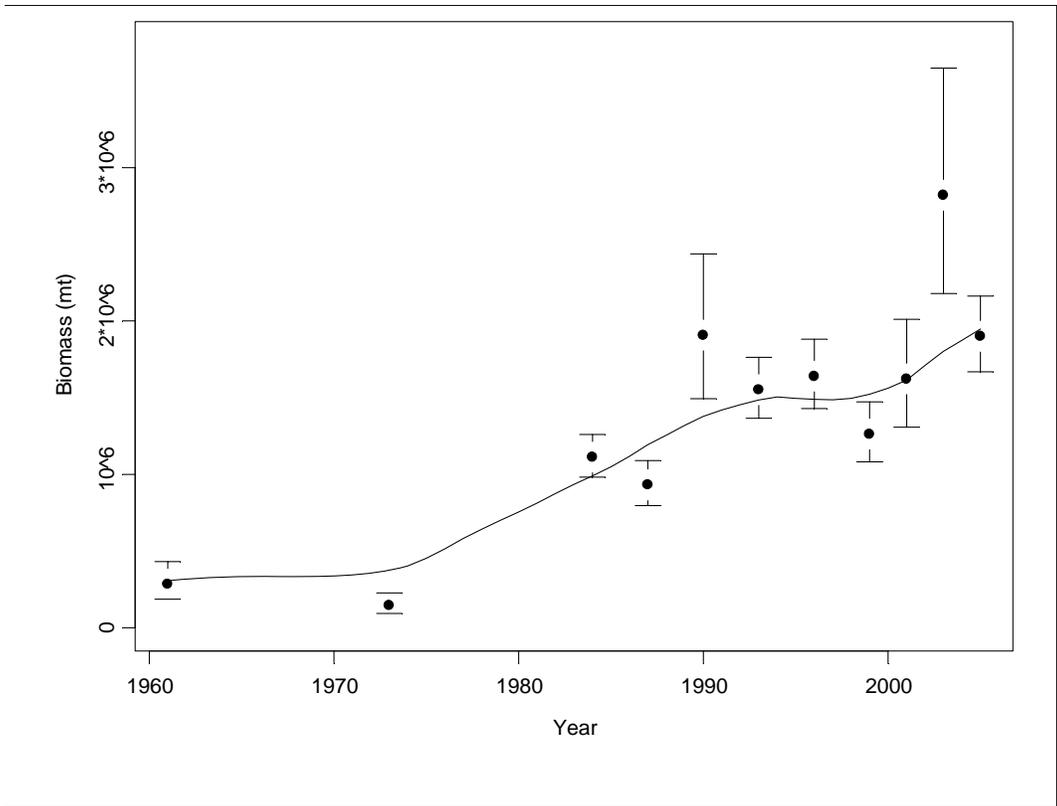


Figure 5.13. Fit to survey biomass estimates with approximate 95% log-normal confidence intervals for the observed survey biomass estimates 1961 to 2005.

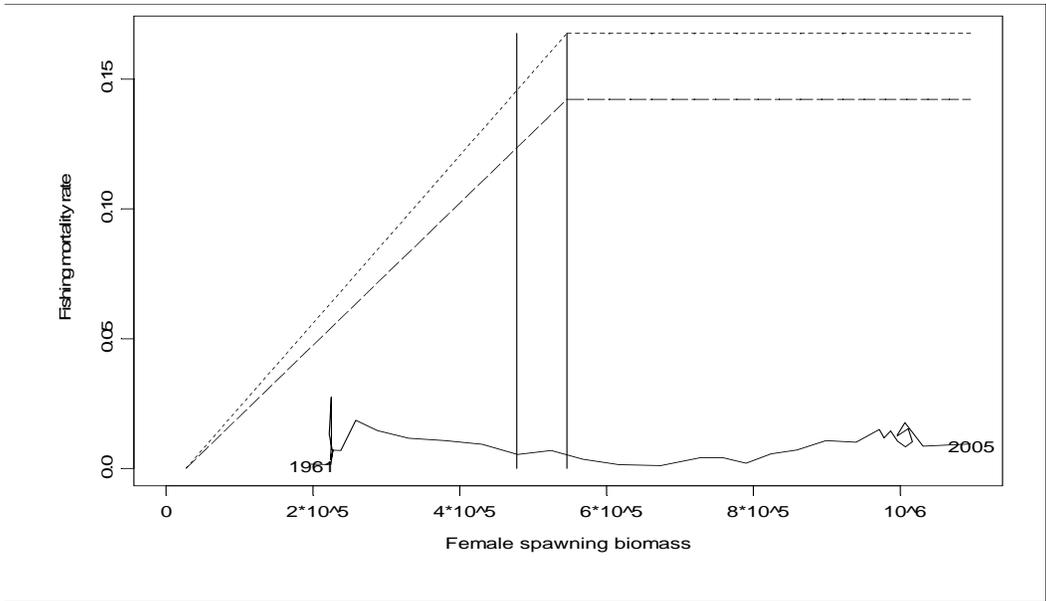


Figure 5.14. Fishing mortality rate and female spawning biomass from 1961 to 2005 (solid line). Dotted line is the overfishing harvest control rule and the dashed line is the target harvest control rule. Vertical lines are B35% and B40%.

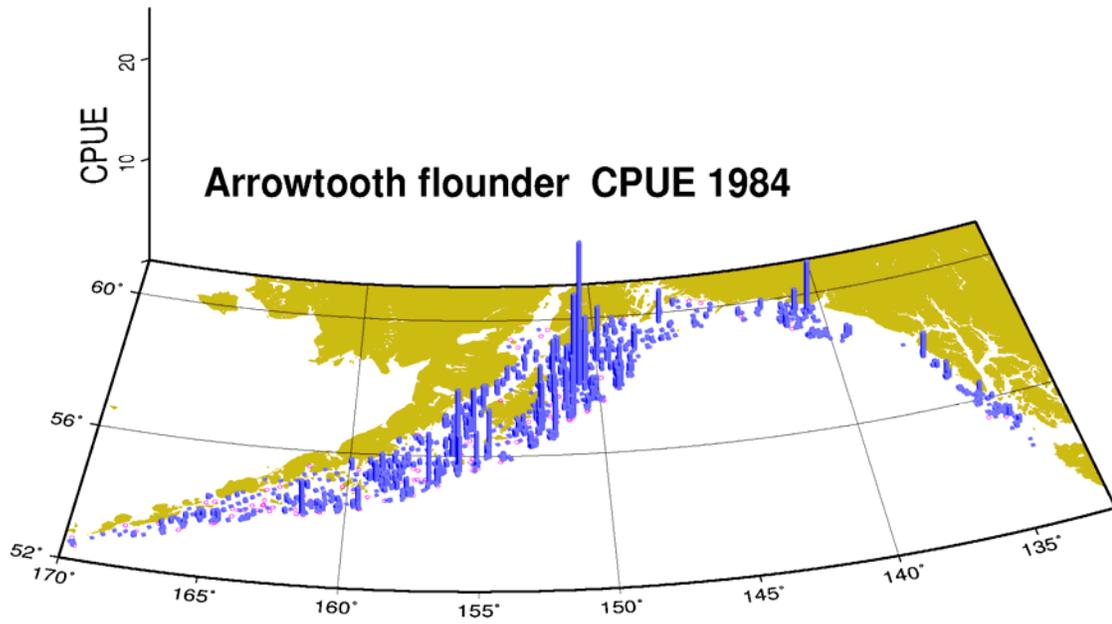


Figure 5.15. Arrowtooth flounder 1984 survey cpue by tow.

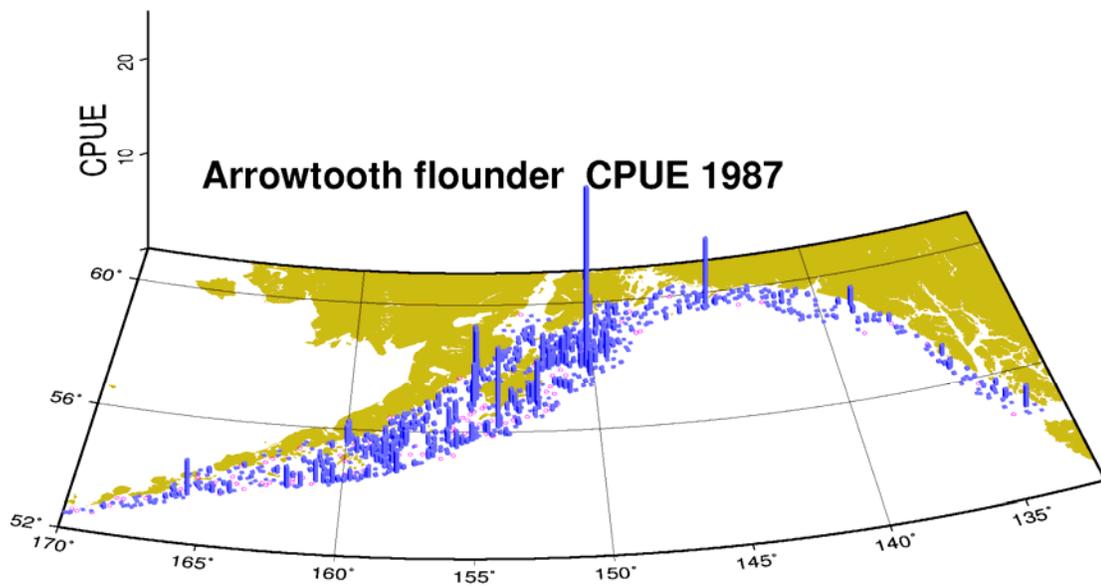


Figure 5.16. Arrowtooth flounder 1987 survey cpue by tow.

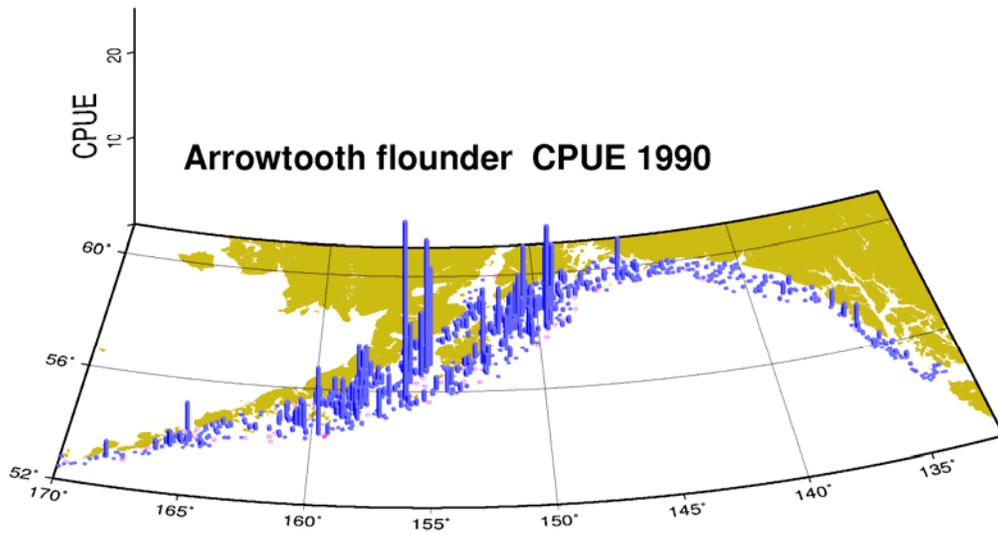


Figure 5.17. Arrowtooth flounder 1990 survey cpue by tow.

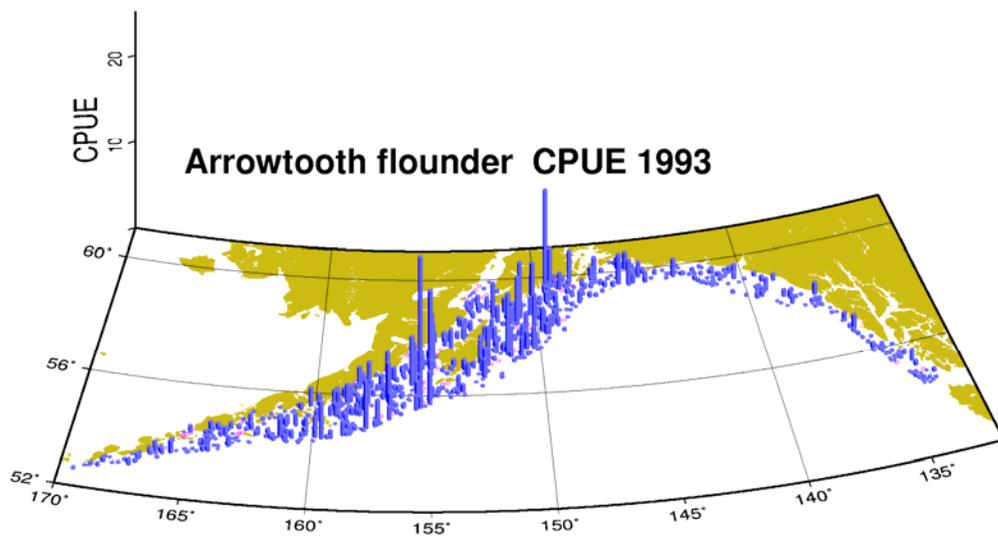


Figure 5.18. Arrowtooth flounder 1993 survey cpue by tow.

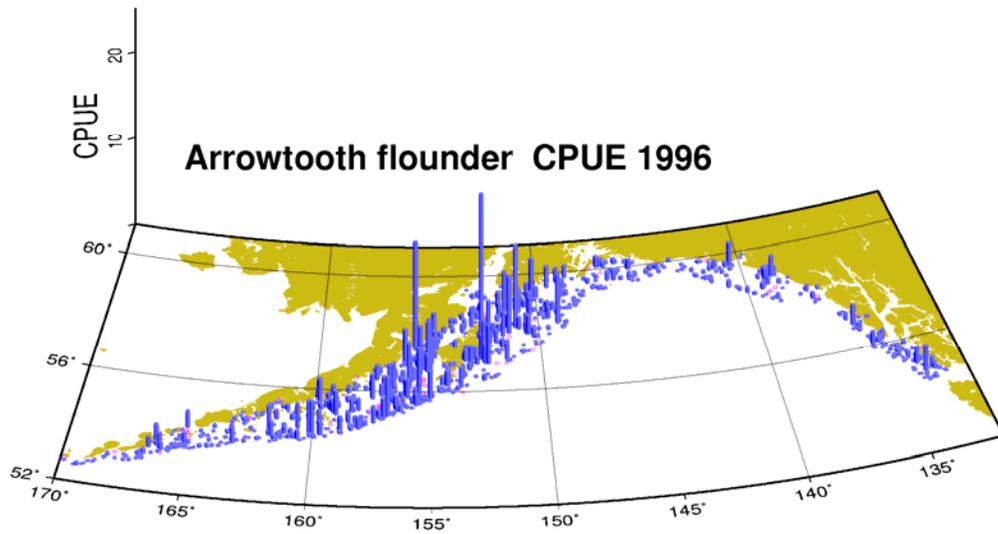


Figure 5.19. Arrowtooth flounder 1996 survey cpue by tow.

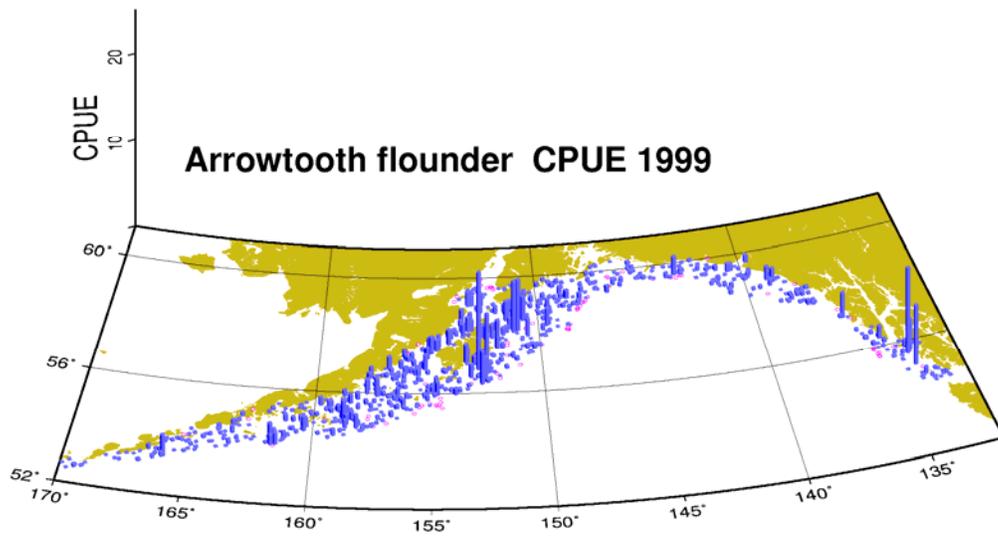


Figure 5.20. Arrowtooth flounder 1999 survey cpue by tow.

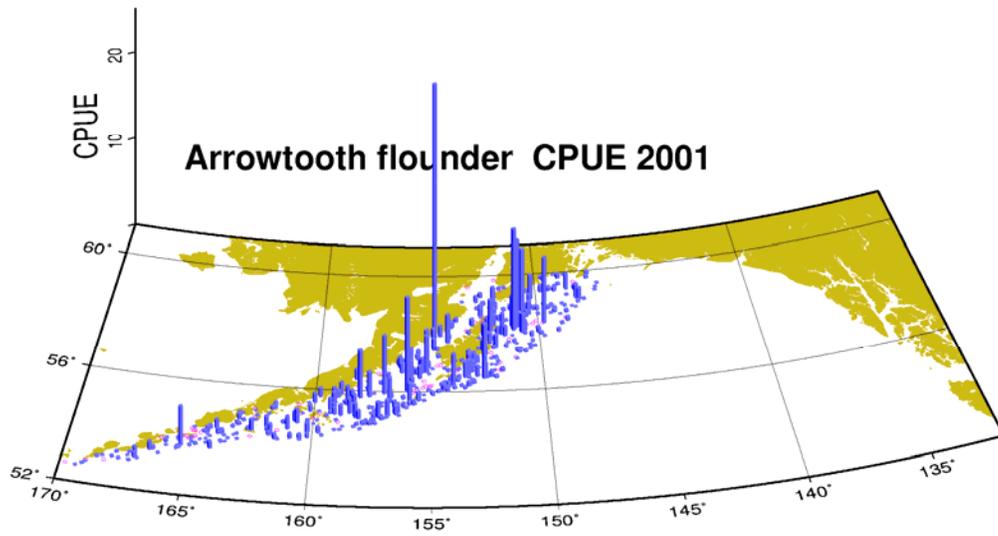


Figure 5.21. Arrowtooth flounder 2001 survey cpue by tow.

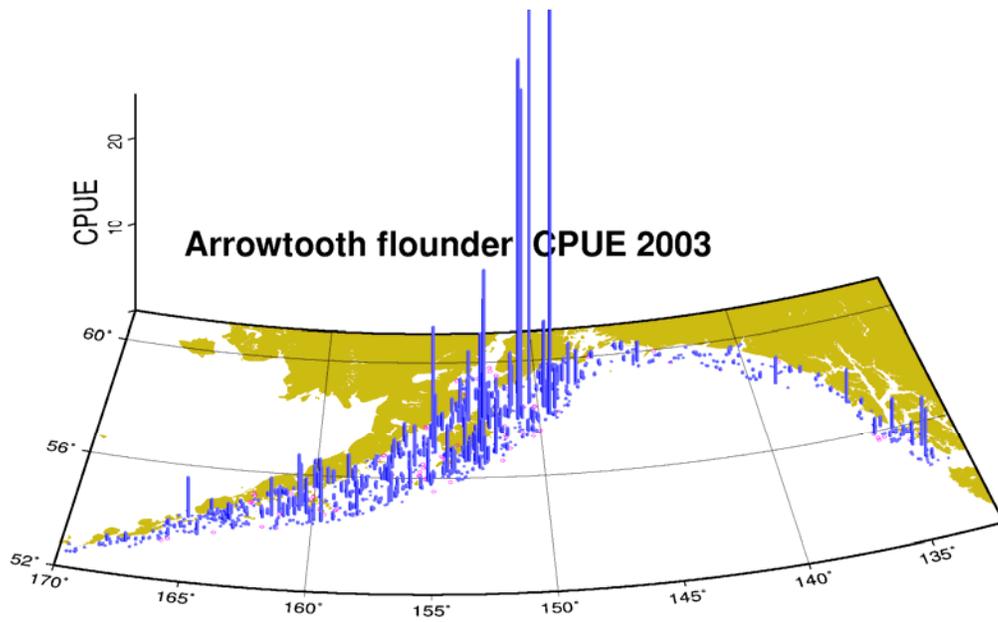


Figure 5.22. Arrowtooth flounder 2003 survey cpue by tow.

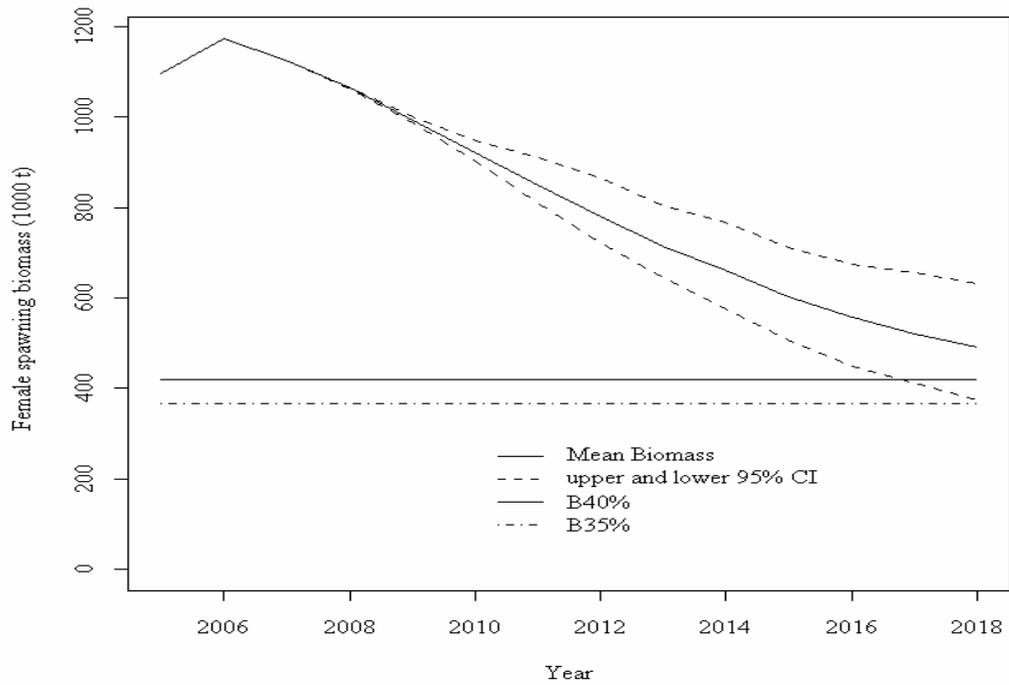


Figure 5.23. Projected female spawning biomass for 2006 to 2018 fishing at the maximum FABC=F40%.

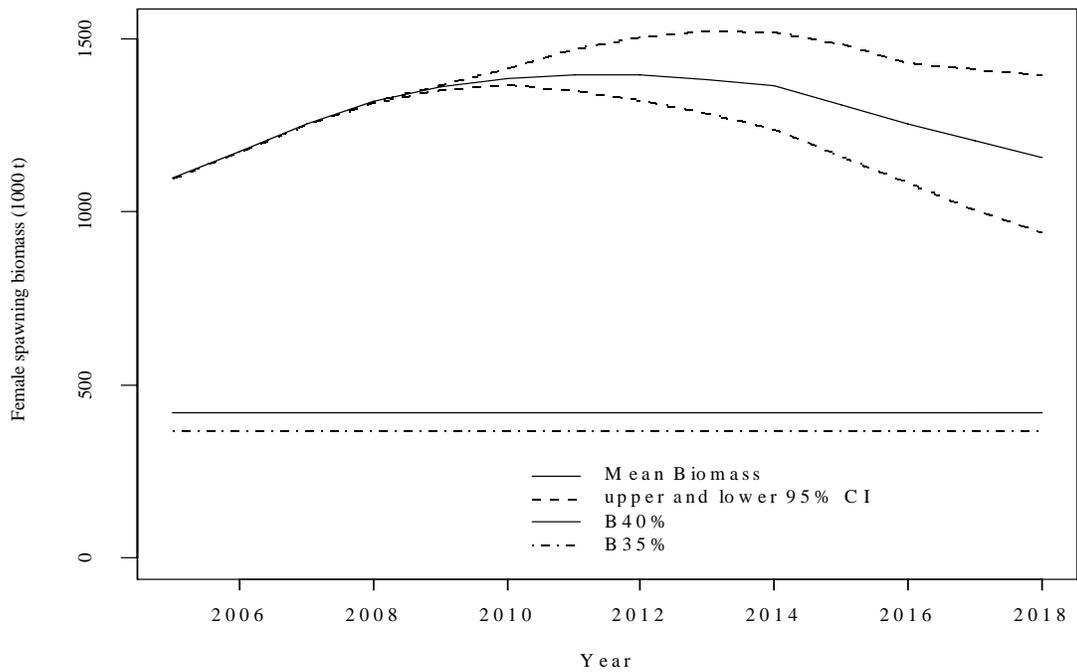


Figure 5.24. Projected female spawning biomass for 2006 to 2018 fishing at the average 5 year F.

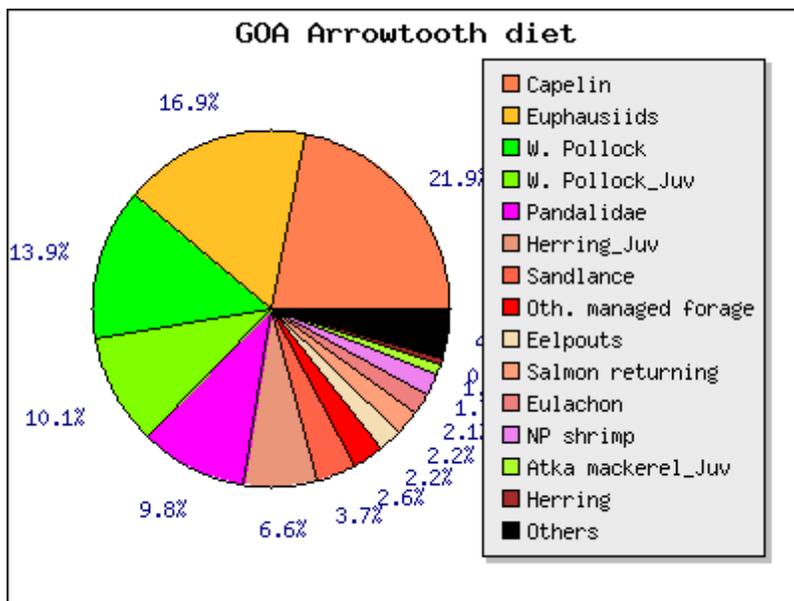


Figure 5.25. GOA arrowtooth flounder diet composition by species.

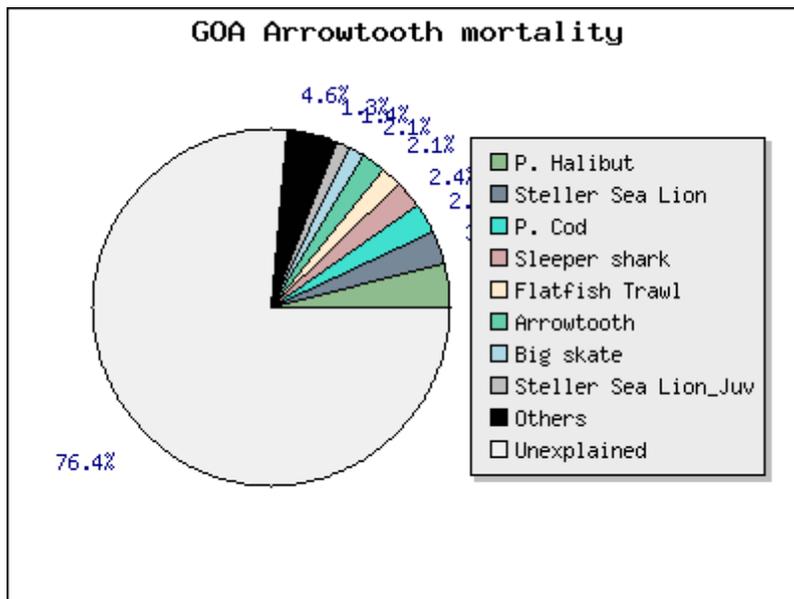


Figure 5.26. GOA arrowtooth flounder predation by species.

Appendix A.

Table A.1. Model equations describing the populations dynamics.

$N_{t,1} = R_t = R_0 e^{\tau_t}$	$\tau_t \sim N(0, \sigma_R^2)$		Recruitment
$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}} (1 - e^{-Z_{t,a}}) N_{t,a}$		$1 \leq t \leq T$	Catch
		$1 \leq a \leq A$	
$N_{t+1,a+1} = N_{t,a} e^{-Z_{t,a}}$		$1 < t \leq T$	Numbers at age
		$1 \leq a < A$	
$FSB_t = \sum_{a=1}^A w_a \phi_a N_{t,a}$			Female spawning biomass
$N_{t+1,A} = N_{t,A-1} e^{-Z_{t,A-1}} + N_{t,A} e^{-Z_{t,A}}$		$1 < t \leq T$	Numbers in “plus” group
$Z_{t,a} = F_{t,a} + M$			Total Mortality
$C_t = \sum_{a=1}^A C_{t,a}$			Total Catch in numbers
$p_{t,a} = C_{t,a} / C$			proportion at age in the catch
$Y_t = \sum_{a=1}^A w_{t,a} C_{t,a}$			Yield
$F_{t,a} = s_{t,a} E_t e^{\varepsilon_t}$	$\varepsilon_t \sim N(0, \sigma_R^2)$		Fishing mortality
$S_a \text{ for } a = 3 \text{ to } 13$			selectivity – smooth monotonically increasing function for fishery
$S_a \text{ for } a = 3 \text{ to } 13$			selectivity – ascending logistic for survey
$SB_t = Q \sum_{a=1}^A w_a s_{t,a}^s N_{t,a}$			survey biomass, Q = 1.

Table A.2. Likelihood components.

$\sum_{t=1}^T [\log(C_{t,obs}) - \log(C_{t,pred})]^2$	Catch using a lognormal distribution.
$\sum_{t=1}^T \sum_{a=1}^A nsamp_t * p_{obs,t,a} \log(p_{pred,t,a})$ - offset	age and length compositions using a multinomial distribution. Nsamp is the observed sample size. Offset is a constant term based on the multinomial distribution.
offset = $\sum_{t=1}^T \sum_{a=1}^A nsamp_t * p_{obs,t,a} \log(p_{obs,t,a})$	the offset constant is calculated from the observed proportions and the sample sizes.
$\sum_{t=1}^{ts} \left[\frac{\log \left[\frac{SB_{obs,t}}{SB_{pred,t}} \right]}{sqrt(2) * s.d.(\log(SB_{obs,t}))} \right]^2$	survey biomass using a lognormal distribution, ts is the number of years of surveys.
$\sum_{t=1}^T (\tau_t)^2$ $\sum_{a=3}^{15} (diff(diff(s_a)))^2$	Recruitment, where $\tau_t \sim N(0, \sigma_R^2)$ Smooth selectivities. The sum of the squared second differences.

Table A.3. List of variables and their definitions used in the model.

Variable	Definition
T	number of years in the model(t=1 is 1961 and t=T is the end year of the model)
A	number of age classes (A =13, corresponding to ages 3(a=1) to 15+)
w _a	mean body weight(kg) of fish in age group a.
ϕ _a	proportion mature at age a
R _t	age 3(a=1) recruitment in year t
R ₀	geometric mean value of age 3 recruitment
τ _t	recruitment deviation in year t
N _{t,a}	number of fish age a in year t
C _{t,a}	catch number of age group a in year t
p _{t,a}	proportion of the total catch in year t that is in age group a
C _t	Total catch in year t
Y _t	total yield(tons) in year t
F _{t,a}	instantaneous fishing mortality rate for age group a in year t
M	Instantaneous natural mortality rate
E _t	average fishing mortality in year t
ε _t	deviations in fishing mortality rate in year t
Z _{t,a}	Instantaneous total mortality for age group a in year t
s _a	selectivity for age group a

Table A.4. Estimated parameters for the Admodel builder model. There were 124 total parameters estimated in the model.

Parameter	Description
$\log(R_0)$	log of the geometric mean value of age 3 recruitment
τ_t 1961 $\leq t \leq$ 2005 , plus 14 parameters for the initial age composition equals 59.	Recruitment deviation in year t
$\log(f_0)$	log of the geometric mean value of fishing mortality
ε_t 1961 $\leq t \leq$ 2005 , 45 parameters	deviations in fishing mortality rate in year t
s_a for ages 3 to 13, 22 parameters	selectivity parameters for the fishery for males and females.
Slope and 50% for logistic function, 2 parameters	selectivity parameters for the survey for males and females.

Table A.5. Fixed parameters in the Admodel builder model.

Parameter	Description
$M = 0.2$ females , $M=0.35$ males	Natural mortality
$Q = 1.0$	Survey catchability
L_{inf} , L_{age2} , k , cv of length at age 2 and age 20 for males and females	von Bertalanffy Growth parameters estimated from the 1984-1996 survey length and age data.