7. Gulf of Alaska Arrowtooth Flounder Stock Assessment

Benjamin J. Turnock and Thomas K. Wilderbuer
NMFS Alaska Fisheries Science Center

Executive Summary

Changes in the input data

The 2009 survey biomass and length data were added to the model. Catch for 2007 was updated and 2008 and 2009 catch (to October 3, 2009) were added to the model. Fishery length data for 2007 was updated and 2008 added to the model. No fishery length data are currently available for 2009. No new survey age data are available. The 2007 and 2009 otoliths are scheduled to be aged and may be incorporated into the next full assessment in 2011.

Changes in assessment methodology

An age-based model was used with the same configuration as the 2007 assessment.

Changes in assessment results

The estimated age 3+ biomass from the model increased from 331,298 t in 1961 to a high of 2,187,450 t in 2006 and a slight decrease in biomass to 2009 at 2,155,780 t. Female spawning biomass in 2009 was estimated at 1,252,550 t, a 4% decline from the projected 2009 biomass (fishing at the average 5 year F) of 1,306,870 t from the 2007 assessment. The 2010 ABC using F40% was 215,882 t, a decrease from the 2009 ABC of 221,512 t. The 2010 OFL using F35% was 254,271 t. The 2011 ABC using F40% was estimated at 212,719 t and the 2011 OFL was 250,559 t, using the projection model and catch in 2010 estimated using the recent 5 year average F=0.0205. Projected biomass values, ABC and OFL, fishing at the average F=0.0205 in 2010 are,

	Age 3+ Biomass	**Female spawning biomass (t)**	**ABC**	**OFL**
2010	2,139,000	1,253,210	215,882	254,271
2011	2,118,000	1,243,920	212,719	250,559

The ABC by management area using $F_{40\%}$ was estimated by calculating the fraction of the 2009 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
2009 survey biomass percent by area	16.11%	67.82%	10.58%	5.50%	100.0%
ABC 2010	34,773	146,407	22,835	11,867	215,882
ABC 2011	34,263	144,262	22,501	11,693	212,719

SSC comments specific to arrowtooth flounder assessment

There were no specific SSC comments on the GOA arrowtooth flounder assessment in 2007 or 2008.

Introduction

Arrowtooth flounder (*Atheresthes stomias*) range from central California to the eastern Bering Sea and are currently one of 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, euphausids, 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 (see ecosystem considerations section).

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). Arrowtooth flounder spawn in deep waters (>400m) along the continental shelf break in winter (Blood et al. 2007).

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 7.1). Catch through 3 October 2009 was 22,072 t, a decrease from the 2008 catch of 29,293 t. Total allowable catch for 2009 was 8,000 t for the Western GOA, 5,000 t for the Eastern GOA, and 30,000 t for the Central GOA (43,000 t total). Table 7.2 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 54% to 69% in 2005-2009. 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%
2005	12,020	8,000	60.0%
2006	16,031	11,721	57.8%
2007	15,105	10,396	59.2%
2008	20,524	9,089	69.3%
2009	11,728	9,969	54.1%

Abundance and exploitation trends

The survey biomass estimates used in this assessment are from International Pacific Halibut Commission (IPHC) trawl surveys and NMFS groundfish surveys (Table 7.3). 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 7.3) 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 NMFS triennial surveys (starting in 1984) 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 80% at 27 cm (about age 3) to about 96% at greater than 45cm (equal to or greater than age 7 for females and age 10 for males) (Somerton et al. 2007). Somerton et al. (2007) estimated the effect of herding combined with escapement under the net to be an effective multiplier of about 1.3 on survey catch for arrowtooth flounder. The combination of escapement under the net and herding into the net indicates that abundance would be about 23% less than the estimated survey abundance (Q= 1.3).

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, unpub.). 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. Survey biomass in 2009 declined to 1,772,029 t from the 2007 estimate of 1,939,055 t. The 1984, 1987, 1999 2007 and 2009 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 7.4). 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 7.17 to 7.24). 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 7.23 and 7.24).

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	1960-2009
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, 2003,2005,2007,2009
Fishery size compositions	1977-1981,1984-1993,1995-2008
NMFS survey size compositions	1975,2007,2009
NMFS triennial trawl survey age composition data	1984,1987,1990,1993,1996,1999,2001, 2003,2005

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 2005 NMFS trawl surveys have been aged and used in the model (Table 7.5). Otoliths for the 2007 and 2009 surveys are scheduled to be analysed and if available, will be included in the next full assessment. Size composition data for the surveys are shown in Table 7.6.

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 134 parameters estimated in the model (Table A.4). The 18 selectivity parameters estimated in the model for the smooth selectivity functions were constrained so that the number of effectively free parameters would be less than 18. There were 49 fishing mortality deviates in the model which were constrained to be small, plus one mean fishing mortality parameter, to fit the observed catch closely. Twelve initial recruitment deviations were estimated to start the population in 1961. Recruitments deviations from 1961 to 2009 account for 49 parameters, plus one parameter for the mean recruitment. Survey selectivity was estimated separately for males and females (4 parameters total). 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 7.14). Model runs examining the effect of different natural mortality values for male arrowtooth flounder can be found in the Appendix of the 2000 SAFE. Differential natural mortality by sex can be a factor that needs consideration in management of targeted fish stocks, however, since GOA arrowtooth flounder is currently exploited at low levels, this effect is not a concern for this stock (Wilderbeur and Turnock 2009).

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

Growth was estimated from length and age data from 1984 to 2005 surveys. L_{inf} was estimated as 81.9 cm for females and 49.7 cm for males (Figure 7.2). The length at age 2 (L_2) for both sexes was estimated at 21 cm and k was 0.102 for females and 0.236 for males.

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

The mean length at age data from the surveys for older females increases from 1984 to the mid-1990's then decreases in 2005 for females (Table 7.8 and Figure 7.3). Younger females look similar by year. Males show similar trends, but to a lesser degree (Table 7.7 and Figure 7.4). Mean length at age is used to construct the age-length transition matrix for fitting length composition data for the fishery and the survey length data. The mean length at age for age 15 females is about 6 cm (about 4 cm for males) lower (in the current assessment model) than the mean length at age for 15 year-olds used in the 2005 assessment model.

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 1997). 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 2005 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 0.10 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 (2007, 2008 and 2009) of the model were conditioned to be close to the mean recruitment over the 26 year period from 1981 to 2006, due to less data to estimate recruitments for recent years and retrospective patterns. This constraint was also used in the 2005, 2007 and the current (2009) assessments. Without this constraint, recent recruitment would have been higher. Even with this constraint, a retrospective pattern still exists in biomass estimates from the 2009 and 2007 assessments (Figure 7.14).

Selectivity

Separate fishery selectivities were estimated for each age, however the shape of the selectivity curve was constrained to be a smooth function (Figure 7.1). 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 7.5 for females and Figure 7.6 for males. The model fit to the fishery and survey length data was improved from the 2005 model, with the change in growth used in the 2007 and 2009 assessments, however there is still some overestimation of medium to large female fish (Figures 7.5 and 7.7). 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 7.8). Age data are fit well for both females and males (Figures 7.9 and 7.10). The model estimates of survey biomass are higher than the survey for 1999, lower for 2003, close for 2001, 2005 and 2007, and higher than 2009 (Figure 7.13).

Model estimates of biomass

The model estimates of age 3+ biomass increased from a low of 361,298 t in 1961 to a high of 2,187,450 t in 2006 and slight decrease to 2,155,780 t in 2009 (Table 7.9 and Figure 7.11). The age 3+ biomass estimates are lower in the current assessment for recent years then for the 2007 assessment (Figure 7.14). Female spawning biomass is lower in the current assessment than the 2007 assessment due to lower survey biomass in 2009. Biomass is higher for the 2009 and 2007 assessments relative to the 2005 assessment due to the difference in growth used in the 2007 and 2009 assessments.

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 then reached a peak in 2002 (Table 7.9 and Figure 7.12). The 2007, 2008 and 2009 recruits were constrained to be near the long term harmonic mean. Recruitments in the current assessment are slightly lower than the 2007 assessment due the lower survey biomass in 2009 (Figure 7.15).

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, $F_{ofl} = F_{35\%}$, and F_{ABC} is less than or equal to $F_{40\%}$.

Yield for 2010 using $F_{40\%} = 0.183$ (2007 assessment $F_{40\%} = 0.186$) was estimated at 215,882 t (2009 ABC was 221,512 t). Yield at $F_{35\%} = 0.219$ (2007 assessment $F_{35\%} = 0.222$) was estimated at 254,271 t. Model estimates of fishing mortality have been well below target rates (Figure 7.16). Fishing mortality was estimated to be no higher than about 0.04 since 1961 and was about 0.017 in 2009.

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 1,197.060 t. $B_{35\%}$ (equilibrium spawning biomass with fishing at $F_{35\%}$) was estimated at 418,969 t and $B_{40\%}$ was 478,822 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 2009 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2010 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2009. 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 2010, 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 2008. (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 2005-2009 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 2009 and above its MSY level in 2020 under this scenario, then the stock is not overfished.)

Scenario 7: In 2010 and 2011, 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 2022 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 2005 to 2009, F equal to one half $F_{40\%}$, and F=0 from 2010 to 2014 (Table 7.10). Under scenario 6 above, the year 2009 female spawning biomass is 1,252,550 t and the year 2020 spawning biomass is 447,939 t, above the $B_{35\%}$ level of 418,969 t. For scenario 7 above, the year 2022 spawning biomass is 448,679 t also above $B_{35\%}$. Fishing at F40%, female spawning biomass would still be above B40% (478,822 t) in year 2020 (499,952 t, Figure 7.25). Female spawning biomass would be expected to decrease by about 14% over the next 12 years, if fishing continues at the last 5 year average fishing mortality (0.0205) (Figure 7.26).

Acceptable biological catch

ABC for 2010 using $F_{40\%}$ = 0.183 was estimated at 215,882 t. The projection model was used to estimate the 2011 ABC using $F_{40\%}$=0.183 at 212,719 t with the 2010 catch estimated using the average recent 5 year F=0.0205. In the 2007 assessment, the 2009 ABC using $F_{40\%}$ = 0.186 was estimated at 228,405 t (Turnock et al. 2007).

The ABC by management area using $F_{40\%}$ was estimated by calculating the fraction of the 2009 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
2009 survey biomass	285,427	1,201,756	187,441	97,406	1,772,029
ABC 2010	34,773	146,407	22,835	11,867	215,882
ABC 2011	34,263	144,262	22,501	11,693	212,719

Overfishing level

Yield at $F_{35\%}$ = 0.219 was estimated at 254,271 t for 2010 and 250,559 t for 2011 (fishing at average F=0.0205 for 2010).

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 2005 survey; continued aging will allow monitoring of growth trends.

Summary

Table 7.11 shows a summary of model results.

Ecosystem Considerations

See Appendix B.

Literature cited

Blood, D. M., A. C. Matarese, and M. S. Busby. 2007. Spawning, egg development, and early life history dynamics of arrowtooth flounder (Atheresthes stomias) in the Gulf of Alaska. U.S. Dep. Commer., NOAA Prof. Pap. NMFS 7, 28 p.

Brown, E. S. 1986. Preliminary results of the 1984 U.S.-Japan cooperative bottom trawl survey of the central and western Gulf of Alaska. In R.L. Major (editor), Condition of groundfish resources of the Gulf of Alaska as assessed in 1985, p. 259. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-106.

Brown, E.S. in prep. Comparison study of NMFS and ADFG trawl survey nets. NMFS.

Cullenberg, P. 1995. Commercialization of arrowtooth Flounder: The Next Step. Proceedings of the International Symposium on North Pacific Flatfish(1994: Anchorage, Alaska). pp623-630.

Clark, W. G. 1992. Alternative target levels of spawning biomass per recruit. Unpubl. manuscr., 5 p. Int. Pac. Hal. Comm., P.O. Box 95009, Seattle, WA 98145.

Fournier, D.A. and C.P. Archibald. 1982. A general theory for analyzing catch-at-age data. Can. J.Fish.Aquat.Sci. 39:1195-1207.

Greene, D.H., and J.K. Babbitt. 1990. Control of muscle softening and protease-parasite interactions in arrowtooth flounder, Atheresthes stomias. J. Food Sci. 55(2): 579-580.

Greiwank, A. and G.F. Corliss(eds). 1991. Automatic differentiation of algorithms: theory, implementation and application. Proceedings of the SIAM Workshop on the Automatic Differentiation of Algorithms, held Jan. 6-8, Breckenridge, CO. Soc. Indust. And Applied Mathematics, Philadelphia.

Hirshberger, W.A., and G.B. Smith. 1983. Spawning of twelve groundfish species in the Alaska and Pacific coast regions, 1975-81. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC:44, 50p.

Hoenig, J. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82: 898-903.

Hollowed, A.B., E. Brown, P. Livingston, B. Megrey, I. Spies and C. Wilson. 1995. Walleye Pollock. In: Stock Assessment and Fishery Evaluation Report for the 1996 Gulf of Alaska Groundfish Fishery. 79 p. Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

Hollowed, A. B., J. N. Ianelli, and P. A. Livingston. 2000. Including predation mortality in stock assessments: A case study involving Gulf of Alaska walleye pollock. ICES Journal of Marine Science, 57, pp. 279-293.

Methot, R. D. 1990. Synthesis model: An adaptable framework for analysis of diverse stock assessment data. Int. N. Pac. Fish. Comm. Bull. 50:259-277.

Murai, S., H. A. Gangmark, and R. R. French. 1981. All-nation removals of groundfish, Herring, and shrimp from the eastern Bering Sea and northeast Pacific Ocean, 1964-80. NWAFC report. 40 p.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer, 39:175-192.

Porter, R.W., B.J. Kouri, and G. Kudo. 1993. Inhibition of protease activity in muscle extracts and surimi from Pacific Whiting, Merluccius productus, and arrowtooth flounder, Atheresthes stomias. Mar. Fish. Rev. 55(3):10-15.

Press, W.H., S.A. Teukolsky, W.T.Vetterling, B.P. Flannery. 1992. Numerical Recipes in C. Second Ed. Cambridge Univ. Press. 994 p.

Reppond, K.D., D.H. Wasson, and J.K. Babbitt. 1993. Properties of gels produced from blends of arrowtooth flounder and Alaska pollock surimi. J. Aquat. Food Prod. Technol., vol. 2(1):83-98.

Rickey, M.H. 1995. Maturity, spawning, and seasonal movement of arrowtooth flounder, Atheresthes stomias, off Washington. Fish. Bull., U.S. 93(1):127-138.

Somerton, D.A., P.T. Munro, K.L. Weinberg, 2007. Whole-gear efficiency of a benthic survey trawl for flatfish. Fish. Bull. 105:278–291.

Turnock, B.J., T.K. Wilderbuer and E.S. Brown. 2005. Arrowtooth Flounder. In Stock Assessment and Fishery Evaluation Report for the 2005 Gulf of Alaska Groundfish Fishery. 30 p. Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

Turnock, B.J. and T.K. Wilderbuer. 2007. Arrowtooth Flounder. In Stock Assessment and Fishery Evaluation Report for the 2007 Gulf of Alaska Groundfish Fishery. 30 p. Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

Wasson, D.H., K.D. Reppond, J.K. Babbitt, and J.S. French. 1992. Effects of additives on proteolytic and functional properties of arrowtooth flounder surimi. J. Aquat. Food Prod. Technol., vol. 1(3/4):147-165.

Wilderbuer, T. K., and E. S. Brown. 1989. Flatfish. In T. K. Wilderbuer (editor), Condition of groundfish resources of the Gulf of Alaska as assessed in 1988. p. 199-218. U.S. Dep. Commer., NOAA Tech. Memo, NMFS F/NWC-165.

Wilderbuer, T. K., and E. S. Brown. 1995. Flatfish. In Stock Assessment and Fishery Evaluation Report for the 1996 Gulf of Alaska Groundfish Fishery. 21 p. Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

Wilderbuer, T.K. and B.J. Turnock. 2009. Differential Sex-Specific Natural Mortality of Arrowtooth flounder in Alaska: Implications for Exploitation and Management. North American Journal of Fisheries Management Vol. 29 (2).

Yang, M. S. 1993. Food Habits of the Commercially Important Groundfishes in the Gulf of Alaska in 1990. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-AFSC-22, 150p.

Zimmerman, M. 1997. Maturity and fecundity of arrowtooth flounder, Atheresthes stomias, from the Gulf of Alaska. Fish. Bull. 95:598-611.

Zimmerman, M., and P. Goddard. 1996. Biology and distribution of arrowtooth flounder, Atheresthes stomias, and Kamchatka flounders (A. evermanni) in Alaskan waters. Fish. Bull., U.S.

Table 7.1. Catch, ABC, OFL and TAC for arrowtooth flounder in the Gulf of Alaska from 1964 to 3 October, 2009. Arrowtooth flounder ABC was separated from Flatfish ABC after 1990.

Year	Catch(t)	ABC	OFL	TAC
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	343,300		
1991	10,034	340,100		20,000
1992	15,970	303,889	427,220	25,000
1993	15,559	321,287	451,690	30,000
1994	23,560	236,240	275,930	30,000
1995	18,428	198,130	231,420	35,000
1996	22,583	198,130	231,420	35,000
1997	16,319	197,840	280,800	35,000
1998	12,975	208,337	295,970	35,000
1999	16,207	217,106	308,875	35,000
2000	24,252	145,361	173,915	35,000
2001	19,964	148,151	173,546	38,000
2002	21,231	146,264	171,057	38,000
2003	29,994	155,139	181,394	38,000
2004	15,304	194,900	228,134	38,000
2005	19,770	194,900	228,134	38,000
2006	27,653	177,800	207,700	38,000
2007	25,494	184,008	214,828	43,000
2008	29,293	226,470	266,914	43,000
2009	22,072	221,512	261,022	43,000

Table 7.2. Catches from NMFS research cruises from 1977 to 2002.

Year	Catch (t)	Year	Catch (t)
1977	29.3	1994	36.7
1978	30.6	1995	173.5
1979	38.9	1996	154.6
1980	36.7	1997	40.6
1981	151.5	1998	115.6
1982	90.2	1999	101.5
1983	61.4	2000	24.0
1984	223.9	2001	83.9
1985	149.4	2002	11.0
1986	179.0	2003	
1987	297.4	2004	
1988	22.0	2005	
1989	64.1	2006	
1990	228.1	2007	
1991	27.7	2008	
1992	32.1	2009	111.6
1993	255.4		

Table 7.3. 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
NMFS 2007	1,939,055	150,059	820	1000
NMFS 2009	1,772,029	159,402	823	1000

* 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 7.4. Survey biomass estimates (t) for 1993 to 2009 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**	**2007**	**2008**
Western	212,332	202,594	143,374	188,100	341,620	215,287	263,856	285,427
Central	1,117,361	1,176,714	845,176	1,181,848	2,198,829	1,441,111	1,437,886	1,201,756
Eastern	222,015	260,324	273,490	251,943*	282,379	243,381	237,313	284,846

Table 7.5. **Age** 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.

females	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1984	0.01	0.00	3.61	5.87	10.37	15.82	8.55	5.41	2.30	1.65	1.17	1.25	0.70	0.83	2.91	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	1.93	7.86	9.18	7.05	8.00	5.23	11.81	6.98	3.37	0.91	0.98	1.69	0.27	0.30	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	2.81	5.48	6.50	11.40	11.07	6.52	7.34	4.38	2.41	3.77	2.29	1.28	0.74	0.84	0.64	0.96	0.61	0.21	0.00	0.16
1993	0.13	4.40	6.54	6.03	6.44	7.65	8.12	7.88	9.60	4.60	2.54	2.77	1.63	1.05	0.46	0.23	0.33	0.13	0.02	0.02	0.03
1996	0.03	3.93	5.71	6.76	6.83	8.74	8.79	7.17	7.84	8.35	2.27	1.28	0.89	0.55	0.14	0.14	0.00	0.01	0.00	0.01	0.00
1999	0.09	10.46	10.78	12.16	6.74	5.00	4.35	4.62	3.17	2.72	2.62	2.45	1.16	1.13	0.69	0.21	0.43	0.04	0.13	0.00	0.17
2001	0.12	16.06	9.44	12.38	8.60	4.50	5.12	2.76	1.98	1.79	1.41	1.07	0.97	1.27	0.88	0.59	0.42	0.14	0.09	0.07	0.09
2003	0.79	6.73	7.04	13.58	12.84	10.83	6.67	4.03	2.55	2.08	1.58	1.05	0.81	0.56	0.55	0.45	0.17	0.29	0.10	0.11	0.09
2005	0.24	2.75	4.89	5.64	11.87	12.66	12.59	7.10	2.66	1.69	2.45	1.62	0.98	0.75	0.87	0.78	0.28	0.41	0.03	0.14	0.00
Males	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1984	0.00	0.00	0.56	4.42	5.31	4.05	5.10	5.44	3.76	2.72	2.46	1.66	1.05	0.88	2.15	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	8.10	6.95	8.08	3.62	2.40	2.44	0.45	0.00	0.69	1.03	0.35	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	2.51	3.53	4.90	5.10	4.42	4.54	0.67	2.33	1.27	1.24	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.08	2.90	3.75	2.53	2.70	6.70	3.20	2.63	1.93	1.08	0.77	0.45	0.24	0.12	0.09	0.11	0.00	0.04	0.00	0.09	0.00
1996	0.07	2.64	3.47	3.54	3.70	5.82	2.88	4.04	1.48	1.09	1.06	0.50	0.12	0.05	0.05	0.00	0.05	0.00	0.00	0.00	0.00
1999	0.46	6.75	6.62	6.32	3.16	1.60	1.77	1.29	0.83	0.49	0.41	0.69	0.15	0.05	0.14	0.00	0.15	0.00	0.00	0.00	0.00
2001	0.25	8.75	6.88	5.89	3.32	1.82	0.99	0.89	0.41	0.37	0.28	0.23	0.09	0.02	0.02	0.02	0.01	0.00	0.00	0.00	0.00
2003	0.58	3.96	3.80	7.72	4.33	3.00	1.12	0.79	0.26	0.46	0.25	0.31	0.20	0.03	0.18	0.09	0.05	0.00	0.00	0.00	0.00
2005	0.34	1.59	4.32	3.67	4.23	8.27	2.53	0.89	0.92	1.01	0.54	0.60	0.24	0.19	0.17	0.05	0.03	0.01	0.00	0.00	0.00

Table 7.6. **Length** (cm) data from triennial surveys in 1984 through 2009. The numbers are percentages, where the female plus the male numbers add to 100 within a year.

Female	22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58	61	64	67	70	75+
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
2007	2.19	3.08	3.67	1.70	2.76	2.74	2.77	3.32	3.71	6.51	8.98	6.89	8.65	5.61	2.51	1.74	0.81	0.50	0.27	0.31	2.19
2009	1.89	1.72	2.60	3.44	3.89	3.84	3.94	3.71	3.83	4.84	4.10	4.81	7.12	9.04	5.58	2.69	1.21	0.61	0.31	0.26	0.14
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
2007	1.45	2.15	2.54	1.07	1.86	1.72	1.98	2.93	5.20	6.44	2.87	0.67	0.33	0.04	0.00	0.01	0.00	0.00	0.00	0.00	1.45
2009	1.40	1.17	1.80	2.14	2.71	2.49	2.26	2.29	2.30	3.82	4.30	2.47	0.93	0.27	0.06	0.00	0.00	0.00	0.00	0.00	0.00

Table 7.7. Mean length (cm) at age for male arrowtooth flounder from triennial surveys 1984 through 2005.

	1984	1987	1990	1993	1996	1999	2001	2003	2005
1				15.8	14.5	12.7	14.3	15.0	14.8
2		23.8		21.4	20.7	20.3	21.2	21.1	20.1
3	22.3	28.4	28.6	27.6	26.3	26.6	28.0	26.3	25.2
4	26.0	33.1	33.6	31.9	34.0	31.6	34.1	32.5	30.3
5	29.9	36.9	37.2	36.9	35.3	37.0	38.2	34.7	35.3
6	33.6	41.1	39.4	40.9	41.1	40.8	41.2	38.7	38.7
7	36.1	41.2	41.8	42.2	43.6	42.3	43.3	43.1	41.8
8	37.8	42.5	43.7	44.3	44.7	45.3	45.3	47.0	42.6
9	39.3	42.8	44.5	45.7	46.9	46.5	46.8	45.7	45.0
10	40.1		45.3	45.5	46.9	49.0	47.9	47.9	47.5
11	41.7	42.5	46.2	46.2	48.1	47.9	47.8	48.2	46.2
12	42.6	42.9		48.8	49.1	47.8	49.3	48.2	47.4
13	42.9	45.0		47.1	49.3	51.2	50.6	49.0	48.9
14	44.3	45.0	51.0	40.0	51.0	52.0	51.6	52.7	47.6
15	47.5			48.0	52.0	50.8	49.5	50.0	49.9
16				47.0			52.2	51.4	50.0
17					51.0	48.3	51.8	50.7	51.0
18				52.0				63.0	53.0
19								55.0	55.1
20				48.0					

Table 7.8. Mean length (cm) at age for female arrowtooth flounder from triennial surveys 1984 through 2005.

	1984	1987	1990	1993	1996	1999	2001	2003	2005
1				15.4	13.3	12.8	14.4	15.1	14.7
2		23.0	22.6	21.5	21.5	20.3	20.8	21.0	20.4
3	25.2	30.1	27.9	27.6	26.3	26.8	28.1	26.2	26.0
4	31.5	35.3	33.2	32.5	32.9	33.0	34.4	31.1	30.5
5	38.0	38.6	38.1	39.4	37.4	38.5	38.4	37.6	35.2
6	42.3	44.9	43.5	41.7	42.1	42.2	43.5	41.6	40.7
7	46.6	47.2	45.4	46.5	46.6	47.2	46.8	46.1	44.5
8	50.8	50.1	49.1	48.5	49.7	51.2	48.2	49.2	47.8
9	54.0	51.7	51.7	52.5	53.6	54.3	52.6	53.3	53.0
10	56.7	50.4	55.8	55.6	54.8	56.2	55.2	54.0	56.4
11	58.9	50.2	58.3	55.8	59.2	60.4	60.2	58.1	57.3
12	60.8	51.5	58.3	55.9	63.8	63.1	61.0	62.4	57.8
13	62.8	55.2	58.5	61.5	64.7	65.6	64.1	65.3	59.4
14	63.9	51.0	63.8	59.7	68.2	65.6	65.9	66.3	59.1
15	66.8	57.0	56.2	60.5	73.7	68.6	68.4	65.0	61.2
16			60.8	67.2	68.3	68.4	69.8	67.2	64.0
17			74.7	64.4		69.8	70.8	73.0	61.7
18			73.4	69.1	81.0	74.5	75.5	71.9	60.2
19			63.0	76.7		74.5	74.5	73.4	65.5
20				70.6	82.0		73.0	73.2	63.9
21			70.0	81.2		54.0	80.8	71.7	
22						82.0		79.0	
23				79.0			77.7		

Table 7.9. Estimated age 3+ population biomass(t), female spawning biomass(t) and age 3 recruits(1,000’s) from the current assessment and from the 2007 assessment.

Year	age 3+ biomass	Age 3+ biomass 2007 assessment	Female spawning biomass	Female spawning biomass 2007 assessment	Age 3 recruits (1,000's)	Age 3 recruits(1000’s) 20075 assessment
1961	361,298	362,688	197,364	197,773	121,916	122,527
1962	370,784	372,234	203,070	203,554	122,616	122,880
1963	378,146	379,575	207,265	207,858	118,540	118,483
1964	384,997	386,327	210,873	211,591	123,647	123,349
1965	390,786	391,923	214,454	215,285	121,989	121,375
1966	395,169	396,013	218,108	219,009	117,918	116,957
1967	396,438	396,891	220,049	220,958	116,035	114,706
1968	397,890	397,871	221,975	222,825	119,119	117,552
1969	400,741	400,189	224,259	224,985	125,192	123,444
1970	406,079	404,932	226,585	227,123	136,949	134,916
1971	413,032	411,347	228,035	228,318	146,152	144,526
1972	438,381	436,435	229,871	229,843	247,518	247,399
1973	476,909	474,812	229,414	229,018	312,860	312,698
1974	533,354	531,954	226,024	225,229	411,492	415,845
1975	622,288	621,850	229,779	228,639	520,106	524,250
1976	691,226	691,205	242,099	240,734	323,629	323,350
1977	767,176	767,684	265,724	264,331	404,046	405,258
1978	821,990	822,858	298,993	297,844	331,660	332,048
1979	868,710	869,805	345,532	344,913	320,655	320,772
1980	915,817	917,026	397,188	397,150	362,492	362,443
1981	982,879	983,995	443,443	443,824	510,543	509,679
1982	1,054,370	1,055,650	482,720	483,368	512,277	513,554
1983	1,097,550	1,099,110	516,950	517,769	318,178	319,810
1984	1,133,560	1,135,480	548,157	549,071	345,813	347,406
1985	1,190,240	1,192,450	584,754	585,680	502,911	504,002
1986	1,258,660	1,261,770	628,526	629,556	550,929	555,314
1987	1,346,680	1,350,870	669,852	671,017	653,134	658,146
1988	1,417,520	1,422,570	691,999	693,255	583,189	586,922
1989	1,479,190	1,485,560	714,147	715,626	527,679	533,850
1990	1,542,530	1,550,490	744,216	746,026	575,540	582,948
1991	1,579,330	1,588,780	780,936	783,277	471,648	477,823
1992	1,600,380	1,611,650	822,926	825,959	441,759	450,166
1993	1,619,980	1,633,480	860,825	864,642	507,581	518,315
1994	1,620,900	1,636,730	890,289	895,095	422,485	432,799
1995	1,595,760	1,614,180	900,143	906,040	386,668	398,765
1996	1,571,410	1,592,570	906,832	913,895	383,704	396,724
1997	1,550,970	1,575,660	906,927	915,292	433,019	450,979
1998	1,556,850	1,586,500	906,886	916,789	549,989	575,288
1999	1,592,490	1,628,570	904,013	915,555	661,949	693,751
2000	1,667,350	1,712,390	889,964	903,265	872,925	917,319
2001	1,780,740	1,835,900	868,855	884,328	1,052,800	1,098,970
2002	1,959,770	2,022,940	862,483	880,814	1,289,210	1,320,190
2003	2,087,660	2,153,650	871,794	893,944	861,711	866,592
2004	2,136,780	2,202,930	901,761	928,970	506,989	508,789
2005	2,176,790	2,245,770	976,369	1,009,480	537,405	566,704
2006	2,187,450	2,258,230	1,072,660	1,111,220	542,678	564,939
2007	2,185,630	2,256,030	1,166,130	1,208,120	616,167	626,355
2008	2,176,780		1,230,890		597,096	
2009	2,155,780		1,252,550		569,452	

Table 7.10. Projected female spawning biomass and yield from 2010 to 2014.

	Year	Female spawning biomass(1000 t)	Yield(1000 t)
F=F40%			
	2010	1253.21	215.882
	2011	1089.23	188.338
	2012	955.709	166.861
	2013	847.44	150.122
	2014	760.485	136.983
F=0.0205(avg F)			
	2010	1253.21	25.676
	2011	1243.96	25.294
	2012	1235.09	24.995
	2013	1225.34	24.743
	2014	1214.77	24.498
F=0.5 F40%			
	2010	1253.21	110.518
	2011	1174.72	103.289
	2012	1105.50	97.296
	2013	1044.13	92.285
	2014	990.195	88.002
F=0			
	2010	1253.21	0
	2011	1264.98	0
	2012	1275.91	0
	2013	1284.43	0
	2014	1290.48	0

Table 7.11. 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		10 females, 11 males
Reference fishing mortalities		
	$F_{40\%}$	0.183
	$F_{35\%}$	0.219
Biomass at MSY		N/A
Equilibrium unfished Female Spawning biomass		1,197,060
$B_{40\%}$ Female Spawning biomass fishing at $F_{40\%}$		478,822
$B_{35\%}$ Female Spawning biomass fishing at $F_{35\%}$		418,969
Projected 2010 biomass		
	Total(age 3+)	2,139,000
	Spawning	1,253,210
Overfishing level for 2010		254,271

Figures

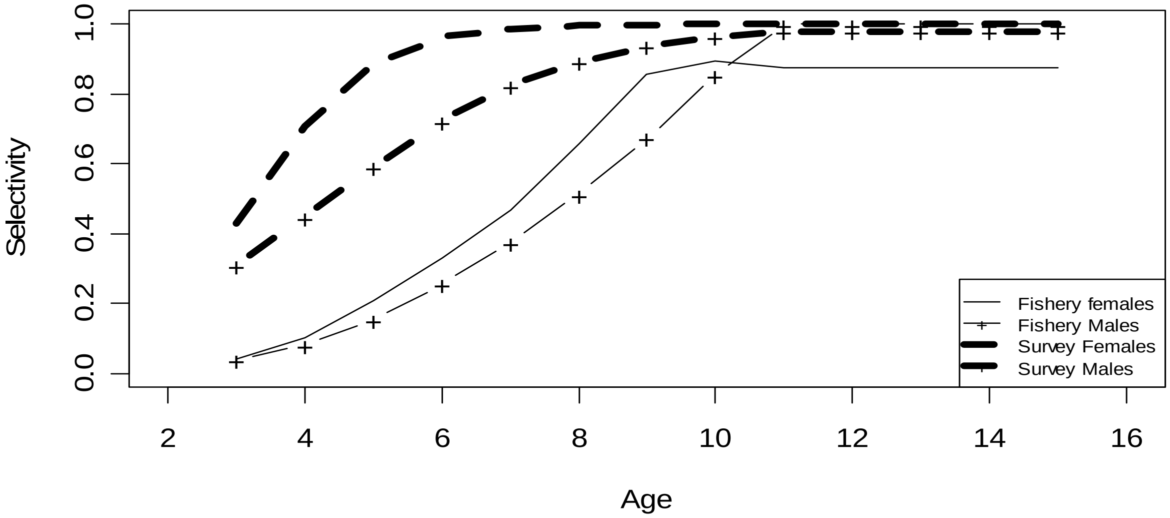

Figure 7.1. Selectivities for the fishery (solid line) and survey (dotted line). Males are the lines with the + symbol.

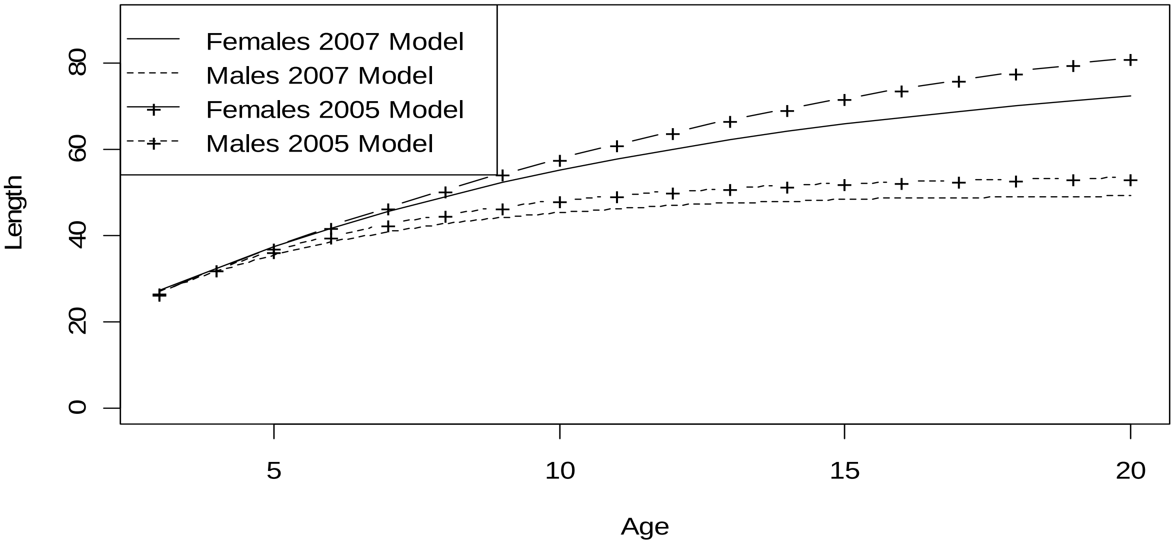

Figure 7.2. Mean length at age estimated from the 1984 through 2005 survey combined used to estimate the length-age transition matrix for the 2007 model, compared to the mean length at age used in the 2005 assessment model.

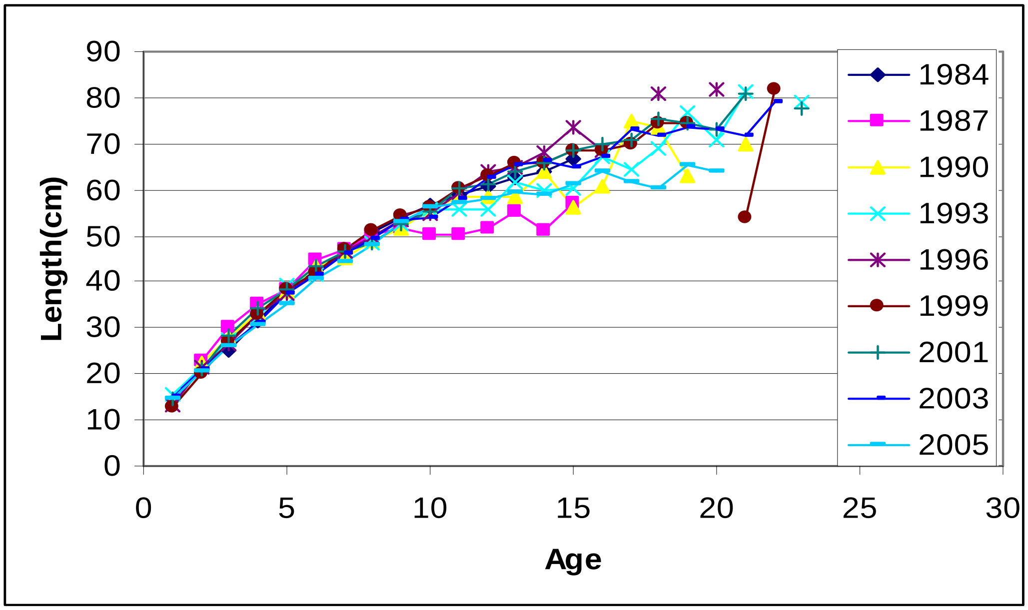

Figure 7.3. Mean length at age for female arrowtooth flounder from survey data 1984 to 2005.

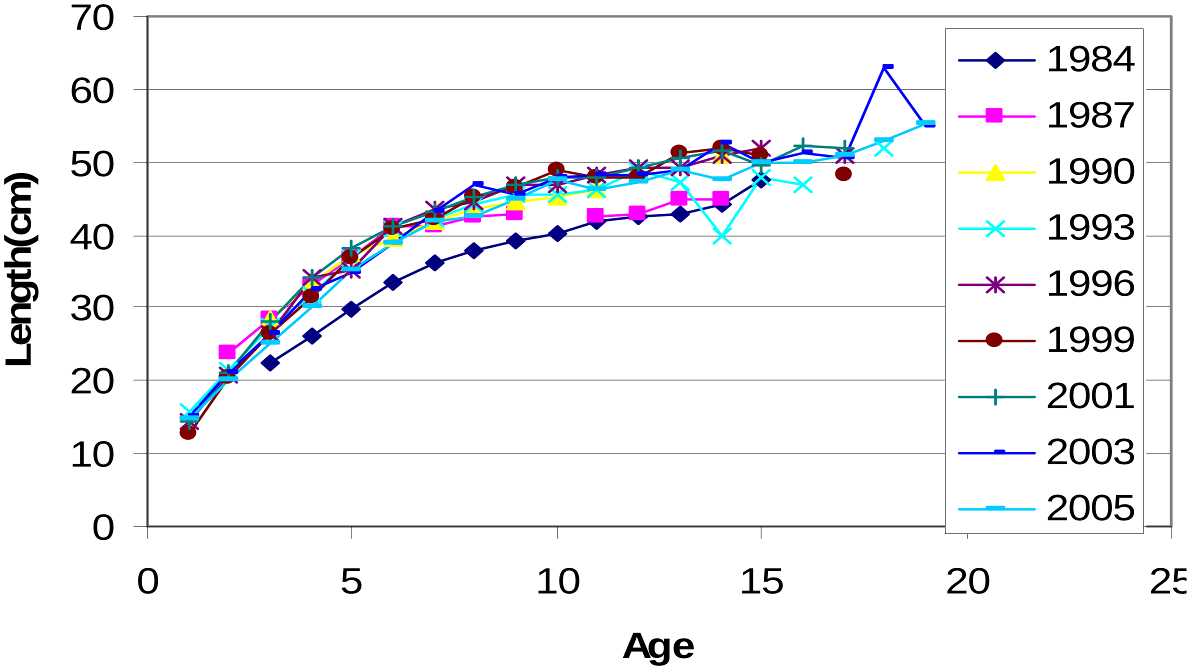

Figure 7.4. Mean length at age for male arrowtooth flounder from survey data 1984 to 2005.

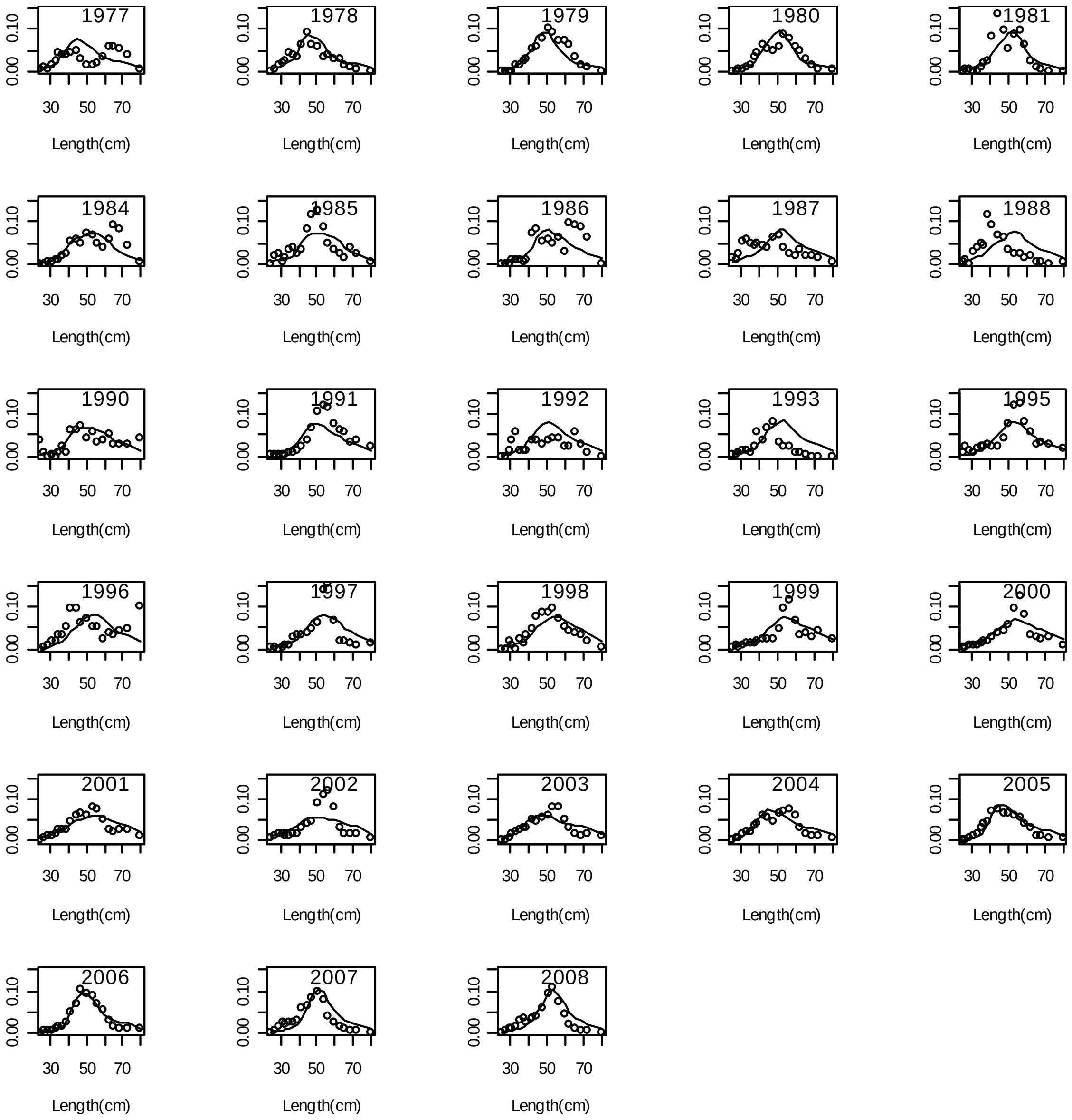

Figure 7.5. Fit to the female fishery length composition data. Solid line is predicted.

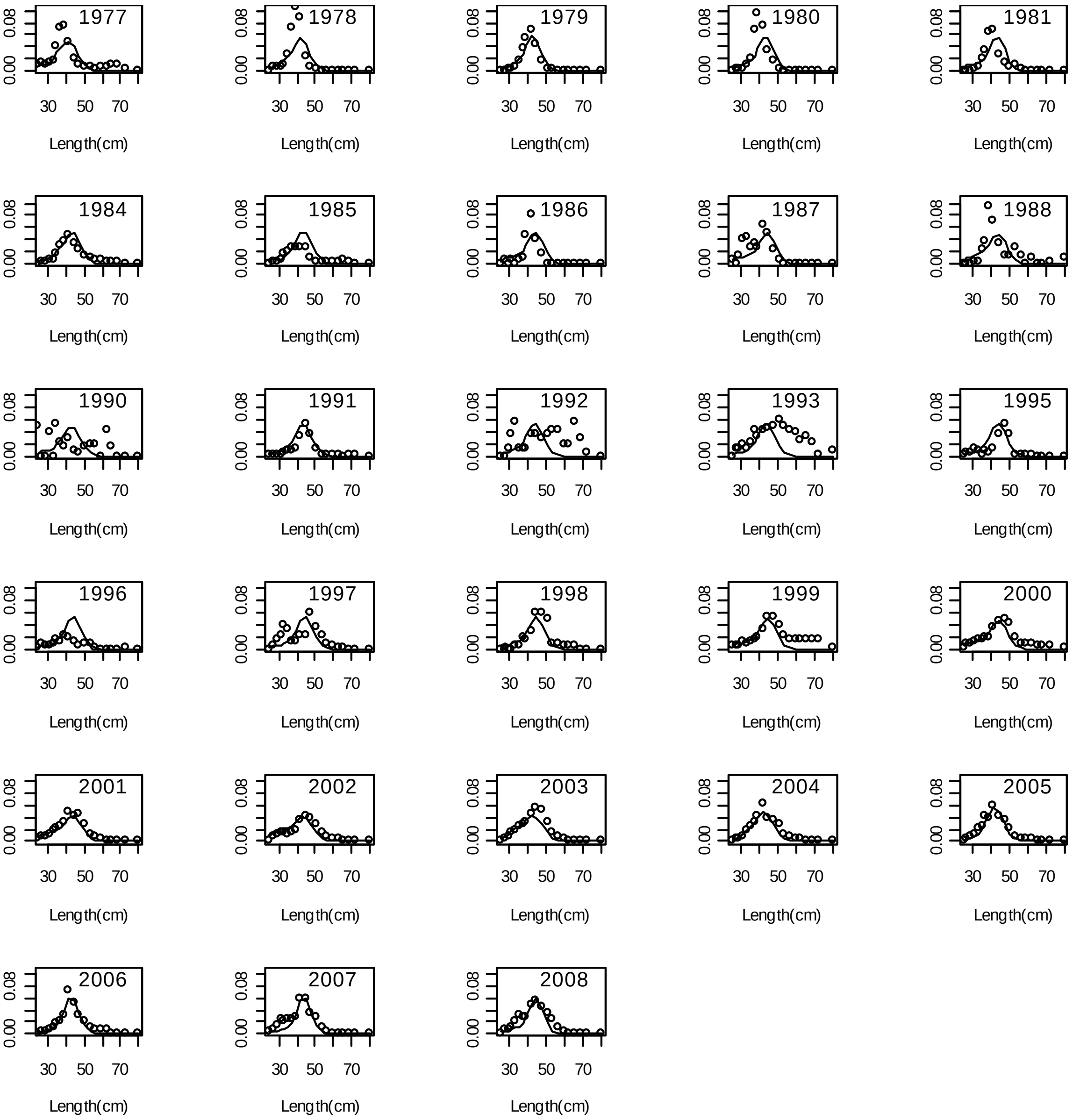

Figure 7.6. Fit to the male fishery length composition data. Solid line is predicted.

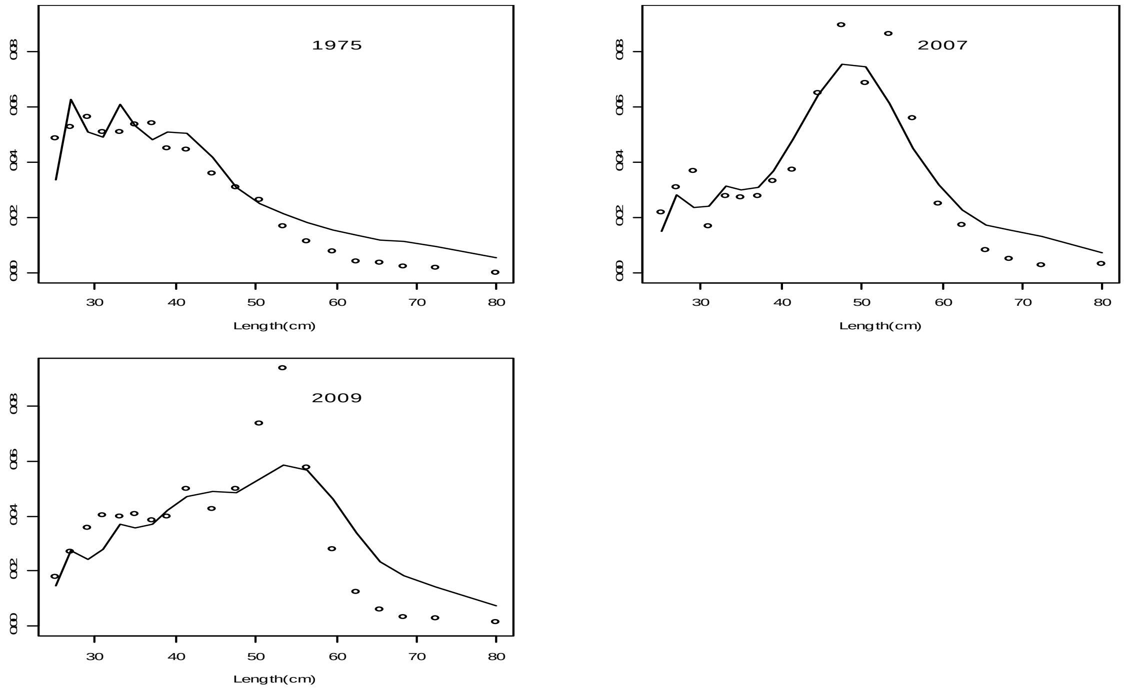

Figure 7.7. Fit to the female survey length data for 1975, 2007 and 2009. Solid line is predicted.

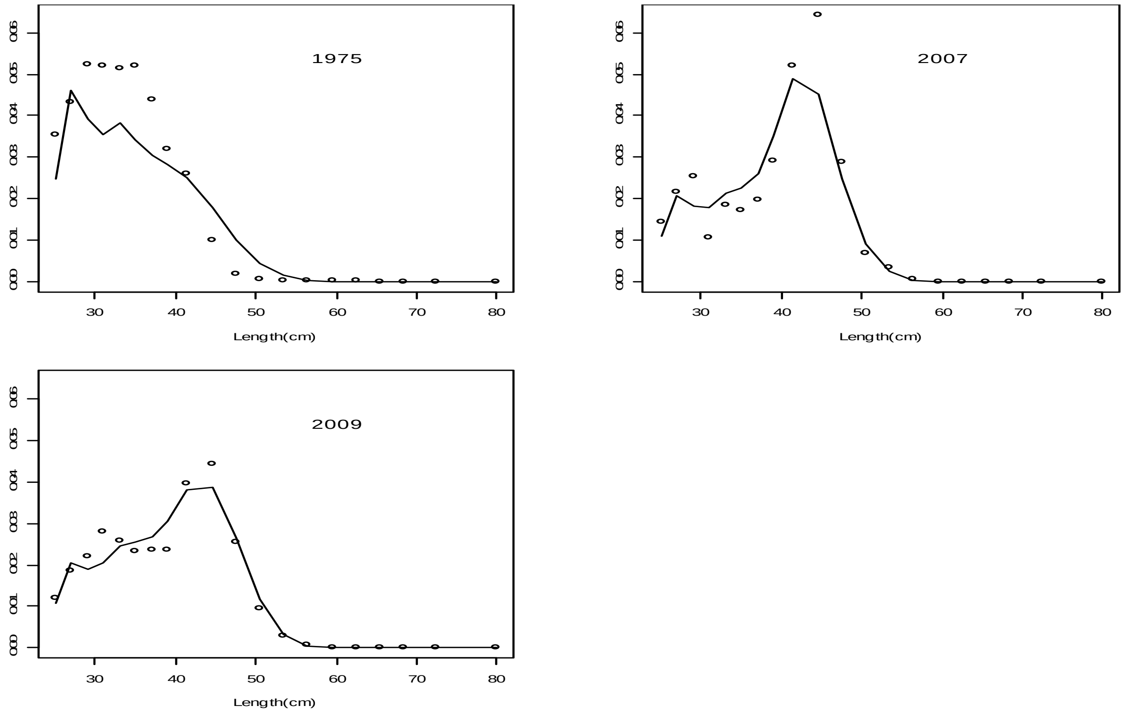

Figure 7.8. Fit to the male survey length data for 1975, 2007 and 2009. Solid line is predicted.

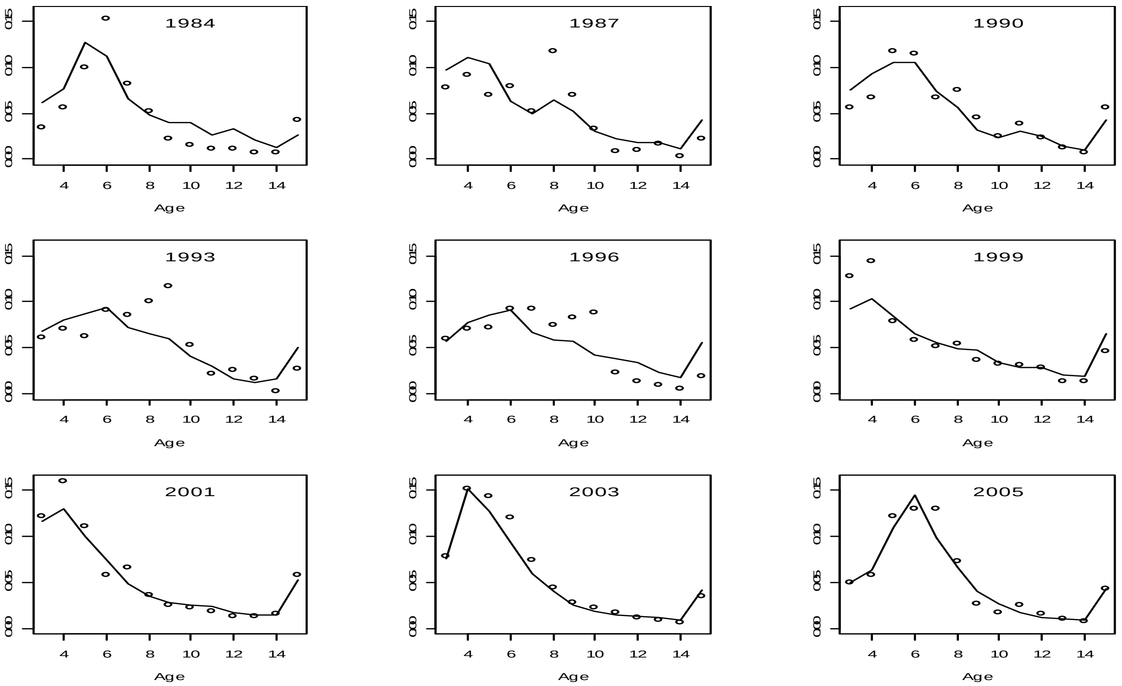

Figure 7.9. Fit to the female survey age data. The last age group is 15+. Solid line is predicted.

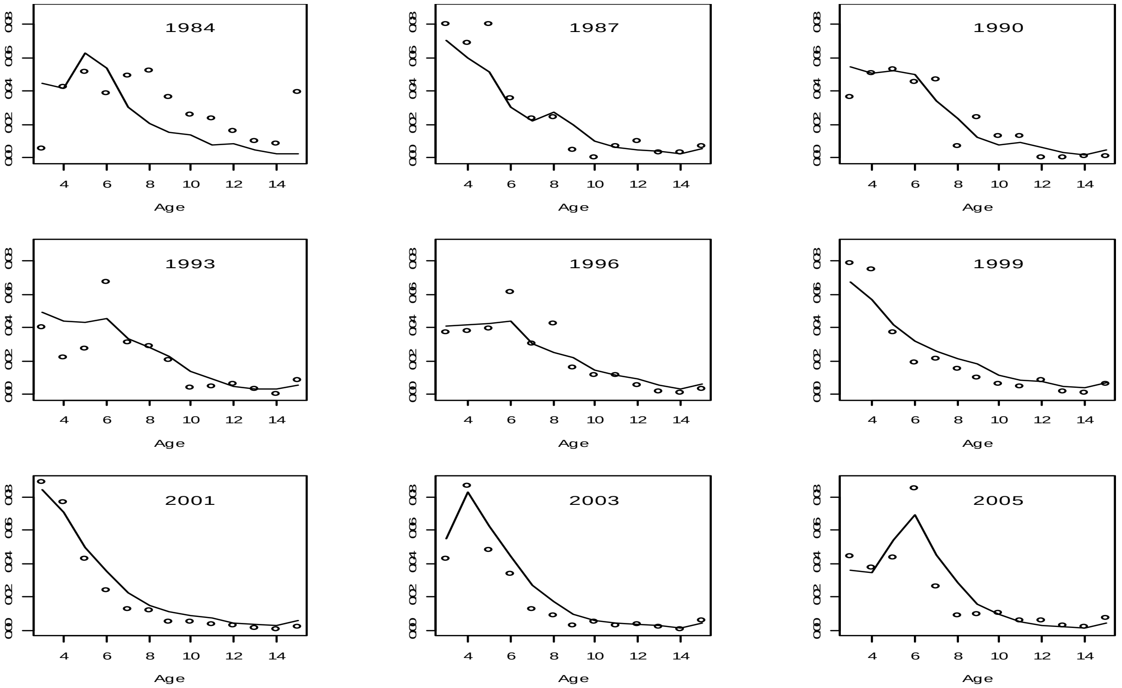

Figure 7.10. Fit to the male survey age data. The last age group is 15+. Solid line is predicted.

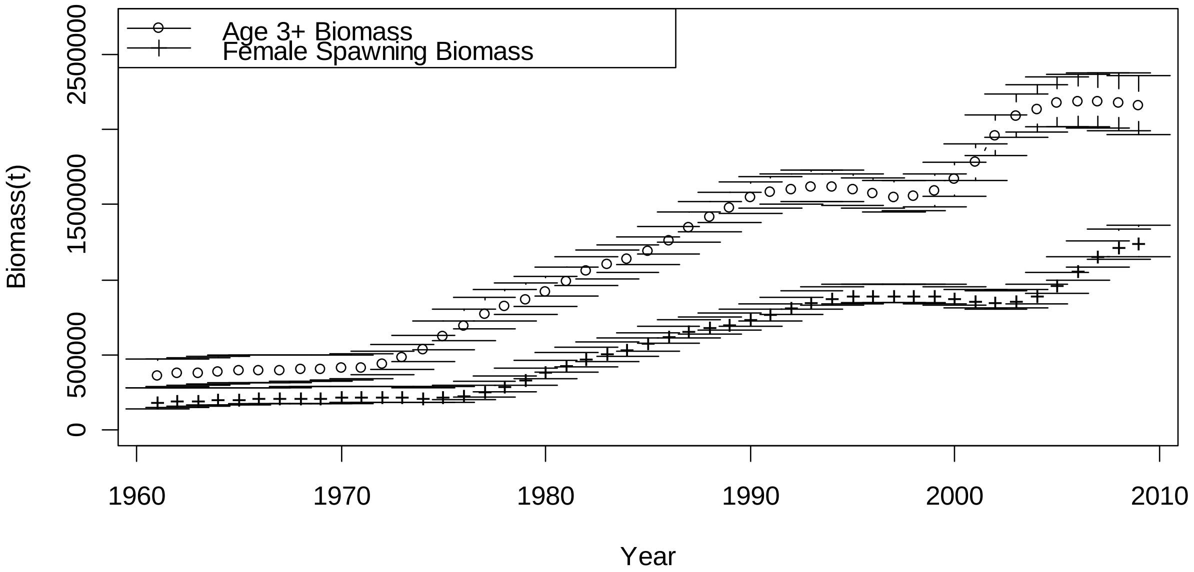

Figure 7.11. Age 3+ biomass and female spawning biomass from 1961 to 2009 with approximate lognormal 95% confidence intervals.

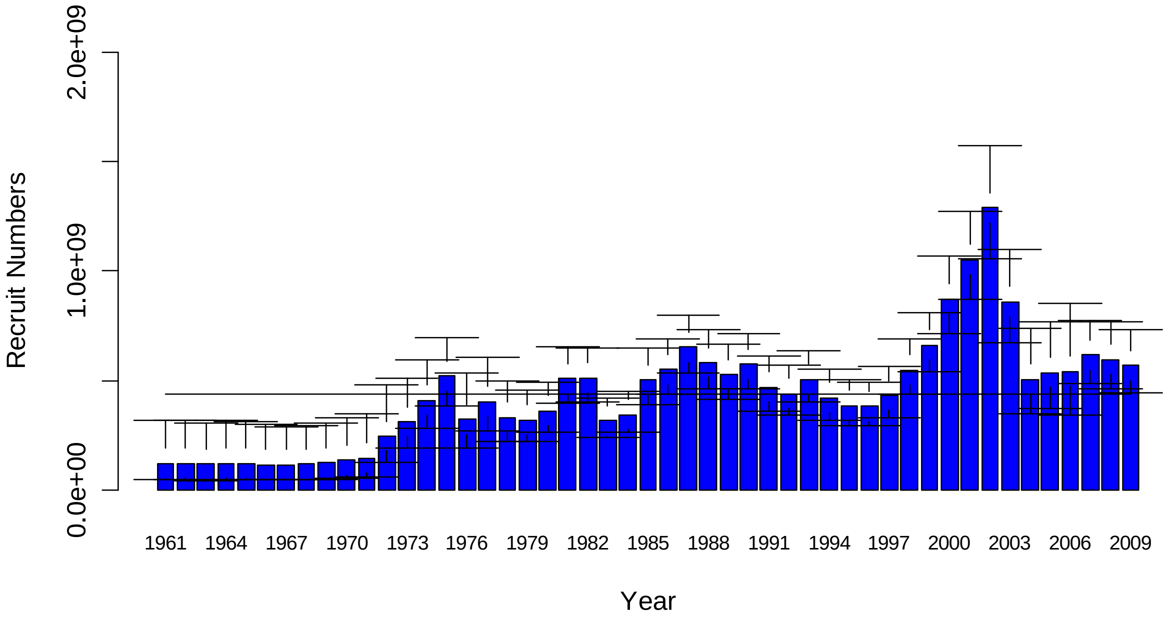

Figure 7.12. Age 3 estimated recruitments (male plus female) in numbers from 1961 to 2009, with approximate 95% confidence intervals. Horizontal line is average recruitment.

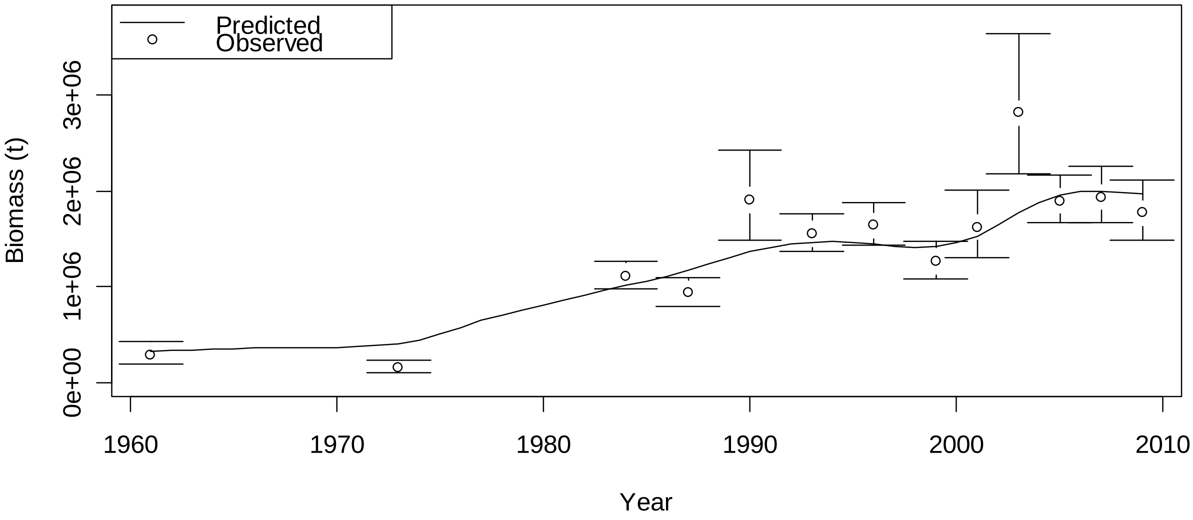

Figure 7.13. Fit to survey biomass estimates with approximate 95% log-normal confidence intervals for the observed survey biomass estimates 1961 to 2009.

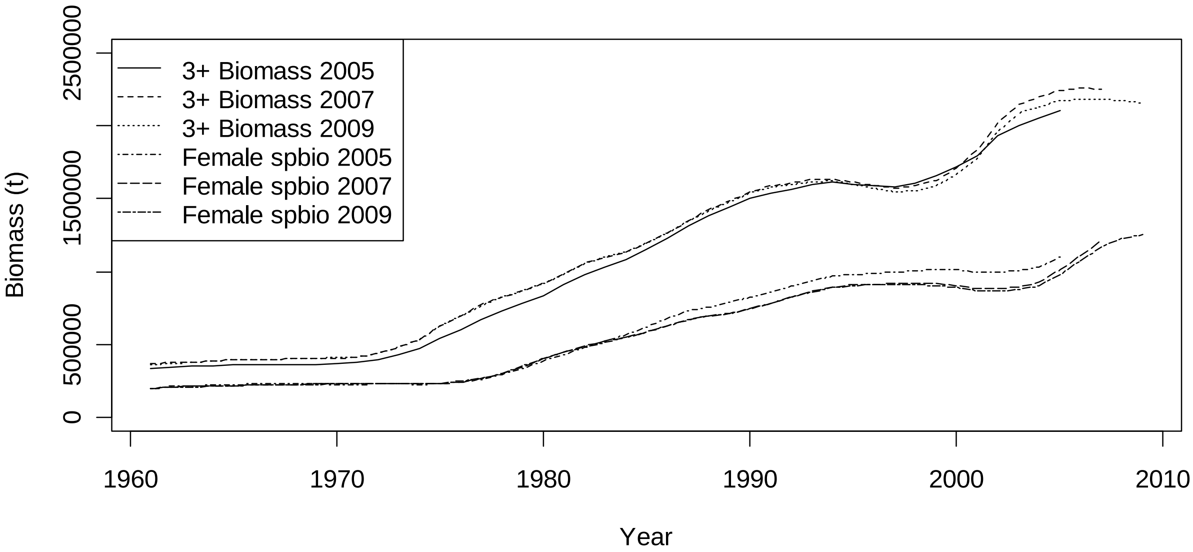

Figure 7.14. 3+ biomass and female spawning biomass(spbio) from 2005, 2007 and 2009 assessments.

Figure 7.15. Recruitment estimates from 2005, 2007 and 2009 assessments.

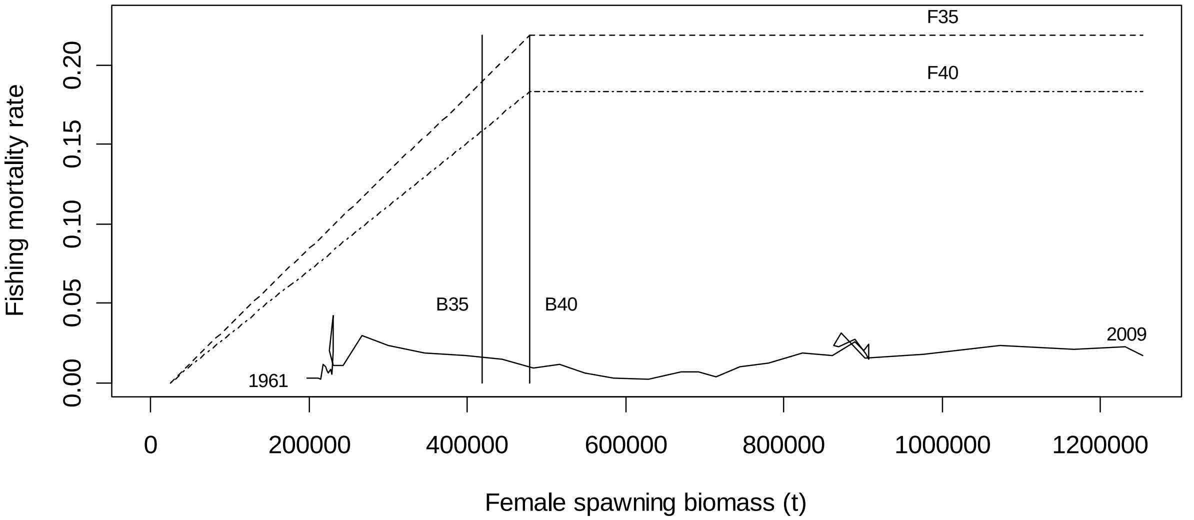

Figure 7.16. Fishing mortality rate and female spawning biomass from 1961 to 2009 compared to the F35% and F40% control rules. Vertical lines are B35% and B40%.

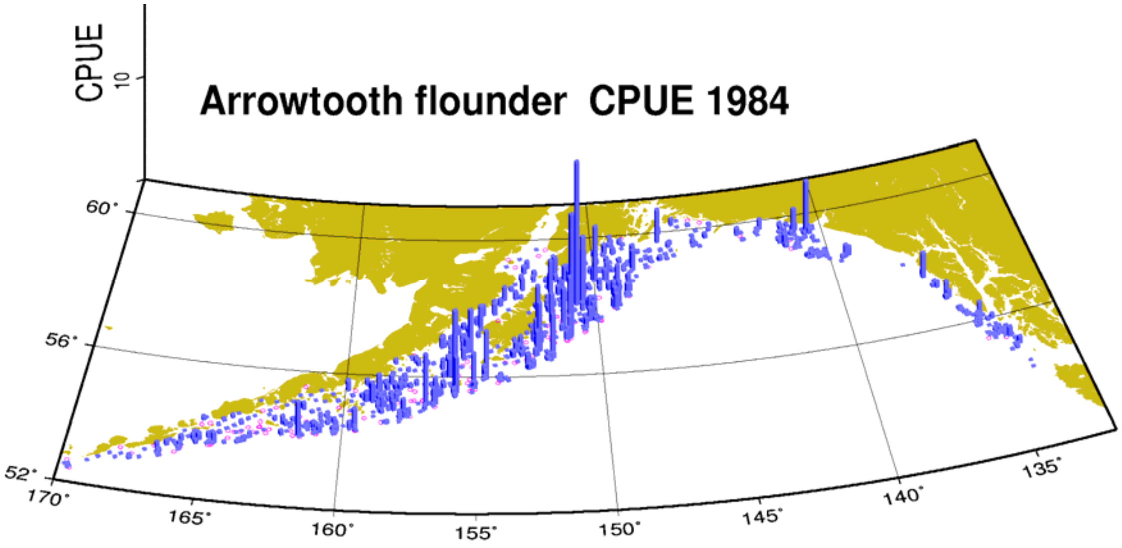

Figure 7.17. Arrowtooth flounder 1984 survey cpue by tow.

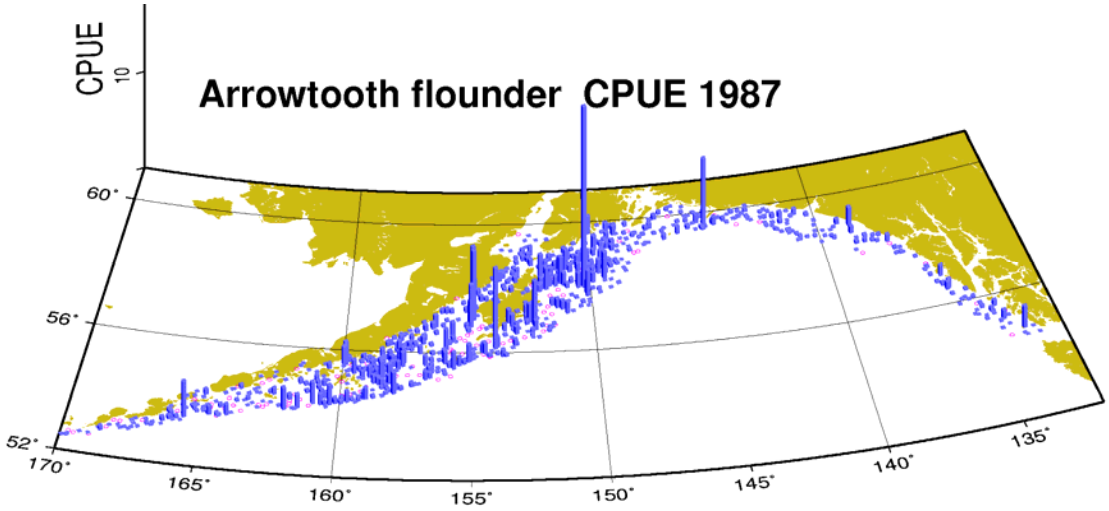

Figure 7.18. Arrowtooth flounder 1987 survey cpue by tow.

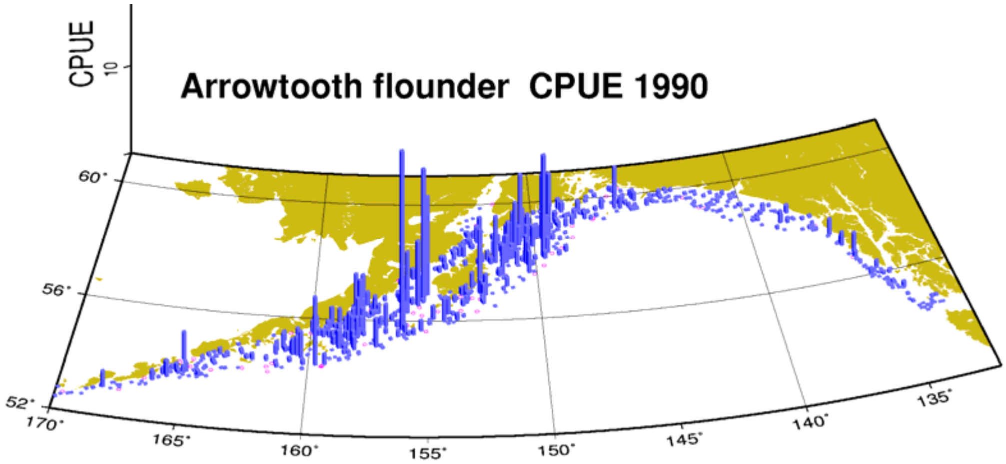

Figure 7.19. Arrowtooth flounder 1990 survey cpue by tow.

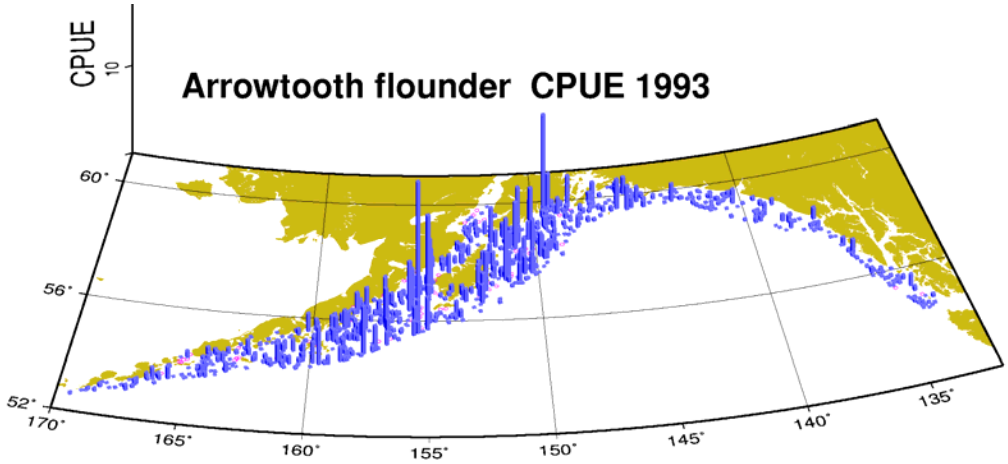

Figure 7.20. Arrowtooth flounder 1993 survey cpue by tow.

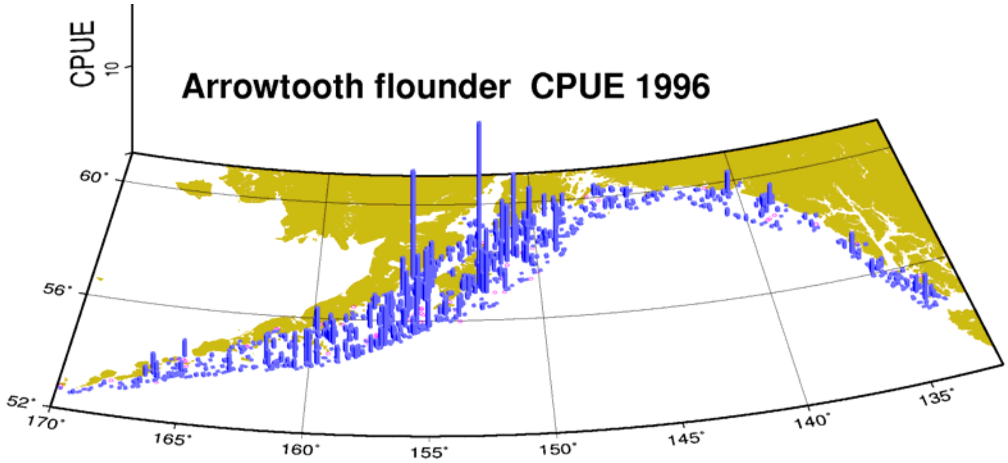

Figure 7.21. Arrowtooth flounder 1996 survey cpue by tow.

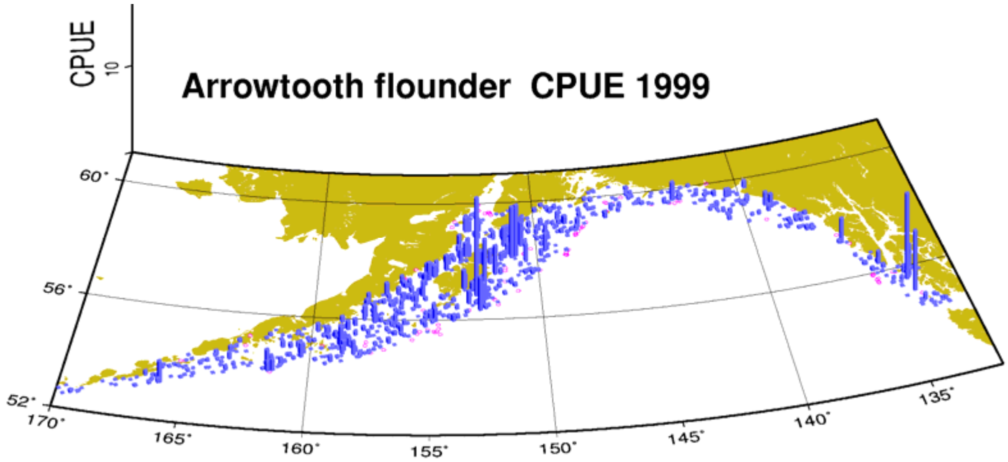

Figure 7.22. Arrowtooth flounder 1999 survey cpue by tow.

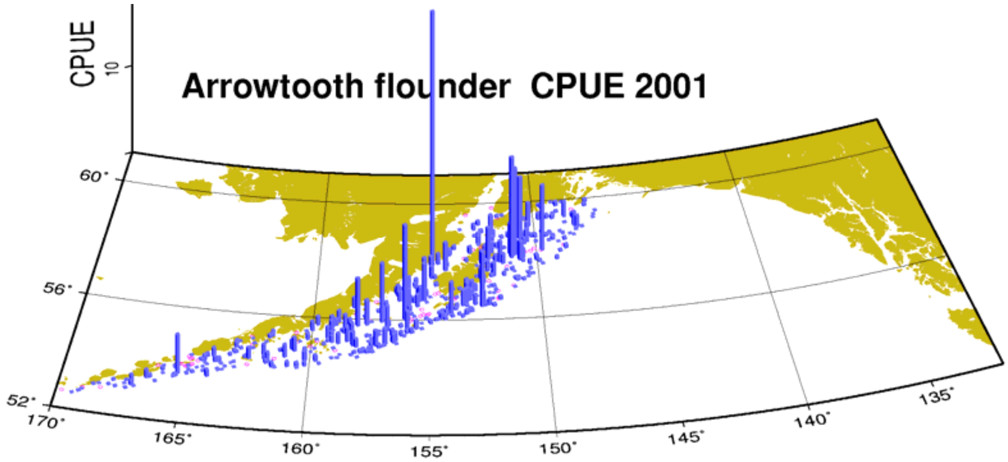

Figure 7.23. Arrowtooth flounder 2001 survey cpue by tow.

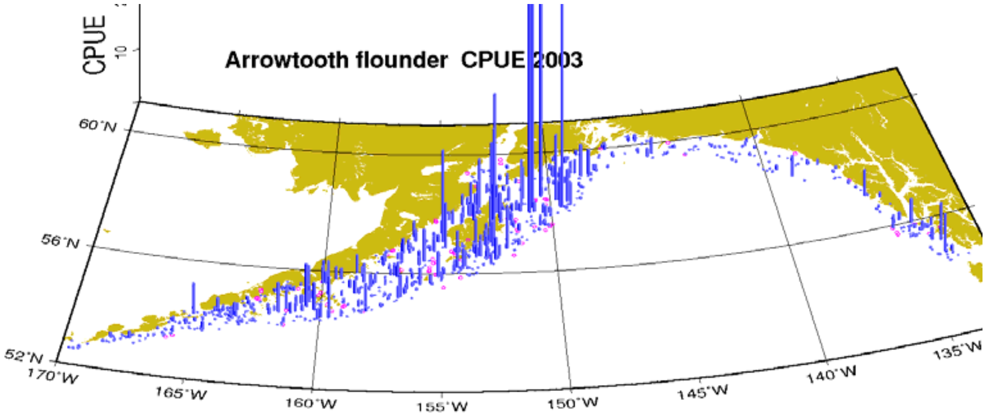

Figure 7.24. Arrowtooth flounder 2003 survey cpue by tow.

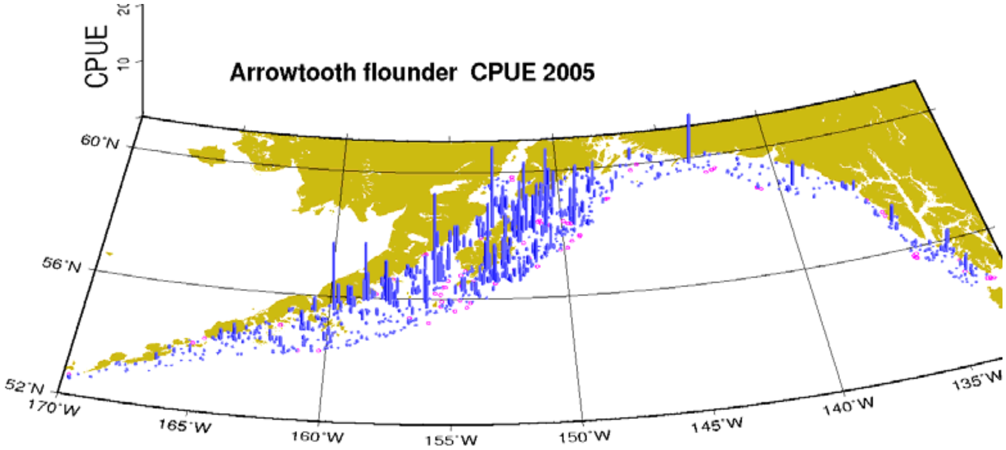

Figure 7.24b. Arrowtooth flounder 2005 survey cpue by tow.

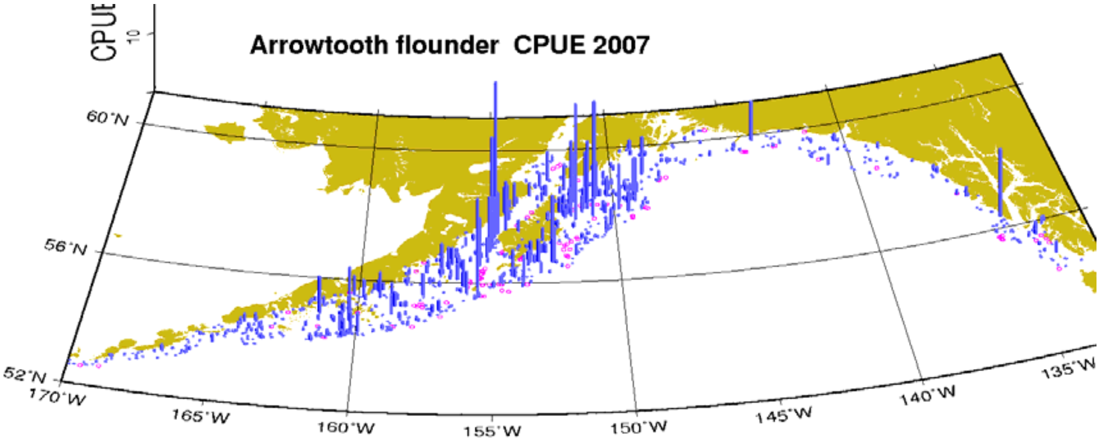

Figure 7.24c. Arrowtooth flounder 2007 survey cpue by tow.

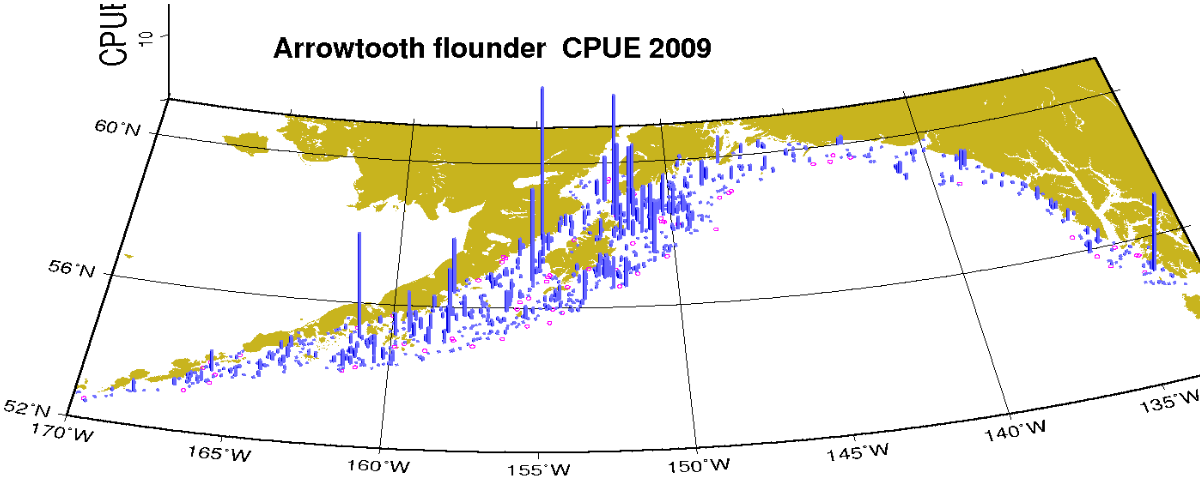

Figure 7.24d. Arrowtooth flounder 2009 survey cpue by tow.

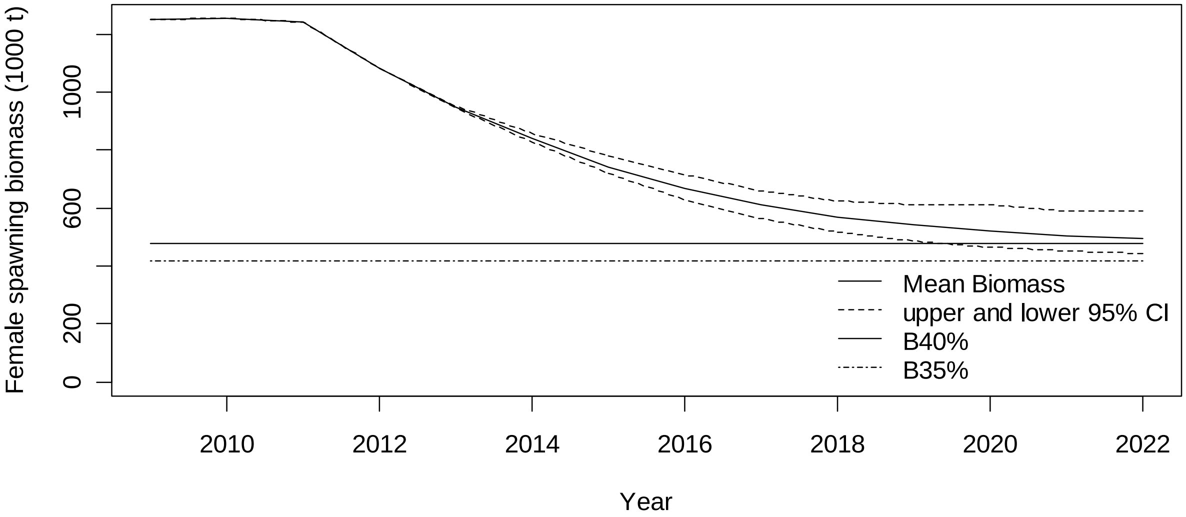

Figure 7.25. Projected female spawning biomass for 2010 to 2022 fishing at the maximum FABC=F40%.

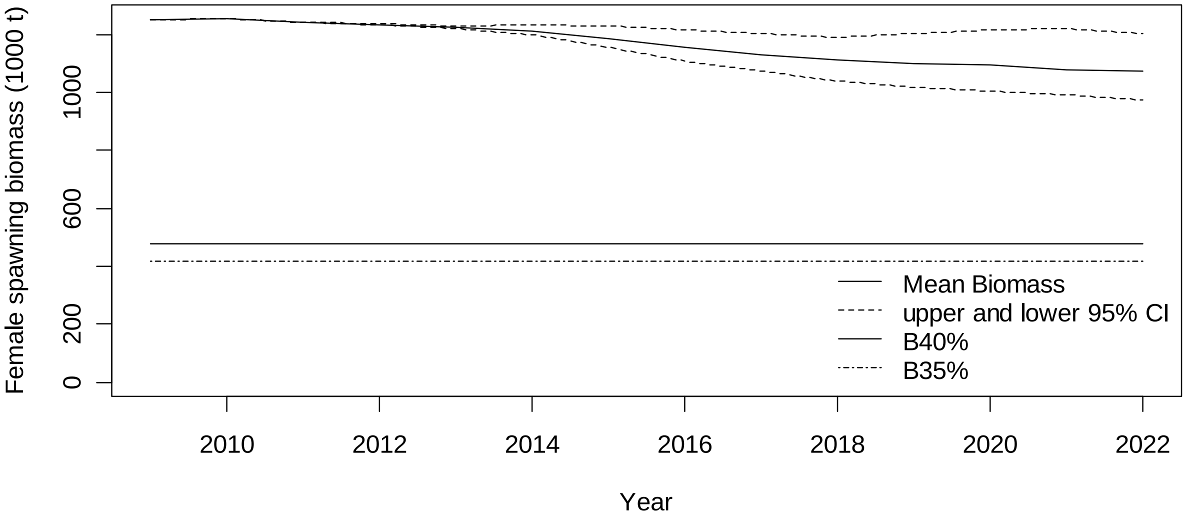

Figure 7.26. Projected female spawning biomass for 2010 to 2022 fishing at the average 5 year F.

Appendix A.

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

$N_{t,1}=R_t=R_0e^{\tau_t}$	$\tau_t \sim N(0,\sigma_R^2)$	Recruitment
$C_{t,a}=\frac{F_{t,a}}{Z_{t,a}}(1-e^{-Z_{t,a}})N_{t,a}$	$1\le t\le T$ $1\le a\le A$	Catch
$N_{t+1,a+1}=N_{t,a}e^{-Z_{t,a}}$	$1<t\le T$ $1\le a<A$	Numbers at age
$FSB_t=\sum_{a=1}^{A}w_a\phi_a N_{t,a}$		Female spawning biomass
$N_{t+1,A}=N_{t,A-1}e^{-Z_{t,A-1}}+N_{t,A}e^{-Z_{t,A}}$	$1<t\le T$	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
$F_{t,a}=s_{t,a}E_te^{\varepsilon_t}$	$\varepsilon_t \sim N(0,\sigma_R^2)$	Fishing mortality
S_a for a = 3 to 12		Fishery selectivity – smooth monotonically increasing
S_a for a = 3 to 12		selectivity –ascending logistic for survey
$SB_t=Q\sum_{a=1}^{A}w_a s^{s}_{t,a}N_{t,a}$		survey biomass, Q = 1.

Table A.2. Likelihood components.

$\sum_{t=1}^{T}\left[\log(C_{t,obs})-\log(C_{t,pred})\right]^2$	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. the offset constant is calculated from the observed proportions and the sample sizes.
offset = $\sum_{t=1}^{T}\sum_{a=1}^{A}nsamp_t * p_{obs,t,a}\log(p_{obs,t,a})$	
$\sum_{t=1}^{ts}\left[\frac{\log\left[\frac{SB_{obs,t}}{SB_{pred,t}}\right]}{sqrt(2)*s.d.(\log(SB_{obs,t}))}\right]^2$	survey biomass using a lognormal distribution, ts is the number of years of surveys.
$\sum_{t=1}^{T}(\tau_t)^2$	Recruitment, where $\tau_t \sim N(0,\sigma_R^2)$
$\sum_{a=3}^{15}(diff\,(diff\,(s_a)))^2$	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 134 total parameters estimated in the model.

Parameter	Description
log(R_0) 1 parameter	log of the geometric mean value of age 3 recruitment
τ_t 1961 $\leq t \leq$ 2009, plus 12 parameters for the initial age composition equals 61.	Recruitment deviation in year t
log(f_0) 1 parameter	log of geometric mean value of fishing mortality
ε_t 1961 $\leq t \leq$ 2009, 49 parameters	deviations in fishing mortality rate in year t
s_a for ages 3 to 12, 18 parameters	selectivity for fishery males and females.
Slope and 50% for logistic function, 4 parameters	selectivity for survey 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.

Appendix B. Ecosystem Considerations

Arrowtooth flounder are important predators of other groundfish in Alaskan ecosystems. In this section, we give an overview of diet data and ecosystem model results for arrowtooth flounder in the Gulf of Alaska (GOA). While arrowtooth flounder are present in the Aleutian Islands (AI) and Eastern Bering Sea (EBS or BS in figures), the density of arrowtooth flounder as measured in survey-estimated tons per square kilometer is by far the greatest in the GOA (Fig. 1, left). Although the density of arrowtooth differs between ecosystems, the relative effects of fishing and predation mortality as estimated within food web models constructed for each ecosystem (Aydin et al. in press) are similar between the AI, EBS, and GOA. Here, sources of mortality are compared against the total production of arrowtooth as estimated in the BSAI and GOA arrowtooth stock assessment models (see Appendix A, "Production rates," for detailed methods). The "unknown" mortality in Figure 1 (right) represents the difference between the stock assessment estimated arrowtooth production and the known sources of fishing and predation mortality. Nearly half of arrowtooth production as estimated by the stock assessment appears to be "unused" in the AI and GOA, which is consistent with results for other predator species such as Pacific cod and halibut. In the EBS, considerably more mortality is accounted for; please see the discussion of arrowtooth mortality rates in the EBS in the BSAI arrowtooth assessment (Wilderbuer et al. 2007). Of the accounted sources of mortality, fishing mortality is generally lower for arrowtooth flounder than predation mortality in all three ecosystems (Fig. 1, right). This is consistent with the currently low fishing effort directed at this species.

To explore ecosystem relationships of arrowtooth flounder in more detail, we first examine the diet data collected for arrowtooth. Diet data are collected aboard NMFS bottom trawl surveys in the GOA during the summer (May – August); this comparison uses diet data collected in the early 1990s. In the GOA a total of 1704 arrowtooth stomachs were collected between the 1990 and 1993 bottom trawl surveys (n=654 and 1050, respectively) and used in this analysis and to build the GOA food web model. The diet compositions reported here reflect the size and spatial distribution of arrowtooth in each survey (see Appendix A, "Diet calculations" for detailed methods). While the diet compositions summarized here most accurately reflect early 1990's conditions in the GOA, we also examine changes in arrowtooth diets over time below.

Arrowtooth flounder have a varied diet comprised of zooplankton, fish, and benthic invertebrates as both juveniles (0-20 cm TL fish) and adults (>20 cm TL; Fig. 2). Capelin, euphausiids, adult and juvenile pollock, Pandalid shrimp, herring, and other forage fish comprise the majority of adult arrowtooth flounder diet, but none of these prey account for more than 22% of diet. As juveniles, arrowtooth prey mainly on euphausiids, which make up nearly 60% of diet, followed by capelin at 24% (Fig. 2). When the uncertainty in food web model parameters is included (see Aydin et al in press for Ecosense methods), we estimate fairly high annual consumption of these prey by arrowtooth flounder. For example, estimated consumption of all forage fish (capelin, sandlance, eulachon, etc.) by adult arrowtooth ranges from 300,000 to 1.2 million metric tons, and estimated consumption of pollock by adult arrowtooth ranges from 400,000 to 800,000 metric tons annually (Fig. 3, upper panel). Consumption of euphausiids by adult arrowtooth is estimated to range from 100,000 to 800,000 tons annually, with another 60,000 to 490,000 tons consumed annually by juvenile arrowtooth flounder (Fig. 3, upper and lower).

Using diet data for all predators of arrowtooth flounder and consumption estimates for those predators, as well as fishery catch data, we next estimate the sources of arrowtooth mortality in the GOA (see detailed methods in Appendix A). As described above, sources of mortality are compared against the total production of arrowtooth as estimated in the GOA stock assessment model for the early 1990s. There are few sources of mortality for arrowtooth flounder in the GOA as both adults and juveniles, as indicated by the large proportion of unexplained mortality (76% for adults, 88% for juveniles) in Figure 4. Predators explain more mortality than fisheries for arrowtooth flounder (at least in this model based on early 1990s data where the fishery for arrowtooth flounder was extremely limited). Pacific halibut, Steller sea lions, and Pacific cod together explain about 10% of adult arrowtooth mortality, while the flatfish trawl fishery accounts for 2% (Fig. 4, upper panel). Juvenile arrowtooth flounder mortality is caused by adult arrowtooth flounder, and both adult and juvenile pollock in the GOA, but the total of these mortality sources is less than 7% of juvenile arrowtooth production (Fig. 4, lower panel). The total tonnage consumed by predators of arrowtooth flounder is low relative to their biomass for both adults and juveniles: the most important predators of arrowtooth, pinnipeds and halibut, are each estimated to consume between 13,000 and 30,000 or 20,000 tons of arrowtooth annually, respectively (Fig. 5, upper panel). Adult arrowtooth flounder are estimated to consume 4,000 to 12,000 tons of juvenile arrowtooth flounder annually, with pollock consuming nearly the same small amount (Fig. 5, lower panel). Few mortality sources for arrowtooth flounder are consistent with an increasing population, which has been observed in the Gulf of Alaska since the 1960s.

After comparing the different diet compositions and mortality sources of arrowtooth flounder, we shift focus slightly to view them within the context of the larger GOA food webs (Fig. 6). Arrowtooth flounder occupy a relatively high trophic level in the GOA, and represent the highest biomass single species group at that high trophic level. The green boxes represent direct prey of arrowtooth, the dark blue boxes the direct predators of arrowtooth, and light blue boxes represent groups that are both predators and prey of arrowtooth. Visually, it is apparent that arrowtooth's direct trophic relationships in each ecosystem include a majority of species groups. In the GOA, the significant predators of arrowtooth (blue boxes joined by blue lines) include the halibut, sea lions, sharks, and fisheries. Significant prey of arrowtooth (green boxes joined by green lines) include several fish groups, Euphausiids, and Pandalid shrimp. The most interesting interaction may be with pollock, which are both prey of adult arrowtooth, and predators on juvenile arrowtooth. This situation is also observed in the EBS, but there the biomass of pollock overwhelms that of arrowtooth so the impact of this interaction on the two populations is very different between ecosystems.

We next use the diet and mortality results integrated with information on uncertainty in the food web using the Sense routines (Aydin et al. in press) and a perturbation analysis with each model food web to explore the ecosystem relationships of arrowtooth flounder further. Two questions are important in determining the ecosystem role of arrowtooth flounder: which species groups are arrowtooth important to, and which species groups are important to arrowtooth? First, the importance of arrowtooth to other groups within the GOA ecosystem was assessed using a model simulation analysis where arrowtooth survival was decreased (mortality was increased) by a small amount, 10%, over 30 years to determine the potential effects on other living groups. This analysis also incorporated the uncertainty in model parameters using the Sense routines, resulting in ranges of possible outcomes which are portrayed as 50% confidence intervals (boxes in Figure 7) and 95% confidence intervals (error bars in Figure 7). Species showing the largest median changes from baseline conditions are presented in descending order from left to right. Therefore, the largest change resulting from a 10% decrease in arrowtooth survival is a highly uncertain increase in herring biomass, and an accompanying increase in herring catches in the fishery (Fig. 7). A more certain outcome of the perturbation is the expected direct effect, a decrease in adult arrowtooth biomass, which has a smaller median change than the herring change. Similarly, sleeper sharks decrease with some certainty, while sablefish and pollock are predicted to increase but with nearly as much uncertainty as herring. In general, the effects of a small change in arrowtooth survival result in a large amount of uncertainty in the ecosystem, with potentially large effects on multiple species due to arrowtooth's ecosystem interactions.

To determine which groups were most important to arrowtooth in each ecosystem, we conducted the inverse of the analysis presented above. In this simulation, each species group in the ecosystem had survival reduced by 10% and the system was allowed to adjust over 30 years. The strongest median effects on GOA arrowtooth are presented in Figure 8. Here the largest impacts on arrowtooth biomass are the direct effects through changes in arrowtooth survival and juvenile arrowtooth survival, but the next largest impacts are more interesting ecologically. Arrowtooth biomass appears strongly influenced by changes in bottom up production, with decreases in survival for large and small phytoplankton and euphausiids having similar biomass effects as direct effects from arrowtooth and juvenile arrowtooth (Fig. 8). While euphausiids are direct prey of arrowtooth, phytoplankton are not. Smaller effects on arrowtooth biomass are seen due to decreased survival of capelin (direct prey), but these are uncertain compared with those due to phytoplankton and euphausiids. There are more unequivocal bottom up effects related to arrowtooth flounder in these simulations than top down effects of arrowtooth on other species.

Finally, we summarize the available food habits collections for arrowtooth flounder in the GOA in Table 1, and make preliminary consumption estimates from this data in Figures 9 and 10 for juvenile and adult arrowtooth. In general, while changes in the amount of consumption have been noted, the arrowtooth diet remains diverse and focused on euphausiids, pollock, capelin, and other fish throughout the time series (Fig. 9). Further analysis of this data will be presented in an upcoming assessment.

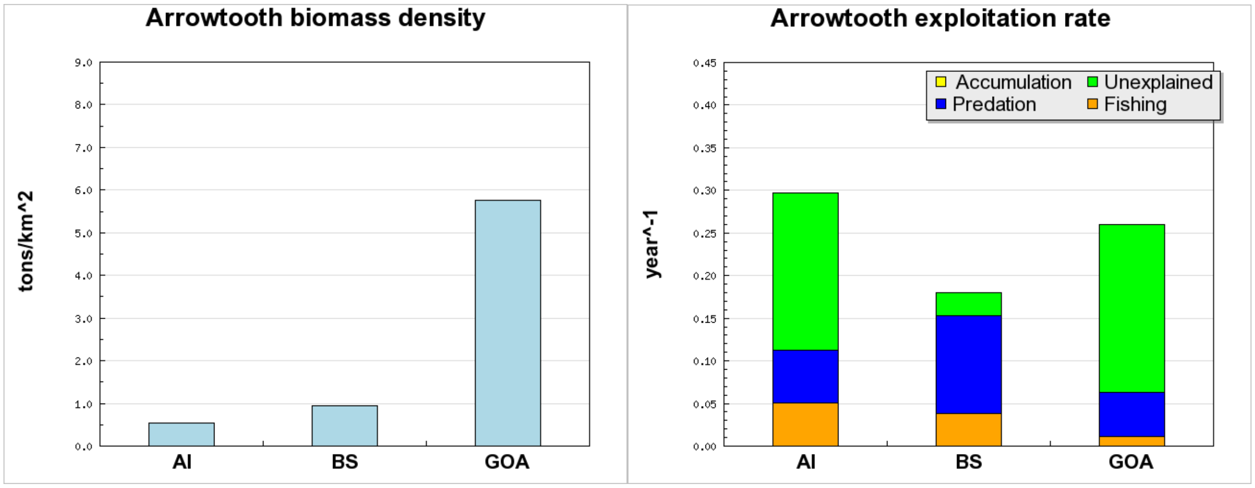

Figure B.1. Comparative biomass density (left) and mortality sources (right) for Arrowtooth flounder in the AI, EBS, and GOA ecosystems. Biomass density (left) is the average biomass from early 1990s NMFS bottom trawl surveys divided by the total area surveyed. Total arrowtooth production (right) is derived from stock assessments for the early 1990's, and partitioned according to fishery catch data and predation mortality estimated from cod predator diet data (Aydin et al. in press). See Appendix A for detailed methods.

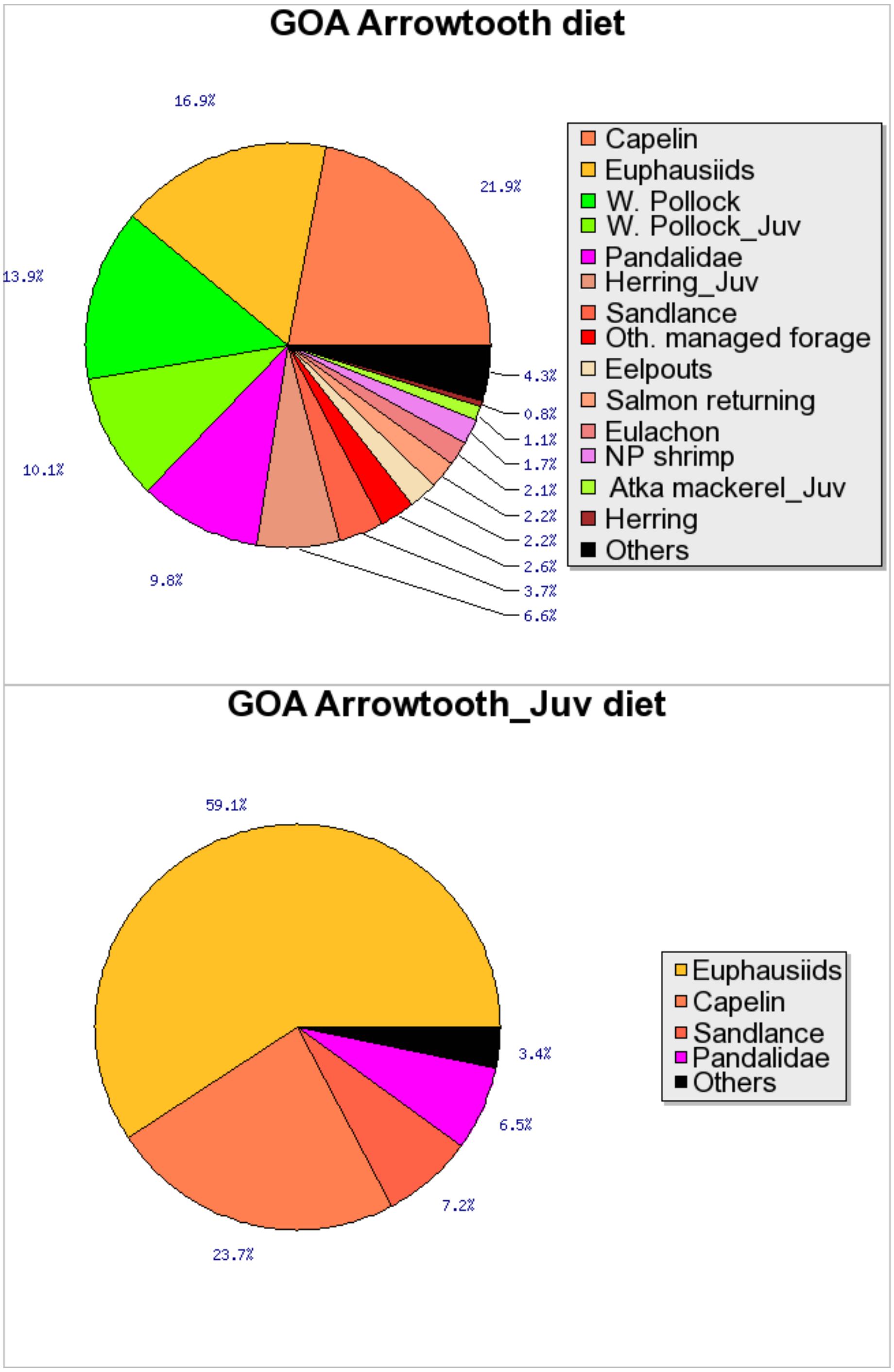

Figure B.2. Arrowtooth flounder diet compositions for the GOA ecosystem, for adults > 20cm (top) and juveniles 0-20 cm in length (bottom). Diets are estimated from stomach collections taken aboard NMFS bottom trawl surveys in 1990-1993. See Appendix A for detailed methods.

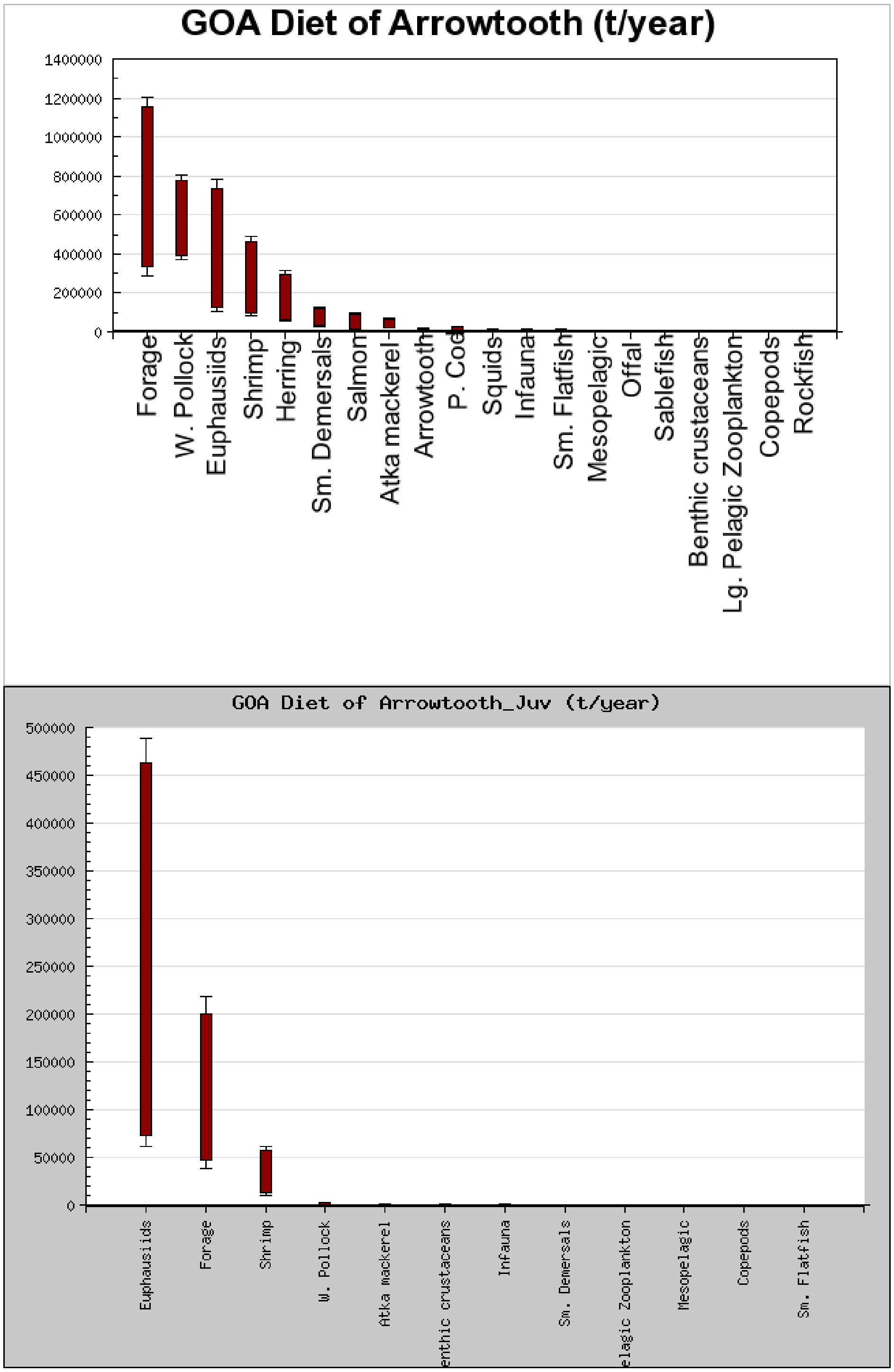

Figure B.3. Estimated annual tons of each prey type consumed by GOA Arrowtooth flounder adults >20 cm (top) and juveniles 0-20 cm (bottom), based on diets in Fig. 2. “Forage” is all forage fish together, including capelin, sand lance, eulachon, and other managed forage.

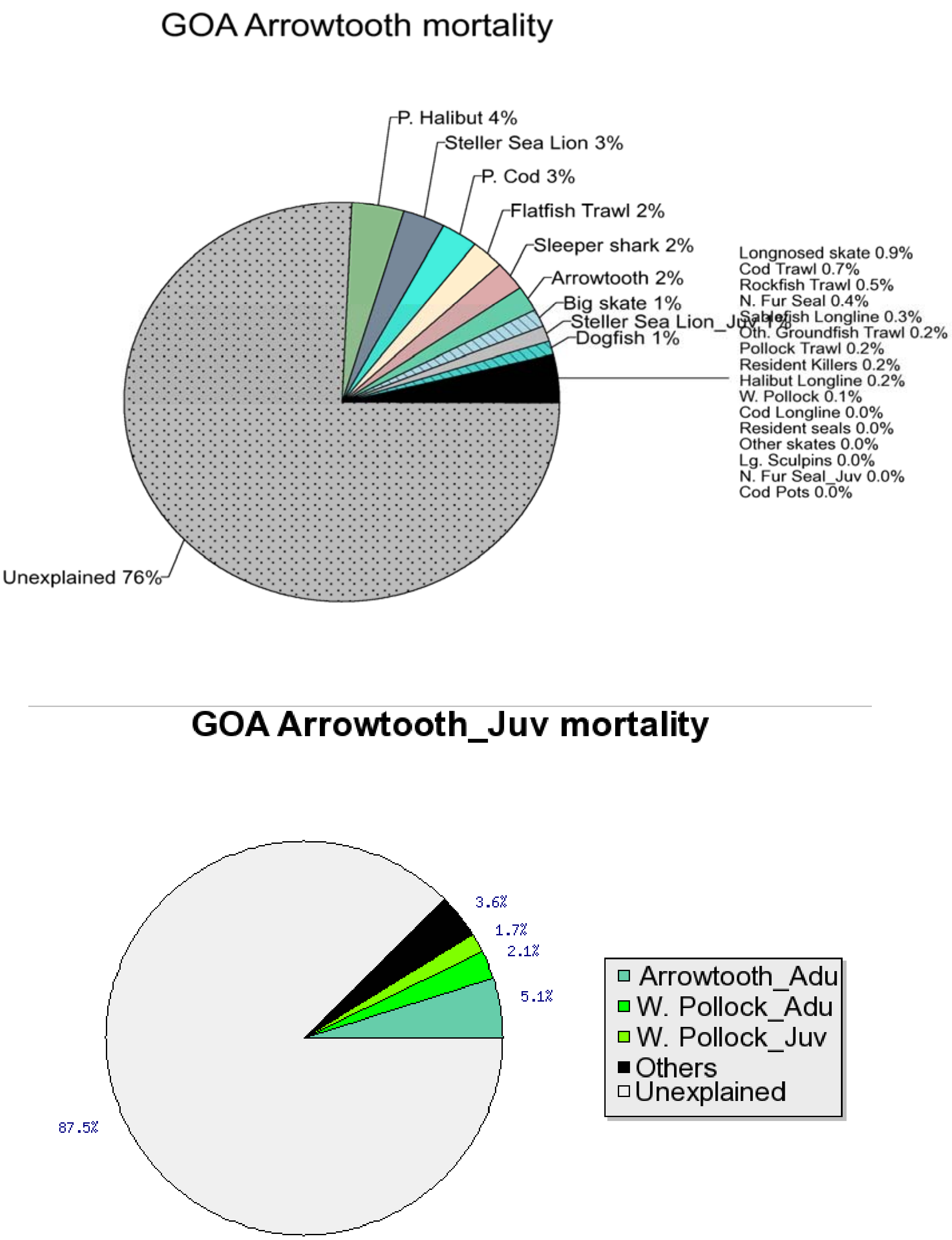

Figure B.4. Arrowtooth flounder mortality sources for the GOA ecosystem, for adults > 20cm (top) and juveniles 0-20 cm in length (bottom). Mortality sources reflect arrowtooth flounder predator diets estimated from stomach collections taken aboard NMFS bottom trawl surveys in 1990-1993, arrowtooth predator consumption rates estimated from stock assessments and other studies, and catch of arrowtooth by all fisheries in the same time periods (Aydin et al. in press). See Appendix A for detailed methods.

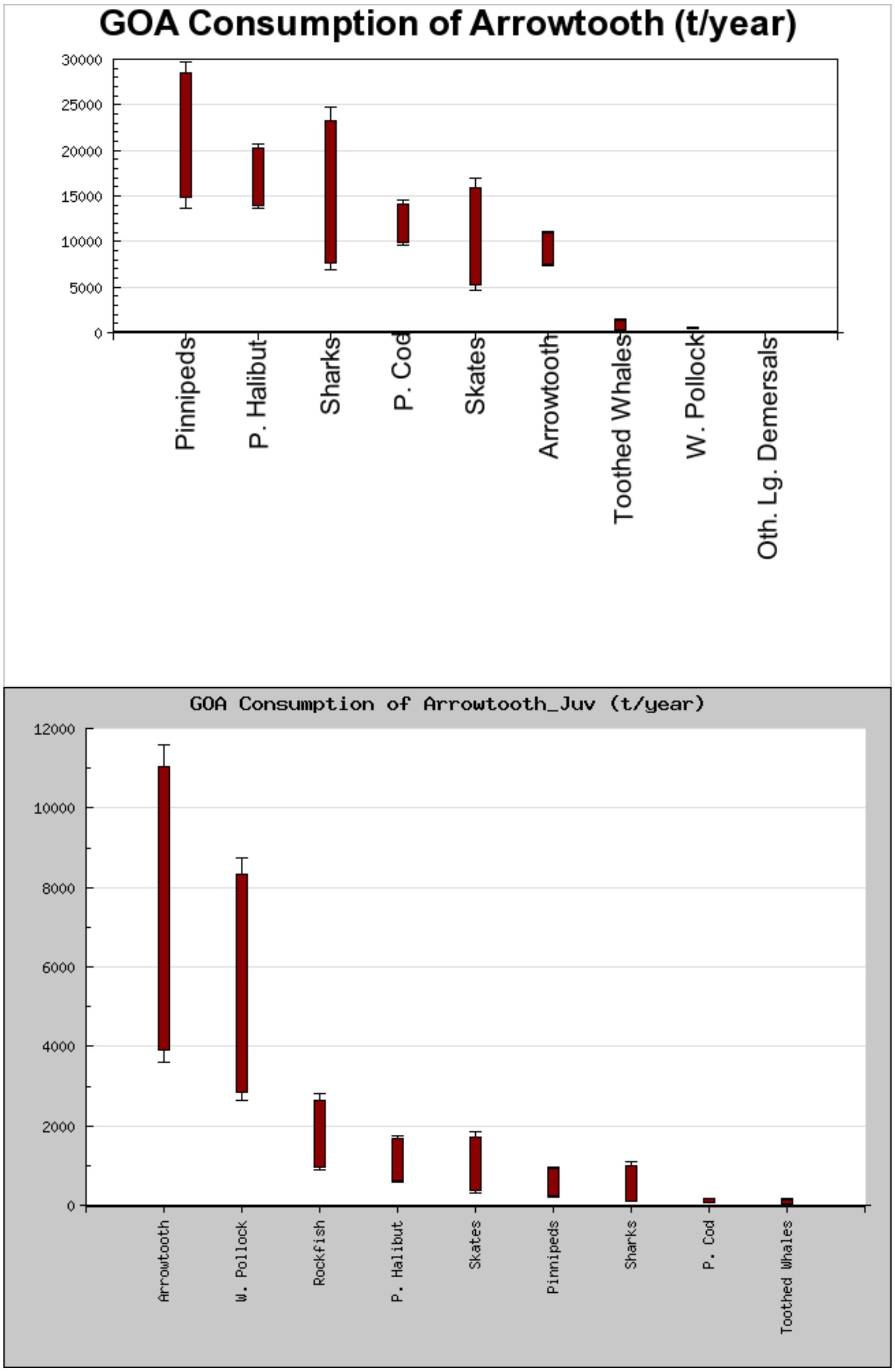

Figure B.5. Estimated annual tons of arrowtooth flounder consumed by predators in the GOA. Consumption of adult arrowtooth 20 cm (top) and juveniles 0-20 cm (bottom), based on mortality estimates in Fig. B.4. “Forage” is all forage fish together, including capelin, sand lance, eulachon, and other managed forage.

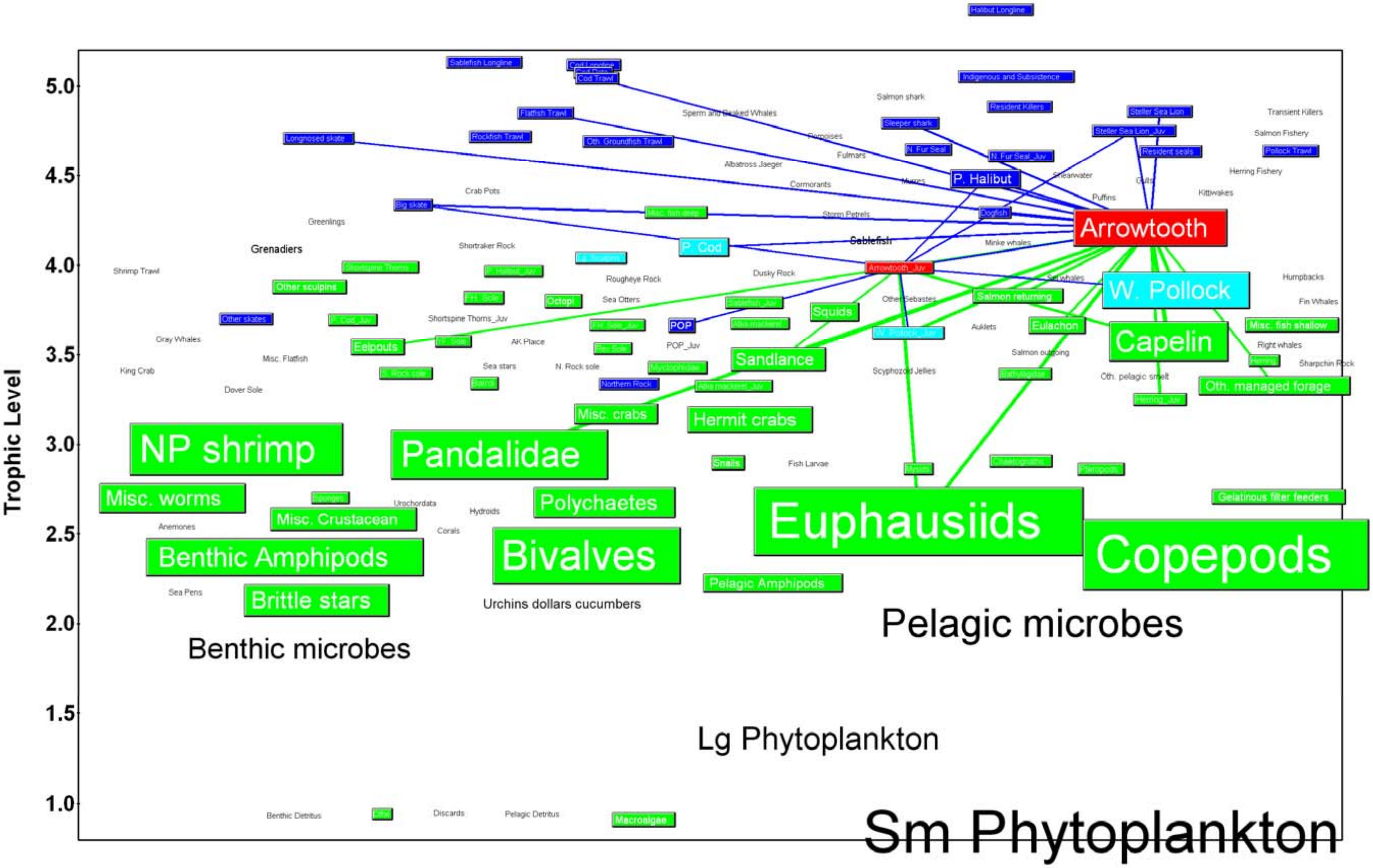

Figure B.6. Adult and juvenile arrowtooth flounder in the GOA food web. Box size is proportional to biomass, and lines between boxes represent the most significant energy flows. Predators of arrowtooth are dark blue, prey of arrowtooth are green, and species that are both predators and prey of arrowtooth are light blue.

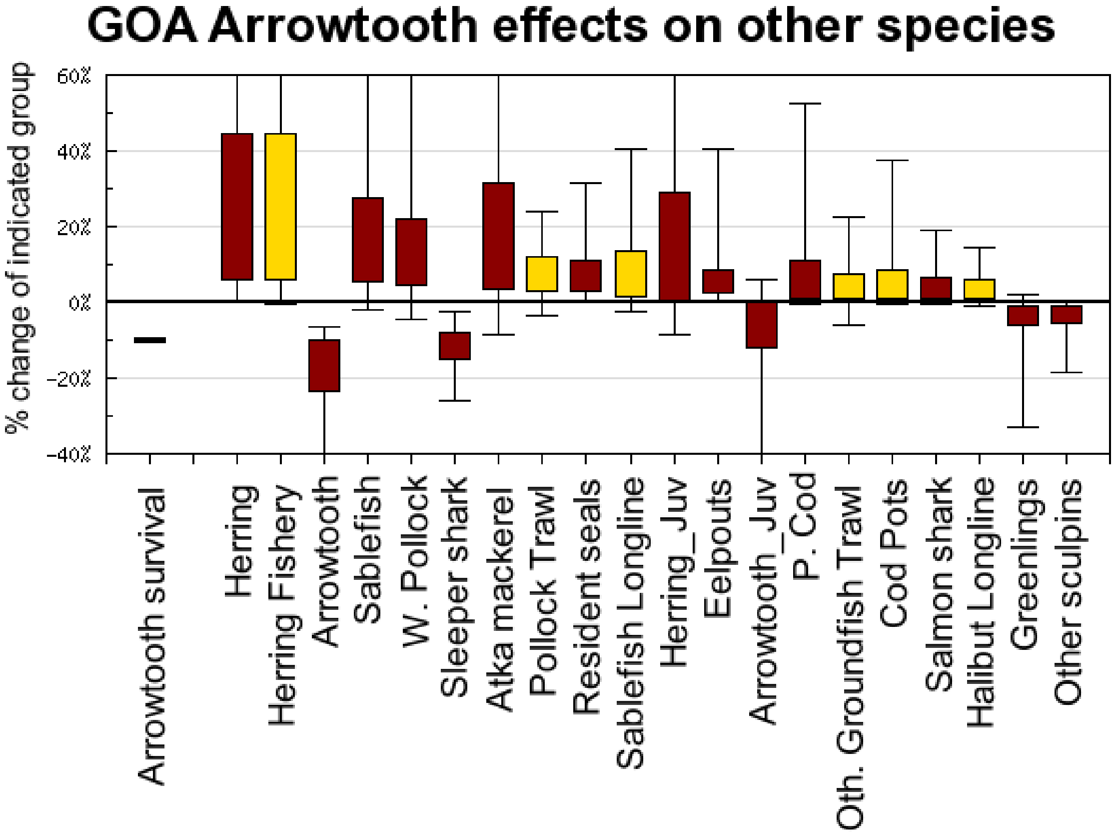

Figure B.7. Effect of changing arrowtooth > 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the GOA, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting percent change in the biomass of each species on the x axis after 30 years for 50% of feasible ecosystems, error bars show results for 95% of feasible ecosystems (see Aydin et al. in press for detailed Sense methods).

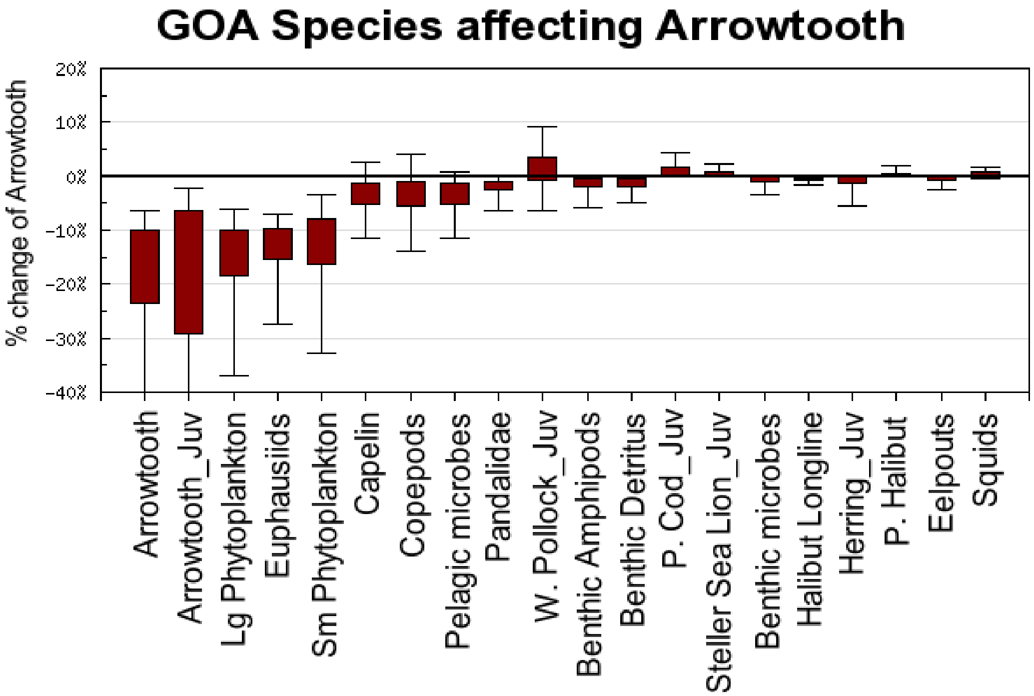

Figure B.8. Effect of reducing fisheries catch (yellow) and other species survival (dark red) on arrowtooth > 20 cm biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting percent change in the biomass of adult arrowtooth after 30 years for 50% of feasible ecosystems, error bars show results for 95% of feasible ecosystems (see Aydin et al. in press for detailed Sense methods).

Following Page: Table B.1 of sample sizes for GOA arrowtooth flounder stomach collections. Season 3 is May-September and Season 1 is the rest of the year (October-April). HAULCOUNT is the number of hauls sampled in a given regional stratum/arrowtooth size cell. PREDCOUNT is the number of arrowtooth stomachs in the same cell. When we calculate diets, our sample unit is the haul, not the individual fish; all fish collected in a given haul have diets combined based on the assumption that foraging in a given area will be sampling the same prey field. (This assumption may not be correct if fish move very far and digest very slowly…). See the full diet calc appendix in this doc. Regional strata include area and depth: West is NMFS area 610, Central is 620-630, East is 640, and Southeast is 650. Shelf is waters 0-200 m, slope is offshore waters 200 m -1000 m (although not all surveys went that deep), and gully is inshore waters ranging from 100-500 m (gullies are defined according to GOA survey strata). NA did not map to these strata, and I'm still figuring out why (may have taken samples for diet from "bad" trawl survey hauls that did not go into official biomass estimates). Divisions under each region are three arrowtooth size classes: 0 cm to 19.9 cm, 20 cm to 39.9 cm, and 40 cm and up. Therefore, the first size class represents our juveniles in the ecosystem model, and the second and third size classes are combined to give us our "adult" group of fish 20 cm and larger. Note that 2007 samples are not yet complete, there are still buckets to be analyzed for this past summer so these numbers will increase.

			Westshelf			Westgully			Westslope			Centralshelf			Centralgully			Centralslope			Eastshelf			Eastgully			Eastslope			Southeastshelf			Southeastgully			NA		
Year	Season	Data	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1985	1	HAULCOUNT									1																											
		PREDCOUNT									2																											
1986	1	HAULCOUNT		1	2																																	
		PREDCOUNT		3	10																																	
1987	1	HAULCOUNT		2	2					1	2																											
		PREDCOUNT		5	9					2	7																											
	3	HAULCOUNT											4	7		2	3																					
		PREDCOUNT											11	28		2	9																					
1990	3	HAULCOUNT		2	1		2	1				3	34	35	2	27	29		1	2		2	2						1									
		PREDCOUNT		8	11		10	5				4	150	212	7	80	131		1	5		14	10						6									
1991	3	HAULCOUNT												3						2																		
		PREDCOUNT												12						6																		
1992	1	HAULCOUNT												1		2	3																					
		PREDCOUNT												6		2	10																					
1993	3	HAULCOUNT	5	12	10		3	3				12	36	45	12	34	46			5	2	7	8															
		PREDCOUNT	16	52	32		6	6				44	146	253	22	158	228			14	16	22	35															
1994	1	HAULCOUNT												1		1	7																					
		PREDCOUNT												2		5	22																					
1995	1	HAULCOUNT		1	1								1				2																					
		PREDCOUNT		4	1								1				11																					
	3	HAULCOUNT	1	8	7		1	1					3	3																								
		PREDCOUNT	1	35	14		1	5					16	15																								
1996	1	HAULCOUNT												1		1	3																					
		PREDCOUNT												1		1	19																					
	3	HAULCOUNT	21	48	38	2	10	10	1	1	9	16	67	88	3	34	52		1	11			1															
		PREDCOUNT	36	177	150	3	33	35	1	1	23	32	256	429	3	100	308		1	25			2															
1997	1	HAULCOUNT																																			2	10
		PREDCOUNT																																			2	31
1998	1	HAULCOUNT										1	9	7	2	7	7																					
		PREDCOUNT										4	44	51	9	32	19																					
	3	HAULCOUNT										4	8	9		4	4																					
		PREDCOUNT										26	31	43		15	17																					
1999	1	HAULCOUNT										8	14	13	5	5	6																					
		PREDCOUNT										21	56	55	7	24	28																					
	3	HAULCOUNT	5	9	10	2	3	3			2	8	34	33	1	23	25			4																		
		PREDCOUNT	18	26	27	3	21	6			3	8	138	146	1	70	100			9																		
2000	1	HAULCOUNT																																			1	3
		PREDCOUNT																																			1	3
	3	HAULCOUNT																																				1
		PREDCOUNT																																				2
2001	1	HAULCOUNT																																		14	28	30
		PREDCOUNT																																		33	102	103
	3	HAULCOUNT	11	20	14	1	5	4		1	2	24	58	48	11	26	27		3	8																		8
		PREDCOUNT	78	98	59	3	30	22		2	4	56	354	292	20	166	144		4	31																		28
2002	1	HAULCOUNT																																				1
		PREDCOUNT																																				3
	3	HAULCOUNT																																				2
		PREDCOUNT																																				4
2003	1	HAULCOUNT																																				3
		PREDCOUNT																																				5
	3	HAULCOUNT	5	11	12							5	16	16		1	1				2	5	5			1					3	3					5	8
		PREDCOUNT	8	73	65							9	139	91		8	5				3	25	8			6					12	5					11	20
2004	1	HAULCOUNT																													2	2					1	7
		PREDCOUNT																													2	4					2	11
	3	HAULCOUNT																													1	2					1	8
		PREDCOUNT																													1	4					1	24
2005	3	HAULCOUNT	3	7	6		1	2		1	1	2	6	15		6	8			6	2	5	10		1			1		1	4	5			3			
		PREDCOUNT	5	13	10		2	2		2	1	7	16	40		21	24			8	2	16	26		3			7		1	7	13			8			
2007	3	HAULCOUNT	3	9	11		2			1	1	2	13	17		10	11				1	6	7			1					1	1		1	1			
		PREDCOUNT	12	27	33		2			1	1	2	31	47		17	19				1	7	14			3					5	7		1	1			

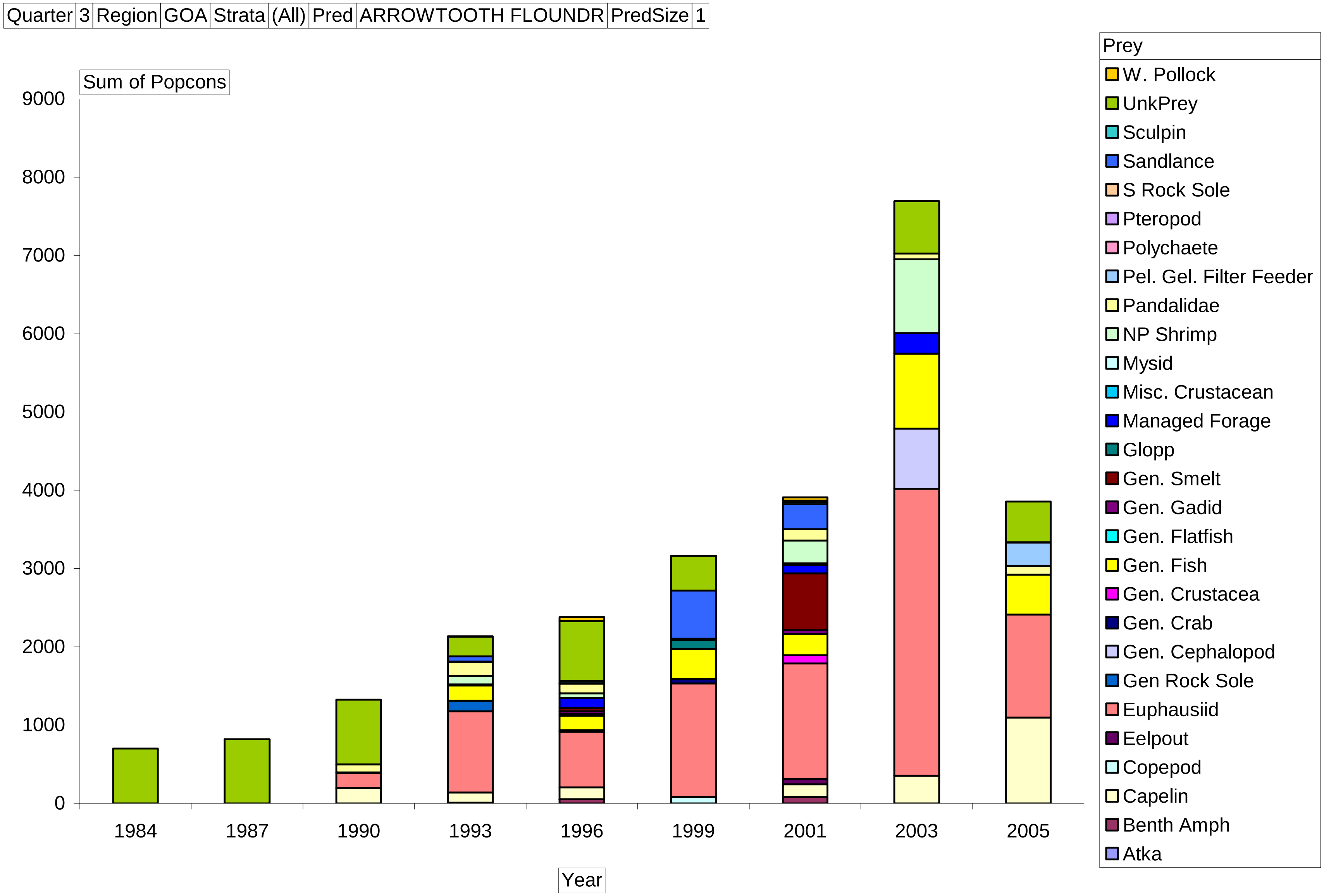

Figure B.9. Juvenile (<20 cm) arrowtooth estimated consumption of prey by survey year in the GOA.

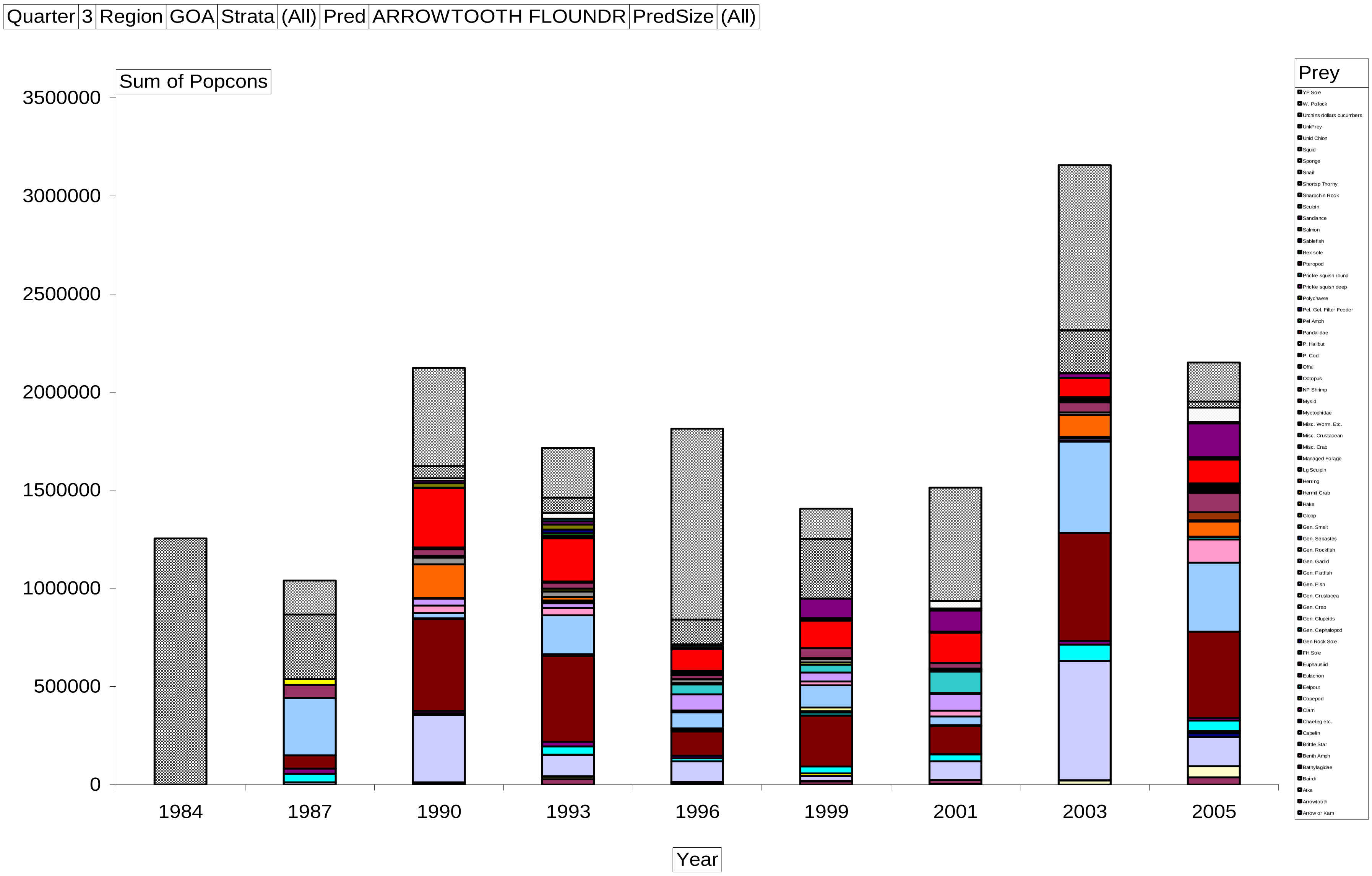

Figure B.10. Adult (20+ cm) arrowtooth estimated consumption of prey by survey year in the GOA.

BACKGROUND INFO ON MODEL PARAMETERS: REPRINTED FROM Aydin, et al., TECH MEMO

Arrowtooth flounder (*Atherestes stomias*) are relatively large, piscivorous flatfish in the family Pleuronectidae (right-eyed flounders) which range from Kamchatka, Russia in the Bering Sea through the Gulf of Alaska to Santa Barbara, CA on the U.S. west coast. It is found in benthic habitats from less than 10m to over 1000 m depth (Love et al. 2005). Arrowtooth flounder are currently the most abundant groundfish in the GOA (Turnock et al. 2003a). They exhibit differential growth by sex, with females reaching a maximum size of 1 m and age of 23, and males growing to 54 cm and 20 years. Females reach 50% maturity at 47 cm in the GOA, and display exponentially increasing fecundity with length, with large females producing over 2 million eggs annually (Zimmerman 1997). Until recently, arrowtooth flounder were not a desirable commercial species because their flesh quality was considered poor; however recently developed processing techniques have allowed a moderate commercial fishery to develop around Kodiak Island (AFSC website http://www.afsc.noaa.gov/species/Arrowtooth_flounder.php).

Adult arrowtooth flounder

In the EBS model, adult arrowtooth biomass is the NMFS bottom trawl survey estimate from 1991. GOA adult biomass is the average of 1990 and 1993 GOA NMFS bottom trawl survey estimates. In the AI biomass is the average of 1991 and 1994 estimates from the AI bottom trawl survey. The biomass was proportioned across the subareas according to survey estimates in each one.

In the EBS, the P/B ratio of 0.18 was estimated from the 1991 age structure in the EBS arrowtooth/Kamchatka flounder stock assessment (Wilderbuer and Sample 2003), and weight at age data collected on NMFS bottom trawl surveys for the EBS (see Appendix B for methods). The EBS Q/B ratio of 1.16 was estimated using weight at age data fit a generalized von Bertalanffy growth function (Essington et al. 2001) and scaled to the 1991 age structure from the EBS stock assessment. The GOA P/B ratio of 0.26 and Q/B ratio of 1.44 were estimated using the same methods as in the EBS from the 1990-1993 age structure in the GOA arrowtooth flounder stock assessment (Turnock et al. 2003a) and weight at age data collected on NMFS bottom trawl surveys. Values for the AI P/B and Q/B ratios of 0.297 and 2.61 were estimated using the age structure for 1991 in the BSAI stock assessment for arrowtooth/ Kamchatka flounder (Wilderbuer and Sample 2003), and weight at age data collected on NMFS bottom trawl surveys for the Gulf of Alaska.

Adult arrowtooth diet composition was estimated from food habits collections made during bottom trawl surveys in each ecosystem. The EBS diet was derived from 1991 collections, the GOA diet was derived from the 1990 and 1993 bottom trawl surveys of the GOA, and in the AI it comes from stomachs collected in 1991 and 1994 as part of the bottom trawl surveys.

The adult arrowtooth biomass data pedigree was 2 for the EBS and AI models (data is a direct estimate from surveys in AI and EBS but the assessment is conducted for the combined area), and 1 for the GOA model (direct estimate from surveys which agrees with the GOA assessment). P/B and Q/B parameters were rated differently by system: 3 in the GOA model (proxy with known and consistent bias), 4 in the EBS model (proxy for combined BSAI with some species mixing), and 5 in the AI model (proxy for combined BSAI with some species mixing plus weight at age from adjacent area). Diet composition data rated 1 in all systems (data established and substantial,with resolution on multiple spatial scales).

Arrowtooth flounder adults have a significantly higher density in the GOA (5.7 t/km^2) than in either the EBS or AI (<1 t/km^2). They are preyed upon by pollock, Alaska skates and sleeper sharks which jointly account for 60% of the total mortality in the EBS, but have relatively few predators in the AI; sleeper sharks are the only significant ones (16% of total mortality). In the GOA, there are no major predators on arrowtooth, as sleeper sharks, cod, pollock and cannibalism barely account for 11% of the total mortality. The fisheries in aggregate cause 15%-17% of the mortality in the EBS and AI respectively, while only

4% in the GOA. In all three systems adult arrowtooth flounder eat primarily pelagic prey. In the GOA they eat mostly capelin (22% of diet) and euphausiids (17%), followed by adult pollock (14%), and juvenile pollock (10%). In the EBS, arrowtooth flounder eat primarily juvenile pollock (47% of diet), followed by adult pollock (20%) and euphausiids (10%). In the AI, arrowtooth mostly prey on myctophids (27%), juvenile Atka mackerel (16%), and pandalid shrimp (16%).

Juvenile arrowtooth flounder

In all three models, juveniles were defined as fish less than 20 cm in length, which roughly corresponds to 0 through 1 year old arrowtooth. In the AI, juvenile arrowtooth biomass is based on an EE of 0.8. In the EBS and GOA models, initial attempts at estimating juvenile biomass using top-down methods were not successful because there are apparently few predators of juvenile arrowtooth flounder in either ecosystem. Therefore, in the EBS juvenile arrowtooth flounder biomass in each model stratum was assumed to be 10% of adult arrowtooth biomass in that stratum. In the GOA, we estimated juvenile arrowtooth mortality to be 0.5, a rate comparable to those estimated by MSVPA model runs in the EBS (Jurado-Molina 2001). This mortality rate was used to estimate juvenile biomass given the numbers and weight at age estimated for those years.

In the EBS, the P/B ratio of 1.58 was estimated by the same methods as described above for adults. In the GOA, the estimated juvenile mortality rate of 0.5 was used to estimate the P/B ratio to 0.90 for 1990-1993 based on stock assessment age structure. The juvenile arrowtooth P/B in the AI was estimated using the same method as that described above for adults, resulting in a value of 1.01. In all three ecosystems, Q/B ratios were estimated by the same method and using the same information as for adults. The EBS juvenile arrowtooth Q/B was therefore 3.31, the GOA juvenile arrowtooth Q/B was 2.45, and the AI Q/B ratio was 3.77.

Juvenile arrowtooth flounder diet composition was estimated from food habits collections made during bottom trawl surveys in each ecosystem. The EBS diet was derived from 1991 collections, the GOA diet was derived from the 1990 and 1993 bottom trawl surveys of the GOA, and in the AI it comes from stomachs collected in 1991 and 1994 as part of the bottom trawl surveys.

The juvenile arrowtooth biomass data pedigree was 8 for the EBS and AI models (no estimate available, top down balance), and 4 for the GOA (proxy with limited confidence). P/B and Q/B parameters were rated differently by system: 4 in the GOA model (proxy with limited confidence), 5 in the EBS model (downgraded from adult rating of 4), and 6 in the AI model (downgraded from adult rating of 5). Diet composition data rated 1 in all systems (data established and substantial, with resolution on multiple spatial scales).

Arrowtooth flounder juveniles have a low fraction of total mortality due to predation in the EBS and GOA, so the assumption of an EE=0.8 in the AI model to top down balance this group might be re-examined in revisions to that model. The major source of mortality in the EBS and GOA are adult arrowtooth (3-5%, respectively), but they are preyed upon mostly by Pacific cod (20%) in the AI. Juvenile arrowtooth flounder appear to eat from different sections of the food web in each system. They eat primarily benthic invertebrates (pandalids and benthic amphipods) in the AI, show approximately equal feeding from benthic and pelagic groups (non pandalids and juvenile pollock) in the EBS, but feed predominantly on pelagic euphausiids and capelin in the GOA.

[*NOTE: Parameter estimation methods below are reprinted from tech memo*]

Fish Production rates

Production/biomass (P/B) and consumption/biomass (Q/B) for a given population depend heavily on the age structure, and thus mortality rate of that population. For a population with an equilibrium age structure, assuming exponential mortality and Von Bertalanffy growth, P/B is in fact equal to total mortality Z (Allen 1971) and Q/B is equal to (Z+3K)/A, where K is Von Bertalanffy's K, and A is a scaling factor for indigestible proportions of prey (Aydin 2004). If a population is not in equilibrium, P/B may differ substantially from Z although it will still be a function of mortality.

For the Bering Sea, Aleutian Islands, and Gulf of Alaska ECOPATH models, P/B and Q/B values depend on available mortality rates, which were taken from estimates or literature values used in single-species models of the region. It is noted that the single-species model assumptions of constant natural mortality are violated by definition in multispecies modeling; therefore, these estimates should be seen as "priors" to be input into the ECOPATH balancing procedures or other parameter-fitting (e.g. Bayesian) techniques.

Several methods were used to calculate P/B, depending on the level of data available. Proceeding from most data to least data, the following methods were used:

1. If a population is not in equilibrium, total production P for a given age class over the course of a year can be approximated as ($N_{at} \cdot \Delta W_{at}$), where N_{at} is the number of fish of a given age class in a given year, exponentially averaged to account for mortality throughout the year, and ΔW_{at} is the change in body weight of that age class over that year. For a particular stock, if weight-at-age data existed for multiple years, and stock-assessment reconstructed numbers-at-age were also available, production was calculated by summing this equation over all assessed age classes. Walleye pollock P/B for both the EBS and GOA were calculated using this method: examining the components of this sum over the years showed that numbers-at-age variation was responsible for considerably more variability in overall P/B than was weight-at-age variation.
2. If stock assessment numbers-at-age were available, but a time series of weight-at-age was not available and some weight-at-age data was available, the equation in (1), above, was used, however, the change in body weight over time was estimated using fits to the generalized Von Bertalanffy equations described in the consumption section, below.
3. If no stock assessment of numbers-at-age was available, the population was assumed to be in equilibrium, so that P/B was taken to equal Z. In cases for many nontarget species, estimates of Z were not available so estimates of M were taken from conspecifics with little assumed fishing mortality for this particular calculation.

Fish Consumption rates

There are multiple methods for estimating the consumption rates (Q/B, consumption per unit biomass) for fish. Four methods were considered in the construction of these models: bioenergetics models (based on laboratory and field experiments), allometric fitting to weight-at-age data (e.g. Essington et al. 2001), evacuation rate calculation from field stomach contents data (e.g. MAXIMS, Jarre et al. 1991) and empirical methods based on morphological characteristics (Pauly 1986). One goal in selecting methods was to choose options which could be used consistently in all three ecosystem models and thus provide reasonable bases for comparison.

It was determined that insufficient data existed for the application of bioenergetics models or evacuation rate calculations; while models existed for a very limited number species, input data such as foraging rates and water temperature specific to the Alaska region were not consistently available, and lack of these data could result in extremely broad error ranges or bias in estimates. Pauly's (1986) empirical methods have an order-of-magnitude error range and thus were considered as a worst-case solution only.

While bioenergetics data was limited, weight-at-age data existed for many species throughout the region: the method of fitting the generalized Von Bertalanffy growth equations to these data (Essington et al. 2001) was thus selected. (The solution for Q/B given above, (Z+3K)/A, is a solution for a specialized case of the equations, as described below).

The generalized Von Bertalanffy growth equation assumes that both consumption and respiration scale allometrically with body weight, and change in body weight over time (dW/dT) is calculated as follows (Paloheimo and Dickie 1965):

$$\frac{dW_t}{dt} = H \cdot W_t^d - k \cdot W_t^n \qquad (1)$$

Here, W_t is body mass, t is the age of the fish (in years), and H, d, k, and n are allometric parameters. The term $H \cdot W_t^d$ is an allometric term for "useable" consumption over a year, in other words, the consumption (in wet weight) by the predator after indigestible portions of the prey have been removed and assuming constant caloric density between predator and prey. Total consumption (Q) is calculated as $(1/A) \cdot H \cdot W_t^d$, where A is a scaling fraction between predator and prey wet weights that accounts for indigestible portions of the prey and differences in caloric density. The term $k \cdot W_t^n$ is an allometric term for the amount of biomass lost yearly as respiration.

Based on an analysis performed across a range of fish species, Essington et al. (2001) suggested that it is reasonable to assume that the respiration exponent n is equal to 1 (respiration linearly proportional to body weight). In this case, the differential equation above can be integrated to give the following solution for weight-at-age:

$$W_t = W_\infty \cdot \left(1 - e^{-k(1-d)(t-t_0)}\right)^{\frac{1}{1-d}} \qquad (2)$$

Where W_∞ (asymptotic body mass) is equal to $(H/k)^{\frac{1}{1-d}}$, and t_0 is the weight of the organism at time=0. If the consumption exponent d is set equal to 2/3, this equation simplifies into the "specialized" von Bertalanffy length-at-age equation most used in fisheries management, with the "traditional" von Bertalanffy K parameter being equal to the k parameter from the above equations divided by 3.

From measurements of body weight and age, equation 2 can be used to fit four parameters (W_∞, d, k, and t_0) and the relationship between W_∞ and the H, k, and d parameters can then be used to determine the consumption rate $H \cdot W_t^d$ for any given age class of fish. For these calculations, weight-at-age data available and specific to the modeled regions were fit by minimizing the difference between log(observed) and log(predicted) body weights as calculated by minimizing negative log likelihood: observation error was assumed to be in weight but not aging. A process-error model was also examined but did not give significantly different results.

Initial fitting of 4-parameter models showed, in many cases, poor convergence to unique minima and shallow sum-of-squares surfaces: the fits suffered especially from lack of data at the younger age classes that would allow fitting to body weights near t=0 or during juvenile, rapidly growing life stages. To counter this, the following multiple models were tested for goodness-of-fit:

1. All four parameters estimated by minimization;
2. *d* fixed at 2/3 (specialized von Bertalanffy assumption)
3. *d* fixed at 0.8 (median value based on metaanalysis by Essington et al. 2001).
4. t_0 fixed at 0.
5. *d* fixed at 2/3 with t_0 fixed at 0, and *d* fixed at 0.8 with t_0 fixed at 0.

The multiple models were evaluated using Aikeike's Information Criterion, AIC (Anderson and Burnham 2002). In general, the different methods resulted in a twofold range of consumption rate estimates; consistently, model #3, *d* fixed at 0.8 while the other three parameters were free, gave the most consistently good results using the AIC. In some cases model #1 was marginally better, but in some cases, model #1 failed to converge. The poorest fits were almost always obtained by assuming that d was fixed at 2/3.

To obtain absolute consumption (*Q*) for a given age class, the additional parameter *A* is required to account for indigestible and otherwise unassimilated portions of prey. We noted that the range of indigestible percentage for a wide range of North Pacific zooplankton and fish summarized in Davis (2003) was between 5-30%, with major zooplankton (copepods and euphasiids), as well as many forage fish, having a narrower range of indigestible percentages, generally between 10-20%. Further, bioenergetics models, for example for walleye pollock (Buckley and Livingston 1994), indicate that nitrogenous waste (excretion) and egestion resulted in an additional 20-30% loss of consumed biomass. As specific bioenergetics models were not available for most species, we made a uniform assumption of a total non-respirative loss of 40% (from a range of 25-60%) for all fish species, with a corresponding *A* value of 0.6.

Finally, consumption for a given age class was scaled to population-level consumption using the available numbers-at-age data from stock assessments, or using mortality rates and the assumption of an equilibrium age structure in cases where numbers-at-age reconstructions were not available.

Diet queries for fish

The most central parameter set for food web models are the diet composition matrices, obtainable through stomach sampling or other analyses. In particular, the elaboration of our food web models with respect to fished species depends heavily on the analysis of 250,000+ stomachs collected by the Resource Ecology and Ecosystem Management (REEM) program. Continuation of this collection will allow for a regular update and improvement of these models. Due to the high resolution and coverage of this diet data, we were able to model functional groups at a relatively high resolution: over 120 functional groups are specifically and separately accounted with survey strata-level resolution (rough depth and location), with specific juvenile and adult accounting for several of the commercial groundfish, crab, and pinniped species. Diets estimated directly from stomach samples collected in the same area that a model covers are considered “direct”.

The diet composition for a species is calculated from stomach sampling beginning at the level of the individual survey haul (1), combining across hauls within a survey stratum (2), weighting stratum diet compositions by stratum biomass (3), and finally combining across predator size classes by weighting according to size-specific ration (consumption rate) estimates and biomass from stock assessment estimated age structure (4). Consumption rate calculations are described in detail above.

Notation:

DC = diet composition
W = weight in stomach
n = prey
p = predator
s = predator size class
h = survey haul
r = survey stratum
B = biomass estimate
v = survey
a = assessment
R = Q/B = ration estimate

Diet composition (DC) of prey n in predator p of size s in haul h is the total weight of prey n in all of the stomachs of predator p of size s in the haul divided by the sum over all prey in all of the stomachs for that predator size class in that haul:

$$DC_{n,p,s,h} = W_{n,p,s,h} \Big/ \sum_{n} W_{n,p,s,h} \qquad (1)$$

Diet composition of prey n in predator p of size s in survey stratum r is the average of the diet compositions across hauls within that stratum:

$$DC_{n,p,s,r} = \sum_{h} DC_{n,p,s,h} \Big/ h \qquad (2)$$

Diet composition of prey n in predator p of size s for the entire area t is the sum over all strata of the diet composition in stratum r weighted by the survey biomass proportion of predator p of size s in stratum r:

$$DC_{n,p,s,t} = \sum_{r} DC_{n,p,s,r} * B^{v}_{p,s,r} \Big/ \sum_{r} B^{v}_{p,s,r} \qquad (3)$$

Diet composition of prey n in predator p for the entire area t is the sum over all predator sizes of the diet composition for predator p of size s as weighted by the relative stock assessment biomass of predator size s times the ration of predator p of size s:

$$DC_{n,p,t} = \sum_{s} DC_{n,p,s,t} * B^{a}_{p,s} * R_{p,s} \Big/ \sum_{s} B^{a}_{p,s} * R_{p,s} \qquad (4)$$

Diets for fish and shellfish not included in the REEM database were taken from published literature sources or the nearest survey samples. For example, diets estimated from stomachs collected in the EBS may be used as surrogates in the AI and GOA if these last systems lack specific diet information. However these diets would be considered “general” for the AI and GOA in the sense that they are not from stomach samples taken as part of the REEM program and are neither weighted by depth nor location (but they would be for the EBS); in these cases prey items were assigned fixed percentages.

References

Aydin, K.Y. 2004. Age structure or functional response? Reconciling the energetic of surplus production between single species models and ecosim. Ecosystem approaches to fisheries in the Southern Benguela, African Journal of Marine Science 26: 289-301.

Aydin, K., S. Gaichas, I. Ortiz, D. Kinzey, and N. Friday. In press. A comparison of the Bering Sea, Gulf of Alaska, and Aleutian Islands large marine ecosystems through food web modeling. NOAA NMFS Tech Memo. 294 p.

Allen, K.R. 1971. Relation between production and biomass. Journal of the Fishery Research Board of Canada 28: 1573-1581.

Buckley, T. W., and Livingston, P. A. 1994. A bioenergetics model of walleye pollock (*Theragra chalcogramma*) in the Eastern Bering Sea: structure and documentation. U.S. Department of Commerce, NOAA Tech. Memo. NMFS-AFSC-37.

Davis, N. D. 2003. Feeding ecology of Pacific salmon (*Oncorhynchus* spp.) in the central North Pacific Ocen and central Bering Sea, 1991-2000. Ph.D. Dissertation, Hokkaido University, Hakodate, Japan.

Essington, T.E., J.F. Kitchell, and C.J. Walters, 2001. The von Bertalanffy growth function, bioenergetics, and the consumption rates of fish. Canadian Journal of Fisheries and Aquatic Science 58: 2129-2138.

Paloheimo, J.E., and L.M. Dickie. 1965. Food and growth of fishes. I. A growth curve derived from experimental data. J. Fish. Res. Board Can. 22: 521–542.