8. Gulf of Alaska Flathead Sole Stock Assessment

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Executive Summary

Changes in the Input Data

1) The fishery catch and length compositions for 2006 and 2007 (through Sept. 22, 2007) were incorporated in the model.
2) The 2005 fishery catch and length compositions were updated.
3) The 2007 GOA groundfish survey biomass estimate and length composition data were added to the model. Survey biomass increased from 213,221 t in 2005 to 280,990 t in 2007. Survey biomass estimates and length compositions were recalculated for all survey years.

Changes in the Assessment Model

No changes were made to the structure of the assessment model.

Changes in the Assessment Results

1. The recommended ABC, based on an $F_{40\%}$ harvest level of 0.380, is 44,735 t for 2008 and 46,505 t for 2009.
2. The OFL, based on an $F_{35\%}$ harvest level of 0.494, is 55,787 t for 2008 and 57,962 t for 2009.
3. Projected female spawning biomass is estimated at 106,566 t for 2008 and 109,533 t for 2009.
4. Total biomass (age 3+) is estimated at 324,197 t for 2008 and 324,524 t for 2009.

A summary of the recommended ABCs from the 2007 assessment, relative to the 2006 SAFE projections, is as follows:

Quantity	2007 Assessment Recommendations for 2008	2006 Assessment Recommendations for 2008	2006 Assessment Recommendations for 2007
Tier	**3a**	**3a**	**3a**
Total biomass (Age 3+; t)	324,197	297,757	297,353
Female Spawning Biomass (t)	106,566	100,195	96,425
ABC (t)	44,735	41,104	39,110
Overfishing (t)	55,787	51,146	48,658
$F_{ABC} = F_{40\%}$	0.380	0.359	0.359
$F_{OFL} = F_{35\%}$	0.494	0.463	0.463

SSC Comments Specific to the Flathead Sole Assessments

SSC comment: *The SSC encouraged authors to consider adding more detailed ecosystem consideration information in the flatfish chapters and exploring survey catchability and temperature relationships.*

Author response: We have incorporated more detailed information for ecosystem considerations into the SAFE. We have not yet incorporated temperature-dependent survey catchability into the assessment model; we are currently working on a model that does this.

<u>SSC Comments on Assessments in General</u>

SSC request: *The SSC requested that the next round of assessments consider the possible use of ADF&G bottom trawl survey data to expand the spatial and depth coverage.*

Author response: We have not yet investigated this suggestion. We will do so prior to the next assessment.

Introduction

Flathead sole (*Hippoglossoides elassodon*) are distributed from northern California, off Point Reyes, northward along the west coast of North America and throughout the GOA and the BS, the Kuril Islands, and possibly the Okhotsk Sea (Hart 1973). They occur primarily on mixed mud and sand bottoms (Norcross et al., 1997; McConnaughey and Smith, 2000) in depths < 300 m (Stark and Clausen, 1995). The flathead sole distribution overlaps with the similar-appearing Bering flounder (*Hippoglossoides robustus*) in the northern half of the Bering Sea and the Sea of Okhotsk (Hart, 1973), but not in the Gulf of Alaska.

Adults exhibit a benthic lifestyle and occupy separate winter spawning and summertime feeding distributions on the EBS shelf and in the GOA. From over-winter grounds near the shelf margins, adults begin a migration onto the mid and outer continental shelf in April or May each year for feeding. The spawning period may range from as early as January but is known to occur in March and April, primarily in deeper waters near the margins of the continental shelf. Eggs are large (2.75 to 3.75 mm) and females have egg counts ranging from about 72,000 (20 cm fish) to almost 600,000 (38 cm fish). Eggs hatch in 9 to 20 days depending on incubation temperatures within the range of 2.4 to 9.8°C and have been found in ichthyoplankton sampling on the southern portion of the BS shelf in April and May (Waldron 1981). Larvae absorb the yolk sac in 6 to 17 days, but the extent of their distribution is unknown. Nearshore sampling indicates that newly settled larvae are in the 40 to 50 mm size range (Norcross et al. 1996). Fifty percent of flathead sole females in the GOA are mature at 8.7 years, or at about 33 cm (Stark, 2004). Juveniles less than age 2 have not been found with the adult population and probably remain in shallow nearshore nursery areas.

Fishery

Flathead sole in the Gulf of Alaska are caught in a directed fishery using bottom trawl gear. Typically 25 or fewer shore-based catcher vessels from 58-125' participate in this fishery, as do 5 catcher-processor vessels (90-130'). Fishing seasons are driven by seasonal halibut PSC apportionments, with approximately 7 months of fishing occurring between January and November. Catches of flathead sole occur only in the Western and Central management areas in the gulf (statistical areas 610 and 620 + 630, respectively). Recruitment to the fishery begins at about age 3.

Historically, catches of flathead sole have exhibited decadal-scale trends (Table 8.1, Fig. 8.1). From a high of ~2000 t in 1980, annual catches declined steadily to a low of ~150 t in 1986 but thereupon increased steadily, reaching a high of ~3100 t in 1996. Catches subsequently declined over the next three years, reaching a low of ~900 t in 1999, followed by an increasing trend until 2006, when the catch reached its highest level ever (3,134 t). As of Sept. 22, catch in 2007 was 2,854 t.

Based on observer data, the majority of the flathead sole catch in the Gulf of Alaska is taken in the Shelikof Strait and on the Albatross Bank near Kodiak Island, as well as near Unimak Island (Figure 8.2a, b). The spatial pattern of catches has been reasonably consistent over the past three years. Most of the catch is taken in the first and second quarters of the year (Figure 8.2b).

Annual catches of flathead sole have been well below TACs in recent years, although the population appears to be capable of supporting higher exploitation rates (Table 8.2a). Limits on flathead sole catches are driven by within-season closures of the directed fishery due to restrictions on halibut PSC, not by attainment of the TAC (Table 8.2b). Recognizing this, TACs have been typically set much less than the recommended ABC. Prior to 2003, flathead sole were a Tier 5 species and ABC's were based on natural mortality rates. Following the development and adoption of an age-structured assessment model in 2003, ABCs for flathead sole in the Gulf of Alaska almost doubled from 2002 to 2003, from ~23,000 to 42,000 t. However, TACs increased only moderately as a result.

Flathead sole are also caught in the pursuit of other species as bycatch. They are caught in the Pacific cod, bottom pollock and other flatfish fisheries and are caught with these species in the flathead sole-directed fishery. The gross discard rate for flathead sole over all fisheries in was 11% in both 2006 and 2007 (Table 8.2a).

Data

Fishery Data

This assessment used fishery catches from 1984 through 22 September, 2007 (Table 8.1, Fig. 8.1), as well as estimates of the proportion of individuals caught by length group and sex for the years 1985-2007 (as of Sept. 22; Tables 8.3a, b). Sample sizes for the size compositions are shown in Table 8.4a. Age composition data from the fishery is not currently used in the assessment model.

Survey Data

Because flathead sole is often taken incidentally in target fisheries for other species, CPUE from commercial fisheries seldom reflects trends in abundance for this species. It is therefore necessary to use fishery-independent survey data to assess the condition of this stock.

This assessment used estimates of total biomass for flathead sole in the Gulf of Alaska from triennial (1984-1999) and biennial (2001-2007) groundfish surveys conducted by the Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering (RACE) division to provide an index of population abundance (Table 8.5). Although survey depth coverage has been inconsistent for depth strata > 500 m (Table 8.5), the fraction of the flathead sole stock occurring in these depth strata is miniscule (Table 8.6), so we have not attempted to correct the survey estimates of total biomass for missing depth strata. We have, however, corrected the 2001 survey estimate of total biomass, because the eastern section of the Gulf was not sampled that year. We estimated the average fraction of stock biomass occurring in the unsampled area from the 1993, 1996 and 1999 surveys (~11%) and expanded the 2001 estimate to correct for the missing area (Table 8.5). Since 1984, survey estimates of total biomass have fluctuated about a mean of ~220,000 t, with no apparent trend. Estimated total biomass was ~280,000 t in 2007, the largest in the time series, and a 33% increase over the 2005 estimate of ~210,000 t.

Estimates of total population numbers-at-age from the RACE surveys were also incorporated in the assessment model, where available (1984, 1993, 1996, 2003 and 2005; Table 8.7). Estimates of the total number of individuals by length group from the RACE surveys (Table 8.8) were used for survey years where age composition data was not available (1987, 1990, 1999, 2001 and 2007). Sample sizes for the survey age and size compositions are shown in Table 8.4.

Data on individual growth was incorporated in the assessment using sex-specific age-length transition matrices (Table 8.9a, b). These matrices were also used in the previous assessment (Stockhausen et al., 2005). Sex-specific weight-at-age relationships and female maturity schedules used in the previous assessment (Stockhausen et al., 2005) were also used in this assessment (Table 8.10).

To summarize, the following data was incorporated in the assessment:

Source	type	years
Fishery	catch	1984-2007
	length compositions	1985-2007
Survey	biomass	1984-1999 (triennial); 2001-2007 (biennial)
	length compositions	1987, 1990, 1999, 2001, 2007
	age compositions	1984, 1993, 1996, 2003, 2005

Analytic Approach

Model structure

The assessment was conducted using a split-sex, age-structured model with parameters evaluated in a maximum likelihood context. The model structure (Appendix A) was 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 minimum of an objective function via a quasi-Newton function minimization routine (e.g., Press et al. 1992). It also gives simple and rapid access to these routines and provides the ability to estimate the variance-covariance matrix for all parameters of interest.

The model covers 1984-2007. Age classes included in the model run from age 3 to 20. Age at recruitment was set at 3 years in the model due to the small number of fish caught at younger ages. The oldest age class in the model, age 20, serves as a plus group in the model; the maximum age of flathead sole based on otolith age determinations has been estimated at 25 years (Turnock et al., 2003a). Details of the population dynamics and estimation equations, description of variables and likelihood components are presented in Appendix A (Tables A.1, A.2, and A.3). Model parameters that are typically fixed are presented in Table A.4. A total of 75 parameters were estimated in the final model (Table A.5).

Parameters estimated independently

Model parameters related to natural mortality, growth, weight, maturity and survey catchability were fixed in the final model (Table A.4).

Natural mortality
As in the previous assessment (Stockhausen et al., 2005), natural mortality (M) was fixed at 0.2 yr^{-1} for both sexes in all age classes. This value was based on maximum observed age for flathead sole (Spencer et al., 1999).

Growth
Individual growth was incorporated in the model using sex-specific age-length transition matrices. These were identical to those used in the previous assessment (Stockhausen et al., 2005). In terms of the von Bertalanffy growth equation, L_{inf} was estimated at 44.37 cm for females and 37.36 cm for males (Figure 8.6). The length at age 2 (L_2) was estimated at 10.17 cm for males and 13.25 cm for females. The growth parameter k was estimated at 0.157 for females and 0.204 for males. Length at age t was modeled as:

$$L_t = L_{\inf} + (L_2 - L_{\inf})\, e^{-k(t-2)}$$

Weight at length
The weight-length relationship used for flathead sole was identical to that used in the previous assessment (Stockhausen et al., 2005): $W = 0.00428\, L^{3.2298}$ for both sexes combined (weight in grams and length in centimeters). Weight-at-age (Table 8.10) was estimated using the mean length-at-age and the weight-length relationship.

Maturity
The maturity schedule for Gulf of Alaska flathead sole was estimated using histological analysis of ovaries collected in January 1999 (Stark, 2004; Table 8.10). A total of 180 samples were analyzed for estimation of age at maturity. Size at 50% mature was estimated to be 33.3 cm with a slope of 0.52 cm^{-1} from a sample of 208 fish. Age at 50% mature was 8.74 years with a slope of 0.773 yr^{-1}. Size at 50% mature was estimated at 32.0 cm for Bering Sea flathead sole (not significantly different from the GOA results), however, age at 50% mature was 9.7 due to slower growth in the Bering sea.

Survey catchability
For the assessment, survey catchability (Q in Table A.1) was fixed at 1. An alternative model with Q allowed to vary was explored, but, as in the previous assessment, estimability was poor (see below).

Parameters estimated conditionally

A total of 75 parameters were estimated in the final model (Table A.5). These consist primarily of parameters on the recruitment of flathead sole to the population (42 parameters total, including ones determining the initial age composition) and values related to annual fishing mortality (25 parameters total). The separable age-component of fishing mortality was modeled using a two parameter ascending logistic function estimated separately for males and females (4 parameters total). The same form of curve was also used to estimate relative age-specific survey catchability (4 parameters total).

Annual recruitment to the age 3 year class was parameterized in the model using one parameter for the log-scale mean recruitment and 41 parameters for the annual log-scale deviation from the mean. Recruitments were estimated back to 1967 to provide an initial age distribution for the model in its starting year (1984). In an analogous fashion, fully-recruited fishing mortality was parameterized in the model using one parameter for the log-scale mean and 22 parameters for the annual log-scale deviation from the mean.

Parameters in the model were selected based on minimizing an objective function equivalent to a negative log-likelihood function, hence the parameter estimates are maximum likelihood estimates. Components that contribute to the overall negative log likelihood include those related to observed fishery catches, fishery size compositions, survey biomass estimates, survey size compositions, survey age composition, and recruitment deviations (Table A.3). The observed fishery catch was assumed to have a lognormal error structure, as was estimated survey biomass. The recruitment deviation parameters were incorporated directly into the overall likelihood via three components: “early” recruitment, “ordinary” recruitment and “late” recruitment (Table A.3). The “early” recruitment component incorporated deviations from 1967 to 1983 (i.e., prior to the modeled age structure), “ordinary” recruitment incorporated deviations from 1984-2004 and “late” recruitment incorporated deviations from 2005-2007. All three components were formulated assuming a lognormal error structure. The size and age compositions were assumed to be drawn from different sex-specific multinomial distributions. If this assumption were strictly correct, then the number of individuals contributing to each composition would be the appropriate corresponding sample size. However, because fish of the same size and age tend to be found together, size and age compositions tend to be overdispersed with respect to actual multinomial distributions. Also, the use of high sample sizes can lead to numerical problems in estimating the model parameters. Previous experience indicates that using a uniform sample size of 200 for compositions with more than 200 individuals provides an adequately simple solution to the problem of assigning sample sizes. Thus, a sample size of 200 was used for all compositions used in the likelihood (all age compositions and size compositions from years with no corresponding age compositions).

Different weights can be assigned to each likelihood component to increase or decrease the relative degree of model fit to the data underlying the respective component; a larger weight induces a closer fit to a given likelihood component. Typically, a relatively large weight (e.g., 30) is applied to the catch component while smaller weights (e.g., 1) are applied to the survey biomass, recruitment, and size and age composition components. This reflects a belief that total catch data are reasonably well known (smaller variance) than the other types of data. For the recruitment components, larger weights applied to a component force the deviations contributing to that component closer to zero (and thus force recruitment closer to the geometric mean over the years that contribute to the component).

Model evaluation

Several alternative model configurations were considered in the previous assessment (Stockhausen et al., 2005). Here, we used the model configuration selected in that assessment. We assigned a weight of 30 to the catch-specific likelihood component and weights of 1 to all other likelihood components (Table 8.11). Based on results from the 2003 assessment (Turnock et al., 2003a), which indicated that estimating survey catchability was problematic, we also fixed survey catchability as a constant in the model (Q =1). Initial values for the remaining parameters were set as listed in Table 8.12. To test whether the resulting model solution (Table 8.13) was indeed a global, rather than local, maximum on the likelihood surface, we conducted a Markov Chain Monte Carlo (MCMC) study using ADModel Builder's built-in MCMC capability in which we evaluated the likelihood at 1000 different parameter combinations and compared the resulting values with that from the model solution. The results of this study indicated that the model solution was in fact a global maximum. We further tested the convergence of the solution by starting the model with several different parameter sets. All model runs converged to the same final solution, providing additional evidence that the original solution was indeed the global maximum.

Final parameter estimates

The parameter estimates considered final for this assessment are given in Table 8.13 for all model parameters.

Schedules implied by parameter estimates

The estimated selectivity curves for the fishery and survey indicate that the fishery generally catches older flathead sole than the survey (Figure 8.7). For the fishery, age at 95% selection was 13.1 for females and 12.6 for males. For the survey, the ages at 95% selection were younger: 10.0 for females and 9.6 for males.

Results

Given the large relative weight assigned to the catch-specific likelihood component, it was not surprising that the model estimates of fishery catch closely matched the observed values (Table 8.14 and Figure 8.8). The model did not fit the fishery size compositions nearly as well, although its performance appeared to be reasonably good in most years (Figures 8.9 and 8.10 for females and males, respectively). Fits to the fishery size compositions were poorest when the observed size composition was dominated by a single size class and thus sharply peaked (e.g., 1987 in Figure 8.9). The smoothing inherent in using an age-length transition matrix to convert age classes to size classes precludes close fits to peaked size compositions.

The model does not fit observed survey biomass values as closely as it does the catch (Table 8.14 and Figure 8.11), but model estimates of survey biomass fall outside the 95% confidence intervals of the actual surveys for only two out of nine survey years (1984 and 2001) so the fit is deemed satisfactory. As with the fishery size compositions, model fits to the survey size compositions were poorest when the observed size compositions were sharply peaked, but still generally reasonable (Figures 8.12 and 8.13). Finally, the model also fits the survey age compositions reasonably well (Figures 8.14 and 8.15), although more so when the observed age distributions are similar between the sexes (e.g., for 1984).

The model also estimates other population variables of interest, such as time series of total biomass, spawning biomass, recruitment and fully-selected fishing mortality. In this assessment, total biomass is represented by age 3+ biomass whereas spawning biomass is female spawning biomass. Model estimates of age 3+ biomass increased moderately from 244,000 t in 1984 to 284,000 t in 1996, then declined slowly to a low of 274,000 t in 1999 and subsequently have risen steadily in recent years to achieve their highest level in 2007 at 322,000 t (Table 8.15 and Figure 8.16). The estimated age 3+ biomass in this assessment is generally lower than that estimated in the 2003 assessment but higher than that estimated in the 2005 assessment (Table 8.15). The estimated female spawning biomass is quite similar to that from the 2005 assessment, but is lower, on average by 16%, than that estimated in the 2003 assessment. A different maturity schedule was used in the 2003 assessment.

Model estimates of annual recruitment (age 3 numbers) ranged from a low of 133,000,000 in 1999 to a high of 447,000,000 in 2006 (Table 8.16 and Figure 8.17). Prior to 2000, recruitment was generally below the long-term average (249,000,000), while it has generally been higher since 2000. In 2007, recruitment was estimated below the long-term average. Results from the current assessment are similar to those estimated in the 2005 assessment (Table 8.16).

A control rule plot showing the temporal trajectory of estimated fishing mortality and spawning biomass indicates that the GOA flathead sole stock has not been overfished nor has overfishing occurred (Figure 8.13).

Projections and Harvest Alternatives

The reference fishing mortality rate for flathead sole is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{40\%}$, $F_{35\%}$, and $SPR_{40\%}$ were obtained from a spawner-per-recruit analysis. Assuming that the average recruitment from the 1981-2003 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{40\%}$ is calculated as the product of $SPR_{40\%}$ times the equilibrium number of recruits; this quantity is 45,329 t. The 2007 spawning stock biomass is estimated at 103,000 t. Since reliable estimates of the 2007 spawning biomass (B), $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and $B > B_{40\%}$ (103,000 t > 45,329 t), the flathead sole reference fishing mortality is defined in Tier 3a. For this tier, F_{ABC} is constrained to be $\leq F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. The values of these quantities are:

2007 SSB estimate (B)	=	103,000 t
$B_{40\%}$	=	45,329 t
$F_{40\%}$	=	0.380
F_{ABC}	$\leq$	0.380
$B_{35\%}$	=	39,663 t
$F_{35\%}$	=	0.494

$$F_{OFL} = 0.494$$

Because the flathead sole stock has not been overfished in recent years and the stock biomass is relatively high, it is not recommended to adjust F_{ABC} downward from its upper bound; thus, the year 2008 recommended ABC associated with F_{ABC} of 0.380 is 44,735 t.

The fishing mortality for year 2008 associated with overfishing (F_{OFL}) is 0.494. The corresponding OFL is 55,787 t.

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 Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2007 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2008 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2007. 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 2008, 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 2008 recommended in the assessment to the *max* F_{ABC} for 2006. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

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

Scenario 4: In all future years, F is set equal to the 2003-2007 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.)

The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, so scenarios 1 and 2 yield identical results. The 12-year projections of the mean harvest and spawning stock biomass for the five scenarios are shown in Table 8.17.

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the flathead sole stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (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 its MSY level in 2008, then the stock is not overfished.)

Scenario 7: In 2006 and 2007, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2020 under this scenario, then the stock is not approaching an overfished condition.)

The results of these two scenarios indicate that the flathead sole are not overfished and is not approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2008 of scenario 6 is 106,566 t, over 2.5 times $B_{35\%}$ (39,663 t). Thus the stock is not currently overfished. With regard to whether the stock is approaching an overfished condition, the expected spawning stock size in the year 2020 of scenario 7 (41,708 t) is greater than $B_{35\%}$; thus, the stock is not approaching an overfished condition.

Estimating an ABC and OFL for 2009 is somewhat problematic as these values depend on the catch that will be taken in 2008. The actual catch taken in the GOA flathead sole fishery has been substantially smaller than the TAC for the past several years, but the catch has been rising steadily since 1999 (Figure 8.1) and the 2007 catch was the second largest in recent years. Thus, we assumed that a reasonable estimate of the catch to be taken in 2008 was a linear extrapolation of the catch taken over the past five years. Thus, the total catch taken was projected to be 2,987 t in 2007 and 3,147 in 2008. Using these values and the estimated population size at the start of 2007 from the model, we projected the stock ahead through 2007-2008 and calculated the ABC and OFL for 2009. The estimated ABC for 2009 is 46,505 t while the estimated OFL is 57,962. Total biomass for 2009 is estimated at 324,524 t, while female spawning biomass is estimated at 109,533.

Area allocation of harvests

TAC's for flathead sole in the Gulf of Alaska are divided among four smaller management areas (Western, Central, West Yakutat and Southeast Outside). As in the previous assessment, the area-specific ABC's for flathead sole in the GOA are divided up over the four management areas by applying the fraction of the most recent survey biomass estimated for each area (relative to the total over all areas) to the 2008 and 2009 ABC's. The area-specific allocations for 2008 and 2009 are:

ABC Allocation by management area

	Western Gulf	Central Gulf	West Yakutat	Southeast Outside	Grand Total
apportionment	28.0%	63.0%	7.6%	1.4%	100.0%
2008 ABC (t)	12,507	28,174	3,420	634	44,735
2009 ABC (t)	13,001	29,289	3,556	659	46,505

Ecosystem Considerations

Ecosystem effects on the stock

Prey availability/abundance trends

Based on results from an ecosystem model for the Gulf of Alaska (Aydin et al., in press), flathead sole in the Gulf of Alaska occupy an intermediate trophic level as both juvenile and adults (Fig. 8.19). Pandalid shrimp and brittle stars were the most important prey for adult flathead sole in the Gulf of Alaska (64% by weight in sampled stomachs; Yang and Nelson, 2000; Fig. 8.20a), while euphausids and mysids constituted the most important prey items for juvenile flathead sole (Fig. 8.20b).. Other major prey items included polychaetes, mollusks, bivalves and hermit crabs for both juveniles and adults. Commercially important species that were consumed included age-0 Tanner crab (3%) and age-0 walleye pollock (< 0.5% by weight). Little to no information is available to assess trends in abundance for the major benthic prey species of flathead sole.

Predator population trends

Important predators on flathead sole include arrowtooth flounder, walleye pollock, Pacific cod, and other groundfish (Fig. 8.21). Pacific cod and Pacific halibut are the major predators on adults, while arrowtooth flounder, sculpins, walleye pollock and Pacific cod are the major predators on juveniles. The flatfish-directed fishery constitutes the third-largest known source of mortality on flathead sole adults. However, the largest component of mortality on adults is unexplained.

Arrowtooth flounder are currently the most abundant groundfish in the Gulf of Alaska, and have steadily increased in abundance since the early 1970’s (Turnock et al., 2003b). The abundance of walleye pollock has declined rather steadily since the early 1990’s, but recent evidence suggests the stock may be starting to increase again (Dorn et al., 2004). Pacific cod abundance in the Gulf of Alaska has been declining since 1990 (Thompson et al., 2004). Although the continued increase in abundance of arrowtooth flounder is cause for some concern, the abundance of flathead sole has actually increased in recent years. Predation by arrowtooth may be limiting the potential rate of increase of flathead sole under current conditions, but it does not appear to represent a threat to the stock.

Fishery effects on ecosystem

Catches of flathead sole have been concentrated in several areas in the Gulf of Alaska over the past few years (Figure 8.2). These areas include Shelikof Straight, Portlock Bank and Davidson Bank. The ecosystem effects of this spatial concentration of fishing activity are unknown.

Prohibited species such as halibut, salmon, and crab are also taken to some extent in the flathead sole-directed fishery (Table 8.20). In 2006, the overall prohibited species catch (PSC) rate for halibut was 70 kg halibut/t of flathead caught—a decrease from the 2005 rate of 83.5 and the lowest rate in the past four years. The PSC rates for salmon and crab in 2006 directed fishery were 3.1 crabs/t flathead sole and 0.11 salmon/t flathead sole, respectively. The 2006 PSC rate for crab was nearly four times larger than that in 2005. However, the 2006 rates for both crab and salmon were the next to lowest over the past four years.

The flathead sole-directed fishery caught more arrowtooth flounder in both 2005 and 2006 than any other non-prohibited species, including flathead sole (Table 8.21). Flathead sole was the second most-caught species in the directed fishery. The catch of arrowtooth flounder constituted 196% of the retained catch of flathead sole in 2006 and 336% in 2005. Only small amounts of arrowtooth were retained (9-10%), while more than 80% of flathead sole was retained.

Effects of discards and offal production on the ecosystem are unknown for the flathead sole fishery.

Data gaps and research priorities

The amount of age data for flathead sole in the Gulf of Alaska is minimal, at best, from either the groundfish survey or the fishery (nonexistent, in the latter case). Additional age data should improve future stock assessments by allowing improved estimates of individual growth and age-length transition matrices, and by filling in missing years with age composition data.

Further modeling research should address the use of length-based approaches to fishery and survey selectivity in the assessment model, as well as alternative forms for the selectivity function. The utility of potential environmental predictors of recruitment (e.g., temperature) should also be investigated.

Summary

Tier	3a	
Reference mortality rates		
M	0.2 yr^{-1}	
$F_{35\%}$	0.494	
$F_{40\%}$	0.380	
Equilibrium female spawning biomass		
$B_{100\%}$	113,323 t	
$B_{40\%}$	45,329 t	
$B_{35\%}$	39,663 t	
Fishing rates		
F_{OFL}	0.494	
F_{ABC} (maximum permissible)	0.380	
F_{ABC} (recommended)	0.380	
Projected biomass	**2008**	**2009**
Age 3+ biomass (t)	324,197	324,524
Female spawning biomass (t)	106,566	109,533
Harvest limits	**2008**	**2009**
OFL (t)	55,787	57,962
ABC (maximum permissible; t)	44,735	46,505
ABC (recommended; t)	44,735	46,505

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Tables

Table 8.1. Annual catch of flathead sole in the Gulf of Alaska from 1978. 2007 catch is through Sept. 22.

year	total catch (t)
1978	452
1979	165
1980	2,068
1981	1,070
1982	1,368
1983	1,080
1984	549
1985	320
1986	147
1987	151
1988	520
1989	747
1990	1,447
1991	1,717
1992	2,034
1993	2,366
1994	2,580
1995	2,181
1996	3,107
1997	2,446
1998	1,742
1999	900
2000	1,547
2001	1,911
2002	2,145
2003	2,425
2004	2,390
2005	2,530
2006	3,134
2007	2,854

Table 8.2a. Time series of recent reference points (ABC, OFL), TACs, total catch and retention rates for flathead sole.

Year	Author ABC (t)	ABC (t)	TAC (t)	OFL (t)	Total Catch (t)	% Retained
1995	--	28,790	9,740	31,557	2,181	
1996	--	52,270	9,740	31,557	3,107	
1997	--	26,110	9,040	34,010	2,446	
1998	--	26,110	9,040	34,010	1,742	
1999	--	26,010	9,040	34,010	900	
2000	--	26,270	9,060	34,210	1,547	
2001	--	26,270	9,060	34,210	1,911	
2002	22,684	22,690	9,280	29,530	2,145	
2003	41,402	41,390	11,150	51,560	2,425	88
2004	51,721	51,270	10,880	64,750	2,390	80
2005	36,247	45,100	10,390	56,500	2,530	87
2006	37,820	37,820	9,077	47,003	3,134	89
2007	39,196	39,110	9,148	48,658	2,854	89

Table 8.2b. Status of flathead sole fishery in recent years.

Year	Dates	Status
2003	Jan 20-Jun 19	open
	Jun 19-Jun 29	halibut bycatch status
	Jun 29-Sep 12	open
	Sep 12-Oct 1	halibut bycatch status
	Oct 1-Oct 15	open
	Oct 15-Dec 31	halibut bycatch status
2004	Jan 20-Sep 10	open
	Seo 10-Oct 1	halibut bycatch status
	Oct 1-Oct 1	open
	Oct 1-Dec 31	halibut bycatch status
2005	Jan 20-Aug 19	open
	Aug 19-Sep 1	halibut bycatch status
	Sep 1-Sep 4	open
	Sep 4-Dec 31	halibut bycatch status
2006	Jan 20-Feb 23	open
	Feb 23-Feb 27	halibut bycatch status
	Feb 27-Jun 10	open
	Jun 10-Jul 1	halibut bycatch status
	Jul 1-Sep 1	open
	Sep 1-Sep 6	halibut bycatch status
	Sep 6-Sep 6	open
	Sep 6-Sep 20	halibut bycatch status
	Sep 20-Sep 20	open
	Sep 20-Sep 25	halibut bycatch status
	Sep 25-Sep 25	open
	Sep 25-Oct 1	halibut bycatch status
	Oct 1-Oct. 8	open
	Oct. 8-Dec 31	halibut bycatch status
2007	Jan 20-Jun 4	open
	Jun 4-Jul 1	halibut bycatch status
	Jul 1-Aug 10	open
	Aug 10-Sep 1	halibut bycatch status
	Sep 1-Sep 1	open
	Sep 1-Sep 6	halibut bycatch status
	Sep 6-Sep 6	open
	Sep 6-Sep 11	halibut bycatch status
	Sep 11-Sep 11	open
	Sep 11-Sep 21	halibut bycatch status
	Sep 21-Sep 23	open
	Sep 23-Oct 1	halibut bycatch status
	Oct 1-Oct 8	open
	Oct 8-Oct 10	halibut bycatch status
	Oct 10-Oct 15	open
	Oct 15-Oct 22	halibut bycatch status
	Oct 22-	open

Table 8.3a. Annual fishery length compositions for female flathead sole. The 2007 composition is based on observer reports through Sept. 22.

	Length cutpoints (cm)																	
year	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**40**	**42**	**44**	**46**	**48**
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	5	28	33	41	57	42	24	11	3	1	0
1986	0	0	0	0	0	0	2	1	12	13	14	10	9	3	2	2	0	0
1987	0	0	0	1	0	1	2	8	18	24	44	12	6	0	0	0	0	0
1988	0	0	0	0	0	1	6	10	13	67	188	241	252	216	159	79	27	5
1989	0	0	0	0	0	0	0	0	0	11	10	28	41	42	19	6	4	1
1990	0	0	0	0	0	0	0	0	0	3	21	14	14	6	7	0	0	0
1991	0	0	0	0	3	7	28	57	90	111	158	256	244	155	71	22	7	4
1992	0	0	3	4	18	30	41	98	131	171	232	266	222	154	85	89	57	49
1993	4	2	3	4	13	23	12	20	41	76	142	210	207	188	152	132	106	88
1994	0	0	1	6	14	21	54	78	87	145	139	160	147	120	63	52	29	59
1995	0	0	1	1	4	4	16	33	113	155	217	241	204	91	61	31	32	76
1996	0	2	7	14	21	26	25	52	113	156	275	348	371	299	200	128	89	170
1997	2	2	4	7	20	34	44	91	112	215	270	353	320	186	106	70	43	40
1998	0	1	2	2	6	14	25	68	121	176	314	449	479	358	204	139	87	124
1999	0	0	0	0	0	0	1	0	3	5	6	13	17	10	7	1	5	2
2000	0	0	1	2	1	5	11	24	39	66	103	109	92	59	55	26	17	10
2001	0	0	0	0	1	3	2	12	32	34	54	66	86	71	65	46	41	50
2002	0	1	3	1	3	5	16	26	54	63	72	98	94	80	60	35	13	21
2003	1	0	1	0	0	7	10	12	33	57	70	113	158	143	129	79	53	48
2004	0	0	0	1	3	8	19	15	37	44	71	84	98	108	99	64	38	42
2005	0	0	0	0	4	15	19	24	53	59	83	137	144	138	86	36	24	20
2006	1	1	3	2	7	10	17	24	44	63	98	138	125	122	84	46	27	21
2007	0	0	0	2	6	3	20	25	40	67	73	73	55	38	37	18	31	44

Table 8.3b. Annual fishery length compositions for male flathead sole. The 2007 composition is based on observer reports through Sept. 22.

	Length cutpoints (cm)																	
year	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**40**	**42**	**44**	**46**	**48**
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	1	1	0	7	34	67	83	46	13	4	1	0	0	0	0
1986	0	0	0	1	0	0	2	10	21	24	10	7	8	4	0	0	0	0
1987	0	0	0	1	0	4	4	11	18	16	2	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	8	27	106	181	153	90	44	13	4	2	0	0
1989	0	0	0	0	0	3	9	40	28	88	47	16	17	12	6	1	0	0
1990	0	0	0	0	0	0	0	5	8	35	25	7	4	0	0	0	0	0
1991	1	1	2	1	19	33	79	103	211	398	359	148	39	16	4	3	1	0
1992	2	14	10	34	53	85	128	220	386	433	364	183	74	31	13	1	0	0
1993	3	4	5	11	24	46	87	137	301	459	519	333	120	65	11	4	1	8
1994	0	0	0	3	16	33	46	68	154	235	188	87	35	9	14	9	2	31
1995	0	0	5	5	13	25	39	124	212	276	266	163	67	42	35	18	7	4
1996	2	3	11	26	30	37	53	135	305	479	506	320	211	128	54	25	2	2
1997	2	3	9	20	27	63	76	169	324	449	415	314	146	51	13	6	2	24
1998	2	0	7	16	22	41	87	213	367	612	628	444	209	87	76	39	23	22
1999	0	0	0	0	0	0	2	2	7	11	13	9	4	6	1	0	0	0
2000	0	1	0	5	10	25	41	77	97	130	145	103	58	37	23	6	4	1
2001	0	2	1	4	3	9	13	28	74	130	125	118	79	39	12	9	7	3
2002	0	2	0	4	5	8	19	45	96	131	138	86	52	34	8	10	2	3
2003	0	1	1	6	19	28	60	105	185	241	356	294	175	68	44	8	2	2
2004	0	0	0	2	6	12	40	46	84	110	122	105	70	49	12	10	0	2
2005	0	0	1	1	6	9	28	64	144	179	167	158	69	30	6	4	7	5
2006	0	0	1	5	6	15	27	87	180	226	194	132	70	32	9	3	2	1
2007	0	1	1	2	12	16	25	48	93	107	103	100	59	24	15	10	8	4

Table 8.4. Sample sizes: a) sample sizes for length compositions from the domestic fishery and b) sample sizes for estimated biomass, age and size compositions from the GOA groundfish survey.

a). Fishery length compositions.

year	# of hauls	# of individuals
1989	3	429
1990	2	149
1991	63	2,631
1992	114	3,684
1993	90	3,565
1994	44	2,105
1995	80	2,581
1996	146	4,627
1997	122	4,039
1998	229	5,465
1999	12	125
2000	183	1,463
2001	150	1,421
2002	163	1,288
2003	324	2,529
2004	154	1,581
2005	226	1,829
2006	242	1,825
2007	151	1,266

b). GOA groundfish surveys.

	Survey biomass	Size compositions				Age compositions			
		Males		Females		Males		Females	
year	# of hauls	# of hauls	# of individuals	# of hauls	# of individuals	# of hauls	# of individuals	# of hauls	# of individuals
1984	929	254	13,875	252	11,291		284		369
1987	783	195	15,931	195	11,350				
1990	708	285	12,939	276	11,255				
1993	775	362	13,592	338	12,294	30	179	26	132
1996	807	388	11,086	379	9,975	48	285	41	243
1999	764	346	7,941	332	8,023				
2001	489	227	5,962	209	5,899				
2003	809	407	13,279	387	12,479	71	249	67	250
2005	839	381	12,501	373	10,907	67	296	62	243
2007	820	365	11,862	385	13,563				

Table 8.5. Biomass estimates (t) by NPFMC regulatory area for GOA flathead sole from the NMFS bottom trawl surveys. Note that in 2001 the eastern GOA was not surveyed. The estimated eastern GOA survey biomass, based on previous surveys, was added to the 2001 biomass (153,747 t). This increased the total survey biomass by about 11%. The maximum depth stratum included in each survey is also noted.

Year	Western Gulf (t)	Central Gulf (t)	West Yakutat (t)	Southeast (t)	Total Gulf (t)	Std. Dev (t)	Max Depth (m)
1984	45,100	158,539	45,694	9	249,341	30,355	1000
1987	33,603	113,483	30,455	5	177,546	18,956	1000
1990	58,740	161,257	23,019	40	243,055	28,877	500
1993	57,871	113,976	16,720	124	188,690	24,486	500
1996	66,732	122,730	12,751	3,308	205,521	18,430	500
1999	49,636	139,356	15,115	3,482	207,590	24,404	1000
2001	68,164	85,430	**	**	153,594	18,300	500
2003	67,055	170,852	17,154	2,234	257,294	19,913	700
2005	59,458	142,043	11,400	312	213,213	16,944	1000
2007	78,361	176,529	21,430	3,970	280,290	23,778	1000

Table 8.6. Biomass estimates (t) by depth stratum for GOA flathead sole from the NMFS bottom trawl surveys. Note that in 2001 the eastern GOA was not surveyed and no correction is made in this table.

	Depth strata (m)					
year	1-100	100-200	200-300	300-500	500-700	700-1000
1984	118,974	121,791	8,571	5	0	0
1987	91,482	75,475	10,553	36	0	0
1990	157,014	76,306	9,713	22	**	**
1993	113,072	65,143	10,278	198	**	**
1996	119,657	78,545	7,270	50	**	**
1999	145,347	58,641	3,581	14	8	0
2001	93,433	56,133	4,006	22	**	**
2003	146,018	101,421	9,855	0	0	**
2005	114,895	92,869	5,297	151	0	0
2007	139,806	130,661	9,823	0	0	0

Table 8.7. Survey age compositions for flathead sole. Numbers are in 1000's of individuals.

a) Females.

	Age Bins																
year	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1984	2,554	5,732	6,984	36,300	74,155	104,300	74,810	47,661	24,199	24,848	4,627	2,992	0	0	0	0	0	0
1993	12,043	23,746	18,705	18,484	22,728	23,396	24,017	49,392	25,997	22,142	19,556	17,817	4,674	10,333	10,345	5,432	758	9,712
1996	14,353	40,180	36,747	26,716	45,246	32,697	20,360	22,297	24,929	16,811	17,244	14,740	6,557	12,507	2,794	4,049	803	1,423
2003	27,825	39,592	50,233	52,481	13,806	37,912	43,306	50,772	16,791	14,290	10,785	24,386	3,205	2,332	382	4,405	4,587	3,712
2005	21,097	46,779	48,192	56,383	33,181	23,400	32,891	24,245	16,342	14,216	9,983	10,575	9,960	4,152	5,346	2,470	1,387	7,602

b) Males.

	Age Bins																
year	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1984	0	10,403	29,061	41,741	48,344	96,634	61,205	16,899	21,343	9,159	1,421	4,745	2,773	0	0	0	0	0
1993	8,357	31,800	26,579	38,034	21,547	48,187	19,371	15,327	30,706	12,449	14,387	13,195	6,993	5,117	1,902	0	68	7,770
1996	16,381	37,078	30,360	23,837	44,421	34,830	34,399	31,534	16,454	9,247	6,710	6,140	6,892	3,200	2,905	232	1,202	345
2003	32,103	53,090	64,911	68,289	28,709	16,977	39,693	21,243	18,447	5,498	10,919	3,074	3,654	1,189	3,116	3,308	4,701	4,686
2005	29,361	48,735	39,610	56,586	60,672	38,238	22,515	14,721	15,575	3,836	14,354	10,745	1,379	6,296	1,724	2,006	2,560	336

Table 8.8. Survey length compositions for flathead sole. Numbers are in 1000's of individuals. Survey length compositions from 1984, 1993, 1996 and 2003 were not included in the assessment since age compositions were available for these years.

a) Females.

	Length bin cutpoints (cm)																	
year	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**40**	**42**	**44**	**46**	**48**
1984	567,465	3,098,108	3,337,159	7,305,870	14,169,956	20,489,162	29,800,385	45,645,110	63,474,582	76,302,201	69,591,987	48,287,658	28,086,779	17,405,505	10,171,892	4,751,216	2,111,659	193,358
1987	883,259	2,085,267	2,837,985	4,498,808	6,056,209	12,188,586	17,592,640	25,161,244	36,187,932	50,278,894	54,302,119	45,326,816	26,572,841	14,468,498	8,168,661	5,712,751	2,720,288	2,085,675
1990	1,268,575	3,346,538	6,036,264	6,002,045	9,283,076	15,445,754	19,887,061	24,582,524	37,464,126	46,873,785	55,346,517	60,531,727	52,045,343	30,967,343	12,911,785	6,738,462	1,978,790	758,505
1993	2,583,792	5,009,533	7,743,609	12,730,226	13,216,393	15,422,965	20,371,508	21,819,860	25,208,013	31,170,043	41,270,306	43,395,725	36,634,119	23,356,173	11,688,318	5,118,408	2,936,819	2,441,181
1996	3,360,212	6,318,403	10,043,054	14,294,438	16,103,955	19,497,226	21,344,730	25,058,664	29,740,792	34,374,950	37,894,318	40,167,804	33,866,513	23,395,342	12,836,849	7,593,095	3,705,309	2,456,596
1999	2,895,203	2,939,825	5,795,458	8,717,984	10,040,764	16,134,106	18,845,354	21,287,122	25,158,066	28,740,916	31,885,594	35,669,069	31,739,445	27,828,950	17,274,132	7,845,278	3,579,636	2,808,707
2001	2,777,165	4,699,305	5,728,049	8,069,787	9,821,936	7,348,338	9,241,731	12,441,020	17,972,827	20,460,041	29,032,715	26,924,782	24,105,579	18,520,270	11,972,321	7,875,292	3,744,753	4,068,863
2003	3,066,432	6,646,680	10,771,364	15,271,010	20,514,041	25,006,346	23,932,247	24,519,862	28,684,878	35,373,436	46,890,868	47,205,367	42,591,196	35,523,638	21,997,332	10,068,526	5,086,863	4,419,992
2005	4,989,074	7,390,602	10,306,021	14,897,509	20,013,948	22,233,793	27,090,409	30,485,599	33,435,425	38,117,266	37,288,926	35,591,815	34,358,741	24,142,013	14,563,408	7,606,267	4,252,634	2,076,921
2007	2,429,265	6,104,812	10,257,690	20,783,927	19,668,819	18,961,527	23,766,611	25,094,850	35,365,916	40,487,677	50,423,214	51,275,567	44,433,178	33,154,809	20,016,160	12,980,262	9,750,098	6,983,922

b) Males.

	Length bin cutpoints (cm)																	
year	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**40**	**42**	**44**	**46**	**48**
1984	957,820	2,650,965	3,871,954	10,794,170	19,758,224	34,521,675	54,302,747	81,720,274	76,268,637	40,785,111	19,367,949	10,317,216	5,446,400	1,989,948	540,588	93,773	198,929	0
1987	1,256,844	2,623,233	3,875,703	5,447,712	6,444,915	15,111,905	26,506,742	48,972,545	53,591,441	33,388,943	14,119,074	7,290,234	3,550,317	1,730,614	480,124	109,870	48,914	172531
1990	1,061,268	4,054,727	5,882,651	8,099,168	11,657,224	19,989,908	29,710,052	45,839,467	65,958,207	73,287,697	42,626,423	12,663,621	3,977,353	849,844	386,033	50,518	32,023	0
1993	2,204,875	5,315,496	9,756,934	12,897,063	16,986,761	23,212,650	29,095,054	39,372,220	50,735,420	54,630,549	36,488,435	12,636,266	5,512,594	2,599,322	343,443	94,964	6,132	0
1996	4038969	6250042	9608016	14129323	18420590	22021297	27806512	37471930	49772336	52355582	41352232	17459273	5026360	1607273	464052	91503	0	53817
1999	2484269	4313164	7246418	11893102	17227234	21066822	30363655	42405263	59242785	60991739	49671640	24468751	7967139	1647206	1492130	338337	17783	36582
2001	2518694	5015289	7128442	8810173	10980943	13831279	17031051	27452639	37616570	39651163	36558139	19204678	6124929	2013279	431799	698449	21213	306463
2003	4633700	6573870	11065399	17329333	24994315	31229775	36233285	41028933	54996612	57971815	53125682	33016518	14060644	4857342	989833	578368	82360	117892
2005	4727936	7282874	12202736	15830931	23303361	33864385	45028995	49440480	52297224	49895320	37689609	24343157	9652698	2244399	542507	334185	14049	33805
2007	4192802	6756201	13903868	23941892	25572487	25987113	33840443	43611350	53832477	57059696	48575889	34409222	14457346	5923883	1710666	493481	124704	69774

Table 8.9a. Age-length transition matrices for female flathead sole. Values at a row/column combination correspond to the fraction of individuals at the age indicated by the row that fall into the length group indicated by the column.

	length cutpts (cm)																	
age	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**40**	**42**	**44**	**46**	**48**
3	0.154	0.396	0.348	0.094	0.008	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.004	0.038	0.175	0.348	0.302	0.113	0.018	0.001	0	0	0	0	0	0	0	0	0	0
5	0	0.002	0.018	0.09	0.235	0.321	0.229	0.086	0.017	0.002	0	0	0	0	0	0	0	0
6	0	0	0.002	0.013	0.063	0.174	0.281	0.265	0.146	0.047	0.009	0.001	0	0	0	0	0	0
7	0	0	0	0.002	0.013	0.056	0.15	0.251	0.263	0.173	0.071	0.018	0.003	0	0	0	0	0
8	0	0	0	0	0.003	0.016	0.061	0.148	0.237	0.251	0.175	0.08	0.024	0.005	0.001	0	0	0
9	0	0	0	0	0.001	0.005	0.023	0.074	0.159	0.235	0.236	0.162	0.075	0.024	0.005	0.001	0	0
10	0	0	0	0	0	0.002	0.009	0.035	0.095	0.179	0.236	0.217	0.139	0.063	0.02	0.004	0.001	0
11	0	0	0	0	0	0.001	0.004	0.017	0.055	0.125	0.202	0.233	0.19	0.111	0.046	0.013	0.003	0
12	0	0	0	0	0	0	0.002	0.009	0.032	0.085	0.161	0.221	0.218	0.155	0.079	0.029	0.008	0.002
13	0	0	0	0	0	0	0.001	0.005	0.019	0.057	0.125	0.196	0.225	0.188	0.114	0.05	0.016	0.004
14	0	0	0	0	0	0	0	0.003	0.012	0.04	0.096	0.169	0.219	0.208	0.144	0.073	0.027	0.009
15	0	0	0	0	0	0	0	0.002	0.008	0.028	0.074	0.144	0.206	0.217	0.169	0.096	0.04	0.016
16	0	0	0	0	0	0	0	0.001	0.005	0.02	0.058	0.122	0.191	0.22	0.187	0.117	0.054	0.024
17	0	0	0	0	0	0	0	0.001	0.004	0.015	0.046	0.104	0.175	0.218	0.2	0.136	0.068	0.034
18	0	0	0	0	0	0	0	0	0.003	0.011	0.037	0.09	0.161	0.213	0.209	0.151	0.081	0.044
19	0	0	0	0	0	0	0	0	0.002	0.009	0.03	0.078	0.148	0.207	0.215	0.164	0.093	0.054
20	0	0	0	0	0	0	0	0	0.001	0.007	0.025	0.069	0.137	0.201	0.218	0.175	0.103	0.063

Table 8.9b. Age-length transition matrices for male flathead sole. Values at a row/column combination correspond to the fraction of individuals at the age indicated by the row that fall into the length group indicated by the column.

age	length cutpts (cm)																	
	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
3	0.706	0.265	0.029	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.038	0.205	0.405	0.279	0.067	0.005	0	0	0	0	0	0	0	0	0	0	0	0
5	0.001	0.015	0.095	0.274	0.353	0.204	0.052	0.006	0	0	0	0	0	0	0	0	0	0
6	0	0.001	0.011	0.067	0.205	0.323	0.26	0.108	0.023	0.002	0	0	0	0	0	0	0	0
7	0	0	0.001	0.013	0.066	0.188	0.298	0.263	0.13	0.036	0.005	0	0	0	0	0	0	0
8	0	0	0	0.003	0.019	0.081	0.199	0.288	0.245	0.122	0.036	0.006	0.001	0	0	0	0	0
9	0	0	0	0.001	0.006	0.033	0.112	0.227	0.281	0.212	0.097	0.027	0.005	0	0	0	0	0
10	0	0	0	0	0.002	0.014	0.06	0.158	0.257	0.261	0.165	0.065	0.016	0.002	0	0	0	0
11	0	0	0	0	0.001	0.007	0.033	0.106	0.213	0.271	0.217	0.11	0.035	0.007	0.001	0	0	0
12	0	0	0	0	0	0.003	0.019	0.071	0.17	0.258	0.248	0.153	0.06	0.015	0.002	0	0	0
13	0	0	0	0	0	0.002	0.012	0.049	0.135	0.236	0.263	0.188	0.086	0.025	0.005	0.001	0	0
14	0	0	0	0	0	0.001	0.007	0.035	0.108	0.212	0.267	0.214	0.11	0.036	0.008	0.001	0	0
15	0	0	0	0	0	0.001	0.005	0.026	0.088	0.191	0.264	0.234	0.132	0.047	0.011	0.002	0	0
16	0	0	0	0	0	0	0.003	0.019	0.072	0.172	0.259	0.248	0.151	0.058	0.014	0.002	0	0
17	0	0	0	0	0	0	0.002	0.015	0.061	0.156	0.253	0.258	0.167	0.068	0.017	0.003	0	0
18	0	0	0	0	0	0	0.002	0.012	0.052	0.143	0.246	0.266	0.18	0.076	0.02	0.003	0	0
19	0	0	0	0	0	0	0.001	0.009	0.045	0.132	0.241	0.272	0.191	0.083	0.022	0.004	0	0
20	0	0	0	0	0	0	0.001	0.008	0.039	0.122	0.235	0.278	0.201	0.089	0.024	0.004	0	0

Table 8.10. Age-specific schedules for flathead sole in the Gulf of Alaska. Maturity ogive is based on Stark (2004).

Age	Length (cm)		Weight (kg)		Maturity ogive
	Males	Females	Males	Females	
3	15.2	17.8	0.03	0.05	0.0117
4	19.3	21.6	0.06	0.09	0.0251
5	22.6	24.9	0.10	0.14	0.0527
6	25.3	27.8	0.15	0.20	0.1076
7	27.6	30.2	0.20	0.26	0.2072
8	29.4	32.2	0.24	0.32	0.3615
9	30.8	34.0	0.28	0.38	0.5508
10	32.0	35.5	0.32	0.44	0.7265
11	33.0	36.8	0.35	0.49	0.8520
12	33.8	37.9	0.37	0.54	0.9257
13	34.5	38.8	0.40	0.58	0.9643
14	35.0	39.6	0.42	0.62	0.9832
15	35.4	40.3	0.43	0.66	0.9922
16	35.8	40.9	0.45	0.69	0.9964
17	36.1	41.4	0.46	0.72	0.9983
18	36.3	41.8	0.47	0.74	0.9992
19	36.5	42.2	0.48	0.76	0.9996
20	36.7	42.5	0.48	0.83	0.9998

Table 8.11. Baseline model settings.

			Likelihood Component Multipliers						
		Fishery			Survey			Recruitment	
			length		length	age			
Case	**Q**	**catch**	**compositions**	**biomass**	**compositions**	**compositions**	**early**	**ordinary**	**late**
base	1	30	1	1	1	1	1	1	1

Table 8.12. Initial parameter values.

Case					**Fishery**				**Survey**			
					slope		A_{50}		**slope**		A_{50}	
	$\overline{\ln R_0}$	τ_t	$\overline{\ln F}$	ε_t	**female**	**male**	**female**	**male**	**female**	**male**	**female**	**male**
base	17	0	-6	0.001	2.505	2.505	13	13	2.505	2.505	13	13

Table 8.13. Final parameter estimates.

$\overline{\ln R_0}$	18.315022									
						1967-2007:	-1.7788	-0.9354	-1.0195	-1.1052
	-1.1865	-1.1103	-0.9508	-1.1048	-0.2641	-0.0839	0.0325	0.6833	1.0179	0.5864
	0.2665	0.1898	0.1961	-0.0894	0.3167	0.2824	0.0025	0.4034	0.1578	0.2204
	0.2789	0.5950	0.0423	0.1788	0.4136	0.2352	0.1635	-0.1564	-0.3008	0.6687
τ_t	0.6613	0.7103	0.6273	-0.0767	0.5178	0.9103	-0.1962			
$\overline{\ln F}$	-4.5087759									
			1984-2007:	-0.2985	-1.0329	-1.9603	-2.0608	-0.9315	-0.6122	0.0233
	0.1910	0.3564	0.5074	0.5922	0.4298	0.7635	0.5312	0.1983	-0.4505	0.0622
ε_t	0.2659	0.3796	0.5055	0.5082	0.5754	0.7820	0.6751			
Fishery Selectivity										
	females	**males**								
slope	0.9007452	0.9848417								
$\mathbf{A_{50}}$	9.8470754	9.6430139								
Survey Selectivity										
	females	**males**								
slope	0.7364752	0.8066966								
$\mathbf{A_{50}}$	6.0365078	5.9227882								
Reference points										
F40%	0.3802									
F35%	0.4936									

Table 8.14. Model-estimated catch and survey biomass.

	catch (t)			survey biomass (t)		
year	estimated	std dev	observed	estimated	std dev	observed
1984	556	71	549	180,220	11,536	249,341
1985	331	42	320	194,930	11,472	
1986	157	20	147	204,640	11,235	
1987	162	21	151	210,580	10,926	177,546
1988	538	68	520	214,350	10,604	
1989	766	97	747	216,550	10,288	
1990	1,459	186	1,447	217,930	9,980	243,055
1991	1,721	220	1,717	218,390	9,676	
1992	2,021	257	2,034	218,950	9,384	
1993	2,337	298	2,366	219,460	9,101	188,690
1994	2,529	321	2,580	220,250	8,839	
1995	2,147	273	2,181	221,500	8,614	
1996	2,995	378	3,107	223,030	8,417	205,521
1997	2,377	300	2,446	222,990	8,239	
1998	1,719	218	1,742	222,900	8,091	
1999	911	116	900	222,490	7,975	207,590
2000	1,536	195	1,547	221,870	7,895	
2001	1,885	239	1,911	219,860	7,859	170,745
2002	2,106	267	2,145	218,670	7,897	
2003	2,366	299	2,425	220,460	8,079	257,294
2004	2,335	296	2,390	225,530	8,556	
2005	2,462	312	2,530	233,170	9,466	213,221
2006	3,028	383	3,134	241,120	10,810	
2007	2,790	354	2,854	247,020	12,512	280,290

Table 8.15. Estimated age 3+ population biomass and female spawning biomass.

	Age 3+ Biomass (1000's t)					Female Spawning Stock Biomass (1000's t)				
	2007 Assessment		2005 Assessment		2003 Assessment	2007 Assessment		2005 Assessment		2003 Assessment
year	mean	std dev	mean	std dev	mean	mean	std dev	mean	std dev	mean
1984	244	13	248	13	257	61	4	65	4	78
1985	254	13	256	13	265	73	4	76	4	93
1986	262	13	263	13	272	83	5	85	5	103
1987	266	12	266	12	274	90	5	91	5	109
1988	271	12	270	12	278	94	5	95	5	111
1989	274	12	271	12	282	96	5	97	5	111
1990	275	12	271	11	285	97	5	97	5	110
1991	276	11	271	11	287	97	5	97	4	110
1992	280	11	274	11	292	97	4	97	4	110
1993	281	11	273	11	292	97	4	96	4	110
1994	282	11	272	11	293	97	4	95	4	111
1995	283	11	272	11	297	97	4	95	4	112
1996	284	11	272	11	299	98	4	95	4	114
1997	283	11	269	11	296	98	4	95	4	114
1998	279	11	265	11	292	99	4	95	4	114
1999	274	11	258	11	288	99	4	95	4	115
2000	275	11	259	11	287	100	4	95	4	116
2001	279	12	262	12	287	100	4	94	4	116
2002	288	13	269	14	291	99	4	93	4	114
2003	297	14	280	16	291	98	4	92	4	112
2004	302	16	286	18		97	4	91	4	
2005	308	18	292	20		98	4	91	5	
2006	320	21				100	5			
2007	322	24				103	5			

Table 8.16. Estimated age 3 recruitment.

	2007 Assessment		2005 Assessment		2003 Assessment
Year	**Mean (millions)**	**Std Dev (millions)**	**Mean (millions)**	**Std Dev (millions)**	**Mean (millions)**
1984	165	36	163	35	139
1985	247	43	241	42	241
1986	239	39	233	38	250
1987	180	32	175	32	162
1988	269	39	259	38	275
1989	211	34	201	33	277
1990	224	34	212	33	251
1991	238	36	222	34	249
1992	326	42	305	40	308
1993	188	33	175	31	165
1994	215	38	200	36	261
1995	272	42	253	39	356
1996	228	38	211	36	199
1997	212	39	193	36	149
1998	154	34	140	31	198
1999	133	32	121	29	181
2000	351	54	320	52	294
2001	349	57	327	57	285
2002	366	69	359	73	318
2003	337	75	352	86	201
2004	167	80	192	96	
2005	302	114	242	105	
2006	447	174			
2007	148	113			

Table 8.17. Projected catch (t) for the seven projection scenarios.

	Catch (t)						
year	**scenario 1**	**scenario 2**	**scenario 3**	**scenario 4**	**scenario 5**	**scenario 6**	**scenario 7**
2007	2,987	2,987	2,987	2,987	2,987	2,987	2,987
2008	44,735	44,735	23,979	2,740	0	55,787	44,735
2009	36,440	36,440	22,202	2,860	0	42,232	36,440
2010	30,459	30,459	20,577	2,943	0	33,438	38,048
2011	26,310	26,310	19,160	2,994	0	27,959	30,726
2012	23,777	23,777	18,111	3,033	0	24,959	26,565
2013	22,026	22,026	17,266	3,057	0	22,965	23,901
2014	20,393	20,393	16,376	3,047	0	20,476	21,168
2015	18,997	18,997	15,530	3,010	0	18,755	19,065
2016	18,042	18,042	14,887	2,970	0	18,125	18,242
2017	17,569	17,569	14,446	2,936	0	18,001	18,035
2018	17,343	17,343	14,138	2,907	0	17,996	18,001
2019	17,227	17,227	13,919	2,881	0	18,004	18,000
2020	17,167	17,167	13,764	2,858	0	18,014	18,010

Table 8.18. Female spawning biomass (t) for the seven projection scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 42,250 t and 36,969 t, respectively.

	Female spawning biomass (t)						
year	**scenario 1**	**scenario 2**	**scenario 3**	**scenario 4**	**scenario 5**	**scenario 6**	**scenario 7**
2007	102,993	102,993	102,993	102,993	102,993	102,993	102,993
2008	106,566	106,566	106,566	106,566	106,566	106,566	106,566
2009	87,969	87,969	98,676	109,747	111,182	82,323	87,969
2010	74,893	74,893	91,828	111,903	114,703	66,909	74,893
2011	66,097	66,097	86,273	113,440	117,496	57,501	62,279
2012	60,245	60,245	81,782	114,343	119,522	51,821	54,601
2013	55,771	55,771	77,681	114,268	120,432	47,730	49,308
2014	52,063	52,063	73,829	113,384	120,399	44,453	45,316
2015	49,374	49,374	70,586	112,129	119,852	42,572	42,946
2016	47,780	47,780	68,164	110,874	119,165	41,877	42,018
2017	46,973	46,973	66,476	109,882	118,646	41,710	41,754
2018	46,560	46,560	65,268	108,958	118,085	41,688	41,696
2019	46,342	46,342	64,409	108,139	117,543	41,695	41,692
2020	46,233	46,233	63,801	107,400	117,007	41,712	41,708

Table 8.19. Fishing mortality for the seven projection scenarios.

	Fishing mortality						
year	**scenario 1**	**scenario 2**	**scenario 3**	**scenario 4**	**scenario 5**	**scenario 6**	**scenario 7**
2007	0.0232	0.0232	0.0232	0.0232	0.0232	0.0232	0.0232
2008	0.3802	0.3802	0.1901	0.0204	0.0000	0.4936	0.3802
2009	0.3802	0.3802	0.1901	0.0204	0.0000	0.4936	0.3802
2010	0.3802	0.3802	0.1901	0.0204	0.0000	0.4936	0.4936
2011	0.3802	0.3802	0.1901	0.0204	0.0000	0.4936	0.4936
2012	0.3802	0.3802	0.1901	0.0204	0.0000	0.4936	0.4936
2013	0.3802	0.3802	0.1901	0.0204	0.0000	0.4928	0.4935
2014	0.3801	0.3801	0.1901	0.0204	0.0000	0.4735	0.4792
2015	0.3779	0.3779	0.1901	0.0204	0.0000	0.4554	0.4585
2016	0.3730	0.3730	0.1901	0.0204	0.0000	0.4486	0.4498
2017	0.3703	0.3703	0.1901	0.0204	0.0000	0.4474	0.4477
2018	0.3691	0.3691	0.1901	0.0204	0.0000	0.4475	0.4475
2019	0.3687	0.3687	0.1901	0.0204	0.0000	0.4476	0.4476
2020	0.3685	0.3685	0.1901	0.0204	0.0000	0.4477	0.4477

Table 8.20. Prohibited species catch (PSC) in the flathead sole target fishery.

year	Flathead sole (t)	Halibut kg	Halibut kg/t	Crab #	Crab #/t	Salmon #	Salmon #/t
2003	812	203,806	251.1	5,405	6.7	631	0.78
2004	909	101,754	112.0	2,070	2.3	1,479	1.63
2005	632	52,797	83.5	2,404	3.8	16	0.03
2006	522	36,527	70.0	1,643	3.1	56	0.11

Table 8.21. Catch of non-prohibited species in the flathead sole target fishery. The "Percent of retained target" gives the species catch as a percentage of the flathead sole catch retained in the flathead sole target fishery.

	2006			2005		
Species	total (t)	% retained	% of retained target	total (t)	% retained	% of retained target
Atka mackerel	17	84%	4%	2	89%	0%
arrowtooth flounder	839	10%	196%	1,756	9%	336%
Dover sole and turbot	3	80%	1%	2	1%	0%
flathead sole	522	82%	122%	632	83%	121%
northern rockfish	2	0%	0%	11	0%	2%
all sculpins, sharks, squid, octopus	16	0%	4%	74	0%	14%
pacific cod	38	92%	9%	153	88%	29%
pelagic shelf rockfish	0	100%	0%	0	0%	0%
pollock	33	94%	8%	11	99%	2%
POP	4	75%	1%	8	0%	2%
rex sole	68	93%	16%	332	86%	63%
rougheye	2	14%	0%	1	47%	0%
other rockfish complex	0	99%	0%	0	0%	0%
sablefish	4	87%	1%	1	93%	0%
shallow water flatfish	29	27%	7%	2	94%	0%
shortraker	7	71%	2%	1	79%	0%
thornyhead	6	94%	1%	1	100%	0%
unidentified skate	0	0%	0%	38	22%	7%
big skate	30	64%	7%	21	97%	4%
longnose skate	11	55%	3%	11	100%	2%

Figures

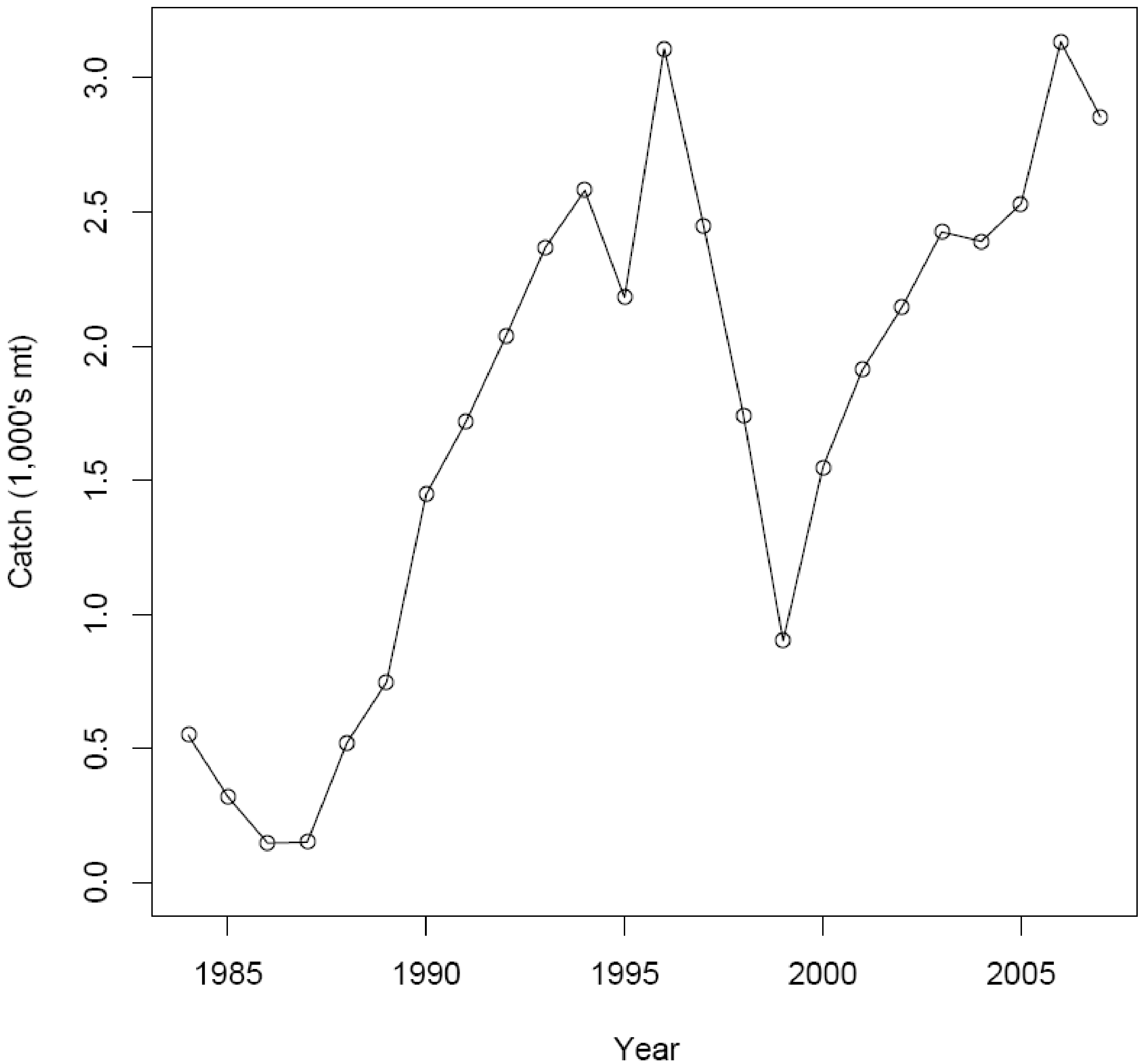


Figure 8.1. Fishery catches for GOA flathead sole, 1984-2007.

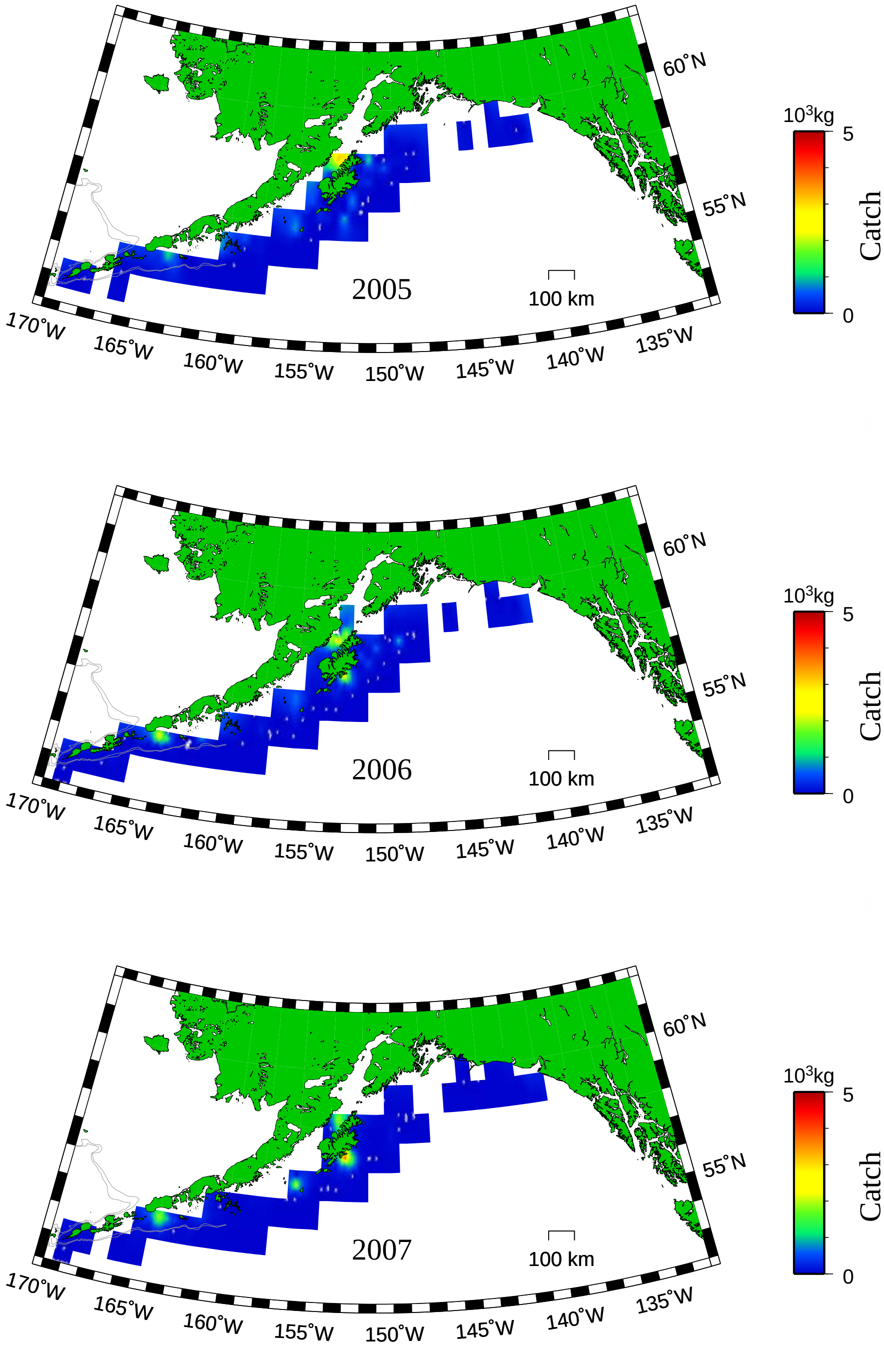


Figure 8.2. Spatial patterns of fishery catches for GOA flathead sole, 2005-2007.

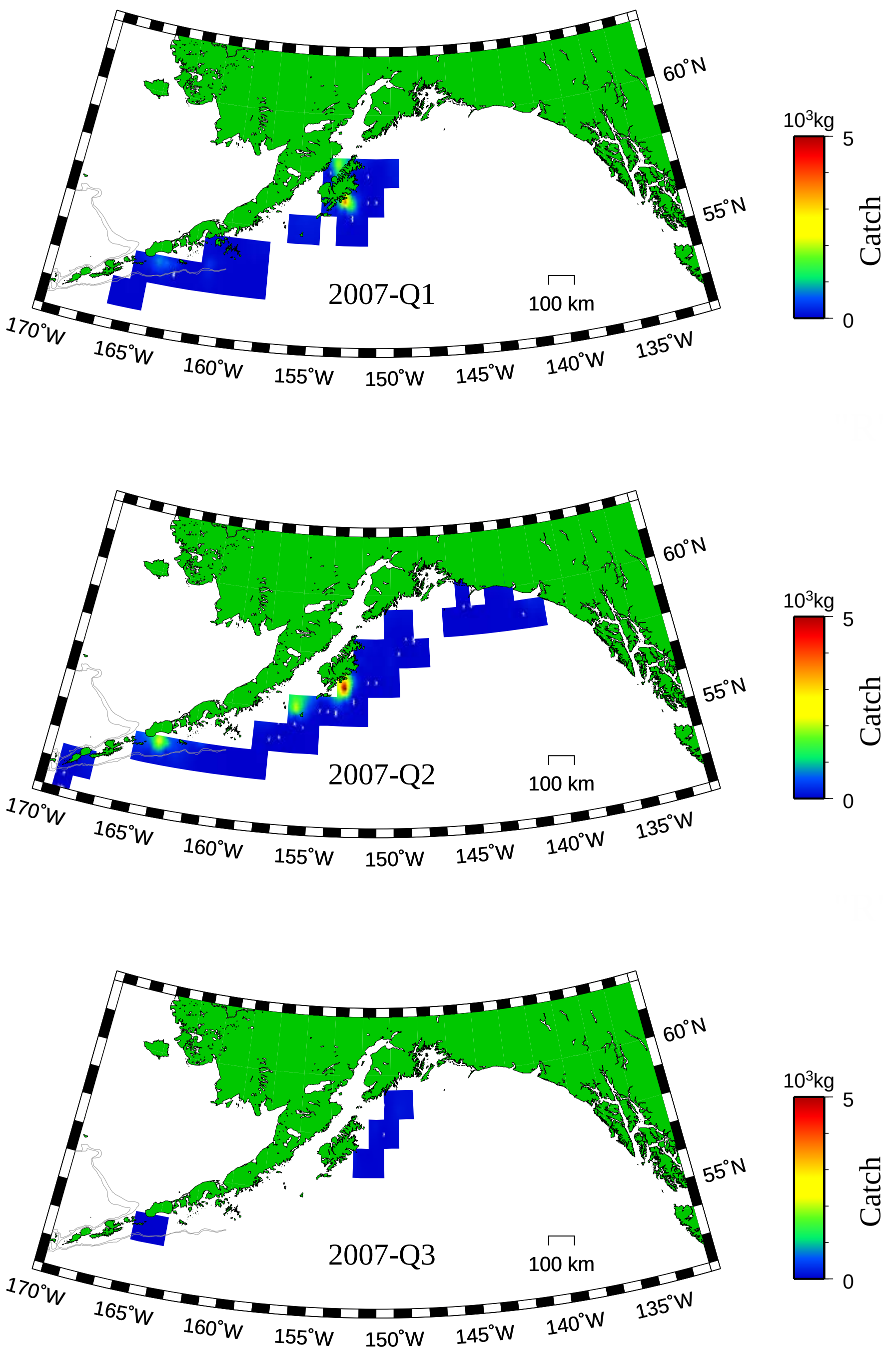


Figure 8.3. Spatial patterns of fishery catches for GOA flathead sole from the first three quarters of 2007.

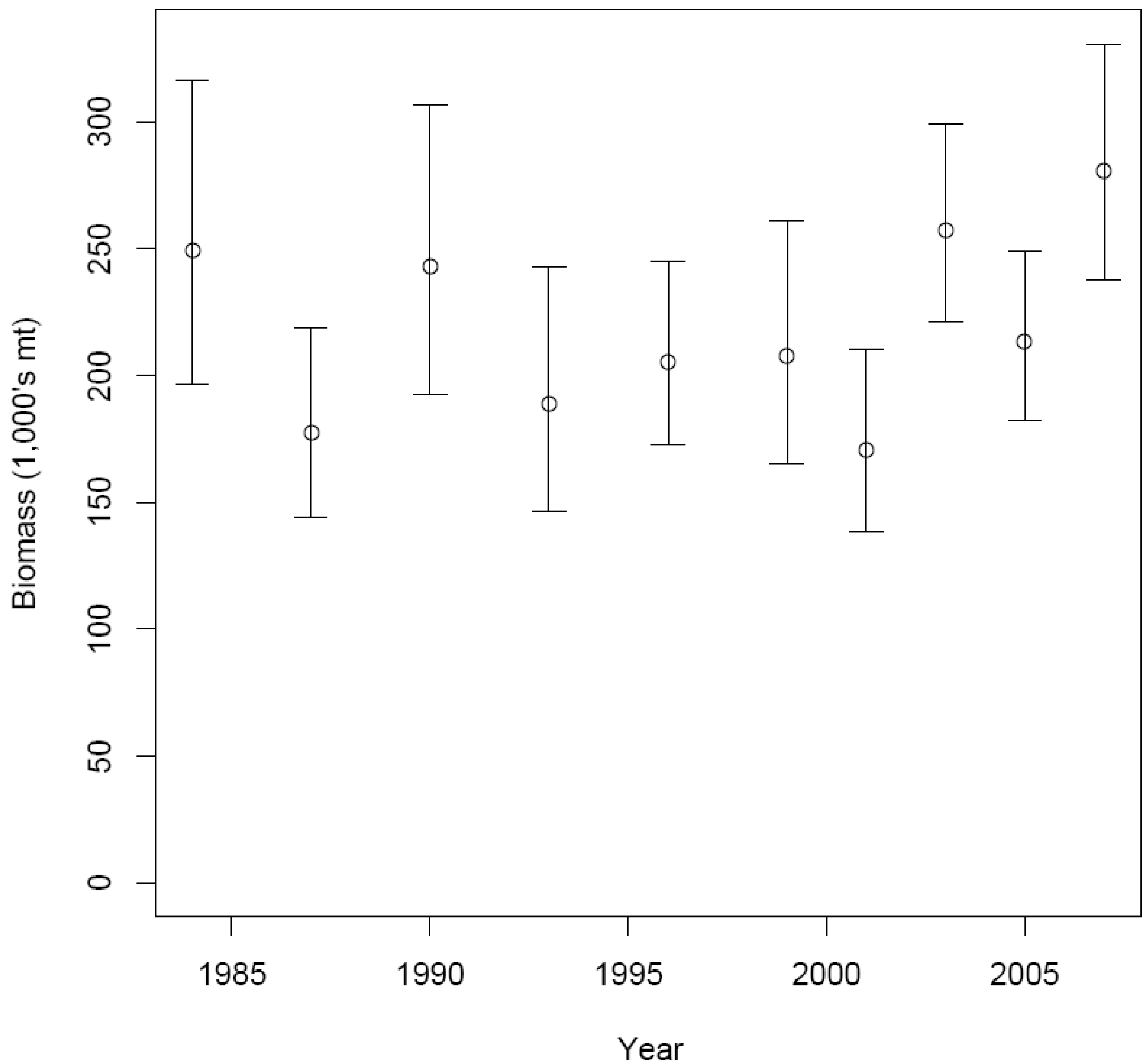


Figure 8.4. GOA survey biomass for flathead sole. Error bars represent 95% lognormal confidence intervals. The GOA survey did not include the eastern gulf in 2001. The value shown here for 2001 has been corrected to account for this (see text).

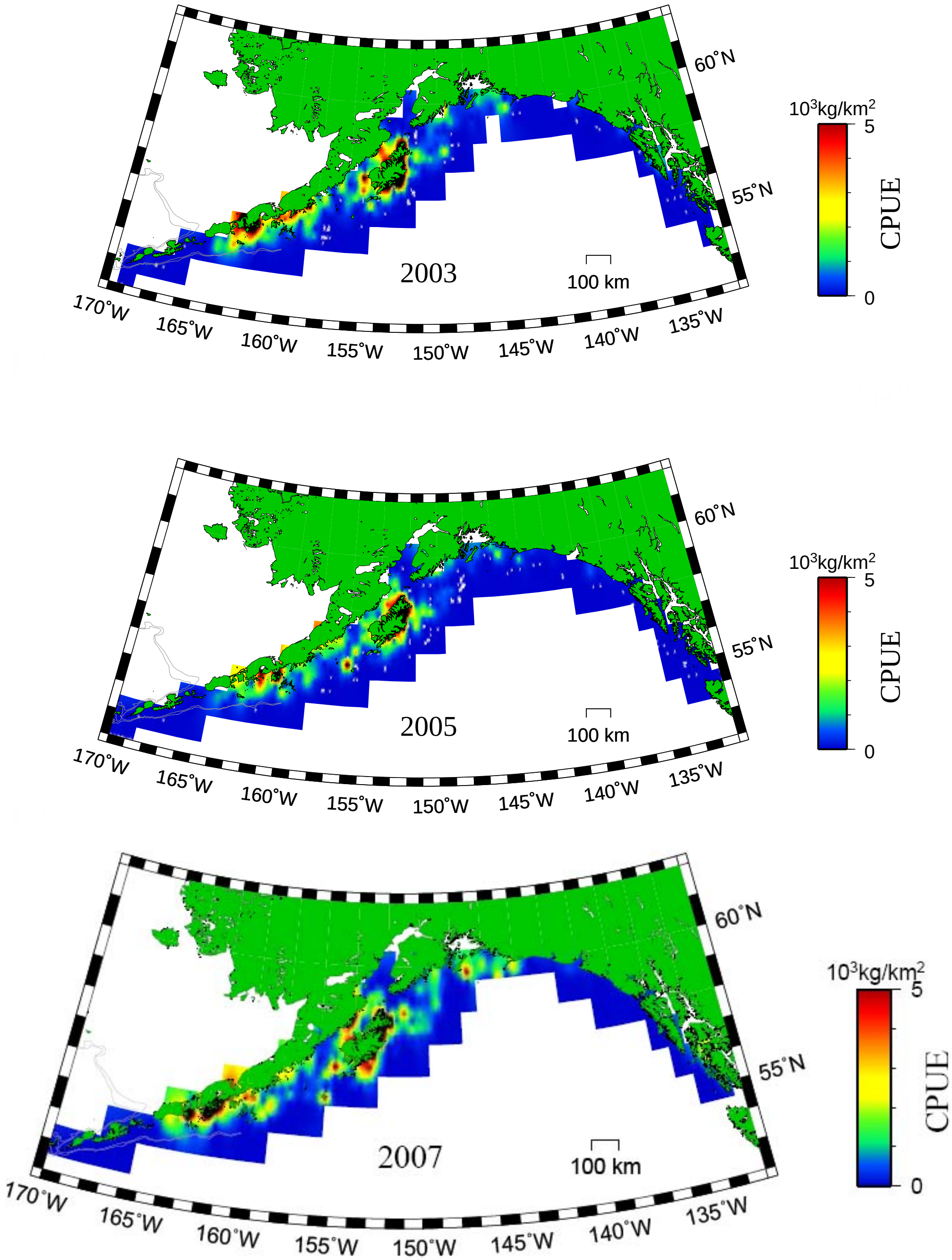
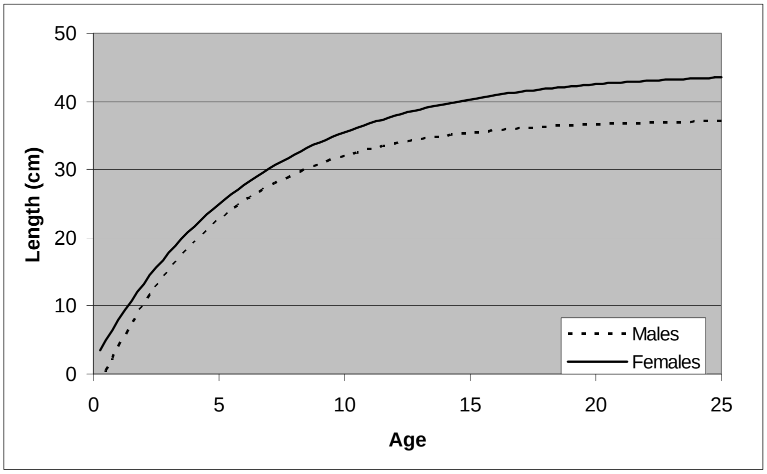
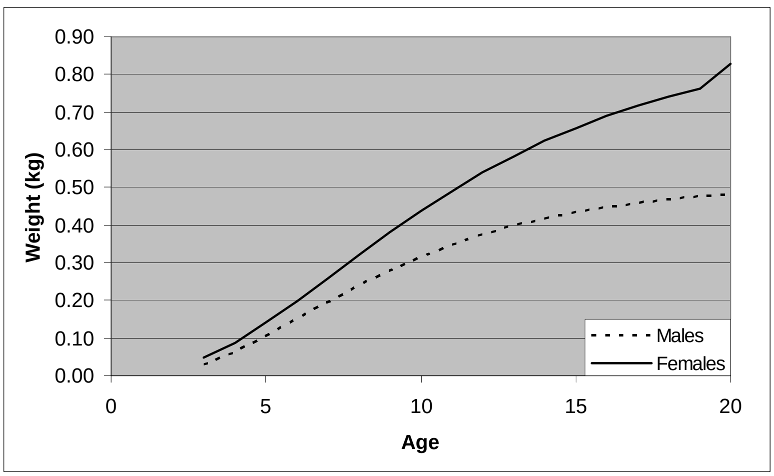


Figure 8.5. Spatial patterns of CPUE for flathead sole in the GOA groundfish surveys for 2003, 2005 and 2007.

a) Length-at-age.



b) Weight –at-age.



c) Maturity-at-age (females).

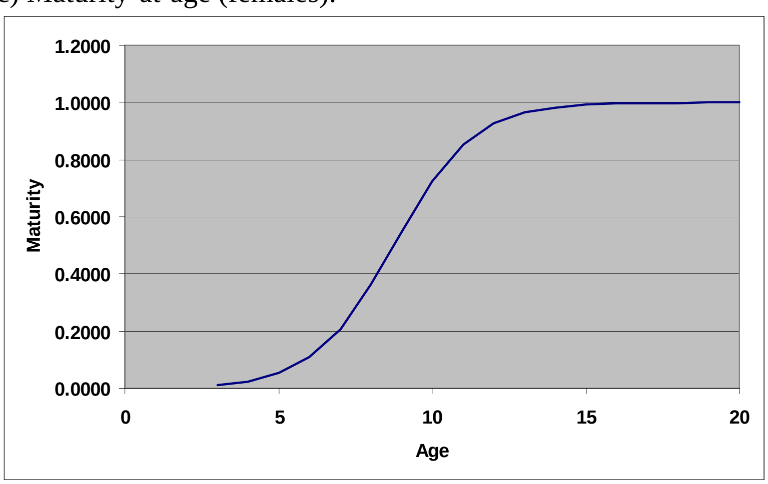


Figure 8.6. Age-specific chedules for GOA flathead sole: females solid line, males dotted line.

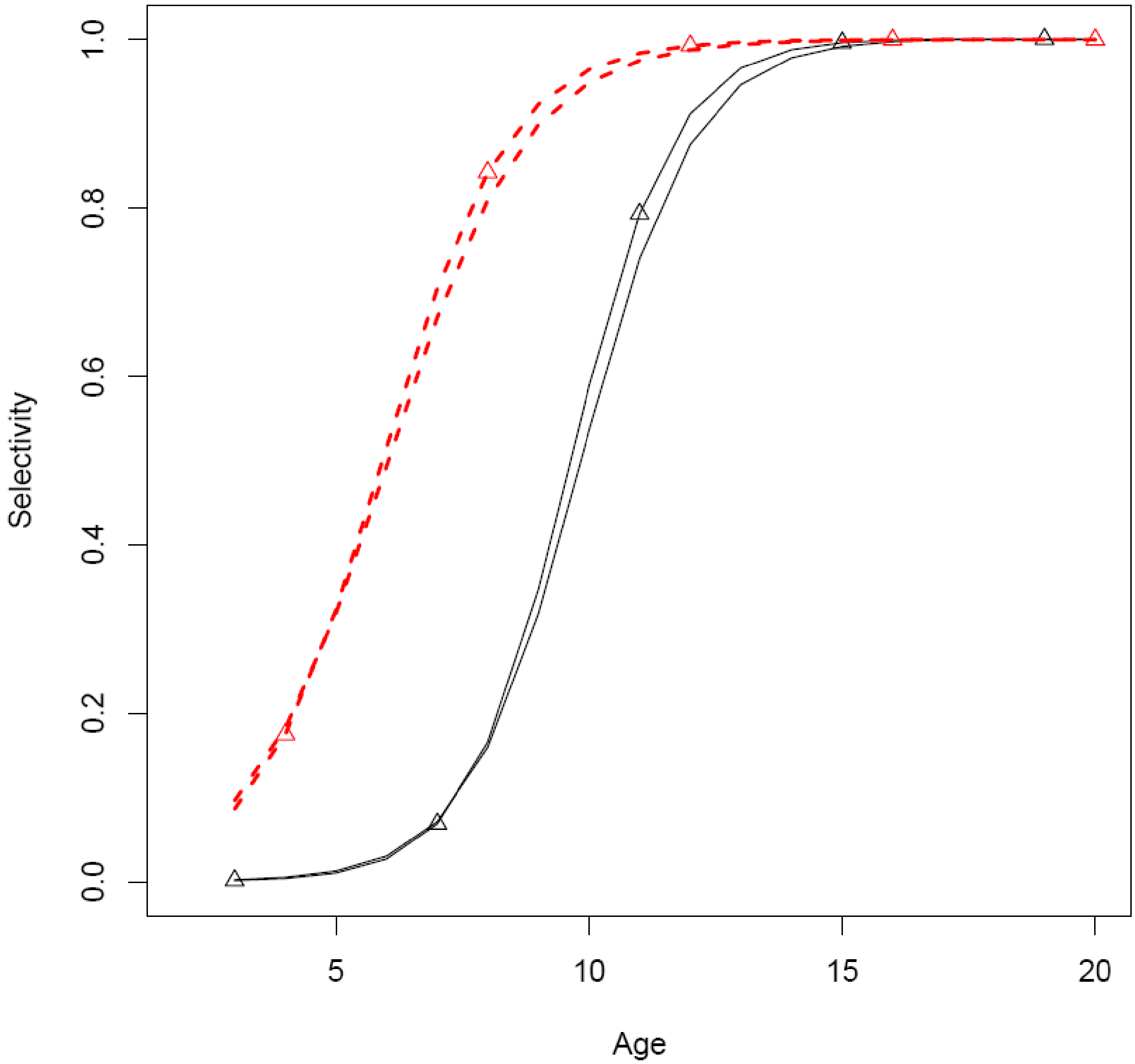


Figure 8.7. Selectivities for GOA flathead sole for the survey (red, dotted line) and fishery (solid line). Male curve with + symbol, female curve without symbol.

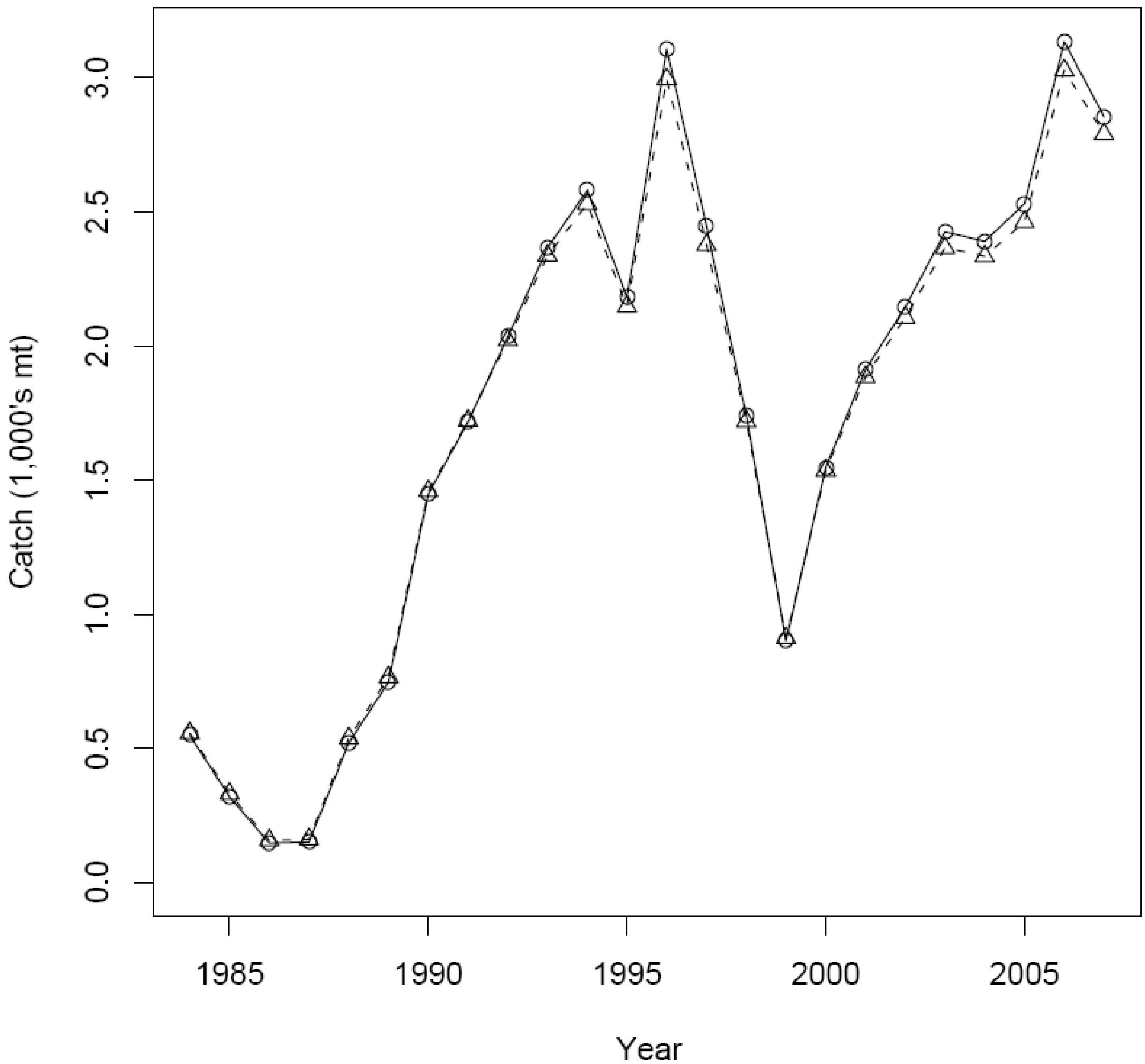


Figure 8.8. Predicted and observed annual catches for GOA flathead sole. Predicted catch = solid line, observed catch = dotted line with circles.

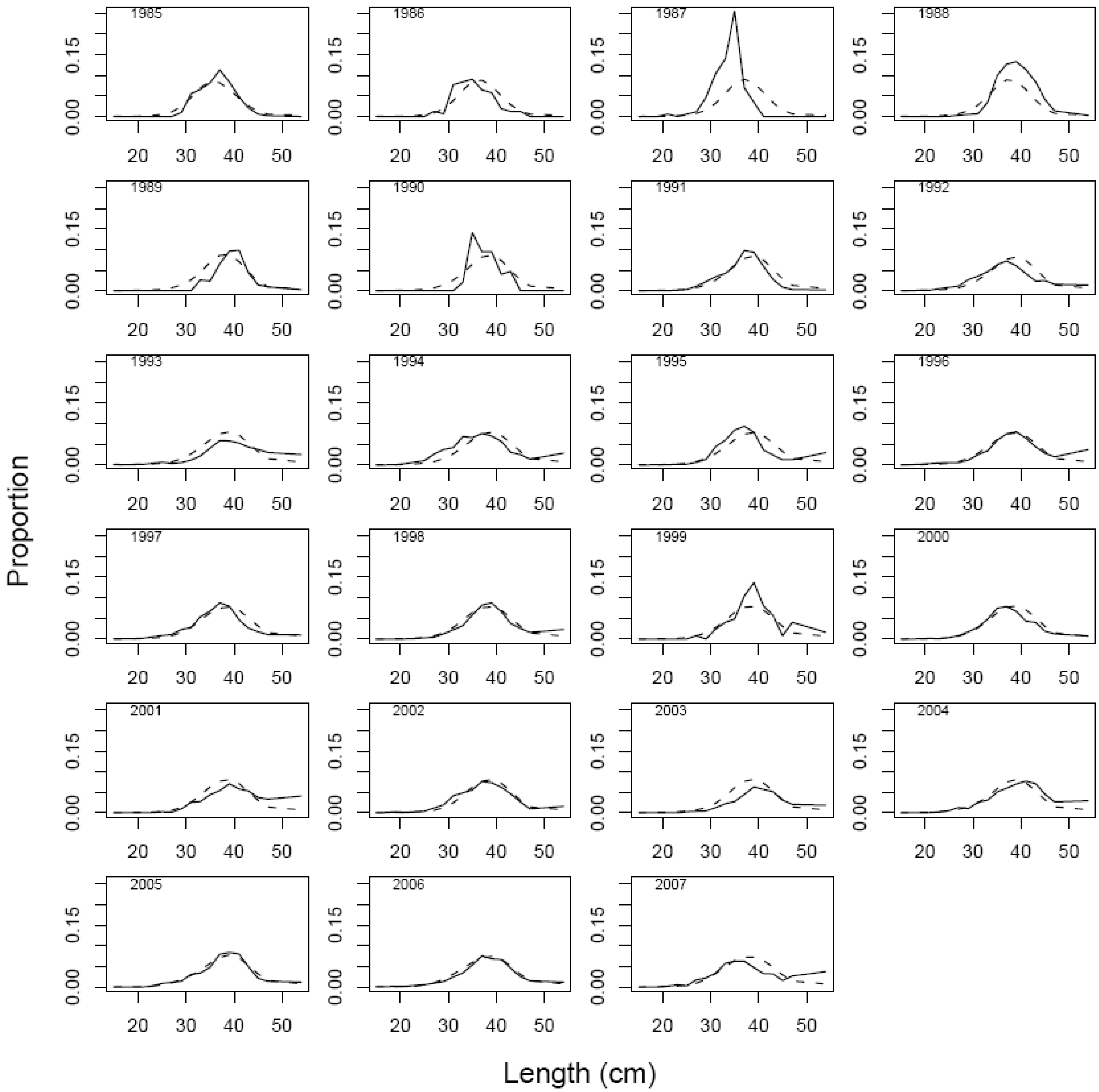


Figure 8.9. Fit to female GOA flathead sole fishery length composition data. Dashed lines represent the model prediction, solid lines represent the data.

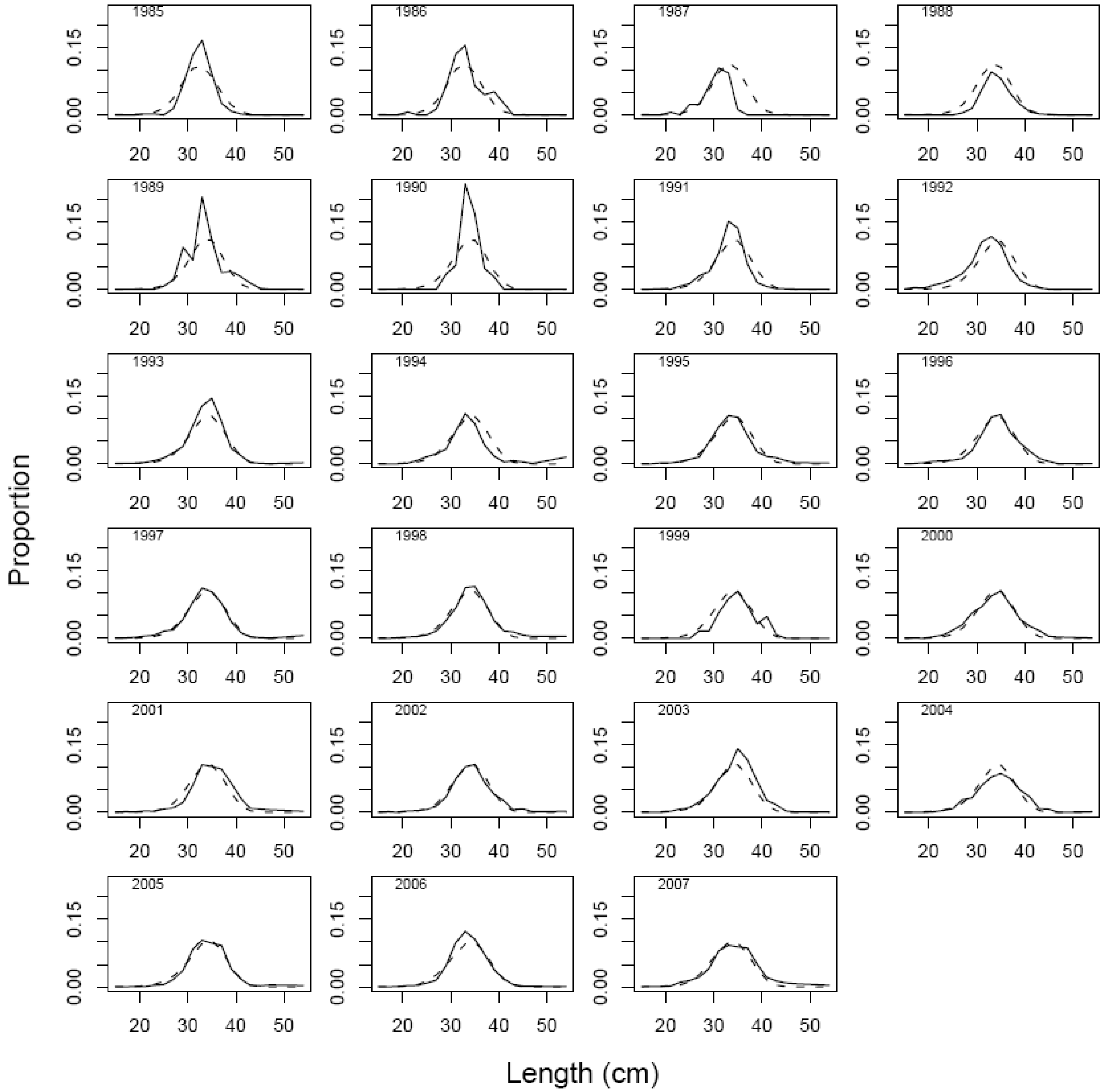


Figure 8.10. Fit to male GOA flathead sole fishery length composition data. Dashed lines represent the model prediction, solid lines represent the data.

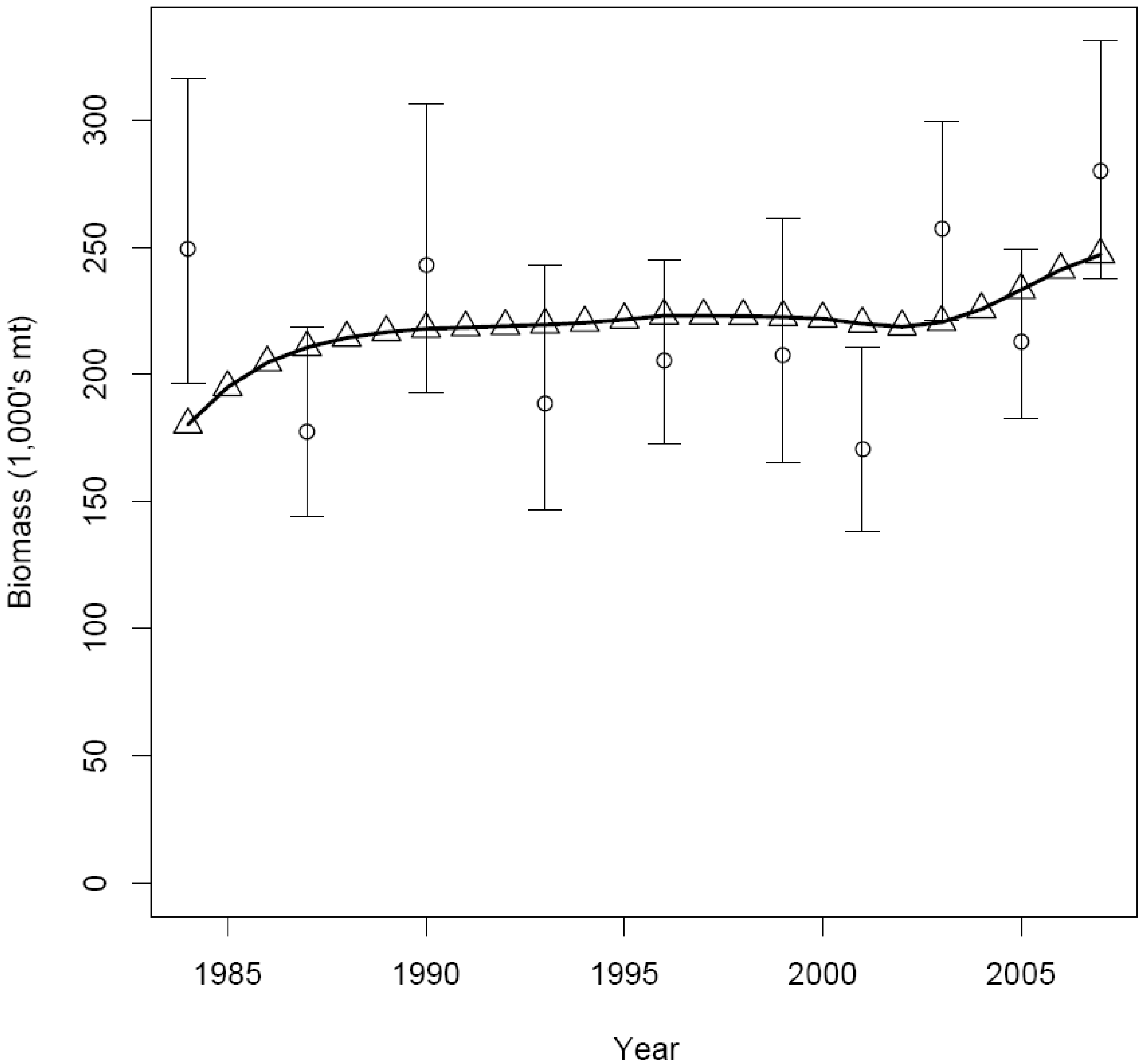


Fig. 8.11. Predicted and observed survey biomass for GOA flathead sole. Predicted survey biomass = triangles, observed survey biomass = circles (error bars are approximate lognormal 95% confidence intervals).

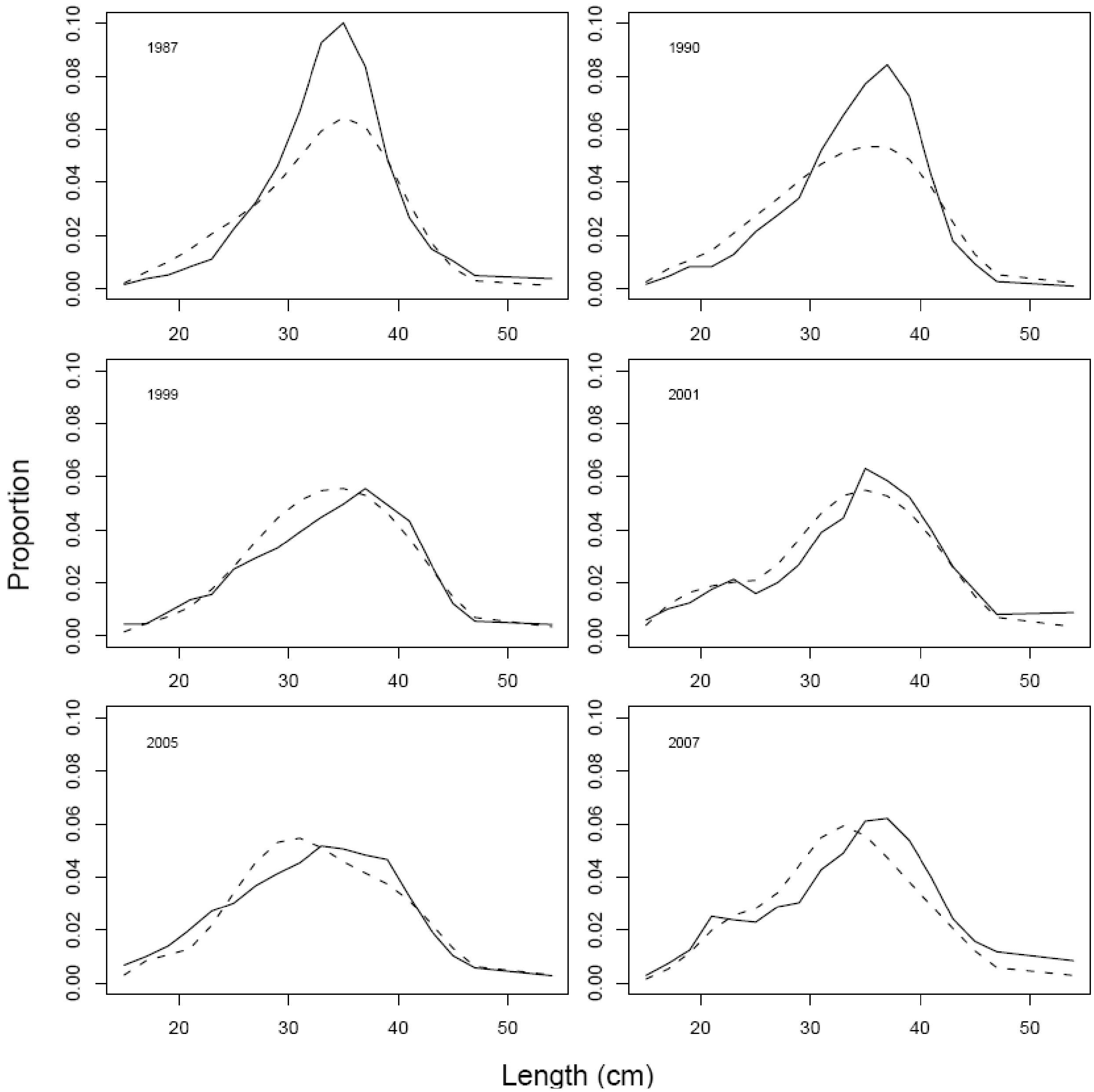


Figure 8.12. Fit to the female GOA flathead sole survey length composition data. Dashed lines represent the model prediction, solid lines represent the data.

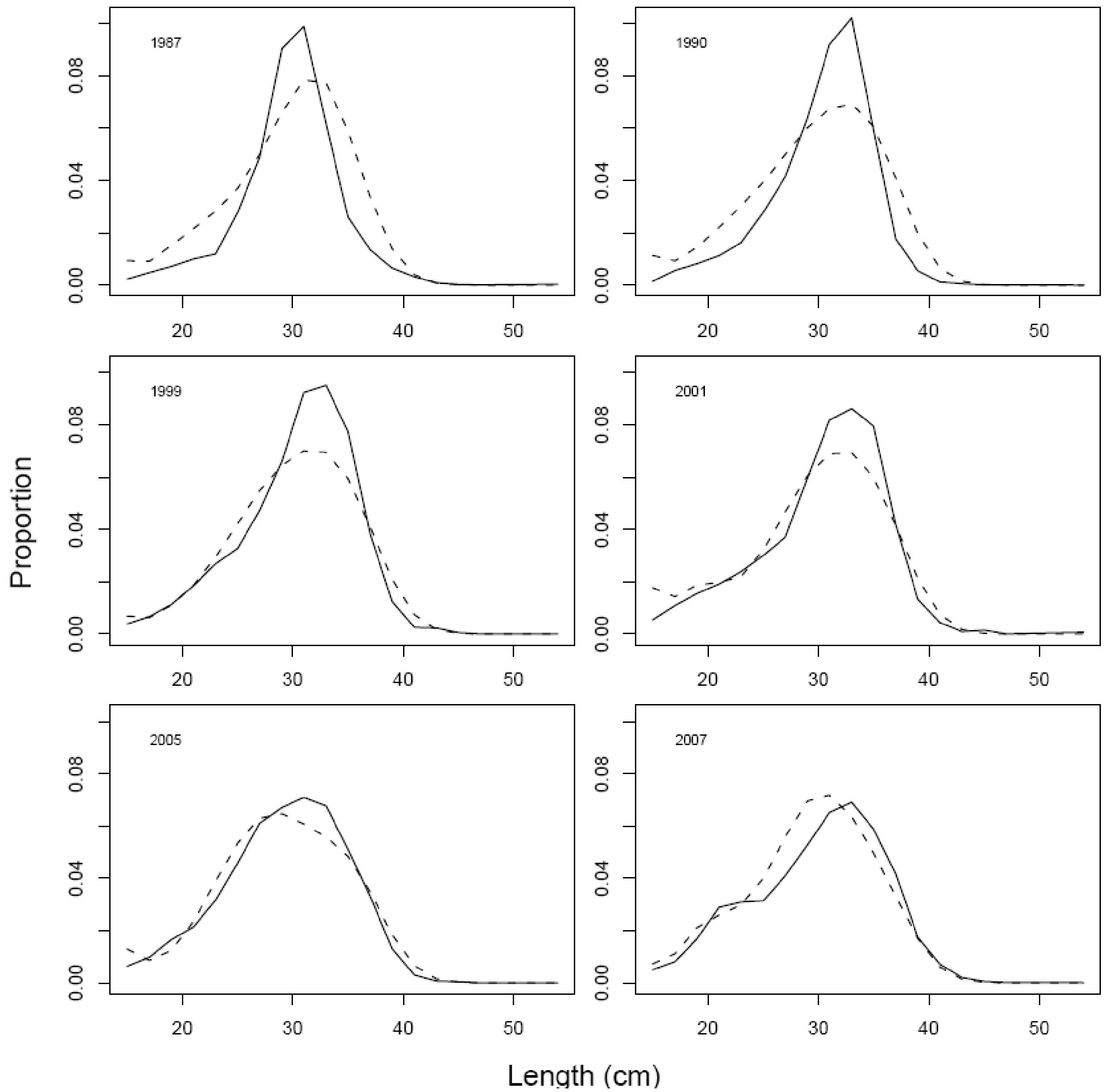


Figure 8.13. Fit to the male GOA flathead sole survey length composition data. Dashed lines represent the model prediction, solid lines represent the data.

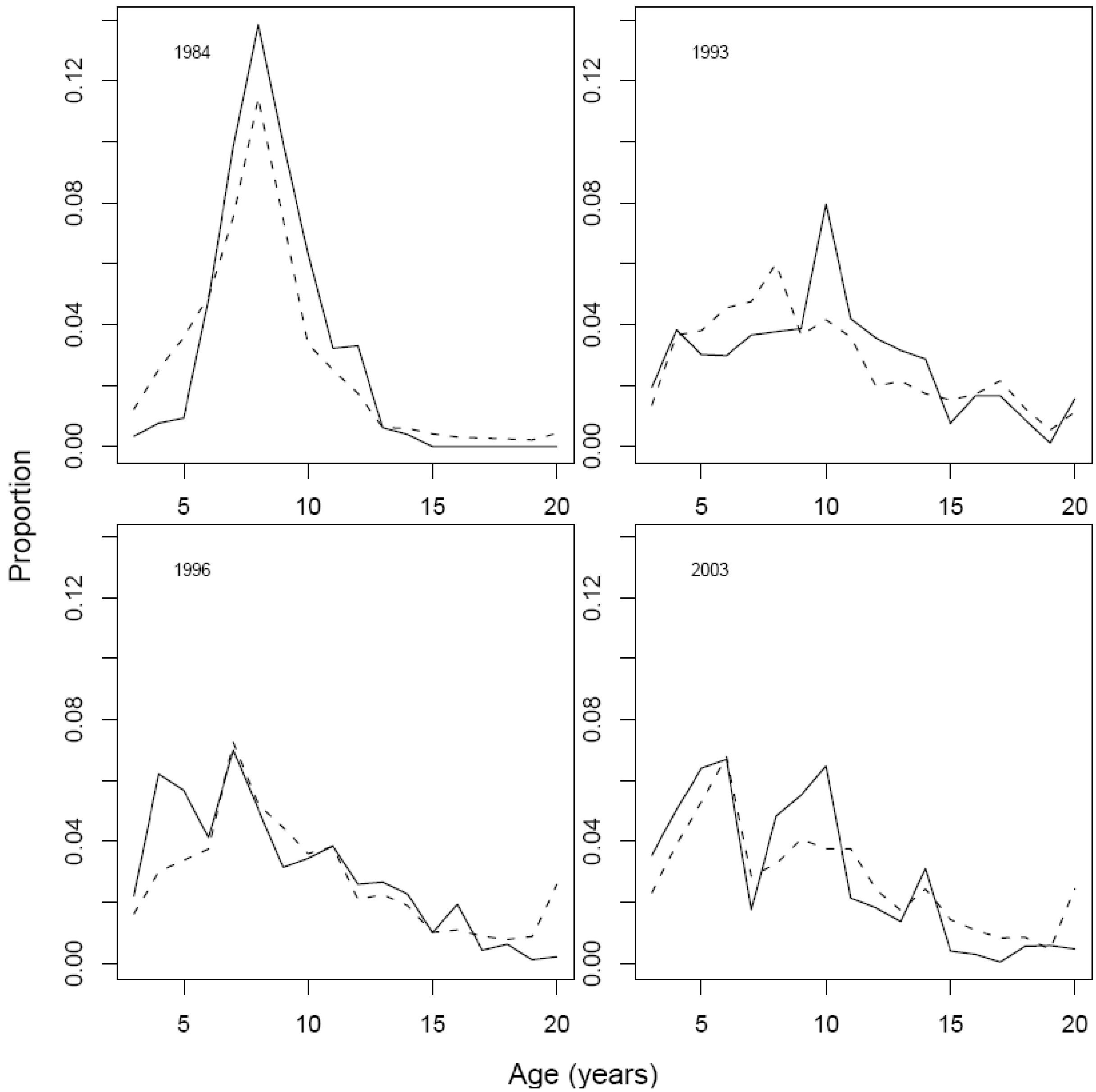


Figure 8.14. Fit to the female survey GOA flathead sole age composition data. Dashed lines represent the model prediction, solid lines represent the data.

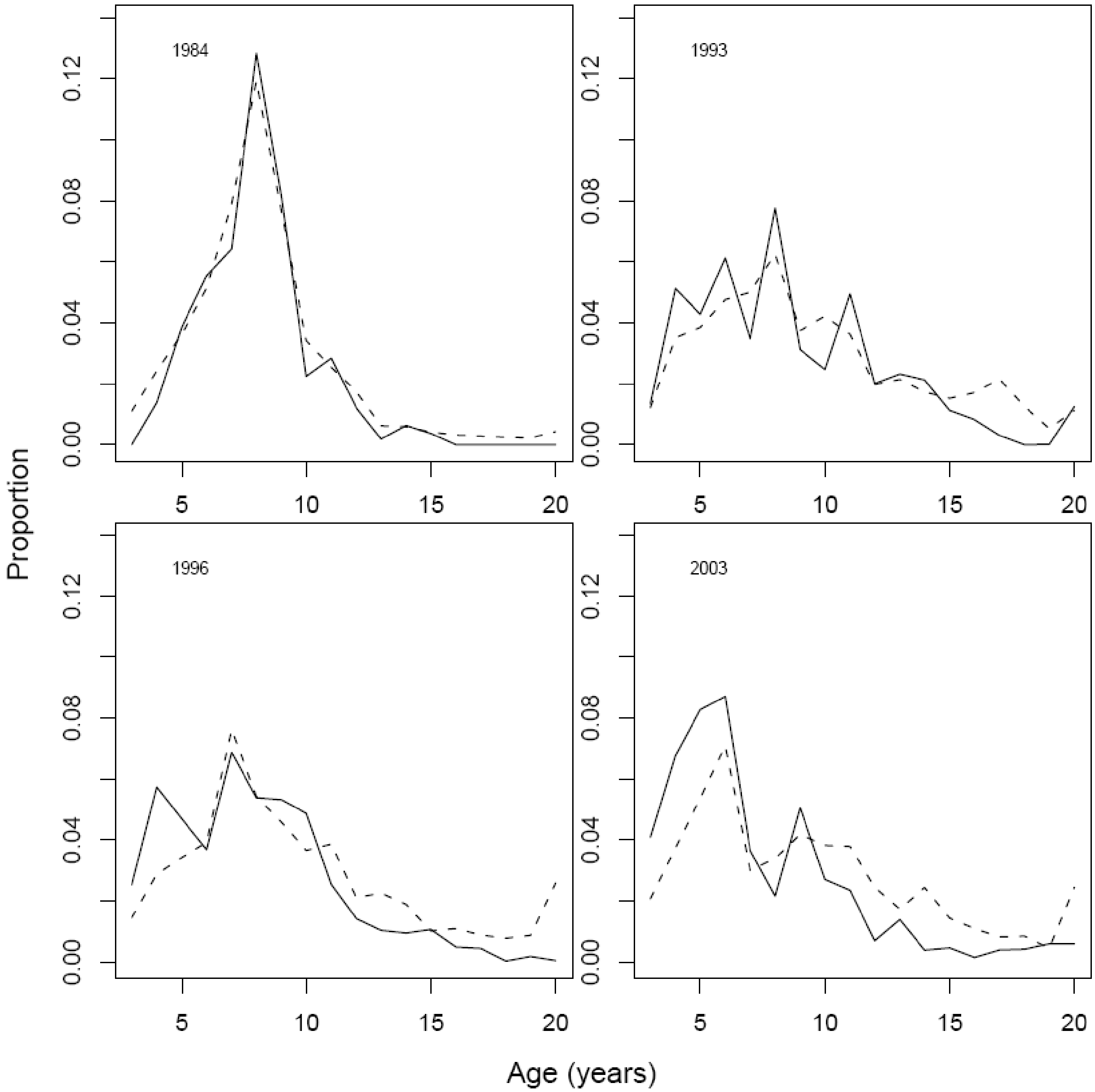


Figure 8.15. Fit to the male survey GOA flathead sole age composition data. Dashed lines represent the model prediction, solid lines represent the data.

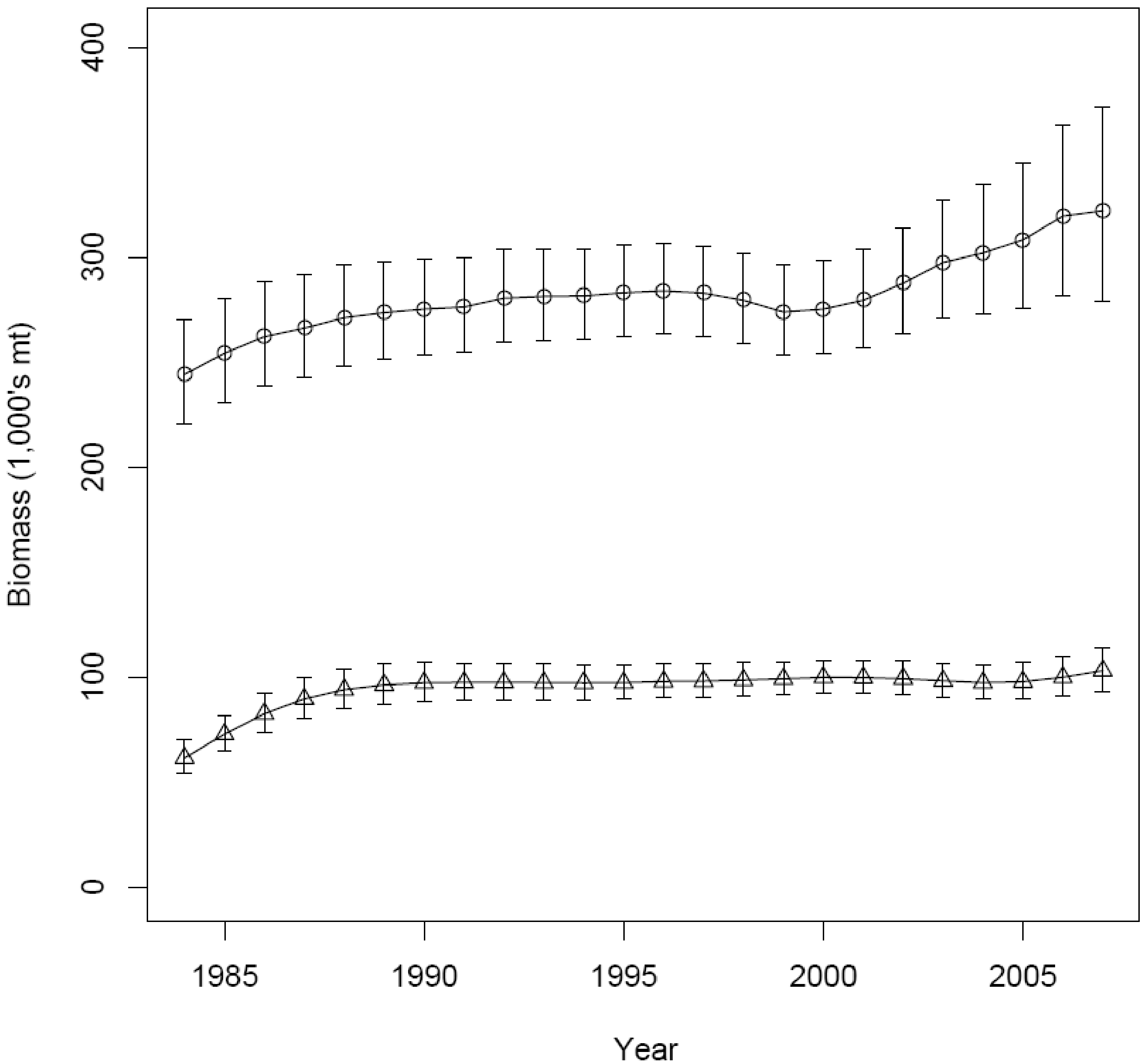


Figure 8.16. Estimated age 3+ biomass (circles) and female spawning biomass (triangles) for GOA flathead sole. Error bars are approximate lognormal 95% confidence intervals.

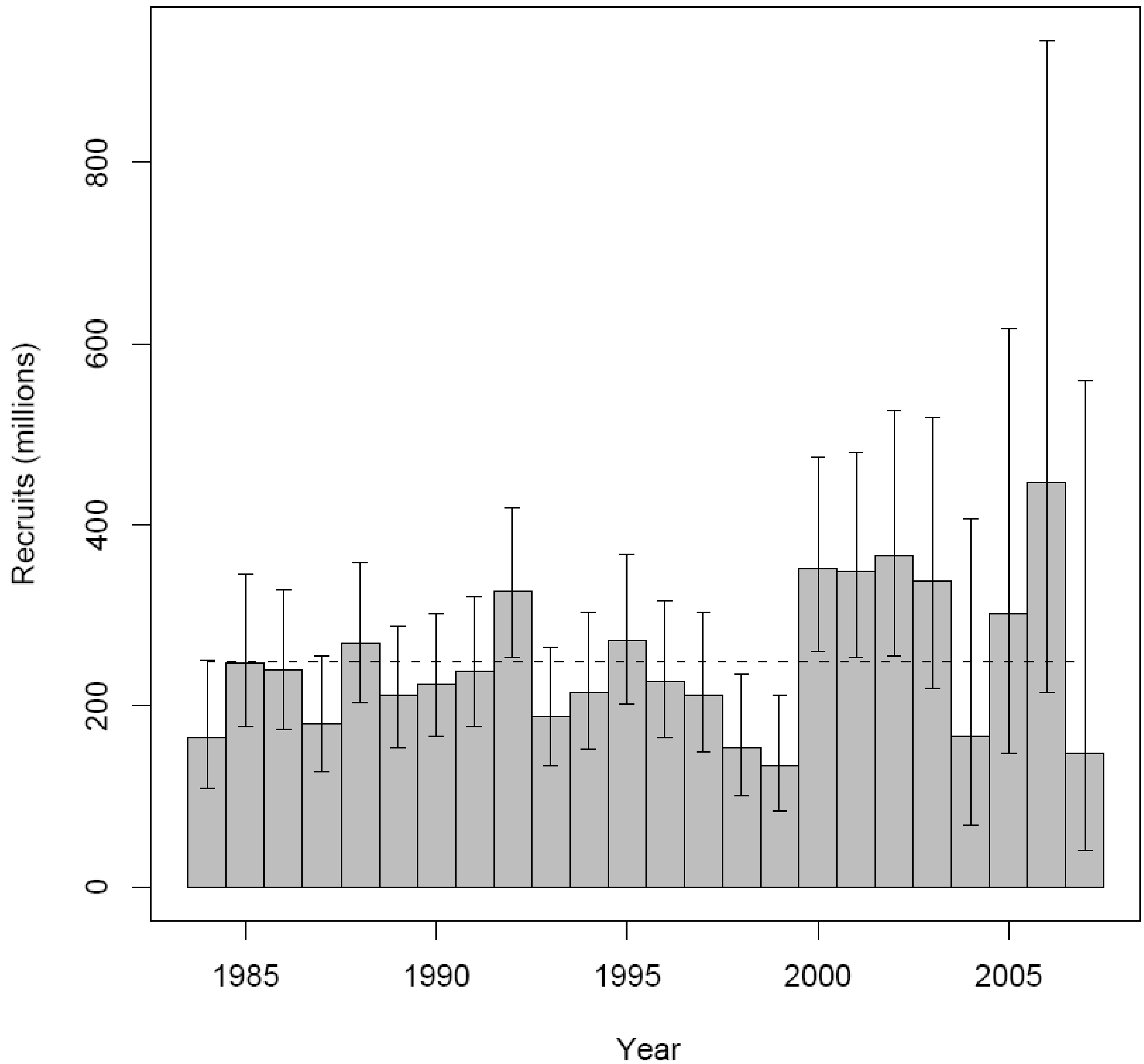


Figure 8.17. Estimated age 3 recruitments of GOA flathead sole with approximate 95% lognormal confidence intervals. Horizontal line is mean recruitment.

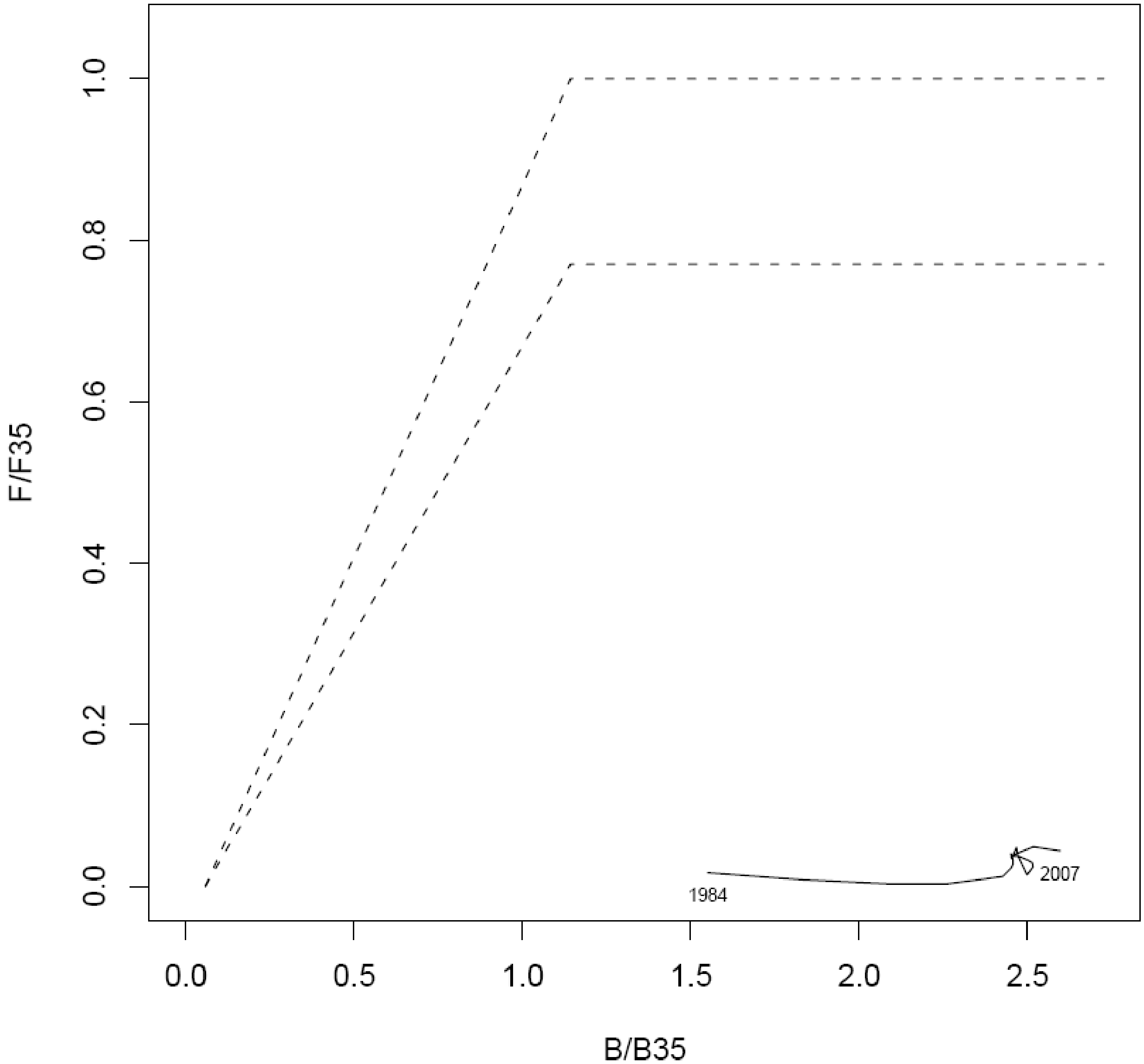


Figure 8.18. Control rule plot of estimated fishing mortality versus estimated female spawning biomass for GOA flathead sole. F_{OFL} = solid line, $F_{max\ ABC}$ = dashed line.

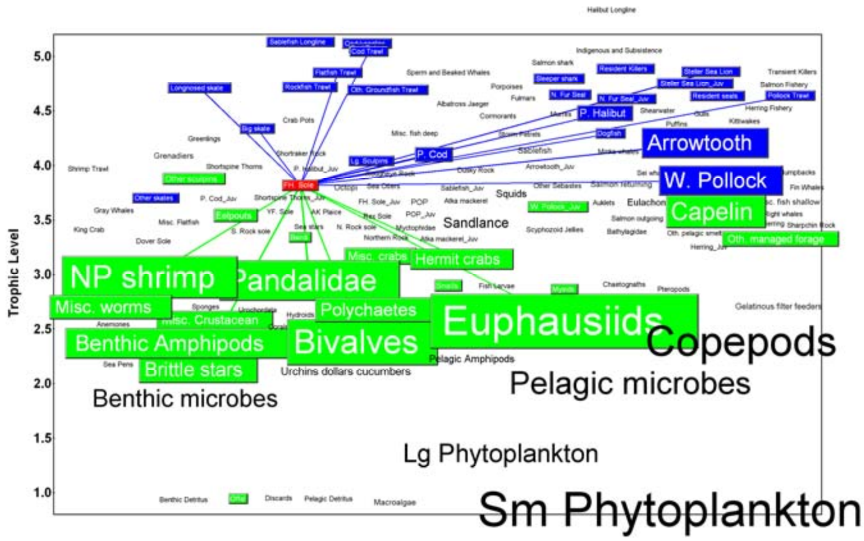


Figure 8.19a. Gulf of Alaska food web from the GOA ecosystem model (Aydin et al., in press) highlighting adult flathead sole links to predators (blue boxes and lines) and prey (green boxes and lines). Box size reflects relative standing stock biomass.

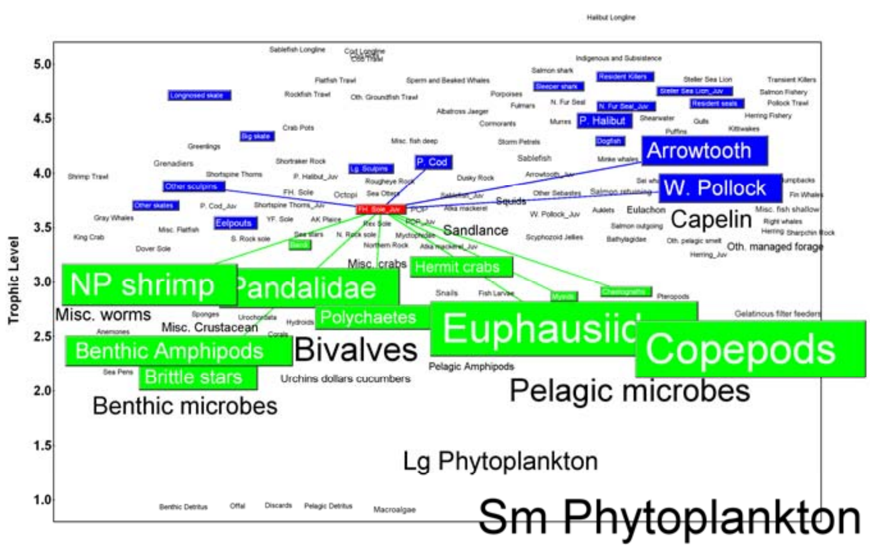


Figure 8.19b. Gulf of Alaska food web from the GOA ecosystem model (Aydin et al., in press) highlighting juveile flathead sole links to predators (blue boxes and lines) and prey (green boxes and lines). Box size reflects relative standing stock biomass.

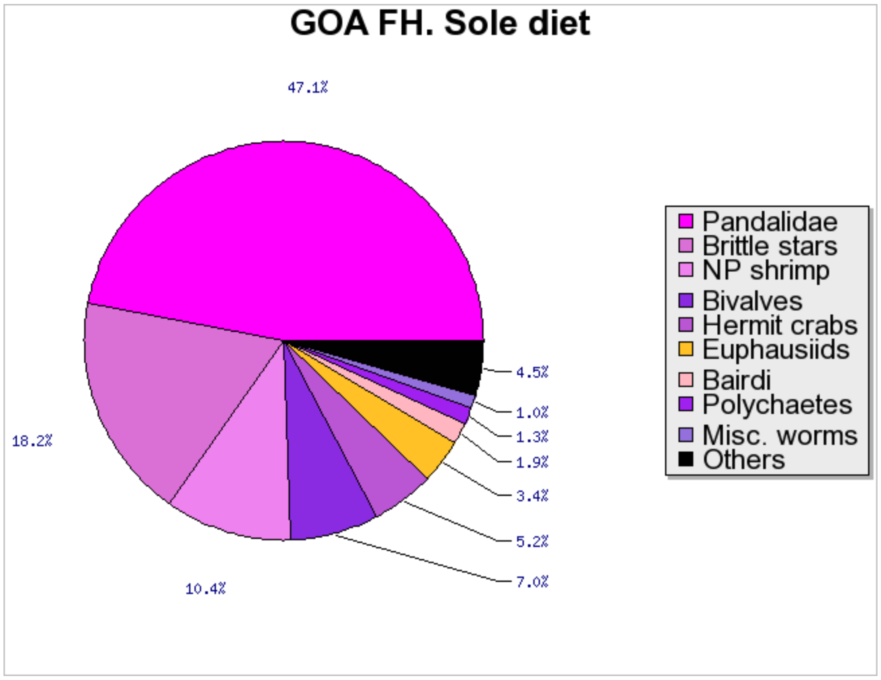


Figure 8.20a. Diet composition for Gulf of Alaska adult flathead sole from the GOA ecosystem model (Aydin et al., in press).

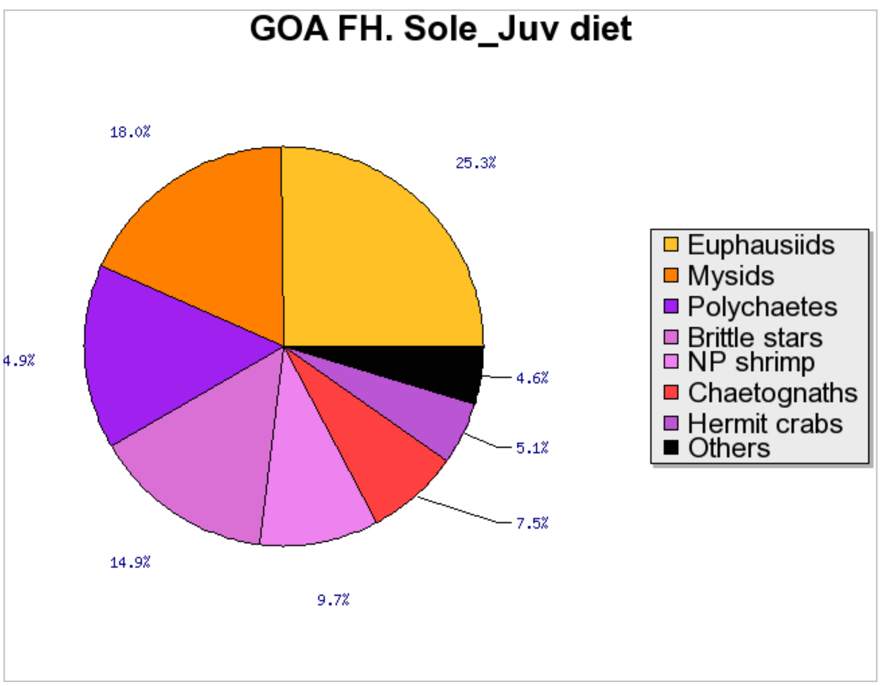


Figure 8.20b. Diet composition for Gulf of Alaska juvenile flathead sole from the GOA ecosystem model (Aydin et al., in press).

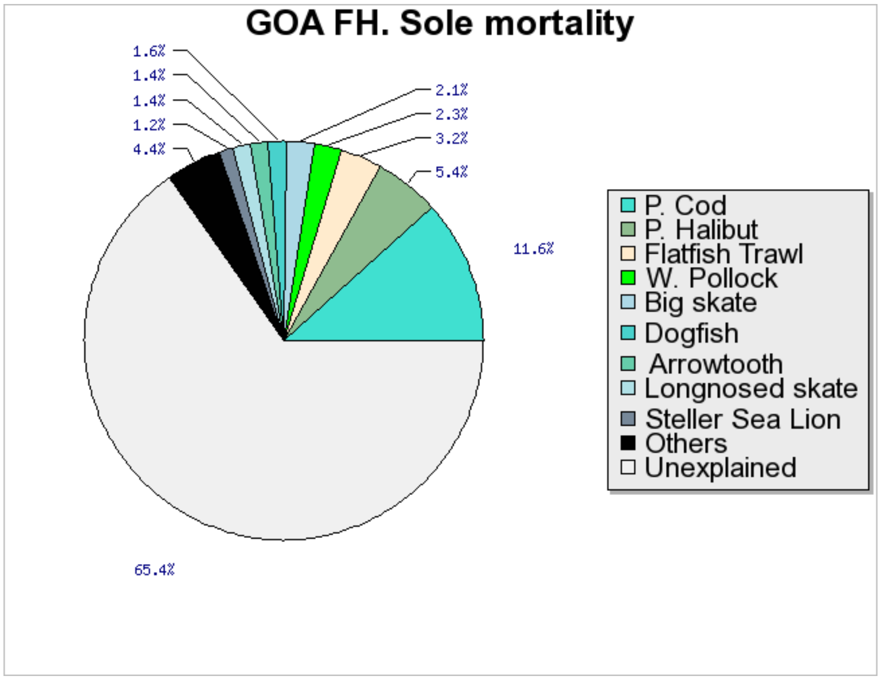


Figure 8.21a. Decomposition of natural mortality for Gulf of Alaska adult flathead sole from the GOA ecosystem model (Aydin et al., in press).

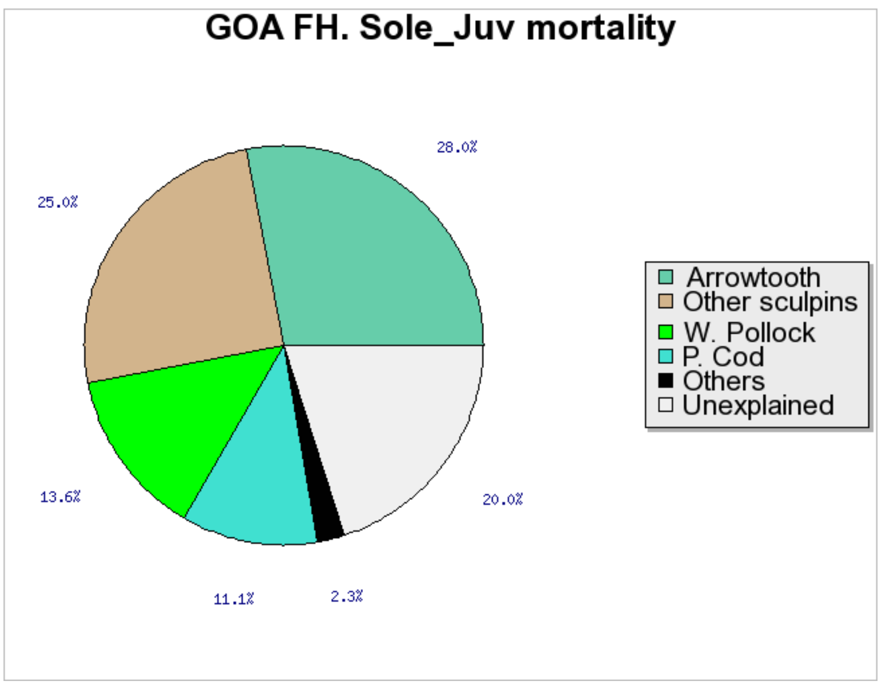


Figure 8.21b. Decomposition of natural mortality for Gulf of Alaska juvenile flathead sole from the GOA ecosystem model (Aydin et al., in press).

Appendix A.

Table A.1. List of variables and their definitions used in the model.

Variable	Definition
T	number of years in the model
A	number of age classes
L	number of length classes
t	time index ($1984 \le t \le 2007$)
a	age index ($1 \le a \le A$; a=1 corresponds to age 3)
x	sex index ($1 \le x \le 2$; 1=male, 2=female)
l	length index ($1 \le l \le L$)
$\{t^S\}$	set of years for which survey biomass data is available
$\{t^{F,A}\}$	set of years for which fishery age composition data is available
$\{t^{F,L}\}$	set of years for which fishery length composition data is available
$\{t^{S,A}\}$	set of years for which survey age composition data is available
$\{t^{S,L}\}$	set of years for which survey length composition data is available
$L^x_{l,a}$	element of length-age matrix (proportion of sex x fish in age class a that are in length class l)
$w_{x,a}$	mean body weight (kg) of sex x fish in age group a.
ϕ_a	proportion of females mature at age a
R_t	recruitment in year t
$\overline{\ln R_0}$	mean value of log-transformed recruitment
τ_t	recruitment deviation in year t
$N_{t,x,a}$	number of fish of sex x and age class a in year t
$C_{t,x,a}$	catch (number) of fish of sex x and age class a in year t
$p^{F,A}_{t,x,a}$	proportion of the total catch in year t that is sex x and in age class a
$p^{F,L}_{t,x,l}$	proportion of the total catch in year t that is sex x and in length class l
$p^{S,A}_{t,x,a}$	proportion of the survey biomass in year t that is sex x and in age group a
$p^{S,L}_{t,x,l}$	proportion of the survey biomass in year t that is sex x and in age group a
C_t	Total catch in year t (observed)
Y_t	total yield(tons) in year t
$F_{t,x,a}$	instantaneous fishing mortality rate for sex x and age group a in year t
M	Instantananeous natural mortality rate
$\overline{\ln F}$	mean value of log-transformed fishing mortality
ε_t	deviations in fishing mortality rate in year t
$Z_{t,x,a}$	Instantantaneous total mortality for sex x and age group a in year t
$s^F_{x,a}$	fishery selectivity for sex x and age group a
$s^S_{x,a}$	survey selectivity for sex x and age group a

Table A.2. Model equations describing the populations dynamics.

$\tau_t \sim N(0,\sigma_R^2)$	Random deviate associated with recruitment.
$N_{t,x,1} = R_t = \exp\left(\overline{\ln R_0} + \tau_t\right)$	Recruitment (assumed equal for males and females).
$N_{t+1,x,a+1} = N_{t,x,a} e^{-Z_{t,x,a}}$	Numbers at age.
$N_{t+1,x,A} = N_{t,x,A-1} e^{-Z_{t,x,A-1}} + N_{t,x,A} e^{-Z_{t,x,A}}$	Numbers in "plus" group.
$C_{t,x,a} = \frac{F_{t,x,a}}{Z_{t,x,a}}(1-e^{-Z_{t,x,a}})N_{t,x,a}$	Catch at age (in numbers caught).
$C_t = \sum_{x=1}^{2}\sum_{a=1}^{A} w_{x,a} C_{t,x,a}$	Total catch in tons (i.e., yield).
$FSB_t = \sum_{a=1}^{A} w_{1,a}\phi_a N_{t,1,a}$	Female spawning biomass.
$Z_{t,x,a} = F_{t,x,a} + M$	Total mortality.
$F_{t,x,a} = s^F_{x,a} \cdot \exp\left(\overline{\ln F} + \varepsilon_t\right)$	Fishing mortality.
$\varepsilon_t \sim N(0,\sigma_F^2)$	Random deviate associated with fishing mortality.
$s^F_{x,a} = \frac{1}{1+e^{(-b^F_x(age-{}_{50}A^F_x))}}$	Fishery selectivity- 2 parameter ascending logistic - separate for males and females.
$s^S_{x,a} = \frac{1}{1+e^{(-b^S_x(age-{}_{50}A^S_x))}}$	Survey selectivity- 2 parameter ascending logistic - separate for males and females.
$N^S{}_{t,x,a} = Q\, s^S_{x,a} N_{t,x,a}$	Survey numbers for sex *x*, age *a* at time *t*.
$SB_t = \sum_{x=1}^{2}\sum_{a=1}^{A} w_{x,a}\; N^S{}_{t,x,a}$	Total survey biomass.
$p^{F,A}_{t,x,a} = C_{t,x,a} / \sum_{x=1}^{2}\sum_{a=1}^{A} C_{t,x,a}$	Proportion at age in the catch.
$p^{F,L}_{t,x,l} = \sum_{a=1}^{A} L^x_{l,a} \cdot p^{F,A}_{t,x,a}$	Proportion at length in the catch.
$p^{S,A}_{t,x,a} = N^S{}_{t,x,a} / \sum_{x=1}^{2}\sum_{a=1}^{A} N^S{}_{t,x,a}$	Proportion at age in the survey.
$p^{S,L}_{t,x,l} = \sum_{a=1}^{A} L^x_{l,a} \cdot p^{S,A}_{t,x,a}$	Proportion at length in the survey.

Table A.3. Likelihood components.

Component	Description
$\sum_{t=1}^{T}\left[\log(C_t^{obs})-\log(C_t)\right]^2$	Catch; uses a lognormal distribution.
$\sum_{t\in\{t^{F,A}\}}\sum_{x=1}^{2}\sum_{a=1}^{A} n_{t,x}^{samp}\cdot p_{t,x,a}^{F,A,obs}\cdot\log(p_{t,x,a}^{F,A})$ - offset	Fishery age composition; uses a multinomial distribution. n^{samp} is the observed sample size.
$\sum_{t\in\{t^{F,L}\}}\sum_{x=1}^{2}\sum_{l=1}^{L} n_{t,x}^{samp}\cdot p_{t,x,l}^{F,L,obs}\cdot\log(p_{t,x,l}^{F,L})$ - offset	Fishery length composition; uses a multinomial distribution. n^{samp} is the observed sample size.
$\sum_{t\in\{t^{F,A}\}}\sum_{x=1}^{2}\sum_{a=1}^{A} n_{t,x}^{samp}\cdot p_{t,x,a}^{S,A,obs}\cdot\log(p_{t,x,a}^{S,A})$ - offset	Survey age composition; uses a multinomial distribution. n^{samp} is the observed sample size.
$\sum_{t\in\{t^{F,L}\}}\sum_{x=1}^{2}\sum_{l=1}^{L} n_{t,x}^{samp}\cdot p_{t,x,l}^{S,L,obs}\cdot\log(p_{t,x,l}^{S,L})$ - offset	Survey length composition; uses a multinomial distribution. n^{samp} is the observed sample size.
offset $=\sum_{t}\sum_{x=1}^{2}\sum_{a=1}^{A} n_{t,x}^{samp}\cdot p_{t,x,a}^{obs}\cdot\log(p_{t,x,a}^{obs}))$	The offset constants for age composition components are calculated from the observed proportions and the sample sizes. A similar formula is used for length composition component offsets.
$\sum_{t\in\{t^{S}\}}\left[\dfrac{\log\left[\dfrac{SB_t^{obs}}{SB_t}\right]}{\sqrt{2}\cdot s.d.(\log(SB_t^{obs}))}\right]^2$	Survey biomass; uses a lognormal distribution.
$\sum_{t=1984}^{2002}(\tau_t)^2$	Recruitment; uses a lognormal distribution, since τ_t is on a log scale.
$\sum_{t=2003}^{2005}(\tau_t)^2$	“Late” recruitment; uses a lognormal distribution, since τ_t is on a log scale.
$\sum_{t=1967}^{1983}(\tau_t)^2$	“Early” recruitment; uses a lognormal distribution, since τ_t is on a log scale. Determines age composition at starting year of model.

Table A.4. Fixed parameters in the model.

Parameter	Description
M = 0.2	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.

Table A.5. Estimated parameters for the model. A total of 75 parameters were estimated in the model.

Parameter	Subscript range	Total no. of Parameters	Description
$\ln(R_0)$	NA	1	natural log of the geometric mean value of age 3 recruitment
τ_t	$1967 \le t \le 2007$	41 (24 + 17 from initial age composition)	Recruitment deviation in year *t* (log-scale)
$\ln(f_0)$	NA	1	natural log of the geometric mean value of fishing mortality
ε_t	$1984 \le t \le 2007$	24	deviations in fishing mortality rate in year t
b^F_x, $_{50}A^F_x$	$1 \le x \le 2$	4	selectivity parameters (slope and age at 50% selected) for the fishery for males and females.
b^S_x, $_{50}A^S_x$	$1 \le x \le 2$	4	selectivity parameters (slope and age at 50% selected) for the survey data, for males and females.