8. Assessment of the Flathead Sole Stock in the Gulf of Alaska

By

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Executive Summary

Changes in the Input Data

1) The fishery catch and length compositions for 2008 and 2009 (through Sept. 26, 2009) were incorporated in the model.
2) The 2007 fishery catch and length compositions were updated.
3) The 2009 GOA groundfish survey biomass estimate and length composition data were added to the model. Survey biomass decreased from 280,990 t in 2007 to 225,377 t in 2009. Survey biomass estimates and length compositions were recalculated for all survey years.
4) Age compositions from the 1990, 1999, and 2007 groundfish surveys were added to the model.

Changes in the Assessment Model

Estimable scaling offset parameters for male selectivity (relative to asymptotic female selectivity) were incorporated into the assessment model for both fishery and survey selectivities. As a consequence, the fishing mortality experienced by fully-selected males may now differ from that experienced by fully-selected females. Fishing mortality is reported relative to fully-selected females.

Changes in the Assessment Results

1. The preferred model configuration incorporates the new option for male selectivity scaling parameters.
2. Based on the preferred model, the recommended ABC, based on an $F_{40\%}$ harvest level of 0.371, is 52,721 t for 2010 and 54,865 t for 2011.
3. The OFL, based on an $F_{35\%}$ harvest level of 0.481, is 65,567 t for 2010 and 68,206 t for 2011.
4. Projected female spawning biomass is estimated at 124,674 t for 2010 and 128,585 t for 2011.
5. Total biomass (age 3+) is estimated at 370,332 t for 2010 and 367,217 t for 2011.

The area apportionments corresponding to the recommended ABCs from the preferred model are:

	Western Gulf	Central Gulf	West Yakutat	Southeast Outside	Grand Total
apportionment	35.5%	57.2%	4.2%	3.1%	100.0%
2010 ABC (t)	18,741	30,155	2,212	1,613	52,721
2011 ABC (t)	19,503	31,381	2,302	1,679	54,865

A summary of important reference values from the preferred model for this assessment, relative to the 2008 SAFE projections, is as follows:

Quantity	2009 Assessment Recommendations for 2010	2009 Assessment Recommendations for 2011	2008 Assessment Recommendations for 2010	2008 Assessment Recommendations for 2009
Tier	**3a**	**3a**	**3a**	**3a**
age 3+ biomass (t)	370,332	367,217	322,714	323,937
Female spawning biomass (t)	124,674	128,585	109,441	111,463
ABC (t)	52,721	54,865	47,652	46,464
OFL (t)	65,567	68,206	59,349	57,911
$F_{ABC} = F_{40\%}$	0.371	0.371	0.380	0.380
$F_{OFL} = F_{35\%}$	0.481	0.481	0.494	0.494

SSC Comments Specific to the Flathead Sole Assessments

SSC Comments on Assessments in General

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: The current assessment model can not accommodate surveys from multiple sources. We are developing a new assessment model that will incorporate surveys from multiple sources as one of its new features. When completed, this new model will allow us to explore the utility of using the ADF&G bottom trawl survey data in future assessments.

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 through 2008, when the catch reached its highest level ever (3,419 t). As of Sept. 26, catch in 2009 was 2,740 t and is expected to be similar to that in 2008 by year’s end (3,398 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 8.2). 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 8.3).

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 typically been set much lower than the recommended ABC. Prior to 2003, flathead sole was 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. TACs, however, 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 retention rate for flathead sole over all fisheries has been 87% or larger since 2005 (Table 8.2a).

Data

Fishery Data

This assessment used fishery catches from 1984 through 26 September, 2009 (Table 8.1, Fig. 8.1), as well as estimates of the proportion of individuals caught by length group and sex for the years 1985-2009 (as of Sept. 26; 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 are 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 (2001-2009) 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, Figure 8.4). Although survey depth coverage has been inconsistent for depth strata > 500 m, 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. In addition, the 2001 survey estimate did not sample the eastern section of the Gulf. We estimated the average fraction of stock biomass occurring in the unsampled area from the 1993, 1996 and 1999 surveys (~11%) and assigned a corresponding availability factor of 0.9 to the 2001 survey 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 ~225,000 t in 2009, a 20% decrease from the 2007 survey estimate of ~280,000 t (the largest in the time series) but a 6% increase over the 2005 estimate of ~213,000 t.

Estimates of the total number of individuals by length group from each RACE GOA groundfish survey (Table 8.7) were also incorporated into the assessment, as were estimates of total population numbers-at-age (Table 8.8). Survey age compositions were available for 1984, 1990, 1993, 1996, 1999, 2003, 2005 and 2007. Because age compositions were calculated from age-length data using the corresponding size compositions, size compositions were de-weighted in the model likelihood for years where age composition data was available to avoid double counting. Survey size composition data was fully weighted in the model likelihood for years when age compositions were unavailable (1987, 2001 and 2009). Sample sizes for the survey size and age compositions are given in Table 8.4b.

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 previous assessments (Stockhausen et al., 2005 and 2007). Sex-specific weight-at-age relationships and female maturity schedules used in previous assessments (Stockhausen et al., 2005 and 2007) were also used in this assessment (Table 8.10).

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

Source	type	years
Fishery	catch	1984-2009
	size compositions	1985-2009
Survey	biomass	1984-1999 (triennial); 2001-2009 (biennial)
	size compositions	1984-1999 (triennial); 2001-2009 (biennial)
	age compositions	1984, 1990, 1993, 1996, 1999, 2003, 2005, 2007

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.

This year, we expanded the options for normalizing fishery and survey selectivity curves in the model. Previously, sex-specific selectivity curves (for both fisheries and surveys) were normalized to the maximum (unnormalized) value for female selectivity. In this assessment, we added options to estimate the maximum selectivity for males relative to females for either fisheries or surveys (or both). The maximum selectivity for females is still set to 1 and fishing mortality values are relative to fully-selected females. Thus, selectivity curves are now calculated in the following manner:

$$s_F^N(a) = s_F^U(a) / \max\{s_F^U(a)\}$$

$$s_M^N(a) = [s_M^U(a) / \max\{s_F^U(a)\}] \cdot e^r$$

where $s_F^N(a)$ is the normalized selectivity curve for females as a function of age, $s_F^U(a)$ is the corresponding unnormalized curve, $s_M^N(a)$ and $s_M^U(a)$ are the corresponding curves for males, and r is the log-scale parameter for the relative scale between males and females. The previous scheme for normalizing selectivities is obtained if r is set to 0 and not estimated.

The current assessment model covers 1984-2009. 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 typical 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 81 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., 2007), natural mortality (*M*) was fixed at 0.2 yr^{-1} for both sexes in all age classes. This value was based on a maximum observed age for flathead sole of 22 years (Spencer et al., 1999). Although maximum observed age has increased to 31 years in the Bering Sea, a preliminary analysis of independent estimates of natural mortality for BSAI flathead sole is not inconsistent with continued use of this value (Stockhausen, unpublished data).

Growth

Individual growth was incorporated in the model using sex-specific age-length transition matrices (Table 8.9). These were identical to those used in the previous assessment (Stockhausen et al., 2007). 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 8.6a). 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., 2007): $W = 0.00428\ L^{3.2298}$ for both sexes combined (weight in grams and length in centimeters). Weight-at-age (Table 8.10, Figure 8.6b) 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, Figure 8.6c). 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

Based on results from the 2003 assessment (Turnock et al., 2003a), which indicated that estimating survey catchability was problematic, we fixed overall survey catchability (*Q* in Table A.1) in the model to a value of 1.

Parameters estimated conditionally

A total of 81 parameters were estimated in the final model (Table A.5). These consisted primarily of parameters on the recruitment of flathead sole to the population (44 parameters total, including ones determining the initial age composition) and values related to annual fishing mortality (27 parameters total). The separable age-component of fishing mortality was modeled using ascending logistic functions estimated separately for males and females (5 parameters total). The same approach was also used to estimate relative age-specific survey catchability (5 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 43 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 26 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. those that determined the initial model age structure and were thus uninformed by contemporaneous catch data. The “ordinary” recruitment component incorporated deviations from 1984-2006, while the “late” recruitment component incorporated deviations from 2007-2009. "Late" recruitments are weighted separately in the likelihood from "ordinary" recruitments because there is generally little data to constrain recruitment estimates for the final few years in the model. This partitioning does not reflect any assumptions regarding changes in productivity with time: 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, as well as 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). The weights used in this assessment are given in Table 8.11.

Model evaluation

Several alternative model configurations were considered in a previous assessment (Stockhausen et al., 2005). Here, we took the model configuration selected in that assessment as a base case. As an alternative model, we allowed the model to estimate the relative scaling parameter for male selectivity for both the fishery and the survey. For both models, we assigned a weight of 30 to the catch-specific likelihood component and weights of 1 to all other likelihood components (Table 8.11). Initial values for the estimable parameters were set as listed in Table 8.12. To test whether resulting model solutions were indeed global, rather than local, maximum on the likelihood surface, we started the two model cases using several different parameter sets. All runs for a given case converged to the same final solution, providing evidence that the original solution was indeed the global maximum.

Fishery and survey selectivity functions for both model cases are illustrated in Figure 8.7. Ignoring the issue of scaling for the moment, the resulting functions are very similar for the two cases. The age by which fish are selected at 95% of their asymptotic rate in the fishery is 13.5 yrs for females and 13.0 yrs for males in the base case. In the alternative case, females reach 95% selectivity at a slightly younger age (13.0 yrs) while males reach 95% of their asymptotic rate at a slightly older age (13.5 yrs). For the survey, the age by which females are selected at 95% of their asymptotic rate is 9.8 yrs in the base case and 10.76 yrs in the alternative case while males reach 95% of their asymptotic rate at 9.0 yrs in the base case and 8.2 yrs in the alternative case. However, the log-scale male selectivity scaling parameters for both the fishery and survey are both different from 0 (the base case value) in the alternative model (0.159 for the fishery, -0.235 for the survey). As a result, asymptotic selectivity for males was slightly lower (21%) in the survey than that for females and higher in the fishery (17%). Somerton et al. (2007) showed that gear selectivity for flathead sole in the survey increases logistically with size. Because males reach a smaller asymptotic size than females, one would thus expect that age-specific survey selectivity for older males would be somewhat smaller than that for females of similar age.

Further comparison of the results from the two model cases are shown for several variables of interest in Fig. 8.8. Estimates for total biomass, spawning biomass and recruitment were consistently higher in the alternative case when compared with the base case, although the discrepancy was somewhat larger for total biomass and somewhat smaller for recruitment. This appears to be a consequence of the alternative model estimate for the survey male selectivity scale parameter being less than one (negative on a log scale). Estimates for survey biomass (not shown) are nearly identical for both models. When the male scaling parameter for the survey is less than 1, the underlying population must be larger to result in the same estimated survey biomass. Because the alternative and base models result in the same estimated survey biomass, the underlying population must be larger in the case of the alternative model to offset the fact that the survey in the alternative model is not "seeing" all the fish that the survey in the base case sees.

In contrast with the population estimates, estimates for fishing mortality (relative to older females) were consistently higher in the base model than in the alternative model. This may be either, to first order, a consequence of the value of the male scaling parameter for the fishery *or* for the survey. In the latter case, as we have already discussed, a negative (log-scale) estimate for the survey scaling parameter results in higher population biomass estimates. Because both models are constrained to closely fit the observed catch, estimates of fishing mortality from the alternative model will be smaller than those from the base model simply because the total population size is larger in the alternative model. In the case of the fishery scaling parameter, the alternative model estimated a positive (log-scale) value for that parameter, indicating that more (male) fish would be caught in the alternative model for the same value of fishing mortality as were caught in the base model (for the same population size). Because both models were constrained to fit the observed catch history, this could be achieved in the alternative model at lower fishing mortality than in the base model, since population sizes were similar. The results we obtained from the alternative model probably represent contributions from both these factors.

Likelihood profiles for the fishery and survey selectivity parameters were calculated for both model cases and profiles for individual selectivity parameters were visually compared (Fig. 8.9). In general, the profiles for individual parameters overlap to some extent between the two cases. The widths (i.e., standard deviations) of the profiles tend to be slightly larger for the alternative case, compared with the base case. It is clear from the profiles for the scaling parameters, though, that the estimated parameters are significantly different from 0, indicating that male and female asymptotic selectivities are not identical (as assumed in the base model). In addition, the overall fit to the data is about 10 likelihood units better in the alternative model than the base model (Table 8.13). While the base model fits survey biomass slightly better than the alternative model (~0.5 units), the alternative model fits the fishery size compositions (~3.5 units), the survey size compositions (~0.9 units), and the survey age compositions

(~5.1 units) better than base model. As such, we have selected the alternative model as the preferred model to use for population projection, evaluation of harvest alternatives and status determination, and reference value calculation. However, we also provide a complementary summary table with reference values calculated using the base model at the end of the text portion of the chapter.

Final parameter estimates

The parameter estimates, based on the preferred alternative model, considered final for this assessment are given in Table 8.14 for all model parameters.

Schedules implied by parameter estimates

The estimated relative scaling parameter for male selectivity was significantly different from 0 for both the fishery and the survey (Figure 8.7). Asymptotic male selectivity was 21% smaller than female selectivity for the survey, while it was 17% larger for the fishery. 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 13.0 for females and 13.5 for males. For the survey, the ages at 95% selection were younger: 10.8 for females and 8.2 for males.

Results

As expected, the accepted model (the alternative model) estimates of fishery catch closely matched the observed values (Table 8.15 and Figure 8.10). The model did not fit the fishery size compositions nearly as well, although its performance appeared to be reasonably good in most years (Figures 8.11 and 8.12 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 8.11). 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 did not fit observed survey biomass values as closely as it did the catch (Table 8.15 and Figure 8.13), but model estimates of survey biomass fell outside the 95% confidence intervals of the actual surveys for only two out of eleven survey years (1984 and 2001) so the fit was 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 8.14 and 8.15). Finally, the model also fit the survey age compositions reasonably well (Figures 8.16 and 8.17).

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 246,000 t in 1984 to 299,000 t in 1996 and 1997, then declined to a low of 293,000 t in 2000 and subsequently rose steadily in recent years to achieve their highest level in 2009 at 372,000 t (Table 8.16 and Figure 8.18). The estimated age 3+ biomass in this assessment is higher than that estimated in both the 2005 and 2007 assessments (Table 8.16, Figure 8.18). The estimated female spawning biomass is quite similar to that from the 2007 and 2005 assessments, but is slightly higher (4%, on average).

Model estimates of annual recruitment (age 3 numbers) ranged from a low of 180,000,000 individuals in 1999 to highs of 413,000,000 in 2002 and 411,000,000 in 2006 (Table 8.17 and Figure 8.19). Prior to 2000, recruitment was generally below the long-term average (278,000,000), while it has generally been higher since 2000. In 2009, recruitment was estimated below the long-term average, but this is expected because of the structure of the recruitment likelihood. Results from the current assessment are generally similar to those estimated in the 2007 assessment (Table 8.17, Figure 8.19). The only dramatic change has been to revise the 2004 recruitment (2001 year class) from 167,000,000 individuals to 382,000,000. This is a result of the more complete entrance into the survey by this year class in the current survey.

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 8.20).

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 1981-2007 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 49,899 t. The 2009 spawning stock biomass is estimated at 120,000 t. Since reliable estimates of the 2009 spawning biomass (B), $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and B>$B_{40\%}$ (120,000 t > 49,899 t), the flathead sole reference fishing mortality is defined in Tier 3a.

For this tier, F_{ABC} is constrained to be ≤ $F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. The values of these quantities are:

estimated 2009 SSB	=	120,070 t
$B_{40\%}$	=	49,899 t
$F_{40\%}$	=	0.371
F_{ABC}	≤	0.371
$B_{35\%}$	=	43,661 t
$F_{35\%}$	=	0.481
F_{OFL}	=	0.481

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 2010 recommended ABC associated with F_{ABC} of 0.371, is 52,721 t. The fishing mortality associated with overfishing (F_{OFL}) is 0.481. The corresponding OFL for 2010 is 65,567 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 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 2010 recommended in the assessment to the *max* F_{ABC} for 2010. (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.)

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, spawning stock biomass and fishing mortality for the five scenarios are shown in Tables 8.18-20.

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 2010, 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.)

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 2010 of scenario 6 is 124,674 t, almost 3 times $B_{35\%}$ (43,661 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 2022 of scenario 7 (45,825 t) is greater than $B_{35\%}$; thus, the stock is not approaching an overfished condition.

Estimating an ABC and OFL for 2011 is somewhat problematic as these values depend on the catch that will be taken in 2010. 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). The year end 2009 catch was predicted to be 3,398 t, almost as much as in 2008 (3,419 t; the largest catch in the time series). Thus, we assumed that a reasonable estimate of the catch to be taken in 2010 was the same as that taken in 2008. Using these values and the estimated population size at the start of 2009 from the model, we projected the stock ahead through 2009-2010 and calculated the ABC and OFL for 2011. The estimated ABC for 2011 is 54,865 t while the estimated OFL is 68,206. Total biomass for 2011 is estimated at 367,217 t, while female spawning biomass is estimated at 128,585.

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 2010 and 2011 ABC's. The area-specific allocations for 2010 and 2011 are:

	Western Gulf	Central Gulf	West Yakutat	Southeast Outside	Grand Total
apportionment	35.5%	57.2%	4.2%	3.1%	100.0%
2010 ABC (t)	18,741	30,155	2,212	1,613	52,721
2011 ABC (t)	19,503	31,381	2,302	1,678	54,865

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., 2007), flathead sole in the Gulf of Alaska occupy an intermediate trophic level as both juvenile and adults (Fig. 8.21). 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. 8.22a), while euphausids and mysids constituted the most important prey items for juvenile flathead sole (Fig. 8.22b).. 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. 8.23). 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 8.21). In 2009 thus far, the overall prohibited species catch (PSC) for halibut was almost 52,000 kg halibut—a decrease from the 2008 catch of almost 92,000 kg but larger than the 2007 and 2006 catches (approximately 27,000 and 37,000 kg, respectively). The PSC for crab in the directed fishery is mainly Bairdi tanner crab, with catches sometimes fluctuating by factors of 3-4 between years. The PSC for crab thus far in the 2009 directed fishery was approximately 7,000 Bairdi tanner crab, similar to that caught in 2008. The PSC for salmon in the directed fishery is mainly Chinook, with 118 individuals caught in 2009. No individuals were caught in the two previous years.

Over the past four years, the flathead sole-directed fishery caught more arrowtooth flounder than any other non-prohibited species, including flathead sole (Table 8.22). Flathead sole was the second most-caught species in the directed fishery. Only small amounts of arrowtooth were retained (typically 10%), while generally more than 90% of flathead sole was retained. Pacific cod was the third most-caught species, with retention rates typically greater than 90%.

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

Data gaps and research priorities

The AFSC's Age and Growth Program has made substantial progress in processing survey age data for flathead sole in the Gulf of Alaska. While this information has been incorporated in the current stock assessment in the form of survey age compositions, age information also enters the assessment in the form of age-length conversion matrices estimated outside the assessment model. The matrices currently used in the assessment are now several years old. One of our goals for the next assessment is to use the newly-available age data to revise growth schedules for GOA flathead and reassess these age-length conversion matrices. In addition, we anticipate incorporating such estimation directly into the assessment model, rather than performing it outside the model. This approach will also allow us to incorporate ageing error into the model structure.

Although the AFSC's Age and Growth Program has made substantial progress in processing survey age data for flathead sole in the Gulf of Alaska, the amount of fishery age data is almost nonexistent. Additional age data (both survey and fishery) 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. We will also revisit the estimates used for natural mortality in the model.

Summary

Preferred model.

Tier	3a	
Reference mortality rates		
M	0.2	
$F_{35\%}$	0.481	
$F_{40\%}$	0.371	
Equilibrium female spawning biomass		
$B_{100\%}$	124,747 t	
$B_{40\%}$	49,899 t	
$B_{35\%}$	43,661 t	
Fishing rates		
F_{OFL}	0.481	
F_{ABC} (maximum permissible)	0.371	
F_{ABC} (recommended)	0.371	
Projected biomass	**2010**	**2011**
Age 3+ biomass (t)	370,332	367,217
Female spawning biomass (t)	124,674	128,585
Harvest limits	**2010**	**2011**
OFL (t)	65,567	68,206
ABC (maximum permissible;	52,721	54,865
ABC (recommended; t)	52,721	54,865

Base model.

Tier	3a	
Reference mortality rates		
M	0.2	
$F_{35\%}$	0.530	
$F_{40\%}$	0.406	
Equilibrium female spawning biomass		
$B_{100\%}$	111,884 t	
$B_{40\%}$	44,754 t	
$B_{35\%}$	39,159 t	
Fishing rates		
F_{OFL}	0.530	
F_{ABC} (maximum permissible)	0.406	
F_{ABC} (recommended)	0.406	
Projected biomass	**2010**	**2011**
Age 3+ biomass (t)	328,862	325,922
Female spawning biomass (t)	110,387	113,717
Harvest limits	**2010**	**2011**
OFL (t)	59,295	61,601
ABC (maximum permissible;	47,422	49,286
ABC (recommended; t)	47,422	49,286

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Tables

Table 8.1. Annual catch of flathead sole in the Gulf of Alaska, from 1978 to 2009. 2009 catch is through Sept. 26, 2009.

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	3,163
2008	3,419
2009	2,740

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	39,110	39,110	9,148	48,658	3,163	89
2008	44,735	44,735	11,054	55,787	3,419	90
2009	46,464	46,464	11,181	57,911	2,740	96

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

Year	Dates	Status
2005	Jan 20	open
	Aug 19	halibut bycatch status
	Sep 1	open
	Sep 4	halibut bycatch status
2006	Jan 20	open
	Feb 23	halibut bycatch status
	Feb 27	open
	Jun 10	halibut bycatch status
	Jul 1	open
	Sep 1	halibut bycatch status
	Spe 6	open
	Sep 6	halibut bycatch status
	Sep 20	open
	Spe 20	halibut bycatch status
	Sep 25	open
	Sep 25	halibut bycatch status
	Oct 1	open
	Oct 8	halibut bycatch status
2007	Jan 20	open
	Jun 4	halibut bycatch status
	Jul 1	open
	Aug 10	halibut bycatch status
	Sep 1	open
	Sep 1	halibut bycatch status
	Sep 6	open
	Sep 6	halibut bycatch status
	Sep 11	open
	Sep 11	halibut bycatch status
	Sep 21	open
	Sep 23	halibut bycatch status
	Oct 1	open
	Oct. 8	halibut bycatch status
	Oct 10	open
	Oct 15	halibut bycatch status
	Oct 22	open
2008	Jan 20	open
	Jan 23	A80 vessels subject to sideboard limits: halibut bycatch status
	Jan 29	A80 vessels subject to sideboard limits: open
	Mar 10	halibut bycatch status
	Mar 21	open
	May 21	halibut bycatch status
	Jul 1	open
	Aug 7	halibut bycatch status
	Sep 1	open
	Sep 3	halibut bycatch status
	Sep 10	open
	Sep 11	halibut bycatch status
	Oct 1	open
	Nov 6	halibut bycatch status
	Nov 16	open
2009	Jan 20	open
	Sep 2	halibut bycatch status
	Oct 1	open

Table 8.3a. Annual fishery length compositions for female flathead sole. The 2009 composition is based on observer reports through Sept. 26. Fishery length compositions are normalized to 1 over both sexes.

	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	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0100	0.0558	0.0657	0.0817	0.1135	0.0837	0.0478	0.0219	0.0060	0.0020	0.0000
1986	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0129	0.0065	0.0774	0.0839	0.0903	0.0645	0.0581	0.0194	0.0129	0.0129	0.0000	0.0000
1987	0.0000	0.0000	0.0000	0.0058	0.0000	0.0058	0.0116	0.0465	0.1047	0.1395	0.2558	0.0698	0.0349	0.0000	0.0000	0.0000	0.0000	0.0000
1988	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.0032	0.0053	0.0069	0.0354	0.0994	0.1274	0.1332	0.1142	0.0840	0.0418	0.0143	0.0026
1989	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0256	0.0233	0.0653	0.0956	0.0979	0.0443	0.0140	0.0093	0.0023
1990	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0201	0.1409	0.0940	0.0940	0.0403	0.0470	0.0000	0.0000	0.0000
1991	0.0000	0.0000	0.0000	0.0000	0.0011	0.0027	0.0106	0.0217	0.0342	0.0422	0.0601	0.0973	0.0927	0.0589	0.0270	0.0084	0.0027	0.0015
1992	0.0000	0.0000	0.0008	0.0011	0.0049	0.0081	0.0111	0.0266	0.0356	0.0465	0.0630	0.0723	0.0603	0.0418	0.0231	0.0242	0.0155	0.0133
1993	0.0011	0.0006	0.0008	0.0011	0.0037	0.0065	0.0034	0.0056	0.0115	0.0213	0.0399	0.0590	0.0581	0.0528	0.0427	0.0371	0.0298	0.0247
1994	0.0000	0.0000	0.0005	0.0029	0.0067	0.0100	0.0257	0.0371	0.0413	0.0689	0.0660	0.0760	0.0698	0.0570	0.0299	0.0247	0.0138	0.0280
1995	0.0000	0.0000	0.0004	0.0004	0.0015	0.0015	0.0062	0.0128	0.0438	0.0601	0.0841	0.0934	0.0790	0.0353	0.0236	0.0120	0.0124	0.0294
1996	0.0000	0.0004	0.0015	0.0030	0.0045	0.0056	0.0054	0.0112	0.0244	0.0337	0.0595	0.0752	0.0802	0.0646	0.0432	0.0277	0.0192	0.0368
1997	0.0005	0.0005	0.0010	0.0017	0.0050	0.0084	0.0109	0.0226	0.0278	0.0533	0.0670	0.0875	0.0794	0.0461	0.0263	0.0174	0.0107	0.0099
1998	0.0000	0.0002	0.0004	0.0004	0.0011	0.0026	0.0046	0.0124	0.0221	0.0322	0.0575	0.0822	0.0877	0.0655	0.0373	0.0254	0.0159	0.0227
1999	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0080	0.0000	0.0240	0.0400	0.0480	0.1040	0.1360	0.0800	0.0560	0.0080	0.0400	0.0160
2000	0.0000	0.0000	0.0007	0.0014	0.0007	0.0036	0.0080	0.0174	0.0282	0.0477	0.0745	0.0788	0.0665	0.0427	0.0398	0.0188	0.0123	0.0072
2001	0.0000	0.0000	0.0000	0.0000	0.0008	0.0025	0.0016	0.0098	0.0263	0.0279	0.0443	0.0541	0.0705	0.0582	0.0533	0.0377	0.0336	0.0410
2002	0.0000	0.0008	0.0023	0.0008	0.0023	0.0039	0.0124	0.0202	0.0419	0.0489	0.0559	0.0761	0.0730	0.0621	0.0466	0.0272	0.0101	0.0163
2003	0.0004	0.0000	0.0004	0.0000	0.0000	0.0028	0.0040	0.0048	0.0132	0.0227	0.0279	0.0450	0.0630	0.0570	0.0514	0.0315	0.0211	0.0191
2004	0.0000	0.0000	0.0000	0.0007	0.0021	0.0057	0.0136	0.0107	0.0264	0.0314	0.0507	0.0600	0.0700	0.0771	0.0707	0.0457	0.0271	0.0300
2005	0.0000	0.0000	0.0000	0.0000	0.0023	0.0087	0.0110	0.0140	0.0308	0.0343	0.0483	0.0797	0.0837	0.0802	0.0500	0.0209	0.0140	0.0116
2006	0.0005	0.0005	0.0016	0.0011	0.0038	0.0055	0.0093	0.0132	0.0241	0.0346	0.0538	0.0757	0.0686	0.0669	0.0461	0.0252	0.0148	0.0115
2007	0.0000	0.0000	0.0000	0.0012	0.0043	0.0031	0.0160	0.0185	0.0314	0.0579	0.0672	0.0702	0.0598	0.0333	0.0333	0.0197	0.0222	0.0327
2008	0.0000	0.0007	0.0042	0.0023	0.0021	0.0105	0.0064	0.0168	0.0300	0.0320	0.0579	0.0915	0.0785	0.0686	0.0315	0.0242	0.0189	0.0219
2009	0.0000	0.0000	0.0005	0.0024	0.0021	0.0087	0.0117	0.0263	0.0249	0.0283	0.0549	0.0756	0.0654	0.0526	0.0483	0.0190	0.0137	0.0280

Table 8.3b. Annual fishery length compositions for male flathead sole. The 2009 composition is based on observer reports through Sept. 26. Fishery length compositions are normalized to 1 over both sexes.

	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	0.0000	0.0000	0.0000	0.0020	0.0020	0.0000	0.0139	0.0677	0.1335	0.1653	0.0916	0.0259	0.0080	0.0020	0.0000	0.0000	0.0000	0.0000
1986	0.0000	0.0000	0.0000	0.0065	0.0000	0.0000	0.0129	0.0645	0.1355	0.1548	0.0645	0.0452	0.0516	0.0258	0.0000	0.0000	0.0000	0.0000
1987	0.0000	0.0000	0.0000	0.0058	0.0000	0.0233	0.0233	0.0640	0.1047	0.0930	0.0116	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1988	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0042	0.0143	0.0560	0.0957	0.0809	0.0476	0.0233	0.0069	0.0021	0.0011	0.0000	0.0000
1989	0.0000	0.0000	0.0000	0.0000	0.0000	0.0070	0.0210	0.0932	0.0653	0.2051	0.1096	0.0373	0.0396	0.0280	0.0140	0.0023	0.0000	0.0000
1990	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0336	0.0537	0.2349	0.1678	0.0470	0.0268	0.0000	0.0000	0.0000	0.0000	0.0000
1991	0.0004	0.0004	0.0008	0.0004	0.0072	0.0125	0.0300	0.0391	0.0802	0.1513	0.1365	0.0563	0.0148	0.0061	0.0015	0.0011	0.0004	0.0000
1992	0.0005	0.0038	0.0027	0.0092	0.0144	0.0231	0.0348	0.0598	0.1049	0.1176	0.0989	0.0497	0.0201	0.0084	0.0035	0.0003	0.0000	0.0000
1993	0.0008	0.0011	0.0014	0.0031	0.0067	0.0129	0.0244	0.0385	0.0845	0.1289	0.1457	0.0935	0.0337	0.0183	0.0031	0.0011	0.0003	0.0022
1994	0.0000	0.0000	0.0000	0.0014	0.0076	0.0157	0.0219	0.0323	0.0732	0.1116	0.0893	0.0413	0.0166	0.0043	0.0067	0.0043	0.0010	0.0147
1995	0.0000	0.0000	0.0019	0.0019	0.0050	0.0097	0.0151	0.0480	0.0821	0.1069	0.1031	0.0632	0.0260	0.0163	0.0136	0.0070	0.0027	0.0015
1996	0.0004	0.0006	0.0024	0.0056	0.0065	0.0080	0.0115	0.0292	0.0659	0.1036	0.1094	0.0692	0.0456	0.0277	0.0117	0.0054	0.0004	0.0004
1997	0.0005	0.0007	0.0022	0.0050	0.0067	0.0156	0.0188	0.0419	0.0804	0.1114	0.1029	0.0779	0.0362	0.0126	0.0032	0.0015	0.0005	0.0060
1998	0.0004	0.0000	0.0013	0.0029	0.0040	0.0075	0.0159	0.0390	0.0672	0.1120	0.1149	0.0813	0.0383	0.0159	0.0139	0.0071	0.0042	0.0040
1999	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0160	0.0160	0.0560	0.0880	0.1040	0.0720	0.0320	0.0480	0.0080	0.0000	0.0000	0.0000
2000	0.0000	0.0007	0.0000	0.0036	0.0072	0.0181	0.0296	0.0557	0.0701	0.0940	0.1048	0.0745	0.0419	0.0268	0.0166	0.0043	0.0029	0.0007
2001	0.0000	0.0016	0.0008	0.0033	0.0025	0.0074	0.0107	0.0230	0.0607	0.1066	0.1025	0.0968	0.0648	0.0320	0.0098	0.0074	0.0057	0.0025
2002	0.0000	0.0016	0.0000	0.0031	0.0039	0.0062	0.0148	0.0349	0.0745	0.1017	0.1071	0.0668	0.0404	0.0264	0.0062	0.0078	0.0016	0.0023
2003	0.0000	0.0004	0.0004	0.0024	0.0076	0.0112	0.0239	0.0418	0.0737	0.0961	0.1419	0.1172	0.0697	0.0271	0.0175	0.0032	0.0008	0.0008
2004	0.0000	0.0000	0.0000	0.0014	0.0043	0.0086	0.0286	0.0328	0.0600	0.0785	0.0871	0.0749	0.0500	0.0350	0.0086	0.0071	0.0000	0.0014
2005	0.0000	0.0000	0.0006	0.0006	0.0035	0.0052	0.0163	0.0372	0.0837	0.1041	0.0971	0.0919	0.0401	0.0174	0.0035	0.0023	0.0041	0.0029
2006	0.0000	0.0000	0.0005	0.0027	0.0033	0.0082	0.0148	0.0477	0.0987	0.1240	0.1064	0.0724	0.0384	0.0176	0.0049	0.0016	0.0011	0.0005
2007	0.0000	0.0012	0.0037	0.0074	0.0117	0.0154	0.0259	0.0376	0.0733	0.0998	0.0844	0.0776	0.0462	0.0179	0.0117	0.0074	0.0055	0.0025
2008	0.0004	0.0000	0.0034	0.0025	0.0038	0.0096	0.0204	0.0396	0.0480	0.1102	0.1234	0.0899	0.0279	0.0151	0.0042	0.0015	0.0019	0.0001
2009	0.0000	0.0000	0.0026	0.0042	0.0092	0.0149	0.0304	0.0389	0.0658	0.1130	0.1223	0.0835	0.0278	0.0155	0.0087	0.0000	0.0011	0.0001

Table 8.4a. Sample sizes the domestic fishery.

year	Size compositions			
	hauls	total indiv.s	females	males
1990	3	274	65	84
1991	48	4301	1213	1418
1992	77	4958	1650	2034
1993	55	4801	1425	2140
1994	56	4089	1175	930
1995	46	2818	1280	1301
1996	174	11207	2297	2330
1997	72	4827	1926	2113
1998	128	6509	2569	2896
1999	7	130	70	55
2000	111	1464	667	796
2001	80	1446	664	757
2002	86	1326	645	643
2003	168	2592	920	1609
2004	79	1590	816	765
2005	118	1838	882	947
2006	124	1872	835	990
2007	122	1830	840	985
2008	100	1628	815	798
2009	72	1249	556	679

Table 8.4 b. Sample sizes the groundfish survey.

year	biomass	Size compositions				Age compositions			
	total hauls	hauls	total indiv.s	females	males	hauls	total indiv.s	females	males
1984	929	264	25316	13875	11291		653	369	284
1987	783	197	27298	15931	11350				
1990	708	286	24322	12939	11255	22	247	138	107
1993	775	364	26124	13592	12294	36	312	179	132
1996	807	417	21416	11086	9975	55	528	285	243
1999	764	389	16052	7941	8023	47	605	316	288
2001	489	245	11877	5962	5899				
2003	809	434	25885	13279	12479	87	499	249	250
2005	839	413	23499	12501	10907	76	551	296	243
2007	820	411	25539	13563	11860	82	755	410	345
2009	823	454	21010	10304	10360				

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. This was accounted for in the assessment model by assuming, based on previous surveys, that availability for this year was was 0.9. The maximum depth stratum included in each survey is also noted.

Year	Western Gulf	Central Gulf	West Yakutat	Southeast	Total	Std. Dev	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
2009	80,115	128,910	9,458	6,894	225,377	25,041	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.

year	Depth range (m)				
	1-100	101-200	201-300	301-500	>500
1984	118,974	121,791	8,571	5	0
1987	91,482	75,475	10,553	36	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
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
2007	139,806	130,661	9,823	0	0
2009	138,824	80,395	6,157	0	0

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

a) Females.

year	Length bin cutpoints (cm)													
	14	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**40**
1984	567	3,098	3,337	7,306	14,170	20,489	29,800	45,645	63,475	76,302	69,592	48,288	28,087	17,406
1987	883	2,085	2,838	4,499	6,056	12,189	17,593	25,161	36,188	50,279	54,302	45,327	26,573	14,468
1990	1,269	3,347	6,036	6,002	9,283	15,446	19,887	24,583	37,464	46,874	55,347	60,532	52,045	30,967
1993	2,584	5,010	7,744	12,730	13,216	15,423	20,372	21,820	25,208	31,170	41,270	43,396	36,634	23,356
1996	3,360	6,318	10,043	14,294	16,104	19,497	21,345	25,059	29,741	34,375	37,894	40,168	33,867	23,395
1999	2,895	2,940	5,795	8,718	10,041	16,134	18,845	21,287	25,158	28,741	31,886	35,669	31,739	27,829
2001	2,777	4,699	5,728	8,070	9,822	7,348	9,242	12,441	17,973	20,460	29,033	26,925	24,106	18,520
2003	3,066	6,647	10,771	15,271	20,514	25,006	23,932	24,520	28,685	35,373	46,891	47,205	42,591	35,524
2005	4,988	7,391	10,305	14,894	20,011	22,229	27,086	30,483	33,432	38,116	37,285	35,590	34,358	24,141
2007	2,429	6,105	10,258	20,784	19,669	18,962	23,767	25,095	35,366	40,488	50,423	51,276	44,433	33,155
2009	4,488	3,880	7,286	10,748	14,502	16,873	24,109	28,080	35,058	28,175	38,788	43,340	39,670	24,950

b) Males.

year	Length bin cutpoints (cm)													
	14	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**40**
1984	958	2,651	3,872	10,794	19,758	34,522	54,303	81,720	76,269	40,785	19,368	10,317	5,446	1,990
1987	1,257	2,623	3,876	5,448	6,445	15,112	26,507	48,973	53,591	33,389	14,119	7,290	3,550	1,731
1990	1,061	4,055	5,883	8,099	11,657	19,990	29,710	45,839	65,958	73,288	42,626	12,664	3,977	850
1993	2,205	5,315	9,757	12,897	16,987	23,213	29,095	39,372	50,735	54,631	36,488	12,636	5,513	2,599
1996	4,039	6,250	9,608	14,129	18,421	22,021	27,807	37,472	49,772	52,356	41,352	17,459	5,026	1,607
1999	2,484	4,313	7,246	11,893	17,227	21,067	30,364	42,405	59,243	60,992	49,672	24,469	7,967	1,647
2001	2,519	5,015	7,128	8,810	10,981	13,831	17,031	27,453	37,617	39,651	36,558	19,205	6,125	2,013
2003	4,634	6,574	11,065	17,329	24,994	31,230	36,233	41,029	54,997	57,972	53,126	33,017	14,061	4,857
2005	4,727	7,283	12,201	15,830	23,301	33,863	45,026	49,439	52,297	49,895	37,689	24,343	9,653	2,244
2007	4,193	6,756	13,904	23,942	25,572	25,987	33,840	43,611	53,832	57,060	48,576	34,409	14,457	5,924
2009	3,558	4,350	8,914	16,447	23,573	31,578	41,192	46,564	52,118	56,359	47,310	28,938	11,366	3,234

Table 8.8. Survey age compositions for flathead sole. Numbers are in 1000's of individuals.

a) Females.

year	Age bins																
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
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
1990	5,347	5,317	22,314	39,700	22,879	41,042	42,977	12,137	29,626	31,845	39,978	45,470	16,957	16,633	3,215	9,072	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
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
1999	6,932	13,068	23,768	20,784	21,354	37,554	32,344	30,160	22,069	19,428	20,935	9,843	11,778	7,231	6,379	7,171	1,791
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
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
2007	19,430	40,782	39,390	31,793	27,646	56,536	51,835	24,194	28,467	23,274	12,986	28,465	12,683	6,019	12,586	4,512	1,923

b) Males.

year	Age bins																
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
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
1990	7,392	11,683	29,810	33,483	28,696	36,881	38,549	35,774	13,969	12,160	26,810	24,797	17,194	4,452	0	3,360	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
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
1999	9,794	16,733	31,988	29,956	21,892	61,304	44,990	33,109	26,041	22,030	10,088	13,624	4,753	1,572	7,129	3,766	1,975
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
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
2007	22,275	40,202	42,624	50,946	38,777	53,200	51,102	11,551	9,996	12,398	8,488	20,029	5,047	8,021	7,169	4,120	0

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
3	0.154	0.396	0.348	0.094	0.008	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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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

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.

	length cutpts (cm)																
age	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46
3	0.706	0.265	0.029	0.001	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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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

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. Likelihood multiplier settings for all model cases.

Fishery		Survey			Recruitment		
catch	length compositions	biomass	length compositions	age compositions	early	ordinary	late
30	1	1	1	1	1	1	1

Table 8.12. Initial parameter values for all model cases.

$\overline{\ln R_0}$	17										
τ_t							1967-2007:	0.0000	0.0000	0.0000	0.0000
		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
$\overline{\ln F}$	0										
ε_t				1984-2007:	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	

Fishery Selectivity

	females	males
slope	0.4	0.4
A_{50}	5	5
scale par.	--	0

Survey Selectivity

	females	males
slope	0.8	0.4
A_{50}	4	4
scale par.	--	0

Table 8.13. Comparison of likelihood components for the base case and Alternative 1 models. Highlighted values are at least 0.5 log-likelihood units larger than the corresponding component from the other model.

likelihood component	Case	
	base	Alternative 1
ordinary recruitment	15.737	15.7209
"late" recruitment	0.343677	0.356455
"early" recruitment	12.4452	12.3782
fishery catch	0.0175164	0.0170343
fishery size composition	545.242	541.772
survey biomass	14.245	14.6922
survey size composition	34.0818	33.1606
survey age composition	147.314	142.214

Table 8.14. Final parameter estimates from the preferred model (Alternative 1 Model).

$\overline{\ln R_0}$	18.413415									
τ_t						1967-2009:	-1.6349	-0.8287	-0.8996	-0.9693
	-1.0271	-1.0748	-1.1125	-1.1407	-0.4489	-0.8817	-0.0217	0.3868	0.9026	0.7113
	0.1486	0.1754	0.1344	0.1698	0.1793	0.0248	0.1004	0.3508	0.0913	0.1693
	0.2070	0.4533	0.1653	0.3409	0.1858	0.2231	0.1685	-0.0546	-0.0970	0.3280
	0.6279	0.7322	0.4791	0.6547	0.6061	0.7284	0.5712	0.1738	0.0014	
$\overline{\ln F}$	-4.515926									
ε_t			1984-2009:	-0.2622	-0.9900	-1.9309	-2.0551	-0.9499	-0.6492	-0.0260
	0.1327	0.2953	0.4449	0.5319	0.3657	0.7022	0.4683	0.1314	-0.5235	-0.0146
	0.1825	0.2941	0.4177	0.4161	0.4742	0.6835	0.6802	0.7209	0.4595	
Fishery Selectivity										
	females	**males**								
slope	0.9206304	10.17185706								
A_{50}	9.761787	0								
scale par.	--	0.158825192								
Survey Selectivity										
	females	**males**								
slope	0.6389232	0.912693831								
A_{50}	6.1550805	4.997881639								
scale par.	--	-0.235182306								

Table 8.15. Estimated catch and survey biomass from the preferred model.

year	catch (t)			survey biomass (t)		
	estimated	std dev	observed	estimated	std dev	observed
1984	556	71	549	165,550	10,165	249,341
1985	331	42	320	180,350	10,260	
1986	157	20	147	191,230	10,198	
1987	162	21	151	198,900	10,050	177,546
1988	538	68	520	204,160	9,850	
1989	767	98	747	207,340	9,615	
1990	1,466	187	1,447	209,470	9,364	243,055
1991	1,733	222	1,717	210,590	9,104	
1992	2,040	261	2,034	211,600	8,850	
1993	2,358	301	2,366	212,450	8,605	188,690
1994	2,560	327	2,580	213,740	8,392	
1995	2,166	276	2,181	215,340	8,207	
1996	3,035	386	3,107	217,530	8,050	205,521
1997	2,406	306	2,446	218,500	7,908	
1998	1,733	220	1,742	219,180	7,776	
1999	916	116	900	219,370	7,655	207,590
2000	1,547	197	1,547	219,200	7,551	
2001	1,900	241	1,911	196,270	6,735	170,745
2002	2,127	270	2,145	217,860	7,485	
2003	2,392	304	2,425	219,990	7,608	257,294
2004	2,362	300	2,390	225,360	7,954	
2005	2,477	314	2,530	233,510	8,597	213,221
2006	3,045	386	3,134	243,230	9,569	
2007	3,085	391	3,163	253,140	10,883	280,290
2008	3,335	423	3,419	262,590	12,552	
2009	2,698	343	2,740	270,060	14,573	225,377

Table 8.16. Estimated age 3+ population biomass and female spawning biomass from the preferred model.

year	Age 3+ Biomass (1000's t)						Female Spawning Stock Biomass (1000's t)					
	2009 Assessment		2007 Assessment		2005 Assessment		2009 Assessment		2007 Assessment		2005 Assessment	
	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev
1984	246	15	244	13	248	13	59	4	61	4	65	4
1985	259	15	254	13	256	13	70	5	73	4	76	4
1986	267	15	262	13	263	13	81	5	83	5	85	5
1987	273	15	266	12	266	12	89	5	90	5	91	5
1988	279	15	271	12	270	12	95	6	94	5	95	5
1989	283	15	274	12	271	12	98	6	96	5	97	5
1990	285	15	275	12	271	11	100	6	97	5	97	5
1991	287	15	276	11	271	11	101	6	97	5	97	4
1992	290	15	280	11	274	11	101	5	97	4	97	4
1993	292	15	281	11	273	11	101	5	97	4	96	4
1994	295	15	282	11	272	11	101	5	97	4	95	4
1995	297	15	283	11	272	11	101	5	97	4	95	4
1996	299	15	284	11	272	11	102	5	98	4	95	4
1997	299	15	283	11	269	11	103	5	98	4	95	4
1998	297	15	279	11	265	11	103	5	99	4	95	4
1999	294	15	274	11	258	11	104	5	99	4	95	4
2000	293	15	275	11	259	11	106	5	100	4	95	4
2001	297	15	279	12	262	12	106	5	100	4	94	4
2002	305	16	288	13	269	14	106	5	99	4	93	4
2003	314	17	297	14	280	16	105	5	98	4	92	4
2004	326	19	302	16	286	18	104	6	97	4	91	4
2005	338	21	308	18	292	20	105	6	98	4	91	5
2006	352	23	320	21			107	6	100	5		
2007	365	26	322	24			110	6	103	5		
2008	371	28					115	7				
2009	372	31					120	8				

Table 8.17. Estimated age 3 recruitment from the preferred model.

Year	2009 Assessment (millions)		2007 Assessment (millions)		2005 Assessment (millions)	
	Mean	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**
1984	235	35	165	36	163	35
1985	238	32	247	43	241	42
1986	204	29	239	39	233	38
1987	220	30	180	32	175	32
1988	282	36	269	39	259	38
1989	218	31	211	34	201	33
1990	235	31	224	34	212	33
1991	244	33	238	36	222	34
1992	312	36	326	42	305	40
1993	234	30	188	33	175	31
1994	279	35	215	38	200	36
1995	239	31	272	42	253	39
1996	248	32	228	38	211	36
1997	235	32	212	39	193	36
1998	188	28	154	34	140	31
1999	180	28	133	32	121	29
2000	276	37	351	54	320	52
2001	372	44	349	57	327	57
2002	413	51	366	69	359	73
2003	321	47	337	75	352	86
2004	382	61	167	80	192	96
2005	364	66	302	114	242	105
2006	411	90	447	174		
2007	352	102	148	113		
2008	236	136				
2009	199	111				

Table 8.18. 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**
2009	3,398	3,398	3,398	3,398	3,398	3,398	3,398
2010	52,721	52,721	28,326	3,281	0	65,567	52,721
2011	42,609	42,609	26,106	3,421	0	49,204	42,609
2012	35,805	35,805	24,289	3,537	0	39,256	44,645
2013	30,981	30,981	22,684	3,615	0	32,851	36,072
2014	27,100	27,100	21,058	3,633	0	28,096	29,964
2015	23,807	23,807	19,367	3,589	0	24,159	25,377
2016	21,359	21,359	17,834	3,505	0	20,486	21,323
2017	19,818	19,818	16,704	3,421	0	19,234	19,543
2018	19,080	19,080	15,995	3,354	0	19,199	19,290
2019	18,854	18,854	15,571	3,305	0	19,448	19,459
2020	18,810	18,810	15,306	3,266	0	19,638	19,626
2021	18,804	18,804	15,133	3,235	0	19,722	19,708
2022	18,799	18,799	15,013	3,209	0	19,748	19,738

Table 8.19. Female spawning biomass (t) for the seven projection scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 49,899 t and 43,661 t, respectively.

	Female spawning biomass (t)						
year	**scenario 1**	**scenario 2**	**scenario 3**	**scenario 4**	**scenario 5**	**scenario 6**	**scenario 7**
2009	120,066	120,066	120,066	120,066	120,066	120,066	120,066
2010	124,674	124,674	124,674	124,674	124,674	124,674	124,674
2011	103,337	103,337	115,805	128,656	130,343	96,800	103,337
2012	88,143	88,143	107,918	131,249	134,538	78,865	88,143
2013	76,554	76,554	100,299	131,997	136,772	66,444	72,063
2014	67,154	67,154	92,705	130,867	136,982	57,145	60,446
2015	59,860	59,860	85,705	128,523	135,793	50,445	52,327
2016	55,020	55,020	80,127	125,929	134,144	46,522	47,485
2017	52,397	52,397	76,264	123,727	132,687	45,336	45,706
2018	51,249	51,249	73,776	122,008	131,544	45,328	45,448
2019	50,827	50,827	72,171	120,639	130,612	45,563	45,586
2020	50,669	50,669	71,084	119,439	129,727	45,730	45,723
2021	50,598	50,598	70,349	118,486	129,017	45,803	45,793
2022	50,564	50,564	69,841	117,678	128,382	45,833	45,825

Table 8.20. Fishing mortality for the seven projection scenarios.

	Fishing mortality						
year	**scenario 1**	**scenario 2**	**scenario 3**	**scenario 4**	**scenario 5**	**scenario 6**	**scenario 7**
2009	0.0218	0.0218	0.0218	0.0218	0.0218	0.0218	0.0218
2010	0.3713	0.3713	0.1857	0.0201	0.0000	0.4812	0.3713
2011	0.3713	0.3713	0.1857	0.0201	0.0000	0.4812	0.3713
2012	0.3713	0.3713	0.1857	0.0201	0.0000	0.4812	0.4812
2013	0.3713	0.3713	0.1857	0.0201	0.0000	0.4812	0.4812
2014	0.3713	0.3713	0.1857	0.0201	0.0000	0.4812	0.4812
2015	0.3713	0.3713	0.1857	0.0201	0.0000	0.4769	0.4810
2016	0.3713	0.3713	0.1857	0.0201	0.0000	0.4454	0.4539
2017	0.3681	0.3681	0.1857	0.0201	0.0000	0.4337	0.4371
2018	0.3642	0.3642	0.1857	0.0201	0.0000	0.4336	0.4346
2019	0.3628	0.3628	0.1857	0.0201	0.0000	0.4359	0.4361
2020	0.3626	0.3626	0.1857	0.0201	0.0000	0.4377	0.4376
2021	0.3627	0.3627	0.1857	0.0201	0.0000	0.4383	0.4382
2022	0.3627	0.3627	0.1857	0.0201	0.0000	0.4385	0.4384

Table 8.21. Prohibited species catch (PSC) in the flathead sole target fishery.

	Halibut	**Salmon (#'s)**			**Crab (#'s)**					
year	**(kg)**	**Chinook**	**non-Chinook**	**Total**	**Opilio Tanner**	**Bairdi Tanner**	**Red King**	**Blue King**	**Golden King**	**Total**
2003	203,807	612	19	631	174	17,330	0	0	533	18,037
2004	101,755	1,389	90	1,479	0	7,275	0	0	0	7,275
2005	52,798	16	0	16	0	32,471	0	0	0	32,471
2006	36,528	56	0	56	0	25,884	0	0	0	25,884
2007	27,029	0	0	0	0	254	0	0	0	254
2008	91,959	0	0	0	272	7,077	0	0	0	7,349
2009	51,777	118	0	118	0	7,073	0	0	0	7,073

Table 8.22. Catch of non-prohibited species in the flathead sole target fishery. The species accounting for the two largest totals are highlighted.

	2009		**2008**		**2007**		**2006**	
Species	**total (t)**	**% retained**	**total (t)**	**% retained**	**total (t)**	**% retained**	**total (t)**	**% retained**
Atka mackerel	18	99%	3	98%	36	71%	17	84%
arrowtooth flounder	779	7%	801	21%	723	10%	839	10%
Dover sole and turbot	1	100%	4	98%	1	0%	3	80%
flathead sole	367	97%	572	92%	423	90%	522	82%
northern rockfish	1	89%	0	100%	2	0%	2	0%
all sculpins, sharks, squid, octopus	6	78%	14	74%	35	0%	16	0%
pacific cod	108	94%	125	84%	131	90%	38	92%
pelagic shelf rockfish	1	82%	2	100%	2	0%	0	100%
pollock	57	94%	45	97%	27	99%	33	94%
POP	2	6%	2	2%	11	13%	4	75%
rex sole	77	86%	86	98%	110	98%	68	93%
rougheye	2	16%	0	42%	0	100%	2	14%
other rockfish complex	0	0%	2	53%	0	99%	0	99%
sablefish	8	98%	1	61%	4	100%	4	87%
shallow water flatfish	56	97%	41	98%	26	95%	29	27%
shortraker	2	97%	0	0%	0	0%	7	71%
thornyhead	5	100%	0	100%	7	100%	6	94%
unidentified skate	9	52%	5	28%	20	64%	0	0%
big skate	39	94%	66	84%	23	99%	30	64%
longnose skate	12	95%	11	81%	13	19%	11	55%

Figures

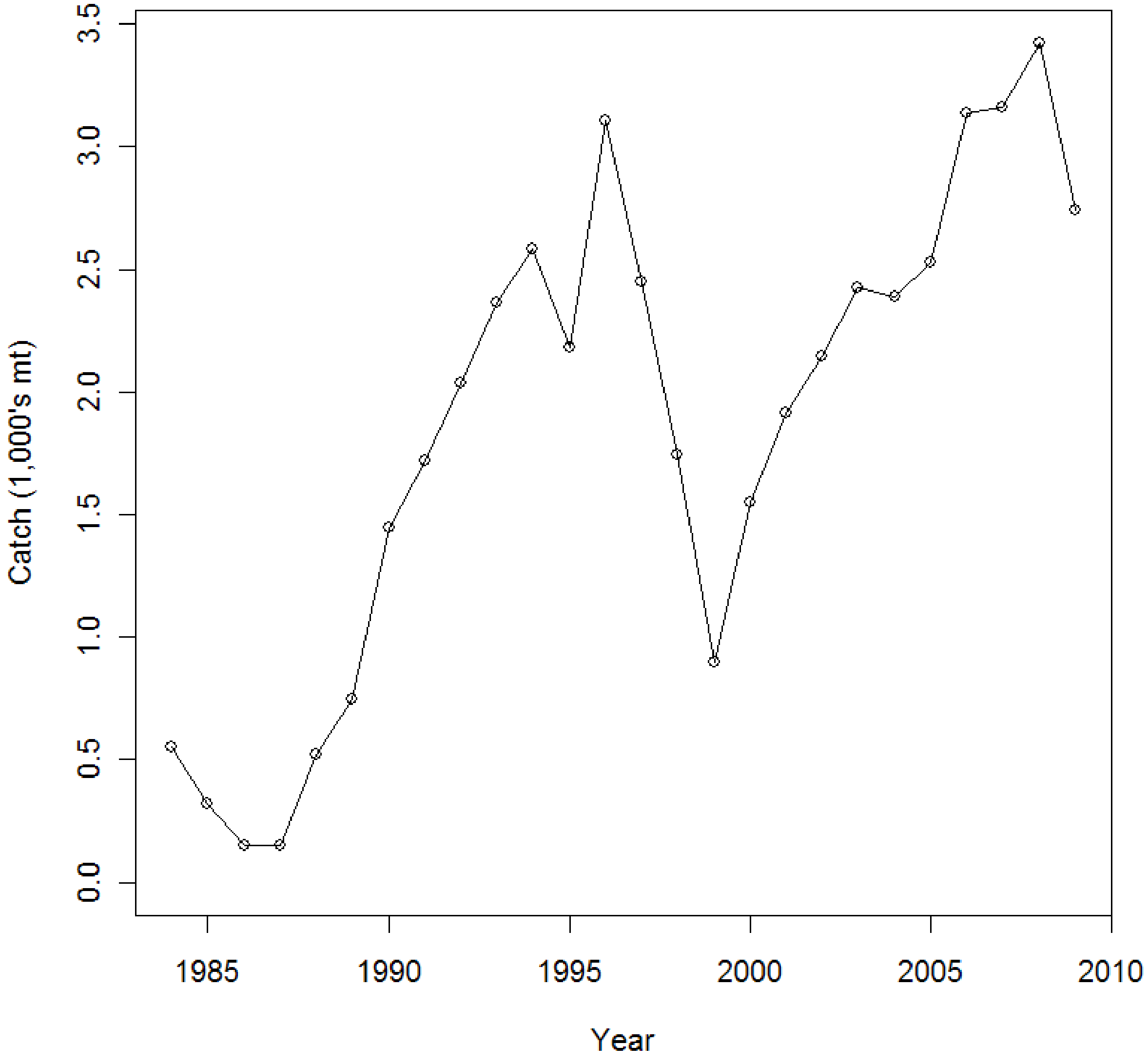


Figure 8.1. Fishery catches for GOA flathead sole, 1984-2009 (as of Sept. 26, 2009).

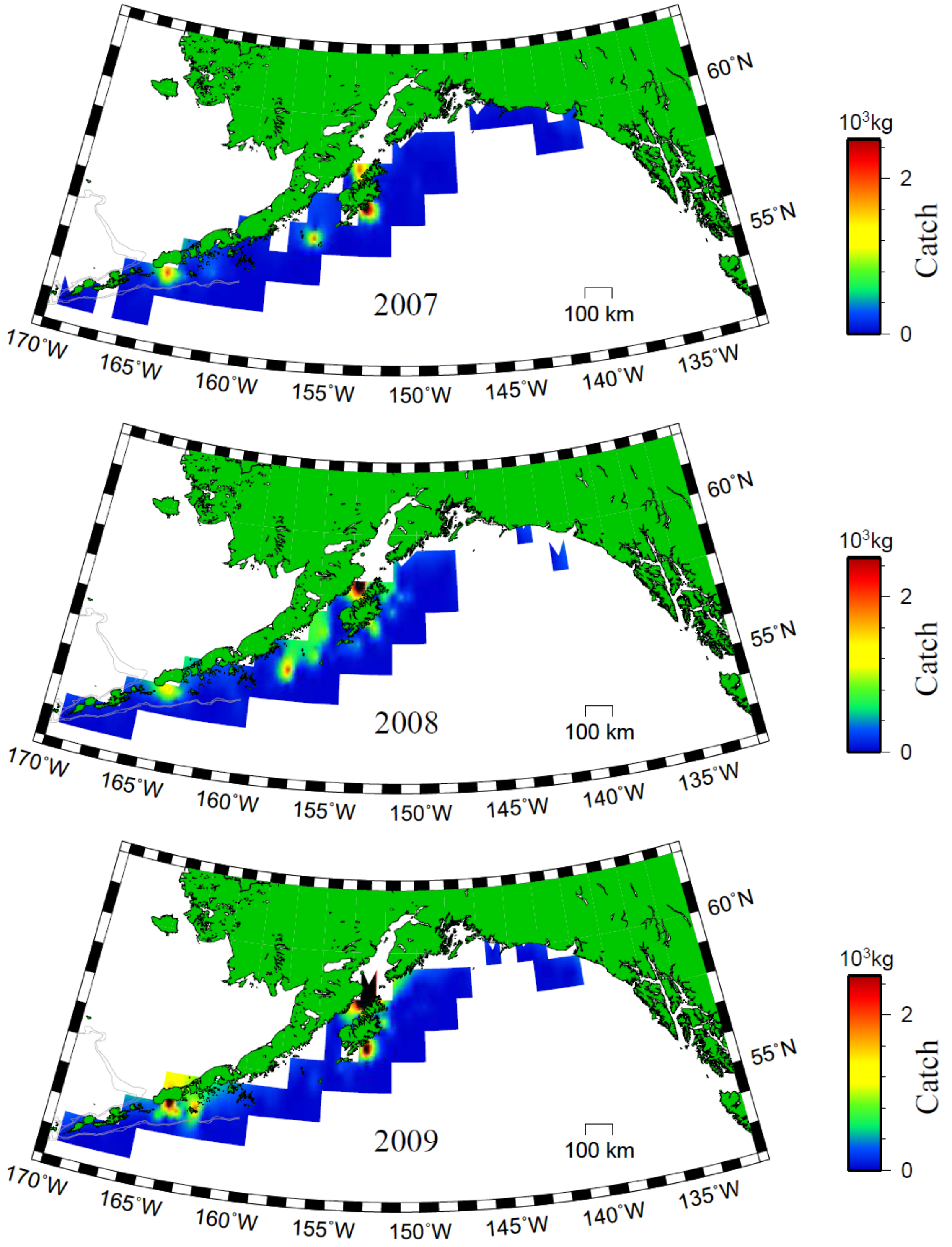


Figure 8.2. Spatial patterns of fishery catches for GOA flathead sole, 2007-2009.

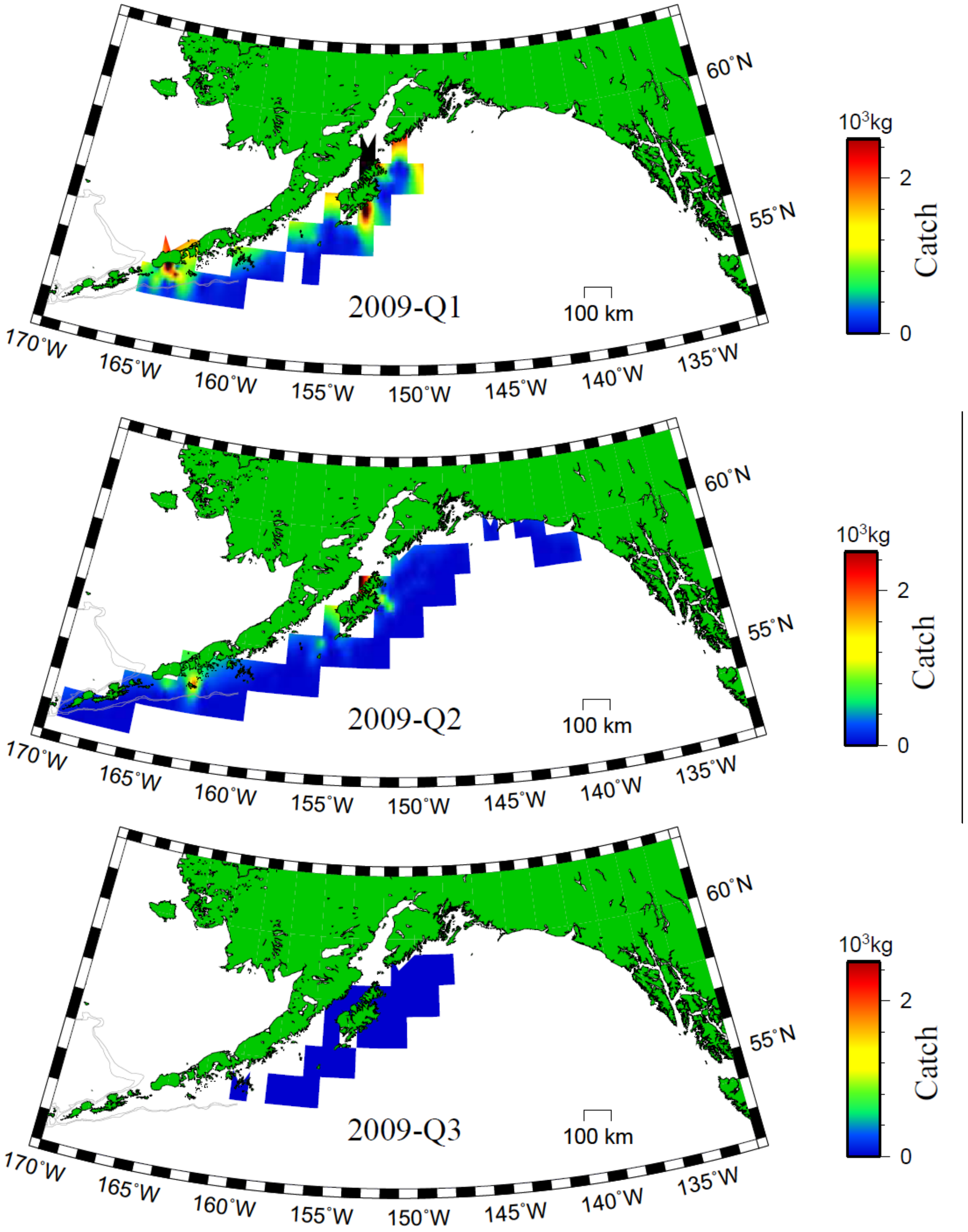


Figure 8.3. Spatial patterns of fishery catches for GOA flathead sole from the first three quarters of 2009.

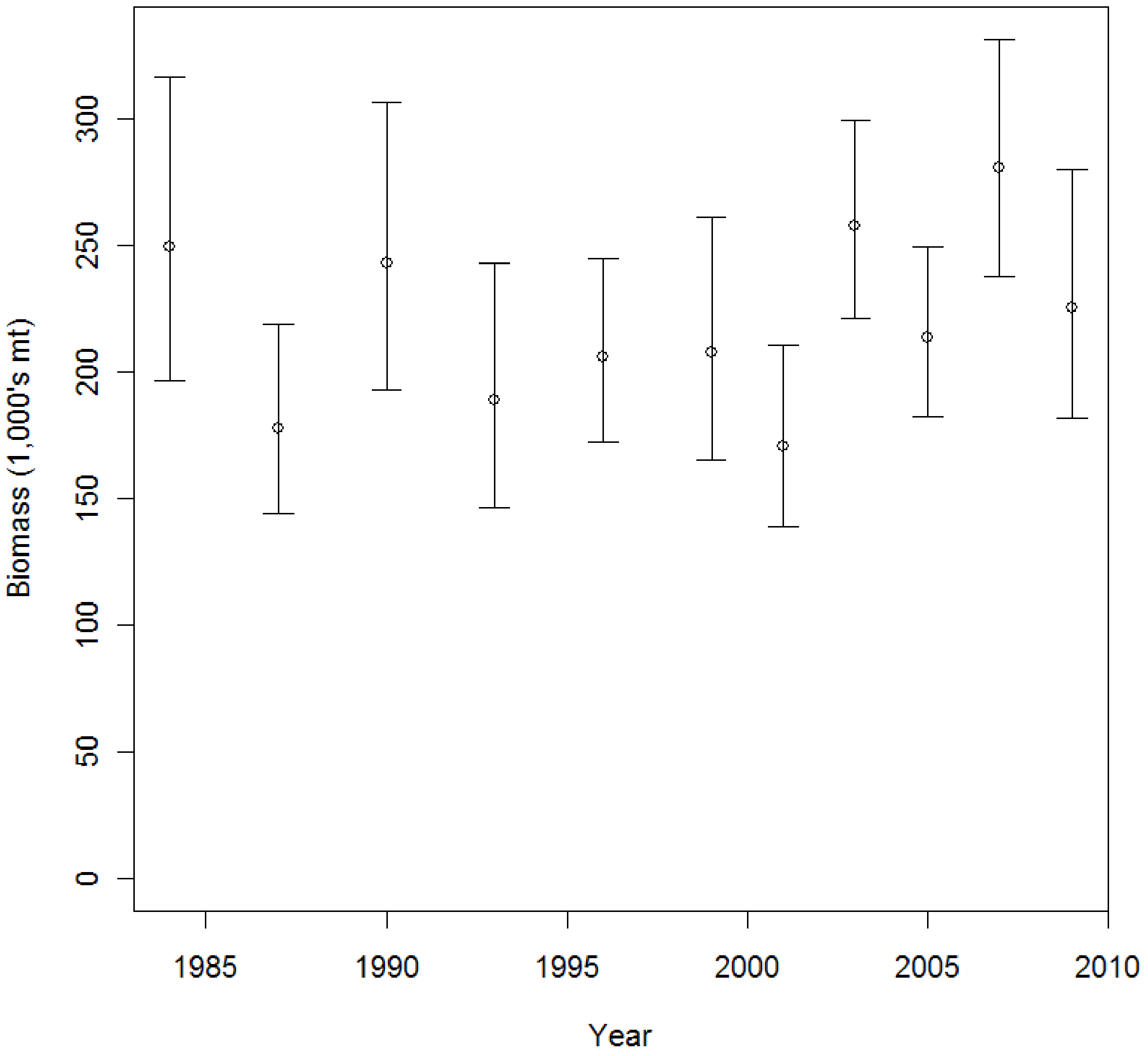


Figure 8.4. GOA survey biomass for flathead sole. Error bars represent 95% lognormal confidence intervals. The GOA survey did not include the eastern gulf in 2001. The value shown here for 2001 has been corrected to account for this (see text).

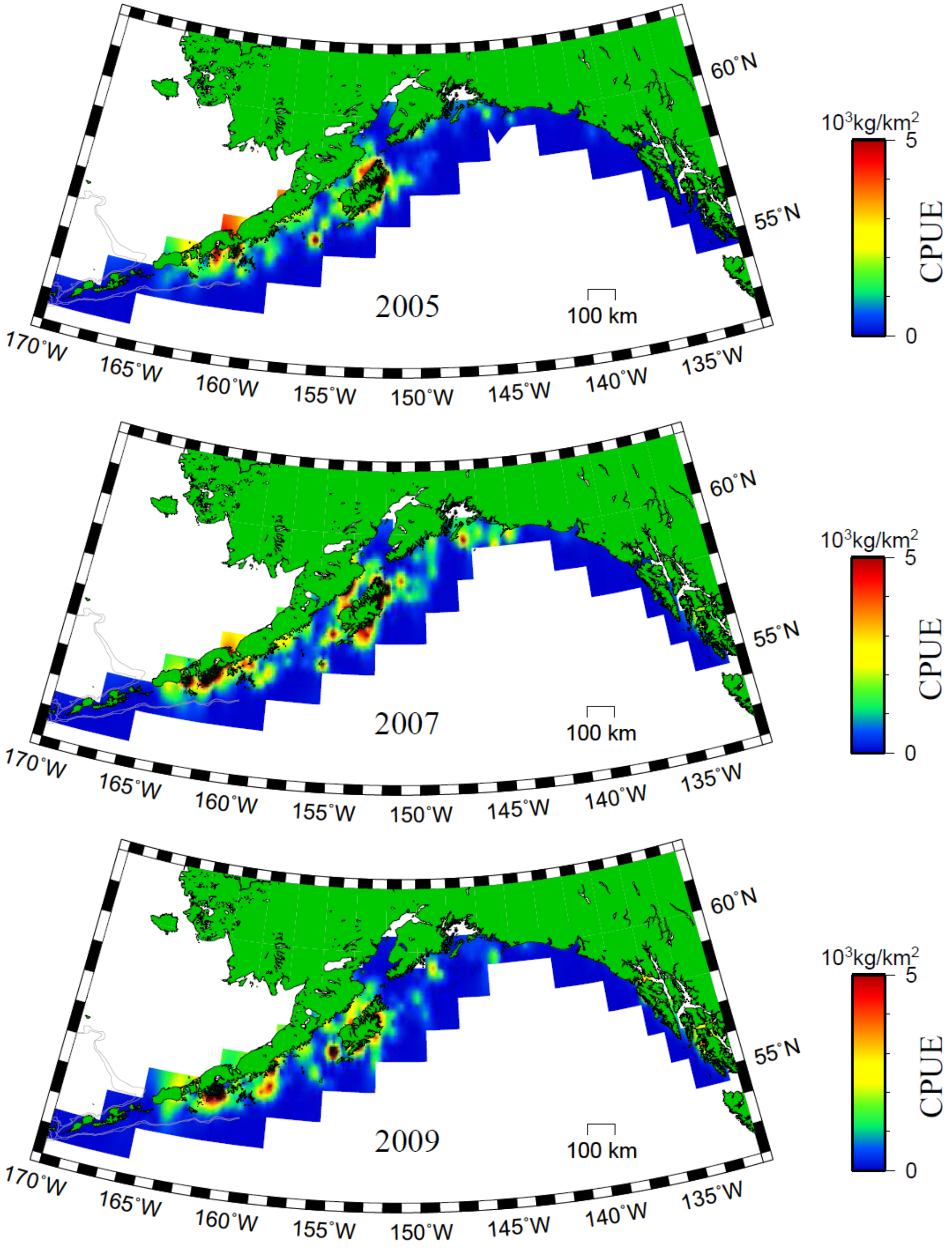
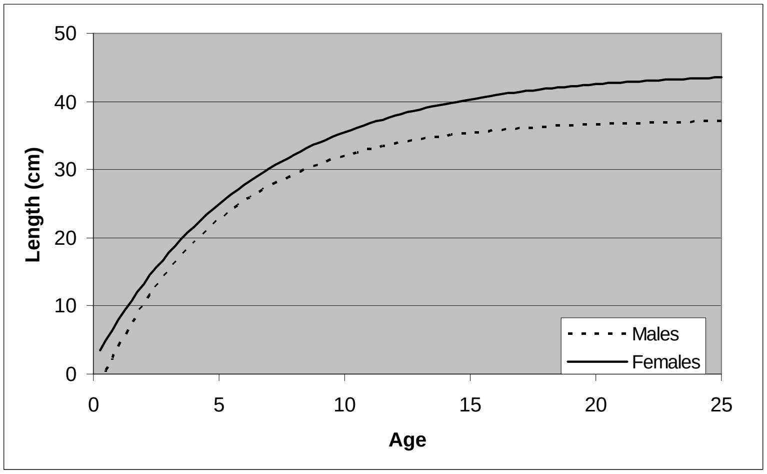
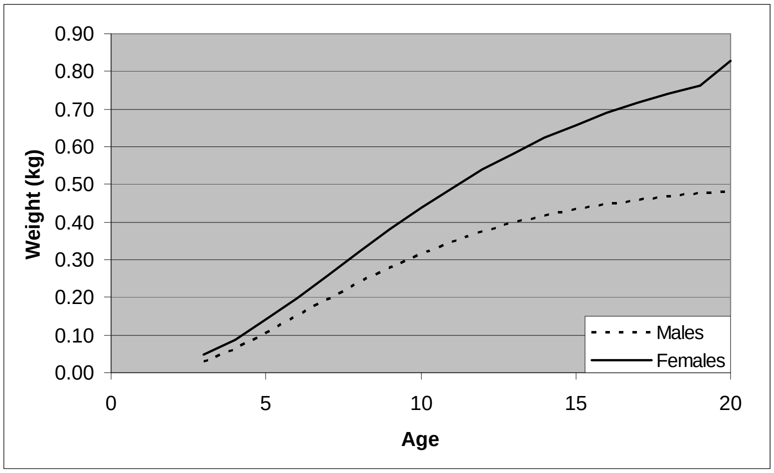


Figure 8.5. Spatial patterns of CPUE for flathead sole in the GOA groundfish surveys for 2005, 2007 and 2009.

a) Length-at-age.



b) Weight –at-age.



c) Maturity-at-age (females).

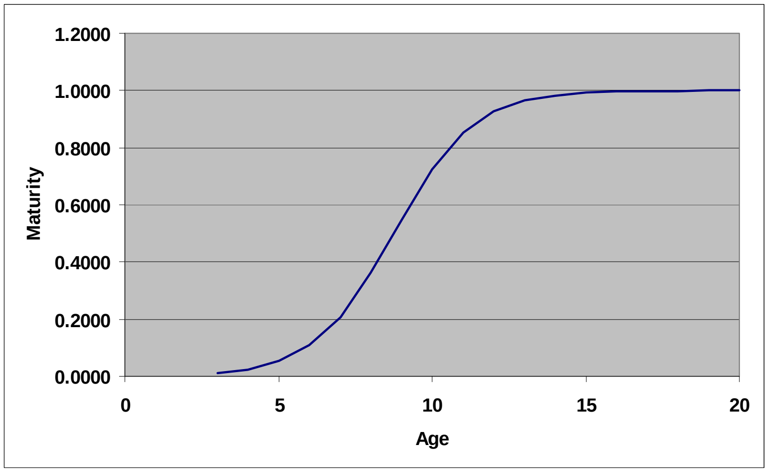


Figure 8.6. Age-specific chedules for GOA flathead sole: females solid line, males dotted line.

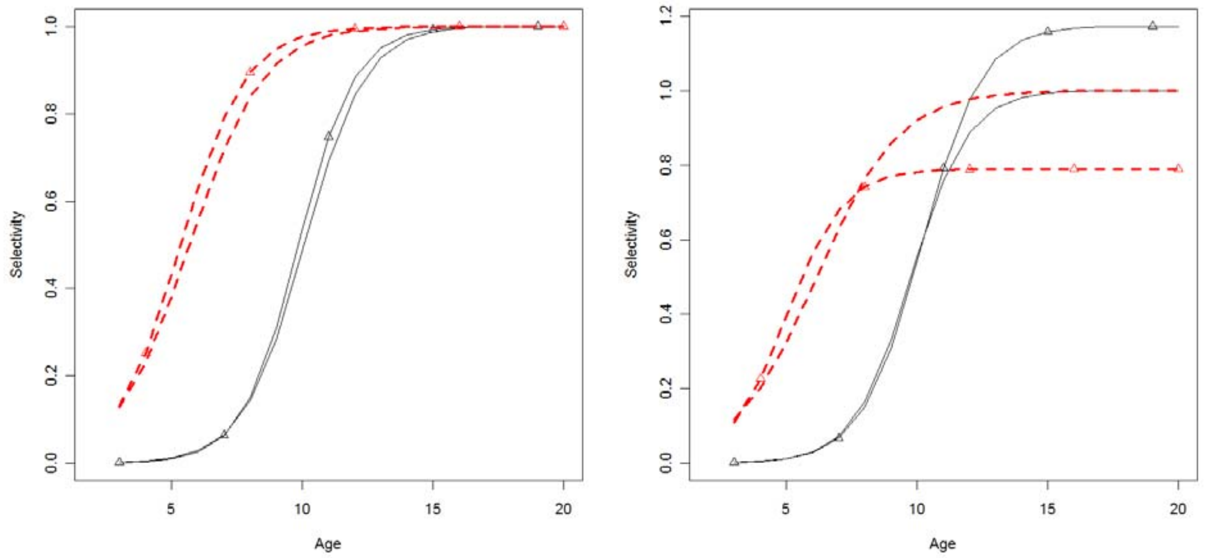


Figure 8.7. Comparison of selectivity functions from: a) the base case (left) and b) alternative 1 (right). Survey selectivities are plotted in red with a dotted line, fishery selectivities are plotted in black with asolid line. Male selectivity functions are plotted with a triangle symbol, female selectivity functions are plotted without a symbol.

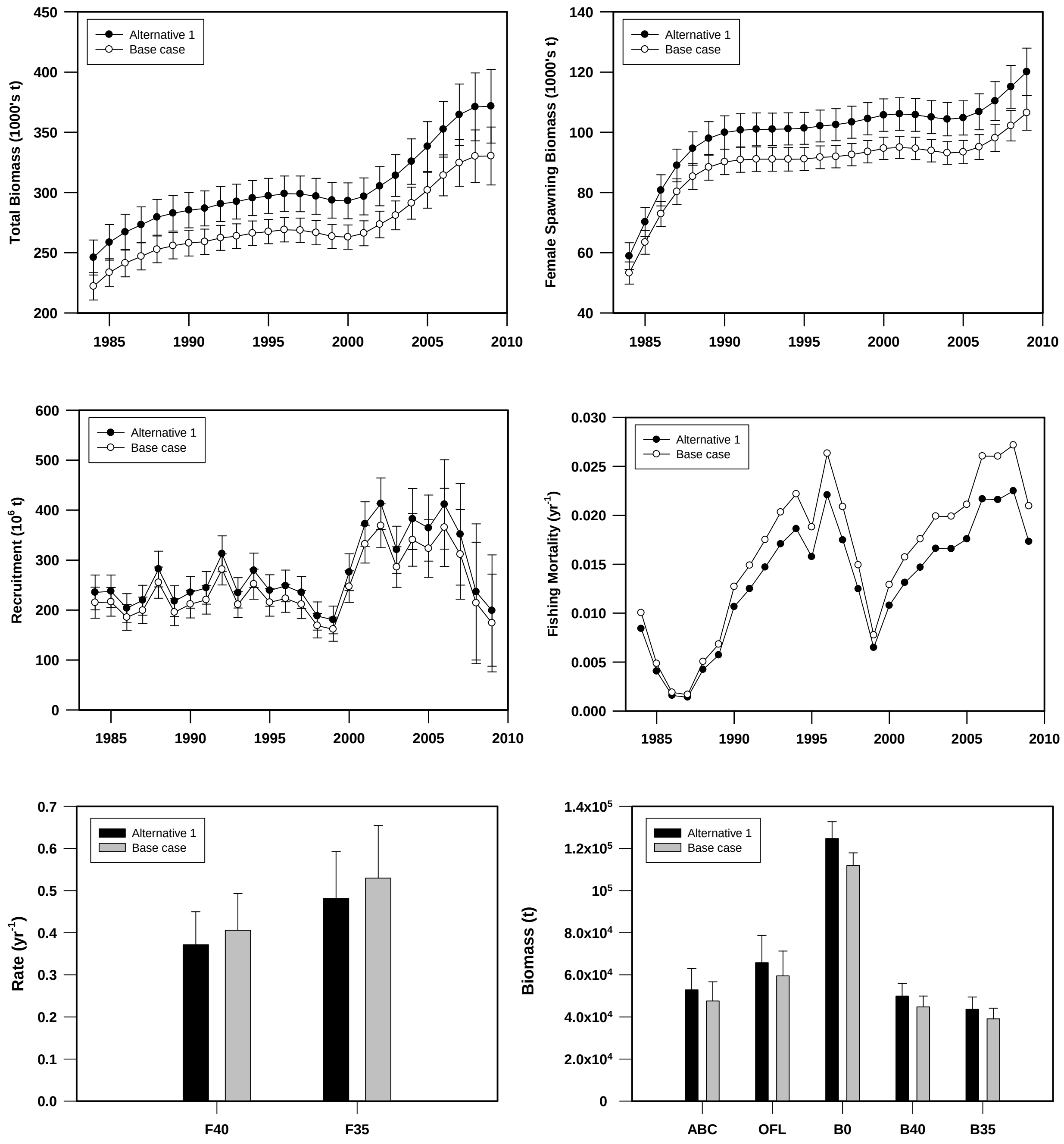


Figure 8.8. Further comparison of model results between the base case and the alternative using: a) estimated total biomass (upper left), b) estimated spawning biomass (upper right), c) recruitment (middle left), d) annual fishing mortality (middle right), e) $F_{40\%}$ and $F_{35\%}$,(lower left), and f) ABC, OFL, virgin biomass (B0), $B_{40\%}$, and $B_{35\%}$ (lower right).

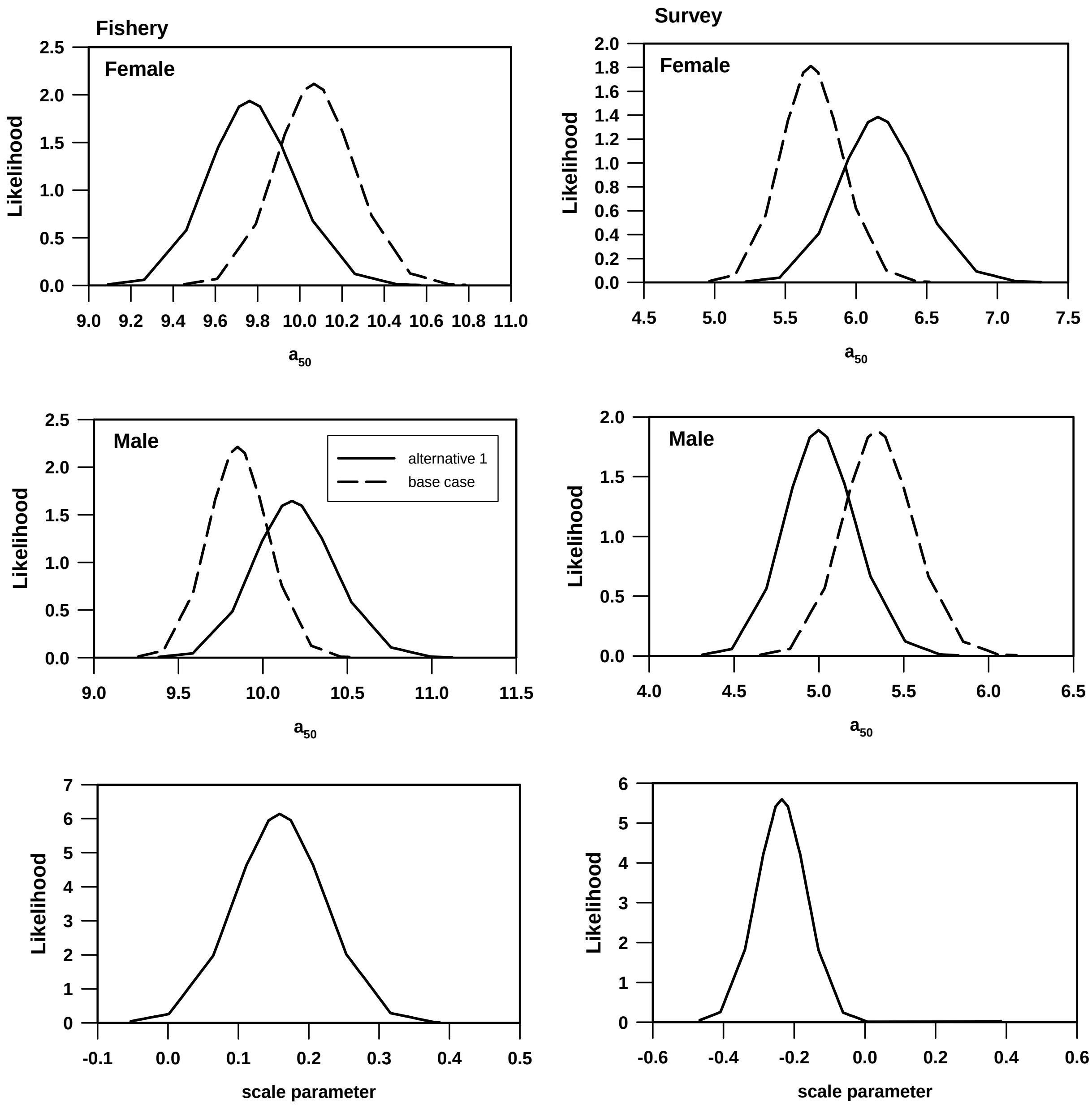


Figure 8.9. Comparison of likelihood profiles for fishery and survey selectivity-related parameters from the base case (dashed line) and the alternative case (solid line). “a50” denotes the parameter for the age at which the unscaled logistic function is 50%. “scale parameter” denotes the log-scale offset for scaling male selectivity relative to asymptotic female selectivity .

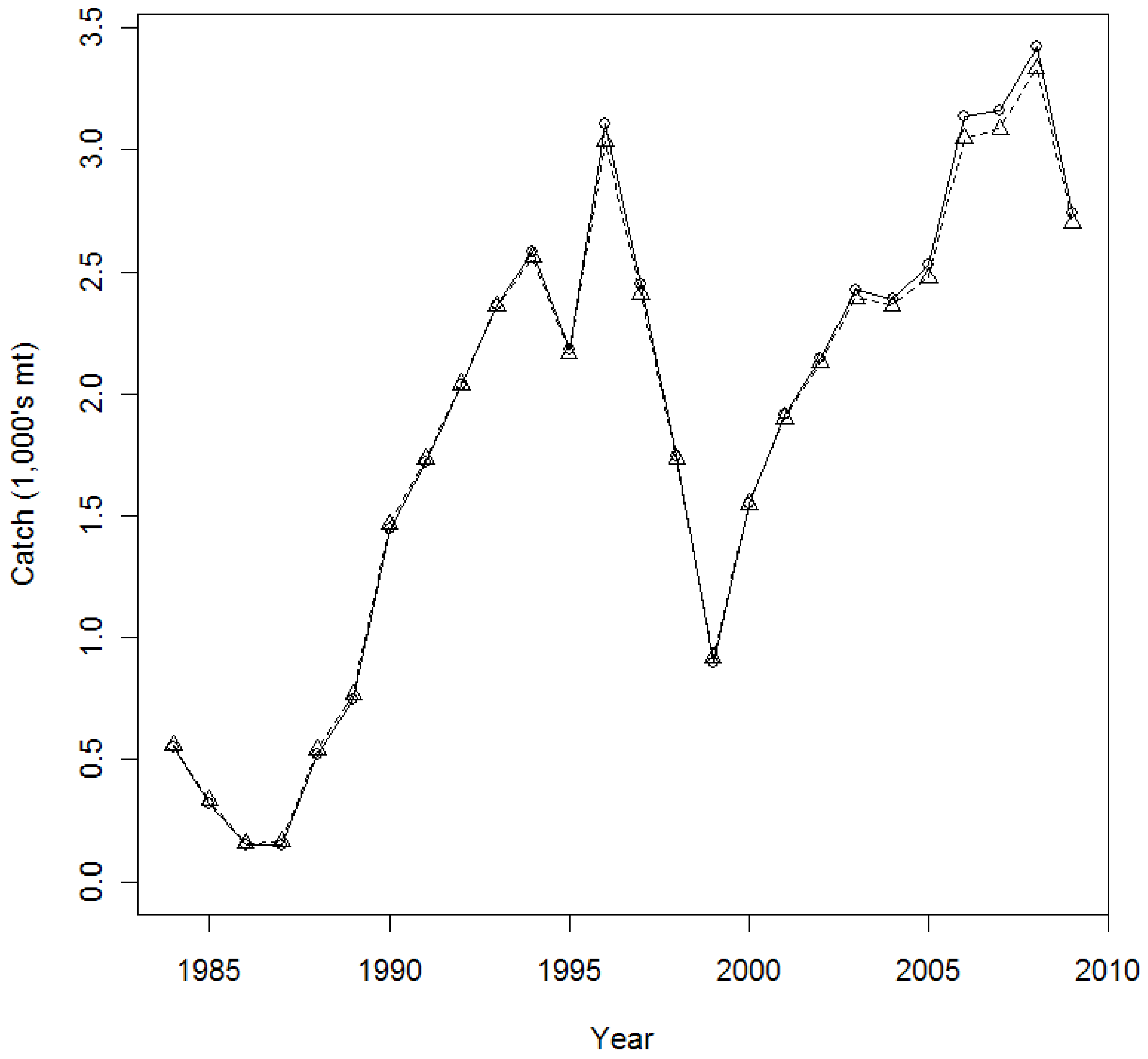


Figure 8.10. Predicted and observed annual catches for GOA flathead sole from the preferred model. Predicted catch = solid line, observed catch = dotted line with circles.

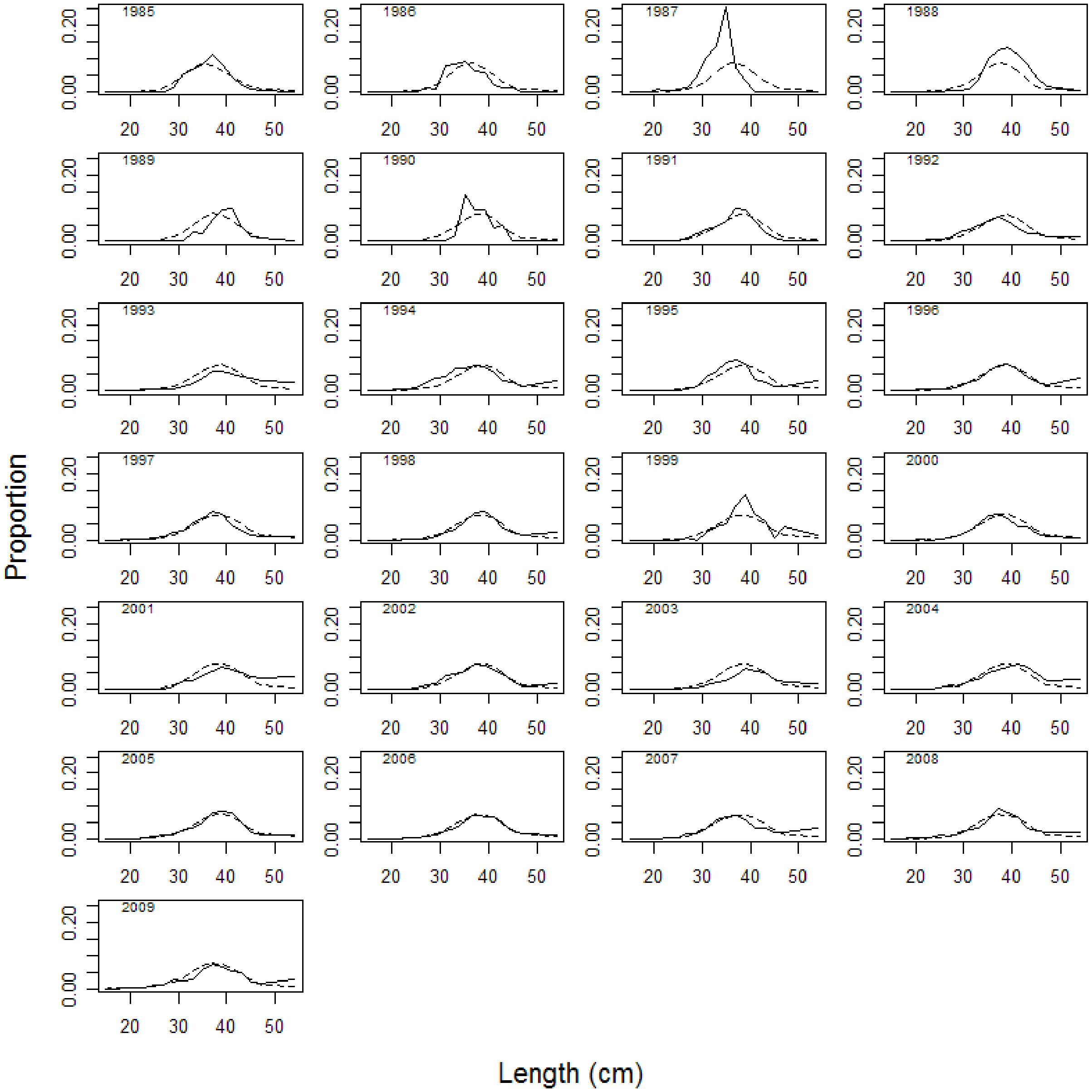


Figure 8.11. Fit to female GOA flathead sole fishery length composition data from the preferred model. Dashed lines represent the model prediction, solid lines represent the data.

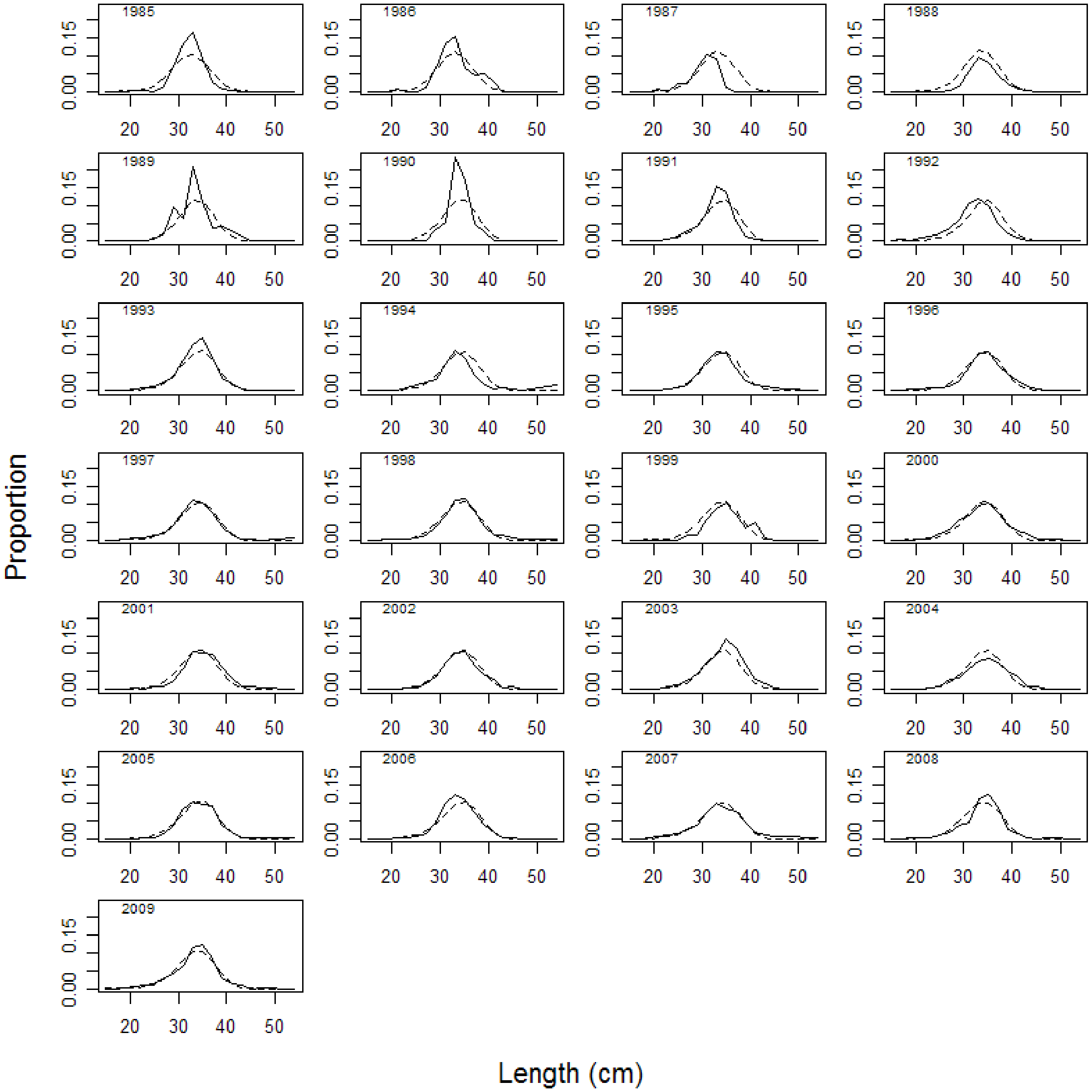


Figure 8.12. Fit to male GOA flathead sole fishery length composition data from the preferred model. Dashed lines represent the model prediction, solid lines represent the data.

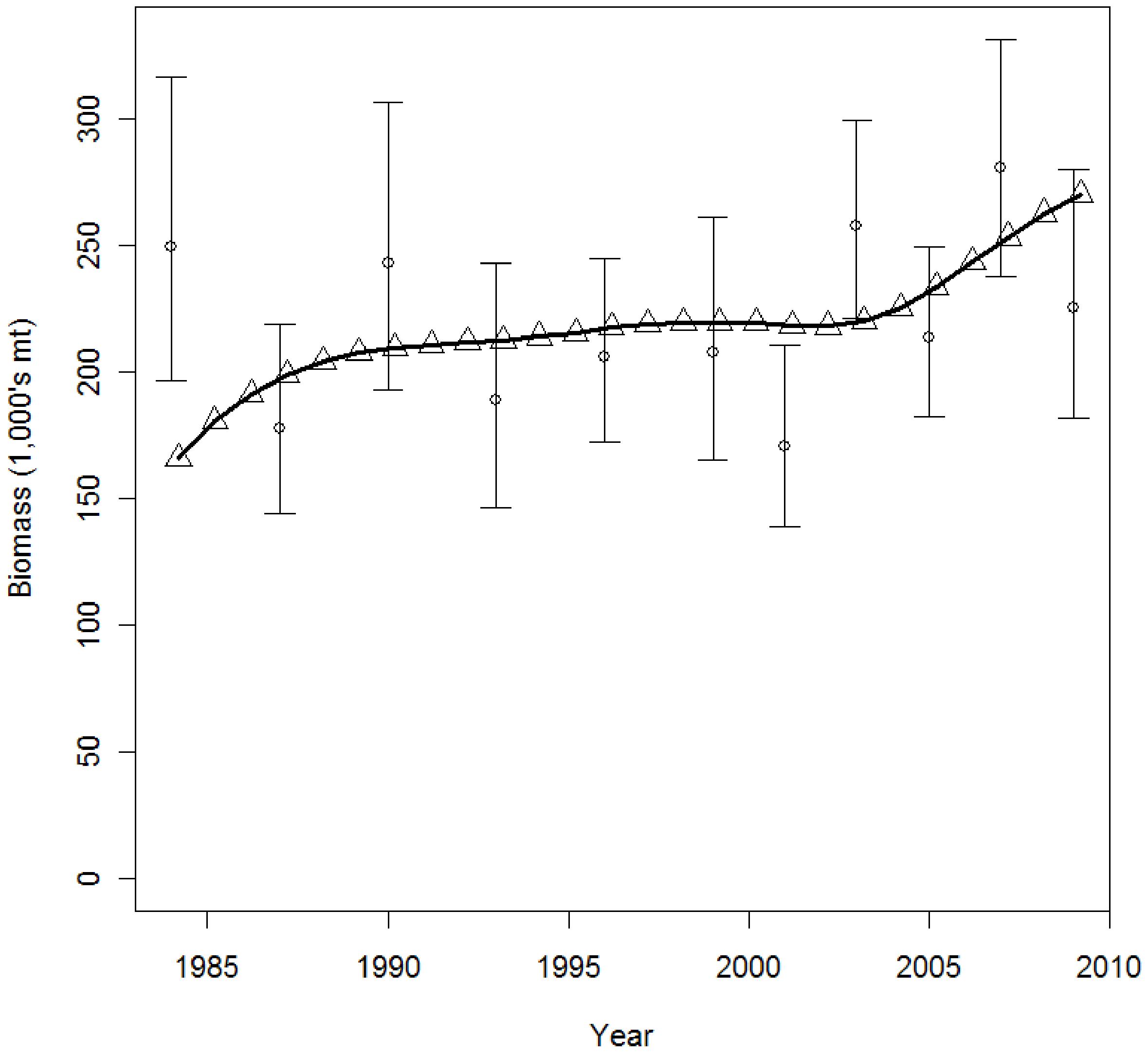


Fig. 8.13. Predicted and observed survey biomass for GOA flathead sole from the preferred model. Predicted survey biomass = triangles, observed survey biomass = circles (error bars are approximate lognormal 95% confidence intervals).

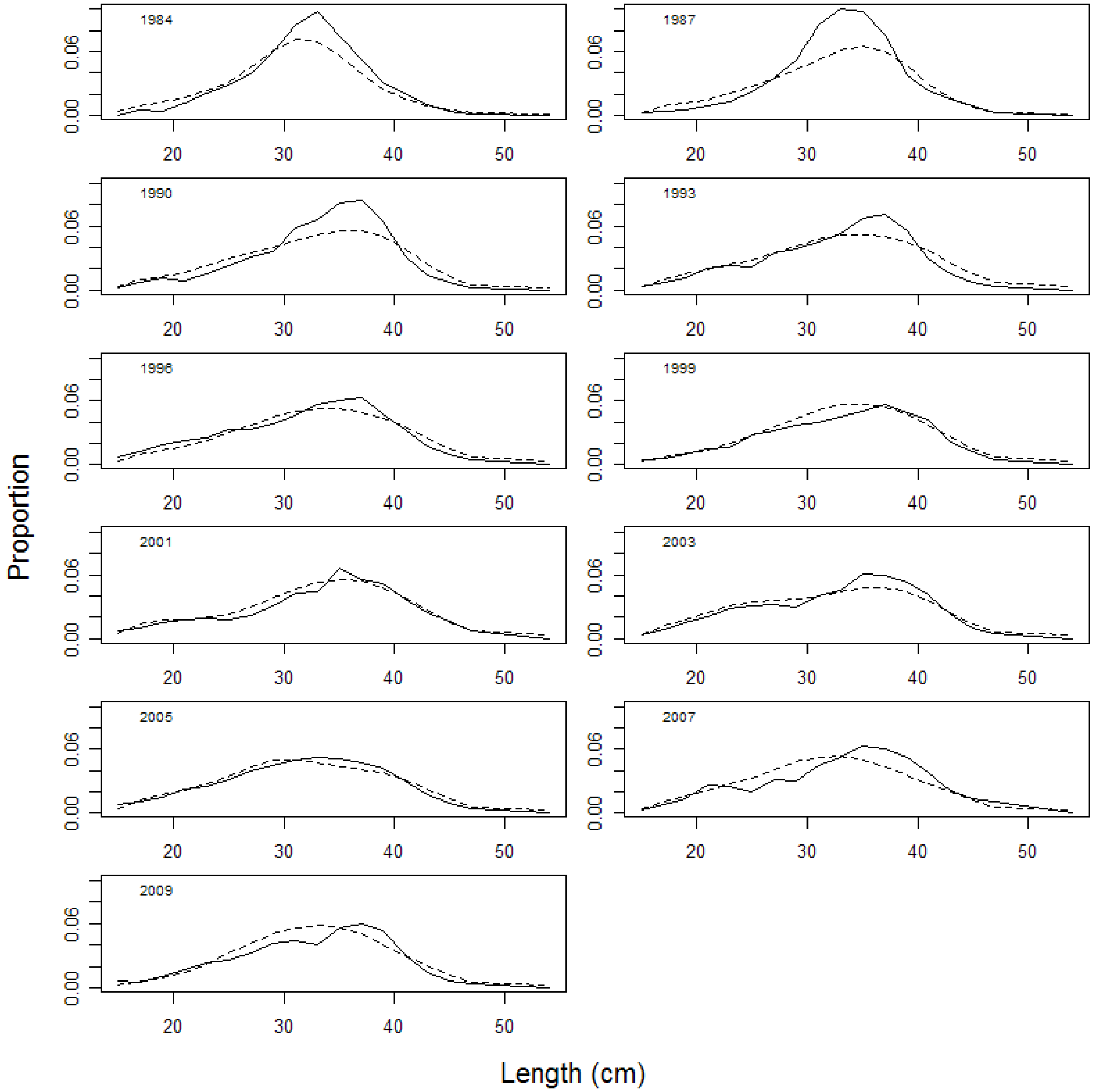


Figure 8.14. Fit to the female GOA flathead sole survey length composition data from the preferred model. Dashed lines represent the model prediction, solid lines represent the data.

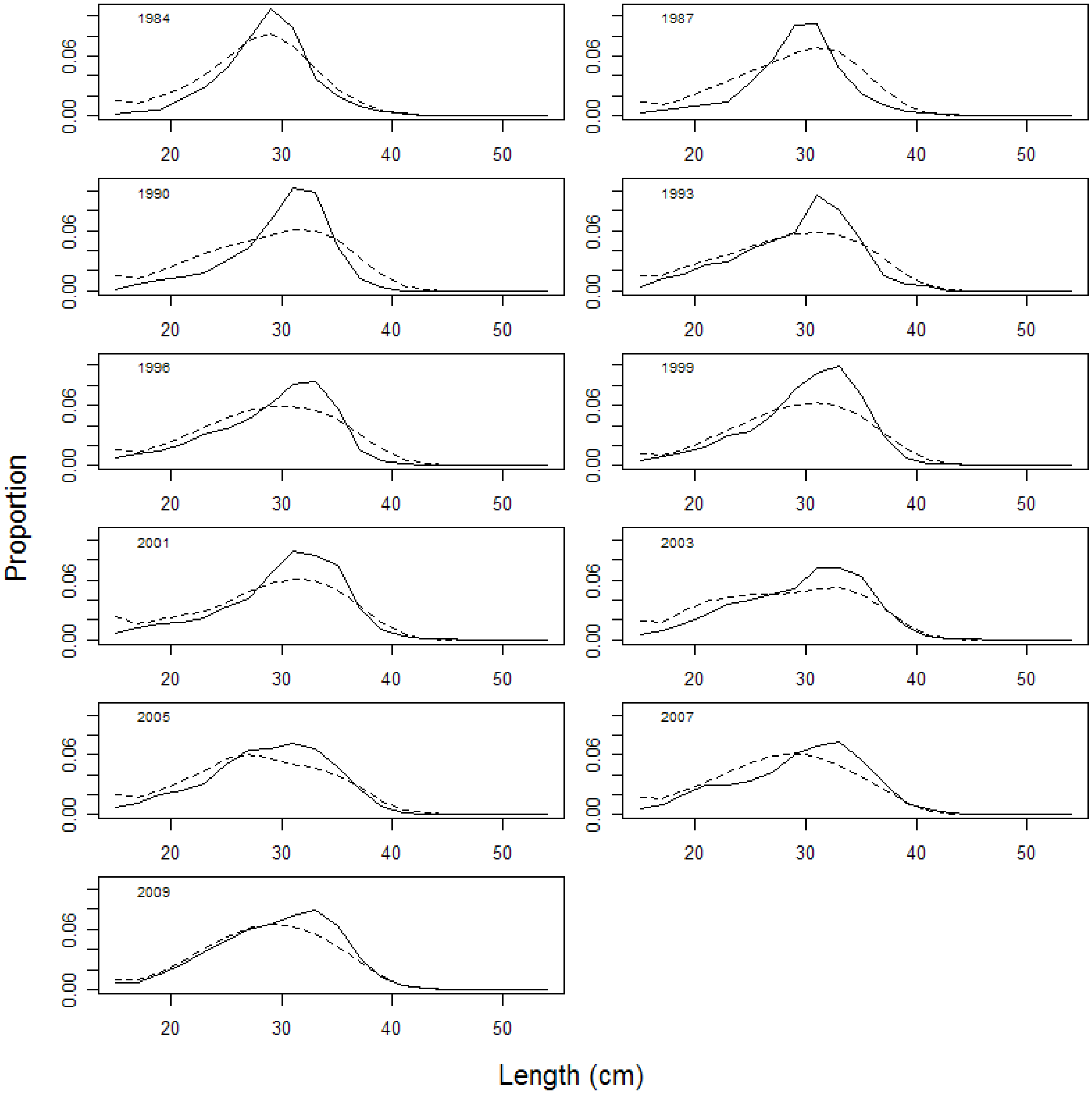


Figure 8.15. Fit to the male GOA flathead sole survey length composition data from the preferred model. Dashed lines represent the model prediction, solid lines represent the data.

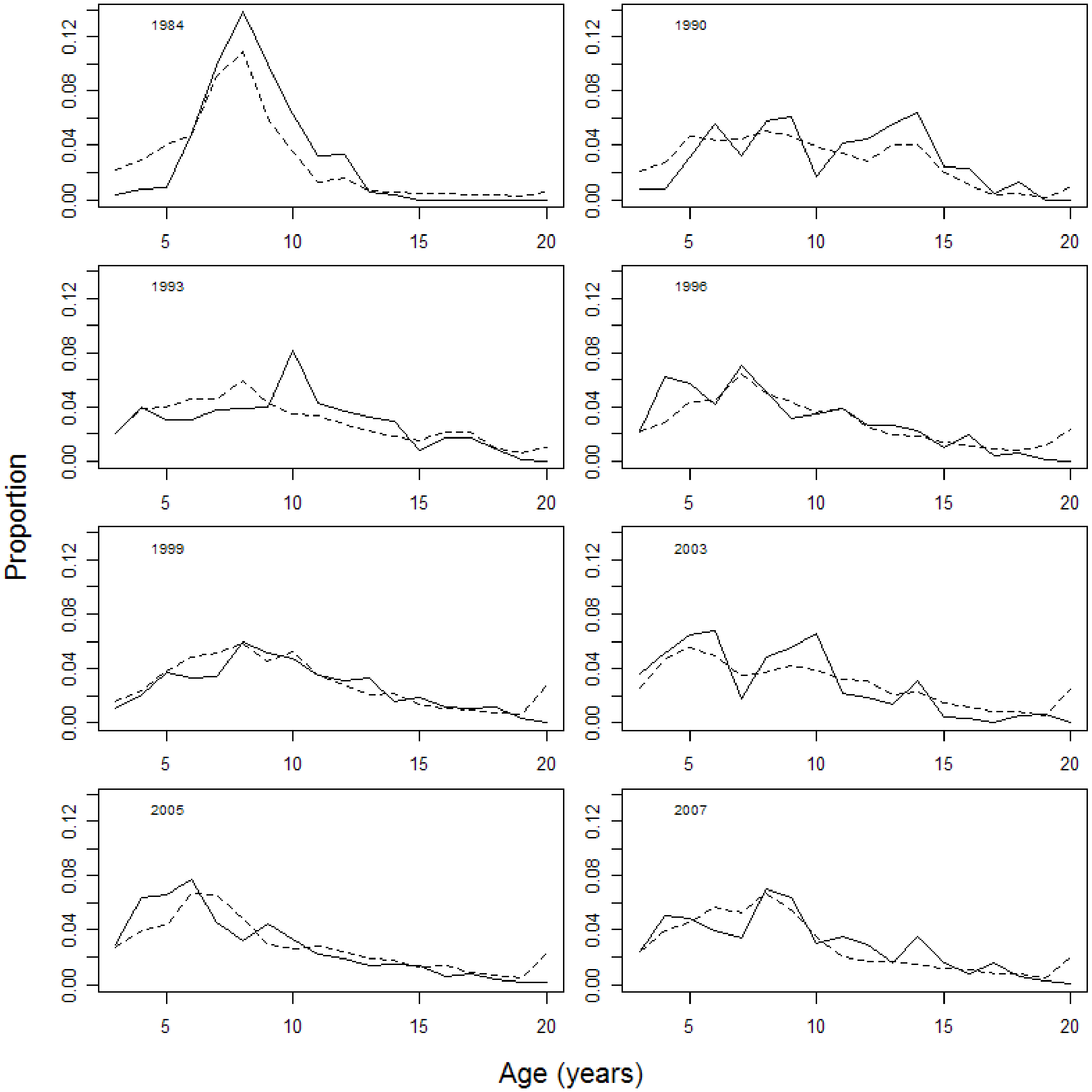


Figure 8.16. Fit to the female survey GOA flathead sole age composition data from the preferred model. Dashed lines represent the model prediction, solid lines represent the data.

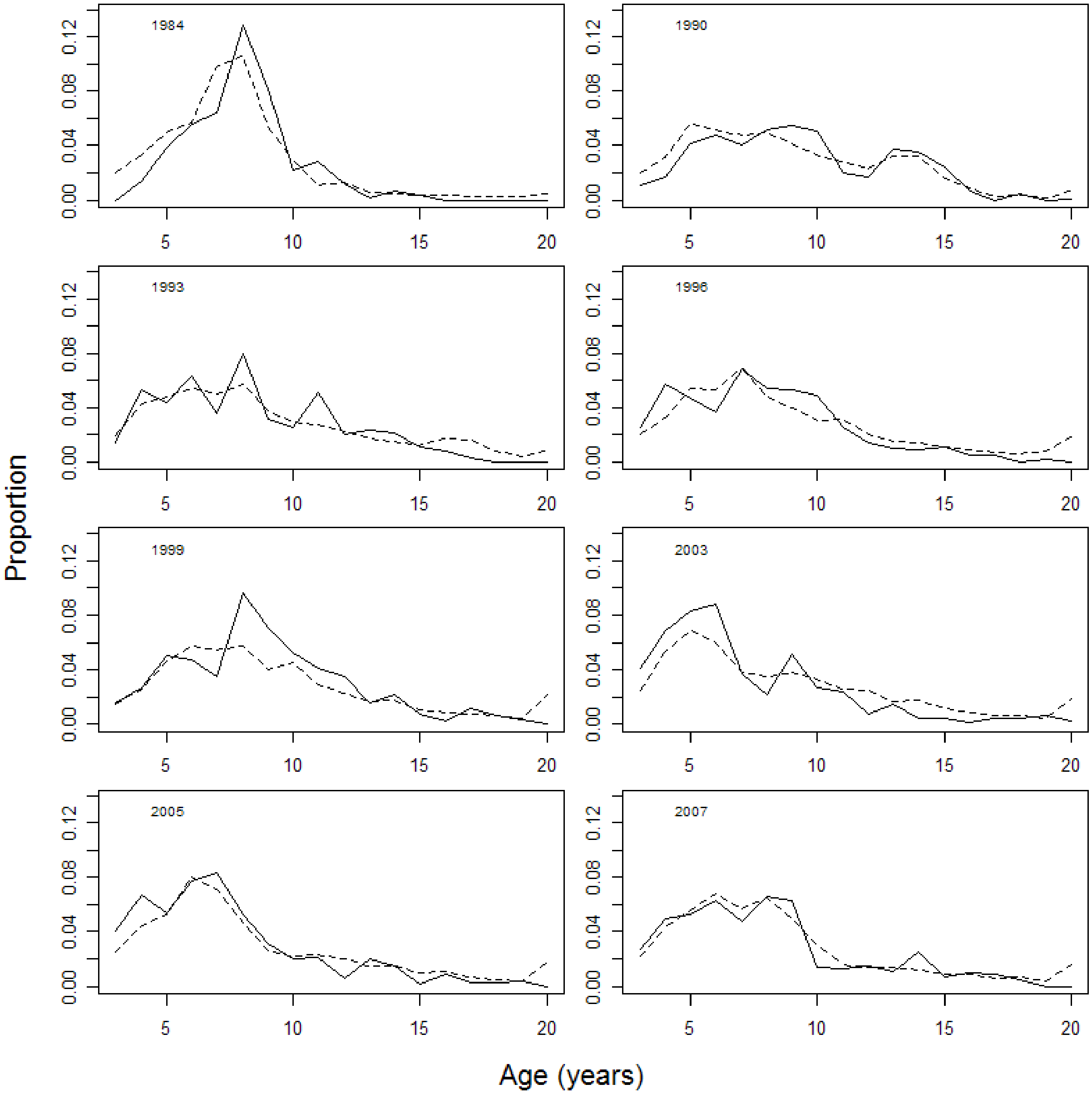


Figure 8.17. Fit to the male survey GOA flathead sole age composition data from the preferred model. Dashed lines represent the model prediction, solid lines represent the data.

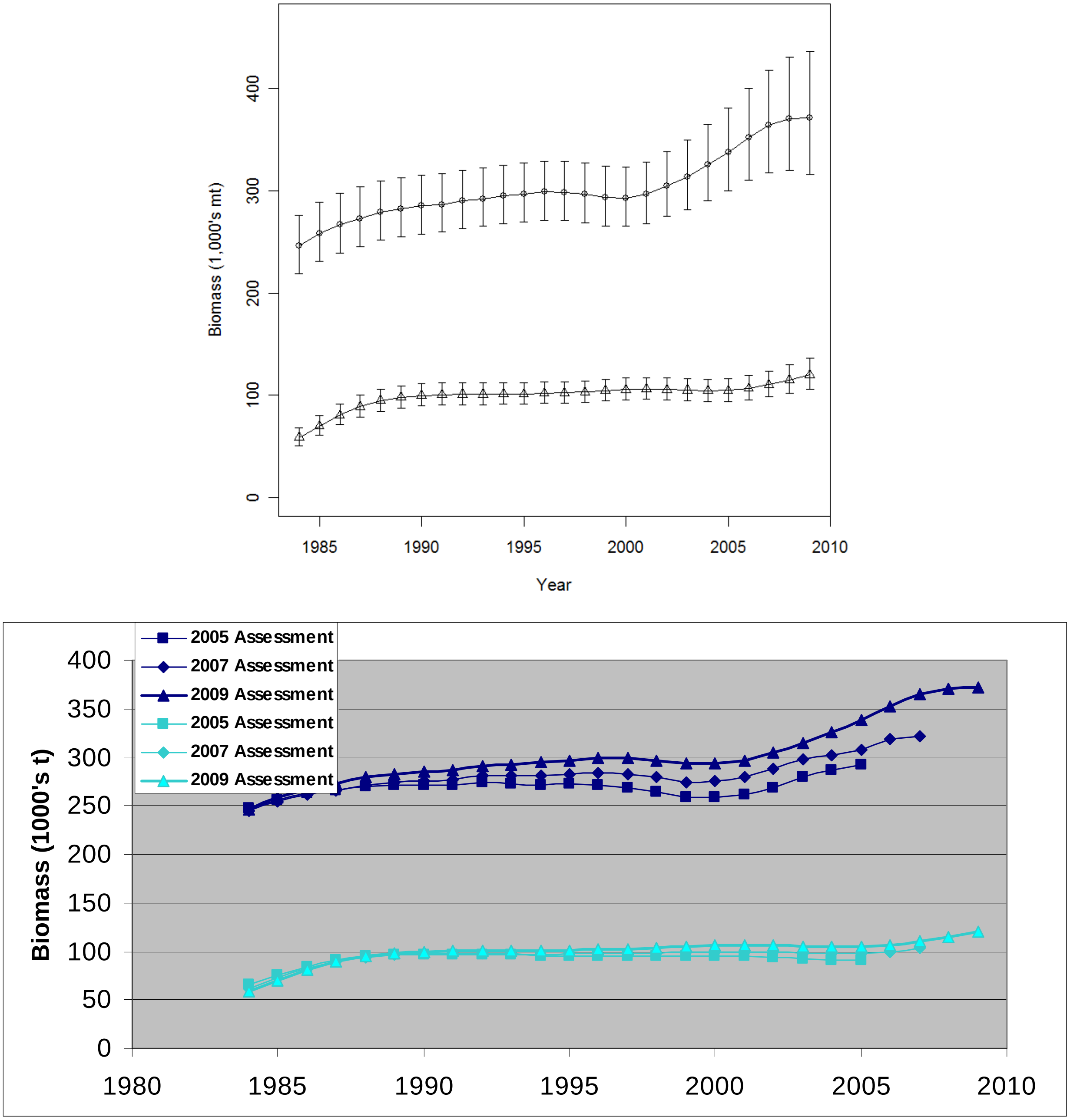
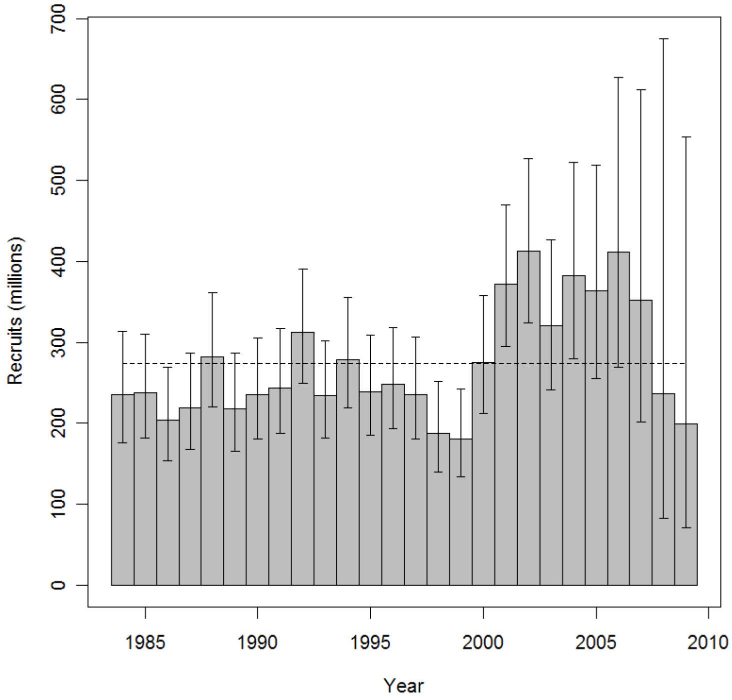


Figure 8.18. Upper: Estimated age 3+ biomass (circles) and female spawning biomass (triangles) for GOA flathead sole. Error bars are approximate lognormal 95% confidence intervals. Lower: Comparison of total biomass (dark blue) and spawning biomass (light blue) estimates from the 2009, 2007, and 2005 assessments.



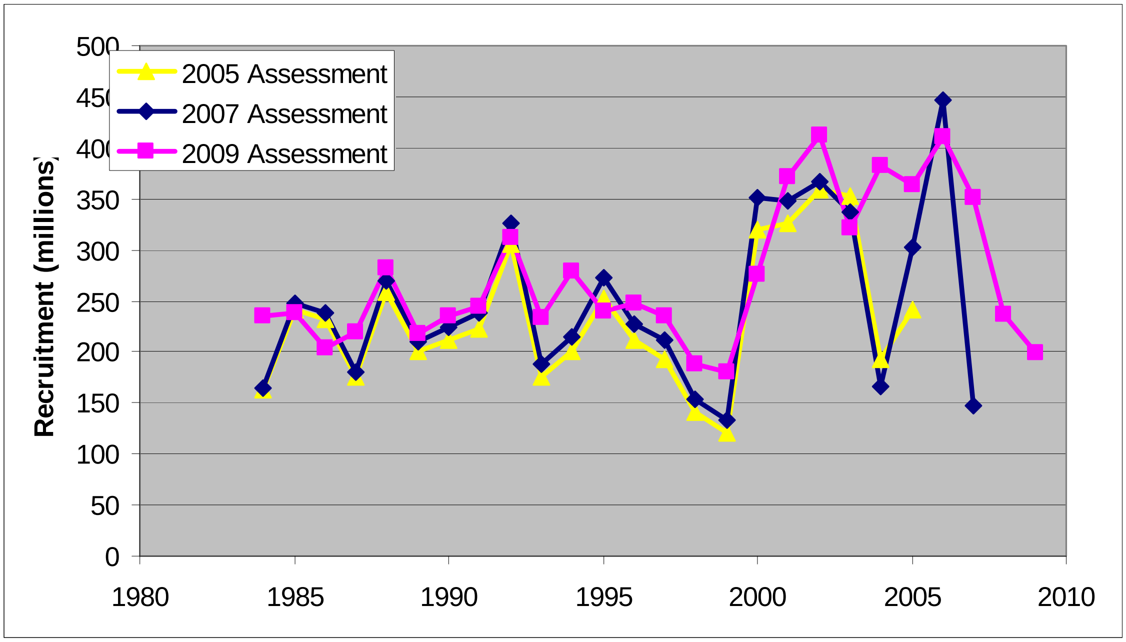


Figure 8.19. Upper: Estimated age 3 recruitments of GOA rex sole with approximate 95% lognormal confidence intervals. Horizontal line is mean recruitment. Lower: Comparison of recruitment estimates from the 2009, 2007, and 2005 assessments.

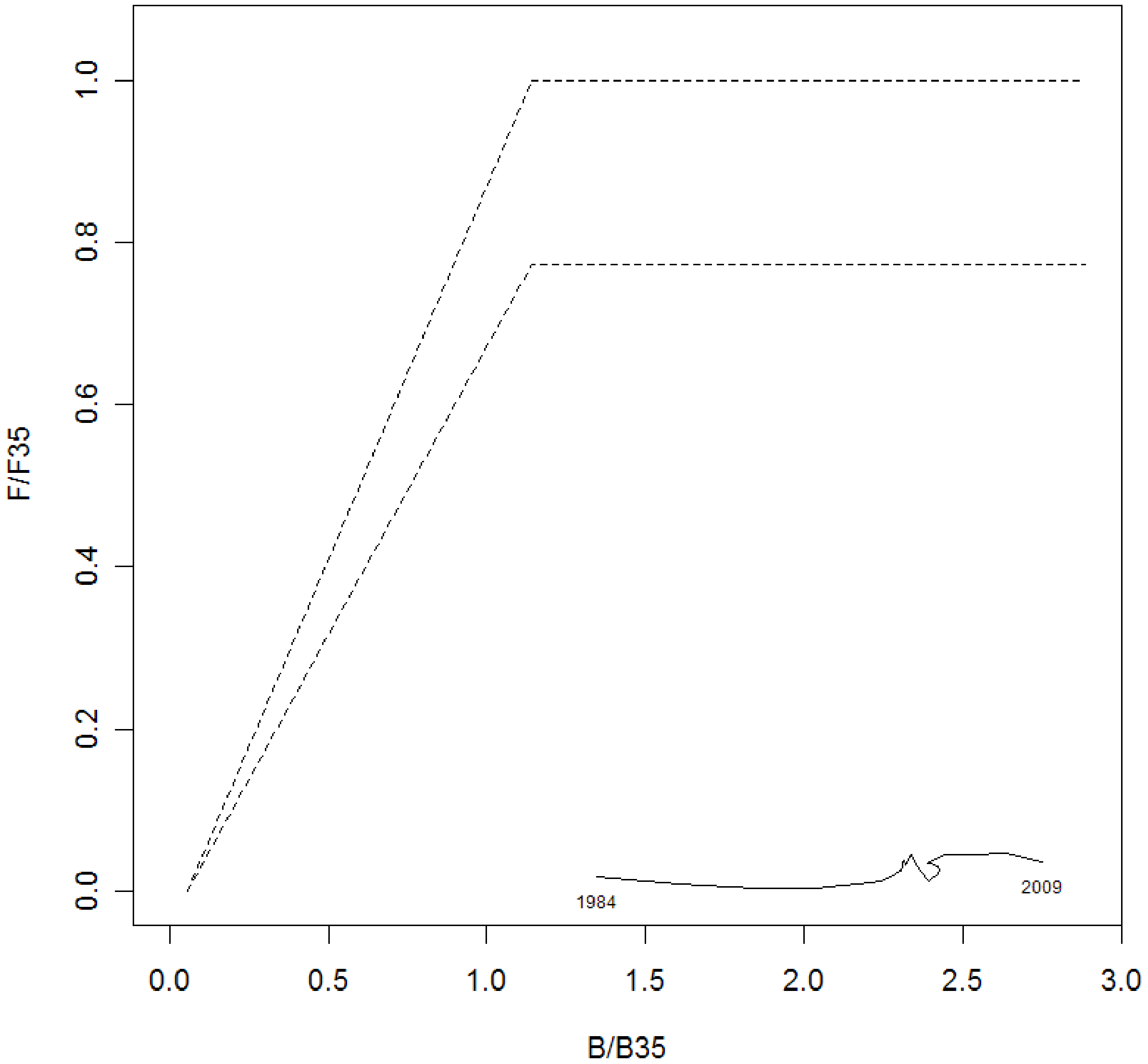


Figure 8.20. Control rule plot of estimated fishing mortality versus estimated female spawning biomass for GOA flathead sole from the preferred model. F_{OFL} = solid line, $F_{max\ ABC}$ = dashed line.

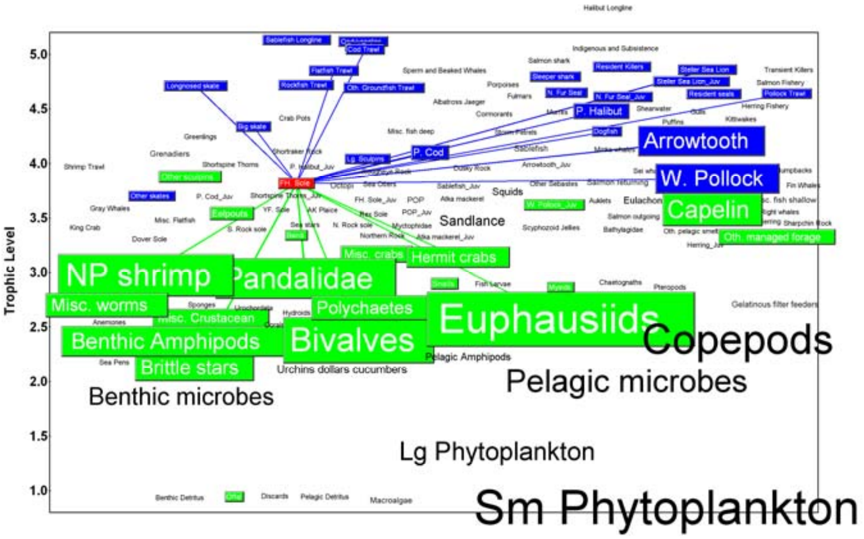


Figure 8.21a. Gulf of Alaska food web from the GOA ecosystem model (Aydin et al., 2007) highlighting adult flathead sole links to predators (blue boxes and lines) and prey (green boxes and lines). Box size reflects relative standing stock biomass.

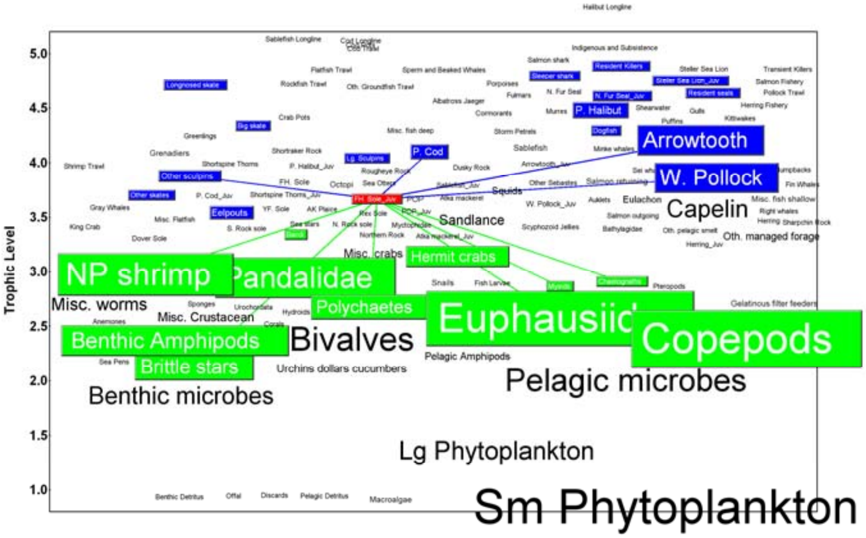


Figure 8.21b. Gulf of Alaska food web from the GOA ecosystem model (Aydin et al., 2007) highlighting juveile flathead sole links to predators (blue boxes and lines) and prey (green boxes and lines). Box size reflects relative standing stock biomass.

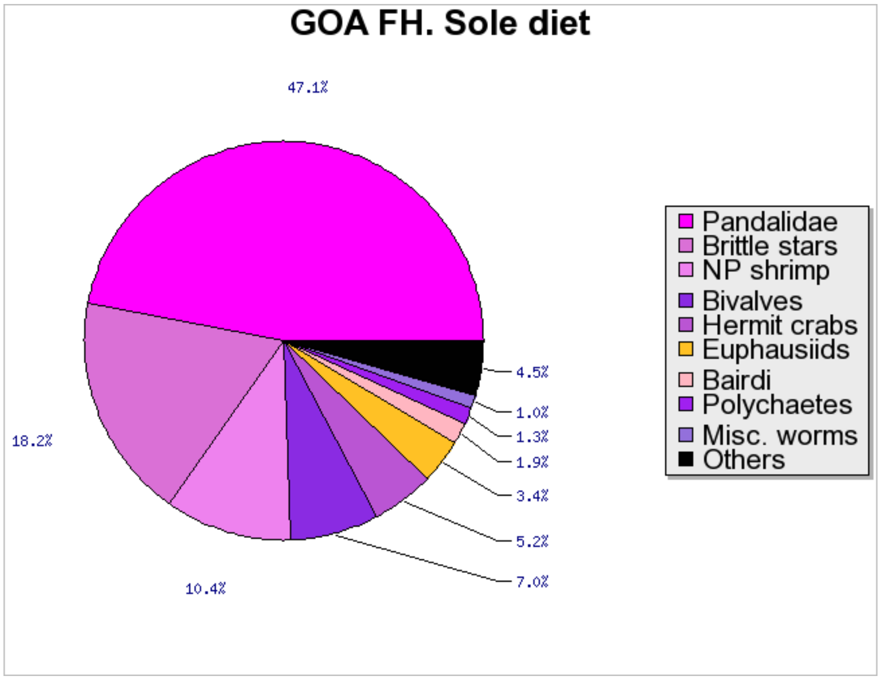


Figure 8.22a. Diet composition for Gulf of Alaska adult flathead sole from the GOA ecosystem model (Aydin et al., 2007).

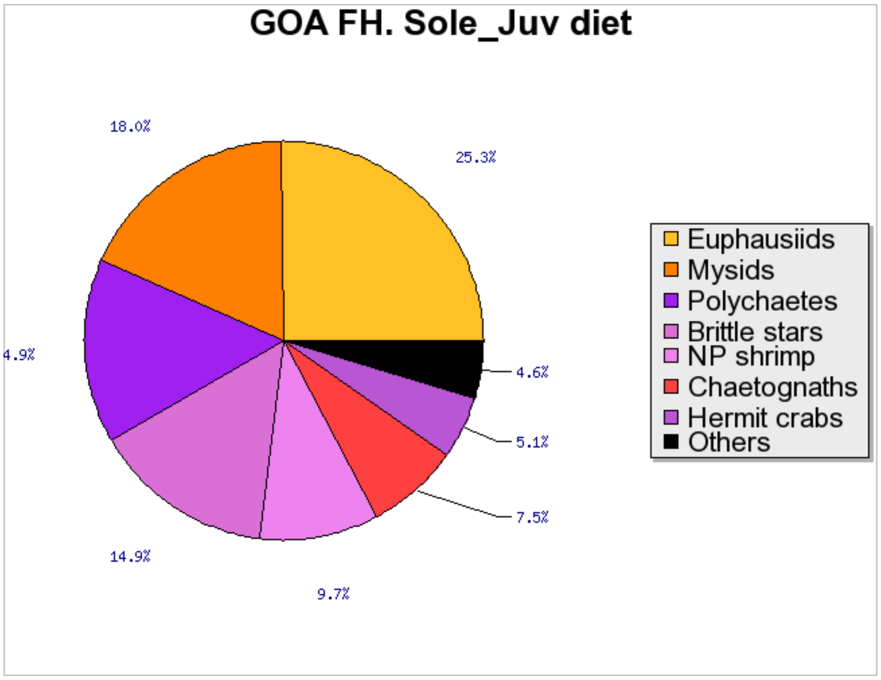


Figure 8.22b. Diet composition for Gulf of Alaska juvenile flathead sole from the GOA ecosystem model (Aydin et al., 2007).

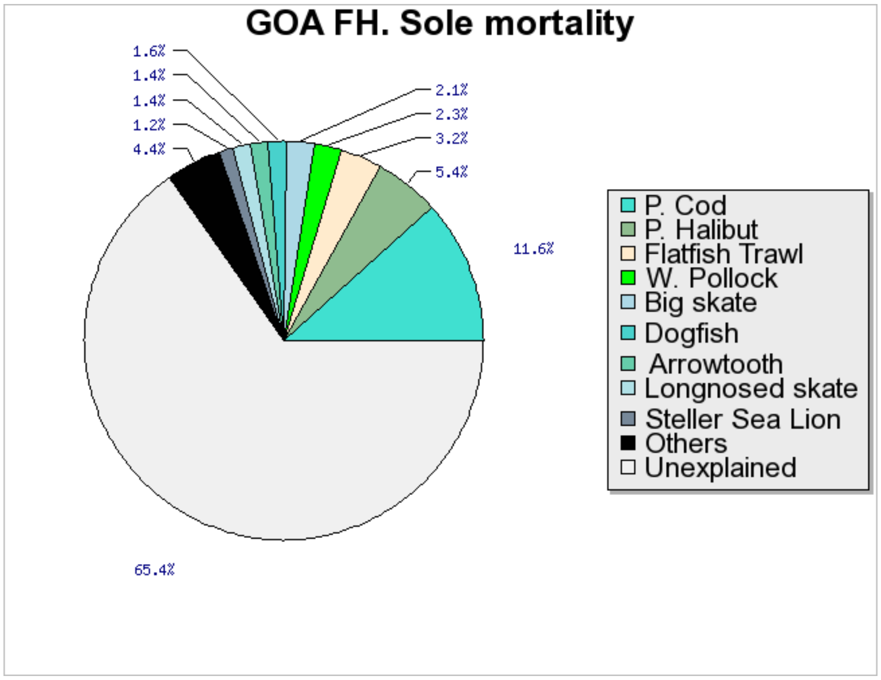


Figure 8.23a. Decomposition of natural mortality for Gulf of Alaska adult flathead sole from the GOA ecosystem model (Aydin et al., 2007).

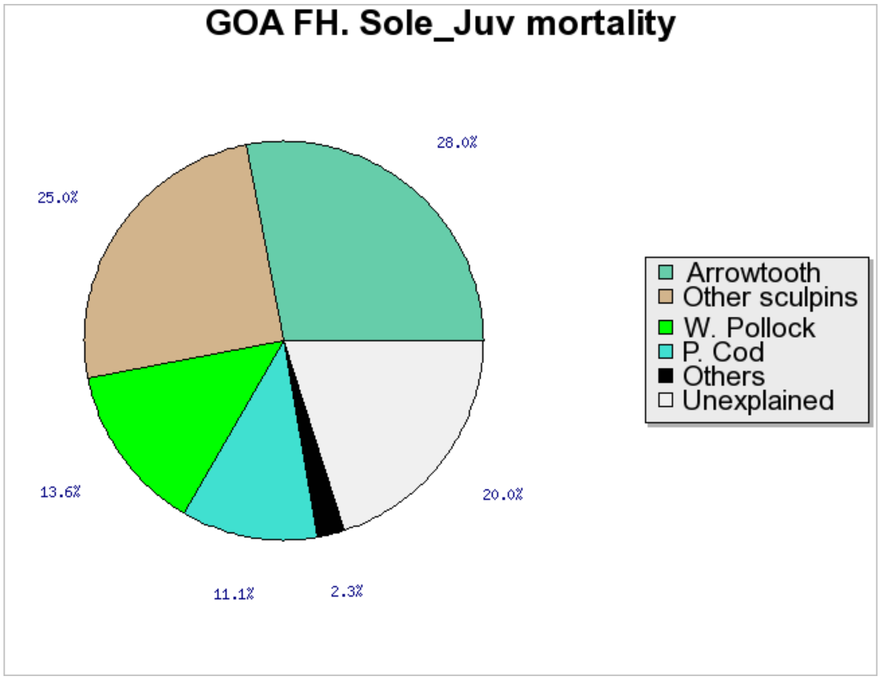


Figure 8.23b. Decomposition of natural mortality for Gulf of Alaska juvenile flathead sole from the GOA ecosystem model (Aydin et al., 2007).

Appendix A.

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

Quantity	Definition
T	number of years in the model.
A	number of age classes (18).
L	number of length classes (18).
T_{min}	model start year (1984).
T_{max}	assessment year (2009).
t	time index.
a	age index ($1 \le a \le A$; a=1 corresponds to age at recruitment).
x	sex index ($1 \le x \le 2$; 1=female, 2=male).
l	length index ($1 \le l \le L$; l=1 corresponds to minimum length class).
$\{t^S\}$	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.
$L^x_{l,a}$	elements of length-age conversion matrix (proportion of sex *x* fish in age class *a* that are in length class *l*). (fixed)
$w_{x,a}$	mean body weight (kg) of sex *x* fish in age group *a*. (fixed)
ϕ_a	proportion of females mature at age *a*. (fixed)
$\overline{\ln R_0}$	mean value of log-transformed recruitment. (estimable)
τ_t	recruitment deviation in year *t*. (estimable)
M_x	instantaneous natural mortality rate. (fixed)
$\overline{\ln F}$	mean value of log-transformed fishing mortality. (estimable)
ε_t	deviations in fishing mortality rate in year *t*. (estimable)
R_t	recruitment 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 (yield) in tons in year *t*.
$F_{t,x,a}$	instantaneous fishing mortality rate for sex *x* and age group *a* in year *t*.
$Z_{t,x,a}$	instantaneous total mortality for sex *x* and age group *a* in year *t*.
$s^{FU}_{x,a}$	unnormalized fishery selectivity for sex *x* and age group *a*.
$s^{SU}_{x,a}$	unnormalized survey selectivity for sex *x* and age group *a*.
$s^{FN}_{x,a}$	normalized fishery selectivity for sex *x* and age group *a*.
$s^{SN}_{x,a}$	normalized survey selectivity for sex *x* and age group *a*.

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

Equation	**Description**
$\tau_t \sim N(0,\sigma_R^2)$	Random deviate associated with recruitment.
$N_{t,x,1} = R_t = \exp\left(\ln R_0 + \tau_t\right)$	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.
$F_{t,x,a} = s_{x,a}^F \cdot \exp\left(\ln F + \varepsilon_t\right)$	Fishing mortality.
$\varepsilon_t \sim N(0,\sigma_F^2)$	Random deviate associated with fishing mortality.
$s_{x,a}^{FU} = \frac{1}{1 + e^{(-b_x^F(age - {}_{50}A_x^F))}}$	Unnormalized fishery selectivity- 2 parameter ascending logistic - separate for males and females.
$s_{x,a}^{SU} = \frac{1}{1 + e^{(-b_x^S(age - {}_{50}A_x^S))}}$	Unnormalized survey selectivity- 2 parameter ascending logistic - separate for males and females.
$s_{x,a}^{FN} = \exp(r_x^F) \frac{s_{x,a}^{FU}}{\max\{s_{1,a}^{FU}\}}$	Normalized fishery selectivity. $r^F_1 \equiv 0$.
$s_{x,a}^{SN} = \exp(r_x^S) \frac{s_{x,a}^{SU}}{\max\{s_{1,a}^{SU}\}}$	Normalized survey selectivity. $r^S_1 \equiv 0$.
$N^S{}_{t,x,a} = Q\ s^S{}_{x,a} N_{t,x,a}$	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.
$p_{t,x,a}^{F,A} = C_{t,x,a} / \sum_{x=1}^{2} \sum_{a=1}^{A} C_{t,x,a}$	Proportion at age in the catch.
$p_{t,x,l}^{F,L} = \sum_{a=1}^{A} L_{l,a}^x \cdot p_{t,x,a}^{F,A}$	Proportion at length in the catch.
$p_{t,x,a}^{S,A} = N^S{}_{t,x,a} / \sum_{x=1}^{2} \sum_{a=1}^{A} N^S{}_{t,x,a}$	Proportion at age in the survey.
$p_{t,x,l}^{S,L} = \sum_{a=1}^{A} L_{l,a}^x \cdot p_{t,x,a}^{S,A}$	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; assumes a lognormal distribution.
$\sum_{t\in\{t^{F,A}\}}\sum_{x=1}^{2}\sum_{a=1}^{A}n_t^{samp}\cdot p_{t,x,a}^{F,A,obs}\cdot\log(p_{t,x,a}^{F,A})$ - offset	Fishery age composition; assumes a multinomial distribution. Observed sample size is n_t^{samp}.
$\sum_{t\in\{t^{F,L}\}}\sum_{x=1}^{2}\sum_{l=1}^{L}n_t^{samp}\cdot p_{t,x,l}^{F,L,obs}\cdot\log(p_{t,x,l}^{F,L})$ - offset	Fishery length composition; assumes a multinomial distribution. Observed sample size is n_t^{samp}.
$\sum_{t\in\{t^{F,A}\}}\sum_{x=1}^{2}\sum_{a=1}^{A}n_t^{samp}\cdot p_{t,x,a}^{S,A,obs}\cdot\log(p_{t,x,a}^{S,A})$ - offset	Survey age composition; assumes a multinomial distribution. Observed sample size is n_t^{samp}.
$\sum_{t\in\{t^{F,L}\}}\sum_{x=1}^{2}\sum_{l=1}^{L}n_t^{samp}\cdot p_{t,x,l}^{S,L,obs}\cdot\log(p_{t,x,l}^{S,L})$ - offset	Survey length composition; uses a multinomial distribution. Observed sample size is n_t^{samp}.
offset $=\sum_{t}\sum_{x=1}^{2}\sum_{a=1}^{A}n_t^{samp}\cdot p_{t,x,a}^{obs}\cdot\log(p_{t,x,a}^{obs}))$	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.
$\sum_{t\in\{t^S\}}\left[\frac{\log\left[\frac{SB_t^{obs}}{SB_t}\right]}{\sqrt{2}\cdot s.d.(\log(SB_t^{obs}))}\right]^2$	Survey biomass; assumes a lognormal distribution.
$\sum_{t=T_{\min}}^{T_{\max}-3}(\tau_t)^2$	Recruitment; assumes a lognormal distribution, since τ_t is on a log scale.
$\sum_{t=T_{\max}-2}^{T_{\max}}(\tau_t)^2$	"Late" recruitment; assumes a lognormal distribution, since τ_t is on a log scale.
$\sum_{t=T_{\min}-A+1}^{T_{\min}-1}(\tau_t)^2$	"Early" recruitment; assumes a lognormal distribution, since τ_t is on a log scale. Determines age composition at starting year of model.

Table A.4. Parameters fixed in the model.

Parameter	Description
$M_x = 0.2$	sex-specific natural mortality rate.
$Q = 1.0$	survey catchability.
$L^x_{l,a}$	sex-specific length-at-age conversion matrix.
$w_{x,a}$	sex-specific weight-at-age.
ϕ_a	proportion of females mature at age *a*.

Table A.5. Parameters estimated in the model. A total of 81 parameters were estimated.

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	$T_{\min} - A + 1 \le t \le T_{\max}$	43	log-scale recruitment deviation in year *t*.
$\ln(f_0)$	NA	1	natural log of the geometric mean value of fishing mortality.
ε_t	$T_{\min} \le t \le T_{\max}$	26	log-scale deviations in fishing mortality rate in year *t*.
r^F_2	NA	1	scaling from female to male fishery selectivity (log-scale).
b^F_x , $_{50}\mathrm{A}^F_x$	$1 \le x \le 2$	4	sex-specific selectivity parameters (slope and age at 50% selected) for the fishery.
r^S_2	S=1	1	scaling from female to male survey selectivity (log-scale).
b^S_x , $_{50}\mathrm{A}^S_x$	$1 \le x \le 2$ S=1	4	sex-specific selectivity parameters (slope and age at 50% selected) for the survey.