6. Assessment of the Rex Sole Stock in the Gulf of Alaska

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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 increased from 103,776 t in 2007 to 124,744 t in 2009. Survey biomass estimates and length compositions were recalculated for all survey years.
4) Four years (2001, 2003, 2005, 2007) of survey age compositions were added to the model. Based on the advice of AFSC's Age and Growth staff, the survey age composition for one year (1990) was removed from consideration because the underlying ages were probably underestimated due to the technique (surface age reading) used.

Changes in the Assessment Model

Estimable scaling offset parameters were incorporated into the assessment model for male fishery and survey selectivity functions. As a consequence, the fishing mortality experienced by fully-selected males may now differ from that experienced by fully-selected females. The nominal fishing mortality is reported relative to fully-selected females. However, this option was not used in the accepted model, which was the same as that adopted in the previous assessment.

Changes in the Assessment Results

1. Tier 3a calculations are used in this assessment to calculate ABC, OFL and related quantities. As recommended by the SSC, ABC and OFL determinations were based on using the female maturity ogive as a substitute for the estimated fishery selectivity curves. In the previous assessment, Tier 5 calculations were used.
2. F_{ABC} was found to correspond to a harvest level of 0.223 yr^{-1} on fully-selected females, while F_{OFL} corresponded to a harvest level of 0.275 yr^{-1}.
3. Using the age-structured projection model and our best estimates for harvest levels in 2009-10, the recommended ABC for 2010 is 16,756 t and the recommended ABC for 2011 is 16,383 t.
4. The OFL for 2010 is 20,207 t and the OFL for 2011 is 19,754 t.
5. Projected female spawning biomass is estimated at 52,151 t for 2010 and 51,129 t for 2011.
6. Total biomass (age 3+) is estimated at 115,395 t for 2010 and 112,483 t for 2011.

The area apportionments corresponding to the recommended ABCs are:

	Western Gulf	Central Gulf	West Yakutat	Southeast Outside	Total
apportionment	15.9%	65.8%	9.1%	9.3%	100.0%
2010 ABC (t)	2,657	11,027	1,520	1,552	16,756
2011 ABC (t)	2,598	10,781	1,486	1,518	16,383

A summary of the recommended ABCs from the 2009 assessment, relative to the 2008 SAFE projections, is as follows:

Quantity	2009 Assessment Recommendations for 2010	2008 Assessment Recommendations for 2010	2008 Assessment Recommendations for 2009
Tier	**3a**	**5**	**5**
adult biomass (t)	--	80,037	81,572
age 3+ biomass (t)	115,395	--	--
Female spawning biomass (t)	52,151	--	--
ABC (t)	16,756	8,827	8,996
OFL (t)	20,207	11,535	11,756
F_{ABC}	0.223	0.128	0.128
F_{OFL}	0.275	0.170	0.170

SSC Comments Specific to the Rex Sole Assessments

SSC comment: *The SSC requests that the next assessment re-evaluate the assumed age-length transition matrix to determine how it influences the estimated fishery selection curve. Also, the next assessment should provide analyses of mechanisms…that might account for the large differences between the survey and the fishery selection curves.*

Author response: B. Matta of AFSC's Age and Growth Program has found potential differences in growth patterns for rex sole between the eastern portion of the Gulf of Alaska and the western and central portions, with individuals growing more slowly and attaining smaller maximum sizes in the eastern Gulf. While this result may have important implications for stock structure, the analysis is not yet complete. In addition, the Age and Growth Program completed processing of several years of survey age data this year. Age composition data based on these new ages have been incorporated into this assessment. The principal assessment author is also using the new age data to re-evaluate the age-length conversion matrices used in the assessment. Unfortunately, we were not able to complete this analysis in time for inclusion in this assessment.

SSC comment: *The SSC requests that the next assessment provide likelihood profiles or similar analyses that illustrate the consistency of the model fits to the various input data sources.*

Author response: Likelihood profiles for a limited number of model parameters/estimates have been developed and incorporated into the current assessment. While these appear to address the issue of consistency of the model fits with respect to the entirety of the data sources, they do not address the issue of consistency of model fits with respect to individual data sources. Further guidance from the SSC on this issue would be greatly appreciated.

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

Rex sole (*Glyptocephalus zachirus*) is a right-eyed flatfish occurring from southern California to the Bering sea and ranging from shallow water (<100m) to about 800 meters depth (Mecklenburg et al., 2002). They are most abundant at depths between 100 and 200m and are found fairly uniformly throughout the Gulf of Alaska (GOA).

Rex sole appear to exhibit latitudinal changes in growth rates and size at sexual maturity. Abookire (2006) found marked differences in growth rates and female size at maturity between stocks in the GOA and off the coast of Oregon. Size at sexual maturity was greater for fish in the GOA than in Oregon, as was size-at-age. However, these trends offset each other such that age-at-maturity was similar between the two regions.

Rex sole are batch spawners with a protracted spawning season in the GOA (Abookire, 2006). The spawning season for rex sole spans at least 8 months, from October to May. Eggs are fertilized near the sea bed, become pelagic, and probably require a few weeks to hatch (Hosie et al. 1977). Hatched eggs produce pelagic larvae that are about 6 mm in length and are thought to spend about a year in a pelagic stage before settling out to the bottom as 5 cm juveniles.

Rex sole are benthic feeders, preying primarily on amphipods, polychaetes, and some shrimp.

Management units and stock structure

In 1993 rex sole was split out of the deep-water management category because of concerns regarding the Pacific ocean perch bycatch in the rex sole target fishery. The stock within the GOA is managed as a unit stock but with area-specific ABC and TAC apportionments to avoid the potential for localized depletion. Little is known on the stock structure of this species.

Fishery

Rex sole in the Gulf of Alaska are caught in a directed fishery using bottom trawl gear. Fishing seasons are driven by seasonal halibut PSC apportionments, with approximately 7 months of fishing occurring between January and November. Catches of rex sole occur primarily 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 5.

Catch is currently reported for rex sole by management area (Table 6.1, Fig. 6.1). Catches for rex sole were estimated from 1982 to 1994 by multiplying the deepwater flatfish catch by the fraction of rex sole in the observed catch. Historically, catches of rex sole have exhibited decadal-scale trends. Catches increased from a low of 93 t in 1986 to a high of 5,874 t in 1996, then declined to about 3,000 t thereafter. Catch in 2008 was 2,703 t and 4,230 in 2009 (as of Sept. 26; 2009). The 2009 catch is the largest since 1996.

Based on observer data, the catch of rex sole is widely distributed across the central and western portions of the Gulf (Figures 6.2-3). 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.

The rex sole resource has been moderately harvested in recent years (Table 6.2). The fishery catches in 2007 and 2008 each represented about 30% of the rex sole ABC. As of Sept. 26, catch in 2009 was 47% of the ABC.

Estimates of retained and discarded catch (t) in the rex sole fishery since 1995 were calculated from discard rates observed from at-sea sampling and industry reported retained catch (Table 6.2a). Retention of rex sole is high and has generally been over 95%.

Data

Fishery Data

This assessment used fishery catches from 1982 through 26 September, 2009 (Table 6.1, Fig. 6.1), as well as estimates of the proportion of individuals caught by length group and sex for the years 1982-2009 (as of Sept. 26; Table 6.3). Sample sizes for the size compositions are shown in Table 6.4a. Currently, otoliths collected from the fishery have not undergone age determination, so fishery age compositions are unavailable. Consequently, fishery age composition data is not currently used in the assessment model.

Survey Data

Because rex 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 rex 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 6.5, Fig. 6.4). Although survey depth coverage has been inconsistent for depth strata > 500 m (Table 6.5a), the fraction of the rex sole stock occurring in these depth strata is typically small (Table 6.5b), so we have not attempted to correct the survey estimates of total biomass for missing depth strata. We have, however, corrected the 2001 survey estimate of total biomass, because the eastern section of the Gulf was not sampled that year. We estimated the average stock biomass occurring in the unsampled area from the 1993, 1996 and 1999 surveys and expanded the 2001 estimate to correct for the missing area. Survey biomass has fluctuated on decadal time scales. From an initial low of ~60,000 t in 1984, estimated biomass increased to a high of almost 100,000 t in 1990, then declined during the 1990s to slightly above 70,000 t. Subsequently, survey biomass increased to high levels once again and has been above 100,000 t since 2005. The estimate of biomass from the 2009 groundfish survey in the Gulf was the largest thus far at124,744 t, over a 20% increase from the 2007 survey (103,776).

Estimates of the total number of individuals by length group from each RACE GOA groundfish survey (Table 6.6) were also incorporated into the assessment, as were estimates of total population numbers-at-age (Table 6.7). Survey age compositions were available for 1984, 1987, 1990, 1993, 1996, 2001, 2003, 2005 and 2007, although the age composition for 1990 was excluded this year from the model because the underlying ages were probably biased low due to the age reading technique (surface age reading) used to process the otoliths. 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 (1990, 1999 and 2009). Sample sizes for the survey size and age compositions are given in Table 6.4b.

Data on individual growth was incorporated in the assessment using sex-specific age-length conversion matrices (Table 6.8a, b). These matrices were also used in the previous full assessment (Turnock et al., 2005). Sex-specific weight-at-age relationships and female maturity schedules from the previous full assessment (Turnock et al., 2005) were also used in this assessment (Table 6.9). Ideally, these relationships would have been updated to reflect the new survey age data available this year, but we were unable to complete the growth analysis in time for inclusion in this assessment.

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

Source	type	years
Fishery	catch	1982-2009
	length compositions	1982-1984; 1990-2009
Survey	biomass	1984-1999 (triennial); 2001-2009 (biennial)
	length compositions	1984-1999 (triennial); 2001-2009 (biennial)
	age compositions	1984,1987, 1993, 1996, 2001, 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.

Age classes included in the model run from age 3 to 20. Age at recruitment was set at 3 years in the model due to the small number of fish caught at younger ages. The oldest age class in the model, age 20, serves as a plus group in the model; the maximum age of rex sole based on otolith age determinations has been estimated at 27 years (Turnock et al., 2005). 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 83 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 full assessment (Turnock et al., 2005), natural mortality (*M*) was fixed at 0.17 yr^{-1} for both sexes in all age classes. This value was based on maximum observed age of 27 years for rex sole (Turnock et al., 2005).

Growth
The model estimates size compositions using fixed sex-specific age-length conversion matrices (Table 6.8). The distribution of size-at-age was assumed to be normally-distributed, with mean size-at-age modeled using the standard von Bertalanffy growth equation (Table 6.9, Fig. 6.6a):

$$L_t = L_{\inf}(1 - e^{-k(t-t_0)})$$

and age-varying variance. Sex-specific parameter values for the von Bertalanffy equation were estimated from mean length-at-age data collected during the 1984, 1987, 1990, 1993 and 1996 groundfish surveys (Turnock et al., 2005). The estimated values are

Sex	L_∞	k	t_0
Males	39.5	0.38	0.79
Females	44.9	0.31	0.69

Coefficients of variation (CVs) for length-at-age were also estimated from the survey data, and varied linearly from 0.13 for age 3 to 0.08 for age 20+ (Turnock et al., 2005) for both sexes.

Weight at length
Weight-at-length was modeled using the equation $W = aL^b$, with L in centimeters and W in grams. The parameter values for this equation, estimated from survey data, are

Sex	a	b
Males	1.0770E-06	3.30571
Females	4.7933E-07	3.44963
Combined	5.9797E-07	3.41049

and are the same as used in the previous assessment. Weight-at-age (Table 6.9, Fig. 6.6b) was estimated using the weight-length relationship and the age-length conversion matrices.

Maturity
Abookire (2006) modeled female rex sole size-at-maturity using a logistic model, obtaining a value for size at 50% maturity of 351.7 mm with a slope of 0.0392 mm^{-1}. About half of the maturity samples were obtained from fishery catches and half from research trawls during 2000-2001. Using the mean length-at-age relationship estimated from the 1984-1996 survey data, the age at 50%-maturity was estimated at 5.6 years, (Table 6.9, Fig. 6.6). Estimates of mean size-at-age for the maturity samples were similar to those for mean size-at-age estimated from the survey data (Turnock et al., 2005).

Survey catchability
For the assessment, survey catchability (*Q* in Table A.1) was fixed at 1.

Parameters estimated conditionally

A total of 83 parameters were estimated in the final model (Table A.5), including parameters on the recruitment of rex sole to the population (46 parameters total, including ones determining the initial age composition) and values related to annual fishing mortality (29 parameters total). The separable age component of fishing mortality was modeled using ascending logistic functions estimated separately for males and females (4 parameters total). The same approach was also used to estimate relative age-specific survey selectivity (4 parameters total). We also evaluated an alternative model that attempted to estimate scaling offsets for asymptotic male survey and fishery selectivities relative to the associated asymptotic female selectivity. This alternative model had two additional parameters (85 total), one for the male survey selectivity scaling and one for the male fishery scaling.

Annual recruitment to the age 3 year class was parameterized in the model using one parameter for the log-scale mean recruitment and 45 parameters for the annual log-scale deviation from the mean. Recruitments were estimated back to 1965 to provide an initial age distribution for the model in its starting year (1982). In an analogous fashion, fully-recruited fishing mortality was parameterized in the model using one parameter for the log-scale mean and 28 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 1965 to 1981 (i.e., prior to the modeled age structure), “ordinary” recruitment incorporated deviations from 1982-2006 and “late” recruitment incorporated deviations from 2007-2009. 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 fully-weighted compositions (all age compositions and size compositions from years with no corresponding age compositions) and 1 for de-weighted compositions (size compositions with 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., 20) 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 6.11.

Model evaluation

Several alternative model configurations were considered in a previous assessment (Turnock 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 (2 additional parameters). For both models, as in the previous full assessment (Stockhausen et al., 2007), we assigned a weight of 20 to the catch-specific likelihood component, a weight of 2 to the survey length compostion likelihood component, and weights of 1 to the other likelihood components (Table 6.10). Initial values for the estimable parameters were set as listed in Table 6.11. 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 6.7. 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 11.6 yrs for females and 13.5 yrs for males in the base case. In the alternative case, females reach 95% selectivity at a slightly younger age (10.4 yrs) while males reach 95% of their asymptotic rate at a somewhat older age (17.9 yrs). For the survey, the age by which females are selected at 95% of their asymptotic rate is 6.4 yrs in the base case and 7.1 yrs in the alternative case while males reach 95% of their asymptotic rate at 5.3 yrs in the base case and 5.1 yrs in the alternative case. In the alternative model, the log-scale male selectivity scaling parameters for both the fishery and survey were both different from 0 (the base case value), with values of 0.81 for the fishery and -0.15 for the survey. As a result, asymptotic selectivity for males in the alternative model was higher in the fishery (124%) relative to that for females and lower (14%) in survey.

Further comparison of the results from the two model cases are shown for several variables of interest in Fig. 6.8. 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 rather small (9% max). This appears to be a consequence of the alternative model's 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 (Fig. 6.8, middle right graph). 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. Considering 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.

As in previous assessments, the model-estimated values for $F_{40\%}$ and $F_{35\%}$ were highly uncertain for both the base model (3.9±3.4 and 9.2±12.1, respectively) and the alternative model (4.7±5.7 and 20.0 with no valid error estimate, respectively) because the estimated fishery selectivities were far to the right of the female maturity curve.

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. 6.9). In general, the profiles for individual parameters overlap to some extent between the two cases. The widths (i.e., standard deviations) of the profiles tended to be only slightly larger for the alternative case, compared with the base case, except for age-at-50%-selection for males in the fishery (middle left graph in Fig. 6.9) where the width was substantially larger for the alternative model. 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 were not identical (as assumed in the base model). The likelihood profile for the fishery selectivity scaling parameter reflects the upper limit placed on this parameter (1.0 on the log-scale) in that the profile is truncated just to the right of the mode, which is barely just determined. The profile for the survey selectivity, on the other hand, appears to be well-behaved.

The alternative model fits the data substantially better than the base model, based on a difference between the models of almost 13 log-likelihood units in favor of the alternative model (Table 6.12). While the base model fits survey size composition slightly better than the alternative model (~0.2 units), the alternative model fits the fishery size compositions (~1.9 units), the survey biomass (~1.6 units), and the survey age compositions (~9.5 units) better than base model. Thus, simply comparing the likelihood components between the two models strongly favors the alternative model.

However, two lines of reasoning have led us to adopt the base model as the preferred model for this assessment. First, the likelihood profile for the male fishery selectivity scaling parameter indicates that the alternative model estimate for this parameter is highly constrained by the bounds placed on it. Second, and more importantly, the estimated scaling parameter value is such that the ratio of asymptotic fishery selectivity for males vis-à-vis females, over a factor of two, is too large to be credible without further evidence to support it. In fact, because the rex sole fishery primarily targets spawning females for their roe, it would be more credible if the scaling parameter was much less than one (negative on a log-scale) since one would expect females to be more highly targeted than males, if that were possible. One might also expect the scaling parameter to be less than one if the argument were based strictly on trawl net selectivity, which tends to increase with size for most (although not all) flatfish (Somerton et al., 2007). Because L_∞ for males (asymptotic size) is smaller than that for females, one would thus expect the oldest males to be less vulnerable to capture than the oldest females.

As such, we have selected the base model as the preferred model to use for population projection, evaluation of harvest scenarios and status determination, and reference value determination.

Final parameter estimates

The base model parameter estimates, considered final for this assessment, are given in Table 6.13.

Schedules implied by parameter estimates

In the base model, the relative scaling parameter for male selectivity was set to 1 (0 on the log-scale) for both the fishery and the survey (Figure 6.7, left-hand graph). Asymptotic male selectivity was identical to asymptotic female selectivity for both the fishery and the survey. The estimated selectivity curves for the fishery and survey indicate that the fishery generally catches older flathead sole than the survey. For the fishery, age at 95% selection was 11.6 for females and 13.5 for males. For the survey, the ages at 95% selection were younger: 6.4 yrs for females and 5.3 yrs for males.

Results

Given the large relative weight assigned to the catch-specific likelihood component, it was not surprising that the model estimates of fishery catch closely matched the observed values (Table 6.14 and Figure 6.10). Catch in the 1990s was somewhat underestimated by the model, while catch in the 1980s and 2000s is estimated very precisely. The model did not fit the fishery size compositions nearly as well, although its performance appeared to be reasonably good in most years (Figure 6.11). 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., 1982 in Figure 6.11a). The smoothing inherent in using an age-length conversion 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 does the catch (Table 6.14 and Figure 6.12), but model estimates of survey biomass were within the 95% confidence intervals of the actual surveys for all years. Thus, the fit was deemed quite 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 were on the whole generally reasonable (Figure 6.13). Finally, the model fit the survey age compositions marginally well (Figure 6.14), although more so when the observed age distributions were similar between the sexes (e.g., for 2001).

The model also estimated 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 and recruitment is the number of age 3 fish entering the population. Model estimates of the temporal evolution of these three quantities show somewhat out-of-phase decadal-scale oscillations (Tables 6.15-16, Figures 6.15-16). Recruitment at age 3 leads age 3+ biomass by 3-4 years and female spawning biomass by 5-6 years.

Model estimates of age 3+ biomass increased moderately from 79,000 t in 1982 to 100,000 t in 1991, then declined slowly to a low of 76,000 t in 1998 (Table 6.15; Figure 6.15). Subsequently, age 3+ biomass has risen steadily in recent years to achieve its highest level in the time series at 118,000 t in 2008 and 2009. The time series of estimated age 3+ biomass in this assessment was slightly higher (a few t at most) than that estimated in the 2007 assessment and very similar to that estimated in the 2005 assessment.

Model estimates of female spawning biomass indicate that it reached a peak in 2009 of 52,000 t, after rebounding from a low of 33,000 t during 1999-2000 (Table 6.15; Figure 6.15). Prior to that, spawning biomass peaked at 44,000 t in 1991 and 1993. The estimated time series of female spawning biomass was quite similar to that from both the 2007 and 2005 assessments.

Model estimates of annual recruitment (age 3 numbers) achieved a recent high at 116,000,000 individuals in 2006 after increasing from a low of 31,000,000 individuals in 1995 (Table 6.16; Figure 6.16). Recruitments since 1998 have been at or above the longterm average (59,000,000) in all years except 1995 and 2009, although the most recent recruitments must be viewed with some skepticism as there is little data to support these estimates. Currently, recruitment may be entering a decreasing phase in its apparent multi-year cycle, with 2009 recruitment estimated at an intermediate level of 58,000,000 individuals. Eliminating the 1990 survey age composition from the model fit had the effect of decreasing the large spike in recruitment seen in 1988 in the 2007 and 205 assessment results from ~100,000,000 to ~70,000,000 in the current model results. It does not, however, account for the more recent discrepancy between the current results and the earlier models. The addition of the 2001, 2003, 2005 and 2007 survey age compositions to the current model data accounts for some of these differences.

Model estimates for quantities based on spawner-per-recruit analyses such as $F_{35\%}$ and $B_{35\%}$ are highly uncertain because the fishery mainly catches fish that have been mature for several years. As a consequence, a standard control rule plot for this stock was not included in the assessment.

Reference fishing mortality rates

The fishery selectivity curves estimated in this assessment are similar to those estimated in the last two full assessments (Turnock et al, 2005 and Stockhausen et al., 2007). As in the previous assessments, the combination of relatively young age-at-maturity and relatively old ages selected by the fishery leads to very high, and uncertain, estimates for reference mortality rates such as $F_{40\%}$ (~4 yr^{-1}). If used further in the assessment process, these selectivity curves and reference mortality rate would lead to the evaluation of unrealistic harvest scenarios and the recommendation of unreasonably high Tier 3a ABC's and OFL's for the stock. The basic problem is one of inconsistency because, in order to take the high ABC's recommended under this approach, fishery selectivity would have to shift substantially toward younger individuals, thus invalidating an assumption in the standard approach to status determination and reference value calculation that selectivity does not change. Thus, it makes little sense to calculate ABC's and OFL's, as well as future catches under the various harvest scenarios, based on the current fishery selectivity curves.

In previous assessments, we used a Tier 5 approach to recommending ABC's and OFL's based on model estimates of "total adult biomass" (rather than survey biomass) projected out over the next two years. In 2008, the SSC recommended that we abandon this approach and use Tier 3 calculations (no spawner-recruit curve exists for rex sole) based on the age-at-maturity curve as fishery selectivity for both sexes. We have complied with this recommendation in subsequent sections of this assessment for determining reference fishing mortality rates, making population projections, evaluating various harvest alternatives, and computing ABC's and OFL's. The following table summarizes the reference fishing mortality rates and associated spawning biomass values resulting from the SSC's recommendation:

estimated 2009 SSB	=	52,349 t
$B_{40\%}$	=	22,646 t
$F_{40\%}$	=	0.223
F_{ABC}	≤	0.223
$B_{35\%}$	=	19,815 t
$F_{35\%}$	=	0.275
F_{OFL}	=	0.275

Projections and Harvest Alternatives

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 2009 recommended in the assessment to the *max* F_{ABC} for 2009. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

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

Scenario 4: In all future years, *F* is set equal to the 2005-2009 average *F*. (Rationale: For some stocks, TAC can be well below ABC, and recent average *F* may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, *F* is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the rex 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 2006 and 2007, *F* is set equal to *max* F_{ABC}, and in all subsequent years, *F* is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2022 under this scenario, then the stock is not approaching an overfished condition.)

Because the 2009 spawning biomass (*B*) satisfies $B > B_{40\%}$ (52,270 t > 22,195 t), the rex sole reference fishing mortality is defined by Tier 3a. For this tier, F_{ABC} is constrained to be $\leq F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. Thus:

$$F_{ABC} \leq 0.223$$
$$F_{OFL} = 0.275$$

Ordinarily, the recommended F_{ABC} and the maximum F_{ABC} would be 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 seven scenarios are shown in Tables 6.17-19. Scenario 4 most closely reflects the recent history of the rex sole fishery, where catches have been much smaller than the ABCs (Table 6.2a).

The results from scenarios 6 and 7 indicate that the rex sole stock is not overfished and is not approaching an overfished condition. With regard to assessing the current stock level, the expected spawning stock size in the year 2010 of scenario 6 is 52,151 t, over 2.5 times $B_{35\%}$ (19,421 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 (20,651 t) is greater than $B_{35\%}$; thus, the stock is not approaching an overfished condition.

Acceptable Biological Catch and Overfishing Level

Following the SSC's recommended approach for this stock, rex sole is considered a Tier 3a stock. Estimating ABCs and OFLs for 2010 and 2011 requires estimates for the total catch taken in 2009 and 2010. Because the 2009 fishery is not yet complete, we estimated the total catch taken in 2009 (4,539 t) by multiplying the catch through Sept. 26, 2009 (4,230 t) by an inflation factor (1.07305) based on the ratio of the catch taken in 2008 up to the same week of the year to the final 2008 catch. Since the 2009 catch is the largest in recent years, we assumed the same catch would be taken in 2010 as well. Using these values and the estimated numbers-at-age at the start of 2009 from the model, we projected the stock ahead and calculated the ABCs and OFLs for 2010-11 based on Tier 3a calculations. The estimated ABCs for 2010 and 2011 are 16,756 t and 16,383 t, respectively, while the estimated OFLs are 20,207 t and 19,754 t. Total biomass for 2010-11 was projected to be 115,395 t and 112,483 t, respectively, while female spawning biomass was projected to be 52,151 t and 51,129 t.

Area allocation of harvests

TACs for rex 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 ABCs for rex 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 ABCs. The area-specific allocations for 2010 and 2011 are:

	Western Gulf	Central Gulf	West Yakutat	Southeast Outside	Total
apportionment	15.9%	65.8%	9.1%	9.3%	100.0%
2010 ABC (t)	2,657	11,027	1,520	1,552	16,756
2011 ABC (t)	2,598	10,781	1,486	1,518	16,383

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), rex sole in the Gulf of Alaska occupy an intermediate trophic level (Fig. 6.17). Polychaetes, euphasiids, and miscellaneous worms were the most important prey for rex sole in the Gulf of Alaska (Fig. 6.18).. Other major prey items included benthic amphipods, polychaetes, and shrimp (Livingston and Goiney, 1983; Yang, 1993; Yang and Nelson, 2000). Little to no information is available to assess trends in abundance for the major benthic prey species of rex sole.

Predator population trends

Important predators on rex sole include longnosed skate and arrowtooth flounder (Fig. 6.19). The flatfish-directed fishery constitutes the second-largest known source of mortality on rex sole. However, unexplained mortality is the second largest component of mortality.

The longnose skate population appears to be stable. 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). Although the continued increase in abundance of arrowtooth flounder is cause for some concern, the abundance of rex sole has actually increased in recent years, as well. Increased predation by arrowtooth may be limiting the potential rate of increase of rex sole under current conditions, but it does not appear to represent a threat to the stock.

Fishery effects on ecosystem

Catches of rex sole are widely distributed in the Gulf of Alaska over the past few years (Figure 6.2). The ecosystem effects of this spatial distribution of fishing activity are unknown.

Prohibited species such as halibut, salmon, and crab are also taken to some extent in the rex sole-directed fishery (Table 6.20). In 2009 (through September), the overall prohibited species catch (PSC) rate for halibut was 384,211 t—more than double that of the 2008 catch of 173,430 and the largest since 2003. The PSC for salmon and crab in the 2009 directed fishery were 2,035 salmon and 10,888 crabs. The majority of salmon caught were Chinook. Most of the crabs caught were Bairdi tanner crab, although a few golden king crab were taken, as well. The 2009 PSC for salmon was the highest since 2003. The 2009 crab PSC was the smallest since 2005 (although the season is not yet complete).

The rex sole-directed fishery has caught more arrowtooth flounder since 2006 than any other non-prohibited species, including rex sole (Table 6.21). Rex sole was the second most-caught species in the directed fishery. Only small amounts of arrowtooth were retained (<10%), while more than 97% of rex sole was retained. Lesser amounts of Pacific cod and flathead sole were also taken.

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

Data gaps and research priorities

The AFSC's Age and Growth Program has made substantial progress in processing survey age data for rex 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 rex sole 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 rex 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.

We will also investigate potential growth rate differences for rex sole between the eastern Gulf and the central/western Gulf. Although little catch is taken from the eastern Gulf, divergent growth patterns may have management implications for the stock as they may influence the perceived productivity of the stock.

Finally, 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

Tier	3a		
Reference mortality rates			
M	0.17		
$F_{35\%}$	0.275		
$F_{40\%}$	0.223		
Equilibrium female spawning biomass			
$B_{100\%}$	55,488	t	
$B_{40\%}$	22,195	t	
$B_{35\%}$	19,421	t	
Fishing rates			
F_{OFL}	0.275		
F_{ABC} (maximum permissible)	0.223		
F_{ABC} (recommended)	0.223		
Projected biomass	**2010**		**2011**
Age 3+ biomass (t)	115,395		112,483
Female spawning biomass (t)	52,151		51,129
Harvest limits	**2010**		**2011**
OFL (t)	20,207		19,754
ABC (maximum permissible;	16,756		16,383
ABC (recommended; t)	16,756		16,383

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Tables

Table 6.1. Annual catch of rex sole in the Gulf of Alaska, from 1982 to 2009. 2009 catch is through Sept. 26.

Year	Catch (t)
1982	959
1983	595
1984	365
1985	154
1986	93
1987	1,151
1988	1,192
1989	599
1990	1,269
1991	4,636
1992	3,000
1993	3,000
1994	3,673
1995	4,021
1996	5,874
1997	3,294
1998	2,669
1999	3,060
2000	3,591
2001	2,940
2002	2,941
2003	3,485
2004	1,464
2005	2,176
2006	3,294
2007	2,852
2008	2,703
2009	4,230

Table 6.2a. Time series of recent reference points (ABC, OFL), TACs, total catch and retention rates for rex sole.

Year	ABC (t)	TAC (t)	OFL (t)	Total Catch (t)	Retained	Discarded	Percent Retained
1995	11,210	9,690	13,091	4,021	3,619	402	90%
1996	11,210	9,690	13,091	5,874	5,580	294	95%
1997	9,150	9,150	11,920	3,294	3,030	264	92%
1998	9,150	9,150	11,920	2,669	2,589	80	97%
1999	9,150	9,150	11,920	3,060	2,938	122	96%
2000	9,440	9,440	12,300	3,591	3,483	108	97%
2001	9,440	9,440	12,300	2,940	2,793	147	95%
2002	9,470	9,470	12,320	2,941	2,794	147	95%
2003	9,470	9,470	12,320	3,485	3,311	174	95%
2004	12,650	12,650	16,480	1,464	1,355	108	93%
2005	12,650	12,650	16,480	2,176	1,989	187	91%
2006	9,200	9,200	12,000	3,294	3,141	153	95%
2007	9,100	9,100	11,900	2,852	2,783	69	98%
2008	9,132	9,132	11,933	2,703	2,614	89	97%
2009	8,996	8,996	11,756	4,230	4,187	43	99%

Table 6.2b. Status of the rex sole fishery in recent years.

Year	Dates	Status
2005	Jan 20	open
	Mar 23	halibut bycatch status
	Apr 1	open
	Apr 8	halibut bycatch status
	Apr 24	open
	May 3	halibut bycatch status
	Jul 5	open
	Jul 24	halibut bycatch status
	Sep 1	open
	Sep 4	halibut bycatch status
	Sep8	open
	Sep 10	halibut bycatch status
	Oct 1	open
	Oct 1	halibut bycatch status
2006	Jan 20	open
	Apr 27	halibut bycatch status
	Jul 1	open
	Sep 5	halibut bycatch status
	Oct 1	open
	Oct 8	halibut bycatch status
2007	Jan 20	open
	May 17	halibut bycatch status
	Jul 1	open
	Aug 10	halibut bycatch status
	Sep 1	open
	Sep 8	halibut bycatch status
	Oct 1	open
	Oct 15	halibut bycatch status
	Oct 22	open
2008	Jan 20	open
	Apr 21	halibut bycatch status
	Jul 1	open
	Sep 9	A80 vessels subject to sideboard limits
	Sep 11	halibut bycatch status
	Oct 1	open
	Nov 6	halibut bycatch status
	Nov 16	open
2009	Jan 20	open
	Mar 3	halibut bycatch status
	Apr 1	open
	Apr 23	halibut bycatch status
	Jul 1	open

Table 6.3a. Annual fishery size compositions for female rex sole. The 2009 composition is based on observer reports through Sept. 26.

year	Length cutpoints (cm)																
	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41
1982	0.0001	0.0000	0.0010	0.0018	0.0000	0.0004	0.0003	0.0004	0.0005	0.0015	0.0057	0.0362	0.1111	0.1040	0.0590	0.0332	0.0153
1983	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0046	0.0185	0.0386	0.0974	0.1097	0.0788	0.0216
1984	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0101	0.0067	0.0236	0.0471	0.0404	0.0640
1990	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0011	0.0003	0.0055	0.0050	0.0151	0.0225	0.0291	0.0366	0.0491	0.0530
1991	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0008	0.0017	0.0009	0.0032	0.0070	0.0117	0.0226	0.0414	0.0717	0.0920
1992	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0005	0.0003	0.0010	0.0021	0.0055	0.0075	0.0131	0.0256	0.0382	0.0588	0.0946
1993	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0006	0.0010	0.0028	0.0050	0.0121	0.0345	0.0778	0.1167
1994	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0005	0.0006	0.0015	0.0029	0.0092	0.0244	0.0476	0.0865	0.1066
1995	0.0000	0.0000	0.0002	0.0002	0.0000	0.0006	0.0006	0.0004	0.0008	0.0015	0.0025	0.0075	0.0098	0.0137	0.0315	0.0653	0.0960
1996	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0003	0.0003	0.0007	0.0012	0.0038	0.0082	0.0213	0.0449	0.0791
1997	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0003	0.0007	0.0030	0.0025	0.0047	0.0074	0.0126	0.0172	0.0279	0.0381	0.0451
1998	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0004	0.0009	0.0018	0.0038	0.0115	0.0309	0.0635
1999	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0007	0.0007	0.0012	0.0037	0.0056	0.0133	0.0239	0.0418	0.0634
2000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0005	0.0006	0.0009	0.0031	0.0056	0.0101	0.0138	0.0342	0.0479	0.0702
2001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0009	0.0020	0.0026	0.0040	0.0072	0.0187	0.0448	0.0701
2002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0004	0.0005	0.0007	0.0018	0.0070	0.0174	0.0303	0.0548	0.0711
2003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0008	0.0016	0.0038	0.0081	0.0146	0.0309	0.0526	0.0597
2004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0019	0.0010	0.0029	0.0038	0.0318	0.0318	0.0760	0.0914
2005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0042	0.0050	0.0126	0.0378	0.0739	0.0849	0.0941
2006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0021	0.0103	0.0206	0.0351	0.0557	0.0804	0.0701
2007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.0000	0.0014	0.0019	0.0019	0.0094	0.0174	0.0334	0.0763	0.1149
2008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0012	0.0024	0.0047	0.0144	0.0309	0.0567	0.0825	0.0722
2009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0009	0.0009	0.0018	0.0022	0.0046	0.0137	0.0280	0.0467	0.0720	0.0770

Table 6.3b. Annual fishery size compositions for male rex sole. The 2009 composition is based on observer reports through Sept. 26.

year	Length cutpoints (cm)																
	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41
1982	0.0000	0.0003	0.0022	0.0022	0.0009	0.0006	0.0017	0.0006	0.0022	0.0056	0.0227	0.0968	0.2051	0.1560	0.0822	0.0342	0.0082
1983	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0015	0.0015	0.0031	0.0185	0.0371	0.0526	0.0680	0.1963	0.1901	0.0541	0.0046
1984	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0067	0.0572	0.1313	0.3502	0.2088	0.0370
1990	0.0000	0.0000	0.0000	0.0000	0.0000	0.0019	0.0006	0.0023	0.0055	0.0086	0.0177	0.0322	0.0536	0.1082	0.1467	0.1283	0.0622
1991	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0009	0.0025	0.0045	0.0078	0.0089	0.0259	0.0649	0.1251	0.1349	0.0664
1992	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0008	0.0015	0.0020	0.0054	0.0127	0.0239	0.0498	0.0812	0.1053	0.0774
1993	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0002	0.0004	0.0013	0.0028	0.0087	0.0219	0.0590	0.1195	0.1214	0.0766
1994	0.0000	0.0000	0.0000	0.0000	0.0002	0.0001	0.0003	0.0005	0.0006	0.0013	0.0028	0.0084	0.0314	0.0751	0.1260	0.1150	0.0634
1995	0.0000	0.0000	0.0000	0.0002	0.0002	0.0010	0.0000	0.0015	0.0010	0.0019	0.0077	0.0160	0.0292	0.0502	0.0701	0.0805	0.0541
1996	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0007	0.0010	0.0032	0.0051	0.0080	0.0249	0.0522	0.0786	0.0990	0.0850
1997	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0007	0.0022	0.0038	0.0057	0.0101	0.0185	0.0421	0.0636	0.0846	0.0959	0.0898
1998	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0003	0.0011	0.0014	0.0047	0.0168	0.0290	0.0486	0.0573	0.0559
1999	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0004	0.0011	0.0023	0.0045	0.0076	0.0186	0.0356	0.0589	0.0763	0.0832	0.0838
2000	0.0000	0.0000	0.0000	0.0002	0.0005	0.0008	0.0014	0.0026	0.0051	0.0050	0.0118	0.0189	0.0386	0.0626	0.0694	0.0603	0.0534
2001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0009	0.0020	0.0052	0.0083	0.0210	0.0419	0.0554	0.0718	0.0781	0.0758
2002	0.0000	0.0000	0.0000	0.0004	0.0000	0.0002	0.0004	0.0005	0.0027	0.0048	0.0115	0.0319	0.0665	0.0801	0.0867	0.0711	0.0430
2003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002	0.0000	0.0005	0.0030	0.0071	0.0236	0.0621	0.1016	0.1085	0.1084	0.0748
2004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0010	0.0000	0.0019	0.0000	0.0000	0.0212	0.0539	0.1309	0.1405	0.0972	0.0423
2005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0059	0.0261	0.0571	0.1084	0.1328	0.0891	0.0429
2006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0041	0.0041	0.0247	0.0330	0.1031	0.1010	0.0866	0.0701
2007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0009	0.0005	0.0024	0.0052	0.0028	0.0094	0.0212	0.0523	0.0853	0.1069	0.0923	0.0546
2008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0013	0.0009	0.0027	0.0089	0.0218	0.0612	0.0955	0.1181	0.0950	0.0745
2009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0008	0.0031	0.0043	0.0208	0.0444	0.0961	0.1606	0.1470	0.0770

Table 6.4a. Sample sizes from the domestic fishery.

year	Size compositions			
	hauls	total indiv.s	females	males
1990	74	7438	2482	3693
1991	257	18652	4724	4339
1992	220	19586	8045	6420
1993	372	25972	9067	7293
1994	328	19756	6935	6038
1995	257	11868	3282	1897
1996	277	18548	8212	6474
1997	193	10305	4962	5070
1998	213	10509	4609	3313
1999	393	8294	4466	3816
2000	347	7435	4484	2881
2001	194	3546	1949	1594
2002	320	5790	3110	2667
2003	352	6414	2662	3706
2004	62	1039	484	555
2005	71	1205	615	590
2006	37	501	256	229
2007	140	2261	1189	1057
2008	159	2677	1205	1459
2009	210	3831	1773	1975

Table 6.4b. Sample sizes from the GOA groundfish survey.

year	biomass	Size compositions				Age compositions			
	total hauls	hauls	total indiv.s	females	males	hauls	total indiv.s	females	males
1984	929	310	16927	6739	7191	5	233	155	78
1987	783	105	11577	5364	5998	5	189	102	87
1990	708	237	14387	7593	6793	27	270	156	114
1993	775	374	19100	9943	8166	29	332	193	139
1996	807	517	14496	6768	7718	77	370	212	158
1999	764	469	11652	5408	6204				
2001	489	278	7675	3861	3814	57	290	167	122
2003	809	520	17833	8778	9028	95	596	328	266
2005	839	551	19233	9393	9806	102	588	310	278
2007	820	514	17305	8606	8555	55	416	220	196
2009	823	555	19933	9969	9941				

Table 6.5. Biomass estimates (t) for GOA rex sole from the NMFS groundfish trawl surveys. Note that the Eastern Gulf (West Yakutat + Southeast) was not surveyed in 2001.

a) Biomass by NPFMC regulatory area. "Max Depth" is the maximum depth stratum surveyed.

Year	Western Gulf	Central Gulf	West Yakutat	Southeast	Total Gulf	Std. Dev	Max Depth (m)
1984	6,672	40,688	9,209	4,102	60,670	6,023	1000
1987	8,801	39,722	11,160	4,144	63,826	5,906	1000
1990	6,765	75,147	12,745	3,569	98,225	10,731	500
1993	10,700	55,310	15,761	5,140	86,911	6,211	500
1996	9,419	43,778	9,855	9,705	72,757	5,301	500
1999	12,755	42,750	10,138	9,326	74,969	8,655	1000
2001	9,571	41,687	--	--	51,258	4,404	500
2003	13,265	57,973	10,566	18,093	99,897	7,559	700
2005	12,766	60,600	11,539	16,351	101,255	8,195	1000
2007	11,614	76,490	5,914	9,758	103,776	9,646	1000
2009	19,780	82,091	11,318	11,555	124,744	9,608	1000

b) Biomass by depth stratum.

year	Depth strata (m)				
	1-100	100-200	200-300	300-500	> 500
1984	3,987	37,040	13,083	5,161	1,399
1987	5,691	40,244	14,508	1,812	1,572
1990	15,460	59,833	21,791	1,140	--
1993	11,233	54,064	16,995	4,619	--
1996	10,403	43,419	14,929	4,006	--
1999	14,682	40,239	15,766	3,841	440
2001	7,742	29,206	11,045	3,265	--
2003	17,529	58,787	19,094	4,017	470
2005	14,783	65,060	16,731	4,535	146
2007	9,081	71,514	18,368	4,504	309
2009	16,017	79,662	25,032	2,980	1,054

Table 6.6. Survey size compositions for rex sole.

a) Females.

year	Length cutpoints (cm) 9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39
1984	0	0	0	0	3	23	19	97	840	1,308	2,470	4,097	5,170	7,447	7,045	5,718
1987	0	0	31	0	16	248	305	549	842	1,195	2,553	3,356	6,358	6,603	5,176	4,301
1990	0	0	0	10	160	395	817	865	1,153	1,805	2,024	4,762	5,067	6,251	6,752	9,871
1993	0	14	11	62	196	277	459	289	617	873	1,772	2,711	4,842	6,108	7,378	6,743
1996	0	33	120	228	526	648	723	871	1,597	1,771	2,511	2,752	3,881	4,426	4,488	3,901
1999	22	19	143	385	691	1,267	1,285	1,847	2,048	3,265	4,183	3,902	4,201	4,891	4,706	3,885
2001	31	29	117	281	713	1,278	1,489	1,269	2,358	2,101	2,634	3,570	3,685	2,669	2,591	3,175
2003	54	381	621	810	1,540	2,067	3,045	4,036	5,512	7,409	7,732	8,741	9,200	10,279	8,154	6,297
2005	0	142	248	1,041	1,058	1,165	1,355	1,959	2,656	4,609	6,658	8,276	9,409	9,552	9,096	8,051
2007	11	0	278	1,188	2,479	3,241	3,434	2,656	3,480	3,725	5,202	6,154	6,364	6,491	7,605	8,993
2009	0	23	37	350	1,075	1,826	1,651	3,067	4,814	5,104	6,365	9,590	9,865	9,195	9,644	8,556

b) Males.

year	Length cutpoints (cm) 9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39
1984	0	0	7	7	14	110	103	272	1,441	2,394	3,914	7,600	8,668	5,440	2,989	1,524
1987	0	0	0	51	21	605	1,141	1,580	1,842	2,571	4,669	6,414	8,499	7,086	5,178	3,249
1990	0	0	26	58	345	550	1,342	1,139	1,864	2,859	5,108	8,256	9,449	10,553	8,447	5,284
1993	11	0	5	156	233	557	466	814	1,230	2,473	4,023	6,611	8,960	8,551	7,814	5,786
1996	40	42	128	421	492	740	964	1,476	2,845	4,087	5,543	6,851	7,833	6,484	5,014	3,618
1999	22	90	178	383	1,138	2,380	1,900	2,469	3,991	4,981	5,258	8,072	7,394	6,979	5,540	4,035
2001	0	33	74	373	1,062	1,352	1,669	2,292	2,087	3,714	3,721	4,025	3,111	2,431	3,114	3,019
2003	0	302	661	1,179	1,426	2,817	4,467	6,065	7,026	9,971	11,989	14,253	11,998	8,905	5,776	3,914
2005	112	26	531	577	1,153	1,226	1,667	3,036	5,553	8,066	10,148	11,558	12,135	9,826	6,806	4,956
2007	0	0	73	549	1,434	2,301	2,703	2,626	3,529	5,238	8,630	8,576	9,674	9,157	9,447	6,897
2009	7	0	95	480	872	1,939	2,639	4,150	5,567	8,132	10,714	15,152	16,407	14,480	10,365	6,841

Table 6.7. Survey age compositions (in 1000's) for rex sole. The age composition for 1990 was not used in the assessment model because the ages were probably underestimated due to the ageing technique (surface age reading) used.

a) Females.

year	Age bin 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1984	0	4,034	5,375	6,379	6,153	6,211	6,291	4,308	4,791	5,447	6,145	2,685	8,774	7,386	3,001	2,307
1987	0	5,468	2,088	5,579	7,797	11,349	6,408	10,242	10,505	2,668	4,923	2,270	2,518	2,310	600	395
1990	9,751	10,080	41,666	29,769	23,529	12,381	1,245	205	217	0	0	0	0	0	0	0
1993	903	1,415	21,052	16,290	21,540	16,457	9,562	9,713	5,134	2,389	1,834	243	994	90	0	0
1996	1,983	4,792	6,637	8,970	7,879	4,544	10,244	11,775	9,820	8,374	4,782	5,606	3,214	814	2,459	780
2001	4,096	13,765	14,387	9,901	6,724	3,507	3,157	733	2,089	1,360	2,606	1,102	615	1,317	1,790	3,784
2003	8,022	19,580	23,987	29,895	15,374	13,203	8,809	5,058	3,482	5,708	7,820	2,817	3,308	3,968	4,726	5,719
2005	5,506	11,846	26,923	14,655	21,590	17,008	12,093	9,703	5,542	4,492	4,891	5,493	4,762	2,518	1,226	1,829
2007	9,128	16,469	14,031	10,915	14,489	25,930	21,932	7,248	6,418	4,838	752	1,329	1,774	882	1,316	1,129

b) Males.

year	Age bin 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1984	0	11,696	14,404	5,642	3,556	9,754	1,817	3,148	1,956	1,734	996	4,661	0	3,497	1,976	2,588
1987	1,580	6,167	13,342	7,596	12,547	8,620	2,872	8,290	3,110	12,695	1,142	516	1,260	780	0	0
1990	11,896	24,450	52,356	26,245	8,333	688	0	0	0	0	0	0	0	0	0	0
1993	2,389	4,926	24,642	24,216	15,868	6,658	11,018	6,722	5,870	708	59	1,302	436	0	0	0
1996	4,905	7,138	17,588	14,689	11,723	7,396	12,189	7,105	7,346	4,370	3,153	340	991	0	0	0
2001	6,295	11,848	13,670	14,098	4,190	1,538	0	0	3,037	1,452	608	1,378	515	1,421	778	1,016
2003	15,432	18,937	22,860	38,205	25,693	10,704	11,233	4,742	8,781	3,591	5,540	5,426	2,027	2,122	3,482	2,351
2005	7,794	19,670	30,953	29,080	16,589	7,876	6,651	6,396	4,657	3,923	4,912	3,258	3,449	5,568	1,312	1,011
2007	6,681	20,353	7,348	20,081	19,098	19,882	15,149	6,522	2,449	0	962	962	3,996	2,876	3,616	2,326

Table 6.8. Age-length conversion matrices for rex 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.

a) Females.

age	length cutpoints (cm) 9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
3	0	0.0002	0.0022	0.0143	0.0589	0.1528	0.2504	0.2594	0.1698	0.0702	0.0183	0.003	0.0003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0.0001	0.0004	0.0024	0.0107	0.0351	0.0855	0.1551	0.2091	0.2096	0.1561	0.0865	0.0356	0.0109	0.0025	0.0004	0.0001	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0.0003	0.0013	0.0051	0.0164	0.0421	0.0858	0.1396	0.1811	0.1872	0.1544	0.1015	0.0532	0.0222	0.0074	0.002	0.0004	0.0001	0	0	0	0	0	0	0	0
6	0	0	0	0	0.0001	0.0003	0.0012	0.0045	0.0132	0.0323	0.0653	0.1093	0.1513	0.1731	0.1639	0.1283	0.0831	0.0445	0.0197	0.0072	0.0022	0.0005	0.0001	0	0	0	0	0	0
7	0	0	0	0	0	0.0001	0.0005	0.0017	0.0055	0.0147	0.0332	0.0635	0.1027	0.1404	0.162	0.1581	0.1303	0.0907	0.0534	0.0266	0.0112	0.004	0.0012	0.0003	0.0001	0	0	0	0
8	0	0	0	0	0	0.0001	0.0002	0.0009	0.0029	0.0081	0.0195	0.0404	0.0715	0.1084	0.1408	0.1566	0.1492	0.1217	0.0851	0.0509	0.0261	0.0114	0.0043	0.0014	0.0004	0.0001	0	0	0
9	0	0	0	0	0	0	0.0001	0.0005	0.0018	0.0052	0.0131	0.0284	0.0532	0.0862	0.1205	0.1456	0.1521	0.1372	0.1069	0.072	0.0419	0.0211	0.0092	0.0034	0.0011	0.0003	0.0001	0	0
10	0	0	0	0	0	0	0.0001	0.0004	0.0013	0.0038	0.0097	0.0218	0.0424	0.0715	0.1051	0.1341	0.1488	0.1435	0.1202	0.0876	0.0555	0.0305	0.0146	0.0061	0.0022	0.0007	0.0002	0	0
11	0	0	0	0	0	0	0.0001	0.0003	0.001	0.003	0.0078	0.0179	0.0356	0.062	0.094	0.1246	0.144	0.1453	0.1279	0.0983	0.066	0.0386	0.0197	0.0088	0.0034	0.0012	0.0003	0.0001	0
12	0	0	0	0	0	0	0.0001	0.0002	0.0008	0.0025	0.0067	0.0155	0.0313	0.0556	0.0863	0.1173	0.1395	0.1452	0.1323	0.1056	0.0737	0.0451	0.0241	0.0113	0.0046	0.0017	0.0005	0.0001	0
13	0	0	0	0	0	0	0.0001	0.0002	0.0007	0.0022	0.006	0.0139	0.0285	0.0513	0.0808	0.1118	0.1357	0.1444	0.1348	0.1104	0.0793	0.05	0.0276	0.0134	0.0057	0.0021	0.0007	0.0002	0.0001
14	0	0	0	0	0	0	0	0.0002	0.0007	0.002	0.0055	0.0129	0.0266	0.0483	0.077	0.1078	0.1327	0.1435	0.1363	0.1137	0.0834	0.0537	0.0304	0.0151	0.0066	0.0025	0.0008	0.0003	0.0001
15	0	0	0	0	0	0	0	0.0002	0.0006	0.0019	0.0051	0.0121	0.0252	0.0462	0.0742	0.1049	0.1305	0.1427	0.1372	0.116	0.0863	0.0564	0.0324	0.0164	0.0073	0.0029	0.001	0.0003	0.0001
16	0	0	0	0	0	0	0	0.0002	0.0006	0.0018	0.0049	0.0116	0.0243	0.0447	0.0722	0.1028	0.1288	0.142	0.1377	0.1176	0.0883	0.0584	0.034	0.0174	0.0078	0.0031	0.0011	0.0003	0.0001
17	0	0	0	0	0	0	0	0.0002	0.0006	0.0018	0.0047	0.0113	0.0237	0.0436	0.0708	0.1013	0.1275	0.1414	0.1381	0.1187	0.0899	0.0599	0.0352	0.0182	0.0083	0.0033	0.0012	0.0004	0.0001
18	0	0	0	0	0	0	0	0.0002	0.0006	0.0017	0.0046	0.011	0.0232	0.0429	0.0698	0.1002	0.1266	0.141	0.1383	0.1195	0.0909	0.061	0.036	0.0187	0.0086	0.0035	0.0012	0.0004	0.0001
19	0	0	0	0	0	0	0	0.0002	0.0005	0.0017	0.0046	0.0109	0.0228	0.0423	0.0691	0.0993	0.1259	0.1406	0.1384	0.12	0.0917	0.0618	0.0367	0.0192	0.0088	0.0036	0.0013	0.0004	0.0001
20	0	0	0	0	0	0	0	0.0002	0.0005	0.0017	0.0045	0.0107	0.0226	0.0419	0.0685	0.0987	0.1254	0.1404	0.1385	0.1204	0.0923	0.0624	0.0371	0.0195	0.009	0.0037	0.0013	0.0004	0.0002

b) Males.

age	length cutpoints (cm) 9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
3	0	0.0006	0.0047	0.0254	0.0873	0.1906	0.2649	0.2344	0.1321	0.0474	0.0108	0.0016	0.0001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0.0001	0.001	0.0052	0.0204	0.059	0.1251	0.1947	0.2221	0.1857	0.1139	0.0512	0.0169	0.0041	0.0007	0.0001	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0.0001	0.0006	0.0029	0.0112	0.0331	0.076	0.1353	0.1867	0.1998	0.1658	0.1067	0.0533	0.0206	0.0062	0.0014	0.0003	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0.0001	0.0007	0.003	0.0106	0.0299	0.0669	0.1192	0.169	0.1907	0.1712	0.1223	0.0695	0.0314	0.0113	0.0032	0.0007	0.0001	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0.0002	0.0011	0.0043	0.0139	0.036	0.0751	0.1261	0.1706	0.1856	0.1626	0.1146	0.0651	0.0297	0.0109	0.0032	0.0008	0.0001	0	0	0	0	0	0	0
8	0	0	0	0	0	0.0001	0.0005	0.0021	0.0075	0.0217	0.0506	0.0956	0.1459	0.1798	0.179	0.144	0.0936	0.0491	0.0208	0.0071	0.002	0.0004	0.0001	0	0	0	0	0	0
9	0	0	0	0	0	0	0.0002	0.0011	0.0045	0.0143	0.0367	0.0758	0.1263	0.1699	0.1845	0.1616	0.1143	0.0652	0.03	0.0112	0.0033	0.0008	0.0002	0	0	0	0	0	0
10	0	0	0	0	0	0	0.0001	0.0007	0.0029	0.0101	0.0281	0.0626	0.1121	0.1611	0.1861	0.1727	0.1288	0.0772	0.0372	0.0144	0.0045	0.0011	0.0002	0	0	0	0	0	0
11	0	0	0	0	0	0	0.0001	0.0004	0.002	0.0075	0.0225	0.0535	0.1017	0.1544	0.1869	0.1806	0.1393	0.0857	0.0421	0.0165	0.0052	0.0013	0.0003	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0.0003	0.0014	0.0057	0.0184	0.0468	0.0941	0.1496	0.1881	0.1871	0.1472	0.0916	0.0451	0.0176	0.0054	0.0013	0.0003	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0.0002	0.001	0.0044	0.0154	0.0416	0.0882	0.1462	0.1898	0.1929	0.1534	0.0956	0.0466	0.0178	0.0053	0.0012	0.0002	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0.0001	0.0007	0.0035	0.0129	0.0374	0.0834	0.144	0.1923	0.1986	0.1587	0.098	0.0469	0.0173	0.0049	0.0011	0.0002	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0.0001	0.0005	0.0027	0.0109	0.0337	0.0793	0.1425	0.1953	0.2044	0.1632	0.0994	0.0462	0.0164	0.0044	0.0009	0.0001	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0.0004	0.0021	0.0092	0.0304	0.0756	0.1414	0.1989	0.2103	0.1672	0.0999	0.0449	0.0151	0.0038	0.0007	0.0001	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0.0002	0.0016	0.0076	0.0273	0.072	0.1406	0.203	0.2166	0.1709	0.0996	0.043	0.0137	0.0032	0.0006	0.0001	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0.0002	0.0012	0.0063	0.0244	0.0685	0.14	0.2074	0.2232	0.1743	0.0988	0.0406	0.0121	0.0026	0.0004	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0.0001	0.0009	0.0051	0.0216	0.065	0.1393	0.2123	0.2301	0.1775	0.0973	0.038	0.0105	0.0021	0.0003	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0.0004	0.0032	0.0164	0.0577	0.1378	0.2232	0.2453	0.1829	0.0926	0.0318	0.0074	0.0012	0.0001	0	0	0	0	0	0	0

Table 6.9. Age-specific schedules for rex sole in the Gulf of Alaska. The maturity ogive is based on Abookire (2006).

	Length (cm)		Weight (g)		Maturity
Age	Males	Females	Males	Females	ogive
3	22.44	22.96	31.52	23.74	0.0083
4	27.84	28.81	64.22	51.93	0.0763
5	31.52	33.10	96.88	83.82	0.3073
6	34.05	36.24	124.95	114.66	0.6037
7	35.77	38.55	147.12	141.86	0.7901
8	36.95	40.24	163.77	164.52	0.8796
9	37.76	41.48	175.89	182.70	0.9224
10	38.31	42.39	184.53	196.91	0.9444
11	38.68	43.06	190.60	207.82	0.9566
12	38.94	43.55	194.84	216.08	0.9639
13	39.12	43.91	197.77	222.29	0.9685
14	39.24	44.18	199.79	226.93	0.9715
15	39.32	44.37	201.18	230.37	0.9736
16	39.38	44.51	202.14	232.92	0.9749
17	39.42	44.61	202.79	234.80	0.9759
18	39.44	44.69	203.24	236.19	0.9766
19	39.46	44.75	203.55	237.21	0.9771
20	39.47	44.79	203.76	237.96	0.9775

Table 6.10. Likelihood multiplier settings for all model cases.

Fishery		Survey			Recruitment		
catch	size compositions	biomass	size compositions	age compositions	early	ordinary	late
20	1	1	2	1	1	1	1

Table 6.11. Initial parameter values. Subscripts for recruitment deviations (τ) run from 1965 to 2009, with the subscript increasing moving across, then down. Subscripts for fishing mortality deviations (ε) run from 1982 to 2009 in the same manner.

Recruitment											
$\overline{\ln R_0}$	17										
$\boldsymbol{t_t}$					1965-2009:	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	0.0000	0.0000	
Fishing mortality											
$\overline{\ln F}$	0										
$\boldsymbol{e_t}$	1982-2009:		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	

Fishery Selectivity

	females	**males**
slope	0.4	0.4
$\mathbf{A_{50}}$	5	5
scale par.	--	0

Survey Selectivity

	females	**males**
slope	0.8	0.4
$\mathbf{A_{50}}$	4	4
scale par.	--	0

Table 6.12. Comparison of likelihood components for the base case and the alternative models. Highlighted values are at least 0.5 log-likelihood units larger than the corresponding component from the other model, indicating better fit.

likelihood component	Case	
	base	Alternative 1
ordinary recruitment	5.67736	5.68131
"late" recruitment	0.112798	0.115397
"early" recruitment	1.93932	2.04959
fishery catch	0.153363	0.125684
fishery size composition	671.18	669.234
survey biomass	8.36697	6.77655
survey size composition	38.4412	38.6448
survey age composition	254.281	244.747

Table 6.13. Final parameter estimates. Subscripts for recruitment deviations (τ) run from 1965 to 2009, with the subscript increasing moving across, then down. Subscripts for fishing mortality deviations (ε) run from 1982 to 2009 in the same manner.

Recruitment										
$\overline{\ln R_0}$	16.997814									
τ_t				1965-2009:	-1.0084	-0.3541	-0.3952	-0.3397	-0.1538	-0.2098
	0.1121	-0.0955	-0.2172	-0.1569	-0.1767	-0.3209	-0.2503	-0.0214	0.0255	-0.1197
	-0.3899	0.0184	-0.0359	-0.5116	0.1290	0.3280	0.3313	0.3910	0.2431	0.2342
	0.1016	-0.3432	-0.1287	-0.3379	-0.4374	-0.4806	-0.0426	0.3374	0.4880	0.5300
	0.4995	0.5351	0.5452	0.2365	-0.0157	0.8768	0.2076	0.1952	0.1778	
Fishing mortality										
$\overline{\ln F}$	-2.7963879									
ε_t	1982-2009:	-0.6007	-1.0598	-1.5300	-2.3799	-2.8920	-0.4883	-0.4374	-1.0995	-0.3744
	0.9602	0.5666	0.4770	0.6203	0.6760	1.0121	0.5238	0.3494	0.4894	0.6935
	0.5656	0.6218	0.8771	0.0521	0.3566	0.6689	0.4294	0.2908	0.6314	

Fishery Selectivity

	females	**males**
slope	1.7271	0.9136
A_{50}	9.94	10.31
scale par.	--	0.0000

Survey Selectivity

	females	**males**
slope	1.2994	1.7734
A_{50}	4.12	3.64
scale par.	--	0.0000

Table 6.14. Model-estimated fishery catch and survey biomass.

year	catch (t)			survey biomass (t)		
	estimated	std dev	observed	estimated	std dev	observed
1982	1,014	159	959	73,022	3,931	
1983	636	99	595	72,999	3,784	
1984	399	62	365	73,517	3,661	60,670
1985	174	27	154	73,946	3,527	
1986	108	17	93	74,952	3,384	
1987	1,202	187	1,151	77,555	3,283	63,826
1988	1,244	194	1,192	80,610	3,237	
1989	639	99	599	84,498	3,226	
1990	1,322	206	1,269	88,921	3,230	98,225
1991	4,746	748	4,636	91,888	3,222	
1992	3,044	477	3,000	90,378	3,174	
1993	2,842	430	3,000	89,089	3,072	86,911
1994	3,400	510	3,673	86,587	2,948	
1995	3,686	550	4,021	82,688	2,815	
1996	5,098	743	5,874	77,917	2,686	72,757
1997	3,063	460	3,294	71,773	2,583	
1998	2,546	386	2,669	68,918	2,504	
1999	2,821	421	3,060	69,047	2,505	74,969
2000	3,241	479	3,591	71,769	2,599	
2001	2,659	394	2,940	76,254	2,743	71,326
2002	2,641	390	2,941	82,380	2,927	
2003	3,225	485	3,485	88,769	3,146	99,897
2004	1,445	222	1,464	94,176	3,416	
2005	2,174	337	2,176	99,643	3,690	101,255
2006	3,311	518	3,294	102,590	3,960	
2007	2,881	451	2,852	104,800	4,313	103,776
2008	2,751	431	2,703	107,710	4,879	
2009	4,107	634	4,230	109,030	5,297	124,744

Table 6.15. Estimated age 3+ population biomass and female spawning biomass.

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
1982	79	4	75	4	77		36	2	34	2	35	
1983	79	4	74	4	76		36	2	34	2	35	
1984	79	4	73	4	75		36	2	34	2	35	
1985	80	4	73	3	74		37	2	34	2	35	
1986	83	3	74	3	75		37	2	34	2	35	
1987	86	3	76	3	77		37	2	34	2	35	
1988	90	3	82	3	82		38	2	34	2	34	
1989	94	3	88	3	87		39	2	35	2	35	
1990	98	3	95	3	93		42	2	37	2	37	
1991	100	3	99	3	97		44	2	41	2	40	
1992	97	3	97	3	95		43	2	42	2	41	
1993	95	3	95	3	93		44	2	44	2	42	
1994	92	3	92	3	89		43	2	44	2	42	
1995	88	3	86	3	84		42	1	42	2	41	
1996	83	3	79	3	77		40	1	39	2	38	
1997	77	3	74	3	72		36	1	35	1	34	
1998	76	3	72	3	70		34	1	33	1	31	
1999	78	3	73	3	71		33	1	31	1	30	
2000	83	3	74	3	72		33	1	31	1	30	
2001	88	3	79	3	78		34	1	31	1	30	
2002	94	3	86	3	90		36	1	32	1	31	
2003	101	4	95	4	99		39	1	34	1	34	
2004	105	4	102	4	105		42	2	38	2	40	
2005	109	4	107	5	109		46	2	43	2	46	
2006	114	5	109	5			49	2	47	2		
2007	116	5	108	5			49	2	49	2		
2008	118	6					51	2				
2009	118	6					52	3				

Table 6.16. Estimated age 3 recruitment (in millions).

Year	2009 Assessment		2007 Assessment		2005 Assessment	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1982	49	7	43	6	42	
1983	47	7	37	5	37	
1984	29	6	23	4	24	
1985	55	9	44	7	41	
1986	67	9	50	7	48	
1987	67	10	65	8	66	
1988	71	9	100	11	93	
1989	61	7	72	9	69	
1990	61	7	70	8	69	
1991	53	6	53	7	52	
1992	34	5	25	5	25	
1993	42	6	31	6	32	
1994	34	5	34	6	33	
1995	31	5	19	5	20	
1996	30	5	23	7	27	
1997	46	7	68	20	64	
1998	68	8	40	16	40	
1999	79	8	67	13	70	
2000	82	8	47	16	45	
2001	79	8	121	20	130	
2002	82	9	75	24	145	
2003	83	10	120	22	51	
2004	61	9	49	17	48	
2005	47	9	48	6	47	
2006	116	21	47	6		
2007	59	7	59	7		
2008	59	8				
2009	58	7				

Table 6.17. Projected catch (t) for the seven projection scenarios.

year	Catch (t)						
	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5	scenario 6	scenario 7
2009	4,539	4,539	4,539	4,539	4,539	4,539	4,539
2010	16,756	16,756	8,780	9,308	0	20,207	16,756
2011	14,295	14,295	8,206	8,649	0	16,531	14,295
2012	12,312	12,312	7,653	8,024	0	13,743	14,851
2013	10,832	10,832	7,179	7,495	0	11,771	12,550
2014	9,770	9,770	6,794	7,069	0	10,430	10,963
2015	9,022	9,022	6,488	6,733	0	9,476	9,875
2016	8,486	8,486	6,246	6,469	0	8,703	9,008
2017	8,080	8,080	6,054	6,262	0	8,184	8,379
2018	7,789	7,789	5,905	6,102	0	7,888	7,998
2019	7,594	7,594	5,792	5,982	0	7,728	7,785
2020	7,468	7,468	5,709	5,894	0	7,658	7,685
2021	7,389	7,389	5,646	5,828	0	7,633	7,644
2022	7,332	7,332	5,594	5,774	0	7,622	7,626

Table 6.18. Female spawning biomass (t) for the seven projection scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 22,195 t and 19,421 t, respectively.

year	Female spawning biomass (t)						
	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5	scenario 6	scenario 7
2009	52,270	52,270	52,270	52,270	52,270	52,270	52,270
2010	52,151	52,151	52,151	52,151	52,151	52,151	52,151
2011	44,529	44,529	48,833	48,548	53,590	42,673	44,529
2012	38,311	38,311	45,575	45,072	54,427	35,393	38,311
2013	33,611	33,611	42,741	42,082	54,949	30,185	32,252
2014	30,210	30,210	40,414	39,650	55,297	26,611	28,033
2015	27,798	27,798	38,552	37,719	55,528	24,207	25,165
2016	26,094	26,094	37,067	36,193	55,665	22,623	23,236
2017	24,894	24,894	35,888	34,991	55,730	21,658	22,018
2018	24,082	24,082	34,972	34,064	55,759	21,119	21,316
2019	23,556	23,556	34,273	33,362	55,775	20,842	20,943
2020	23,231	23,231	33,751	32,841	55,792	20,723	20,771
2021	23,034	23,034	33,358	32,453	55,806	20,679	20,700
2022	22,894	22,894	33,040	32,140	55,796	20,642	20,651

Table 6.19. Fishing mortality for the seven projection scenarios.

year	Fishing mortality						
	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5	scenario 6	scenario 7
2009	0.0560	0.0560	0.0560	0.0560	0.0560	0.0560	0.0560
2010	0.2229	0.2229	0.1114	0.1185	0.0000	0.2746	0.2229
2011	0.2229	0.2229	0.1114	0.1185	0.0000	0.2746	0.2229
2012	0.2229	0.2229	0.1114	0.1185	0.0000	0.2746	0.2746
2013	0.2229	0.2229	0.1114	0.1185	0.0000	0.2746	0.2746
2014	0.2229	0.2229	0.1114	0.1185	0.0000	0.2746	0.2746
2015	0.2229	0.2229	0.1114	0.1185	0.0000	0.2725	0.2741
2016	0.2226	0.2226	0.1114	0.1185	0.0000	0.2653	0.2684
2017	0.2213	0.2213	0.1114	0.1185	0.0000	0.2588	0.2613
2018	0.2197	0.2197	0.1114	0.1185	0.0000	0.2548	0.2563
2019	0.2184	0.2184	0.1114	0.1185	0.0000	0.2523	0.2532
2020	0.2174	0.2174	0.1114	0.1185	0.0000	0.2511	0.2515
2021	0.2167	0.2167	0.1114	0.1185	0.0000	0.2507	0.2508
2022	0.2162	0.2162	0.1114	0.1185	0.0000	0.2508	0.2508

Table 6.20. Prohibited species catch (PSC) in the rex sole target fishery.

year	Halibut (kg)	Salmon (#'s) Chinook	non-Chinook	Total	Crab (#'s) Opilio Tanner	Bairdi Tanner	Red King	Blue King	Golden King	Total
2003	393,373	2,900	520	3,420	0	28,780	0	0	0	28,780
2004	304,274	494	1,049	1,543	0	9,014	0	0	0	9,014
2005	86,281	525	98	623	0	7,949	0	0	0	7,949
2006	208,398	1,445	557	2,002	0	73,530	0	0	0	73,530
2007	60,735	715	663	1,378	0	45,272	0	0	0	45,272
2008	173,430	0	140	140	0	48,204	0	0	0	48,204
2009	384,211	1,569	466	2,035	0	10,834	0	0	54	10,888

Table 6.21. Catch of non-prohibited species in the rex sole target fishery.

	2009		2008		2007		2006	
species	Total (t)	% retained	Total (t)	% retained	Total (t)	% retained	Total (t)	% retained
Atka mackerel	225	83%	0	0%	1	89%	6	88%
arrowtooth flounder	5,628	10%	2,501	12%	3,108	8%	4,321	3%
big skate	214	83%	70	96%	74	99%	99	69%
deep water flatfish	269	7%	227	3%	68	0%	48	0%
flathead sole	497	93%	283	81%	264	92%	269	83%
longnose skate	76	93%	36	97%	24	97%	29	93%
northern rockfish	37	38%	12	0%	12	0%	7	0%
all sharks, squid, sculpin, octopus	31	1%	9	0%	15	0%	67	0%
Pacific cod	557	86%	238	96%	409	88%	271	95%
pelagic rockfish complex	35	89%	5	94%	31	94%	4	58%
pollock	550	70%	70	95%	110	99%	51	100%
POP	399	34%	76	2%	68	10%	100	48%
rex sole	3,142	99%	1,091	98%	1,556	100%	1,714	98%
rougheye	10	27%	14	41%	4	94%	17	61%
other rockfish	3	9%	1	0%	0	0%	0	0%
sablefish	122	93%	35	76%	42	83%	38	89%
shallow water flatfish	32	88%	12	82%	10	100%	40	100%
shortraker	20	62%	4	71%	4	92%	11	100%
thornyheads	52	99%	29	100%	24	95%	20	99%
unidentified skates	50	66%	22	56%	103	50%	0	0%

Figures

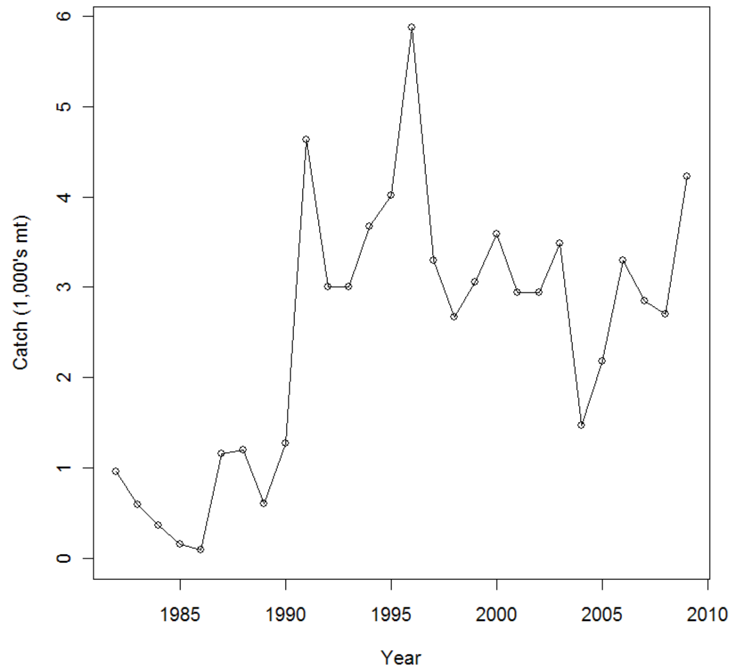


Figure 6.1. Fishery catches for GOA rex sole, 1982-2009. Catch for 2009 is through Sept. 26.

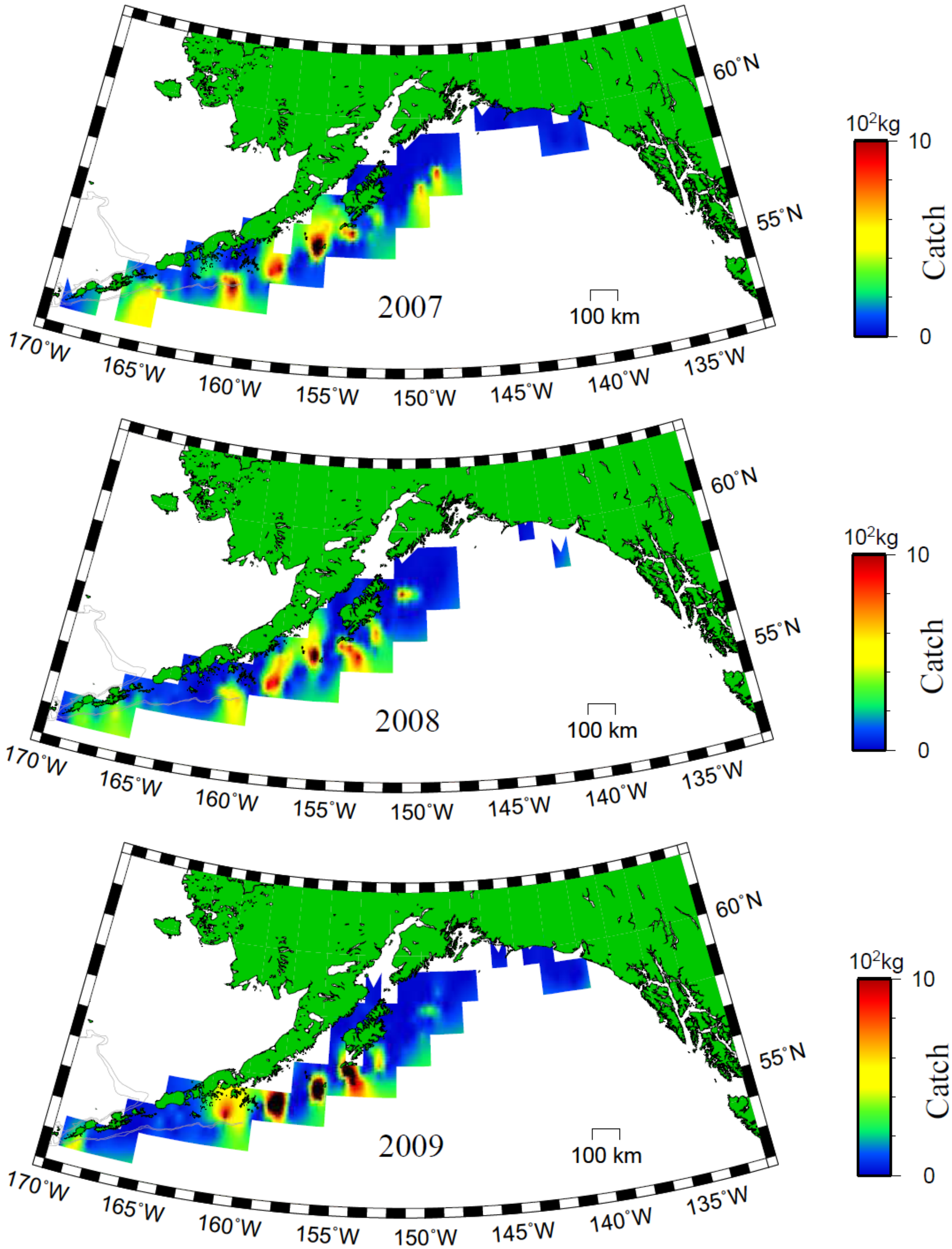


Figure 6.2. Spatial patterns of fishery catches for GOA rex sole, 2007-2009.

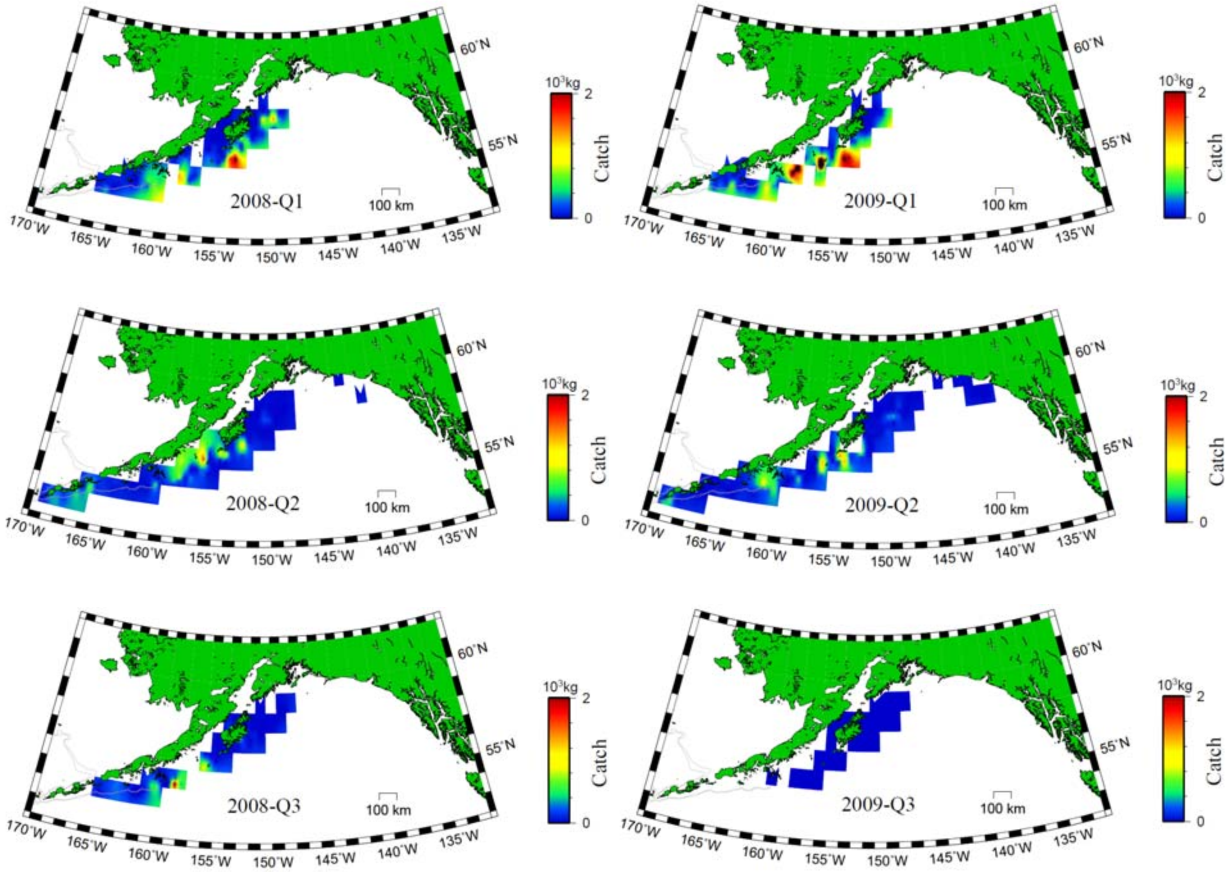


Figure 6.3. Spatial patterns of fishery catches for GOA rex sole from the first three quarters of 2008 and 2009.

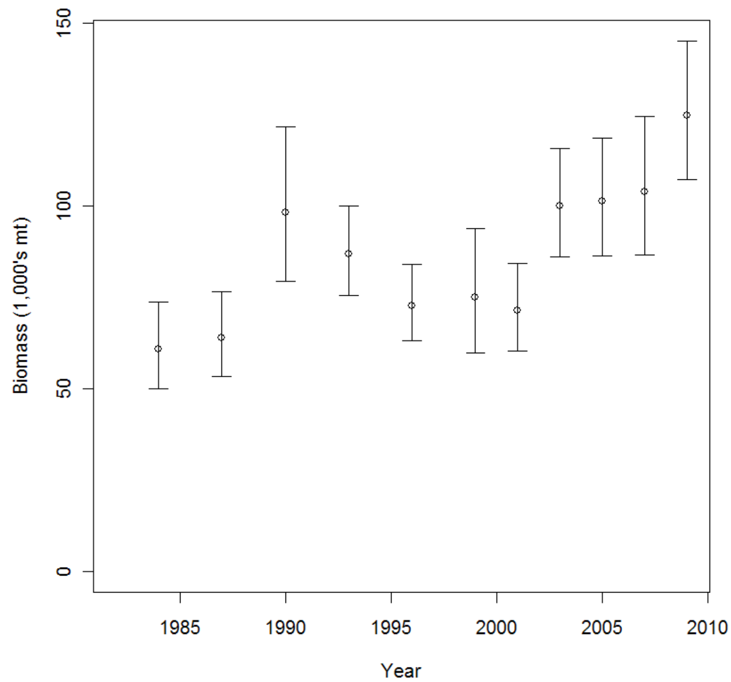


Figure 6.4. GOA survey biomass for rex sole. Error bars represent 95% lognormal confidence intervals. The 2001 GOA survey did not survey the Eastern Gulf. The value shown here for 2001 has been corrected to account for this (see text).

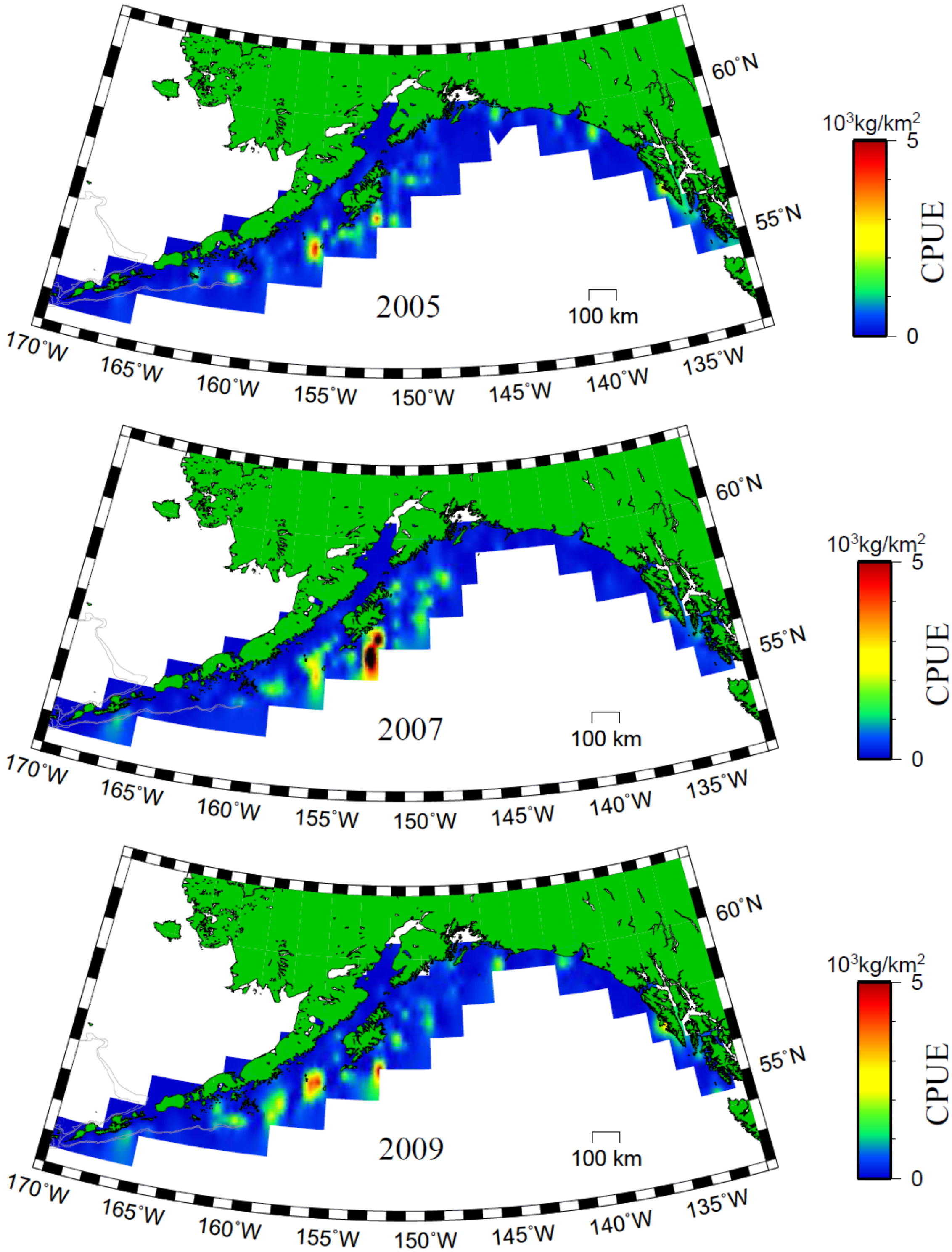
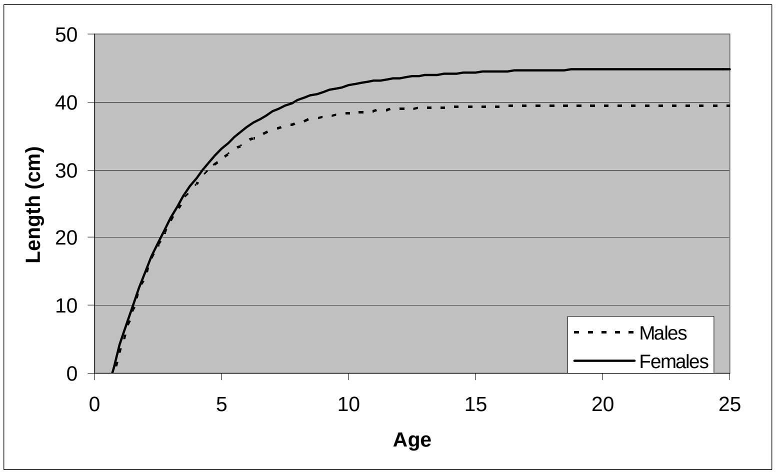
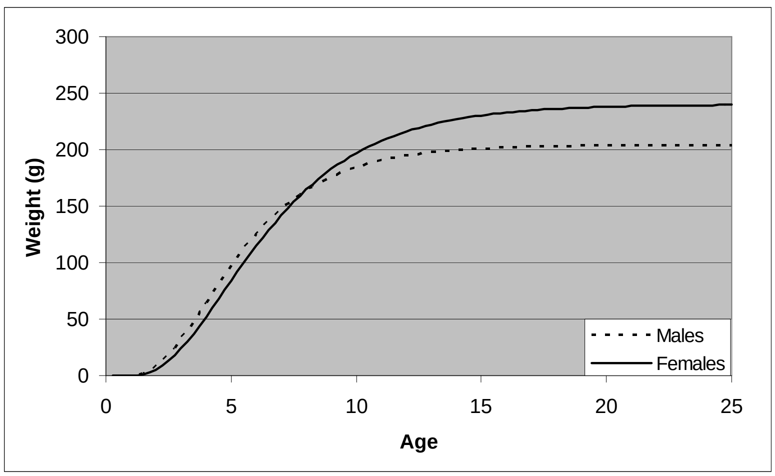


Figure 6.5. Spatial patterns of CPUE for rex sole in the GOA groundfish surveys for 2005, 2007 and 2009.

a) Length-at-age.



b) Weight-at-age.



c) Maturity-at-age (females).

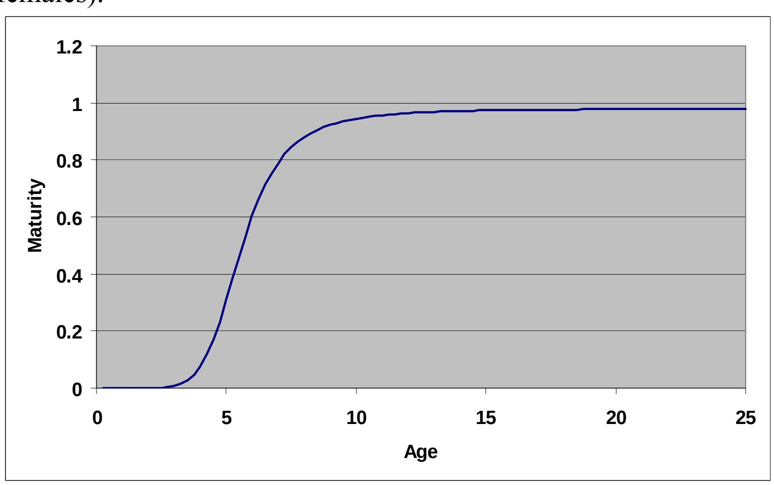


Figure 6.6. Age-specific schedules for GOA rex sole: females solid line, males dotted line.

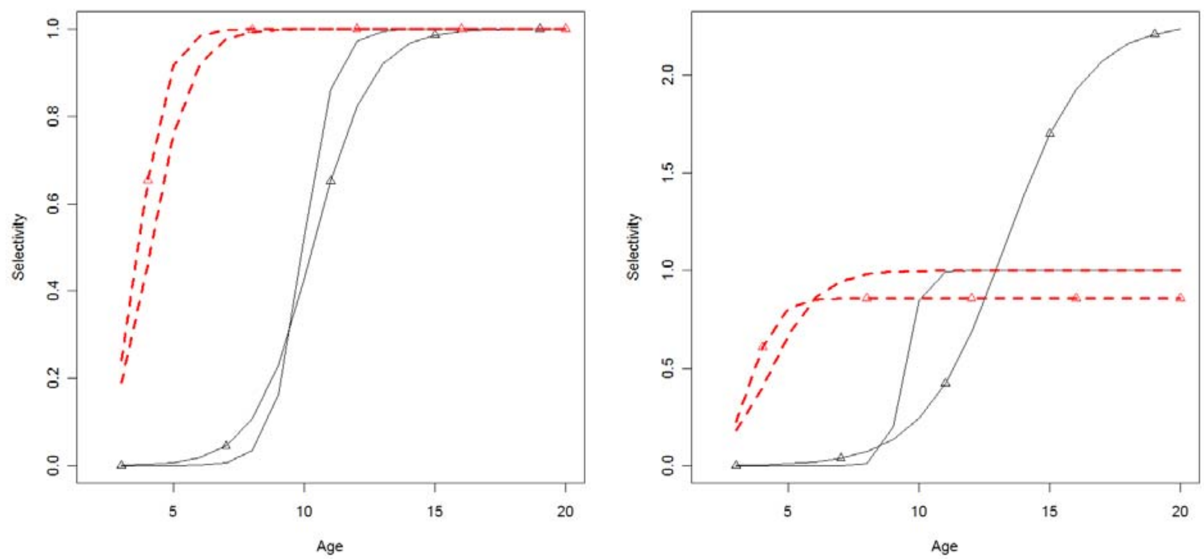


Figure 6.7. Comparison of selectivity functions from: a) the base case (left) and b) alternative 1 (right). Survey selectivities are plotted in red with a dotted line, fishery selectivities are plotted in black with asolid line. Male selectivity functions are plotted with a triangle symbol, female selectivity functions are plotted without a symbol.

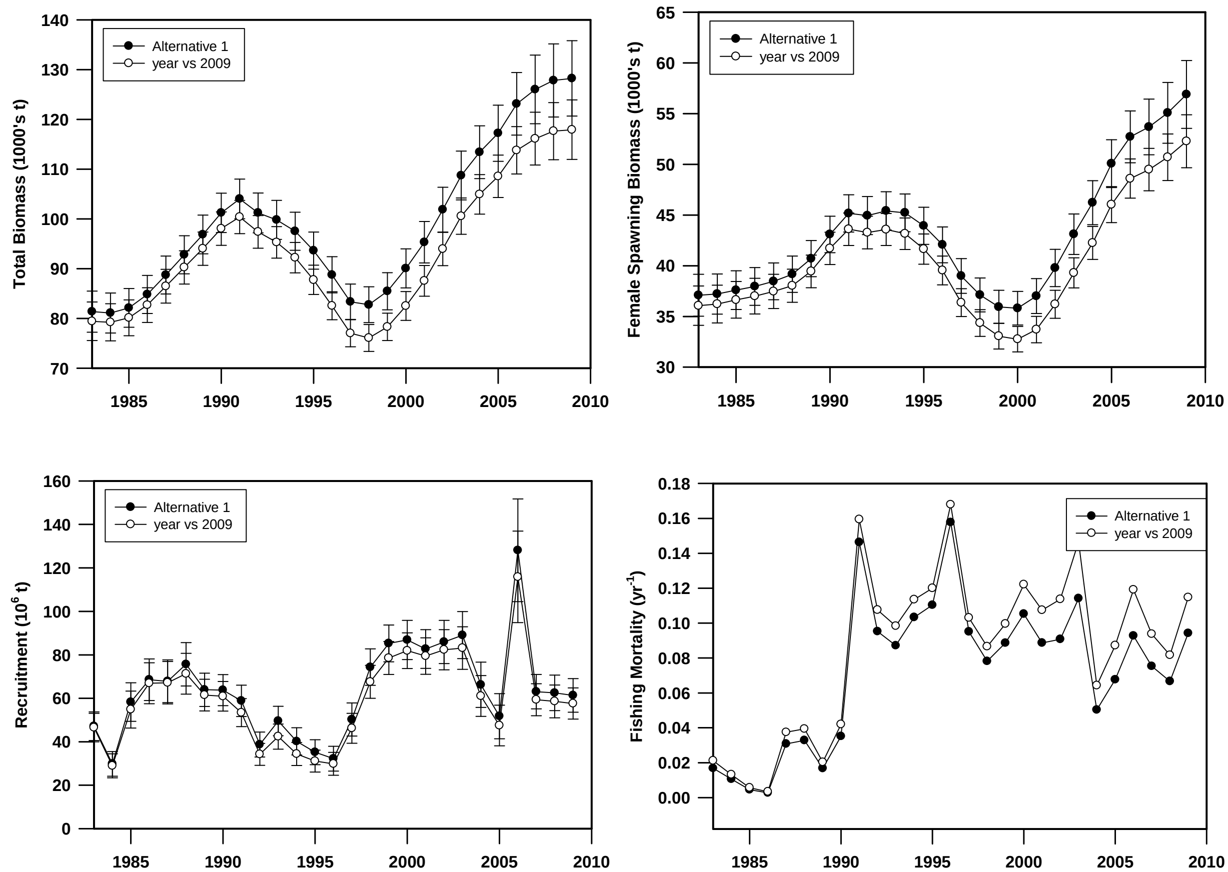


Figure 6.8. Further comparison of model results between the base case and the alternative using: a) estimated total biomass (upper left), b) estimated spawning biomass (upper right), c) recruitment (lower left), d) annual fishing mortality (lower right).

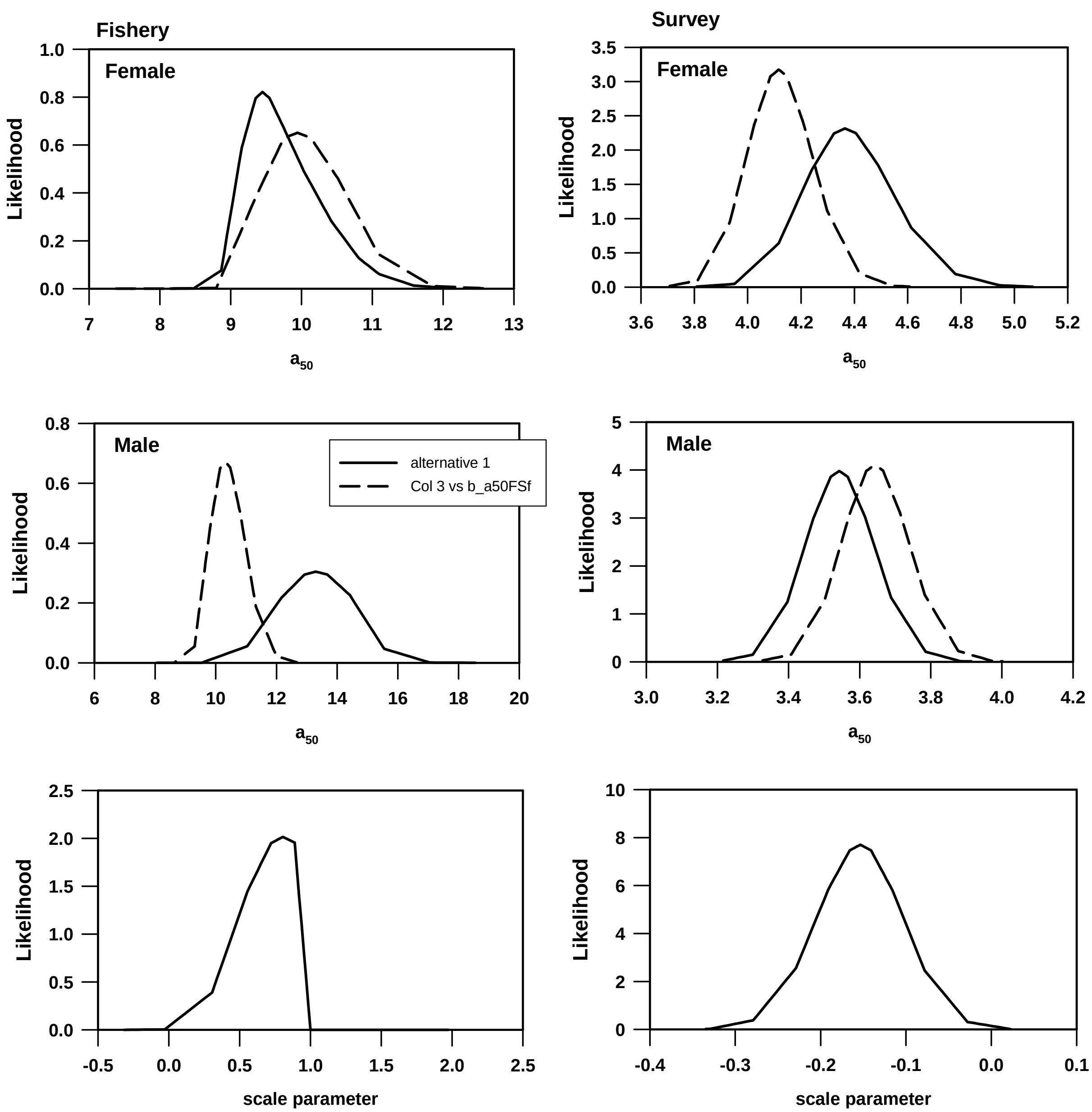


Figure 6.9. Comparison of likelihood profiles for fishery and survey selectivity-related parameters from the base case (dashed line) and the alternative case (solid line). "a50" denotes the parameter for the age at which the unscaled logistic function is 50%. "scale parameter" denotes the log-scale offset for scaling male selectivity relative to asymptotic female selectivity. Note that the (log-scale) upper limit on the scale parameter is 1.0, hence the odd shape of the likelihood in the lower left graph.

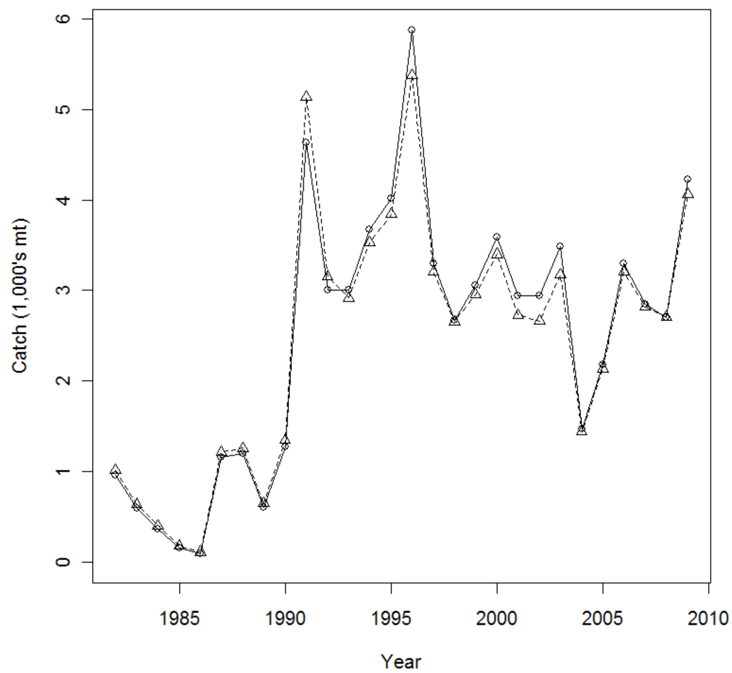


Figure 6.10. Predicted and observed annual catches for GOA rex sole from the preferred model. Predicted catch = dotted line with circles, observed catch = solid line.

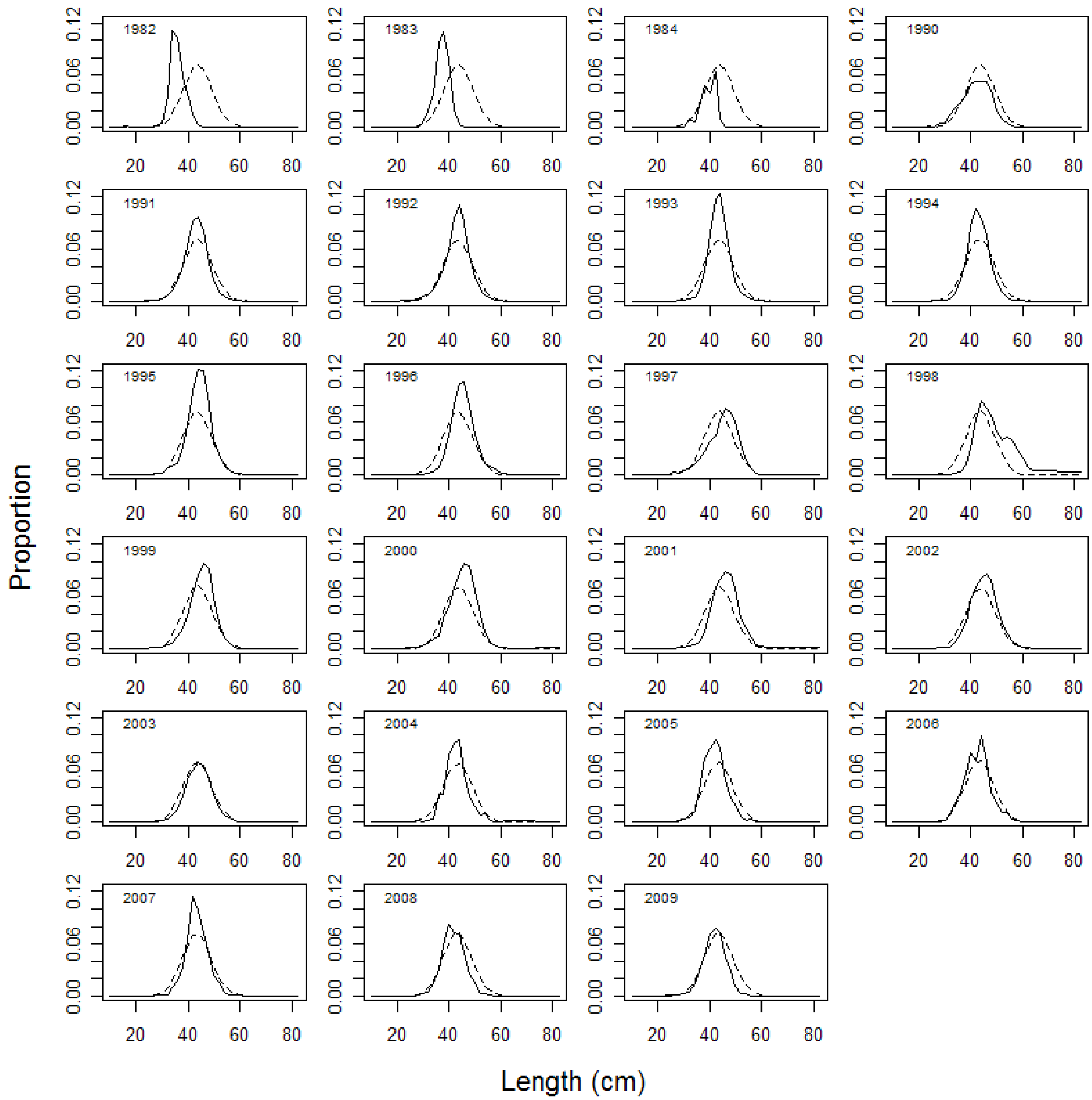


Figure 6.11a. Fit to female GOA rex sole fishery size composition data for the preferred model. Dashed lines represent the model prediction, solid lines represent the data.

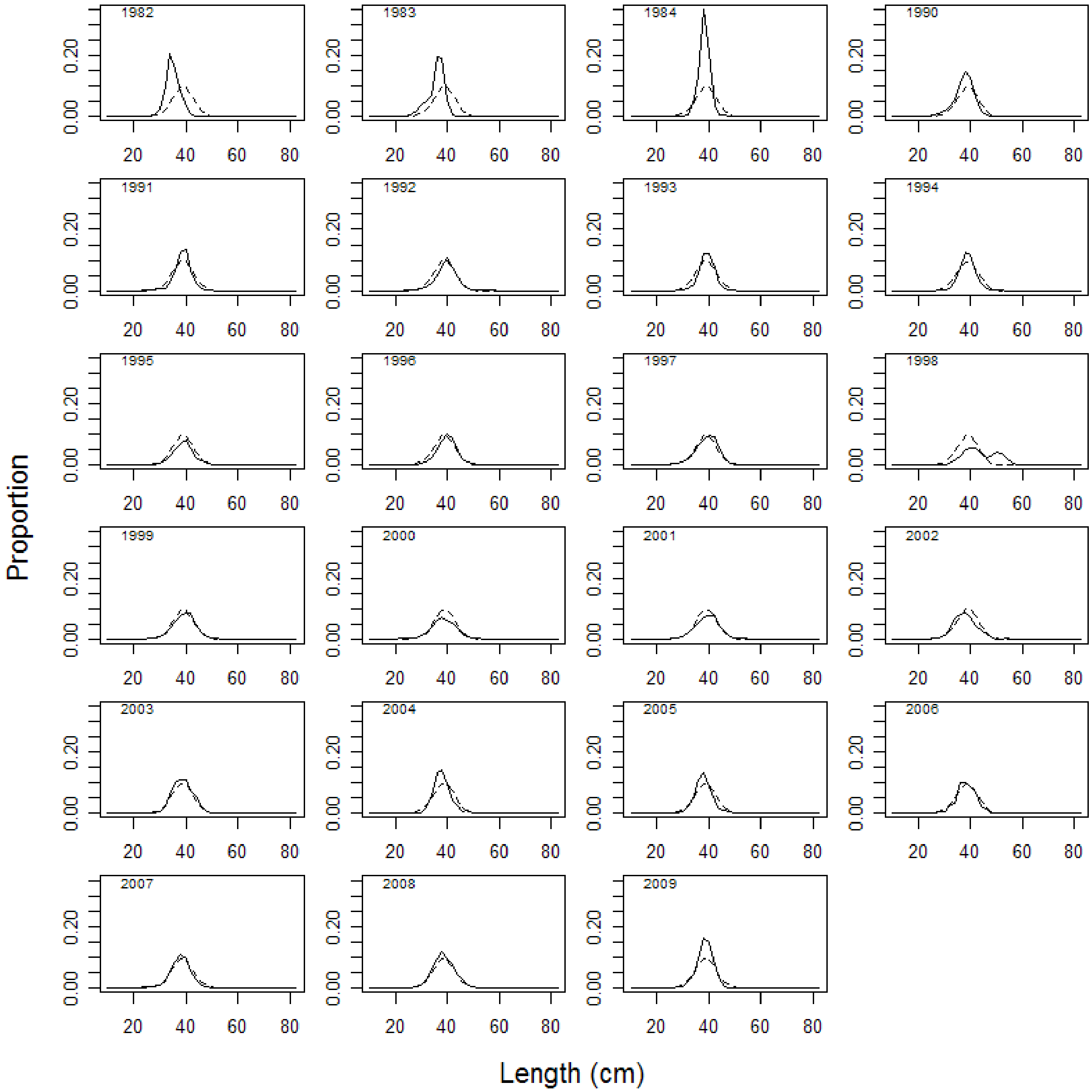


Figure 6.11b. Fit to male GOA rex sole fishery size composition data for the preferred model. Dashed lines represent the model prediction, solid lines represent the data.

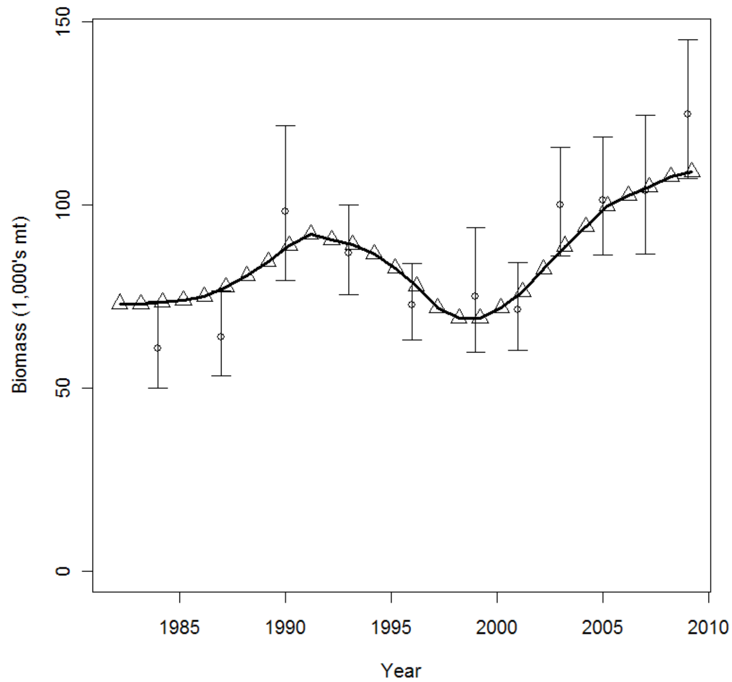


Fig. 6.12. Predicted and observed survey biomass for GOA rex sole for the preferred model. Predicted survey biomass = triangles, observed survey biomass = circles (error bars are approximate lognormal 95% confidence intervals).

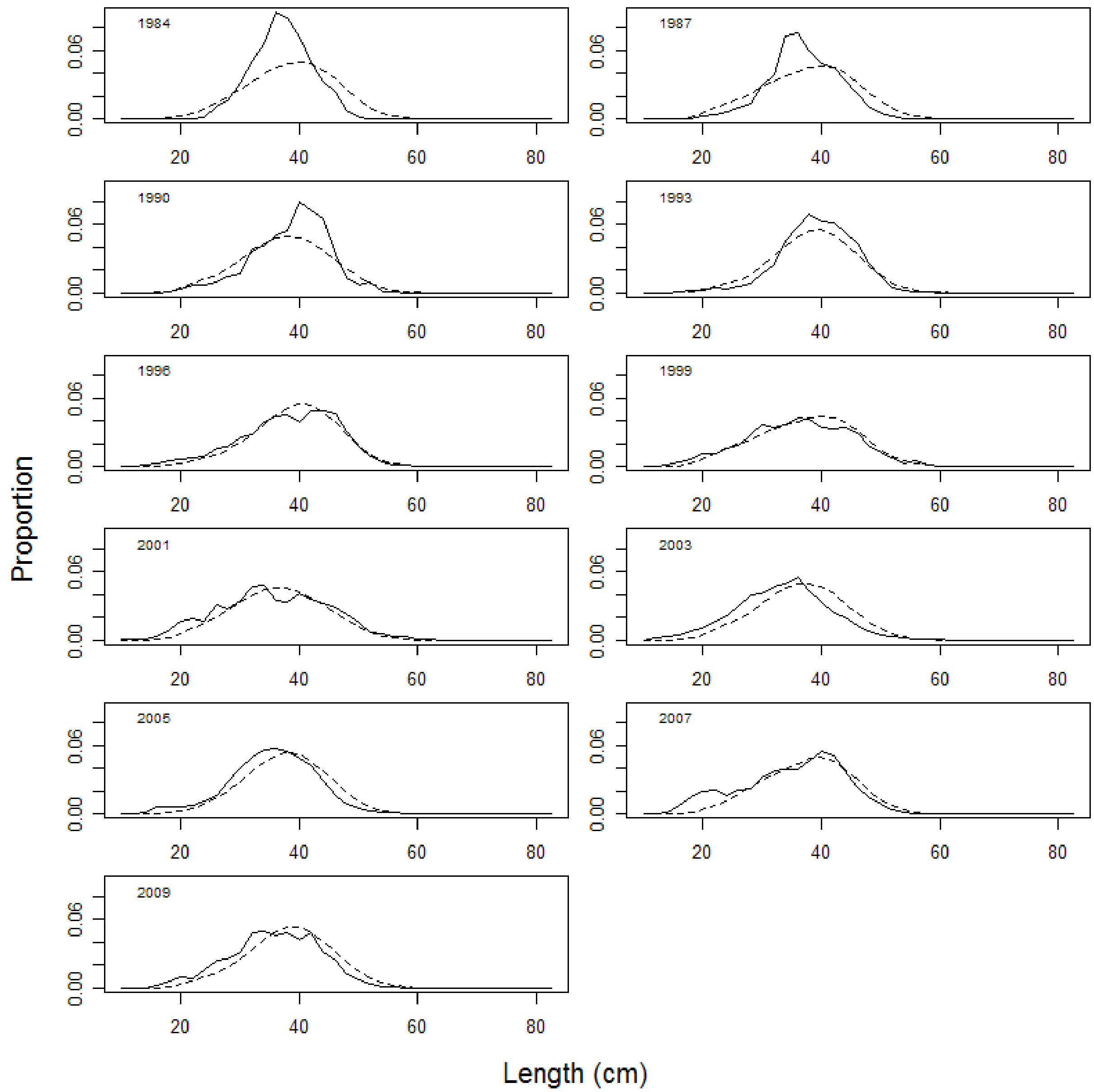


Figure 6.13a. Fit to the female GOA rex sole survey size composition data for the preferred model. Dashed lines represent the model prediction, solid lines represent the data.

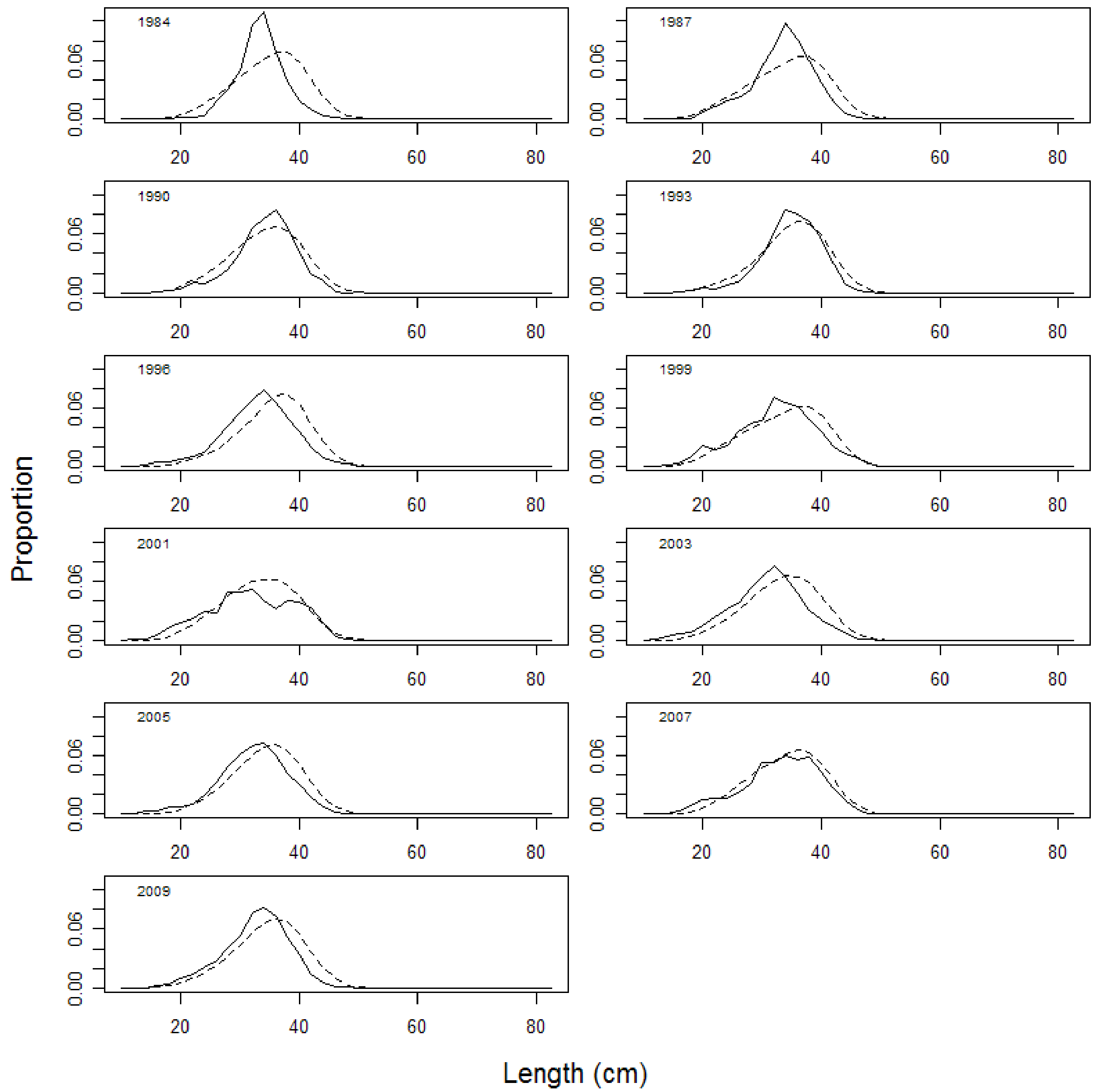


Figure 6.13b. Fit to the male GOA rex sole survey size composition data for the preferred model. Dashed lines represent the model prediction, solid lines represent the data.

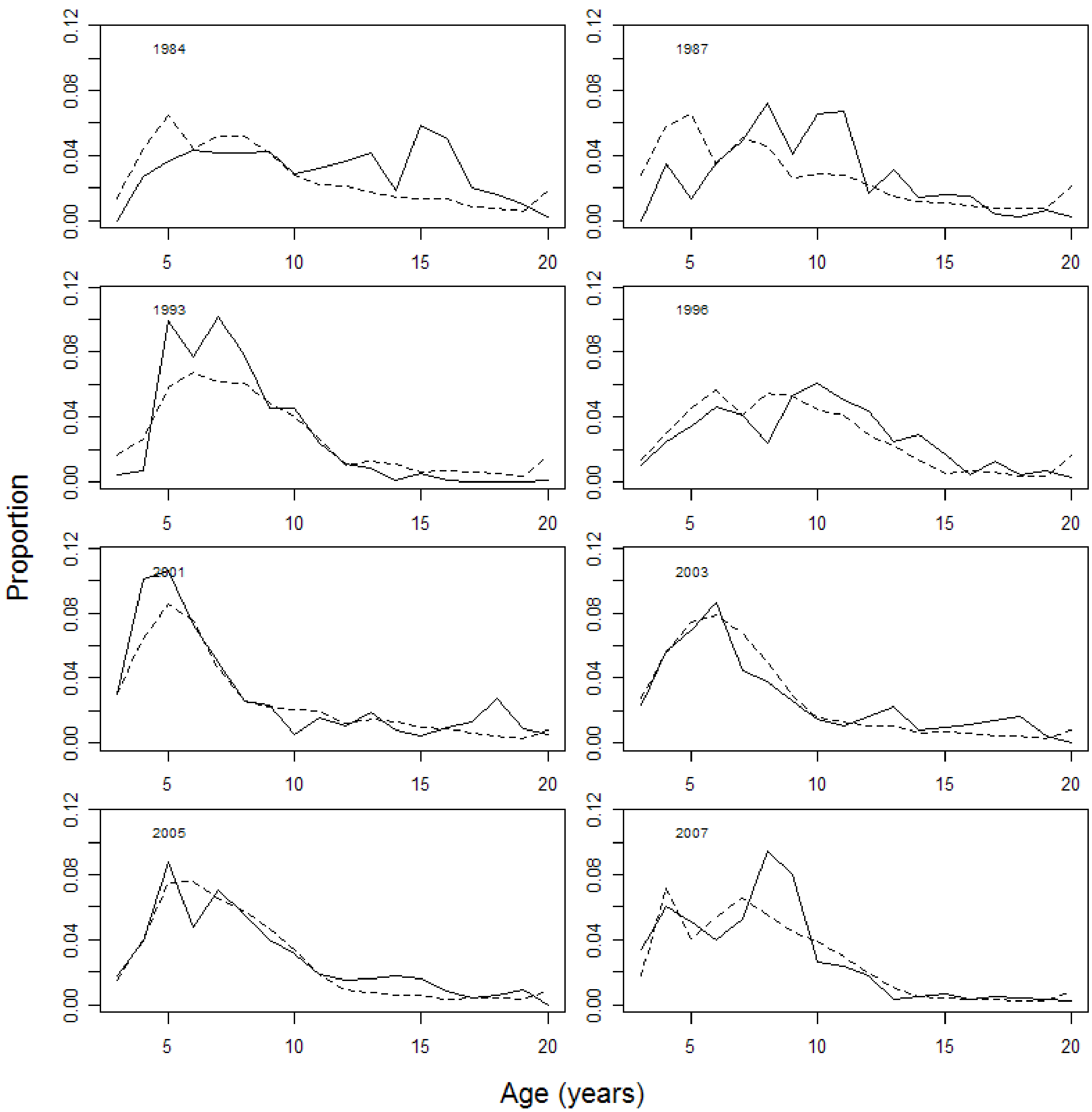


Figure 6.14a. Fit to the female survey GOA rex sole age composition data for the preferred model. Dashed lines represent the model prediction, solid lines represent the data.

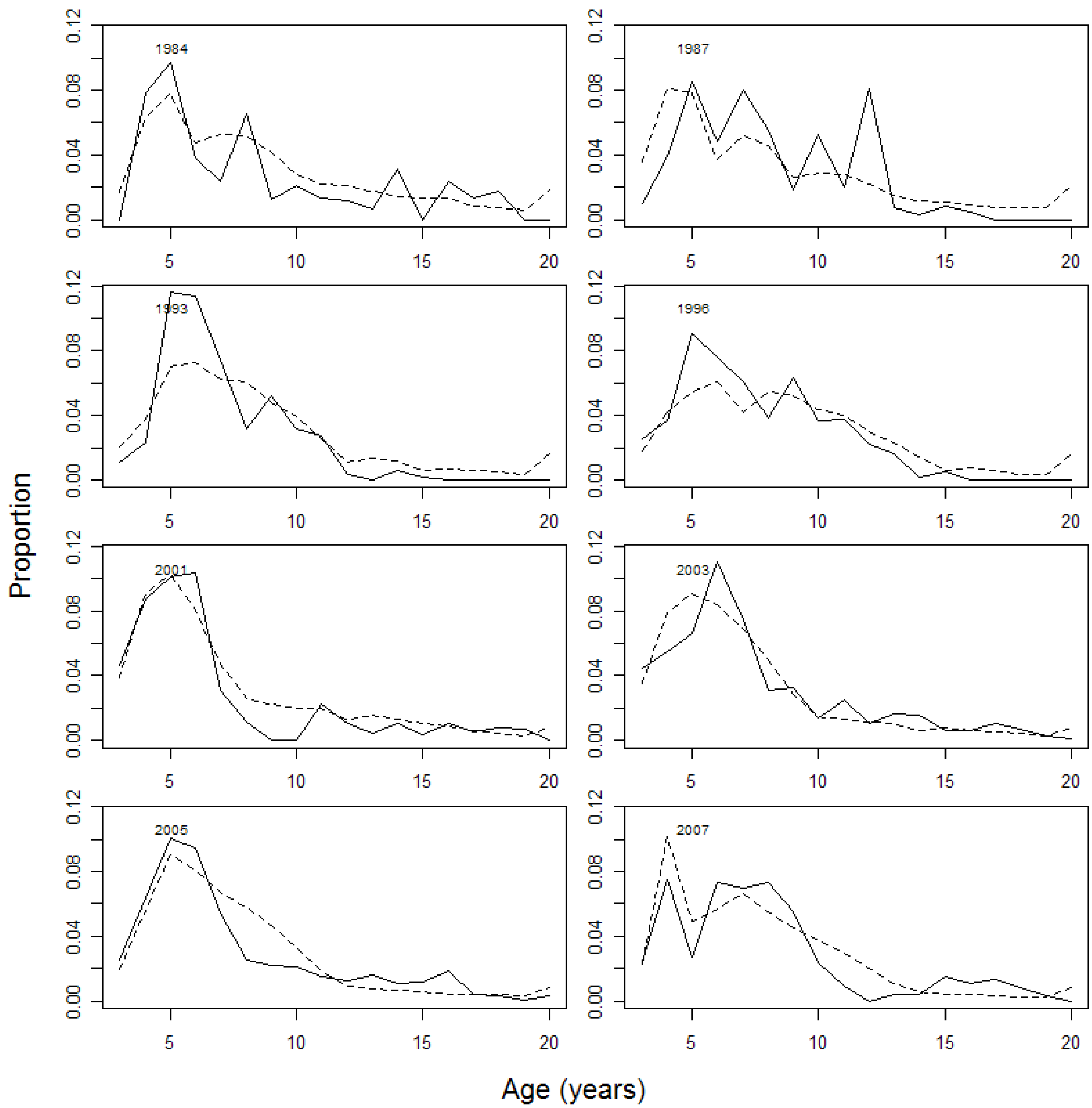
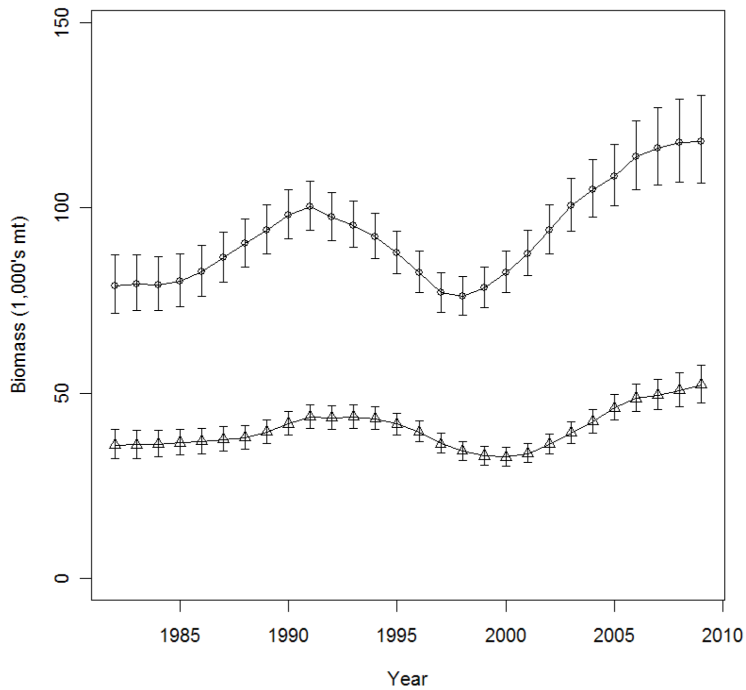


Figure6.14b. Fit to the male survey GOA rex sole age composition data for the preferred model. Dashed lines represent the model prediction, solid lines represent the data.



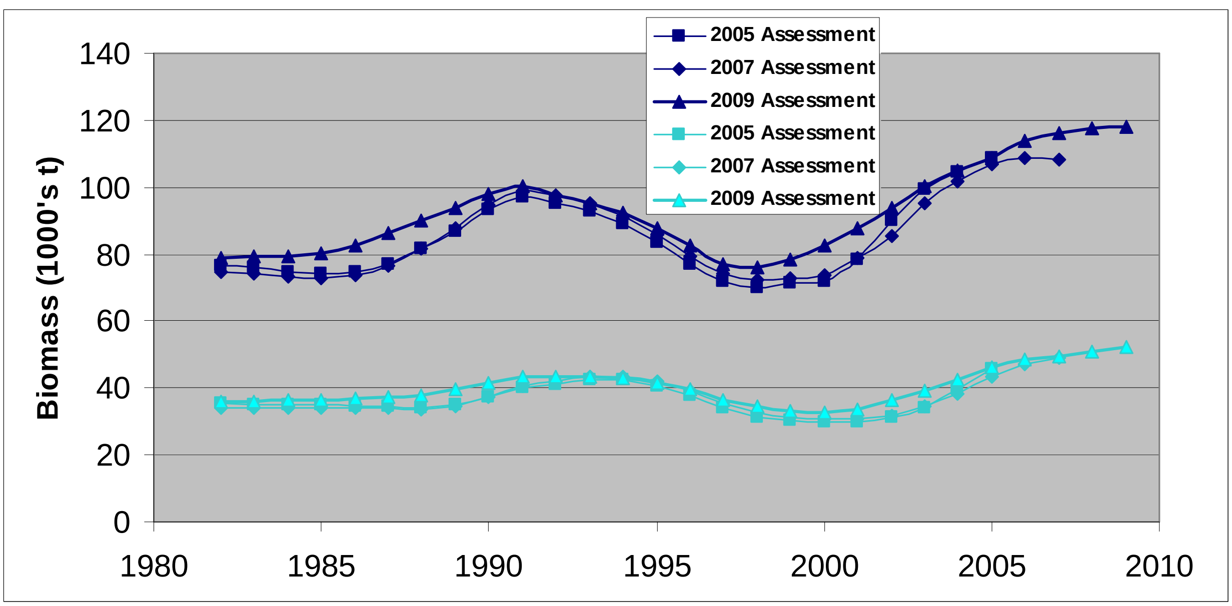
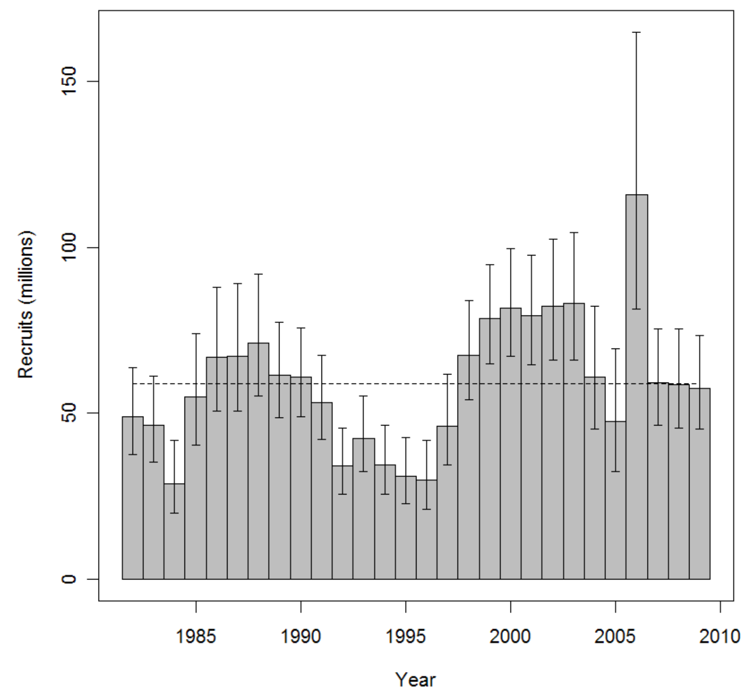


Figure 6.15. Upper: Estimated age 3+ biomass (circles) and female spawning biomass (triangles) for GOA rex sole. Error bars are approximate lognormal 95% confidence intervals. Lower: Comparison of total biomass (dark blue) and spawning biomass (light blue) estimates from the 2009, 2007, and 2005 assessments.



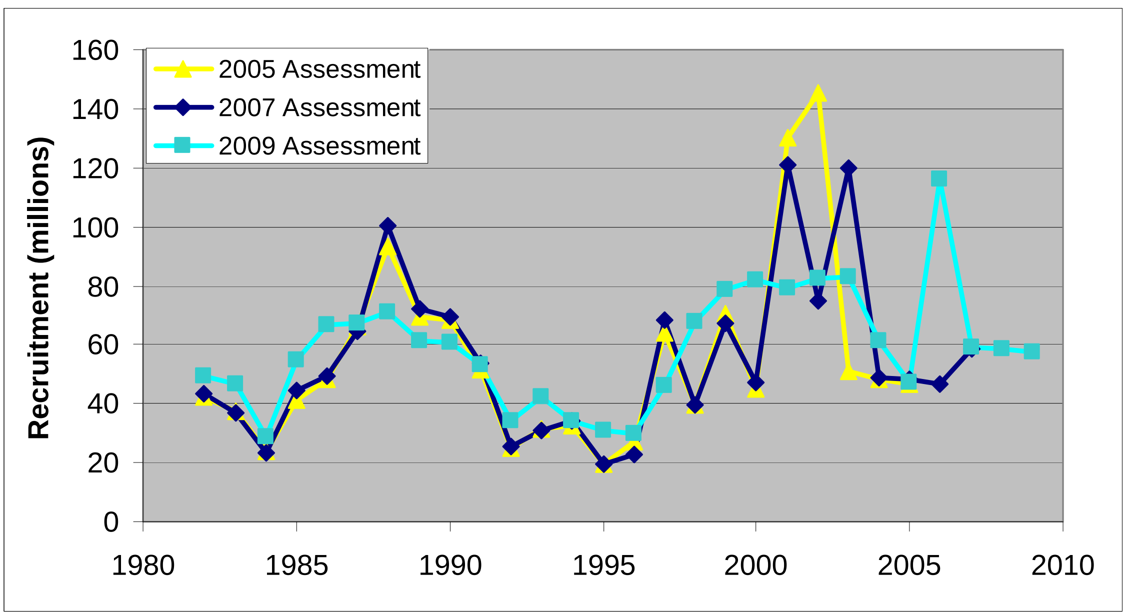


Figure 6.16.Left: Upper: Estimated age 3 recruitments of GOA rex sole with approximate 95% lognormal confidence intervals. Horizontal line is mean recruitment. Lower: Comparison of recruitment estimates from the 2009, 2007, and 2005 assessments.

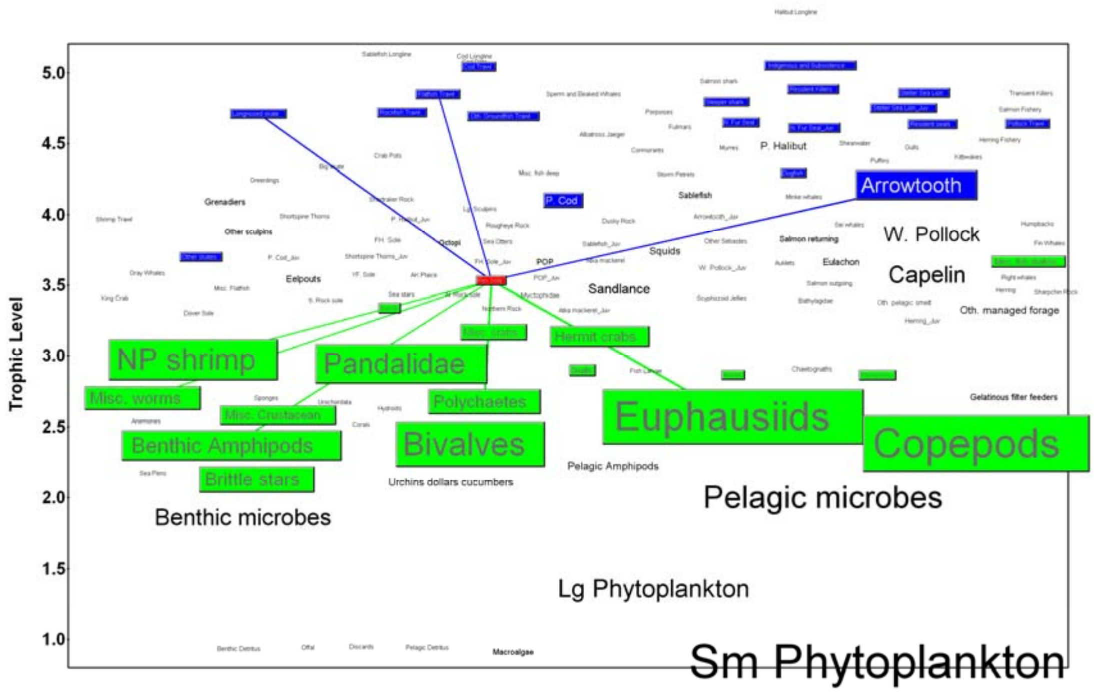


Figure 6.17. Gulf of Alaska food web from the GOA ecosystem model (Aydin et al., 2007) highlighting rex sole links to predators (blue boxes and lines) and prey (green boxes and lines). Box size reflects relative standing stock biomass.

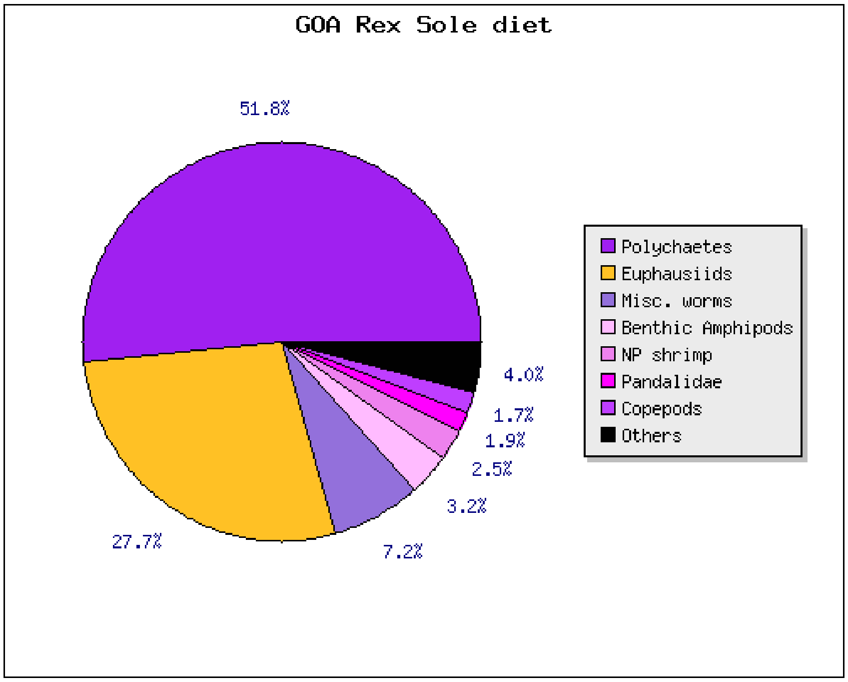


Figure 6.18. Diet composition for Gulf of Alaska rex sole from the GOA ecosystem model (Aydin et al., 2007).

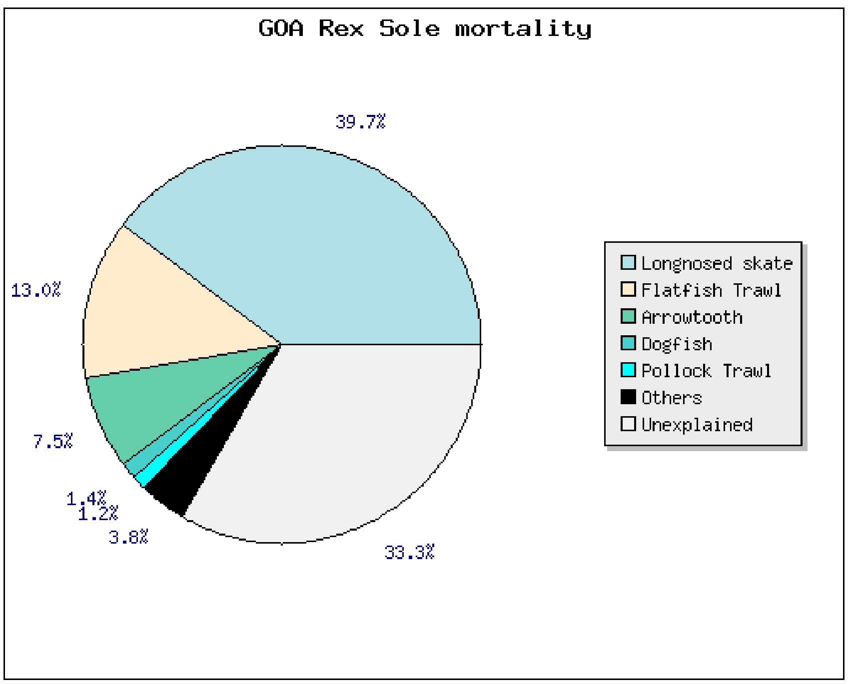


Figure 6.19. Decomposition of natural mortality for Gulf of Alaska rex sole from the GOA ecosystem model (Aydin et al., 2007).

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 (29).
T_{min}	model start year (1982).
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.
$N_{t,x,1} = R_t = \exp\left(\overline{\ln R_0} + \tau_t\right)$	Recruitment (assumed equal for males and females).
$N_{t+1,x,a+1} = N_{t,x,a} e^{-Z_{t,x,a}}$	Numbers at age.
$N_{t+1,x,A} = N_{t,x,A-1} e^{-Z_{t,x,A-1}} + N_{t,x,A} e^{-Z_{t,x,A}}$	Numbers in "plus" group.
$C_{t,x,a} = \frac{F_{t,x,a}}{Z_{t,x,a}}(1-e^{-Z_{t,x,a}})N_{t,x,a}$	Catch at age (in numbers caught).
$C_t = \sum_{x=1}^{2}\sum_{a=1}^{A} w_{x,a} C_{t,x,a}$	Total catch in tons (i.e., yield).
$FSB_t = \sum_{a=1}^{A} w_{1,a}\phi_a N_{t,1,a}$	Female spawning biomass.
$Z_{t,x,a} = F_{t,x,a} + M$	Total mortality.
$F_{t,x,a} = s_{x,a}^F \cdot \exp\left(\overline{\ln F} + \varepsilon_t\right)$	Fishing mortality.
$\varepsilon_t \sim N(0,\sigma_F^2)$	Random deviate associated with fishing mortality.
$s_{x,a}^{FU} = \frac{1}{1+e^{(-b_x^F(age-{}_{50}A_x^F))}}$	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.
$\sum_{t\in\{t^{S}\}}\left[\dfrac{\log\left[\dfrac{SB_t^{obs}}{SB_t}\right]}{\sqrt{2}\cdot s.d.(\log(SB_t^{obs}))}\right]^2$	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
$M_x = 0.17$	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 accepted model. A total of 83 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	$T_{\min} - A + 1 \leq t \leq T_{\max}$	45	log-scale recruitment deviation in year *t*.
$\ln(f_0)$	NA	1	natural log of the geometric mean value of fishing mortality.
ε_t	$T_{\min} \leq t \leq T_{\max}$	28	log-scale deviations in fishing mortality rate in year *t*.
r^F_2	NA	not estimated	scaling from female to male fishery selectivity (log-scale).
b^F_x, $_{50}A^F_x$	$1 \leq x \leq 2$	4	sex-specific selectivity parameters (slope and age at 50% selected) for the fishery.
r^S_2	S=1	not estimated	scaling from female to male survey selectivity (log-scale).
b^S_x, $_{50}A^S_x$	$1 \leq x \leq 2$ S=1	4	sex-specific selectivity parameters (slope and age at 50% selected) for the survey.

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