6. Gulf of Alaska Rex Sole Stock Assessment

By
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Executive Summary

Changes in the Input Data

1) The fishery catch and length compositions for 2006 and 2007 (through Sept. 22, 2007) were incorporated in the model.
2) The 2005 fishery catch and length compositions were updated.
3) The 2007 GOA groundfish survey biomass estimate and length composition data were added to the model. Survey biomass increased slightly from 101,255 t in 2005 to 103,776 t in 2007. Survey biomass estimates and length compositions were recalculated for all survey years.

Changes in the Assessment Model

Slope and age at 50% selectivity were estimated as parameters to characterize survey selectivity in the current model, rather than ages at 50% and 95% selectivity as in the previous assessment (Turnock et al., 2005). This was more a matter of convenience than substance, as both approaches yield similar results.

Changes in the Assessment Results

1. Although we assessed current stock status using an age-structured model, ABC and OFL determinations were based on Tier 5 considerations using estimates of adult biomass from the age-structured model.
2. The recommended ABC for 2008, based on an F_{ABC} harvest level of 0.1275 and 2008 adult biomass estimate of 82,801 t, is 9,132 t. The recommended ABC for 2009, based on an F_{ABC} harvest level of 0.1275 and 2009 adult biomass estimate of 76,782 t, is 8,468 t.
3. The OFL for 2008, based on an F_{OFL} harvest level of 0.17 and 2008 adult biomass estimate of 82,801 t, is 11,933 t. The OFL for 2009, based on an F_{OFL} harvest level of 0.17 and 2009 adult biomass estimate of 76,782 t, is 11,065 t.
4. Using the age-structured model and our best estimate for harvest levels in 2008, projected female spawning biomass is estimated at 49,010 t for 2008 and 47,998 t for 2009.
5. Total biomass (age 3+) is estimated at 107,544 t for 2008 and 105,688 t for 2009.

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

Quantity	2007 Assessment Recommendations for 2008	2006 Assessment Recommendations for 2008	2006 Assessment Recommendations for 2007
Tier	**5**	**5**	**5**
Total adult biomass (t)	82,801	82,403	83,475
ABC (t)	9,132	8,900	9,100
Overfishing (t)	11,933	11,600	11,900
$F_{ABC} = 0.75\ M$	0.128	0.128	0.128
$F_{OFL} = M$	0.170	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.*

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 to both comments: As a result of a change in assessment responsibilities, we were not able to address these comments for this assessment. We will endeavor to address them prior to the next assessment.

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

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

Author response: We have incorporated more detailed information for ecosystem considerations into the SAFE by including results from the Gulf of Alaska ecosystem model in the ecosystem considerations section. We have not yet incorporated temperature-dependent survey catchability into the assessment model; we are currently working on a model that does this.

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

Author response: We were not able to address this request in time for this assessment. We shall try to address this issue prior to the next assessment.

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 5cm 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 2006 was 3,294 t and 2,609 in 2007 (as of Sept. 22; 2007).

Based on observer data, the catch of rex sole is widely distributed across the central and western portions of the Gulf (Figure 6.2a, b). The spatial pattern of catches has been reasonably consistent over the past three years. Most of the catch is taken in the first and second quarters of the year.

The rex sole resource has been moderately harvested in recent years (Table 6.2a). The catch in 2005 represented only 17% of the rex sole ABC, while catch in 2006 was 36% of the ABC. As of Sept. 22, catch in 2007 was 29% of the ABC. The lower catch in 2005 may have been due to more extensive fishery closures in that year, as compared with 2006 and 2007 (Table 6.2b).

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 22 September, 2007 (Table 6.1, Fig. 6.1), as well as estimates of the proportion of individuals caught by length group and sex for the years 1982-2007 (as of Sept. 22; Tables 6.3a, b). 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 (2001-2005) 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 6.5), the fraction of the rex sole stock occurring in these depth strata is typically small (Table 6.6), so we have not attempted to correct the survey estimates of total biomass for missing depth strata. We have, however, corrected the 2001 survey estimate of total biomass, because the eastern section of the Gulf was not sampled that year. We estimated the average 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 (Table 6.5). 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 ~100,000 t since 2003. The estimate of biomass from the 2007 groundfish survey in the Gulf was the largest thus far at103,776 t, slightly greater than that from the 2005 survey (101,255).

Estimates of numbers-at-age from the RACE surveys were also incorporated in the assessment model, where available (1984, 1987, 1990, 1993 and 1996; Table 6.6). Length frequencies from the RACE surveys (Table 6.7) were included in the assessment model for all survey years. Length compositions from years where corresponding age composition data was available were included in the model to aid in estimating model fit and consistency, but were substantially downweighted in the likelihood to avoid "double counting". Sample sizes for the survey age and size compositions are shown in Table 6.4.

Data on individual growth was incorporated in the assessment using sex-specific age-length transition 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).

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

Source	type	years
Fishery	catch	1982-2007
	length compositions	1982-1984; 1990-2007
Survey	biomass	1984-1999 (triennial); 2001-2007 (biennial)
	length compositions	1984-1999 (triennial); 2001-2007 (biennial)
	age compositions	1984,1987, 1990, 1993, 1996

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.

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 79 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 transition matrices (Table 6.8). The distribution of lengths-at-age was assumed to be normally-distributed, with mean length-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 age and length data collected during the 1984, 1987, 1990, 1993 and 1996 groundfish surveys (Turnock et al., 2005). These values were

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 transition 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 79 parameters were estimated in the final model (Table A.5), including parameters on the recruitment of rex sole to the population (44 parameters total, including ones determining the initial age composition) and values related to annual fishing mortality (27 parameters total). The separable age-component of fishing mortality was modeled using a two parameter ascending logistic function estimated separately for males and females (4 parameters total). The same form of curve was also used to estimate relative age-specific survey catchability (4 parameters total).

Annual recruitment to the age 3 year class was parameterized in the model using one parameter for the log-scale mean recruitment and 43 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 26 parameters for the annual log-scale deviation from the mean.

Parameters in the model were selected based on minimizing an objective function equivalent to a negative log-likelihood function; hence, the parameter estimates are maximum likelihood estimates. Components that contribute to the overall (-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 1982-2004 and "late" recruitment incorporated deviations from 2005-2007. All three components were formulated assuming a lognormal error structure. The size and age compositions were assumed to be drawn from different sex-specific multinomial distributions. If this assumption were strictly correct, then the number of individuals contributing to each composition would be the appropriate corresponding sample size. However, because fish of the same size and age tend to be found together, size and age compositions tend to be overdispersed with respect to actual multinomial distributions. Also, the use of high sample sizes can lead to numerical problems in estimating the model parameters. Previous experience indicates that using a uniform sample size of 200 for compositions with more than 200 individuals provides an adequately simple solution to the problem of assigning sample sizes. Thus, a sample size of 200 was used for 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).

Model evaluation

Several alternative model configurations were considered in the previous assessment (Turnock et al., 2005). Here, we used the model configuration selected in that assessment (Table 6.10). Initial values for the parameters were set as listed in Table 6.11. To test whether the resulting model solution (Table 6.12) was indeed a global, rather than local, maximum on the likelihood surface, we conducted a Markov Chain Monte Carlo (MCMC) study using ADModel Builder's built-in MCMC capability in which we evaluated the likelihood at 1000 different parameter combinations and compared the resulting values with that from the model solution. The results of this study indicated that the model solution was in fact a global maximum. We further tested the convergence of the solution by starting the model with several different parameter sets. All model runs converged to the same final solution, providing additional evidence that the original solution was indeed the global maximum.

Final parameter estimates

The parameter estimates considered final for this assessment are given in Table 6.12 for all model parameters.

Schedules implied by parameter estimates

The estimated selectivity curves for the fishery and survey indicate that the fishery generally catches older rex sole than the survey (Figure 6.7). For the fishery, age at 50% selection was 9.9 for females and 10.5 for males. For the survey, the ages at 50% selection were younger: 3.6 for females and 3.3 for males. The resulting curves are similar to those estimated in the previous full assessment (Turnock et al, 2005) the 2005 assessment.

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 6.13 and Figure 6.8). 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 6.9). 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 6.9a). The smoothing inherent in using an age-length transition matrix to convert age classes to size classes precludes close fits to peaked size compositions.

The model does not fit observed survey biomass values as closely as it does the catch (Table 6.13 and Figure 6.10), but model estimates of survey biomass are within the 95% confidence intervals of the actual surveys for all years. Thus, the fit is 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 still generally reasonable (Figure 6.11). Finally, the model fit the survey age compositions marginally well (Figure 6.12), although more so when the observed age distributions are similar between the sexes (e.g., for 1984).

The model also estimates other population variables of interest, such as time series of total biomass, spawning biomass, recruitment and fully-selected fishing mortality. In this assessment, total biomass is represented by age 3+ biomass whereas spawning biomass is female spawning biomass and recruitment is the number of age 3 fish entering the population. Model estimates of the temporal evolution of these three variables show somewhat out-of-phase decadal-scale oscillations (Tables 6.14-15, Figures 6.13-14). 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 75,000 t in 1982 to 99,000 t in 1991, then declined slowly to a low of 72,000 t in 1998 (Table 6.14). Subsequently, age 3+ biomass has risen steadily in recent years to achieve its highest level in the time series at 109,000 t in 2006, while its level in 2007 was only slightly lower (108,000 t). The time series of estimated age 3+ biomass in this assessment was quite similar to that estimated in the 2005 assessment, and generally similar to that from the 2004 assessment.

Model estimates of female spawning biomass indicate that it reached a peak in 2007 of 49,000 t, after rebounding from a low of 31,000 t during 1999-2001 (Table 6.14). Prior to that, spawning biomass had peaked at 44,000 t in 1993-94. The estimated time series of female spawning biomass was quite similar to that from both the 2005 and 2004 assessments.

Model estimates of annual recruitment (age 3 numbers) achieved a recent high at 121,000,000 individuals in 2001 after increasing from a low of 19,000,000 individuals in 1995 (Table 6.15). Currently, recruitment appears to be in the decreasing phase of its cycle, with 2007 recruitment estimated at an intermediate level of 59,000,000 individuals. Results from this assessment are similar to those from the 2005 assessment.

Reference fishing mortality rates

As noted previously, the fishery selectivity curves estimated in this assessment are similar to those estimated in the last full assessment (Turnock et al, 2005). Thus, as in the previous full assessment, the combination of relatively young age-at-maturity combined with relatively old ages selected by the fishery leads to very high estimates of $F_{40\%}$ and associated reference points:

Reference point	Value	
$F_{40\%}$	4.780	
$F_{35\%}$	10.230	
$B_{40\%}$	20,805	t
$B_{35\%}$	18,877	t

In Figure 6.15, we show a control rule plot with the temporal trajectory of estimated fishing mortality and spawning biomass. The plot indicates that the GOA rex sole stock has not been overfished nor has overfishing occurred.

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 2007 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2008 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2007. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2008, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

> *Scenario 1*: In all future years, *F* is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
>
> *Scenario 2*: In all future years, *F* is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2008 recommended in the assessment to the *max* F_{ABC} for 2006. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)
>
> *Scenario 3*: In all future years, *F* is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)
>
> *Scenario 4*: In all future years, *F* is set equal to the 2003-2007 average *F*. (Rationale: For some stocks, TAC can be well below ABC, and recent average *F* may provide a better indicator of F_{TAC} than F_{ABC}.)

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

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 2008, then the stock is not overfished.)

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

If reliable estimates of the 2007 spawning biomass (B), $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ existed, and since B>$B_{40\%}$ (49,000 t > 20,805 t), the rex sole reference fishing mortality would be defined in Tier 3a. For this tier, F_{ABC} is constrained to be ≤ $F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. Thus:

$$F_{ABC} \leq 4.780$$
$$F_{OFL} = 10.230$$

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 and spawning stock biomass for the five scenarios are shown in Table 6.16. 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 2008 of scenario 6 is 49,010 t, over 2 times $B_{35\%}$ (18,877 t). Thus the stock is not currently overfished. With regard to whether the stock is approaching an overfished condition, the expected spawning stock size in the year 2020 of scenario 7 (19,301 t) is greater than $B_{35\%}$; thus, the stock is not approaching an overfished condition.

Acceptable Biological Catch and Overfishing Level

The reference fishing mortality rate for rex sole is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands).

Given that the current $F_{40\%}$ is 4.78, the associated ABC for 2008 under Tier 3a would be 48,049 t. However, the stock is currently lightly exploited, and thus only older fish are targeted. If fishing pressure increased in an attempt to actually take this ABC in 2008, younger fish would be increasingly targeted and the selectivity curves would shift toward younger ages. As a consequence, $F_{40\%}$ would decrease—probably dramatically. This, in turn, would substantially change what the ABC should have been (if the resulting fishery selectivity had been known). As a consequence, we find that the estimates of $B_{35\%}$, $F_{35\%}$, and $F_{40\%}$ are unreliable and cannot recommend that rex sole be considered as a Tier 3a stock.

Although estimates of $B_{35\%}$, $F_{35\%}$, and $F_{40\%}$ are considered unreliable, natural mortality (M) and stock biomass estimated either from the age-structured model or survey biomass are considered reliable, rex sole can be regarded as a Tier 5 stock. Under Tier 5, F_{ABC} = 0.75M and F_{OFL} = M (= 0.17 for rex sole).

ABC and OFL can then calculated using the appropriate value for F, the catch equation, and the selected estimate of biomass. Here, as in the 2005 assessment, we present ABCs and OFLs based on biomass estimates from both the current survey and the age-structured model.

Using the catch equation and survey biomass from the 2007 GOA groundfish survey, the values for maximum ABC and OFL for 2008 are

ABC ≤ 13,231 t
OFL = 17,642 t

For a GOA stock in Tier 5, the ABC and OFL for 2009 is the same as that for 2008 because no survey will be conducted in 2008 to update the estimate of survey biomass.

Using the age-structured model, estimates of “adult” biomass can be calculated for both 2008 and 2009. For 2008, we used the estimated numbers-at-age at the beginning of 2008 from the age-structured model, applied the maturity ogive to both female and male numbers-at-age to obtain “adult” numbers-at-age. “Adult” numbers-at-age were then weighted by the sex-specific weights at age and summed to obtain an estimate of “adult” biomass at the start of 2008 (82,801 t). Using the appropriate F’s and the catch equation, the maximum ABC and OFL for 2008 based on the age-structured model are

ABC ≤ 9,132 t
OFL = 11,933 t

To obtain the ABC and OFL for 2009, we used the projection model to project numbers-at-age to the beginning of 2009 under the assumption that fishery selectivity was equivalent to the maturity ogive and that the 2008 ABC was taken by the fishery. Because the projection model reports total (age 3+) biomass, not “adult” biomass, we estimated adult biomass in 2009 by applying the ratio of 2008 adult biomass to total biomass to the 2009 total biomass reported by the projection model. Again using the appropriate F’s and the catch equation, the maximum ABC and OFL for 2009 based on the projected 2009 adult biomass (76,782) are

ABC ≤ 8,468 t
OFL = 11,065 t

For completeness, we also calculated the ABCs and OFLs for rex sole for 2008 and 2009 under Tier 3a considerations (and assuming no change in fishery selectivity). Estimating an ABC and OFL for 2009 is somewhat problematic as these values depend on the catch that will be taken in 2008. The actual catch taken in the GOA rex sole fishery has been substantially smaller than the TAC for the past several years, but it has varied by a factor of 3 over the past few years (Figure 6.1). Thus, we assumed that a reasonable estimate of the catch to be taken in 2008 was the maximum catch taken over the past five years (3,485 t in 1993). Thus, the total catch taken was projected to be 2,609 t in 2007 and 3,485 in 2008. Using these values and the estimated population size at the start of 2007 from the model, we projected the stock ahead and calculated the ABCs and OFLs for 2008-09 based on a Tier 3a calculation. The estimated ABCs for 2008 and 2009 are 48,049 t and 51,705 t, respectively, while the estimated OFLs are 57,919 t and 61,198. Total biomass for 2008-09 was projected to be 107,544 t and 105,688 t, respectively, while female spawning biomass was projected to be 49,010 and 47,998.

Although the approach using projected “adult” biomass is somewhat ad hoc, we consider it (as in 2005) to be the best approach and regard the ABCs and OFLs based on projected “adult” biomass as our recommended values.

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 2008 and 2009 ABCs. Under the recommended Tier 5 "adult" biomass approach, the area-specific allocations for 2008 and 2009 are:

	Western Gulf	Central Gulf	West Yakutat	Southeast Outside	Total
apportionment	11.2%	73.7%	5.7%	9.4%	100.0%
2008 ABC (t)	1,022	6,731	520	859	9,132
2009 ABC (t)	948	6,241	483	796	8,468

For completeness, the area-specific allocations for 2008-09 under Tier 5 using survey biomass and Tier 3a considerations (not recommended) are:

Tier 5 using survey biomass

	Western Gulf	Central Gulf	West Yakutat	Southeast Outside	Total
apportionment	11.2%	73.7%	5.7%	9.4%	100.0%
2008 ABC (t)	1,481	9,752	754	1,244	13,231
2009 ABC (t)	1,481	9,752	754	1,244	13,231

Tier 3a

	Western Gulf	Central Gulf	West Yakutat	Southeast Outside	Total
apportionment	11.2%	73.7%	5.7%	9.4%	100.0%
2008 ABC (t)	1,481	9,752	754	1,244	48,049
2009 ABC (t)	1,481	9,752	754	1,244	51,705

Ecosystem Considerations

Ecosystem effects on the stock

Prey availability/abundance trends
Based on results from an ecosystem model for the Gulf of Alaska (Aydin et al., in press), rex sole in the Gulf of Alaska occupy an intermediate trophic level (Fig. 6.16). Polychaetes, euphasiids, and miscellaneous worms were the most important prey for rex sole in the Gulf of Alaska (Fig. 6.17).. 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. 6.18). 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 6.19). In 2006, the overall prohibited species catch (PSC) rate for halibut was 121.6 t kg halibut/t of rex caught—an increase from the 2005 rate of 98.6 t kg halibut/t of rex caught, but the second lowest rate in the past four years. The PSC rates for salmon and crab in 2006 directed fishery were 42.9 crabs/t rex sole and 1.17 salmon/t rex sole, respectively. The majority of salmon caught were Chinook, while the only crab species caught was Bairdi tanner crab. The 2006 PSC rate for crab (Bairdi tanner crab exclusively) was the largest among the last four years and over four times larger than that in 2005. The 2006 rate for salmon was the second lowest over the past four years.

The rex sole-directed fishery caught more arrowtooth flounder in both 2005 and 2006 than any other non-prohibited species, including rex sole (Table 6.20). Rex sole was the second most-caught species in the directed fishery. The catch of arrowtooth flounder constituted 257% of the retained catch of rex sole in 2006 and 204% in 2005. Only small amounts of arrowtooth were retained (<10%), while more than 97% of rex sole was retained.

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

Data gaps and research priorities

The rex sole assessment, together with assessments conducted by the AFSC for other flatfish species, was recently reviewed by a panel of three scientists from the Center for Independent Experts (CIE). On the whole, the review was very complimentary of the assessments. In regards to the rex sole assessment, the reviewers noted that the F-based reference points used for Tier 3 stocks (e.g.., F_{ABC}=$F_{40\%}$≈5) were "problematic" for this species for setting catch levels. The high values for F40% and F35% estimated in the rex sole assessment are a result of the current fishery catching only old, large fish. The stock can withstand fishing at these high F's as long as the fishery continues to catch only old fish. The CIE panel expressed concern that, in order to take TACs based on the high F's, the fishery's selectivity would change to target younger fish--a change that could, in turn, lead to overexploitation. The CIE panel suggested that "the implications of alternative selectivity and maturity ogives on assessment results" be examined in a Management Strategy Evaluation (MSE) context.

In addition, the CIE review also noted that recent age data for rex sole in the Gulf of Alaska is nonexistent from either the fishery or the groundfish survey. Additional age data should improve future stock assessments by allowing improved estimates of individual growth and age-length transition matrices, and by filling in missing years with age composition data. The CIE review also suggested that additional age information would allow trends in length-at-age to be evaluated and, if necessary, incorporated, into the assessment model.

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 functions. The utility of potential environmental predictors of recruitment and survey catchability (e.g., temperature) should also be investigated.

Summary

Tier	5	
Reference mortality rates		
M	0.17	
Adult biomass	**2008**	**2009**
(t)	82,801	76,782
Fishing rates		
F_{OFL}	0.170	
F_{ABC} (maximum permissible)	0.128	
F_{ABC} (recommended)	0.128	
Harvest limits	**2008**	**2009**
OFL (t)	11,933	11,065
ABC (maximum permissible; t)	9,132	8,468
ABC (recommended; t)	9,132	8,468

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Tables

Table 6.1. Annual catch of rex sole in the Gulf of Alaska from 1982. 2007 catch is through Sept. 22.

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	2,609

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	2,609	2,601	59	98%

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

Year	Dates	Status
2005	Jan 20-Mar 23	open
	Mar 23-Apr 1	halibut bycatch status
	Apr 1-Apr 8	open
	Apr 8-Apr 24	halibut bycatch status
	Apr 24-May 3	open
	May 3-Jul 5	halibut bycatch status
	Jul 5-Jul 24	open
	Jul 24-Sep 1	halibut bycatch status
	Sep 1-Sep 4	open
	Sep 4-Sep 8	halibut bycatch status
	Sep 8-Sep 10	open
	Sep 10-Oct 1	halibut bycatch status
	Oct 1-Oct 1	open
	Oct 1-Dec31	halibut bycatch status
2006	Jan 20-Apr 27	open
	Apr 27-Jul 1	halibut bycatch status
	Jul 1-Sep 5	open
	Sep 5-Oct 1	halibut bycatch status
	Oct 1-Oct 8	open
	Oct. 8-Dec 31	halibut bycatch status
2007	Jan 20-May 17	open
	May 17-Jul 1	halibut bycatch status
	Jul 1-Aug 10	open
	Aug 10-Sep 1	halibut bycatch status
	Sep 1-Oct 8	open
	Oct 8-Oct 10	halibut bycatch status
	Oct 10-Oct 15	open
	Oct 15-Oct 22	halibut bycatch status
	Oct 22-	open

Table 6.3. Annual fishery length compositions for rex sole. The 2007 composition is based on observer reports through Sept. 22.

a) Females

	Length cutpoints (cm)																												
year	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
1982	1	0	9	17	0	4	3	4	5	14	54	340	1,045	978	555	312	144	37	9	8	5	2	1	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0	0	3	12	25	63	71	51	14	2	0	0	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0	0	0	3	2	7	14	12	19	3	0	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	7	2	34	31	93	139	180	226	303	327	324	328	263	116	60	33	8	1	1	1	1	4
1991	0	0	0	0	0	0	0	7	15	8	29	63	106	205	375	650	834	867	737	402	220	96	60	30	9	9	2	0	0
1992	0	0	0	0	0	3	7	5	14	31	79	109	190	370	552	851	1,368	1,598	1,307	752	401	190	101	62	26	24	2	2	1
1993	0	0	0	0	0	0	0	2	3	9	16	46	82	198	565	1,273	1,910	2,011	1,425	798	393	168	86	42	28	9	2	1	0
1994	0	0	0	0	0	0	1	0	6	8	19	37	119	316	617	1,122	1,383	1,238	993	569	275	137	59	22	4	7	2	0	1
1995	0	0	1	1	0	3	3	2	4	8	13	39	51	71	163	338	497	631	615	414	208	123	53	26	10	8	0	0	0
1996	0	0	0	0	2	1	2	1	4	4	10	17	56	120	313	660	1,162	1,554	1,568	1,147	678	405	200	152	92	34	20	7	3
1997	0	0	0	1	0	2	3	7	30	25	48	75	127	174	282	386	456	630	770	728	628	353	160	62	27	5	1	1	1
1998	0	0	0	0	0	0	0	0	0	2	3	7	14	30	91	245	503	671	612	542	390	315	346	314	234	153	69	42	26
1999	0	0	0	1	0	0	1	1	6	6	10	31	46	110	198	346	525	699	814	758	488	253	106	51	14	1	1	0	0
2000	0	0	0	0	0	0	1	3	4	6	20	36	65	89	221	309	453	565	635	610	424	251	118	44	22	11	4	2	3
2001	0	0	0	0	0	0	0	0	1	3	7	9	14	25	65	156	244	275	311	298	240	121	82	42	17	9	6	3	3
2002	0	0	0	0	0	0	0	1	2	3	4	10	39	97	169	306	397	452	474	444	276	170	93	55	25	9	6	1	0
2003	0	0	0	0	0	0	0	0	2	5	10	24	51	92	195	332	377	435	414	300	199	106	51	32	11	5	1	2	0
2004	0	0	0	0	0	0	0	0	0	2	1	3	4	33	33	79	95	98	59	31	18	9	10	3	1	1	2	2	0
2005	0	0	0	0	0	0	0	0	0	0	5	6	15	45	88	101	112	102	58	33	25	8	2	5	0	1	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	1	5	10	17	27	39	34	48	33	17	10	6	6	2	1	0	0	0	0
2007	0	0	0	0	0	0	0	1	0	2	4	2	12	24	58	123	191	176	138	91	48	26	10	2	3	3	0	1	0

b) Males.

	Length cutpoints (cm)																												
year	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
1982	0	3	21	21	8	6	16	6	21	53	213	910	1,929	1,467	773	322	77	10	0	0	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	1	1	2	12	24	34	44	127	123	35	3	0	0	0	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0	0	0	2	17	39	104	62	11	1	1	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	12	4	14	34	53	109	199	331	668	906	792	384	125	35	8	4	6	5	0	0	1	1	1	1
1991	0	0	0	0	1	1	2	8	23	41	71	81	235	588	1,134	1,223	602	229	60	23	9	4	2	2	0	0	0	0	0
1992	0	0	0	0	0	0	4	12	22	29	78	183	345	720	1,175	1,523	1,120	612	313	125	67	28	15	28	20	1	0	0	0
1993	0	0	0	0	1	2	1	3	6	21	45	143	358	965	1,955	1,986	1,253	403	96	26	20	9	0	0	0	0	0	0	0
1994	0	0	0	0	2	1	4	6	8	17	36	109	407	974	1,635	1,492	822	317	121	46	20	11	3	1	4	1	1	0	0
1995	0	0	0	1	1	5	0	8	5	10	40	83	151	260	363	417	280	129	78	42	13	9	0	0	2	0	0	0	0
1996	0	0	1	0	0	0	2	10	15	47	75	118	365	766	1,155	1,454	1,248	698	282	116	51	43	17	5	3	2	0	0	1
1997	0	0	0	0	1	1	7	22	38	58	102	187	426	644	856	970	909	568	233	70	34	6	3	1	0	0	0	0	0
1998	0	0	0	0	0	0	1	0	2	9	11	37	133	230	385	454	443	279	202	225	327	312	150	73	20	14	5	1	0
1999	0	0	0	0	0	2	3	9	19	37	63	154	295	488	632	689	694	421	186	56	36	18	7	5	1	0	0	0	1
2000	0	0	0	1	3	5	9	17	33	32	76	122	249	404	448	389	345	237	115	41	13	15	5	1	0	0	0	0	0
2001	0	0	0	0	0	0	0	3	7	18	29	73	146	193	250	272	264	149	87	23	17	7	5	4	1	2	0	0	0
2002	0	0	0	2	0	1	2	3	15	27	64	178	371	447	484	397	240	166	95	37	6	5	8	2	0	0	0	0	0
2003	0	0	0	0	0	1	1	0	3	19	45	149	392	641	685	684	472	349	154	50	14	5	1	1	0	0	0	1	0
2004	0	0	0	0	0	0	1	0	2	0	0	22	56	136	146	101	44	26	8	10	2	0	1	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	7	31	68	129	158	106	51	18	10	5	1	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	2	2	12	16	50	49	42	34	12	8	1	1	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	2	1	5	10	4	17	42	97	157	190	172	102	46	18	7	2	2	0	0	0	1	0	0	0

Table 6.4. Sample sizes: a) sample sizes for length compositions from the domestic fishery and b) sample sizes for estimated biomass, age and size compositions from the GOA groundfish survey.

a). Fishery length compositions.

	Males		Females	
year	# of hauls	# of individuals	# of hauls	# of individuals
1990	56	3,693	56	2,482
1991	118	4,339	120	4,724
1992	159	6,420	161	8,045
1993	242	7,293	245	9,067
1994	222	6,038	225	6,935
1995	111	1,897	133	3,282
1996	221	6,474	224	8,212
1997	182	5,070	181	4,962
1998	156	3,313	154	4,609
1999	388	3,816	392	4,466
2000	330	2,881	341	4,484
2001	187	1,594	194	1,949
2002	311	2,667	314	3,110
2003	342	3,706	346	2,662
2004	60	555	62	484
2005	67	590	70	615
2006	32	229	35	256
2007	110	924	119	989

b). GOA groundfish surveys.

	Survey biomass	Size compositions				Age compositions			
		Males		Females		Males		Females	
year	# of hauls	# of hauls	# of individuals	# of hauls	# of individuals	# of hauls	# of individuals	# of hauls	# of individuals
1984	929	221	7,191	225	6,739	5	78	5	155
1987	783	102	5,998	103	5,364	5	87	5	102
1990	708	227	6,793	237	7,593	20	114	26	156
1993	775	319	8,166	359	9,943	20	139	26	193
1996	807	401	7,718	487	6,768	43	158	59	212
1999	764	374	6,204	430	5,408				
2001	489	229	3,814	255	3,861				
2003	809	440	9,028	490	8,778				
2005	839	461	9,806	512	9,393				
2007	820	435	8,555	489	8,606				

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. The average survey biomass in the Eastern Gulf from the 1993, 1996 and 1999 GOA surveys (19,979 t) was used as an estimate of survey biomass in the Eastern Gulf in 2001. This was added to the measured 2001 survey biomass (51,258 t) to obtain an estimate of survey biomass across the entire Gulf for 2001.

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

Year	Western Gulf (t)	Central Gulf (t)	West Yakutat (t)	Southeast (t)	Total Gulf (t)	Std. Dev (t)	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	8,656	1000
2001	9,571	41,687	**	**	71,326	6,129	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

b) Biomass by depth stratum.

	Depth strata (m)					
year	1-100	100-200	200-300	300-500	500-700	700-1000
1984	3,987	37,040	13,083	5,161	1,057	342
1987	5,691	40,244	14,508	1,812	1,542	30
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	0
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	136	10
2007	9,081	71,514	18,368	4,504	309	0

Table 6.6. Survey age compositions for rex sole.

a) Females.

year	Age bin 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1984	0	4,033,557	5,375,245	6,379,210	6,152,567	6,210,772	6,290,816	4,308,020	4,790,735	5,446,834	6,144,928	2,685,287	8,773,885	7,385,750	3,001,257	2,306,856	1,448,899	1,716,906
1987	0	5,468,095	2,088,490	5,579,048	7,797,108	11,349,315	6,407,896	10,241,803	10,504,642	2,667,776	4,922,638	2,270,117	2,517,552	2,309,873	600,372	395,301	1,060,655	1,021,014
1990	9,237,319	10,337,012	41,923,304	29,768,794	23,529,019	12,381,210	1,245,296	205,035	217,237	0	0	0	0	0	0	0	0	0
1993	903,206	1,415,501	21,053,041	16,291,164	21,541,218	16,457,684	9,562,268	9,713,414	5,134,067	2,389,570	1,833,839	243,263	993,973	89,877	0	0	0	73,174
1996	1,983,385	4,791,713	6,637,210	8,970,292	7,878,765	4,543,863	10,243,879	11,774,995	9,820,463	8,374,248	4,781,979	5,606,428	3,214,371	813,549	2,458,937	779,868	1,352,854	1,355,598

b) Males.

year	Age bin 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1984	0	11,696,337	14,403,975	5,642,214	3,556,341	9,753,966	1,816,740	3,147,749	1,956,060	1,733,521	996,369	4,660,901	0	3,496,949	1,975,592	2,587,519	0	664,711
1987	1,579,783	6,166,527	13,341,583	7,595,731	12,547,124	8,620,120	2,872,296	8,290,363	3,109,514	12,694,497	1,142,189	516,409	1,259,945	780,403	0	0	0	0
1990	12,067,441	23,763,060	52,699,733	26,416,302	8,333,126	688,142	0	0	0	0	0	0	0	0	0	0	0	0
1993	2,388,854	4,925,856	24,643,679	24,216,889	15,868,520	6,658,097	11,018,226	6,721,983	5,869,971	707,758	59,334	1,302,425	435,735	0	0	0	0	190,591
1996	4,905,608	7,138,037	17,588,642	14,689,786	11,723,148	7,396,114	12,189,270	7,105,352	7,345,990	4,369,874	3,153,040	340,332	990,976	0	0	0	0	314,453

Table 6.7. Survey length compositions for rex sole. Survey length compositions from 1984, 1987, 1990, 1993, and 1996 were downweighted in fitting the assessment model because age compositions were available for these years.

a) Females.

	Length cutpoints (cm)																												
year	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
1984	0	0	0	0	3,003	22,721	64,486	215,025	1,362,726	2,472,589	4,417,700	6,918,862	9,932,222	14,851,932	14,809,989	12,028,370	8,940,967	5,979,068	3,819,744	1,963,074	493,807	116,234	38,843	15,749	0	0	0	0	0
1987	0	0	62,822	0	15,536	267,298	394,036	976,694	1,484,335	2,431,843	4,289,807	5,623,223	11,103,820	12,967,178	10,273,573	8,840,757	8,183,029	6,565,897	4,051,670	2,440,816	1,073,019	546,749	313,224	27,258	6,120	3,754	0	0	0
1990	0	0	0	39,759	342,496	654,622	1,427,516	2,221,501	1,939,596	3,213,602	4,694,565	7,845,136	9,512,903	12,188,064	13,151,306	18,024,432	18,355,703	15,895,641	10,377,903	4,262,586	3,106,707	1,957,850	389,522	215,192	56,153	0	0	0	0
1993	0	13,635	16,585	87,085	291,884	495,031	633,846	535,840	875,659	1,511,566	3,360,761	5,114,155	8,929,617	11,924,617	13,903,570	13,508,621	13,518,182	11,323,794	9,503,695	6,524,195	3,374,367	1,297,415	640,754	251,880	157,273	27,150	0	0	8,268
1996	9,123	32,586	218,742	325,829	756,794	1,358,571	1,240,943	1,608,513	2,570,703	3,452,417	4,295,157	5,587,536	6,900,810	8,139,941	8,485,033	8,170,320	9,411,903	9,445,003	9,243,631	6,813,244	4,231,237	2,393,076	995,834	633,453	277,196	111,396	0	0	0
1999	22,005	38,444	162,516	537,758	1,033,592	2,131,056	2,430,602	3,179,848	3,935,277	6,402,490	7,864,498	7,557,048	9,026,274	8,957,829	9,480,666	7,987,069	8,172,822	7,666,496	6,709,113	4,596,708	3,219,887	2,015,785	1,296,693	922,284	253,235	67,244	72,018	0	0
2001	30,947	84,008	186,757	383,876	1,157,618	2,340,359	2,718,016	2,681,260	4,197,287	4,780,936	5,099,113	6,946,200	8,044,700	6,025,534	5,386,813	6,187,362	5,685,794	5,143,181	4,964,604	3,802,399	2,551,063	1,401,357	924,558	738,880	373,950	163,386	108,389	12,268	0
2003	91,964	380,833	1,024,437	1,272,070	2,137,081	4,563,305	5,881,011	6,973,715	10,070,597	13,521,525	15,947,235	18,049,570	19,261,675	20,527,055	17,516,206	13,654,387	10,210,376	8,027,506	5,779,564	3,431,606	2,248,940	1,393,082	913,875	656,826	425,574	215,677	54,740	0	0
2005	0	142,213	414,209	1,774,486	1,977,643	2,152,729	2,312,088	3,379,183	5,195,293	8,559,665	12,016,532	15,688,923	17,295,762	18,966,850	19,284,572	17,499,544	14,443,078	10,950,155	6,496,743	3,478,029	2,261,332	1,294,853	572,354	395,749	268,862	128,332	17,789	24,829	0
2007	71,153	0	338,891	1,597,436	3,731,833	4,959,705	6,524,004	5,212,373	6,499,962	6,987,548	9,776,391	11,966,198	11,982,098	12,662,065	14,063,152	16,091,059	16,974,749	12,802,469	9,308,192	5,593,871	3,183,761	1,407,833	718,128	314,241	277,261	21,868	73,888	10,555	63,084

b) Males.

	Length cutpoints (cm)																												
year	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
1984	0	0	6,810	6,725	13,906	186,288	192,911	581,245	2,282,061	5,130,645	7,178,239	12,590,116	16,569,975	12,058,330	6,898,225	4,048,513	2,173,916	713,487	339,341	34,372	40,023	20,768	23,772	13,535	0	0	0	0	0
1987	0	0	0	50,976	72,051	1,110,092	1,786,873	3,320,372	4,529,519	4,742,329	7,919,894	11,331,081	16,219,320	14,295,662	11,420,889	8,455,518	4,223,136	1,619,853	374,355	48,889	0	2,050	0	0	0	0	0	0	0
1990	0	0	34,007	97,788	393,488	969,572	2,090,768	2,119,210	3,476,265	4,873,831	9,361,115	15,469,414	18,819,974	21,143,140	20,689,077	12,463,694	7,418,343	3,668,104	1,184,914	100,647	66,040	0	0	0	0	0	0	0	0
1993	10,826	0	20,876	205,800	333,714	1,102,814	1,041,776	1,429,973	2,120,864	4,303,208	7,026,243	11,694,765	17,235,165	19,453,639	16,650,011	12,094,580	6,609,430	2,936,839	750,466	239,485	5,718	0	14,580	0	0	0	14,046	14,046	28,092
1996	47,874	41,668	163,977	741,113	952,043	1,690,918	1,694,164	2,721,625	4,900,907	7,640,376	10,057,547	13,671,404	15,124,525	13,727,674	10,597,385	7,770,278	4,953,102	2,304,570	1,257,422	671,571	245,847	53,562	11,050	0	0	0	0	0	0
1999	46,514	129,675	215,466	597,773	1,760,656	3,858,100	4,594,072	4,305,573	6,833,812	9,561,601	10,476,535	14,753,038	16,054,502	14,202,960	12,253,986	8,654,407	6,217,260	4,018,067	1,965,609	518,327	195,955	90,449	15,239	0	0	0	0	0	0
2001	0	62,698	110,877	686,501	1,888,512	2,123,202	3,177,541	3,794,338	4,403,453	6,705,694	6,813,737	7,222,837	6,419,737	5,470,530	6,493,700	6,258,042	5,960,542	3,394,396	1,114,380	223,323	144,135	0	0	0	0	0	0	0	0
2003	55,789	448,819	998,326	1,808,509	2,698,251	5,225,971	8,478,504	11,193,577	13,354,091	18,594,951	22,049,008	28,362,361	26,512,929	21,152,258	13,636,181	8,689,275	6,162,716	3,406,006	882,538	374,157	131,000	21,857	60,480	10,745	10,983	0	0	0	0
2005	145,626	36,002	598,531	947,331	1,828,197	2,490,341	3,151,918	5,557,932	9,965,820	16,061,399	19,653,351	23,120,621	23,994,567	20,691,102	15,771,409	11,621,501	6,786,062	2,895,735	989,973	389,911	146,757	9,813	59,822	19,625	0	0	0	0	0
2007	42,070	34,167	84,680	946,126	2,632,636	4,160,610	5,676,642	5,411,781	6,108,372	10,053,330	15,187,205	17,473,422	19,136,693	17,812,611	20,015,742	16,052,375	9,341,374	5,389,009	1,981,002	591,745	178,384	0	0	0	0	0	0	0	68,999

Table 6.8. Age-length transition 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
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
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
5	0	0	0	0	0.0003	0.0013	0.0051	0.0164	0.0421	0.0858	0.1396	0.1811	0.1872
6	0	0	0	0	0.0001	0.0003	0.0012	0.0045	0.0132	0.0323	0.0653	0.1093	0.1513
7	0	0	0	0	0	0.0001	0.0005	0.0017	0.0055	0.0147	0.0332	0.0635	0.1027
8	0	0	0	0	0	0.0001	0.0002	0.0009	0.0029	0.0081	0.0195	0.0404	0.0715
9	0	0	0	0	0	0	0.0001	0.0005	0.0018	0.0052	0.0131	0.0284	0.0532
10	0	0	0	0	0	0	0.0001	0.0004	0.0013	0.0038	0.0097	0.0218	0.0424
11	0	0	0	0	0	0	0.0001	0.0003	0.001	0.003	0.0078	0.0179	0.0356
12	0	0	0	0	0	0	0.0001	0.0002	0.0008	0.0025	0.0067	0.0155	0.0313
13	0	0	0	0	0	0	0.0001	0.0002	0.0007	0.0022	0.006	0.0139	0.0285
14	0	0	0	0	0	0	0	0.0002	0.0007	0.002	0.0055	0.0129	0.0266
15	0	0	0	0	0	0	0	0.0002	0.0006	0.0019	0.0051	0.0121	0.0252
16	0	0	0	0	0	0	0	0.0002	0.0006	0.0018	0.0049	0.0116	0.0243
17	0	0	0	0	0	0	0	0.0002	0.0006	0.0018	0.0047	0.0113	0.0237
18	0	0	0	0	0	0	0	0.0002	0.0006	0.0017	0.0046	0.011	0.0232
19	0	0	0	0	0	0	0	0.0002	0.0005	0.0017	0.0046	0.0109	0.0228
20	0	0	0	0	0	0	0	0.0002	0.0005	0.0017	0.0045	0.0107	0.0226

age	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.0356	0.0109	0.0025	0.0004	0.0001	0	0	0	0	0	0	0	0	0	0	0
5	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	0.1731	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	0.1404	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	0.1084	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	0.0862	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	0.0715	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	0.062	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	0.0556	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	0.0513	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	0.0483	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	0.0462	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	0.0447	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	0.0436	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	0.0429	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	0.0423	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	0.0419	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
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
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
5	0	0	0	0.0001	0.0006	0.0029	0.0112	0.0331	0.076	0.1353	0.1867	0.1998	0.1658
6	0	0	0	0	0.0001	0.0007	0.003	0.0106	0.0299	0.0669	0.1192	0.169	0.1907
7	0	0	0	0	0	0.0002	0.0011	0.0043	0.0139	0.036	0.0751	0.1261	0.1706
8	0	0	0	0	0	0.0001	0.0005	0.0021	0.0075	0.0217	0.0506	0.0956	0.1459
9	0	0	0	0	0	0	0.0002	0.0011	0.0045	0.0143	0.0367	0.0758	0.1263
10	0	0	0	0	0	0	0.0001	0.0007	0.0029	0.0101	0.0281	0.0626	0.1121
11	0	0	0	0	0	0	0.0001	0.0004	0.002	0.0075	0.0225	0.0535	0.1017
12	0	0	0	0	0	0	0	0.0003	0.0014	0.0057	0.0184	0.0468	0.0941
13	0	0	0	0	0	0	0	0.0002	0.001	0.0044	0.0154	0.0416	0.0882
14	0	0	0	0	0	0	0	0.0001	0.0007	0.0035	0.0129	0.0374	0.0834
15	0	0	0	0	0	0	0	0.0001	0.0005	0.0027	0.0109	0.0337	0.0793
16	0	0	0	0	0	0	0	0	0.0004	0.0021	0.0092	0.0304	0.0756
17	0	0	0	0	0	0	0	0	0.0002	0.0016	0.0076	0.0273	0.072
18	0	0	0	0	0	0	0	0	0.0002	0.0012	0.0063	0.0244	0.0685
19	0	0	0	0	0	0	0	0	0.0001	0.0009	0.0051	0.0216	0.065
20	0	0	0	0	0	0	0	0	0	0.0004	0.0032	0.0164	0.0577

age	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.0169	0.0041	0.0007	0.0001	0	0	0	0	0	0	0	0	0	0	0	0
5	0.1067	0.0533	0.0206	0.0062	0.0014	0.0003	0	0	0	0	0	0	0	0	0	0
6	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	0.1856	0.1626	0.1146	0.0651	0.0297	0.0109	0.0032	0.0008	0.0001	0	0	0	0	0	0	0
8	0.1798	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	0.1699	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	0.1611	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	0.1544	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	0.1496	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	0.1462	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	0.144	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	0.1425	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	0.1414	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	0.1406	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	0.14	0.2074	0.2232	0.1743	0.0988	0.0406	0.0121	0.0026	0.0004	0	0	0	0	0	0	0
19	0.1393	0.2123	0.2301	0.1775	0.0973	0.038	0.0105	0.0021	0.0003	0	0	0	0	0	0	0
20	0.1378	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).

Age	Length (cm) Males	Length (cm) Females	Weight (g) Males	Weight (g) Females	Maturity 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. Baseline model settings.

			Likelihood Component Multipliers						
		Fishery			Survey		Recruitment		
Case	**Q**	**catch**	**length compositions**	**biomass**	**length compositions**	**age compositions**	**early**	**ordinary**	**late**
base	1	20	1	1	2	1	1	1	1

Table 6.11. Initial parameter values.

Case					**Fishery**				**Survey**			
					slope		A_{50}		**slope**		A_{50}	
	$\overline{\ln R_0}$	τ_t	$\overline{\ln F}$	ε_t	**female**	**male**	**female**	**male**	**female**	**male**	**female**	**male**
base	17	0	-6	0.0	2.505	2.505	13	13	2.505	2.505	13	13

Table 6.12. Final parameter estimates. Subscripts for recruitment deviations (τ) run from 1965 to 2007, with the subscript increasing moving across, then down. Subscripts for fishing mortality deviations (ε) run from 1982 to 2007 in the same manner.

Recruitment										
$\overline{\ln R_0}$	16.896015									
τ_t				1965-2007:	-0.8823	-0.2889	-0.3231	-0.3003	-0.1073	-0.1598
	0.1615	-0.0472	-0.1710	-0.1139	-0.1400	-0.2924	-0.2190	0.0276	0.0756	-0.0795
	-0.3683	-0.0064	-0.1625	-0.6281	0.0197	0.1303	0.3962	0.8341	0.5052	0.4683
	0.2056	-0.5360	-0.3354	-0.2455	-0.8038	-0.6490	0.4505	-0.0932	0.4326	0.0849
	1.0196	0.5423	1.0137	0.1157	0.0999	0.0706	0.2991			

Fishing mortality										
$\overline{\ln F}$	-2.7460398									
ε_t	1982-2007:	-0.6053	-1.0569	-1.5191	-2.3680	-2.8809	-0.4698	-0.4087	-1.0626	-0.3440
	0.9723	0.6249	0.5662	0.6884	0.6911	0.9840	0.4558	0.2782	0.4623	0.7150
	0.6670	0.7798	1.0349	0.1553	0.4351	0.7673	0.4375			

Fishery Selectivity		
	females	**males**
slope	2.0501	0.8696
$\mathbf{A_{50}}$	9.86	10.52

Survey Selectivity		
	females	**males**
slope	1.3343	2.6334
$\mathbf{A_{50}}$	3.60	3.28

Table 6.13. Model-estimated fishery catch and survey biomass.

	catch (t)			survey biomass (t)		
year	**estimated**	**std dev**	**observed**	**estimated**	**std dev**	**observed**
1982	1,007	157	959	70,959	3,792	
1983	633	98	595	70,629	3,651	
1984	399	62	365	70,322	3,516	60,670
1985	174	27	154	69,610	3,364	
1986	108	17	93	69,731	3,230	
1987	1,206	188	1,151	71,286	3,155	63,826
1988	1,250	195	1,192	74,282	3,144	
1989	641	100	599	80,331	3,225	
1990	1,295	200	1,269	87,614	3,332	98,225
1991	4,446	679	4,636	93,210	3,423	
1992	2,913	447	3,000	93,363	3,443	
1993	2,770	416	3,000	91,941	3,361	86,911
1994	3,325	495	3,673	88,568	3,224	
1995	3,662	546	4,021	83,550	3,064	
1996	5,148	757	5,874	77,236	2,914	72,757
1997	3,070	462	3,294	70,174	2,736	
1998	2,562	389	2,669	67,914	2,640	
1999	2,903	440	3,060	67,735	2,675	74,969
2000	3,379	511	3,591	68,743	2,746	
2001	2,898	449	2,940	71,107	2,831	71,326
2002	2,915	454	2,941	77,613	3,048	
2003	3,438	537	3,485	85,790	3,337	99,897
2004	1,478	230	1,464	94,205	3,858	
2005	2,142	331	2,176	101,340	4,384	101,255
2006	3,225	500	3,294	103,970	4,798	
2007	2,551	393	2,609	103,200	4,999	103,776

Table 6.14. Estimated age 3+ population biomass and female spawning biomass.

	Age 3+ Biomass (1000's t)				Female Spawning Stock Biomass (1000's t)			
	2007 Assessment		2005	2004	2007 Assessment		2005	2004
year	mean	std dev	mean	mean	mean	std dev	mean	mean
1982	75	4	77	78	34	2	35	36
1983	74	4	76	78	34	2	35	36
1984	73	4	75	77	34	2	35	36
1985	73	3	74	76	34	2	35	36
1986	74	3	75	77	34	2	35	36
1987	76	3	77	80	34	2	35	36
1988	82	3	82	85	34	2	34	35
1989	88	3	87	91	35	2	35	36
1990	95	3	93	98	37	2	37	39
1991	99	3	97	102	41	2	40	42
1992	97	3	95	100	42	2	41	44
1993	95	3	93	98	44	2	42	45
1994	92	3	89	94	44	2	42	45
1995	86	3	84	88	42	2	41	43
1996	79	3	77	82	39	2	38	40
1997	74	3	72	76	35	1	34	36
1998	72	3	70	74	33	1	31	34
1999	73	3	71	74	31	1	30	32
2000	74	3	72	75	31	1	30	31
2001	79	3	78	77	31	1	30	31
2002	86	3	90	79	32	1	31	32
2003	95	4	99	81	34	1	34	33
2004	102	4	105	82	38	2	40	34
2005	107	5	109		43	2	46	
2006	109	5			47	2		
2007	108	5			49	2		

Table 6.15. Estimated age 3 recruitment.

	2007 Assessment		2005 Assessment	2004 Assessment
Year	Mean (millions)	Std Dev (millions)	Mean (millions)	Mean (millions)
1982	43	6	42	45
1983	37	5	37	38
1984	23	4	24	25
1985	44	7	41	46
1986	50	7	48	51
1987	65	8	66	67
1988	100	11	93	102
1989	72	9	69	73
1990	70	8	69	70
1991	53	7	52	53
1992	25	5	25	26
1993	31	6	32	33
1994	34	6	33	36
1995	19	5	20	21
1996	23	7	27	26
1997	68	20	64	57
1998	40	16	40	43
1999	67	13	70	71
2000	47	16	45	49
2001	121	20	130	64
2002	75	24	145	56
2003	120	22	51	53
2004	49	17	48	43
2005	48	6	47	
2006	47	6		
2007	59	7		

Table 6.16. Projected catch (t) for the seven projection scenarios.

	Catch (t)						
year	**scenario 1**	**scenario 2**	**scenario 3**	**scenario 4**	**scenario 5**	**scenario 6**	**scenario 7**
2007	2,609	2,609	2,609	2,609	2,609	2,609	2,609
2008	48,049	48,049	37,055	3,504	0	57,919	48,049
2009	15,746	15,746	16,629	3,925	0	15,094	15,746
2010	10,984	10,984	12,197	4,237	0	8,663	15,242
2011	7,384	7,384	8,338	4,261	0	7,581	7,849
2012	7,402	7,402	7,051	4,054	0	8,006	8,145
2013	7,932	7,932	7,210	3,830	0	8,615	8,673
2014	8,277	8,277	7,685	3,679	0	8,590	8,608
2015	8,174	8,174	7,733	3,584	0	8,520	8,522
2016	8,182	8,182	7,728	3,514	0	8,520	8,520
2017	8,145	8,145	7,714	3,462	0	8,459	8,459
2018	8,084	8,084	7,661	3,419	0	8,416	8,416
2019	8,077	8,077	7,627	3,382	0	8,439	8,439
2020	8,101	8,101	7,634	3,352	0	8,462	8,462

Table 6.17. Female spawning biomass (t) for the seven projection scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 20,805 t and 18,877 t, respectively.

	Female spawning biomass (t)						
year	**scenario 1**	**scenario 2**	**scenario 3**	**scenario 4**	**scenario 5**	**scenario 6**	**scenario 7**
2007	48,783	48,783	48,783	48,783	48,783	48,783	48,783
2008	49,010	49,010	49,010	49,010	49,010	49,010	49,010
2009	26,039	26,039	30,495	47,987	49,984	22,641	26,039
2010	21,751	21,751	25,246	46,644	50,644	18,430	21,751
2011	19,861	19,861	22,351	45,201	51,130	18,252	18,179
2012	20,544	20,544	22,199	43,917	51,491	19,027	19,022
2013	21,202	21,202	22,820	42,946	51,751	19,572	19,572
2014	21,405	21,405	23,213	42,225	51,916	19,527	19,527
2015	21,266	21,266	23,167	41,655	52,002	19,410	19,410
2016	21,195	21,195	23,085	41,197	52,047	19,340	19,340
2017	21,122	21,122	23,014	40,839	52,074	19,269	19,269
2018	21,095	21,095	22,975	40,578	52,108	19,263	19,263
2019	21,122	21,122	22,981	40,382	52,134	19,306	19,306
2020	21,121	21,121	22,975	40,197	52,115	19,301	19,301

Table 6.18. Fishing mortality for the seven projection scenarios.

	Fishing mortality						
year	**scenario 1**	**scenario 2**	**scenario 3**	**scenario 4**	**scenario 5**	**scenario 6**	**scenario 7**
2007	0.1018	0.1018	0.1018	0.1018	0.1018	0.1018	0.1018
2008	4.7798	4.7798	2.3899	0.1185	0.0000	10.2276	4.7798
2009	4.7798	4.7798	2.3899	0.1185	0.0000	10.2276	4.7798
2010	4.7780	4.7780	2.3899	0.1185	0.0000	8.9907	10.2239
2011	4.4487	4.4487	2.3731	0.1185	0.0000	8.8289	8.7861
2012	4.4625	4.4625	2.3237	0.1185	0.0000	9.0209	9.0183
2013	4.4659	4.4659	2.3138	0.1185	0.0000	9.0726	9.0726
2014	4.4398	4.4398	2.3039	0.1185	0.0000	8.9705	8.9705
2015	4.4101	4.4101	2.2913	0.1185	0.0000	8.9361	8.9361
2016	4.4102	4.4102	2.2877	0.1185	0.0000	8.9319	8.9319
2017	4.4024	4.4024	2.2869	0.1185	0.0000	8.9048	8.9048
2018	4.3992	4.3992	2.2866	0.1185	0.0000	8.9018	8.9018
2019	4.4048	4.4048	2.2886	0.1185	0.0000	8.9143	8.9143
2020	4.4104	4.4104	2.2902	0.1185	0.0000	8.9295	8.9295

Table 6.19. Prohibited species catch (PSC) in the rex sole target fishery. The "rex sole (t)" column lists the catch of rex sole attributed to the targeted fishery. "Crab" is Bairdi tanner crab exclusively.

year	rex sole (t)	Halibut kg	kg/t	Crab #	#/t	Chinook Salmon #	#/t	Non-Chinook Salmon #	#/t	Total Salmon #	#/t
2003	2,077	393,373	189.4	28,780	13.9	2,900	1.40	520	0.25	3,420	1.65
2004	697	304,274	436.5	9,014	12.9	494	0.71	1,049	1.51	1,543	2.21
2005	875	86,281	98.6	7,949	9.1	525	0.60	98	0.11	623	0.71
2006	1,714	208,398	121.6	73,530	42.9	1,445	0.84	557	0.32	2,002	1.17

Table 6.20. Catch of non-prohibited species in the rex sole target fishery. The "Percent of retained target" gives the species catch as a percentage of the rex sole catch retained in the targeted fishery.

	2006			2005		
species	Total (t)	% retained	% of retained target	Total (t)	% retained	% of retained target
atka mackerel	6	88%	0%	9	34%	1%
arrowtooth flounder	4,321	3%	257%	1,723	9%	204%
dover sole and turbot (GOA)	48	0%	3%	49	2%	6%
flathead sole	269	83%	16%	125	85%	15%
northern rf	7	0%	0%	31	10%	4%
all sharks, squid, sculpin octopus	67	0%	4%	29	0%	3%
pacific cod	271	95%	16%	115	88%	14%
pelagic rockfish complex	4	58%	0%	5	97%	1%
pollock	51	100%	3%	22	99%	3%
POP	100	48%	6%	116	1%	14%
rex sole	1,714	98%	102%	875	97%	104%
rougheye	17	61%	0	4	0%	1%
other rockfish	--	--	--	0	100%	0%
sablefish	38	89%	2%	11	90%	1%
shallow water flatfish	40	100%	2%	8	99%	1%
shortraker	11	100%	1%	7	93%	1%
thornyheads	20	99%	0	10	99%	1%
unidentified skates	--	--	--	36	59%	4%
big skate	99	69%	6%	49	96%	6%
longnose skate	29	93%	2%	19	100%	2%

Figures

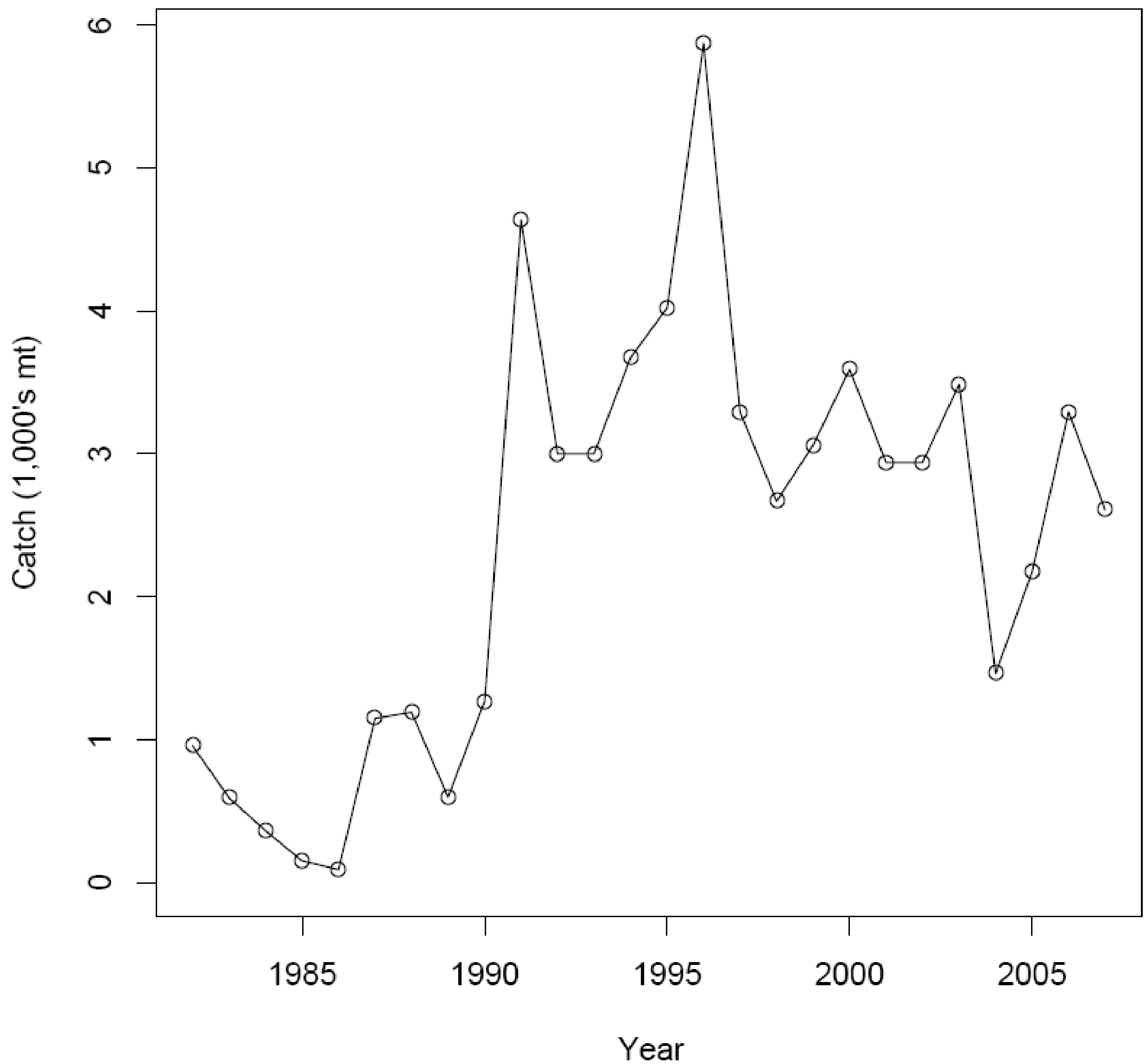


Figure 6.1. Fishery catches for GOA rex sole, 1982-2007.

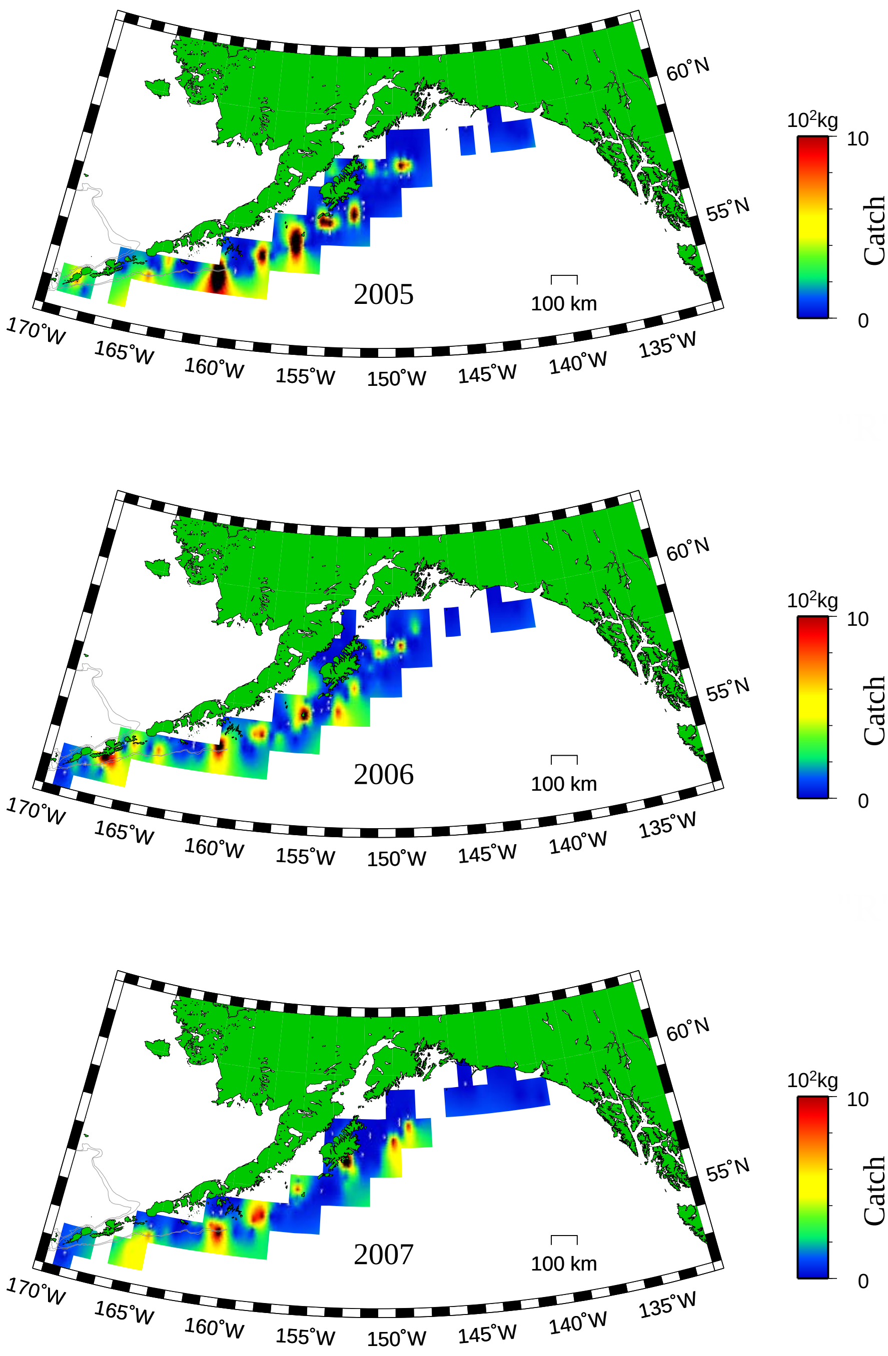


Figure 6.2. Spatial patterns of fishery catches for GOA rex sole, 2005-2007.

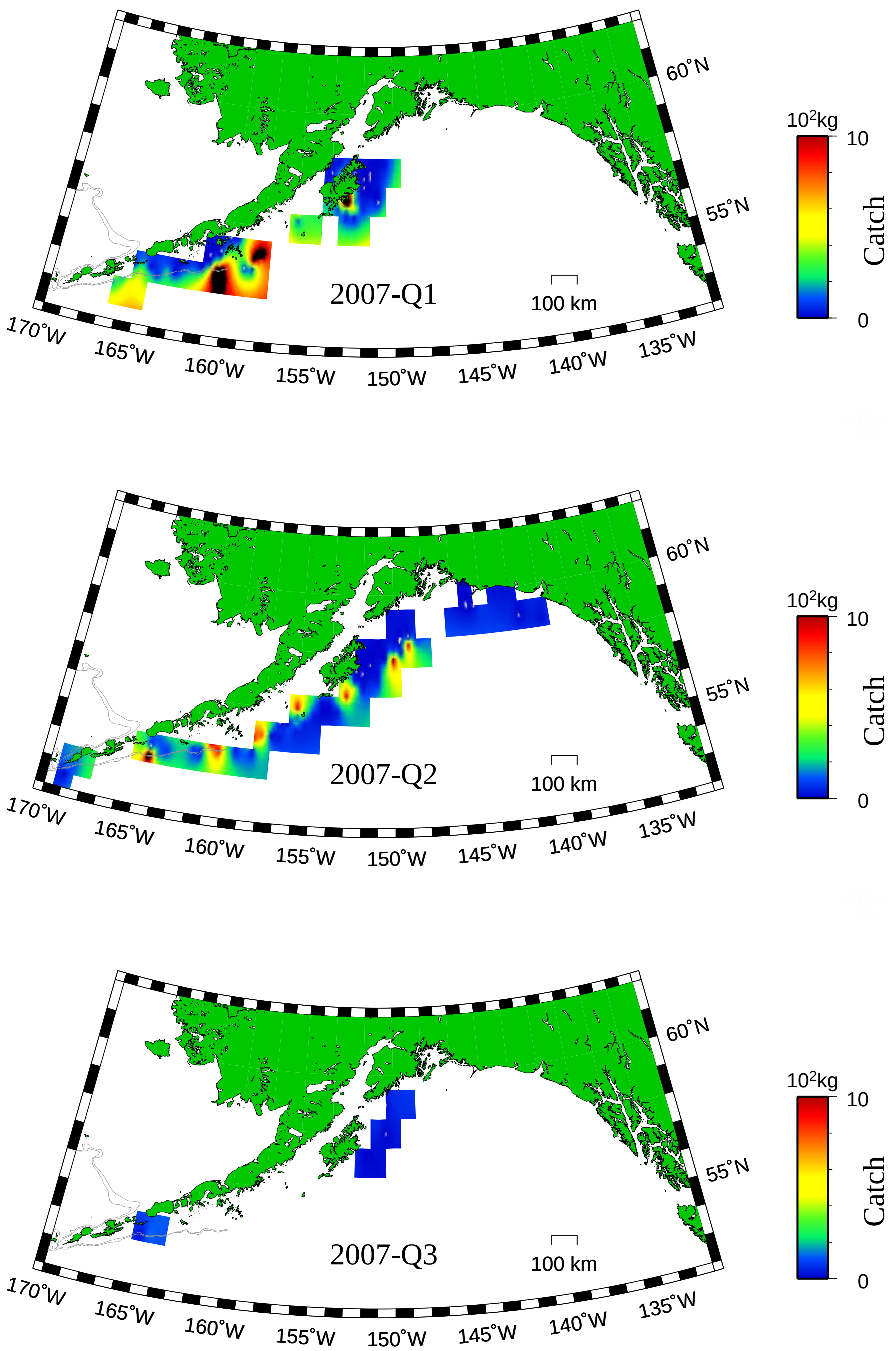


Figure 6.3. Spatial patterns of fishery catches for GOA rex sole from the first three quarters of 2007.

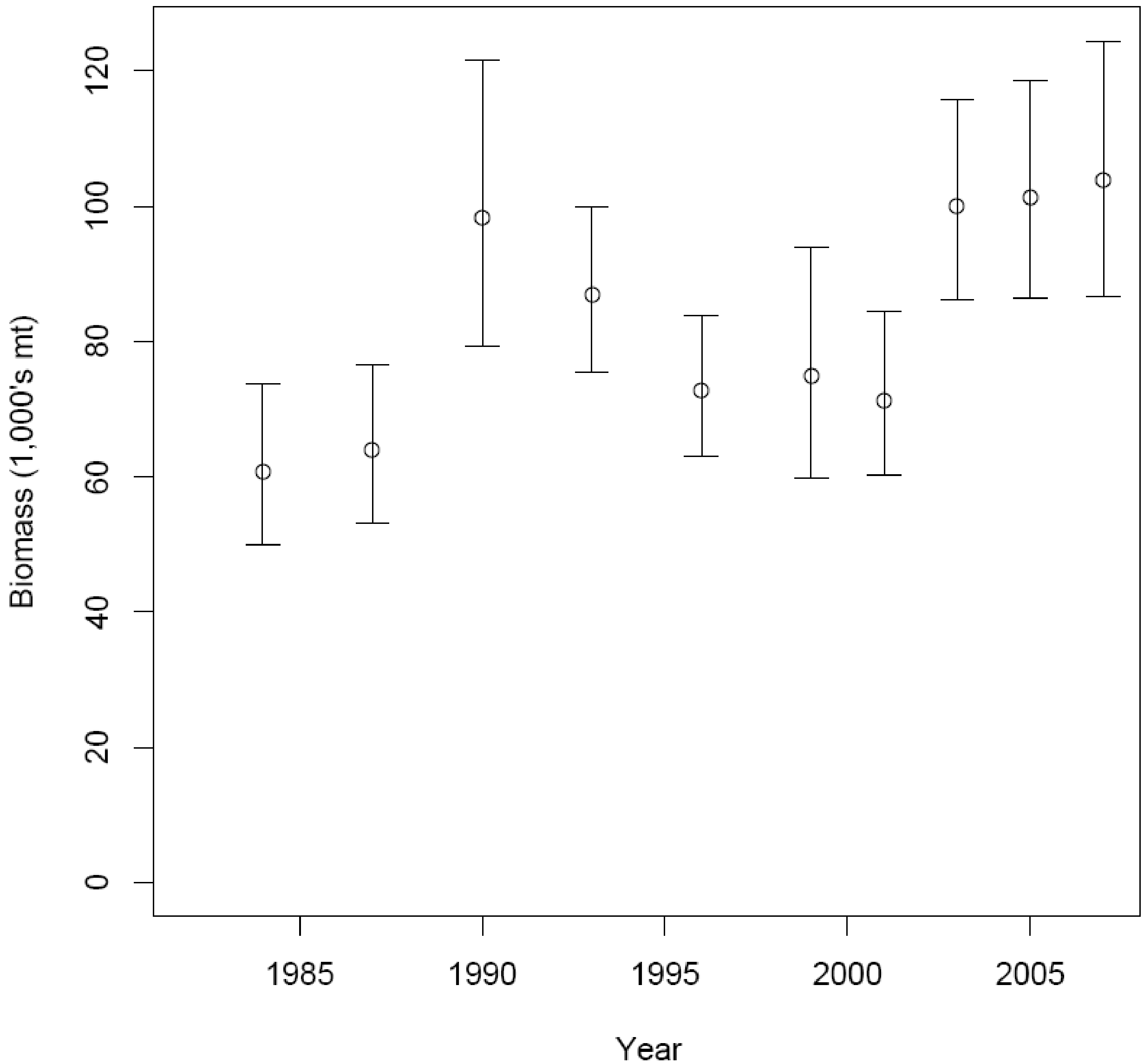


Figure 6.4. GOA survey biomass for rex sole. Error bars represent 95% lognormal confidence intervals. The 2001 GOA survey did not survey the Eastern Gulf. The value shown here for 2001 has been corrected to account for this (see text).

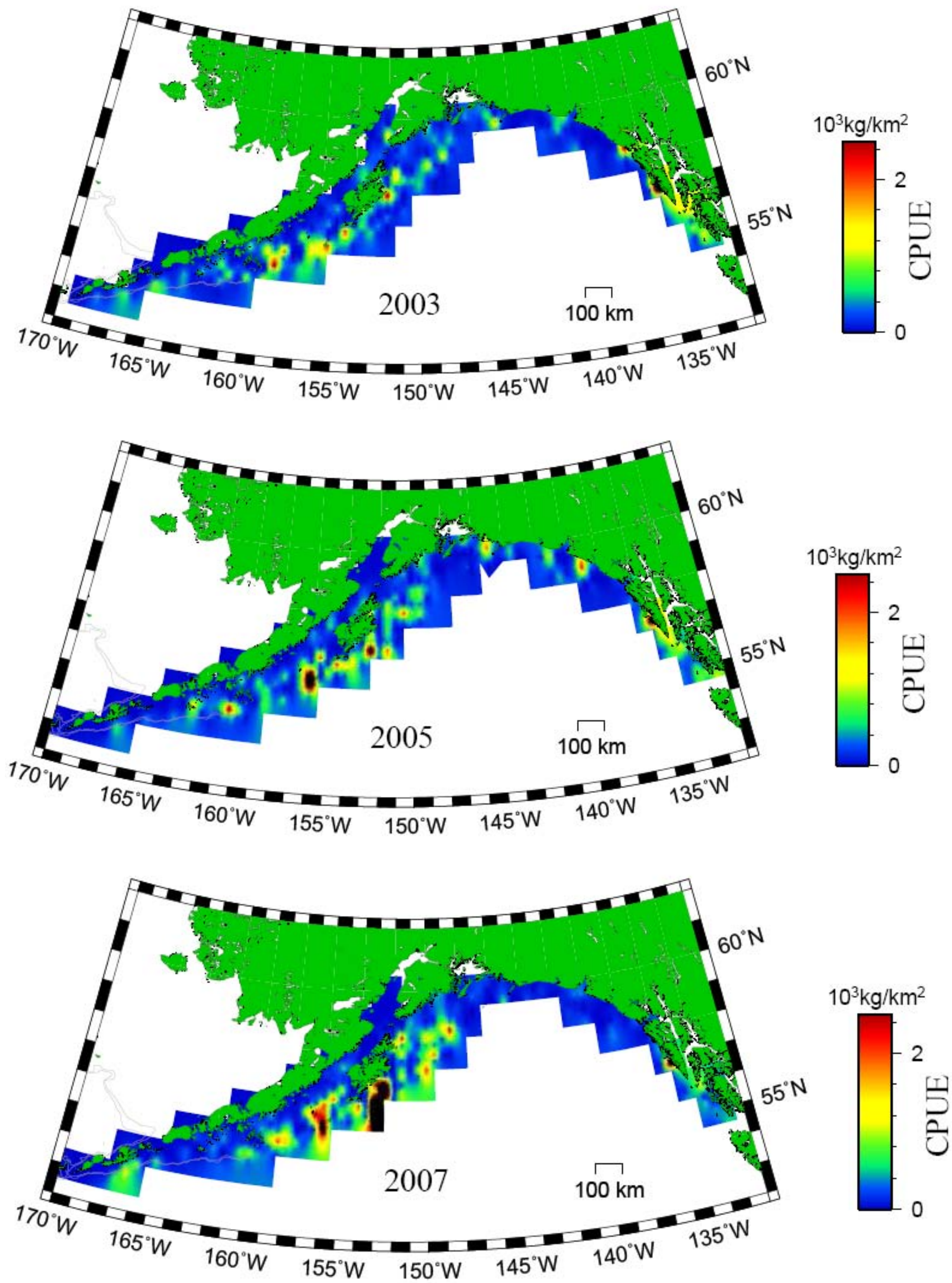
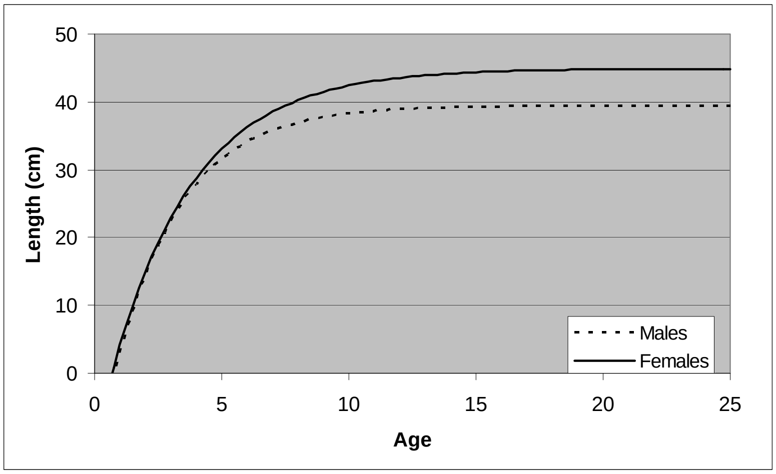
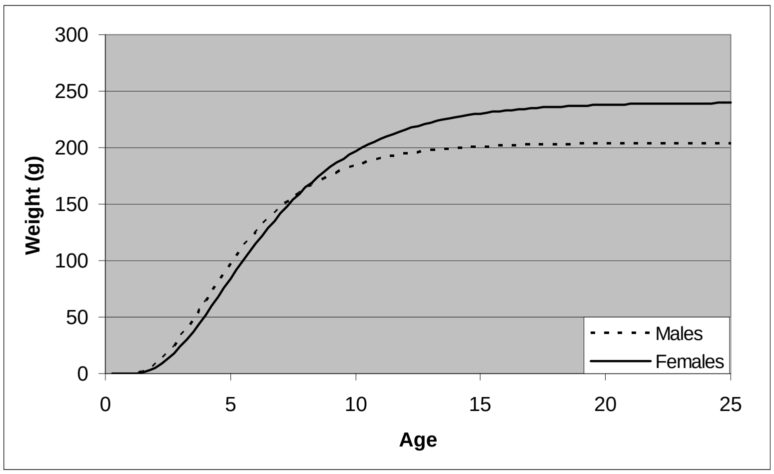


Figure 6.5. Spatial patterns of CPUE for rex sole in the GOA groundfish surveys for 2003, 2005 and 2007.

a) Length-at-age.



b) Weight-at-age.



c) Maturity-at-age (females).

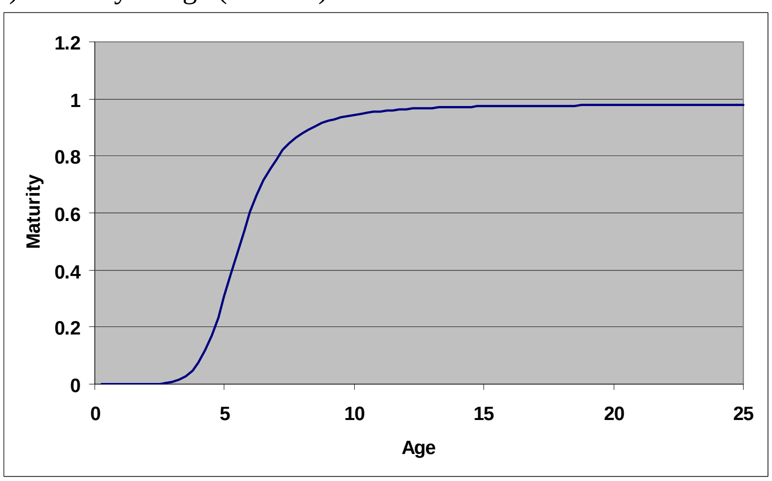


Figure 6.6. Age-specific schedules for GOA rex sole: females solid line, males dotted line.

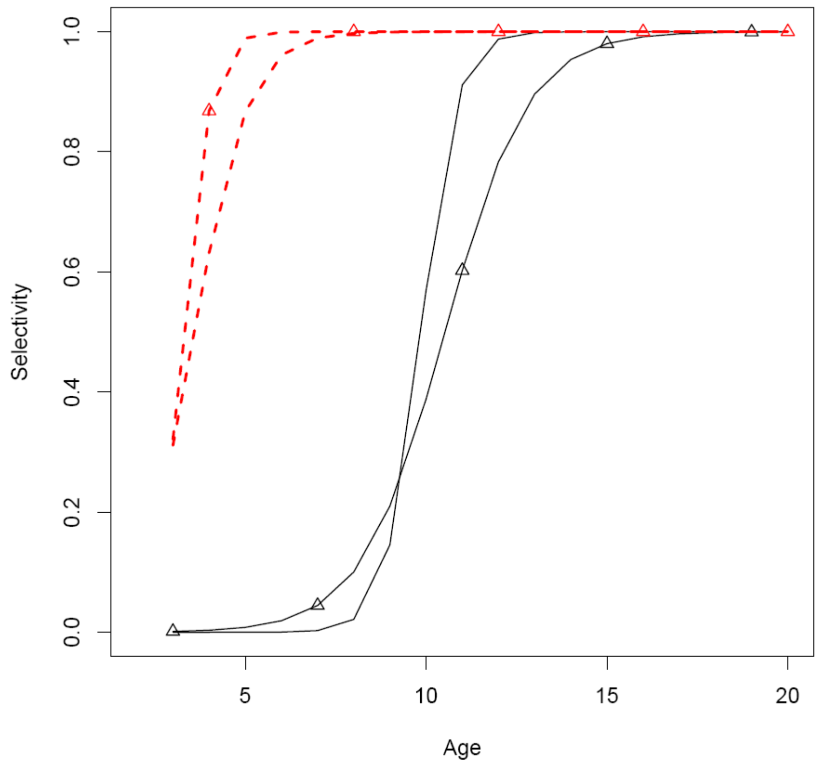


Figure 6.7. Selectivities for GOA rex sole for the survey (red, dotted line) and fishery (solid line). Male curve with triangle symbol, female curve without symbol.

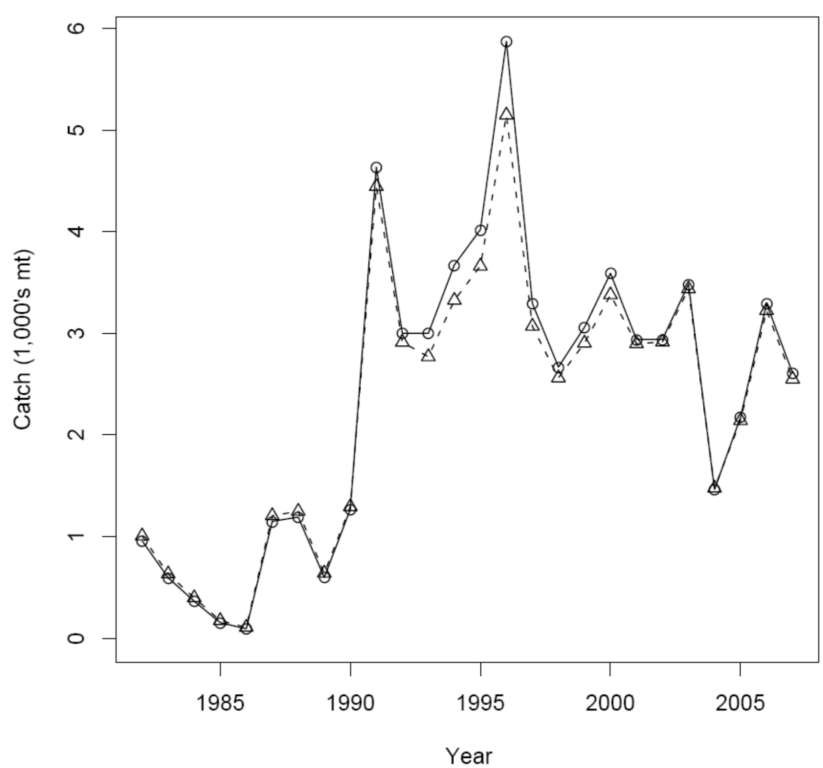


Figure 6.8. Predicted and observed annual catches for GOA rex sole. Predicted catch = dotted line with circles, observed catch = solid line.

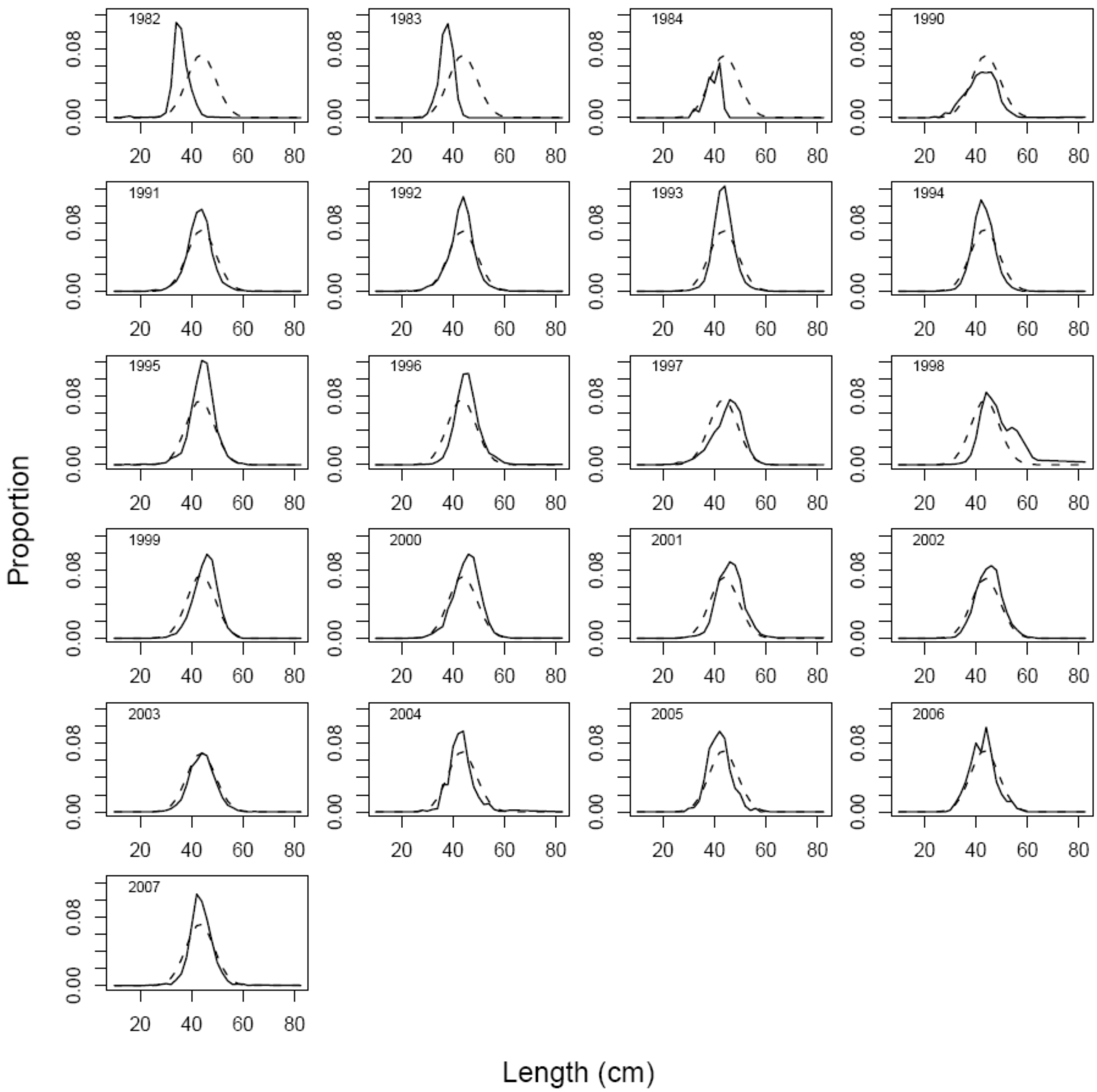


Figure 6.9a. Fit to female GOA rex sole fishery length composition data. Dashed lines represent the model prediction, solid lines represent the data.

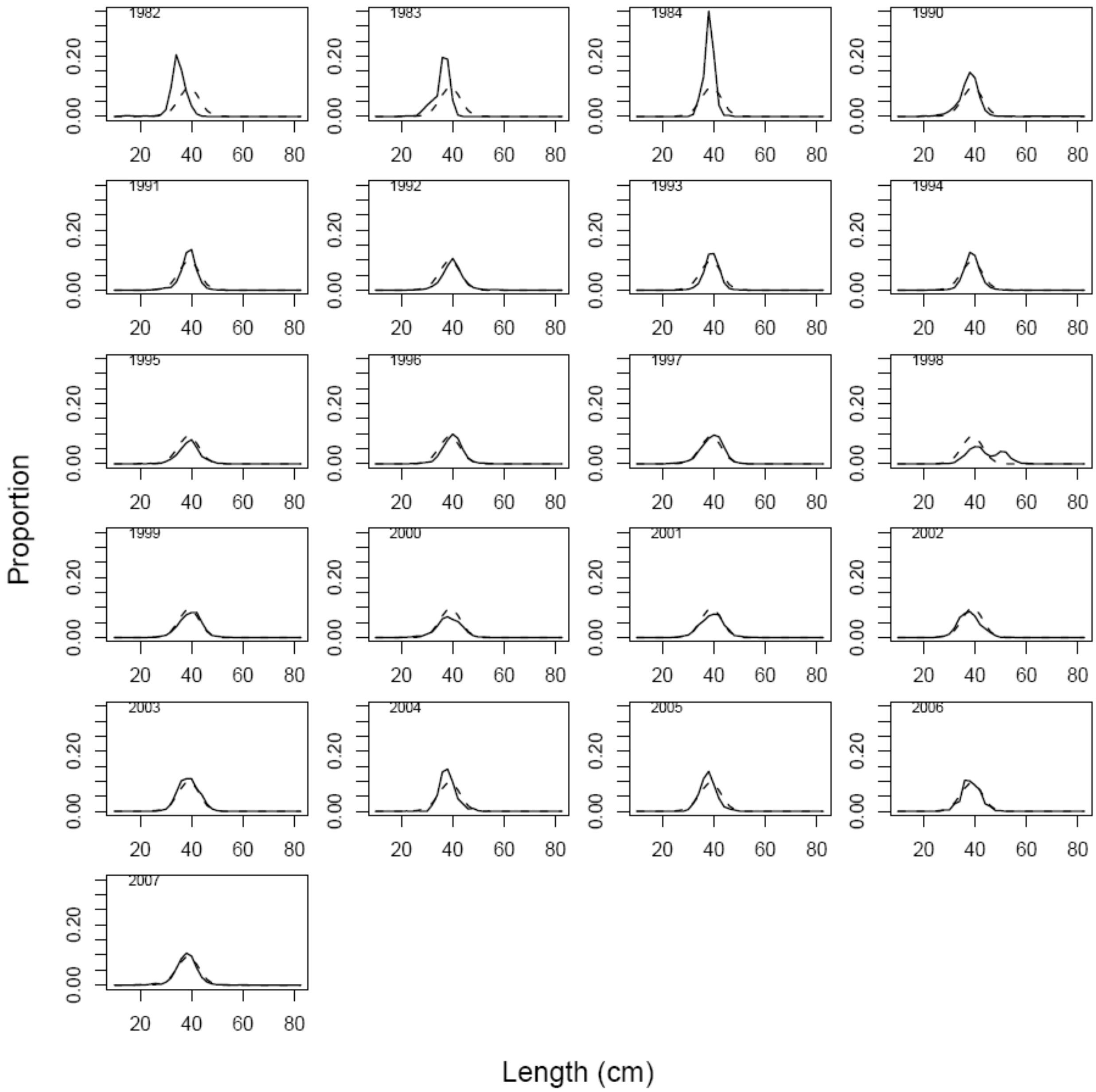


Figure 6.9b. Fit to male GOA rex sole fishery length composition data. Dashed lines represent the model prediction, solid lines represent the data.

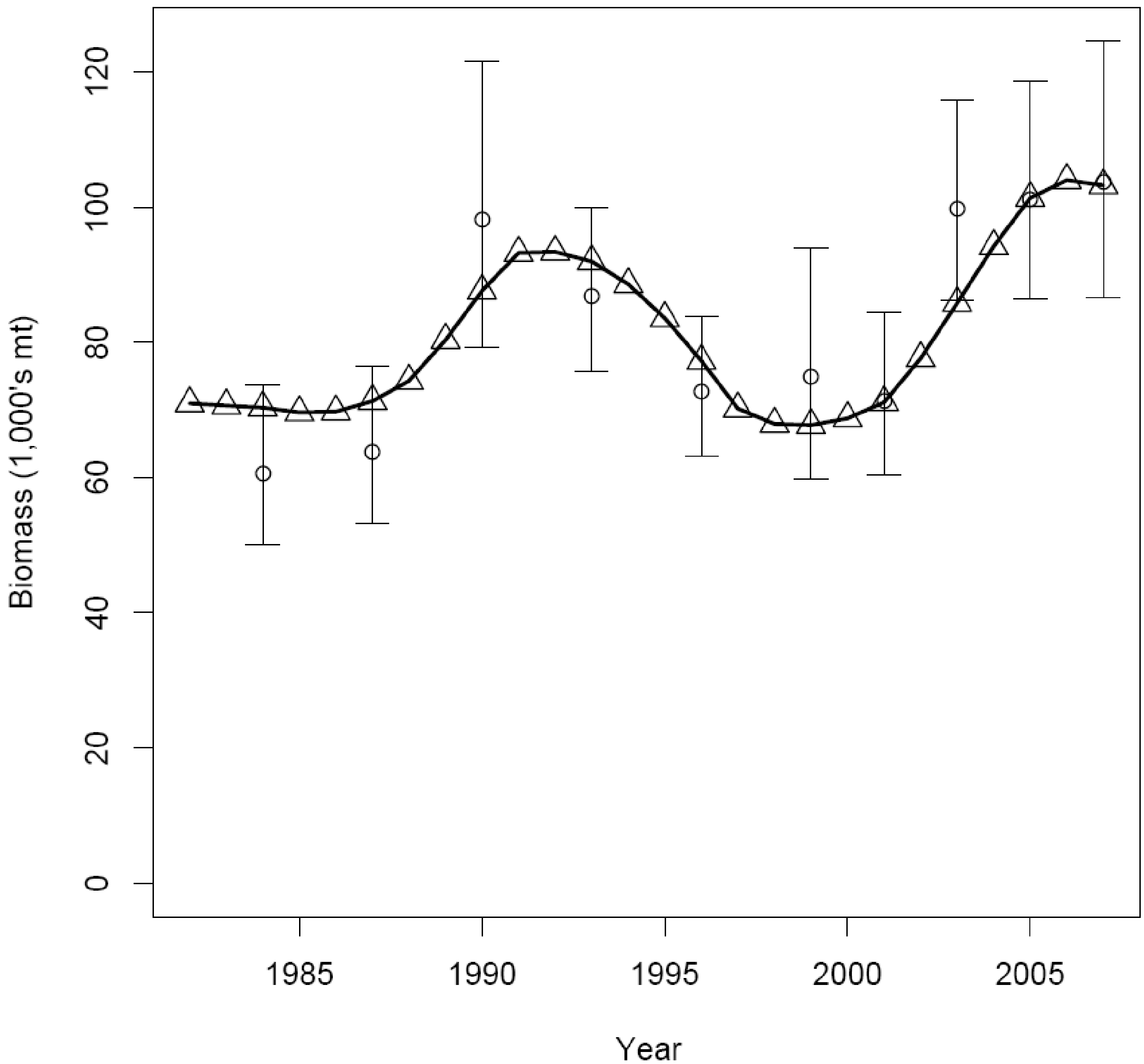


Fig. 6.10. Predicted and observed survey biomass for GOA rex sole. Predicted survey biomass = triangles, observed survey biomass = circles (error bars are approximate lognormal 95% confidence intervals).

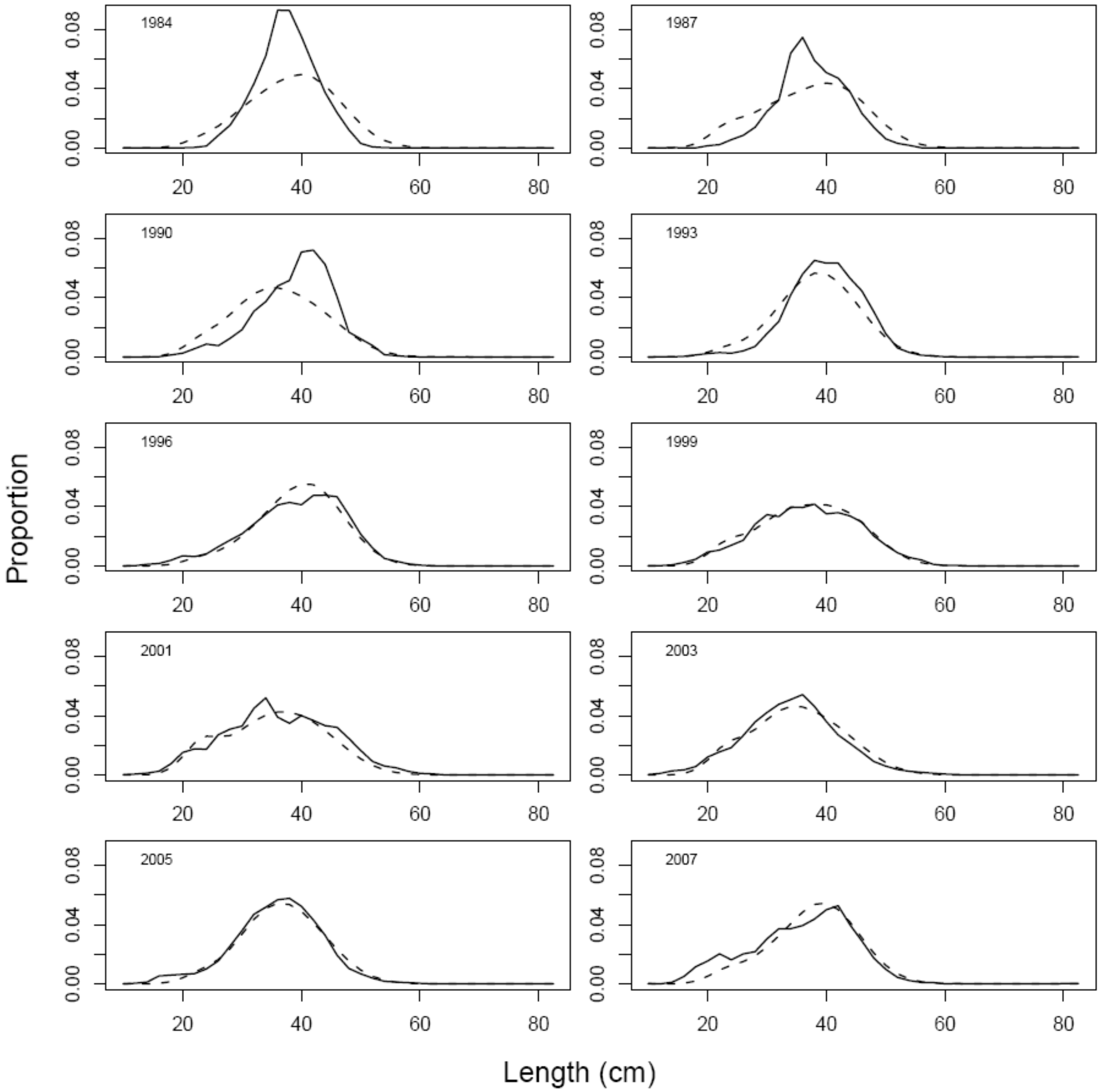


Figure 6.11a. Fit to the female GOA rex sole survey length composition data. Dashed lines represent the model prediction, solid lines represent the data.

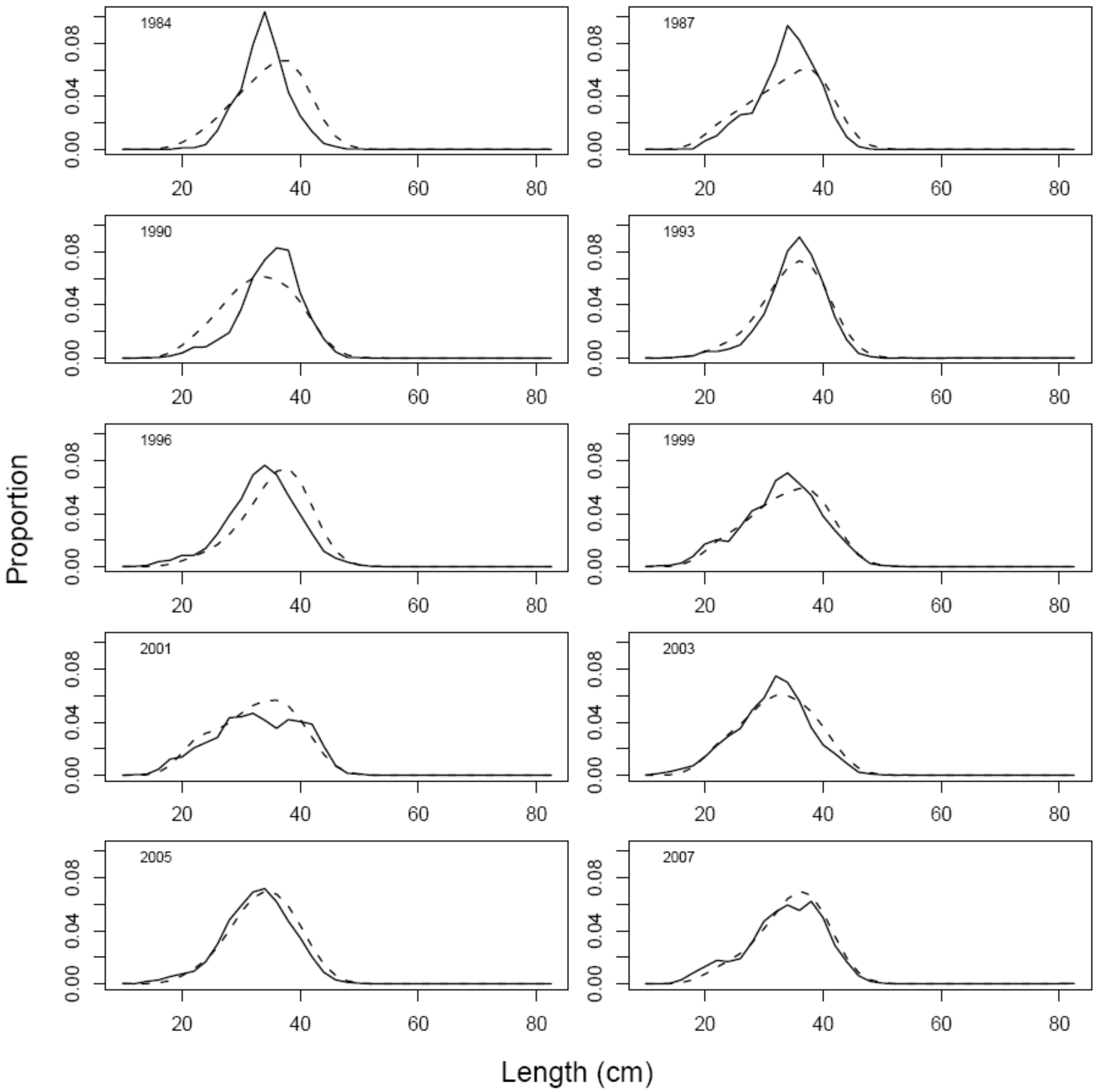


Figure 6.11b. Fit to the male GOA rex sole survey length composition data. Dashed lines represent the model prediction, solid lines represent the data.

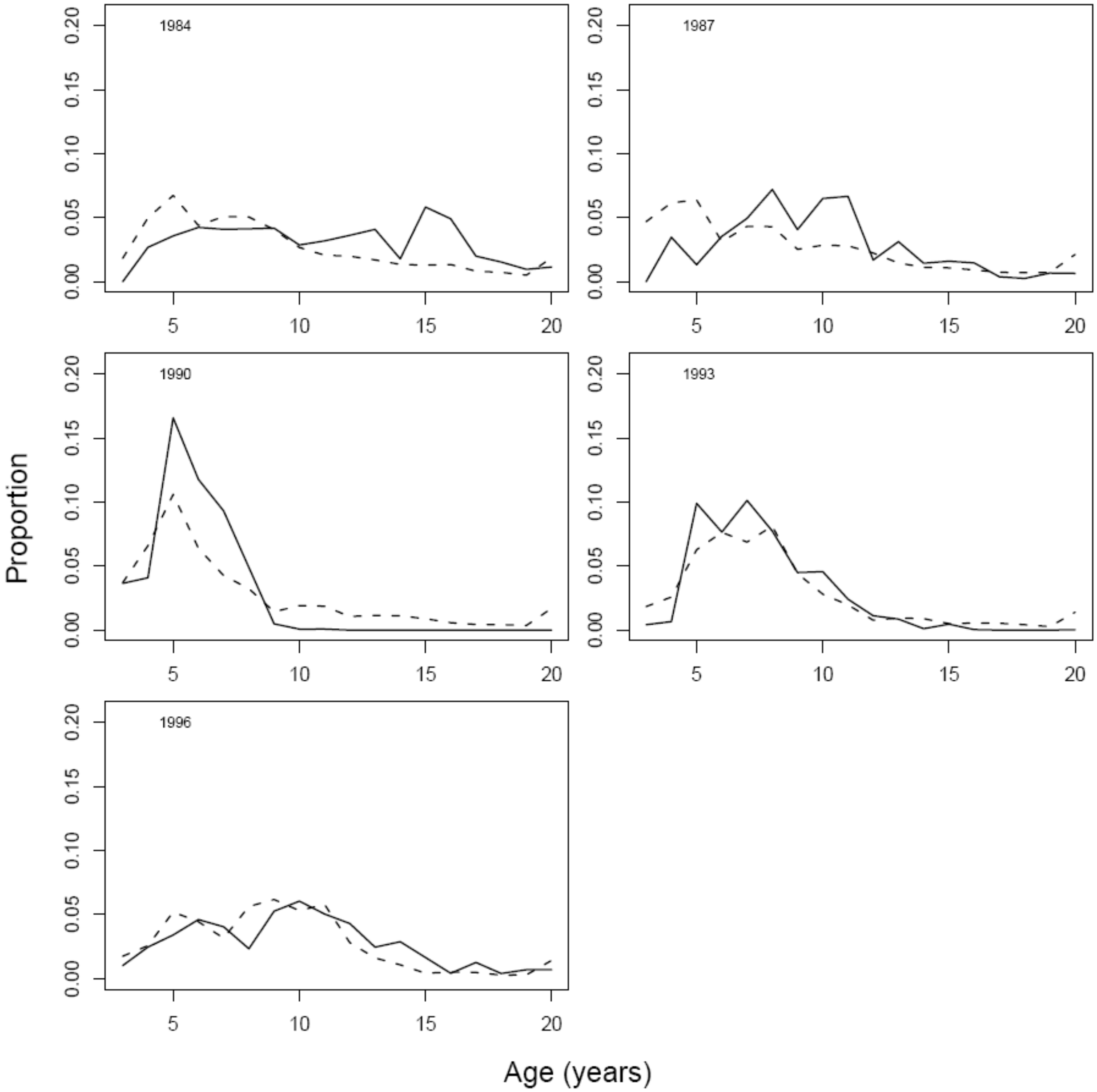


Figure 6.12a. Fit to the female survey GOA rex sole age composition data. Dashed lines represent the model prediction, solid lines represent the data.

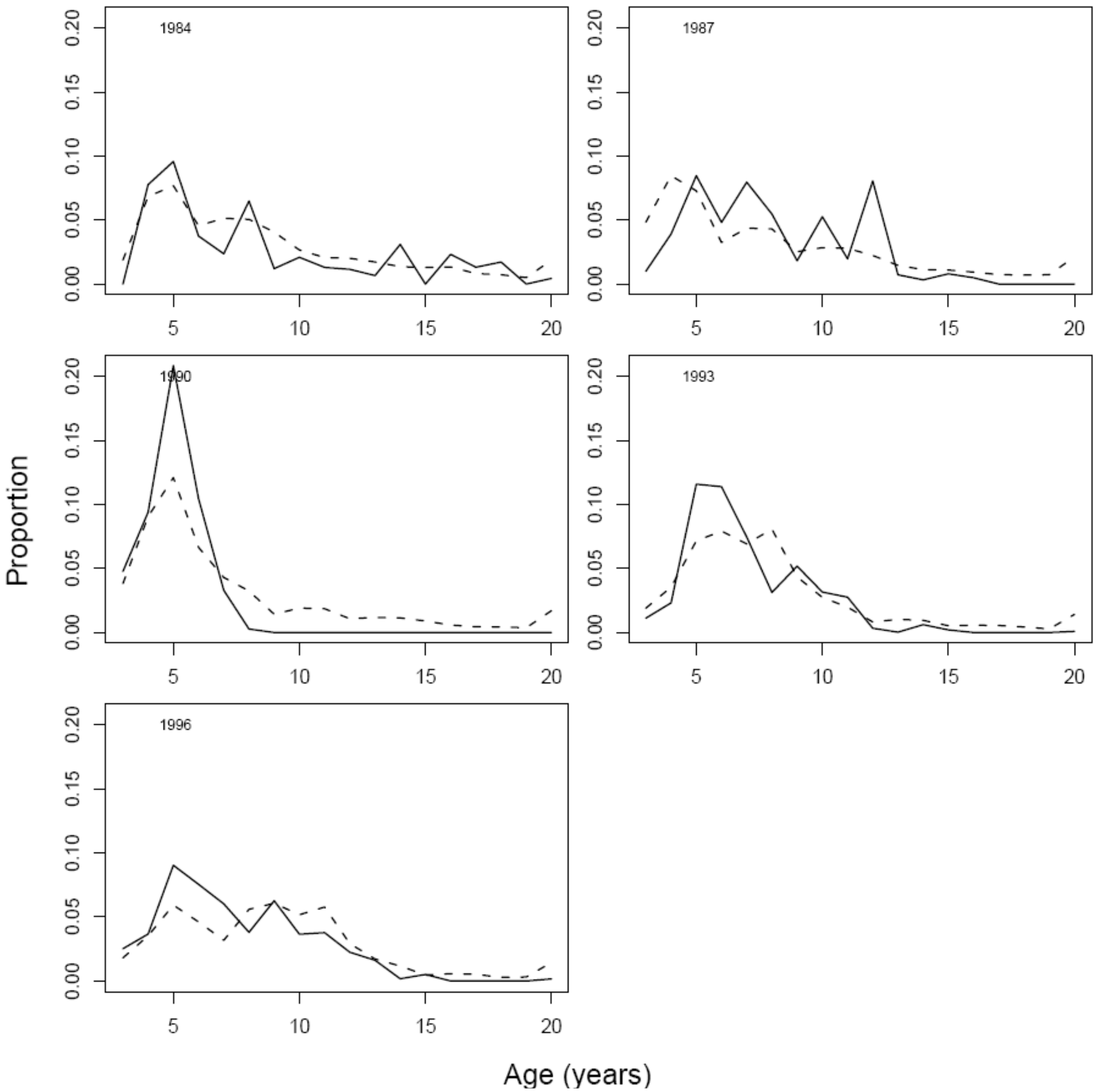


Figure6.12b. Fit to the male survey GOA rex sole age composition data. Dashed lines represent the model prediction, solid lines represent the data.

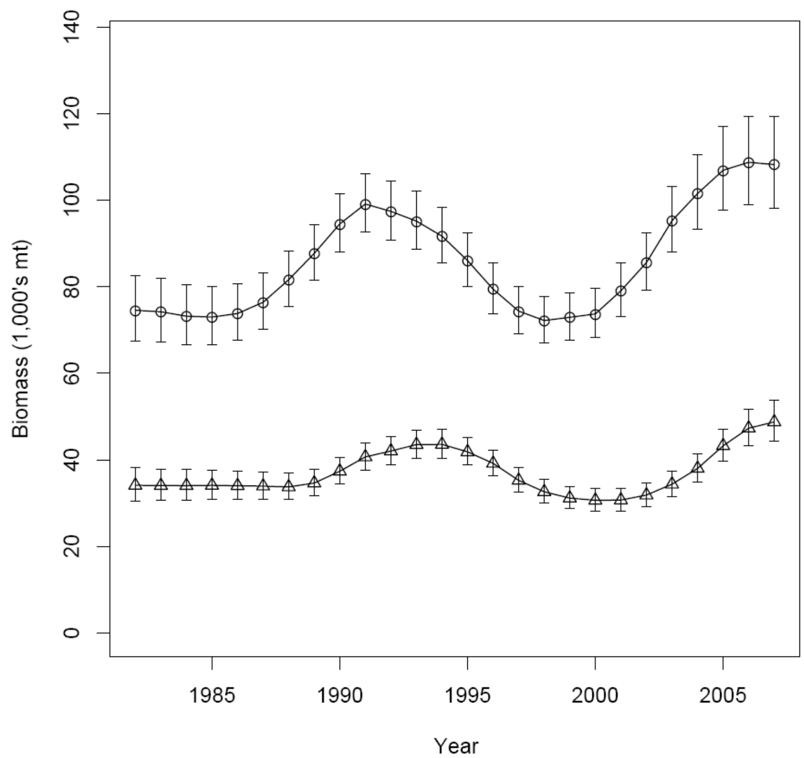


Figure 6.13. Estimated age 3+ biomass (circles) and female spawning biomass (triangles) for GOA rex sole. Error bars are approximate lognormal 95% confidence intervals.

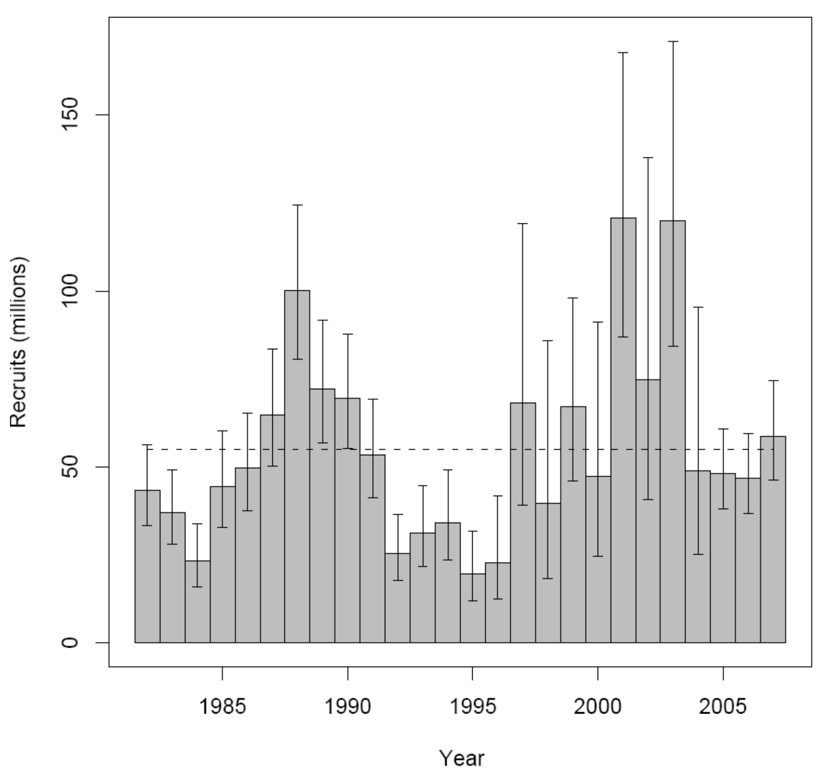


Figure 6.14. Estimated age 3 recruitments of GOA rex sole with approximate 95% lognormal confidence intervals. Horizontal line is mean recruitment.

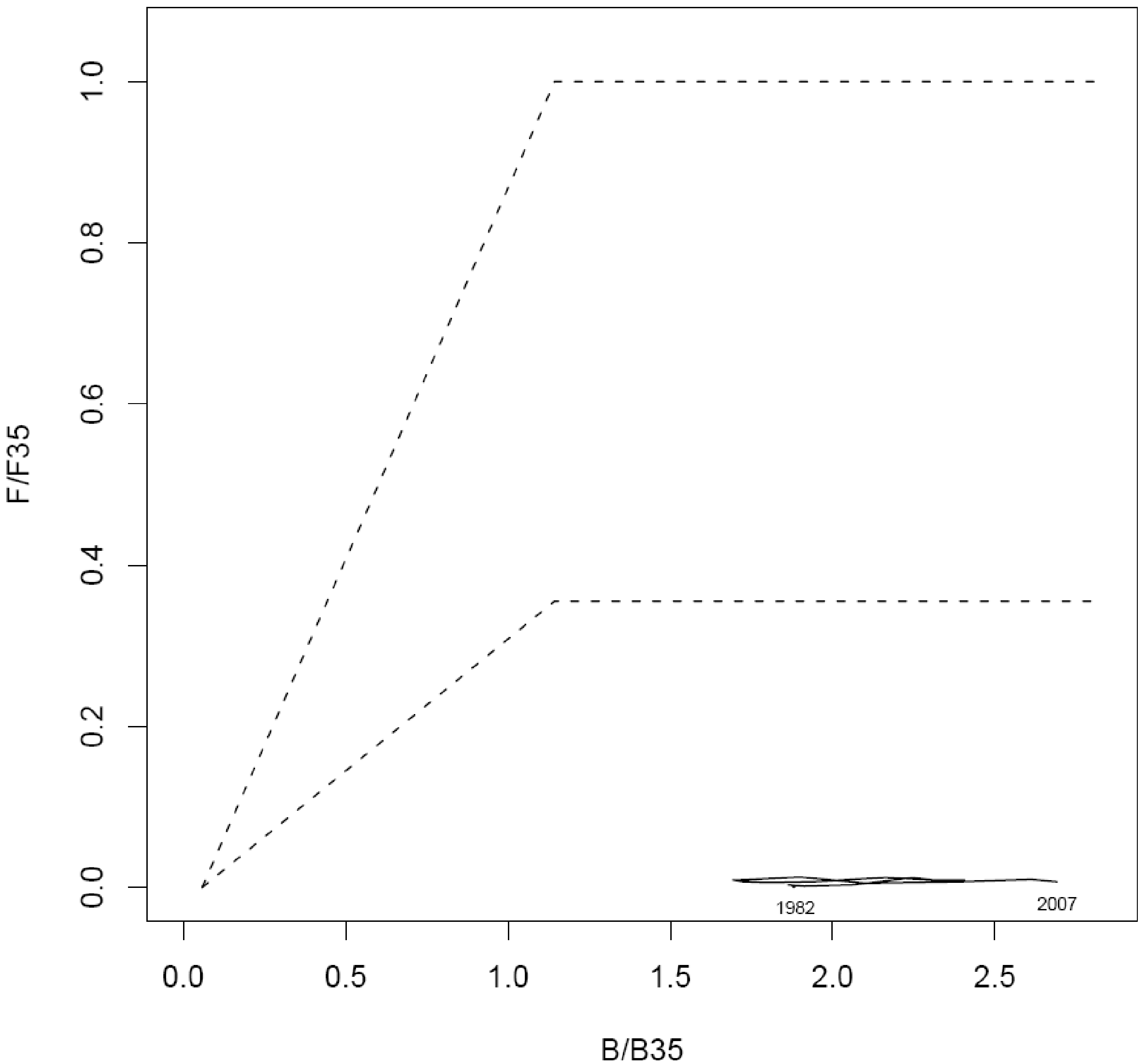


Figure 6.15. Control rule plot of estimated fishing mortality versus estimated female spawning biomass for GOA rex sole. F_{OFL} = upper dashed line, $F_{max\ ABC}$ = lower dashed line.

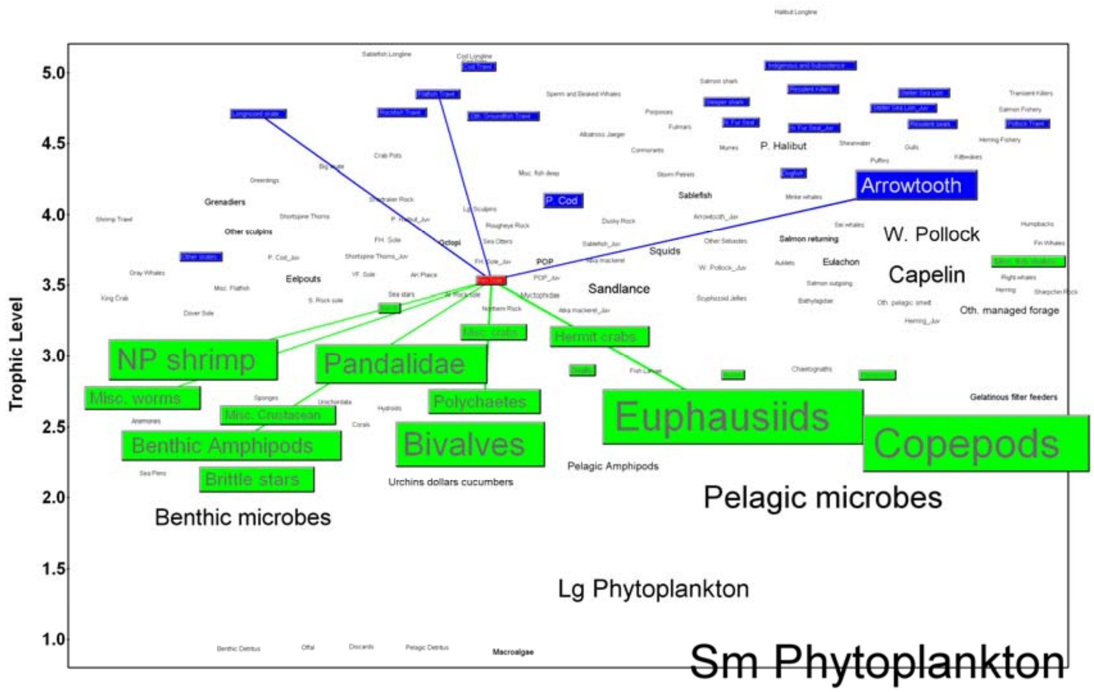


Figure 6.16. Gulf of Alaska food web from the GOA ecosystem model (Aydin et al., in press) highlighting rex sole links to predators (blue boxes and lines) and prey (green boxes and lines). Box size reflects relative standing stock biomass.

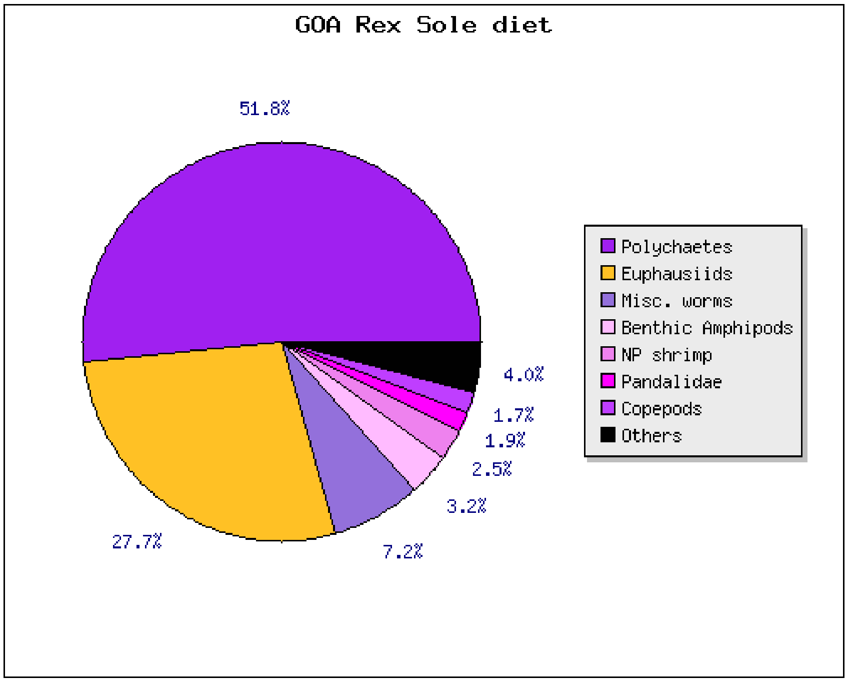


Figure 6.17. Diet composition for Gulf of Alaska rex sole from the GOA ecosystem model (Aydin et al., in press).

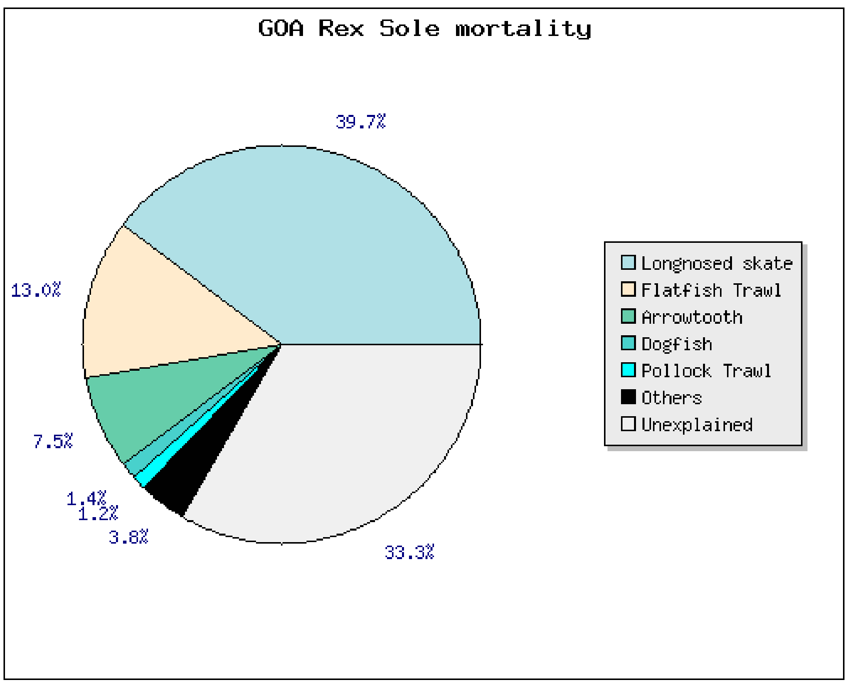


Figure 6.18. Decomposition of natural mortality for Gulf of Alaska rex sole from the GOA ecosystem model (Aydin et al., in press).

Appendix A.

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

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

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

$\tau_t \sim N(0,\sigma_R^2)$	Random deviate associated with recruitment.
$N_{t,x,1} = R_t = \exp\left(\overline{\ln R_0} + \tau_t\right)$	Recruitment (assumed equal for males and females).
$N_{t+1,x,a+1} = N_{t,x,a} e^{-Z_{t,x,a}}$	Numbers at age.
$N_{t+1,x,A} = N_{t,x,A-1} e^{-Z_{t,x,A-1}} + N_{t,x,A} e^{-Z_{t,x,A}}$	Numbers in “plus” group.
$C_{t,x,a} = \frac{F_{t,x,a}}{Z_{t,x,a}}(1-e^{-Z_{t,x,a}})N_{t,x,a}$	Catch at age (in numbers caught).
$C_t = \sum_{x=1}^{2}\sum_{a=1}^{A} w_{x,a} C_{t,x,a}$	Total catch in tons (i.e., yield).
$FSB_t = \sum_{a=1}^{A} w_{1,a}\phi_a N_{t,1,a}$	Female spawning biomass.
$Z_{t,x,a} = F_{t,x,a} + M$	Total mortality.
$F_{t,x,a} = s_{x,a}^F \cdot \exp\left(\overline{\ln F} + \varepsilon_t\right)$	Fishing mortality.
$\varepsilon_t \sim N(0,\sigma_F^2)$	Random deviate associated with fishing mortality.
$s_{x,a}^F = \frac{1}{1+e^{(-b_x^F(age-{}_{50}A_x^F))}}$	Fishery selectivity- 2 parameter ascending logistic - separate for males and females.
$s_{x,a}^S = \frac{1}{1+e^{(-b_x^S(age-{}_{50}A_x^S))}}$	Survey selectivity- 2 parameter ascending logistic - separate for males and females.
$N^S{}_{t,x,a} = Q\, s^S_{x,a} N_{t,x,a}$	Survey numbers for sex *x*, age *a* at time *t*.
$SB_t = \sum_{x=1}^{2}\sum_{a=1}^{A} w_{x,a}\; N^S{}_{t,x,a}$	Total survey biomass.
$p_{t,x,a}^{F,A} = C_{t,x,a} / \sum_{x=1}^{2}\sum_{a=1}^{A} C_{t,x,a}$	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; uses a lognormal distribution.
$\sum_{t\in\{t^{F,A}\}}\sum_{x=1}^{2}\sum_{a=1}^{A} n_{t,x}^{samp}\cdot p_{t,x,a}^{F,A,obs}\cdot\log(p_{t,x,a}^{F,A})$ - offset	Fishery age composition; uses a multinomial distribution. n^{samp} is the observed sample size.
$\sum_{t\in\{t^{F,L}\}}\sum_{x=1}^{2}\sum_{l=1}^{L} n_{t,x}^{samp}\cdot p_{t,x,l}^{F,L,obs}\cdot\log(p_{t,x,l}^{F,L})$ - offset	Fishery length composition; uses a multinomial distribution. n^{samp} is the observed sample size.
$\sum_{t\in\{t^{F,A}\}}\sum_{x=1}^{2}\sum_{a=1}^{A} n_{t,x}^{samp}\cdot p_{t,x,a}^{S,A,obs}\cdot\log(p_{t,x,a}^{S,A})$ - offset	Survey age composition; uses a multinomial distribution. n^{samp} is the observed sample size.
$\sum_{t\in\{t^{F,L}\}}\sum_{x=1}^{2}\sum_{l=1}^{L} n_{t,x}^{samp}\cdot p_{t,x,l}^{S,L,obs}\cdot\log(p_{t,x,l}^{S,L})$ - offset	Survey length composition; uses a multinomial distribution. n^{samp} is the observed sample size.
offset $=\sum_{t}\sum_{x=1}^{2}\sum_{a=1}^{A} n_{t,x}^{samp}\cdot p_{t,x,a}^{obs}\cdot\log(p_{t,x,a}^{obs}))$	The offset constants for age composition components are calculated from the observed proportions and the sample sizes. A similar formula is used for length composition component offsets.
$\sum_{t\in\{t^S\}}\left[\frac{\log\left[\frac{SB_t^{obs}}{SB_t}\right]}{\sqrt{2}\cdot s.d.(\log(SB_t^{obs}))}\right]^2$	Survey biomass; uses a lognormal distribution.
$\sum_{t=1984}^{2002}(\tau_t)^2$	Recruitment; uses a lognormal distribution, since τ_t is on a log scale.
$\sum_{t=2003}^{2005}(\tau_t)^2$	"Late" recruitment; uses a lognormal distribution, since τ_t is on a log scale.
$\sum_{t=1967}^{1983}(\tau_t)^2$	"Early" recruitment; uses a lognormal distribution, since τ_t is on a log scale. Determines age composition at starting year of model.

Table A.4. Fixed parameters in the model.

Parameter	Description
M = 0.2	Natural mortality
Q = 1.0	Survey catchability
L_{inf} , t_0 , k , cv of length at age 2 and age 20 for males and females	von Bertalanffy Growth parameters estimated from the 1984-1996 survey length and age data.

Table A.5. Estimated parameters for the model. A total of 79 parameters were estimated in the model.

Parameter	Subscript range	Total no. of Parameters	Description
$\ln(R_0)$	NA	1	natural log of the geometric mean value of age 3 recruitment
τ_t	$1965 \le t \le 2007$	43 (26 + 17 from initial age composition)	Recruitment deviation in year *t* (log-scale)
$\ln(f_0)$	NA	1	natural log of the geometric mean value of fishing mortality
ε_t	$1982 \le t \le 2007$	26	deviations in fishing mortality rate in year t
$b^F{}_x$, ${}_{50}A^F{}_x$	$1 \le x \le 2$	4	selectivity parameters (slope and age at 50% selected) for the fishery for males and females.
$b^S{}_x$, ${}_{50}A^S{}_x$	$1 \le x \le 2$	4	selectivity parameters (slope and age at 50% selected) for the survey data, for males and females.