Gulf of Alaska Rex Sole Stock Assessment

by

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Executive Summary

The Gulf of Alaska rex sole resource is evaluated over a period from 1978 through 2005, and the status and potential yield is presented. This report extends from an age-structured assessment first presented in 2004.

Summary of Major Changes

<u>Changes in the input data</u>

The 2005 NMFS summer bottom-trawl survey biomass and length composition information was added.

The 2005 fishery catch biomass and the 2004 fishery length data are included.

<u>Changes in assessment methodology</u>

There were no changes to the assessment model relative to the 2004 age-structured analysis.

<u>Changes in assessment results</u>

Model estimates of 2005 total biomass (age 3+) was 108,900 t, up 32% from the 2004 estimate of 82,300 t from last year's assessment. The 2005 females spawning biomass was estimated at 45,800 t up 29% from the estimate of 35,400 t for the same year in last year's assessment. This value is about 89% of the unfished level of 51,700 t indicating that the stock is at high levels.

Initial estimates of Tier 3 2006 ABC level were 38,100 t ($F_{40\%}$ = 6.0). This high $F_{40\%}$ value results from the fact that selectivity estimates are derived from non-target fishery data (rex sole is primarily a bycatch species from other directed fisheries) and shifted towards older rex sole that have had ample spawning opportunity (the maturity-at-age estimates are much younger than the selectivity-at-age). The $F_{35\%}$ was also high (estimated at 12.0) which gives a 2006 OFL of 46,800 t. The maximum permissible F_{ABC} scenario results in rapidly declining yields and biomass in the next few years. An alternative using the Tier 5 approach applied to the model estimates of adult rex sole population provides more stable projected ABC and biomass levels. The recommended ABC and OFL levels are thus:

Year	Projected adult biomass	ABC	OFL
2006	83,600 t	9,200 t	12,000 t
2007	79,100 t	8,700 t	11,400 t

The 2005 ABC using 2003 survey biomass and tier 5 was 12,650 t.

Response to SSC comments

<u>SSC comments specific to the GOA rex sole assessment:</u>

The first age-structured assessment model for rex sole has been constructed and provided to the Plan Team and SSC for comments. The SSC endorses the new modeling effort and noted that most parameters are estimated with high precision. One main result from the model is that the fishery selectivity curve is centered toward old ages, whereas the age at maturity curve is centered toward lower ages. This creates the perception of a highly resilient stock, because individuals can reproduce several times before the fishery starts. The SSC requests that the analysts provide further insight into whether this situation is *really true and what changes might occur in the future in fishery selectivity if the ABC and/or TAC were increased. Furthermore the estimated biomass is larger than survey biomass, because survey selectivity is estimated. The SSC is interested in whether the analysts believe the survey selectivity curve is well estimated, so that ABC could be determined from biomass estimated from the model rather than from the survey.*

The maturity and fishery selectivity curves appear to be well estimated based. Several alternative selectivity curves were used in projecting the population to investigate the effect on biomass and future catches. The ABC recommended here is based on the model estimated adult biomass and tier 5 calculations.

SSC comments on assessments in general:
From the December, 2004 SSC minutes: *In its review of the SAFE chapter, the SSC noted that there is variation in the information presented. Several years ago, the SSC developed a list of items that should be included in the document. The SSC requests that stock assessment authors exert more effort to address each item contained in the list. Items contained in the list are considered critical to the SSC's ability to formulate advice to the Council. The SSC will review the contents of this list at its February meeting.*

In this assessment the ecosystem section is expanded and other sections were substantially revised to better conform with SAFE guidelines.

Introduction

Description, Scientific Names, and General Distribution
Rex sole (*Errex zachirus*, Lockington 1879) is a right-eyed flatfish occurring from southern California to the Bering sea and ranging from shallow water (<100m) to about 800 meters depth. They are most abundant at depths between 100 and 200m and are found fairly uniformly throughout the GOA.

Management units and stock structure, life history
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.

Recent studies by Abookire (In Press) confirmed that rex sole are batch spawners with a protracted spawning season in the GOA. The spawning season for rex sole spanned 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 feed primarily on amphipods, polychaetes, and some shrimp.

Fishery data

Catch is currently reported for rex sole by management area (Tables 4.1 and 4.2). 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. Catches increased from a low of 93 t in 1986 to 5,874 t in 1996 then declined to about 3,000 t thereafter, with a catch of about 2,138 t through October 1, 2005. Table 4.3 documents annual research catches (1977 - 1998) from NMFS longline, trawl, and echo integration trawl surveys.

The rex sole resource has been moderately harvested in recent years. Catch in 2003 represented only 35% of the rex sole ABC and 2004 catches (1,464 t) were 11% of the ABC. The 2004 rex sole fisheries were closed on March 19, open April 1, closed April 26, and open July 4, closed July 25 to prevent exceeding the halibut bycatch limit. The lower catch in 2004 could be due to the more extensive fishery closures compared to 2003. The 2005 catch was 2,138 t (through October 1), up from 1,464 t in 2004.

Estimates of retained and discarded catch (t) in the rex sole fishery since 1994, by management assemblage, were calculated from discard rates observed from at-sea sampling and industry reported retained catch (Table 4.4). Retention of rex sole has generally been over 90% and has been above 95% since 1998.

Survey Data

The principal source of information for evaluating the condition of rex sole stock in the Gulf of Alaska is the bottom trawl survey conducted from 1984 to 2005 (Tables 4.5, 4.6, 4.8-4.11, and Fig. 4.1). Rex sole biomass estimates from the 1993 to 2005 survey by INPFC area are given in Table 4.9. Sampling for the 2001 survey was conducted in the eastern and central portions of the gulf only. The 2001 survey biomass for the eastern gulf was approximated using the average of the 1993 to 1999 eastern gulf biomass estimates (Table 4.10). The average of the 1993 to 1996 eastern gulf biomass was used for most flatfish species because there was no discernable trend in abundance, or there did not appear to be any correlation in biomass between areas (Table 4.9). On average about 60% of the rex sole biomass has been consistently found at depths between 100 and 200 m with about 15% of the biomass found at shallower depths and the remainder at deeper depths (Table 4.11). About 95% of the biomass is found in depths less than 300m.

The apportionment of survey sampling stations on the shelf and slope followed the methods developed for the shelf portion of the 1984 survey (Brown 1986). There was no sampling deeper than 500 meters during 1990 to 1996, and 2001 because of limited vessel time. The 500-1,000 m depths sampled in 1984 and 1987, and 1999 were generally outside the depth range of most flatfish species with the exception of Dover sole, Greenland turbot, deep-sea sole and, to a lesser extent, rex sole. The 2003 and 2005 survey covered depths to 700 m.

Recent experimental evidence suggests that flatfish biomass estimates derived from the noreastern trawl used in the survey may underestimate true biomass because the escapement portion of the catchability assumption may be large (e.g., Weinberg et al., 2003). Experiments have been conducted to estimate the herding component of catchability for some flatfish species (D. Somerton, NMFS, Seattle, pers. comm.).

Many flatfish species showed an increasing trend in biomass in the 1980’s followed by a decline in the 1990’s. Rex sole survey biomass estimates declined from 95,630 t in 1990 to 71,326 t in 2001, then increased to 99,950 t in 2003 (Table 4.8). Compared to the 1999 survey, which covered depths to 1000 m and covered the entire GOA, the 2003 survey biomass estimate represented a 34% increase. The 2005 survey biomass was close to the 2003 estimate at 101,255 t.

The distribution of CPUE from survey trawls for 1984 to 2005 indicate rex sole are widespread in the Gulf of Alaska (Fig. 4.2). The CPUE in the 2003 and 2005 survey appears to be higher throughout the Gulf.

Analytic approach

Model structure

The model structure was developed following Fournier and Archibald’s (1982), with many similarities to Methot (1990). We implemented the model using automatic differentiation software developed as a set of libraries under C++ (ADModel Builder). ADModel Builder can estimate a large number of parameters in a non-linear model using automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries. This software provides the derivative calculations needed for finding the objective function via a quasi-Newton function minimization routine (e.g., Press et al. 1992). The model implementation language (ADModel Builder) gives simple and rapid access to these routines and provides the ability to estimate the variance-covariance matrix for all parameters of interest.

Details of the population dynamics and estimation equations, descriptions of variables and likelihood equations are presented in Appendix A (Tables A.1, A.2 and A.3). A total of 76 parameters were estimated in the model (Table A.4). Forty two recruitment deviates were estimated in the model, eighteen to initialize the starting population and twenty four for 1982 to 2005. There were 24 fishing mortality deviates in the model which were conditioned to fit the observed catch closely. One mean recruitment and one mean fishing mortality parameter were estimated in the model. Eight selectivity parameters were estimated, four for fishery selectivities and four for survey selectivities. The instantaneous natural mortality rate, survey catchability and the Von Bertalanffy growth parameters were fixed in the model (Table A.5).

Data

The following data sources and years of availability were used in the model:

Data component	Years
Fishery catch	1982 – 2005
NMFS bottom trawl survey biomass	1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003, 2005
Fishery size compositions	1982 - 1984,1990 – 2005
NMFS trawl survey size compositions	1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003, 2005
NMFS trawl survey age compositions	1984, 1987, 1990, 1993, 1996

Tables 4.5 and 4.6 contain the survey age and length data used in the assessment. The survey length data for 1984 through 1996 were included in the model but the effective sample size was down-weighted to 1 since age data for those years were included. Leaving the survey length data in the model allowed the their consistency to be evaluated relative to predicted values of length frequency distributions. Sample sizes for the fishery length data ranged from about 3,500 to 26,000 lengths measured, with about 6,400 lengths measured in the 2003 fishery. The mean size of observer sampled rex sole by fishery haul was quite variable, from about 30 to 55 cm with sampled hauls concentrated at depths between about 125 m and 225 m (Fig. 4.3). The observed fishery hauls were distributed between Kodiak Island and Unalaska Island during 2001, 2002 and 2003 (Fig. 4.4).

Likelihood weights and other model structure

The likelihood components on fishery and survey length frequencies, survey age compositions, and survey biomass, were given equal weight implying that the variances and sample sizes specified for each data component were approximately correct. The estimated length-at-age relationship is used to convert population age compositions into estimated size compositions. The current model estimated size compositions using a fixed length-age transition matrix. This matrix was estimated from the 1984, 1987, 1990, 1993 and 1996 survey age and length data where the distribution of lengths within ages was assumed to be normal with coefficients of variation (CVs) estimated from the length at age data. The CVs were 0.13 for age 3 and 0.08 for age 20+. The data were organized in size groups or “bins” with widths of 2 cm ranging from 9 cm to 65+ cm. The model was dimensioned to cover 18 age groups from age 3 to age 20+ yrs.

Parameters Estimated Independently

Natural mortality, Age of Recruitment, and Maximum Age

Natural mortality used in the model for rex sole was estimated to be 0.17 using Hoenig (1983) and a maximum age of 27 years from recent age data.

Length and Weight at Age
Values for the parameters in the Von Bertalanffy age-length relationship were estimated from age structures collected during the trawl surveys and are shown in Table 4.12. Length composition data from the commercial fisheries and the groundfish trawl surveys are shown later relative to the fits. Aging of Gulf of Alaska flatfish species has been sporadic since the inception of the triennial surveys. Survey mean length at age shows fish tended to be large in 1990 and smaller in 1984 (Fig. 4.5). However, the 1990 sample may not be representative, since the oldest ages in the sample were 8 years for males and 11 years for females.

The parameters calculated for the length (cm) - weight (g) relationship: $W = aL^b$ are shown below:

	A	*B*
Male	1.07698e-6	3.30571
Female	4.79333e-7	3.44963
Combined	5.97967e-7	3.41049

Maturity at Age
Female rex sole size at 50% maturity was 351.7 mm with a slope of 0.0392 (A. Abookire, NMFS, Kodiak, pers. com.). About one half of the maturity samples were obtained from the fishery catch and one half from research trawls (Figure 4.6). The age-at-50%-maturity was estimated at 5.6 years using the mean length estimated from the 1984 to 1996 survey data (Figure 4.7). Estimates of mean size at age for the maturity samples is similar to the mean size at age estimated from the survey data.

Parameters Estimated Conditionally
Recruitment was parameters as a mean value and deviations from the mean for each year (1978-2005). Recruitment deviates in 2003 to 2005 were constrained to be close to the historical harmonic mean recruitment by adding a penalty to the likelihood. This was done as a precautionary approach since the harmonic mean recruitment is less than the arithmetic mean recruitment.

Separate fishery selectivities were estimated for males and females using a two parameter ascending logistic function. Sex-specific survey selectivities were also modeled using a two parameter ascending logistic function.

Model evaluation
This is the first implementation of an age-structured assessment for GOA rex sole. Current model evaluations are focused on the impact of selectivity estimates to ABC and OFL recommendations and these are presented in the section below. In general, the current implementation appears to fit the observations well. Further evaluations of model sensitivities will be undertaken in future assessments.

Results
Selectivity estimates show that the fishery generally catches rex sole at older ages than the survey (Fig. 4.8 and Table 4.13). Fits to the size composition data from the fishery are shown in Figure 4.9a for females and Figure 4.9b for males. The fit to the survey size composition data are in Figure 4.10a for females and Figure 4.10b for males. The survey age composition data are shown in Figures 4.11a and 4.11b. Likelihood values and estimates for selectivity parameters are given in Table 4.13.

Model estimates of age 3+ biomass increased from 76,629 t in 1982 to about 97,341 t in 1991, decreased to 70,033 t in 1998, then increased to 108,926 t in 2005 (Table 4.14 and Fig. 4.12). The fit to the survey biomass estimates is shown in Figure 4.13. The model estimated a lower biomass than the survey in 2003 but closely matched the 2005 biomass. The current model estimates in recent years are higher than in the 2004 assessment document. The addition of the 2005 survey biomass at a level similar to the 2003 survey biomass resulted in higher model estimates of current biomass. This also resulted in revised estimates of recent recruitments in 2001 and 2002 (over double the 2004 estimates; Table 4.14).

The model estimates of age 3 recruits were lower than average for 1992 to 1996, then slightly higher than average or near average for 1999 to 2003 (Table 4.14 and Fig. 4.11). Recruitment in 2004 was estimated at slightly below average. No spawner-recruit curve was used in the Model. Recruitments were estimated as deviations from a mean value on a log scale with a modest penalty on outliers (Table A.2).

Reference fishing mortality rates and yields

While reliable estimates of $B_{35\%}$, , $F_{35\%}$, and $F_{40\%}$, are not available, since an age structured model has been developed, projections were still conducted as if rex sole were in tier 3a of the ABC and overfishing definitions. Under this definition, $F_{ofl}= F_{35\%}$, and F_{ABC} is less than or equal to $F_{40\%}$. Current biomass is above B40%.

$F_{40\%}$ and $F_{35\%}$ were estimated at 6.0 and 12.0 due the selectivity of the fishery for much older fish than the when they mature. The uncertainty in the estimated fishing mortality reference points is large, with standard deviations of 7.6 and 26.1 for $F_{40\%}$ and $F_{35\%}$, respectively. Yield for 2006 using $F_{40\%}$ = 6.0 was estimated at 38,093 t. Yield for 2006 using $F_{35\%}$ = 12.0 was estimated at 46,843 t. The fishing mortality values that produce a similar ABC to that estimated in 2005 were also estimated. Yield for 2006 using F = 0.7 was estimated at 11,932 t. The F = 0.7 was estimated so the yield was comparable to the yield estimated in the 2004 flatfish SAFE. The estimated F40% is very high, which results in a large initial yield, then rapidly declining yields over time. A criterion for yield stability could to be used to estimate more stable F target values. Fishing mortality values are relatively high because the age at 50% selected in the fishery is about 10 years, while the age at 50% mature is about 5 years (Figures 4.6 and 4.8). The fishery selectivities reach 95% at about age 13 for females.

Since there is no estimate of the spawner-recruit relationship for rex sole, no attempt was made to estimate MSY. However, using the projection model described in the next section, female spawning biomass with F=0 was estimated at 51,687 t. $B_{35\%}$ (equilibrium female spawning biomass with fishing at $F_{35\%}$) is estimated at 18,825 t.

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

For each scenario, the projections begin with the vector of 2005 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2006 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2005. 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 1,000 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 2006, are as follows ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

> *Scenario 1*: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
>
> *Scenario 2*: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2006 recommended in the assessment to the *max* F_{ABC} for 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 2001-2005 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
>
> *Scenario 5*: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as 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 ½ of its MSY level in 2006 and above its MSY level in 2016 under this scenario, 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 2018 under this scenario, then the stock is not approaching an overfished condition.)

Projected catch and abundance were estimated using $F_{40\%}$, F equal to the average F from 2001 to 2005, F equal 0.7, $F_{35\%}$, and F=0 from 2006 to 2010 (Table 4.15). Under scenario 6 above, the year 2006 female spawning biomass is 49,242 t and the year 2016 spawning biomass is 19,056 t, above the $B_{35\%}$ level of 18,825 t. For scenario 7 above, the year 2018 spawning biomass is 19,168 t also above $B_{35\%}$. Female spawning biomass decreases to the B40% level in about 4 years when fishing at F40% (Figure 4.26). If fishing continues at the recent average F= 0.15, then females spawning biomass was about 46,000 t in 2010, well above B40% (Fig. 4.27).

Acceptable biological catch and overfishing level

Reference fishing mortality rates prior to 2004 for rex sole were calculated using F_{ABC}= 0.75M and F_{OFL} = M (Tier 5) since maturity information was unavailable. In this study, maturity information was available and incorporated within an age-structured analysis.

While the age-structured model is useful for evaluating the stock condition, projections based on catch levels that are 5-6 times greater than current catch levels are likely to change the way the fishery is currently prosecuted. Namely, the estimates of age-specific selectivity is likely to be much different. Alternative selectivity values were used for projections for sensitivity but objective approaches to selecting an appropriate level were lacking. As an alternative, the model estimate of adult biomass was computed and Tier 5 calculations applied to estimate the ABC. Adult biomass was estimated by applying the female maturity curve by age to numbers at age for both males and females. The catch equation was used to estimate ABC, since the adult biomass values were estimates for the beginning of the year. 2006 and 2007 ABC's were also estimate using the 2005 survey biomass and tier 5 calculations. These results (compared to other alternatives for calculating ABC and OFL) are shown in bold:

ABC Method	Year	Biomass Type	Biomass or F	ABC	OFL
Tier 5	2006	2005 Survey estimate	101,255 t	12,900 t	17,200 t
Tier 5	2007	2005 Survey estimate	101,255 t	12,900 t	17,200 t
Tier 5	2006	Projected adults	83,600 t	**9,200 t**	**12,000 t**
Tier 5	2007	Projected adults	79,100 t	**8,700 t**	**11,400 t**
Tier 3	2006	Age-structured model	$F_{ABC} = F_{40\%}$, $F_{OFL} = F_{35\%}$	38,100 t	46,800 t
Tier 3	2007	Age-structured model	$F_{ABC} = F_{40\%}$, $F_{OFL} = F_{35\%}$	16,900 t	19,100 t

Several projection alternatives were considered to investigate the long term yields that would occur under different fishing mortality values and fishery selectivity curves. Rex sole are somewhat unique compared to other flatfish in that they grow quickly and reach maturity at a relatively young age (age at 50% mature 5.6 years) compared to a longevity of about 27 years. Other flatfish that have target fisheries are caught at smaller sizes, however don't grow as quickly. The estimated selectivity curves for other flatfish species would not be appropriate for rex sole as there are differences in growth and maturity.

Since the fishery selectivities under a target fishery for rex sole are not known, two alternatives in addition to the model estimates of fishery selectivity were considered for sensitivity analysis: 1) fishery selectivity set equal to the female maturity curve, and 2) fishery selectivity set midway between the female maturity curve and the model estimates of selectivity.

		Selectivity curve	
	Equal to maturity	midway	model estimated
F40%	0.23	0.41	6.0
2006 ABC	16,000	19,700	38,100
mean long term yield (t)	6,700	7,200	8,000
mean long term sp biomass (t)	21,200	21,100	20,940
lower 95% CI sp biomass (t)	16,800	16,300	15,000
upper 95% CI sp biomass (t)	26,300	26,800	27,800

The long term mean yield from projections using the model estimated fishery selectivities and F40% = 6.0 was 8,000 t (95% CI 5,200 t to 11,200 t). The long term mean values were estimated from 100 year projections using the last 75 years only. Projections with fishery selectivity set equal to the maturity curve (F40% = 0.23) have long term mean yields of about 6,700 t, with a 2006 ABC of 16,000 t. If fishery selectivity is set midway between the maturity curve and the model estimated selectivity, long term mean catch is 7,200 t and 2006 ABC is 19,700 t. The variability in catch and female spawning biomass is greater as the F increases and selectivity shifts to older fish, which results in a higher probability of the stock being below B40%. The F is reduced from F40% when female spawning biomass falls below B40%, following the harvest control rule for tier 3 stocks, this results in a lower long term mean yield than when using a deterministic yield projection.

Other considerations: Area-apportionment of ABC

The ABC by management area using F40%=6.0, tier 5 with 2005 survey biomass, and tier 5 calculation with model estimated adult biomass, was estimated by calculating the fraction of the 2005 survey biomass in each area and applying that fraction to the ABC:

Rex sole ABC (t) by INPFC area for 2006:

	Western	Central	West Yakutat	East Yakutat/SE	Total
Tier 5 Adult spawning biomass	1,159	5,506	1,049	1,486	9,200
Tier 5 2005 Survey biomass	1,626	7,720	1,470	2,083	12,900
F_{ABC} =Max permissible	4,803	22,800	4,339	6,158	38,100

Ecosystem Considerations

Ecosystem effects on the stock

Based on food habits studies, polychaetes, euphausiids and pandalid shrimp were the most important prey for rex sole in the Gulf of Alaska (Livingston and Goiney 1983, Yang 1993, Yang and Nelson, 2000). Trends in abundance are not available for important prey items.

Important predators include arrowtooth flounder, walleye pollock, Pacific cod, and other groundfish. Arrowtooth flounder are currently the most abundant groundfish in the Gulf of Alaska, and have steadily increased in abundance since the early 1970's (Turnock et al., 2003b). The abundance of walleye pollock has declined rather steadily since the early 1990's, but recent evidence suggests the stock may be starting to increase again (Dorn et al., 2004). Pacific cod abundance in the Gulf of Alaska has been declining since 1990 (Thompson et al., 2004). Although the continued increase in abundance of arrowtooth flounder is cause for some concern, the abundance of rex sole has actually increased in recent years, as well. 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

Protected species such as halibut, salmon, and crab are taken to some extent in flatfish fisheries. Observed fishery catches of rex sole have been fairly wide spread throughout the central and western Gulf (Figures 4.23-4.25). The ecosystem effects of this spatial concentration of fishing activity are unknown.

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

Data Gaps and Research Priorities

Simulation studies are needed to explore the effects of high reference fishing mortality values and variability in yield and spawning biomass.

The extent that a directed fishery may alter the current estimates of selectivity are needed prior to developing a rex sole fishery closer to optimum levels (e.g., at F_{ABC} harvest rates).

Summary

Table 4.16 shows a summary of model results.

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Tables

Table 4.1. Catch (t) of rex sole in the Gulf of Alaska 1982 to October 1, 2005. (Includes discards 1992-2005).

Year	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**
Catch (t)	959	595	365	154	93	1,151	1,192	599	1,269	4,636	3,000	3,000
Year	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Catch (t)	3,673	4,021	5,874	3,294	2,669	3,060	3,591	2,940	2,941	3,485	1,464	2,138

Table 4.2. Composition of the 1994 to 2004 Gulf of Alaska rex sole catch by management category and North Pacific Fishery Management Council regulatory area.

		Area			
Year	Western	Central	Eastern	Total	Percent ABC
1994	49	3,540	84	3,673	28
1995	220	3,627	174	4,021	29
1996	504	5,180	190	5,874	29
1997	681	2,436	177	3,294	19
1998	439	2,195	35	2,669	26
1999	604	2,393	63	3,060	35
2000	884	2,701	6	3,591	28
2001	434	2506	0	2940	25
2002	376	2565	0	2941	25
2003	767	2716	2	3,485	38
2004	527	937	0	1,464	11
2005	574	1564	0	2,138	

Table 4.3. Catch (t) from longline and trawl and echo integration trawl research cruises from 1977 to 1998**.**

Year	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**
Catch (t)	1.97	8.47	12.6	4.64	17.2	7.73	7.21	18.27	14.05	3.74	21.12	0.08	1.77	12
Year	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Catch (t)	0.01	0.04	12.7	0.03	0	7.04	0	4.09						

Table 4.4. Percent (by weight) of rex sole catch that is retained for the Gulf of Alaska flatfish fisheries. Source: NMFS blend database and catch accounting system.

	1994	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Rex sole percent retained	89%	90%	95%	92%	97%	96%	97%	95%	95%	95%	93%

Table 4.5. Age data of GOA rex sole from trawl surveys from 1984 through 1996. The numbers are percentages, where the female plus the male numbers add to 100 within a year.

Age	1984 Female	1984 Male	1987 Female	1987 Male	1990 Female	1990 Male	1993 Female	1993 Male	1996 Female	1996 Male
3	0.0%	0.0%	0.0%	1.0%	3.7%	4.8%	0.4%	1.1%	1.0%	2.5%
4	2.7%	7.8%	3.5%	3.9%	4.1%	9.4%	0.7%	2.3%	2.5%	3.7%
5	3.6%	9.6%	1.3%	8.5%	16.6%	20.9%	9.9%	11.6%	3.4%	9.0%
6	4.2%	3.8%	3.5%	4.8%	11.8%	10.5%	7.7%	11.4%	4.6%	7.6%
7	4.1%	2.4%	4.9%	8.0%	9.3%	3.3%	10.1%	7.5%	4.1%	6.0%
8	4.1%	6.5%	7.2%	5.5%	4.9%	0.3%	7.7%	3.1%	2.3%	3.8%
9	4.2%	1.2%	4.1%	1.8%	0.5%	0.0%	4.5%	5.2%	5.3%	6.3%
10	2.9%	2.1%	6.5%	5.3%	0.1%	0.0%	4.6%	3.2%	6.1%	3.7%
11	3.2%	1.3%	6.7%	2.0%	0.1%	0.0%	2.4%	2.8%	5.1%	3.8%
12	3.6%	1.2%	1.7%	8.1%	0.0%	0.0%	1.1%	0.3%	4.3%	2.3%
13	4.1%	0.7%	3.1%	0.7%	0.0%	0.0%	0.9%	0.0%	2.5%	1.6%
14	1.8%	3.1%	1.4%	0.3%	0.0%	0.0%	0.1%	0.6%	2.9%	0.2%
15	5.8%	0.0%	1.6%	0.8%	0.0%	0.0%	0.5%	0.2%	1.7%	0.5%
16	4.9%	2.3%	1.5%	0.5%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%
17	2.0%	1.3%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	1.3%	0.0%
18	1.5%	1.7%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%
19	1.0%	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%
20+	1.1%	0.4%	0.7%	0.0%	0.0%	0.0%	0.0%	0.1%	0.7%	0.2%

Table 4.6. GOA rex sole length frequency data (percentages by year) from NMFS bottom trawl surveys from 1984 through 2005. Female (F) and male (M) sex ratios are given in the last row as the sum of each column.

cm	1984 F	1984 M	1987 F	1987 M	1990 F	1990 M	1993 F	1993 M	1996 F	1996 M	1999 F	1999 M	2001 F	2001 M	2003 F	2003 M	2005 F	2005 M
9	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
11	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%
13	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.3%	0.3%	0.1%	0.2%
15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.4%	0.2%	0.3%	0.3%	0.4%	0.3%	0.5%	0.5%	0.3%
17	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.1%	0.2%	0.4%	0.5%	0.5%	0.8%	0.8%	1.2%	0.6%	0.7%	0.6%	0.6%
19	0.0%	0.1%	0.2%	0.6%	0.3%	0.4%	0.2%	0.5%	0.7%	0.9%	0.9%	1.7%	1.5%	1.4%	1.2%	1.4%	0.6%	0.8%
21	0.0%	0.1%	0.2%	1.0%	0.6%	0.8%	0.3%	0.5%	0.6%	0.9%	1.1%	2.0%	1.8%	2.1%	1.6%	2.2%	0.7%	0.9%
23	0.1%	0.4%	0.6%	1.9%	0.9%	0.8%	0.3%	0.7%	0.8%	1.4%	1.4%	1.9%	1.7%	2.5%	1.8%	3.0%	1.0%	1.7%
25	0.9%	1.4%	0.9%	2.6%	0.8%	1.4%	0.4%	1.0%	1.3%	2.5%	1.7%	3.0%	2.7%	2.9%	2.7%	3.5%	1.6%	3.0%
27	1.6%	3.2%	1.4%	2.7%	1.3%	1.9%	0.7%	2.0%	1.8%	3.9%	2.8%	4.2%	3.1%	4.3%	3.6%	4.9%	2.6%	4.8%
29	2.8%	4.5%	2.5%	4.6%	1.9%	3.7%	1.6%	3.3%	2.2%	5.1%	3.5%	4.6%	3.3%	4.4%	4.2%	5.8%	3.6%	5.9%
31	4.3%	7.9%	3.2%	6.5%	3.1%	6.1%	2.4%	5.5%	2.8%	6.9%	3.3%	6.5%	4.5%	4.7%	4.8%	7.5%	4.7%	6.9%
33	6.2%	10.4%	6.4%	9.4%	3.7%	7.4%	4.2%	8.1%	3.5%	7.7%	4.0%	7.1%	5.2%	4.2%	5.1%	7.0%	5.2%	7.2%
35	9.3%	7.6%	7.5%	8.2%	4.8%	8.3%	5.6%	9.1%	4.1%	6.9%	3.9%	6.3%	3.9%	3.5%	5.4%	5.6%	5.7%	6.2%
37	9.3%	4.3%	5.9%	6.6%	5.2%	8.1%	6.5%	7.8%	4.3%	5.4%	4.2%	5.4%	3.5%	4.2%	4.6%	3.6%	5.8%	4.7%
39	7.5%	2.5%	5.1%	4.9%	7.1%	4.9%	6.3%	5.7%	4.1%	3.9%	3.5%	3.8%	4.0%	4.1%	3.6%	2.3%	5.2%	3.5%
41	5.6%	1.4%	4.7%	2.4%	7.2%	2.9%	6.3%	3.1%	4.8%	2.5%	3.6%	2.7%	3.7%	3.9%	2.7%	1.6%	4.3%	2.0%
43	3.8%	0.5%	3.8%	0.9%	6.3%	1.4%	5.3%	1.4%	4.8%	1.2%	3.4%	1.8%	3.3%	2.2%	2.1%	0.9%	3.3%	0.9%
45	2.4%	0.2%	2.3%	0.2%	4.1%	0.5%	4.5%	0.4%	4.7%	0.6%	3.0%	0.9%	3.2%	0.7%	1.5%	0.2%	2.0%	0.3%
47	1.2%	0.0%	1.4%	0.0%	1.7%	0.0%	3.1%	0.1%	3.5%	0.3%	2.0%	0.2%	2.5%	0.1%	0.9%	0.1%	1.0%	0.1%
49	0.3%	0.0%	0.6%	0.0%	1.2%	0.0%	1.6%	0.0%	2.1%	0.1%	1.4%	0.1%	1.7%	0.1%	0.6%	0.0%	0.7%	0.0%
51	0.1%	0.0%	0.3%	0.0%	0.8%	0.0%	0.6%	0.0%	1.2%	0.0%	0.9%	0.0%	0.9%	0.0%	0.4%	0.0%	0.4%	0.0%
53	0.0%	0.0%	0.2%	0.0%	0.2%	0.0%	0.3%	0.0%	0.5%	0.0%	0.6%	0.0%	0.6%	0.0%	0.2%	0.0%	0.2%	0.0%
55	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.3%	0.0%	0.4%	0.0%	0.5%	0.0%	0.2%	0.0%	0.1%	0.0%
57	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.2%	0.0%	0.1%	0.0%	0.1%	0.0%
59	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%
61	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
63	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
65	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	55%	45%	47%	53%	51%	49%	51%	49%	49%	51%	47%	53%	53%	47%	49%	51%	50%	50%

Table 4.7. Domestic fishery length sampling effort for GOA rex sole by year.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Hauls sampled	74	257	220	372	328	257	277	194	213	393	347	194	320	352	
Lengths recorded	7,438	18,652	19,586	25,972	19,756	11,868	18,548	10,391	10,509	8,294	6,526	3,484	5,595	6,357	

Table 4.8. Maximum depth, GOA rex sole biomass estimates, standard errors, and coefficients of variation (CV) from NMFS trawl surveys, 1984 to 2005.

Survey year	Max Depth (m)	Biomass (t)	Std. Error	CV
1984	1,000	60,480	6,023	10%
1987	1,000	63,800	5,906	9%
1990	500	98,225	10,731	11%
1993	500	86,911	6,211	7%
1996	500	72,757	5,301	7%
1999	1,000	74,980	8,656	12%
2001	500	71,326	6,129	9%
2003	700	99,897	7,559	8%
2005	700	101,255	8,195	8%

Table 4.9. Survey biomass estimates (t) for Gulf of Alaska rex sole for 1993 to 2005 by North Pacific Fishery Management Council regulatory area.

		Area		
Year	Western	Central	Eastern	Total
2005	12,766	60,600	27,889	101,255
2003	13,265	58,027	28,659	99,950
2001	9,624	41,723	19,979	71,326
1999	12,333	42,796	19,476	74,605
1996	9,419	43,778	19,560	72,757
1993	10,700	55,442	20,901	87,042

Table 4.10. Survey biomass of rex sole in the Eastern Gulf of Alaska for 1993, 1996 and 1999. The biomass used for the Eastern Gulf in 2001 is shown in the column labeled estimated 2001. See text for the method used to estimate the 2001 biomass.

Species	1993	1996	1999	Estimate 2001
Rex sole	20,901	19,560	19,476	19,979

Table 4.11. Rex sole survey biomass by depth from 1984 to 2005.

Depth (m)	1984	1987	1990	1993	1996	1999	2001	2003	2005
<100	3,987	5,691	15,460	11,233	10,403	14,682	7,742	17,529	
101-200	37,040	40,244	59,833	54,064	43,419	40,239	29,206	58,787	
201-300	13,083	14,508	21,791	16,995	14,929	15,766	11,045	19,094	
301-500	5,161	1,812	1,140	4,619	4,006	3,841	3,265	4,017	
501-700	1,057	1,542				451		470	
701-1000	342	30				0			

Table 4.12. Von Bertalanffy parameter estimates for rex sole in the Gulf of Alaska from survey length and age data 1984, 1987, 1990, 1993 and 1996.

Species	Linf	K	t0
males	39.5	0.38	0.79
females	44.9	0.31	0.69

Table 4.13. Key parameter estimates and likelihood values for the reference model of GOA rex sole.

	Description	**Value**
	fishery selectivity	
Females	slope	1.7
	age at 50%	10.3
Males	slope	0.84
	age at 50%	10.9
	survey selectivity	
Females	age at 50%	3.8
	age at 95%	5.6
Males	age at 50%	3.4
	age at 95%	4.5
	Survey Q (fixed)	1
Likelihoods		
	Recruitment	20
	survey biomass estimates	12
	survey length compositions	338
	survey age compositions	299
	fishery length compositions	570
	Total	1,239

Table 4.14. Estimated GOA rex sole age 3+ population biomass, female spawning biomass (thousands of t) and age 3 recruits (millions). Estimates from the 2004 assessment are shown in italics.

	Age 3+ biomass		Female spawning biomass		Age 3 recruits	
Year	Current	*Last year*	Current	*Last year*	Current	*Last year*
1982	76.6	*78.2*	35.4	*35.9*	42.4	*44.6*
1983	76.0	*77.8*	35.2	*35.8*	37.4	*37.9*
1984	74.8	*76.7*	35.0	*35.8*	23.6	*24.8*
1985	74.2	*76.4*	35.0	*35.8*	41.4	*45.9*
1986	74.6	*77.1*	34.7	*35.6*	48.1	*50.7*
1987	76.9	*79.7*	34.5	*35.5*	66.2	*67.4*
1988	81.5	*84.9*	34.1	*35.3*	93.2	*102.3*
1989	86.9	*91.0*	34.8	*36.2*	69.3	*73.4*
1990	93.2	*97.8*	37.3	*38.9*	68.5	*69.6*
1991	97.3	*102.1*	40.3	*42.3*	51.6	*53.0*
1992	95.1	*100.2*	41.2	*43.6*	25.0	*25.7*
1993	92.7	*97.8*	42.4	*45.0*	31.6	*33.0*
1994	89.1	*94.1*	42.3	*44.8*	32.5	*35.5*
1995	83.5	*88.4*	40.6	*43.0*	19.6	*21.0*
1996	77.2	*81.9*	37.9	*40.2*	27.3	*26.3*
1997	72.0	*76.1*	33.9	*36.3*	64.2	*56.7*
1998	70.0	*73.5*	31.4	*33.6*	39.6	*42.8*
1999	71.2	*74.1*	30.2	*32.0*	70.4	*70.8*
2000	72.1	*74.8*	29.7	*31.2*	45.2	*48.8*
2001	78.2	*76.5*	29.9	*31.1*	130.3	*64.1*
2002	90.0	*78.8*	31.2	*32.1*	145.4	*55.9*
2003	99.2	*80.9*	34.3	*33.3*	51.2	*52.6*
2004	104.7	*81.7*	39.5	*34.4*	48.4	*43.4*
2005	108.9		45.8		46.8	
Average	84.0	*83.5*	36.1	*36.9*	55.0	*49.8*

Table 4.15. Projected GOA rex sole female spawning biomass and yield from 2006 to 2010.

	Year	Female spawning biomass(t)	Yield (t)
F=$F_{40\%}$			
	2006	49,242	38,093
	2007	33,892	16,860
	2008	29,301	16,542
	2009	23,090	11,988
	2010	19,789	7,417
F=$F_{35\%}$			
	2006	49,242	46,843
	2007	31,118	19,130
	2008	24,997	15,570
	2009	19,130	9,301
	2010	17,911	7,264
Average 5 yr. F=0.15			
	2006	49,242	3,038
	2007	49,897	3,376
	2008	49,266	3,907
	2009	47,944	4,593
	2010	46,048	4,943
0.5 F40%			
	2006	49,242	29,373
	2007	37,025	14,720
	2008	33,121	15,366
	2009	27,640	13,678
	2010	22,982	9,040
Author F=0.51			
	2006	49,258	9,223
	2007	46,841	8,445
	2008	45,111	8,871
	2009	43,858	9,790
	2010	42,137	9,495
F=0			
	2006	49,242	0
	2007	51,569	0
	2008	52,570	0
	2009	52,988	0
	2010	53,064	0

Table 4.16. Summary of results of rex sole assessment in the Gulf of Alaska.

Biological features	
Natural Mortality	0.17 females and males
Age of full(95%) fishery selection	13 yrs for females, 15 yrs for males
Reference fishing mortalities	
$F_{40\%}$	6.0
$F_{35\%}$	12.0
Reference biomass levels	
Unfished female spawning biomass ($B_{100\%}$)	51,700 t
$B_{35\%}$	18,100 t
$B_{40\%}$	20,700 t
2006 total (age 3+) biomass	110,257 t
2006 female spawning biomass	49,242 t
Yield levels	
2006 Recommended ABC (Tier 5 adult biomass)	9,200 t
2006 Yield at $F_{40\%}$	38,100 t
2006 Overfishing level for 2006 ($F_{35\%}$)	46,800 t

Figures

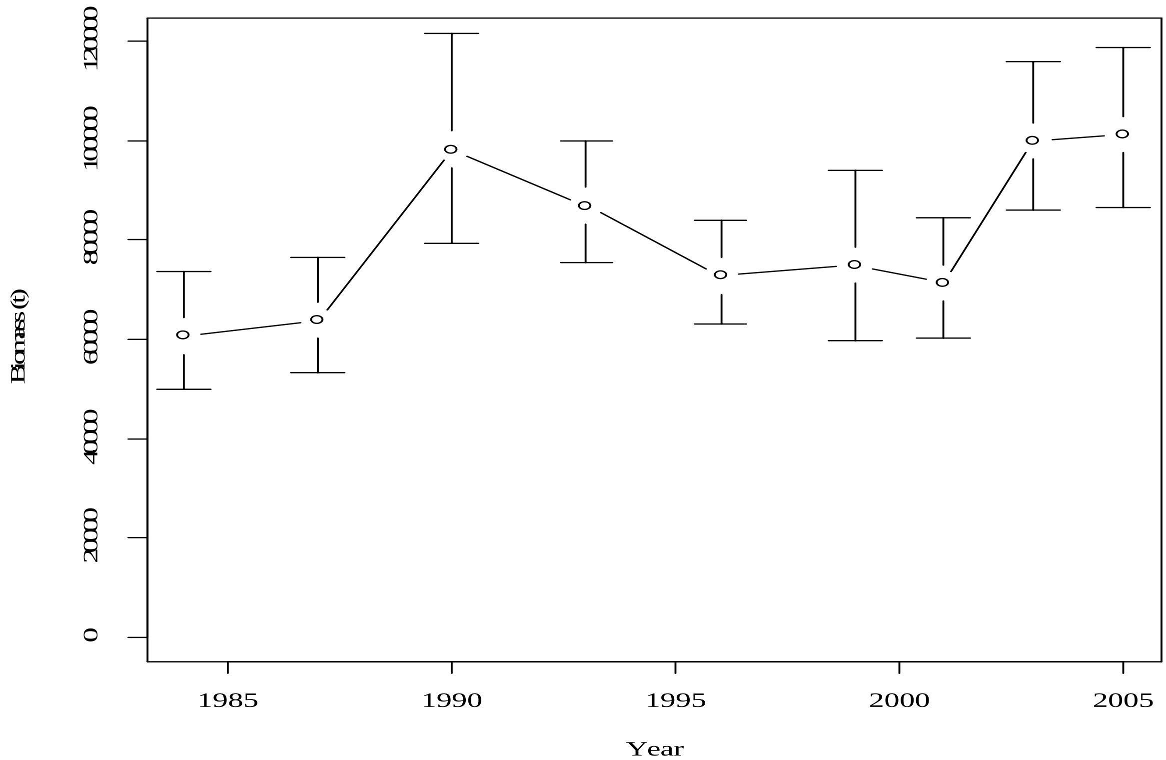

Figure 4.1. NMFS survey biomass estimates and approximate lognormal 95% confidence intervals for 1984 to 2005.

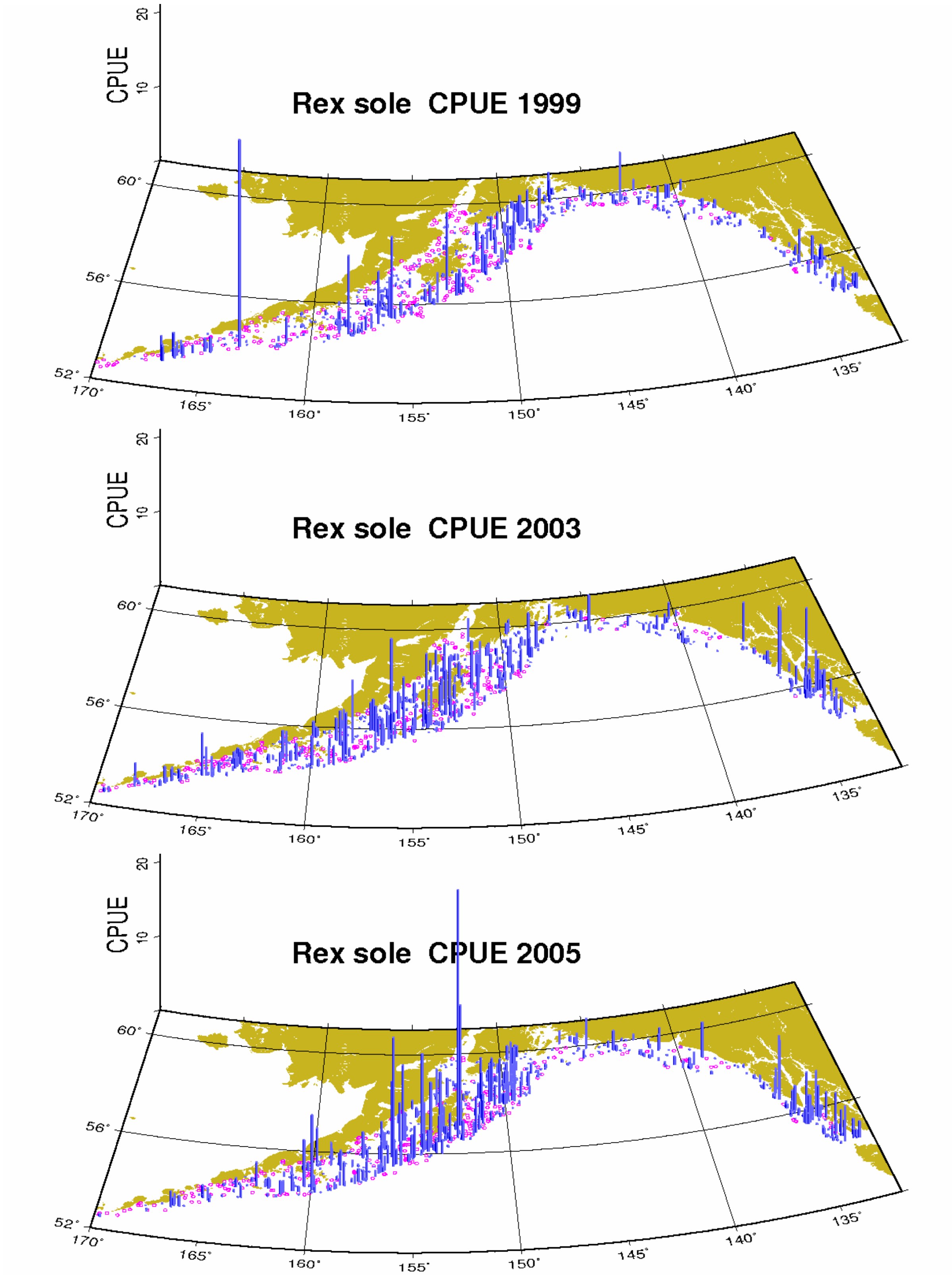

Figure 4.2. Rex sole bottom-trawl survey CPUE by tow. Circles represent tows locations where rex sole were absent, height of the vertical columns represent the magnitude of CPUE.

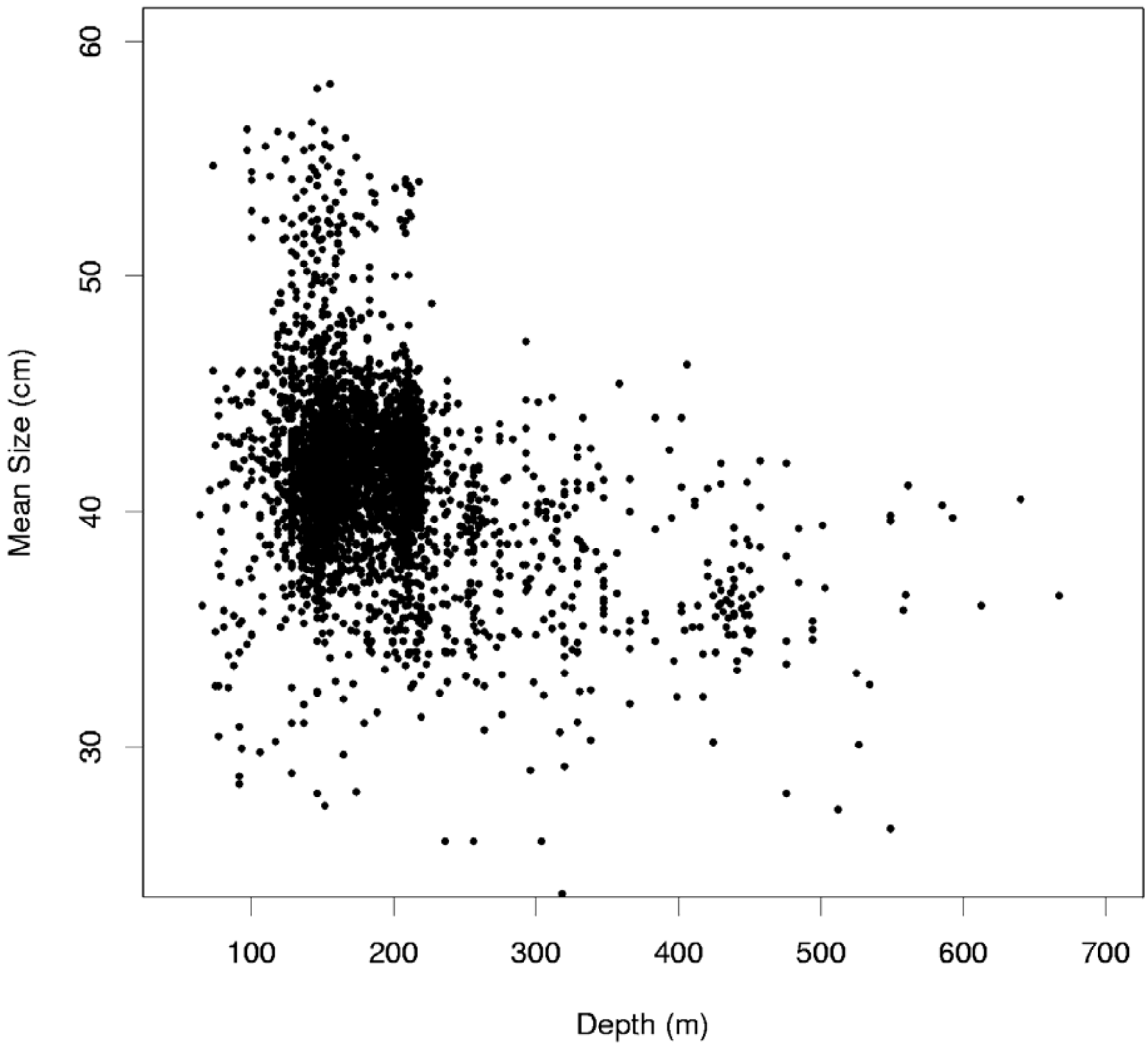

Figure 4.3. Mean GOA rex sole length (cm) within haul by depth for fishery length data from 1990 to 2003.

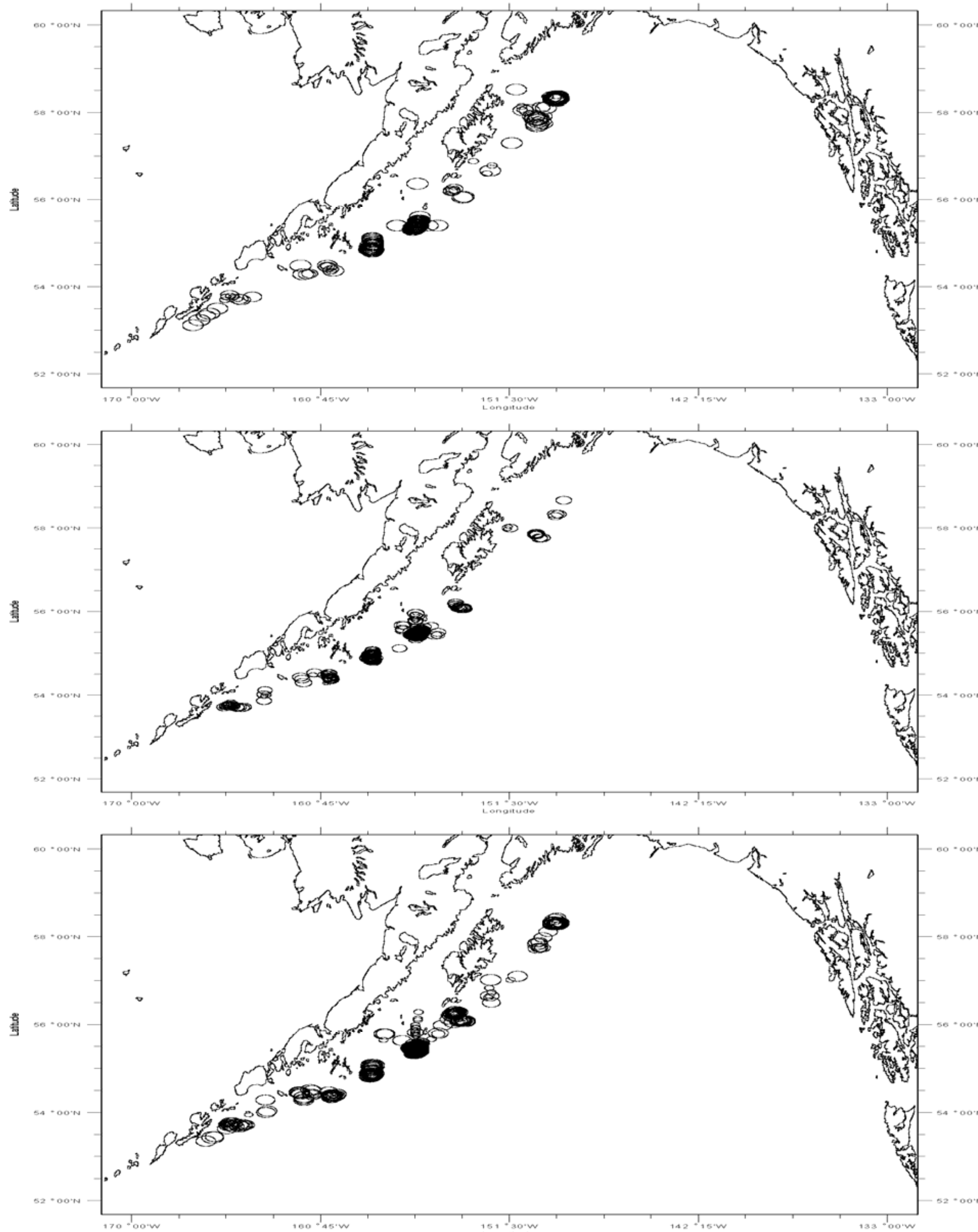

Figure 4.4. Location of fishery hauls sampled for lengths in 2001 (top), 2002 (middle), and 2003 (bottom). Area of the circle is proportional to the sample size.

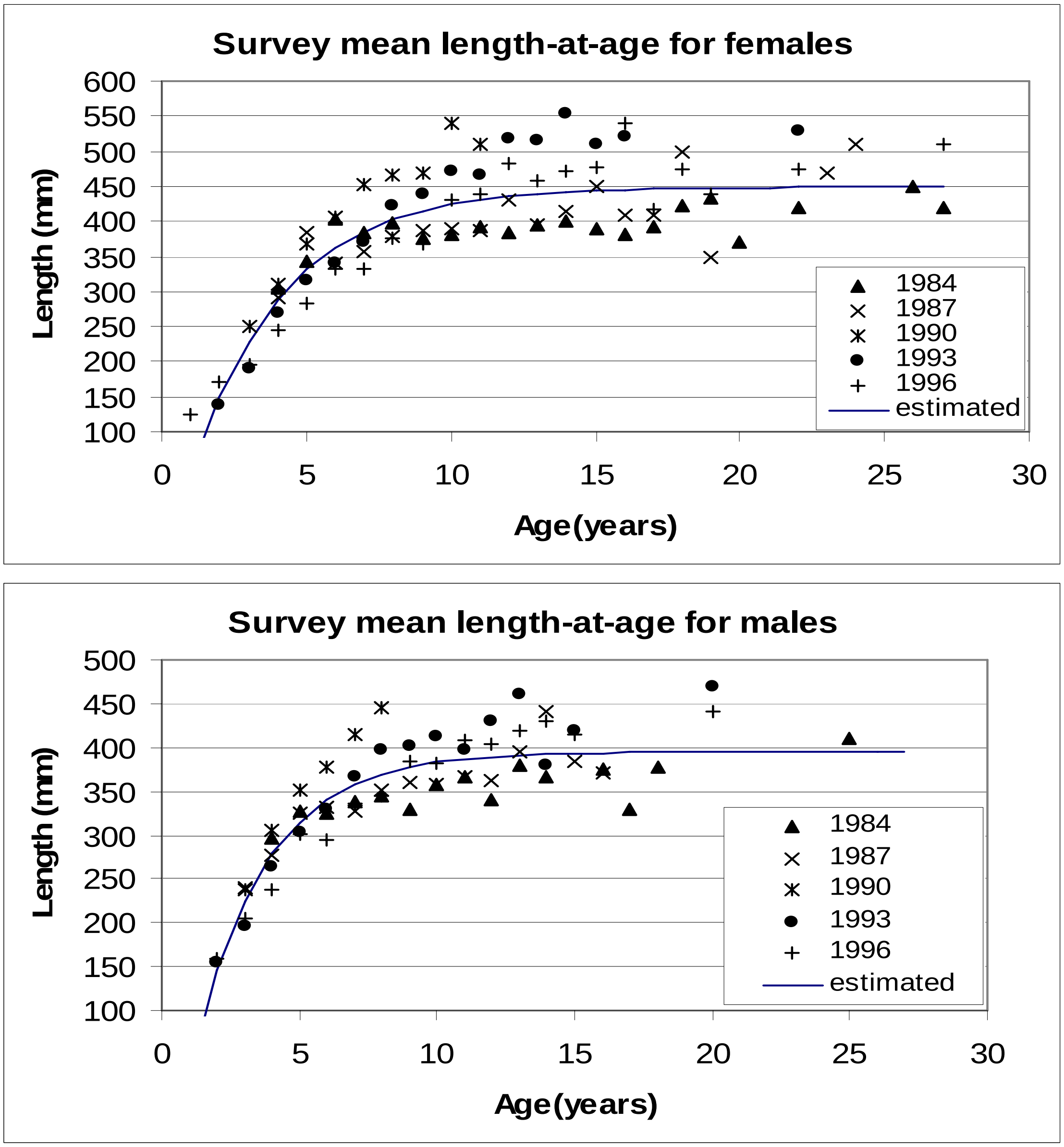

Figure 4.5. Mean length at age for GOA rex sole females (top) and males (bottom) based on survey data 1984 through 1996. Estimated mean length at age was used to estimate the age-length transition matrix.

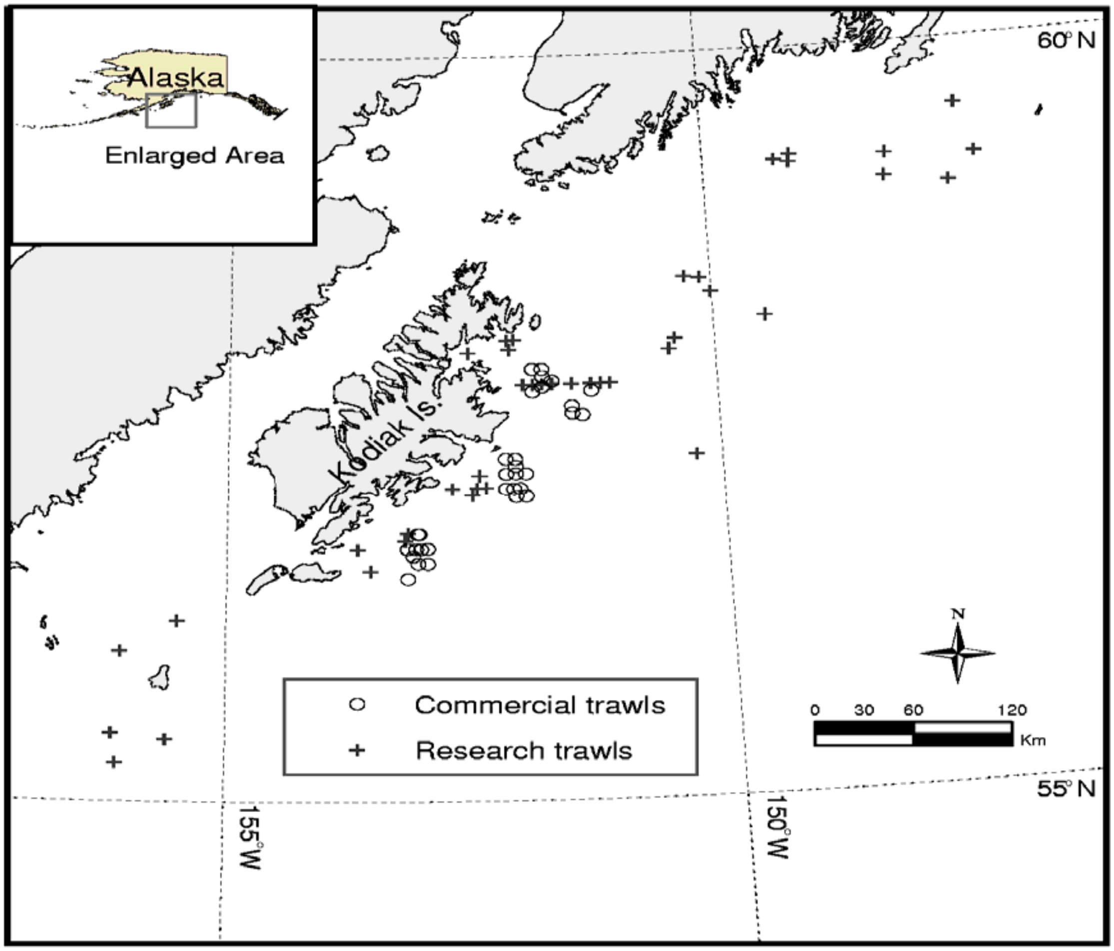

Figure 4.6. Locations of fishery trawls and research trawls sampled to estimate rex sole maturity (from A. Abookire, in press).

Figure 4.7. Female Rex sole estimated fraction mature by age.

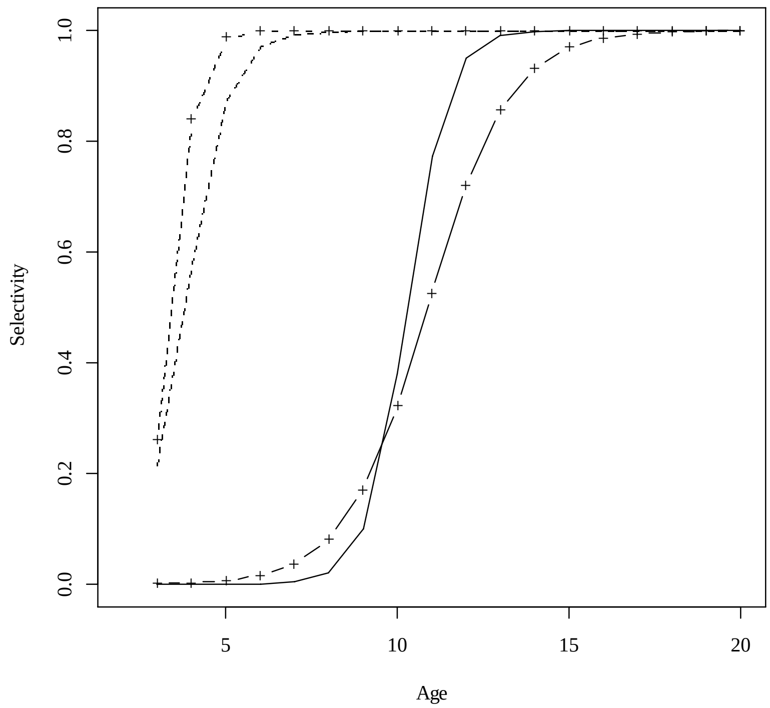

Figure 4.8. Estimated selectivity curves, fishery (solid line) and survey (dashed line), females (no symbol) and males (plus symbol).

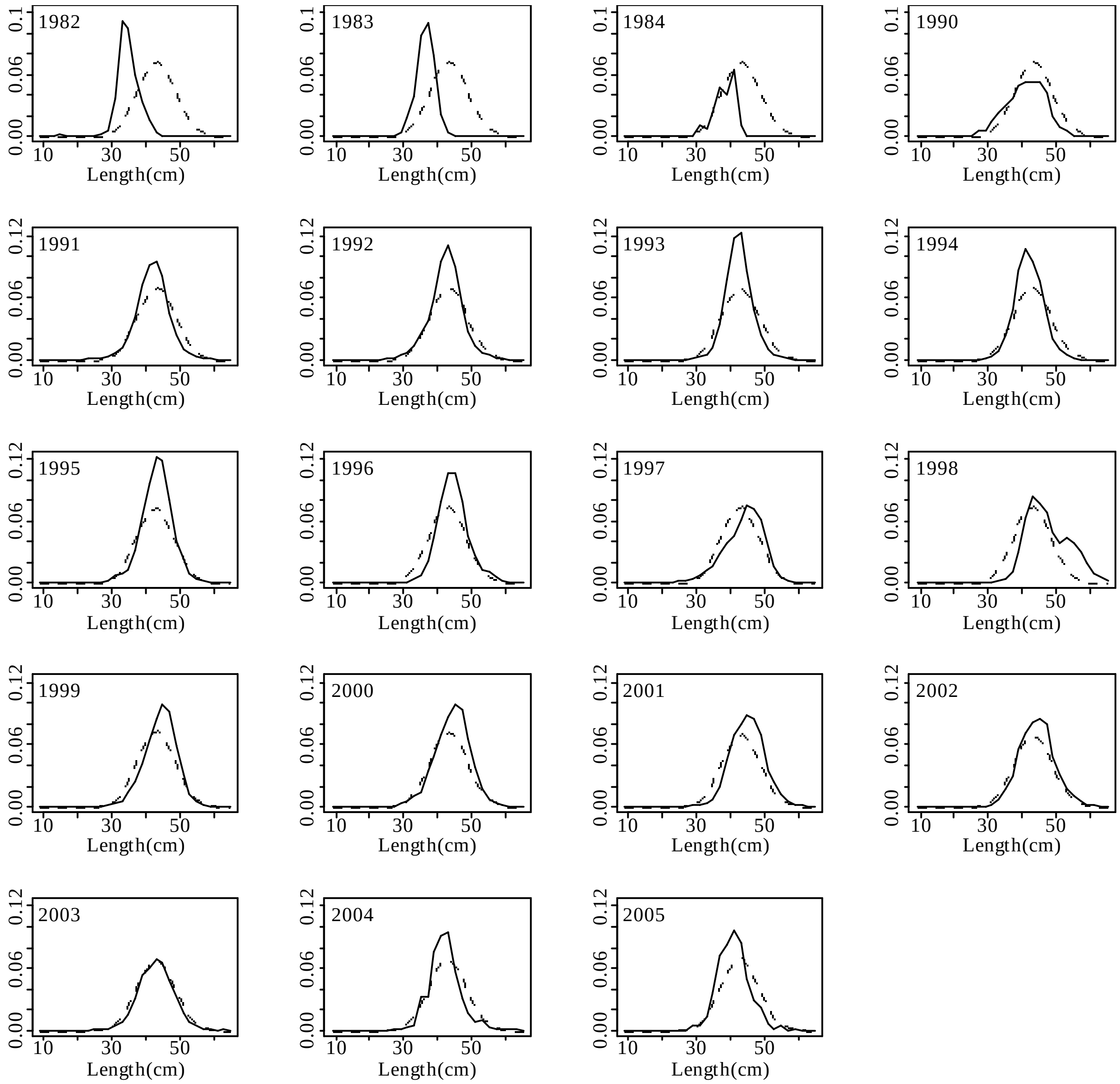

Figure 4.9a Fit to the **female** fishery length composition data for GOA rex sole. The dashed line represents values predicted by the model.

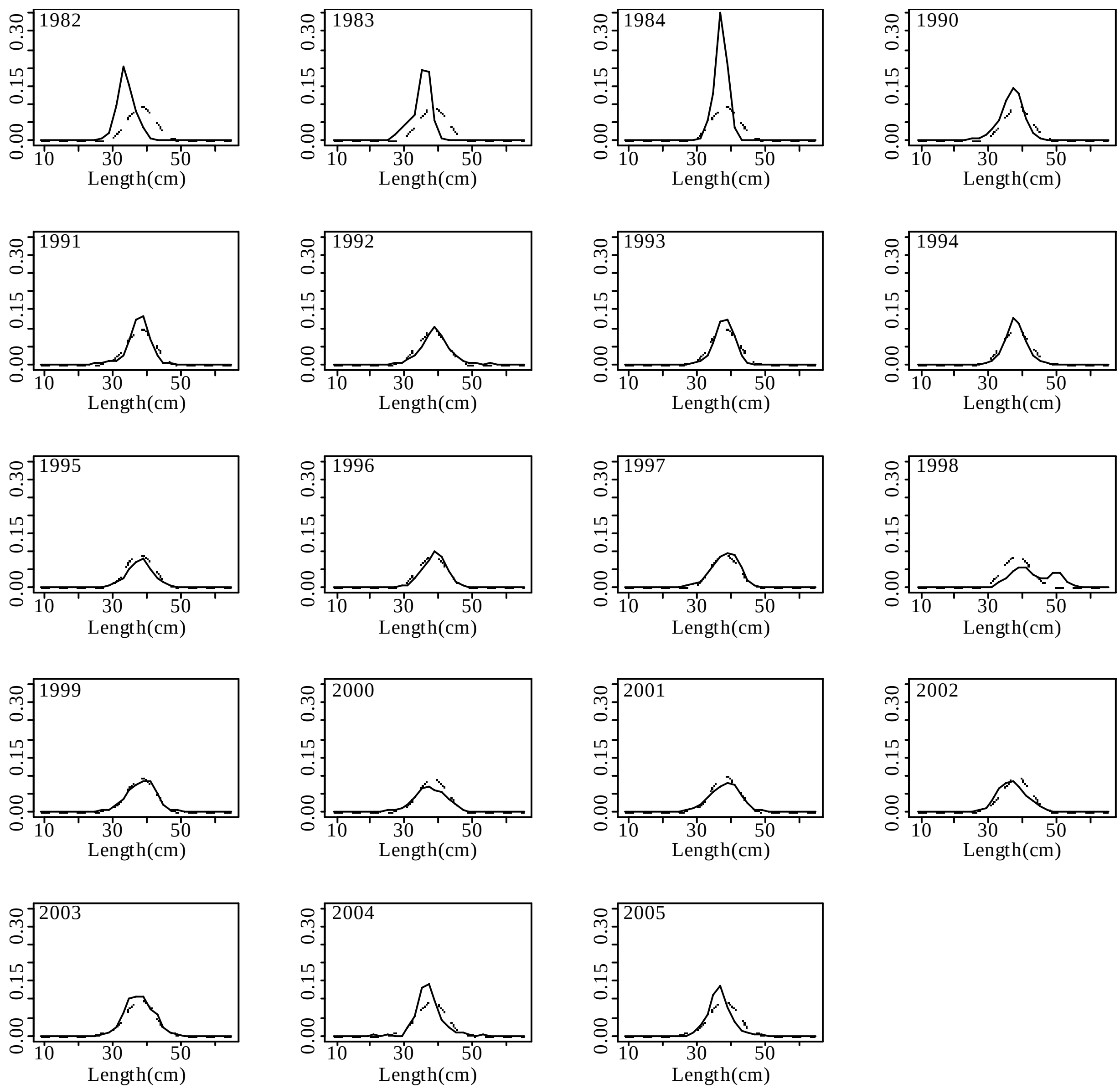

Figure 4.9b Fit to the **male** fishery length composition data for GOA rex sole. The dashed line represents values predicted by the model.

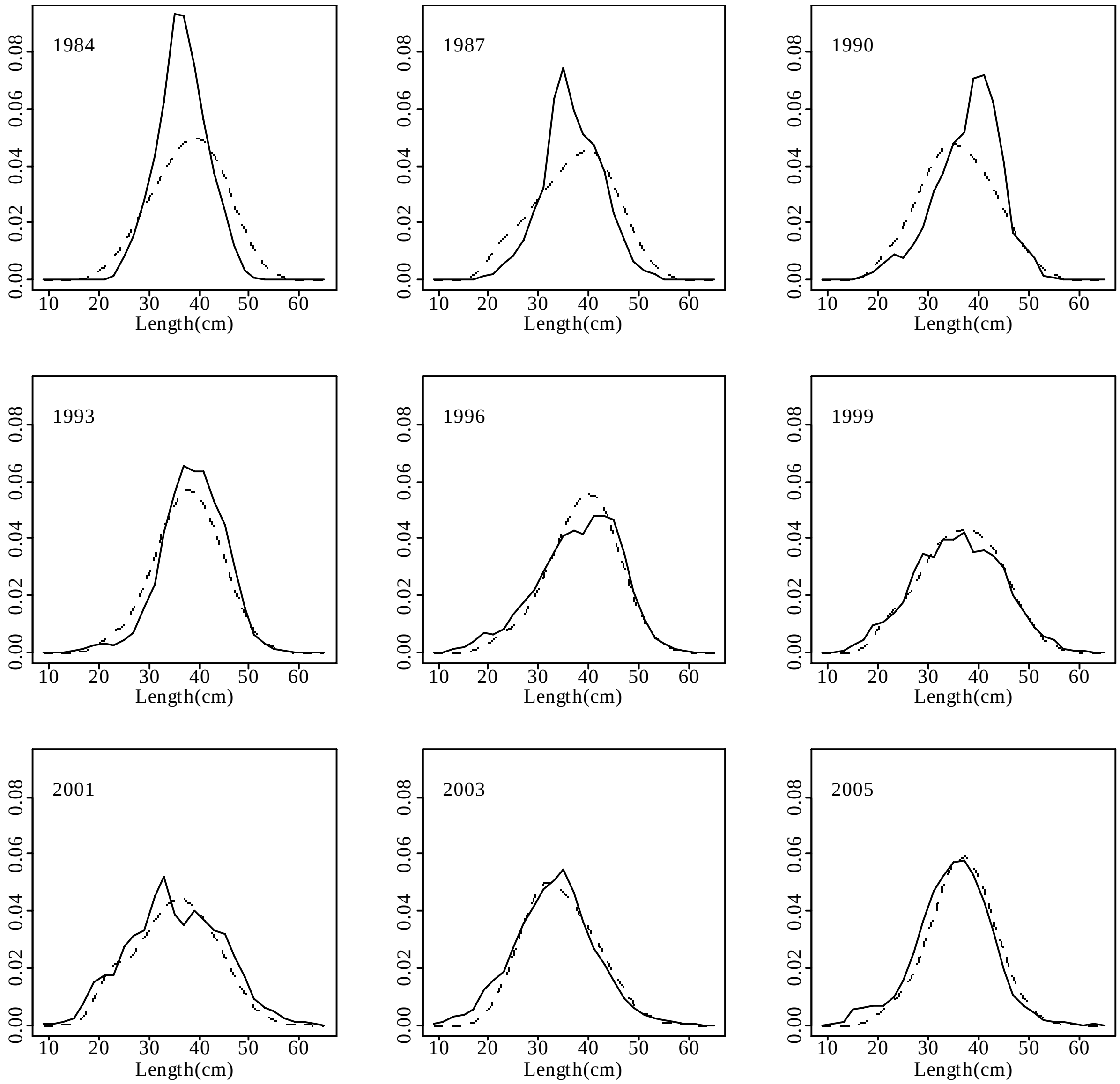

Figure 4.10a Fit to the **female** survey length composition data for GOA rex sole. The dashed line represents values predicted by the model.

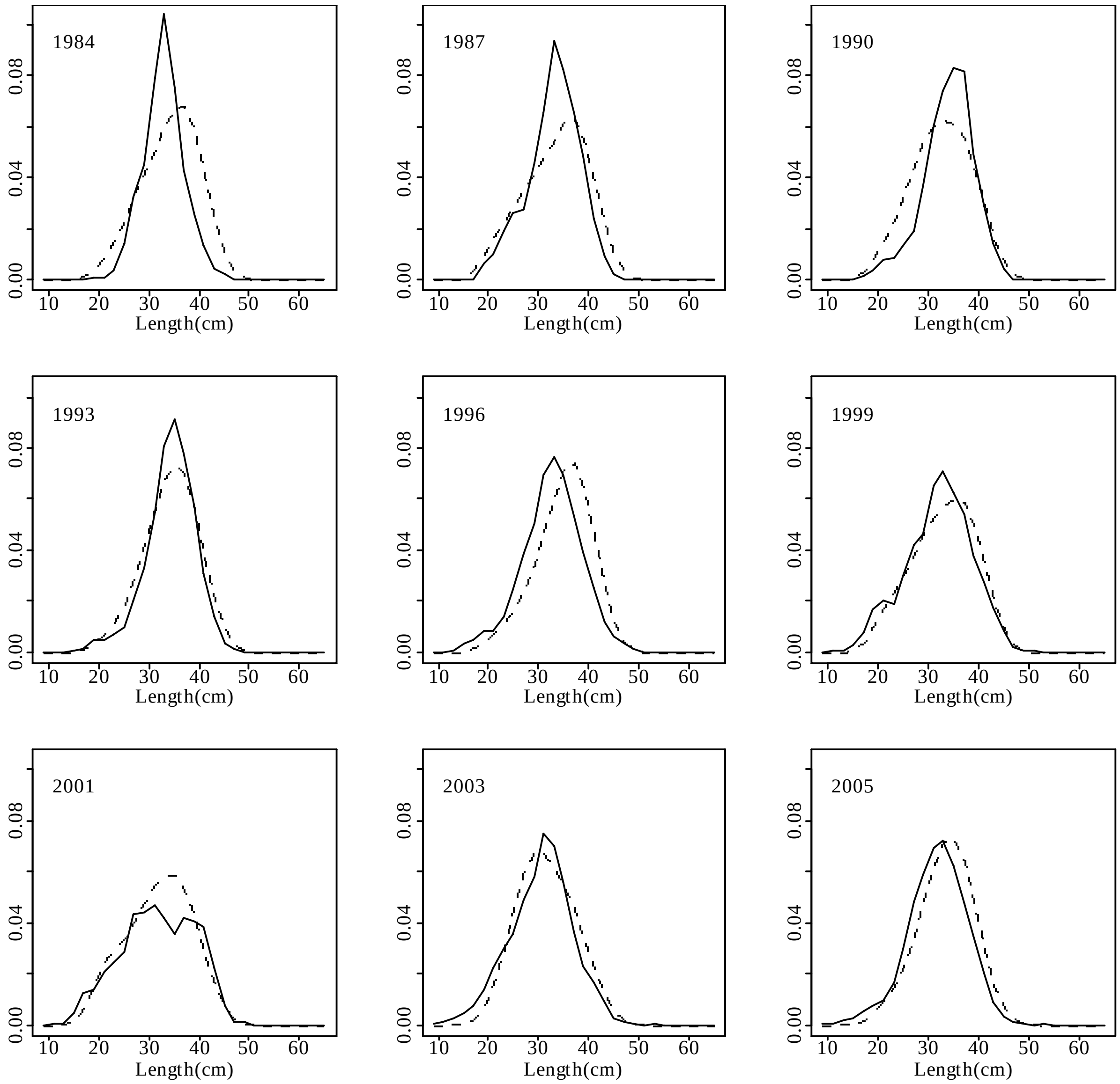

Figure 4.10b Fit to the **male** survey length composition data for GOA rex sole. The dashed line represents values predicted by the model.

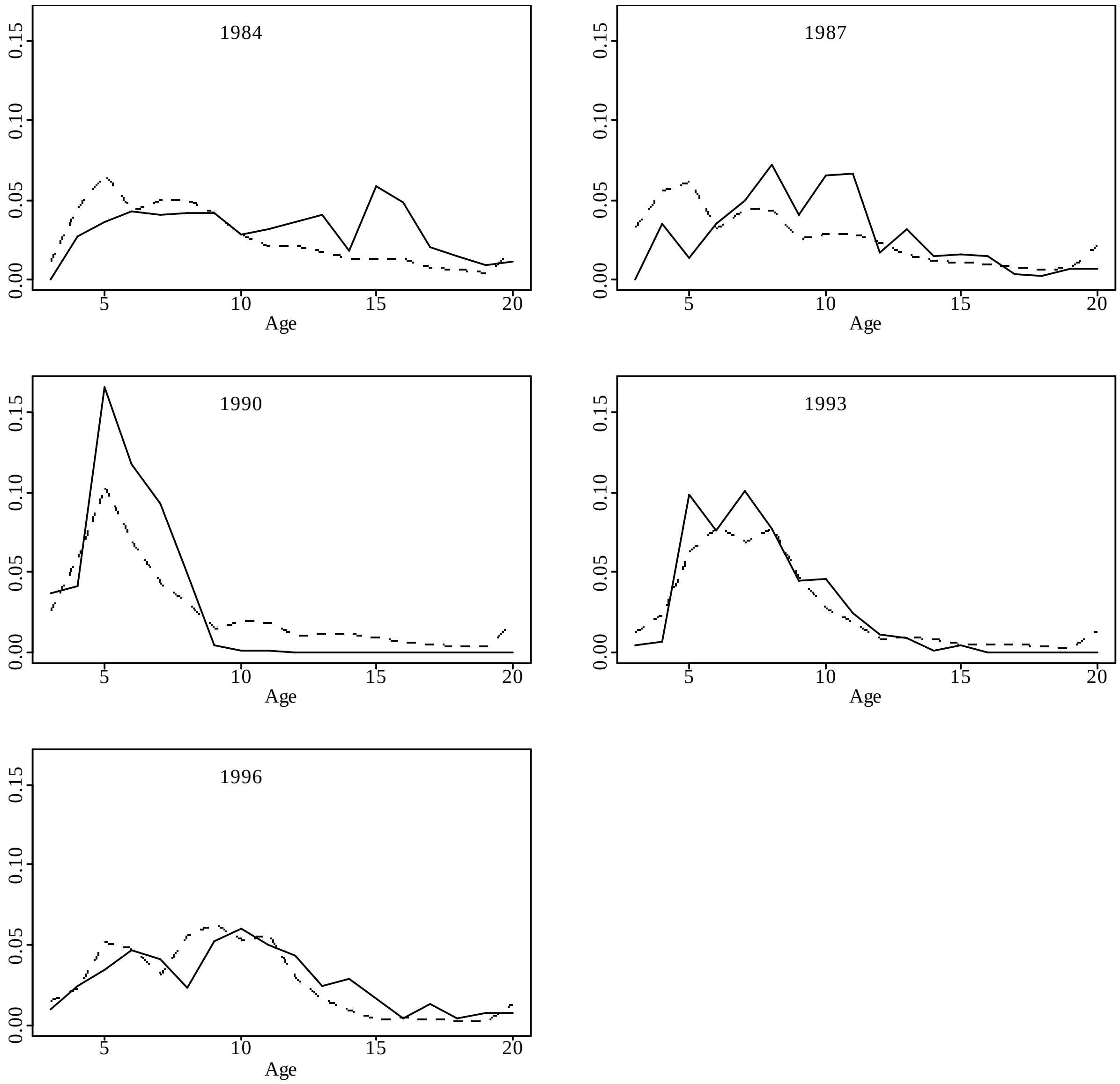

Figure 4.11a Fit to the **female** survey age composition data for GOA rex sole. The dashed line represents values predicted by the model.

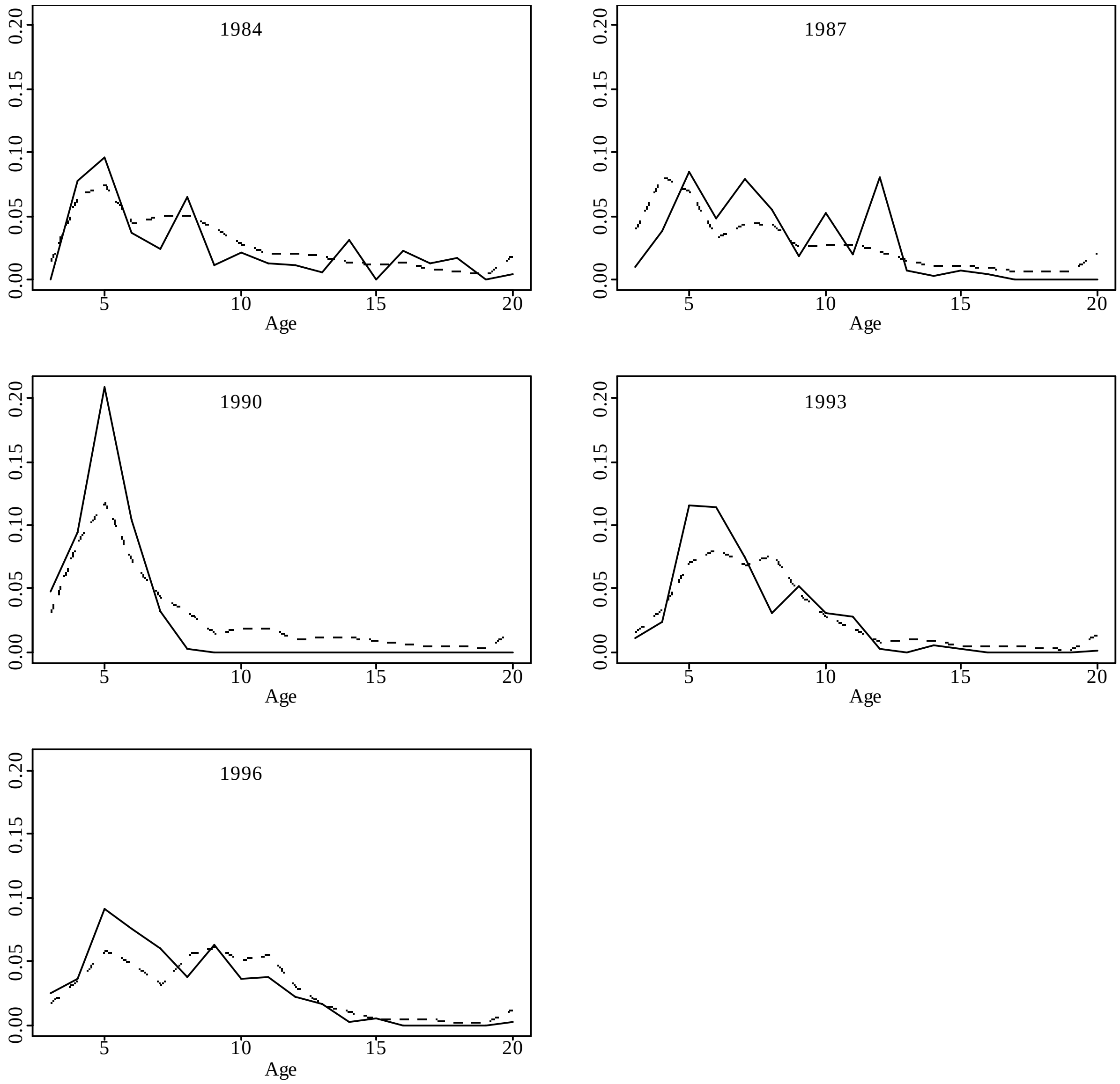

Figure 4.11b Fit to the **male** survey age composition data for GOA rex sole. The dashed line represents values predicted by the model. (it would be good to line these up so trends can be more easily tracked over time (sideways doesn't work so well).

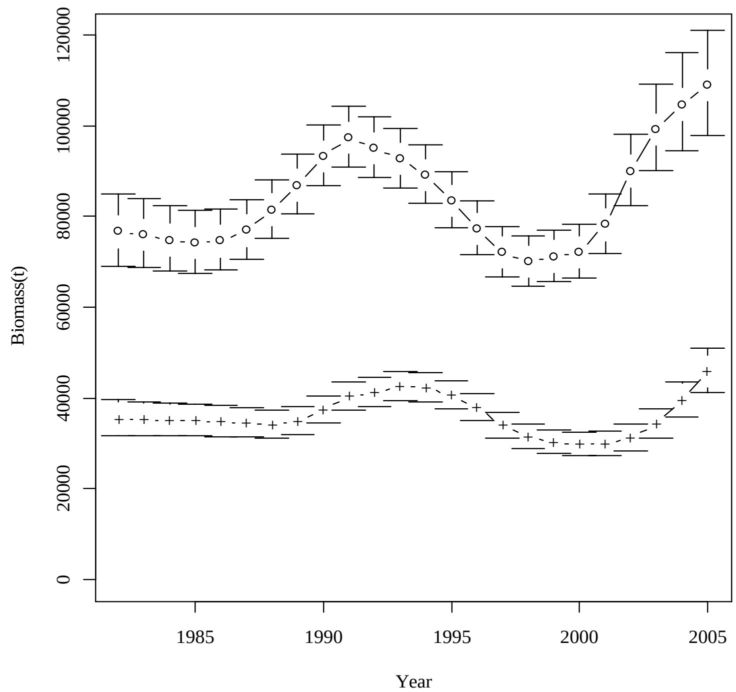

Figure 4.12. Age 3+ biomass and female spawning biomass from 1982 to 2005 for GOA rex sole. The 95% confidence intervals shown underestimate the uncertainty because variance in natural mortality and survey catchability as well as other parameters are assumed to be known without error.

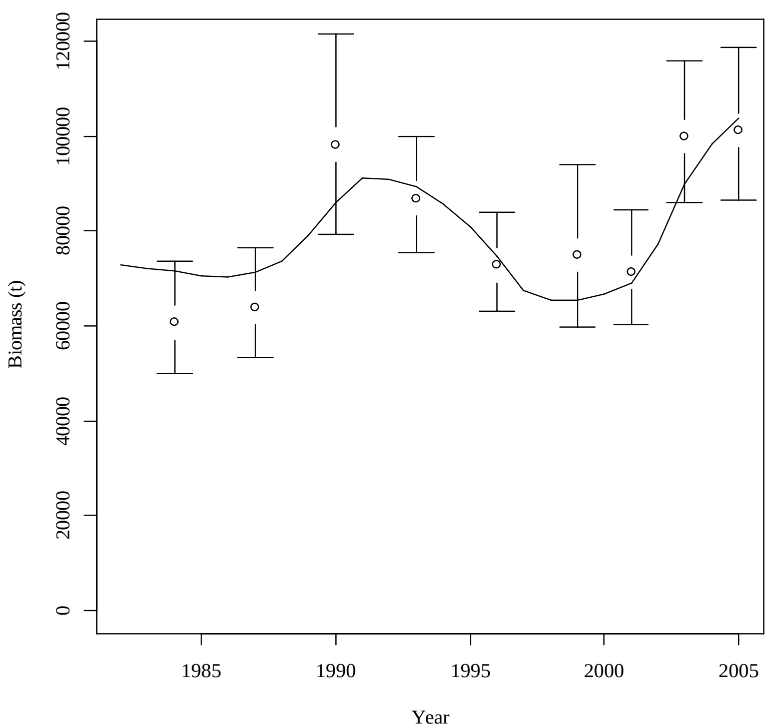

Figure 4.13. Model fit to survey biomass estimates for GOA rex sole with 95% log-normal confidence intervals for the observed survey biomass estimates 1984 to 2005.

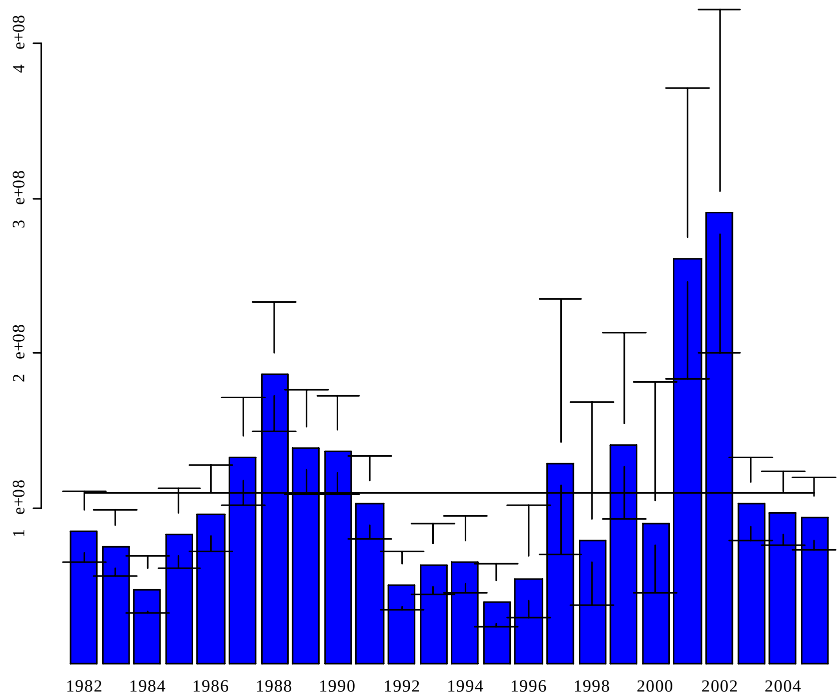

Figure 4.14. Age 3 estimated GOA rex sole recruitments (male plus female) in numbers from 1982 to 2005, with 95% confidence intervals. Horizontal line is average recruitment.

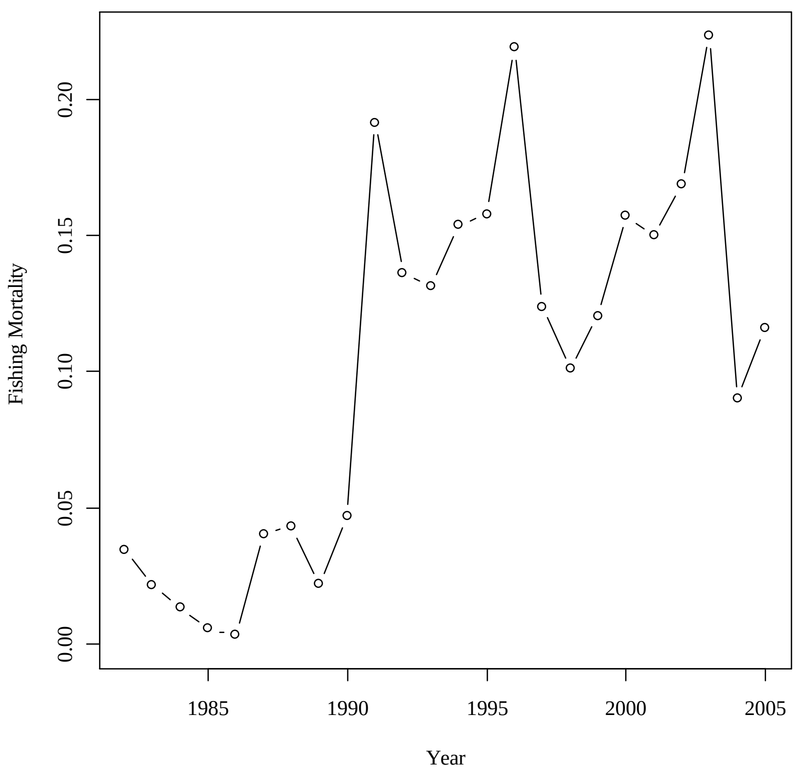

Figure 4.15. Fishing mortality rate estimates for GOA rex sole from 1982 to 2005.

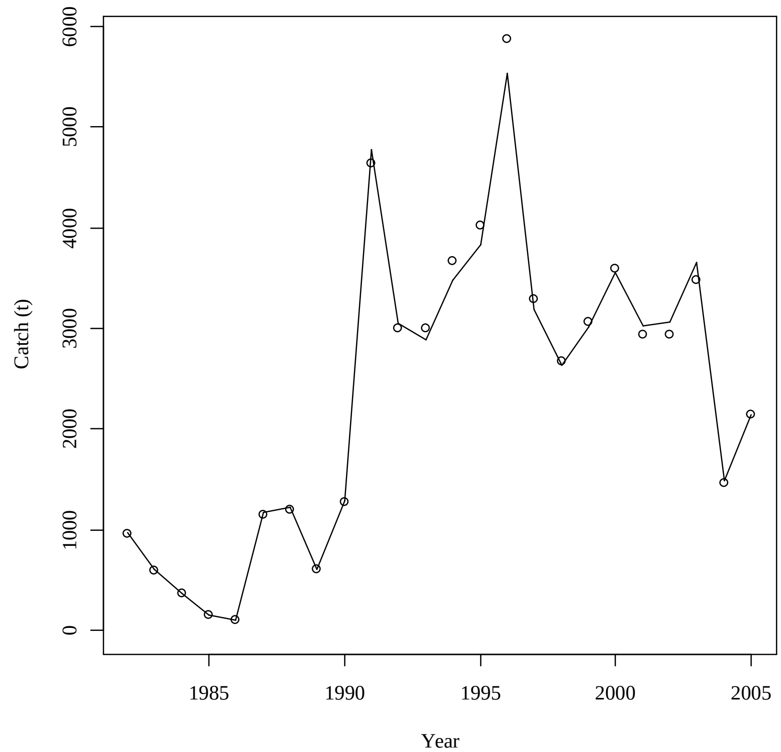

Figure 4.16. Observed (open circles) and model predicted (line) GOA rex sole catch,1982 to 2005.

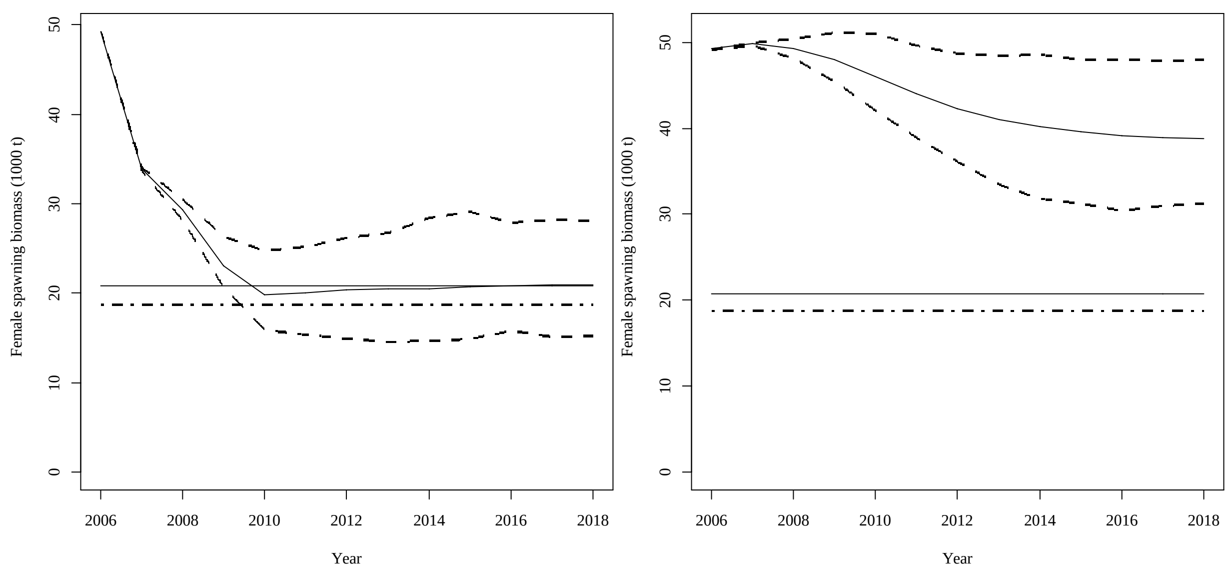

Figure 4.17. Projected female spawning biomass from 2006 to 2018 fishing at maximum permissible FABC (=$F_{40\%}$; left panel) compared to the recent 5-year average F (=0.15; right panel).

Appendix A—model details

Table A.1 Model equations describing the population dynamics.

$N_{t,1}=R_t=R_0 e^{\tau_t}$	$\tau_t \sim N(0,\sigma_R^2)$		Recruitment
$C_{t,a}=\frac{F_{t,a}}{Z_{t,a}}(1-e^{-Z_{t,a}})N_{t,a}$		$1\le t\le T$ $1\le a\le A$	Catch
$N_{t+1,a+1}=N_{t,a}e^{-Z_{t,a}}$		$1<t\le T$ $1\le a<A$	Numbers at age
$FSB_t=\sum_{a=1}^{A} w_a \phi_a N_{t,a}$			Female spawning biomass
$N_{t+1,A}=N_{t,A-1}e^{-Z_{t,A-1}}+N_{t,A}e^{-Z_{t,A}}$		$1<t\le T$	Numbers in “plus” group
$Z_{t,a}=F_{t,a}+M$			Total Mortality
$C_t=\sum_{a=1}^{A} C_{t,a}$			Total Catch in numbers
$p_{t,a}=C_{t,a}/C$			proportion at age in the catch
$Y_t=\sum_{a=1}^{A} w_{t,a} C_{t,a}$			Yield
$F_{t,a}=s_{t,a}E_t e^{\varepsilon_t}$	$\varepsilon_t \sim N(0,\sigma_R^2)$		Fishing mortality
$S_a = \frac{1}{1+e^{-slope(a-a50\%)}}$			selectivity –ascending logistic for survey and fishery
$SB_t=Q\sum_{a=1}^{A} w_a s^s_{t,a} N_{t,a}$			survey biomass, Q = 1.

Table A.2 Likelihood components

$\sum_{t=1}^{T}\left[\log(C_{t,obs})-\log(C_{t,pred})\right]^2$	Catch using a lognormal distribution.
$\sum_{t=1}^{T}\sum_{a=1}^{A} nsamp_t * p_{obs,t,a}\log(p_{pred,t,a})$ - offset	Age and length compositions using a multinomial distribution. *nsamp* is the observed sample size. Offset is a constant term based on the multinomial distribution.
offset = $\sum_{t=1}^{T}\sum_{a=1}^{A} nsamp_t * p_{obs,t,a}\log(p_{obs,t,a})$	The offset constant is calculated from the observed proportions and the sample sizes.
$\sum_{t=1}^{ts}\frac{\ln\left(SB_{obs,t}/SB_{pred,t}\right)^2}{2\operatorname{var}\left(\ln\left(SB_{obs,t}\right)\right)}$	survey biomass using a lognormal distribution, *ts* is the number of years of surveys.
$\sum_{t=1}^{T}(\tau_t)^2$	Recruitment, where $\tau_t \sim N(0,\sigma_R^2)$

Table A.3 List of variables and their definitions used in the model.

T	number of years in the model(t=1 is 1982 and t=T is 2005
A	number of age classes (A =18, corresponding to ages 3(a=1) to 20+)
w_a	mean body weight(kg) of fish in age group a.
ϕ_a	proportion mature at age a
R_t	age 3(a=1) recruitment in year t
R_0	geometric mean value of age 3 recruitment
τ_t	recruitment deviation in year t
$N_{t,a}$	number of fish age a in year t
$C_{t,a}$	catch number of age group a in year t
$p_{t,a}$	proportion of the total catch in year t that is in age group a
C_t	Total catch in year t
Y_t	total yield(tons) in year t
$F_{t,a}$	instantaneous fishing mortality rate for age group a in year t
M	Instantaneous natural mortality rate
E_t	average fishing mortality in year t
ε_t	deviations in fishing mortality rate in year t
$Z_{t,a}$	Instantaneous total mortality for age group a in year t
s_a	selectivity for age group a

Table A.4 Estimated parameters for the AD Model builder model. There were P total parameters estimated in the model.

$\log(R_0)$	log of the geometric mean value of age 3 recruitment
τ_t $1982 \le t \le 2005$, plus 18 parameters for the initial age composition equals 42.	Recruitment deviation in year t
$\log(f_0)$	log of the geometric mean value of fishing mortality
ε_t $1982 \le t \le 2005$, 24 parameters	deviations in fishing mortality rate in year t
Slope and 50% for logistic function, 4 parameters	selectivity parameters for the fishery for males and females.
Slope and 50% for logistic function, 4 parameters	selectivity parameters for the survey for males and females.

Table A.5 Fixed parameters in the AD Model Builder model.

Parameter	Description
M = 0.17 females , M=0.17 males	Natural mortality
Q = 1.0	catchability for surveys
L_{inf} , k , t_0, CV of length at age 3 and age 20 for males and females	von Bertalanffy Growth parameters estimated from the 1984-1996 survey length and age data.