Gulf of Alaska Rex Sole Stock Assessment

by
Benjamin J. Turnock and Z. Teresa A'mar

Executive Summary

An age-based model using age and length data was developed for rex sole. Survey biomass estimates, survey age and length data, and fishery length data were used in the model. Length composition data were fit using a fixed length-age transition matrix estimated from survey length at age data.

Survey biomass from NMFS trawl surveys from 1984 to 2003 were included in the model. Surveys covered depths to 500 m in 1990, 1993, 1996 and 2001. Surveys in 1984, 1987, 1999 extended to depths of 1000 m. The 2003 survey covered depths to 700 m.

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 1,441 t through October 9, 2004. Rex sole was harvested at about 11% of the ABC level through October 9, 2004. Fishing mortality was estimated at about 0.15 for 2002 and 2003.

Survey abundance estimates increased from 71,326 t in 2001 (adjusted for the eastern GOA) to 99,897 t in 2003.

The 2003 NMFS bottom-trawl survey biomass was used as current biomass for calculation of ABC. The 2004 ABC of 12,650 t increased from 9,466 t in 2003, based on the 2003 survey. The 12,650 t ABC in 2005 is unchanged from 2004.

Model estimates of F40% and F35% were high for rex sole due to the selection of larger fish by the fishery compared to the female maturity curve. F40% was 5.38 which results in a 2005 ABC 30,145 t. An F=0.6 results in an 2005 ABC of 12,374 t, close to that estimated for 2004. F35% was estimated at 10.09, resulting in an overfishing level of 36,983 t. Model estimates of F40% result in rapidly declining yield over time.

Model estimates of 2005 total biomass (age 3+) was 82,298 t. 2005 females spawning biomass was estimated at 35,397 t.

Introduction

Rex sole occurs from southern California to the Bering sea to about 800 meters depth. 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.
This report describes rex sole catches taken from 1978 through October 9, 2004, and presents information on the status and potential yield of the rex sole stock based on Gulf of Alaska demersal trawl survey data through 2003.

Catch history

Catch is currently reported for rex sole by management area (Table 4.1 and 4.2). The catch in each year previous to 1993 was estimated by using the fraction of rex sole from observer sampling relative to the deep water complex catch. 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 (1,441 t through October 9) 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 fishery remained closed from July 25 through October 9 due to the halibut bycatch limit. The lower catch in 2004 could be due to the more extensive fishery closures compared to 2003.

Estimates of retained and discarded catch (t) in the rex sole fishery since 1991, 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 was 95% for 2002.

Condition of stocks

Survey Abundance

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 2003 (Tables 4.5, 4.6, 4.8-4.10, and Figure 4.1). Rex sole biomass estimates from the 1993 to 2003 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).

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 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, however, analysis is not complete (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 extended down to 1000 m and covered the entire GOA, the 2003 survey biomass estimate represented a 34% increase.

The distribution of CPUE from survey trawls for 1984 to 2003 indicate rex sole are widespread in the Gulf of Alaska (Figures 4.14 to 4.21). The CPUE in the 2003 survey appears to be higher throughout the Gulf, including the southeast region.

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 74 parameters were estimated in the model (Table A.4). Forty one recruitment deviates were estimated in the model, eighteen to initialize the starting population and twenty three for 1982 to 2004. There were 23 fishing mortality deviates in the model which were constrained 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).

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 (Table 4.11). Length composition data from the commercial fisheries and the groundfish trawl surveys are shown in Figures 4.3a and b and 4.4a and b. Aging of Gulf of Alaska flatfish species has been sporadic since the inception of the triennial surveys. Estimates of survey age compositions for rex sole are shown in Figures 4.5a and b. Survey mean length at age shows fish tended to be large in 1990 and smaller in 1984 (Figures 2a and b). 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 4.7). The age-at-50%-maturity was estimated at 5.6 years using the mean length estimated from the 1984 to 1996 survey data (Figure 4.6). Estimates of mean size at age for the maturity samples is similar to the mean size at age estimated from the survey data.

Data

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

Data component	Years
Fishery catch	1982 - 2004
NMFS bottom trawl survey biomass and S.E.	1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003
Fishery size compositions	1982 - 1984,1990 - 2003
NMFS trawl survey size compositions	1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003
NMFS trawl survey age compositions	1984, 1987, 1990, 1993, 1996

Tables 4.5 and 4.6 contain survey age and length data. The survey length data for 1984 through 1996 were included in the model, however, the sample size was reduced to 1, so that the model was fitting the survey age data in those years, not the length data. However, leaving the survey length data in the model allows fits to be examined. 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 (Figure 4.22). Most of the observed fishery hauls were at depths between about 125 m and 225 m. The observed fishery hauls were distributed between Kodiak Island and Unalaska Island during 2001, 2002 and 2003 (Figures 4.23 to 4.25).

Likelihood weights and other model structure

Weights used on the likelihood values were 1.0 for the fishery length, survey length and survey age data, and the survey biomass, simply 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 Conditionally

Recent recruitments

Recruitment deviates in 2002 to 2004 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.

Selectivity

Separate fishery selectivities were estimated for males and females using a two parameter ascending logistic function (Figure 4.8). Sex-specific survey selectivities were also modeled using a two parameter ascending logistic function.

Results

Selectivity estimates show that the fishery generally catches rex sole at older ages than the survey (Figure 4.8 and Table 4.15). Fits to the size composition data from the fishery are shown in Figure 4.3a for females and Figure 4.3b for males. The fit to the survey size composition data are in Figure 4.4a for females and Figure 4.4b for males. The survey age composition data are shown in Figures 4.5a and 4.5b. Likelihood values are in Table 4.15.

Model estimates of biomass

Model estimates of age 3+ biomass increased from 78,200 t in 1982 to about 102,000 t in 1991, decreased to 73,500 t in 1998, then increased to 82,000 t in 2004 (Table 4.12 and Fig. 4.9). The fit to the survey biomass estimates is shown in Figure 4.10. The model estimated a lower biomass than the survey in 2003.

Model estimates of recruitment

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 4.12 and Fig. 4.11). Recruitment in 2004 was estimated at slightly below average.

Spawner-Recruit Relationship

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

Reliable estimates of biomass, $B_{35\%}$, , $F_{35\%}$, and $F_{40\%}$, are available, and current biomass is greater than $B_{40\%}$. Therefore, rex sole is 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 $F_{40\%}$.

$F_{40\%}$ and $F_{35\%}$ were estimated at 5.38 and 10.09 due the selectivity of the fishery for much older fish than the when they mature. Yield for 2005 using $F_{40\%}$ = 5.38 was estimated at 30,145 t. Yield for 2005 using $F_{35\%}$ = 10.09 was estimated at 36,983 t. The fishing mortality values that produce a similar ABC to that estimated in 2004 were also estimated. Yield for 2005 using F = 0.6 was estimated at 12,374 t. The F = 0.6 was estimated so the yield was comparable to the yield estimated in the 2003 flatfish SAFE. The estimated F values were very high which resulted 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.

Maximum sustainable yield

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 46,742 t. $B_{35\%}$ (equilibrium female spawning biomass with fishing at $F_{35\%}$) is estimated at 16,360 t.

Projected catch and abundance

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 2004 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2005 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2004. 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 2005, 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 2005 recommended in the assessment to the *max* F_{ABC} for 2005. (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 1999-2003 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 2005 and above its MSY level in 2015 under this scenario, then the stock is not overfished.)

Scenario 7: In 2005 and 2006, 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 2017 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 1999 to 2003, F equal to one half $F_{40\%}$, and F=0 from 2005 to 2009 (Table 4.13). Under scenario 6 above, the year 2005 female spawning biomass is 35,393 t and the year 2015 spawning biomass is 16,766 t, above the $B_{35\%}$ level of 16,360 t. For scenario 7 above, the year 2017 spawning biomass is 16,806 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 will remain near 35,000 t, well above B40% (Figure 4.27).

Acceptable biological catch

Reference fishing mortality rates for rex sole were calculated using F_{ABC}= 0.75 M and F_{OFL} = M (tier 5), since maturity information was not available prior to 2004. The 2004 ABC for rex sole increased to 12,650 t from 9,466 t in 2003. The 2005 ABC using tier 5 definitions is the same as the 2004 ABC at 12,650 t, since no new survey data are available.

For comparison purposes, the F that results in a similar ABC to the 2004 ABC was estimated. ABC for 2005 using F = 0.6 was estimated at 12,374 t. The ABC by management area using F40%=5.38 and F =0.6 was estimated by calculating the fraction of the 2003 survey biomass in each area and applying that fraction to the ABC:

Rex sole ABC (t) by INPFC area

	Western	Central	West Yakutat	East Yakutat/SE	Total
ABC 2005 F40%=5.38	4,000	17,499	3,186	5,457	30,145
ABC 2005 F40%=0.75M (M=0.2)	1,679	7,344	1,337	2,290	12,650
ABC 2005 F=0.6	1,642	7,183	1,308	2,240	12,374

Overfishing definition

Yield at $F_{35\%}$ = 10.09 was estimated at 36,983 t.

Ecosystem Considerations

Food habits

Flatfish consume a variety of benthic organisms (Livingston and Goiney 1983, Yang 1993). Rex sole consume polychaetes, snow crabs, euphausiids and pandalids.

Summary

Table 4.14 shows a summary of model results.

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Tables

Table 4.1. Catch (t) of rex sole in the Gulf of Alaska 1978 to October 9, 2004. (Includes discards 1992-2004).

Year	Catch (t)
1982	959
1983	595
1984	365
1985	154
1986	93
1987	1151
1988	1192
1989	599
1990	1269
1991	4636
1992	3000
1993	3000
1994	3673
1995	4021
1996	5874
1997	3294
1998	2669
1999	3060
2000	3591
2001	2940
2002	2941
2003	3330
2004	1441

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	727	2,601	2	3,330	38
2004	499	942	0	1,441	11

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

Year	Rex sole
1977	1.97
1978	8.47
1979	12.60
1980	4.64
1981	17.2
1982	7.73
1983	7.21
1984	18.27
1985	14.05
1986	3.74
1987	21.12
1988	0.08
1989	1.77
1990	12.0
1991	0.01
1992	0.04
1993	12.7
1994	0.03
1995	0.00
1996	7.04
1997	0.00
1998	4.09

Table 4.4. Percent (by weight) of catch that is retained for the Gulf of Alaska flatfish fisheries.

Year	rex sole
1994	89%
1995	90%
1996	95%
1997	92%
1998	97%
1999	96%
2000	97%
2001	95%
2002	95%

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

Year	Sex	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1984	female	0.00	2.68	3.57	4.24	4.09	4.13	4.18	2.86	3.18	3.62	4.08	1.78	5.83	4.91	1.99	1.53	0.96	1.14
1984	male	0.00	7.77	9.57	3.75	2.36	6.48	1.21	2.09	1.30	1.15	0.66	3.10	0.00	2.32	1.31	1.72	0.00	0.44
1987	female	0.00	3.47	1.32	3.54	4.94	7.20	4.06	6.49	6.66	1.69	3.12	1.44	1.60	1.46	0.38	0.25	0.67	0.65
1987	male	1.00	3.91	8.46	4.82	7.96	5.47	1.82	5.26	1.97	8.05	0.72	0.33	0.80	0.49	0.00	0.00	0.00	0.00
1990	female	3.65	4.09	16.58	11.78	9.31	4.90	0.49	0.08	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	male	4.77	9.40	20.85	10.45	3.30	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	female	0.42	0.67	9.90	7.66	10.13	7.74	4.50	4.57	2.41	1.12	0.86	0.11	0.47	0.04	0.00	0.00	0.00	0.03
1993	male	1.12	2.32	11.59	11.39	7.46	3.13	5.18	3.16	2.76	0.33	0.03	0.61	0.20	0.00	0.00	0.00	0.00	0.09
1996	female	1.02	2.46	3.41	4.61	4.05	2.33	5.26	6.05	5.05	4.30	2.46	2.88	1.65	0.42	1.26	0.40	0.70	0.70
1996	male	2.52	3.67	9.04	7.55	6.02	3.80	6.26	3.65	3.77	2.25	1.62	0.17	0.51	0.00	0.00	0.00	0.00	0.16

Table 4.6. Length data from trawl surveys from 1984 through 2003. The numbers are percentages where the female plus the male numbers add to 100 within a year.

		9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47
1984	female	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.13	0.85	1.55	2.77	4.34	6.22	9.31	9.28	7.54	5.60	3.75	2.39	1.23
1984	male	0.00	0.00	0.00	0.00	0.01	0.12	0.12	0.36	1.43	3.22	4.50	7.89	10.38	7.56	4.32	2.54	1.36	0.45	0.21	0.02
1987	female	0.00	0.00	0.04	0.00	0.01	0.15	0.23	0.56	0.86	1.40	2.47	3.24	6.40	7.48	5.92	5.10	4.72	3.79	2.34	1.41
1987	male	0.00	0.00	0.00	0.03	0.04	0.64	1.03	1.91	2.61	2.73	4.57	6.53	9.35	8.24	6.58	4.87	2.43	0.93	0.22	0.03
1990	female	0.00	0.00	0.00	0.02	0.13	0.26	0.56	0.87	0.76	1.26	1.85	3.08	3.74	4.79	5.17	7.09	7.22	6.25	4.08	1.68
1990	male	0.00	0.00	0.01	0.04	0.15	0.38	0.82	0.83	1.37	1.92	3.68	6.08	7.40	8.31	8.14	4.90	2.92	1.44	0.47	0.04
1993	female	0.00	0.01	0.01	0.04	0.14	0.23	0.30	0.25	0.41	0.71	1.58	2.40	4.19	5.59	6.52	6.34	6.34	5.31	4.46	3.06
1993	male	0.01	0.00	0.01	0.10	0.16	0.52	0.49	0.67	0.99	2.02	3.30	5.49	8.09	9.13	7.81	5.67	3.10	1.38	0.35	0.11
1996	female	0.00	0.02	0.11	0.16	0.38	0.69	0.63	0.81	1.30	1.75	2.17	2.83	3.49	4.12	4.29	4.13	4.76	4.78	4.67	3.45
1996	male	0.02	0.02	0.08	0.37	0.48	0.86	0.86	1.38	2.48	3.86	5.09	6.91	7.65	6.94	5.36	3.93	2.50	1.17	0.64	0.34
1999	female	0.01	0.02	0.07	0.24	0.46	0.94	1.07	1.40	1.73	2.82	3.46	3.34	3.97	3.94	4.18	3.52	3.60	3.38	2.95	2.02
1999	male	0.02	0.06	0.09	0.26	0.78	1.70	2.02	1.90	3.01	4.21	4.61	6.50	7.08	6.26	5.39	3.81	2.74	1.77	0.87	0.23
2001	female	0.02	0.05	0.12	0.25	0.75	1.51	1.76	1.73	2.72	3.09	3.30	4.49	5.20	3.90	3.48	4.00	3.68	3.33	3.21	2.46
2001	male	0.00	0.04	0.07	0.44	1.22	1.37	2.06	2.45	2.85	4.34	4.41	4.67	4.15	3.54	4.20	4.05	3.86	2.20	0.72	0.14
2003	female	0.02	0.10	0.27	0.34	0.56	1.21	1.55	1.84	2.66	3.57	4.21	4.77	5.09	5.42	4.63	3.61	2.70	2.12	1.53	0.91
2003	male	0.01	0.12	0.26	0.48	0.71	1.38	2.24	2.96	3.53	4.91	5.82	7.49	7.00	5.59	3.60	2.30	1.63	0.90	0.23	0.10

Table 4.6 continued. Length data from trawl surveys from 1984 through 2003. The numbers are percentages where the female plus the male numbers add to 100 within a year.

		49	51	53	55	57	59	61	63	65
1984	Female	0.31	0.07	0.02	0.01	0.00	0.00	0.00	0.00	0.00
1984	Male	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
1987	Female	0.62	0.32	0.18	0.02	0.00	0.00	0.00	0.00	0.00
1987	Male	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	Female	1.22	0.77	0.15	0.08	0.02	0.00	0.00	0.00	0.00
1990	Male	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	Female	1.58	0.61	0.30	0.12	0.07	0.01	0.00	0.00	0.00
1993	Male	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.01
1996	Female	2.14	1.21	0.50	0.32	0.14	0.06	0.00	0.00	0.00
1996	Male	0.12	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1999	Female	1.42	0.89	0.57	0.41	0.11	0.03	0.03	0.00	0.00
1999	Male	0.09	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00
2001	Female	1.65	0.91	0.60	0.48	0.24	0.11	0.07	0.01	0.00
2001	Male	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	female	0.59	0.37	0.24	0.17	0.11	0.06	0.01	0.00	0.00
2003	male	0.03	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00

Table 4.7. Domestic fishery length sample sizes by year.

Year	Hauls sampled	Lengths measured
1990	74	7438
1991	257	18652
1992	220	19586
1993	372	25972
1994	328	19756
1995	257	11868
1996	277	18548
1997	194	10391
1998	213	10509
1999	393	8294
2000	347	6526
2001	194	3484
2002	320	5595
2003	352	6357

Table 4.8. Biomass estimates and standard errors from the trawl survey from 1984 to 2003.

Survey	Max Depth (m)	Biomass (t)	Std. Error
NMFS trawl 1984	1000	60480	6023
NMFS trawl 1987	1000	63800	5906
NMFS trawl 1990	500	98225	10731
NMFS trawl 1993	500	86911	6211
NMFS trawl 1996	500	72757	5301
NMFS trawl 1999	1000	74980	8656
NMFS trawl 2001	500	71326	6129
NMFS trawl 2003	700	99897	7559

Table 4.9. Survey biomass estimates (t) for Gulf of Alaska rex sole for 1993 to 2003 by North Pacific Fishery Management Council regulatory area and species.

	Area			
Year	Western	Central	Eastern	Total
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 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. 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 4.12. Estimated age 3+ population biomass(t), female spawning biomass(t) and age 3 recruits(1,000's).

Year	age 3+ biomass	Female spawning biomass	Age 3 recruits (1,000's)
1982	78,244	35,909	44,615
1983	77,776	35,831	37,947
1984	76,667	35,782	24,816
1985	76,368	35,791	45,881
1986	77,090	35,645	50,672
1987	79,691	35,499	67,419
1988	84,937	35,294	102,345
1989	91,036	36,176	73,375
1990	97,753	38,937	69,649
1991	102,135	42,263	52,951
1992	100,179	43,605	25,669
1993	97,751	44,965	32,987
1994	94,125	44,845	35,491
1995	88,387	42,965	20,997
1996	81,895	40,200	26,318
1997	76,100	36,283	56,694
1998	73,470	33,640	42,809
1999	74,053	32,001	70,792
2000	74,831	31,218	48,794
2001	76,457	31,138	64,123
2002	78,831	32,088	55,901
2003	80,932	33,305	52,610
2004	81,731	34,422	43,360

Table 4.13. Projected female spawning biomass and yield from 2005 to 2009.

Year	Female spawning biomass(t)	Yield(t)
F=F40%		
2005	35,593	30,145
2006	22,776	11,408
2007	20,636	9,143
2008	19,505	8,284
2009	18,761	7,620
F=F35%		
2005	35,593	36,983
2006	19,996	11,864
2007	17,891	9,357
2008	16,818	8,374
2009	16,191	7,643
Average 5 yr. F=0.15		
2005	35,593	2,561
2006	37,005	2,664
2007	37,124	2,804
2008	37,017	2,936
2009	36,815	3,034
F=0.6		
2005	35,593	12,375
2006	30,714	9,768
2007	27,821	8,287
2008	26,058	7,617
2009	24,814	7,025
F=0		
2005	35,593	0
2006	37,560	0
2007	39,117	0
2008	40,347	0
2009	41,377	0

Table 4.14. Summary of results of rex sole assessment in the Gulf of Alaska.

Natural Mortality	0.17 females and males
Age of full(95%) fishery selection	13 females, 15 males
Reference fishing mortalities	
F40%	5.38
F35%	10.09
Biomass at MSY	N/A
Equilibrium unfished Spawning biomass (B0)	46,742 t
B35% Spawning biomass fishing at F35%	16,360 t
B40% Spawning biomass fishing at F40%	18,697 t
Projected 2005 biomass	
Total(age 3+)	82,298 t
Spawning	35,397 t
2005 Yield at F=0.6	12,374 t
2005 yield at F40%	30,145 t
Overfishing level for 2005 (F35%)	36,983 t

Table 4.15. Parameter estimates and likelihood values.

Description		Value
fishery selectivity		
females	slope	1.16
	age at 50%	11.03
males	slope	0.69
	age at 50%	11.67
survey selectivity		
females	slope	3.67
	age at 50%	5.56
males	slope	3.24
	age at 50%	4.23
Survey Q (fixed)		1
Likelihoods		
recruitment		20
survey biomass		12
survey length		338
survey age		299
fishery length		570
total		1,239

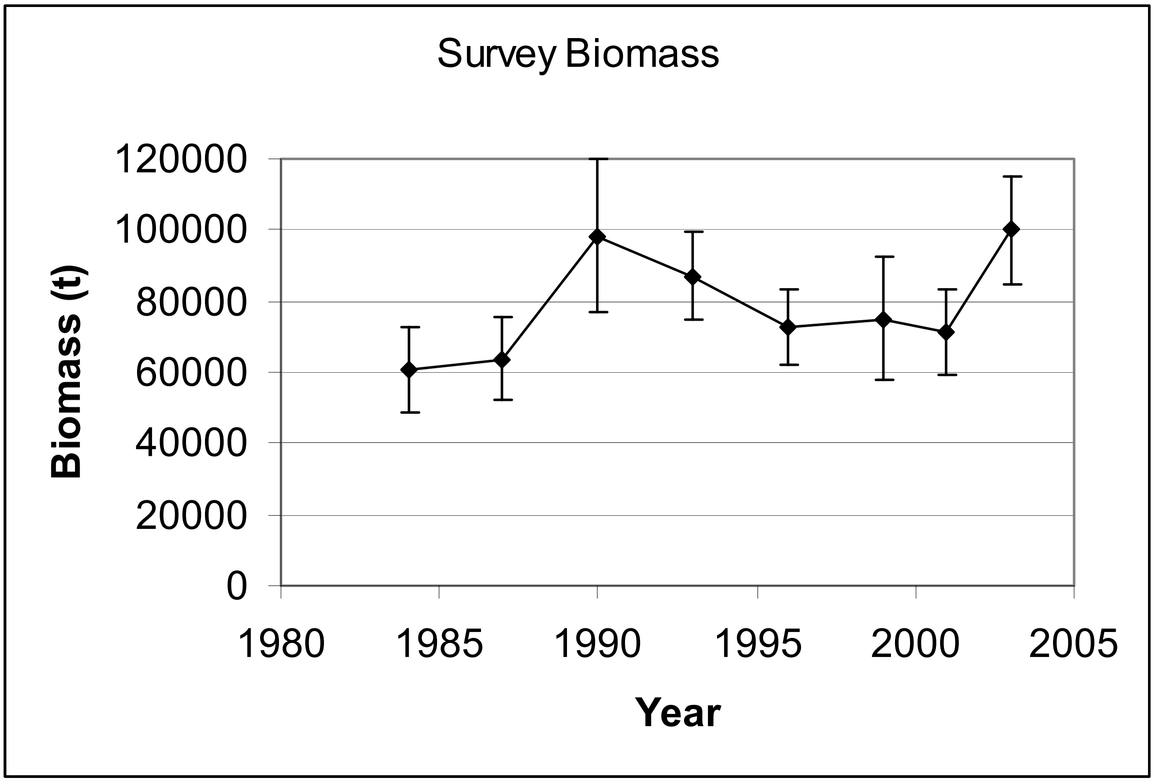


Figure 4.1. NMFS survey biomass estimates and 95% confidence intervals using 2*standard error for rex sole from 1984 to 2003.

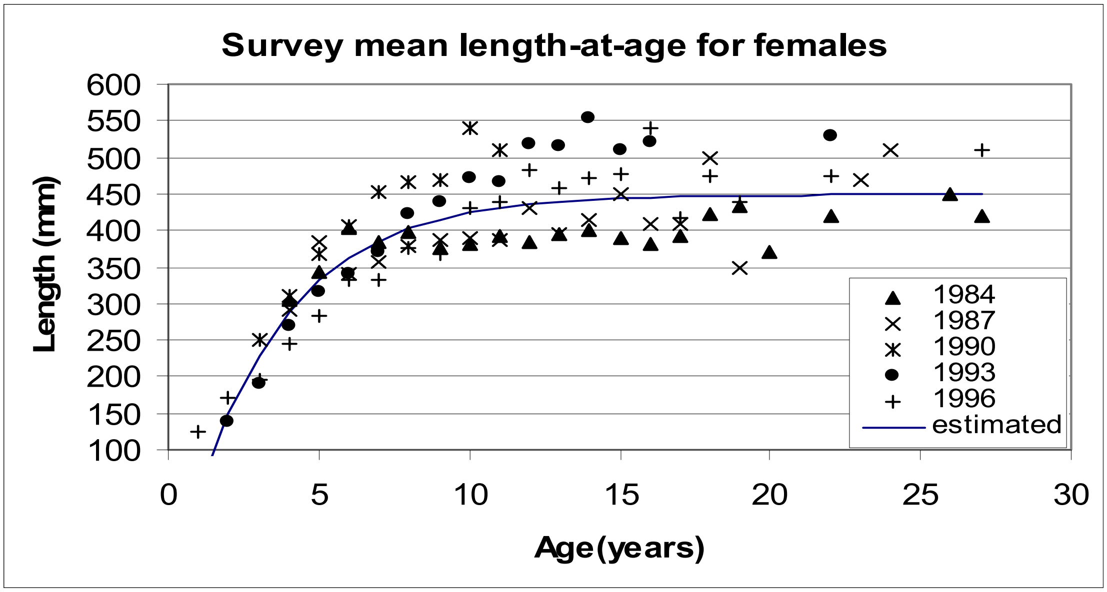


Figure 4.2a. Mean length at age for female rex sole from survey data 1984 through 1996. Estimated mean length at age was used to estimate the age-length transition matrix.

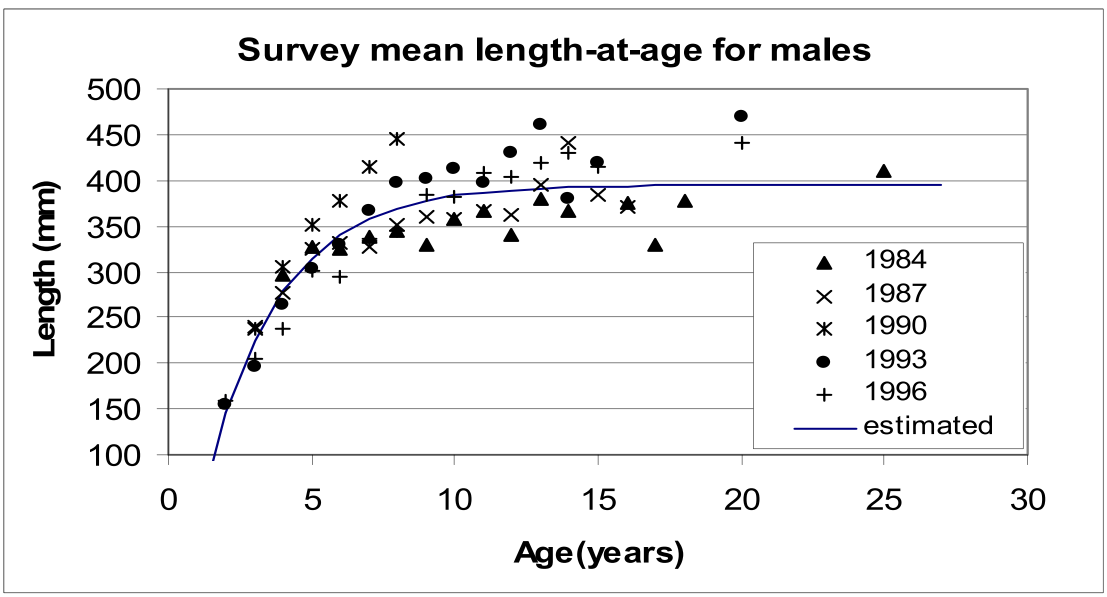


Figure 4.2b. Mean length at age for male rex sole from survey data 1984 through 1996. Estimated mean length at age was used to estimate the age-length transition matrix.

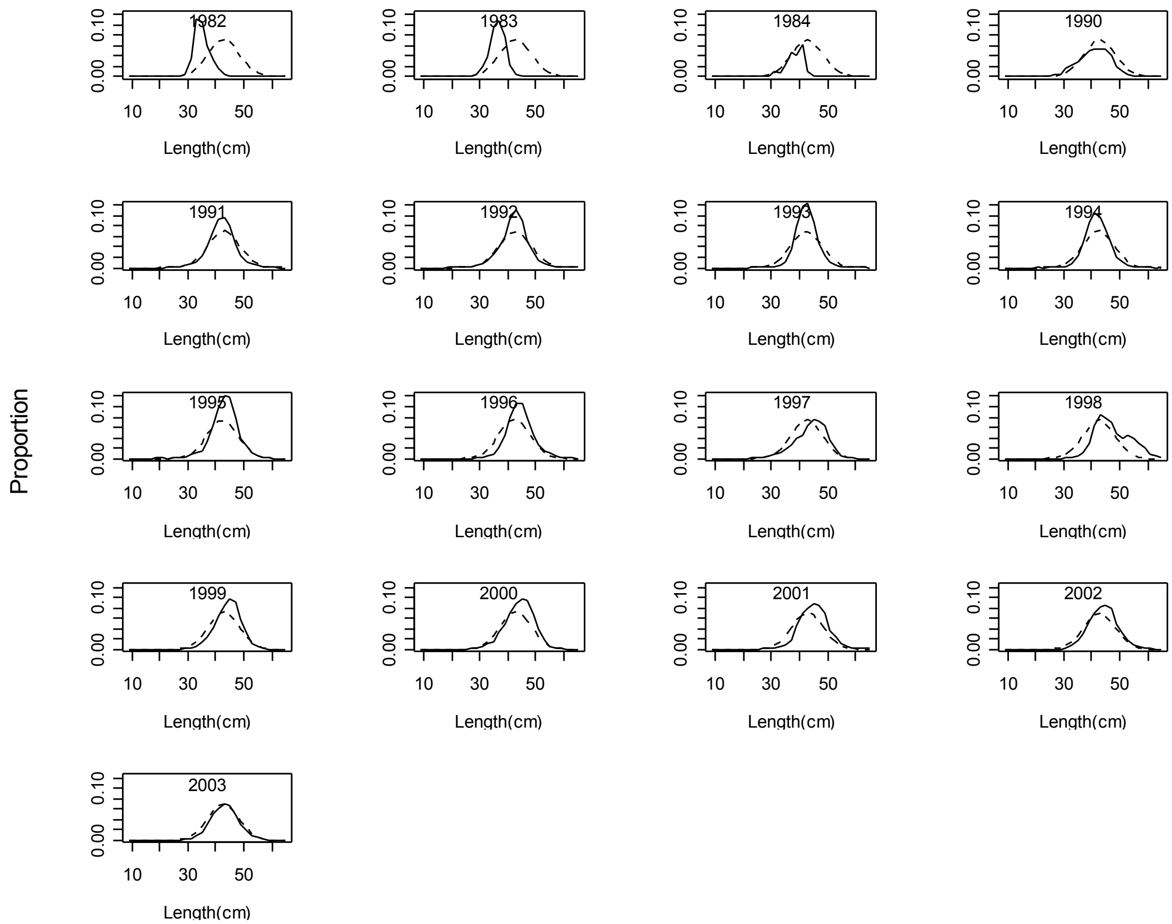


Figure 4.3a Fit to the female fishery length composition data. The dotted line is predicted.

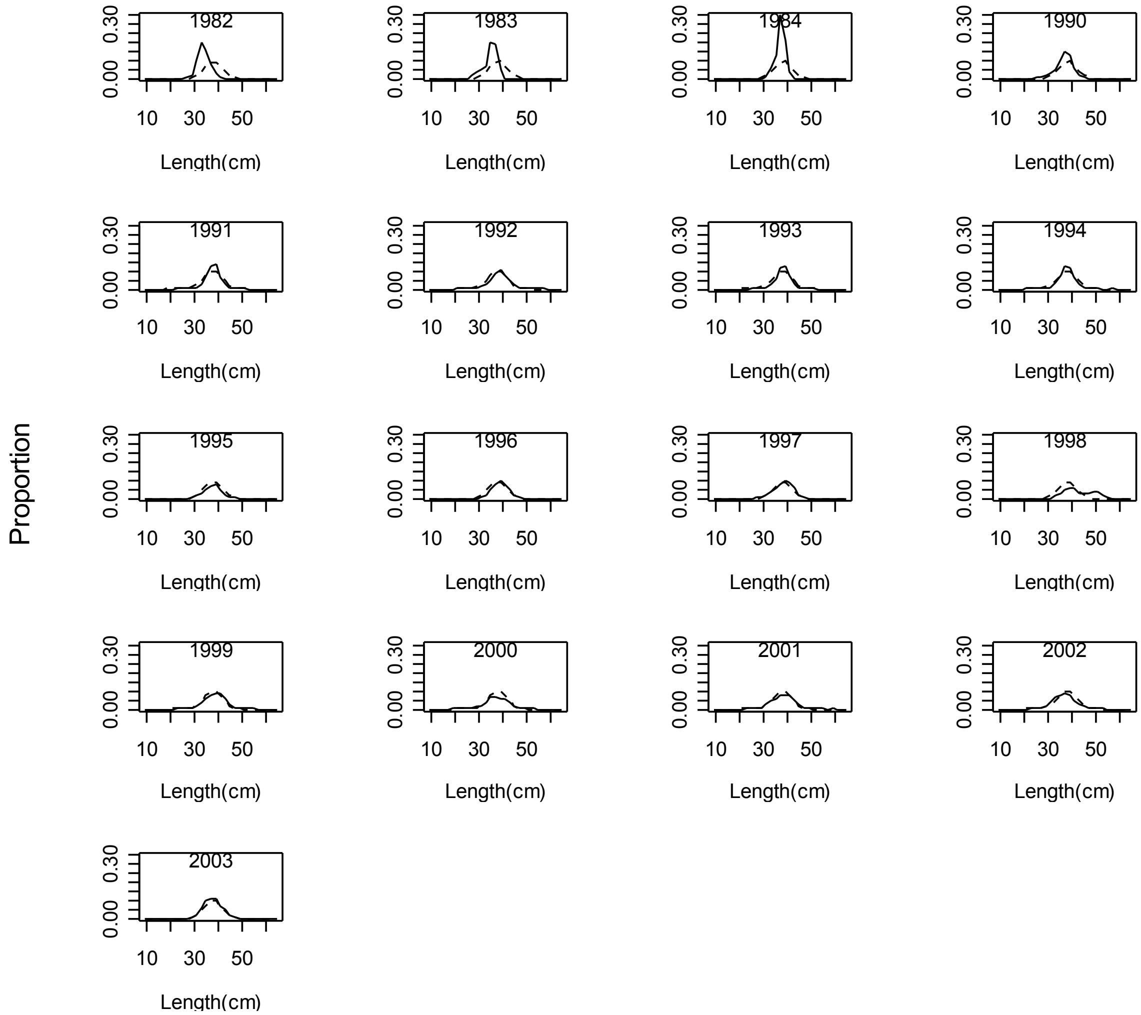


Figure 4.3b Fit to the male fishery length composition data. The dotted line is predicted.

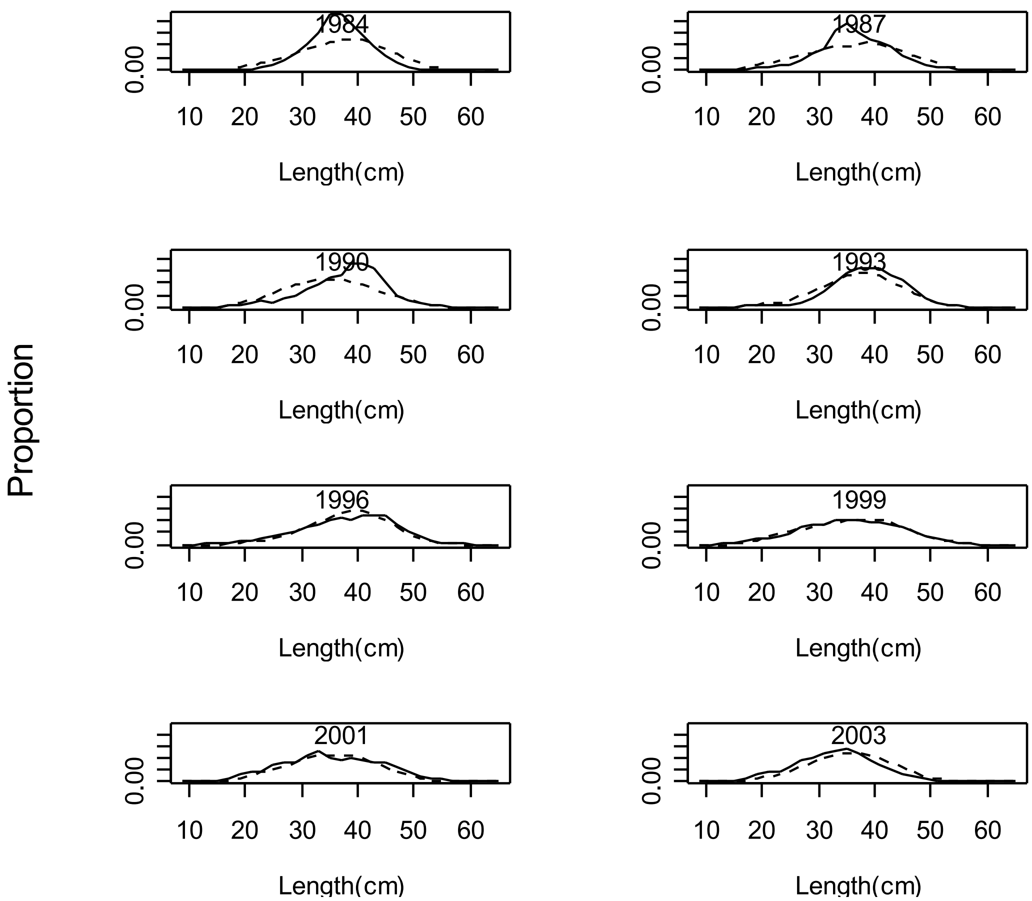


Figure 4.4a Fit to the female survey length composition data. The dotted line is predicted.

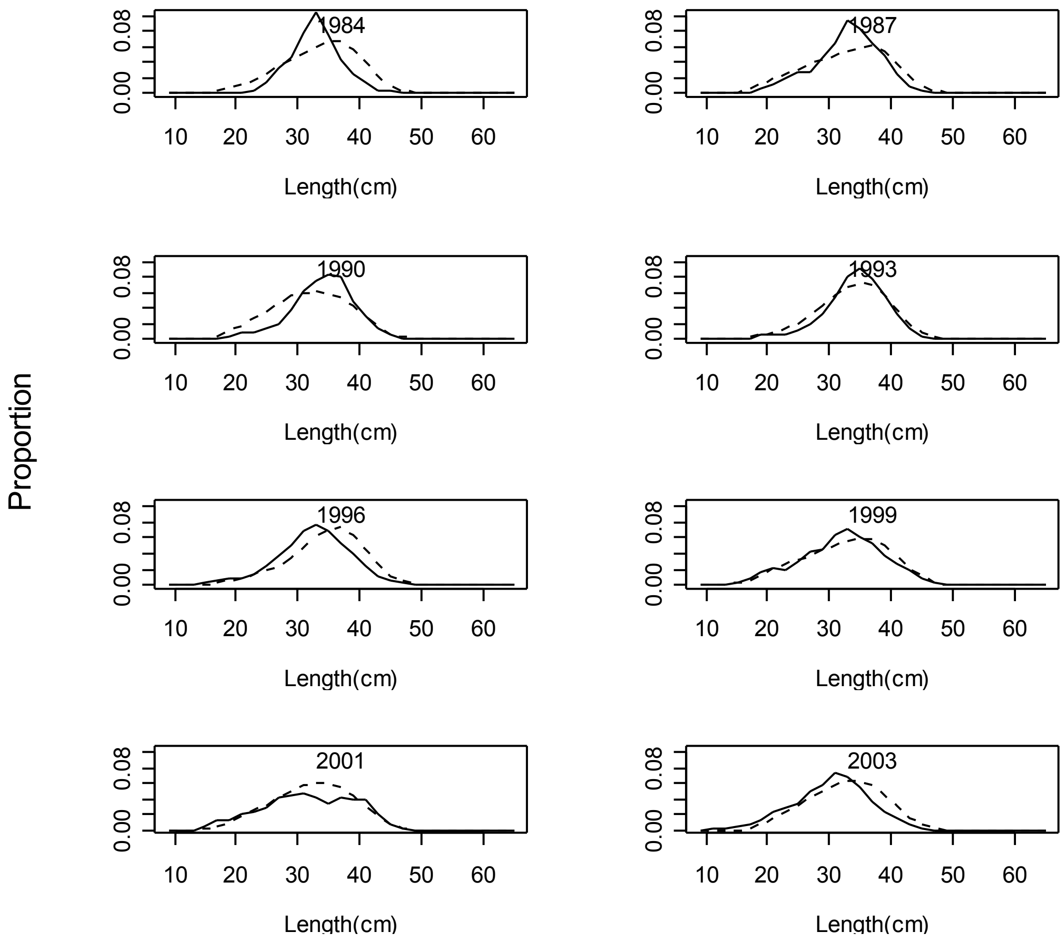


Figure 4.4b Fit to the male survey length composition data. The dotted line is predicted.

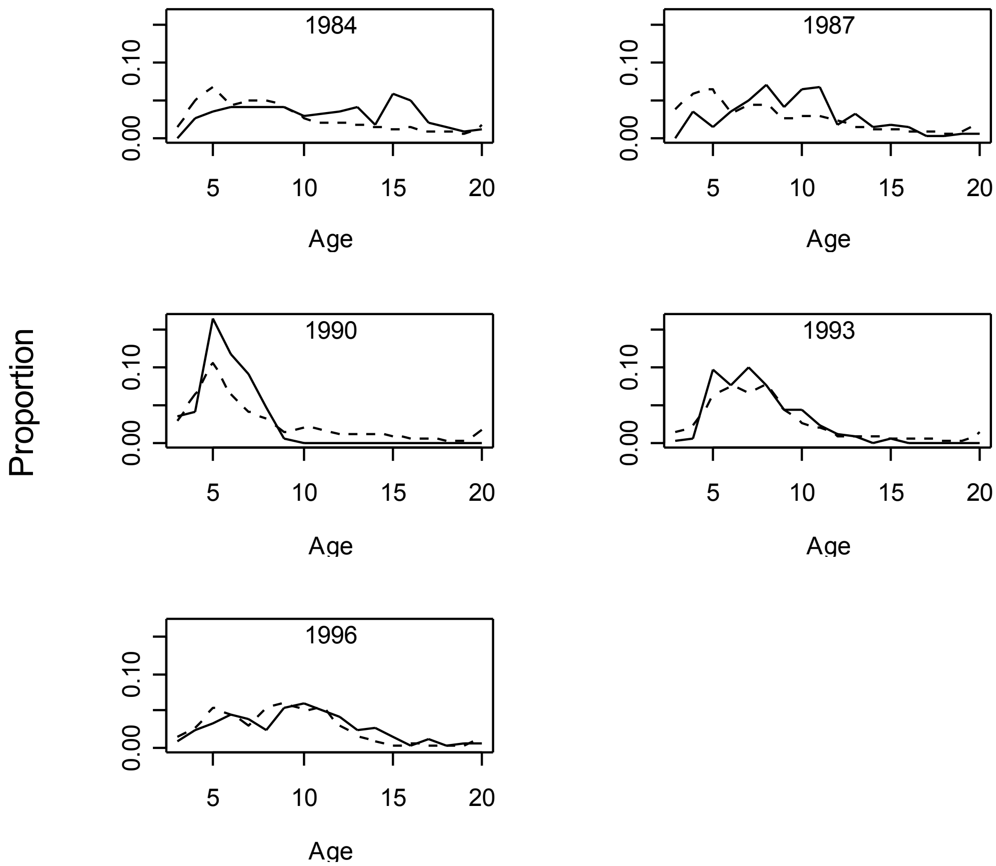


Figure 4.5a Fit to the female survey age composition data. The dotted line is predicted.

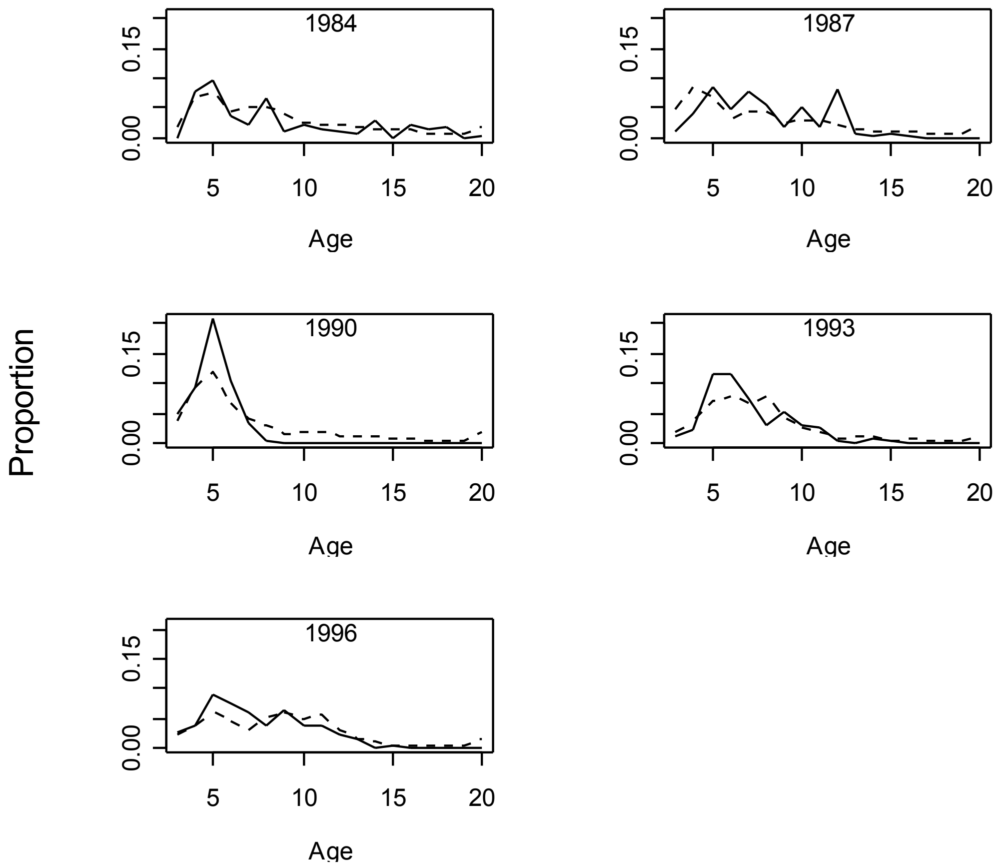


Figure 4.5b Fit to the male survey age composition data. The dotted line is predicted.

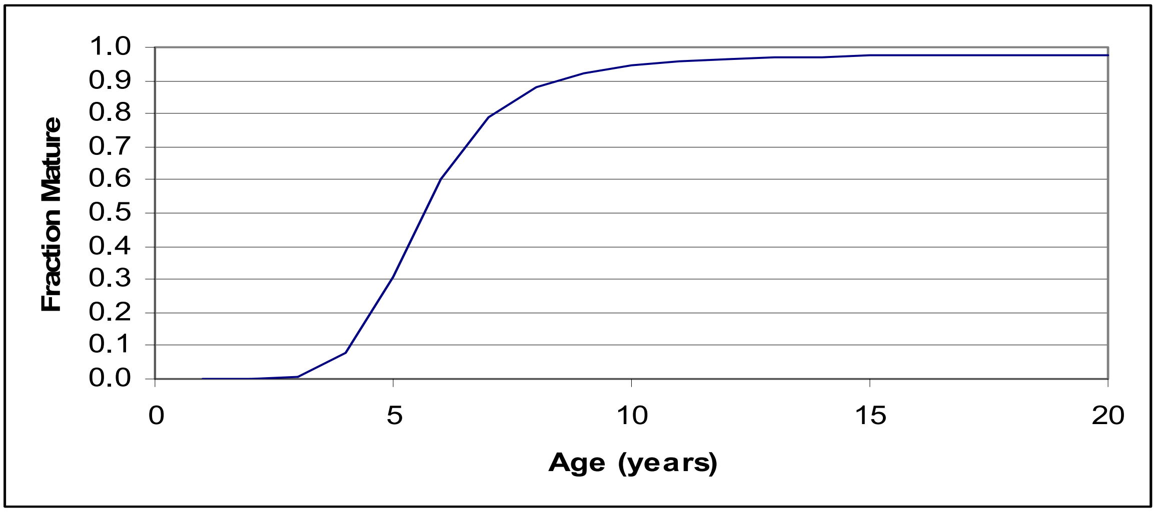
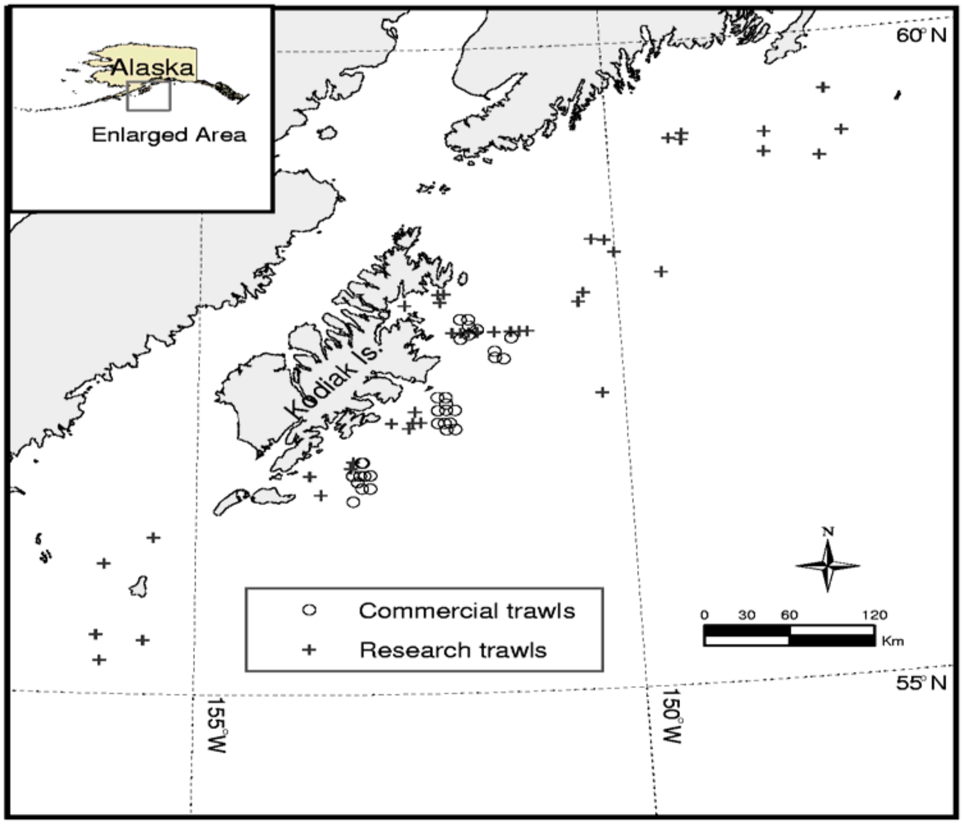


Figure 4.6. Female Rex sole fraction maturity by age.



Abookire, Figure 1

Figure 4.7. Locations of fishery trawls and research trawls sampled to estimate rex sole maturity (from A. Abookire, in press).

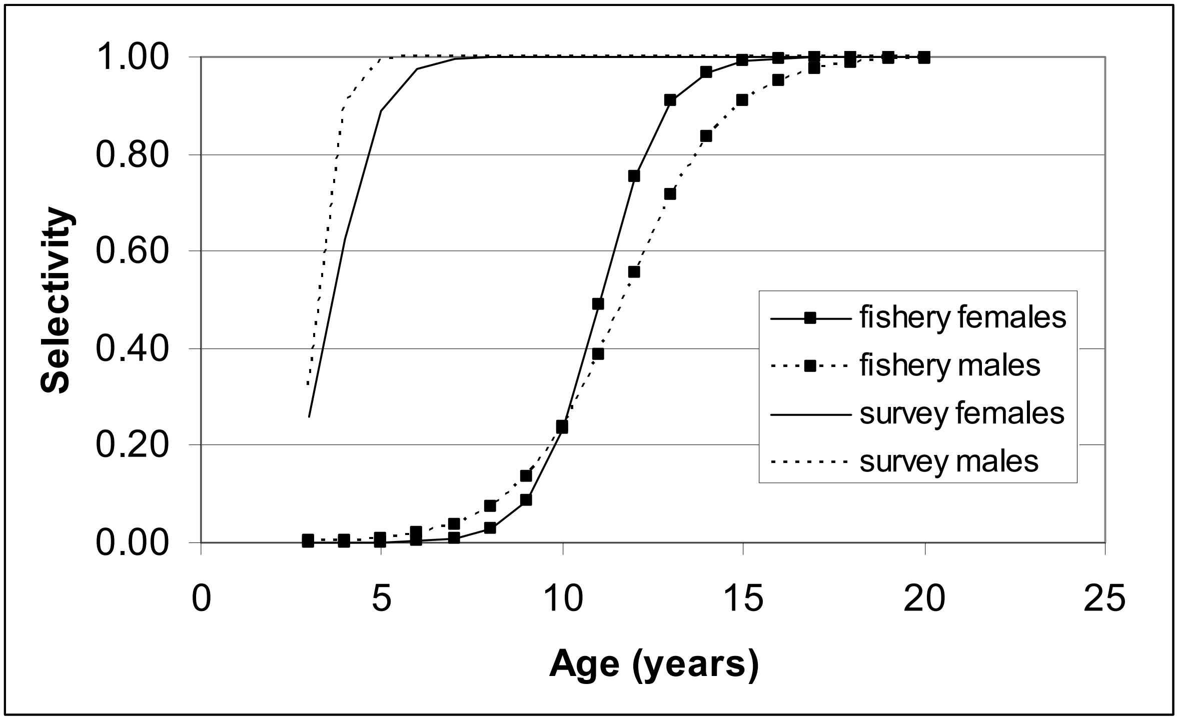


Figure 4.8. Selectivity curves, fishery and survey, females and males.

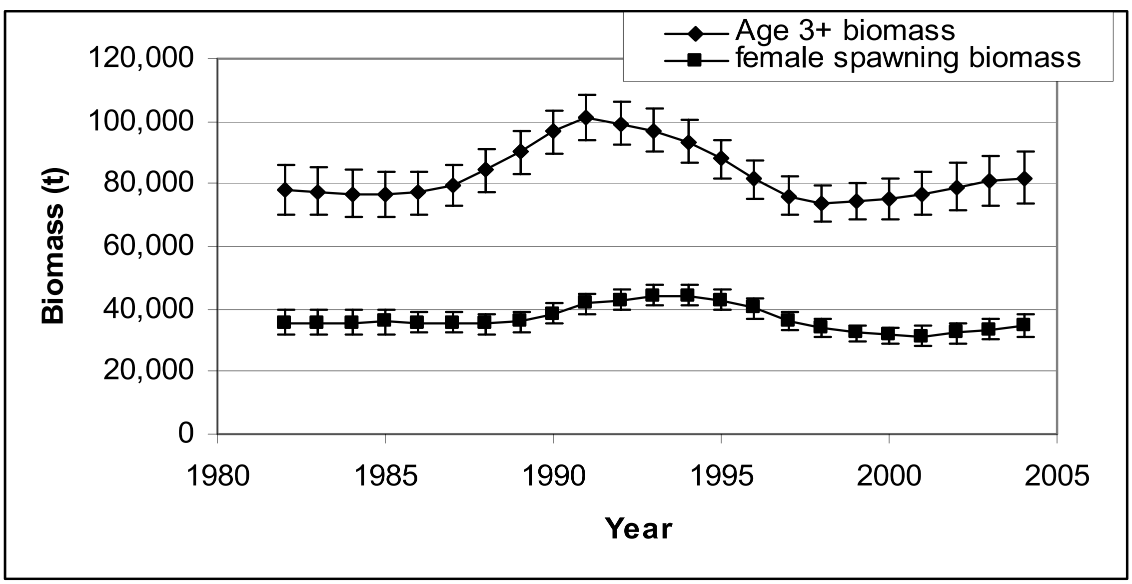


Figure 4.9. Age 3+ biomass and female spawning biomass from 1982 to 2004. The 95% confidence intervals shown underestimate the uncertainty because variance in natural mortality and survey Q as well as other fixed parameters are not accounted for.

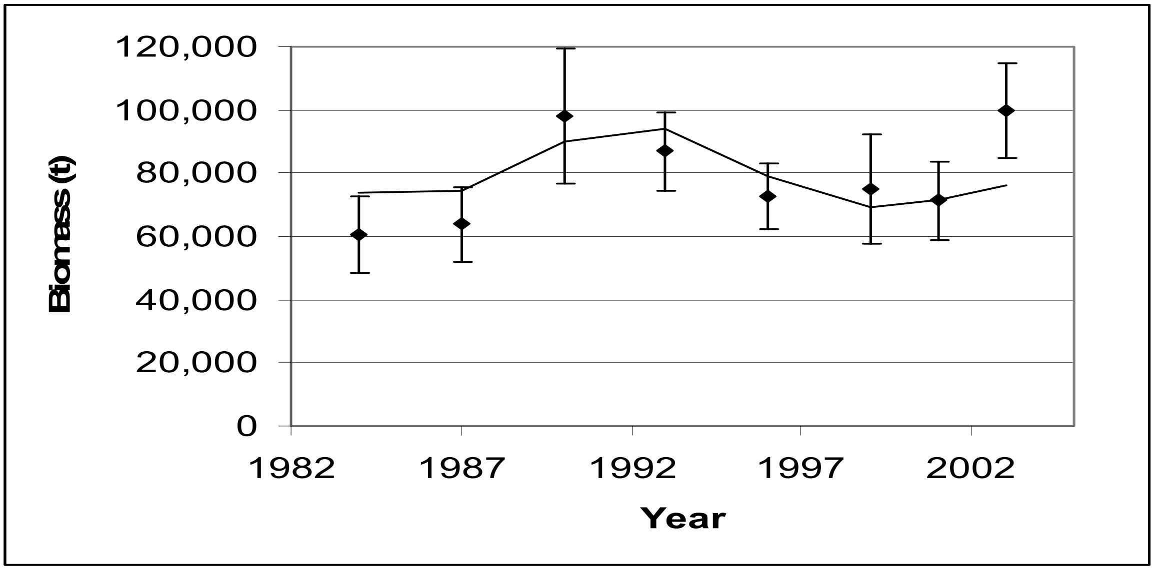


Figure 4.10. Fit to survey biomass estimates with 95% log-normal confidence intervals for the observed survey biomass estimates 1984 to 2003.

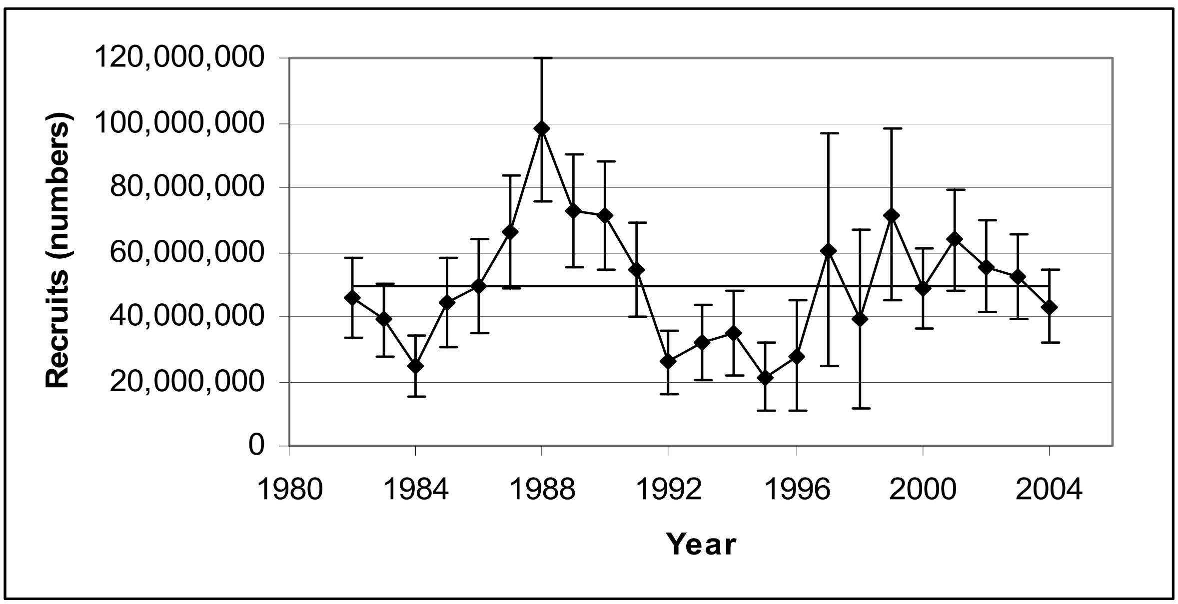


Figure 4.11. Age 3 estimated recruitments (male plus female) in numbers from 1982 to 2004, with 95% confidence intervals. Horizontal line is average recruitment.

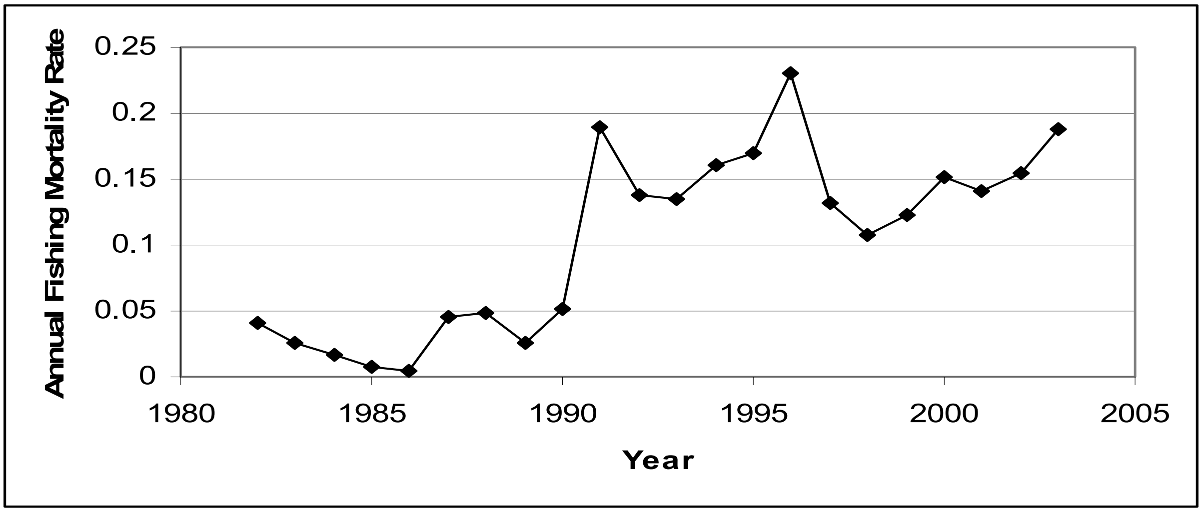


Figure 4.12. Fishing mortality rate from 1982 to 2003.

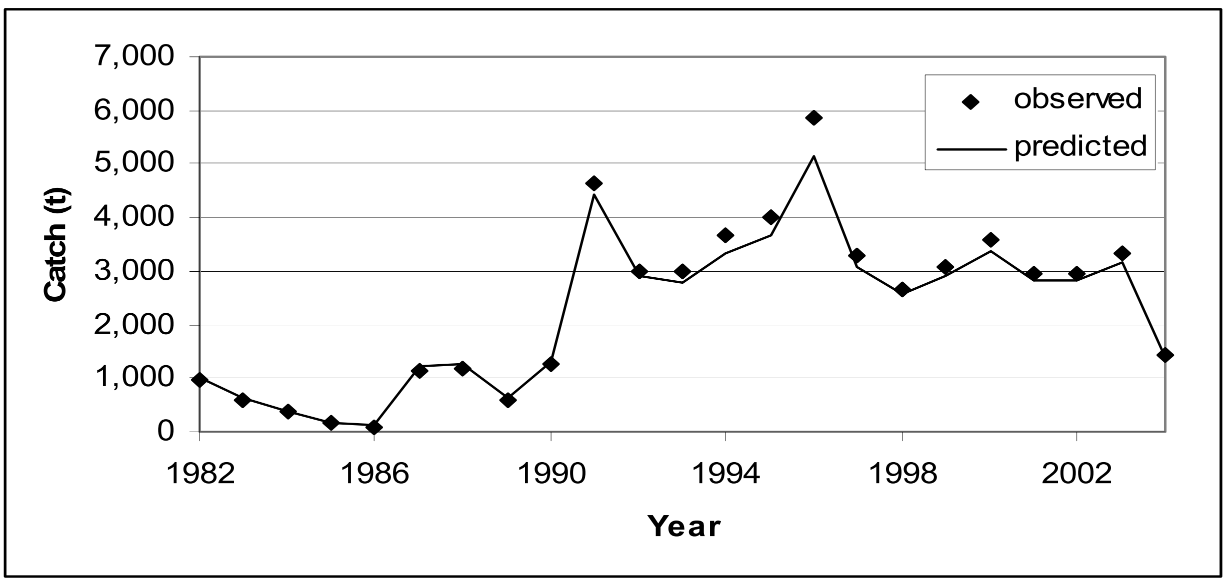


Figure 4.13. Observed and predicted catches from 1982 to 2004.

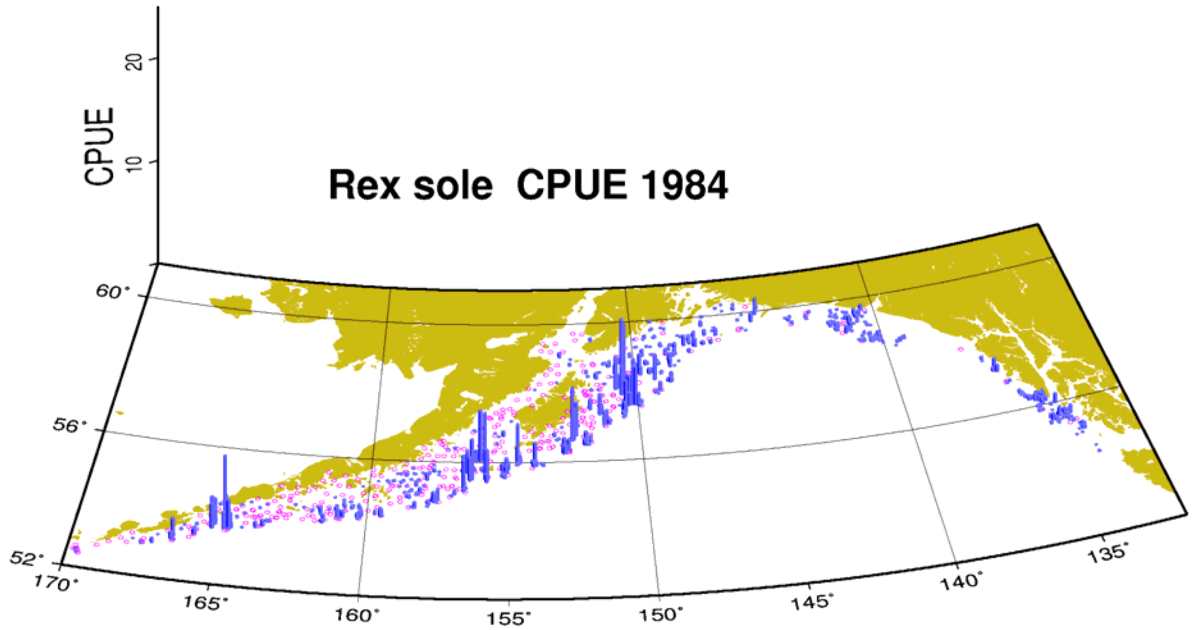


Figure 4.14. Rex sole 1984 survey cpue by tow. Circles are tow locations with no rex sole catch.

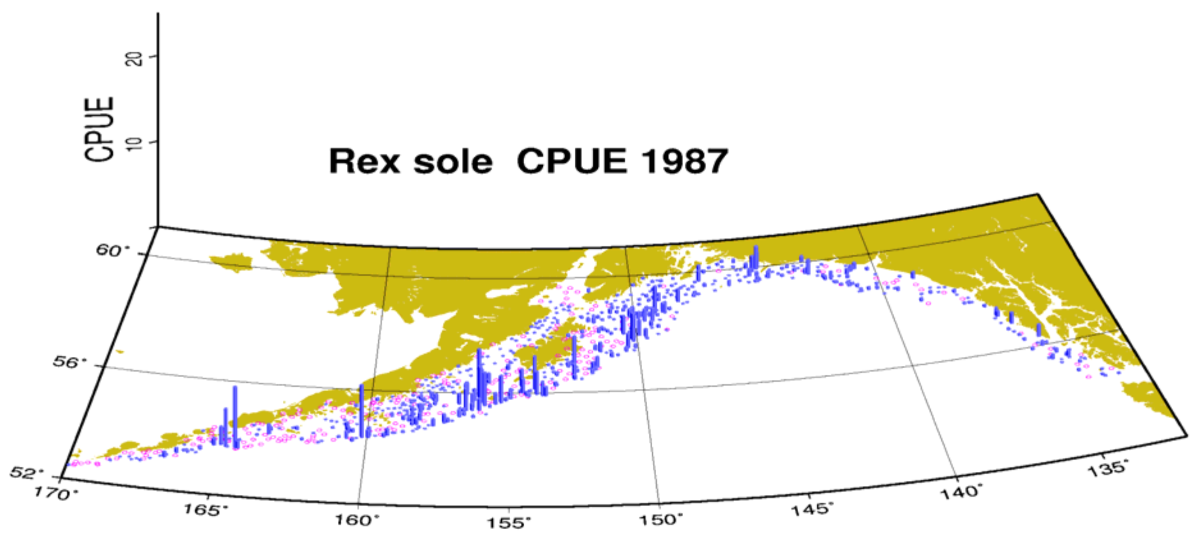


Figure 4.15. Rex sole 1987 survey cpue by tow. Circles are tow locations with no rex sole catch.

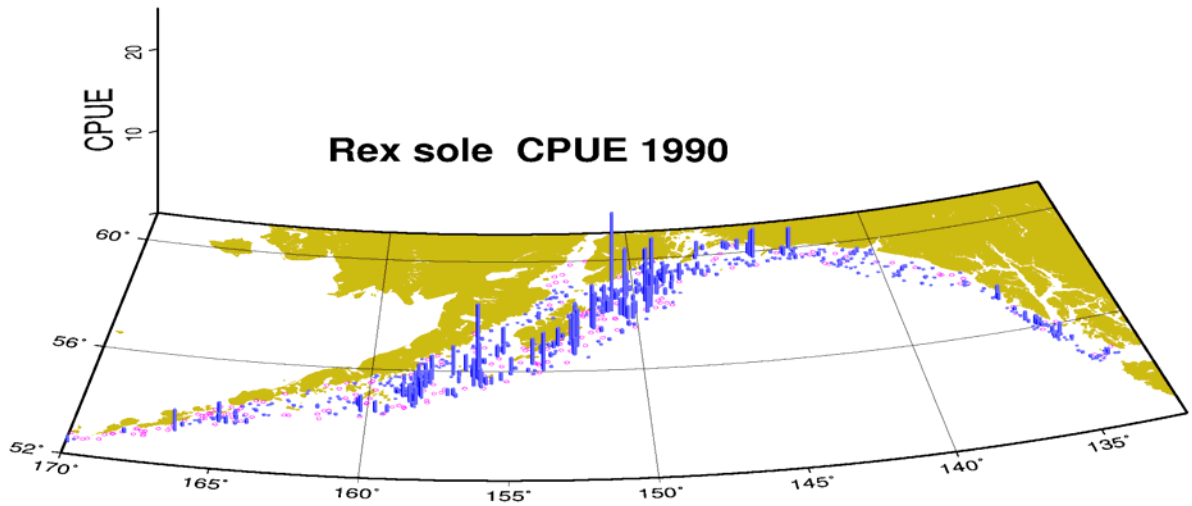


Figure 4.16. Rex sole 1990 survey cpue by tow. Circles are tow locations with no rex sole catch.

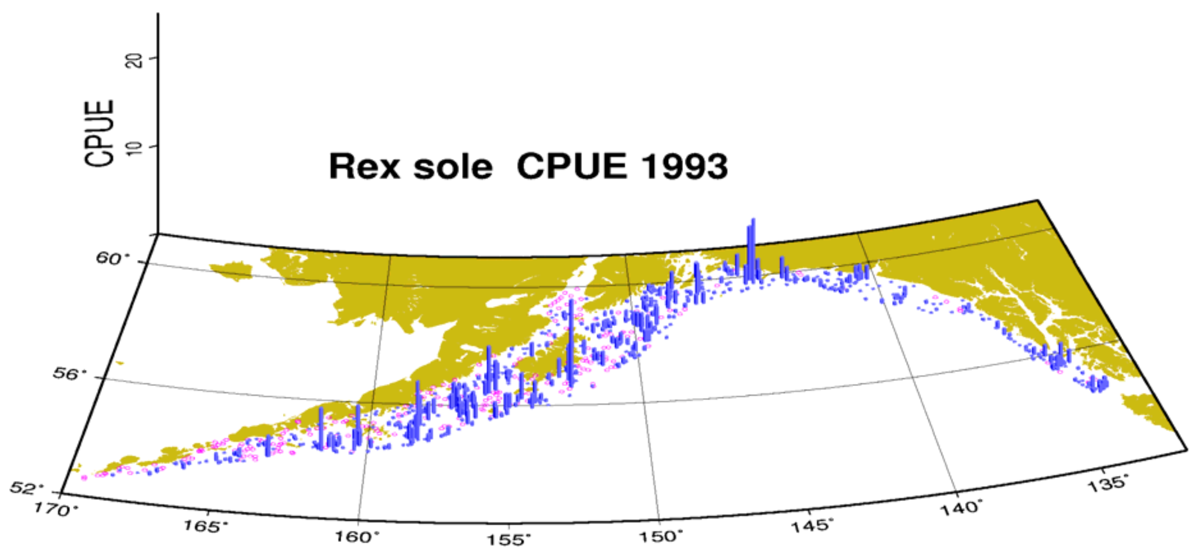


Figure 4.17. Rex sole 1993 survey cpue by tow. Circles are tow locations with no rex sole catch.

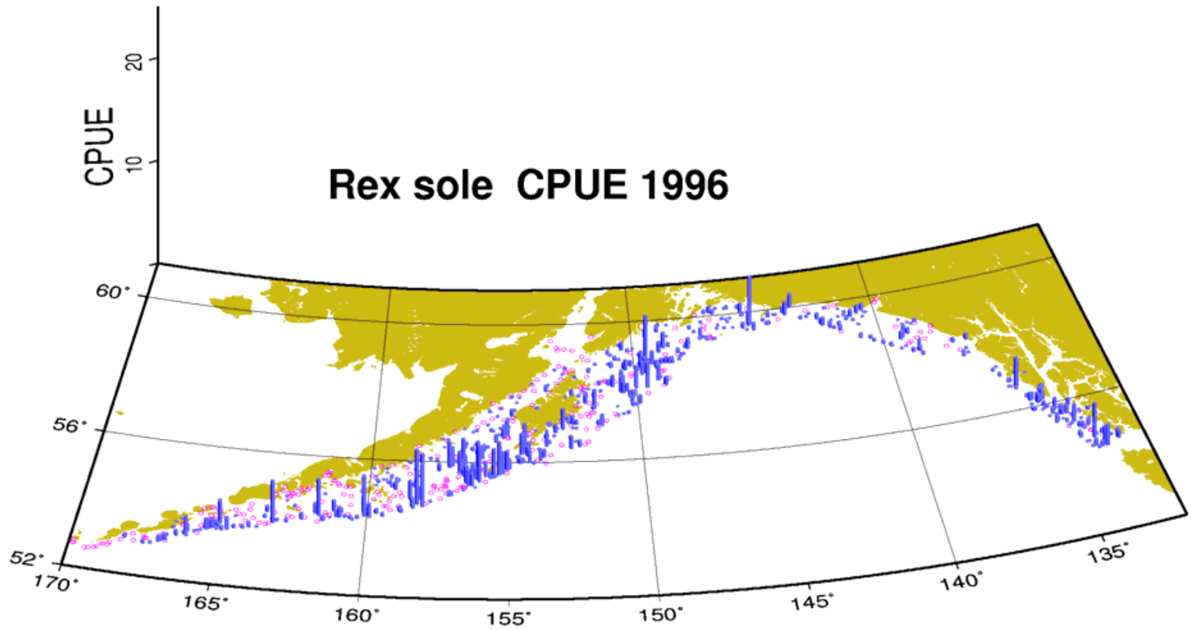


Figure 4.18. Rex sole 1996 survey cpue by tow. Circles are tow locations with no rex sole catch.

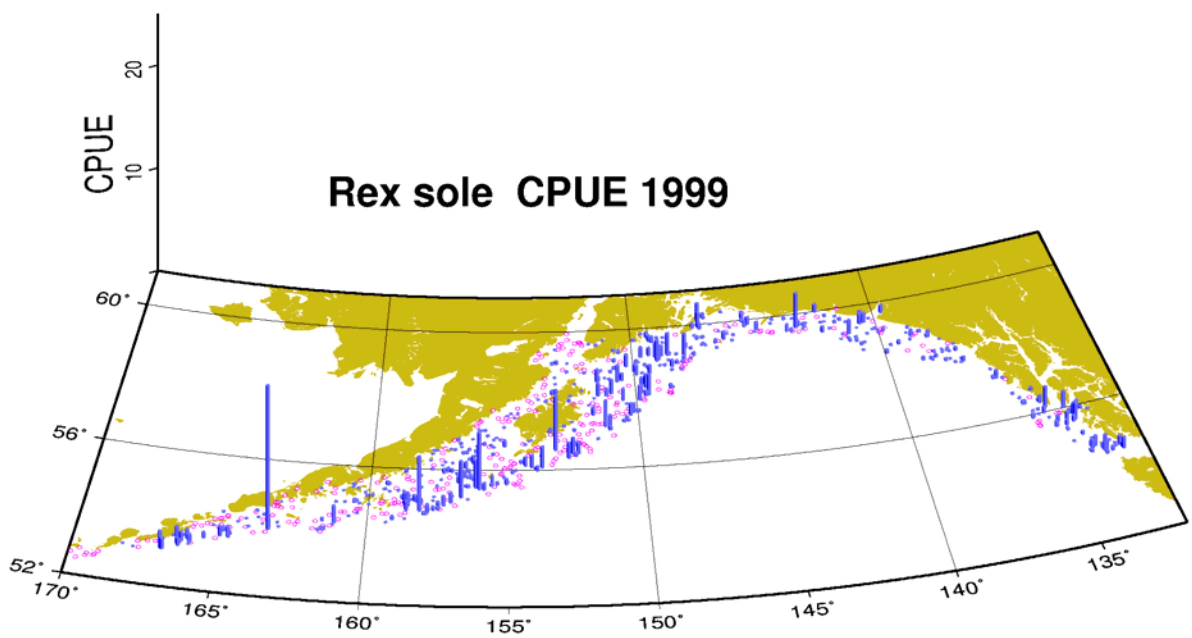


Figure 4.19. Rex sole 1999 survey cpue by tow. Circles are tow locations with no rex sole catch.

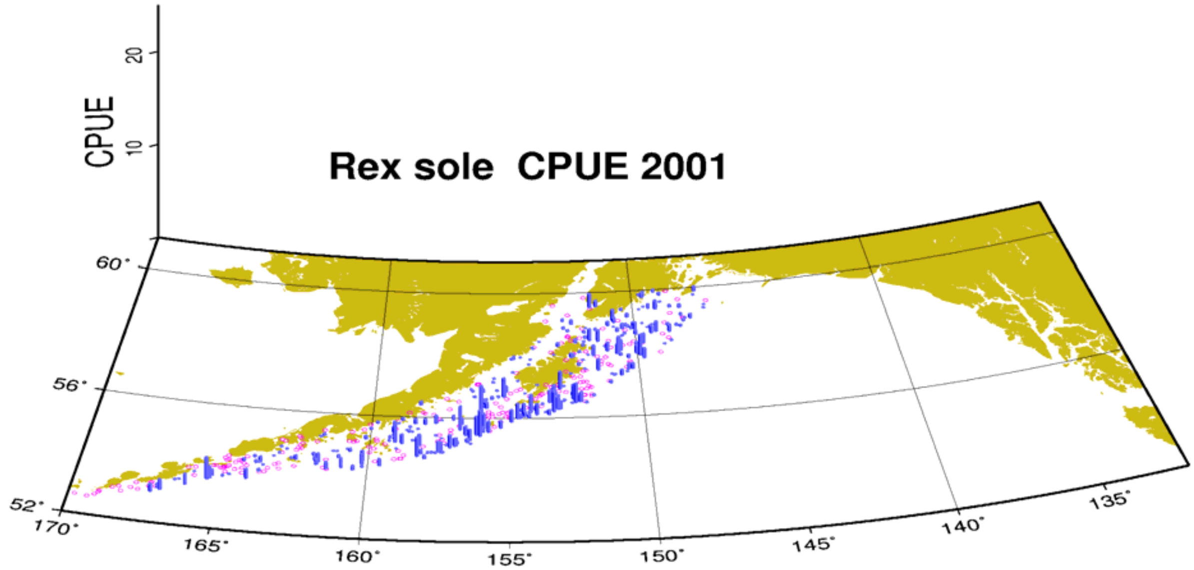


Figure 4.20. Rex sole 2001 survey cpue by tow. Circles are tow locations with no rex sole catch.

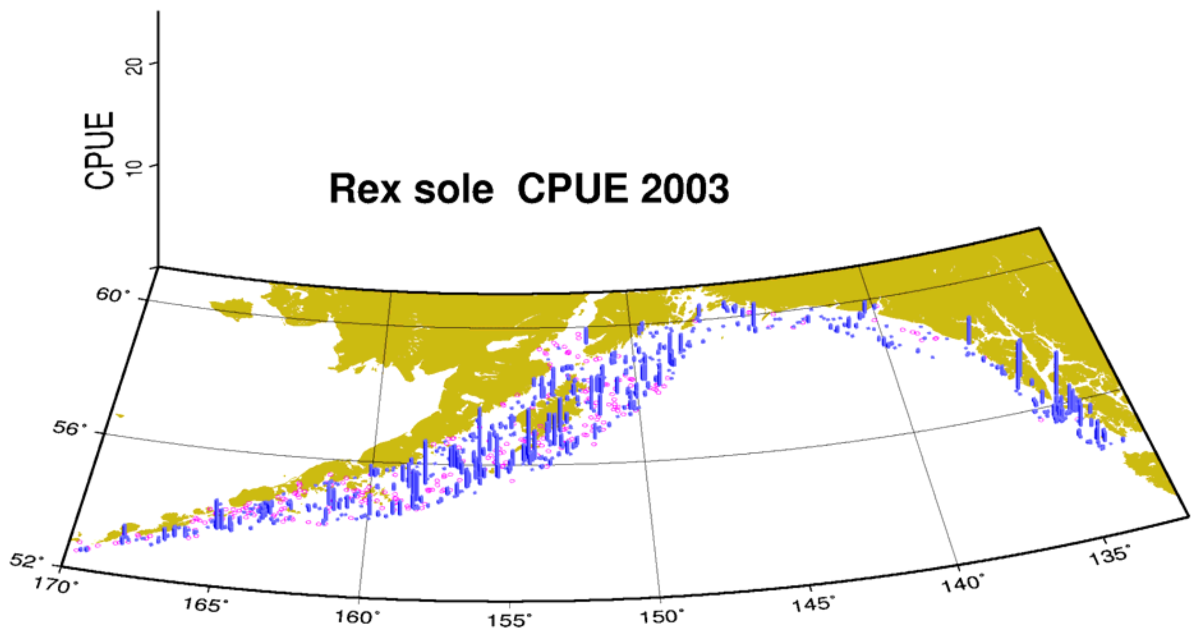


Figure 4.21. Rex sole 2003 survey cpue by tow. Circles are tow locations with no rex sole catch.

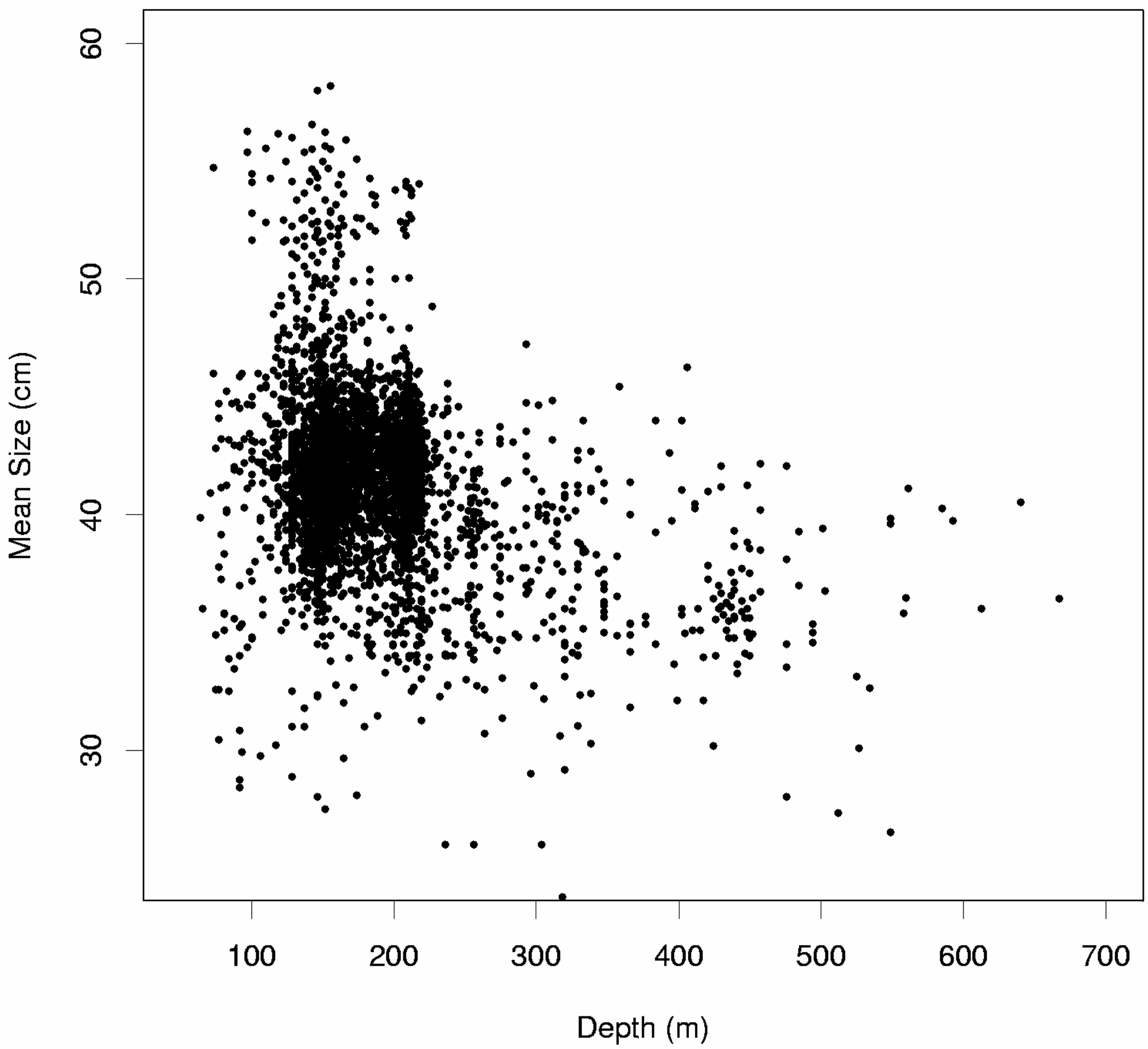


Figure 4.22. Mean size within haul by depth for fishery length data from 1990 to 2003.

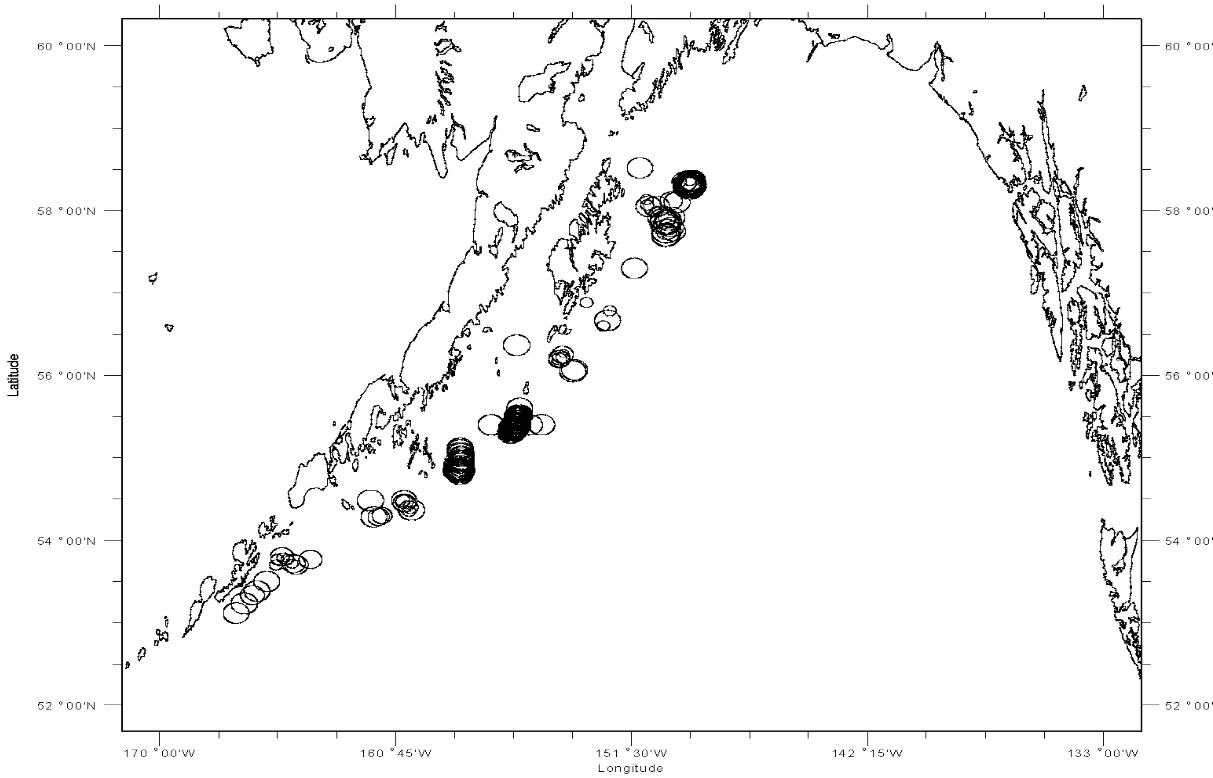


Figure 4.23. Location of fishery hauls sampled for lengths in 2001. Area of the circle is proportional to the sample size.

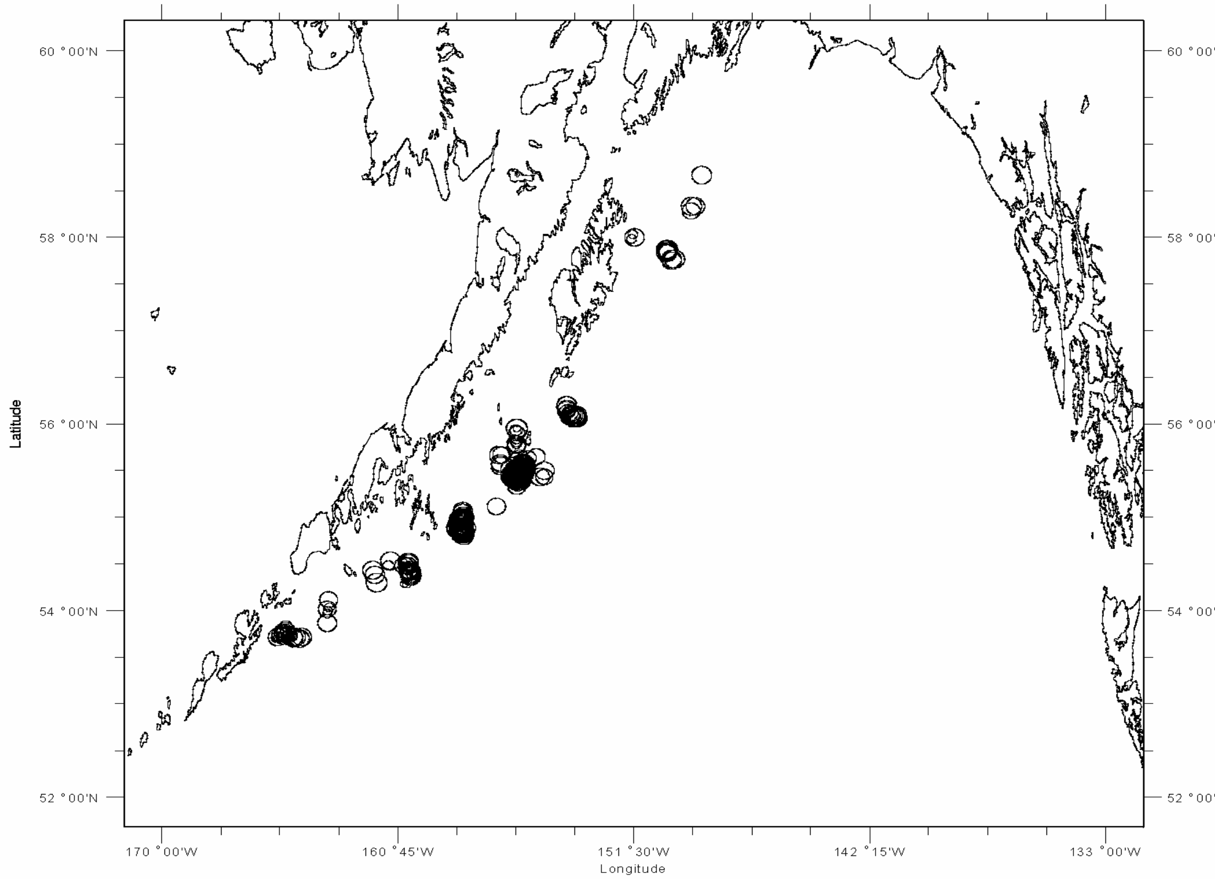


Figure 4.24. Location of fishery hauls sampled for lengths in 2002. Area of the circle is proportional to the sample size.

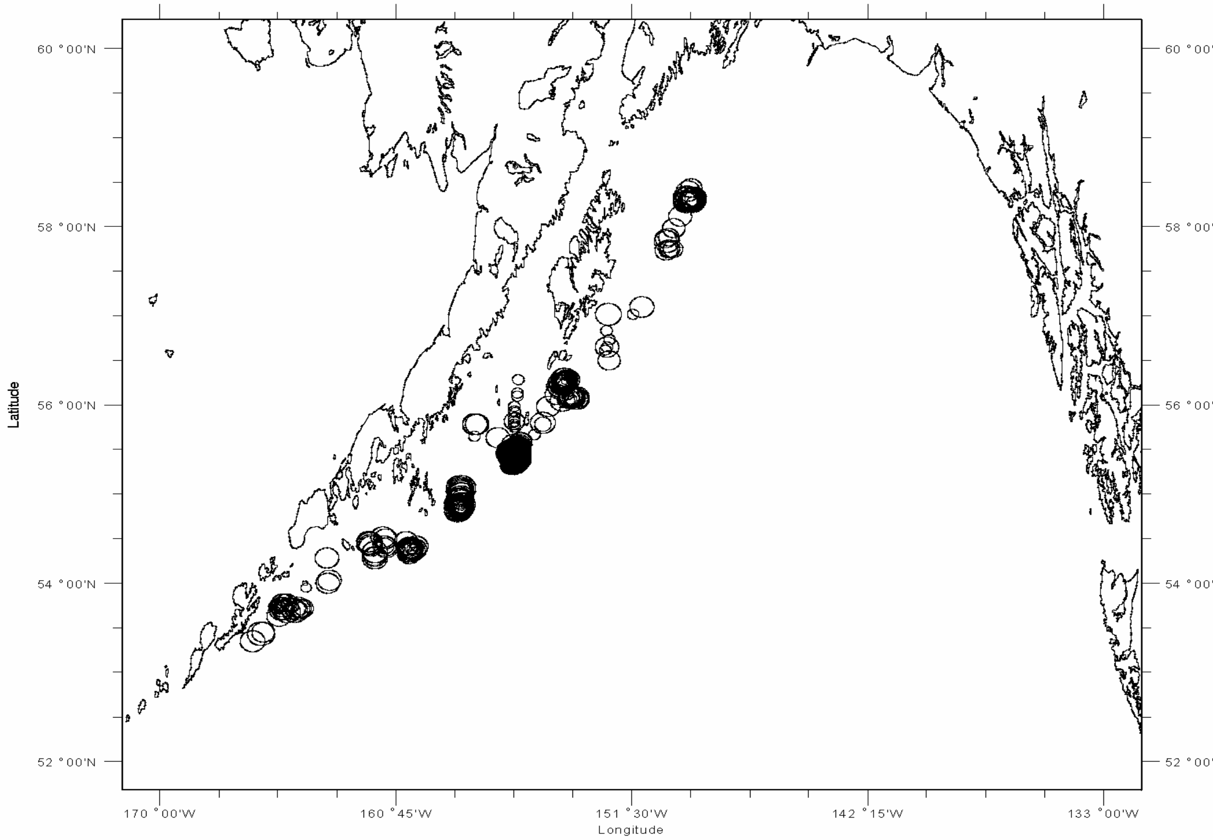


Figure 4.25. Location of fishery hauls sampled for lengths in 2003. Area of the circle is proportional to the sample size.

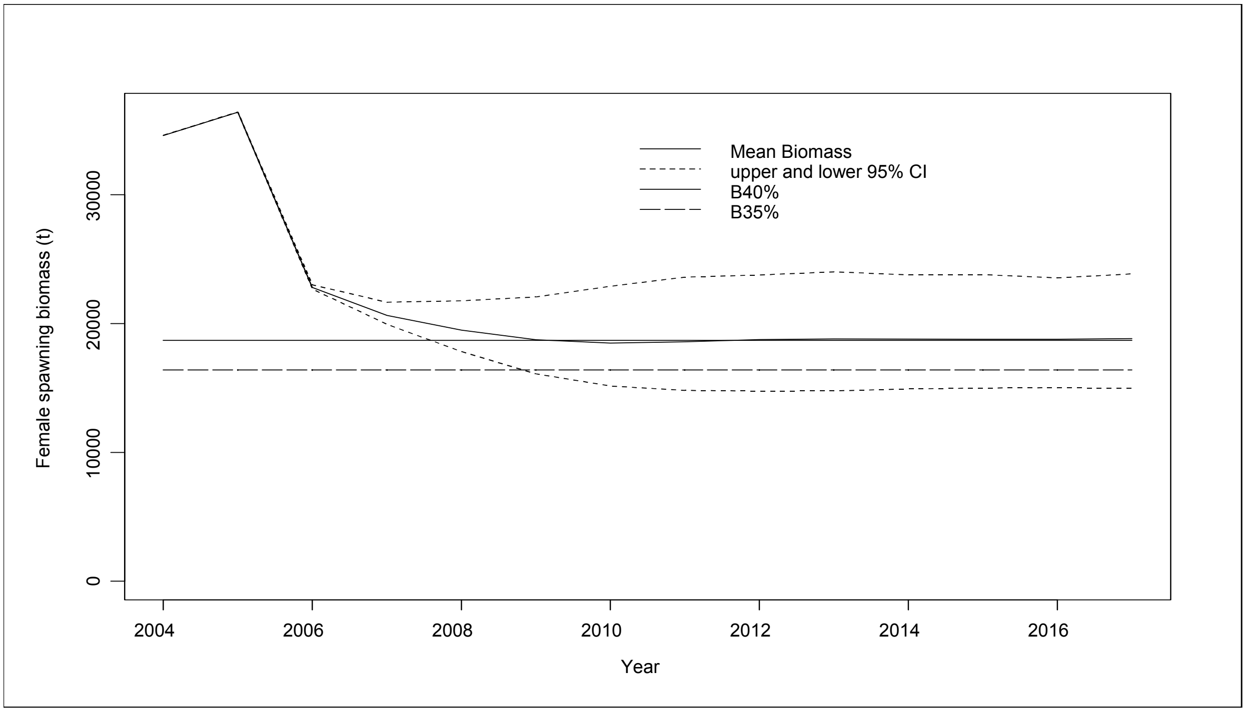


Figure 4.26. Projected female spawning biomass from 2005 to 2017 fishing at FABC = F40%.

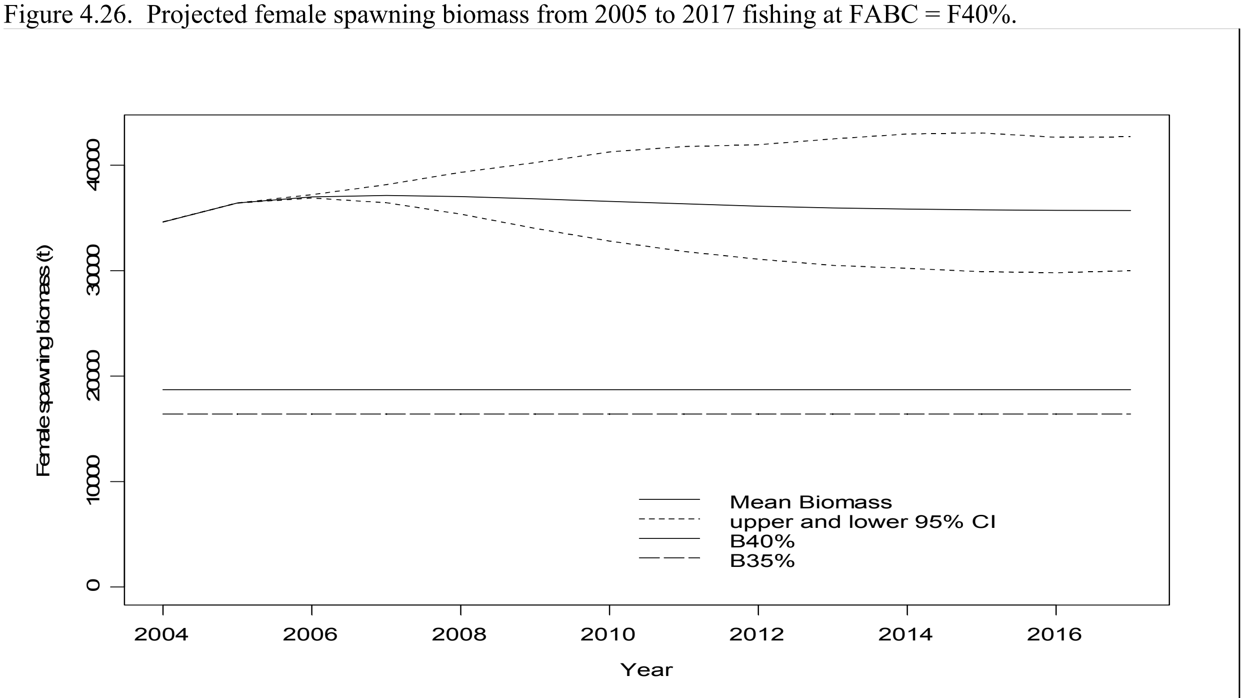


Figure 4.27. Projected female spawning biomass from 2005 to 2017 fishing at FABC = average 5 year F=0.15.

Appendix A

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.
$\sum_{t=1}^{ts}\left[\dfrac{\log\left[\dfrac{SB_{obs,t}}{SB_{pred,t}}\right]}{sqrt(2)*s.d.(\log(SB_{obs,t}))}\right]^2$	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 2004
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 $1982 \le t \le 2004$, plus 18 parameters for the initial age composition equals 41.	Recruitment deviation in year t
$\log(f_0)$	log of the geometric mean value of fishing mortality
ε_t $1982 \le t \le 2004$, 23 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.

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