Dover Sole

by

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Executive Summary

An age-based model using age and length data was developed for Dover 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. Survey biomass estimates from years when the survey extended to 1000 m (700 m in 2003) had q fixed at 1.0. Years when the survey only sampled to 500 m had a q of 0.82, which was the average fraction of the biomass in depths less than 500 m estimated from surveys that covered all depths. The 2001 survey did not sample the eastern gulf, and did not extend into waters greater than 500 m. The 2001 survey q was fixed at 0.42 which is the average fraction of the biomass in the western and central areas multiplied times the average fraction of the biomass in water less than 500 m. Natural mortality was decreased from 0.1 (used in previous assessments) to 0.085 due more extensive age data containing a maximum age of 54 years.

The estimated biomass from the model decreased from about 169,000 t in the mid-1980's to about 97,238 t in 2003. The 2004 ABC using Tier 3 F40% was 6,630 t. OFL using F35% was 8,231 t. For comparison, the Tier 5 estimated Dover sole ABC and OFL would be 5,884 t and 7,760 t, respectively.

Introduction

Dover sole occur from Northern Baja California to the Bering Sea in depths to 1500 m. Larvae are large and have an extended pelagic phase that averages about 21 months (Markle, Harris and Toole 1992). Dover sole are batch spawners with spawning occurring in winter months. Dover sole move to deeper water as they age and older female Dover sole may have seasonal migrations from deep water where spawning occurs to shallower water in summer time to feed (tagging data from California to British Columbia, Demory et al. 1984, Westrheim et al. 1992). Older male Dover sole may also migrate seasonally but to a lesser extent than females. Dover sole feed commonly on polychaete worms, pelecypod and scaphopod mollusks, shrimp, and brittle stars.

Catch History

Catch was estimated by applying the fraction of the deep-water catch that was Dover sole from observer data (Table A.4.1). Catches declined from 827 t in 1978 to 23 t in 1986, increased to a high of 9,741 t in 1991 then declined to 492 t in 2002. Catch in to October 2, 2003 was 917 t. Table 4.2 documents annual research catches (1977 - 1998) from NMFS longline, trawl, and echo integration trawl surveys.

Abundance and exploitation trends

NMFS bottom trawl surveys covered depths to 1000 m in 1984, 1987, and 1999. The 2003 survey extended to 700 m. The surveys in 1990, 1993, 1996 and 2001 sampled depths to 500 m. The 2001 survey did not cover the eastern gulf where about 50% of the total Dover sole biomass occurs. The average fraction of Dover sole biomass in depths less than 500 m is 0.82 (Table A.4.5). Survey biomass estimates increased from about 68,500 t in 1984 to 96,600 t in 1990, then declined to about 64,000 t in 2001 (adjusting for the missing eastern gulf area). The 2003 survey biomass estimate is 99,300 t (depths to 700 m), a 56% increase from the adjusted 2001 estimate. Compared to the 1999 survey (which extended down to 1000m and covered the entire GOA), the 2003 survey biomass estimate represented a 34% increase.

Data

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

Data component	Years
Fishery catch	1984-2003
NMFS bottom trawl survey biomass and S.E.	1984,1987,1990,1993, 1996,1999,2001,2003
Fishery size compositions	1991-2003
NMFS trawl survey size compositions	1984,1987,1990,2003
NMFS trawl survey age compositions	1993,1996,1999,2001

Analytic approach

Model Structure

The model structure is developed following Fournier and Archibald's (1982) methods, with many similarities to Methot (1990). We implemented the model using automatic differentiation software developed as a set of libraries under C++ (ADModel Builder). ADModel Builder can estimate a large number of parameters in a non-linear model using automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries. This software provides the derivative calculations needed for finding the 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, description of variables and likelihood equations are presented in Appendix A (Tables A.1, A.2 and A.3). There were a total of 96 parameters estimated in the model (Table A.4). There were 20 fishing mortality deviates in the model which were constrained to be small, to fit the observed catch closely. The instantaneous natural mortality rate, catchability for the survey 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 was estimated to be 0.085 for Dover sole using Hoenig (1983) and a maximum age of 54 years. Previous assessments used M=0.1 based on a maximum age of 45 years.

Weight at Length

The weight-length relationship for Dover sole is, $W = 0.0029 L^{3.3365}$, for females and males, where weight is in grams and length in centimeters (Abookire and Macewicz in press).

Growth

In the growth equation shown below, L_{inf} was estimated as 51.51 cm for females and 42.42 cm for males (Figures A.4.2, A.4.3 and A.4.4). The estimate of *k* was 0.127 for females and 0.195 for males and t_0 was -2.66 for females and -1.97 for males from the survey age and length data in 1984, 1993,1996, 1999, and 2001.

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

Maturity

Female Dover sole length at 50% mature was estimated at 43.9 cm (about age 12.5 years), with a slope of -0.062 (Abookire and Macewicz, in press).

Likelihood weights and other model structure

Weights used on the likelihood values were 1.0 for the survey length, survey age data and the survey biomass (simply implying that the variances and sample sizes specified for each data component were approximately correct). A weight of 0.5 was used for the fishery length data. The fishery length data is essentially from bycatch and in some years has low sample sizes. A lower weight on the fishery length data allows the model to fit the survey data components better. 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, 1993, 1996, 1999 and 2001 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 40+. The data were organized in size groups or “bins” with widths of 2 cm ranging from 18 cm to 66+ cm. The model was dimensioned to cover 38 age groups from age 3 to age 40+ yrs. For fitting purposes, data and model predictions were aggregated into 22 age bins defined as follows: 17 annual bins covering ages 3 to 19, four 5-year age bins for ages 20-39, and 1 age bin for Dover sole age 40 and older (40+).

Parameters Estimated Conditionally

Recent recruitments

Recruitment in 2003 was constrained to be close to the historical harmonic mean recruitment. This was done as a precautionary approach since the harmonic mean recruitment is less than the arithmetic mean recruitment. Data are lacking to reliably estimate the most recent recruitment.

Selectivity

Separate fishery selectivities were estimated for males and females using a two parameter ascending logistic function (Figure A.4.1). Sex-specific survey selectivities were also modeled using a two parameter ascending logistic function for surveys extending into deep water (1984, 1987, 1999 and 2003; Figure A.4.1). For the years where survey sampling depths were limited to 500m and shallower (1990, 1993, 1996 and 2001), a four parameter logistic function was used.. The four parameter function allows the selectivity curve to be dome-shaped, indicating that the older fish may be less available to these surveys.

Results

Fits to the size composition data from the fishery are shown in Figure A.4.5 for females and Figure A.4.6 for males. The observed sizes are larger in recent years indicating a possible change in selectivity over time. Fishery selectivities are above 95% at about age 12 for males (about 40 cm) and age 14 for females (about 45 cm). The survey length fits in general are smoother than the observed lengths resulting in more small and large fish and fewer fish in the 35 cm to 45 cm length bins (Figures A.4.7 and A.4.8). The 2003 length data show more small fish indicating the possibility of a larger than average recruitment, however, future survey data is needed to verify this. The survey age data are not always consistent between males and females (Figures A.4.9 and A.4.10). As Dover sole age they move to deeper water, and older females may seasonally migrate to shallower water in the summer time to feed, leaving mostly older males in deeper water. Differences in age composition between sexes may be due to migration patterns and the depths covered by the survey in that year. Male survey selectivities for surveys covering depths to 500 m were higher for smaller males than for surveys extending to deeper water (Figure A.4.1). In 1993 and 2001 the survey data show large numbers of females at ages greater than 25 years. The male age data in 2001 do show large numbers of animals greater than 25 years, but do not in 1993.

The model estimates of survey biomass are higher than the observed survey 1984, 1987 and 1990, then follows the declining trend in survey biomass to 2001. The model underestimates the 2003 survey biomass (Figure A.4.13). Rapid changes in biomass are unexpected due to the longevity of Dover sole and may be due to sampling variability or changes in survey catchability.

Model estimates of biomass

The model estimates of age 3+ biomass decreased from a high of about 169,000 t in 1985 to about 97,000 t in 2003 (Table A.4.10 and Figure A.4.11). Female spawning biomass increased from about 56,000 t in 1984 to about 63,000 t in 1990 then declined to about 38,000 t in 2003.

Model estimates of recruitment

The model estimates of age 3 recruits have a decreasing trend from 1984 to the mid-1990's then increase and fluctuate about the mean recruitment in recent years (Table A.4.10 and Figure A.4.12). The most recent recruitment is constrained to be similar to the mean, which results in a estimate of uncertainty that is lower than the actual indicated by the 95% confidence interval in Figure A.4.12. In general, the uncertainty in recruitment increases from the starting years to the ending years of the model.

Spawner-Recruit Relationship

No spawner-recruit curve was used in the model. Recruitments were freely estimated but with a modest penalty on extreme deviations from the mean value.

Reference fishing mortality rates and yields

The NPFMC SSC has determined that reliable estimates of biomass, $B_{35\%}$, $F_{35\%}$ and $F_{40\%}$, are available. Given that the current biomass is greater than $B_{40\%,}$ Dover 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 $F_{40\%}$.

Yield for 2004 using $F_{40\%} = 0.121$ was estimated at 6,630 t. Yield at $F_{35\%} = 0.153$ was estimated at 8,231 t. Model estimates of historical fishing mortality have been well below target rates (Figure A.4.14). Fishing mortality increased from close to 0 in 1984 to a high of about 0.09 in 1991 then declined to about 0.01 in 2003. Female spawning biomass in 2003 (37,574 t) is estimated to be close to B0 (38,771 t), and well above B40% (15,509 t).

Maximum sustainable yield

Since there is no estimate of the spawner-recruit relationship for Dover sole, no attempt has been made to estimate MSY. However, using the projection model described in the next section, spawning biomass with F=0 was estimated at 38,771 t. $B_{35\%}$ (equilibrium spawning biomass with fishing at $F_{35\%}$) is estimated at 13,570 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 2003 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2004 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2003. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2004, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

> *Scenario 1*: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
>
> *Scenario 2*: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2004 recommended in the assessment to the *max* F_{ABC} for 2004. (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 follow (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 2004 and above its MSY level in 2014 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2004 and 2005, 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 2016 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 2004 to 2008 (Table A.4.11). Under scenario 6 above, the year 2004 female spawning biomass is 36,564 t and the year 2014 spawning biomass is 16,900 t, above the $B_{35\%}$ level of 13,570 t. For scenario 7 above, the year 2016 spawning biomass is 15,960 t also above $B_{35\%}$. Fishing at F40%, female spawning biomass is projected to be 18,288 t in year 2016.

Acceptable biological catch

ABC for 2004 using $F_{40\%}$ = 0.121 was estimated at 6,630 t. The ABC by management area using $F_{40\%}$ was estimated by calculating the fraction of the 2003 survey biomass in each area and applying that fraction to the total ABC:

Dover sole ABC by INPFC area

	Western	Central	West Yakutat	East Yakutat/SE	Total
ABC 2004	210	3,292	2,110	1,018	6,630

Overfishing level

Yield at $F_{35\%}$ = 0.153 was estimated at 8,231 t.

Summary

Table A.4.12 shows a summary of model results.

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Tables

Table A.4.1. Catch of Dover sole in the Gulf of Alaska from 1978 to 2 October, 2003.

Year	Catch (t)
1978	827
1979	530
1980	570
1981	457
1982	457
1983	354
1984	132
1985	43
1986	23
1987	56
1988	1087
1989	1521
1990	2348
1991	9741
1992	8364
1993	3804
1994	3053
1995	2082
1996	2178
1997	3659
1998	2174
1999	2263
2000	957
2001	536
2002	492
2003	917

Table A.4.2. Catches from NMFS research cruises from 1977 to 1998.

Year	Catch (t)
1977	1.12
1978	5.99
1979	5.04
1980	0.92
1981	15.80
1982	5.71
1983	7.71
1984	15.79
1985	17.58
1986	1.25
1987	16.16
1988	0.06
1989	1.90
1990	11.65
1991	0.02
1992	0.97
1993	14.80
1994	0.06
1995	0.00
1996	7.39
1997	0.01
1998	5.00

Table A.4.3. Biomass estimates and standard errors from the trawl survey from 1984 to 2003. In 1984, 1987 and 1999 depths surveyed were to 1000 m. In 2003 depths surveyed were to 700 m. In 1990, 1993, 1996 and 2001 depths were surveyed to 500 m.

Survey	Biomass(t)	Stand.
NMFS trawl 1984	68,525	6,136
NMFS trawl 1987	63,397	7,388
NMFS trawl 1990	96,602	12,375
NMFS trawl 1993	85,422	6,443
NMFS trawl 1996	79,531	5,624
NMFS trawl 1999	74,365	5,267
NMFS trawl 2001	63,794	7,516
NMFS trawl 2003	99,327	10,442

* A value for the eastern gulf survey biomass was estimated by using the average of the 1993 to 1999 biomass estimates in the eastern gulf, which was added to the 2001 survey biomass in the central and western gulf to obtain a survey biomass for the total area.

Table A.4.4. Survey biomass estimates (t) for 1993 to 2003 by area. *The 2001 survey biomass for the eastern gulf was estimated by using the average ratio of the eastern gulf biomass to the total biomass for 1993, 1996, 1999 and 2003.

Area	1993	1996	1999	2001	2003
Western	2,371	1,458	1,430	896	3,149
Central	43,388	37,144	34,323	31,639	49,314
Eastern	39,664	40,928	38,612	31,259*	46,865

Table A.4.5. Survey biomass estimates by depth and the fraction of biomass in depths greater than 500 m.

Depth (m)	1984	1987	1990	1993	1996	1999	2001	2003	Average fraction
1-100	2,829	4,402	12,290	4,760	6,561	6,432	3,909	10,185	
100-200	30,221	25,832	57,777	44,002	37,858	28,704	16,298	45,181	
200-300	7,928	12,040	19,986	19,931	18,102	19,578	7,491	17,832	
300-500	6,822	8,935	6,549	16,735	17,014	12,318	4,836	13,593	
500-700	8,166	10,542				6,014		12,537	
700-1000	12,558	1,647				1,323			
Total	68,525	63,397	96,602	85,427	79,535	74,367	32,534	99,327	
fraction>500	0.30	0.19				0.10		0.13	0.18
fraction<500	0.70	0.81				0.90		0.87	0.82

Table A.4.6. Age data from trawl surveys in 1984 through 2001. The numbers are percentages, where the female plus the male numbers add to 100 within a year.

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Males															
1984	0.00	0.00	1.18	0.78	4.31	13.33	7.45	4.31	1.57	1.18	1.57	1.96	0.78	1.57	4.31
1993	0.00	0.00	1.90	5.71	7.62	4.76	7.62	6.67	4.76	4.76	3.81	3.81	1.90	2.86	4.76
1996	0.00	0.00	2.94	4.71	10.00	5.29	4.71	4.71	6.47	2.94	2.94	7.06	8.24	5.88	5.88
1999	0.00	0.00	1.16	6.40	7.56	4.65	1.74	4.07	1.16	1.74	1.74	2.91	1.74	2.33	0.58
2001	0.41	0.00	3.69	10.25	13.11	10.25	6.97	3.28	2.46	1.23	0.82	0.41	0.00	1.23	2.05
Females															
1984	0.00	0.00	0.00	0.00	6.22	12.92	4.78	2.39	0.96	2.39	0.96	0.48	2.39	1.91	5.26
1993	0.00	0.00	1.36	2.04	2.72	3.40	5.44	2.04	3.40	4.08	3.40	4.08	4.76	4.08	4.08
1996	0.00	0.47	2.82	2.82	8.92	2.35	1.88	3.76	6.10	1.88	4.23	3.76	4.23	1.41	4.69
1999	0.00	0.00	0.55	2.76	7.73	4.42	1.66	2.76	2.76	1.10	3.31	1.66	3.87	2.21	6.08
2001	0.00	1.00	2.01	6.35	8.36	9.70	5.69	5.35	1.67	3.01	0.67	0.00	1.34	0.67	1.34

Age	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Males															
1984	4.31	3.53	3.92	3.14	3.14	4.31	3.14	5.10	3.14	4.71	3.92	3.53	1.57	0.78	1.57
1993	2.86	2.86	4.76	2.86	1.90	2.86	0.95	3.81	5.71	0.95	0.95	0.95	0.00	0.95	0.95
1996	3.53	1.76	3.53	2.94	3.53	2.35	1.18	2.35	0.00	1.18	0.00	0.59	0.59	1.76	0.00
1999	2.33	1.16	5.23	0.58	1.16	5.23	2.33	4.65	4.65	1.74	2.33	1.74	1.16	1.74	1.74
2001	1.64	2.05	1.23	2.46	2.46	0.82	0.41	2.05	3.28	2.05	0.82	2.05	1.23	0.00	0.82
Females															
1984	1.91	3.83	3.35	2.39	5.74	2.87	3.83	6.70	3.83	7.18	3.35	1.44	2.39	2.39	0.96
1993	0.68	2.04	3.40	0.68	2.72	5.44	0.68	2.72	4.08	4.08	2.72	2.72	2.04	2.72	2.72
1996	3.29	1.88	2.35	2.35	6.10	4.23	1.88	1.41	1.88	1.88	0.94	2.35	2.35	0.94	1.88
1999	6.08	2.76	2.21	2.76	2.21	0.55	5.52	3.87	1.66	2.76	1.66	2.76	0.55	1.10	1.10
2001	0.33	2.68	2.01	0.67	1.67	1.34	1.34	1.00	3.68	2.68	2.34	1.67	0.67	1.00	2.01

Age	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Males															
1984	1.18	1.57	1.18	0.39	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.39	0.39	0.00
1993	0.95	0.95	0.00	0.00	0.95	0.95	0.95	0.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.00	1.18	0.59	0.00	0.59	0.00	0.00	0.59	0.00	0.00	0.00
1999	1.74	2.33	1.74	0.58	2.33	2.33	1.74	0.58	2.33	0.58	0.00	1.16	1.74	0.00	1.16
2001	0.82	1.23	1.23	2.87	1.64	2.87	1.23	1.23	1.64	0.82	0.41	0.41	0.82	1.64	1.23
Females															
1984	1.91	1.44	0.96	0.48	0.00	1.44	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48
1993	1.36	3.40	3.40	1.36	1.36	1.36	0.68	1.36	0.68	0.00	0.00	0.00	0.68	0.00	0.00
1996	0.00	3.29	1.41	0.94	0.00	0.47	2.35	1.88	0.94	1.41	0.47	0.47	0.47	0.47	0.47
1999	0.55	1.10	2.76	1.66	1.66	0.00	1.10	2.21	0.00	2.21	1.10	2.21	1.10	1.10	0.00
2001	2.68	1.34	2.01	2.34	1.00	2.01	1.67	3.34	1.67	1.67	1.00	0.67	1.67	0.67	1.67

Age	46	47	48	49	50	51	52	53
Males								
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	1.16	2.33	0.58	0.00	0.00	0.00	0.00	0.00
2001	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.00
Females								
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	1.10	0.55	0.55	0.00	0.00	0.00	0.00	0.55
2001	1.34	0.33	0.33	0.00	0.00	0.00	0.33	0.00

Table A.4.7. Length data from trawl surveys in 1984 through 2001. The numbers are percentages, where the female plus the male numbers add to 100 within a year

Length	18	20	22	24	26	28	30	32	34	36	38	40	42	44
Males														
1984	0.00	0.00	0.39	0.00	1.96	4.31	2.75	14.12	18.04	21.96	21.57	10.59	1.96	1.57
1993	0.00	0.95	1.90	0.95	0.95	0.00	0.95	3.81	5.71	11.43	9.52	13.33	14.29	14.29
1996	0.00	0.00	1.18	2.94	4.12	2.94	7.06	7.65	10.59	8.24	11.18	10.00	9.41	8.82
1999	0.00	0.00	0.00	1.74	2.33	6.40	4.07	8.14	8.72	8.14	9.30	9.30	9.30	10.47
2001	0.82	1.23	0.82	2.05	4.51	5.33	6.97	7.38	7.79	6.56	8.61	8.20	8.20	8.20
Females														
1984	0.00	0.00	0.00	0.48	0.00	0.96	1.91	5.74	8.13	11.96	10.53	11.00	14.35	12.44
1993	0.00	0.00	0.68	0.68	2.04	1.36	0.00	3.40	2.04	4.08	5.44	6.12	8.84	9.52
1996	0.47	0.94	0.00	1.41	2.82	2.82	2.82	4.69	6.10	4.69	4.69	5.63	8.92	7.98
1999	0.00	0.55	0.00	1.10	1.66	3.31	1.66	3.31	3.87	7.18	4.97	6.63	8.29	7.18
2001	0.67	1.00	0.67	1.00	2.34	4.68	3.34	4.35	5.02	5.35	4.68	3.68	4.35	5.69

Length	46	48	50	52	54	56	58	60	62	64	66
Males											
1984	0.39	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	10.48	3.81	4.76	1.90	0.95	0.00	0.00	0.00	0.00	0.00	0.00
1996	7.65	5.29	2.35	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	9.88	6.40	5.23	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	9.43	6.97	3.28	2.46	1.23	0.00	0.00	0.00	0.00	0.00	0.00
Females											
1984	11.00	7.66	2.87	0.48	0.48	0.00	0.00	0.00	0.00	0.00	0.00
1993	10.20	9.52	6.80	6.12	7.48	6.12	5.44	3.40	0.68	0.00	0.00
1996	7.51	7.98	6.57	7.04	5.63	5.16	3.29	1.88	0.94	0.00	0.00
1999	7.73	8.29	8.84	7.73	7.18	5.52	3.87	1.10	0.00	0.00	0.00
2001	5.35	6.69	6.69	6.35	6.02	5.35	5.02	5.02	2.68	2.68	1.34

Table A.4.8. Mean length (cm) at age for male Dover sole from triennial surveys 1984 through 2001.

Age	1984	1993	1996	1999	2001
1	0.0	0.0	0.0	0.0	18.0
2	0.0	0.0	0.0	0.0	0.0
3	26.7	36.0	25.2	25.5	25.2
4	30.0	31.0	29.1	29.7	28.8
5	32.4	33.5	31.6	31.2	31.8
6	32.1	33.6	33.6	32.3	34.5
7	33.0	38.1	34.4	31.3	35.1
8	35.0	40.7	34.0	35.6	35.9
9	34.8	40.4	34.9	36.5	40.8
10	40.0	39.2	35.2	32.3	41.3
11	35.8	43.0	35.8	34.3	43.5
12	34.2	42.0	41.0	43.2	47.0
13	36.0	41.0	39.2	38.3	0.0
14	39.0	45.0	42.6	35.5	43.3
15	38.2	44.2	43.9	50.0	44.4
16	37.5	44.0	40.7	44.3	45.3
17	35.6	44.3	44.3	44.0	44.8
18	37.9	49.4	44.0	44.3	50.7
19	36.8	47.7	42.6	50.0	44.8
20	38.8	50.5	46.3	46.0	46.8
21	36.8	44.0	43.0	45.3	52.0
22	36.8	40.0	45.0	40.8	43.0
23	38.2	46.5	43.5	45.5	49.6
24	39.1	41.8	0.0	44.4	49.3
25	36.4	44.0	40.0	44.3	45.8
26	37.5	41.0	0.0	40.8	48.0
27	38.7	43.0	41.0	40.7	48.0
28	37.0	0.0	47.0	45.5	43.3
29	36.5	46.0	41.0	40.3	0.0
30	38.3	43.0	0.0	39.7	49.0
31	39.0	41.0	0.0	44.7	48.0
32	38.0	37.0	0.0	45.0	46.3
33	41.0	0.0	0.0	41.7	44.3
34	40.0	0.0	0.0	42.0	42.4
35	41.0	40.0	0.0	41.5	45.5
36	0.0	45.0	44.5	42.5	43.6
37	0.0	45.0	50.0	42.3	43.3
38	0.0	45.0	0.0	35.0	40.3
39	0.0	0.0	48.0	39.8	40.5
40	0.0	0.0	0.0	37.0	38.5
41	0.0	0.0	0.0	0.0	39.0
42	44.0	0.0	44.0	43.0	45.0
43	41.0	0.0	0.0	39.7	42.0
44	45.0	0.0	0.0	0.0	42.3
45	0.0	0.0	0.0	39.0	39.3
46	0.0	0.0	0.0	43.5	0.0
47	0.0	0.0	0.0	41.5	44.0
48	0.0	0.0	0.0	36.0	0.0

Table A.4.9. Mean length (cm) at age for female Dover sole from trawl surveys 1984 through 2001.

Age	1984	1993	1996	1999	2001
1	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	18.0	0.0	19.0
3	0.0	29.0	26.5	21.0	24.5
4	0.0	33.7	28.7	26.8	29.4
5	33.4	39.5	33.2	32.5	32.7
6	34.9	33.8	27.6	35.4	35.4
7	35.7	33.4	33.8	32.0	36.3
8	35.4	37.3	36.5	35.6	39.0
9	37.0	45.2	38.9	41.0	42.8
10	38.2	42.0	35.5	32.5	44.9
11	39.5	42.6	39.0	41.3	48.5
12	39.0	43.5	46.1	44.3	0.0
13	40.0	44.1	42.1	46.0	45.8
14	40.0	45.5	44.3	44.5	51.0
15	41.4	47.3	46.6	44.5	48.8
16	45.0	59.0	47.3	47.2	43.0
17	43.6	51.7	49.3	45.4	51.1
18	43.0	52.4	48.6	47.5	53.2
19	42.4	54.0	48.2	52.0	54.0
20	41.9	55.3	50.5	52.5	56.2
21	42.3	51.9	47.2	53.0	55.0
22	44.1	58.0	48.5	52.7	60.5
23	43.1	57.8	51.7	48.6	58.3
24	45.0	52.2	45.5	52.0	56.7
25	44.2	53.0	50.3	54.0	56.4
26	43.7	51.5	55.0	54.3	58.4
27	45.3	48.5	53.2	48.8	55.4
28	45.8	48.3	52.0	49.0	50.5
29	45.6	49.8	48.0	48.5	51.0
30	45.5	42.5	51.5	52.0	49.3
31	43.8	57.5	0.0	50.0	52.1
32	43.3	46.0	51.0	53.5	55.3
33	46.5	49.0	54.3	52.2	55.2
34	50.0	45.5	54.0	44.0	49.0
35	0.0	52.0	0.0	49.7	57.7
36	48.7	55.5	42.0	0.0	58.2
37	39.0	44.0	55.8	48.0	56.8
38	0.0	49.0	50.8	54.5	53.2
39	0.0	45.0	52.0	0.0	53.0
40	0.0	0.0	50.0	45.8	57.8
41	0.0	0.0	60.0	45.5	47.7
42	0.0	0.0	46.0	45.5	46.0
43	0.0	43.0	46.0	45.5	52.8
44	0.0	0.0	61.0	45.5	49.0
45	48.0	0.0	54.0	0.0	51.2
46	0.0	0.0	0.0	53.5	57.3
47	0.0	0.0	0.0	41.0	58.0
48	0.0	0.0	0.0	40.0	51.0
49	0.0	0.0	0.0	0.0	0.0
50	0.0	0.0	0.0	0.0	0.0
51	0.0	0.0	0.0	0.0	0.0
52	0.0	0.0	0.0	0.0	57.0
53	0.0	0.0	0.0	47.0	0.0

Table A.4.10. 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)
1984	168,351	55,889	18,489
1985	168,867	57,166	14,806
1986	169,083	58,585	18,867
1987	168,565	60,151	14,219
1988	167,007	61,769	10,525
1989	163,457	62,761	8,612
1990	158,845	63,267	8,840
1991	153,030	62,958	8,765
1992	139,580	58,409	5,457
1993	127,703	54,339	6,844
1994	120,920	52,523	10,491
1995	114,736	50,914	5,098
1996	110,047	49,593	11,250
1997	106,567	47,959	18,613
1998	102,594	45,285	16,823
1999	100,258	43,289	11,283
2000	97,837	41,149	10,793
2001	96,870	39,730	12,164
2002	96,815	38,595	15,877
2003	97,238	37,574	16,800

Table A.4.11. Projected female spawning biomass and yield from 2004 to 2008.

	Year	Female spawning biomass(t)	Yield(t)
F=F40%			
	2004	36,641	6,630
	2005	32,626	5,902
	2006	29,630	5,392
	2007	27,320	5,043
	2008	25,407	4,739
F=0.016(avg F)			
	2004	36,641	894
	2005	35,854	880
	2006	35,421	877
	2007	35,164	885
	2008	34,985	890
F=0.5 F40%			
	2004	36,641	3,405
	2005	34,436	3,215
	2006	32,803	3,087
	2007	31,520	3,013
	2008	30,424	2,940
F=0			
	2004	36,641	0
	2005	36,359	0
	2006	36,382	0
	2007	36,540	0
	2008	36,755	0

Table A.4.12. Summary of results of Dover sole assessment in the Gulf of Alaska.

Natural Mortality	0.085
Age of full(95%) selection	14 females, 12 males
Reference fishing mortalities	
F40%	0.121
F35%	0.153
Biomass at MSY	N/A
Equilibrium unfished Female Spawning biomass	38,771 t
B40% Female Spawning biomass fishing at F40%	15,509 t
B35% Female Spawning biomass fishing at F35%	13,570 t
Projected 2004 biomass	
Total(age 3+)	97,333 t
Spawning	36,641 t
Overfishing level for 2004	8,231 t

Figures

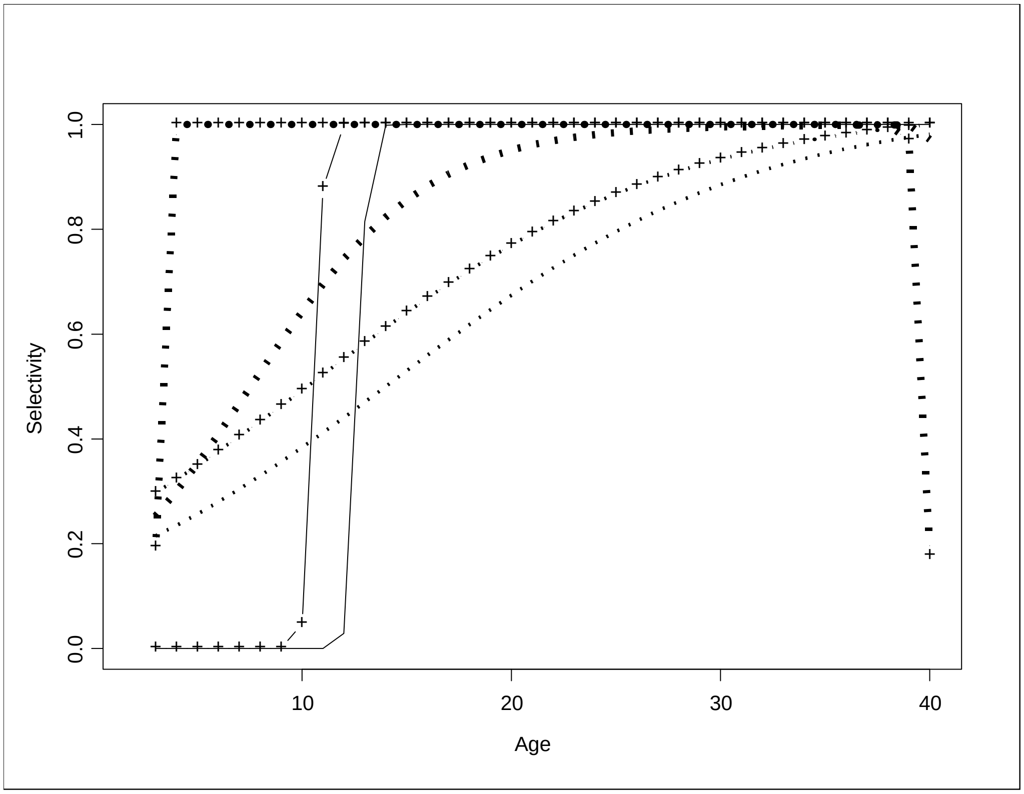

Figure A.4.1. Selectivities for the fishery (solid line), deep survey(to 1000 m) (dotted line) and shallow survey (to 500 m)(dashed line). Males are the lines with the + symbol.

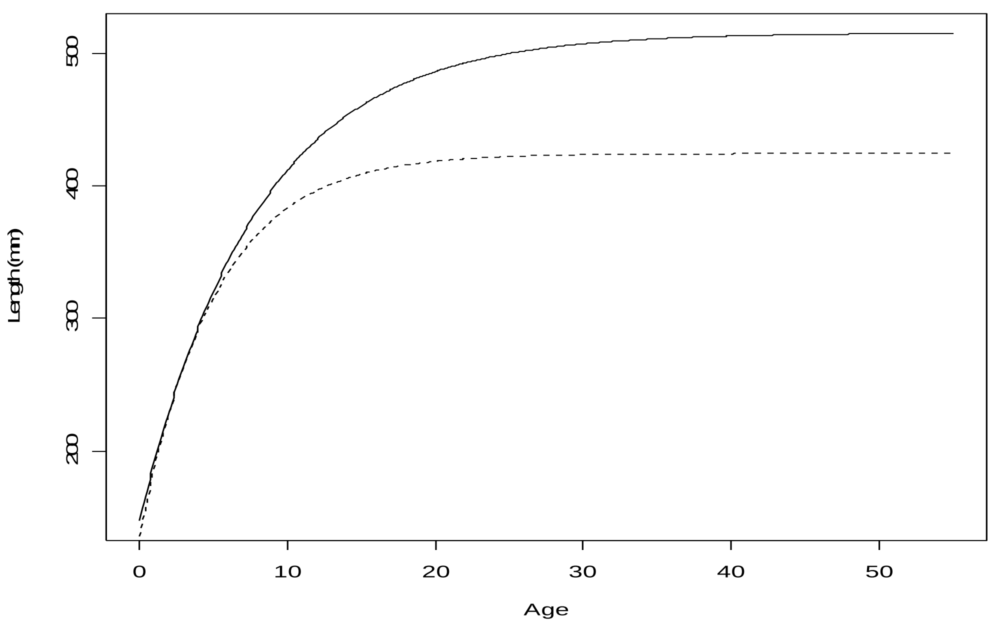

Figure A.4.2. Mean length at age estimated from the 1984 through 1996 survey combined(females solid line, males dotted line), used to estimate the length-age transition matrix.

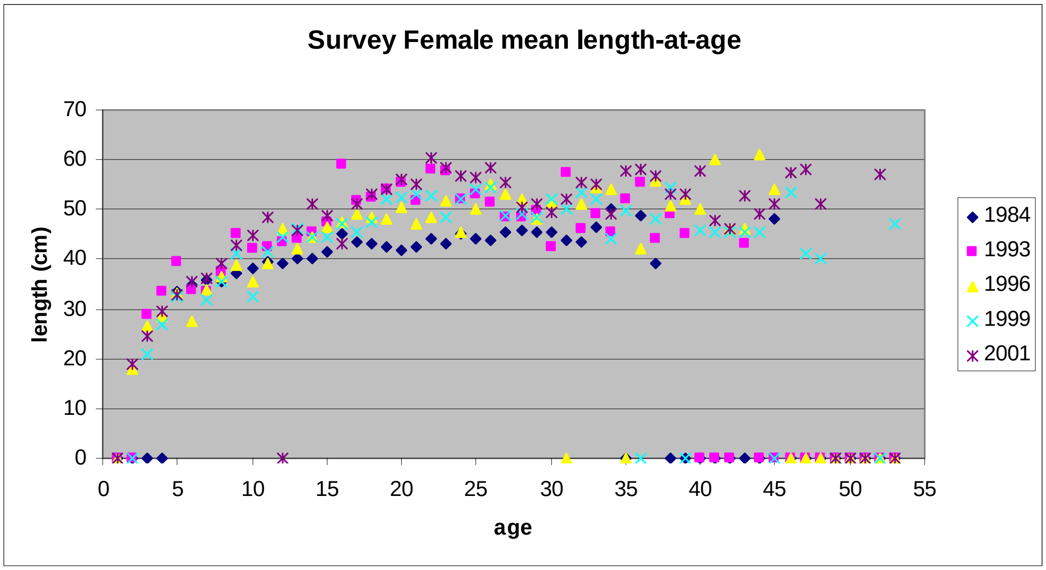

Figure A.4.3. Mean length at age for female Dover sole from survey data 1984 and 1993 to 2001.

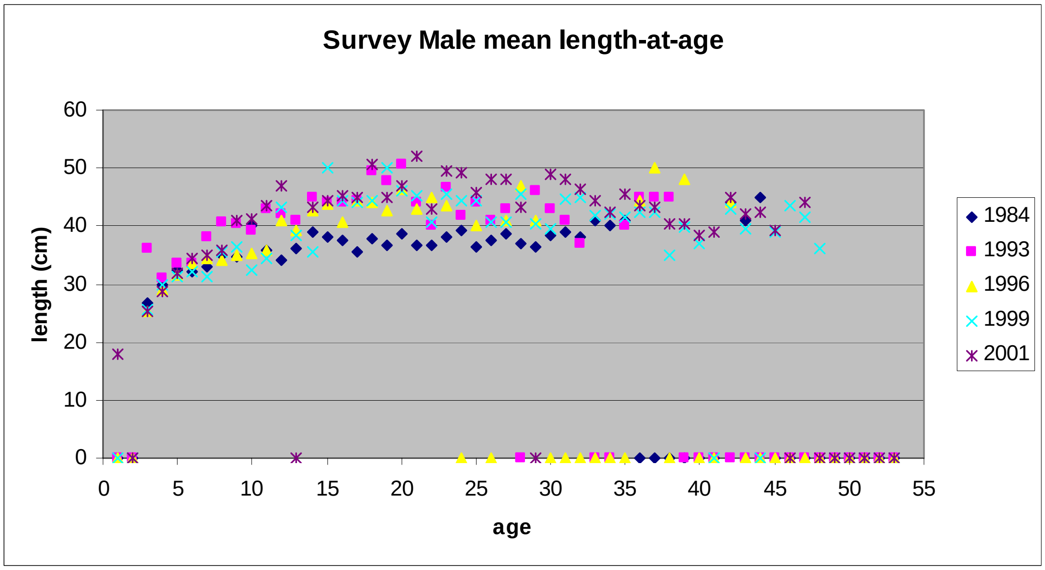

Figure A.4.4. Mean length at age for male Dover sole from survey data 1984 and 1993 to 2001.

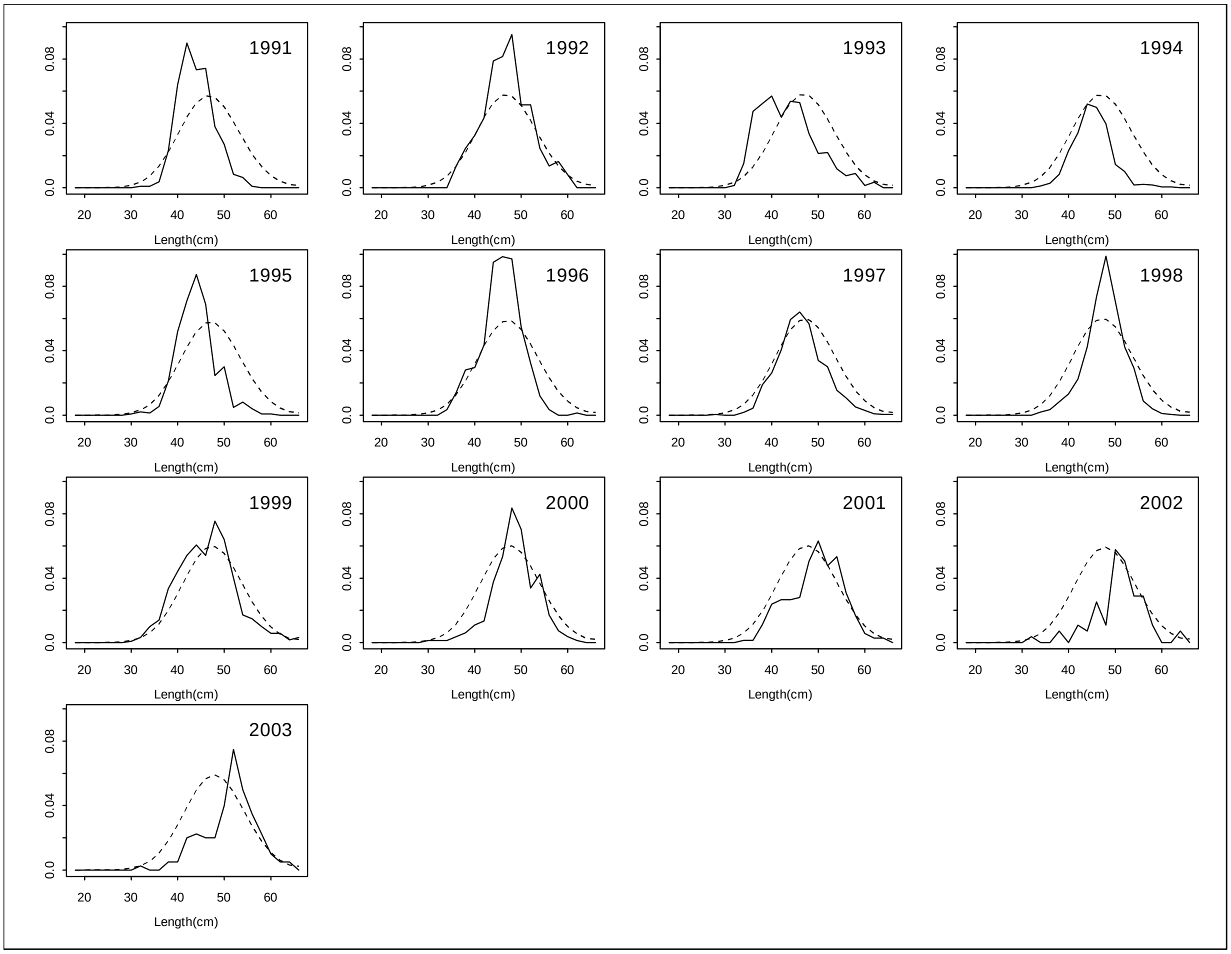

Figure A.4.5. Fit to the female fishery length composition data. Dotted line is predicted.

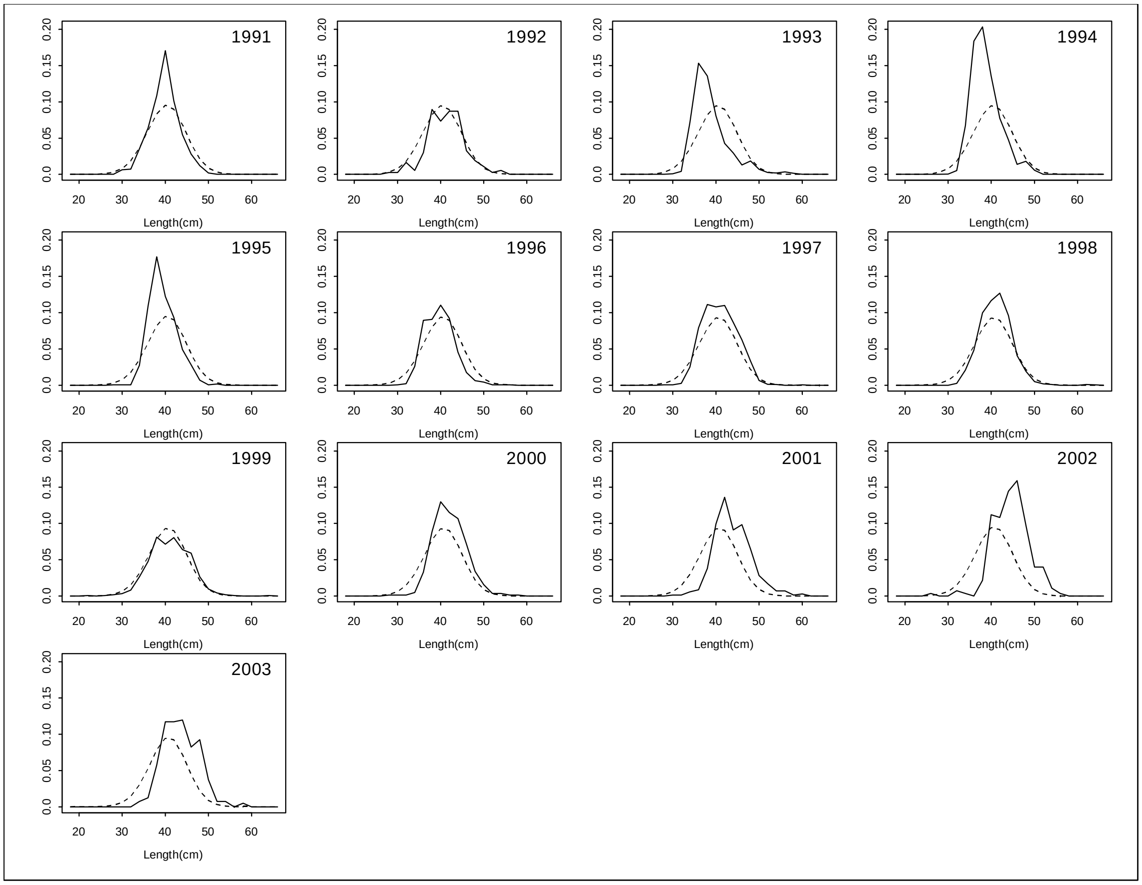

Figure A.4.6. Fit to the male fishery length composition data. Dotted line is predicted.

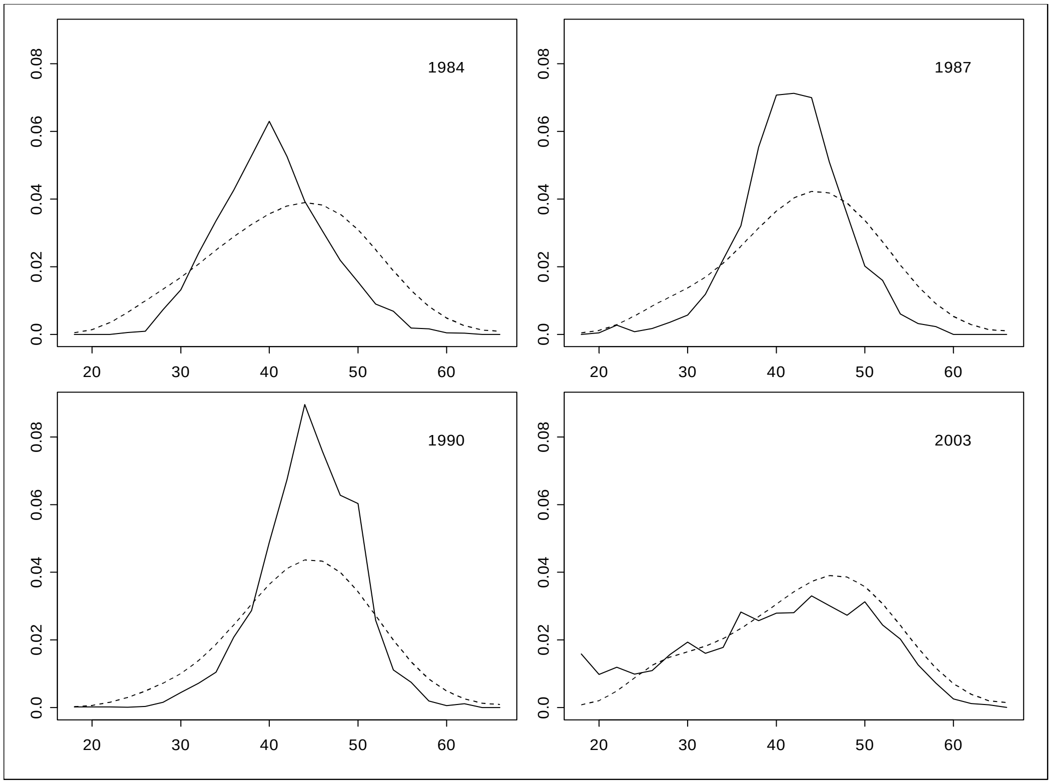

Figure A.4.7. Fit to the female survey length data. Dotted line is predicted.

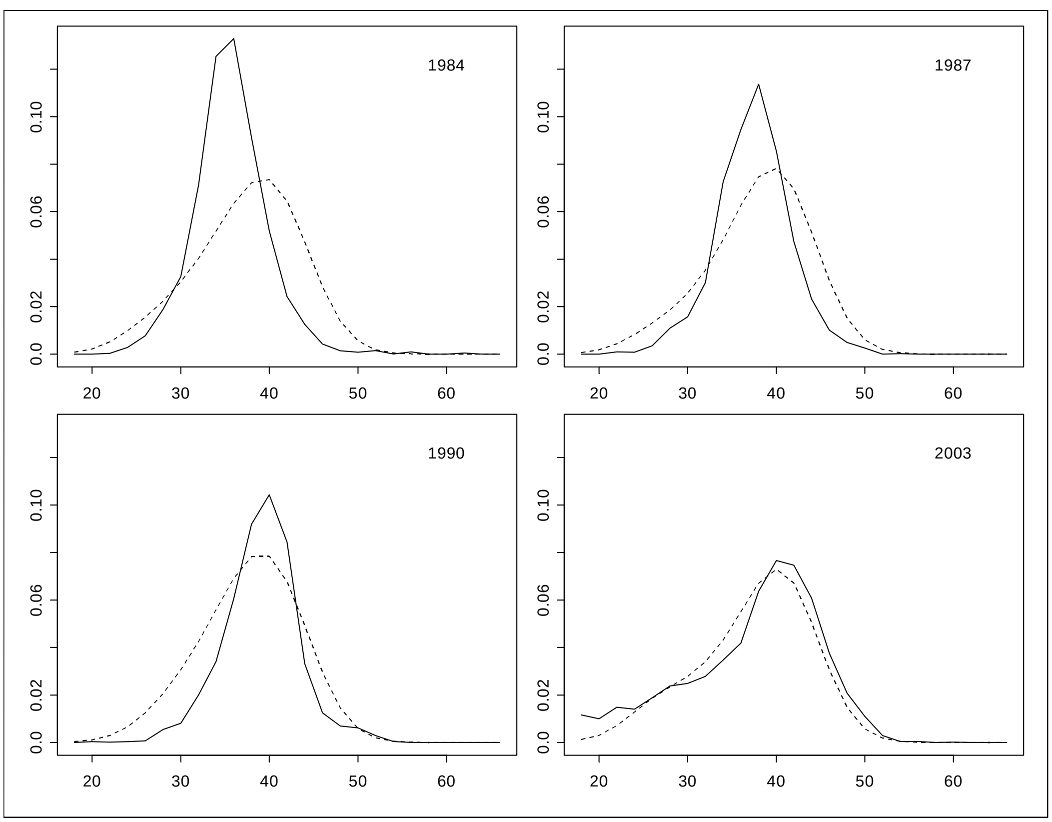

Figure A.4.8. Fit to the male survey length data. Dotted line is predicted.

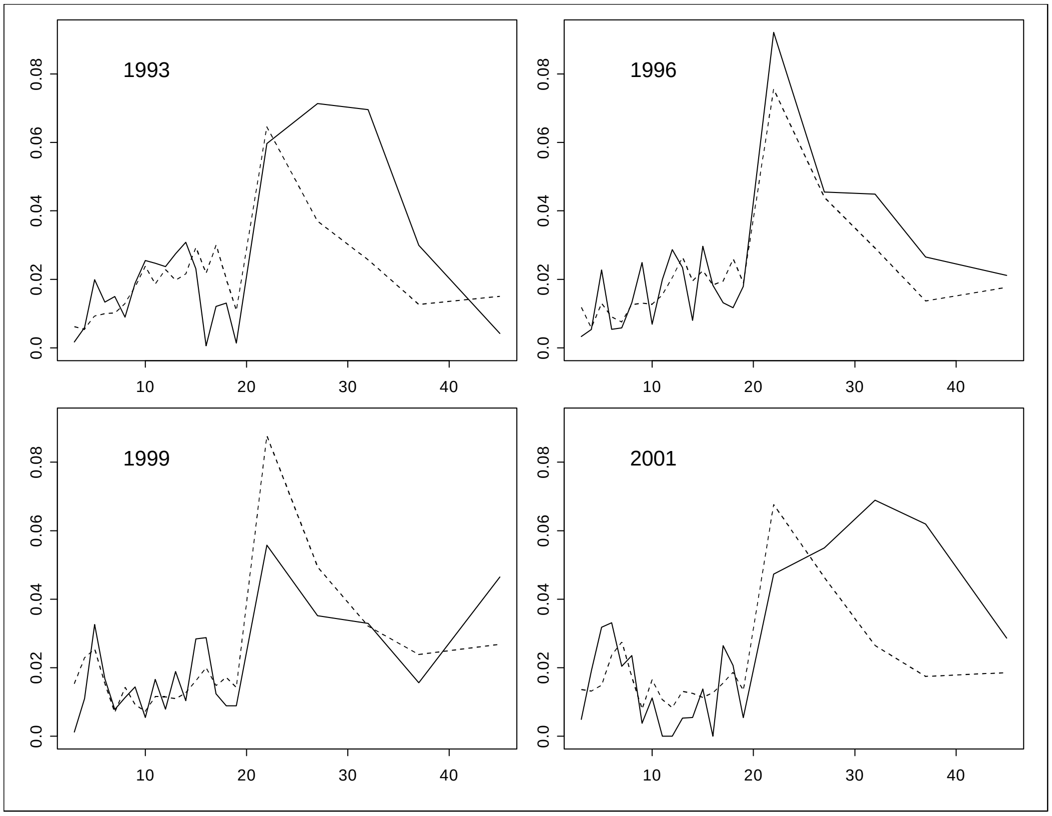

Figure A.4.9. Fit to the female survey age data. Age groups are 3 to 19 by 1 year and 5 year bins starting at 20-24. The last age group is 40+. Dotted line is predicted.

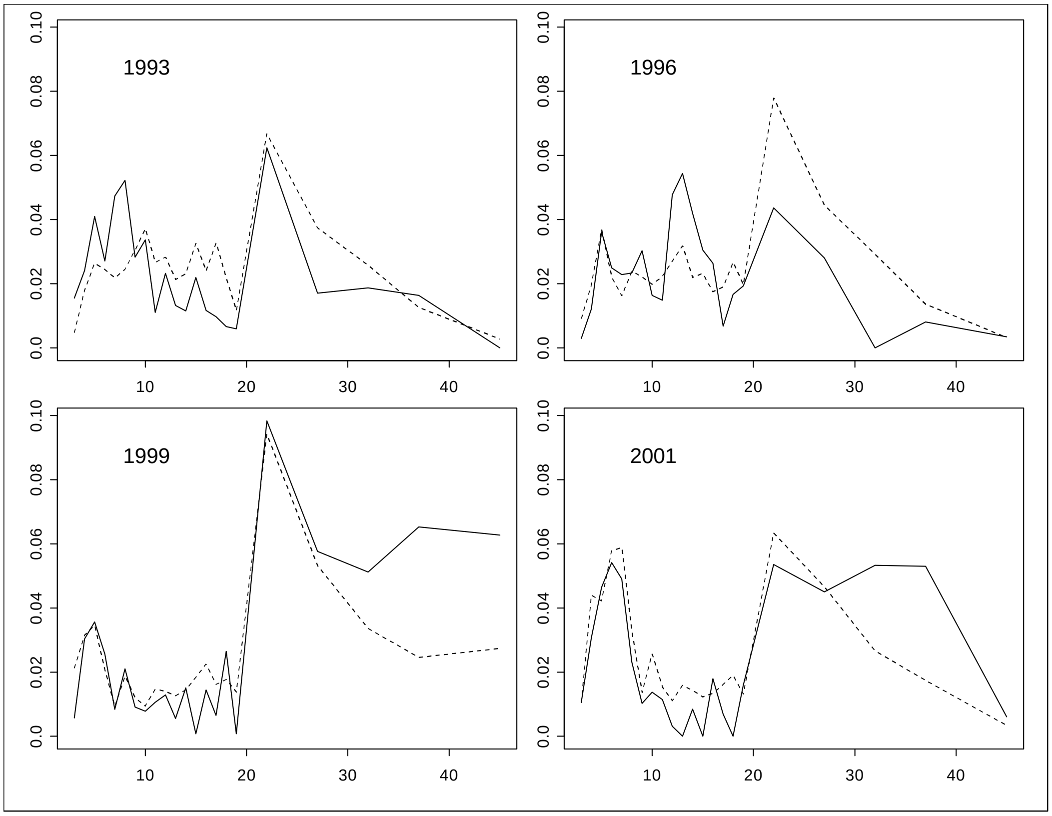

Figure A.4.10. Fit to the male survey age data. Age groups used for model fitting are age 3 to 19 years by 1 year and 5 year bins starting at age 20. The last age group is 40+. The dotted line is predicted.

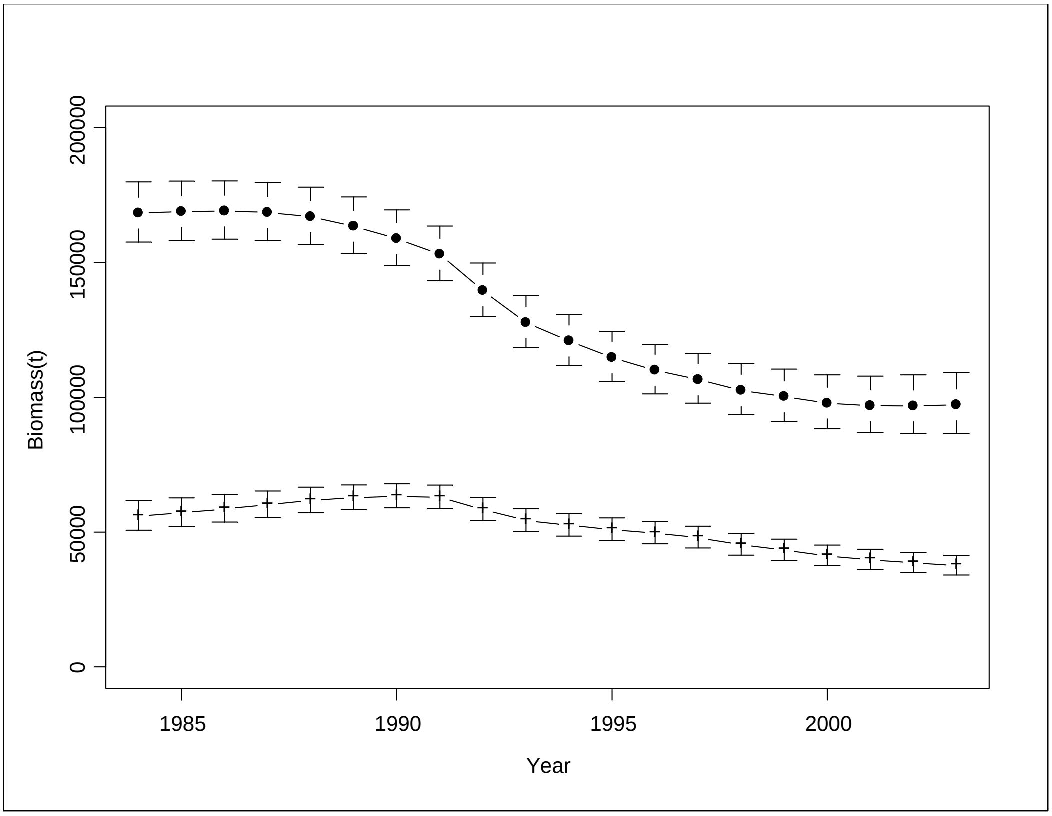

Figure A.4.11. Age 3+ biomass (solid line) and female spawning biomass (line with +) from 1984 to 2003. The approximate lognormal 95% confidence intervals shown underestimate the uncertainty because variance in natural mortality and survey Q as well as other fixed parameters are not accounted for.

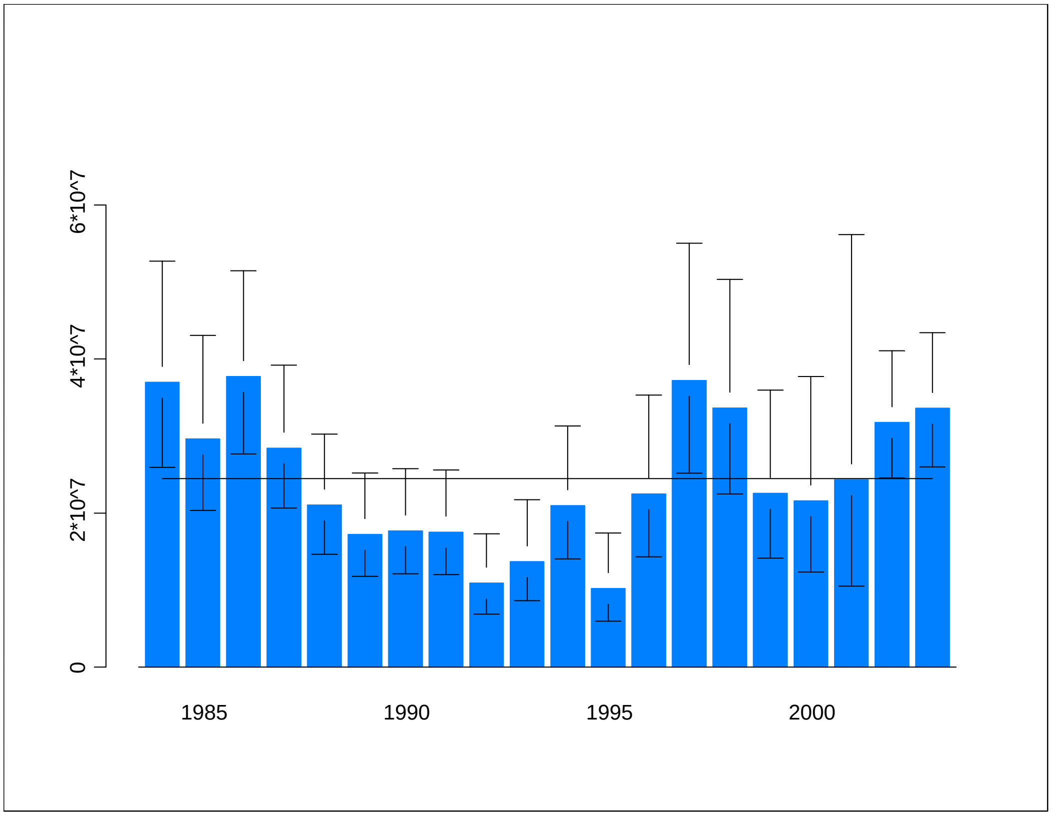

Figure A.4.12. Age 3 estimated recruitments (male plus female) in numbers from 1984 to 2003, with approximate 95% confidence intervals. Horizontal line is average recruitment.

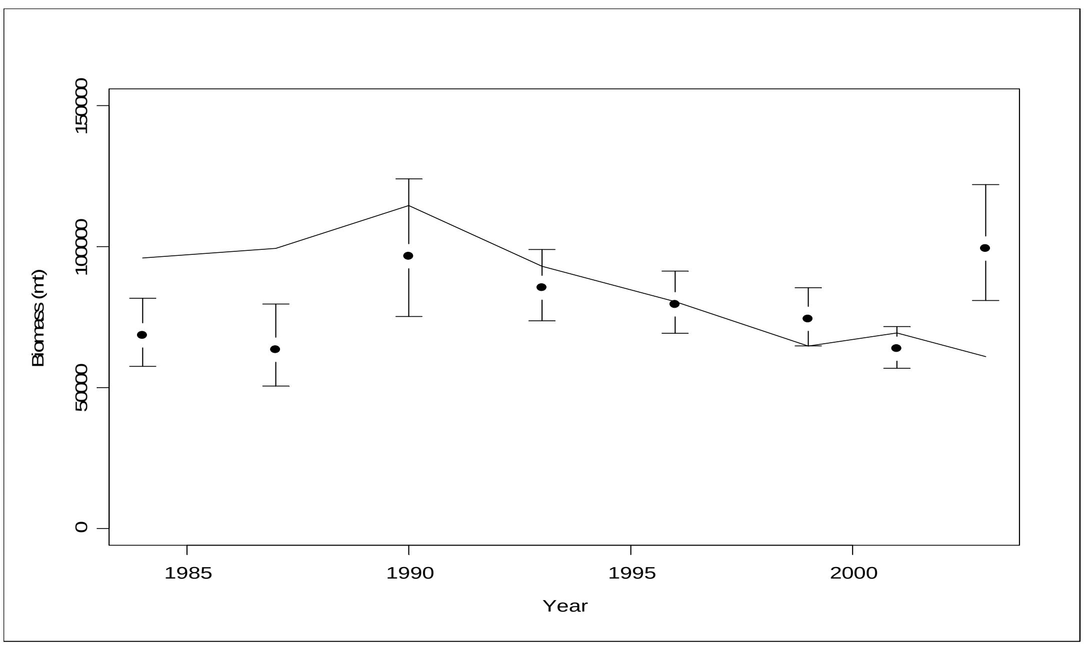

Figure A.4.13. Fit to survey biomass estimates with approximate 95% log-normal confidence intervals for the observed survey biomass estimates 1984 to 2003.

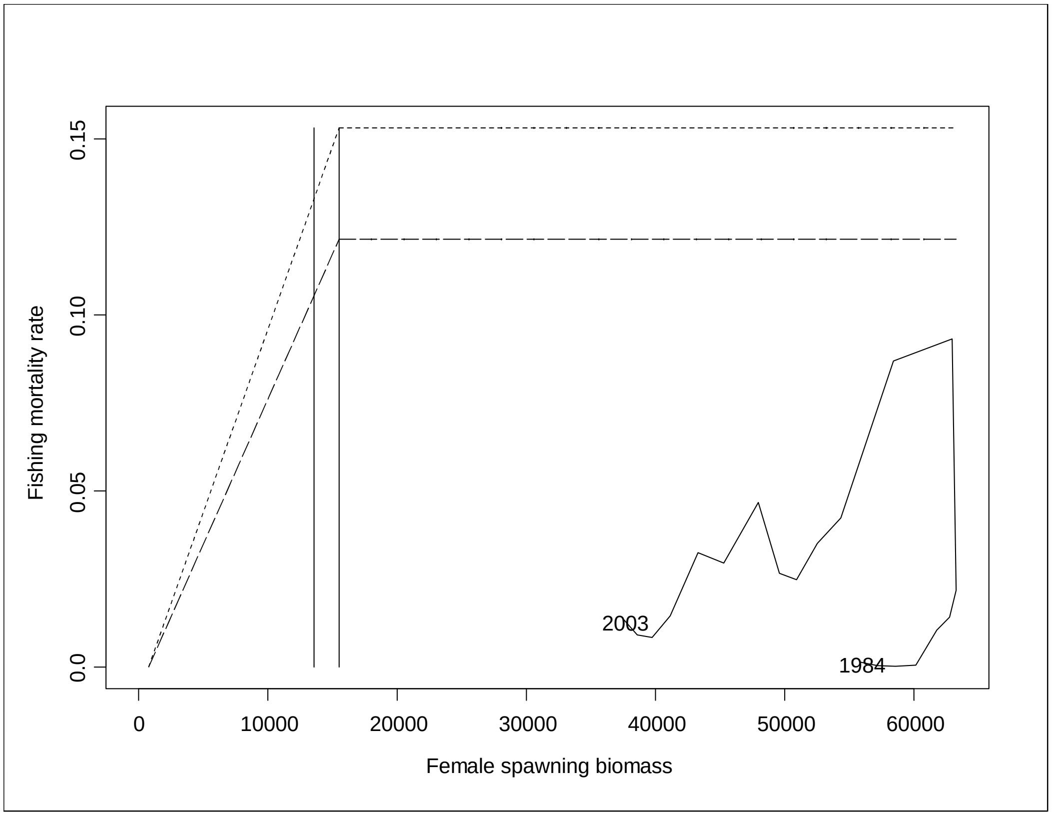

Figure A.4.14. Fishing mortality rate and female spawning biomass from 1984 to 2003 (solid line, start and end years labeled). Dotted line is the overfishing harvest control rule and the dashed line is the target harvest control rule. Vertical lines are B35% and B40%.

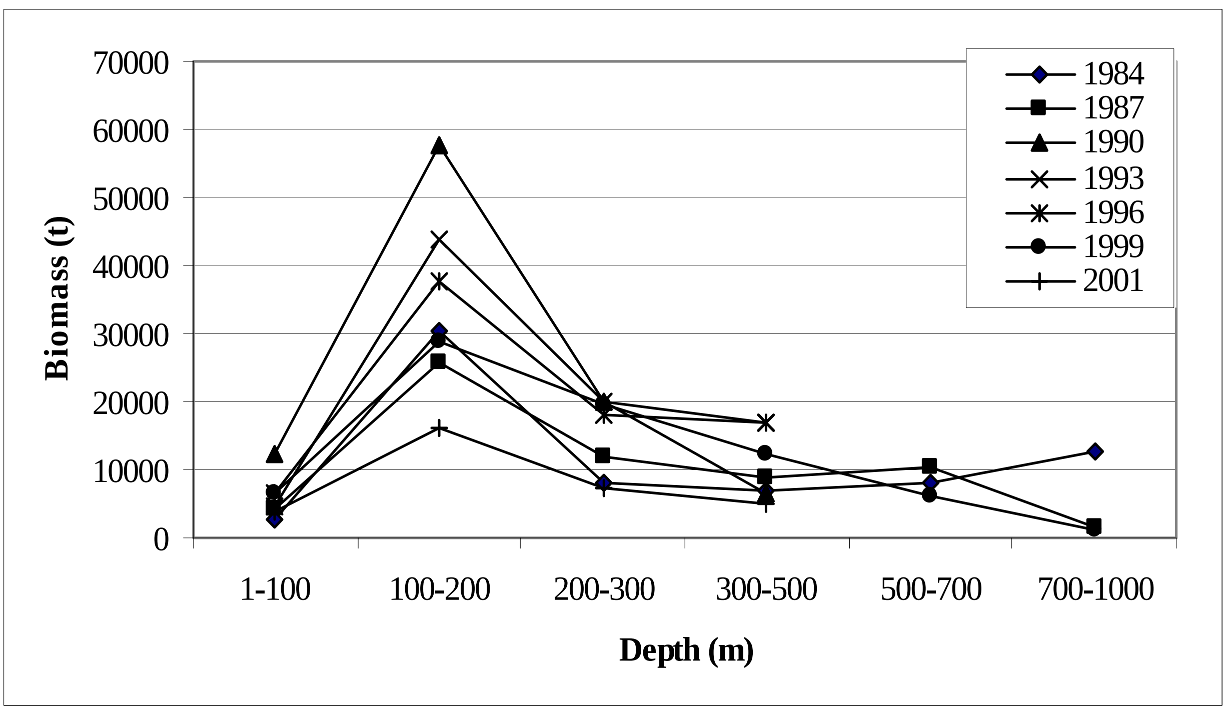

Figure A.4.15. Biomass by depth interval for trawl surveys.

Appendix A.

Table A.1. Model equations describing the populations 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			selectivity –ascending logistic for survey
$SB_t = Q \sum_{a=1}^{A} w_a s^{s}_{t,a} N_{t,a}$			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.
$\sum_{t=1}^{ts}\left[\frac{\log\left[\frac{SB_{obs,t}}{SB_{pred,t}}\right]}{sqrt(2)*s.d.(\log(SB_{obs,t}))}\right]^2$	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.

Variable	Definition
T	number of years in the model(t=1 is 1984 and t=T is 2003
A	number of age classes (A =38, corresponding to ages 3(a=1) to 40+)
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 Admodel builder model. There were 96 total parameters estimated in the model.

Parameter	Description
$\log(R_0)$	log of the geometric mean value of age 3 recruitment
τ_t $1984 \le t \le 2003$, plus 38 parameters for the initial age composition equals 58.	Recruitment deviation in year t
$\log(f_0)$	log of the geometric mean value of fishing mortality
ε_t $1984 \le t \le 2003$, 20 parameters	deviations in fishing mortality rate in year t
Slope and 50% for logistic function, 2 parameters	selectivity parameters for the fishery for males and females.
Slope and 50% for ascending and descending logistic function, 4 parameters	selectivity parameters for the shallow water survey for males and females.
Slope and 50% for logistic function, 2 parameters	selectivity parameters for the deep water survey for males and females.

Table A.5. Fixed parameters in the Admodel builder model.

Parameter	Description
M = 0.085 females , M=0.085 males	Natural mortality
Q = 1.0	catchability for surveys to 1000 m
Q=0.82	Catchability for surveys to 500 m
Q=0.42	Catchability for 2001 survey
L_{inf} , k , t_0,CV of length at age 2 and age 20 for males and females	von Bertalanffy Growth parameters estimated from the 1984-1996 survey length and age data.