CHAPTER 8

FLATHEAD SOLE

by

Paul D. Spencer, Gary E. Walters, and Thomas K. Wilderbuer

Executive Summary

The following changes have been made to this assessment relative to the November 2002 SAFE:

Changes in the input data

1) 2003 total catch through 20 September, 2003.
2) 2003 trawl survey biomass estimate and standard error.
3) 2003 length composition of the survey abundance.
4) 2000 and 2001 age composition of the fishery catch.
5) 2002 length composition of the fishery catch

Changes in assessment methodology

1) The relationship between temperature anomalies and survey biomass anomalies was investigated, and the survey catchability coefficient was modeled as function of temperature anomalies.

2) A Monte-Carlo Markov Chain algorithm was used to obtain estimates of uncertainty of modeled quantities.

Changes in assessment results

1) Estimated 3+ total biomass for 2004 is 470,319 t.
2) Projected female spawning biomass for 2004 is 204,886 t.
3) Recommended ABC for 2004 is 61,900 t based on an $F_{40\%}$ (0.30) harvest level.
4) 2004 overfishing level is 75,234 t based on a $F_{35\%}$ (0.37) harvest level.

The following summarizes our recommendations for flathead sole fisheries conservation measures.

	2002 Assessment recommendations for the 2003 harvest	2003 Assessment recommendations for the 2004 harvest
ABC	66,410 t	61,900 t
Overfishing	80,563 t	75,234 t
F_{ABC}	$F_{0.40} = 0.29$	$F_{0.40} = 0.30$
$F_{overfishing}$	$F_{0.35} = 0.35$	$F_{0.35} = 0.37$

Introduction

The flathead sole (*Hippoglossoides elassodon*) is distributed from northern California, off Point Reyes, northward along the west coast of North America and throughout Alaska (Hart 1973). In the northern part of its range it overlaps with the related and morphologically similar Bering Flounder (*Hippoglossoides robustus*) whose range extends north to the Chukchi Sea and into the western Bering Sea. The two species are very similar morphologically and at-sea identification is extremely difficult on the production schedule of the annual trawl survey. However, we feel there has been increasing accuracy during recent years. The growth and distribution differences between the species were described in Walters and Wilderbuer (1997), which illustrated the possible ramifications of combining information. For the purposes of this section, these two species are combined under the heading, *Hippoglossoides* sp.

Hippoglossoides sp. are managed as a unit stock in the Bering Sea and Aleutian Islands and were formerly a constituent of the "other flatfish" SAFE chapter. In June 1994, the Council requested the Plan Team to assign a separate ABC for flathead sole (*Hippoglossoides* sp.) in the BSAI, rather than combining flathead sole (*Hippoglossoides* sp.) with other flatfish as in past assessments. This request was based on a change in the directed fishing standards to allow increased retention of flatfish.

Catch History

Prior to 1977, catches of *Hippoglossoides* sp. were combined with the species of the "other flatfish" category, which increased from around 25,000 t in the 1960s to a peak of 52,000 t in 1971. At least part of this apparent increase was due to better species identification and reporting of catches in the 1970s. After 1971, catches declined to less than 20,000 t in 1975. Catches from 1977-89 averaged 5,286 t increasing to an annual average of 17,700 t from 1990-2002 (Table 8.1). The resource remains lightly harvested as the 2003 catch through 20 September is only 77% of the 2003 TAC of 17,000 t. The catch of flathead sole taken in research surveys from 1979-2003 are shown in Table 8.2.

Although flathead sole (*Hippoglossoides* sp.) receive a separate ABC and TAC they are still managed in the same PSC classification as rock sole and "other flatfish" and receive the same apportionments and seasonal allowances of bycaught prohibited species. In recent years, the flathead sole fishery has been closed prior to attainment of the TAC due to the bycatch of halibut (Table 8.3).

Substantial amounts of flathead sole are discarded overboard in various eastern Bering Sea target fisheries. Retained and discarded amounts are estimated for recent years using observer estimates of discard rate applied to the “blend” estimate of observer and industry reported retained catch (Table 8.4). A substantial portion of the discards in 2002 occurred in the Pacific cod, pollock, and rock sole fisheries.

Data

Fishery Catch and Catch-at-age Data

This assessment uses fishery catches from 1977 through 20 September, 2003 (Table 8.1), estimates of number caught by length group and sex for the years 1977-2001 and 2003 (Tables 8.5-8.6), and estimates of the numbers caught by age for 2001 and 2002.

Survey Data

Because *Hippoglossoides* sp. are often taken incidentally in target fisheries for other species, CPUE from commercial fisheries seldom reflect trends in abundance for these species. It is therefore necessary to use research vessel survey data to assess the condition of these stocks.

Survey estimates of total biomass and numbers by length group and sex for the years 1982-2003 are shown in Figure 8.1 and Tables 8.7-8.9. The survey gear changed after 1981, and as in previous assessments (Spencer et al. 1999) only the data from 1982 to the present are used. Since the early 1980s, estimated *Hippoglossoides* sp. biomass has approximately quadrupled to the 1997 peak estimate of 807,825 t (Figure 8.2). However, estimated biomass declined to 394,822 t in 1999 and 399,298 t in 2000, respectively, before increasing to 574,946 t in the 2002 survey. The estimated 2003 biomass level was 529,188 t.

Assessments for other BSAI flatfish have suggested a relationship between bottom temperature and survey catchability (Wilderbuer et al. 2002), where bottom temperatures are hypothesized to affect survey catchability by affecting either stock distributions and/or the activity level of flatfish. This relationship was investigated for flathead sole by using the temperature anomalies from data collected at all survey stations. Much of the trend in survey biomass estimates of flathead sole is expected to be explained by changes in stock biomass rather than survey catchability, and this trend was fit with a LOWESS smoother. The residuals from the smoothed trend produce a detrended estimate of survey biomass, which was then standardized and compared to the bottom temperature anomalies (Figure 8.2). A two time series are closely related from 1998 to 2003, including the unusually cold year in 1999 when both indices reached a low point. The cross correlation coefficient of 0.42 was significant at the 0.05 level, and the relationship between bottom temperature and survey catchability was pursued in the model fitting procedure.

In the 2001 flathead sole assessment, an evaluation of temporal changes in length at age was made based upon data from the 1982, 1985, 1992, 1994, 1995 and 2000 EBS shelf surveys (Spencer et al . 2001). This examination of growth rates was motivated by the finding of temporal variability in growth for some flatfish species, such as rock sole and Pacific halibut. The size-at-age data for flathead sole were similar across years, leading to the conclusion that a single growth curve across all year could adequately represent the data. The estimated parameters were

Von Bertalanffy growth parameters

Sex	t_0	l_{inf}	**K**
Male (n=1148)	-0.42	39.70	0.15
Female (n=1371)	-0.79	54.93	0.09

A length (cm) – weight (g) relationship of the form $W = aL^b$ was also fit to *Hippoglossoides* sp. survey data, with the estimated parameters of a = 0.00326 and b = 3.3 applying to both sexes.

In summary, the data available for flathead sole are

1) Total catch weight, 1982-2003;
2) Proportional catch numbers by length group, 1982-2001, 2003;
3) Fishery age composition, 2001-2002;
4) Survey biomass and standard error, 1982-2003;
5) Survey age composition 1982, 1985, 1992, 1995, and 2000;
6) Proportional survey numbers by length group, 1983-1984,1986-1991,1993-1994,1996-1999, and 2001-2003.

Analytical Approach

Model Structure

The assessment model has a length-based formulation, which is underlaid by an age-based model. A transition matrix (**TR**) is used to convert the selectivity at length to selectivity at age, and to convert the predicted catch and numbers at age to catch and numbers at length.

An age-structured, split-sex population dynamics model was used to obtain estimates of recruitment, numbers at age, and catch at age for each sex. Population size in numbers at age a in year t for sex s was modeled as

$$N_{s,t,a} = N_{s,t-1,a-1} e^{-Z_{s,t-1,a-1}} \qquad 4 \le a < A, \quad 2 \le t \le T$$

where Z is the sum of the instantaneous fishing mortality rate ($F_{s,t,a}$) and the natural mortality rate (M_s), A is the maximum number of ages in the population, and T is the terminal year of the analysis (2001). The numbers at age A are a "pooled" group consisting of fish of age A and older, and are estimated as

$$N_{s,t,A} = N_{s,t-1,A-1} e^{-Z_{s,t-1,A-1}} + N_{t-1,A} e^{-Z_{s,t-1,A}}$$

The total numbers of age 3 fish over all years are estimated as parameters in the model, and modeled with a lognormal distribution

$$N_{t,3} = e^{(\mu_R + \nu_t)}$$

where ν is a time-variant deviation. The number of recruits is divided equally between males and females. The numbers at age in the first year are modeled to be in equilibrium with an historical catch of 1500 t, and requires estimation of a historic recruitment parameter (R_0) and a historic fishing mortality rate (f_{hist}).

The fishing mortality rate for a specific age and time ($F_{t,a}$) is modeled as the product of a fishery age-specific selectivity function (*fishasel*) and a year-specific fully-selected fishing mortality rate f. The fully selected mortality rate is modeled as the product of a mean (μ_f) and a year-specific deviation (ϵ_t), thus $F_{t,a}$ is

$$F_{t,a} = fishasel_a * f_t \equiv fishasel_a * e^{(\mu_f + \varepsilon_t)}$$

The fishery selectivity at age is obtained from the selectivity at length and the transition matrix $\mathbf{TR_s}$, where the transition matrix $\mathbf{TR_s}$ indicates the proportion of each age (rows) in each length group (columns) for each sex; the sum across each age is equal to one. Because of growth differences between the sexes, there is a separate transition matrix and age –based selectivity vector for each sex; these matrices were computed as described above. The selectivity at age vector is computed from the fishery selectivity at length vector (**fishlsel**) as

$$\mathbf{fishasel_s} = \mathbf{TR_s} * \mathbf{fishlsel}$$

Finally, the selectivity at length vector, assumed identical for each sex, was modeled as

$$fishlsel_l = \frac{1}{1+e^{-slope(l-fifty)}}$$

where the parameter *slope* affects the steepness of the curve and the parameter *fifty* is the length at which $fishlsel_l$ equals 0.5. There are 24 length bins ranging from 6 to 58 cm, and 19 age groups ranging from 3 to 21+. The age- and length-based selectivity for the survey is modeled in a similar manner.

The mean numbers at age for each year and sex were computed as

$$\overline{N}_{s,t,a} = N_{s,t,a} * (1-e^{-Z_{s,t,a}}) / Z_{s,t,a}$$

The transition matrix and vector of mean numbers at age were used to compute the vector of mean numbers at length, by sex and year, as

$$\overline{\mathbf{NL}}_{s,t} = \overline{\mathbf{NA}}_{s,t} * \mathbf{TR}_s^{\mathbf{T}}$$

The vector of mean numbers at length was used to compute the catch as

$$C_{l,s,t} = \overline{NL}_{l,s,t} * fishlsel_l * f_t$$

$$pred\_cat_t = \sum_{l,s} C_{l,s,t} * FW_{l,s}$$

where $FW_{l,s}$ is the fishery weights by length and sex, and *pred_cat* is the predicted catch from the model. Similarly, the predicted survey biomass (*pred_biom*) is computed as

$$pred\_biom_t = qsurv \sum_{l,s} \left(NL_{l,s,t} * survlsel_l * PW_{l,s} \right)$$

where $PW_{l,s}$ is the population weight by length and sex, and *qsurv* is the trawl survey catchability.

The effect of temperature on survey catchability was modeled as

$$qsurv_t = e^{q\_a + q\_b * temp_i}$$

where the survey catchability in year *t* is a function of the temperature anomaly in year *t*, with parameters *q_a* and *q_b* being potentially estimable within the model from the model. In practice, it was found that *q_a* was not estimable from the data and was fixed at 0.0, corresponding to a mean survey selectivity of 1.0 (consistent with previous assessments).

Finally, age composition data are assumed to be unbiased, but with some aging error. The distribution of read ages around the “true” age is assumed to be normal with a variance of 0.02 times the true age, resulting in a coefficient of variation of 0.14. The vector of mean number of fish by age available to the survey is multiplied by the aging error matrix in order to produce the observed survey age compositions.

Parameters Estimated Independently

The parameters estimated independently include the age error matrix, the transition matrix, individual weight at length, the mean survey selectivity (as described above), and the natural mortality. The age error matrix was taken directly from the stock synthesis model used in previous assessments. The individual weights at age were obtained from trawl survey data, whereas *M* was fixed at 0.2, consistent with recent assessments.

Parameters Estimated Conditionally

Parameter estimation is facilitated by comparing the model output to several observed quantities, such as the age compositions of the survey, length composition of the fishery and survey catches, the survey biomass, and the catch biomass. The general approach is to assume that deviations between model estimates and observed quantities are attributable to observation error and can be described with statistical distributions. Each data component provides a contribution to a total log-likelihood function, and parameter values that minimize the log-likelihood are selected.

The log-likelihood of the initial recruitments were modeled with a lognormal distribution

$$\lambda_1 \sum_t \frac{\left(\nu_t + \frac{\sigma^2}{2}\right)^2}{2\sigma^2} + n\ln(\sigma)$$

where σ is a parameter representing the standard deviation of recruitment, respectively, on a log scale. The adjustment of adding $\sigma^2/2$ to the deviation was made to correct for bias and produce deviations from the mean, rather than the median, recruitment.

The log-likelihoods of the fishery and survey age and length compositions were modeled with a multinomial distribution. The log of the multinomial function (excluding constant terms) for the fishery length composition data, with the addition of a term that scales the likelihood, is

$$n_{f,s,t,l} \sum_{s,t,l} p_{f,s,t,l} \ln(\hat{p}_{f,s,t,l}) - p_{f,s,t,l} \ln(p_{f,s,t,l})$$

where *n* is the number of fish aged, and $p_{f,s,t,l.}$ and $\hat{p}_{f,s,t,l}$ are the observed and estimated proportion at length in the fishery by sex, year and length. The likelihood for the age and length proportions in the survey, $p_{surv,s,t,a}$ and $p_{surv,s,t,l}$, respectively, follow similar equations.

The log-likelihood of the survey biomass was modeled with a lognormal distribution:

$$\lambda_2 \sum_t (\ln(obs\_biom_t) - \ln(pred\_biom_t))^2 / 2cv_t^2$$

where obs_biom_t is the observed survey biomass at time *t*, cv_t is the coefficient of variation of the survey biomass in year *t*, and λ_2 is a weighting factor.

The log-likelihood of the catch biomass was modeled with a lognormal distribution:

$$\lambda_3 \sum_t (\ln(obs\_cat_t) - \ln(pred\_cat_t))^2$$

where obs_cat_t and $pred\_cat_t$ are the observed and predicted catch. Because the catch biomass is generally thought to be observed with higher precision that other variables, λ_3 was given a very high weight so as to fit the catch biomass nearly exactly. This can be accomplished by varying the *F* levels, and the deviations in *F* are not included in the overall likelihood function. The overall negative log-likelihood function (excluding the catch component) is

$$\lambda_1 \left(\sum_t \left(\frac{(\nu_t + \sigma^2/2)^2}{2\sigma^2} \right) + n\ln(\sigma) \right) +$$

$$\lambda_2 \sum_t (\ln(obs\_biom_t) - \ln(pred\_biom_t))^2 / 2 * cv_t^2 +$$

$$n_{f,s,t,l} \sum_{s,t,l} p_{f,s,t,l} \ln(\hat{p}_{f,s,t,l}) - p_{f,s,t,l} \ln(p_{f,s,t,l}) +$$

$$n_{surv,s,t,a} \sum_{s,t,a} p_{surv,s,t,a} \ln(\hat{p}_{surv,s,t,a}) - p_{surv,s,t,a} \ln(p_{surv,s,t,a}) +$$

$$n_{surv,s,t,l} \sum_{s,t,a} p_{surv,s,t,l} \ln(\hat{p}_{surv,s,t,l}) - p_{surv,s,t,l} \ln(p_{surv,s,t,l}) +$$

$$\lambda_3 \sum_t (\ln(obs\_cat_t) - \ln(pred\_cat_t))^2$$

For the model run in this analysis, λ_1, λ_2, and λ_3 were assigned weights of 1,1, and 500, respectively, and *n* was set to 200 for the age and length composition data. The likelihood function was minimized by varying the following parameters:

Parameter type	Number
1) fishing mortality mean (μ_f)	1
2) fishing mortality deviations (ϵ_t)	27
3) recruitment mean (μ_r)	1
4) recruitment deviations (ν_t)	27
5) historic recruitment (R_0)	1
6) historic fishing mortality (f_{hist})	1
7) fishery selectivity parameters	2
8) survey selectivity parameters	2
9) survey catchability parameters	1
Total parameters	63

Finally, a Monte Carlo Markov Chain (MCMC) algorithm was used to obtain estimates of parameter uncertainty (Gelman et al. 1995). One million MCMC simulations were conducted, with every 1,000th sample saved for the sample from the posterior distribution. Ninety-five percent confidence intervals were produced as the values corresponding to the 5th and 95th percentiles of the MCMC evaluation. For this assessment, confidence intervals on total biomass, spawning biomass, and recruitment strength are presented.

Model Results

The utility of temperature anomaly data in fitting the survey biomass trend can be seen in the Figure 8.3, which compares the survey fit both with and without use of the temperature data. The two models track each other fairly closely until about 1996, at which point the model incorporating temperature-driven variations in survey catchability appear to correspond more closely to the observed survey biomass levels. Although neither model matches the high biomass levels of 1994,1997, and 1998, the sharp decline from the 1998 survey biomass estimate to the 1999 survey biomass estimate is more closely matched by including the temperature data, as well as the higher survey biomass levels from 2001-2003. A significant reduction in the negative log-likelihood is achieved with the inclusion of the additional parameter to fit the temperature anomalies, and this model fit was used in for the subsequent analyses

The model results show that estimated total biomass (ages 3+) increased from a low of 138,937 t in 1977 to a peak of 786,122 t in 1993 (Figure 8.4, Table 8.10). Since 1993, estimated total biomass has declined to an estimated value of 470,319 t for 2003. Female spawning biomass shows a similar trend, although the peak value (328,834 t) occurred in 1996.

The model provided a good fit to the survey size compositions for the past 10 years for females and males as shown Figures 8.5 and 8.6. Reasonable fits also resulted for fishery size composition observations (Figures 8.7 and 8.8) and the survey age composition (Figures 8.9 and 8.10). The best fit to the size and age composition data was achieved with the survey length compositions, which resulted in an average effective *n* of 319 and 223 for females and males, respectively, exceeding the input weights of 200. The fishery age composition data (Figure 8.11 and 8.12) is new for this assessment, and produced an average effective *n* of 69 and 124 for the female and male data, respectively. The limited data (2 years) for the fishery age compositions is likely related to the lack of fit.

The changes in stock biomass are primarily a function of recruitment, as fishing pressure has been relatively light. The fully selected fishing mortality estimates remain small, and have averaged 0.055 from 1990 to 2002 (Figure 8.13), and the fishery shows little selectivity for flathead sole less that 30 cm (Figure 8.14). Estimated recruitment at age 3 has generally been higher during the early portion of the data series, averaging 8.3×10^8 for the 1975-1988 year classes, and 3.9×10^8 for the 1989-2000 year classes (Figure 8.15). The scattterplot of stock and recruitment data reveals a decreasing trend in recruitment with an increasing trend in spawner biomass (Figure 8.16). The survey size composition from 1994-2003 indicates that the proportion of fish at smaller sizes is reduced from the high recruitment years of the 1980s, corresponding to the declines in recruitment and estimated biomass.

The extent to which the density-dependence observed in the scatterplot of spawer-recruit data (Figure 8.16) is affected by environmental conditions is unresolved. For example, a series of high spawner stock biomasses and low recruitments were observed for the post-1988 year classes, coinciding with changes in the environmental indices such as the Aleutian low pressure index (Hare and Mantua 2000). Stock-recruitment analyses that consider this environmental variability are a high priority for future flathead sole research.

Projections and Harvest Alternatives

The reference fishing mortality rate for flathead sole is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{0.40}$, $F_{0.35}$, and $SPR_{0.40}$ were obtained from a spawner-per-recruit analysis. Assuming that the average recruitment from the 1977-2000 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{0.40}$ is calculated as the product of $SPR_{0.40}$ * equilibrium recruits, and this quantity is 119,124 t. The year 2004 spawning stock biomass is estimated as 204,886 t. Since reliable estimates of the 2003 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B>B_{0.40}$ (204,886 t > 119,124 t), flathead sole reference fishing mortality is defined in tier 3a. For this tier, F_{ABC} is constrained to be ≤ $F_{0.40}$, and F_{OFL} is defined to be $F_{0.35}$. The values of these quantities are:

2004 SSB estimate (B)	=	204,886 t
$B_{0.40}$	=	119,124 t
$F_{0.40}$	=	0.300
F_{ABC}	≤	0.300
$F_{0.35}$	=	0.373
F_{OFL}	=	0.373

The estimated catch level for year 2004 associated with the overfishing level of F = 0.373 is 75,234 t. Because the flathead sole stock has not been overfished in recent years and the stock biomass is relatively high, it is not recommended to adjust F_{ABC} downward from it upper bound; thus, the year 2004 recommended ABC associated with F_{ABC} of 0.300 is 61,900 t.

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 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 2003. (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 1998-2002 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.)

The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, and five-year projections of the mean harvest and spawning stock biomass for the remaining four scenarios are shown in Table 8.11.

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the flathead sole stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY level in 2004, 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 2006 under this scenario, then the stock is not approaching an overfished condition.)

The results of these two scenarios indicate that the flathead sole are neither overfished or approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2004 of scenario 6 is 1.95 times its $B_{35\%}$ value of 104,234 t. With regard to whether the stock is likely to be in an overfished condition in the near future, the expected stock size in the year 2004 of scenario 7 is 1.24 times its $B_{35\%}$ value.

Ecosystem considerations

Flathead sole feed upon a variety of species, including walleye pollock and other miscellaneous fish, brittlestars, polychaetes, and crustaceans. The proportion of the diet composed of fish appears to increase with flathead sole size (Lang et al. 2003). The population of walleye pollock has fluctuated but remained relatively stable over the past twenty years. Information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not be re-sampled since. The large populations of flatfish which have occupied the middle shelf of the Bering Sea over the past twenty years for summertime feeding do not appear food-limited. These populations have fluctuated due to the variability in recruitment success which suggests that the primary infaunal food source has been at an adequate level to sustain the flathead sole resource.

Limited data exists on the predators of flathead sole, but survey sampling from 1993-1996 indicates that Pacific cod, arrowtooth flounder, and skates are common predators. Arrowtooth flounder appear to feed upon intermediate-sized fish (8-18 cm), whereas skates feed upon larger fish (15-20 cm) and Pacific cod feed upon a wide range of sizes (Lang et al. 2003).

Changes in the physical environment which may affect flathead sole distribution patterns, recruitment success, migration timing and patterns and are catalogued in the Ecosystem Considerations Appendix of this SAFE report. Habitat quality may be enhanced during years of favorable cross-shelf advection (juvenile survival) and warmer bottom water temperatures with reduced ice cover (higher metabolism with more active feeding).

Sculpins and skates appear as bycatch in the flathead sole fishery, due to its location near the EBS slope. In 2002, the flathead sole fishery accounted for 16% and 11% of the sculpin and skate bycatch, respectively, in the EBS management area.

Summary

In summary, several quantities pertinent to the management of the flathead sole are listed below.

Quantity	Value
M	0.20
Tier	3a
Year 2004 Total Biomass	470,319 t
Year 2004 Spawning stock biomass	204,886 t
$B_{100\%}$	297,810 t
$B_{40\%}$	119,124 t
$B_{35\%}$	104,234 t
F_{OFL}	0.373
Maximum F_{ABC}	0.300
Recommended F_{ABC}	0.300
OFL	75,234 t
Maximum allowable ABC	61,900 t
Recommended ABC	61,900 t

References

Gelman, A., J.B. Carlin, H.S. Stern, and D.A. Rubin. 1995. Bayesian data analysis. Chapman and Hall, New York. 552 pp.

Haflinger, K. 1981. A survey of benthic infaunal communities of the southeastern Bering Sea shelf. In D.W Hood and J.A. Calder (eds), The eastern Bering Sea shelf: oceanography and resources. Univ. of Wash. Press, Seattle, pp 1091-1104.

Hare, S.R and N.J. Mantua. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progress in Oceanography 47:103-145.

Hart, J. L. 1973. Pacific fishes of Canada. Canadian Government Publishing Centre, Supply and Services Canada, Ottawa, Canada KIA OS9.

Hilborn, R. and M. Mangel. 1997. The ecological detective: confronting models with data. Princeton University Press, Princeton, NJ. 315 pp.

Lang, G.M., C.W. Derah, and P.A. Livingston. 2003. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1993 to 1996. U.S. Dep. Commer., AFSC Proc. Rep. 2003-04. 351 pp.

Spencer, P.D., Walters, G. E., and T. K. Wilderbuer. 1999. Flathead sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 1999, p.391-430. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage Alaska 99510

Walters, G. E., and T. K. Wilderbuer. 1997. Flathead sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 1998, p.271-295. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage Alaska 99510.

Table 8.1. Harvest (t) of flathead sole from 1977-2003.

Year	Catch Biomass
1977	7909
1978	6957
1979	4351
1980	5247
1981	5218
1982	4509
1983	5240
1984	4458
1985	5636
1986	5208
1987	3595
1988	6783
1989	3604
1990	20245
1991	15602
1992	14239
1993	13664
1994	18455
1995	14707
1996	17344
1997	20704
1998	24397
1999	17842
2000	19983
2001	17586
2002	15108
2003	13066

*NMFS Regional Office Report through September 20, 2003

Table 8.2. Research catches (t) of flathead sole in the BSAI area from 1979 to 2003.

Year	Research Catch (t)
1979	11.85
1980	6.19
1981	11.23
1982	20.36
1983	13.86
1984	13.51
1985	44.83
1986	13.79
1987	12.97
1988	29.86
1989	24.60
1990	26.76
1991	35.92
1992	18.92
1993	21.86
1994	30.23
1995	26.52
1996	20.87
1997	30.31
1998	23.02
1999	16.82
2000	19.09
2001	18.50
2002	26.89
2003	18.49

Table 8.3. Restrictions on the flathead sole fishery from 1994 to 2001 in the Bering Sea – Aleutian Islands management area. Unless otherwise indicated, the closures were applied to the entire BSAI management area. Zone 1 consists of areas 508, 509, 512, and 516, whereas zone 2 consists of areas 513, 517, and 521.

Year	Dates	Bycatch Closure
1994	2/28 – 12/31	Red King crab cap (Zone 1 closed)
	5/7 – 12/31	Bairdi Tannner crab (Zone 2 closed)
	7/5 – 12/31	Annual halibut allowance
1995	2/21 – 3/30	First Seasonal halibut cap
	4/17 – 7/1	Second seasonal halibut cap
	8/1 – 12/31	Annual halibut allowance
1996	2/26 – 4/1	First Seasonal halibut cap
	4/13 – 7/1	Second seasonal halibut cap
	7/31 – 12/31	Annual halibut allowance
1997	2/20 – 4/1	First Seasonal halibut cap
	4/12 – 7/1	Second seasonal halibut cap
	7/25 – 12/31	Annual halibut allowance
1998	3/5 – 3/30	First Seasonal halibut cap
	4/21 – 7/1	Second seasonal halibut cap
	8/16 – 12/31	Annual halibut allowance
1999	2/26 – 3/30	First Seasonal halibut cap
	4/27 – 7/04	Second seasonal halibut cap
	8/31 – 12/31	Annual halibut allowance
2000	3/4 – 3/31	First Seasonal halibut cap
	4/30 – 7/03	Second seasonal halibut cap
	8/25 – 12/31	Annual halibut allowance
2001	3/20 – 3/31	First Seasonal halibut cap
	4/27 – 7/01	Second seasonal halibut cap
	8/24 – 12/31	Annual halibut allowance
2002	2/22 – 12/31	Red King crab cap (Zone 1 closed)
	3/1 – 3/31	First Seasonal halibut cap
	4/20 – 6/29	Second seasonal halibut cap
	7/29 – 12/31	Annual halibut allowance
2003	2/18 – 3/31	First Seasonal halibut cap
	4/1 – 6/21	Second seasonal halibut cap
	7/31 – 12/31	Annual halibut allowance

Table 8.4. Total retained and discarded flathead sole, 1995-2002.

Year	Total Catch	Retained	Discarded	Percent Retained
1995	14707	7521	7186	51
1996	17344	8964	8380	52
1997	20704	10871	9833	53
1998	24397	17208	7189	70
1999	17892	13282	4610	74
2000	19983	14730	5253	74
2001	17586	14355	3231	82
2002	15108	11047	4061	73

Table 5. Eastern Bering Sea flathead sole male catch at length group (millions)

	Length Group (cm)																							
Year	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58
1977	0.00	0.00	0.00	0.04	0.12	0.31	0.86	0.84	0.80	1.64	3.08	4.04	3.63	2.04	0.71	0.13	0.03	0.05	0.04	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.02	0.10	0.18	0.47	0.70	1.00	1.10	1.18	2.17	3.17	2.40	1.22	0.41	0.10	0.01	0.00	0.00	0.01	0.01	0.00	0.00
1979	0.00	0.00	0.00	0.02	0.13	0.22	0.32	0.62	0.70	0.44	0.45	0.66	1.18	1.67	1.15	0.51	0.17	0.05	0.01	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.05	0.18	0.46	0.98	1.20	0.91	1.01	1.98	2.38	1.15	0.22	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.02	0.08	0.35	0.43	0.11	0.18	0.35	1.03	2.29	2.59	1.81	0.83	0.19	0.03	0.05	0.03	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.06	0.08	0.22	0.42	1.12	1.98	1.77	1.08	0.36	0.12	0.04	0.04	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.09	0.14	0.44	1.02	1.52	1.57	1.15	0.49	0.14	0.04	0.02	0.01	0.01	0.01	0.01
1984	0.00	0.00	0.00	0.01	0.02	0.03	0.07	0.28	0.33	0.28	0.48	0.74	0.82	1.41	1.43	0.74	0.32	0.07	0.01	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.01	0.04	0.05	0.22	0.34	0.44	0.57	0.66	0.88	1.01	1.21	1.16	0.59	0.25	0.04	0.02	0.03	0.03	0.04	0.02
1986	0.00	0.00	0.00	0.00	0.03	0.06	0.22	0.31	0.59	1.28	1.62	1.21	1.37	1.15	1.24	0.50	0.40	0.06	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.04	0.10	0.16	0.31	0.50	1.15	1.47	0.84	0.22	0.02	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.01	0.04	0.13	0.19	0.29	0.63	0.97	1.51	2.45	2.74	1.77	0.63	0.15	0.06	0.01	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.13	0.22	0.23	0.45	0.68	0.89	1.04	1.00	0.58	0.22	0.11	0.02	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.12	0.18	0.27	0.39	0.72	1.28	2.34	3.80	4.65	3.43	2.00	0.73	0.48	0.14	0.03	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.12	0.23	0.39	0.97	1.39	2.06	3.18	4.14	2.89	1.28	0.27	0.09	0.07	0.02	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.11	0.04	0.46	0.56	0.70	1.05	1.26	1.96	2.77	3.01	3.08	2.00	1.51	0.04	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.08	0.18	0.53	1.12	1.29	2.21	3.40	3.46	1.98	1.02	0.37	0.06	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.08	0.15	0.43	0.86	1.62	2.69	3.28	3.68	3.25	1.85	1.20	0.50	0.41	0.32	0.20	0.04	0.01
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.14	0.28	0.68	1.32	2.27	3.31	3.55	2.37	1.15	0.43	0.24	0.04	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.09	0.26	0.53	1.48	2.98	4.39	4.29	2.68	1.38	0.32	0.14	0.07	0.04	0.01	0.01
1997	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.15	0.41	1.17	1.99	3.15	4.66	5.18	4.75	2.90	1.35	0.13	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.10	0.21	0.49	1.00	2.15	4.02	5.93	6.00	4.40	2.28	0.39	0.09	0.01	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.22	0.49	1.16	2.08	3.02	4.09	3.95	2.86	1.70	0.34	0.11	0.02	0.01	0.01	0.00
2000	0.00	0.01	0.00	0.00	0.00	0.01	0.03	0.03	0.07	0.18	0.57	1.19	2.55	3.92	4.65	4.01	2.72	1.65	0.52	0.22	0.10	0.04	0.01	0.01
2001	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.06	0.07	0.19	0.32	0.92	1.60	2.79	3.75	3.83	2.87	1.86	0.36	0.15	0.07	0.04	0.03	0.02
2002	0.00	0.00	0.00	0.01	0.00	0.02	0.02	0.04	0.18	0.24	0.43	0.72	1.22	2.33	3.22	3.64	2.57	1.50	0.34	0.11	0.03	0.01	0.00	0.00

Table 6. Eastern Bering Sea flathead sole female catch at length group (millions)

	Length Group (cm)																							
Year	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58
1977	0.00	0.00	0.00	0.04	0.11	0.26	0.67	0.82	0.66	0.76	1.18	1.38	1.77	1.80	1.52	1.21	0.81	0.42	0.06	0.02	0.01	0.00	0.00	0.01
1978	0.00	0.00	0.00	0.01	0.03	0.09	0.22	0.45	0.53	0.57	0.53	0.60	0.88	1.26	1.43	1.19	0.83	0.73	0.20	0.04	0.01	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.01	0.04	0.08	0.18	0.36	0.43	0.32	0.28	0.30	0.30	0.31	0.46	0.60	0.62	0.68	0.32	0.11	0.01	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.01	0.06	0.22	0.48	0.85	1.23	0.98	0.91	0.80	0.67	0.60	0.66	0.65	0.55	0.15	0.02	0.01	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.01	0.01	0.12	0.21	0.09	0.05	0.09	0.29	0.67	0.99	1.12	0.86	0.61	0.54	0.59	0.28	0.07	0.01	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.13	0.35	0.71	1.15	1.02	0.72	0.37	0.39	0.52	0.24	0.06	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.02	0.05	0.12	0.23	0.34	0.58	1.02	0.71	0.30	0.11	0.03	0.03	0.00
1984	0.00	0.00	0.00	0.01	0.02	0.03	0.06	0.16	0.17	0.12	0.16	0.25	0.28	0.36	0.68	0.89	0.72	0.61	0.25	0.08	0.01	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.01	0.01	0.03	0.03	0.09	0.16	0.16	0.19	0.22	0.26	0.38	0.51	0.72	0.81	1.06	0.41	0.12	0.06	0.02	0.03	0.01
1986	0.00	0.00	0.00	0.00	0.02	0.11	0.39	0.35	0.50	0.35	0.45	0.65	0.69	0.60	0.63	0.80	0.88	0.56	0.24	0.06	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.04	0.09	0.15	0.22	0.35	0.83	0.87	0.61	0.47	0.09	0.02	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.01	0.02	0.07	0.09	0.13	0.26	0.27	0.52	0.86	1.18	1.27	1.12	0.90	0.77	0.30	0.10	0.02	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.10	0.10	0.11	0.21	0.29	0.40	0.46	0.55	0.52	0.45	0.25	0.12	0.04	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.04	0.06	0.08	0.19	0.23	0.47	0.65	1.28	1.93	2.64	3.58	2.59	1.23	0.25	0.03	0.01	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.08	0.18	0.36	0.52	0.79	1.07	1.31	2.02	2.75	1.94	0.72	0.27	0.05	0.02	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.21	0.27	0.89	1.31	1.63	1.90	2.52	1.57	0.59	0.27	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.10	0.14	0.22	0.46	0.68	0.87	1.21	1.39	2.63	2.10	0.57	0.14	0.02	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.04	0.08	0.14	0.32	0.53	0.73	1.53	2.10	3.21	2.27	1.09	0.56	0.13	0.02	0.02
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.04	0.07	0.16	0.25	0.48	0.66	1.00	1.17	2.26	2.41	1.22	0.29	0.04	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.05	0.08	0.18	0.43	0.93	1.37	1.58	2.53	2.81	1.42	0.31	0.06	0.01	0.00
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.10	0.15	0.31	0.53	0.77	1.18	1.72	2.18	2.97	2.81	1.68	0.45	0.06	0.00	0.00
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.09	0.21	0.43	0.78	1.24	1.84	2.21	3.42	3.20	2.26	0.82	0.11	0.01	0.00
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.03	0.10	0.19	0.45	0.73	1.12	1.41	1.75	2.83	2.32	1.30	0.43	0.06	0.02	0.01
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.13	0.27	0.65	1.07	1.61	1.93	1.83	2.84	2.27	1.53	0.54	0.09	0.01	0.01
2001	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.09	0.26	0.30	0.65	1.02	1.53	1.66	2.60	2.33	1.32	0.48	0.09	0.02	0.01
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.05	0.11	0.21	0.44	0.90	1.28	1.68	2.74	1.84	0.96	0.36	0.07	0.02	0.00

Table 8.7. Estimated biomass of flathead sole from the EBS and Aleutian Islands Trawl survey.

Year	Area	Biomass Estimate	Standard Deviation
1975	EBS	100,700	
1979	EBS	104,900	
1980	EBS	117,500	
	Aleut.	3,300	
1981	EBS	162,900	
1982	EBS	191,988	17,031
1983	EBS	269,419	27,035
	Aleut.	1,500	
1984	EBS	341,697	28,774
1985	EBS	276,350	20,088
1986	EBS	357,951	31,402
	Aleut.	9,000	
1987	EBS	394,758	37,011
1988	EBS	572,805	49,696
1989	EBS	536,433	45.039
1990	EBS	628,235	54,945
1991	EBS	544,893	42,102
	Aleut.	6,885	1,368
1992	EBS	651,384	66,213
1993	EBS	610,259	43,451
1994	EBS	726,212	51,190
	Aleut.	9,917	2,241
1995	EBS	593,412	51,934
1996	EBS	616,373	55,752
1997	EBS	807,825	174,348
	Aleut.	11,540	2,725
1998	EBS	692,234	143,412
1999	EBS	394,822	34,325
2000	EBS	399,298	34,692
2000	Aleut	8,795	1,996
2001	EBS	514,023	53,489
2002	EBS	574,946	102,680
2002	Aleut	9,894	2,410
2003	EBS	529,188	55,983

Table 8. Eastern Bering Sea flathead sole male numbers at length group (millions) estimated from the NMFS trawl surveys

	Length Group (cm)																							
Year	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58
1982	0.27	0.30	1.42	19.37	30.56	27.81	33.61	46.44	54.95	63.58	84.48	90.19	72.52	31.55	10.41	3.08	0.59	0.42	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.47	1.36	16.88	47.98	28.14	49.06	65.83	56.16	49.88	57.29	71.20	85.44	82.41	58.81	23.63	6.70	1.37	0.12	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.72	1.50	10.41	31.20	57.55	94.49	72.63	68.82	79.83	79.91	87.22	96.03	92.24	70.87	34.05	7.58	3.57	0.12	0.00	0.14	0.00	0.00	0.00	0.00
1985	0.03	2.70	4.28	8.83	23.65	39.88	61.01	86.03	75.21	57.16	70.29	74.92	80.93	60.96	38.86	14.30	3.33	0.78	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.47	0.83	7.25	23.71	17.42	22.83	38.52	65.07	74.08	82.94	84.31	69.95	87.56	88.82	49.43	20.70	6.90	1.66	0.11	0.00	0.00	0.00	0.00	0.00
1987	0.06	0.21	7.51	24.00	27.07	44.09	43.98	53.56	63.01	79.70	78.04	90.86	99.30	97.64	55.07	28.65	14.99	3.82	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.54	1.63	5.23	30.89	77.10	101.89	73.97	76.37	64.69	70.87	75.18	86.13	115.63	137.93	120.56	51.74	17.67	5.16	0.26	0.00	0.00	0.00	0.00	0.00
1989	0.00	1.54	17.37	70.04	40.33	43.44	127.71	102.70	102.99	72.95	74.82	76.26	76.47	128.41	127.72	58.91	18.03	3.02	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	1.30	4.75	17.32	74.03	78.17	64.41	94.99	114.40	99.89	96.77	97.86	109.67	136.15	132.40	69.94	27.55	5.46	0.50	0.00	0.00	0.00	0.00	0.00
1991	0.10	0.70	12.03	8.80	10.32	47.57	91.91	125.85	119.07	112.65	111.83	92.10	101.78	95.91	107.64	72.53	21.39	4.77	0.45	0.06	0.00	0.00	0.00	0.00
1992	0.00	0.02	3.46	44.85	74.84	45.93	49.48	91.69	128.81	160.50	144.34	119.00	124.41	135.70	138.54	88.97	32.19	6.55	0.32	0.02	0.18	0.00	0.00	0.00
1993	0.00	0.91	6.95	13.50	19.31	58.28	64.41	61.04	72.45	109.60	139.13	138.74	121.89	128.75	117.83	88.84	26.74	7.10	0.24	0.00	0.00	0.00	0.00	0.00
1994	0.00	0.89	4.97	20.10	43.45	65.78	87.74	75.73	68.50	92.89	126.88	142.66	157.12	153.69	144.32	95.41	31.71	8.37	0.39	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.12	1.97	7.68	19.00	34.32	43.99	60.15	70.08	65.63	106.64	133.01	152.53	138.54	119.62	72.88	31.93	10.52	0.50	0.14	0.00	0.00	0.00	0.00
1996	0.07	0.63	3.15	19.70	38.02	35.65	55.73	69.11	74.66	77.90	89.21	116.17	139.29	145.85	135.79	85.00	33.76	12.38	1.01	0.00	0.00	0.03	0.00	0.00
1997	0.06	0.48	3.01	10.40	12.46	24.23	30.26	40.34	53.39	66.34	73.81	91.47	143.20	152.03	145.64	102.15	53.45	23.84	2.37	1.85	0.00	0.00	0.00	0.00
1998	0.06	1.26	17.18	34.49	18.23	26.35	29.32	37.45	46.66	69.57	77.23	94.44	135.44	161.08	157.74	106.86	59.75	14.97	2.64	0.44	0.00	0.00	0.00	0.00
1999	0.00	0.46	2.61	7.34	20.22	16.06	17.74	29.29	31.18	48.08	59.45	65.48	79.45	98.03	82.37	45.35	21.04	10.86	1.04	0.10	0.00	0.00	0.00	0.00
2000	0.06	0.36	5.35	7.63	11.38	24.17	22.09	25.56	28.20	43.09	63.81	64.82	87.61	87.90	73.77	49.16	19.36	7.65	0.58	0.24	0.03	0.00	0.00	0.00
2001	0.00	0.74	5.02	6.55	16.95	20.75	37.24	63.50	59.97	46.26	59.54	97.84	120.11	122.74	105.09	59.81	30.72	9.79	1.89	0.56	0.02	0.02	0.00	0.00
2002	0.07	0.50	1.93	6.47	13.39	17.91	21.78	35.80	57.22	59.29	59.30	74.40	107.94	115.19	106.72	62.82	25.77	12.38	2.01	2.99	0.02	0.00	0.00	0.00
2003	0.00	0.65	4.48	10.84	12.85	23.97	29.62	31.56	43.59	71.35	87.45	106.06	117.07	101.82	90.18	66.14	33.07	8.76	2.21	0.09	0.00	0.00	0.00	0.00

Table 9. Eastern Bering Sea flathead sole female numbers at length group (millions) estimated from the NMFS trawl surveys

	Length Group (cm)																							
Year	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58
1982	0.00	0.00	1.23	16.77	24.10	19.75	29.37	46.82	48.32	48.18	53.37	66.87	70.42	55.20	32.85	13.48	6.75	8.71	1.67	0.40	0.00	0.00	0.00	0.00
1983	0.00	0.48	11.91	36.92	24.91	43.47	55.95	53.01	45.10	50.33	55.24	61.04	76.61	78.66	70.04	32.20	15.53	9.07	1.57	0.47	0.00	0.00	0.00	0.00
1984	0.00	0.61	6.07	33.44	58.49	80.38	62.89	56.56	71.80	71.37	72.40	83.43	83.20	84.64	84.32	56.00	26.95	12.30	1.26	0.92	0.03	0.00	0.00	0.00
1985	0.00	1.18	1.24	7.94	21.60	33.11	52.72	78.33	67.73	50.09	49.00	53.25	54.64	56.40	52.35	34.41	23.56	14.47	4.18	1.01	0.00	0.00	0.00	0.00
1986	0.00	0.47	3.44	12.09	13.38	17.44	30.88	46.88	64.65	75.02	66.41	60.58	68.37	70.62	74.52	55.19	40.46	30.46	6.97	2.00	0.18	0.00	0.00	0.00
1987	0.00	0.00	4.26	18.41	26.98	39.89	40.57	48.68	45.24	56.28	66.52	70.32	71.67	70.27	78.82	60.34	46.75	35.05	13.75	2.76	0.10	0.00	0.00	0.00
1988	0.00	0.00	2.50	19.33	72.66	98.75	92.24	114.64	80.63	74.65	78.18	78.82	79.20	101.09	104.48	97.85	69.78	63.72	26.02	3.48	1.34	0.00	0.00	0.00
1989	0.00	0.14	15.55	43.40	28.12	39.99	104.40	103.79	109.92	77.05	62.33	67.97	78.15	68.05	85.35	91.01	67.13	65.48	26.59	7.98	0.81	0.00	0.00	0.00
1990	0.00	0.20	1.95	13.16	59.00	70.08	48.57	67.86	91.46	93.57	82.06	74.66	66.36	77.56	72.18	83.78	80.79	91.95	39.88	11.28	2.42	0.00	0.00	0.00
1991	0.00	0.84	5.00	4.75	6.97	31.83	69.33	95.63	94.66	104.16	99.36	89.17	68.35	77.35	86.47	76.83	107.87	124.83	44.33	14.63	0.96	0.00	0.00	0.00
1992	0.00	0.00	3.99	30.73	54.87	42.64	48.51	75.78	102.93	123.14	115.07	114.32	83.74	79.04	84.58	85.11	81.45	94.70	51.89	16.50	2.48	0.13	0.00	0.00
1993	0.04	0.53	4.80	9.93	19.37	50.29	59.06	46.11	70.87	95.05	97.50	109.18	106.75	85.77	73.98	67.04	58.95	95.20	49.32	15.80	2.88	0.09	0.00	0.00
1994	0.00	0.41	2.31	13.29	31.96	47.10	66.62	56.17	47.42	74.66	97.27	118.08	125.57	112.85	96.71	77.87	78.94	103.18	70.94	25.65	3.59	0.32	0.00	0.00
1995	0.00	0.00	1.18	5.24	15.94	30.57	38.90	54.44	50.61	49.62	62.06	80.36	97.65	92.04	80.90	67.28	59.77	69.60	50.84	16.61	5.56	0.25	0.00	0.00
1996	0.00	0.18	3.04	18.72	28.21	43.06	47.93	61.57	61.11	66.25	65.12	64.30	75.83	88.04	93.11	81.05	52.62	72.78	51.34	23.32	3.15	0.28	0.00	0.00
1997	0.00	0.49	1.61	6.57	14.30	21.96	29.35	36.26	41.09	47.46	59.36	63.51	80.61	94.61	112.36	109.09	98.04	129.84	108.43	33.09	7.92	0.61	0.00	0.00
1998	0.00	0.58	12.84	23.99	11.43	20.98	28.26	41.44	45.34	47.69	66.99	72.37	61.31	76.22	94.19	89.04	80.66	87.72	57.85	24.88	11.34	1.39	0.00	0.00
1999	0.00	0.14	2.12	5.82	14.45	15.77	14.68	19.89	28.42	34.79	40.97	40.77	43.54	49.23	64.20	59.79	45.34	42.79	27.76	15.04	7.70	0.95	0.17	0.00
2000	0.25	0.40	1.71	4.95	9.06	17.91	18.47	21.53	20.59	29.62	38.01	40.90	53.51	58.93	64.24	69.28	50.05	51.29	28.99	12.80	4.39	0.53	0.00	0.00
2001	0.16	0.41	3.25	5.06	8.55	15.44	29.09	46.11	48.49	39.58	39.80	59.62	66.61	78.40	88.21	82.83	59.78	62.02	38.83	18.80	4.30	0.86	0.07	0.00
2002	0.19	0.61	2.10	4.97	11.28	14.39	18.01	26.15	37.78	41.69	42.39	49.30	52.47	73.50	83.33	67.14	60.27	65.78	52.45	43.96	24.40	5.21	0.96	0.00
2003	0.40	0.03	2.11	9.43	11.64	15.03	19.36	25.52	30.40	45.28	62.81	73.86	67.65	73.13	78.57	60.01	63.33	76.31	42.24	11.09	2.43	0.17	0.00	0.05

Table 8.10. Estimated total biomass (ages 3+), female spawner biomass, and recruitment (age 3), with comparison to the 2002 SAFE estimates

	Spawning stock biomass (t)		Total biomass (t)		Recruitment (thousands)	
	Assessment		Assessment		Assessment	
	2003	2002	2003	2002	2003	2002
1977	41120	44492	138937	147395	1880450	
1978	37475	40863	165114	173919	299109	295332
1979	34918	38300	201221	210745	605957	629479
1980	35325	38716	241169	251075	553030	553136
1981	42577	46110	290513	301291	1017740	1050990
1982	62306	66188	342560	354046	878775	891554
1983	88075	92361	403197	415692	1201470	1231040
1984	112050	116682	470949	485219	1313650	1371310
1985	134693	139629	528789	544454	561115	573028
1986	158015	163314	579501	596547	666767	686559
1987	184434	190196	627724	646072	960239	985294
1988	215077	221497	678260	697681	1185050	1203230
1989	244868	252176	718640	738525	852923	853650
1990	271003	279135	761775	781561	1109960	1107550
1991	281405	290204	775396	794387	431758	421618
1992	291953	301179	783977	801780	518309	514737
1993	304044	313456	786122	802677	620074	629332
1994	316423	325670	782587	798126	641719	662538
1995	326687	335530	769563	784457	410257	429441
1996	328834	336783	749059	763224	441027	452750
1997	323582	330643	718648	732040	232702	230540
1998	312429	318723	682110	694729	360812	366841
1999	298095	304023	642323	653873	413550	401273
2000	285525	291297	606870	616949	341771	322781
2001	269686	275420	567745	576586	204657	210182
2002	253069	258692	529805	538042	204990	232759
2003	235724		493339		261526	

Table 8.11. Projections of spawning biomass, catch, fishing mortality rate, and catch for each of the several scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 119,124 t and 104,234 t, respectively.

Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2003	226452	226452	226452	226452	226452	226452	226452
2004	204886	204886	208742	211083	212675	203033	204887
2005	162001	162001	182861	196768	206805	152813	162002
2006	129886	129886	160592	182980	200093	117525	128750
2007	105690	105690	140738	168910	191676	93194.4	100261
2008	91585.9	91585.9	126013	157985	185252	81242.4	85133.2
2009	86626.7	86626.7	117621	151405	181790	77985.7	80182.3
2010	88990.1	88990.1	116935	151336	184131	81490.7	82703.3
2011	95103.5	95103.5	121236	155948	190791	88205.9	88816.5
2012	102052	102052	127735	162985	199713	95241.6	95495.2
2013	108106	108106	134501	170517	208911	100967	101028
2014	112776	112776	140874	178113	218303	104999	104974
2015	116015	116015	146287	184914	226803	107508	107456
2016	118323	118323	151061	191457	235338	109082	109032
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2003	0.0547572	0.0547572	0.0547555	0.0547546	0.0547554	0.0547562	0.054754
2004	0.300123	0.300123	0.150061	0.0603965	0	0.373361	0.300123
2005	0.300123	0.300123	0.150061	0.0603965	0	0.373361	0.300123
2006	0.300123	0.300123	0.150061	0.0603965	0	0.368093	0.373361
2007	0.264495	0.264495	0.150061	0.0603965	0	0.287814	0.31113
2008	0.227089	0.227089	0.150061	0.0603965	0	0.248381	0.261218
2009	0.213938	0.213938	0.144112	0.0603965	0	0.237637	0.244884
2010	0.22004	0.22004	0.141459	0.0603965	0	0.249157	0.253151
2011	0.235036	0.235036	0.142928	0.0603965	0	0.270604	0.272589
2012	0.250771	0.250771	0.145076	0.0603965	0	0.292138	0.292948
2013	0.262804	0.262804	0.146761	0.0603965	0	0.30877	0.30897
2014	0.271067	0.271067	0.147834	0.0603965	0	0.319569	0.319519
2015	0.276012	0.276012	0.148578	0.0603965	0	0.325942	0.325818
2016	0.27927	0.27927	0.149145	0.0603965	0	0.329815	0.329695
Catch	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2003	13067.1	13067.1	13066.7	13066.5	13066.7	13066.9	13066.3
2004	61900.5	61900.5	32492.5	13471.2	0	75233.6	61900.6
2005	49485.5	49485.5	28591.2	12569.4	0	57450.4	49485.6
2006	40167	40167	25286.7	11737.9	0	44265.7	48860.4
2007	29557.2	29557.2	22452.9	10941.1	0	28459.1	32827.4
2008	22434.1	22434.1	20315.3	10311.8	0	21825.8	23972.1
2009	19732.7	19732.7	18067.7	9800.64	0	19704.7	20879.7
2010	20025.7	20025.7	17116.1	9554.58	0	20637.4	21320.3
2011	21896.6	21896.6	17295.6	9555.3	0	23183.6	23567.4
2012	24313.4	24313.4	17974.6	9744.17	0	26209.5	26401.6
2013	26561.8	26561.8	18821.6	10035.3	0	28938.1	29013.8
2014	28457	28457	19730	10411.2	0	31057.7	31073.7
2015	29872.1	29872.1	20591.5	10799.1	0	32542.6	32532.3
2016	30953.9	30953.9	21407.4	11206.9	0	33574.6	33557

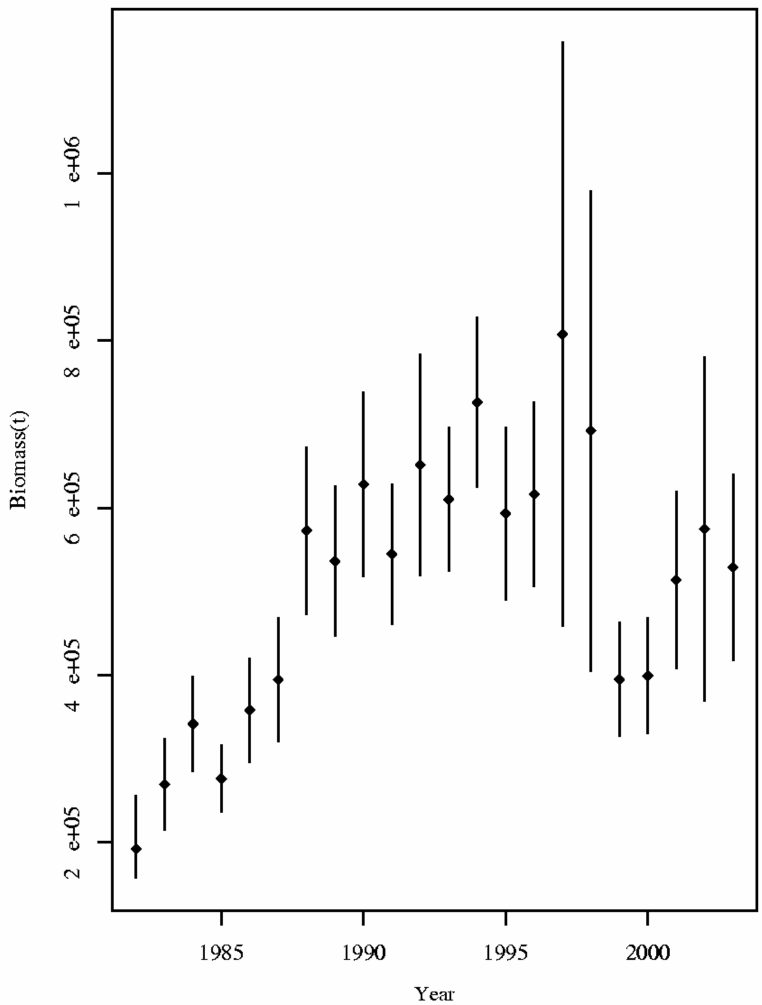

Figure 8.1. Estimated survey biomass and 95% CIs

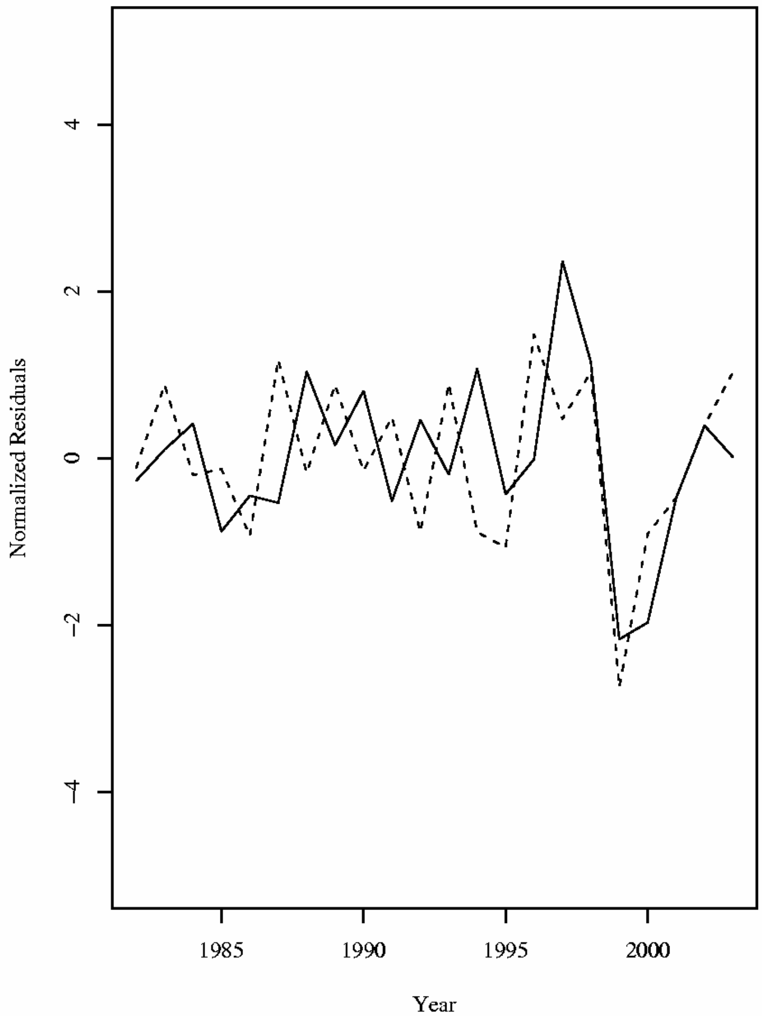

Figure 8.2. Normalized residuals of flathead sole survey biomass (from LOWESS fit; solid line) and average temperature (dashed line)

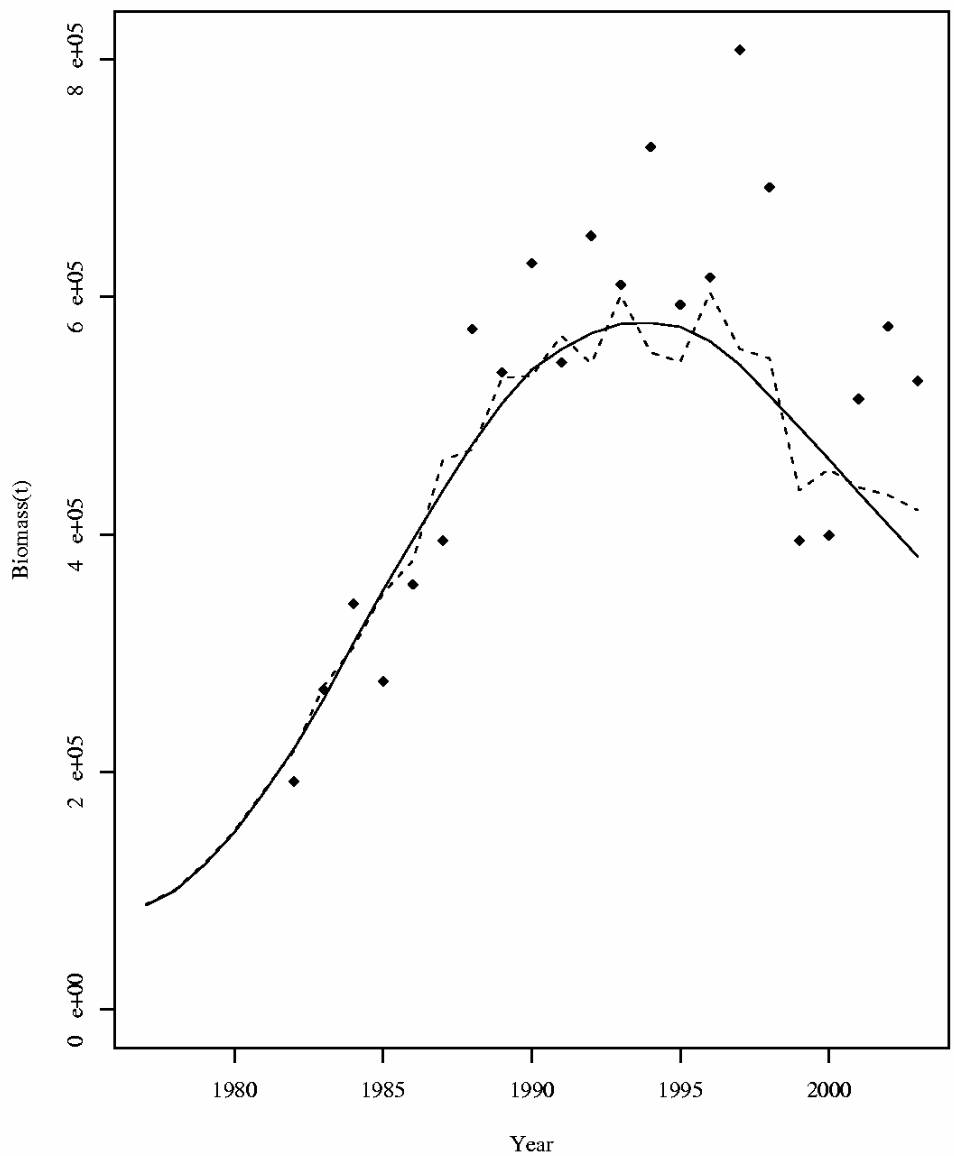

Figure 8.3. Model fits of survey biomass with (dashed line) and without (solid line) temperature dependent survey catchability

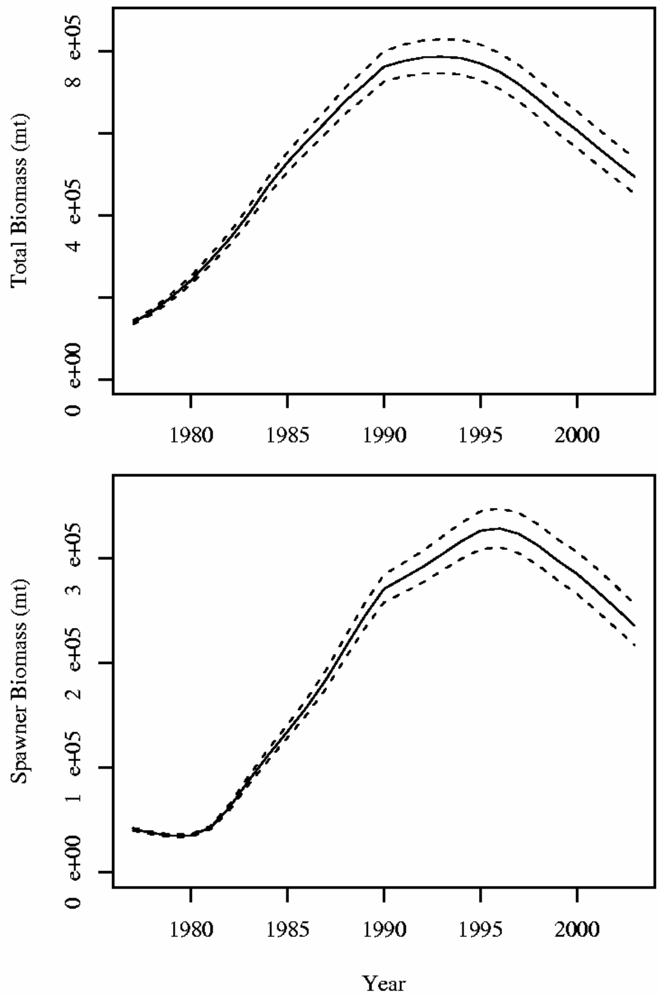

Figure 8.4. Total and spawner biomass for BSAI flathead sole, with 95% confidence intervals from MCMC integration.

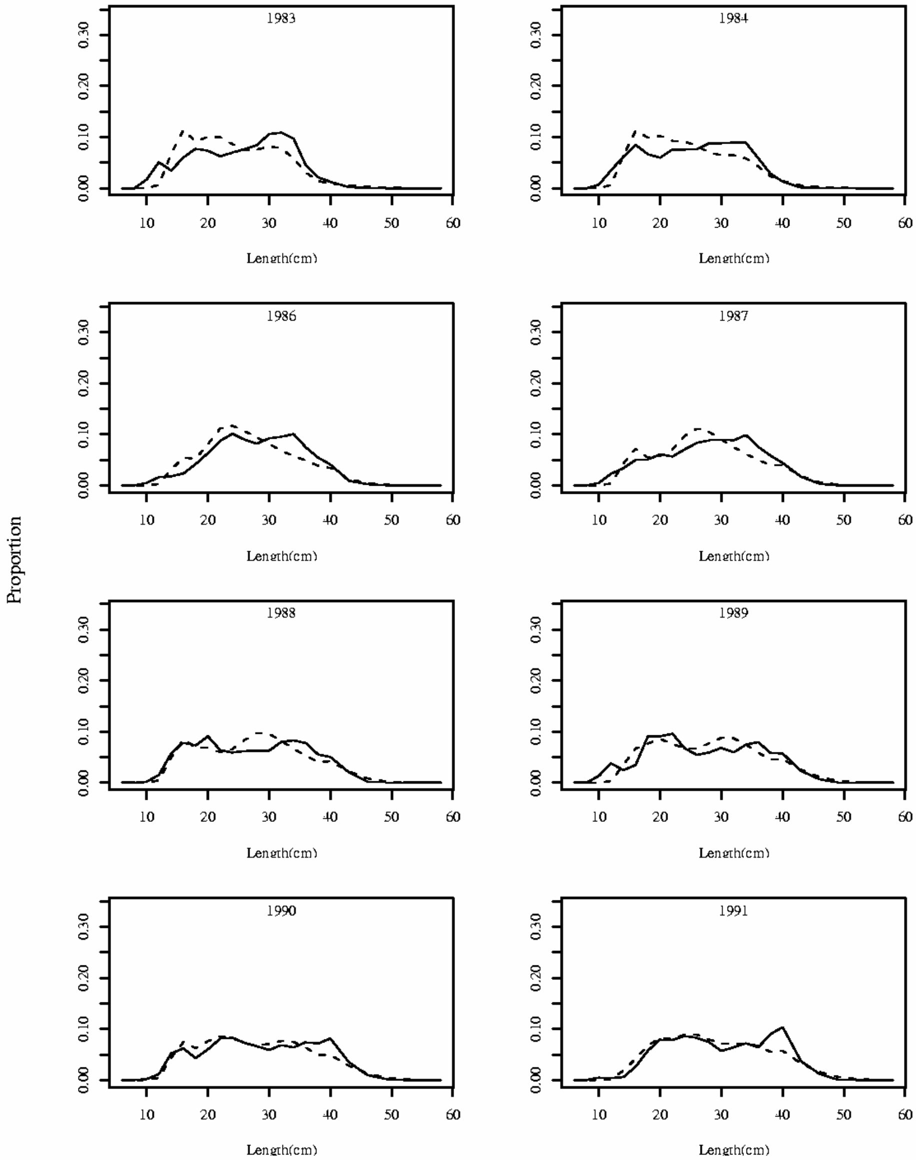

Figure 8.5. Female survey length composition by year (solid line = observed, dotted line = predicted)

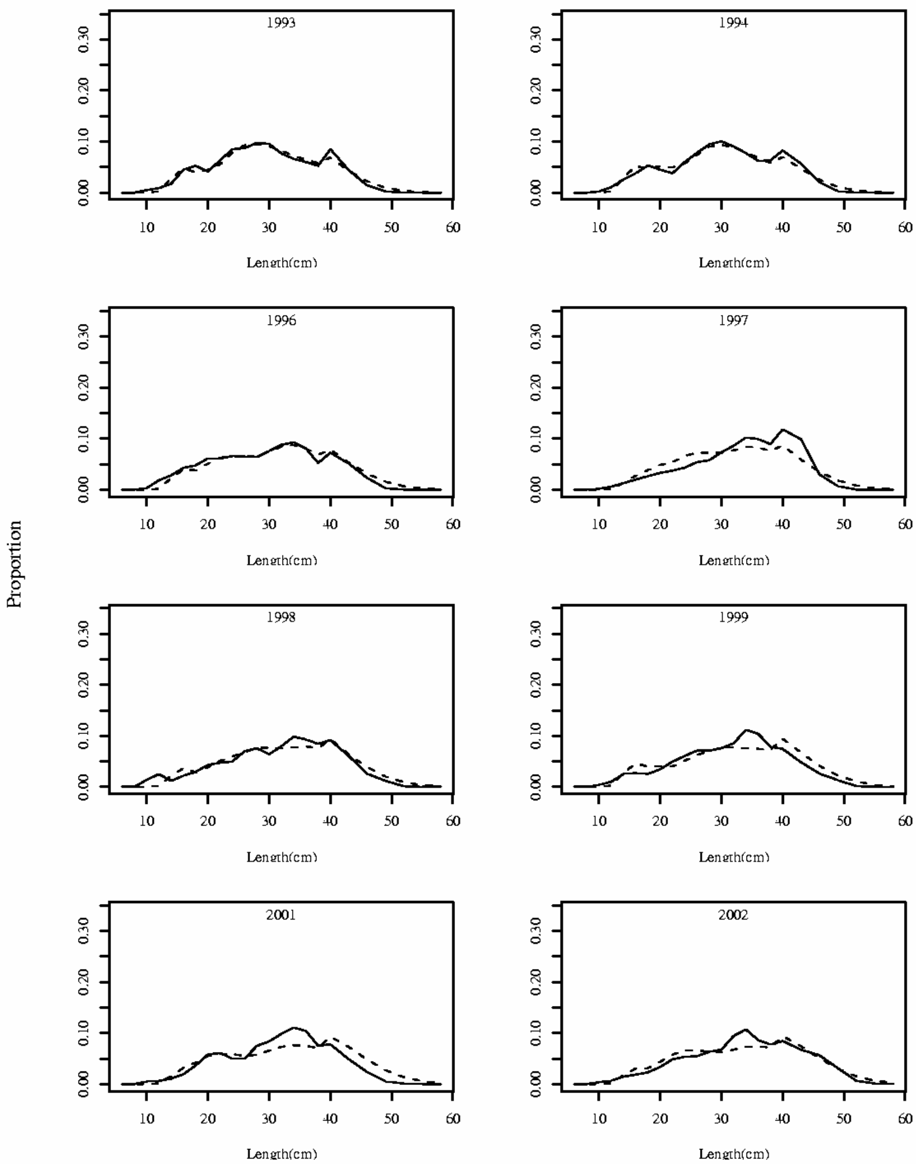

Figure 8.5 (continued). Female survey length composition by year (solid line = observed, dotted line = predicted)

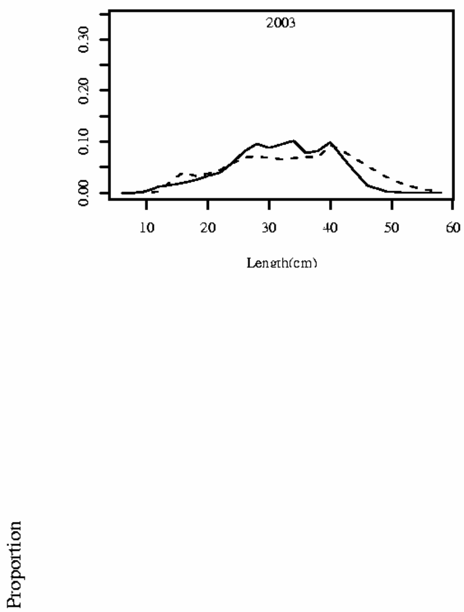

Figure 8.5 (continued). Female survey length composition by year (solid line = observed, dotted line = predicted)

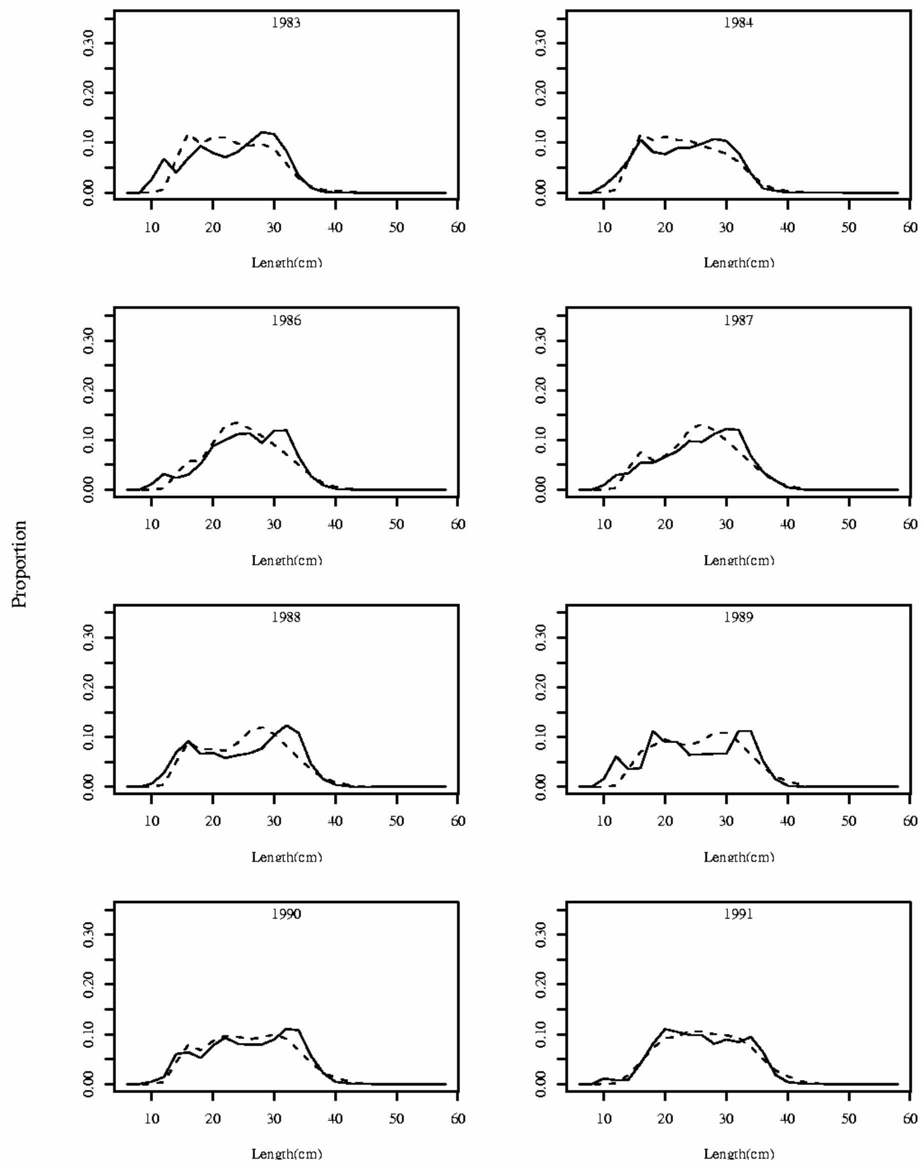

Figure 8.6. Male survey length composition by year (solid line = observed, dotted line = predicted)

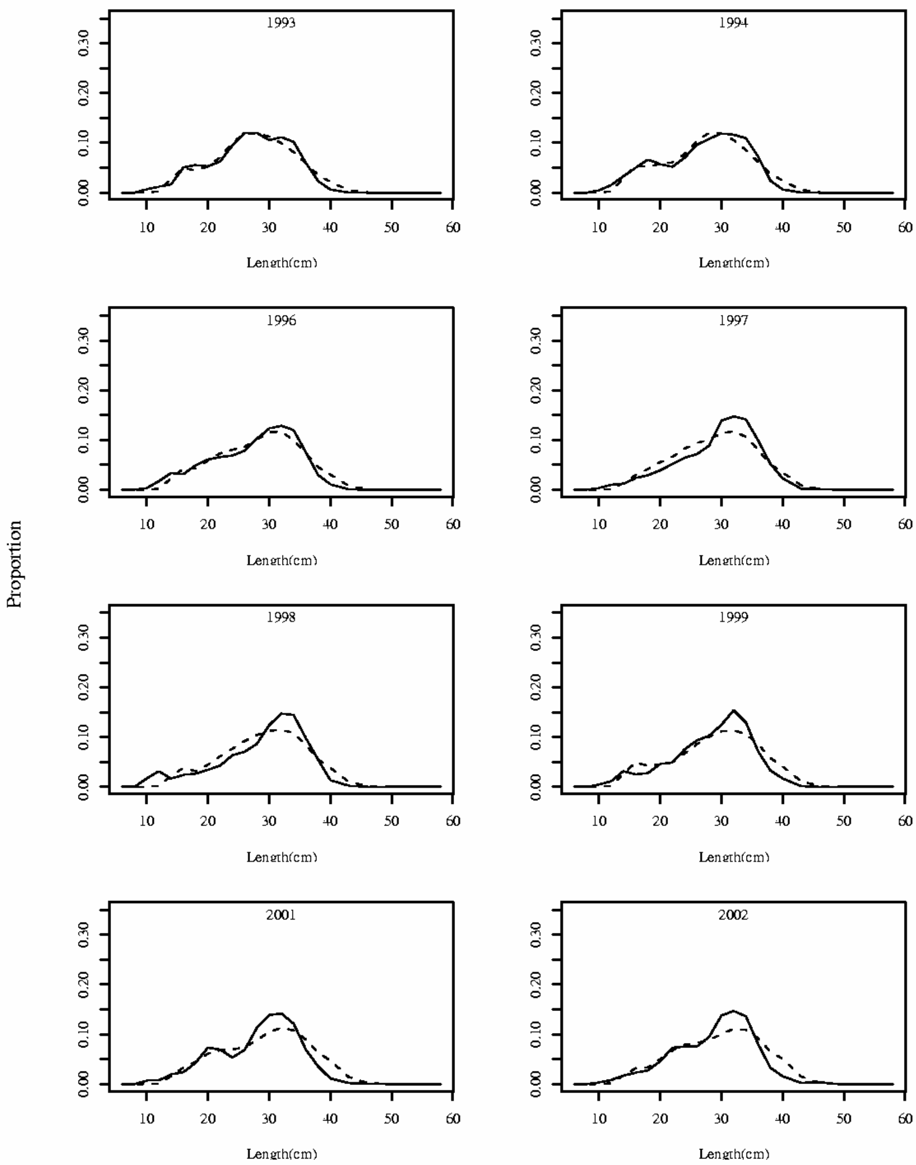

Figure 8.6 (continued). Male survey length composition by year (solid line = observed, dotted line = predicted)

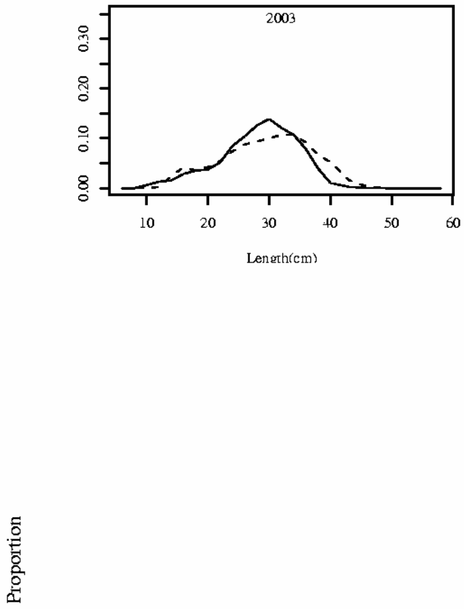

Figure 8.6 (continued). Male survey length composition by year (solid line = observed, dotted line = predicted)

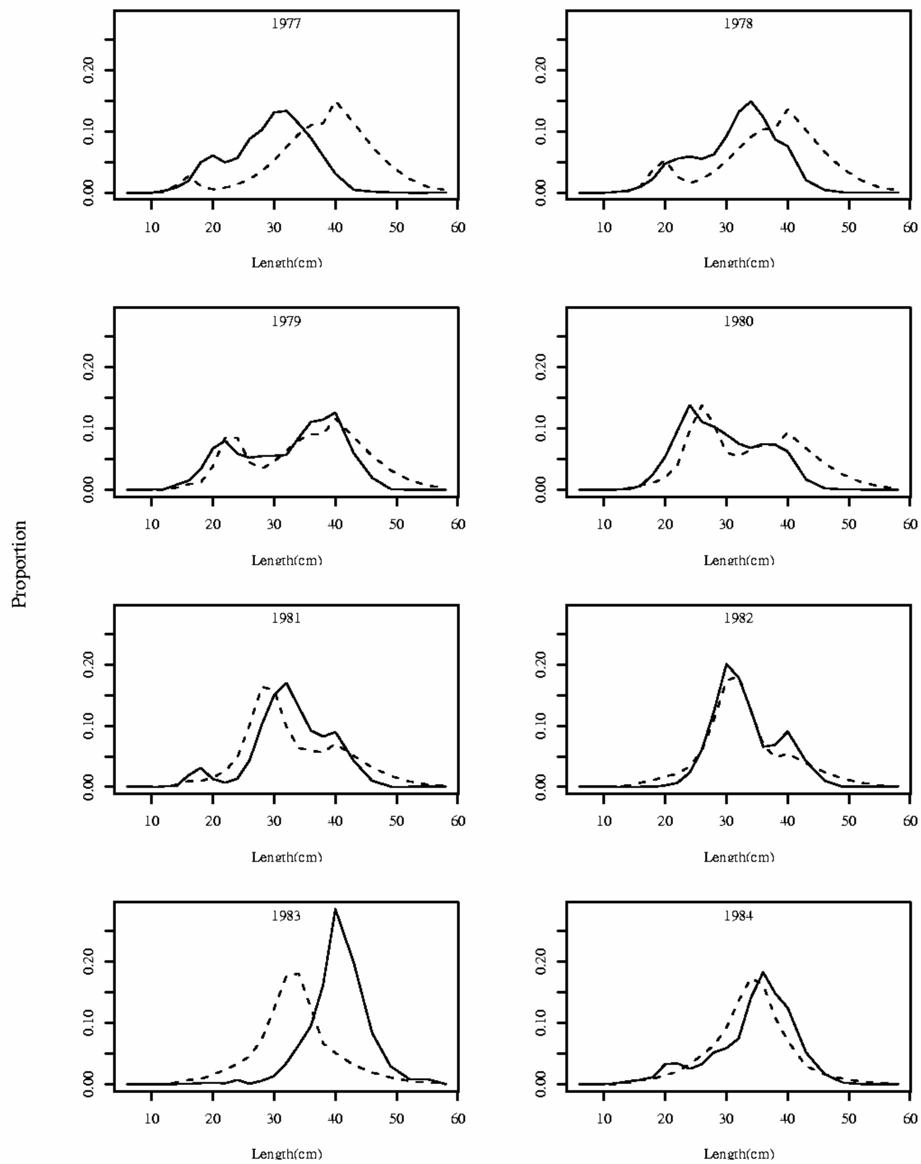

Figure 8.7. Female fishery length composition by year (solid line = observed, dotted line = predicted)

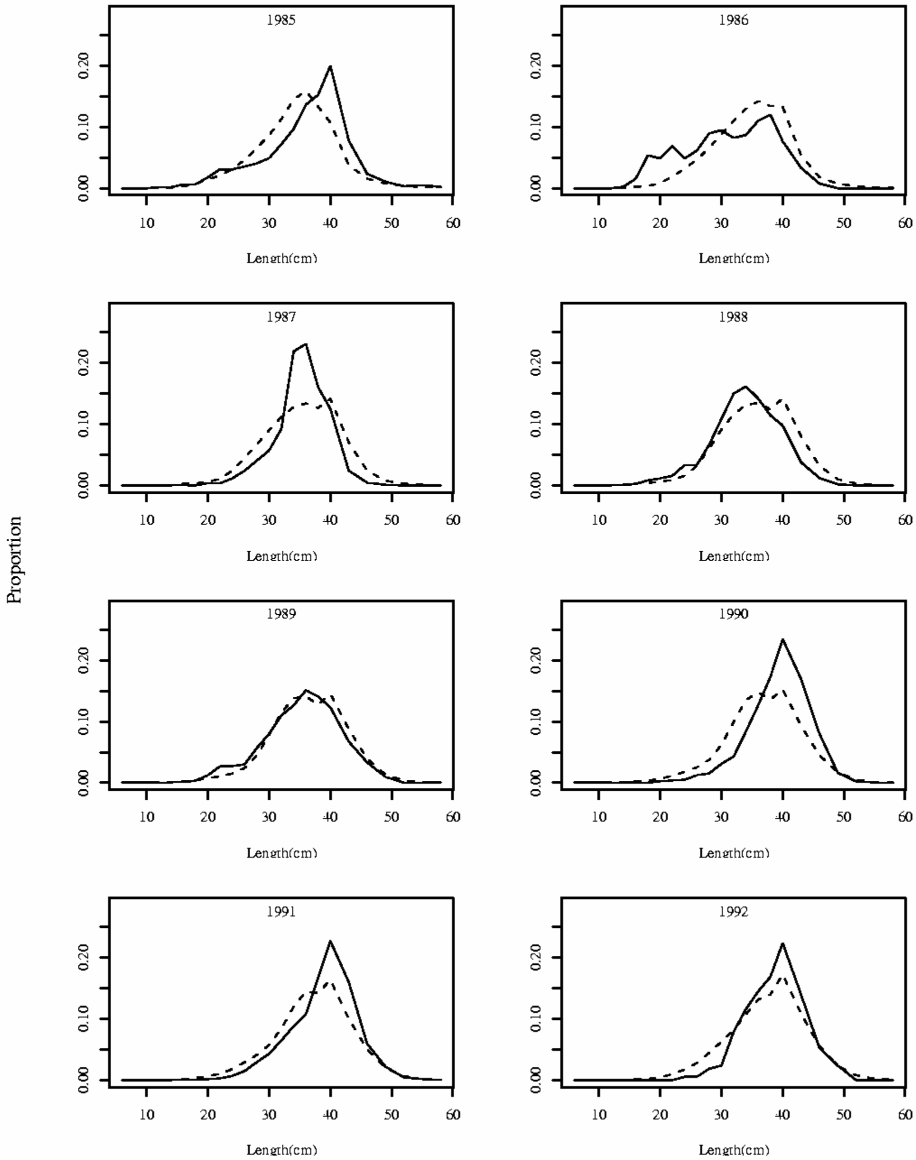

Figure 8.7 (continued). Female fishery length composition by year (solid line = observed, dotted line = predicted)

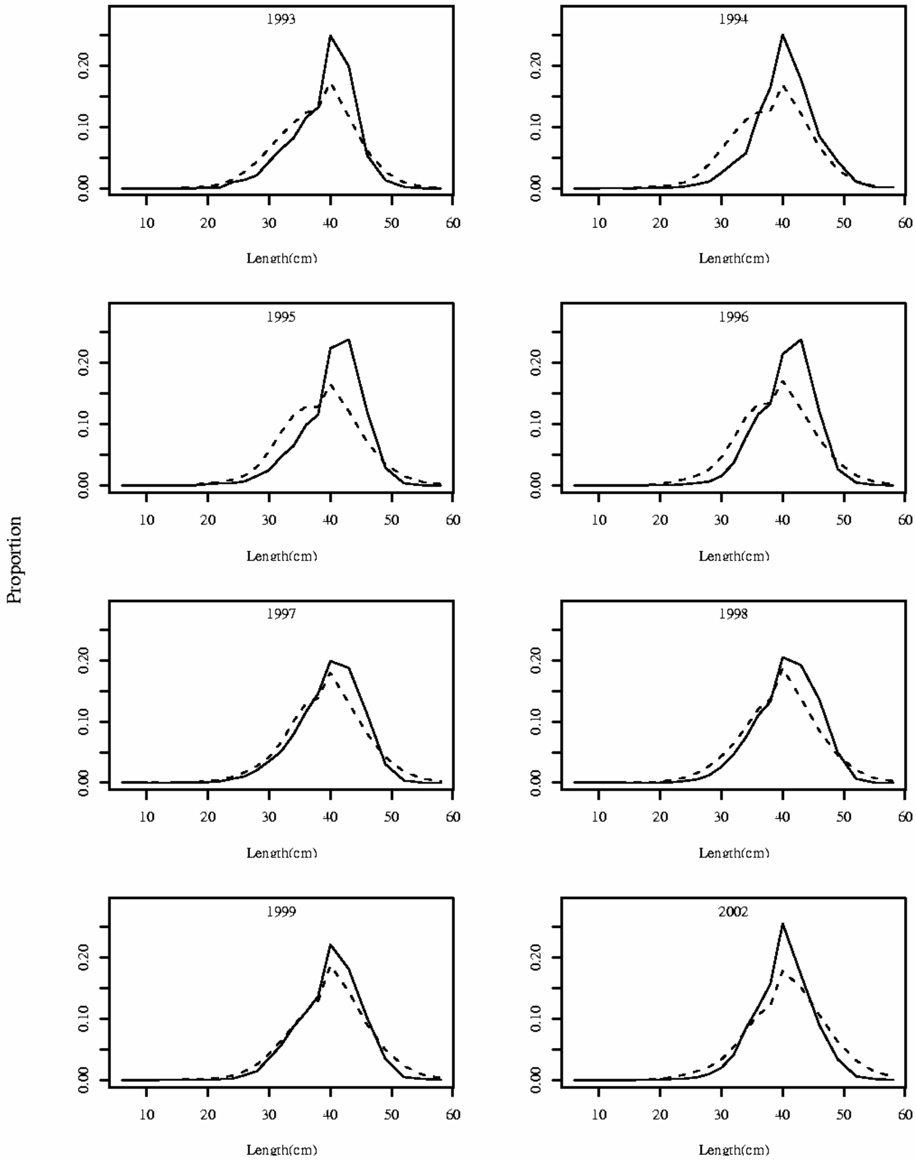

Figure 8.7 (continued). Female fishery length composition by year (solid line = observed, dotted line = predicted)

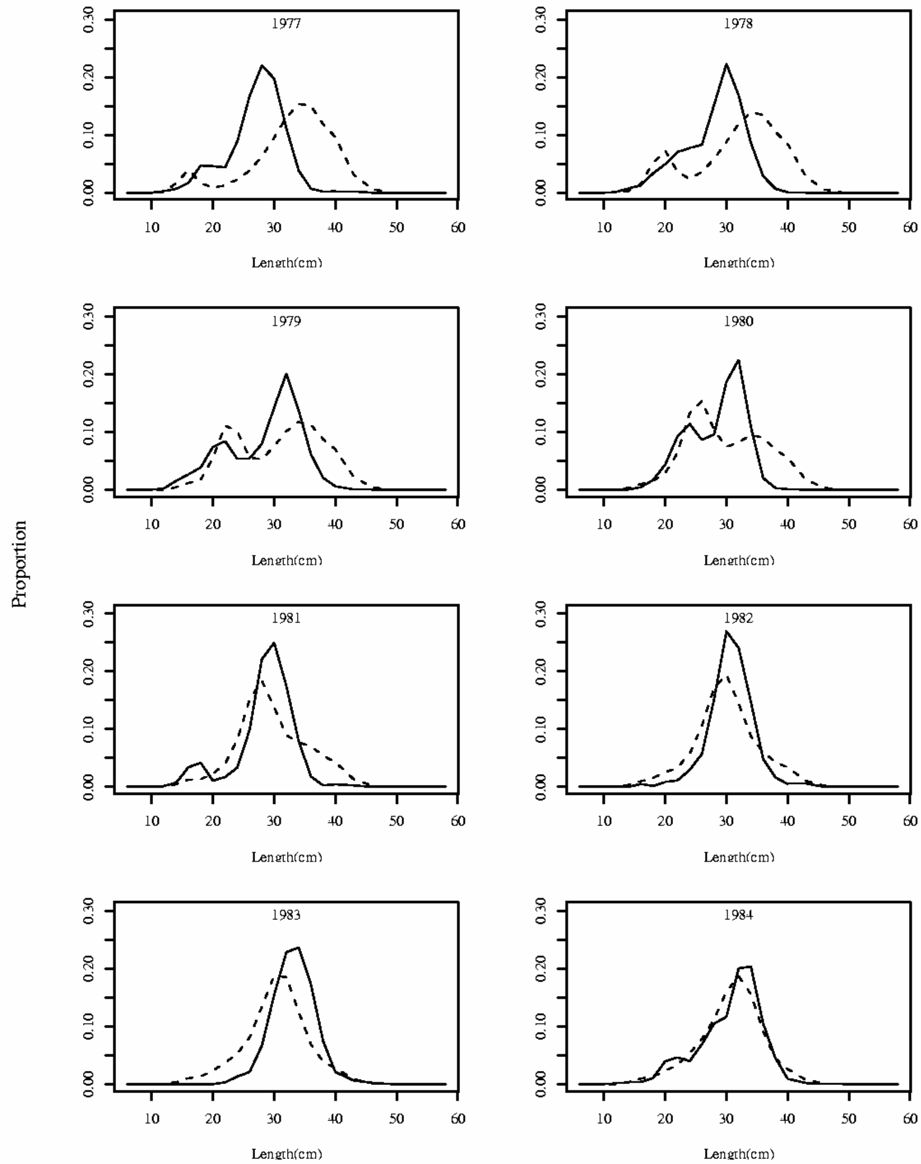

Figure 8.8. Male fishery length composition by year (solid line = observed, dotted line = predicted)

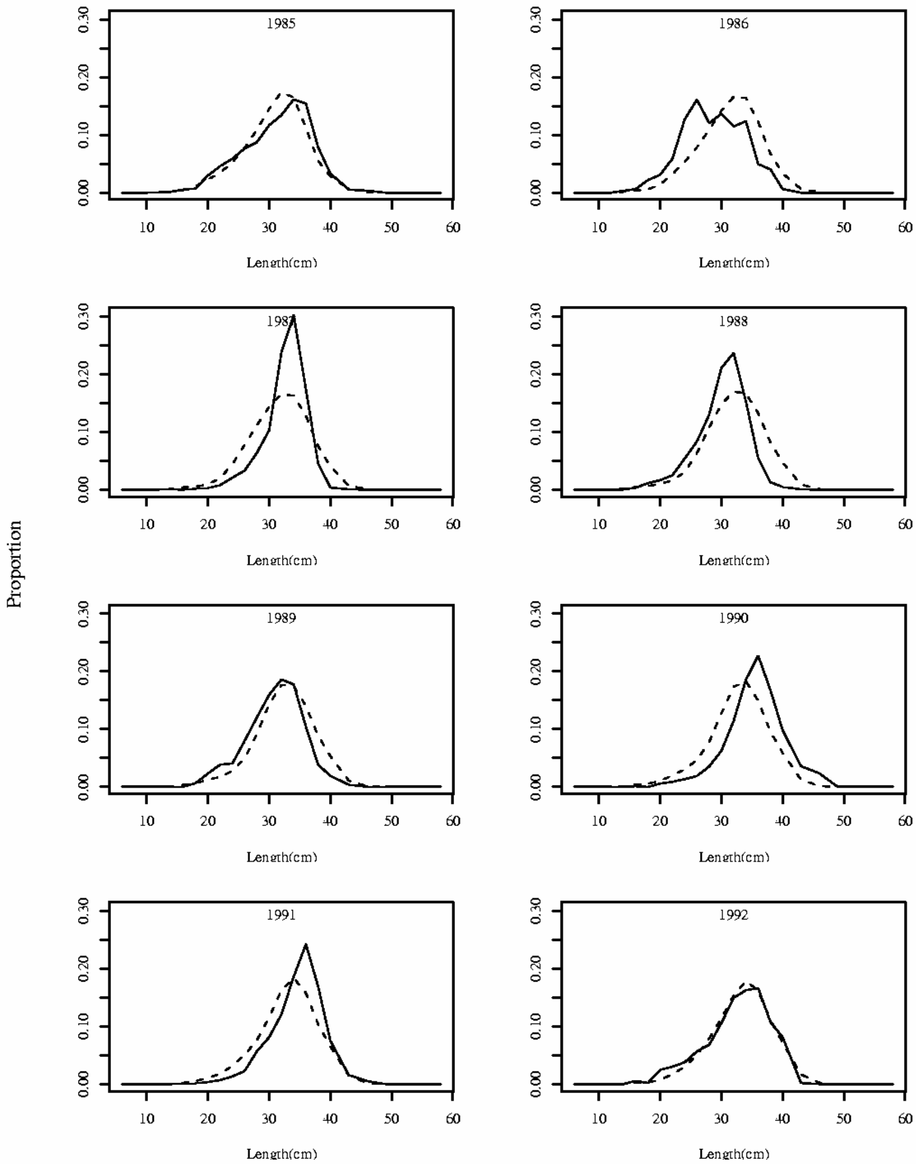

Figure 8.8 (continued). Male fishery length composition by year (solid line = observed, dotted line = predicted)

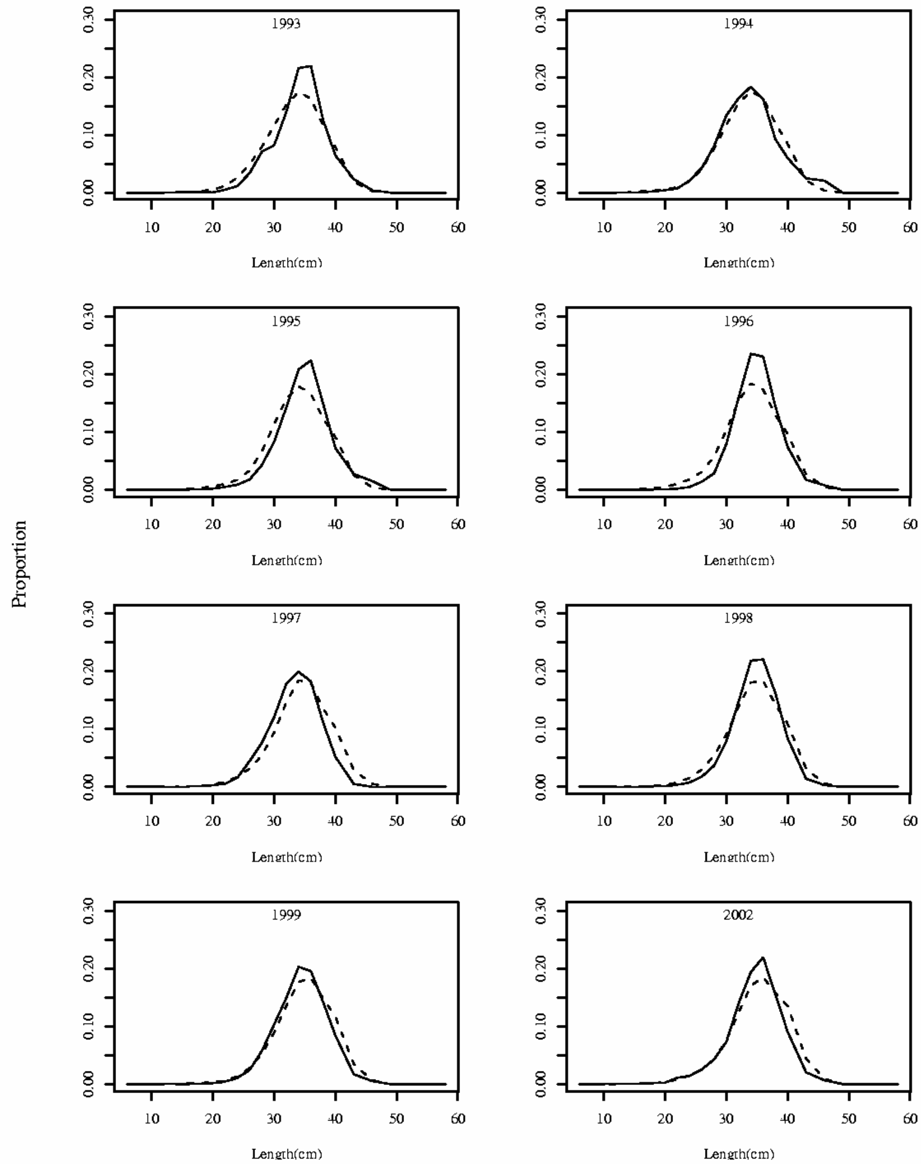

Figure 8.8 (continued). Male fishery length composition by year (solid line = observed, dotted line = predicted)

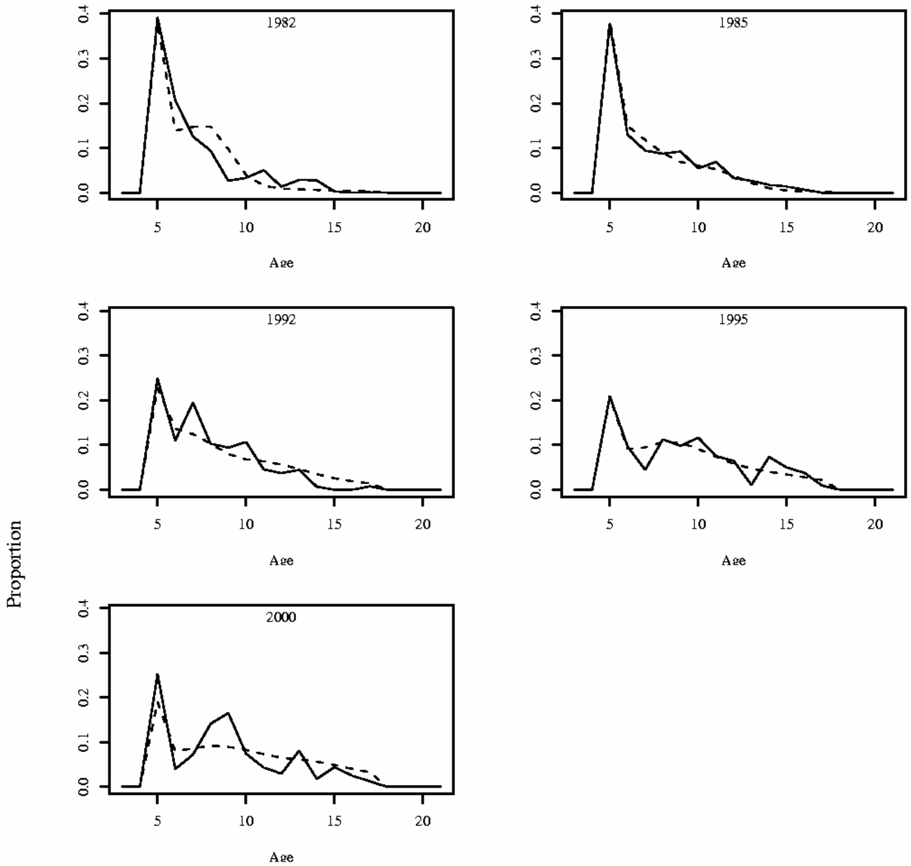

Figure 8.9. Male survey age composition by year (solid line = observed, dotted line = predicted)

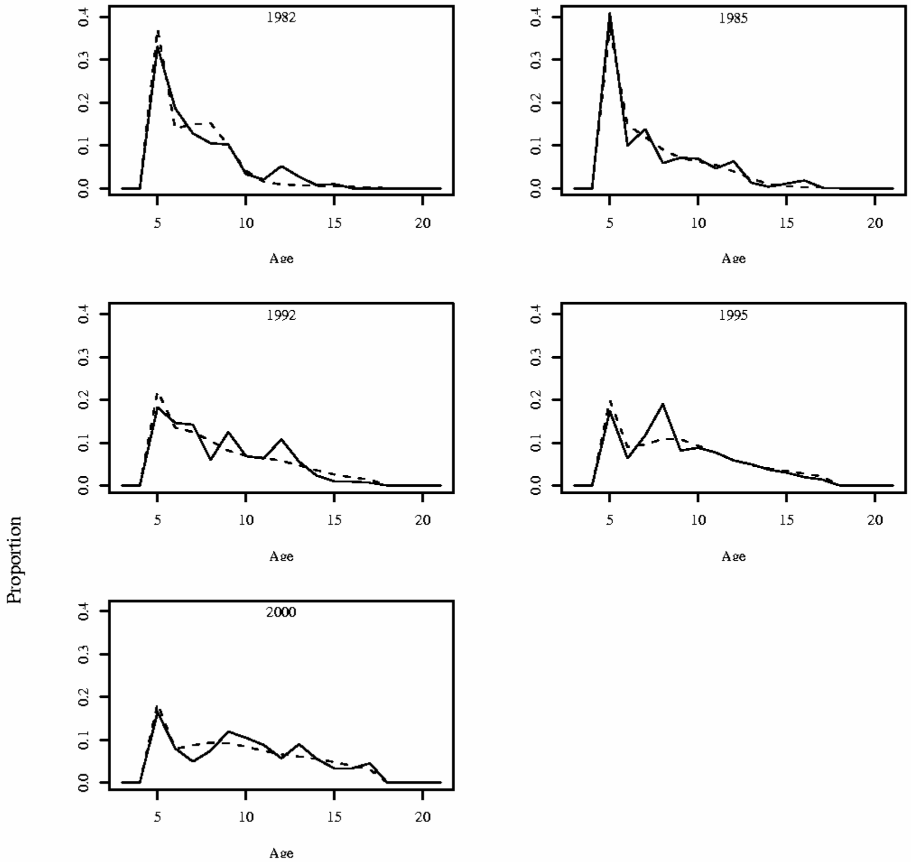

Figure 8.10. Female survey age composition by year (solid line = observed, dotted line = predicted)

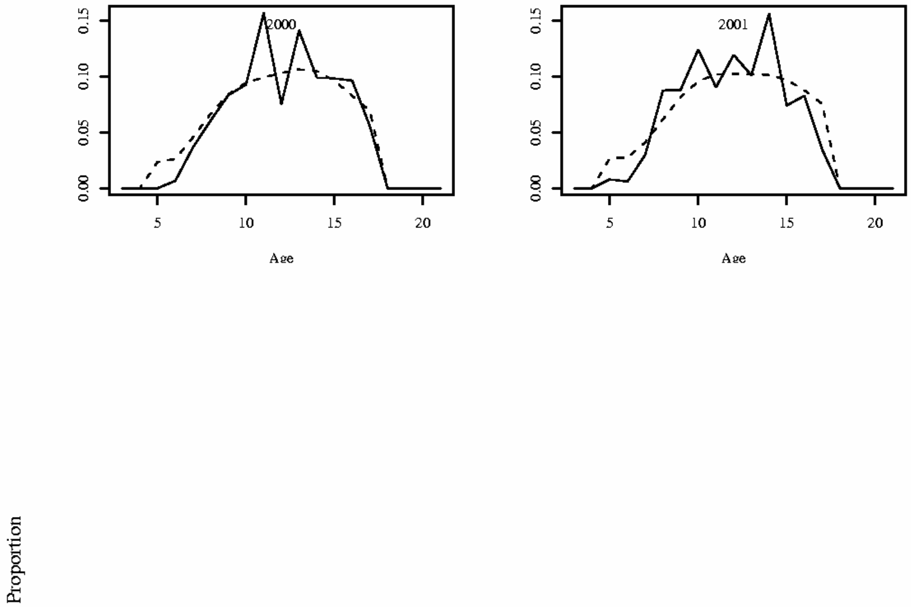

Figure 8.11. Male fishery age composition by year (solid line = observed, dotted line = predicted)

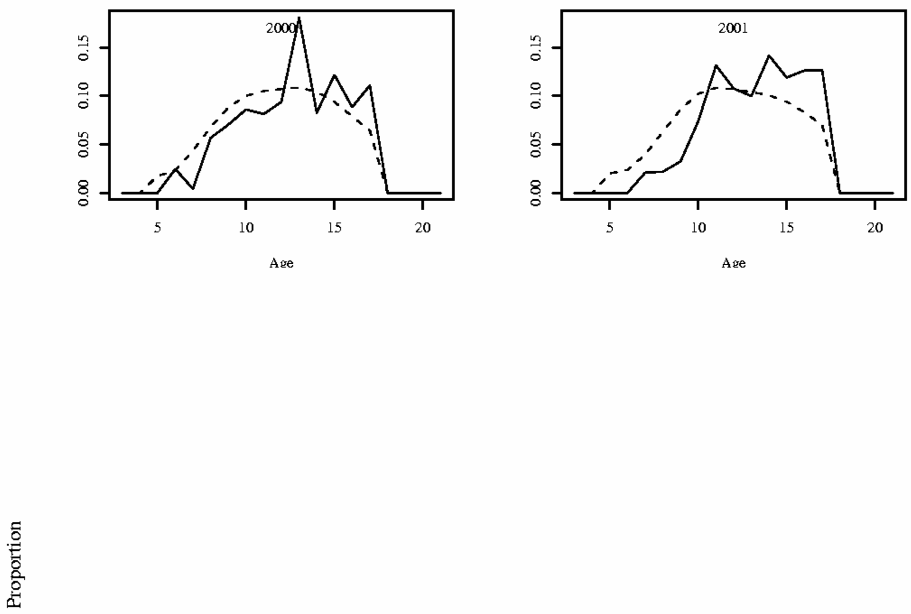

Figure 8.12. Female fishery age composition by year (solid line = observed, dotted line = predicted)

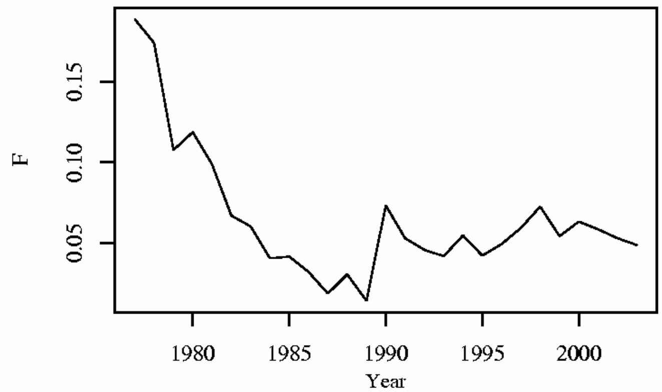

Figure 8.13. Estimated fishing mortality rate of flathead sole

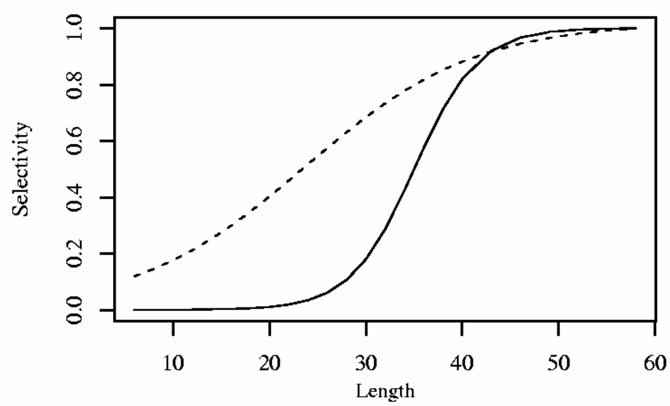

Figure 8.14. Estimated fishery (solid line) and survey (dashed line) selectivity curve by length

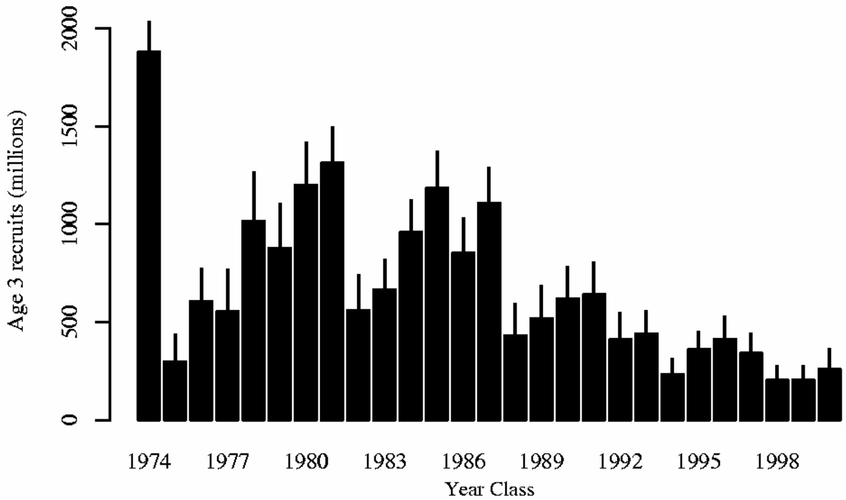

Figure 8.15. Estimated recruitment (age 3) of BSAI flathead sole, with 95% CI limits obtained from MCMC integration.

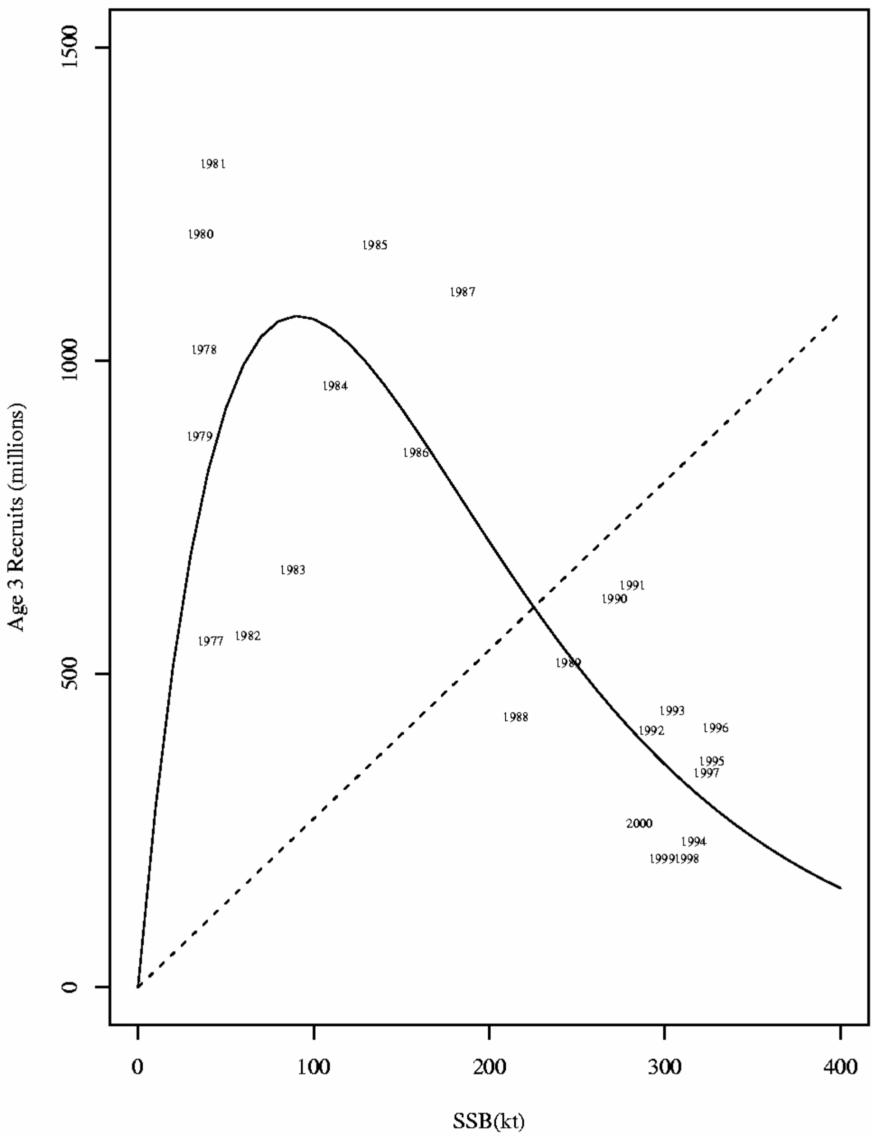

Figure 8.16. Estimated female SSB and recruitment of flathead sole, labeled by year class, with a fitted Ricker curve (solid line).
The replacement line is based on an F40% value of 0.30