# Chapter 7

# Northern Rock Sole

Thomas K. Wilderbuer and Gary E. Walters

## EXECUTIVE SUMMARY

The following changes have been made to this assessment relative to the November 2003 SAFE:

Changes to the input data

1) 2003 fishery age composition.
2) 2003 survey age composition.
3) 2004 trawl survey biomass point estimate and standard error.
4) Estimate of catch (t) and discards through 4, September 2004.
5) Estimate of retained and discarded portions of the 2003 catch.

Assessment results

1) The projected age 2+ biomass for 2005 is 1,376,400 t.
2) The projected female spawning biomass for 2005 is 420,500 t.
3) The recommended 2005 ABC is 131,900 t based on an $F_{40\%}$ (0.15) harvest level.
4) The 2005 overfishing level is 157,200 t based on an $F_{35\%}$ (0.18) harvest level.

New Analysis

Natural mortality was estimated with respect to the best fit to all the observed data and survey catchability was estimated using information on catchability from the results of a herding experiment.

## SUMMARY

| | 2004 Assessment Recommendations for the 2005 harvest | 2003 Assessment Recommendations for the 2004 harvest |
|---|---|---|
| Total biomass | 1,376,400 t | 1,164,200 t |
| ABC | 131,900 t | 139,300 t |
| Overfishing | 157,200 t | 166,300 t |
| $F_{ABC}$ | $F_{0.40} = 0.15$ | $F_{0.40} = 0.173$ |
| $F_{overfishing}$ | $F_{0.35} = 0.18$ | $F_{0.35} = 0.21$ |

## INTRODUCTION

Northern rock sole (Lepidopsetta polyxystra n. sp.) are distributed primarily on the eastern Bering Sea continental shelf and in much lesser amounts in the Aleutian Islands region. Two species of rock sole are known to occur in the North Pacific ocean, a northern rock sole (L. polyxystra) and a southern rock sole (L. bilineata) (Orr and Matarese 2000). These species have an overlapping distribution in the Gulf of Alaska, but the northern species comprise the majority of the Bering Sea and Aleutian Islands populations where they are managed as a single stock.

Centers of abundance occur off the Kamchatka Peninsula (Shubnikov and Lisovenko 1964), British Columbia (Forrester and Thompson 1969), the central Gulf of Alaska, and in the southeastern Bering Sea (Alton and Sample 1975). Adults exhibit a benthic lifestyle and, in the eastern Bering Sea and occupy separate winter (spawning) and summertime feeding distributions on the continental shelf. Northern rock sole spawn during the winter-early spring period of December-March.

## CATCH HISTORY

Rock sole catches increased from an average of 7,000 t annually from 1963-69 to 30,000 t between 1970 to 1975. Catches (t) since implementation of the MFCMA in 1977 are shown in Table 7.1, with catch data for 1980-88 separated into catches by non-U.S. fisheries; joint venture operations and DAP catches (where available). Prior to 1987, the classification of rock sole in the "other flatfish" management category prevented reliable estimates of DAP catch. Catches from 1989 - 2003 (domestic only) have averaged 49,480 t annually. The size composition of the 2003 catch from observer sampling, by sex and management area, are shown in Figure 7.1 and the catch locations in 2001, by quarter, are shown in the Appendix.

Rock sole are important as the target of a high value roe fishery occurring in February and March which accounts for the majority of the annual catch. The 2003 catch of 35,395 t was 32% of the ABC of 110,000 t (80% of the TAC). The 2004 catch total is 47,600 t through September 4. Thus, rock sole remain lightly harvested in the Bering Sea and Aleutian Islands.

During the 2004 fishing season rock sole harvesting was temporarily closed in the Bering Sea and Aleutian Islands due to halibut bycatch restrictions on February 24. On April 1 directed rock sole harvesting was closed, after which the species could only be retained as bycatch. On May 23 the Alaska NMFS Regional office released 3,075 t of reserve catch to supplement the 2004 TAC.

Although female rock sole are highly desirable when in spawning condition, large amounts of rock sole are discarded overboard in the various Bering Sea trawl target fisheries. At-sea sampling provides the following annual estimates for 1987-2003.

| Year | Retained | Discard | % Retained |
|---|---|---|---|
| 1987 | 14,209 t | 14,701 t | 49 |
| 1988 | 22,374 t | 23,148 t | 49 |
| 1989 | 23,544 t | 24,358 t | 49 |
| 1990 | 12,170 t | 12,591 t | 49 |
| 1991 | 25,406 t | 35,181 t | 42 |
| 1992 | 21,317 t | 35,681 t | 37 |
| 1993 | 22,589 t | 45,669 t | 33 |
| 1994 | 20,951 t | 39,945 t | 34 |
| 1995 | 21,761 t | 33,108 t | 40 |
| 1996 | 19,770 t | 27,158 t | 42 |
| 1997 | 27,743 t | 39,821 t | 41 |
| 1998 | 12,645 t | 20,999 t | 38 |
| 1999 | 15,224 t | 25,286 t | 38 |
| 2000 | 22,151 t | 27,113 t | 45 |
| 2001 | 19,299 t | 9,956 t | 66 |
| 2002 | 23,607 t | 17,724 t | 57 |
| 2003 | 19,492 t | 15,903 t | 55 |

From 1987 to 2000 rock sole were discarded in greater amounts than they were retained. The past three years indicate increased utilization of the catch. Fisheries with the highest discard rates include the rock sole roe fishery, the yellowfin sole, flathead sole, the Pacific cod fisheries (Table 7.2).

## DATA

The data used in this assessment include estimates of total catch, trawl fishery catch-at-age, trawl survey age composition, trawl survey biomass estimates and sampling error, maturity observations from observer sampling and mean weight-at-age.

### Fishery Catch and Catch-at-Age

Available information include fishery total catch data from 1975-September 4, 2004 (Table 7.1) and fishery catch-at-age numbers from 1980-2003 (Table 7.3).

### Survey CPUE

Since rock sole are lightly exploited and are often taken incidentally in target fisheries for other species, CPUE from commercial fisheries are considered an unreliable method for detecting trends in abundance. It is therefore necessary to use research vessel survey data to assess the condition of these stocks.

Abundance estimates from the 1982 AFSC survey were substantially higher than from the 1981 survey data for a number of bottom-tending species such as flatfishes. This is coincident with the change in research trawl to the 83/112 with better bottom tending characteristics. The increase in survey CPUE was particularly large for rock sole (6.5 to 12.3 kg/ha, Figure 7.2). Consequently, CPUE and biomass from the 1975-81 surveys are not used in the assessment model.

The CPUE trend indicates a significantly increasing population from 1982-92 when the mean CPUE more than tripled. The population leveled-off from 1994-98 when CPUE values indicated a high level of abundance. The 1999 value of 36.5 kg/ha was the lowest observed since 1992, possibly due to extremely low water temperatures. Since that time the value seems to be stabilizing and reached 47.1 in 2004.

Absolute Abundance

Estimates of rock sole biomass are also estimated from the AFSC surveys using stratified area-swept expansion of the CPUE data. The estimates are as follows:

| Year | Eastern Bering Sea (t) | Aleutian Islands (t) |
|---|---|---|
| 1975 | 175,500 | |
| 1979 | 194,700 | |
| 1980 | 283,800 | 28,500 |
| 1981 | 302,400 | |
| 1982 | 578,800 | |
| 1983 | 713,000 | 23,300 |
| 1984 | 799,300 | |
| 1985 | 700,100 | |
| 1986 | 1,031,400 | 26,900 |
| 1987 | 1,269,700 | |
| 1988 | 1,480,100 | |
| 1989 | 1,138,600 | |
| 1990 | 1,381,300 | |
| 1991 | 1,588,300 | 37,325 |
| 1992 | 1,543,900 | |
| 1993 | 2,123,500 | |
| 1994 | 2,894,200 | 54,785 |
| 1995 | 2,175,040 | |
| 1996 | 2,183,000 | |
| 1997 | 2,710,900 | 56,154 |
| 1998 | 2,168,700 | |
| 1999 | 1,689,100 | |
| 2000 | 2,127,700 | 45,949 |
| 2001 | 2,135,400 | |
| 2002 | 1,921,400 | 57,700 |
| 2003 | 2,424,800 | |
| 2004 | 2,182,100 | 63,900 |

It should be recognized that the biomass estimates given above are point estimates from an "area-swept" bottom trawl survey. As a result they are uncertain. It is assumed that the sampling plan covers the distribution of the fish and that all fish in the path of the footrope of the trawl are captured. That is, there are no losses due to escape or gains due to gear herding effects. Due to sampling variability alone, the 95% confidence interval for the 2004 point estimate of the Bering Sea surveyed area is 1,820,771 t - 2,543,402 t.

Rock sole biomass was relatively stable through 1979, but then increased substantially in the following years to 799,300 t in 1984. In 1985 the estimate declined to 700,000 t but increased again in 1986 to over 1 million t and continued this trend through 1988. The 1989 and 1990 estimates were at a high and stable level (slightly less than the 1988 estimate) and continued to increase to the highest level estimated by the trawl survey at 2.9 million metric tons in 1994. The 1995, 1996 and 1998 estimates are near the 1993 estimate of 2.1 million metric tons and the 1997 estimate is about the level of 1994.

Sharp increases in trawl survey abundance estimates for most species of Bering Sea flatfish between 1981 and 1982 indicate that the 83-112 trawl was more efficient for capturing these species than the 400-mesh eastern trawl used in 1975, and 1979-81. Allowing the stock assessment model to tune to these early survey estimates would most likely underestimate the true pre-1982 biomass, thus exaggerating the degree to which biomass increased during that period. The pre-1982 survey biomass estimates were omitted from the analysis.

Weight-at-age and Maturity-at-age

In conjunction with the large and steady increase in the rock sole stock size since the early 1980s, it was found that there was also a corresponding decrease in size-at-age for both sexes (Figure 7.3). This also caused a resultant decrease in weight-at-age as the population increased and expanded westward toward the shelf edge (Walters and Wilderbuer 2000). These updated values of weight-at-age (Table 7.4) were used in this assessment to model the population dynamics of the rock sole population.

The length-weight relationship did not change significantly over this time period as discerned from an analysis of observations made in 1975, 1976 and 1988. The following parameters have been calculated for the length (cm)-weight (g) relationship:

$$W = a * L ** {}^{b}$$

No significant differences were found between sexes so that these parameters are for both sexes combined.

| a | b |
|---|---|
| 0.007610 | 3.11976 |

Maturity information available from anatomical scans collected by fishery observers during the 1993 and 1994 Bering Sea rock sole roe fishery are used in this assessment (Table 7.5). These data indicate that the age of 50% maturity occurs at 9-10 years for female rock sole.

Survey and Fishery Age composition

Rock sole otoliths have routinely been collected during the trawl surveys since 1979 to provide estimates of the population age composition (Fig. 7.4, Table 7.6). Fishery size composition data from 1980-97 (prior to 1980 observer coverage was sparse and did not reflect the catch size composition) were applied to age-length keys from these surveys to provide a time-series of catch-at-age assuming that the mean length at age from the trawl survey was the same as the fishery in a given year. Estimation of the fishery age composition since 1997 use age-length keys derived from age structures collected annually from the fishery.

## ANALYTIC APPROACH

Model Structure

The abundance, mortality, recruitment and selectivity of rock sole were assessed with a stock assessment model using the AD Model builder software. The conceptual model is similar to that implemented in the stock synthesis program (Methot 1990, Fournier and Archibald 1982). The model is a separable catch-age analysis that uses survey estimates of biomass and age composition as auxiliary information. The model simulates the dynamics of the population and compares the expected values of the population characteristics to the characteristics observed from surveys and fishery sampling programs. This is accomplished by the simultaneous estimation of the parameters in the model using the maximum likelihood estimation procedure. The fit of the simulated values to the observable characteristics is optimized by maximizing a log(likelihood) function.

The suite of parameters estimated by the model are classified by three likelihood components:

| Data Component | Distribution assumption |
|---|---|
| Trawl fishery catch-at-age | Multinomial |
| Trawl survey population age composition | Multinomial |
| Trawl survey biomass estimates and S.E. | Log normal |

The total log likelihood is the sum of the likelihoods for each data component (Table 7-7). The likelihood components may be weighted by an emphasis factor, however, equal emphasis was placed on fitting each likelihood component in the rock sole assessment except for the catch weight. The AD Model Builder software fits the data components using automatic differentiation (Griewank and Corliss 1991) software developed as a set of libraries (AUTODIFF C++ library). Table 7-7 presents the key equations used to model the rock sole population dynamics in the Bering Sea and Table 7-8 provides a description of the variables used in Table 7-7. The model of rock sole population dynamics was evaluated with respect to the observations of the time-series of survey and fishery age compositions and the survey biomass trend since 1982.

Parameters Estimated Independently

Assessments for rock sole in other areas assume M = 0.20 for rock sole on the basis of the longevity of the species. In a past BSAI assessment, the stock synthesis model was used to entertain a range of M values to evaluate the fit of the observable population characteristics over a range of natural mortality values (Wilderbuer and Walters 1992). The best fit occurred at M = 0.18 with the survey catchability coefficient (q) set equal to 1.0. Since that time eleven more years of fishery and survey age composition data have become available as well as experimental estimates of catchability. This provides motivation to re-examine the estimate of natural mortality as conditional parameters in this assessment.

Rock sole maturity schedules were estimated independently as discussed in a previous section (Table 7.5).

Parameters Estimated Conditionally

The parameters estimated by the model are presented below:

| Fishing mortality | Selectivity | Year class strength | Spawner-recruit | catchability | M | Total |
|---|---|---|---|---|---|---|
| 30 | 4 | 49 | 2 | 1 | 1 | 87 |

The increase in the number of parameters estimated in this assessment compared to last year can be accounted for by the input of another year of fishery data, the entry of another year class into the observed population and an estimate of natural mortality.

Year class strengths

The population simulation specifies the numbers-at-age in the beginning year of the simulation, the number of recruits in each subsequent year, and the survival rate for each cohort as it moves through the population using the population dynamics equations given in Table 7-7.

Selectivity

Fishery and survey selectivity were modeled in this assessment using the logistic function, as shown in Table 7-7. The model was configured with the selectivity curve constrained to provide an asymptotic fit for the older fish in the fishery and survey, but still was allowed to estimate the shape of the logistic curve for young fish. The oldest year classes in the surveys and fisheries were truncated at 20 and allowed to accumulate into the age category 20+ years.

Fishing Mortality

The fishing mortality rates (F) for each age and year are calculated to approximate the catch weight by solving for F while still allowing for observation error in catch measurement. A large emphasis (300) was placed on the catch likelihood component.

Survey Catchability

Unusually low estimates of flatfish biomass were obtained for Bering Sea shelf flatfish species during the very cold year of 1999. These results suggest a relationship between bottom water temperature and trawl survey catchabililty, which has been documented for yellowfin sole and arrowtooth flounder in a recent BSAI SAFE document. To better understand how water temperature may affect the catchability of rock sole to the survey trawl, we estimated catchability in a linear model for each year within the stock assessment model as:

$$q = \alpha + \beta T$$

where q is catchability, T is the average annual bottom water temperature at survey stations less than 100 m, and $\alpha$ and $\beta$ are parameters estimated by the model. The model estimated values of $\alpha$ and $\beta$ at 1.77 and 0.021, respectively. The small value for $\beta$ indicates that temperature has very little effect on trawl catchability of rock sole and the value of 1.77 obtained for $\alpha$ suggests that survey catchability (q) is greater than 1.0, the value used in past assessments.

Experiments conducted in recent years on the standard research trawl used in the annual trawl surveys indicate that rock sole are herded by the bridles (in contact with the seafloor) from the area outside the net mouth into the trawl path (Somerton and Munro 2001). Rock sole survey trawl catchability was estimated at 1.4 from these experiments which indicate that the standard area-swept biomass estimate from the survey is an overestimate of the rock sole population biomass.

These experimental results, in combination with the results of the bottom temperature analysis above, provided a compelling reason to consider an alternative model where survey catchability is estimated. In this assessment we used the value of q from the herding experiment to constrain survey catchabliity and then estimate survey catchabililty as follows:

$$qlike = 0.5\left[\frac{q_{exp} - q_{mod}}{\sigma_{exp}}\right]^2$$

where *qlike* is the survey catchability likelihood component, $q_{mod}$ is the survey catchability parameter estimated by the model, $q_{exp}$ is the estimate of area-swept q from the herding experiment, and σ is the standard error of the experimental estimate of q.

Natural Mortality

With catchability constrained as described above, natural mortality was estimated as a free parameter. The best fit to the total log likelihood occurred at M = 0.1612 (q = 1.52), lower than the value of 0.18 used in the past 11 annual assessments. To gain a better understanding of how changes in M affect the fits to the observed population characteristics (likelihood components), M was fixed at values ranging from 0.1 to 0.21. The total log likelihood profile from these runs is shown below and in Figure 7.5

| | M=0.2 | M=0.18 | M=0.16 | M=0.14 | M=0.12 | M=0.10 |
|---|---|---|---|---|---|---|
| survey biomass | 65.4 | 54.2 | 48.4 | 49.4 | 58.7 | 77.4 |
| catch | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| catch age comp | 640.9 | 634.5 | 630.3 | 628.2 | 628.0 | 629.4 |
| survey age comp | 357.4 | 356.2 | 359.3 | 366.2 | 376.0 | 388.3 |
| Recruitment | 69.3 | 68.2 | 66.6 | 65.1 | 63.6 | 62.2 |
| Q | 1.4 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 |
| ending biomass | 1308.3 | 1331.9 | 1369.3 | 1419.3 | 1481.3 | 1554.8 |
| total likelihood | 1132.9 | 1113.1 | 1104.6 | 1108.9 | 1126.4 | 1157.2 |

Model Evaluation

The log likelihood surface is relatively flat between M values of 0.13 and 0.19 with corresponding changes in q (Figure 7.5). At values outside this range there is a marked decrease in total log likelihood due to the degradation in the fits to the survey biomass and survey age compositions. The posterior distribution of M (Appendix figure), with a prior from the penalty on the likelihood of q if it departs very far from the experimental value, indicates the value of M = 0.18 has a low probability given the data. Therefore, a natural mortality rate of 0.1612 (q = 0.152) is used in this assessment.

## MODEL RESULTS

Fishing Mortality and Selectivity

The assessment model estimates of the annual fishing mortality on fully selected ages and the estimated annual exploitation rates (catch/total biomass) are given Table 7.9. The exploitation rate has averaged 3.5% from 1975-2004, indicating a lightly exploited stock. Age-specific selectivity estimated by the model (Table 7.10, Fig. 7.6) indicate that rock sole are 50% selected by the fishery at age of 8 and are fully selected by age 13 (sexes combined).

Abundance Trend

The stock assessment model indicates that rock sole total biomass was at low levels during the mid 1970s through 1982 (70,000 - 350,000 t, Fig. 7.6 and Table 7.11). From 1985-95, a period characterized by sustained above-average recruitment (1980-88 year classes, Fig. 7.6) and light exploitation, the estimated total biomass rapidly increased at a high rate to nearly 1.9 million t by 1995. Since then, the model indicates the population biomass has declined 29% to 1.36 million t in 2004 and is projected at 1.37 million t for 2005. The decline since 1995 is attributable to the below-average recruitment to the adult portion of the population during the 1990s. The female spawning biomass is estimated to be at a high, but slowly declining level of 452,300 t in 2004 (Table 7.11). The model provides good fits to most of the strong year classes observed in the fishery and surveys during the time-series. These are shown in the Appendix with the model estimates of population numbers at age.

The model estimates of survey biomass (using trawl survey age-specific selectivity and the estimate of q applied to the total biomass, Fig. 7.6) corresponded fairly well with the trawl survey biomass trend through 1998. The 1999 survey point estimate is 500,000 t less than the model estimate whereas the past two survey biomass estimates have ranged from 300,000 t to 400,000 t higher than the model estimate of survey biomass. Both the trawl survey and the model indicate the same increasing biomass trend from the late 1970s to the mid 1990s but the survey does not indicate the declining trend from modeling results. The large variability in the survey biomass estimates during the last 5 years is not consistent with the observed age composition during this period and is not fit well by the model. The model fits the 2000 and 2002 survey estimates but does not match the higher estimates from the 2001, 2003 and 2004 surveys.

Total Biomass

The stock assessment model estimates of total biomass (begin year population numbers multiplied by mid-year weight at age) is used to recommend the ABC for 2005. Including the 2004 catch of 47,600 t through 4 September (including discards), the model projects the total biomass for 2005 at **1,137,600** t.

Recruitment Trends

Increases in abundance described earlier for rock sole can be attributed to the recruitment of a series of strong year classes (Figs. 7.4 and 7.6, Table 7.11). Rock sole ages have now been read for samples obtained in 2003 and show the continuing presence of the 1987 year class (Fig. 7.6). The 1990 year class, as 13 year old fish in 2003, comprise a significant part of the survey and fishery age composition numbers. The 1987 year class is the largest estimated during the recruitment time-series and still comprise 9% of the estimated 2003 survey age composition numbers as sixteen year old fish. Recruitment after 1990 has been below the 26 year average with the exception of the 2000 year class which have been observed for the first time in the 2003 survey age sample and may be strong.

Tier 1 Considerations

The SSC has requested that flatfish assessments which have a lengthy time-series of stock and recruitment estimates explore management under a Tier 1 harvest policy. In the case of rock sole, the time series of recruitment estimates from this assessment is 28 years. MSY is an equilibrium concept and it's calculated value is dependent on both the spawner-recruit data, which we assume represents the equilibrium stock size-recruitment relationship, and the model used to fit the data. In the stock assessment model used here, a Ricker form of the stock-recruit relationship was fit to these data and estimates of $F_{MSY}$ and $B_{MSY}$ (female spawning biomass) were calculated, assuming that the fit to the stock-recruitment data points represent the long-term productivity of the stock. However, very different estimates of $F_{MSY}$ and $B_{MSY}$ were obtained, depending on which years of stock-recruitment data points were included in the fitting procedure. Fitting the full time series since the regime shift in 1977 (1978-99) gives values of **$F_{MSY}$=0.53, $B_{MSY}$=87,510 t, and MSY = 101,230 t**.

A recent analysis of flatfish recruitment give compelling evidence that temporal trends in winter spawning flatfish production in the Eastern Bering Sea are consistent with the hypothesis that decadal scale climate variability influences marine survival during the early life history period (Wilderbuer et al. 2002). Periods of estimated cross-shelf advection of flatfish larvae was found to coincide with synchronous above-average recruitment (1980s) whereas periods of weak advection or advection to the west were associated with poor recruitment (1990s) (Fig 7.7 in the 2003 SAFE). These changes in stock productivity were found to coincide with a decadal scale shift in atmospheric forcing. When the spawner-recruit information from the1978-89 (productive) period were fit, estimates were obtained as follows: **$F_{MSY}$=0.28, $B_{MSY}$=3.72 E+12 t, and MSY = 5.85 E+12 t**. These estimates are clearly unrealistic and unreliable and only result from 12 observations (estimates).

This exercise of fitting spawner-recruit observations calls into concern whether a single fit of stock recruitment time-series data is able to reliably capture the long-term reproductive potential of the rock sole stock, particularly given the length of the time-series and the stock dynamics which have occurred since 1975. The aforementioned analysis was performed for rock sole, arrowtooth flounder and flathead sole, species which spawn in the winter in offshore areas and are seemingly reliant upon advection to nursery areas 3-4 months later. The atmospheric forcing responsible for the advection properties during this time period appears to be the location of the springtime signature of the Aleutian Low Pressure field. Anomalous sea level pressure implies that westerly to south-westerly surface winds (on-shelf) predominated during 1977-1988, whereas during 1989-96 easterly (off-shelf) winds were predominate. These shifts in recruitment production may be a cause of concern if we assume that the long term productivity is closely related to only spawning stock size while ignoring mechanisms governing the variability in production which may correspond to decadal (or longer) shifts in environmental conditions.

Given these concerns, the authors are performing a simulation study to determine the appropriateness of applying a harvest strategy from fitting the full time series for a fish stock experiencing temporal changes in reproductive potential due to changing oceanic conditions (in progress at this time). Until this analysis is complete, we continue to recommend a Tier 3 harvest strategy.

## ACCEPTABLE BIOLOGICAL CATCH

The reference fishing mortality rate for rock 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). Equilibrium female spawning biomass is calculated by applying the female spawning biomass per recruit resulting from a constant $F_{0.40}$ harvest to an estimate of average equilibrium recruitment. For this assessment, year classes spawned in 1977 through 2002 are used to calculate the average equilibrium recruitment. This results in an estimate of **$B_{0.40}$ = 234,100 t**. The stock assessment model estimates the 2005 level of female spawning biomass at **420,500 t** (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and B>$B_{0.40}$ (420,500 > 234,100, fig. 7.7), rock sole reference fishing mortality is defined in tier 3a. For the 2004 harvest: $F_{ABC} \leq F_{0.40} = 0.15$ and $F_{overfishing} = F_{0.35} = 0.18$ (full selection F values).

Acceptable biological catch is estimated for 2005 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the 2005 estimate of age-specific total biomass as follows:

$$ABC = \sum_{a=a_r}^{a_{nages}} \overline{w}_a n_a \left(1 - e^{-M - Fs_a}\right) \frac{Fs_a}{M + Fs_a}$$

where $S_a$ is the selectivity at age, M is natural mortality, $W_a$ is the mean weight at age from 2000, and $n_a$ is the beginning of the year numbers at age. This results in a **2005 ABC of 131,900** t for the eastern Bering Sea portion of the stock.

The stock assessment analysis must also consider harvest limits, usually described as "overfishing" fishing mortality levels with corresponding yield amounts. Amendment 56 to the BS/AI FMP now sets the harvest limit at the $F_{0.35}$ fishing mortality value. The overfishing fishing mortality value, ABC fishing mortality value and their corresponding yields are given as follows:

| Harvest level | F value | 2005 Yield |
|---|---|---|
| $F_{0.35}$ | 0.18 | 157,200 t |
| $F_{0.40}$ | 0.15 | 131,900 t |

BIOMASS PROJECTIONS

As in past years, 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 2004 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2005 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2004. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 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 2005, 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 2005 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 2000-2004 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 2005 and above its MSY level in 2015 under this scenario, then the stock is not overfished.)

*Scenario 7*: In 2005 and 2006, $F$ is set equal to *max* $F_{ABC}$, and in all subsequent years, $F$ is set equal to $F_{OFL}$. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2017 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 7.13 indicate that rock sole are currently not overfished and are not approaching an overfished condition. If harvested at the average F from 2000-2004, rock sole female spawning biomass is projected to decline over the next five years due to the reduced recruitment observed during the 1990s (fig. 7.9).

## ECOSYSTEM CONSIDERATIONS

### Ecosystem Effects on the stock

1) Prey availability/abundance trends

Rock sole diet by life stage varies as follows: Larvae consume plankton and algae, early juveniles consume zooplankton, late juvenile stage and adults prey includes bivalves, polychaetes, amphipods, mollusks and miscellaneous crustaceans. 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 rock sole resource.

2) Predator population trends

As juveniles, it is well-documented from studies in other parts of the world that flatfish are prey for shrimp species in near shore areas. This has not been reported for Bering Sea rock sole due to a lack of juvenile sampling and collections in near shore areas, but is thought to occur. As late juveniles they are found in stomachs of pollock, Pacific cod, yellowfin sole, skates and Pacific halibut; mostly on small rock sole ranging from 5 to 15 cm standard length..

Past, present and projected future population trends of these predator species can be found in their respective SAFE chapters in this volume. Encounters between rock sole and their predators may be limited as their distributions do not completely overlap in space and time.

3) Changes in habitat quality

Changes in the physical environment which may affect rock sole distribution patterns, recruitment success, migration timing and patterns 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).

**Fishery Effects on the ecosystem**

1) The rock sole target fishery contribution to the total bycatch of other non-prohibited species is shown for 1991-2003 in Table 7.14. The rock sole target fishery contribution to the total bycatch of prohibited species is shown for 2002 and 2003 in Table 14 of the Economic SAFE (Appendix C) and is summarized for 2003 as follows:

| Prohibited species | Rock sole fishery % of total bycatch |
|---|---|
| Halibut mortality | 23 |
| Herring | <1 |
| Red King crab | 50 |
| C. bairdi | 22 |
| Other Tanner crab | 5 |
| Salmon | < 1 |

2) Relative to the predator needs in space and time, the rock sole target fishery is not very selective for fish between 5-15 cm and therefore has minimal overlap with removals from predation.

3) The target fishery is not perceived to have an effect on the amount of large size target fish in the population due to it’s history of very light exploitation (3%) over the past 28 years.

4) Rock sole fishery discards are presented in the Catch History section.

5) It is unknown what effect the fishery has had on rock sole maturity-at-age and fecundity.

6) Analysis of the benthic disturbance from the rock sole fishery is available in the Preliminary draft of the Essential Fish Habitat environmental Impact Statement.

| **Ecosystem effects on rock sole** | | | |
|---|---|---|---|
| Indicator | Observation | Interpretation | Evaluation |
| *Prey availability or abundance trends* | | | |
| Benthic infauna | Stomach contents | Stable, data limited | Unknown |
| *Predator population trends* | | | |
| Fish (Pollock, Pacific cod, halibut, yellowfin sole, skates) | Stable | Possible increases to rock sole mortality | |
| *Changes in habitat quality* | | | |
| Temperature regime | Cold years rock sole catchability and herding may decrease | Likely to affect surveyed stock | No concern (dealt with in model) |
| Winter-spring environmental conditions | Affects pre-recruit survival | Probably a number of factors | Causes natural variability |

| ***Rock sole* effects on ecosystem** | | | |
|---|---|---|---|
| Indicator | Observation | Interpretation | Evaluation |
| *Fishery contribution to bycatch* | | | |
| Prohibited species | Stable, heavily monitored | Minor contribution to mortality | No concern |
| Forage (including herring, Atka mackerel, cod, and pollock) | Stable, heavily monitored | Bycatch levels small relative to forage biomass | No concern |
| HAPC biota | Low bycatch levels of (spp) | Bycatch levels small relative to HAPC biota | No concern |
| Marine mammals and birds | Very minor direct-take | Safe | No concern |
| Sensitive non-target species | Likely minor impact | Data limited, likely to be safe | No concern |
| Fishery concentration in space and time | Low exploitation rate | Little detrimental effect | No concern |
| *Fishery effects on amount of large size target fish* | Low exploitation rate | Natural fluctuation | No concern |
| *Fishery contribution to discards and offal production* | Stable trend | Improving, but data limited | Possible concern |
| *Fishery effects on age-at-maturity and fecundity* | unknown | NA | Possible concern |

## REFERENCES

Alton, M. S. and Terry M. Sample 1976. Rock sole (Family Pleuronectidae) p. 461-474. In: Demersal fish and shellfish resources in the Bering Sea in the baseline year 1975. Principal investigators Walter T. Pereyra, Jerry E. Reeves, and Richard Bakkala. U.S. Dep. Comm., Natl. Oceanic Atmos. Admin., Natl. Mar. Serv., Northwest and Alaska Fish Center, Seattle, Wa. Processed Rep., 619 p.

Fournier, D. A. and C.P. Archibald. 1982. A general theory for analyzing catch-at-age data. Can. J. Fish Aquat. Sci. 39:1195-1207.

Greiwank, A. and G. F. Corliss (eds) 1991. Automatic differentiation of algorithms: theory, implementation and application. Proceedings of the SIAM Workshop on the Automatic Differentiation of Algorithms, held Jan. 6-8, Breckenridge, CO. Soc. Indust. And Applied Mathematics, Philadelphia.

Haflinger, K. 1981. A survey of benthic infaunal communities of the Southeastern Bering Sea shelf. *In* Hood and Calder (editors) The Eastern Bering Sea Shelf: Oceanography and Resources, Vol. 2. P. 1091-1104. Office Mar. Pol. Assess., NOAA. Univ. Wash. Press, Seattle, Wa 98105.

Methot, R. D. 1990. Synthesis model: An adaptable framework for analysis of diverse stock assessment data. INPFC Bull. 50:259- 277. Symposium on application of stock assessment techniques to Gadoids.

Orr, J. W. and A.C. Matarese. 2000. Revision of the genus *Lepidopsetta* Gill, 1862 (Teleostei: Pleuronectidae) based on larval and adult morphology, with a description of a new species from the North Pacific Ocean and Bering Sea. Fish.Bull. 98(3), 539-582.

Ricker, W. E. 1958. Handbook of computations for biological statistics of fish populations. Bull. Fish. Res. Bd. Can., (119) 300 p.

Shubnikov, D. A. and L. A. Lisovenko 1964. Data on the biology of rock sole in the southeastern Bering Sea. Tr. Vses. Nauchno-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 49 (Izv. Tikookean. Nauchno-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 51) : 209-214. (Transl. In Soviet Fisheries Investigations in the Northeast Pacific, Part II, p. 220-226, by Israel Program Sci. Transl., 1968, available Natl. Tech. Inf. Serv., Springfield, VA, as TT 67-51204).

Somerton, D. A. and P. Munro. 2001. Bridle efficiency of a survey trawl for flatfish. Fish. Bull. 99:641-652(2001).

Walters, G. E. and T. K. Wilderbuer. 2000. Decreasing length at age in a rapidly expanding population of northern rock sole in the eastern Bering Sea and its effect on management advice. Journal of Sea Research 44(2000)17-26.

Wilderbuer, T. K., and G. E. Walters. 1992. Rock sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 1993. Chapter 6. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage Alaska 99510.

Wilderbuer, T. K., A. B. Hollowed, W. J. Ingraham, Jr., P. D. Spencer, M. E. Conners, N. A. Bond, and G. E. Walters. Flatfish recruitment response to decadal climate variability and ocean conditions in the eastern Bering Sea. Progress Oceanography 55 (2002) 235-247.

Table 7.1--Rock sole catch (t) from 1977 - September 4, 2004.

| Year | Foreign | Joint-Venture | Domestic | Total |
|---|---|---|---|---|
| 1977 | 5,319 | | | 5,319 |
| 1978 | 7,038 | | | 7,038 |
| 1979 | 5,874 | | | 5,874 |
| 1980 | 6,329 | 2,469 | | 8,798 |
| 1981 | 3,480 | 5,541 | | 9,021 |
| 1982 | 3,169 | 8,674 | | 11,844 |
| 1983 | 4,479 | 9,140 | | 13,618 |
| 1984 | 10,156 | 27,523 | | 18,750 |
| 1985 | 6,671 | 12,079 | | 37,678 |
| 1986 | 3,394 | 16,217 | | 23,483 |
| 1987 | 776 | 11,136 | 28,910 | 40,046 |
| 1988 | | 40,844 | 45,522 | 86,366 |
| 1989 | | 21,010 | 47,902 | 68,912 |
| 1990 | | 10,492 | 24,761 | 35,253 |
| 1991 | | | 60,587 | 60,587 |
| 1992 | | | 56,998 | 56,998 |
| 1993 | | | 63,953 | 63,953 |
| 1994 | | | 60,544 | 60,544 |
| 1995 | | | 58,870 | 58,870 |
| 1996 | | | 46,928 | 46,928 |
| 1997 | | | 67,564 | 67,564 |
| 1998 | | | 33,645 | 33,645 |
| 1999 | | | 40,510 | 40,510 |
| 2000 | | | 49,264 | 49,264 |
| 2001 | | | 29,255 | 29,255 |
| 2002 | | | 41,331 | 41,331 |
| 2003 | | | 35,395 | 35,395 |
| 2004 | | | 47,637 | 47,637 |

Table 7.2--Discarded and retained rock sole catch (t), by target fishery, in 2002 and 2003.

**2002**

| target fishery | discard | retained | total |
|---|---|---|---|
| Atka mackerel | 50 | 26 | 75 |
| bottom pollock | 70 | 90 | 160 |
| Pacific cod | 4,482 | 2,343 | 6,825 |
| other flatfish | 128 | 27 | 155 |
| rockfish | 7 | 0 | 7 |
| flathead sole | 1,043 | 709 | 1,752 |
| mid water pollock | 823 | 896 | 1,720 |
| rock sole | 6,995 | 13,182 | 20,177 |
| sablefish | 0 | 0 | 0 |
| Greenland turbot | 1 | 0 | 1 |
| arrowtooth flounder | 13 | 8 | 21 |
| yellowfin sole | 4,112 | 6,326 | 10,438 |
| non-retained groundfish | 0 | 0 | 0 |
| Total catch | | | 41,331 |

**2003**

| | Retained | Discarded | Total |
|---|---|---|---|
| Atka mackerel | 59 | 89 | 148 |
| Bottom pollock | 61 | 12 | 73 |
| Pacific cod | 1,347 | 4,661 | 6,008 |
| Mid-water pollock | 751 | 569 | 1,321 |
| Sablefish | 0 | 4 | 4 |
| Rockfish | 22 | 6 | 27 |
| Arrowtooth flounder | 7 | 7 | 14 |
| Flathead sole | 725 | 427 | 1,152 |
| Rock sole | 12,011 | 6,337 | 18,349 |
| Yellowfin sole | 4,497 | 3,772 | 8,269 |
| Greenland turbot | 1 | 0 | 1 |
| Other flatfish | 1 | 2 | 3 |
| Other species | 11 | 15 | 26 |
| Total catch | | | 35,395 |

Table 7.3--Estimated catch numbers at age, 1980-2002 (in thousands).

| year/age | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1980 | 0 | 181 | 1,506 | 1,287 | 3,814 | 2,191 | 2,219 | 1,627 | 1,544 | 4,058 | 2,521 | 1,332 | 1,050 | 1,013 | 665 | 169 | 50 | 0 | 0 | 0 |
| 1981 | 0 | 0 | 1,613 | 2,674 | 1,527 | 8,407 | 1,764 | 851 | 1,144 | 1,839 | 3,213 | 1,432 | 1,237 | 636 | 888 | 516 | 137 | 28 | 0 | 0 |
| 1982 | 0 | 257 | 1,613 | 2,305 | 2,256 | 5,009 | 8,964 | 5,569 | 2,235 | 2,405 | 2,761 | 3,209 | 2,728 | 1,493 | 129 | 352 | 133 | 0 | 41 | 0 |
| 1983 | 0 | 0 | 4 | 577 | 2,033 | 1,727 | 3,426 | 5,684 | 2,940 | 3,816 | 1,502 | 2,114 | 5,096 | 2,501 | 1,604 | 1,653 | 274 | 165 | 53 | 0 |
| 1984 | 0 | 0 | 0 | 2,540 | 6,889 | 5,574 | 11,672 | 9,182 | 15,211 | 9,508 | 5,396 | 5,693 | 8,549 | 6,187 | 5,604 | 4,556 | 1,285 | 0 | 978 | 0 |
| 1985 | 0 | 1,470 | 3,286 | 11,807 | 20,807 | 12,840 | 8,141 | 6,531 | 4,137 | 5,961 | 1,024 | 413 | 322 | 727 | 2,312 | 1,404 | 528 | 413 | 140 | 322 |
| 1986 | 0 | 0 | 0 | 499 | 8,077 | 17,613 | 13,113 | 7,928 | 9,157 | 2,831 | 8,829 | 1,155 | 1,140 | 976 | 350 | 902 | 946 | 30 | 0 | 313 |
| 1987 | 0 | 0 | 0 | 2,071 | 7,895 | 13,482 | 23,226 | 6,993 | 5,778 | 4,502 | 2,392 | 6,458 | 994 | 267 | 352 | 191 | 673 | 344 | 84 | 718 |
| 1988 | 0 | 0 | 573 | 1,201 | 34,687 | 25,798 | 33,966 | 21,843 | 12,973 | 30,769 | 6,154 | 4,768 | 3,936 | 3,012 | 0 | 628 | 554 | 2,532 | 407 | 998 |
| 1989 | 0 | 0 | 0 | 1,495 | 10,113 | 33,265 | 16,029 | 21,434 | 10,454 | 10,231 | 8,697 | 5,142 | 4,106 | 5,286 | 2,925 | 1,154 | 131 | 0 | 0 | 695 |
| 1990 | 0 | 0 | 0 | 233 | 2,900 | 7,160 | 17,828 | 8,069 | 10,545 | 8,781 | 3,296 | 1,422 | 1,901 | 868 | 2,400 | 1,135 | 253 | 267 | 103 | 1,210 |
| 1991 | 0 | 18 | 2,201 | 7,809 | 4,570 | 12,353 | 17,269 | 41,194 | 28,628 | 19,896 | 15,885 | 8,182 | 3,727 | 3,514 | 3,346 | 3,674 | 1,136 | 728 | 0 | 1,739 |
| 1992 | 0 | 0 | 190 | 1,017 | 9,167 | 9,270 | 14,680 | 35,426 | 32,600 | 14,008 | 23,123 | 11,768 | 4,635 | 5,583 | 2,533 | 224 | 6,255 | 569 | 534 | 706 |
| 1993 | 0 | 0 | 0 | 0 | 0 | 2,875 | 11,020 | 20,443 | 13,895 | 60,531 | 9,742 | 15,812 | 12,138 | 3,354 | 3,354 | 1,757 | 783 | 1,278 | 1,597 | 799 |
| 1994 | 0 | 0 | 0 | 234 | 0 | 2,669 | 16,645 | 29,411 | 28,035 | 28,731 | 27,852 | 6,482 | 9,566 | 8,190 | 3,299 | 2,636 | 746 | 116 | 1,194 | 0 |
| 1995 | 0 | 0 | 0 | 325 | 1,188 | 1,252 | 6,044 | 23,427 | 27,225 | 17,683 | 18,867 | 18,486 | 7,446 | 6,752 | 6,300 | 180 | 422 | 446 | 0 | 0 |
| 1996 | 0 | 0 | 49 | 95 | 419 | 3,981 | 3,228 | 9,103 | 27,430 | 22,065 | 14,249 | 6,238 | 7,367 | 4,843 | 2,509 | 10,142 | 7,206 | 2,166 | 49 | 236 |
| 1997 | 0 | 9 | 126 | 1,849 | 1,549 | 3,650 | 20,448 | 4,834 | 21,812 | 55,524 | 25,705 | 21,732 | 16,669 | 12,100 | 6,795 | 3,554 | 2,037 | 1,344 | 0 | 0 |
| 1998 | 0 | 0 | 0 | 0 | 272 | 338 | 1,215 | 5,109 | 4,450 | 10,220 | 31,567 | 15,830 | 6,707 | 6,525 | 2,552 | 1,181 | 1,655 | 1,145 | 112 | 236 |
| 1999 | 0 | 0 | 0 | 0 | 1,235 | 1,185 | 3,085 | 1,774 | 13,337 | 6,469 | 13,330 | 38,859 | 12,458 | 6,245 | 6,609 | 1,239 | 374 | 497 | 82 | 640 |
| 2000 | 0 | 0 | 0 | 0 | 304 | 970 | 1,873 | 3,289 | 8,431 | 26,140 | 9,296 | 11,979 | 32,324 | 13,049 | 6,887 | 4,048 | 2,564 | 500 | 1,004 | 158 |
| 2001 | 0 | 0 | 0 | 0 | 1,036 | 2,026 | 2,658 | 3,778 | 3,719 | 7,280 | 15,846 | 6,796 | 7,574 | 12,065 | 6,673 | 1,907 | 1,753 | 462 | 205 | 273 |
| 2002 | 0 | 0 | 0 | 195 | 520 | 3,909 | 3,784 | 3,536 | 9,758 | 7,530 | 10,543 | 18,408 | 7,241 | 5,984 | 16,007 | 7,214 | 2,607 | 3,101 | 772 | 298 |
| 2003 | 0 | 0 | 0 | 1,837 | 1,891 | 4,329 | 6,695 | 5,993 | 7,155 | 10,145 | 6,201 | 13,548 | 18,581 | 7,904 | 9,377 | 11,150 | 7,451 | 2,561 | 1,423 | 2,105 |

Table 7-4 --Rock sole weight-at-age (grams) by age and year determined from 1980-2000 from length-at-age and length-weight relationships from the annual trawl survey in the eastern Bering Sea.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1980 | 0 | 6 | 31 | 76 | 135 | 202 | 274 | 344 | 409 | 471 | 523 | 572 | 523 | 572 | 613 | 646 | 677 | 703 | 727 | 745 | 764 | 777 |
| 1981 | 0 | 6 | 31 | 76 | 135 | 202 | 274 | 344 | 409 | 471 | 523 | 572 | 523 | 572 | 613 | 646 | 677 | 703 | 727 | 745 | 764 | 777 |
| 1982 | 0 | 18 | 56 | 87 | 106 | 164 | 215 | 271 | 338 | 395 | 466 | 415 | 466 | 415 | 522 | 544 | 725 | 763 | 742 | 742 | 742 | 742 |
| 1983 | 0 | 17 | 35 | 109 | 160 | 195 | 261 | 296 | 357 | 369 | 400 | 406 | 400 | 406 | 513 | 531 | 588 | 655 | 835 | 948 | 865 | 865 |
| 1984 | 0 | 19 | 30 | 64 | 141 | 187 | 248 | 306 | 365 | 424 | 480 | 450 | 480 | 450 | 496 | 628 | 466 | 588 | 727 | 727 | 727 | 727 |
| 1985 | 0 | 16 | 32 | 54 | 113 | 197 | 264 | 325 | 363 | 469 | 468 | 650 | 468 | 650 | 556 | 477 | 654 | 595 | 556 | 604 | 785 | 807 |
| 1986 | 0 | 19 | 32 | 46 | 110 | 198 | 307 | 346 | 383 | 431 | 475 | 483 | 475 | 483 | 541 | 502 | 616 | 693 | 652 | 795 | 795 | 795 |
| 1987 | 0 | 15 | 36 | 74 | 120 | 212 | 331 | 447 | 450 | 421 | 498 | 522 | 498 | 522 | 543 | 612 | 486 | 682 | 701 | 746 | 696 | 696 |
| 1988 | 0 | 17 | 29 | 55 | 127 | 202 | 302 | 400 | 415 | 520 | 524 | 565 | 524 | 565 | 508 | 615 | 611 | 679 | 643 | 659 | 654 | 654 |
| 1989 | 0 | 16 | 27 | 58 | 106 | 184 | 246 | 373 | 439 | 518 | 521 | 515 | 521 | 515 | 511 | 605 | 594 | 566 | 703 | 703 | 682 | 703 |
| 1990 | 0 | 9 | 17 | 41 | 83 | 151 | 243 | 345 | 409 | 473 | 524 | 559 | 524 | 559 | 536 | 609 | 648 | 755 | 755 | 743 | 743 | 743 |
| 1991 | 0 | 13 | 17 | 36 | 77 | 126 | 198 | 296 | 345 | 432 | 493 | 541 | 493 | 541 | 603 | 611 | 690 | 751 | 751 | 696 | 622 | 688 |
| 1992 | 0 | 10 | 18 | 39 | 64 | 105 | 188 | 239 | 320 | 382 | 429 | 488 | 429 | 488 | 527 | 537 | 565 | 596 | 709 | 709 | 709 | 709 |
| 1993 | 0 | 9 | 24 | 38 | 85 | 114 | 184 | 220 | 314 | 399 | 496 | 547 | 496 | 547 | 565 | 564 | 609 | 661 | 661 | 661 | 739 | 739 |
| 1994 | 0 | 12 | 26 | 50 | 79 | 111 | 176 | 233 | 302 | 378 | 407 | 484 | 407 | 484 | 512 | 574 | 538 | 599 | 791 | 700 | 644 | 644 |
| 1995 | 0 | 12 | 26 | 43 | 79 | 123 | 172 | 236 | 289 | 418 | 442 | 500 | 442 | 500 | 720 | 706 | 672 | 833 | 833 | 752 | 752 | 790 |
| 1996 | 0 | 8 | 24 | 55 | 80 | 135 | 180 | 250 | 271 | 327 | 418 | 454 | 418 | 454 | 434 | 551 | 514 | 610 | 705 | 659 | 770 | 722 |
| 1997 | 0 | 8 | 23 | 49 | 86 | 120 | 178 | 223 | 250 | 318 | 363 | 382 | 363 | 382 | 443 | 513 | 577 | 529 | 546 | 695 | 695 | 695 |
| 1998 | 0 | 8 | 23 | 49 | 86 | 120 | 178 | 223 | 250 | 318 | 363 | 382 | 363 | 382 | 443 | 513 | 577 | 529 | 546 | 695 | 695 | 695 |
| 1999 | 0 | 8 | 23 | 49 | 86 | 120 | 178 | 223 | 250 | 318 | 363 | 382 | 363 | 382 | 443 | 513 | 577 | 529 | 546 | 695 | 695 | 695 |
| 2000 | 0 | 8 | 23 | 49 | 86 | 120 | 178 | 223 | 250 | 318 | 363 | 382 | 363 | 382 | 443 | 513 | 577 | 529 | 546 | 695 | 695 | 695 |

Table 7-5.--Mean length-at-age (cm) and proportion mature for female Bering Sea rock sole from observer anatomical scans during the 1993-94 fishing seasons.

| Age | Length-at-age | Proportion mature |
|---|---|---|
| 1 | 8.2 | 0 |
| 2 | 14.3 | 0.006 |
| 3 | 19.4 | 0.003 |
| 4 | 23.6 | 0.012 |
| 5 | 27.1 | 0.039 |
| 6 | 30.1 | 0.098 |
| 7 | 32.6 | 0.198 |
| 8 | 34.6 | 0.330 |
| 9 | 36.4 | 0.470 |
| 10 | 37.8 | 0.590 |
| 11 | 39.0 | 0.680 |
| 12 | 40.0 | 0.746 |
| 13 | 40.8 | 0.795 |
| 14 | 41.5 | 0.830 |
| 15 | 42.1 | 0.856 |
| 16 | 41.6 | 0.875 |
| 17 | 43.0 | 0.889 |
| 18 | 43.4 | 0.900 |
| 19 | 43.7 | 0.908 |
| 20 | 44.0 | 0.915 |

Table 7.6--Estimated population numbers-at-age (millions) from the annual Bering Sea trawl surveys, 1982- 2003.

| year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1982** | 0 | 226 | 253 | 491 | 536 | 527 | 530 | 245 | 83 | 74 | 62 | 109 | 62 | 25 | 6 | 8 | 8 | 0 | 1 | 0 |
| **1983** | 0 | 70 | 668 | 553 | 633 | 313 | 313 | 354 | 162 | 136 | 53 | 72 | 99 | 52 | 36 | 24 | 4 | 2 | 1 | 0 |
| **1984** | 0 | 155 | 469 | 1,058 | 666 | 367 | 588 | 258 | 323 | 128 | 52 | 57 | 65 | 39 | 51 | 23 | 9 | 0 | 2 | 3 |
| **1985** | 0 | 165 | 413 | 1,129 | 1,128 | 523 | 321 | 247 | 141 | 158 | 36 | 15 | 7 | 17 | 44 | 37 | 8 | 8 | 2 | 2 |
| **1986** | 0 | 117 | 596 | 1,299 | 1,384 | 1,214 | 533 | 288 | 277 | 53 | 202 | 21 | 21 | 21 | 0 | 21 | 21 | 0 | 0 | 11 |
| **1987** | 0 | 64 | 752 | 1,074 | 1,149 | 902 | 1,030 | 269 | 269 | 172 | 75 | 215 | 32 | 11 | 11 | 0 | 0 | 0 | 0 | 0 |
| **1988** | 0 | 335 | 1,104 | 1,468 | 1,931 | 974 | 923 | 505 | 307 | 66 | 164 | 88 | 70 | 58 | 0 | 6 | 11 | 58 | 23 | 8 |
| **1989** | 0 | 131 | 867 | 989 | 1,136 | 1,304 | 749 | 557 | 414 | 129 | 92 | 94 | 68 | 81 | 26 | 24 | 2 | 2 | 17 | 15 |
| **1990** | 0 | 2,985 | 4,733 | 2,497 | 1,352 | 1,650 | 490 | 670 | 457 | 191 | 84 | 95 | 25 | 59 | 2 | 0 | 11 | 0 | 37 | 0 |
| **1991** | 0 | 27 | 168 | 3,633 | 2,308 | 1,338 | 973 | 848 | 508 | 355 | 229 | 151 | 71 | 56 | 33 | 14 | 0 | 44 | 0 | 0 |
| **1992** | 0 | 9 | 244 | 658 | 2,946 | 2,283 | 868 | 1,057 | 506 | 300 | 298 | 185 | 131 | 91 | 46 | 25 | 13 | 0 | 11 | 0 |
| **1993** | 0 | 45 | 995 | 1,384 | 1,251 | 3,957 | 2,181 | 1,020 | 958 | 540 | 161 | 149 | 147 | 97 | 48 | 10 | 0 | 0 | 5 | 10 |
| **1994** | 0 | 43 | 508 | 2,184 | 1,356 | 1,365 | 4,533 | 2,240 | 1,075 | 348 | 664 | 295 | 167 | 190 | 90 | 55 | 14 | 11 | 29 | 16 |
| **1995** | 0 | 0 | 140 | 850 | 1,846 | 848 | 727 | 2,228 | 1,255 | 508 | 462 | 393 | 111 | 134 | 92 | 3 | 9 | 2 | 2 | 10 |
| **1996** | 0 | 38 | 956 | 435 | 687 | 1,832 | 539 | 901 | 2,133 | 1,270 | 369 | 191 | 231 | 69 | 97 | 85 | 32 | 11 | 1 | 9 |
| **1997** | 0 | 4 | 573 | 1,528 | 552 | 904 | 2,558 | 523 | 948 | 2,041 | 783 | 578 | 373 | 281 | 119 | 125 | 55 | 29 | 0 | 14 |
| **1998** | 0 | 2 | 234 | 654 | 763 | 532 | 834 | 1,607 | 495 | 525 | 1,426 | 923 | 304 | 108 | 134 | 46 | 29 | 8 | 11 | 19 |
| **1999** | 0 | 1 | 64 | 105 | 295 | 835 | 116 | 622 | 1,470 | 829 | 584 | 1,376 | 529 | 238 | 112 | 123 | 27 | 27 | 11 | 2 |
| **2000** | 0 | 0 | 41 | 503 | 237 | 377 | 872 | 358 | 960 | 1,416 | 741 | 639 | 1,054 | 442 | 240 | 207 | 60 | 9 | 12 | 14 |
| **2001** | 0 | 28 | 228 | 242 | 633 | 434 | 366 | 916 | 501 | 1,199 | 1,137 | 515 | 657 | 1,039 | 396 | 183 | 64 | 58 | 19 | 4 |
| **2002** | 0 | 150 | 390 | 235 | 240 | 734 | 270 | 225 | 630 | 326 | 514 | 995 | 325 | 218 | 781 | 266 | 97 | 110 | 4 | 24 |
| **2003** | 0 | 719 | 1,127 | 549 | 442 | 211 | 719 | 352 | 202 | 258 | 166 | 548 | 1,171 | 261 | 407 | 739 | 206 | 125 | 83 | 38 |

Table 7.7--Key equations used in the population dynamics model.

| | |
|---|---|
| $N_{t,1} = R_t = R_0 e^{\tau_t}$ , $\tau_t \sim N(0,\delta^2{}_R)$ | Recruitment 1956-75 |
| $N_{t,1} = R_t = R_\gamma e^{\tau_t}$ , $\tau_t \sim N(0,\delta^2{}_R)$ | Recruitment 1976-96 |
| $C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}\left(1 - e^{-Z_{t,a}}\right)N_{t,a}$ | Catch in year *t* for age *a* fish |
| $N_{t+1,a+1} = N_{t,a}e^{-Z_{t,a}}$ | Numbers of fish in year *t+1* at age *a* |
| $N_{t+1,A} = N_{t,A-1}e^{-Z_{t,A-1}} + N_{t,A}e^{-Z_{t,A}}$ | Numbers of fish in the "plus group" |
| $S_t = \sum N_{t,a}W_{t,a}\phi_a$ | Spawning biomass |
| $Z_{t,a} = F_{t,a} + M$ | Total mortality in year *t* at age *a* |
| $F_{t,a} = s_a \mu^F \exp^{\varepsilon^F{}_t}$ , $\varepsilon^F{}_t \sim N(o,\sigma^{2_F})$ | Fishing mortality |
| $s_a = \frac{1}{1+\left(e^{-\alpha+\beta a}\right)}$ | Age-specific fishing selectivity |
| $C_t = \sum C_{t,a}$ | Total catch in numbers |
| $P_{t,a} = {}^{C_{t,a}}\!/_{C_t}$ | Proportion at age in catch |
| $SurB_t = q\sum N_{t,a}W_{t,a}v_a$ | Survey biomass |
| $L = \sum_{t,a} m_t p_{t,a} \ln\frac{\hat{p}_{t,a}}{p_{t,a}} + (-0.5)\sum_t\left[\left(\ln\frac{surB_t}{\hat{surB}_t}\,{}^1\!/_{\sigma_t}\right)^2 - \ln\sigma_t\right]$ | Total log likelihood |

Table 7.8--Variables used in the population dynamics model.

| Variables | |
|---|---|
| $R_t$ | Age 1 recruitment in year $t$ |
| $R_0$ | Geometric mean value of age 1 recruitment, 1956-75 |
| $R_\gamma$ | Geometric mean value of age 1 recruitment, 1976-96 |
| $\tau_t$ | Recruitment deviation in year $t$ |
| $N_{t,a}$ | Number of fish in year $t$ at age $a$ |
| $C_{t,a}$ | Catch numbers of fish in year $t$ at age $a$ |
| $P_{t,a}$ | Proportion of the numbers of fish age $a$ in year $t$ |
| $C_t$ | Total catch numbers in year $t$ |
| $W_{t,a}$ | Mean body weight (kg) of fish age $a$ in year $t$ |
| $\phi_a$ | Proportion of mature females at age $a$ |
| $F_{t,a}$ | Instantaneous annual fishing mortality of age $a$ fish in year $t$ |
| M | Instantaneous natural mortality, assumed constant over all ages and years |
| $Z_{t,a}$ | Instantaneous total mortality for age $a$ fish in year $t$ |
| $s_a$ | Age-specific fishing gear selectivity |
| $\mu^F$ | Median year-effect of fishing mortality |
| $\varepsilon_t^F$ | The residual year-effect of fishing mortality |
| $\nu_a$ | Age-specific survey selectivity |
| $\alpha$ | Slope parameter in the logistic selectivity equation |
| $\beta$ | Age at 50% selectivity parameter in the logistic selectivity equation |
| $\sigma_t$ | Standard error of the survey biomass in year $t$ |

Table 7.9--Model estimates of rock sole fishing mortality and exploitation rate (catch/total biomass).

| year | Full selection F | Exploitation rate |
|---|---|---|
| 1975 | 0.177 | 0.071 |
| 1976 | 0.132 | 0.057 |
| 1977 | 0.061 | 0.028 |
| 1978 | 0.070 | 0.034 |
| 1979 | 0.052 | 0.025 |
| 1980 | 0.072 | 0.033 |
| 1981 | 0.069 | 0.029 |
| 1982 | 0.097 | 0.035 |
| 1983 | 0.095 | 0.031 |
| 1984 | 0.242 | 0.077 |
| 1985 | 0.100 | 0.033 |
| 1986 | 0.103 | 0.032 |
| 1987 | 0.083 | 0.026 |
| 1988 | 0.167 | 0.056 |
| 1989 | 0.098 | 0.035 |
| 1990 | 0.114 | 0.047 |
| 1991 | 0.097 | 0.043 |
| 1992 | 0.104 | 0.047 |
| 1993 | 0.077 | 0.037 |
| 1994 | 0.065 | 0.033 |
| 1995 | 0.043 | 0.025 |
| 1996 | 0.063 | 0.038 |
| 1997 | 0.030 | 0.020 |
| 1998 | 0.035 | 0.024 |
| 1999 | 0.042 | 0.030 |
| 2000 | 0.025 | 0.019 |
| 2001 | 0.034 | 0.026 |
| 2002 | 0.037 | 0.029 |
| 2003 | 0.034 | 0.026 |

Table 7.10 --Model estimates of rock sole age-specific fishery and survey selectivities.

| Age | Fishery (1980-2003) | Survey (1982-2003) |
|---|---|---|
| 1 | 0.002 | 0.012 |
| 2 | 0.005 | 0.066 |
| 3 | 0.012 | 0.294 |
| 4 | 0.028 | 0.712 |
| 5 | 0.066 | 0.936 |
| 6 | 0.147 | 0.989 |
| 7 | 0.294 | 0.998 |
| 8 | 0.502 | 1.000 |
| 9 | 0.710 | 1.000 |
| 10 | 0.856 | 1.000 |
| 11 | 0.935 | 1.000 |
| 12 | 0.972 | 1.000 |
| 13 | 0.988 | 1.000 |
| 14 | 0.988 | 1.000 |
| 15 | 0.988 | 1.000 |
| 16 | 0.988 | 1.000 |
| 17 | 0.988 | 1.000 |
| 18 | 0.988 | 1.000 |
| 19 | 0.988 | 1.000 |
| 20 | 0.988 | 1.000 |

Table 7-11.--Model estimates of rock sole age 2+ total biomass (t) and female spawning biomass (t) from the 2003 and 2004 assessments.

| | 2004 Assessment | | 2003 Assessment | |
|---|---|---|---|---|
| | Age 2+ Total biomass | Female Spawning biomass | Age 2+ Total biomass | Female Spawning biomass |
| **1975** | 168,415 | 29,072 | 196,345 | 33,594 |
| **1976** | 175,711 | 31,404 | 203,931 | 36,210 |
| **1977** | 186,743 | 35,175 | 215,388 | 40,272 |
| **1978** | 208,299 | 40,682 | 238,186 | 45,966 |
| **1979** | 234,163 | 45,342 | 265,944 | 50,625 |
| **1980** | 268,078 | 50,055 | 302,326 | 55,207 |
| **1981** | 306,964 | 54,299 | 344,333 | 59,320 |
| **1982** | 341,357 | 51,292 | 384,665 | 55,532 |
| **1983** | 441,871 | 59,289 | 497,186 | 63,875 |
| **1984** | 491,760 | 68,235 | 550,563 | 73,127 |
| **1985** | 576,004 | 76,172 | 646,295 | 81,880 |
| **1986** | 723,870 | 92,237 | 810,265 | 98,918 |
| **1987** | 988,957 | 123,908 | 1,104,260 | 132,896 |
| **1988** | 1,138,380 | 154,904 | 1,265,170 | 165,574 |
| **1989** | 1,260,370 | 179,587 | 1,400,590 | 191,825 |
| **1990** | 1,284,920 | 213,171 | 1,412,600 | 226,630 |
| **1991** | 1,333,190 | 234,936 | 1,457,740 | 248,703 |
| **1992** | 1,358,130 | 248,282 | 1,475,250 | 261,911 |
| **1993** | 1,596,220 | 307,229 | 1,718,950 | 322,882 |
| **1994** | 1,685,500 | 342,863 | 1,796,710 | 358,682 |
| **1995** | 1,882,670 | 442,944 | 1,976,890 | 458,475 |
| **1996** | 1,796,120 | 440,751 | 1,862,410 | 452,194 |
| **1997** | 1,689,310 | 453,309 | 1,725,830 | 459,089 |
| **1998** | 1,684,370 | 490,579 | 1,692,120 | 489,123 |
| **1999** | 1,615,360 | 504,618 | 1,594,390 | 494,839 |
| **2000** | 1,566,290 | 515,576 | 1,518,380 | 497,226 |
| **2001** | 1,523,540 | 523,810 | 1,451,040 | 496,572 |
| **2002** | 1,437,070 | 505,119 | 1,338,580 | 470,022 |
| **2003** | 1,376,800 | 474,234 | 1,231,270 | 432,515 |
| **2004** | 1,366,620 | 452,332 | | |

Table 7.12--Estimated age 4 recruitment of rock sole (thousands of fish) from the 2003 and 2004 assessments.

| Year class | 2004 Assessment | 2003 Assessment |
|---|---|---|
| **1971** | 104,784 | 126,729 |
| **1972** | 86,847 | 104,485 |
| **1973** | 116,469 | 138,596 |
| **1974** | 159,274 | 188,181 |
| **1975** | 419,121 | 494,410 |
| **1976** | 236,214 | 277,969 |
| **1977** | 357,291 | 419,556 |
| **1978** | 408,029 | 477,320 |
| **1979** | 518,584 | 605,205 |
| **1980** | 1,001,210 | 1,169,670 |
| **1981** | 1,014,550 | 1,187,510 |
| **1982** | 889,814 | 1,044,110 |
| **1983** | 1,585,380 | 1,863,690 |
| **1984** | 1,285,380 | 1,508,480 |
| **1985** | 1,279,530 | 1,497,240 |
| **1986** | 2,041,680 | 2,372,510 |
| **1987** | 3,479,440 | 4,028,470 |
| **1988** | 1,296,800 | 1,454,210 |
| **1989** | 900,291 | 1,001,270 |
| **1990** | 2,019,580 | 2,188,630 |
| **1991** | 933,105 | 978,521 |
| **1992** | 466,906 | 507,763 |
| **1993** | 835,913 | 929,679 |
| **1994** | 425,743 | 446,254 |
| **1995** | 342,215 | 321,718 |
| **1996** | 557,292 | 511,462 |
| **1997** | 243,215 | 216,950 |
| **1998** | 308,531 | |

Table 7.13--Projections of rock sole female spawning biomass (1,000s t), future catch (1,000s t) and full selection fishing mortality rates for seven future harvest scenarios.

**Scenarios 1 and 2**
**Maximum ABC harvest permissible**

| Year | Female spawning biomass | catch | F |
|---|---|---|---|
| 2004 | 444.807 | 41.000 | 0.04 |
| 2005 | 420.454 | **131.928** | 0.15 |
| 2006 | 352.129 | 110.868 | 0.15 |
| 2007 | 306.748 | 98.067 | 0.15 |
| 2008 | 287.905 | 94.948 | 0.15 |
| 2009 | 276.041 | 94.380 | 0.15 |
| 2010 | 269.339 | 94.075 | 0.15 |
| 2011 | 268.959 | 94.561 | 0.15 |
| 2012 | 259.99 | 91.198 | 0.15 |
| 2013 | 251.444 | 87.467 | 0.15 |
| 2014 | 250.621 | 86.267 | 0.15 |
| 2015 | 249.525 | 85.112 | 0.15 |
| 2016 | 245.922 | 83.204 | 0.14 |
| 2017 | 240.175 | 80.454 | 0.14 |

**Scenario 3**
**1/2 Maximum ABC harvest permissible**

| Year | Female spawning biomass | catch | F |
|---|---|---|---|
| 2004 | 444.807 | 41.000 | 0.04 |
| 2005 | 422.967 | 68.224 | 0.08 |
| 2006 | 379.314 | 61.241 | 0.08 |
| 2007 | 350.712 | 57.204 | 0.08 |
| 2008 | 344.322 | 57.492 | 0.08 |
| 2009 | 340.928 | 58.625 | 0.08 |
| 2010 | 341.781 | 59.891 | 0.08 |
| 2011 | 349.837 | 61.710 | 0.08 |
| 2012 | 346.914 | 61.030 | 0.08 |
| 2013 | 343.401 | 60.139 | 0.08 |
| 2014 | 348.589 | 60.807 | 0.08 |
| 2015 | 351.799 | 61.155 | 0.08 |
| 2016 | 349.618 | 60.724 | 0.08 |
| 2017 | 342.105 | 59.532 | 0.08 |

**Scenario 4**
**Harvest at average F over the past 5 years**

| Year | Female spawning biomass | catch | F |
|---|---|---|---|
| 2004 | 444.807 | 41.000 | 0.04 |
| 2005 | 424.585 | 25.057 | 0.03 |
| 2006 | 397.881 | 23.469 | 0.03 |
| 2007 | 382.514 | 22.730 | 0.03 |
| 2008 | 387.395 | 23.463 | 0.03 |
| 2009 | 392.872 | 24.403 | 0.03 |
| 2010 | 402.087 | 25.401 | 0.03 |
| 2011 | 419.403 | 26.661 | 0.03 |
| 2012 | 424.078 | 26.878 | 0.03 |
| 2013 | 427.672 | 26.957 | 0.03 |
| 2014 | 441.171 | 27.667 | 0.03 |
| 2015 | 451.495 | 28.177 | 0.03 |
| 2016 | 453.917 | 28.257 | 0.03 |
| 2017 | 447.865 | 27.886 | 0.03 |

**Scenario 5**
**No fishing**

| Year | Female spawning biomass | catch | F |
|---|---|---|---|
| 2004 | 444.807 | 0 | 0 |
| 2005 | 425.495 | 0 | 0 |
| 2006 | 408.709 | 0 | 0 |
| 2007 | 401.725 | 0 | 0 |
| 2008 | 414.299 | 0 | 0 |
| 2009 | 426.301 | 0 | 0 |
| 2010 | 441.901 | 0 | 0 |
| 2011 | 466.350 | 0 | 0 |
| 2012 | 477.268 | 0 | 0 |
| 2013 | 486.996 | 0 | 0 |
| 2014 | 507.616 | 0 | 0 |
| 2015 | 524.372 | 0 | 0 |
| 2016 | 531.549 | 0 | 0 |
| 2017 | 527.983 | 0 | 0 |

Table 7.13—continued.

**Scenario 6**
**Determination of whether rock sole are currently overfished** **B35=204.852**

| Year | Female spawning biomass | catch | F |
|---|---|---|---|
| 2004 | 444.807 | 41.000 | 0.04 |
| 2005 | 419.413 | 157.180 | 0.18 |
| 2006 | 341.428 | 128.537 | 0.18 |
| 2007 | 290.291 | 111.229 | 0.18 |
| 2008 | 267.762 | 106.206 | 0.18 |
| 2009 | 253.801 | 104.656 | 0.18 |
| 2010 | 245.306 | 103.410 | 0.18 |
| 2011 | 242.829 | 102.984 | 0.18 |
| 2012 | 232.72 | 95.995 | 0.18 |
| 2013 | 224.294 | 89.353 | 0.17 |
| 2014 | 223.889 | 88.366 | 0.17 |
| 2015 | 223.357 | 87.567 | 0.17 |
| 2016 | 220.719 | 85.841 | 0.16 |
| 2017 | 216.379 | 83.238 | 0.16 |

**Scenario 7**
**Determination of whether rock sole are approaching an overfished condition** **B35=204.852**

| Year | Female spawning biomass | catch | F |
|---|---|---|---|
| 2004 | 444.807 | 41.000 | 0.04 |
| 2005 | 420.454 | 131.928 | 0.15 |
| 2006 | 352.129 | 110.868 | 0.15 |
| 2007 | 306.035 | 116.964 | 0.18 |
| 2008 | 280.202 | 110.712 | 0.18 |
| 2009 | 263.37 | 108.113 | 0.18 |
| 2010 | 252.616 | 106.042 | 0.18 |
| 2011 | 248.43 | 105.020 | 0.18 |
| 2012 | 236.862 | 98.372 | 0.18 |
| 2013 | 227.065 | 91.007 | 0.17 |
| 2014 | 225.684 | 89.371 | 0.17 |
| 2015 | 224.477 | 88.150 | 0.17 |
| 2016 | 221.396 | 86.176 | 0.16 |
| 2017 | 216.781 | 83.434 | 0.16 |

Table 7.14—Catch and bycatch in the rock sole target fisheries, 1991-2003, from blend of regional office reported catch and observer sampling.

| Species | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003* | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Walleye Pollock | 9,711 | 9,825 | 18,583 | 15,784 | 7,766 | 7,698 | 9,123 | 3,955 | 5,207 | 5,481 | 4,577 | 9,942 | 4,643 | 112,297 |
| Arrowtooth Flounder | 254 | 473 | 1,143 | 1,782 | 507 | 1,341 | 411 | 300 | 69 | 216 | 835 | 314 | 419 | 8,064 |
| Pacific Cod | 4,262 | 4,651 | 8,160 | 6,358 | 9,796 | 6,965 | 8,947 | 3,529 | 3,316 | 4,219 | 3,391 | 4,366 | 3,195 | 71,153 |
| Groundfish, General | 1,693 | 3,000 | 3,091 | 3,266 | 1,605 | 1,581 | 1,381 | 909 | 537 | 1,186 | 1,198 | 692 | 978 | 21,118 |
| Rock Sole | 22,067 | 24,873 | 39,857 | 40,139 | 29,241 | 18,380 | 32,477 | 13,092 | 16,047 | 29,042 | 14,437 | 20,168 | 18,681 | 318,501 |
| Flathead Sole | | | 2,140 | 1,702 | 1,147 | 1,302 | 2,373 | 1,223 | 575 | 1,806 | 1,051 | 771 | 744 | 14,834 |
| Sablefish | 9 | 0 | 4 | 16 | 3 | 3 | 1 | 0 | 2 | 5 | 12 | 4 | 2 | 62 |
| Atka Mackerel | 3 | 10 | 15 | 0 | | 0 | 0 | 9 | 0 | 38 | 3 | 0 | 1 | 79 |
| Pacific Ocean Perch | 37 | 10 | 15 | 62 | 4 | 2 | | 1 | 0 | 0 | 0 | 0 | | 132 |
| Rex Sole | | | 79 | 145 | 108 | 48 | 11 | 12 | 5 | 4 | 18 | 7 | | 438 |
| Flounder, General | 2,610 | 4,550 | 2,221 | 2,756 | 1,636 | 1,591 | 1,498 | 342 | 362 | 1,184 | 726 | 307 | 783 | 20,566 |
| Squid | | 0 | 0 | 0 | | | | | | | 0 | | | 0 |
| Dover Sole | | | | 0 | | | | | | | | | | 0 |
| Thornyhead | | | | 8 | | | | | | | | | | 8 |
| Shortraker/Rougheye | 8 | 0 | 2 | 21 | | | | 1 | | | | | | 31 |
| Butter Sole | | | 38 | 11 | 1 | 5 | 79 | 53 | 38 | 156 | 72 | 94 | | 642 |
| Unsp. pelagic rockfish | | | | 5 | | | | | | | | | | 5 |
| Rougheye Rockfish | | | 0 | | 0 | | | | | | | | | 0 |
| Starry Flounder | | | 230 | 85 | 0 | 1 | 99 | 72 | 34 | 214 | 152 | 329 | | 1,215 |
| Northern Rockfish | | | | 29 | | | | | 2 | | | 1 | | 32 |
| Dusky Rockfish | | | | | | 0 | | | | 0 | | | | 0 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yellowfin Sole | 2,043 | 4,069 | 6,277 | 5,690 | 6,876 | 6,030 | 7,601 | 1,358 | 1,421 | 2,976 | 3,951 | 3,777 | 6,546 | 58,615 |
| English Sole | | | 1 | | | | | | | 0 | | | | 1 |
| Black Rockfish | | | 4 | | | | | | | | | | | 4 |
| Greenland Turbot | 1 | 3 | 28 | 50 | 3 | 3 | 2 | 1 | 0 | 1 | 15 | 0 | 1 | 109 |
| Alaska Plaice | | | 2,561 | 931 | 173 | 71 | 408 | 250 | 63 | 385 | 75 | 621 | 375 | 5,913 |
| Sculpin, General | | | | | | | | | | 9 | 2 | 271 | | 282 |
| Skate, General | | | | | | | | | | 1 | 5 | 306 | | 312 |
| Sand Sole | | | | | 4 | 1 | 122 | 17 | | | 10 | 25 | | 179 |
| Greenstriped Rockfish | | | | | | | | | 0 | | | | | 0 |
| Copper Rockfish | | | | | | | | | | | | 1 | | 1 |
| Rockfish, General | 0 | 0 | | 0 | 5 | 1 | 0 | 1 | 0 | 15 | 4 | | | 27 |
| Octopus | | | | | | | | | | 1 | | 0 | | 1 |
| Chilipepper | | | | | | | | | | 13 | | | | 13 |
| Eels | | | | | | | | | | | 0 | 0 | | 0 |
| Lingcod | | | | | | | 1 | | | 0 | | | | 1 |
| Lumpsucker | | | 26 | | | | | | | | | | | 26 |
| Jellyfish (unspecified) | | | | | | | | | | 27 | 68 | 80 | | 175 |
| Snails | | | | | | | | | | 0 | 1 | | | 1 |
| Sea cucumber | | | 105 | | | | | | | | 0 | | | 105 |
| Korean horsehair crab | | | | | | | | | | 0 | | | | 0 |
| Pacific sandfish | | | | | | | | | | 0 | | | | 0 |
| Grand Total | 42,699 | 51,464 | 84,581 | 78,839 | 58,875 | 45,024 | 64,534 | 25,125 | 27,680 | 46,980 | 30,606 | 42,077 | 36,369 | 634,852 |

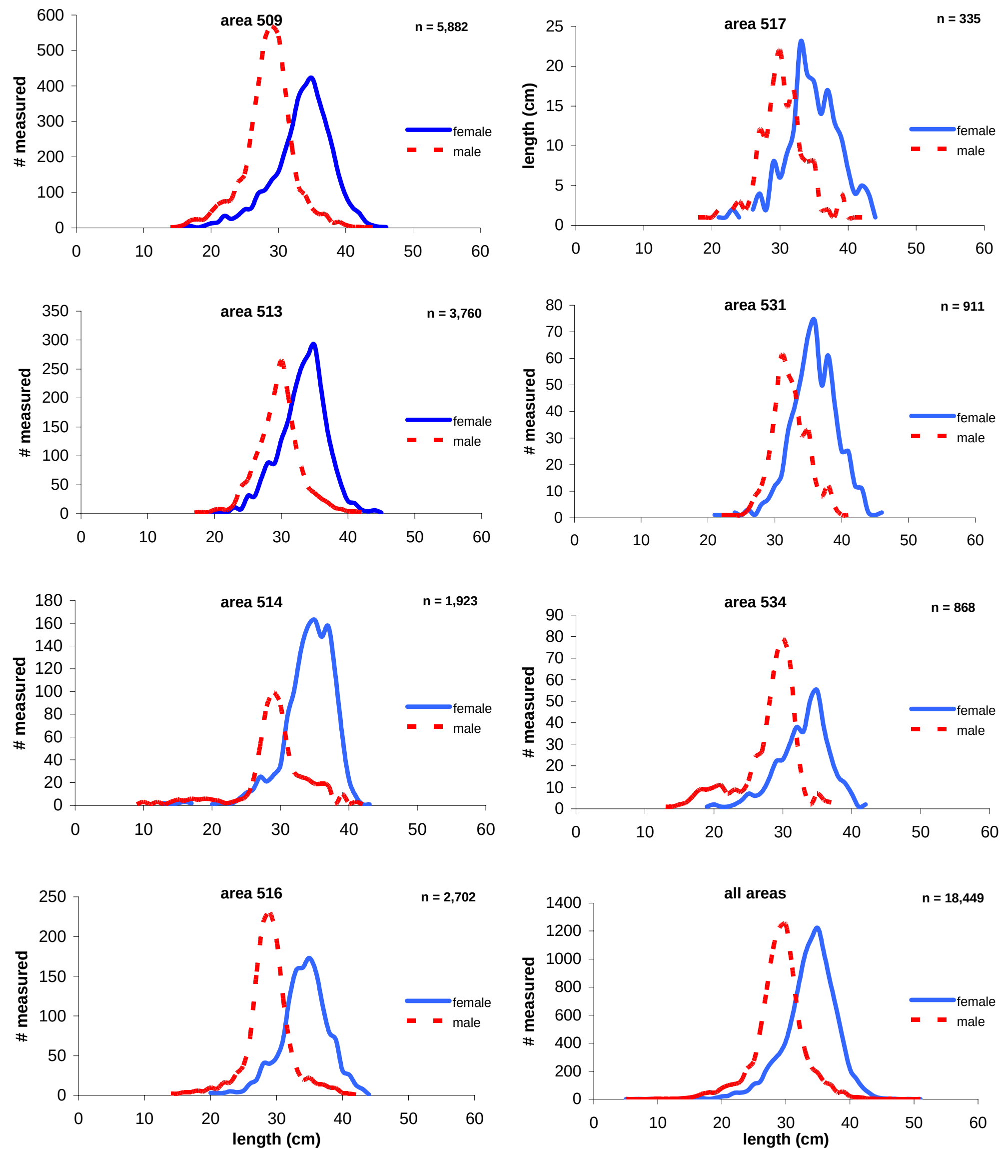



**Figure 7.1—Size composition of rock sole, by sex and area, in the 2003 catch as determined from observer sampling.**

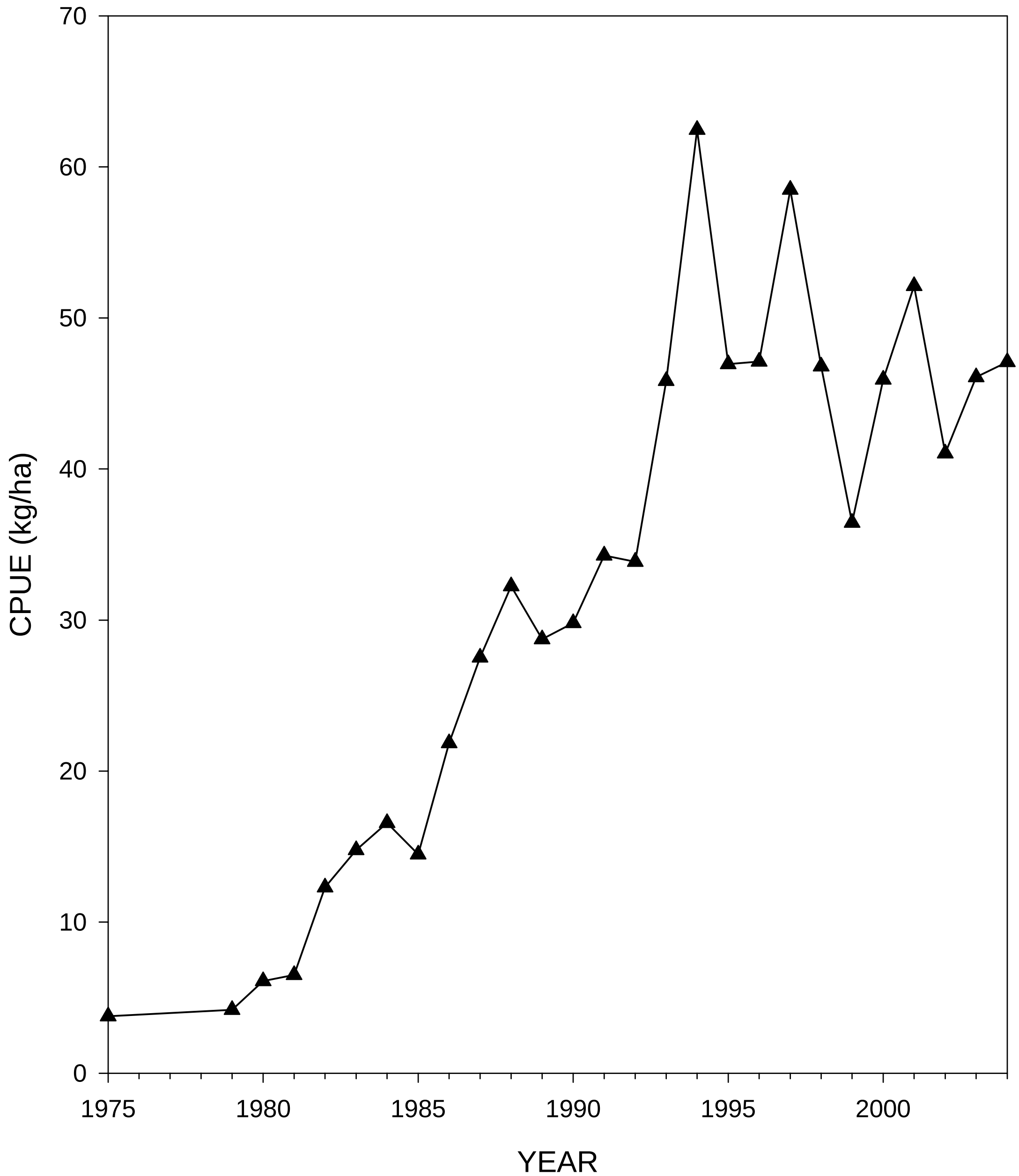



Figure 7.2- Relative abundance (catch per unit effort, CPUE) for rock sole from Alaska Fisheries Science Center bottom trawl survey.

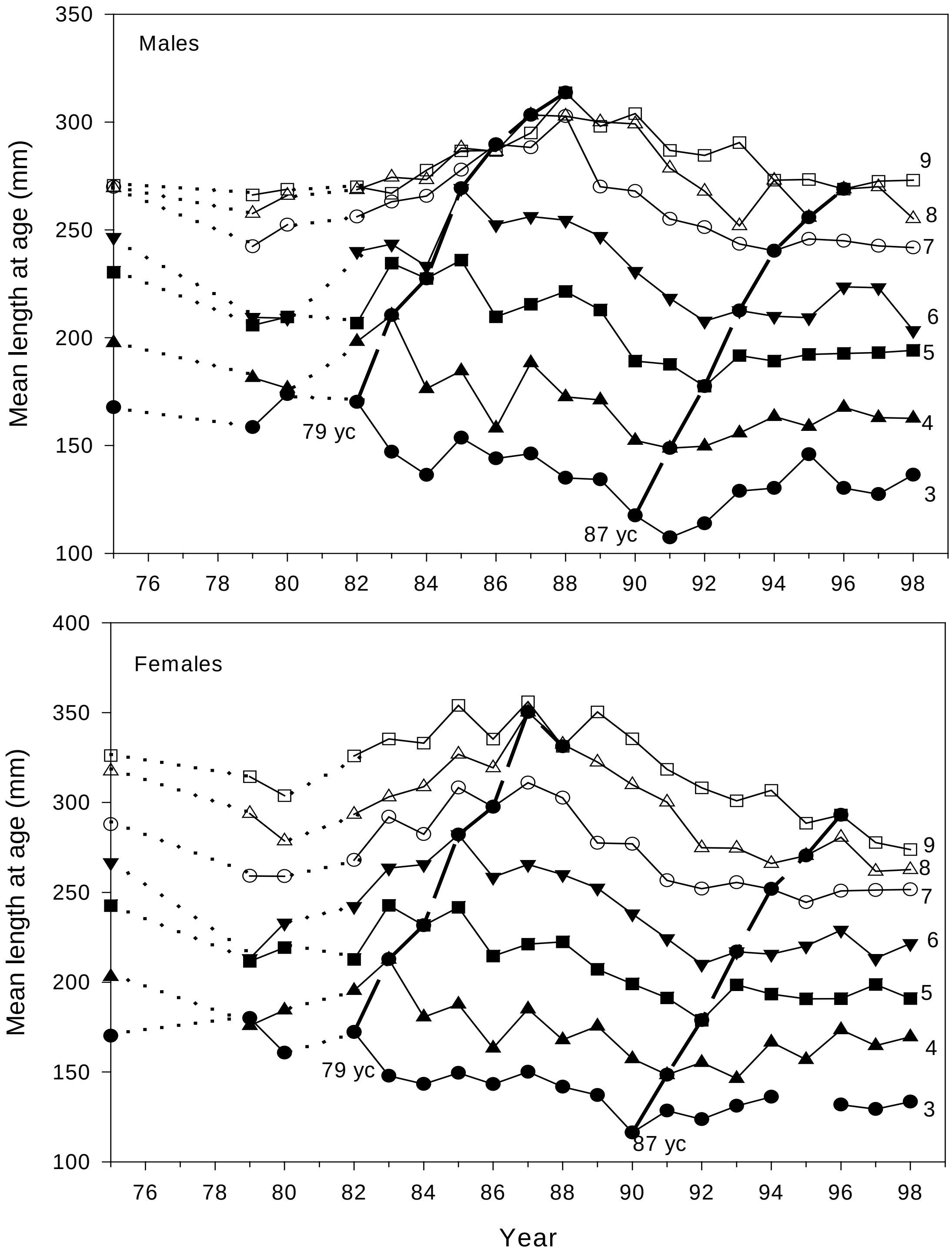



Fig. 7.3. Mean lengths at age (mm) by year of survey for eastern Bering Sea northern rocksole ages 3-9 for each sex during 1975-1998. Growth curves are shown for the 1979 (79yc) and 1987 (87yc) year classes. Dotted lines indicate no data during the period.
(From Walters and Wilderbuer, 2000, p.20)

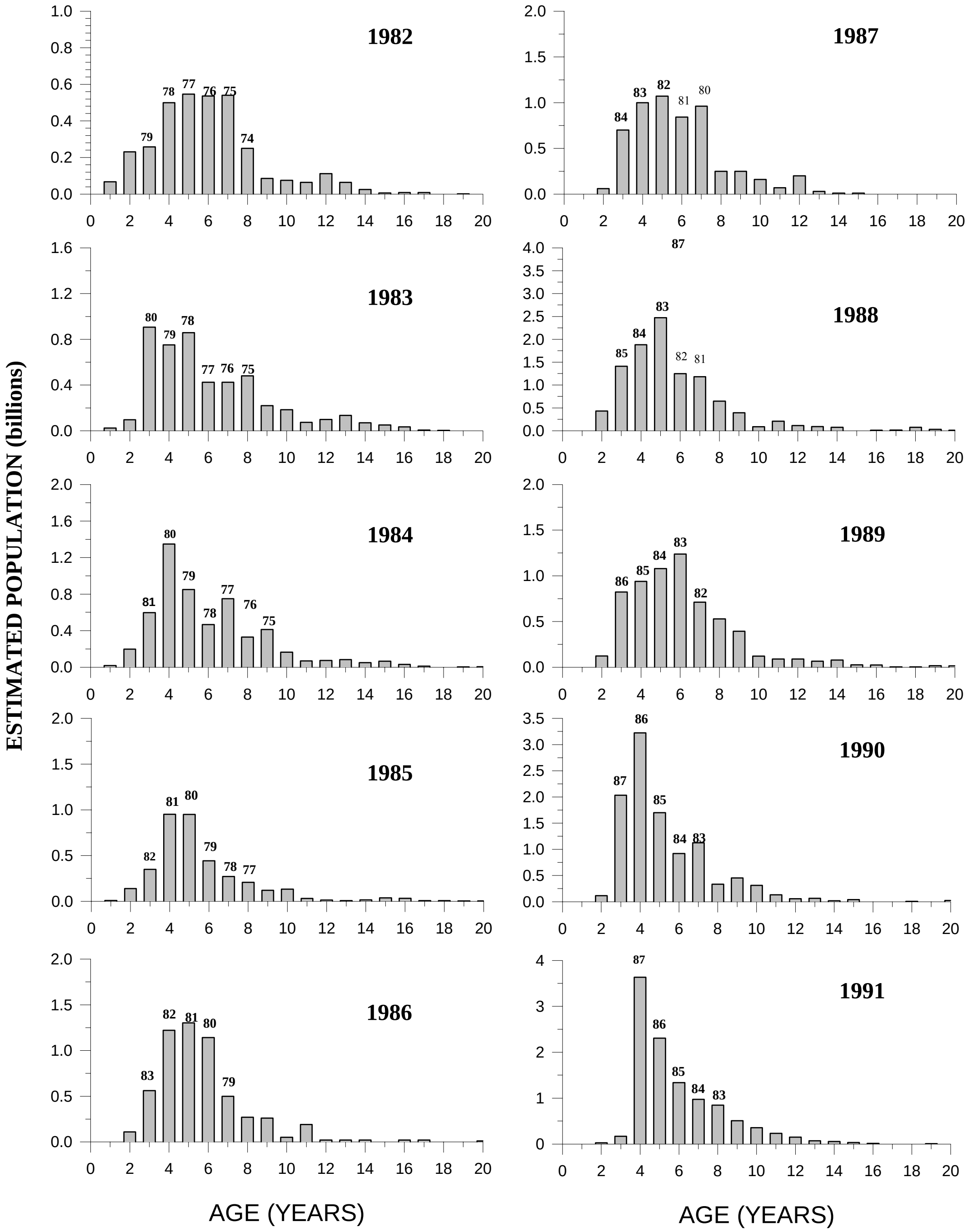



Figure 7.4- Age composition of rock sole as shown by data collected on Alaska Fisheries Science Center demersal trawl surveys.

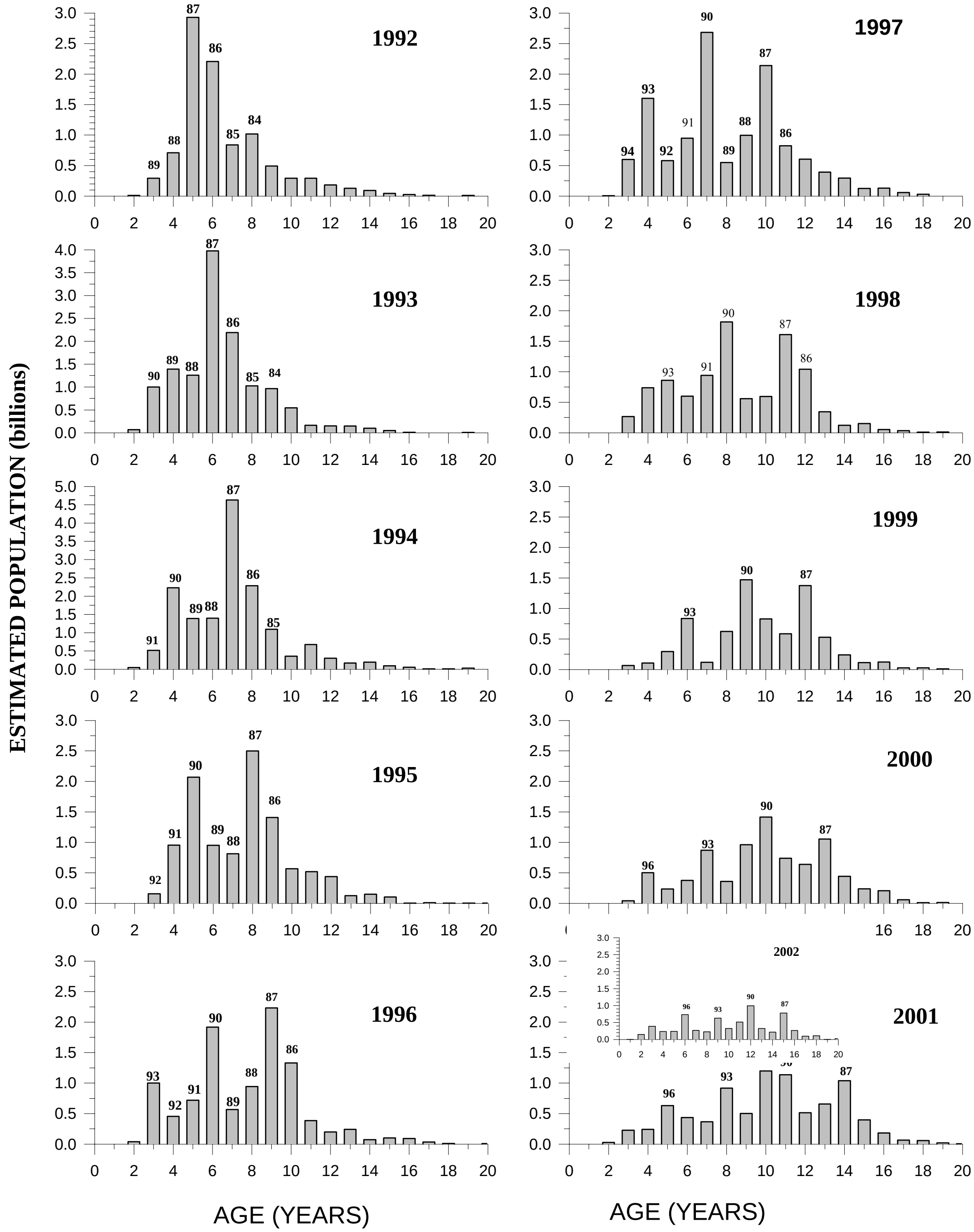



Figure 7.4-(continued)

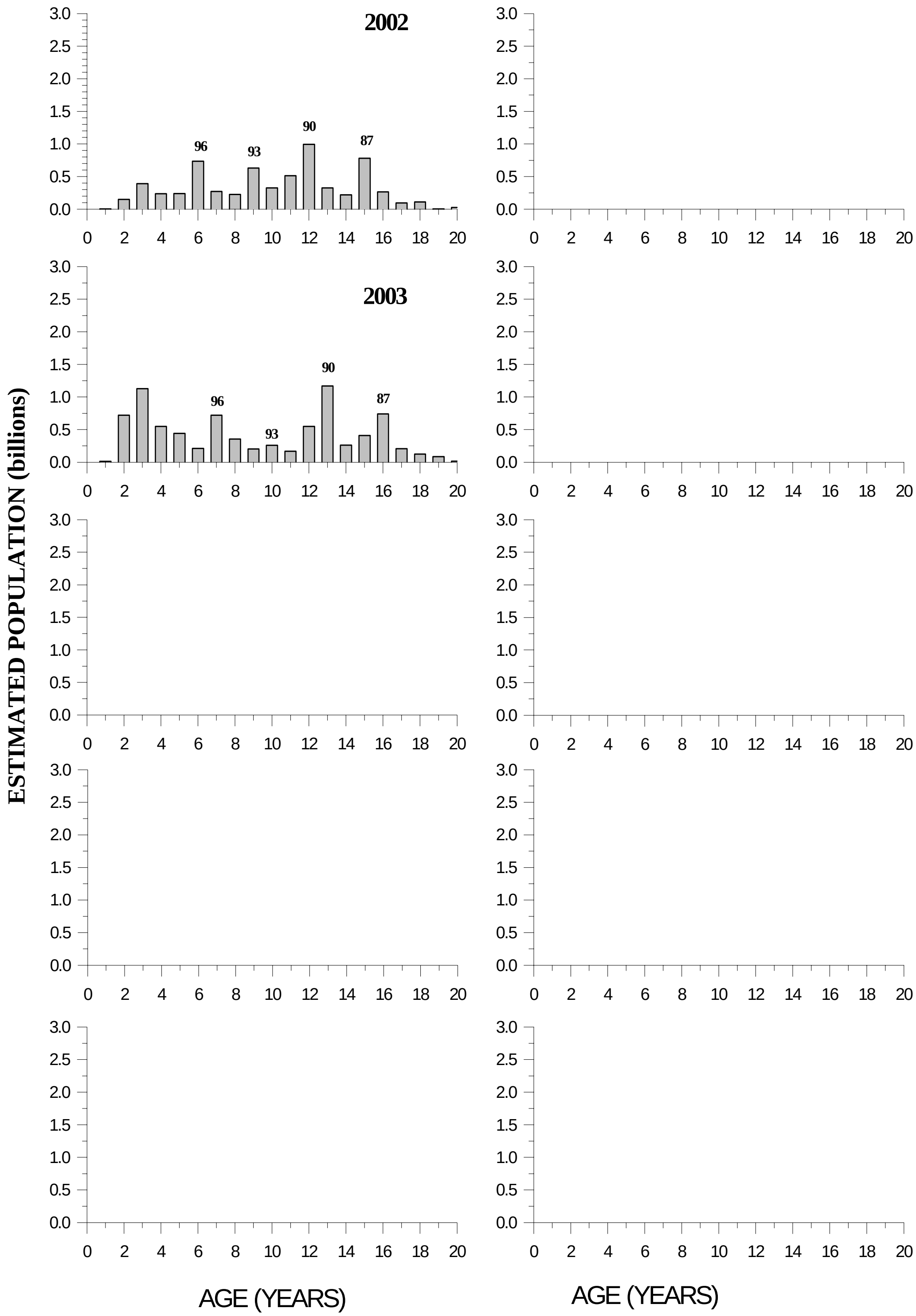



Figure 7.4-(continued)

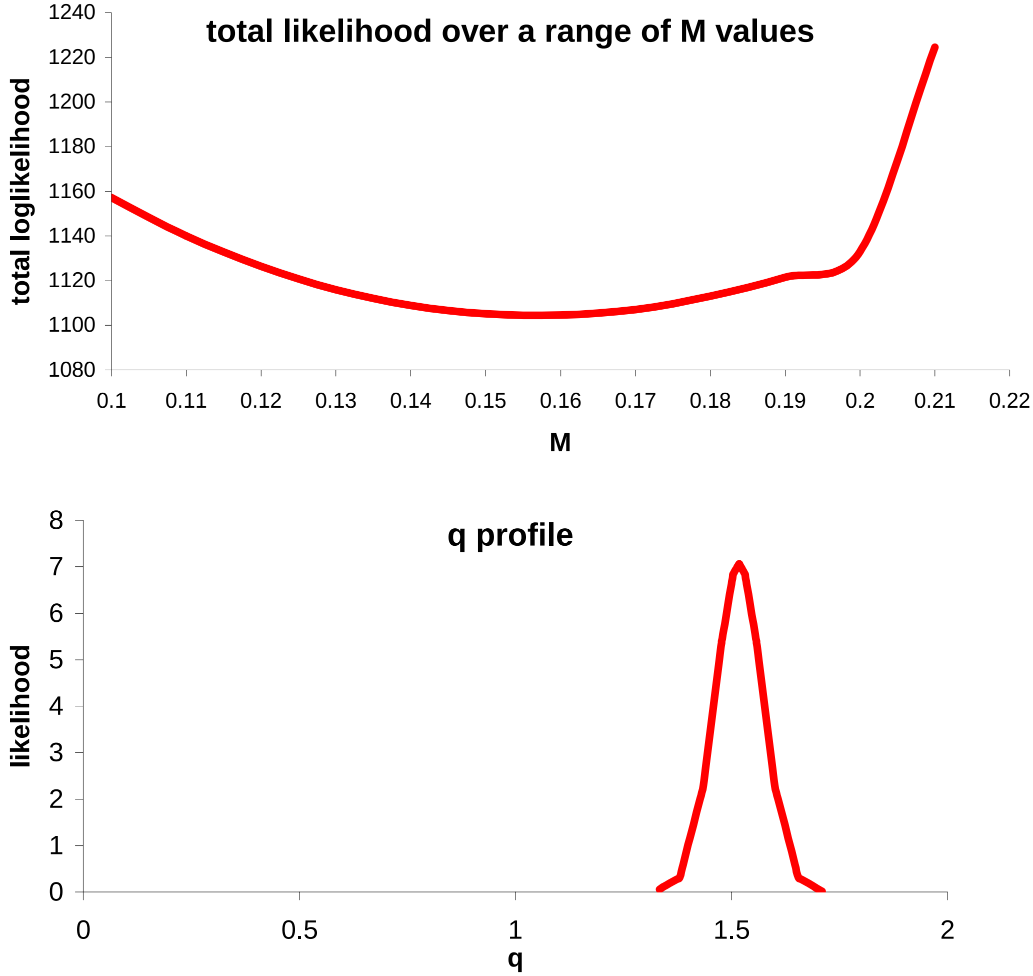



Figure 7.5-- Model fit (total log(likelihood)) to natural mortality values ranging from 0.1 - 0.21 (top panel) and the profile likelihood of survey catchability (q) for rock sole given the observed data and M = 0.1612 (bottom panel).

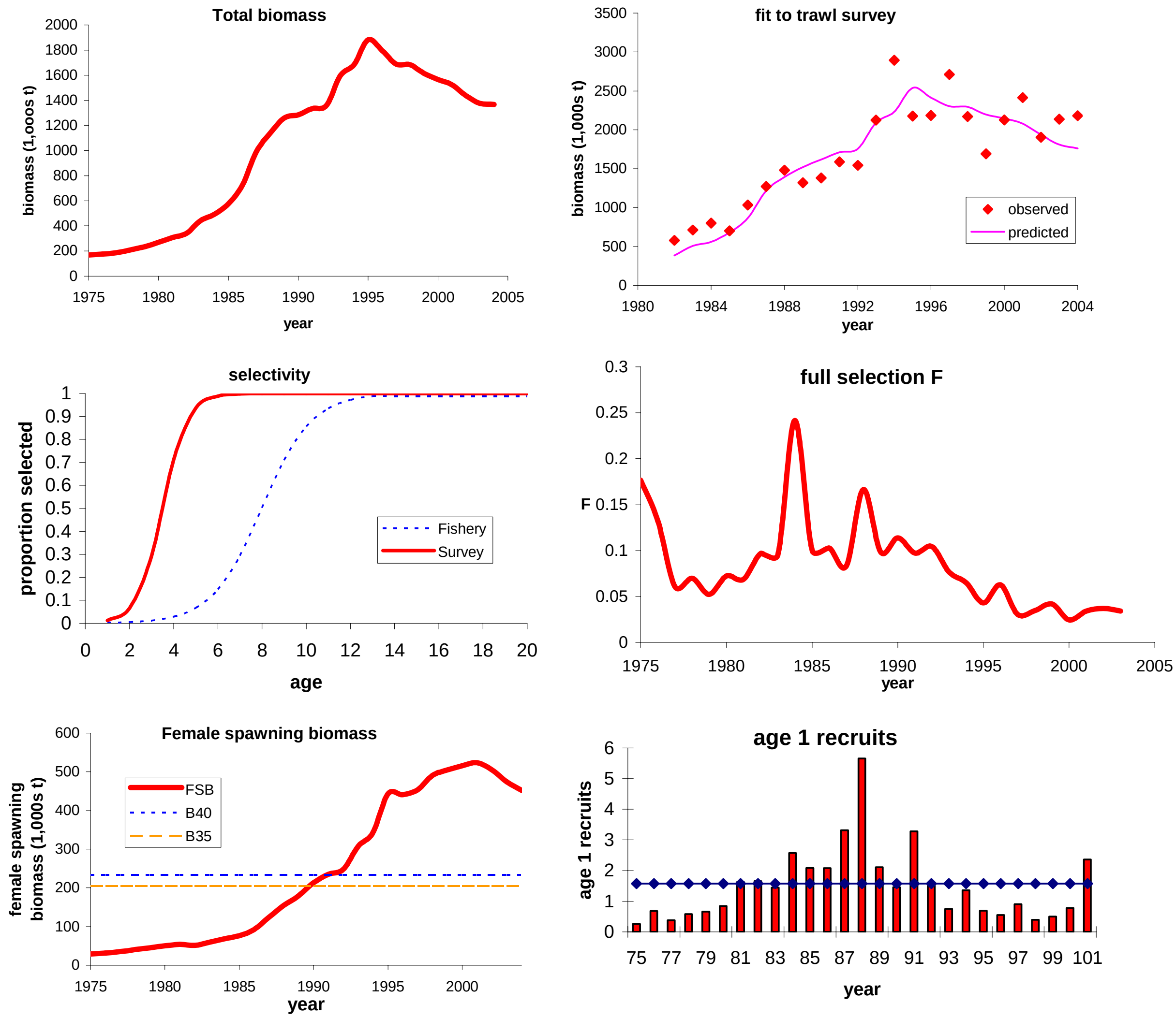



Figure 7.6--Stock assessment model estimates of total 2+ biomass (top left panel), fit to trawl survey biomass (top right panel), age-specific fishery and survey selectivity (middle left panel) and average annual fishing mortality rate (middle right panel), female spawning biomass (bottom right panel) and estimated age 1 recruitment (bottom right panel)..

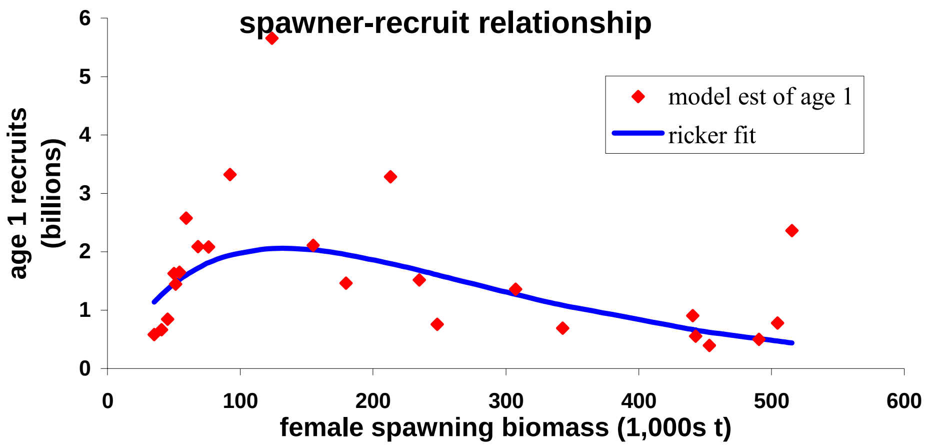



Figure 7.7--Ricker (1958) model fit to spawner-recruit estimates from 22 years.

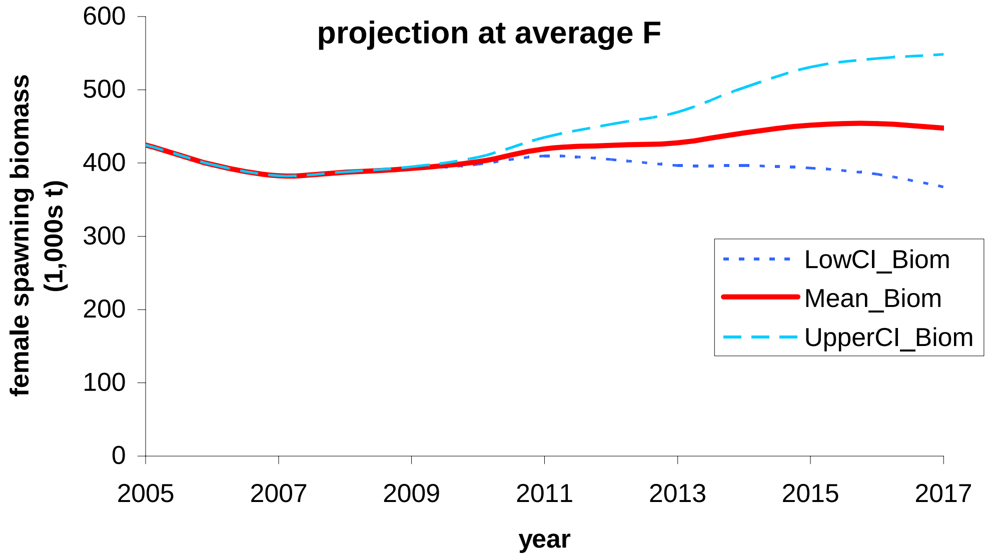



Figure 7.8—Projection of rock sole female spawning biomass when fishing in the future at the average F of the past five years.

Appendix

1) Observed fishery trawl locations, by quarter, for the 2003 fishing season.

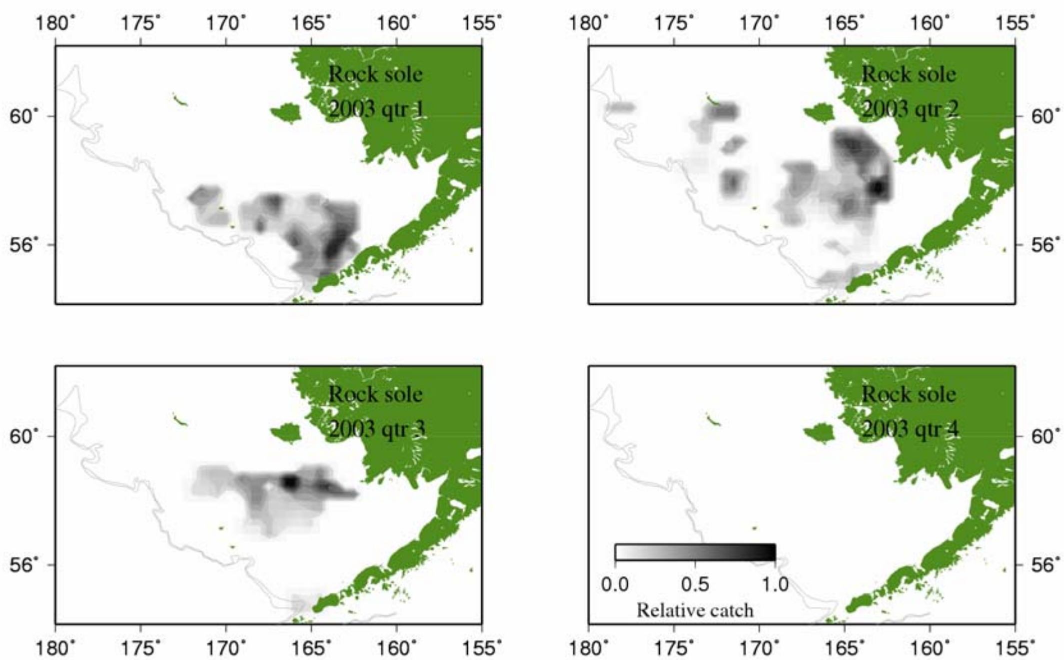
2) Figures showing the fit of the stock assessment model to the time-series of fishery and trawl survey age compositions (survey and fishery observations are the solid lines).

3) Table of the assessment model estimates of population numbers at age 1975- 2002.

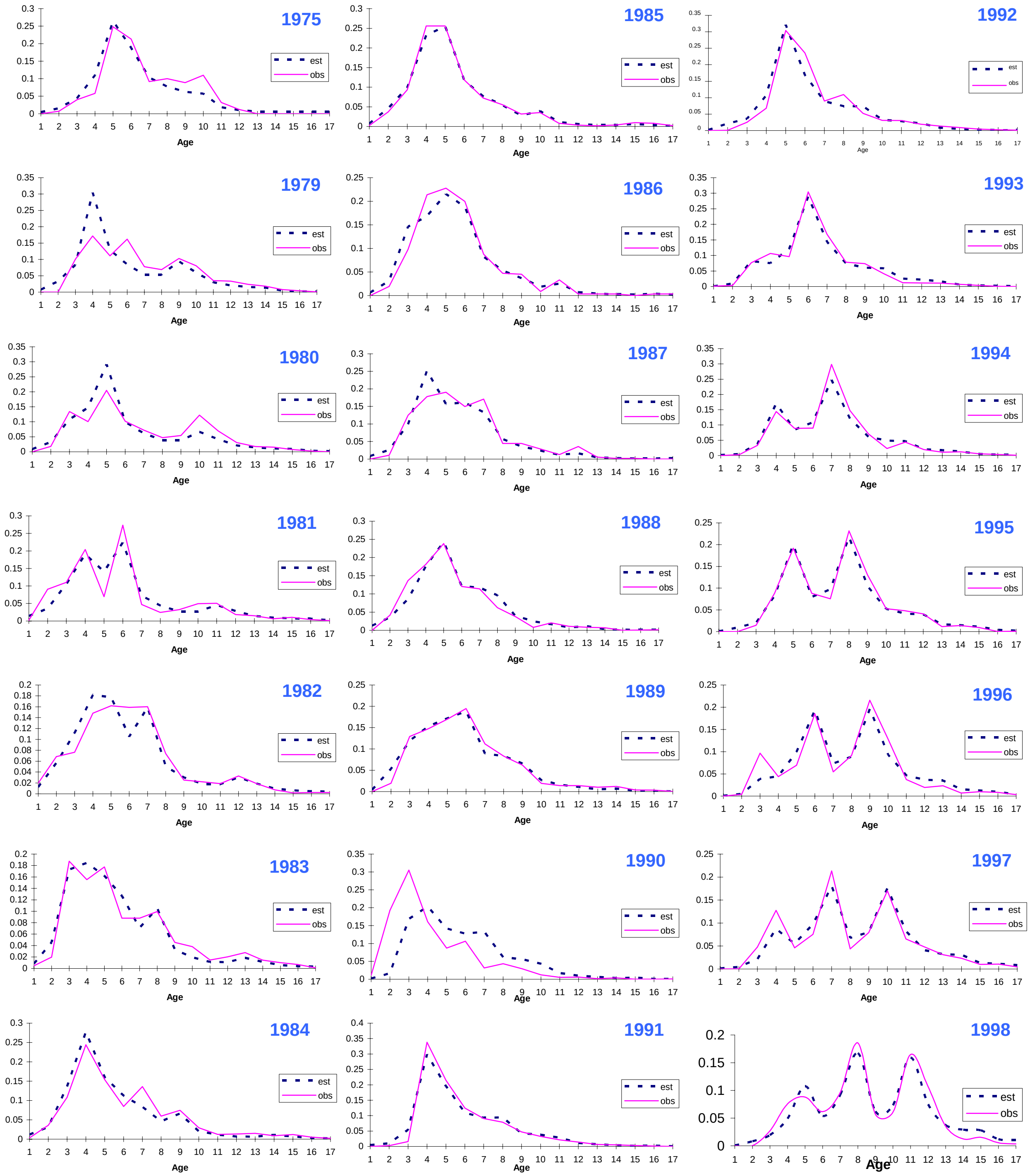
4) Table of total population removals of rock sole from Alaska Fisheries Science Center research activities, 1977-2004.

5) TAC and ABC of BSAI northern rock sole from 1989-2004.

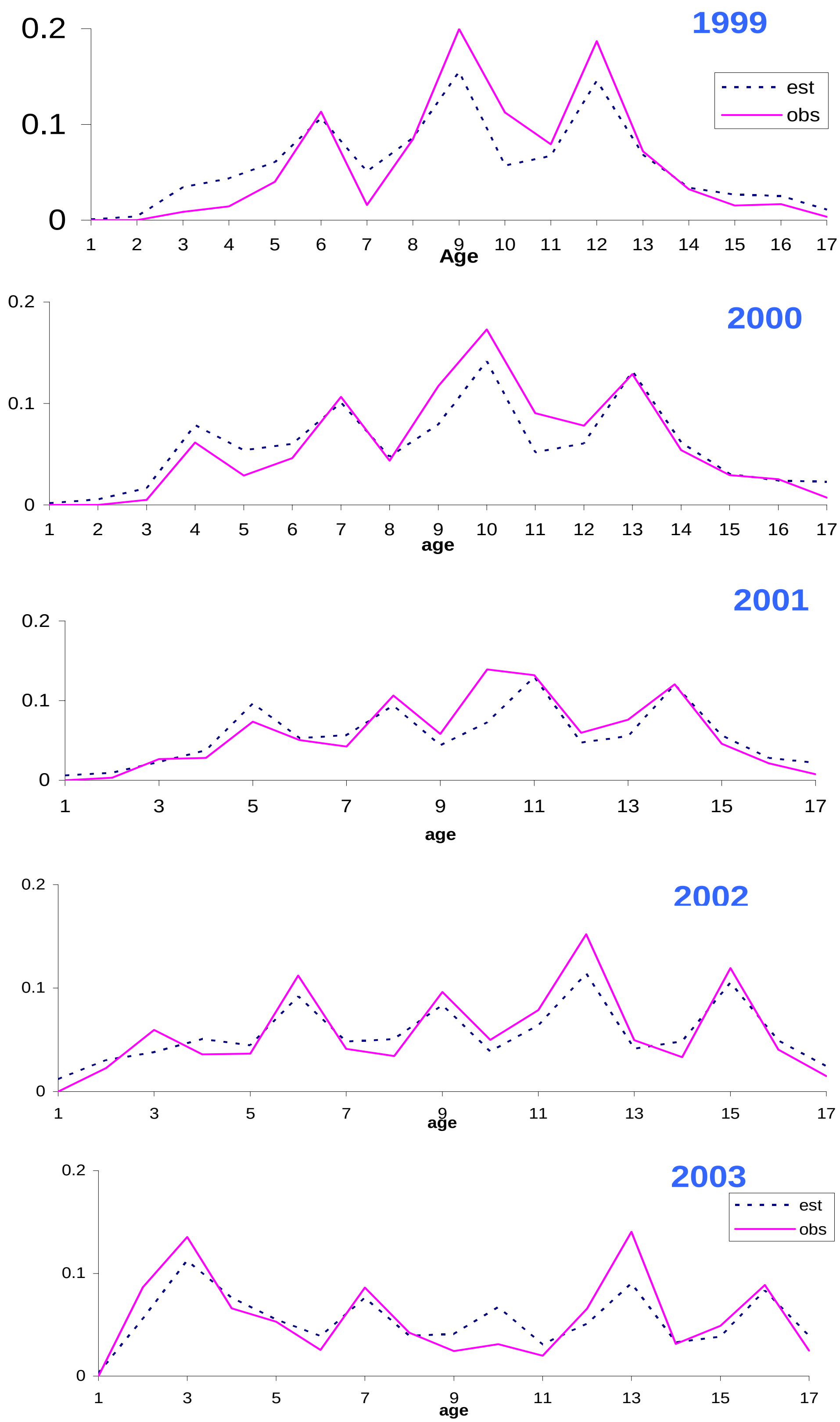
6) Posterior distributions of some parameters of interest from the stock assessment model.



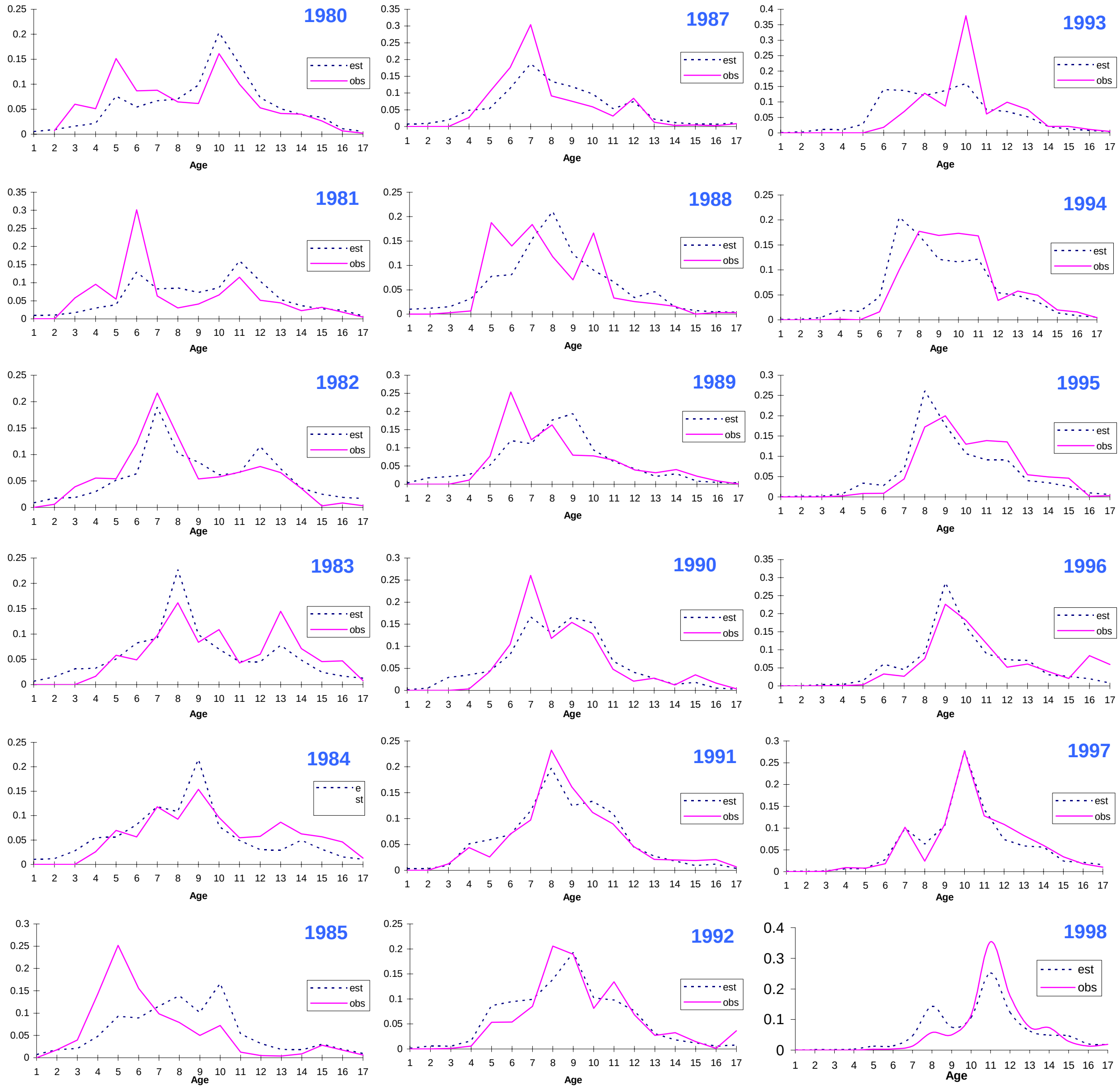
Fits to the survey age composition

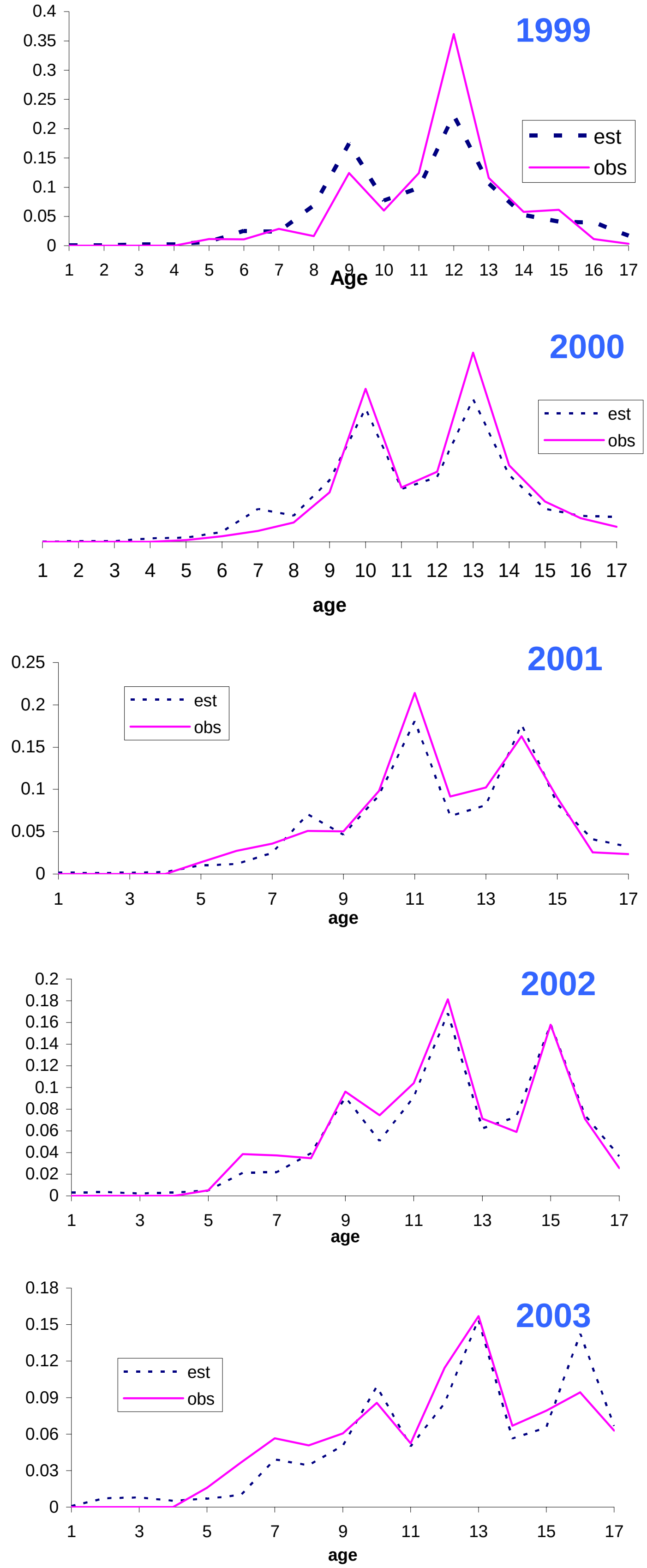


Fits to the survey age composition (continued)



Fits to the fishery age composition






Fits to the fishery age composition continued)

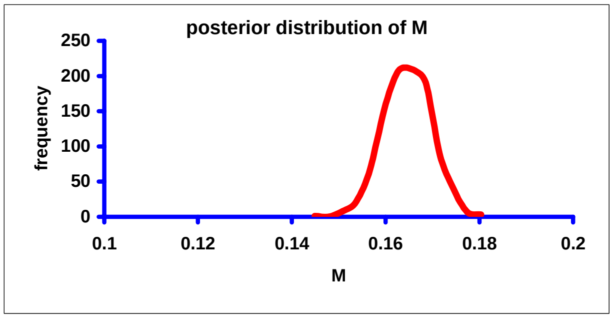
Model estimates of rock sole population numbers-at-age (thousands of fish), 1975-2004.

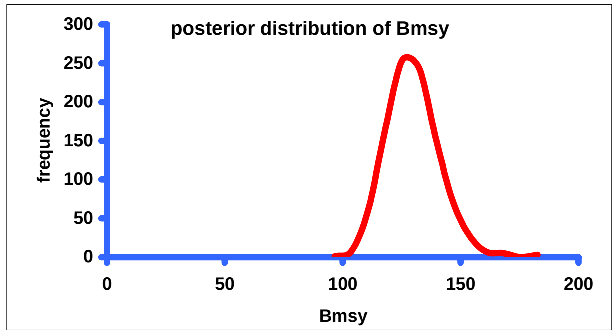
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1975** | 259 | 161 | 102 | 105 | 191 | 129 | 70 | 52 | 43 | 39 | 13 | 7 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **1976** | 681 | 220 | 137 | 87 | 89 | 161 | 107 | 57 | 41 | 32 | 28 | 9 | 5 | 3 | 3 | 3 | 3 | 3 | 3 | 5 |
| **1977** | 384 | 579 | 187 | 116 | 74 | 75 | 134 | 88 | 45 | 32 | 24 | 21 | 7 | 4 | 2 | 2 | 2 | 2 | 2 | 6 |
| **1978** | 580 | 326 | 493 | 159 | 99 | 62 | 63 | 112 | 72 | 37 | 26 | 20 | 17 | 5 | 3 | 2 | 2 | 2 | 2 | 6 |
| **1979** | 663 | 494 | 278 | 419 | 135 | 84 | 53 | 53 | 92 | 59 | 30 | 20 | 16 | 14 | 4 | 2 | 1 | 1 | 1 | 6 |
| **1980** | 843 | 564 | 420 | 236 | 356 | 115 | 71 | 44 | 44 | 76 | 48 | 24 | 17 | 13 | 11 | 3 | 2 | 1 | 1 | 6 |
| **1981** | 1,627 | 717 | 480 | 357 | 201 | 302 | 97 | 59 | 36 | 35 | 60 | 38 | 19 | 13 | 10 | 9 | 3 | 1 | 1 | 6 |
| **1982** | 1,651 | 1,384 | 610 | 408 | 304 | 170 | 254 | 81 | 49 | 29 | 28 | 48 | 30 | 15 | 10 | 8 | 7 | 2 | 1 | 5 |
| **1983** | 1,447 | 1,405 | 1,178 | 519 | 346 | 257 | 143 | 210 | 65 | 39 | 23 | 22 | 37 | 23 | 12 | 8 | 6 | 5 | 2 | 5 |
| **1984** | 2,577 | 1,231 | 1,195 | 1,001 | 440 | 293 | 215 | 118 | 171 | 52 | 30 | 18 | 17 | 29 | 18 | 9 | 6 | 5 | 4 | 5 |
| **1985** | 2,088 | 2,192 | 1,047 | 1,015 | 846 | 369 | 241 | 171 | 89 | 122 | 36 | 21 | 12 | 11 | 19 | 12 | 6 | 4 | 3 | 6 |
| **1986** | 2,081 | 1,777 | 1,865 | 890 | 861 | 716 | 309 | 199 | 138 | 71 | 96 | 28 | 16 | 9 | 9 | 15 | 9 | 5 | 3 | 7 |
| **1987** | 3,319 | 1,771 | 1,512 | 1,585 | 755 | 728 | 600 | 255 | 161 | 109 | 55 | 74 | 21 | 12 | 7 | 7 | 12 | 7 | 4 | 8 |
| **1988** | 5,656 | 2,824 | 1,506 | 1,285 | 1,346 | 639 | 612 | 498 | 208 | 129 | 87 | 43 | 58 | 17 | 10 | 6 | 5 | 9 | 6 | 9 |
| **1989** | 2,107 | 4,812 | 2,402 | 1,280 | 1,089 | 1,133 | 531 | 496 | 390 | 158 | 95 | 63 | 31 | 42 | 12 | 7 | 4 | 4 | 7 | 11 |
| **1990** | 1,463 | 1,793 | 4,094 | 2,042 | 1,086 | 921 | 951 | 439 | 402 | 309 | 123 | 74 | 49 | 24 | 32 | 9 | 5 | 3 | 3 | 13 |
| **1991** | 3,281 | 1,245 | 1,525 | 3,479 | 1,732 | 917 | 771 | 782 | 353 | 315 | 239 | 94 | 56 | 37 | 18 | 25 | 7 | 4 | 2 | 12 |
| **1992** | 1,516 | 2,792 | 1,059 | 1,297 | 2,953 | 1,465 | 770 | 637 | 634 | 280 | 247 | 186 | 73 | 44 | 29 | 14 | 19 | 6 | 3 | 11 |
| **1993** | 758 | 1,290 | 2,375 | 900 | 1,100 | 2,496 | 1,228 | 635 | 515 | 501 | 218 | 191 | 143 | 56 | 33 | 22 | 11 | 15 | 4 | 11 |
| **1994** | 1,357 | 645 | 1,097 | 2,020 | 765 | 932 | 2,101 | 1,022 | 520 | 415 | 400 | 173 | 151 | 113 | 44 | 26 | 17 | 9 | 12 | 12 |
| **1995** | 691 | 1,155 | 549 | 933 | 1,716 | 648 | 786 | 1,754 | 842 | 423 | 334 | 320 | 138 | 120 | 90 | 35 | 21 | 14 | 7 | 19 |
| **1996** | 555 | 588 | 983 | 467 | 793 | 1,456 | 548 | 660 | 1,461 | 695 | 347 | 273 | 261 | 113 | 98 | 73 | 29 | 17 | 11 | 21 |
| **1997** | 905 | 473 | 500 | 836 | 397 | 672 | 1,228 | 458 | 545 | 1,190 | 561 | 279 | 219 | 209 | 90 | 78 | 59 | 23 | 14 | 26 |
| **1998** | 395 | 770 | 402 | 426 | 711 | 337 | 570 | 1,036 | 384 | 454 | 986 | 464 | 230 | 181 | 173 | 74 | 65 | 48 | 19 | 33 |
| **1999** | 501 | 336 | 655 | 342 | 362 | 604 | 285 | 480 | 866 | 319 | 375 | 813 | 382 | 189 | 149 | 142 | 61 | 53 | 40 | 43 |
| **2000** | 776 | 426 | 286 | 557 | 291 | 307 | 511 | 240 | 400 | 716 | 262 | 307 | 664 | 312 | 155 | 121 | 116 | 50 | 44 | 67 |
| **2001** | 2,361 | 660 | 363 | 243 | 474 | 247 | 261 | 431 | 202 | 335 | 597 | 218 | 255 | 552 | 259 | 128 | 101 | 96 | 42 | 92 |
| **2002** | 4,472 | 2,009 | 562 | 309 | 207 | 403 | 209 | 220 | 361 | 168 | 277 | 492 | 179 | 210 | 454 | 213 | 106 | 83 | 79 | 110 |
| **2003** | 1,008 | 3,806 | 1,710 | 478 | 262 | 176 | 341 | 176 | 183 | 299 | 138 | 227 | 404 | 147 | 172 | 373 | 175 | 87 | 68 | 155 |
| **2004** | 1,258 | 858 | 3,238 | 1,455 | 407 | 223 | 149 | 287 | 147 | 152 | 247 | 114 | 187 | 332 | 121 | 142 | 307 | 144 | 71 | 184 |

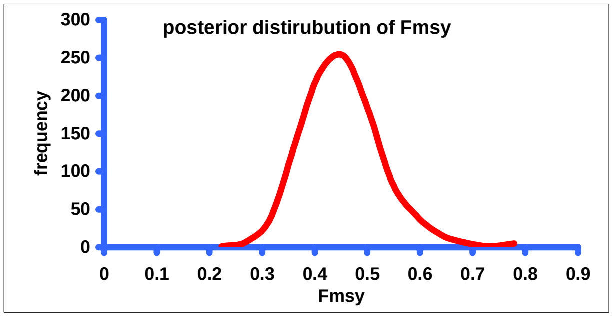
Total catch (t) of rock sole in Alaska Fisheries Science Center research catches in the Bering Sea and Aleutian Islands, 1977-2003.

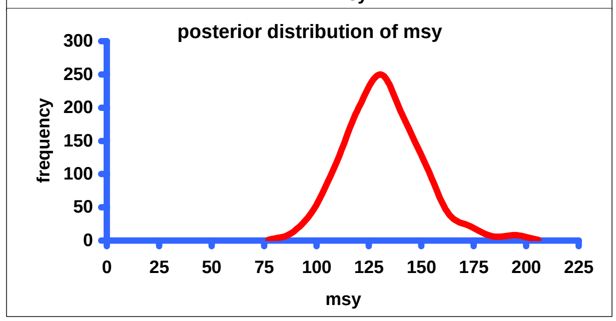
| year | research catch (t) |
|---|---|
| 1977 | 10 |
| 1978 | 14 |
| 1979 | 13 |
| 1980 | 20 |
| 1981 | 12 |
| 1982 | 26 |
| 1983 | 59 |
| 1984 | 63 |
| 1985 | 34 |
| 1986 | 53 |
| 1987 | 52 |
| 1988 | 82 |
| 1989 | 83 |
| 1990 | 88 |
| 1991 | 97 |
| 1992 | 46 |
| 1993 | 75 |
| 1994 | 113 |
| 1995 | 99 |
| 1996 | 72 |
| 1997 | 91 |
| 1998 | 79 |
| 1999 | 72 |
| 2000 | 72 |
| 2001 | 81 |
| 2002 | 69 |
| 2003 | 75 |
| 2004 | 84 |

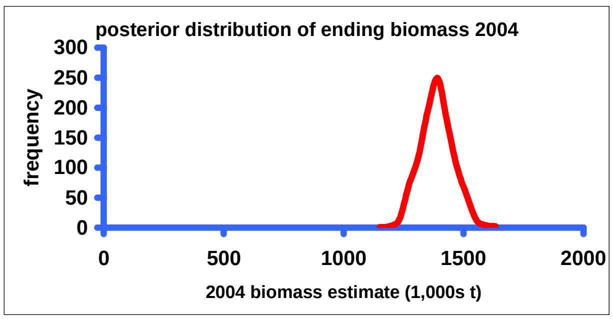
| | TAC | ABC |
|---|---|---|
| **1989** | 90,762 | 171,000 |
| **1990** | 60,000 | 216,300 |
| **1991** | 90,000 | 246,500 |
| **1992** | 40,000 | 260,800 |
| **1993** | 75,000 | 185,000 |
| **1994** | 75,000 | 313,000 |
| **1995** | 60,000 | 347,000 |
| **1996** | 70,000 | 361,000 |
| **1997** | 97,185 | 296,000 |
| **1998** | 100,000 | 312,000 |
| **1999** | 120,000 | 309,000 |
| **2000** | 137,760 | 230,000 |
| **2001** | 75,000 | 228,000 |
| **2002** | 54,000 | 225,000 |
| **2003** | 44,000 | 110,000 |
| **2004** | 41,000 | 139,000 |

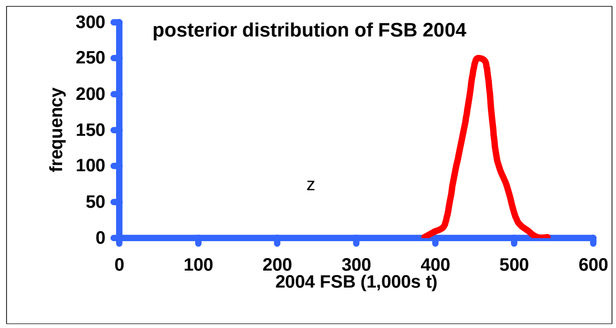

posterior distribution of M
frequency
250
200
150
100
50
0
0.1
0.12
0.14
0.16
0.18
0.2
M

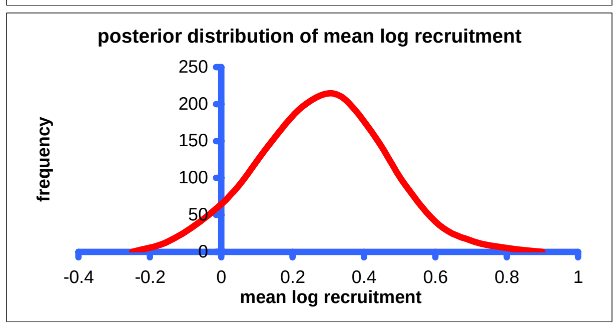

posterior distribution of Bmsy
frequency
300
250
200
150
100
50
0
0
50
100
150
200
Bmsy


posterior distirubution of Fmsy
frequency
300
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Fmsy


posterior distribution of msy
frequency
300
250
200
150
100
50
0
0
25
50
75
100
125
150
175
200
225
msy


posterior distribution of ending biomass 2004
frequency
300
250
200
150
100
50
0
0
500
1000
1500
2000
2004 biomass estimate (1,000s t)


posterior distribution of FSB 2004
frequency
300
250
200
150
100
50
0
z
0
100
200
300
400
500
600
2004 FSB (1,000s t)


posterior distribution of mean log recruitment
frequency
250
200
150
100
50
0
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
mean log recruitment

*(This page intentionally left blank)*