ROCK SOLE

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EXECUTIVE SUMMARY

The following changes have been made to this assessment relative to the November 2001 SAFE:

Changes to the input data

1) 2001 fishery age composition.
2) 2001 survey age composition.
3) 2002 trawl survey biomass point estimate and standard error.
4) Estimate of catch (t) and discards through 14, September 2002.
5) Estimate of retained and discarded portions of the 2001 and 2002 catch.

Assessment results

Using model with revised estimate of survey catchability

1) The projected age 2+ biomass for 2003 is 877,200 t.
2) The projected female spawning biomass for 2003 is 303,100 t.
3) The recommended 2003 ABC is 110,200 t based on an $F_{40\%}$ (0.176) harvest level.
4) The 2003 overfishing level is 131,700 t based on an $F_{35\%}$ (0.213) harvest level.

New Analysis

Survey catchability is estimated and evaluated as an alternative model

SUMMARY

	2001 Assessment Recommendations for the 2002 harvest	2002 Assessment Recommendations for the 2003 harvest
Total biomass	1,849,000 t	877,200 t
ABC	225,100 t	110,200 t
Overfishing	267,900 t	131,700 t
F_{ABC}	$F_{0.40} = 0.162$	$F_{0.40} = 0.176$
$F_{overfishing}$	$F_{0.35} = 0.196$	$F_{0.35} = 0.213$

Response to SSC Comments

The SSC made a number of comments regarding Bering Sea flatfish in their December 2001 minutes. The comment applicable to rock sole regarded harvest considerations in the tier system.

"Many of the flatfish species have 30-40 years of stock recruitment data. Further, the stock recruitment plots are quite similar and indicate density dependent response at high biomass levels as well as strong recruitment response following the 1976-77 climatic change. The SSC recommends that for assessments with a lengthy stock recruitment time series, management under Tier 1 status be explored:"

The use of estimated recruitments and stock size to produce reliable estimates of F_{msy} and B_{msy} for subsequent management in Tier 1 is examined in the *Tier 1 Considerations* section of this document.

INTRODUCTION

The northern rock sole (Lepidopsetta polyxystra n. sp.) is 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 predominates 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, 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 6.1, 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 - 2001 (DAP only) have averaged 50,700 t annually. The size composition of the 2001 catch from observer sampling, by sex and management area, are shown in Figure 6.1 and the catch locations, 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 2001 catch of 29,255 t was only 13% of the ABC of 228,000 t (39% of the TAC). The 2002 catch total is 40,300 t through September 14. Thus, rock sole remain lightly harvested in the Bering Sea and Aleutian Islands.

During the 2002 fishing season rock sole harvesting was periodically closed in the Bering Sea and Aleutian Islands due to bycatch restrictions, as follows:

Area	Date	Bycatch closure
Zone 1	2/22 – 12/31	Annual red king crab cap
BS/AI	3/1 - 4/1	First seasonal halibut cap
BS/AI	4/20 - 7/1	Second seasonal halibut cap
BS/AI	7/29 - 12/31	Annual halibut allowance

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. Observer discard estimates applied to 'blend' estimates of observer sampling and industry reported catch provide the following estimates:

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	23,026 t	17,291 t	57

From 1987 to 2000 rock sole were discarded in greater amounts than they were retained. The past two years indicate increased utilization of the catch. Fisheries with the highest discard rates include the rock sole roe fishery, the yellowfin sole, flathead sole, Pacific cod, and the bottom pollock fisheries (Table 6.2).

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 14, 2002 (Table 6.1) and fishery catch-at-age numbers from 1980-2001 (Table 6.3).

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 6.2). 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. In 2000 and 2001the CPUE increased and then decreased to 41.0 kg/ha in 2002.

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	2,415,000	
2002	1,901,800	57,700

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 2002 point estimate of the Bering Sea surveyed area is 1,556,194 t - 2,247,475 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 672,000 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 2.2 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 6.3). 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 6.4) 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 6.5). 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 1975 to provide estimates of the population age composition (Fig. 6.4, Table 6.6). Age-length keys from these surveys were applied to fishery size composition data from 1980-97 (prior to 1980 observer coverage was sparse and did not reflect the catch size composition) 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 used 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 6-7). 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 6-7 presents the key equations used to model the rock sole population dynamics in the Bering Sea and Table 6-8 provides a description of the variables used in Table 6-7. 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

Most studies assume M = 0.20 for rock sole on the basis of the longevity of the species. In a past 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, which is the value used in this assessment. Past assessments have also set the survey catchability coefficient (q) equal to 1.0.

Rock sole maturity schedules were estimated as discussed in section 6.3.4 (Table 6.5).

Parameters Estimated Conditionally

The parameters estimated by the model are presented below:

Fishing mortality	Selectivity	Year class strength	Total
28	4	47	79

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 and the entry of another year class into the observed population.

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 6-7.

Selectivity

Fishery and survey selectivity were modeled in this assessment using the logistic function, as shown in Table 6-7. The model was configured with the selectivity curve fixed asymptotically 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 was documented for yellowfin sole in the 2001 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 α and β are parameters estimated by the model. The model estimated values of α and β at 1.77 and 0.021, respectively. The small value for β indicates that temperature has very little effect on trawl catchability of rock sole and the value of 1.77 obtained for α 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 1.45 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, provide a compelling reason to consider an alternative model where survey catchability is estimated. Model runs were made to profile the total log(likelihood) over a range of q values from 1.0 to 2.2 (M was fixed at 0.18 and selectivity was estimated) to find which value of q gave the best overall fit to the observed data values. Results from these model runs are shown in Table 6.9 and Figure 6.5 for four likelihood components and the total log(likelihood) and indicate that the best model fit to the observable information occurs when q = 1.82. The model fit best at this value due to the improvement in matching the observed survey age composition data, primarily in the last 5 years.

Model Evaluation

Description of the Alternative Model

Past assessment models have not estimated survey catchability (q) and have set it equal to 1.0. Since the analysis in the previous section indicates that the bottom trawl survey catchability may be greater than 1.0, an alternative model (Model B) is considered which fixes q at 1.8.

Model selection criteria will include:

1) The -log(likelihood) for all data combined (best fit).
2) The likelihood profile of q.

The model results indicate that Model B provides a better fit to the survey abundance estimates and the survey age composition than Model A (see Table below, Table 6.9 and Figure 6.5).

	Model A (q=1.0)	Model B (q=1.8)
Trawl survey abundance	47.63	45.57
Survey age composition	338.37	322.43
Fishery age composition	597.15	599.31
Recruitment	68.78	67.64
Total –log(likelihood)	1,051.93	1,034.95

Since both models have the same number of estimated parameters, the gain in log(likelihood) by Model B of 16.98 is a statistically significant improvement.

In addition, the likelihood profile of q indicates a small variance with a narrow range of likely values (Fig. 6.6). The probability of q being 1.0 as in Model A, given the data, appears to be very low as the 95% confidence intervals of q range from 1.51 to 2.13. The model of choice for this assessment is Model B since: 1) experimental evidence indicates than survey catchability for rock sole is > 1.0; 2) Model B provides a significantly better fit to the overall data; and 3) given the data, a value for q of 1.0 does not appear likely.

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 6.8. The exploitation rate has averaged 4% from 1975-2001, indicating a lightly exploited stock. Age-specific selectivity estimated by the model (Table 6.11, Fig. 6.7) indicate that rock sole are 50% selected by the fishery between the ages of 7 and 8 and are fully selected by age 12 (sexes combined).

Abundance Trend

The stock assessment model B indicates that rock sole total biomass was at low levels during the mid 1970s through 1982 (175,000 - 330,000 t, Fig. 6.7 and Table 6.12). From 1982-95, a period characterized by sustained above-average recruitment (1980-88 year classes, Fig. 6.7) and light exploitation, the estimated total biomass rapidly increased at a high rate to over 1.5 million t by 1995. Since then, the model indicates the population biomass has declined 38% to 970,000 t in 2002 and is projected at 880,000 t for 2003. This decline 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 344,00 t in 2002 (Table 6.12). 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 from Model B applied to the total biomass, Fig. 6.7) corresponded fairly well with the trawl survey biomass trend through 1995. The 1999 survey point estimate is 200,000 t less than the model estimate whereas the past three survey biomass estimates have ranged from 300,000 t to 600,000 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.

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 2003. Including the 2002 catch of 40,300 t through 14 September (including discards), the model projects the total biomass for 2003 at **877,200** 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. 6.4 and 6.7, Table 6.13). Rock sole ages have now been read for samples obtained in 2001 and show the continuing presence of the 1987 year class (Fig. 6.7). The 1990 and 1991year classes, as 10 and 11 year old fish in 2001, comprise a significant part of the survey age composition numbers. The 1987 year class is the largest estimated during the recruitment time-series and still comprise 12% of the estimated 2001 survey age composition numbers as fourteen year old fish. Recruitment after 1990 has been below the 26 year average.

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. If we fit a stock-recruit relationship to these data, we can derive estimates of F_{MSY} and B_{MSY} which assume that the fit to the stock-recruitment data points represents the long-term productivity of the stock. However, recent analysis of flatfish recruitment indicates 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 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). These changes in stock productivity were found to coincide with a decadal scale shift in atmospheric forcing. The presence of decadal shifts in production could be addressed in tier 3 by truncating the recruitment time series used to estimate the biological reference points.

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 plan to perform 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. For this assessment then, we recommend a continued Tier 3 harvest strategy.

Spawner-Recruit Relationship

Model estimates of female spawning biomass and the relationship to estimated age 4 recruitment are shown in Figure 6.8. The twenty-one data points were fit with a Ricker (1958) form of spawner-recruit curve. However, estimation of MSY using these data is not recommended for management purposes since environmental processes which can determine the level of recruitment for a given stock size are not considered.

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 **$B_{0.40}$ = 158,600 t**. The stock assessment model estimates the 2003 level of female spawning biomass at **303,100 t** (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and $B>B_{0.40}$ (303,100 > 158,600, fig. 6.7), rock sole reference fishing mortality is defined in tier 3a. For the 2003 harvest: $F_{ABC} \leq F_{0.40} = 0.176$ and $F_{overfishing} = F_{0.35} = 0.213$ (full selection F values).

Acceptable biological catch is estimated for 2003 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the 2003 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 **2003 ABC of 110,200** 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	2002 Yield
$F_{0.35}$	0.213	131,700 t
$F_{0.40}$	0.176	110,200 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 2002 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2003 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2002. 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 2003, 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 2003 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.)

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 2003 and above its MSY level in 2013 under this scenario, then the stock is not overfished.)

Scenario 7: In 2003 and 2004, *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 2015 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 6.12 indicate that rock sole are currently not overfished and are not approaching an overfished condition. If harvested at the average F from 1998-2002, rock sole female spawning biomass is projected to decline over the next five years due to the reduced recruitment observed during the 1990s (fig. 6.9).

OTHER CONSIDERATIONS

Trophic studies indicate that rock sole groundfish predators include Pacific cod, walleye pollock, skates, Pacific halibut and yellowfin sole, mostly on small rock sole ranging from 5 to 15 cm standard length. Rock sole diet includes bivalves, polychaetes, amphipods and miscellaneous crustaceans.

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Table 6.1--Rock sole catch from 1977 - September 15, 2001.

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			40,317	40,317

Table 6.2--Discarded and retained rock sole catch, by target fishery, in 2001 and 2002.

	2001		
target fishery	discard	retained	total
atka mackerel	45	10	54
bottom pollock	189	168	357
Pacific cod	2,920	2,519	5,440
other flatfish	9	30	39
rockfish	2	0	2
flathead sole	849	1,075	1,924
mid water pollock	501	802	1,303
rock sole	3,463	10,866	14,329
sablefish	0	0	0
Greenland turbot	2	0	3
arrowtooth flounder	17	20	37
yellowfin sole	1,959	3,808	5,767
non-retained groundfish	0	0	0
			29,255

	2002		
target fishery	discard	retained	total
Atka mackerel	49	25	74
bottom pollock	68	88	156
Pacific cod	4,372	2,286	6,657
other flatfish	125	26	151
rockfish	7	0	7
flathead sole	1,017	692	1,709
mid water pollock	803	874	1,677
rock sole	6,823	12,858	19,682
sablefish	0	0	0
Greenland turbot	1	0	1
arrowtooth flounder	13	7	20
yellowfin sole	4,011	6,170	10,182
non-retained groundfish	0	0	0

Table 6.3--Estimated catch numbers at age, 1980-2001 (in thousands).

	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

Table 6-4 --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 6-5.--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	4.0	0
2	8.2	0.006
3	14.3	0.003
4	19.4	0.012
5	23.6	0.039
6	27.1	0.098
7	30.1	0.198
8	32.6	0.330
9	34.6	0.470
10	36.4	0.590
11	37.8	0.680
12	39.0	0.746
13	40.0	0.795
14	40.8	0.830
15	41.5	0.856
16	42.1	0.875
17	42.6	0.889
18	43.0	0.900
19	43.4	0.908
20	43.7	0.915

Table 6.6--Estimated population numbers-at-age (millions) from the annual Bering Sea trawl surveys, 1982- 2001.

	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

Table 6.7--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 6.8--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_γ	Geometric mean value of age 1 recruitment, 1976-96
τ_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*
ϕ_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
μ^F	Median year-effect of fishing mortality
ε_t^F	The residual year-effect of fishing mortality
ν_a	Age-specific survey selectivity
α	Slope parameter in the logistic selectivity equation
β	Age at 50% selectivity parameter in the logistic selectivity equation
σ_t	Standard error of the survey biomass in year *t*

Table 6.9 --Log(likelihood) estimates for each likelihood component and total log(likelihood) for the full model over values of q ranging from 1.0 to 2.2.

q	survey	Fishery age comp	survey age comp	recruitment	
				rec dev	init de
1	47.6364	597.154	338.367	14.8038	53.972
1.1	46.9658	596.695	335.791	14.8492	53.756
1.2	46.3933	596.458	333.388	14.897	53.546
1.3	45.9286	596.439	331.154	14.9473	53.341
1.4	45.5817	596.629	329.088	15.0002	53.142
1.5	45.3624	597.02	327.186	15.0556	52.949
1.6	45.2806	597.604	325.445	15.1136	52.762
1.7	45.3457	598.37	323.862	15.1741	52.581
1.8	45.5666	599.308	322.431	15.2372	52.406
1.9	45.9511	600.408	321.148	15.3029	52.238
2	46.5064	601.659	320.009	15.3709	52.075
2.1	47.2384	603.051	319.009	15.4413	51.919
2.2	48.1519	604.574	318.142	15.5139	51.768

Table 6.10--Model estimates of rock sole fishing mortality and exploitation rate (catch/total biomass).

year	Full selection F	Exploitation rate
1975	0.177	0.068
1976	0.135	0.055
1977	0.063	0.028
1978	0.074	0.033
1979	0.056	0.025
1980	0.079	0.033
1981	0.076	0.030
1982	0.109	0.036
1983	0.110	0.032
1984	0.285	0.081
1985	0.121	0.035
1986	0.125	0.035
1987	0.103	0.029
1988	0.206	0.061
1989	0.123	0.039
1990	0.057	0.022
1991	0.124	0.050
1992	0.112	0.047
1993	0.103	0.046
1994	0.086	0.040
1995	0.064	0.035
1996	0.056	0.032
1997	0.080	0.050
1998	0.039	0.026
1999	0.048	0.034
2000	0.059	0.043
2001	0.037	0.028

Table 6.11. --Model estimates of rock sole age-specific fishery and survey selectivities.

Age	Fishery (1980-2001)	Survey (1982-2001)
1	0	0.01
2	0	0.06
3	0.01	0.27
4	0.03	0.67
5	0.06	0.92
6	0.13	0.98
7	0.26	1.0
8	0.45	1.0
9	0.66	1.0
10	0.82	1.0
11	0.92	1.0
12	0.96	1.0
13	0.98	1.0
14	0.98	1.0
15	0.98	1.0
16	0.98	1.0
17	0.98	1.0
18	0.98	1.0
19	0.98	1.0
20	0.98	1.0

Table 6-12.--Model estimates of rock sole age 2+ total biomass and female spawning biomass from the 2001 and 2002 assessments.

	2002 Assessment Age 2+ Total biomass	Female Spawning biomass	2001 Assessment Age 2+ Total biomass	Female Spawning biomass
1975	177,406	30,655	262,083	44,366
1976	182,524	32,581	276,887	49,325
1977	191,228	35,847	295,715	56,003
1978	210,339	40,709	327,629	64,320
1979	233,338	44,560	366,409	71,390
1980	263,667	48,351	415,933	78,134
1981	297,996	51,566	473,743	84,474
1982	329,142	47,901	528,189	79,525
1983	421,910	54,533	682,587	91,792
1984	464,301	61,869	758,147	104,961
1985	537,825	67,380	902,719	120,817
1986	671,693	80,790	1,130,540	145,222
1987	913,285	108,098	1,539,320	192,997
1988	1,043,510	134,326	1,766,260	239,018
1989	1,144,530	153,507	1,971,280	280,634
1990	1,148,240	180,387	2,000,450	333,143
1991	1,211,080	206,629	2,108,930	379,606
1992	1,209,390	214,434	2,124,480	398,891
1993	1,401,210	263,686	2,478,230	494,777
1994	1,443,010	288,406	2,562,010	542,979
1995	1,568,250	363,990	2,824,940	691,940
1996	1,457,880	354,913	2,612,070	667,967
1997	1,353,620	362,800	2,439,030	682,831
1998	1,280,970	371,385	2,343,820	707,962
1999	1,201,030	374,683	2,207,950	713,694
2000	1,137,970	375,130	2,110,030	717,272
2001	1,056,180	363,614	1,991,090	703,513

Table 6.13--Estimated age 4 recruitment of rock sole (thousands of fish) from the 2001 and 2002 assessments.

Year class	2002 Assessment	2001 Assessment
1971	112,192	170,466
1972	92,153	140,300
1973	121,833	186,424
1974	164,660	252,513
1975	429,466	659,713
1976	239,297	370,683
1977	356,104	557,733
1978	401,834	637,734
1979	506,963	813,656
1980	980,267	1,583,760
1981	991,312	1,615,740
1982	871,754	1,427,640
1983	1,563,010	2,579,960
1984	1,248,960	2,063,200
1985	1,245,960	2,071,640
1986	1,954,020	3,235,900
1987	3,273,260	5,458,160
1988	1,186,240	1,928,850
1989	778,121	1,252,370
1990	1,679,070	2,752,100
1991	731,282	1,098,120
1992	351,992	547,732
1993	694,307	1,203,400
1994	348,939	616,082
1995	215,753	300,570

Table 6.14--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
2002	337.443	40.317	0.055
2003	303.118	110.219	0.176
2004	248.824	89.5389	0.176
2005	205.982	73.506	0.176
2006	165.745	59.1935	0.176
2007	137.933	43.2254	0.152
2008	124.976	36.0571	0.136
2009	119.009	33.5906	0.129
2010	120.024	35.3125	0.130
2011	125.874	39.8003	0.137
2012	132.827	44.6603	0.143
2013	140.032	49.1833	0.149
2014	146.259	52.8343	0.153
2015	151.401	55.6627	0.157

Scenario 3

1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2002	337.443	40.317	0.055
2003	305.222	57.3066	0.088
2004	271.702	50.4346	0.088
2005	243.24	44.6947	0.088
2006	210.142	38.505	0.088
2007	185.121	34.0197	0.088
2008	171.081	31.7545	0.088
2009	161.013	30.0669	0.087
2010	158.011	29.4285	0.084
2011	161.683	30.7346	0.084
2012	167.707	32.4838	0.084
2013	175.653	34.5393	0.085
2014	183.881	36.5078	0.085
2015	191.831	38.2497	0.086

Scenario 4

Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2002	337.443	40.317	0.055
2003	306.075	34.7502	0.052
2004	281.53	31.59	0.052
2005	260.192	28.8827	0.052
2006	231.503	25.5958	0.052
2007	209.208	23.1532	0.052
2008	197.187	21.9808	0.052
2009	187.635	21.2357	0.052
2010	184.572	21.3037	0.052
2011	188.334	22.1522	0.052
2012	194.463	23.2199	0.052
2013	203.009	24.4521	0.052
2014	212.316	25.6601	0.052
2015	221.667	26.7998	0.052

Scenario 5

No fishing

Year	Female spawning biomass	catch	F
2002	337.443	0	0
2003	307.341	0	0
2004	296.752	0	0
2005	287.572	0	0
2006	267.458	0	0
2007	251.42	0	0
2008	244.755	0	0
2009	237.933	0	0
2010	236.657	0	0
2011	242.724	0	0
2012	250.783	0	0
2013	261.832	0	0
2014	274.263	0	0
2015	287.053	0	0

Figures

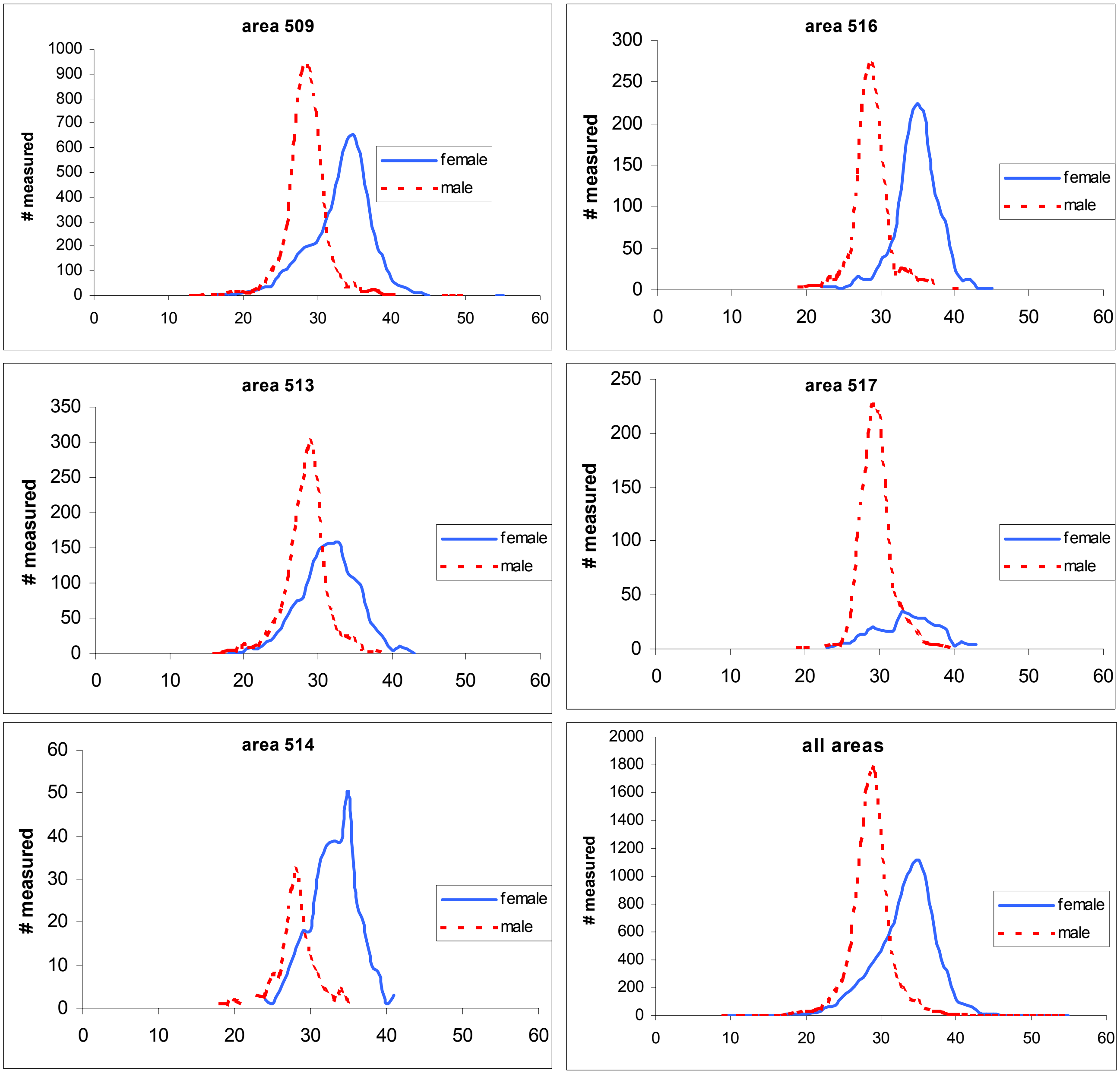


Figure 6.1--Size composition of the rock sole catch in 2001 determined from observer sampling of the commercial catch.

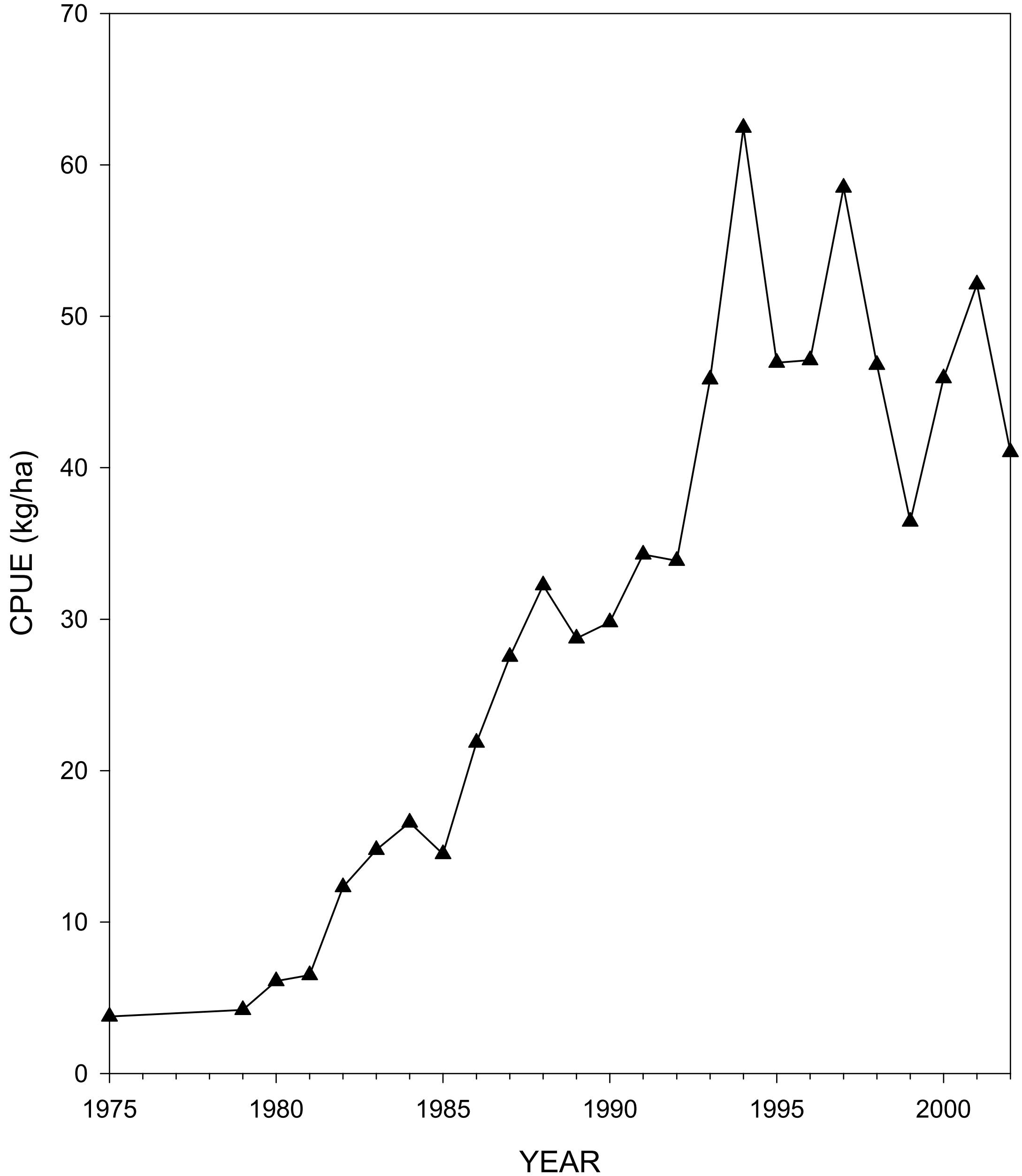


Figure 6.2- Relative abundance (catch per unit effort, CPUE) for rock sole from Alaska Fisheries Science Center bottom trawl survey.

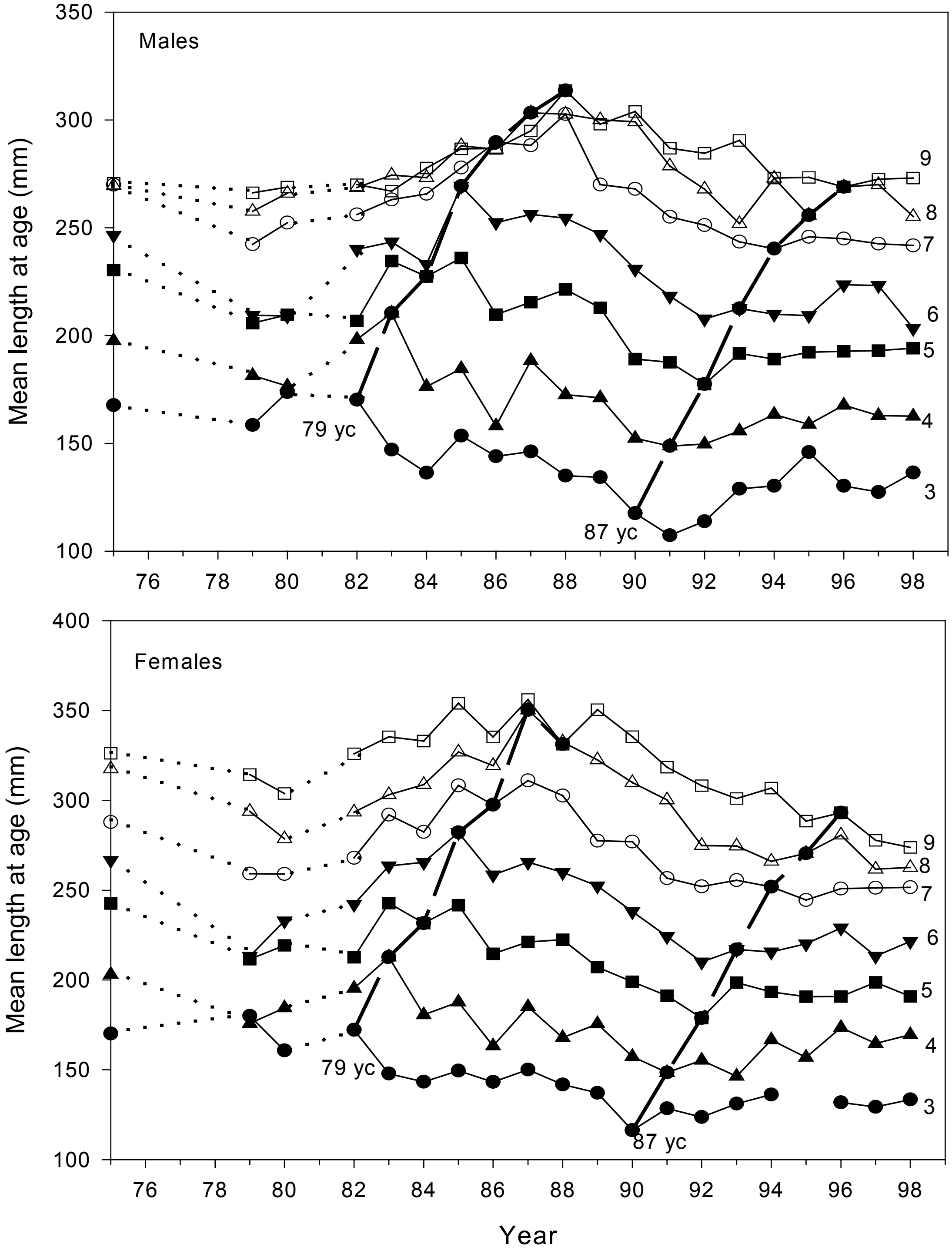


Fig. 6.3. Mean lengths at age (mm) by year of survey for eastern Bering Sea northern rocksole ages 3-9 for each sex during 1975-1998. Growth curves are shown for the 1979 (79yc) and 1987 (87yc) year classes. Dotted lines indicate no data during the period.
(From Walters and Wilderbuer, 2000, p.20)

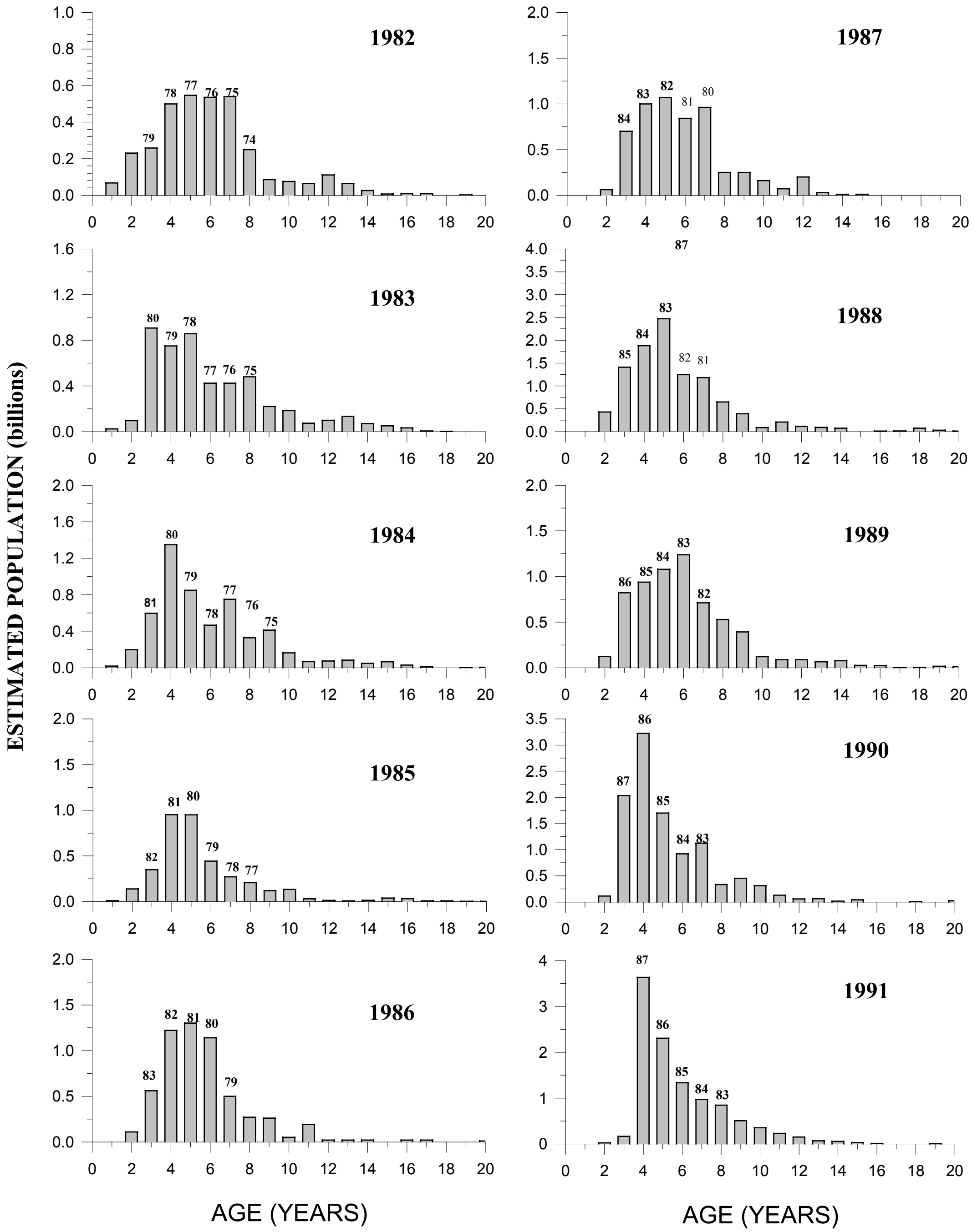


Figure 6.4 - Age composition of rock sole as shown by data collected on Alaska Fisheries Science Center demersal trawl surveys.

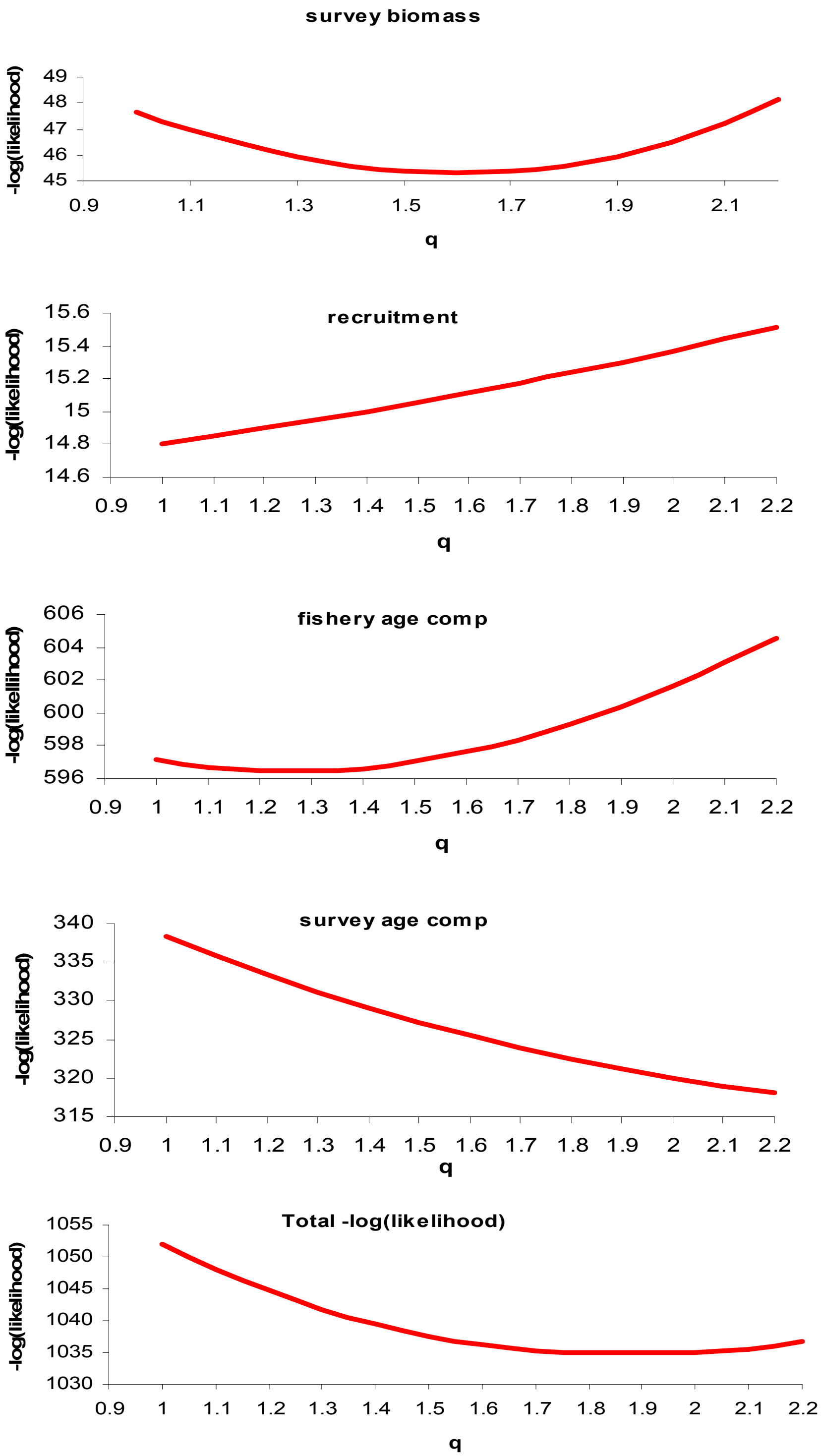


Figure 6.5--Model fit to various data components and the total-log(likelihood) by ranged fixed q values from 1.0 to 2.2 with natural mortality fixed at 0.18 and selectivity estimated.

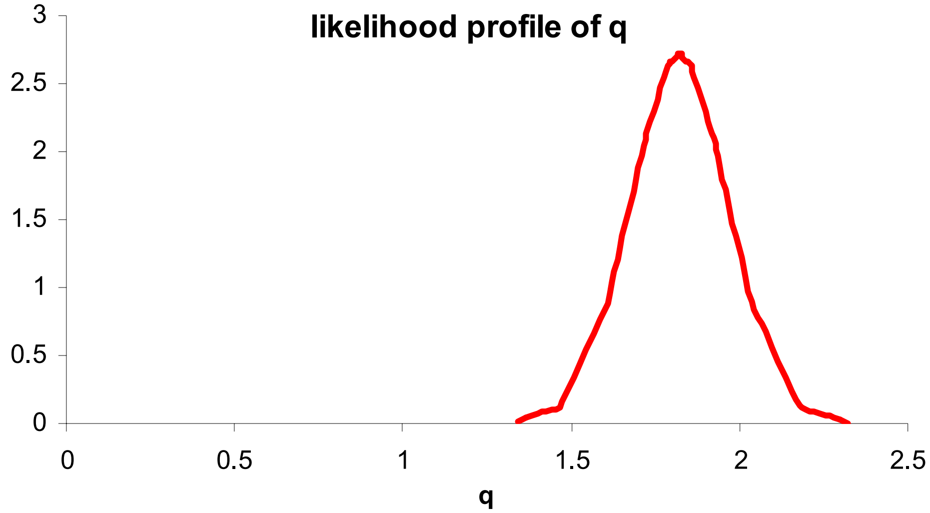


Figure 6.6. The profile likelihood of survey catchability (q) for rock sole given the observed data

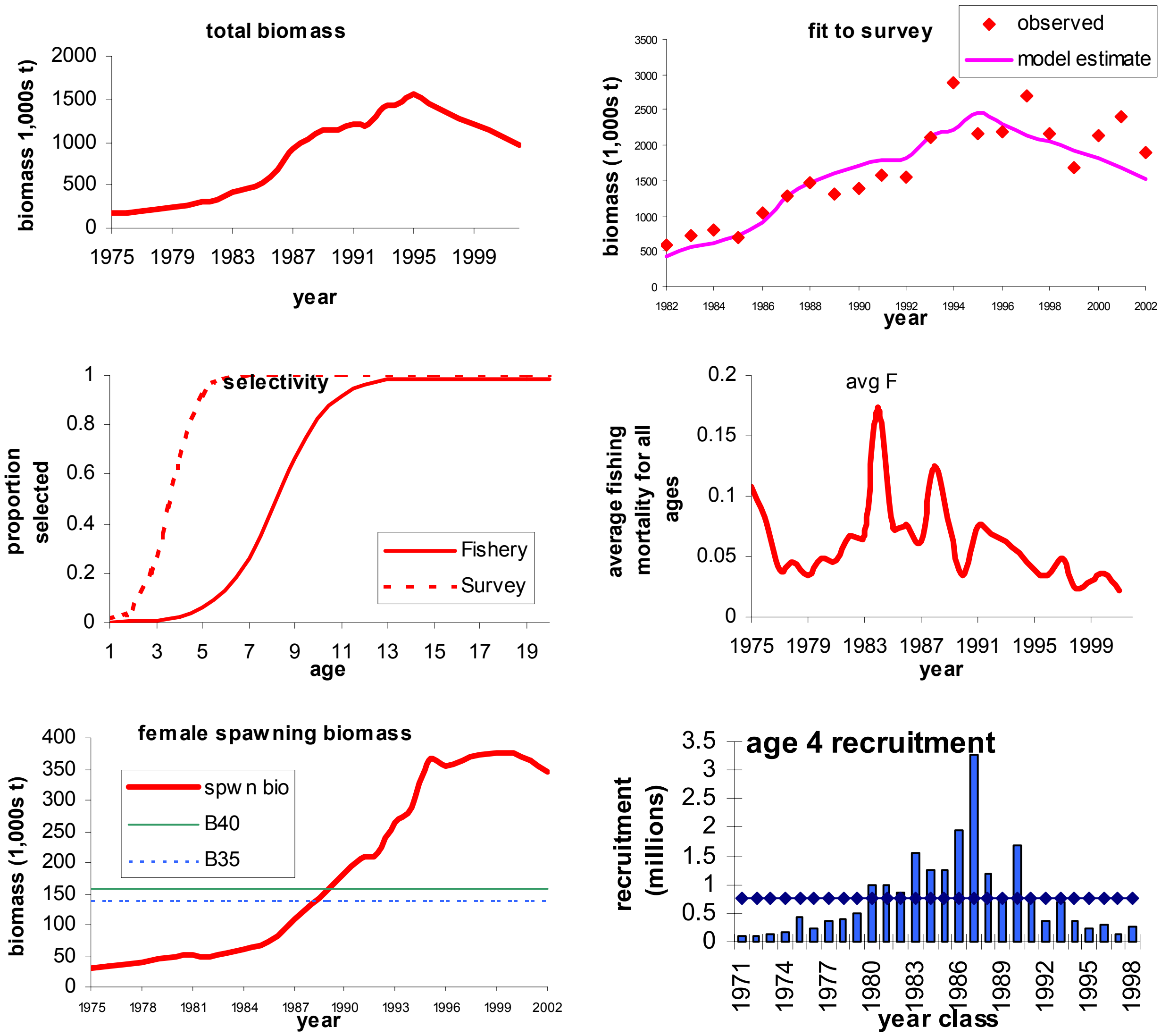


Figure 6.7--Stock assessment model estimates of total 2+ biomass (top left panel), fit to trawl survey biomass (top right panel), age-specific fishery and survey selectivity (middle left panel) and average annual fishing mortality rate (middle right panel), female spawning biomass (bottom right panel) and estimated age 4 recruitment (bottom right panel)..

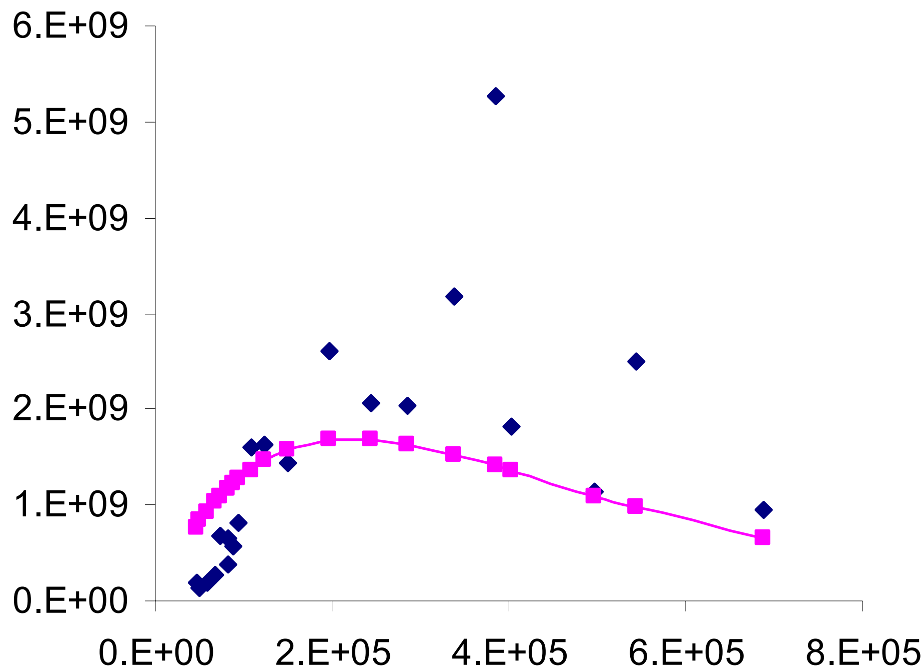


Figure 6.8--Ricker (1958) model fit to twenty-one age 4 recruitment and female spawning biomass estimates from the 2001 model results.

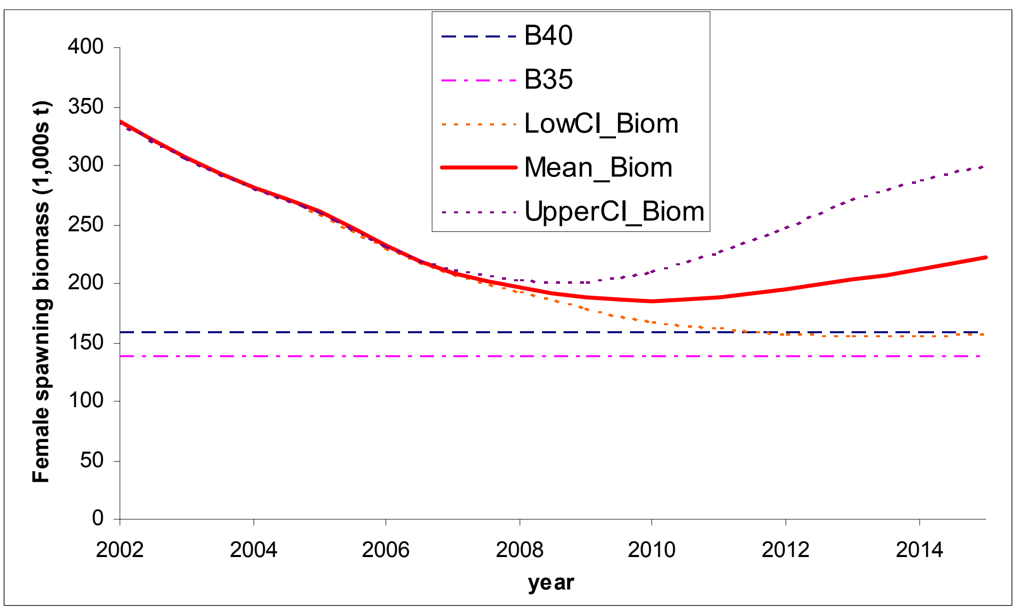


Figure 6.9--Projection of rock sole female spawning biomass at the 1998-2002 average fishing mortality rate through 2015.

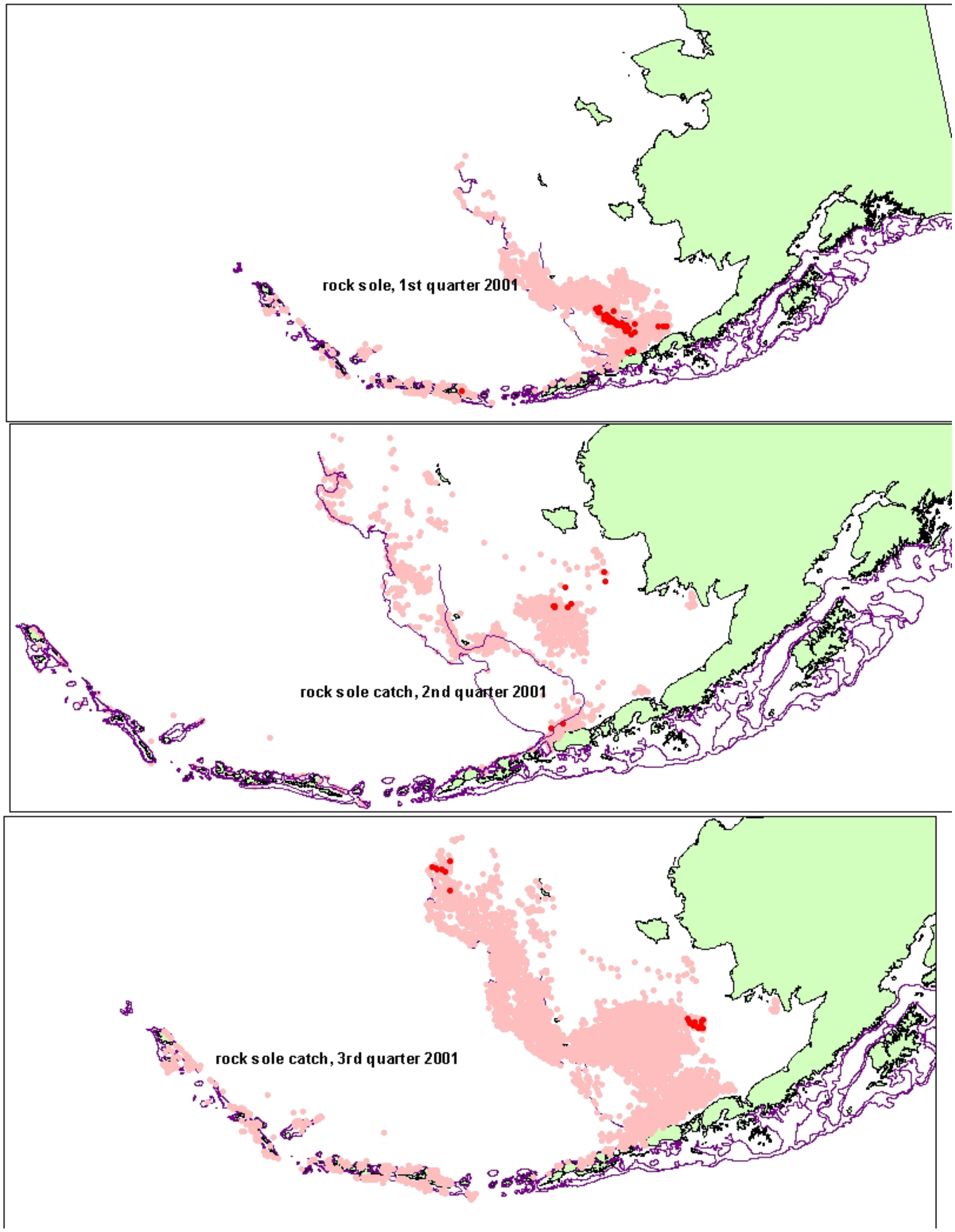
Appendix

1) Observed fishery trawl locations, by quarter, for the 2001 fishing season. Trawl locations where rock sole comprised 20% or more of the catch are identified by darker circles.

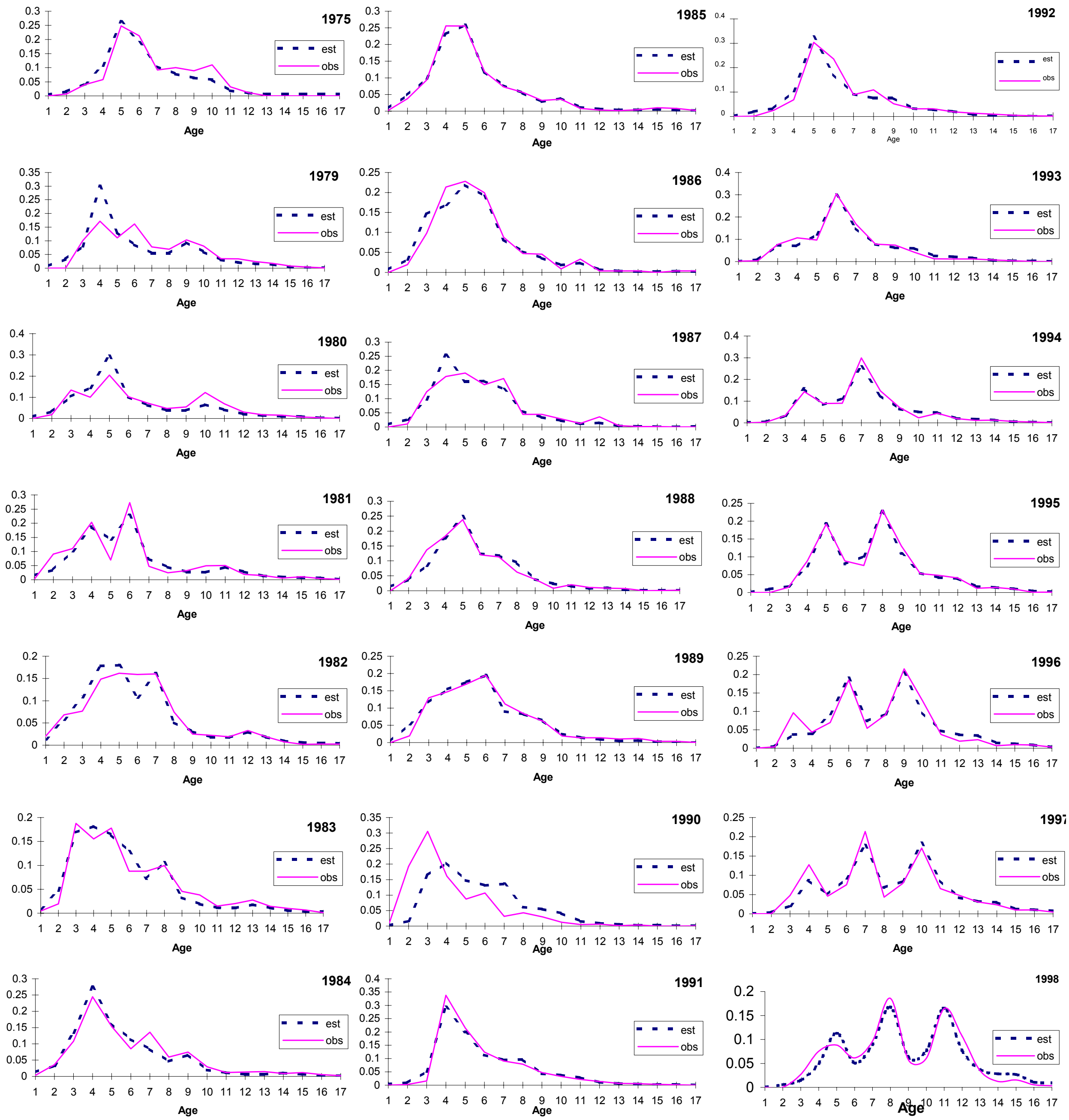
2) Figures showing the fit of the stock assessment model to the time-series of fishery and trawl survey age compositions (survey and fishery observations are the solid lines).

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

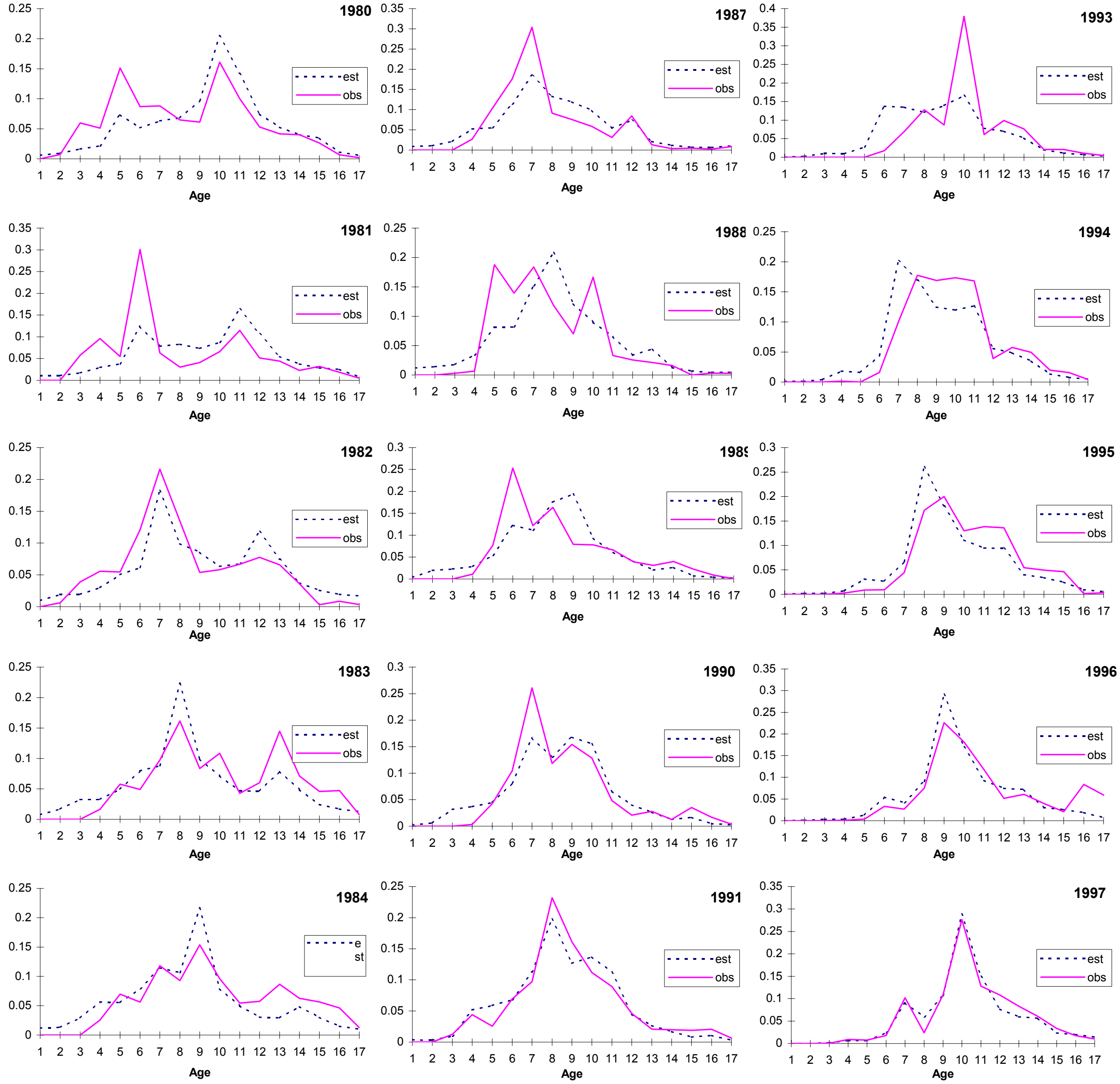
4) Table of total population removals of rock sole from Alaska Fisheries Science Center research activities, 1977-2002.


rock sole, 1st quarter 2001
rock sole catch, 2nd quarter 2001
rock sole catch, 3rd quarter 2001

Fits to the survey age composition



Fits to the fishery age composition



Model estimates of rock sole population numbers-at-age (thousands of fish), 1975-2002.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	283	175	111	112	202	135	73	55	45	41	13	7	4	4	4	4	4	4	4	4
1976	738	236	146	92	93	167	110	59	42	33	29	9	5	3	3	3	3	3	3	5
1977	411	616	197	122	77	77	137	89	46	32	25	22	7	4	2	2	2	2	2	6
1978	612	343	515	165	102	64	64	112	72	37	26	20	17	5	3	2	2	2	2	6
1979	690	511	287	429	137	84	53	52	91	57	29	20	15	13	4	2	1	1	1	6
1980	871	577	427	239	358	114	70	43	43	73	46	23	16	12	10	3	2	1	1	6
1981	1,685	728	481	356	199	298	94	57	35	34	57	36	18	12	9	8	3	1	1	5
1982	1,708	1,407	608	402	297	166	246	77	46	28	27	45	28	14	9	7	6	2	1	5
1983	1,500	1,426	1,175	507	335	246	137	200	62	36	21	20	33	21	10	7	5	5	1	4
1984	2,689	1,253	1,191	980	422	278	203	111	159	48	27	16	15	25	16	8	5	4	4	4
1985	2,147	2,245	1,045	991	813	347	224	157	81	110	32	18	10	10	16	10	5	3	3	5
1986	2,145	1,793	1,874	872	825	674	285	181	124	63	83	24	13	8	7	12	7	4	2	6
1987	3,362	1,791	1,497	1,563	726	684	554	231	143	96	47	62	17	10	6	5	9	5	3	6
1988	5,626	2,807	1,495	1,249	1,302	603	564	451	184	111	73	36	47	13	7	4	4	7	4	7
1989	2,039	4,697	2,343	1,246	1,038	1,074	490	447	343	134	79	51	25	32	9	5	3	3	4	7
1990	1,338	1,703	3,921	1,954	1,037	860	883	396	353	264	101	59	38	18	24	7	4	2	2	9
1991	2,887	1,117	1,422	3,273	1,630	864	713	727	323	284	210	80	46	30	14	19	5	3	2	8
1992	1,257	2,411	933	1,186	2,725	1,351	710	577	574	248	214	157	59	34	22	11	14	4	2	7
1993	605	1,050	2,012	778	988	2,261	1,113	576	458	445	189	161	117	44	26	16	8	10	3	7
1994	1,193	505	876	1,679	648	820	1,864	905	459	357	341	144	122	89	34	19	12	6	8	8
1995	600	996	422	731	1,399	539	678	1,522	727	362	278	264	110	94	68	26	15	10	5	12
1996	371	501	832	352	610	1,164	446	557	1,235	582	287	219	207	87	73	53	20	12	7	13
1997	508	309	418	694	294	508	966	367	453	994	464	228	173	164	68	58	42	16	9	16
1998	251	425	258	349	579	244	420	790	296	359	777	360	176	134	126	53	45	33	12	20
1999	455	210	355	216	291	482	203	347	648	241	290	626	290	142	108	102	42	36	26	26
2000	534	380	175	296	180	243	400	167	284	525	193	232	500	231	113	86	81	34	29	41
2001	813	446	317	146	247	150	201	329	136	228	417	153	183	394	182	89	68	64	27	55
2002	1,060	679	373	265	122	206	125	166	271	111	185	337	123	148	317	147	72	54	51	66

Total catch (t) of rock sole in Alaska Fisheries Science Center research catches in the Bering Sea and Aleutian Islands, 1977-2002.

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