Section 6

ROCK SOLE

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EXECUTIVE SUMMARY

The following changes have been made to this assessment relative to the November 1999 SAFE:

Changes to the input data

1) 1999 fishery age composition.
2) 1999 survey age composition.
3) 2000 trawl survey biomass point estimate and standard error.
4) Estimate of catch (t) and discards through 16, September 2000.
5) Estimate of retained and discarded portions of the 1999 catch.

Assessment results

1) The projected age 2+ biomass for 2001 is 1,938,600 t.
2) The projected female spawning biomass for 2001 is 676,000 t.
3) The recommended 2001 ABC is 227,770 t based on an $F_{40\%}$ (0.158) harvest level.
4) The 2001 overfishing level is 227,770 t based on an $F_{35\%}$ (0.191) harvest level.

SUMMARY

	1999 Assessment Recommendations for the 2000 harvest	2000 Assessment Recommendations for the 2001 harvest
Total biomass	2,073,600 t	1,938,600 t
ABC	229,500 t	227,700 t
Overfishing	272,500 t	270,700 t
F_{ABC}	$F_{0.40} = 0.154$	$F_{0.40} = 0.158$
$F_{overfishing}$	$F_{0.35} = 0.186$	$F_{0.35} = 0.191$

INTRODUCTION

The northern rock sole (Lepidopsetta polyxystra n. sp.) is distributed primarily on the eastern Bering Sea continental shelf and in 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 since 1987 have averaged 49,307 t annually. The size composition of the 1999 catch from observer sampling, by sex and management area, are shown in Figure 6.1.

Rock sole are important as the target of a high value roe fishery occuring in February and March which accounts for the majority of the annual catch. The 1999 catch of 40,510 t was only 13% of the ABC of 309,000 t (34% of the TAC). The 2000 catch total is 48,319 t through September 16. Thus, rock sole remain lightly harvested in the Bering Sea and Aleutian Islands.

During the 2000 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
BS/AI	3/4 - 3/30	First seasonal halibut cap
BS/AI	4/30 - 7/4	Second seasonal halibut cap
BS/AI	8/25 - 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

Since 1987 rock sole have been discarded in greater amounts than they have been retained. Fisheries with the highest discard rates include the rock sole roe fishery, the yellowfin sole, Pacific cod, and the bottom pollock fisheries. Since 1990, retention of rock sole has ranged from 33% in 1993 to 42% in 1996.

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 catch data from 1975-September 16, 2000 (Table 6.1) and fishery catch-at-age numbers from 1980-99 (Table 6.2).

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 the value increased again to 45.92.

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

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 2000 point estimate of the Bering Sea surveyed area is 1,459,900 t - 2,795,500 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. As described in a following section, past recruitment should contribute to a stable stock biomass in the near future.

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 6.3) were used in this assessment to model the population dynamics of the rock sole population and were compared to results obtained from the constant growth model used in past assessments.

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 6.4). 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. 6.3, Table 6.5). 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. For the 1998 and 1999 fishery age compositions, the age-length key was constructed from age structures collected 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 6-6). 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 6-6 presents the key equations used to model the rock sole population dynamics in the Bering Sea and Table 6-7 provides a description of the variables used in Table 6-6. 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. The survey catchability coefficient (q) was set equal to 1.0.

Rock sole maturity schedules were estimated as discussed in section 6.3.4 (Table 6.4).

Parameters Estimated Conditionally

The parameters estimated by the model are presented below:

Fishing mortality	Selectivity	Year class strength	Total
26	4	45	75

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 6-6.

Selectivity

Fishery and survey selectivity were modeled in this assessment using the two parameter formulation of the double logistic function, as shown in Table 6-6. 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 was placed on the catch likelihood component.

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 just over 2% from 1975-2000, indicating a lightly exploited stock. Age-specific selectivity estimated by the model (Table 6.9, Fig. 6.4) 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 indicates that rock sole total biomass was at low levels during the mid 1970s through 1982 (300,000 - 500,000 t, Fig. 6.4 and Table 6.10). From 1982-95, a period characterized by sustained above-average recruitment (1980-88 year classes, Fig. 6.4) and light exploitation, the estimated total biomass rapidly increased at a higher rate to over 2.7 million t by 1995. Since then, the model indicates the population biomass has declined 26% to 2.04 million t in 2000 and is projected at 1,938,600 t for 2001. The female spawning biomass is estimated to be at a high and stable level of 691,000 t in 2000 (Table 6.10). 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 estimate of population numbers at age.

The model estimates of survey biomass (using trawl survey age-specific selectivity applied to the total biomass, Fig. 6.4) closely match the trawl survey biomass trend since 1982. The model corresponds well with the 1993-98 survey biomass trend with the exception of the 1994 and 1997 biomass estimates which were nearly 600,000 t more than the model biomass. The 1999 survey point estimate is 200,000 t less than the model estimate and the 2000 survey estimate is 200,000 t more than the model estimate. Both the trawl survey and the model indicate the same increasing biomass trend from the late 1970s to the mid 1990s and a present high level of abundance.

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 2001. Including the 2000 catch of 48,319 t through 16 September (including discards), the model projects the total biomass for 2001 at **1,938,600** t.

Recruitment Trends

Increases in abundance described earlier for rock sole can be attributed to the recruitment of a series of strong year classes (Fig. 6.4, Table 6.11). Rock sole ages have now been read for samples obtained in 1999 and show the continuing presence of the 1986 and 1987 year classes (Fig. 6.6). The 1990 year class also appears strong, and as 9 year old fish in 1999, 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 19% of the estimated 1999 survey age composition numbers as twelve year old fish. The 1993 year class is estimated to be at a value near the 24 year average.

Spawner-Recruit Relationship

Model estimates of female spawning biomass and the relationship to estimated age 4 recruitment are shown in Figure 6.6. The twenty-one data points were fit with a Ricker (1958) form of spawner-recruit curve. However, estimation of MSY using these data is unreliable and is not recommended for management purposes.

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 the 2000 assessment, the Alaska Fisheries Science Center policy is to use only year classes spawned in 1977 or later to calculate the average equilibrium recruitment. Using the time-series of recruitment from 1978-99 from the stock assessment model results in an estimate of **$B_{0.40}$ = 271,600 t**. The stock assessment model estimates the 2001 level of female spawning biomass at **676,000 t** (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and $B>B_{0.40}$ (676,000 > 271,600), rock sole reference fishing mortality is defined in tier 3a. For the 2001 harvest: $F_{ABC} \leq F_{0.40} = 0.158$and $F_{overfishing} = F_{0.35} = 0.191$ (full selection F values).

Acceptable biological catch is estimated for 2001 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the 2001 estimate of age-specific total biomass as follows:

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

where S_a is the selectivity at age, M is natural mortality, W_a is the mean weight at age from 1998, and n_a is the beginning of the year numbers at age. This results in a **2001 ABC of 227,700** 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. Previous stock assessments used $F_{0.30}$ or the fishing mortality rate which would reduce the spawning biomass per recruit to 30% of its unfished level as the harvest limit. 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	2000 Yield
$F_{0.35}$	0.191	270,700 t
$F_{0.40}$	0.158	227,700 t

BIOMASS PROJECTIONS

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

For each scenario, the projections begin with the vector of 2000 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2001 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2000. 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 2000, 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 2001 recommended in the assessment to the *max* F_{ABC} for 2001. (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 1995-1999 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 2001 and above its MSY level in 2011 under this scenario, then the stock is not overfished.)

Scenario 7: In 2000 and 2001, 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 2013 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.

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 16, 2000.

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			48,319	48,319

Table 6-4.--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

Appendix

1) Observed fishery trawl locations, by quarter, for the 1999 fishing season where rock sole comprised 20% or more of the catch.

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- 2000.

4) Table of total population removals of rock sole from Alaska Fisheries Science Center research activities, 1977-95.