Chapter 7
Northern Rock Sole

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EXECUTIVE SUMMARY

The following changes have been made to this assessment relative to the November 2005 SAFE:

Changes to the input data

1) 2005 fishery age composition.
2) 2005 survey age composition.
3) 2006 trawl survey biomass point estimate and standard error.
4) Estimate of catch (t) and discards through 6, September 2006.
5) Estimate of retained and discarded portions of the 2005 catch.

Assessment results

1) The projected age 2+ biomass for 2007 is 1,674,000 t.
2) The projected female spawning biomass for 2007 is 392,000 t.
3) The recommended 2007 ABC is 121,100 t based on an $F_{40\%}$ (0.144) harvest level.
4) The 2007 overfishing level is 144,000 t based on an $F_{35\%}$ (0.174) harvest level.

	2006 Assessment Recommendations for the 2007 harvest	2005 Assessment Recommendations for the 2006 harvest
Total biomass	1,674,000 t	1,489,600 t
ABC	121,100 t	125,500 t
Overfishing	144,000 t	149,600 t
F_{ABC}	$F_{0.40}$ = 0.144	$F_{0.40}$ = 0.15
$F_{overfishing}$	$F_{0.35}$ = 0.174	$F_{0.35}$ = 0.18
$B_{40\%}$	222,000 t	228,400 t
$B_{35\%}$	194,300 t	199,800 t

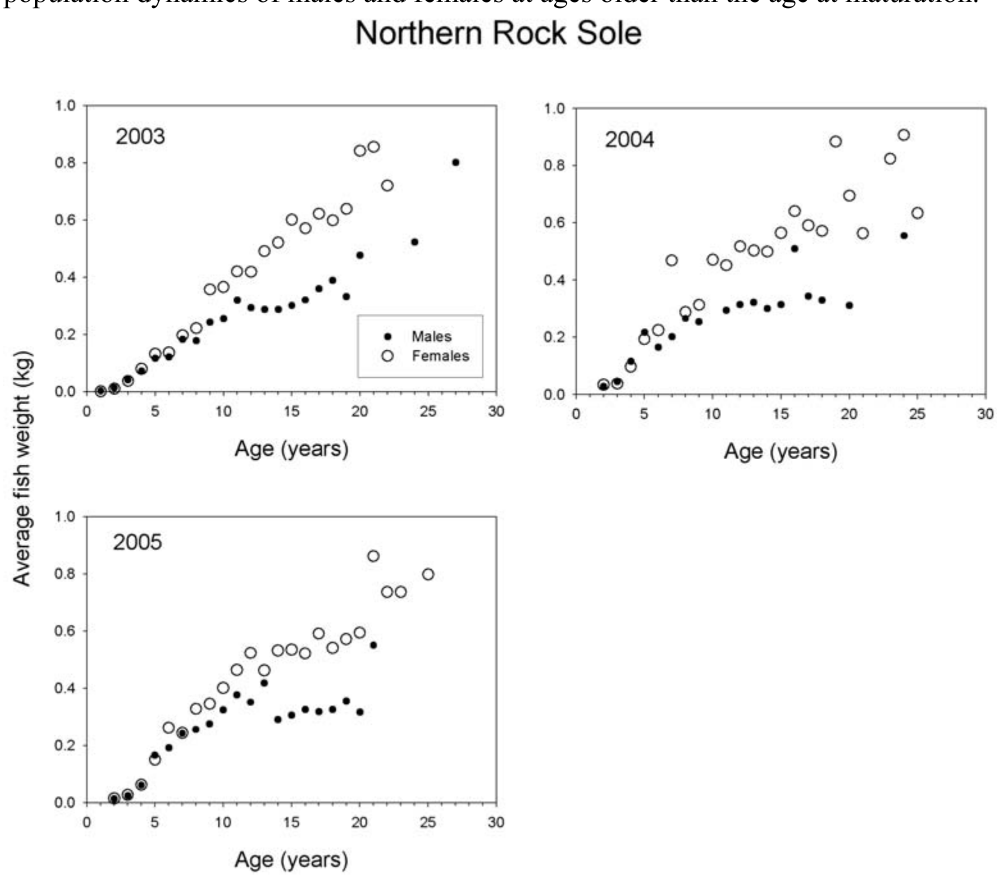
SSC comments from December 2005

The SSC looks forward to seeing the results of the management strategy evaluation to explore the consequences of a non-stationary spawner-recruit relationship.

See Tier 1 considerations section

The age-structured assessment model uses combined sex data but the size composition data shown in the figures suggests sexual dimorphism in growth and sex ratios that differ from 50:50. If there is sexual dimorphism in growth, then size-based selection in the fisheries will generate time-variations in sex ratios that can have important consequences to the stock's productivity. The SSC requests that the authors evaluate whether sex ratios differ from 50:50 and if there have been trends in sex ratio.

Northern rock sole exhibit sexually explicit differences in growth. Instead of implementing a split sex stock assessment model, the weight at age for males and females combined is calculated as the average of their sex-specific weight for each age. Male and female northern rock sole have the same weight-at-age from the juvenile stage until they become sexually mature (age of 50% maturity = 9 years, see figure below). After maturation, when the weights at age diverge, the average is appropriate to calculate population biomass because males and females are found in nearly equal numbers in the shelf trawl surveys (see table below). However, a split sex model is a consideration to improve modeling the population dynamics of males and females at ages older than the age at maturation.



Average weight at age of northern rock sole, by sex, in the population from 2003-2005.

Proportion of male northern rock sole in the population estimated from the past 10 shelf surveys.

year	Proportion male
1997	0.50
1998	0.51
1999	0.54
2000	0.47
2001	0.50
2002	0.47
2003	0.51
2004	0.52
2005	0.54
2006	0.52

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 occupy separate winter (spawning) and summertime feeding distributions on the southeastern Bering Sea 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 - 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 - 2005 (domestic only) have averaged 48,175 t annually. The size composition of the 2006 catch from observer sampling, by sex and management area, are shown in Figure 7.1 and the locations of the 2006 catch are presented for each month 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 (62% in 2006). About 58% of the 2006 catch came from management areas 509 and 513 with the rest from areas 513, 517 and 521. The 2006 catch of 35,907 t comprised 29% of the ABC of 126,000 t (89% of the TAC). Thus, rock sole remain lightly harvested in the Bering Sea and Aleutian Islands.

During the 2006 fishing season rock sole harvesting was temporarily closed in the Bering Sea and Aleutian Islands due to halibut bycatch restrictions on February 21 and April 12 (first and second seasonal apportionments were obtained). On August 7 directed rock sole harvesting was closed due to the attainment of the annual halibut bycatch allowance, after which the species could only be retained as bycatch.

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. Estimates of retained and discarded catch from at-sea sampling for 1987-2005 are shown in Table 7.2. From 1987 to 2000 rock sole were discarded in greater amounts than they were retained, however the past five years there has been increased utilization of the catch. Fisheries with the highest discard amounts include the rock sole roe fishery, the yellowfin sole fishery and the Pacific cod fisheries (shown for 2004 and 2005 in Table 7.3).

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 6, 2006 (Table 7.1) and fishery catch-at-age numbers from 1980-2005 (Table 7.4).

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). Allowing the stock assessment model to fit these early survey estimates would most likely underestimate the true pre-1982 biomass, thus exaggerating the degree to which biomass increased during that period. 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 has been stable with a 2006 value of 47.8 kg/ha..

Absolute Abundance

Estimates of rock sole biomass are also estimated from the AFSC surveys using stratified area-swept expansion of the CPUE data (Table 7.5). It should be recognized that these biomass estimates 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 2006 point estimate of the Bering Sea surveyed area is 1,918,800 t - 2,512,600 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 levels estimated by the trawl survey at 2.9 million metric tons in 1994 and 2.7 million t in 1997. With the exception of the cold year in 1999 when all flatfish biomass estimates declined, the biomass estimates from the trawl survey have exhibited a stable trend since 1997.

The 2006 Aleutian Islands biomass estimate of 77,751 t is 3% of the combined BSAI total. Since it is such a low proportion of the total biomass for this area, the Aleutian Islands biomass is not used in this assessment.

Weight-at-age and Maturity-at-age

In conjunction with the large and steady increase in the rock sole stock size in 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 7.6) were also applied to the populations in 2001-2006 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 7.7). 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 7.8). 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 a separable catch-age analysis that uses survey estimates of biomass and age composition as auxiliary information (Fournier and Archibald 1982). 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 given some distributional assumptions about the data.

The parameters estimated in the stock assessment 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 7-9). 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 7-9 presents the key equations used to model the rock sole population dynamics in the Bering Sea and Table 7-10 provides a description of the variables used in Table 7-9. 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, and estimates of natural mortality and catchability.

Parameters Estimated Independently

Rock sole maturity schedules were estimated independently as discussed in a previous section (Table 7.7) as were length at age and length-weight relationships.

Parameters Estimated Conditionally

The parameters estimated by the model are presented below:

Fishing mortality	Selectivity	Year class strength	Spawner-recruit	catchability	M	Total
32	4	51	2	1	1	91

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 progresses through the population using the population dynamics equations given in Table 7-9.

Selectivity

Fishery and survey selectivity were modeled in this assessment using the logistic function, as shown in Table 7-9. 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.

Natural Mortality

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 twelve more years of fishery and survey age composition data have become available as well as experimental estimates of catchability. This allows for natural mortality to be estimated as a conditional parameter in this assessment.

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 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 earlier 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. As in past assessments we use the value of q from the herding experiment to constrain survey catchabliity and then estimate survey catchabililty as follows:

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

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 = 0.156 (q = 1.52), slightly lower than the value of 0.16 estimated last year. 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 0.2. The log likelihood of the data components and the total log likelihood from these runs are shown below and the posterior probability distributions for M and q (from the model run with the best fit) are shown in Figure 7.5

	M = 0.2	**M = 0.18**	**M = 0.156**	**M = 0.14**	**M = 0.12**	**M =0.1**
Survey biomass likelihood	67.043	52.846	42.875	42.397	51.028	69.59
Catch likelihood	.00108	0.000931	0.0014	0.0024	0.00512	0.0096
Catch age comp likelihood	682.141	674.723	669.257	667.717	667.717	669.342
Survey age comp likelihood	392.868	386.388	386.915	391.447	401.735	414.209
Recruitment likelihood	79.457	77.831	75.923	74.776	73.342	72.178
q likelihood	0.629	0.0798	2.933	7.234	16.68	29.352
q estimate	1.34	1.42	1.52	1.61	1.723	1.83
Ending biomass	1733.67	1647.29	1582.63	1561.21	1559.73	1559.73
Total likelihood	1222.14	1191.869	1177.904	1183.573	1210.508	1254.683

Model Evaluation

The probability of M or q being different than the estimated values from the model run with M = 0.156 and q = 0.152 declines sharply within plus or minus 0.5 of the estimated value (Figure 7.5) indicating that these values are fairly well estimated, given the data. These estimates also provide the best model fit to the observable data. Therefore, a natural mortality rate of 0.156 (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 7.11. The exploitation rate has averaged 3.6% from 1975-2005, indicating a lightly exploited stock. Age-specific selectivity estimated by the model (Table 7.12, Fig. 7.6) indicate that rock sole are 50% selected by the fishery at age of 8 and are nearly 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 (160,000 - 330,000 t, Fig. 7.6 and Table 7.13). 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 over 1.8 million t by 1995. Since then, the model indicates the population biomass declined 25% to 1.41 million t in 2003 before increasing the past three years to 1.58 million t. The decline from 1995-2003 was attributable to the below average recruitment to the adult portion of the population during the 1990s. The increase the past three years is the result of increased recruitment in 2000-2003. The female spawning biomass is estimated to be at a high, but slowly declining level of 416,000 t in 2006 (Table 7.13). 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) correspond fairly well with the trawl survey biomass trend with the exception of the cold year of 1999. The model fits the 2000, 2002 and 2006 survey estimates but does not match the higher estimates from the 2001and 2003-2005 surveys. Although 2006 was a relatively cold year in the eastern Bering Sea, the rock sole biomass estimate increased indicating the lack of a relationship between survey catchability and bottom temperatures, as shown for other flatfish species. 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 after the mid 1990s that the model estimates.

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 2007. Including the 2006 catch of 35,907 t through 6 September (including discards), the model projects the total biomass for 2007 at **1,674,000** t.

Recruitment Trends

Increases in abundance for rock sole during the 1980s can be attributed to the recruitment of a series of strong year classes (Figs. 7.4 and 7.6, Table 7.14). Rock sole ages have now been read for samples obtained in 2005 and show that the 1990 year class, which are 15 year old fish in 2005, comprise a significant part (11%) of the survey and fishery age composition numbers. The 1987 year class is the largest estimated during the recruitment time-series and still comprise 7% of the estimated 2005 survey age composition numbers as eighteen year old fish. Recruitment during the 1990s, with the exception of the 1990 year class, was below the 27 year average but has recently improved as the 2001-2003 year classes appear much stronger as discerned from the 2004 and 2005 survey age samples.

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 (1978-2000) gives values of **F_{MSY}=0.39, B_{MSY}=139,350 t, and MSY = 128,700 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). This trend has continued in recent years where strong-cross shelf advection in 2001-2003 again coincided with strong recruitment (see ecosystem consideration chapter in this SAFE report). 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 was 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, a management strategy simulation study was performed to determine how robust the tier 1 harvest strategy calculations are when fitting the full time series of spawner recruit estimates for a fish stock experiencing temporal changes in reproductive potential due to changing ocean conditions. The simulation study was set up with an operating model which simulated 60 future years of stock and recruitment where a new productivity regime occurred every 15 years alternating between high and low productivity as described above and shown in Figure 7.7 (yellowfin sole s/r from two productivity regimes were used in this simulation). A simulated survey value was produced for each year which incorporated the variability from the changing recruitment productivity schedule. Similarly, survey and fishery age composition "observations" were input into the model for each year. The stock assessment model was then run for each year inside the operating model simulation and re-estimated the spawner recruit time-series (adding a new point each year), fit the Ricker form of the stock recruitment curve to the entire time-series, and calculated MSY and the harmonic mean of F_{MSY} (tier 1 calculations) to set the harvest for the next year. One thousand replicates were made for each year and the results were averaged to compare the "known" population, biomass and recruitment values with those estimated by the stock assessment model. Results indicate a consistent underestimate of the "true" recruitment and spawning biomass by the stock assessment model throughout the 60 year simulation, regardless of the productivity state (Figure 7.8). Thus the Tier 1 harvest control strategy, although it does not explicitly consider environmental change, appears to be robust to underlying changes in stock productivity.

Results from the previous Tier 1 calculations for rock sole indicate that the harmonic mean of the F_{MSY} estimate is very close to the geometric mean value of the F_{MSY} estimate due to the low variability in the parameter estimates. This indicates that the previous analysis was performed with very little uncertainty. To better understand how uncertainty in specific parameter estimates affects the Tier 1 harvest policy calculations for rock sole, the following analysis was undertaken. Selectivity, catchability and M were selected as important parameters whose uncertainty may directly affect the pdf of the estimate of F_{MSY}. Eleven different model configurations were chosen to illustrate the effect of a range of uncertainly in these parameter estimates (varying from small to large (0.03, 0.4 and 0.8)) and how they affect the estimate of the harmonic mean of F_{MSY}.

The analysis provided the following results (Table 7.15). The values of F_{MSY}, B_{MSY} and MSY are dependent on the years of stock size and recruitment selected to be fit by the model (Models 1-3). Using the full time-series (1978-2001, Model 1, Fig. 7.9) to fit the spawner-recruit curve indicates that the rock sole stock is most productive at a smaller stock size with the result that the F_{MSY} value is more than twice as high as the $F_{40\%}$. value (recall that $F_{40\%}$ = 0.156). When the 1989-2001 years are fit (Model 2), the F_{MSY} value is less than twice the $F_{40\%}$ value but only 12 data points are used to discern this relationship. Model 3 fit the 1978-88 data and resulted in an unrealistic high value for B_{MSY} (4.24E+13). Using the estimates of recruitment and stock size from 1978-2001 as the basis for the spawner-recruit relationship (Model 1), uncertainty was introduced for the estimates of selectivity (Models 4and 5), catchability (Models 6 and 7) and natural mortality (Models 8 and 9). Model 10 incorporated high uncertainty in estimating q, M and selectivity. Adding uncertainty to selectivity resulted in the largest difference between the geometric mean and the harmonic mean of the estimate of F_{MSY} for these Model runs, but the introduced uncertainty only resulted in a 5% reduction. Similarly, the addition of uncertainty in estimating catchability and natural mortality resulted in a 1-2% reduction for the estimate of the harmonic mean (Models 6-9). Thus F_{MSY} appears to be well estimated by the model. The posterior distributions of F_{MSY} from the 10 model runs are shown in the Appendix.

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 for Tier 3 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 2001 are used to calculate the average equilibrium recruitment. This results in an estimate of **$B_{0.40}$ = 222,000 t**. The stock assessment model estimates the 2007 level of female spawning biomass at **392,000 t** (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and B>$B_{0.40}$ (392,000 > 222,000, fig. 7.6), rock sole reference fishing mortality can be defined in tier 3a. For the 2007 harvest: F_{ABC} ◂ $F_{0.40}$ = 0.144 and $F_{overfishing} = F_{0.35}$ = 0.174 (full selection F values).

The Tier 3 acceptable biological catch is estimated for 2007 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the 2007 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 determined from recent surveys, and n_a is the beginning of the year numbers at age. This results in a Tier 3a **2007 ABC of 121,100** 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	2007 Yield
$F_{0.35}$	0.174	144,000 t
$F_{0.40}$	0.144	121,100 t

The time series of rock sole fishing mortality rates and female spawning biomass relative to $B_{40\%}$ and $F_{40\%}$ are shown in figure 7.8.

Alternatively, ABC can be calculated using Tier 1 methodology depending on whether the SSC determines that rock sole are in Tier 1 or Tier 3. It is critical for the Tier 1 calculations to identify which subset of the stock recruitment data is used. Using the full time series to fit the spawner recruit curve estimates that the stock is most productive at a small stock size. Thus MSY and F_{MSY} are high values and B_{MSY} is a low value. If the stock was productive in the past at a small stock size because of non density dependent factors (environment), reducing the stock size to low levels could be detrimental to the long-term sustainability of the stock if the environment has changed from the earlier period. Since observations of rock sole recruitment at low stock sizes are not available from multiple time periods, it is uncertain if future recruitment events at low stock conditions would be as productive as during the late 1970s when the stock is estimated to have been at very low levels. The alternative data set to consider would be the model which uses 1989-2001, a period of high productivity, but it results in values of MSY, F_{MSY} and B_{MSY} that are similar to the full data set, but fits only 12 data points.

Therefore it seems acceptable to select the 1978-2001 data set for the Tier 1 harvest recommendation (Model 1 in Table 7.15) where $F_{\text{harmonic mean}}$ = 0.383 which gives a Tier 1 ABC harvest recommendation of **197,600 t** and OFL value of 199,800 t
.
Depending on which stock recruitment subset is used for the Tier 1 calculations, significantly different stock recruitment relationships are found. These results illustrate the non-stationarity of stock-recruitment relationships for Bering Sea rock sole and bring into question whether a single stock recruit curve can adequately define the dynamics of the stock. Therefore, this assessment recommends retaining rock sole in Tier 3.

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 2006 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2007 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2006. 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 2007, are as follows ("*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 2007 recommended in the assessment to the *max* F_{ABC} for 2006. (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 75% 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 2002-2006 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 2007 and above its MSY level in 2017 under this scenario, then the stock is not overfished.)

Scenario 7: In 2007 and 2008, *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 2019 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 7.16 indicate that rock sole are currently not overfished and are not approaching an overfished condition. If harvested at the average F from 2002-2006, rock sole female spawning biomass is projected to decline through 2007 due to the reduced recruitment observed during the 1990s (fig. 7.9), but slowly increase thereafter.

Scenario Projections and Two-Year Ahead Overfishing Level

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2007, it does not provide the best estimate of OFL for 2008, because the mean 2008 catch under Scenario 6 is predicated on the 2007 catch being equal to the 2007 OFL, whereas the actual 2007 catch will likely be less than the 2007 ABC. Therefore, the projection model was re-run with the 2007 catch fixed equal to the 2006 catch and the 2008 fishing mortality rate fixed at F_{ABC}.

Tier 3a

Year	Catch	ABC	OFL
2007	35,907	121,100	144,400
2008	35,907	127,600	152,000

Tier 1

Year	Catch	ABC	OFL
2007	35,900	197,600	199,800
2008	35,900	268,400	271,400

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 1991-2005 in Table 7.17. The rock sole target fishery contribution to the total bycatch of prohibited species is shown for 2003 and 2004 in Table 13 of the Economic SAFE (Appendix C) and is summarized for 2004 as follows:

Prohibited species	Rock sole fishery % of total bycatch
Halibut mortality	13
Herring	<1
Red King crab	40
C. bairdi	19
Other Tanner crab	9
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 the 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

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Table 7.1--Rock sole catch (t) from 1977 - September 3, 2006.

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		11,843
1983	4,479	9,140		13,619
1984	10,156	27,523		37,679
1985	6,671	12,079		18,750
1986	3,394	16,217		19,611
1987	776	11,136	28,910	40,822
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			59,606	59,606
1995			58,870	58,870
1996			46,928	46,928
1997			67,564	67,564
1998			33,642	33,642
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
2005			35,546	35,456
2006			35,907	35,907

Table 7.2 Retained and discarded catch (t) in Bering Sea fisheries, 1987-2005.

Year	Retained (t)	Discarded (t)	% Retained
1987	14,209	14,701	49
1988	22,374	23,148	49
1989	23,544	24,358	49
1990	12,170	12,591	49
1991	25,406	35,181	42
1992	21,317	35,681	37
1993	22,589	45,669	33
1994	20,951	39,945	34
1995	21,761	33,108	40
1996	19,770	27,158	42
1997	27,743	39,821	41
1998	12,645	20,999	38
1999	15,224	25,286	38
2000	22,151	27,113	45
2001	19,299	9,956	66
2002	23,607	17,724	57
2003	19,492	15,903	55
2004	26,600	21,037	56
2005	23,172	12,376	65

Table 7.3--Discarded and retained rock sole catch (t), by target fishery, in 2004 and 2005.

2004

target fishery	Retained	Discarded	total
Atka mackerel	36	113	149
Bottom pollock	209	38	248
Pacific cod	2,601	6,563	9,163
Mid-water pollock	1,330	924	2,254
Sablefish	1	0	1
Rockfish	4	3	7
Arrowtooth flounder	16	31	48
Flathead sole	999	982	1,981
Rock sole	15,655	8,138	23,793
Yellowfin sole	5,696	4,167	9,863
Greenland turbot	0	1	1
Other flatfish	51	39	91
Other species	0	37	38
Total catch			47,637

2005

	Retained	Discarded	Total
Atka mackerel	81	69	151
Bottom pollock	52	28	80
Pacific cod	2,778	4,787	7,565
Mid-water pollock	491	499	990
Sablefish	1	0	1
Rockfish	0	2	2
Arrowtooth flounder	101	36	136
Flathead sole	570	545	1,114
Rock sole	13,300	2,559	15,858
Yellowfin sole	5,779	3,817	9,596
Greenland turbot	0	0	0
Other flatfish	18	32	51
Other species	0	0	0
halibut	0	2	2
Total catch			35,546

Table 7.4--Estimated catch numbers at age, 1980-2005 (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	569	7,095	17,519	43,623	19,745	25,802	21,485	8,065	3,480	4,652	2,125	5,873	2,778	619	653	251	2,962
1991	0	17	2,070	7,347	4,299	11,621	16,246	38,753	26,932	18,717	14,944	7,697	3,506	3,306	3,147	3,456	1,069	685	0	1,636
1992	0	0	213	1,140	10,282	10,398	16,467	39,737	36,568	15,713	25,937	13,201	5,199	6,262	2,841	251	7,016	638	599	792
1993	0	0	0	0	0	2,621	10,046	18,636	12,667	55,180	8,881	14,414	11,065	3,057	3,057	1,602	713	1,165	1,456	728
1994	0	0	0	220	0	2,513	15,670	27,688	26,393	27,048	26,221	6,103	9,006	7,710	3,106	2,482	702	109	1,124	0
1995	0	0	0	278	1,016	1,071	5,169	20,036	23,284	15,123	16,136	15,810	6,368	5,775	5,388	154	361	382	0	0
1996	0	0	70	136	603	5,731	4,648	13,106	39,491	31,768	20,515	8,982	10,607	6,972	3,612	14,601	10,374	3,119	70	340
1997	0	5	63	921	771	1,818	10,182	2,407	10,862	27,650	12,801	10,822	8,301	6,026	3,384	1,770	1,014	670	0	0
1998	0	0	0	0	327	407	1,463	6,152	5,359	12,305	38,008	19,060	8,075	7,857	3,073	1,422	1,992	1,378	135	284
1999	0	0	0	0	1,502	1,441	3,751	2,157	16,219	7,867	16,211	47,256	15,150	7,595	8,037	1,507	454	604	100	779
2000	0	0	0	0	181	576	1,112	1,953	5,007	15,523	5,520	7,113	19,195	7,749	4,090	2,404	1,523	297	596	94
2001	0	0	0	0	1,427	2,792	3,663	5,206	5,126	10,033	21,838	9,366	10,438	16,627	9,196	2,628	2,415	636	282	376
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	1,365	1,405	3,217	4,974	4,453	5,317	7,538	4,608	10,066	13,806	5,873	6,967	8,285	5,536	1,903	1,057	1,564
2004	0	0	0	0	2,489	5,398	2,756	6,019	8,048	4,302	13,435	6,521	9,116	19,303	6,603	2,438	13,094	5,326	2,718	3,473
2005	0	0	366	1,870	4,143	3,331	5,551	2,519	5,612	8,892	4,927	6,237	4,576	6,694	9,396	5,110	4,481	6,356	2,636	3,534

Table 7.5 Bottom trawl survey biomass estimates (t) from the Eastern Bering Sea shelf and the Aleutian Islands for northern rock sole.

year	Bering Sea	Aleutians
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
2005	2,119,100	
2006	2,215,670	77,751

Table 7-6 --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 7-7.--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	6.7	0
2	10.8	0.006
3	15.4	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 7.8--Estimated population numbers-at-age (millions) from the annual Bering Sea trawl surveys, 1982- 2005.

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
2004	0	761	2,360	1,194	751	464	198	549	260	109	616	324	228	611	146	107	501	358	4	105
2005	0	450	2,511	2,395	1,622	349	479	327	403	133	162	152	115	477	316	234	274	433	230	201

Table 7.9--Key equations used in the population dynamics model.

$N_{t,1} = R_t = R_0 e^{\tau_t}, \quad \tau_t \sim N(0,\delta^2{}_R)$	Recruitment 1956-75
$N_{t,1} = R_t = R_\gamma e^{\tau_t}, \quad \tau_t \sim N(0,\delta^2{}_R)$	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*
$F_{t,a} = s_a \mu^F \exp^{\varepsilon^F{}_t}, \quad \varepsilon^F{}_t \sim N(o,\sigma^{2_F})$	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 7.10--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
v_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 7.11--Model estimates of rock sole fishing mortality and exploitation rate (catch/total biomass).

year	Full selection F	Exploitation rate
1975	0.183	0.075
1976	0.137	0.059
1977	0.063	0.029
1978	0.072	0.035
1979	0.054	0.026
1980	0.074	0.034
1981	0.070	0.030
1982	0.098	0.036
1983	0.096	0.032
1984	0.244	0.078
1985	0.101	0.033
1986	0.085	0.028
1987	0.131	0.042
1988	0.236	0.078
1989	0.164	0.058
1990	0.070	0.029
1991	0.108	0.048
1992	0.096	0.044
1993	0.087	0.041
1994	0.072	0.036
1995	0.056	0.032
1996	0.044	0.027
1997	0.062	0.040
1998	0.029	0.020
1999	0.035	0.025
2000	0.041	0.031
2001	0.025	0.019
2002	0.036	0.028
2003	0.033	0.025
2004	0.047	0.033
2005	0.037	0.024
2006		0.023

Table 7.12 --Model estimates of rock sole age-specific fishery and survey selectivities.

Age	Fishery (1980-2005)	Survey (1982-2005)
1	0.00	0.01
2	0.00	0.07
3	0.01	0.31
4	0.03	0.73
5	0.07	0.94
6	0.15	0.99
7	0.30	1.00
8	0.51	1.00
9	0.72	1.00
10	0.86	1.00
11	0.94	1.00
12	0.97	1.00
13	0.99	1.00
14	0.99	1.00
15	0.99	1.00
16	0.99	1.00
17	0.99	1.00
18	0.99	1.00
19	0.99	1.00
20	0.99	1.00

Table 7-13.--Model estimates of rock sole age 2+ total biomass (t) and female spawning biomass (t) from the 2005 and 2006 assessments.

	2006 Assessment		2005 Assessment	
	Age 2+ Total biomass	Female Spawning biomass	Age 2+ Total biomass	Female Spawning biomass
1975	160,817	27,848	166,861	28,832
1976	167,951	30,076	174,053	31,134
1977	178,839	33,742	184,969	34,870
1978	200,139	39,175	206,361	40,343
1979	225,700	43,817	232,018	44,974
1980	259,326	48,558	265,684	49,662
1981	297,975	52,852	304,269	53,879
1982	332,107	50,108	338,300	50,906
1983	430,971	58,123	437,949	58,848
1984	480,610	67,142	487,474	67,731
1985	562,836	75,108	570,795	75,550
1986	707,629	91,285	717,432	91,506
1987	970,799	124,181	980,323	122,955
1988	1,100,660	151,037	1,129,070	153,761
1989	1,193,690	168,745	1,250,680	178,239
1990	1,196,070	194,195	1,275,390	211,603
1991	1,274,350	223,071	1,324,550	233,235
1992	1,300,510	236,212	1,351,000	246,572
1993	1,544,380	296,538	1,590,060	305,326
1994	1,633,760	330,768	1,682,820	341,168
1995	1,828,790	427,806	1,882,750	441,283
1996	1,746,090	424,934	1,801,140	439,875
1997	1,674,820	447,120	1,699,090	453,401
1998	1,645,320	474,604	1,698,000	491,680
1999	1,597,300	494,626	1,632,550	507,024
2000	1,571,670	512,966	1,589,040	519,762
2001	1,521,480	517,297	1,550,680	529,498
2002	1,458,840	507,435	1,464,900	512,040
2003	1,406,200	480,927	1,412,190	482,592
2004	1,432,080	463,318	1,434,280	462,144
2005	1,502,560	443,759	1,489,600	439,752
2006	1,582,630	416,440		

Table 7.14--Estimated age 4 recruitment of rock sole (thousands of fish) from the 2005and 2006 assessments.

Year class	2006 Assessment	2005 Assessment
1971	98,808	103,394
1972	81,991	85,659
1973	110,582	115,024
1974	152,144	157,486
1975	402,202	414,711
1976	227,282	233,752
1977	344,873	353,351
1978	395,694	403,688
1979	504,458	513,323
1980	972,309	991,091
1981	977,751	1,004,120
1982	849,637	880,221
1983	1,504,390	1,567,640
1984	1,213,520	1,269,970
1985	1,205,890	1,265,990
1986	1,947,190	2,039,130
1987	3,324,650	3,476,670
1988	1,229,230	1,269,080
1989	889,434	908,157
1990	1,980,720	2,065,460
1991	930,758	942,572
1992	482,322	492,312
1993	839,262	884,285
1994	408,186	414,131
1995	405,161	378,866
1996	560,748	576,643
1997	263,701	256,290
1998	438,617	388,800
1999	528,293	547,629
2000	1,216,100	
2001	2,607,450	

Table 7.15. Results of the northern rock sole Tier 1 analysis from 10 models that use different levels of uncertainty in the estimates of fishery selectivity, natural mortality and catchability. Values that change between runs are highlighted.

	Years used in S/R fit	Selectivity CV	q sigma	M sigma	F_{MSY}	Harmonic mean of F_{MSY}
Model 1	1978-2001	0.03	0.056	0.05	0.389	0.383
Model 2	1989-2001	0.03	0.056	0.05	0.259	0.236
Model 3	1978-1988	0.03	0.056	0.05	0.296	0.292
Model 4	1978-2001	0.4	0.056	0.05	0.389	0.380
Model 5	1978-2001	0.8	0.056	0.05	0.389	0.371
Model 6	1978-2001	0.03	0.4	0.05	0.409	0.403
Model 7	1978-2001	0.03	0.8	0.05	0.410	0.404
Model 8	1978-2001	0.03	0.056	0.3	0.389	0.383
Model 9	1978-2001	0.03	0.056	0.8	0.389	0.383
Model 10	1978-2001	0.8	0.8	0.8	0.410	0.392

Table 7.16--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. 2006 ABC is highlighted.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spwn bio	catch	F
2006	409.799	35.900	0.040
2007	391.995	121.100	0.144
2008	370.523	117.853	0.144
2009	368.124	122.110	0.144
2010	378.314	129.935	0.144
2011	389.427	135.435	0.144
2012	391.953	135.495	0.144
2013	380.380	129.328	0.144
2014	361.696	120.888	0.144
2015	347.258	114.815	0.144
2016	334.407	110.020	0.144
2017	318.685	104.910	0.144
2018	301.192	99.756	0.144
2019	292.282	96.737	0.144

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spwn bio	catch	F
2006	409.799	35.900	0.040
2007	394.195	60.550	0.070
2008	396.874	24.445	0.027
2009	426.340	27.144	0.027
2010	466.779	30.591	0.027
2011	511.034	33.876	0.027
2012	548.241	36.169	0.027
2013	570.615	37.035	0.027
2014	582.281	37.096	0.027
2015	595.952	37.405	0.027
2016	606.284	37.647	0.027
2017	601.363	37.115	0.027
2018	586.366	36.093	0.027
2019	584.789	35.897	0.027

Scenario 4
Harvest at average F over the past 5 years

Year	Female spwn bio	catch	F
2006	409.799	35.900	0.040
2007	394.841	42.100	0.048
2008	402.762	62.796	0.069
2009	417.972	67.517	0.069
2010	444.325	74.019	0.069
2011	473.133	79.783	0.069
2012	493.855	82.891	0.069
2013	499.836	82.568	0.069
2014	496.153	80.540	0.069
2015	495.130	79.323	0.069
2016	492.678	78.260	0.069
2017	479.671	75.915	0.069
2018	460.520	72.872	0.069
2019	452.602	71.574	0.069

Scenario 5
No fishing

Year	Female spwn bio	catch	F
2006	409.799	0	0
2007	396.276	0	0
2008	421.079	0	0
2009	458.148	0	0
2010	506.550	0	0
2011	560.312	0	0
2012	607.885	0	0
2013	641.272	0	0
2014	663.967	0	0
2015	688.732	0	0
2016	709.266	0	0
2017	711.232	0	0
2018	700.412	0	0
2019	705.191	0	0

Table 7.16—continued.

Scenario 6

Determination of whether rock sole are currently overfished **B35=194.3**

Year	Female spwn bio	catch	F
2006	409.799	35.900	0.040
2007	391.114	144.372	0.174
2008	360.949	137.469	0.174
2009	352.326	140.307	0.174
2010	357.249	147.533	0.174
2011	362.923	151.774	0.174
2012	360.225	149.668	0.174
2013	344.320	140.708	0.174
2014	322.569	129.701	0.174
2015	306.083	121.807	0.174
2016	292.176	115.948	0.174
2017	276.897	110.122	0.174
2018	261.066	104.472	0.174
2019	252.788	98.635	0.169

Scenario 7

Determination of whether rock sole are approaching an overfished condition **B35=194.3**

Year	Female spwn bio	catch	F
2006	409.799	35.900	0.040
2007	391.994	121.110	0.144
2008	370.526	117.853	0.144
2009	367.392	145.788	0.174
2010	369.708	152.113	0.174
2011	373.432	155.670	0.174
2012	369.296	153.071	0.174
2013	352.970	144.024	0.174
2014	331.286	133.224	0.174
2015	315.065	125.662	0.174
2016	301.609	119.915	0.174
2017	285.503	112.460	0.171
2018	269.487	104.216	0.166
2019	261.707	100.051	0.163

Table 7.17—Catch and bycatch in the rock sole target fisheries, 1991-2004, from blend of regional office reported catch and observer sampling.

Species	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003*	2004	2005
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	8,937	7,240
Arrowtooth Flounder	254	473	1,143	1,782	507	1,341	411	300	69	216	835	314	419	346	599
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	5,648	5,192
Groundfish, General	1,693	3,000	3,091	3,266	1,605	1,581	1,381	909	537	1,186	1,198	692	978	801	910
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	24,287	16,667
Flathead Sole			2,140	1,702	1,147	1,302	2,373	1,223	575	1,806	1,051	771	744	881	850
Sablefish	9	0	4	16	3	3	1	0	2	5	12	4	2	9	4
Atka Mackerel	3	10	15	0		0	0	9	0	38	3	0	1	16	48
Pacific Ocean Perch	37	10	15	62	4	2		1	0	0	0	0			
Rex Sole			79	145	108	48	11	12	5	4	18	7			
Flounder, General	2,610	4,550	2,221	2,756	1,636	1,591	1,498	342	362	1,184	726	307	783	820	937
Squid		0	0	0							0				
Dover Sole				0											
Thornyhead				8											
Shortraker/Rougheye	8	0	2	21				1							
Butter Sole			38	11	1	5	79	53	38	156	72	94			
Unsp. pelagic rockfish				5											
Rougheye Rockfish			0		0										
Starry Flounder			230	85	0	1	99	72	34	214	152	329			
Northern Rockfish				29					2			1			

Dusky Rockfish						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	3,888	7,579
English Sole			1							0					
Black Rockfish			4												
Greenland Turbot	1	3	28	50	3	3	2	1	0	1	15	0	1	4	1
Alaska Plaice			2,561	931	173	71	408	250	63	385	75	621	375	1,111	1,352
Sculpin, General										9	2	271			
Skate, General										1	5	306			
Sand Sole					4	1	122	17			10	25			
Greenstriped Rockfish									0						
Copper Rockfish												1			
Rockfish, General	0	0		0	5	1	0	1	0	15	4				
Octopus										1		0			
Chilipepper										13					
Eels											0	0			
Lingcod							1			0					
Lumpsucker			26												
Jellyfish (unspecified)										27	68	80			
Snails										0	1				
Sea cucumber			105								0				
Korean horsehair crab										0					
Pacific sandfish										0					

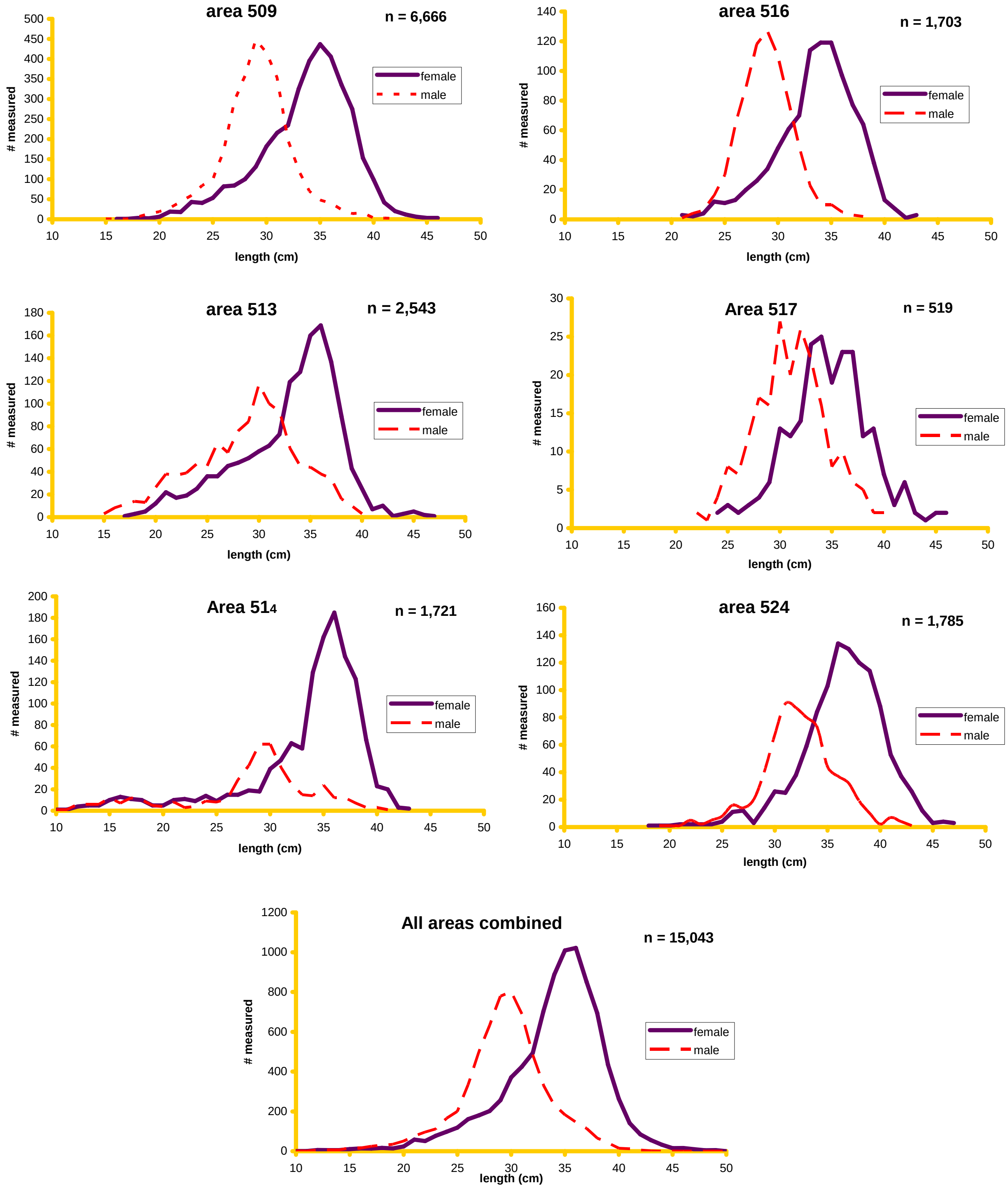
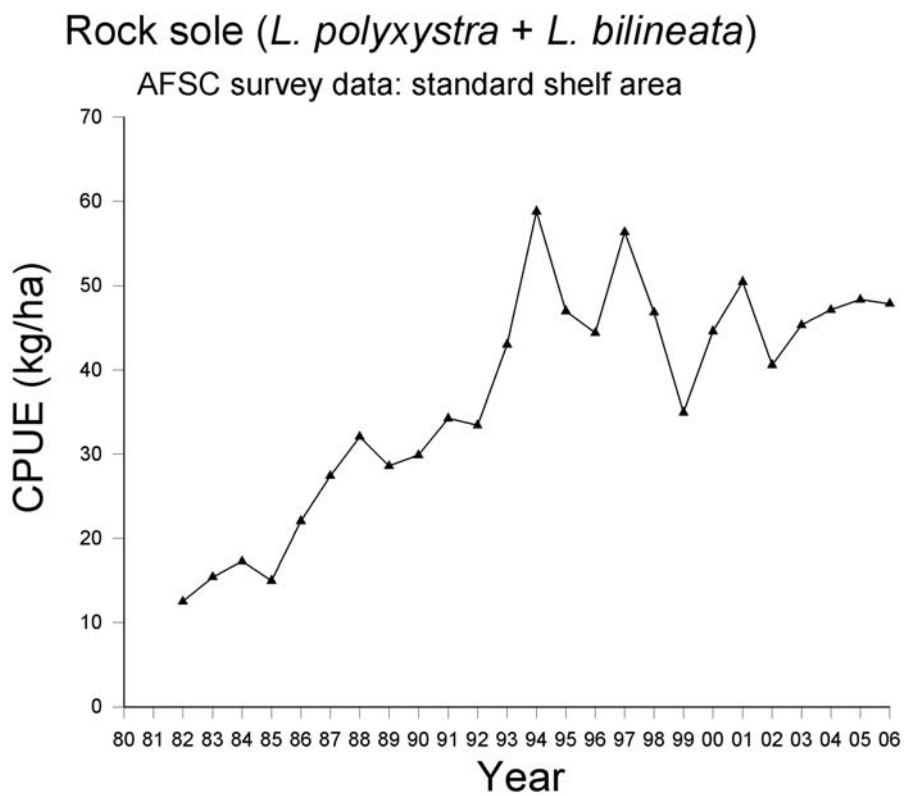


Figure 7.1—Size composition of rock sole, by sex and area, in the 2006 catch as determined from observer sampling.


Rock sole (L. polyxystra + L. bilineata)
AFSC survey data: standard shelf area
CPUE (kg/ha)
70
60
50
40
30
20
10
0
80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06
Year

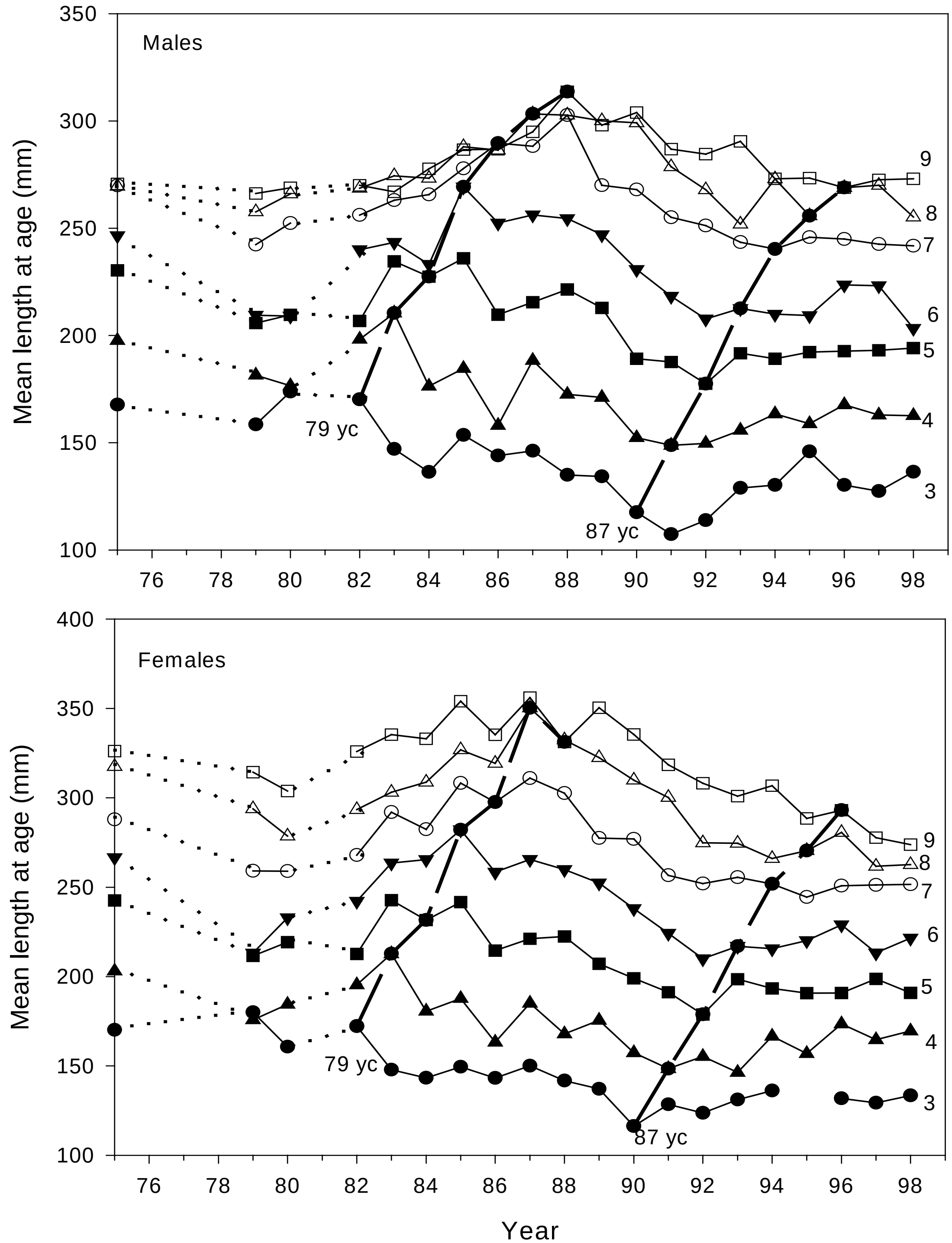


Fig. 7.3. Mean lengths at age (mm) by year of survey for eastern Bering Sea northern rocksole ages 3-9 for each sex during 1975-1998. Growth curves are shown for the 1979 (79yc) and 1987 (87yc) year classes. Dotted lines indicate no data during the period.
(From Walters and Wilderbuer, 2000, p.20)

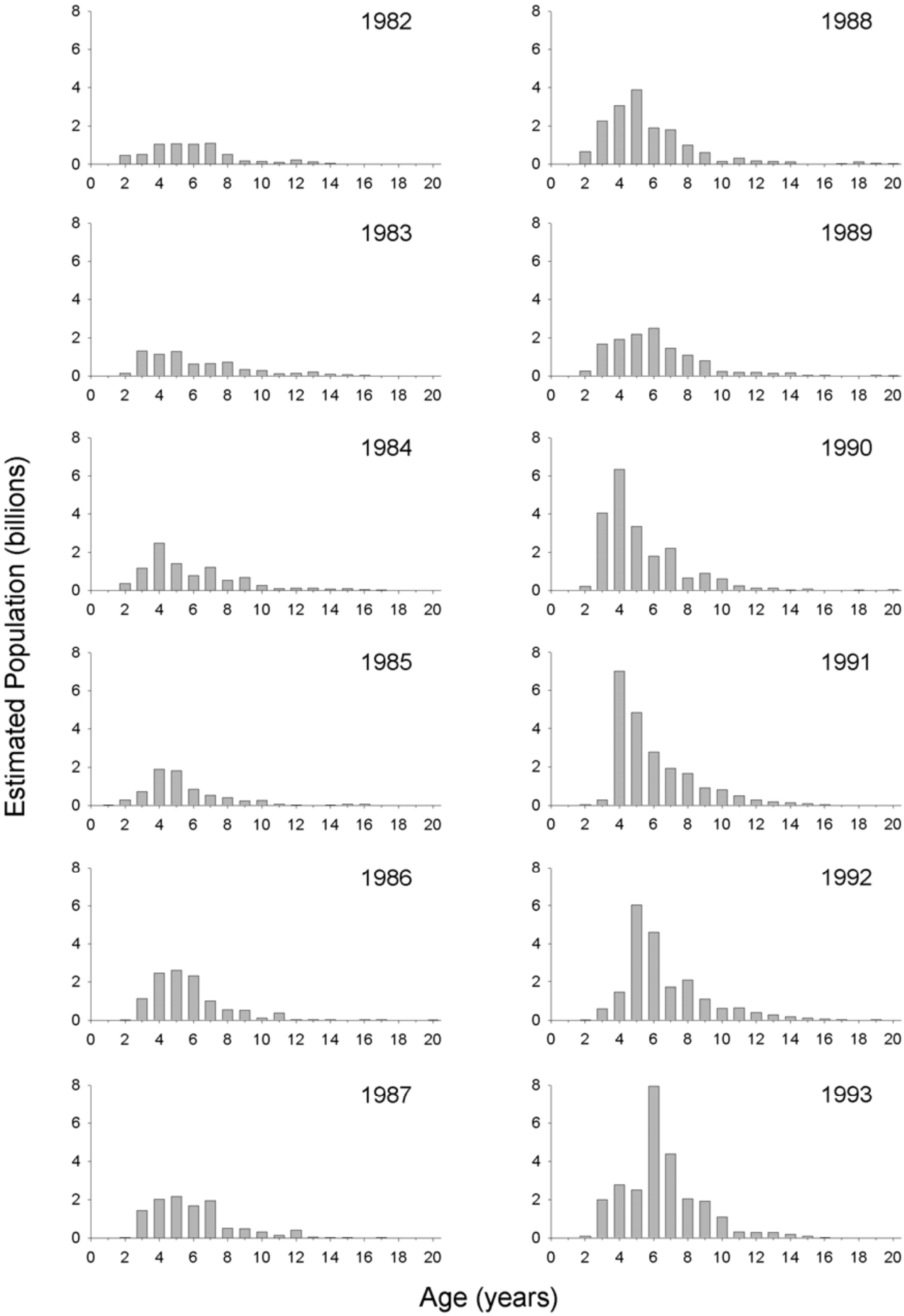


Figure 7.4—Age composition of northern rock sole from the AFSC annual trawl survey.

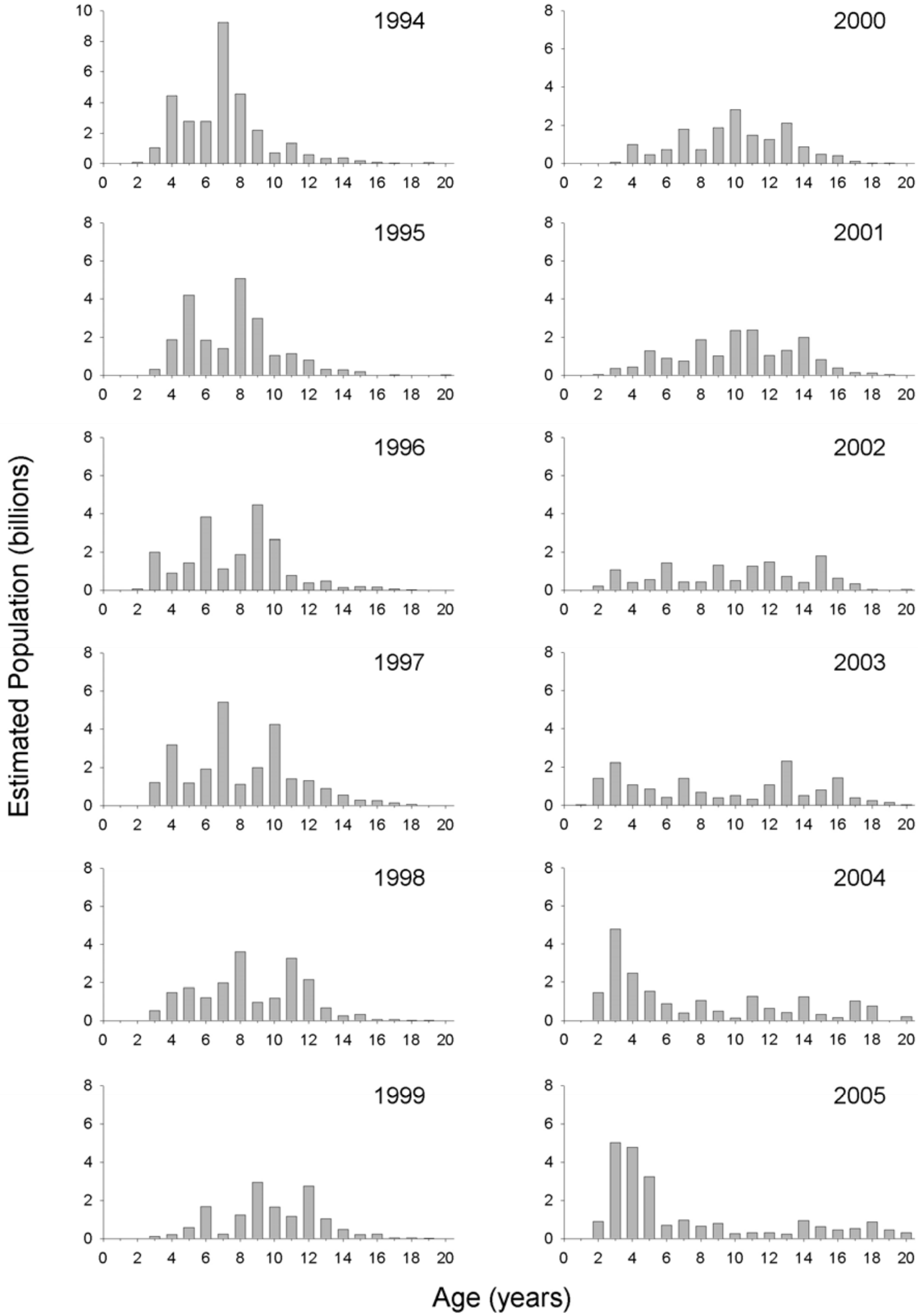


Figure 7.4--continued.

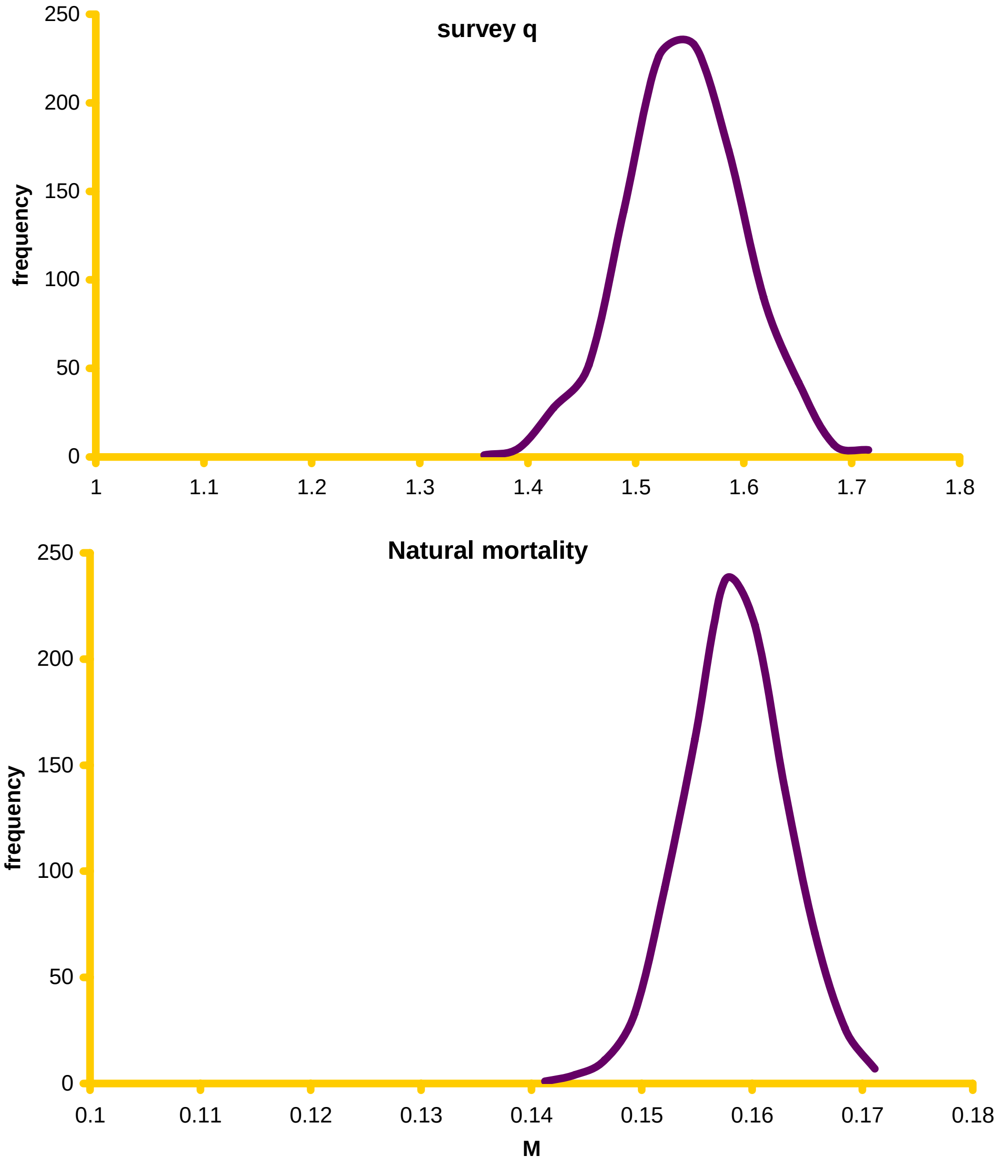


Figure 7.5—Posterior distributions of catchability (top panel) and natural mortality (bottom panel) from a thinned chain of 1,000 results from 1 million MCMC runs of the model with the best fit to all the observed data with natural mortality estimated as a free parameter and catchability estimated with a contraint from the results of a herding experiment.

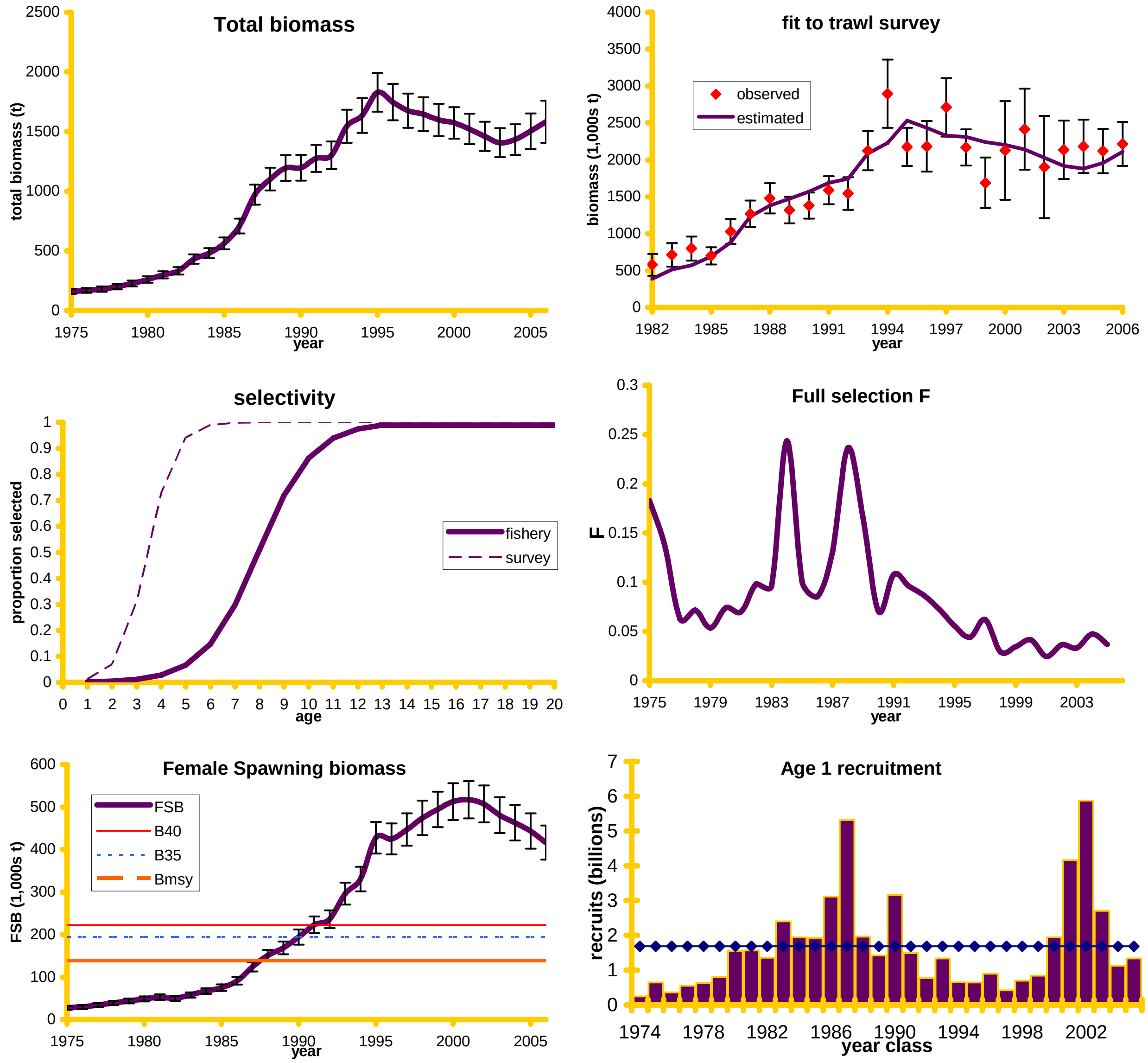


Figure 7.6--Stock assessment model estimates of total 2+ biomass (top left panel), fit to trawl survey biomass (top right panel), age-specific fishery and survey selectivity (middle left panel) and average annual fishing mortality rate (middle right panel), female spawning biomass (bottom right panel)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

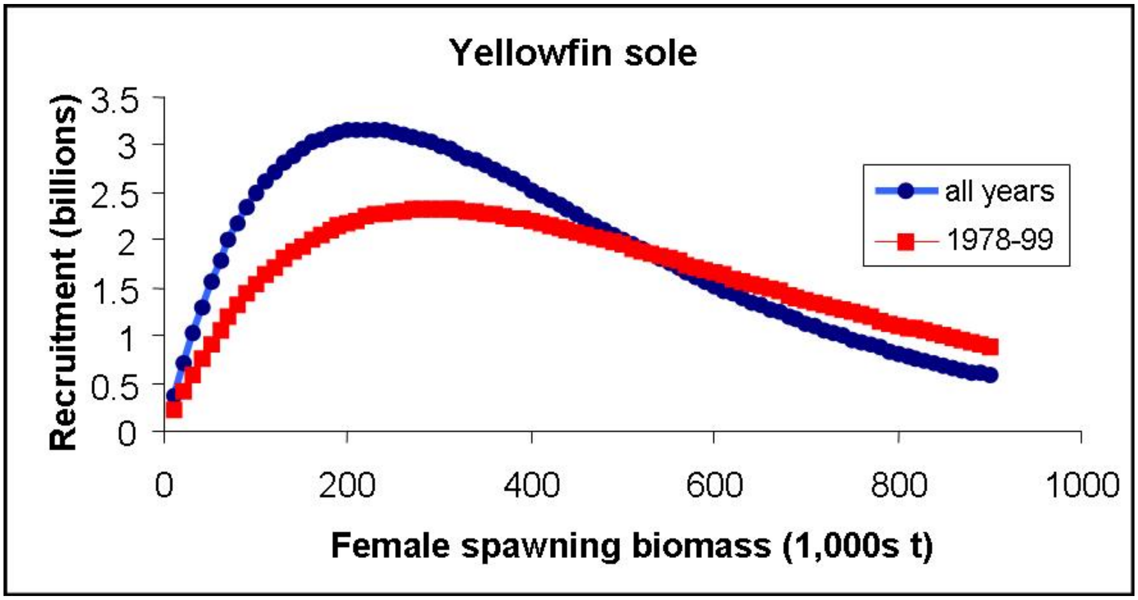


Figure 7.7. Ricker curve fit to yellowfin sole female spawning biomass-age 2 recruitment numbers for two productivity regimes: 1954-99 (all years, red line and open circles) and 1978-99. These estimates provided the foundation for initial simulation trials for underlying "true" operational model.

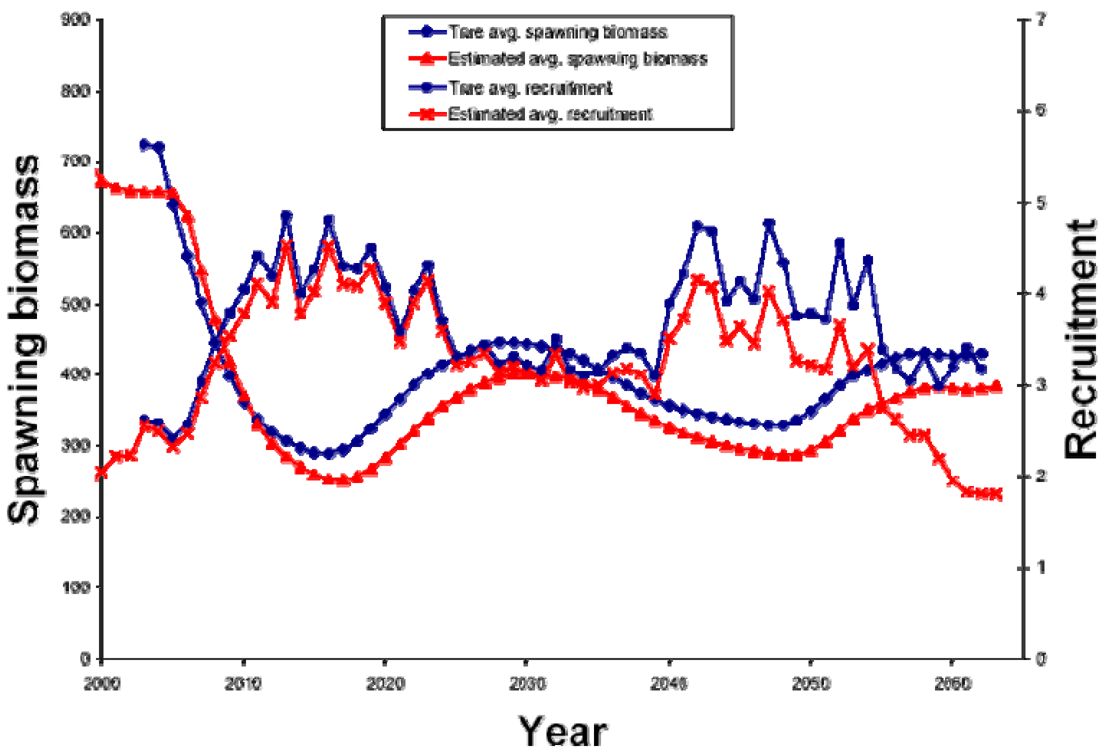


Figure 7.8. Results of the MSE analysis used to evaluate the Tier 1 harvest policy using Bering Sea yellowfin sole population dynamics from two productivity regimes alternative every 15 over a 60 year time horizon

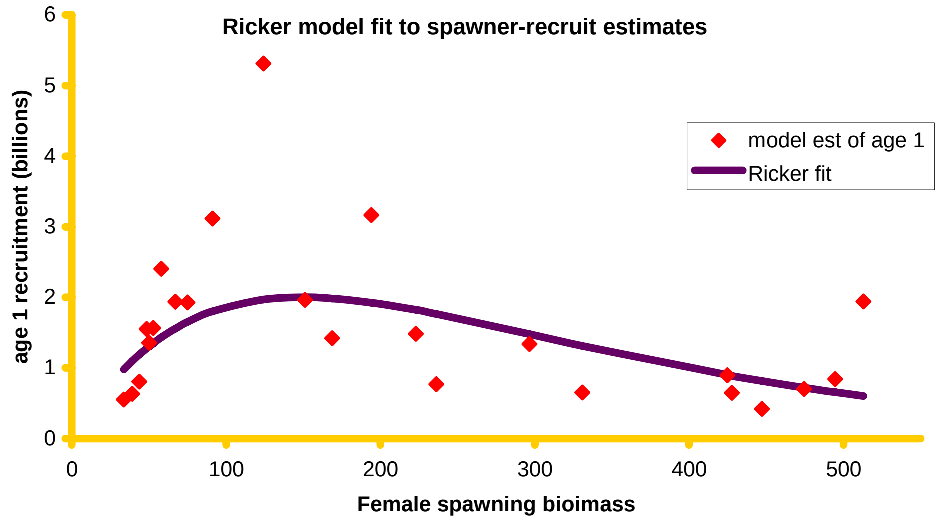


Figure 7.9--Ricker (1958) model fit to spawner-recruit estimates from 22 years.

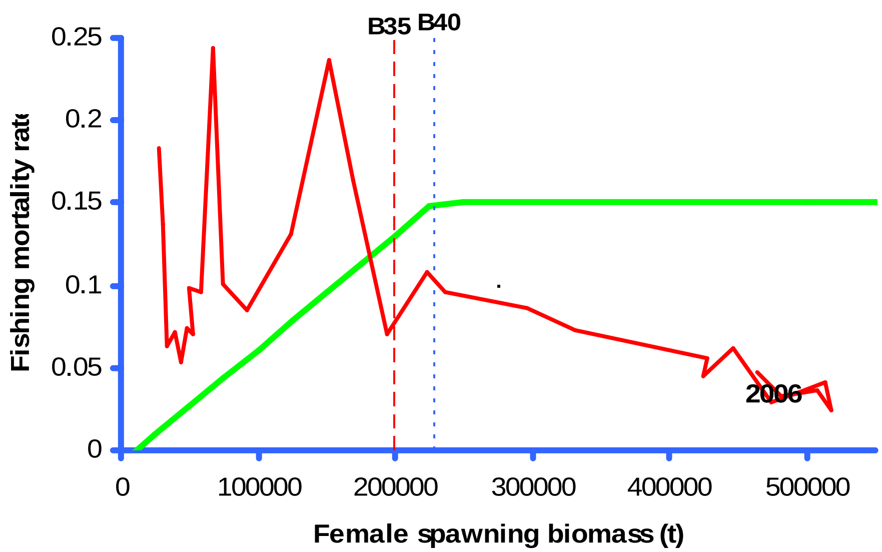


Figure 7.8—Relationship of annual rock sole female spawning biomass and full selection fishing mortality to B40 and F40.

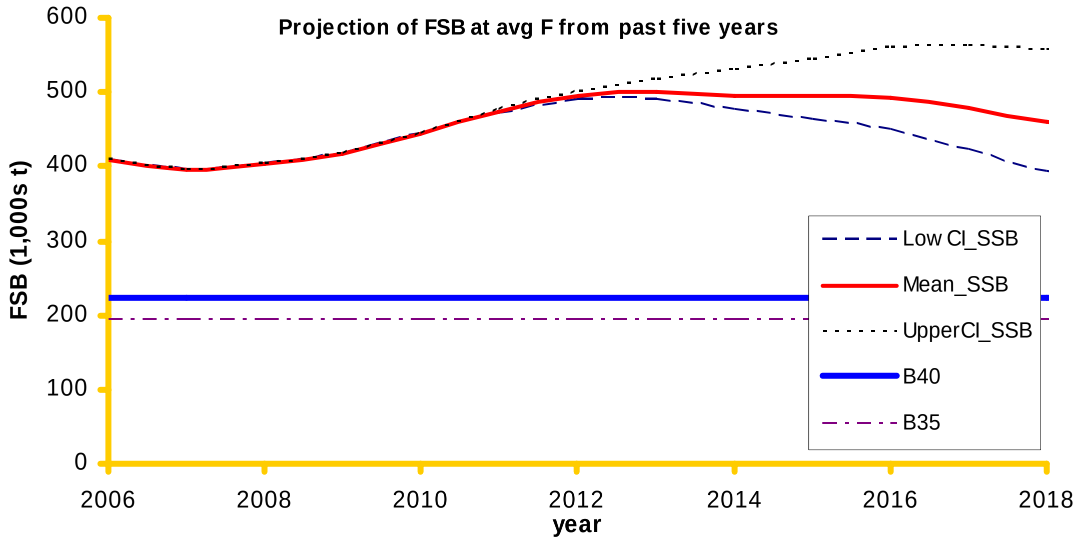


Figure 7.9—Projection of rock sole female spawning biomass when fishing in the future at the average F of the past five years.

Appendix

1) Observed fishery trawl locations, by quarter, for the 2006 fishing season.

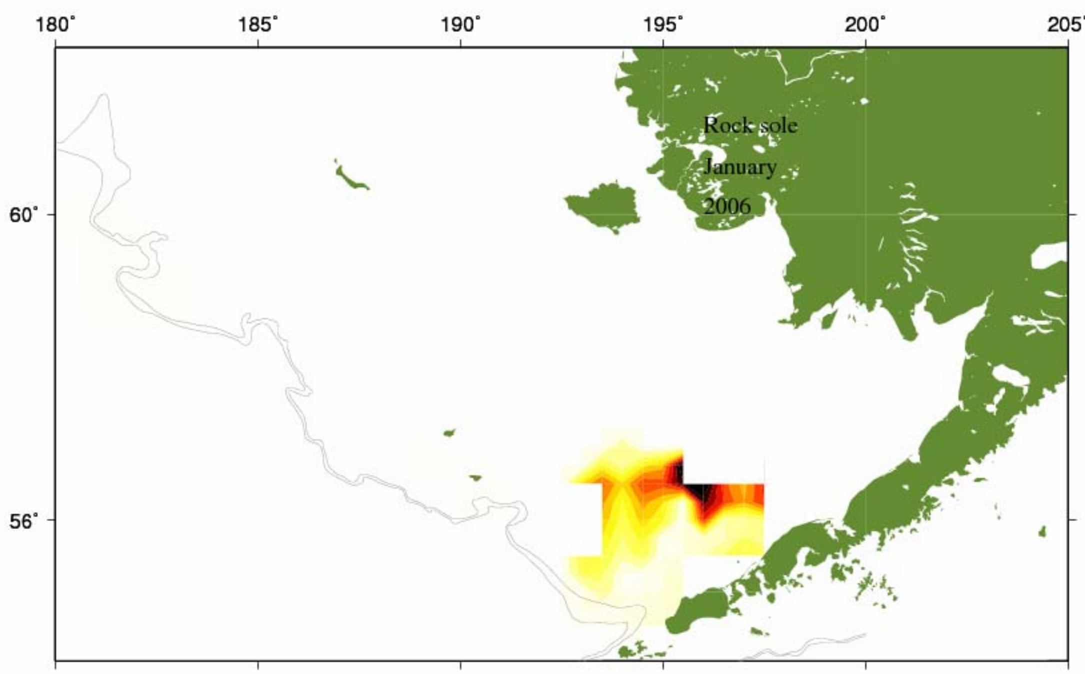
2) Figures showing the fit of the stock assessment model to the time-series of fishery and trawl survey age compositions (survey and fishery observations are the solid lines).

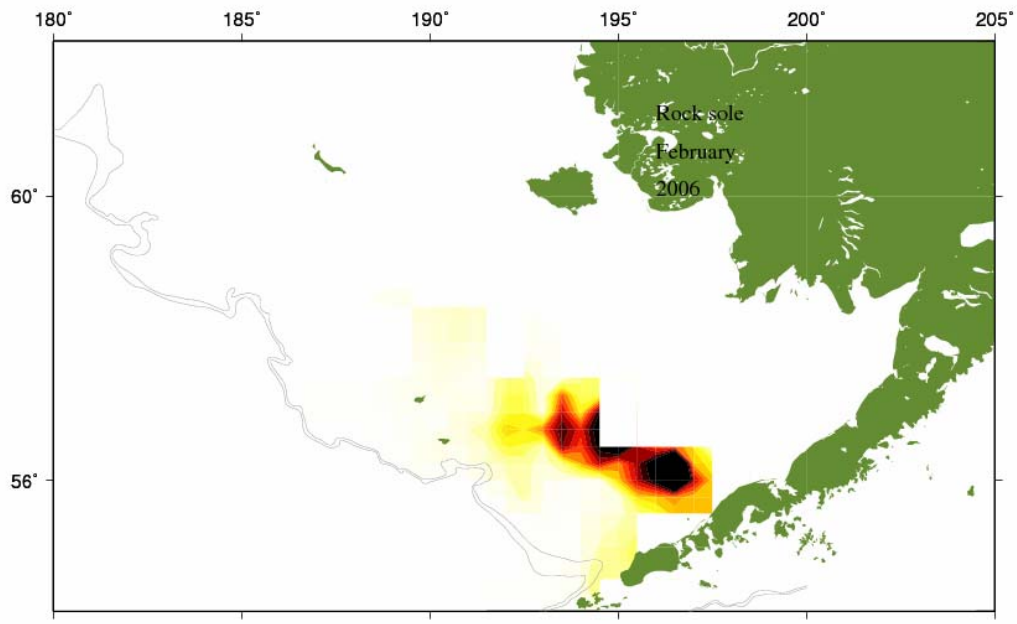
3) Table of the assessment model estimates of population numbers at age 1975- 2005.

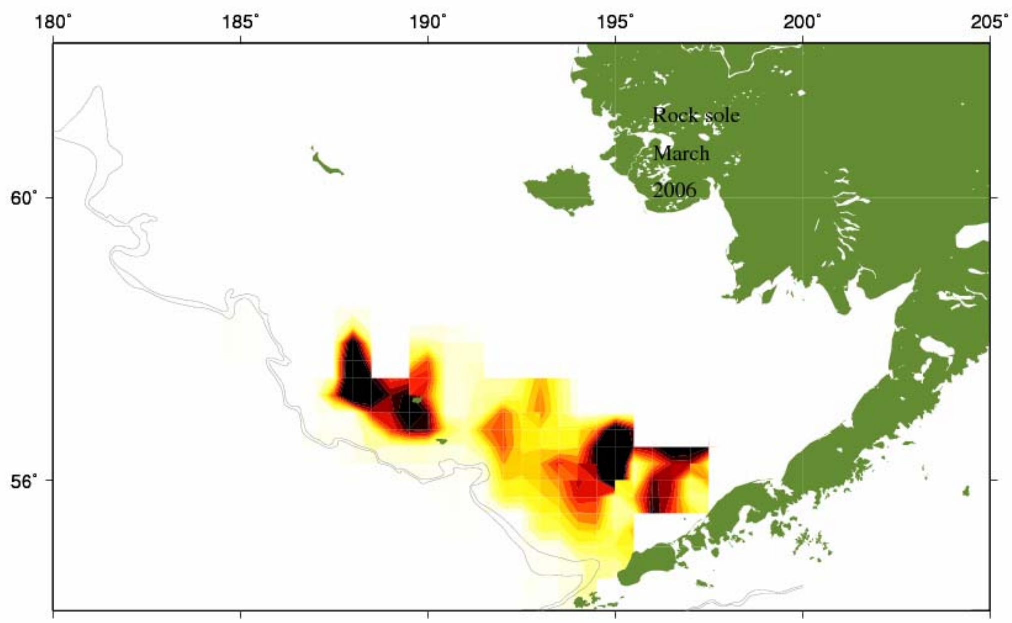
4) Table of total population removals of rock sole from Alaska Fisheries Science Center research activities, 1977-2006.

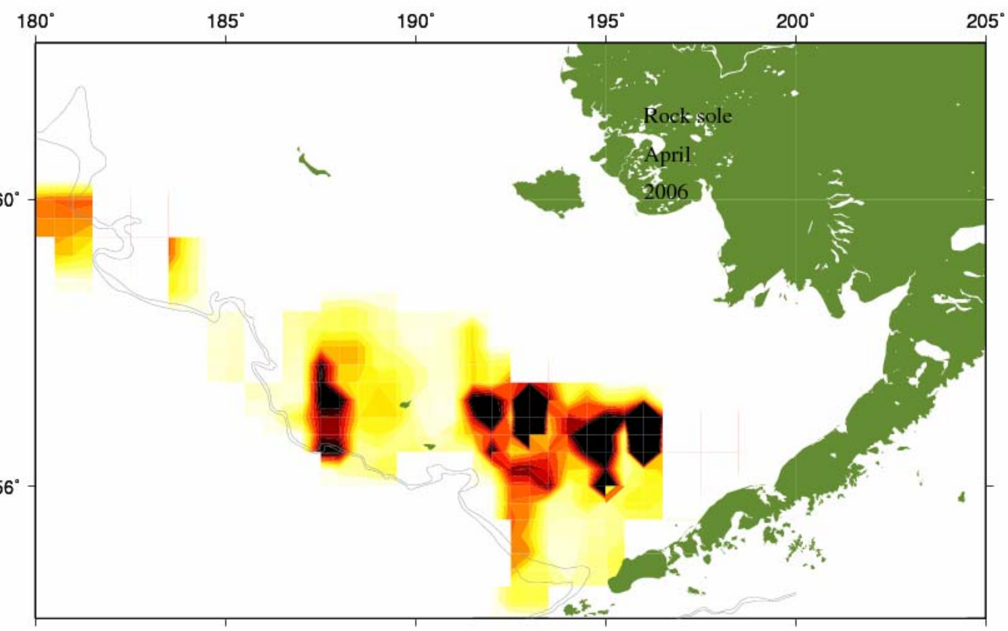
5) TAC and ABC of BSAI northern rock sole from 1989-2006.

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




180˚
185˚
190˚
195˚
200˚
205˚
60˚
56˚
Rock sole
February
2006


180˚
185˚
190˚
195˚
200˚
205˚
60˚
56˚
Rock sole
March
2006


180˚
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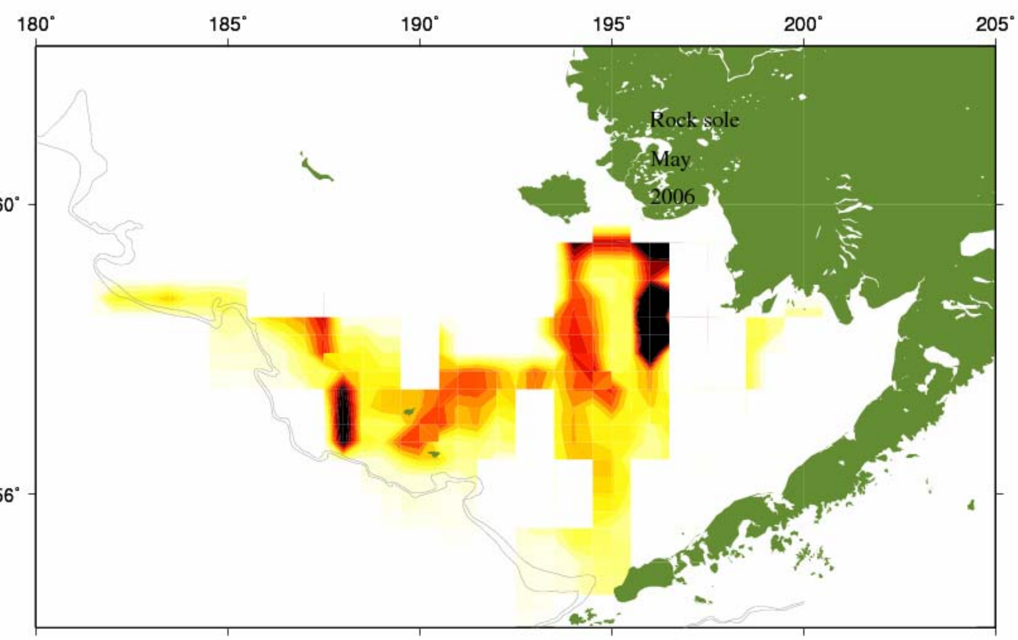
205˚
60˚
56˚
Rock sole
April
2006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205˚
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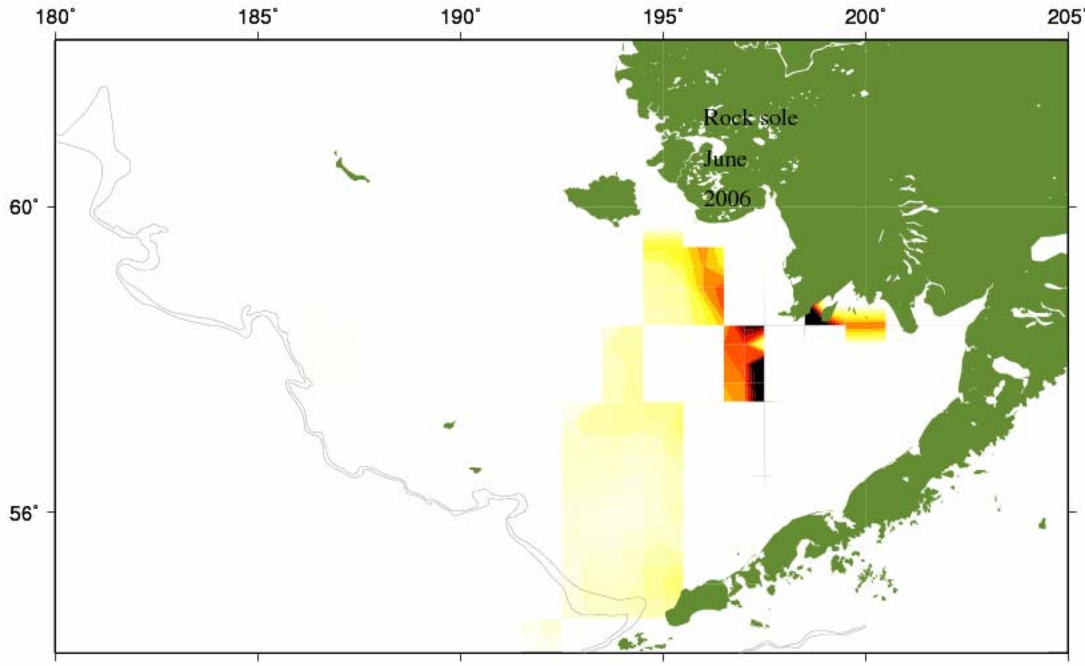
Rock sole
May
2006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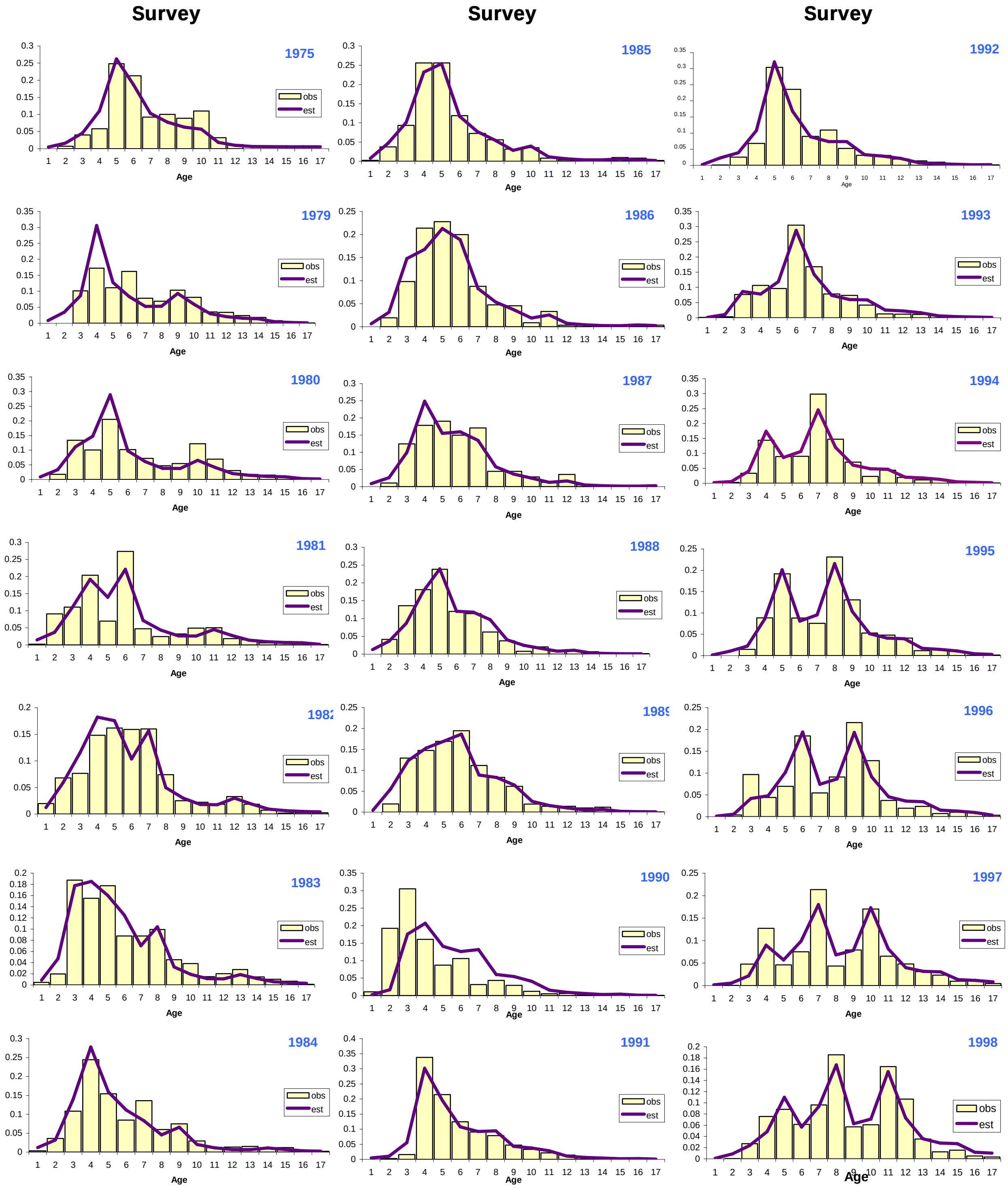
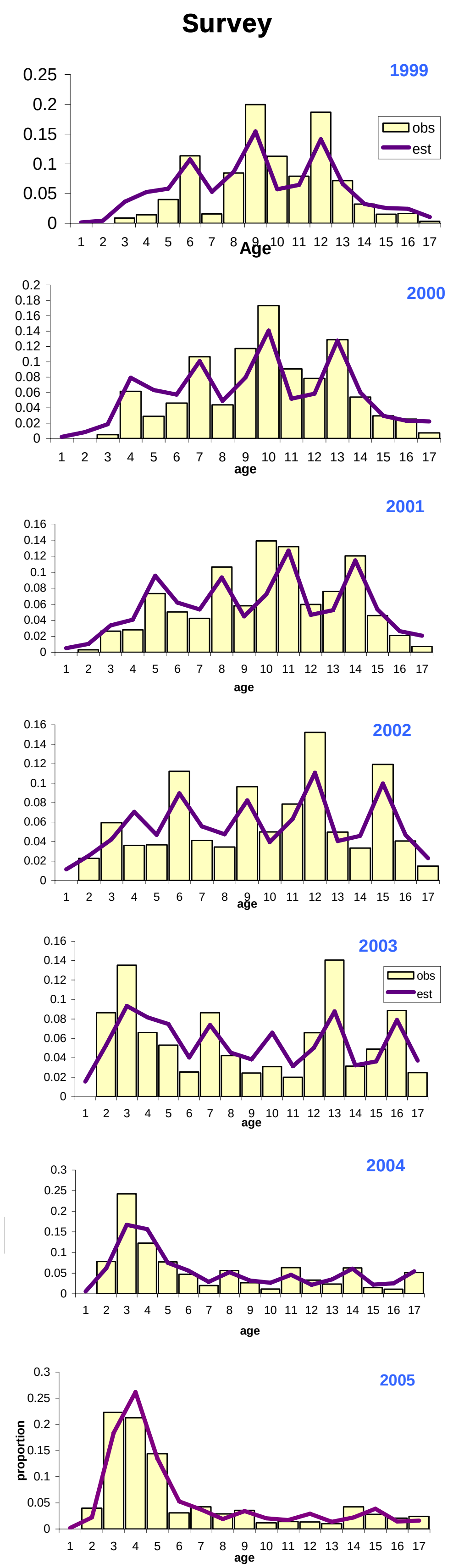
200˚
205˚
60˚
56˚
Rock sole
June
2006

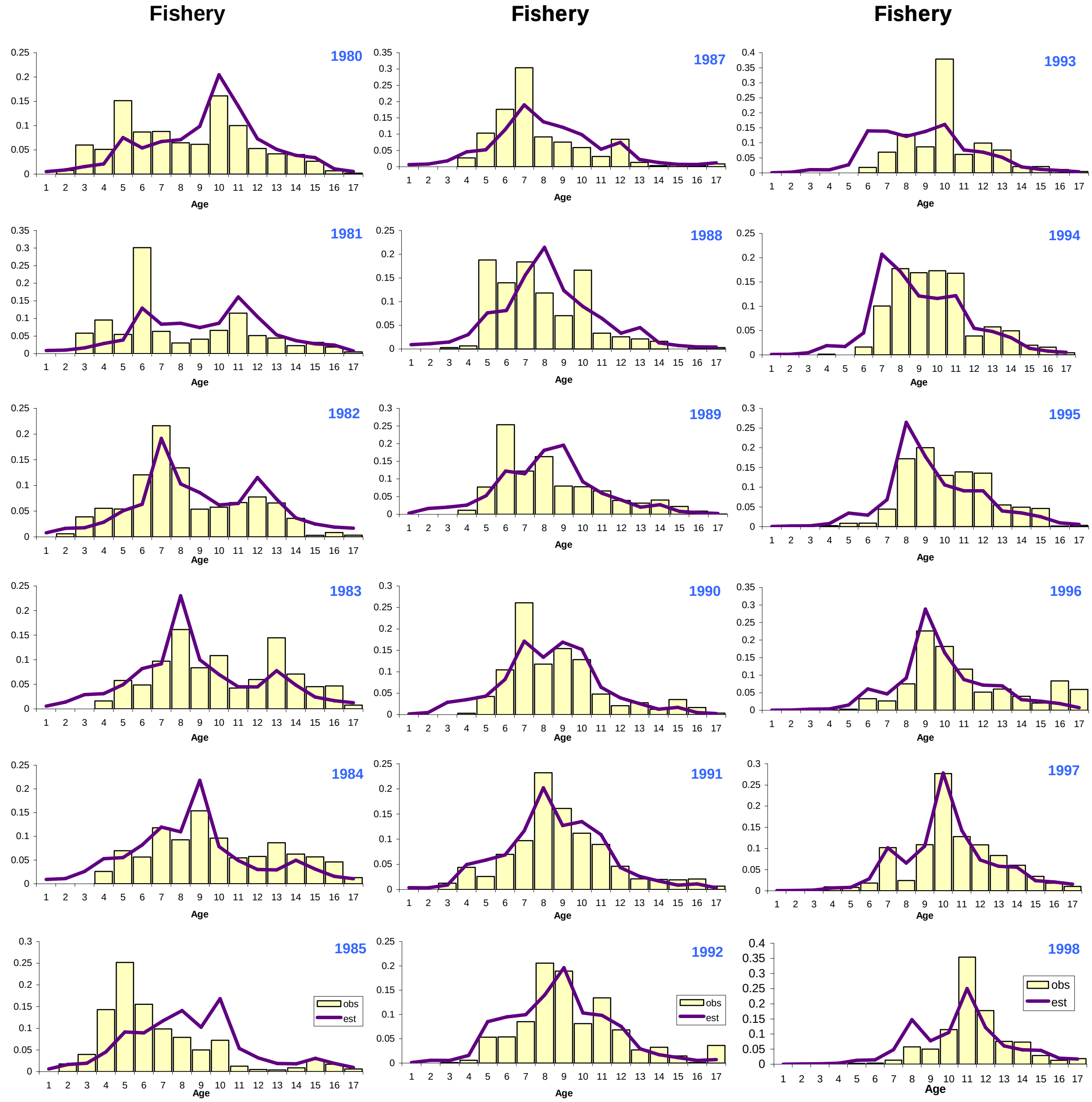
Fits to the survey age composition



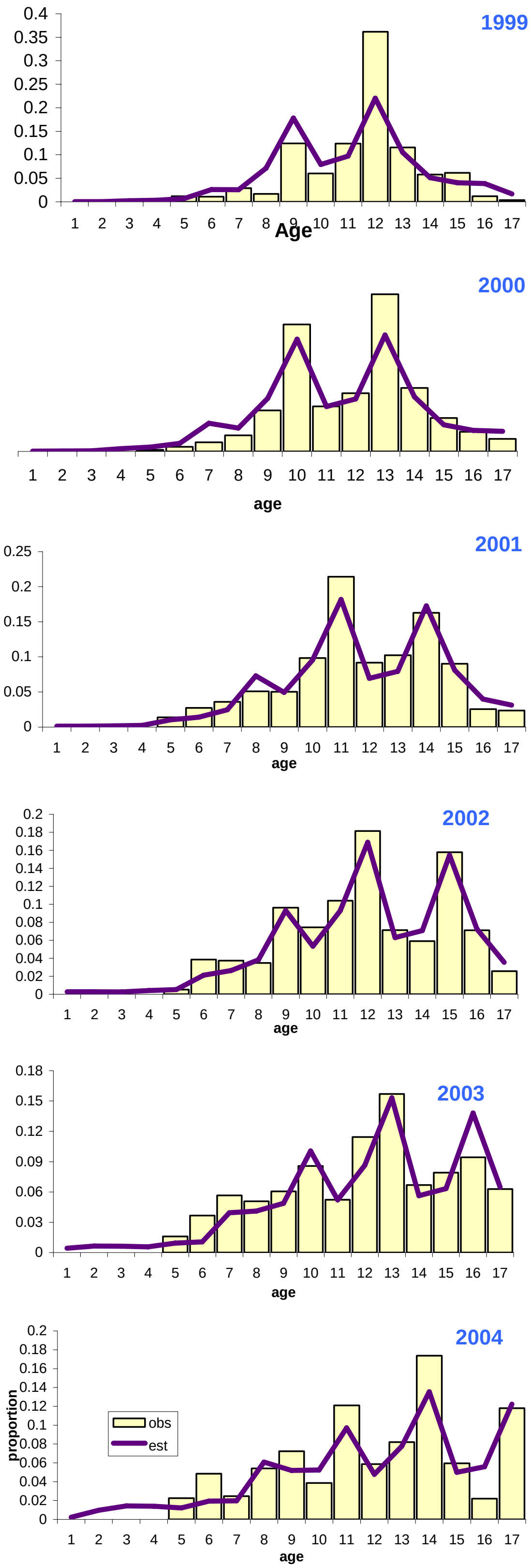


Fit to survey age composition (continued)

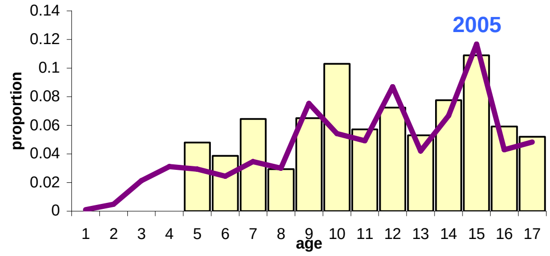
Fit to the fishery age composition age composition (continued)



Fishery



Fishery



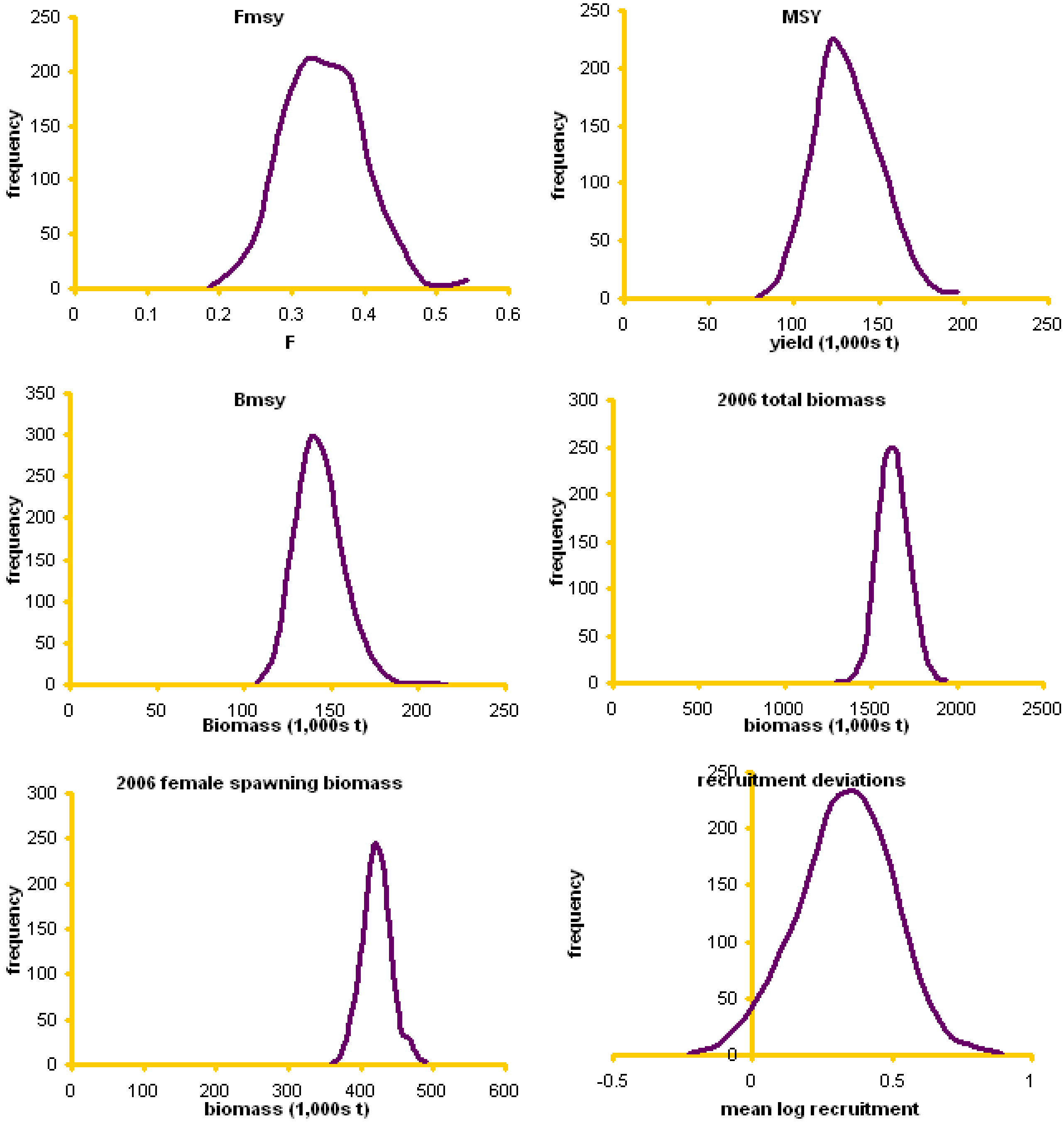
Model estimates of rock sole population numbers-at-age (thousands of fish), 1975-2006.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	255	159	101	103	189	128	70	52	42	38	12	7	4	4	4	4	4	4	4	4
1976	672	217	135	86	88	159	106	56	41	32	28	9	5	3	3	3	3	3	3	5
1977	379	572	185	115	73	74	133	87	45	31	24	21	7	4	2	2	2	2	2	6
1978	572	322	487	157	98	62	62	111	72	37	25	19	17	5	3	2	2	2	2	6
1979	654	487	275	415	134	83	52	52	91	58	29	20	15	13	4	2	1	1	1	6
1980	832	557	415	234	353	114	70	44	43	75	47	24	16	12	11	3	2	1	1	6
1981	1,606	708	474	353	199	299	96	58	36	35	60	38	19	13	10	9	3	1	1	6
1982	1,630	1,368	603	404	300	169	252	80	48	29	28	48	30	15	10	8	7	2	1	5
1983	1,428	1,388	1,165	513	343	254	142	209	65	38	23	22	37	23	12	8	6	5	2	5
1984	2,542	1,216	1,182	991	436	290	214	117	169	52	30	18	17	29	18	9	6	5	4	5
1985	2,058	2,164	1,035	1,004	839	366	239	169	88	121	36	20	12	11	19	12	6	4	3	6
1986	2,053	1,753	1,843	880	853	710	307	197	137	70	95	28	16	9	9	15	9	5	3	7
1987	3,306	1,749	1,492	1,568	748	722	595	254	160	108	55	73	21	12	7	7	11	7	4	8
1988	5,637	2,816	1,489	1,270	1,332	633	607	495	207	128	86	43	58	17	9	6	5	9	6	9
1989	2,057	4,800	2,397	1,266	1,077	1,122	526	492	387	156	94	63	31	42	12	7	4	4	6	11
1990	1,472	1,752	4,087	2,039	1,075	911	942	436	399	307	122	73	48	24	32	9	5	3	3	13
1991	3,347	1,254	1,492	3,477	1,731	909	763	776	350	313	237	94	56	37	18	24	7	4	2	12
1992	1,527	2,850	1,067	1,269	2,953	1,466	764	632	629	278	245	184	73	43	28	14	19	5	3	11
1993	797	1,300	2,427	908	1,078	2,499	1,229	631	510	497	217	189	142	56	33	22	11	15	4	11
1994	1,432	679	1,107	2,065	772	914	2,105	1,024	517	412	397	172	150	112	44	26	17	9	11	12
1995	670	1,220	578	943	1,756	655	771	1,759	844	420	332	318	137	120	90	35	21	14	7	19
1996	613	571	1,039	492	802	1,492	554	648	1,466	697	345	271	260	112	98	73	29	17	11	21
1997	934	522	486	884	419	680	1,259	464	535	1,194	563	277	217	208	90	78	59	23	14	26
1998	415	795	445	414	753	356	577	1,063	389	446	991	466	229	180	172	74	65	48	19	33
1999	629	353	677	379	352	640	302	487	890	323	369	818	384	189	148	142	61	53	40	43
2000	886	536	301	577	322	299	542	254	406	736	266	302	669	314	154	121	116	50	44	67
2001	1,818	755	457	256	491	274	254	458	214	340	614	221	252	556	261	128	101	96	42	92
2002	5,616	1,548	643	389	218	417	232	214	384	178	281	507	182	207	458	215	106	83	79	110
2003	4,641	4,784	1,319	548	331	185	354	196	179	318	147	232	417	150	170	377	177	87	68	156
2004	1,098	3,953	4,075	1,123	466	281	157	298	164	149	264	121	191	344	124	140	311	146	72	185
2005	1,340	935	3,367	3,469	955	396	238	132	248	135	122	215	98	155	279	100	114	252	118	208
2006	1,336	966	1,984	3,681	2,229	888	328	230	116	206	123	103	175	83	132	231	85	95	208	269

Total catch (t) of rock sole in Alaska Fisheries Science Center research catches in the Bering Sea and Aleutian Islands, 1977-2006.

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
2005	74

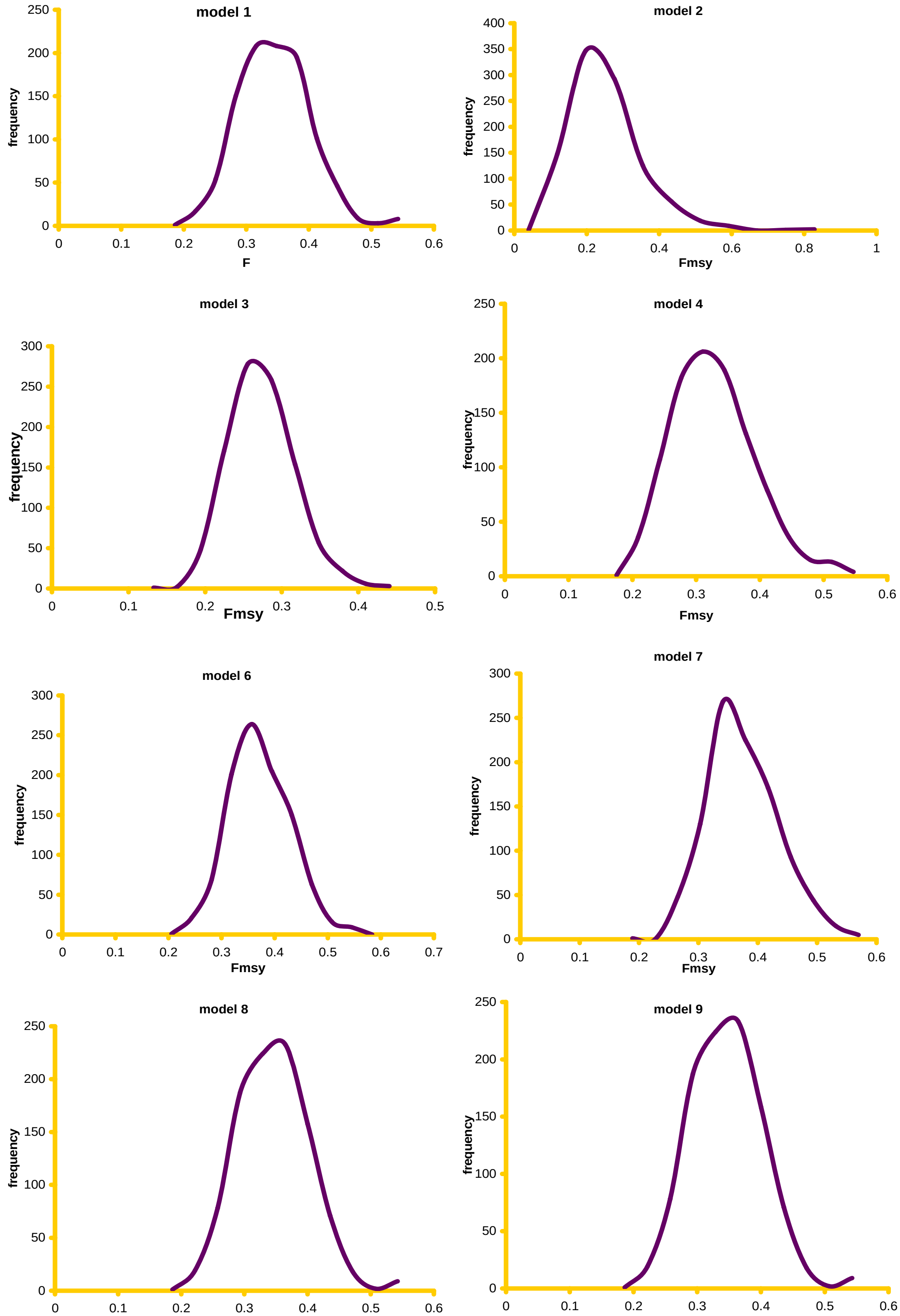
	TAC	ABC
1989	90,762	171,000
1990	60,000	216,300
1991	90,000	246,500
1992	40,000	260,800
1993	75,000	185,000
1994	75,000	313,000
1995	60,000	347,000
1996	70,000	361,000
1997	97,185	296,000
1998	100,000	312,000
1999	120,000	309,000
2000	137,760	230,000
2001	75,000	228,000
2002	54,000	225,000
2003	44,000	110,000
2004	41,000	139,000
2005	41,500	132,000
2006	41,500	126,000



Posterior distributions of selected parameter estimates from the preferred stock assessment model run.

Selected parameter estimates and their standard deviations

	Name	value	standard dev		name	value	Standard dev
	q_survey	1.536	0.054	1984	total biomass	480.610	20.907
	M	0.156	0.005	1985	total biomass	562.840	25.022
	mean_log_rec	0.289	0.146	1986	total biomass	707.630	30.709
	sel_slope_fsh	0.899	0.023	1987	total biomass	970.800	41.192
	sel_slope_srv	1.787	0.077	1988	total biomass	1100.700	46.719
	sel50_fsh	7.954	0.114	1989	total biomass	1193.700	53.073
	sel50_srv	3.449	0.064	1990	total biomass	1196.100	53.294
	F40	0.134	0.005	1991	total biomass	1274.400	55.946
	F35	0.161	0.006	1992	total biomass	1300.500	57.416
	F30	0.195	0.008	1993	total biomass	1544.400	68.152
	R_logalpha	-3.313	0.205	1994	total biomass	1633.800	71.998
	R_logbeta	-5.006	0.119	1995	total biomass	1828.800	79.468
	Fmsy	0.327	0.055	1996	total biomass	1746.100	75.292
	logFmsy	-1.117	0.167	1997	total biomass	1674.800	71.020
	msy	126.100	19.249	1998	total biomass	1645.300	69.899
	Bmsy	136.330	12.527	1999	total biomass	1597.300	66.842
1975	total biomass	160.820	9.567	2000	total biomass	1571.700	65.546
1976	total biomass	167.950	10.100	2001	total biomass	1521.500	64.068
1977	total biomass	178.840	10.640	2002	total biomass	1458.800	61.645
1978	total biomass	200.140	11.335	2003	total biomass	1406.200	60.626
1979	total biomass	225.700	12.206	2004	total biomass	1432.100	63.608
1980	total biomass	259.330	13.276	2005	total biomass	1502.600	71.509
1981	total biomass	297.970	14.565	2006	total biomass	1582.600	83.401
1982	total biomass	332.110	15.397				
1983	total biomass	430.970	19.353				



Posterior distributions of Fmsy from 8 model runs used to analyze a Tier 1 harvest policy.