Chapter 7
Northern Rock Sole

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EXECUTIVE SUMMARY

The following changes have been made to this assessment relative to the November 2008 SAFE:

Changes to the input data

1) 2008 fishery age composition.
2) 2008 survey age composition.
3) 2009 trawl survey biomass point estimate and standard error.
4) Estimate of catch (t) and discards through 26, September 2009.
5) Estimate of retained and discarded portions of the 2008 catch.
6) New female maturity schedule.
7) Weight at age also recalculated for males and females to model time-varying growth.

Assessment results

1) The projected age 2+ biomass for 2010 is 1,768,670 t.
2) The projected female spawning biomass for 2010 is 521,860 t.
3) The recommended 2010 ABC is 239,900 t based on an $F_{harmonic\ mean}$ (0.153) harvest level.
4) The 2010 overfishing level is 243,400 t based on an F_{MSY} (0.155) harvest level.

Assessment Year	2008	2009	
Projections Year	2009	2010	2011
M	0.15	0.15	0.15
Tier	1a	1a	1a
B_{MSY} (t)	217,760 t	242,100 t	--
$B_{40\%}$ (t)	375,000 t	353,130 t	--
Female spawning biomass (t)	531,700	521,860	568,700
Total Biomass (t) (geometric mean 6+)	1,634,500	1,566,000	1,578,000
Tier 1 $F_{overfishing}$	0.184	0.155	0.155
Tier 1 F_{ABC} ($F_{harmonic\ mean}$)	0.181	0.153	0.153
Tier 1 ABC	296,400	239,900	241,700
Tier 1 overfishing	300,500	243,400	245,300
Probability of $FSB_{2010} < B_{20\%}$		0	

The SSC also re-iterates one of its comments from the December 2007 minutes:

> **Because of the very small buffer between ABC and OFL, reflecting very little uncertainty in the estimates of F_{MSY} from a single model, the SSC emphasizes the continuing need for considering several alternative models in future assessments and in MSE analyses.**
>
> No new model exploration this assessment; some progress on MSE regarding model coding but model runs have not formally begun.

The authors noted that they will explore time-varying selectivity in next year's assessment to more accurately reflect the level of uncertainty in F_{MSY}. The SSC looks forward to results from these analyses.

We did not explicitly model time-varying selectivity in the 2009 assessment. However, given the concern of the small buffer between ABC and OFL we do provide an example of how the uncertainty in selectivity propagates through the assessment to determine its role in overall uncertainty. Although we still will include time-varying selectivity in the model it is not expected to increase the buffer relative to our current analysis of selectivity.

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 January-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 Domestic Annual Processing 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 - 2008 (domestic only) have averaged 47,600 t annually. The size composition of the 2009 catch from observer sampling, by sex and management area, are shown in Figure 7.1 and the locations of the 2009 catch are presented for each month in the Appendix.

The management of the northern rock sole fishery changed significantly in 2008 with the implementation of Amendment 80 to the BSAI Fisheries Management Plan. The Amendment directly allocated fishery resources among BSAI trawl harvesters in consideration of their historic harvest patterns and future harvest needs in order to improve retention and utilization of fishery resources by the non-AFA trawl catcher/processor fleet. This was accomplished by extending the groundfish retention standards to all H&G vessels and also by providing the ability to form cooperatives within the newly formed Amendment 80 sector. In addition, Amendment 80 also mandated additional monitoring requirements which included observer coverage on all hauls, motion-compensating scales for weighing samples, flow scales to obtain accurate catch weight estimates for the entire catch, no mixing of hauls and no on-deck sorting.

Rock sole are important as the target of a high value roe fishery occurring in February and March which accounted for 44% of the annual catch in 2009 (Fig 7.2). About 68% of the 2009 catch came from management areas 509 and 521 with the rest from areas 514, 516, 517 and 513 (Fig 7.2). The 2009 catch of 46,910 t comprised 16% of the ABC of 296,000 t (52% of the TAC). Thus, rock sole remain lightly harvested in the Bering Sea and Aleutian Islands. The 2009 catch locations by month are shown in Figure 7.3. During the 2009 fishing season no catch restrictions were place on northern rock sole harvesting in response to bycatch limitations or TAC in the Bering Sea or Aleutian Islands.

Although female rock sole are highly desirable when in spawning condition, large amounts of rock sole were historically discarded overboard in the various Bering Sea trawl target fisheries. Estimates of retained and discarded catch from at-sea sampling for 1987-2008 are shown in Table 7.2. From 1987 to 2000 rock sole were discarded in greater amounts than they were retained, however during the years since

2000 there has been increased utilization of the catch as the proportion retained has trended upward. In 2008, the first year of Amendment 80 mandated fishing practices, 90% of the rock sole caught were retained. Details of the 2007 and 2008 northern rock sole catch by fishery designation are shown 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 26, 2009 (Table 7.1) and fishery catch-at-age numbers from 1980-2008 (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 7.4). 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 trend had been stable with 2007 and 2008 values of 43.9 and 43.8 kg/ha, respectively. The 2009 value of 30.3 kg/ha is the lowest since 1990 and is about 75% of the 2008 CPUE.

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 2009 point estimate of the Bering Sea surveyed area is 1,221,026 t – 1,857,029 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 2008 estimate of 2,031,600 t is nearly the same as the 2007 estimate (2,032,900 t). However, in 2009 the estimated biomass declined unexpectedly to 1,539,028 t.

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. The total tonnage of northern rock sole caught annually in the Bering Sea shelf surveys from 1977-2009 is listed in Table 7.6.

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 7.5). This also caused a resultant decrease in weight-at-age as the population increased and expanded northwestward toward the shelf edge (Walters and Wilderbuer 2000). These updated values of combined-sex weight-at-age were applied to the populations in 2001-2007 in past assessments to model the population dynamics of the rock sole population.

This assessment again re-analyses the time trend of size-at-age and wt-at-age available from the survey data. Northern rock sole growth (mean length-at-age) by sex, indicates that males and females exhibit similar growth until about age 6 after which females grow at a faster rate and obtain a larger size than males (Fig. 7.6). The length at age time series exhibits periods of slow and fast growth from 1982-2006 (shown for 8 year old fish in Figure 7.7). Accordingly, the length-at-age time series was partitioned into periods of faster (1982-1991, 2004-2008) and slower (1992-2003) growth to capture the time-varying differences in growth. In order to produce a growth matrix which was not too abrupt between change point years (1991-1992 and 2003-2004) a three year running average of weight-at-age was used, working backwards from 2008 (Table 7.7). This approach does not underestimate the 1980s biomass or overestimate the 1992-2003 biomass as did the method used in last year's assessment which used the average weight-at-age from all years for each individual year and age.

The length-weight relationship available from 4,469 (2,564 females, 1,905 males) survey samples collected since 1982 indicate that this value did not change significantly over this time period. The following parameters have been calculated for the length (cm)-weight (g) relationship:

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

Males		Females	
a	b	a	b
0.005056	3.224	0.006183	3.11747

The maturity schedule for northern rock sole was updated for this assessment from a histological analysis of 162 ovaries collected from the Bering Sea fishery in February and March 2006 (Stark in Press) and is shown in Table 7.8 and Figure 7.7. Compared to the maturity curve from anatomical scans used previously, the length-based model of Stark indicates nearly the same age at 50% maturity (8.8 years) but has a higher proportion of females spawning at ages older than the age of 50% maturity and a lower proportion spawning at ages younger than the age of 50% maturity.

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. 7.8, Table 7.10). For this assessment all fishery and survey age compositions (1979-2008) were calculated to estimate age composition by sex. Fishery size composition data from 1979-89 (prior to 1990 observer coverage was sparse for this species 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 those years. Estimation of the fishery age composition since 1990 use age-length keys derived from age structures collected annually from the fishery. Northern rock sole occurrence in trawl survey hauls and associated collections of lengths and age structures since 1982 are shown in Table 7.9.

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.

Since the sex-specific weight-at-age for northern rock sole diverges after about age 6, with females growing larger than males, the current assessment model is coded to accommodate the sex-specific aspects of the population dynamics of northern rock sole. The model allows for the input of sex-specific estimates of fishery and survey age composition and weight-at-age and provides sex-specific estimates of population numbers, fishing mortality, selectivity, fishery and survey age composition and allows for the estimation of sex-specific natural mortality and catchability. The model retains the utility to fit combined sex data inputs.

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 7.11). 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 7.11 presents the key equations used to model the rock sole population dynamics in the Bering Sea and Table 7.12 provides a description of the variables used in Table 7.11. 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 7.8) 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
70	8	54	2	0, 1 or 2 (optional)	0, 1 or 2 (optional)	134-138 depending on model run

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 and sex-specific estimates of fishing mortality, selectivity, natural mortality (optional) and catchability (optional).

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 7-11.

Selectivity

Fishery and survey selectivity were modeled in this assessment using the logistic function, as shown in Table 7-11. The logistic model allows the sex-specific selectivity curves to provide an asymptotic fit for the older fish in the fishery and survey, but still 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, sex 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. In last years assessment natural mortality was estimated for both sexes as free parameters with values of 0.142 and 0.17, for males and females respectively, when survey catchability was fixed at 1.5.

Survey Catchability

Unusually low estimates of flatfish biomass were obtained for Bering Sea shelf flatfish species during the very cold year of 1999 and also for 2009 (another cold year). These results suggest a relationship between bottom water temperature and trawl survey catchabililty, which are documented for yellowfin sole, flathead sole and arrowtooth flounder in the 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 non-linear model for each year within the stock assessment model as:

$$q = e^{-\alpha + \beta T}$$

where *q* is the annual 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 -1.0081 and 0.035564, respectively. These small values indicate that temperature has very little effect on trawl catchability of rock sole where bottom temperatures ranging from -2 to 2 degrees Celsius would only affect the value of the estimate of q by 0.04. Furthermore, a linear model of this relationship in an earlier assessment in suggested that q is greater than 1.0.

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 (standard error = 0.056) 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:

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

where *qprior* is the survey catchability prior value, 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.

Model evaluation

With catchability constrained as described above, model runs were made to explore different combinations of fixing and/or estimating male M, female M and q to discern the range of their values and their effect on the resulting estimates of 2009 female spawning biomass, ABC and SPR rates ($F_{40\%}$).

For the runs where q was fixed, it was set at 1.5 since this value was close to the value from the herding experiment (Models A, B and C).

Model exploration	q	female M	male M	2009 FSB	2010 ABC	F40
Model A	1.5	0.15	0.15	484.516	239.876	0.154
q fixed at 1.5, male and female M fixed at 0.15						
Model B	1.5	0.15	0.179	529.995	242.855	0.164
q fixed at 1.5, female M fixed at 0.15 and male M estimated						
Model C	1.5	0.159	0.187	494.0	234.672	0.176
q fixed at 1.5, female M and male M estimated						
Model D	2.02	0.15	0.15	327.831	179.261	0.164
q estimated, Female and male M fixed at 0.15						
Model E	1.83	0.15	0.177	408.196	199.457	0.169
q estimated, female M fixed at 0.15 and male M estimated						
Model F	1.98	0.144	0.172	381.15	188.016	0.164
q, female M and male M all estimated as free parameters						

Model G q estimated with the bottom temperature relationship, male and female M fixed at 0.15	2.74	0.15	0.15	214.73	135.044	0.175

These model runs indicate that fixing q at 1.5 provides a constraint on the estimates of natural mortality with males estimated at a little higher value than females (Models B and C). Fixing the female or both the male and female M (Models D and E) has less of a constraint on q and values are estimated as high as 2.0 (Model D) and 1.83 (Model E). Allowing all three parameters to be freely estimated results in higher estimates of q and lower estimates of stock size (Model F). The model run which estimates q as a function of the annual bottom temperature during the surveys (with male and female M fixed at 0.15) provided minimal constraint on q (estimated at 2.7 in Model G).

Models D, E, F and G provide estimates of survey catchability which range from 1.83 to 2.7. However, this is a large difference in the estimate of q compared to what was estimated from the herding experiment (1.4). These results would indicate that 47% (Model D) and 63% (Model F) of the northern rock sole present in trawl survey catches were herded into the net from the areas between where the sweep lines contact the bottom, compared to a value of 29% from the catchability experiment. The reason for this difference in the q estimate is the trade-off in the model in reconciling the survey biomass trend with the population age composition. Due to poor recruitment in the 1990s the population age composition is very flat for ages 7-20. The 4-7 year olds represent good future recruitment, but are incompletely selected by the survey trawl. Given that the survey biomass estimates of the past 5 years are high (with the exception of 2009 which the model does not fit), the best fit results from increasing the number of fish herded into the trawl path to make up for the lack of age 8+ fish in the population age composition but still allows a good fit to both data indexes. However, this is an increase in estimated survey catchability that is the result of reconciling low past recruitment with very stable survey estimates and is not related to changes in fish behavior in the trawl path. Regarding fitting M as a free parameter in the model (males only or both sexes), both models A and B gave similar results in the level of M and abundance estimates, but they do not fit the observed sex ratio from the observed survey age composition as well as using the fixed M values in Model A (Fig. 7.9). Therefore, the model of choice for this assessment is Model A where q is constrained at a value close to the experimental result, M is fixed at values close to those estimated for each sex, and the model run results in a better fit to the population sex ratio.

MODEL RESULTS

Although the trawl survey point estimate decreased 25% from 2008 to 2009, the stock assessment model did not fit the 2009 survey point estimate and model results indicate that the stock condition is increasing. However, the new survey information scaled the population downwards and the new maturity information increased the proportion of mature females actively spawning at older ages and decreased the proportion of mature females actively spawning at younger ages. Combined, these effects lowered estimates of stock-recruitment productivity (lower slope at the origin; Fig. 7.10). Thus the stock-recruitment steepness is less in 2009, B_{msy} is higher and thus F_{msy} is less as it requires a lower F to maintain FSB at this higher level. The result is that ABC is reduced from 296,000 t in 2009 to 240,000 t in 2010.

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 7.13. The exploitation rate has averaged 3.6% from 1975-2008, indicating a lightly exploited stock. Age and sex-specific selectivity estimated by the model (Table 7.14, Fig. 7.10) indicate that male and female rock sole are 50% selected by the fishery at ages 7 and 8, respectively, and are nearly fully selected by ages 12 and 13.

Abundance Trend

The stock assessment model indicates that rock sole total biomass was at low levels during the mid 1970s through 1982 (160,000 - 360,000 t, Fig. 7.10 and Table 7.15). From 1985-95, a period characterized by sustained above-average recruitment (1980-88 year classes, Fig. 7.10) and light exploitation, the estimated total biomass rapidly increased at a high rate to over 1.7 million t by 1997. Since then, the model indicates the population biomass declined 20% to 1.5 million t in 2004 before increasing the past three years to 1.76 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 2001-2005. The female spawning biomass is estimated to be at a high level and is now increasing after a low 480,000 t in 2008. As the good year classes spawned in 2001-2004 begin to mature the female spawning biomass is expected to increase (Table 7.15). The model provides good fits to most of the strong year classes observed in the fishery and surveys during the time-series (Fig. 7.11).

The model estimates of survey biomass (using trawl survey age-specific selectivity and the estimate of q applied to the total biomass, Fig. 7.10) correspond fairly well with the trawl survey biomass trend with the exception of the cold year of 1999 and also 2009. Although 2006 through 2008 were relatively cold years in the eastern Bering Sea, the rock sole survey biomass estimate remained steady, which may indicate 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. The model fit is within the 95% confidence intervals of the survey biomass point estimates for 24 of the 27 annual surveys. Posterior distributions of some selected model parameters from the preferred stock assessment model are presented in Figure 7.12.

Total Biomass

The stock assessment projection model estimates total biomass (mid year population numbers multiplied by mid-year weight at age) for 2010 at **1,768,700** t (including the 2009 catch of 46,910 t through 26 September).

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. 7.5 and 7.9, Table 7.16). Rock sole ages have now been read for samples obtained in 2008 and show that the 7-10 year old fish are the dominant age classes in the fishery (by numbers). Recruitment during the 1990s, with the exception of the 1990 year class, was below the 34 year average and has resulted in a flat survey age composition for ages 8+. The 2001-2004 year classes appear very strong as discerned from the last 4 survey age samples and should contribute to an increasing stock size in the near future.

The stock assessment model estimates of the population numbers at age for each sex, estimated number of female spawners, and selected parameter estimates and their standared deviations are shown in Tables 7.17-7.19, respectively.

Tier 1 Considerations

The SSC determined in December 2006 that northern rock sole would be managed under the Tier 1 harvest guidelines, and therefore future harvest recommendations would be based on MSY and F_{MSY} values calculated from a spawner-recruit relationship. MSY is an equilibrium concept and its value is dependent on both the spawner-recruit estimates which is assumed to represent the equilibrium stock size-recruitment relationship and the model used to fit the estimates. In the northern rock sole stock assessment model, a Ricker form of the stock-recruit relationship was fit to these data inside the model using a R sigma value of 0.6 to allow variability in the fitting process. Estimates of F_{MSY} and B_{MSY} were calculated, assuming that the fit to the stock-recruitment data represent the long-term productivity of the stock.

For this assessment, 3 different stock-recruitment time-series were again investigated. These include the full time-series 1978-2003, the years of consecutive poor recruitment events (1989-2001), and the period of high recruitment during the 1980s, 1978-90 (Fig. 7.13). Estimates of the harvest rates which would ensure the long-term sustainability of the stock ranged from F_{MSY} values of 0.1 – 0.155, depending on which years of stock-recruitment data points were included in the fitting procedure (Table 7.20). High values are estimated for F_{MSY} when the full time series is used and also when the good recruitment time series is used. The most productive time series (1978-1990) has too few spawner-recruit points to fit, does not converge properly, and gives an unrealistic estimate of Bmsy. Large recruitments of northern rock sole that occurred at a low spawning stock size in the 1980s determine that the stock is most productive at a smaller stock size (B_{MSY} = 242,100 t) with the result that F_{MSY} is highest when fitting the full data set.

Results from these Tier 1 calculations for northern 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 result indicates that the estimates of F_{MSY} are obtained with very little uncertainty. To better understand how uncertainty in certain parameter estimates affects the Tier 1 harvest policy calculations for northern rock sole, the following analysis was undertaken. Selectivity, catchability, natural mortality and recruitment variability (σ_R) 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 individual parameter estimates (0.4 and 0.8 for M and q and 0.8, 1.0, and 1.2 for σ_R) and how they affect the estimate of the harmonic mean of F_{MSY} (Table 7.20).

When the 1989-2003 years are fit (Model 2), the F_{MSY} value is about 63% of the full time-series value (Model 1) and the uncertainty in the relationship between spawners and recruits propagates through the calculation of F_{MSY} to give a harmonic mean estimate of 0.088, an 9.6% reduction due to uncertainty and Model 3 returns a 11% reduction. The fit of the full time series is used to introduce uncertainty in the estimates of selectivity (Model 4), catchability (Models 5 and 6), natural mortality (Models 7 and 8) and recruitment variability (Models 9 – 11). Adding uncertainty to recruitment variability resulted in the largest difference between the geometric mean and the harmonic mean of the estimate of F_{MSY} for these Model runs, a 5% reduction at the highest value considered (Model 11). Placing more uncertainty on selectivity reduced the harmonic mean of the F_{MSY} by only 2% (Model 4). Incorporating more uncertainty in the estimation of catchability and natural mortality resulted in only a 1 - 2% reduction for the estimate of the harmonic mean (Models 5 - 8). Thus F_{MSY} appears to be well estimated by the model. For the 2007 fishing season, the SSC chose an ABC and OFL based on the full data set (1978-2002), which is also considered here (now including 2003 also) as the base model for stock assessment model evaluation and ABC determination. Posterior distributions of F_{MSY} from most of the models considered here are shown in Figure 7.14.

ACCEPTABLE BIOLOGICAL CATCH

The SSC has determined that northern rock sole qualify as a Tier 1 stock and therefore the 2010 ABC is calculated using Tier 1 methodology. 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), then reducing the stock size to low levels could be detrimental to the long-term sustainability of the stock if the environment, and thus productivity, had changed from the earlier period. Since observations of northern 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 1980s. In 2006 the SSC selected the full time-series data set for the Tier 1 harvest recommendation. Using this approach again for the 2010 harvest recommendation (Model 1 in Table 4.20), the $F_{ABC} = F_{harmonic\ mean} = 0.153$. The Tier 1 harvest level is calculated as the product of the harmonic mean of F_{MSY} and the geometric mean of the 2010 6+ biomass estimate, as follows:

$$B_{gm} = e^{\ln \hat{B} - \frac{cv^2}{2}}$$

, where B_{gm} is the geometric mean of the 2010 6+ biomass estimate, $\hat{B}$ is the point estimate of the 2010 6+ biomass from the stock assessment model and cv^2 is the coefficient of variation of the point estimate;
and

$$\bar{F}_{har} = e^{\ln \hat{F}_{msy} - \frac{\ln sd^2}{2}}$$

, where $\bar{F}_{har}$ is the harmonic mean, $\hat{F}_{msy}$ is the peak mode of the F_{MSY} distribution and sd^2 is the square of the standard deviation of the F_{MSY} distribution. **This calculation gives a Tier 1 ABC harvest recommendation of 239,900 t and an OFL of 243,400 t for 2010**.

The projection of 2010 ABC from last year's assessment was 309,900 t and the OFL was projected at 314,200 t.

The stock assessment analysis must also consider harvest limits, usually described as overfishing fishing mortality levels with corresponding yield amounts. Amendment 56 to the BSAI FMP sets the Tier 1 harvest limit at the F_{MSY} fishing mortality value. The overfishing fishing mortality values, ABC fishing mortality values and their corresponding yields are given as follows (Tier 3a values are also included):

Harvest level	F value	2010 Yield
Tier 3 $F_{OFL} = F_{0.35}$	0.19	182,000 t
Tier 3 $F_{ABC} = F_{0.40}$	0.15	152,800 t
Tier 1 $F_{OFL} = F_{MSY}$	**0.155**	**243,400 t**
Tier 1 $F_{ABC} = F_{harmonic\ mean}$	**0.153**	**239,900 t**

BIOMASS PROJECTIONS

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

For each scenario, the projections begin with the vector of 2009 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2010 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2009. 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 2010, 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 2010 recommended in the assessment to the *max* F_{ABC} for 2009. (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 2005-2009 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 2010 and above its MSY level in 2020 under this scenario, then the stock is not overfished.)

Scenario 7: In 2010 and 2011, 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 2022 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 7.21 indicate that rock sole are currently not overfished and are not approaching an overfished condition. If harvested at the average F from 2005-2009, rock sole female spawning biomass is projected to increase due to the strong recruitment observed during the past five years (Fig. 7.15). The ABC and TAC values that have been used to manage the northern rock sole resource since 1989 are shown in Table 7.22 and a phase plane diagram showing the estimated time-series of female spawning biomass relative to the harvest control rule is in Figure 7.16.

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. The 2009 numbers at age from the stock assessment model are projected to 2010 given the 2009 catch and then a 2010 catch of 50,000 t is applied to the projected 2010 population biomass to obtain the 2011 OFL

Tier 1 Projection

Year	Catch	SSB	Geometric mean 6+ total biomass	ABC	OFL
2010	46,910	521,700	1,566,000	239,900	243,400
2011	50,000	568,700	1,578,000	241,700	245,300

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 thirty 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 northern 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 northern 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 target species is shown for 1991-2008 in Table 7.23 and the catch of non-target species from the rock sole fishery is shown in Table 7.24. The rock sole target fishery contribution to the total bycatch of prohibited species is shown for 2006 and 2007 in Table 13 of the Economic SAFE (Appendix C) and is summarized for 2007 as follows:

Prohibited species	Rock sole fishery % of total bycatch
Halibut mortality	27
Herring	1
Red King crab	82
C. bairdi	12
Other Tanner crab	4
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 30 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 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 26, 2009.

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			36,411	36,411
2007			36,768	36,768
2008			51,275	51,275
2009			46,910	46,910

Table 7.2 Retained and discarded catch (t) in Bering Sea fisheries, 1987-2008.

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
2006	28,577	7,834	78
2007	27,826	8,942	76
2008	45,945	5,330	90

Table 7.3--Discarded and retained rock sole catch (t), by target fishery, in 2007 and 2008.

2007			
target fishery	Retained	Discarded	total
Atka mackerel	102	128	230
Bottom pollock	66	35	101
Pacific cod	1,738	2,569	4,307
Mid-water pollock	304	106	410
Sablefish	0	0	0
Rockfish	5	4	9
Arrowtooth flounder	47	10	57
Flathead sole	1,218	865	2,084
Rock sole	18,491	2,727	21,217
Yellowfin sole	5,761	2,456	8,218
Greenland turbot	0	0	0
Alaska plaice	8	2	10
Other flatfish	81	38	119
Other species	4	2	6
halibut	0	0	0
Total catch			36,768

	2008		
	Retained	Discarded	Total
Atka Mackerel	57	120	176
Pollock - bottom	664	32	697
Pacific Cod	298	2,399	2,698
Alaska Plaice	4	99	103
Other Flatfish - BSAI	1	0	1
Halibut	0	4	4
Rockfish	8	9	17
Flathead Sole	1,545	808	2,353
Other Species	0	2,547	2,547
Pollock - midwater	712	2,295	3,007
Rock Sole - BSAI	31,147	0	31,147
Sablefish - BSAI	1	2	3
Greenland Turbot - BSAI	0	36	36
Arrowtooth Flounder	288	2	290
Yellowfin Sole - BSAI	8,196	0	8,196
Total catch			51,275

Table 7.4--Estimated catch numbers at age, 1980-2008 (in millions).

Females estimated catch at age in millions

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1980	0.04	0.08	0.12	0.29	1.32	2.08	1.93	2.54	2.93	2.72	1.23	0.83	0.50	0.48	0.46	0.44	0.44	0.44	0.44	0.44
1981	0.07	0.06	0.12	0.18	0.43	1.87	2.64	2.07	2.19	2.10	1.73	0.73	0.48	0.29	0.27	0.26	0.25	0.25	0.25	0.50
1982	0.02	0.07	0.06	0.11	0.16	0.38	1.47	1.77	1.13	1.00	0.85	0.66	0.27	0.18	0.10	0.10	0.10	0.09	0.09	0.28
1983	0.03	0.04	0.16	0.13	0.26	0.35	0.74	2.45	2.41	1.30	1.03	0.83	0.63	0.26	0.17	0.10	0.09	0.09	0.09	0.34
1984	0.03	0.05	0.07	0.25	0.20	0.37	0.46	0.81	2.21	1.83	0.88	0.66	0.52	0.39	0.16	0.10	0.06	0.06	0.06	0.26
1985	0.05	0.07	0.15	0.19	0.69	0.53	0.88	0.93	1.35	3.11	2.31	1.05	0.77	0.60	0.44	0.18	0.12	0.07	0.06	0.36
1986	0.09	0.10	0.15	0.29	0.37	1.24	0.87	1.22	1.06	1.30	2.67	1.87	0.83	0.60	0.46	0.34	0.14	0.09	0.05	0.33
1987	0.11	0.24	0.25	0.36	0.71	0.85	2.57	1.54	1.75	1.28	1.40	2.73	1.86	0.82	0.59	0.45	0.34	0.14	0.09	0.37
1988	0.11	0.24	0.50	0.53	0.74	1.38	1.49	3.84	1.88	1.80	1.17	1.21	2.29	1.55	0.67	0.48	0.37	0.28	0.11	0.38
1989	0.44	0.59	1.30	2.64	2.72	3.60	6.02	5.46	11.37	4.63	3.94	2.42	2.43	4.55	3.06	1.33	0.95	0.73	0.54	0.96
1990	0.19	0.40	0.55	1.19	2.35	2.30	2.74	3.85	2.82	4.85	1.75	1.39	0.83	0.83	1.54	1.03	0.45	0.32	0.25	0.51
1991	0.15	0.34	0.73	0.98	2.08	3.90	3.45	3.48	3.99	2.44	3.75	1.27	0.99	0.58	0.58	1.07	0.72	0.31	0.22	0.52
1992	0.44	0.55	1.24	2.62	3.42	6.91	11.68	8.70	7.13	6.82	3.72	5.39	1.78	1.37	0.80	0.79	1.47	0.98	0.43	1.02
1993	1.21	1.69	2.09	4.65	9.59	11.81	21.26	29.86	17.74	11.97	10.12	5.18	7.29	2.38	1.82	1.06	1.05	1.94	1.30	1.92
1994	0.28	1.71	2.37	2.90	6.28	12.22	13.44	20.08	22.42	10.89	6.45	5.10	2.53	3.51	1.14	0.87	0.51	0.50	0.92	1.53
1995	0.10	0.24	1.44	1.99	2.37	4.88	8.56	7.93	9.59	8.89	3.83	2.13	1.64	0.80	1.11	0.36	0.27	0.16	0.16	0.77
1996	0.29	0.28	0.70	4.11	5.53	6.26	11.62	17.25	13.03	13.21	10.94	4.45	2.41	1.83	0.89	1.23	0.40	0.30	0.18	1.03
1997	0.12	0.50	0.48	1.20	6.89	8.81	9.01	14.15	17.10	10.81	9.77	7.62	3.01	1.61	1.22	0.59	0.82	0.26	0.20	0.80
1998	0.06	0.26	1.06	1.00	2.43	13.34	15.40	13.34	17.08	17.30	9.75	8.31	6.31	2.47	1.31	0.99	0.48	0.66	0.21	0.81
1999	0.09	0.12	0.46	1.86	1.71	3.96	19.59	19.18	13.56	14.55	13.16	7.00	5.80	4.36	1.69	0.90	0.68	0.33	0.45	0.70
2000	0.04	0.16	0.20	0.80	3.17	2.78	5.81	24.43	19.57	11.62	11.15	9.51	4.93	4.04	3.02	1.17	0.62	0.47	0.23	0.80
2001	0.03	0.06	0.23	0.29	1.12	4.27	3.39	6.03	20.82	14.04	7.46	6.76	5.62	2.88	2.35	1.75	0.68	0.36	0.27	0.59
2002	0.05	0.08	0.16	0.64	0.79	2.86	9.84	6.65	9.71	28.23	17.06	8.57	7.57	6.22	3.17	2.58	1.92	0.75	0.40	0.95
2003	0.01	0.05	0.08	0.16	0.60	0.71	2.33	6.85	3.80	4.68	12.21	6.97	3.41	2.98	2.44	1.24	1.01	0.75	0.29	0.52
2004	0.02	0.03	0.12	0.18	0.36	1.34	1.43	4.04	9.76	4.58	5.07	12.50	6.96	3.37	2.93	2.39	1.21	0.99	0.74	0.80
2005	0.03	0.06	0.09	0.30	0.45	0.84	2.82	2.56	5.95	12.16	5.13	5.37	12.89	7.10	3.42	2.97	2.42	1.23	1.00	1.55
2006	0.04	0.04	0.08	0.11	0.36	0.51	0.88	2.51	1.88	3.70	6.78	2.71	2.76	6.56	3.59	1.73	1.50	1.22	0.62	1.29
2007	0.09	0.12	0.13	0.23	0.31	1.01	1.30	1.90	4.48	2.84	5.01	8.70	3.38	3.41	8.07	4.41	2.12	1.84	1.50	2.34
2008	0.09	0.17	0.23	0.23	0.41	0.53	1.56	1.71	2.06	4.11	2.34	3.90	6.60	2.54	2.55	6.01	3.29	1.58	1.37	2.85

Table 7.4-- continued.

Male estimated catch at age in millions

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1980	0.06	0.07	0.12	0.31	1.17	1.65	1.86	2.13	1.76	1.20	0.67	0.63	0.51	0.49	0.47	0.45	0.45	0.45	0.45	0.45
1981	0.12	0.10	0.11	0.18	0.46	1.59	1.90	1.71	1.58	1.14	0.72	0.39	0.36	0.29	0.28	0.27	0.26	0.26	0.26	0.51
1982	0.03	0.11	0.10	0.10	0.17	0.38	1.14	1.10	0.81	0.65	0.44	0.27	0.14	0.13	0.11	0.10	0.10	0.09	0.09	0.28
1983	0.05	0.07	0.28	0.24	0.23	0.35	0.69	1.64	1.31	0.85	0.64	0.42	0.25	0.13	0.12	0.10	0.09	0.09	0.09	0.35
1984	0.04	0.09	0.12	0.43	0.35	0.31	0.41	0.66	1.29	0.90	0.55	0.40	0.26	0.16	0.08	0.08	0.06	0.06	0.06	0.27
1985	0.08	0.12	0.26	0.34	1.19	0.90	0.68	0.73	0.96	1.66	1.08	0.64	0.46	0.29	0.18	0.09	0.09	0.07	0.07	0.37
1986	0.15	0.17	0.25	0.51	0.64	2.08	1.33	0.82	0.72	0.83	1.35	0.86	0.50	0.36	0.23	0.14	0.07	0.07	0.05	0.34
1987	0.19	0.39	0.43	0.63	1.23	1.42	3.92	2.04	1.03	0.79	0.86	1.35	0.84	0.49	0.35	0.22	0.13	0.07	0.07	0.38
1988	0.18	0.41	0.85	0.92	1.28	2.30	2.27	5.07	2.16	0.96	0.69	0.72	1.12	0.70	0.40	0.29	0.18	0.11	0.06	0.37
1989	0.71	0.99	2.23	4.59	4.72	6.00	9.08	7.13	12.96	4.82	2.00	1.39	1.43	2.21	1.37	0.79	0.57	0.36	0.22	0.83
1990	0.31	0.68	0.94	2.08	4.09	3.83	4.12	4.98	3.16	4.98	1.72	0.69	0.47	0.48	0.74	0.46	0.27	0.19	0.12	0.35
1991	0.25	0.57	1.25	1.70	3.61	6.52	5.20	4.52	4.47	2.49	3.66	1.22	0.48	0.33	0.34	0.52	0.32	0.18	0.13	0.33
1992	0.72	0.92	2.12	4.57	5.95	11.52	17.63	11.31	8.02	6.94	3.60	5.12	1.69	0.66	0.45	0.46	0.71	0.44	0.25	0.63
1993	1.97	2.83	3.58	8.10	16.61	19.55	31.69	38.31	19.76	12.12	9.73	4.87	6.84	2.24	0.88	0.60	0.61	0.94	0.58	1.17
1994	0.46	2.85	4.07	5.05	10.87	20.19	19.89	25.38	24.48	10.85	6.14	4.76	2.35	3.27	1.07	0.42	0.28	0.29	0.45	0.84
1995	0.16	0.40	2.48	3.47	4.12	8.10	12.78	10.09	10.45	8.76	3.61	1.98	1.51	0.74	1.03	0.34	0.13	0.09	0.09	0.40
1996	0.47	0.46	1.19	7.16	9.62	10.44	17.50	22.28	14.42	13.08	10.24	4.09	2.21	1.68	0.82	1.14	0.37	0.15	0.10	0.55
1997	0.20	0.84	0.82	2.08	11.99	14.72	13.62	18.40	19.16	10.84	9.17	6.95	2.74	1.47	1.12	0.55	0.76	0.25	0.10	0.43
1998	0.11	0.43	1.82	1.75	4.24	22.30	23.33	17.43	19.29	17.58	9.28	7.61	5.70	2.23	1.20	0.91	0.44	0.62	0.20	0.43
1999	0.15	0.19	0.78	3.24	2.98	6.62	29.72	25.14	15.40	14.92	12.70	6.50	5.26	3.91	1.53	0.82	0.62	0.30	0.42	0.43
2000	0.06	0.27	0.35	1.39	5.53	4.66	8.83	32.13	22.32	11.99	10.86	8.96	4.52	3.64	2.70	1.06	0.57	0.43	0.21	0.59
2001	0.05	0.10	0.40	0.51	1.96	7.16	5.17	7.97	23.88	14.58	7.32	6.43	5.24	2.63	2.11	1.57	0.61	0.33	0.25	0.46
2002	0.08	0.13	0.28	1.11	1.37	4.80	15.02	8.81	11.20	29.50	16.85	8.21	7.12	5.77	2.89	2.32	1.72	0.67	0.36	0.78
2003	0.02	0.08	0.13	0.27	1.05	1.19	3.57	9.10	4.40	4.92	12.13	6.72	3.23	2.79	2.25	1.13	0.91	0.67	0.26	0.44
2004	0.04	0.06	0.21	0.32	0.63	2.26	2.19	5.38	11.35	4.84	5.07	12.14	6.64	3.18	2.74	2.21	1.11	0.89	0.66	0.69
2005	0.05	0.10	0.15	0.53	0.78	1.41	4.32	3.42	6.95	12.90	5.16	5.24	12.38	6.74	3.22	2.77	2.24	1.12	0.90	1.37
2006	0.07	0.07	0.13	0.19	0.63	0.86	1.35	3.36	2.20	3.94	6.85	2.66	2.67	6.27	3.41	1.63	1.40	1.13	0.56	1.14
2007	0.15	0.21	0.22	0.40	0.55	1.70	1.99	2.54	5.25	3.03	5.08	8.58	3.29	3.28	7.70	4.18	1.99	1.71	1.38	2.09
2008	0.15	0.29	0.39	0.41	0.71	0.90	2.40	2.29	2.41	4.39	2.37	3.86	6.44	2.45	2.45	5.73	3.11	1.48	1.28	2.59

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
2007	2,032,954	
2008	2,031,612	
2009	1,539,030	

Table 7.6—Total tonnage of northern rock sole caught in resource assessment trawl surveys on the Bering Sea shelf, 1977-2009.

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
2006	83
2007	76
2008	76
2009	62

Table 7-7 --Rock sole weight-at-age (grams) by age and year determined from 1983-2008 from length-at-age and length-weight relationships (missing values filled in) from the annual trawl survey in the eastern Bering Sea. Average wt vector at bottom of table was used in the stock assessment.

		Females																		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1982	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1983	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1984	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1985	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1986	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1987	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1988	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1989	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1990	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1991	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1992	9	14	29	56	101	159	233	312	386	441	517	531	573	634	666	730	810	862	844	817
1993	9	12	27	53	90	134	199	261	332	393	457	491	535	600	619	670	758	785	799	819
1994	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
1995	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
1996	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
1997	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
1998	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
1999	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
2000	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
2001	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
2002	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
2003	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
2004	9	13	26	51	90	134	201	230	294	359	405	461	485	545	552	581	659	651	711	758
2005	9	15	26	53	102	158	236	249	311	373	413	470	473	524	533	552	611	594	668	695
2006	9	17	25	54	114	181	272	269	327	387	421	479	462	504	514	523	562	537	626	632
2007	9	17	25	54	114	181	272	269	327	387	421	479	462	504	514	523	562	537	626	632
2008	9	17	25	54	114	181	272	269	327	387	421	479	462	504	514	523	562	537	626	632

Table 7.7 continued.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1982	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1983	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1984	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1985	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1986	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1987	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1988	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1989	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1990	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1991	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1992	7	11	16	32	59	99	152	203	244	250	299	295	311	336	355	339	435	379	384	386
1993	7	11	20	38	63	97	151	194	233	241	286	289	309	318	343	348	414	416	402	412
1994	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
1995	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
1996	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
1997	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
1998	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
1999	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
2000	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
2001	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
2002	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
2003	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
2004	7	11	23	47	86	114	166	201	228	243	276	291	309	303	319	358	369	418	387	403
2005	7	12	23	51	104	132	181	218	234	254	279	300	311	305	308	359	345	383	354	369
2006	7	13	23	55	123	149	196	234	241	265	282	308	314	307	297	360	321	348	321	335
2007	7	13	23	55	123	149	196	234	241	265	282	308	314	307	297	360	321	348	321	335
2008	7	13	23	55	123	149	196	234	241	265	282	308	314	307	297	360	321	348	321	335

Table 7-8.--Mean length-at-age (cm) from the average of annual mean length at age and proportion mature for female Bering Sea rock sole from histological examination of ovaries collected from the 2006 fishery (Stark In Prep).

age	female length at age	male length at age	proportion mature
1	7.5	8.8	0.00
2	11.3	11.0	0.00
3	14.0	13.6	0.00
4	17.2	17.1	0.00
5	20.7	20.4	0.01
6	23.8	22.9	0.01
7	26.9	25.8	0.06
8	29.0	27.3	0.20
9	31.1	28.1	0.51
10	32.8	29.0	0.75
11	34.3	29.7	0.89
12	35.1	30.1	0.93
13	35.8	30.7	0.96
14	37.0	30.9	0.98
15	37.4	30.9	0.98
16	38.3	32.4	0.99
17	39.5	32.1	0.99
18	39.9	33.1	0.99
19	40.2	32.3	0.99
20	40.3	31.3	0.99

Table 7.9—Survey sample sizes of occurrence of northern rock sole and biological collections.

Year	Total hauls	Hauls with length	# of lengths	hauls with otoliths	# otoliths collected	# otoliths aged
1982	334	139	16874	32	312	312
1983	353	149	16285	14	444	444
1984	355	174	18203	22	458	454
1985	358	229	20891	25	571	571
1986	354	310	26078	14	404	404
1987	360	273	26167	6	422	422
1988	373	295	27671	14	350	350
1989	373	307	27434	22	675	675
1990	371	307	31769	30	634	634
1991	372	300	31059	20	551	551
1992	356	299	27188	17	525	525
1993	375	333	27624	12	443	443
1994	376	326	26793	18	467	466
1995	376	340	26764	14	434	378
1996	375	352	35230	14	500	496
1997	376	351	34927	10	339	336
1998	375	362	44055	22	409	405
1999	373	329	34086	26	490	484
2000	372	336	31953	23	410	403
2001	375	341	30113	24	418	411
2002	375	337	27563	34	503	283
2003	376	321	29520	34	518	506
2004	375	338	33373	12	407	401
2005	373	337	31048	19	417	407
2006	376	317	35470	44	539	539
2007	376	332	28467	46	485	463
2008	375	307	29422	23	370	370
2009	376	310	27994	66	599	

Table 7.10--Estimated population numbers-at-age (millions) from the annual Bering Sea trawl surveys, 1982- 2008.

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
2006	0	433	2,552	4,607	2,018	1,285	418	302	348	457	273	149	197	109	420	492	287	127	339	265
2007	1	85	836	1,929	2,179	1,638	1,067	493	173	507	211	210	214	207	302	274	162	156	152	153
2008	1,048	1,066	1,553	1,976	1,586	894	227	225	344	254	149	32	93	129	274	287	60	300	0	0

Table 7.11--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
$qprior = \lambda \frac{0.5(\ln q_{est} - \ln q_{prior})^2}{\sigma_q^2}$	survey catchability prior
$mprior = \lambda \frac{0.5(\ln m_{est} - \ln m_{prior})^2}{\sigma_m^2}$	natural mortality prior

$$reclike = \lambda(\sum_{i=1965}^{endyear} \bar{R} - R_i)^2 + \sum_{a=1}^{20} (\bar{R}_{init} - R_{init,a})^2 + \frac{1}{2((\sum_{i=1965}^{endyear} \bar{R} - R_i)\frac{1}{n+1})})$$

recruitment likelihood

$$catchlike = \lambda \sum_{i=startyear}^{endyear} (\ln C_{obs,i} - \ln C_{est,i})^2$$

catch likelihood

$$surveylike = \lambda \frac{(\ln B - \ln \hat{B})^2}{2\sigma^2}$$

survey likelihood

$$SurvAgelike = \sum_{i,t} m_t P_{t,a} \ln \frac{\hat{P}_{t,a}}{P_{t,a}}$$

survey age composition likelihood

$$FishAgelike = \sum_{i,t} m_t P_{t,a} \ln \frac{\hat{P}_{t,a}}{P_{t,a}}$$

fishery age composition likelihood

Table 7.12--Variables used in the population dynamics model.

Variables	
R_t	Age 1 recruitment in year *t*
R_0	Geometric mean value of age 1 recruitment, 1956-75
R_γ	Geometric mean value of age 1 recruitment, 1976-96
τ_t	Recruitment deviation in year *t*
$N_{t,a}$	Number of fish in year *t* at age *a*
$C_{t,a}$	Catch numbers of fish in year *t* at age *a*
$P_{t,a}$	Proportion of the numbers of fish age *a* in year *t*
C_t	Total catch numbers in year *t*
$W_{t,a}$	Mean body weight (kg) of fish age *a* in year *t*
ϕ_a	Proportion of mature females at age *a*
$F_{t,a}$	Instantaneous annual fishing mortality of age *a* fish in year *t*
M	Instantaneous natural mortality, assumed constant over all ages and years
$Z_{t,a}$	Instantaneous total mortality for age *a* fish in year *t*
s_a	Age-specific fishing gear selectivity
μ^F	Median year-effect of fishing mortality
ε_t^F	The residual year-effect of fishing mortality
ν_a	Age-specific survey selectivity
α	Slope parameter in the logistic selectivity equation
β	Age at 50% selectivity parameter in the logistic selectivity equation
σ_t	Standard error of the survey biomass in year *t*

Table 7.13--Model estimates of rock sole fishing mortality and exploitation rate (catch/total biomass).

year	Full selection F	Exploitation rate
1975	0.149	0.068
1976	0.112	0.052
1977	0.052	0.026
1978	0.059	0.031
1979	0.044	0.024
1980	0.062	0.032
1981	0.059	0.029
1982	0.071	0.033
1983	0.073	0.033
1984	0.191	0.076
1985	0.086	0.033
1986	0.075	0.028
1987	0.132	0.049
1988	0.245	0.085
1989	0.167	0.061
1990	0.069	0.028
1991	0.096	0.040
1992	0.081	0.036
1993	0.083	0.039
1994	0.071	0.037
1995	0.061	0.035
1996	0.043	0.027
1997	0.058	0.039
1998	0.027	0.020
1999	0.032	0.024
2000	0.039	0.030
2001	0.024	0.018
2002	0.035	0.027
2003	0.031	0.023
2004	0.045	0.032
2005	0.037	0.024
2006	0.040	0.023
2007	0.041	0.022
2008	0.056	0.029

Table 7.14 --Model estimates of rock sole age-specific fishery and survey selectivities.

Age	Fishery (1980-2008) males	females	Survey (1982-2008) males	females
1	0.00	0.00	0.01	0.01
2	0.01	0.00	0.06	0.04
3	0.02	0.01	0.39	0.24
4	0.05	0.03	0.87	0.69
5	0.11	0.06	0.99	0.94
6	0.23	0.14	1.00	0.99
7	0.43	0.28	1.00	1.00
8	0.65	0.48	1.00	1.00
9	0.82	0.69	1.00	1.00
10	0.92	0.84	1.00	1.00
11	0.97	0.93	1.00	1.00
12	0.99	0.97	1.00	1.00
13	0.99	0.99	1.00	1.00
14	1.00	0.99	1.00	1.00
15	1.00	1.00	1.00	1.00
16	1.00	1.00	1.00	1.00
17	1.00	1.00	1.00	1.00
18	1.00	1.00	1.00	1.00
19	1.00	1.00	1.00	1.00
20	1.00	1.00	1.00	1.00

Table 7-15.--Model estimates of rock sole age 2+ total biomass (t) and female spawning biomass (t) from the 2008 and 2009 assessments.

	2008 Assessment		2009 Assessment	
	Age 2+ Total biomass	Female Spawning biomass	Age 2+ Total biomass	Female Spawning biomass
1975	162,245	28,175	177,461	49,696
1976	181,601	47,981	192,717	53,446
1977	195,815	54,241	207,092	60,634
1978	213,909	63,041	227,042	74,206
1979	235,562	71,034	246,213	88,603
1980	263,911	78,298	274,170	99,620
1981	297,070	83,495	313,125	104,246
1982	346,253	89,156	360,320	107,030
1983	403,119	95,524	417,714	113,149
1984	477,696	103,167	495,345	124,035
1985	550,587	104,360	568,606	124,795
1986	663,853	118,892	689,540	140,114
1987	797,749	139,711	840,739	158,678
1988	935,351	160,810	1,012,790	182,136
1989	1,042,480	176,466	1,127,400	205,398
1990	1,175,130	206,095	1,276,130	248,734
1991	1,361,840	254,312	1,511,990	316,385
1992	1,521,660	302,392	1,601,600	349,013
1993	1,659,440	360,399	1,624,970	377,421
1994	1,769,460	426,004	1,609,480	399,774
1995	1,831,510	494,323	1,671,500	480,785
1996	1,852,000	559,088	1,709,980	578,688
1997	1,864,490	616,336	1,742,970	661,617
1998	1,812,160	648,844	1,710,630	701,288
1999	1,760,150	675,700	1,690,090	745,334
2000	1,696,630	686,653	1,649,050	773,574
2001	1,613,240	681,229	1,587,440	771,844
2002	1,551,420	665,509	1,545,880	753,292
2003	1,512,540	639,858	1,511,220	726,387
2004	1,504,710	613,108	1,495,530	671,146
2005	1,516,080	571,686	1,495,500	594,501
2006	1,580,440	540,960	1,581,890	531,661
2007	1,664,730	522,575	1,671,730	500,180
2008	1,754,700		1,740,370	479,705
2009			1,765,910	484,516

Table 7.16--Estimated age 4 recruitment of rock sole (thousands of fish) from the 2008 and 2009 assessments. Average of 1971-2004 (2009 assessment) is 1,617,212.

Year class	2008 Assessment	2009 Assessment
1971	164,619	156,417
1972	134,384	128,434
1973	183,602	176,429
1974	191,830	184,950
1975	465,912	450,056
1976	262,376	253,896
1977	414,340	401,954
1978	418,928	407,948
1979	593,406	580,384
1980	1,136,824	1,118,992
1981	1,130,560	1,123,264
1982	1,043,472	1,050,126
1983	1,563,712	1,600,284
1984	1,472,226	1,538,868
1985	1,318,154	1,406,248
1986	2,164,380	2,342,500
1987	3,176,540	3,464,260
1988	1,095,788	1,195,264
1989	891,354	978,944
1990	1,940,826	2,115,800
1991	951,864	1,056,624
1992	494,976	550,304
1993	827,018	890,694
1994	423,232	457,910
1995	417,940	461,498
1996	579,576	621,464
1997	331,880	367,214
1998	454,700	531,834
1999	585,912	606,462
2000	1,191,614	1,204,932
2001	1,970,498	1,881,762
2002	2,332,360	2,046,540
2003	1,838,274	1,484,858
2004		986,386

Table 7.17—Model estimates of population number by age, year and sex.

Females (millions of fish)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	145	119	75	78	154	110	51	40	32	25	10	7	4	4	4	3	3	3	3	3
1976	353	125	103	64	67	132	93	43	32	25	19	8	5	3	3	3	3	3	3	5
1977	199	304	108	88	55	57	112	78	35	25	20	15	6	4	2	2	2	2	2	6
1978	316	171	262	92	76	47	49	95	65	29	21	16	12	5	3	2	2	2	2	6
1979	320	272	148	225	79	65	40	41	79	54	24	17	13	10	4	3	1	1	1	7
1980	456	276	234	127	193	68	56	34	35	66	45	19	14	11	8	3	2	1	1	6
1981	879	392	237	201	109	166	58	47	29	29	54	36	16	11	9	6	3	2	1	6
1982	883	756	337	204	173	94	142	49	39	24	24	44	30	13	9	7	5	2	1	6
1983	825	760	651	290	175	148	80	120	41	32	19	19	35	24	10	7	6	4	2	6
1984	1257	710	654	559	249	150	126	67	99	34	26	15	15	28	19	8	6	5	3	6
1985	1209	1081	611	562	479	212	126	103	53	75	25	19	11	11	20	13	6	4	3	7
1986	1107	1041	930	525	482	410	180	106	85	43	60	20	15	9	9	16	11	5	3	8
1987	1843	952	895	800	451	413	349	152	88	70	35	48	16	12	7	7	13	9	4	9
1988	2722	1586	819	769	686	385	349	290	123	69	54	26	36	12	9	5	5	10	6	9
1989	939	2342	1363	703	658	582	320	281	222	89	48	37	18	25	8	6	4	3	6	11
1990	769	808	2014	1171	602	560	489	263	223	170	67	36	27	13	18	6	4	3	3	13
1991	1662	662	695	1732	1006	516	478	413	219	183	138	54	29	22	11	14	5	4	2	12
1992	830	1430	569	598	1487	861	439	401	340	177	145	109	42	22	17	8	11	4	3	11
1993	432	714	1230	489	513	1274	733	369	332	277	142	116	87	34	18	13	7	9	3	11
1994	699	372	614	1058	420	440	1084	617	305	270	222	113	92	69	27	14	11	5	7	11
1995	359	602	320	528	909	360	375	915	513	250	219	179	91	74	55	21	11	9	4	15
1996	362	309	518	275	454	779	307	317	765	423	205	178	145	74	60	45	17	9	7	15
1997	488	312	266	445	237	390	667	262	267	639	351	169	147	120	61	49	37	14	8	18
1998	288	420	268	229	383	203	333	565	219	221	524	287	138	119	97	49	40	30	12	21
1999	417	248	361	231	197	329	174	284	480	185	186	439	240	115	100	82	41	34	25	27
2000	476	359	213	311	198	169	282	148	241	404	155	155	367	200	96	83	68	34	28	44
2001	945	410	309	184	267	170	145	240	125	202	336	129	129	304	166	80	69	56	29	59
2002	1477	814	352	266	158	230	146	124	204	106	170	283	108	108	255	139	67	58	47	74
2003	1606	1271	700	303	229	136	197	125	105	172	89	142	236	90	90	212	116	56	48	101
2004	1165	1382	1094	602	261	196	116	168	106	88	144	74	119	197	75	75	177	97	46	124
2005	774	1003	1189	941	518	224	168	99	141	88	73	119	61	98	162	62	62	146	80	140
2006	911	666	863	1023	809	445	192	143	84	119	74	61	99	51	81	134	51	51	121	182
2007	419	784	573	742	880	695	381	163	121	70	99	61	50	82	42	67	111	42	42	251
2008	622	360	675	493	638	755	594	324	138	101	58	82	50	42	67	35	55	92	35	242
2009	671	536	310	580	424	547	645	504	271	114	83	48	67	41	34	55	28	45	75	225

Males (millions of fish)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	145	61	44	48	79	52	32	25	16	10	5	5	4	4	4	4	3	4	4	4
1976	353	125	52	38	41	67	44	26	19	12	8	4	4	3	3	3	3	3	3	5
1977	199	304	107	45	32	35	56	36	21	15	10	6	3	3	2	2	2	2	2	6
1978	316	171	262	92	39	28	30	47	30	17	12	8	5	3	2	2	2	2	2	7
1979	320	272	148	225	79	33	23	25	39	24	14	10	6	4	2	2	1	1	1	7
1980	456	276	234	127	193	68	28	20	21	32	20	12	8	5	3	2	2	1	1	7
1981	879	392	237	201	109	165	58	24	16	17	26	16	9	7	4	3	1	1	1	6
1982	883	756	337	204	172	93	140	48	20	13	14	21	13	8	5	3	2	1	1	6
1983	825	760	650	290	175	147	79	117	40	16	11	11	17	11	6	4	3	2	1	6
1984	1257	710	654	559	249	149	125	66	96	32	13	9	9	14	9	5	4	2	1	5
1985	1209	1081	610	561	477	210	123	99	50	71	23	9	6	6	10	6	3	3	2	5
1986	1107	1040	930	524	481	407	177	102	80	40	56	18	7	5	5	8	5	3	2	5
1987	1843	952	895	799	450	410	344	147	84	65	32	45	15	6	4	4	6	4	2	5
1988	2722	1586	819	768	684	382	342	280	116	65	50	24	34	11	4	3	3	5	3	6
1989	939	2341	1362	701	654	573	310	265	205	82	44	34	16	23	7	3	2	2	3	6
1990	769	808	2012	1169	599	553	475	249	205	154	61	32	25	12	17	5	2	1	1	7
1991	1662	662	695	1730	1003	512	468	397	205	167	125	49	26	20	10	13	4	2	1	6
1992	830	1430	569	597	1482	854	431	387	321	163	131	98	38	20	15	8	11	3	1	6
1993	432	714	1230	489	512	1265	721	358	316	258	130	105	78	30	16	12	6	8	3	6
1994	699	372	614	1057	419	437	1068	599	292	254	206	103	83	62	24	13	10	5	7	7
1995	359	602	320	528	907	358	370	892	493	237	205	166	83	67	49	19	10	8	4	11
1996	362	309	518	275	453	775	304	310	738	403	193	166	134	67	54	40	16	8	6	12
1997	488	312	266	445	236	388	661	257	259	613	334	159	137	111	55	44	33	13	7	15
1998	288	420	268	229	382	202	330	555	213	213	500	272	130	111	90	45	36	27	10	18
1999	417	248	361	231	197	328	173	280	469	179	179	419	227	109	93	75	38	30	22	24
2000	476	359	213	311	198	169	280	147	236	393	150	149	350	190	90	78	63	31	25	38
2001	945	410	309	184	267	170	144	237	123	197	326	124	123	289	157	75	64	52	26	53
2002	1477	814	352	266	158	229	145	123	201	104	166	275	104	104	243	132	63	54	44	66
2003	1606	1271	700	303	228	135	196	123	103	168	87	138	228	87	86	202	110	52	45	91
2004	1165	1382	1094	602	261	196	116	166	104	87	141	72	115	191	72	72	169	92	44	114
2005	774	1003	1189	940	517	223	167	98	139	86	71	116	60	95	157	60	59	139	75	129
2006	911	666	863	1023	808	443	190	141	82	116	72	59	96	49	79	130	49	49	115	170
2007	419	784	573	742	879	692	378	161	119	68	96	59	49	79	41	65	108	41	41	236
2008	622	360	675	493	637	753	590	320	135	99	57	80	49	41	66	34	54	89	34	228
2009	671	536	310	580	423	545	640	496	265	111	81	46	65	40	33	53	27	44	72	213

Table 7.18—Stock assessment model estimates of the number of female spawners (millions).

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	1	3	8	16	19	9	6	4	4	4	3	3	3	3	3
1976	1	6	9	16	19	17	7	5	3	3	3	3	3	3	5
1977	0	7	16	18	19	17	14	6	4	2	2	2	2	2	6
1978	0	3	19	33	22	18	15	11	5	3	2	2	2	2	6
1979	1	2	8	40	40	21	16	13	10	4	3	1	1	1	6
1980	1	3	7	18	50	40	18	13	11	8	3	2	1	1	6
1981	1	4	9	14	22	48	34	15	11	9	6	3	2	1	6
1982	1	9	10	20	18	21	41	28	13	9	7	5	2	1	6
1983	1	5	24	21	24	17	18	34	23	10	7	6	4	2	6
1984	1	8	13	50	25	23	14	15	28	19	8	6	5	3	6
1985	2	8	21	27	56	22	17	11	11	20	13	6	4	3	7
1986	3	11	21	43	32	53	18	14	9	8	16	11	5	3	8
1987	3	21	30	44	52	31	45	15	12	7	7	13	8	4	9
1988	3	21	58	62	52	48	24	35	12	9	5	5	10	6	9
1989	5	20	56	112	67	43	34	17	24	8	6	4	3	6	11
1990	4	30	53	113	128	59	33	26	13	18	6	4	3	3	12
1991	4	29	83	111	137	123	50	27	21	10	14	5	4	2	12
1992	7	27	80	172	133	129	101	40	22	17	8	11	4	3	11
1993	10	45	74	167	207	126	108	83	33	18	13	6	9	3	11
1994	4	66	123	154	202	197	105	88	67	26	14	11	5	7	11
1995	3	23	183	259	188	194	166	87	73	54	21	11	9	4	14
1996	6	19	63	386	317	182	165	139	72	59	44	17	9	7	15
1997	3	41	52	135	479	312	157	140	117	60	49	37	14	8	18
1998	2	20	113	111	166	465	266	132	117	96	49	40	30	12	21
1999	3	11	57	242	139	165	408	229	113	98	81	41	34	25	27
2000	1	17	30	122	303	138	144	350	196	95	83	68	34	28	43
2001	1	9	48	63	151	299	119	123	297	163	79	69	56	28	59
2002	2	9	25	103	80	151	263	103	106	251	138	67	58	47	74
2003	1	12	25	53	129	79	132	225	88	88	210	115	55	48	100
2004	2	7	34	53	66	128	69	113	193	74	74	176	96	46	124
2005	2	10	20	71	66	65	110	58	96	159	61	62	145	79	140
2006	4	12	29	42	89	65	57	94	50	80	133	51	51	121	182
2007	6	23	33	61	52	88	57	48	80	41	66	111	42	42	250
2008	6	36	65	70	76	52	76	48	41	66	34	55	91	35	241
2009	4	39	101	137	85	74	44	64	40	33	54	28	45	74	225

Table 7.19—Selected parameter estimates and their stand deviations from the preferred stock assessment model run.

	name	value	standard deviation		name	value	standard deviation
	mean_log_recruitment	0.295	0.126	1983	total biomass	417.710	10.962
	sel_slope_fishery	0.879	0.027	1984	total biomass	495.350	11.519
	sel50_fishery	8.093	0.111	1985	total biomass	568.610	12.203
	sel_slope_fsh_males	0.035	0.040	1986	total biomass	689.540	13.347
	sel50_fsh_males	-0.101	0.014	1987	total biomass	840.740	14.737
	sel_slope_srrvey	1.958	0.118	1988	total biomass	1012.800	16.601
	sel50_survey	3.587	0.065	1989	total biomass	1127.400	18.589
	sel_slope_survey_males	0.198	0.080	1990	total biomass	1276.100	20.841
	sel50_survey_males	-0.119	0.020	1991	total biomass	1512.000	23.742
	F40	0.155	0.003	1992	total biomass	1601.600	25.005
	F35	0.186	0.004	1993	total biomass	1625.000	25.693
	F30	0.227	0.005	1994	total biomass	1609.500	26.076
	Ricker_logalpha	-3.940	0.197	1995	total biomass	1671.500	27.989
	Ricker_logbeta	-5.701	0.137	1996	total biomass	1710.000	29.639
	Fmsyr	0.154	0.019	1997	total biomass	1743.000	31.075
	logFmsyr	-1.869	0.120	1998	total biomass	1710.600	31.867
	ABC_biom1	1567.000	68.924	1999	total biomass	1690.100	32.231
	ABC_biom2	1579.800	81.835	2000	total biomass	1649.100	32.379
	msy	289.540	45.859	2001	total biomass	1587.400	32.296
	Bmsy	242.100	24.291	2002	total biomass	1545.900	32.213
1975	total biomass	177.460	7.835	2003	total biomass	1511.200	32.701
1976	total biomass	192.720	8.390	2004	total biomass	1495.500	34.333
1977	total biomass	207.090	8.878	2005	total biomass	1495.500	38.050
1978	total biomass	227.040	9.270	2006	total biomass	1581.900	46.100
1979	total biomass	246.210	9.522	2007	total biomass	1671.700	55.080
1980	total biomass	274.170	9.795	2008	total biomass	1740.400	64.603
1981	total biomass	313.130	10.136	2009	total biomass	1765.900	74.563

Table 7.20. Results of the northern rock sole Tier 1 analysis from 11 models that use different levels of uncertainty in the estimates of fishery selectivity, natural mortality, catchability and recruitment variability. Values that change between runs are highlighted.

	Years used in S/R fit	Selectivity CV	q sigma	M sigma	R sigma	F_{MSY}	Harmonic mean of F_{MSY}	% reduction in F_{msy}
Model 1	1978-2004	0.2	0.056	0.2	0.6	0.155	0.153	1.4
Model 2	1989-2004	0.2	0.056	0.2	0.6	0.098	0.088	9.6
Model 3	1978-1990	0.2	0.056	0.2	0.6	0.143	0.141	1.4
Model 4	1978-2004	0.8	0.056	0.2	0.6	0.156	0.153	2.4
Model 5	1978-2004	0.2	0.4	0.2	0.6	0.155	0.153	1.4
Model 6	1978-2004	0.2	0.8	0.2	0.6	0.155	0.153	1.4
Model 7	1978-2004	0.2	0.056	0.4	0.6	0.155	0.153	1.4
Model 8	1978-2004	0.2	0.056	0.8	0.6	0.155	0.153	1.4
Model 9	1978-2004	0.2	0.056	0.2	0.8	0.156	0.152	2.4
Model 10	1978-2004	0.2	0.056	0.2	1.0	0.157	0.151	3.7
Model 11	1978-2004	0.2	0.056	0.2	1.2	0.158	0.150	5.3

Table 7.21--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. 2009 ABC is highlighted.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2009	484,518	46,910	0.05
2010	517,590	**152,792**	0.15
2011	517,584	147,527	0.15
2012	511,923	140,271	0.15
2013	485,477	129,864	0.15
2014	449,061	119,161	0.15
2015	406,912	109,886	0.15
2016	369,666	103,621	0.15
2017	346,068	98,406	0.15
2018	336,214	94,448	0.14
2019	340,143	95,194	0.14
2020	345,999	96,618	0.14
2021	352,673	98,601	0.14
2022	356,494	99,808	0.14

Scenario 3
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2009	484,518	46,910	0.05
2010	521,864	45,283	0.04
2011	571,002	47,545	0.04
2012	613,402	48,899	0.04
2013	629,151	48,758	0.04
2014	625,869	47,803	0.04
2015	607,545	46,543	0.04
2016	585,306	45,610	0.04
2017	571,218	45,438	0.04
2018	565,573	45,600	0.04
2019	573,695	46,247	0.04
2020	583,228	46,880	0.04
2021	594,734	47,649	0.04
2022	602,450	48,132	0.04

Scenario 4
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2009	484,518	46,910	0.05
2010	520,661	76,396	0.07
2011	555,490	77,277	0.07
2012	583,444	77,782	0.07
2013	585,663	75,974	0.07
2014	570,915	73,096	0.07
2015	543,497	70,033	0.07
2016	514,653	67,785	0.07
2017	495,622	66,950	0.07
2018	486,486	66,802	0.07
2019	490,938	67,486	0.07
2020	497,197	68,185	0.07
2021	505,333	69,091	0.07
2022	510,331	69,621	0.07

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2009	484,518	46,910	0.05
2010	523,568	0	0
2011	593,777	0	0
2012	659,493	0	0
2013	698,509	0	0
2014	716,427	0	0
2015	716,448	0	0
2016	709,126	0	0
2017	707,536	0	0
2018	711,974	0	0
2019	730,391	0	0
2020	749,425	0	0
2021	770,463	0	0
2022	786,301	0	0

Table 7.21—continued.

Scenario 6
Determination of whether northern rock sole are currently overfished **B35=309,000**

Year	Female spawning biomass	catch	F
2009	484,518	46,910	0.05
2010	516,366	182,027	0.19
2011	503,223	171,639	0.19
2012	486,218	159,659	0.19
2013	451,142	144,855	0.19
2014	409,153	130,648	0.19
2015	364,116	118,944	0.19
2016	326,497	103,178	0.17
2017	307,086	95,465	0.16
2018	302,331	94,756	0.16
2019	309,196	98,426	0.16
2020	316,441	101,620	0.16
2021	323,304	104,632	0.16
2022	326,827	106,255	0.17

Scenario 7
Determination of whether the stock is approaching an overfished condition **B35=309,000**

Year	Female spawning biomass	catch	F
2009	484,518	46,910	0.05
2010	517,590	152,792	0.15
2011	517,584	147,527	0.15
2012	510,700	167,015	0.19
2013	471,410	150,762	0.19
2014	425,193	135,231	0.19
2015	376,459	122,406	0.19
2016	335,685	108,480	0.18
2017	312,737	98,552	0.16
2018	305,736	96,514	0.16
2019	311,170	99,370	0.16
2020	317,545	102,103	0.16
2021	323,885	104,865	0.16
2022	327,099	106,350	0.17

Table 7.22—Northern rock sole ABC and TAC used to manage the resource since 1989.

	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
2007	55,000	198,000
2008	75,000	301,000
2009	90,000	296,000

Table 7.23—Catch and bycatch in the rock sole target fisheries, 1992-2008, from blend of regional office reported catch and observer sampling.

Species	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Walleye Pollock	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	6,922	3,212	4,995
Arrowtooth Flounder	473	1,143	1,782	507	1,341	411	300	69	216	835	314	419	346	599	516	220	464
Pacific Cod	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	4,901	3,238	3,927
Groundfish, General	3,000	3,091	3,266	1,605	1,581	1,381	909	537	1,186	1,198	692	978	801	910	1,605	1,807	3
Rock Sole	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	20,129	21,217	35,180
Flathead Sole		2,140	1,702	1,147	1,302	2,373	1,223	575	1,806	1,051	771	744	881	850	1,691	1,061	1,945
Sablefish	0	4	16	3	3	1	0	2	5	12	4	2	9			3	1
Atka Mackerel	10	15	0		0	0	9	0	38	3	0	1	16	48	87	210	4
Pacific Ocean Perch	10	15	62	4	2		1	0	0	0	0					<1	
Rex Sole		79	145	108	48	11	12	5	4	18	7						33
Flounder, General	4,550	2,221	2,756	1,636	1,591	1,498	342	362	1,184	726	307	783	820	937	620	1,009	2
Shortraker/Rougheye	0	2	21				1										
Butter Sole		38	11	1	5	79	53	38	156	72	94						560
Starry Flounder		230	85	0	1	99	72	34	214	152	329						622
Northern Rockfish			29					2			1					4	<1
Yellowfin Sole	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	9,983	8,916	12,903
Greenland Turbot	3	28	50	3	3	2	1	0	1	15	0	1	4	1	27	8	
Alaska Plaice		2,561	931	173	71	408	250	63	385	75	621	375	1,111	1,352	1,828	1,810	2,710
Sculpin, General									9	2	271						1,104
Skate, General									1	5	306						559

Table 7.24—Non-target species catch in the northern rock sole fishery.

	2003	2004	2005	2006	2007	2008	2009
Benthic urochordata	118.7	220.9	318.8	97.7	12.7	31.0	8.3
Birds albastross/Jaeger	0.0	0.0	0.0	0.1	0.7	0.0	0.2
murres	0.0	0.0	0.2	0.0	0.0	0.0	0.0
other birds	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bivalves	4.7	0.3	0.2	0.4	0.4	0.3	0.3
Brittle star unidentified	0.0	0.9	1.8	7.1	1.5	1.1	0.3
Capelin	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Corals Bryozoans	0.7	0.7	0.0	0.9	0.0	0.1	0.0
Eelpouts	1.0	4.3	2.2	3.1	6.9	1.3	0.0
Eulachon	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Giant Grenadier	0.0	0.0	0.0	0.0	4.6	0.1	0.0
Greenlings	1.2	0.3	0.4	0.3	0.3	0.0	0.0
Grenadier	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Hermit crab unidentified	19.2	7.2	7.6	9.0	5.8	2.7	0.5
Invertebrate unidentified	105.9	3.1	84.2	6.5	24.2	1.6	2.4
Large Sculpins	183.6	252.6	439.5	460.8	630.6	1060.9	1224.9
Misc crabs	18.8	6.4	9.3	6.4	13.6	8.9	3.2
Misc crustaceans	0.4	0.2	0.0	0.5	0.2	0.2	0.2
Misc fish	12.9	16.9	22.4	16.7	70.9	25.2	11.2
Misc inverts (worms etc)	0.0	0.1	0.0	0.0	0.1	0.0	0.0
Octopus	19.3	21.5	13.5	0.7	4.4	9.4	7.3
Other osmerids	3.7	0.1	0.7	0.3	0.2	0.6	0.1
Other Sculpins	255.2	17.2	34.6	182.4	131.4	32.9	32.0
Pacific Sand lance	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Pandalid shrimp	0.2	0.1	0.0	0.0	0.1	0.0	0.1
Polychaete unidentified	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Scypho jellies	257.8	304.9	393.5	73.2	94.4	185.2	209.2
Sea anemone unidentified	18.4	13.3	6.5	9.0	6.3	6.7	2.5
Sea pens whips	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sea star	1171.1	333.4	555.4	717.8	710.4	207.2	26.9
Shark, pacific sleeper	0.0	0.0	1.4	0.0	4.3	0.5	0.0
Shark, salmon	0.5	0.0	0.1	0.0	0.0	0.0	0.0
Shark, spiny dogfish	0.0	0.0	0.0	0.0	0.3	0.2	0.0
Skate, Big	0.0	13.0	20.1	13.2	15.6	37.0	4.4
Skate, Longnose	1.1	0.0	0.0	0.0	0.9	0.8	0.0
Skate, Other	528.6	495.6	403.0	902.8	983.9	521.7	913.0
Snails	23.8	24.0	12.9	25.3	24.4	9.3	2.4
Sponge unidentified	198.4	67.6	69.9	41.0	19.2	19.3	64.6
Squid	0.0	0.3	0.0	0.0	0.4	0.0	0.0
Stichaeidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0
urchins dollars cucumbers	13.4	8.9	9.3	3.9	32.2	6.0	0.5

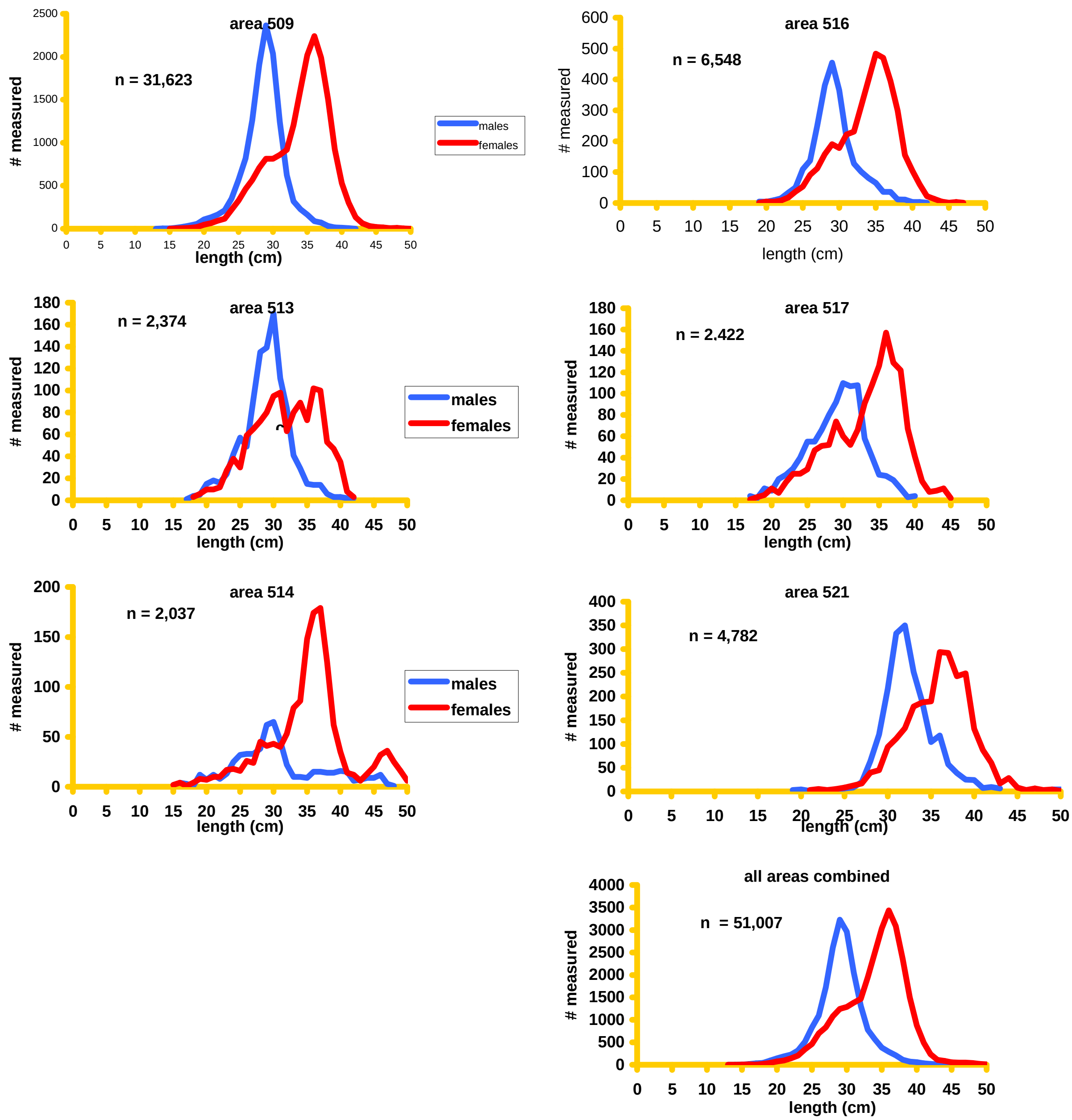
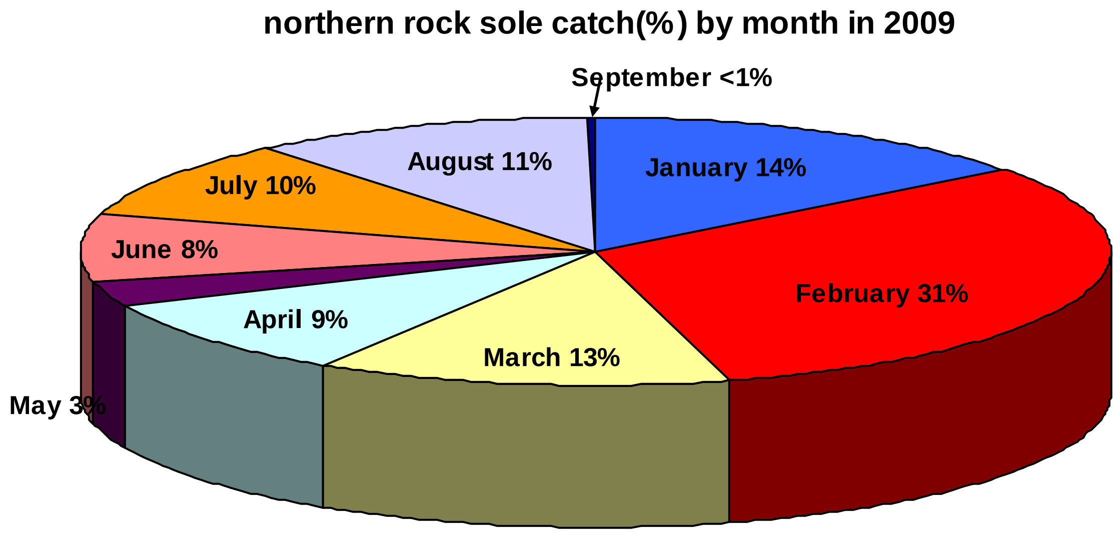


Figure 7.1—Size composition of rock sole, by sex and area, in the 2009 catch as determined from observer sampling.



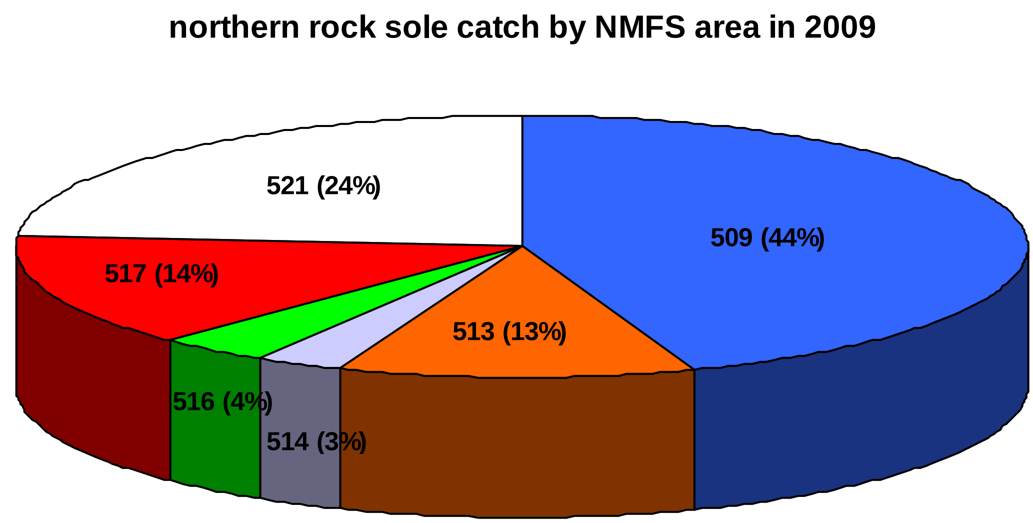
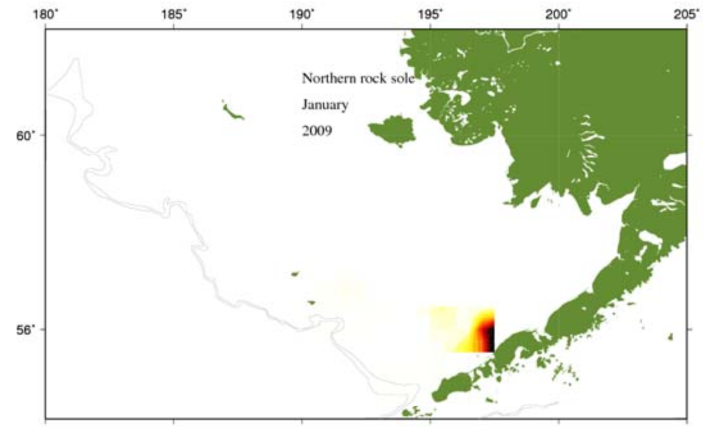


Figure 7.2—Bering Sea northern rock sole fishery catch by month and area in 2008 (percent of total).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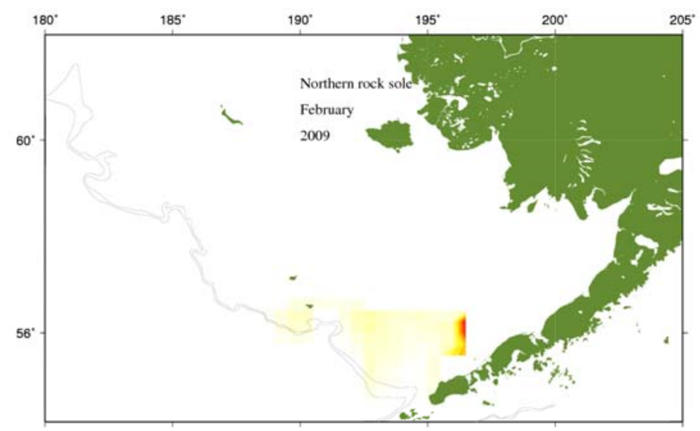
56˚
Northern rock sole
January
2009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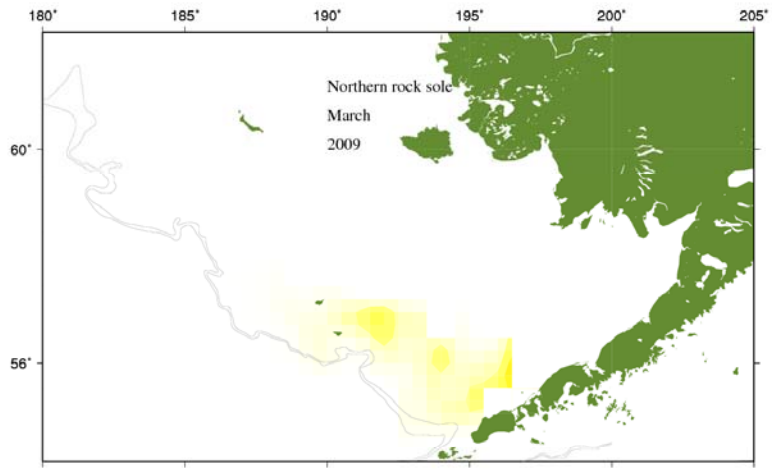
Northern rock sole
February
2009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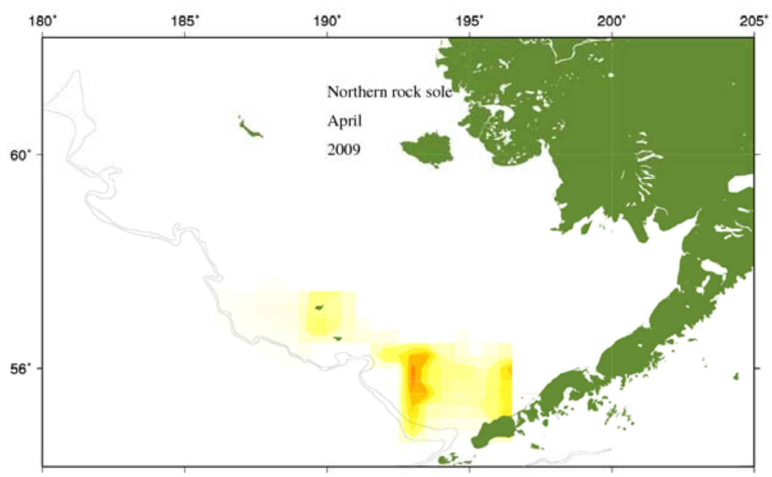
56°
Northern rock sole
March
2009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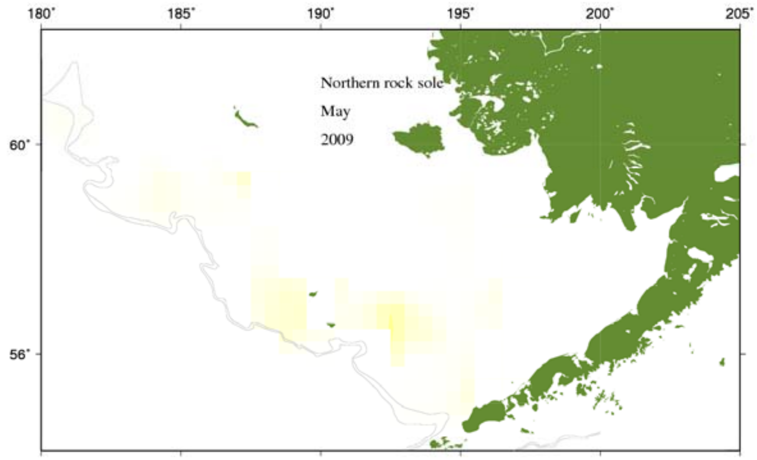
Northern rock sole
April
2009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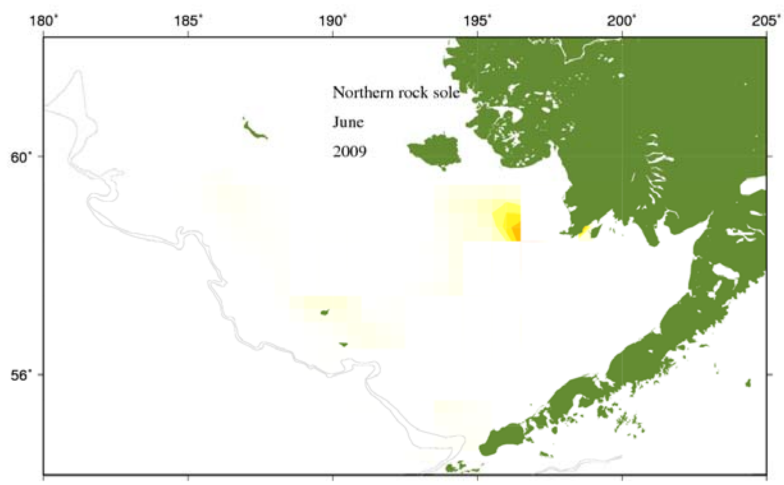
Northern rock sole
May
2009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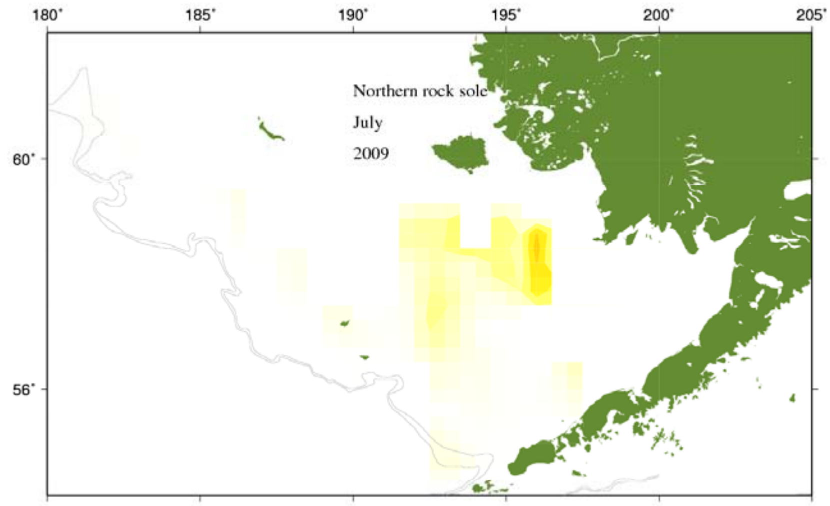
Northern rock sole
June
2009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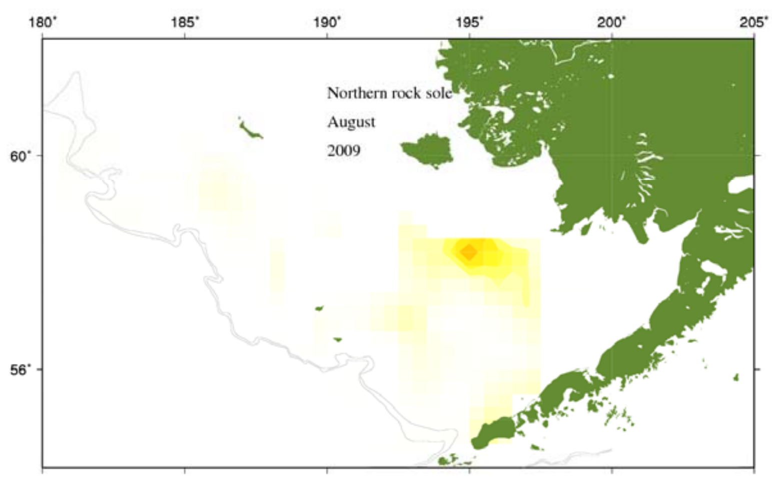
Northern rock sole
July
2009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60˚
56˚
Northern rock sole
August
2009

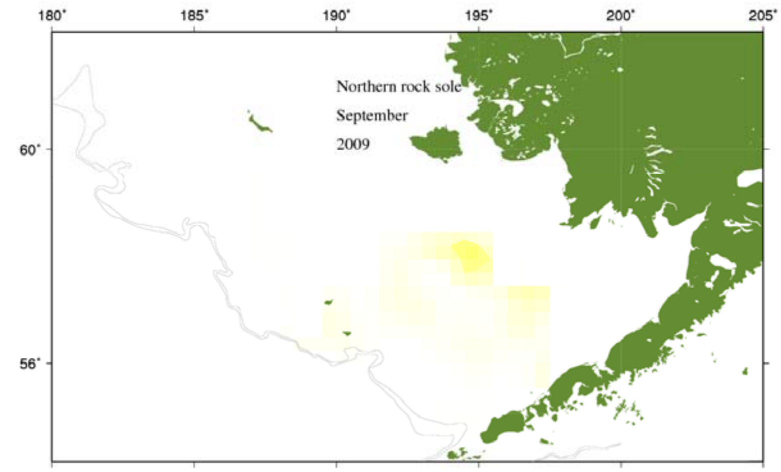


Figure 7.3—Catch locations, by month, of northern rock sole.

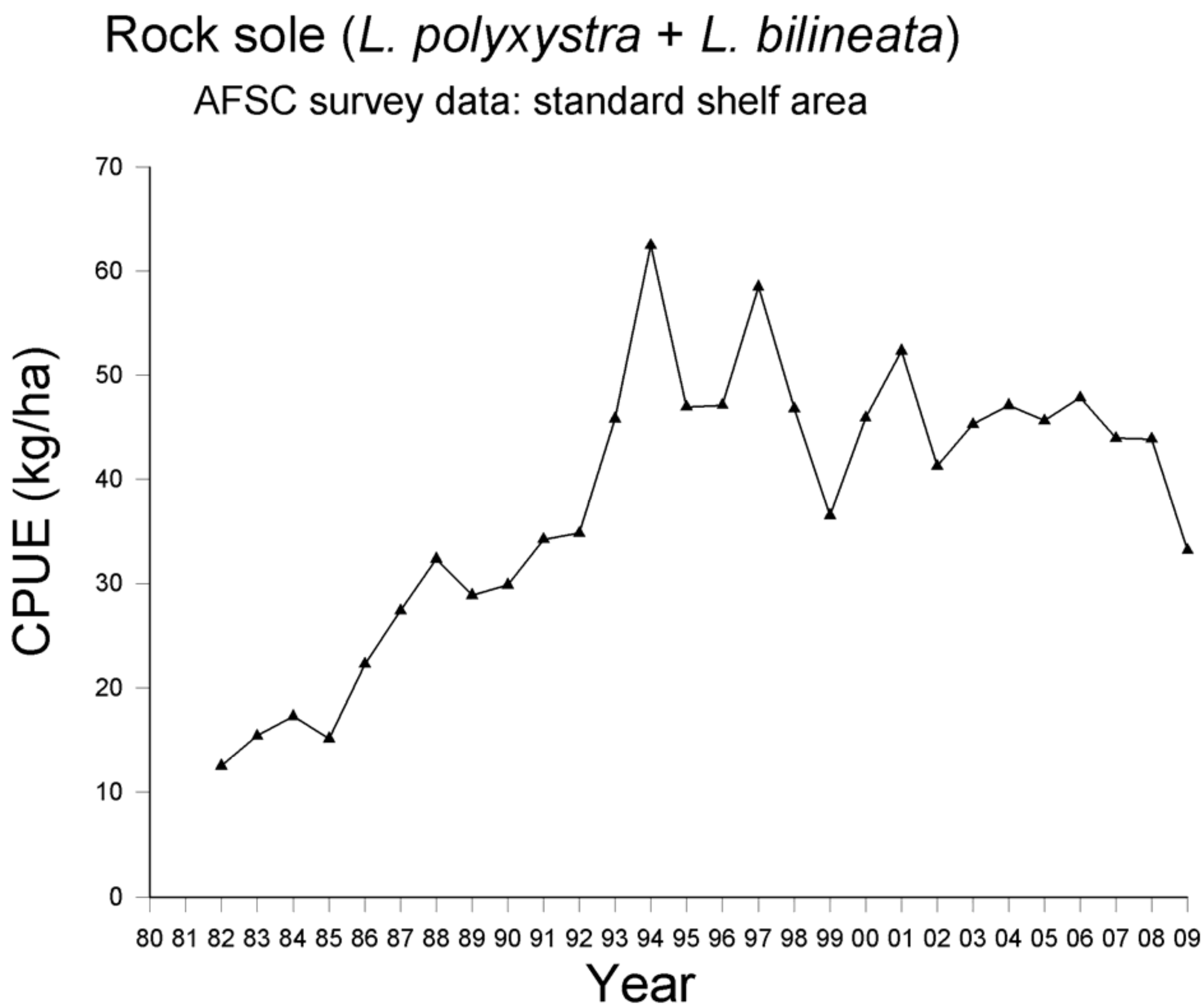


Figure 7.4—Catch per unit effort of *Lepidopsetta polyxystra* and *Lepidopsetta bilineata* (kg/ha) from Bering Sea shelf trawl surveys, 1982-2009.

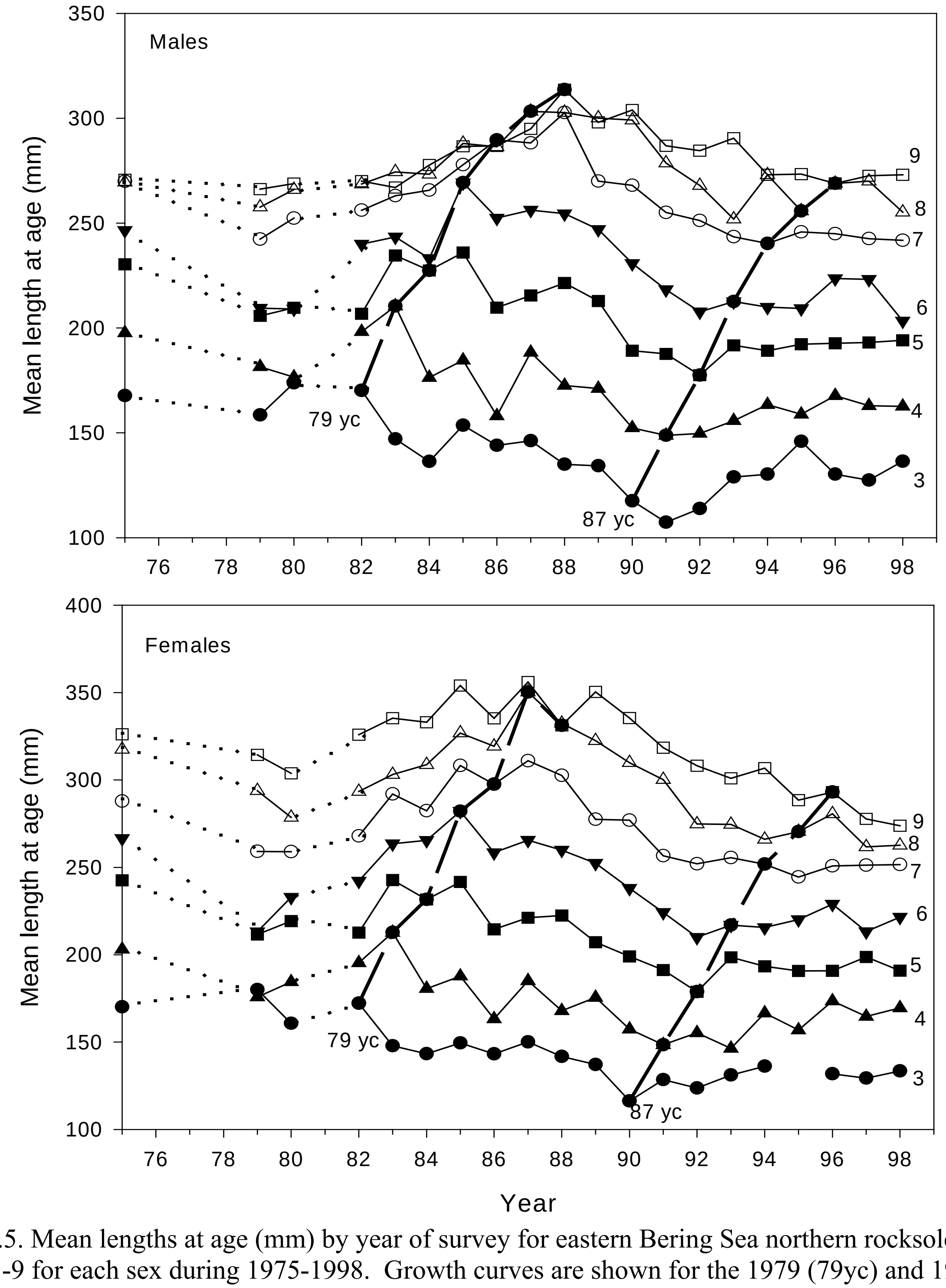


Fig. 7.5. Mean lengths at age (mm) by year of survey for eastern Bering Sea northern rocksole ages 3-9 for each sex during 1975-1998. Growth curves are shown for the 1979 (79yc) and 1987 (87yc) year classes. Dotted lines indicate no data during the period.
(From Walters and Wilderbuer, 2000, p.20)

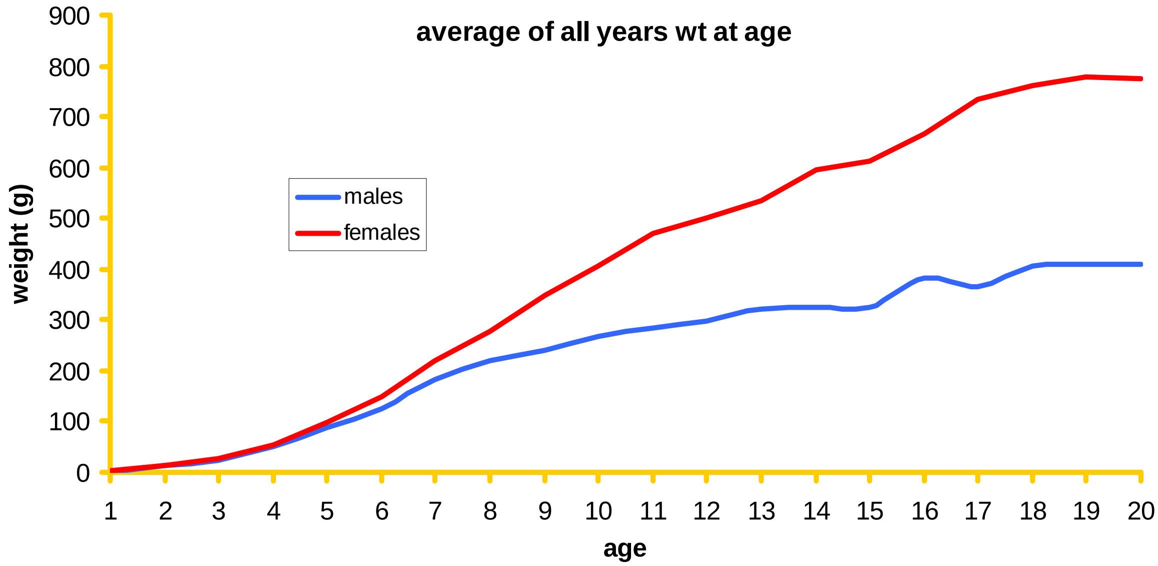
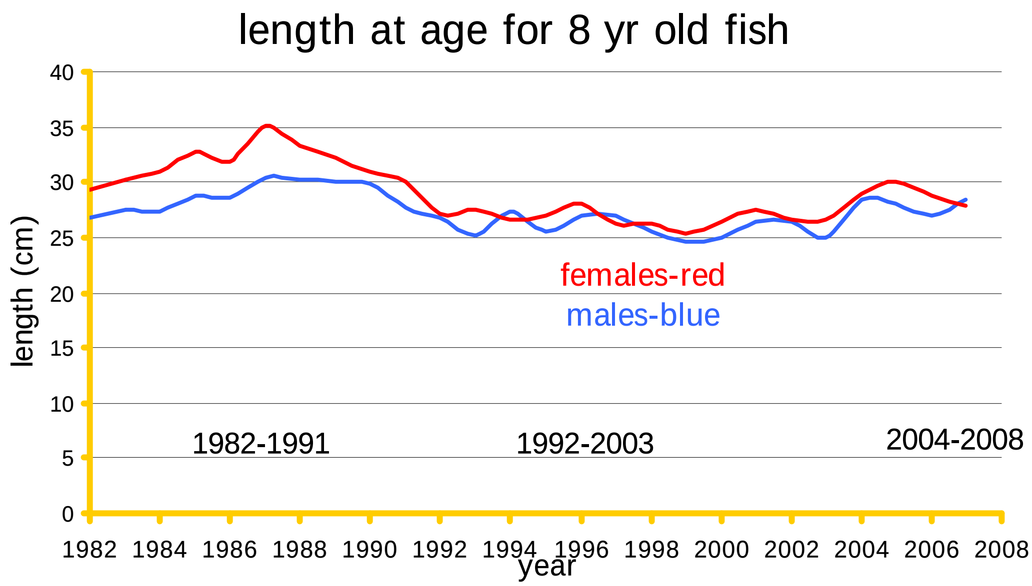


Figure 7.6-Mean weight-at-age for northern rock sole averaged over all years of survey age data.



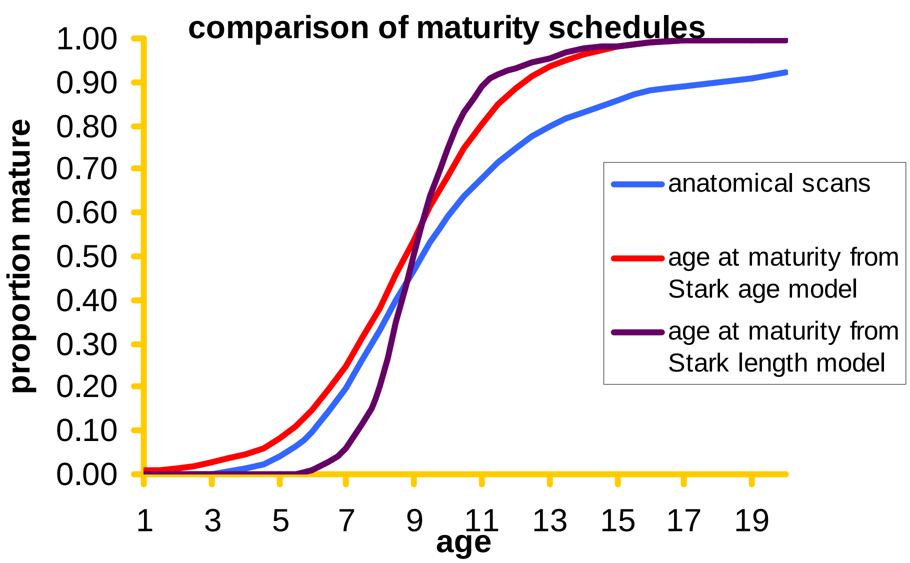


Fig. 7.7-Time-varying length-at-age for 8 year old northern rock sole with 3 time periods identified for modeling growth differently (top panel). Maturity schedule for northern rock sole from three methods (bottom panel). Stark (2009) length model, based on histology, is used in the stock assessment replacing the curve from anatomical scanning of fish.

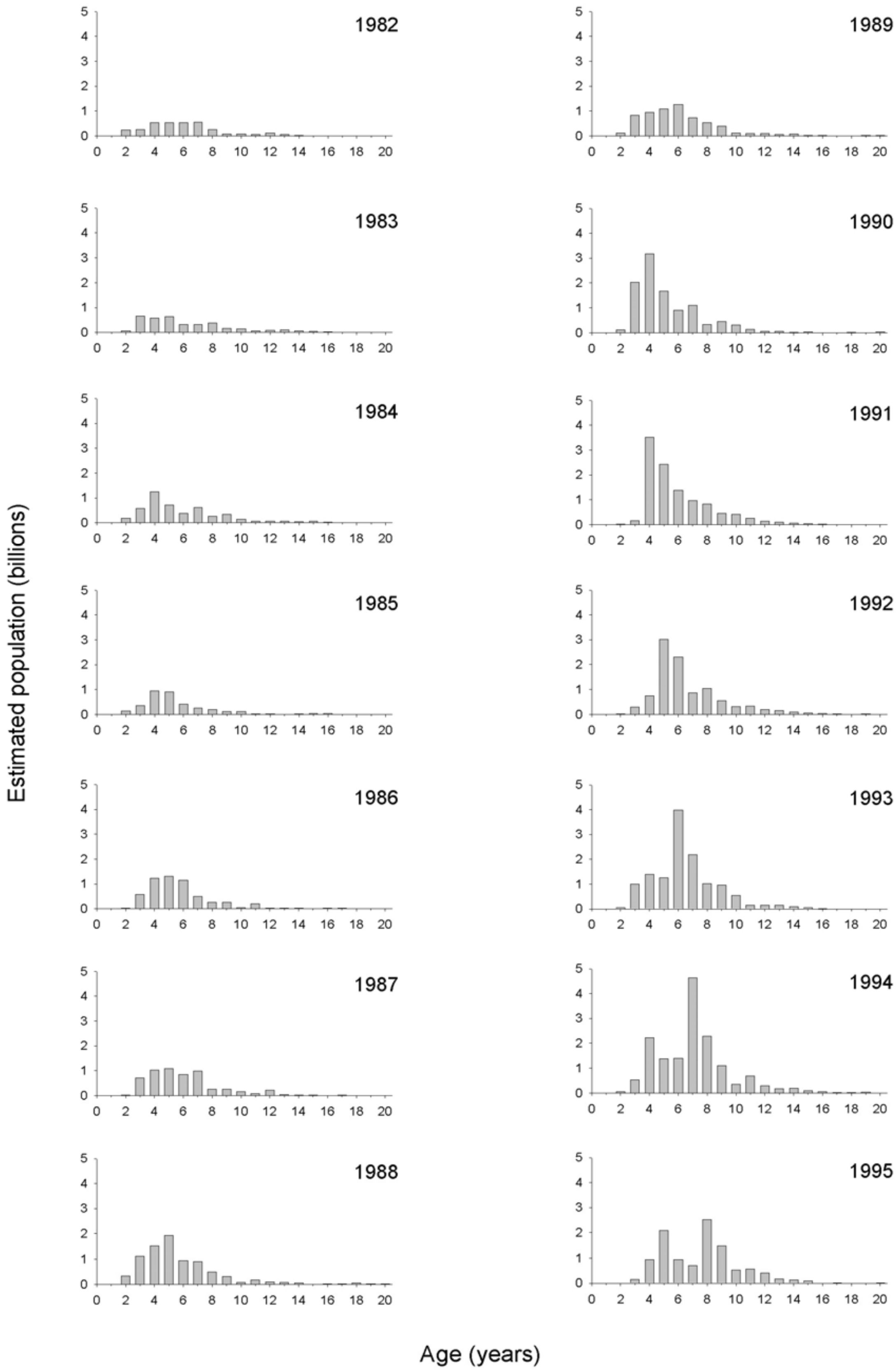


Figure 7.8—Age composition of northern rock sole from the AFSC annual trawl survey.

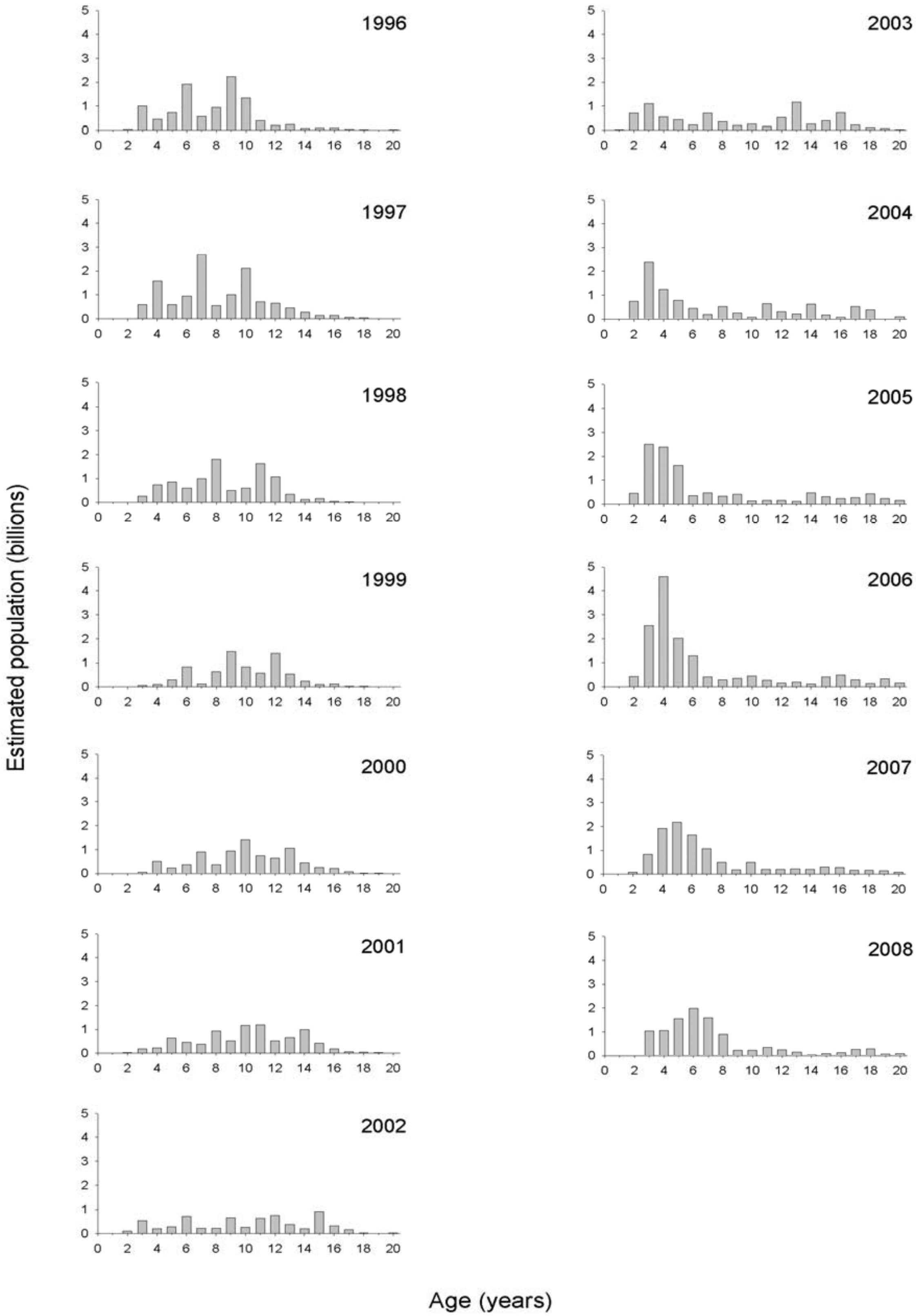


Figure 7.8--continued.

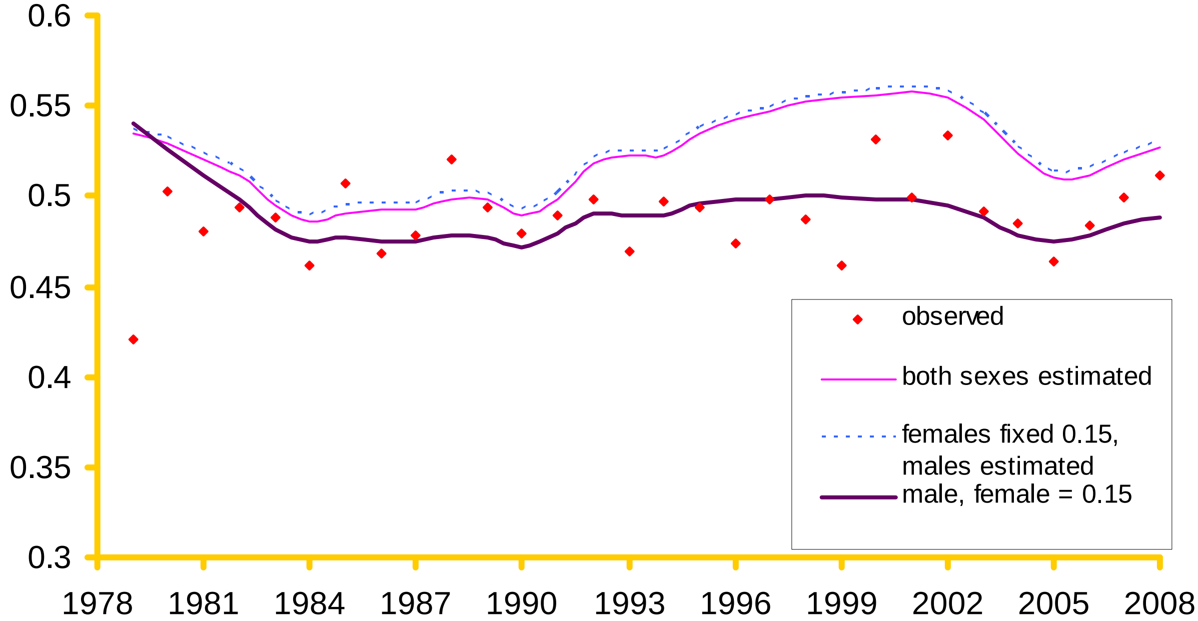


Figure 7.9—Fits to the population sex ratio from the results of Models A, B and C.

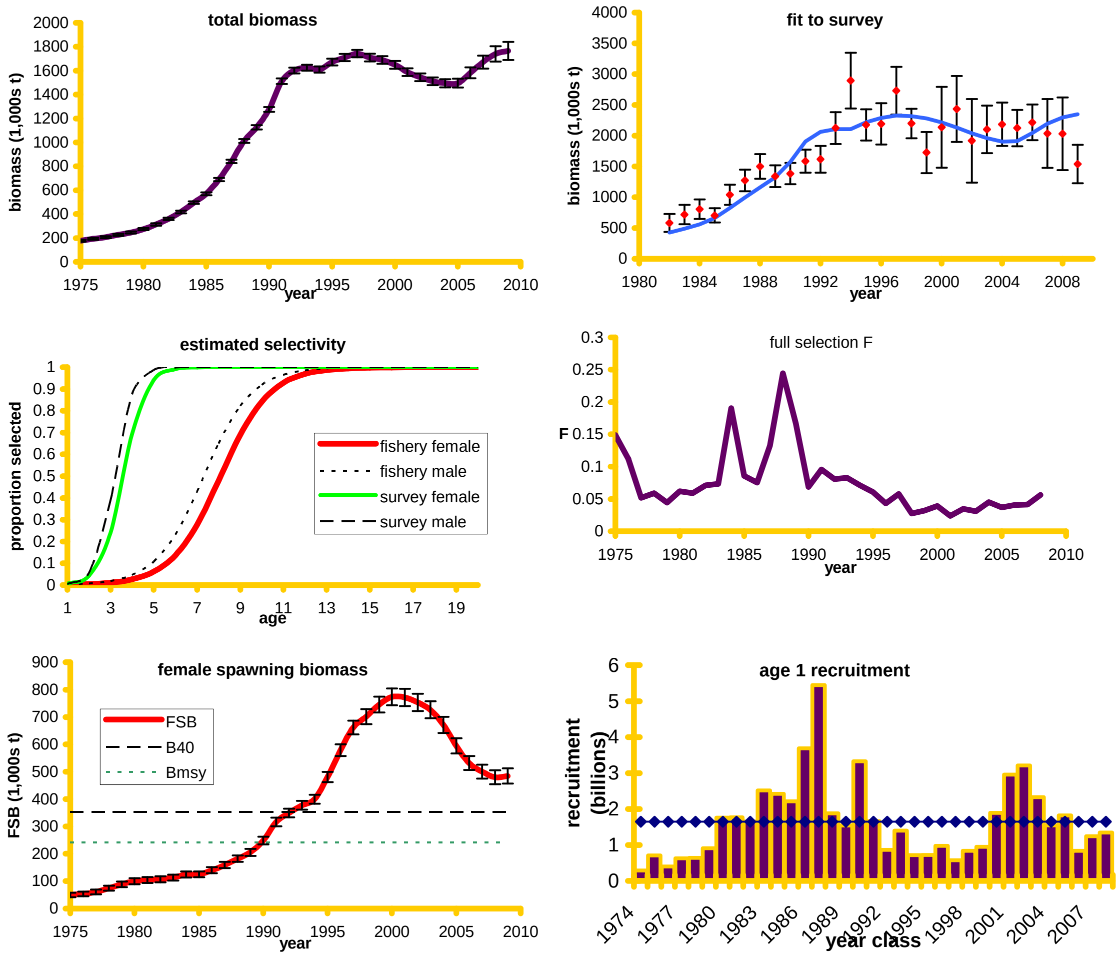


Figure 7.10--Stock assessment model estimates of total 2+ biomass (top left panel), fit to trawl survey biomass (top right panel), age-specific fishery and survey selectivity (middle left panel) and average annual fishing mortality rate (middle right panel), female spawning biomass (bottom right panel) and estimated age 1 recruitment (bottom right panel).

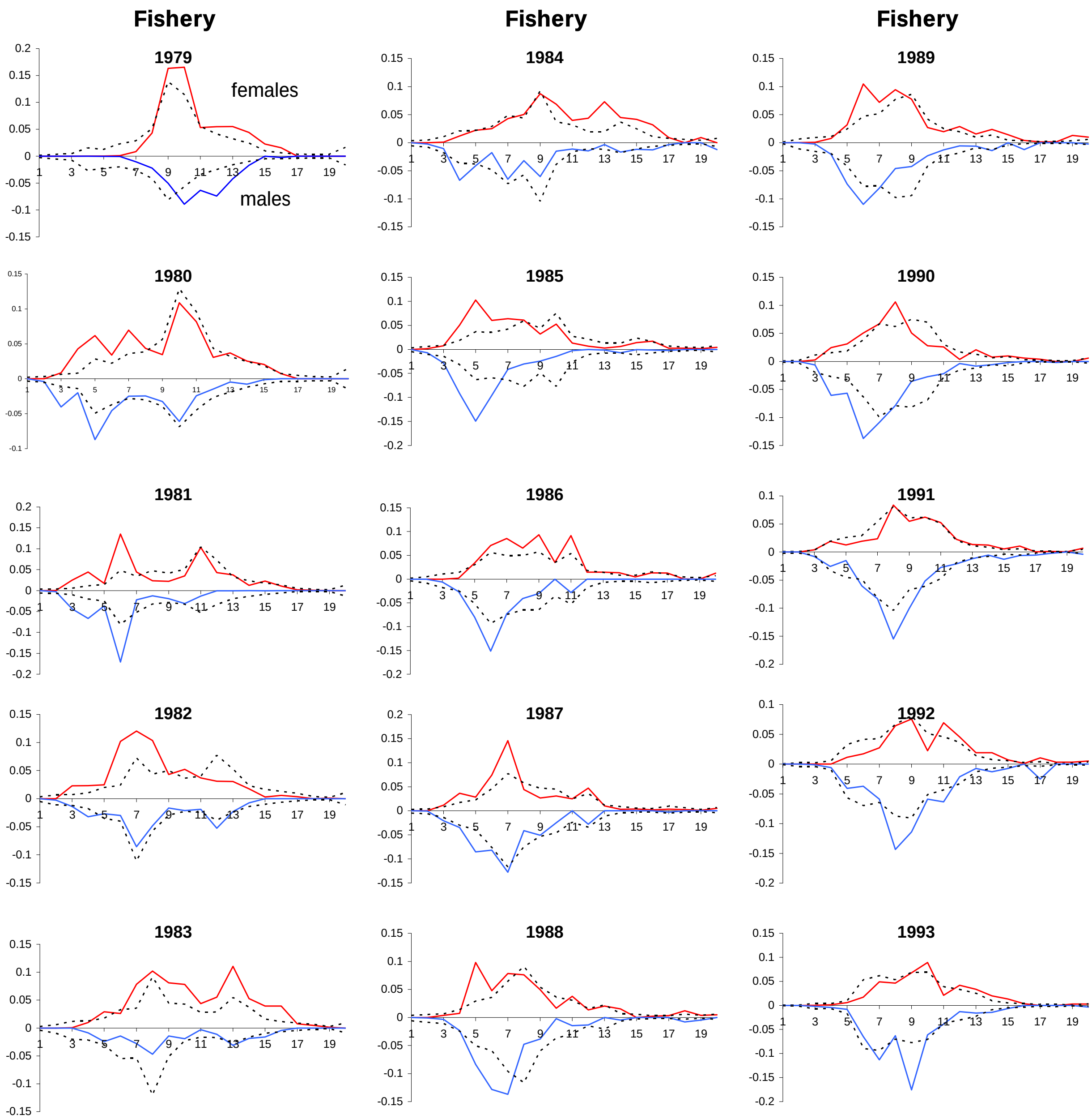


Figure 7.11—Stock assessment model fit to the fishery and survey age compositions, by sex.

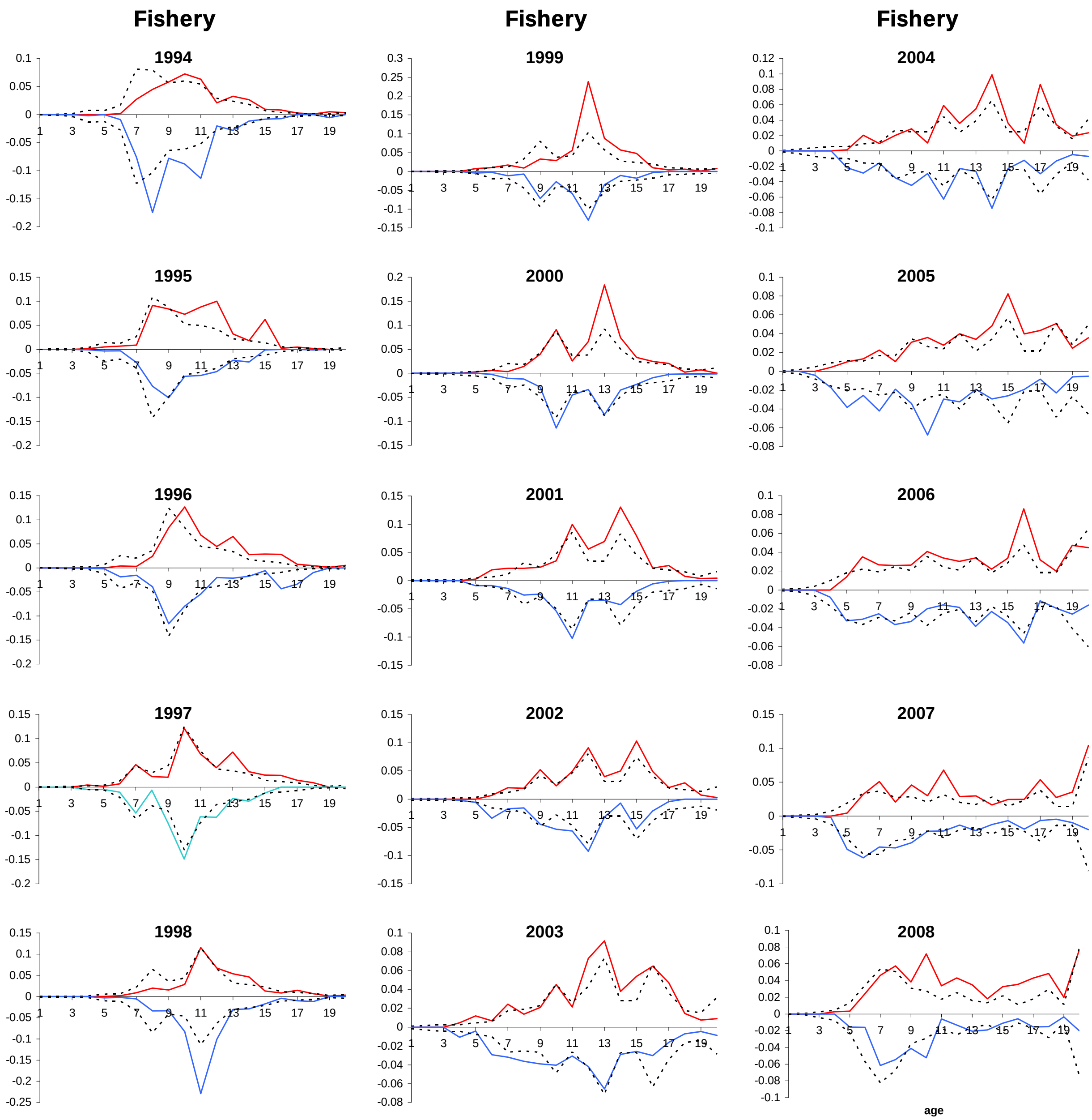
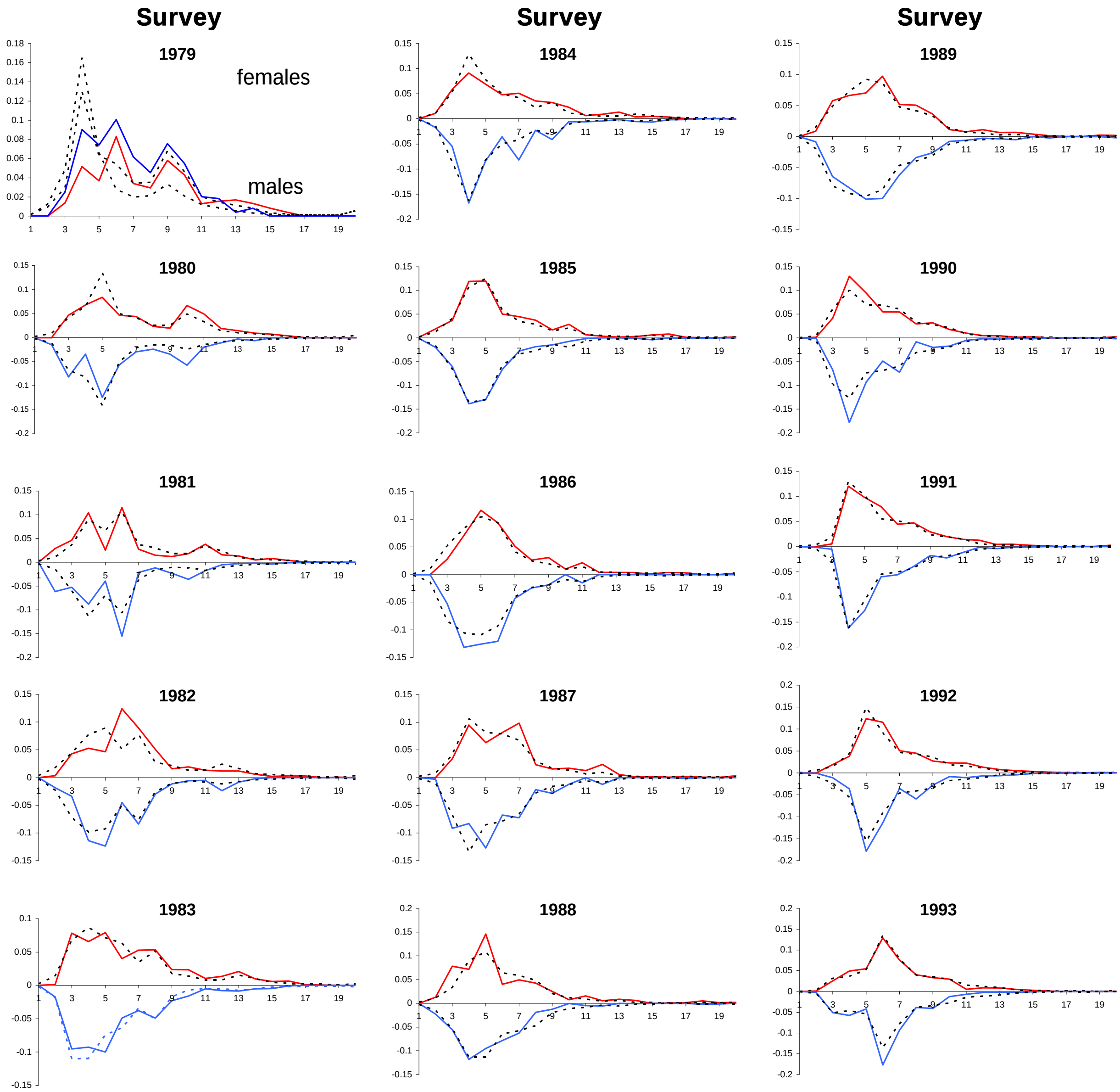


Figure 7.11—continued.



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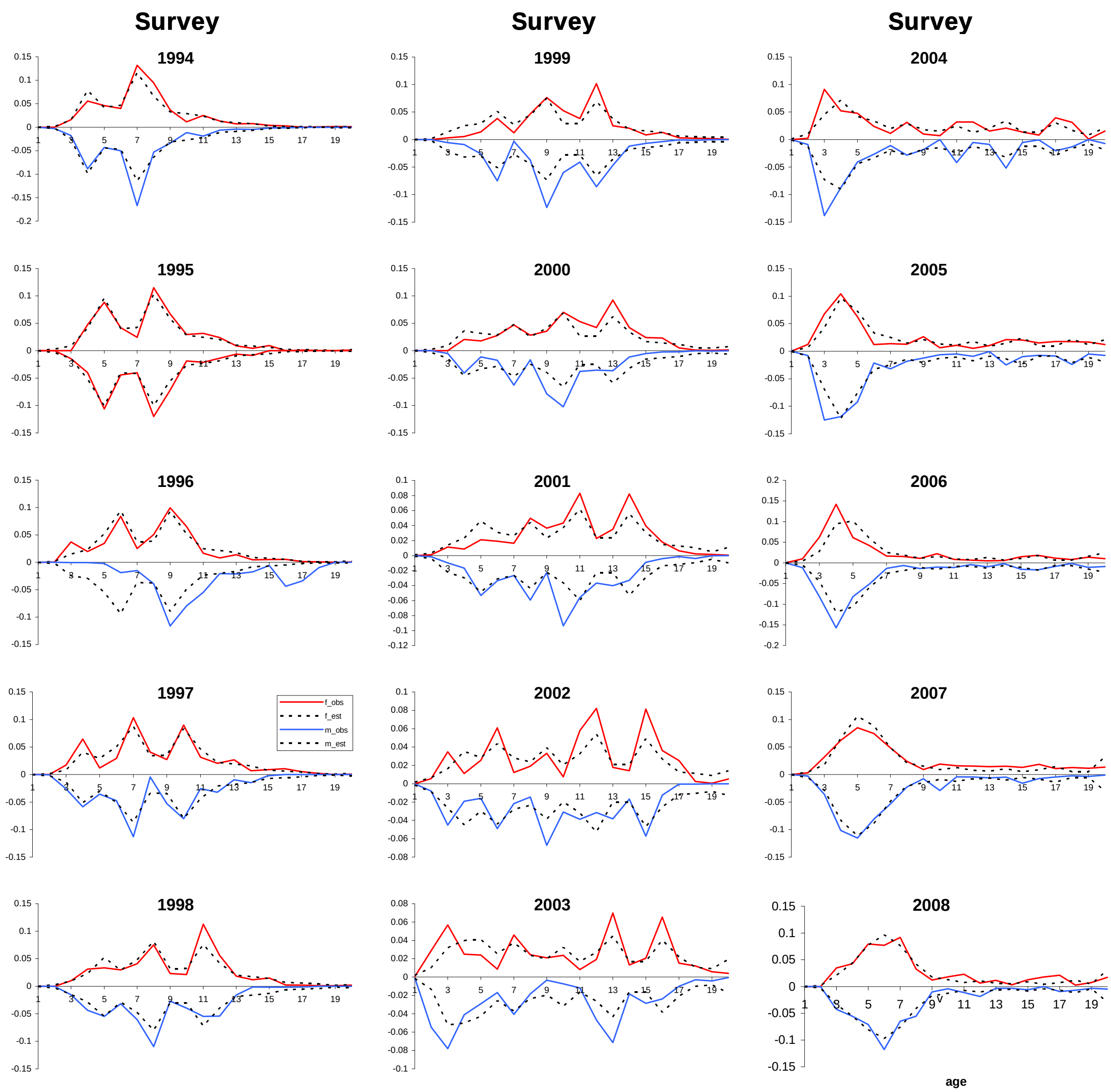

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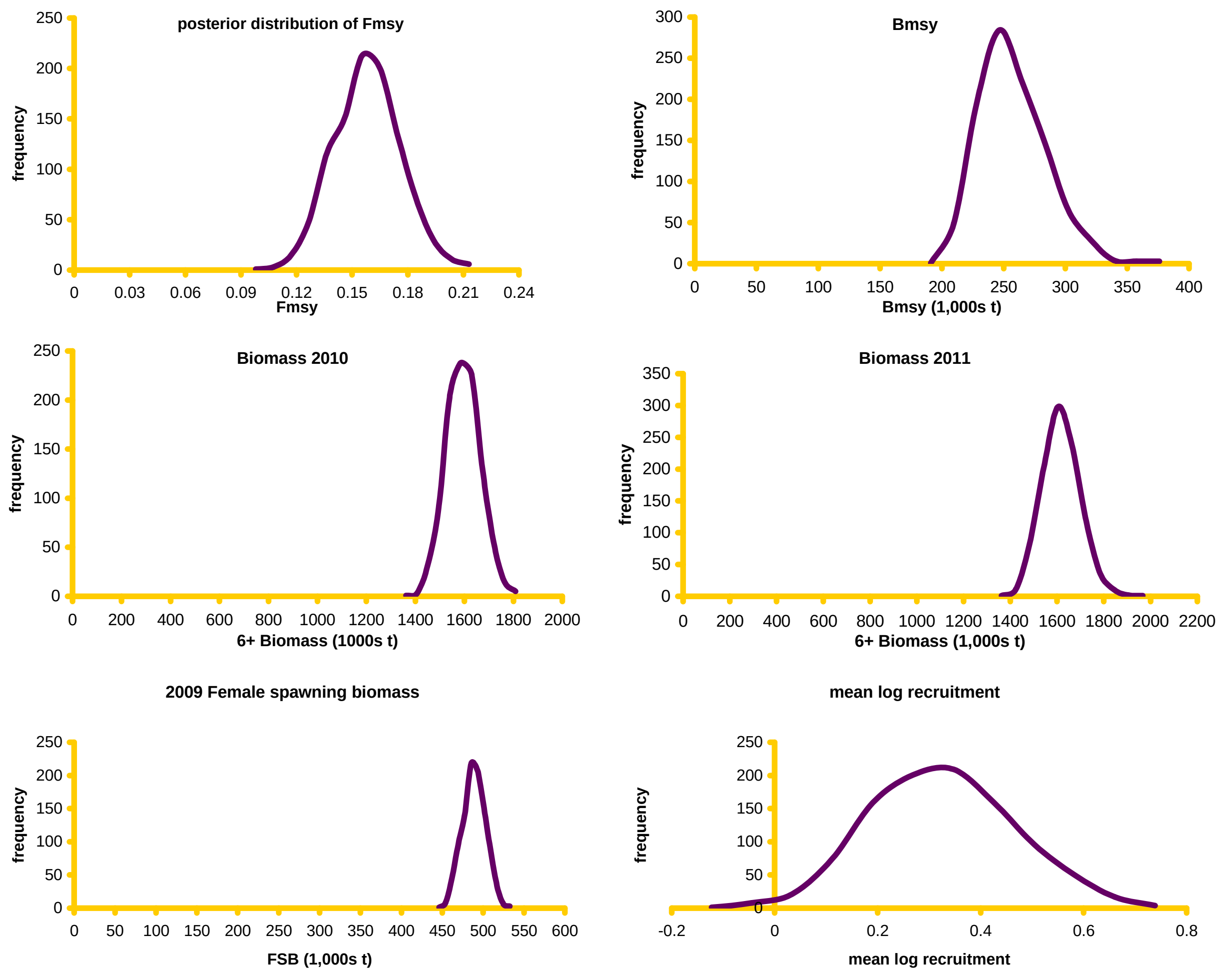

Figure 7.12—Posterior distributions of some selected model estimates from the preferred stock assessment model.

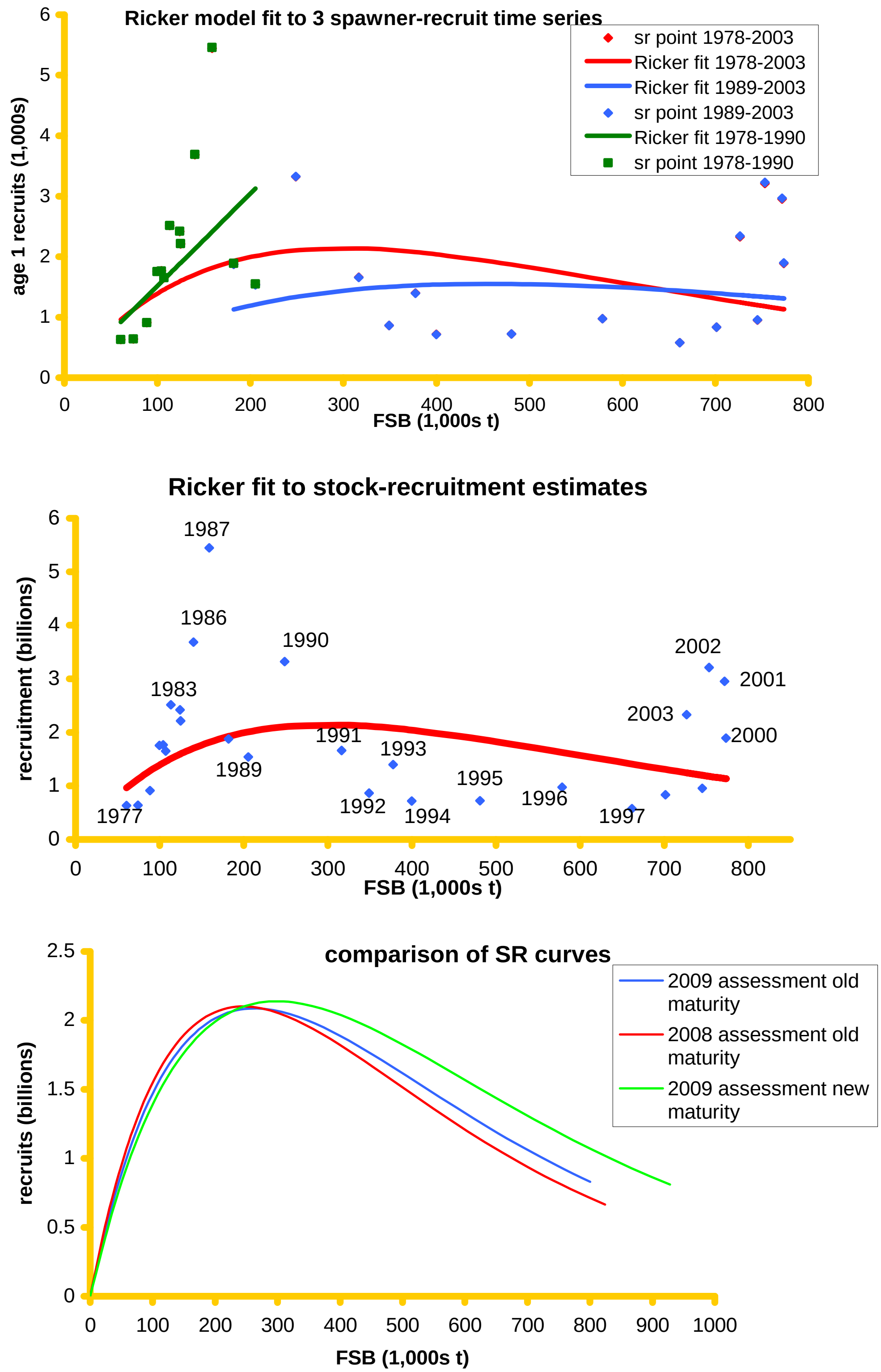

Figure 7.13—Ricker (1958) model fit to spawner-recruit estimates from three time periods; 1978-2003, 1989-2003 and 1978-90 (top panel), the fit to the spawner-recruit estimates from Model A (middle panel) and the effect of a new maturity schedule on the estimated spawner-recruitment curve and the implications for reduced stock productivity with the new maturity schedule (bottom panel).

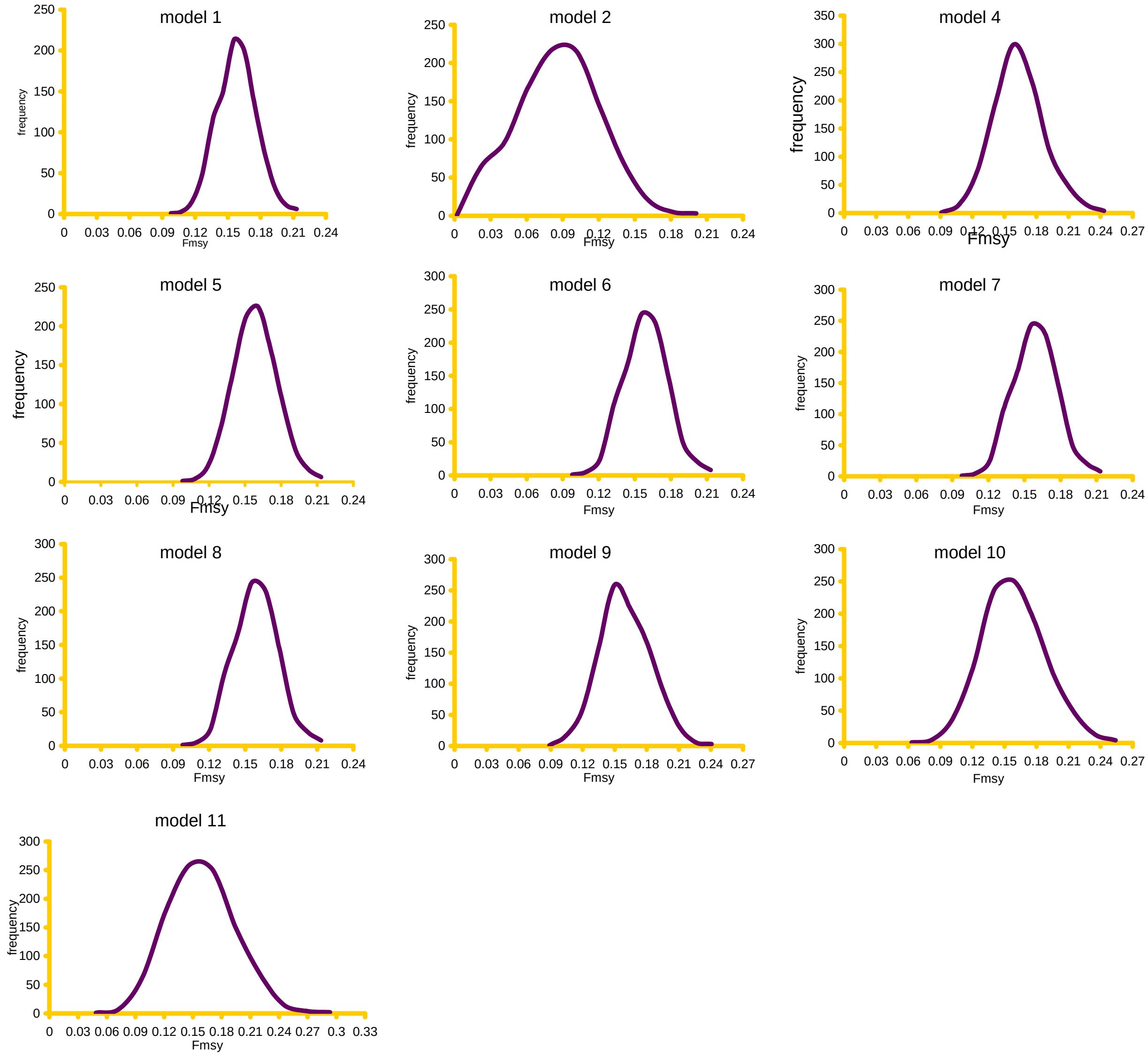

Figure 7.14—Posterior distributions of F_{msy} from 10 of the models considered in the tier 1 analysis.

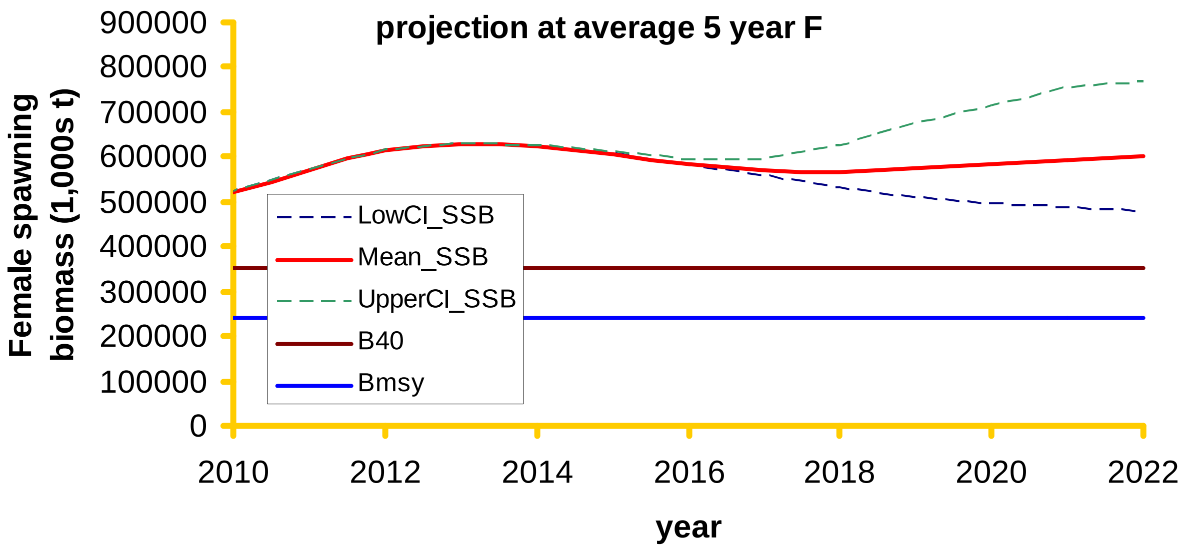

Figure 7.15—Projection of rock sole female spawning biomass when fishing each future year at the average F of the past five years.

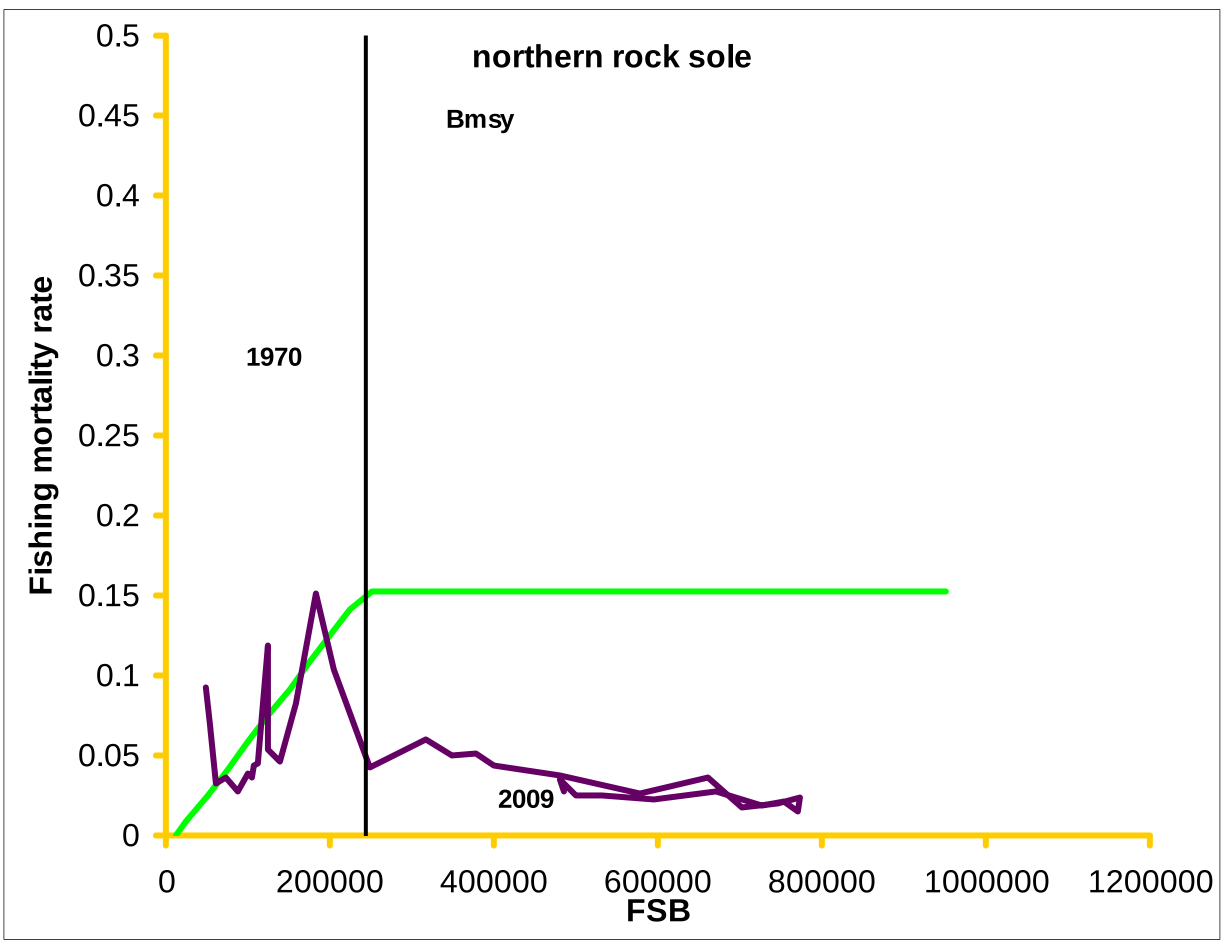

Figure 7.16—Phase-plane diagram of female spawning biomass relative to the harvest control rule.

Appendix

This section is provided to inform the Council of a recent application of the use of downscaled IPCC scenarios of possible future climate to describe possible future effects on northern rock sole productivity given some assumptions regarding the correspondence between recruitment and springtime winds. This report is primarily a summary of Hollowed et al. 2009 but also includes an additional model.

In order to forecast the implications of climate change on the production of marine fish and shelfish, a framework has been developed which involves five steps: 1.) identification of mechanisms underlying the reproductive success, growth and distribution of major fish and shellfish populations; 2.) assessment of the feasibility of down-scaling implications of IPCC scenarios on regional ecosystems to select environmental indicators; 3.) evaluation of climate model scenarios and select IPCC models that appear to provide valid representations of forcing for the region of study; 4.) extracting environmental indicators from climate scenarios to and incorporating indicators into projection models for fish and shellfish; and 5.) evaluation of the mean, variance, and trend in fish and shellfish production under a changing ecosystem.

Climate models

Sets of global climate simulations have been carried out for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. A total of 23 different coupled atmosphere-ocean general circulation models were employed under common emission scenarios.

A protocol has been designed for using these simulations towards the projection of environmental factors known or suspected to be important to fisheries. The method relies on critical evaluation of the models' 20th century hindcast simulations. The first step has been to determine the degree to which each available model was able to replicate the spatial pattern, temporal scale and magnitude of variance associated with the leading mode of variability in North Pacific SST, i.e., the Pacific Decadal Oscillation (PDO). The subset of 12 models successful at replicating the PDO were then examined further using a technique representing an adaptation of Bayesian Model Averaging (BMA). This technique provides weighted ensemble means and estimates of uncertainties in the models' predictions for individual parameters in specific regions. It has been applied to the transport of larval flatfish in the Bering Sea, and feeding conditions for juvenile salmon along the Pacific Northwest coast, among other examples. As long as the physical environmental controls for a specific population or region are known, and can be forecast with some reliability, the present protocol represents a reasonable way to achieve an early indication of the likely trends in selected populations. It should be considered as complementary to direct simulations, in which climate scenarios are used to force regional ocean numerical models, which in turn are linked to biological models, i.e., dynamical downscaling.

Application for Rock Sole

Temporal trends in northern rock sole production have been found to be consistent with the hypothesis that decadal scale (or shorter) climate variability influences marine survival during the early life history period (Wilderbuer *et al.*, 2002). After spawning in February-March, northern rock sole larvae are subject to advection from wind, currents, and tidal forcing during April-June. Using an ocean surface current model (OSCURS, Ingraham *et al.*, 1988), Wilderbuer *et al.* (2002) found that wind-driven advection of larvae towards favorable nursery areas in the inner domain coincided with above-average recruitment. The inner domain of the Bering Sea is a productive region due to tidal mixing (Coachman, 1986 and McRoy *et al*., 1986). Ocean forcing resulting from onshelf (easterly) winds during the 1980s and again in 2001-2003 coincided with periods of above-average recruitment whereas offshelf (westerly) or midshelf (northerly) winds during the 1990s corresponded with periods of poor or average recruitment (Figure 4). This suggested that patterns of future recruitment for northern rock sole will depend on wind patterns that are influenced by future climate conditions. Thus, to predict future recruitment for northern rock sole, it is also necessary to predict future climate conditions.

Following the framework for projecting environmental indicators outlined above, spring wind and the associated advection on the Bering Sea shelf was estimated from a weighted ensemble of IPCC model output. The various IPCC models used were rated based on how well their hindcasts for the latter half of the 20th century matched observations. The two specific criteria for this rating were the IPCC model's ability to reproduce the overall mean April-June winds on the southeast Bering Sea shelf, and the interannual variance in the seasonal mean winds. The weights for each model were then used to form a projection of the winds out to 2050 and converted to ending longitude of surface-drifting larvae. This projection, with the attendant year-to-year variability was provided by the Bayesian scheme, and indicates a slight tendency towards increased shoreward transports, with substantial variability on top of this weak trend (Figure A2-1).

Based on these results from the IPCC climate models, the future production of northern rock sole can be projected for the period (2001 to 2050) using the Category 1 type recruitment function. A hierarchical bootstrap algorithm was applied to estimate for annual variability in future springtime climate (i.e., wind direction and subsequent larval drift) as well as variability in recruitment under a given climate condition. First, three climate conditions (corresponding to the three production regimes identified by Wilderbuer et al., 2002) were characterized according to the range of the ending longitude (*L)* expected for larval drift under each condition: A) onshelf drift (L<165^o West), B) midshelf drift (165^o West <L≤168^o West), and C) offshelf drift (168^o West ≤ L). Then, for each projected year, the corresponding predicted mean drift longitude and variance from the IPCC model results were used (Figure A2-1) to draw a sample drift longitude from a normally-distributed population. Next, the climate condition corresponding to the sample longitude was identified based on the limits shown in Figure 5. Finally, a value for recruitment was randomly selected (with replacement) from the set of "observed" recruitments corresponding to the given climate condition. This was repeated 20,000 times to generate bootstrap realizations for each projected year. For each year, the probability of occurrence for each climate condition was computed (Figure A2-2), as well as the mean and distribution of recruitment (Figure A2-3).

Not surprisingly, the temporal trend in probability of occurrence of each climate scenario follows a pattern similar to that of the mean ending longitude of larval drift. These results suggest a moderate increase in expected recruitment with time because the trend indicates more frequent occurrence of the onshelf climate condition (A in Figure 6) with time, which corresponds to the highest expected mean recruitment. However, Figure 6 does not incorporate the variation in recruitment which is displayed in Figure 7.

Once the variation of recruitment within a climate condition is incorporated, any trend toward larger recruitments with time is much reduced (Figure 7). The mean of expected recruitment displays a comparatively smaller trend toward larger values with time while the median displays no trend whatsoever. The reduction in trend from mean to median occurs because of the asymmetrical nature of the distribution of recruitment under each of the three climate conditions. As such, the model suggests that, to the best of our current knowledge, rock sole production will not be substantially impacted by future climate change--at least in regard to the effects of that change on patterns of springtime larval advection.

A second analysis was also performed with a Ricker stock recruitment curve with environmental factors and fit for the Eastern Bering Sea northern rock sole stock as follows:

$$R = \alpha S e^{(-\beta S + \varepsilon_1 V_1 + \varepsilon_2 V_2 + \varepsilon_3 V_3)}$$

where *R* and *S* are recruitment and stock in millions and kilotons, respectively, α is a density-independent parameter, β is a density-dependent parameter, and *V1* through *V3* are the following environmental variables:

V1 = on-shelf wind, *V2* = mid-shelf wind and *V3* = off-shelf wind. The resulting productivity curves for each climate condition are shown in Figure A2-4.

An age-structured projection model was then run as follows: The projections begin with the vector of numbers at age, wt at age, fishery selectivity, natural mortality and maturity at age estimated in the most recent assessment. Fishing was set at the maximum allowable from the NPFMC and was constrained by the present harvest control rule. Future recruitment was drawn from the spawner-recruit curves in Figure A2-4 depending on the IPCC predicted future springtime wind regime, with variability (lognormal with σ=0.6). The projection was then repeated for 100 stochastic recruitment scenarios which were generated from each of 100 future climate scenarios out to year 2050.

Results are shown in Figure A2-5 and indicate a modest trend favoring on-shelf winds and higher productivity of northern rock sole, with a high amount of variability in the projection. Both methods presented here indicate:

1) The coupled model simulations carried out for IPCC provide the opportunity to project Bering Sea winds for the next few decades.

2) The magnitude of the projected change in the cross-shelf wind is comparable to the decadal variations observed in the 20th century.

3) An ensemble climate forecast yields a modest mean increase in the cross-shelf wind and estimated recruitment from 2000 to 2050.

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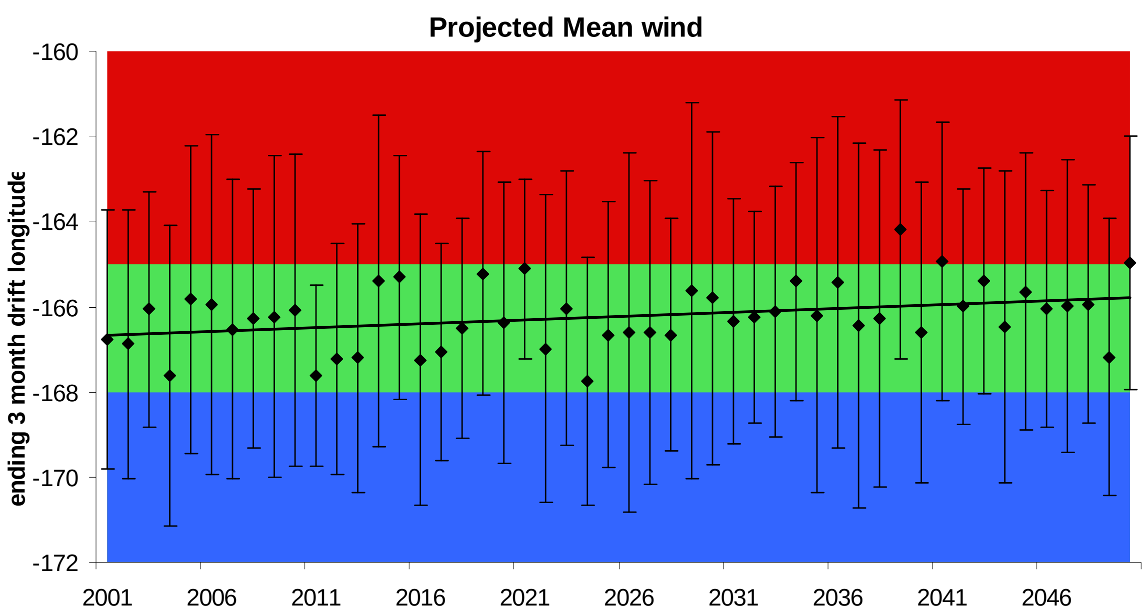

Figure A-1 Predicted mean and standard deviation of the longitudinal endpoint of projected larval drift from spring winds for 2001–2050. Background plot shading reflects classification of projected endpoints according to spring climate condition: on-shelf wind drift (red shading), off-shelf wind drift (blue shading), and mid-shelf wind drift (green shading).

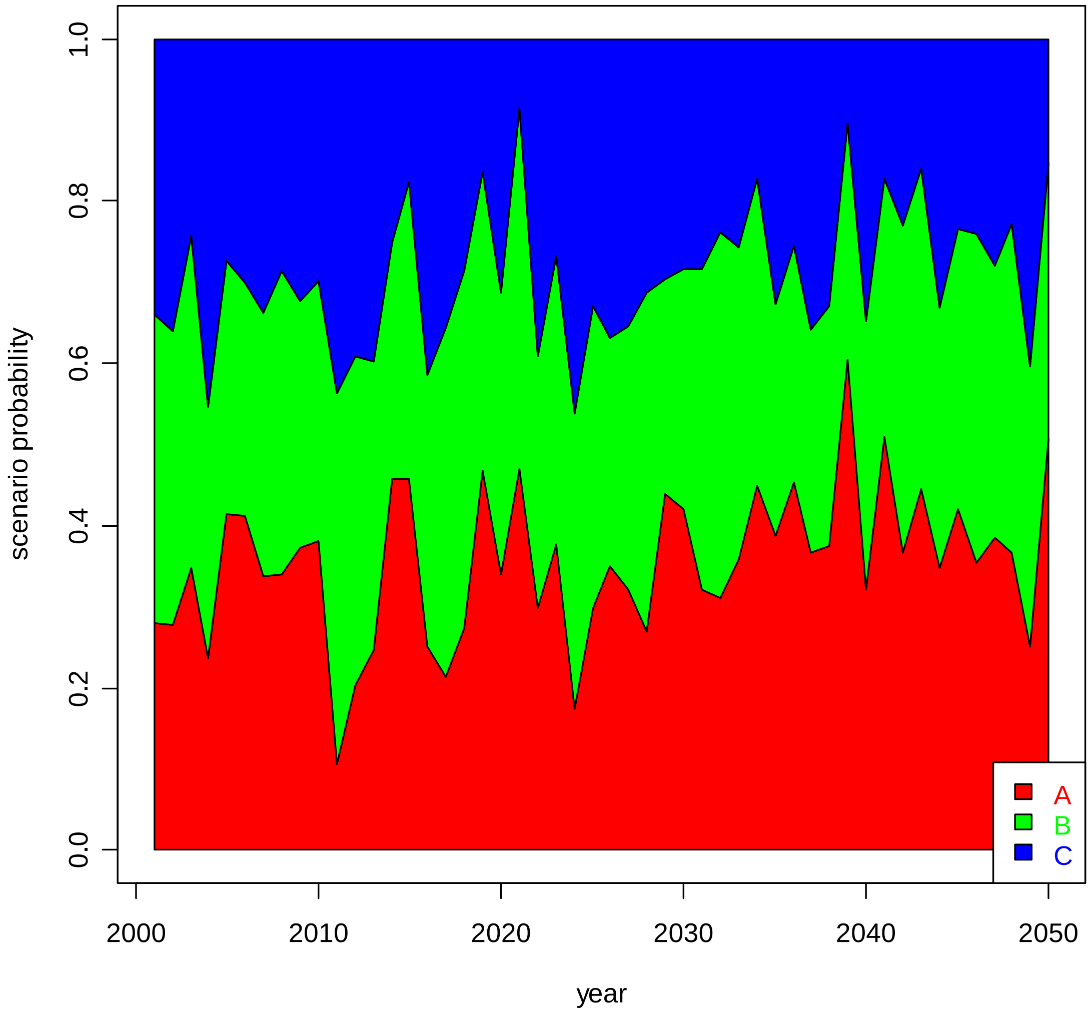

Figure A-2 Probability of occurrence for each climate scenario based on 20,000 bootstrap samples per year. A=on shelf winds, B=mid shelf winds, C=off shelf winds.

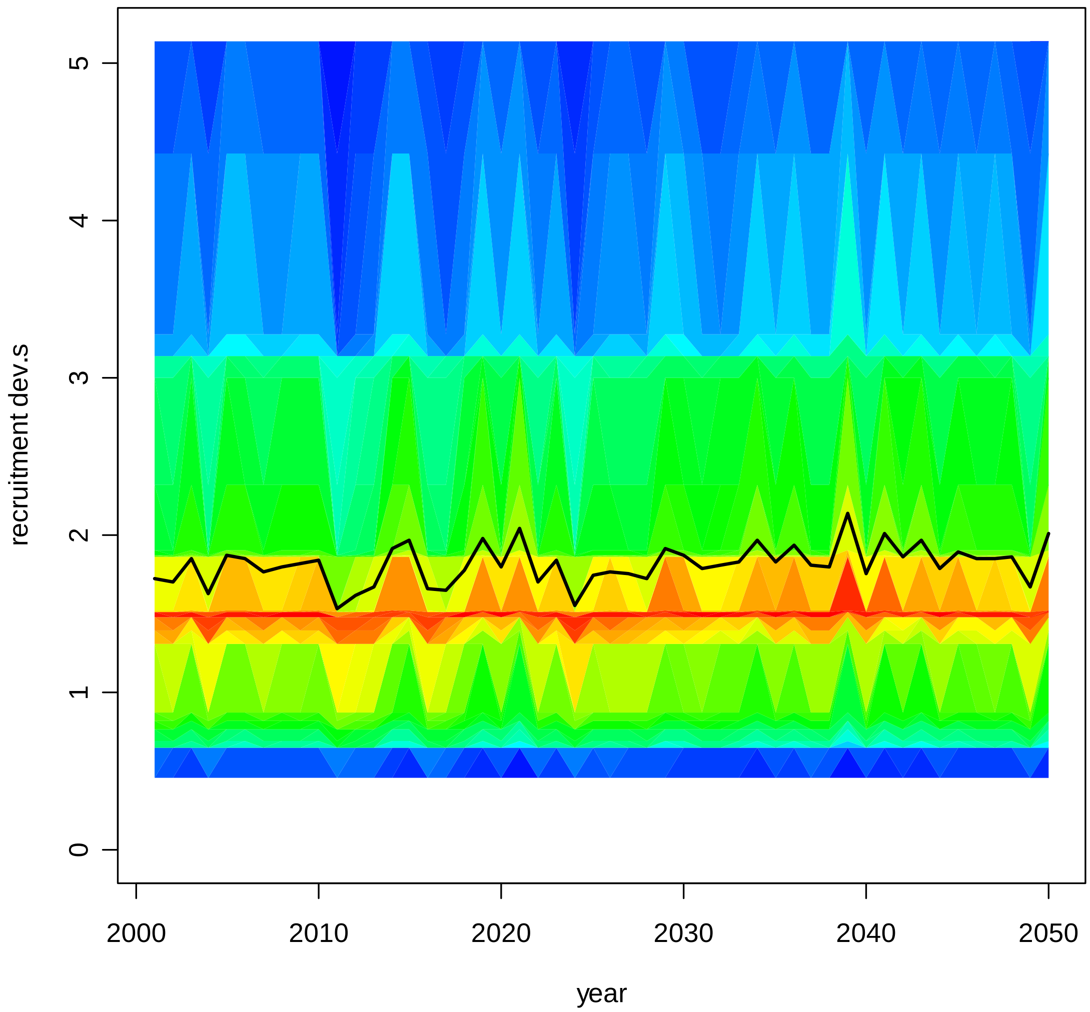

Figure A-3 Projected mean (black line) and quantiles (coloured shading) for northern rock sole productivity (recruitment) by year. Quantiles are colour-coded symmetrically from the median (bright red) to 0 or 100% (dark blue).

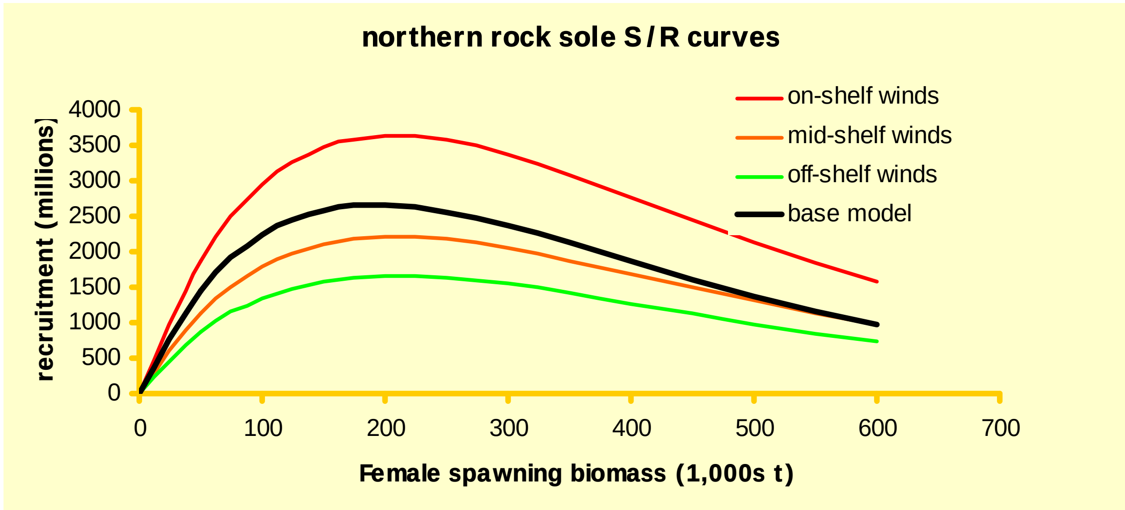

Figure A-4 Productivity curves from fitting the Ricker stock-recruitment relationship to the three climate conditions.

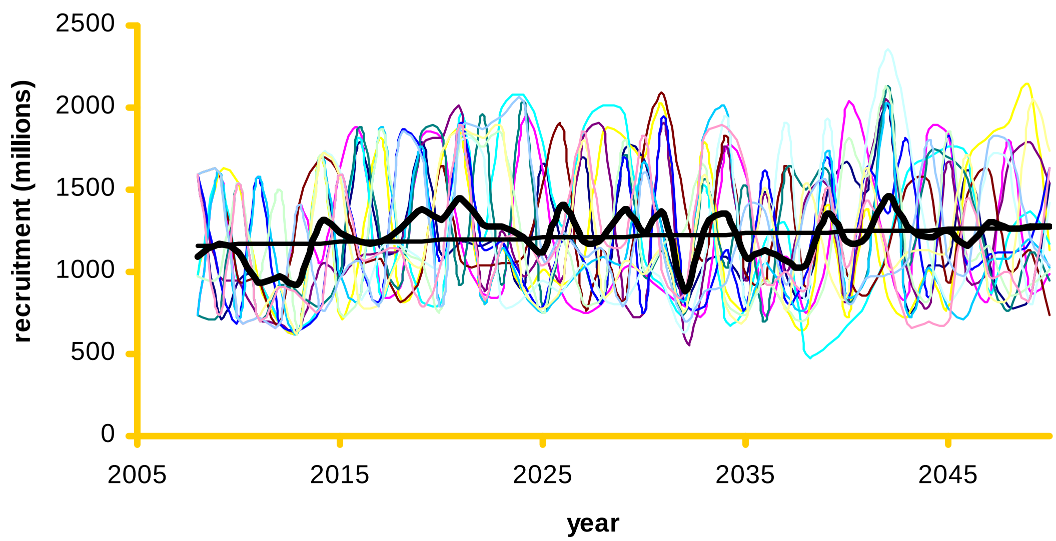

Figure A-5 Projected northern rock sole recruitment through 2050 using IPCC climate scenarios and Ricker stock recruitment formulation which relate recruitment to wind direction. Thick black line is annual mean of 10,000 model realizations and straight black line is trend line fit to annual mean.