Chapter 7
Northern Rock Sole

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EXECUTIVE SUMMARY

The following changes have been made to this assessment relative to the November 2009 SAFE:

Changes to the input data

1) 2009 fishery age composition.
2) 2009 survey age composition.
3) 2010 trawl survey biomass point estimate and standard error.
4) Estimate of catch (t) and discards through 26, September 2010.
5) Estimate of retained and discarded portions of the 2009 catch.

Changes to the assessment methodology

Implemented a formulation of time-varying, sex-specific fishery selectivity into the assessment model.

Assessment results

1) The projected age 2+ biomass for 2011 is 1,868,400 t.
2) The projected female spawning biomass for 2011 is 587,700 t.
3) The recommended 2011 ABC is 224,100 t based on an $F_{\text{harmonic mean}}$ (0.13) harvest level.
4) The 2011 overfishing level is 248,000 t based on an F_{MSY} (0.145) harvest level.

	Last year		This year	
Quantity/Status	2010	2011	**2011**	2012
M (natural mortality)	0.15	0.15	**0.15**	0.15
Specified/recommended Tier	1a	1a	**1a**	1a
Projected total biomass (ages 2+)	1,566,000	1,578,000	**1,868,400**	1,855,200
Female spawning biomass (t)				
Projected	521,860	568,700	**587,700**	640,500
B_0			**694,900**	
B_{msy}	242,000	242,000	**259,000**	259,000
F_{OFL}	0.155	0.155	**0.145**	0.145
$maxF_{ABC}$	0.153	0.153	**0.13**	0.13
Recommended F_{ABC}	0.153	0.153	**0.13**	0.13
Recommended OFL (t)	243,400	245,300	**248,000**	242,500
Recommended ABC (t)	239,900	241,700	**224,100**	219,000
Is the stock being subjected to overfishing?	No		**No**	
Is the stock currently overfished?	No		**No**	
Is the stock approaching a condition of being overfished?	no		**No**	

From the December 2007 minutes:
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.

Time-varying, gender-specific fishery selectivity is incorporated into the model (finally).

From the December 2009 minutes:
The SSC shares the Plan Team's concerns about the small separation of ABC from OFL. Over the long term, as mentioned under the SSC's general comments about flatfish assessments, a workshop should be convened to explore formal procedures to address such situations. The SSC commends the authors' analysis of northern rock sole under IPCC model scenarios in the appendix and looks forward to the possibility of a full research paper on this topic.

Workshop has not been scheduled but the use of a time-varying fishery selectivity has increased the buffer between ABC and OFL from 1.4% in the 2009 assessment to 9.6% in the present assessment.

INTRODUCTION

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

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

CATCH HISTORY

Rock sole catches increased from an average of 7,000 t annually from 1963-69 to 30,000 t between 1970 - 1975. Catches (t) since implementation of the MFCMA in 1977 are shown in Table 7.1, with catch data for 1980-88 separated into catches by non-U.S. fisheries; joint venture operations and 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 2010 catch from observer sampling, by sex and management area, are shown in Figure 7.1 and the locations of the 2010 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 57% of the annual catch in 2010 (Fig 7.2). About 66% of the 2010 catch came from management areas 509 and 521 with the rest from areas 514, 516, 517 and 513 (Fig 7.2). The 2010 catch (through the end of September) of 49,000 t comprised 20% of the ABC of 240,000 t (54% of the TAC). Thus, rock sole remain lightly harvested in the Bering Sea and Aleutian Islands. The 2010 catch locations by month are shown in Figure 7.3. Fishing for northern rock sole by vessels participating in the Amendment 80 limited access fishery was closed on May 28 to prevent exceeding the 2010 halibut bycatch allowance specified for the trawl rock sole, flathead sole, and “other flatfish” fishery category by vessels participating in this sector in the BSAI.

Northern rock sole are usually headed and gutted, frozen at sea, and then shipped to Asian countries for further processing (see “market profile” in the economic SAFE report for details (Appendix C)). In 2010, following a comprehensive assessment process, the northern rock sole fishery was certified under the Marine Stewardship Council environmental standard for sustainable and well-managed fisheries. The certification also applies to all the major flatfish fisheries in the BSAI and GOA.

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 1987-2009 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. Since 2008, the first year of Amendment 80 mandated fishing practices, 90% of the rock sole caught have been retained. Details of the 2009 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, 2010 (Table 7.1) and fishery catch-at-age numbers from 1980-2009 (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 41.0 kg/ha. The 2010 value of 41.7 kg/ha indicates that the stock remains at a stable level.

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 2010 point estimate of the Bering Sea surveyed area is 1,658,138 t – 2,471,599 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). Three of the last four years (2008, 2009 and 2010) have had similar estimates, all just over 2 million t.

The 2010 Aleutian Islands biomass estimate of 55,286 t is less than 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 1977-2010 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.

Last years' assessment again re-analysed 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 previous assessments 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 in the 2009 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 (1979-2009) 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 age 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 the estimates of natural mortality, catchability and sex ratio.

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
72	152	55	2	0, 1 or 2 (optional)	0, 1 or 2 (optional)	281-285 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), and time-varying fisheries selectivity.

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 was modeled separately for males and females using the two parameter formulation of the logistic function (Table 7-11). The model was run with an asymptotic selectivity curve for the older fish in the fishery and survey, but still was allowed to estimate the shape of the logistic curve for young fish. The oldest year classes in the surveys and fisheries were truncated at 20 and allowed to accumulate into the age category 20+ years. Sex-specific selectivity curves were fit for all years of survey data.

Given that there have been annual changes in management, vessel participation and most likely gear selectivity, the SSC has requested that time-varying fishing selectivity curves be evaluated. A logistic equation was used to model fishery selectivity and is a function of time-varying parameters specifying the age and slope at 50% selection, φ_t and η_t, respectively. The fishing selectivity (S^f) for age *a* and year *t* is modeled as,

$$S^f_{a,t} = \left[1 + e^{\eta_t (a - \varphi_t)}\right]^{-1}$$

where η_t and φ_t are time-varying and partitioned (for estimation) into parameters representing the mean and a vector of deviations (log-scale) conditioned to sum to zero. The deviations are constrained by a lognormal prior with a variance that was iteratively estimated. The process of iterating was to first set the variance to a high value (diffuse prior) of 0.5^2 and estimate the deviations. The next step was to compare the variability of model estimates. These values were then rounded up slightly and fixed for subsequent runs.

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, which results in predicted catches closely matching observed catches.

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 0.159 and 0.187, 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 predict 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 -1.047 and 0.0452, respectively. These values indicate that temperature may have some effect on trawl catchability of rock sole where bottom temperatures anomalies ranging from -2 to 2 degrees Celsius would affect the value of the estimate of q by 0.5. However the estimated mean value of q in the absence of any temperature effect is 2.8, an unrealistic value indicating that 64% of the fish caught were herded into the trawl path. This value is contrary to experimental results (discussed below) and indicates that the temperature-catchability model estimates q with very little constraint on the estimate of q.

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:

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

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

The model evaluation for this stock assessment first evaluates the productivity of the northern rock sole stock by an examination of which data sets to include for spawner-recruit fitting and then evaluates various combinations of natural mortality and catchability estimates using a preferred set of spawner-recruit time-series data.

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 are 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 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 represents 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 1978-2004 (Model 1), the years of consecutive poor recruitment events (1989-2001) (Model 2), and the period of high recruitment during the 1980s, 1978-90 (Model 3) (Fig. 7.14). Estimates of the harvest rates which would ensure the long-term sustainability of the stock ranged from F_{MSY} values of 0.1 – 0.144, depending on which years of stock-recruitment data points were included in the fitting procedure. High values are estimated for F_{MSY} when the full time series is used (Model 1) and lower values were obtained (as expected) when the poor recruitment time-series (Model 2) was used. Model 3 (the most productive time series 1978-1990) was data limited and does not have enough contrast in spawning stock size to fit, does not converge properly, and gives an unrealistic estimate of B_{msy}. 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} = 374,000 t) with the result that F_{MSY} is highest when fitting the full data set. Since the time-series is only available for 26 years now, we use the full time-series (Model 1) for our estimate of the productivity of the stock.

Model runs were then 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 2010 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 1, 4 and 5).

Model exploration	q	female M	male M	2010 FSB	2011 ABC	F40
Model 1 q fixed at 1.5, male and female M fixed at 0.15	1.5	0.15	0.15	532.764	224.083	0.164
Model 4 q fixed at 1.5, female M fixed at 0.15 and male M estimated	1.5	0.15	0.18	583.918	225.125	0.173
Model 5 q fixed at 1.5, female M and male M estimated	1.5	0.167	0.197	515.687	207.790	0.2
Model 6 q estimated, Female and male M fixed at 0.15	2.12	0.15	0.15	315.804	150.813	0.173
Model 7 q estimated, female M fixed at 0.15 and male M estimated	2.00	0.15	0.177	398.798	168.477	0.178

Model 8 q, female M and male M all estimated as free parameters	2.01	0.148	0.175	378.723	162.093	0.177
Model 9 q estimated with the bottom temperature relationship, male and female M fixed at 0.15	2.85	0.15	0.15	221.96	124.92	0.18

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 4 and 5). Fixing the female or both the male and female M (Models 6 and 7) has less of a constraint on q and values are estimated as high as 2.12 (Model 6) and 2.0 (Model 7). Allowing all three parameters to be freely estimated results in higher estimates of q and lower estimates of stock size (Model 8). 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 2.85 in Model 9).

Models 6, 7, 8 and 9 provide estimates of survey catchability which range from 2.0 to 2.85. 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 52% (Model 6) and 50% (Model 8) 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 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 4 and 5 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 1 (Fig. 7.9). Therefore, the model of choice for this assessment is Model 1 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 observed population sex ratio.

MODEL RESULTS

Although annual bottom trawl survey point estimate increased 34% from 2009 to 2010 and is at about the same level estimated in the 2007 and 2008 trawl surveys, the stock assessment model does not fit the 2010 survey point estimate and model results indicate that the stock condition is increasing. This is the result of the combination of strong recruitment from the 2001-2003 year classes which are now nearing the age of maximum cohort biomass and light fishery exploitation.

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 3.4% from 1975-2009, 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 about 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 - 400,000 t, Fig. 7.11 and Table 7.15). From 1985-95, a period characterized by sustained above-average recruitment (1980-88 year classes, Fig. 7.11) 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 1.78 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 of 492,000 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. 7.12).

The model estimates of survey biomass (using trawl survey age-specific selectivity and the estimate of q applied to the total biomass, Fig. 7.11) 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 (Model 1) are presented in Figure 7.13.

Total Biomass

The stock assessment projection model estimates total biomass (mid year population numbers multiplied by mid-year weight at age) for 2011 at **1,864,400** t (including the 2010 catch of 49,000 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 2009 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 10+. The 2001-2004 year classes appear very strong as discerned from the last 5 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, selected parameter estimates and their standared deviations and estimated annual fishing mortality by age and sex are shown in Tables 7.17-7.20, respectively.

ACCEPTABLE BIOLOGICAL CATCH

The SSC has determined that northern rock sole qualify as a Tier 1 stock and therefore the 2011 ABC is calculated using Tier 1 methodology. In 2006 the SSC selected the full time-series data set for the Tier 1 harvest recommendation. Using this approach again for the 2011 harvest recommendation (Model 1), the F_{ABC} = $F_{harmonic\ mean}$ = 0.13. The Tier 1 harvest level is calculated as the product of the harmonic mean of F_{MSY} and the geometric mean of the 2011 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 2011 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 224,900 t and an OFL of 248,000 t for 2011**. The projection of 2011 ABC from last year's assessment was 241,000 t and the OFL was projected at 245,300 t.

An alternative ABC and OFL can be calculated from the time-invariant fishery selectivity model used in the most recent assessments prior to 2010. This model produces ABC and OFL estimates of 246,304 t and 249,900 t, respectively, which only gives a 1.43% buffer between ABC and OFL. The new model introduced in this assessment uses the fishery selectivity estimated for 2010 to calculate the 2011 and 2012 ABC and OFL values. Since no age data is currently available for 2010, the ABC and OFL are estimated with more uncertainty than the time-invariant selectivity method (which uses the time-series mean), and results in a buffer between these values of 9.7% or 23,100 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:

Harvest level	F value	2011 Yield
Tier 1 F_{OFL} = F_{MSY}	**0.145**	**248,000 t**
Tier 1 F_{ABC} = $F_{harmonic\ mean}$	**0.131**	**224,100 t**

BIOMASS PROJECTIONS

Status Determination

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 2010 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2011 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2010. 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 2011, 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 2011 recommended in the assessment to the *max* F_{ABC} for 2011. (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 2006-2010 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 follows (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 its MSY level in 2010 and above its MSY level in 2022 under this scenario, then the stock is not overfished.)

Scenario 7: In 2011 and 2012, *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 2023 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 2006-2010, rock sole female spawning biomass is projected to increase due to the strong recruitment observed during the past five years (Fig. 7.16). 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 7.17.

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 2010 numbers at age from the stock assessment model are projected to 2011 given the 2010 catch and then a 2011 catch of 50,000 t is applied to the projected 2011 population biomass to obtain the 2012 OFL

Tier 1 Projection

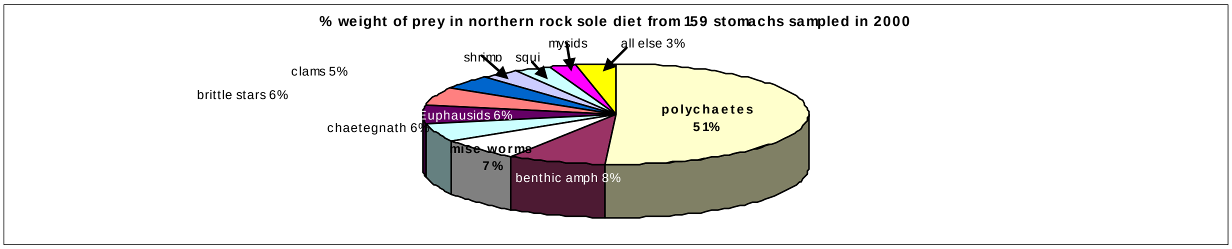
Year	Catch	SSB	Geometric mean 6+ total biomass	ABC	OFL
2011	49,000	587,600	1,566,000	239,900	243,400
2012	50,000	640,500	1,578,000	241,700	245,300

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 1991-2009 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 2007 and 2008 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	19
Herring	<1
Red King crab	35
C. bairdi	7
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, 2010.

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			48,649	48,649
2010			49,000	49,000

Table 7.2 Retained and discarded catch (t) in Bering Sea fisheries, 1987-2009.

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
2009	43,478	5,172	89

Table 7.3--Discarded and retained rock sole catch (t), by target fishery, in 2009.

	Discarded	Retained	Total
Atka Mackerel	34	84	118
Pollock - bottom	267	5,543	5,810
Pacific Cod	658	551	1,209
Alaska Plaice	0	3	3
Other Flatfish	0	1	1
Halibut	0	0	0
Rockfish	15	9	24
Flathead Sole	82	1,447	1,529
Other Species	0	0	0
Pollock - midwater	1,224	557	1,782
Rock Sole	1,345	27,688	29,033
Sablefish - BSAI	0	0	0
Greenland Turbot	0	0	0
Arrowtooth Flounder	2	41	43
Yellowfin Sole	1,543	7,554	9,097
Total catch			48,649

Table 7.4--Estimated catch numbers at age, 1980-2010 (in millions).
Females

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1980	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.06	0.15	0.22	0.44	0.61	0.90	1.03	1.04	1.04	1.05	1.07	1.08
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.12	0.18	0.36	0.50	0.74	0.84	0.84	0.83	0.83	1.70
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.11	0.15	0.28	0.33	0.41	0.42	0.38	0.37	1.14
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.07	0.11	0.24	0.35	0.58	0.48	0.44	1.75
1984	0.00	0.00	0.00	0.02	0.02	0.06	0.14	0.45	2.01	2.18	1.16	0.91	0.73	0.57	0.25	0.15	0.06	0.03	0.03	0.12
1985	0.07	0.14	0.35	0.52	1.95	1.42	1.73	1.42	1.65	3.11	1.99	0.84	0.61	0.48	0.37	0.16	0.09	0.04	0.02	0.10
1986	0.15	0.23	0.47	1.17	1.47	3.80	1.77	1.58	1.11	1.21	2.24	1.42	0.60	0.43	0.34	0.26	0.11	0.07	0.03	0.08
1987	0.06	0.21	0.36	0.81	2.07	2.35	5.08	2.09	1.77	1.22	1.32	2.44	1.55	0.65	0.47	0.37	0.29	0.12	0.07	0.12
1988	0.02	0.06	0.18	0.26	0.53	1.31	1.67	4.50	2.17	1.98	1.40	1.53	2.84	1.80	0.76	0.55	0.43	0.33	0.14	0.23
1989	0.11	0.17	0.45	1.09	1.41	2.37	4.74	4.74	10.42	4.53	3.99	2.79	3.06	5.66	3.59	1.52	1.10	0.86	0.66	0.74
1990	0.14	0.51	1.14	3.76	8.65	6.79	5.20	4.53	2.28	3.21	1.12	0.89	0.60	0.65	1.20	0.76	0.32	0.23	0.18	0.30
1991	0.01	0.05	0.19	0.49	1.93	5.59	5.36	4.44	3.94	1.99	2.80	0.97	0.78	0.53	0.57	1.05	0.66	0.28	0.20	0.42
1992	0.32	0.51	1.53	4.29	6.87	13.69	17.82	9.63	6.41	5.38	2.69	3.78	1.31	1.05	0.71	0.77	1.41	0.89	0.38	0.84
1993	0.71	1.37	2.29	6.86	17.85	22.66	31.86	31.58	15.02	9.56	7.91	3.94	5.52	1.91	1.53	1.04	1.12	2.06	1.30	1.77
1994	0.04	0.44	1.10	2.39	8.70	22.51	21.50	22.35	19.04	8.59	5.37	4.43	2.20	3.08	1.07	0.85	0.58	0.62	1.15	1.72
1995	0.05	0.16	1.30	2.35	3.47	7.88	12.20	8.48	8.01	6.71	3.02	1.89	1.56	0.78	1.09	0.38	0.30	0.20	0.22	1.01
1996	0.11	0.12	0.32	2.06	2.96	3.62	7.49	12.54	10.54	11.69	10.72	5.02	3.20	2.65	1.32	1.85	0.64	0.51	0.35	2.10
1997	0.02	0.09	0.10	0.30	2.10	3.24	4.18	8.71	13.57	10.01	9.90	8.48	3.86	2.42	2.00	0.99	1.39	0.48	0.39	1.84
1998	0.01	0.04	0.21	0.24	0.73	5.21	7.91	9.19	15.07	17.03	9.72	8.39	6.79	3.02	1.88	1.55	0.77	1.08	0.37	1.72
1999	0.00	0.01	0.03	0.19	0.23	0.72	5.27	8.11	9.16	13.91	14.45	7.84	6.62	5.31	2.36	1.47	1.21	0.60	0.84	1.63
2000	0.00	0.02	0.03	0.13	0.67	0.75	2.18	13.85	16.78	13.38	14.42	12.15	6.03	4.93	3.92	1.73	1.08	0.89	0.44	1.82
2001	0.00	0.00	0.01	0.02	0.11	0.59	0.69	2.05	12.81	14.21	9.85	9.47	7.52	3.64	2.95	2.34	1.03	0.64	0.53	1.34
2002	0.05	0.06	0.12	0.40	0.44	1.49	5.02	3.63	6.47	24.09	17.35	9.37	8.25	6.47	3.16	2.58	2.06	0.91	0.56	1.64
2003	0.00	0.01	0.01	0.02	0.08	0.11	0.41	1.61	1.33	2.67	10.65	7.79	4.12	3.51	2.68	1.29	1.04	0.82	0.36	0.88
2004	0.00	0.00	0.02	0.03	0.07	0.31	0.42	1.70	6.21	4.18	5.93	16.24	8.82	3.89	3.02	2.21	1.04	0.83	0.66	0.99
2005	0.00	0.01	0.01	0.05	0.09	0.22	1.00	1.33	4.56	12.47	6.01	6.62	15.78	8.04	3.45	2.65	1.93	0.91	0.73	1.44
2006	0.03	0.03	0.07	0.10	0.38	0.59	1.08	3.12	2.31	4.44	7.97	3.06	3.06	7.01	3.52	1.50	1.15	0.84	0.39	0.94
2007	0.02	0.03	0.04	0.10	0.19	0.86	1.45	2.40	5.53	3.35	5.75	9.79	3.68	3.64	8.32	4.18	1.78	1.37	0.99	1.58
2008	0.06	0.13	0.20	0.22	0.47	0.67	2.03	2.16	2.42	4.54	2.55	4.29	7.26	2.72	2.69	6.16	3.09	1.32	1.01	1.91
2009	0.03	0.09	0.20	0.32	0.37	0.84	1.21	3.38	3.18	3.22	5.74	3.16	5.25	8.85	3.32	3.28	7.50	3.76	1.61	3.55
2010	0.02	0.06	0.22	0.49	0.80	0.90	1.73	1.84	3.58	2.59	2.31	3.91	2.12	3.50	5.89	2.21	2.18	4.99	2.50	3.43

Males

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1980	0.00	0.00	0.00	0.01	0.04	0.07	0.15	0.38	0.81	1.37	1.37	1.63	1.40	1.37	1.38	1.32	1.31	1.34	1.34	1.35
1981	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.11	0.29	0.64	1.10	1.11	1.32	1.13	1.10	1.11	1.07	1.06	1.08	2.17
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.05	0.11	0.27	0.54	0.79	0.64	0.66	0.54	0.52	0.52	0.50	0.49	1.52
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.05	0.14	0.33	0.62	0.75	1.05	0.97	0.96	0.96	0.92	3.72
1984	0.00	0.00	0.00	0.01	0.01	0.02	0.07	0.24	0.95	0.99	0.70	0.54	0.34	0.17	0.06	0.03	0.02	0.01	0.01	0.07
1985	0.14	0.25	0.59	0.79	2.61	1.65	1.09	0.95	1.08	1.63	0.93	0.51	0.36	0.22	0.11	0.04	0.02	0.01	0.01	0.05
1986	0.20	0.37	0.88	2.27	2.41	4.86	1.94	0.96	0.73	0.80	1.18	0.66	0.36	0.26	0.16	0.08	0.03	0.01	0.01	0.04
1987	0.11	0.27	0.35	0.61	1.30	1.47	3.73	1.80	0.98	0.78	0.86	1.28	0.72	0.40	0.28	0.17	0.09	0.03	0.02	0.05
1988	0.05	0.10	0.19	0.20	0.29	0.53	0.59	1.69	1.06	0.76	0.73	0.90	1.41	0.82	0.46	0.33	0.20	0.10	0.04	0.08
1989	0.75	0.93	1.88	3.49	3.40	4.30	6.52	5.30	10.52	4.47	2.32	1.81	1.99	2.96	1.67	0.92	0.65	0.40	0.20	0.23
1990	0.24	1.02	2.60	8.20	13.91	8.07	5.41	4.54	2.30	3.31	1.15	0.54	0.40	0.43	0.63	0.36	0.19	0.14	0.08	0.09
1991	0.05	0.19	0.75	1.81	5.74	10.74	6.76	4.67	3.95	2.01	2.88	1.01	0.47	0.35	0.38	0.55	0.31	0.17	0.12	0.15
1992	0.38	0.71	2.42	7.43	11.55	18.98	20.16	9.93	6.41	5.35	2.71	3.88	1.36	0.64	0.47	0.51	0.74	0.42	0.23	0.37
1993	0.20	0.67	1.91	9.45	32.67	35.69	37.77	32.38	14.88	9.42	7.82	3.96	5.67	1.98	0.93	0.69	0.74	1.08	0.61	0.87
1994	0.08	0.94	2.41	5.18	16.82	32.04	22.95	21.56	18.13	8.31	5.26	4.37	2.21	3.17	1.11	0.52	0.38	0.41	0.61	0.83
1995	0.04	0.23	2.65	6.49	10.42	17.20	16.88	8.98	7.78	6.42	2.93	1.85	1.54	0.78	1.12	0.39	0.18	0.14	0.15	0.51
1996	0.08	0.12	0.44	3.84	7.30	10.57	20.42	24.70	14.58	13.09	10.92	5.00	3.17	2.63	1.33	1.91	0.67	0.31	0.23	1.11
1997	0.02	0.12	0.18	0.67	5.90	10.81	13.73	21.04	21.00	11.38	9.93	8.22	3.76	2.38	1.97	1.00	1.43	0.50	0.23	1.01
1998	0.01	0.04	0.31	0.48	1.92	16.75	25.80	21.84	22.23	18.00	9.08	7.76	6.39	2.91	1.84	1.53	0.77	1.11	0.39	0.96
1999	0.00	0.00	0.02	0.18	0.37	1.91	20.31	30.93	21.27	18.66	14.31	7.11	6.05	4.97	2.27	1.43	1.19	0.60	0.86	1.05
2000	0.00	0.02	0.03	0.16	0.83	0.97	2.89	18.04	19.51	13.15	12.56	10.17	5.16	4.43	3.65	1.67	1.05	0.87	0.44	1.41
2001	0.01	0.03	0.10	0.13	0.53	2.13	1.86	4.07	18.20	14.66	8.25	7.41	5.95	3.03	2.62	2.16	0.99	0.63	0.52	1.10
2002	0.03	0.04	0.10	0.41	0.56	2.27	8.94	7.01	12.08	38.47	22.01	9.63	7.47	5.58	2.75	2.34	1.92	0.88	0.55	1.43
2003	0.00	0.00	0.00	0.01	0.04	0.08	0.57	3.62	3.93	7.02	19.56	9.91	4.05	3.05	2.25	1.10	0.94	0.77	0.35	0.79
2004	0.00	0.00	0.01	0.02	0.06	0.29	0.43	1.84	6.96	4.57	6.07	15.51	7.79	3.20	2.41	1.78	0.88	0.74	0.61	0.91
2005	0.00	0.00	0.01	0.03	0.07	0.20	1.01	1.49	5.30	13.87	6.21	6.43	14.59	6.98	2.82	2.11	1.56	0.76	0.65	1.32
2006	0.02	0.02	0.05	0.08	0.31	0.52	1.02	3.10	2.33	4.46	7.89	2.96	2.88	6.40	3.05	1.23	0.92	0.68	0.33	0.86
2007	0.05	0.10	0.14	0.37	0.66	2.45	2.93	3.36	6.25	3.48	5.78	9.66	3.55	3.42	7.60	3.61	1.45	1.09	0.80	1.41
2008	0.05	0.13	0.27	0.41	1.09	1.63	3.93	3.07	2.81	4.81	2.61	4.29	7.15	2.63	2.54	5.62	2.67	1.08	0.81	1.64
2009	0.03	0.13	0.38	0.83	1.23	2.89	3.16	5.73	3.95	3.48	5.88	3.18	5.23	8.71	3.20	3.09	6.85	3.25	1.31	2.97
2010	0.03	0.15	0.66	1.72	3.01	2.96	3.92	2.73	4.10	2.68	2.32	3.91	2.11	3.47	5.79	2.13	2.05	4.55	2.16	2.85

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	
2010	2,064,870	55,286

Table 7.6—Total tonnage of northern rock sole caught in resource assessment trawl surveys on the Bering Sea shelf, 1977-2010.

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
2010	80

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	579
2010	376	292	19365			

Table 7.10--Estimated population numbers-at-age (millions) from the annual Bering Sea trawl surveys, 1982- 2009.

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
2009	0	1,151	2,389	3,905	3,765	2,532	1,294	718	516	761	360	242	307	335	576	561	222	457	152	153

Table 7.11--Key equations used in the population dynamics model.

Equation	Description
$N_{t,1} = R_t = R_0 e^{\tau_t}, \quad \tau_t \sim N(0,\delta^2{}_R)$	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
1977	0.304	0.022
1978	1.446	0.027
1979	0.051	0.020
1980	0.040	0.028
1981	0.034	0.025
1982	0.045	0.029
1983	0.065	0.030
1984	0.168	0.072
1985	0.046	0.032
1986	0.049	0.028
1987	0.082	0.050
1988	0.156	0.089
1989	0.116	0.066
1990	0.052	0.030
1991	0.111	0.044
1992	0.108	0.038
1993	0.109	0.042
1994	0.110	0.039
1995	0.104	0.037
1996	0.079	0.028
1997	0.088	0.039
1998	0.044	0.020
1999	0.042	0.024
2000	0.045	0.030
2001	0.023	0.018
2002	0.033	0.026
2003	0.029	0.023
2004	0.043	0.031
2005	0.035	0.023
2006	0.038	0.022
2007	0.039	0.021
2008	0.059	0.028
2009	0.050	0.026

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

	survey selectivity																
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
females	0.005932	0.042344	0.24679	0.708281	0.947345	0.992555	0.998989	0.999863	0.999982	0.999998	1	1	1	1	1	1	1
males	0.005273	0.055685	0.396136	0.879485	0.987832	0.998894	0.9999	0.999991	0.999999	1	1	1	1	1	1	1	1

	Female fishery selectivity																
year / age	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1975	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.08	0.22	0.49	0.76	0.92	0.97	0.99	0.99	0.99	0.99
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.17	0.41	0.71	0.89	0.97	0.97	0.97	0.97
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.07	0.21	0.48	0.76	0.91	0.91	0.91	0.91
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.15	0.39	0.39	0.39	0.39
1979	0.00	0.01	0.02	0.06	0.18	0.42	0.71	0.89	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1980	0.10	0.26	0.51	0.75	0.90	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1981	0.17	0.40	0.69	0.88	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1982	0.09	0.27	0.58	0.84	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1983	0.02	0.05	0.14	0.34	0.63	0.84	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1984	0.01	0.04	0.10	0.23	0.46	0.70	0.87	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1985	0.18	0.46	0.78	0.93	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1986	0.02	0.10	0.33	0.70	0.91	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1987	0.08	0.23	0.50	0.77	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1988	0.07	0.21	0.48	0.77	0.92	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1989	0.03	0.14	0.43	0.78	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1990	0.04	0.13	0.34	0.64	0.86	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1991	0.01	0.03	0.08	0.18	0.37	0.61	0.81	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1992	0.00	0.01	0.04	0.10	0.25	0.50	0.74	0.89	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1993	0.00	0.01	0.04	0.11	0.27	0.53	0.77	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1994	0.00	0.00	0.02	0.05	0.13	0.32	0.60	0.82	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00

1995	0.00	0.01	0.02	0.06	0.15	0.34	0.61	0.82	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1996	0.00	0.00	0.01	0.03	0.08	0.22	0.46	0.73	0.89	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1997	0.01	0.02	0.04	0.08	0.16	0.27	0.44	0.61	0.76	0.87	0.93	0.97	0.98	0.99	0.99	0.99	0.99
1998	0.00	0.01	0.01	0.03	0.06	0.14	0.27	0.46	0.67	0.83	0.92	0.96	0.98	0.99	0.99	0.99	0.99
1999	0.00	0.01	0.02	0.06	0.14	0.29	0.52	0.74	0.88	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00
2000	0.00	0.01	0.03	0.08	0.20	0.41	0.66	0.84	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2001	0.03	0.07	0.16	0.33	0.57	0.78	0.90	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2002	0.01	0.04	0.12	0.32	0.62	0.85	0.95	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2003	0.03	0.08	0.19	0.39	0.64	0.83	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2004	0.01	0.04	0.11	0.27	0.52	0.77	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2005	0.02	0.05	0.13	0.32	0.60	0.82	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2006	0.01	0.05	0.16	0.40	0.71	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2007	0.01	0.03	0.11	0.33	0.66	0.89	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2008	0.01	0.02	0.07	0.21	0.50	0.78	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2009	0.01	0.02	0.08	0.25	0.57	0.84	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2010	0.01	0.02	0.06	0.18	0.41	0.69	0.88	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

male fishery selectivity

year / age	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	0.00	0.00	0.00	0.02	0.06	0.18	0.44	0.74	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1976	0.00	0.00	0.00	0.00	0.01	0.04	0.13	0.36	0.67	0.88	0.96	0.99	1.00	1.00	1.00	1.00	1.00
1977	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.18	0.45	0.75	0.91	0.97	0.99	1.00	1.00	1.00	1.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.10	0.29	0.61	0.86	0.96	0.96	0.96	0.96
1979	0.00	0.00	0.01	0.04	0.14	0.38	0.69	0.89	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1980	0.16	0.34	0.59	0.80	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1981	0.33	0.67	0.89	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1982	0.07	0.17	0.37	0.62	0.82	0.93	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1983	0.01	0.03	0.06	0.12	0.23	0.41	0.60	0.77	0.88	0.95	0.97	0.99	0.99	1.00	1.00	1.00	1.00
1984	0.04	0.09	0.18	0.32	0.51	0.69	0.83	0.91	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1985	0.39	0.75	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1986	0.09	0.30	0.66	0.90	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

1987	0.14	0.39	0.71	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1988	0.10	0.39	0.80	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1989	0.08	0.28	0.65	0.90	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1990	0.12	0.40	0.77	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1991	0.02	0.07	0.23	0.52	0.80	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1992	0.01	0.04	0.13	0.36	0.68	0.89	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1993	0.01	0.04	0.13	0.37	0.70	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1994	0.00	0.01	0.04	0.18	0.54	0.86	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1995	0.00	0.01	0.03	0.08	0.20	0.44	0.71	0.88	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1996	0.01	0.01	0.03	0.08	0.17	0.32	0.53	0.73	0.86	0.94	0.97	0.99	1.00	1.00	1.00	1.00	1.00
1997	0.01	0.03	0.06	0.15	0.30	0.52	0.74	0.87	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1998	0.00	0.00	0.01	0.04	0.14	0.41	0.74	0.92	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1999	0.00	0.01	0.02	0.06	0.15	0.33	0.59	0.80	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2000	0.00	0.01	0.03	0.08	0.22	0.48	0.74	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2001	0.02	0.05	0.14	0.32	0.56	0.78	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2002	0.05	0.14	0.36	0.66	0.87	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2003	0.05	0.18	0.45	0.76	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2004	0.03	0.13	0.37	0.71	0.91	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2005	0.06	0.18	0.45	0.75	0.92	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2006	0.02	0.08	0.22	0.49	0.76	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2007	0.03	0.10	0.26	0.53	0.79	0.92	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2008	0.01	0.03	0.08	0.24	0.52	0.79	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2009	0.01	0.05	0.13	0.32	0.60	0.83	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2010	0.01	0.05	0.14	0.36	0.66	0.87	0.96	0.99	1.00	1.00	1.00	1.00	1.00	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 2009 and 2010 assessments.

	2010 Assessment		2009 Assessment	
	Age 2+ Total biomass	Female Spawning biomass	Age 2+ Total biomass	Female Spawning biomass
1975	198,582	54,928	177,461	49,696
1976	218,048	57,836	192,717	53,446
1977	237,985	66,080	207,092	60,634
1978	263,705	83,033	227,042	74,206
1979	287,722	103,463	246,213	88,603
1980	318,648	119,344	274,170	99,620
1981	358,220	128,120	313,125	104,246
1982	402,761	132,927	360,320	107,030
1983	455,843	139,712	417,714	113,149
1984	526,013	148,724	495,345	124,035
1985	588,842	147,623	568,606	124,795
1986	692,843	164,891	689,540	140,114
1987	821,405	182,818	840,739	158,678
1988	966,669	204,031	1,012,790	182,136
1989	1,050,680	220,499	1,127,400	205,398
1990	1,170,850	249,952	1,276,130	248,734
1991	1,386,810	299,389	1,511,990	316,385
1992	1,483,200	315,711	1,601,600	349,013
1993	1,523,460	333,201	1,624,970	377,421
1994	1,529,600	351,042	1,609,480	399,774
1995	1,606,230	427,972	1,671,500	480,785
1996	1,662,650	526,814	1,709,980	578,688
1997	1,714,270	616,532	1,742,970	661,617
1998	1,697,470	669,273	1,710,630	701,288
1999	1,689,940	728,441	1,690,090	745,334
2000	1,657,200	768,376	1,649,050	773,574
2001	1,602,000	776,485	1,587,440	771,844
2002	1,563,740	764,432	1,545,880	753,292
2003	1,533,340	741,873	1,511,220	726,387
2004	1,524,240	690,843	1,495,530	671,146
2005	1,529,240	613,512	1,495,500	594,501
2006	1,628,880	549,121	1,581,890	531,661
2007	1,737,830	515,609	1,671,730	500,180
2008	1,821,610	492,057	1,740,370	479,705
2009	1,870,800	494,529	1,765,910	484,516
2010	1,891,370	532,764		

Table 7.16--Estimated age 4 recruitment of rock sole (thousands of fish) from the 2009 and 2010 assessments. Average of 1971-2004 (2010 assessment) is 1,020,619.

Year class	2010 Assessment	2009 Assessment
1971	199,646	156,417
1972	157,247	128,434
1973	196,715	176,429
1974	204,486	184,950
1975	476,208	450,056
1976	267,834	253,896
1977	428,596	401,954
1978	425,912	407,948
1979	563,480	580,384
1980	1,024,880	1,118,992
1981	1,005,700	1,123,264
1982	923,936	1,050,126
1983	1,388,986	1,600,284
1984	1,344,112	1,538,868
1985	1,273,466	1,406,248
1986	2,257,340	2,342,500
1987	3,531,500	3,464,260
1988	1,252,990	1,195,264
1989	1,047,112	978,944
1990	2,330,540	2,115,800
1991	1,161,806	1,056,624
1992	593,410	550,304
1993	931,874	890,694
1994	470,078	457,910
1995	461,532	461,498
1996	606,724	621,464
1997	360,352	367,214
1998	528,138	531,834
1999	563,620	606,462
2000	1,217,392	1,204,932
2001	1,921,506	1,881,762
2002	2,272,140	2,046,540
2003	1,640,548	1,484,858
2004	1,100,062	986,386
2005	1,591,802	

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	160	133	91	100	186	120	51	37	29	23	11	8	5	5	5	4	4	4	4	5
1976	373	138	114	79	86	160	103	44	32	25	20	9	6	4	3	3	3	3	3	6
1977	210	321	119	98	68	74	138	89	38	28	22	17	7	5	3	2	2	2	2	5
1978	337	181	277	102	85	58	64	119	76	33	24	19	14	6	4	2	1	1	1	4
1979	335	290	156	238	88	73	50	55	102	66	28	20	16	12	5	3	1	1	1	3
1980	443	288	249	134	205	76	63	43	47	86	55	23	17	13	10	4	3	1	1	3
1981	804	381	248	214	115	175	64	52	36	39	71	45	19	14	11	8	4	2	1	3
1982	789	692	328	213	183	97	147	53	44	30	32	59	38	16	12	9	7	3	2	3
1983	726	679	596	282	183	156	82	122	44	36	24	26	49	31	13	9	7	6	2	4
1984	1090	625	585	512	242	157	133	69	100	36	29	20	21	39	25	11	8	6	5	5
1985	1056	938	538	503	440	207	133	110	55	77	27	21	14	16	29	18	8	6	4	7
1986	1003	909	807	462	429	371	172	109	91	45	63	22	18	12	13	24	15	6	5	9
1987	1774	863	782	694	397	368	314	143	90	74	37	52	18	14	10	10	19	12	5	11
1988	2772	1526	742	672	594	335	304	254	114	72	59	29	41	14	11	8	8	15	10	13
1989	983	2386	1313	637	572	495	268	232	189	84	53	43	22	30	10	8	6	6	11	17
1990	821	846	2053	1129	546	484	405	211	179	145	65	40	33	17	23	8	6	4	5	22
1991	1828	707	728	1766	969	467	410	337	173	147	119	53	33	27	14	19	7	5	4	21
1992	911	1573	608	626	1518	832	398	346	279	139	115	92	41	25	21	10	15	5	4	19
1993	465	784	1354	524	539	1305	713	339	289	227	111	90	72	32	20	16	8	11	4	18
1994	731	401	675	1165	450	463	1118	606	283	235	180	86	70	55	24	15	12	6	9	17
1995	369	629	345	581	1003	387	398	957	514	235	189	141	67	54	43	19	12	10	5	20
1996	362	317	541	297	500	862	333	341	811	427	190	150	110	52	42	33	15	9	7	19
1997	476	312	273	466	255	430	742	286	291	686	354	154	120	88	42	33	26	12	7	21
1998	283	410	268	235	401	219	369	634	243	245	568	289	124	96	70	33	26	21	9	22
1999	414	243	352	231	202	345	189	317	544	208	208	479	241	103	79	58	27	22	17	26
2000	442	357	209	303	199	174	296	162	271	463	175	174	398	200	85	65	48	22	18	36
2001	955	380	307	180	261	171	150	254	138	229	387	145	143	328	164	70	54	39	18	44
2002	1507	822	327	264	155	224	147	128	216	117	193	325	122	121	275	138	59	45	33	52

2003	1782	1297	707	282	227	133	192	125	108	181	97	161	271	101	100	229	115	49	38	71
2004	1287	1534	1116	609	242	195	114	164	105	90	151	82	135	226	85	84	192	96	41	91
2005	863	1107	1320	961	524	208	167	97	138	88	75	125	67	111	187	70	69	158	79	109
2006	1248	743	953	1136	826	450	178	142	82	115	73	62	104	56	92	155	58	57	131	156
2007	471	1074	639	820	977	710	385	151	119	68	96	61	52	86	46	76	129	48	48	238
2008	487	406	925	550	706	840	608	327	127	99	56	79	50	43	71	38	63	106	40	237
2009	657	419	349	796	473	607	720	517	273	104	81	46	64	41	35	58	31	51	86	224
2010	679	565	360	301	685	407	520	612	433	226	86	66	38	53	33	28	47	25	42	254

	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	160	78	60	65	98	56	32	24	16	12	7	7	6	6	6	6	5	6	6	6
1976	373	138	67	51	56	84	48	27	20	13	9	5	5	4	4	4	4	3	4	7
1977	210	321	119	58	44	48	72	42	23	17	11	7	3	3	2	2	2	2	2	6
1978	337	181	277	102	50	38	42	62	36	20	14	9	5	2	2	1	1	1	1	5
1979	335	290	156	238	88	43	33	36	54	31	17	12	7	4	1	1	0	0	0	1
1980	443	288	249	134	205	76	37	28	31	45	26	14	10	6	3	1	1	0	0	1
1981	804	381	248	214	115	174	64	31	23	25	37	21	12	8	5	3	1	0	0	1
1982	789	692	328	212	182	96	145	53	26	19	21	31	18	10	7	4	2	1	0	1
1983	726	679	595	282	182	156	82	122	44	21	16	17	26	14	8	6	3	2	1	1
1984	1090	625	585	512	242	157	133	70	103	37	18	13	14	21	12	6	5	3	1	2
1985	1056	938	537	501	438	205	131	109	55	79	28	13	10	10	15	8	5	3	2	2
1986	1003	909	806	460	424	364	169	108	89	45	65	23	11	8	8	12	7	4	3	3
1987	1774	863	782	693	394	360	303	139	88	73	37	53	19	9	6	7	10	6	3	5
1988	2772	1526	742	671	590	329	292	242	111	70	58	29	42	15	7	5	5	8	5	6
1989	983	2386	1313	637	569	477	250	216	179	82	52	43	22	31	11	5	4	4	6	8
1990	821	846	2053	1128	543	474	381	194	166	137	63	40	33	17	24	8	4	3	3	11
1991	1828	707	728	1764	965	458	392	312	158	136	112	51	32	27	14	19	7	3	2	11
1992	911	1573	608	626	1515	824	384	319	246	123	105	86	39	25	21	10	15	5	2	11
1993	465	784	1354	523	538	1299	699	318	255	192	95	81	67	30	19	16	8	12	4	10
1994	731	401	675	1165	450	462	1102	578	254	199	149	74	63	51	23	15	12	6	9	11

1995	369	629	345	581	1003	387	396	930	469	199	154	115	57	48	40	18	11	9	5	15
1996	362	317	541	297	500	862	332	338	784	385	159	121	89	44	37	31	14	9	7	16
1997	476	312	273	466	255	430	740	284	287	658	318	129	97	71	35	30	24	11	7	18
1998	283	410	268	235	401	219	368	629	238	236	530	253	102	77	56	28	23	19	9	20
1999	414	243	352	231	202	345	189	316	538	201	196	438	209	84	63	46	23	19	16	24
2000	442	357	209	303	199	174	296	162	270	456	169	163	363	173	69	52	38	19	16	33
2001	955	380	307	180	261	171	150	254	138	228	380	140	135	299	142	57	43	32	15	40
2002	1507	822	327	264	155	224	147	128	216	117	192	320	118	113	251	119	48	36	27	47
2003	1782	1297	707	282	227	133	191	123	107	180	97	160	266	98	94	209	99	40	30	61
2004	1287	1534	1116	609	242	194	113	161	103	89	151	81	134	223	82	79	175	83	33	76
2005	863	1107	1320	961	523	207	165	94	133	85	74	124	67	110	184	67	65	144	69	90
2006	1248	743	953	1136	825	447	176	138	79	111	71	61	103	56	92	153	56	54	120	132
2007	471	1074	639	820	977	708	382	148	115	65	92	59	51	85	46	76	126	46	45	209
2008	487	406	925	550	705	837	603	322	124	96	54	76	49	42	71	38	63	105	38	210
2009	657	419	349	796	473	606	717	512	269	102	78	44	62	40	34	57	31	51	85	201
2010	679	565	360	301	684	406	518	607	428	222	84	64	36	50	32	28	47	25	42	234

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
2010	3	32	122	219	169	76	61	36	51	33	28	47	25	42	254

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	0.306	1.24E-01	1983	total biomass	455.840	12.227
	sel_slope_fishery_female	1.157	6.68E-02	1984	total biomass	526.010	12.472
	sel50_fishery_female	8.312	5.01E-01	1985	total biomass	588.840	12.809
	sel_slope_fsh_males	1.243	7.28E-02	1986	total biomass	692.840	13.640
	sel50_fsh_males	7.449	4.51E-01	1987	total biomass	821.400	14.694
	sel_slope_survey_females	2.003	1.21E-01	1988	total biomass	966.670	16.196
	sel50_survey_females	3.557	6.27E-02	1989	total biomass	1050.700	17.793
	sel_slope_survey_males	0.185	7.96E-02	1990	total biomass	1170.900	19.681
	sel50_survey_males	-0.114	2.01E-02	1991	total biomass	1386.800	22.293
	F40	0.165	1.05E-01	1992	total biomass	1483.200	23.615
	F35	0.200	1.39E-01	1993	total biomass	1523.500	24.563
	F30	0.246	1.89E-01	1994	total biomass	1529.600	25.312
	Ricker_logalpha	-4.144	2.04E-01	1995	total biomass	1606.200	27.545
	Ricker_logbeta	-5.834	1.64E-01	1996	total biomass	1662.700	29.565
	Fmsy	0.269	2.15E-01	1997	total biomass	1714.300	31.388
	logFmsy	-1.315	8.00E-01	1998	total biomass	1697.500	32.519
	ABC_biomass 2011	1717.100	3.19E-01	1999	total biomass	1689.900	33.123
	ABC_biomass 2012	1678.900	7.91E+01	2000	total biomass	1657.200	33.391
	msy	261.980	8.69E+01	2001	total biomass	1602.000	33.299
	Bmsy	259.330	5.88E+01	2002	total biomass	1563.700	33.003
1975	total biomass	198.580	3.25E+01	2003	total biomass	1533.300	33.113
1976	total biomass	218.050	9.67E+00	2004	total biomass	1524.200	34.127
1977	total biomass	237.990	1.04E+01	2005	total biomass	1529.200	36.950
1978	total biomass	263.700	1.11E+01	2006	total biomass	1628.900	44.316
1979	total biomass	287.720	1.15E+01	2007	total biomass	1737.800	53.333
1980	total biomass	318.650	1.18E+01	2008	total biomass	1821.600	62.657
1981	total biomass	358.220	1.19E+01	2009	total biomass	1870.800	72.259
1982	total biomass	402.760	1.20E+01	2010	total biomass	1891.400	82.152

Table 7.20. Stock assessment model estimates of average age-specific fishing mortality, by gender, 1975-2010.

females

	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	0.000	0.000	0.000	0.000	0.001	0.002	0.007	0.023	0.065	0.145	0.228	0.273	0.290	0.296	0.296	0.296	0.296
1976	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.007	0.022	0.066	0.162	0.277	0.350	0.379	0.379	0.379	0.379
1977	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.007	0.022	0.064	0.145	0.230	0.278	0.278	0.278	0.278
1978	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.020	0.068	0.217	0.560	0.560	0.560	0.560
1979	0.000	0.000	0.001	0.003	0.009	0.021	0.036	0.046	0.049	0.050	0.051	0.051	0.051	0.051	0.051	0.051	0.051
1980	0.004	0.010	0.020	0.030	0.036	0.039	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
1981	0.006	0.014	0.024	0.030	0.033	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
1982	0.004	0.012	0.026	0.038	0.043	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
1983	0.001	0.003	0.009	0.022	0.041	0.055	0.061	0.064	0.064	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065
1984	0.002	0.006	0.016	0.039	0.077	0.118	0.146	0.160	0.165	0.167	0.168	0.168	0.168	0.168	0.168	0.168	0.168
1985	0.008	0.021	0.036	0.043	0.045	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
1986	0.001	0.005	0.016	0.034	0.045	0.048	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049
1987	0.007	0.019	0.041	0.063	0.075	0.080	0.081	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082
1988	0.011	0.033	0.075	0.120	0.144	0.152	0.155	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156
1989	0.004	0.017	0.050	0.090	0.109	0.115	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116
1990	0.002	0.007	0.018	0.033	0.044	0.049	0.051	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052
1991	0.001	0.003	0.008	0.020	0.041	0.068	0.090	0.102	0.108	0.110	0.111	0.111	0.111	0.111	0.111	0.111	0.111
1992	0.001	0.001	0.004	0.011	0.028	0.054	0.080	0.097	0.104	0.107	0.108	0.108	0.108	0.108	0.108	0.108	0.108
1993	0.000	0.001	0.004	0.012	0.030	0.058	0.084	0.099	0.105	0.108	0.108	0.109	0.109	0.109	0.109	0.109	0.109
1994	0.000	0.001	0.002	0.005	0.015	0.035	0.066	0.090	0.103	0.107	0.109	0.110	0.110	0.110	0.110	0.110	0.110
1995	0.000	0.001	0.002	0.006	0.016	0.036	0.063	0.085	0.097	0.102	0.103	0.104	0.104	0.104	0.104	0.104	0.104
1996	0.000	0.000	0.001	0.002	0.007	0.017	0.036	0.057	0.070	0.076	0.078	0.079	0.079	0.079	0.079	0.079	0.079
1997	0.001	0.002	0.004	0.007	0.014	0.024	0.039	0.054	0.068	0.077	0.082	0.085	0.087	0.088	0.088	0.088	0.088
1998	0.000	0.000	0.001	0.001	0.003	0.006	0.012	0.020	0.029	0.036	0.040	0.042	0.043	0.044	0.044	0.044	0.044
1999	0.000	0.000	0.001	0.002	0.006	0.012	0.022	0.031	0.037	0.040	0.041	0.042	0.042	0.042	0.042	0.042	0.042
2000	0.000	0.001	0.001	0.004	0.009	0.018	0.029	0.038	0.042	0.044	0.044	0.045	0.045	0.045	0.045	0.045	0.045
2001	0.001	0.002	0.004	0.008	0.013	0.018	0.021	0.022	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
2002	0.000	0.001	0.004	0.011	0.020	0.028	0.031	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033

2003	0.001	0.002	0.005	0.011	0.019	0.024	0.027	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
2004	0.001	0.002	0.005	0.011	0.023	0.033	0.039	0.042	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
2005	0.001	0.002	0.005	0.011	0.021	0.028	0.032	0.034	0.034	0.034	0.035	0.035	0.035	0.035	0.035	0.035	0.035
2006	0.001	0.002	0.006	0.015	0.027	0.034	0.037	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
2007	0.000	0.001	0.004	0.013	0.026	0.035	0.038	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
2008	0.000	0.001	0.004	0.013	0.029	0.046	0.055	0.058	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
2009	0.000	0.001	0.004	0.012	0.028	0.042	0.047	0.049	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
2010	0.000	0.001	0.003	0.008	0.019	0.033	0.041	0.045	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047

males

	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	0.000	0.000	0.001	0.005	0.017	0.054	0.132	0.221	0.272	0.290	0.296	0.297	0.298	0.298	0.298	0.298	0.298
1976	0.000	0.000	0.000	0.001	0.004	0.016	0.052	0.141	0.264	0.346	0.379	0.389	0.392	0.393	0.393	0.393	0.393
1977	0.000	0.000	0.000	0.000	0.001	0.005	0.017	0.055	0.135	0.226	0.278	0.296	0.301	0.303	0.303	0.303	0.303
1978	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.011	0.041	0.143	0.424	0.884	1.238	1.384	1.384	1.384	1.384
1979	0.000	0.000	0.001	0.002	0.007	0.019	0.035	0.046	0.049	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051
1980	0.006	0.014	0.024	0.032	0.037	0.039	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
1981	0.011	0.023	0.031	0.033	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
1982	0.003	0.008	0.017	0.028	0.037	0.042	0.044	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
1983	0.001	0.002	0.004	0.008	0.015	0.026	0.039	0.050	0.057	0.061	0.063	0.064	0.064	0.065	0.065	0.065	0.065
1984	0.007	0.015	0.030	0.054	0.085	0.116	0.140	0.154	0.161	0.165	0.167	0.168	0.168	0.168	0.168	0.168	0.168
1985	0.018	0.035	0.043	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
1986	0.004	0.015	0.032	0.044	0.048	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049
1987	0.012	0.032	0.058	0.074	0.080	0.081	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082
1988	0.015	0.061	0.124	0.150	0.155	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156
1989	0.009	0.032	0.075	0.104	0.113	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116
1990	0.006	0.021	0.040	0.049	0.051	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052
1991	0.002	0.008	0.025	0.058	0.089	0.104	0.109	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111
1992	0.001	0.004	0.014	0.039	0.074	0.096	0.105	0.107	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108
1993	0.001	0.004	0.014	0.041	0.077	0.099	0.106	0.108	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109

1994	0.000	0.001	0.004	0.020	0.059	0.095	0.107	0.109	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110
1995	0.000	0.001	0.003	0.008	0.021	0.046	0.074	0.092	0.100	0.103	0.104	0.104	0.104	0.104	0.104	0.104	0.104
1996	0.000	0.001	0.003	0.006	0.013	0.025	0.042	0.058	0.068	0.074	0.077	0.078	0.079	0.079	0.079	0.079	0.079
1997	0.001	0.002	0.006	0.013	0.027	0.046	0.065	0.077	0.084	0.086	0.088	0.088	0.088	0.088	0.088	0.088	0.088
1998	0.000	0.000	0.000	0.002	0.006	0.018	0.033	0.040	0.043	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044
1999	0.000	0.000	0.001	0.002	0.006	0.014	0.025	0.034	0.039	0.041	0.042	0.042	0.042	0.042	0.042	0.042	0.042
2000	0.000	0.000	0.001	0.004	0.010	0.021	0.033	0.040	0.043	0.044	0.045	0.045	0.045	0.045	0.045	0.045	0.045
2001	0.000	0.001	0.003	0.007	0.013	0.018	0.021	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
2002	0.001	0.005	0.012	0.022	0.029	0.032	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
2003	0.002	0.005	0.013	0.022	0.027	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
2004	0.001	0.005	0.016	0.031	0.039	0.042	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
2005	0.002	0.006	0.015	0.026	0.032	0.034	0.034	0.034	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
2006	0.001	0.003	0.009	0.019	0.029	0.035	0.037	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
2007	0.001	0.004	0.010	0.021	0.031	0.036	0.038	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
2008	0.000	0.002	0.005	0.014	0.031	0.047	0.055	0.058	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
2009	0.001	0.002	0.007	0.016	0.030	0.041	0.047	0.049	0.049	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
2010	0.001	0.002	0.007	0.017	0.031	0.041	0.045	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047

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. .

Scenarios 1 and 2

Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2010	532,765	49,000	0.05
2011	582,386	174,827	0.16
2012	575,181	167,154	0.16
2013	545,486	154,926	0.16
2014	507,874	140,155	0.16
2015	459,447	125,301	0.16
2016	408,093	112,969	0.16
2017	370,086	105,929	0.16
2018	343,740	97,682	0.16
2019	339,777	96,397	0.15
2020	344,573	98,045	0.15
2021	352,143	100,553	0.15
2022	359,602	102,792	0.15
2023	362,702	103,952	0.15

Scenario 3

Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2010	532,765	49,000	0.05
2011	**587,738**	46,740	0.04
2012	642,756	33,494	0.03
2013	677,657	34,359	0.03
2014	694,817	34,181	0.03
2015	689,199	33,294	0.03
2016	667,624	32,227	0.03
2017	648,979	31,711	0.03
2018	631,701	31,512	0.03
2019	634,328	31,857	0.03
2020	643,444	32,410	0.03
2021	656,656	33,084	0.03
2022	670,714	33,611	0.03
2023	677,058	33,990	0.03

Scenario 4

1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2010	532,765	49,000	0.05
2011	586,091	87,414	0.08
2012	620,832	87,009	0.08
2013	629,506	85,960	0.08
2014	622,565	82,514	0.08
2015	596,399	77,766	0.08
2016	558,773	73,150	0.08
2017	528,047	70,440	0.08
2018	502,997	68,990	0.08
2019	498,305	69,125	0.08
2020	501,367	69,905	0.08
2021	508,491	70,954	0.08
2022	516,741	71,761	0.08
2023	519,545	72,280	0.08

Scenario 5

No fishing

Year	Female spawning biomass	catch	F
2010	532,765	49,000	0.05
2011	589,573	0	0
2012	666,775	0	0
2013	718,050	0	0
2014	750,826	0	0
2015	759,272	0	0
2016	749,572	0	0
2017	740,759	0	0
2018	730,748	0	0
2019	740,525	0	0
2020	755,951	0	0
2021	775,520	0	0
2022	795,574	0	0
2023	806,030	0	0

Table 7.21—continued.

Scenario 6

Determination of whether northern rock sole are currently overfished **B35=315,800**

Year	Female spawning biomass	catch	F
2010	532,765	49,000	0.05
2011	580,855	209,342	0.20
2012	557,340	194,733	0.20
2013	514,716	176,017	0.20
2014	468,135	155,652	0.20
2015	414,376	136,477	0.20
2016	360,926	121,268	0.20
2017	323,490	101,614	0.18
2018	304,081	94,166	0.17
2019	305,635	96,960	0.17
2020	313,735	101,885	0.17
2021	322,540	106,282	0.17
2022	329,939	109,515	0.18
2023	332,679	110,951	0.18

Scenario 7

Determination of whether the stock is approaching an overfished condition **B35=315,800**

Year	Female spawning biomass	catch	F
2010	532,765	49,000	0.05
2011	582,386	174,827	0.16
2012	575,181	167,154	0.16
2013	544,010	185,408	0.20
2014	491,406	162,913	0.20
2015	432,170	141,900	0.20
2016	374,203	125,285	0.20
2017	333,132	107,255	0.18
2018	309,847	97,370	0.17
2019	309,047	98,775	0.17
2020	315,686	102,849	0.17
2021	323,635	106,781	0.17
2022	330,516	109,755	0.18
2023	332,962	111,056	0.18

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
2010	90,000	240,000

Table 7.23—Catch and bycatch in the rock sole target fisheries, 1993-2009, from blend of regional office reported catch and observer sampling.

Species	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Walleye Pollock	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	6,124
Arrowtooth Flounder	1,143	1,782	507	1,341	411	300	69	216	835	314	419	346	599	516	220	464	600
Pacific Cod	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	3,608
Groundfish, General	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	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	29,703
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	1,770
Sablefish	4	16	3	3	1	0	2	5	12	4	2	9			3	1	
Atka Mackerel	15	0		0	0	9	0	38	3	0	1	16	48	87	210	4	<1
Pacific Ocean Perch	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	2,221	2,756	1,636	1,591	1,498	342	362	1,184	726	307	783	820	937	620	1,009	2	691
Shortraker / Rougheye	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	<1
Yellowfin Sole	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	6,608
Greenland Turbot	28	50	3	3	2	1	0	1	15	0	1	4	1	27	8		7
Alaska Plaice	2,561	931	173	71	408	250	63	385	75	621	375	1,111	1,352	1,828	1,810	2,710	2,299
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	2010
Benthic urochordata	118.6782	220.8681	318.778	105.5442	12.74301	31.0486	9.09298	58.75642
Birds	0	0.046	0.156	0.119	0.717	0	0.173	0.036
Bivalves	4.7001	0.33889	0.20578	0.36476	0.39608	0.29944	0.288	0.40396
Brittle star unidentified	0.03228	0.86538	1.77368	7.29008	1.5373	1.10305	0.25871	1.24443
Capelin	0.0013	0.38838	0.02442	0.00435	0.00644	0.02226	0.04344	0.10299
Corals Bryozoans	0.6898	0.69316	0.01588	1.34697	0.0206	0.10029	0.01896	1.98383
Eelpouts	1.00013	4.29625	2.15567	3.24469	6.89493	1.31358	0.1368	4.87805
Eulachon	0	0.01426	0	0	0.00153	0.00383	0.00232	0.03101
Giant Grenadier	0	0	0	0	4.56552	0.09546	0	3.33141
Greenlings	1.15007	0.33424	0.42882	0.33532	0.26723	0.04459	0	0.01729
Grenadier	0.00001	0.50251	0	0	0	0.01205	0	0
Hermit crab unidentified	19.1692	7.1501	7.58756	10.40132	5.758	2.6869	0.63421	3.85806
Invertebrate unidentified	105.8659	3.12894	84.18135	6.93809	24.21111	1.58226	2.39059	14.3149
Large Sculpins	183.5924	252.6131	439.4593	480.8095	630.6488	1060.857	1237.959	880.8155
Misc crabs	18.83036	6.42386	9.29316	6.50753	13.60515	8.93187	3.25769	6.40173
Misc crustaceans	0.38019	0.15176	0.04536	0.4997	0.19827	0.1802	0.25717	1.04273
Misc fish	12.85703	16.94373	22.42171	17.28098	70.90519	25.20286	11.67353	10.70967
Misc inverts (worms etc)	0.00144	0.05171	0	0.02414	0.1	0.00824	0.01054	0.12164
Octopus	19.29	21.495	13.493	0.749	4.378	9.37	7.339	9.356
Other osmerids	3.71591	0.0635	0.72558	0.26783	0.18439	0.62718	0.08226	0.01595
Other Sculpins	255.1995	17.24813	34.57763	182.3534	131.4067	32.88852	33.12419	5.3918
Pacific Sand lance	0.01611	0.04472	0.00695	0.03267	0.042	0.03067	0.10466	0.01561
Pandalid shrimp	0.20089	0.08594	0.02959	0.02026	0.0526	0.0215	0.05929	0.0566
Polychaete unidentified	0.0018	0.00702	0	0.00119	0.10299	0.02106	0.01914	0.01526
Scypho jellies	257.8468	304.9247	393.491	73.28145	94.41773	185.1541	233.1118	337.494
Sea anemone unidentified	18.44918	13.29101	6.45626	8.99476	6.33835	6.74671	2.5595	8.71352
Sea pens whips	0	0.01931	0.0362	0.00015	0	0.02939	0.04999	0.18281
Sea star	1171.098	333.4326	555.3511	731.0409	710.4139	207.1707	30.97824	173.1054
Shark, pacific sleeper	0	0	1.41	0	4.272	0.456	0	0
Shark, salmon	0.508	0	0.08	0	0	0	0	0
Shark, spiny dogfish	0	0	0.041	0	0.293	0.241	0	0.387
Skate, Alaska	0	0	0	0	0	0	0	1145.447
Skate, Big	0	13.001	20.111	13.166	15.6	36.983	24.154	24.084
Skate, Longnose	1.121	0	0	0	0.873	0.846	0	0.724
Skate, Other	528.588	495.635	403.027	917.832	983.904	521.648	920.032	9.724
Snails	23.79537	23.96673	12.92255	28.38612	24.38393	9.32004	2.68593	10.61551
Sponge unidentified	198.3708	67.55506	69.9373	40.98467	19.22467	19.27466	64.70774	141.0009
Squid	0.024	0.255	0.032	0	0.372	0.041	0	0
Stichaeidae	0.04187	0.00128	0.00286	0	0.00041	0.00356	0.00067	0.00353
urchins dollars cucumbers	13.42033	8.88978	9.27999	3.89954	32.16461	6.03498	1.10536	2.63697
Grand Total	2958.636	1814.726	2407.537	2641.721	2801.001	2170.401	2586.311	2857.02

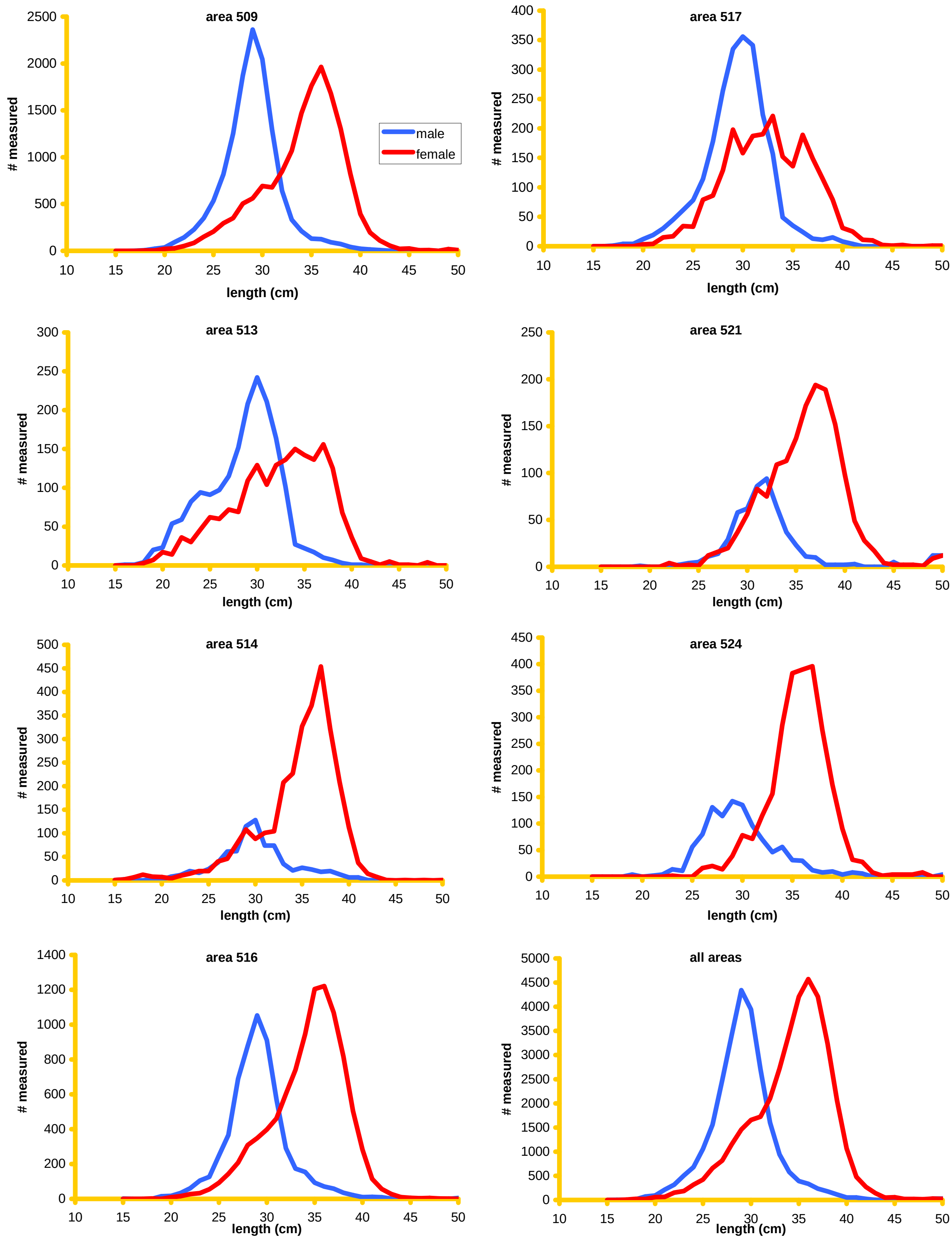
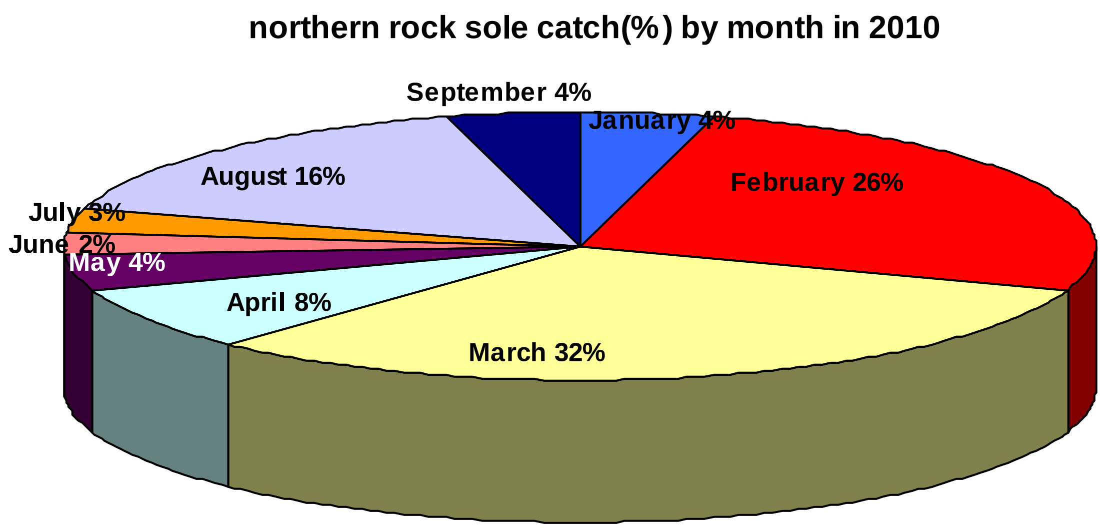


Figure 7.1—Size composition of rock sole, by sex and area, in the 2009 catch as determined from observer sampling.



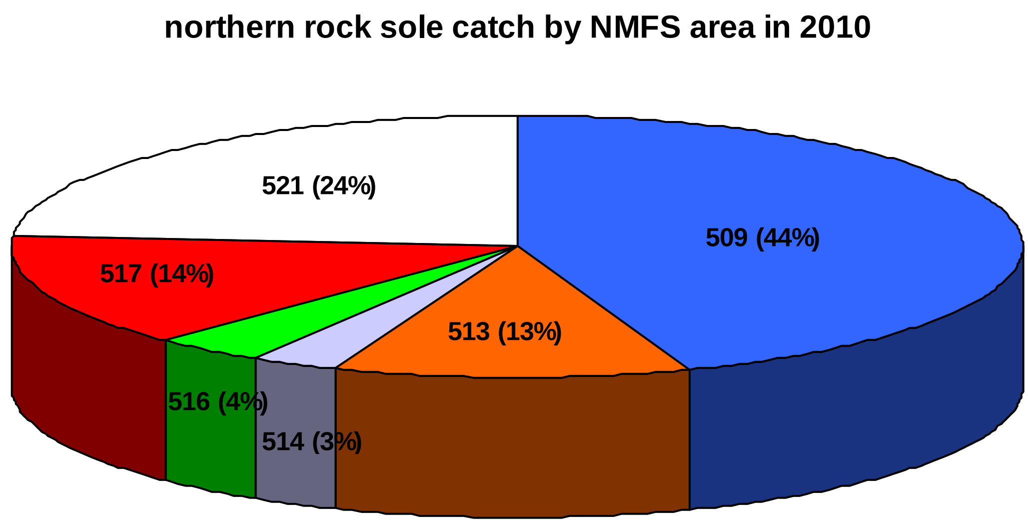
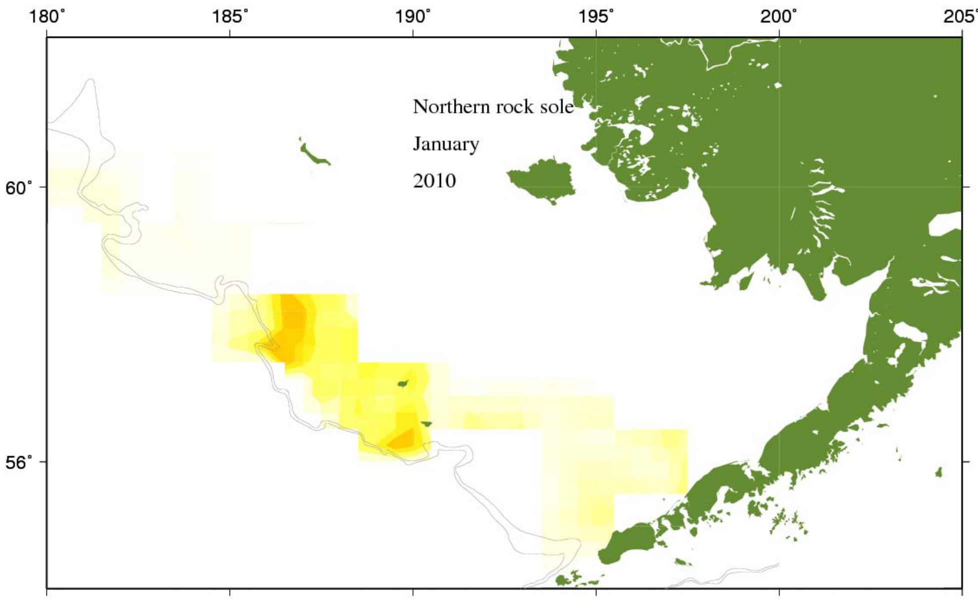


Figure 7.2—Bering Sea northern rock sole fishery catch by month and area in 2010 (percent of total).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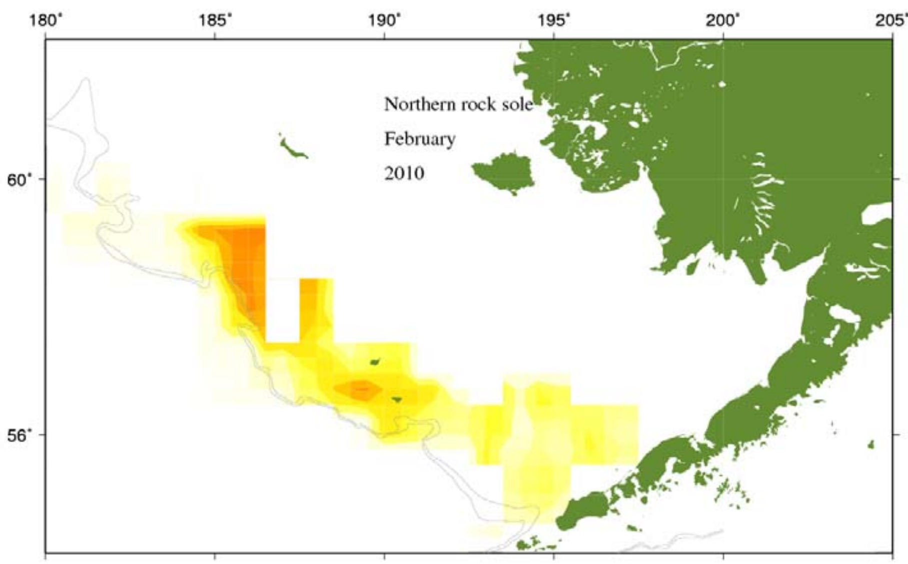
185°
190°
195°
200°
205°
60°
56°
Northern rock sole
January
2010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195°
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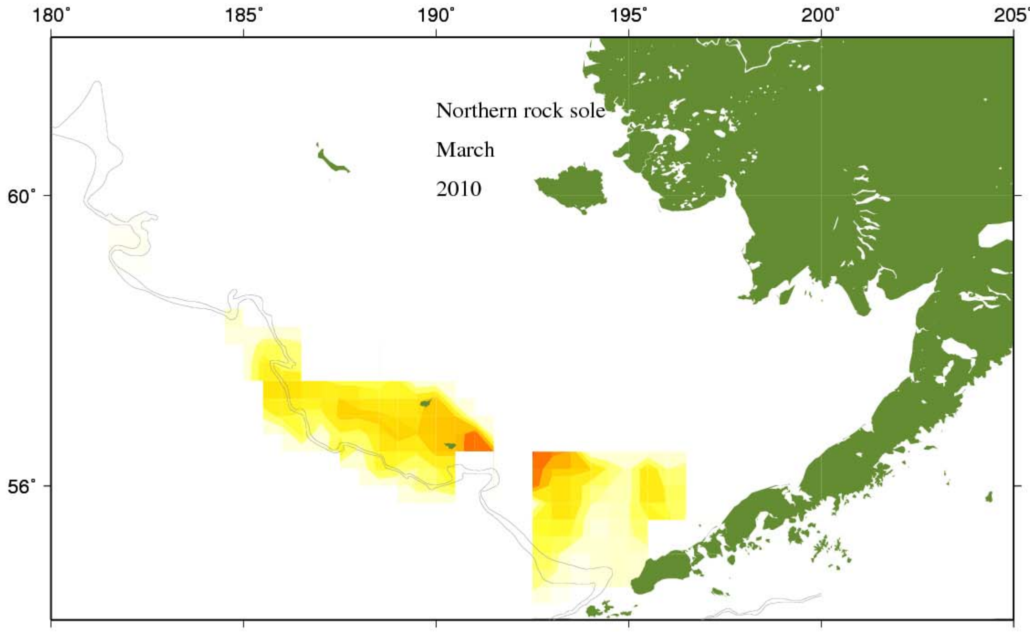
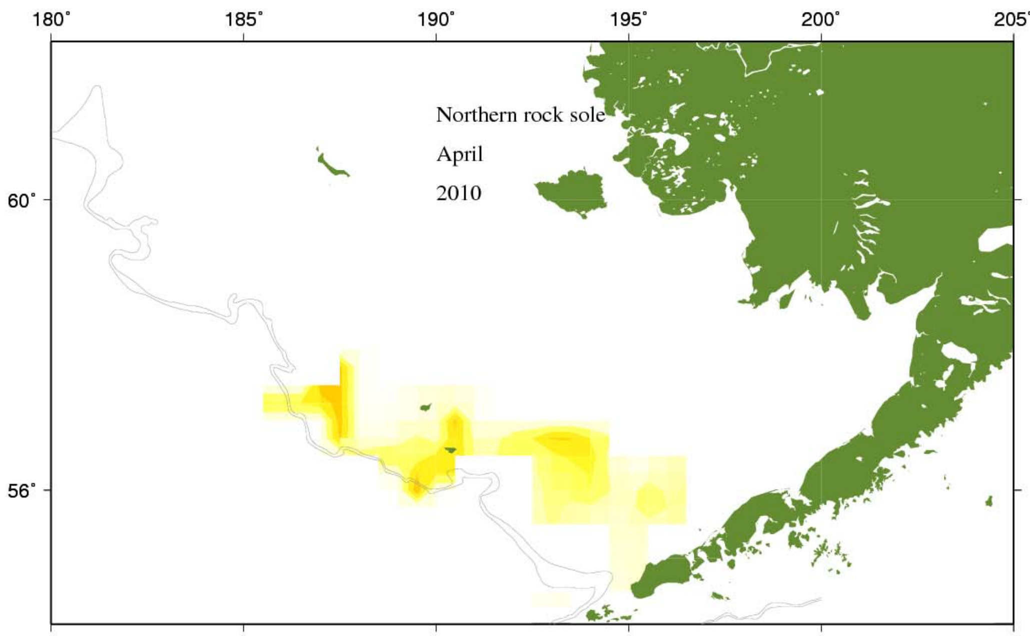
205°
60°
56°
Northern rock sole
February
2010


180˚
185˚
190˚
195˚
200˚
205˚
60˚
56˚
Northern rock sole
March
2010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Northern rock sole
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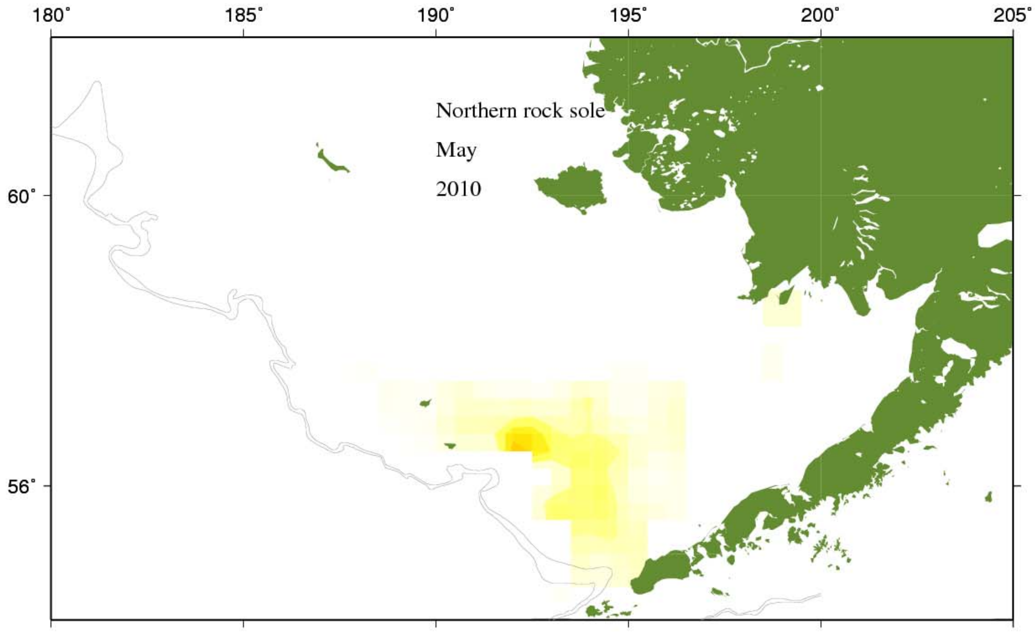
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Northern rock sole
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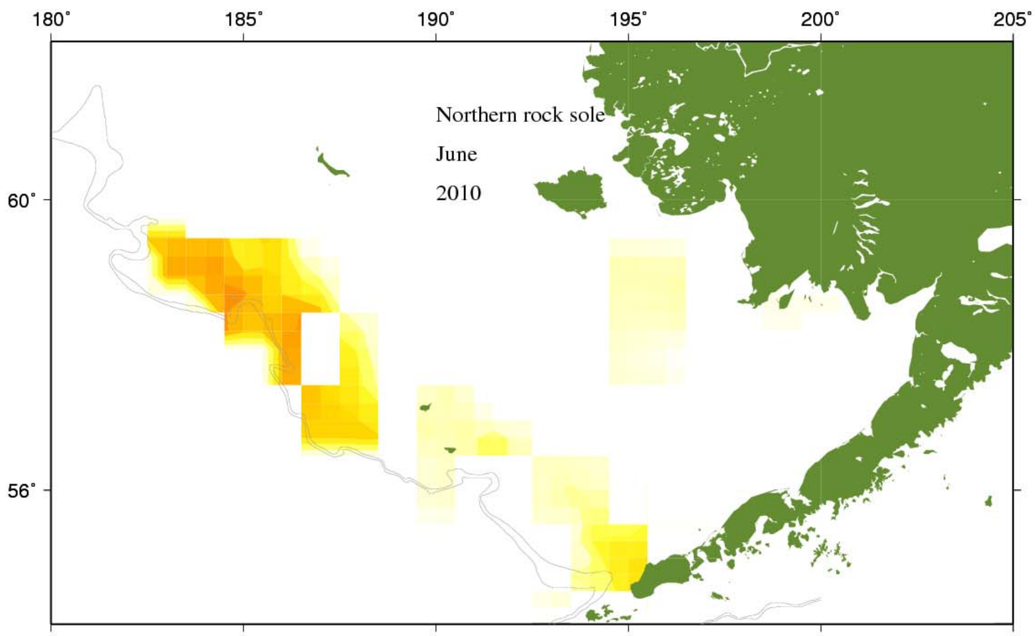
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Northern rock sole
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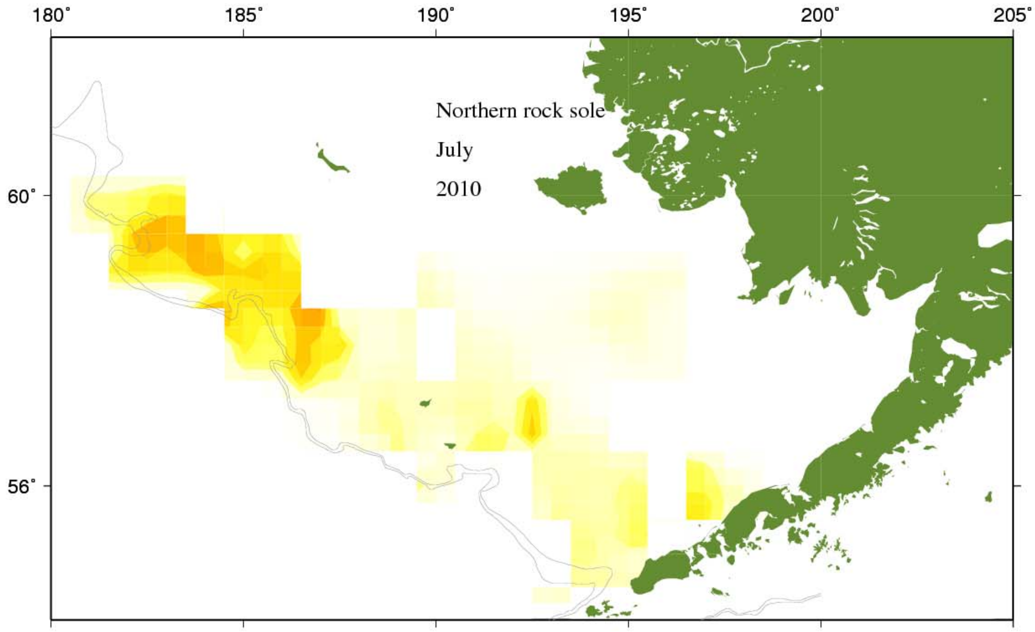
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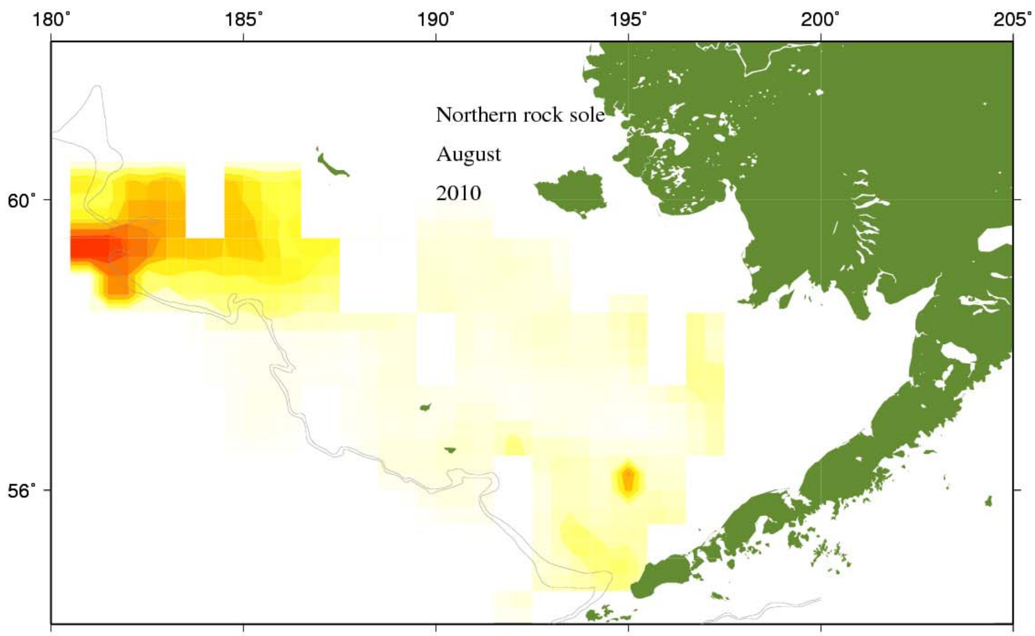
Northern rock sole
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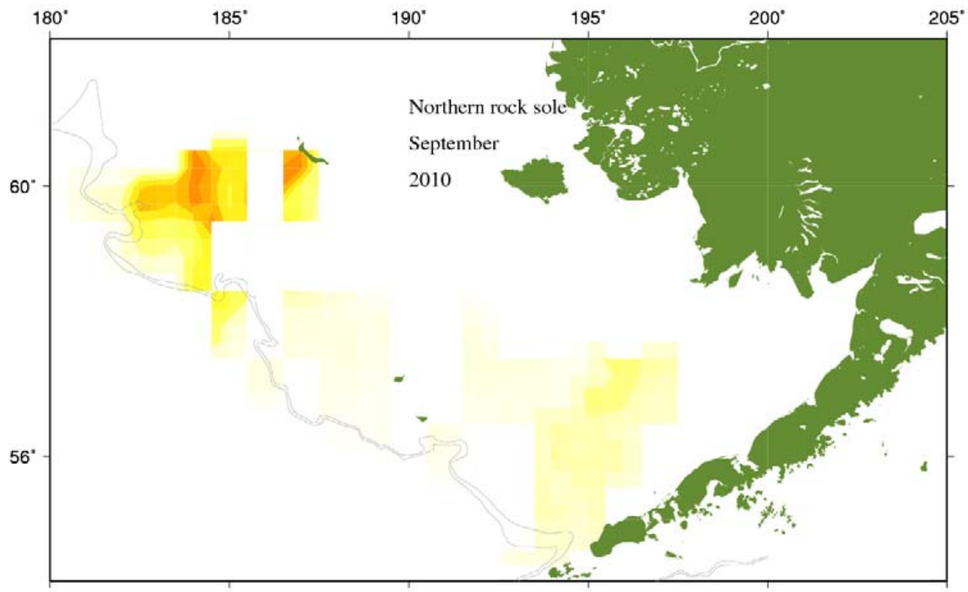


Figure 7.3—Catch locations, by month, of northern rock sole.

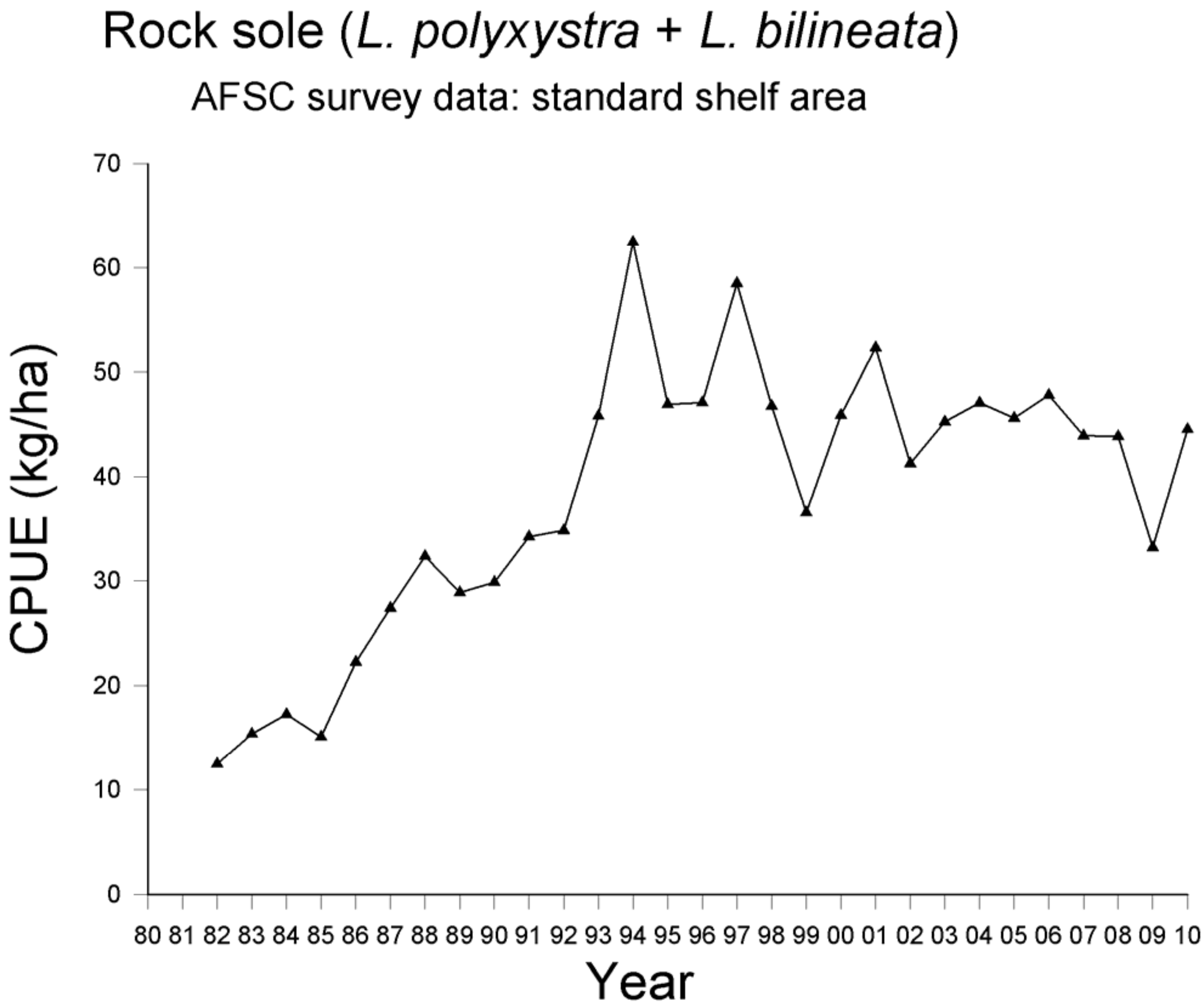


Figure 7.4—Catch per unit effort of *Lepidopsetta polyxystra* and *Lepidopsetta bilineata* (kg/ha) from Bering Sea shelf trawl surveys, 1982-2010.

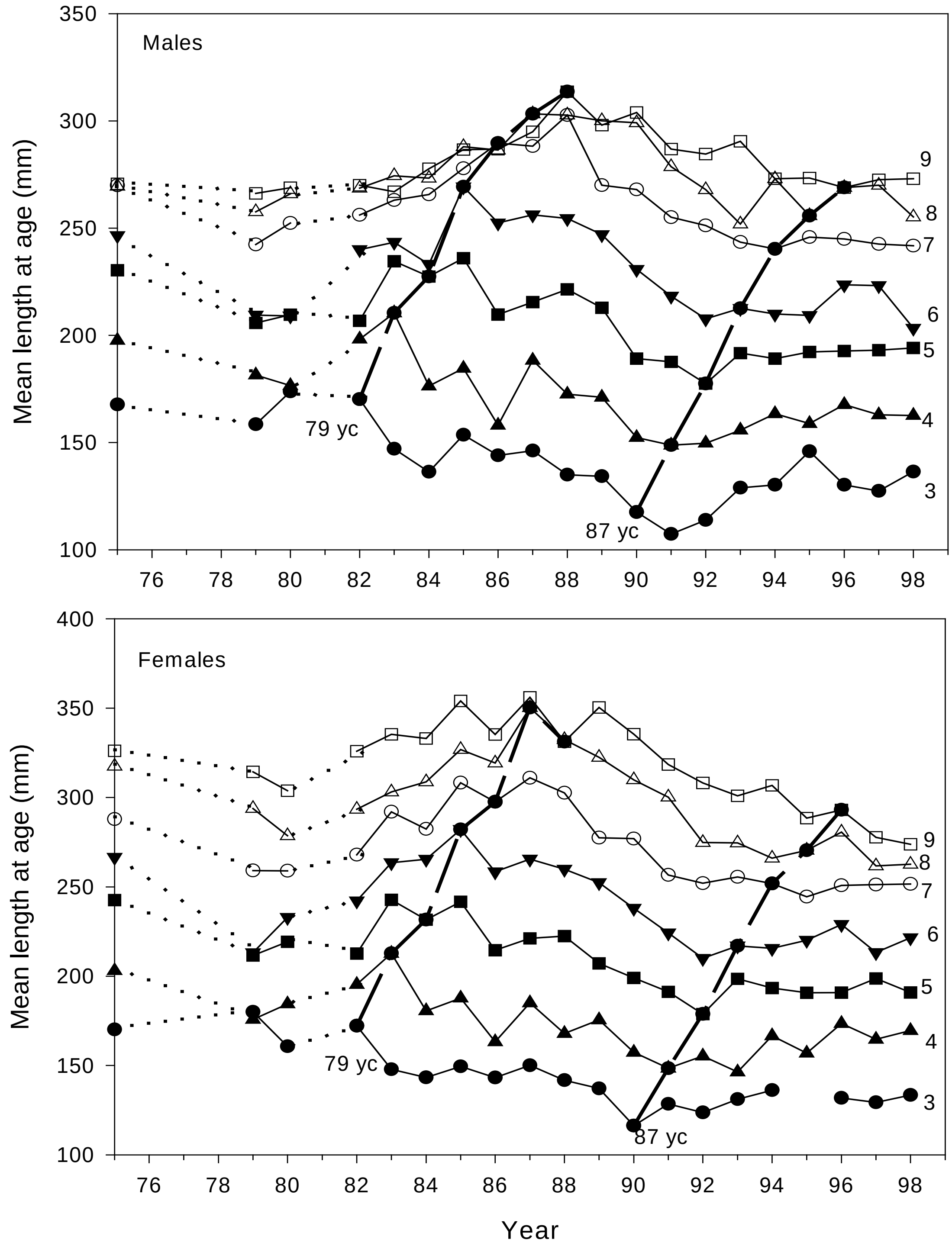


Fig. 7.5. Mean lengths at age (mm) by year of survey for eastern Bering Sea northern rocksole ages 3-9 for each sex during 1975-1998. Growth curves are shown for the 1979 (79yc) and 1987 (87yc) year classes. Dotted lines indicate no data during the period.
(From Walters and Wilderbuer, 2000, p.20)

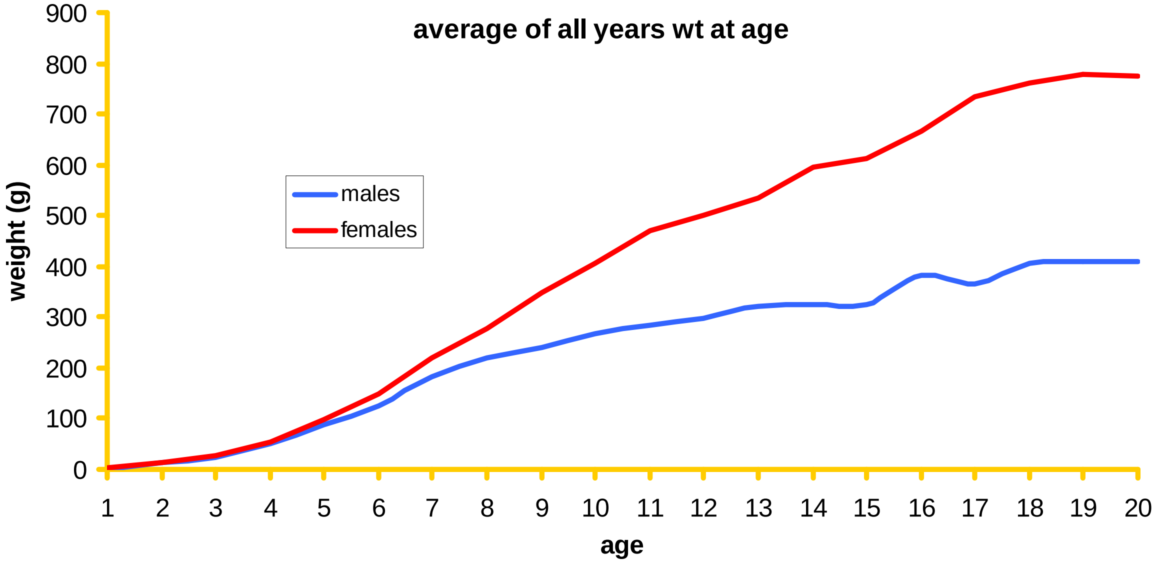
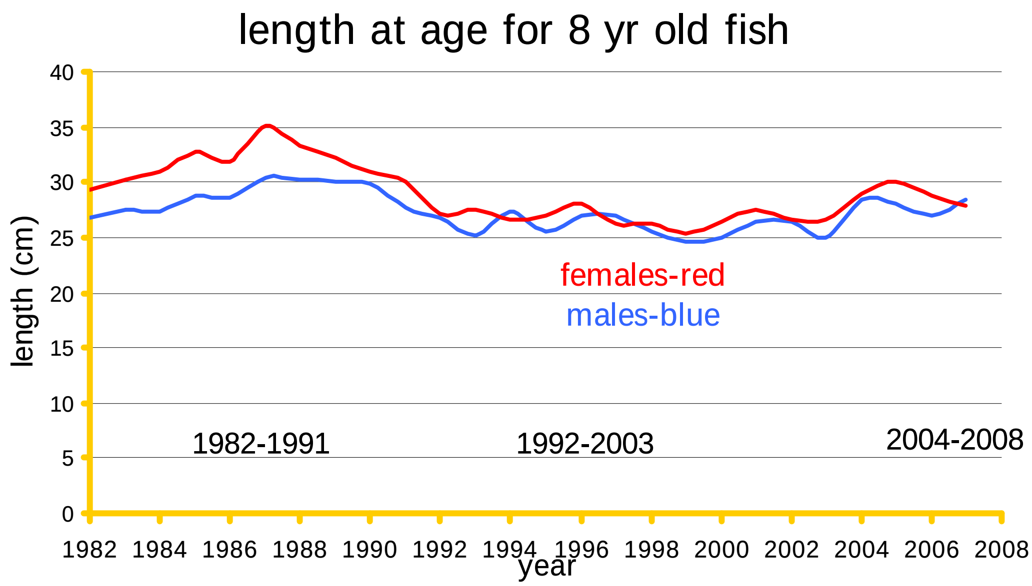


Figure 7.6-Mean weight-at-age for northern rock sole averaged over all years of survey age data.



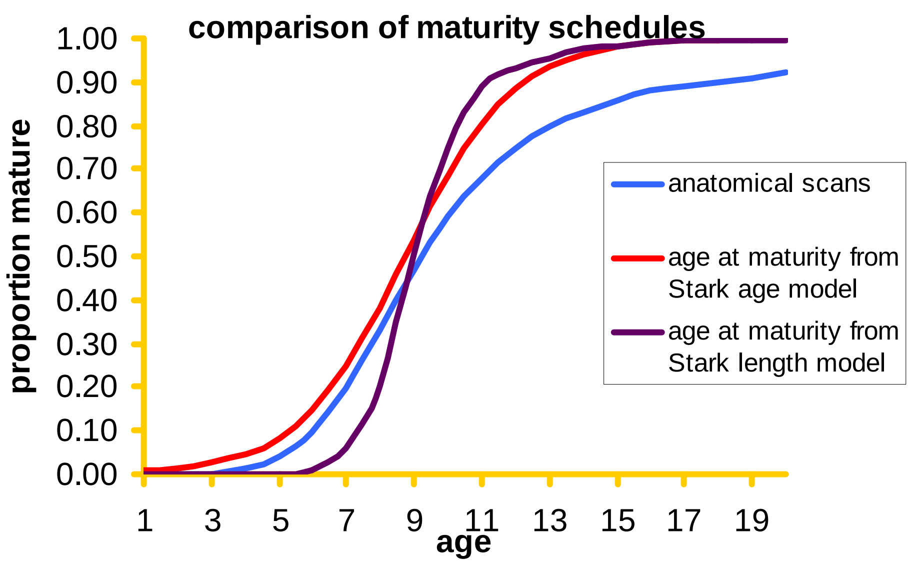


Fig. 7.7-Time-varying length-at-age for 8 year old northern rock sole with 3 time periods identified for modeling growth differently (top panel). Maturity schedule for northern rock sole from three methods (bottom panel). Stark (2009) length model, based on histology, is used in the stock assessment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

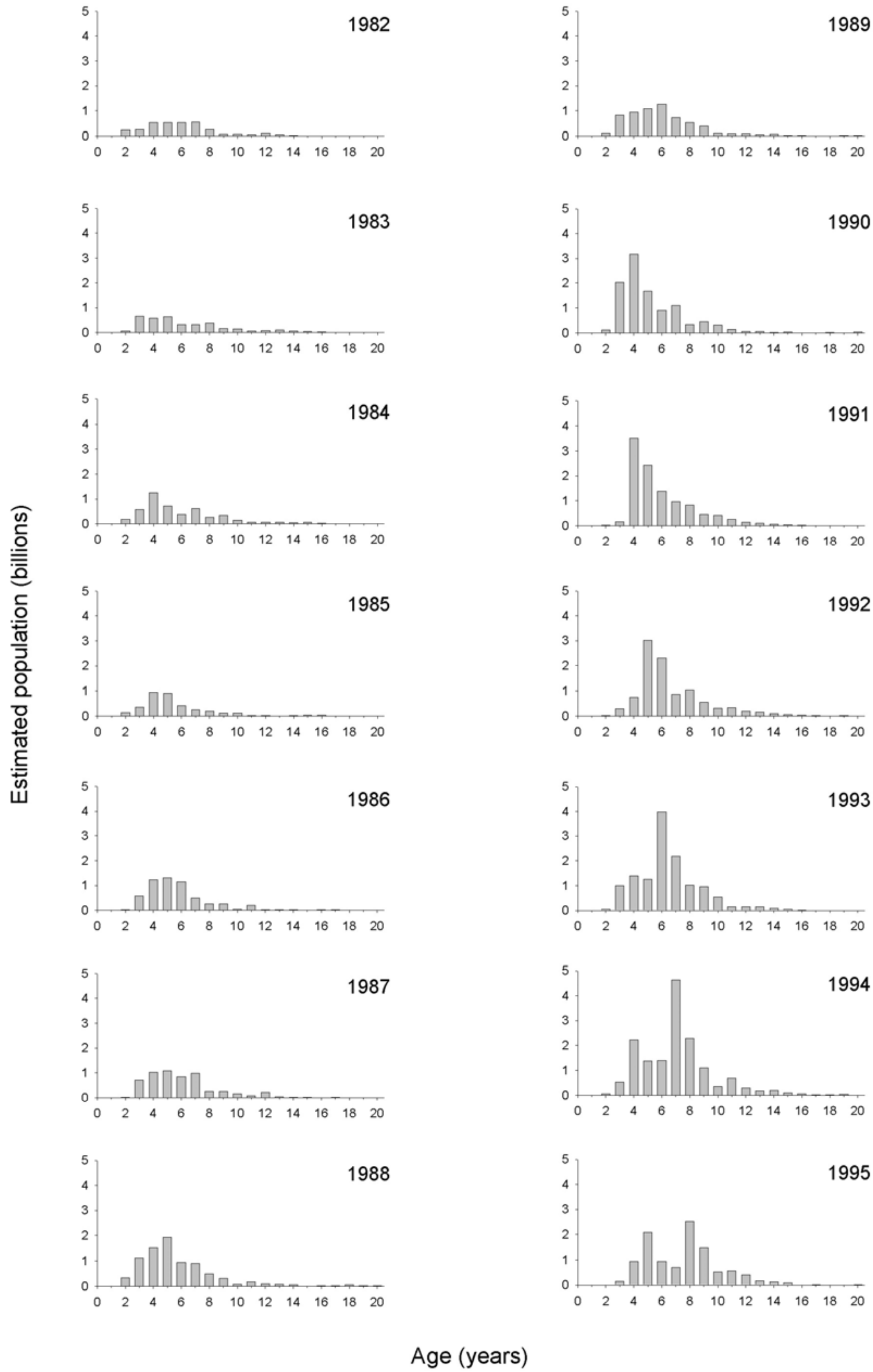


Figure 7.8—Age composition of northern rock sole from the AFSC annual trawl survey.

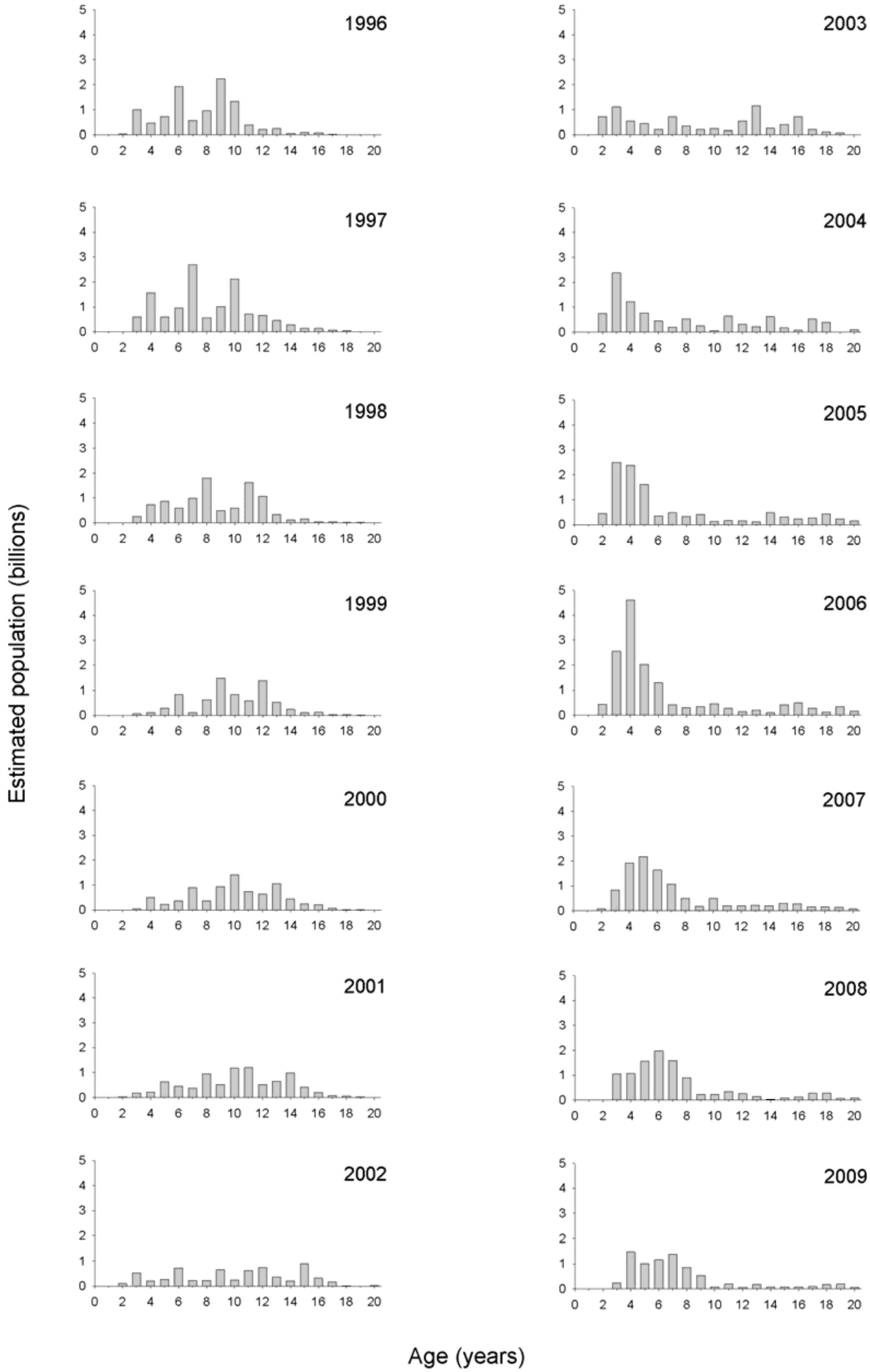


Figure 7.8--continued.

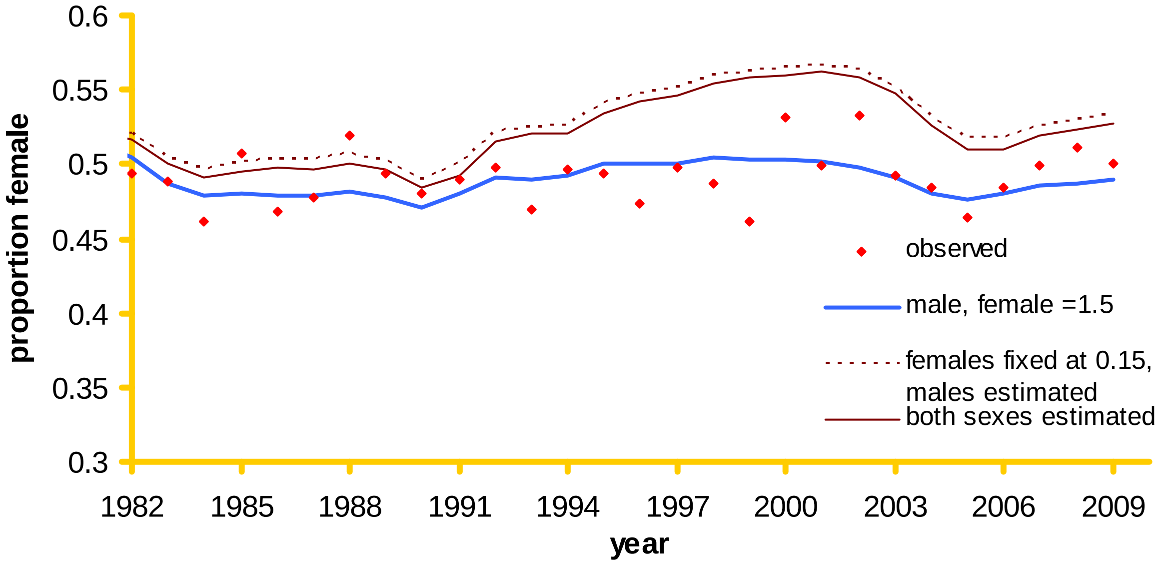


Figure 7.9—Fits to the population sex ratio from the results of Models 1, 4 and 5.

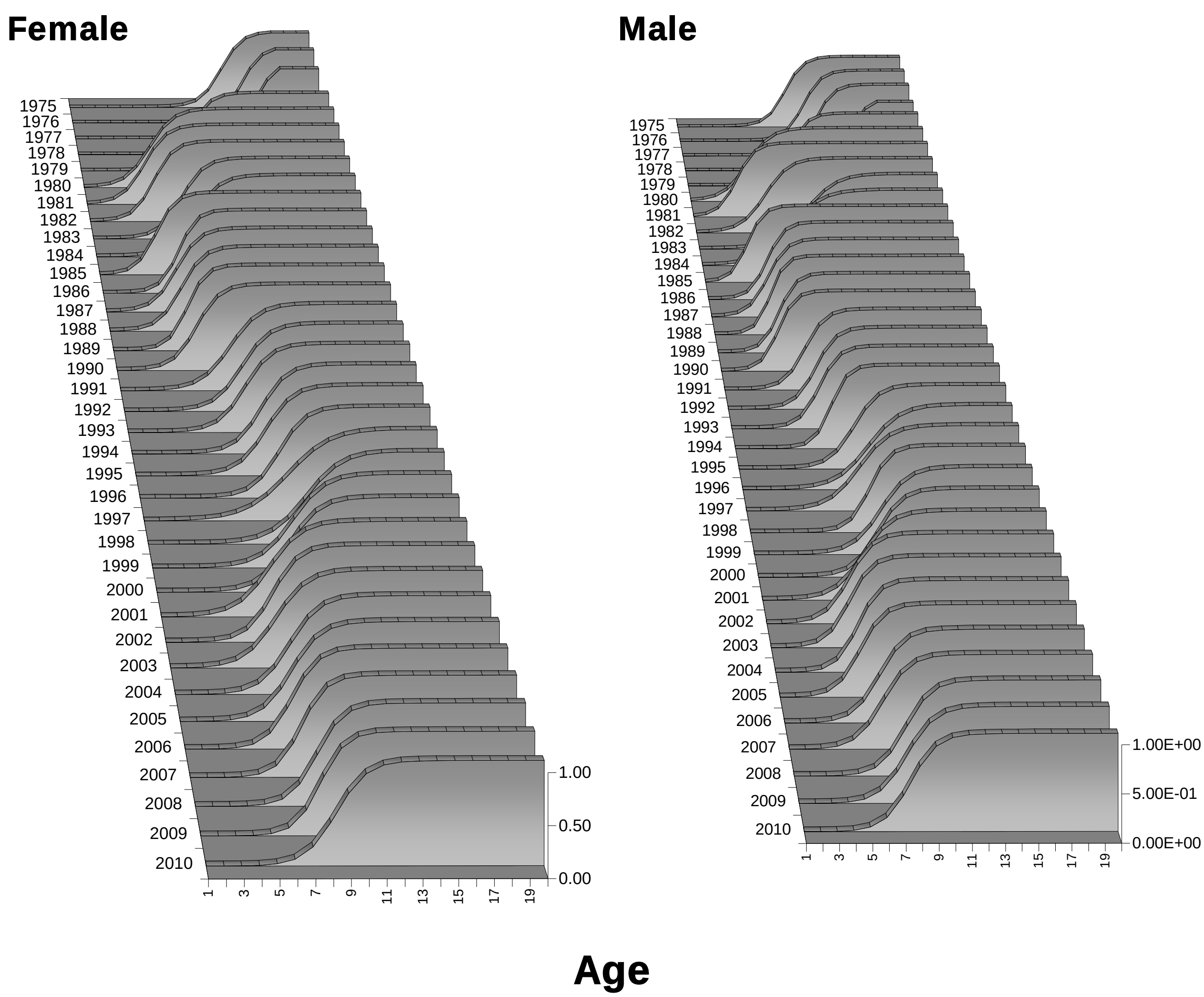


Figure 7.10—Stock assessment model estimates of fishery selectivity at age, by year and gender.

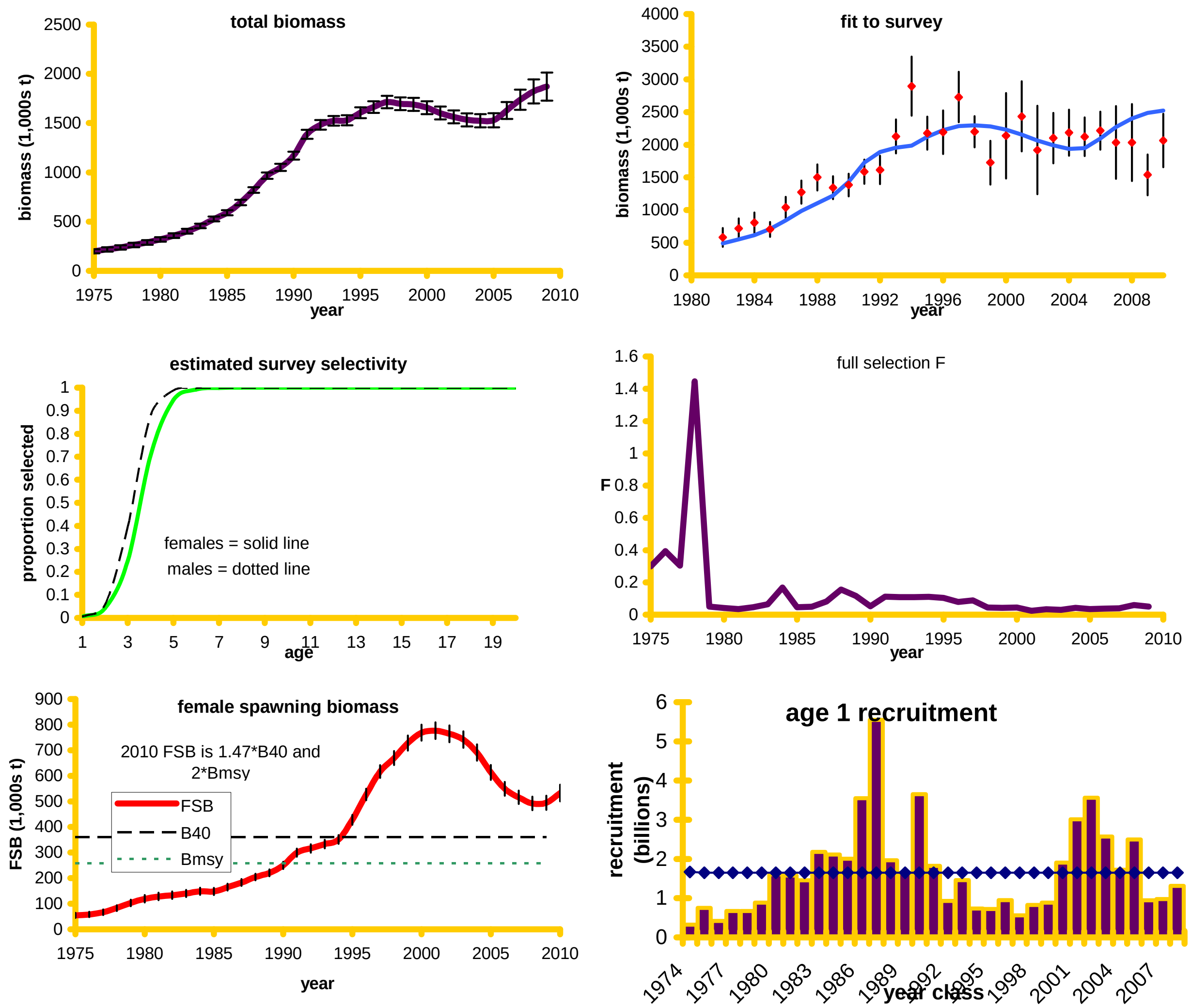


Figure 7.11--Stock assessment model estimates of total 2+ biomass (top left panel), fit to trawl survey biomass (top right panel), age-specific fishery and survey selectivity (middle left panel) and average annual fishing mortality rate (middle right panel), female spawning biomass (bottom right panel) and estimated age 1 recruitment (bottom right panel).

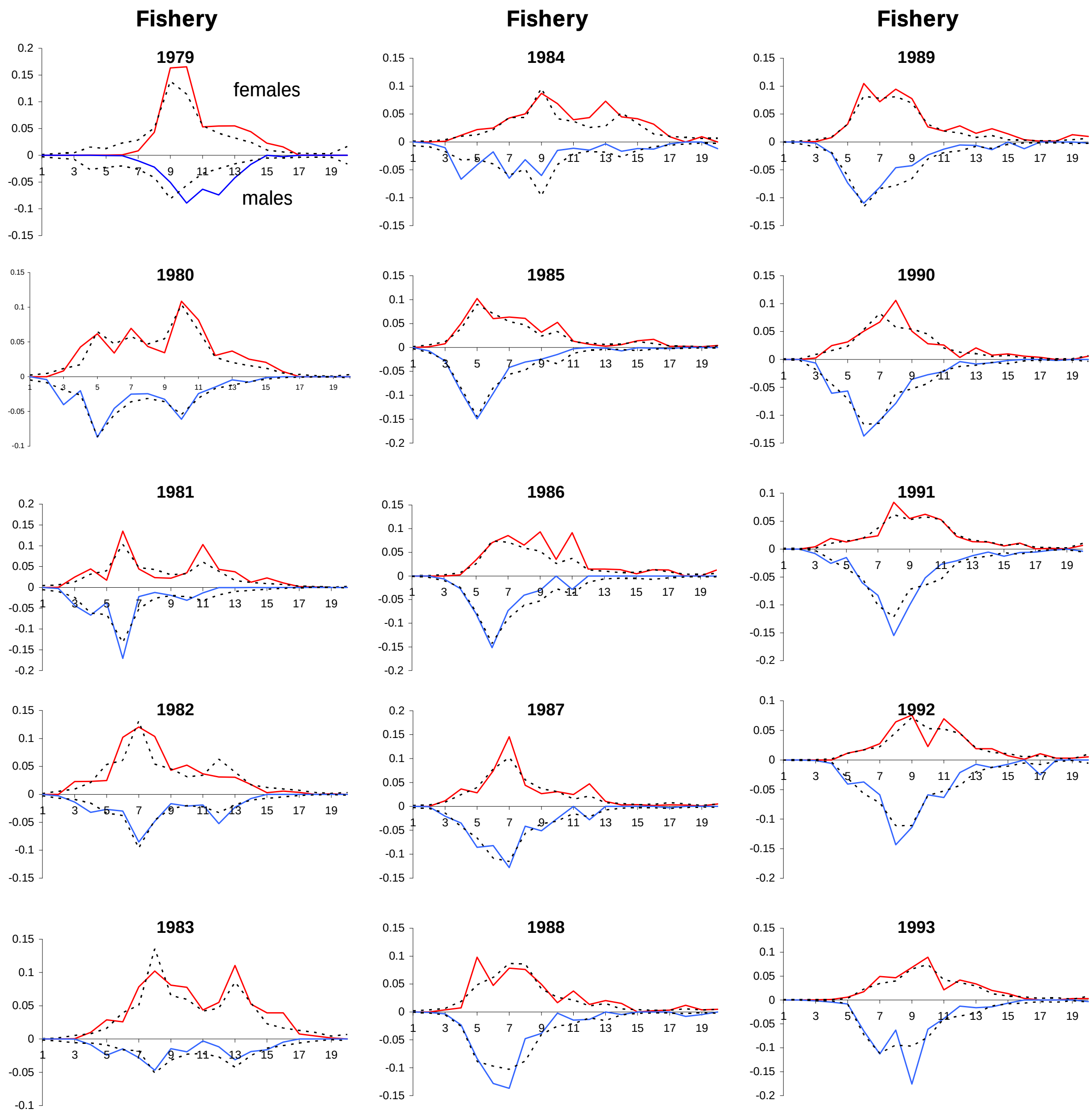


Figure 7.12—Stock assessment model fit to the fishery and survey age compositions, by sex.

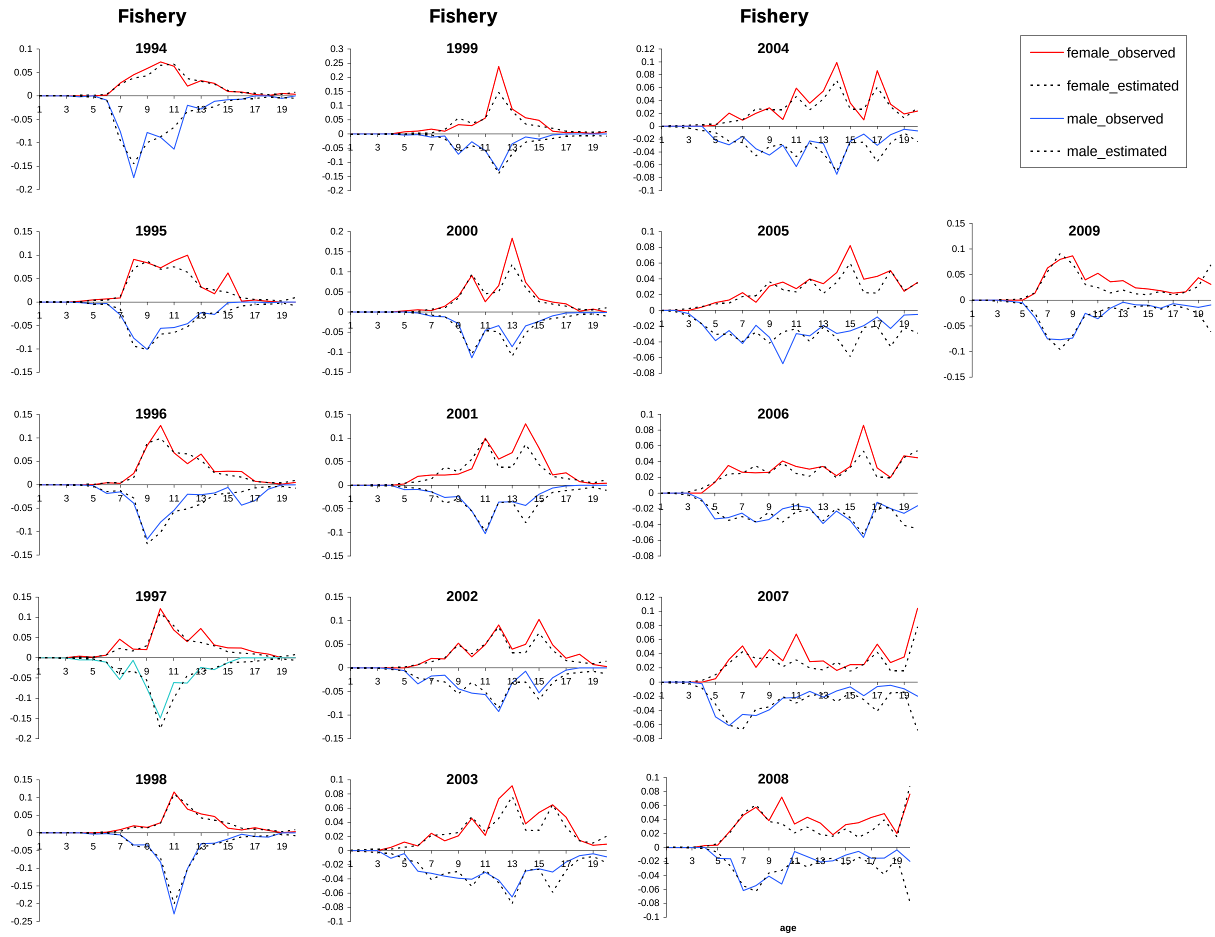


Figure 7.12—continued.

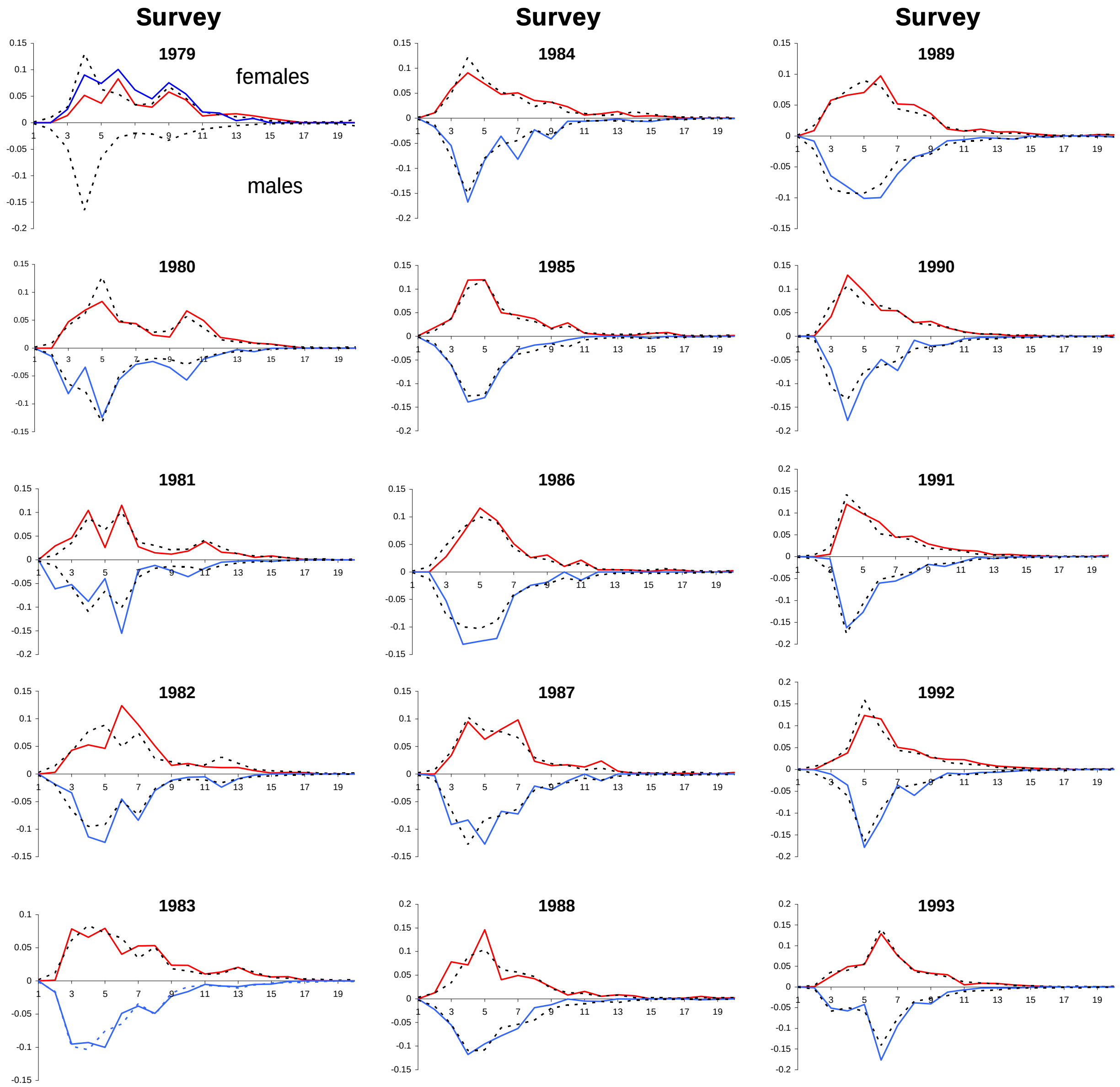


Figure 7.12—continued.

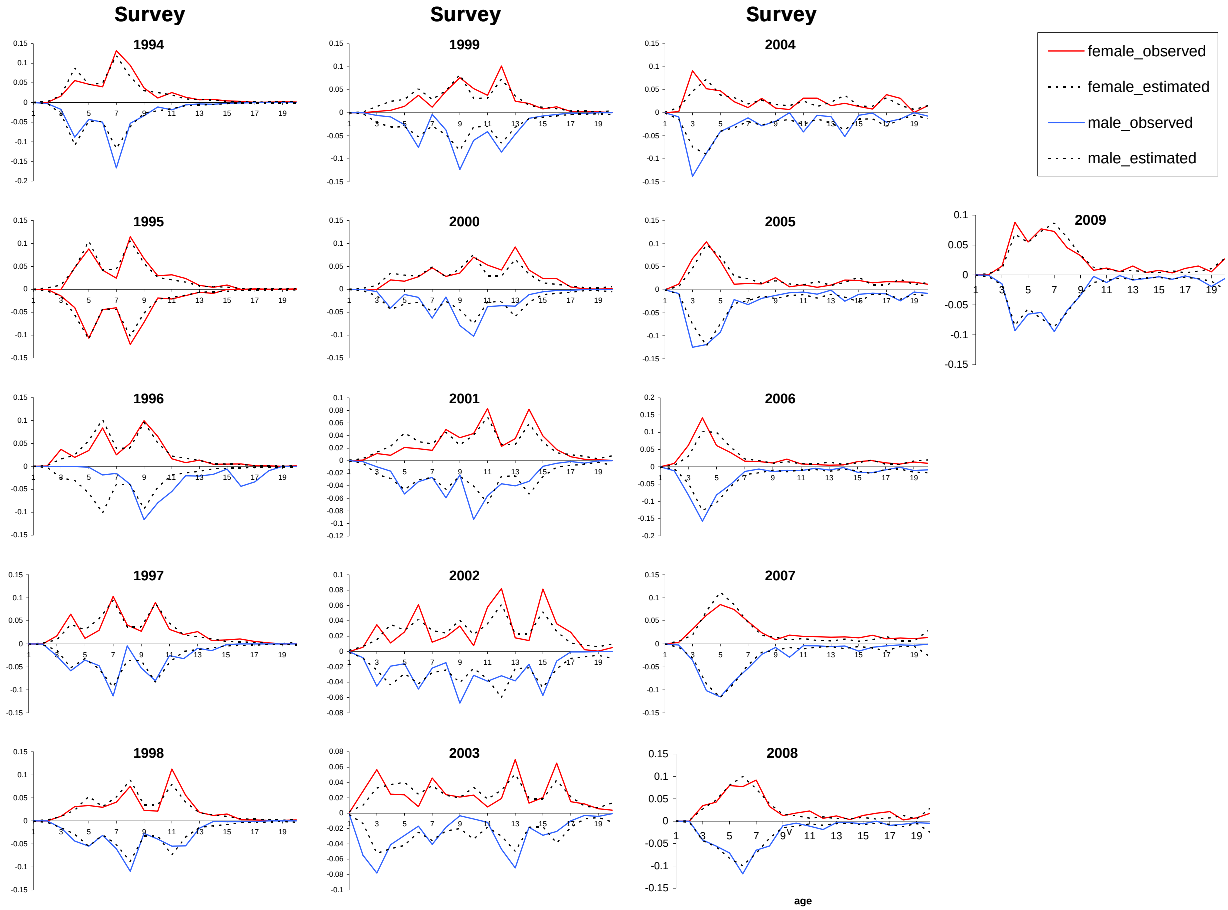


Figure 7.12—continued.

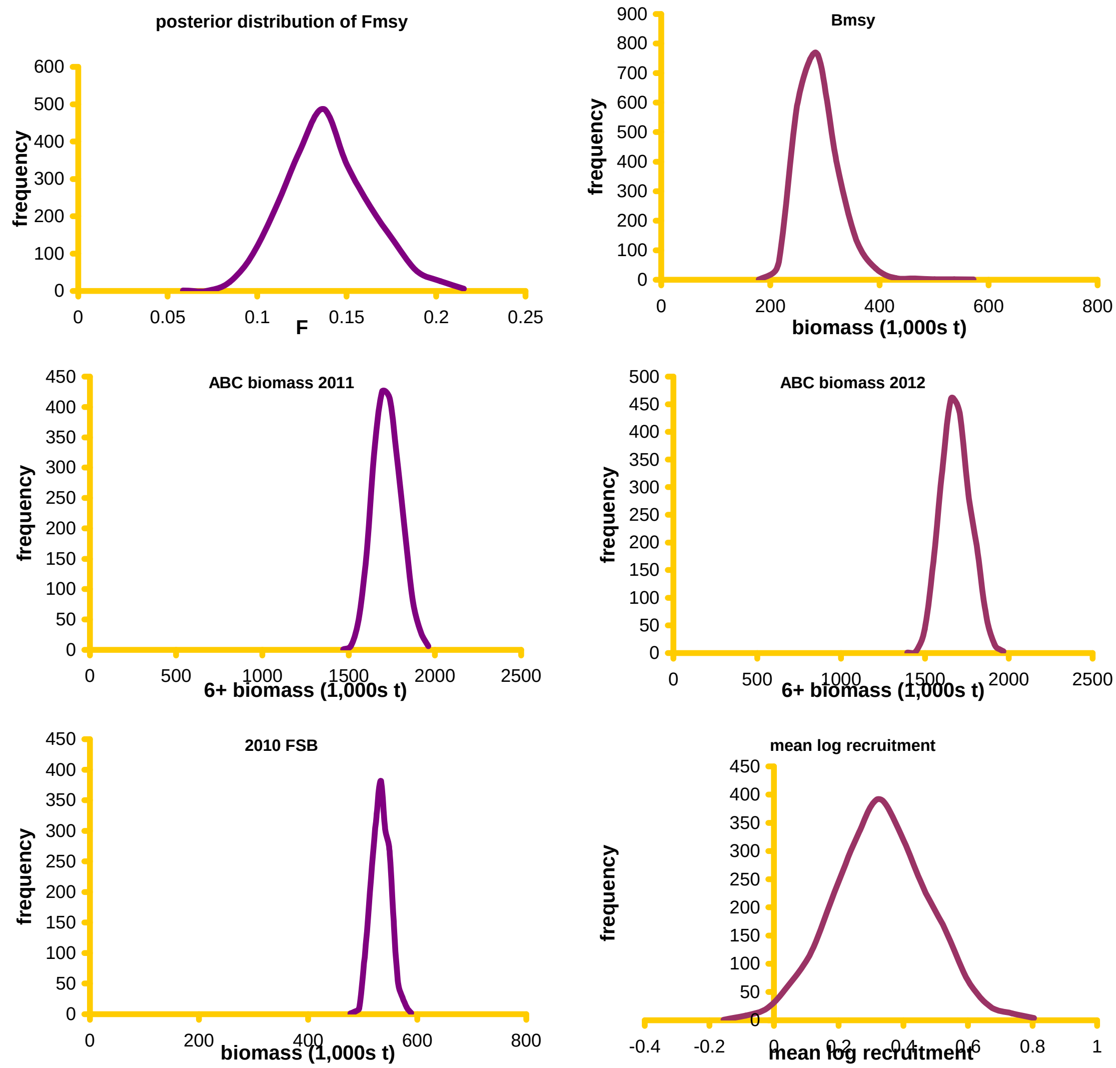


Figure 7.13—Posterior distributions of some selected model estimates from the preferred stock assessment model.

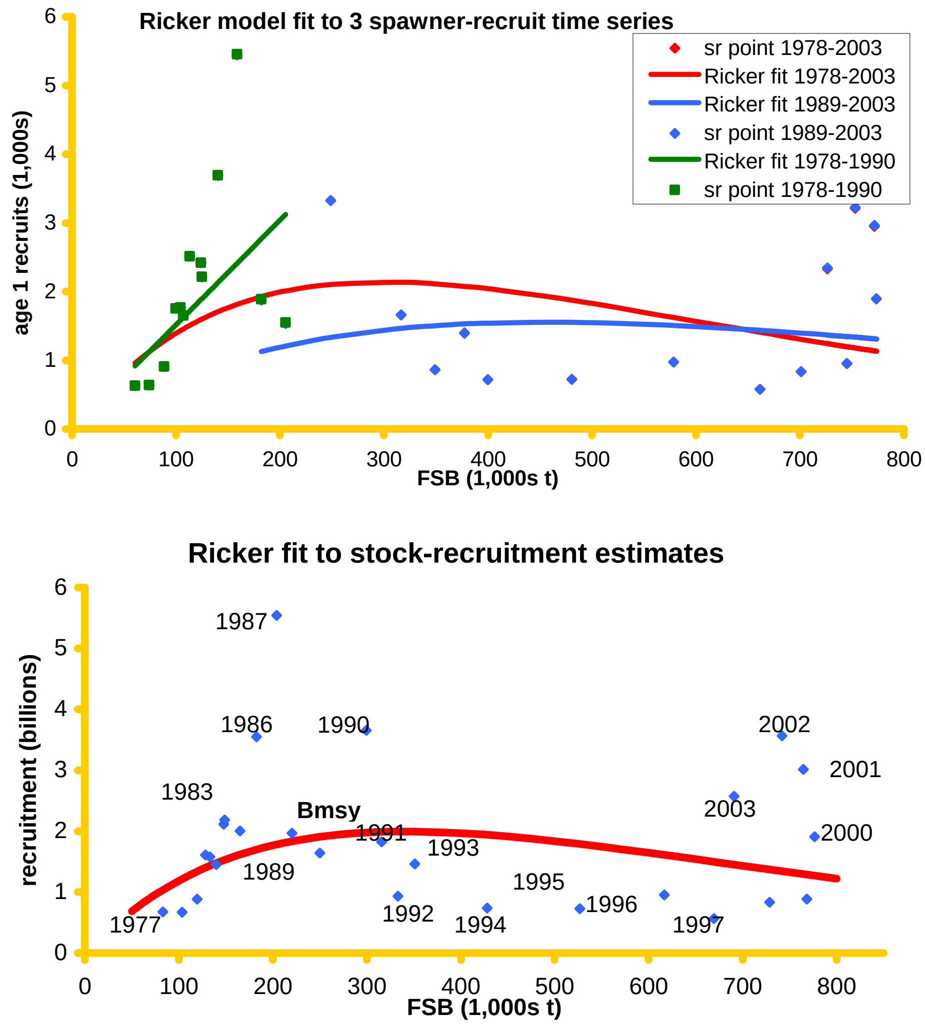


Figure 7.14—Ricker (1958) model fit to spawner-reruit estimates from three time periods; 1978-2003, 1989-2003 and 1978-90 (top panel), the fit to the spawner-recruit estimates from Model 1 (bottom panel).

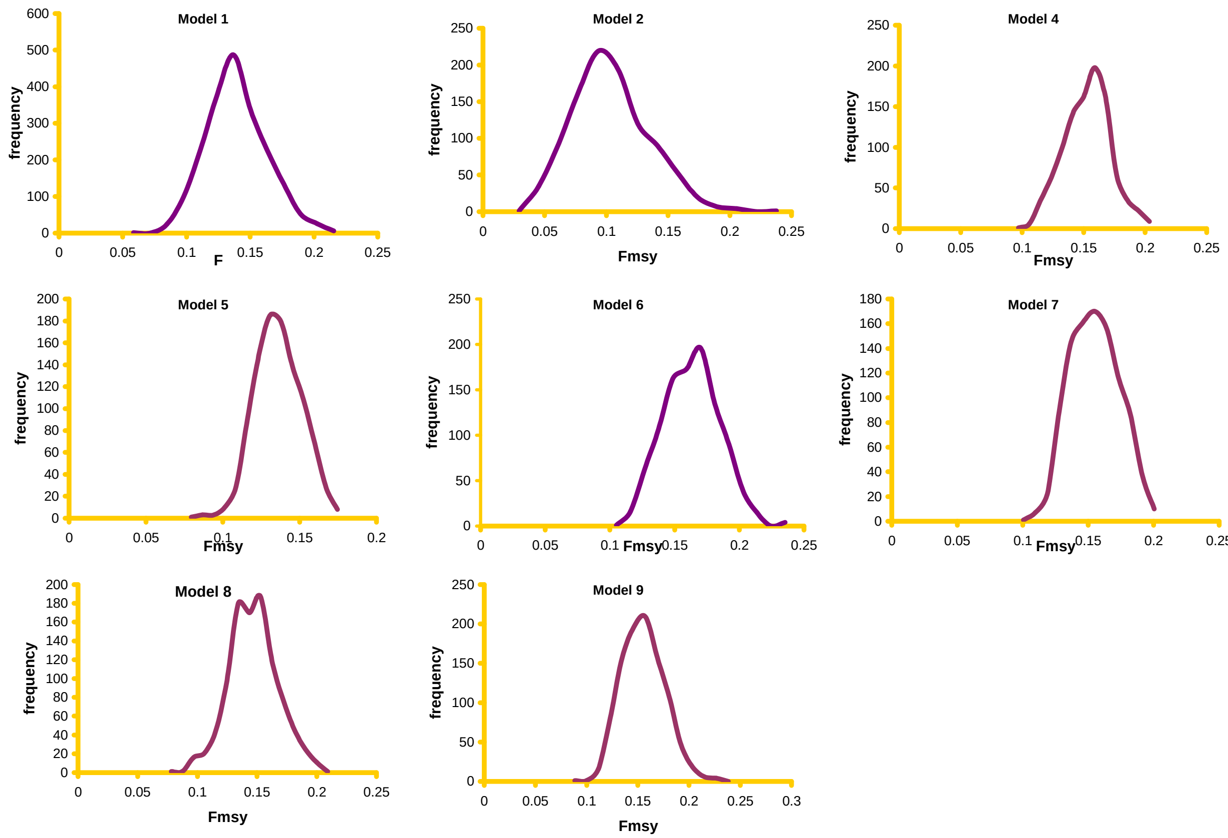


Figure 7.15—Posterior distributions of F_{msy} from 8 of the models considered in the analysis.

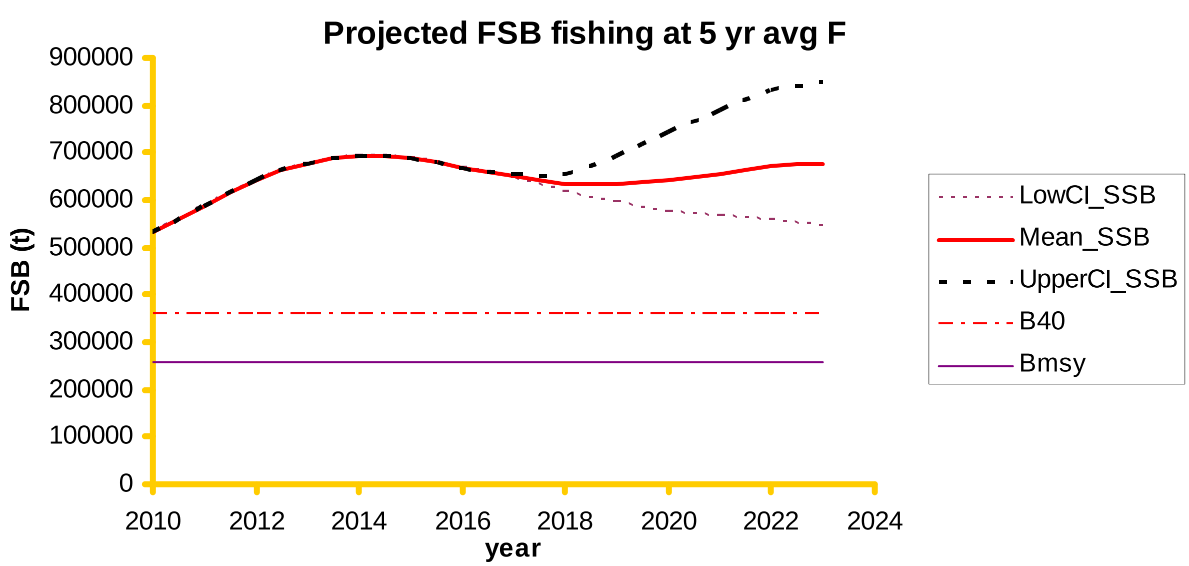


Figure 7.16—Projection of rock sole female spawning biomass when fishing each future year at the average F of the past five years.

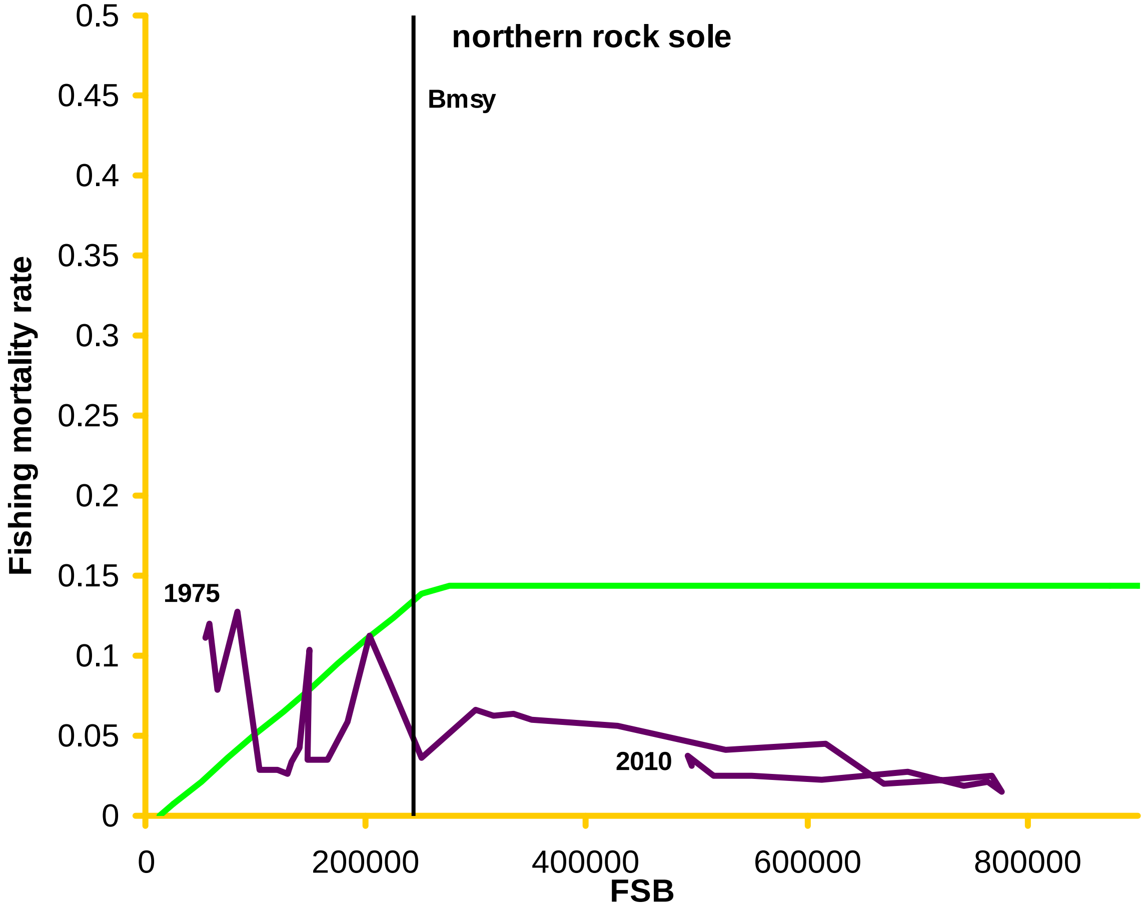


Figure 7.17—Phase-plane diagram of female spawning biomass relative to the harvest control rule.

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:

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

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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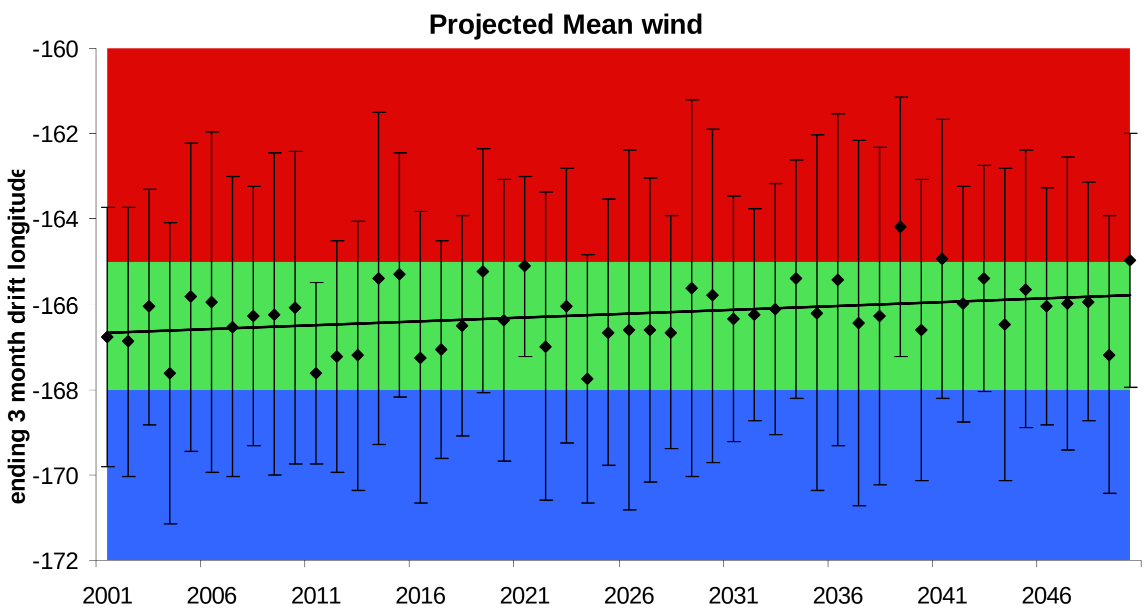

Figure A-1 Predicted mean and standard deviation of the longitudinal endpoint of projected larval drift from spring winds for 2001–2050. Background plot shading reflects classification of projected endpoints according to spring climate condition: on-shelf wind drift (red shading), off-shelf wind drift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

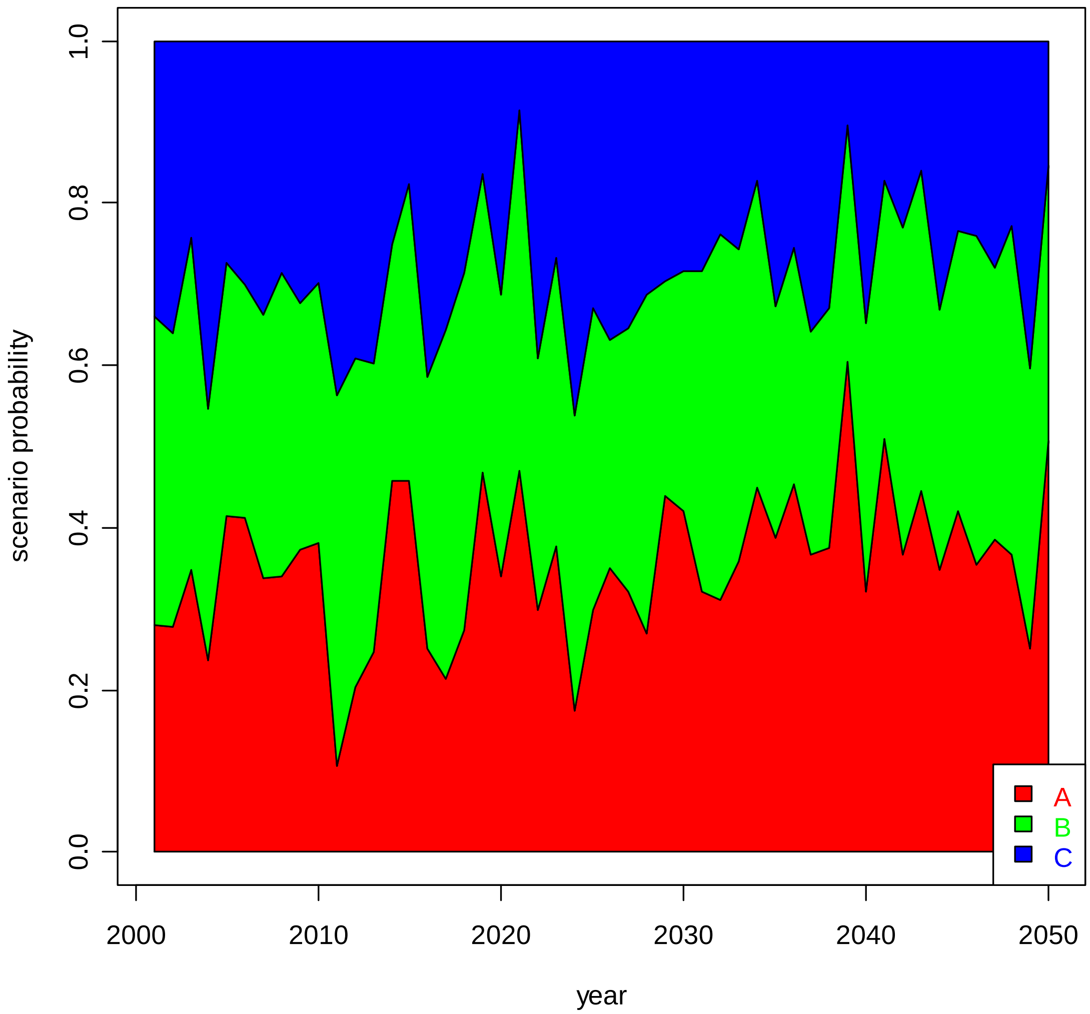

Figure A-2 Probability of occurrence for each climate scenario based on 20,000 bootstrap samples per year. A=on shelf winds, B=mid shelf winds, C=off shelf winds.

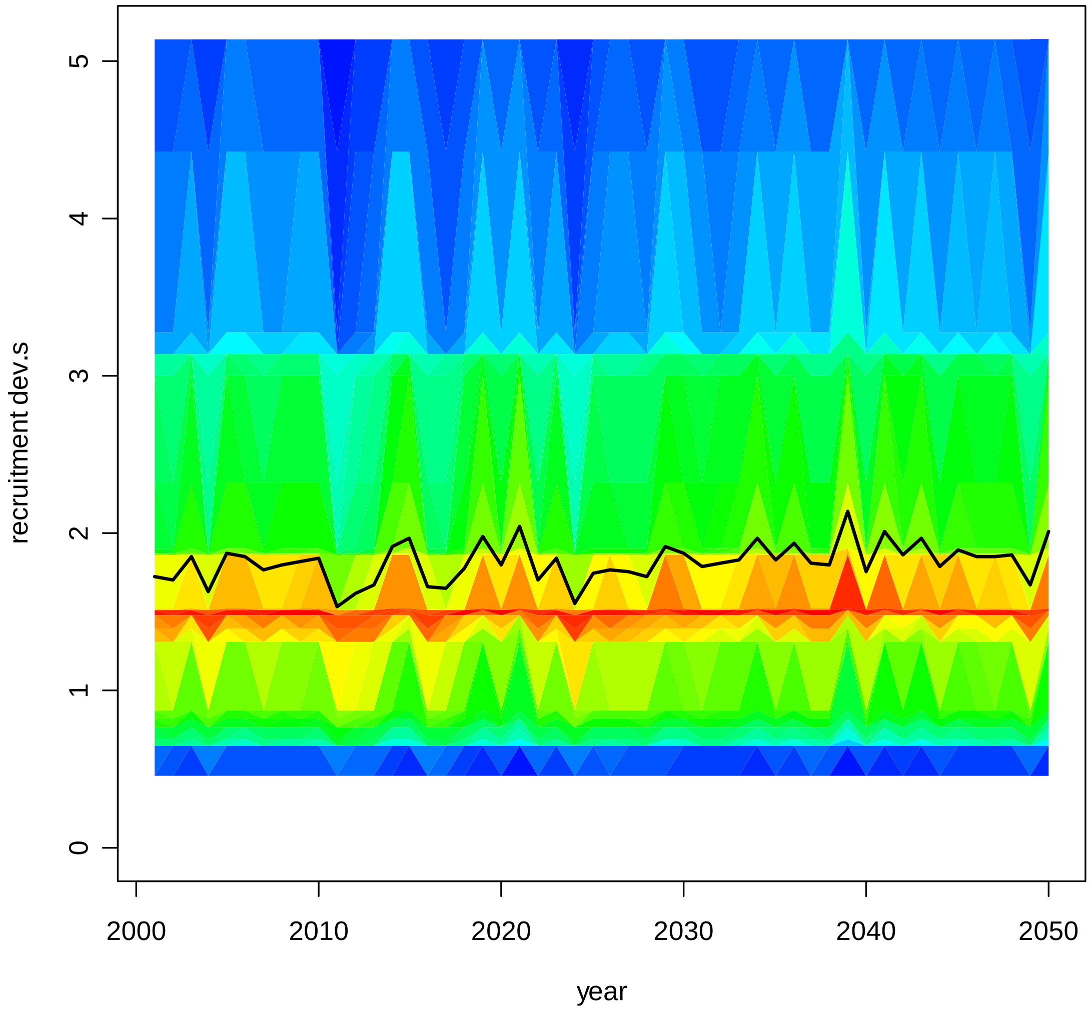

Figure A-3 Projected mean (black line) and quantiles (coloured shading) for northern rock sole productivity (recruitment) by year. Quantiles are colour-coded symmetrically from the median (bright red) to 0 or 100% (dark blue).

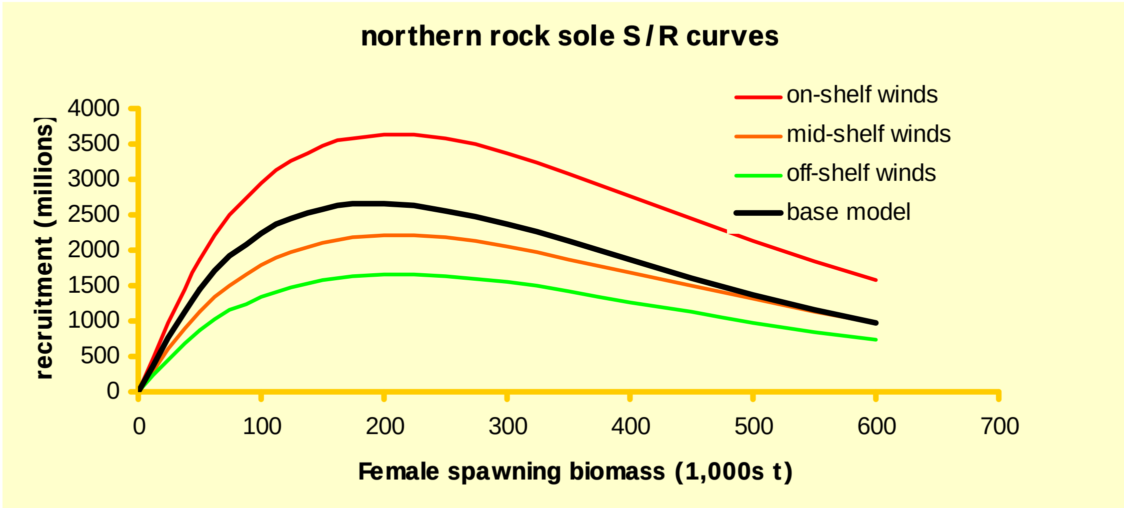

Figure A-4 Productivity curves from fitting the Ricker stock-recruitment relationship to the three climate conditions.

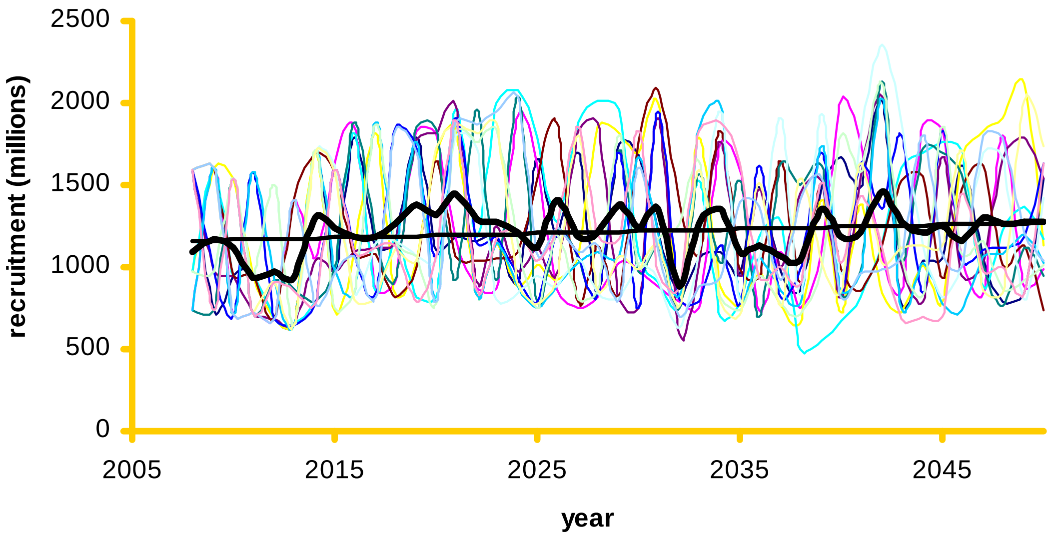

Figure A-5 Projected northern rock sole recruitment through 2050 using IPCC climate scenarios and Ricker stock recruitment formulation which relate recruitment to wind direction. Thick black line is annual mean of 10,000 model realizations and straight black line is trend line fit to annual mean.