Chapter 8

Assessment of the Northern Rock Sole stock in the Bering Sea and Aleutian Islands

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Executive Summary

The following changes have been made to this assessment relative to the November 2011 SAFE:

Summary of changes to the assessment input

1) 2011 fishery age composition.
2) 2011 survey age composition.
3) 2012 trawl survey biomass point estimate and standard error.
4) Estimate of catch (t) and discards for 2012.
5) Estimate of retained and discarded portions of the 2011 catch.
6) Recalculated the weight at age of fish in 2008-2011 from survey length-at-age samples.

Summary of Results

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2012	2013	2013	2014
M (natural mortality rate)	0.15	0.15	0.15	0.15
Tier	1a	1a	1a	1a
Projected total (age 6+)	1,857,000	1,841,400	1,465,600	1,393,200
Female spawning biomass (t)	605,600	622,800	628,300	638,300
Projected				
B_0	683,400		694,500	
B_{MSY}	255,000	255,000	260,000	260,000
F_{OFL}	0.146	0.146	0.164	0.164
$maxF_{ABC}$	0.131	0.131	0.146	0.146
F_{ABC}	0.131	0.131	0.146	0.146
OFL (t)	231,000	216,700	241,000	229,000
maxABC (t)	208,000	195,500	214,000	204,000
ABC (t)	208,400	195,500	214,000	204,000
Status	As determined *last* year for:		As determined *this* year	
	2010	2011	2011	2012
Overfishing	No	No	No	No
Overfished	No	No	No	No
Approaching overfished	No	No	No	No

SSC Comments

The SSC understands that CIE reviews are being considered for some flatfish stocks in spring 2012. For the BSAI, the SSC's recommended priorities for CIE reviews are yellowfin sole, northern rock sole, and Greenland turbot.

The BSAI part of the review included only yellowfin sole. One of the reasons yellowfin sole was chosen is that many of the comments received from the CIE reviewers for yellowfin sole would also be relevant to the northern rock sole assessment.

The preferred assessment model was unchanged from last year, although a set of alternatives was explored. One of these was a model that expressed survey catchability (q) as a function of annual average bottom water temperature. Although there was evidence for such a relationship, the estimated mean value of q for this model was considered unrealistically high. The SSC suggests exploring an alternative formulation of this model that allows q to be a function of bottom temperature while constraining q to realistic values.

In response to this SSC suggestion, the model that estimates q as a function of annual bottom water temperature was formulated with q estimated using the trawl catchability experiment value as a strong prior to constrain the estimate (sigma was quite small at 0.056, mean = 1.4). This model formulation had the effect of constraining q to a realistic value (1.5) since the effect of the penalty of q being different from the experimental value was applied in every survey year.

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 for rock soles 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 seem to 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 from 1970-1975. Catches (t) since implementation of the MFCMA in 1977 are shown in Table 8.1, 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 1989-2012 (domestic only) have averaged 49,700 t annually. The size composition of the 2012 catch from observer sampling, by sex and management area, are shown in Figure 8.1 and the locations of the 2012 catch by month through September are shown in Figure 8.3.

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, with the added stipulation of no mixing of hauls and no on-deck sorting.

Northern rock sole are important as the target of a high value roe fishery occurring in February and March which accounted for 70% of the annual catch in 2012 (Fig 8.2). About 78% of the 2012 catch came from management area 509 with the rest from areas 513, 514, 516, 517 and 521 (Fig 8.2). The 2012 catch is estimated at 74,400 t based on the Alaska regional office estimate through mid September projected forward to the end of the year using 2011 catch rates for September through December. The projected catch is 36% of the 2012 ABC of 208,000 t and 86% of the 87,000 t TAC. Thus, rock sole remain lightly harvested in the Bering Sea and Aleutian Islands. The fishery in the past has been affected by seasonal and annual closures to prevent exceeding halibut bycatch allowances specified for the trawl rock sole, flathead sole, and “other flatfish” fishery category by vessels participating in this sector in the BSAI. There were no closures in 2011 and 2012.

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). 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 in the past. Estimates of retained and discarded catch from at-sea sampling for 1987-2011 are shown in Table 8.2. From 1987 to 2000, more rock sole were discarded than were retained. However since 2000 retention has trended upward and since 2008, the first year of Amendment 80 mandated fishing practices, retention has been at least 90%. Details of the 2011 northern rock sole catch by fishery designation are shown in Table 8.3.

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 through September 2012 (Table 8.1) and fishery catch-at-age numbers from 1980-2010 (Table 8.4). The 2012 catch total used in the model is based on the 2011 catch rates from October through December to provide an estimate of 2012 annual catch.

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 8.4). 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 through 2012 estimates are nearly the same and indicate that the stock remains at a stable level.

Absolute Abundance

Rock sole biomasses are also estimated from the AFSC surveys using stratified area-swept expansion of the CPUE data (Table 8.5). These biomass estimates are point estimates from an "area-swept" bottom trawl survey. Some assumptions add uncertainty to these estimates. 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 2012 point estimate of the Bering Sea surveyed area is 1,552,284 – 2,288,414 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). Five of the last six years (2007, 2008, 2010, 2011and 2012) have had similar estimates, close to 2 million t.

The 2012 Aleutian Islands biomass estimate of 65,460 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 1977-2012 is listed in Table 8.6 and an Appendix where other non-commercial catch is shown.

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 8.5). 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.

The 2012 assessment again re-analyzed the time trend of size-at-age and weight-at-age available from the survey data. Northern rock sole growth (mean length-at-age) indicates that males and females grow similarly until about age 6 after which females grow faster and larger than males (Fig. 8.6). The length-at-age time series exhibits periods of slow and fast growth from 1982-2011 (shown for 8 year old fish in Figure 8.7). 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 8.7). Predicted and observed biomasses match better (does not underestimate the 1980s biomass or overestimate the 1992-2003 biomass) compared to previous assessments which used the average weight-at-age from all years. This method was continued for this assessment.

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 2012) and is shown in Table 8.8 and Figure 8.8. Compared to the maturity curve from anatomical scans used previously, the length-based model of Stark indicates nearly the same age at 50% maturity (7.8 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 been routinely collected during the trawl surveys since 1979 to provide estimates of the population age composition (Fig. 8.8, Table 8.10). For this assessment all fishery and survey age compositions (1979-2010) 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 the small age collections did not reflect the catch-at-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 8.9.

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 8.11). 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 which was weighted more/less. 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 8.11 presents the key equations used to model the rock sole population dynamics in the Bering Sea and Table 8.12 provides a description of the variables used in Table 8.11. 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 8.8) 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
76	152	57	2	0, 1 or 2 (optional)	0, 1 or 2 (optional)	287-291 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, sex-specific estimates of fishing mortality and the entry of another year class into the observed population.

Year class strengths

The population simulation specifies the numbers-at-age in the beginning year of the simulation, the number of recruits in each subsequent year, and the survival rate for each cohort as it progresses through the population using the population dynamics equations given in Table 7-11.

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, time-varying fishing selectivity curves are estimated. 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, a 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 this assessment natural mortality was estimated for both sexes as free parameters with values of 0.159 and 0.19, 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 again in 2009, another cold year. Results were also a bit lower for 2012, the second coldest year in the survey time-series. These results may suggest a relationship between bottom water temperature and trawl survey catchability, 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. Past attempts to model catchability using this formulation resulted in values of α and β at -1.028 and 0.0296, 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 0.4. 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. To constrain the estimates of q to more realistic values, the catchability of northern rock sole was formulated as discussed below while still allowing annual effects on q as a function of water temperature.

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 catchability and then estimate survey catchability 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.

<u>Model evaluation</u>

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.

This analysis was not repeated for this assessment, but is summarized as follows: Three different stock-recruitment time-series were investigated including the full time-series 1978-2004 (Model A, preferred method based on guidance from a recent Plan Team stock recruitment workshop and report), the years of consecutive poor recruitment events (1989-2001) (Model B), and the period of high recruitment during the 1980s, 1978-90 (Model C) (Fig. 8.14). 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 A) and lower values were obtained (as expected) when the poor recruitment time-series (Model B) was used. Model C (the most productive time series 1978-1990) was data limited and does not have enough contrast in spawning stock size to fit the spawner-recruit data, 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 27 years now, we use the full time-series (Model A) for our estimate of the productivity of the stock.

For this assessment model runs were made to explore different states of nature by examining 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 2012 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, 2 and 3). In runs where q is estimated, a strong prior was used to constrain q to the value from the trawl herding study.

Model exploration	q	female M	male M	2012 FSB	2013 ABC	F_{ABC}
Model 1 q fixed at 1.5, male and female M fixed at 0.15	1.5	0.15	0.15	628.300	214.400	0.146
Model 2 q fixed at 1.5, female M fixed at 0.15 and male M estimated	1.5	0.15	0.18	688.900	216.100	0.153
Model 3 q fixed at 1.5, female M and male M estimated	1.5	0.165	0.20	626.200	199.000	0.150
Model 4 q estimated, Female and male M fixed at 0.15	2.22	0.15	0.15	376.000	141.600	0.156
Model 5 q estimated, female M fixed at 0.15 and male M estimated	1.97	0.15	0.179	480.900	161.20	0.158
Model 6 q, female M and male M all estimated as free parameters	2.09	0.14	0.18	454.100	154.200	0.160

Model 7	1.15	0.15	0.15	612.022	208.200	0.146
q estimated with the bottom temperature relationship, male and female M fixed at 0.15						

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 2 and 3). Fixing the female or both the male and female M (Models 4 and 5) has less of a constraint on q and values are estimated as high as 2.04 (Model 4) and 1.85 (Model 5). Allowing all three parameters to be freely estimated results in estimates of q and female stock size in-between Models 4 and 5 (Model 6). The model run which estimates q as a function of the annual bottom temperature (Model 7) during the surveys (with male and female M fixed at 0.15) provided a realistic estimate of q at 1.5 and fits the experimental value of q better than model 4 (also with M fixed for both sexes) since the effect of the penalty is greater in Model 7 since it's applied in every year rather than only for 1 q in each year as in model 4. The results of Model 7 are very similar to Model 1.

Models 6 provide estimates of survey catchability which range from 1.97 to 2.22. These estimates represent a large difference in the estimate of q compared to what was estimated from the herding experiment (1.4). These results would indicate that 55% (Model 4) and 50% (Model 5) 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 2 and 3 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. 8.9). 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

The 2012 bottom trawl survey point estimate is 3% less than the 2011 estimate and the stock abundance is at the same levels estimated in the 2007 and 2008 trawl surveys. The stock assessment model does not fit the declining trend of three of the last four survey point estimates and model results indicate that the stock condition is stable to increasing. This is the result of the combination of strong recruitment from the 2001-2003 and 2005 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 8.13. The exploitation rate has averaged 3.9% from 1975-2011, indicating a lightly exploited stock. Age and sex-specific selectivity estimated by the model (Table 8.14, Fig. 8.10) indicate that male and female rock sole are 50% selected by the fishery at about ages 8 and 9, respectively, and are nearly fully selected by ages 12 and 13.

<u>Abundance Trend</u>

The stock assessment model indicates that rock sole total biomass was at low levels during the mid 1970s through 1982 (200,000 - 400,000 t, Fig. 8.11 and Table 8.15). From 1985-95, a period characterized by sustained above-average recruitment (1980-88 year classes, Fig. 8.11) 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 12% to 1.3 million t in 2004 before increasing to the present level of 1.63 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 (604,000 in 2012) and is increasing after a low of 500,000 t in 2008. As the strong year classes spawned in 2001-2004 are now maturing the female spawning biomass is increasing (Table 8.15). The model provides good fits to most of the strong year classes observed in the fishery and surveys during the time-series (Fig. 8.12).

The model estimates of survey biomass (using trawl survey age-specific selectivity and the estimate of q applied to the total biomass, Fig. 8.11) correspond fairly well with the trawl survey biomass trend with the exception of the cold year of 1999 and also 2009. Although 2006 through 2012 have been 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 25 of the 31 annual surveys. Posterior distributions of some selected model parameters from the preferred stock assessment model (Model 1) are presented in Figure 8.13.

<u>Total Biomass</u>

The stock assessment projection model estimates total biomass (mid-year population numbers multiplied by mid-year weight at age) for 2013 at **1,626,800** t (including the 2012 catch estimated at 74,400 t).

<u>Recruitment Trends</u>

Increases in abundance for rock sole during the 1980s can be attributed to the recruitment of a series of strong year classes (Figs. 8.5 and 8.9, Table 8.16). 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 2001-2005 year classes are estimated to be strong (2004 is average) as discerned from the last 6 survey age samples and should contribute to an increasing spawning 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 standard deviations and estimated annual fishing mortality by age and sex are shown in Tables 8.17-8.20, respectively.

ACCEPTABLE BIOLOGICAL CATCH

The SSC has determined that northern rock sole qualify as a Tier 1 stock and therefore the 2013 ABC is calculated using Tier 1 methodology. Using this approach the 2013 fishing mortality recommendation is $F_{ABC} = F_{harmonic\ mean} = 0.146$. The Tier 1 harvest level is calculated as the product of the harmonic mean of F_{MSY} and the geometric mean of the 2013 6+ biomass estimate, as follows:

$B_{gm} = e^{\ln \hat{B} - \frac{cv^2}{2}}$, where B_{gm} is the geometric mean of the 2013 6+ biomass estimate, $\hat{B}$ is the point estimate of the 2013 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 214,400 t and an OFL of 240,600 t for 2013**. The projection of 2013 ABC from last year's assessment was 195,500 t and the OFL was projected at 216,700 t.

These ABC and OFL values represent a 11% (26,200 t) buffer between ABC catch and overfishing.

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	2013 Yield
Tier 1 $F_{OFL} = F_{MSY}$	**0.164**	**240,600 t**
Tier 1 $F_{ABC} = F_{harmonic\ mean}$	**0.146**	**214,400 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 2012 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2013 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2012. 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 2013, 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 2013 recommended in the assessment to the *max* F_{ABC} for 2013. (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 2008-2012 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 2012 and above its MSY level in 2024 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2013 and 2014, 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 2025 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 8.21 indicate that rock sole are currently not overfished and are not approaching an overfished condition. If harvested at the average F from 2008-2012, rock sole female spawning biomass is projected to increase due to the strong recruitment from 2001-2005 (Fig. 8.16). The ABC and TAC values that have been used to manage the northern rock sole resource since 1989 are shown in Table 8.22 and a phase plane diagram showing the estimated time-series of female spawning biomass and fishing mortality relative to the harvest control rule is in Figure 8.17.

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 2012 numbers at age from the stock assessment model are projected to 2013 given the 2012 catch and then a 2013 catch of 60,000 t is applied to the projected 2013 population biomass to obtain the 2014 OFL.

Tier 1 Projection

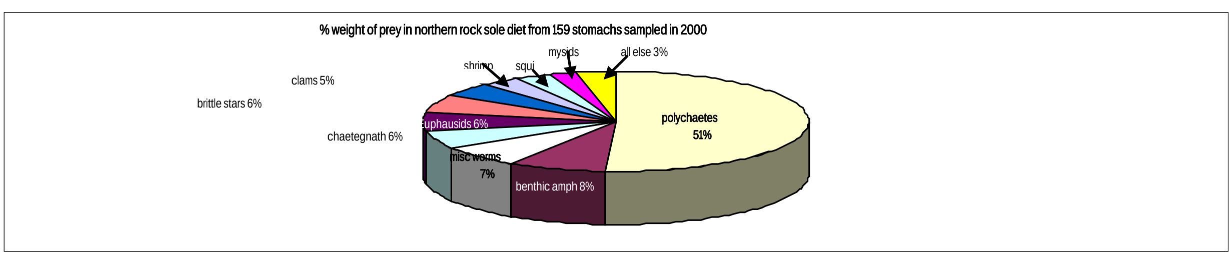
Year	Catch	SSB	Geometric mean 6+ total biomass	ABC	OFL
2013	65,000	628,200	1,465,600	214,400	240,600
2014	65,000	638,300	1,393,200	203,800	228,700

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 8.23 and the catch of non-target species from the rock sole fishery is shown in Table 8.24. The northern rock sole target fishery contribution to the total bycatch of prohibited species is shown for 2008 and 2009 in Table 13 of the Economic SAFE (Appendix C) and is summarized for 2009 as follows:

Prohibited species	Rock sole fishery % of total bycatch
Halibut mortality	27
Herring	<1
Red King crab	57
C. bairdi	33
Other Tanner crab	<1
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 8.1--Rock sole catch (t) from 1977 - September 30, 2012.

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			53,221	53,221
2011			60,401	60,401
2012			74,400	74,400

Table 8.2 Retained and discarded catch (t) in Bering Sea fisheries, 1987-2011.

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
2010	50,160	3,061	94
2011	56,105	4,527	93

Table 8.3--Discarded and retained rock sole catch (t), by target fishery, in 2011.

	Discarded	Retained
Atka Mackerel	18	57
Pollock - bottom	303	5,069
Pacific Cod	864	681
Alaska Plaice		5
Other Flatfish		
Halibut		
Rockfish	3	97
Flathead Sole	10	880
Other Species		
Pollock - midwater	2,201	892
Rock Sole	686	38,997
Sablefish		
Greenland Turbot		
Arrowtooth Flounder	1	41
Yellowfin Sole	435	9,327
Total catch		**60,632**

Table 8.4--Estimated catch numbers at age, 1980-2012 (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	0.16	0.22	0.44	0.60	0.90	1.03	1.04	1.05	1.05	1.07	1.08
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.05	0.13	0.19	0.37	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	0.09	0.14	0.30	0.42	0.62	0.50	0.46	1.83
1984	0.00	0.00	0.00	0.02	0.02	0.06	0.14	0.45	2.00	2.17	1.17	0.92	0.74	0.58	0.25	0.15	0.06	0.03	0.02	0.11
1985	0.08	0.14	0.36	0.52	1.93	1.40	1.72	1.42	1.65	3.13	2.00	0.84	0.61	0.48	0.37	0.16	0.09	0.04	0.02	0.09
1986	0.16	0.24	0.47	1.16	1.45	3.78	1.77	1.58	1.11	1.22	2.25	1.42	0.60	0.43	0.34	0.26	0.11	0.07	0.03	0.07
1987	0.07	0.21	0.36	0.81	2.06	2.34	5.10	2.10	1.78	1.22	1.33	2.45	1.55	0.65	0.47	0.37	0.28	0.12	0.07	0.11
1988	0.02	0.07	0.18	0.27	0.53	1.30	1.66	4.48	2.18	1.99	1.41	1.54	2.86	1.81	0.76	0.55	0.43	0.33	0.14	0.21
1989	0.12	0.18	0.47	1.11	1.40	2.33	4.64	4.67	10.38	4.55	4.01	2.82	3.08	5.71	3.61	1.53	1.10	0.86	0.67	0.71
1990	0.15	0.53	1.17	3.77	8.63	6.83	5.27	4.61	2.32	3.22	1.10	0.87	0.59	0.63	1.17	0.74	0.31	0.22	0.18	0.28
1991	0.01	0.05	0.20	0.50	1.94	5.59	5.39	4.51	4.01	2.02	2.81	0.96	0.76	0.51	0.55	1.02	0.64	0.27	0.20	0.40
1992	0.33	0.53	1.56	4.32	6.85	13.72	18.03	9.77	6.50	5.46	2.71	3.77	1.29	1.02	0.69	0.74	1.36	0.86	0.36	0.80
1993	0.80	1.48	2.39	6.92	17.54	22.27	31.95	32.09	15.25	9.67	7.99	3.95	5.48	1.88	1.48	1.00	1.08	1.98	1.25	1.69
1994	0.04	0.47	1.15	2.43	8.67	22.37	21.80	22.84	19.31	8.60	5.33	4.38	2.16	2.99	1.02	0.81	0.55	0.59	1.08	1.60
1995	0.05	0.17	1.33	2.37	3.46	7.85	12.30	8.64	8.12	6.73	2.99	1.86	1.52	0.75	1.04	0.36	0.28	0.19	0.20	0.94
1996	0.12	0.12	0.33	2.09	2.98	3.62	7.44	12.49	10.55	11.74	10.71	4.98	3.15	2.61	1.29	1.79	0.61	0.49	0.33	1.96
1997	0.02	0.10	0.11	0.32	2.15	3.26	4.14	8.55	13.43	10.04	9.95	8.47	3.80	2.37	1.95	0.96	1.34	0.46	0.36	1.70
1998	0.01	0.05	0.23	0.26	0.76	5.26	7.81	9.00	14.95	17.24	9.88	8.42	6.70	2.93	1.81	1.48	0.73	1.01	0.35	1.57
1999	0.01	0.01	0.04	0.22	0.25	0.76	5.34	7.96	8.90	13.76	14.65	7.97	6.62	5.22	2.28	1.40	1.15	0.57	0.79	1.49
2000	0.00	0.02	0.03	0.15	0.71	0.77	2.18	13.56	16.49	13.50	14.91	12.59	6.13	4.89	3.80	1.65	1.02	0.83	0.41	1.64
2001	0.00	0.00	0.02	0.03	0.13	0.66	0.72	2.05	12.42	13.88	10.01	9.89	7.85	3.72	2.94	2.27	0.99	0.61	0.50	1.22
2002	0.06	0.07	0.13	0.41	0.46	1.48	4.83	3.46	6.17	23.35	17.34	9.60	8.52	6.62	3.16	2.52	1.96	0.85	0.52	1.48
2003	0.00	0.01	0.01	0.02	0.09	0.11	0.43	1.60	1.31	2.60	10.48	7.84	4.21	3.57	2.67	1.24	0.98	0.75	0.33	0.77
2004	0.00	0.01	0.02	0.03	0.07	0.31	0.43	1.68	6.06	4.14	6.00	16.73	9.15	3.99	3.03	2.14	0.97	0.75	0.58	0.84
2005	0.00	0.01	0.01	0.06	0.10	0.23	0.97	1.31	4.44	12.24	6.06	6.79	16.29	8.30	3.51	2.63	1.85	0.84	0.65	1.23
2006	0.03	0.04	0.08	0.11	0.38	0.55	1.02	2.91	2.30	4.51	8.11	3.14	3.14	7.19	3.60	1.51	1.13	0.80	0.36	0.81
2007	0.02	0.03	0.04	0.11	0.20	0.85	1.38	2.37	5.43	3.47	5.93	9.98	3.75	3.71	8.46	4.22	1.77	1.33	0.93	1.37

2008	0.07	0.13	0.20	0.21	0.47	0.64	1.94	2.07	2.44	4.51	2.65	4.42	7.38	2.77	2.74	6.24	3.12	1.31	0.98	1.70
2009	0.03	0.09	0.19	0.32	0.36	0.82	1.12	3.19	3.07	3.29	5.73	3.28	5.41	9.00	3.37	3.33	7.59	3.79	1.59	3.25
2010	0.02	0.07	0.23	0.48	0.77	0.84	1.67	1.77	3.59	2.62	2.40	3.92	2.19	3.58	5.94	2.22	2.19	5.00	2.50	3.19
2011	0.02	0.04	0.16	0.60	1.38	2.36	2.37	3.60	2.67	4.11	2.61	2.26	3.62	2.01	3.27	5.42	2.03	2.00	4.56	5.19
2012	0.00	0.03	0.06	0.28	1.13	2.78	4.53	3.62	4.09	2.50	3.55	2.19	1.89	3.01	1.67	2.72	4.50	1.68	1.66	8.10

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	0.08	0.16	0.38	0.80	1.33	1.34	1.61	1.39	1.37	1.38	1.33	1.32	1.35	1.35	1.35
1981	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.12	0.30	0.64	1.07	1.08	1.30	1.12	1.10	1.11	1.07	1.06	1.08	2.17
1982	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.11	0.27	0.54	0.77	0.63	0.66	0.54	0.52	0.52	0.50	0.50	1.52
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.16	0.34	0.62	0.71	0.98	0.89	0.89	0.88	0.85	3.41
1984	0.00	0.00	0.00	0.01	0.01	0.03	0.07	0.24	0.95	1.00	0.71	0.55	0.34	0.17	0.06	0.03	0.02	0.01	0.01	0.06
1985	0.15	0.26	0.59	0.79	2.59	1.64	1.09	0.95	1.09	1.65	0.94	0.51	0.36	0.22	0.11	0.04	0.02	0.01	0.01	0.05
1986	0.21	0.38	0.88	2.25	2.40	4.89	1.95	0.97	0.74	0.80	1.18	0.67	0.36	0.26	0.16	0.08	0.03	0.01	0.01	0.04
1987	0.11	0.28	0.36	0.61	1.30	1.47	3.72	1.80	0.99	0.78	0.86	1.28	0.72	0.40	0.28	0.17	0.09	0.03	0.01	0.05
1988	0.05	0.10	0.20	0.21	0.29	0.54	0.58	1.68	1.04	0.75	0.72	0.90	1.42	0.83	0.46	0.33	0.20	0.10	0.03	0.07
1989	0.78	0.96	1.91	3.52	3.40	4.27	6.48	5.30	10.59	4.51	2.35	1.84	2.02	3.00	1.69	0.93	0.66	0.40	0.20	0.22
1990	0.25	1.05	2.63	8.20	14.04	8.21	5.51	4.62	2.33	3.32	1.15	0.53	0.39	0.42	0.62	0.35	0.19	0.13	0.08	0.09
1991	0.05	0.20	0.78	1.83	5.73	10.77	6.85	4.74	4.02	2.03	2.89	1.00	0.47	0.34	0.37	0.54	0.30	0.16	0.12	0.15
1992	0.40	0.74	2.48	7.46	11.53	19.17	20.53	10.09	6.50	5.41	2.73	3.88	1.34	0.62	0.46	0.49	0.72	0.40	0.22	0.35
1993	0.22	0.72	2.00	9.64	33.03	36.63	39.02	33.24	15.13	9.53	7.89	3.97	5.64	1.95	0.91	0.67	0.72	1.05	0.59	0.83
1994	0.09	1.02	2.53	5.26	16.74	32.11	23.27	21.84	18.21	8.27	5.20	4.31	2.17	3.08	1.06	0.50	0.37	0.39	0.57	0.78
1995	0.05	0.24	2.75	6.54	10.41	17.49	17.34	9.14	7.82	6.38	2.88	1.81	1.50	0.75	1.07	0.37	0.17	0.13	0.14	0.47
1996	0.09	0.12	0.46	3.94	7.39	10.61	20.62	25.22	14.85	13.22	10.91	4.95	3.11	2.58	1.30	1.84	0.64	0.30	0.22	1.04
1997	0.02	0.13	0.19	0.70	6.03	10.90	13.84	21.49	21.58	11.57	9.98	8.16	3.69	2.32	1.92	0.97	1.37	0.47	0.22	0.94
1998	0.01	0.05	0.33	0.50	1.99	17.08	26.30	22.59	23.08	18.43	9.10	7.66	6.22	2.81	1.76	1.46	0.73	1.04	0.36	0.88
1999	0.00	0.00	0.02	0.21	0.40	2.02	20.80	31.73	22.25	19.46	14.64	7.10	5.94	4.82	2.17	1.37	1.13	0.57	0.81	0.96
2000	0.00	0.02	0.03	0.17	0.87	1.00	2.96	18.32	19.87	13.43	12.77	10.17	5.06	4.27	3.48	1.57	0.99	0.82	0.41	1.28
2001	0.01	0.03	0.11	0.15	0.56	2.19	1.89	4.08	18.23	14.81	8.37	7.48	5.93	2.97	2.53	2.07	0.94	0.59	0.49	1.01

2002	0.03	0.05	0.11	0.45	0.60	2.35	8.91	6.95	12.15	39.79	23.17	10.06	7.64	5.56	2.68	2.24	1.81	0.82	0.51	1.31
2003	0.00	0.00	0.00	0.01	0.04	0.09	0.60	3.67	3.95	7.23	20.51	10.34	4.12	3.00	2.15	1.03	0.85	0.69	0.31	0.69
2004	0.00	0.00	0.02	0.03	0.07	0.30	0.46	1.89	6.97	4.60	6.16	15.77	7.84	3.14	2.29	1.64	0.78	0.65	0.53	0.77
2005	0.00	0.01	0.01	0.04	0.08	0.21	1.02	1.52	5.35	14.01	6.35	6.58	14.83	6.98	2.74	1.98	1.42	0.68	0.56	1.12
2006	0.02	0.02	0.06	0.09	0.33	0.52	1.02	3.01	2.38	4.58	8.05	3.03	2.92	6.44	3.01	1.18	0.85	0.61	0.29	0.72
2007	0.06	0.11	0.15	0.39	0.67	2.44	2.89	3.46	6.29	3.63	5.97	9.82	3.60	3.45	7.56	3.53	1.38	1.00	0.71	1.19
2008	0.05	0.13	0.28	0.41	1.13	1.63	4.02	3.15	2.96	4.87	2.72	4.43	7.26	2.66	2.54	5.58	2.60	1.02	0.74	1.40
2009	0.03	0.14	0.39	0.84	1.20	2.90	3.19	5.98	4.09	3.66	5.95	3.31	5.38	8.83	3.23	3.09	6.78	3.17	1.24	2.60
2010	0.04	0.18	0.70	1.68	2.96	2.93	4.18	2.90	4.35	2.76	2.43	3.93	2.18	3.55	5.81	2.13	2.04	4.47	2.09	2.53
2011	0.04	0.08	0.29	1.02	2.23	3.49	3.04	3.97	2.67	3.97	2.52	2.22	3.58	1.99	3.24	5.31	1.94	1.86	4.08	4.21
2012	0.02	0.13	0.27	1.02	3.39	6.38	7.41	4.35	4.18	2.41	3.39	2.11	1.84	2.98	1.65	2.69	4.41	1.61	1.54	6.88

Table 8.5 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
2011	1,977,086	
2012	1,920,350	65,460

Table 8.6—Total tonnage of northern rock sole caught in resource assessment trawl surveys on the Bering Sea shelf, 1977-2012.

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
2011	67
2012	70

Table 8-7 --Rock sole weight-at-age (grams) by age and year determined from 1983-2011 from length-at-age and length-weight relationships (missing values filled in) from the annual trawl survey in the eastern Bering Sea. Three year running average was used to model rock sole weight-at-age in the 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	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
1993	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
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	17	25	54	114	181	272	269	327	387	421	479	462	504	514	523	562	537	626	632
2005	9	17	25	54	114	181	272	269	327	387	421	479	462	504	514	523	562	537	626	632
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	15	19	39	52	123	157	326	336	477	437	568	499	0	415	548	573	556	588	714
2009	9	15	16	33	54	101	161	254	313	316	391	432	456	443	545	609	576	600	615	649
2010	9	15	22	49	72	117	151	232	307	347	453	461	449	534	604	520	537	578	456	583
2011	9	15	31	87	123	138	174	221	299	359	421	447	485	537	493	695	690	815	336	621

Table 8.7 continued.

	males																			
	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	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
1993	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
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	13	23	55	123	149	196	234	241	265	282	308	314	307	297	360	321	348	321	335
2005	7	13	23	55	123	149	196	234	241	265	282	308	314	307	297	360	321	348	321	335
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	7	19	29	47	111	146	234	243	234	324	279	360	337	308	526	310	357	303	360
2009	7	7	15	31	54	91	153	206	232	292	285	368	303	285	319	330	398	354	298	290
2010	7	9	27	39	65	103	136	187	240	292	253	315	290	306	409	263	366	325	339	312
2011	7	9	23	56	78	110	163	192	254	223	264	275	360	341	336	340	344	340	390	370

Table 8-8.--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 8.9—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	61	524	490
2011	376	308	23140	54	390	384
2012	376	289	18192	48	355	

Table 8.10--Estimated population numbers-at-age (millions) from the annual Bering Sea trawl surveys, 1982- 2011.

year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1982	0	69	243	525	537	533	546	254	86	78	57	112	64	26	6	9	8	0	1	0
1983	0	65	624	570	644	321	325	368	168	142	56	76	105	54	38	25	5	2	1	0
1984	0	127	521	1,189	709	385	612	268	338	133	55	62	69	41	53	24	9	0	3	3
1985	9	141	353	937	906	423	263	202	116	130	29	13	6	14	37	31	7	7	2	8
1986	0	0	432	1,086	1,299	1,151	508	271	264	53	196	21	20	18	5	19	17	1	0	12
1987	0	17	714	1,014	1,081	848	972	256	251	164	72	206	30	8	10	4	18	4	2	17
1988	0	289	1,077	1,517	1,927	947	896	492	301	67	164	88	70	59	0	7	11	58	23	14
1989	0	108	777	947	1,092	1,256	723	538	399	123	89	89	65	76	25	23	2	2	15	22
1990	0	18	944	2,677	1,634	900	1,101	327	447	304	127	56	64	17	39	1	0	8	0	37
1991	0	12	98	2,717	2,165	1,346	967	830	452	409	254	133	84	61	37	14	0	4	5	27
1992	0	8	300	737	3,021	2,295	860	1,044	549	312	328	196	143	96	50	27	13	0	11	5
1993	0	39	998	1,390	1,256	3,977	2,192	1,025	964	543	158	150	141	98	48	11	0	0	5	10
1994	0	43	517	2,230	1,385	1,395	4,629	2,286	1,098	356	678	302	171	194	92	56	14	12	30	17
1995	0	0	157	942	2,096	932	699	2,533	1,503	524	570	406	164	140	100	0	10	4	4	9
1996	0	36	941	455	720	1,921	566	945	2,237	1,332	387	200	242	72	102	90	33	11	1	9
1997	0	4	539	1,531	590	958	2,693	562	1,000	2,113	707	653	447	273	138	134	66	30	0	15
1998	0	0	246	727	861	600	984	1,798	489	593	1,628	1,069	336	126	163	37	33	12	11	20
1999	0	0	62	105	295	836	116	623	1,473	831	586	1,381	530	239	112	123	27	27	11	2
2000	0	0	41	505	238	369	904	370	942	1,417	746	641	1,057	443	240	208	60	9	11	15
2001	0	22	181	218	637	452	371	938	510	1,178	1,193	512	647	989	416	189	67	53	16	4
2002	0	134	427	202	254	757	268	230	629	322	505	1,007	346	227	791	256	102	69	5	34
2003	11	682	1,108	542	436	209	709	348	199	255	164	539	1,154	257	402	729	204	123	82	38
2004	0	99	1,985	1,201	760	434	193	516	245	60	634	320	209	625	165	73	516	386	4	197
2005	0	213	2,011	2,336	1,616	349	479	326	405	133	161	152	115	476	313	234	274	432	229	205
2006	0	300	2,009	4,173	1,994	1,283	418	302	348	457	273	149	197	109	419	491	287	127	339	264
2007	1	61	710	1,720	2,105	1,632	1,067	493	173	507	211	210	214	207	302	274	161	156	152	153
2008	0	0	780	991	1,525	1,976	1,586	894	227	225	344	254	149	32	93	129	274	287	60	300
2009	0	9	233	1,423	948	1,097	1,314	823	523	81	190	54	186	77	86	84	98	173	193	262
2010	0	20	209	856	1,390	1,099	1,068	1,375	976	498	264	257	113	228	74	121	54	87	193	382
2011	0	0	226	293	729	1,366	899	1,004	1,124	598	412	180	126	88	133	26	39	48	29	292

Table 8.11--Key equations used in the population dynamics model.

$N_{t,1} = R_t = R_0 e^{\tau_t}$, $\tau_t \sim N(0, \delta^2{}_R)$	Recruitment 1956-75
$N_{t,1} = R_t = R_\gamma e^{\tau_t}$, $\tau_t \sim N(0, \delta^2{}_R)$	Recruitment 1976-96
$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}\left(1 - e^{-z_{t,a}}\right) N_{t,a}$	Catch in year *t* for age *a* fish
$N_{t+1,a+1} = N_{t,a} e^{-z_{t,a}}$	Numbers of fish in year *t+1* at age *a*
$N_{t+1,A} = N_{t,A-1} e^{-z_{t,A-1}} + N_{t,A} e^{-z_{t,A}}$	Numbers of fish in the “plus group”
$S_t = \sum N_{t,a} W_{t,a} \phi_a$	Spawning biomass
$Z_{t,a} = F_{t,a} + M$	Total mortality in year *t* at age *a*
$F_{t,a} = s_a \mu^F \exp^{\varepsilon^F{}_t}$, $\varepsilon^F{}_t \sim N(o, \sigma^{2_F})$	Fishing mortality
$s_a = \frac{1}{1 + \left(e^{-\alpha + \beta a}\right)}$	Age-specific fishing selectivity
$C_t = \sum C_{t,a}$	Total catch in numbers
$P_{t,a} = {}^{C_{t,a}}\!/\!_{C_t}$	Proportion at age in catch
$SurB_t = q \sum N_{t,a} W_{t,a} v_a$	Survey biomass
$qprior = \lambda \frac{0.5(\ln q_{est} - \ln q_{prior})^2}{\sigma_q^2}$	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 8.12--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 8.13--Model estimates of rock sole fishing mortality and exploitation rate (catch/total biomass).

year	Full selection F	Exploitation rate
1975	0.30	0.06
1976	0.38	0.05
1977	0.28	0.02
1978	0.54	0.03
1979	0.05	0.02
1980	0.04	0.03
1981	0.03	0.03
1982	0.05	0.03
1983	0.06	0.03
1984	0.16	0.07
1985	0.05	0.03
1986	0.05	0.03
1987	0.08	0.05
1988	0.16	0.09
1989	0.12	0.07
1990	0.05	0.03
1991	0.11	0.04
1992	0.11	0.04
1993	0.11	0.04
1994	0.11	0.04
1995	0.10	0.04
1996	0.08	0.03
1997	0.09	0.04
1998	0.04	0.02
1999	0.04	0.02
2000	0.05	0.03
2001	0.02	0.02
2002	0.03	0.03
2003	0.03	0.02
2004	0.04	0.03
2005	0.03	0.02
2006	0.04	0.02
2007	0.04	0.02
2008	0.06	0.03
2009	0.05	0.03
2010	0.06	0.03
2011	0.06	0.04
2012	0.06	0.05

Table 8.14 --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	0.00	0.00	0.00	0.01	0.02	0.06	0.17	0.39	0.67	0.86	0.95	0.98	0.99	1.00	1.00	1.00	1.00
males	0.00	0.00	0.00	0.01	0.05	0.14	0.36	0.65	0.86	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00

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	0.48	0.75	0.91	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	0.40	0.69	0.88	0.96	0.96	0.96	0.96
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.07	0.21	0.47	0.74	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	0.37	0.37	0.37	0.37
1979	0.00	0.01	0.02	0.06	0.17	0.41	0.70	0.89	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1980	0.11	0.26	0.51	0.76	0.90	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	0.17	0.40	0.68	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	0.57	0.83	0.95	0.98	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	0.35	0.64	0.85	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	0.24	0.48	0.72	0.88	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1985	0.17	0.44	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	1.00
1986	0.03	0.10	0.32	0.67	0.90	0.97	0.99	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	0.49	0.76	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
1988	0.07	0.20	0.47	0.75	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
1989	0.04	0.14	0.41	0.75	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
1990	0.04	0.13	0.34	0.63	0.85	0.95	0.98	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	0.07	0.18	0.37	0.62	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	0.01	0.02	0.05	0.13	0.32	0.59	0.82	0.93	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	0.35	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	0.47	0.74	0.90	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	0.29	0.47	0.65	0.80	0.90	0.95	0.98	0.99	0.99	0.99	0.99	0.99
1998	0.00	0.00	0.01	0.02	0.06	0.13	0.27	0.47	0.69	0.84	0.93	0.97	0.99	0.99	0.99	0.99	0.99
1999	0.00	0.01	0.02	0.05	0.13	0.29	0.52	0.75	0.89	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00
2000	0.00	0.01	0.03	0.08	0.19	0.40	0.66	0.85	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2001	0.02	0.06	0.15	0.33	0.58	0.79	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2002	0.01	0.04	0.12	0.31	0.59	0.83	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2003	0.03	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
2004	0.01	0.03	0.10	0.24	0.49	0.74	0.89	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2005	0.02	0.04	0.12	0.30	0.56	0.79	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2006	0.02	0.05	0.15	0.36	0.66	0.86	0.95	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	0.32	0.63	0.86	0.96	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	0.22	0.49	0.77	0.92	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	0.26	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	0.01	0.04	0.12	0.28	0.53	0.77	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2011	0.00	0.01	0.04	0.13	0.34	0.65	0.87	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2012	0.01	0.02	0.06	0.17	0.39	0.67	0.86	0.95	0.98	0.99	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	0.01	0.02	0.06	0.18	0.44	0.73	0.90	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	0.14	0.35	0.66	0.87	0.96	0.99	1.00	1.00	1.00	1.00	1.00
1977	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.18	0.44	0.73	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	0.28	0.59	0.84	0.95	0.95	0.95	0.95
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	0.35	0.61	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	1.00
1981	0.33	0.65	0.88	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	0.63	0.83	0.93	0.98	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	0.13	0.25	0.44	0.65	0.82	0.91	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00
1984	0.04	0.10	0.20	0.36	0.56	0.74	0.87	0.94	0.97	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1985	0.37	0.73	0.92	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	1.00

1986	0.09	0.29	0.63	0.88	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
1987	0.14	0.38	0.70	0.90	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	0.38	0.77	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	1.00
1989	0.08	0.27	0.62	0.88	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
1990	0.12	0.39	0.74	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
1991	0.02	0.07	0.23	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	1.00
1992	0.01	0.04	0.13	0.36	0.67	0.88	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	0.90	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	0.05	0.19	0.52	0.84	0.96	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	0.21	0.45	0.72	0.89	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	0.34	0.56	0.76	0.89	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00
1997	0.01	0.02	0.06	0.16	0.33	0.57	0.78	0.91	0.96	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1998	0.00	0.00	0.01	0.04	0.15	0.41	0.73	0.92	0.98	0.99	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	0.34	0.61	0.82	0.93	0.98	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	0.75	0.91	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	0.58	0.80	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2002	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
2003	0.05	0.17	0.42	0.73	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
2004	0.03	0.12	0.34	0.66	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
2005	0.06	0.17	0.42	0.72	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2006	0.03	0.08	0.22	0.48	0.75	0.91	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	0.27	0.54	0.79	0.93	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	0.09	0.25	0.53	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	0.14	0.34	0.63	0.85	0.95	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2010	0.02	0.05	0.13	0.29	0.54	0.77	0.91	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2011	0.01	0.04	0.12	0.30	0.58	0.81	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2012	0.01	0.05	0.14	0.36	0.65	0.86	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 8-15.--Model estimates of rock sole age 2+ total biomass (t) and female spawning biomass (t) from the 2011 and 2012 assessments.

	2012 Assessment		2011 Assessment	
	Age 2+ Total biomass	Female Spawning biomass	Age 2+ Total biomass	Female Spawning biomass
1975	198,784	54,945	198,609	54,907
1976	218,249	57,877	218,102	57,817
1977	238,163	66,165	238,063	66,070
1978	263,790	83,185	263,798	83,039
1979	287,631	103,695	287,819	103,488
1980	318,327	119,611	318,734	119,384
1981	357,635	128,381	358,259	128,168
1982	401,896	133,105	402,709	132,981
1983	454,728	139,778	455,651	139,776
1984	524,744	148,715	525,602	148,788
1985	587,442	147,651	588,125	147,657
1986	691,435	164,635	691,744	164,874
1987	819,992	182,373	819,730	182,714
1988	964,896	203,498	964,092	203,795
1989	1,048,540	219,892	1,047,190	220,084
1990	1,168,080	249,352	1,166,190	249,364
1991	1,382,610	298,961	1,380,260	298,615
1992	1,477,340	315,365	1,475,050	314,786
1993	1,516,200	332,776	1,513,970	332,069
1994	1,520,980	350,317	1,518,860	349,596
1995	1,596,670	426,510	1,594,250	425,798
1996	1,652,150	524,322	1,649,520	523,539
1997	1,703,390	613,114	1,700,250	612,131
1998	1,686,930	664,778	1,683,260	663,938
1999	1,680,830	723,035	1,676,290	722,207
2000	1,649,630	762,671	1,644,110	761,577
2001	1,597,120	770,869	1,589,530	769,553
2002	1,560,730	759,095	1,551,340	757,585
2003	1,532,460	736,902	1,519,230	735,127
2004	1,527,440	686,888	1,507,730	684,668
2005	1,536,600	611,461	1,507,540	608,586
2006	1,635,500	549,547	1,593,020	545,746
2007	1,744,210	518,370	1,686,520	513,307
2008	1,738,660	499,869	1,755,860	489,817
2009	1,688,750	500,065	1,790,150	489,495
2010	1,634,890	524,317	1,800,260	521,731
2011	1,650,160	563,512	1,765,420	565,651
2012	1,626,770	603,935		

Table 8.16--Estimated age 4 recruitment of rock sole (thousands of fish) from the 2011 and 2012 assessments.

Year class	2012 Assessment	2011 Assessment
1971	199,824	165,081
1972	157,253	129,975
1973	196,587	156,438
1974	203,140	204,485
1975	473,120	476,208
1976	266,300	267,835
1977	426,326	428,379
1978	424,174	425,438
1979	563,032	563,326
1980	1,026,604	1,024,780
1981	1,006,494	1,004,317
1982	923,376	921,965
1983	1,388,382	1,387,620
1984	1,342,432	1,343,110
1985	1,269,452	1,273,633
1986	2,242,280	2,256,630
1987	3,498,720	3,530,200
1988	1,240,766	726,407
1989	1,036,376	602,183
1990	2,306,440	1,263,564
1991	1,165,866	682,473
1992	601,308	533,265
1993	914,752	599,087
1994	480,346	448,202
1995	466,196	442,853
1996	632,204	584,878
1997	380,952	693,478
1998	577,568	767,316
1999	586,710	743,498
2000	1,241,580	1,302,887
2001	1,847,268	1,631,969
2002	2,198,500	1,770,796
2003	1,681,994	1,941,414
2004	1,199,502	2,507,620
2005	1,622,094	1,393,808

Table 8.17—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	159	133	91	100	187	120	51	37	29	23	11	8	5	5	5	4	4	4	4	5
1976	371	137	114	79	86	161	103	44	32	25	20	9	6	4	3	3	3	3	3	6
1977	209	319	118	98	68	74	138	89	38	28	22	17	7	5	3	2	2	2	2	5
1978	335	180	275	102	85	58	64	119	77	33	24	19	14	6	4	2	1	1	1	4
1979	333	288	155	237	87	73	50	55	103	66	28	20	16	12	5	3	1	1	1	3
1980	442	287	248	133	204	75	63	43	47	86	55	23	17	13	10	4	3	1	1	3
1981	806	381	247	213	114	173	63	52	36	39	72	45	19	14	11	8	4	2	1	3
1982	790	693	327	212	182	97	146	53	44	30	32	59	38	16	12	9	7	3	2	3
1983	726	680	597	282	182	155	81	121	44	36	24	26	49	31	13	9	7	6	2	4
1984	1090	625	585	513	242	156	132	68	100	36	29	20	21	39	25	11	8	6	5	5
1985	1055	938	538	503	441	207	132	109	54	76	26	21	14	16	29	18	8	6	4	7
1986	1000	908	807	462	430	372	172	109	90	45	63	22	18	12	13	24	15	6	5	9
1987	1762	860	782	694	397	368	315	143	90	74	37	51	18	14	10	11	19	12	5	12
1988	2747	1517	740	671	594	335	304	254	114	71	58	29	41	14	11	8	8	15	10	13
1989	974	2364	1304	635	571	495	268	233	190	84	52	43	21	30	10	8	6	6	11	17
1990	813	838	2034	1121	544	484	406	211	180	145	65	40	33	16	23	8	6	4	5	22
1991	1809	700	721	1749	963	465	409	338	174	147	119	53	33	27	13	19	6	5	4	21
1992	914	1557	602	620	1504	826	397	345	279	140	116	92	41	25	21	10	14	5	4	19
1993	472	787	1340	518	534	1292	708	338	289	228	111	90	72	32	20	16	8	11	4	18
1994	717	406	677	1153	446	459	1108	602	282	235	180	87	70	55	24	15	12	6	9	17
1995	377	617	349	583	992	383	394	949	511	234	189	141	67	54	43	19	12	10	5	20
1996	366	324	531	301	502	854	329	337	804	424	189	150	111	52	42	33	15	9	7	19
1997	496	315	279	457	259	432	734	283	288	680	352	154	120	88	42	33	26	12	7	21
1998	299	427	271	240	393	222	370	628	240	242	562	286	124	96	70	33	26	21	9	22
1999	453	257	367	233	207	339	191	318	539	206	206	474	239	103	79	58	27	22	17	26
2000	460	390	221	316	201	178	291	164	272	458	173	172	393	198	85	65	48	22	18	35
2001	974	396	336	190	272	173	153	250	140	230	383	143	142	324	163	70	54	39	18	44
2002	1449	838	341	289	164	234	148	131	212	118	194	322	121	119	272	137	59	45	33	52

2003	1724	1247	721	293	248	141	200	126	110	178	99	162	268	100	99	226	114	49	38	71
2004	1319	1484	1073	621	252	213	121	171	107	93	149	83	135	224	84	83	189	95	41	91
2005	941	1136	1277	924	534	217	183	103	144	89	77	123	68	111	185	69	68	156	78	108
2006	1272	810	977	1099	795	459	186	156	87	120	74	64	102	57	93	154	57	57	130	155
2007	606	1095	697	841	946	683	393	158	131	72	100	61	53	85	47	77	127	48	47	236
2008	322	522	942	600	724	813	585	334	132	109	60	83	51	44	70	39	63	105	39	234
2009	456	277	449	811	516	622	697	497	279	109	89	49	67	41	36	57	32	52	85	222
2010	442	393	238	387	698	444	533	592	416	231	90	73	40	55	34	29	47	26	42	252
2011	642	381	338	205	333	600	381	456	502	348	190	73	59	32	45	27	24	38	21	239
2012	665	553	328	291	177	286	515	326	385	416	285	155	60	48	26	36	22	19	31	212

	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	159	78	59	65	98	56	32	24	17	12	7	7	6	6	6	6	5	6	6	6
1976	371	137	67	51	56	84	48	27	20	13	9	5	5	4	4	4	4	3	4	7
1977	209	319	118	58	44	48	72	42	23	17	11	7	3	3	2	2	2	2	2	6
1978	335	180	275	102	50	38	41	62	36	20	14	9	5	2	2	1	1	1	1	5
1979	333	288	155	237	87	43	33	36	54	31	17	12	7	4	1	1	0	0	0	1
1980	442	287	248	133	204	75	37	28	30	45	26	14	10	6	3	1	1	0	0	1
1981	806	381	247	213	114	173	63	31	23	25	37	21	12	8	5	3	1	0	0	1
1982	790	693	327	212	181	96	144	53	25	19	21	31	18	10	7	4	2	1	0	1
1983	726	680	596	281	182	155	81	121	44	21	16	17	26	14	8	6	3	2	1	1
1984	1090	625	585	513	242	156	133	69	102	36	17	13	14	21	12	6	5	3	1	2
1985	1055	937	537	502	439	205	130	108	54	78	27	13	10	10	15	9	5	3	2	2
1986	1000	908	806	460	425	365	169	107	88	45	64	22	10	8	8	12	7	4	3	3
1987	1762	860	781	693	394	360	304	139	88	73	37	52	18	9	6	7	10	6	3	5
1988	2747	1516	740	670	589	329	293	243	111	70	57	29	41	15	7	5	5	8	5	7
1989	974	2364	1304	635	567	478	251	217	179	81	51	42	21	30	11	5	4	4	6	8
1990	813	838	2034	1120	541	473	382	194	167	137	62	39	32	16	23	8	4	3	3	11
1991	1809	700	721	1748	958	457	392	313	159	136	112	51	32	26	13	19	7	3	2	11
1992	914	1557	602	620	1501	818	383	318	247	123	105	86	39	25	20	10	15	5	2	10

1993	472	787	1340	518	533	1286	694	317	255	193	96	81	67	30	19	16	8	11	4	10
1994	717	406	677	1153	445	457	1091	573	253	199	149	74	63	51	23	15	12	6	9	11
1995	377	617	349	583	992	383	391	920	466	198	154	115	57	48	40	18	11	9	5	15
1996	366	324	531	301	502	853	329	334	775	383	158	121	90	44	37	31	14	9	7	15
1997	496	315	279	457	259	431	733	281	284	650	315	128	97	72	35	30	24	11	7	18
1998	299	427	271	240	393	222	369	622	235	233	523	251	102	77	57	28	24	19	9	20
1999	453	257	367	233	207	338	191	317	532	199	194	432	207	84	63	47	23	19	16	23
2000	460	390	221	316	201	178	291	164	271	451	167	161	358	171	69	52	39	19	16	32
2001	974	396	336	190	272	173	153	250	140	228	376	138	133	294	141	57	43	32	16	40
2002	1449	838	341	289	164	234	148	131	212	118	192	316	116	112	248	118	48	36	27	47
2003	1724	1247	721	293	248	140	199	125	109	177	98	160	263	97	93	206	98	40	30	61
2004	1319	1484	1073	621	252	213	119	168	105	91	148	82	134	220	81	78	172	82	33	76
2005	941	1135	1277	923	533	216	180	100	139	86	75	122	68	110	181	66	64	142	68	90
2006	1272	810	977	1099	793	456	183	151	83	116	72	63	101	56	92	151	55	53	118	131
2007	606	1095	697	841	945	681	389	155	127	69	96	59	52	84	47	76	125	46	44	206
2008	322	522	942	600	723	810	580	328	129	105	57	79	49	43	69	39	63	103	38	207
2009	456	277	449	811	516	621	694	492	274	106	86	47	64	40	35	56	31	51	84	199
2010	442	393	238	386	697	443	531	587	410	226	87	70	38	53	33	29	46	26	42	232
2011	642	381	338	205	332	599	378	449	490	338	185	71	57	31	43	27	23	38	21	223
2012	665	553	328	291	176	285	512	320	374	403	276	151	58	47	25	35	22	19	31	198

Table 8.18—Stock assessment model estimates of the number of female spawners (millions).

Estimate of the number of female spawners (millions of fish).

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	1	3	7	15	17	9	7	5	5	5	4	4	4	4	5
1976	1	6	9	16	19	18	8	6	4	3	3	3	3	3	6
1977	1	8	18	19	21	19	16	7	5	3	2	2	2	2	5
1978	0	4	24	39	25	21	17	14	6	4	2	1	1	1	4
1979	1	3	11	52	49	25	19	15	12	5	3	1	1	1	3
1980	1	4	9	24	65	49	21	16	13	10	4	3	1	1	3
1981	1	4	10	18	29	64	42	18	14	11	8	4	2	1	3
1982	1	9	11	22	22	29	55	36	16	11	9	7	3	2	3
1983	1	5	24	22	27	22	25	47	30	13	9	7	6	2	4
1984	1	8	14	50	27	26	18	20	39	25	10	8	6	5	5
1985	2	8	22	27	57	24	20	14	15	28	18	8	6	4	7
1986	3	10	22	45	34	56	20	17	12	13	23	15	6	5	9
1987	3	19	29	45	55	33	48	17	14	10	10	19	12	5	11
1988	3	19	51	58	53	52	27	39	14	11	8	8	15	10	13
1989	4	16	47	96	63	47	40	20	29	10	8	6	6	11	17
1990	4	25	42	91	109	57	37	31	16	22	8	6	4	5	21
1991	4	25	68	88	110	106	49	31	26	13	19	6	5	4	21
1992	7	24	69	141	105	103	86	39	25	20	10	14	5	4	19
1993	10	43	68	146	171	99	84	68	31	19	16	8	11	4	18
1994	4	68	120	143	176	160	80	67	54	24	15	12	6	9	17
1995	3	24	190	258	176	168	131	64	53	42	19	12	9	5	20
1996	7	20	67	406	318	168	139	106	51	41	33	14	9	7	19
1997	3	45	57	146	510	312	143	115	86	41	33	26	12	7	21
1998	2	23	126	121	182	499	266	118	94	69	33	26	21	9	22
1999	3	12	64	272	154	183	440	228	100	78	57	27	22	17	26
2000	1	18	33	138	344	154	160	375	194	83	65	47	22	18	35
2001	1	9	50	71	173	340	133	135	317	160	69	53	39	18	44
2002	2	9	26	107	89	172	299	115	117	267	136	58	45	33	52
2003	1	12	25	56	133	88	150	256	98	97	224	113	49	37	71
2004	2	7	34	54	69	132	77	129	219	82	82	188	95	41	91
2005	2	11	21	73	67	68	114	65	109	182	68	68	155	78	108
2006	4	11	31	44	90	66	59	97	55	91	152	57	57	129	155

2007	5	24	32	66	54	89	57	50	83	46	76	127	47	47	235
2008	7	36	67	67	82	53	77	49	43	69	39	63	105	39	234
2009	5	42	99	141	82	79	45	64	40	35	56	31	51	85	222
2010	4	33	118	210	173	80	68	38	54	33	29	46	26	42	251
2011	5	23	91	253	261	169	68	57	32	44	27	24	38	21	239
2012	2	31	65	194	312	253	144	57	47	26	36	22	19	31	211

Table 8.19—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	0.29	0.12	1984	total biomass	524.74	12.44
	sel_slope_fishery_female	1.15	0.06	1985	total biomass	587.44	12.76
	sel50_fishery_female	8.36	0.49	1986	total biomass	691.43	13.59
	sel_slope_fsh_males	1.22	0.06	1987	total biomass	819.99	14.63
	sel50_fsh_males	7.47	0.44	1988	total biomass	964.90	16.12
	sel_slope_survey_females	2.01	0.12	1989	total biomass	1048.50	17.68
	sel50_survey_females	3.55	0.06	1990	total biomass	1168.10	19.53
	sel_slope_survey_males	0.18	0.08	1991	total biomass	1382.60	22.04
	sel50_survey_males	-0.11	0.02	1992	total biomass	1477.30	23.24
	F40	0.16	0.10	1993	total biomass	1516.20	24.06
	F35	0.20	0.13	1994	total biomass	1521.00	24.66
	F30	0.24	0.18	1995	total biomass	1596.70	26.75
	Ricker_logalpha	-4.15	0.20	1996	total biomass	1652.20	28.61
	Ricker_logbeta	-5.84	0.17	1997	total biomass	1703.40	30.28
	Fmsy	0.26	0.20	1998	total biomass	1686.90	31.29
	logFmsy	-1.36	0.77	1999	total biomass	1680.80	31.80
	ABC_biomass 2012	1466.80	60.81	2000	total biomass	1649.60	31.99
	ABC_biomass 2013	1394.70	64.69	2001	total biomass	1597.10	31.83
	msy	259.310	58.020	2002	total biomass	1560.70	31.43
	Bmsy	259.510	32.730	2003	total biomass	1532.50	31.31
1975	total biomass	198.78	9.63	2004	total biomass	1527.40	31.79
1976	total biomass	218.25	10.38	2005	total biomass	1536.60	33.47
1977	total biomass	238.16	11.03	2006	total biomass	1635.50	38.30
1978	total biomass	263.79	11.50	2007	total biomass	1744.20	44.46
1979	total biomass	287.63	11.74	2008	total biomass	1738.70	47.37
1980	total biomass	318.33	11.89	2009	total biomass	1688.70	49.52
1981	total biomass	357.64	12.01	2010	total biomass	1634.90	51.75
1982	total biomass	401.90	12.02	2011	total biomass	1650.20	57.80
1983	total biomass	454.73	12.20	2012	total biomass	1626.80	63.30

Table 8.20. Stock assessment model estimates of average age-specific fishing mortality, by gender, 1975-2012.

females

	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	0.00	0.01	0.02	0.06	0.14	0.22	0.27	0.29	0.30	0.30	0.30	0.30
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.07	0.16	0.27	0.35	0.38	0.38	0.38	0.38
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.14	0.23	0.28	0.28	0.28	0.28
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.07	0.21	0.54	0.54	0.54	0.54
1979	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1980	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1981	0.01	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
1982	0.00	0.01	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1983	0.00	0.00	0.01	0.02	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1984	0.00	0.01	0.02	0.04	0.08	0.12	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
1985	0.01	0.02	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1986	0.00	0.00	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1987	0.01	0.02	0.04	0.06	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
1988	0.01	0.03	0.07	0.12	0.14	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
1989	0.00	0.02	0.05	0.09	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
1990	0.00	0.01	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1991	0.00	0.00	0.01	0.02	0.04	0.07	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1992	0.00	0.00	0.00	0.01	0.03	0.05	0.08	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1993	0.00	0.00	0.00	0.01	0.03	0.06	0.08	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1994	0.00	0.00	0.00	0.01	0.01	0.04	0.07	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1995	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
1996	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
1997	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.06	0.07	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09
1998	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1999	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2000	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05
2001	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

2002	0.00	0.00	0.00	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2003	0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2004	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2005	0.00	0.00	0.00	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2006	0.00	0.00	0.01	0.01	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2007	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2008	0.00	0.00	0.00	0.01	0.03	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2009	0.00	0.00	0.00	0.01	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2010	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2011	0.00	0.00	0.00	0.01	0.02	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2012	0.00	0.00	0.00	0.01	0.03	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

males

	4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1975	0.00	0.00	0.00	0.01	0.02	0.05	0.13	0.22	0.27	0.29	0.30	0.30	0.30	0.30	0.30	0.30	0.30
1976	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.14	0.26	0.34	0.38	0.39	0.39	0.39	0.39	0.39	0.39
1977	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.13	0.22	0.28	0.30	0.30	0.30	0.30	0.30	0.30
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.15	0.42	0.87	1.23	1.40	1.40	1.40	1.40
1979	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1980	0.01	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1981	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
1982	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1983	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1984	0.01	0.02	0.03	0.06	0.09	0.12	0.14	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
1985	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1986	0.00	0.01	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1987	0.01	0.03	0.06	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
1988	0.02	0.06	0.12	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
1989	0.01	0.03	0.07	0.10	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
1990	0.01	0.02	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

1991	0.00	0.01	0.03	0.06	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1992	0.00	0.00	0.01	0.04	0.07	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1993	0.00	0.00	0.01	0.04	0.08	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1994	0.00	0.00	0.01	0.02	0.06	0.09	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1995	0.00	0.00	0.00	0.01	0.02	0.05	0.07	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
1996	0.00	0.00	0.00	0.01	0.01	0.03	0.04	0.06	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08
1997	0.00	0.00	0.01	0.01	0.03	0.05	0.07	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1998	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1999	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2000	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05
2001	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2002	0.00	0.00	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2003	0.00	0.00	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2004	0.00	0.01	0.01	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2005	0.00	0.01	0.01	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2006	0.00	0.00	0.01	0.02	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2007	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2008	0.00	0.00	0.01	0.01	0.03	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2009	0.00	0.00	0.01	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2010	0.00	0.00	0.01	0.02	0.03	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2011	0.00	0.00	0.01	0.02	0.03	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2012	0.00	0.00	0.01	0.02	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

Table 8.21--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
2012	603,777	74,398	0.07
2013	621,460	170,995	0.16
2014	577,421	154,401	0.16
2015	517,112	134,775	0.16
2016	457,420	116,851	0.16
2017	396,775	102,620	0.16
2018	348,241	92,550	0.16
2019	316,912	81,125	0.15
2020	303,288	77,879	0.14
2021	307,402	81,320	0.14
2022	318,653	86,626	0.15
2023	333,508	92,014	0.15
2024	344,932	95,986	0.15
2025	355,719	99,333	0.15

Scenario 3
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2012	525,754	74,397	0.08
2013	544,731	56,199	0.06
2014	558,003	32,388	0.03
2015	559,407	31,637	0.03
2016	551,709	30,446	0.03
2017	529,582	29,263	0.03
2018	507,525	28,280	0.03
2019	491,747	27,826	0.03
2020	483,161	28,069	0.03
2021	487,414	28,731	0.03
2022	499,711	29,765	0.03
2023	519,384	30,910	0.03
2024	533,907	31,872	0.03
2025	553,908	32,932	0.03

Scenario 4
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2012	525,754	74,397	0.08
2013	544,337	64,999	0.07
2014	551,599	72,325	0.08
2015	532,168	68,003	0.08
2016	505,499	63,107	0.08
2017	468,250	58,702	0.08
2018	434,608	55,216	0.08
2019	410,632	53,300	0.08
2020	396,505	53,156	0.08
2021	396,669	54,140	0.08
2022	405,049	55,898	0.08
2023	419,925	57,881	0.08
2024	431,460	59,566	0.08
2025	445,989	61,284	0.08

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2012	525,754	74,397	0.08
2013	544,337	0	0
2014	551,599	0	0
2015	532,168	0	0
2016	505,499	0	0
2017	468,250	0	0
2018	434,608	0	0
2019	410,632	0	0
2020	396,505	0	0
2021	396,669	0	0
2022	405,049	0	0
2023	419,925	0	0
2024	431,460	0	0
2025	445,989	0	0

Table 8.21—continued.

Scenario 6: Determination of whether northern rock sole are currently overfished B35=299,000			
Year	Female spawning biomass	catch	F
2012	603,777	74,398	0.07
2013	619,831	203,977	0.20
2014	559,168	178,929	0.20
2015	486,898	151,923	0.20
2016	419,256	128,453	0.20
2017	354,978	110,547	0.20
2018	306,122	88,442	0.17
2019	280,790	77,591	0.16
2020	272,711	76,942	0.15
2021	280,718	83,571	0.16
2022	293,856	91,378	0.16
2023	308,711	98,600	0.17
2024	319,367	103,478	0.17
2025	328,314	107,096	0.18

Scenario 7: Determination of whether the stock is approaching an overfished condition B35=299,000			
Year	Female spawning biomass	catch	F
2012	603,777	74,398	0.07
2013	621,461	170,980	0.16
2014	577,428	154,403	0.16
2015	515,728	160,715	0.20
2016	442,228	135,221	0.20
2017	372,602	115,655	0.20
2018	319,262	95,702	0.18
2019	288,787	81,677	0.16
2020	277,510	79,334	0.16
2021	283,441	84,879	0.16
2022	295,318	92,029	0.17
2023	309,448	98,886	0.17
2024	319,673	103,570	0.17
2025	328,433	107,112	0.18

Table 8.22—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
2011	85,000	224,000
2012	87,000	208,000

Table 8.23—Catch and bycatch in the rock sole target fisheries, 1993-2011, 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	2010	2011
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	6,016.33	7,091.35
Arrowtooth Flounder	1,143	1,782	507	1,341	411	300	69	216	835	314	419	346	599	516	220	464	600	1,841.27	447.60
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	6,658.66	7,331.82
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			6
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	37,311.26	39,682.50
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	3,446.22	2,027.85
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	<1	<1
Pacific Ocean Perch	15	62	4	2		1	0	0	0	0					<1			<1	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	517.11	411.21
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	<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	12,037.54	9,827.40
Greenland Turbot	28	50	3	3	2	1	0	1	15	0	1	4	1	27	8		7	3	1
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	2,445.89	3,162.49
Sculpin, General								9	2	271						1,104			904.90
Skate, General								1	5	306						559			711.18

Table 8.24—Non-target species catch in the northern rock sole fishery.

NONTARGET_GROUP_NAME	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Benthic urochordata	118678.21	220868.12	318778.02	105544.22	12743.01	30837.08	9764.36	58513.05	5800.61	14243.14
Birds		0	0	0	0		0	0		0
Bivalves	4700.1	338.89	205.78	364.76	396.08	299.4	288.47	477.22	383.14	170.95
Brittle star unidentified	32.28	865.38	1773.68	7290.08	1537.3	1102.53	261.76	1397.61	82.92	69.71
Capelin	1.3	388.38	24.42	4.35	6.44	22.24	43.44	102.71	316.39	56.41
Corals Bryozoans	689.8	693.16	15.88	1346.97	20.6	100.19	19.44	1983.59	104.55	303.5
Eelpouts	1000.13	4296.25	2155.67	3244.69	6894.93	135.7	149.5	4899.66	1860.63	83.87
Eulachon		14.26			1.53	3.83	2.32	33.36	92.83	3.89
Giant Grenadier					4565.52			3331.41		
Greenlings	1150.07	334.24	428.82	335.32	267.23	44.59		18.06	35.12	
Grenadier	0.01	502.51								
Hermit crab unidentified	19169.2	7150.1	7587.56	10401.32	5758	2683.38	636.88	4087.12	2307.71	3464.48
Invertebrate unidentified	105865.92	3128.94	84181.35	6938.09	24211.11	1582.26	2392.49	14526.44	6896.9	2786.48
Misc crabs	18830.36	6423.86	9293.16	6507.53	13605.15	8921.52	3262.82	6369.49	2877.41	6161.04
Misc crustaceans	380.19	151.76	45.36	499.7	198.27	180.15	257.17	1045.61	173.51	354.09
Misc fish	12857.03	16943.73	22421.71	17280.98	70905.19	25201.73	11690.28	14957.04	16735.97	17440.07
Misc inverts (worms etc)	1.44	51.71		24.14	100	8.26	11.34	121.36	16.07	10.82
Other osmerids	3715.91	63.5	725.58	267.83	184.39	627.18	82.26	22.35	124.17	39.69
Pacific Sand lance	16.11	44.72	6.95	32.67	42	30.67	104.59	15.33	6.18	7.45
Pandalid shrimp	200.89	85.94	29.59	20.26	52.6	21.5	59.3	59.84	58.4	55.19
Polychaete unidentified	1.8	7.02		1.19	102.99	21.06	19.14	15.27	4.29	12.42
Scypho jellies	257846.79	304924.73	393490.99	73281.45	94417.73	185158	233299.12	348530.19	264224.6	312587.28
Sea anemone unidentified	18449.18	13291.01	6456.26	8994.76	6338.35	6735.32	2559.5	8769.55	9462.29	4326.69
Sea pens whips		19.31	36.2	0.15		29.39	50	200.88	28.48	78.72
Sea star	1171098.13	333432.64	555351.08	731040.88	710413.9	206604.53	30564.78	174184.47	67505.41	86306.41
Snails	23795.37	23966.73	12922.55	28386.12	24383.93	9313.33	2694.03	11207.04	9697.99	13697.13
Sponge unidentified	198370.76	67555.06	69937.3	40984.67	19224.67	19270.16	64698.87	139966.11	115984.83	63068.37
Stichaeidae	41.87	1.28	2.86		0.41	3.56	0.67	3.32	6.1	
urchins dollars cucumbers	13420.33	8889.78	9279.99	3899.54	32164.61	6035	1104.59	4173.13	3449.36	1601.22

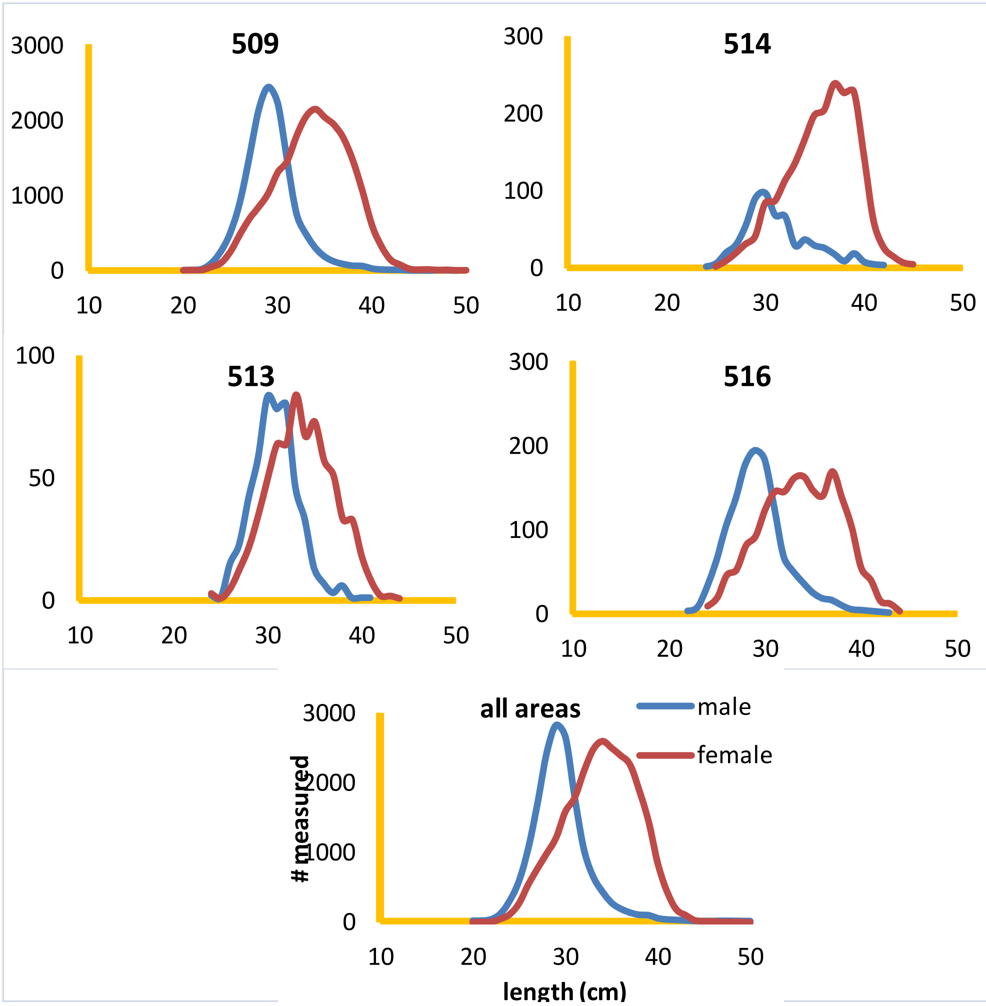


Figure 8.1—Size composition of rock sole, by sex and area, in the 2012 catch as determined from observer sampling.

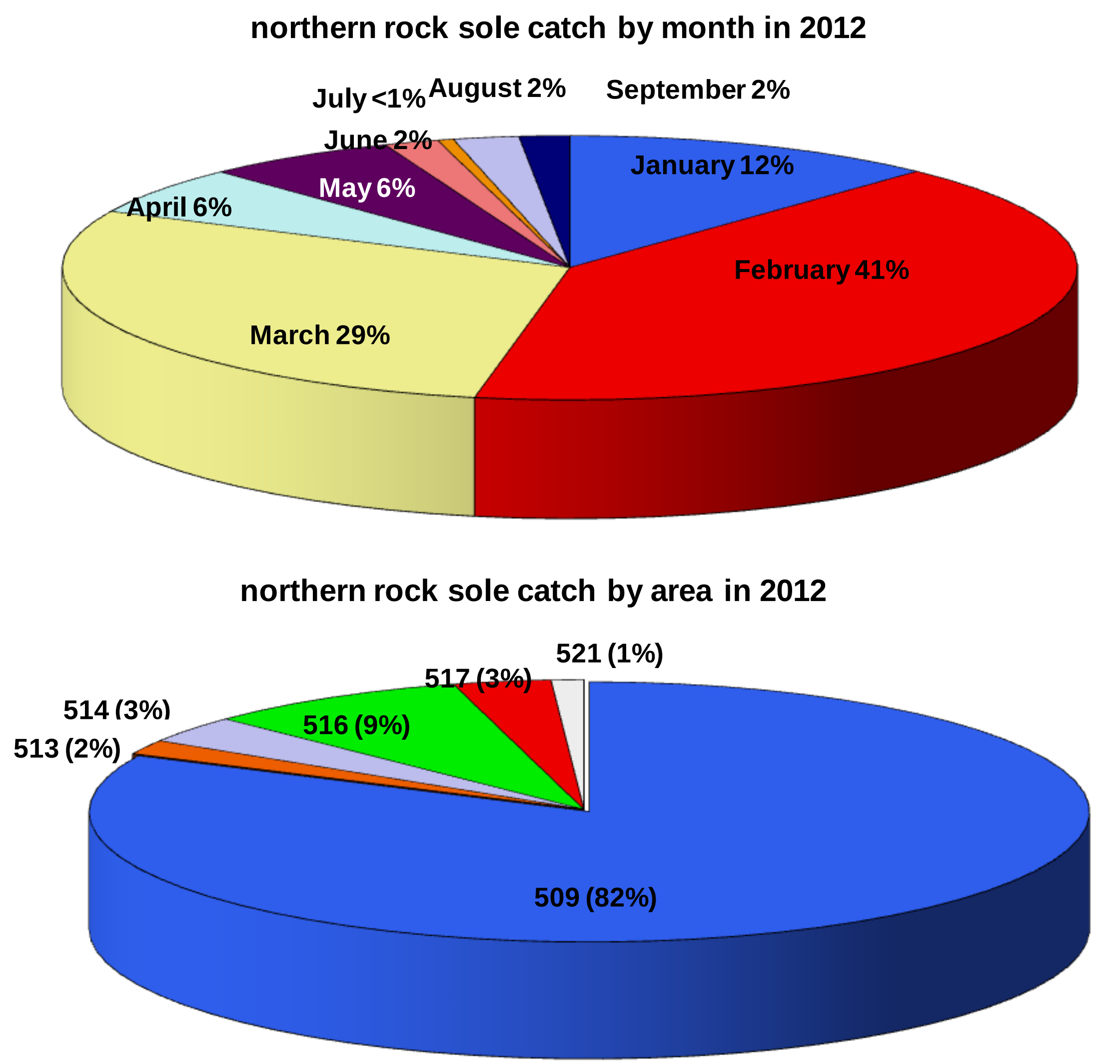


Figure 8.2—Bering Sea northern rock sole fishery catch by month and area in 2012 (percent of total).

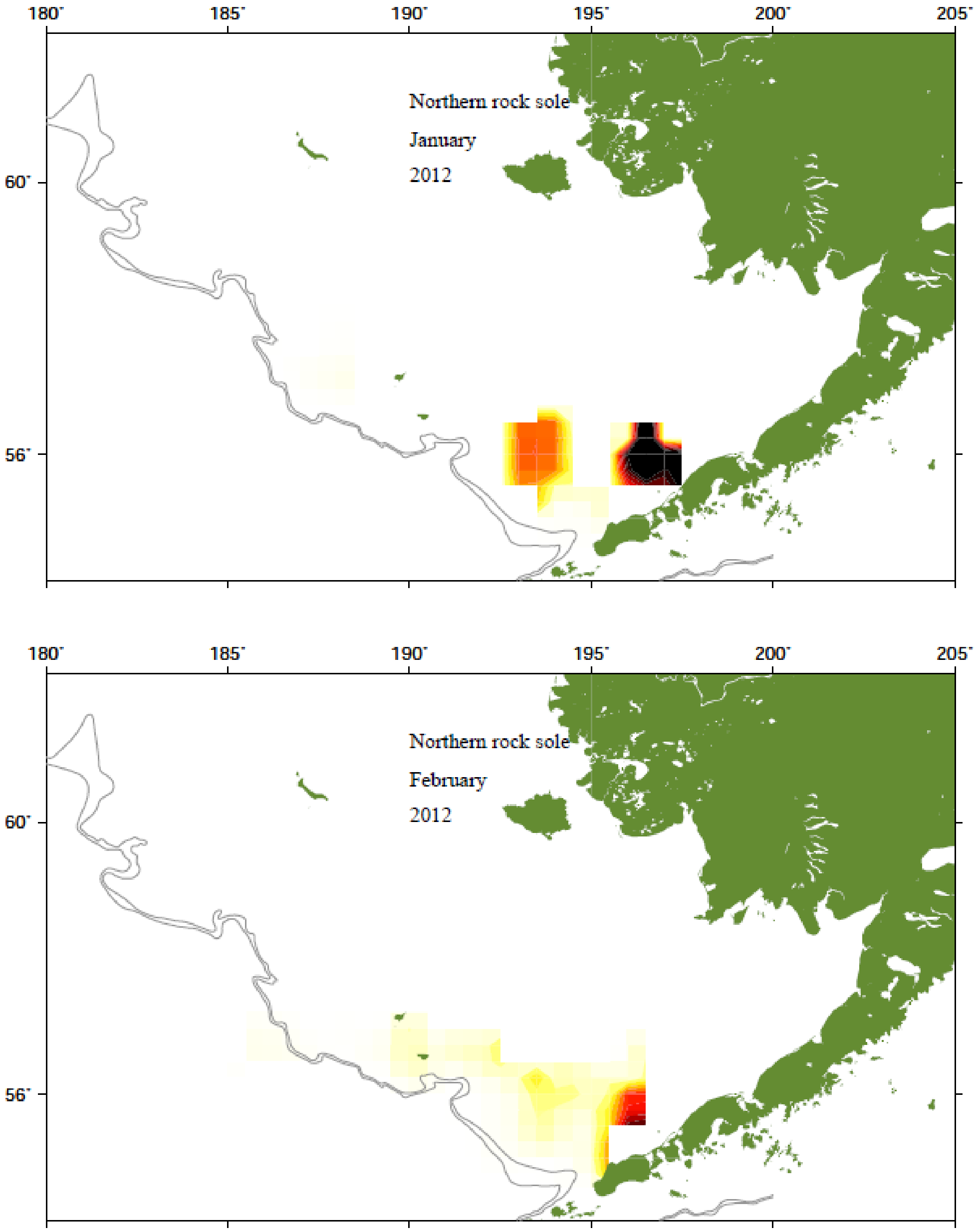


Figure 8.3—Catch locations, by month, of northern rock sole.

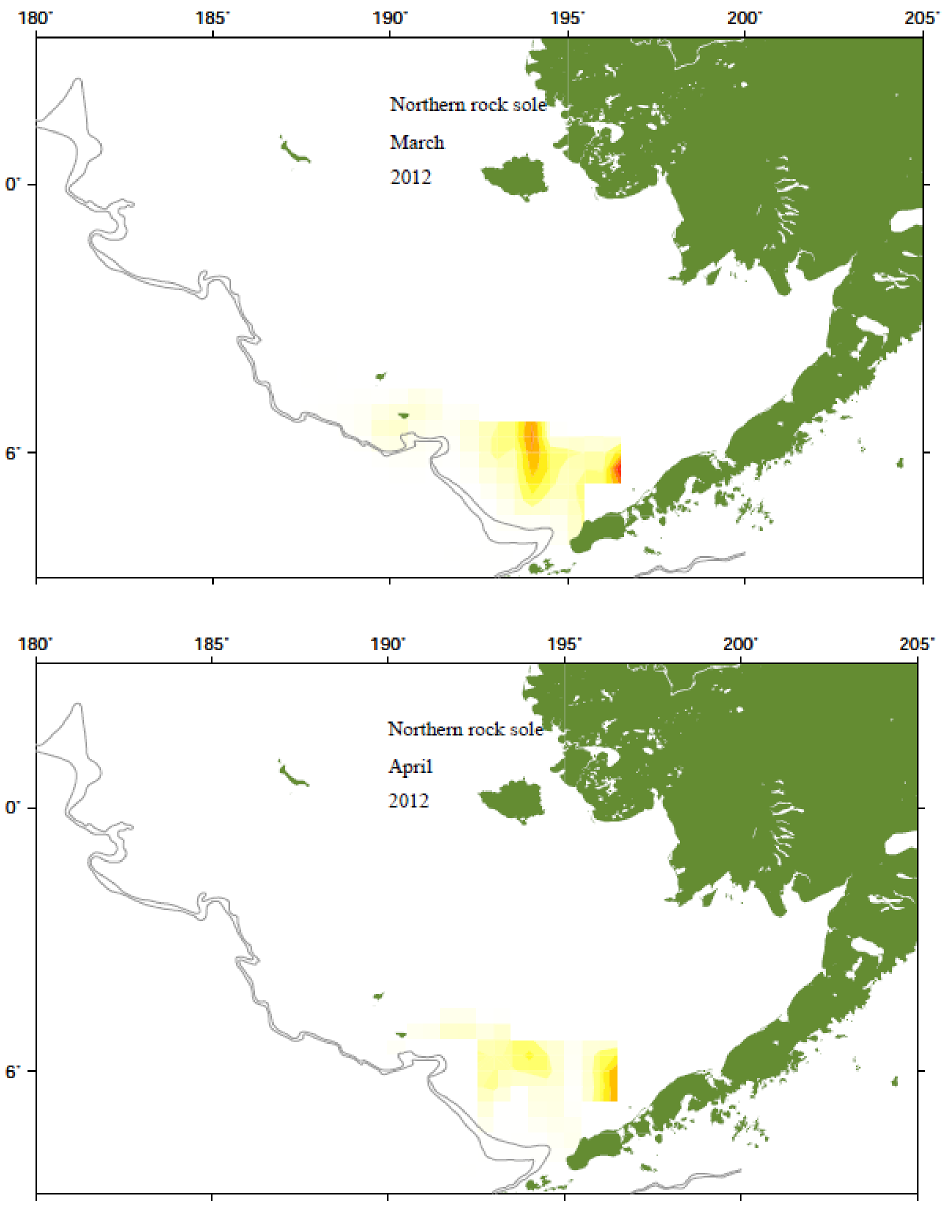


Figure 8.3—Continued.

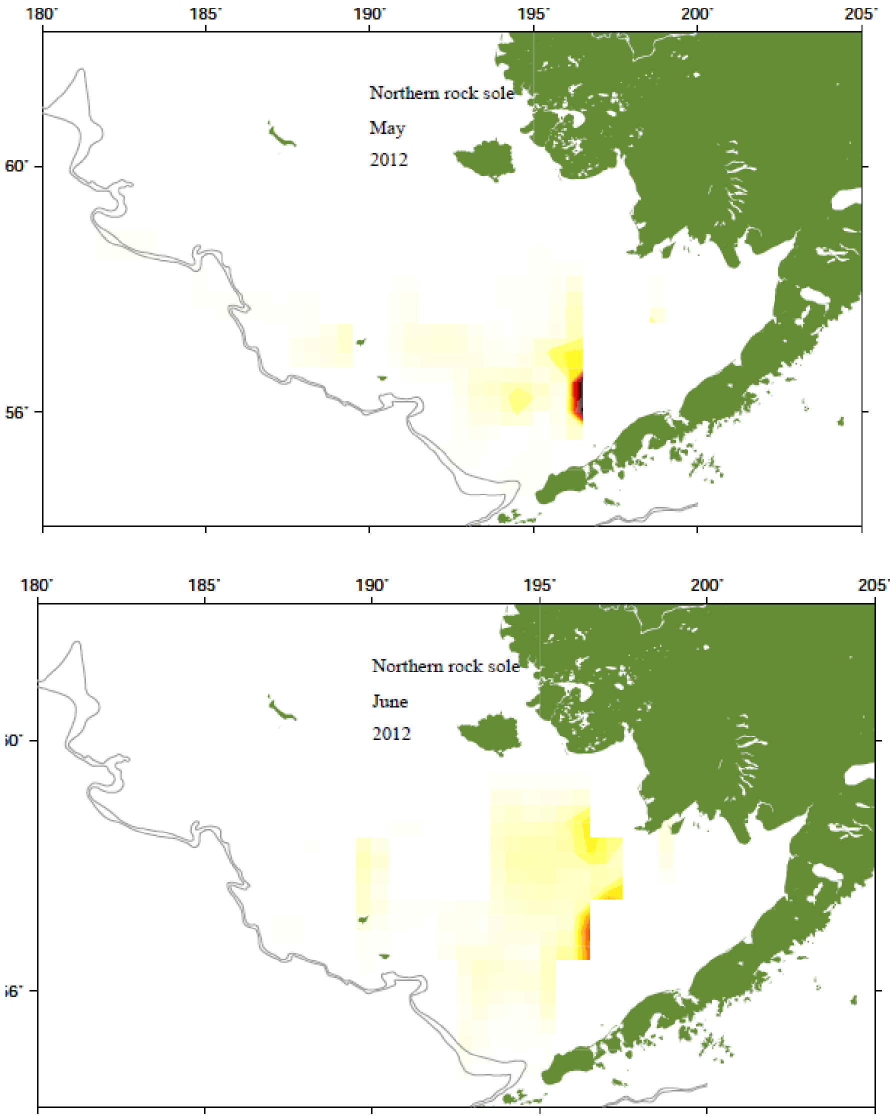


Figure 8.3—Continued.

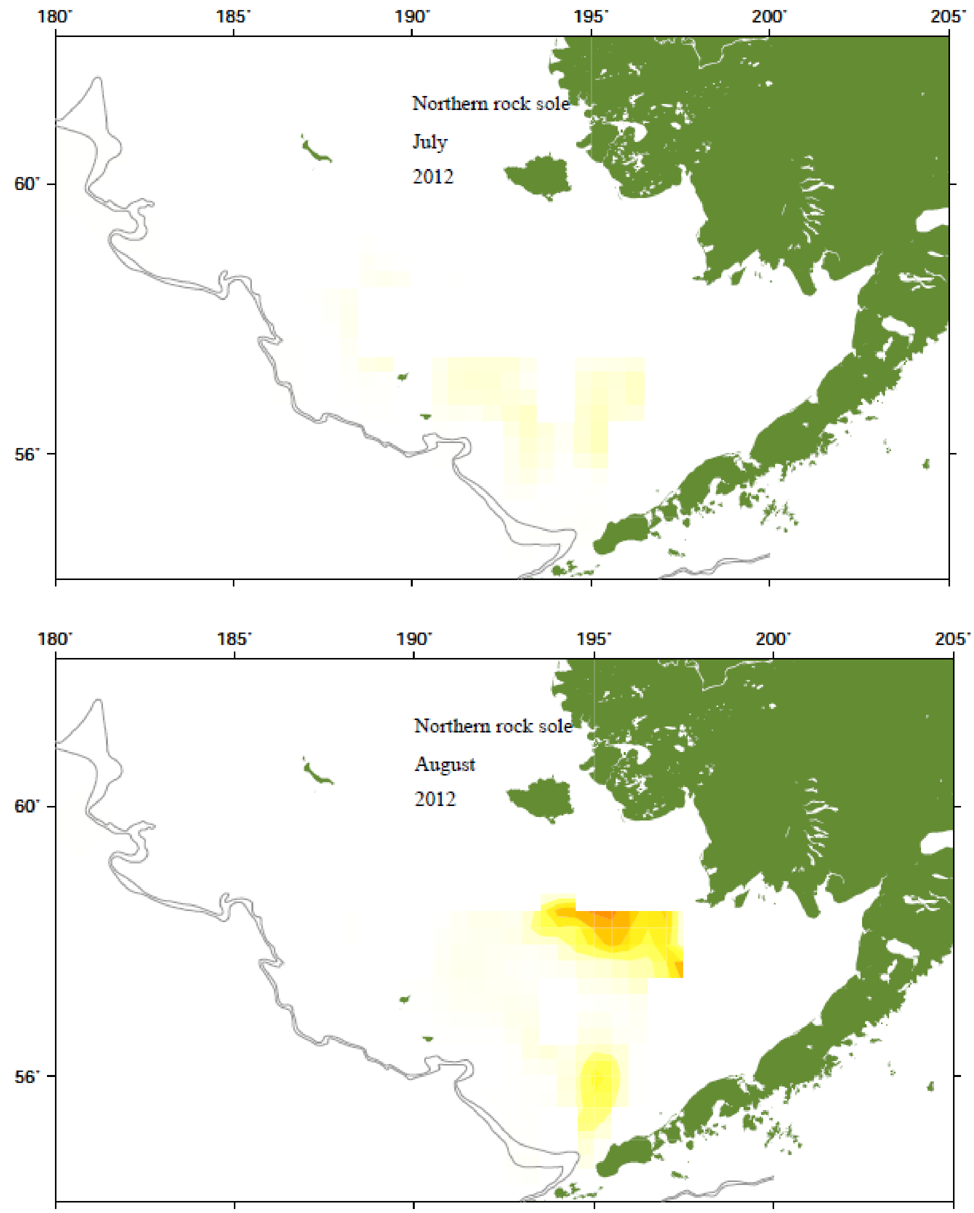


Figure 8.3—Continued.

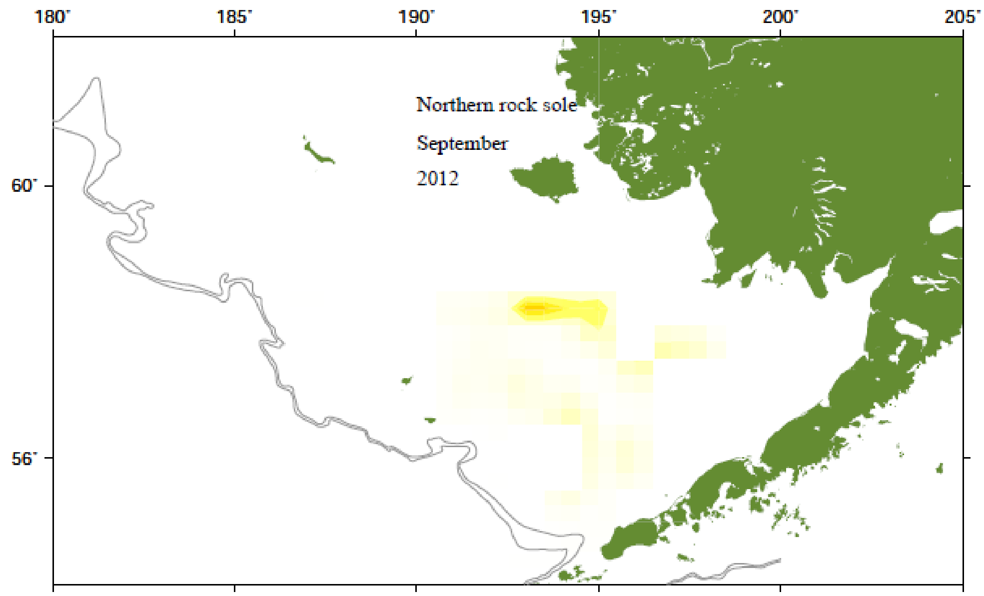


Figure 8.3—Continued.

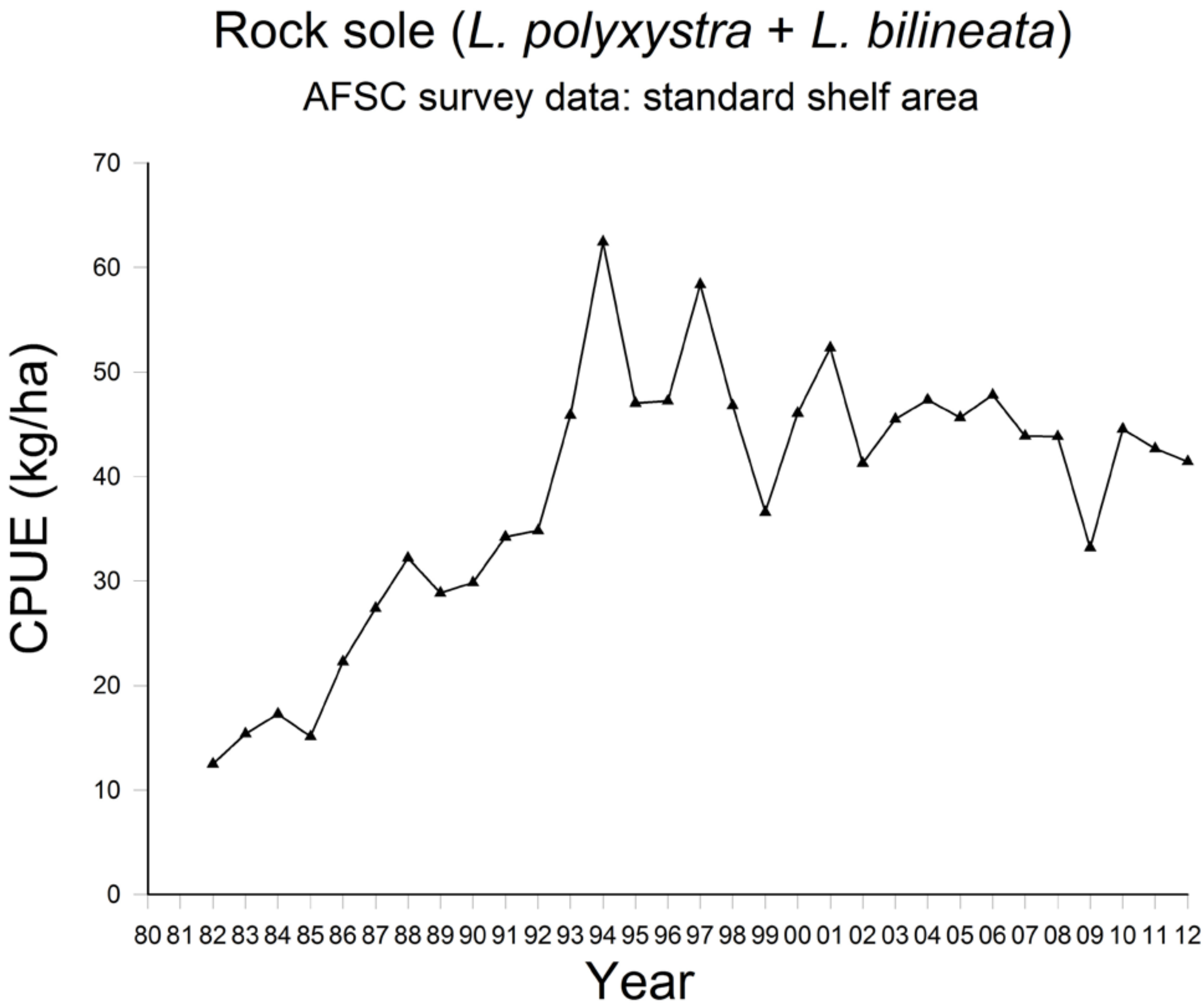


Figure 8.4—Catch per unit effort of *Lepidopsetta polyxystra* and *Lepidopsetta bilineata* (kg/ha) from Bering Sea shelf trawl surveys, 1982-2012.

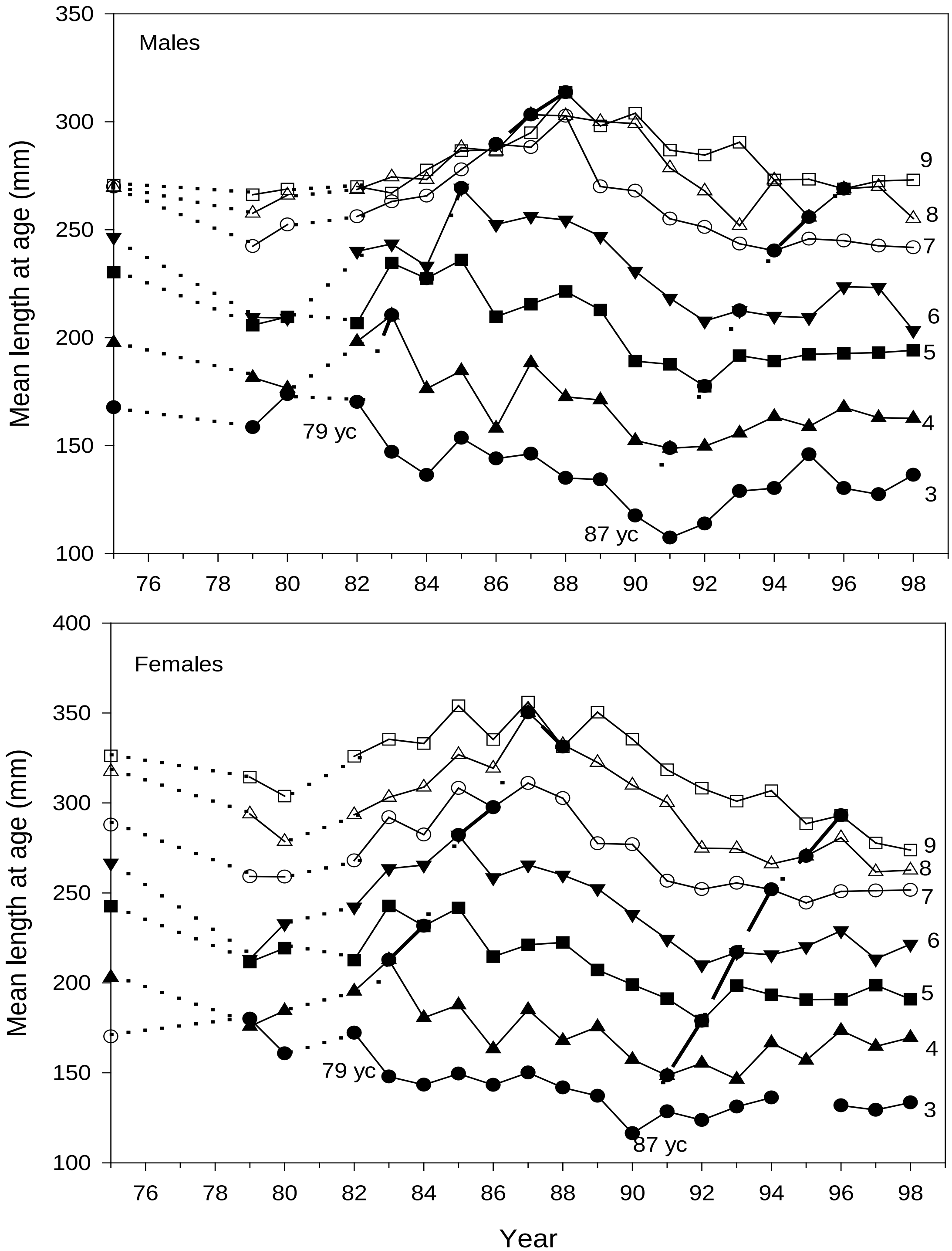


Fig. 8.5. Mean lengths at age (mm) by year of survey for eastern Bering Sea northern rocksole ages 3-9 for each sex during 1975-1998. Growth curves are shown for the 1979 (79yc) and 1987 (87yc) year classes. Dotted lines indicate no data during the period.
(From Walters and Wilderbuer, 2000, p.20)

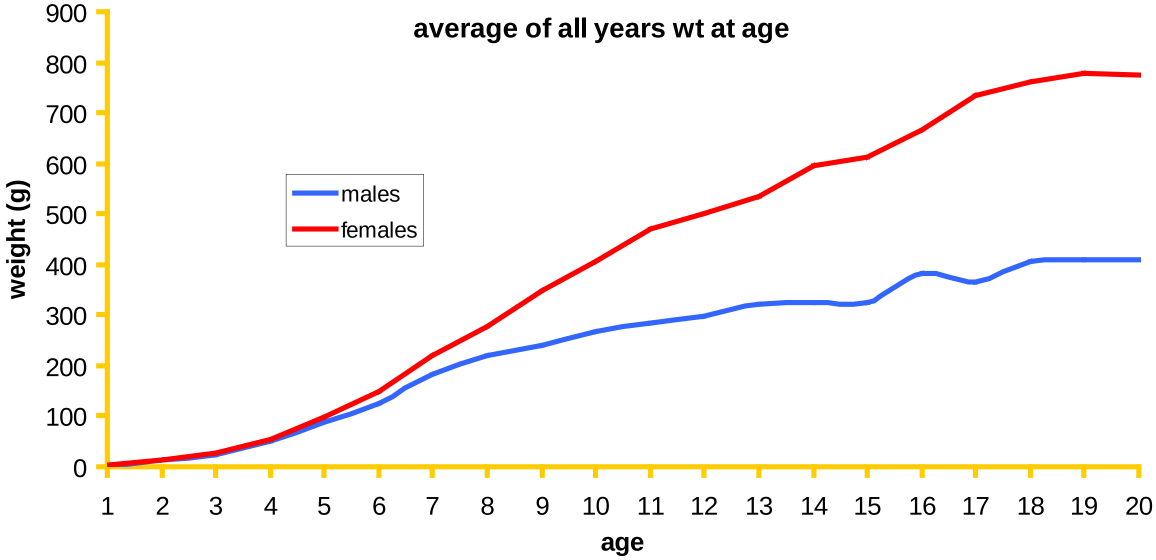
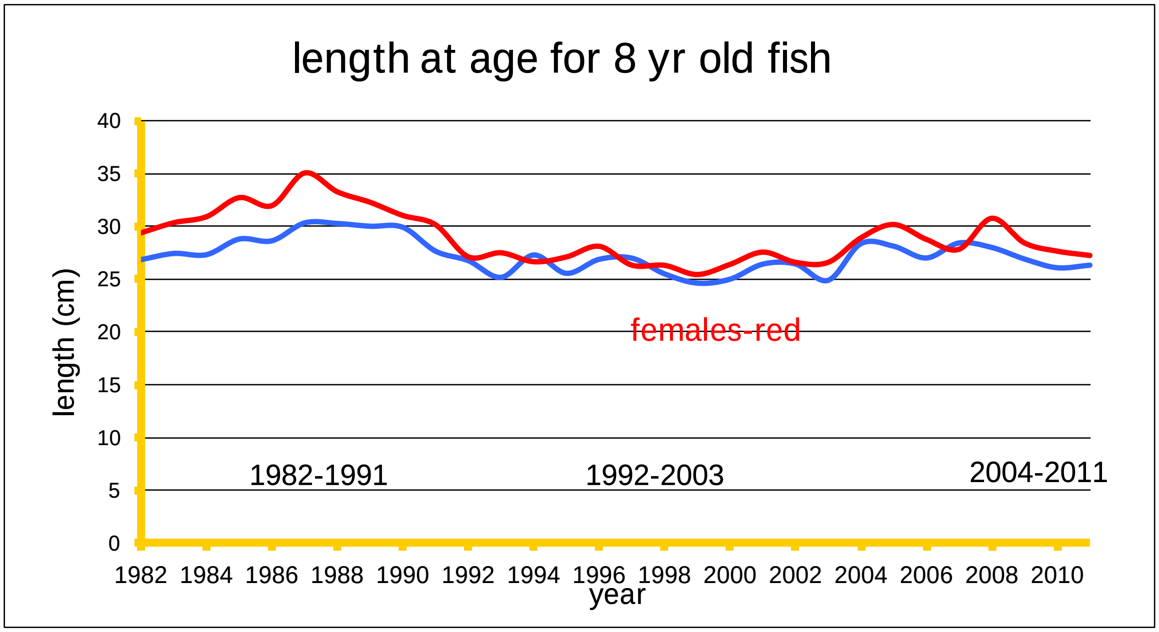


Figure 8.6-Mean weight-at-age for northern rock sole averaged over all years of survey age data.



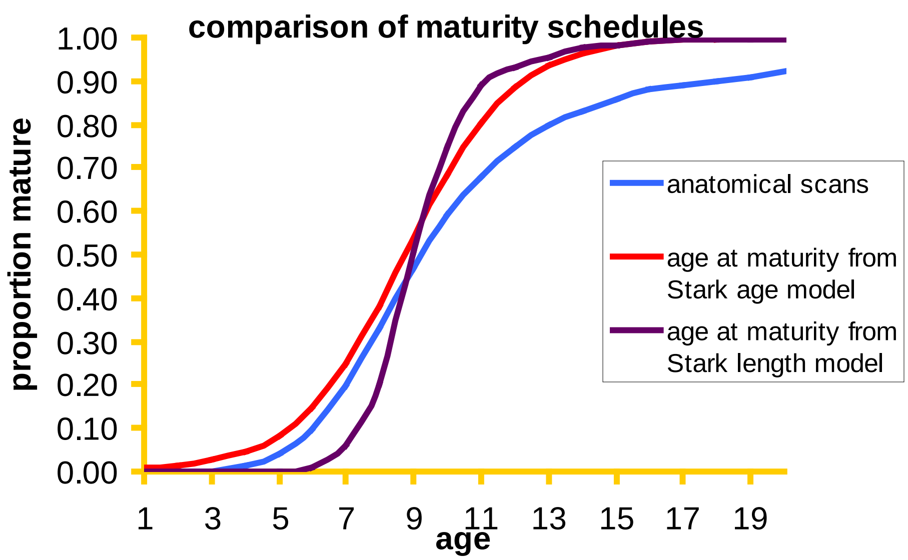


Fig. 8.7-Time-varying length-at-age for 8 year old northern rock sole with 3 time periods identified for modeling growth differently (top panel). Maturity schedule for northern rock sole from three methods (bottom panel). Stark (2012) length model, based on histology, is used in the stock assessment replacing the curve from anatomical scanning of fish used in past assessments.

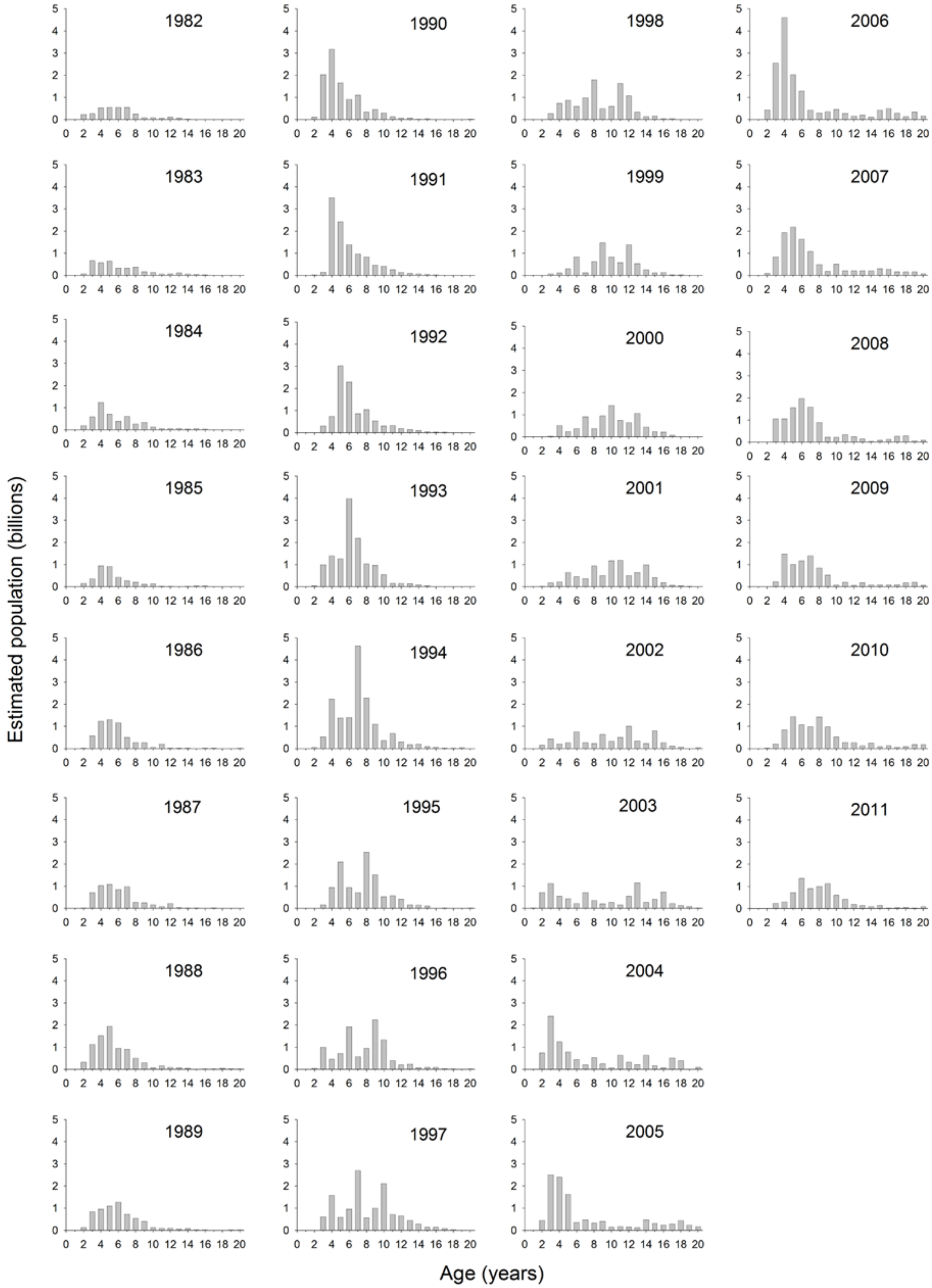


Figure 8.8—Age composition of northern rock sole from the AFSC annual trawl survey.

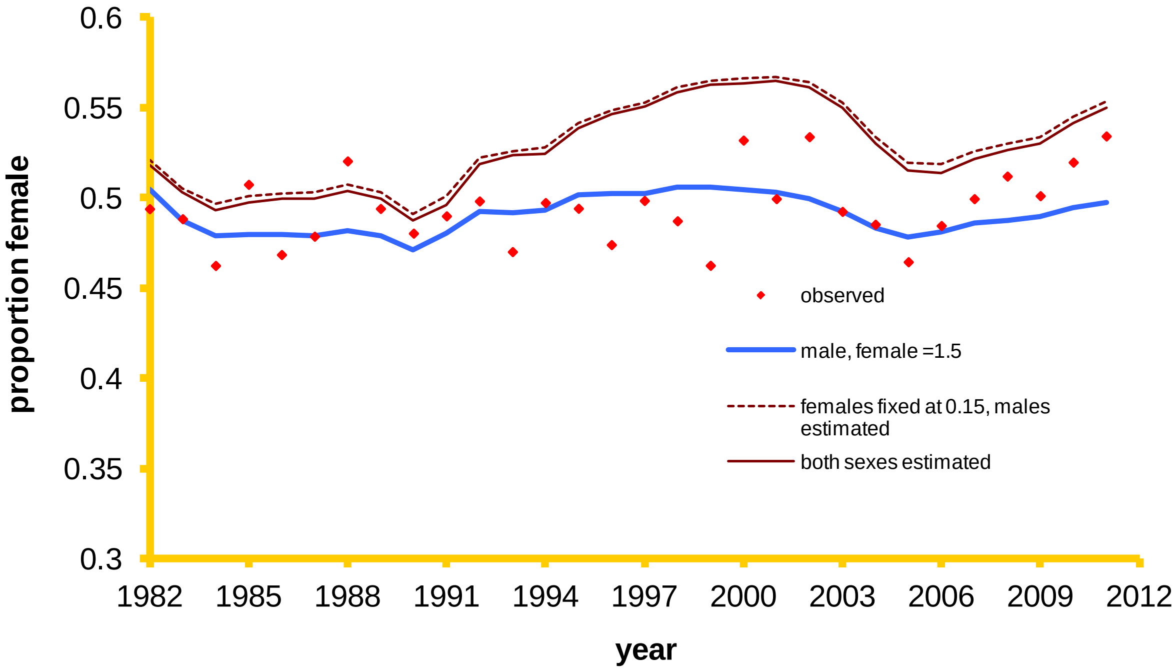


Figure 8.9—Fits to the population sex ratio from the results of Models 1, 2 and 3.

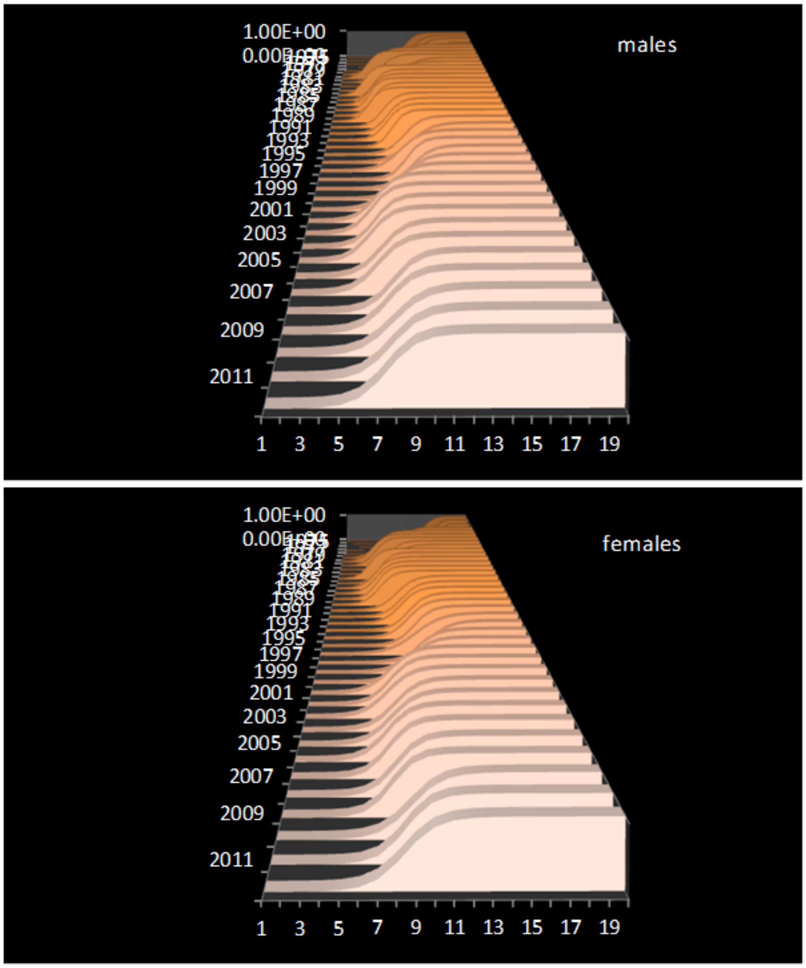


Figure 8.10—Stock assessment model estimates of fishery selectivity at age, by year and gender.

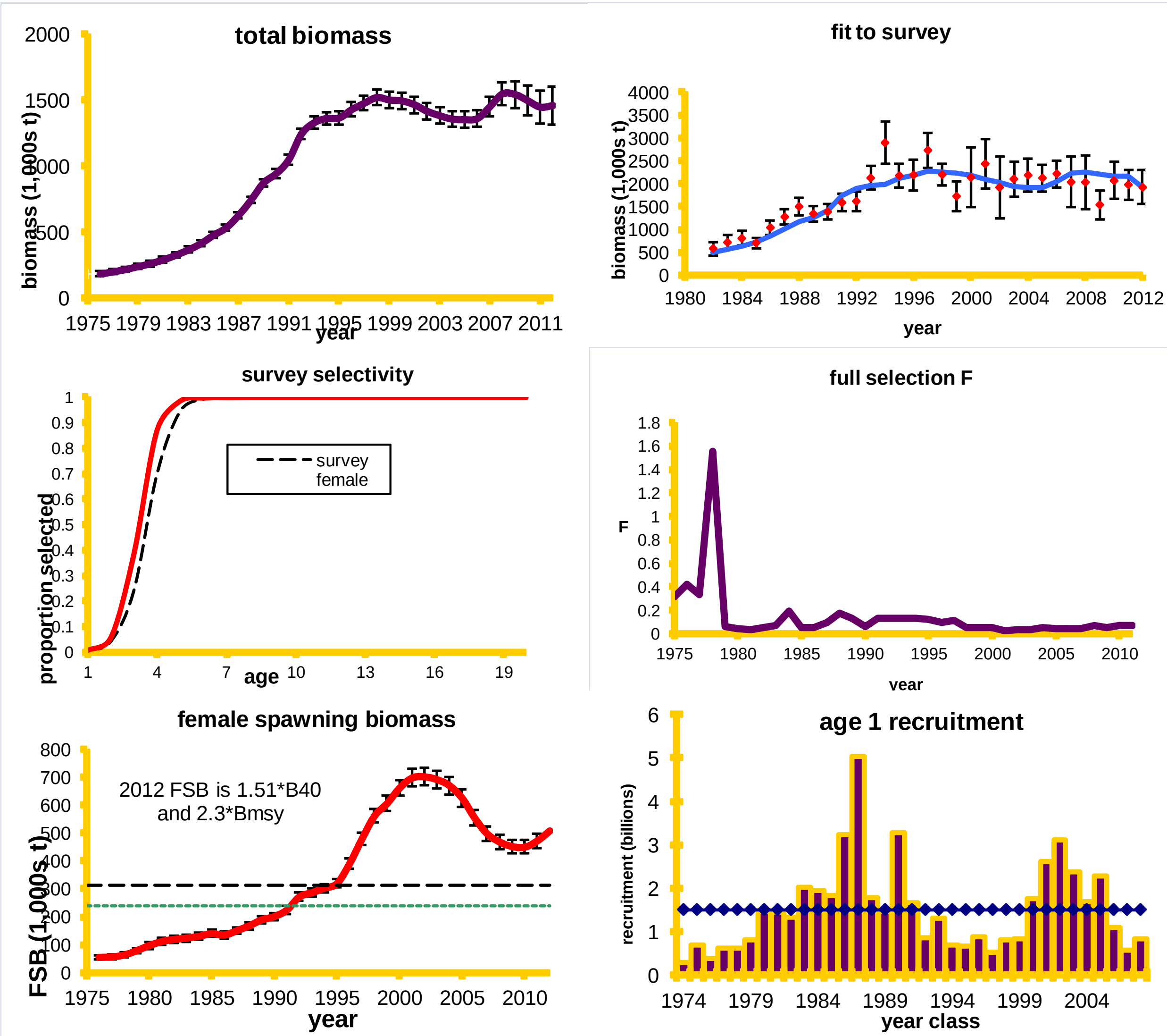


Figure 8.11--Stock assessment model estimates of total 2+ biomass (top left panel), fit to trawl survey biomass (top right panel), age-specific fishery and survey selectivity (middle left panel) and average annual fishing mortality rate (middle right panel), female spawning biomass (bottom left panel) and estimated age 1 recruitment (bottom right panel).

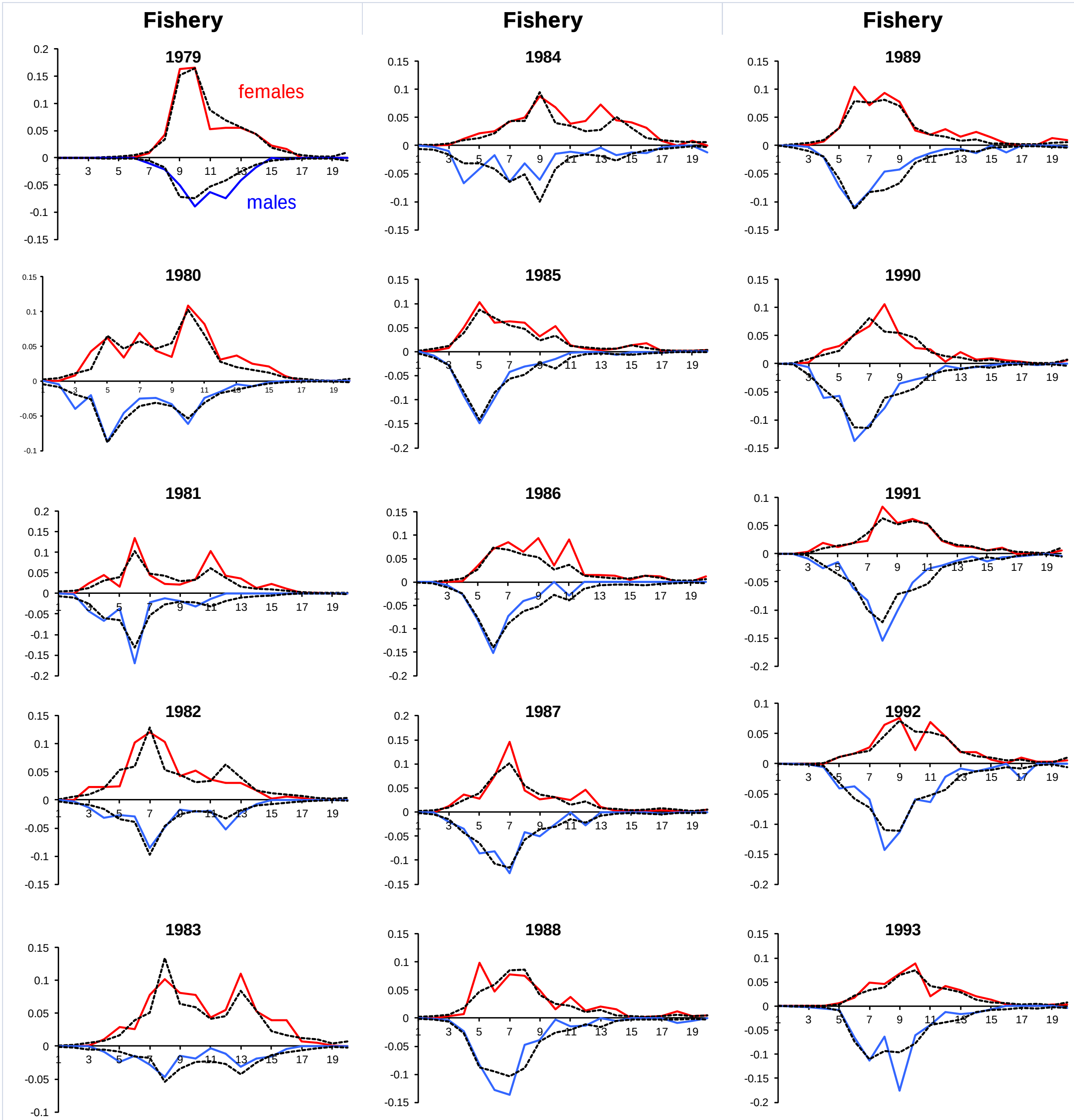


Figure 8.12—Stock assessment model fit to the fishery and survey age compositions, by sex.

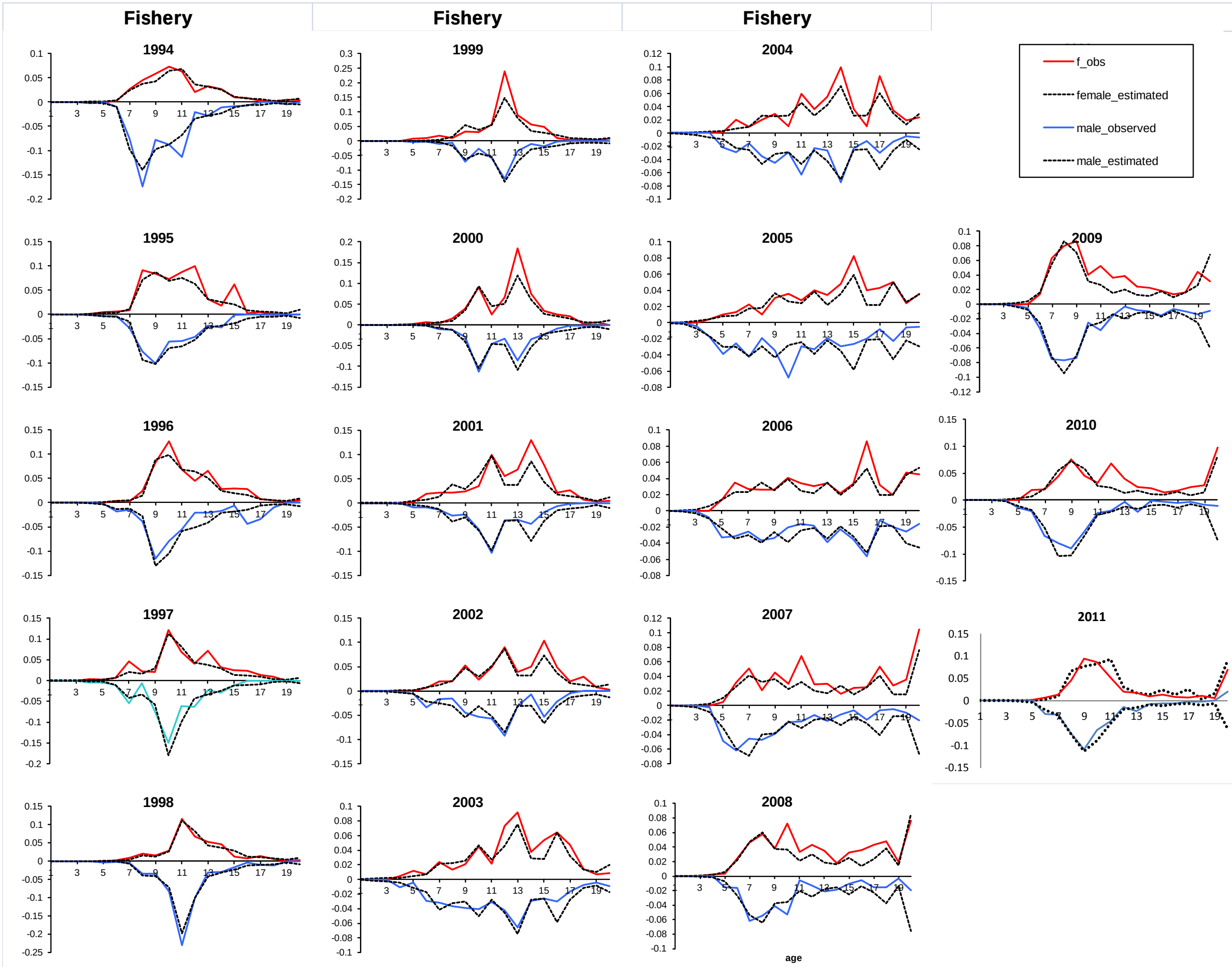
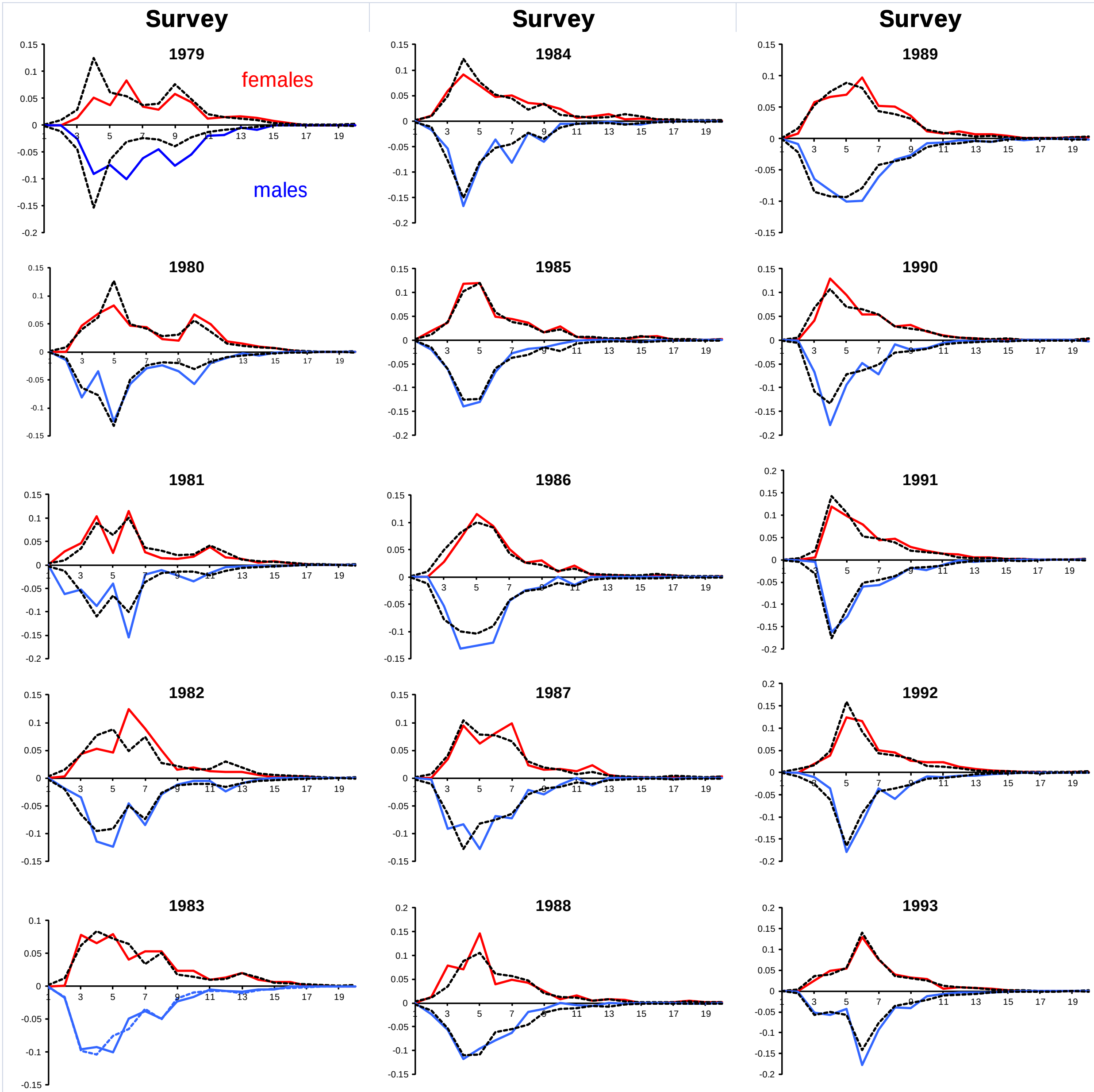


Figure 8.12—continued.



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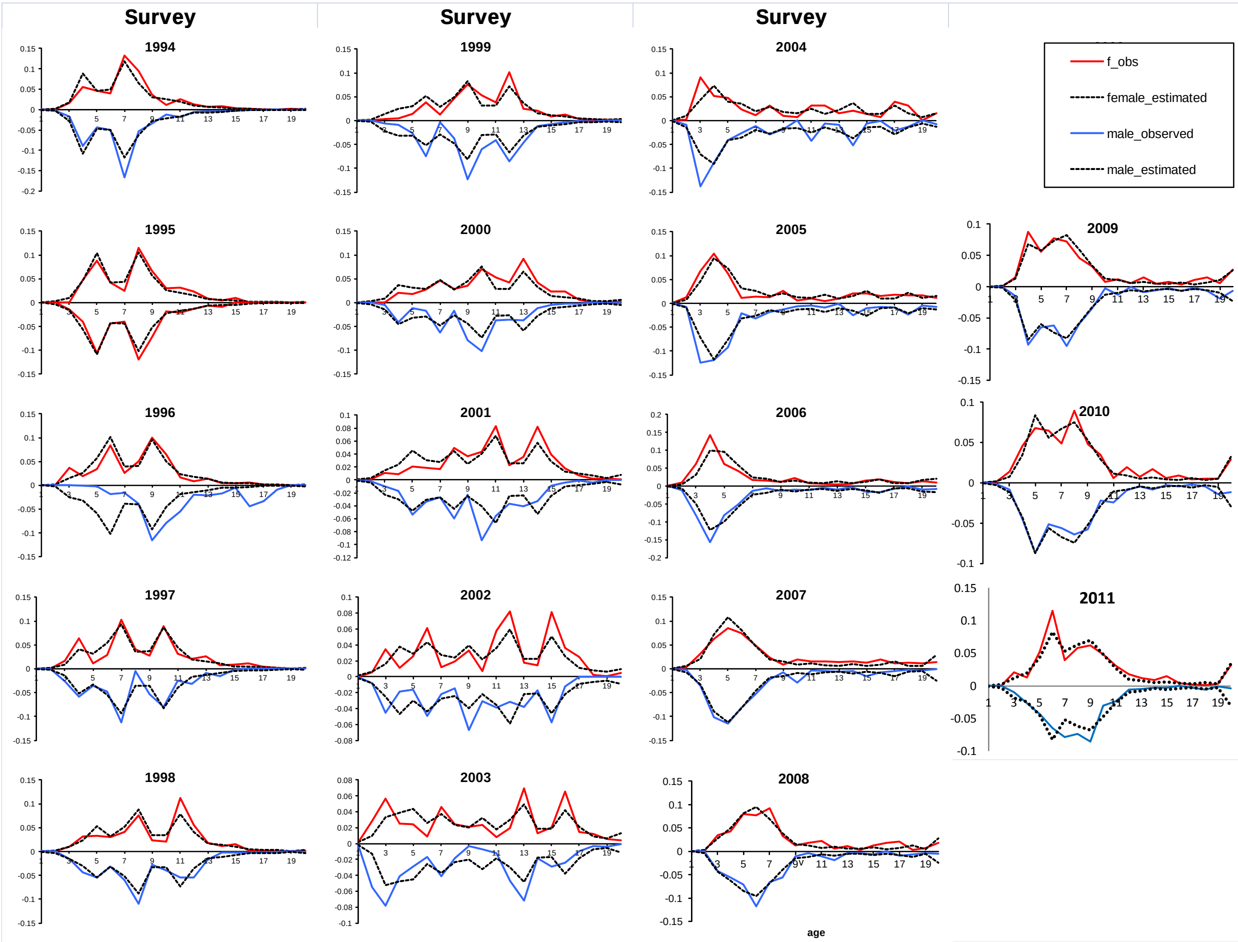

Figure 8.12—continued.

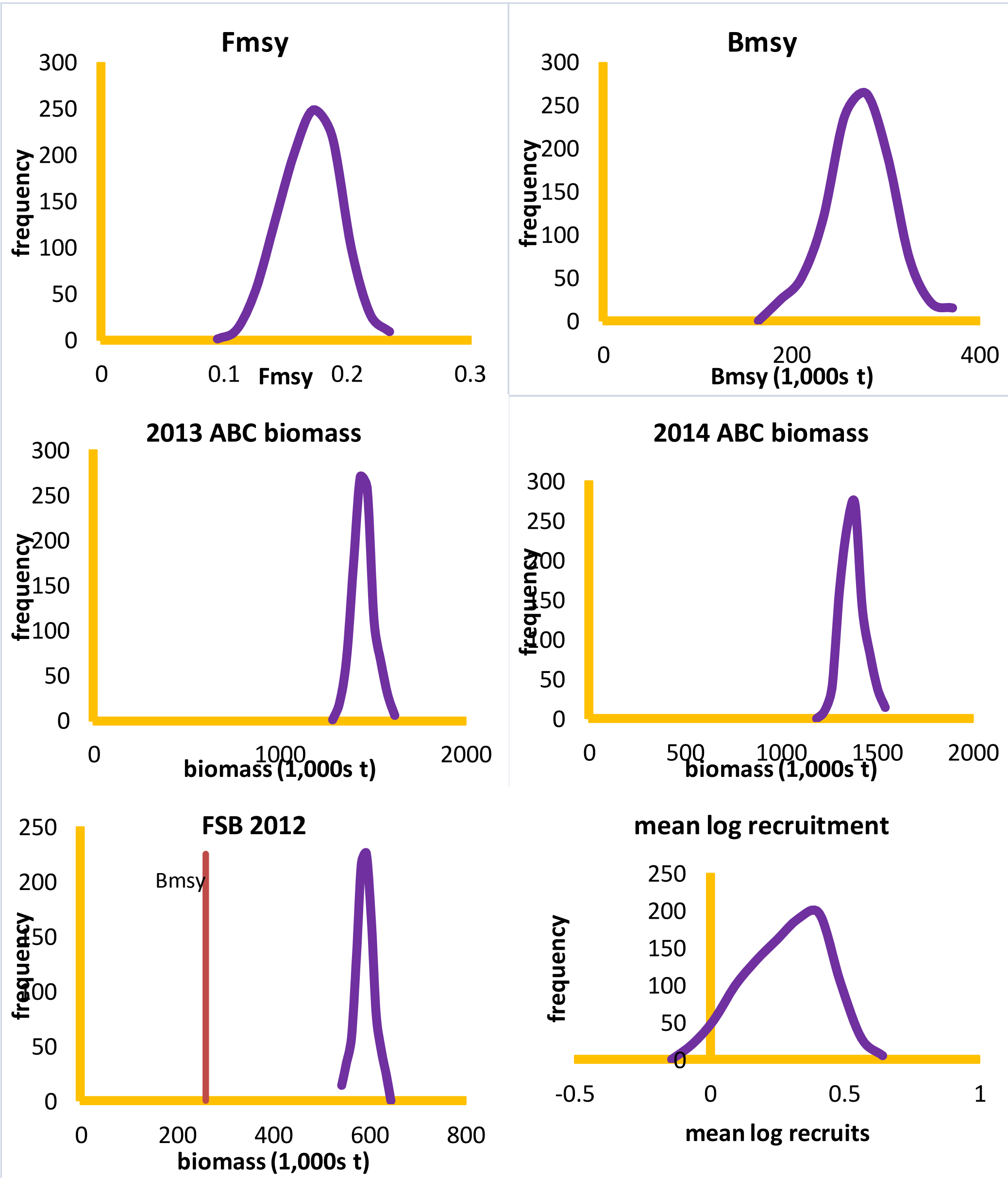

Figure 8.13—Posterior distributions of some selected model estimates from the preferred stock assessment model.

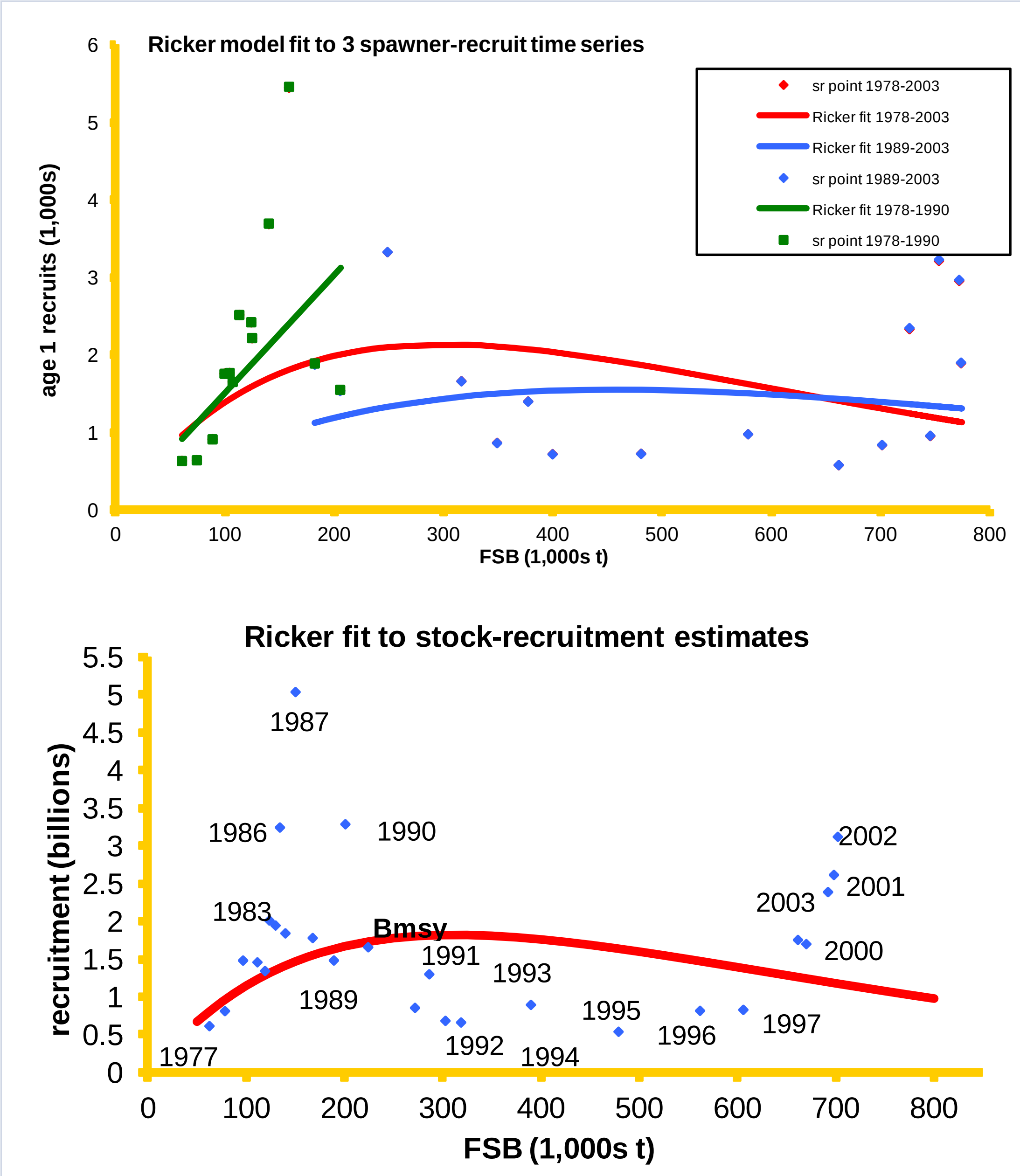

Figure 8.14—Ricker (1958) model fit to spawner-reruit estimates from three time periods; 1978-2003, 1989-2003 and 1978-90 (top panel), and the fit to the spawner-recruit estimates from Model 1 (bottom panel).

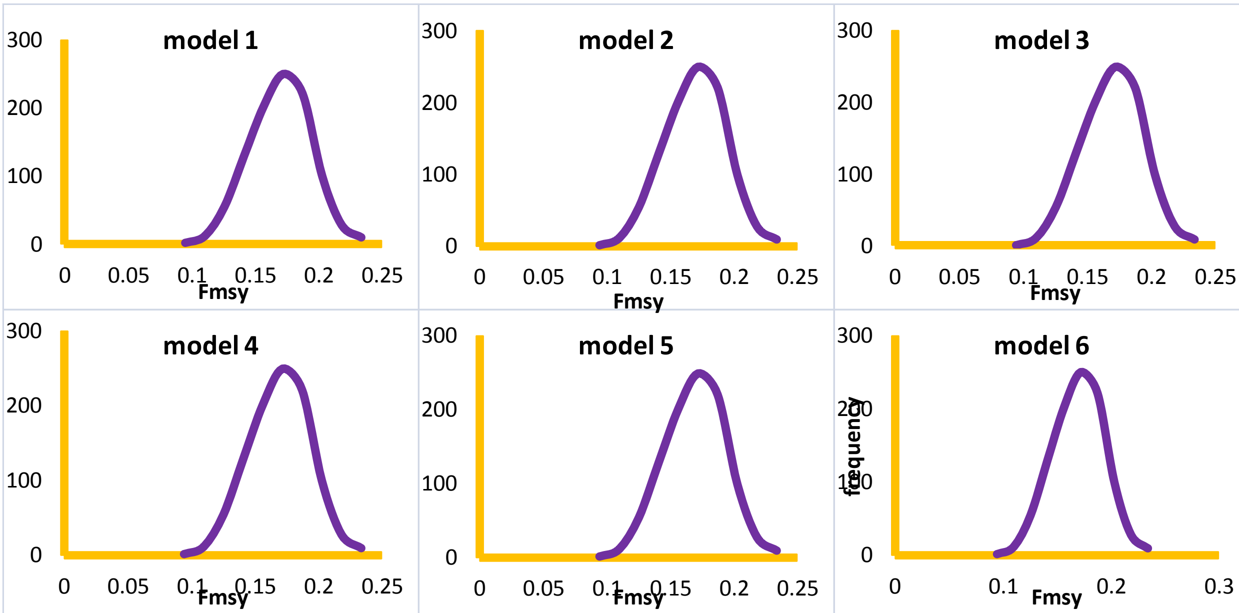

Figure 8.15—Posterior distributions of F_{msy} from 7 of the models considered in the analysis.

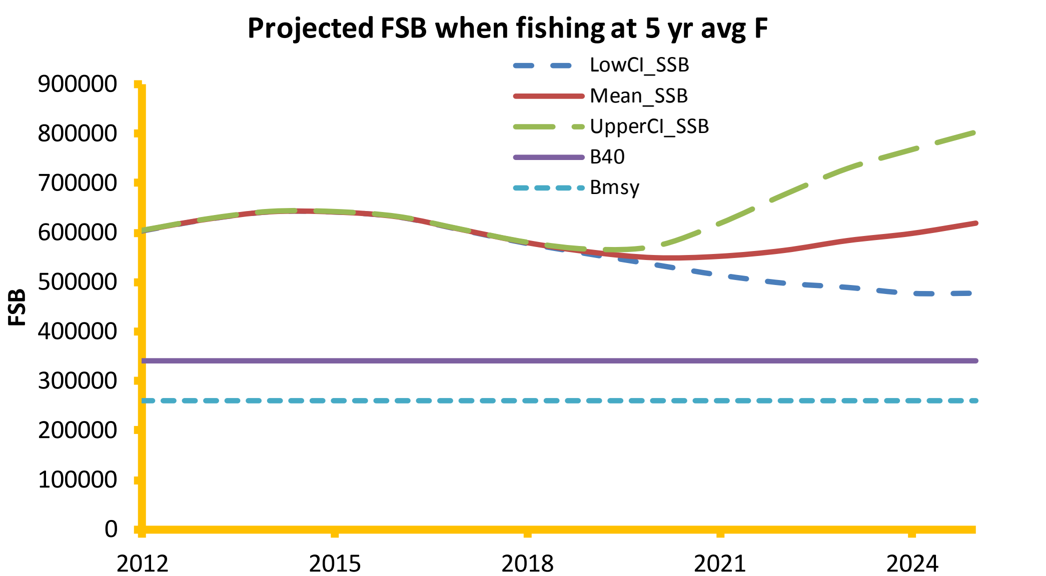

Figure 8.16—Projection of rock sole female spawning biomass when fishing each future year at the average F of the past five years.

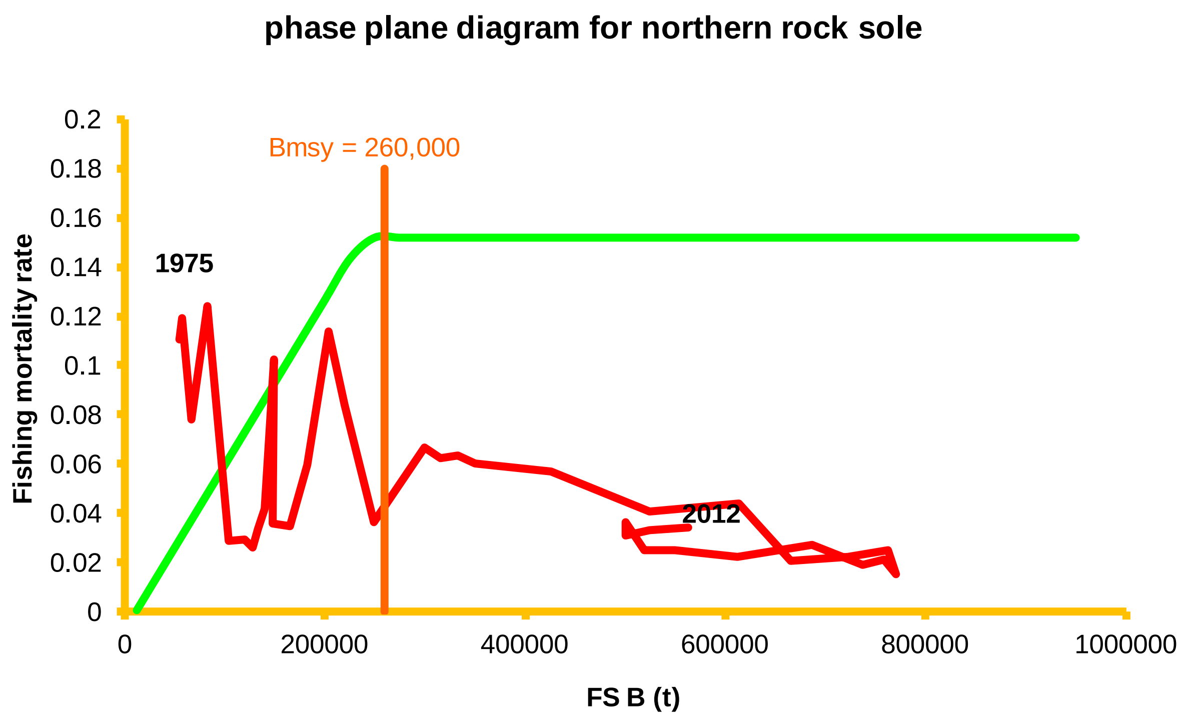

Figure 8.17—Phase-plane diagram of female spawning biomass relative to the harvest control rule.

Appendix

International Pacific halibut Commission survey catch (kg)

2001	0	0	0	0
2002	0	0	0	0
2003	0	0	0	0
2004	0	0	0	0
2005	0	0	0	0
2006	0	0	0	0
2007	0.707	0.502	0.707	0.502
2008	0	0	0	0
2009	0	0	0	0
2010	0.898	0.741	0.898	0.741

National Marine Fisheries Service catch (tons)

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
2011	67
2012	70

Southern rock sole biomass (t)

	biomass (t)
1997	65
1998	701
1999	126
2000	3
2001	86
2002	23
2003	166
2004	152
2005	428
2006	942
2007	3401
2008	1322
2009	5156
2010	209
2011	800
2012	746