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 last full assessment in November 2015:

Summary of changes to the assessment input

1) 2015 fishery age composition.
2) 2015 survey age composition.
3) 2016 trawl survey biomass point estimates and standard errors.
4) Estimate of catch (t) for 2016.
5) Estimate of retained and discarded portions of the 2016 catch.

Summary of Results

Models 1 is the preferred model evaluated in this assessment. Models 2-7 represent Model runs made to examine alternate states of nature for contrast to the primary models results. Northern rock sole continue to be moderately exploited and the female spawning biomass is in a slow decline but well-above B_{MSY}.

Model 1

Quantity	As estimated or *specified last* year for: 2016	2017	As estimated or *recommended this* year for: 2017	2018
M (natural mortality rate)	0.15	0.15	0.15	0.15
Tier	1a	1a	1a	1a
Projected total (age 6+)	1,085,200	977,200	1,000,600	923,200
Female spawning biomass (t)	584,400	522,600	539,500	472,200
Projected				
B_0	682,800		918,500	
B_{MSY}	257,000	257,000	257,000	257,000
F_{OFL}	0.152	0.152	0.160	0.160
$maxF_{ABC}$	0.148	0.148	0.155	0.155
F_{ABC}	0.148	0.148	0.155	0.155
OFL (t)	165,900	149,400	159,700	147,300
maxABC (t)	161,000	145,000	155,100	143,100
ABC (t)	161,000	145,000	155,100	143,100
Status	As determined *last* year for:		As determined *this* year	

	2014	2015	2015	2016
Overfishing	No	No	No	No
Overfished	No	No	No	No
Approaching overfished	No	No	No	No

Model 1

Responses to SSC and Plan Team Comments to Assessments in General

The Plan Team discussion relative to its choice of a preferred model for the BSAI northern rock sole assessment raised an important issue about using localized gear performance studies (e.g. Somerton and Munro 2001) to inform or fix estimates of catchability (*Q*). The PT pointed out that gear herding experiments can inform the estimation of *Q*, but support a very limited scope of inference given the broad spatial and temporal distributions of the factors influencing *Q*. Currently assessment authors are applying a variety of approaches to calculating Q including fixing the value, fitting it in the assessment model, fitting it with priors based on field studies, and estimating it as a temperature-dependent parameter. The SSC notes that *Q* relates survey abundance to stock size and fishing mortality to fishing effort for the stock area and survey or fishery time series, and as such is a direct scalar on the survey abundance estimates. Both the fish herding characteristics of the survey trawl and the timing of fish migrations (especially flatfish) impact *Q*, and these factors are known to be influenced by water temperature. The SSC recommends that assessment authors work with AFSC's survey program scientist to develop some objective criteria to inform the best approaches for calculating *Q* with respect to information provided by previous survey trawl performance studies (e.g. Somerton and Munro 2001), and fish-temperature relationships which may impact *Q*.

Please see the SSC comments section of the yellowfin sole assessment.

Responses to the SSC and Plan Team Comments specific to this assessment

Due to a recent period of low recruitment and the corresponding offshore advection shown in the OSCURS model, the assessment authors are collaborating with Dan Cooper to combine the OSCURS springtime wind patterns and temperature data as environmental covariates in a Ricker spawner-recruit model. These estimates of recruitment could then be used as estimates of the unobserved recruitment for age 1 in the stock assessment model for the first 4 years of their life. The SSC supports the author's efforts to develop a model that estimates an environmental effect on recruitment and looks forward to seeing the results of this work in the next assessment.

Due to maternity leave by one of the Appendix co-authors, the promised predictions of ages 1-4 northern rock sole is not included in our Appendix this time.

The authors plotted retrospective patterns in female spawning biomass and reported Mohn's rho (-0.04654) but did not discuss the pattern. While the low value of Mohn's rho suggests that retrospective bias is not a substantial issue, the SSC recommends including a complete retrospective analysis, including a description of the results and Mohn's rho, in the next full assessment for this stock.

Hopefully we made some progress in this assessment toward describing the retrospective results in a more pleasing way to the SSC. We will keep working on it.

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 1989-2016 (domestic only) have averaged 49,900 t annually, well below ABC values. The size composition of the 2016 catch from observer sampling, by sex and management area, are shown in Figure 8.1 and the locations of the 2016 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 46% of the annual catch in 2016 (Fig 8.2). About 66% of the 2016 catch came from management areas 514 and 516 with the rest from areas 509, 513, 517 and 521 (Fig 8.2). The 2016 catch is estimated at 45,800 t based on the Alaska regional office estimate through mid-September projected forward to the end of the year by applying the catch rates from the previous 5 weeks for September through December. The projected catch is 28% of the 2016 ABC of 161,000 t and 80% of the 57,100 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 2016.

Northern rock sole are usually headed and gutted, frozen at sea, and then shipped to Asian countries for further processing (AFSC 2016). Unique to northern rock sole relative to other BSAI flatfish is a high value roe-in market that accounts for 1/3 of the wholesale value and is worth about twice as much as the standard H&G product on a per pound basis. The wholesale market value of all northern rock sole products is estimated at $40 million in 2014. 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 discarded overboard in the various Bering Sea trawl target fisheries in the past. Estimates of retained and discarded catch from at-sea sampling for 1987-2014 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 2014 northern rock sole catch by fishery designation are shown in Table 8.3. In 2016 the Pacific halibut PSC was reduced by a new regulatory decree. Amendment 111 to the FMP reduced the halibut PSC limits for the Amendment 80 sector by 25% (from 2,325 to 1,745 t); for the BSAI trawl limited access fishery by 15% (875 to 745 t); for the BSAI non-trawl sector by 15% (833 to 710 t) and the CDQ sector by 20% (392 to 315).

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 2016 (Table 8.1) and fishery catch-at-age numbers from 1980-2015 (Table 8.4). The 2016 catch total used in the model is based on the 2016 catch rates from August through mid-September applied to fishing through the end of the year to provide an estimate of 2016 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 survey 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 2016 estimate is a 3% increase relative to 2015.

Absolute Abundance

Rock sole biomass is 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. Survey estimates assume 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 2016 point estimate (1,461,300 t) of the Bering Sea surveyed area is 1,201,960 – 1,720,583 t.

Survey sampling indicates that northern rock sole biomass was at low levels through 1985, but then increased substantially in the following years to 2.7 million t in 1994. In the 22 years since the peak estimate of 1994, the survey estimates have averaged 2.0 million t with a peak value of 2.34 million t in 2001 and a low of 1.411 million t in 2015. The 2016 estimate is a 3% increase from 2015 but still indicates that the stock is in a slow decline. Overall, the survey indicates that the northern rock sole stock has been at a high and stable level since the mid-1990s.

The 2014 Aleutian Islands biomass estimate of 43,259 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 1977-2014 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 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).

Survey and Fishery Age composition

Northern 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). This assessment used sex-specific fishery and survey age compositions for the period 1979-2015. 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 the same-year 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 northern 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 Outside the Assessment Model

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 Inside the Assessment Model

The parameters estimated by the model are presented below:

Fishing mortality	Selectivity	Year class strength	Spawner-recruit	Catchability	M	Total
43	176	82	2	0, 1 or 2 (optional)	0, 1 or 2 (optional)	303-307 depending on model run

The increase in the number of parameters estimated in this assessment compared to last year (6) can be accounted for by the input of another year of fishery data (annual fishing mortality), sex-specific estimates of fishery selectivity (4) 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. The base assessment model (Model 1) fixes M at 0.15 for both sexes and catchability at 1.5.

Survey Catchability

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.

In addition, 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 that a relationship also exists between bottom water temperature and trawl survey catchability, which are documented for yellowfin sole in Chapter 4 of the BSAI SAFE document.

In this assessment, catchability (q) was formulated in two ways. 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. In this temperature/q model, α was fixed at -0.336 to constrain q to the experimental value of 1.4 while allowing β to be estimated to calculate an annual q as a function of bottom water temperature. In this formulation q estimation is not part of the likelihood function.

In the 2nd method q is estimated as a free parameter, and 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. In this formulation the estimation is part of the penalized likelihood.

<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.

An analysis of the effect that various data sets had on the estimates of the productivity of the stock from the spawner-recruit model was performed in a past assessment and is not repeated for this assessment, but is summarized as follows: Three different stock-recruitment time-series were investigated including the full time-series 1978-2006 (Model A, preferred method based on guidance from a 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). 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 was 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 did not have enough contrast in spawning stock size to fit the spawner-recruit data, does not converge properly, and gave 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} = 257,000 t) with the result that F_{MSY} is highest when fitting the full data set. The full time-series (Model A) is the preferred model and now includes 31 years of spawner-recruit data to estimate of the productivity of the stock (MSY, B_{MSY}, F_{MSY}, Fig. 8.14).

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 2016 female spawning biomass, ABC and SPR rates ($F_{40\%}$). The model runs are essentially the same as last year (2015) updated with new information.

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 15.1, 16.2 and 16.3). 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	2017 FSB	2017 ABC	F_{ABC}
Model 15.1	1.5	0.15	0.15	539,500	155,100	0.155
q fixed at 1.5, male and female M fixed at 0.15						
Model 16.2	1.5	0.15	0.18	594,500	153,000	0.159
q fixed at 1.5, female M fixed at 0.15 and male M estimated						
Model 16.3	1.5	0.164	0.192	542,900	141,000	0.157
q fixed at 1.5, female M and male M estimated						

Model 16.4 q estimated, Female and male M fixed at 0.15	2.22	0.15	0.15	320,300	101,200	0.168
Model 16.5 q estimated, female M fixed at 0.15 and male M estimated	1.98	0.15	0.177	409,500	112,700	0.166
Model 16.6 q, female M and male M all estimated as free parameters	2.17	0.140	0.17	378,800	106,400	0.17
Model 16.7 q fixed at 1.5 but allowed to vary annually with bottom temperature relationship, male and female M fixed at 0.15	1.5	0.15	0.15	540,000	155,300	0.155

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 16.2 and 16.3). Fixing the female or both the male and female M (Models 16.4 and 16.5) has less of a constraint on q and values are estimated as high as 2.22 (Model 16.4) and 1.98 (Model 16.5). Allowing all three parameters to be freely estimated (Model 16.6) results in estimates of q and female stock size in-between Models 16.4 and 16.5. The model run which estimates q as a function of the annual bottom temperature (Model 16.7) during the surveys (with male and female M fixed at 0.15) sets q at 1.5 by fixing the alpha value in the temperature-q equation and then allows the beta value to co-vary with annual bottom temperature. The result is an improved fit to the survey biomass time-series where the survey residuals are reduced, but only by 3% relative to Model 15.1.

Models 16.4-16.6 provide estimates of survey catchability which range from 1.98 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. Models 16.4 and 16.5 also affect the fit of the spawner-recruit by reducing productivity and result in low F_{ABC} and ABC values.

Regarding fitting M as a free parameter in the model (males only or both sexes), both models 16.2 and 16.3 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 15.1 (Fig. 8.9).

Model 16.7 gives similar results to Model 15.1 and fits the survey biomass better by fixing the alpha value of the temperature_q equation to the Model 15.1 value (0.15) but allowing the beta parameter to be estimated annually with survey bottom temperatures. Model 16.7 is selected as the model of choice from an updated AIC analysis. However, given the concerns regarding temperature-dependent herding that are presently under investigation at the AFSC (see response to SSC comments in the BSAI yellowfin sole assessment), Model 16.7 was not chosen as the model of choice in the present assessment to recommend ABC and OFL for the 2017 fishing season. Therefore, the model of choice for this assessment is Model 15.1 where q is constrained to 1.5, 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 15.1 gives a 4% (5,000 t) decrease in ABC relative to last year's assessment.

MODEL RESULTS

The 2016 bottom trawl survey point estimate is a 3.5% increase from the 2015 estimate. These two estimates are the lowest in the past 25 years and have the effect of lowering the time series abundance estimates relative to the 2014 assessment. The model results indicate that the stock condition has been at a high and stable level but in a slow decline for the past 9 years. The female spawning biomass is now at a peak and is starting to decline as a result of the combination of strong recruitment from the 2001-2003 and 2005 year classes which are presently at 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 3.6% from 1975-2016, indicating a lightly exploited stock. Age and sex-specific annual 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. The selectivity estimates also indicate a change in fishery selectivity during the mid-1990s as the fleet behavior changed due to a large spatial closure (red king crab savings area) imposed on the fleet by the NPFMC (Abbott et al. 2015).

Abundance Trend

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 1.6 million t by 1997. Since then, the model indicates the population biomass declined 11% to 1.4 million t in 2004 before increasing to 1.68 million t in 2007 and then declining to the present level of 1.19 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 from 2006 - 2009 is the result of increased recruitment in 2001-2005. The female spawning biomass is estimated to be at a high level (592,000 in 2016) and has been increasing after a low of 473,000 t in 2008. As the strong year classes spawned in 2001-2004 have now matured the female spawning biomass has peaked and is projected to now be declining (Table 8.15). The model nd 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 15.1 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 2013 have been relatively cold years in the eastern Bering Sea, the northern rock sole survey biomass estimate remained steady, which may indicate a more casual relationship between survey catchability and bottom temperatures, as shown for other flatfish species. Both the trawl survey and model 15.1 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 2015 estimate is the lowest since 1990 and is not fit by the model. The model fit is within the 95% confidence intervals of the survey biomass point estimates for 25 of the 35 annual surveys. Posterior distributions of some selected model parameters from the preferred stock assessment model (Model 15.1) are presented in Figure 8.13.

Total Biomass

The stock assessment model projections estimate the total biomass (mid-year population numbers multiplied by mid-year weight at age) for 2017 at 1,000,600 t (including the 2016 catch estimated at 45,800 t).

Recruitment Trends

Increases in abundance for rock sole during the 1980s can be attributed to the recruitment of a series of strong year classes (Figs. 8.5 and 8.9, Table 8.16). The 8-12 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 7 survey age samples and are now contributing to an increased spawning stock size.

Studies on the influence of environmental variables on BSAI northern rock sole recruitment have shown that both on-shelf springtime winds (Wilderbuer et al. 2002, Wilderbuer et al. 2013) and above average water-temperatures in nursery areas (Cooper et al. 2014, Cooper and Nichol 2016) are positively correlated with northern rock sole recruitment. In the Appendix, the two environmental covariates are used in regression modeling to estimate the unknown recruitment of ages 1-4 that do not show up in survey catches, and then compare those estimates with future estimates derived from fitting full age composition data in the stock assessment model.

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. Posterior distributions of F_{MSY} from Models 1-6 are shown in Figure 8.15. Retrospective plots of the time-series of female spawning biomass from the past 10 stock assessments, when configured similar to the present assessment model, are shown in Figure 8.16. No retrospective pattern of concern that would indicate model mis-specification have emerged for northern rock sole as past year’s terminal estimates of female spawning biomass are close to the present assessment estimates.

ACCEPTABLE BIOLOGICAL CATCH

The SSC has determined that northern rock sole qualify as a Tier 1 stock and therefore the 2017 ABC is calculated using Tier 1 methodology. Using this approach the 2017 fishing mortality recommendation is F_{ABC} = $F_{harmonic\ mean}$ = 0.155. The Tier 1 harvest level is calculated as the product of the harmonic mean of F_{MSY} and the geometric mean of the 2017 6+ biomass estimate, as follows:

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

, where B_{gm} is the geometric mean of the 2017 6+ biomass estimate, $\hat{B}$ is the point estimate of the 2017 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 155,100 t and an OFL of 159,700 t for 2017**. The projection of 2017 ABC from last year's assessment was 161,000 t and the OFL was projected at 165,900 t.

These ABC and OFL values represent a 3% (4,600 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	2017 Yield
Tier 1 F_{OFL} = F_{MSY}	**0.159**	**159,700 t**
Tier 1 F_{ABC} = $F_{harmonic\ mean}$	**0.155**	**155,100 t**

BIOMASS PROJECTIONS

Status Determination

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

For each scenario, the projections begin with the vector of 2016 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2017 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2016. 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 2017, 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 2017 recommended in the assessment to the *max* F_{ABC} for 2017. (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 2012-2016 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 2016 and above its MSY level in 2028 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2017 and 2018, 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 2029 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 8.21 indicate that northern rock sole are currently not overfished and are not approaching an overfished condition. If harvested at the average F from 2012-2016, northern rock sole female spawning biomass is projected to decrease slowly due to the ageing of the strong recruitment from 2002-2006 that has built the FSB to a peak level in recent years (Fig. 8.17). 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 8.18.

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 2016 numbers at age from the stock assessment model are projected to 2017 given the 2016 catch and then a 2017 catch of 65,000 t is applied to the projected 2017 population biomass to obtain the 2018 OFL.

Tier 1 Projection

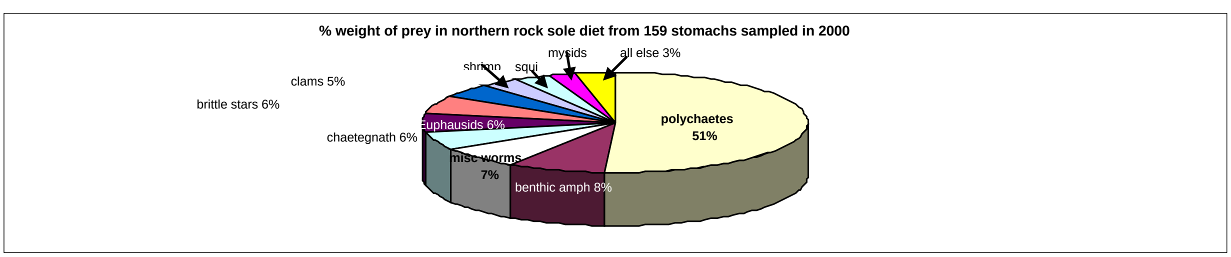
Year	Catch	FSB	Geometric mean 6+ total biomass	ABC	OFL
2017	65,000	539,500	1,000,600	155,100	159,700
2018	65,000	472,200	923,200	143,100	147,300

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the stock

1) Prey availability/abundance trends

Rock sole diet by life stage varies as follows: Larvae consume plankton and algae, early juveniles consume zooplankton, late juvenile stage and adults prey includes bivalves, polychaetes, amphipods, mollusks and miscellaneous crustaceans. Information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not be re-sampled since. The large populations of flatfish which have occupied the middle shelf of the Bering Sea over the past thirty years for summertime feeding do not appear food-limited. These populations have fluctuated due to the variability in recruitment success which suggests that the primary infaunal food source has been at an adequate level to sustain the northern rock sole resource.



2) Predator population trends

As juveniles, it is well-documented from studies in other parts of the world that flatfish are prey for shrimp species in near shore areas. This has not been reported for Bering Sea northern rock sole due to a lack of juvenile sampling and collections in near shore areas, but is thought to occur. As late juveniles they are found in stomachs of pollock, Pacific cod, yellowfin sole, skates and Pacific halibut; mostly on small rock sole ranging from 5 to 15 cm standard length.

Past, present and projected future population trends of these predator species can be found in their respective SAFE chapters in this volume. Encounters between rock sole and their predators may be limited as their distributions do not completely overlap in space and time.

3) Changes in habitat quality

Changes in the physical environment which may affect rock sole distribution patterns, recruitment success, migration timing and patterns are catalogued in the Ecosystem Considerations Appendix of this SAFE report. Habitat quality may be enhanced during years of favorable cross-shelf advection (juvenile survival) and warmer bottom water temperatures with reduced ice cover (higher metabolism with more active feeding).

Fishery Effects on the ecosystem

1) The rock sole target fishery contribution to the total bycatch of other target species is shown for 1991-2015 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 2013 and 2014 in Table 13 of the Economic SAFE (Appendix C) and is summarized for 2014 as follows:

Prohibited species	Rock sole fishery % of total bycatch
Halibut mortality	19.4
Herring	<1
Red King crab	13.4
C. bairdi	9.4
Other Tanner crab	2
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—BSAI Rock sole catch (t) from 1977 - September 17, 2016.

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			76,099	76,099
2013			59,773	59,773
2014			51,946	51,946
2015			45,466	45,466
2016			45,800	45,800

Table 8.2 Retained and discarded catch (t) in Bering Sea fisheries, 1987-2015.

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
2012	70,772	5,327	93
2013	56,784	2,989	95
2014	49,792	1,933	96
2015	44,330	1,136	98

Table 8.3--Discarded and retained rock sole catch (t), by target fishery, in 2015.

	Discarded	Retained
Atka Mackerel	10	43
Pollock - bottom	2	604
Pacific Cod	389	1,350
Alaska Plaice	1	99
Other Flatfish		
Halibut	0	
Rockfish	15	23
Flathead Sole	10	717
Kamchatka flounder		<1
Other Species		
Pollock - midwater	300	803
Rock Sole	274	31,029
Sablefish		
Greenland Turbot		
Arrowtooth Flounder	<1	24
Yellowfin Sole	135	9,638
Total catch		**45,466**

Table 8.4--Estimated catch numbers at age, 1980-2016 (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	0.43	0.59	0.88	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	0.18	0.36	0.48	0.72	0.83	0.84	0.82	0.83	1.69
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.11	0.15	0.28	0.32	0.40	0.42	0.38	0.37	1.13
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	0.08	0.12	0.24	0.34	0.57	0.47	0.42	1.68
1984	0.00	0.00	0.00	0.02	0.02	0.06	0.14	0.45	2.00	2.16	1.16	0.91	0.74	0.57	0.25	0.15	0.06	0.04	0.03	0.13
1985	0.07	0.14	0.35	0.52	1.96	1.42	1.74	1.42	1.64	3.11	1.99	0.84	0.61	0.48	0.37	0.16	0.10	0.04	0.02	0.10
1986	0.15	0.23	0.47	1.16	1.45	3.74	1.75	1.58	1.11	1.22	2.26	1.43	0.61	0.44	0.34	0.26	0.11	0.07	0.03	0.09
1987	0.07	0.22	0.37	0.82	2.06	2.30	4.99	2.06	1.77	1.22	1.33	2.46	1.56	0.66	0.48	0.37	0.29	0.12	0.07	0.13
1988	0.02	0.06	0.18	0.27	0.54	1.33	1.68	4.48	2.14	1.96	1.39	1.52	2.82	1.79	0.76	0.55	0.43	0.33	0.14	0.24
1989	0.10	0.16	0.43	1.08	1.42	2.42	4.86	4.82	10.42	4.46	3.93	2.75	3.01	5.57	3.54	1.50	1.08	0.85	0.65	0.75
1990	0.17	0.56	1.19	3.73	8.34	6.58	5.11	4.50	2.28	3.24	1.13	0.92	0.62	0.67	1.24	0.79	0.33	0.24	0.19	0.31
1991	0.02	0.06	0.23	0.54	1.98	5.45	5.18	4.36	3.92	2.00	2.83	0.99	0.80	0.54	0.59	1.09	0.69	0.29	0.21	0.44
1992	0.33	0.53	1.55	4.30	6.80	13.49	17.65	9.59	6.39	5.38	2.70	3.82	1.33	1.08	0.73	0.79	1.47	0.93	0.39	0.87
1993	0.77	1.44	2.35	6.86	17.41	21.90	31.20	31.49	15.13	9.64	8.00	4.00	5.65	1.97	1.60	1.08	1.17	2.17	1.37	1.87
1994	0.05	0.55	1.28	2.57	8.71	21.53	20.79	22.18	19.20	8.71	5.45	4.49	2.24	3.17	1.10	0.90	0.61	0.66	1.21	1.82
1995	0.05	0.17	1.33	2.36	3.44	7.74	12.03	8.44	8.02	6.77	3.06	1.91	1.58	0.79	1.11	0.39	0.31	0.21	0.23	1.06
1996	0.10	0.11	0.30	1.94	2.85	3.54	7.45	12.62	10.62	11.76	10.77	5.05	3.20	2.66	1.33	1.88	0.66	0.53	0.36	2.19
1997	0.02	0.09	0.10	0.29	2.04	3.18	4.14	8.67	13.56	10.02	9.92	8.54	3.89	2.44	2.01	1.00	1.42	0.50	0.40	1.93
1998	0.01	0.04	0.20	0.24	0.72	5.11	7.78	9.07	14.95	17.02	9.76	8.45	6.87	3.06	1.91	1.57	0.78	1.11	0.39	1.82
1999	0.00	0.01	0.04	0.19	0.23	0.72	5.20	7.94	8.96	13.71	14.45	7.91	6.71	5.42	2.41	1.50	1.23	0.61	0.87	1.73
2000	0.00	0.02	0.03	0.13	0.65	0.73	2.14	13.64	16.62	13.32	14.39	12.15	6.03	4.94	3.94	1.74	1.08	0.89	0.44	1.88
2001	0.00	0.00	0.01	0.02	0.11	0.58	0.68	2.04	12.76	14.11	9.75	9.34	7.42	3.59	2.91	2.32	1.02	0.64	0.52	1.36
2002	0.04	0.05	0.09	0.31	0.38	1.32	4.59	3.46	6.39	24.28	17.60	9.48	8.28	6.45	3.13	2.55	2.04	0.90	0.56	1.66
2003	0.00	0.01	0.01	0.02	0.07	0.09	0.37	1.47	1.26	2.61	10.65	7.89	4.19	3.58	2.74	1.31	1.06	0.84	0.37	0.92
2004	0.00	0.00	0.02	0.03	0.06	0.27	0.40	1.62	6.03	4.14	5.92	16.23	8.83	3.90	3.04	2.23	1.05	0.85	0.67	1.02
2005	0.00	0.01	0.01	0.05	0.09	0.21	0.92	1.29	4.49	12.33	5.99	6.62	15.80	8.08	3.49	2.69	1.97	0.93	0.74	1.49
2006	0.02	0.03	0.07	0.10	0.38	0.58	1.08	3.05	2.35	4.50	7.95	3.05	3.05	7.00	3.53	1.52	1.17	0.85	0.40	0.97
2007	0.02	0.03	0.04	0.11	0.19	0.87	1.39	2.33	5.29	3.37	5.80	9.79	3.68	3.65	8.37	4.22	1.81	1.39	1.02	1.64
2008	0.06	0.11	0.17	0.19	0.46	0.63	2.01	2.12	2.44	4.42	2.59	4.33	7.24	2.72	2.70	6.17	3.11	1.34	1.03	1.96
2009	0.03	0.09	0.18	0.28	0.33	0.81	1.10	3.29	3.11	3.25	5.60	3.20	5.31	8.86	3.32	3.29	7.53	3.80	1.63	3.65
2010	0.02	0.07	0.22	0.46	0.72	0.80	1.71	1.77	3.73	2.64	2.37	3.82	2.13	3.51	5.84	2.19	2.17	4.96	2.50	3.47
2011	0.02	0.05	0.16	0.62	1.40	2.25	2.28	3.67	2.64	4.24	2.63	2.23	3.53	1.96	3.21	5.34	2.00	1.98	4.53	5.45
2012	0.00	0.03	0.07	0.29	1.19	2.81	4.29	3.47	4.17	2.48	3.68	2.22	1.87	2.95	1.63	2.67	4.44	1.66	1.65	8.31
2013	0.00	0.01	0.10	0.22	0.84	3.23	6.75	8.37	5.37	5.60	3.16	4.62	2.77	2.33	3.67	2.03	3.33	5.54	2.08	12.43
2014	0.00	0.00	0.02	0.23	0.55	2.18	7.95	12.71	10.21	4.65	4.14	2.21	3.18	1.90	1.59	2.51	1.39	2.28	3.78	9.90
2015	0.00	0.00	0.02	0.08	0.55	1.00	2.97	8.33	11.30	8.87	4.19	3.84	2.08	3.01	1.80	1.51	2.39	1.32	2.17	13.02
2016	0.00	0.00	0.00	0.02	0.15	1.22	2.50	7.41	16.85	16.00	9.31	3.74	3.21	1.70	2.43	1.45	1.22	1.92	1.06	12.20

Males

Male estimated catch at age in millions

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1980	0.00	0.00	0.00	0.01	0.04	0.08	0.16	0.40	0.82	1.36	1.36	1.62	1.40	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	0.13	0.31	0.65	1.09	1.09	1.31	1.13	1.11	1.12	1.07	1.06	1.09	2.18
1982	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.12	0.29	0.55	0.78	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	0.02	0.03	0.06	0.16	0.36	0.64	0.76	1.07	0.99	0.99	0.99	0.95	3.81
1984	0.00	0.00	0.00	0.01	0.01	0.03	0.07	0.24	0.95	0.99	0.70	0.54	0.34	0.17	0.06	0.03	0.02	0.01	0.01	0.07
1985	0.13	0.24	0.57	0.79	2.66	1.68	1.09	0.94	1.08	1.62	0.93	0.51	0.36	0.22	0.11	0.04	0.02	0.01	0.01	0.05
1986	0.22	0.39	0.89	2.22	2.34	4.77	1.91	0.95	0.73	0.79	1.18	0.67	0.37	0.26	0.16	0.08	0.03	0.02	0.01	0.04
1987	0.10	0.26	0.34	0.60	1.31	1.50	3.78	1.80	0.98	0.77	0.86	1.28	0.72	0.40	0.28	0.17	0.09	0.03	0.02	0.06
1988	0.04	0.08	0.16	0.18	0.27	0.53	0.61	1.81	1.14	0.80	0.75	0.91	1.41	0.82	0.45	0.32	0.20	0.10	0.04	0.08
1989	0.63	0.83	1.76	3.47	3.55	4.63	7.10	5.69	10.98	4.52	2.30	1.78	1.95	2.90	1.65	0.90	0.64	0.39	0.20	0.23
1990	0.28	1.12	2.65	7.92	13.41	7.92	5.35	4.51	2.29	3.31	1.16	0.55	0.41	0.44	0.65	0.37	0.20	0.14	0.09	0.10
1991	0.06	0.22	0.82	1.85	5.62	10.41	6.64	4.62	3.93	2.00	2.89	1.02	0.48	0.36	0.38	0.57	0.32	0.18	0.12	0.16
1992	0.41	0.75	2.49	7.45	11.34	18.62	19.98	9.88	6.38	5.32	2.70	3.90	1.37	0.64	0.48	0.52	0.77	0.43	0.24	0.38
1993	0.30	0.89	2.28	10.07	31.87	34.52	37.42	32.56	15.01	9.50	7.88	3.99	5.76	2.02	0.95	0.71	0.77	1.13	0.64	0.92
1994	0.10	1.12	2.67	5.35	16.43	30.94	22.62	21.59	18.32	8.41	5.32	4.41	2.24	3.23	1.13	0.53	0.40	0.43	0.63	0.87
1995	0.06	0.26	2.88	6.58	10.06	16.61	16.66	8.97	7.80	6.47	2.96	1.87	1.55	0.79	1.13	0.40	0.19	0.14	0.15	0.53
1996	0.09	0.12	0.46	3.95	7.42	10.61	20.26	24.47	14.47	13.02	10.91	5.00	3.16	2.62	1.33	1.92	0.67	0.32	0.24	1.15
1997	0.02	0.13	0.19	0.70	6.06	10.93	13.68	20.82	20.88	11.36	9.94	8.27	3.78	2.39	1.98	1.00	1.45	0.51	0.24	1.05
1998	0.01	0.05	0.35	0.52	2.03	17.18	25.72	21.55	22.04	18.01	9.12	7.82	6.46	2.95	1.86	1.54	0.78	1.13	0.40	1.00
1999	0.00	0.00	0.03	0.25	0.46	2.18	20.92	30.01	20.78	18.58	14.43	7.20	6.14	5.07	2.31	1.46	1.21	0.61	0.89	1.10
2000	0.00	0.02	0.03	0.15	0.81	0.96	2.92	18.33	19.84	13.25	12.56	10.16	5.16	4.43	3.66	1.67	1.06	0.88	0.44	1.43
2001	0.01	0.02	0.08	0.11	0.47	1.97	1.81	4.14	19.00	15.31	8.48	7.47	5.94	3.01	2.59	2.15	0.98	0.62	0.51	1.10
2002	0.02	0.03	0.08	0.34	0.51	2.21	9.10	7.38	12.67	39.22	21.88	9.45	7.30	5.47	2.70	2.30	1.90	0.87	0.55	1.43
2003	0.00	0.00	0.00	0.01	0.04	0.10	0.63	3.76	3.90	6.86	19.17	9.80	4.04	3.06	2.27	1.12	0.95	0.79	0.36	0.82
2004	0.00	0.00	0.01	0.02	0.05	0.26	0.42	1.86	7.13	4.69	6.13	15.46	7.74	3.19	2.42	1.80	0.89	0.75	0.62	0.93
2005	0.00	0.00	0.01	0.04	0.07	0.21	1.01	1.54	5.45	13.97	6.20	6.38	14.46	6.95	2.82	2.13	1.58	0.78	0.66	1.36
2006	0.02	0.02	0.05	0.08	0.32	0.53	1.06	3.11	2.40	4.53	7.85	2.93	2.84	6.32	3.02	1.23	0.92	0.69	0.34	0.88
2007	0.05	0.10	0.13	0.39	0.65	2.49	2.90	3.40	6.12	3.53	5.84	9.63	3.54	3.41	7.56	3.61	1.46	1.10	0.82	1.45
2008	0.06	0.14	0.28	0.40	1.13	1.58	4.08	3.14	2.90	4.73	2.64	4.33	7.12	2.61	2.51	5.58	2.66	1.08	0.81	1.68
2009	0.04	0.16	0.42	0.83	1.16	2.90	3.09	6.12	4.11	3.61	5.81	3.23	5.28	8.69	3.19	3.07	6.80	3.25	1.32	3.04
2010	0.05	0.18	0.73	1.73	2.90	2.90	4.34	2.91	4.52	2.80	2.40	3.83	2.13	3.47	5.71	2.10	2.02	4.48	2.14	2.86
2011	0.04	0.08	0.28	1.04	2.28	3.44	3.06	4.18	2.69	4.14	2.55	2.19	3.50	1.94	3.18	5.22	1.91	1.84	4.09	4.57
2012	0.02	0.13	0.27	0.97	3.46	6.58	7.33	4.34	4.36	2.42	3.54	2.14	1.83	2.92	1.62	2.64	4.35	1.59	1.54	7.21
2013	0.00	0.02	0.13	0.29	1.06	4.01	8.01	9.22	5.49	5.48	3.03	4.42	2.68	2.28	3.64	2.02	3.30	5.42	1.99	10.91
2014	0.00	0.01	0.07	0.54	1.11	3.66	10.81	14.21	10.24	4.51	3.97	2.10	3.03	1.83	1.56	2.48	1.38	2.25	3.70	8.81
2015	0.00	0.01	0.06	0.28	1.87	3.07	7.72	16.68	16.73	10.43	4.36	3.79	2.00	2.88	1.74	1.48	2.36	1.31	2.14	11.91
2016	0.01	0.01	0.02	0.11	0.56	3.85	6.10	12.89	21.26	16.90	9.22	3.64	3.08	1.62	2.32	1.40	1.19	1.90	1.05	11.28

Table 8.5 Bottom trawl survey biomass estimates (t), variance and confidence intervals from the Eastern Bering Sea shelf and the Aleutian Islands for northern rock sole.

	Shelf survey				Aleutian Islands			
	biomass	variance	lower CI	upper CI	biomass	variance	lower CI	upper CI
1982	578714.1	5.49E+09	430550.1	726878.2				
1983	714093.1	6.7E+09	550390.7	877795.5				
1984	799423.5	6.7E+09	635774.4	963072.5				
1985	699969	3.47E+09	582089.2	817848.8				
1986	1032096	7.19E+09	864187.5	1200004				
1987	1269577	8.32E+09	1088960	1450195				
1988	1492482	1.04E+10	1290721	1694242				
1989	1337187	8.47E+09	1154987	1519386				
1990	1382913	7.92E+09	1206654	1559172				
1991	1585258	9.21E+09	1395242	1775275				
1992	1614281	1.32E+10	1386855	1841707				
1993	2126444	1.79E+10	1861272	2391617				
1994	2893472	5.42E+10	2427783	3359162				
1995	2179967	1.7E+10	1921497	2438437				
1996	2190383	1.65E+10	1936321	2444446				
1997	2705723	3.92E+10	2313799	3097647	49,912	1.49E+08	25,995	73,829
1998	2168130	1.53E+10	1923569	2412691				
1999	1695630	2.93E+10	1356762	2034498				
2000	2135919	1.12E+11	1465897	2805940	44,436	3.87E+07	32,239	56,632
2001	2425022	7.53E+10	1876119	2973924				
2002	1912884	2.97E+10	1568482	2257285	51,590	4.87E+07	37,918	65,263
2003	2108938	3.85E+10	1720479	2497397				
2004	2193822	3.37E+10	1826683	2560962	51,896	1.52E+07	44,256	59,537
2005	2115731	2.26E+10	1818046	2413417				
2006	2215550	2.25E+10	1918624	2512475	77,760	9.58E+07	58,576	96,945
2007	2032966	7.78E+10	1475085	2590848				
2008	2031618	9.04E+10	1430313	2632924				
2009	1538656	2.53E+10	1220655	1856657				
2010	2065542	4.14E+10	1658826	2472258	55,286	2.05E+07	46,416	64,155
2011	1977099	2.71E+10	1647936	2306262				
2012	1920072	3.46E+10	1552007	2288138	65,460	5.00E+07	51,601	79,318
2013	1752594	1.87E+10	1482149	2023038				
2014	1857330	1.67E+10	1601255	2113404	46,650	2.14E+07	37,586	55,713
2015	1411826	1.70E+10	1153562	1670091				
2016	1461272	1.70E+10	1201960	1720583				

Table 8.6—Total tonnage of northern rock sole caught in resource assessment trawl surveys on the Bering Sea shelf, 1977-2014.

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
2013	63
2014	66
2015	51
2016	53

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
2012	9	15	31	87	123	138	174	221	299	359	421	447	485	537	493	695	690	815	336	621
2013	9	15	31	87	123	138	174	221	299	359	421	447	485	537	493	695	690	815	336	621
2014	9	15	31	87	123	138	174	221	299	359	421	447	485	537	493	695	690	815	336	621
2015	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
2012	7	9	23	56	78	110	163	192	254	223	264	275	360	341	336	340	344	340	390	370
2013	7	9	23	56	78	110	163	192	254	223	264	275	360	341	336	340	344	340	390	370
2014	7	9	23	56	78	110	163	192	254	223	264	275	360	341	336	340	344	340	390	370
2015	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—BSAI shelf 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	348
2013	376	313	21189	44	358	352
2014	376	273	22808	32	283	279
2015	376	280	18282	52	374	372
2016	376	306	53590	59	526	

Table 8.10--Estimated population numbers-at-age (millions) from the annual Bering Sea trawl surveys, 1982- 2015.

millions of fish

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
2012	52	216	305	788	698	1,183	843	503	592	261	170	38	185	94	203	45	83	71	22	587
2013	1	140	37	101	228	434	941	806	786	604	514	267	72	122	19	85	31	54	40	445
2014	0	42	210	261	68	95	61	125	766	431	700	1,081	445	216	90	175	16	85	84	331
2015	0	1	51	39	298	893	682	609	600	567	197	462	389	215	100	160	178	74	98	806

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

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

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

recruitment likelihood

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

catch likelihood

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

survey likelihood

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

survey age composition likelihood

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

fishery age composition likelihood

Table 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	0.29	0.06
1976	0.37	0.04
1977	0.27	0.02
1978	0.51	0.03
1979	0.05	0.02
1980	0.04	0.03
1981	0.03	0.02
1982	0.04	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	0.11	0.04
1996	0.08	0.03
1997	0.09	0.04
1998	0.05	0.02
1999	0.04	0.03
2000	0.05	0.03
2001	0.02	0.02
2002	0.04	0.03
2003	0.03	0.02
2004	0.05	0.03
2005	0.04	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	0.07	0.05
2013	0.05	0.04
2014	0.05	0.04
2015	0.05	0.04
2016	0.05	0.04

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	0.01	0.04	0.25	0.72	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
males	0.01	0.06	0.40	0.89	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

	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	0.21	0.47	0.74	0.90	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	0.16	0.39	0.68	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	0.46	0.74	0.90	0.90	0.90	0.90
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.14	0.35	0.35	0.35	0.35
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	0.52	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	0.69	0.88	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1982	0.09	0.27	0.58	0.83	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1983	0.02	0.05	0.15	0.36	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	0.11	0.25	0.49	0.73	0.89	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1985	0.18	0.45	0.76	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	0.33	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	0.50	0.77	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1988	0.07	0.21	0.47	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	0.08	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	0.11	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	0.31	0.59	0.81	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	0.09	0.22	0.47	0.73	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	0.28	0.46	0.64	0.79	0.89	0.95	0.97	0.99	0.99	0.99	0.99	0.99
1998	0.00	0.00	0.01	0.02	0.06	0.13	0.26	0.47	0.68	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	0.74	0.89	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00
2000	0.00	0.01	0.03	0.08	0.19	0.40	0.65	0.84	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	0.32	0.57	0.78	0.91	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2002	0.01	0.04	0.11	0.29	0.58	0.82	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2003	0.02	0.06	0.16	0.35	0.60	0.81	0.92	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	0.09	0.22	0.45	0.71	0.88	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2005	0.01	0.04	0.11	0.27	0.53	0.76	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2006	0.01	0.05	0.14	0.34	0.63	0.85	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2007	0.01	0.03	0.11	0.31	0.62	0.85	0.95	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	0.20	0.46	0.75	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2009	0.01	0.02	0.07	0.23	0.53	0.81	0.94	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

2010	0.00	0.01	0.04	0.10	0.24	0.48	0.73	0.89	0.96	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2011	0.00	0.01	0.03	0.11	0.30	0.59	0.83	0.95	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2012	0.01	0.02	0.07	0.17	0.39	0.66	0.85	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2013	0.03	0.10	0.26	0.53	0.79	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2014	0.00	0.00	0.01	0.04	0.13	0.34	0.64	0.86	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2015	0.00	0.01	0.02	0.05	0.15	0.36	0.64	0.85	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2016	0.01	0.02	0.06	0.17	0.39	0.66	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	0.01	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	1.00
1976	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	1.00
1977	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	1.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.10	0.28	0.58	0.84	0.95	0.95	0.95	0.95	0.95
1979	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	1.00
1980	0.36	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	1.00
1981	0.66	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	1.00
1982	0.18	0.38	0.64	0.83	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1983	0.03	0.06	0.13	0.26	0.45	0.66	0.82	0.91	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1984	0.10	0.20	0.37	0.57	0.75	0.88	0.94	0.97	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1985	0.73	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	1.00	1.00
1986	0.30	0.64	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
1987	0.39	0.71	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1988	0.39	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	1.00
1989	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	1.00
1990	0.40	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	1.00	1.00
1991	0.08	0.23	0.52	0.80	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1992	0.04	0.14	0.37	0.68	0.89	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1993	0.04	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
1994	0.01	0.05	0.19	0.53	0.84	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1995	0.01	0.03	0.08	0.21	0.46	0.73	0.89	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1996	0.01	0.03	0.08	0.18	0.35	0.57	0.77	0.89	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1997	0.03	0.07	0.16	0.34	0.58	0.79	0.91	0.96	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1998	0.00	0.01	0.04	0.15	0.41	0.74	0.92	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1999	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	1.00
2000	0.01	0.03	0.08	0.23	0.49	0.75	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2001	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	1.00
2002	0.13	0.32	0.62	0.84	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
2003	0.16	0.40	0.71	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2004	0.11	0.32	0.63	0.87	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2005	0.17	0.42	0.71	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2006	0.08	0.21	0.47	0.74	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
2007	0.09	0.26	0.53	0.79	0.92	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2008	0.03	0.08	0.24	0.52	0.79	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2009	0.04	0.12	0.32	0.60	0.83	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

2010	0.04	0.11	0.26	0.50	0.73	0.88	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2011	0.04	0.11	0.27	0.52	0.77	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2012	0.06	0.14	0.29	0.52	0.74	0.88	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2013	0.06	0.20	0.49	0.79	0.94	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2014	0.01	0.05	0.15	0.39	0.69	0.89	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2015	0.05	0.16	0.40	0.71	0.89	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2016	0.05	0.14	0.35	0.65	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

Table 8-15.--Model estimates of rock sole age 2+ total biomass (t) and female spawning biomass (t) from the 2015 and 2016 assessments.

	2015 Assessment		2016 Assessment	
	Age 2+ Total biomass	Female Spawning biomass	Age 2+ Total biomass	Female Spawning biomass
1975	211,495	57,993	202,385	55,833
1976	233,369	61,760	222,478	59,016
1977	255,418	71,118	242,924	67,620
1978	283,057	89,666	268,986	85,082
1979	308,712	112,108	293,125	106,137
1980	341,350	129,412	324,018	122,434
1981	382,942	139,096	363,333	131,435
1982	429,401	144,370	407,308	136,266
1983	484,745	151,797	459,615	143,060
1984	557,518	161,808	528,521	152,134
1985	622,973	161,636	589,364	151,060
1986	730,215	179,584	690,899	167,891
1987	861,866	198,113	815,574	185,249
1988	1,010,330	220,212	954,639	205,635
1989	1,096,730	237,527	1,031,970	220,717
1990	1,218,990	268,267	1,144,000	248,690
1991	1,437,090	319,403	1,347,990	296,525
1992	1,531,340	335,444	1,433,620	311,090
1993	1,568,440	352,306	1,465,550	326,519
1994	1,571,200	369,237	1,464,330	341,815
1995	1,647,560	446,662	1,532,250	413,668
1996	1,703,320	546,174	1,580,900	505,763
1997	1,754,880	636,371	1,626,330	589,082
1998	1,737,860	688,439	1,606,190	636,296
1999	1,731,620	746,848	1,598,790	690,179
2000	1,699,870	786,590	1,567,240	725,869
2001	1,647,060	794,334	1,515,440	731,484
2002	1,611,660	781,621	1,481,600	718,854
2003	1,585,450	758,837	1,455,800	696,389
2004	1,582,740	707,767	1,453,290	648,384
2005	1,597,320	631,581	1,467,170	576,999
2006	1,705,820	569,248	1,571,710	519,077
2007	1,822,700	538,511	1,683,360	489,848
2008	1,818,630	520,759	1,682,020	472,846
2009	1,763,480	521,519	1,632,730	472,601
2010	1,701,170	548,824	1,576,240	497,904
2011	1,701,190	592,803	1,580,490	539,309

2012	1,654,470	637,847	1,537,900	582,623
2013	1,573,520	665,257	1,464,080	610,100
2014	1,482,260	679,755	1,375,700	627,106
2015	1,376,800	665,547	1,274,560	615,535
2016			1,191,820	592,085

Table 8.16--Estimated age 4 recruitment of rock sole (thousands of fish) from the 2015 and 2016 assessments.

Year class	2015 Assessment	2016 Assessment
1971	214,564	203,842
1972	168,862	160,407
1973	210,746	200,366
1974	216,426	206,040
1975	502,290	478,822
1976	281,154	268,102
1977	448,694	427,552
1978	445,076	423,740
1979	587,546	559,942
1980	1,063,932	1,016,016
1981	1,037,320	991,376
1982	948,696	906,114
1983	1,424,112	1,357,666
1984	1,374,858	1,306,760
1985	1,297,316	1,228,858
1986	2,286,580	2,158,120
1987	3,562,900	3,349,120
1988	1,261,666	1,182,170
1989	1,052,660	983,588
1990	2,344,280	2,183,980
1991	1,183,816	1,099,750
1992	609,254	564,742
1993	929,040	860,038
1994	494,484	456,848
1995	492,256	453,882
1996	676,966	631,798
1997	396,484	366,016
1998	627,062	575,282
1999	597,336	556,410
2000	1,262,166	1,165,428
2001	1,967,512	1,834,568
2002	2,362,780	2,224,980
2003	1,722,968	1,637,120
2004	1,306,852	1,279,274
2005	1,705,508	1,712,206
2006	664,092	598,444
2007	329,030	292,154
2008		170,784

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	162	135	93	102	191	123	52	38	30	24	11	8	5	5	5	4	4	4	5	5
1976	375	139	116	80	88	164	106	45	33	26	20	9	6	4	3	3	3	3	3	6
1977	210	323	120	100	69	76	141	91	39	28	22	17	8	5	3	2	2	2	2	5
1978	336	181	278	103	86	59	65	122	78	33	24	19	15	6	4	2	2	1	1	4
1979	333	289	156	239	89	74	51	56	105	67	29	21	16	13	5	3	1	1	1	3
1980	440	287	249	134	206	76	64	44	48	88	56	24	17	13	10	4	3	1	1	3
1981	797	379	247	214	115	176	64	53	36	40	73	46	20	14	11	9	4	2	1	3
1982	778	686	326	212	183	98	148	54	44	30	33	61	39	16	12	9	7	3	2	3
1983	712	670	590	280	182	156	82	122	44	37	25	27	50	32	13	10	8	6	3	4
1984	1066	613	576	508	241	156	133	69	101	36	30	20	22	40	26	11	8	6	5	5
1985	1027	917	528	496	436	206	132	110	55	77	27	22	15	16	30	19	8	6	5	7
1986	968	884	789	453	423	368	171	109	90	45	64	22	18	12	13	24	15	7	5	10
1987	1696	833	761	679	389	362	311	142	90	74	37	52	18	15	10	11	20	13	5	12
1988	2630	1460	716	653	580	329	299	252	114	71	59	29	41	14	12	8	9	16	10	14
1989	928	2263	1255	614	556	483	263	229	188	84	52	43	22	30	11	9	6	6	12	17
1990	772	798	1947	1079	526	470	396	207	176	144	64	40	33	16	23	8	7	4	5	22
1991	1713	664	687	1675	927	450	398	330	170	144	117	52	33	27	13	19	7	5	4	22
1992	862	1474	571	591	1440	795	384	335	272	137	113	91	40	25	21	10	15	5	4	20
1993	443	742	1269	492	508	1237	681	327	281	222	108	88	70	31	19	16	8	11	4	18
1994	674	381	639	1092	423	437	1060	579	273	228	175	84	68	54	24	15	12	6	9	17
1995	358	580	328	550	940	364	375	908	491	226	183	137	65	53	42	18	11	9	5	20
1996	356	308	500	282	473	808	313	321	769	407	183	144	107	51	41	32	14	9	7	19
1997	496	306	265	430	243	407	695	268	275	650	337	148	116	85	40	32	26	11	7	21
1998	287	426	264	228	370	209	349	594	228	230	537	274	119	92	67	32	25	20	9	22
1999	451	247	367	227	197	318	180	300	510	195	196	452	229	98	76	55	26	21	17	25
2000	436	388	213	316	195	169	274	154	257	433	164	163	374	189	81	62	46	21	17	35
2001	914	376	334	183	272	168	145	235	132	217	362	136	134	307	155	66	51	37	18	42
2002	1439	787	323	288	157	234	144	124	199	111	183	304	114	113	258	130	56	43	31	50
2003	1745	1239	677	278	247	135	200	123	105	167	92	152	252	95	94	214	108	46	36	68

2004	1284	1502	1066	583	239	213	116	171	104	88	139	77	127	211	79	78	179	90	39	87
2005	1003	1105	1293	917	501	206	182	99	144	86	73	115	63	104	173	65	64	147	74	103
2006	1343	864	951	1112	789	431	176	155	83	120	72	60	95	53	86	144	54	53	122	147
2007	469	1156	743	819	957	678	369	150	130	69	100	59	50	79	44	71	119	44	44	222
2008	229	404	995	640	704	823	581	313	126	108	57	82	49	41	65	36	59	98	37	220
2009	134	197	348	856	550	605	705	494	262	103	88	46	67	40	33	52	29	48	79	207
2010	79	115	170	299	737	473	519	599	413	216	84	72	38	54	32	27	43	24	39	234
2011	258	68	99	146	257	634	406	444	508	345	178	69	58	31	44	26	22	35	19	221
2012	312	222	59	85	126	221	544	347	375	422	282	144	56	47	25	36	21	18	28	194
2013	616	268	191	50	73	108	190	463	291	308	342	227	116	45	38	20	29	17	14	178
2014	374	530	231	164	43	63	92	159	384	240	253	281	186	95	37	31	16	23	14	158
2015	534	322	456	199	142	37	54	79	136	324	199	208	230	152	78	30	25	13	19	140
2016	565	460	277	393	171	122	32	46	67	115	271	165	172	189	125	64	25	21	11	131

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	162	79	60	66	99	57	32	24	17	12	8	7	6	6	6	6	6	6	6	6
1976	375	139	68	52	57	85	49	28	20	14	9	5	5	4	4	4	4	4	4	7
1977	210	323	120	58	45	49	74	42	24	17	11	7	3	3	2	2	2	2	2	6
1978	336	181	278	103	50	38	42	63	36	20	15	9	5	2	2	1	1	1	1	5
1979	333	289	156	239	89	43	33	36	54	31	17	12	8	4	1	1	0	0	0	1
1980	440	287	249	134	206	76	37	28	31	46	26	14	10	6	3	1	1	0	0	1
1981	797	379	247	214	115	175	64	31	24	26	38	22	12	8	5	3	1	0	0	1
1982	778	686	325	211	182	97	146	53	26	20	21	32	18	10	7	4	2	1	0	1
1983	712	670	590	280	181	155	82	122	44	21	16	18	26	15	8	6	3	2	1	1
1984	1066	613	576	508	241	156	133	70	104	37	18	13	14	21	12	7	5	3	1	2
1985	1027	917	527	494	434	204	130	108	55	79	28	13	10	11	16	9	5	3	2	2
1986	968	884	788	451	418	361	168	107	89	45	65	23	11	8	9	13	7	4	3	4
1987	1696	833	761	677	387	355	301	139	88	73	37	53	19	9	7	7	10	6	3	5
1988	2630	1460	716	652	576	322	288	241	110	70	58	29	42	15	7	5	6	8	5	7
1989	928	2263	1256	614	552	466	245	213	177	81	51	42	21	31	11	5	4	4	6	8
1990	772	798	1947	1078	524	460	373	190	164	135	62	39	32	16	24	8	4	3	3	11
1991	1713	664	687	1673	922	441	381	305	155	134	111	50	32	26	13	19	7	3	2	12

1992	862	1474	571	591	1436	787	370	309	240	120	103	85	39	25	20	10	15	5	2	11
1993	443	742	1269	492	508	1231	667	306	246	187	93	79	66	30	19	16	8	11	4	10
1994	674	381	639	1092	423	435	1043	550	243	192	145	72	61	50	23	15	12	6	9	11
1995	358	581	328	550	940	363	373	879	446	190	148	111	55	47	39	18	11	9	5	15
1996	356	308	500	282	473	808	312	318	739	365	151	116	86	43	36	30	14	9	7	15
1997	496	306	265	430	243	407	694	267	270	619	300	123	93	69	34	29	24	11	7	18
1998	287	426	264	228	370	209	348	589	223	221	496	238	97	73	54	27	23	19	9	19
1999	451	247	367	227	197	318	179	299	503	188	183	409	196	79	60	44	22	19	15	23
2000	436	388	213	316	195	169	274	154	256	426	158	152	338	161	65	49	37	18	15	32
2001	914	376	334	183	272	168	145	235	131	215	354	130	125	277	133	54	41	30	15	39
2002	1439	787	323	288	157	234	144	124	199	111	181	297	109	105	233	111	45	34	25	45
2003	1745	1239	677	278	247	135	199	121	104	166	92	150	247	91	87	194	92	37	28	58
2004	1284	1502	1066	583	239	212	115	167	102	87	138	77	125	206	76	73	161	77	31	72
2005	1003	1105	1293	917	501	205	180	96	138	84	71	114	63	103	169	62	60	133	63	85
2006	1343	864	951	1112	788	428	173	151	80	115	69	59	94	52	85	140	52	50	110	123
2007	469	1156	743	818	956	676	365	146	126	66	95	57	49	78	43	71	116	43	41	192
2008	229	404	995	639	703	820	576	308	122	104	55	79	47	40	64	36	58	96	35	193
2009	134	197	348	856	550	604	702	488	256	100	85	44	64	38	33	52	29	47	77	184
2010	79	115	170	299	736	472	517	594	407	211	82	69	36	52	31	27	42	24	38	214
2011	258	68	99	146	257	632	404	438	496	335	172	66	56	29	42	25	22	34	19	204
2012	312	222	59	85	126	221	540	342	365	407	272	140	54	45	24	34	20	17	28	181
2013	616	268	191	50	73	108	188	455	284	298	329	219	112	43	36	19	27	16	14	167
2014	374	530	231	164	43	63	92	158	378	233	245	270	180	92	35	30	16	22	13	149
2015	534	322	456	199	142	37	54	78	133	313	192	200	221	147	75	29	24	13	18	132
2016	565	460	277	393	171	122	32	46	65	110	258	158	164	181	121	62	24	20	10	124

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

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	1	3	8	15	18	10	7	5	5	5	4	4	4	5	5
1976	1	6	9	17	19	18	8	6	4	3	3	3	3	3	6
1977	1	9	18	20	21	20	16	7	5	3	2	2	2	2	5
1978	0	4	24	40	25	22	18	14	6	4	2	2	1	1	4
1979	1	3	11	53	51	26	19	16	12	5	3	1	1	1	3
1980	1	4	9	24	66	50	22	16	13	10	4	3	1	1	3
1981	1	4	11	18	30	65	43	19	14	11	8	4	2	1	3
1982	1	9	11	22	23	29	57	37	16	12	9	7	3	2	3
1983	1	5	24	22	27	22	25	48	31	13	10	8	6	3	4
1984	1	8	14	51	27	26	19	21	40	25	11	8	6	5	5
1985	2	8	22	28	58	24	20	14	16	29	19	8	6	5	7
1986	3	10	22	46	34	57	21	17	12	13	24	15	7	5	10
1987	3	19	28	45	56	33	48	17	14	10	11	20	13	5	12
1988	3	18	50	57	53	52	27	40	14	12	8	9	16	10	14
1989	4	16	46	95	63	46	40	21	30	10	9	6	6	12	17
1990	4	24	41	89	108	57	37	31	16	23	8	7	4	5	22
1991	4	24	66	86	108	104	49	31	26	13	19	7	5	4	22
1992	6	23	67	137	103	101	85	39	25	20	10	15	5	4	20
1993	10	42	65	142	166	96	82	67	31	19	16	8	11	4	18
1994	3	65	116	138	171	155	78	65	53	24	15	12	6	9	17
1995	3	23	182	248	170	163	128	62	51	41	18	11	9	5	20
1996	6	19	64	388	305	162	134	102	49	40	32	14	9	7	19
1997	3	42	54	139	487	300	138	111	83	39	32	26	11	7	21
1998	2	21	119	115	173	477	255	113	90	66	31	25	20	9	22
1999	3	11	60	258	146	174	420	218	96	75	55	26	21	17	25
2000	1	17	31	130	325	146	152	357	185	80	62	45	21	17	34
2001	1	9	47	66	163	321	126	128	301	152	66	51	37	18	42
2002	2	9	25	101	83	162	282	109	110	254	129	56	43	31	50
2003	1	12	25	53	125	82	141	241	93	92	212	108	46	36	68
2004	2	7	34	52	66	124	72	121	206	78	77	178	90	39	86

2005	2	11	20	73	65	64	107	61	102	170	64	64	146	74	103
2006	3	11	31	42	90	64	56	91	52	85	142	54	53	121	146
2007	5	22	30	66	52	88	55	48	77	43	71	118	44	44	221
2008	7	35	63	63	81	51	76	47	40	64	36	59	98	37	219
2009	5	43	99	132	77	78	43	64	39	33	52	29	47	79	207
2010	4	32	120	209	162	75	67	36	53	32	27	43	24	39	233
2011	5	25	89	257	259	158	64	56	30	43	26	22	35	19	220
2012	2	33	69	190	316	251	134	53	46	24	35	21	18	28	194
2013	1	12	93	147	231	303	211	111	44	37	20	28	17	14	178
2014	1	6	32	194	180	225	261	178	93	36	31	16	23	14	157
2015	0	3	16	69	243	177	194	219	149	76	30	25	13	19	140
2016	1	2	9	34	86	241	153	164	185	123	63	25	21	11	131

Table 8.19—Selected parameter estimates and their standard deviations from the preferred stock assessment model run. Biomass is in millions of tons.

name	value	standard deviation		name	value	standard deviation
mean_log_recruitment	0.12	0.11	1987	total biomass	815.57	14.45
sel_slope_fishery_female	1.14	0.05	1988	total biomass	954.64	15.82
sel50_fishery_female	8.40	0.47	1989	total biomass	1032.00	17.25
sel_slope_fsh_males	1.22	0.06	1990	total biomass	1144.00	18.87
sel50_fsh_males	7.49	0.42	1991	total biomass	1348.00	21.02
sel_slope_survey_females	2.03	0.12	1992	total biomass	1433.60	21.81
sel50_survey_females	3.54	0.06	1993	total biomass	1465.50	22.25
sel_slope_survey_males	0.18	0.08	1994	total biomass	1464.30	22.48
sel50_survey_males	-0.11	0.02	1995	total biomass	1532.30	24.11
Ricker_logalpha	-4.18	0.21	1996	total biomass	1580.90	25.55
Ricker_logbeta	-5.83	0.17	1997	total biomass	1626.30	26.80
Fmsyr	0.15	0.02	1998	total biomass	1606.20	27.50
logFmsyr	-1.80	0.17	1999	total biomass	1598.80	27.78
ABC_biomass 2016	10012	34.27	2000	total biomass	1567.20	27.78
ABC_biomass 2017	9239.80	37.98	2001	total biomass	1515.40	27.47
msy	254.00	42.66	2002	total biomass	1481.60	26.94
Bmsy	257.00	29.76	2003	total biomass	1455.80	26.58
total biomass	202.00	10.00	2004	total biomass	1453.30	26.51
total biomass	222.48	10.55	2005	total biomass	1467.20	27.06
total biomass	242.92	11.18	2006	total biomass	1571.70	29.54
total biomass	268.99	11.64	2007	total biomass	1683.40	32.72
total biomass	293.13	11.86	2008	total biomass	1682.00	33.81
total biomass	324.02	11.99	2009	total biomass	1632.70	34.33
total biomass	363.33	12.07	2010	total biomass	1576.20	34.80
total biomass	407.31	12.06	2011	total biomass	1580.50	36.74
total biomass	459.61	12.20	2012	total biomass	1537.90	38.00
total biomass	528.52	12.41	2013	total biomass	1464.10	38.89
total biomass	589.36	12.70	2014	total biomass	1375.70	39.03
total biomass	690.90	13.47	2015	total biomass	1274.60	39.06
			2016	total biomass	1191.8	40.545

Table 8.20. Stock assessment model estimates of average age-specific fishing mortality, by gender, 1975-2016.

	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	0.29	0.29	0.29	0.29
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.15	0.26	0.34	0.37	0.37	0.37	0.37
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	0.22	0.27	0.27	0.27	0.27
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	0.20	0.51	0.51	0.51	0.51
1979	0.00	0.00	0.00	0.00	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
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	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
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	0.14	0.15	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	0.01	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
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	0.06	0.08	0.10	0.11	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	0.09	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	0.11	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	0.04	0.07	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11
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	0.03	0.04	0.06	0.07	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	0.00	0.01	0.01	0.02	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05
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	0.05	0.05	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	0.00	0.01	0.02	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2003	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
2004	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2005	0.00	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
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	0.03	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	0.00	0.01	0.03	0.05	0.06	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	0.05	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	0.00	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
2012	0.00	0.00	0.00	0.01	0.03	0.05	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2013	0.00	0.00	0.01	0.03	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
2014	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

2015	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2016	0.00	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

	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	0.29	0.29	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	0.37	0.38	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	0.05	0.13	0.22	0.27	0.29	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	0.14	0.41	0.86	1.22	1.39	1.39	1.39	1.39
1979	0.00	0.00	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
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	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
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	0.12	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	0.11	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	0.02	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
1993	0.00	0.00	0.02	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	0.10	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	0.08	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1996	0.00	0.00	0.00	0.01	0.01	0.03	0.05	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	0.01	0.01	0.03	0.05	0.07	0.08	0.09	0.09	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	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1999	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
2000	0.00	0.00	0.00	0.00	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
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	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
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	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2005	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	0.04
2006	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
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	0.02	0.03	0.05	0.06	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	0.05	0.05	0.06	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	0.06	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	0.05	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2013	0.00	0.00	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
2014	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	0.05

2015	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
2016	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

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
2016	592,082	45,799	0.05
2017	535,763	130,007	0.16
2018	432,624	104,921	0.16
2019	351,158	87,060	0.16
2020	292,342	71,994	0.15
2021	258,279	57,792	0.14
2022	239,295	51,574	0.12
2023	234,852	51,759	0.12
2024	236,171	56,142	0.12
2025	258,239	67,559	0.13
2026	283,690	78,040	0.14
2027	309,062	86,678	0.14
2028	330,748	93,540	0.15
2029	345,359	97,778	0.15

Scenario 3
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch
2016	592,082	45,799
2017	540,391	48,187
2018	483,101	41,802
2019	432,453	37,932
2020	391,944	35,379
2021	366,423	33,651
2022	348,588	32,951
2023	342,790	33,338
2024	339,121	34,761
2025	362,231	37,722
2026	392,502	40,949
2027	427,286	44,240
2028	461,584	47,307
2029	488,780	49,794

Scenario 4
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2016	592,082	45,799	0.05
2017	539,474	65,003	0.08
2018	472,674	55,958	0.08
2019	414,946	49,873	0.08
2020	369,608	45,822	0.08
2021	340,809	43,082	0.08
2022	320,640	41,826	0.08
2023	312,957	42,135	0.08
2024	308,698	43,933	0.08
2025	329,925	47,727	0.08
2026	358,145	51,843	0.08
2027	390,361	55,983	0.08
2028	421,587	59,781	0.08
2029	445,990	62,789	0.08

Scenario 5
No fishing

Year	Female spawning biomass	catch
2016	592,082	45,799
2017	542,933	0
2018	513,014	0
2019	483,585	0
2020	459,152	0
2021	445,922	0
2022	437,953	0
2023	440,832	0
2024	441,534	0
2025	473,253	0
2026	512,286	0
2027	557,197	0
2028	603,265	0
2029	641,177	0

Table 8.21—continued.

Scenario 6
Determination of whether northern rock sole are currently overfished **B35=268,500**

Year	Female spawning biomass	catch	F
2016	592,082	45,799	0.048957
2017	534,262	154,976	0.196627
2018	417,366	121,130	0.196633
2019	328,390	97,736	0.196633
2020	266,675	72,359	0.169496
2021	235,191	58,039	0.148263
2022	218,604	52,245	0.137077
2023	216,013	53,274	0.13533
2024	219,160	58,968	0.137425
2025	241,518	72,751	0.149994
2026	266,087	85,136	0.160614
2027	289,296	95,169	0.168595
2028	308,006	102,560	0.174164
2029	319,655	106,736	0.177002

Scenario 7
Determination of whether the stock is approaching an overfished condition **B35=268,500**

Year	Female spawning biomass	catch	F
2016	592,082	45,799	0.05
2017	535,762	130,015	0.16
2018	432,620	104,920	0.16
2019	350,183	103,831	0.20
2020	282,698	80,800	0.18
2021	245,055	62,643	0.15
2022	224,804	54,959	0.14
2023	219,880	54,945	0.14
2024	221,395	59,947	0.14
2025	242,828	73,293	0.15
2026	266,766	85,378	0.16
2027	289,600	95,247	0.17
2028	308,107	102,563	0.17
2029	319,667	106,711	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
2013	92,380	214,000
2014	85,000	203,800
2015	69,250	181,700
2016	57,100	161,000

Table 8.23—Catch and bycatch (t) in the rock sole target fisheries, 1993-2015, 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
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
Arrowtooth Flounder	1,143	1,782	507	1,341	411	300	69	216	835	314	419	346	599	516	220	464	600	1,841
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	6,659
Groundfish, General	3,091	3,266	1,605	1,581	1,381	909	537	1,186	1,198	692	978	801	910	1,605	1,807	3		
Rock Sole	39,857	40,139	29,241	18,380	32,477	13,092	16,047	29,042	14,437	20,168	18,681	24,287	16,667	20,129	21,217	35,180	29,703	37,311
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
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
Pacific Ocean Perch	15	62	4	2		1	0	0	0	0					<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
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	12,038
Greenland Turbot	28	50	3	3	2	1	0	1	15	0	1	4	1	27	8		7	3
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	2,446
Sculpin, General								9	2	271						1,104		
Kamchatka flounder																		
Octopus																		
Other rockfish																		
Skate, General								1	5	306								

Species	2011	2012	2013	2014	2015
Walleye Pollock	7,091	6,779	7,372	11,259	9382
Arrowtooth Flounder	448	101	683	681	337
Pacific Cod	7,332	9,777	8,599	10,982	10954
Groundfish, General	6				
Rock Sole	39,682	58,178	42,433	36,981	31,303
Flathead Sole	2,028	769	2,019	1,317	812
Sablefish				<1	5
Atka Mackerel	<1	<1	<1	<1	<1
Pacific Ocean Perch	1	<1	45	<1	<1
Rex Sole					
Flounder, General	411	1144	313	530	455
Shortraker / Rougheye					
Butter Sole					
Starry Flounder					
Northern Rockfish		<1	1		<1
Yellowfin Sole	9,827	9557	8,477	8,739	12861
Greenland Turbot	1	<1	3	5	1
Alaska Plaice	3,162	1653	4,339	3,103	1443
Sculpin, General	905	969	1,288	807	447
Kamchatka flounder		17	109	94	39
Octopus		1			2
Other rockfish		10	<1	<1	<1
Skate, General	711	653	529	689	284

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

Row Labels	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Benthic urochordata	216.0	318.5	107.4	12.7	30.9	10.8	58.2	5.3	20.5	7.8	15.1	15.8	18.1
Birds													
Bivalves	0.3	0.2	0.4	0.4	0.3	0.3	0.5	0.4	0.2	0.2	0.3	0.4	0.6
Brittle star unidentified	0.9	1.8	7.3	1.5	1.2	0.3	1.4	0.1	0.1	0.1	0.2	0.3	0.5
Capelin	0.4	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.0	4.9	0.1
Corals Bryozoans	0.7	0.0	1.4	0.0	0.1	0.0	2.0	0.1	0.3	0.2	0.2	0.1	0.3
Eelpouts	4.3	2.2	3.3	6.9	0.1	0.2	5.0	1.9	0.1	2.1	3.7	1.4	0.9
Eulachon	0.0			0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.7	0.2
Giant Grenadier				4.6			3.3						
Greenlings	0.3	0.4	0.3	0.3	0.0		0.0	0.0			0.0	0.0	0.1
Grenadier	0.5		0.1										
Gunnels													0.1
Hermit crab unidentified	7.1	7.2	10.4	5.7	2.7	0.9	3.9	2.3	3.8	1.9	2.6	1.6	1.0
Invertebrate unidentified	3.0	83.0	7.0	23.7	1.6	2.4	14.3	6.9	3.0	37.8	6.0	3.0	1.0
Large Sculpins	251.1	428.4	491.4	630.0	1056.6	1259.0	912.5	896.3	947.4	1262.3	786.3	435.8	609.2
Misc crabs	6.1	8.9	6.7	13.3	8.9	3.3	6.4	3.2	5.2	4.3	6.2	4.4	7.2
Misc crustaceans	0.2	0.0	0.5	0.2	0.2	0.3	1.0	0.2	0.5	0.1	0.1	0.1	0.2
Misc fish	17.3	22.1	17.2	70.4	25.3	11.9	14.9	16.8	17.6	6.8	10.3	10.6	10.4
Misc inverts (worms etc)	0.1		0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Other osmerids	0.1	0.7	0.3	0.2	0.6	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.4
Other Sculpins	17.2	34.6	183.2	130.0	33.2	32.8	5.8	1.0	0.5	1.3	0.3	2.0	1.3
Pacific Sand lance	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0		0.0	0.1	0.2
Pacific Sandfish								0.0			0.0	0.0	0.0
Pandalid shrimp	0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.1
Polychaete unidentified	0.0		0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scypho jellies	302.1	389.8	72.5	94.6	184.7	233.3	349.5	268.5	311.9	135.2	567.7	426.9	134.4
Sea anemone unidentified	11.9	6.1	9.0	6.3	6.7	2.7	8.9	9.5	4.5	11.5	16.1	2.8	3.5
Sea pens whips	0.0	0.0	0.0		0.0	0.1	0.2	0.0	0.1	0.1	0.0	0.0	0.0
Sea star	335.0	543.9	745.4	704.2	207.0	31.8	176.1	67.6	84.4	111.7	134.6	243.0	429.9
Snails	23.9	12.8	28.4	24.1	9.3	3.5	10.8	9.7	14.2	6.5	8.8	5.8	5.0
Sponge unidentified	67.9	70.0	40.1	19.2	19.2	64.8	141.6	112.2	62.8	154.0	186.6	76.4	1.4
Stichaeidae	0.0	0.0		0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0
urchins dollars cucumbers	9.0	8.7	3.9	32.2	6.0	1.1	4.2	3.4	1.6	0.4	5.1	4.9	3.2

Table 8.25-International Pacific halibut Commission survey catch of northern rock sole and shelf survey estimates of southern rock sole, 1997-2016.

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

	southern rock sole	
	biomass (t)	CV
1997	65	1
1998	701	0.87
1999	126	0.89
2000	3	1.00
2001	86	1.00
2002	23	1.00
2003	166	0.71
2004	152	0.82
2005	428	0.75
2006	942	0.71
2007	3401	0.70
2008	1322	0.81
2009	2465	0.99
2010	209	1.00
2011	800	0.63
2012	746	0.91
2013	613	0.71
2014	730	1.00
2015	2450	0.96
2016	1174	0.93

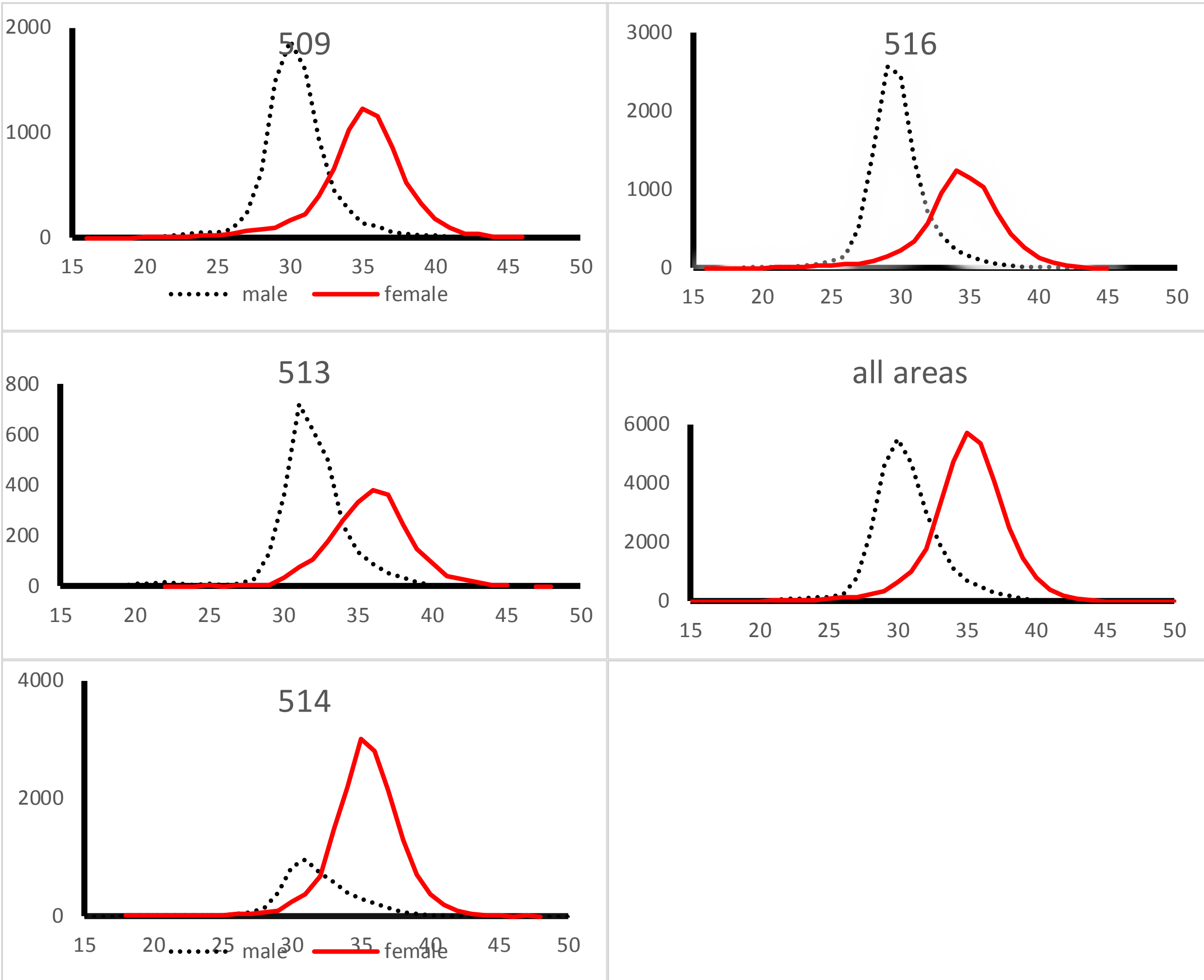
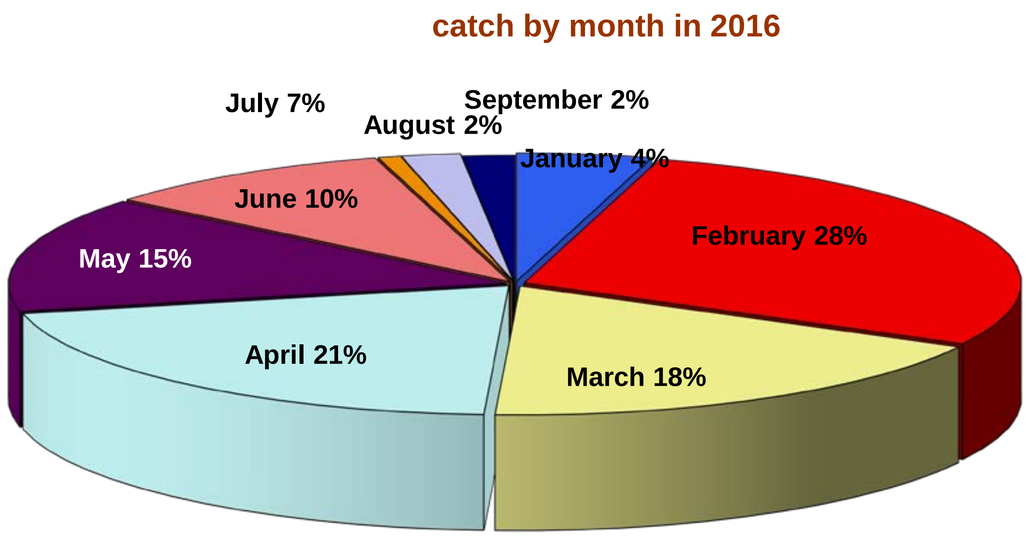


Figure 8.1—Size composition of rock sole, by sex and area, in the 2016 catch as determined from observer sampling.



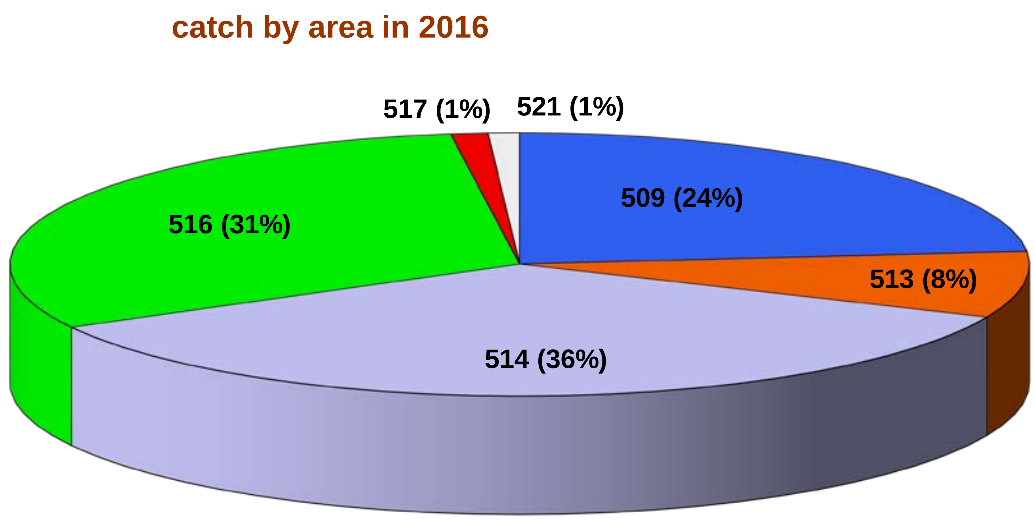


Figure 8.2—Bering Sea northern rock sole fishery catch by month and area in 2016 (percent of total).

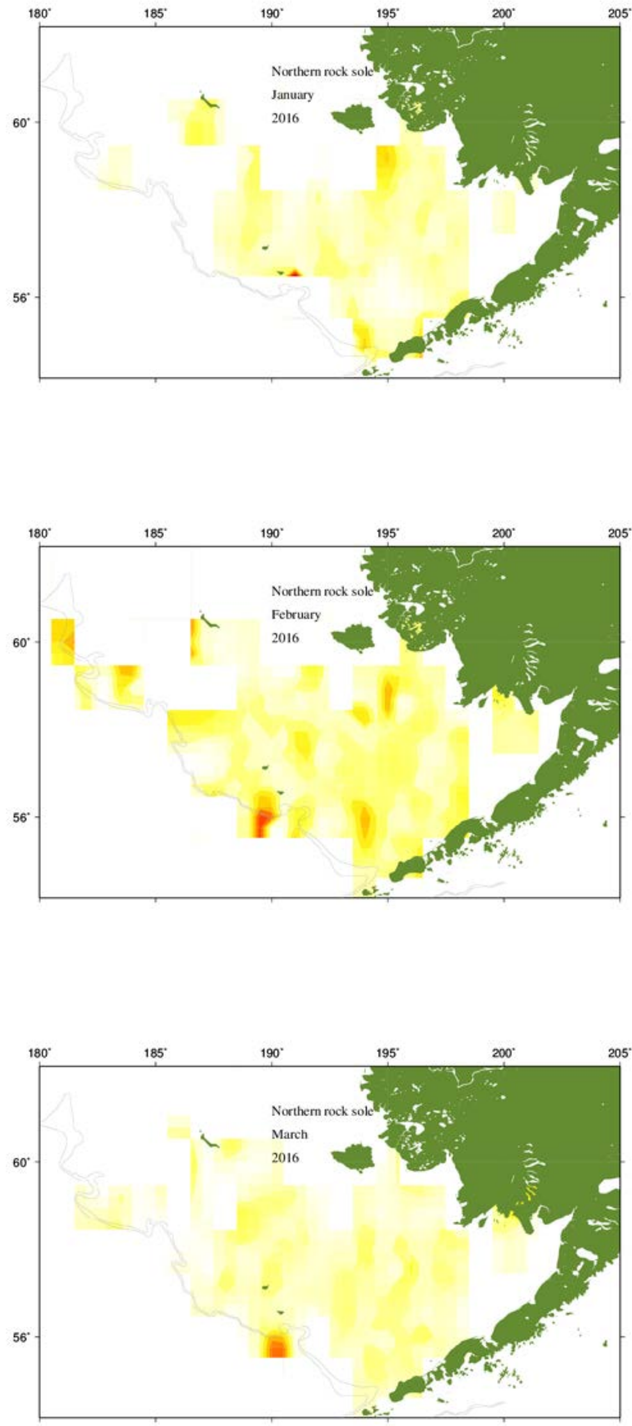
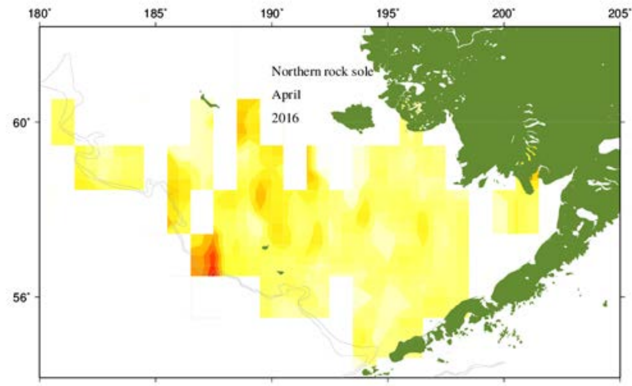
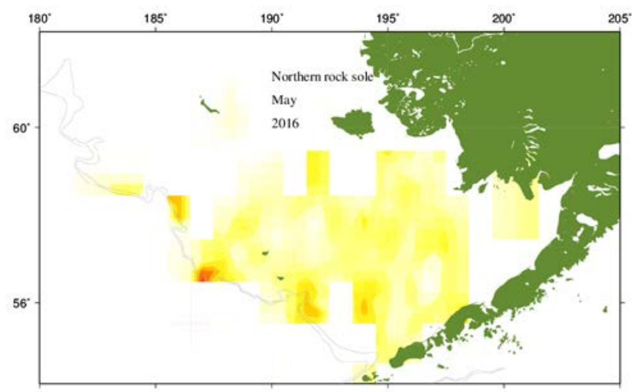


Figure 8.3. Northern rock sole catch locations by month in 2016.





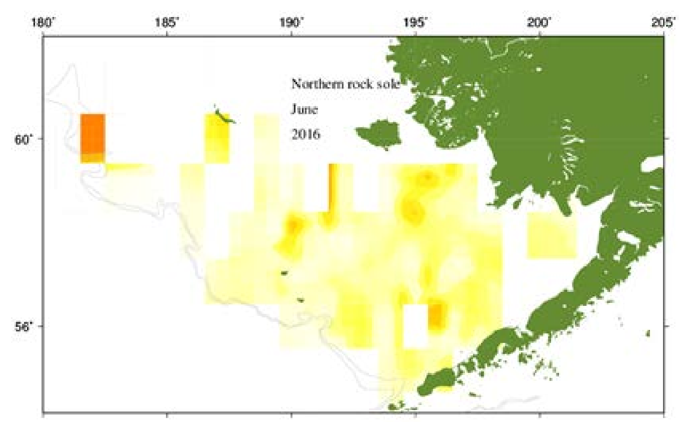
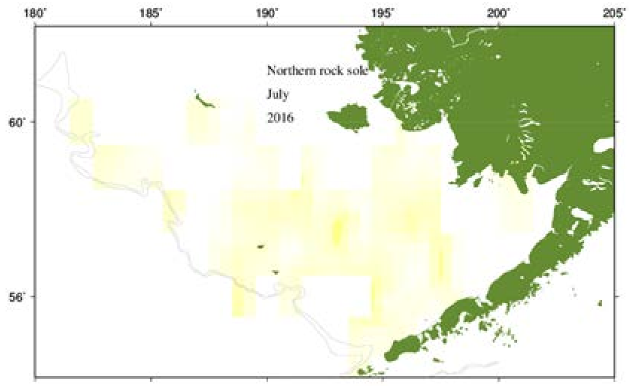
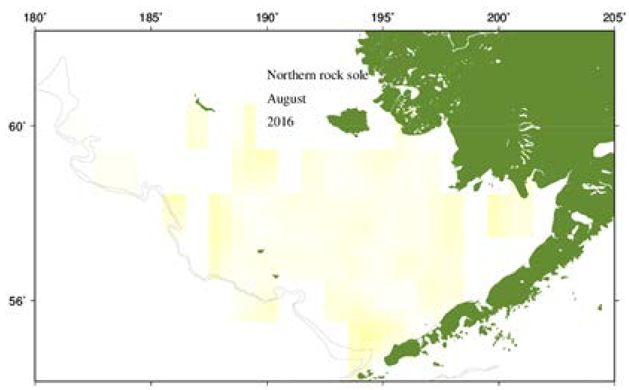


Figure 8.3—Continued.





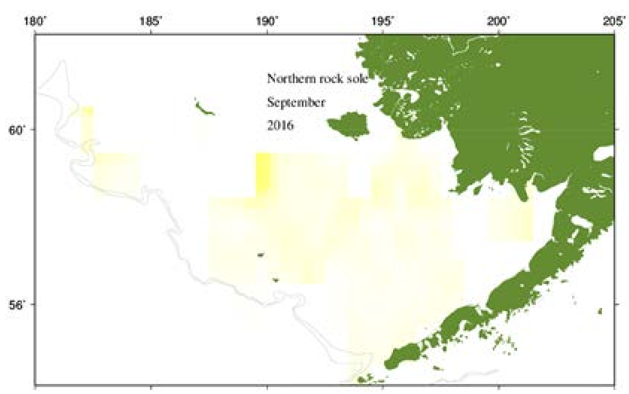


Figure 8.3—Continued.

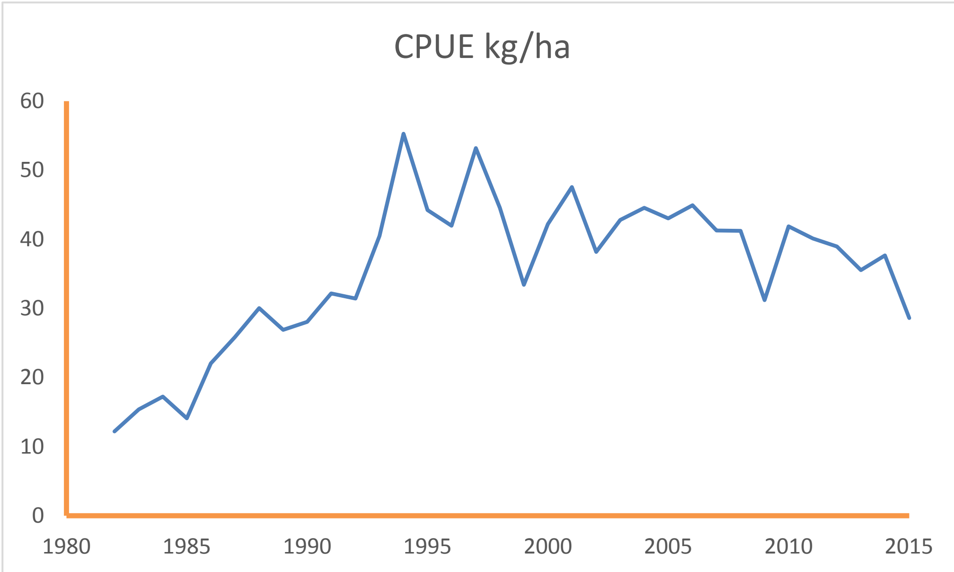


Figure 8.4—Catch per unit effort of *Lepidopsetta polyxystra* and *Lepidopsetta bilineata* (kg/ha) from Bering Sea shelf trawl surveys, 1982-2016.

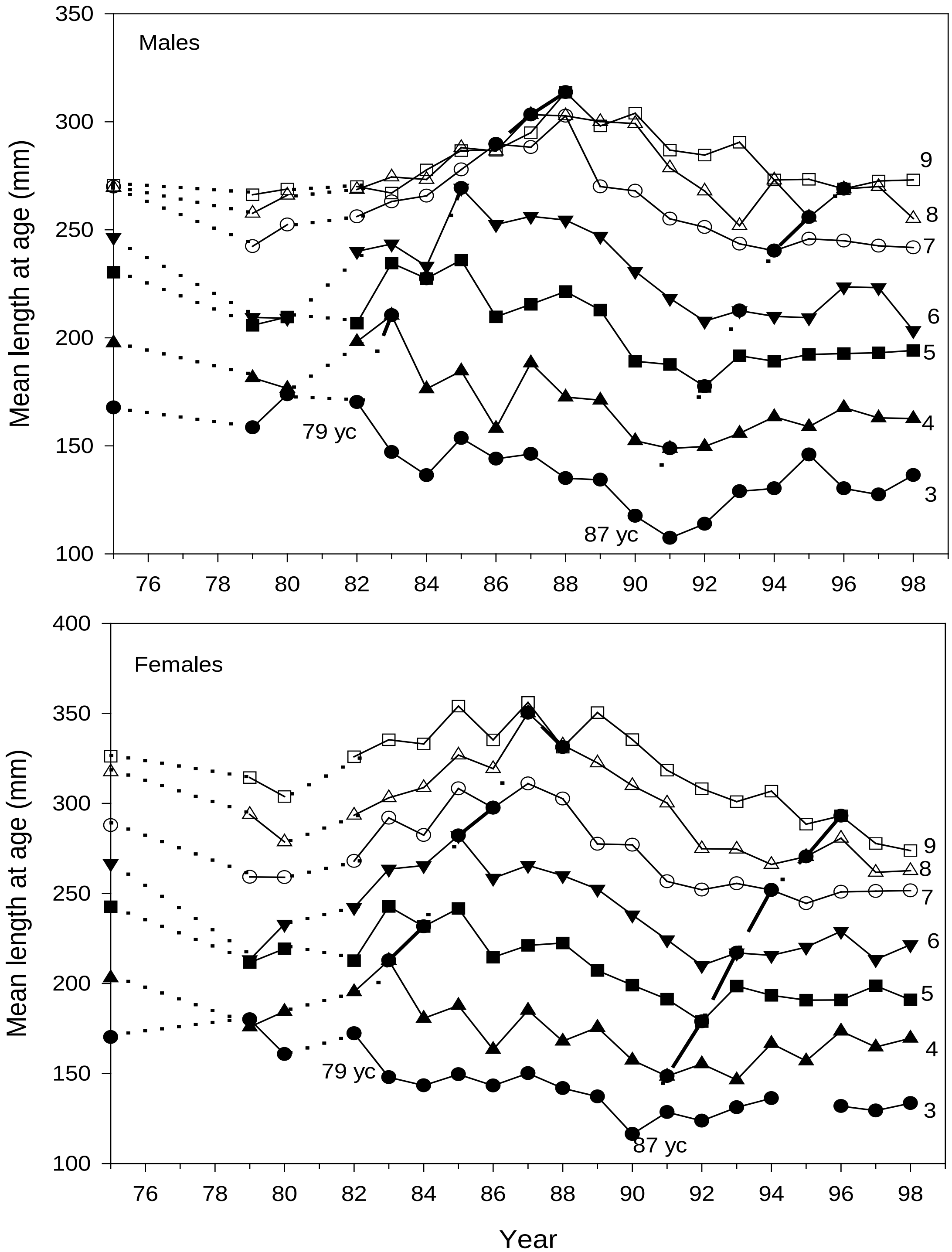


Fig. 8.5. Mean lengths at age (mm) by year of survey for eastern Bering Sea northern rocksole ages 3-9 for each sex during 1975-1998. Growth curves are shown for the 1979 (79yc) and 1987 (87yc) year classes. Dotted lines indicate no data during the period.
(From Walters and Wilderbuer, 2000, p.20)

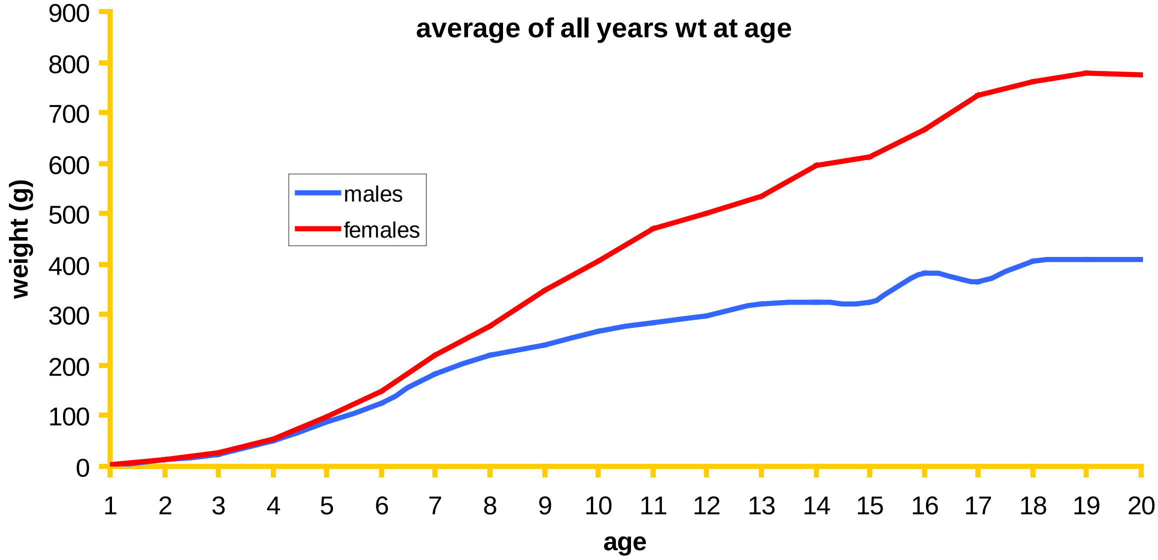
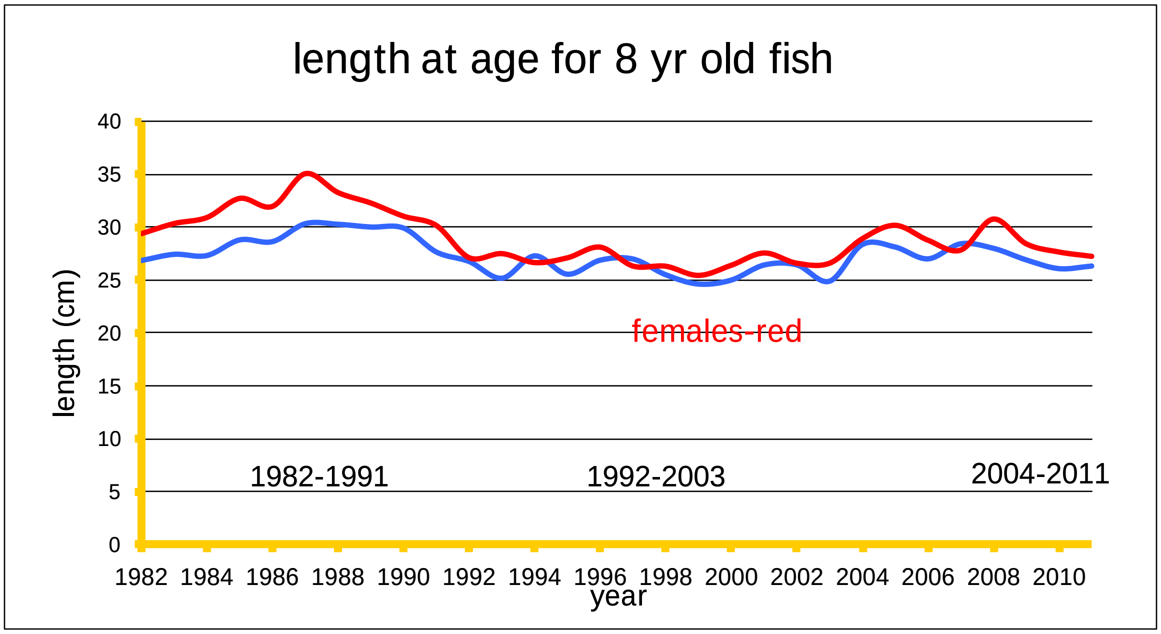


Figure 8.6-Mean weight-at-age for northern rock sole averaged over all years of survey age data.



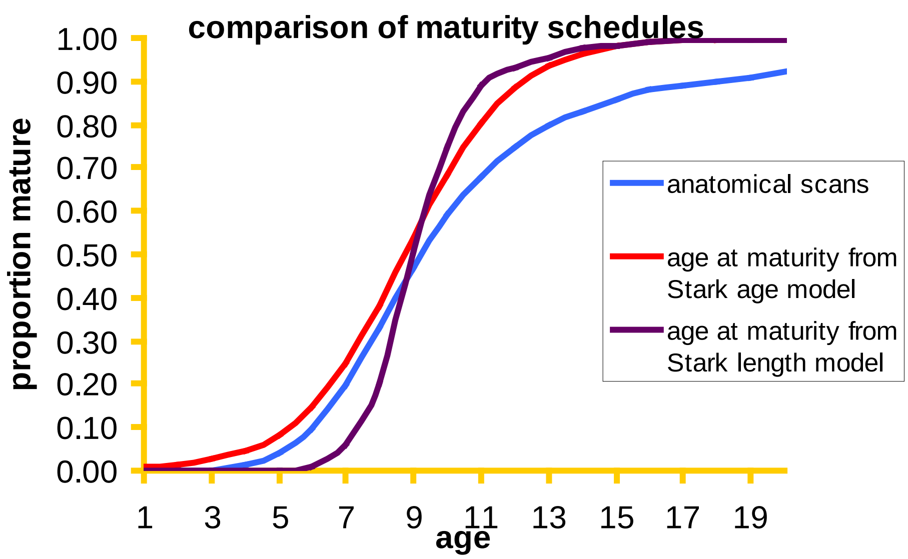


Fig. 8.7-Time-varying length-at-age for 8 year old northern rock sole with 3 time periods identified for modeling growth differently (top panel). Maturity schedule for northern rock sole from three methods (bottom panel). Stark (2012) length model, based on histology, is used in the stock assessment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

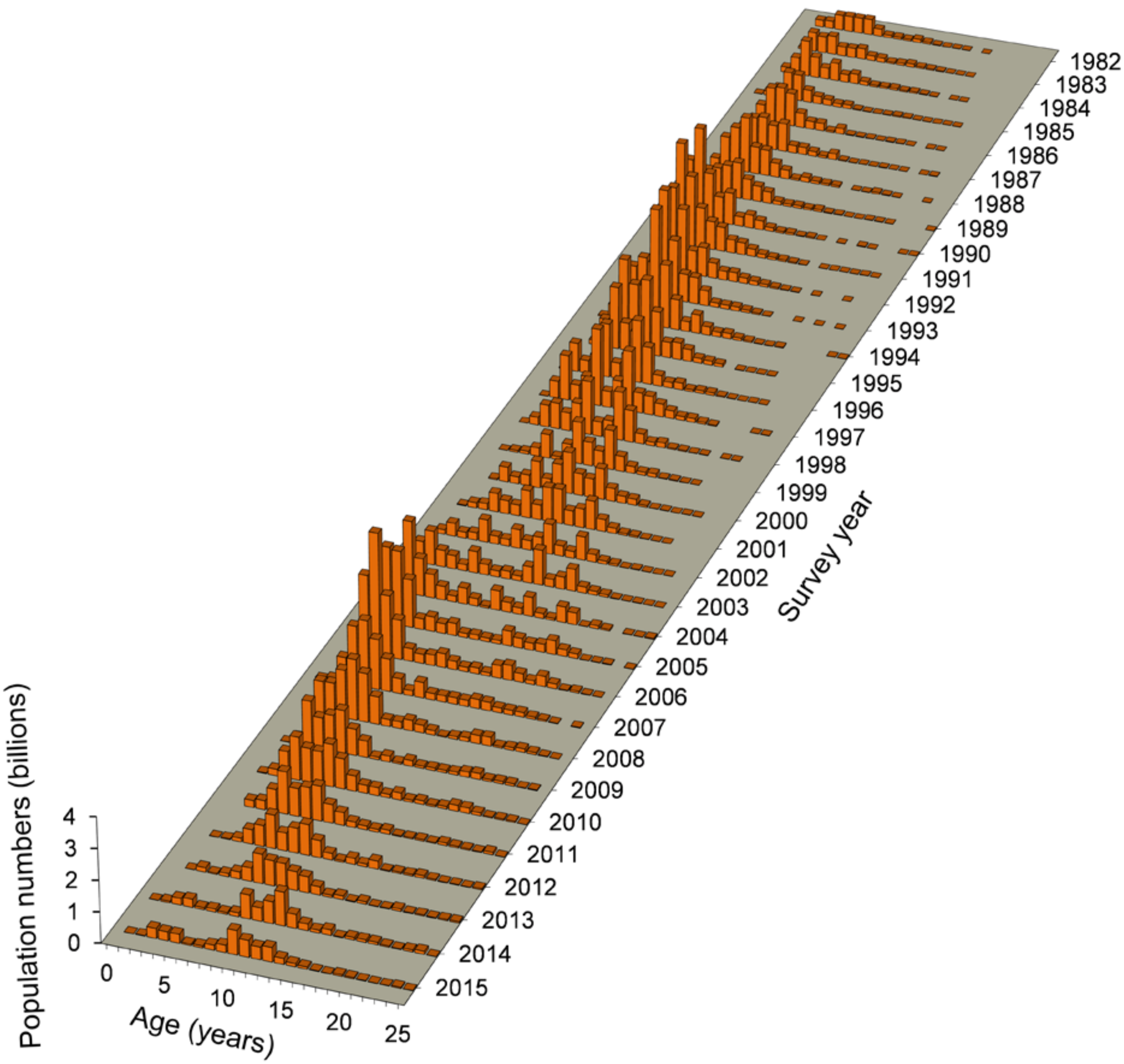


Figure 8.8—Age composition of northern rock sole from the AFSC annual trawl survey.

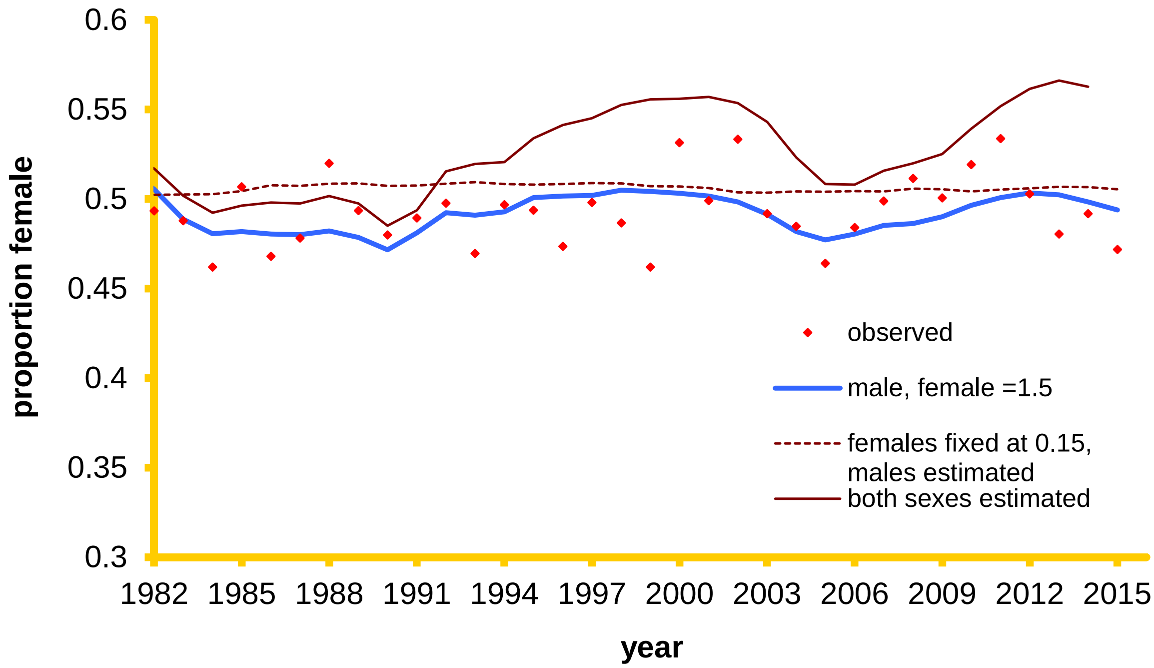


Figure 8.9—Fits to the population sex ratio from the results of Models 1, 2 and 3.

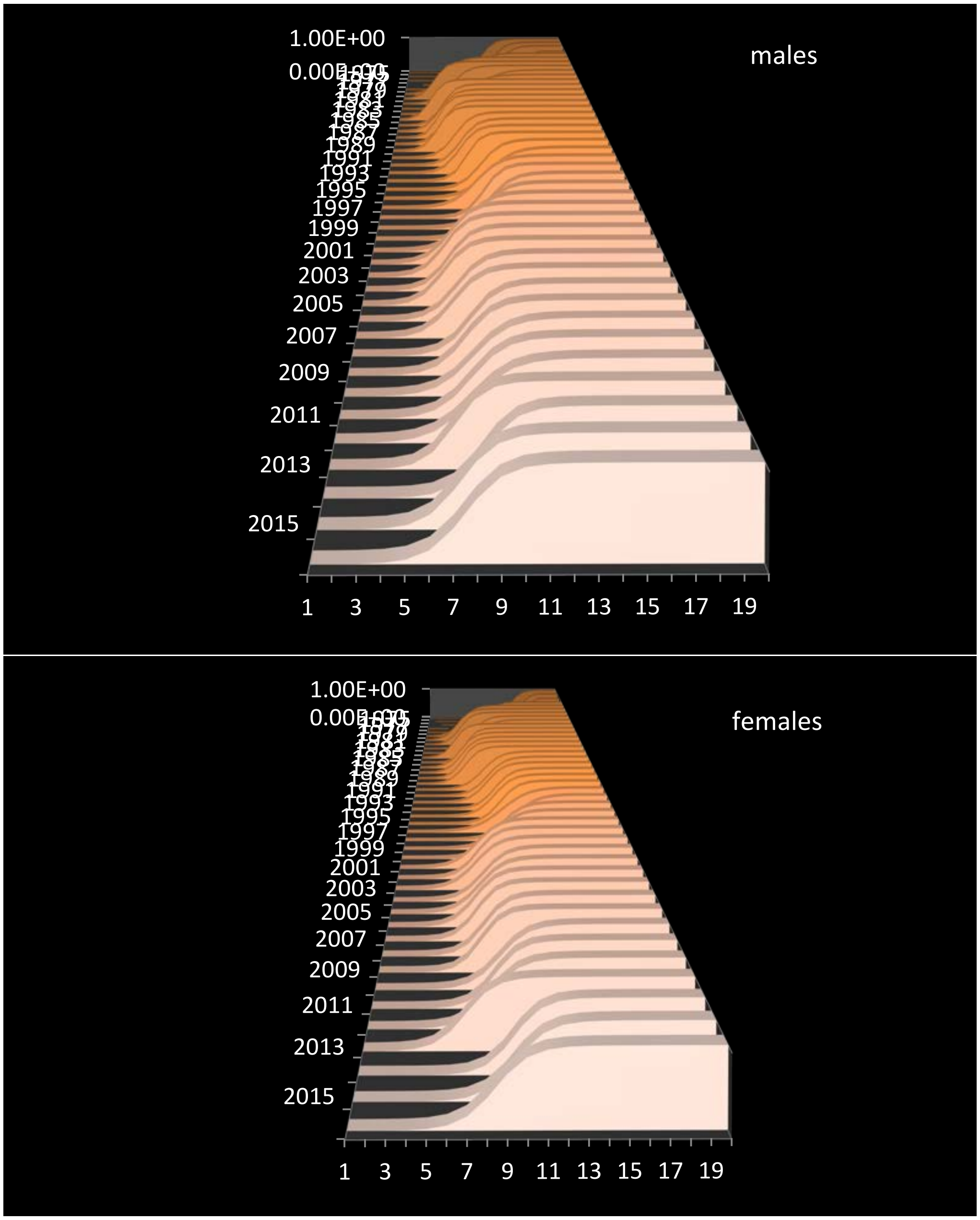
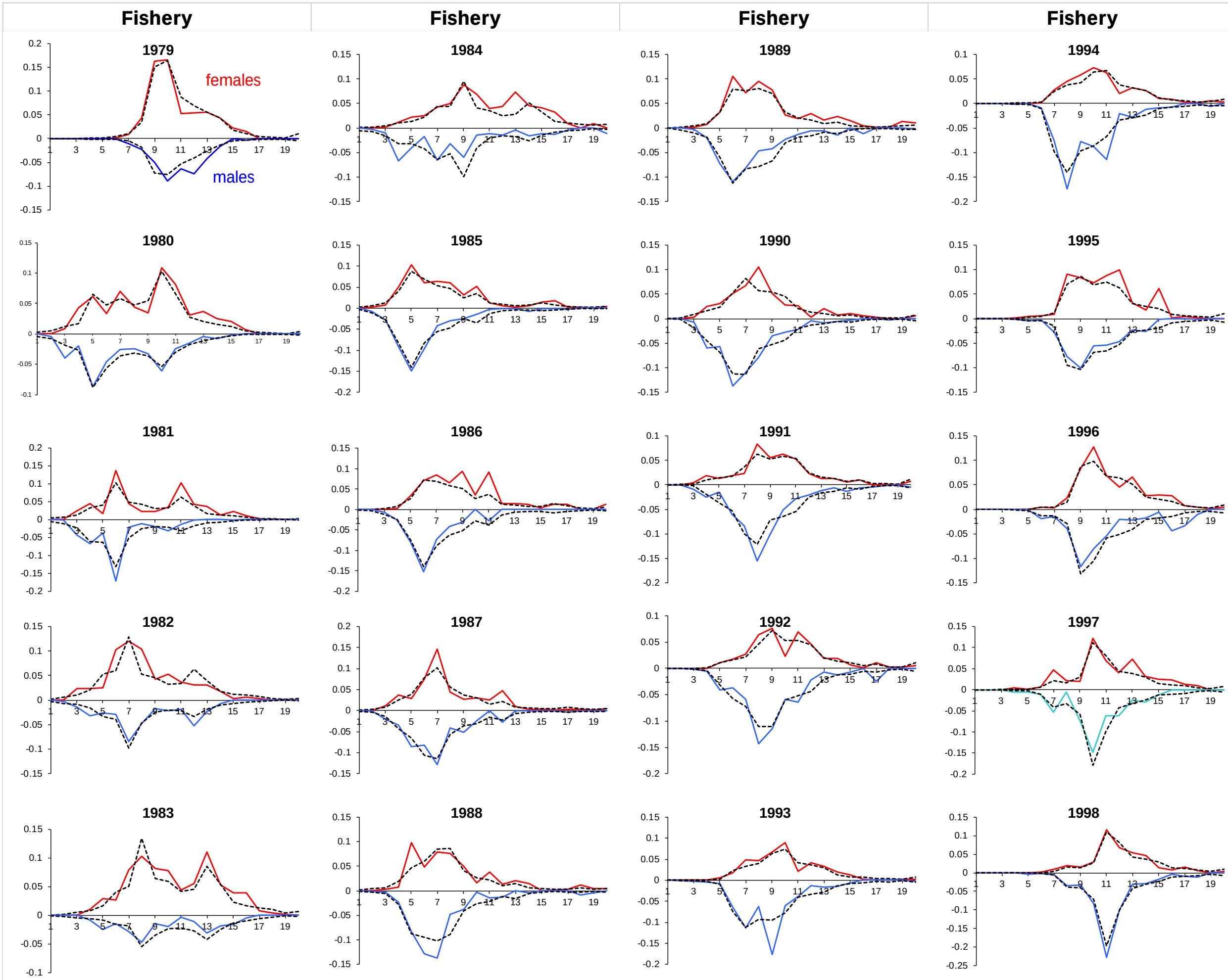


Figure 8.10—Stock assessment model estimates of fishery selectivity at age, by year and gender.

Figure 8.11—BSAI 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).


Fishery
Fishery
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Fishery
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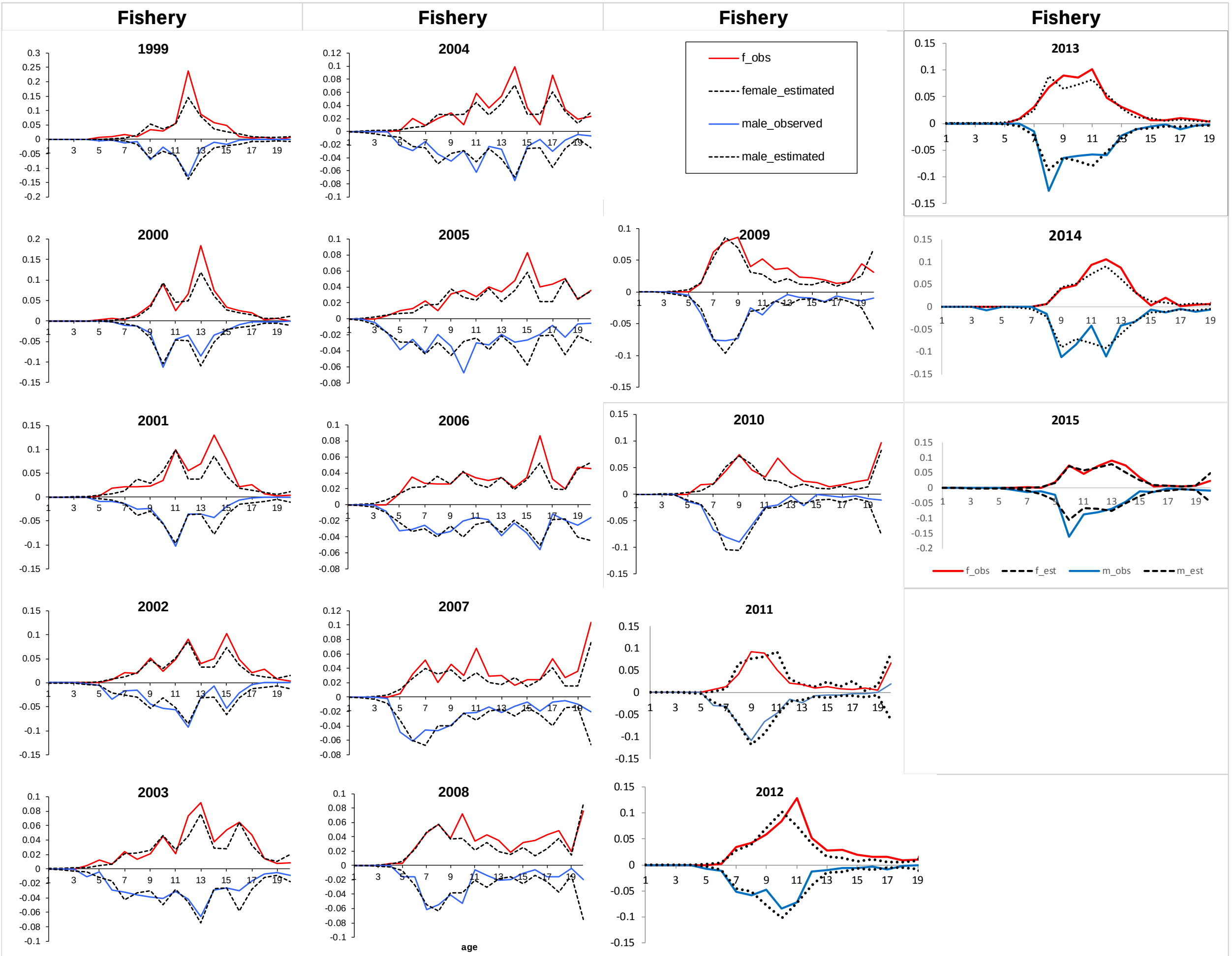


Figure 8.12—BSAI stock assessment model 15.1 fit to the fishery and survey age compositions, by sex.

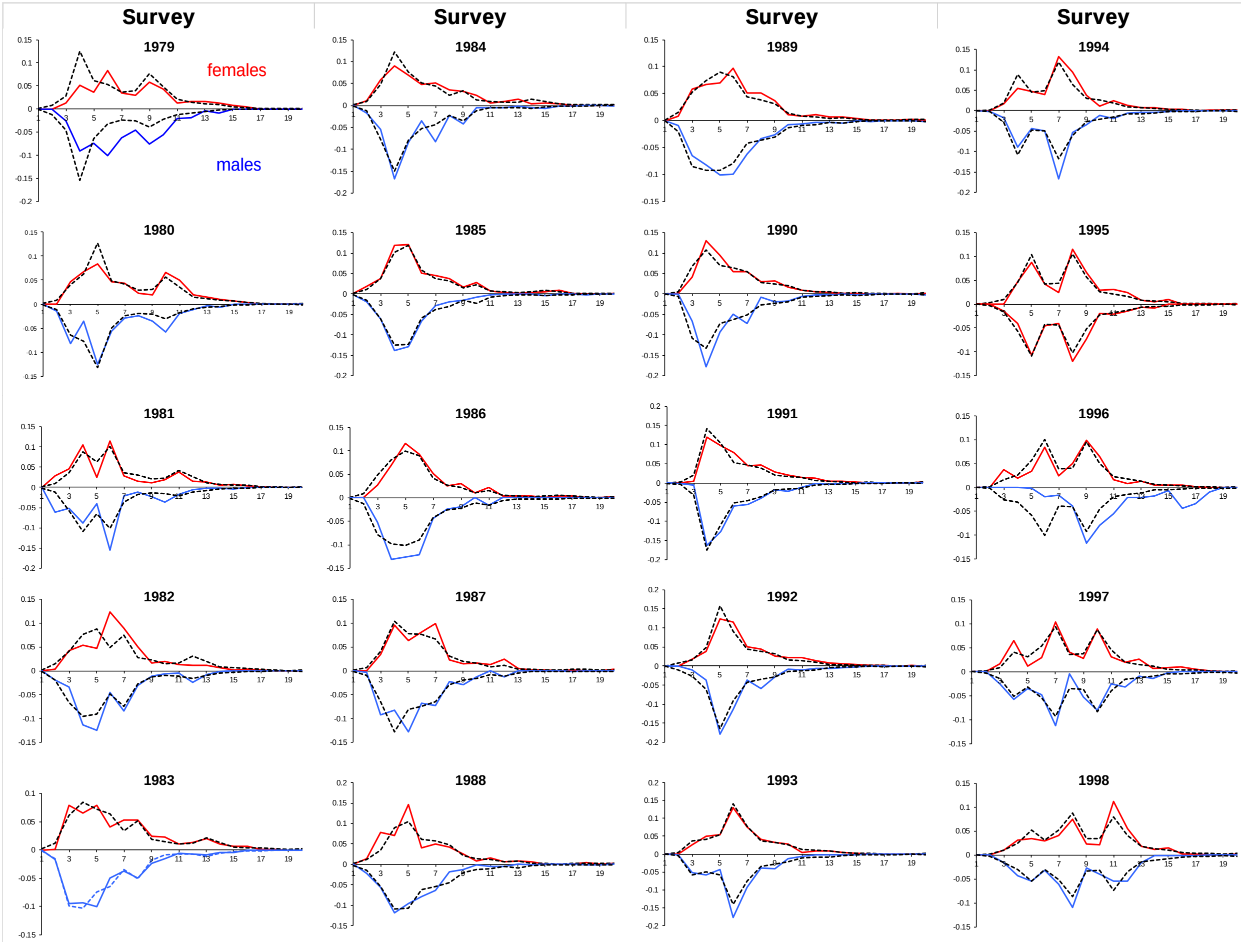


Figure 8.12—continued.

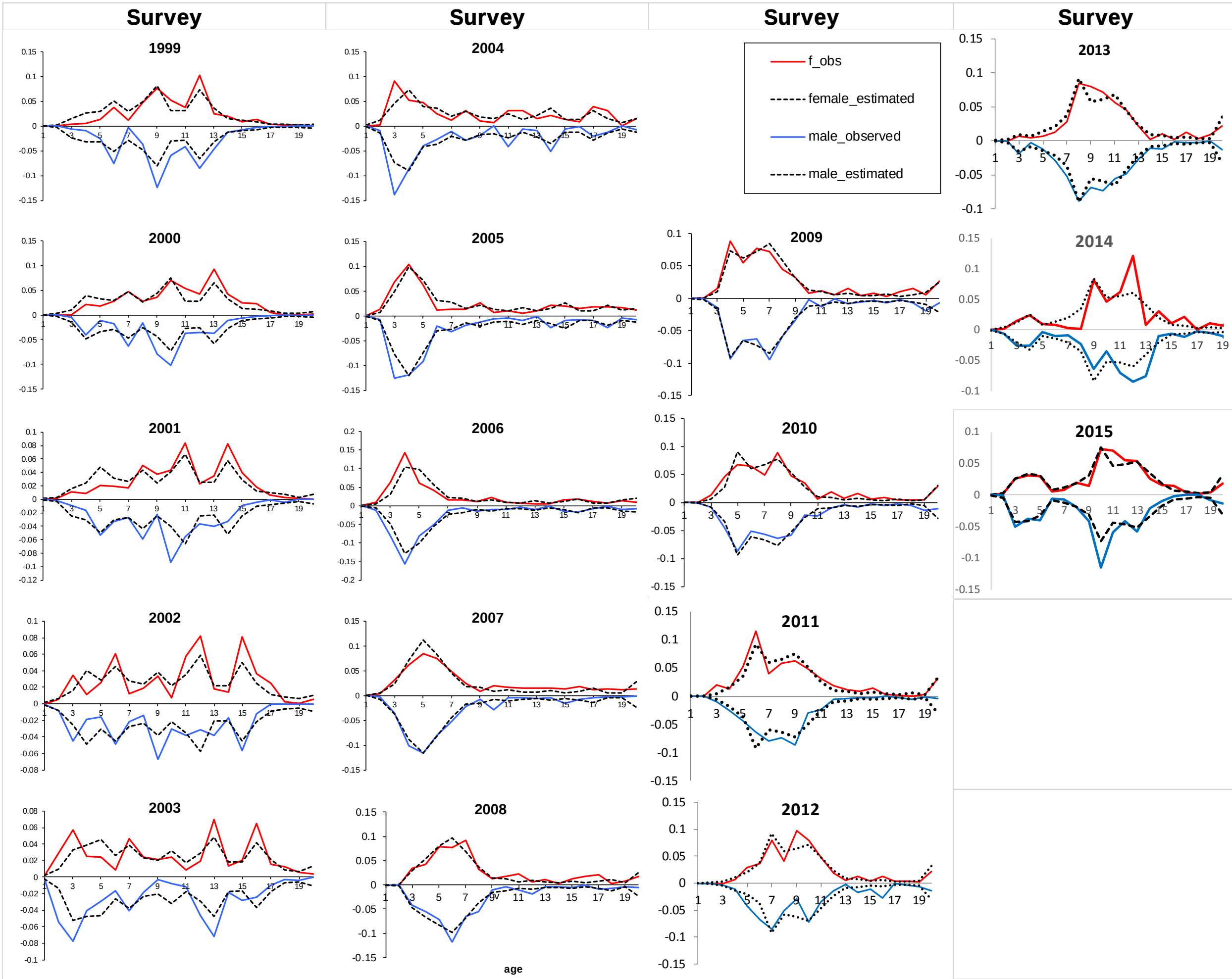


Figure 8.12—continued.

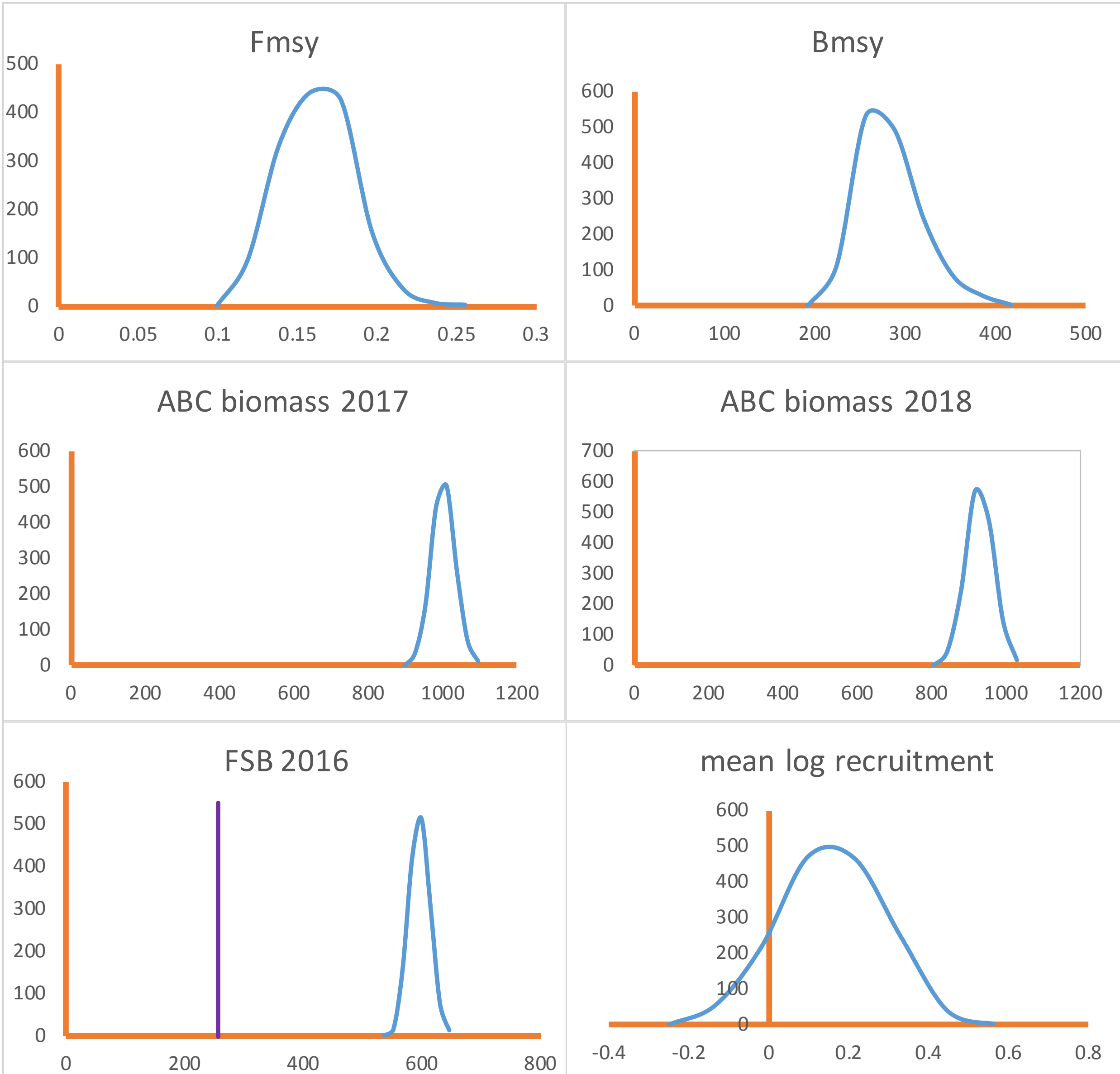


Figure 8.13—Posterior distributions of some selected model estimates from the preferred BSAI stock assessment model 15.1.

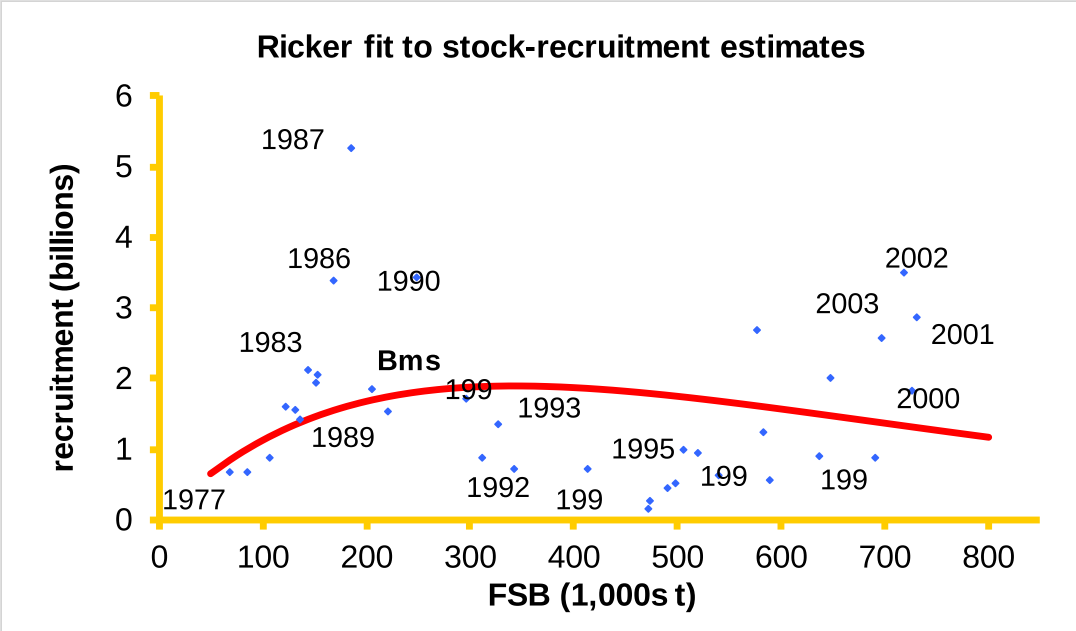


Figure 8.14—Ricker (1958) model fit to spawner-reruit estimates 1978-2010 from Model 1.

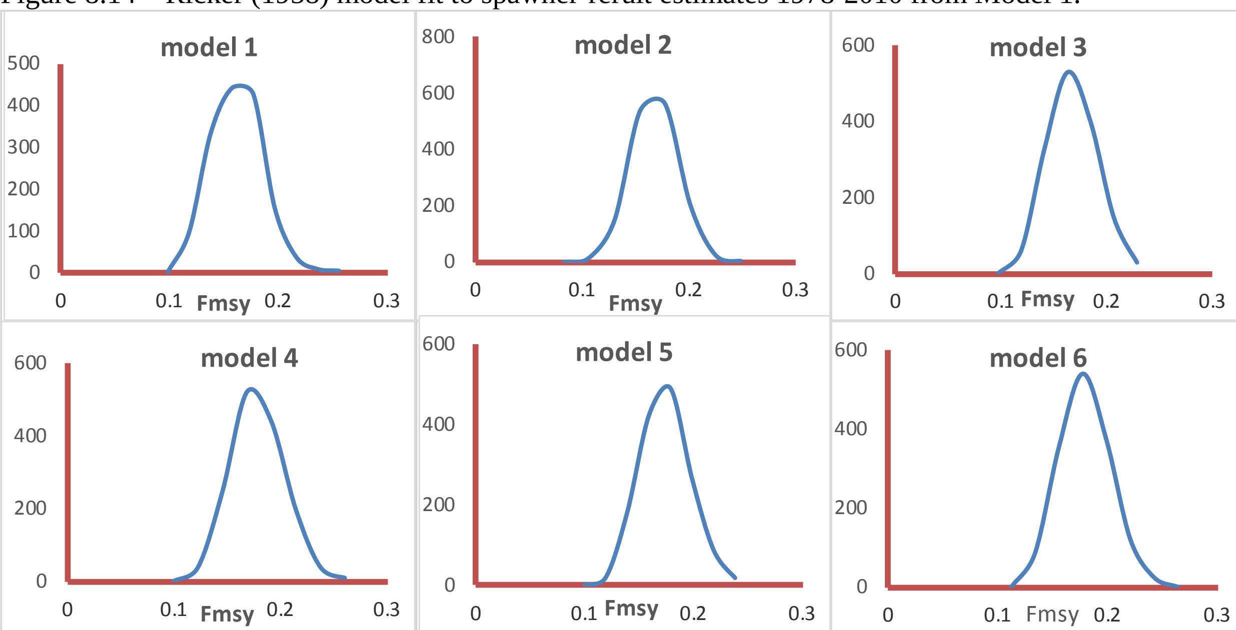


Figure .15—Posterior distributions of F_{msy} from 6 of the models considered in the analysis.

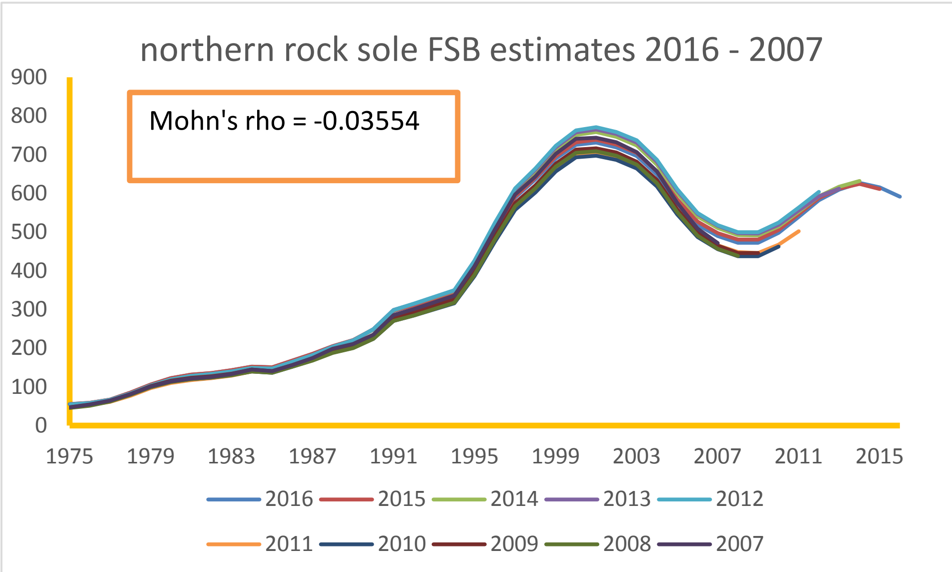


Figure 8.16. Retrospective plot female spawning biomass from 2003-2015. Mohn's rho = -0.03554.

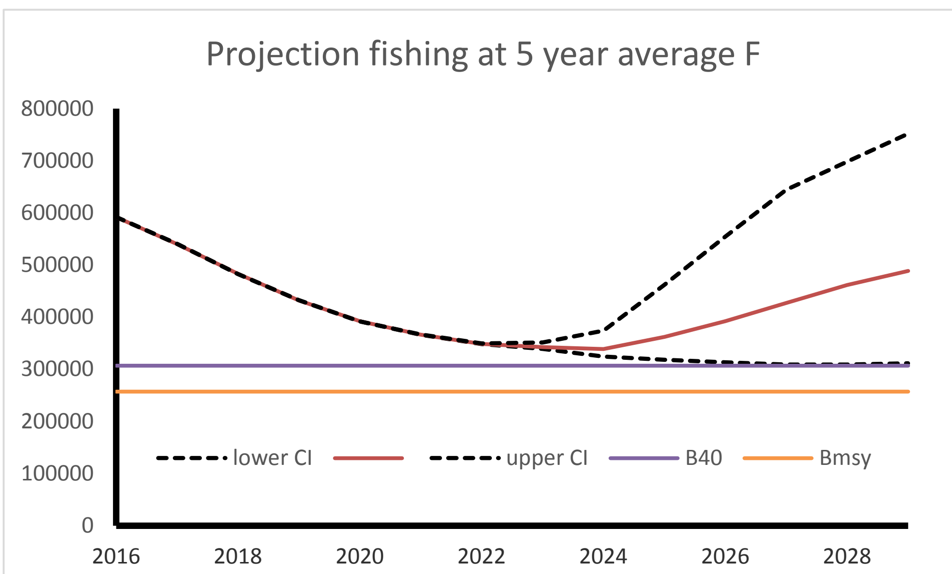


Figure 8.17—Projection of rock sole female spawning biomass when fishing each future year at the average F of the past five years.

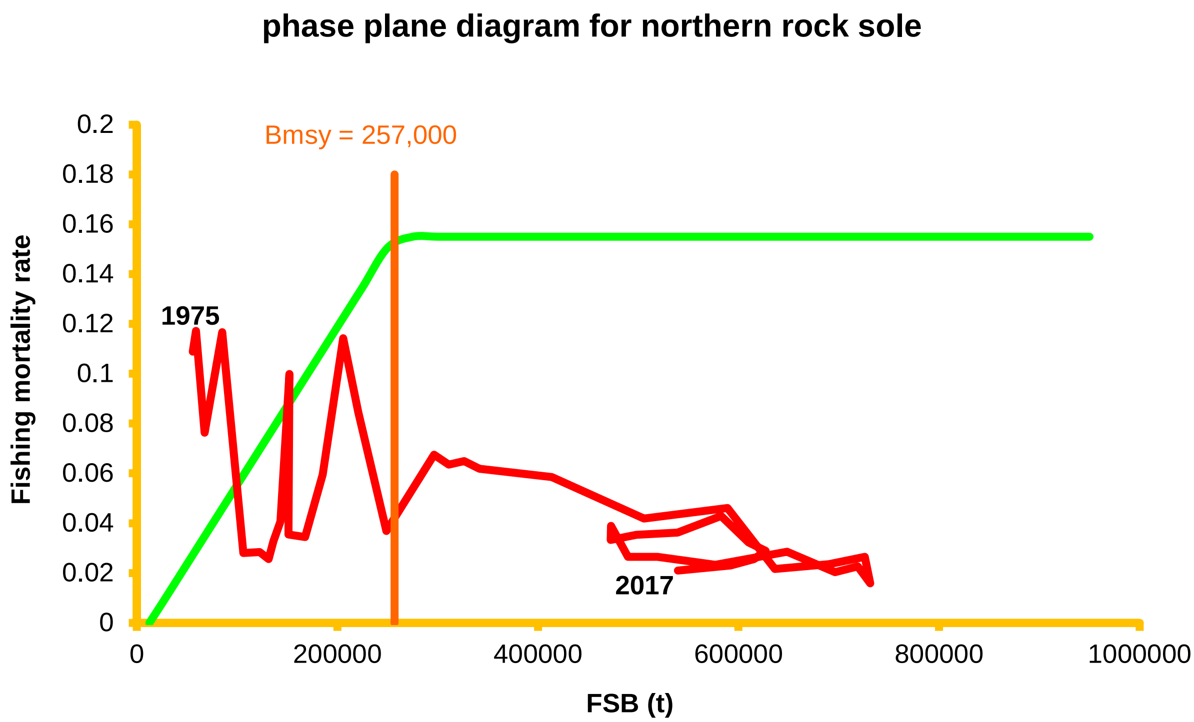


Figure 8.18—Phase-plane diagram of female spawning biomass relative to the harvest control rule.

Appendix

Estimating Northern Rock Sole recruitment in the last (most recent) 6 years of the assessment using environmental covariates

Dan Cooper, Lauren Rodgers and Tom Wilderbuer

Difficulties exist in estimating northern rock sole recruitment at young ages since they do not appear in BSAI survey catches until age 3 and not in survey age sampling until age 4 or 5. They are estimated to be 25 and 40% selected by the survey trawl (males and females respectively) at age 3 and 95 and 98% selected at age 5. The age 4 and 5 fish that do end up in the age samples are quite rare, typically only 7 fish out of 500 on an annual basis. Therefore there is not a lot of information to inform the stock assessment model estimates of year class strength for the last (most recent) 6 years. Some assessments provide estimates for the last 3 years by using an average of the estimated values to provide more credible values of year class strength. Here we propose to use two environmental covariates in regression modeling to estimate the unknown recruitment, and then compare those estimates with future estimates derived from fitting full age composition data in the stock assessment model.

Studies on the influence of environmental variables on BSAI northern rock sole recruitment have shown that both on-shelf springtime winds (Wilderbuer et al. 2002, Wilderbuer et al. 2013) and above average water-temperatures in nursery areas (Cooper et al. 2014, Cooper and Nichol 2016) are positively correlated with northern rock sole recruitment. Spring wind direction was obtained from the Ocean Surface Current Simulation Model (OSCURS) and was classified as either on- or across-shelf or off-shelf, depending on the ending longitude position after 90 days of drift starting from a locale in a known spawning area. Water temperature effects were calculated from the percent of the known northern rock sole nursery area that is in the cold pool each year from survey temperature data. Both indexes extend back to 1982 for this analysis. Estimates of female spawning stock biomass were also included in the analysis for model runs when recruitment was estimated from a Ricker stock-recruitment model with environmental variables.

The analysis seeks to answer the following questions using multiple models.
Question: Do onshore winds and the size of the cold pool (as a percentage of the nursery area) affect recruitment of Northern Rock Sole?
Question: Does the effect of the cold pool on recruitment depend on the presence of favorable winds? (i.e. is there a significant interaction?)
Question: Does including wind and cold pool covariates in the stock-recruitment model improve predictions of age-4 recruitment?

How: Compare models by including single and multiple covariates in Ricker stock-recruitment models. To be parsimonious, it is worth comparing these to models without an assumed Ricker relationship, as well as more simple forecasting models. Test for an interaction between temperature and winds, because temperature may only matter if winds were onshore (i.e. the fish had to get there in the first place). Assess model performance using standard model-selection tools (e.g. AIC) as well as by using out-of-sample predictions and one-year-ahead forecasts.

We assess 13 models.

1) Ricker model
2) Ricker model with % cold pool covariate
3) Ricker model with wind covariate

4) Ricker model with % cold pool covariate + wind covariate
5) Ricker model with an interaction between % cold pool and wind (hypothesis is that the thermal conditions on the nursery grounds only matter if winds are favorable).
6) Same as above, but cold pool slope set to 0 if unfavorable winds.
7) Regression model with % cold pool
8) Regression model with wind
9) Regression model with % cold pool + wind
10) Regression model with interaction between % cold pool and wind.
11) Same as above, but cold pool slope set to 0 if unfavorable winds.
12) Previous year recruitment (t-1)
13) Running mean recruitment (t:(t-1))

We also considered GAMs, but they had overall poor predictive performance and were likely over-parameterized.

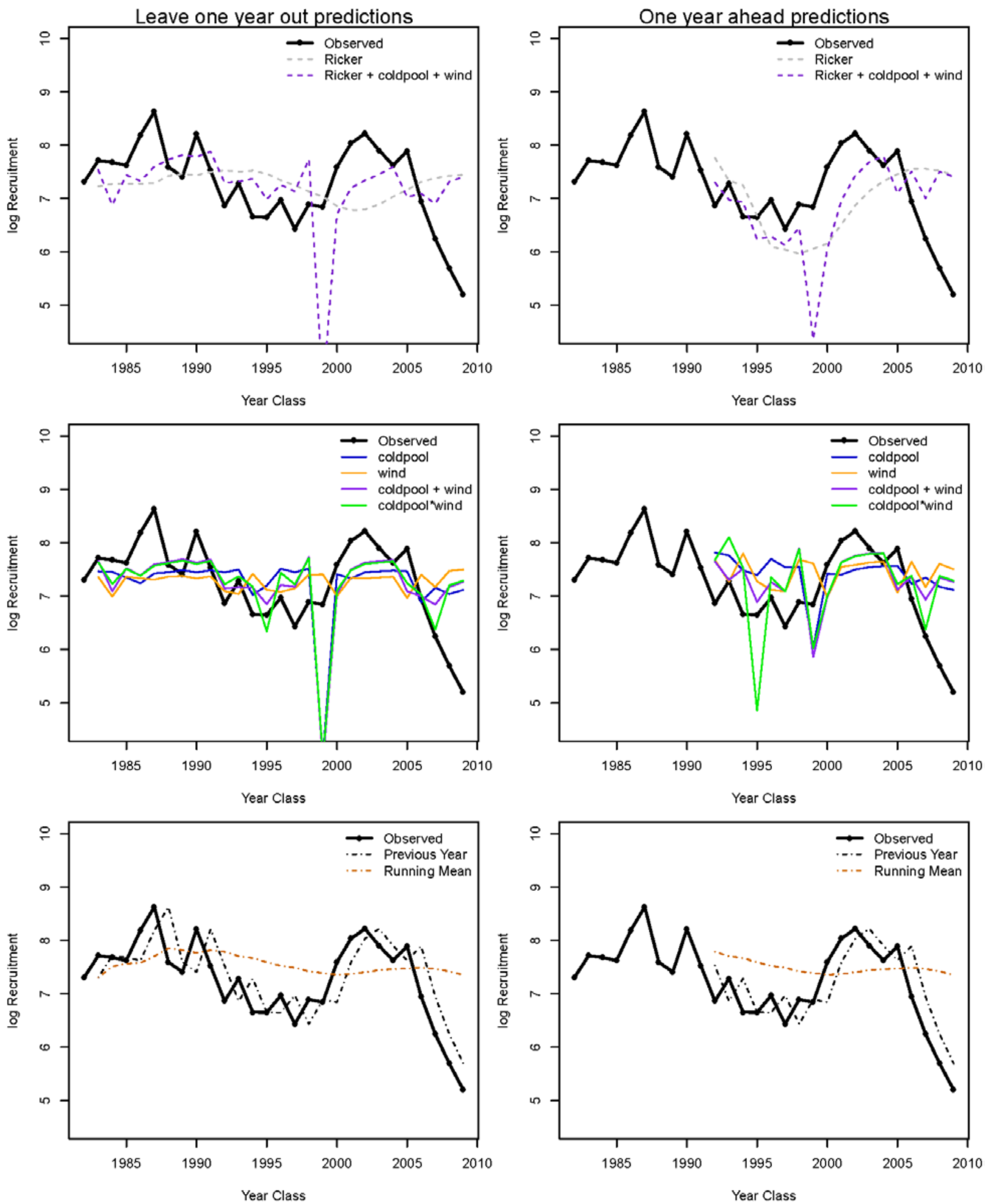
We compare model performance using traditional statistical methodology on all data (AIC), as well as by using two prediction methods. First we do a leave-one-year out analysis: we leave out one year of data, fit the model to the remaining 27 years of data, and then compare the prediction for the left-out year to the observed value. Second, we do a one-step-ahead forecast: beginning with year 11 (1992), we use the data collected up to that year to fit the model, and then compare the prediction for that year with the observation. We repeat for all remaining years. In the case of the final two models, the prediction methods will be identical.

We calculated the mean squared error for each prediction: (Observed – Predicted)^2. Because the models were fit using log(recruitment) as the response, the mean squared error is for the difference between the observed and predicted log(Recruitment). However, if the absolute difference between observed and expected recruitment is more relevant to management, the mean squared error can also be calculated based on the predicted recruitment on the real scale. In this case, Duan's smearing estimate for the log-normal re-transformation bias is used to adjust the mean of the exponentiated log-Recruitment to be equal to the mean recruitment. Both results are given in the table below.

Table: Mean squared error (MSE) is the mean of the squared prediction errors for each model. LOYO = Leave one year out. Lower values for MSE indicate lower prediction errors.

Model	df	AIC	MSE (LOYO, log-scale)	MSE (1 step ahead, log-scale)	MSE (LOYO, real scale)	MSE (1 step ahead, real scale)
Ricker	3	75.1	0.82	1.17	2,069,732	1,795,617
Ricker + coldpool	4	72.4	1.06	1.33	1,783,790	1,372,482
Ricker + wind	4	76.0	0.84	1.16	2,018,072	1,849,097
Ricker + coldpool + wind	5	71.3	1.04	1.19	1,547,723	1,160,685
Ricker + coldpool*wind	6	72.0	1.01	1.43	1,567,966	1,173,292
Ricker + coldpool*wind (slope=0)	5	72.9	1.08	1.25	1,639,531	1,276,978
coldpool	3	**64.8**	0.80	**0.76**	1,360,140	1,246,889
wind	3	70.0	**0.68**	0.90	1,623,021	1,510,268
coldpool + wind	4	**63.7**	0.80	**0.72**	**1,180,171**	**980,932**

coldpool*wind	5	**64.5**	**0.77**	0.90	**1,191,203**	1,219,212
coldpool*wind (slope=0)	4	**65.5**	0.83	**0.76**	**1,254,250**	**1,075,218**
Previous Year	NA	NA	**0.28**	**0.26**	1,371,833	**525,885**
Running Mean	NA	NA	**0.66**	0.89	1,531,793	1,299,166


Leave one year out predictions
One year ahead predictions
Observed
Ricker
Ricker + coldpool + wind
coldpool
wind
coldpool + wind
coldpool*wind
Previous Year
Running Mean
log Recruitment
Year Class

Cooper, D.W. and Nicol, D. 2016. Juvenile Northern Rock Sole spatial distribution and abundance are correlated in the eastern Bering Sea: spatially-dependent production linked to temperature. Marine Ecology Progress Series.

Cooper D, Duffy-Anderson J.T., Norcross B.L., Holladay B.A., Stabeno P.J. 2014. Northern rock sole (*Lepidopsetta polyxystra*) juvenile nursery areas in the eastern Bering Sea in relation to hydrography and thermal regimes. ICES Journal of Marine Science **72**, 515-527.

Wilderbuer, T., A., Hollowed, A., Ingraham, J., Spencer, P., Conner, L., Bond, N., Walters, G. 2002. Flatfish recruitment response to decadal climatic variability and ocean conditions in the eastern Bering Sea. Progress in Oceanography, **55**, 235-247.

Wilderbuer, T., W. Stockhausen, N. Bond. 2013. Updated analysis of flatfish recruitment response to climate variability and ocean conditions in the Eastern Bering Sea. Deep Sea Research II, **94**, 157-164.