Chapter 8. Assessment of the Northern Rock Sole stock in the Bering Sea and Aleutian Islands

Thomas K. Wilderbuer , James Ianelli and Daniel G. Nichol

Executive Summary

BSAI northern rock sole are managed on a biennial basis with full assessments completed in even years. The following changes have been made to this assessment relative to the last full assessment in November 2016:

Summary of changes to the assessment input

1) 2016 and 2017 fishery age composition.
2) 2016 and 2017 survey age composition.
3) 2017 and 2018 trawl survey biomass point estimates and standard errors.
4) Estimate of catch (t) for 2017 and 2018.
5) Estimate of retained and discarded portions of the 2017 catch.

Summary of Results

The 2018 bottom trawl survey point estimate is a 21% decrease from the 2017 estimate. These two estimates are the lowest in the past 25 years and have the effect of lowering the assessment model time series abundance estimates relative to the last full assessment conducted in 2016. 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. Model 15.1 is the preferred model evaluated in this assessment. Models 18.1 through 18.3 represent Model runs made to examine alternate states of nature for contrast to the primary models results. Ensemble modeling was also investigated.

Quantity	As estimated or *specified last* year for: 2018	2019	As estimated or *recommended this* year for: 2019	2020
M (natural mortality rate)	0.15	0.15	0.15	0.15
Tier	1a	1a	1a	1a
Projected total (age 6+)	923,200	852,000	828,000	1,001,400
Female spawning biomass (t)	472,200	413,300	417,800	338,300
Projected				
B_0	678,310		515,680	
B_{MSY}	257,000	257,000	186,000	186,000
F_{OFL}	0.16	0.16	0.147	0.147
$maxF_{ABC}$	0.155	0.155	0.144	0.144
F_{ABC}	0.155	0.155	0.144	0.144
OFL (t)	147,300	136,000	122,000	147,500
maxABC (t)	143,100	132,000	118,900	143,700
ABC (t)	143,100	132,000	118,900	143,700
Status	As determined *last* year for: 2016	2017	As determined *this* year 2017	2018
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

The northern rock sole stock is not overfished or approaching overfishing

Responses to SSC and Plan Team Comments on Assessments in General

In this section, we list new or outstanding comments on assessments in general from the last full assessment in 2017.

"The SSC recommends that, for those sets of environmental and fisheries observations that support the inference of an impending severe decline in stock biomass, the issue of concern be brought to the SSC, with an integrated analysis of the indices in future stock assessment cycles. To be of greatest value, to the extent possible, this information should be presented at the October Council meeting so that there is sufficient time for the Plan Teams and industry to react to the possible reduction in fishing opportunity." (SSC October 2017)

To facilitate a coordinated response to this request, the co-chairs and coordinators of the BSAI and GOA Groundfish Plan Teams, with concurrence from stock assessment program leadership at the AFSC, have suggested that authors address it by using the previous year's Ecosystem Status Report (ESR) as follows:

"No later than the summer of each year, the lead author of each assessment should review the previous year's ESR and determine whether any factor or set of factors described in that ESR implies an impending severe decline in stock/complex biomass, where "severe decline" means a decline of at least 20% (or any alternative value that may be established by the SSC), and where biomass is measured as spawning biomass for Tiers 1-3 and survey biomass as smoothed by the standard Tier 5 random effects model for Tiers 4-5. If an author determines that an impending severe decline is likely and if that decline was not anticipated in the most recent stock assessment, he or she should summarize that evidence in a document that will be reviewed by the respective Team in September of that year and by the SSC in October of that year, including a description of at least one plausible mechanism linking the factor or set of factors to an impending severe decline in biomass, and also including an estimate or range of estimates regarding likely impacts on ABC. In the event that new survey or relevant ESR data become

available after the document is produced but prior to the October Council meeting of that year, the document should be amended to include those data prior to its review by the SSC, and the degree to which they corroborate or refute the predicted severe decline should be noted, with the estimate or range of estimates regarding likely impacts on ABC modified in light of the new data as necessary."

"Stock assessment authors are encouraged to work with ESR analysts to identify a small subset of indicators prior to analysis, and preferably based on mechanistic hypotheses." (SSC October 2018)

Four papers have been published that analyze the relationship between 2 environmental indices and recruitment strength. This work has been formally analyzed in models that combine both indices in a fifth paper that is summarized in the Appendix section of this report. Stock assessment authors would welcome the chance to work with an ESR analysis to think about indicators.

"The SSC also recommends explicit consideration and documentation of ecosystem and stock assessment status for each stock ... during the December Council meeting to aid in identifying stocks of concern." (SSC October 2017)

Clarification during December 2017 SSC meeting and then re-clarified during June 2018 SSC meeting. In the interest of efficiency, the clarification from the December 2017 minutes is not included here. The relevant portion of the clarification from the June 2018 minutes reads as follows:

"This request was recently clarified by the SSC by replacing the terms 'ecosystem status' and 'stock assessment status' with 'Ecosystem Status Report information' and 'Stock Assessment Information,' where the potential determinations for each will consist of 'Okay' and 'Not Okay,' and by issuing the following guidance:

- *The SSC clarifies that 'stock assessment status' is a fundamental requirement of the SAFEs and is not really very useful to this exercise, because virtually all stocks are never overfished nor is overfishing occurring.*
- *Rather the SSC suggests that recent trends in recruitment and stock abundance could indicate warning signs well before a critical official status determination is reached. It may also be useful to consider some sort of ratio of how close a stock is to a limit or target reference point (e.g., B/B35). Thus, additional results for the stock assessments will need to be considered to make the 'Okay' or 'Not Okay' determinations.*
- *The SSC retracts its previous request for development of an ecosystem status for each stock/complex. Instead, while considering ecosystem status report information, it may be useful to attempt to develop thresholds for action concerning broad-scale ecosystem changes that are likely to impact multiple stocks/complexes.*
- *Implementation of these stock and ecosystem determinations will be an iterative process and will require a dialogue between the stock assessment authors, Plan Teams, ecosystem modelers, ESR editors, and the SSC."*

"The Teams recommend that the terms 'current and future ecosystem condition' and 'current and future stock condition' be used in place of 'ESR information' and 'stock assessment information'." (Plan Team September 2018)

"The SSC recognized that because formal criteria for these categorizations have not been developed by the PT, they will not be presented in December 2018." (SSC October 2018)

The iterative process described in the final bullet above was scheduled to begin at the September 2018 meeting of the Joint BSAI and GOA Plan Teams. However, no formal criteria for these categorizations were developed by the Plan Teams in September 2018. As specified by the SSC in October, we will not provide determinations for northern rock sole at this time and will provide determinations when formal criteria are established.

"The Team recommended that the authors simply report in words or a table whether catches exceed ABC as an indicator for "partial update" stocks. (Plan Team November 2017)

Does not apply to northern rock sole SAFE report since it is not a "partial update stock".

"The SSC reminds authors of the need to balance the desire to improve model fit with increased risk of model misspecification." (SSC December 2017)

Clarification: *"In the absence of strict objective guidelines, the SSC recommends that thorough documentation of model evaluation and the logical basis for changes in model complexity be provided in all cases."* (SSC June 2018)

This is an important point even though the current assessment recommends the same base model as in past years with the same number of parameters estimated. Attempts to improve fit to data in the future needs to consider the trade-offs of model mis-specification and model fit and to also consider mechanisms that make sense with respect to the biology of the species.

"Report a consistent metric (or set of metrics) to describe fish condition among assessments and ecosystem documents where possible." (SSC December 2017)

We do not yet report fish condition for northern rock sole. However, if we do report this metric in the future we will be consistent with the weight-length residual approach to report fish condition as described in the Ecosystem Status Report.

"Projections ... clearly illustrate the lack of uncertainty propagation in the 'proj' program used by assessment authors. The SSC encourages authors to investigate alternative methods for projection that incorporate uncertainty in model parameters in addition to recruitment deviations. Further, the SSC noted that projections made on the basis of fishing mortality rates (Fs) only will tend to underestimate the uncertainty (and perhaps introduce bias if the population distribution is skewed). Instead, a two-stage approach that first includes a projection using F to find the catch associated with that F and then a second projection using that fixed catch may produce differing results that may warrant consideration." (SSC December 2017)

Please see model evaluation section for alternative Tier 1 projection with uncertainty in F.

"The Teams recommend that the appropriate use, or non-use, of new model based estimates in this assessment cycle be left to individual authors' discretion. The Teams further recommend that, if an author chooses to incorporate these into the assessment, the assessment should also contain appropriate comparative models and a full set of diagnostics." (Plan Team September 2018)

"The SSC supports the PT recommendation to make the use of model-based survey estimates at the individual author's discretion for 2018." (SSC October 2018)

This assessment did not utilize any model based survey estimates. In the future, model-based estimates produced by the Groundfish Assessment Program (GAP) will be used to fit the assessment model as a contrast to the current use of survey estimates. A working group was formed to investigate criteria for use of the model-based estimates in a variety of groundfish life histories. We will consult the guidelines from this working group for determining the usefulness of the model-based estimates for northern rock sole when they become available.

"The SSC also noted that, in order to save resources, authors should not conduct additional assessments beyond the prioritized schedule unless they specifically trigger one or more of the criteria identified." (SSC October 2018)

OK, we will not do that.

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

No comments were received specific to the northern rock sole stock at the December 2017 meeting. The SSC encouraged the authors to pursue ensemble modeling for this species at their October 2018 meeting. Ensemble modeling was investigated in this assessment.

INTRODUCTION

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

Centers of abundance 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 1989-2018 (domestic only) have averaged 48,600 t annually, well below ABC values. The size composition of the 2018 catch from observer sampling, by sex and management area, are shown in Figure 8.1 and the locations of the 2018 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 34% of the annual catch in 2018 (Fig 8.2). About 77% of the 2018 catch came from management areas 509 and 514 with the rest from areas 509, 513, 516, 517 and 521 (Fig 8.2). The 2018 catch is estimated at 28,065 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 20% of the 2018 ABC of 143,000 t and 60% of the 47,100 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 2018.

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 was 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 1987-2017 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 2017 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 1980-2017 (Table 8.4). The 2018 catch total used in the model is based on the 2018 catch rates from August through mid-September applied to fishing through the end of the year to provide an estimate of 2018 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 1982-94 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. From 2006 through 2010 the CPUE was in a slow decline but has become a steeper decline through 2018 resulting in a CPUE about level about half of the 2006 estimate.

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 2018 point estimate (1,051,503 t) of the Bering Sea surveyed area is 822,268 – 1, 280,739 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 24 years since the peak estimate of 1994, the survey estimates have averaged 1.9 million t with a peak value of 2.34 million t in 2001 and a low of 1.005 million t in 2018. The 2018 estimate is a 21% decline from 2017, the lowest estimate in the time-series since 1982. Overall, the survey indicates that the northern rock sole stock has been at a high and stable level since the mid-1990s but is about half that level now.

The 2018 Aleutian Islands biomass estimate of 44,119 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 1977-2018 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 updated and 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 3, 5 and 8 year old fish in Figure 8.6) as annual growth has been shown to be temperature dependent in flatfish chronologies (Matta et al. 2010). 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 to model the year effect on the changes in growth (Table 8.7). The 3 periods of growth method was abandoned for this assessment and instead the actual empirical data of weight-at-age from survey sampling for each age and year was used for ages 1-14. Ages 15-20 were smoothed using a 3 year running average.

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
45	184	84	2	0, 1 or 2 (optional)	0, 1 or 2 (optional)	315-319 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,

$$S_{a,t}^{f} = \left[1 + e^{\eta_t (a - \phi_t)}\right]^{-1}$$

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.

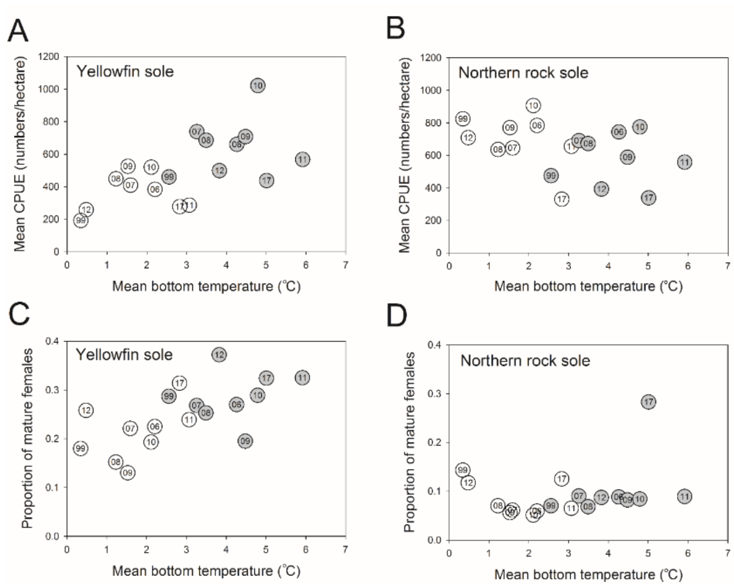
Natural Mortality

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. However, no relationship between survey CPUE and annual bottom temperature was found for BSAI northern rock sole in a recent analysis (Nichol et al., In final review, Fisheries Research).



In this assessment, catchability (q) was formulated by estimating q 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.

Model evaluation

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

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

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 15.1, preferred method based on guidance from a Plan Team stock recruitment workshop and report), the years of consecutive poor recruitment events (1989-2001) (Model 15.2), and the period of high recruitment during the 1980s, 1978-90 (Model 15.3). 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 15.1) and lower values were obtained (as expected) when the poor recruitment time-series (Model 15.2) was used. Model 15.3 (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, did 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 15.1) 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 the 2018 assessment, four models were selected for evaluation in an ensemble. One was based on the current accepted model in use (15.1) and the three others were nested in that they allow estimation of natural mortality for male northern rock sole (Model 18.1) followed by survey catchability (Model 18.2), and lastly a model same as 18.2 but with a selectivity offset for male northern rock sole (model 18.3). Whereas this set of models lacks strong structural differences, three key assumptions in Model 15.1 are evaluated with respect to uncertainty (i.e., male natural mortality, survey catchability, and sex-specific targeting in the fishery).

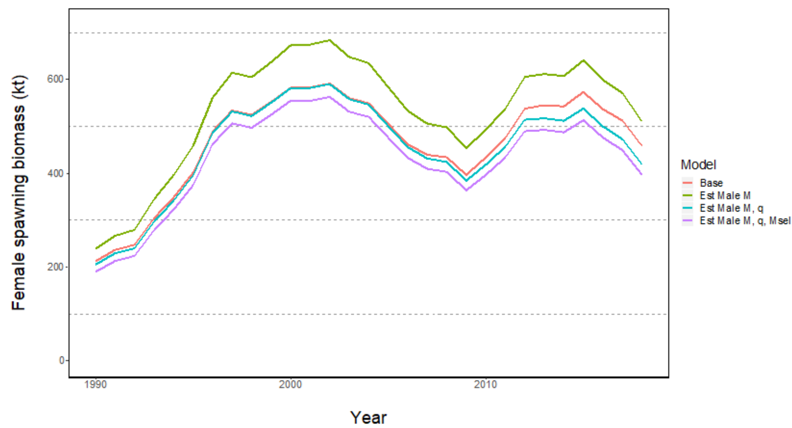
Table showing negative log-likelihood values relative to the four models and the ensemble (computed as a simple mean value). Lower values indicate a better fit

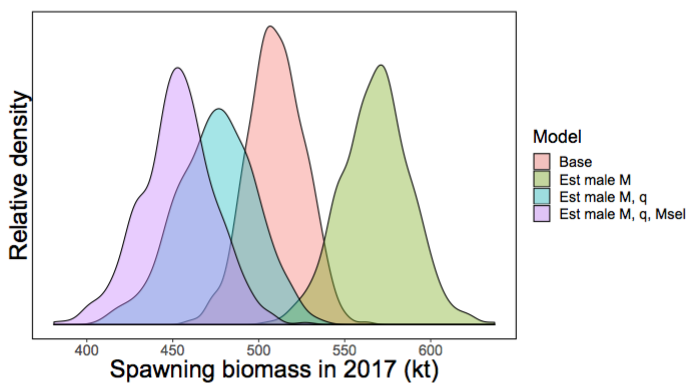
Model	Description	Number of parameters	Fishery age	Survey age	Survey biomass	Priors	Total
15.1	Base	366	706	630	70	167	1574
18.1	Est. male M	367	582	646	60	167	1473
18.2	Est. male M, q	367	571	642	53	176	1460
18.3	Est. male M, q, and male sel.	368	568	631	54	177	1448
18.4	*Ensemble*	*NA*	*607*	*637*	*59*	*172*	*1489*

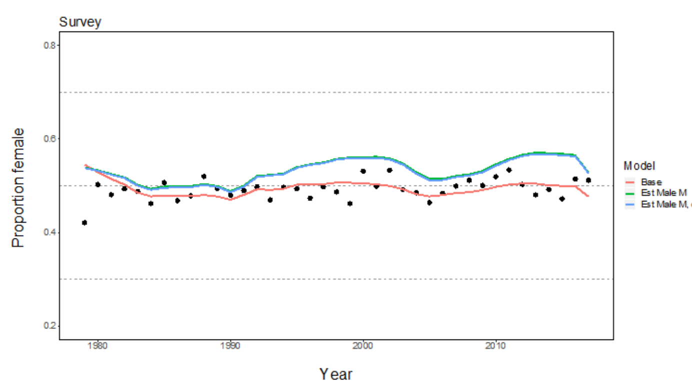
Table showing negative log-likelihood values relative to the four models and the ensemble (computed as a simple mean value) but with the minimum value subtracted off. Lower values indicate a better fit (and a value of zero indicates the best fit of the four models).

Model	Description	Number of parameters	Fishery age	Survey age	Survey biomass	Priors	Total
15.1	Base	366	138	0	17	0	125
18.1	Est. male M	367	14	16	6	0	25
18.2	Est. male M, q	367	3	11	0	9	11
18.3	Est. male M, q, and male sel.	368	0	1	1	10	0
18.4	*Ensemble*	*NA*	*39*	*7*	*6*	*5*	*40*

These results indicate that model 18.3 fits the data best with only 2 additional parameters. Although the support for 18.3 is strongest, for this assessment model 15.1 has been accepted and is recommended going forward for this year's ABC/OFL estimation (q is constrained to 1.5, M is fixed at values close to those estimated for each sex, and the model provides a better fit to the observed population sex ratio). In future years, Model 18.3 and/or an ensemble would seem appropriate.







Model Results

The 2018 bottom trawl survey point estimate is a 21% decline from the 2017 estimate. These two estimates are the lowest in the past 32 years and have the effect of lowering the time series abundance estimates relative to the 2017 assessment. The model results indicate that the stock condition has been at a high and stable level but in a steady decline for the past 4 years. The female spawning biomass has declined from a peak in 2015 as a result of the lack of good recruitment since the strong recruitment from the 2001-2003 and 2005 year classes that are presently past the age of maximum cohort biomass. The stock continues to be lightly harvested.

Fishing Mortality and Selectivity

The assessment model estimates of the annual fishing mortality on fully selected ages and the estimated annual exploitation rates (catch/total biomass) are given Table 8.13. The exploitation rate has averaged 3.9% from 1975-2018, 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 1.5 million t by 1996. Since then, the model indicates the population biomass was at a high level through 2012 before declining for 3 years and then increasing to a peak level in 2018. 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 (459,000 in 2018) but has been decreasing the last 4 years. As the strong year classes spawned in 2001-2004 have now matured the female spawning biomass has peaked and is projected to continue declining (Table 8.15). The model provides good fits to most of the strong year classes observed in the fishery and surveys during the time-series (Fig. 8.12).

The model 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 low estimates of 2017 and 2018. 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 2017 and 2018 estimates are the lowest since 1990 and fit by the model. The model fit is within the 95% confidence intervals of the survey biomass point estimates for 30 of the 36 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 geometric mean 6+ total biomass for 2019 at 828,000 t (including the 2018 catch estimated at 28,065 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. The 2014 year class, appearing as 3 year olds in the 2018 survey, may be historically strong and is predicted by the model to increase the stock (although only observed once).

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 15.1, 18.1, 18.2, 18.3 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.

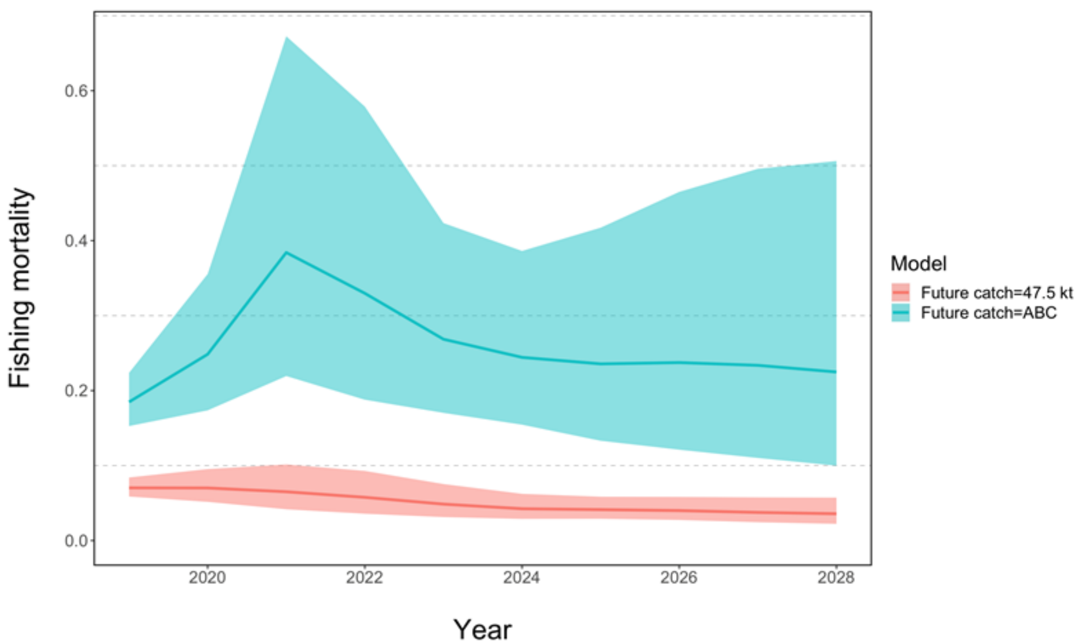
Acceptable Biological Catch

The SSC has determined that northern rock sole qualify as a Tier 1 stock and therefore the 2019-2021 ABC is estimated according to the FMP. The 2019 fishing mortality recommendation is the harmonic mean value of F_{MSY} such that $F_{ABC}=F_{har}=0.144$. The product of this value with the geometric mean of the 2019 6+ biomass estimate, as follows:

$B_{gm} = e^{\ln \hat{B} \; - \frac{cv^2}{2}}$, where B_{gm} is the geometric mean of the 2019 6+ biomass estimate, $\hat{B}$ is the point estimate of the projected 6+ biomass in a given future year, and cv is the coefficient of variation of the point estimate. For fishing mortality,

$\bar{F}_{har} = e^{\ln \hat{F}_{msy} - \frac{\ln sd^2}{2}}$, where $\bar{F}_{har}$ is the harmonic mean, $\hat{F}_{msy}$ is the mode of the F_{MSY} distribution and sd^2 is the square of the standard deviation of the F_{MSY} distribution. **For the recommended model 15.1 this results in a Tier 1 ABC of 118,900 t and an OFL of 122,000 t for 2019**. Projections to future years are provided in the following table (conditional on the catch assumed) with F_{ABC} and F_{OFL} at 0.144, and 0.147, respectively. For added precaution and given the unclear guidance on how to select future ABCs given unknown catches, we recommend using the ABCs corresponding to the assumed catches set equal to the ABC values. Incidentally, these catch trajectories result in future F's (given assessment and recruitment uncertainty) depicted in the in-text figure below (this was requested by the SSC at their December 2017 meeting).

Year	Catch assumed	ABC	OFL	SSB	Age6+ biomass
2019	118.9	118.9	122.0	417.8	828.0
2020	143.7	143.7	147.5	338.3	1,001.4
2021	209.8	209.8	215.3	271.5	1,461.4
2022	184.1	184.4	189.3	231.6	1,285.0
2023	171.1	172.7	177.2	282.7	1,203.3
2024	172.0	176.7	181.3	371.3	1,231.0
2025	161.2	170.0	174.5	373.7	1,184.5
2026	161.9	176.2	180.8	364.1	1,227.4
2027	168.6	190.0	195.0	364.0	1,323.9
2028	172.3	201.9	207.1	375.1	1,406.3
	Catch assumed	ABC	OFL	SSB	Age6+ biomass
2019	47.5	118.9	122.0	421.1	828.0
2020	47.5	153.3	157.3	380.6	1,067.9
2021	47.5	230.7	236.8	356.0	1,607.5
2022	47.5	223.3	229.1	365.4	1,555.4
2023	47.5	227.4	233.4	450.5	1,584.5
2024	47.5	245.4	251.8	576.7	1,709.5
2025	47.5	247.3	253.8	620.4	1,722.9
2026	47.5	257.8	264.5	649.8	1,796.0
2027	47.5	275.7	282.9	675.9	1,920.7
2028	47.5	288.4	296.0	703.5	2,009.4



Future fishing mortality rates given fixed catch trajectories, shade represents upper and lower 90% credible intervals.

Ensemble model considerations

For contrast, using the MCMC results for each of the four models and giving them equal weight, it was possible to construct a fifth model (the ensemble, Model 18.4). Given this limited set of model alternatives in the 18.4 model, the biomass estimates varied inversely with the fishing mortality rate, the impact on ABC and OFL was relatively low (each model gives ABC and OFL values within 10% of the models examined). The buffer between ABC and OFL (which reflects some scientific uncertainty) increases slightly (1.9% to 2.3%) for the ensemble (Model 18.4).

Table showing MCMC calculations for 2019 age 6+ biomass and fishing mortality rates where F_{OFL} and F_{ABC} are the arithmetic and harmonic means of the marginal pdf for F_{MSY}, respectively. Biomass units are in kt.

Model	F_{OFL}	F_{ABC}	Arithmetic mean biomass	Geometric mean biomass	ABC	OFL	Buffer
15.1, Base	0.142	0.140	819.0	818.4	114.3	116.5	1.9%
18.1, Est male M	0.145	0.143	799.1	798.5	114.0	115.9	1.7%
18.2, Est male M, q	0.146	0.144	670.2	669.3	96.3	98.0	1.7%
18.3, Est male M, q, male selectivity	0.156	0.154	663.9	663.1	102.3	103.8	1.5%
18.4, Equally weighted ensemble	0.147	0.145	738.4	734.3	106.3	108.8	2.3%

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 2018 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2019 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2018. 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 2019, 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 2019 recommended in the assessment to the *max* F_{ABC} for 2019. (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 2014-2018 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 2018 and above its MSY level in 2030 under this scenario, then the stock is not overfished.)

Scenario 7: In 2019 and 2020, *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 2031 under this scenario, then the stock is not approaching an overfished condition.)

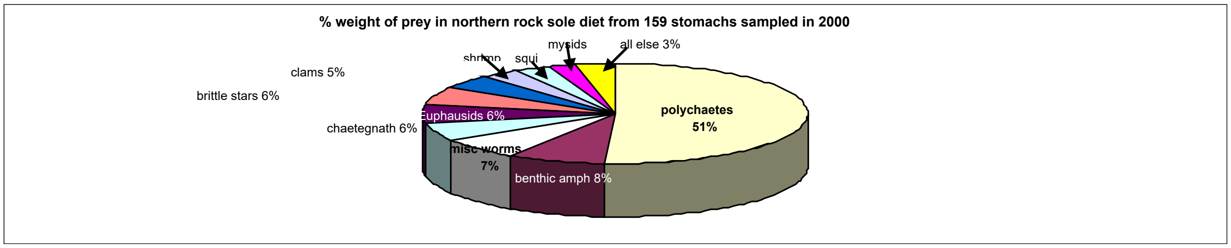
Simulation results shown in Table 8.21 indicate that northern rock sole are currently not overfished and are not approaching an overfished condition. If harvested at the average F from 2014-2018, northern rock sole female spawning biomass is projected to decrease slowly due to the ageing of the strong recruitment from 2002-2006 that has built the FSB to a peak level in recent years (Fig. 8.17). Future stock size should increase due to the strong 2014 year class. 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.

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).

<u>Fishery Effects on the ecosystem</u>

1) The rock sole target fishery contribution to the total bycatch of other target species is shown for 1991-2017 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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Tables

Table 8.1. BSAI Rock sole catch (t) from 1977 – mid-September, 2018.

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			45,101	45,101
2017			35,272	35,272
2018			28,065	28,065

Table 8.2. Retained and discarded catch (t) in Bering Sea fisheries, 1987-2017.

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
2016	43,256	1,849	96
2017	33,941	1,273	96

Table 8.3. Discarded and retained rock sole catch (t), by target fishery, in 2017.

	Discarded	Retained
Atka Mackerel	17	55
Pollock - bottom	1	228
Pacific Cod	229	1,075
Alaska Plaice	<1	15
Other Flatfish	<1	22
Halibut	0	
Rockfish	12	20
Flathead Sole	23	1,133
Kamchatka flounder		<1
Other Species	3	3
Pollock - midwater	432	1,164
Rock Sole	246	18,283
Sablefish		
Greenland Turbot		1
Arrowtooth Flounder	4	53
Yellowfin Sole	305	11,889
Total catch		35,214

Table 8.4. Estimated catch numbers at age, 1980-2018 (in billions).

	Females																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1980	0.394	0.253	0.218	0.117	0.180	0.066	0.055	0.038	0.041	0.076	0.048	0.020	0.015	0.011	0.009	0.004	0.002	0.001	0.000	0.002
1981	0.722	0.339	0.218	0.187	0.100	0.153	0.056	0.046	0.031	0.034	0.062	0.039	0.017	0.012	0.009	0.007	0.003	0.002	0.001	0.002
1982	0.718	0.621	0.291	0.187	0.160	0.085	0.128	0.046	0.038	0.026	0.028	0.052	0.033	0.014	0.010	0.008	0.006	0.003	0.002	0.002
1983	0.667	0.618	0.534	0.250	0.160	0.136	0.071	0.106	0.038	0.031	0.021	0.023	0.042	0.027	0.011	0.008	0.006	0.005	0.002	0.003
1984	1.011	0.574	0.532	0.460	0.215	0.137	0.116	0.060	0.087	0.031	0.025	0.017	0.018	0.034	0.021	0.009	0.006	0.005	0.004	0.004
1985	0.981	0.870	0.494	0.457	0.395	0.184	0.116	0.095	0.047	0.065	0.022	0.018	0.012	0.013	0.024	0.015	0.006	0.005	0.004	0.006
1986	0.924	0.844	0.749	0.424	0.390	0.332	0.152	0.095	0.078	0.038	0.053	0.018	0.014	0.010	0.010	0.019	0.012	0.005	0.004	0.008
1987	1.611	0.795	0.726	0.644	0.364	0.334	0.281	0.126	0.078	0.063	0.031	0.043	0.015	0.012	0.008	0.008	0.016	0.010	0.004	0.009
1988	2.465	1.386	0.684	0.624	0.550	0.307	0.275	0.225	0.099	0.061	0.049	0.024	0.034	0.011	0.009	0.006	0.007	0.012	0.008	0.010
1989	0.861	2.121	1.192	0.586	0.530	0.458	0.245	0.208	0.164	0.071	0.044	0.035	0.017	0.024	0.008	0.007	0.004	0.005	0.009	0.013
1990	0.712	0.741	1.825	1.024	0.502	0.448	0.374	0.191	0.158	0.124	0.054	0.033	0.026	0.013	0.018	0.006	0.005	0.003	0.004	0.016
1991	1.572	0.613	0.638	1.570	0.879	0.429	0.379	0.311	0.157	0.128	0.100	0.043	0.026	0.021	0.011	0.015	0.005	0.004	0.003	0.016
1992	0.789	1.353	0.527	0.549	1.349	0.754	0.366	0.319	0.256	0.125	0.099	0.076	0.033	0.020	0.016	0.008	0.011	0.004	0.003	0.014
1993	0.404	0.679	1.165	0.454	0.472	1.159	0.646	0.311	0.267	0.208	0.098	0.076	0.058	0.025	0.015	0.012	0.006	0.008	0.003	0.013
1994	0.613	0.348	0.585	1.002	0.390	0.405	0.993	0.549	0.259	0.216	0.162	0.075	0.058	0.044	0.019	0.011	0.009	0.004	0.006	0.012
1995	0.324	0.527	0.299	0.503	0.862	0.336	0.348	0.850	0.465	0.215	0.173	0.126	0.057	0.044	0.033	0.014	0.009	0.007	0.003	0.014
1996	0.318	0.279	0.454	0.258	0.433	0.742	0.288	0.298	0.719	0.385	0.172	0.135	0.097	0.043	0.033	0.025	0.011	0.006	0.005	0.013
1997	0.442	0.274	0.240	0.391	0.222	0.372	0.638	0.247	0.254	0.607	0.318	0.139	0.107	0.076	0.034	0.026	0.020	0.008	0.005	0.014
1998	0.259	0.380	0.236	0.206	0.336	0.191	0.319	0.545	0.210	0.213	0.500	0.257	0.111	0.084	0.059	0.026	0.020	0.015	0.006	0.015
1999	0.401	0.223	0.327	0.203	0.178	0.289	0.164	0.275	0.467	0.179	0.181	0.421	0.214	0.091	0.069	0.048	0.022	0.016	0.012	0.017
2000	0.387	0.346	0.192	0.282	0.175	0.153	0.249	0.141	0.235	0.397	0.151	0.150	0.347	0.176	0.075	0.056	0.040	0.018	0.013	0.024
2001	0.809	0.333	0.297	0.165	0.242	0.150	0.131	0.213	0.120	0.198	0.330	0.124	0.123	0.283	0.144	0.061	0.046	0.032	0.014	0.031
2002	1.281	0.696	0.286	0.256	0.142	0.208	0.129	0.112	0.181	0.101	0.166	0.277	0.104	0.103	0.237	0.120	0.051	0.038	0.027	0.038
2003	1.525	1.102	0.599	0.247	0.220	0.122	0.178	0.110	0.094	0.151	0.084	0.138	0.229	0.086	0.085	0.196	0.099	0.042	0.032	0.054
2004	1.160	1.312	0.949	0.516	0.212	0.189	0.104	0.152	0.092	0.079	0.126	0.070	0.114	0.190	0.071	0.071	0.163	0.083	0.035	0.071
2005	0.939	0.998	1.130	0.816	0.444	0.182	0.162	0.089	0.128	0.077	0.065	0.103	0.057	0.093	0.155	0.058	0.058	0.133	0.067	0.087
2006	1.153	0.808	0.859	0.972	0.702	0.381	0.156	0.138	0.075	0.107	0.064	0.054	0.085	0.047	0.077	0.128	0.048	0.048	0.110	0.127
2007	0.356	0.992	0.696	0.739	0.836	0.603	0.326	0.132	0.115	0.062	0.088	0.052	0.044	0.070	0.039	0.063	0.105	0.040	0.039	0.195
2008	0.154	0.307	0.854	0.599	0.636	0.718	0.517	0.277	0.111	0.095	0.051	0.072	0.043	0.036	0.057	0.032	0.052	0.087	0.032	0.192
2009	0.107	0.133	0.264	0.735	0.515	0.547	0.615	0.438	0.231	0.090	0.077	0.041	0.058	0.034	0.029	0.046	0.025	0.042	0.069	0.180
2010	0.081	0.092	0.114	0.227	0.632	0.443	0.468	0.523	0.366	0.189	0.073	0.062	0.033	0.047	0.028	0.023	0.037	0.021	0.034	0.202
2011	0.169	0.070	0.079	0.098	0.195	0.544	0.380	0.400	0.443	0.305	0.155	0.059	0.050	0.027	0.037	0.022	0.019	0.030	0.016	0.188
2012	0.240	0.145	0.060	0.068	0.085	0.168	0.467	0.325	0.338	0.366	0.247	0.124	0.047	0.040	0.021	0.030	0.018	0.015	0.024	0.163
2013	0.295	0.206	0.125	0.052	0.059	0.073	0.144	0.397	0.272	0.277	0.294	0.197	0.098	0.037	0.032	0.017	0.024	0.014	0.012	0.148
2014	0.160	0.253	0.178	0.108	0.045	0.050	0.061	0.120	0.327	0.222	0.226	0.240	0.160	0.080	0.031	0.026	0.014	0.019	0.011	0.130
2015	1.508	0.137	0.218	0.153	0.093	0.038	0.043	0.053	0.102	0.276	0.184	0.184	0.194	0.130	0.065	0.025	0.021	0.011	0.016	0.114
2016	2.925	1.298	0.118	0.188	0.131	0.080	0.033	0.037	0.045	0.086	0.229	0.151	0.151	0.159	0.106	0.053	0.020	0.017	0.009	0.106
2017	0.516	2.517	1.117	0.102	0.162	0.113	0.068	0.028	0.031	0.037	0.071	0.187	0.123	0.123	0.129	0.086	0.043	0.016	0.014	0.093
2018	0.517	0.444	2.167	0.961	0.087	0.139	0.097	0.058	0.024	0.026	0.031	0.058	0.153	0.101	0.100	0.105	0.070	0.035	0.013	0.087

Males

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1980	0.394	0.253	0.218	0.117	0.180	0.066	0.032	0.025	0.027	0.040	0.022	0.012	0.009	0.005	0.003	0.001	0.000	0.000	0.000	0.001
1981	0.722	0.339	0.218	0.187	0.100	0.152	0.055	0.027	0.020	0.022	0.033	0.018	0.010	0.007	0.004	0.002	0.001	0.000	0.000	0.001
1982	0.718	0.621	0.291	0.187	0.159	0.084	0.126	0.046	0.022	0.017	0.018	0.027	0.015	0.008	0.006	0.004	0.002	0.001	0.000	0.001
1983	0.667	0.618	0.534	0.250	0.160	0.136	0.071	0.105	0.038	0.018	0.014	0.015	0.022	0.012	0.007	0.005	0.003	0.001	0.001	0.001
1984	1.011	0.574	0.531	0.460	0.215	0.138	0.116	0.060	0.089	0.032	0.015	0.011	0.012	0.018	0.010	0.005	0.004	0.002	0.001	0.001
1985	0.981	0.870	0.493	0.456	0.393	0.182	0.114	0.094	0.047	0.066	0.023	0.011	0.008	0.009	0.013	0.007	0.004	0.003	0.002	0.002
1986	0.924	0.844	0.748	0.422	0.385	0.325	0.149	0.093	0.076	0.038	0.054	0.019	0.009	0.006	0.007	0.010	0.006	0.003	0.002	0.003
1987	1.611	0.795	0.726	0.643	0.362	0.326	0.270	0.122	0.076	0.062	0.031	0.044	0.015	0.007	0.005	0.006	0.008	0.005	0.003	0.004
1988	2.465	1.386	0.684	0.623	0.546	0.301	0.263	0.213	0.095	0.059	0.048	0.024	0.034	0.012	0.006	0.004	0.004	0.006	0.004	0.005
1989	0.861	2.122	1.192	0.586	0.527	0.440	0.225	0.190	0.153	0.068	0.042	0.034	0.017	0.024	0.008	0.004	0.003	0.003	0.005	0.006
1990	0.712	0.741	1.825	1.024	0.500	0.438	0.350	0.172	0.143	0.114	0.051	0.032	0.026	0.013	0.018	0.006	0.003	0.002	0.002	0.008
1991	1.572	0.613	0.638	1.568	0.875	0.421	0.361	0.285	0.140	0.116	0.093	0.041	0.026	0.021	0.010	0.015	0.005	0.002	0.002	0.008
1992	0.789	1.353	0.527	0.548	1.346	0.746	0.352	0.291	0.221	0.106	0.087	0.070	0.031	0.019	0.016	0.008	0.011	0.004	0.002	0.008
1993	0.404	0.679	1.165	0.454	0.471	1.153	0.632	0.290	0.230	0.170	0.080	0.066	0.053	0.023	0.015	0.012	0.006	0.008	0.003	0.007
1994	0.613	0.348	0.585	1.002	0.390	0.404	0.976	0.519	0.228	0.176	0.128	0.061	0.050	0.040	0.018	0.011	0.009	0.004	0.006	0.008
1995	0.324	0.527	0.299	0.503	0.862	0.335	0.345	0.820	0.418	0.176	0.133	0.097	0.046	0.037	0.030	0.013	0.008	0.007	0.003	0.010
1996	0.318	0.279	0.454	0.258	0.433	0.741	0.288	0.295	0.689	0.341	0.138	0.103	0.074	0.035	0.028	0.023	0.010	0.006	0.005	0.010
1997	0.442	0.274	0.240	0.391	0.222	0.372	0.636	0.246	0.250	0.575	0.279	0.111	0.081	0.058	0.027	0.022	0.018	0.008	0.005	0.012
1998	0.259	0.380	0.236	0.206	0.336	0.190	0.318	0.539	0.205	0.203	0.457	0.218	0.086	0.063	0.045	0.021	0.017	0.014	0.006	0.013
1999	0.401	0.223	0.327	0.203	0.178	0.289	0.164	0.273	0.461	0.173	0.168	0.375	0.178	0.070	0.051	0.037	0.017	0.014	0.011	0.016
2000	0.387	0.346	0.192	0.282	0.175	0.153	0.249	0.141	0.234	0.390	0.144	0.139	0.308	0.146	0.058	0.042	0.030	0.014	0.011	0.022
2001	0.809	0.333	0.297	0.165	0.242	0.150	0.131	0.213	0.120	0.196	0.322	0.118	0.114	0.251	0.119	0.047	0.034	0.024	0.011	0.027
2002	1.281	0.696	0.286	0.256	0.142	0.208	0.129	0.112	0.180	0.101	0.164	0.270	0.099	0.095	0.210	0.100	0.039	0.029	0.020	0.032
2003	1.525	1.102	0.599	0.246	0.220	0.122	0.177	0.108	0.093	0.150	0.083	0.136	0.223	0.082	0.079	0.174	0.083	0.033	0.024	0.044
2004	1.160	1.312	0.949	0.515	0.212	0.188	0.103	0.149	0.090	0.078	0.124	0.069	0.113	0.186	0.068	0.065	0.145	0.069	0.027	0.056
2005	0.939	0.998	1.130	0.816	0.443	0.181	0.159	0.086	0.122	0.074	0.063	0.102	0.057	0.092	0.152	0.056	0.053	0.118	0.056	0.068
2006	1.153	0.808	0.859	0.972	0.701	0.379	0.153	0.133	0.071	0.101	0.061	0.052	0.084	0.047	0.076	0.125	0.046	0.044	0.097	0.102
2007	0.356	0.992	0.695	0.739	0.835	0.601	0.323	0.129	0.111	0.059	0.083	0.050	0.043	0.069	0.038	0.063	0.103	0.038	0.036	0.164
2008	0.154	0.307	0.854	0.598	0.635	0.716	0.511	0.271	0.107	0.091	0.048	0.068	0.041	0.035	0.057	0.031	0.051	0.084	0.031	0.164
2009	0.107	0.133	0.264	0.735	0.515	0.546	0.612	0.432	0.224	0.087	0.073	0.039	0.055	0.033	0.028	0.045	0.025	0.041	0.068	0.156
2010	0.081	0.092	0.114	0.227	0.632	0.442	0.466	0.517	0.359	0.184	0.071	0.059	0.031	0.044	0.027	0.023	0.037	0.020	0.033	0.181
2011	0.169	0.070	0.079	0.098	0.195	0.542	0.377	0.394	0.430	0.293	0.148	0.057	0.048	0.025	0.035	0.021	0.018	0.029	0.016	0.171
2012	0.240	0.145	0.060	0.068	0.084	0.168	0.463	0.319	0.327	0.350	0.236	0.119	0.045	0.038	0.020	0.028	0.017	0.015	0.023	0.150
2013	0.295	0.206	0.125	0.052	0.058	0.072	0.143	0.390	0.264	0.265	0.280	0.187	0.094	0.036	0.030	0.016	0.022	0.013	0.012	0.137
2014	0.160	0.253	0.178	0.108	0.045	0.050	0.061	0.119	0.321	0.215	0.216	0.228	0.152	0.076	0.029	0.024	0.013	0.018	0.011	0.121
2015	1.508	0.137	0.218	0.153	0.093	0.038	0.043	0.052	0.100	0.264	0.175	0.175	0.184	0.123	0.062	0.024	0.020	0.010	0.015	0.106
2016	2.925	1.298	0.118	0.188	0.131	0.079	0.033	0.036	0.043	0.082	0.215	0.143	0.142	0.150	0.100	0.050	0.019	0.016	0.008	0.099
2017	0.516	2.517	1.117	0.102	0.161	0.111	0.066	0.027	0.029	0.035	0.066	0.175	0.116	0.116	0.122	0.082	0.041	0.016	0.013	0.087
2018	0.517	0.444	2.166	0.961	0.087	0.138	0.094	0.055	0.022	0.024	0.029	0.054	0.143	0.095	0.095	0.100	0.067	0.033	0.013	0.082

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	34,976	1.82E+07	26,624	43,328
2017	1331780	1.31E+10	1134557	1529004				
2018	1051503	1.31E+10	822268	1280739	44,119	2.02E+07	35,315	52,924

Table 8.6. Total tonnage of northern rock sole caught in resource assessment trawl surveys on the Bering Sea shelf, 1977-2018.

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
2017	50
2018	40

Table 8.7. Rock sole weight-at-age (grams) by age and year determined from 1982-2018 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 smooth ages 15-20.

Females

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1976	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1977	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1978	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1979	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1980	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1981	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1982	9	18	52	77	101	153	212	282	391	421	538	494	643	614	908	969	935	935	948	880
1983	9	13	32	102	154	200	277	312	431	418	497	466	608	630	817	864	992	1080	1022	880
1984	9	14	29	60	133	205	249	331	421	473	588	543	584	799	729	803	963	1022	983	880
1985	9	21	33	68	152	249	330	397	511	503	615	620	539	615	717	757	896	1013	993	910
1986	9	15	29	44	104	188	295	369	430	510	545	515	611	547	720	777	875	1015	970	864
1987	9	15	34	65	115	205	339	494	521	487	614	598	634	746	647	755	866	1020	956	864
1988	9	15	28	48	117	192	311	419	414	508	604	708	615	647	631	731	806	913	881	830
1989	9	16	25	55	93	175	236	380	495	559	609	564	566	723	661	727	801	908	870	830
1990	9	9	15	39	82	145	235	335	431	547	612	620	614	685	680	793	838	896	835	794
1991	9	9	22	31	72	117	184	306	349	462	549	574	705	667	694	802	856	855	798	819
1992	9	9	18	37	58	95	166	218	332	416	445	544	585	628	716	767	841	826	795	806
1993	9	9	22	31	82	108	182	228	305	410	534	629	555	645	720	790	854	851	828	826
1994	9	9	25	47	75	105	174	207	325	430	442	544	555	656	696	788	870	838	803	813
1995	9	9	25	39	72	112	157	218	268	390	410	465	681	673	666	729	869	803	785	812
1996	9	7	22	53	72	128	171	245	281	354	448	514	520	621	638	686	856	780	821	813
1997	9	16	21	45	82	102	173	199	238	344	393	418	468	665	632	660	808	782	824	810
1998	9	16	23	49	72	115	173	198	226	318	339	393	420	556	604	659	791	758	811	808
1999	9	16	17	29	45	86	114	178	237	245	320	387	437	489	591	646	745	737	803	838
2000	9	16	0	33	62	94	136	200	245	293	339	406	410	472	560	617	687	735	816	851
2001	9	16	40	82	80	114	169	230	236	298	336	370	439	462	520	584	641	751	786	851
2002	2	12	37	75	120	130	185	205	322	325	378	378	440	462	502	575	637	692	723	838
2003	2	12	37	75	120	130	185	205	322	325	378	378	440	462	503	526	601	660	672	826
2004	2	33	35	89	175	203	430	268	293	432	418	479	458	457	502	527	565	622	699	761
2005	2	15	24	55	134	244	230	307	326	381	435	494	432	501	508	522	559	572	640	697
2006	2	11	22	39	87	156	222	264	346	368	375	492	472	531	515	517	551	527	607	666
2007	2	7	20	33	62	123	205	237	342	369	458	451	486	525	518	519	560	536	614	654
2008	4	14	19	39	52	123	157	326	336	477	437	568	499	595	494	528	565	541	618	648
2009	4	14	16	33	54	101	161	254	313	316	391	432	456	443	501	531	570	557	578	650
2010	4	14	22	49	72	117	151	232	307	347	453	461	449	534	521	539	567	573	564	655
2011	4	14	31	87	123	138	174	221	299	359	421	447	485	537	521	578	595	626	519	649
2012	4	14	28	32	140	147	189	254	304	365	447	519	540	642	530	593	623	651	517	631
2013	4	9	39	95	112	153	227	224	319	358	409	500	528	539	554	622	629	690	525	606
2014	4	13	31	66	103	193	169	130	316	330	376	459	536	570	573	617	681	698	483	573
2015	4	16	33	92	138	267	273	308	322	394	455	504	509	565	578	628	715	742	535	605
2016	0	24	69	71	194	184	252	216	393	414	460	484	494	528	588	603	702	696	609	644
2017	4	35	102	172	276	287	318	371	500	462	486	527	509	555	585	630	709	790	681	716
2018	4	35	102	172	276	287	318	371	500	462	486	527	509	555	585	630	709	790	681	716

Males

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1976	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1977	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1978	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1979	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1980	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1981	2	14	47	78	88	145	176	205	208	282	339	239	273	352	310	582	373	325	360	399
1982	2	14	47	78	88	145	176	205	208	282	339	239	273	352	310	582	373	325	360	399
1983	2	15	29	93	132	149	191	219	201	240	208	255	297	306	306	490	373	325	360	399
1984	2	18	23	53	120	130	198	216	228	284	256	251	292	293	294	447	346	325	360	399
1985	2	18	34	61	135	206	228	256	252	327	335	327	575	369	298	481	353	325	360	399
1986	2	18	27	37	92	168	261	252	253	260	299	327	575	369	300	501	357	325	360	399
1987	2	12	29	65	101	176	257	303	277	260	299	327	575	369	300	501	354	325	360	399
1988	2	14	22	49	110	172	233	301	337	438	324	278	345	458	302	538	352	342	360	399
1989	2	12	22	48	97	156	208	293	286	368	313	356	345	341	310	562	365	358	360	372
1990	2	6	14	33	66	125	203	290	305	292	314	377	336	398	320	542	363	374	360	350
1991	2	12	11	30	62	105	174	225	243	312	322	425	351	422	340	521	360	391	360	350
1992	2	8	13	31	53	89	166	202	244	234	323	311	345	318	347	477	376	407	360	350
1993	2	7	19	35	69	96	149	166	263	309	353	340	471	355	369	432	391	407	360	350
1994	2	11	20	41	66	93	143	216	216	242	286	317	361	362	383	420	399	407	368	377
1995	2	11	29	39	69	93	153	175	218	247	281	303	379	306	387	408	406	407	375	399
1996	2	6	20	45	70	113	152	205	205	232	302	294	245	359	352	391	420	422	383	399
1997	2	6	18	40	71	112	147	208	215	219	272	263	323	255	362	398	419	437	390	399
1998	2	6	23	41	72	83	148	174	225	225	232	257	245	325	356	407	417	478	398	399
1999	2	6	15	31	41	92	142	155	190	200	239	255	229	262	338	404	425	505	398	399
2000	2	6	15	38	34	68	120	163	205	205	230	260	277	269	318	382	406	520	406	399
2001	2	18	28	53	66	95	147	194	227	229	221	263	286	257	339	365	396	484	434	399
2002	2	15	37	67	93	112	173	195	224	219	247	258	256	285	317	349	389	467	415	407
2003	2	12	35	64	104	107	166	161	218	227	291	266	261	260	294	326	369	415	396	415
2004	2	24	36	99	195	148	186	244	228	227	272	292	297	278	295	341	346	367	384	392
2005	2	12	21	54	150	175	226	238	256	306	356	329	398	272	295	340	344	332	363	371
2006	2	9	18	37	83	149	208	209	230	246	245	300	287	352	285	343	332	348	316	357
2007	2	5	15	30	63	126	166	246	250	243	253	312	273	325	292	346	322	349	320	355
2008	2	10	19	29	47	111	146	234	243	234	324	279	360	337	299	394	318	350	320	340
2009	2	10	15	31	54	91	153	206	232	292	285	368	303	285	305	363	334	360	313	341
2010	2	10	27	39	65	103	136	187	240	292	253	315	290	306	329	355	348	364	314	344
2011	2	10	23	56	78	110	163	192	254	223	264	275	360	341	339	363	353	355	331	353
2012	2	10	16	38	114	148	182	188	267	269	287	303	379	303	347	354	355	340	347	329
2013	2	8	38	46	88	185	177	195	228	265	272	309	344	306	355	329	374	354	382	326
2014	2	16	36	74	108	119	176	186	234	247	262	293	278	375	368	332	374	370	383	339
2015	2	20	36	89	137	158	234	238	257	283	281	312	329	333	355	359	373	383	388	361
2016	4	22	56	78	175	197	220	262	278	251	303	303	295	305	356	358	373	427	373	392
2017	5	14	36	91	167	212	208	234	272	292	256	294	303	331	346	368	378	460	395	434
2018	5	14	36	91	167	212	208	234	272	292	256	294	303	331	346	368	378	460	395	434

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 2009).

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	517
2017	376	309	20914	62	508	502
2018	376	338	25302	58	571	

Table 8.10. Estimated population numbers-at-age (millions) from the annual Bering Sea trawl surveys, 1982- 2017.

millions of fish

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1982	69	243	525	537	533	546	254	86	78	57	112	64	26	6	9	8	0	1	0
1983	65	624	570	644	321	325	368	168	142	56	76	105	54	38	25	5	2	1	0
1984	127	521	1,189	709	385	612	268	338	133	55	62	69	41	53	24	9	0	3	3
1985	141	353	937	906	423	263	202	116	130	29	13	6	14	37	31	7	7	2	8
1986	0	432	1,086	1,299	1,151	508	271	264	53	196	21	20	18	5	19	17	1	0	12
1987	17	714	1,014	1,081	848	972	256	251	164	72	206	30	8	10	4	18	4	2	17
1988	289	1,077	1,517	1,927	947	896	492	301	67	164	88	70	59	0	7	11	58	23	14
1989	108	777	947	1,092	1,256	723	538	399	123	89	89	65	76	25	23	2	2	15	22
1990	18	944	2,677	1,634	900	1,101	327	447	304	127	56	64	17	39	1	0	8	0	37
1991	12	98	2,717	2,165	1,346	967	830	452	409	254	133	84	61	37	14	0	4	5	27
1992	8	300	737	3,021	2,295	860	1,044	549	312	328	196	143	96	50	27	13	0	11	5
1993	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	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	157	942	2,096	932	699	2,533	1,503	524	570	406	164	140	100	0	10	4	4	9
1996	36	941	455	720	1,921	566	945	2,237	1,332	387	200	242	72	102	90	33	11	1	9
1997	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	246	727	861	600	984	1,798	489	593	1,628	1,069	336	126	163	37	33	12	11	20
1999	0	62	105	295	836	116	623	1,473	831	586	1,381	530	239	112	123	27	27	11	2
2000	0	41	505	238	369	904	370	942	1,417	746	641	1,057	443	240	208	60	9	11	15
2001	22	181	218	637	452	371	938	510	1,178	1,193	512	647	989	416	189	67	53	16	4
2002	134	427	202	254	757	268	230	629	322	505	1,007	346	227	791	256	102	69	5	34
2003	682	1,108	542	436	209	709	348	199	255	164	539	1,154	257	402	729	204	123	82	38
2004	99	1,985	1,201	760	434	193	516	245	60	634	320	209	625	165	73	516	386	4	197
2005	213	2,011	2,336	1,616	349	479	326	405	133	161	152	115	476	313	234	274	432	229	205
2006	300	2,009	4,173	1,994	1,283	418	302	348	457	273	149	197	109	419	491	287	127	339	264
2007	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	780	991	1,525	1,976	1,586	894	227	225	344	254	149	32	93	129	274	287	60	300
2009	9	233	1,423	948	1,097	1,314	823	523	81	190	54	186	77	86	84	98	173	193	262
2010	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	226	293	729	1,366	899	1,004	1,124	598	412	180	126	88	133	26	39	48	29	292
2012	216	305	788	698	1,183	843	503	592	261	170	38	185	94	203	45	83	71	22	587
2013	140	37	101	228	434	941	806	786	604	514	267	72	122	19	85	31	54	40	445
2014	42	210	261	68	95	61	125	766	431	700	1,081	445	216	90	175	16	85	84	331
2015	1	51	39	298	893	682	609	600	567	197	462	389	215	100	160	178	74	98	806
2016	874	121	401	281	156	54	36	50	134	467	479	581	356	272	182	93	31	72	124
2017	661	1341	195	352	236	93	56	116	37	142	526	431	242	416	241	71	13	0	57

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	0.32	0.07
1976	0.43	0.05
1977	0.34	0.03
1978	1.60	0.03
1979	0.06	0.02
1980	0.05	0.03
1981	0.04	0.03
1982	0.05	0.03
1983	0.08	0.03
1984	0.20	0.08
1985	0.06	0.03
1986	0.06	0.03
1987	0.10	0.05
1988	0.19	0.09
1989	0.14	0.07
1990	0.06	0.04
1991	0.13	0.06
1992	0.13	0.05
1993	0.13	0.05
1994	0.14	0.04
1995	0.13	0.04
1996	0.10	0.03
1997	0.11	0.05
1998	0.05	0.02
1999	0.05	0.03
2000	0.05	0.04
2001	0.03	0.02
2002	0.04	0.03
2003	0.04	0.03
2004	0.05	0.03
2005	0.04	0.03
2006	0.05	0.03
2007	0.05	0.03
2008	0.07	0.04
2009	0.06	0.04
2010	0.07	0.04
2011	0.07	0.04
2012	0.09	0.05
2013	0.06	0.05
2014	0.06	0.04
2015	0.06	0.04
2016	0.06	0.04
2017	0.05	0.03
2018	0.05	0.02

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	0.71	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	0.41	0.88	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	0.03	0.08	0.22	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	0.17	0.40	0.68	0.87	0.95	0.95	0.95	0.95
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.21	0.45	0.72	0.89	0.89	0.89	0.89
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	0.19	0.44	0.44	0.44	0.44
1979	0.00	0.01	0.02	0.06	0.17	0.40	0.68	0.87	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1980	0.10	0.25	0.50	0.74	0.89	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1981	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	1.00	1.00	1.00
1982	0.09	0.26	0.56	0.82	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
1983	0.02	0.05	0.14	0.34	0.62	0.83	0.94	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	0.09	0.22	0.45	0.69	0.86	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1985	0.16	0.42	0.73	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1986	0.02	0.09	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
1987	0.07	0.21	0.45	0.73	0.90	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1988	0.06	0.18	0.41	0.69	0.88	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1989	0.04	0.13	0.37	0.70	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1990	0.04	0.12	0.31	0.59	0.82	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1991	0.01	0.03	0.07	0.16	0.33	0.57	0.78	0.90	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1992	0.00	0.01	0.04	0.09	0.22	0.44	0.69	0.86	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1993	0.00	0.01	0.04	0.10	0.24	0.47	0.72	0.88	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1994	0.00	0.01	0.02	0.04	0.12	0.27	0.52	0.76	0.90	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1995	0.00	0.01	0.02	0.05	0.14	0.31	0.55	0.78	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1996	0.00	0.00	0.01	0.03	0.08	0.19	0.41	0.67	0.85	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00
1997	0.01	0.02	0.04	0.07	0.14	0.25	0.41	0.59	0.75	0.86	0.93	0.96	0.98	0.99	0.99	0.99	0.99
1998	0.00	0.00	0.01	0.02	0.05	0.12	0.24	0.43	0.63	0.80	0.90	0.96	0.98	0.99	0.99	0.99	0.99
1999	0.00	0.01	0.02	0.05	0.13	0.28	0.50	0.72	0.87	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	0.18	0.38	0.63	0.82	0.93	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2001	0.02	0.06	0.14	0.31	0.54	0.76	0.89	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2002	0.01	0.04	0.11	0.29	0.56	0.80	0.92	0.97	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	0.33	0.58	0.79	0.91	0.96	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	0.21	0.43	0.68	0.86	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2005	0.02	0.04	0.11	0.26	0.50	0.74	0.89	0.96	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2006	0.02	0.05	0.13	0.33	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
2007	0.01	0.03	0.11	0.29	0.59	0.84	0.95	0.98	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	0.19	0.44	0.73	0.90	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	0.22	0.50	0.79	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2010	0.00	0.01	0.03	0.09	0.22	0.44	0.69	0.86	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2011	0.00	0.01	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
2012	0.01	0.02	0.06	0.15	0.33	0.57	0.79	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2013	0.05	0.13	0.30	0.57	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
2014	0.00	0.00	0.01	0.04	0.13	0.31	0.59	0.82	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2015	0.00	0.01	0.02	0.06	0.16	0.36	0.61	0.82	0.93	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2016	0.01	0.03	0.09	0.21	0.43	0.67	0.85	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2017	0.01	0.02	0.06	0.15	0.33	0.58	0.79	0.91	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2018	0.01	0.02	0.06	0.16	0.36	0.63	0.84	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 8.14. Model estimates of rock sole age-specific fishery and survey selectivities.

	male fishery selectivity																
year/age	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1975	0.00	0.00	0.01	0.02	0.07	0.19	0.45	0.74	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1976	0.00	0.00	0.00	0.00	0.01	0.04	0.14	0.36	0.66	0.87	0.96	0.99	1.00	1.00	1.00	1.00	1.00
1977	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.18	0.43	0.73	0.90	0.97	0.99	1.00	1.00	1.00	1.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.10	0.29	0.59	0.84	0.95	0.95	0.95	0.95
1979	0.00	0.00	0.01	0.04	0.14	0.37	0.68	0.88	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1980	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	1.00	1.00
1981	0.32	0.64	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	1.00
1982	0.07	0.17	0.37	0.62	0.83	0.93	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1983	0.01	0.02	0.06	0.12	0.25	0.43	0.64	0.81	0.91	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00
1984	0.04	0.09	0.18	0.34	0.54	0.73	0.86	0.93	0.97	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1985	0.35	0.70	0.91	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1986	0.08	0.27	0.60	0.86	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
1987	0.13	0.35	0.66	0.88	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1988	0.09	0.35	0.74	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1989	0.07	0.24	0.58	0.85	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
1990	0.11	0.36	0.71	0.92	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1991	0.02	0.07	0.21	0.48	0.77	0.92	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1992	0.01	0.04	0.12	0.33	0.64	0.86	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1993	0.01	0.04	0.12	0.35	0.67	0.89	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1994	0.00	0.01	0.04	0.18	0.49	0.82	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1995	0.00	0.01	0.02	0.07	0.19	0.42	0.69	0.87	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1996	0.01	0.01	0.03	0.07	0.15	0.31	0.52	0.73	0.87	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00
1997	0.01	0.02	0.06	0.14	0.31	0.53	0.75	0.89	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1998	0.00	0.00	0.01	0.04	0.14	0.39	0.71	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1999	0.00	0.01	0.02	0.06	0.15	0.34	0.60	0.81	0.93	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2000	0.00	0.01	0.03	0.08	0.22	0.48	0.75	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2001	0.02	0.05	0.14	0.31	0.57	0.80	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2002	0.04	0.13	0.33	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
2003	0.05	0.16	0.40	0.71	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2004	0.03	0.11	0.32	0.63	0.86	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2005	0.06	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
2006	0.02	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
2007	0.03	0.09	0.25	0.53	0.79	0.92	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2008	0.01	0.03	0.08	0.24	0.52	0.79	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2009	0.01	0.04	0.12	0.31	0.60	0.83	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2010	0.02	0.04	0.11	0.25	0.47	0.71	0.87	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2011	0.01	0.04	0.10	0.24	0.49	0.74	0.89	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2012	0.02	0.05	0.12	0.26	0.47	0.69	0.85	0.93	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2013	0.02	0.08	0.24	0.54	0.81	0.94	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2014	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	1.00
2015	0.02	0.07	0.21	0.48	0.77	0.92	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2016	0.10	0.29	0.61	0.85	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
2017	0.03	0.11	0.33	0.67	0.89	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2018	0.01	0.05	0.14	0.36	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

Table 8.15. Model estimates of rock sole age 2+ total biomass (t) and female spawning biomass (t) from the 2016 and 2018 assessments.

	2018 Assessment		2016 Assessment	
	Age 2+ Total biomass	Female Spawning biomass	Age 2+ Total biomass	Female Spawning biomass
1975	178,978	50,702	202,385	55,833
1976	194,291	52,348	222,478	59,016
1977	210,415	58,910	242,924	67,620
1978	232,256	73,498	268,986	85,082
1979	252,431	90,913	293,125	106,137
1980	278,895	104,487	324,018	122,434
1981	337,652	111,621	363,333	131,435
1982	370,813	111,475	407,308	136,266
1983	449,531	116,576	459,615	143,060
1984	501,015	131,303	528,521	152,134
1985	665,067	128,280	589,364	151,060
1986	674,267	136,003	690,899	167,891
1987	900,957	164,617	815,574	185,249
1988	1,000,280	175,836	954,639	205,635
1989	1,024,480	191,638	1,031,970	220,717
1990	999,939	212,380	1,144,000	248,690
1991	1,071,830	236,621	1,347,990	296,525
1992	1,082,280	247,343	1,433,620	311,090
1993	1,307,880	304,312	1,465,550	326,519
1994	1,402,340	348,113	1,464,330	341,815
1995	1,419,510	401,313	1,532,250	413,668
1996	1,501,340	489,119	1,580,900	505,763
1997	1,462,400	533,817	1,626,330	589,082
1998	1,348,890	524,585	1,606,190	636,296
1999	1,244,330	551,728	1,598,790	690,179
2000	1,239,270	582,137	1,567,240	725,869
2001	1,262,150	583,076	1,515,440	731,484
2002	1,280,470	591,189	1,481,600	718,854
2003	1,238,980	560,198	1,455,800	696,389
2004	1,438,270	548,998	1,453,290	648,384
2005	1,360,580	505,161	1,467,170	576,999
2006	1,259,400	461,842	1,571,710	519,077
2007	1,252,720	439,295	1,683,360	489,848
2008	1,326,230	434,053	1,682,020	472,846
2009	1,297,660	396,534	1,632,730	472,601
2010	1,363,840	433,499	1,576,240	497,904
2011	1,408,640	475,401	1,580,490	539,309
2012	1,425,790	537,843	1,537,900	582,623
2013	1,291,310	544,956	1,464,080	610,100
2014	1,156,360	542,624	1,375,700	627,106
2015	1,184,380	573,222	1,274,560	615,535
2016	1,147,460	536,456	1,191,820	592,085
2017	1,331,420	512,473		
2018	1,510,210	458,572		

Table 8.16. Estimated age 4 recruitment of rock sole (thousands of fish) from the 2016 and 2018 assessments.

Year class	2018 Assessment	2016 Assessment
1971	145	168
1972	114	132
1973	137	159
1974	179	206
1975	417	479
1976	234	268
1977	374	427
1978	374	423
1979	501	560
1980	920	1,016
1981	913	990
1982	846	904
1983	1,287	1,356
1984	1,246	1,306
1985	1,173	1,229
1986	2,048	2,157
1987	3,138	3,348
1988	1,097	1,182
1989	907	983
1990	2,004	2,184
1991	1,006	1,100
1992	515	565
1993	781	860
1994	413	457
1995	406	454
1996	563	632
1997	330	366
1998	512	575
1999	493	556
2000	1,031	1,165
2001	1,633	1,834
2002	1,944	2,224
2003	1,478	1,637
2004	1,197	1,279
2005	1,470	1,712
2006	454	598
2007	196	292
2008	136	171
2009	104	101
2010	215	329
2011	306	397
2012	375	786
2013	203	
2014	1,922	

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	140	116	80	87	164	106	45	33	26	21	10	7	4	4	4	4	4	4	4	4
1976	327	121	100	69	75	142	91	39	28	22	18	8	6	3	3	3	3	3	3	5
1977	184	282	104	86	59	65	122	78	33	24	19	15	7	4	2	2	2	2	1	5
1978	294	158	242	89	74	51	56	105	67	29	21	16	13	6	4	2	1	1	1	4
1979	294	253	136	209	77	64	44	48	90	58	25	18	14	11	5	3	1	1	0	2
1980	394	253	218	117	180	66	55	38	41	76	48	20	15	11	9	4	2	1	0	2
1981	722	339	218	187	100	153	56	46	31	34	62	39	17	12	9	7	3	2	1	2
1982	718	621	291	187	160	85	128	46	38	26	28	52	33	14	10	8	6	3	2	2
1983	667	618	534	250	160	136	71	106	38	31	21	23	42	27	11	8	6	5	2	3
1984	1011	574	532	460	215	137	116	60	87	31	25	17	18	34	21	9	6	5	4	4
1985	981	870	494	457	395	184	116	95	47	65	22	18	12	13	24	15	6	5	4	6
1986	924	844	749	424	390	332	152	95	78	38	53	18	14	10	10	19	12	5	4	8
1987	1611	795	726	644	364	334	281	126	78	63	31	43	15	12	8	8	16	10	4	9
1988	2465	1386	684	624	550	307	275	225	99	61	49	24	34	11	9	6	7	12	8	10
1989	861	2121	1192	586	530	458	245	208	164	71	44	35	17	24	8	7	4	5	9	13
1990	712	741	1825	1024	502	448	374	191	158	124	54	33	26	13	18	6	5	3	4	16
1991	1572	613	638	1570	879	429	379	311	157	128	100	43	26	21	11	15	5	4	3	16
1992	789	1353	527	549	1349	754	366	319	256	125	99	76	33	20	16	8	11	4	3	14
1993	404	679	1165	454	472	1159	646	311	267	208	98	76	58	25	15	12	6	8	3	13
1994	613	348	585	1002	390	405	993	549	259	216	162	75	58	44	19	11	9	4	6	12
1995	324	527	299	503	862	336	348	850	465	215	173	126	57	44	33	14	9	7	3	14
1996	318	279	454	258	433	742	288	298	719	385	172	135	97	43	33	25	11	6	5	13
1997	442	274	240	391	222	372	638	247	254	607	318	139	107	76	34	26	20	8	5	14
1998	259	380	236	206	336	191	319	545	210	213	500	257	111	84	59	26	20	15	6	15
1999	401	223	327	203	178	289	164	275	467	179	181	421	214	91	69	48	22	16	12	17
2000	387	346	192	282	175	153	249	141	235	397	151	150	347	176	75	56	40	18	13	24
2001	809	333	297	165	242	150	131	213	120	198	330	124	123	283	144	61	46	32	14	31
2002	1281	696	286	256	142	208	129	112	181	101	166	277	104	103	237	120	51	38	27	38
2003	1525	1102	599	247	220	122	178	110	94	151	84	138	229	86	85	196	99	42	32	54
2004	1160	1312	949	516	212	189	104	152	92	79	126	70	114	190	71	71	163	83	35	71
2005	939	998	1130	816	444	182	162	89	128	77	65	103	57	93	155	58	58	133	67	87
2006	1153	808	859	972	702	381	156	138	75	107	64	54	85	47	77	128	48	48	110	127
2007	356	992	696	739	836	603	326	132	115	62	88	52	44	70	39	63	105	40	39	195
2008	154	307	854	599	636	718	517	277	111	95	51	72	43	36	57	32	52	87	32	192
2009	107	133	264	735	515	547	615	438	231	90	77	41	58	34	29	46	25	42	69	180
2010	81	92	114	227	632	443	468	523	366	189	73	62	33	47	28	23	37	21	34	202
2011	169	70	79	98	195	544	380	400	443	305	155	59	50	27	37	22	19	30	16	188
2012	240	145	60	68	85	168	467	325	338	366	247	124	47	40	21	30	18	15	24	163
2013	295	206	125	52	59	73	144	397	272	277	294	197	98	37	32	17	24	14	12	148
2014	160	253	178	108	45	50	61	120	327	222	226	240	160	80	31	26	14	19	11	130
2015	1508	137	218	153	93	38	43	53	102	276	184	184	194	130	65	25	21	11	16	114
2016	2925	1298	118	188	131	80	33	37	45	86	229	151	151	159	106	53	20	17	9	106
2017	516	2517	1117	102	162	113	68	28	31	37	71	187	123	123	129	86	43	16	14	93
2018	517	444	2167	961	87	139	97	58	24	26	31	58	153	101	100	105	70	35	13	87

Table 8.17. Model estimates of population number by age, year and sex, continued.

	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	140	69	52	57	86	50	28	21	15	11	7	7	6	5	5	5	5	5	5	5
1976	327	121	59	45	49	74	43	24	18	12	8	5	4	4	3	3	3	3	3	7
1977	184	282	104	51	39	43	64	37	20	15	10	6	3	3	2	2	2	2	2	6
1978	294	158	242	89	44	33	37	55	32	18	13	8	4	2	2	1	1	1	1	5
1979	294	253	136	209	77	38	29	32	47	27	15	11	6	3	1	1	0	0	0	1
1980	394	253	218	117	180	66	32	25	27	40	22	12	9	5	3	1	0	0	0	1
1981	722	339	218	187	100	152	55	27	20	22	33	18	10	7	4	2	1	0	0	1
1982	718	621	291	187	159	84	126	46	22	17	18	27	15	8	6	4	2	1	0	1
1983	667	618	534	250	160	136	71	105	38	18	14	15	22	12	7	5	3	1	1	1
1984	1011	574	531	460	215	138	116	60	89	32	15	11	12	18	10	5	4	2	1	1
1985	981	870	493	456	393	182	114	94	47	66	23	11	8	9	13	7	4	3	2	2
1986	924	844	748	422	385	325	149	93	76	38	54	19	9	6	7	10	6	3	2	3
1987	1611	795	726	643	362	326	270	122	76	62	31	44	15	7	5	6	8	5	3	4
1988	2465	1386	684	623	546	301	263	213	95	59	48	24	34	12	6	4	4	6	4	5
1989	861	2122	1192	586	527	440	225	190	153	68	42	34	17	24	8	4	3	3	5	6
1990	712	741	1825	1024	500	438	350	172	143	114	51	32	26	13	18	6	3	2	2	8
1991	1572	613	638	1568	875	421	361	285	140	116	93	41	26	21	10	15	5	2	2	8
1992	789	1353	527	548	1346	746	352	291	221	106	87	70	31	19	16	8	11	4	2	8
1993	404	679	1165	454	471	1153	632	290	230	170	80	66	53	23	15	12	6	8	3	7
1994	613	348	585	1002	390	404	976	519	228	176	128	61	50	40	18	11	9	4	6	8
1995	324	527	299	503	862	335	345	820	418	176	133	97	46	37	30	13	8	7	3	10
1996	318	279	454	258	433	741	288	295	689	341	138	103	74	35	28	23	10	6	5	10
1997	442	274	240	391	222	372	636	246	250	575	279	111	81	58	27	22	18	8	5	12
1998	259	380	236	206	336	190	318	539	205	203	457	218	86	63	45	21	17	14	6	13
1999	401	223	327	203	178	289	164	273	461	173	168	375	178	70	51	37	17	14	11	16
2000	387	346	192	282	175	153	249	141	234	390	144	139	308	146	58	42	30	14	11	22
2001	809	333	297	165	242	150	131	213	120	196	322	118	114	251	119	47	34	24	11	27
2002	1281	696	286	256	142	208	129	112	180	101	164	270	99	95	210	100	39	29	20	32
2003	1525	1102	599	246	220	122	177	108	93	150	83	136	223	82	79	174	83	33	24	44
2004	1160	1312	949	515	212	188	103	149	90	78	124	69	113	186	68	65	145	69	27	56
2005	939	998	1130	816	443	181	159	86	122	74	63	102	57	92	152	56	53	118	56	68
2006	1153	808	859	972	701	379	153	133	71	101	61	52	84	47	76	125	46	44	97	102
2007	356	992	695	739	835	601	323	129	111	59	83	50	43	69	38	63	103	38	36	164
2008	154	307	854	598	635	716	511	271	107	91	48	68	41	35	57	31	51	84	31	164
2009	107	133	264	735	515	546	612	432	224	87	73	39	55	33	28	45	25	41	68	156
2010	81	92	114	227	632	442	466	517	359	184	71	59	31	44	27	23	37	20	33	181
2011	169	70	79	98	195	542	377	394	430	293	148	57	48	25	35	21	18	29	16	171
2012	240	145	60	68	84	168	463	319	327	350	236	119	45	38	20	28	17	15	23	150
2013	295	206	125	52	58	72	143	390	264	265	280	187	94	36	30	16	22	13	12	137
2014	160	253	178	108	45	50	61	119	321	215	216	228	152	76	29	24	13	18	11	121
2015	1508	137	218	153	93	38	43	52	100	264	175	175	184	123	62	24	20	10	15	106
2016	2925	1298	118	188	131	79	33	36	43	82	215	143	142	150	100	50	19	16	8	99
2017	516	2517	1117	102	161	111	66	27	29	35	66	175	116	116	122	82	41	16	13	87
2018	517	444	2166	961	87	138	94	55	22	24	29	54	143	95	95	100	67	33	13	82

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	7	13	15	8	6	4	4	4	4	4	4	4	4
1976	1	6	8	14	17	16	7	5	3	3	3	3	3	3	5
1977	1	7	16	17	18	17	14	6	4	2	2	2	2	1	5
1978	0	3	21	34	22	19	15	12	5	3	2	1	1	1	4
1979	1	3	10	46	44	22	17	13	11	5	3	1	1	0	2
1980	1	3	8	21	57	43	19	14	11	9	4	2	1	0	2
1981	1	3	9	16	25	55	37	16	12	9	7	3	2	1	2
1982	1	8	9	19	19	25	48	31	13	10	8	6	3	2	2
1983	1	4	21	19	23	19	21	40	26	11	8	6	5	2	3
1984	1	7	12	44	23	22	16	17	33	21	9	6	5	4	4
1985	1	7	19	24	49	20	16	11	13	23	15	6	5	4	6
1986	3	9	19	39	29	47	17	14	9	10	19	12	5	4	8
1987	3	17	25	39	47	28	40	14	11	8	8	16	10	4	9
1988	2	17	45	50	46	44	23	32	11	9	6	7	12	8	10
1989	4	15	42	83	54	39	33	17	23	8	6	4	5	9	13
1990	4	23	38	80	93	48	30	25	13	18	6	5	3	4	16
1991	3	23	62	79	96	89	40	25	21	10	14	5	4	3	16

1992	6	22	64	129	94	88	71	31	19	16	8	11	4	3	14
1993	9	39	62	135	156	87	71	55	24	15	12	6	8	3	13
1994	3	61	110	131	162	144	70	55	43	18	11	9	4	6	12
1995	3	21	170	235	161	153	117	55	43	32	14	8	7	3	13
1996	6	18	60	363	289	153	125	92	43	33	25	11	6	5	13
1997	3	39	49	128	455	283	129	102	74	33	26	19	8	5	14
1998	2	19	109	106	160	444	239	106	82	58	26	20	15	6	15
1999	2	10	55	236	135	161	391	205	89	68	48	21	16	12	17
2000	1	15	28	119	298	134	140	331	172	73	56	39	18	13	24
2001	1	8	43	61	148	293	115	118	277	141	60	46	32	14	31
2002	2	8	22	91	76	148	257	99	101	233	119	51	38	27	38
2003	1	11	22	48	113	74	128	219	84	84	194	99	42	32	53
2004	2	6	30	47	59	112	65	109	186	70	70	162	82	35	71
2005	1	10	18	64	58	58	96	54	92	153	58	58	133	67	86
2006	3	10	28	38	80	56	50	81	46	76	127	48	48	110	127
2007	5	20	26	58	47	78	49	42	68	38	63	105	39	39	194
2008	6	32	55	56	72	45	67	41	36	56	31	52	86	32	192
2009	4	38	88	116	68	68	38	55	34	29	45	25	42	69	179
2010	4	29	105	185	142	65	58	32	46	27	23	37	21	34	201
2011	4	23	80	223	229	137	55	48	26	37	22	19	30	16	187
2012	1	28	65	171	275	220	115	45	39	21	30	18	15	24	163
2013	1	9	79	137	208	261	183	94	37	31	17	23	14	12	147
2014	0	4	24	165	167	200	223	153	78	30	25	14	19	11	129
2015	0	3	11	52	207	164	171	186	127	64	24	21	11	15	114
2016	1	2	7	23	65	204	141	144	155	104	52	20	17	9	105
2017	1	4	6	16	28	63	174	118	120	127	85	43	16	14	93
2018	1	6	12	12	19	27	54	146	99	99	104	70	35	13	87

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	6.94	0.11	1988	total biomass	1000.30	17.55
	sel_slope_fishery_female	1.10	0.05	1989	total biomass	1024.50	18.07
	sel50_fishery_female	8.51	0.46	1990	total biomass	999.94	18.35
	sel_slope_fsh_males	1.21	0.06	1991	total biomass	1071.80	18.47
	sel50_fsh_males	7.47	0.41	1992	total biomass	1082.30	18.35
	sel_slope_survey_females	1.99	0.11	1993	total biomass	1307.90	22.07
	sel50_survey_females	3.54	0.06	1994	total biomass	1402.30	23.78
	sel_slope_survey_males	0.19	0.07	1995	total biomass	1419.50	24.65
	sel50_survey_males	-0.12	0.02	1996	total biomass	1501.30	26.65
	Ricker_logalpha	2.89	0.21	1997	total biomass	1462.40	26.45
	Ricker_logbeta	-5.40	0.13	1998	total biomass	1348.90	25.30
	Fmsyr	0.15	0.02	1999	total biomass	1244.30	23.74
	logFmsyr	-1.93	0.16	2000	total biomass	1239.30	24.08
	ABC_biomass 2018	829	31	2001	total biomass	1262.20	24.70
	ABC_biomass 2019	1004	65	2002	total biomass	1280.50	25.13
	msy	213	35	2003	total biomass	1239.00	24.28
	Bmsy	186	17	2004	total biomass	1438.30	27.56
1975	total biomass	178.98	8.36	2005	total biomass	1360.60	26.80
1976	total biomass	194.29	9.06	2006	total biomass	1259.40	24.81
1977	total biomass	210.42	9.68	2007	total biomass	1252.70	25.05
1978	total biomass	232.26	10.15	2008	total biomass	1326.20	27.09
1979	total biomass	252.43	10.42	2009	total biomass	1297.70	27.42
1980	total biomass	278.89	10.62	2010	total biomass	1363.80	29.89
1981	total biomass	337.65	11.17	2011	total biomass	1408.60	32.36
1982	total biomass	370.81	10.76	2012	total biomass	1425.80	34.71
1983	total biomass	449.53	11.54	2013	total biomass	1291.30	33.48
1984	total biomass	501.02	11.89	2014	total biomass	1156.40	31.54
1985	total biomass	665.07	14.05	2015	total biomass	1184.40	34.20
1986	total biomass	674.27	13.56	2016	total biomass	1147.50	35.96
1987	total biomass	900.96	16.49	2017	total biomass	1331.40	56.86
				2018	total biomass	1510.20	95.31

Table 8.20. Stock assessment model estimates of average age-specific fishing mortality, by gender, 1975-2018.

	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	0.03	0.07	0.15	0.23	0.29	0.31	0.31	0.31	0.31	0.31
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.07	0.17	0.29	0.37	0.41	0.41	0.41	0.41
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.07	0.16	0.25	0.31	0.31	0.31	0.31
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.11	0.30	0.70	0.70	0.70	0.70
1979	0.00	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
1980	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	0.05	0.05
1981	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	0.04
1982	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
1983	0.00	0.00	0.01	0.03	0.05	0.06	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
1984	0.00	0.01	0.02	0.04	0.09	0.14	0.17	0.19	0.19	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
1985	0.01	0.02	0.04	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1986	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	0.06
1987	0.01	0.02	0.04	0.07	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
1988	0.01	0.03	0.08	0.13	0.16	0.18	0.18	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
1989	0.00	0.02	0.05	0.10	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
1990	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	0.06
1991	0.00	0.00	0.01	0.02	0.05	0.08	0.10	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
1992	0.00	0.00	0.00	0.01	0.03	0.06	0.09	0.11	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
1993	0.00	0.00	0.00	0.01	0.03	0.06	0.10	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
1994	0.00	0.00	0.00	0.01	0.02	0.04	0.07	0.10	0.12	0.13	0.13	0.14	0.14	0.14	0.14	0.14	0.14
1995	0.00	0.00	0.00	0.01	0.02	0.04	0.07	0.10	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13
1996	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.08	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10
1997	0.00	0.00	0.00	0.01	0.01	0.03	0.04	0.06	0.08	0.09	0.10	0.10	0.10	0.11	0.11	0.11	0.11
1998	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.04	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	0.01	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2000	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
2001	0.00	0.00	0.00	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2002	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2003	0.00	0.00	0.01	0.01	0.02	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2004	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	0.05
2005	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2006	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	0.05
2007	0.00	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
2008	0.00	0.00	0.00	0.01	0.03	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2009	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
2010	0.00	0.00	0.00	0.01	0.02	0.03	0.05	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2011	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2012	0.00	0.00	0.01	0.01	0.03	0.05	0.07	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
2013	0.00	0.01	0.02	0.03	0.04	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2014	0.00	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
2015	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2016	0.00	0.00	0.00	0.01	0.02	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2017	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
2018	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

Table 8.20. Stock assessment model estimates of average age-specific fishing mortality, by gender, 1975-2018.

	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	0.06	0.14	0.23	0.29	0.31	0.32	0.32	0.32	0.32	0.32	0.32	0.32
1976	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.15	0.28	0.38	0.41	0.43	0.43	0.43	0.43	0.43	0.43
1977	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.15	0.25	0.31	0.33	0.34	0.34	0.34	0.34	0.34
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.16	0.46	0.94	1.34	1.52	1.52	1.52	1.52
1979	0.00	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
1980	0.01	0.02	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1981	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	0.04	0.04	0.04
1982	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
1983	0.00	0.00	0.00	0.01	0.02	0.03	0.05	0.06	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08
1984	0.01	0.02	0.04	0.07	0.11	0.14	0.17	0.19	0.19	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
1985	0.02	0.04	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1986	0.00	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	0.06	0.06
1987	0.01	0.03	0.06	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
1988	0.02	0.07	0.14	0.18	0.18	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
1989	0.01	0.03	0.08	0.12	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
1990	0.01	0.02	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1991	0.00	0.01	0.03	0.06	0.10	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
1992	0.00	0.00	0.02	0.04	0.08	0.11	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
1993	0.00	0.00	0.02	0.05	0.09	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
1994	0.00	0.00	0.01	0.02	0.07	0.11	0.13	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
1995	0.00	0.00	0.00	0.01	0.02	0.05	0.09	0.11	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
1996	0.00	0.00	0.00	0.01	0.02	0.03	0.05	0.07	0.08	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10
1997	0.00	0.00	0.01	0.02	0.03	0.06	0.08	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1998	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1999	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
2000	0.00	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
2001	0.00	0.00	0.00	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2002	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	0.04	0.04	0.04
2003	0.00	0.01	0.01	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	0.04
2004	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	0.05	0.05	0.05
2005	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
2006	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
2007	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
2008	0.00	0.00	0.01	0.02	0.04	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2009	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
2010	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
2011	0.00	0.00	0.01	0.02	0.04	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2012	0.00	0.00	0.01	0.02	0.04	0.06	0.07	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
2013	0.00	0.00	0.01	0.03	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2014	0.00	0.00	0.00	0.01	0.03	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2015	0.00	0.00	0.01	0.03	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2016	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	0.06	0.06
2017	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	0.05	0.05	0.05
2018	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

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
2018	457,499	28,064	0.04
2019	417,209	110,367	0.18
2020	341,556	97,483	0.18
2021	293,632	95,129	0.18
2022	285,786	104,907	0.18
2023	351,936	126,197	0.18
2024	448,953	140,404	0.18
2025	451,281	130,518	0.18
2026	428,156	117,278	0.18
2027	383,870	106,148	0.18
2028	338,289	94,709	0.18
2029	310,641	87,637	0.18
2030	287,342	81,874	0.18
2031	270,990	77,597	0.18

Scenario 3
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2018	457499	28064	0.040044
2019	420597	50228.9	0.077225
2020	378359	34605.8	0.0551
2021	358672	36105.2	0.0551
2022	370332	41052.9	0.0551
2023	455023	50143.5	0.0551
2024	576890	57587.1	0.0551
2025	609360	57000.7	0.0551
2026	615941	54665	0.0551
2027	589777	52511.3	0.0551
2028	552119	49292.6	0.0551
2029	532741	47460.6	0.0551
2030	511149	45600.7	0.0551
2031	496852	44165.6	0.0551

Scenario 4
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2018	457499	28064	0.040044
2019	420338	54998.6	0.084846
2020	374896	50530.2	0.081886
2021	347322	51800.2	0.081886
2022	352834	58282.8	0.081886
2023	431590	70722.8	0.081886
2024	546160	80505.9	0.081886
2025	569947	78506.9	0.081886
2026	567606	74127.2	0.081886
2027	535068	70171.6	0.081886
2028	493457	64999.8	0.081886
2029	470040	61889.2	0.081886
2030	446253	58934.9	0.081886
2031	429750	56650.3	0.081886

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2018	457499	28064	0.040044
2019	423228	0	0
2020	408279	0	0
2021	403968	0	0
2022	428429	0	0
2023	526076	0	0
2024	663921	0	0
2025	716656	0	0
2026	745376	0	0
2027	736819	0	0
2028	712180	0	0
2029	706659	0	0
2030	694786	0	0
2031	690661	0	0

Scenario 6
Determination of whether northern rock sole are currently overfished **B35=142,000**

Year	Female spawning biomass	catch	F
2018	457499	28064	0.040044
2019	415876	132718	0.217009
2020	328270	113639	0.217025
2021	273845	108884	0.217025
2022	262623	119445	0.217025
2023	325588	143432	0.217025
2024	417233	158180	0.217025
2025	413092	144301	0.217025
2026	384359	127252	0.217025
2027	338086	113347	0.217025
2028	293282	99969.6	0.217025
2029	266219	91818.1	0.217025
2030	244731	85500.9	0.216975
2031	229915	80556.2	0.215216

Scenario 7
Determination of whether the stock is approaching an overfished condition **B35=142,000**

Year	Female spawning biomass	catch	F
2018	457499	28064	0.040044
2019	417209	110371	0.177375
2020	341554	97482.2	0.177382
2021	292749	114743	0.217025
2022	276655	123839	0.217025
2023	335984	146731	0.217025
2024	424746	160577	0.217025
2025	418524	146020	0.217025
2026	388255	128477	0.217025
2027	340846	114215	0.217025
2028	295237	100585	0.217025
2029	267599	92252.9	0.217025
2030	245697	85809.6	0.21699
2031	230590	80791.4	0.215319

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
2017	47,100	155,100
2018	47,100	143,100

Table 8.23. Catch and bycatch (t) in the rock sole target fisheries, 1993-2017, 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	2016	2017
Walleye Pollock	7,091	6,779	7,372	11,259	9382	11,852	5,617
Arrowtooth Flounder	448	101	683	681	337	371	1263
Pacific Cod	7,332	9,777	8,599	10,982	10954	13,812	8,329
Groundfish, General	6						
Rock Sole	39,682	58,178	42,433	36,981	31,303	32,754	18,529
Flathead Sole	2,028	769	2,019	1,317	812	1,141	860
Sablefish				<1	5	4	<1
Atka Mackerel	<1	<1	<1	<1	<1	<1	<1
Pacific Ocean Perch	1	<1	45	<1	<1	<1	<1
Rex Sole							
Other flatfish	411	1144	313	530	455	432	1,224
Shortraker/Rougheye							
Northern Rockfish		<1	1		<1		
Yellowfin Sole	9,827	9557	8,477	8,739	12861	22,244	16,440
Greenland Turbot	1	<1	3	5	1	<1	<1
Alaska Plaice	3,162	1653	4,339	3,103	1443	4,235	2,744
Sculpin, General	905	969	1,288	807	447	689	613
Kamchatka flounder		17	109	94	39	32	14
Octopus		1			2		<1
Other rockfish		10	<1	<1	<1	<1	<1
Skate, General	711	653	529	689	284	280	214

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

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Benthic urochordata	105.5	12.7	30.9	10.8	58.2	5.3	20.5	7.8	15.1	15.8	24.0	16.0	3.4
Birds													
Bivalves	0.4	0.4	0.3	0.3	0.5	0.4	0.2	0.2	0.3	0.4	0.6	0.2	0.1
Brittle star unidentified	7.3	1.5	1.2	0.3	1.4	0.1	0.1	0.1	0.2	0.3	0.5	0.1	0.6
Capelin	0.0	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.0	4.9	0.1	0.1	0.0
Corals Bryozoans - Corals Bryozoans Unidentified	1.3	0.0	0.1	0.0	2.0	0.1	0.3	0.2	0.2	0.1	0.3	0.0	0.0
Eelpouts	3.2	6.9	0.1	0.2	5.0	1.9	0.1	2.1	3.7	1.4	0.8	0.2	0.2
Eulachon		0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.7	0.2	0.0	0.0
Giant Grenadier		4.6			3.3								
Greenlings	0.3	0.3	0.0		0.0	0.0			0.0	0.0	0.1	0.2	0.4
Grenadier - Ratail Grenadier Unidentified	0.1												
Gunnels											0.1		
Hermit crab unidentified	10.4	5.7	2.7	0.9	4.0	2.3	3.5	1.9	2.6	1.6	1.1	0.2	0.2
Invertebrate unidentified	6.9	24.2	1.6	2.4	14.3	6.9	3.0	37.8	6.0	3.0	1.0	0.2	0.0
Large Sculpins	480.4	630.8											
Misc crabs	6.5	13.6	8.9	3.3	6.4	3.2	5.2	4.3	6.2	4.4	8.0	2.1	1.0
Misc crustaceans	0.5	0.2	0.2	0.3	1.0	0.2	0.5	0.1	0.1	0.1	0.2	0.0	
Misc fish	17.4	70.7	25.3	11.8	15.0	16.8	17.6	6.1	10.2	10.5	11.2	8.0	5.8
Misc inverts (worms etc)	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other osmerids	0.3	0.2	0.6	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.4	1.3	0.9
Other Sculpins	182.4	130.5	33.2	32.8									
Pacific Sand lance	0.0	0.0	0.0	0.1	0.0	0.0	0.0		0.0	0.1	0.2	0.1	0.1
Pacific Sandfish						0.0			0.0	0.0	0.0		0.1
Pandalid shrimp	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1
Polychaete unidentified	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
Scypho jellies	73.3	94.5	184.7	225.1	349.6	268.2	311.9	134.6	567.8	426.9	136.6	47.2	118.0
Sea anemone unidentified	9.0	6.3	6.7	2.7	9.3	9.5	4.5	11.5	16.1	2.8	4.3	2.0	0.7
Sea pens whips	0.0		0.0	0.1	0.2	0.0	0.1	0.1	0.0	0.0	0.0	0.4	0.0
Sea star	730.7	705.2	207.0	31.8	176.8	67.6	84.4	111.7	134.7	243.0	467.2	280.2	219.2
Snails	28.4	24.3	9.3	3.5	11.2	9.7	14.2	6.5	8.8	5.8	5.1	2.1	0.9
Sponge unidentified	41.0	19.2	19.2	64.8	141.6	112.2	62.8	154.0	186.6	76.4	9.1	0.6	1.6
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	3.9	32.2	6.0	1.1	4.2	3.4	1.6	0.4	5.1	4.9	3.3	5.1	2.8

Table 8.25 Southern rock sole biomass estimates (t) and CV from the Bering Sea shelf surveys and Aleutian Islands surveys.

southern rock sole

	shelf survey		**Aleutian Islands**	
	biomass (t)	CV	biomass (t)	CV
1997	65	1	6257	0.23
1998	701	0.87		
1999	126	0.89		
2000	3	1	5560	0.35
2001	86	1		
2002	23	1	6684	0.21
2003	166	0.71		
2004	152	0.82	11962	0.11
2005	428	0.75		
2006	942	0.71	7026	0.25
2007	3401	0.7		
2008	1322	0.81		
2009	2465	0.99		
2010	209	1	7593	0.52
2011	800	0.63		
2012	746	0.91	8661	0.35
2013	613	0.71		
2014	730	1	10709	0.45
2015	2450	0.96		
2016	1174	0.93	7760	0.23
2017	10287	0.94		
2018	2795	1.0	10652	0.12

Figures

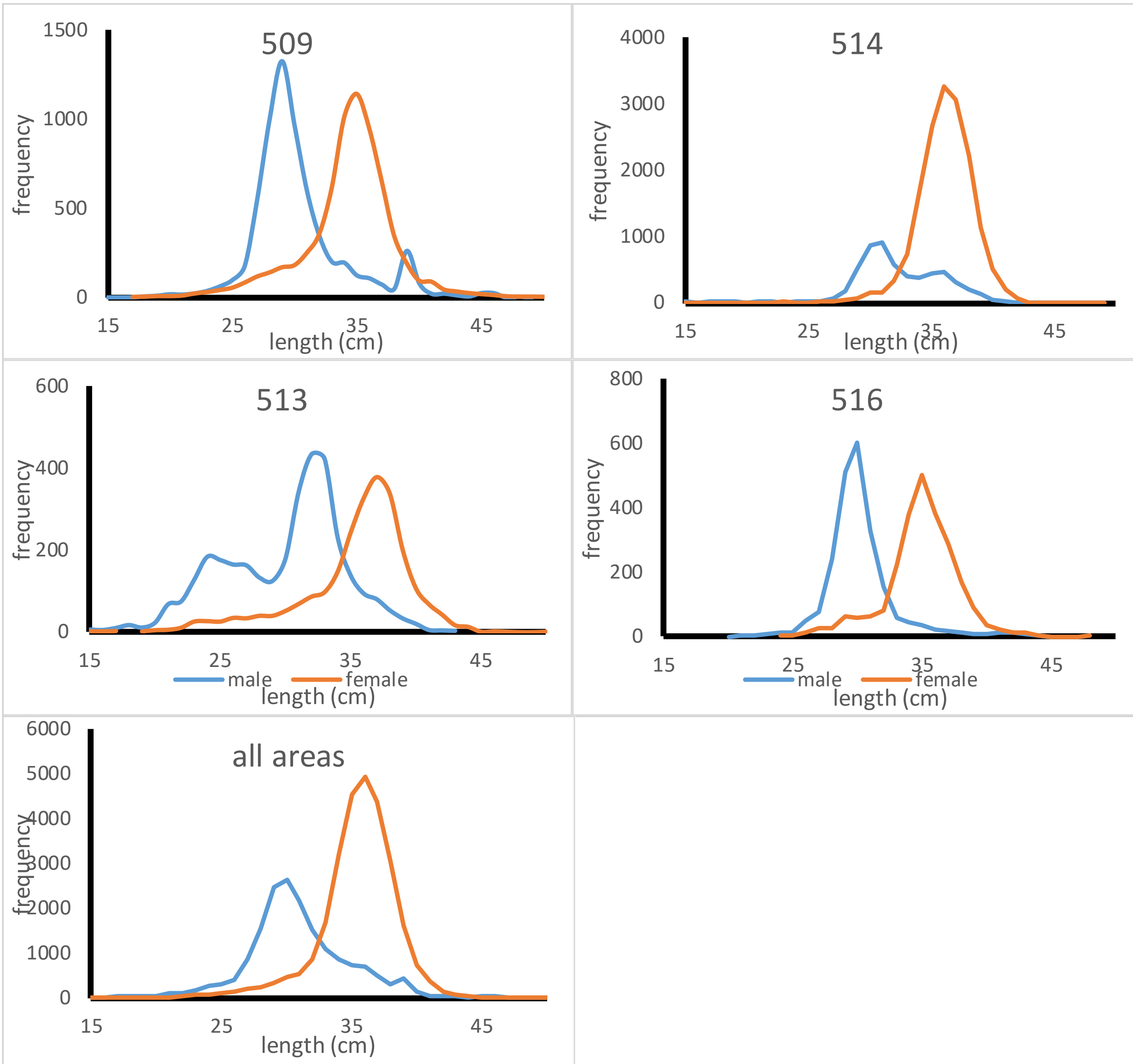
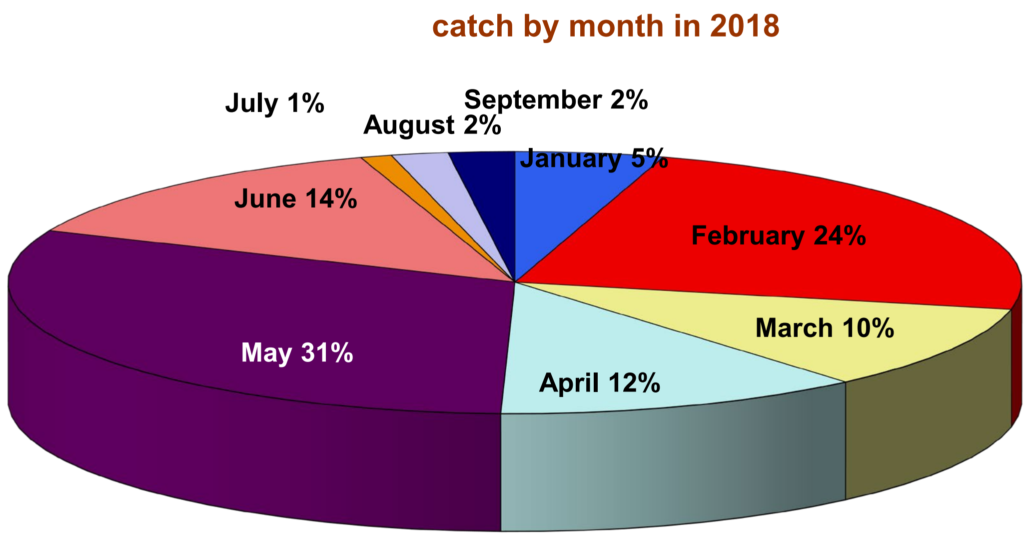


Figure 8.1. Size composition of rock sole, by sex and area, in the 2018 catch as determined from observer sampling.



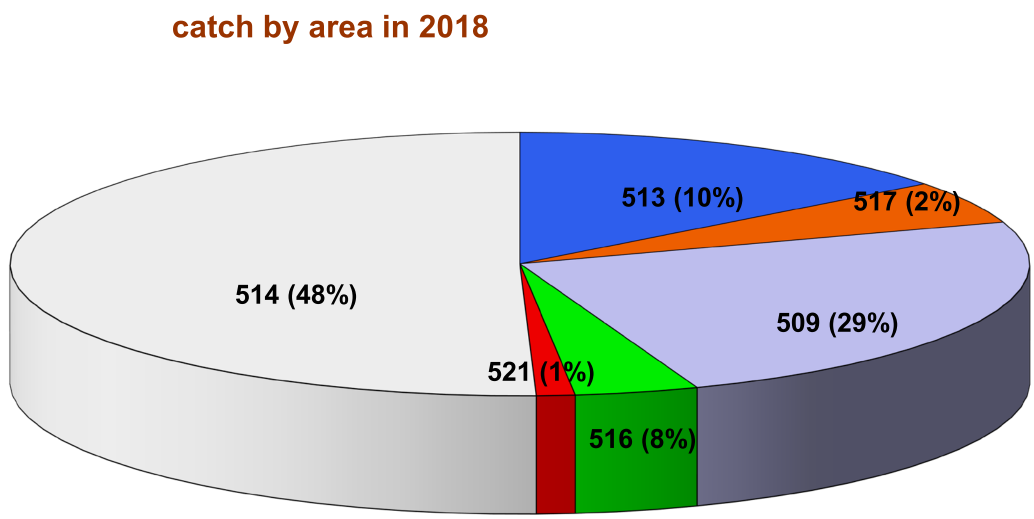


Figure 8.2. Bering Sea northern rock sole fishery catch by month and area in 2018 (percent of total).

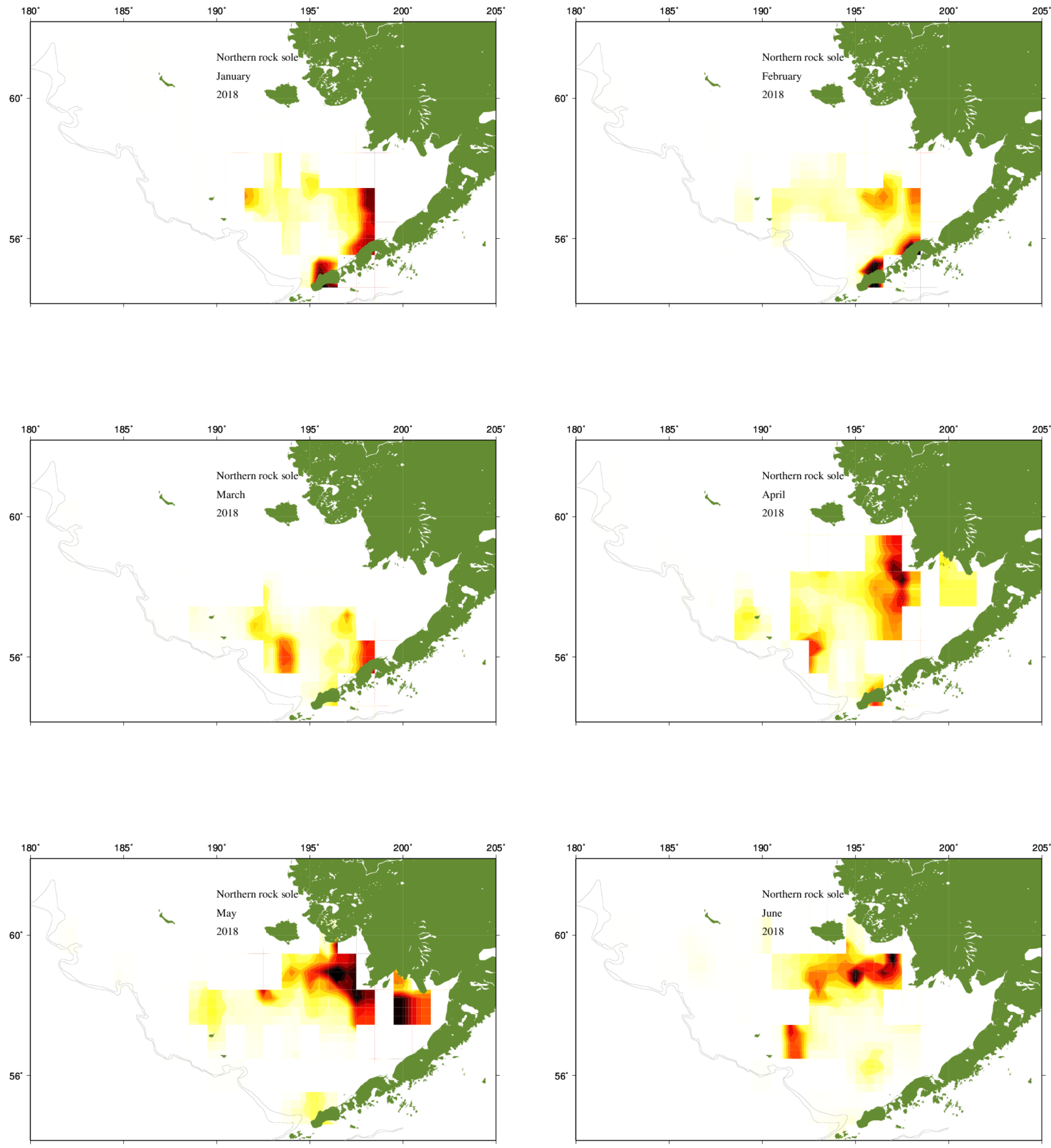


Figure 8.3. Northern rock sole catch locations by month in 2018.

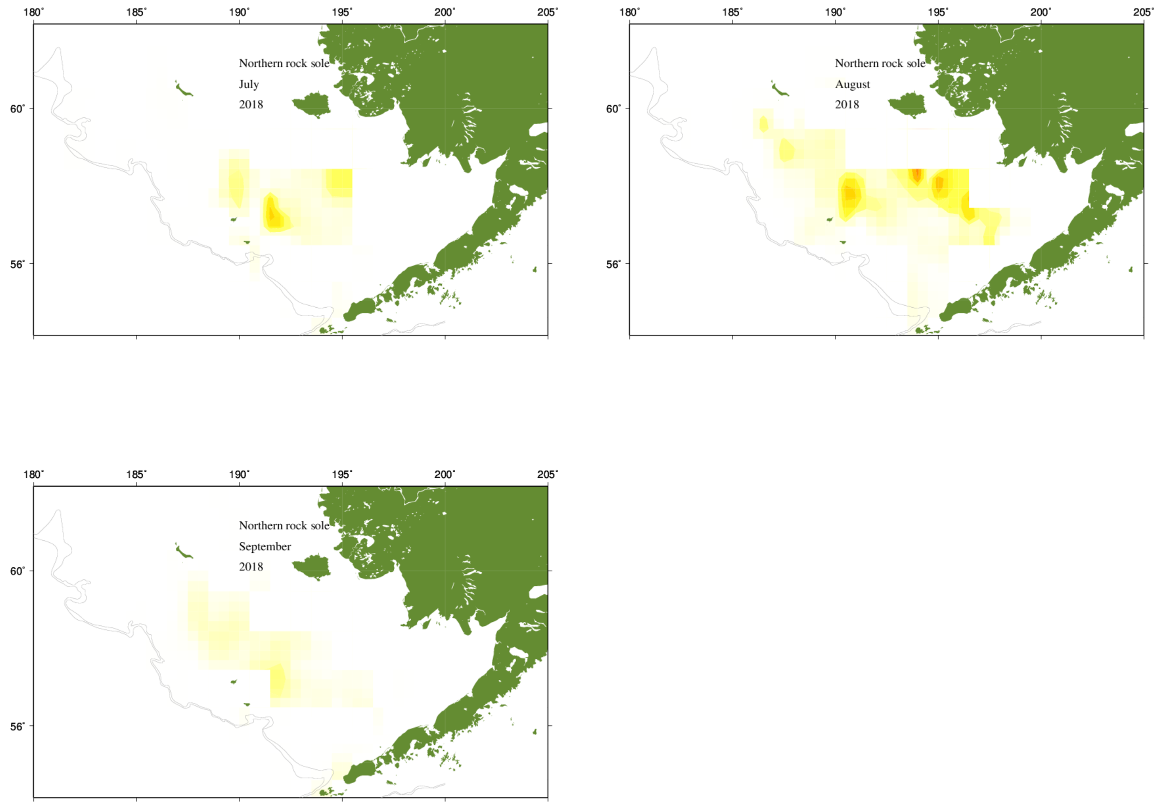


Figure 8.3. Continued.

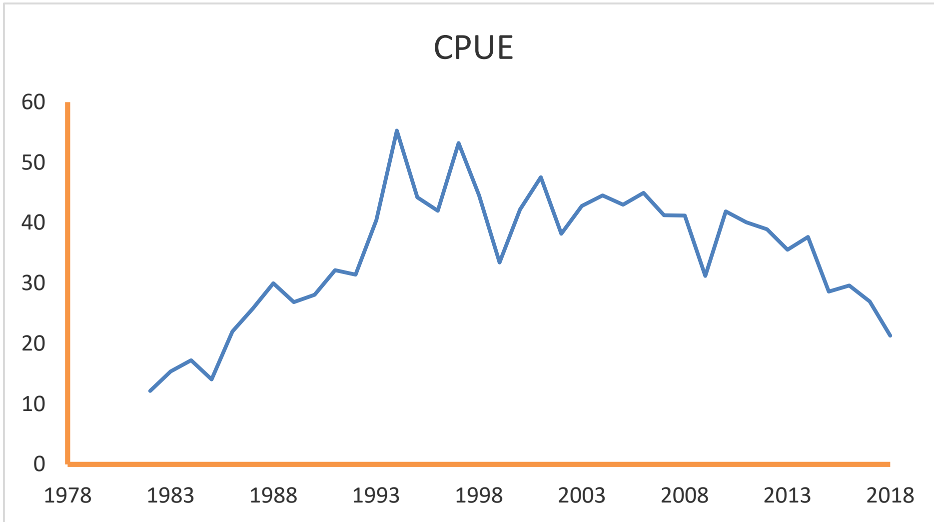


Figure 8.4. Catch per unit effort of *Lepidopsetta polyxystra* and *Lepidopsetta bilineata* (kg/ha) from Bering Sea shelf trawl surveys, 1982-2018.

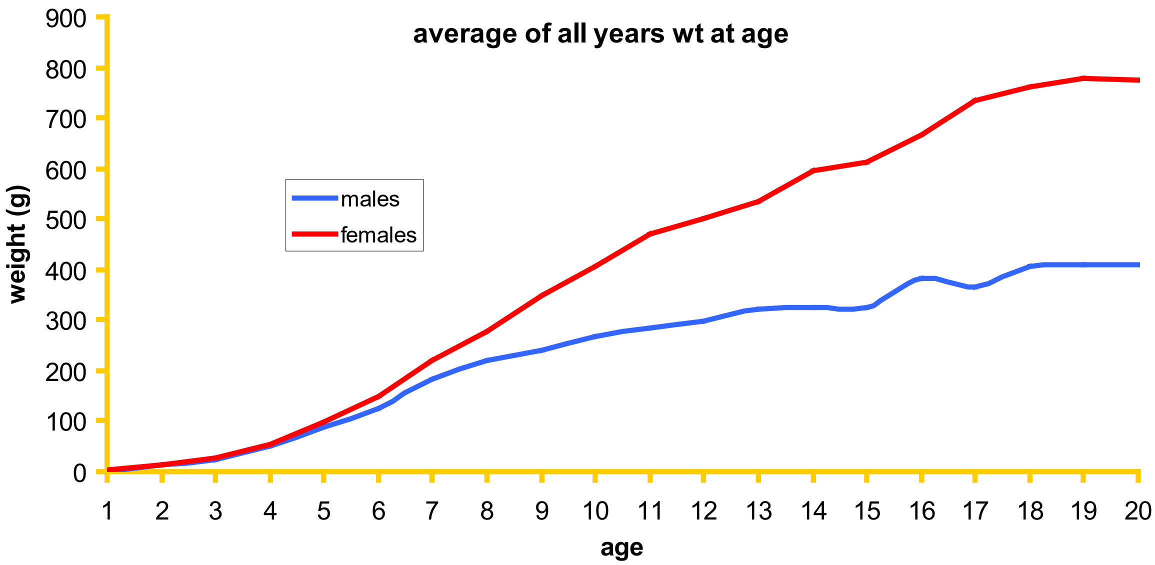


Figure 8.5-Mean weight-at-age for northern rock sole averaged over all years of survey age data.

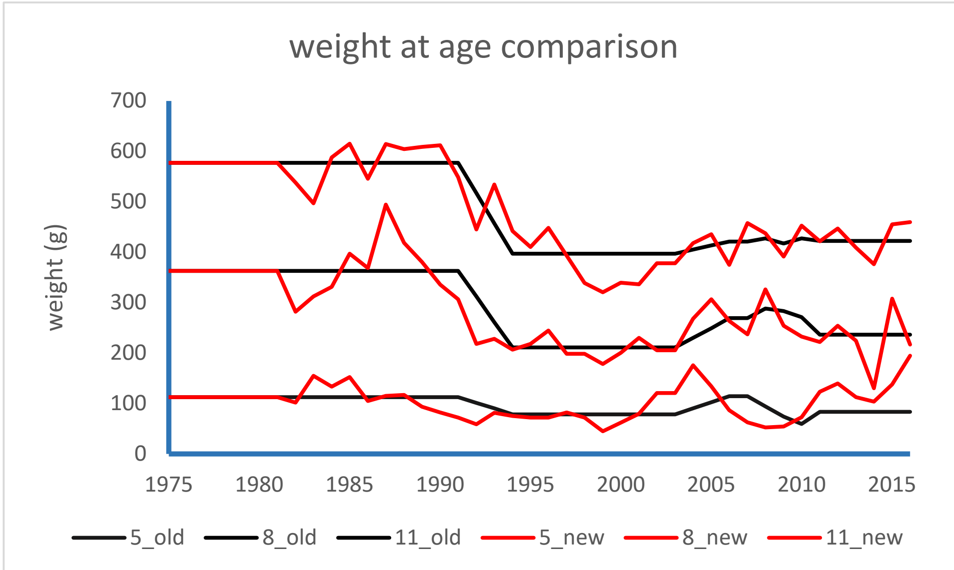


Fig. 8.6- Mean population weight-at-age (g) by year for eastern Bering Sea northern rock sole shown for ages 5, 8 and 11 year old fish. Black lines are the values used in previous assessments to model annual changes in growth, red lines are empirical estimates, by year, used in the 2018 assessment.

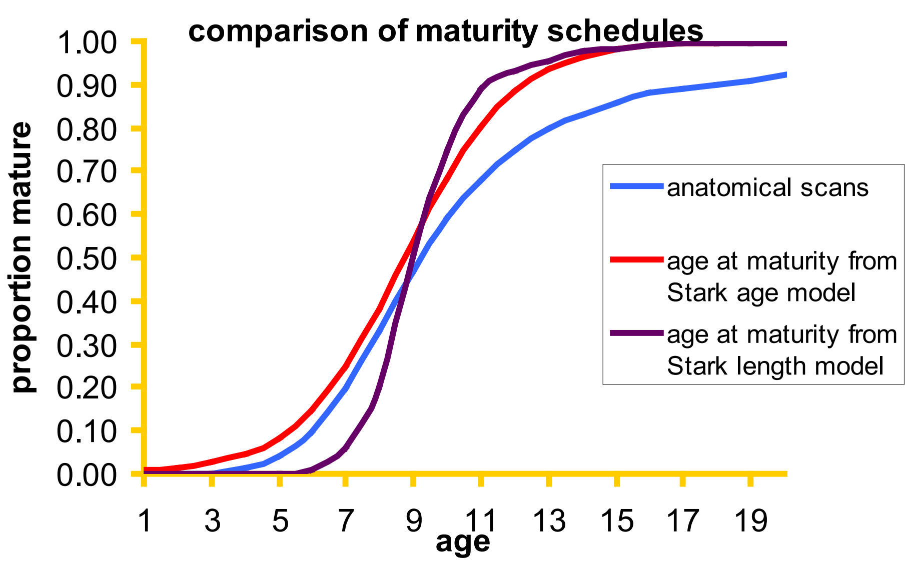


Fig. 8.7-Time-varying length-at-age for 8 year old northern rock sole with 3 time periods identified for modeling growth differently (top panel). Maturity schedule for northern rock sole from three methods (bottom panel). Stark (2012) length model, based on histology, is used in the stock assessment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

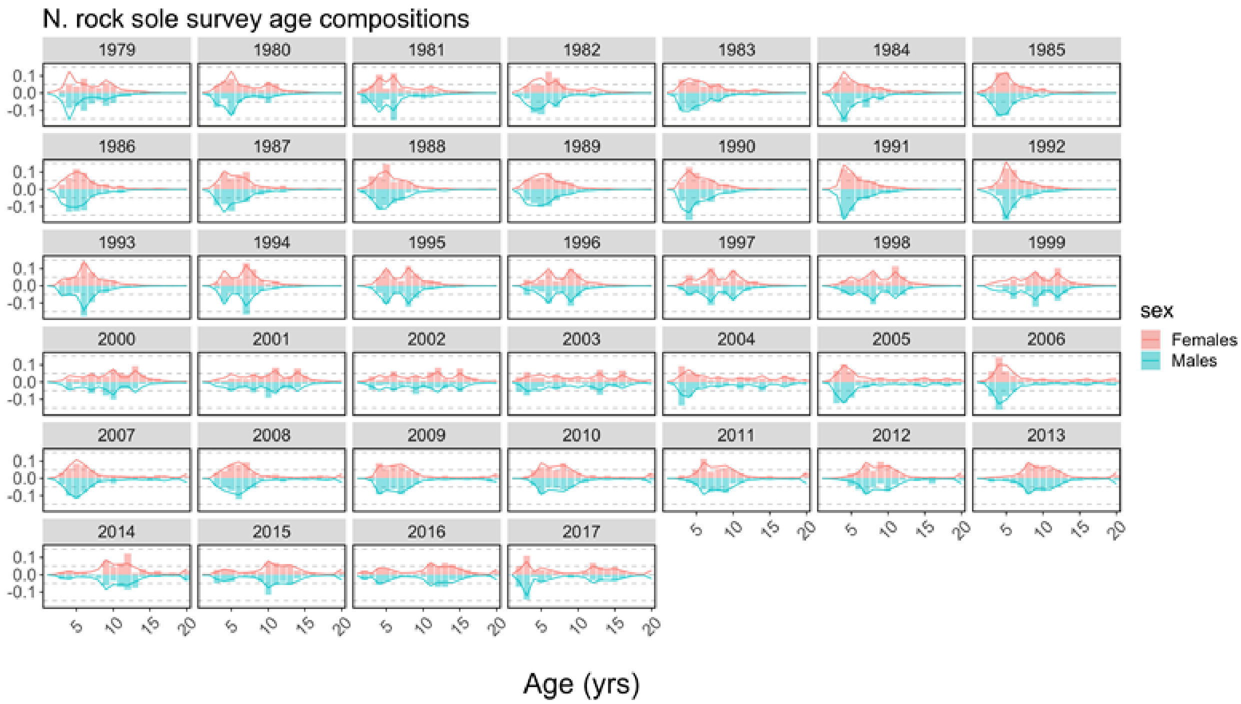


Figure 8.8. Age composition of northern rock sole from the AFSC annual trawl survey.

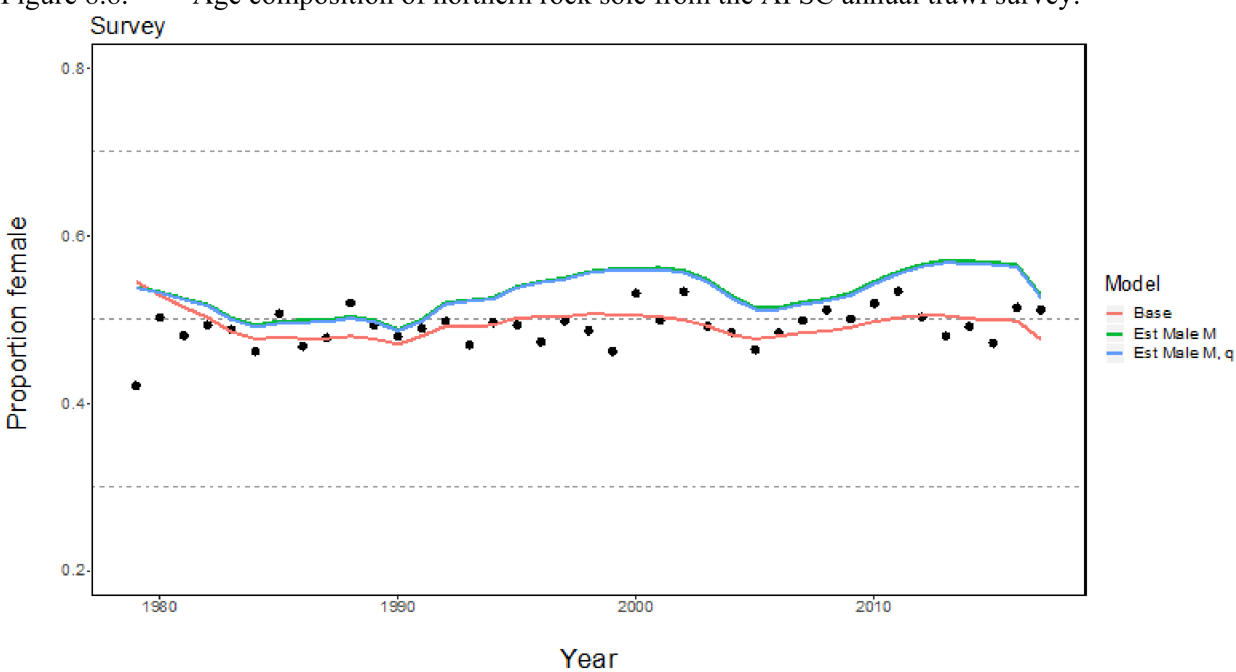


Figure 8.9. Fits to the population sex ratio from the results of Models 15.1 (M and q fixed), 18.1 (male M estimated and q fixed) and 18.2 (male M and q estimated).

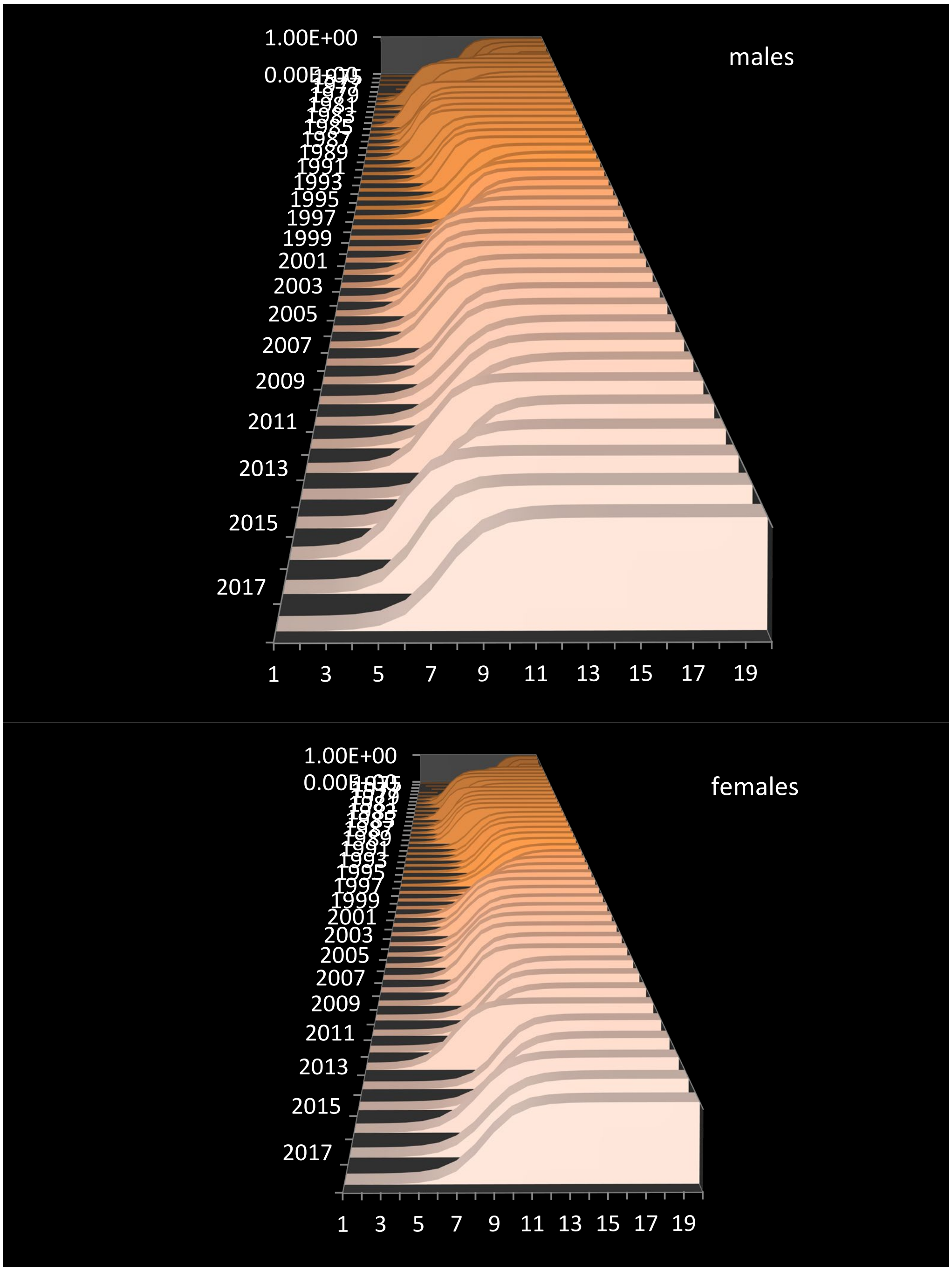


Figure 8.10. Stock assessment model estimates of fishery selectivity at age, by year and gender.

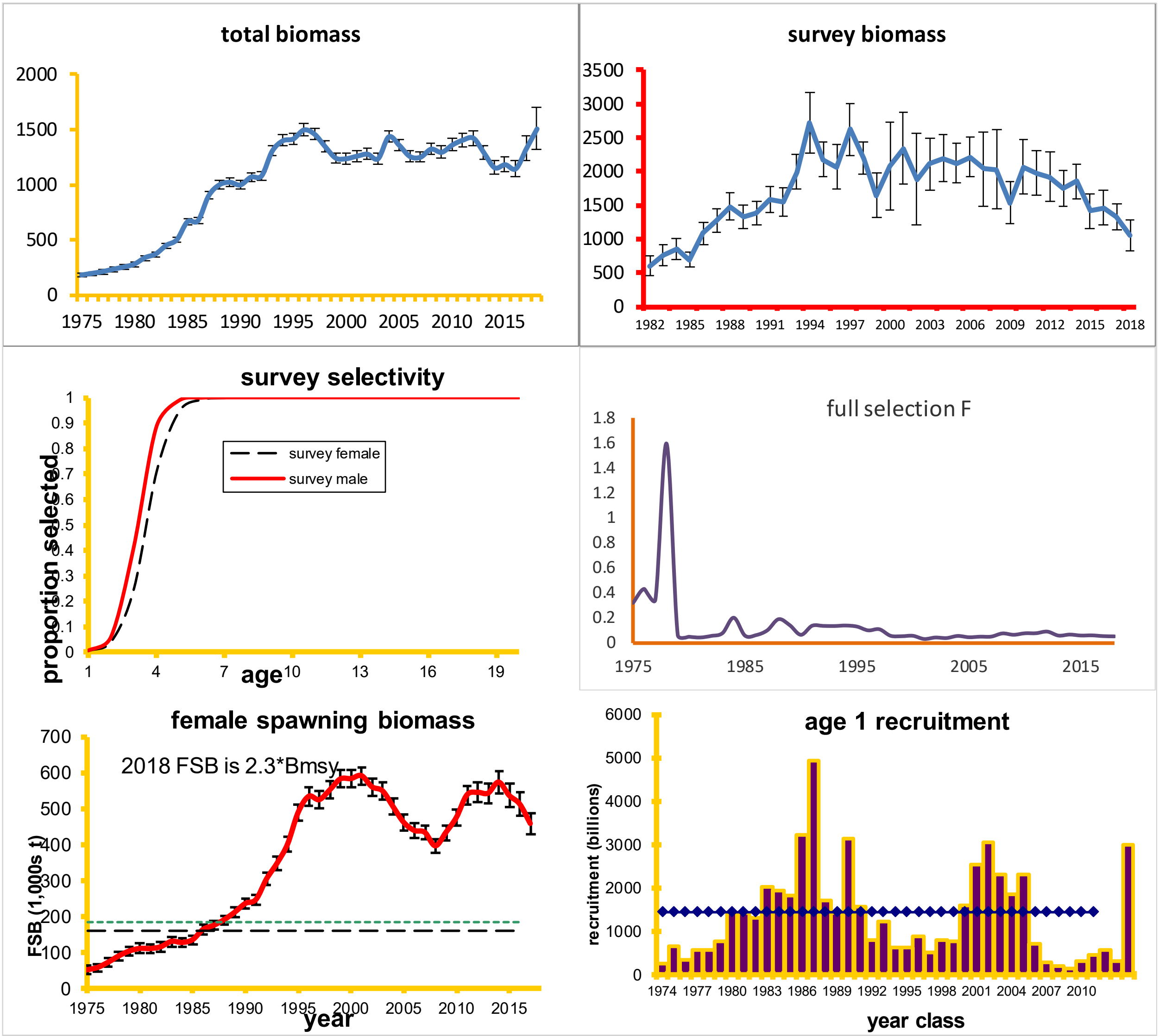


Figure 8.11. BSAI stock assessment model estimates of total 2+ biomass (top left panel), fit to trawl survey biomass (top right panel), age-specific fishery and survey selectivity (middle left panel) and average annual fishing mortality rate (middle right panel), female spawning biomass (bottom left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

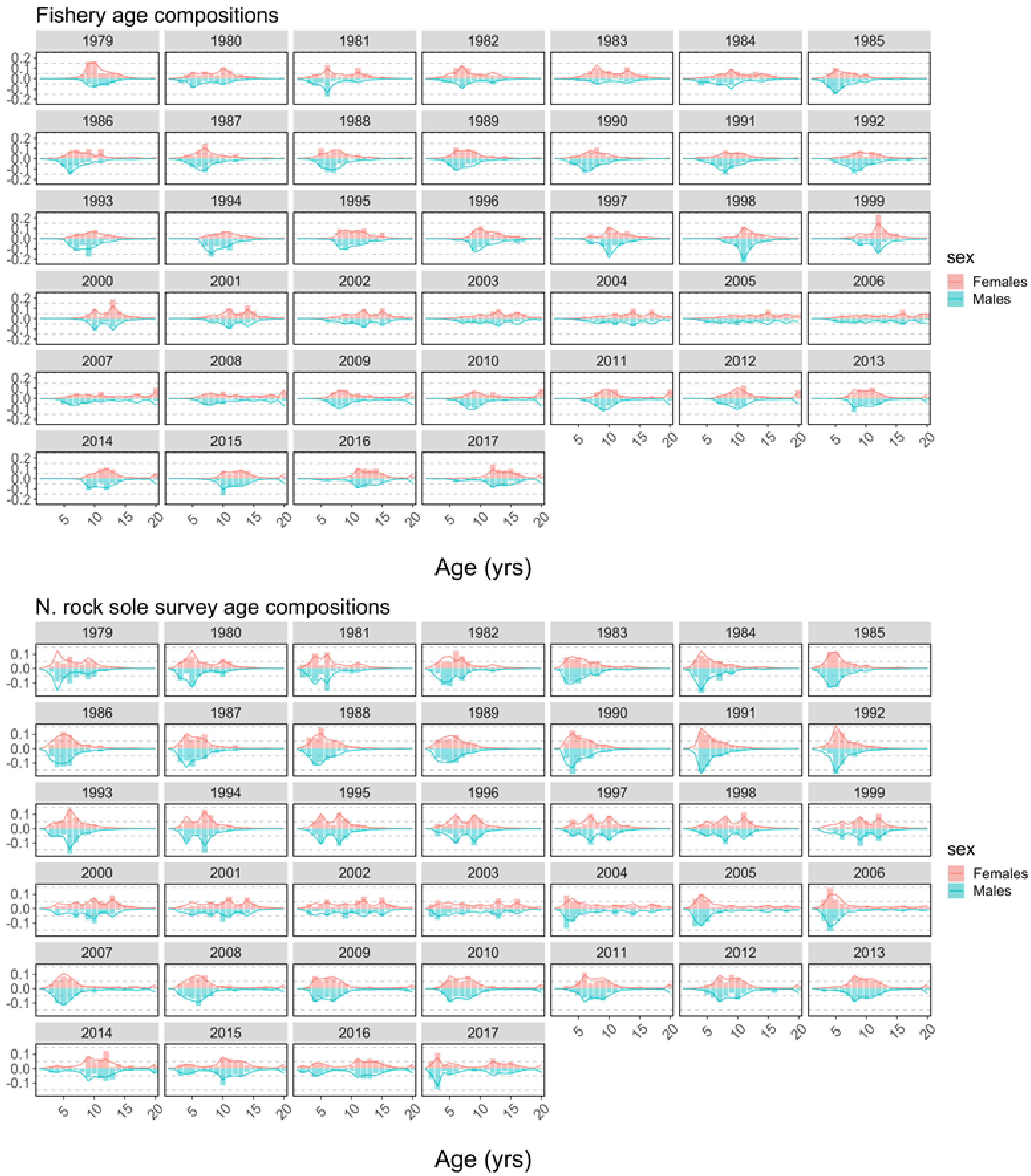


Figure 8.12. BSAI stock assessment model 15.1 fit to the fishery and survey age compositions, by sex.

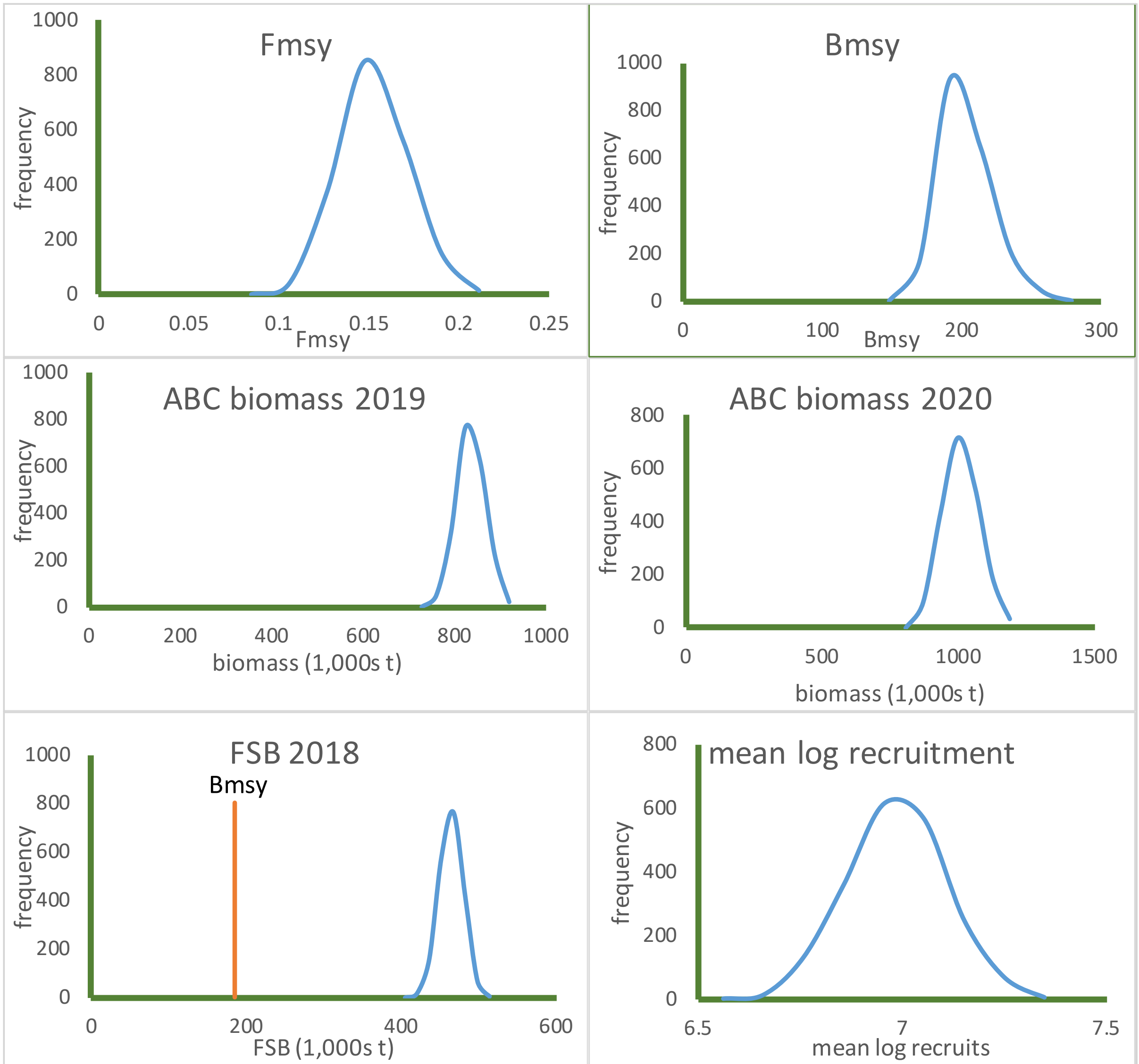


Figure 8.13. Posterior distributions of some selected model estimates from the preferred BSAI stock assessment model 15.1.

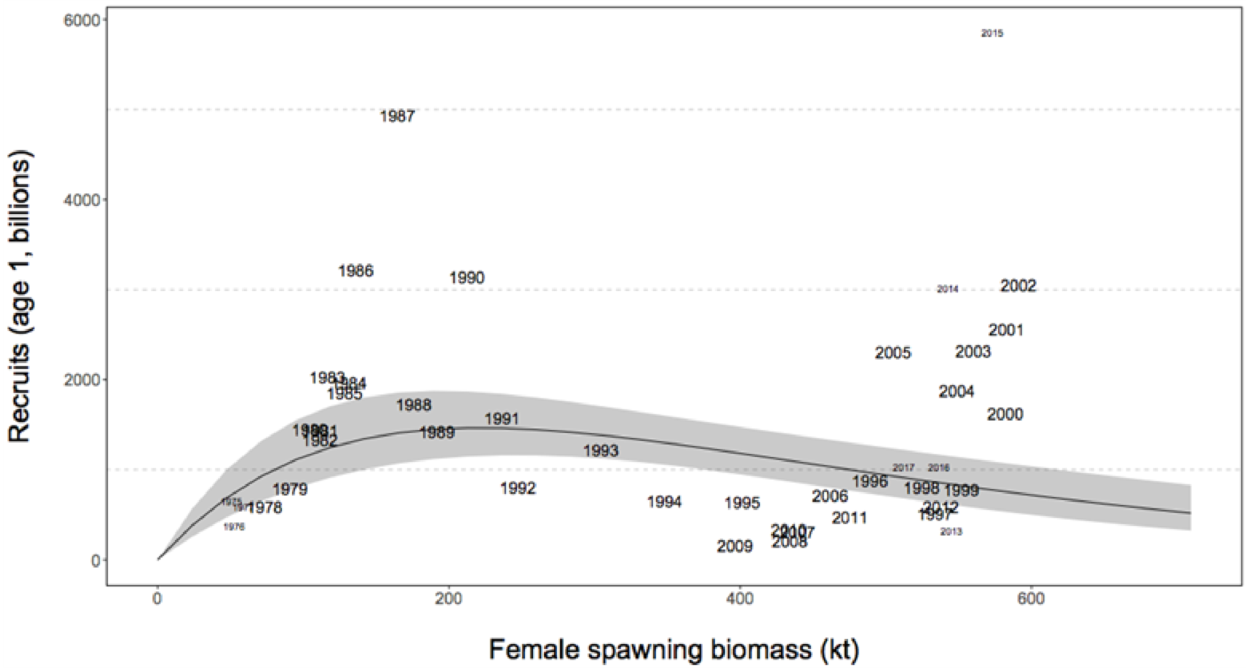


Figure 8.14. Ricker (1958) model fit to spawner-reruit estimates 1978-2014 from Model 15.1.

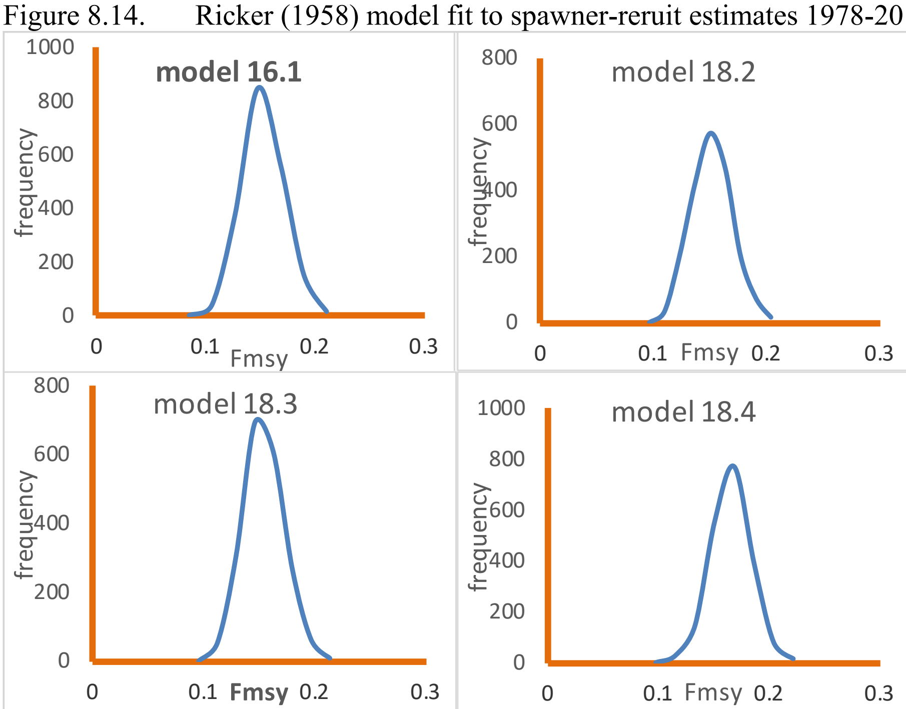


Figure 8.15. Posterior distributions of F_{msy} from 4 of the models considered in the analysis.

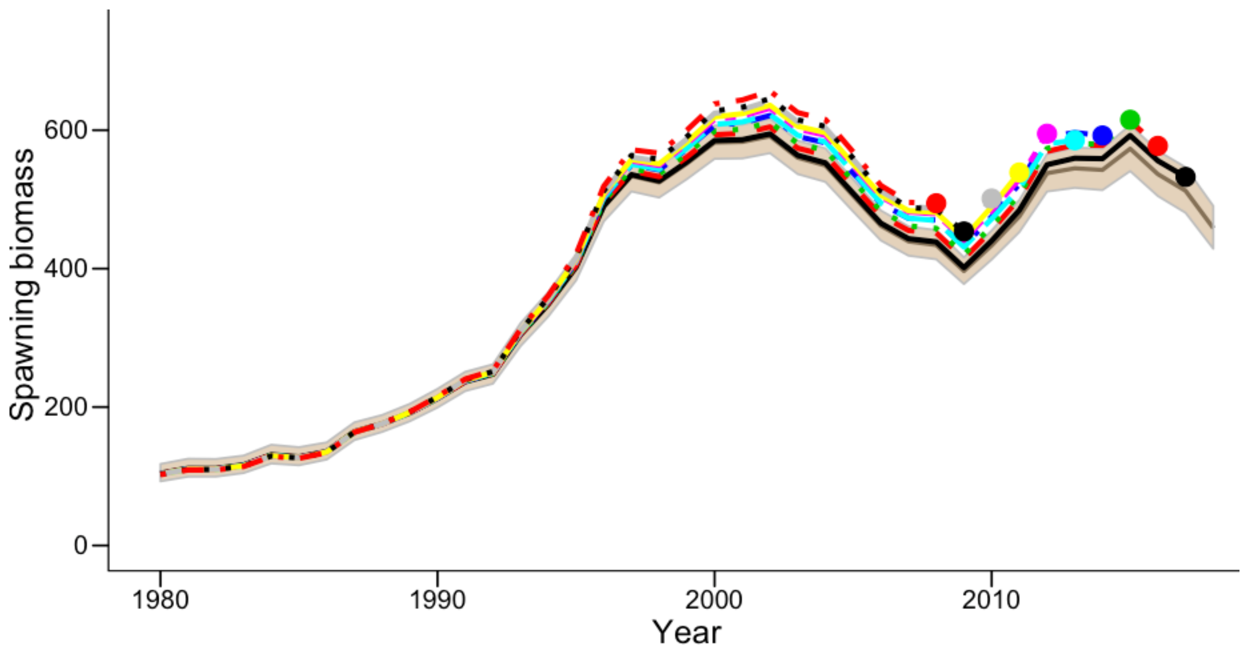


Figure 8.16. Retrospective plot female spawning biomass from 2009-2018. Mohn's rho = -0.03554.

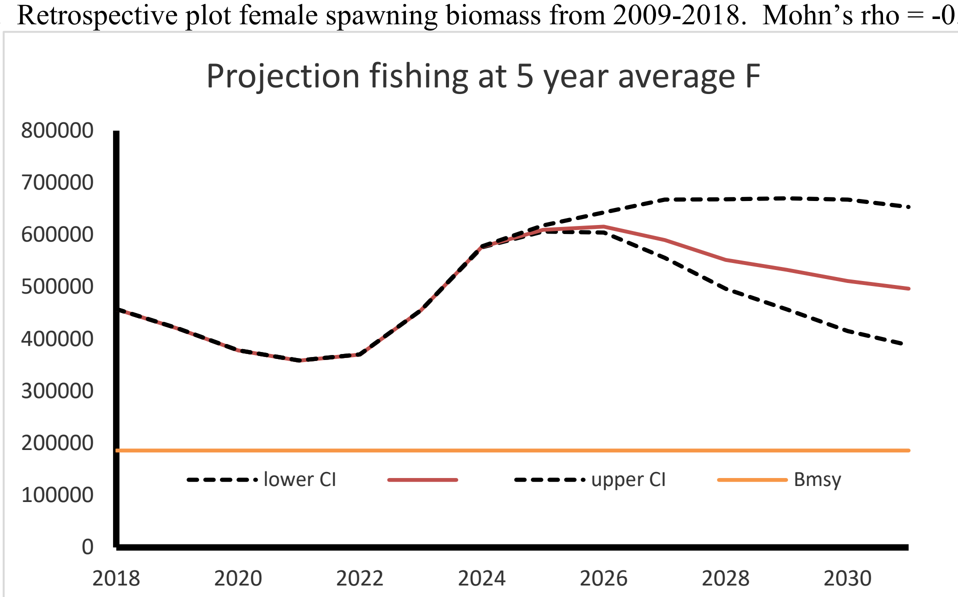


Figure 8.17. Projection of rock sole female spawning biomass when fishing each future year at the average F of the past five years.

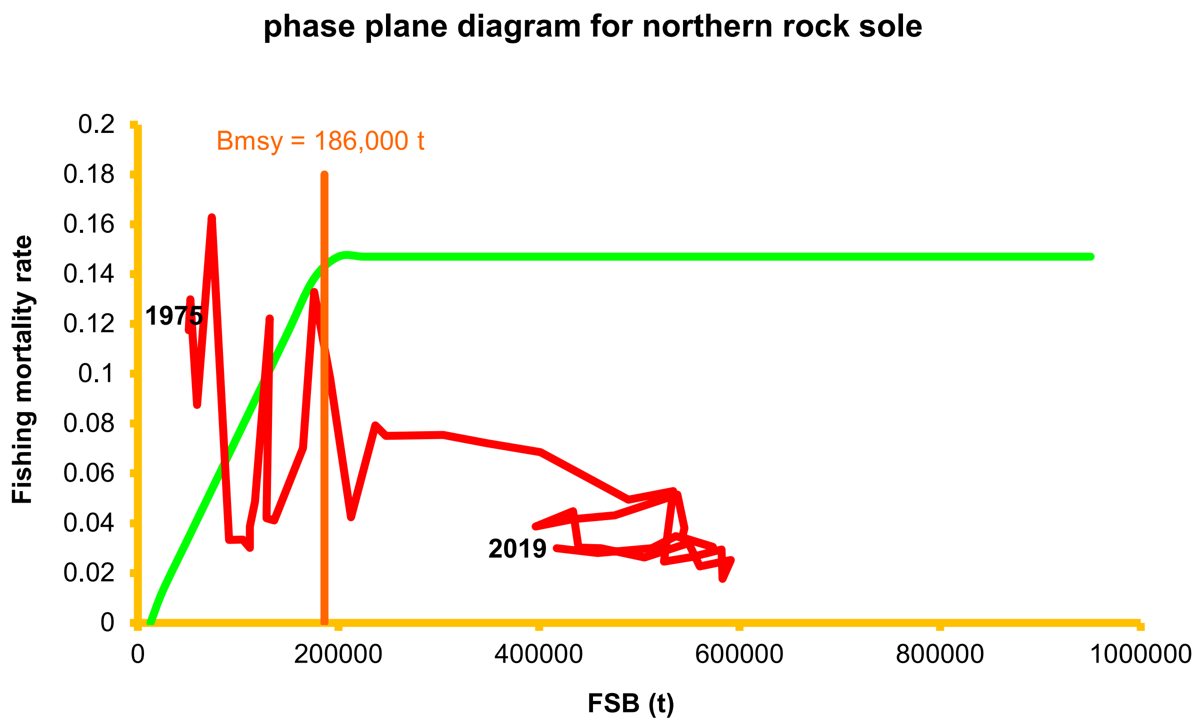


Figure 8.18. Phase-plane diagram of female spawning biomass relative to the harvest control rule.

Appendix

Estimating Northern Rock Sole recruitment using environmental covariates

Lauren Rogers, Dan Cooper 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, and little or no information for the most recent 4 years. Here we propose to use two environmental covariates to estimate the unknown recruitment, and compare the performance of a suite of regression models for predicting recruitment from environmental conditions. Ultimately, these predictions can be compared with future estimates derived from fitting full age composition data in the stock assessment model to evaluate the skill of the regression models. This is the third year we have provided this analysis as an appendix to the stock assessment, and the first year we have provided predictions for the most recent year classes.

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 (Cooper et al. 2014) that is in the cold pool each year from annual trawl survey bottom temperature data. For most models, percentage of the northern nursery area covered by the cold pool was used as a continuous variable. In one model, the percent cold pool was used a categorical variable, dividing years into cold and not-cold categories under the hypothesis that there is some amount of cold pool coverage of the northern nursery area that inhibits use of the northern nursery area and precluded high overall recruitment for the EBS in that year. Both indices 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.

Q1: Do onshore winds and the size of the cold pool (as a percentage of the nursery area) affect recruitment of Northern Rock Sole?

Q2: Does the effect of the cold pool on recruitment depend on the presence of favorable winds? (i.e. is there a significant interaction?)

Q3: Does including wind and cold pool covariates in the stock-recruitment model improve predictions of age-4 recruitment?

We assessed the performance of a suite of models, ranging from a simple Ricker stock-recruit model, to Ricker models with environmental covariates, to models with only environmental covariates. For parsimony, we also assessed simpler forecasting models that used the previous year recruitment or running mean recruitment. We also tested for an interaction between the cold pool effect and winds, because nursery habitat conditions may only matter if winds were favorable for onshore transport (i.e. the fish have to get there in the first place).

We assessed 12 models. Estimates of female spawning biomass and recruitment at age-4 were available for the 1982–2014 year classes.

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) Regression model with % cold pool
7) Regression model with wind
8) Regression model with % cold pool + wind
9) Regression model with interaction between % cold pool and wind
10) Categorical model with threshold low temperature for recruitment success (hypothesis is that there is a some amount of coverage by the cold pool which inhibits use of the northern nursery area and precludes high recruitment)

11) Previous year recruitment (t-1)

12) Running mean recruitment (t:(t-1))

We compared model performance using traditional statistical methodology on all data (AICc), as well as by using two prediction methods. First we used a leave-one-year out (LOYO) analysis: we left out one year of data, fit the model to the remaining 32 years of data, and then compared the prediction for the left-out year to the observed value. Second, we did a one-step-ahead forecast: beginning with year 11 (1992), we used the data collected up to that year to fit the model, and then compared the prediction for that year with the observation. We repeated for all remaining years. We calculated the mean squared error (MSE) for each prediction: (Observed – Predicted)^2. Models were fit using log(recruitment) as the response, so the mean squared error is for the difference between the observed and predicted log(recruitment).
In this assessment, we also use models #1-12 to predict recruitment for the 2015 through 2018 year classes using the environmental covariates and estimated spawning stock biomass (Figure 1, Table 2).

The Previous Year Model had the lowest (best) MSE for both the one step ahead and LOYO prediction methods (Table 1), indicating some autocorrelation in recruitment; however, the Previous Year Model is capable of predicting recruitment only one year class into the future, limiting its utility. The environmental-factors based recruitment models with the lowest prediction errors included both the wind and cold pool indices (Table 1). Other than the Previous Year Model, the Categorical Model had the lowest MSE in both the one step ahead and LOYO prediction methods (Table 1). The models with the next best predictive scores include the coldpool + wind model and the coldpool*wind model. While the model with an interaction between the coldpool and wind had reasonable predictive ability, the interaction term was not statistically significant, and the purely additive model had stronger performance in terms of one step ahead predictions. The five models including a Ricker spawning biomass term had the highest (worst) AICc scores and generally had poor MSE scores relative to the other models. The model results do not provide strong evidence of density dependence.

Recruitment predictions from models with environmental covariates suggest that conditions were conducive to relatively strong recruitment in 2015 and 2018, and moderate to weak recruitment in 2016 and 2017 (Table 2, Figure 1). As recruitment estimates become available from the stock assessment model, we will continue to assess the suitability of these models for forecasting northern rock sole recruitment.

Table 1. 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. The three (or four in case of ties) best (lowest) AICc and MSE scores are in bold.

	Model	df	AICc	MSE (LOYO, log-scale)	MSE (1 step ahead, log-scale)	R^2

1	Ricker	3	90.9	0.76	0.91	0.09
2	Ricker + coldpool	4	88.1	0.80	0.91	0.23
3	Ricker + wind	4	92.5	0.77	0.91	0.11
4	Ricker + coldpool + wind	5	88.1	0.78	0.85	0.28
5	Ricker + coldpool*wind	6	89.0	0.78	0.93	0.32
7	coldpool	3	83.1	0.74	0.82	0.18
8	wind	3	88.6	0.77	0.86	0.04
9	coldpool + wind	4	**82.3**	**0.70**	**0.77**	0.26
10	coldpool*wind	5	**82.9**	**0.70**	0.84	**0.31**
12	Categorical	4	**70.1**	**0.51**	**0.60**	**0.49**
13	Previous Year	NA	NA	**0.50**	**0.52**	**0.49**
14	Running Mean	NA	NA	0.75	0.89	0.12

Table 2. Predicted recruitment (thousands) for selected models for the 2014–2018 year classes.

Year	coldpool + wind	coldpool*wind	Categorical	Previous Year	Running Mean
2014	1,344,983	1,275,386	1,411,862	203,215	675,238
2015	1,344,983	1,275,386	1,411,862	1,922,151	696,987
2016	791,525	1,026,132	821,997	NA	696,987
2017	717,167	761,500	821,997	NA	696,987
2018	1,344,983	1,275,386	1,411,862	NA	696,987

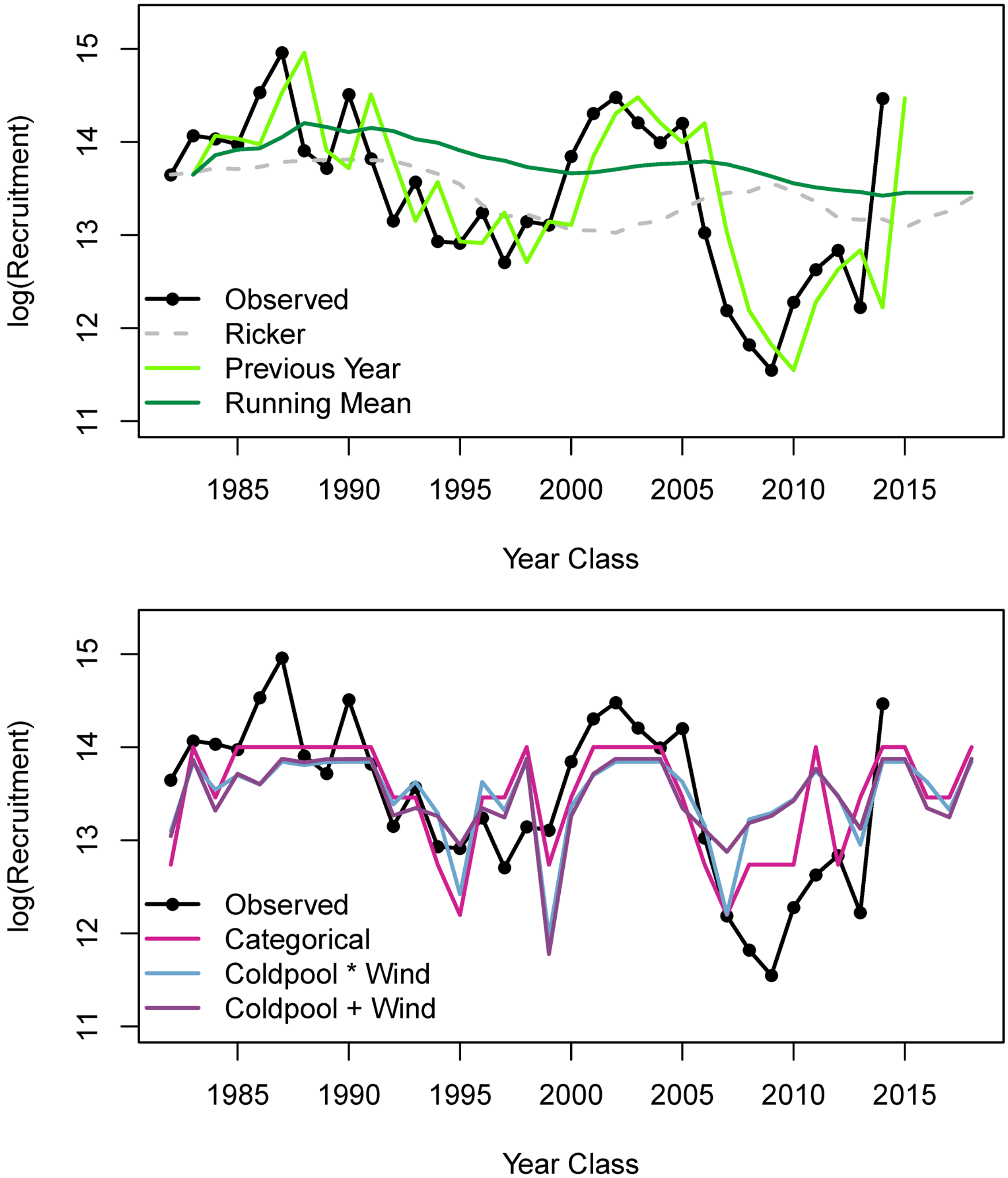


Figure 1. Observed (estimated from stock assessment model) and predicted recruitment from selected models for the 1982 through 2014 northern rock sole year classes.

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