8 Assessment of the northern rock sole stock in the Bering Sea and Aleutian Islands

By

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Executive Summary

Summary of Changes in Assessment Inputs

(1) 2022 catch biomass through October 10, 2022 and 2021 catches were added to the model
(2) 2020 catch biomass was updated to reflect October – December 2020 catches
(3) 2020-2021 fishery age composition data were added to the model
(4) 2020-2021 survey age composition data were added to the model
(5) 2021-2022 Eastern Bering Sea (EBS) shelf survey biomass was added to the model

Summary of Changes in Assessment Methodology

No changes were made to the assessment model methodology.

Summary of Results

The key results of this year's assessment are compared to the key results of the accepted 2021 update assessment in the table below. The ABC is reduced from maxABC due model structural uncertainty indicating that a plausible alternative model exists for which the OFL is smaller than the base model's maxABC. Therefore, the ABC is reduced to the value of the OFL for this alternative model.

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2022	2023	2023	2024
M (natural mortality rate)	0.15 (f),0.17 (m)	0.15 (f),0.17 (m)	0.15 (f),0.19 (m)	0.15 (f),0.19 (m)
Tier	1a	1a	1a	1a
Projected age 6+ geometric mean biomass (t)	1,363,592	1,787,395	941,359	1,111,320
Projected Female spawning biomass (t)	287,600	320,399	260,887	291,774
B_0	476,820	476,820	447,795	447,795
B_{MSY}	158,972	158,972	155,293	155,293
F_{OFL}	0.157	0.157	0.176	0.176
$maxF_{ABC}$	0.152	0.152	0.169	0.169
F_{ABC}	0.152	0.152	0.129	0.108
OFL (t)	214,084	280,621	166,034	196,011
maxABC (t)	206,896	271,199	158,935	187,631
ABC (t)	206,896	271,199	121,719	119,969
Status	As determined *last* year for:		As determined *this* year for:	
	2020	2021	2021	2022
Overfishing	no	n/a	no	n/a
Overfished	n/a	no	n/a	no
Approaching overfished	n/a	no	n/a	no

* Projections are based on estimated catches of 16,0143 t used in place of maximum permissible ABC for 2022 and 40,760 t used in place of maximum permissible ABC for 2023 and 2024. The catch for 2022 was set equal to 2022 catch as of October 10, 2022. The 2021 and 2022 catch was estimated as the average over the past decade of final catches.

Responses to SSC and Plan Team Comments on Assessments in General

***From the December 2021 SSC minutes:* "*With respect to Risk Tables, the SSC would like to highlight that "risk" is the risk of the ABC exceeding the true (but unknown) OFL, as noted in the October 2021 SSC Risk Table workshop report. Therefore, for all stocks with a risk table, assessment authors should evaluate the risk of the ABC exceeding the true (but unknown) OFL and whether a reduction from maximum ABC is warranted, even if past TACs or exploitation rates are low."*

The risk of the ABC exceeding the true (but unknown) OFL was not evaluated within the preferred model's results due to time constraints. Model structural uncertainty was taken into account by looking at whether the ABC recommendations from this year's base model would exceed the OFLs estimated from plausible alternative model runs that either improved model fits or used widely accepted updated methodology.

"*The Team recommends that the AFSC prioritize research on best practices for specifying the selectivity schedules used in projections for Tier 1-3 stocks in general.***"**

The author is participating in research to develop a climate-enhanced projection model that includes carefully considered options for specifying selectivity in these projections. BSAI NRS is the main example species for this exercise.

From the September 2022 Joint GOA and BSAI Plan Team minutes:
There were no comments on assessments in general from the September 2022 Joint, GOA and BSAI Plan Team minutes.

Responses to SSC and Plan Team Comments on Assessments specific to this assessment

From the December 2020 SSC minutes: *The SSC suggests that the authors experiment with fixing M at high values or forcing dome-shaped selectivity to see if this helps address the poor fit. In addition, northern rock sole has a rich age composition history. It might be useful to examine the model when previous large recruitment groups were entering the population to see if the poor fit to survey biomass data is a persistent feature of the model that dissipates as the incoming cohorts age, or if this issue is only happening in this instance. The SSC agrees with the authors' and BSAI GPT's recommendations regarding model choice and for setting ABC and OFL under Tier 1a.*

The author developed an alternative model (presented in Appendix A) that estimates both female and male natural mortality and applies data weighting according to the methodology presented in Francis (2011), which prioritizes fits to the survey biomass index, and better accounts for the fact that the newer large year classes are still not old enough to be caught in the fishery and have not been observed many times. The estimates of natural mortality from the alternative model were reasonable with small standard deviations, suggesting that as configured, the model can provide natural mortality estimates. This corroborates the fact that the stock is underutilized and lightly fished, and therefore age observations contain valuable information on natural mortality. In addition, the model that estimates both female and male natural mortality led to estimates of catchability that were closer to estimates from previous research on catchability and herding of BSAI NRS. This, along with the Francis (2011) data weighting methodology, led to much improved fits to the survey biomass index in recent years. Further analysis of whether this updated approach would have encountered the same mismatch between fits to survey biomass and fits to survey age composition data are forthcoming and can be presented within the context of the next CIE review.

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. The two species were undistinguished prior to 1996. Given the relatively small proportion of Southern rock sole in the BSAI, observations of unidentified rock sole in the BSAI are considered as Northern rock sole in this assessment.

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. Recent research has identified a northern spawning area near the Pribilof Islands that appears to be particularly successful in years with warm bottom temperatures (Cooper et al. 2020).

Fishery

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 1991-2022 (domestic only) have averaged 44,724 t annually, and catches from 2013-2022 averaged 34,763 t, well below ABC values.

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.

Catches over the past decade were highest in NMFS Regulatory Areas 509 (19-81%) and 514 (17-55%; Table 8.2). Northern rock sole are also typically caught in areas 513, 516, 517, and 521 with some frequency (Table 8.2, Figure 8.2). In 2021, first quarter catches were concentrated in areas 509, 513, and 516 (Table 8.4). The highest catches in 2021 occurred in the second quarter and were concentrated in area 514.

Northern rock sole are important as the target of a high value roe fishery occurring in February and March. Table 8.3 shows that catches are highest the first quarter of the year, corresponding with the roe-in fishery. Over the past decade the first quarter accounted for 34-80% of catches by quarter, followed by second quarter catches (accounting for 14-57% catches by quarter over the past decade). Typically, few catches occur in October to December in the northern rock sole fishery.

Table 8.5 shows that historically, TACs have been set much lower than ABCs. Over the past decade, ABCs have ranged from 224,000 t – 140,306 t, while TACs ranged from 92,380 t- 47,100 t. In addition, over the past decade the percent of the TAC caught has been between 31% and 87%. 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. From 1987 to 2000, more rock sole were discarded than were retained. Retention of catches in the BSAI fishery has been very high since the implementation of Amendment 80 in 2008 (89% to 98% over the past decade). Thus, northern rock sole are consistently under-utilized relative to ABCs 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.

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. 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.

Data

Fishery

This assessment used fishery catches for northern rock sole from 1975 through September 12, 2022 (Table 8.1), as well as fishery age composition data and yearly estimates of fishery weight-at-age.

Fishery catch-at-age composition for 1979-1994 and 1998-2021 were included in the assessment model. Fishery ages were unavailable in 1995-1997. The fishery catch-at-age composition for the available data estimated using the methods described by Kimura (1989) and modified by Dorn (1992). Length-stratified age data are used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates are then weighted by the catch within each stratum to arrive at an overall age composition for each year. Data were collected through shore- side sampling and at-sea observers. This method was used to derive the age compositions from 1991–2021 (the period for which all the necessary information is readily available).

Patterns in the fishery spatially shows that most of the northern rock sole catches occurred in NMFS area 509 followed by area 513 and 514, so primarily in the southern part of the EBS (Table 8.2). Traditionally more than half of the northern rock sole catch occurred in the period Jan-March but since 2016 this has been shifted towards later to the April-June period (Table 8.3). For example, in 2021 the peak catch occurred in area 514 in May (Table 8.4). Some of these patterns may be related to a general decrease in the proportion of the TAC that is caught (Table 8.5).

Survey

Survey Biomass
Groundfish surveys are conducted annually by the Resource Assessment and Conservation Engineering (RACE) Division of the AFSC on the continental shelf in the EBS using bottom trawl gear. These surveys are conducted using a fixed grid of stations and have used the same standardized research trawl gear since 1982. The "standard" survey area has been sampled annually since 1982, while the "northwest extension" has been sampled since 1987 (Figure 8.8). In 2010, 2017, and 2018, RACE extended the groundfish survey into the northern Bering Sea (Figure 8.8) and conducted standardized bottom trawls at 142 new stations. Survey-based estimates of total biomass use an “area-swept” approach and implicitly assume a catchability of 1. EBS surveys conducted prior to 1982 were not included in the assessment because the survey gear changed after 1981. To maintain consistent spatial coverage across time, only survey strata that have been consistently sampled since 1982 (i.e., those comprising the "standard" area) are included in the EBS biomass estimates.

The assessment used survey biomass from the EBS shelf trawl survey standard area from 1982-2019 and 2021-2022 within the assessment model; survey biomass of BSAI northern rock sole in the Aleutian Islands and the Northern Bering Sea is relatively low (Table 8.6, Figure 8.4-Figure 8.5). Areas of consistently high survey CPUE of northern rock sole are Bristol Bay, north of Bristol Bay, the Pribilof Islands, and one particular area north of the Pribilof Islands (Figure 8.4-Figure 8.5).

Survey Age composition
Northern rock sole otoliths have been routinely collected during the trawl surveys since 1979 to provide estimates of the population age composition. This assessment used sex-specific survey age compositions for the period 1979-2019 and 2021. The combined-sex abundance-at-age is shown in Figure 8.6.

Survey weight-at-age
Estimates of survey weight-at-age data were used directly within the assessment. Prior to 2001, estimates of weight-at-age were calculated based on survey length composition data and an estimated allometric weight-length relationship (described below in "parameters estimated outside of the assessment model." From 2001 onward, increased collection of individual fish weights allow for calculation of empirical yearly mean weight-at-age, which are used as inputs to the assessment. The mean weight-at-age for ages 15-20 are calculated using a rolling three year average to account for the effects of smaller sample sizes at older ages. The model is not fit to weight-at-age data within the objective function.

Analytical approach

General Model Structure

The assessment of BSAI northern rock sole was conducted using a statistical catch-at-age model AD Model builder (Appendix B; Fournier et al. 2013). 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 a maximum likelihood estimation procedure. Specifically, the model fits to estimates of survey biomass, survey age composition and fishery age composition, as follows:

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

Additionally, the model uses time-varying and sex-specifc fishery and survey weight-at-age data as inputs. The model provides sex-specific estimates of population numbers, fishing mortality, selectivity, fishery and survey age composition. The model retains the utility to fit combined-sex data inputs which are not used in any configuration presented in this assessment. The model allows for the estimation of sex-specific natural mortality, but is estimated only for males in this year's base model. Age classes included in the model were ages 1 to 20. The oldest age class in the model (20 years) served as a plus group. Survey catchability was estimated with a normal prior in this year's model runs. Survey and fishery selectivity were logistic, age-based, and sex-specific. Fishery selectivity was allowed to vary over time. The model estimated mean recruitment and fishing mortality, as well as yearly deviations from those means. A Ricker stock-recruitment curve was estimated within the modeling code, but not used to determine recruitment deviations in each year. Rather, the stock-recruit curve is used to estimate F_{MSY} and future ABCs according to the Tier 1 control rule, as detailed in the BSAI FMP. Details of the population dynamics and estimation equations, description of variables and likelihood components are presented in Appendix B of this chapter.

Description of Alternative Models

In this assessment, we present only the previously accepted model, updated with new data. In addition, we present two alternative model runs that are described in Appendix A.

Parameters estimated outside the assessment model

Natural mortality rates, variability of recruitment (σ_R), the maturity ogive, and the weight-at-age in each year were estimated outside of the assessment model and σ_R was equal to 0.6, consistent with previous assessments. The natural mortality rate was fixed at 0.15 for females.

Weight-at-age estimates
Survey weights-at-age for 1975-2000 were estimated using length observations and the following allometric length (cm) - weight (g) relationship.

$W = a L^b$			
Males		Females	
a	*b*	*a*	*b*
0.005056	3.224	0.006183	3.11747

From 2001 onward, empirical mean survey weight-at-age by year and sex was available and used within the assessment. For ages 15-20, a 3-year rolling average of empirical weight-at-age was used.

Estimates of fishery mean weights-at-age (and variances) were used, which are useful for evaluating general patterns in growth and growth variability.

The maturity ogive for northern rock sole is given in Figure 8.7. 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). Compared to the maturity curve from anatomical scans used previously, the length-based model of Stark indicates nearly the same age at 50% maturity as for the 2009 estimates (7.8 years).

Parameters estimated inside the assessment model

Initial mean numbers-at-age, yearly log mean recruitment and recruitment deviations, log mean fishing mortality, and yearly fishing mortality deviations are estimated within the assessment. Additionally, male natural mortality and log survey catchability are estimated. Log of survey catchability is estimated with a normal prior with a mean of 1.5 and a standard deviation of 0.2, based on the results of experiments conducted in recent years on the standard research trawl used in the annual trawl surveys. These experiments 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 with an estimated catchability of 1.4 and a standard error of 0.056 (Somerton and Munro 2001).

Sex-specific fishery and survey selectivity were modeled using the two-parameter formulation of the logistic function (slope and age at 50% selectivity for females, and difference in slope and age at 50% selectivity from females for males; Appendix B). Survey selectivity was time-invariant, while fishery selectivity was estimated yearly (based on annual changes in management, vessel participation, and gear selectivity). Time-varying fishery selectivity parameters were partitioned 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.

Results

Model Evaluation

Trends in population dynamics
The model estimates relatively large recruitments in 2015-2020, with a particularly large recruitment estimate in 2020 (Figure 8.12). These large estimates are informed by a large number of observed 2-5 year olds in the survey data (Figure 8.10). A small proportion of age 2 fish are selected by the survey (Figure 8.13) with full selectivity occurring around age 4 for males and age 5-6 for females. In contrast, fishery selectivity is near zero for ages 1-5 (Figure 8.14). While the very large estimate of recruitment in 2020 is informed by the data, these fish have been observed only once and only by the survey. Models 22.1 and 22.2 presented in Appendix A show that reducing the weighting of survey age composition data (and therefore the influence of the 2020 age composition data) leads to substantially improved fits to the survey biomass data. Models 22.1 and 22.2 used the Francis (2011) methodology for data weighting. In addition, a comparison of the retrospective patterns for Models 18.3 and 22.2 for spawning biomass show a much-reduced retrospective pattern when the survey age composition data were downweighted; Mohn's rho was 0.18 for Model 18.3, 0.1 for Model 22.1, and -0.04 for Model 22.2. This shift in retrospective patterns between models suggests that it is a feature of the currently accepted model configuration to overestimate the biomass based on heavily weighted new recruitment observations.

Estimates of spawning biomass have been declining since 2015 (Figure 8.12, Table 8.9), as a series of large cohorts that occurred between 2001 and 2006 disappears (Figure 8.6, Figure 8.12,

Table 8.10). Fishing mortality has been relatively low in recent years (Figure 8.16).

Model fits
The model showed reasonable fits to survey biomass for most of the time series with the exception of the most recent data points (2019, 2021, and 2022), where survey biomass is overestimated by the model (Figure 8.9). This pattern is driven by observations in recent years of a large number of young individuals and few observations of older age classes (Figure 8.6), leading to a conflict between fits to survey age composition data (Figure 8.10) and the survey biomass index. In Models 22.1 and 22.2 (Appendix A) where the survey age composition data were downweighted according to the methodology and philosophy outlined in Francis (2011), fits to the survey biomass in recent years were substantially improved, but the model did not capture the high proportion of young fish observed by the survey.

Fits to fishery age composition data were very reasonable, as is expected in a model where fishery selectivity is allowed to vary over time (Figure 8.11). Fits to the proportion female was variable (Figure 8.15).

The stock-recruit relationship showed a high degree of variability but was broadly consistent with past fits for the Ricker stock-recruit relationship (Figure 8.17).

Time series results

Time series of estimated total biomass, spawning biomass, and recruitment are shown in Table 8.9 and

Table 8.10.

Harvest Recommendations

Status Summary
BSAI northern rock sole is currently managed as a Tier 1 stock. The Tier 1 estimate of B_{MSY} for 2023 is 155,293 t, which is less than the projected 2023 spawning biomass of 260,887 t and thus would be in Tier

1a. The estimate of B_0 is 447,795 t. The Tier 1 maximum permissible ABC is 158,935 t and the OFL is 166,034 t. However, for reasons provided in the Risk Table (below) we recommend an ABC of 121,719 t.

Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines overfishing level (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC (F_{ABC}). The F_{ABC} may be less than this maximum permissible level, but not greater. Estimates of reference points related to maximum sustainable yield (MSY) are currently available and therefore the BSAI northern rock sole stock currently uses Tier 1 calculations of reference points. However, in the case of uncertainties about estimates of B_{MSY}, Tier 3 calculations of these reference points are also provided. In addition, the Tier 3 reference points are used to determine whether the stock is overfished or approaching an overfished condition based on a set of standard projection scenarios as specified in the section below entitled "Standard Harvest Scenarios and Projection Methodology."

Assuming future catches equal to average yearly catch over the past decade (40,760 t), the Tier 1 biological reference points for 2023 as defined in the BSAI Fishery Management Plan are:

B_0 = 447,795 t female spawning biomass

B_{MSY} = 155,293 t female spawning biomass

The Tier 3 biological reference points for 2023 as defined in the BSAI Fishery Management Plan (also assuming future catches of 40,760 t) are:

$B_{100\%}$ = 394,349 t female spawning biomass

$B_{40\%}$ = 157,740 t female spawning biomass

$B_{35\%}$ = 138,022 t female spawning biomass

Specification of OFL and Maximum Permissible ABC

Assuming future catches equal to 40,760 t (average yearly catch over the past decade), the Tier 1 and Tier 3 estimates of OFL and maximum permissible ABC for 2023 are as follows:

Tier 1:

OFL = 166,034 t

maxABC= 158,935 t

Tier 3:

OFL = 81,397 t

maxABC= 66,958 t

Standard Harvest Scenarios and Projection Methodology

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 2022 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2023 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2022. 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 to 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 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 2023 recommended in the assessment to the *max* F_{ABC} for 2023. (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 2018-2022 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 2022 and above its MSY level in 2034 under this scenario, then the stock is not overfished.)

Scenario 7: In 2023 and 2024, 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 2035 under this scenario, then the stock is not approaching an overfished condition.)

The results of these two scenarios indicate that the stock is not overfished and is not approaching an overfished condition. Regarding assessing the current stock level, the expected stock size in the current year of scenario 6 is 250,337 t and in 2034 is 218,463 t, which are both higher than $B_{35\%}$ (138,022 t). Thus the stock is not currently overfished. With regard to whether the stock is approaching an overfished condition, the expected spawning stock size in the year 2035 of scenario 7 (192,222 t) is greater than $B_{35\%}$; thus, the stock is not approaching an overfished condition. These projections are based on a Tier 3 management approach. Given that the Tier 3 standard set of projections for status determination is more conservative (higher B_{MSY} proxy), this application should suffice in lieu of more extensive Tier 1 projections (which become more complex because they reflect future uncertainty and hence should include future data collections akin to a closed-loop management strategy approach).

Risk Table and ABC Recommendation

Overview

The following template is used to complete the risk table:

	Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment.	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental/ecosystem concerns	No apparent fishery/resource-use performance and/or behavior concerns
Level 2: Substantially increased concerns	Substantially increased assessment uncertainty/ unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing adverse signals relevant to the stock but the pattern is not consistent across all indicators.	Some indicators showing adverse signals but the pattern is not consistent across all indicators
Level 3: Major Concern	Major problems with the stock assessment; very poor fits to data; high level of uncertainty; strong retrospective bias.	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns.	Multiple indicators showing consistent adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock)	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types
Level 4: Extreme concern	Severe problems with the stock assessment; severe retrospective bias. Assessment considered unreliable.	Stock trends are unprecedented; More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; Potential for cascading effects on other ecosystem components	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

The table is applied by evaluating the severity of four types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. These considerations are stock assessment considerations, population dynamics considerations, environmental/ecosystem considerations, and fishery performance. Examples of the types of concerns that might be relevant include the following:

1. Assessment considerations—data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data; model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs; model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds; estimation uncertainty: poorly-estimated but influential year classes; retrospective bias in biomass estimates.

2. Population dynamics considerations—decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.

3. Environmental/ecosystem considerations—adverse trends in environmental/ecosystem indicators, ecosystem model results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.

4. Fishery performance—fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings.

Assessment considerations
The BSAI northern rock sole assessment data inputs of survey biomass, survey age composition, fishery age composition, and weight-at-age are generally adequate. There is a conflict in fits between the fit to survey biomass and age composition data. In particular, the age composition data showed a very large recruitment of age 1 fish in 2020; this led to an increasing trend in model predicted survey biomass but the observed estimates declined. While the very large estimate of recruitment in 2020 is informed by the data, these fish have been observed only once and only by the survey. In addition, comparing the retrospective patterns of models 18.3 and 22.2, it appears that it is a general feature of the base model (18.3) to overestimate recruitment in the most recent years based on little data, and for the model to overestimate spawning biomass in the terminal year(s), with additional years of data leading to lower estimates for both (it has a positive retrospective pattern). It is possible that changes in availability of young fish has shifted in recent years and future work should be done to model time-varying availability to the survey to explore this possibility. Changes in availability could occur due to changes in environmental conditions in habitat for young northern rock sole, for instance. Models 22.1 and 22.2 adjust the weighting of the data to give more emphasis to the survey biomass index, which led to reduced retrospective bias. In addition, Models 22.1 and 22.2 lead to lower estimates of ABC and OFL, and the estimates of OFL for Models 22.1 and 22.2 exceed the estimate of maxABC for Model 18.3 (the base model). We therefore assigned a 3 for the assessment considerations column of the risk table: “major concerns” based on model structural uncertainty and the existence of two plausible alternative models that display smaller retrospective patterns and better fits to the survey biomass index.

Population dynamics considerations
The base assessment model and alternative model runs each estimated recent large recruitment years for BSAI northern rock sole in 2016-2018, which are supported by raw data on absolute survey numbers at age 1 (Figure 8.6 and Figure 8.20). These new, relatively strong year classes will grow to accumulate to the spawning stock biomass (if they continue to show up in future data), but are still too young to have matured. At the same time, the stock assessment and survey numbers-at-age show that some older, large year classes are dying out or are almost completely gone, which contributes to a multi-year decline in spawning stock biomass estimates. According to the base model (previously accepted), both the recent recruitment estimates and spawning stock biomass estimates are within range of historical population dynamics for this stock. Therefore, we assigned a risk table value of 1 for population dynamics considerations, or “Stock trends are typical for the stock; recent recruitment is within normal range.”

Environmental/Ecosystem considerations

Environmental processes: The extended warm phase experienced in the eastern Bering Sea (EBS) that began in approximately 2014 has largely relaxed to normal conditions over the past year (August 2021 - August 2022). The NPI has been positive during 5 out of the last 6 winters, with the exception being the winter of 2018-19. Positive values mean a weak Aleutian Low Pressure System and generally calmer conditions. Sea surface temperature (SST) was within one standard deviation of the long term average and marine heatwaves were relatively weak and short-lived compared to recent years. Estimates of bottom temperature derived from the ROMS model suggest that bottom temperatures in the northern Bering Sea (NBS) over the past year were within normal ranges while the southeastern Bering Sea (SEBS) was significantly cooler than average. The Bering Sea ice extent was generally higher than average throughout much of the 2021-2022 winter. Ice advanced rapidly in November, though there was an abrupt springtime retreat beginning in mid-April. These cool-to-normal winter conditions were favorable to cold pool formation, though not to the areal extent in the years preceding 2014. The 2022 cold pool was near the historical average and resembled other average-to-cool years, most similar to 2017 (Hennon et al., 2022).

Northern rock sole (NRS) is a winter-spawning flatfish; increased young-of-the-year recruitment is correlated to years with onshore winds during the larval period and when the cold pool does not extend over the northern nursery area (Cooper et al., 2020). The along- and cross-slope wind components along the Bering shelf break may be informative to understanding the larval dispersal in the upper ocean. Cross-slope winds will be parallel to the shelf break, and in Jan-Apr 2022 may have enhanced transport to the northwest, while Jul-Sep 2022 winds may have inhibited transport (winds to the southeast). Along-shelf winds were variable from month to month in 2022, but favored onshelf Ekman transport in April and June which overlaps with the NRS larval period (Hennon et al., 2022).

Laboratory studies have looked at the effects of CO2 on larval NRS (Hurst et al., 2016; 2017), but results suggest that the effects of elevated CO2 levels are relatively modest compared to other aspects of the rearing environment, such as prey availability (Hurst et al., 2017).

Prey: Larval NRS consume plankton and algae. The 2022 spring bloom timing was average while production varied across the shelf (Nielsen et al., 2022). Depending on the spatial and temporal overlap between larvae and available primary production, this can result in a match or mismatch with favorable feeding conditions.

Juvenile NRS consume zooplankton. Copepod abundances over the southeastern Bering Sea shelf were surveyed in spring and late-summer 2022. Trends in the zooplankton community in 2022 match those observed during recent warm years, with the notable exception of reduced small copepod numbers observed during the summer. Reduced overall copepod productivity was somewhat countered by increased euphausiid abundance (Kimmel et al., 2022).

Adult NRS consume benthic infauna such as bivalves, polychaete worms, and amphipods. Direct measurements of infaunal abundance trends are not available, however, abundance trends of motile epifauna that also consume infauna (i.e., indirect measurements) are quantified from the NOAA bottom trawl survey. Trends in motile epifauna biomass indicate benthic productivity, although individual species and/or taxa may reflect varying time scales of productivity. The biomass of motile epifauna peaked in 2017 and remains above their long-term mean in 2022. Brittle stars, sea stars, and other echinoderms are well above their long-term means, while king crabs, tanner crab, and snow crab are all below their long-term means (Whitehouse, 2022). The condition of NRS (as measured by length-weight residuals) was above-average in 2022 (Rohan et al., 2022), indicating sufficient prey is available over the southern shelf, supported by similar trends in motile epifauna.

Competitors: Competitors for NRS habitat and prey resources include other benthic foragers, like yellowfin sole and flathead sole. The trend in biomass of the benthic foragers guild increased 18% from 2021 to 2022 but remains below the time series mean. There were increases in biomass for the four most dominant species in this guild (yellowfin sole, northern rock sole, flathead sole, and Alaska plaice), though all but flathead sole remain below their long term mean (1982–2022) (Whitehouse, 2022). Trends in benthic forager biomass indirectly indicate availability of infauna (i.e., prey of these species), suggesting competition for prey resources remains low in 2022.

Predators: Predators of late-juvenile NRS include pollock, Pacific cod, yellowfin sole, skates, and Pacific halibut. The pelagic foragers guild includes pollock and increased sharply from 2021 to 2022.In 2022, the survey index for pollock increased 50% from 2021. The biomass of the apex predator guild, largely driven by Pacific cod, increased from 2021 to 2022 to nearly equal to their long term mean. As stated above, the trend in biomass of the benthic foragers guild, including yellowfin sole, increased 18% from 2021 to 2022 but remains below the time series mean (Whitehouse, 2022). The relative abundance of predators has increased over the shelf, suggesting potential increased risk of predation, although spatial and/or temporal refuges may exist. Examining such spatio-temporal overlaps would better inform the potential predation impacts for NRS in the EBS.

Summary for Environmental/Ecosystem considerations:

Environment: The extended warm phase experienced by the eastern Bering Sea (EBS) that began in approximately 2014 has largely relaxed to normal conditions over the past year (August 2021 - August 2022).

Winds: Along-shelf winds were variable in 2022, but favored onshelf Ekman transport in April and June that supported transport to suitable nursery habitat.

Larval prey: The 2022 spring bloom timing was average while production varied across the shelf

Juvenile prey: Reduced overall copepod productivity was somewhat countered by increased euphausiid abundance

Adult prey: The condition of NRS was above-average in 2022, indicating sufficient prey is available over the southern shelf. Trends in benthic forager biomass suggest competition for prey resources remains low in 2022. The relative abundance of predators has increased over the shelf, suggesting potential increased risk of predation, although spatial and/or temporal refuges may exist.

Together, the most recent data available suggest an ecosystem risk Level 1 – Normal: "No apparent environmental/ecosystem concerns."

Fishery performance
No major changes in fishery characteristics were identified, as except for an increased proportion of fishing in quarter three of the year, relative to previous years (23%). No concerns regarding fishery performance were identified.

Summary and ABC recommendation

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ ecosystem considerations*	*Fishery Performance considerations*
Level 3: Major concern	Level 1: no increased concerns	Level 1: no increased concerns	Level 1: no increased concerns

The SSC requested that authors "*evaluate the risk of the ABC exceeding the true (but unknown) OFL and whether a reduction from maximum ABC is warranted, even if past TACs or exploitation rates are low.*" Here, we find that a reduction from maximum ABC is warranted based on the probability that the maximum ABC exceeds the true but unknown OFL when taking into account structural uncertainty in the model, as described in the subsection "Assessment considerations." Therefore, the ABC is set to the OFL for Model 22.1 (which is lower than the OFL for Model 22.2), a reduction from maximum ABC to lower the risk of exceeding the true, but unknown OFL.

Ecosystem considerations

Ecosystem effects on the stock

See "Environmental/Ecosystem Considerations" for determining risk table scores.

Data gaps and research priorities

The conflict between survey biomass and age composition data in recent assessments could be explored through data analysis and further work to identify environmental influences on Northern rock sole and the mechanisms behind these influences. One hypothesis to explore would be whether the distribution and availability of young fish to the survey changed in these years.

Updates such as use of a formal data-weighting approach (as is used in M22.1 and M22.2 in Appendix A), estimation of both female and male natural mortality (as in M22.2 in Appendix A), and inclusion of ageing error estimates in the assessment would improve this assessment. In addition, the model could be fit to empirical weight-at-age data.

Several research projects are underway for northern rock sole or were recently completed, including the development of a climate-enhanced projection model using BSAI Northern rock sole as a primary example, further investigations of effects of wind and temperature conditions on recruitment of northern rock sole, the influence of ocean acidification of northern rock sole dynamics, and an examination of diet data.

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Tables

Table 8.1. Catch (in tons) of BSAI northern rock sole through Sept 12, 2022 (denoted by asterisk).

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			56,058	56,058
1992			52,723	52,723
1993			64,261	64,261
1994			59,607	59,607
1995			55,029	55,029
1996			46,929	46,929
1997			67,815	67,815
1998			33,644	33,644
1999			41,090	41,090
2000			49,668	49,668
2001			29,477	29,477
2002			41,867	41,867
2003			36,086	36,086
2004			48,681	48,681
2005			37,362	37,362
2006			36,456	36,456
2007			37,126	37,126
2008			51,276	51,276
2009			48,716	48,716
2010			53,200	53,200
2011			60,534	60,534
2012			75,945	75,945
2013			59,751	59,751
2014			51,690	51,690
2015			45,468	45,468
2016			45,084	45,084
2017			35,222	35,222
2018			28,269	28,269
2019			25,800	25,800
2020			25,938	25,938
2021			14,393	14,393
2022			16,014	16,014

Table 8.2. Proportion of catches by NMFS reporting area through Nov 9, 2022. Green-white shading indicates areas with high proportions of catches (green) to low proportions of catches (white).

Year	509	511	512	513	514	516	517	518	519	521	522	523	524	540	541	542	543
1991	0.00	0.35	0.00	0.20	0.19	0.14	0.03	0.00	0.01	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.38	0.00	0.21	0.15	0.15	0.03	0.00	0.00	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.43	0.00	0.00	0.18	0.09	0.16	0.07	0.00	0.00	0.04	0.00	0.00	0.02	0.00	0.00	0.00	0.00
1994	0.36	0.00	0.00	0.20	0.06	0.27	0.03	0.00	0.00	0.06	0.00	0.00	0.01	0.00	0.00	0.00	0.00
1995	0.53	0.00	0.00	0.05	0.15	0.10	0.15	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00
1996	0.54	0.00	0.00	0.09	0.20	0.06	0.08	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00
1997	0.47	0.00	0.00	0.12	0.22	0.04	0.14	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.57	0.00	0.00	0.16	0.03	0.05	0.15	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.00
1999	0.51	0.00	0.00	0.08	0.11	0.20	0.05	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.00
2000	0.80	0.00	0.00	0.09	0.03	0.01	0.03	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00
2001	0.55	0.00	0.00	0.13	0.05	0.12	0.07	0.00	0.00	0.05	0.00	0.00	0.01	0.00	0.01	0.00	
2002	0.44	0.00	0.00	0.14	0.12	0.13	0.08	0.00	0.00	0.04	0.00	0.00	0.01	0.00	0.02	0.00	0.00
2003	0.46	0.00	0.00	0.11	0.17	0.13	0.02	0.00	0.01	0.05	0.00	0.00	0.02	0.00	0.02	0.01	0.00
2004	0.47	0.00	0.00	0.06	0.12	0.20	0.02	0.00	0.01	0.07	0.00	0.00	0.04	0.00	0.01	0.00	0.00
2005	0.42	0.00	0.00	0.08	0.27	0.13	0.02	0.00	0.01	0.03	0.00	0.00	0.04	0.00	0.01	0.00	0.00
2006	0.36	0.00	0.00	0.13	0.26	0.09	0.04	0.00	0.00	0.10	0.00	0.00	0.01	0.00	0.01	0.00	0.00
2007	0.36	0.00	0.00	0.09	0.25	0.13	0.04	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.02	0.00	0.00
2008	0.73	0.00	0.00	0.04	0.03	0.11	0.05	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	0.64	0.00	0.00	0.05	0.05	0.15	0.07	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.01	0.00	0.00
2010	0.49	0.00	0.00	0.07	0.03	0.31	0.06	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.00
2011	0.58	0.00	0.00	0.10	0.08	0.19	0.04	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.81	0.00	0.00	0.02	0.03	0.08	0.04	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2013	0.64	0.00	0.00	0.06	0.02	0.16	0.09	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	0.66	0.00	0.00	0.09	0.03	0.15	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.59	0.00	0.00	0.07	0.22	0.09	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2016	0.24	0.00	0.00	0.09	0.35	0.29	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2017	0.33	0.00	0.00	0.21	0.24	0.19	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00
2018	0.28	0.00	0.00	0.11	0.48	0.07	0.03	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.01	0.00	0.00
2019	0.19	0.00	0.00	0.12	0.55	0.08	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.01	0.00	0.00
2020	0.34	0.00	0.00	0.24	0.17	0.20	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2021	0.40	0.00	0.00	0.20	0.29	0.08	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2022	0.46	0.00	0.02	0.33	0.07	0.01	0.01	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8.3. Proportion of catches by quarter through Nov 9, 2022. Asterisk denotes that 2022 data are still incomplete.

Year	Jan-Mar	Apr-June	July-Sep	Oct-Dec
1991	0.61	0.22	0.16	0.02
1992	0.56	0.15	0.24	0.05
1993	0.68	0.17	0.12	0.03
1994	0.78	0.14	0.05	0.03
1995	0.68	0.12	0.20	0.01
1996	0.57	0.28	0.14	0.02
1997	0.60	0.22	0.16	0.02
1998	0.71	0.15	0.11	0.03
1999	0.63	0.23	0.11	0.03
2000	0.75	0.16	0.08	0.01
2001	0.57	0.16	0.24	0.03
2002	0.64	0.19	0.16	0.01
2003	0.60	0.22	0.18	0.00
2004	0.68	0.27	0.05	0.00
2005	0.57	0.34	0.09	0.00
2006	0.49	0.24	0.26	0.01
2007	0.53	0.19	0.27	0.00
2008	0.64	0.21	0.10	0.04
2009	0.69	0.15	0.12	0.04
2010	0.57	0.13	0.24	0.06
2011	0.68	0.20	0.10	0.03
2012	0.80	0.14	0.04	0.02
2013	0.68	0.17	0.12	0.03
2014	0.69	0.22	0.06	0.03
2015	0.64	0.23	0.11	0.02
2016	0.48	0.44	0.06	0.02
2017	0.42	0.46	0.10	0.02
2018	0.38	0.55	0.05	0.01
2019	0.34	0.57	0.07	0.03
2020	0.43	0.30	0.23	0.04
2021	0.37	0.51	0.07	0.05
2022*	0.50	0.35	0.13	0.02

Table 8.4. Catches by NMFS regulatory area and month in 2021.

Month	509	513	514	516	517	519	521	524	541	542	543	Total
Jan	748	2		80	0		0		0			829
Feb	1,215	541	0	656	8	0	61	7	1	1	0	2,491
Mar	798	712	274	137	20	0	19	5	2	1	0	1,969
Apr	2,473	141	271		3	0	3	5	19	2	1	2,918
May	95	2	3,119		1	0	2	0	6	0	0	3,225
Jun	1	919	317		1	0	15	0	1	4	1	1,259
Jul	8	141	0		14	12	2	3	2	7	6	195
Aug	255	76	14		7	15	2	1	1	5	6	382
Sep	75	121	139	8	2	9	3	25	0	4	1	385
Oct	0	139	31		2	12	1	2	16	2	0	205
Nov	21	44	1		0	9	0	0	8	0	0	85
Dec	71	19	27	317	14	0	0	3	0			451
Total	5,758	2,857	4,193	1,197	73	58	108	51	56	28	15	14,393

Table 8.5. Historical final harvest specifications, proportion of TAC caught, and proportion of catches retained through 2022. Asterisk denotes a change in harvest specifications as of Sept 2020 to correct specifications due to an error found in an assessment input file.

Year	ABC	TAC	Proportion of TAC caught	Proportion of Catches Retained
1991	246,500	90,000	0.62	0.45
1992	260,800	40,000	1.32	0.40
1993	185,000	75,000	0.86	0.35
1994	313,000	75,000	0.79	0.35
1995	347,000	60,000	0.92	0.40
1996	361,000	70,000	0.67	0.42
1997	296,000	97,185	0.70	0.41
1998	312,000	100,000	0.34	0.38
1999	309,000	120,000	0.34	0.38
2000	230,000	137,760	0.36	0.45
2001	228,000	75,000	0.39	0.66
2002	225,000	54,000	0.78	0.57
2003	110,000	44,000	0.82	0.57
2004	139,000	41,000	1.19	0.56
2005	132,000	41,500	0.90	0.65
2006	126,000	41,500	0.88	0.78
2007	198,000	55,000	0.68	0.75
2008	301,000	75,000	0.68	0.90
2009	296,000	90,000	0.54	0.89
2010	240,000	90,000	0.59	0.94
2011	224,000	85,000	0.71	0.93
2012	208,000	87,000	0.87	0.93
2013	214,000	92,380	0.65	0.95
2014	203,800	85,000	0.61	0.96
2015	181,700	69,250	0.66	0.98
2016	161,000	57,100	0.79	0.96
2017	155,100	47,100	0.75	0.97
2018	143,100	47,100	0.60	0.96
2019	132,000	49,100	0.53	0.94
2020 Original*	153,300	47,100		
2020Corrected*	163,700	47,100	0.55	0.95
2021	140,306	54,500	0.31	0.93
2022	206,896	66,000	0.29	0.97

Table 8.6. Survey biomass estimates (thousands of t; Bio) and standard errors (Std Err) for the EBS shelf trawl survey, Aleutian Islands trawl survey, and the Northern Bering Sea trawl survey.

	EBS Standard Area		Aleutian Islands		Northern Bering Sea	
Year	Bio	Std. Err.	Bio	Std. Err.	Bio	Std. Err.
1982	578.71	74.08				
1983	714.09	81.85				
1984	799.42	81.82				
1985	693.06	58.77				
1986	1,021.23	83.74				
1987	1,269.58	91.22				
1988	1,478.97	101.51				
1989	1,323.30	91.08				
1990	1,382.91	89.02				
1991	1,585.26	95.97				
1992	1,548.69	112.28				
1993	1,994.68	122.05				
1994	2,723.80	223.25				
1995	2,179.97	130.54				
1996	2,074.10	122.57				
1997	2,621.21	190.97	49.91	12.20		
1998	2,181.45	124.16				
1999	1,628.71	162.92				
2000	2,088.36	320.29	44.26	6.22		
2001	2,350.47	258.82				
2002	1,891.01	171.31	51.59	6.98		
2003	2,121.95	196.91				
2004	2,207.76	184.93	51.90	3.90		
2005	2,127.16	151.18				
2006	2,231.49	151.01	77.70	9.78		
2007	2,050.77	280.40				
2008	2,046.51	302.06				
2009	1,551.65	159.94				
2010	2,081.81	204.59	55.29	4.53	21.26	3.64
2011	1,993.62	166.00				
2012	1,933.84	186.95	65.46	7.07		
2013	1,766.60	137.63				
2014	1,872.15	130.29	46.65	4.62		
2015	1,424.67	131.51				
2016	1,472.07	131.96	34.98	4.26		
2017	1,349.68	100.82			55.47	9.40
2018	1,058.61	115.61	44.12	4.49		
2019	981.36	92.30			99.04	17.75
2020						
2021	1037.05	86.79			76.63	15.14
2022	1296.54	111.72	28.77	4.07	46.44	10.93

Table 8.7. A comparison of likelihood components for the base model (18.3), Model 22.1, and Model 22.2. Model 18.3 weighted the data differently than the other two models and therefore the boxes in grey cannot be compared directly to the other two models.

	Model		
	18.3	**22.1**	**22.2**
Objective Function	1537.08	1731.91	1664.51
Survey Biomass	68.8067	57.9606	39.4759
Fishery Age Composition	541.928	1271.45	1249.31
Survey Age Composition	705.847	129.911	131.533

Table 8.8. Parameter estimates for Model 18.3 in 2020 and 2022. “std. dev” is the standard deviation of the parameter estimate.

Parameter	**Model 18.3 (2020)**		**Model 18.3 (2022)**	
	value	**std.dev**	**value**	**std.dev**
log catchability	0.65	0.03	0.67	0.03
male natural mortality	0.17	0.00	0.17	0.00
mean log recruitment	6.85	0.11	6.78	0.11
mean log initial age composition	3.37	0.12	3.38	0.12
log average fishing mortality	-2.24	0.09	-2.26	0.09
average slope of fishery selectivity (f)	0.97	0.05	1.00	0.05
average age at 50% fishery selectivity (f)	9.26	0.50	9.05	0.48
average slope of fishery selectivity (m)	1.22	0.06	1.26	0.40
selectivity offset for males	-0.12	0.05	-0.13	0.05
slope of survey selectivity (f)	1.84	0.10	1.87	0.10
slope of survey selectivity (m)	0.27	0.07	0.26	0.07
age at 50% survey selectivity (f)	3.60	0.06	3.51	0.06
age at 50% survey selectivity (m)	-0.14	0.02	-0.14	0.02
log alpha of Ricker stock-recruit curve	2.88	0.20	2.87	0.20
log beta of Ricker stock-recruit curve	-5.28	0.11	-5.25	0.11
maximum sustainable yield	208.79	37.45	220.50	40.93
Fmsy	0.43	0.21	0.33	0.16
logFmsy	-0.85	0.48	-1.11	0.50
Fmsyr	0.15	0.03	0.17	0.04
logFmsyr	-1.87	0.18	-1.76	0.21
Bmsy	158.97	13.15	155.29	12.35
Bmsyr	1350.60	145.14	1277.80	154.30

Table 8.9. Time series of spawning stock biomass (SSB) estimates. The years 2023-2024 for the 2022 assessment and the years 2021-2022 for the 2020 assessment use estimates that are projected from the stock assessment model based on a Tier 1 approach to management and catches of 40,760 t (2022 model) and 47,500 t (2020 model).

	2020 Assessment		2022 Assessment	
Year	**SSB**	**Std. Dev**	**SSB**	**Std. Dev**
1975	47.974	3.704	48.499	3.755
1976	48.272	3.879	48.897	3.928
1977	53.391	4.178	54.144	4.223
1978	66.049	4.646	67.006	4.692
1979	81.166	5.321	82.396	5.369
1980	93.036	5.833	94.486	5.878
1981	99.089	6.079	100.706	6.121
1982	98.773	6.015	100.453	6.053
1983	103.889	6.060	105.690	6.092
1984	117.520	6.674	119.585	6.696
1985	115.031	6.691	116.998	6.692
1986	121.940	6.616	123.639	6.599
1987	147.155	7.269	148.617	7.217
1988	155.048	7.402	155.766	7.305
1989	164.215	8.201	163.769	8.037
1990	179.209	9.197	177.721	8.949
1991	201.157	9.821	199.031	9.501
1992	218.422	10.119	215.356	9.733
1993	278.106	12.046	272.954	11.517
1994	323.399	12.972	317.170	12.353
1995	373.868	14.197	366.632	13.512
1996	456.984	17.157	450.015	16.403
1997	501.213	18.502	493.620	17.737
1998	493.398	18.089	485.398	17.308
1999	517.755	18.473	509.759	17.634
2000	541.496	19.063	533.741	18.152
2001	562.802	20.290	549.379	18.997
2002	568.853	20.334	557.758	19.070
2003	567.455	20.553	568.449	19.744
2004	568.277	20.752	551.987	19.269
2005	491.878	18.696	470.123	17.075
2006	439.329	17.134	431.805	16.178
2007	414.982	16.502	407.609	15.551
2008	389.125	15.617	388.716	14.819
2009	368.942	15.182	354.036	13.862
2010	388.980	15.716	375.854	14.433
2011	447.295	17.693	429.022	16.064
2012	483.656	19.438	461.090	17.432
2013	496.567	20.808	469.144	18.401
2014	502.464	21.761	473.966	19.181
2015	520.204	23.200	485.950	20.271
2016	471.196	21.975	433.155	18.937
2017	428.015	21.152	390.781	18.152
2018	378.740	19.755	338.873	16.660
2019	348.794	18.877	304.586	15.620
2020	314.380	17.679	274.107	14.705
2021	294.627	17.454	254.990	14.163
2022	286.381	18.482	250.336	13.818
2023			260.887	15.044
2024			291.774	19.899

Table 8.10. Time series age 1 recruitment estimates.

	2020 Assessment		2022 Assessment	
Year	**Recruits (Age 1)**	**Std. Dev**	**Recruits (Age 1)**	**Std. Dev**
1975	280.484	21.995	284.548	22.2529
1976	647.828	36.326	655.012	36.5287
1977	359.735	25.638	360.542	25.6073
1978	564.100	35.038	561.190	34.7508
1979	547.123	35.854	548.746	35.7285
1980	720.728	43.459	721.748	43.2004
1981	1,329.290	64.779	1,306.698	63.4403
1982	1,353.240	68.948	1,333.532	67.6708
1983	1,240.120	68.695	1,231.608	67.72
1984	2,031.330	95.655	2,021.300	93.9636
1985	1,766.010	91.649	1,749.664	90.1258
1986	1,670.380	93.125	1,670.152	92.5853
1987	2,832.060	132.762	2,828.500	131.194
1988	4,311.520	175.589	4,331.740	173.015
1989	1,515.570	90.793	1,503.016	89.43
1990	1,303.470	82.044	1,287.028	80.60
1991	2,904.200	131.647	2,884.820	128.47
1992	1,431.870	83.409	1,423.796	81.84
1993	743.060	55.988	733.734	54.90
1994	1,085.820	67.460	1,084.664	66.17
1995	586.844	46.988	572.596	45.56
1996	566.987	45.322	556.412	43.97
1997	784.060	53.640	767.384	51.74
1998	461.042	39.880	439.974	38.03
1999	735.786	51.348	673.512	47.51
2000	657.179	48.677	628.094	45.94
2001	1,420.860	77.024	1,333.994	70.69
2002	2,227.280	104.459	2,074.980	93.76
2003	2,621.850	119.395	2,458.620	106.21
2004	1,935.470	99.099	1,847.466	89.15
2005	1,616.640	89.277	1,493.104	78.32
2006	1,902.670	101.194	1,784.992	88.87
2007	597.367	48.634	556.434	42.71
2008	241.217	28.915	220.036	25.00
2009	174.268	24.261	155.804	20.42
2010	119.262	19.831	106.671	16.30
2011	248.647	31.528	200.974	23.38
2012	310.132	38.309	241.358	26.61
2013	476.105	54.795	317.554	32.71
2014	249.756	42.709	161.040	23.77
2015	1,462.320	157.850	870.410	75.25
2016	2,356.940	287.758	1,426.226	124.89
2017	4,405.590	664.199	1,705.856	176.75
2018	4,156.650	1,207.490	1,425.496	206.05
2019	875.653	592.315	2,152.680	373.08
2020	942.190	674.315	4,235.100	1063.83
2021	-	-	840.112	567.16
2022	-	-	880.472	629.52
Average	1,321.102	135.871	1,221.862	118.883

Table 8.11. Projected spawning biomass for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2022	250,337	250,337	250,337	250,337	250,337	250,337	250,337
2023	260,109	260,109	260,109	260,109	260,109	257,918	258,715
2024	280,758	280,758	282,943	283,439	284,236	257,718	266,319
2025	303,608	303,608	330,123	336,515	347,082	276,762	290,886
2026	339,319	339,319	390,094	402,983	424,842	309,161	320,425
2027	392,070	392,070	468,537	488,832	524,056	358,134	366,880
2028	452,132	452,132	557,646	586,691	638,107	413,165	419,793
2029	462,169	462,169	598,549	637,360	707,343	417,545	422,440
2030	434,251	434,251	597,618	645,748	734,202	385,341	388,817
2031	393,320	393,320	577,644	634,103	740,076	342,079	344,527
2032	344,219	344,219	539,034	601,394	721,283	293,706	295,421
2033	300,942	300,942	498,594	564,864	695,585	253,002	254,208
2034	262,162	262,162	454,152	521,653	658,487	218,463	219,317
2035	230,500	230,500	412,039	478,922	618,351	191,620	192,222

Table 8.12 Projected fishing mortality rates for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2022	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2023	0.11	0.11	0.11	0.11	0.11	0.23	0.19
2024	0.19	0.19	0.07	0.04	0.00	0.23	0.19
2025	0.19	0.19	0.07	0.04	0.00	0.23	0.23
2026	0.19	0.19	0.07	0.04	0.00	0.23	0.23
2027	0.19	0.19	0.07	0.04	0.00	0.23	0.23
2028	0.19	0.19	0.07	0.04	0.00	0.23	0.23
2029	0.19	0.19	0.07	0.04	0.00	0.23	0.23
2030	0.19	0.19	0.07	0.04	0.00	0.23	0.23
2031	0.19	0.19	0.07	0.04	0.00	0.23	0.23
2032	0.19	0.19	0.07	0.04	0.00	0.23	0.23
2033	0.19	0.19	0.07	0.04	0.00	0.23	0.23
2034	0.19	0.19	0.07	0.04	0.00	0.23	0.23
2035	0.19	0.19	0.07	0.04	0.00	0.23	0.23

Table 8.13. Projected catches for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2022	16,014	16,014	16,014	16,014	16,014	16,014	16,014
2023	40,760	40,760	40,760	40,760	40,760	81,397	66,958
2024	77,197	77,197	29,722	18,463	0	87,791	73,936
2025	87,948	87,948	36,102	22,761	0	99,627	103,741
2026	101,039	101,039	43,513	27,755	0	114,378	117,658
2027	114,106	114,106	51,124	32,933	0	128,935	131,417
2028	121,535	121,535	56,786	36,961	0	136,344	138,144
2029	116,958	116,958	57,607	37,980	0	129,331	130,612
2030	105,946	105,946	55,493	37,138	0	114,973	115,883
2031	91,208	91,208	50,790	34,520	0	97,190	97,827
2032	77,685	77,685	45,639	31,474	0	81,619	82,062
2033	68,241	68,241	41,880	29,258	0	71,030	71,339
2034	61,317	61,317	38,829	27,421	0	63,545	63,764
2035	56,007	56,007	36,161	25,755	0	57,240	57,425

Figures

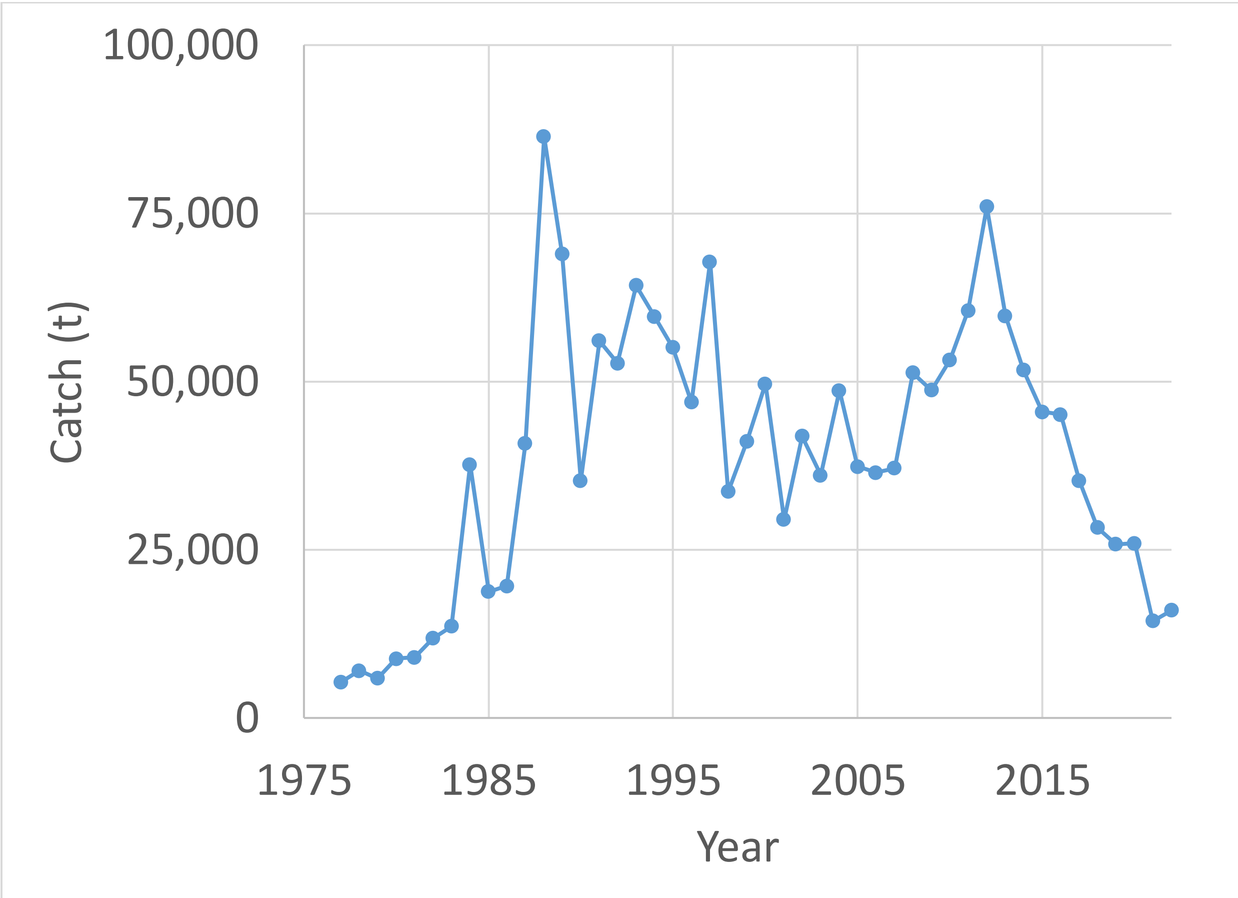


Figure 8.1. Total catch (t) of rock sole by year.

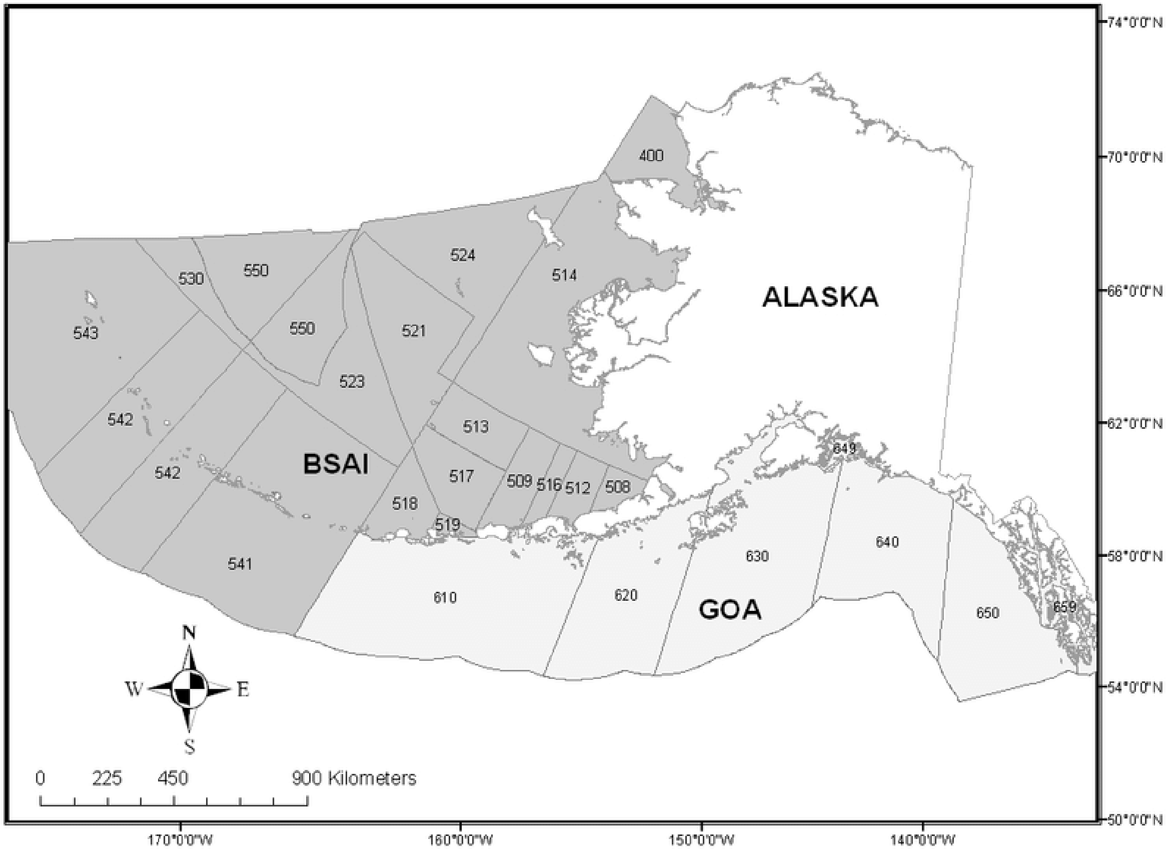


Figure 8.2. Map of NMFS Regulatory Areas in the BSAI and GOA.

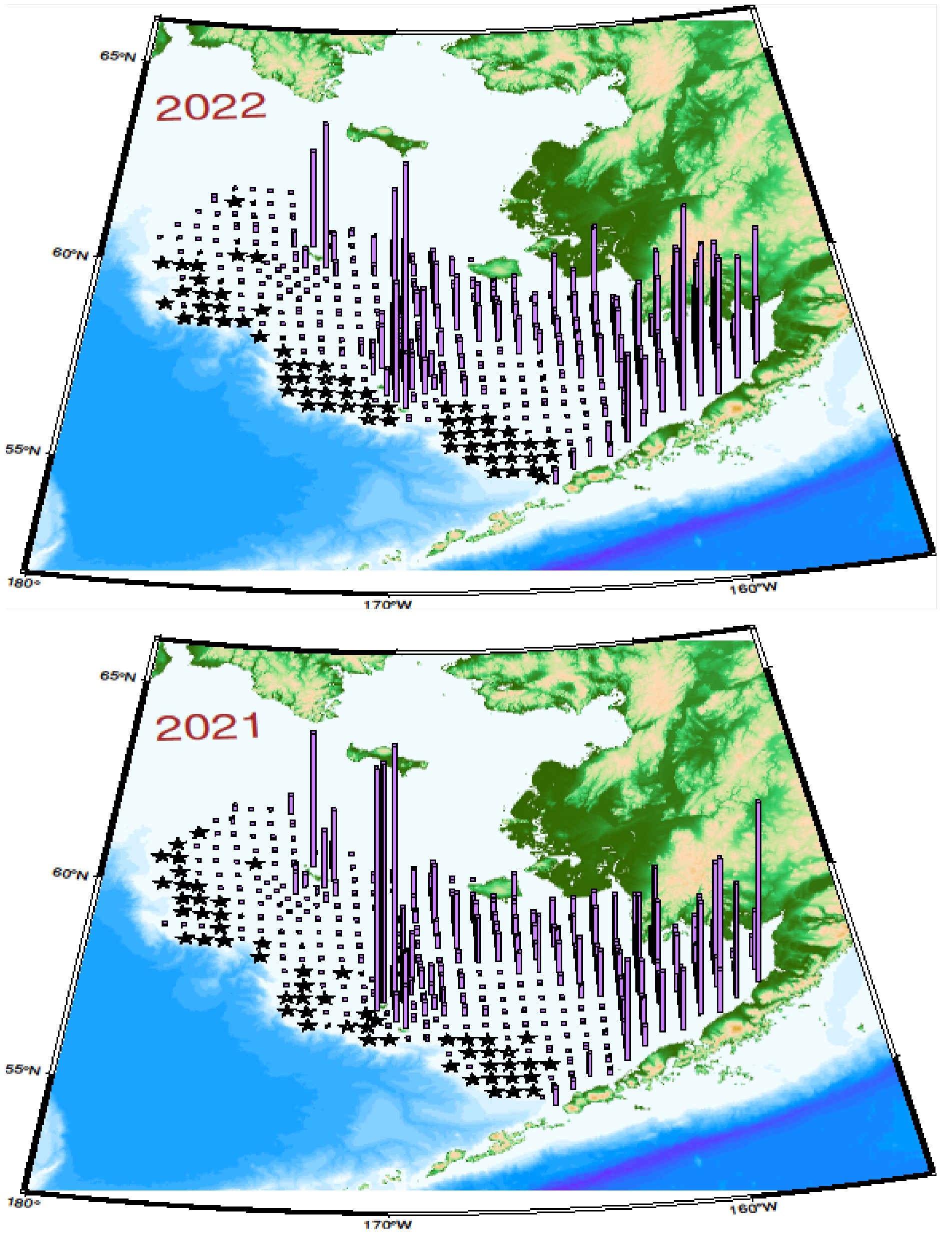


Figure 8.3. Survey catch-per-unit-effort of northern rock sole for 2021-2022 (purple bars). Hauls with zero northern rock sole are denoted with red stars.

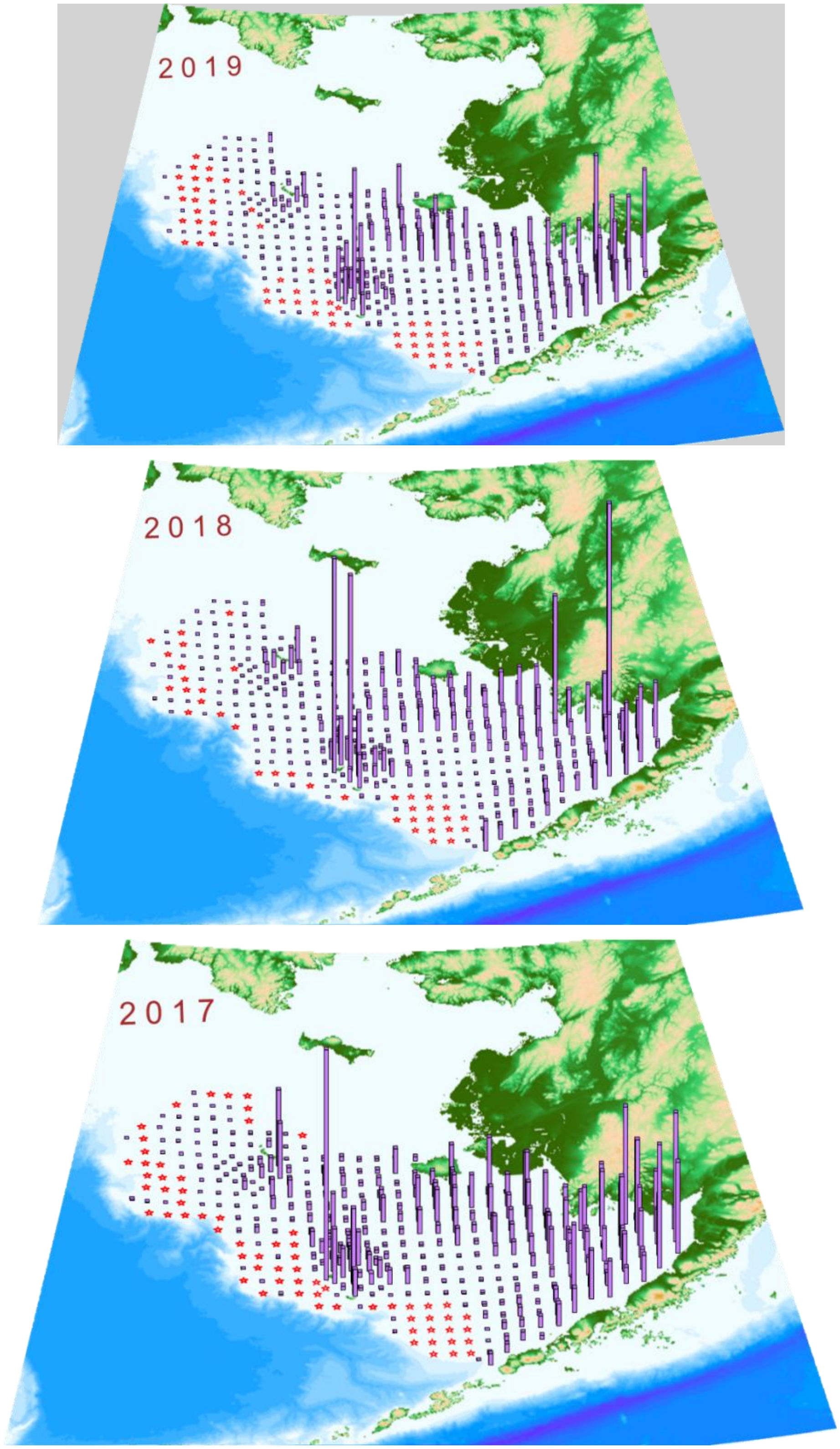


Figure 8.4. Survey catch-per-unit-effort of northern rock sole for 2017-2019 (purple bars). Hauls with zero northern rock sole are denoted with red stars.

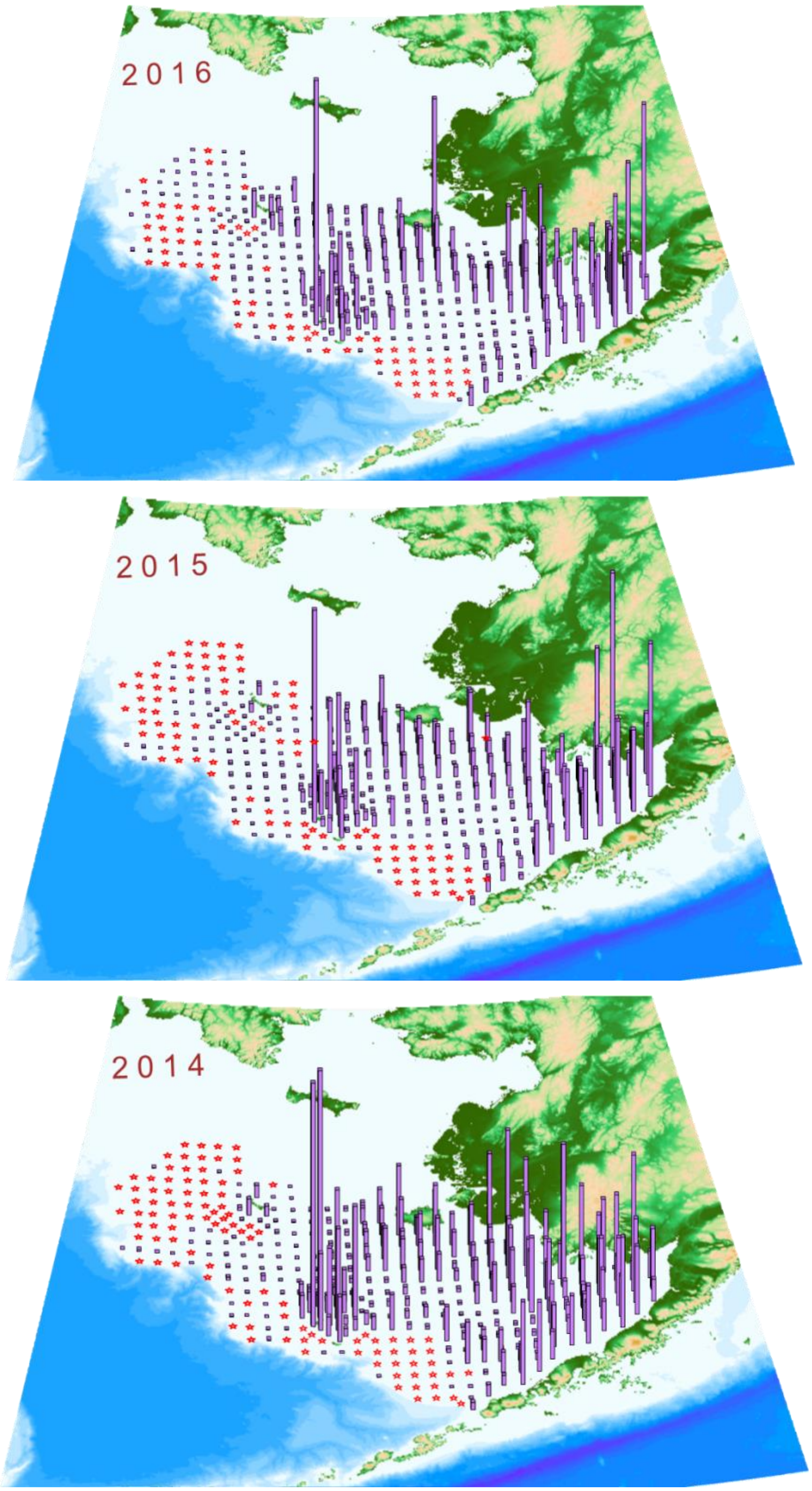


Figure 8.5. Survey catch-per-unit-effort of northern rock sole for 2014-2016 (purple bars). Hauls with zero northern rock sole are denoted with red stars.

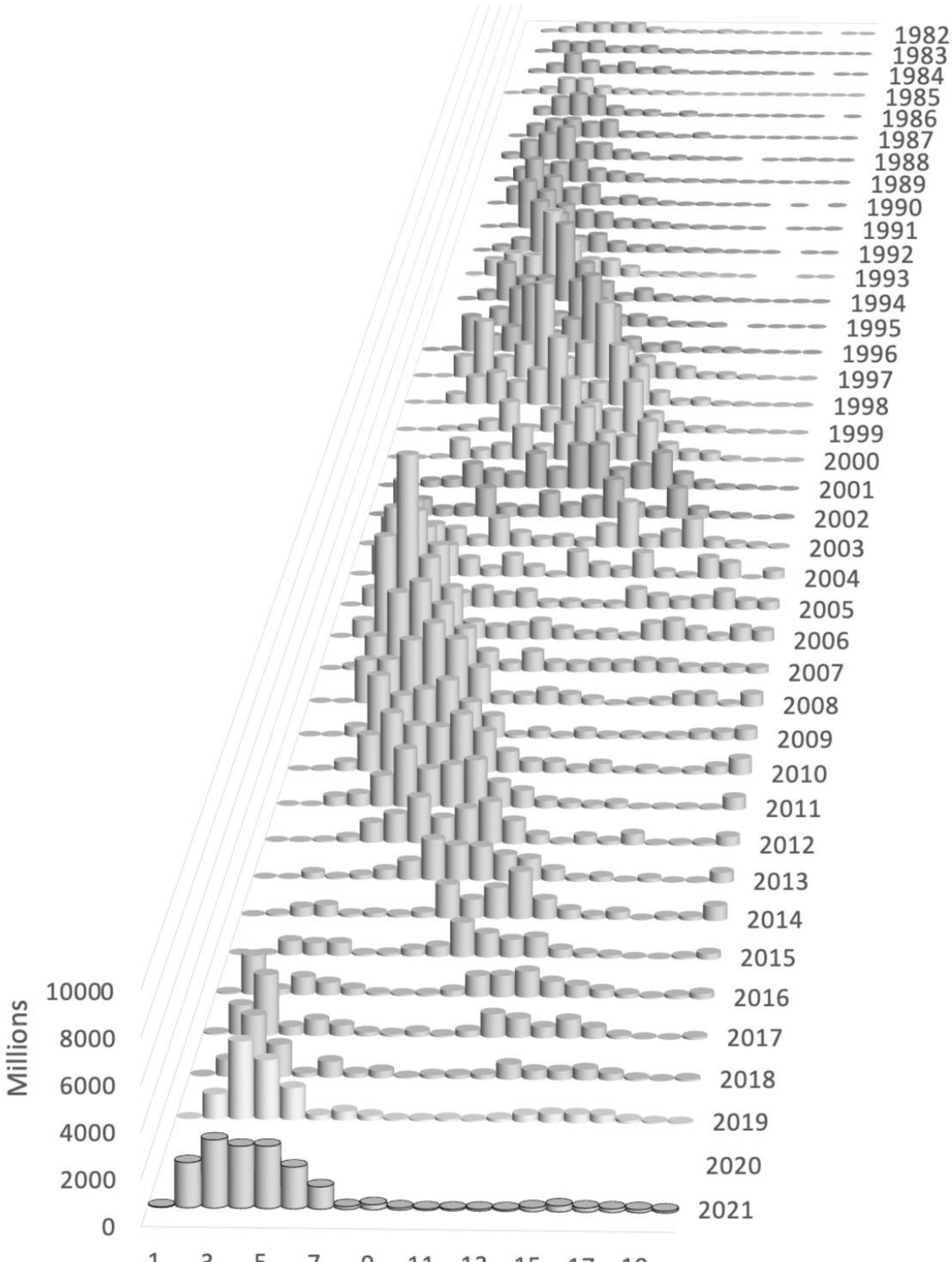


Figure 8.6. Survey age composition data in absolute numbers (age on the x-axis and millions of fish on the y-axis; both sexes summed) over time.

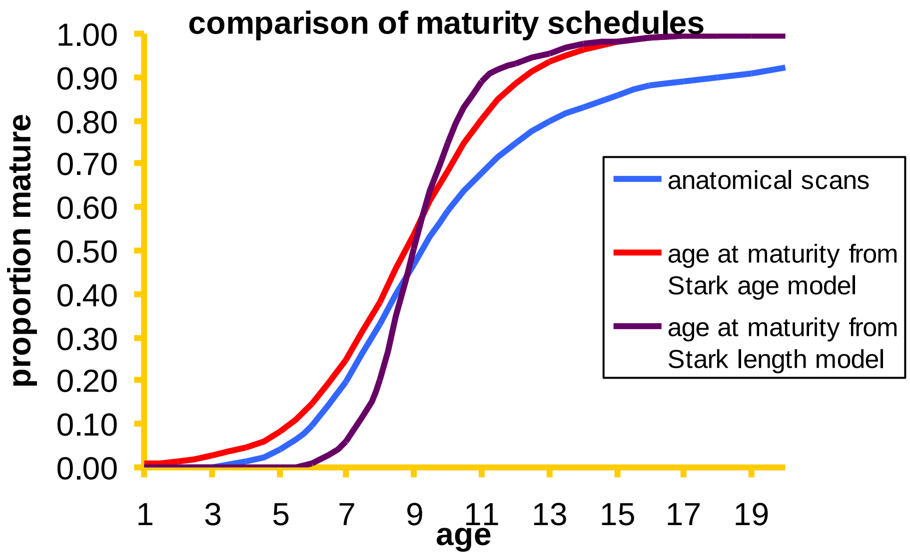


Figure 8.7. Maturity schedule for northern rock sole from three methods (bottom panel). The Stark (2012) length model, based on histology, is used in the stock assessment replacing the curve from anatomical scanning of fish used in past assessments.

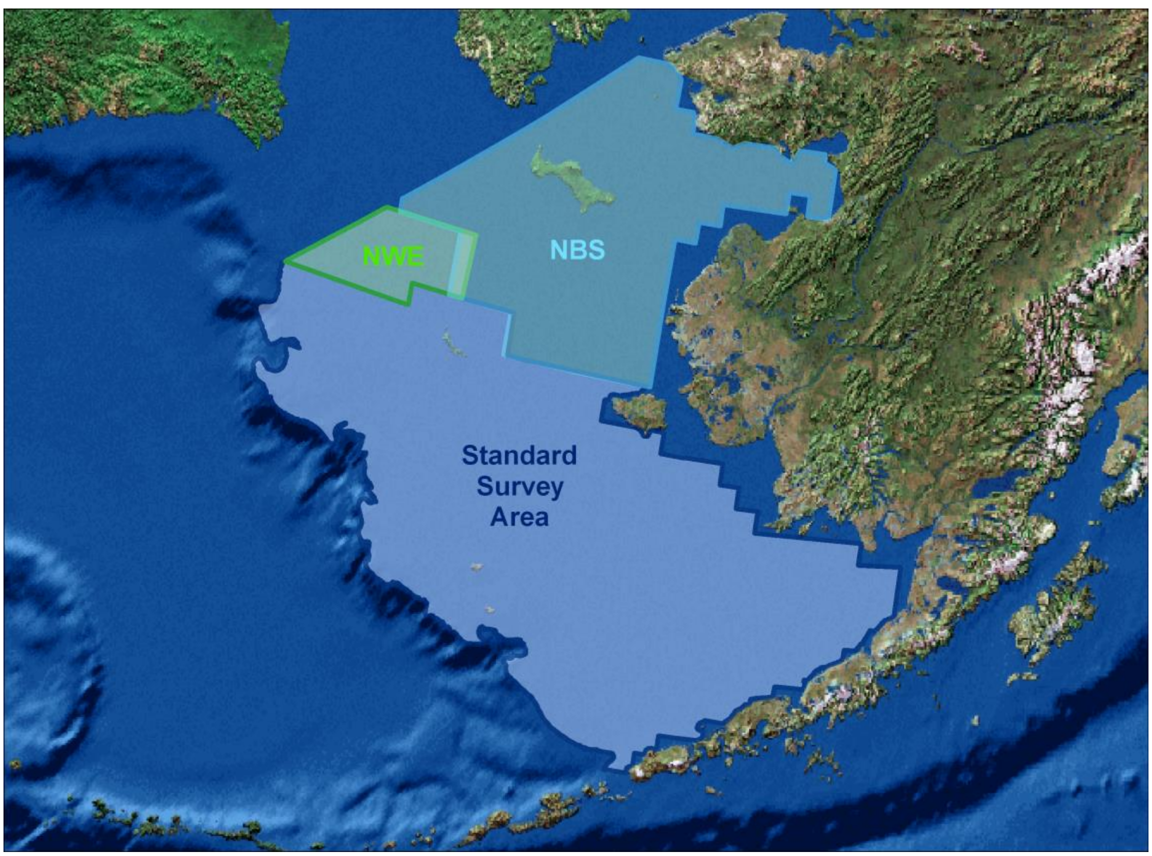


Figure 8.8. Eastern Bering Sea shelf survey areas. Only data from the standard survey area are used in the assessment model; data from the Northwest Extension (NWE) and Northern Bering Sea (NBS) are excluded.

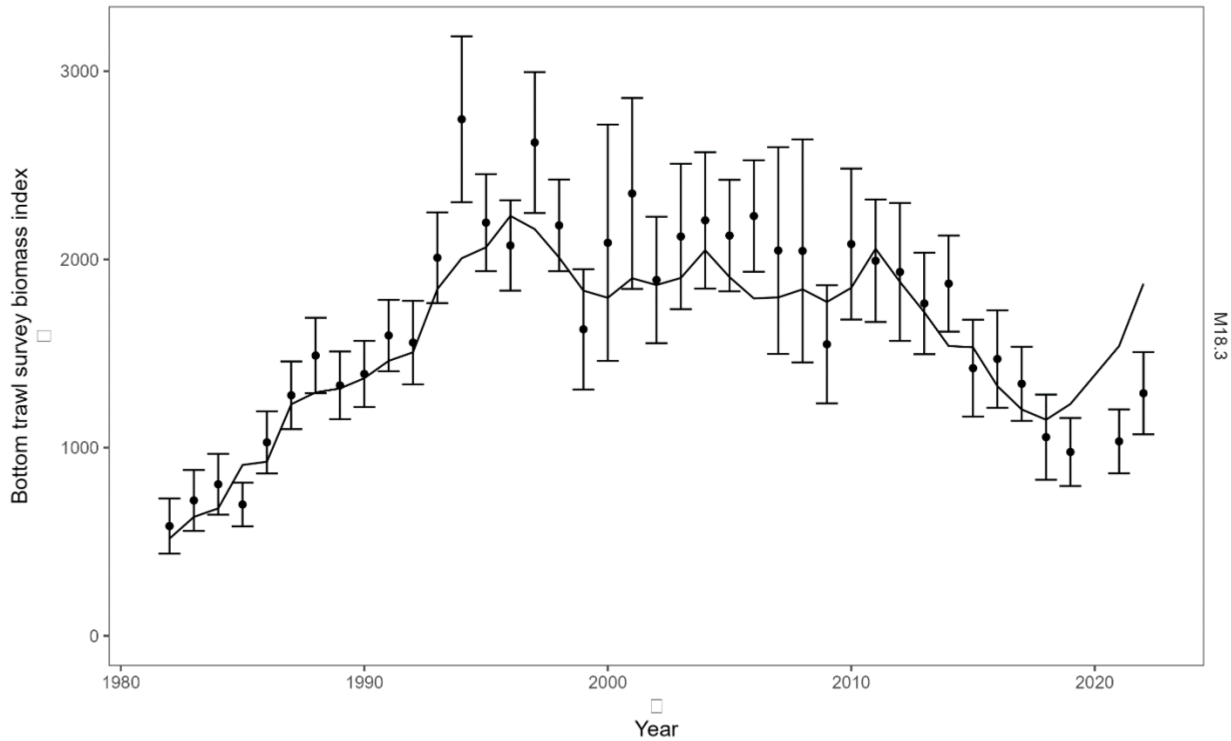


Figure 8.9. Survey biomass and asymptotic 95% confidence intervals (black dots and vertical lines) and fits to the survey biomass for Models 18.3 (the previously accepted model with new data.

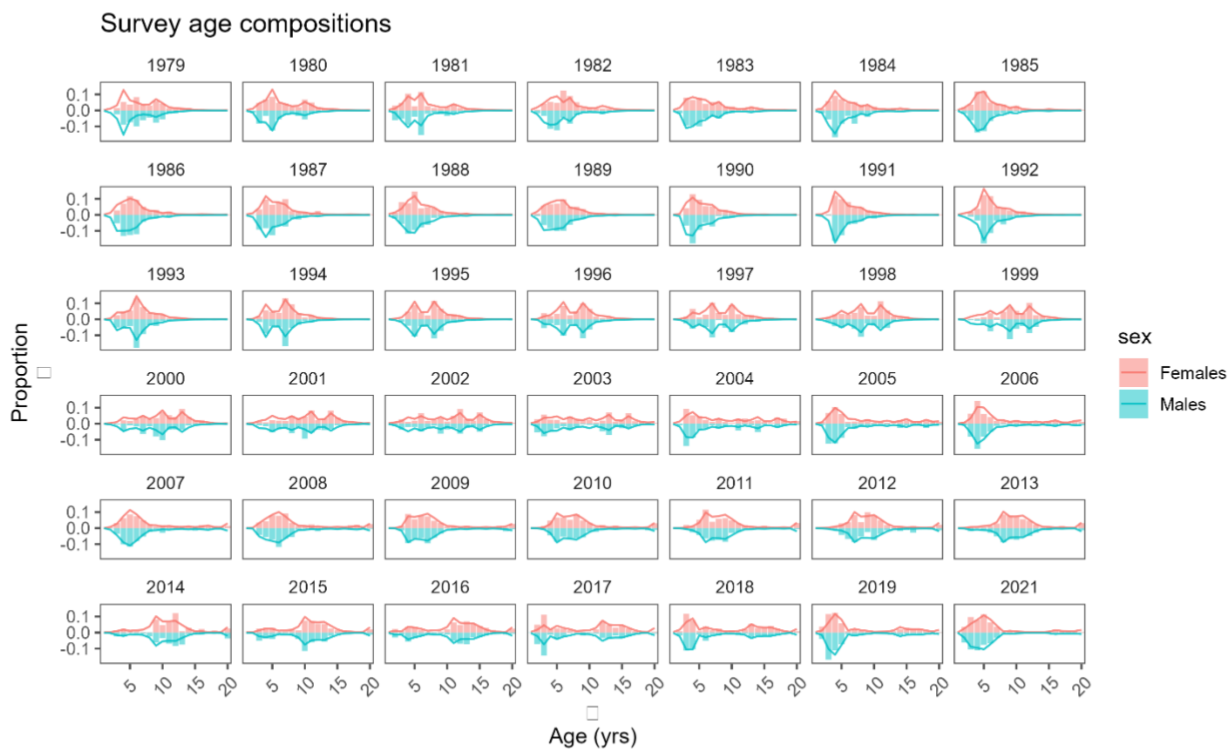


Figure 8.10. Observed (histograms) and expected (lines) survey age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for Model 18.3.

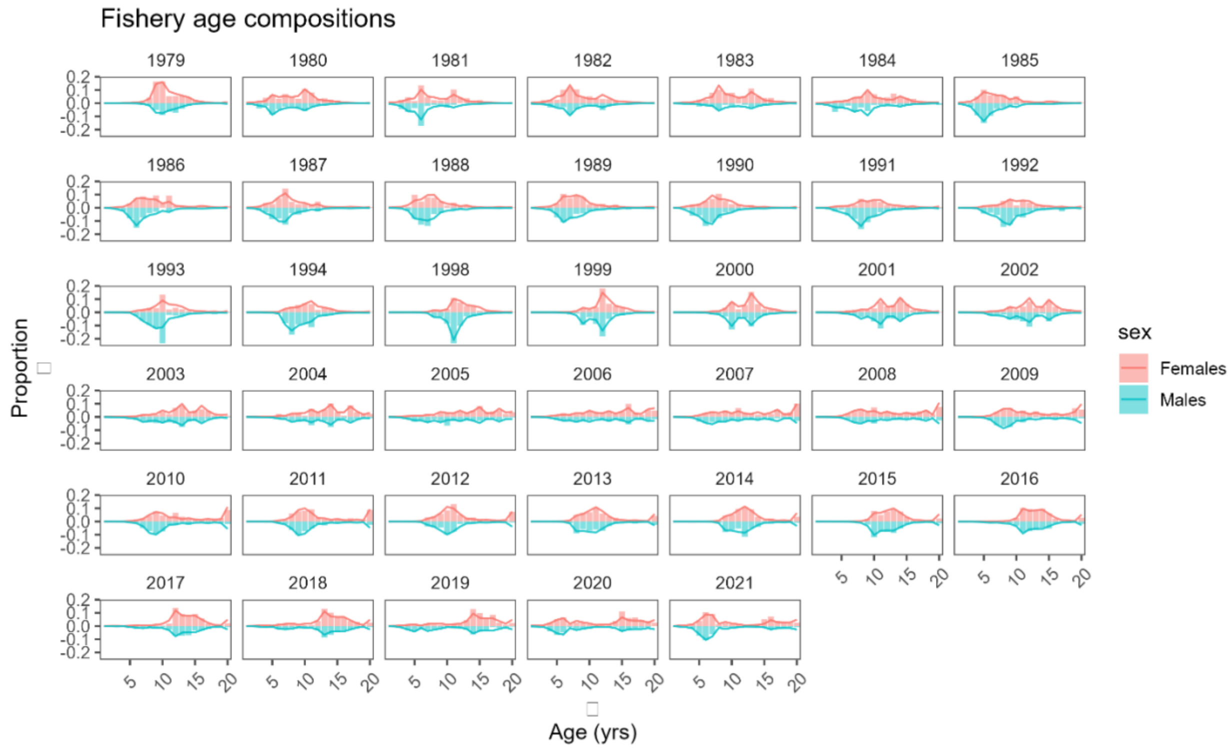


Figure 8.11. Observed (histograms) and expected (lines) fishery age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for Model 18.3.

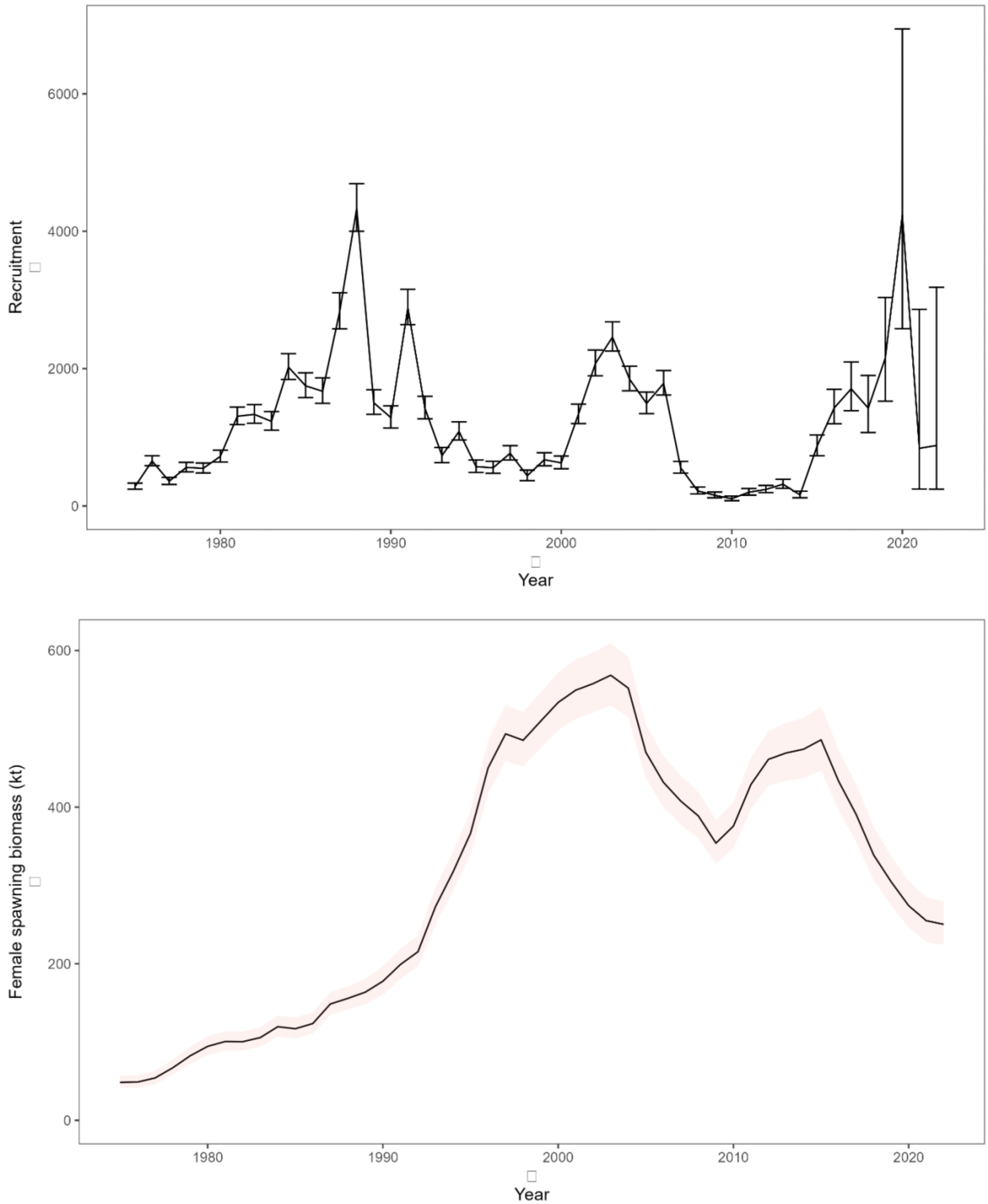


Figure 8.12. Recruitment estimates (top panel) and spawning stock biomass estimates (bottom panel) with 95% asymptotic confidence intervals for Model 18.3.

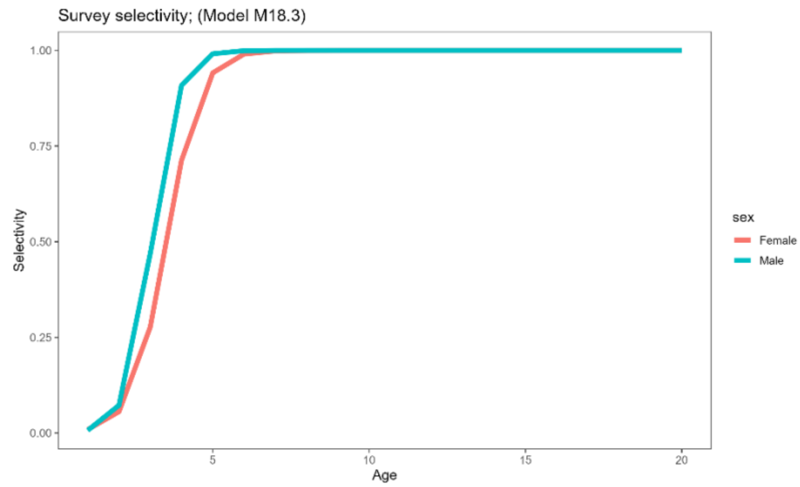


Figure 8.13. Male (red) and female (blue) survey selectivity for Model 18.3.

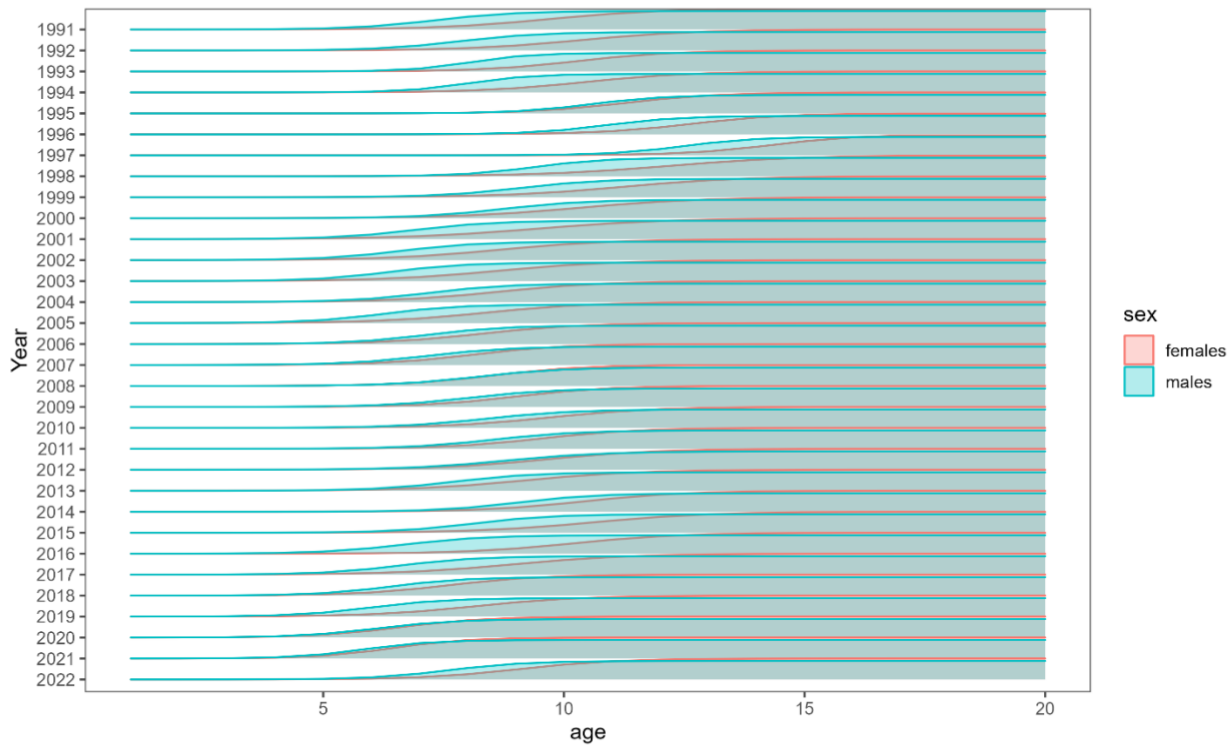


Figure 8.14. Yearly time-varying logistic fishery selectivity for Model 18.3.

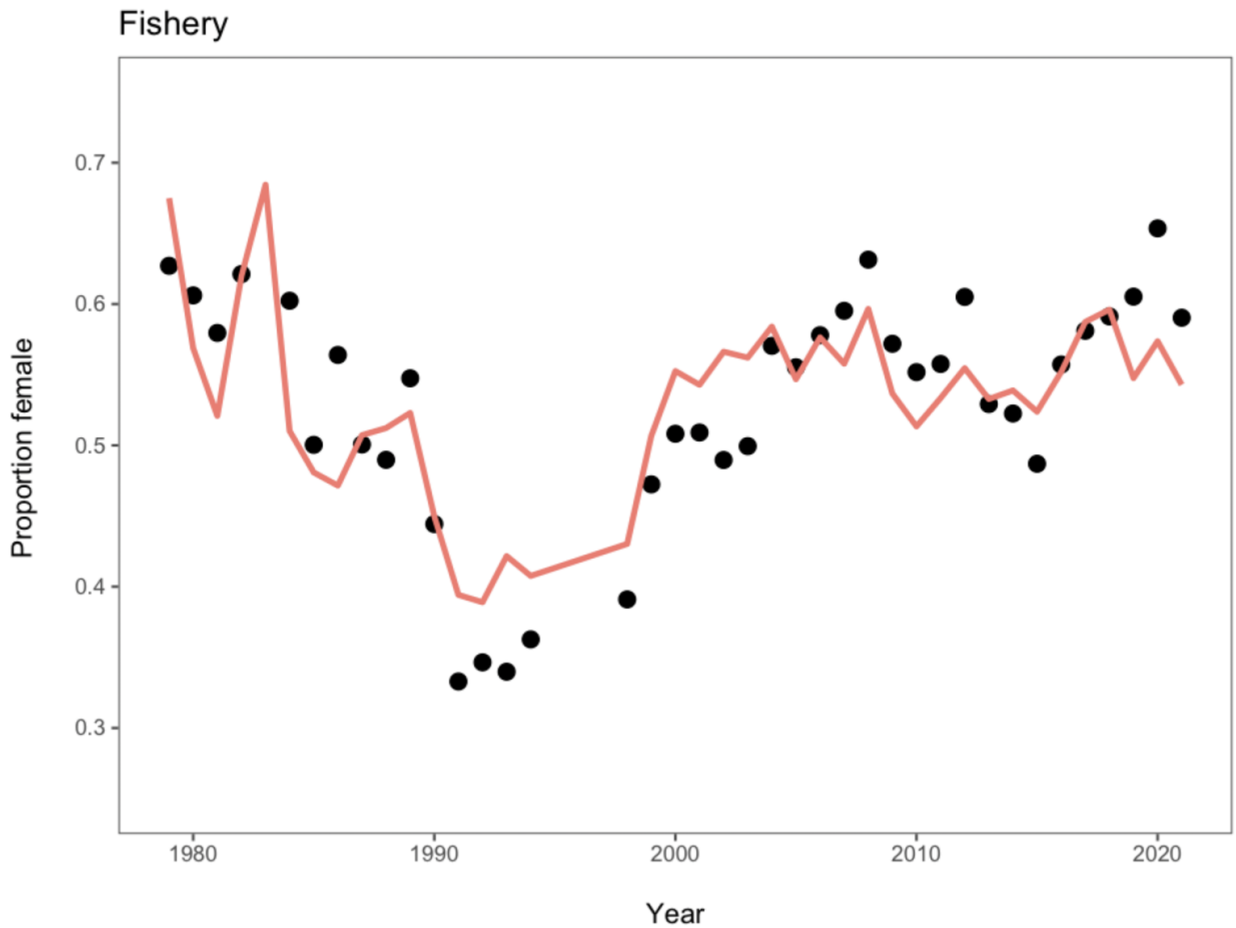


Figure 8.15. Time series of predicted (line) and observed (dots) proportion female in the catch for rock sole.

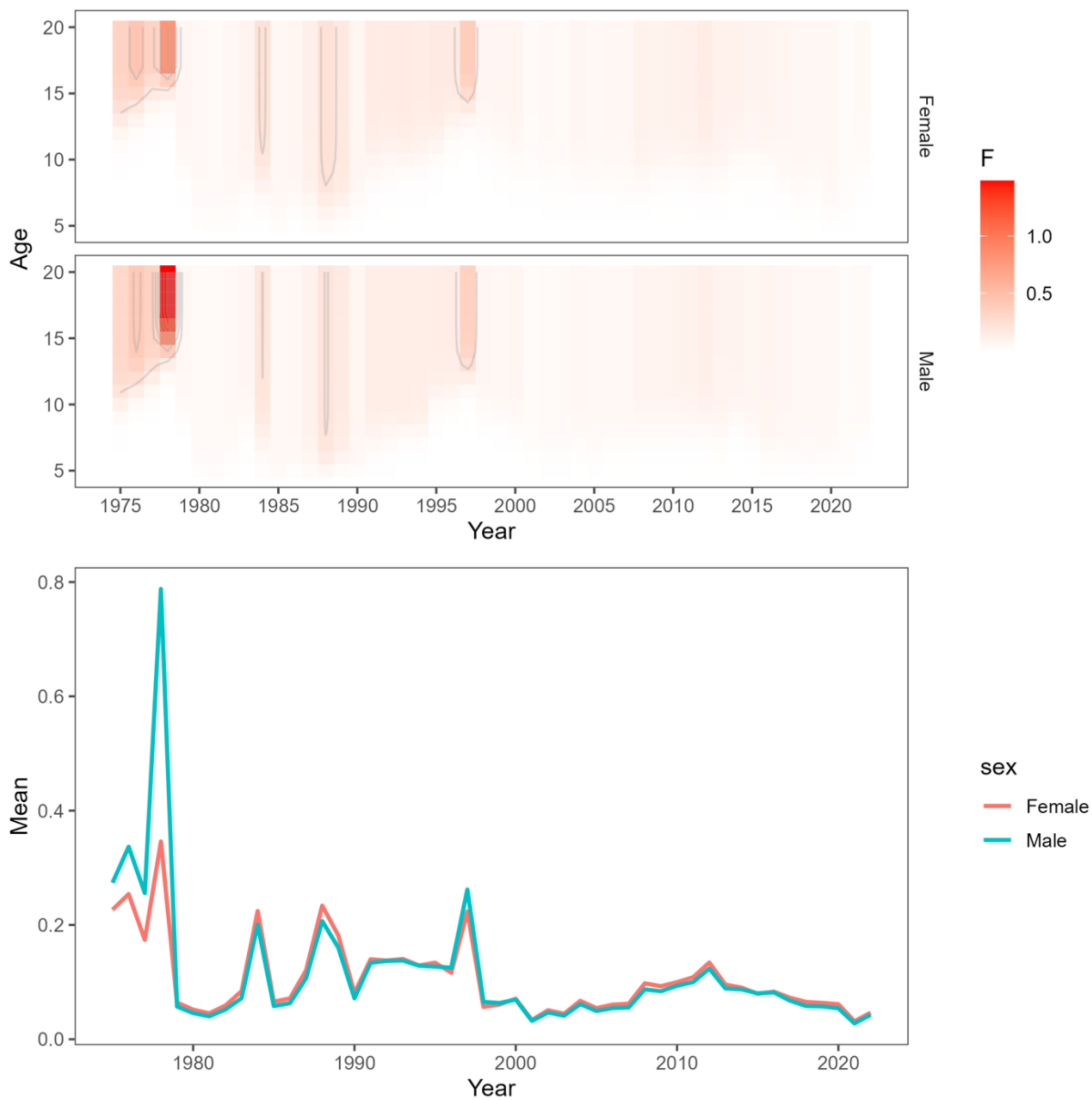


Figure 8.16. A comparison of fishing mortality across ages and time for Model 18.3. The top sub-panel shows fishing mortality by age and year for females and males and the bottom sub-panel shows mean fishing mortality over time. The plots are sex-specific.

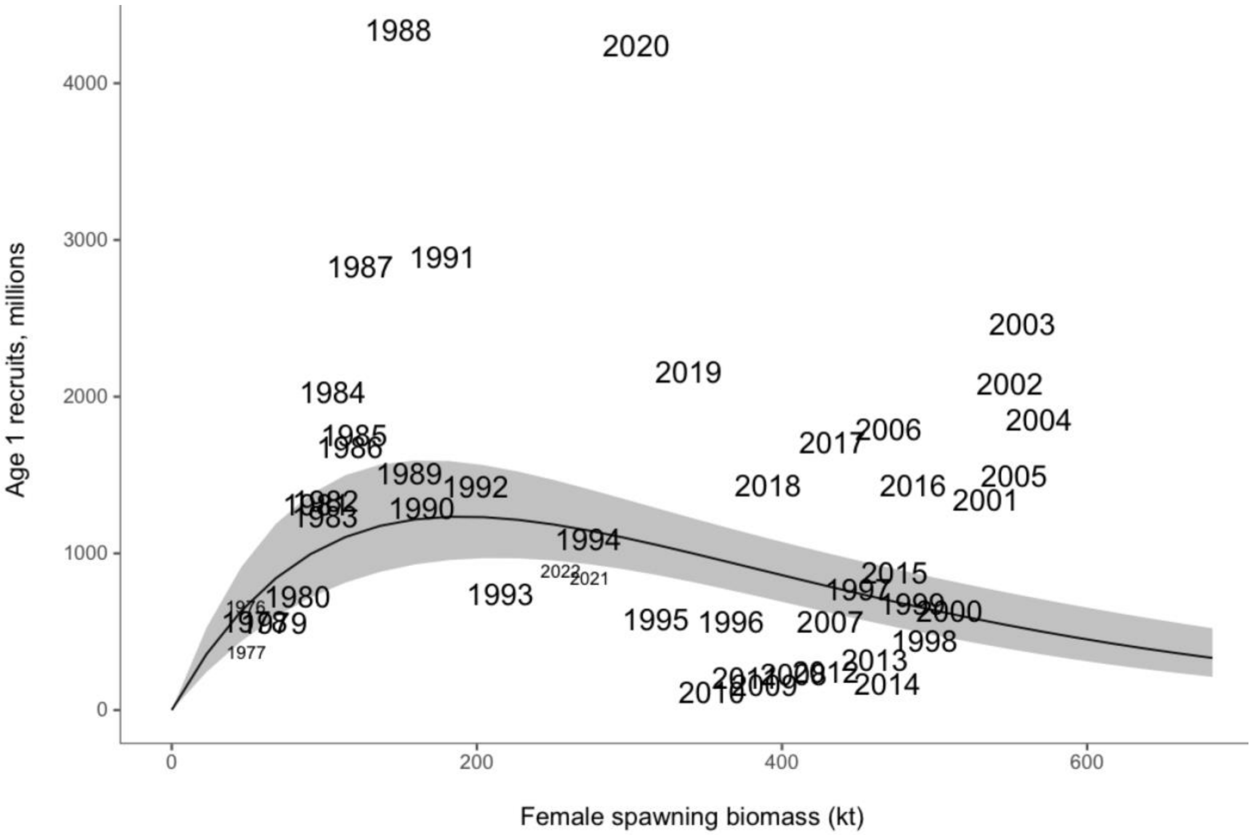


Figure 8.17. Stock-recruit relationship for rock sole. Years presented as labels and larger font size are used in fitting the curve.

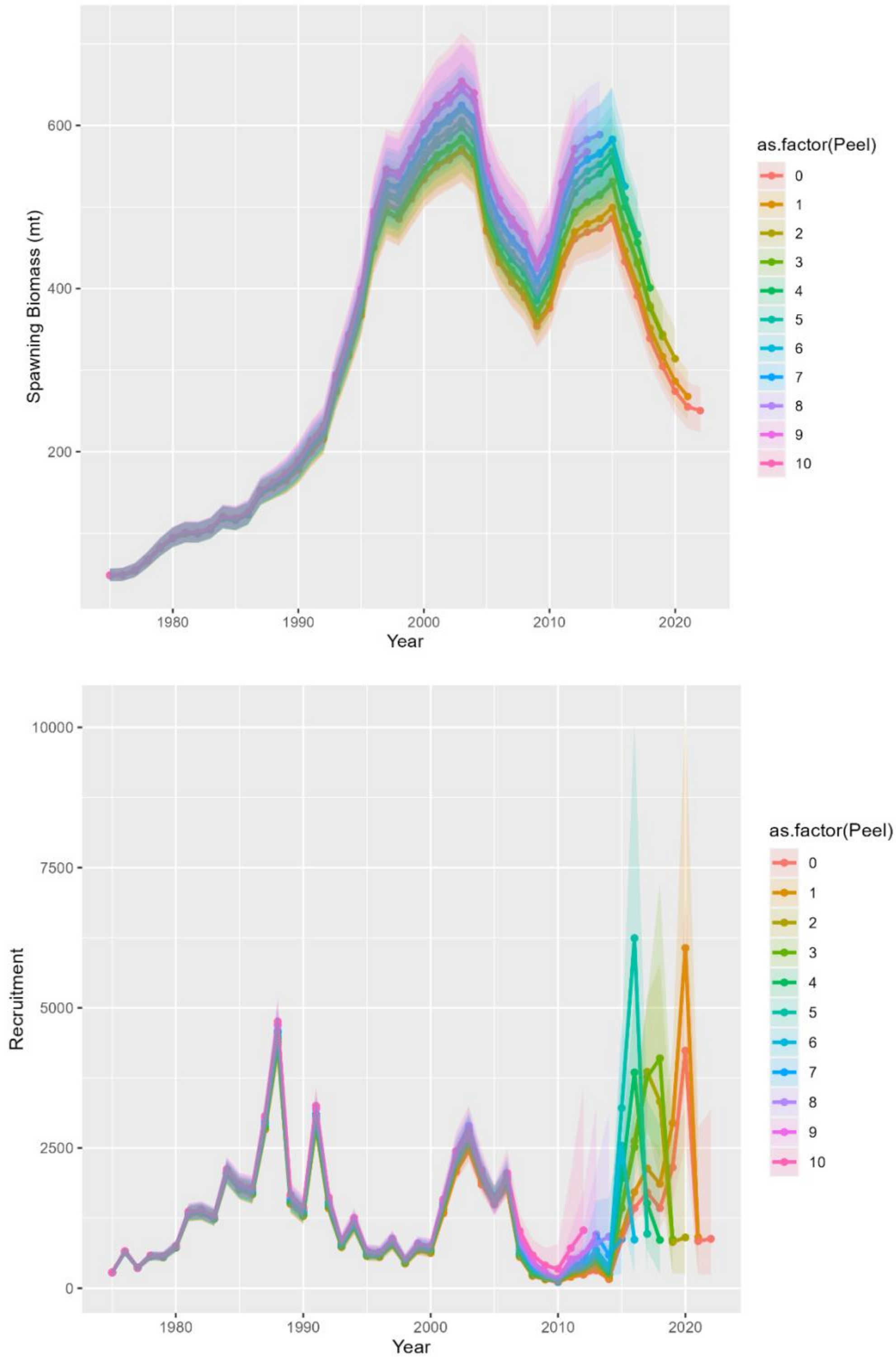


Figure 8.18. Retrospective patterns for spawning biomass (top panel) and recruitment (bottom panel) for Model 18.3.

Appendix A

Summary of Alternative Model Results

M18.3 is the previously accepted model shown in the main document for 2022. M22.1 is as for M18.3, but uses the Francis (2011) methodology for data weighting, which substantially reduced the influence of survey age composition data and increased the influence of fishery age composition data. M22.2 is as for M22.1, but additionally estimates female natural mortality (male natural mortality is estimated in all models) with a normal prior with mean 0.15 and a standard deviation of 0.2. In M22.2 the standard deviations of estimates of male and female natural mortality as well as the log of survey catchability were quite small, and uncertainty intervals corresponding to spawning biomass and recruitment estimates were only slightly larger, both indications that there is information in the model to inform these estimates. This is an underutilized stock with particularly low fishing mortality rates over time and in recent years, which may provide substantial information on natural mortality and allow the model to distinguish between estimates of natural mortality and survey catchability. However, further supporting analyses could be done for this run, such as likelihood profiling over natural mortality and catchability and/or running MCMCs and calculating posterior distributions for these parameters, performing a sensitivity analysis to starting values and phase for estimation, and making sure the natural mortality and catchability parameters do not change significantly over the peels of the retrospective analysis.

Below is a summary of key results for model run M22.1, which uses the Francis (2011) methodology for weighting age composition data. Projections use the same catch estimates as for the table presented in the Executive Summary (based on M18.3).

Quantity (M22.1)	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2022	2023	2023	2024
M (natural mortality rate)	0.15 (f),0.17 (m)	0.15 (f),0.17 (m)	0.15 (f),0.19 (m)	0.15 (f),0.19 (m)
Tier	1a	1a	1a	1a
Projected total (age 6+) biomass (t)	1,361,360	1,784,460	666,361	656,779
Projected Female spawning biomass (t)	287,600	320,399	255,669	258,601
B_0	476,820	476,820	447,795	447,795
B_{MSY}	158,972	158,972	146,995	146,995
F_{OFL}	0.157	0.157	0.183	0.183
$maxF_{ABC}$	0.152	0.152	0.174	0.174
F_{ABC}	0.152	0.152	0.174	0.174
OFL (t)	214,084	280,621	121,719	119,969
maxABC (t)	206,896	271,199	116,002	114,334
ABC (t)	206,896	271,199	116,002	114,334
Status	As determined *last* year for:		As determined *this* year for:	
	2020	2021	2021	2022
Overfishing	no	n/a	no	n/a
Overfished	n/a	no	n/a	no
Approaching overfished	n/a	no	n/a	no

Below is a summary of key quantities for model run M22.2, which estimates both female and male natural mortality and uses the Francis (2011) methodology for weighting age composition data. Projections use the same catch estimates as for the table presented in the Executive Summary (based on M18.3).

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2022	2023	2023	2024
M (natural mortality rate)	0.15 (f),0.17 (m)	0.15 (f),0.17 (m)	0.15 (f),0.19 (m)	0.15 (f),0.19 (m)
Tier	1a	1a	1a	1a
Projected total (age 6+) biomass (t)	1,361,360	1,784,460	811,324	804,351
Projected Female spawning biomass (t)	287,600	320,399	256,816	266,079
B_0	476,820	476,820		
B_{MSY}	158,972	158,972	173,946	173,946
F_{OFL}	0.157	0.157	0.171	0.171
$maxF_{ABC}$	0.152	0.152	0.161	0.161
F_{ABC}	0.152	0.152	0.161	0.161
OFL (t)	214,084	280,621	138,942	137,748
maxABC (t)	206,896	271,199	130,985	129,859
ABC (t)	206,896	271,199	130,985	129,859
Status	As determined *last* year for:		As determined *this* year for:	
	2020	2021	2021	2022
Overfishing	no	n/a	no	n/a
Overfished	n/a	no	n/a	no
Approaching overfished	n/a	no	n/a	no

Tables for Appendix A

Table 8.14. A comparison of parameter estimates across model alternatives, including the base model for 2022.

Parameter	Model 18.3 (2022)		Model 22.1 (2022)		Model 22.2 (2022)	
	value	std.dev	value	std.dev	value	std.dev
log catchability	0.67	0.026	0.73	0.025	0.50	0.031
female natural mortality					0.19	0.004
male natural mortality	0.17	0.002	0.19	0.002	0.22	0.004
mean log recruitment	6.78	0.108	6.67	0.108	7.25	0.118
mean log initial age composition	3.38	0.125	3.26	0.120	3.60	0.127
log average fishing mortality	-2.26	0.087	-2.15	0.084	-2.30	0.086
average slope of fishery selectivity (f)	1.00	0.047	0.96	0.036	0.96	0.035
average age at 50% fishery selectivity (f)	9.05	0.477	9.18	0.476	9.44	0.490
average slope of fishery selectivity (m)	1.26	0.400	1.19	0.047	1.20	0.047
selectivity offset for males	-0.13	0.052	0.01	0.050	-0.14	0.055
slope of survey selectivity (f)	1.87	0.100	2.15	0.313	1.76	0.233
slope of survey selectivity (m)	0.26	0.070	0.20	0.188	0.28	0.173
age at 50% survey selectivity (f)	3.51	0.060	3.32	0.136	3.66	0.162
age at 50% survey selectivity (m)	-0.14	0.020	-0.13	0.049	-0.15	0.050
log alpha of Ricker stock-recruit curve	2.87	0.200	2.94	0.203	3.23	0.204
log beta of Ricker stock-recruit curve	-5.25	0.110	-5.18	0.108	-5.43	0.115
maximum sustainable yield	220.50	40.930	212.38	39.515	257.95	54.467
Fmsy	0.33	0.164	0.33	0.171	0.34	0.195
logFmsy	-1.11	0.501	-1.11	0.521	-1.07	0.572
Fmsyr	0.17	0.036	0.18	0.039	0.17	0.040
logFmsyr	-1.76	0.209	-1.72	0.219	-1.79	0.243
Bmsy	155.29	12.346	146.99	11.647	173.95	13.654
Bmsyr	1277.8	154.30	1191.0	150.43	1551.30	199.450

Figures for Appendix A

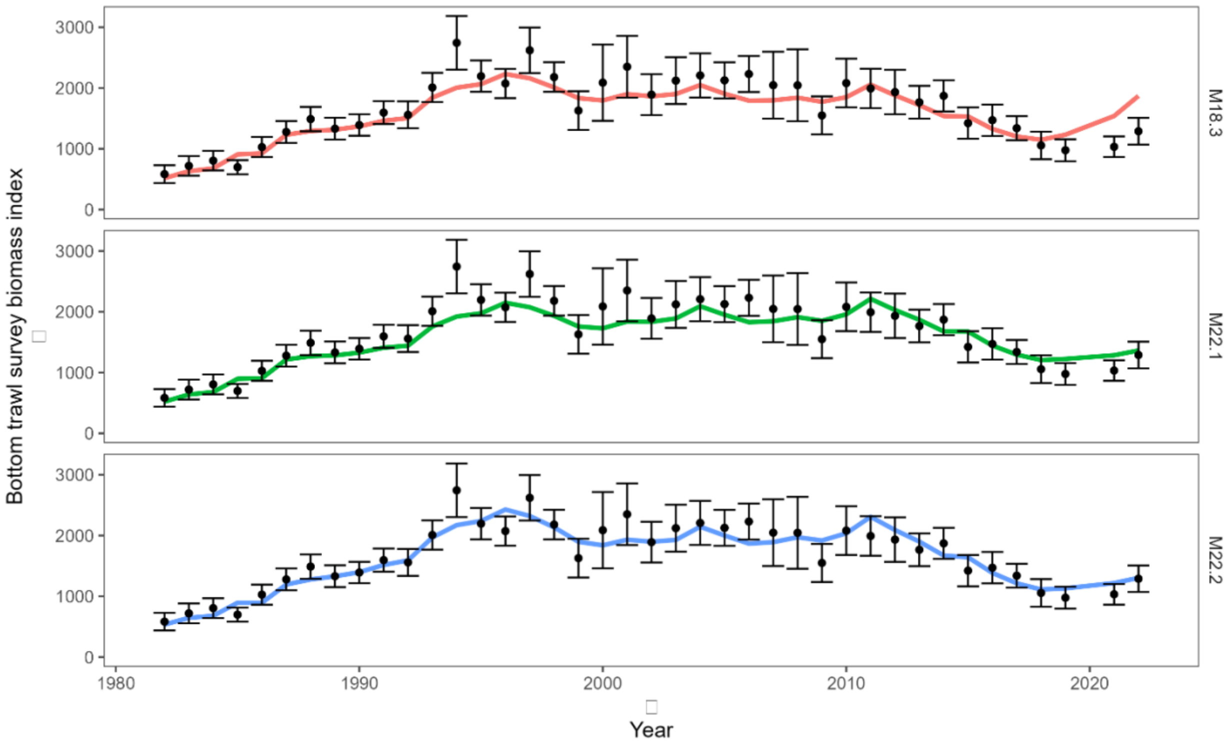
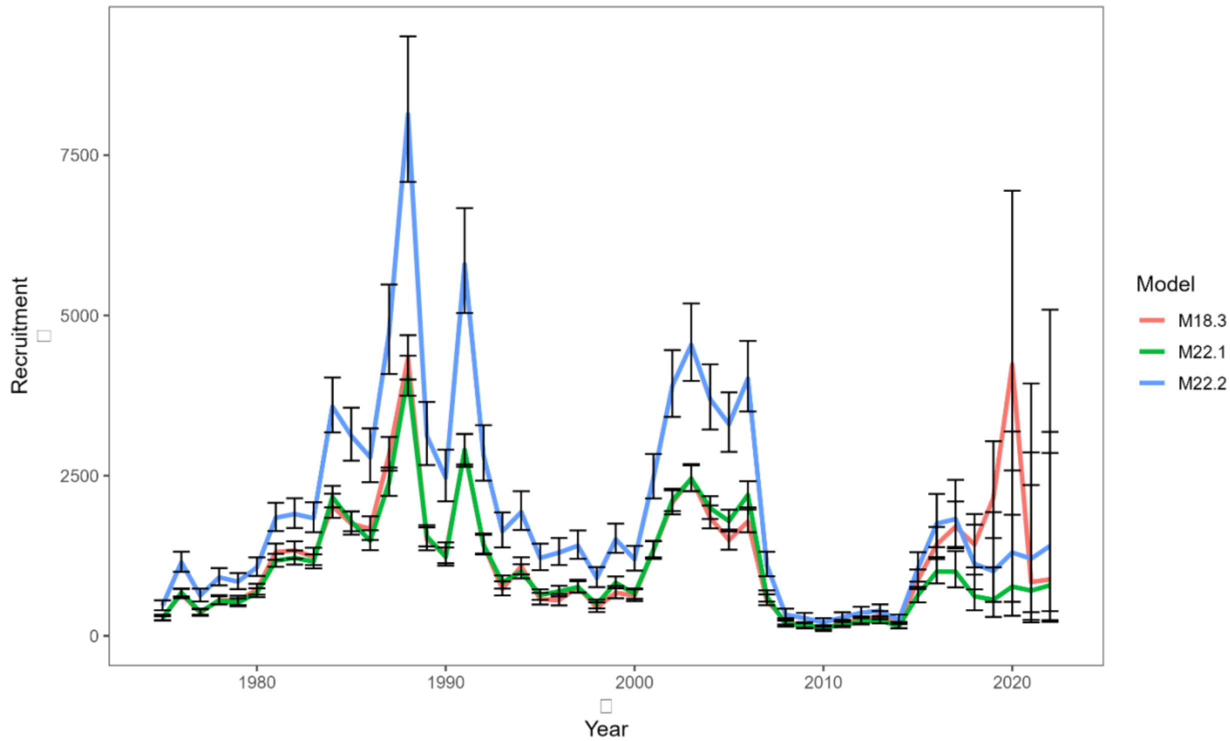


Figure 8.19. Survey biomass and asymptotic 95% confidence intervals (black dots and vertical lines) and fits to the survey biomass for Models 18.3 (the previously accepted model with new data; top panel), 22.1 (with Francis data weighting; middle panel, green line), and 22.2 (estimation of both female and male M and Francis data weighting; bottom panel, blue line).



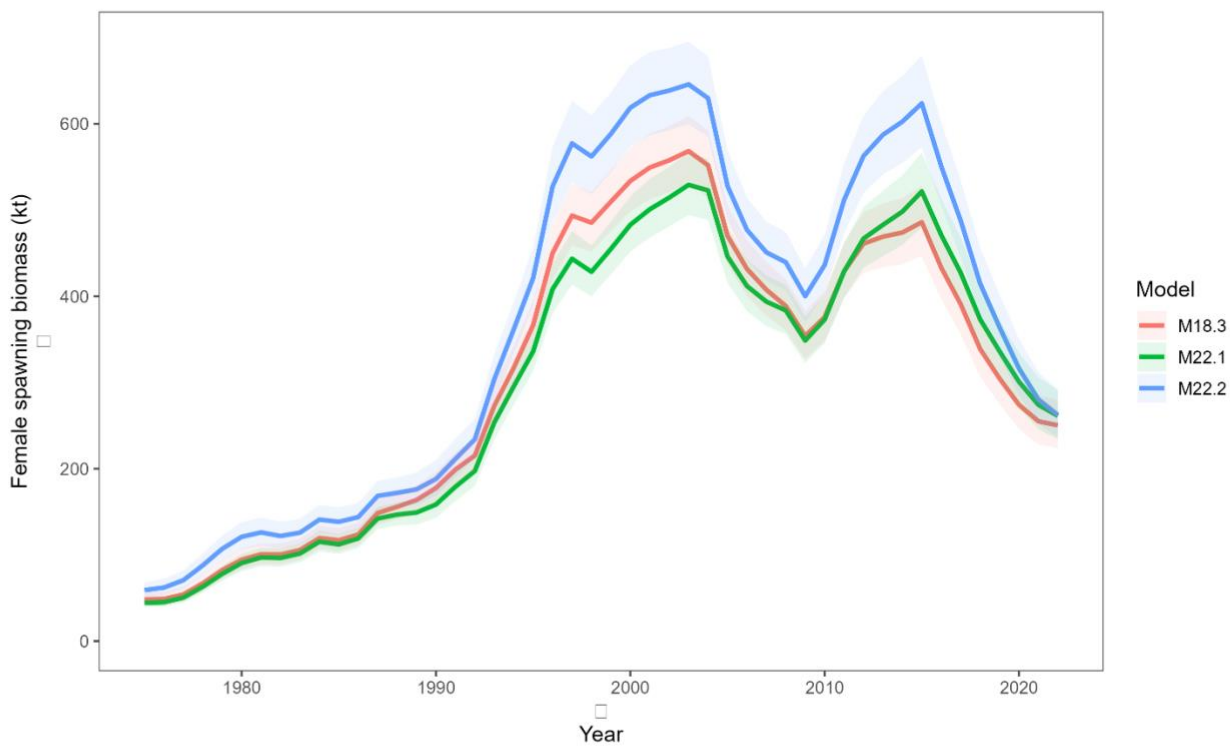
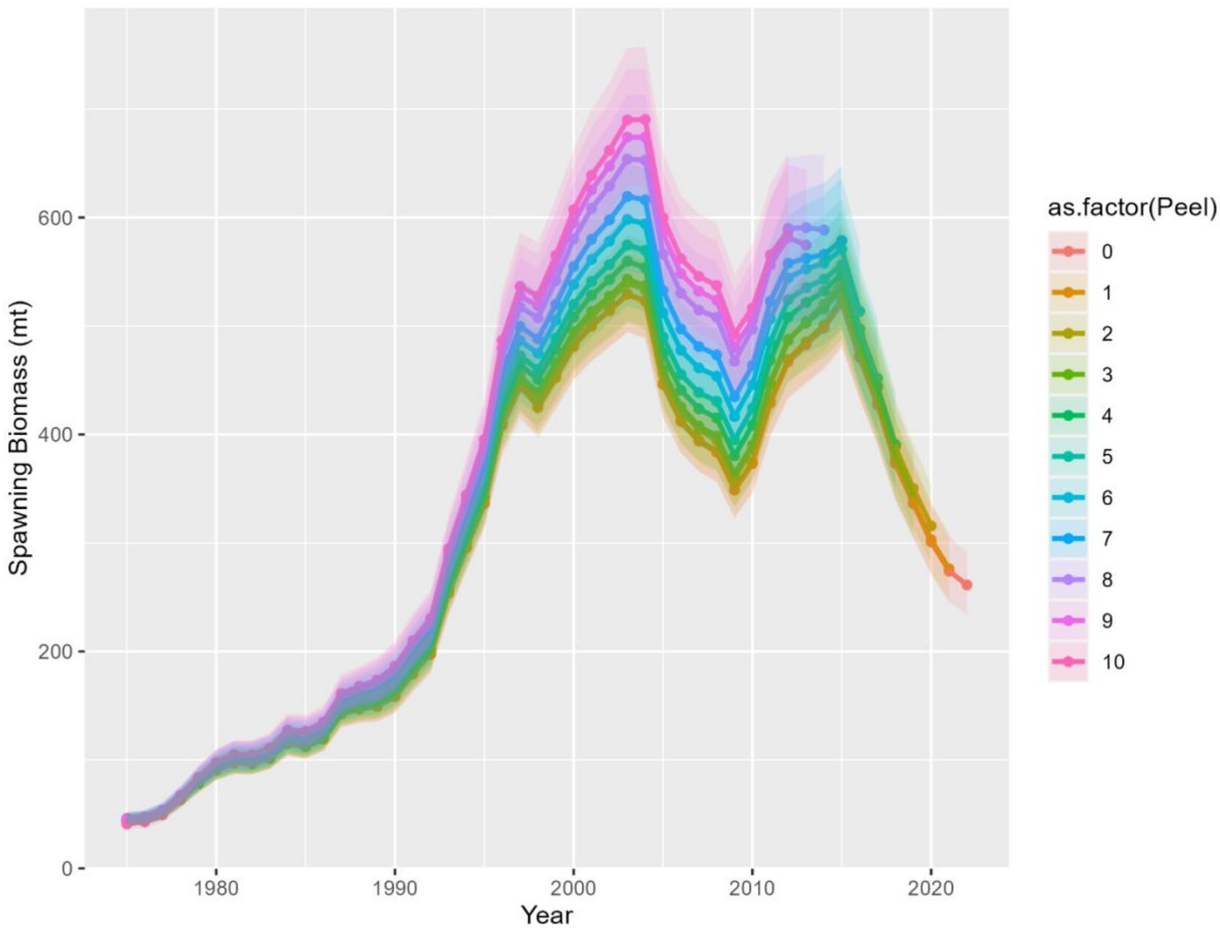


Figure 8.20. Recruitment estimates (top panel) and spawning stock biomass estimates (bottom panel) with 95% asymptotic confidence intervals for Models 18.3 (red), 22.1 (green), and 22.2 (blue).



Spawning Biomass (mt)
0
200
400
600
1980
1990
2000
2010
2020
Year
as.factor(Peel)
0
1
2
3
4
5
6
7
8
9
10

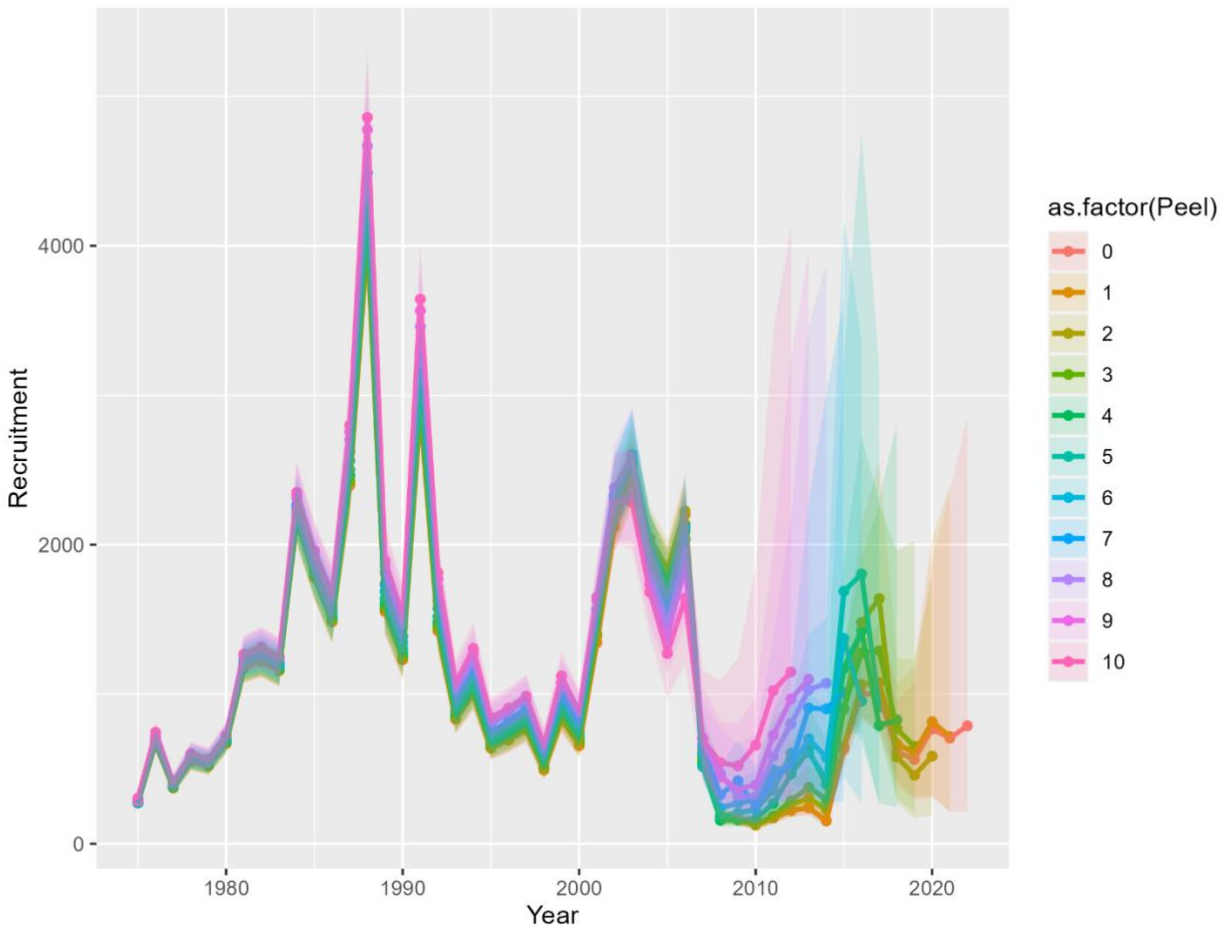
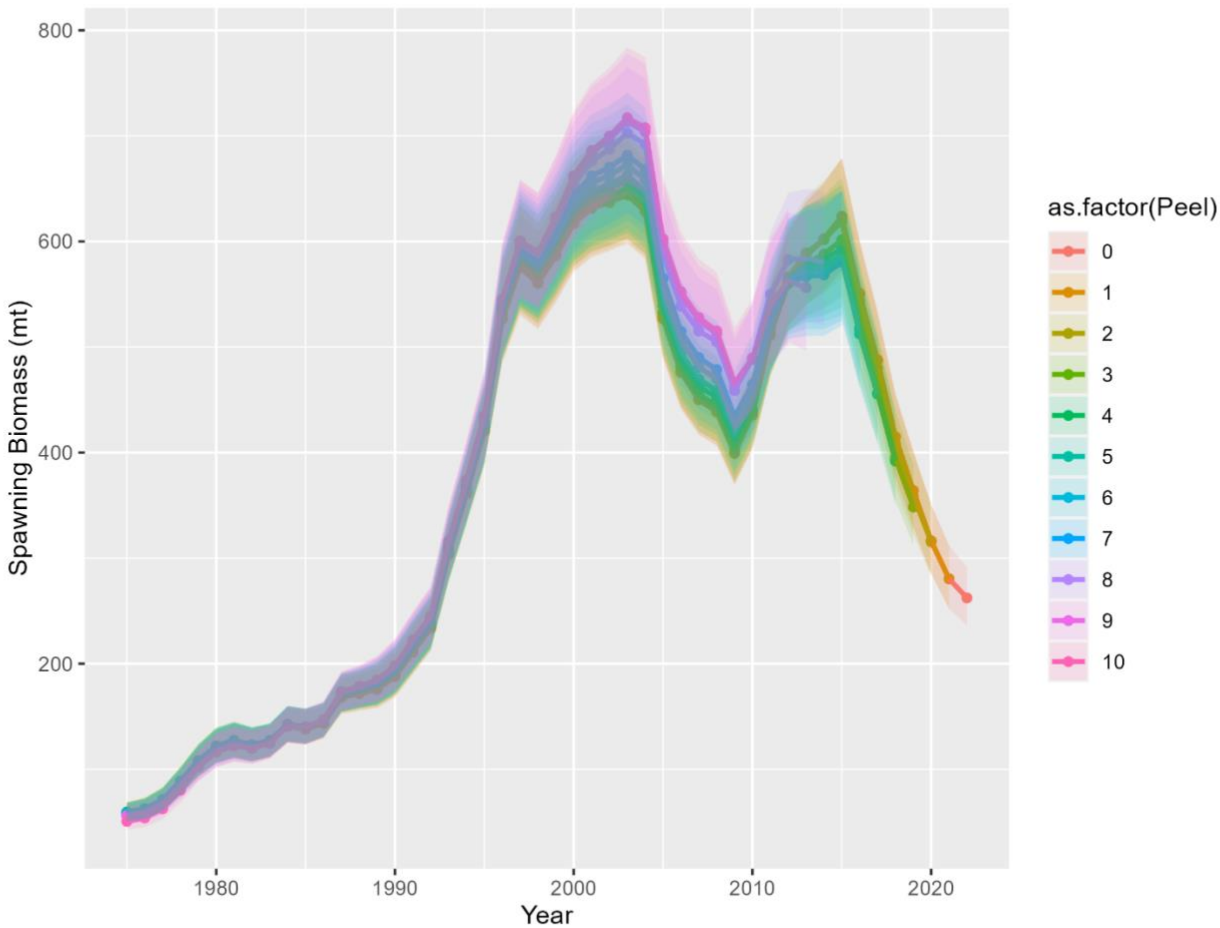


Figure 8.21. Retrospective patterns in spawning biomass and recruitment Model 22.1.


800
600
400
200
Spawning Biomass (mt)
1980
1990
2000
2010
2020
Year
as.factor(Peel)
0
1
2
3
4
5
6
7
8
9
10

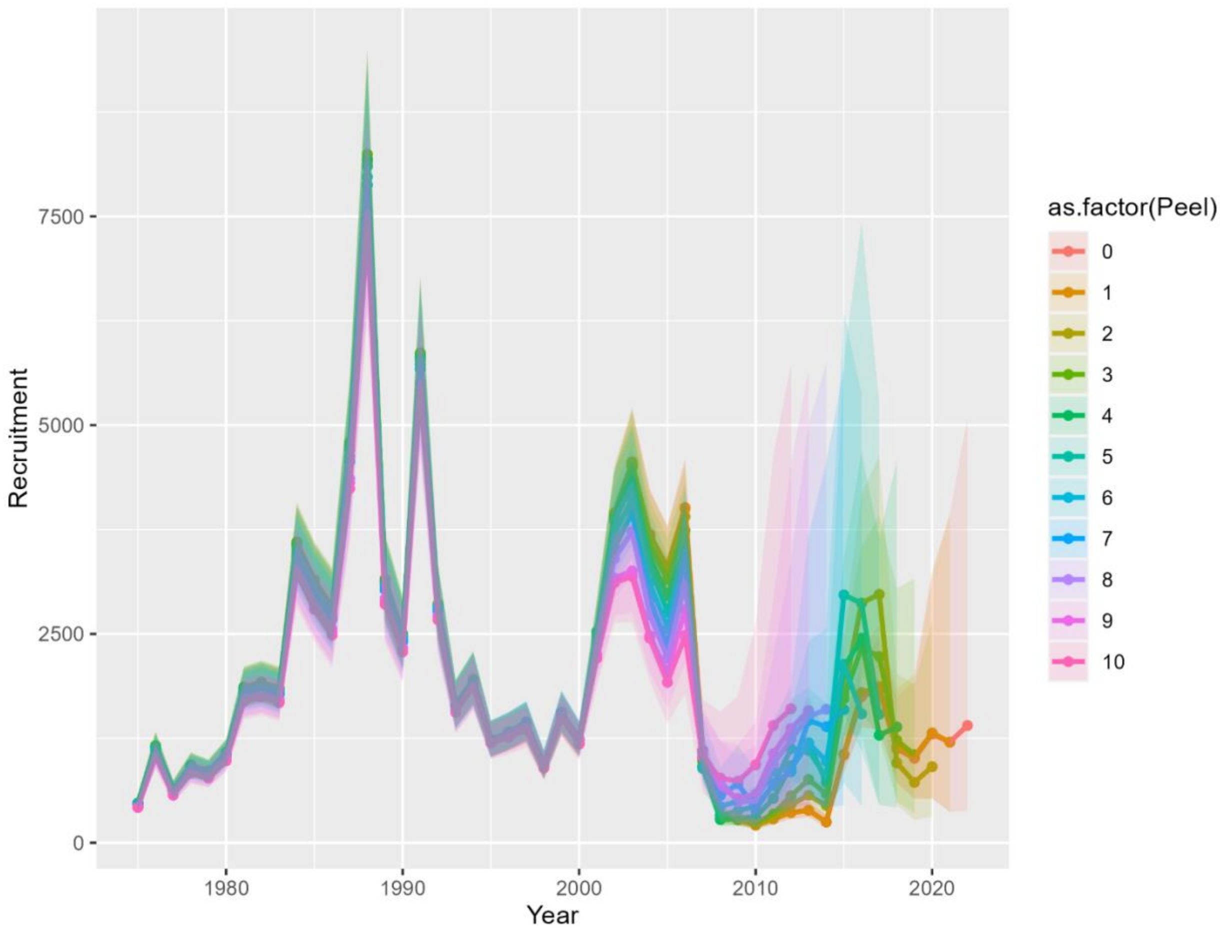


Figure 8.22. Retrospective patterns in spawning biomass and recruitment Model 22.2.

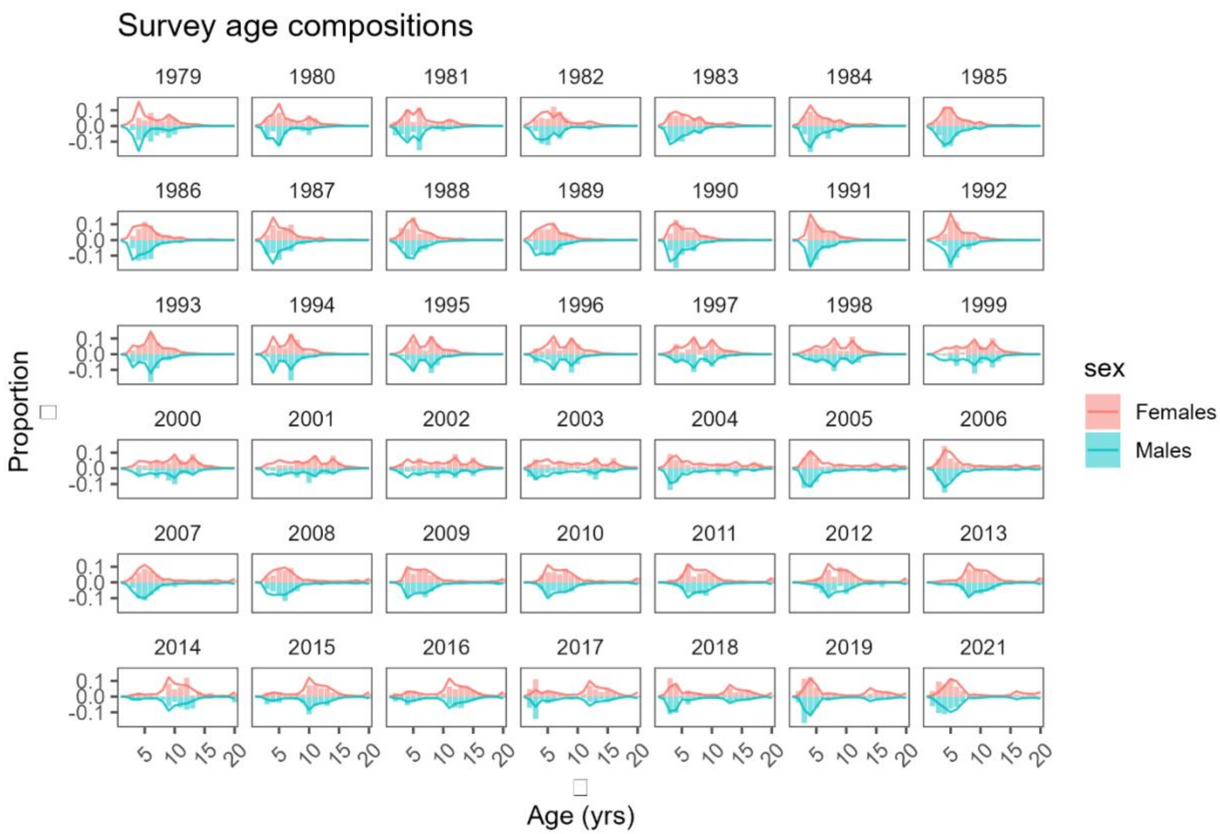


Figure 8.23. Observed (histograms) and expected (lines) survey age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for Model 22.1.

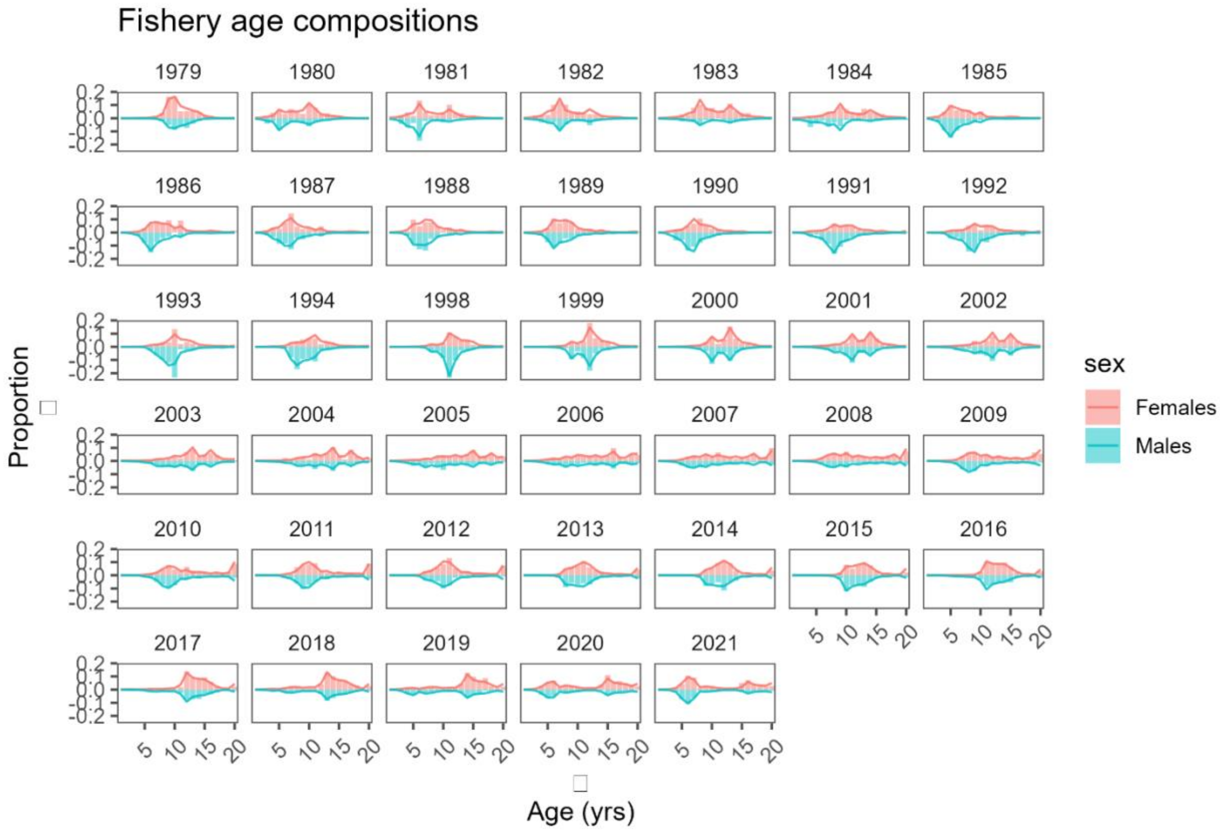


Figure 8.24. Observed (histograms) and expected (lines) fishery age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for Model 22.1.

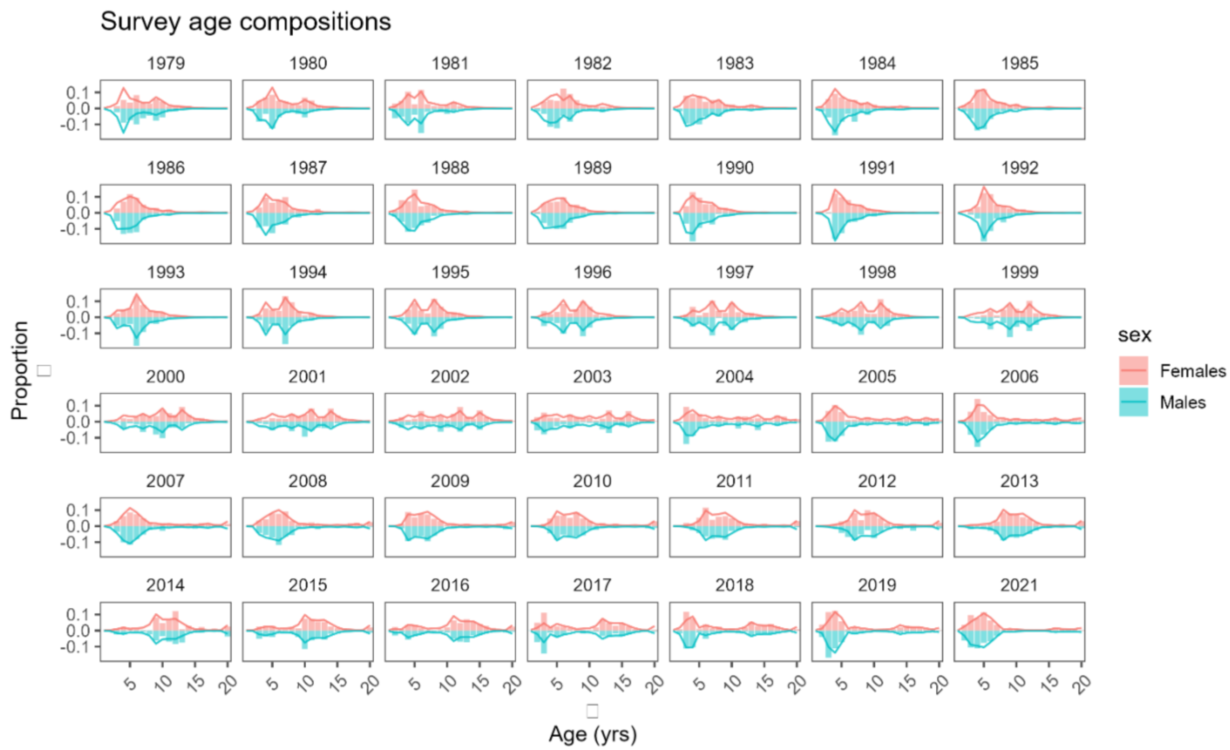


Figure 8.25. Observed (histograms) and expected (lines) survey age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for Model 22.2.

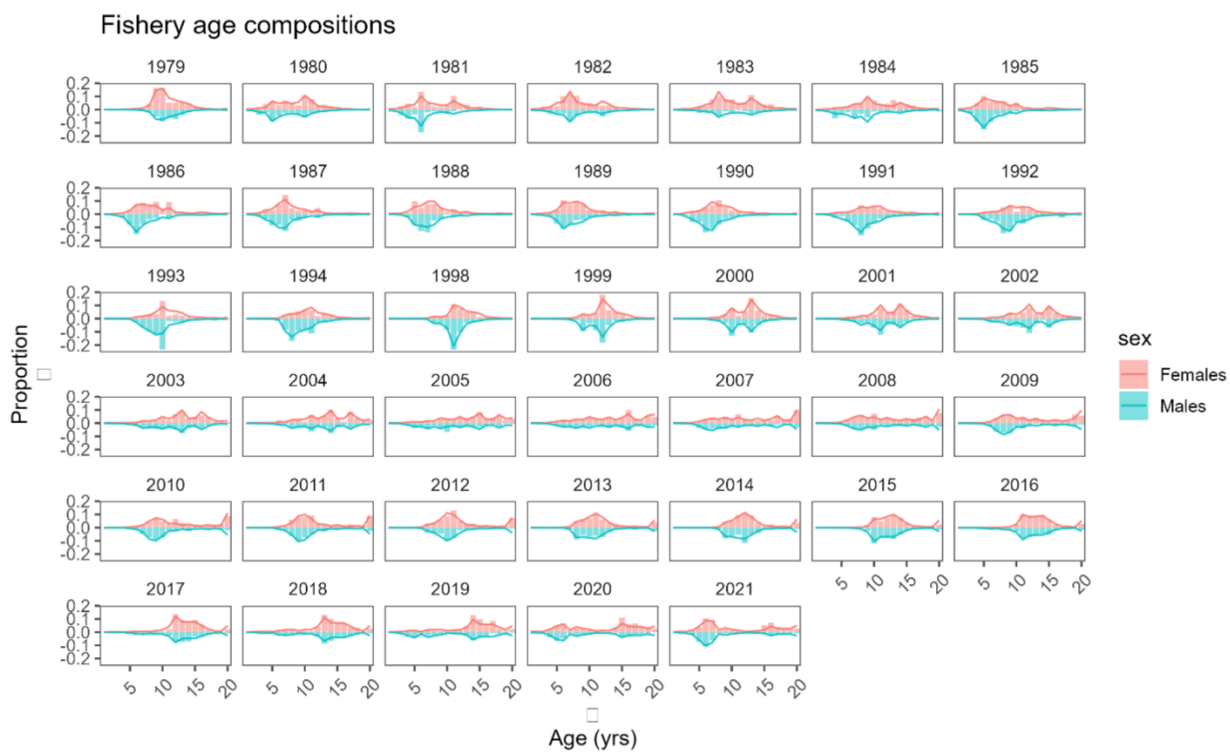


Figure 8.26. Observed (histograms) and expected (lines) fishery age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for Model 22.2.

Appendix B

Population dynamics for the northern rock sole stock assessment modeling framework

2.2.1 Basic dynamics

The basic dynamics are governed by the equation:

$$N^s_{t+1,a} = \begin{cases} 0.5R_{t+1} & \text{if } a = 1 \\ N^s_{t,a-1}e^{-Z^s_{t,a-1}} & \text{if } 1 < a < A \\ N^s_{t,A-1}e^{-Z^s_{t,A-1}} + N^s_{t,A}e^{-Z^s_{t,A}} & \text{if } a = A \end{cases} \tag{1}$$

where $N^s_{t,a}$ is the number of animals of sex *s* and age *a* at the start of year *t*, $Z^s_{t,a}$ is the total mortality for animals of sex *s* and age *a* during year *t*:

$$Z^s_{t,a} = M^s + F^s_{t,a} \tag{2}$$

M^s is the rate of natural mortality for animals of sex *s* aged one and older, $F^s_{t,a}$ is the fishing mortality for animals of sex *s* and age *a* during year *t*:

$$F^s_{t,a} = S^s_{t,a}F_t \tag{3}$$

$S^s_{t,a}$ is selectivity as a function of age, sex, and time:

$$S^s_{t,a} = \left(1 + \exp(s^s e^{\omega^{s,s}_t}(a - a^s_{50}e^{\omega^{a_{50},s}_t})\right)^{-1} \tag{4}$$

where s^s is the reference selectivity slope parameter for sex *s*, a^s_{50} reference selectivity intercept parameter for sex *s*, $\omega^{s,s}_t$ is the annual selectivity slope deviation for sex *s*, $\omega^{a_{50},s}_t$ is the annual selectivity intercept deviation for sex *s*, F_t is the fully-selected fishing mortality during year *t*:

$$F_t = \tilde{F}e^{\delta_t} \tag{5}$$

$\bar{F}$ is the reference level of fully-selected fishing mortality, δ_t is the fishing mortality deviation for year *t*, R_t is the recruitment (at age 1) during year *t*, and *A* is the plus-group age.

The total catch in mass is given by:

$$C_t = \sum_s \sum_{a=1}^{A} w^s_{t,a} \frac{F^s_{t,a}}{Z^s_{t,a}} N^s_{t,a}(1 - e^{-Z^s_{t,a}}) \tag{6}$$

where $w^s_{t,a}$ is the weight of an animal of sex *s* and age *a* during year *t*.

2.2.2 Parameter estimation

The parameters of the population dynamics model (see Table B2 for the estimable parameters) are estimated by fitting the model to data catch data, a survey index of abundance, fishery and survey age-composition data, and survey weight-at-age data. The estimation can be conducted within a penalized maximum likelihood framework or a Bayesian framework, with most of the priors taken to be uniform (Table B2). The samples from the posterior distributions for the parameters of the population dynamics model are obtained using the Markov chain Monte Carlo algorithm include AD Model Builder (Fournier and Archibald 1982). The rate of natural mortality, *M*, can be fixed or estimated for both sexes.

2.3 Projections

2.3.1 Recruitment

The number of age-1 animals at the start of year *t* is either predicted based on a stock-recruitment relationship (Eqn 7a) or based on the assumption that recruitment is independent of spawning biomass over the range of spawning biomass levels expected in the future (Eqn 5b). Expected recruitment can optionally be related to wind and temperature indices (Cooper et al., 2020) and pH (Hurst et al., 2016), but are omitted from the assessment models.

$$R_t = \alpha \tilde{S}_{t-1} e^{-\beta \tilde{S}_{t-1} + \gamma_1 W_{t-1} + \gamma_2 C_{t-1} + \gamma_3 P_{t-1}} e^{\varepsilon_t - \sigma_R^2/2}, \quad \varepsilon_t \sim N(0;\sigma_R^2) \tag{7a}$$

$$R_t = \bar{R} e^{\gamma_1 W_{t-1} + \gamma_2 C_{t-1} + \gamma_3 P_{t-1}} e^{\varepsilon_t - \sigma_R^2/2}, \quad \varepsilon_t \sim N(0;\sigma_R^2) \tag{7b}$$

where α, β are the parameters of the Ricker stock-recruitment relationship, W_t is wind during year *t*, C_t is cold pool during year *t*, P_t is pH during year *t*, $\gamma_1, \gamma_2, \gamma_3$ are parameters relating wind, cold pool size and pH to recruitment success, $\tilde{S}_t$ is spawning biomass during year *t* (at the start of February after 1/12 of total mortality):

$$\tilde{S}_t = \sum_{a=1}^{A} \phi_a \, \tilde{w}_{t,a}^{\mathrm{f}} \, N_{t,a}^{\mathrm{f}} \, e^{-Z_{t,a}^{\mathrm{f}}/12} e^{\lambda P_t} \tag{8}$$

ϕ_a is the proportion of animals of age *a* that are mature, $\tilde{w}_{t,a}^{s}$ is the weight of animals of sex *s* and age *a* in the population during year y, λ is the effect of pH on larval mortality, $\bar{R}$ is median recruitment, and σ_R is the extent of variation in recruitment about expected recruitment. γ_3 and λ respectively reflect the impact of pH after and before density dependence. Wind, temperature and pH effects on population dynamics are not estimated or assumed in this assessment.

2.3.3 Selectivity

Fishery survey is allowed to varying inter-annually in the assessment, subject to a prior on the extent of inter-annual variation (see Equation B.10). For the purposes of the projections, selectivity is taken to be average of the last five years of assessment (2018-2022).

2.5 Reference points and projections

Two projection methods were applied. First, the Tier-3 calculations were run which provide $F_{35\%}$ and $F_{40\%}$ and analogous biomass reference points.

Secondly, the F_{MSY}, and B_{MSY} and B_0 reference points (and the uncertainty) were estimated to apply near-term Tier 1 estimates of ABC and OFL.

The objective function for the northern rock sole stock assessment framework

In common with most age-structured integrated stock assessments (Fournier and Archibald, 1982; Maunder and Punt, 2013), the objective function contains contributions from the data as well as from various priors. The assessment of northern rock sole contains five contributions to the likelihood function and five priors.

B.1. Likelihood

The data included in the likelihood function are the catches, the survey index of abundance, the fishery and survey age-composition data, and the survey weight-at-age data (see Table B.1 for a summary of the available data).

The contribution of catch data to the negative of the logarithm of the likelihood function is based on the assumption that the catches are subject to log-normal error, i.e.:

$$L_1 = 300\sum_t \left(\ell n C_t^{\text{obs}} - \ell n \hat{C}_t\right)^2 \tag{B.1}$$

where C_t^{obs} is the observed catch-in-weight for year *t*, and $\hat{C}_t$ is the model-estimate of the catch-in-weight for year *t* (Equation 6).

The contribution of the survey index of abundance to the negative of the logarithm of the likelihood function is based on the assumption that the survey index is subject to log-normal error, i.e.:

$$L_2 = \sum_t \frac{\left(\ell n I_t^{\text{obs}} - \ell n(q\hat{B}_t)\right)^2}{2\sigma_t^2} \tag{B.2}$$

where I_t^{obs} is the survey index of abundance for year *t*, *q* is the catchability coefficient, $\hat{B}_t$ is the model-estimate of the survey-selected biomass at the time of the survey during year *t*, and σ_t is the sampling coefficient of variation for the survey during year *t*.

The contribution of the fishery age-composition data to the negative of the logarithm of the likelihood function is based on assumption the age-composition data are multinomially distributed, i.e.

$$L_3 = \sum_t \tilde{N}_{t,a}^C \sum_s \sum_a \ell n(\rho_{t,a}^{\text{C},s} / \hat{\rho}_{t,a}^{\text{C},s}) \tag{B.3}$$

where $\rho_{t,a}^{\text{C},s}$ is the observed proportion of the catch in numbers during year *t* that was of sex *s* and age *a*, $\hat{\rho}_{t,a}^{\text{C},s}$ is the model-estimate of the proportion of the catch in numbers during year *t* that was of sex *s* and age *a*, and $\tilde{N}_{t,a}^{\text{C}}$ is the effective sample size for the fishery age-composition data.

The contribution of the survey age-composition data to the negative of the logarithm of the likelihood function is based on assumption the age-composition data are multinomially distributed, i.e.

$$L_4 = \sum_t \tilde{N}_{t,a}^{\text{S}} \sum_s \sum_a \ell n(\rho_{t,a}^{\text{S},s} / \hat{\rho}_{t,a}^{\text{S},s}) \tag{B.4}$$

where $\rho_{t,a}^{S,s}$ is the observed proportion of the survey catch in numbers during year *t* that was of sex *s* and age *a*, $\hat{\rho}_{t,a}^{S,s}$ is the model-estimate of the proportion of the survey catch in numbers during year *t* that was of sex *s* and age *a*, and $\tilde{N}_{t,a}^{S}$ is the effective sample size for the survey age-composition data.

B.2. Priors

Informative priors are placed on the recruitment deviations, survey catchability, time-variation in the parameter of the fishery selectivity pattern, and fishing mortality.

The priors on the recruitment deviations relates to the recruitments from 1975, those that determine the initial age-structure, and priors on the difference between the estimated recruitments and those expected from a Ricker stock-recruitment relationship.

$$P_1 = \left(\sum_t \varepsilon_t^2 + \sum_s \sum_{a>2} (\eta_a^s)^2 + \frac{1}{2\sigma_R^2} \sum_t \tau_t^2 \right) \tag{B.6}$$

where ε_t is the random deviation in recruitment about the average recruitment, η_a^s is the deviation for age *a* to determine the initial age-structure, i.e.:

$$N_{1975,s}^{s} = N^I e^{\eta_a^s} \tag{B.7}$$

N^I is a parameter to determine the initial age-structure, and τ_t is the deviation between the estimates of recruitments and the values expected from the stock-recruitment relationship:

$$\tau_t = \ell n\left(2N_{t,1}^{\mathrm{f}}\right) - \ell n\left(\alpha \tilde{S}_{t-1} e^{-\beta \tilde{S}_{t-1}}\right) \tag{B.8}$$

α, β are the parameters of the stock-recruitment relationship, and σ_R (0.6) determines the extent of variation about the stock-recruitment relationship.

The prior on the survey catchability coefficient is:

$$P_2 = (\ell n q - \ell n q_p)^2 / 2\sigma_q^2 \tag{B.9}$$

where q_p is the prior value for *q* (1.5), and σ_q is the standard deviation of the prior for log-*q* (0.05).

The prior on the changes to the selectivity parameters over time is given by:

$$P_3 = \frac{1}{2\sigma_s^2} \sum_s \sum_t (\omega_t^{s,s})^2 + \frac{1}{2\sigma_{a_{50}}^2} \sum_s \sum_t (\omega_t^{a_{50},s})^2 \tag{B.10}$$

where σ_s is the standard deviation of the selectivity slope deviations (0.2), and $\sigma_{a_{50}}$ is the standard deviation of the selectivity intercept deviations (0.35).

The prior on fishing mortality relates to the annual fishing mortalities and the mean of the finishing mortality deviates, i.e.:

$$P_4 = 0.01 \sum_f (F_t - 0.2)^2 + 100 \left(\sum_t \delta_t \right)^2 \tag{B.11}$$

The prior on the initial recruitment deviates aims to impose the *a priori* assumption that the sex ratio of the initial age structure is 1:1, i.e.:

$$P_5 = \sum_t (\eta_a^{\mathrm{f}} - \eta_a^{\mathrm{m}})^2 \tag{B.12}$$

The prior on the extent of variation in recruitment is:

$$P_6 = (\ell \mathrm{n} \sigma_R - \ell \mathrm{n} \sigma_{R,p})^2 / (2\sigma_{R,\sigma}^2) \tag{B.13}$$

where q_p is the prior value for $\sigma_{R,p}$ (0.6), and $\sigma_{R,\sigma}$ is the standard deviation of the prior for $\log \sigma_R$ (0.6).

References

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Tables

Table B.1. Summary of the data used in the assessment of northern rock sole.

Data source	Years available
Catch-in-weight	1975 - 2020
Fishery catch-at-age	1979 - 2019
Survey index	1982 - 2019
Survey age-composition	1979 - 2019
Survey weight-at-age	1982 - 2019

Table B.2. The estimable parameters of the population dynamics models and their priors.

Parameter	Prior
Recruitment	
Log mean recruitment, $\ell n\bar{R}$	U[-∞,∞]
Log initial recruitment, $\ell n N^{I}$	U[-∞,∞]
Annual recruitment deviations, ε_t , η_a	Equations B.6 and B.12
Logs of the Ricker parameters, $\ell\mathrm{n}\alpha$, $\ell\mathrm{n}\beta$	Equation B.8
Impact of cold pool and wind on recruitment (not used), γ	U[-∞,∞]
Extent of recruitment variation, σ_R	Equation B.13
Fishing mortality and selectivity	
Log median fishing mortality, $\bar{F}$	U[-∞,∞]
Annual fishing mortality deviations,	Equation B.11
Reference selectivity intercept, a_{50}	U[-∞,∞]
Reference selectivity slope, *s*	U[-∞,∞]
Annual selectivity intercept deviations, $\omega_t^{a_{50}}$	Equation B.10
Annual selectivity slope deviations, ω_t^{s}	Equation B.10
Survey-related	
Survey catchability, q	Equation B.9
Selectivity intercept	U[-∞,∞]
Selectivity slope	U[-∞,∞]

Appendix D. Estimating Northern Rock Sole recruitment using environmental covariates (this section was carried over without changes from the 2020 assessment)

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 little 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 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 recruitment prediction effort is described in more detail in Cooper et al. (2020). This is the fifth year we have provided this analysis as an appendix to the stock assessment. However, due to survey cancelations, we do not provide a prediction for 2020 (details below).

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.

This 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 13 models (Table 8D.1), 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). Models were fit to estimates of recruitment at age-1 for the 1982–2016 year classes.

Environmental covariates included spring winds and measures of thermal conditions. 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 (Wilderbuer et al., 2002 and 2013). Water temperature effects were calculated from the percent of the known northern rock sole nursery area (Cooper et al. 2014) that is covered by 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 two models, the percent cold pool was used a categorical variable (“ColdpoolCat”), 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.

We compared model performance using AICc based on fits to all data, as well as by using two out-of-sample 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 34 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 #1-13 to predict recruitment for the 2017 through 2019 year classes using the environmental covariates and estimated spawning stock biomass.

The Previous Year Model had the lowest (best) MSE for both the one step ahead and LOYO prediction methods (Table 8D.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 recruitment models based on environmental factors that performed the best included both the wind and cold pool indices. Of these models, the ColdpoolCat + Wind model had the lowest AICc and the lowest prediction error using both the one-step-ahead and LOYO prediction methods, and explained 44% of the variance in log recruitment (Table 1). After the Coldpool Cat + Wind model, the environmental-factors based models with the lowest prediction errors were the Coldpool*Wind and Coldpool+Wind using the LOYO method, and the Coldpool+Wind using the one-step-ahead method (Table 1).

All of the Ricker models with environmental covariates performed worse than their corresponding models without Ricker terms. Ricker models had the highest AICc scores and the highest MSE of all models, except for the Wind model evaluated using the one-step-ahead prediction method (Table 1). Notably, all but one Ricker + environment model performed worse than predictions based on only the historical mean recruitment (Running Mean model). At the observed biomass levels in this study, the models do not provide evidence that recruitment is strongly related to spawning stock size. The Ricker + ColdpoolCat + Wind model did perform better than many models, but performed worse than the simpler ColdpoolCat + Wind model.

Recruitment predictions from models with environmental covariates suggest that conditions were conducive to relatively strong recruitment in 2018, and moderate to strong recruitment in 2017, and 2019 (Table 8D.2, Figure 8D.1). Predictions from last year for the 2015 and 2016 year classes were for strong and moderate recruitment, respectively. Both appear to be strong year classes based on the current stock assessment. 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.

For the 2020 year class, winds during the larval period were classified as offshore, which is generally associated with below average recruitment. However, the recruitment model using the wind index as the only predictor is one the more poorly-performing predictive models (Table 1). Unfortunately, the bottom temperatures used to create the cold pool index were unavailable for 2020 due to cancellation of the eastern Bering Sea shelf trawl survey. Modeled bottom temperatures from the Regional Ocean Modeling System (ROMS) model were evaluated as a possible substitute by creating a cold pool index using ROMS temperature output and comparing it with the index derived from measured bottom temperatures. Although the cold pool index and the ROMS model-derived cold pool index were correlated, the unexplained variance was high enough that we feel using the ROMS model-derived cold pool index for a single year (2020) is inappropriate, and we do not make recruitment predictions for the 2020 year class. A ROMS model-derived cold pool index may be appropriate for other applications of the recruitment models which do not require a precise cold pool index estimate for a single year, such as projecting average recruitment many years into the future based on climate projections.

Table 8D.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 best (lowest) AICc and MSE scores are in bold. Models were fit to recruitment estimates from 1982-2016.

	Model	df	AICc	MSE (LOYO, log-scale)	MSE (1 step ahead, log-scale)	R^2
1	Ricker	3	102.4	0.85	1.00	0.05
2	Ricker + coldpool	4	98.5	0.86	0.98	0.21
3	Ricker + wind	4	104.7	0.85	1.01	0.06
4	Ricker + coldpool + wind	5	99.7	0.85	0.92	0.23
5	Ricker + coldpool*wind	6	99.2	0.83	0.98	0.30
6	Ricker + ColdpoolCat + wind	6	**87.0**	**0.64**	**0.74**	0.44
7	coldpool	3	**92.1**	0.76	0.85	0.19
8	wind	3	99.2	0.82	0.91	0.01
9	coldpool + wind	4	93.0	0.74	0.80	0.23
10	coldpool*wind	5	92.2	0.73	0.85	0.30
11	ColdpoolCat + wind	4	**81.5**	**0.55**	**0.65**	0.44
12	Previous Year	NA	NA	**0.50**	**0.51**	0.59
13	Running Mean	NA	NA	0.79	0.93	0.07

Table 8D.2. Predicted recruitment (thousands) for selected models for the 2017–2020 year classes.

Year	coldpool + wind	coldpool*wind	ColdpoolCat + wind	Previous Year	Running Mean
2017	1,189,084	1,229,497	1,357,603	4,405,590	990,676
2018	1,934,174	1,776,685	2,020,010	NA	990,676
2019	1,321,318	1,788,323	1,357,603	NA	990,676
2020	NA	NA	NA	NA	990,676

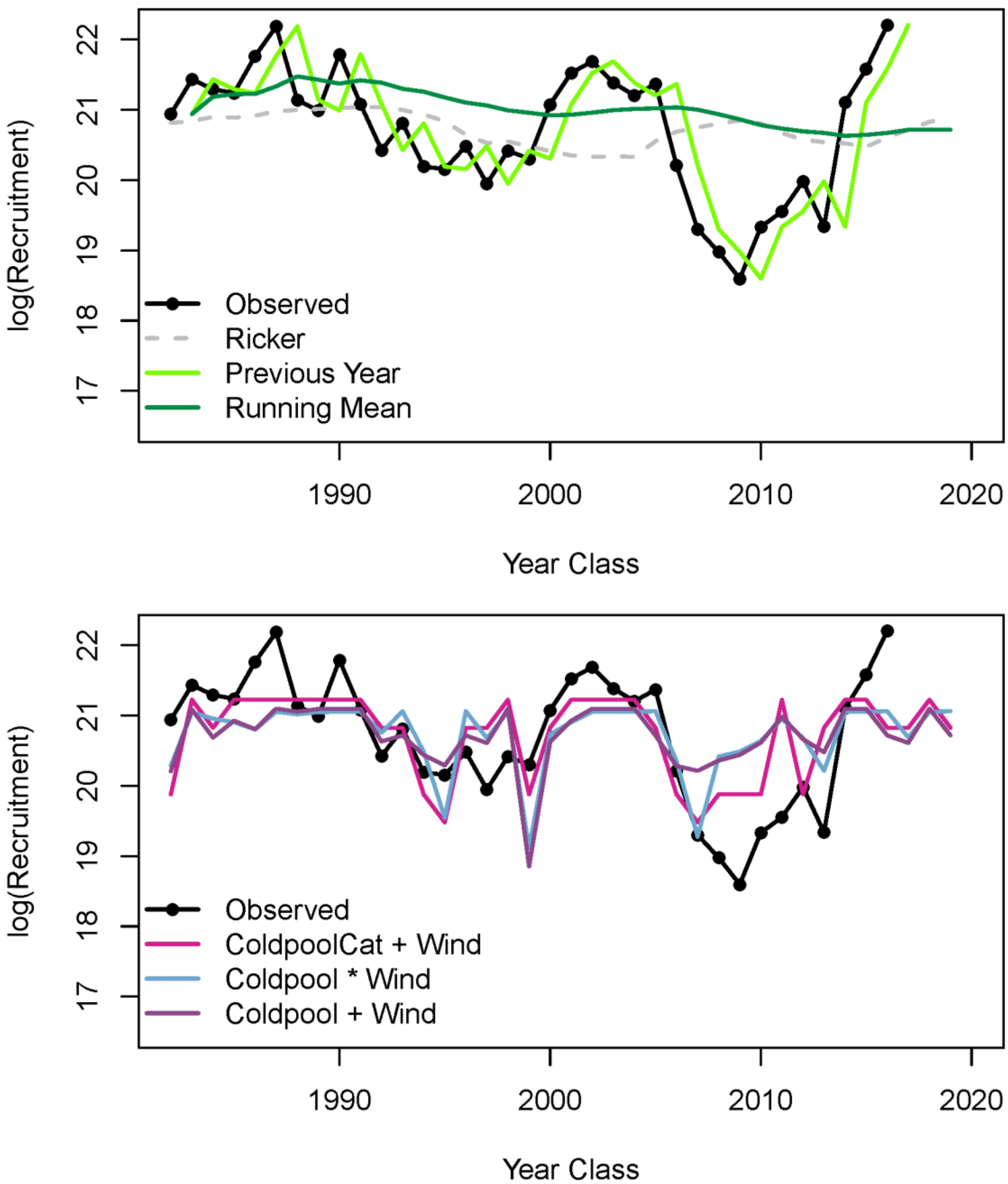

Figure 8D.1. Observed (estimated from stock assessment model) and predicted recruitment from selected models for the 1982 through 2016 northern rock sole year classes, and predicted recruitment for the 2017 through 2019 year classes.

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