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) 2020 catch biomass through October 28, 2020 and 2018 catches were added to the model
(2) 2018 catch biomass was updated to reflect October – December 2018 catches
(3) 2018-2019 fishery age composition data were added to the model
(4) 2018-2019 survey age composition data were added to the model
(5) 2019 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 the assessment, based on the author's preferred model, are compared to the key results of the accepted 2019 update assessment (Wilderbuer et al. 2019, Appendix C) in the table below.

Quantity	As estimated or *specified last* year for: 2020	2021	As estimated or *recommended this* year for: 2021*	2022*
M (natural mortality rate)	0.15	0.15	0.15 (f) 0.17 (m)	0.15 (f) 0.17 (m)
Tier	1a	1a	1a	1a
Projected total (age 6+) biomass (t)	1,154,000	1,729,000	923,197	1,359,440
Projected Female spawning biomass (t)	415,000	389,000	294,627	286,381
B_0	546,800	546,800	476,820	476,820
B_{MSY}	197,400	197,400	158,972	158,972
F_{OFL}	0.147	0.147	0.157	0.157
$maxF_{ABC}$	0.146	0.146	0.152	0.152
F_{ABC}	0.142	0.142	0.152	0.152
OFL (t)	168,000	251,800	145,180	213,783
maxABC (t)	163,700	245,400	140,306	206,605
ABC (t)	163,700	245,400	140,306	206,605
Status	As determined *last* year for: 2018	2019	As determined *this* year for: 2019	2020
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 25,800 t used in place of maximum permissible ABC for 2020 and 47,500 t used in place of maximum permissible ABC for 2021 and 2022. The final catch for 2020 was set equal to the 2019 final catch. 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

The SSC recommends thinking beyond the current (2020) situation to develop methods for making stock assessment analyses more robust to possible future survey reductions/loss. These may include:

- *Renewed investigation of data conflicts in the assessment models, perhaps addressed through data weighting and/or identification of un-modelled processes, or occasional anomalous data points.*
- *Model-based survey time series (e.g., vector-autoregressive spatio-temporal (VAST) models) that can accommodate incomplete data, changes in survey design, or alternative survey platforms and still produce indices of abundance with statistical variance estimates. These may be particularly helpful for stocks (e.g., Tier 4 crab and Tier 5 groundfish) where harvest levels are informed directly by trends in survey data rather than solely by the results of the stock assessment.*
- *Exploration of harvest control rules that are explicitly linked to survey and assessment uncertainty and the lag between surveys and assessments.*

A data conflict between recent survey biomass and age composition data was explored in the 2020 assessment by evaluating an exploratory model downweighting age composition data. The RACE Division is now providing VAST survey biomass estimates for northern rock sole. Due to COVID-19, these estimates were not explored within models for this assessment cycle, but is planned for the next assessment cycle.

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

Four new models (18.1-4) were introduced this year in addition to the base model that has been in use since 2006 (15.1). The new models all estimated separate natural mortality rates for males. Model 18.2 estimates survey catchability in addition to male M and model 18.3 adds an offset for male selectivity in the fishery (allowing the asymptote to differ from females) based on earlier recommendations to address sex-specific targeting in the fishery. Model 18.4 was an equally weighted ensemble of the other four models. This model was included in response to an SSC request in October to pursue ensemble modeling in this assessment. While the models resulted in considerable differences in spawning stock biomass, the resulting reference points differed little among models. Model 15.1 provided a better fit to the survey sex ratios and survey age composition. Therefore, and because the other models were not presented in September, the PT recommended model 15.1 but noted that model 18.3 was a good candidate for future assessments.

Model 18.3 is the author's preferred model for 2020.

BSAI Plan Team comment 11/2018: The Team thanks the authors for volunteering to examine a model averaging approach. The Team recommends that the authors consider alternative weightings if they decide to pursue model averaging further; noting that, if the ensemble consists of nested models, the choice of weighting approach may be simplified somewhat. The Team also encourages the authors to consider whether the present ensemble might usefully be expanded by including models that span a greater range of structural uncertainty. Finally, the Team recommends that the authors further investigate Model 18.3, which may be the most biologically plausible model in the present ensemble.

Model 18.3 is presented as the author's preferred model in 2020.

BSAI Plan Team comment 11/2019: The Team recommended that the Bering Sea survey group conduct a spatial analysis looking specifically at the spatial overlap of this species (and other commercially important flatfish species) with Pacific cod.

Author Response: CRM is conducting two studies that could be expanded to address this question: (1) a study of length-specific species overlap of small-bodied flatfish species in the EBS and (2) a study of spatial distribution and seasonal movement of two flatfish species in the EBS using a spatio-temporal modeling approach.

Introduction

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

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

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 1989-2020 (domestic only) have averaged 46,914 t annually, 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.

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.

Catches over the past decade were highest in NMFS Regulatory Areas 509 (20-39%) and 513 (12-31%; Table 8.2). Northern rock sole are also typically caught in areas 514, 517, 521 with some frequency (Table 8.2, Figure 8.2). In 2019, first quarter catches were concentrated in areas 509 and 516. The highest catches in 2019 occurred in the second quarter and were concentrated in area 514.

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 – 163,700 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 53% 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.

In 2016 the Pacific halibut PSC was reduced by a new regulation. Amendment 111 to the FMP reduced the halibut PSC limits for the Amendment 80 sector by 25% (from 2,325 to 1,745 t); for the BSAI trawl limited access fishery by 15% (875 to 745 t); for the BSAI non-tr`+awl sector by 15% (833 to 710 t) and the CDQ sector by 20% (392 to 315).

Data

Fishery

This assessment used fishery catches for northern rock sole from 1975 through October 25, 2020 (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 1998-2019 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. The three strata for the EBS were: i) January–June (all areas, but mainly east of 170◦W); ii) INPFC area 51 (east of 170◦W) from July–December; and iii) INPFC area 52 (west of 170◦W) from July–December. This method was used to derive the age compositions from 1991–2019 (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 2019 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 8.7). In 2010, 2017, and 2018, RACE extended the groundfish survey into the northern Bering Sea (Figure 8.7) 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 within the assessment model; survey biomass of BSAI northern rock sole in the Aleutian Islands and the Northern Bering Sea is relatively low (Table 8.2, Figure 8.3-Figure 8.4). Areas of consistent 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 8.3-Figure 8.4).

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.

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 natural mortality is fixed in the 2018 accepted model to the same value for males and females, and estimated only for males in this year's preferred 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 narrow prior in the 2018 model and a larger variance in this year's preferred model. 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

Four models were presented at the November 2018 Plan Team Meeting. Model 15.1 was accepted for use in 2018. Model 15.1 fixed natural mortality for both males and females at 0.15, estimated catchability with a very narrow prior and a mean of 1.5, and estimated sex-specific survey and fishery selectivity, but assumed that selectivity reached 1 for both males and females at some age. The three other models were nested in that they allow estimation of natural mortality for male northern rock sole (Model 18.1) followed by survey catchability (Model 18.2), and lastly a model same as 18.2 but with a selectivity offset for male northern rock sole such that apical selectivity could vary from 1 (model 18.3). In 2018, Model 15.1 was presented as a stand-alone option, as it was the previous accepted model, and the four models together were presented as an ensemble. The BSAI Plan Team and SSC noted that Model 18.3 improved model fits and should be considered further.

In this assessment, we present two candidate models (Model 15.1 and 18.3), as well as one exploratory model to show the influence of the age composition data in Model 18.3 by reducing weighting to age composition data by 75% (input sample sizes in Models 15.1 and 18.3 for age composition data were 200 in every year for both survey and fishery age compositions).

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 rates for Model 15.1 were fixed at 0.15 for both sexes in Model 15.1 and for females only in Model 18.3 and in the exploratory model based on Model 18.3.

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 stratum-specific fishery mean weights-at-age (and variances) were used, which are useful for evaluating general patterns in growth and growth variability. For example, Ianelli et al. (2007) showed that seasonal aspects of pollock condition factor could affect estimates of mean weight-at-age. They showed that within a year, the condition factor for pollock varies by more than 15%, with the heaviest pollock caught late in the year from October- December (although most fishing occurs during other times of the year) and the thinnest fish at length tending to occur in late winter.

The maturity ogive for northern rock sole is given in Figure 8.6. 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, Model 18.3 (the recommended model) and the exploratory model based on 18.3, but down-weighting age composition data estimate male natural mortality. All models estimate log survey catchability, but Model 15.1 specifies a very narrow prior standard deviation such that it is nearly fixed at 1.5, according to the results 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; this indicates that the standard area-swept biomass estimate from the survey is an overestimate of the rock sole population biomass (Somerton and Munro 2001).

Models 18.3 and the exploratory model down-weighting age composition data estimate log catchability more freely with a larger standard deviation on the prior distribution.

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

Comparison of models

Models 15.1, Model 18.3, and an exploratory model based on 18.3, but with 75% down-weighting of age composition data fits changed the fits to the survey biomass (Figure 8.8). In 2018 and 2019 the survey biomass model predictions showed an increase but the observations declined, indicating a conflict in data fitting within the model. Although this pattern is most pronounced for Model 15.1, the fit to survey biomass increased in 2019 for Models 18.3 and the exploratory model like 18.3 but down-weighting age data. This pattern appears to be driven by observations in recent years of a large number of young individuals and few observations of older age classes (Figure 8.5), leading to a conflict between fits to age composition data (both survey and fishery) and the survey biomass. The three models presented show differences in their ability to fit age composition data and survey biomass simultaneously.

Model 18.3 led to improved values for all three major likelihood components (survey biomass, survey and fishery age composition data relative to Model 15.1 (Table 8.6 and Table 8.7). by allowing male natural mortality to be estimated, allowing an offset of fishery selectivity for males, and allowing more flexibility the estimation of q (Table 8.8). The estimate of q for Model 18.3 is higher than for Model 15.1 (Table 8.8), and also male fishery selectivity in many years in Model 18.3 is less than one (offsetting the effect of a higher q somewhat; Table 8.8). In addition, male natural mortality is estimated to be greater than for females for Model 18.3 (male M= 0.17 instead of 0.15 in Model 15.1; Table 8.8). While Model 18.3 lessened the data conflict between survey biomass and age composition data relative to Model 15.1, it remains that the fit to survey biomass showed an increase in 2019 when observed survey biomass declined (Figure 8.8). Figure 8.20 show observed and estimated sex ratios over time, demonstrating differences in sex ratios over time in the fishery, as well as differences in sex ratios by life stage in population estimates. While the sex ratio plots are shown only for Model 18.3, these plots were visually identical for Models 15.1, 18.3, and the exploratory model. These differences in sex ratios add support for allowing sex-specific estimates of natural mortality and maximum fishery selectivity, as is done in Model 18.3 and in the exploratory model. Additionally, Model 18.3 provides more realistic estimates of fishery selectivity in years where age data are missing than for Model 15.1 (1995-1997; Figure 8.11-Figure 8.12).

An exploratory model based on 18.3 with survey and fishery age composition data downweighted by 75% (input sample sizes equal to 50 in each year rather than 200) was developed to understand whether less weight on fitting age composition data would lead to better fits to the survey biomass observations. Exploratory Model 18.3 with down-weighted age composition data showed fits to age composition data that were more similar to those from Model 15.1, but with improved fits to survey biomass in recent years relative to the two candidate models (Figure 8.8, Figure 8.16-Figure 8.19 (18.3), Figure 8.21-Figure 8.24 (15.1), Figure 8.25-Figure 8.28 (exploratory model), Table 8.6-Table 8.7).

Figure 8.3-Figure 8.4 show that a large portion of the northern rock sole stock was typically observed by the summer survey in Bristol Bay. Parts of the stock are also typically found by the survey north of Bristol Bay and near the Pribilof Islands. Bristol Bay has been particularly warm in the past couple of

years. One hypothesis is that these warm temperatures or some other factor may have influenced the distribution of young and/or old northern rock sole at the time of the survey in 2018 and 2019, leading to differences in availability of young and/or old fish in the 2018 and 2019 surveys relative to other years. For instance, a larger proportion of young fish may have been observed by the survey in 2018 and 2019 than is typical, or a smaller proportion of the older component of the population may have been observed. Therefore, the large recent recruitments estimated in recent years (Figure 8.9) may be legitimate large recruitment years, or they may be more like average…where availability of young fish to the survey was greater than for other survey years. Neither candidate model (15.1 or 18.3) completely solves this mystery, but Model 18.3 shows better fits to all major data sources than Model 15.1, indicating a lesser conflict between survey biomass and age composition data. In addition, Model 18.3 estimates recent recruitment that is not as unusually large as for Model 15.1.

A comparison of the three model configuration results are shown for survey and fishery selectivity, and fishing mortality is provided in Figure 8.10 - Figure 8.14. We also evaluated Model 15.1 and 18.3 for retrospective patterns and found that they were nearly identical based on Mohn's rho (0.12; Figure 8.15).

In summary, Model 18.3 offers improved fits to survey biomass, survey age composition data, and fishery age composition data. There is a smaller mismatch between recent fits and observations of survey biomass. Model 18.3 allows for estimation of male natural mortality and an offset for male fishery selectivity that is supported by time-varying sex ratio observations. Recent recruitment estimates are large, but not as large as for Model 15.1. Neither model attempts to estimate potential survey availability differences between 2018-2019 survey biomass estimates relative to previous years, but if availability differences are contributing to artificially large recruitment estimates in recent years, Model 18.3 would be a closer match to reality than Model 15.1. Therefore, Model 18.3 is the author's recommended model for 2020. Future northern rock sole research and models should explore whether age-based availability issues may exist in the survey for this species subject to changes in environmental conditions. Fits to the age composition data and implied sex-ratio information for Model 18.3 is shown in Figure 8.16 - Figure 8.20.

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 2021 is 158,972 t, which is less than the projected 2021 spawning biomass of 294,627 t. The estimate of B_0 is 476,820. The Tier 1 catch limit (with maxABC set equal to ABC) is 140,306 t and the overfishing limit (OFL) is 145,180 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 (47,500 t), the Tier 1 biological reference points for 2021 as defined in the BSAI Fishery Management Plan are:

B_0 = 476,820 t female spawning biomass

B_{MSY} = 158,972 t female spawning biomass

The Tier 3 biological reference points for 2021 as defined in the BSAI Fishery Management Plan (also assuming future catches of 47,00 t) are:

$B_{100\%}$ = 786,700 t female spawning biomass

$B_{40\%}$ = 315,680 t female spawning biomass

$B_{35\%}$ = 275,345 t female spawning biomass

These estimates suggest that $B_{35\%}$ is not a close proxy for B_{MSY} for BSAI northern rock sole.

Specification of OFL and Maximum Permissible ABC

Assuming future catches equal to 47,500 t (average yearly catch over the past decade), the Tier 1 and Tier 3 estimates of OFL and maximum permissible ABC for 2021 are as follows:

Tier 1:

OFL = 145,180 t

maxABC = 140,306 t

Tier 3:

OFL = 77,023 t

maxABC = 63,503 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 2020 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2021 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2020. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives 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 2021 recommended in the assessment to the *max* F_{ABC} for 2021. (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 2016-2020 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 2020 and above its MSY level in 2032 under this scenario, then the stock is not overfished.)

Scenario 7: In 2021 and 2022, 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 2033 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. With regard to assessing the current stock level, the expected stock size in the current year of scenario 6 is 314,380 t and in 2032 is 332,063, which are both higher than $B_{35\%}$ (275,345 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 2032 of scenario 7 (332,505 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. As noted above, $B_{35\%}$ as a B_{MSY} proxy for BSAI northern rock sole differs substantially from the estimated B_{MSY} (the B_{MSY} is about 58% of $B_{35\%}$). Future assessments should compare and contrast these reference points (and proxies). Given that the Tier 3 standard set of projections for status determination is much more conservative (higher B_{MSY} proxy), this application should suffice in lieu of more extensive Tier 1 projections (which become more complex because the reflect future uncertainty and hence should include future data collections akin to a closed-loop management strategy approach).

To fulfill reporting requirements for the Species Information System, each model was used to reverse-engineer the fishing mortality rate corresponding to the specified OFL for the last complete year (2019). The reverse-engineered F_{OFL} values (*RE* F_{OFL}) for this year's recommended northern rock sole model is 0.278.

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. In the 2018 and 2019 data there appears to be a conflict in fits between the fit to survey biomass and fits to survey and especially fishery age composition data. In particular, the age composition data showed large recruitments of age 1 fish in 2017 and 2018; this led to an increasing trend in model predicted survey biomass but the observed estimates declined. 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. Additionally, the lack of a 2020 EBS bottom trawl survey meant no confirmation of the positive recruitment pattern nor of the biomass decline. Additionally, the retrospective pattern was modest (Mohn's rho of 0.12). Combined we therefore assigned a 2 for the assessment considerations column of the risk table: "substantially increased uncertainty/unresolved issues."

Population dynamics considerations

The assessment model estimated two very large recruitment years (2017 and 2018) for BSAI northern rock sole, which are supported by raw data on absolute survey numbers at age 1. These new strong year classes, if they continue to show up in future surveys, will grow to accumulate to the spawning stock biomass, 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 author's recommended model, 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

<u>Overview</u>

NOAA AFSC bottom trawl surveys have been conducted over the southern Bering Sea since 1982 and in the northern Bering Sea in 2010 and 2017-2019. Over the southern Bering Sea shelf, Northern rock sole (NRS) biomass decreased 21% from 2018 while abundance increased 23% (L. Britt, pers comm). NRS biomass has declined steadily since 2010 and decreased 10% from 2018 to 2019 (Whitehouse, 2019). Concurrently, NRS condition over the southern shelf, as measured by length-weight residuals, was positive in all strata in 2019 and continued an upward trend that began in 2017 (Laman, 2019). Combined, this indicates favorable growth and survival of juvenile NRS consistent with above average water temperatures in recent years (Britt et al., 2019) and favorable springtime drift patterns in 2015 and 2018 (Cooper and Wilderbuer, 2020b). Over the northern Bering Sea, biomass increased 84% and abundance increased 100% from 2017 indicating favorable conditions for growth and survival for juvenile NRS in the northern Bering Sea (L. Britt, pers comm).

Environmental Processes
Northern rock sole (NRS) is a winter-spawning flatfish; on-shelf winds during spring and above average water temperatures in nursery habitats are positively correlated with recruitment (Cooper et al., 2020). Wind patterns in 2008, 2015, and 2018 may have promoted average to above-average recruitment while the 2019 and 2020 springtime drift patterns appear consistent with below-average recruitment for northern rock sole. (Wilderbuer et al. 2016; Cooper and Wilderbuer, 2020b). Tidal transport may also play a role in larval dispersal (Wilderbuer et al. 2016).

Laboratory studies have looked at the effects of CO_2 on larval NRS (Hurst et al., 2016; 2017), but results suggest that the effects of elevated CO_2 levels are relatively modest compared to other aspects of the rearing environment, such as prey availability (Hurst et al., 2017).

Seafloor habitat disturbance due to fishing gear has decreased steadily since 2008 and the impacts of fishing gear across the Bering Sea shelf region are very low (Olson, 2019).

Prey
Larval NRS consume plankton and algae. In 2020, the springtime drift pattern likely retained larvae over the southern middle domain (Cooper and Widerbuer, 2020b). In that region, the 2020 spring bloom timing occurred about a week earlier than the long-term mean while production was below the long-term mean (Nielsen et al., 2020). 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. Direct measurements of zooplankton abundance and species composition are not available for 2020. In spring and fall 2019, over the southern middle domain, the abundance of small, generally more lipid-poor, copepods was higher relative to large, lipid-rich, taxa. Small copepod abundances increased after 2013 compared to historical values and remained higher through 2019 (Kimmel et al., 2020).

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. The biomass of motile epifauna (e.g., brittle stars, urchins, sand dollars) remained above the long-term mean in 2019, although decreased 10% from 2018. The decrease was due to brittle stars (-3%) and urchins, sand dollars, and cucumbers (-28%); both groups remain above their long-term means. This indicates sufficient prey availability for adult NRS over the southern Bering Sea shelf (Whitehouse, 2019).

Predators
Predators of late-juvenile NRS include pollock, Pacific cod, yellowfin sole, skates, and Pacific halibut. In 2019, the survey biomass of pollock over the southern Bering Sea shelf increased 75% while the survey abundance increased 53%. Pacific cod survey biomass increased only 2% over the southern shelf, but survey abundance increased 112% (i.e., strong year classes of young fish) (L. Britt, pers comm). This dramatic increase of predators over the shelf suggests potential increased risk of predation, although spatial and/or temporal refuges may exist.

Competitors
Competitors of NRS for habitat and prey resources include other flatfish species. Yellowfin sole is the biomass-dominant flatfish competitor. In 2019, YFS survey abundance and survey biomass over the southeastern Bering Sea shelf were largely stable from 2018 and remained below the long-term mean. Over the northern Bering Sea shelf, both survey abundance and survey biomass increased between 2017 and 2019 (L. Britt, pers comm).

Summary for Environmental/Ecosystem considerations:

- Over the southern shelf, survey biomass has declined since 2010, yet fish condition (length-weight residuals) has been positive since 2017. In the northern Bering Sea, both survey biomass and survey abundance have increased since 2017. This indicates favorable growth and survival of juvenile northern rock sole across the eastern Bering Sea shelf;
- 2018 springtime drift pattern was favorable for NRS recruitment (northward winds);
- 2019 and 2020 springtime drift patterns appear consistent with years of below-average recruitment (westerly winds);
- Seafloor habitat impacts due to fishing gear are very low;
- The spring bloom (indicator of larval prey availability) was earlier than the long-term mean and production was below the long-term mean;
- Zooplankton composition (indicator of juvenile NRS prey availability) was dominated by small, generally more lipid-poor, copepods relative to large, lipid-rich, taxa;
- Indirect measurements of adult NRS prey availability (e.g., polychaetes) suggest sufficient prey resources;
- Increase of predators over the eastern Bering Sea shelf indicates increased predation risk, although spatial and/or temporal refuges may exist;
- Competitors include yellowfin sole, whose abundance and biomass remained stable over the southeastern Bering Sea shelf and increased over the northern Bering Sea shelf, and may suggest increased pressure for habitat and prey resources in the northern Bering Sea.

A mix of positive and negative indicators of potential environmental influences on BSAI northern rock sole exist, and there is not a clear and persistent signal that indicates an impeding substantial decline in the stock due to these considerations that is not taken into account in the stock assessment. Therefore, we assign a value of 1 for environmental and ecosystem considerations.

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 2: Substantially increased concerns	Level 1: no increased concerns	Level 1: no increased concerns	Level 1: no increased concerns

The author's recommended model is the model that best fits the data and best accounts for assessment-related concerns about fits to recent survey biomass and whether recent recruitment trends in the survey are valid or a result of changes in availability of young fish to the survey. While more work should be done to explore this availability issue and data conflict through the development of future models, Model 18.3 is already conservative in that it estimates a high value for catchability (1.9) that the authors believe is adequate for addressing issues of availability this year. An estimate for catchability of 1.9 is already above the previously-used fixed value of 1.4 that was derived based on an experimental study showing herding behavior of northern rock sole into the net. Therefore, the authors do not recommend a reduction in ABC for 2020.

Ecosystem Considerations

Ecosystem effects on the stock

This section is repeated from "Environmental/Ecosystem Considerations" for determining risk table scores.

Prey availability/abundance trends

Larval NRS consume plankton and algae. In 2020, the springtime drift pattern likely retained larvae over the southern middle domain (Cooper and Widerbuer, 2020b). In that region, the 2020 spring bloom timing occurred about a week earlier than the long-term mean while production was below the long-term mean (Nielsen et al., 2020). 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.

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Changes in habitat quality

<u>Overview</u>

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- Competitors include yellowfin sole, whose abundance and biomass remained stable over the southeastern Bering Sea shelf and increased over the northern Bering Sea shelf, and may suggest increased pressure for habitat and prey resources in the northern Bering Sea.

Data Gaps and Research Priorities

The conflict between survey biomass and age composition data in the 2020 assessment could be explored further through exploratory models including time-varying parameters that may explain why there was an uptick in estimated survey biomass while observed survey biomass decreased in 2018 and 2019. One hypothesis to explore would be whether the distribution and availability of young fish to the survey changed in these years. The survey biomass of northern rock sole is consistently high in Bristol Bay where temperatures were particularly high in 2018 and 2019. Further investigation could be done as to whether these high temperatures appear to influence the distribution and behavior of various life stages of northern rock sole.

Updates such as use of a formal data-weighting approach and inclusion of ageing error estimates in the assessment could be made. In addition, the model could be fit to empirical weight-at-age data.

Several research projects are underway for northern rock sole, including investigations of wind and temperature conditions on recruitment of northern rock sole, the influence of ocean acidification of northern rock sole dynamics, and climate-enhanced projections of the species including these influences. In addition, an investigation is underway to explore relationships between environmental variables, habitat, and the distribution of northern rock sole at various life stages, relative to other BSAI small-bodied flatfish species.

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Tables

Table 8.1. Catch (in tons) of BSAI northern rock sole through Oct. 25, 2020 (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			22,248	22,248

Table 8.2. Proportion of catches by NMFS reporting area through Oct 25, 2020. 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	0.16	0.00	0.13	0.16	0.03	0.15	0.01	0.03	0.24	0.04	0.00	0.00	0.04	0.00	0.00	0.00
1992	0.00	0.16	0.00	0.18	0.15	0.04	0.13	0.02	0.03	0.19	0.04	0.00	0.00	0.07	0.00	0.00	0.00
1993	0.20	0.00	0.00	0.20	0.12	0.04	0.15	0.01	0.01	0.13	0.00	0.01	0.04	0.07	0.01	0.01	0.00
1994	0.27	0.00	0.00	0.23	0.05	0.06	0.15	0.01	0.03	0.12	0.00	0.01	0.01	0.00	0.04	0.03	0.00
1995	0.26	0.00	0.00	0.20	0.06	0.03	0.22	0.02	0.05	0.08	0.00	0.01	0.02	0.00	0.03	0.02	0.01
1996	0.32	0.00	0.00	0.18	0.06	0.03	0.19	0.01	0.05	0.06	0.00	0.01	0.01	0.00	0.03	0.02	0.02
1997	0.23	0.00	0.00	0.23	0.09	0.01	0.19	0.00	0.06	0.10	0.00	0.01	0.02	0.00	0.04	0.02	0.01
1998	0.29	0.00	0.00	0.18	0.02	0.02	0.21	0.01	0.05	0.12	0.00	0.01	0.01	0.00	0.05	0.03	0.01
1999	0.25	0.00	0.00	0.17	0.04	0.04	0.23	0.01	0.03	0.12	0.00	0.01	0.00	0.00	0.05	0.02	0.01
2000	0.29	0.00	0.00	0.19	0.03	0.01	0.21	0.01	0.02	0.12	0.00	0.01	0.01	0.00	0.05	0.03	0.01
2001	0.26	0.00	0.00	0.19	0.02	0.05	0.16	0.01	0.05	0.16	0.00	0.01	0.01	0.00	0.03	0.03	0.02
2002	0.23	0.00	0.00	0.18	0.04	0.04	0.20	0.00	0.04	0.15	0.00	0.00	0.02	0.00	0.04	0.03	0.02
2003	0.30	0.00	0.00	0.18	0.11	0.05	0.10	0.00	0.04	0.13	0.00	0.00	0.02	0.00	0.04	0.02	0.01
2004	0.31	0.00	0.00	0.13	0.11	0.07	0.09	0.00	0.05	0.16	0.00	0.00	0.03	0.00	0.03	0.02	0.01
2005	0.29	0.00	0.00	0.14	0.12	0.06	0.07	0.00	0.03	0.15	0.00	0.00	0.06	0.00	0.04	0.01	0.01
2006	0.31	0.00	0.00	0.17	0.08	0.02	0.11	0.00	0.02	0.21	0.00	0.00	0.02	0.00	0.04	0.02	0.01
2007	0.25	0.00	0.00	0.16	0.12	0.02	0.10	0.00	0.02	0.20	0.00	0.00	0.03	0.00	0.06	0.02	0.01
2008	0.44	0.00	0.00	0.13	0.04	0.02	0.11	0.00	0.02	0.15	0.00	0.00	0.03	0.00	0.02	0.01	0.01
2009	0.47	0.00	0.00	0.10	0.02	0.03	0.12	0.00	0.01	0.15	0.00	0.00	0.03	0.00	0.03	0.03	0.01
2010	0.34	0.00	0.00	0.12	0.06	0.13	0.09	0.00	0.02	0.16	0.00	0.00	0.00	0.00	0.04	0.02	0.02
2011	0.36	0.00	0.00	0.18	0.08	0.04	0.15	0.00	0.03	0.11	0.00	0.00	0.01	0.00	0.03	0.01	0.00
2012	0.39	0.00	0.00	0.12	0.12	0.02	0.14	0.00	0.03	0.10	0.00	0.00	0.00	0.00	0.06	0.01	0.00
2013	0.36	0.00	0.00	0.17	0.04	0.06	0.15	0.00	0.01	0.16	0.00	0.00	0.00	0.00	0.02	0.01	0.00
2014	0.37	0.00	0.00	0.24	0.07	0.04	0.11	0.00	0.02	0.12	0.00	0.00	0.00	0.00	0.02	0.01	0.00
2015	0.27	0.00	0.00	0.20	0.23	0.04	0.07	0.00	0.03	0.14	0.00	0.00	0.00	0.00	0.02	0.01	0.00
2016	0.21	0.00	0.00	0.28	0.22	0.07	0.05	0.01	0.03	0.08	0.00	0.00	0.02	0.00	0.02	0.01	0.00
2017	0.35	0.00	0.00	0.25	0.13	0.06	0.05	0.00	0.01	0.07	0.00	0.00	0.01	0.00	0.03	0.02	0.01
2018	0.24	0.00	0.00	0.24	0.23	0.04	0.06	0.00	0.02	0.05	0.00	0.00	0.07	0.00	0.03	0.01	0.01
2019	0.20	0.00	0.00	0.31	0.24	0.05	0.03	0.00	0.02	0.05	0.00	0.00	0.04	0.00	0.03	0.02	0.01
2020	0.28	0.00	0.00	0.23	0.13	0.05	0.08	0.01	0.03	0.13	0.00	0.00	0.03	0.00	0.03	0.02	0.01

Table 8.3. Proportion of catches by quarter through Nov 9, 2020. Asterisk denotes that 2020 data are still incomplete.

Year	Jan-March	April-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*	0.44	0.30	0.23	0.03

Table 8.4. Catches by NMFS regulatory area and month in 2019.

Month	509	513	514	516	517	519	521	524	541	542	543	Total
Jan	424	78		415	3	0	0		2	0		922
Feb	2,375	424	11	1,295	4	1	1	0	36			4,147
March	1,733	813	39	410	40	1	507	1	146	2	0	3,693
April	228	233	2,616	2	3	0	1	1	5	1	1	3,089
May	0	1	9,452			0	0	0	3	0	1	9,457
June	3	74	1,849	0	1	1	24	31	9	5	1	2,000
July	1	210	2		4	6	2	2	1	30	9	268
August	0	545	19		16	7	39	27	18	10	5	686
Sept	76	386	91	7	12	6	41	94	20	4		738
Oct	21	100	116	1	4	8	1	10	4			266
Nov	89	239	20	45	0	2	2	27	6			429
Dec	24	2					0	0				26
Total	4,974	3,105	14,216	2,176	86	33	619	194	249	52	17	25,721

Table 8.5. Historical final harvest specifications, proportion of TAC caught, and proportion of catches retained through 2020. 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		

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	2,062.35	121.95				
1997	2,605.53	190.30	49.91	12.20		
1998	2,168.83	123.52				
1999	1,619.90	162.03				
2000	2,073.30	317.09	44.26	6.22		
2001	2,336.76	259.01				
2002	1,879.62	171.43	51.59	6.98		
2003	2,109.10	196.19				
2004	2,193.97	183.57	51.90	3.90		
2005	2,114.33	150.25				
2006	2,216.31	149.97	77.70	9.78		
2007	2,036.43	278.95				
2008	2,032.94	300.65				
2009	1,541.09	159.02				
2010	2,065.75	203.36	55.29	4.53	21.26	3.64
2011	1,977.90	164.58				
2012	1,920.82	185.89	65.46	7.07		
2013	1,753.21	136.59				
2014	1,858.06	129.33	46.65	4.62		
2015	1,414.17	130.46				
2016	1,461.85	130.97	34.98	4.26		
2017	1,340.06	100.07			53.96	9.14
2018	1,051.13	114.63	44.12	4.49		
2019	974.65	91.64			99.04	17.75

Table 8.7. Components of the objective function for Models 15.1, 18.3, and the exploratory model based on 18.3, but with 75% down-weighting of survey and age composition data. The age composition components (and therefore the total likelihood) from the exploratory model cannot be compared directly to the other two models because of the differences in data weighting.

Likelihood Component	15.1	18.3	18.3 Downwt*
Total	1599	1476	519
Survey Biomass	87	59	44
Survey Age	680	673	188
Fishery Age	646	541	168

*Cannot directly compare values in grey boxes to the other models due to smaller input sample sizes

Table 8.8. Parameter estimates for Models 15.1, 18.3, and 18.3 with age composition downweighted by 75%. "std. dev" is the standard deviation of the parameter estimate.

Parameter	Model 15.1		Model 18.3		Model 18.3 Downwt	
	value	**std.dev**	**value**	**std.dev**	**value**	**std.dev**
log catchability	0.43	0.01	0.65	0.03	0.50	0.03
male natural mortality			0.17	0.00	0.18	0.00
average log recruitment	6.94	0.11	6.85	0.11	6.97	0.11
average log initial age composition	3.41	0.13	3.37	0.12	3.73	0.15
log average fishing mortality	-2.50	0.08	-2.24	0.09	-2.64	0.11
average slope of fishery selectivity (f)	1.08	0.05	0.97	0.05	1.00	0.08
average age at 50% fishery selectivity (f)	8.97	0.48	9.26	0.50	8.90	0.53
average slope of fishery selectivity (f)	1.20	0.06	1.22	0.06	1.21	0.09
selectivity offset for males			-0.12	0.05	-0.03	0.10
slope of survey selectivity (f)	2.06	0.11	1.84	0.10	1.85	0.20
slope of survey selectivity (m; offset from f value)	0.17	0.07	0.27	0.07	0.28	0.14
age at 50% survey selectivity (f)	3.43	0.06	3.60	0.06	3.56	0.12
age at 50% survey selectivity (m; offset from f value)	-0.11	0.02	-0.14	0.02	-0.15	0.04
log alpha of Ricker stock-recruit curve	2.76	0.20	2.88	0.20	2.84	0.21
log beta of Ricker stock-recruit curve	-5.46	0.11	-5.28	0.11	-5.49	0.12

Table 8.9. Time series of spawning stock biomass (SSB) estimates. 2021 and 2022 estimates are projected from the stock assessment model based on a Tier 1 approach to management and catches of 47,500 t.

	2018 Assessment		2020 Assessment	
Year	**SSB**	**Std. Dev**	**SSB**	**Std. Dev**
1975	52.153	4.211	47.974	3.704
1976	54.301	4.441	48.272	3.879
1977	61.526	4.780	53.391	4.178
1978	76.971	5.300	66.049	4.646
1979	95.482	6.105	81.166	5.321
1980	109.866	6.626	93.036	5.833
1981	117.565	6.849	99.089	6.079
1982	117.602	6.731	98.773	6.015
1983	123.191	6.662	103.889	6.060
1984	138.985	7.149	117.520	6.674
1985	136.988	6.881	115.031	6.691
1986	145.243	6.536	121.940	6.616
1987	175.610	6.762	147.155	7.269
1988	187.703	6.431	155.048	7.402
1989	205.851	6.630	164.215	8.201
1990	228.955	7.091	179.209	9.197
1991	254.587	7.317	201.157	9.821
1992	266.194	7.365	218.422	10.119
1993	326.874	8.702	278.106	12.046
1994	373.146	9.254	323.399	12.972
1995	429.415	9.933	373.868	14.197
1996	521.924	11.246	456.984	17.157
1997	569.201	11.993	501.213	18.502
1998	559.989	11.781	493.398	18.089
1999	588.182	12.076	517.755	18.473
2000	620.247	12.637	541.496	19.063
2001	621.786	12.884	562.802	20.290
2002	629.994	13.114	568.853	20.334
2003	597.573	12.731	567.455	20.553
2004	585.536	12.752	568.277	20.752
2005	539.527	12.189	491.878	18.696
2006	493.791	11.428	439.329	17.134
2007	470.197	11.134	414.982	16.502
2008	464.582	11.110	389.125	15.617
2009	425.443	10.149	368.942	15.182
2010	464.833	11.052	388.980	15.716
2011	509.509	12.213	447.295	17.693
2012	576.200	14.322	483.656	19.438
2013	585.067	15.291	496.567	20.808
2014	583.290	15.824	502.464	21.761
2015	617.071	17.526	520.204	23.200
2016	578.867	17.203	471.196	21.975
2017	554.877	17.336	428.015	21.152
2018	498.028	16.258	378.740	19.755
2019			348.794	18.877
2020			314.380	17.679
Average	371.225	10.136	320.641	13.724
2021			294.627	19.070
2022			286.381	24.337

Table 8.10. Time series age 1 recruitment estimates.

	2018 Assessment		2020 Assessment	
Year	**Recruits (Age 1)**	**Std. Dev**	**Recruits (Age 1)**	**Std. Dev**
1975	294.14	22.55	280.48	22.00
1976	685.33	36.43	647.83	36.33
1977	384.84	26.54	359.74	25.64
1978	616.97	36.36	564.10	35.04
1979	618.15	38.15	547.12	35.85
1980	825.68	46.20	720.73	43.46
1981	1,510.74	66.22	1,329.29	64.78
1982	1,498.91	69.49	1,353.24	68.95
1983	1,391.95	69.81	1,240.12	68.70
1984	2,112.06	89.99	2,031.33	95.66
1985	2,047.85	91.96	1,766.01	91.65
1986	1,929.95	92.68	1,670.38	93.13
1987	3,368.35	129.43	2,832.06	132.76
1988	5,164.46	168.57	4,311.52	175.59
1989	1,805.76	96.46	1,515.57	90.79
1990	1,493.31	87.47	1,303.47	82.04
1991	3,301.58	133.47	2,904.20	131.65
1992	1,658.27	90.50	1,431.87	83.41
1993	849.68	62.61	743.06	55.99
1994	1,288.09	75.93	1,085.82	67.46
1995	680.76	53.65	586.84	46.99
1996	669.09	52.18	566.99	45.32
1997	928.65	61.64	784.06	53.64
1998	544.72	46.62	461.04	39.88
1999	844.17	58.75	735.79	51.35
2000	813.12	58.51	657.18	48.68
2001	1,702.33	89.00	1,420.86	77.02
2002	2,699.22	119.20	2,227.28	104.46
2003	3,218.95	136.15	2,621.85	119.40
2004	2,452.09	118.55	1,935.47	99.10
2005	1,988.63	106.53	1,616.64	89.28
2006	2,445.23	122.92	1,902.67	101.19
2007	756.62	64.01	597.37	48.63
2008	327.32	41.53	241.22	28.92
2009	226.81	35.09	174.27	24.26
2010	172.63	30.82	119.26	19.83
2011	358.48	50.18	248.65	31.53
2012	508.73	67.82	310.13	38.31
2013	625.12	90.68	476.11	54.80
2014	337.54	82.84	249.76	42.71
2015	3,190.22	462.73	1,462.32	157.85
2016	6,227.83	1,422.80	2,356.94	287.76
2017	1,087.91	746.94	4,405.59	664.20
2018	1,089.39	779.49	4,156.65	1,207.49
2019			875.65	592.32
2020			942.19	674.32
Average	1,516.86	146.12	1,321.10	135.87

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
2020	314,380	314,380	314,380	314,380	314,380	314,380	314,380
2021	292,930	293,978	295,007	294,969	296,905	292,017	292,930
2022	268,059	278,207	290,406	289,981	312,899	258,885	268,059
2023	287,647	294,523	322,351	321,615	362,787	274,695	286,941
2024	347,040	351,672	395,570	394,538	454,141	330,772	338,815
2025	431,942	435,342	499,975	498,599	579,692	409,239	415,148
2026	509,159	511,645	605,113	603,239	715,081	477,138	481,481
2027	541,909	543,704	670,686	668,213	817,408	499,265	502,367
2028	539,621	540,919	701,169	698,061	888,556	487,371	489,571
2029	480,845	481,784	658,441	654,958	874,002	425,764	427,298
2030	422,714	423,392	606,042	602,346	841,944	368,713	369,777
2031	400,063	400,552	590,877	586,934	849,908	346,976	347,680
2032	381,129	381,465	573,034	568,961	848,296	332,063	332,505
2033	372,973	373,200	566,895	562,645	862,088	326,741	327,019

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
2020	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2021	0.18	0.13	0.08	0.09	0.00	0.22	0.18
2022	0.16	0.17	0.08	0.09	0.00	0.19	0.16
2023	0.17	0.18	0.08	0.09	0.00	0.20	0.21
2024	0.19	0.19	0.08	0.09	0.00	0.24	0.24
2025	0.19	0.19	0.08	0.09	0.00	0.24	0.24
2026	0.19	0.19	0.08	0.09	0.00	0.24	0.24
2027	0.19	0.19	0.08	0.09	0.00	0.24	0.24
2028	0.19	0.19	0.08	0.09	0.00	0.24	0.24
2029	0.19	0.19	0.08	0.09	0.00	0.24	0.24
2030	0.19	0.19	0.08	0.09	0.00	0.23	0.23
2031	0.19	0.19	0.08	0.09	0.00	0.22	0.22
2032	0.18	0.18	0.08	0.09	0.00	0.21	0.21
2033	0.17	0.17	0.08	0.09	0.00	0.20	0.20

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
2020	25,800	25,800	25,800	25,800	25,800	25,800	25,800
2021	63,503	47,500	31,298	31,895	0	77,023	63,503
2022	59,354	63,459	33,771	34,382	0	68,208	59,354
2023	74,338	77,440	40,212	40,917	0	83,899	90,557
2024	99,683	100,581	50,139	51,000	0	117,340	119,382
2025	116,795	117,455	60,518	61,533	0	135,810	137,327
2026	126,943	127,423	68,336	69,444	0	145,304	146,407
2027	126,086	126,433	71,130	72,231	0	141,610	142,396
2028	117,446	117,696	69,680	70,702	0	129,346	129,899
2029	107,132	107,313	66,470	67,393	0	116,133	116,522
2030	99,154	99,285	63,644	64,487	0	105,658	105,992
2031	93,587	93,700	61,995	62,786	0	96,002	96,254
2032	87,388	87,476	60,434	61,183	0	89,441	89,597
2033	83,734	83,793	59,121	59,836	0	86,438	86,534

Figures

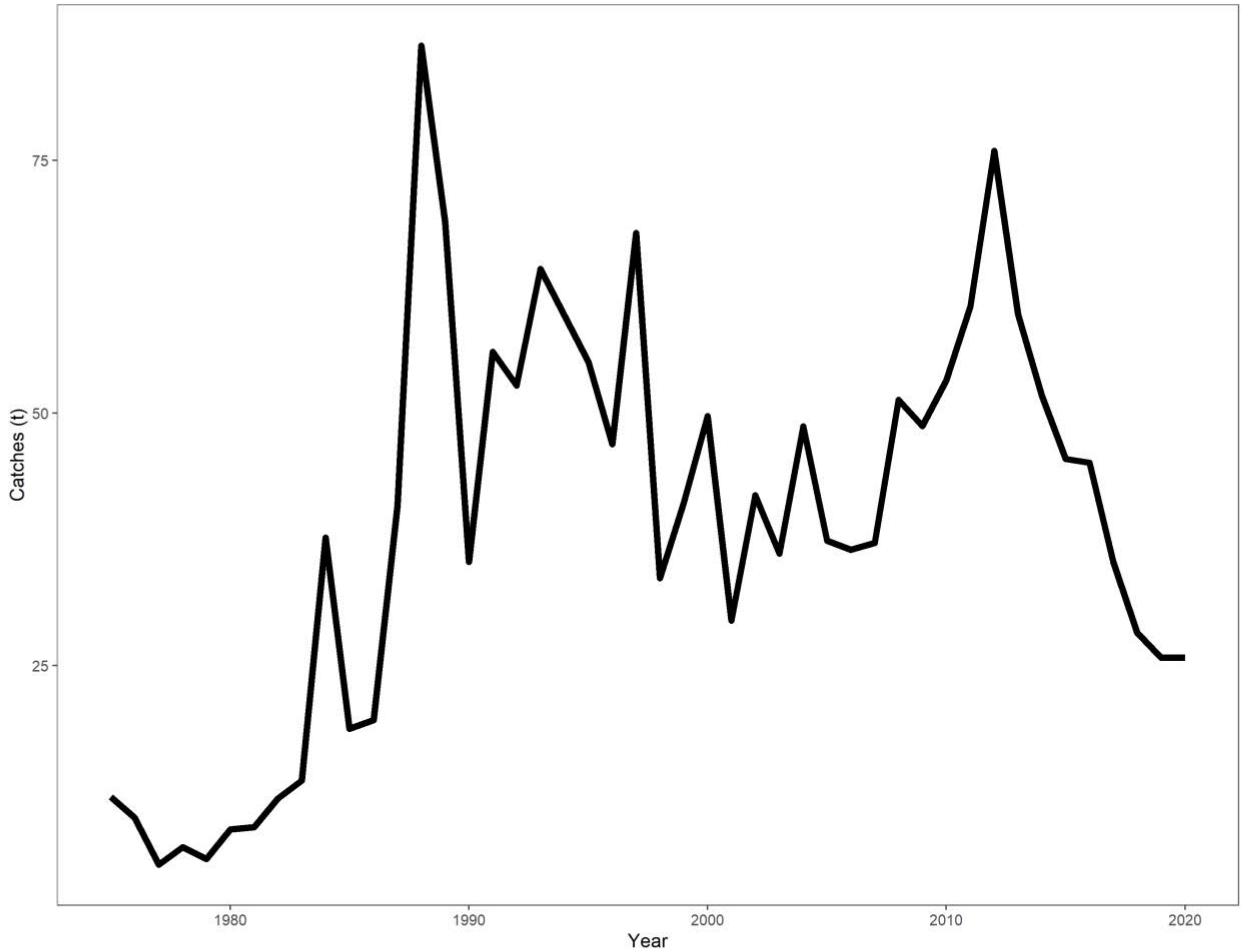

Figure 8.1. Catch (in metric tons) of by year including all sectors.

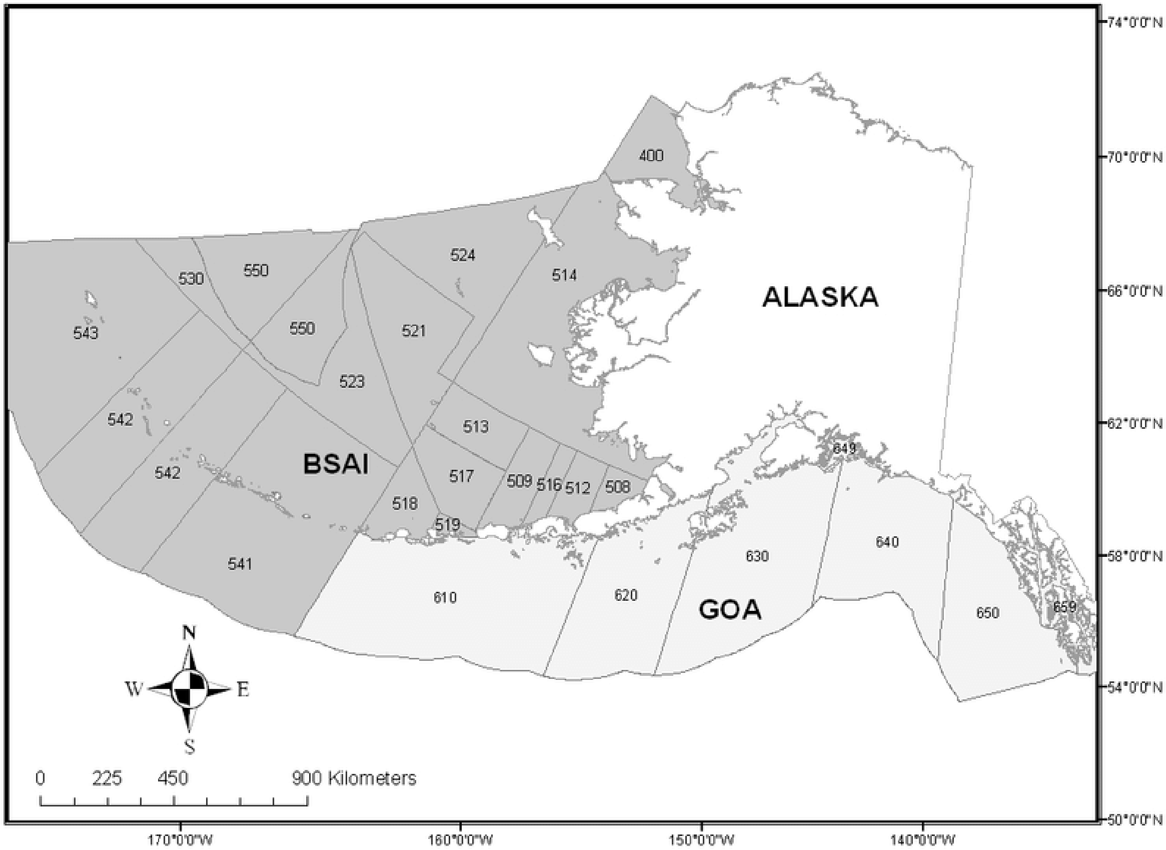

Figure 8.2. Map of NMFS Regulatory Areas in the BSAI and GOA.

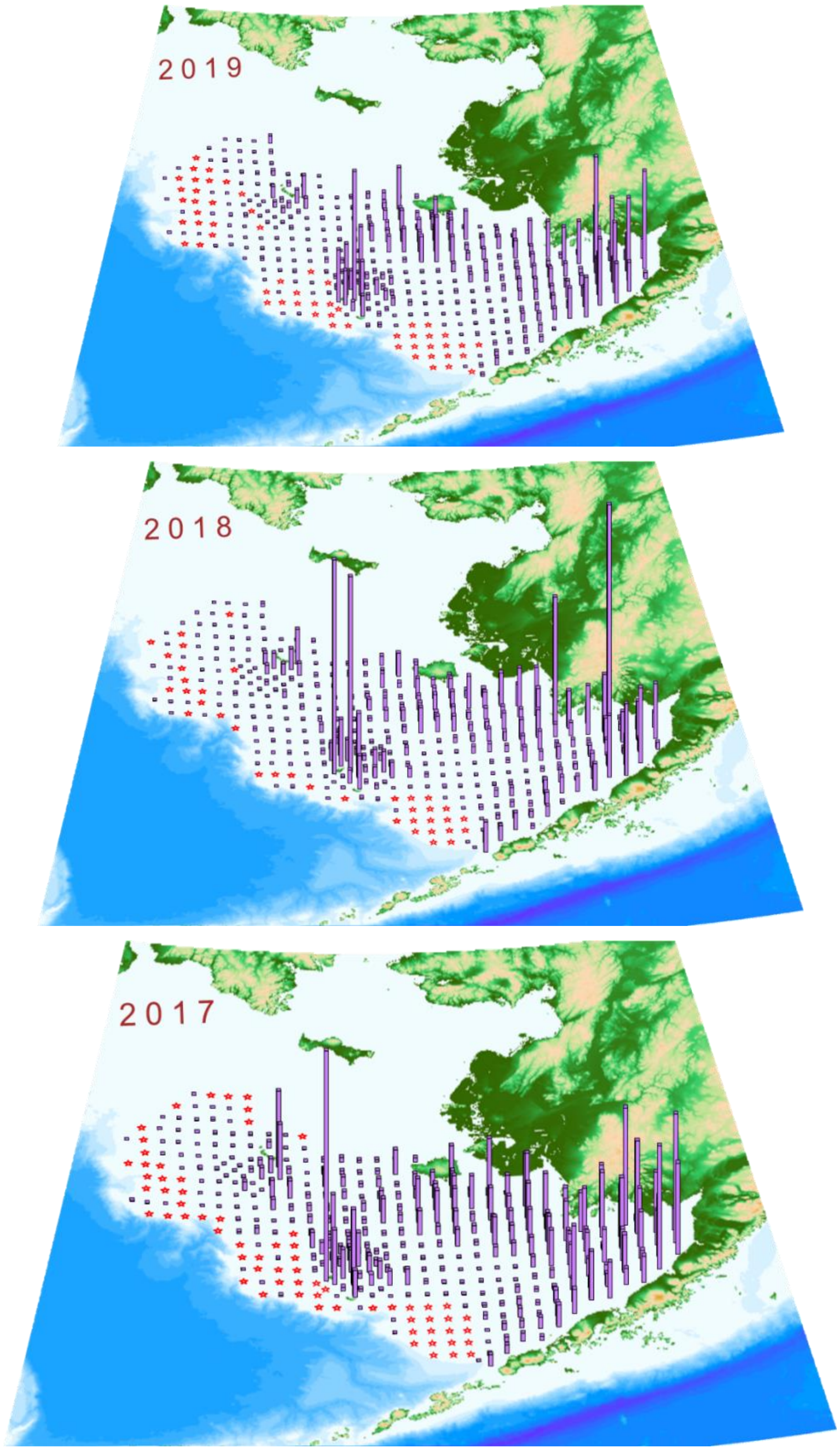

Figure 8.3. Survey catch-per-unit-effort of northern rock sole for 2017-2019 (purple bars). Hauls with zero northern rock sole are denoted with red stars.

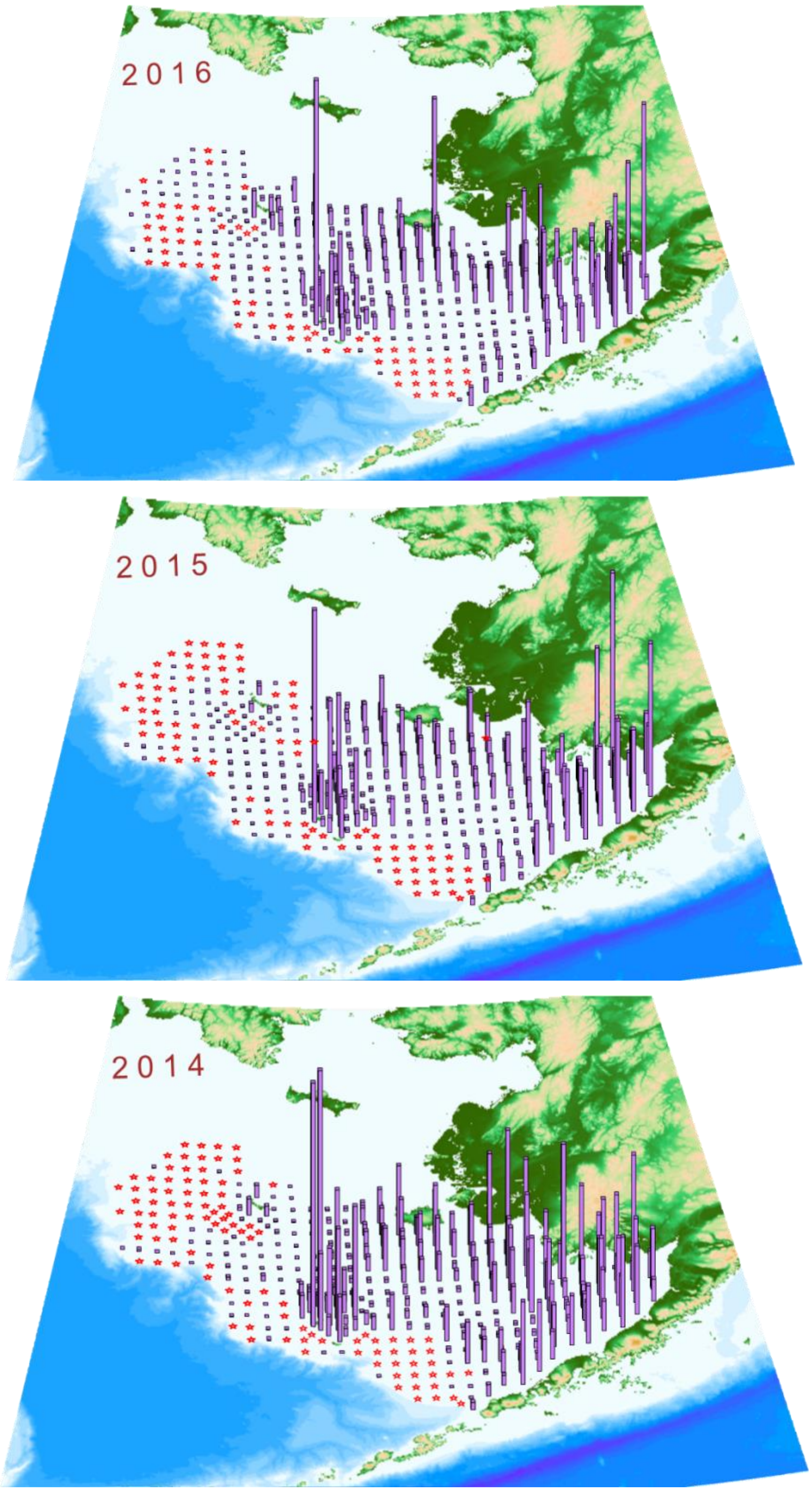

Figure 8.4. Survey catch-per-unit-effort of northern rock sole for 2014-2016 (purple bars). Hauls with zero northern rock sole are denoted with red stars.

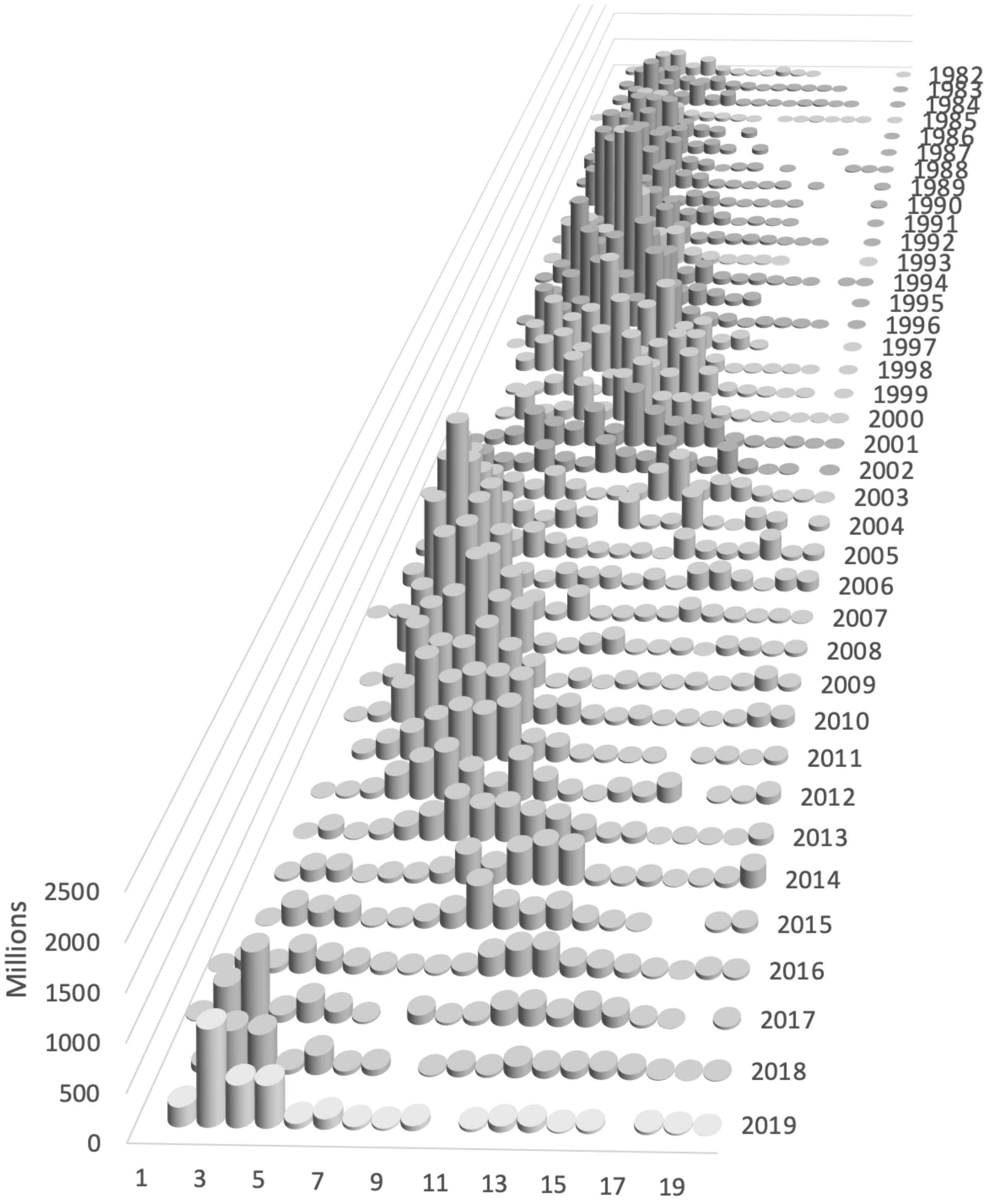

Figure 8.5. Survey age composition data in absolute numbers (age on the x-axis and millions of fish on the y-axis) over time.

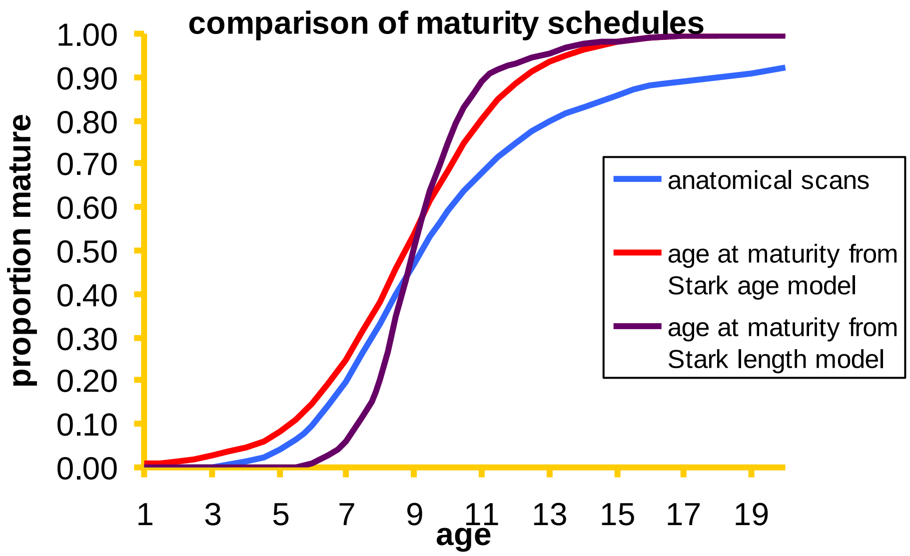

Figure 8.6. Maturity schedule for northern rock sole from three methods (bottom panel). The Stark (2012) length model, based on histology, is used in the stock assessment replacing the curve from anatomical scanning of fish used in past assessments.

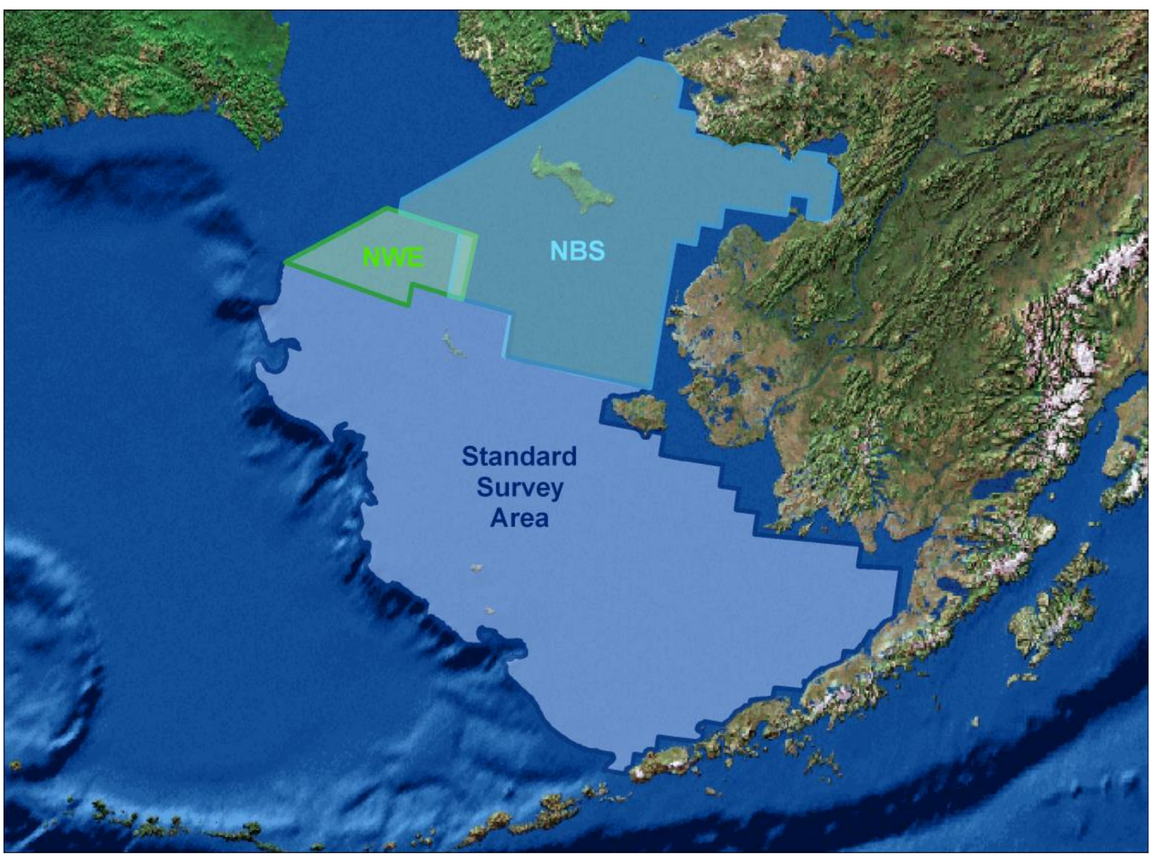

Figure 8.7. Eastern Bering Sea shelf survey areas. Only data from the standard survey area are used in the assessment model; data from the Northwest Extension (NWE) and Northern Bering Sea (NBS) are excluded.

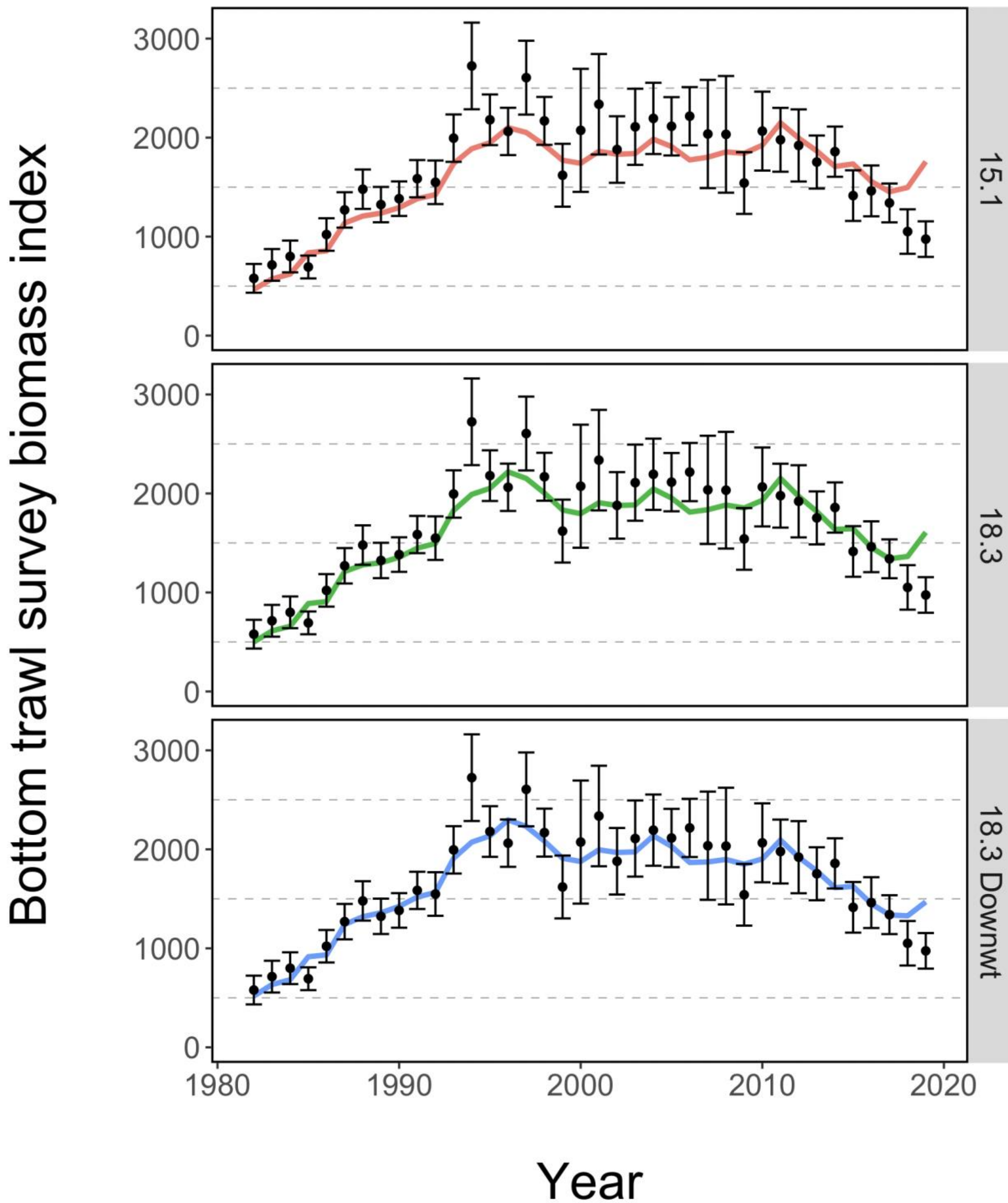

Figure 8.8. Survey biomass and asymptotic 95% confidence intervals (black dots and vertical lines) and fits to the survey biomass for Models 15.1 (top panel), 18.3 (middle panel, green line), and the exploratory model down-weighting age composition data by 75% (bottom panel, blue line).

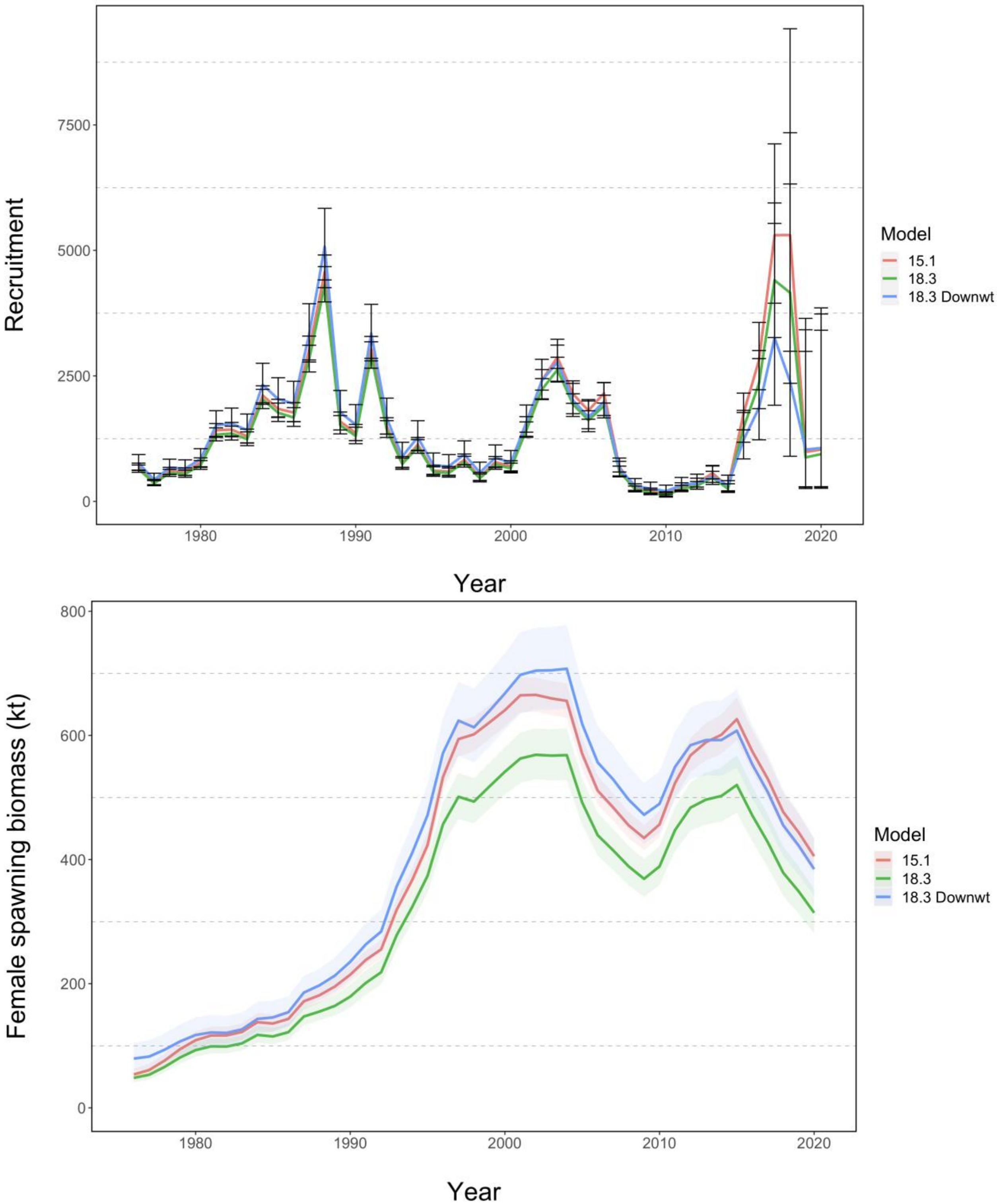

Figure 8.9. Recruitment estimates with 95% asymptotic confidence intervals (top panel) and spawning stock biomass estimates (bottom panel) for Models 15.1 (red), 18.3 (green), and the exploratory model downweighting age composition data by 75% (blue).

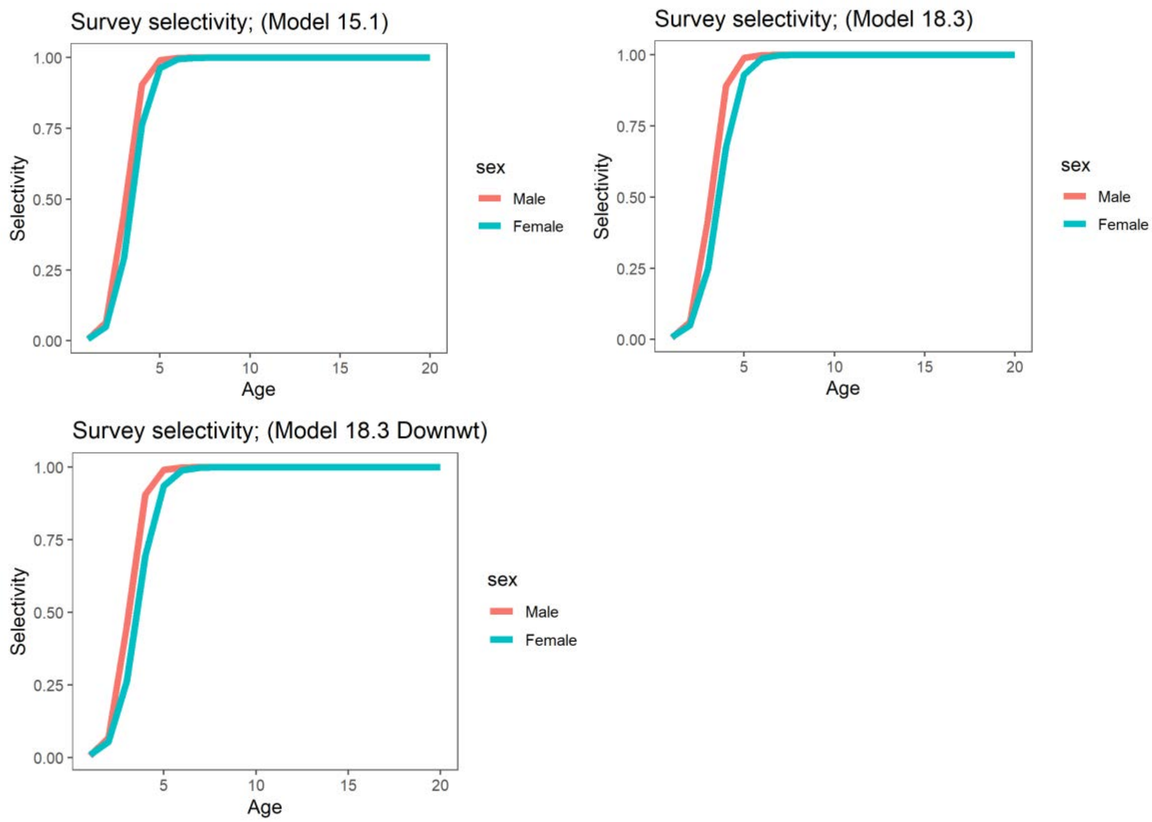

Figure 8.10. Male (red) and female (blue) survey selectivity for Models 15.1 (top left), 18.3 (top right), and the exploratory model downweighting age composition data by 75% (bottom left).

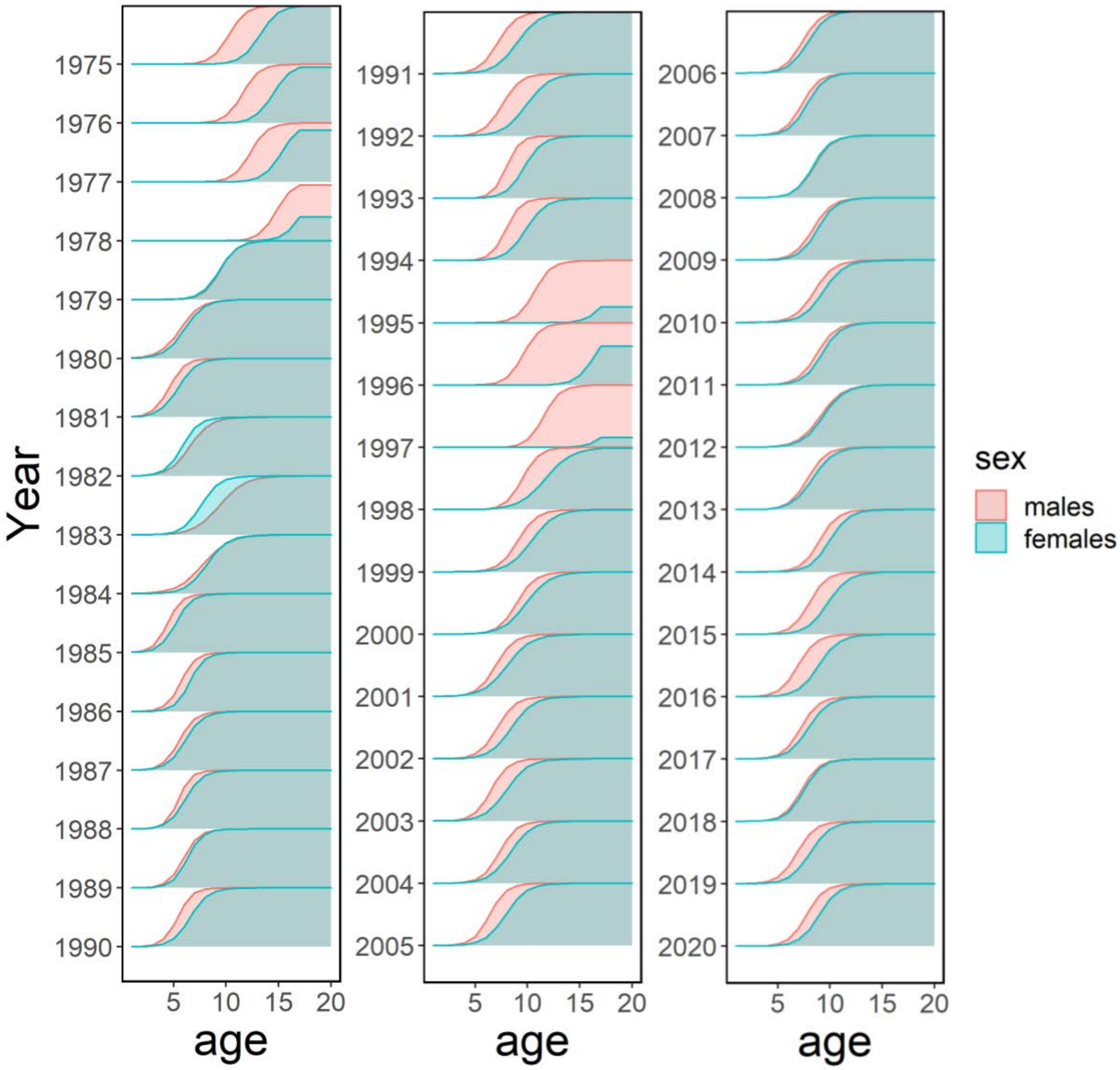

Figure 8.11. Yearly time-varying logistic fishery selectivity for Model 15.1.

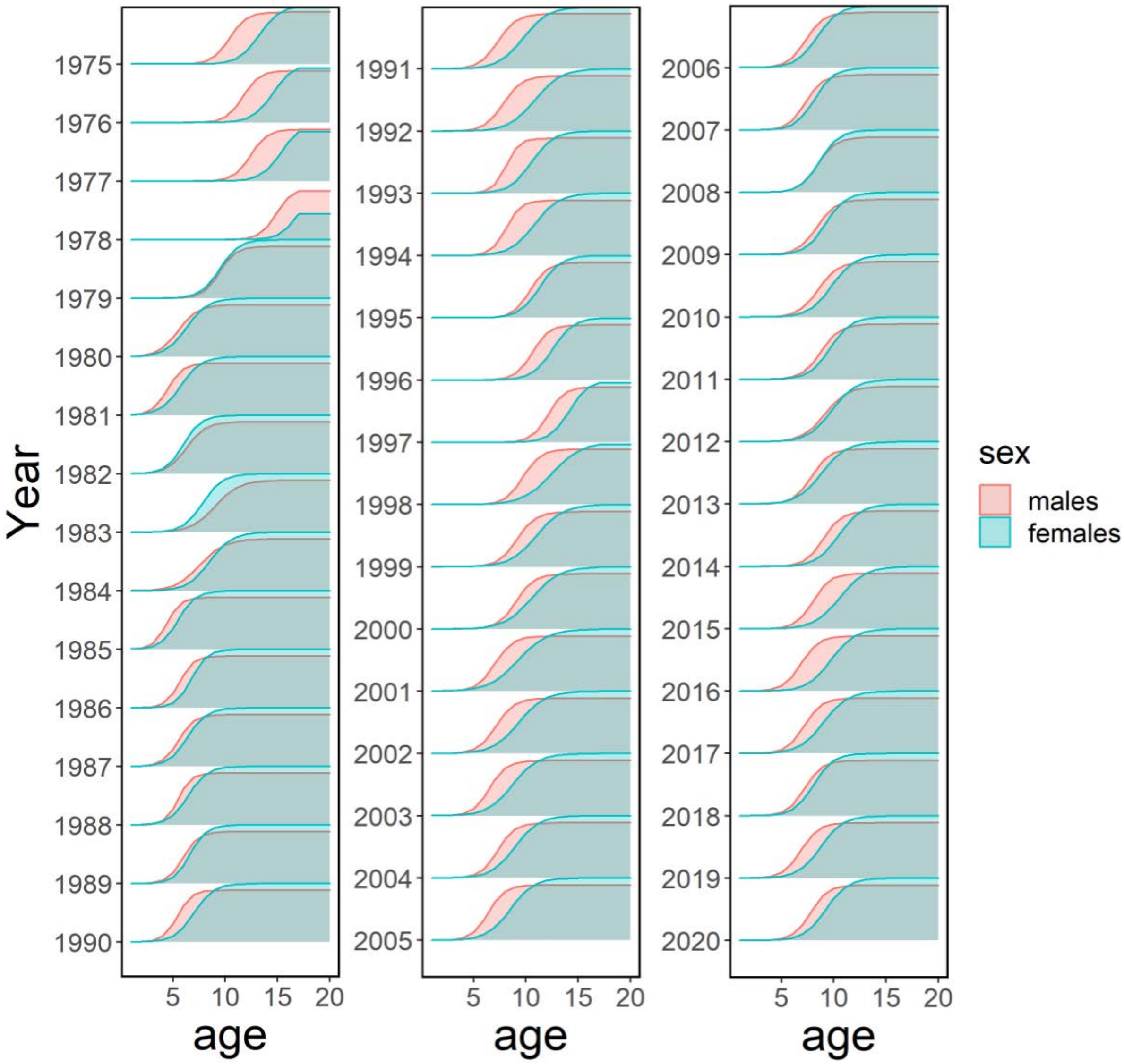

Figure 8.12. Yearly time-varying logistic fishery selectivity for Model 18.3.

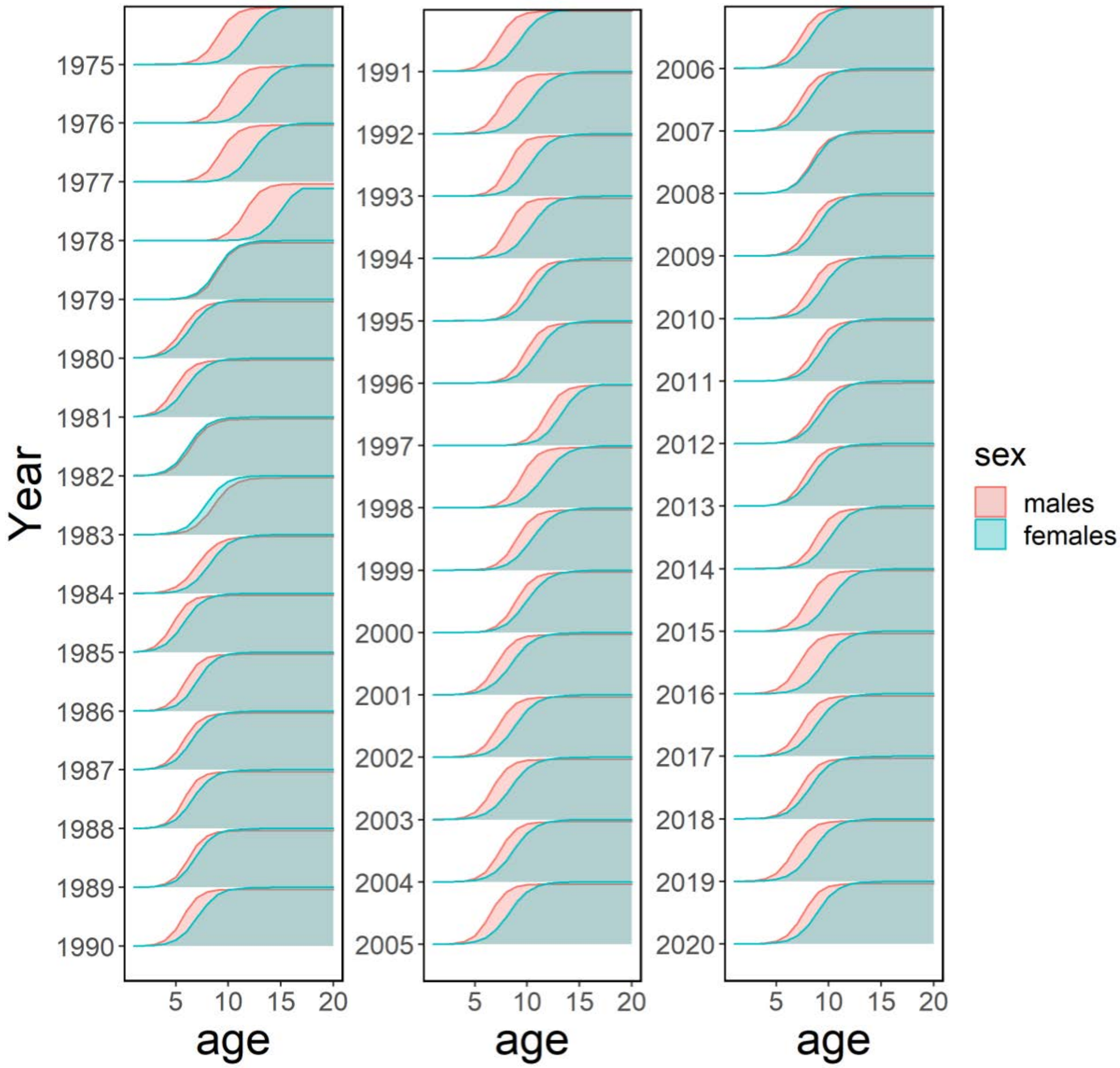

Figure 8.13. Yearly time-varying logistic fishery selectivity for the exploratory model downweighting Model 18.3's age composition data by 75%.

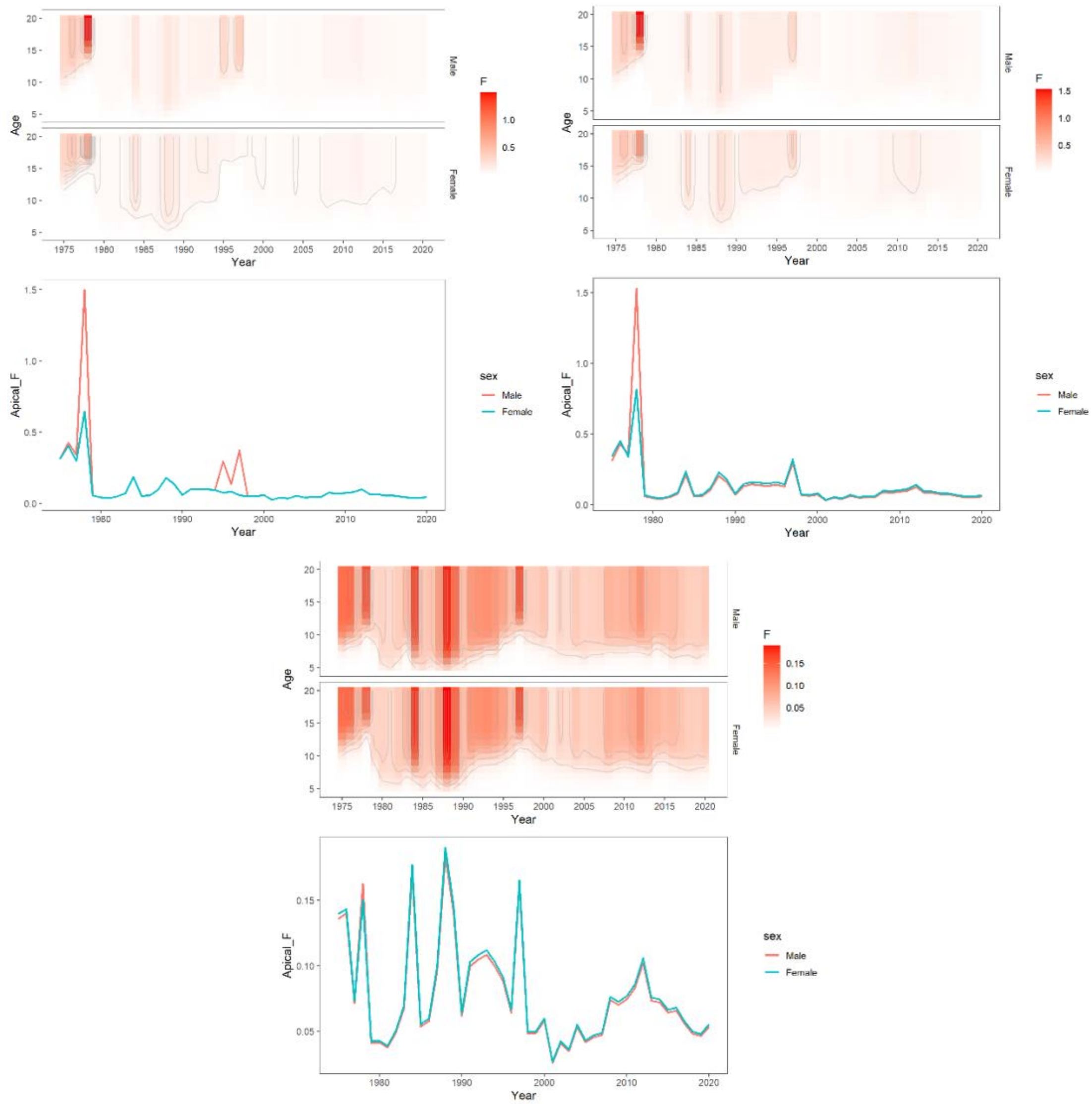

Figure 8.14. A comparison of fishing mortality for Models 15.1 (top left), 18.3 (top right), and an exploratory model downweighting 18.3's age composition data by 75% (bottom right). Within each panel, the top sub-panel shows fishing mortality by age and year and the bottom sub-panel shows apical fishing mortality over time. The plots are sex-specific.

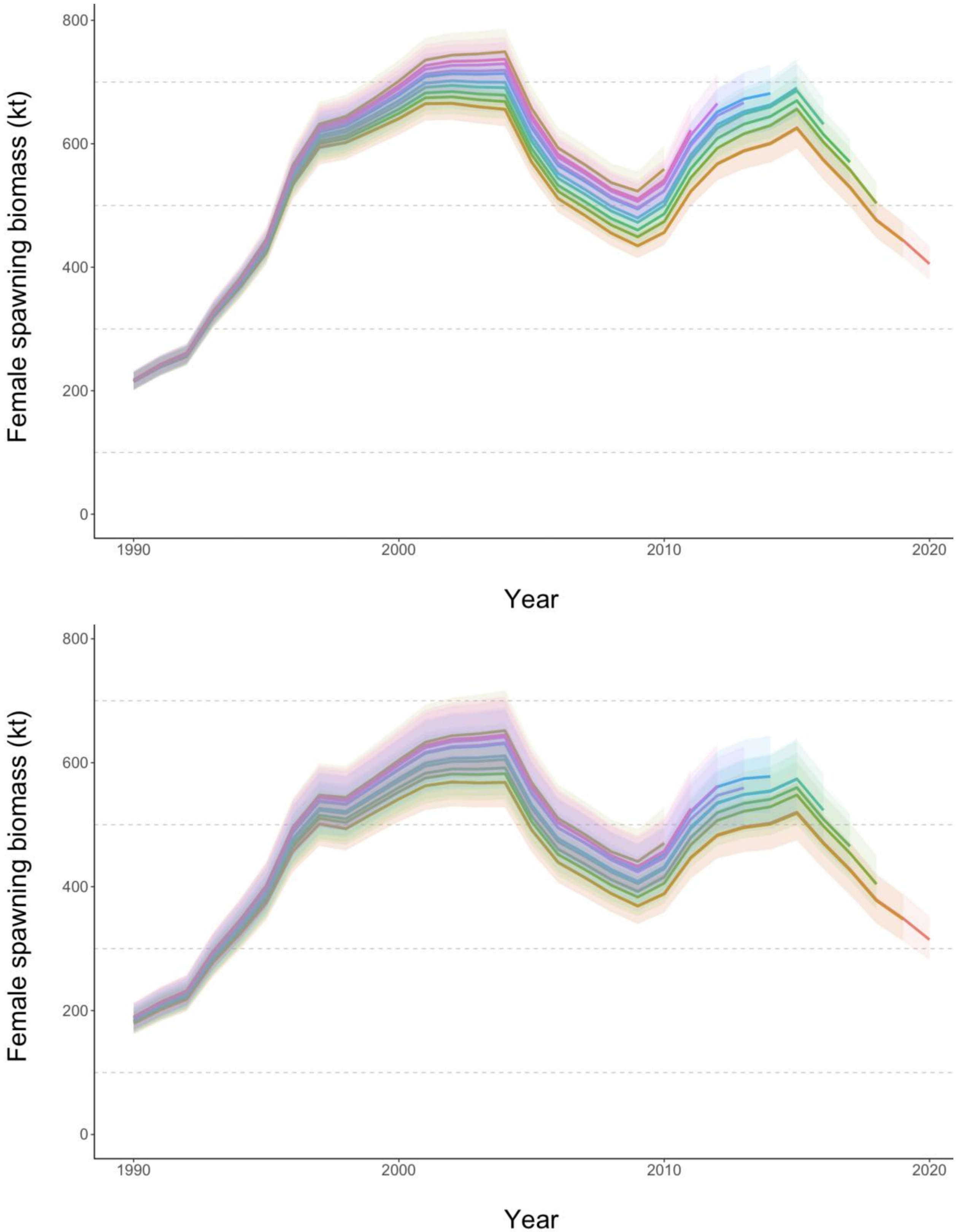

Figure 8.15. A comparison of northern rock sole spawning biomass retrospective patterns for Models 15.1 (top), and 18.3 (bottom). Mohn's rho was 0.12 for both model configurations.

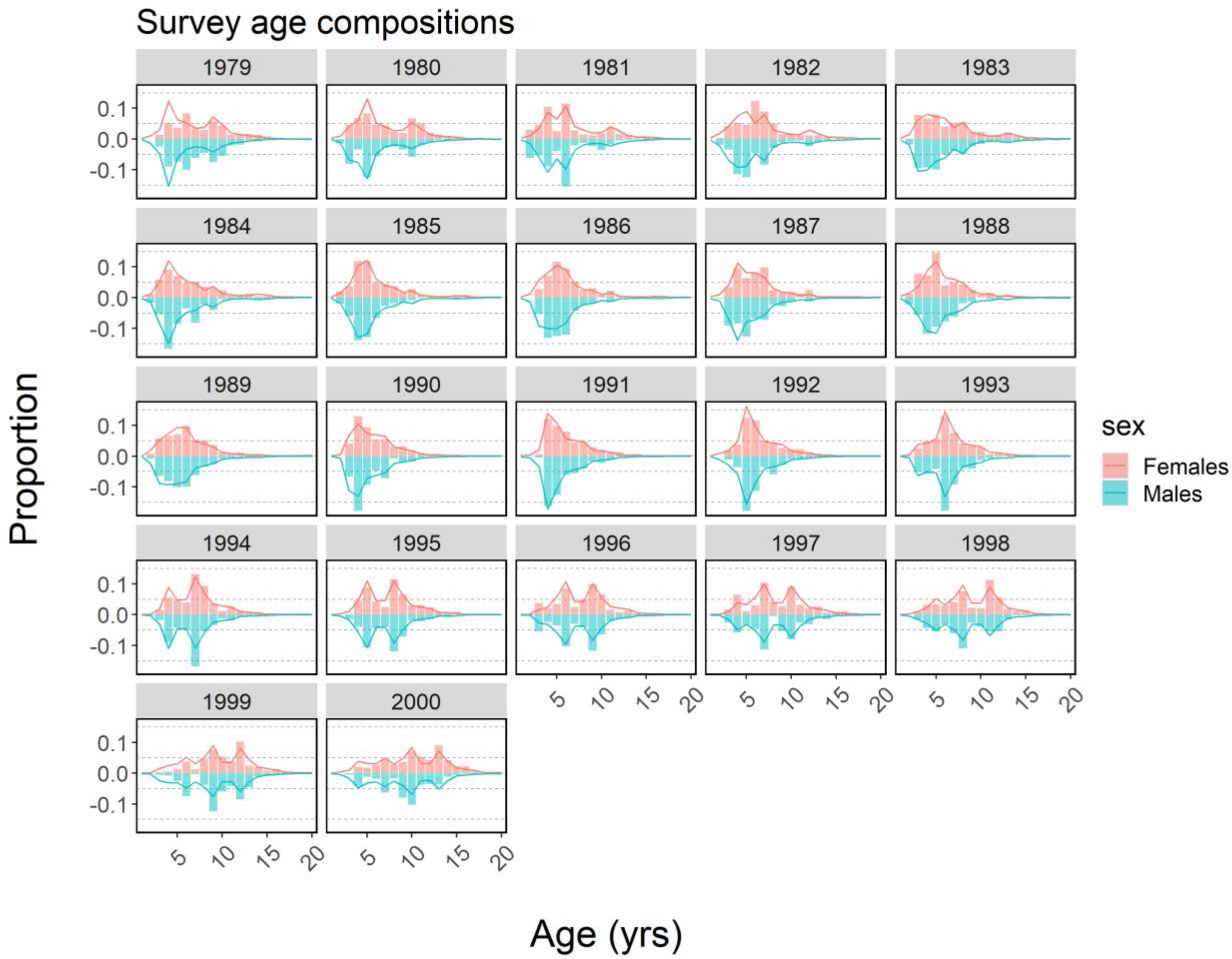

Figure 8.16. Observed (histograms) and expected (lines) survey age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for 1979-2000 for Model 18.3.

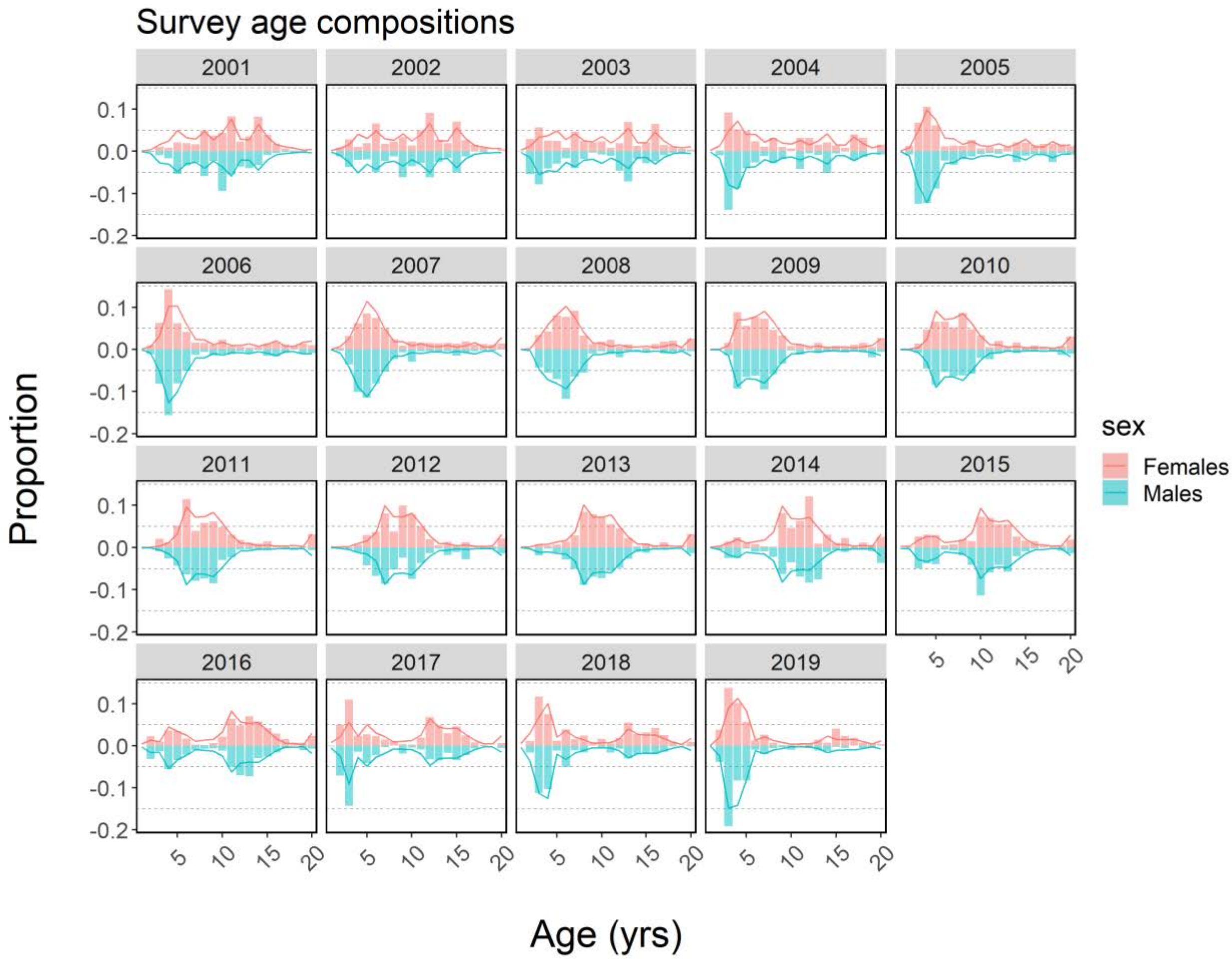

Figure 8.17. Observed (histograms) and expected (lines) survey age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for 2001-2019 for Model 18.3.

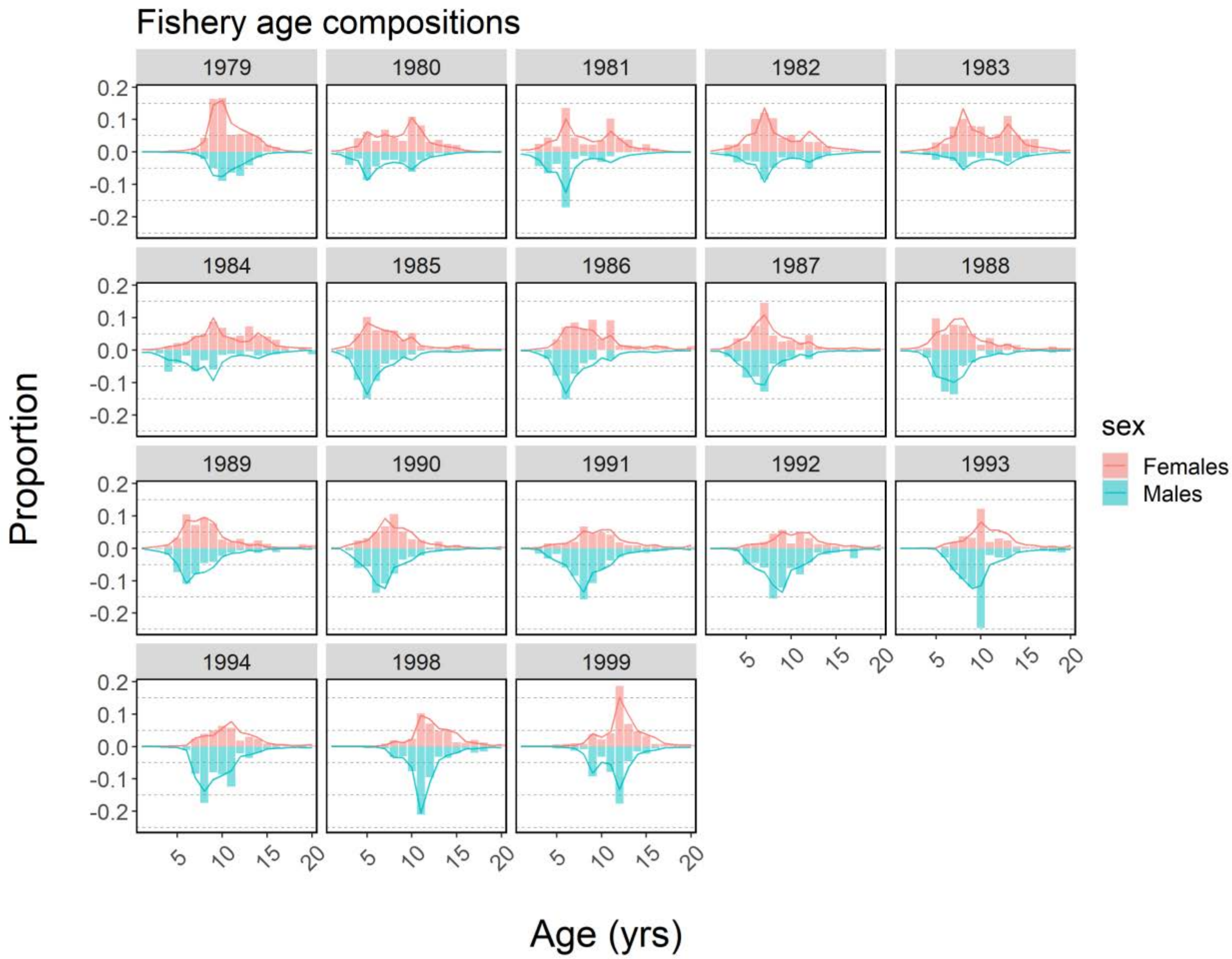

Figure 8.18. Observed (histograms) and expected (lines) fishery age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for 1979-1999 for Model 18.3.

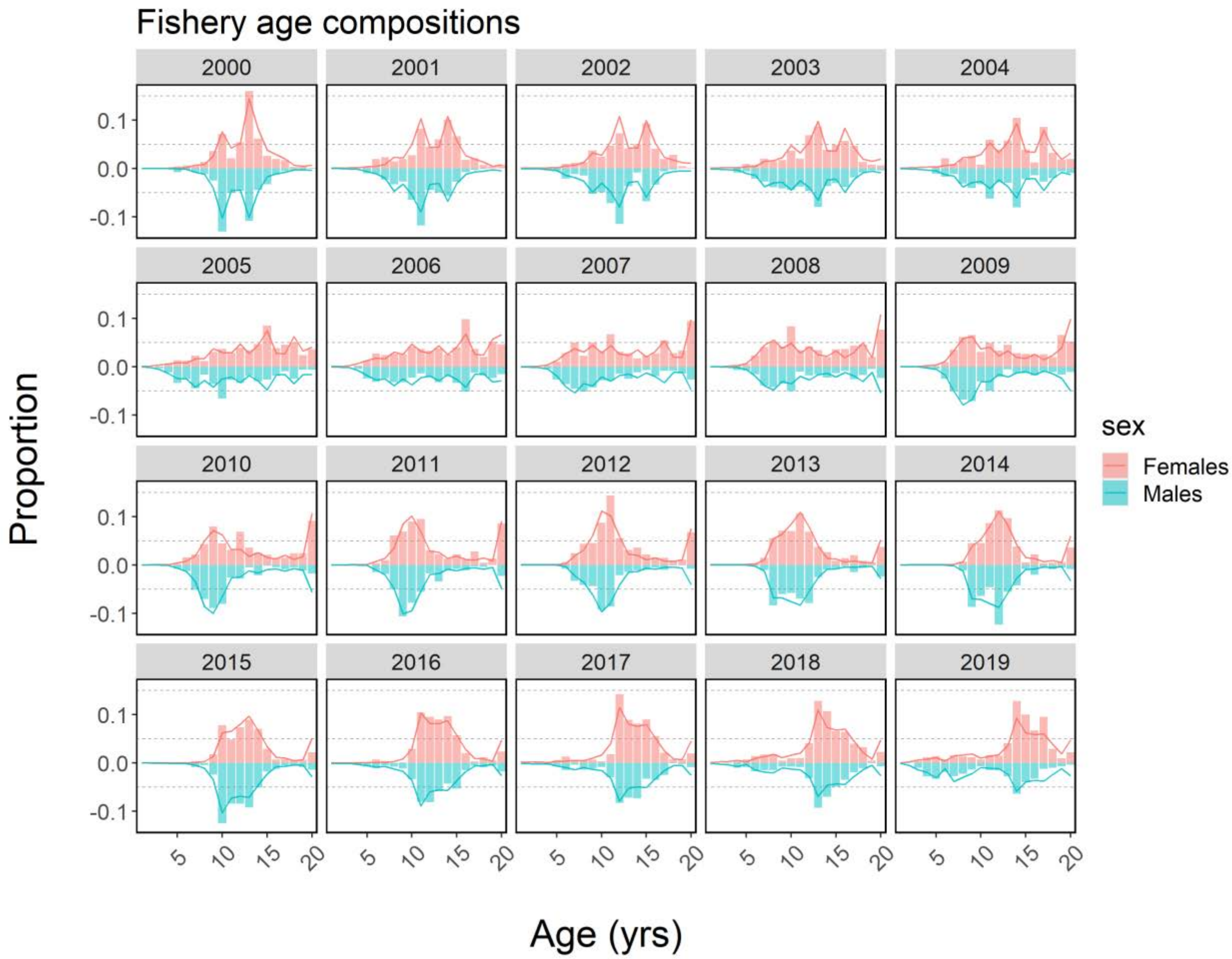

Figure 8.19. Observed (histograms) and expected (lines) fishery age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for 2000-2019 for Model 18.3.

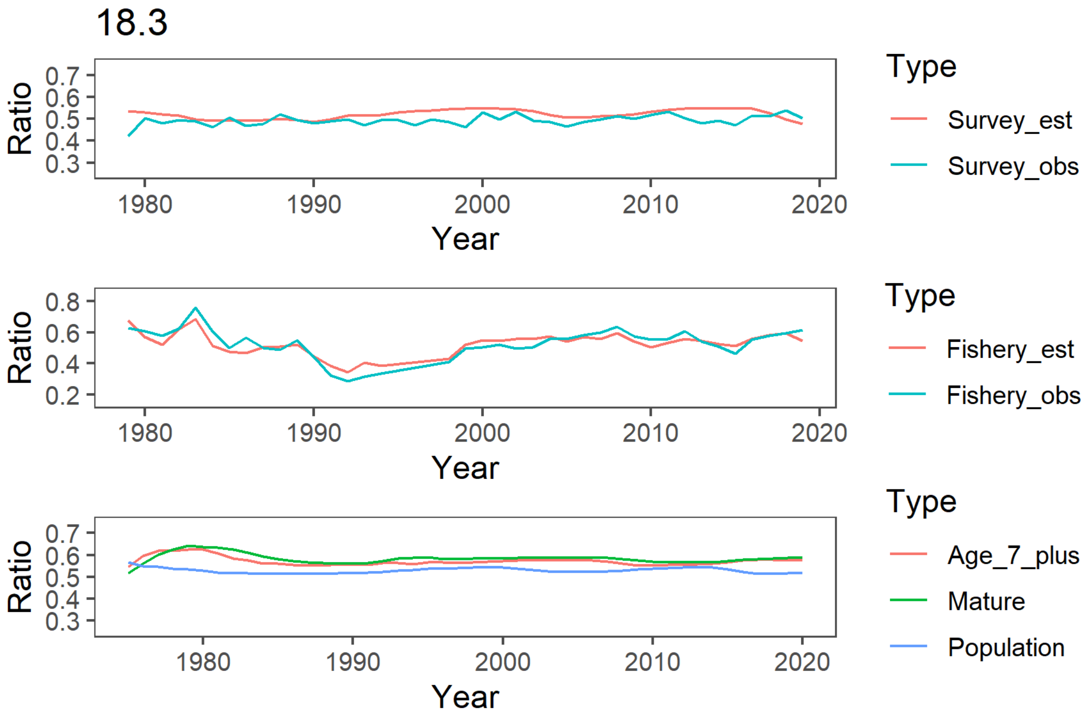

Figure 8.20. Observed (red) and expected (blue) survey sex ratios (top panel), observed (red) and expected (blue) fishery sex ratios (middle panel), and age 7+ (red), mature (green), and all-ages (blue) expected sex ratios (bottom panel) for 1975-2020.

Appendix A

Summary of Results and additional plots for Model 15.1 (the 2018 accepted model with new data added)

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2020	2021	2021*	2022*
M (natural mortality rate)	0.15	0.15	0.15	0.15
Tier	1a	1a	1a	1a
Projected total (age 6+) biomass (t)	1,068,000	1,608,000	1,236,920	1,795,500
Projected Female spawning biomass (t)	380,600	356,000	384,547	377,866
B_0	515,680	515,680	546,127	546,127
B_{MSY}	186,000	186,000	187,790	187,790
F_{OFL}	0.147	0.147	0.145	0.145
$maxF_{ABC}$	0.144	0.144	0.14	0.14
F_{ABC}	0.144	0.144	0.14	0.14
OFL (t)	157,300	236,800	179,645	260,771
maxABC (t)	153,300	230,700	173,427	251,746
ABC (t)	153,300	230,700	173,427	251,746
Status	As determined *last* year for:		As determined *this* year for:	
	2018	2019	2019	2020
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 25,800 t used in place of maximum permissible ABC for 2020 and 47,500 t used in place of maximum permissible ABC for 2021 and 2022. The final catch for 2020 was set equal to the 2019 final catch. The 2021 and 2022 catch was estimated as the average over the past decade of final catches.

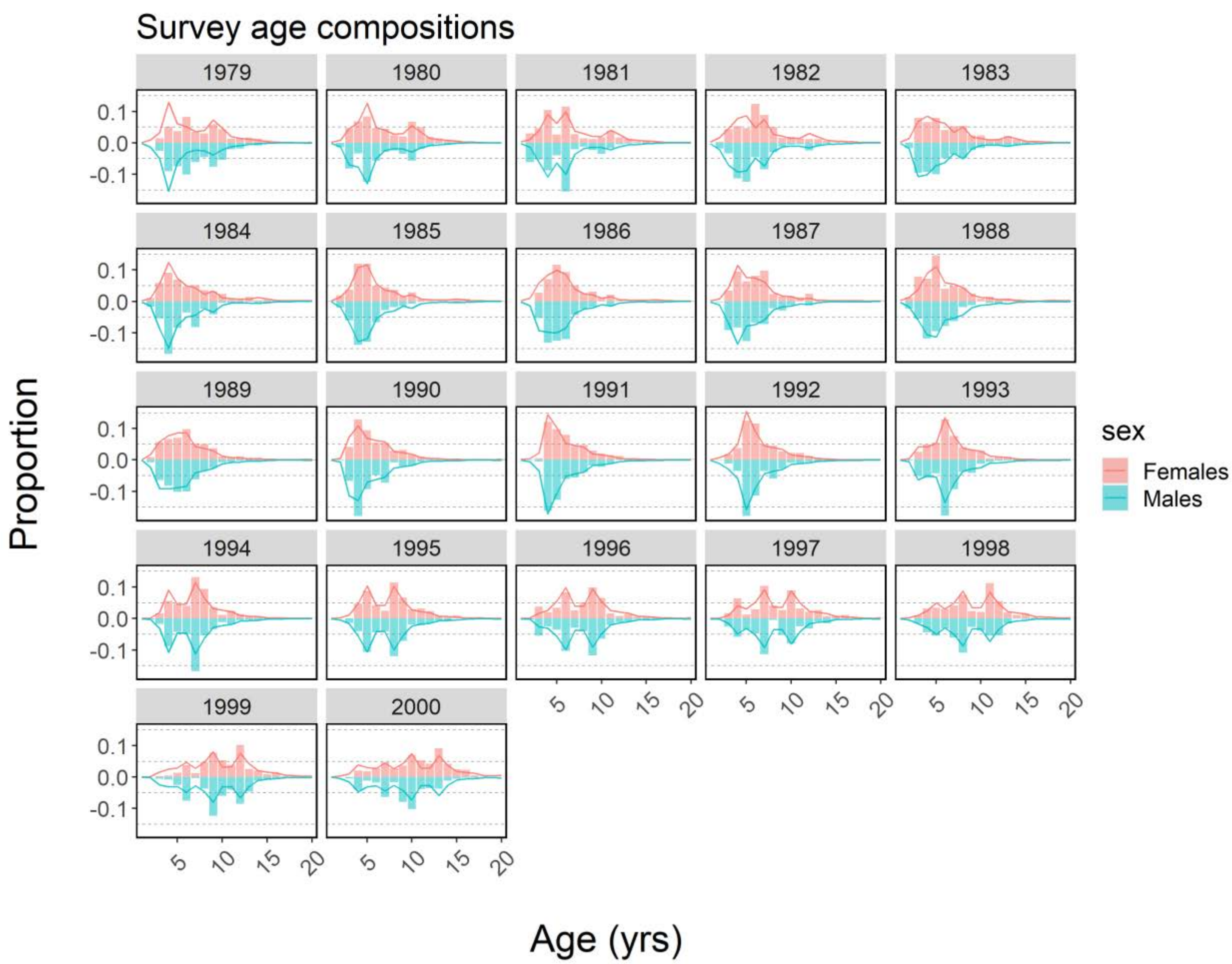

Figure 8.21. Observed (histograms) and expected (lines) survey age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for 1979-2000 for Model 15.1.

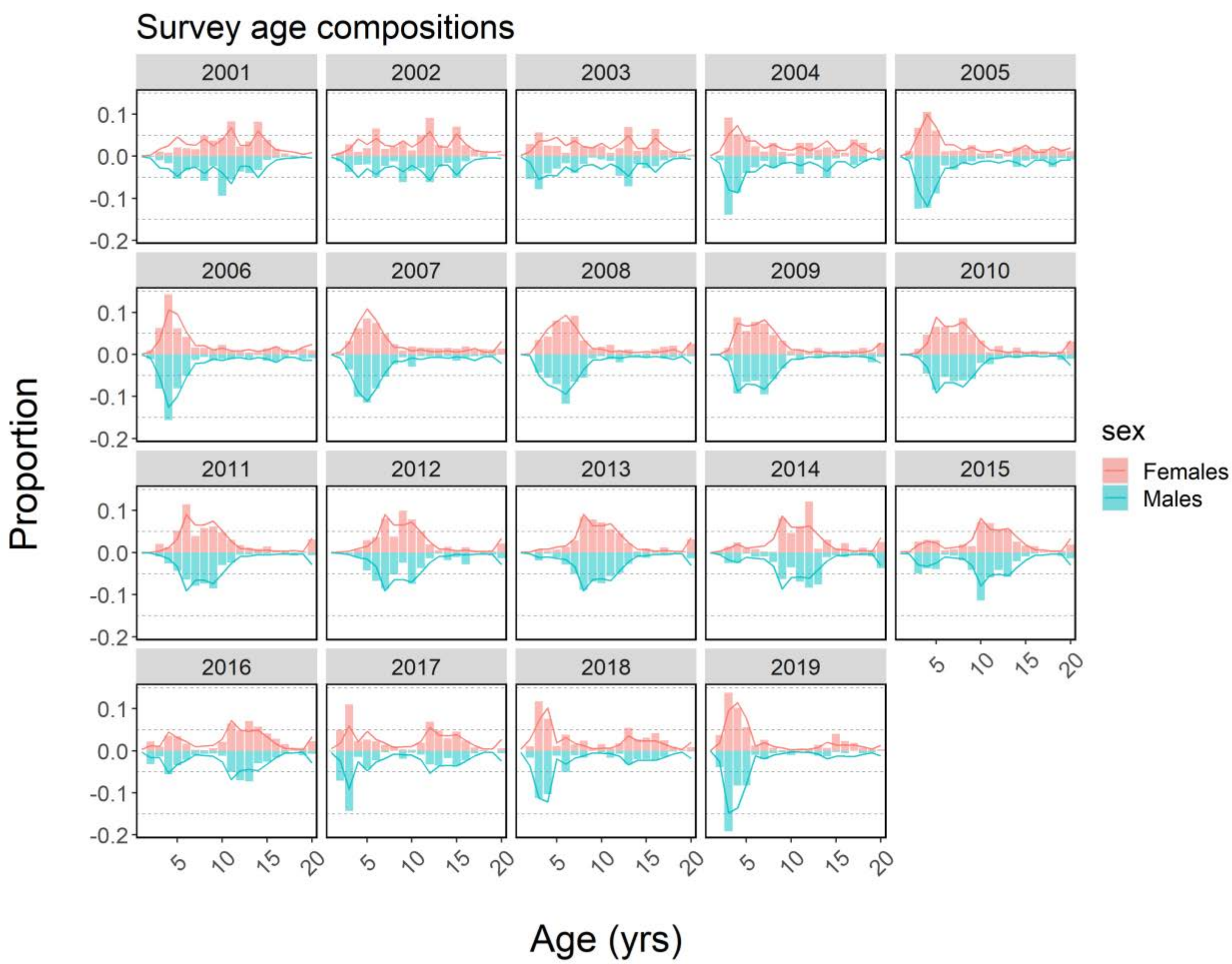

Figure 8.22. Observed (histograms) and expected (lines) survey age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for 2001-2019 for Model 15.1.

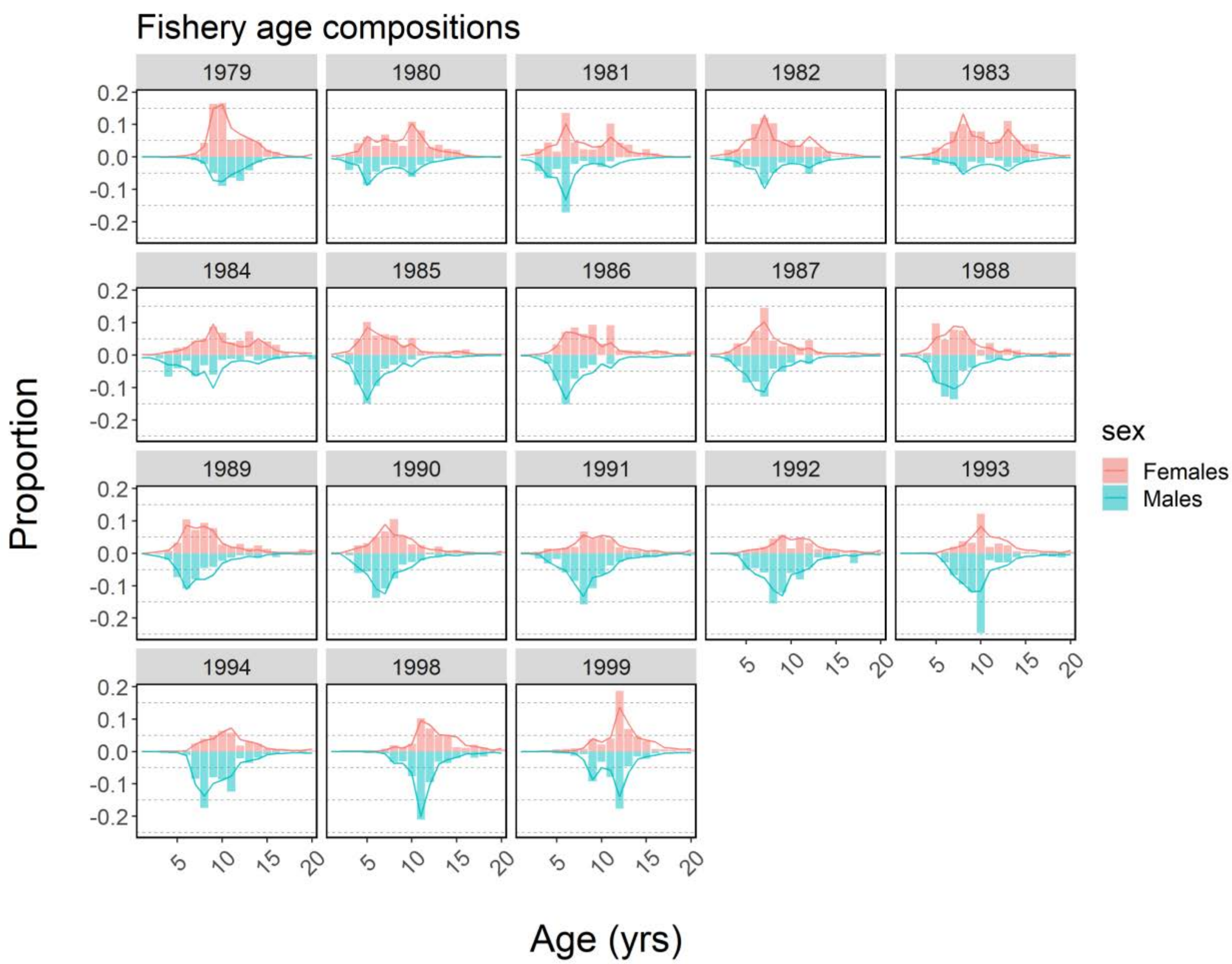

Figure 8.23. Observed (histograms) and expected (lines) fishery age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for 1979-1999 for Model 15.1.

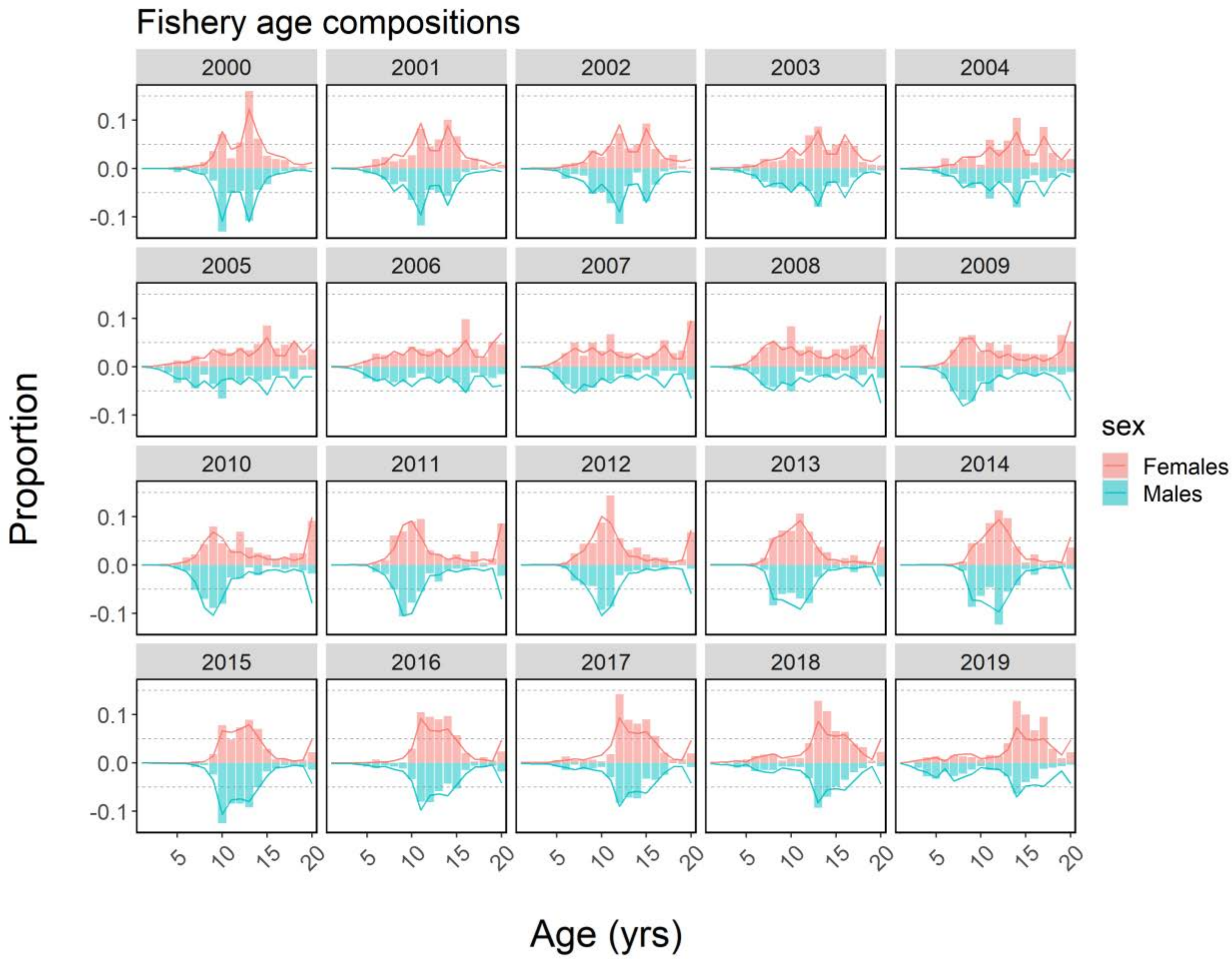

Figure 8.24. Observed (histograms) and expected (lines) fishery age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for 2000-2019 for Model 15.1.

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:

$$S^s_{t,a} = \left(1 + \exp(s^s e^{\omega_t^{s,s}} (a - a^s_{50} e^{\omega_t^{a50,s}}))\right)^{-1} \tag{4}$$

where s^s is the reference selectivity slope parameter for sex *s*, a^s_{50} reference selectivity intercept parameter for sex *s*, $\omega_t^{s,s}$ is the annual selectivity slope deviation for sex *s*, $\omega_t^{a_{50},s}$ 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., 2019) and pH (Hurst et al., 2016), but are not in the 2020 stock assessment models.

$$R_t = \alpha \tilde{S}_{t-1} e^{-\beta \tilde{S}_{t-1} + \gamma_1 W_{t-1} + \gamma_2 C_{t-1} + \gamma_3 P_{t-1}} e^{\varepsilon_t - \sigma_R^2/2}, \quad \varepsilon_t \sim N(0;\sigma_R^2)$$ in Figure 8.16 - Figure 8.20. (7a)

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

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):

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

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 the 2020 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 (2016-2020).

2.5 Reference points and projections

The reference points computed as:

$F_{35\%}$ and $F_{40\%}$ - the fully-selected fishing mortality rates corresponding to a 35% and 40% reductions in spawning biomass-per-recruit (required to apply the OFL and ABC control rules), but note that Tier 3 projections in the 2020 assessment were projected using the “proj model.”

F_{MSY}, MSY, B_{MSY}/B_0 the fully-selected fishing mortality rate, yield and spawning biomass expressed relative to unfished spawning biomass corresponding to maximum sustainable yield, i.e. the value of Eqn 4 in equilibrium.

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 $\rho^{S,s}_{t,a}$ is the observed proportion of the survey catch in numbers during year *t* that was of sex *s* and age *a*, $\hat{\rho}^{S,s}_{t,a}$ 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 $\tilde{N}^{S}_{t,a}$ 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.

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

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.:

$$N^s_{1975,s} = N^I e^{\eta_a^s} \qquad \text{(B.7)}$$

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:

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

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:

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

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:

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

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.:

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

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.:

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

The prior on the extent of variation in recruitment is:

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

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

Fournier, D, Archibald, P.S., 1982. A General Theory for Analyzing Catch at Age Data. Can. J. Fish. Aquat. Sci. 39, 1195–1207.

Maunder, M.N., Punt, A.E., 2013. A review of integrated analysis in fisheries stock assessment. Fish. Res. 142, 61–74.

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, ℓnN^{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 C

Note on update of Chapter 8 Assessment of the northern rock sole stock in the Bering Sea and Aleutian Islands

James Ianelli

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Northern rock sole (*Lepidopsetta polyxystra*) are assessed on a biennial stock assessment schedule as part of the National Marine Fisheries Service assessment prioritization plan implemented in 2017. The most recent "full" assessment for this stock was in 2018. In the process of making refinements for 2020, an error was detected in an input file to the 2018 assessment. The purpose of this document is to highlight the extent of the difference this error caused in preparing for the "full" 2020 assessment to be presented in November 2020. In 2019 the following table was updated from the 2018 assessment (and applies to both the 2018 and 2019 assessments):

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2019	2020	2020	2021
M (natural mortality rate)	0.15	0.15	0.15	0.15
Tier	1a	1a	1a	1a
Projected total (age 6+)	828,000	1,001,400	1,068,000	1,608,000
Female spawning biomass (t)	417,800	380,600	380,600	356,000
Projected				
B_0	515,680		515,680	
B_{MSY}	186,000	186,000	186,000	186,000
F_{OFL}	0.147	0.147	0.147	0.147
$maxF_{ABC}$	0.144	0.144	0.144	0.144
F_{ABC}	0.144	0.144	0.144	0.144
OFL (t)	122,000	157,300	**157,300**	236,800
maxABC (t)	118,900	153,300	**153,300**	230,700
ABC (t)	118,900	153,300	**153,300**	230,700
Status	As determined *last* year for: 2017	2018	As determined *this* year 2018	2019
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Using the same data files, the updated table should have read:

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2019	2020	2020	2021
M (natural mortality rate)	0.15	0.15	0.15	0.15
Tier	1a	1a	1a	1a
Projected total (age 6+)	899,800	1,154,000	1,154,000	1,729,000
Female spawning biomass (t)	458,100	415,000	415,000	389,000
Projected				
B_0	546,800		546,800	
B_{MSY}	197,400	197,400	197,400	197,400
F_{OFL}	0.147	0.147	0.147	0.147
$maxF_{ABC}$	0.146	0.146	0.146	0.146
F_{ABC}	0.142	0.142	0.142	0.142
OFL (t)	131,100	168,000	168,000	251,800
maxABC (t)	127,700	163,700	163,700	245,400
ABC (t)	127,700	163,700	163,700	245,400
Status	As determined *last* year for:		As determined *this* year	
	2017	2018	2018	2019
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

The error was traced to a line near the end of the datafile that was intended to be commented out. The 2016 version of the model was also investigated for this error and it was found to be free from this transcription issue.

To summarize, the following shows the relative change from the original table used for specifications:

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2019	2020	2020	2021
M (natural mortality rate)	0.15	0.15	0.15	0.15
Tier	1a	1a	1a	1a
Projected total (age 6+) biomass (t)	9%	15%	8%	8%
Female spawning biomass (t)	10%	9%	9%	9%
Projected				
B_0	6%		6%	
B_{MSY}	6%		6%	
F_{OFL}	-0.9%	-0.9%	-0.9%	-0.9%
$maxF_{ABC}$	-1.4%	-1.4%	-1.4%	-1.4%
F_{ABC}	-1.4%	-1.4%	-1.4%	-1.4%
OFL (t)	7.5%	6.8%	6.8%	6.3%
maxABC (t)	7.4%	6.8%	6.8%	6.4%
ABC (t)	7.4%	6.8%	6.8%	6.4%

Appendix D

Additional plots for the exploratory model based on Model 18.3, but down-weighting age composition data by 75%

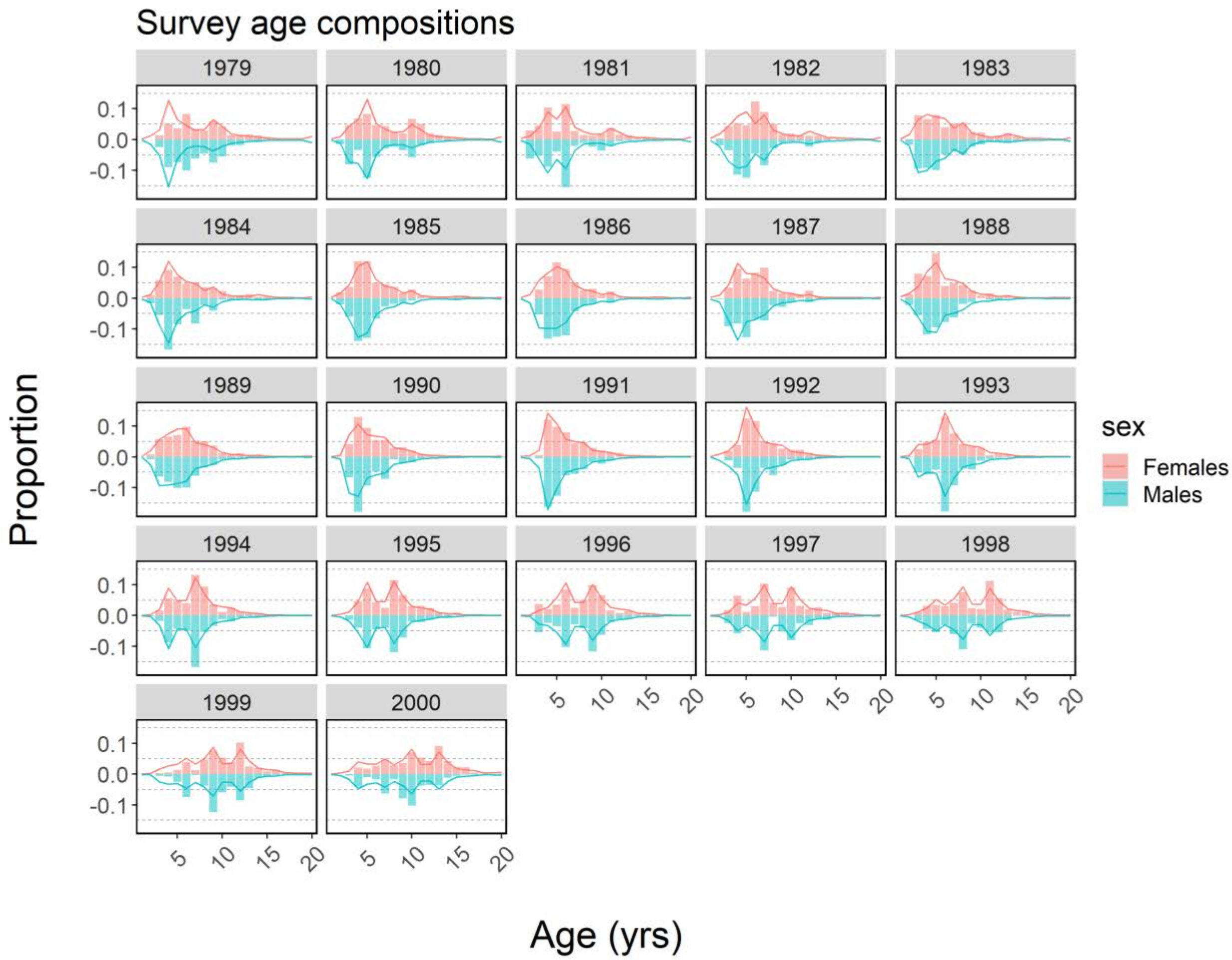

Figure 8.25. Observed (histograms) and expected (lines) survey age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for 1979-2000 for the exploratory model down-weighting age-composition data.

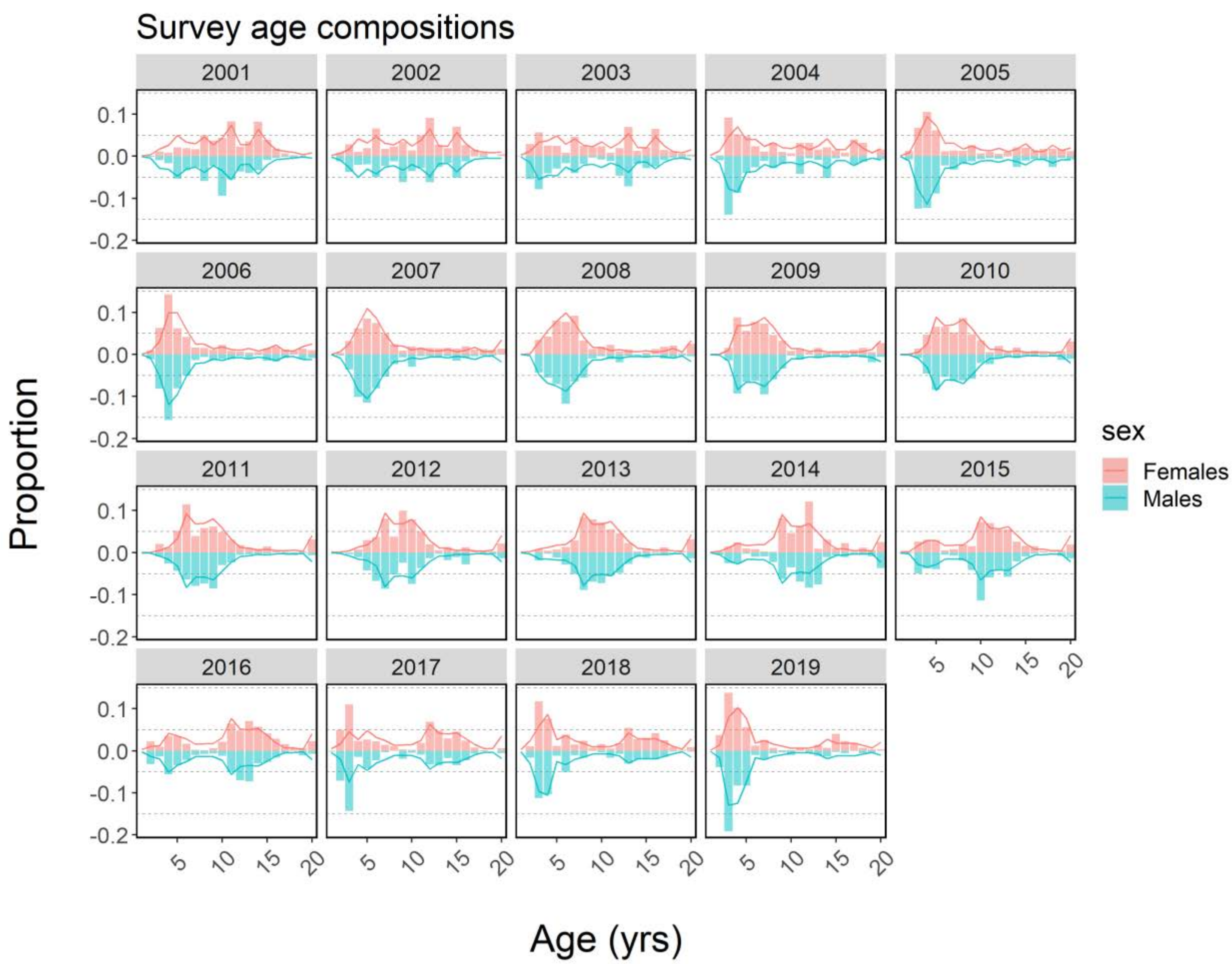

Figure 8.26. Observed (histograms) and expected (lines) survey age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for 2001-2019 for the exploratory model down-weighting age-composition data.

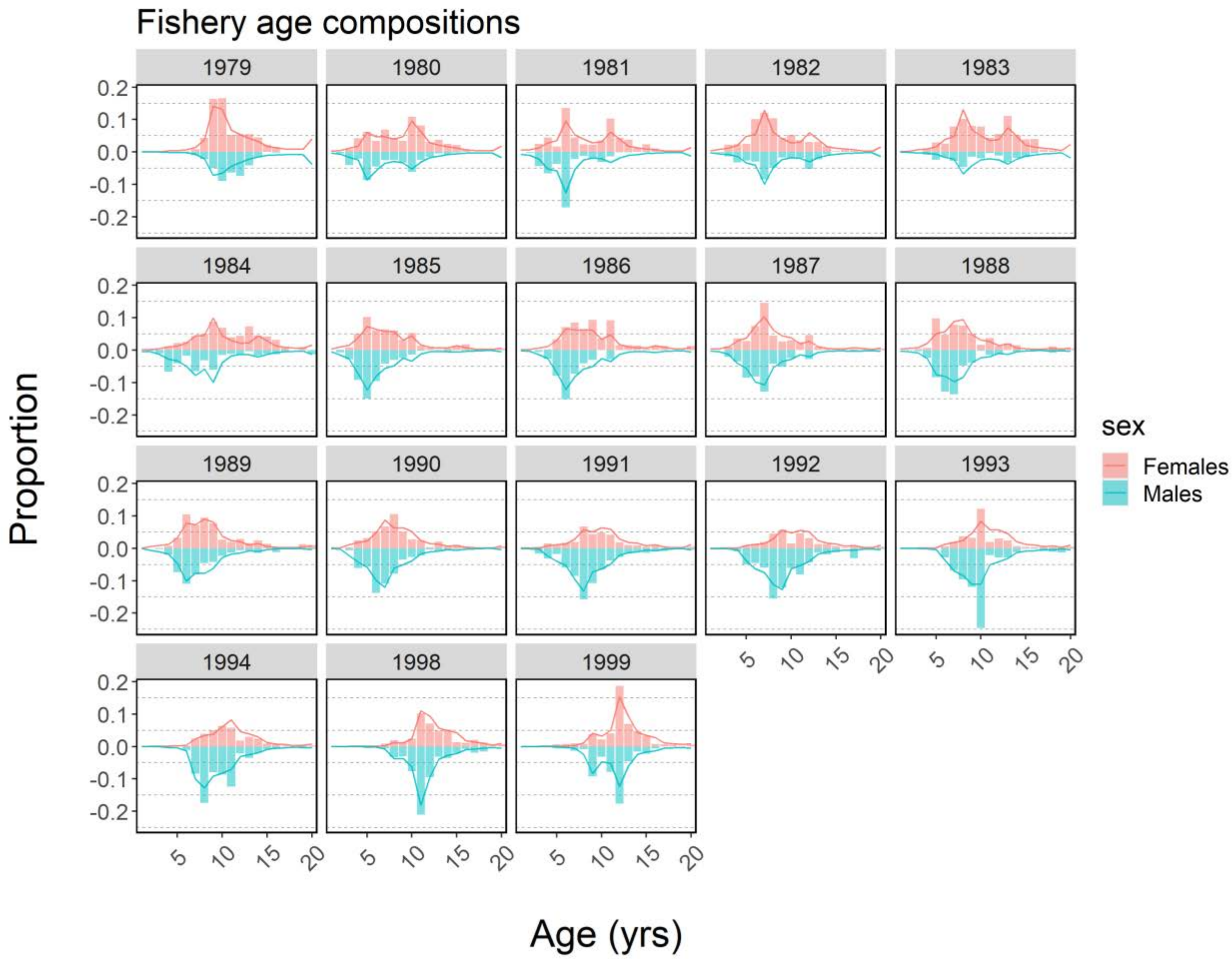

Figure 8.27. Observed (histograms) and expected (lines) fishery age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for 1979-1999 for the exploratory model down-weighting age-composition data.

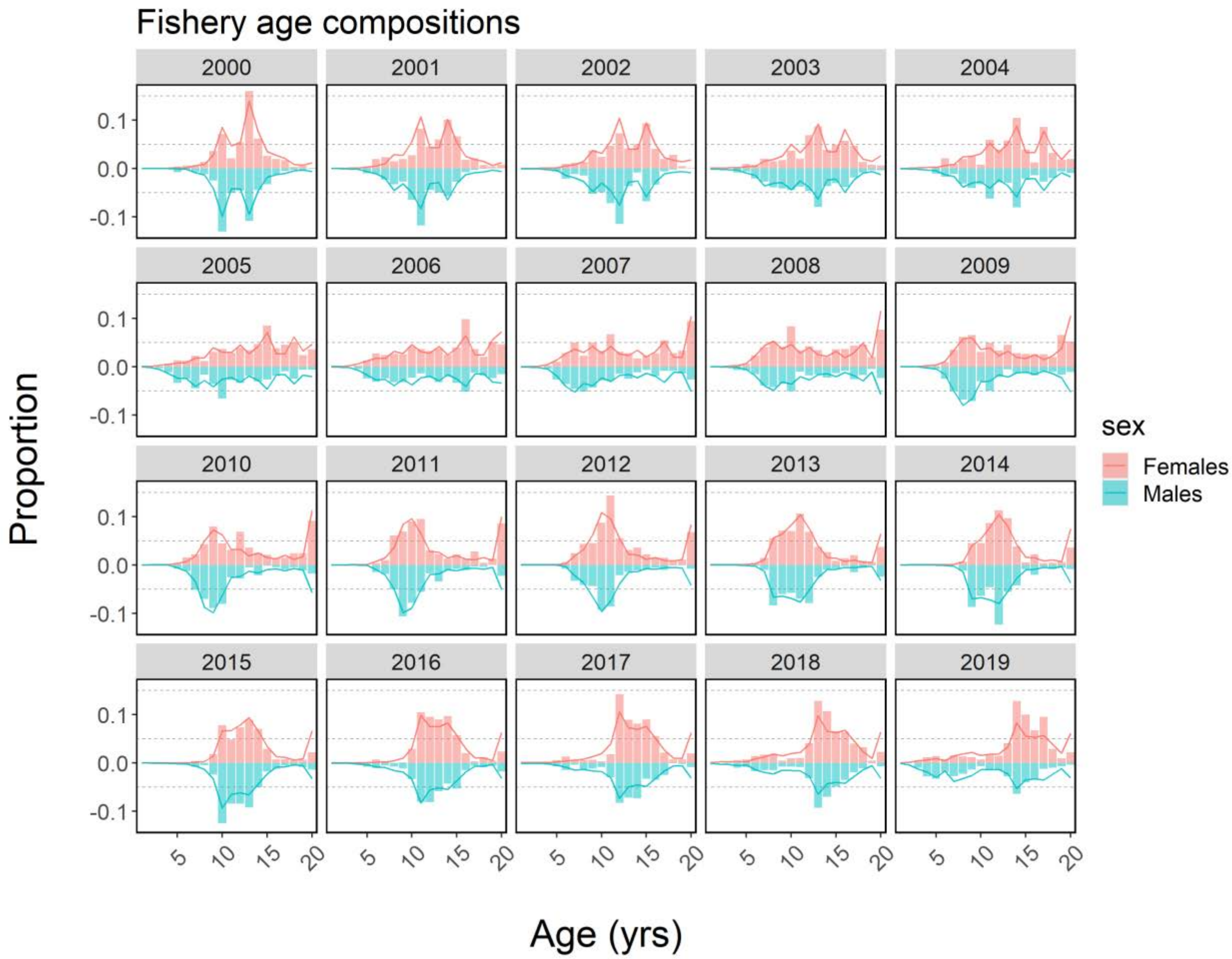

Figure 8.28. Observed (histograms) and expected (lines) fishery age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for 2000-2019 for the exploratory model down-weighting age-composition data.

Appendix E. Estimating Northern Rock Sole recruitment using environmental covariates

Lauren Rogers, Dan Cooper and Tom Wilderbuer

Difficulties exist in estimating northern rock sole recruitment at young ages since they do not appear in BSAI survey catches until age 3 and not in survey age sampling until age 4 or 5. They are estimated to be 25 and 40% selected by the survey trawl (males and females respectively) at age 3 and 95 and 98% selected at age 5. The age 4 and 5 fish that do end up in the age samples are quite rare, typically only 7 fish out of 500 on an annual basis. Therefore, there is 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 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 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 2, Figure 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 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 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

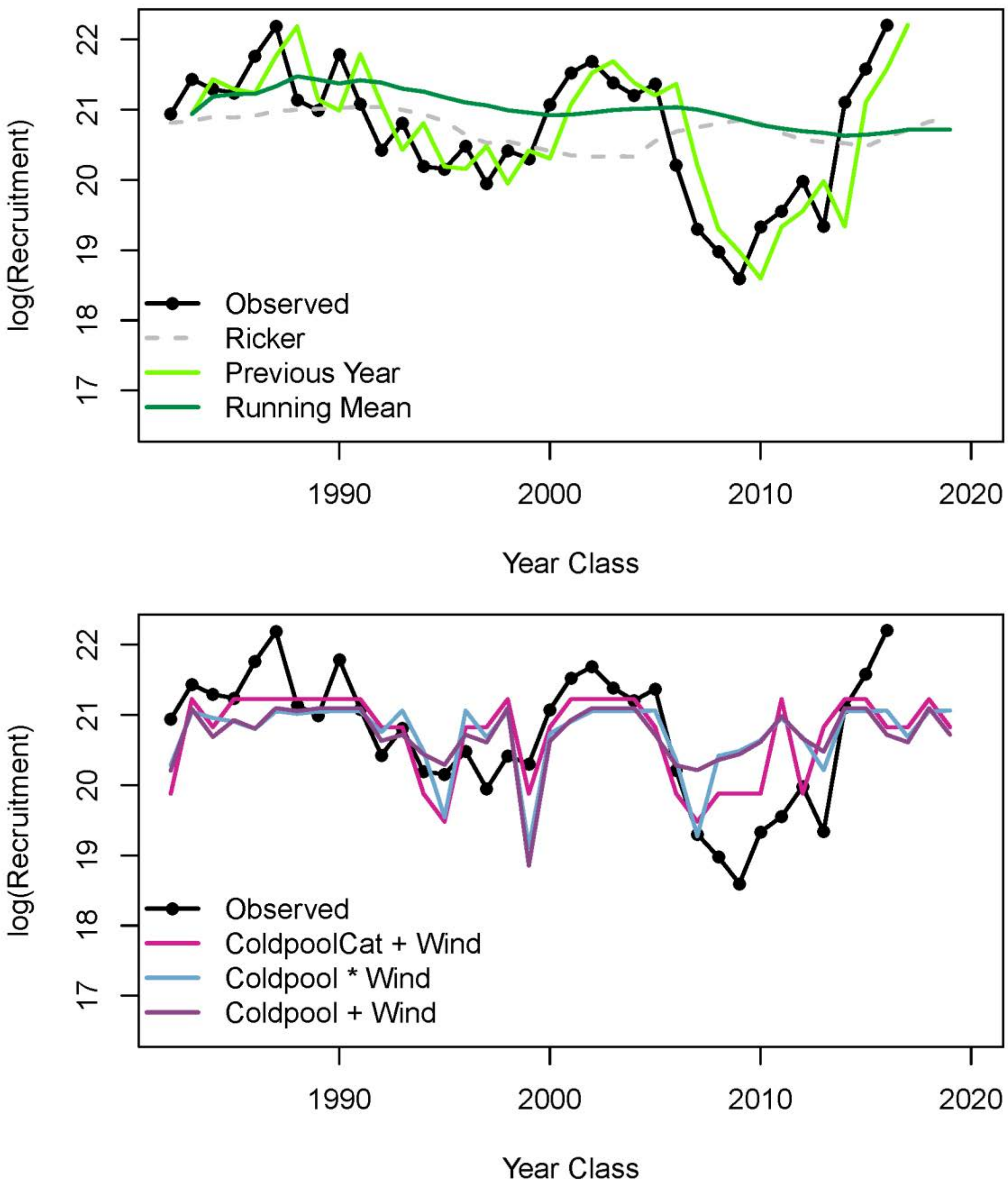

Figure 1. Observed (estimated from stock assessment model) and predicted recruitment from selected models for the 1982 through 2016 northern rock sole year classes, and predicted recruitment for the 2017 through 2019 year classes.

Literature Cited

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