8. Proposed alternative models for the assessment of the northern rock sole stock in the Bering Sea and Aleutian Islands

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Abbreviated Executive Summary

Summary of Changes in Assessment Inputs

This stock assessment is on a two year cycle, thus any data that became available after the 2022 full stock assessment was added to the models for consideration this September. New data include:

(1) Catch biomass through August 1, 2024
(2) 2022 catch biomass was updated to reflect October – December 2022 catches
(3) 2022 fishery age composition data
(4) 2022 survey age composition data
(5) 2023 Eastern Bering Sea (EBS) shelf survey biomass

Summary of Changes in Assessment Methodology

This document puts forward two models that are minor modifications of Models 22.1 and 22.2 that were presented in Appendix A of the 2022 assessment. Model 24.1 is as for the currently accepted model, but uses input sample sizes for survey age compositions derived using the methods described in (Hulson et al., 2023; Stewart and Hamel, 2014), and subsequently applies data weighting following that in Francis (2011), equation TA1.8. Model 24.2 builds on Model 24.1 by allowing estimation of female natural mortality (male natural mortality is already estimated in all models presented). Francis (2011) prioritizes fits to the survey biomass index, and better accounts for the fact that the newer large year classes are still not old enough to be caught in the fishery and have not been observed many times. The estimates of natural mortality from Model 24.2 were reasonable with small standard deviations, suggesting that as configured, the model can provide natural mortality estimates. This corroborates the fact that the stock is underutilized and lightly fished, and therefore age observations contain valuable information on natural mortality. In addition, the model that estimates both female and male natural mortality led to estimates of catchability that were closer to estimates from previous research on catchability and herding of BSAI NRS. This, along with the Francis (2011) data weighting methodology and Hulson et al. (2023)/Stewart and Hamel (2014) input sample size methodology, led to much improved fits to the survey biomass index in recent years.

Responses to SSC and Plan Team Comments

From the November 2022 Plan Team minutes: *The Team recommended the authors put Models 22.1 and 22.2 forward - with likelihood profiles and an evaluation of performance - as alternative models to the base model in the 2024 assessment cycle, to be presented in September 2024.*

See “Summary of Changes in Assessment Methodology” above, which is in direct response to this Plan Team comment.

From the December 2022 SSC minutes: *The SSC thanks the authors for being responsive to the SSC comments <from Dec 2020>. In particular, the alternative model provided reasonable estimates of* *natural mortality and shows promise for estimating catchability closer to empirical results. The SSC looks forward to future analyses on weighting to address model fits to survey and age composition data as well as development of the climate-enhanced projection model.*

See "Summary of Changes in Assessment Methodology" above. In addition, Matthieu Veron (former AFSC/UW postdoc) continues to work on a climate-enhanced projection model using Northern rock sole as an example. Before the next assessment we hope to explore alternative model runs that account for relationships between environmental variables and Northern rock sole population dynamics, and to further explore these relationships in a mechanistic context as a follow-on from Punt et al. (2021).

Introduction

Northern rock sole (Lepidopsetta polyxystra n. sp.) are distributed primarily on the eastern Bering Sea continental shelf and in much lesser amounts in the Aleutian Islands region. Two species of rock sole are known to occur in the North Pacific Ocean, a northern rock sole (L. polyxystra) and a southern rock sole (L. bilineata) (Orr and Matarese 2000). These species have an overlapping distribution in the Gulf of Alaska, but the northern species comprise the majority of the Bering Sea and Aleutian Islands populations where they are managed as a single stock. The two species were undistinguished prior to 1996. Given the relatively small proportion of Southern rock sole in the BSAI, observations of unidentified rock sole in the BSAI are considered as Northern rock sole in this assessment.

Centers of abundance for rock soles occur off the Kamchatka Peninsula (Shubnikov and Lisovenko 1964), British Columbia (Forrester and Thompson 1969), the central Gulf of Alaska, and in the southeastern Bering Sea (Alton and Sample 1975). Adults exhibit a benthic lifestyle and seem to occupy separate winter (spawning) and summertime feeding distributions on the southeastern Bering Sea continental shelf. Northern rock sole spawn during the winter-early spring period of December-March. Recent research has identified a northern spawning area near the Pribilof Islands that appears to be particularly successful in years with warm bottom temperatures (Cooper et al. 2020).

Fishery

Please see the most recent full assessment of Northern rock sole from 2022 for a full description of the fishery: https://apps-afsc.fisheries.noaa.gov/Plan_Team/2022/BSAIrocksole.pdf.

A time-series of catches is shown in Figure 8.1; Northern rock sole is caught by bottom trawl.

Data

Fishery

This assessment used fishery catches for northern rock sole from 1975 through August 1, 2024 (Figure 8.1), as well as fishery age composition data and yearly estimates of fishery weight-at-age.

Fishery catch-at-age composition for 1979-1994 and 1998-2021 were included in the assessment model. Fishery ages were unavailable in 1995-1997. The fishery catch-at-age composition for the available data estimated using the code in the sampler repository, following methods described by Kimura (1989), modified by Dorn (1992) and further modified by Ianelli to include bootstrap resampling of age and weight data (1000 boostraps were conducted). Length-stratified age data are used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates are then weighted by the catch within each stratum to arrive at an overall age composition for each year. Data were collected through shore- side sampling and at-sea observers. This method was used to derive the age compositions from 1991–2021 (the period for which all the necessary information is readily available).

An analysis of historical fishery data was included in the full 2022 stock assessment: https://apps-afsc.fisheries.noaa.gov/Plan_Team/2022/BSAIrocksole.pdf.

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. In 2010, 2017, and 2018, RACE extended the groundfish survey into the northern Bering Sea and conducted standardized bottom trawls at 142 new stations. Survey-based estimates of total biomass use an “area-swept” approach and implicitly assume a catchability of 1. EBS surveys conducted prior to 1982 were not included in the assessment because the survey gear changed after 1981. To maintain consistent spatial coverage across time, only survey strata that have been consistently sampled since 1982 (i.e., those comprising the "standard" area) are included in the EBS biomass estimates.

The assessment used survey biomass from the EBS shelf trawl survey standard area from 1982-2019 and 2021-2022 within the assessment model (Table 8.2); survey biomass of BSAI northern rock sole in the Aleutian Islands and the Northern Bering Sea is relatively low. Areas of consistently high survey CPUE of northern rock sole are Bristol Bay, north of Bristol Bay, the Pribilof Islands, and one particular area north of the Pribilof Islands.

Survey Age composition

Northern rock sole otoliths have been routinely collected during the trawl surveys since 1979 to provide estimates of the population age composition. This assessment used sex-specific survey age compositions for the period 1979-2019 and 2021. Age composition data are calculated with a two-stage expansion approach which is explained in detail in Hulson et al. (2023). First, sex-specific length samples are expanded by catch within strata to calculate population abundance-at-length within survey strata, and subsequently summing across strata. Second, the resulting length composition data are multiplied by proportions of age-at-length (an age-length key) to derive age composition data. The package afscISS (https://github.com/afsc-assessments/afscISS) was used to perform these calculations and to develop input sample sizes for the survey age composition data.

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 allowed 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.

Survey age composition and weight-at-age data can be found in the BSAI NRS github repository at https://github.com/afsc-assessments/BSAI_NRS.

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-specific 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 that are not used in any configuration presented in this assessment. The model allows for the estimation of sex-specific natural mortality. Only male natural mortality was estimated in the accepted 2022 assessment model. However, an alternative model run (Model 24.2) estimates both male and female natural mortality with lognormal priors and is presented in this document. 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. The oldest age observed in the Eastern Bering Sea survey data was 37. Survey catchability is estimated with a lognormal prior with a median of 1.5 and a standard deviation of 0.2. 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. Parameters of a Ricker stock-recruitment curve were estimated based on estimates spawning biomass from the model and fitting to differences between model-estimated recruitment and that calculated from the stock recruit curve, as a component of the stock assessment model's objective function. The stock-recruit curve is used to estimate F_{MSY} and future ABCs according to the Tier 1 control rule, as detailed in the BSAI FMP. Details of the population dynamics and estimation equations, description of variables and likelihood components are presented in Appendix B of this chapter.

Description of Alternative Models

In this assessment, we present the previously accepted model (Model 18.3), along with a version of Model 18.3 updated with new data (Model 18.3_new). The ABC in 2022 was reduced and set to the OFL from Model 22.1, which was as for Model 18.3, but re-weighted the data sources relative to one another using the Francis (2011) approach. In this document, we show Model 22.1 updated with new available data for the purpose of comparison, but it is not included in the set of proposed models for 2024. Instead, we present two alternative model runs as candidates for the 2024 assessment. Model 24.1 incorporates new data, updates survey input sample sizes according to methods described in Hulson et al., (2023) and Stewart and Hamel (2014) using the R package afscISS (https://github.com/afsc-assessments/afscISS) and additionally re-weights compositional data sources relative to one another using equation TA1.8 from Francis (2011). Model 24.2 builds on Model 24.1 by allowing estimation of female natural mortality with a lognormal prior with a median of 0.15 and a standard deviation of 0.2; (male natural mortality and logspace catchability are estimated in all models presented).

Parameters estimated outside the assessment model

Natural mortality rates, variability of recruitment (σ_R), the maturity ogive, and the weight-at-age in each year were estimated outside of the assessment model and σ_R was equal to 0.6, consistent with previous assessments. The natural mortality rate was fixed at 0.15 for females in all models, except for Model 24.2 (which estimates female natural mortality within the assessment).

In addition, parameters defining the variability of lognormal deviations in the fishery selectivity parameters age at 50% selectivity and the slope of selectivity curve are fixed to 0.35 and 0.2, respectively.

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 due to sparse sample sizes in these age bins.

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

The maturity ogive for northern rock sole is given in Figure 8.2. The maturity schedule for northern rock sole was updated in the 2009 assessment from a histological analysis of 162 ovaries collected from the Bering Sea fishery in February and March 2006 (Stark 2012). Compared to the maturity curve from anatomical scans used previously, the length-based model of Stark indicates nearly the same age at 50% maturity as for the 2009 estimates (7.8 years).

Parameters estimated inside the assessment model

Initial mean numbers-at-age, yearly log mean recruitment and recruitment deviations, log mean fishing mortality, and yearly fishing mortality deviations are estimated within the assessment. Additionally, male natural mortality and survey catchability are estimated. Survey catchability is estimated with a lognormal prior with a median of 1.5 and a standard deviation of 0.2, based on the results of experiments conducted in recent years on the standard research trawl used in the annual trawl surveys. These experiments indicate that rock sole are herded by the bridles (in contact with the seafloor) from the area outside the net mouth into the trawl path with an estimated catchability of 1.4 and a standard error of 0.056 (Somerton and Munro 2001). In each model male natural mortality is estimated with a lognormal prior with a median of 0.15 and a standard deviation of 0.2. Female natural mortality is estimated in model 24.2 with a lognormal prior with a median of 0.15 and a standard deviation of 0.2.

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 (a parameterization 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.

Results

Model Evaluation

Comparison across models

Figure 8.3 shows that both M18.3 and M18.3_new (the two model configurations using arbitrary data weighting) overestimate survey biomass in the most 3-5 years. Re-weighting data sources relative to each other according to Francis (2011) leads to weights assigned to survey age data that are much lower than for models with arbitrary adjusted input sample sizes of 200 (Table 8.3), while those assigned to fishery data are higher, ranging from 543 to 592 across models M22.1, M24.1, and M24.2 (

Table 8.4). These changes lead to an improved fit to survey biomass values overall (Table 8.5) and in the most recent 5 years (Figure 8.3) for models M22.1, M24.1, and M24.2; the model that estimates both female and male natural mortality (M24.2) shows the best fit to the survey biomass data.

Adjusting the input sample sizes for survey age composition data according to Hulson et al. (2023) and Stewart and Hamel (2014), model M24.1, makes a small difference to aggregated fits to survey age composition data (Figure 8.4), but otherwise models M22.1 and M24.1 show very similar results with nearly identical time-series of spawning biomass and recruitment (Figure 8.5), estimated selectivity curves (Figure 8.6-Figure 8.8), sex ratios (Figure 8.9), and stock recruit curve results (Figure 8.10).

Model 24.2 estimates female natural mortality (all models estimate male natural mortality; Table 8.6). Aggregated age composition data are standardized by sample size (considering both input sample sizes and data weighting), therefore there are differences in the proportion at age in the data across models (Figure 8.4). Fits to aggregated age compositions show that M24.2 captures the proportion of the population in the plus group (age 20+) more accurately for both fishery and survey age compositions than any of the other models, consistently across data source and sex. Otherwise all models show similar fits to fishery age composition data. Models that do not incorporate Francis data weighting (M18.3 and M18.3_new) estimate a greater proportion of age 4-6 year old fish and a lesser proportion of age 8-13 year old fish, which is consistent with calculations of proportion in each age class of the input data, adjusted for the input sample sizes and data-weighting used. Yearly plots of fits to fishery and survey age composition data are shown for Models 18.3_new, 24.1, and 24.2 in Appendix A (Figure 8.17-Figure 8.18, Figure 8.20-Figure 8.21, and Figure 8.23-Figure 8.24).

The estimates of female and male natural mortality in M24.2 are 0.19 and 0.23, respectively, with standard deviations of 0.004 and 0.003 (Table 8.6). Northern rock sole is an underutilized stock with older fish present in the data, and therefore there should be more information in the data on these parameters than for a more heavily-fished stock.

The estimates of natural mortality in Model 24.2 are slightly higher than for the other models (Table 8.6), and therefore recruitment estimates are larger in magnitude for this model (Figure 8.5), leading to historical spawning biomass estimates that are larger than for the other models without estimation of female natural mortality (Figure 8.5). Both incorporating data weighting and updated input sample sizes and estimating female natural mortality reduce retrospective bias in spawning biomass and recruitment estimates (Figure 8.11-Figure 8.12). All models led to estimates of survey selectivity curves that were nearly identical (Figure 8.6) and very similar trends were estimated for male and female fishery selectivity over time for M18.3_new, M24.1, and M24.2 (Figure 8.8). Estimated sex ratios are similar across models for the fishery (Figure 8.9). Model 24.1 estimates slightly higher survey and population ratios of female fish. The stock recruit curve for M24.2 differs from that of other models, estimating a larger magnitude of recruits at a given spawning biomass value (Figure 8.10). In particular, the log_alpha parameter of the stock recruit curve is estimated to be larger (3.223) for model M24.2 than for the other models, where it is consistently equal to 2.9 (Table 8.6).

Figure 8.19, Figure 8.22, and Figure 8.25 show mean fishing mortality and fishing mortality-at-age over time for the three candidate models, and Table 8.9 shows yearly deviations from mean fishing mortality. In 1978 the model estimates a spike in mean fishing mortality between 0.8-1 (depending on the model) and selectivity-at-age is focused only on old fish (primarily age 15-20); this can also be seen in Figure 8.7, which also shows that fishery selectivity never reaches 1 in 1978. There are not many age 15-20 year old fish and catches are quite low in 1978 (Figure 8.1 and Table 8.1), so the impact to the model of the unusual 1978 fishery selectivity and mean fishing mortality is quite small.

Deviations from equilibrium initial ages and asymptotic standard deviations about these parameter estimates are shown in Table 8.7 and Table 8.8-Table 8.11 show time-varying deviations for fishing mortality and sex-specific fishery selectivity parameters, along with corresponding asymptotic standard deviations.

Bayesian analysis

MCMCs run with adnuts (https://github.com/Cole-Monnahan-NOAA/adnuts) for Model 24.2 show bimodal posterior distributions for the slowest mixing parameters; these are the fishing mortality deviation and fishery selectivity parameter deviations from 1978 (Figure 8.13). In 1978 there are no fishery age data to support the estimation of these parameters, and MLE estimates for these parameters show high fishing mortality on only the oldest fish for all three candidate models (Figure 8.19, Figure 8.22, and Figure 8.25). However, a sensitivity analysis initializing all fishing mortality deviations at the larger mode of the 1978 fishing mortality deviation's posterior distribution leads to the same estimates for fishing mortality deviations and fishery selectivity as for initializing fishing mortality deviations at 0. In addition, there were no differences in the MLE estimates across parameters, indicating that the MLE results are stable, even for fishery selectivity and mortality parameters from 1978. Otherwise, the diagnostics for these MCMC runs are reasonable. There are no divergences (Figure 8.15), high effective sample sizes (the minimum effective sample size was 107) and effective sample sizes (ESS) which can be seen in Figure 8.13 and Figure 8.14. In addition, the maximum Rhat was 1.025 for 6 chains and 1,000 iterations.

Figure 8.14 shows the joint posterior distribution for survey catchability in log-space (ln_q) and female and male natural mortality parameters, along with correlation coefficients. While there is some correlation between log catchability and natural mortality parameters (-0.57 to -0.59), the posterior distributions are in-line with MLE estimates and the level of uncertainty in parameter values appears to be reasonable. Figure 8.16 shows posterior distributions for derived parameters B_{MSY} and F_{MSYR} (the F_{MSY} parameter that is used for Tier 1 calculations) for models 24.1 and 24.2 (without and with estimation of female natural mortality, respectively). Model 24.2 estimates a larger B_{MSY} and a smaller F_{MSYR} than Model 24.1.

Additional work should be done to simplify the parameterization of fishery selectivity in early years without fishery age data. This may resolve the bimodality in the slowest mixing parameters and lead to more reasonable estimates of fishery selectivity and fishing mortality in 1978. Although it may be argued by some that these MCMCs did not converge because of this bimodality, the catches in 1978 were quite low (Figure 8.1 and Table 8.1) and it is unlikely that they contribute meaningfully to model outcomes. It appears that the model may be using these deviation parameters to fine-tune estimated initial age compositions.

Time series results

Time series tables for spawning biomass, total biomass, and recruitment are presented in Table 8.12-Table 8.14. Numbers-at-age over time for the three candidate models are shown in Appendix A.

Harvest Recommendations

Harvest recommendations will be provided for the November 2024 SAFE.

Data gaps and research priorities

The conflict between survey biomass and age composition data in recent assessments could be explored through data analysis and further work to identify environmental influences on Northern rock sole and the mechanisms behind these influences. One hypothesis to explore would be whether the distribution and availability of young fish to the survey have changed over time. In some historical assessments, it was assumed that catchability was a function of temperature, as for yellowfin sole. Subsequent research and assessment models showed that this relationship did not always hold and that the mechanism behind the temperature-catchability relationship for yellowfin sole was not the same for northern rock sole (Nichol et al., 2019; Olmos et al., 2023). However, further research could be done to investigate whether age-specific availability of northern rock sole to the survey may be occurring and any mechanisms that would drive this.

Other advances that could be made to this assessment include further analysis of uncertainty in maturity as well as analysis of ageing error (the current assessment does not incorporate estimates of ageing uncertainty or bias). Research is underway to develop tools for calculating input sample sizes for fishery age data. We hope that in two years we will be able to update input sample sizes for fishery age data based on this work. Research models exist for BSAI northern rock sole, linking population dynamics to environmental factors. Further research could explore how research models might be used to inform management and whether any of these linkages should be included in the production stock assessment model (e.g. (Punt et al., 2021).

Further work should be done to simplify the parameterization of fishery selectivity in the first four years of the model where no fishery age data exist.

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Tables

Table 8.1. Catch (in tons) of BSAI northern rock sole through August 22, 2024 (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

Year	Domestic	Total
2001	29,477	29,477
2002	41,867	41,867
2003	36,086	36,086
2004	48,681	48,681
2005	37,362	37,362
2006	36,456	36,456
2007	37,126	37,126
2008	51,276	51,276
2009	48,716	48,716
2010	53,200	53,200
2011	60,534	60,534
2012	75,945	75,945
2013	59,751	59,751
2014	51,690	51,690
2015	45,468	45,468
2016	45,084	45,084
2017	35,222	35,222
2018	28,269	28,269
2019	25,800	25,800
2020	25,938	25,938
2021	14,394	14,394
2022	18,399	18,399
2023	27,211	27,211
2024*	24,284	24,284

Table 8.2. Survey biomass estimates (thousands of t; Bio) and standard errors (Std Err) for the EBS shelf trawl survey standard area.

	EBS Standard Area	
Year	Bio	Std. Err.
1982	578.71	74.08
1983	714.09	81.85
1984	799.42	81.82
1985	693.06	58.77
1986	1,021.23	83.74
1987	1,269.58	91.22
1988	1,478.97	101.51
1989	1,323.30	91.08
1990	1,382.91	89.02
1991	1,585.26	95.97
1992	1,548.69	112.28
1993	1,994.68	122.05
1994	2,723.80	223.25
1995	2,179.97	130.54
1996	2,074.10	122.57
1997	2,621.14	190.97
1998	2,180.74	124.16
1999	1,628.59	162.92
2000	2,088.35	320.29
2001	2,350.39	258.82
2002	1,890.99	171.31
2003	2,121.78	196.91
2004	2,207.60	184.93
2005	2,126.73	151.18
2006	2,230.54	151.01
2007	2,047.35	280.40
2008	2,045.18	302.06
2009	1,549.17	159.94
2010	2,081.60	204.59
2011	1,992.82	166.00
2012	1,933.16	186.95
2013	1,765.99	137.63
2014	1,871.41	130.29

2015	1,422.21	131.51
2016	1,470.89	131.96
2017	1,339.34	100.82
2018	1,055.80	115.61
2019	976.87	92.30
2020		
2021	1033.33	86.79
2022	1289.23	111.72
2023	1379.88	137.61

Table 8.3. Survey age composition input sample sizes and those adjusted for data-weighting, all models.

Year	Input Sample Size M18.3, M18.3_new, M22.1	Input Sample Size M24.1 and M24.2	Std Dev of Input Sample Size	Number of Age Samples	Number of Hauls	M18.3 and M18.3_new Adjusted Sample Size	M22.1 Adjusted Sample Size	M24.1 Adjusted Sample Size	M24.2 Adjusted Sample Size
1982	200	55	1.32	294	31	200	27.44	11.11	9.74
1983	200	99	2.62	444	14	200	27.44	20.00	17.53
1984	200	120	2.85	454	21	200	27.44	24.24	21.25
1985	200	144	4.47	571	25	200	27.44	29.09	25.50
1986	200	129	3.51	392	14	200	27.44	26.06	22.84
1987	200	85	3.58	422	6	200	27.44	17.17	15.05
1988	200	95	2.66	350	14	200	27.44	19.19	16.82
1989	200	211	5.53	675	22	200	27.44	42.62	37.36
1990	200	219	5.87	618	30	200	27.44	44.24	38.78
1991	200	202	6.14	551	20	200	27.44	40.80	35.77
1992	200	141	4.93	522	17	200	27.44	28.48	24.97
1993	200	130	3.89	443	12	200	27.44	26.26	23.02
1994	200	134	3.95	466	18	200	27.44	27.07	23.73
1995	200	139	3.76	378	13	200	27.44	28.08	24.61
1996	200	138	3.64	496	14	200	27.44	27.88	24.44
1997	200	84	2.29	336	10	200	27.44	16.97	14.87
1998	200	101	2.79	399	22	200	27.44	20.40	17.89
1999	200	96	1.91	476	26	200	27.44	19.39	17.00
2000	200	101	2.25	403	23	200	27.44	20.40	17.89
2001	200	104	2.22	411	24	200	27.44	21.01	18.42
2002	200	110	2	477	33	200	27.44	22.22	19.48
2003	200	138	2.37	506	34	200	27.44	27.88	24.44
2004	200	97	2.43	383	12	200	27.44	19.59	17.18
2005	200	128	2.89	404	19	200	27.44	25.86	22.67
2006	200	174	4.94	530	43	200	27.44	35.15	30.81
2007	200	151	3.07	463	46	200	27.44	30.50	26.74
2008	200	120	2.48	369	23	200	27.44	24.24	21.25
2009	200	208	4.18	579	65	200	27.44	42.02	36.83
2010	200	171	3.1	490	60	200	27.44	34.54	30.28
2011	200	121	2.26	384	54	200	27.44	24.44	21.43
2012	200	90	1.79	348	48	200	27.44	18.18	15.94
2013	200	106	2.36	352	44	200	27.44	21.41	18.77
2014	200	64	1.45	268	32	200	27.44	12.93	11.33
2015	200	86	2.03	365	50	200	27.44	17.37	15.23

2016	200	112	2.22	462	55	200	27.44	22.62	19.83
2017	200	147	2.82	496	60	200	27.44	29.69	26.03
2018	200	171	3.26	541	58	200	27.44	34.54	30.28
2019	200	163	4.69	538	50	200	27.44	32.93	28.86
2021	200	207	5.28	637	51	200	27.44	41.81	36.66
2022	200	217	5.46	859	262	200	27.44	43.83	38.43

Table 8.4. Fishery age composition input sample sizes and those adjusted for data-weighting, all models, and for all years.

Year	Input Sample Size (all models)	M18.3 and M18.3_new Adjusted Input Sample Size	M22.1 Adjusted Input Sample Size	M24.1 Adjusted Input Sample Size	M24.2 Adjusted Input Sample Size
All years	200	200	542	543	592

Table 8.5. A comparison of likelihood components for all models. Models 18.3 and 18.3_new use input use adjusted sample sizes of 200 for all years of fishery and survey composition data. Model 22.1 re-weights age composition data sets using the methods from Francis (2011), and Models 24.1 and 24.2 use input sample sizes following Hulson et al. (2023) with iterative re-weighting of survey and fishery age composition data following Francis (2011). Therefore, the objective function for survey biomass is the only metric that can be compared across all models incorporating new data.

	M18.3	M18.3_new	M22.1	M24.1	M24.2
Total	1537.08	1564.71	1715.31	1702.28	1731.55
Survey biomass	68.81	69.43	58.45	58.33	39.11
Fishery age comp	541.93	551.87	1255.21	1258.14	1338.35
Survey age comp	705.85	721.71	130.98	114.64	104.69

Table 8.6. Estimated time-invariant parameter values and asymptotic standard deviations for all models.

	Estimate					Standard Deviation				
Parameter	**M18.3**	**M18.3_new**	**M22.1**	**M24.1**	**M24.2**	**M18.3**	**M18.3_new**	**M22.1**	**M24.1**	**M24.2**
male M	0.173	0.174	0.188	0.188	0.225	0.002	0.002	0.002	0.002	0.004
female M	fixed	fixed	fixed	fixed	0.190	fixed	fixed	fixed	fixed	0.003
mean log recruitment	6.781	6.756	6.698	6.708	7.271	0.108	0.107	0.107	0.107	0.117
mean log initial age composition	3.380	3.393	3.280	3.272	3.608	0.125	0.125	0.121	0.121	0.127
log average fishing mortality	-2.260	-2.304	-2.222	-2.223	-2.352	0.087	0.087	0.084	0.084	0.086
log alpha (stock recruit curve)	2.871	2.867	2.925	2.934	3.223	0.204	0.206	0.205	0.205	0.206
log beta (stock recruit curve)	-5.247	-5.247	-5.204	-5.198	-5.442	0.111	0.111	0.110	0.110	0.116
survey catchability	1.946	1.941	2.061	2.058	1.638	0.051	0.050	0.051	0.051	0.050
logFmsyr (basis for Fabc and Fofl)	-1.757	-1.647	-1.633	-1.630	-1.682	0.209	0.241	0.247	0.246	0.278
Bmsy	155.290	156.390	151.020	150.400	178.520	12.346	12.666	12.240	12.127	14.437
female survey slope (selectivity)	1.868	1.869	2.139	2.208	1.839	0.102	0.102	0.316	0.334	0.272
survey age at 50% selectivity	3.514	3.498	3.318	3.247	3.553	0.061	0.060	0.137	0.132	0.168
smale survey slope (selectivity)	0.260	0.268	0.225	0.214	0.297	0.069	0.069	0.189	0.193	0.191
female fishery mean slope (selectivity)	0.997	1.012	0.977	0.980	0.971	0.047	0.047	0.037	0.037	0.035
female fishery mean age at 50% selectivity	9.047	8.915	9.003	8.999	9.286	0.477	0.464	0.462	0.462	0.477
male fishery	1.262	1.288	1.202	1.203	1.212	0.061	0.062	0.047	0.047	0.046

slope (selectivity)										
male fishery selectivity offset	-0.125	-0.115	0.058	0.071	-0.083	0.052	0.050	0.049	0.049	0.053

Table 8.7. Estimated initial age composition deviations from equilibrium conditions for the candidate models.

	Females						**Males**					
	M18.3_new		**M24.1**		**M24.2**		**M18.3_new**		**M24.1**		**M24.2**	
Age	**Dev**	**Std Dev**	**Dev**	**Std Dev**	**Dev**	**Std Dev**	**Dev**	**Std Dev**	**Dev**	**Std Dev**	**Dev**	**Std Dev**
2	1.99	0.16	2.05	0.14	2.22	0.14	1.64	0.18	1.26	0.18	1.49	0.18
3	1.61	0.17	1.75	0.15	1.91	0.15	1.38	0.19	1.13	0.18	1.36	0.18
4	1.70	0.17	1.86	0.14	2.02	0.14	1.48	0.19	1.28	0.17	1.51	0.17
5	2.33	0.15	2.46	0.13	2.61	0.14	1.89	0.17	1.69	0.15	1.92	0.15
6	1.89	0.15	2.00	0.14	2.14	0.14	1.33	0.18	1.20	0.16	1.43	0.16
7	1.04	0.18	1.14	0.15	1.27	0.15	0.74	0.21	0.73	0.17	0.95	0.17
8	0.72	0.20	0.81	0.16	0.94	0.16	0.44	0.23	0.47	0.19	0.67	0.18
9	0.49	0.21	0.55	0.17	0.67	0.17	0.06	0.28	0.10	0.24	0.23	0.22
10	0.25	0.23	0.35	0.19	0.45	0.18	-0.28	0.34	-0.36	0.31	-0.36	0.29
11	-0.50	0.31	-0.48	0.25	-0.43	0.24	-0.76	0.41	-0.85	0.39	-0.92	0.38
12	-0.80	0.35	-0.71	0.30	-0.77	0.29	-0.75	0.43	-0.66	0.41	-0.77	0.40
13	-1.21	0.40	-1.29	0.39	-1.45	0.38	-0.96	0.45	-0.97	0.45	-1.12	0.44
14	-1.20	0.40	-1.20	0.40	-1.38	0.39	-0.99	0.45	-0.97	0.45	-1.12	0.44
15	-1.22	0.40	-1.21	0.40	-1.39	0.39	-0.98	0.45	-0.97	0.45	-1.12	0.44
16	-1.26	0.40	-1.25	0.40	-1.44	0.39	-1.02	0.45	-1.00	0.45	-1.16	0.44
17	-1.27	0.40	-1.26	0.40	-1.45	0.39	-1.03	0.45	-1.01	0.45	-1.17	0.44
18	-1.27	0.40	-1.25	0.40	-1.44	0.39	-1.01	0.45	-0.98	0.45	-1.15	0.44
19	-1.25	0.40	-1.24	0.40	-1.43	0.39	-1.01	0.45	-0.98	0.45	-1.14	0.44
20	-1.24	0.40	-1.23	0.40	-1.41	0.39	-1.00	0.45	-0.98	0.45	-1.14	0.44

Table 8.8. Estimated yearly recruitment deviations and asymptotic standard deviations for the candidate models

	M18.3_new		**M24.1**		**M24.2**	
Year	**Rec Dev**	**Std Dev**	**Rec Dev**	**Std Dev**	**Rec Dev**	**Std Dev**
1975	-1.09	0.13	-1.08	0.12	-1.10	0.12
1976	-0.26	0.12	-0.16	0.11	-0.19	0.11
1977	-0.86	0.12	-0.74	0.12	-0.79	0.12
1978	-0.41	0.12	-0.35	0.12	-0.41	0.12
1979	-0.44	0.12	-0.42	0.12	-0.50	0.12
1980	-0.16	0.12	-0.17	0.12	-0.27	0.12
1981	0.43	0.11	0.40	0.11	0.27	0.11
1982	0.45	0.11	0.42	0.11	0.29	0.11

1983	0.36	0.12	0.35	0.11	0.24	0.11
1984	0.85	0.11	0.97	0.11	0.90	0.11
1985	0.71	0.12	0.77	0.11	0.76	0.11
1986	0.67	0.12	0.62	0.12	0.67	0.12
1987	1.21	0.11	1.11	0.11	1.22	0.11
1988	1.63	0.11	1.62	0.11	1.74	0.11
1989	0.56	0.12	0.65	0.12	0.78	0.12
1990	0.41	0.12	0.43	0.12	0.55	0.12
1991	1.22	0.11	1.28	0.11	1.40	0.11
1992	0.50	0.12	0.57	0.11	0.68	0.11
1993	-0.16	0.13	0.03	0.12	0.13	0.12
1994	0.24	0.12	0.21	0.12	0.30	0.12
1995	-0.40	0.13	-0.23	0.12	-0.15	0.12
1996	-0.43	0.13	-0.15	0.12	-0.09	0.12
1997	-0.11	0.12	-0.06	0.12	-0.01	0.12
1998	-0.68	0.13	-0.49	0.12	-0.46	0.12
1999	-0.24	0.12	0.02	0.12	0.05	0.12
2000	-0.32	0.13	-0.22	0.12	-0.19	0.12
2001	0.43	0.11	0.49	0.11	0.53	0.11
2002	0.88	0.11	0.95	0.11	1.00	0.11
2003	1.04	0.11	1.08	0.11	1.14	0.11
2004	0.76	0.11	0.89	0.11	0.95	0.11
2005	0.55	0.11	0.78	0.11	0.84	0.11
2006	0.73	0.11	0.99	0.11	1.05	0.11
2007	-0.42	0.12	-0.26	0.12	-0.22	0.12
2008	-1.36	0.15	-1.47	0.15	-1.46	0.15
2009	-1.69	0.16	-1.55	0.15	-1.56	0.15
2010	-2.07	0.18	-1.81	0.16	-1.84	0.16
2011	-1.45	0.15	-1.49	0.15	-1.54	0.15
2012	-1.29	0.14	-1.28	0.14	-1.36	0.14
2013	-1.06	0.14	-1.28	0.14	-1.37	0.14
2014	-1.67	0.17	-1.62	0.16	-1.73	0.16
2015	-0.06	0.13	-0.23	0.13	-0.34	0.13
2016	0.43	0.12	0.25	0.13	0.16	0.13
2017	0.63	0.13	0.37	0.14	0.32	0.14
2018	0.48	0.15	0.07	0.17	0.04	0.17
2019	0.58	0.16	-0.17	0.23	-0.22	0.23
2020	1.37	0.17	0.35	0.28	0.25	0.29
2021	-0.39	0.52	-0.37	0.57	-0.42	0.56
2022	-0.08	0.67	-0.05	0.68	-0.09	0.67
2023	0.00	0.71	0.00	0.71	0.00	0.71
2024	0.00	0.71	0.00	0.71	0.00	0.71

Table 8.9. Estimated yearly fishing mortality deviations and asymptotic standard deviations for the candidate models

	M18.3_new		**M24.1**		**M24.2**	
Year	**F Dev**	**Std Dev**	**F Dev**	**Std Dev**	**F Dev**	**Std Dev**
1975	1.22	0.24	1.19	0.22	1.27	0.24

1976	1.54	0.31	1.57	0.27	1.65	0.30
1977	1.35	0.45	1.49	0.39	1.56	0.44
1978	2.84	0.59	3.49	0.71	3.35	0.78
1979	-0.41	0.15	-0.40	0.13	-0.57	0.13
1980	-0.68	0.10	-0.68	0.10	-0.82	0.10
1981	-0.81	0.10	-0.85	0.10	-0.96	0.10
1982	-0.55	0.10	-0.58	0.10	-0.67	0.10
1983	-0.18	0.11	-0.17	0.11	-0.23	0.11
1984	0.81	0.12	0.87	0.12	0.81	0.12
1985	-0.44	0.10	-0.54	0.09	-0.60	0.09
1986	-0.35	0.10	-0.45	0.09	-0.48	0.09
1987	0.17	0.10	0.10	0.09	0.09	0.10
1988	0.83	0.11	0.76	0.09	0.77	0.10
1989	0.57	0.11	0.55	0.10	0.54	0.10
1990	-0.22	0.11	-0.26	0.10	-0.26	0.10
1991	0.29	0.12	0.34	0.11	0.37	0.11
1992	0.28	0.13	0.36	0.12	0.41	0.12
1993	0.28	0.11	0.30	0.11	0.32	0.11
1994	0.28	0.12	0.32	0.11	0.33	0.11
1995	0.50	0.54	0.50	0.45	0.48	0.52
1996	0.53	0.56	0.57	0.45	0.49	0.51
1997	1.52	0.49	1.46	0.29	1.40	0.36
1998	-0.31	0.13	-0.24	0.11	-0.25	0.11
1999	-0.31	0.12	-0.22	0.11	-0.24	0.11
2000	-0.22	0.11	-0.13	0.10	-0.15	0.11
2001	-1.02	0.11	-0.94	0.10	-0.96	0.10
2002	-0.64	0.10	-0.58	0.10	-0.58	0.10
2003	-0.77	0.10	-0.75	0.09	-0.77	0.10
2004	-0.36	0.09	-0.36	0.09	-0.38	0.09
2005	-0.58	0.09	-0.60	0.09	-0.61	0.09
2006	-0.48	0.09	-0.50	0.09	-0.50	0.09
2007	-0.46	0.10	-0.51	0.09	-0.50	0.09
2008	0.00	0.10	-0.04	0.09	-0.03	0.09
2009	-0.03	0.10	-0.07	0.09	-0.04	0.10
2010	0.08	0.11	0.06	0.10	0.09	0.10
2011	0.16	0.11	0.13	0.10	0.15	0.10
2012	0.38	0.12	0.40	0.11	0.42	0.11
2013	0.03	0.11	0.04	0.11	0.08	0.12
2014	0.03	0.11	0.00	0.10	0.02	0.11
2015	-0.06	0.11	-0.10	0.11	-0.08	0.11
2016	-0.05	0.10	-0.17	0.10	-0.17	0.10
2017	-0.25	0.10	-0.36	0.10	-0.34	0.10
2018	-0.40	0.09	-0.57	0.09	-0.56	0.09
2019	-0.41	0.10	-0.56	0.09	-0.52	0.09
2020	-0.47	0.10	-0.60	0.09	-0.54	0.10
2021	-1.13	0.10	-1.24	0.09	-1.16	0.10
2022	-1.11	0.10	-1.19	0.10	-1.09	0.10
2023	-0.36	0.54	-0.34	0.45	-0.19	0.52
2024	-0.64	0.59	-0.53	0.50	-0.37	0.59

Table 8.10. Estimated yearly fishery selectivity age-at-50% selectivity (a50) deviations and asymptotic standard deviations for the candidate models

	Females						Males					
	M18.3_new		M24.1		M24.2		M18.3_new		M24.1		M24.2	
Year	a50 Dev	Std Dev	a50 Dev	Std Dev	a50 Dev	Std Dev	a50 Dev	Std Dev	a50 Dev	Std Dev	a50 Dev	Std Dev
1975	0.39	0.14	0.38	0.13	0.38	0.13	0.32	0.18	0.28	0.16	0.32	0.17
1976	0.48	0.12	0.48	0.11	0.47	0.11	0.44	0.15	0.40	0.14	0.43	0.15
1977	0.54	0.13	0.54	0.11	0.53	0.11	0.50	0.15	0.47	0.13	0.50	0.14
1978	0.65	0.08	0.63	0.07	0.62	0.08	0.68	0.12	0.76	0.10	0.73	0.12
1979	0.06	0.06	0.06	0.06	0.03	0.06	0.23	0.06	0.18	0.06	0.17	0.06
1980	-0.36	0.08	-0.34	0.07	-0.36	0.07	-0.33	0.08	-0.29	0.07	-0.32	0.07
1981	-0.45	0.08	-0.46	0.07	-0.46	0.07	-0.54	0.08	-0.52	0.07	-0.54	0.07
1982	-0.40	0.07	-0.40	0.06	-0.41	0.06	-0.19	0.08	-0.16	0.06	-0.18	0.06
1983	-0.14	0.07	-0.11	0.06	-0.13	0.06	0.16	0.08	0.20	0.06	0.18	0.06
1984	-0.06	0.07	-0.02	0.06	-0.05	0.06	-0.02	0.09	0.09	0.07	0.07	0.07
1985	-0.49	0.07	-0.57	0.06	-0.58	0.06	-0.55	0.07	-0.60	0.06	-0.62	0.06
1986	-0.28	0.06	-0.32	0.06	-0.34	0.06	-0.30	0.07	-0.35	0.06	-0.37	0.06
1987	-0.34	0.07	-0.37	0.06	-0.39	0.06	-0.32	0.07	-0.34	0.06	-0.36	0.06
1988	-0.32	0.08	-0.37	0.06	-0.36	0.06	-0.32	0.06	-0.35	0.06	-0.36	0.05
1989	-0.30	0.07	-0.32	0.06	-0.32	0.06	-0.24	0.07	-0.24	0.06	-0.25	0.06
1990	-0.24	0.07	-0.26	0.06	-0.25	0.06	-0.33	0.07	-0.36	0.06	-0.34	0.06
1991	0.01	0.07	0.03	0.06	0.01	0.06	-0.03	0.07	-0.03	0.06	-0.02	0.06
1992	0.07	0.07	0.09	0.06	0.09	0.06	0.03	0.06	0.03	0.06	0.04	0.06
1993	0.05	0.06	0.05	0.06	0.04	0.06	0.08	0.06	0.04	0.06	0.05	0.05
1994	0.12	0.07	0.13	0.06	0.11	0.06	0.05	0.06	0.01	0.05	0.02	0.06
1995	0.25	0.16	0.21	0.12	0.20	0.12	0.34	0.18	0.33	0.19	0.28	0.21
1996	0.36	0.15	0.31	0.10	0.29	0.11	0.37	0.16	0.41	0.17	0.35	0.17
1997	0.50	0.11	0.41	0.07	0.39	0.07	0.52	0.11	0.57	0.10	0.53	0.11
1998	0.30	0.06	0.30	0.06	0.29	0.06	0.22	0.06	0.21	0.06	0.21	0.06
1999	0.22	0.07	0.24	0.06	0.24	0.06	0.20	0.06	0.20	0.06	0.20	0.06
2000	0.14	0.07	0.19	0.06	0.20	0.06	0.15	0.07	0.17	0.06	0.17	0.06
2001	0.05	0.09	0.12	0.07	0.15	0.06	-0.08	0.09	-0.03	0.07	-0.01	0.06
2002	-0.03	0.09	0.07	0.08	0.12	0.07	-0.13	0.09	-0.07	0.07	-0.05	0.07
2003	-0.03	0.09	0.03	0.07	0.06	0.07	-0.16	0.08	-0.13	0.06	-0.12	0.06
2004	-0.03	0.08	0.01	0.07	0.03	0.06	-0.04	0.08	-0.01	0.06	-0.01	0.06
2005	-0.06	0.08	-0.03	0.07	-0.01	0.06	-0.18	0.08	-0.15	0.06	-0.14	0.06
2006	-0.07	0.08	-0.05	0.06	-0.03	0.06	-0.05	0.07	-0.02	0.06	-0.01	0.06
2007	-0.09	0.07	-0.09	0.06	-0.08	0.06	-0.04	0.07	-0.04	0.06	-0.03	0.06
2008	-0.05	0.06	-0.05	0.06	-0.05	0.06	0.09	0.06	0.09	0.06	0.09	0.06
2009	0.01	0.06	0.01	0.06	0.01	0.06	0.08	0.06	0.07	0.06	0.08	0.06
2010	0.09	0.06	0.09	0.06	0.09	0.06	0.11	0.06	0.11	0.06	0.13	0.06
2011	0.07	0.06	0.08	0.06	0.08	0.06	0.13	0.07	0.14	0.06	0.15	0.06
2012	0.07	0.07	0.10	0.06	0.11	0.06	0.16	0.07	0.20	0.06	0.21	0.06
2013	0.03	0.07	0.09	0.06	0.11	0.06	0.03	0.08	0.10	0.07	0.13	0.07
2014	0.16	0.06	0.18	0.06	0.18	0.06	0.19	0.07	0.21	0.06	0.22	0.06
2015	0.18	0.07	0.22	0.06	0.22	0.06	0.09	0.10	0.13	0.07	0.15	0.07

2016	0.15	0.07	0.16	0.06	0.15	0.06	-0.11	0.12	-0.05	0.11	-0.03	0.11
2017	0.03	0.13	0.10	0.08	0.11	0.07	-0.12	0.10	-0.15	0.08	-0.15	0.08
2018	-0.16	0.09	-0.23	0.08	-0.22	0.08	-0.16	0.09	-0.23	0.08	-0.24	0.07
2019	-0.09	0.09	-0.13	0.08	-0.13	0.07	-0.23	0.08	-0.30	0.07	-0.30	0.07
2020	-0.31	0.07	-0.38	0.06	-0.37	0.06	-0.21	0.07	-0.28	0.07	-0.27	0.06
2021	-0.33	0.07	-0.41	0.06	-0.40	0.06	-0.25	0.07	-0.34	0.06	-0.32	0.06
2022	-0.31	0.07	-0.40	0.06	-0.37	0.06	-0.27	0.07	-0.38	0.06	-0.35	0.06
2023	0.00	0.34	0.00	0.35	0.00	0.35	0.01	0.35	0.00	0.35	0.00	0.35
2024	0.00	0.35	0.00	0.35	0.00	0.35	0.00	0.35	0.00	0.35	0.00	0.35

Table 8.11. Estimated yearly fishery selectivity slope parameter deviations and asymptotic standard deviations for the candidate models

	Females						**Males**					
	M18.3_new		**M24.1**		**M24.2**		**M18.3_new**		**M24.1**		**M24.2**	
Year	**slope Dev**	**Std Dev**	**slope Dev**	**Std Dev**	**slope Dev**	**Std Dev**	**slope Dev**	**Std Dev**	**slope Dev**	**Std Dev**	**slope Dev**	**Std Dev**
1975	0.04	0.19	0.05	0.19	0.06	0.19	0.02	0.20	0.03	0.20	0.03	0.20
1976	0.05	0.19	0.07	0.19	0.07	0.19	0.03	0.20	0.03	0.20	0.03	0.20
1977	0.05	0.19	0.07	0.19	0.08	0.19	0.03	0.20	0.04	0.20	0.04	0.20
1978	0.11	0.18	0.22	0.17	0.21	0.17	0.04	0.19	0.02	0.19	0.03	0.19
1979	0.11	0.14	0.13	0.11	0.15	0.11	0.02	0.14	0.07	0.11	0.07	0.10
1980	0.00	0.14	0.00	0.11	0.02	0.10	-0.16	0.14	-0.17	0.10	-0.15	0.09
1981	0.04	0.13	0.08	0.10	0.08	0.09	0.10	0.14	0.12	0.11	0.13	0.10
1982	0.17	0.12	0.21	0.09	0.21	0.08	-0.14	0.13	-0.17	0.09	-0.16	0.08
1983	0.07	0.11	0.06	0.08	0.07	0.07	-0.34	0.13	-0.39	0.09	-0.38	0.09
1984	-0.04	0.11	-0.07	0.08	-0.04	0.07	-0.36	0.13	-0.50	0.08	-0.48	0.08
1985	0.20	0.14	0.39	0.11	0.41	0.10	0.21	0.13	0.39	0.10	0.43	0.09
1986	0.29	0.13	0.45	0.10	0.47	0.09	0.18	0.13	0.33	0.10	0.37	0.09
1987	0.10	0.12	0.21	0.09	0.25	0.08	0.06	0.13	0.15	0.10	0.20	0.09
1988	0.11	0.13	0.24	0.10	0.26	0.09	0.27	0.13	0.41	0.10	0.45	0.09
1989	0.25	0.13	0.36	0.10	0.39	0.09	0.10	0.13	0.12	0.09	0.18	0.09
1990	0.07	0.12	0.11	0.09	0.15	0.08	0.17	0.14	0.24	0.11	0.24	0.10
1991	-0.13	0.12	-0.15	0.08	-0.08	0.07	-0.04	0.12	-0.05	0.08	-0.01	0.07
1992	-0.13	0.12	-0.17	0.08	-0.12	0.07	-0.04	0.12	-0.05	0.09	-0.04	0.08
1993	0.13	0.13	0.14	0.09	0.17	0.08	0.22	0.13	0.33	0.09	0.32	0.09
1994	-0.02	0.14	-0.06	0.10	-0.01	0.09	0.22	0.15	0.41	0.12	0.37	0.12
1995	0.04	0.20	0.06	0.20	0.05	0.20	0.03	0.19	0.03	0.20	0.03	0.20
1996	0.04	0.20	0.08	0.20	0.06	0.20	0.04	0.20	0.04	0.20	0.04	0.20
1997	0.07	0.19	0.19	0.19	0.15	0.20	0.06	0.19	0.04	0.19	0.04	0.19
1998	-0.31	0.13	-0.34	0.10	-0.31	0.09	0.08	0.16	0.12	0.12	0.11	0.12
1999	-0.20	0.15	-0.25	0.11	-0.25	0.10	-0.07	0.15	-0.09	0.11	-0.10	0.11
2000	-0.22	0.16	-0.35	0.11	-0.37	0.10	-0.08	0.17	-0.16	0.12	-0.17	0.12
2001	-0.31	0.15	-0.47	0.10	-0.48	0.09	-0.04	0.17	-0.12	0.13	-0.15	0.12
2002	-0.15	0.18	-0.36	0.13	-0.45	0.11	-0.02	0.17	-0.09	0.12	-0.11	0.11
2003	-0.17	0.16	-0.30	0.11	-0.33	0.10	0.03	0.16	0.04	0.12	0.03	0.11
2004	-0.09	0.15	-0.15	0.10	-0.17	0.09	-0.02	0.16	-0.04	0.11	-0.05	0.11
2005	-0.09	0.14	-0.15	0.10	-0.15	0.09	0.03	0.15	0.00	0.11	-0.01	0.10

2006	-0.01	0.14	-0.05	0.10	-0.06	0.09	-0.01	0.15	-0.06	0.11	-0.06	0.11
2007	0.07	0.14	0.10	0.10	0.09	0.09	-0.07	0.14	-0.08	0.10	-0.08	0.10
2008	0.07	0.13	0.11	0.10	0.11	0.09	-0.08	0.14	-0.09	0.10	-0.08	0.10
2009	0.06	0.14	0.11	0.10	0.10	0.09	-0.10	0.14	-0.09	0.10	-0.09	0.09
2010	-0.08	0.13	-0.07	0.09	-0.06	0.08	-0.14	0.14	-0.15	0.10	-0.16	0.09
2011	0.00	0.14	0.04	0.10	0.02	0.09	-0.10	0.16	-0.12	0.12	-0.15	0.11
2012	-0.12	0.14	-0.14	0.10	-0.15	0.09	-0.24	0.17	-0.39	0.13	-0.41	0.12
2013	-0.14	0.17	-0.26	0.13	-0.33	0.12	-0.04	0.20	-0.29	0.17	-0.36	0.16
2014	-0.04	0.17	-0.06	0.13	-0.10	0.12	-0.04	0.19	-0.16	0.15	-0.20	0.15
2015	-0.17	0.17	-0.32	0.13	-0.35	0.12	-0.02	0.18	-0.12	0.15	-0.16	0.15
2016	-0.08	0.20	-0.19	0.16	-0.22	0.15	-0.07	0.19	-0.23	0.18	-0.27	0.19
2017	-0.21	0.17	-0.39	0.11	-0.40	0.09	-0.02	0.17	-0.02	0.14	-0.02	0.14
2018	0.05	0.16	0.12	0.15	0.11	0.14	0.03	0.16	0.13	0.14	0.15	0.14
2019	-0.09	0.14	-0.11	0.12	-0.11	0.11	0.02	0.15	0.09	0.12	0.11	0.12
2020	0.12	0.14	0.17	0.12	0.19	0.11	-0.03	0.14	-0.01	0.12	0.00	0.11
2021	0.24	0.13	0.34	0.12	0.34	0.11	0.10	0.14	0.17	0.12	0.17	0.12
2022	0.21	0.13	0.30	0.12	0.26	0.11	0.22	0.15	0.34	0.13	0.30	0.13
2023	0.00	0.20	0.00	0.20	0.00	0.20	0.00	0.20	0.00	0.20	0.00	0.20
2024	0.00	0.20	0.00	0.20	0.00	0.20	0.00	0.20	0.00	0.20	0.00	0.20

Table 8.12. Estimated spawning biomass (SSB) and corresponding asymptotic standard deviations (Std. Dev) for the previous assessment and the three candidate models for 2024.

	2022 Assessment		M18.3_new		M24.1		M24.2	
Year	SSB	Std. Dev	SSB	Std. Dev	SSB	Std. Dev	SSB	Std. Dev
1975	48.499	3.755	49.045	3.815	44.968	2.749	59.858	4.327
1976	48.897	3.928	49.601	3.991	46.007	2.879	63.236	4.754
1977	54.144	4.223	55.026	4.290	51.684	3.215	72.209	5.363
1978	67.006	4.692	68.140	4.766	64.674	3.816	89.949	6.311
1979	82.396	5.369	83.845	5.457	79.971	4.580	109.681	7.429
1980	94.486	5.878	96.209	5.972	92.997	5.281	124.081	8.175
1981	100.706	6.121	102.618	6.216	99.730	5.679	129.528	8.389
1982	100.453	6.053	102.432	6.148	99.301	5.641	125.436	7.967
1983	105.690	6.092	107.789	6.185	104.743	5.718	129.604	7.808
1984	119.585	6.696	122.052	6.797	119.299	6.306	145.662	8.358
1985	116.998	6.692	119.626	6.788	117.034	6.208	143.911	8.126
1986	123.639	6.599	126.347	6.689	124.877	6.149	149.972	7.859
1987	148.617	7.217	151.686	7.303	149.415	6.814	175.765	8.561
1988	155.766	7.305	158.988	7.377	155.000	7.026	179.844	8.693
1989	163.769	8.037	167.358	8.095	158.905	7.784	184.634	9.574
1990	177.721	8.949	181.549	8.995	169.074	8.700	196.762	10.610
1991	199.031	9.501	202.641	9.534	189.401	9.254	218.971	11.217
1992	215.356	9.733	217.648	9.744	205.595	9.432	239.086	11.562
1993	272.954	11.517	273.131	11.474	259.710	10.930	305.752	13.748
1994	317.170	12.353	314.428	12.293	298.169	11.434	360.166	15.107
1995	366.632	13.512	363.635	13.436	339.029	12.216	420.183	16.927
1996	450.015	16.403	447.971	16.382	413.266	14.881	528.667	21.712
1997	493.620	17.737	493.262	17.723	450.811	15.881	580.574	23.521
1998	485.398	17.308	487.106	17.248	437.522	15.100	566.698	22.565
1999	509.759	17.634	511.487	17.534	464.296	15.626	593.248	22.823
2000	533.741	18.152	535.526	18.012	492.783	16.380	624.350	23.531
2001	549.379	18.997	551.233	18.830	511.277	17.359	639.346	24.026
2002	557.758	19.070	559.615	18.887	524.987	17.619	645.169	23.677
2003	568.449	19.744	570.385	19.545	540.135	18.389	652.796	23.842
2004	551.987	19.269	553.671	19.061	533.431	18.174	637.036	23.120
2005	470.123	17.075	471.690	16.885	455.795	16.167	534.484	19.708
2006	431.805	16.178	433.196	15.989	421.128	15.398	483.195	17.995
2007	407.609	15.551	408.806	15.360	402.470	14.938	456.734	17.134
2008	388.716	14.819	389.459	14.618	391.299	14.463	444.696	16.642
2009	354.036	13.862	354.307	13.650	355.091	13.561	404.180	15.429
2010	375.854	14.433	375.421	14.174	378.364	14.250	439.634	16.760
2011	429.022	16.064	427.586	15.719	432.854	15.992	514.508	19.641
2012	461.090	17.432	458.799	17.012	469.605	17.573	565.358	22.033
2013	469.144	18.401	466.154	17.917	484.191	18.807	590.264	23.840
2014	473.966	19.181	470.575	18.646	498.780	19.927	606.433	24.967
2015	485.950	20.271	482.386	19.688	521.988	21.409	629.402	26.353
2016	433.155	18.937	430.038	18.390	471.830	20.211	557.172	23.861
2017	390.781	18.152	387.853	17.620	428.293	19.415	494.459	21.985
2018	338.873	16.660	336.259	16.165	374.696	17.865	421.863	19.469
2019	304.586	15.620	302.213	15.153	338.134	16.798	371.240	17.744
2020	274.107	14.705	271.609	14.259	303.112	15.775	323.261	16.101
2021	254.990	14.163	246.671	13.377	271.029	14.623	281.412	14.519
2022	250.336	13.818	237.204	12.668	253.616	13.572	258.929	13.300
2023	NA	NA	251.757	13.206	255.473	13.496	259.096	13.160
2024	NA	NA	286.017	15.969	269.509	15.159	276.129	15.270

Table 8.13. Estimated total biomass (all ages) and corresponding asymptotic standard deviations (Std. Dev) for the previous assessment and the three candidate models for 2024.

	2022 Assessment		M18.3_new		M24.1		M24.2	
Year	Biomass	Std. Dev	Biomass	Std. Dev	Biomass	Std. Dev	Biomass	Std. Dev
1975	173.07	8.16	175.52	8.32	162.93	6.60	244.04	14.72
1976	186.26	8.87	189.10	9.03	175.20	7.46	264.59	16.13
1977	200.27	9.49	203.44	9.66	188.11	8.20	281.71	16.96
1978	219.93	10.00	223.39	10.18	206.74	8.77	303.01	17.41
1979	237.85	10.35	241.54	10.52	224.09	9.12	321.54	17.46
1980	261.52	10.68	265.43	10.85	247.74	9.40	347.51	17.53
1981	313.33	11.55	317.68	11.73	299.02	10.08	414.05	19.01
1982	339.95	11.49	344.38	11.64	323.60	10.02	442.05	18.93
1983	408.63	12.82	413.52	12.98	390.17	11.38	524.82	21.31
1984	452.02	13.57	457.05	13.71	431.15	12.16	570.65	22.21
1985	591.82	16.80	597.46	16.93	559.84	15.15	746.49	28.70
1986	593.55	16.44	598.59	16.53	557.24	14.68	736.74	27.52
1987	789.84	20.63	795.23	20.69	738.63	18.44	974.62	35.44
1988	867.86	22.35	872.74	22.34	806.75	19.72	1082.56	39.92
1989	875.84	23.57	880.49	23.48	809.15	20.44	1124.43	44.03
1990	842.50	23.82	846.42	23.69	772.61	20.44	1076.23	42.83
1991	895.70	24.49	899.79	24.32	819.27	20.77	1163.14	46.58
1992	909.02	24.51	912.86	24.31	827.90	20.64	1190.83	48.13
1993	1101.07	29.41	1105.40	29.16	999.25	24.70	1451.26	59.07
1994	1189.40	31.57	1192.48	31.29	1079.10	26.63	1580.05	64.72
1995	1202.49	32.40	1205.03	32.10	1089.76	27.39	1591.42	64.87
1996	1283.46	34.51	1285.07	34.18	1169.26	29.41	1696.87	68.22
1997	1250.69	33.76	1251.89	33.43	1139.62	28.78	1629.52	63.91
1998	1154.42	31.69	1155.30	31.33	1051.64	26.96	1489.05	57.56
1999	1056.73	29.48	1057.21	29.13	960.03	25.06	1324.24	49.35
2000	1040.15	29.42	1040.36	29.05	948.84	25.14	1289.11	47.13
2001	1097.88	31.41	1097.54	31.00	1005.54	26.85	1362.12	49.62
2002	1094.08	30.98	1093.26	30.54	1016.87	26.89	1361.86	48.61
2003	1134.40	32.15	1132.81	31.66	1061.60	28.15	1416.39	50.29
2004	1282.22	34.91	1278.29	34.26	1224.08	31.28	1674.03	61.18
2005	1156.08	31.84	1151.73	31.20	1103.07	28.52	1501.87	54.77
2006	1067.52	29.79	1062.77	29.14	1017.20	26.74	1369.83	49.39
2007	1055.64	29.57	1050.00	28.87	1012.69	26.79	1358.68	48.93
2008	1081.24	30.28	1074.14	29.49	1047.12	27.79	1406.26	50.98
2009	1027.72	29.47	1020.00	28.64	996.09	27.14	1337.07	49.02
2010	1067.50	31.19	1058.63	30.25	1048.11	29.25	1408.78	52.39
2011	1187.23	35.57	1176.69	34.42	1183.13	34.08	1593.40	60.45
2012	1096.27	34.40	1085.68	33.26	1096.13	33.09	1451.23	54.95
2013	998.77	33.48	988.53	32.36	1004.39	32.51	1318.67	51.14
2014	895.24	31.87	884.81	30.77	899.70	30.94	1160.59	45.59
2015	895.04	33.36	883.77	32.18	900.90	32.44	1147.74	45.89
2016	790.51	30.99	778.69	29.85	789.32	29.94	988.04	40.22
2017	728.61	30.08	714.50	28.87	714.26	28.55	880.64	36.66
2018	712.06	30.43	693.64	28.94	674.86	27.76	827.47	35.08
2019	776.39	34.47	749.00	32.02	694.76	29.04	855.58	37.35
2020	859.10	40.68	815.45	36.30	712.06	30.77	877.84	40.28
2021	978.62	51.46	902.58	42.65	732.26	33.56	903.25	44.83
2022	1174.27	72.17	1049.11	53.74	785.48	39.57	971.59	54.63
2023	NA	NA	1216.95	69.66	839.64	48.89	1035.51	68.37
2024	NA	NA	1320.23	83.55	868.92	60.00	1068.47	84.06

Table 8.14. Estimated age 1 recruitment and corresponding asymptotic standard deviations (Std. Dev) for the previous assessment and the three candidate models for 2024.

	2022 Assessment		M18.3_new		M24.1		M24.2	
Year	Recruits	Std. Dev	Recruits	Std. Dev	Recruits	Std. Dev	Recruits	Std. Dev
1975	284.548	22.253	287.998	22.558	277.965	18.406	480.89	38.8579
1976	655.011	36.529	664.195	37.074	697.830	34.479	1186.28	80.102
1977	360.541	25.607	364.547	25.915	389.682	25.155	653.634	50.9853
1978	561.191	34.751	568.480	35.215	575.619	34.027	950.856	69.5204
1979	548.746	35.729	554.247	36.152	538.010	32.451	869.772	63.1564
1980	721.748	43.200	728.600	43.699	691.856	37.199	1095.14	72.9571
1981	1306.700	63.440	1323.710	64.272	1215.580	53.901	1890.07	111.651
1982	1333.530	67.671	1343.000	68.263	1245.780	57.528	1923.91	116.003
1983	1231.610	67.720	1231.200	67.817	1160.560	56.192	1821.66	114.085
1984	2021.310	93.964	2013.150	93.521	2156.820	85.271	3535.93	207.784
1985	1749.660	90.126	1740.690	89.799	1771.550	79.401	3085.01	201.718
1986	1670.150	92.585	1680.430	92.903	1521.020	79.647	2822.04	207.342
1987	2828.500	131.194	2873.180	132.160	2491.090	114.521	4851.95	349.892
1988	4331.740	173.015	4376.460	173.602	4128.870	160.048	8229	563.314
1989	1503.020	89.433	1511.410	89.723	1573.730	85.167	3144.17	243.278
1990	1287.030	80.597	1300.460	81.086	1256.000	73.109	2504.33	200.662
1991	2884.810	128.469	2897.340	128.496	2936.430	121.222	5841.92	405.644
1992	1423.800	81.844	1419.860	81.661	1445.630	75.170	2852.82	215.218
1993	733.733	54.897	731.541	54.813	840.271	52.819	1642.7	135.037
1994	1084.660	66.174	1089.360	66.261	1011.910	56.836	1944.86	149.652
1995	572.596	45.559	576.716	45.721	651.696	42.915	1236.21	102.66
1996	556.412	43.968	557.029	43.951	702.443	43.724	1316.59	105.086
1997	767.383	51.739	769.928	51.738	771.848	45.517	1421.85	109.431
1998	439.975	38.030	436.844	37.837	499.224	35.001	910.008	76.9901
1999	673.512	47.505	674.200	47.391	835.711	46.907	1518.68	112.733
2000	628.093	45.941	626.076	45.698	655.482	40.951	1192.45	94.2826
2001	1333.990	70.691	1323.250	69.886	1338.080	63.614	2454.98	169.825
2002	2074.980	93.757	2067.420	92.598	2111.010	87.545	3906.79	257.014
2003	2458.620	106.209	2432.740	104.052	2421.140	98.814	4511.29	296.379
2004	1847.470	89.149	1839.430	87.545	1989.900	88.331	3727.21	252.7
2005	1493.100	78.317	1483.830	76.707	1776.810	83.907	3325.73	230.115
2006	1784.990	88.873	1779.170	86.911	2203.790	101.099	4091.48	276.835
2007	556.434	42.714	562.646	42.257	633.912	44.376	1158.22	97.2999
2008	220.036	24.999	219.643	24.568	188.019	21.884	334.74	41.1386
2009	155.804	20.420	158.576	20.218	173.507	20.470	302.573	37.3964
2010	106.671	16.297	108.409	16.107	134.382	17.332	229.058	30.4995
2011	200.974	23.382	201.964	22.710	184.726	20.646	308.099	36.2384
2012	241.357	26.612	236.591	25.208	226.493	23.422	370.901	40.481
2013	317.555	32.712	297.095	29.707	228.679	23.803	364.37	39.7396
2014	161.040	23.770	161.308	22.157	161.904	20.004	255.583	32.3644
2015	870.409	75.250	806.500	64.476	648.334	52.589	1021.42	92.0157
2016	1426.230	124.888	1319.400	102.595	1049.010	84.002	1692.96	154.497
2017	1705.860	176.745	1612.240	140.943	1185.040	115.429	1979.79	215.053
2018	1425.500	206.053	1387.840	154.648	875.507	127.230	1495.56	228.181
2019	2152.690	373.075	1529.810	203.226	693.289	149.070	1153.32	257.961
2020	4235.110	1063.830	3378.010	490.965	1159.330	316.794	1843.18	532.614
2021	840.111	567.162	584.113	306.819	563.700	320.924	946.38	530.944
2022	880.472	629.522	794.588	537.017	777.488	534.332	1320.35	889.233
2023	NA	NA	858.712	613.934	818.405	585.250	1438.04	1030.63
2024	NA	NA	859.146	614.404	818.513	585.368	1438.12	1030.73

Figures

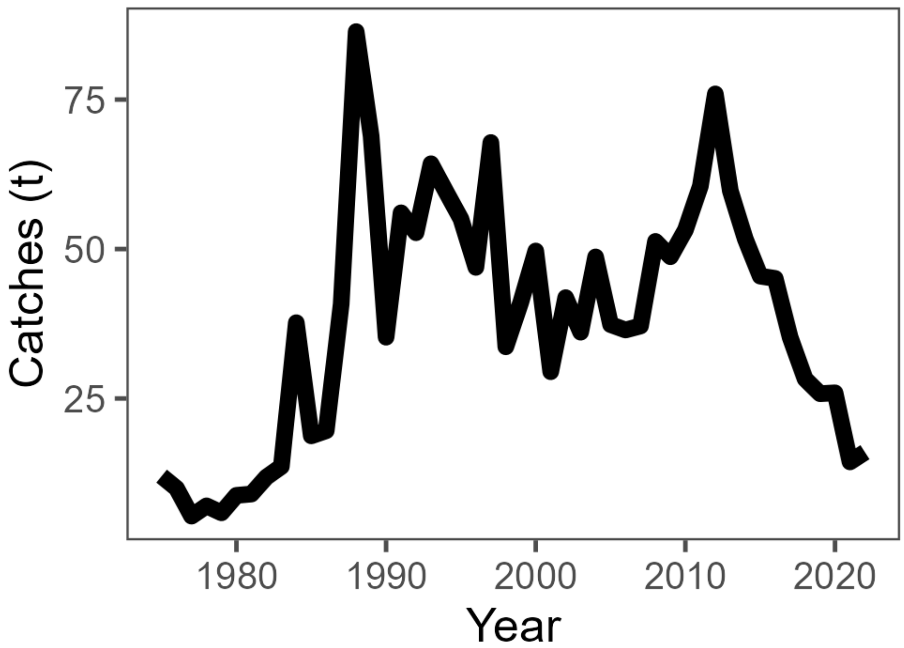

Figure 8.1. Total catch (t) of rock sole by year.

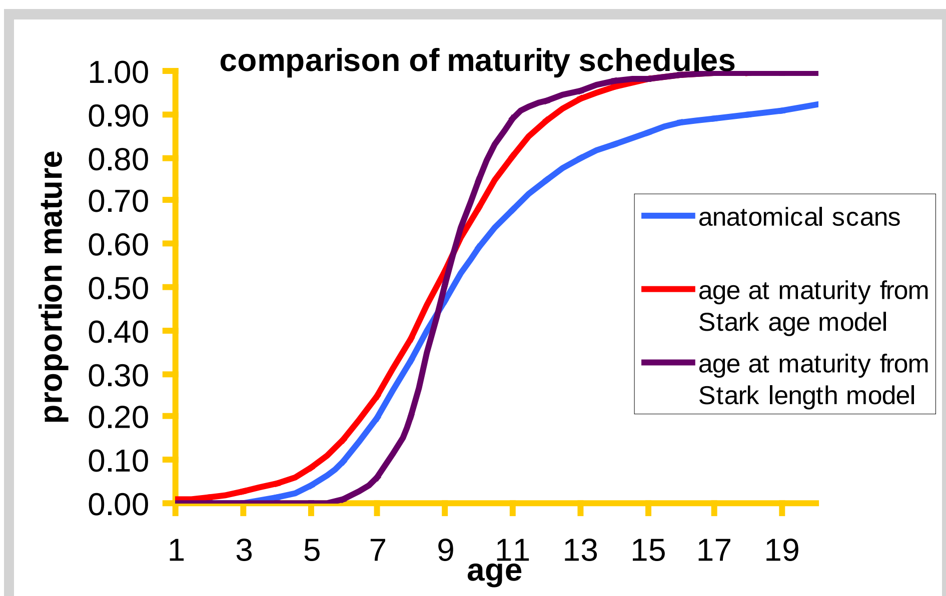

Figure 8.2. Maturity schedule for northern rock sole from three methods (bottom panel). The Stark (2012) length model, based on histology, is used in the stock assessment replacing the curve from anatomical scanning of fish used in past assessments.

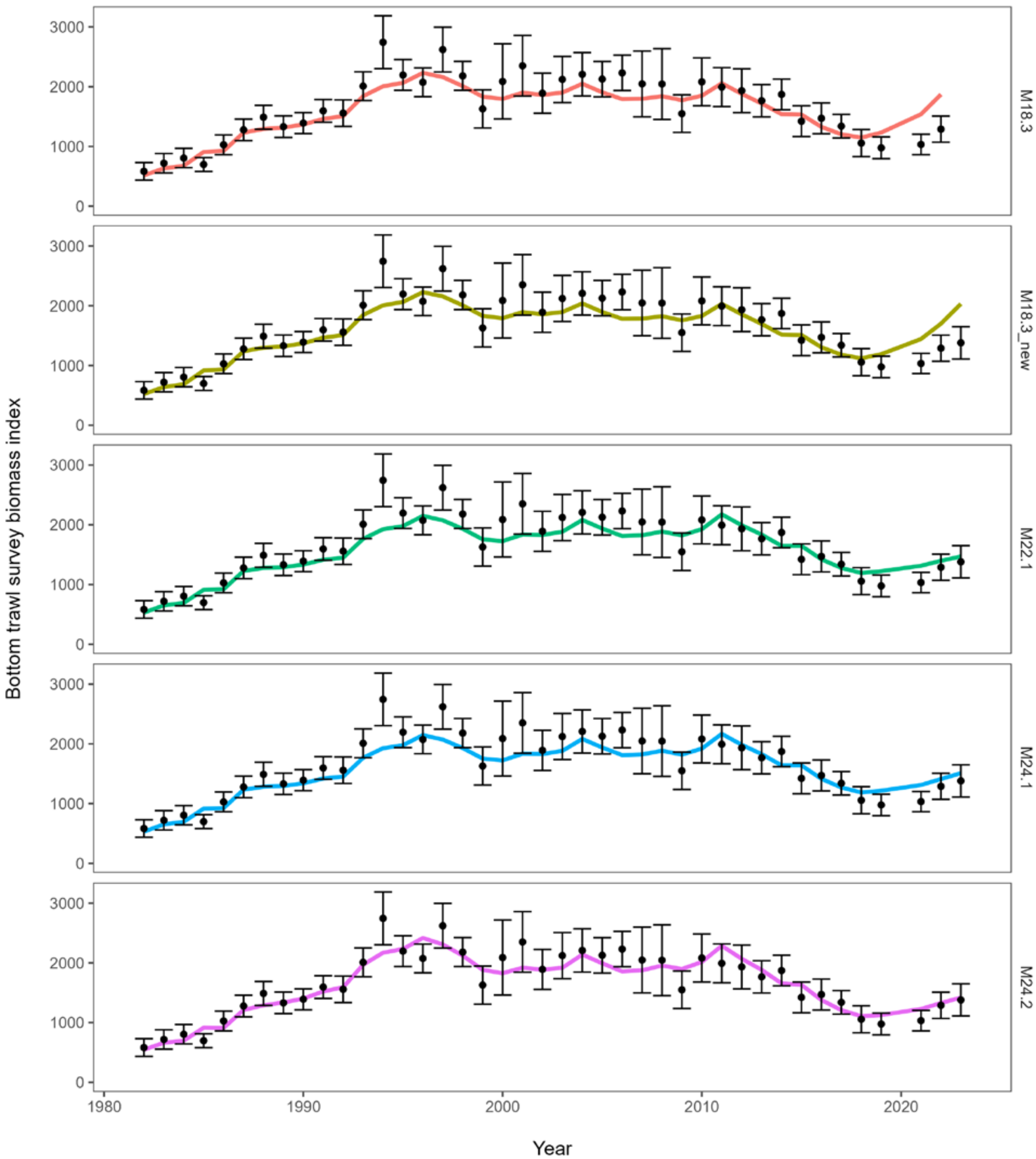

Figure 8.3. Survey biomass and asymptotic 95% confidence intervals (black dots and vertical lines) and fits to the survey biomass for all models presented.

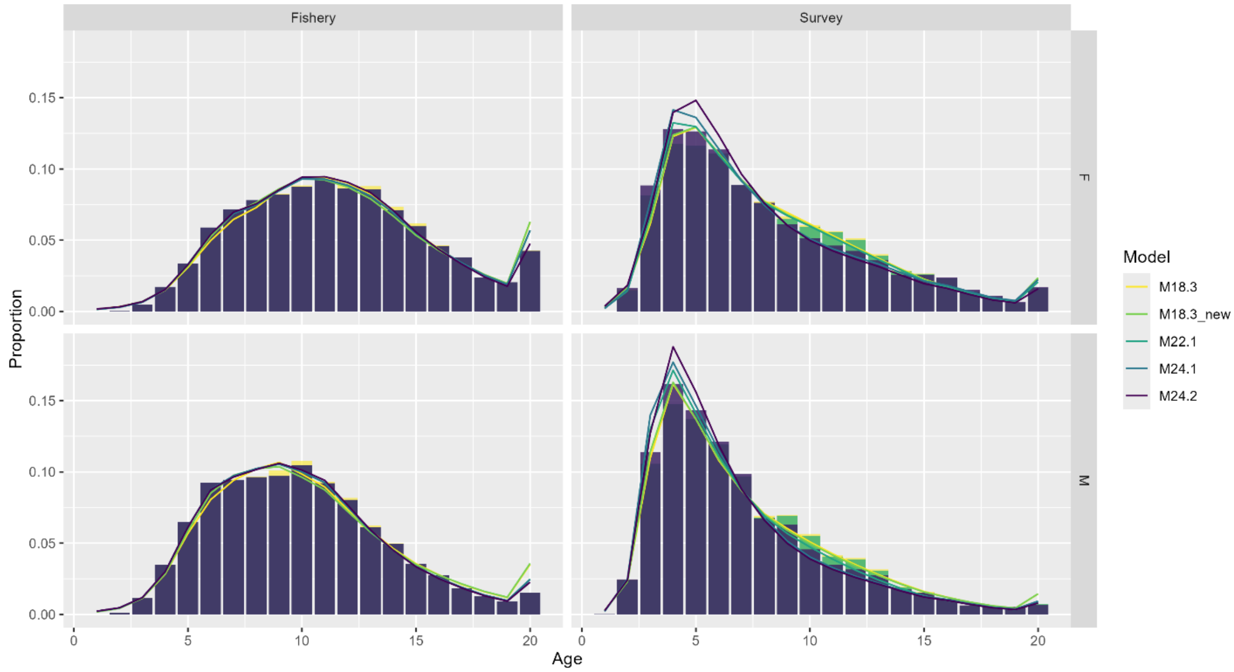

Figure 8.4. Observed (histograms) and expected (lines) fishery (left panels) and survey (right panels) age compositions aggregated over years for females (upper panels) and males (lower panels) for all models. Plots of yearly fits to age composition data for each candidate model are shown in Appendix A.

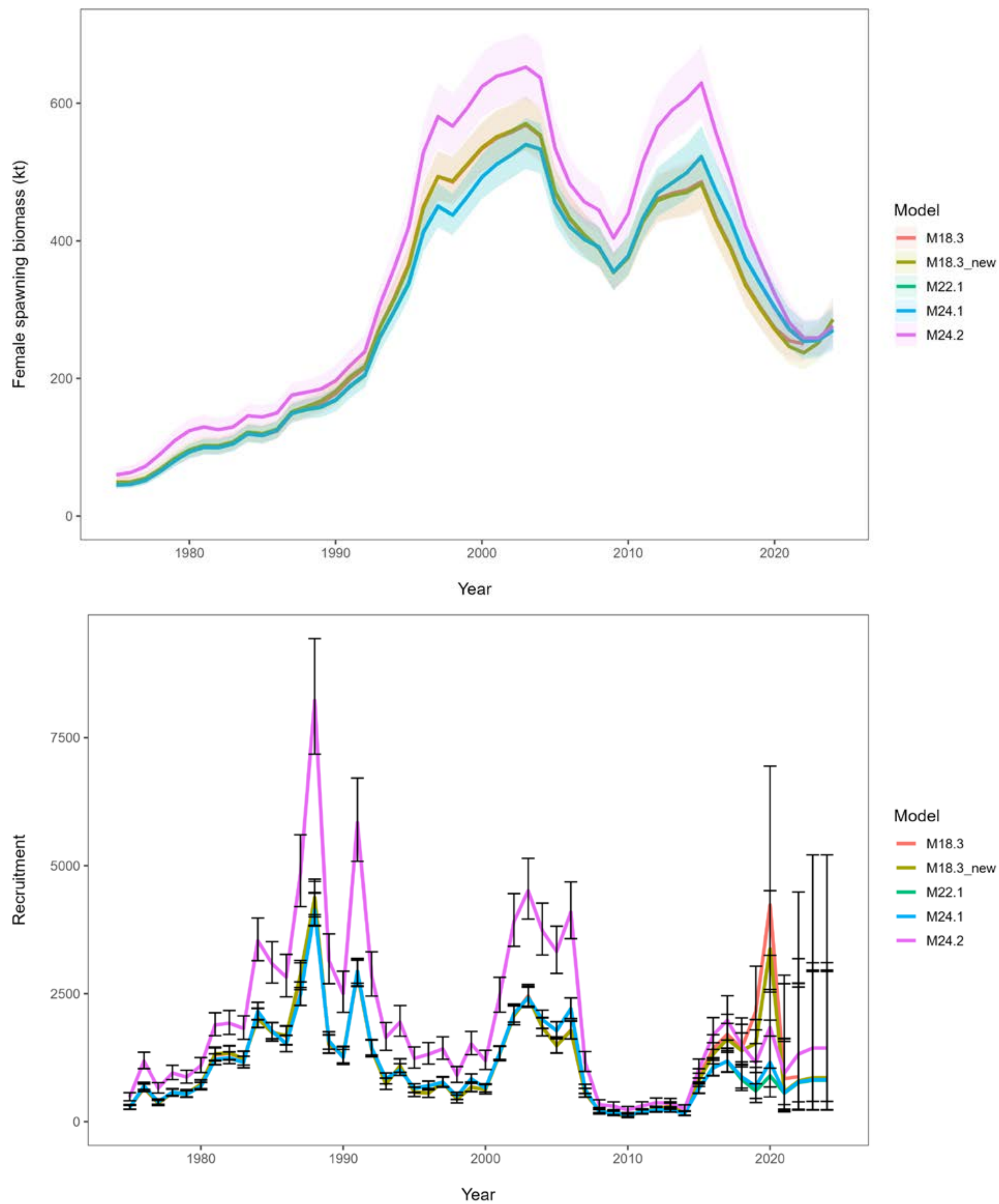

Figure 8.5. Spawning stock biomass estimates (top panel) and recruitment estimates (bottom panel) and with 95% asymptotic confidence intervals for all alternative models.

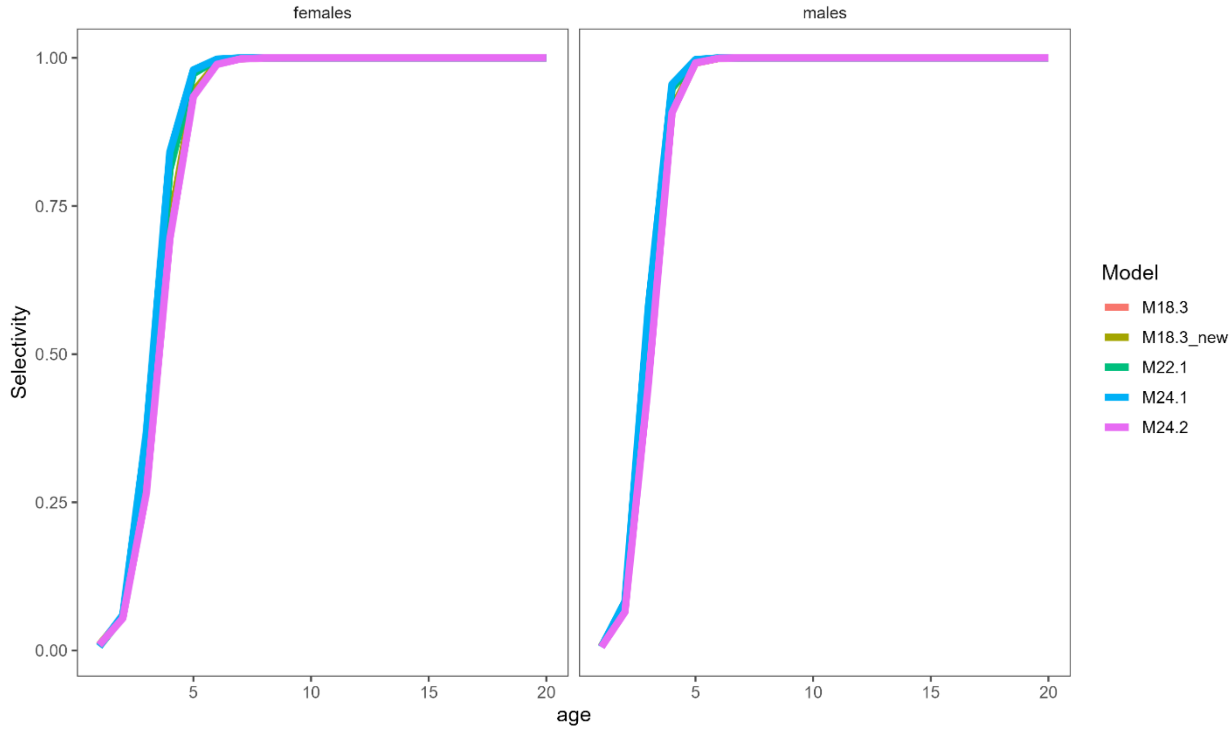

Figure 8.6. Female (left panel) and male (right panel) survey selectivity for all alternative models.

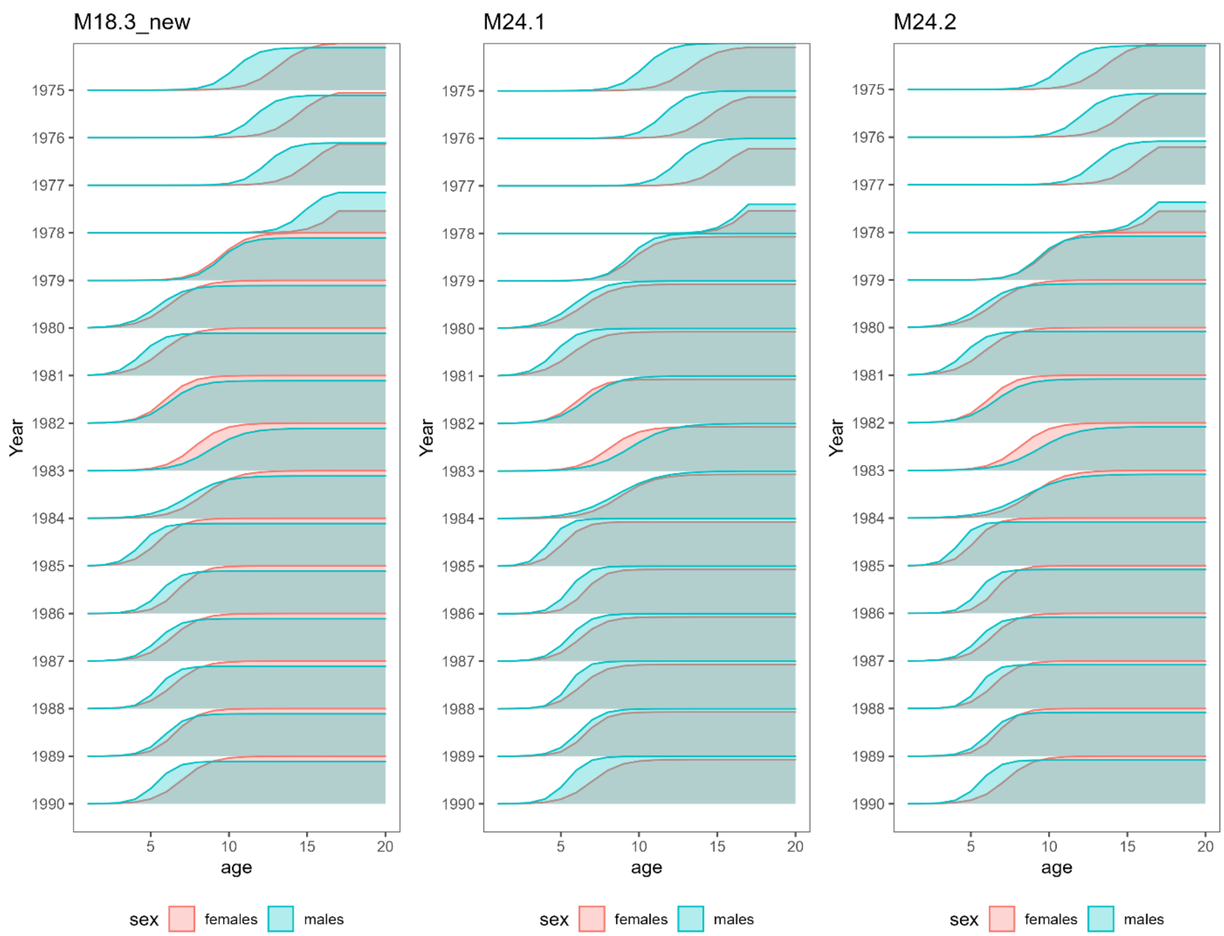

Figure 8.7. Yearly time-varying logistic fishery selectivity for candidate alternative models for 1975-1990. Females are shown in red and males are in blue.

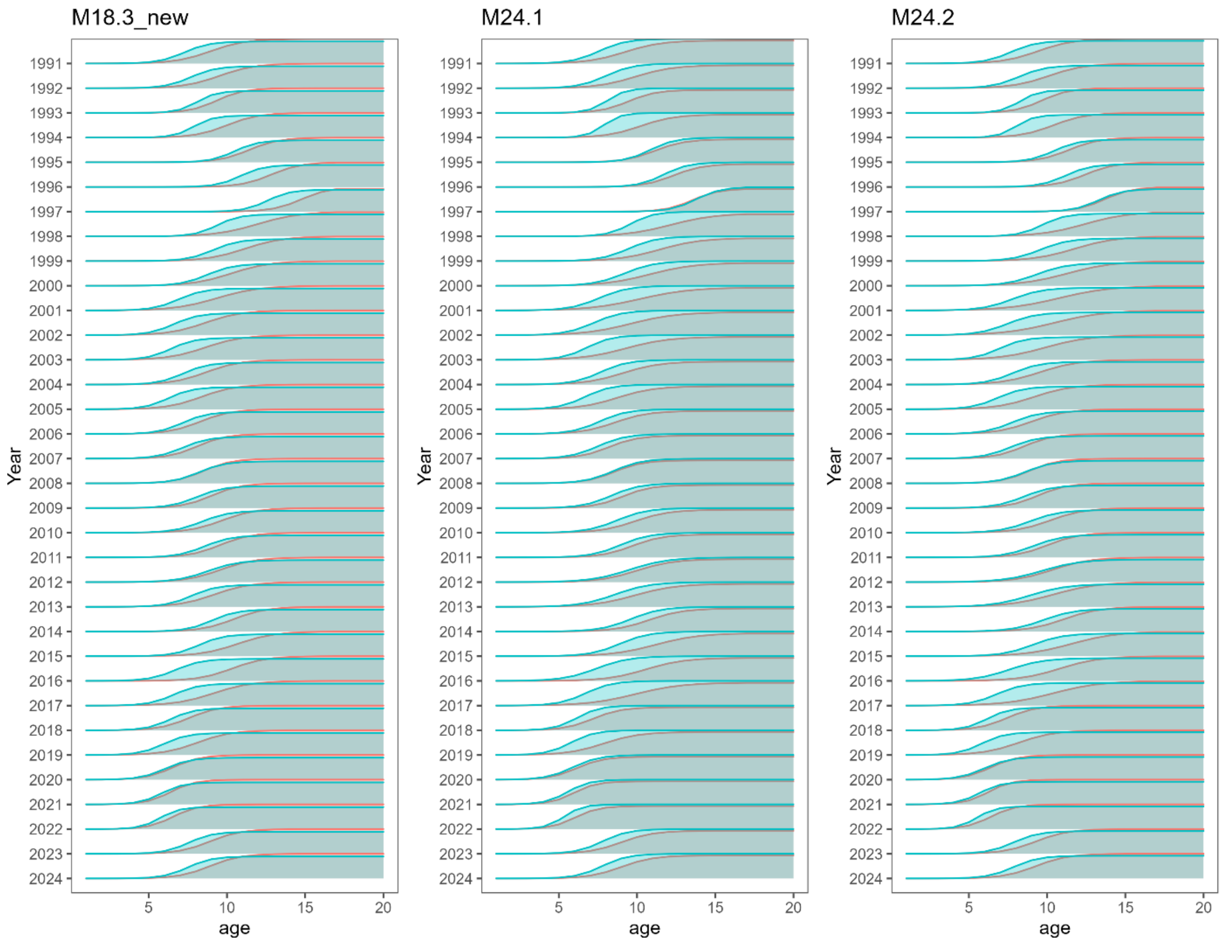

Figure 8.8. Yearly time-varying logistic fishery selectivity for candidate alternative models for 1991-2024. Females are shown in red and males are in blue.

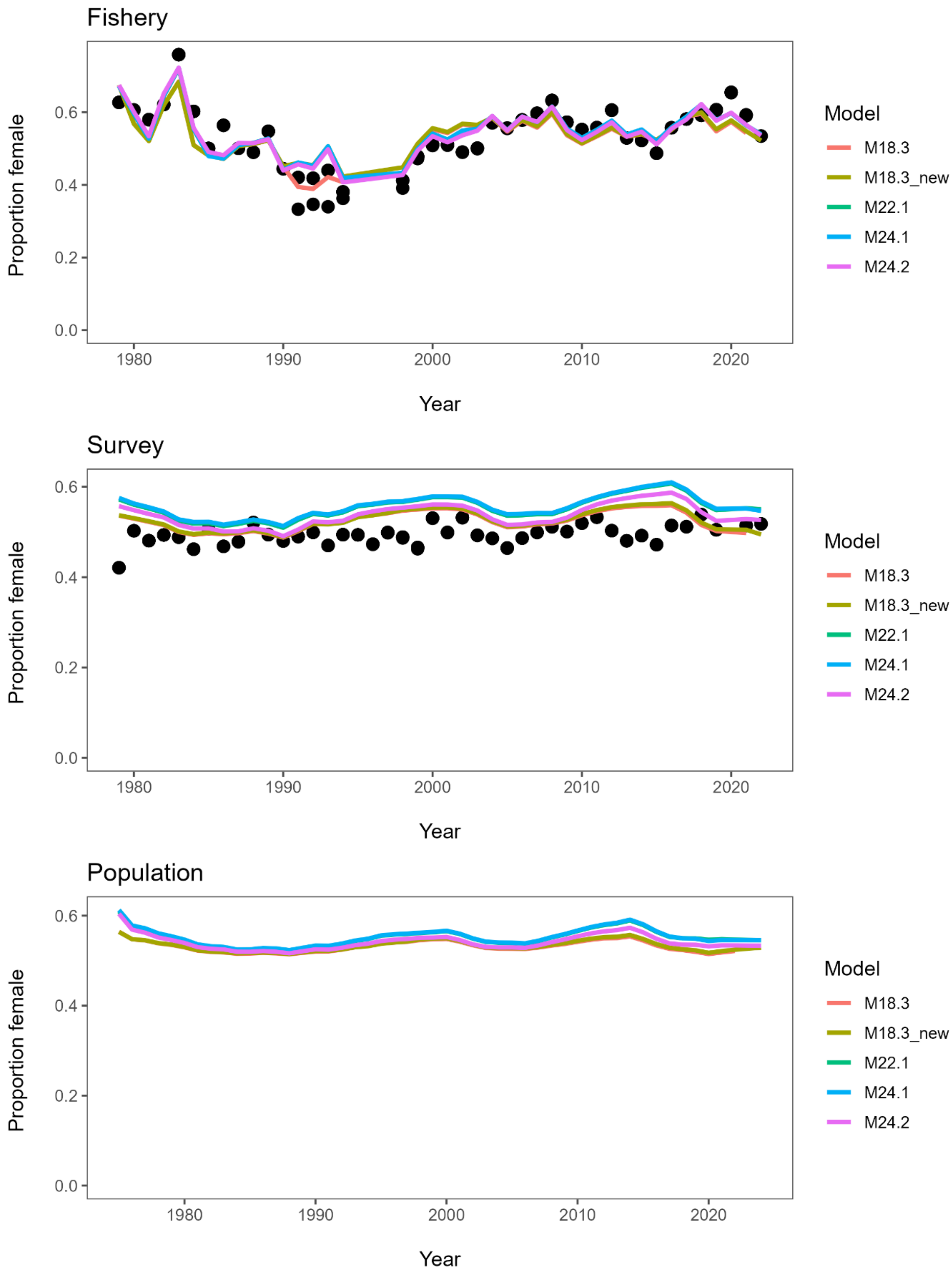

Figure 8.9. Time series of predicted (lines) and observed (dots) proportion female in the fishery (top panel), survey (middle panel), and in the estimated population (bottom panel) for Northern rock sole.

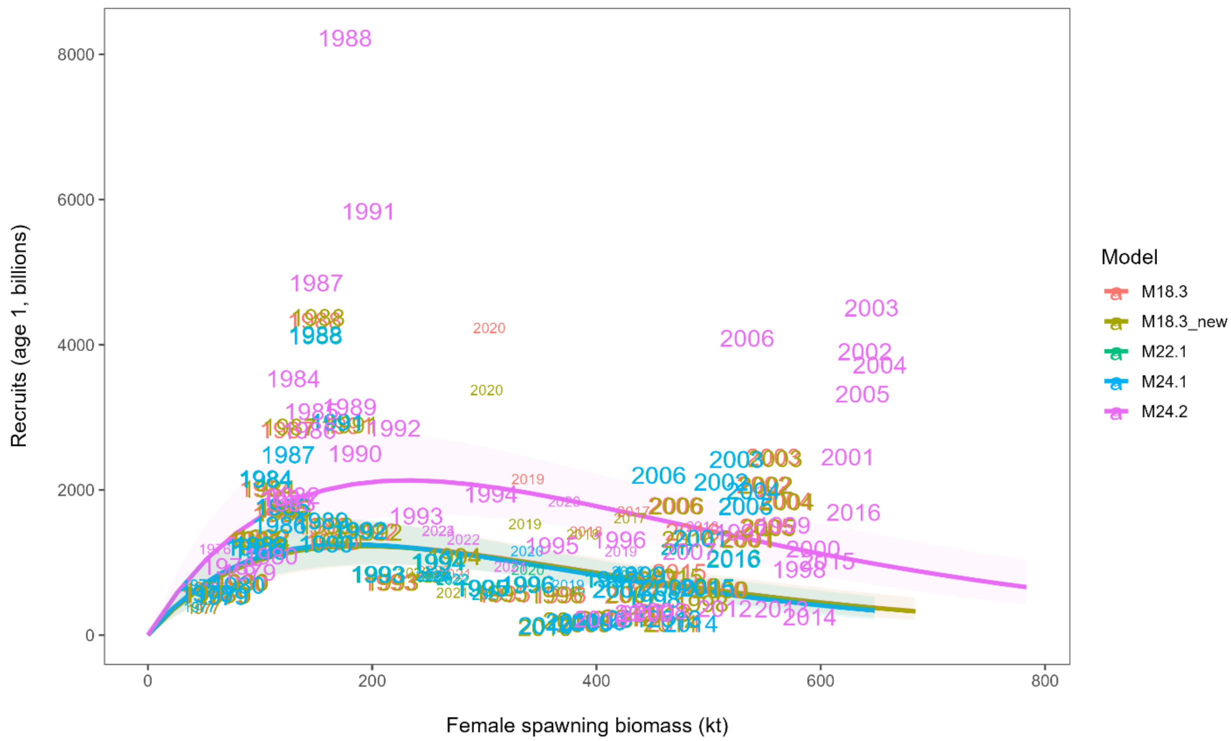

Figure 8.10. Stock-recruit relationship for rock sole. Years presented as labels and larger font size are used in fitting the curve. The stock recruit curve is fit within the objective function using estimates of spawning biomass and recruitment, but it is not fully integrated into the population dynamics.

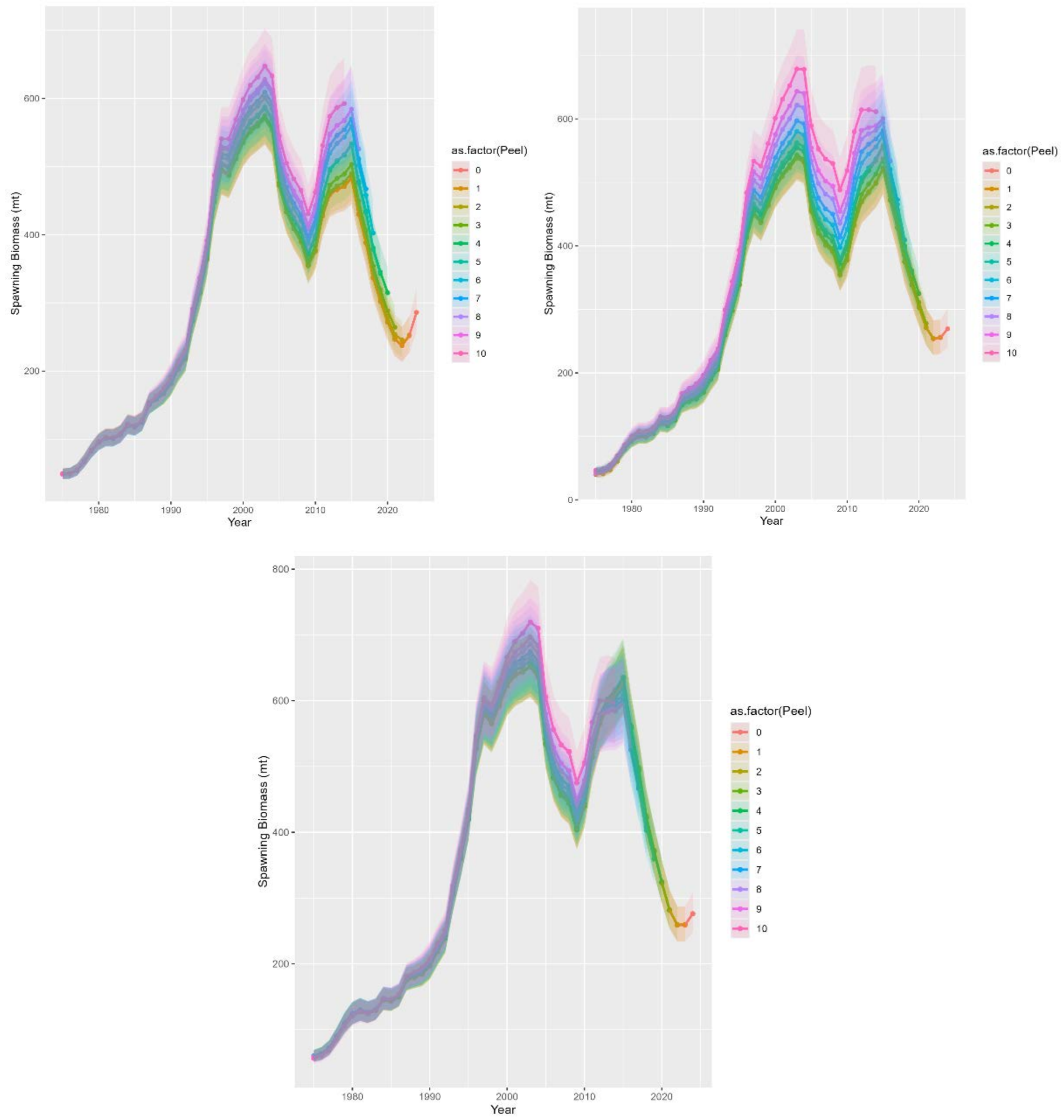

Figure 8.11. Retrospective patterns for spawning biomass for Model 18.3_new (top left), Model 24.1 (top right), and Model 24.2 (bottom).

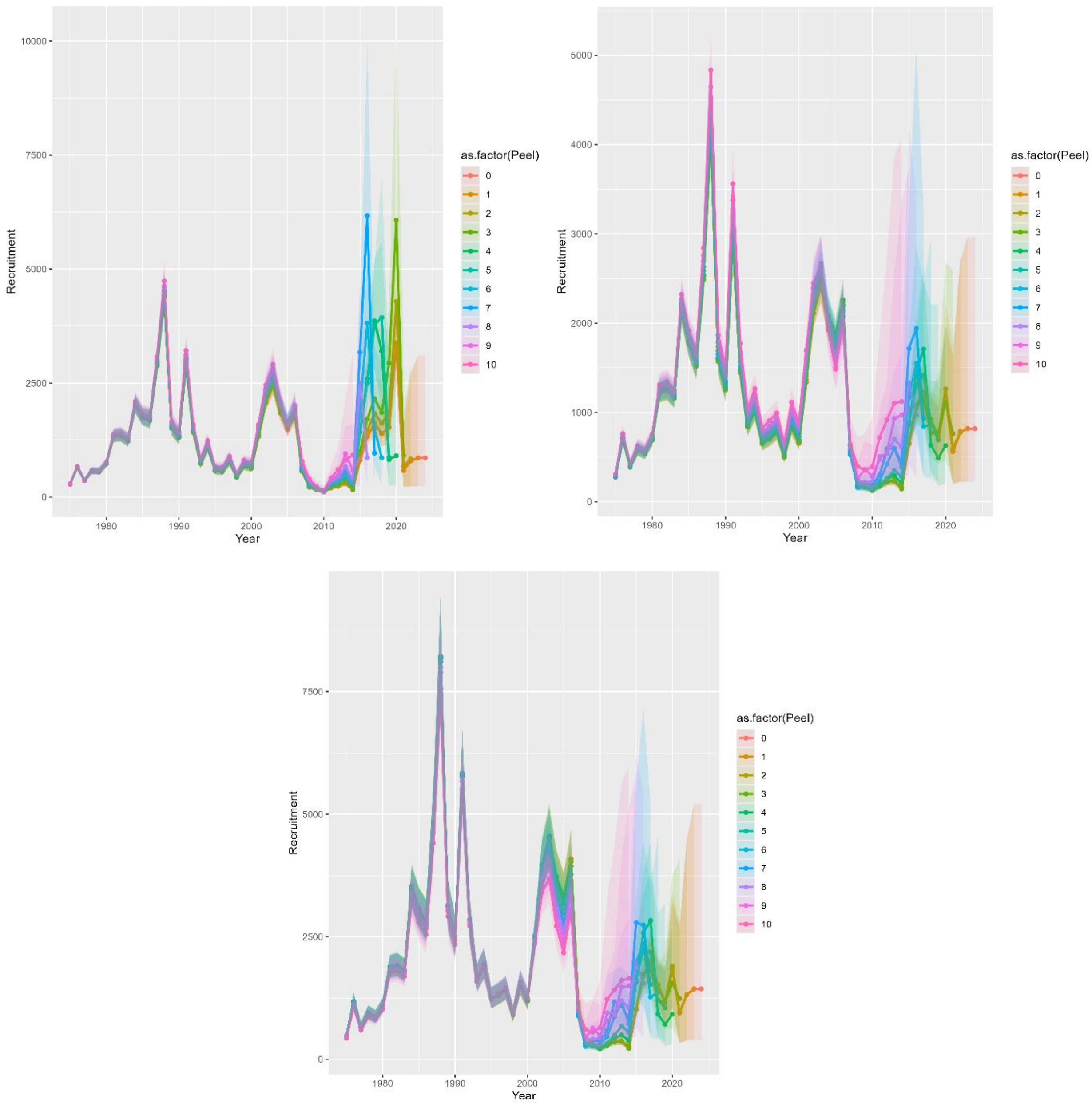

Figure 8.12. Retrospective patterns for recruitment for Model 18.3_new (top left), Model 24.1 (top right), and Model 24.2 (bottom).

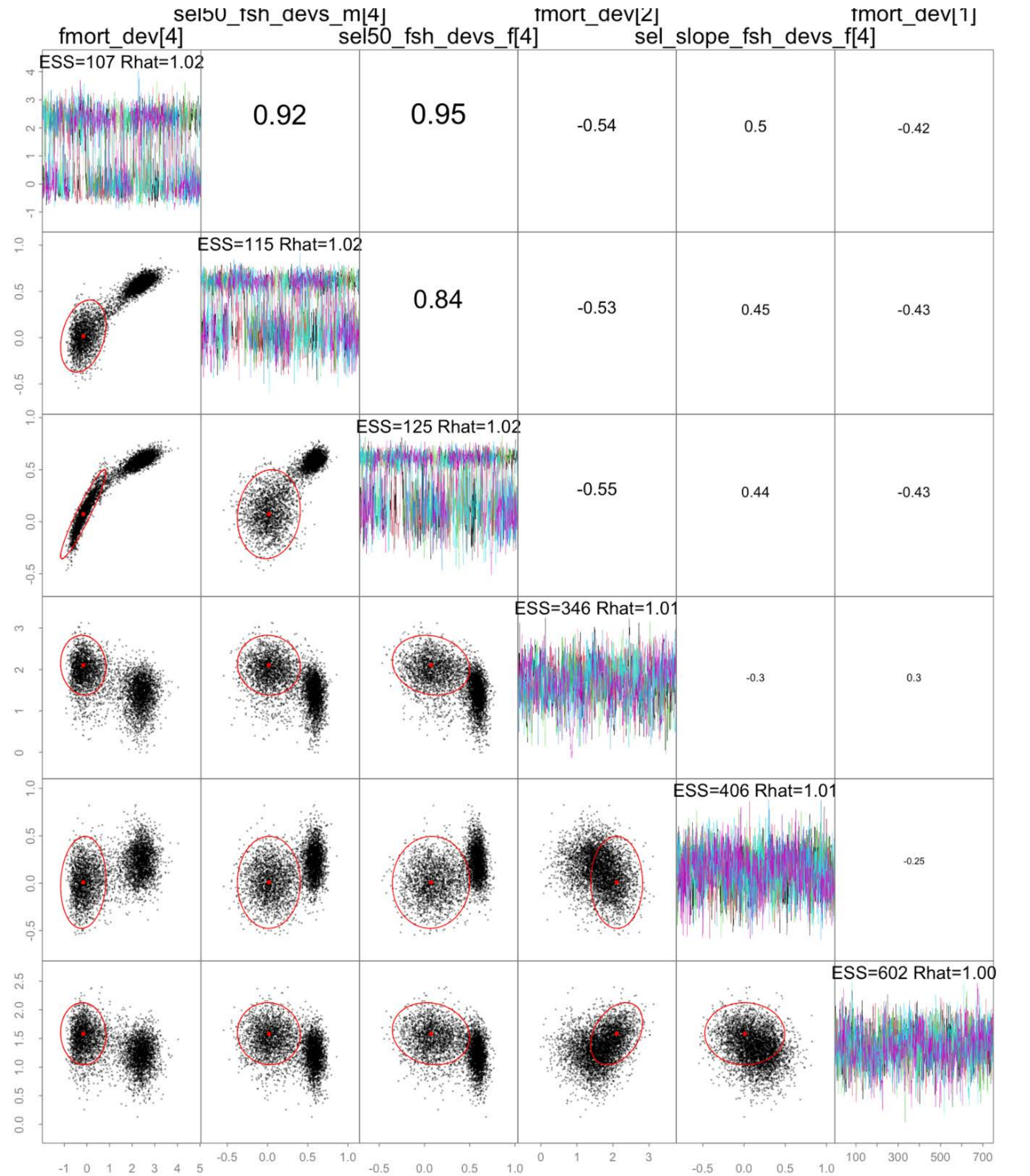

Figure 8.13. Joint posterior plots for the slowest mixing parameters: early fishing mortality deviations and selectivity parameters from the same year (1978). There are no fishery age data to support the estimation of these parameters. The absence of green dots on this plot indicate no divergences during adnuts MCMC sampling. The red dots and circles indicate MLE results. Trace plots are shown on the diagonals. Upper off-diagonals show correlation coefficients between parameters.

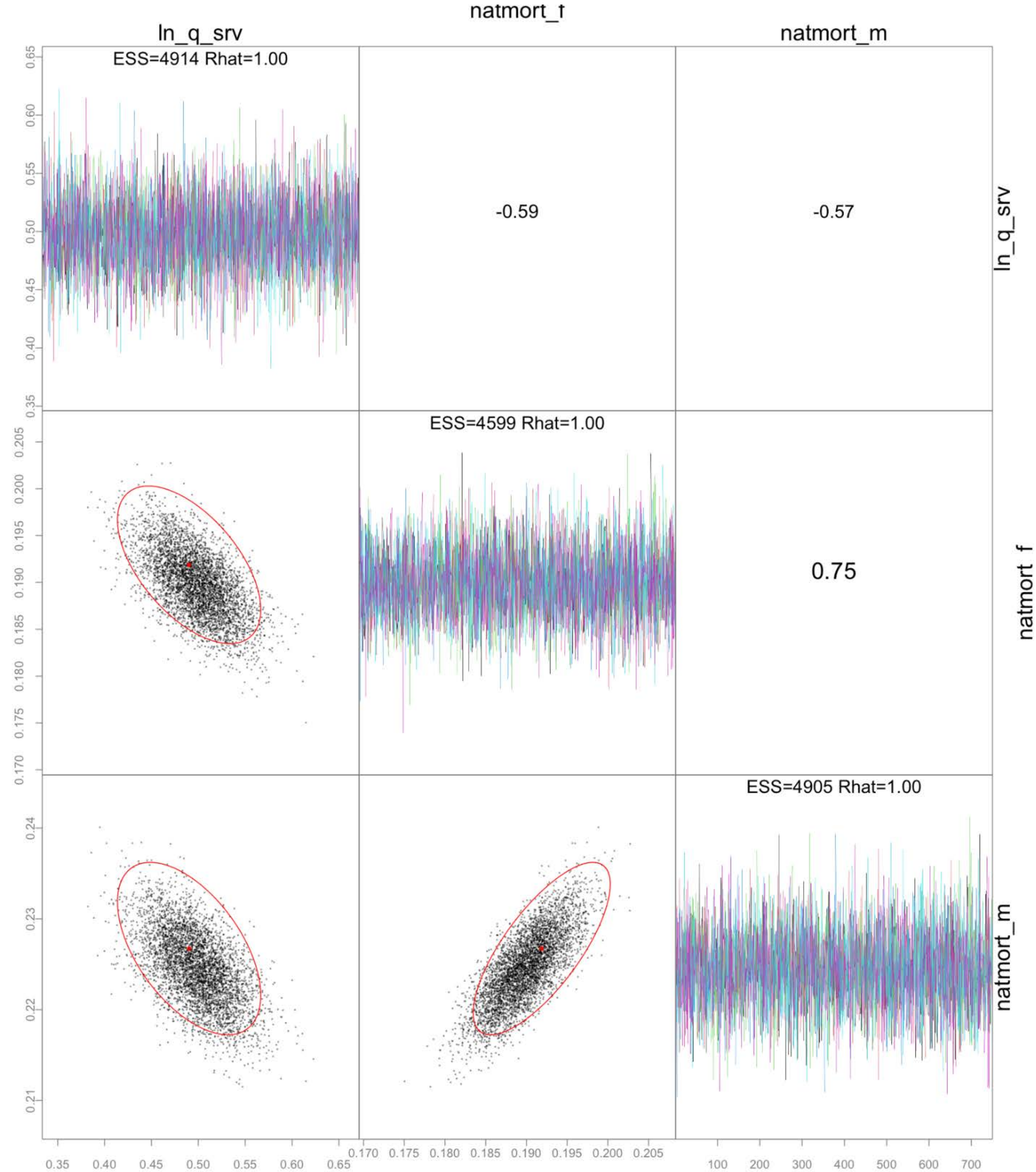

Figure 8.14. Joint posterior plots for catchability in log-space (ln_q) and female and male natural mortality parameters (natmort_f and natmort_m, respectively). The absence of green dots on this plot indicate no divergences during adnuts MCMC sampling. The red dots and circles indicate MLE results. Trace plots are shown on the diagonals. Upper off-diagonals show correlation coefficients between parameters.

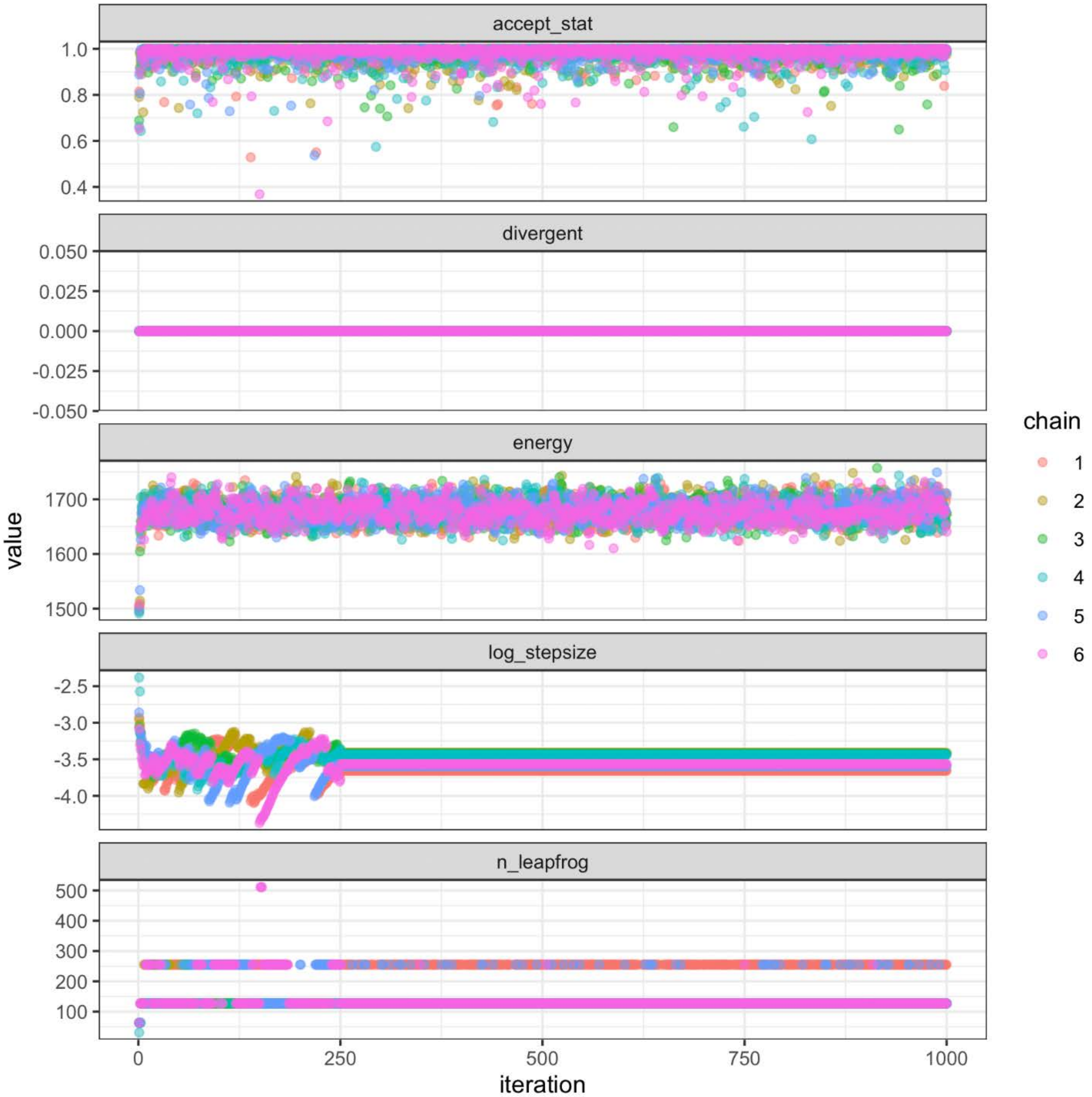

Figure 8.15. Diagnostic plots for MCMCs run with adnuts for Model 24.2.

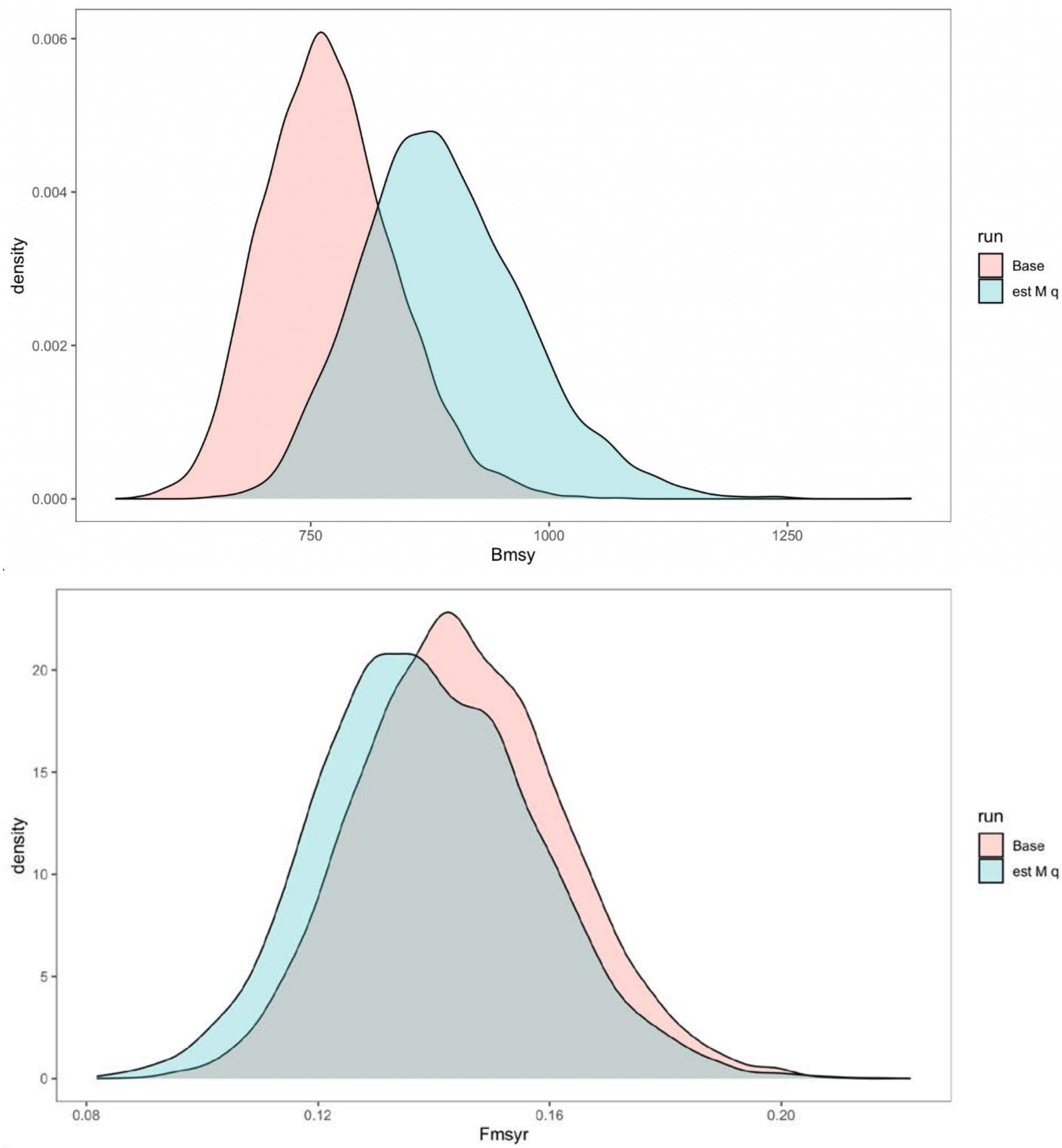

Figure 8.16. Marginal posterior distributions for Bmsy (top panel) and Fmsyr (Fmsy value used as the basis for ABC calculations; bottom panel) from M24.1 (labeled Base; pink) and M24.2 (labeled est M q; blue).

Appendix A

Additional results for candidate models (M18.3_new, M24.1, and M24.2)

Model 18.3_new: The currently accepted model with newer data added

Table 8.15. Estimated female numbers-at-age for M18.3_new

	Age (Females)																			
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	144	109	75	82	153	98	42	30	24	19	9	7	4	4	4	4	4	4	4	4
1976	332	124	94	64	70	131	85	36	26	21	16	8	5	3	3	3	3	3	3	5
1977	182	286	107	81	55	61	113	73	31	23	18	14	6	4	2	2	2	1	1	4
1978	284	157	246	92	70	48	52	97	63	27	19	15	12	5	3	2	1	1	1	4
1979	277	245	135	212	79	60	41	45	84	54	23	17	13	10	4	3	1	1	0	2
1980	364	239	211	116	182	68	52	35	38	70	44	19	13	11	8	3	2	1	0	2
1981	662	313	205	181	100	155	57	43	29	31	58	36	15	11	9	7	3	2	1	2
1982	671	569	270	176	155	84	130	48	35	24	26	47	30	13	9	7	5	2	1	2
1983	616	578	490	232	151	131	71	107	39	29	19	21	38	24	10	7	6	4	2	3
1984	1007	530	497	421	199	129	112	59	88	31	23	15	17	31	19	8	6	5	3	4
1985	870	866	456	428	362	170	109	92	47	66	22	16	11	11	21	13	6	4	3	5
1986	840	749	745	391	365	304	140	89	74	38	53	18	13	9	9	17	11	4	3	6
1987	1437	723	645	641	336	312	257	116	72	60	30	42	14	10	7	7	14	9	4	8
1988	2188	1236	622	553	547	283	256	204	90	55	46	23	32	11	8	5	6	10	7	9
1989	756	1883	1062	533	470	454	224	190	144	62	38	31	16	22	8	5	4	4	7	10
1990	650	650	1620	913	456	396	369	172	140	105	45	27	23	11	16	5	4	3	3	13
1991	1449	560	560	1393	783	389	334	305	140	112	84	36	22	18	9	13	4	3	2	12
1992	710	1247	482	481	1197	672	332	282	253	112	88	64	27	16	14	7	10	3	2	11
1993	366	611	1073	414	414	1028	575	282	236	207	89	68	49	21	12	10	5	7	2	10
1994	545	315	526	923	356	356	882	491	237	193	163	68	52	37	16	9	8	4	5	9
1995	288	469	271	453	794	307	306	754	416	197	156	127	52	39	28	12	7	6	3	11
1996	279	248	403	233	390	684	264	263	646	354	165	125	98	39	29	21	9	5	4	10
1997	385	240	214	347	201	335	588	227	226	555	302	139	103	77	30	21	15	6	4	11
1998	218	331	206	184	299	173	289	506	195	194	476	258	117	83	58	20	13	8	4	8
1999	337	188	285	178	158	257	149	248	434	167	165	400	214	96	68	47	16	10	7	9
2000	313	290	162	245	153	136	221	128	212	370	141	137	328	173	77	54	37	13	8	13
2001	662	269	250	139	211	131	117	189	109	179	307	115	111	263	138	61	43	30	10	17
2002	1034	569	232	215	120	181	113	100	161	92	151	257	96	92	218	115	51	36	25	22
2003	1216	890	490	199	185	103	155	96	84	135	76	124	211	78	75	178	94	42	29	38
2004	920	1047	766	422	172	159	88	133	81	71	112	63	102	173	64	62	147	77	34	55
2005	742	792	901	659	363	147	136	75	111	67	58	90	51	82	139	52	50	118	62	72
2006	890	639	681	775	566	311	126	115	63	92	55	47	74	41	67	113	42	40	96	109
2007	281	766	550	586	667	486	266	107	97	52	76	45	38	60	33	54	92	34	33	166
2008	110	242	659	473	504	573	416	226	89	80	42	61	36	31	48	27	44	74	28	160
2009	79	95	208	567	407	433	490	352	187	72	63	33	48	28	24	38	21	34	58	146
2010	54	68	81	179	488	350	371	417	296	154	58	50	26	37	22	19	29	16	27	159
2011	101	47	59	70	154	419	300	317	353	246	124	46	39	20	29	17	15	23	13	143
2012	118	87	40	51	60	133	360	256	267	291	197	97	35	30	15	22	13	11	17	120
2013	149	102	75	35	43	52	114	306	214	218	230	151	74	27	22	12	16	10	8	102
2014	81	128	88	64	30	37	44	96	256	176	175	182	118	57	21	17	9	13	8	86
2015	403	69	110	75	55	26	32	38	82	216	145	141	144	93	45	16	13	7	10	72
2016	660	347	60	95	65	48	22	27	32	70	180	119	113	114	73	35	13	11	5	64
2017	806	568	299	51	81	56	41	19	23	27	58	145	94	89	89	57	27	10	8	55
2018	694	694	489	257	44	70	48	35	16	19	22	46	117	75	71	71	46	22	8	50
2019	765	597	597	420	221	38	60	40	29	13	16	18	37	94	61	57	57	37	18	47
2020	1689	658	514	514	361	189	32	50	34	24	11	13	15	30	76	49	46	46	30	52
2021	292	1454	566	442	441	308	160	27	41	27	19	9	10	12	24	61	40	37	37	66
2022	397	251	1251	487	380	377	262	134	22	34	23	16	7	9	10	20	51	33	31	86
2023	429	342	216	1076	419	326	321	221	112	19	29	19	13	6	7	8	17	42	27	97
2024	430	370	294	186	926	360	279	274	186	93	15	23	15	11	5	6	7	14	34	100

Table 8.16. Estimated male numbers-at-age for M18.3_new

	Age (Males)																			
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	144	77	59	66	99	56	31	23	16	11	7	7	6	6	6	5	5	5	5	5
1976	332	121	65	50	55	83	47	26	19	13	8	5	4	4	3	3	3	3	3	7
1977	182	279	102	54	42	46	70	40	22	16	10	6	3	3	2	2	2	2	2	6
1978	284	153	234	85	46	35	39	59	33	18	13	8	5	2	2	1	1	1	1	4
1979	277	239	129	197	72	38	29	33	49	28	15	11	7	3	1	1	0	0	0	1
1980	364	233	201	108	165	60	32	25	27	40	23	12	9	5	3	1	0	0	0	1
1981	662	306	195	168	90	137	49	26	20	22	32	18	10	7	4	2	1	0	0	1
1982	671	556	257	163	139	74	111	40	21	16	18	26	15	8	6	3	2	1	0	1
1983	616	564	467	215	137	116	60	90	32	17	13	14	21	12	6	4	3	1	0	1
1984	##	517	474	392	181	115	97	50	74	26	13	10	11	16	9	5	3	2	1	1
1985	870	845	434	397	326	149	92	75	37	52	18	9	7	8	11	6	3	2	1	2
1986	840	731	709	362	326	263	118	73	59	29	42	14	7	6	6	9	5	3	2	2
1987	##	706	614	595	303	269	212	94	58	47	23	33	11	6	4	5	7	4	2	3
1988	##	##	592	514	493	245	210	162	71	44	35	18	25	9	4	3	4	5	3	4
1989	756	##	##	496	425	389	178	146	111	49	30	24	12	17	6	3	2	2	4	5
1990	650	635	##	849	413	345	300	131	106	80	35	21	17	9	12	4	2	2	2	6
1991	##	546	533	##	708	338	275	236	103	83	62	27	17	14	7	10	3	2	1	6
1992	710	##	459	448	##	590	278	220	182	78	62	47	20	13	10	5	7	2	1	6
1993	366	596	##	385	376	908	490	226	172	139	58	46	35	15	9	8	4	5	2	5
1994	545	307	501	859	324	315	760	404	179	132	104	44	35	26	11	7	6	3	4	5
1995	288	458	258	421	721	272	263	624	319	136	99	78	33	26	19	9	5	4	2	7
1996	279	242	384	217	354	606	228	221	521	263	109	75	57	24	19	14	6	4	3	6
1997	385	234	204	323	182	297	509	191	185	433	213	84	56	42	17	14	10	4	3	7
1998	218	323	197	171	271	153	250	427	161	155	359	172	62	36	25	10	8	6	2	5
1999	337	183	272	165	144	228	129	209	356	132	124	285	135	49	28	19	8	6	4	6
2000	313	283	154	228	139	121	191	107	173	290	105	98	224	106	39	22	15	6	5	8
2001	662	263	238	130	192	116	101	159	88	140	230	83	77	176	83	30	18	12	5	10
2002	##	556	221	200	109	161	97	83	130	72	114	187	67	63	143	68	25	14	10	12
2003	##	868	467	186	168	91	133	79	67	105	58	91	150	54	50	115	54	20	11	18
2004	920	##	729	392	156	140	75	109	64	54	85	47	74	121	44	41	92	44	16	23
2005	742	773	858	613	329	130	116	61	87	51	43	67	37	58	95	34	32	73	35	31
2006	890	623	649	721	513	274	107	94	49	70	41	34	53	29	46	76	27	26	58	52
2007	281	747	524	545	605	430	228	88	76	39	56	32	27	42	23	37	61	22	20	88
2008	110	236	628	440	457	506	357	187	71	61	31	44	26	22	34	19	29	48	17	86
2009	79	92	199	527	369	383	423	295	151	56	47	24	34	20	17	26	14	23	37	79
2010	54	67	78	167	443	309	320	348	238	119	43	36	19	26	15	13	20	11	17	90
2011	101	46	56	65	140	371	258	264	282	187	92	33	28	14	20	12	10	15	8	82
2012	118	85	38	47	55	117	310	214	214	222	144	70	25	21	11	15	9	7	12	68
2013	149	99	71	32	39	46	98	256	173	167	168	108	52	19	16	8	11	6	5	59
2014	81	125	83	60	27	33	38	80	204	134	129	129	83	40	14	12	6	9	5	49
2015	403	68	105	70	50	23	28	32	66	164	105	100	99	63	30	11	9	5	7	42
2016	660	339	57	88	59	42	19	23	26	52	127	81	77	77	49	24	8	7	4	37
2017	806	554	285	48	74	49	35	15	18	20	40	98	63	59	59	38	18	7	5	31
2018	694	677	465	239	40	61	40	28	12	14	16	32	77	49	47	46	30	14	5	29
2019	765	583	569	391	200	33	51	32	22	10	11	12	25	61	39	37	37	23	11	27
2020	##	643	490	477	327	166	27	40	26	18	8	9	10	20	48	31	29	29	19	30
2021	292	##	540	411	399	271	136	22	32	21	14	6	7	8	16	38	25	23	23	39
2022	397	245	##	453	344	333	224	111	18	26	17	11	5	6	6	13	31	20	19	51
2023	429	334	206	##	380	287	275	184	91	15	22	14	9	4	5	5	10	26	16	57
2024	430	361	280	173	840	319	240	226	148	72	12	17	11	7	3	4	4	8	20	58

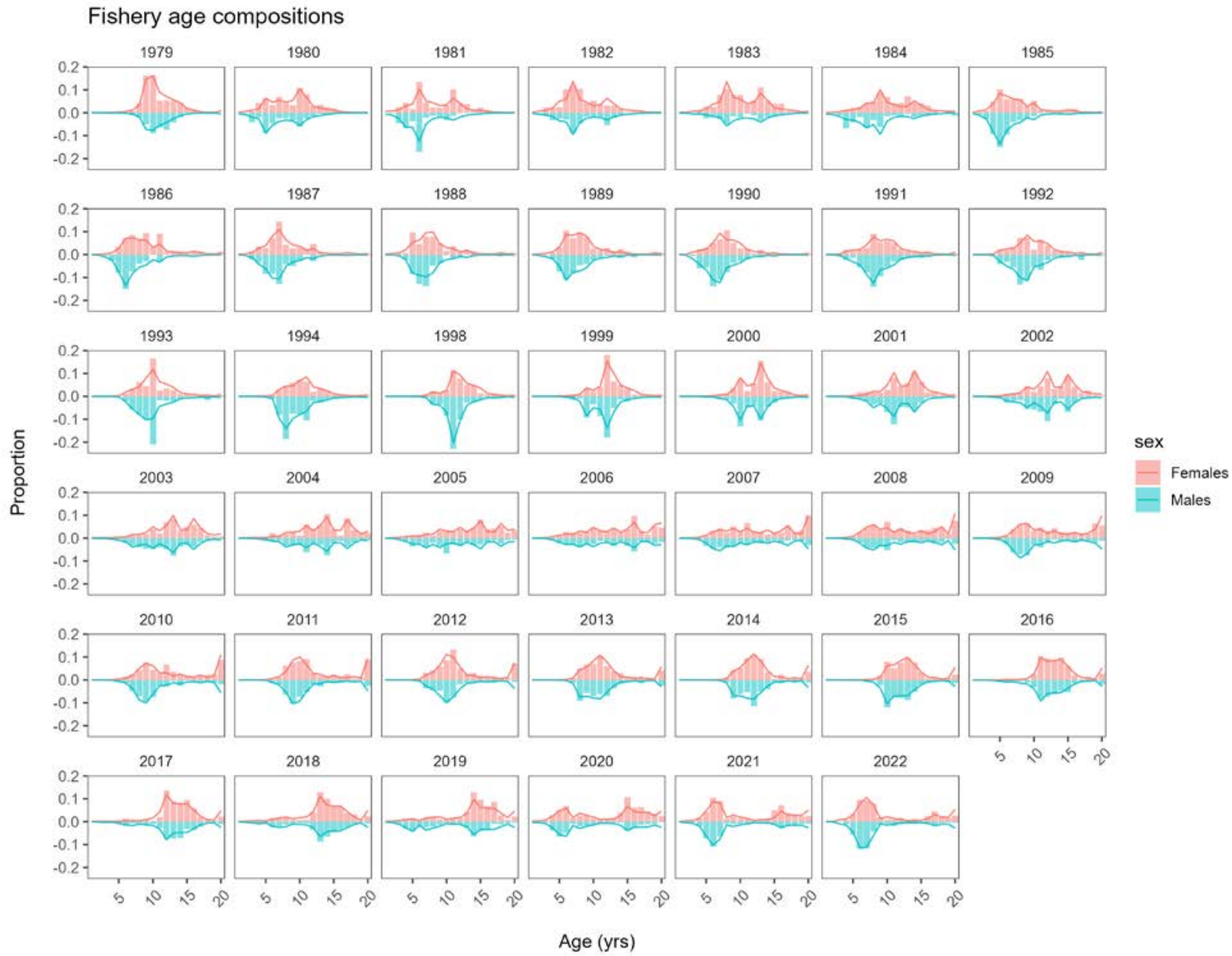

Figure 8.17. Observed (histograms) and expected (lines) fishery age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for Model 18.3_new.

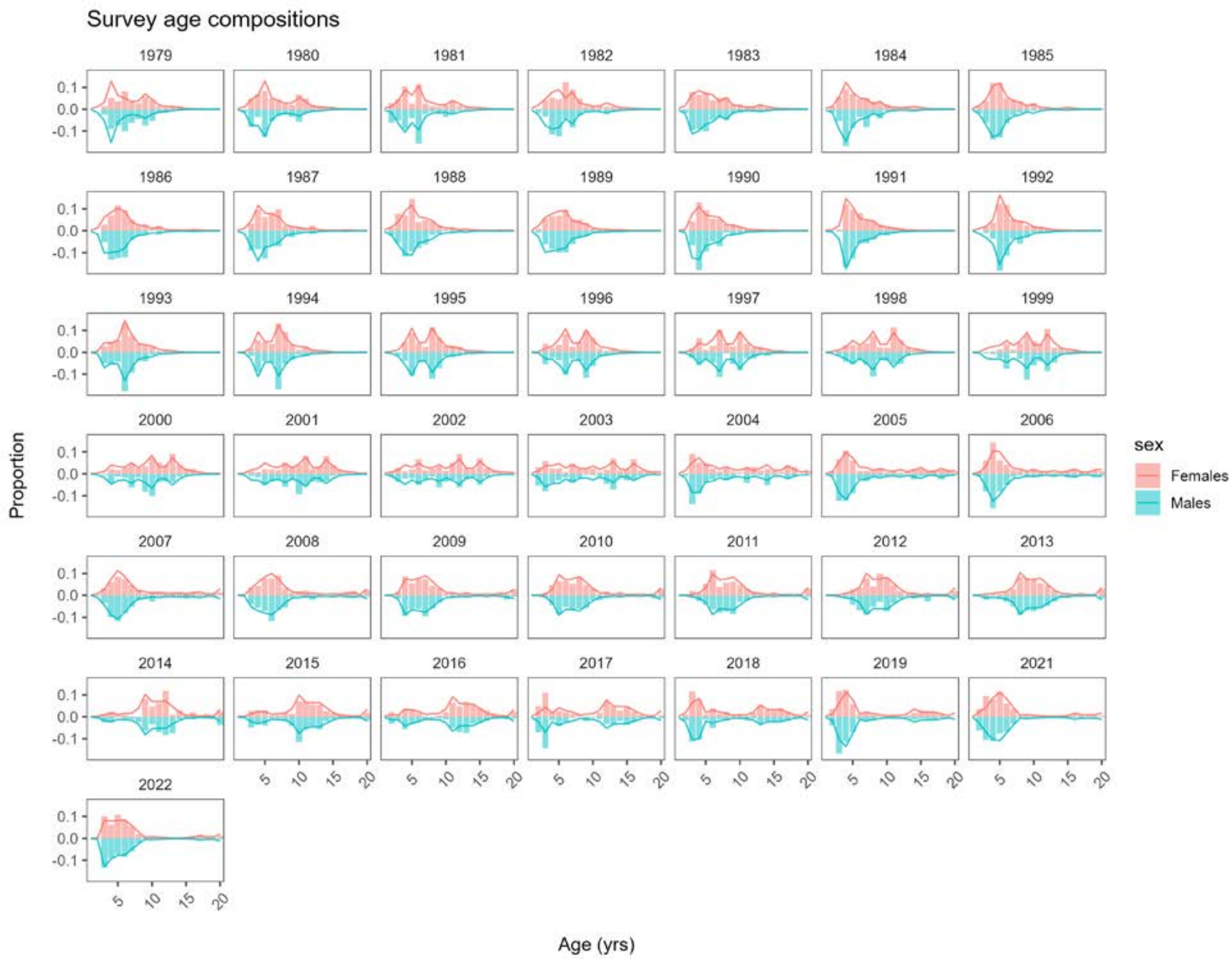

Figure 8.18. Observed (histograms) and expected (lines) survey age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for Model 18.3_new.

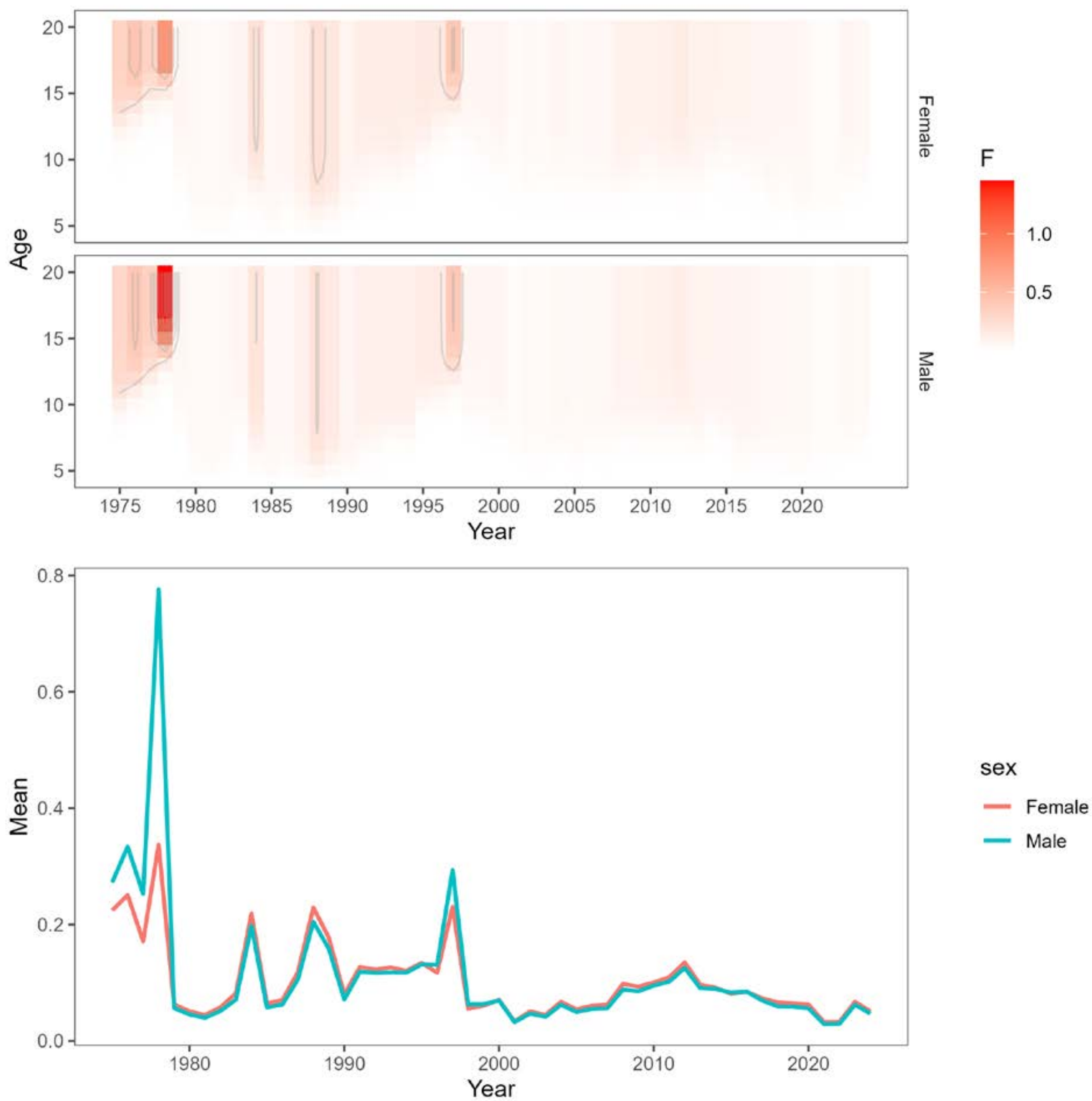

Figure 8.19. A comparison of fishing mortality across ages and time for Model 18.3_new. The top sub-panel shows fishing mortality by age and year for females and males and the bottom sub-panel shows mean fishing mortality over time. The plots are sex-specific.

Model 24.1: As for the currently accepted model, but incorporating new input sample sizes for survey age compositions and Francis data-weighting

Table 8.17. Estimated female numbers-at-age for M24.1

	Age (Females)																			
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	139	102	76	85	155	97	41	30	23	19	8	6	4	4	4	4	4	4	4	4
1976	349	120	88	65	73	133	84	35	25	20	16	7	5	3	3	2	2	2	2	5
1977	195	300	103	76	56	63	115	72	30	22	17	13	6	4	2	2	1	1	1	4
1978	288	168	258	89	65	48	54	99	62	26	19	14	11	5	3	1	1	1	1	3
1979	269	248	144	222	76	56	42	47	85	53	23	16	12	10	4	2	1	0	0	0
1980	346	232	213	124	191	66	48	36	40	71	44	18	13	10	8	3	2	0	0	0
1981	608	298	199	183	106	163	55	40	29	33	58	36	15	11	8	6	2	1	0	0
1982	623	523	256	171	157	90	137	46	33	24	27	48	29	12	9	7	5	2	1	1
1983	580	536	450	220	146	133	75	112	37	27	20	22	39	24	10	7	5	4	2	1
1984	1078	499	461	387	189	126	113	63	92	30	21	15	17	30	19	8	6	4	3	2
1985	886	928	430	397	332	161	106	94	50	69	21	15	10	11	20	12	5	4	3	4
1986	761	762	798	369	338	278	132	86	76	41	56	17	12	8	9	16	10	4	3	5
1987	1246	655	656	687	317	289	234	109	70	61	33	45	14	9	7	7	13	8	3	7
1988	2064	1072	563	563	586	267	236	184	84	53	47	25	34	11	7	5	6	10	6	8
1989	787	1776	921	483	478	485	208	172	129	58	36	32	17	23	7	5	4	4	7	9
1990	628	677	1528	792	413	404	393	158	125	92	41	26	23	12	17	5	4	2	3	12
1991	1468	540	583	1314	680	353	340	324	128	100	73	33	21	18	10	13	4	3	2	11
1992	723	1264	465	501	1129	583	301	287	268	103	78	56	24	15	13	7	10	3	2	10
1993	420	622	1087	400	431	969	498	255	241	220	82	60	42	18	11	10	5	7	2	9
1994	506	362	535	936	344	370	832	425	215	196	172	62	45	31	14	8	7	4	5	8
1995	326	435	311	461	805	296	318	711	360	178	158	134	47	34	23	10	6	5	3	10
1996	351	280	375	268	397	693	254	273	608	304	147	125	101	35	24	17	7	5	4	9
1997	386	302	241	323	231	341	596	219	234	520	258	122	99	77	25	18	12	5	3	9
1998	250	332	260	208	278	198	294	513	188	201	445	217	98	73	49	15	10	7	3	7
1999	418	215	286	224	179	239	171	252	440	161	171	373	180	80	59	39	12	8	5	8
2000	328	360	185	246	193	154	205	146	216	374	135	142	304	145	64	46	31	9	6	10
2001	669	282	309	159	212	166	132	176	125	182	311	111	114	242	114	50	36	24	7	13
2002	1056	576	243	266	137	182	142	113	150	106	153	261	92	95	201	94	41	30	20	16
2003	1211	908	495	209	229	117	156	121	96	126	88	126	213	75	77	163	77	34	24	30
2004	995	1042	782	426	179	197	101	133	103	81	105	73	104	175	62	63	133	63	28	44
2005	888	856	897	672	366	154	168	86	112	85	66	85	58	83	140	49	50	106	50	57
2006	1102	765	737	771	578	315	132	143	72	93	70	54	69	47	68	113	40	41	86	87
2007	317	948	658	634	663	497	269	112	120	60	76	57	44	56	38	54	91	32	33	140
2008	94	273	816	566	545	570	425	229	94	99	49	62	46	35	45	31	44	74	26	139
2009	87	81	235	702	487	468	487	360	190	76	78	38	48	36	27	35	24	34	57	128
2010	67	75	70	202	604	419	402	416	303	155	60	61	30	37	28	21	27	19	27	144
2011	92	58	64	60	174	519	359	343	352	251	126	48	48	23	29	21	16	21	14	131
2012	113	79	50	55	52	149	446	307	290	291	202	98	37	37	17	22	16	12	16	111
2013	114	97	68	43	48	44	128	379	258	238	231	155	74	27	27	13	16	12	9	93
2014	81	98	84	59	37	41	38	109	319	213	193	183	121	57	21	21	10	12	9	78
2015	324	70	85	72	51	32	35	33	93	270	177	156	145	95	44	16	16	8	10	67
2016	525	279	60	73	62	44	27	30	28	79	226	146	126	116	75	35	13	13	6	60
2017	593	451	240	52	63	53	37	23	26	23	65	184	117	100	91	59	27	10	10	52
2018	438	510	388	207	44	54	46	32	20	21	19	53	149	94	80	73	47	22	8	49
2019	347	377	439	334	177	38	46	38	26	16	17	16	43	121	76	65	59	38	18	46
2020	580	298	324	377	287	152	32	39	32	22	13	14	13	35	98	62	53	48	31	52
2021	282	499	257	279	323	244	127	27	31	26	18	11	11	10	28	79	50	43	39	67
2022	389	243	429	221	239	276	207	107	22	26	22	15	9	10	9	24	66	42	36	88
2023	409	335	209	369	190	205	234	173	89	19	22	18	12	7	8	7	20	55	35	103
2024	409	352	288	180	318	163	175	200	146	74	15	18	14	10	6	6	6	16	44	110

Table 8.18. Estimated male numbers-at-age for M24.1

	Age (Males)																			
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	139	46	41	47	72	44	27	21	15	9	6	7	5	5	5	5	5	5	5	5
1976	349	115	38	34	39	59	36	22	17	11	7	4	4	3	3	3	3	3	3	6
1977	195	289	95	32	28	33	49	30	18	14	9	5	2	2	1	1	1	1	1	4
1978	288	161	239	79	26	23	27	41	25	15	11	7	3	1	1	1	1	1	1	3
1979	269	238	134	198	65	22	19	22	34	21	13	9	6	2	1	1	0	0	0	0
1980	346	223	197	111	164	54	18	16	18	27	16	10	7	4	2	1	0	0	0	0
1981	608	286	184	163	91	134	43	14	12	14	21	13	8	6	3	1	1	0	0	0
1982	623	503	237	152	133	73	106	34	11	10	11	17	10	6	4	3	1	0	0	0
1983	580	516	417	196	125	109	59	84	27	9	8	9	13	8	5	3	2	1	0	0
1984	1078	481	427	345	162	103	90	48	68	21	7	6	7	10	6	3	3	2	1	1
1985	886	892	397	352	283	132	83	69	36	48	14	4	4	4	6	4	2	2	1	1
1986	761	733	738	327	284	222	102	64	54	28	37	11	3	3	3	5	3	2	1	1
1987	1246	630	607	611	269	230	175	79	49	41	21	29	9	3	2	3	4	2	1	2
1988	2064	1031	521	501	499	214	175	129	58	36	30	16	21	6	2	2	2	3	2	2
1989	787	1710	854	430	409	384	148	115	83	37	23	19	10	13	4	1	1	1	2	3
1990	628	652	1415	705	353	326	290	105	79	57	25	16	13	7	9	3	1	1	1	3
1991	1468	520	539	1169	579	283	254	221	80	60	43	19	12	10	5	7	2	1	1	3
1992	723	1216	431	446	966	475	229	199	165	57	42	30	13	8	7	4	5	1	0	2
1993	420	599	1007	356	369	796	388	182	151	121	41	30	21	9	6	5	3	3	1	2
1994	506	348	496	834	295	305	656	314	141	110	86	29	21	15	7	4	3	2	2	2
1995	326	419	288	411	691	244	252	529	238	101	78	61	20	15	11	5	3	2	1	3
1996	351	270	347	239	340	572	202	208	436	194	80	58	43	14	10	7	3	2	2	3
1997	386	291	224	287	198	282	474	167	172	358	157	62	43	30	10	7	5	2	1	3
1998	250	320	241	185	238	164	233	392	139	142	295	128	49	31	19	5	4	2	1	2
1999	418	207	265	200	153	197	136	193	322	112	111	226	97	37	23	14	4	3	2	3
2000	328	346	171	219	165	127	163	112	157	257	87	85	171	73	28	18	11	3	2	3
2001	669	271	287	142	181	137	105	134	90	124	198	66	64	128	55	21	13	8	2	4
2002	1056	554	225	237	117	150	112	85	108	72	99	157	52	51	102	43	17	10	6	5
2003	1211	874	459	186	196	97	123	90	68	84	56	77	122	41	39	79	34	13	8	9
2004	995	1003	724	380	154	162	79	98	72	53	66	44	60	96	32	31	62	26	10	13
2005	888	824	830	599	314	127	132	64	78	56	41	51	34	46	73	24	24	47	20	18
2006	1102	736	682	687	495	258	103	106	50	61	43	32	39	26	36	57	19	18	37	29
2007	317	913	609	565	568	409	212	83	84	39	47	33	24	30	20	28	44	15	14	51
2008	94	262	756	504	467	469	335	171	66	65	30	36	26	19	23	16	21	34	11	50
2009	87	78	217	626	417	386	386	272	136	51	49	23	27	19	14	17	12	16	25	46
2010	67	72	64	180	518	345	317	313	216	105	38	37	17	20	14	10	13	9	12	53
2011	92	56	60	53	149	428	284	258	249	167	79	28	27	12	15	10	8	9	6	47
2012	113	76	46	49	44	123	352	231	206	193	125	58	21	20	9	11	8	6	7	39
2013	114	94	63	38	41	36	101	286	184	159	144	90	41	15	14	6	7	5	4	32
2014	81	95	78	52	32	34	30	82	227	142	120	107	67	30	11	10	5	5	4	26
2015	324	67	78	64	43	26	28	25	66	180	110	91	79	49	22	8	7	3	4	22
2016	525	268	56	65	53	36	22	23	20	52	138	83	68	59	37	17	6	6	3	19
2017	593	434	222	46	54	44	29	17	18	15	39	104	62	51	45	28	12	4	4	16
2018	438	491	360	184	38	44	35	23	13	14	12	30	79	47	39	34	21	10	3	16
2019	347	363	406	298	152	31	35	28	18	10	11	9	23	61	37	30	26	16	7	15
2020	580	287	300	336	245	124	25	28	22	14	8	8	7	18	48	29	23	20	13	17
2021	282	480	238	248	277	200	99	20	22	17	11	6	6	5	14	37	22	18	16	23
2022	389	233	397	197	205	227	162	80	16	17	13	9	5	5	4	11	30	18	15	31
2023	409	322	193	329	162	167	183	130	64	13	14	11	7	4	4	3	9	24	14	37
2024	409	339	267	160	272	134	137	148	102	49	10	11	8	5	3	3	3	7	18	39

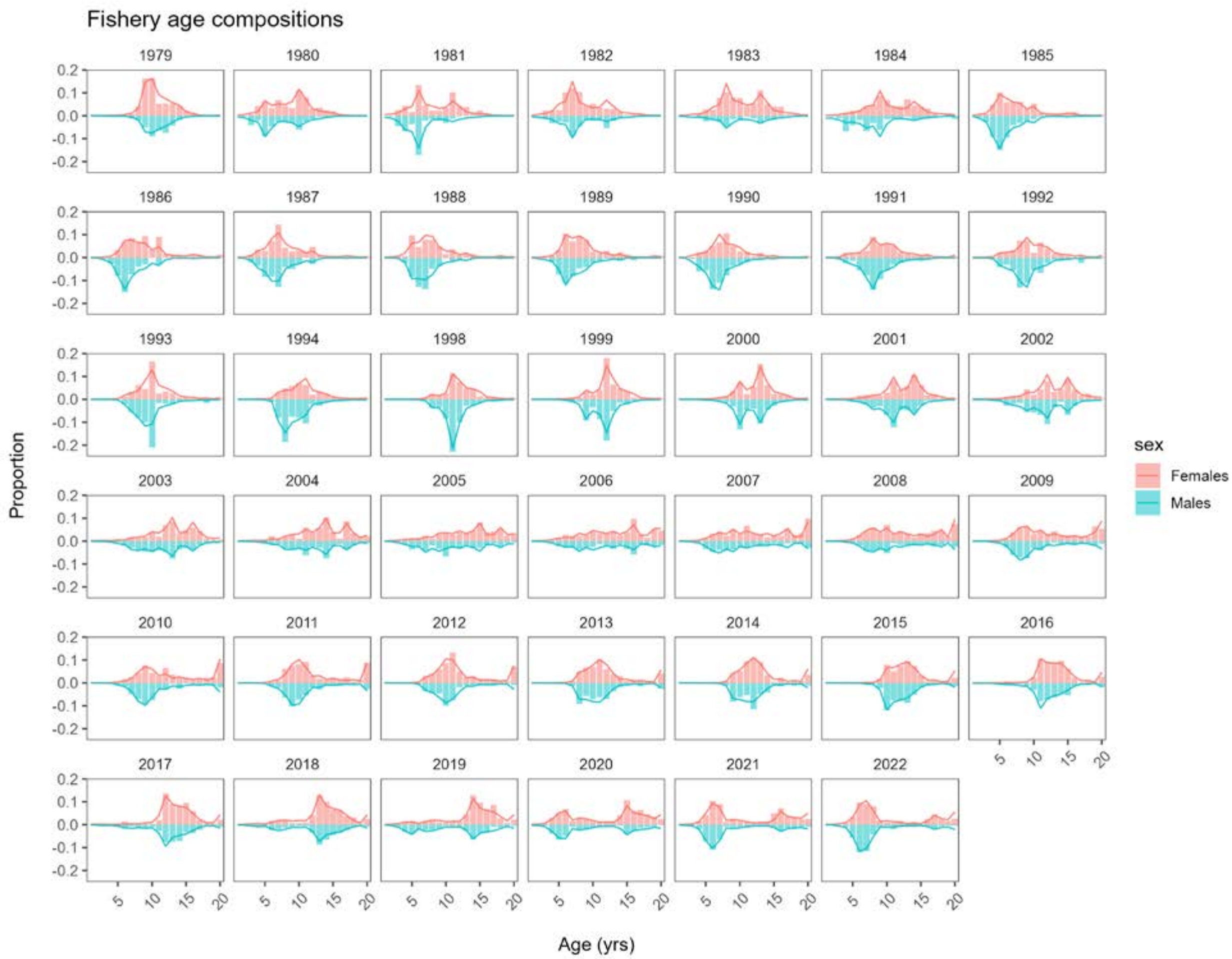

Figure 8.20. Observed (histograms) and expected (lines) fishery age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for Model 24.1.

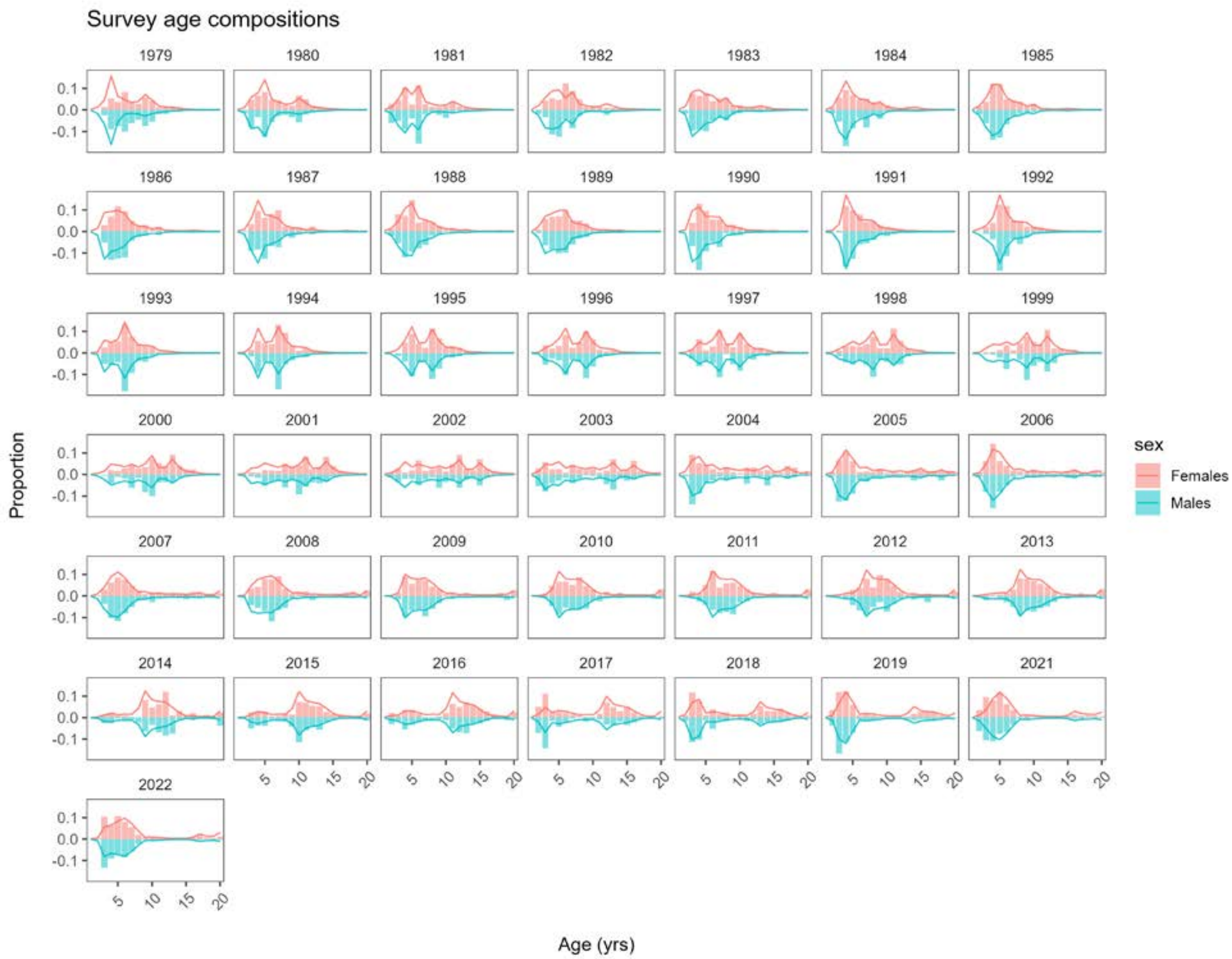

Figure 8.21. Observed (histograms) and expected (lines) survey age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for Model 24.1.

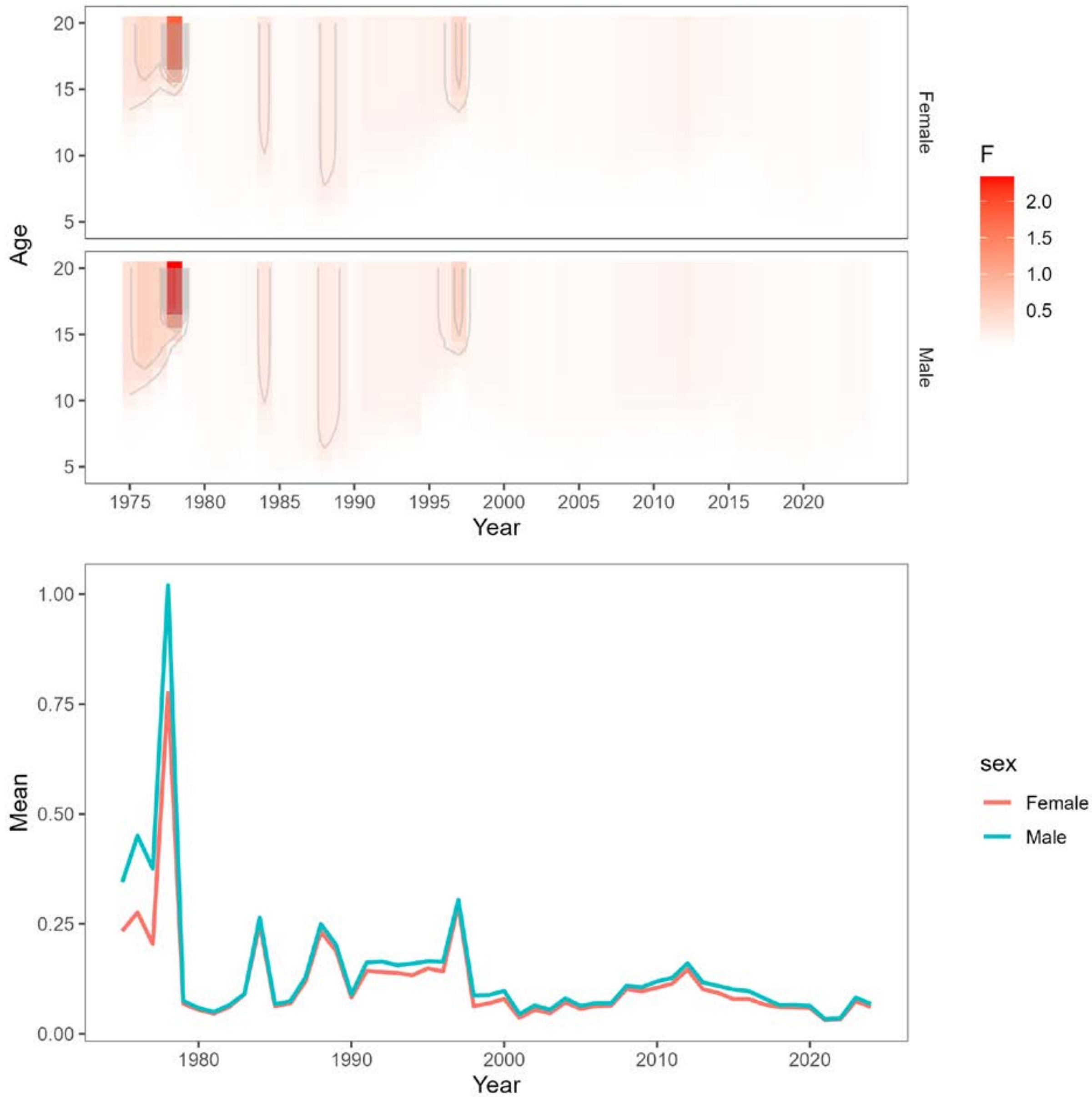

Figure 8.22. A comparison of fishing mortality across ages and time for Model 24.1. The top sub-panel shows fishing mortality by age and year for females and males and the bottom sub-panel shows mean fishing mortality over time. The plots are sex-specific.

Model 24.2: As for Model 24.1 but, estimating female natural mortality (in addition to male natural mortality, which was already estimated in the currently accepted model and in 24.1).

Table 8.19. Estimated female numbers-at-age for M24.2

	Age (Females)																			
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	240	170	124	139	252	157	66	47	36	29	12	9	4	5	5	4	4	4	4	4
1976	593	199	141	103	115	208	129	55	39	30	24	10	7	3	3	3	3	3	3	5
1977	327	490	164	116	85	95	172	107	45	32	24	19	8	5	2	2	2	1	1	4
1978	475	270	405	136	96	70	79	142	88	37	27	20	16	6	4	2	1	1	1	3
1979	435	393	223	335	112	79	58	65	118	73	31	22	17	13	5	3	1	0	0	1
1980	548	360	325	185	277	93	66	48	53	95	58	24	17	13	10	4	2	1	0	1
1981	945	453	297	268	152	227	76	53	38	42	76	46	19	14	10	8	3	2	0	1
1982	962	781	374	245	221	125	184	61	42	31	34	60	37	15	11	8	6	2	1	1
1983	911	795	646	309	202	181	101	147	48	33	24	27	48	29	12	9	6	5	2	2
1984	1768	753	657	534	255	167	148	82	117	38	26	19	20	36	22	9	7	5	4	3
1985	1543	1462	622	543	440	210	136	119	63	87	27	18	13	14	24	15	6	4	3	5
1986	1411	1275	1208	514	446	356	167	107	93	50	68	21	14	10	11	19	12	5	3	6
1987	2426	1167	1054	998	424	367	289	133	84	73	39	53	16	11	8	8	15	9	4	8
1988	4115	2006	964	870	821	345	291	222	100	63	54	29	39	12	8	6	6	11	7	8
1989	1572	3401	1657	795	713	660	265	210	154	68	42	37	19	27	8	5	4	4	7	10
1990	1252	1300	2812	1369	655	582	523	199	151	109	48	30	26	14	19	6	4	3	3	12
1991	2921	1035	1074	2323	1130	539	474	419	156	117	84	37	23	20	10	14	4	3	2	12
1992	1426	2415	856	888	1919	932	443	387	336	122	89	62	27	17	14	8	10	3	2	10
1993	821	1179	1996	707	734	1584	767	363	313	267	94	66	45	19	12	10	5	7	2	9
1994	972	679	975	1651	585	606	1307	631	295	249	204	70	49	33	14	9	7	4	5	8
1995	618	804	561	806	1364	483	500	1075	515	237	195	155	52	36	24	10	6	5	3	10
1996	658	511	665	464	666	1128	399	413	885	421	191	152	116	38	25	17	7	4	4	9
1997	711	544	423	550	384	551	932	330	341	729	344	153	118	87	27	18	12	5	3	9
1998	455	588	450	349	454	317	455	771	273	281	599	279	120	86	57	16	10	7	3	7
1999	759	376	486	372	289	376	262	376	635	224	230	485	224	95	67	44	13	8	5	8
2000	596	628	311	402	308	239	310	216	310	521	182	185	385	175	74	52	34	10	6	10
2001	1227	493	519	257	332	254	197	255	177	252	420	145	146	299	135	57	40	26	7	12
2002	1953	1015	407	429	212	274	210	162	210	145	206	341	117	117	240	108	45	32	21	16
2003	2256	1615	839	337	354	175	226	172	133	171	117	165	271	93	92	188	85	35	25	29
2004	1864	1865	1335	693	278	293	145	186	141	108	138	94	132	215	74	73	149	67	28	42
2005	1663	1541	1542	1103	573	230	241	119	151	114	86	109	74	102	167	57	57	116	52	54
2006	2046	1375	1274	1274	912	473	189	198	97	122	91	68	86	58	80	131	45	44	91	84
2007	579	1691	1137	1053	1053	753	390	155	161	78	97	71	53	67	45	63	102	35	35	136
2008	167	479	1398	940	870	869	620	319	126	128	61	76	56	42	52	35	49	80	27	133
2009	151	138	396	1156	776	718	716	507	257	99	99	47	57	42	31	39	27	37	60	121
2010	115	125	114	327	955	641	593	588	412	205	77	76	35	43	32	24	30	20	28	137
2011	154	95	103	95	270	789	529	487	480	332	162	59	57	26	32	24	18	22	15	123
2012	185	127	78	85	78	223	651	435	398	386	260	123	44	43	20	24	18	13	16	102
2013	182	153	105	65	71	65	184	534	353	317	300	196	91	32	31	14	17	13	9	85
2014	128	151	127	87	53	58	53	151	434	284	251	233	150	69	24	23	11	13	9	70
2015	511	106	125	105	72	44	48	44	124	354	229	198	180	114	52	18	17	8	10	60
2016	846	422	87	103	87	59	36	40	36	101	287	183	156	140	88	40	14	13	6	53
2017	990	700	349	72	85	72	49	30	33	29	81	227	142	120	107	67	30	11	10	45
2018	748	818	578	288	60	70	59	40	25	26	23	65	178	111	93	83	52	23	8	42
2019	577	618	676	478	238	49	57	48	32	19	21	18	51	140	87	73	65	41	18	40
2020	922	477	511	559	395	196	40	47	38	26	15	16	14	40	109	68	57	51	32	45
2021	473	762	394	422	461	323	159	32	37	30	20	12	13	11	31	85	53	45	40	60
2022	660	391	630	326	349	379	264	128	26	30	24	16	10	10	9	25	69	43	36	80
2023	719	546	323	521	269	287	310	214	103	21	24	19	13	8	8	7	20	55	34	93
2024	719	594	451	267	430	222	236	254	174	83	16	18	15	10	6	6	6	15	42	97

Table 8.20. Estimated male numbers-at-age for M24.2

	Age (Males)																			
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	240	81	72	83	126	77	47	36	23	13	7	9	6	6	6	6	6	6	6	6
1976	593	192	65	57	67	101	61	38	28	18	9	5	5	4	4	4	3	3	3	7
1977	327	474	153	52	46	53	80	49	30	23	14	7	3	3	2	2	2	2	2	5
1978	475	261	378	123	42	37	43	64	39	24	18	11	5	2	2	1	1	1	1	4
1979	435	380	209	302	98	33	29	34	51	31	19	14	8	4	1	1	0	0	0	1
1980	548	347	303	167	241	78	26	23	27	40	24	15	11	6	3	1	1	0	0	1
1981	945	437	277	242	132	191	61	21	18	21	31	19	11	8	5	2	1	1	0	1
1982	962	755	349	221	191	103	148	47	16	14	16	24	14	9	6	4	2	1	0	1
1983	911	768	603	278	176	152	81	115	36	12	11	12	18	11	7	5	3	1	0	1
1984	1768	728	614	481	222	140	121	64	90	28	9	8	9	14	8	5	4	2	1	1
1985	1543	1411	580	489	382	175	109	92	47	64	19	6	5	6	9	5	3	2	1	1
1986	1411	1232	1126	461	383	293	133	83	70	36	49	15	5	4	5	7	4	2	2	2
1987	2426	1127	984	899	367	301	225	101	63	53	27	37	11	4	3	3	5	3	2	3
1988	4115	1938	900	784	711	284	225	165	74	46	38	20	27	8	3	2	3	4	2	3
1989	1572	3287	1547	718	620	539	198	150	109	49	30	25	13	18	5	2	1	2	2	4
1990	1252	1256	2624	1234	569	483	402	140	104	75	34	21	17	9	12	4	1	1	1	4
1991	2921	1000	1003	2094	981	446	369	302	105	78	56	25	15	13	7	9	3	1	1	4
1992	1426	2333	799	801	1670	779	351	284	224	76	55	40	18	11	9	5	6	2	1	3
1993	821	1139	1864	638	639	1330	617	273	214	162	54	39	28	12	8	6	3	4	1	3
1994	972	656	910	1489	510	510	1059	486	208	155	116	38	27	20	9	5	5	2	3	3
1995	618	777	524	727	1189	407	406	832	366	150	110	82	27	19	14	6	4	3	2	4
1996	658	494	620	419	581	950	325	324	660	286	114	80	58	19	13	10	4	3	2	4
1997	711	526	394	496	334	464	758	259	258	523	223	85	58	41	13	9	7	3	2	4
1998	455	568	420	315	396	267	371	606	207	206	415	175	64	40	25	8	5	4	2	4
1999	759	363	454	336	252	316	213	295	481	162	158	313	131	48	30	19	6	4	3	4
2000	596	607	290	362	268	201	252	170	234	375	124	119	234	98	36	22	14	4	3	5
2001	1227	476	485	232	289	214	160	200	133	181	285	93	89	174	72	26	16	10	3	6
2002	1953	980	380	387	185	231	170	127	157	104	140	220	72	68	134	56	20	13	8	7
2003	2256	1560	783	304	309	147	183	133	98	120	79	107	168	55	52	102	42	16	10	11
2004	1864	1802	1246	625	242	246	117	143	103	75	92	61	82	129	42	40	78	33	12	16
2005	1663	1489	1439	995	499	193	195	92	110	79	57	70	46	62	97	32	30	59	25	21
2006	2046	1328	1189	1149	794	397	152	152	70	84	60	43	53	35	47	74	24	23	45	35
2007	579	1634	1061	949	917	633	315	120	118	54	64	45	33	40	26	35	56	18	17	60
2008	167	463	1305	847	758	731	502	247	93	90	41	49	34	25	30	20	27	42	14	59
2009	151	134	369	1042	676	604	581	396	192	70	67	30	36	25	18	22	15	20	31	53
2010	115	121	107	295	832	539	480	458	307	145	52	49	22	26	19	13	16	11	14	62
2011	154	91	97	85	236	664	429	379	356	233	108	38	36	16	19	13	10	12	8	55
2012	185	123	73	77	68	188	528	339	296	271	173	79	28	26	12	14	10	7	9	46
2013	182	148	98	58	61	54	149	416	264	225	201	125	56	20	18	8	10	7	5	38
2014	128	146	118	78	47	49	43	117	323	200	168	148	92	41	14	13	6	7	5	31
2015	511	102	116	94	63	37	39	34	92	250	152	125	109	67	30	10	10	4	5	26
2016	846	408	82	93	75	50	30	31	27	71	189	113	93	81	49	22	8	7	3	23
2017	990	676	326	65	74	60	39	23	24	20	53	140	84	69	60	37	16	6	5	20
2018	748	791	540	260	52	59	47	30	17	18	15	40	105	63	52	45	28	12	4	19
2019	577	597	632	431	207	41	46	36	23	13	14	12	30	80	48	39	34	21	9	17
2020	922	461	477	504	343	163	32	35	27	18	10	10	9	23	61	36	30	26	16	20
2021	473	736	368	381	401	271	127	24	27	21	13	8	8	7	17	46	28	23	20	27
2022	660	378	588	294	303	318	213	99	19	21	16	10	6	6	5	14	36	21	18	37
2023	719	527	302	469	234	240	249	165	77	15	16	13	8	5	5	4	10	28	17	42
2024	719	574	421	241	375	187	190	195	127	58	11	12	9	6	3	3	3	8	21	44

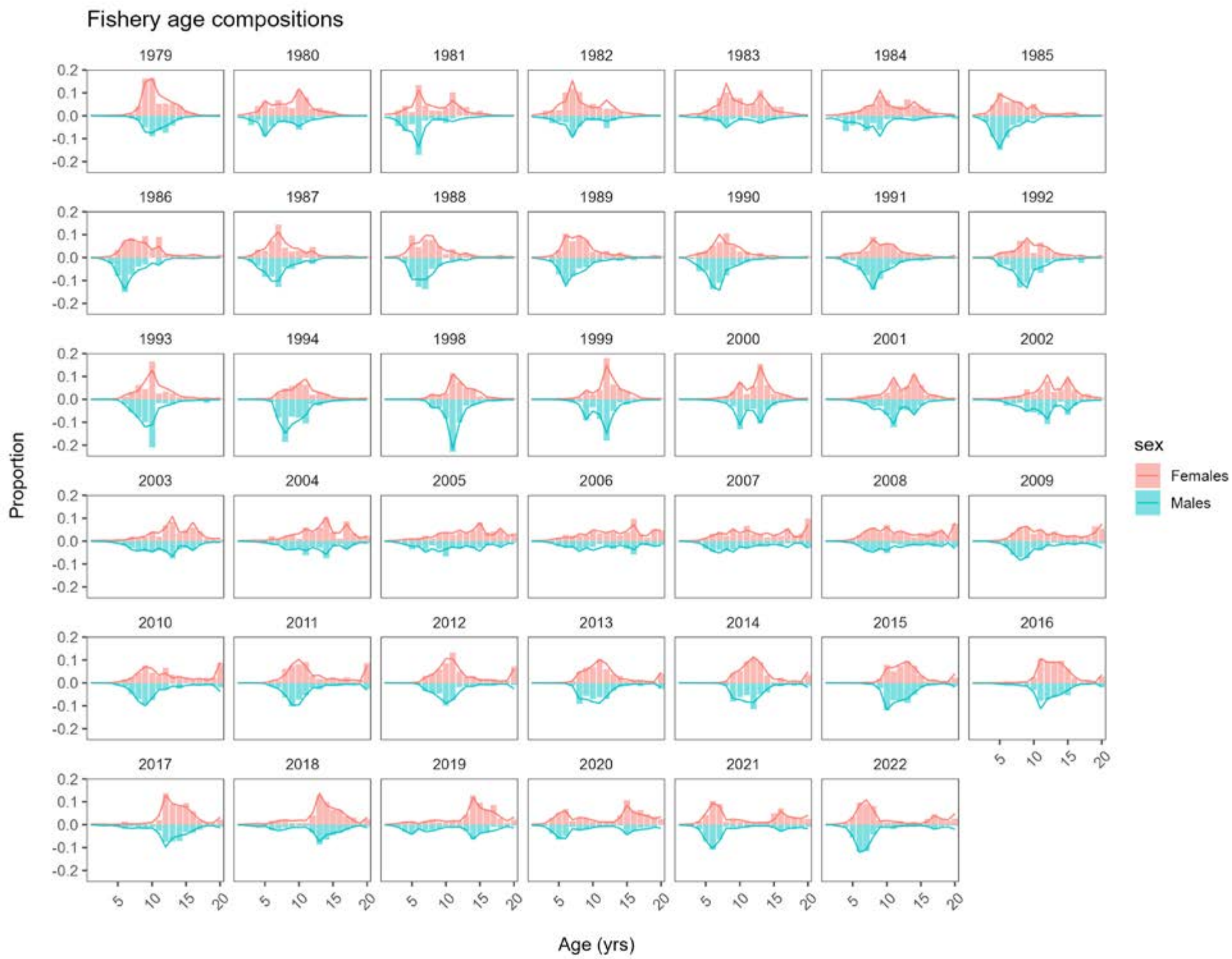

Figure 8.23. Observed (histograms) and expected (lines) fishery age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for Model 24.2.

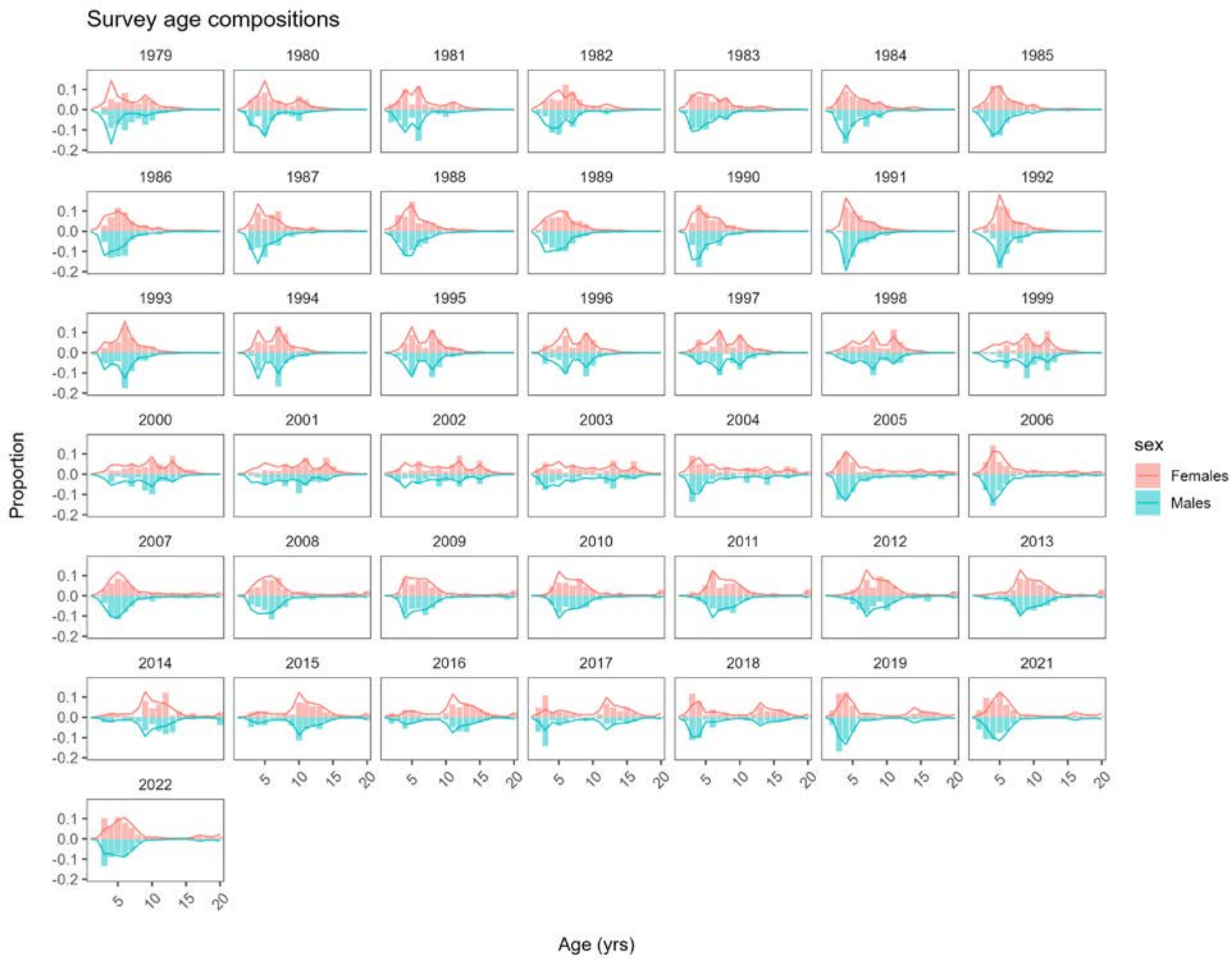

Figure 8.24. Observed (histograms) and expected (lines) survey age compositions for males (blue, below 0 on the y-axes) and females (red, above 0 on y-axes) for Model 24.2.

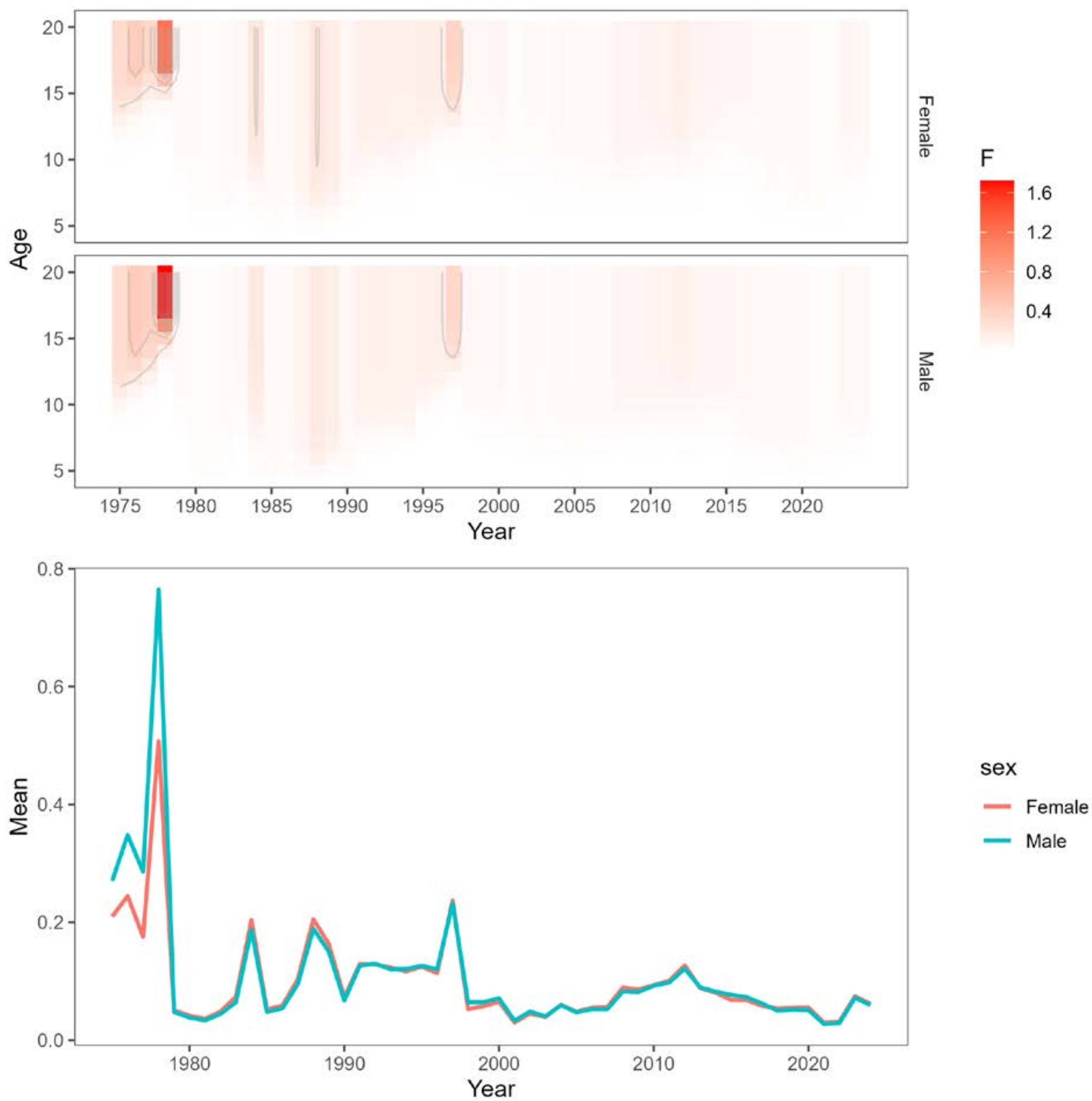

Figure 8.25. A comparison of fishing mortality across ages and time for Model 24.2. The top sub-panel shows fishing mortality by age and year for females and males and the bottom sub-panel shows mean fishing mortality over time. The plots are sex-specific.

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:

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

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

$$Z_{t,a}^{s} = M^{s} + F_{t,a}^{s} \tag{2}$$

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

$$F_{t,a}^{s} = S_{t,a}^{s} F_{t} \tag{3}$$

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

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

where s^{s} is the reference selectivity slope parameter for sex *s*, a_{50}^{s} 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:

$$C_t = \sum_{s} \sum_{a=1}^{A} w_{t,a}^{s} \frac{F_{t,a}^{s}}{Z_{t,a}^{s}} N_{t,a}^{s} (1 - e^{-Z_{t,a}^{s}}) \tag{6}$$

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

2.2.2 Parameter estimation

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

2.3 Projections

2.3.1 Recruitment

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

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

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

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

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

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

2.3.3 Selectivity

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

2.5 Reference points and projections

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

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

The objective function for the northern rock sole stock assessment framework

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

B.1. Likelihood

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

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

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

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.:

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

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.

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

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.

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

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

B.2. Priors

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

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

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

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

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

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

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

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

The prior on the survey catchability coefficient is:

$$P_2 = (\ell nq - \ell nq_p)^2 / 2\sigma_q^2 \tag{B.9}$$

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

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

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

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

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

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

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

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

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

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Tables

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

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

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

Parameter	Prior
Recruitment	
Log mean recruitment, $\ell n\bar{R}$	U[-∞,∞]
Log initial recruitment, ℓnN^{I}	U[-∞,∞]
Annual recruitment deviations, ε_t , η_a	Equations B.6 and B.12
Logs of the Ricker parameters, $\ell\text{n}\alpha$, $\ell\text{n}\beta$	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[-∞,∞]