Atlantic States Marine Fisheries Commission

2025 Atlantic Menhaden Stock Assessment Update

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Sustainable and Cooperative Management of Atlantic Coastal Fisheries

Atlantic States Marine Fisheries Commission

Atlantic Menhaden Stock Assessment Update

Prepared by the
ASMFC Atlantic Menhaden Stock Assessment Sub-Committee:
Amy Schueller (Chair), NOAA Fisheries
Sydney Alhale, NOAA Fisheries
Kristen Anstead, Atlantic States Marine Fisheries Commission
James Boyle, Atlantic States Marine Fisheries Commission
Jeffrey Brust, New Jersey Division of Fish and Wildlife
Matt Cieri, Maine Department of Marine Resources
Caitlin Craig, New York Department of Environmental Conservation
Katie Drew, Atlantic States Marine Fisheries Commission
Keilin Gamboa-Salazar, South Carolina Department of Natural Resources
Brooke Lowman, Virginia Marine Resource Commission
Jason McNamee, Rhode Island Department of Environmental Management
Alexei Sharov, Maryland Department of Natural Resources
Chris Swanson, Florida Fish and Wildlife Research Institute

And the
ASMFC Atlantic Menhaden Technical Committee:
Caitlin Craig (Chair), New York Department of Environmental Conservation
James Boyle, Atlantic States Marine Fisheries Commission
Ingrid Braun-Ricks, Potomac River Fisheries Commission
Jeffrey Brust, New Jersey Division of Fish and Wildlife
Matt Cieri, Maine Department of Marine Resources
Robert Corbett, North Carolina Department of Environmental Quality
Micah Dean, Massachusetts Division of Marine Fisheries
Keilin Gamboa-Salazar, South Carolina Department of Natural Resources
Gary Glanden, Delaware Division of Fish and Wildlife
Eddie Leonard, Georgia Department of Natural Resources
Shanna Madsen, Virginia Marine Resource Commission
Jason McNamee, Rhode Island Department of Environmental Management
Kelli Mosca, Connecticut Department of Energy and Environmental Protection
Ray Mroch, NOAA Fisheries
Amy Schueller, NOAA Fisheries
Alexei Sharov, Maryland Department of Natural Resources
Chris Swanson, Florida Fish and Wildlife Research Institute
Heather Walsh, US Fish and Wildlife Service

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EXECUTIVE SUMMARY

The purpose of this assessment was to update the 2020 Atlantic Menhaden Single-Species Benchmark Stock Assessment (SEDAR 2020a) and recent stock assessment update (ASMFC 2022) with data from 2022-2023. The stock assessment update reran the peer-reviewed Beaufort Assessment Model (BAM) with a terminal year of 2023.

As part of the assessment process, the Atlantic Menhaden Stock Assessment Subcommittee (SAS) identified an error in the publication used to estimate the natural mortality rate used in the assessment. The SAS developed a revised estimate of M to use in the base run of the assessment, which was lower than the estimate used in the 2020 benchmark. This resulted in a lower estimate of biomass and fecundity and a higher estimate of fishing mortality over the time-series compared to the previous assessment update.

The ecological reference points (ERPs) for Atlantic menhaden were updated and refined through the 2025 ERP Benchmark Assessment (SEDAR 2025), and the new estimates of ERPs were used to evaluate stock status in this update.

Landings

The Atlantic menhaden commercial fishery has two major components, a purse-seine reduction sector that harvests fish for fish meal and oil and a bait sector that supplies bait to other commercial and recreational fisheries. The first coastwide total allowable catch (TAC) for commercial landings of Atlantic menhaden was implemented in 2013 and has changed in value depending on the most recent stock assessment and management document. Incidental catch and recreational harvest are not counted toward the TAC. The current TAC for the 2023 – 2025 fishing seasons is 233,550 mt. Reduction landings have been steady since the implementation of the TAC, while bait landings have increased, particularly in the northern states. For 2022-2023, reduction landings comprised about 70% of the coastwide landings. In 2023, bait and recreational landings were approximately 50,000 mt and reduction landings were approximately 131,800 mt.

Indices of Relative Abundance

The juvenile Atlantic menhaden index developed from 16 fishery-independent surveys showed the highest young-of-year abundance occurred during the 1970s and 1980s. Abundance has been lower since the 1990s with some moderate increases in the mid-2000s, 2016, and 2021-2023.

Three coastwide indices of adult abundance were developed from eight fishery independent survey data sets: northern (NAD; age-2+), Mid-Atlantic (MAD; age-1+), and southern (SAD; age-1) adult indices. The NAD indicated that age-2+ relative abundance has been variable, but abundance was high in 2012 and 2019-2022 before declining again in 2023. The MAD showed high relative abundance in the late 1980s and then variable abundance with peaks in recent years, including 2022 before declining again in 2023. The SAD indicated that age-1 abundance was high in 1990 and then declined through the 1990s. Abundance peaked again in 2006 and then remained variable with low abundance in the terminal years.

Fishing Mortality

Highly variable fishing mortalities were noted throughout the entire time series and are dependent upon fishing and management policies, as well as stock biomass. The fishing mortality rate was highest in the 1970s and 1980s and has been relatively stable since the early 2000s.

Biomass

Age-1+ biomass has fluctuated over time with a time-series high in 1959 and a time-series low in 1973. During the 1990s, age-1+ biomass increased and has remained relatively stable over the past decades.

Fecundity

Population fecundity (i.e., number of maturing ova), used as a measure of spawning potential, was highest in the early 1960s, low in the 1970s and 1980s, and high again from the 1990s to the present. The largest values of population fecundity were in 1955, 1961, and 2012. Fecundity estimates have been declining since the high in 2012.

Stock Status

Based on the current definition of the ERPs used in management, as updated by the 2025 ERP benchmark assessment, the Atlantic menhaden population is not overfished and overfishing is not occurring. Fecundity was below the target but above the threshold, while the fishing mortality rate was above the target but below the threshold value.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

This Terms of Reference (TOR) report describes the update to the single-species benchmark stock assessment for Atlantic menhaden (SEDAR 2020a). The benchmark was updated in 2022 (ASMFC 2022) to extend the fishery-independent and -dependent data for Atlantic menhaden through 2021, rerun the peer-reviewed Beaufort Assessment Model (BAM), and determine stock status of Atlantic menhaden using the ecological reference points (ERPs) defined in SEDAR (2020b) and accepted for management use in 2020. This update further extends the data, model, and assessment through 2023. This update includes a revised estimate of M, which was peer-reviewed through the concurrent 2025 ERP Benchmark Assessment, and uses ERPs based on the Board's definition of the ERP target and threshold, as updated and refined through the 2024 ERP Benchmark Assessment, to determine stock status.

TOR 1. Fishery-Dependent Data

Update fishery-dependent data (landings, discards, catch-at-age, etc.) that were used in the previous peer-reviewed and accepted benchmark stock assessment.

The commercial reduction, commercial bait, and recreational landings time series were extended from the previous assessment (SEDAR 2020a; ASMFC 2022) through 2023, along with the associated age compositions from the reduction and bait fisheries. For use in the BAM, landings were split into northern and southern regions as defined by waters north and south of Machipongo Inlet, Virginia, where the Chesapeake Bay is in the southern region.

Reduction landings were provided by the NOAA Fisheries Beaufort Lab. Reduction landings in the southern region have been increasing since the last assessment update while the northern reduction landings were decreasing. Southern landings are consistently larger than those in the north (Figure 1). Total reduction landings in 2023 were 131,800 mt.

Bait landings from 1955-1984 were compiled from historic records and considered incomplete, whereas bait landings for 1985-2023 were validated with the states by the Atlantic Coastal Cooperative Statistics Program (ACCSP). Bait landings in the north increased in recent years and were over twice as much as bait landings in the south for the last four years (Figure 2). Total bait landings were relatively constant for 2019-2022, averaging 57,140 mt, but decreased in 2023, in both the north and south, to 48,550 mt.

The Marine Recreational Fisheries Statistics Survey (MRFSS, 1981-2003) and the Marine Recreational Information Program (MRIP, 2004-2023) data sets were used to derive a time series of recreational landings of Atlantic menhaden. The uncertainty associated with recreational estimates for Atlantic menhaden is high and the landings are variable but have increased approximately 2-3 times in the last decade compared to earlier years. (Figure 3). For use in the BAM, recreational harvest, which comprises less than 1% of coastwide harvest, was added to the bait landings.

Coastwide reduction landings have remained relatively steady since 2000 with bait landings increasing over time, comprising 27% of coastwide landings in 2023 (Figure 4).

Commercial reduction and bait catch-at-age matrices were developed from the available biological data collected in each fishery by region. Age proportions of the bait catch were applied to the MRIP estimates of recreational catch and pooled with the bait catch-at-age.

See Appendix for supplemental tables (Table A1 – Table A5) for TOR 1.

TOR 2. Fishery-Independent Data

Update fishery-independent data (abundance indices, age-length data, etc.) that were used in the previous peer-reviewed and accepted benchmark stock assessment.

Sixteen fishery-independent surveys from Rhode Island to South Carolina were used to develop young-of-year (YOY) abundance indices, which were then combined into a coastwide index of relative YOY abundance using the Conn method (Conn 2010; Table 1). Eight fishery-independent surveys from Connecticut to Georgia were developed into age 1+ abundance indices and were combined into three regional adult surveys: a northern adult index (NAD), a Mid-Atlantic adult index (MAD), and a southern adult index (SAD). Several surveys were affected by the COVID-19 pandemic and had no or limited sampling in 2020 and 2021 (Table 1).

The coastwide YOY index of relative abundance for Atlantic menhaden indicated high abundance in the 1970s and 1980s, with declines through the 1990s before stabilizing at pre-1970s levels (Figure 5). YOY abundance remained low but there was a slight increase in the terminal years of 2021-2023. The NAD index predicted variable abundance throughout the time series with high abundance occurring in the recent years of 2019-2022 before declining again in the terminal year of 2023 (Figure 6). The MAD index predicted higher than average abundance in the beginning of the time series followed by a lower but variable abundance through the late 1990s-early 2010s (Figure 7). Abundance in the Mid-Atlantic region began to increase in the mid-2010s but then decreased and was variable through the terminal years with 2020 representing a time series low. Abundance increased in 2021-2022 but declined in 2023. The SAD index predicted high abundance in 1990 followed by low abundance through the mid-2000s (Figure 8). The index peaked again in 2006 but then decreased and was variable through the terminal year. The terminal years of 2022-2023 both indicated relatively low abundance in the region.

For the adult indices, length compositions were developed by combining data from each of the surveys and weighting the data by the inverse of the squared sigma values outputted from the Conn method.

An index of Atlantic menhaden spawning biomass was developed using larval abundance data collected from two regional ichthyoplankton surveys (MARMAP and EcoMon; Figure 9). The index increased in the last few years to an EcoMon time series peak in 2019, after which it started to decline again. The index was updated through 2022, although data from 2021 were not available due to COVID. This index was included in the base run of the assessment model in SEDAR 2020a but was excluded from the 2022 update and this update's base run due to issues with model fitting (ASMFC 2022).

See Appendix for supplemental tables (Table A6 – Table A7) and figures (Figure A1- Figure A4) for TOR 2.

TOR 3. Life History Information and Model Parameterization

Tabulate or list the life history information used in the assessment and/or model parameterization (M, age plus group, start year, maturity, sex ratio, etc.) and note any differences (e.g., new selectivity block, revised M value) from benchmark.

Tabulated life history information and model inputs can be found in Table 2. The benchmark assessment was updated with all available data through the terminal year of 2023. The same time blocks for catch selectivity estimations used in SEDAR 2020a were used in this update. Since the last assessment (SEDAR 2020a), the fecundity information was updated by the Virginia Institute of Marine Science (R. Latour and J. Gartland, VIMS, unpublished data; Latour et al 2023) using the same methods as was used for the benchmark.

Three changes were made to the updated run from the benchmark assessment during the 2022 assessment update which were carried through to this update:

1. Censoring of the MARMAP/EcoMon (MARECO) ichthyoplankton index;
2. Censoring of the commercial bait south age compositions for 2020;
3. The inclusion of penalties on some of the selectivity parameters that were hitting bounds during the estimation process.

These changes to the assessment update were considered thoroughly during the last assessment update and were discussed thoroughly in that documentation (ASMFC 2022). Briefly, the quality and quantity of data during the COVID-19 pandemic years caused some problems with estimation of parameters and the determination of year-class strength (recruitment). This update assessment retained the same method of recruitment estimation as used during the benchmark assessment. There is no formal stock-recruitment structure, rather median recruitment is estimated along with annual recruitment deviations from that median for the duration of the time series.

The only new change for this update assessment is the inclusion of a new vector of natural mortality based on a revised analysis of the historical tagging data that was completed by the M Working Group. The 2020 benchmark assessment used the estimate of M from Liljestrand et al.'s (2019) analysis of the tagging data to scale the Lorenzen (1996) curve of M-at-age, assuming that the M estimated from the tagging data represented the M for age-1.5 menhaden, based on the size of the tagged fish. During the 2025 benchmark assessment process, Ault et al. (2023) submitted a working paper to the Atlantic menhaden SAS and the Ecological Reference Points Work Group (ERP WG) that re-analyzed the historical tagging data and produced an estimate of M = 0.56, significantly lower than the M = 1.17 reported by Liljestrand et al. (2019).

However, Ault et al. (2023) had used a different subset of the data and a different approach to handling key parameters, which made direct comparisons with Liljestrand et al. (2019) difficult. The SAS formed a working group to review the datasets and methods in consultation with the primary authors to determine the best estimate of M for use in the Atlantic menhaden stock assessment. The M WG and SAS determined that the main cause of the difference in the M estimates was the handling of the magnet efficiency parameter, which was equivalent to the tag reporting rate in conventional tagging models. The M WG and SAS found that Liljestrand et al. (2019) had overestimated the magnet efficiency rate in their analysis, but did not agree with the stepwise estimation approach proposed by Ault et al. (2023) to estimate this parameter. In the end, the M WG and SAS recommended a revised estimate of M = 0.92 from the tagging study, based on the corrected magnet efficiency rate and updated effort and landings datasets, which was lower than the value used in the 2020 benchmark, but higher than the value estimated from Ault et al.'s (2023) method. This revised estimate of M was used to scale the Lorenzen (1996) curve to develop M-at-age estimates so that the estimate of M-at-age for age-1.5 was equal to the estimate from the tagging model, based on the size of the tagged fish, as was done for the benchmark (Table 2). The estimate developed using the Ault et al. (2023) stepwise approach was used as a sensitivity run (Table 2). See the working paper SEDAR 102 WP-01 for a full description of the data, methods, and M WG findings. The revised estimate of M was peer reviewed through SEDAR 102, as part of the ERP Benchmark Assessment.

TOR 4. Updated Beaufort Assessment Model

Update accepted model(s) or trend analyses and estimate uncertainty. Include sensitivity runs and retrospective analysis if possible and compare with the benchmark assessment results. Include bridge runs to sequentially document each change from the previously accepted model to the updated model.

In order to bridge from the benchmark assessment to the current updated assessment with the new M vector, we provided bridging runs including the benchmark assessment, the 2022 update assessment, and this update assessment both with the old natural mortality vector and the new vector.

In general, the updated base run assessment is similar to the 2020 benchmark assessment, the 2022 update assessment, and the continuity run for this assessment with main differences being in the scale of this assessment given the difference in the scale of natural mortality. Generally, the trends over time are similar across metrics, and the largest change is in the estimation of mean recruitment from the time series, which is an expected change. The model fit well to the landings for all four fleets. In general, the patterns in the age compositions were random and did not exhibit any patterning. The fits to the indices were similar to the fits during the benchmark assessment and did not have runs in residuals. The fits to the NAD and MAD length compositions were also similar to the fits during the benchmark assessment. Selectivity for the fisheries and the indices were similar to the last assessment.

The fishing mortality rate (*F*) increased slightly in 2022 and then decreased again in 2023 and has been relatively stable since 2000 (Figure 10). The recruitment classes for 2022 and 2023 appear to be slightly larger than average over the last two decades (Figure 11). However, the model does have difficulty estimating year-classes in the terminal year of the model, as evidenced by the 2022 update to the benchmark assessment. Age-1+ biomass increased slightly during the last two years but is still below average for the last few decades (Figure 12). Finally, fecundity has been stable during the most recent years (Figure 13).

A sensitivity run was completed to show how an alternative natural mortality estimate impacted assessment outcomes. In general, natural mortality is one of the components in stock assessments that is the most uncertain. However, in the case of Atlantic menhaden the SAS has an extensive tagging study that addressed many assumptions for use in estimating the scale of natural mortality.

The sensitivity run with the lower values of M estimated by Ault et al. (2023) resulted in very similar fits to all of the indices of abundance. The largest differences between the base run and the sensitivity run with the lower M values were the estimates of the recruitment time series and the full fishing mortality rate time series, both of which scaled with assumptions about natural mortality. In general, natural mortality scales an assessment, along with landings, to give an indication of the overall mortality, Z, and thus the fishing mortality. In addition, the recruitment estimates will also scale to the appropriate level associated with the anticipated mortality rates and the catch levels. One interesting response for this sensitivity run compared to the base run was that the geometric mean fishing mortality rate was the same for both runs from the 1990s to the present. This occurred because the geometric mean fishing mortality rate is focused on age-2 to -4, and the proportion of older aged individuals was increasing in the population causing reduced fishing mortality for older ages, which was in line with the base run values.

A retrospective analysis was also completed for the update assessment. A series of runs were done removing the terminal year data in sequence. The update assessment had a terminal year of 2023, and the retrospective analysis was run back through a terminal year of 2018. Overall, the retrospective runs fall within the uncertainty bounds from the uncertainty analysis. The fits to the indices for the retrospective runs are very similar to the base run. All of the retrospective plots have good overlap in the estimated historical values across fishing mortality, fecundity, and recruitment. In general, the recruitment retrospectives did a good job estimating terminal year recruitment values, especially 2022 and 2021, which were the values estimated in the base run with the terminal year of 2023. The geometric mean fishing mortality rate and the fecundity values were generally estimated close to the base run, but the terminal geometric mean fishing mortality was generally lower in all years of the retrospective than the base run while fecundity was generally higher.

A Monte Carlo bootstrap (MCB) uncertainty analysis was completed as was done for the last benchmark assessment. The configuration was kept exactly the same with uncertainty in natural mortality and fecundity. The range of uncertainty surrounding natural mortality was updated to reflect the tagging reanalysis. Specifically, the range of natural mortality estimates for age-1.5 was [0.83, 0.97]; the Lorenzen curve for the age-varying M for each run was rescaled to the estimate of age-1.5 M drawn for that run. A total of 5,000 runs were completed. Some runs were excluded due to large gradients, leaving 4,734 MCB runs for analysis. Overall, the uncertainty was much narrower for all the metrics of interest when compared to the last update assessment and the benchmark assessment. During the benchmark and update assessments, the MCB analyses provided outcomes that were bimodal in nature. With this update, that bimodality was reduced substantially.

See Appendix for supplemental tables and figures for TOR 4: model fits to landings (Figure A5 - Figure A8) and associated age comps (Figure A9 - Figure A16), model fits to indices (Figure A17 - Figure A20) and associated length comps (Figure A21 - Figure A24), estimated selectivities

(Figure A25 - Figure A30), model estimated *F*, recruitment, biomass, and fecundity (Figure A31 - Figure A38), bridge runs (Figure A39 - Figure A46), sensitivity runs (Figure A47), and the retrospective analysis (Figure A55 - Figure A62).

TOR 5. Stock Status

Update the biological reference points or trend-based indicators/metrics for the stock. Determine stock status.

The Atlantic Menhaden Management Board (Board) adopted ERPs in Amendment 3 to account for menhaden's ecological role as a forage species. Thus, stock status is determined using ERPs. The 2025 ERP Benchmark Assessment incorporated the revised estimate of M into the ERP models and re-estimated the ERP *F* target and *F* threshold using the new ERP model and the definitions adopted by the Management Board in 2020. The ERPs from the 2025 Benchmark Assessment are lower than the ERPs developed through the 2020 benchmark assessment and used in the 2022 menhaden single-species update (Table 3), due to both the change in *M* for the single-species model and the refinements made during the 2025 benchmark process (SEDAR 2025). The 2025 ERP Benchmark Assessment provides a tool for the Board to use to evaluate tradeoffs in their goals and objectives for Atlantic menhaden. Thus, stock status may change if the Board chooses a different definition of the ERPs going forward.

Using the current definition of the ERP benchmarks, as re-estimated by the 2025 ERP Benchmark Assessment, the Atlantic menhaden population is not overfished and overfishing is not occurring (Table 4). The fishing mortality rate for the terminal year of 2023 is below the ERP threshold and above the ERP target ($F_{2023}/F_{ERPThreshold}$ = 0.56; $F_{2023}/F_{ERPTarget}$ = 1.69; Figure 14), and the fecundity for the terminal year of 2023 is above the ERP threshold and but below the ERP target ($FEC_{2023}/FEC_{ERPThreshold}$ = 1.05; $FEC_{2023}/FEC_{ERPTarget}$ = 0.71; Figure 15). Therefore, overfishing is not occurring and the stock is not overfished (Table 3).

The uncertainty in the stock status was evaluated through the MCB analysis. The terminal year *F* was below the ERP threshold for all of the MCB runs (Figure 16) and the terminal year fecundity was above the ERP threshold for 77% of the runs (Figure 17). The SAS does note that each MCB run was not run through the ERP's Northwest Atlantic Coastal Shelf Model of Intermediate Complexity for Ecosystems (NWACS-MICE) model, thus the benchmark comparisons were to those from the base run. The MCB plots are not internally consistent for each run, but do give an idea of the uncertainty related to the ERP benchmarks, which agrees with the base run stock status determinations.

TOR 6. Projections

Conduct short term projections when appropriate. Discuss assumptions if different from the benchmark and describe alternate runs.

Short-term projections at the current Total Allowable Catch (TAC) of 233,550 mt were provided (Figure 18). Under a constant TAC of 233,550 mt, *F* will be between the *F* target and the *F* threshold, with a 4% probability that *F* will be above the ERP *F* threshold and a 100% probability that it will be above the *F* target in 2028 (Table 4). Further projections based on the Board's requests were conducted after the Peer Review and provided in Appendix 1.

The projections have the same methods and assumptions as those run for the benchmark assessment. It is important to note that uncertainty is accounted for in the projections. Additionally, during the benchmark (SEDAR 2020a), the SAS used a new procedure for recruitment in the projections. Instead of assuming a static median value for recruitment, as is done for many assessment projection methodologies, recruitment was projected using nonlinear time series analysis methods (Deyle et al 2018). Specifically, projections were based on the MCB runs, which allows recruitment to change from year to year in the projections based on how recruitment has changed in the past under similar conditions. Thus, uncertainty is recognized in the recruitment time series, and the methods used for projections adequately accounted for that uncertainty using the best scientific methods available. However, the Board should still consider these uncertainties in the context of risk when using the projection information for management.

TOR 7. Research Recommendations

Comment on research recommendations from the benchmark stock assessment and note which have been addressed or initiated. Indicate which improvements should be made before the stock undergoes a benchmark assessment.

All research recommendations from SEDAR 2020a and 2020b remain important to the continued assessment of Atlantic menhaden, including those updated in this section. Please refer to the appendices at the end of this report for the complete list.

A long-standing research recommendation for Atlantic menhaden is to develop and implement a multi-year coastwide fishery-independent survey. It was noted in SEDAR 2020a that even area-specific surveys could provide substantial improvements over the indices currently used in the assessment. Pilot studies combining hydroacoustics and aerial or trawl surveys have been conducted successfully in Chesapeake Bay and mid-Atlantic ocean waters (e.g., Wilberg et al. 2020; Nesslage et al. 2024). However, no funding has been secured for long-term implementation of these projects.

Despite the research recommendation to continue the current level of sampling from the fisheries, some sampling was reduced or temporarily discontinued due to the COVID-19 pandemic. However, sample sizes have returned to pre-pandemic levels in the years since the 2022 assessment update. The TC is planning to meet this summer to evaluate the adequacy of the current bait sampling requirements for the states.

In preparation for shifting ageing responsibilities to the states, ASMFC coordinated an age exchange in 2023 – 2024, with the final report due in 2025. During the exchange, 65 paired scale and otolith samples and 11 scale-only samples were read by staff from 12 states and the NOAA Beaufort lab. True age was not known for any of the samples, so comparisons only provide information on variability among users. Preliminary results indicate that precision was generally low across labs and structures, and bias was commonly detected, likely due to the fact that many of the participating labs do not regularly age menhaden. ASMFC is scheduling a follow-up meeting to review results and discuss ways to improve precision among partners before fully transitioning bait ageing to the states.

Although a seasonal and spatially-explicit model has not been developed, the SAS has recently completed a thorough review of data from an extensive mark-recapture study conducted by the NOAA Beaufort lab during the late 1960s that could provide insight into age-specific movement patterns needed for such a model (see SEDAR 102 WP-01 for more details on the dataset and estimated movement patterns).

During the next benchmark stock assessment process (scheduled for 2031), the SAS recommends that the MARECO index still be considered for inclusion in the model, but further investigation is necessary. One option the SAS could consider is using nonlinear relationships between *q* and the MARECO index. Additionally, the SAS recommends that ACCSP continues to work with the states to validate bait landings and resolve the transition in the time series from pre-1985 bait landings in the northern region.

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TABLES

Table 1. Fishery-independent surveys included in the coastwide young-of-year (YOY) and regional adult Atlantic menhaden abundance indices (Northern Adult Index, NAD; Mid-Atlantic Index, MAD; Southern Adult Index, SAD).

Conn Index	Fishery-Independent Survey (years of data)	Months	Length
NAD	CT LISTS (1996-2009, 2011-2019, 2021-2023)	Sept-lagged Jan	1990-2023
	DB Adult Trawl (1990-2023)		
	NJ Ocean Trawl (1990-1997, 1999-2019)		
MAD	MD Gill Net (1985-1995, 1998-2002, 2005-2023)	March-May	1985-2023
	VIMS Shad Gill Net (1998-2023)		
SAD	NC p915 (2008-2019, 2021-2023)	April-July	1990-2023
	SEAMAP (1990-2019, 2022-2023)		
	GA EMTS (2003-2023)		
YOY	RI Trawl (1990-2023)	Varies by survey	1959-2023
	CT LISTS (1996-2009, 2011-2019, 2021-2023)		
	CT River Alosine (1987-2023)		
	CT Thames River Alosine (1998-2016)		
	NY Juvenile Striped Bass Seine (2000-2023)		
	NY Peconic Bay Trawl (1987-1988, 1990-1992, 1994-2007, 2009-2023)		
	NY WLIS Seine (1986-2023)		
	NJ Ocean Trawl (1990-2019)		
	NJ Striped Bass YOY Seine (1986-2019, 2021-2023)		
	DB Inner Bays (1986-2023)		
	MD Coastal Trawl (1972-1992, 1994, 1998-2023)		
	MD Juvenile Striped Bass (1959-2023)		
	VIMS Juvenile Trawl (1990-2023)		
	VIMS Striped Bass Seine (1968-1972, 1980, 1982, 1985-2023)		
	NC p120 (1989-2023)		
	SC Electrofishing (2001-2023)		

Table 2. Model structure and life history information used in the stock assessment.

	Value(s)
Years in Model	1955-2023
Age Plus Group	6+
Fleets	4 (north and south regions for bait and reduction fisheries)
Fecundity	Time-varying fecundity-at-age
Natural Mortality	Age-varying natural mortality scaled to tagging based estimate, revised for 2025
Maturity	Time-varying maturity-at-age based on length-at-age
Sex Ratio	Fixed at 1:1 for males:females

	Age Group						
Natural Mortality	0	1	2	3	4	5	6+
2020 Benchmark	1.76	1.31	1.03	0.9	0.81	0.76	0.72
2025 Update Base Run	**1.39**	**1.03**	**0.82**	**0.71**	**0.64**	**0.60**	**0.57**
2025 Update Sensitivity	0.71	0.52	0.42	0.36	0.33	0.30	0.29

Table 3. Ecological Reference Points for *F* and fecundity used in the 2022 and 2025 single-species updates. Fecundity is in billions of eggs.

	F		**Fecundity**	
	Target	**Threshold**	**Target**	**Threshold**
2022 Update	0.19	0.57	2,003,986	1,492,854
2025 Update	0.15	0.46	1,758,288	1,184,339

Table 4. Stock status based on fishing mortality (*F*) and fecundity (*FEC*) ecological reference points (ERP targets and thresholds) from the 2025 ERP assessment and terminal year values from the base run of the BAM for the stock assessment update. Fishing mortality is the full fishing mortality. Fecundity is in billions of eggs.

Reference Point	ERP Value	2023 Value	Stock Status
$F_{THRESHOLD}$	0.458	0.26	Not Overfishing
F_{TARGET}	0.151		
$FEC_{THRESHOLD}$	1,758,288	1,240,272	Not Overfished
FEC_{TARGET}	1,184,339		

Table 5. Probability of ERP *F* threshold and target for 2026-2028 under a constant status quo TAC.

	2026	2027	2028
ERP *F* threshold	1%	4%	4%
ERP *F* target	100%	100%	100%

FIGURES

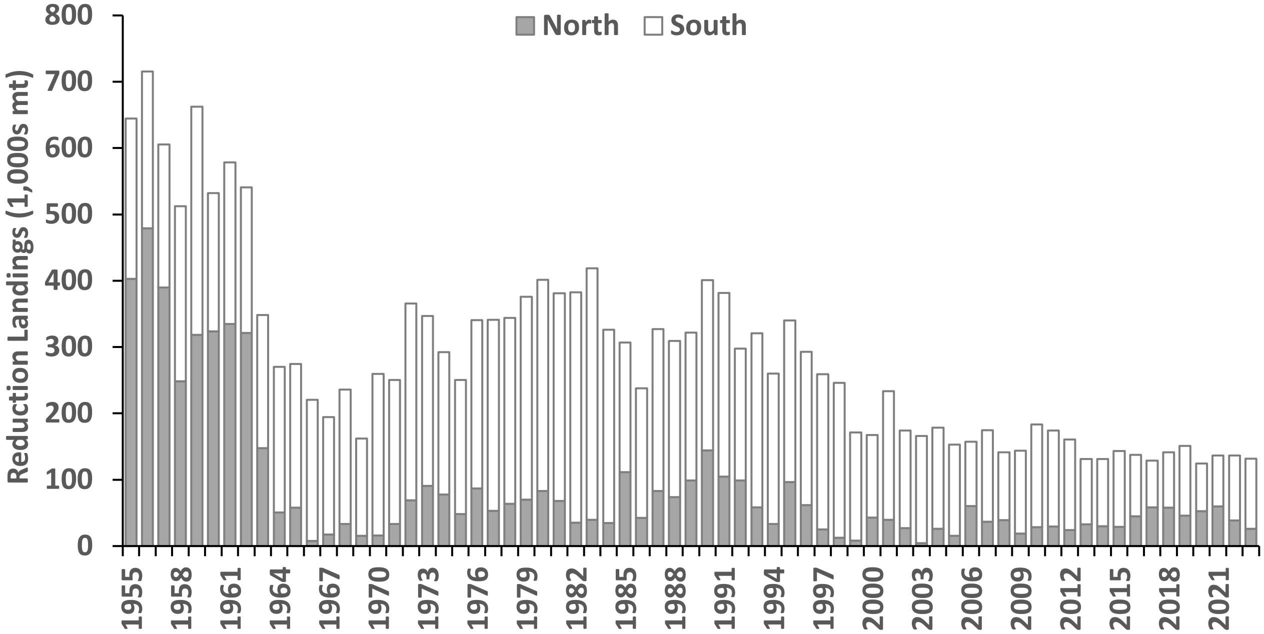

Figure 1. Atlantic menhaden reduction landings (1000s mt) from 1955-2023. The northern region is comprised of landings from Maine to Maryland's Eastern Shore, excluding the Chesapeake Bay, and the southern region is comprised of landings from Virginia Eastern Shore and Chesapeake Bay through Florida (Source: NOAA Fisheries Beaufort).

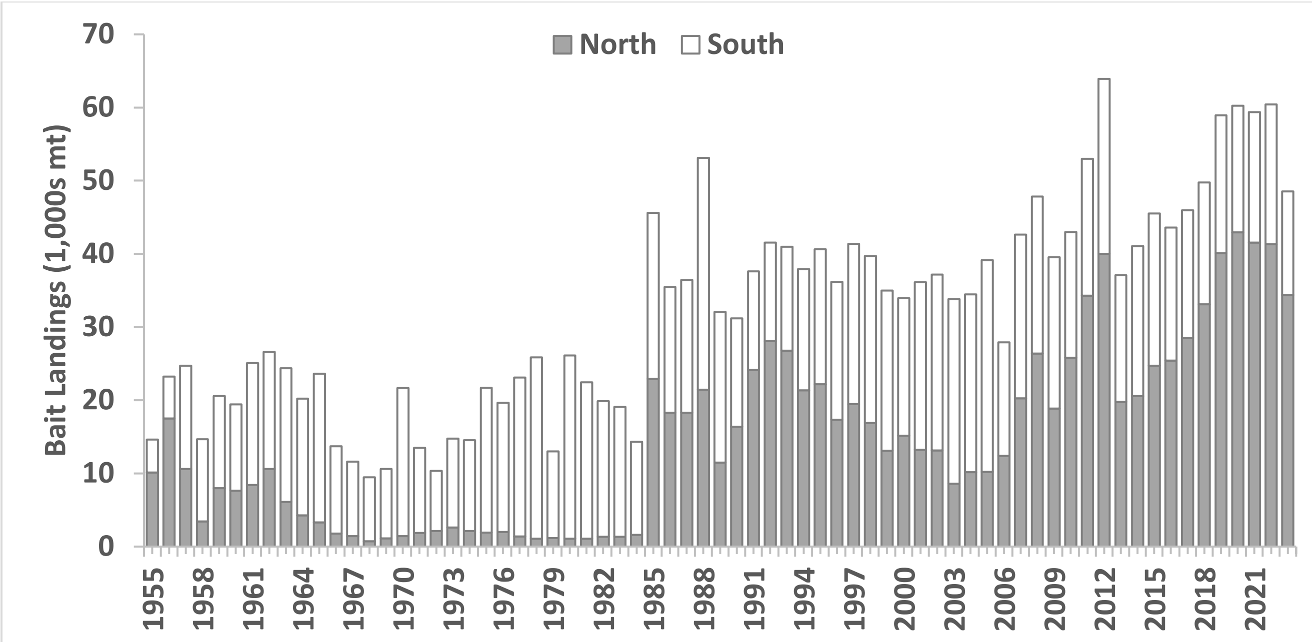

Figure 2. Atlantic menhaden bait landings (1000s mt) from 1955-2023. The northern region includes landings from Maine to Maryland's Eastern Shore, excluding the Chesapeake Bay, and the southern region is comprised of landings from Virginia Eastern Shore and Chesapeake Bay through Florida Only landings from 1985 on can be validated (Source: ACCSP).

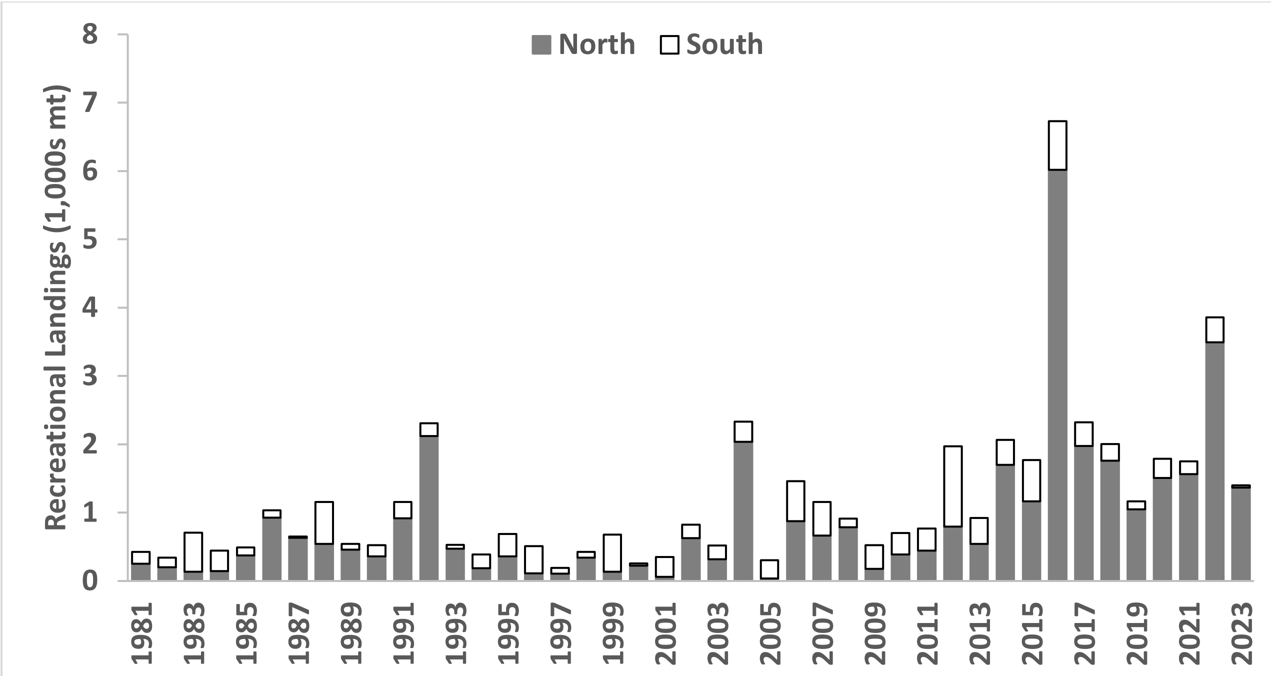

Figure 3. Atlantic menhaden recreational landings (1000s mt) from 1981-2023. The northern region includes landings from Maine to Maryland's Eastern Shore, excluding the Chesapeake Bay, and the southern region is comprised of landings from Virginia Eastern Shore and Chesapeake Bay through Florida (Source: MRIP).

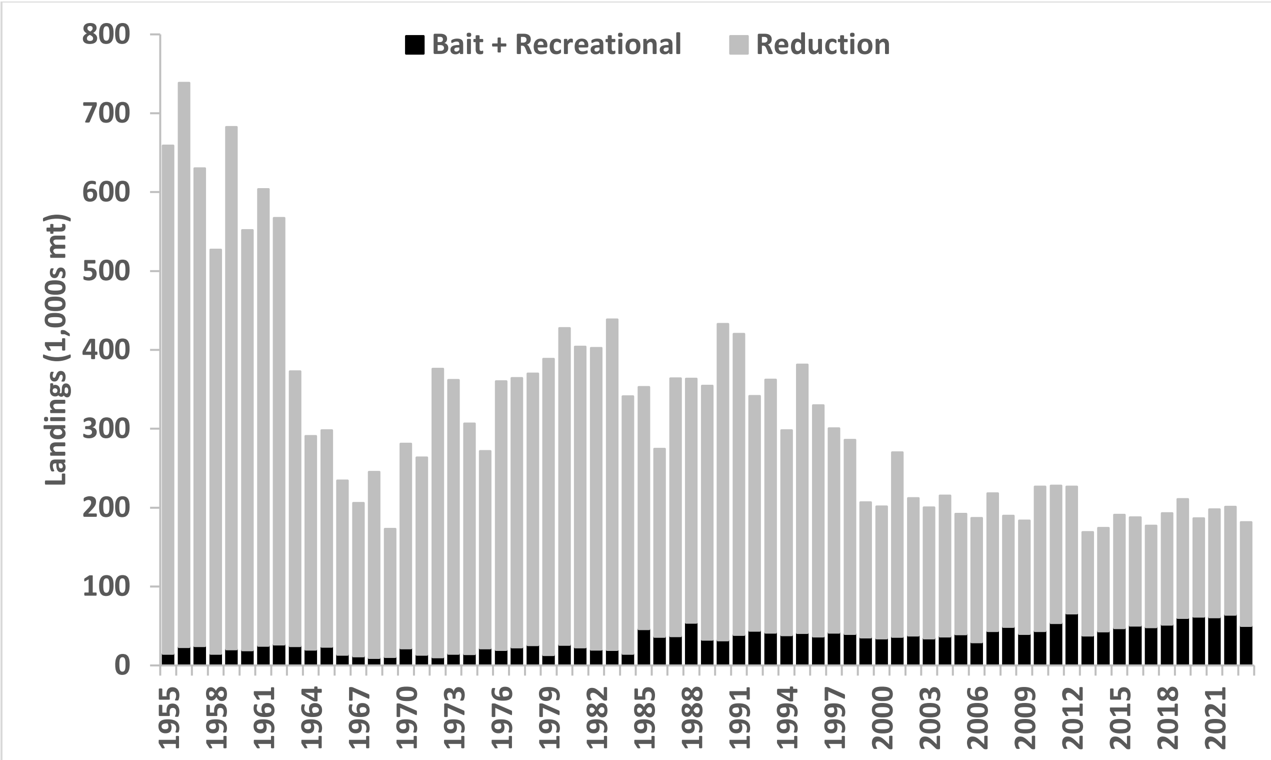

Figure 4. Coastwide Atlantic menhaden landings for the reduction and bait fisheries (1955-2023).

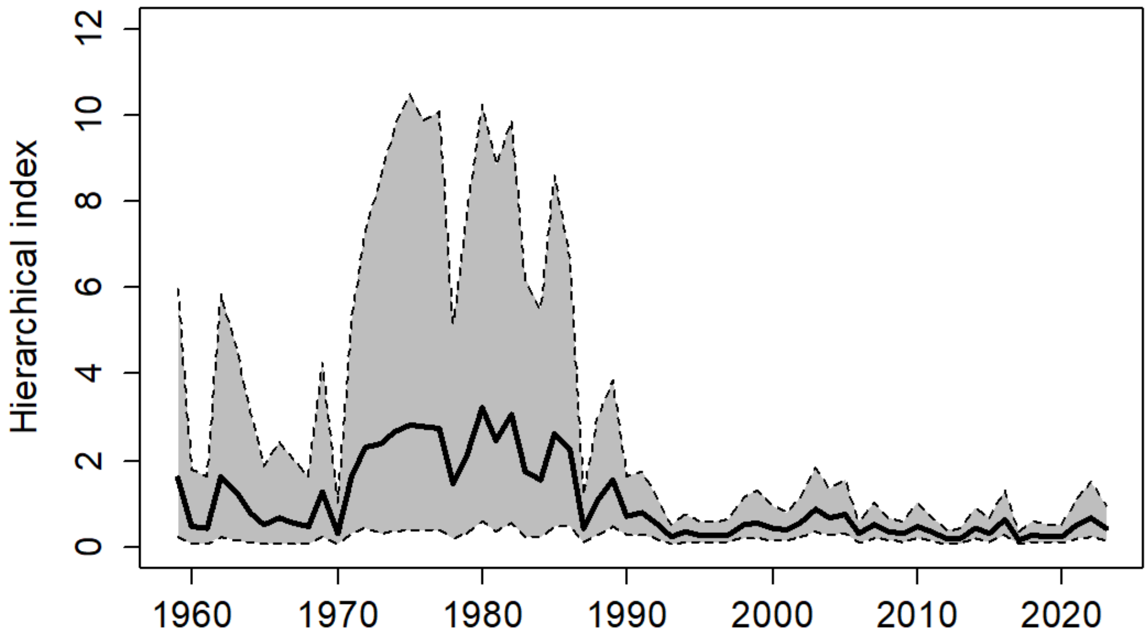

Figure 5. Time series of the young-of-year (YOY) Atlantic menhaden relative abundance index as estimated from hierarchical analysis (Conn 2010). The black line gives the posterior mean and the grey, dashed lines represent a 95% credible interval about the time series.

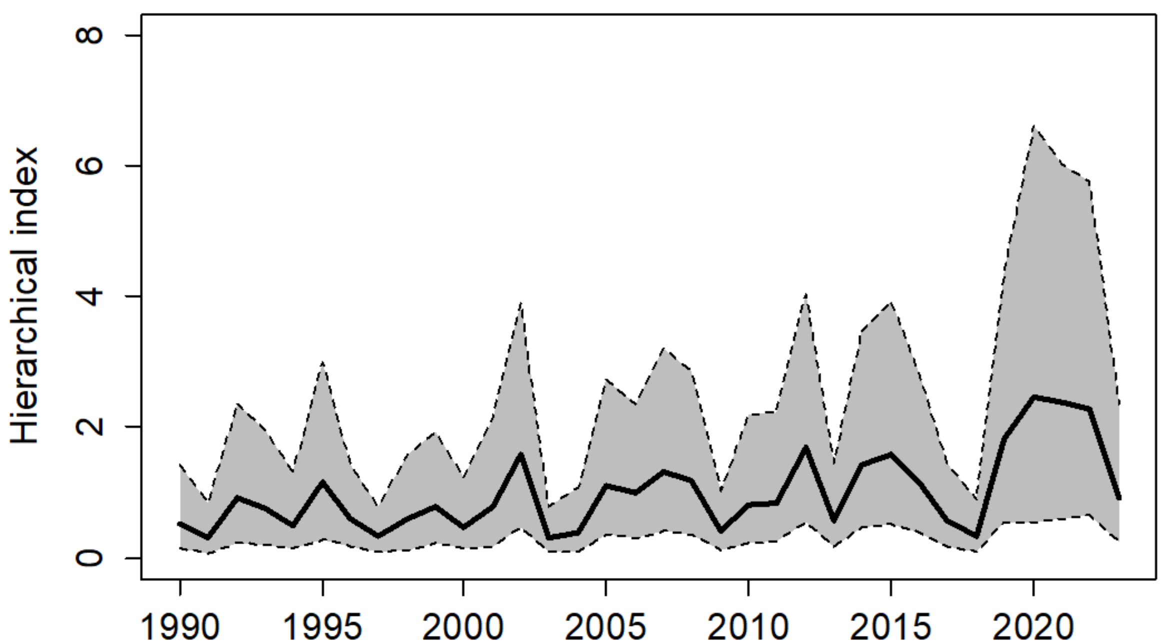

Figure 6. Time series of the northern adult Atlantic menhaden relative abundance index (NAD) as estimated from hierarchical analysis (Conn 2010). The black line gives the posterior mean and the grey, dashed lines represent a 95% credible interval about the time series.

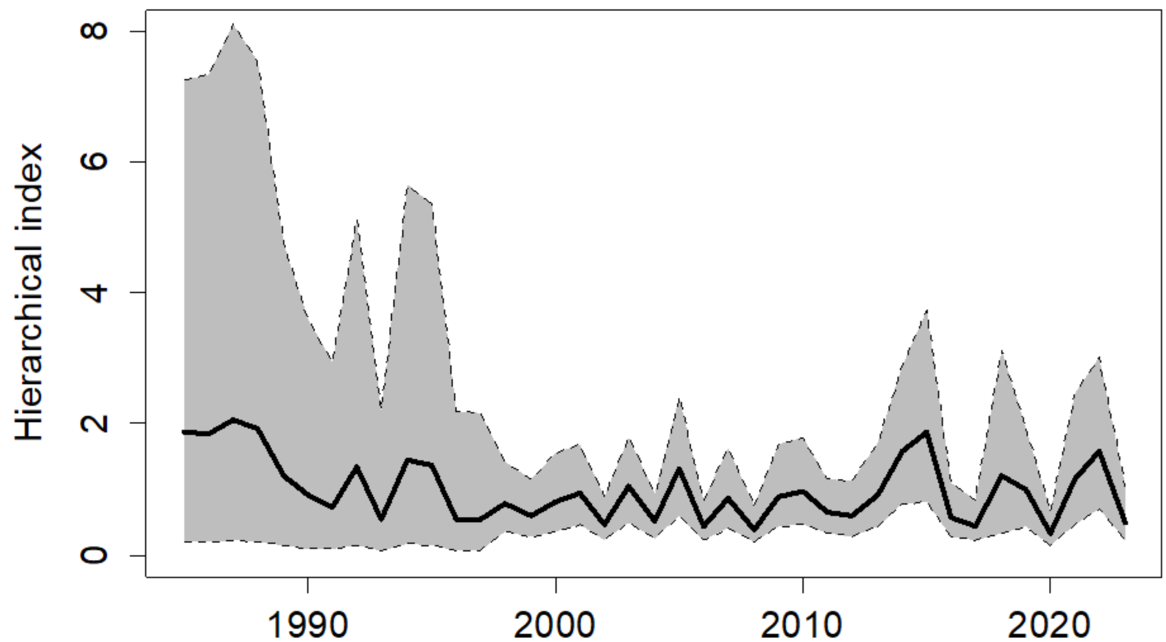

Figure 7. Time series of the Mid-Atlantic adult menhaden relative abundance index (MAD) as estimated from hierarchical analysis (Conn 2010). The black line gives the posterior mean and the grey, dashed lines represent a 95% credible interval about the time series.

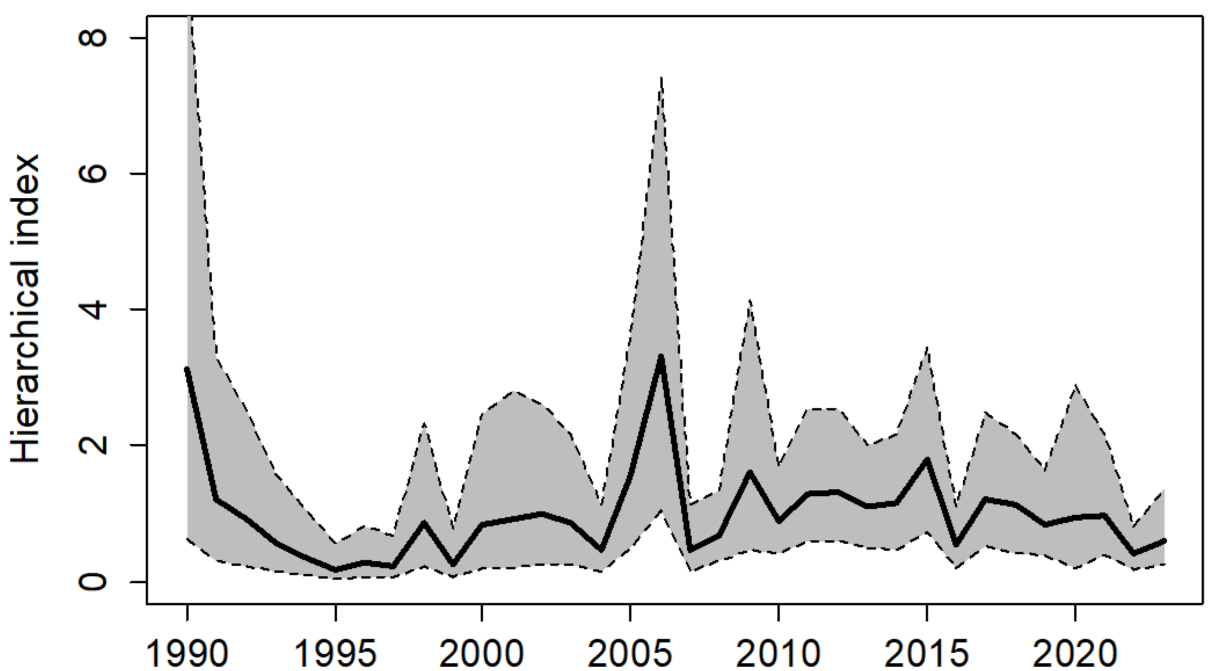

Figure 8. Time series of the southern adult Atlantic menhaden relative abundance index (SAD) as estimated from hierarchical analysis (Conn 2010). The black line gives the posterior mean and the grey, dashed lines represent a 95% credible interval about the time series.

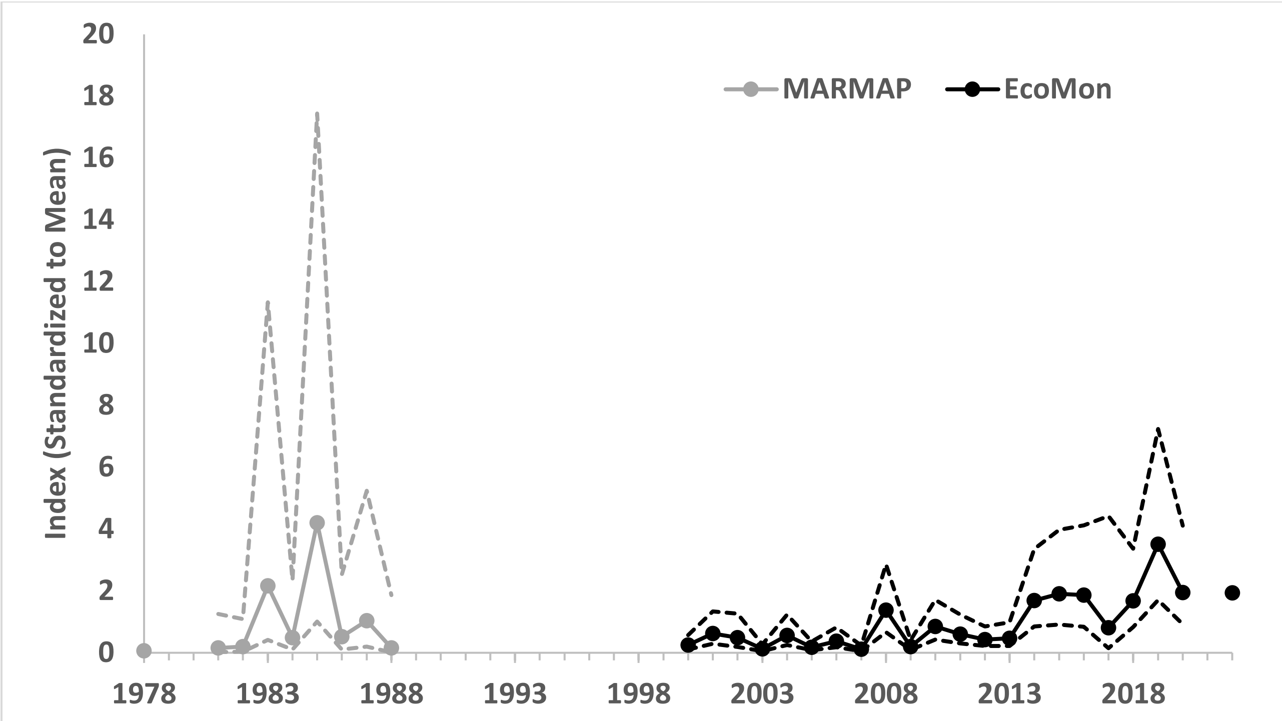

Figure 9. Standardized index of relative spawning stock biomass of Atlantic menhaden developed from the MARMAP and EcoMon ichthyoplankton surveys. Dashed lines represent 95% confidence intervals. The 1978 upper confidence interval has not been included on the graph because of its large value (94).

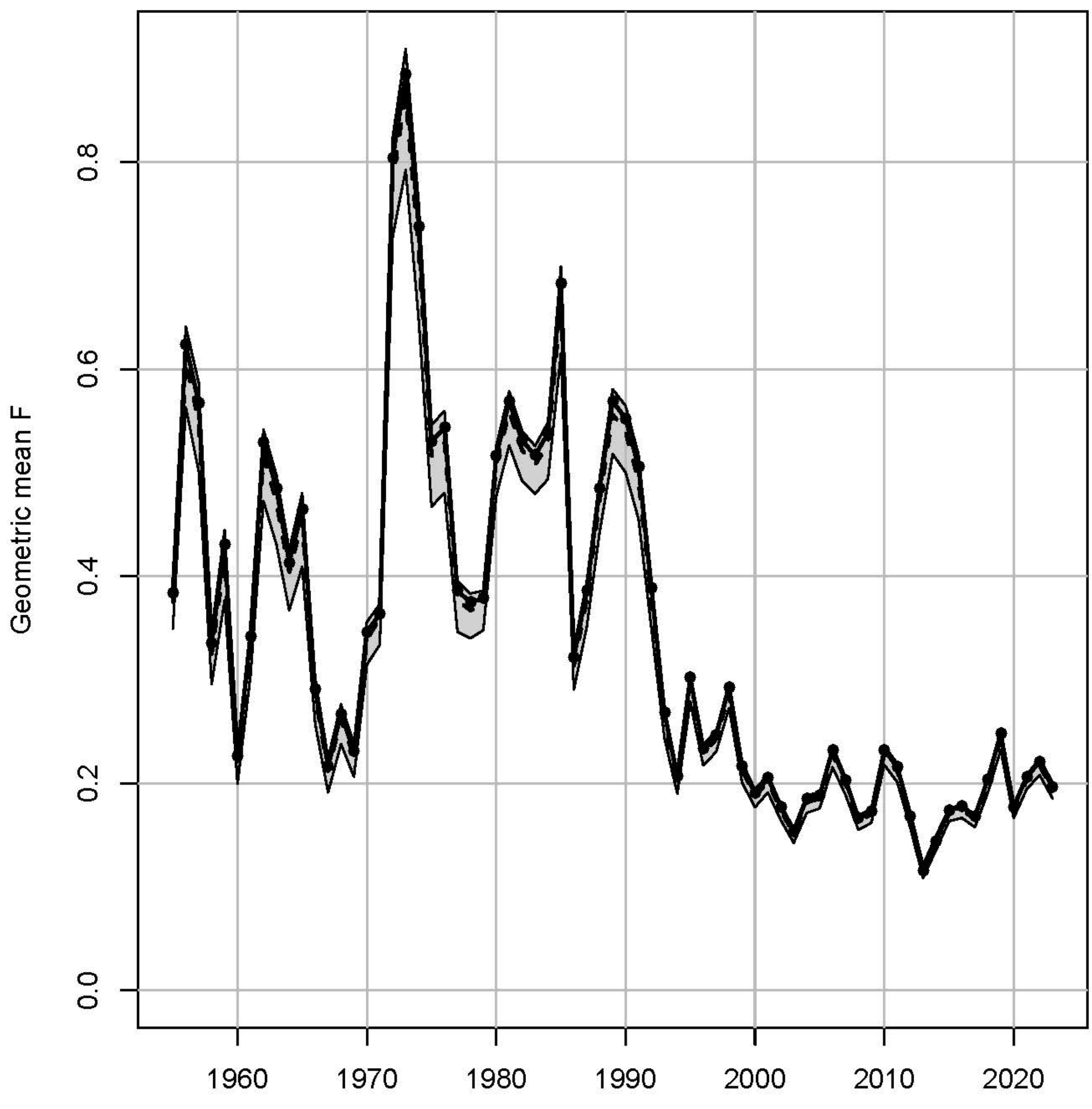

Figure 10. Time series of the geometric mean fishing mortality rate for ages-2 to 4 from 1955-2023 for the Monte Carlo bootstrap runs. The grey represents the 5th and 95th percentiles across the runs, while the black line with closed black circles represents the base run. The dashed line represents the median of the MCB runs.

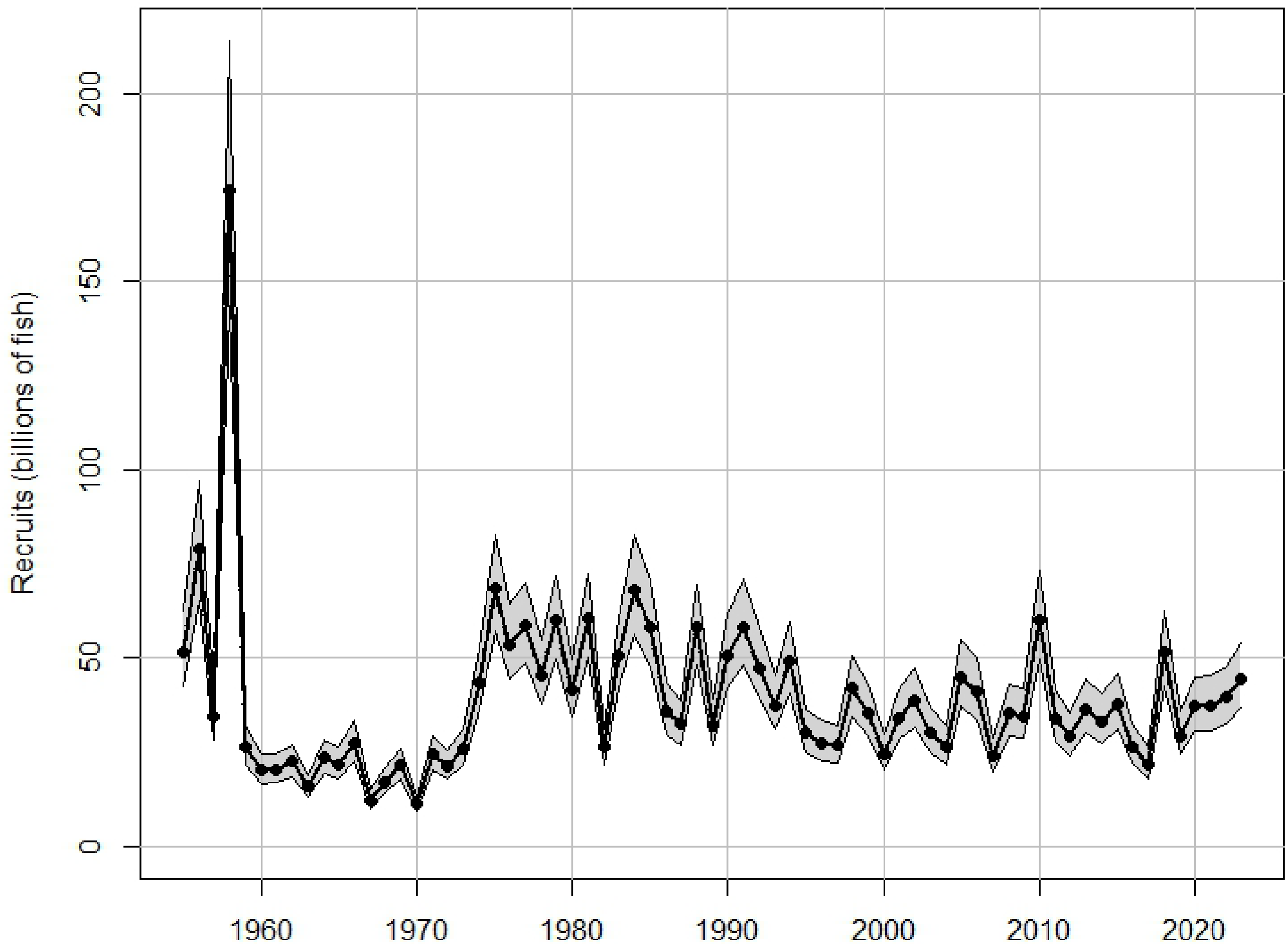

Figure 11. Estimated recruitment (billion fish) over time from 1955-2023 for the Monte Carlo bootstrap runs. The grey represents the 5th and 95th percentiles across the runs, while the black line with closed black circles represents the base run.

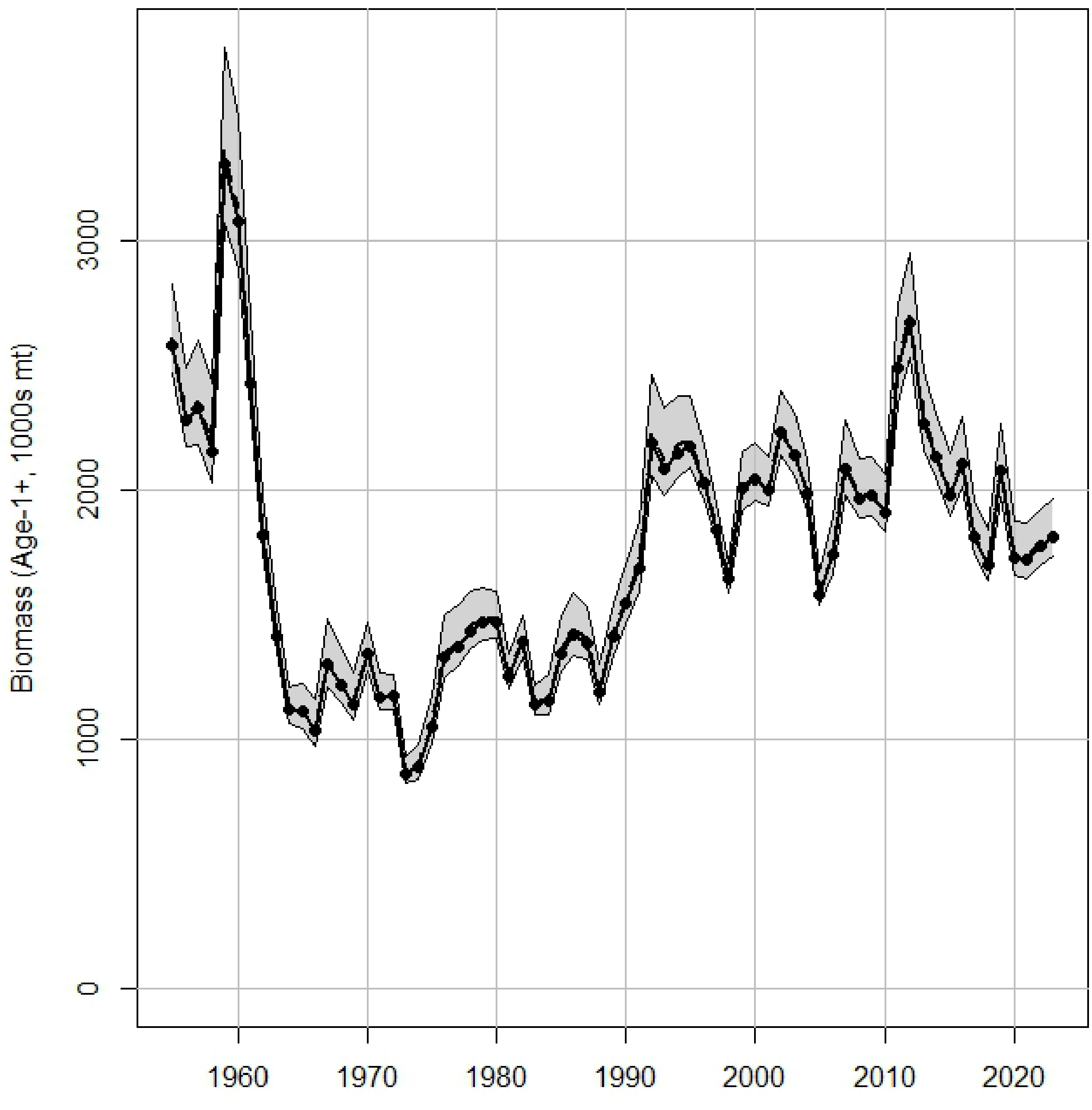

Figure 12. Time series of age-1+ biomass (1,000s metric tons) from 1955-2023 for the Monte Carlo bootstrap runs. The grey represents the 5th and 95th percentiles across the runs, while the black line with closed black circles represents the base run. The dashed line represents the median of the MCB runs.

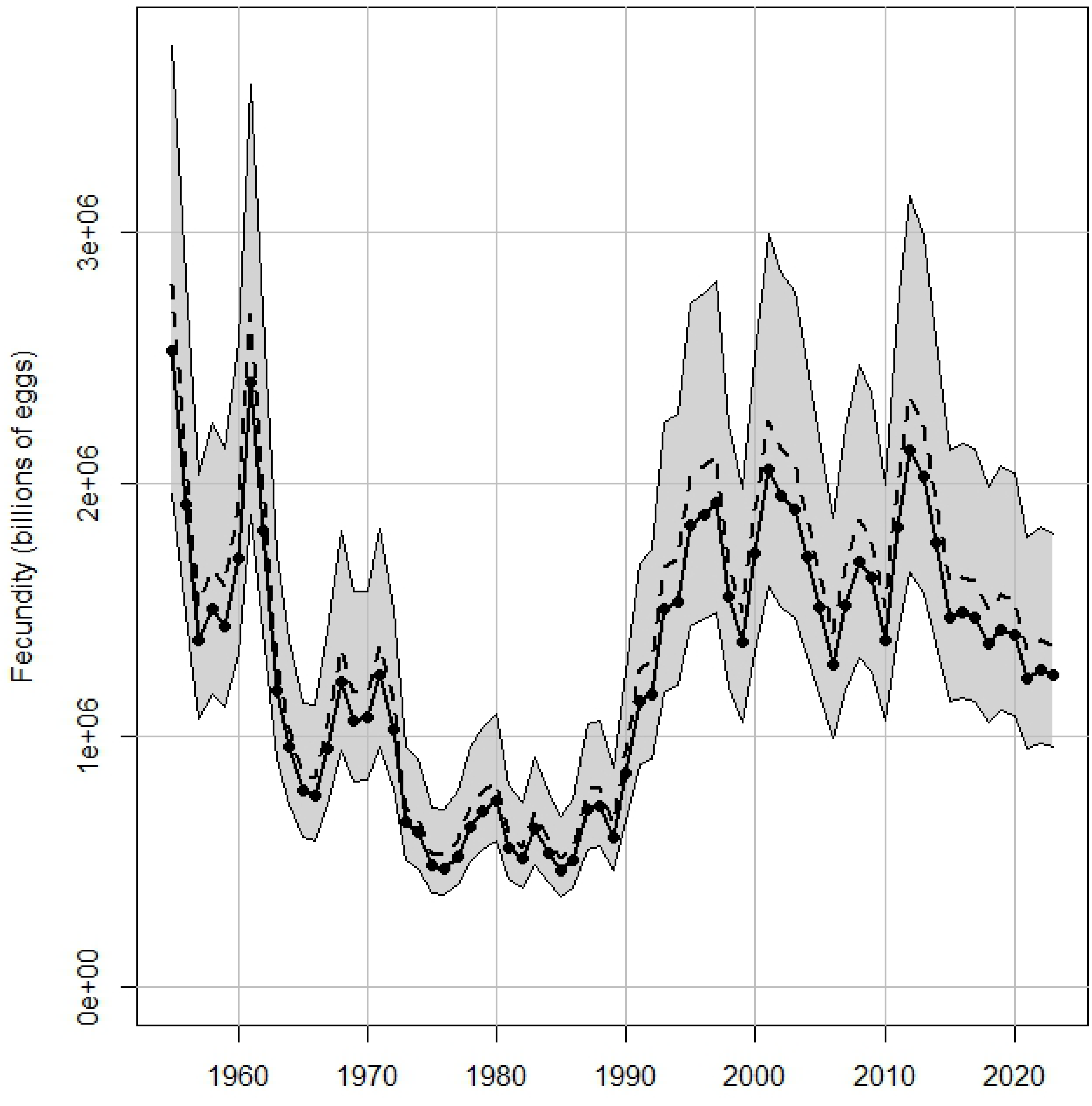

Figure 13. Time series of fecundity (billions of eggs) from 1955-2023 for the Monte Carlo bootstrap runs. The grey represents the 5th and 95th percentiles across the runs, while the black line with closed black circles represents the base run. The dashed line represents the median of the MCB runs.

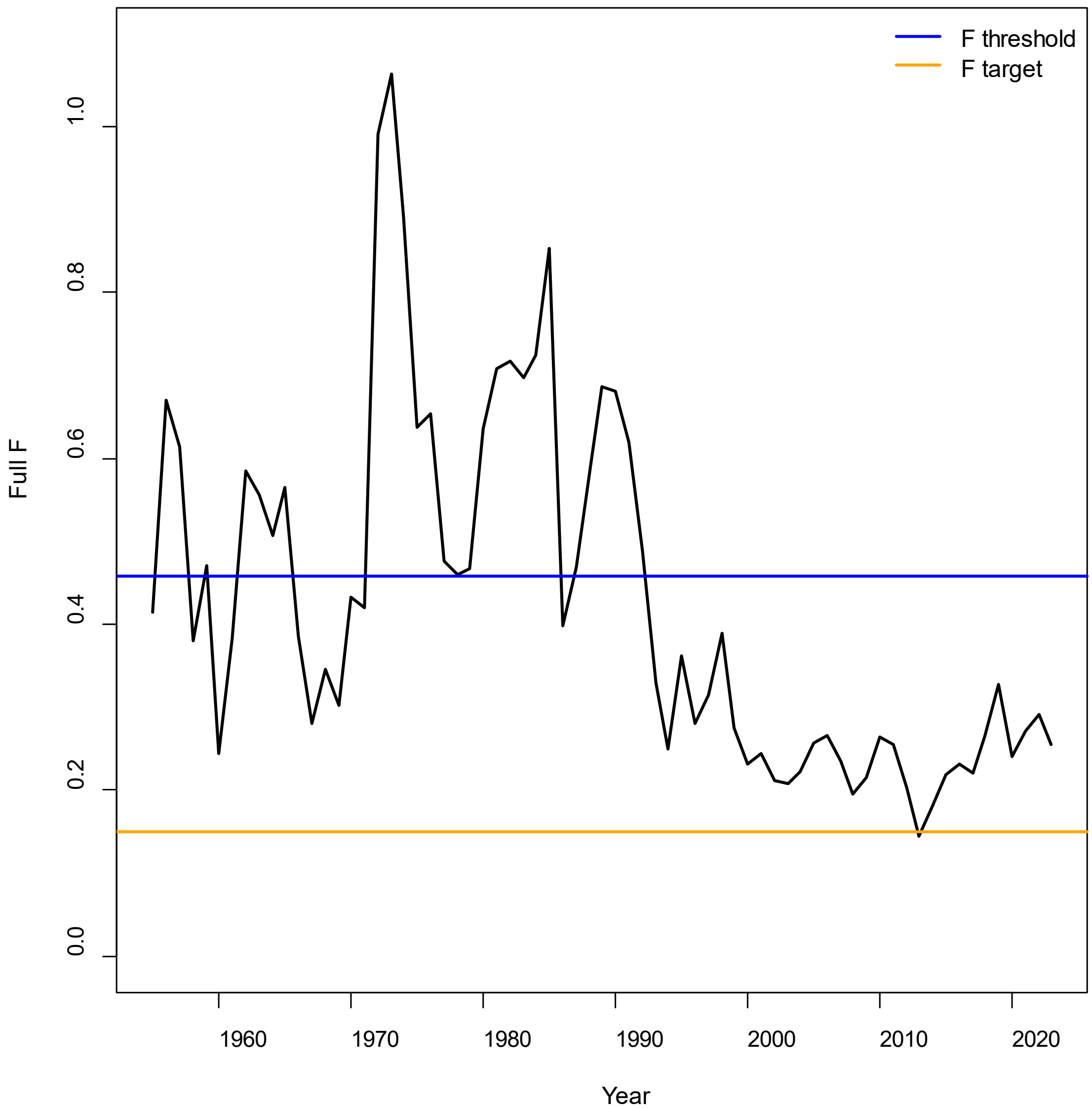

Figure 14. The full fishing mortality rate for 1955-2023 compared to the current ERP threshold and target for fishing mortality rate. The full fishing mortality is dependent upon selectivity for the fisheries, and thus can represent ages-2 to 4, depending upon the year.

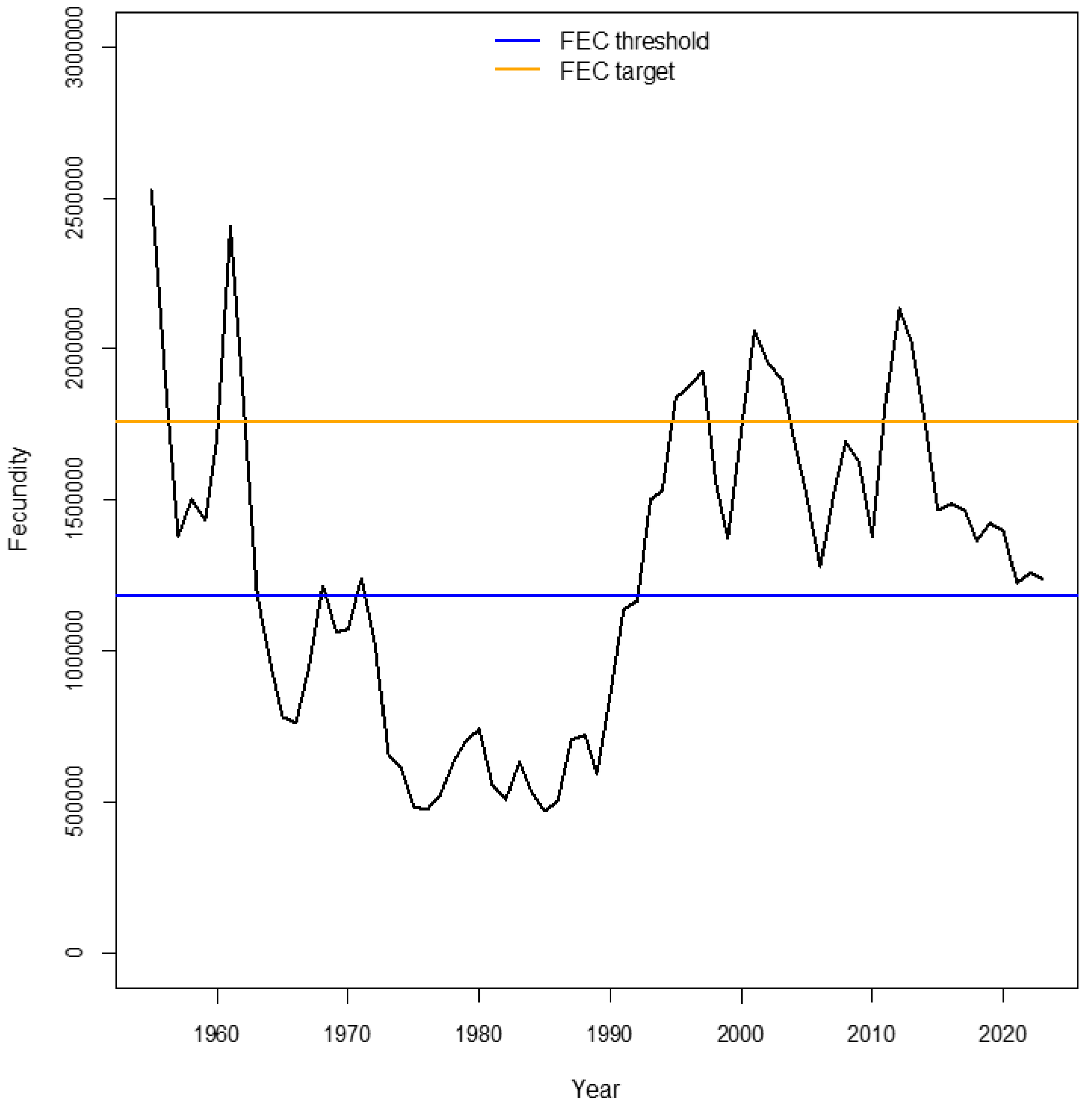

Figure 15. The fecundity for 1955-2023 compared to the current ERP threshold and target for fecundity.

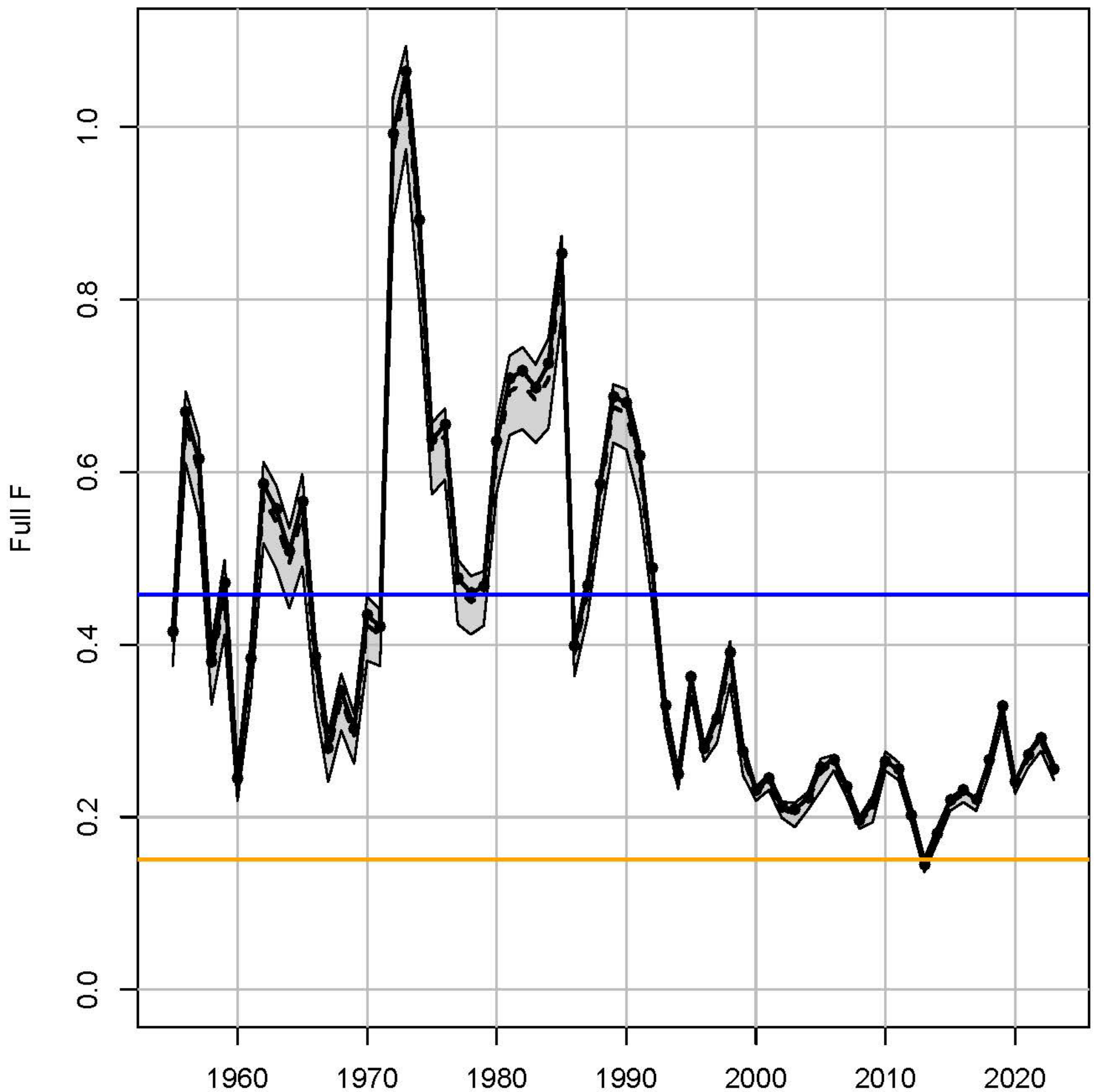

Figure 16. Fishing mortality rate from the MCB analysis plotted with the current ERP *F* threshold and target. The grey represents the 5th and 95th percentiles across the runs, while the black line with closed black circles represents the base run. The dashed line represents the median of the MCB run.

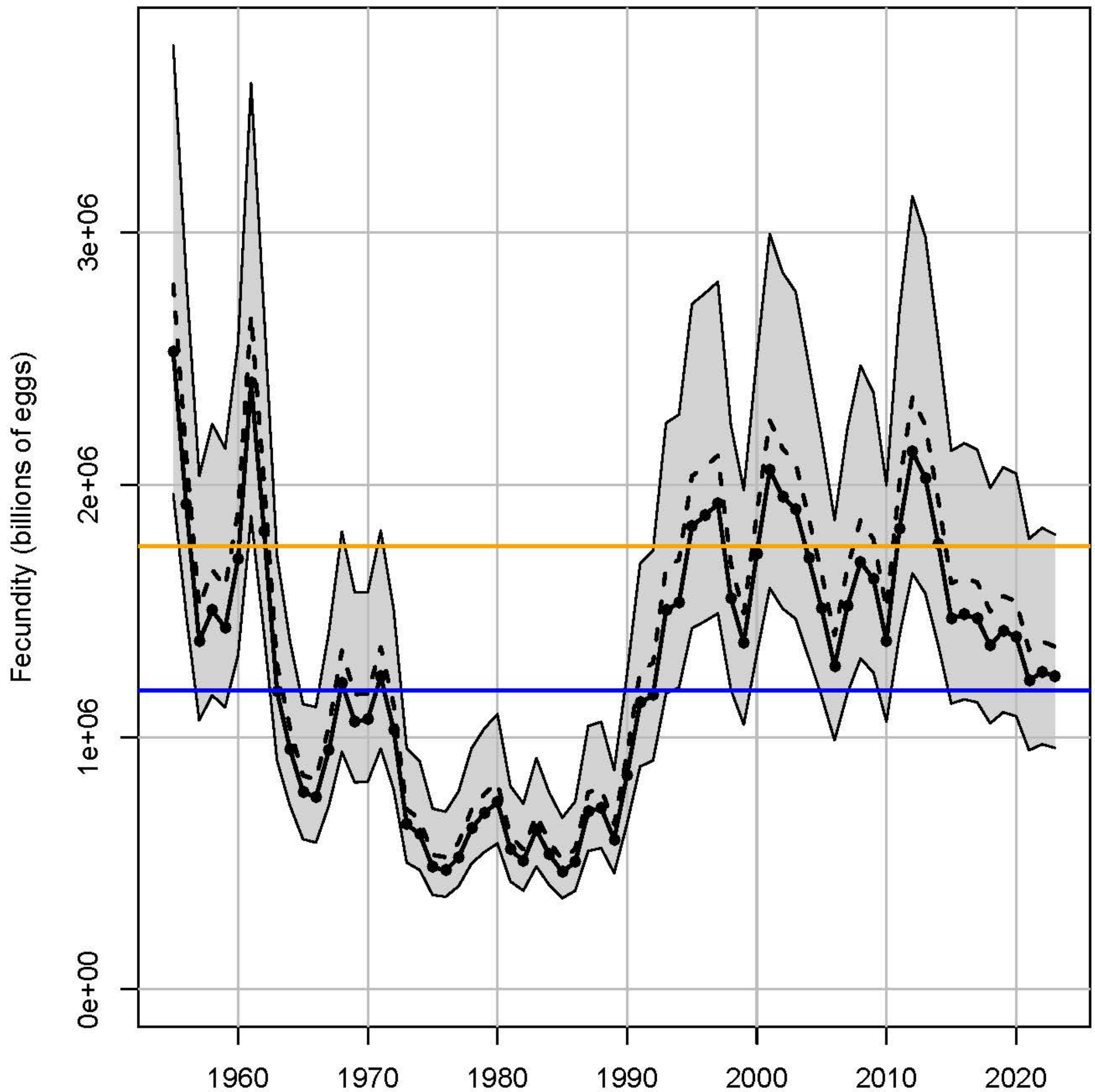

Figure 17. Fecundity from the MCB analysis plotted with the current ERP fecundity threshold and target. The grey represents the 5th and 95th percentiles across the runs, while the black line with closed black circles represents the base run. The dashed line represents the median of the MCB runs.

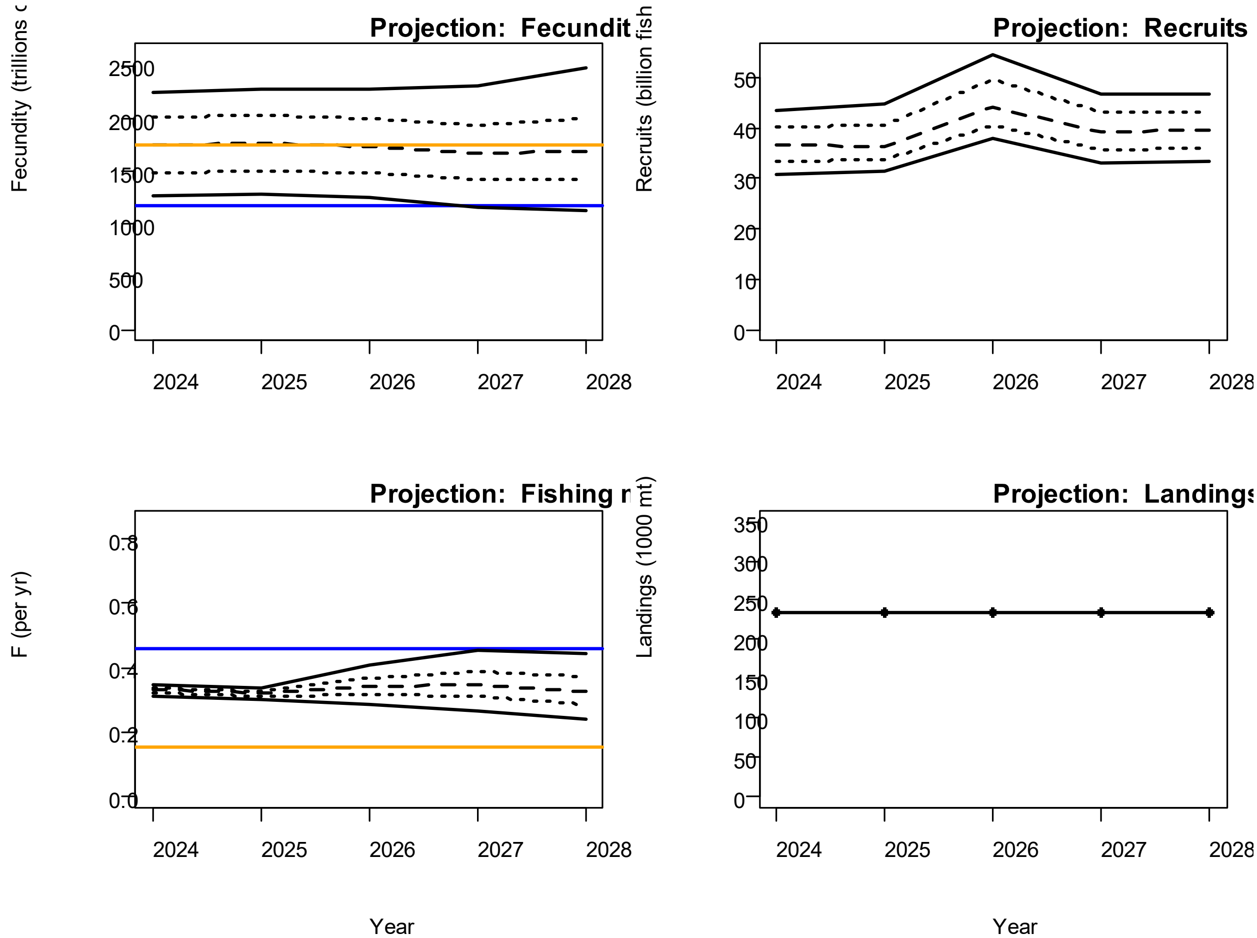

Figure 18. Fecundity, full fishing mortality rate, and recruits projected from 2024 to 2028 for a coastwide total allowable catch of 233,550 mt. The orange lines represent the current ERP target fishing mortality rate and fecundity, while the blue lines represent the current threshold fishing mortality rate and fecundity for the ecological reference points. The dashed black line is the 50th percentile (median), the dotted black lines are the 25th and 75th percentiles, and the solid black lines are the 5th and 95th percentiles.

APPENDIX 1: STOCK PROJECTIONS MEMO

Atlantic States Marine Fisheries Commission

1050 N. Highland Street • Suite 200A-N • Arlington, VA 22201
703.842.0740 • asmfc.org

MEMORANDUM

TO: Atlantic Menhaden Management Board

FROM: Atlantic Menhaden Technical Committee and Ecological Reference Point Workgroup

DATE: October 9, 2025

SUBJECT: Stock Projections to Inform 2026-2028 Total Allowable Catch Levels

The Atlantic Menhaden Management Board (Board) will discuss the 2026-2028 total allowable catch (TAC) for Atlantic menhaden at its October 2025 meeting. Per Amendment 3, the TAC is set through Board action, either on an annual basis or for multiple years, based on the best available science. If the Board does not set a TAC for 2026 by December 31, 2025, next year's TAC will automatically be set at the level of the 2025 TAC (233,550 mt).

Since the implementation of coastwide quota management the TAC has varied but has overall increased from 170,800 metric tons for 2013–2014 to 233,550 mt for 2023-2025 (Table 1). Table 2 provides each jurisdiction's Addendum I allocations.

At the May meeting, the Board tasked the Atlantic Menhaden Technical Committee (TC) with developing projections using the ecological reference points (ERPs) and the single-species assessment model (Beaufort Assessment Model, or BAM). Specifically, the Board requested the following projections:

- The TACs that have a 40%-60% probability of exceeding the ERP target, in 5% increments, using 2026-2028 combined and as separate years.
- The percent risk of exceeding the ERP target and threshold if the current TAC was changed by -20% to +20% in 5% increments, including 0% (the current TAC).

This memo outlines the methods for the projections and the results of the analysis that the Board requested to support the specifications process.

<u>TAC Setting Process</u>

As in recent years, the TAC has been informed by the results of projection analysis, which explores a range of TAC alternatives to determine the percent risk of exceeding the ERP reference points adopted in 2020:

- **ERP target**: the maximum fishing mortality rate (*F*) on Atlantic menhaden that sustains Atlantic striped bass at their biomass target when striped bass are fished at their *F*

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target and the other ERP species in the model (bluefish, spiny dogfish, weakfish, and Atlantic herring) are fished at their current levels

- **ERP threshold**: the maximum *F* on Atlantic menhaden that keeps Atlantic striped bass at their biomass threshold when striped bass are fished at their *F* target and the other ERP species in the model (bluefish, spiny dogfish, weakfish, and Atlantic herring) are fished at their current levels

Monte Carlo Bootstrap (MCB) runs of the base model run from the BAM are used as the basis for the projection analysis (see main stock assessment update report for details on BAM base run and MCB runs).

Sources of Uncertainty

Single-Species Model

The projections have the same methods and assumptions as those run for the benchmark assessment. It is important to note that key uncertainties about natural mortality and fecundity are accounted for in the projections. Additionally, during the benchmark assessment (SEDAR 2020), the SAS used a new procedure for projecting recruitment. Instead of assuming a static median value for recruitment, as is done for many assessment projection methodologies and as was done in the past, recruitment was projected using nonlinear time series analysis methods (Deyle et al 2018). Nonlinear time series analysis methods project recruitment based on how recruitment has changed in the past under similar conditions. This is done for each MCB run to account for uncertainty. Thus, uncertainty is recognized in the recruitment time series and the methods used for projections adequately accounted for that uncertainty using the best scientific methods available. As usual, projections are highly uncertain and subject to model assumptions (i.e., no changes in fishing effort, seasonality of the fishery is not modeled, there is no structural model uncertainty in projections).

The assumption that the full 2023-2025 TAC would be utilized in 2024 and 2025 is also a source of uncertainty, as compliance report data indicated that only 80% of the TAC was landed in 2024. After the initial presentation of results to the TC and SAS, sensitivity runs were conducted using the 2024 bait and reduction landings from the compliance reports and assuming either (1) full utilization of the TAC in 2025, or (2) 80% utilization of the TAC in 2025.

The TC used the Commission's Retrospective Pattern Advice flowchart (ASMFC 2024) to determine whether a retrospective adjustment was warranted. The estimates of Mohn's rho for *F* (ρ=-0.09) and fecundity (ρ=0.12) were within the acceptable limits for a short-lived species. The rho values for both values were closer to zero than in the 2022 assessment update, indicating a smaller retrospective pattern in the 2025 update. The retrospectively adjusted value of fecundity was within the 90% confidence intervals of the unadjusted estimate, and all of the retrospective peels for fecundity were inside the confidence intervals of the base run. However, the adjusted value of *F* and 2 of the 3 most recent peels were outside the confidence intervals. Because *F* is not used in the projections, and because adjusting *F* would not change stock status, the TC elected not to apply a retrospective adjustment for the projections. The TC noted that the confidence intervals on *F* were extremely narrow in the 2025 update, which likely affected the outcome of the flowchart for that metric. The TC also recommended that the Assessment Science Committee review the flowchart performance in this case and consider revising the guidance document to provide explicit guidance on situations where the recommendations for *F* and spawning stock biomass or fecundity are different.

Ecological Reference Point Model

The projections do not incorporate any uncertainty around the ERP target and threshold values, because there is not a comprehensive, quantitative way to estimate that uncertainty in the current model framework. Better quantification of uncertainty around the reference points themselves was a recommendation from the 2025 peer review panel (SEDAR 2025), but some of the uncertainty can be captured through sensitivity runs. Uncertainty in the ecological reference points includes both model uncertainty and ecosystem uncertainty. The ecosystem model was sensitive to the relationship between spiny dogfish and striped bass, and small changes in the parameters of that relationship affected striped bass's ability to rebuild to their biomass target under different combinations of striped bass and menhaden *F* rates. A sensitivity run where spiny dogfish diet composition data was adjusted to reflect the assumption that not all of the biomass estimated by the new spiny dogfish assessment was present within the ERP model domain resulted in a lower *F* target for Atlantic menhaden compared to the base run.

Uncertainty about future ecosystem conditions also contributes to uncertainty in the ERP target and threshold. For example, in the base run, it was assumed that the current low recruitment regime that Atlantic herring were experiencing at the end of the time-series would persist into the future. A sensitivity run was done where it was assumed that Atlantic herring recruitment would return to the long-term average, which resulted in a slightly higher ERP target, indicating Atlantic menhaden could experience a higher *F* rate and striped bass would remain at their biomass target when Atlantic herring were more abundant.

<u>*Results*</u>

The TACs with a 40%-60% probability of exceeding the *F* target are presented in Table 3. The probabilities of exceeding the *F* target and threshold for a range of TACs representing a 20% decrease to a 20% increase from the current TAC are presented in Table 4, and the probability of falling below the ERP fecundity target and threshold for those TACs is shown in Table 5.

Instead of providing figures for all the scenarios the Board requested, the TC provided figures of the fecundity, recruits, *F*, and landings for the current TAC (233,550 mt), a TAC of 106,100 mt (associated with a 40% probability of exceeding the *F* target in 2026), and a TAC of 280,260 mt (an increase of 20% from the status quo TAC). These three plots provide the bounds of the highest and lowest risk scenarios requested by the Board, in comparison to the status quo scenario (Figure 1 - Figure 3).

The assumption about levels of removals in 2024 and 2025 had a minimal effect on the results. The estimates of the combined year TACs that would have a 40%-60% probability of achieving the ERP *F* target for 2026-2028 were approximately 1,000-4,000 mt greater under the lower

2024-2025 removals assumptions (Table 6 - Table 7). The risk of exceeding the ERP *F* target and threshold under the status quo TAC showed at most a 1% difference in risk (Table 8).

The TACs with the 40%-60% probability of achieving the *F* target are significantly lower than the current TAC and the TACs with the same risk levels presented in 2022. This is driven largely by the change in natural mortality (*M*) in the single-species model: the lower *M* used in 2025 resulted in a lower biomass compared to the 2022 update (Figure 4)(ASMFC 2025). The time-series average of age-1+ biomass for the 2025 update with the lower M was 37% lower than the time-series average of the 2022 update. In addition, the 2022 update showed a large increase in biomass at the end of the time-series that was not present at the end of the 2025 update. As a result, the 2021 biomass that was projected forward to inform the 2023-2025 TAC options was approximately 60% higher than the 2023 biomass, which is informing the 2026-2028 TAC.

In addition, the ERP *F* target changed as a result of the benchmark assessment (SEDAR 2025): the ERP target from the 2020 benchmark was 0.19 and the ERP target from the 2025 benchmark is 0.15. Although the change in the ERP *F* target appears relatively small, it did have an impact on the scale of the projections. The probability of exceeding the ERP target for a specific TAC in Table 4 were higher for the new, lower ERP target, and the TACs required to have a 40%-60% probability of exceeding the ERP target were lower for the new ERP target. This change in the ERP target was due to both the lower estimate of menhaden biomass going into the ERP models as a result of the lower *M* in the single-species model, and also to other factors including an increase in spiny dogfish biomass estimates, refinements to other inputs like diet data, and changes to the model structure (SEDAR 2025).

In addition, it is important to note that the values for the ERP target and threshold were based on the definitions currently used in management. The Board can use the ecosystem model developed through the ERP benchmark assessment (SEDAR 2020, SEDAR 2025) to evaluate the trade-offs between predator biomass and menhaden fishing mortality under different ecosystem assumptions and consider choosing a different ERP target and threshold definition to best meet their management objectives for Atlantic menhaden. If the Board redefined the ERP target and threshold – for example, using different assumptions about the biomass levels of other species in the ecosystem in the future or about striped bass fishing mortality – the values of the reference points and the associated TACs would change.

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Deyle, E., A.M. Schueller, H. Ye, G.M Pao, and G. Sugihara. 2018. Ecosystem-based forecasts of recruitment in two menhaden species. Fish and Fisheries 19: 769-781.

Southeast Data, Assessment, and Review (SEDAR). 2025. SEDAR 102 Stock Assessment Report – ASMFC Atlantic Menhaden and Ecological Reference Points. SEDAR, North Charleston, SC. 424 pp. Available online: https://sedarweb.org/assessments/sedar-102-asmfc-atlantic-menhaden/

Tables

Table 1. History of Atlantic menhaden TAC levels.

TAC Period	TAC (mt)
2013-2014	170,800
2015-2016	187,880
2017	200,000
2018-2020	216,000
2021-2022	194,400
2023-2025	233,550

Table 2. Allocation of the coastwide Atlantic menhaden TAC by state, as set by Addendum I to Amendment 3.

State	Allocation (%)
ME	4.80%
NH	1.19%
MA	2.12%
RI	0.81%
CT	0.33%
NY	0.84%
NJ	11.00%
PA	0.01%
DE	0.27%
MD	1.17%
PRFC	1.09%
VA	75.21%
NC	0.37%
SC	0.25%
GA	0.25%
FL	0.29%

Table 3. The TACs associated with a 40-60% probability of exceeding the ERP F target for 2026-2028 combined and as separate years. For the combined years, the TAC is chosen such that the probability of exceeding the F target for 2026-2028 is no greater than the specified percent in any one year.

Probability of exceeding the ERP F Target	TAC for 2026-2028	2026 TAC	2027 TAC	2028 TAC
40%	106,100	106,100	111,800	120,900
45%	107,400	107,400	113,500	123,000
50%	108,450	108,450	115,300	124,800
55%	109,700	109,700	117,000	127,200
60%	111,000	111,000	119,200	129,700

Table 4. Percent risk of exceeding the ERP *F* target and ERP *F* threshold for different TAC projections.

TAC (Status quo -/+)	Probability of Exceeding the ERP *F* Target			Probability of Exceeding the ERP *F* Threshold		
	2026	2027	2028	2026	2027	2028
186,840 (-20%)	100%	100%	100%	0%	0%	0%
198,518 (-15%)	100%	100%	100%	0%	0%	0%
210,195 (-10%)	100%	100%	100%	0%	1%	1%
221,872 (-5%)	100%	100%	100%	0%	1%	1%
233,550 (0%)	100%	100%	100%	1%	4%	4%
245,228 (+5%)	100%	100%	100%	1%	10%	8%
256,905 (+10%)	100%	100%	100%	4%	18%	14%
268,583 (+15%)	100%	100%	100%	11%	29%	23%
280,260 (+20%)	100%	100%	100%	22%	41%	32%

Table 5. Percent risk of falling below the ERP fecundity target and ERP fecundity threshold for different TAC projections.

TAC (Status quo -/+)	Probability of Falling Below the ERP Fecundity Target			Probability of Falling Below the ERP Fecundity Threshold		
	2026	2027	2028	2026	2027	2028
186,840 (-20%)	52%	52%	46%	2%	4%	4%
198,518 (-15%)	52%	54%	49%	2%	4%	5%
210,195 (-10%)	52%	56%	51%	2%	5%	5%
221,872 (-5%)	52%	58%	54%	2%	6%	7%
233,550 (0%)	52%	59%	57%	2%	6%	8%
245,228 (+5%)	52%	61%	59%	2%	7%	9%
256,905 (+10%)	52%	62%	61%	2%	8%	10%
268,583 (+15%)	52%	64%	64%	2%	8%	12%
280,260 (+20%)	52%	66%	66%	2%	9%	13%

Table 6. Sensitivity run results showing the TACs associated with a 40-60% probability of exceeding the ERP *F* target for 2026-2028 for the scenario using 2024 landings from compliance reports and assuming full utilization of the TAC in 2025.

Probability of exceeding the ERP F Target	TAC for 2026-2028	2026 TAC	2027 TAC	2028 TAC
40%	107,100	107,100	111,900	120,900
50%	109,500	109,500	115,500	124,800
60%	112,200	112,200	119,600	129,700

Table 7. Sensitivity run results showing the TACs associated with a 40%-60% probability of exceeding the ERP *F* target for 2026-2028 for the scenario using 2024 landings from compliance reports and assuming 80% utilization of the TAC in 2025.

Probability of exceeding the ERP F Target	TAC for 2026-2028	2026 TAC	2027 TAC	2028 TAC
40%	110,200	110,200	112,900	120,900
50%	112,600	112,600	116,600	124,900
60%	115,100	115,100	120,300	129,700

Table 8. Sensitivity run results showing the percent risk of exceeding the ERP *F* target and ERP *F* threshold for status quo TAC projections under different assumptions about 2024 and 2025 removals.

Assumption for 2024 and 2025 Removals	Probability of Exceeding the ERP Target			Probability of Exceeding the ERP Threshold		
	2026	2027	2028	2026	2027	2028
2024 & 2025 = full TAC utilization	100%	100%	100%	1%	4%	4%
2024 = compliance report data 2025 = full TAC utilization TAC	100%	100%	100%	1%	4%	4%
2024 = compliance report data 2025 = 80% TAC utilization	100%	100%	100%	0%	3%	3%

Figures

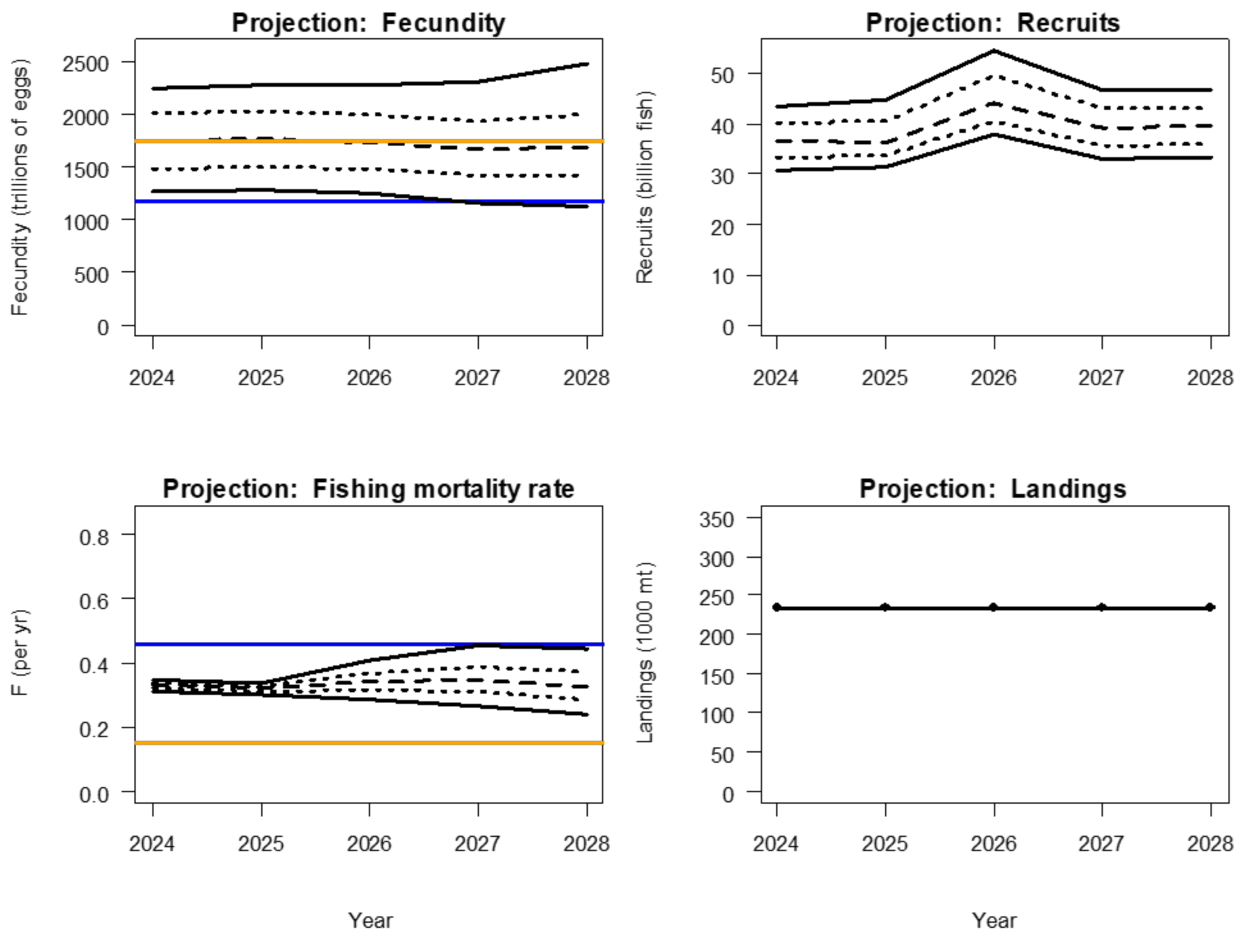


Figure 1. Fecundity, full fishing mortality rate, and recruits projected from 2024 to 2028 for a coastwide total allowable catch of 233,550 mt. The orange lines represent ERP target fishing mortality rate and fecundity, while the blue lines represent the ERP threshold fishing mortality rate and fecundity. The dashed black line is the 50th percentile (median), the dotted black lines are the 25th and 75th percentiles, and the solid black lines are the 5th and 95th percentiles.

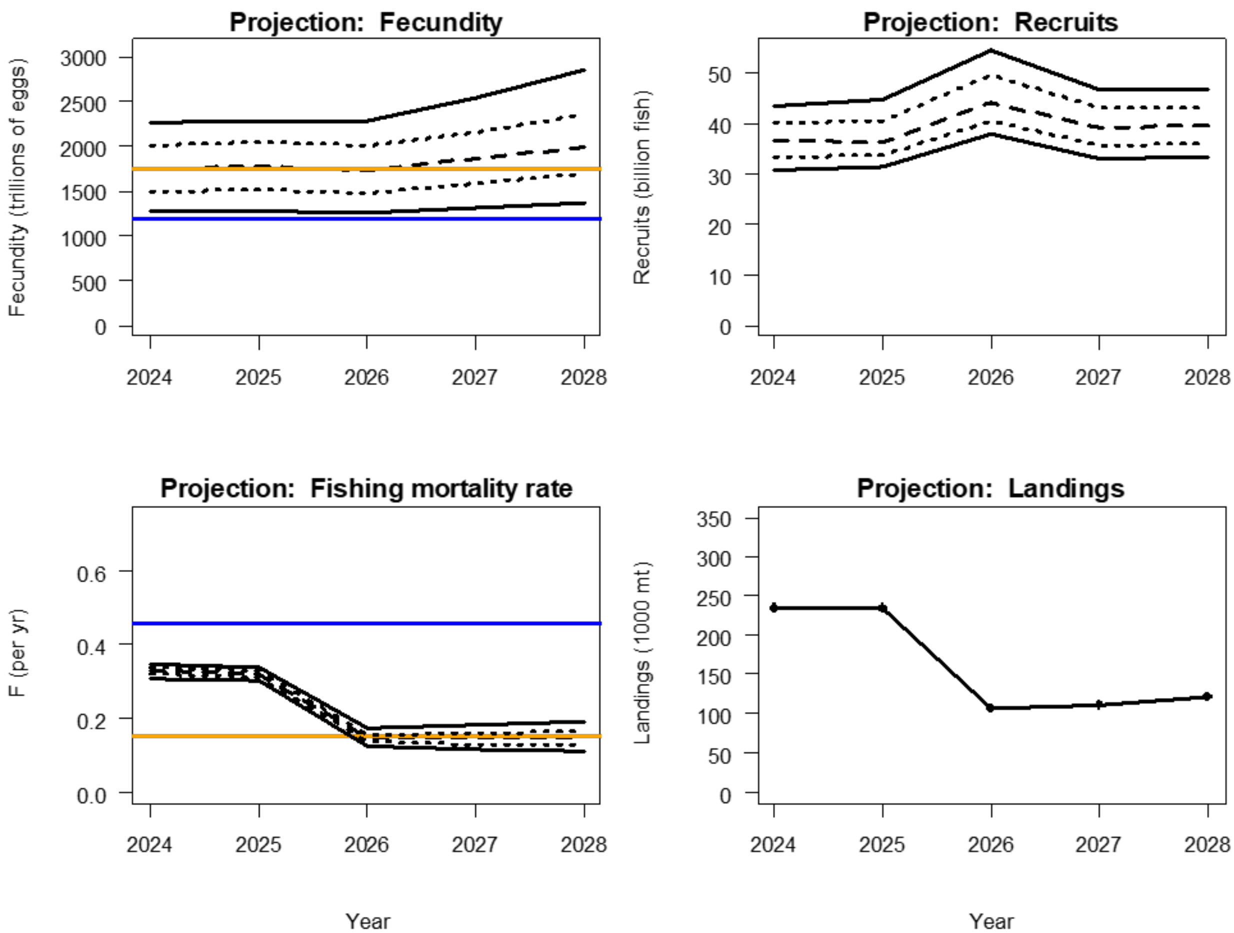


Figure 2. Fecundity, full fishing mortality rate, and recruits projected from 2024 to 2028 for a coastwide total allowable catch with a 40% probability of exceeding the ERP *F* target (106,100 mt). The orange lines represent ERP target fishing mortality rate and fecundity, while the blue lines represent the ERP threshold fishing mortality rate and fecundity. The dashed black line is the 50th percentile (median), the dotted black lines are the 25th and 75th percentiles, and the solid black lines are the 5th and 95th percentiles.

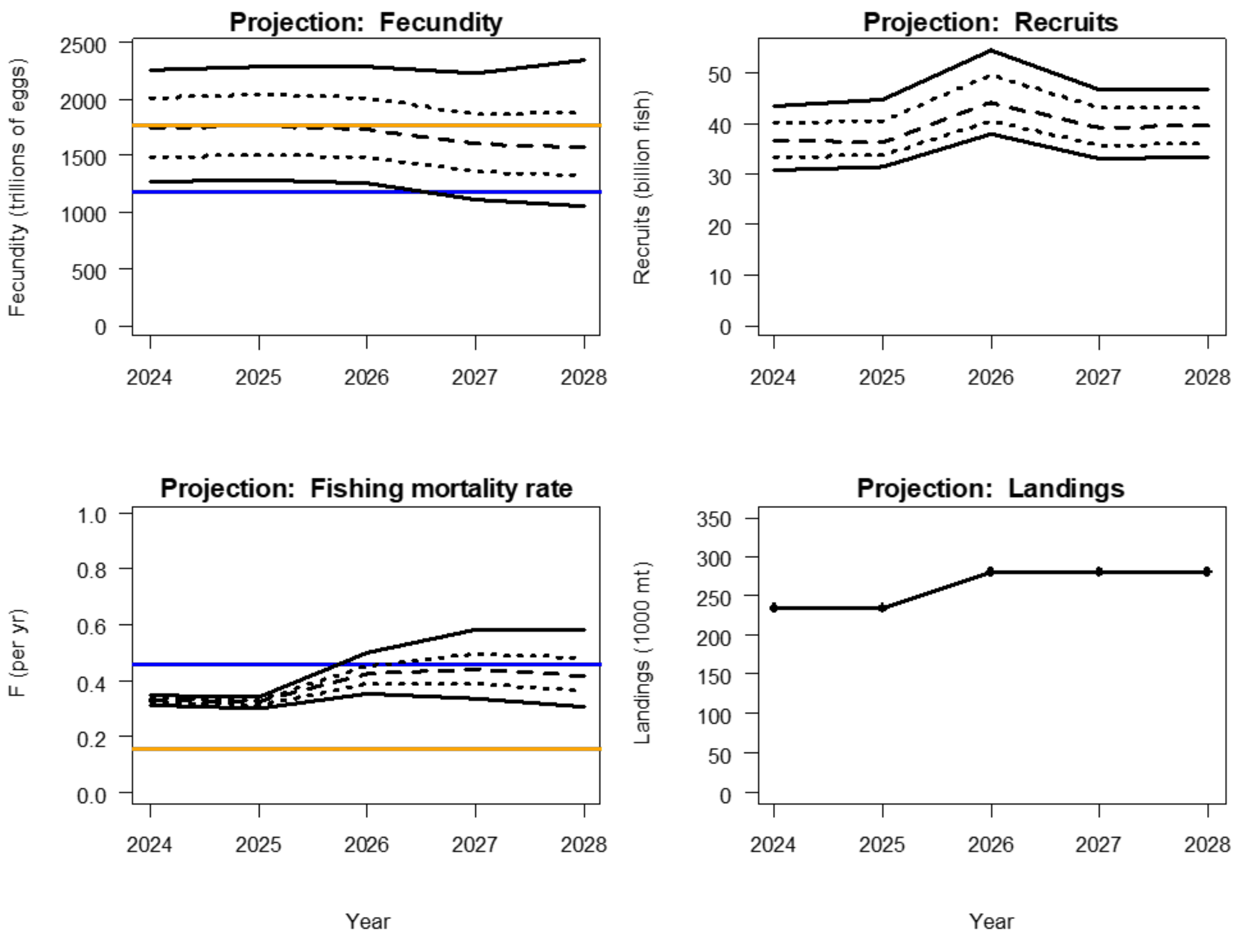


Figure 3. Fecundity, full fishing mortality rate, and recruits projected from 2024 to 2028 for a 20% increase to the coastwide total allowable catch (280,260 mt). The orange lines represent ERP target fishing mortality rate and fecundity, while the blue lines represent the ERP threshold fishing mortality rate and fecundity. The dashed black line is the 50th percentile (median), the dotted black lines are the 25th and 75th percentiles, and the solid black lines are the 5th and 95th percentiles.

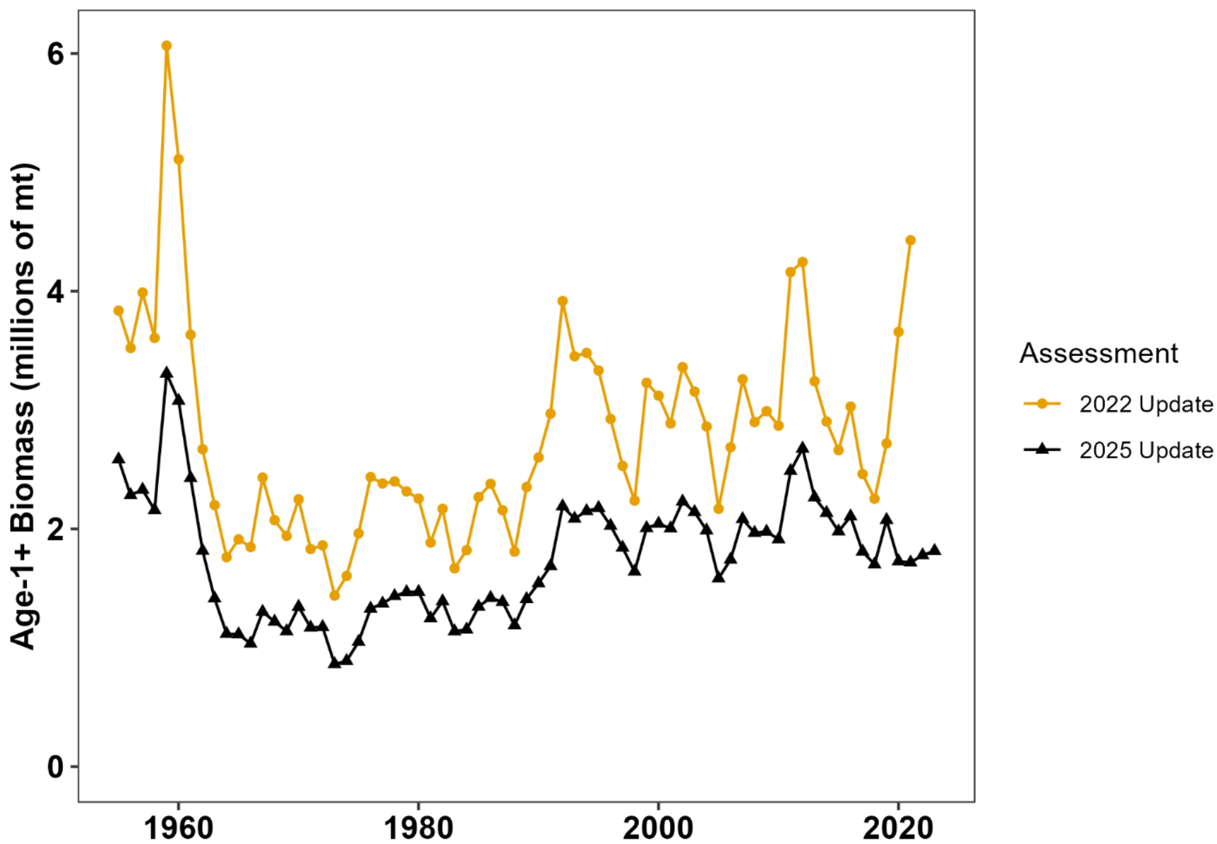


Figure 4. Age-1+ biomass estimates from the 2022 update and the 2025 update of the Atlantic menhaden single-species assessment model.

APPENDIX 2: SUPPLEMENTAL ASSESSMENT INFORMATION

Appendix Tables

Table A1. Atlantic menhaden landings (in 1,000s of metric tons) by fishery and region, 1955-2023. Bait landings are considered incomplete until 1985.

Year	Reduction Landings			Bait Landings			Recreational Landings			Total Landings
	Total	North	South	Total	North	South	Total	North	South	
1955	644.48	402.74	241.74	14.64	10.14	4.50				659.12
1956	715.25	478.89	236.36	23.25	17.51	5.74				738.50
1957	605.58	389.80	215.78	24.71	10.60	14.11				630.29
1958	512.39	248.34	264.05	14.69	3.46	11.23				527.07
1959	662.17	318.44	343.73	20.58	7.98	12.61				682.76
1960	532.24	323.86	208.37	19.44	7.61	11.83				551.68
1961	578.61	334.76	243.85	25.07	8.44	16.63				603.68
1962	540.66	321.36	219.31	26.58	10.60	15.98				567.24
1963	348.44	147.55	200.89	24.39	6.11	18.28				372.83
1964	270.40	50.61	219.80	20.23	4.27	15.97				290.64
1965	274.60	57.96	216.64	23.62	3.30	20.32				298.22
1966	220.69	7.89	212.80	13.72	1.76	11.96				234.41
1967	194.39	17.21	177.18	11.61	1.44	10.17				206.00
1968	235.86	33.07	202.80	9.46	0.75	8.71				245.32
1969	162.33	15.41	146.92	10.61	1.11	9.50				172.94
1970	259.39	15.80	243.59	21.64	1.41	20.23				281.03
1971	250.32	33.44	216.87	13.47	1.87	11.60				263.79
1972	365.87	69.09	296.78	10.35	2.14	8.21				376.22
1973	346.92	90.69	256.23	14.77	2.61	12.16				361.69
1974	292.20	77.90	214.31	14.54	2.11	12.43				306.74
1975	250.21	48.40	201.81	21.69	1.89	19.80				271.90
1976	340.54	86.84	253.70	19.63	1.98	17.65				360.17
1977	341.16	53.31	287.85	23.09	1.39	21.70				364.25
1978	344.08	63.53	280.55	25.87	1.07	24.80				369.95
1979	375.74	70.19	305.55	13.02	1.17	11.85				388.76
1980	401.53	83.02	318.51	26.11	1.07	25.05				427.64
1981	381.31	68.06	313.25	22.44	1.08	21.36	0.42	0.25	0.17	404.17
1982	382.46	35.08	347.38	19.86	1.32	18.54	0.34	0.20	0.14	402.66
1983	418.63	39.37	379.26	19.06	1.36	17.71	0.68	0.14	0.54	438.38
1984	326.30	34.97	291.33	14.33	1.59	12.75	0.42	0.15	0.27	341.05
1985	306.67	111.25	195.42	45.59	22.92	22.66	0.52	0.38	0.14	352.78

Table A1. ***Continued***

Year	Reduction Landings			Bait Landings			Recreational Landings			Total Landings
	Total	North	South	Total	North	South	Total	North	South	
1986	237.99	42.57	195.42	35.46	18.30	17.17	1.03	0.93	0.10	274.49
1987	326.90	82.99	243.91	36.43	18.30	18.13	0.65	0.63	0.02	363.98
1988	309.29	73.64	235.65	53.14	21.44	31.70	1.16	0.54	0.61	363.58
1989	322.00	98.82	223.18	32.06	11.49	20.57	0.54	0.46	0.09	354.61
1990	401.15	144.10	257.05	31.19	16.35	14.84	0.52	0.36	0.16	432.86
1991	381.43	104.55	276.87	37.62	24.17	13.45	1.16	0.92	0.24	420.20
1992	297.64	99.14	198.50	41.56	28.08	13.48	2.31	2.12	0.19	341.51
1993	320.60	58.37	262.23	40.98	26.76	14.22	0.53	0.47	0.06	362.11
1994	259.99	33.39	226.60	37.89	21.35	16.54	0.39	0.19	0.20	298.27
1995	339.92	96.30	243.62	40.64	22.17	18.47	0.69	0.36	0.33	381.25
1996	292.93	61.55	231.38	36.19	17.34	18.85	0.51	0.11	0.40	329.63
1997	259.14	25.17	233.98	41.35	19.49	21.86	0.19	0.11	0.08	300.68
1998	245.91	12.33	233.58	39.70	16.88	22.81	0.43	0.34	0.08	286.03
1999	171.19	8.42	162.77	35.00	13.11	21.89	0.68	0.13	0.54	206.87
2000	167.26	43.19	124.08	33.95	15.15	18.80	0.26	0.22	0.03	201.47
2001	233.56	39.62	193.94	36.14	13.24	22.91	0.35	0.06	0.29	270.05
2002	174.07	27.17	146.89	37.18	13.13	24.05	0.82	0.63	0.19	212.07
2003	166.11	4.15	161.96	33.79	8.60	25.19	0.52	0.32	0.20	200.42
2004	178.47	25.91	152.55	34.46	10.19	24.27	2.33	2.03	0.30	215.26
2005	152.85	15.37	137.48	39.15	10.23	28.91	0.30	0.04	0.27	192.30
2006	157.36	60.15	97.21	27.91	12.38	15.53	1.46	0.88	0.58	186.73
2007	174.48	36.63	137.84	42.62	20.28	22.34	1.16	0.66	0.49	218.25
2008	141.14	39.30	101.84	47.84	26.37	21.47	0.91	0.79	0.12	189.90
2009	143.75	18.66	125.09	39.55	18.87	20.68	0.52	0.18	0.35	183.82
2010	183.10	28.67	154.43	43.00	25.81	17.19	0.70	0.39	0.32	226.80
2011	174.02	29.57	144.45	52.98	34.27	18.70	0.77	0.44	0.32	227.76
2012	160.62	23.91	136.71	63.91	40.01	23.90	1.97	0.80	1.18	226.50
2013	131.02	32.70	98.32	37.10	19.77	17.32	0.92	0.54	0.38	169.04
2014	131.10	29.90	101.20	41.06	20.57	20.49	2.07	1.70	0.37	174.23
2015	143.50	28.80	114.70	45.52	24.73	20.79	1.77	1.17	0.61	190.79
2016	137.40	45.00	92.40	43.60	25.44	18.16	6.73	6.02	0.71	187.73
2017	128.92	58.45	70.47	45.97	28.54	17.42	2.32	1.97	0.35	177.21
2018	141.31	57.72	83.59	49.76	33.09	16.68	2.00	1.76	0.24	193.08
2019	150.82	45.78	105.05	58.94	40.10	18.83	1.17	1.05	0.11	210.92
2020	124.60	52.55	72.05	60.24	42.93	17.31	1.79	1.51	0.28	186.63
2021	136.69	59.62	77.07	59.36	41.54	17.82	1.75	1.57	0.19	197.80
2022	136.70	38.70	98.00	60.42	41.33	19.09	3.86	3.49	0.37	200.98
2023	131.80	26.00	105.80	48.55	34.38	14.17	1.40	1.37	0.03	181.75

Table A2. Catch-at-age for the northern commercial reduction fishery from 1955-2023.

Year	0	1	2	3	4	5	6+	# of fish sampled
1955	0	0.015	0.471	0.217	0.253	0.032	0.012	8408
1956	0	0.133	0.555	0.195	0.025	0.072	0.020	11050
1957	0	0.270	0.610	0.051	0.033	0.017	0.020	11247
1958	0	0.025	0.908	0.042	0.010	0.008	0.009	8777
1959	0	0.531	0.291	0.159	0.009	0.004	0.007	10470
1960	0	0.009	0.892	0.037	0.049	0.009	0.004	9346
1961	0	0.003	0.160	0.803	0.012	0.018	0.003	8059
1962	0	0.015	0.245	0.218	0.457	0.033	0.032	9598
1963	0	0.296	0.438	0.095	0.068	0.080	0.023	6058
1964	0	0.034	0.357	0.345	0.128	0.065	0.072	4619
1965	0	0.160	0.370	0.373	0.071	0.013	0.014	6564
1966	0	0.201	0.467	0.212	0.100	0.009	0.012	1859
1967	0	0.055	0.296	0.567	0.072	0.009	0.000	1840
1968	0	0.007	0.479	0.388	0.116	0.009	0.001	5701
1969	0	0.001	0.251	0.594	0.149	0.005	0	3621
1970	0	0.150	0.793	0.050	0.007	0	0	700
1971	0	0.126	0.288	0.433	0.137	0.017	0	760
1972	0	0.169	0.286	0.452	0.085	0.008	0	759
1973	0	0.021	0.821	0.133	0.024	0.001	0	729
1974	0	0.028	0.844	0.117	0.006	0.004	0	1280
1975	0	0	0.798	0.175	0.025	0.001	0	1850
1976	0	0.092	0.823	0.071	0.013	0	0	2010
1977	0	0.022	0.567	0.326	0.079	0.006	0.001	2200
1978	0	0	0.298	0.567	0.120	0.015	0	1861
1979	0	0.007	0.579	0.332	0.076	0.006	0	1688
1980	0	0.002	0.237	0.462	0.243	0.051	0.004	1744
1981	0	0.001	0.357	0.357	0.210	0.070	0.006	2220
1982	0	0.042	0.393	0.473	0.063	0.025	0.004	840
1983	0	0.012	0.826	0.120	0.037	0.005	0	840
1984	0	0.024	0.343	0.506	0.097	0.029	0.001	3110
1985	0	0.020	0.760	0.089	0.111	0.017	0.003	1490
1986	0	0.010	0.795	0.107	0.050	0.031	0.006	530
1987	0	0.005	0.652	0.277	0.058	0.006	0.002	940
1988	0	0	0.225	0.486	0.260	0.026	0.003	1650
1989	0	0.081	0.623	0.173	0.097	0.025	0	1360

Table A2. ***Continued***

Year	0	1	2	3	4	5	6+	# of fish sampled
1990	0	0.011	0.788	0.134	0.049	0.018	0.001	1660
1991	0	0.085	0.430	0.385	0.072	0.023	0.005	1460
1992	0	0.058	0.687	0.107	0.118	0.026	0.004	1180
1993	0	0.045	0.675	0.226	0.036	0.017	0.002	640
1994	0	0.017	0.420	0.333	0.183	0.047	0	300
1995	0	0.020	0.567	0.329	0.079	0.006	0	710
1996	0	0	0.579	0.320	0.092	0.008	0	500
1997	0	0	0.495	0.293	0.158	0.055	0	130
1998	0	0	0.657	0.281	0.062	0	0	100
1999	0	0	0.389	0.428	0.168	0.015	0	120
2000	0	0.005	0.559	0.406	0.019	0.011	0	490
2001	0	0	0.150	0.796	0.055	0	0	380
2002	0	0.040	0.347	0.491	0.120	0.002	0	290
2003	0	0	0.474	0.378	0.139	0.010	0	90
2004	0	0.004	0.615	0.320	0.061	0	0	290
2005	0	0	0.219	0.605	0.174	0.002	0	240
2006	0	0.022	0.456	0.422	0.099	0.001	0	1040
2007	0	0.022	0.761	0.174	0.041	0.002	0	520
2008	0	0.002	0.216	0.668	0.106	0.008	0	550
2009	0	0.123	0.299	0.463	0.102	0.013	0	240
2010	0	0	0.456	0.348	0.193	0.003	0	380
2011	0	0.058	0.726	0.190	0.023	0.003	0	410
2012	0	0.001	0.778	0.192	0.029	0	0	330
2013	0	0.028	0.724	0.233	0.015	0	0	370
2014	0	0.085	0.518	0.274	0.119	0.004	0	290
2015	0	0.006	0.593	0.362	0.038	0	0	390
2016	0	0.075	0.413	0.481	0.031	0	0	700
2017	0	0.017	0.572	0.393	0.015	0.003	0	1070
2018	0	0.088	0.680	0.211	0.021	0	0	590
2019	0.002	0.464	0.437	0.089	0.009	0	0	640
2020								0
2021	0	0.106	0.849	0.045	0	0	0	80
2022	0	0.155	0.752	0.086	0.007	0	0	140
2023	0.009	0.167	0.674	0.130	0.020	0	0	130

Table A3. Catch-at-age for the southern commercial reduction fishery from 1955-2023.

Year	0	1	2	3	4	5	6+	# of fish sampled
1955	0.374	0.323	0.269	0.016	0.016	0.002	0	7742
1956	0.017	0.885	0.049	0.018	0.004	0.022	0.004	8831
1957	0.151	0.598	0.217	0.010	0.011	0.007	0.006	8467
1958	0.059	0.466	0.443	0.018	0.005	0.005	0.004	7008
1959	0.003	0.855	0.099	0.034	0.005	0.002	0.002	7490
1960	0.052	0.192	0.701	0.018	0.025	0.008	0.004	4167
1961	0	0.538	0.217	0.234	0.004	0.007	0	5158
1962	0.040	0.387	0.491	0.033	0.044	0.003	0.002	6197
1963	0.079	0.460	0.386	0.059	0.007	0.008	0.002	6977
1964	0.187	0.433	0.349	0.028	0.002	0	0	5824
1965	0.184	0.528	0.269	0.018	0.001	0	0	13017
1966	0.265	0.414	0.299	0.020	0.001	0	0	13848
1967	0.007	0.663	0.269	0.057	0.003	0	0	13648
1968	0.143	0.349	0.468	0.037	0.003	0	0	21168
1969	0.188	0.442	0.330	0.038	0.002	0	0	11511
1970	0.016	0.650	0.309	0.022	0.003	0	0	7761
1971	0.083	0.288	0.569	0.054	0.005	0.001	0	7510
1972	0.033	0.618	0.285	0.061	0.003	0	0	5800
1973	0.036	0.372	0.591	0.001	0	0	0	5640
1974	0.196	0.388	0.413	0.003	0	0	0	4330
1975	0.154	0.371	0.469	0.006	0.001	0	0	5450
1976	0.101	0.572	0.324	0.003	0	0	0	4720
1977	0.140	0.289	0.567	0.003	0	0	0	5080
1978	0.158	0.230	0.558	0.050	0.003	0	0	5250
1979	0.413	0.172	0.403	0.012	0.001	0	0	4680
1980	0.028	0.476	0.452	0.038	0.004	0.001	0	5548
1981	0.316	0.186	0.460	0.038	0	0	0	7000
1982	0.038	0.306	0.558	0.096	0.001	0	0	8230
1983	0.279	0.148	0.547	0.016	0.008	0.001	0	4340
1984	0.396	0.311	0.244	0.040	0.007	0.002	0	8580
1985	0.235	0.394	0.364	0.006	0	0	0	6230
1986	0.056	0.126	0.797	0.019	0.002	0.001	0	4880
1987	0.022	0.253	0.691	0.031	0.003	0	0	6460
1988	0.175	0.146	0.573	0.099	0.006	0.001	0	5708
1989	0.069	0.514	0.402	0.014	0.001	0	0	5530

Table A3. ***Continued***

Year	0	1	2	3	4	5	6+	# of fish sampled
1990	0.190	0.078	0.697	0.023	0.010	0.002	0	5180
1991	0.317	0.360	0.281	0.038	0.004	0.001	0	6230
1992	0.243	0.428	0.313	0.014	0.002	0	0	4430
1993	0.049	0.266	0.608	0.074	0.003	0	0	4680
1994	0.064	0.197	0.609	0.094	0.035	0.002	0	4410
1995	0.044	0.408	0.366	0.150	0.031	0.002	0	3900
1996	0.036	0.226	0.630	0.092	0.015	0.001	0	3720
1997	0.027	0.260	0.423	0.236	0.047	0.007	0.001	3970
1998	0.073	0.187	0.535	0.123	0.073	0.009	0.001	3740
1999	0.188	0.292	0.428	0.069	0.020	0.003	0	3500
2000	0.140	0.205	0.510	0.127	0.016	0.002	0	2550
2001	0.039	0.073	0.604	0.265	0.018	0.001	0	3540
2002	0.242	0.284	0.321	0.140	0.012	0	0	3310
2003	0.088	0.185	0.643	0.073	0.010	0.001	0	3400
2004	0.020	0.234	0.670	0.060	0.015	0.001	0	3880
2005	0.020	0.131	0.618	0.210	0.018	0.003	0	3290
2006	0.016	0.525	0.378	0.072	0.008	0	0	2530
2007	0.001	0.306	0.631	0.054	0.008	0	0	3270
2008	0.017	0.115	0.812	0.053	0.003	0	0	2220
2009	0.007	0.515	0.311	0.147	0.019	0.001	0	2590
2010	0.017	0.447	0.494	0.034	0.008	0	0	2890
2011	0	0.477	0.467	0.048	0.007	0.002	0	2820
2012	0.007	0.183	0.789	0.020	0.001	0	0	2300
2013	0.043	0.457	0.388	0.095	0.016	0	0	1760
2014	0.007	0.482	0.377	0.106	0.026	0.002	0	1790
2015	0	0.141	0.759	0.092	0.009	0	0	2170
2016	0.022	0.303	0.509	0.160	0.006	0	0	1800
2017	0	0.249	0.581	0.144	0.026	0	0	1280
2018	0.036	0.334	0.479	0.136	0.015	0	0	1520
2019	0.002	0.755	0.202	0.037	0.004	0.001	0	1620
2020	0.0	0.177	0.819	0.003	0	0	0	450
2021	0.0	0.831	0.167	0.002	0.001	0	0	660
2022	0	0.530	0.412	0.047	0.010	0	0	1320
2023	0.010	0.322	0.608	0.056	0.004	0	0	915

Table A4. Catch-at-age for the northern commercial bait fishery (includes MRIP estimates of recreational catch).

Year	0	1	2	3	4	5	6+	# of fish sampled
1985	0.000	0.010	0.754	0.116	0.093	0.022	0.006	0
1986	0.000	0.001	0.207	0.563	0.116	0.091	0.023	0
1987	0.000	0.002	0.215	0.531	0.226	0.016	0.010	0
1988	0.000	0.000	0.070	0.521	0.363	0.041	0.004	0
1989	0.000	0.010	0.216	0.374	0.310	0.089	0.001	30
1990	0.000	0.003	0.534	0.262	0.144	0.053	0.005	0
1991	0.000	0.012	0.228	0.553	0.143	0.051	0.012	0
1992	0.000	0.025	0.335	0.212	0.330	0.079	0.019	0
1993	0.000	0.008	0.327	0.494	0.099	0.065	0.008	29
1994	0.000	0.000	0.098	0.505	0.347	0.045	0.004	401
1995	0.000	0.000	0.088	0.475	0.435	0.001	0.000	190
1996	0.000	0.000	0.413	0.442	0.137	0.008	0.000	203
1997	0.000	0.000	0.144	0.324	0.396	0.118	0.018	111
1998	0.000	0.000	0.103	0.379	0.420	0.084	0.013	225
1999	0.000	0.000	0.149	0.479	0.318	0.043	0.011	201
2000	0.000	0.004	0.415	0.315	0.229	0.030	0.007	266
2001	0.000	0.000	0.112	0.735	0.135	0.014	0.004	678
2002	0.000	0.000	0.053	0.552	0.336	0.058	0.000	524
2003	0.000	0.000	0.127	0.661	0.201	0.011	0.000	101
2004	0.000	0.007	0.438	0.381	0.161	0.013	0.000	29
2005	0.000	0.002	0.188	0.626	0.162	0.022	0.000	0
2006	0.000	0.004	0.278	0.566	0.147	0.001	0.004	259
2007	0.000	0.000	0.382	0.482	0.126	0.008	0.002	729
2008	0.000	0.000	0.262	0.585	0.139	0.013	0.000	973
2009	0.000	0.000	0.204	0.608	0.175	0.013	0.000	435
2010	0.000	0.000	0.365	0.380	0.228	0.025	0.002	466
2011	0.000	0.000	0.142	0.486	0.327	0.045	0.000	449
2012	0.000	0.000	0.392	0.468	0.130	0.008	0.002	547
2013	0.000	0.000	0.257	0.555	0.159	0.029	0.000	236
2014	0.000	0.000	0.066	0.525	0.387	0.020	0.002	806
2015	0.000	0.002	0.377	0.522	0.099	0.000	0.000	1291
2016	0.000	0.021	0.392	0.528	0.053	0.007	0.000	1018
2017	0.000	0.017	0.566	0.380	0.036	0.001	0.000	1487
2018	0.000	0.000	0.274	0.595	0.121	0.010	0.000	331
2019	0.000	0.037	0.356	0.446	0.142	0.015	0.004	837
2020	0.000	0.007	0.684	0.255	0.046	0.007	0.002	754
2021	0.000	0.018	0.546	0.283	0.134	0.019	0.000	471
2022	0.000	0.064	0.578	0.264	0.085	0.009	0.000	467
2023	0.000	0.132	0.435	0.352	0.077	0.005	0.000	428

Table A5. Catch-at-age for the southern commercial bait fishery (includes MRIP estimates of recreational catch).

Year	0	1	2	3	4	5	6+	# of fish sampled
1985	0.004	0.310	0.661	0.016	0.007	0.002	0.000	800
1986	0.001	0.064	0.860	0.066	0.006	0.003	0.001	420
1987	0.001	0.089	0.836	0.068	0.006	0.000	0.000	220
1988	0.004	0.060	0.663	0.232	0.038	0.003	0.000	10
1989	0.004	0.341	0.577	0.063	0.013	0.003	0.000	0
1990	0.005	0.061	0.903	0.026	0.003	0.001	0.000	10
1991	0.012	0.301	0.595	0.084	0.005	0.001	0.000	78
1992	0.000	0.554	0.446	0.000	0.000	0.000	0.000	70
1993	0.008	0.357	0.530	0.097	0.006	0.003	0.000	121
1994	0.001	0.142	0.650	0.150	0.052	0.005	0.000	139
1995	0.000	0.392	0.374	0.217	0.017	0.000	0.000	174
1996	0.000	0.006	0.757	0.199	0.037	0.000	0.000	156
1997	0.000	0.055	0.531	0.346	0.056	0.008	0.004	293
1998	0.036	0.065	0.539	0.237	0.108	0.012	0.003	411
1999	0.000	0.105	0.663	0.174	0.052	0.006	0.000	338
2000	0.008	0.222	0.659	0.112	0.000	0.000	0.000	270
2001	0.004	0.043	0.658	0.275	0.017	0.004	0.000	286
2002	0.000	0.047	0.265	0.494	0.173	0.020	0.002	180
2003	0.007	0.095	0.740	0.142	0.015	0.000	0.000	328
2004	0.000	0.066	0.733	0.167	0.031	0.003	0.000	327
2005	0.000	0.008	0.515	0.447	0.027	0.003	0.000	316
2006	0.000	0.327	0.451	0.197	0.024	0.000	0.000	220
2007	0.000	0.243	0.671	0.067	0.019	0.000	0.000	434
2008	0.005	0.044	0.809	0.112	0.017	0.013	0.000	366
2009	0.004	0.241	0.367	0.341	0.047	0.000	0.000	573
2010	0.003	0.306	0.527	0.102	0.059	0.002	0.000	435
2011	0.000	0.338	0.470	0.121	0.051	0.020	0.000	508
2012	0.000	0.068	0.825	0.085	0.017	0.002	0.002	408
2013	0.007	0.449	0.289	0.173	0.054	0.027	0.000	434
2014	0.000	0.437	0.365	0.138	0.055	0.005	0.000	559
2015	0.010	0.309	0.589	0.089	0.002	0.000	0.000	251
2016	0.000	0.225	0.423	0.324	0.021	0.007	0.000	205
2017	0.000	0.267	0.496	0.229	0.008	0.000	0.000	137
2018	0.000	0.328	0.446	0.166	0.060	0.001	0.000	280
2019	0.000	0.580	0.250	0.125	0.039	0.003	0.003	684
2020	0.000	0.004	0.023	0.972	0.000	0.000	0.000	65
2021	0.000	0.271	0.256	0.424	0.043	0.005	0.000	266
2022	0.005	0.334	0.492	0.124	0.040	0.006	0.000	233
2023	0.049	0.146	0.523	0.199	0.062	0.013	0.009	262

Table A6. Young-of-year abundance index (YOY), northern adult index (NAD), Mid-Atlantic adult index (MAD), and southern adult index (SAD) of abundance for Atlantic menhaden developed from the Conn method with associated coefficients of variation (CV).

Year	YOY		NAD		MAD		SAD	
	Index	CV	Index	CV	Index	CV	Index	CV
1959	1.60	1.03						
1960	0.47	1.07						
1961	0.42	1.10						
1962	1.60	1.03						
1963	1.24	1.08						
1964	0.80	1.15						
1965	0.49	1.06						
1966	0.64	1.09						
1967	0.53	1.10						
1968	0.48	0.90						
1969	1.28	0.90						
1970	0.30	0.90						
1971	1.62	0.86						
1972	2.29	0.84						
1973	2.39	1.00						
1974	2.68	0.99						
1975	2.83	1.00						
1976	2.77	0.98						
1977	2.76	1.01						
1978	1.45	0.99						
1979	2.11	1.00						
1980	3.20	0.83						
1981	2.45	1.01						
1982	3.05	0.84						
1983	1.74	0.99						
1984	1.53	0.98						
1985	2.64	0.86			1.88	1.09		
1986	2.27	0.76			1.87	1.13		
1987	0.41	0.72			2.06	1.13		
1988	1.06	0.69			1.94	1.11		
1989	1.54	0.59			1.21	1.12		

Table A6. ***Continued***

Year	YOY		NAD		MAD		SAD	
	Index	CV	Index	CV	Index	CV	Index	CV
1990	0.71	0.51	0.53	0.67	0.93	1.12	3.12	0.75
1991	0.76	0.50	0.31	0.67	0.74	1.15	1.23	0.67
1992	0.52	0.51	0.92	0.63	1.34	1.11	0.92	0.66
1993	0.20	0.55	0.77	0.62	0.55	1.18	0.57	0.70
1994	0.32	0.52	0.50	0.63	1.46	1.12	0.36	0.79
1995	0.26	0.51	1.15	0.64	1.38	1.11	0.18	0.81
1996	0.25	0.51	0.59	0.56	0.54	1.16	0.28	0.77
1997	0.28	0.50	0.32	0.58	0.54	1.17	0.24	0.75
1998	0.50	0.50	0.60	0.65	0.78	0.36	0.85	0.68
1999	0.56	0.53	0.78	0.58	0.60	0.39	0.27	0.77
2000	0.43	0.48	0.48	0.63	0.83	0.39	0.84	0.74
2001	0.37	0.46	0.80	0.67	0.95	0.34	0.93	0.77
2002	0.53	0.44	1.59	0.58	0.46	0.39	1.00	0.66
2003	0.86	0.45	0.30	0.63	1.05	0.32	0.86	0.59
2004	0.65	0.44	0.39	0.66	0.52	0.34	0.47	0.57
2005	0.74	0.44	1.12	0.55	1.31	0.36	1.56	0.53
2006	0.28	0.44	1.00	0.54	0.45	0.37	3.31	0.50
2007	0.49	0.44	1.33	0.55	0.87	0.37	0.46	0.58
2008	0.32	0.44	1.20	0.55	0.39	0.39	0.68	0.39
2009	0.29	0.42	0.41	0.57	0.90	0.36	1.60	0.61
2010	0.47	0.45	0.81	0.68	0.97	0.36	0.90	0.37
2011	0.33	0.45	0.83	0.65	0.65	0.33	1.29	0.39
2012	0.17	0.45	1.70	0.54	0.59	0.39	1.32	0.38
2013	0.20	0.43	0.58	0.58	0.91	0.36	1.09	0.36
2014	0.43	0.43	1.44	0.56	1.60	0.34	1.15	0.38
2015	0.31	0.45	1.59	0.57	1.89	0.40	1.81	0.39
2016	0.61	0.45	1.17	0.56	0.57	0.39	0.56	0.43
2017	0.15	0.46	0.58	0.60	0.45	0.37	1.21	0.43
2018	0.28	0.44	0.34	0.63	1.22	0.61	1.14	0.40
2019	0.23	0.46	1.83	0.55	1.00	0.39	0.84	0.38
2020	0.23	0.50	2.47	0.67	0.34	0.43	0.96	0.77
2021	0.51	0.47	2.40	0.60	1.16	0.45	0.99	0.47
2022	0.67	0.50	2.28	0.60	1.60	0.38	0.42	0.39
2023	0.43	0.48	0.92	0.62	0.51	0.44	0.60	0.49

Table A7. List of surveys used in the Conn indices and their associated sigma (σ^p) values, or the standard deviation of the process error. Benchmark and update values are provided for comparison.

	Survey	2019 Benchmark	2022 Update	2025 Update
Age 1+ Surveys	CT Long Island Sound Trawl	0.96	1.90	1.20
	DE Adult Trawl	0.88	0.44	0.60
	NJ Ocean Trawl	1.53	1.15	0.80
	MD Striped Bass Spring Gill Net	2.23	2.22	2.10
	VIMS Shad and River Herring Monitoring	0.24	0.21	0.20
	NC Program 915 Pamlico Sound Gill Net	0.92	0.71	0.50
	SEAMAP	0.4	0.52	0.50
	GA Ecological Monitoring Trawl	0.5	0.73	0.90
YOY Surveys	RI Coastal Trawl	2.96	2.94	2.90
	CT River Juvenile Alosine Seine	2.5	2.52	2.70
	CT Thames River Seine	3.16	3.16	3.20
	CT Long Island Sound Trawl	1.34	1.28	1.70
	NY Peconic Bay Small Mesh Trawl	3.78	3.58	2.20
	NY Western Long Island Seine	2.99	3.10	3.00
	NY Juvenile Striped Bass Beach Seine	1.18	2.09	2.10
	NJ Ocean Trawl	1.85	1.89	1.90
	NJ Delaware River Striped Bass Seine	1.81	1.81	1.60
	DE Inland Bays	11.34	4.93	4.90
	MD Coastal Bays Trawl	2.17	1.33	4.50
	MD Juvenile Striped Bass Seine	1.64	1.44	1.50
	VIMS Juvenile Fish and Blue Crab Trawl	1.31	1.22	1.30
	VIMS Juvenile Striped Bass Seine	3.05	1.50	1.30
	NC Program 120 Estuarine Trawl	0.82	1.00	1.00
	SC Electrofishing	0.92	0.97	0.90

Appendix Figures

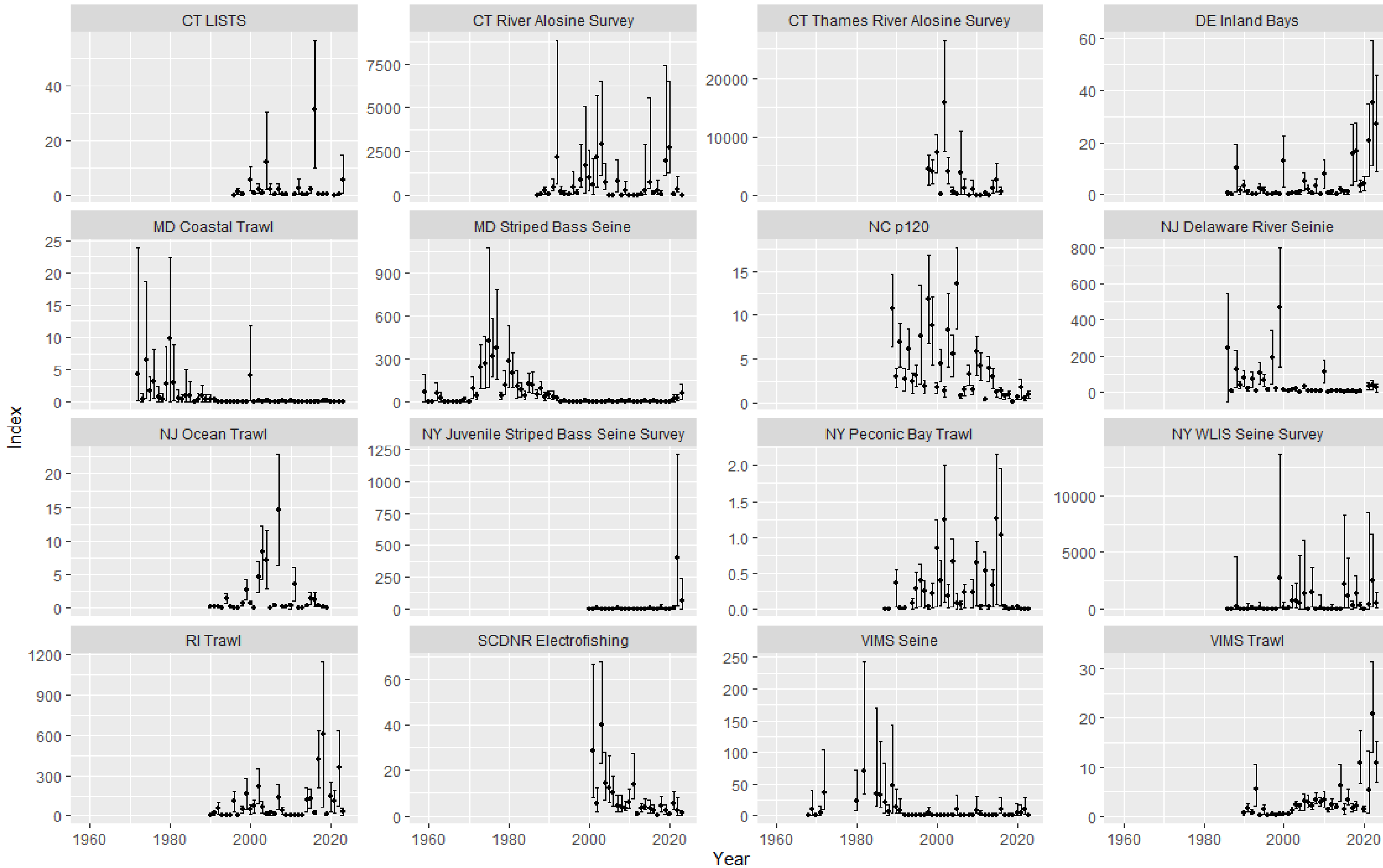


Figure A1. Individual YOY indices with 95% confidence intervals used in the coastwide YOY index.

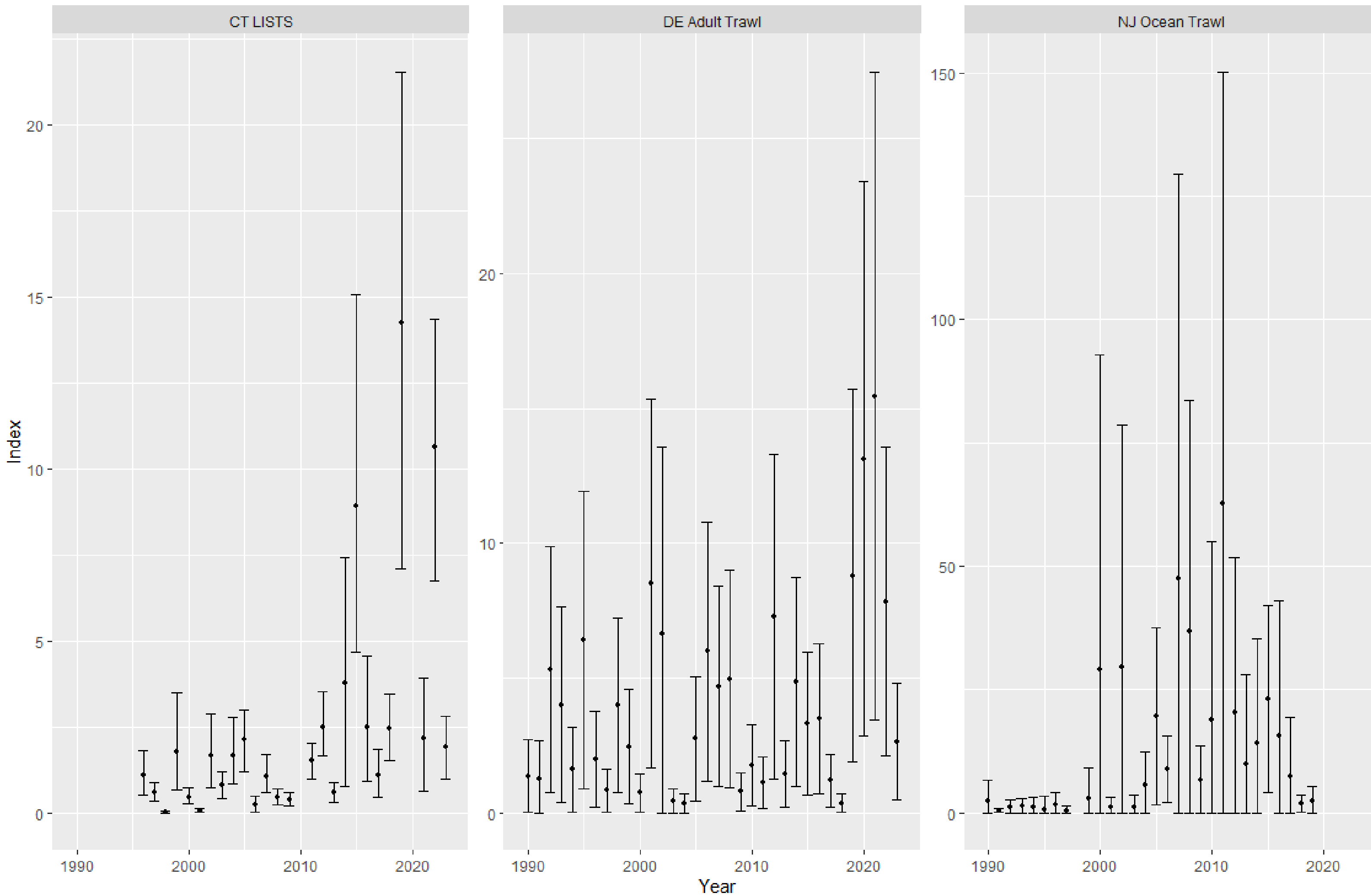


Figure A2. Individual adult indices with 95% confidence intervals used in the NAD index.

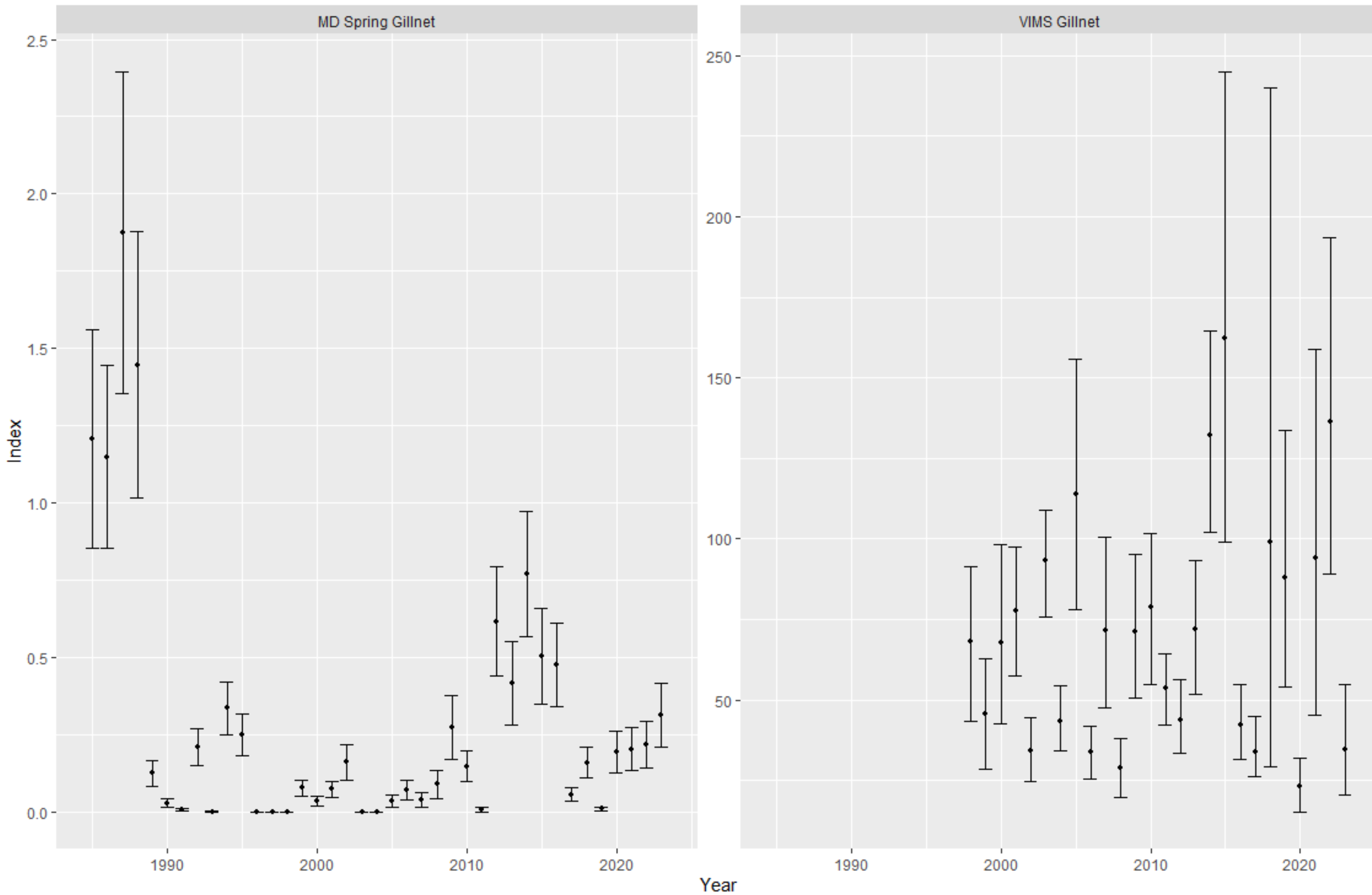


Figure A3. Individual adult indices with 95% confidence intervals used in the MAD index.

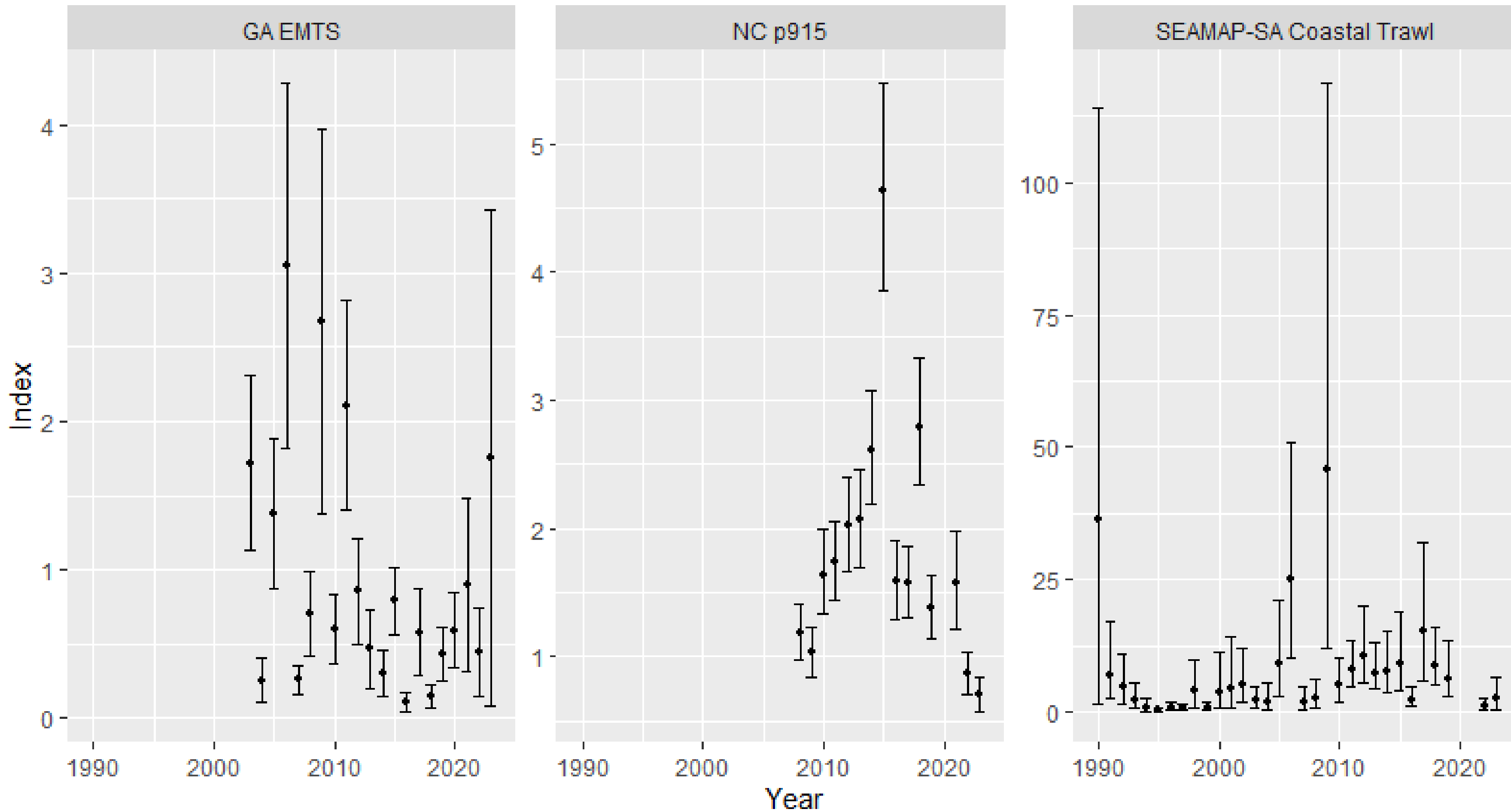


Figure A4. Individual adult indices with 95% confidence intervals used in the SAD index

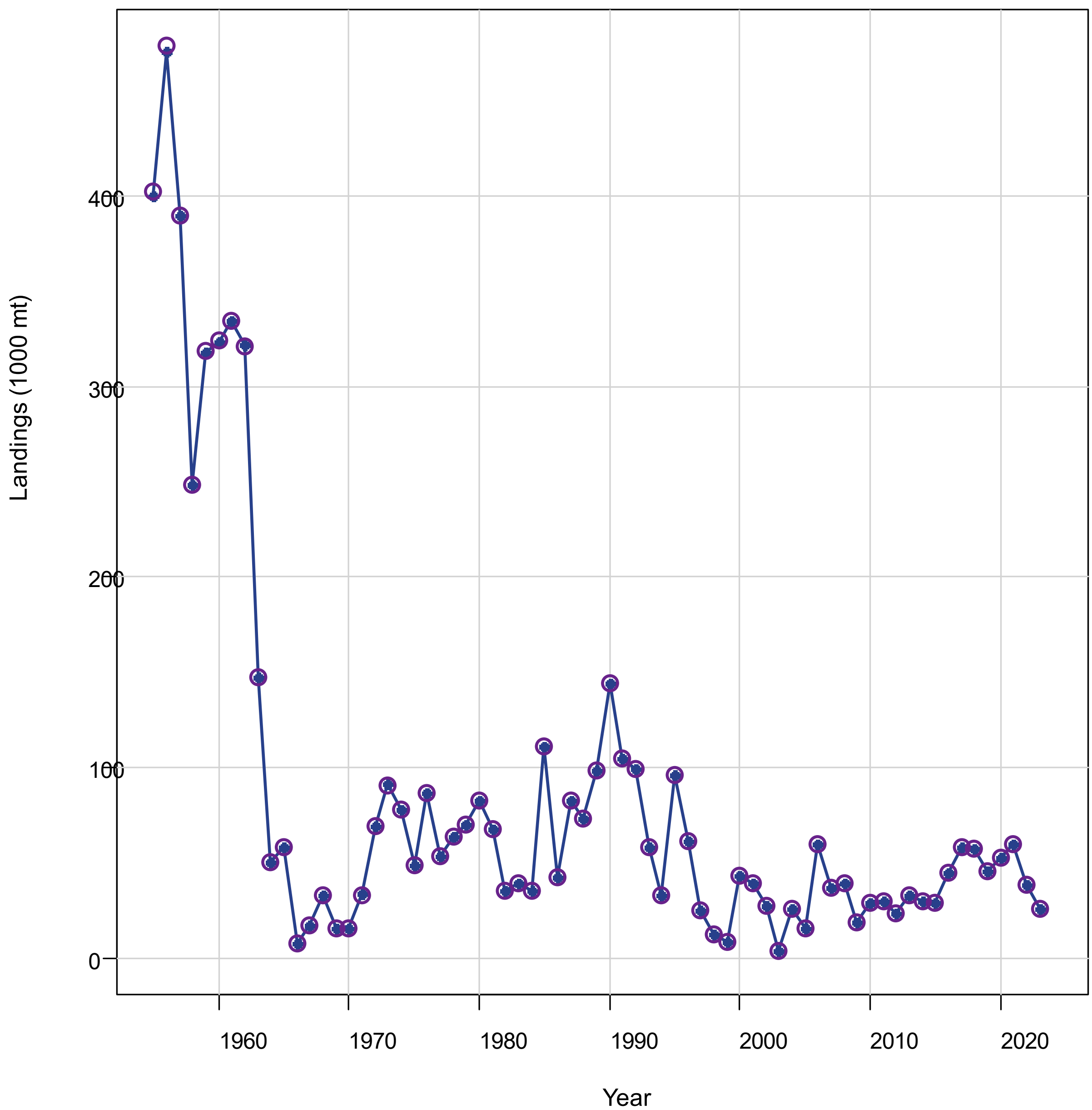


Figure A5. Predicted fit to the observed landings for the commercial reduction north fleet for 1955-2023. Predicted = solid circles + line; observed = open circles.

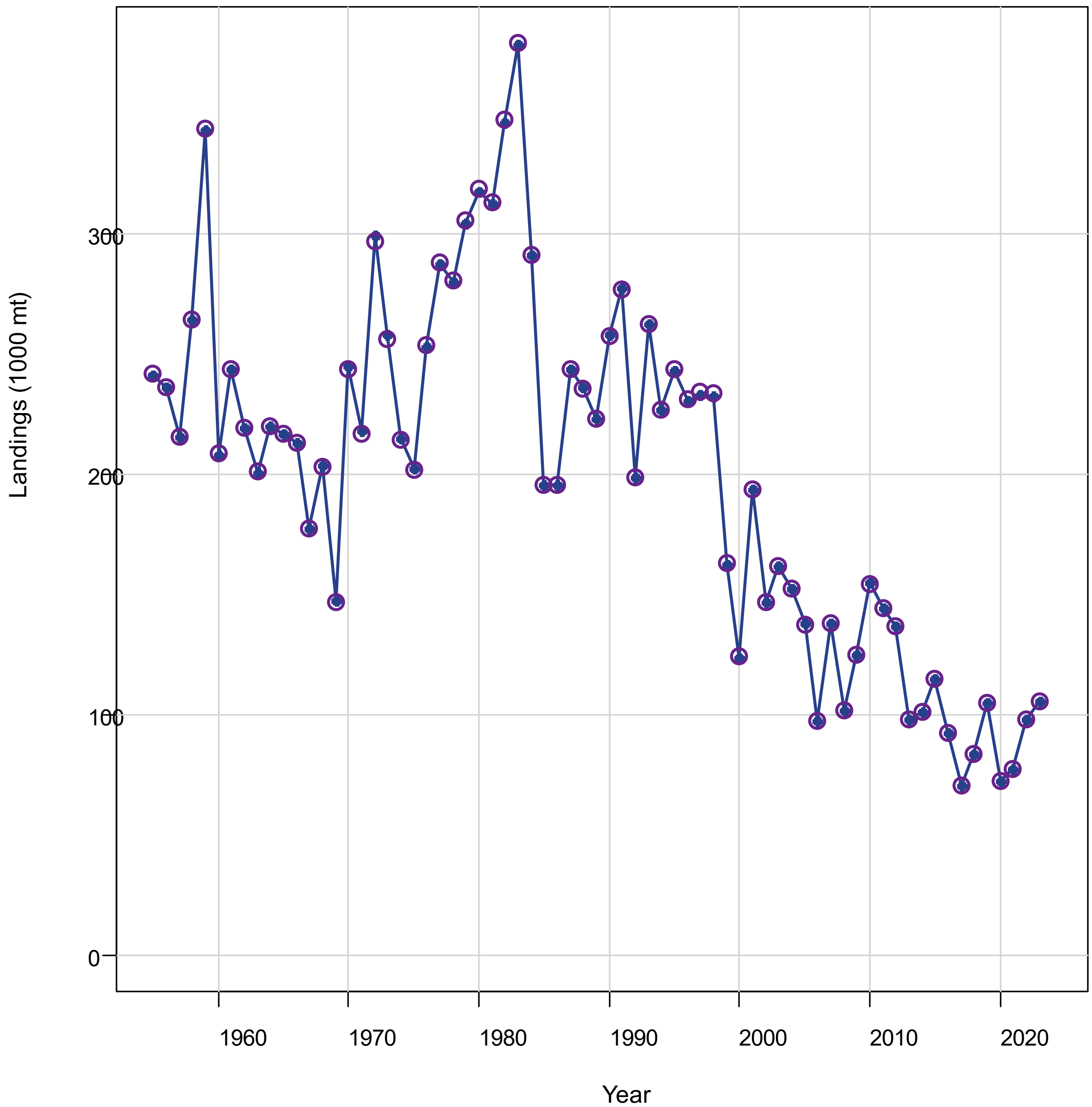


Figure A6. Predicted fit to the observed landings for the commercial reduction south fleet for 1955-2023. Predicted = solid circles + line; observed = open circles.

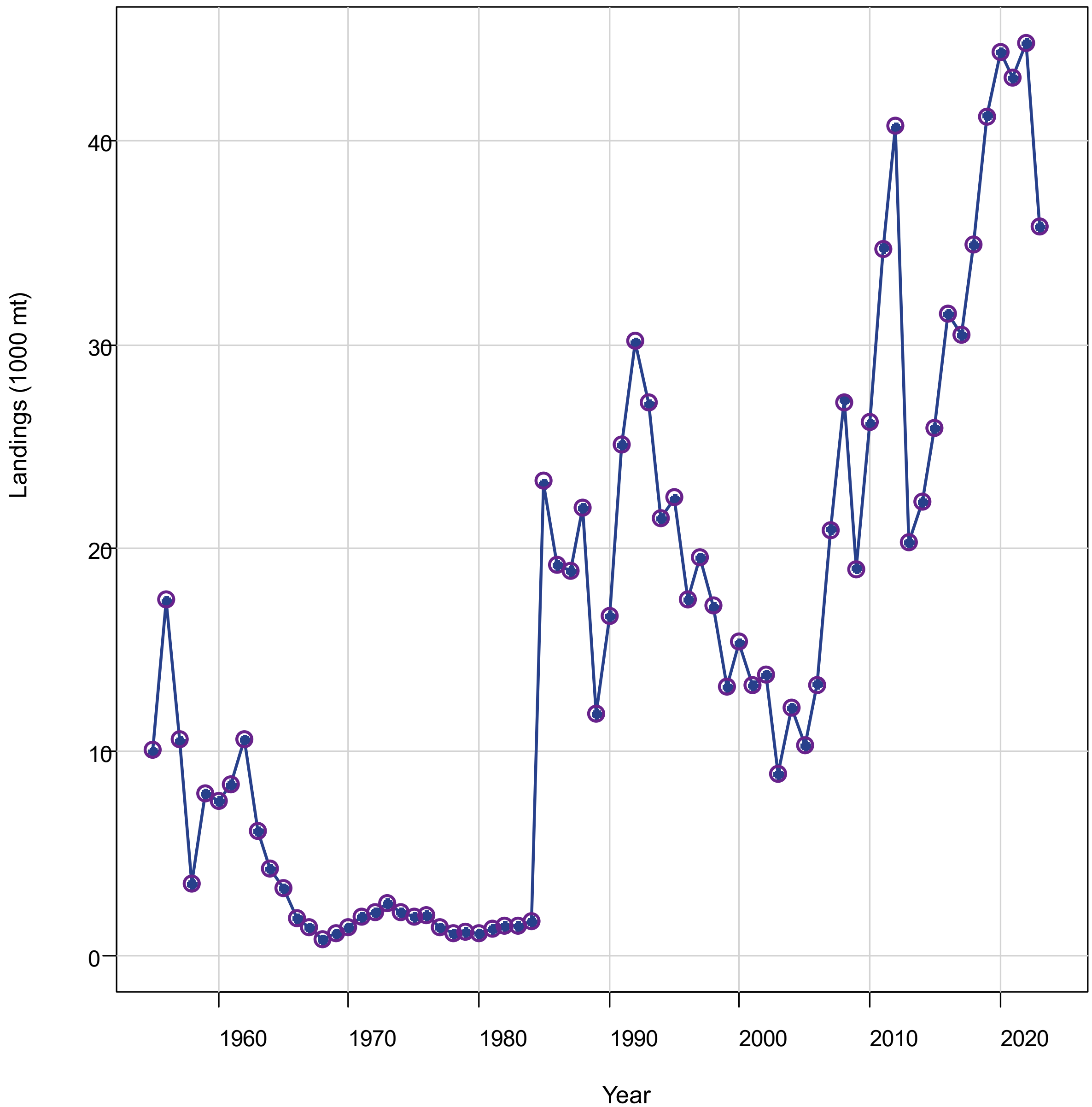


Figure A7. Predicted fit to the observed landings for the commercial bait north fleet for 1955-2023. Predicted = solid circles + line; observed = open circles.

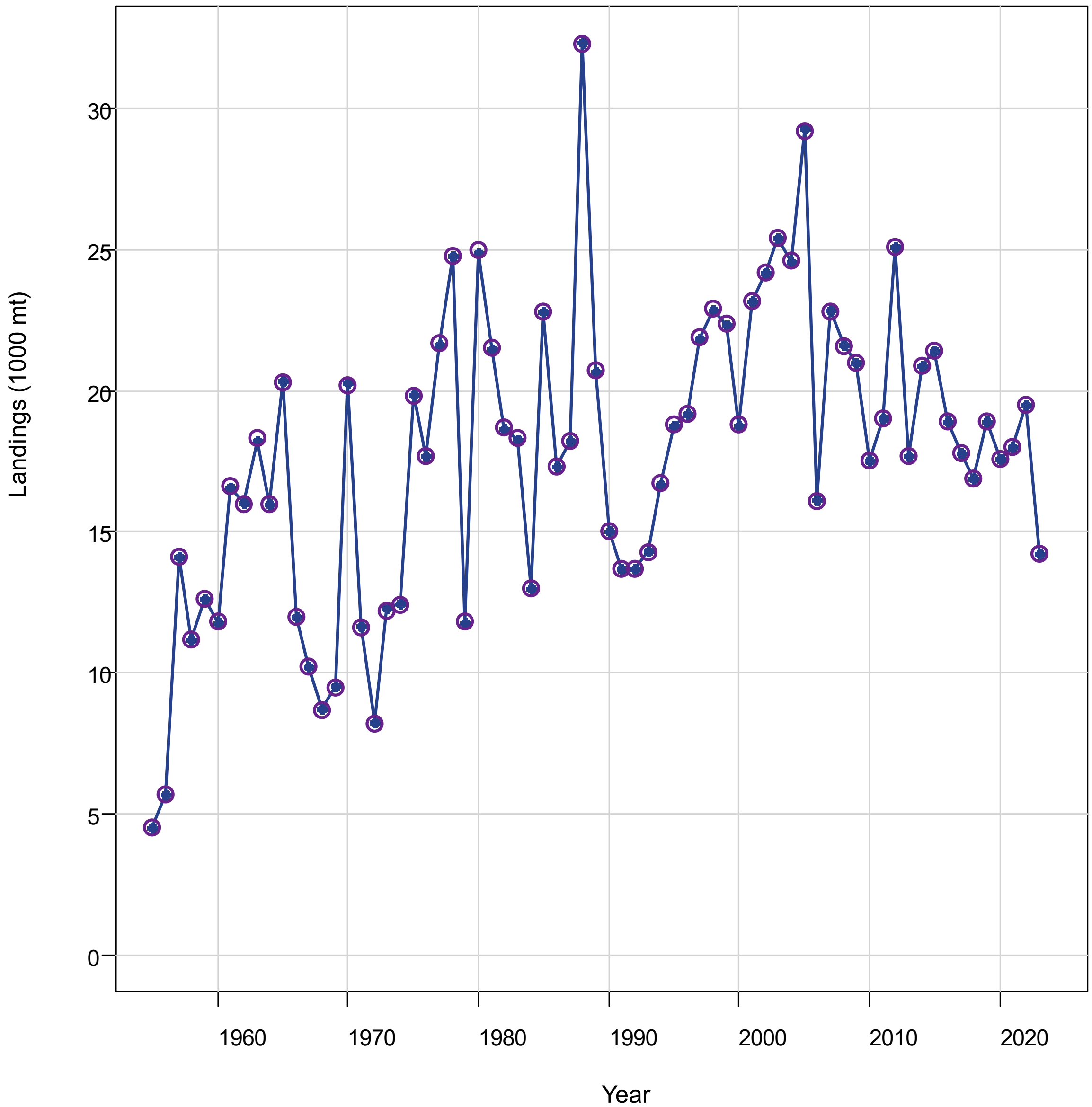


Figure A8. Predicted fit to the observed landings for the commercial bait south fleet for 1955-2023. Predicted = solid circles + line; observed = open circles.

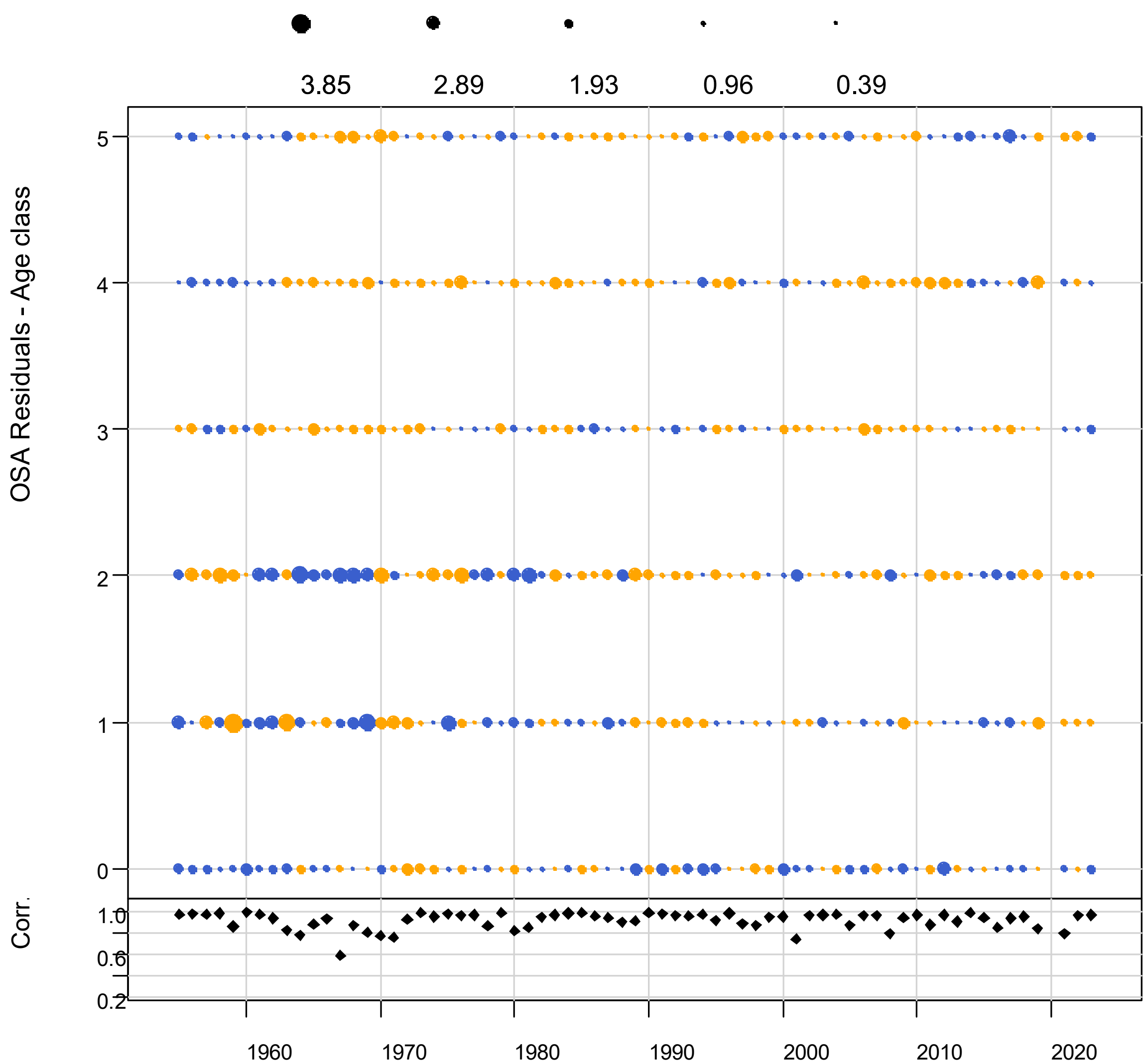


Figure A9. Bubble plot of the fits to the age compositions for the commercial reduction north fleet. Orange indicates an underestimate, while blue indicates an overestimate. OSA is one step ahead residuals. The bottom panel indicates the correlation between the observed data and the model prediction.

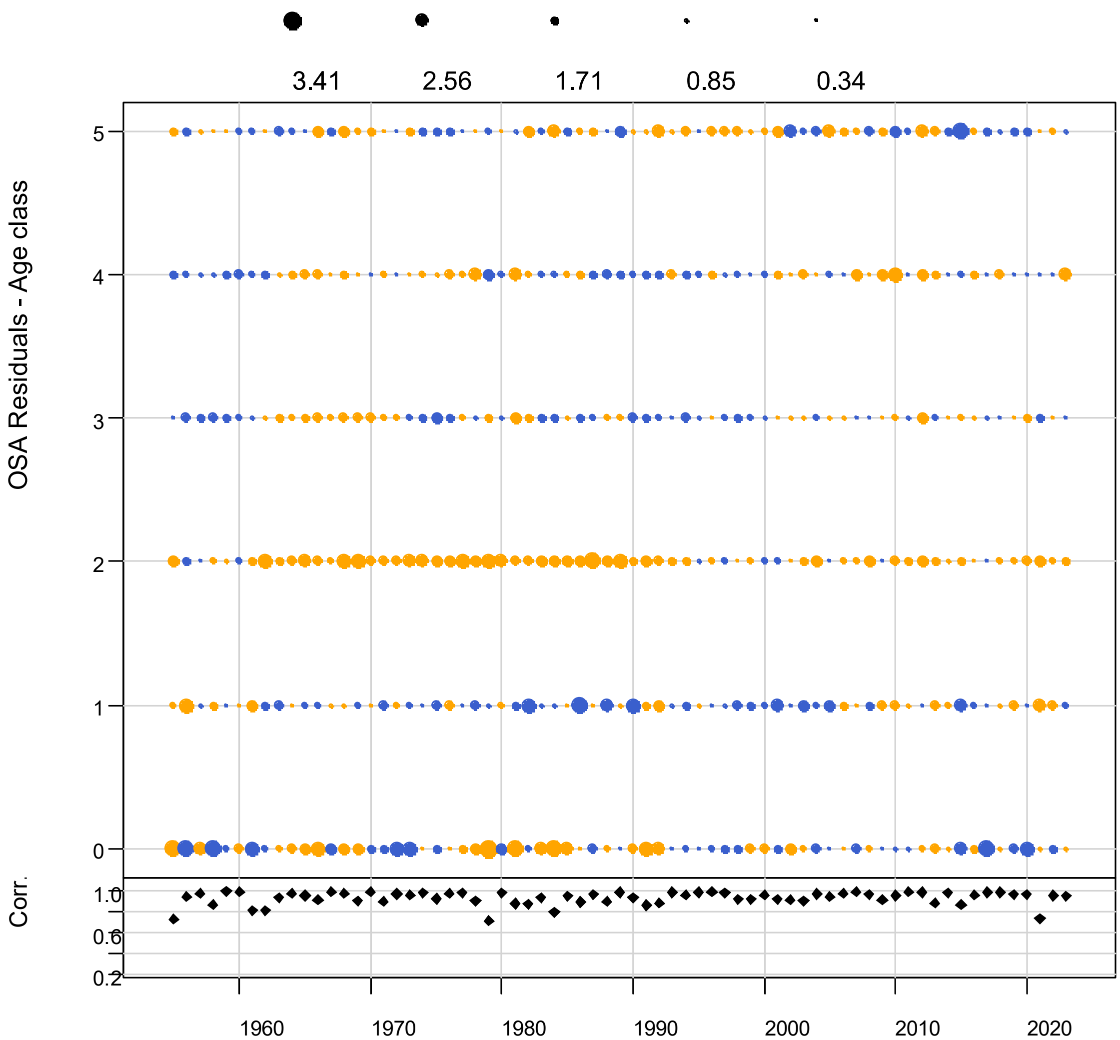


Figure A10. **Bubble plot of the fits to the age compositions for the commercial reduction south fleet. Orange indicates an underestimate, while blue indicates an overestimate. OSA is one step ahead residuals. The bottom panel indicates the correlation between the observed data and the model prediction.**

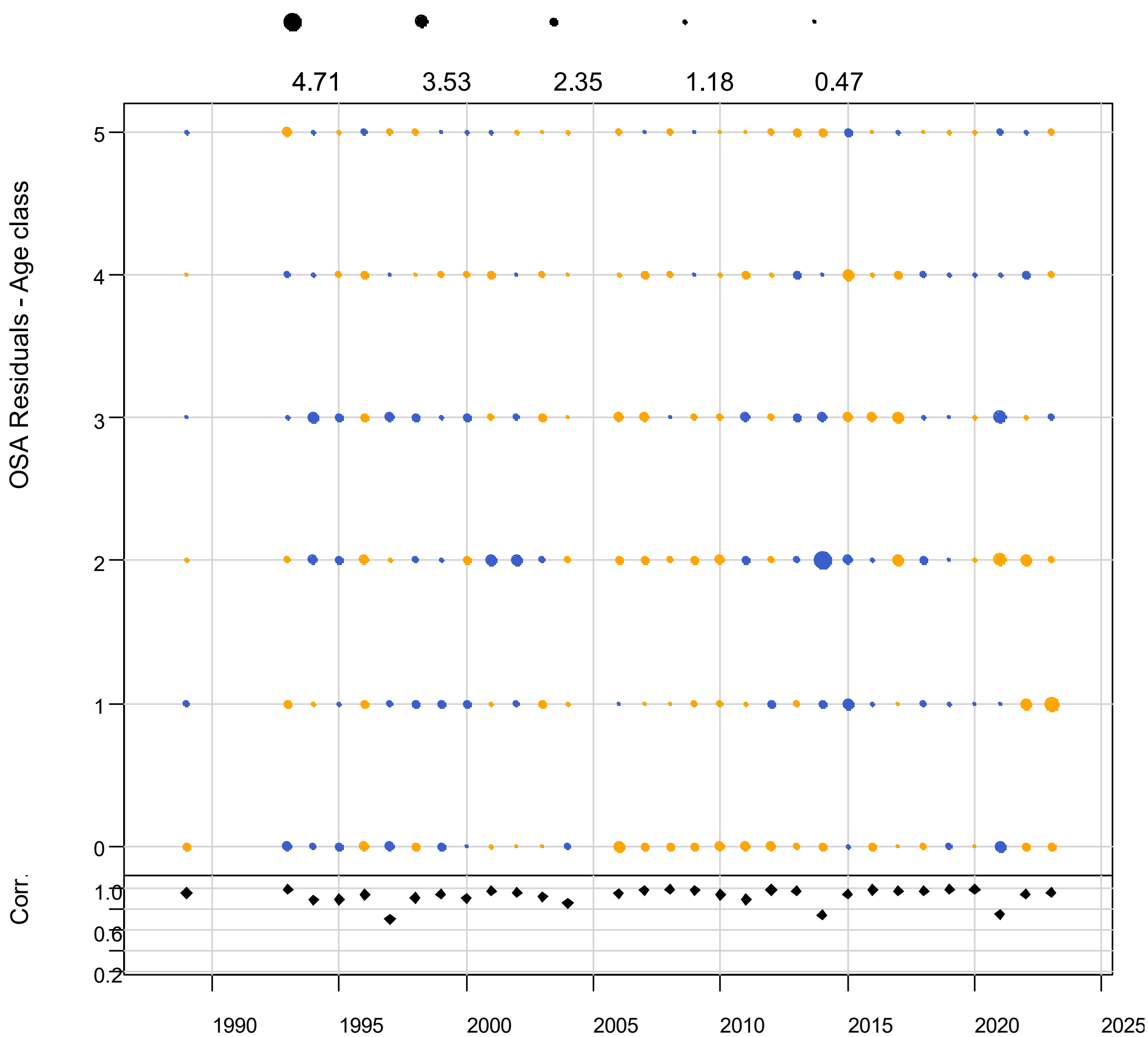


Figure A11. **Bubble plot of the fits to the age compositions for the commercial bait north fleet. Orange indicates an underestimate, while blue indicates an overestimate. OSA is one step ahead residuals. The bottom panel indicates the correlation between the observed data and the model prediction.**

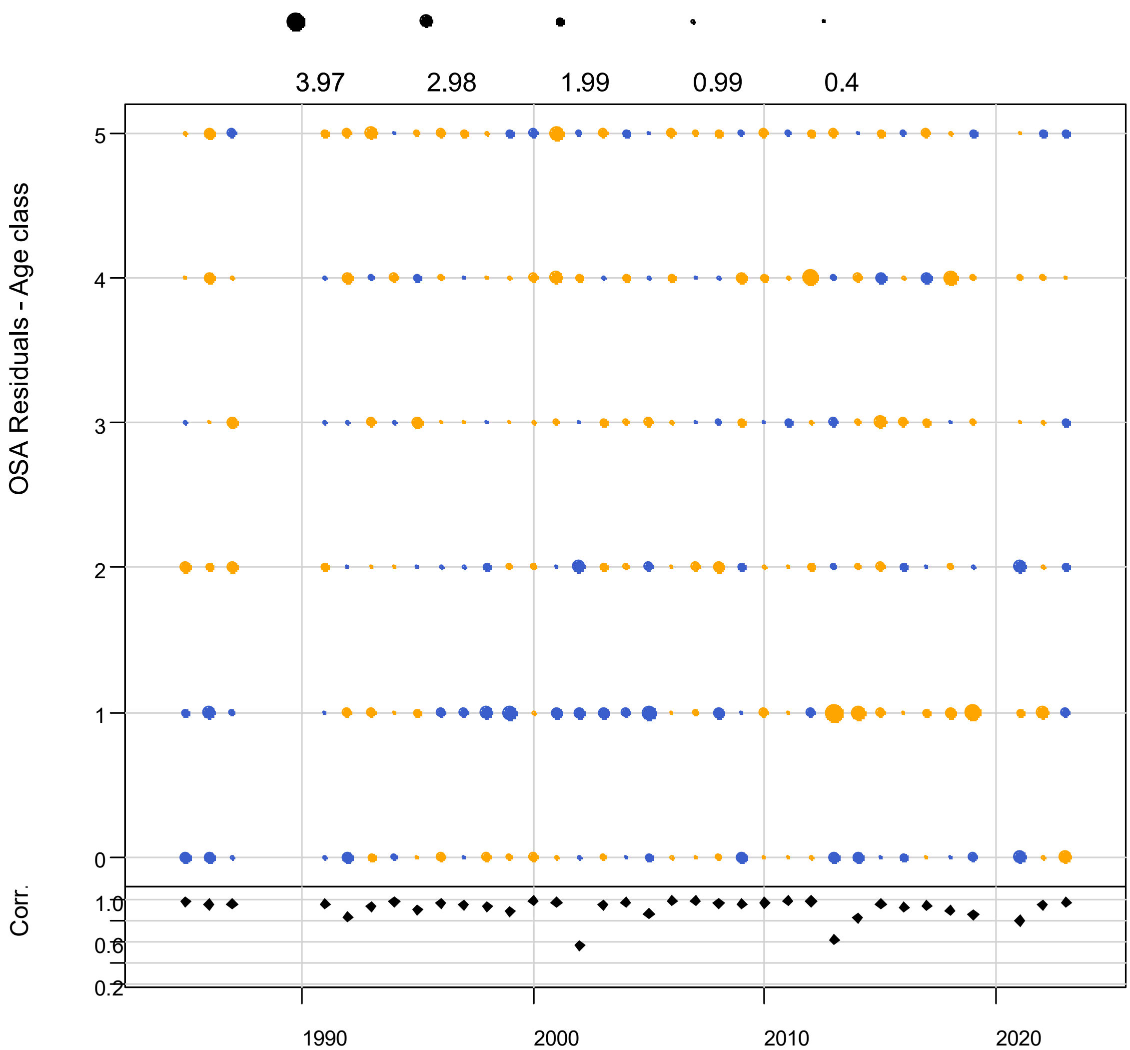


Figure A12. **Bubble plot of the fits to the age compositions for the commercial bait south fleet. Orange indicates an underestimate, while blue indicates an overestimate. OSA is one step ahead residuals. The bottom panel indicates the correlation between the observed data and the model prediction.**

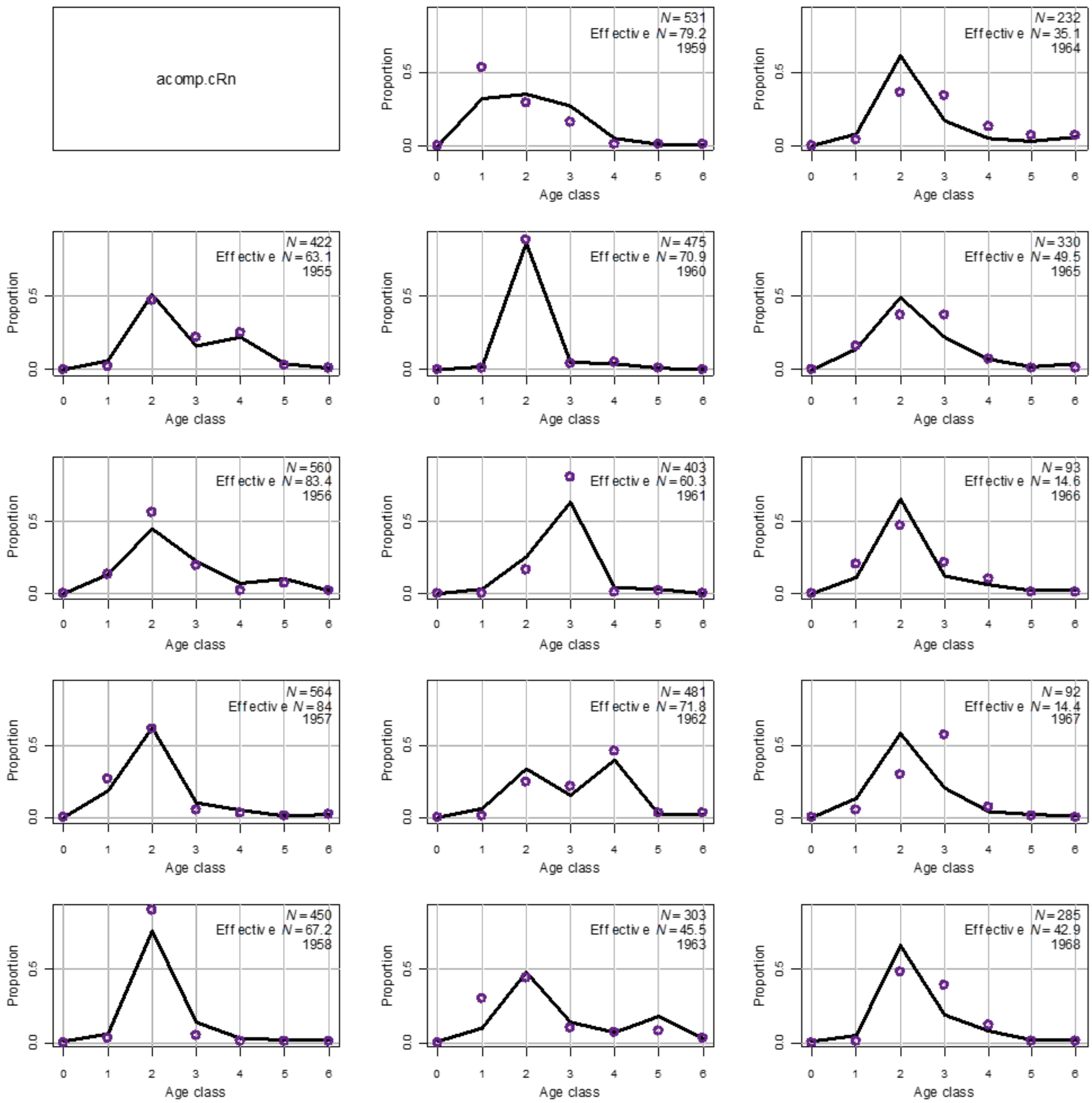
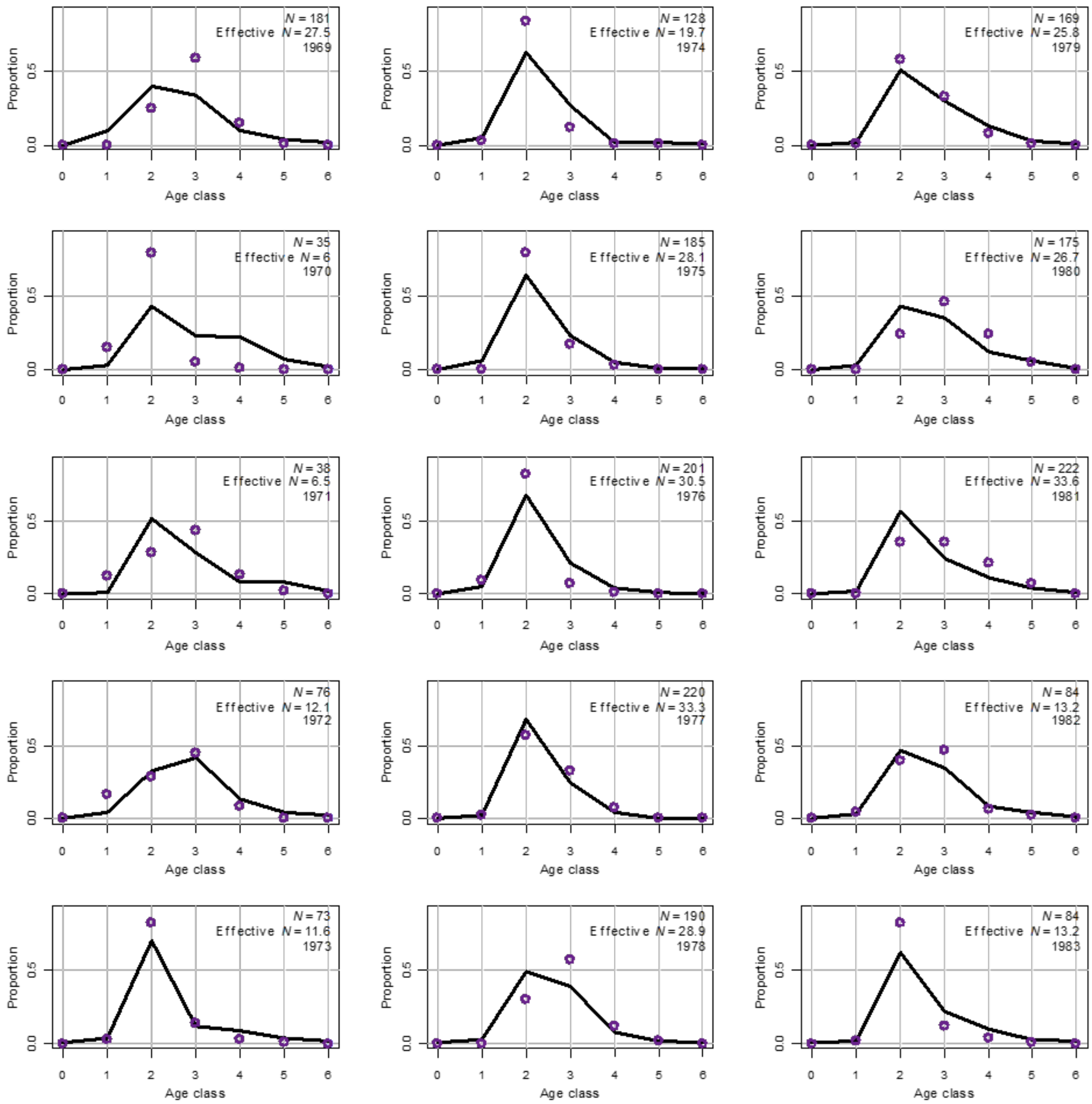


Figure A13. Annual age composition plots for the commercial reduction north fleet for 1955-2023. Open circles are the observed data, while the line indicates the model fit.



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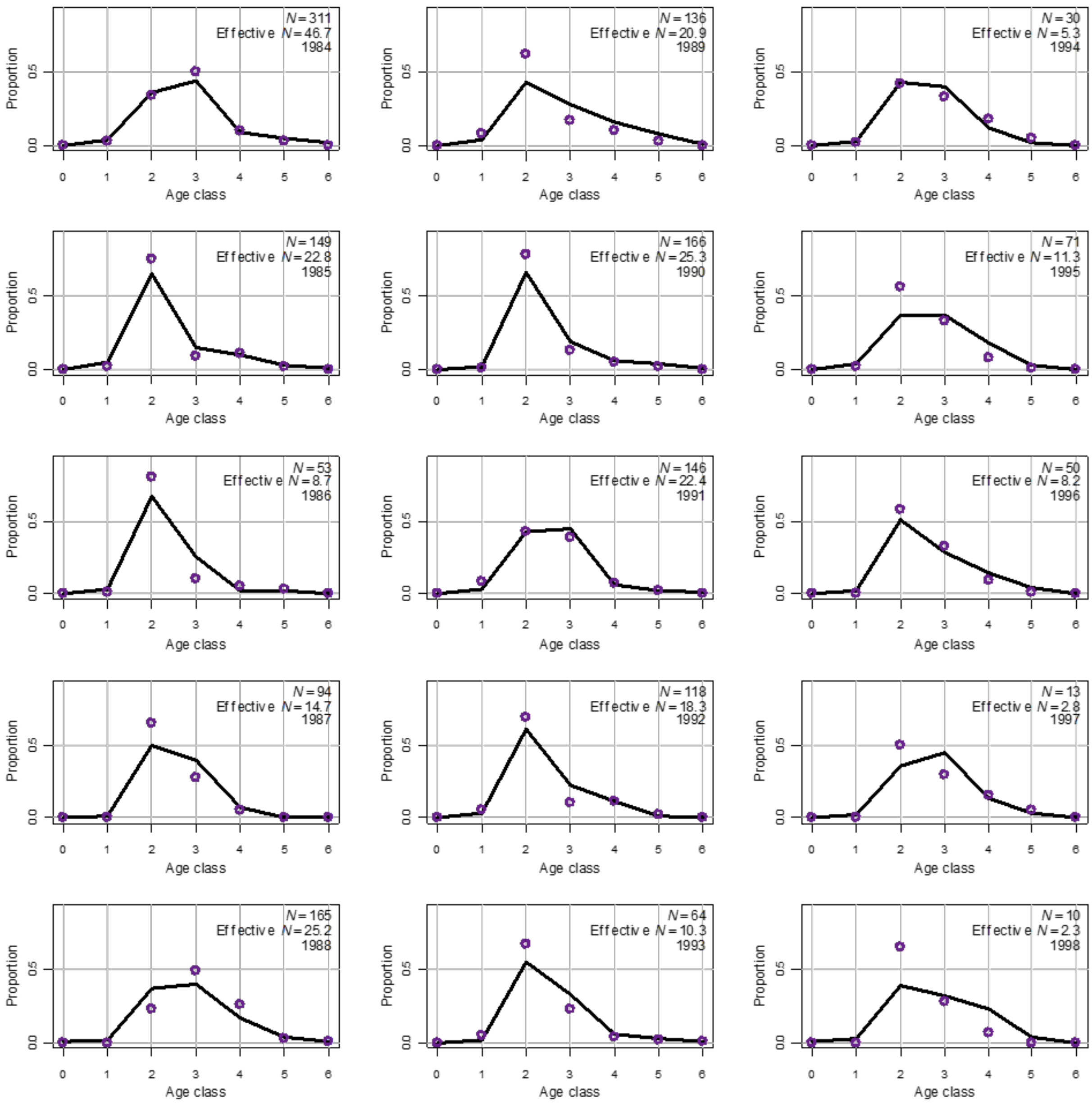

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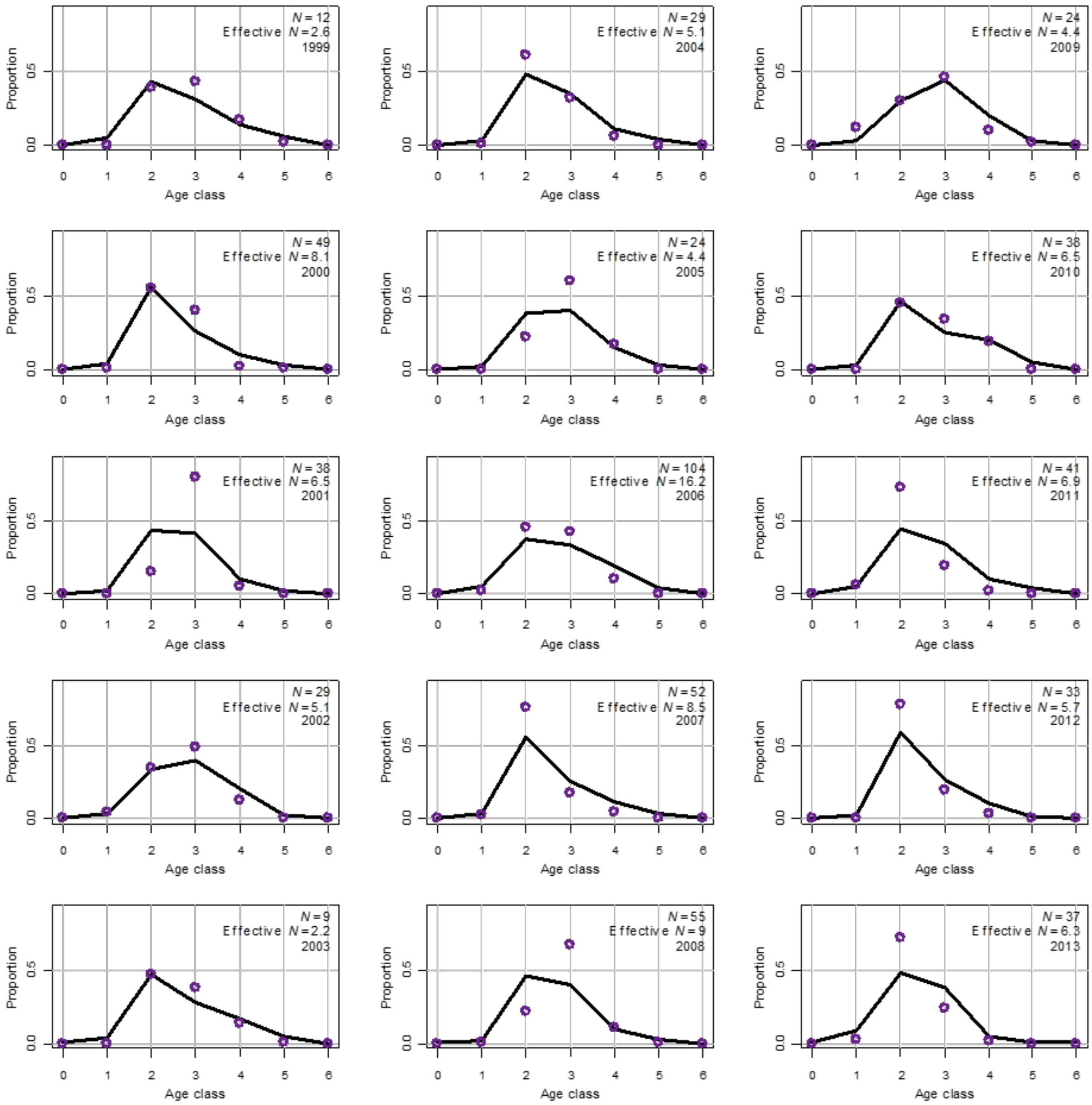

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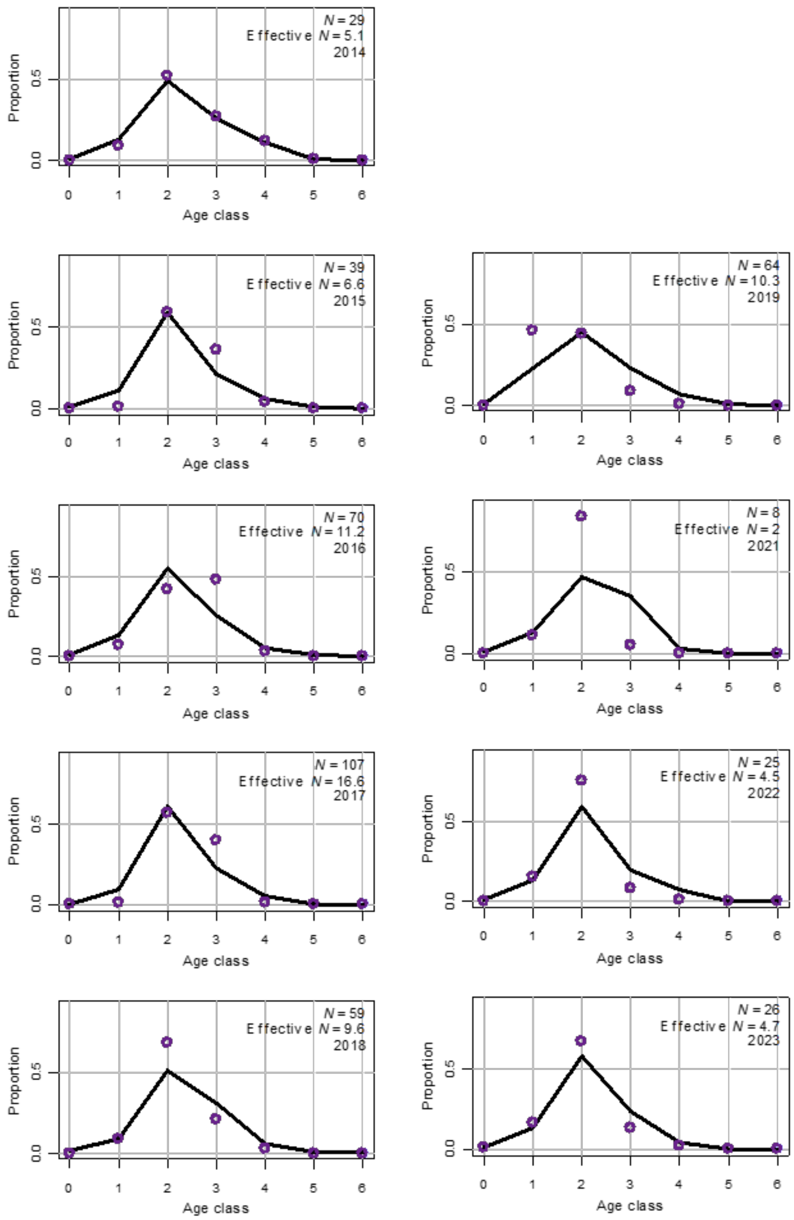

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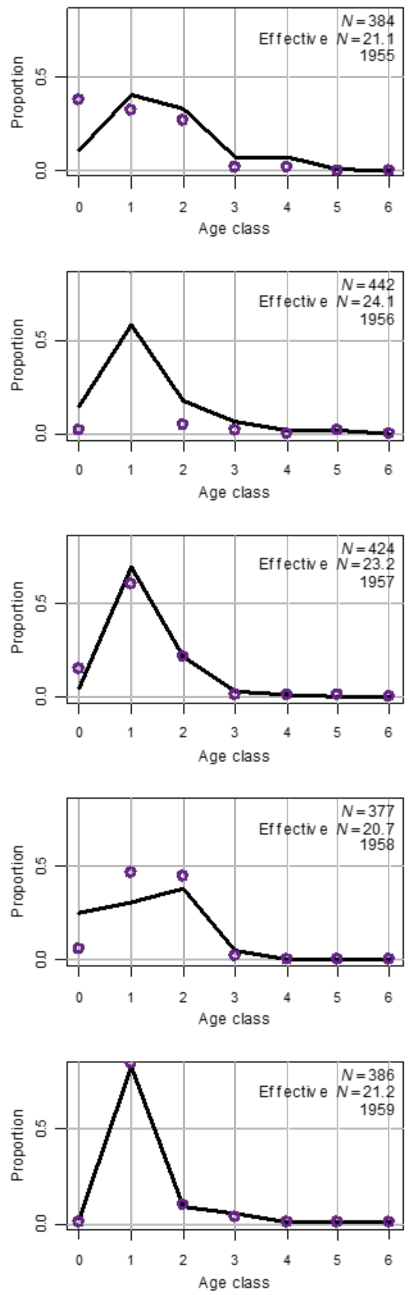
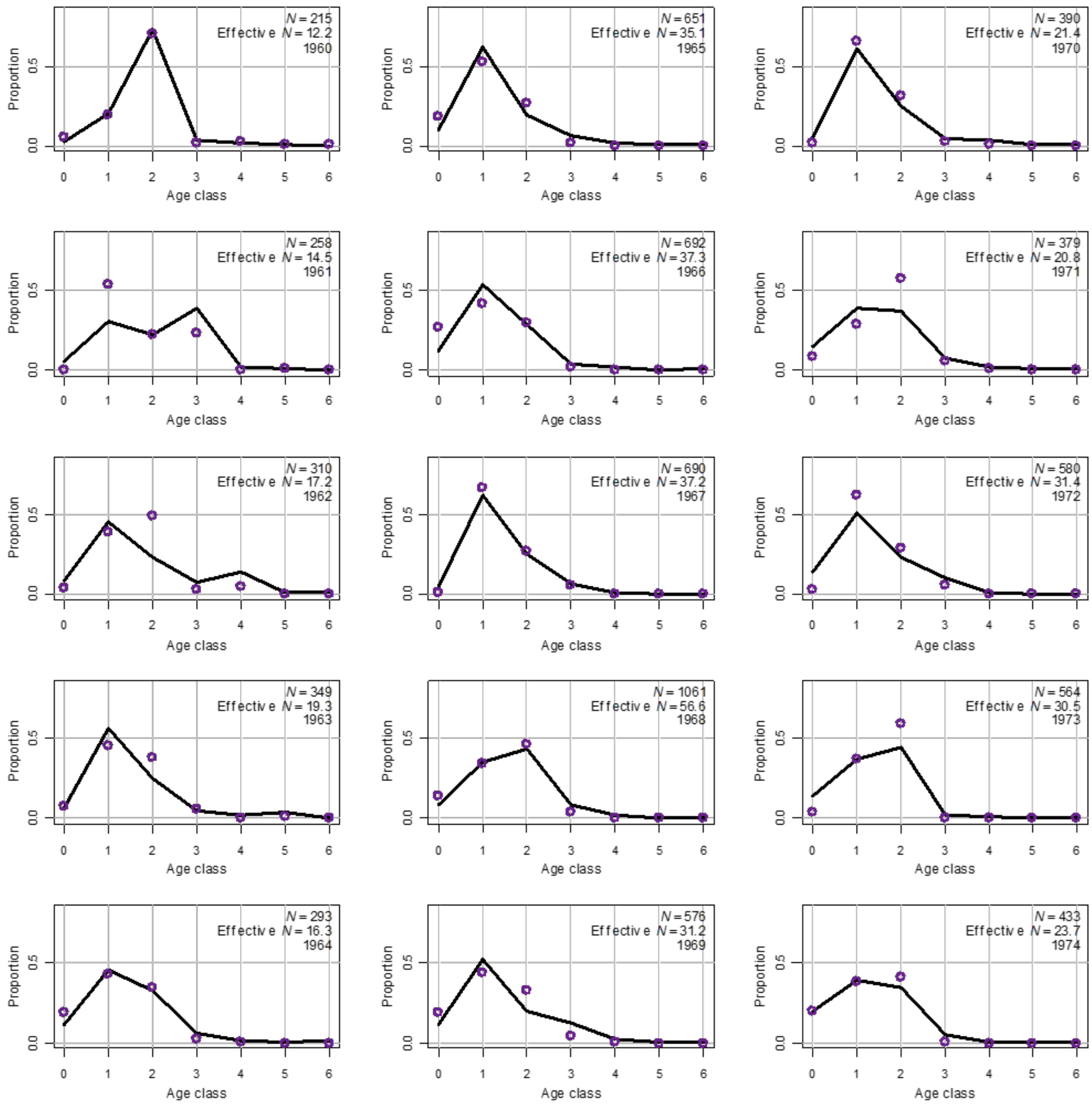


Figure A14. Annual age composition plots for the commercial reduction south fleet for 1955-2023. Open circles are the observed data, while the line indicates the model fit.



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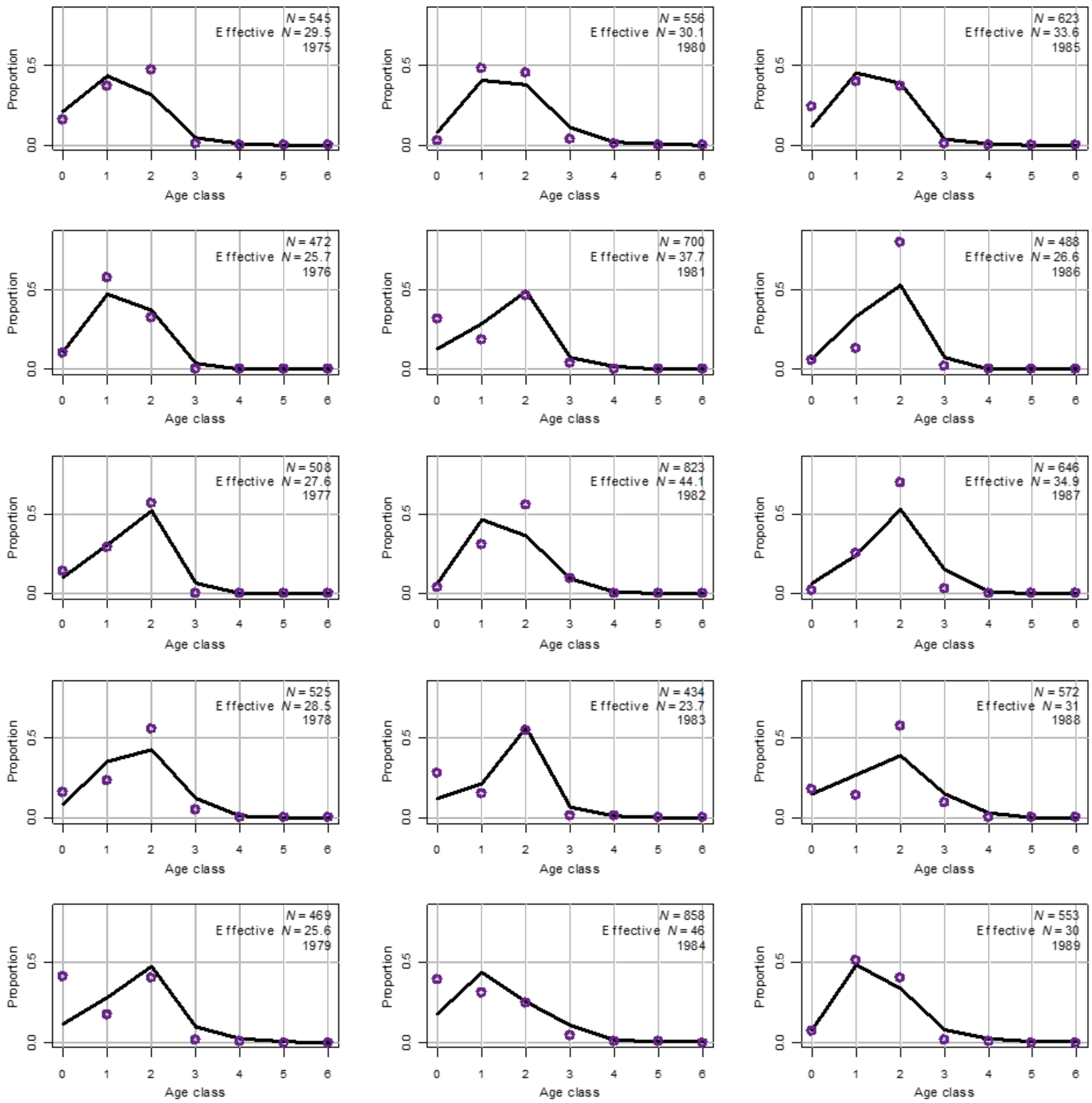

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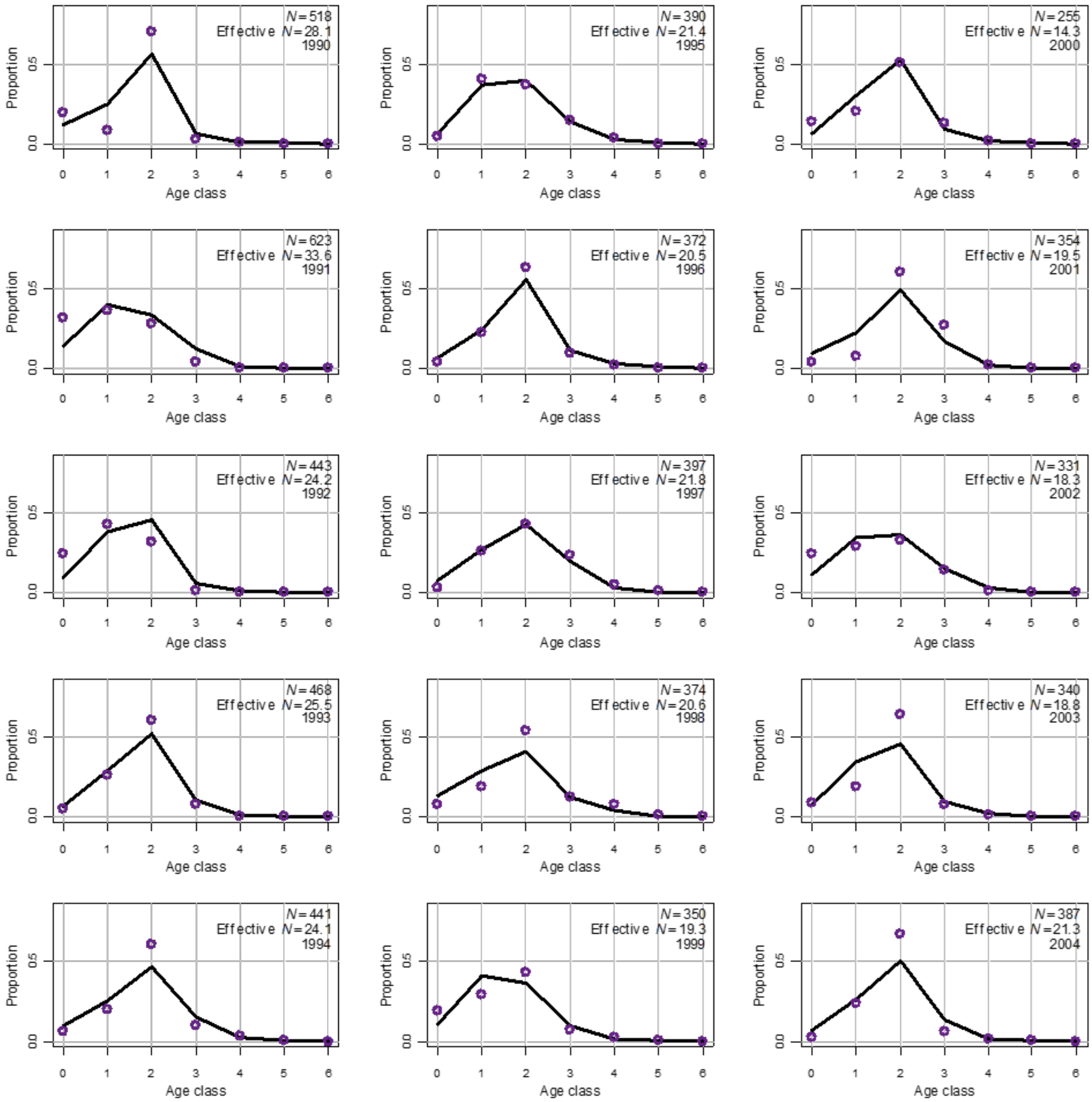

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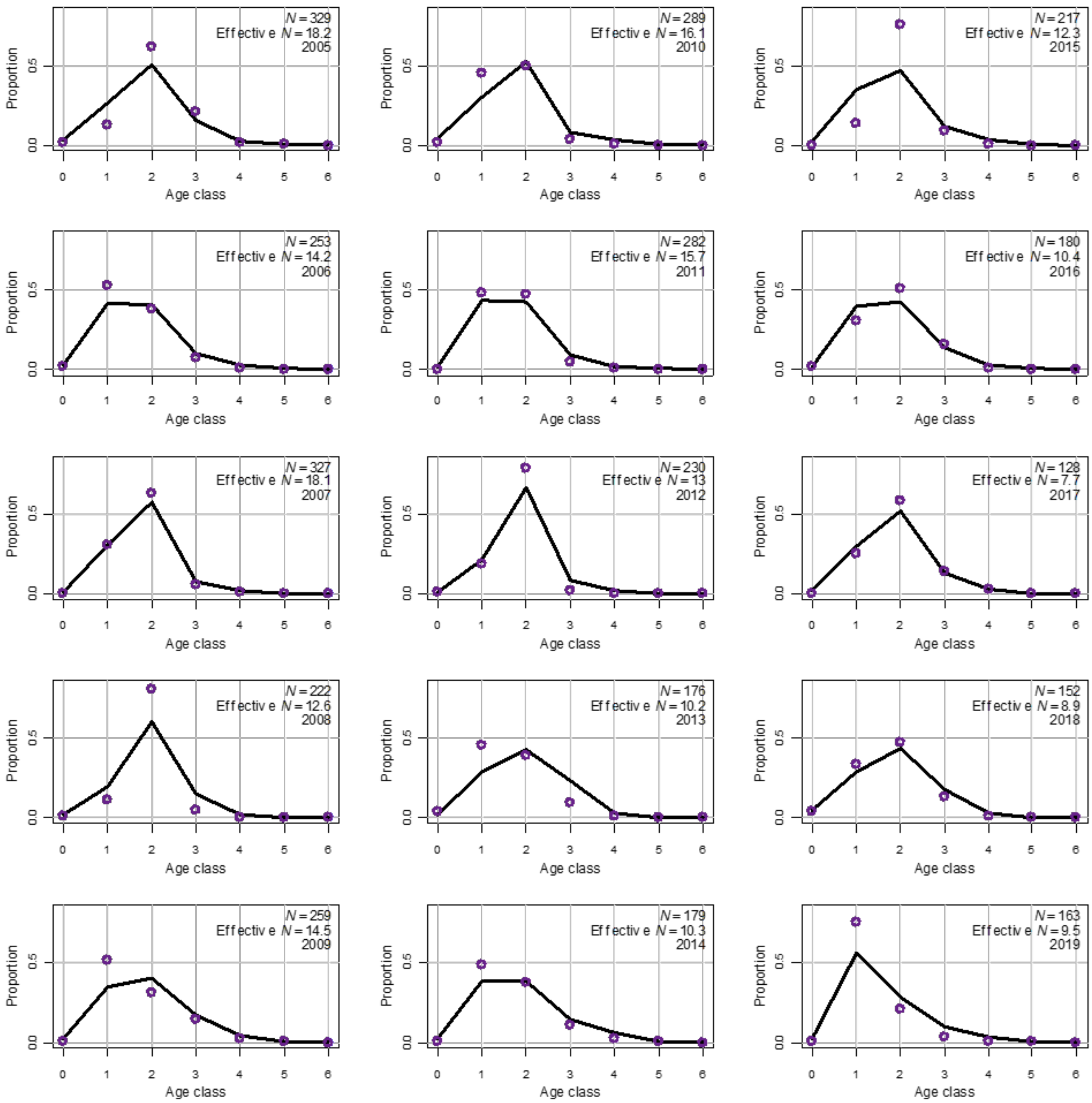

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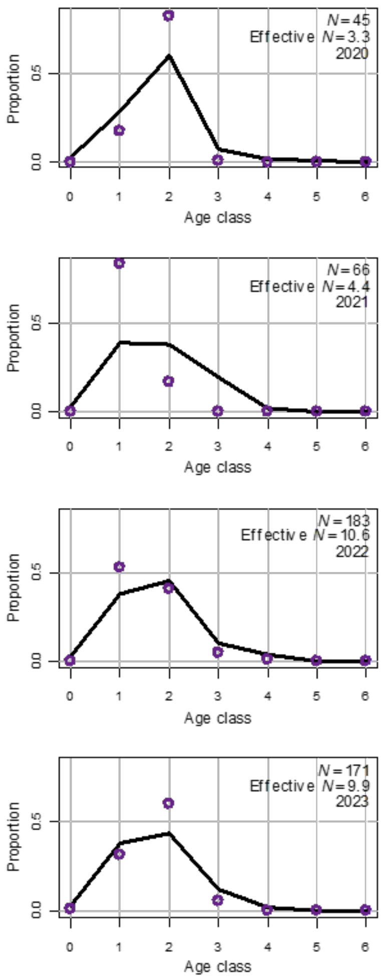

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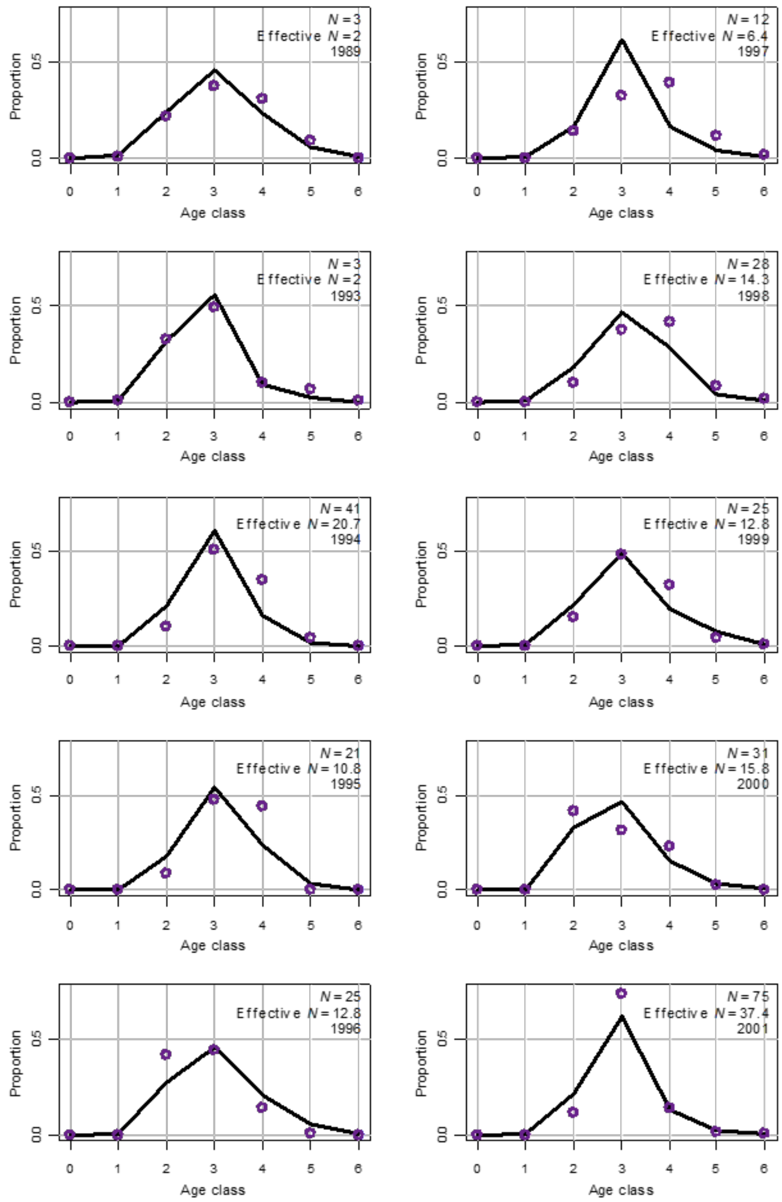

Figure A15. Annual age composition plots for the commercial bait north fleet for 1985-2023. Open circles are the observed data, while the line indicates the model fit.

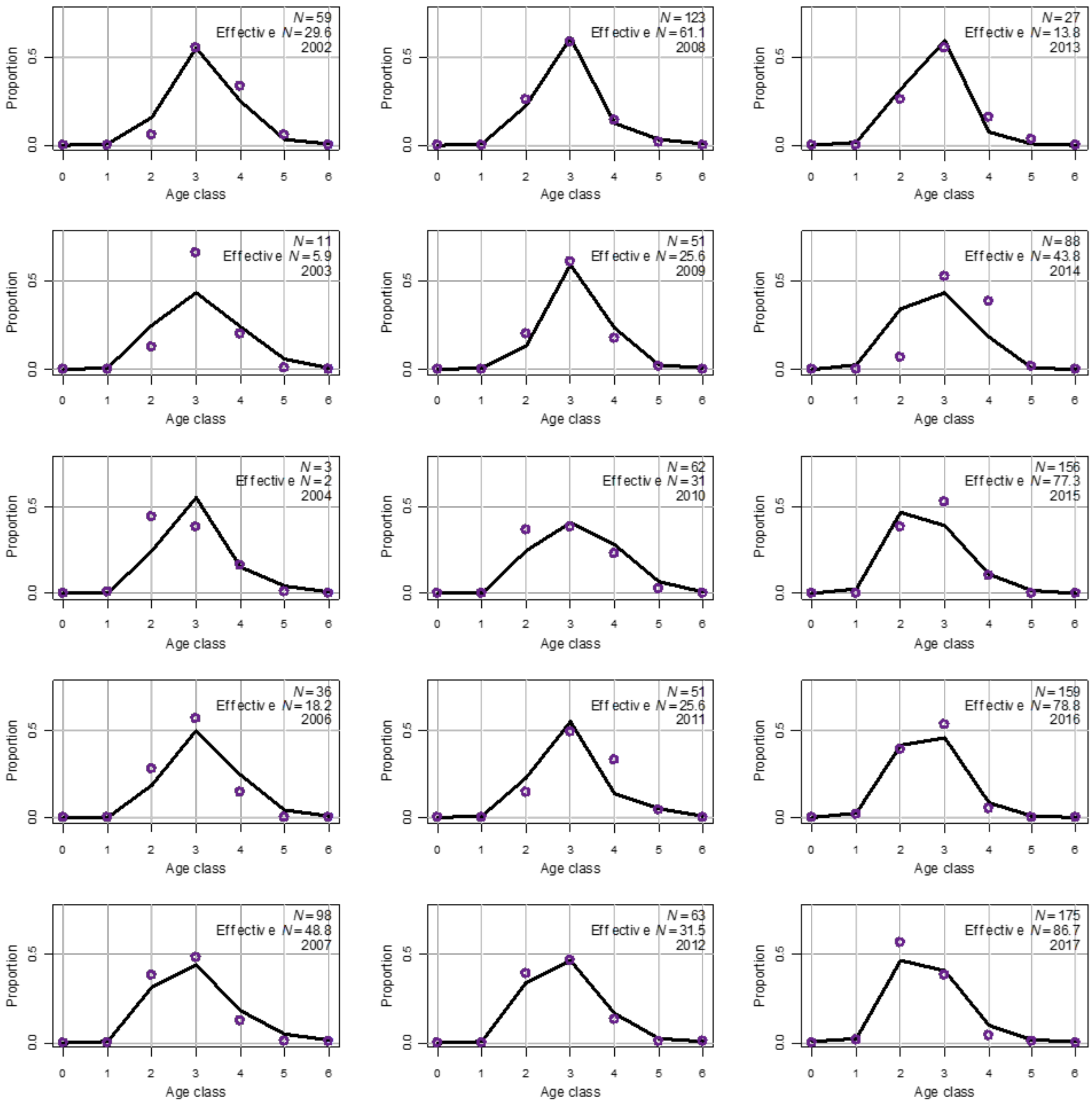

Figure A15. ***Continued***

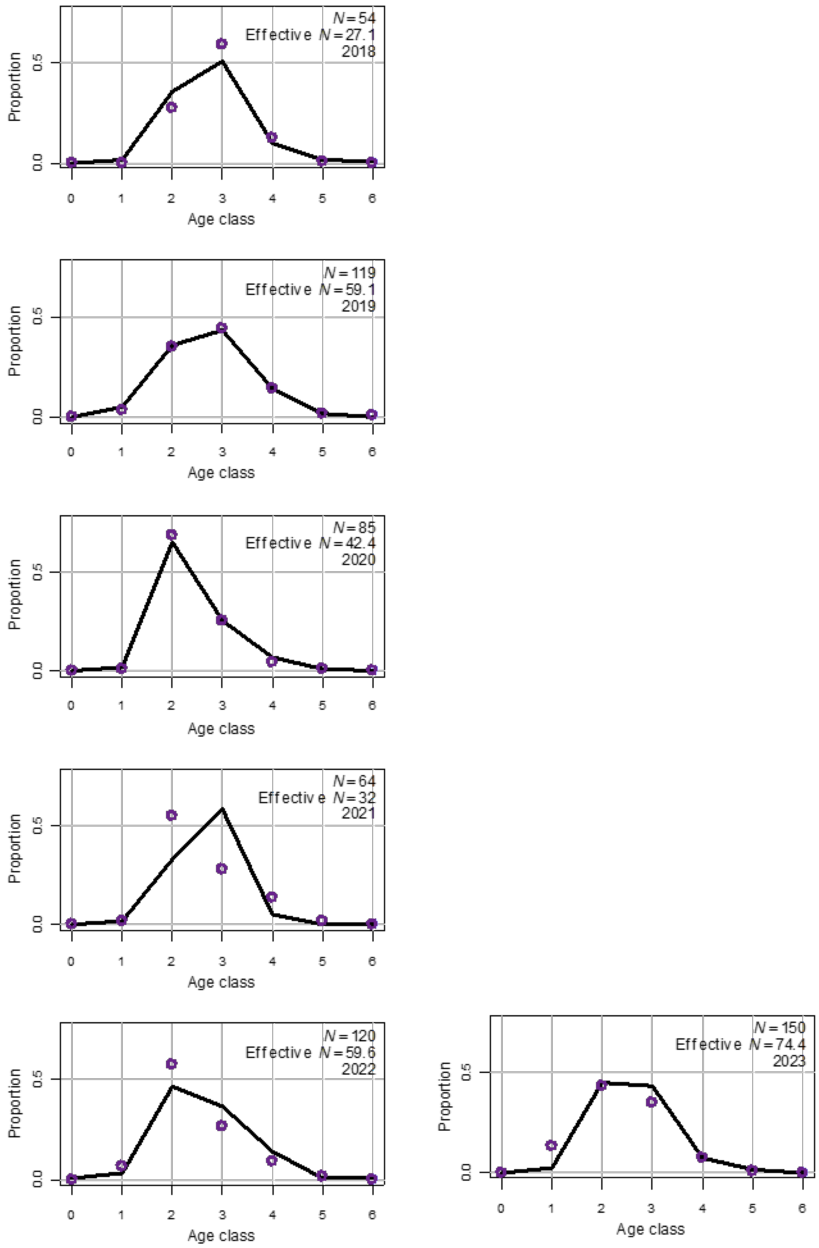

Figure A15. *Continued*

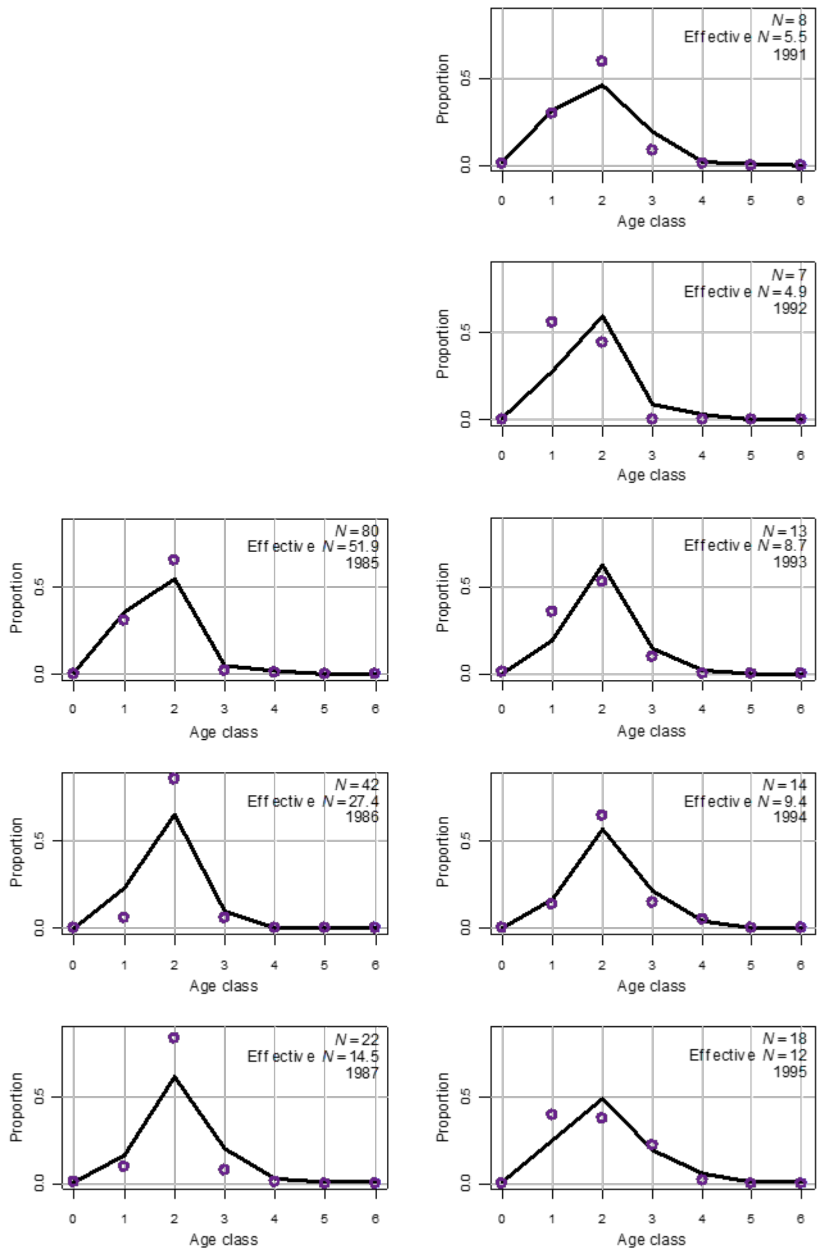

Figure A16. **Annual age composition plots for the commercial bait south fleet for 1985-2023. Open circles are the observed data, while the line indicates the model fit.**

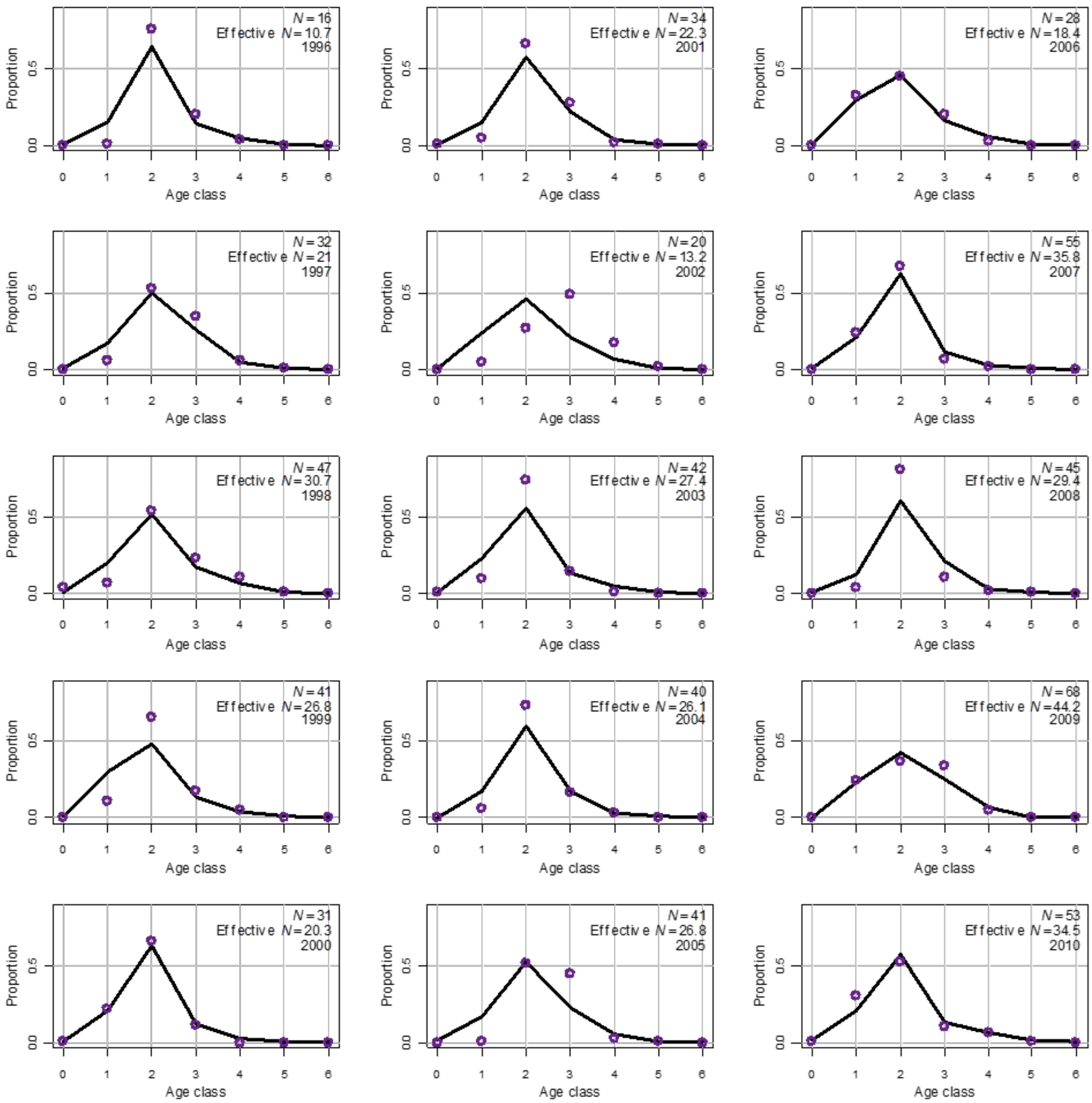

Figure A16. ***Continued***

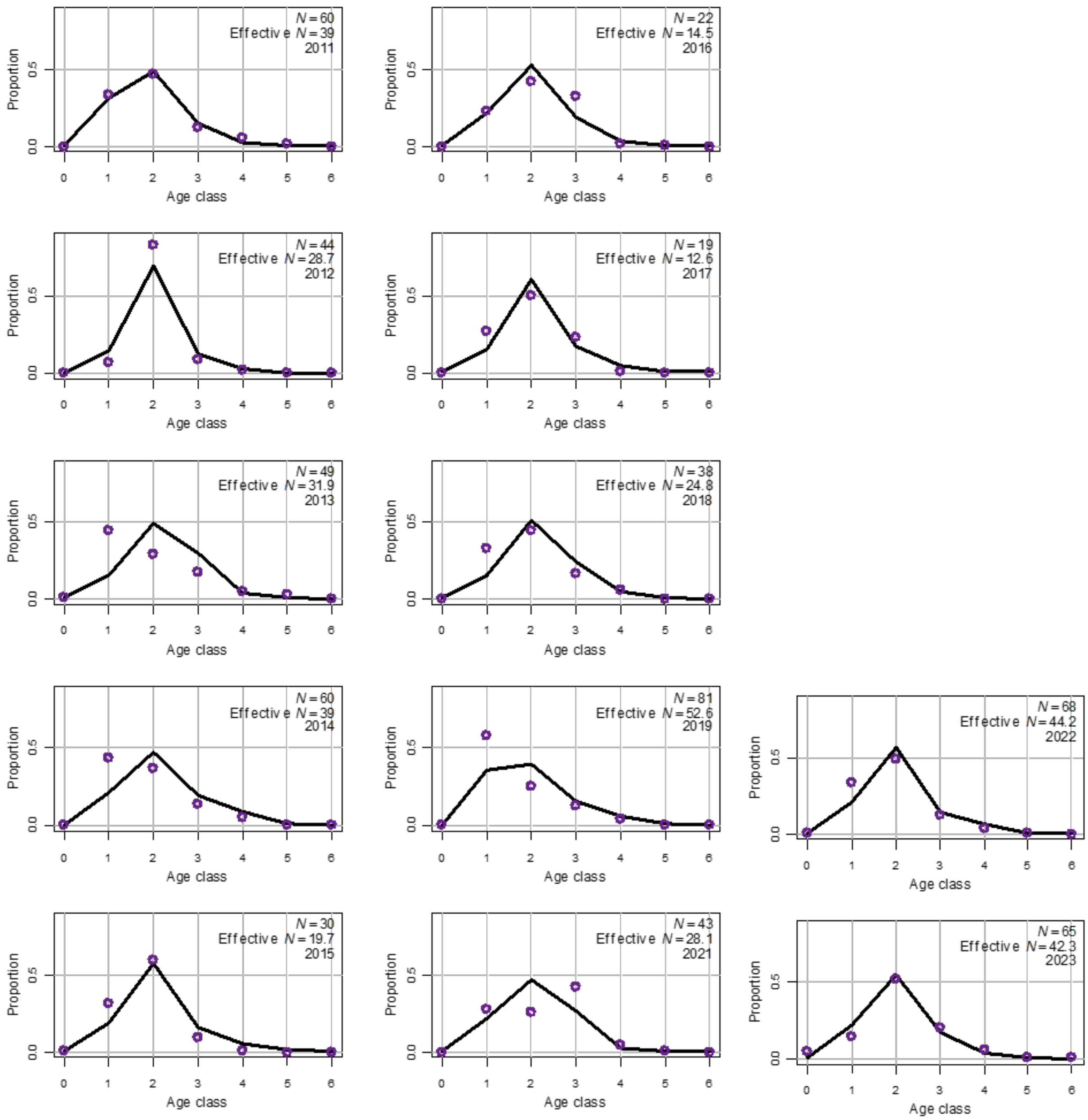

Figure A16. *Continued*

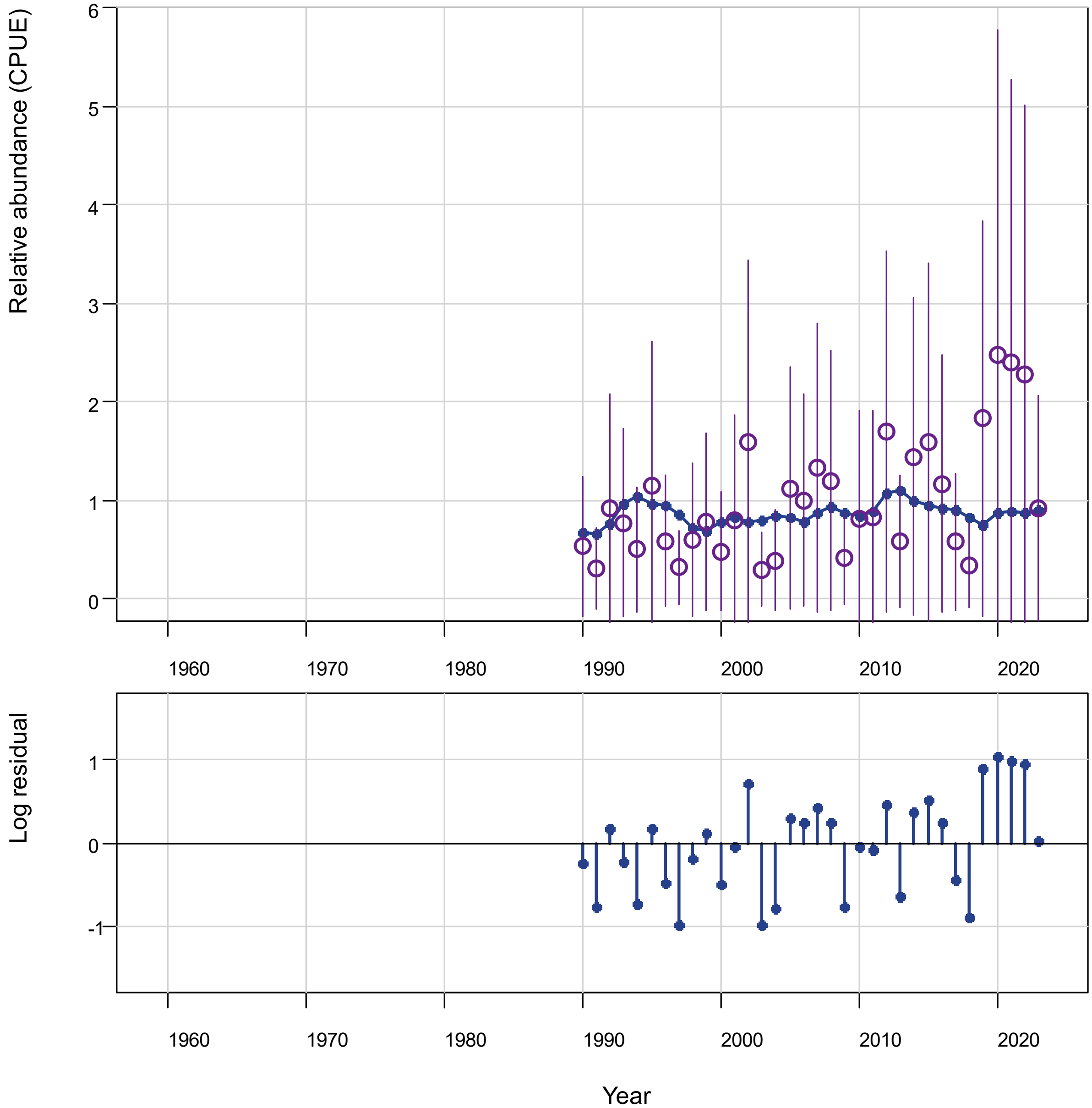

Figure A17. **Predicted fit (blue, closed circle with line) to the observed (open circle) NAD index. The lower panel indicates the residual for each data point.**

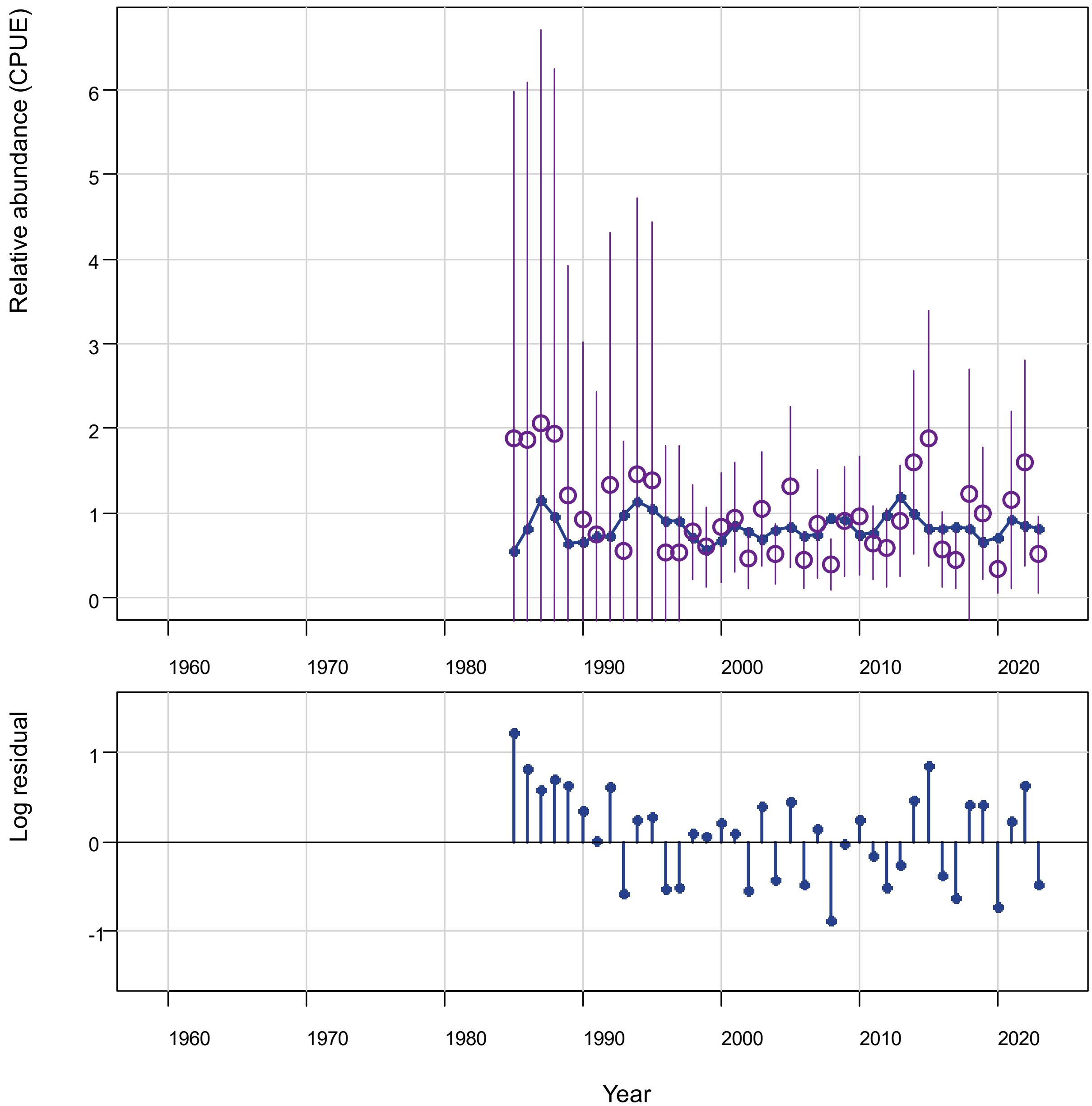

Figure A18. **Predicted fit (blue, closed circle with line) to the observed (open circle) MAD index. The lower panel indicates the residual for each data point.**

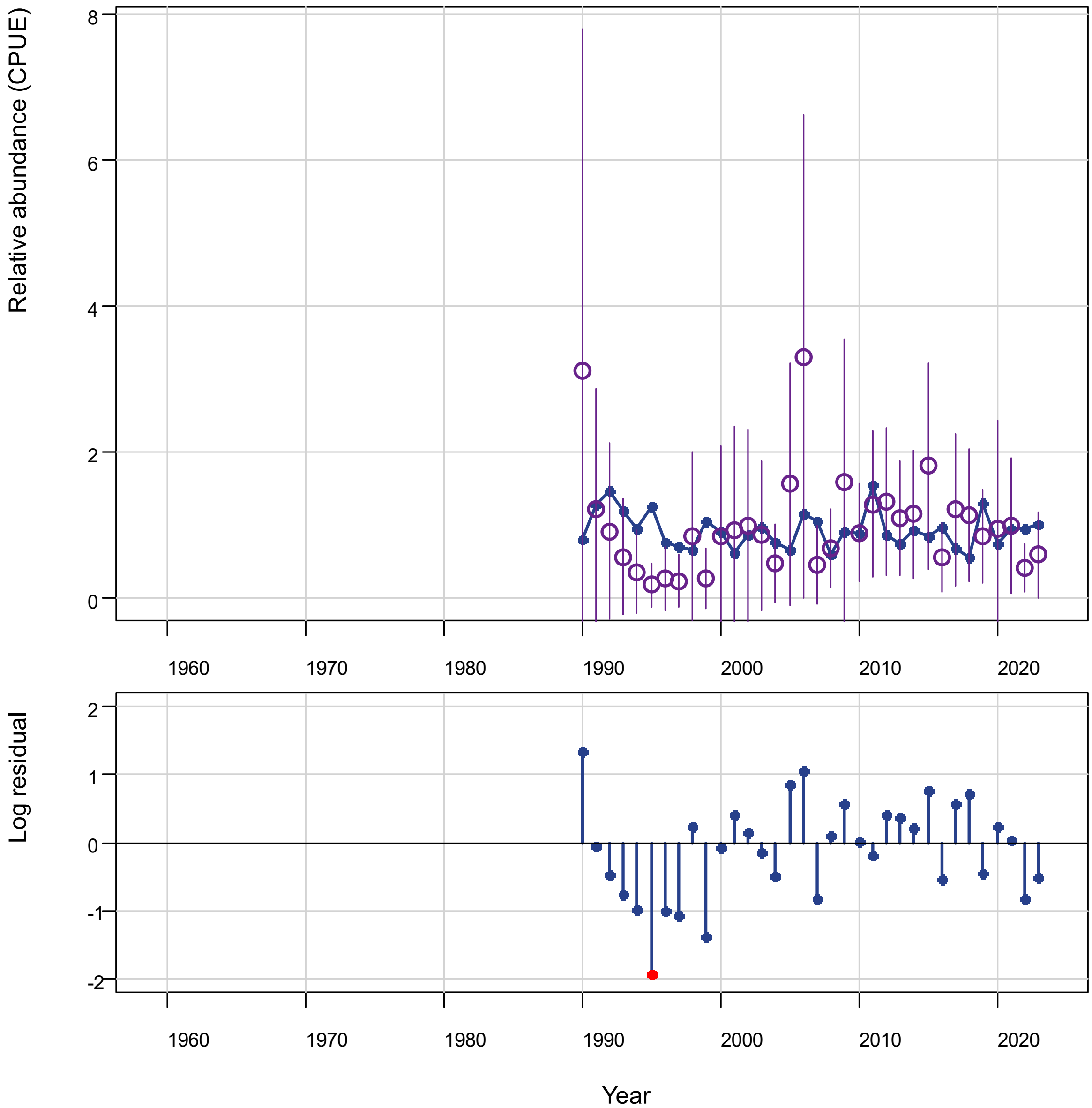

Figure A19. **Predicted fit (blue, closed circle with line) to the observed (open circle) SAD index. The lower panel indicates the residual for each data point.**

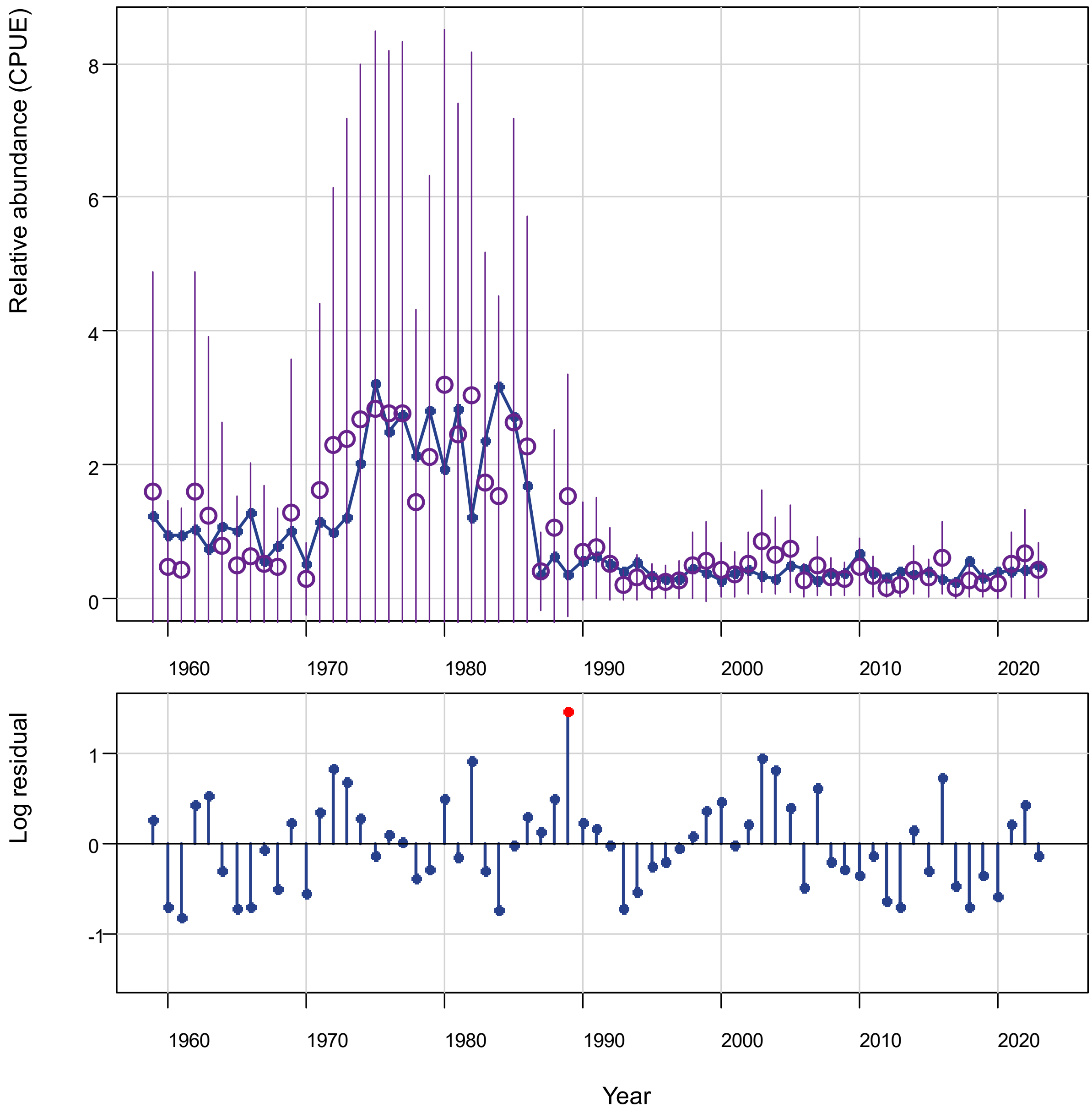

Figure A20. Predicted fit (blue, closed circle with line) to the observed (open circle) recruitment index. The lower panel indicates the residual for each data point.

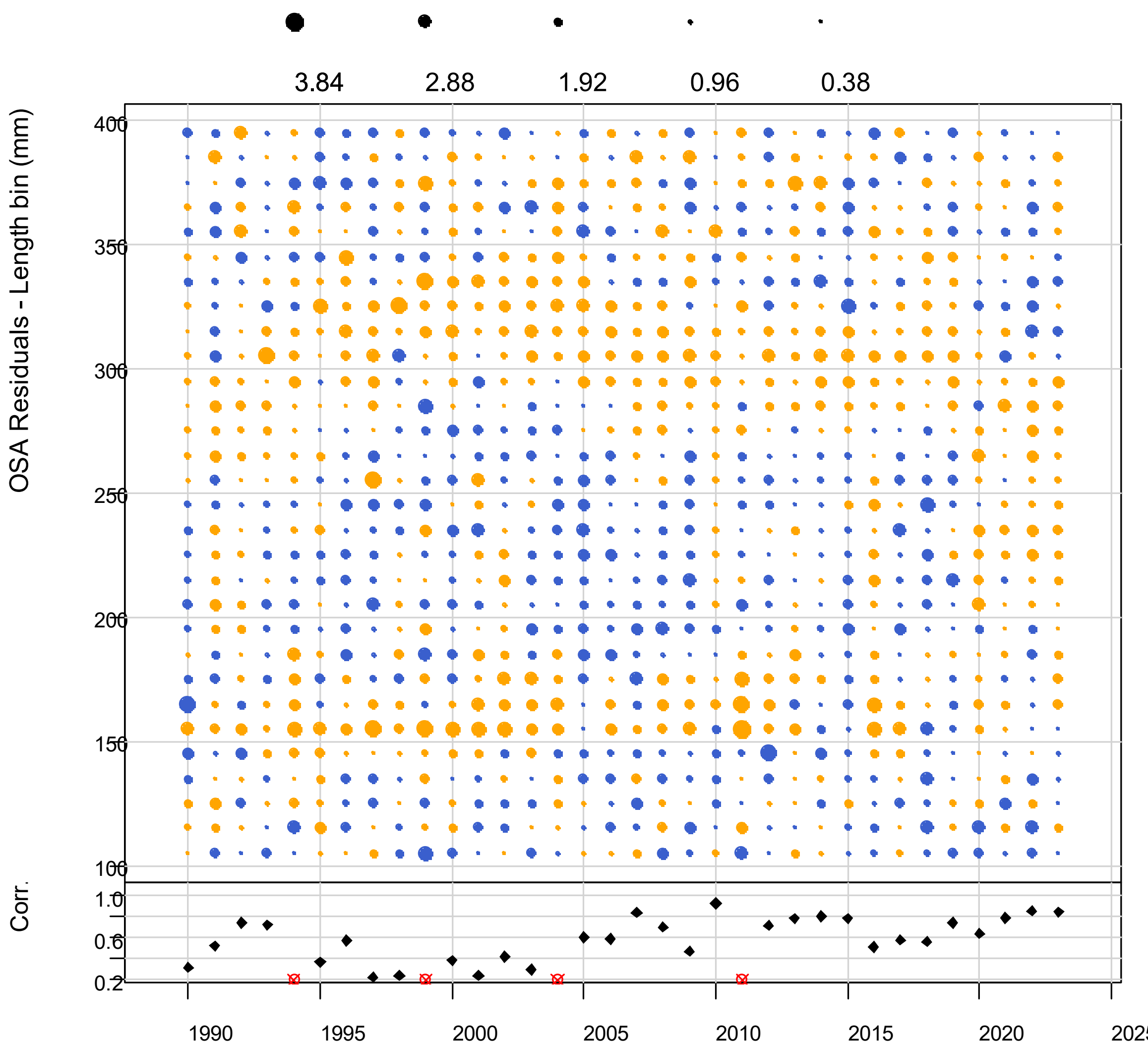

Figure A21. **Bubble plot of the fits to the length compositions for the NAD index. Orange indicates an underestimate, while blue indicates an overestimate. OSA is one step ahead residuals. The bottom panel indicates the correlation between the observed data and the model prediction.**

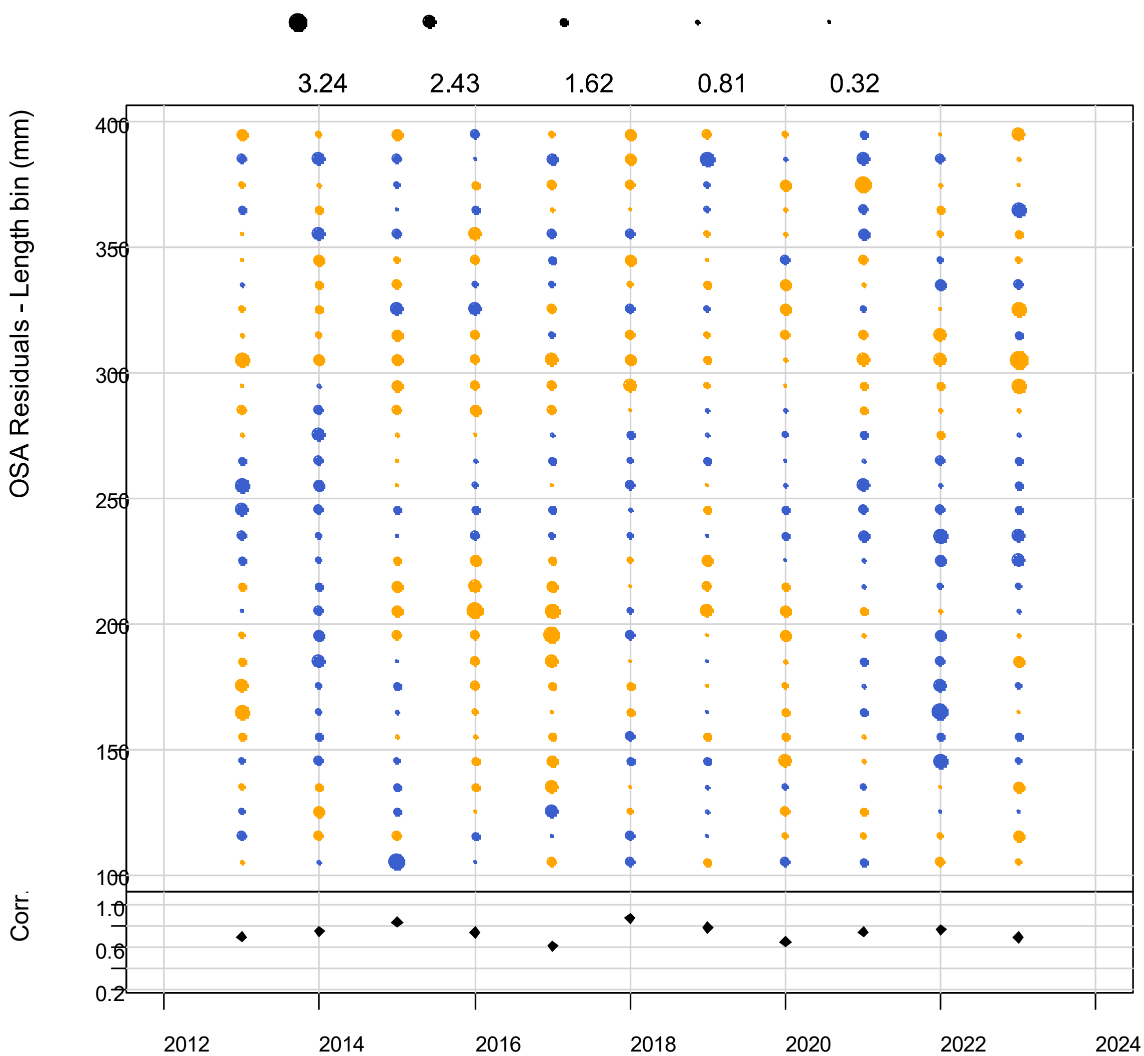

Figure A22. **Bubble plot of the fits to the length compositions for the MAD index. Orange indicates an underestimate, while blue indicates an overestimate. OSA is one step ahead residuals. The bottom panel indicates the correlation between the observed data and the model prediction.**

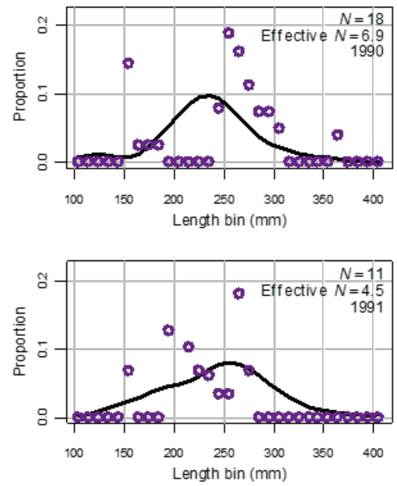

Figure A23. Annual length composition plots for the NAD index for 1990-2023. Open circles are the observed data, while the line indicates the model fit. Continued on the following pages.

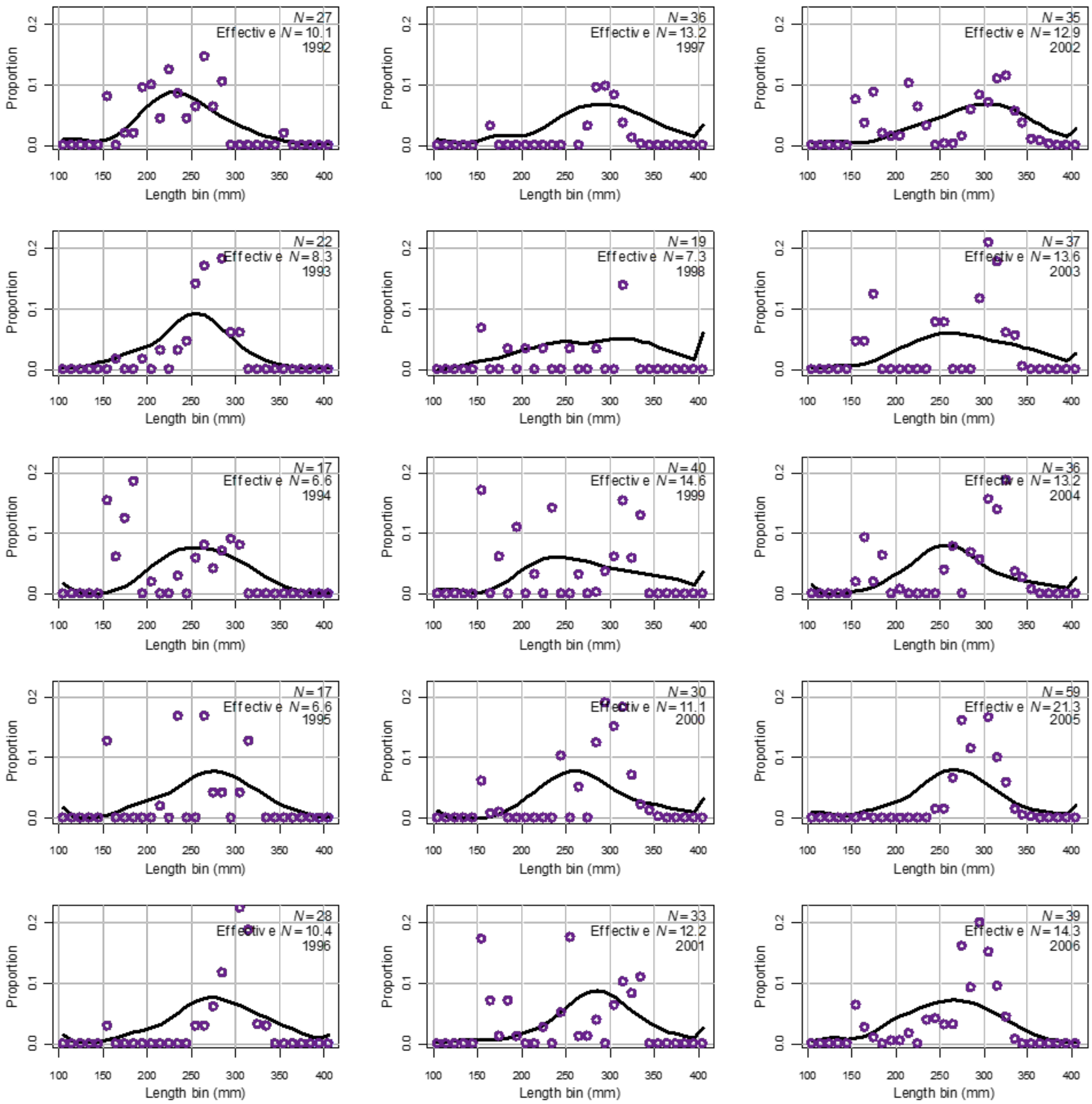

Figure A23. ***Continued***

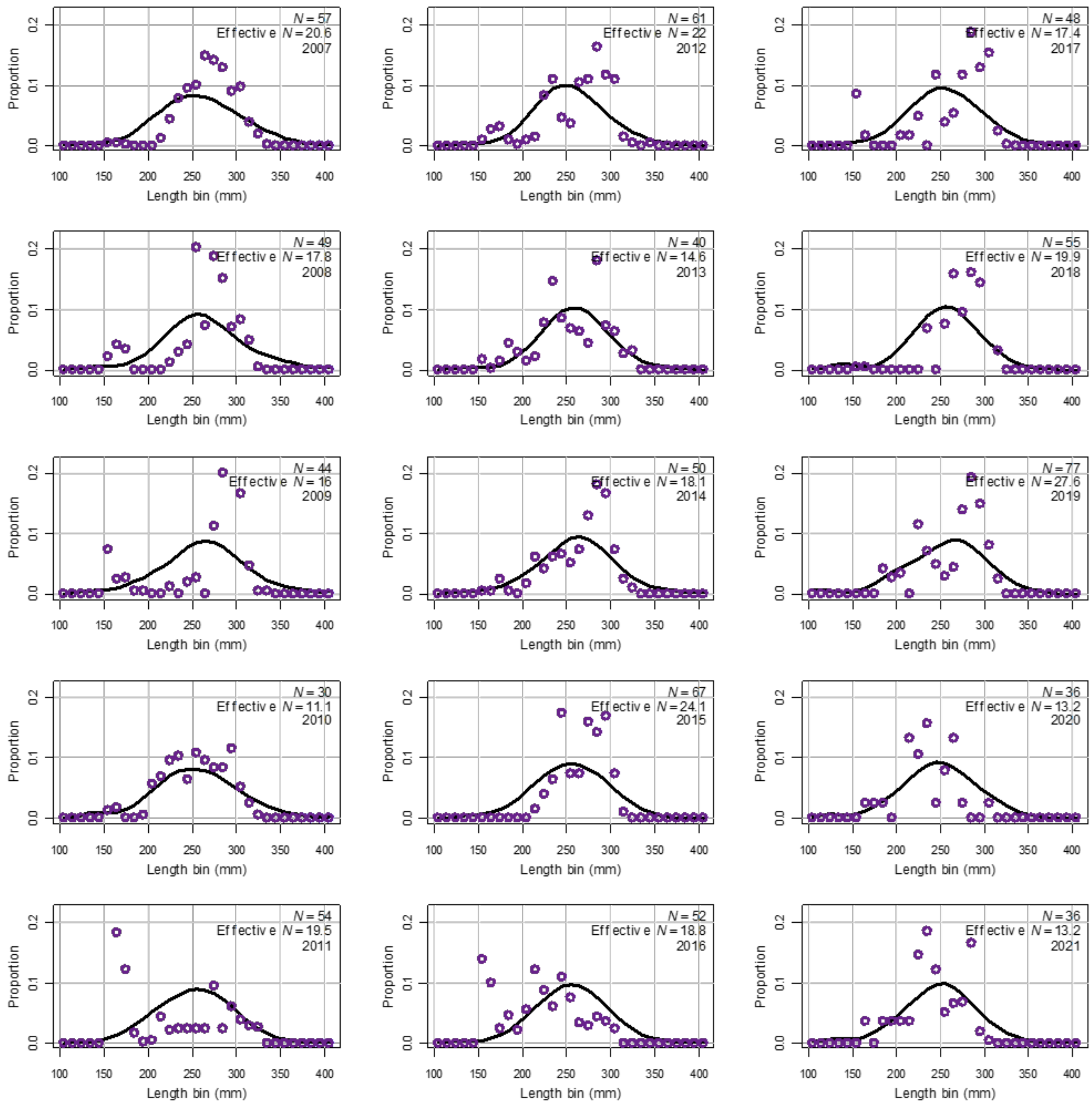

Figure A23. ***Continued***

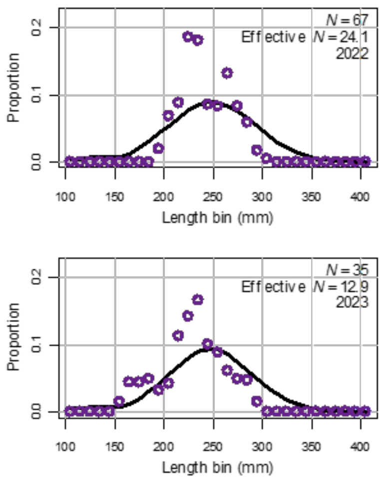

Figure A23. *Continued*

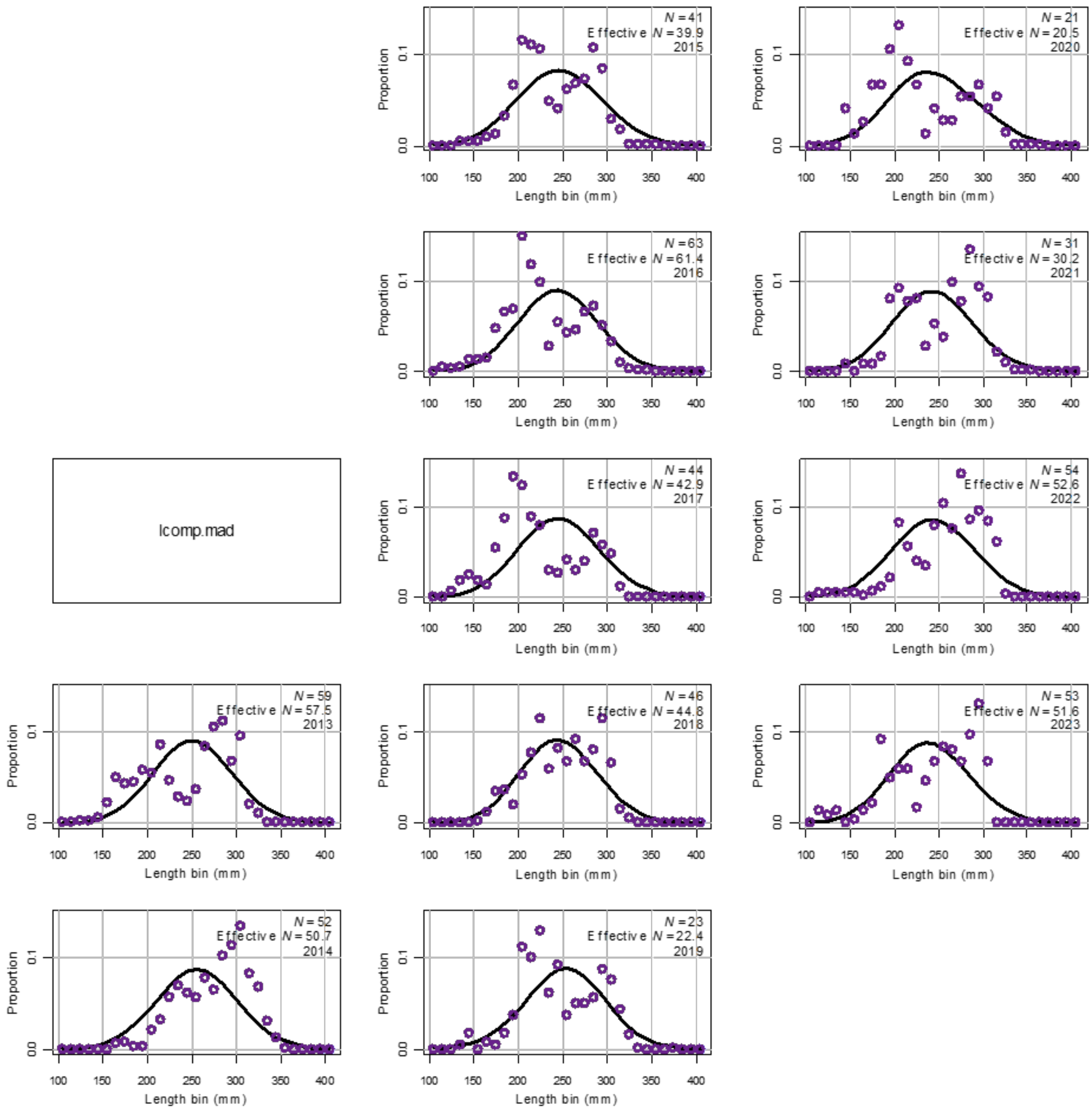

Figure A24. Annual length composition plots for the MAD index for 2013-2023. Open circles are the observed data, while the line indicates the model fit.

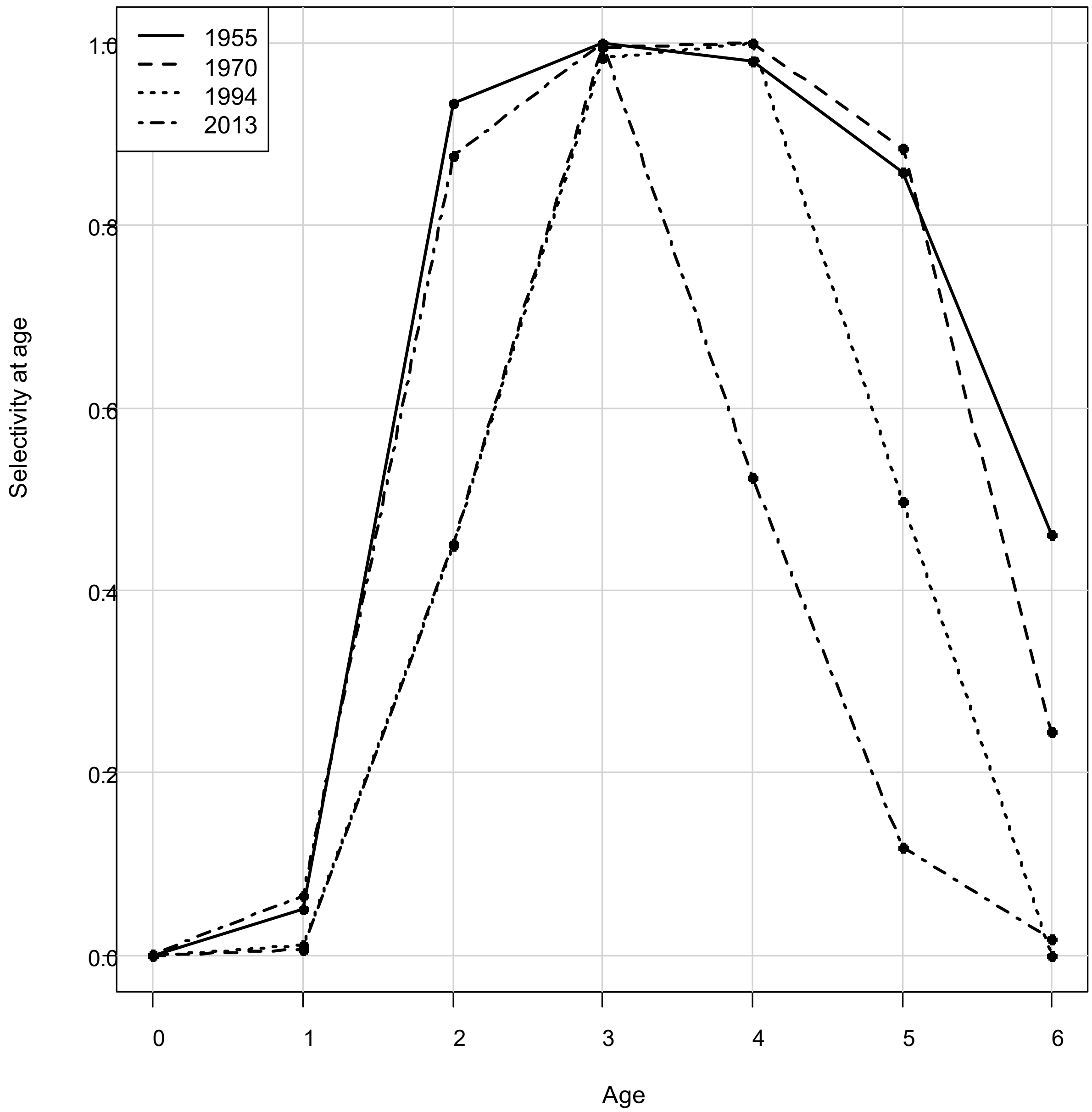

Figure A25. **Estimated selectivity of the northern commercial reduction landings for 1955-1969, 1970-1993, 1994-2012, and 2013-2023.**

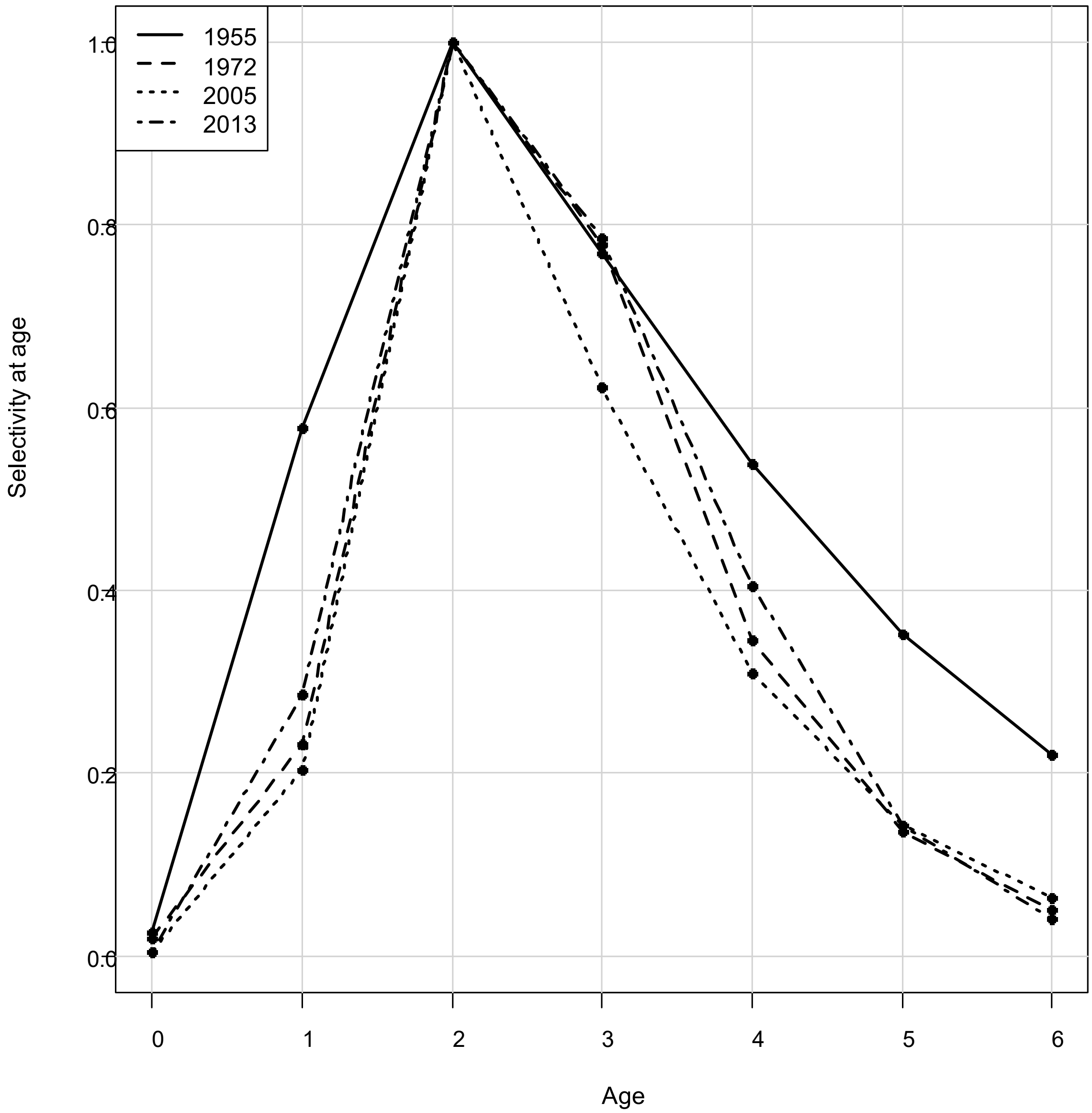

Figure A26. Estimated selectivity of the southern commercial reduction landings for 1955-1971, 1972-2004, 2005-2012, and 2013-2023.

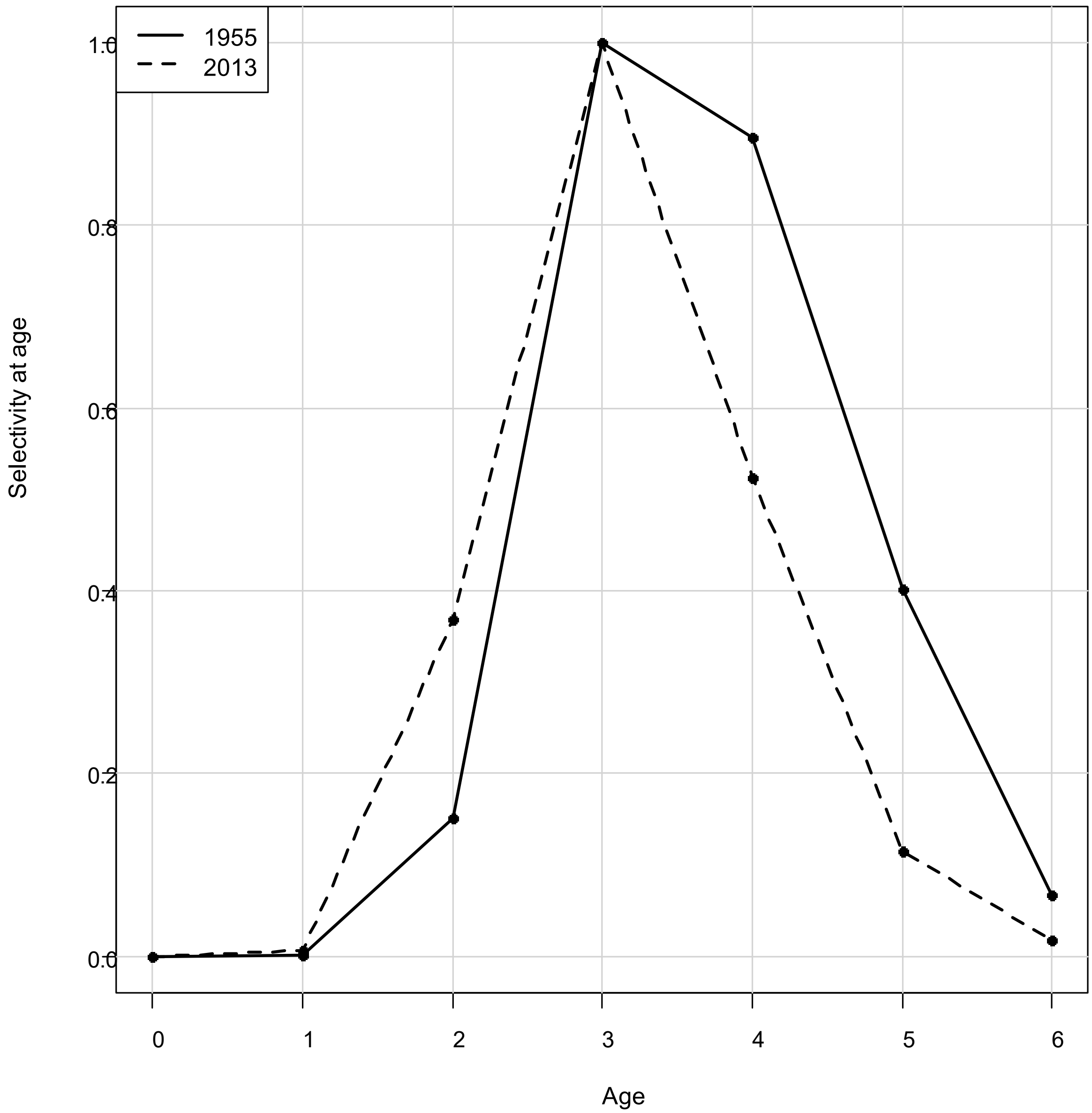

Figure A27. **Estimated selectivity of the northern commercial bait landings for 1955-2012 and 2013-2023.**

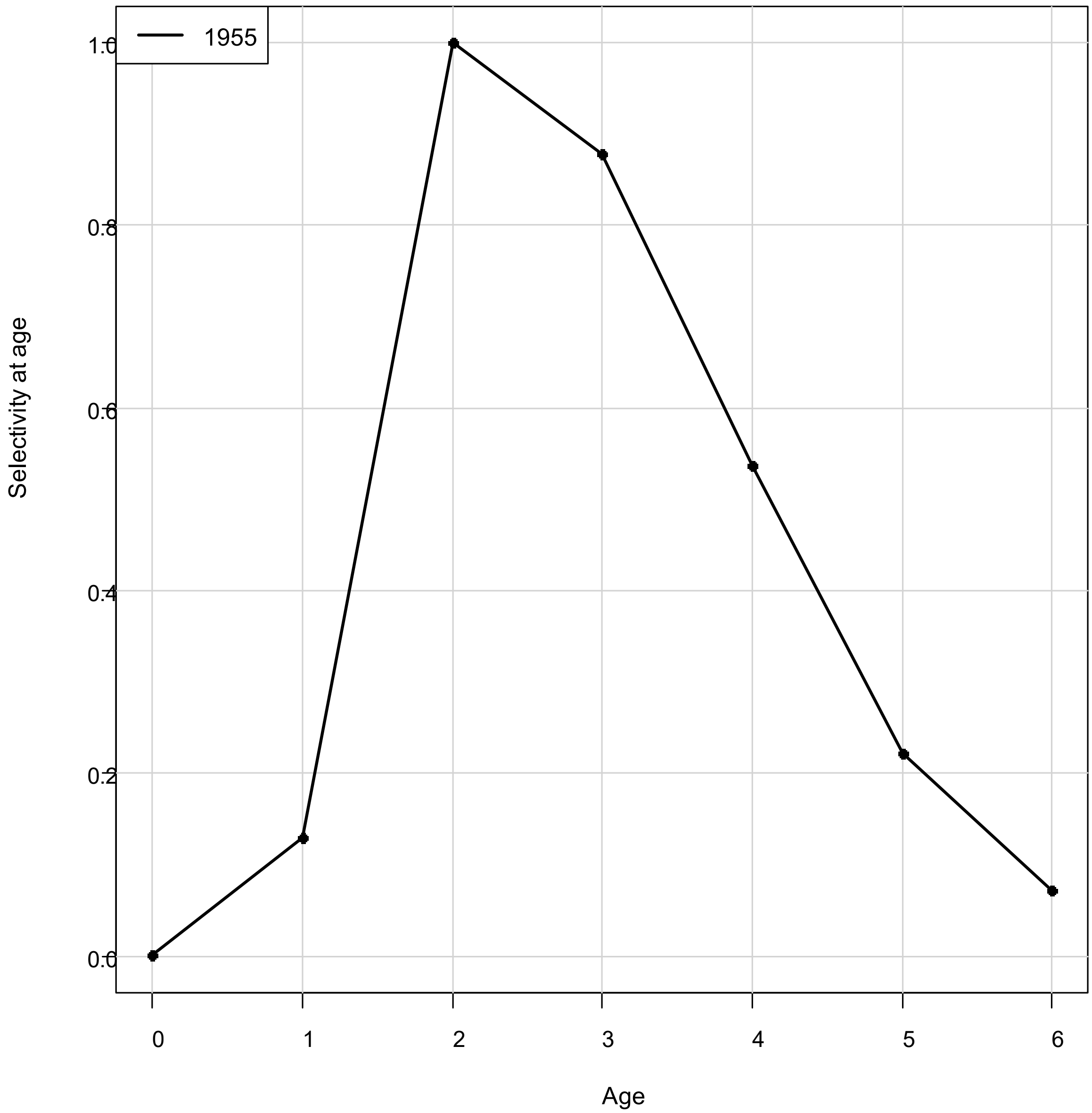

Figure A28. Estimated selectivity of the southern commercial bait landings for 1955-2023.

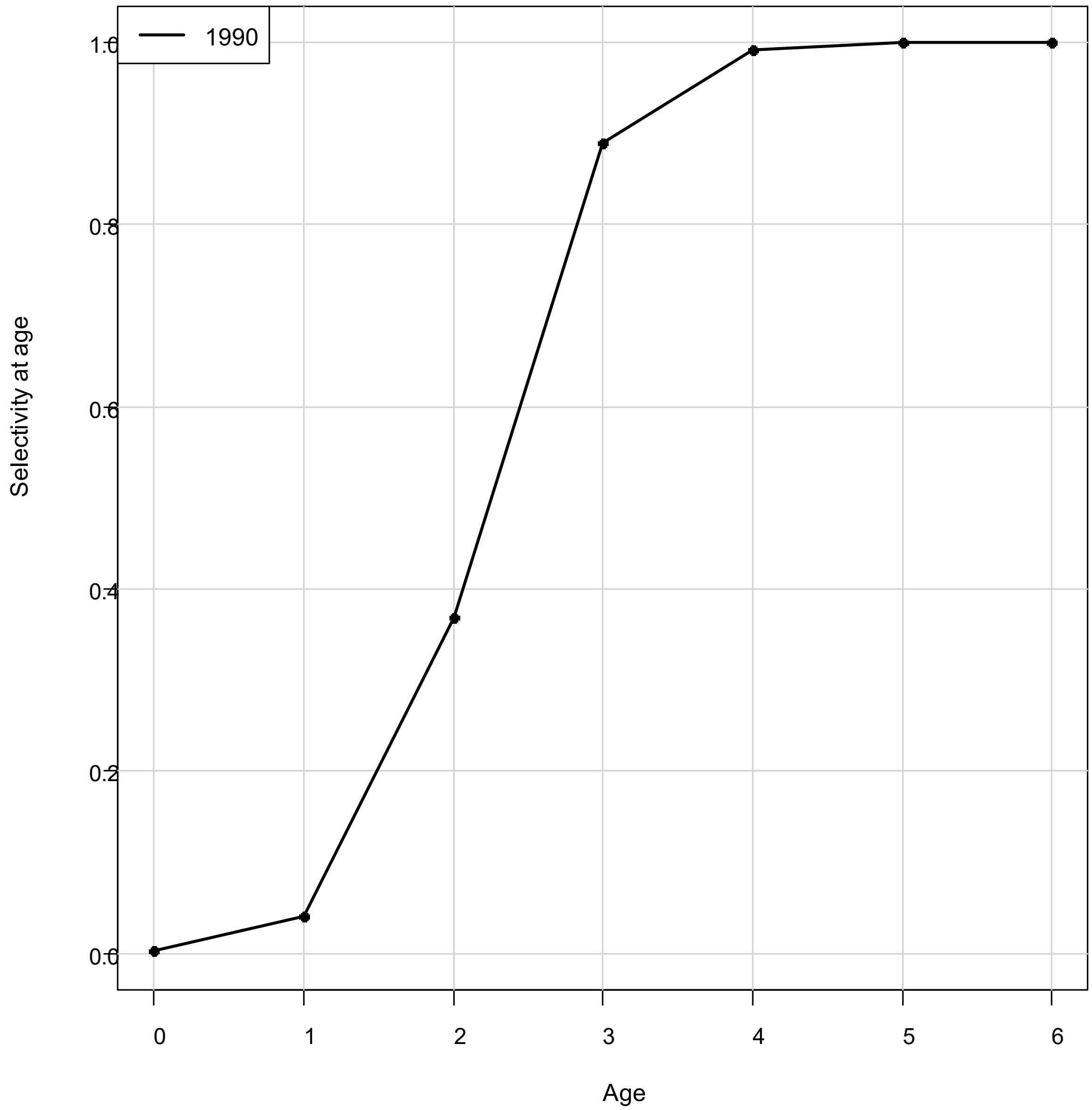

Figure A29. Estimated selectivity for the NAD index for 1990-2023.

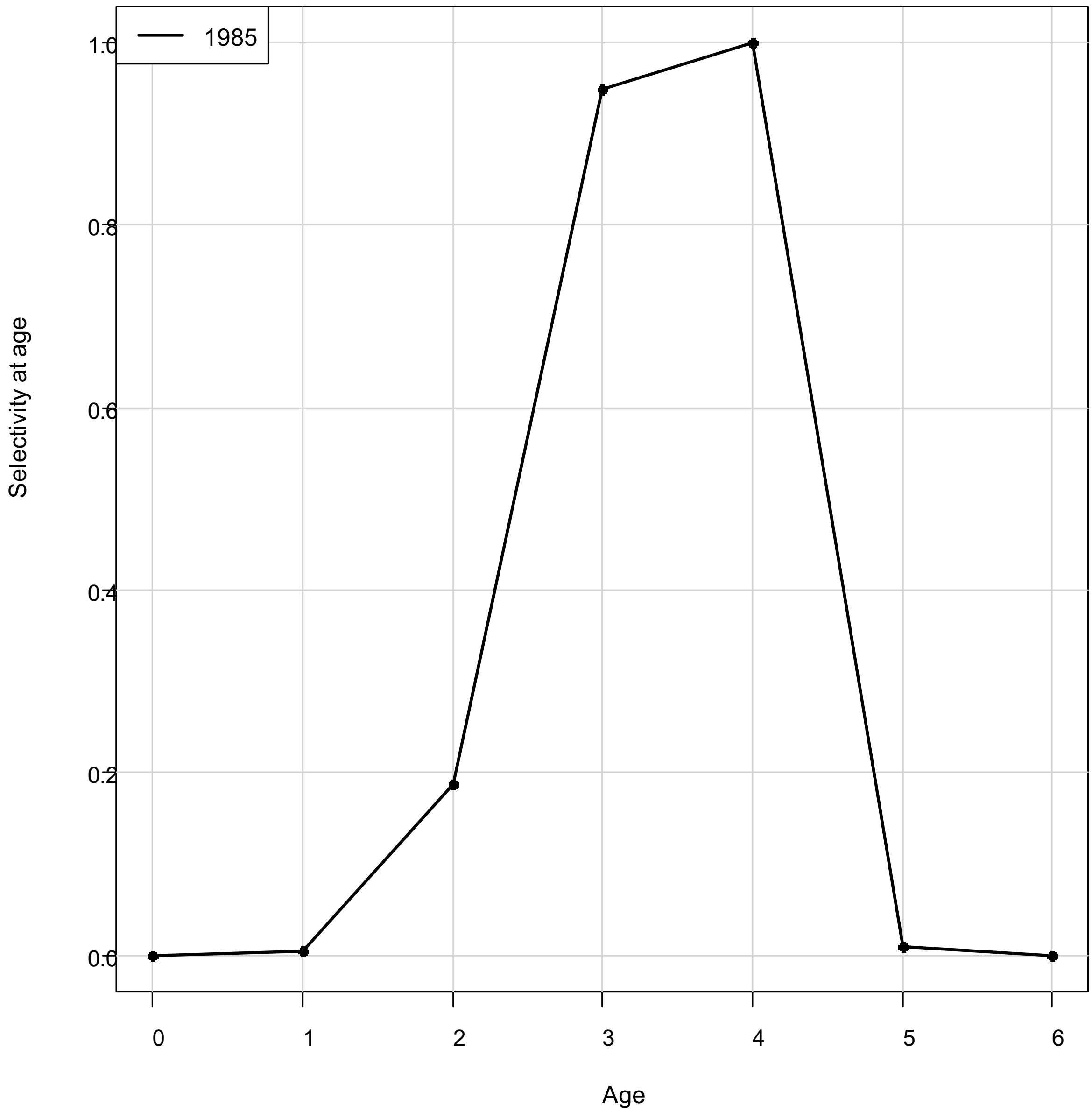

Figure A30. **Estimated selectivity for the MAD index for 1985-2023.**

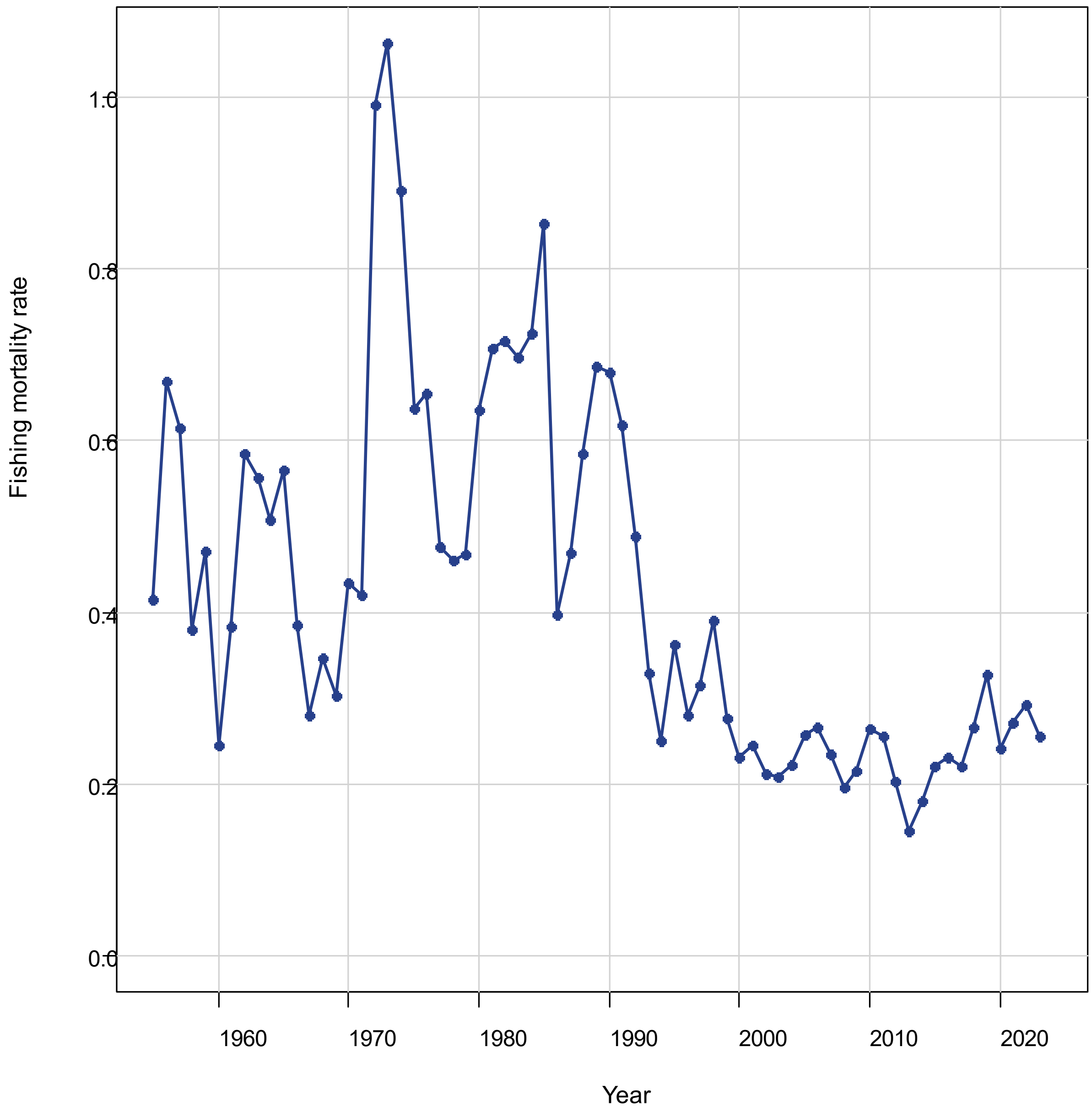

Figure A31. **The full fishing mortality rate for 1955-2023.**

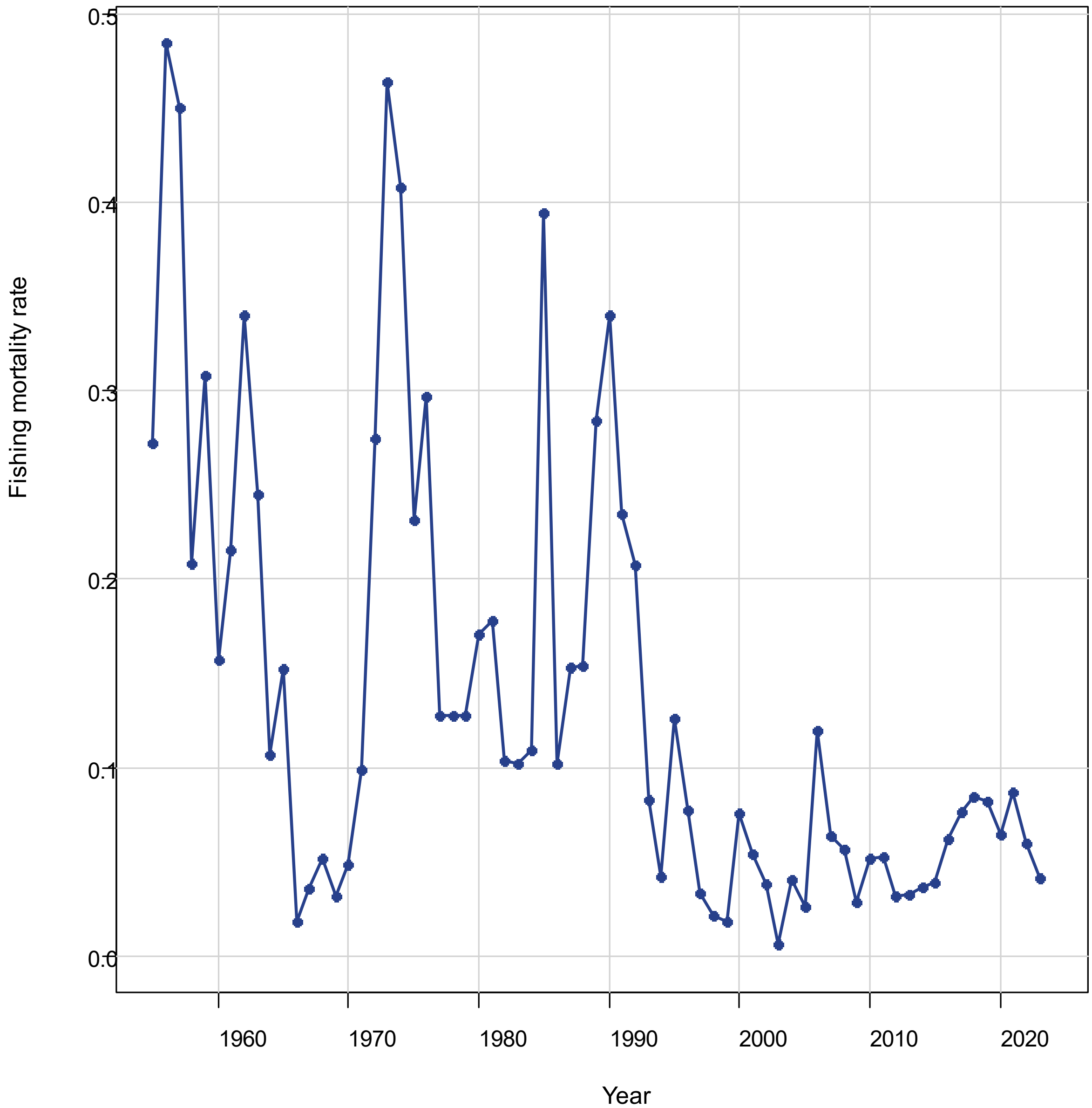

Figure A32. **The full fishing mortality rate for the commercial reduction north fleet for 1955-2023.**

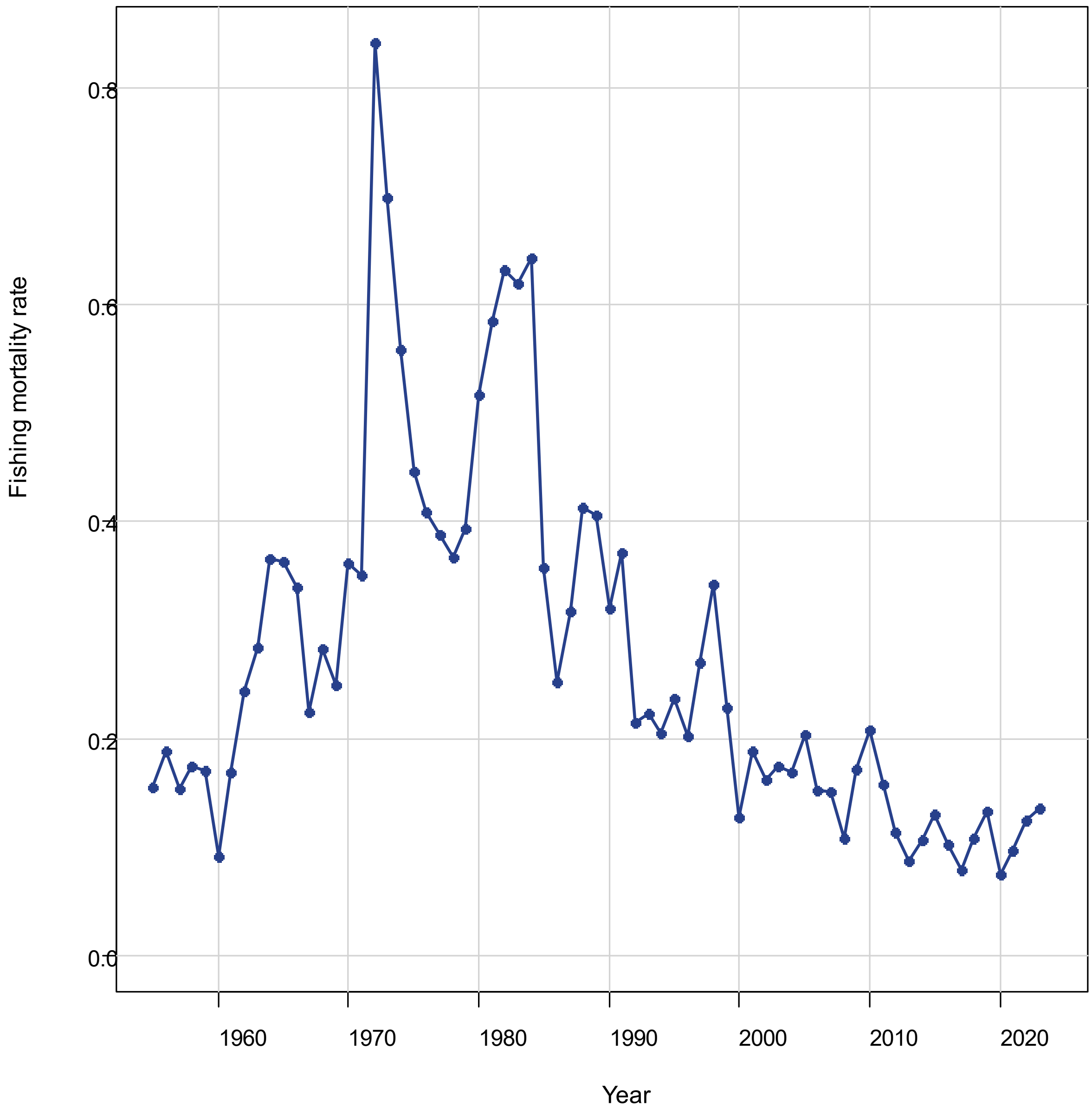

Figure A33. **The full fishing mortality rate for the commercial reduction south fleet for 1955-2023.**

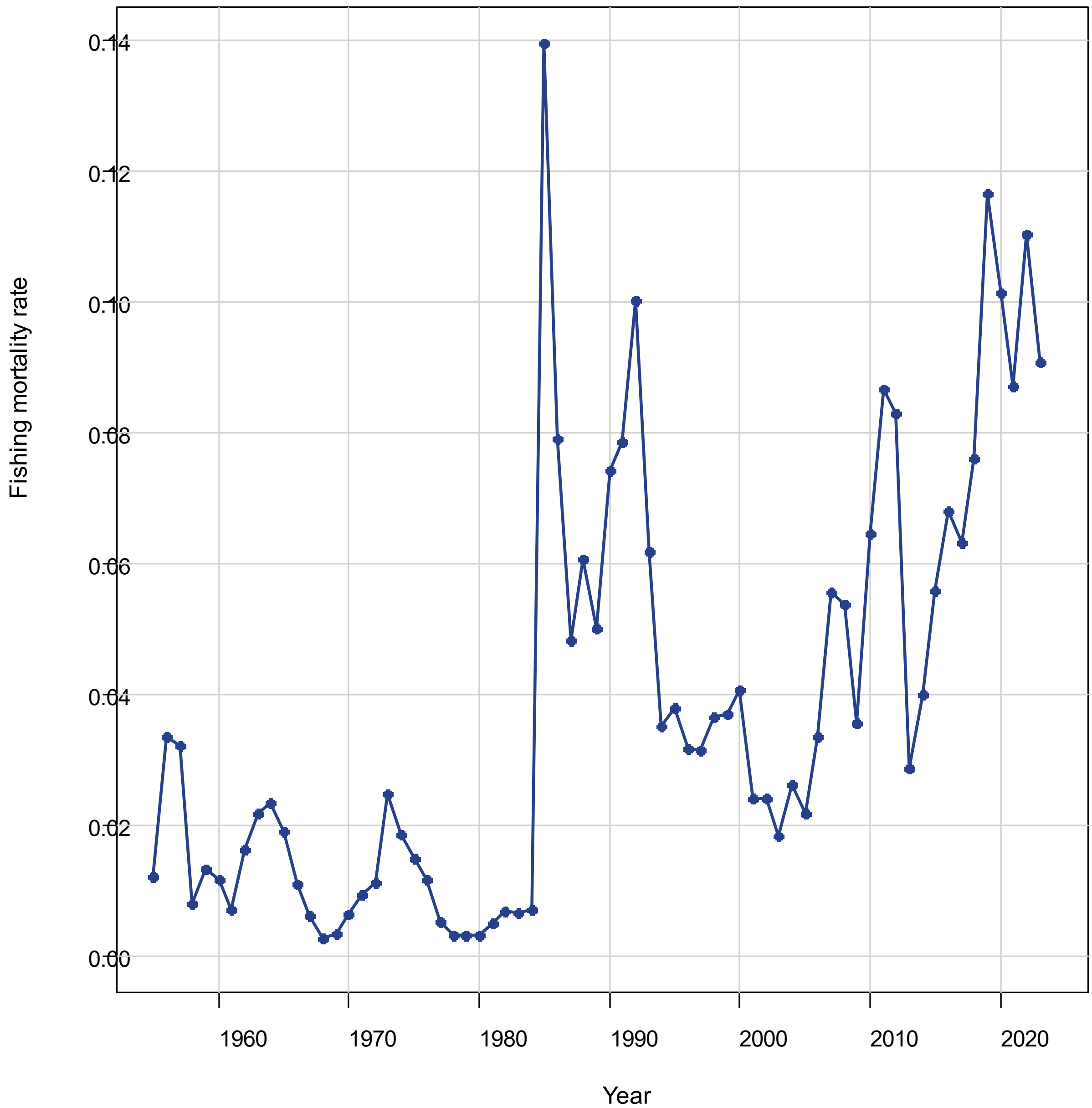

Figure A34. **The full fishing mortality rate for the commercial bait north fleet for 1955-2023.**

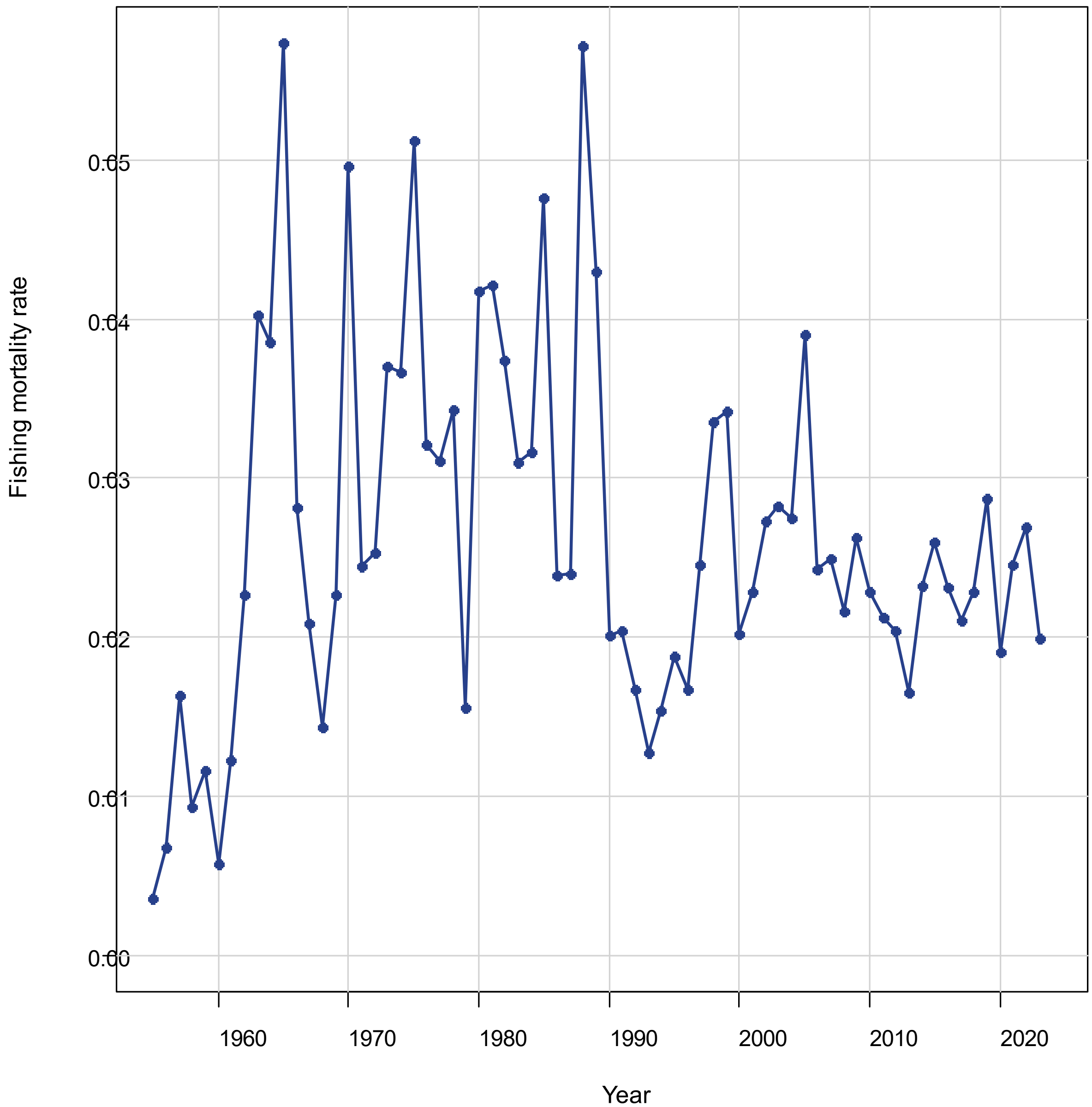

Figure A35. The full fishing mortality rate for the commercial bait south fleet for 1955-2023.

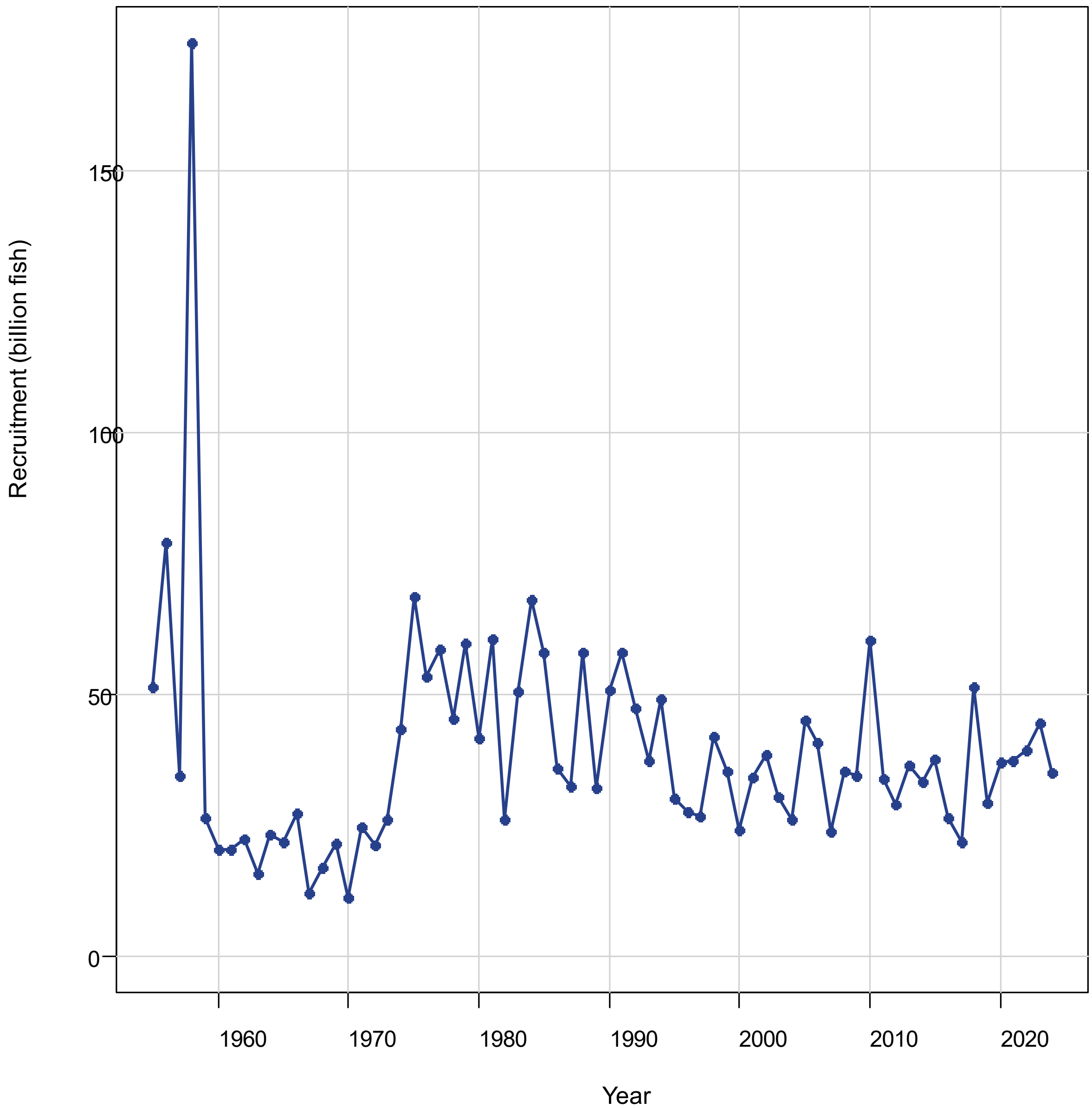

Figure A36. **The estimated time series of recruitment for 1955-2023. The 2024 point is a projected recruitment point.**

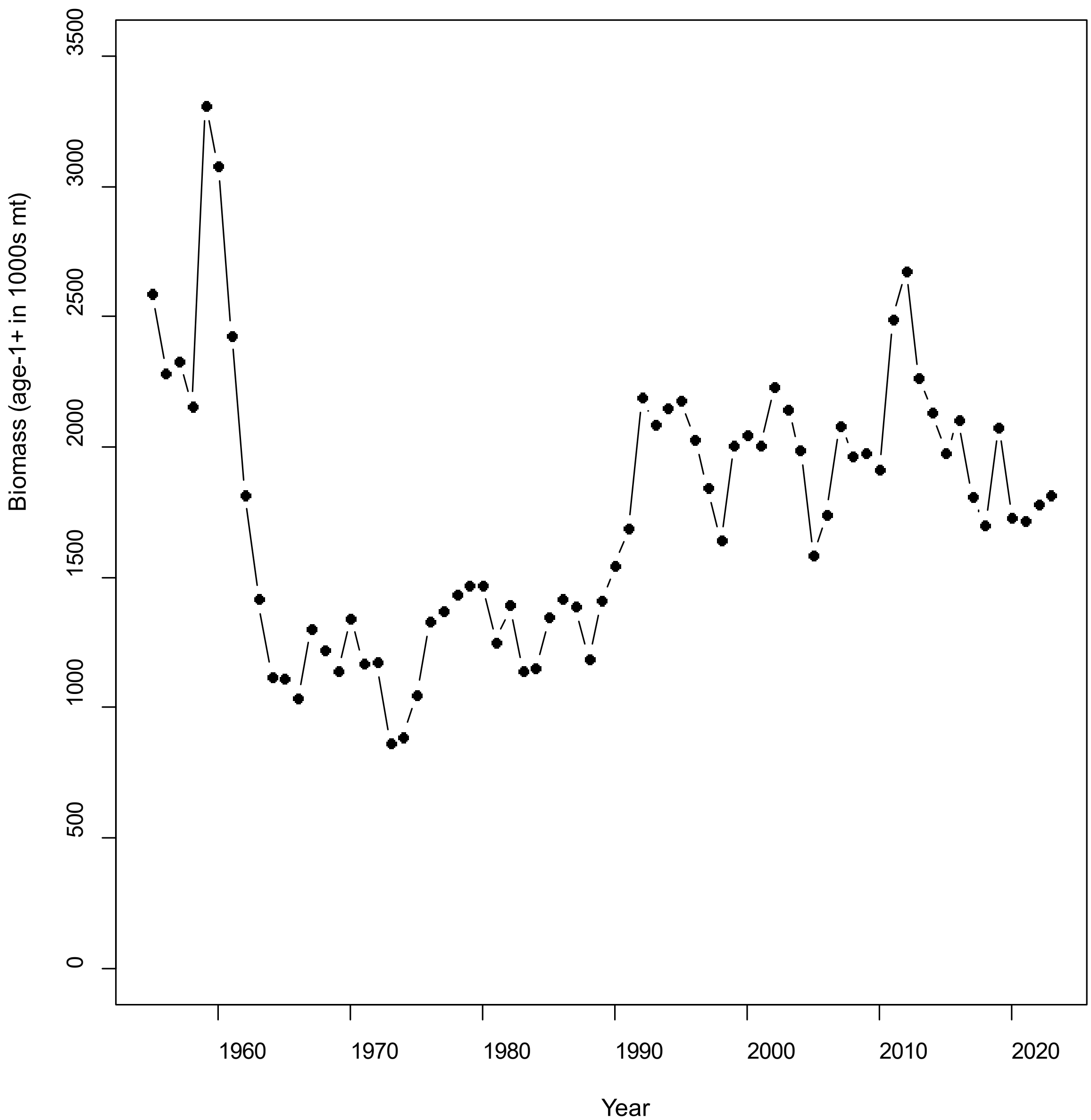

Figure A37. **Age-1+ biomass in 1000s of mt for 1955-2023.**

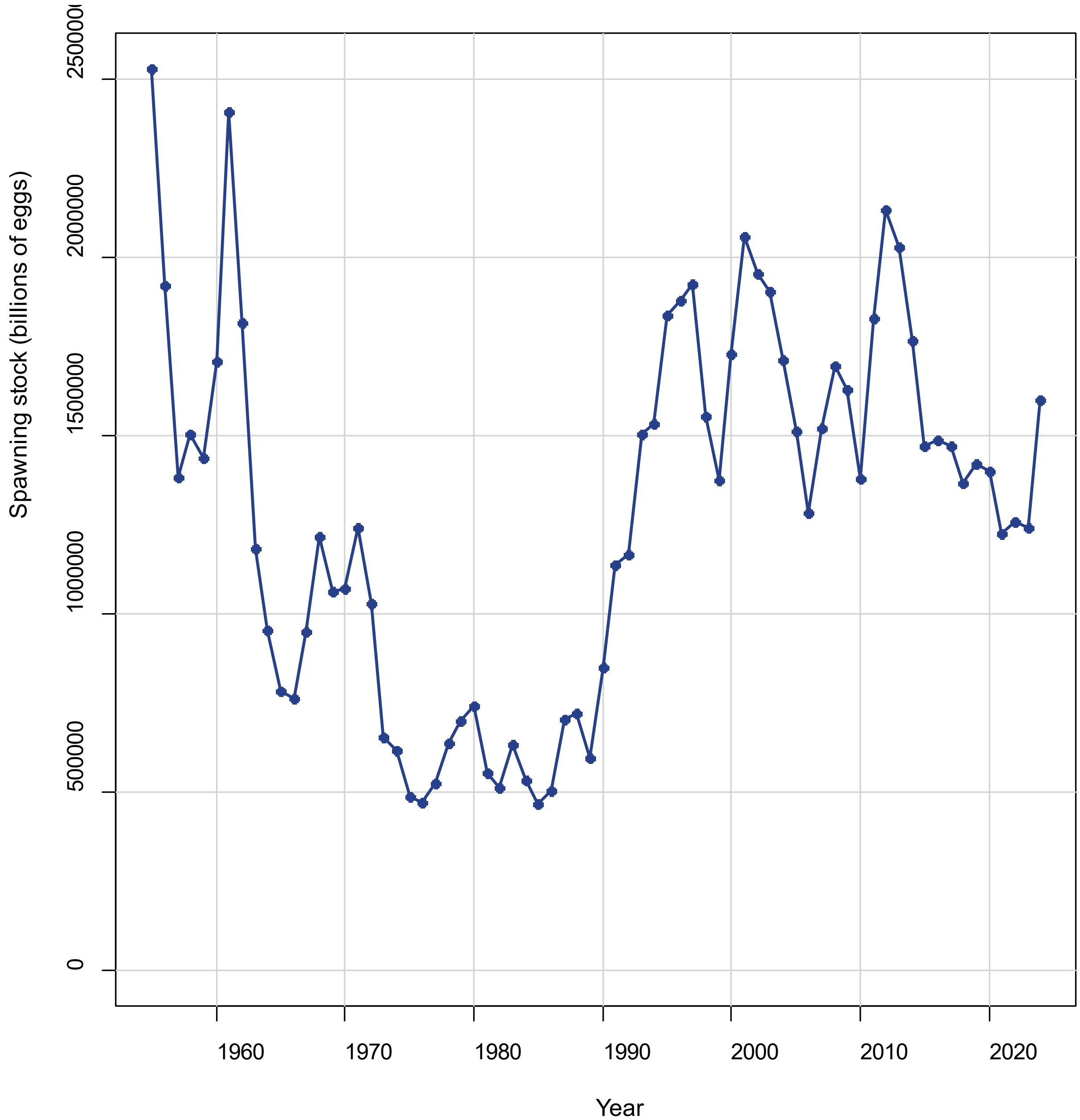

Figure A38. **Fecundity in billions of ova for 1955-2023. The 2024 value is a projected value.**

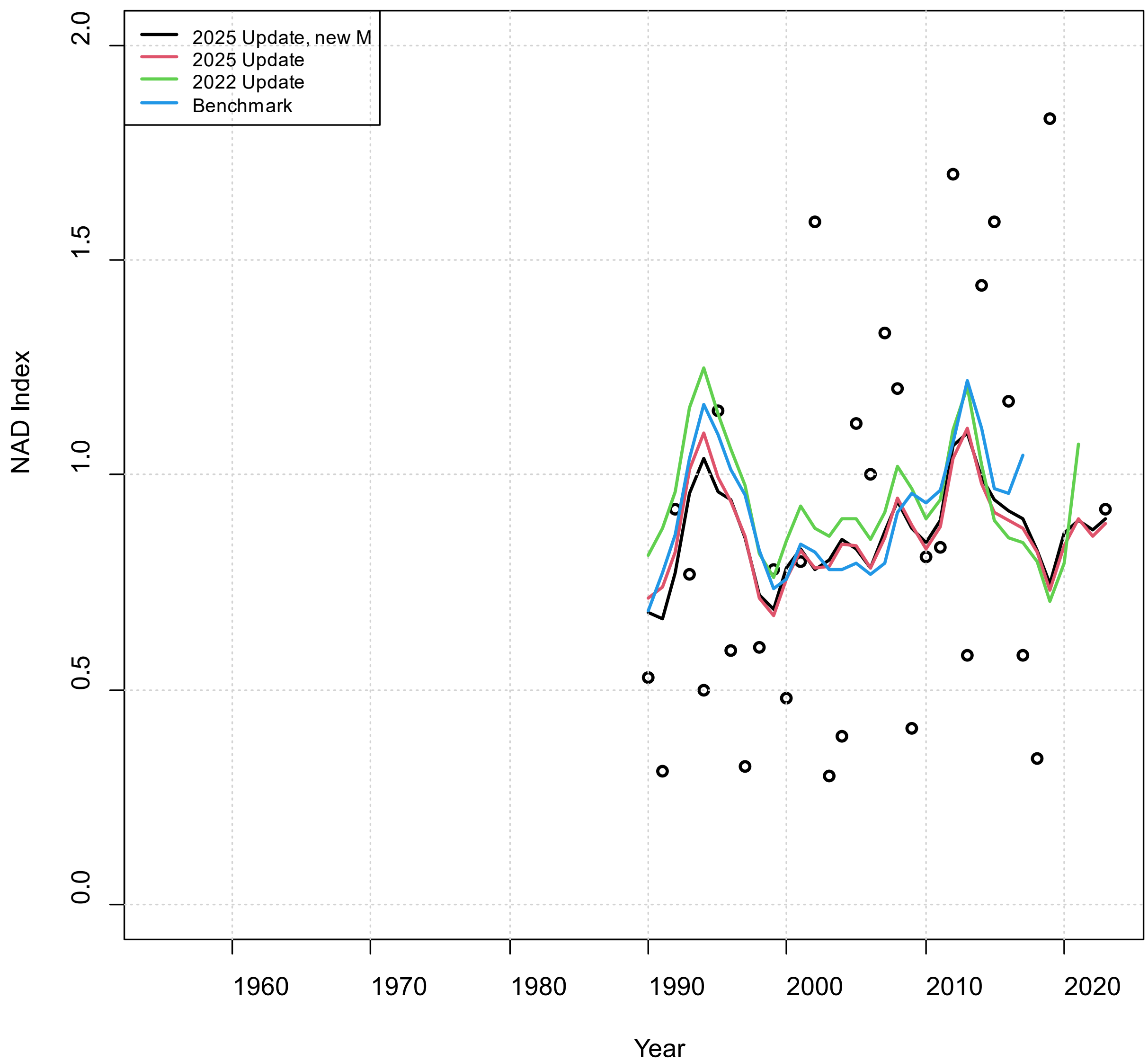

Figure A39. **Fit to the observed (open circles) NAD index for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, the 2022 update assessment, and the last benchmark assessment.**

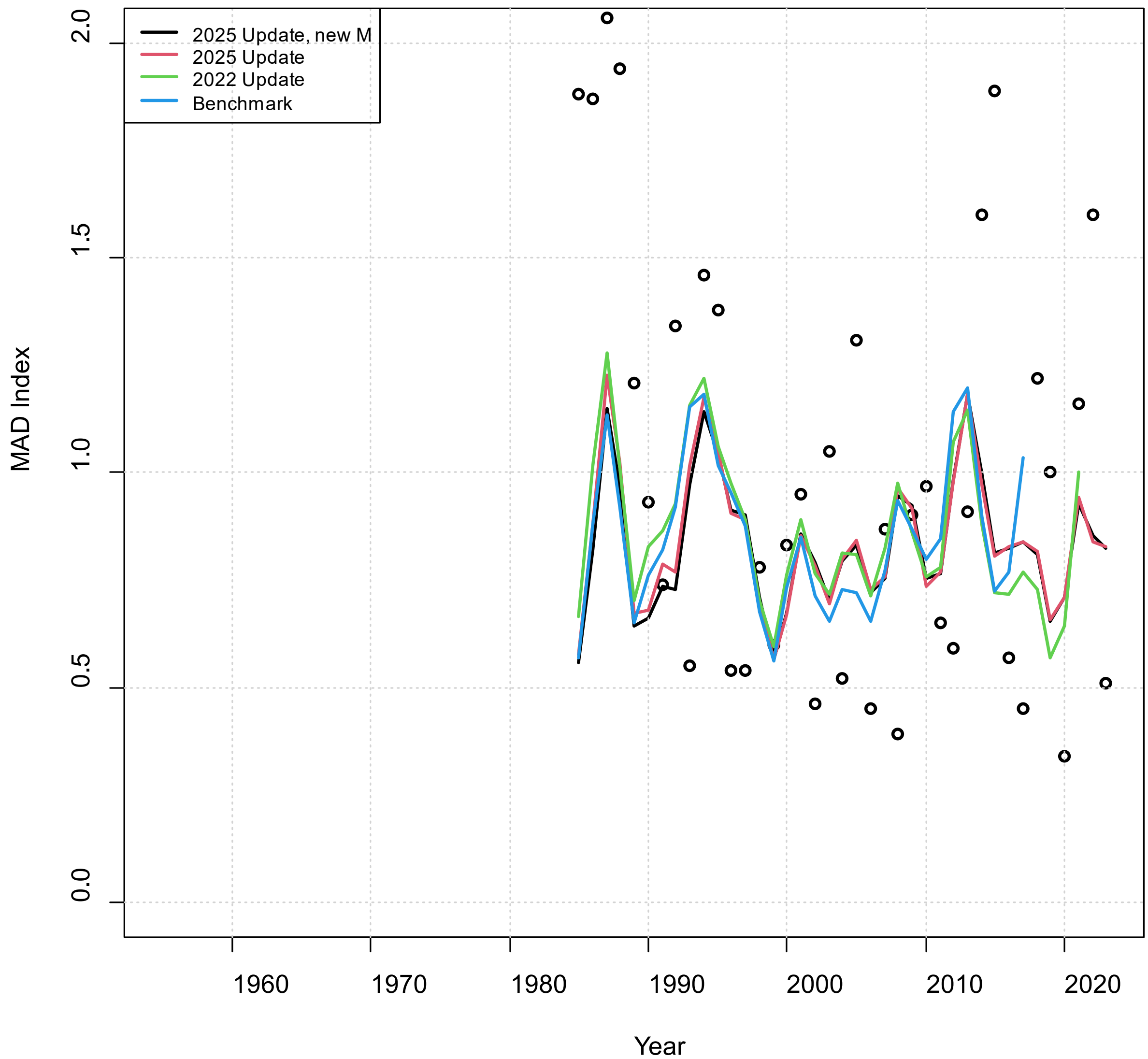

Figure A40. **Fit to the observed (open circles) MAD index for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, the 2022 update assessment, and the last benchmark assessment.**

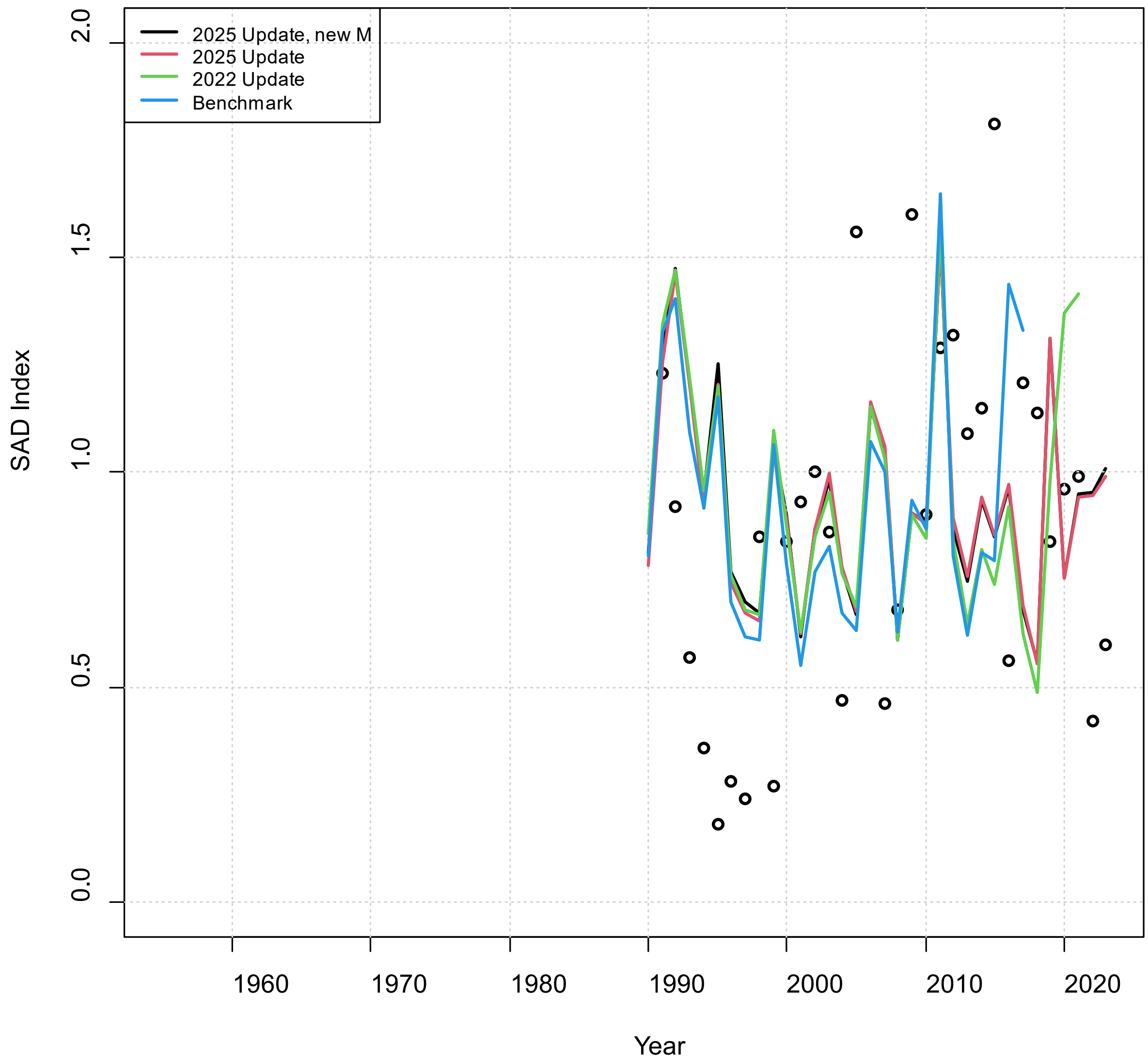

Figure A41. **Fit to the observed (open circles) SAD index for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, the 2022 update assessment, and the last benchmark assessment.**

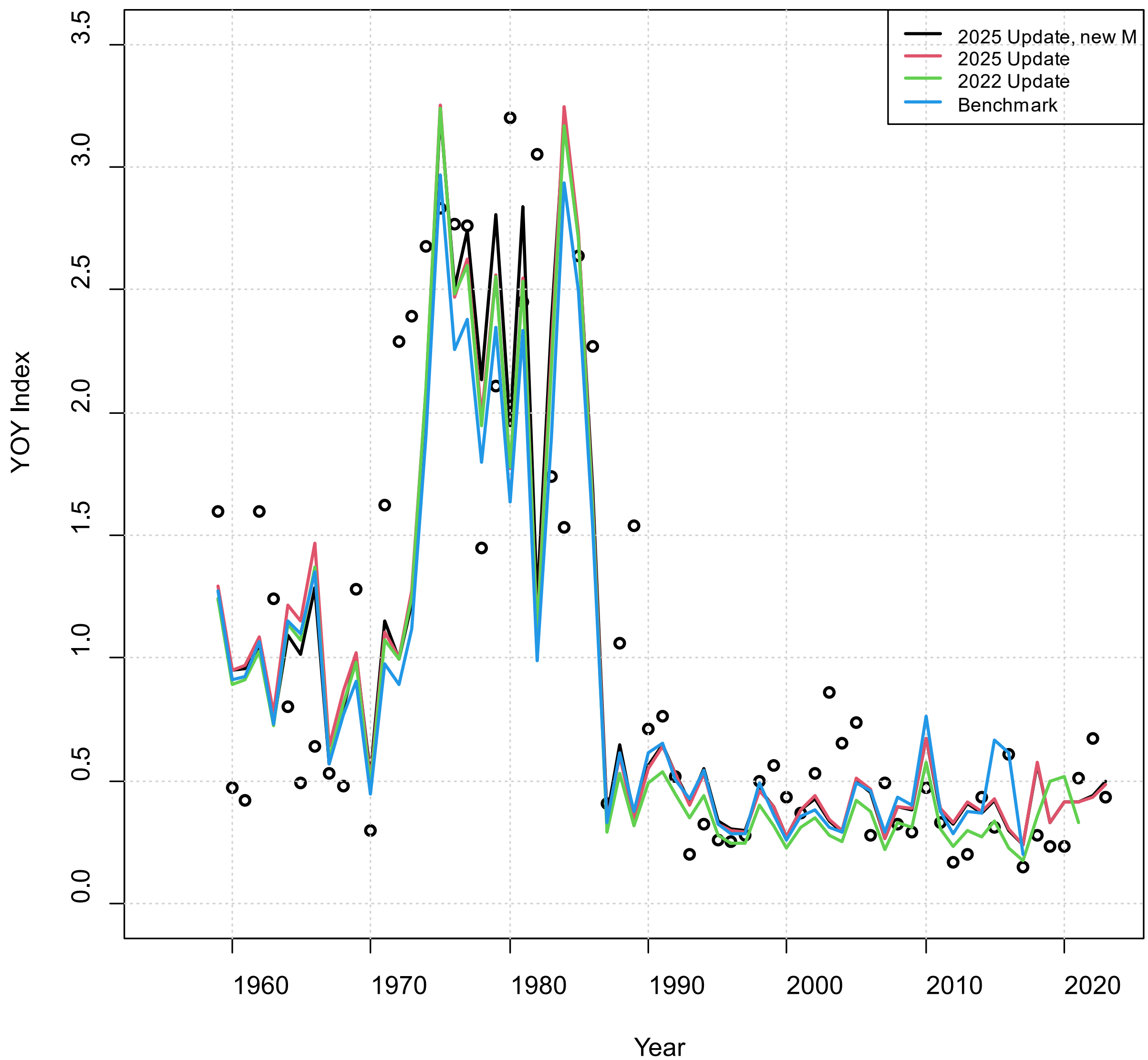

Figure A42. **Fit to the observed (open circles) recruitment index for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, the 2022 update assessment, and the last benchmark assessment.**

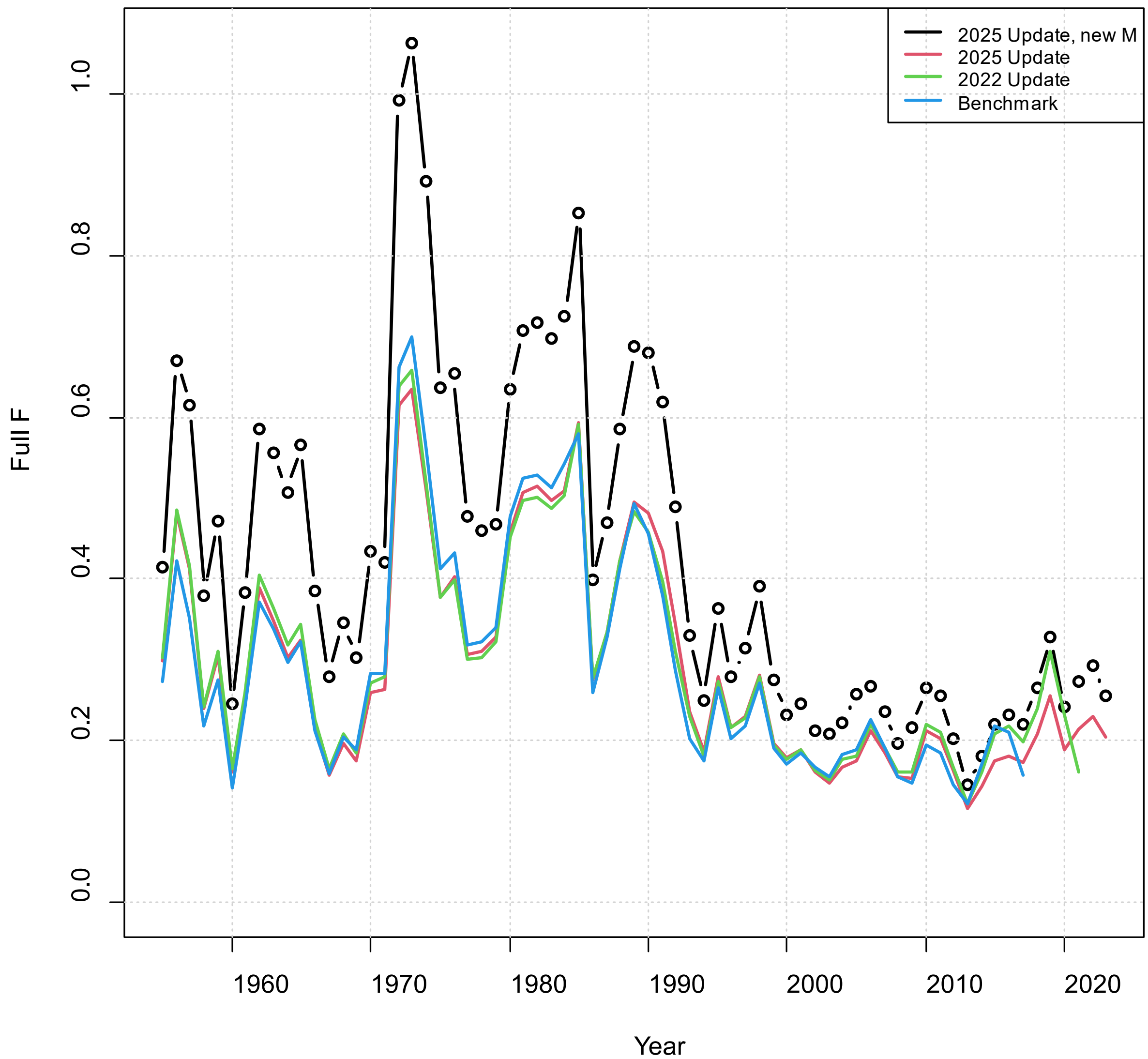

Figure A43. **Estimates of the full fishing mortality rate for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, the 2022 update assessment, and the last benchmark assessment.**

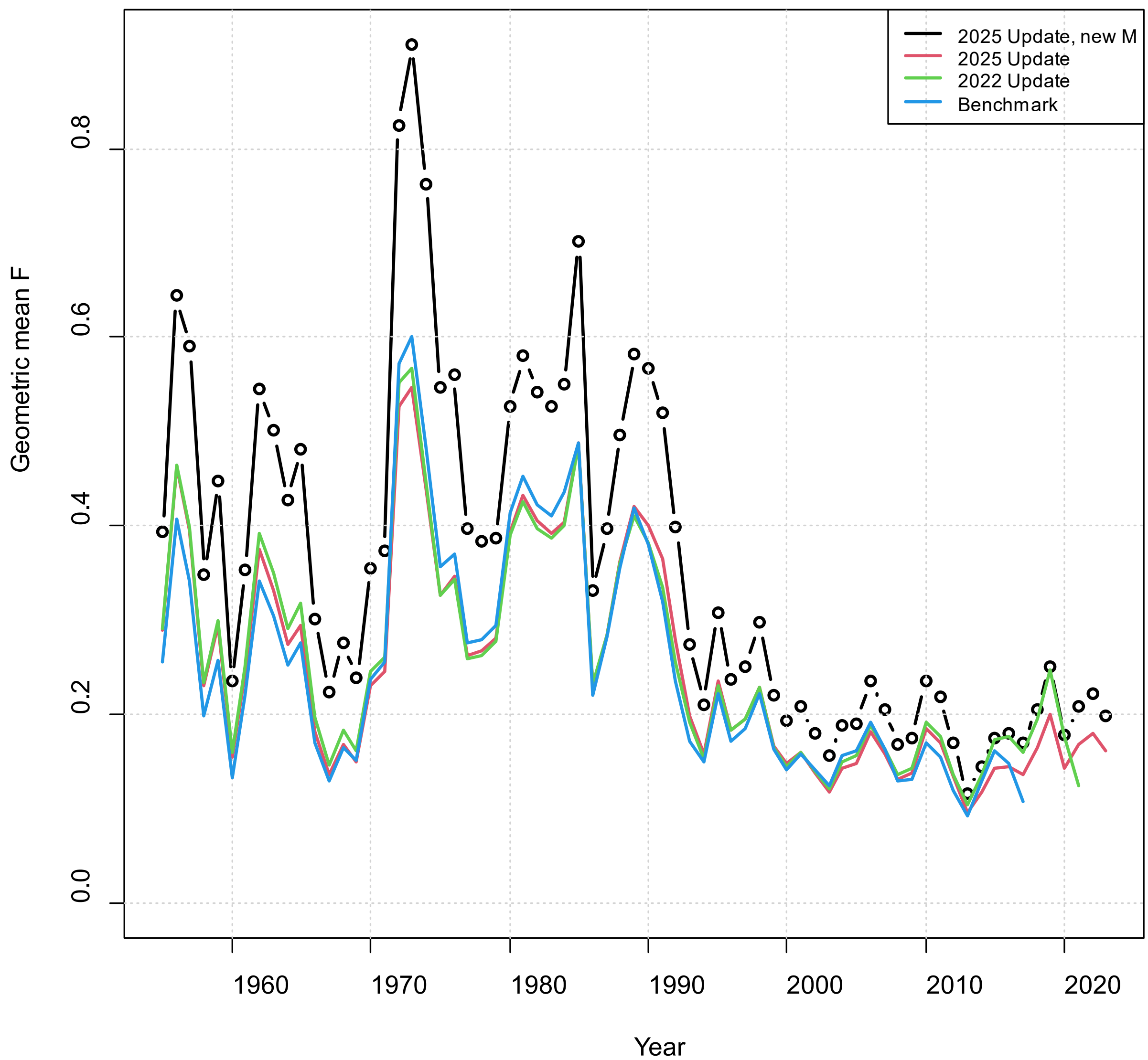

Figure A44. **Estimates of the geometric mean fishing mortality rate for ages-2 to -4 for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, the 2022 update assessment, and the last benchmark assessment.**

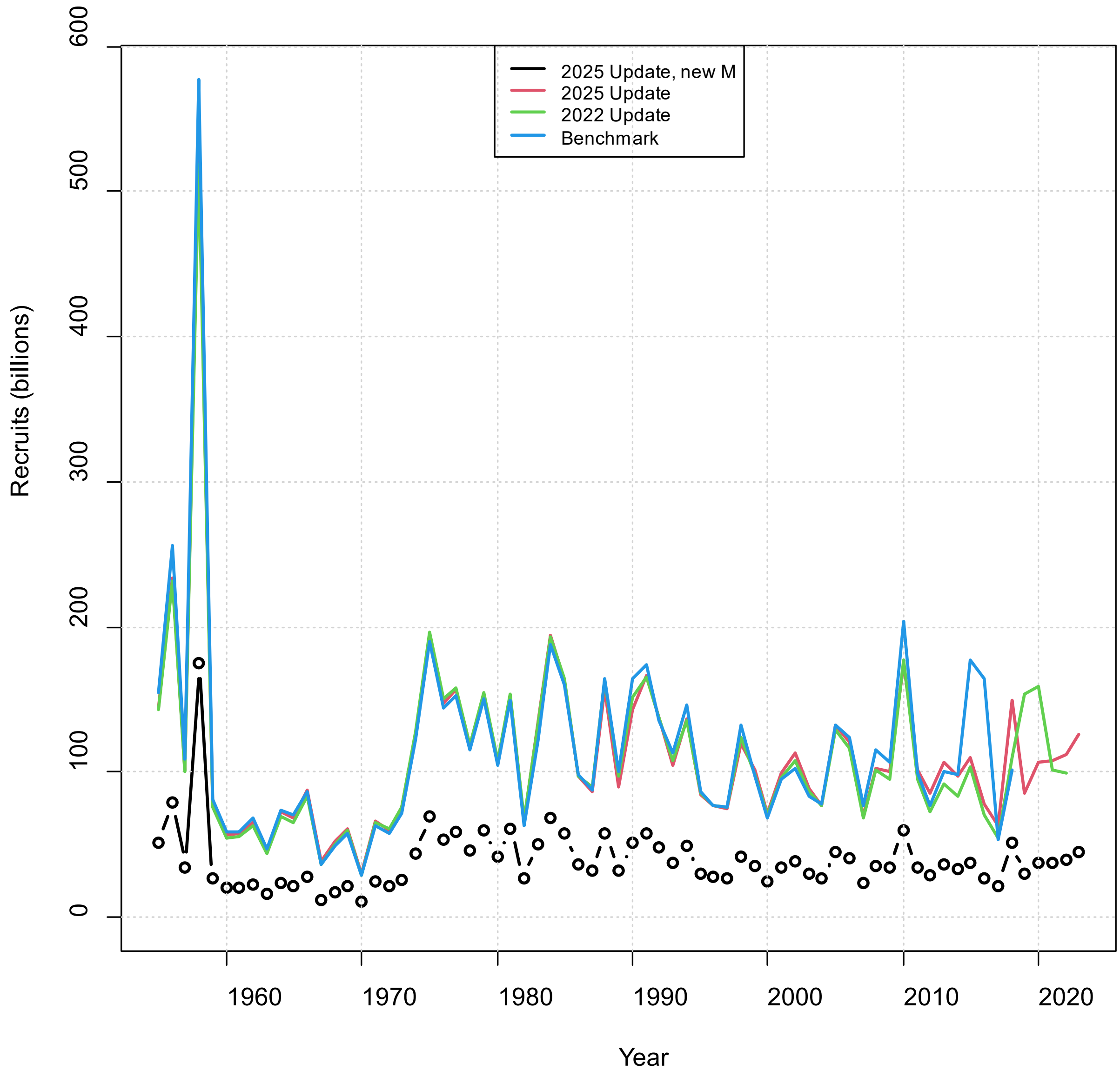

Figure A45. **Estimates of the recruitment time series for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, the 2022 update assessment, and the last benchmark assessment.**

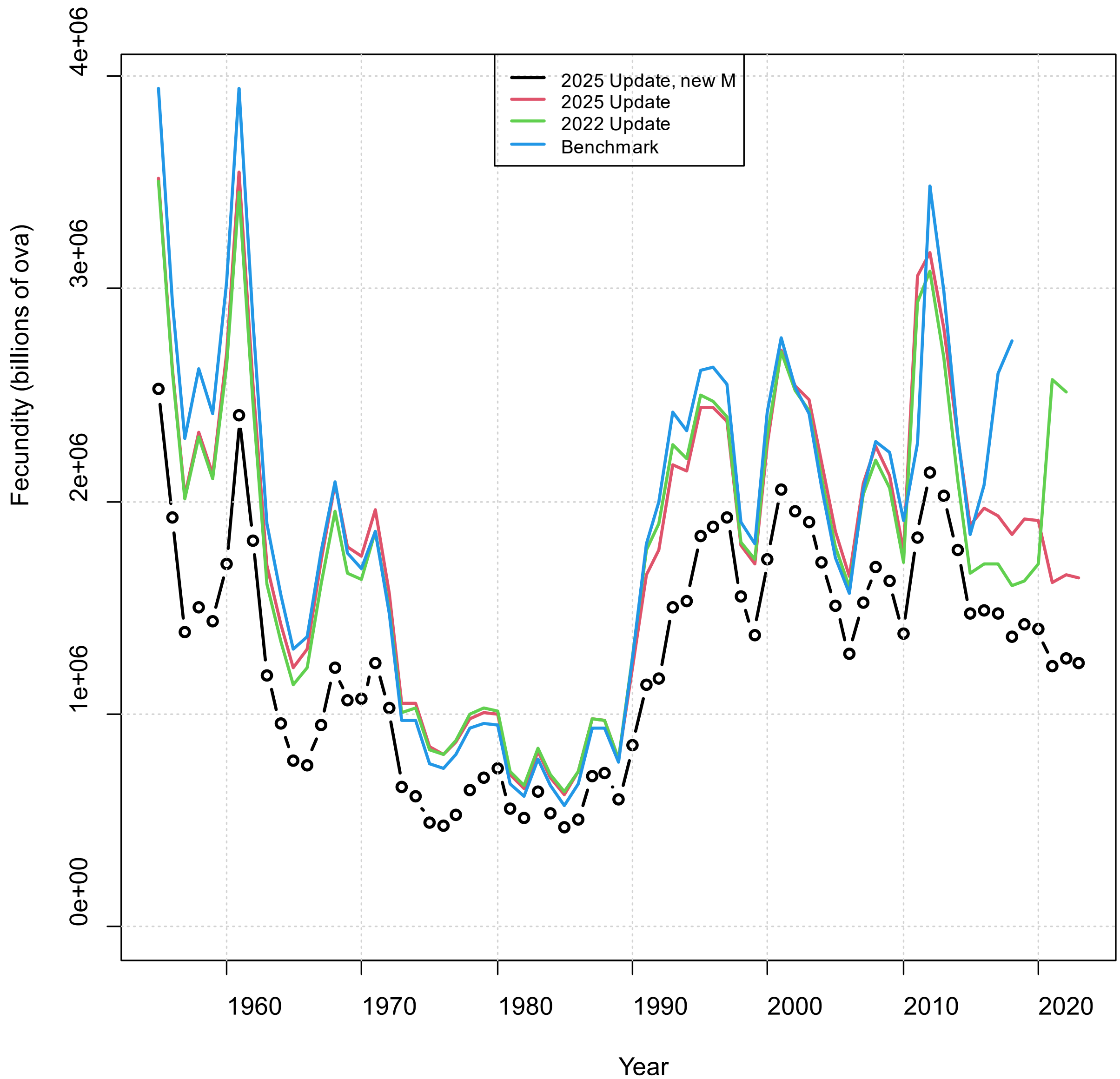

Figure A46. **Estimates of the fecundity (billions of ova) for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, the 2022 update assessment, and the last benchmark assessment.**

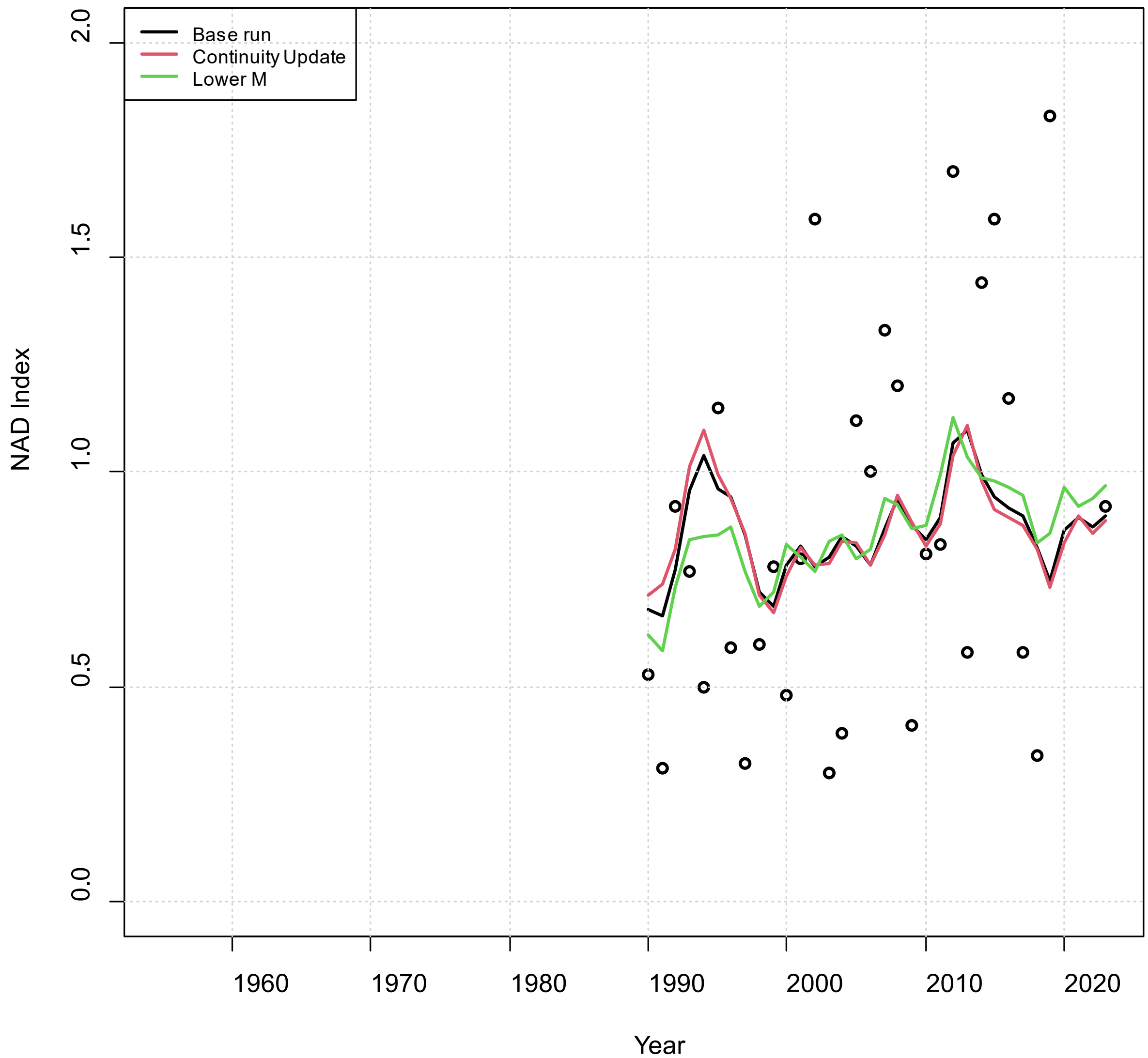

Figure A47. **Fit to the observed (open circles) NAD index for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, and a sensitivity run with a lower M.**

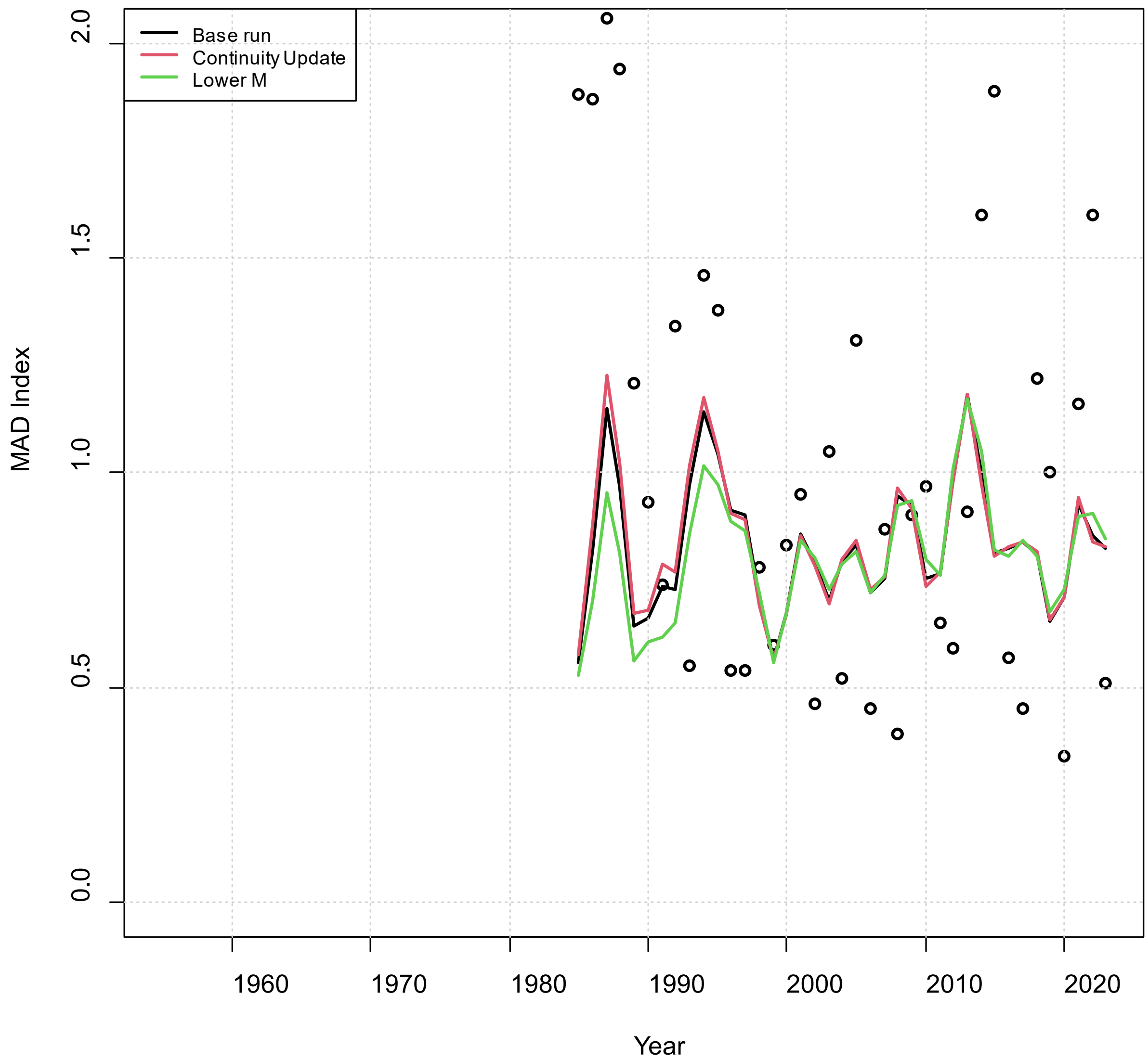

Figure A48. **Fit to the observed (open circles) MAD index for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, and a sensitivity run with a lower M.**

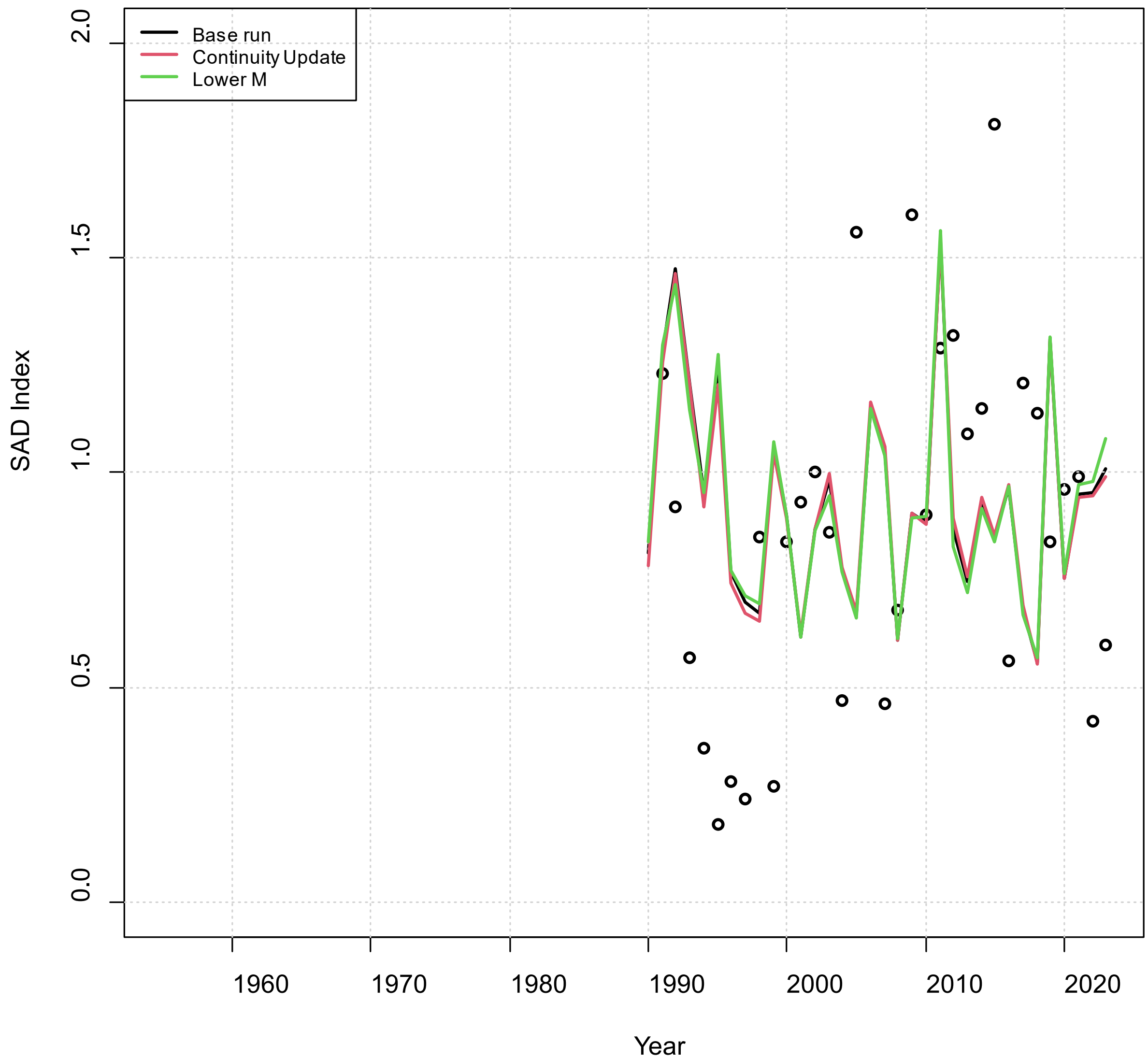

Figure A49. **Fit to the observed (open circles) SAD index for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, and a sensitivity run with a lower M.**

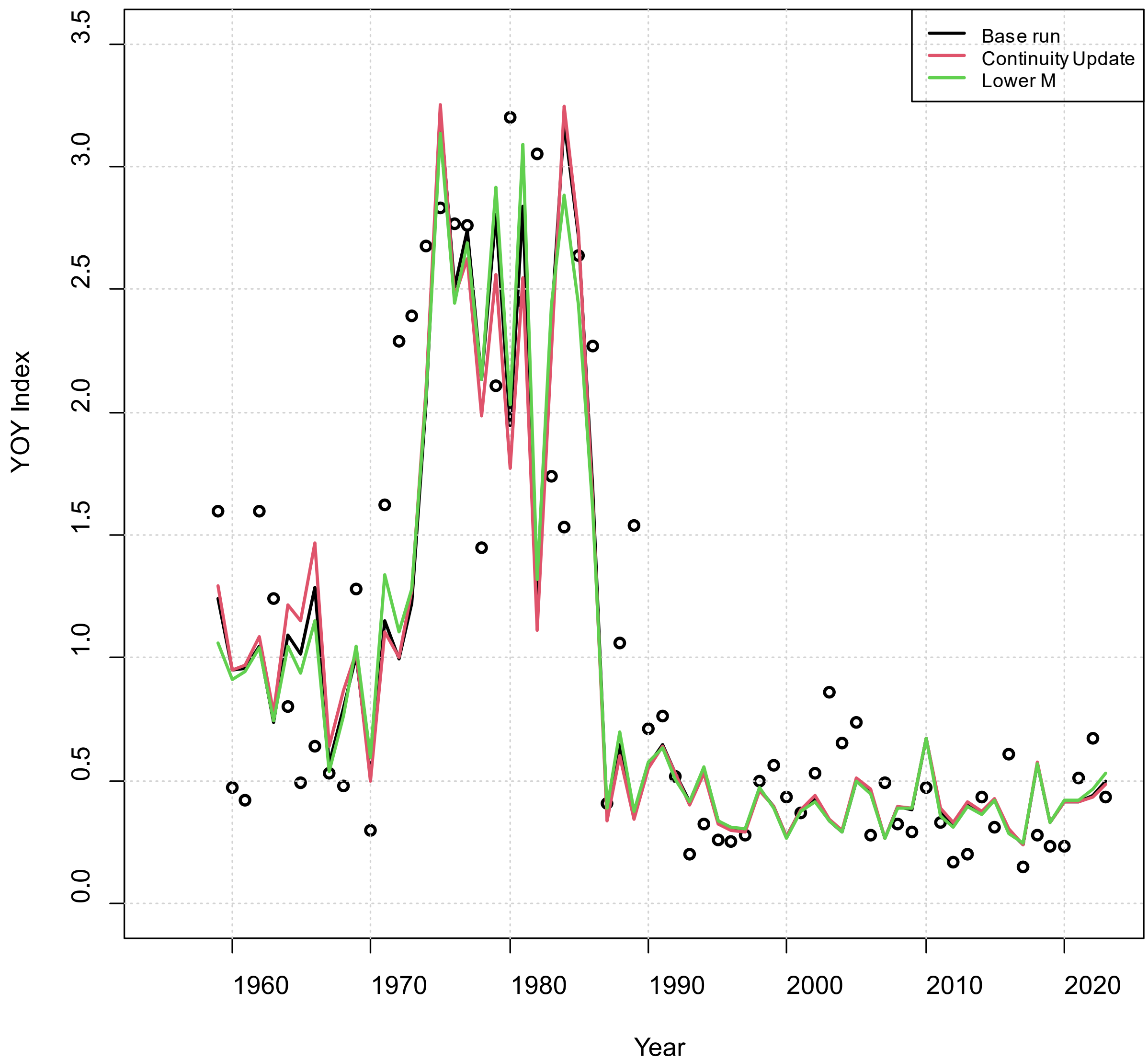

Figure A50. **Fit to the observed (open circles) recruitment index for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, and a sensitivity run with a lower M.**

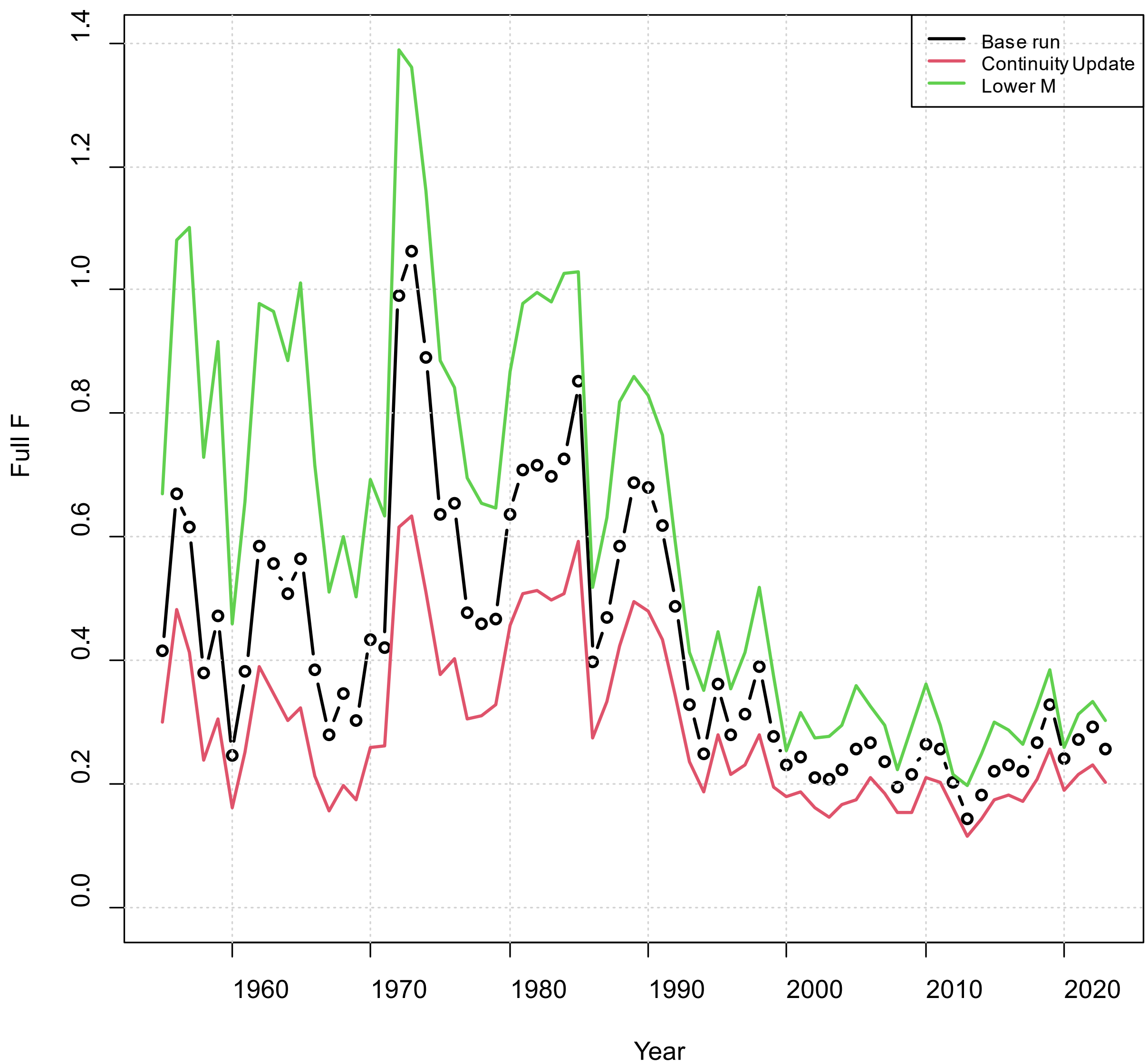

Figure A51. **Estimates of the full fishing mortality rate for the base run for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, and a sensitivity run with a lower M.**

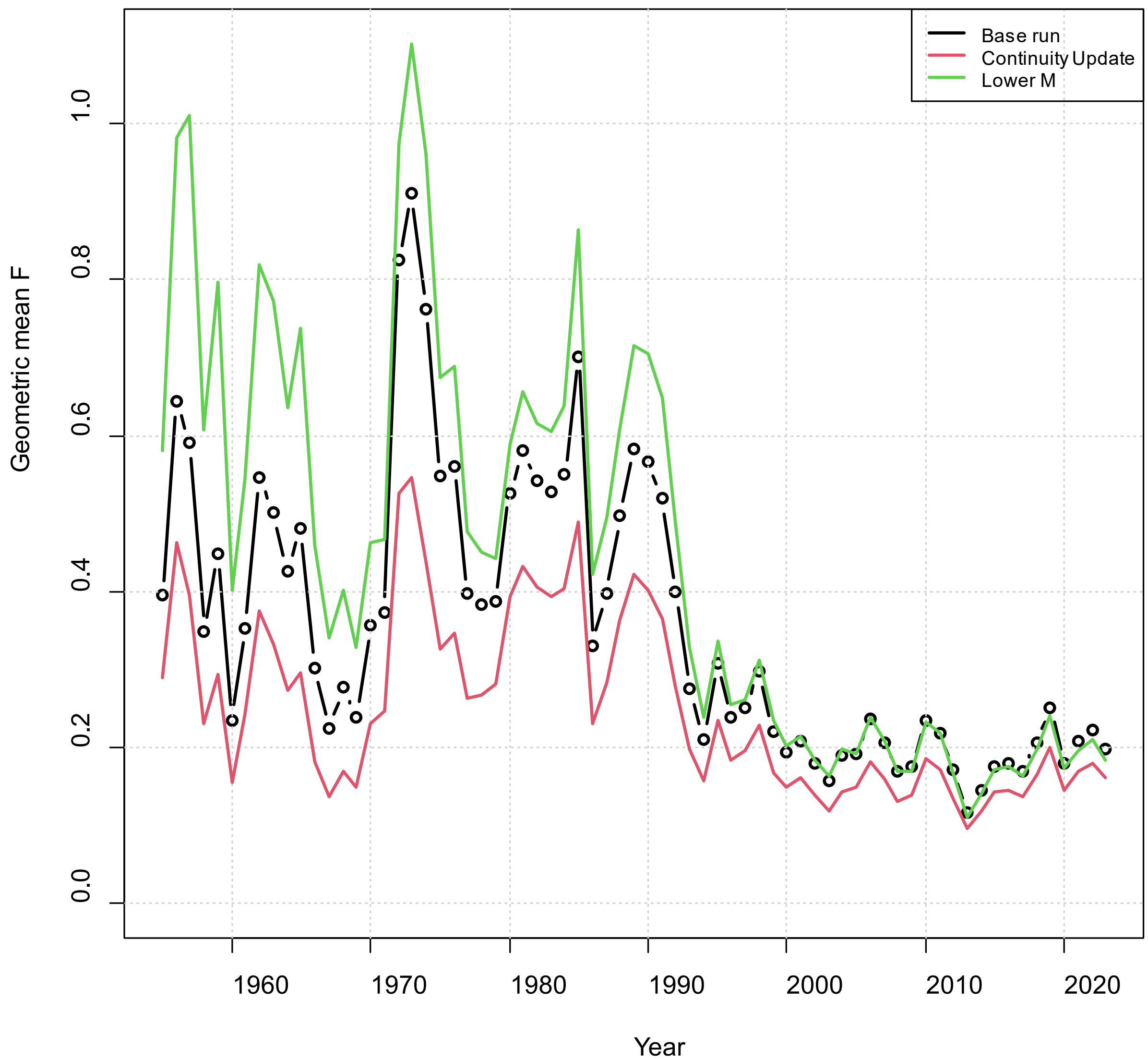

Figure A52. **Estimates of the geometric mean fishing mortality rate for ages-2 to -4 for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, and a sensitivity run with a lower M.**

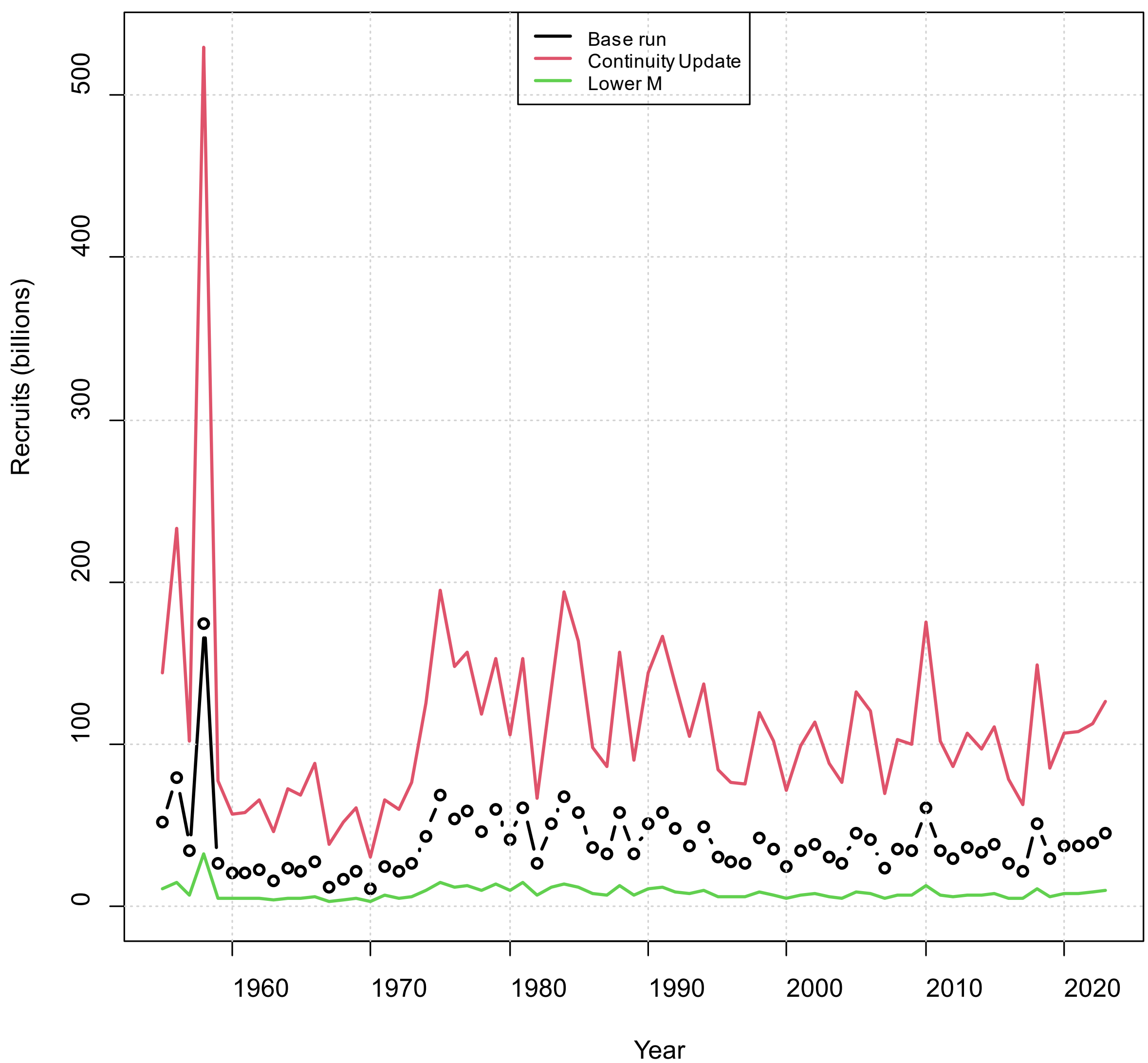

Figure A53. **Estimates of the recruitment time series for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, and a sensitivity run with a lower M.**

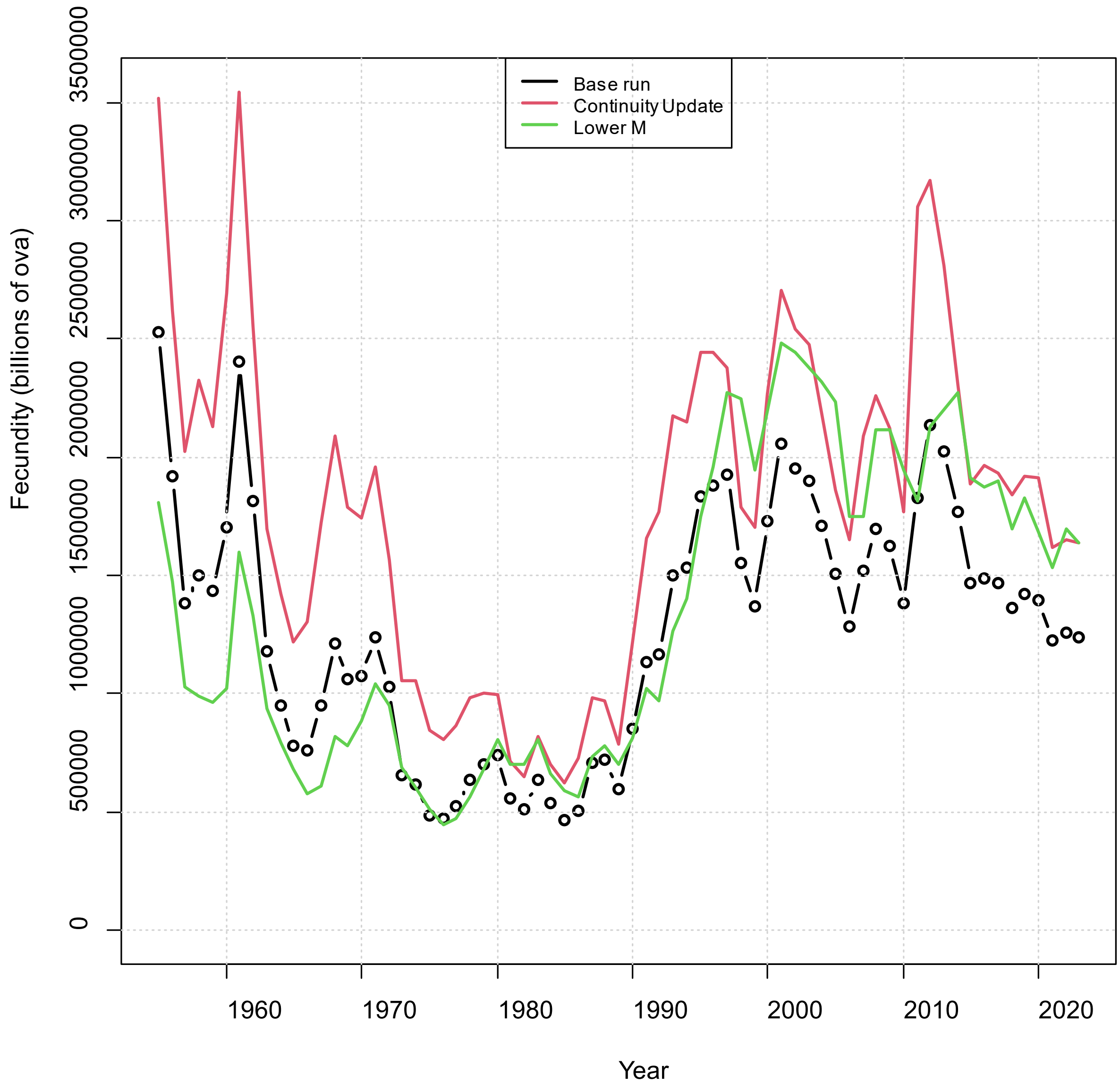

Figure A54. **Estimates of the fecundity (billions of ova) for the base run for this update assessment with a new natural mortality value (M), the 2025 update assessment as a continuity run, and a sensitivity run with a lower M.**

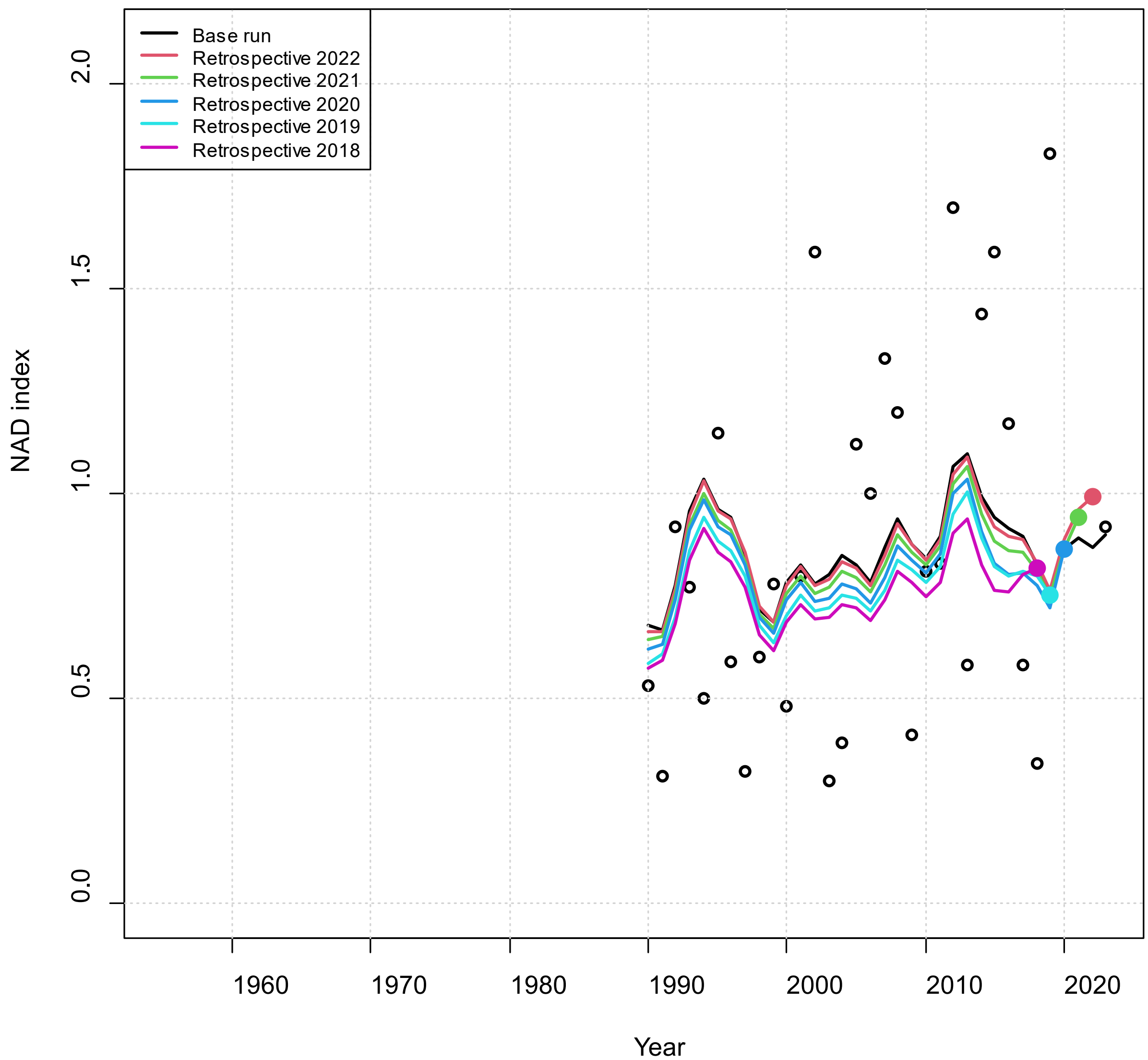

Figure A55. **Fit to the observed (open circles) NAD index for the retrospective analysis with terminal years from 2023 to 2018.**

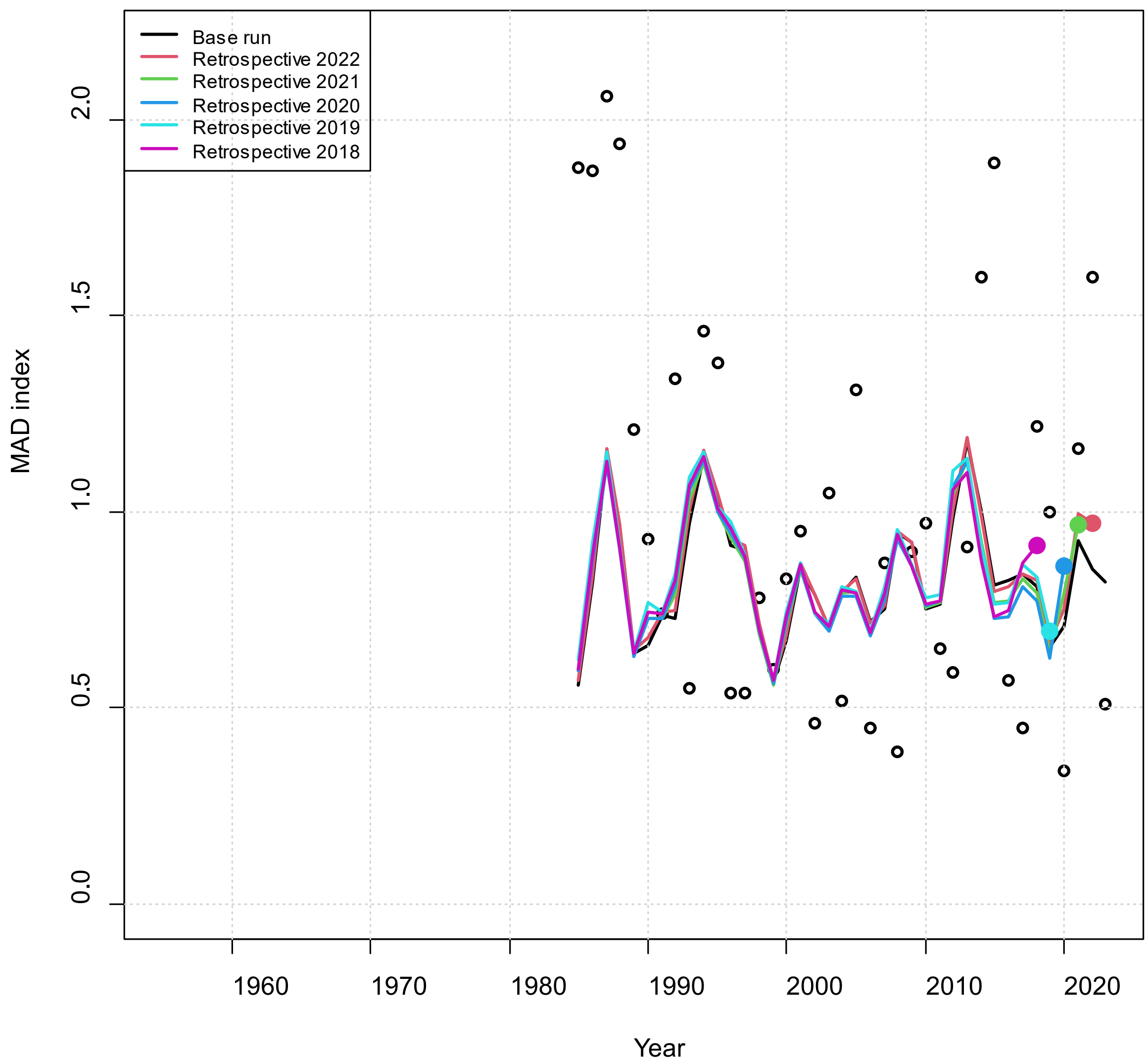

Figure A56. **Fit to the observed (open circles) MAD index for the retrospective analysis with terminal years from 2023 to 2018.**

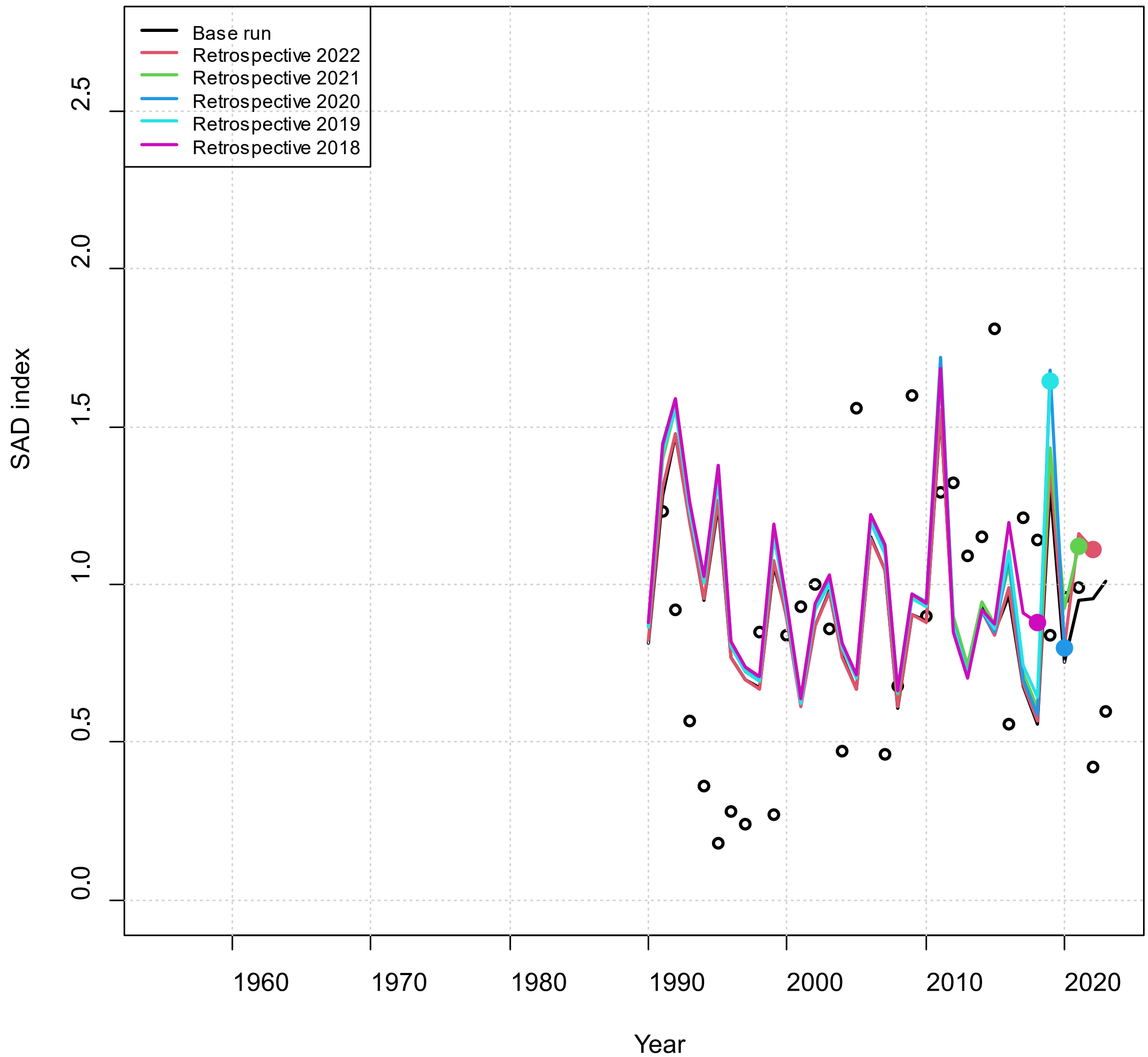

Figure A57. Fit to the observed (open circles) SAD index for the retrospective analysis with terminal years from 2021 to 2016.

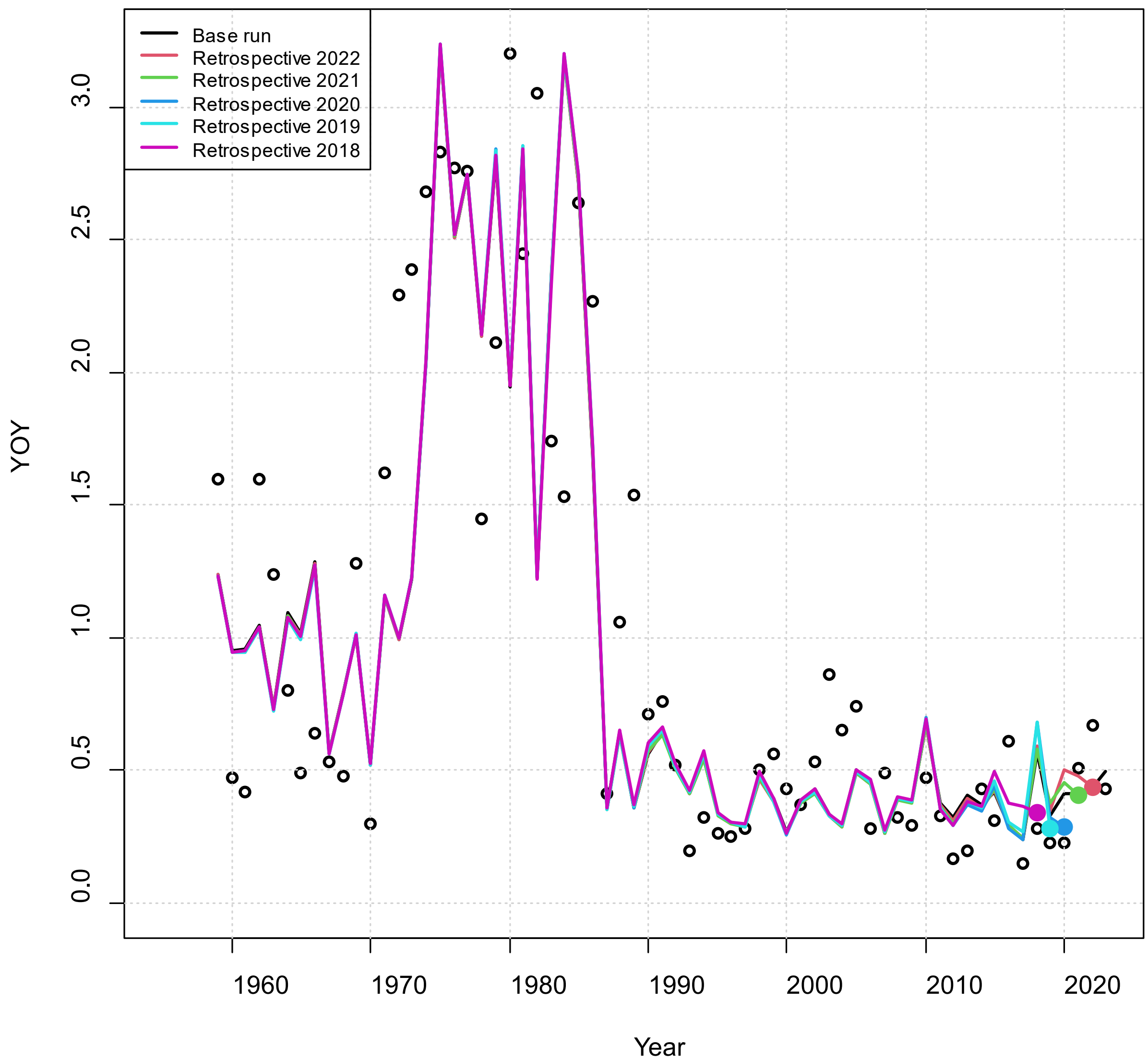

Figure A58. **Fit to the observed (open circles) recruitment index for the retrospective analysis with terminal years from 2023 to 2018.**

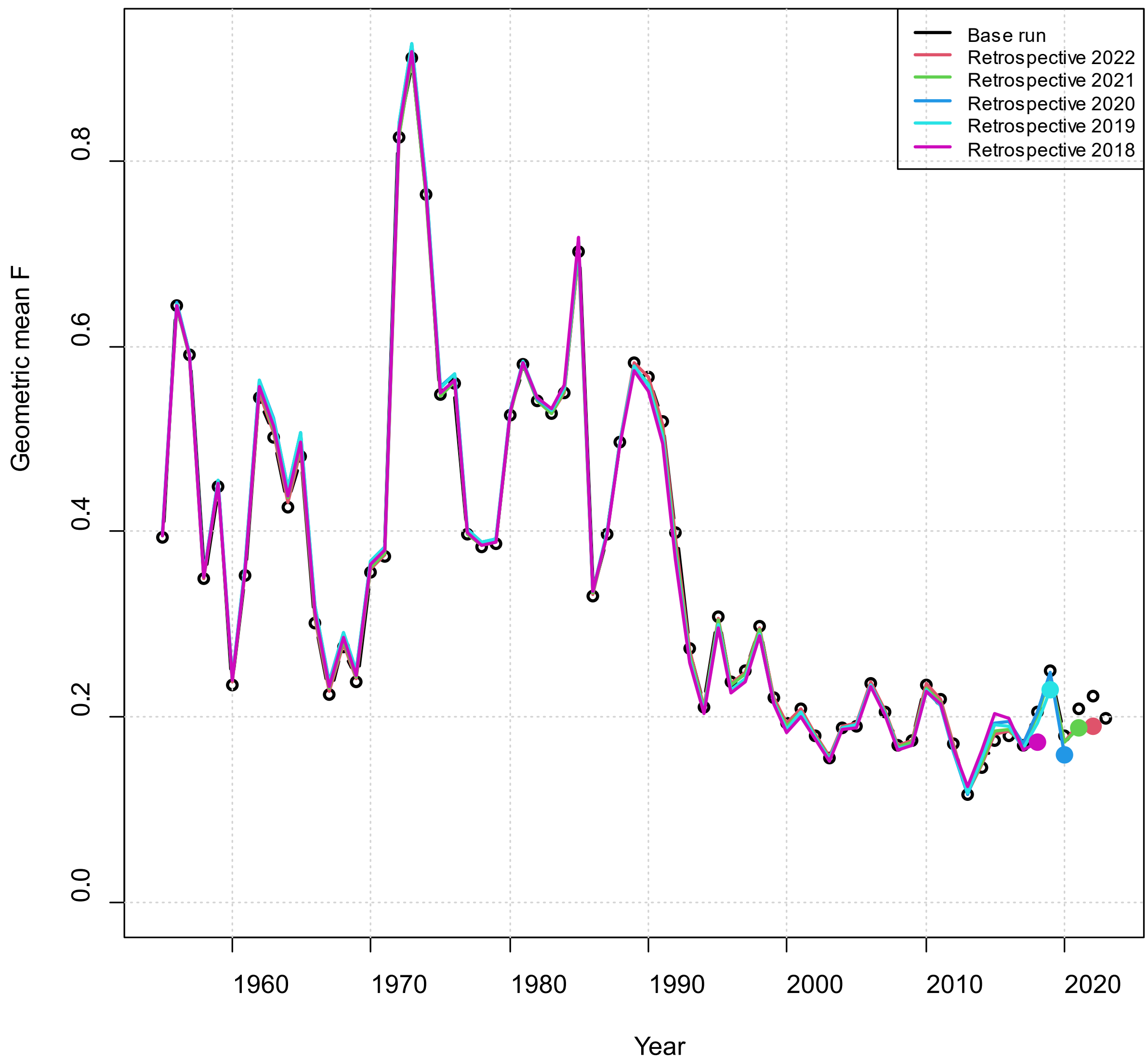

Figure A59. **Estimates of the geometric mean fishing mortality rate for ages-2 to -4 for the retrospective analysis with terminal years from 2023 to 2018.**

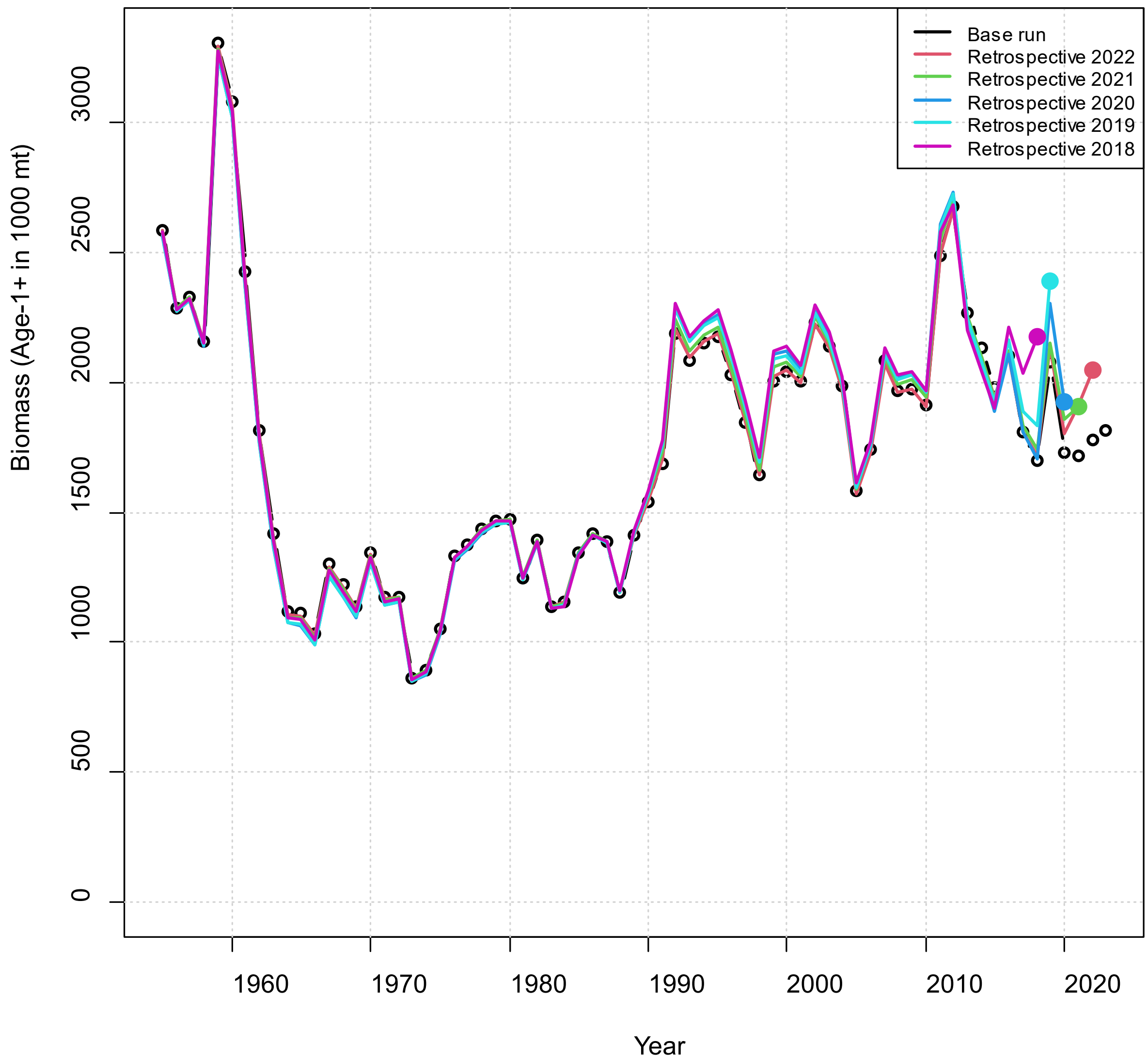

Figure A60. **Estimates of the age-1+ biomass for the retrospective analysis with terminal years from 2023 to 2018.**

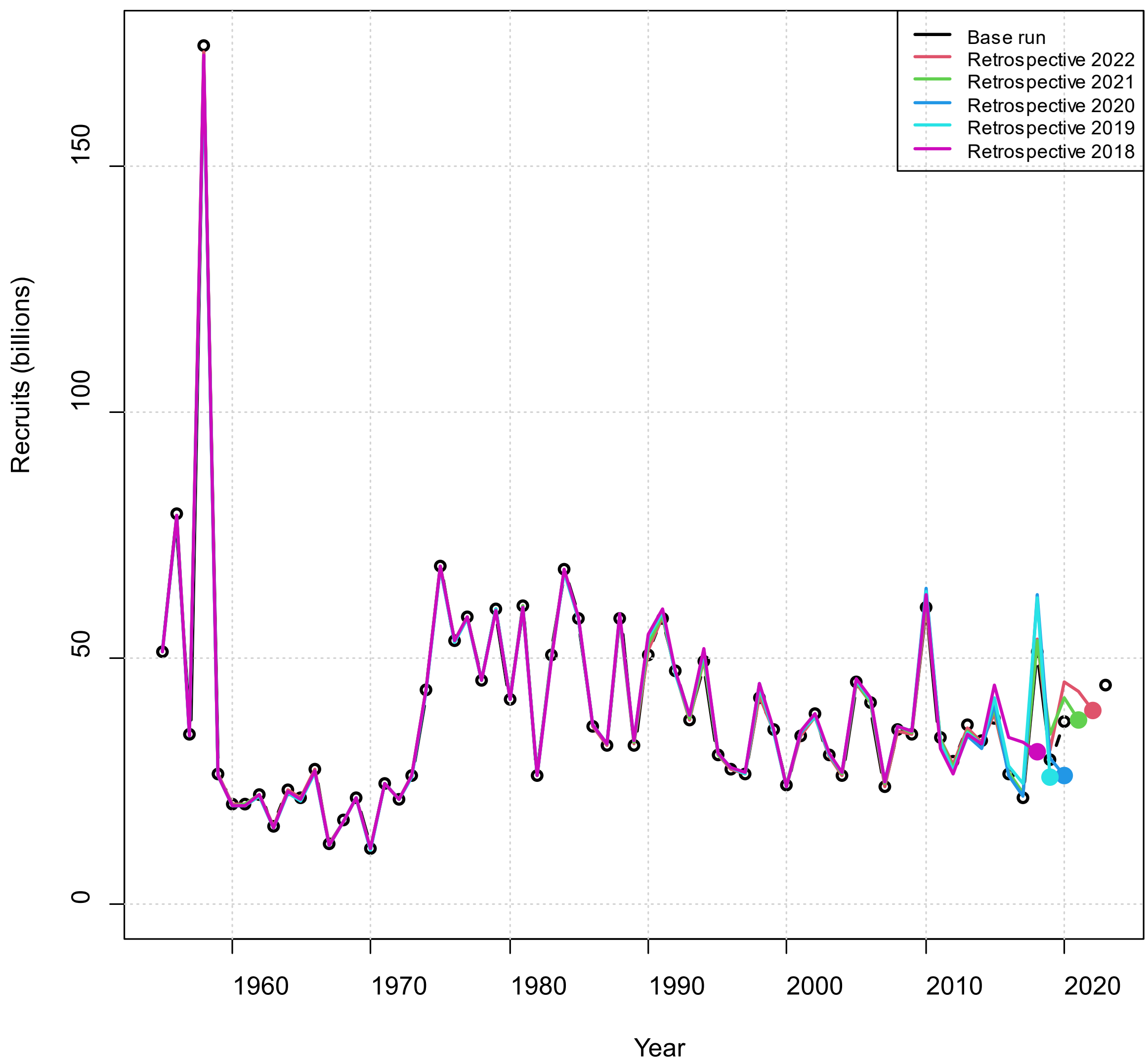

Figure A61. **Estimates of the recruitment for the retrospective analysis with terminal years from 2023 to 2018.**

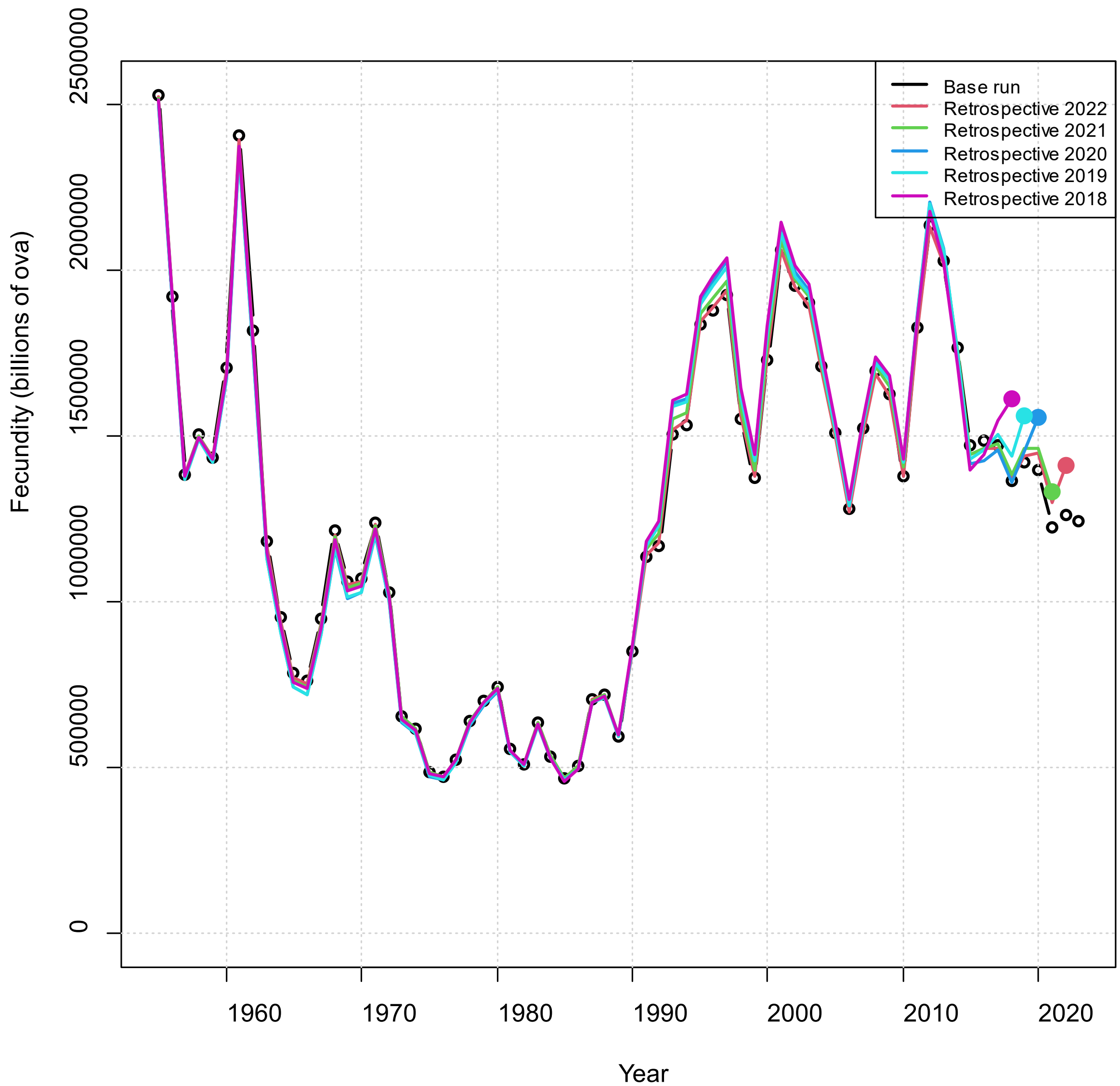

Figure A62. Estimates of the fecundity (billions of ova) for the retrospective analysis with terminal years from 2023 to 2018.

Single-Species Research Recommendations

The following is the complete list of research recommendations from the single-species benchmark assessment (SEDAR 2020a).

Research recommendations are broken down into two categories: future research and data collection, and assessment methodology. While all recommendations are high priority, the first recommendation is the highest priority. Each category is further broken down into recommendations that can be completed in the short term and recommendations that will require long term commitment. For the single-species assessment, the SAS recommends an update be considered in three years and a new benchmark be considered in six years.

Future Research and Data Collection

Short Term

1. Continue current level of sampling from bait fisheries, particularly in the Mid-Atlantic and New England. Analyze sampling adequacy of the reduction fishery and effectively sample areas outside of that fishery (e.g., work with industry and states to collect age structure data and biological data outside the range of the fishery).
2. Place observers on boats to collect at-sea samples from purse-seine sets, or collect samples at dockside during vessel pump-out operations (as opposed to current top of hold sampling) to address sampling adequacy.
3. Evaluate which proportion of bait landings by state are captured by gear versus which proportion are sampled for length and age composition to determine if current biosampling requirements are appropriate and adequate.
4. Continue to improve data validation processes for the bait fishery through ACCSP.
5. Conduct an ageing workshop to assess precision and error among readers with the intention of switching bait fishery age reading to state ageing labs.
6. Re-age historic old age samples (i.e., ages >7) to confirm the max age of Atlantic menhaden.
7. Investigate the relationship between fish size and school size to address selectivity (specifically addressing fisher behavior related to harvest of specific school sizes).
8. Investigate the relationship between fish size and distance from shore (addressing selectivity).

Long Term

1. Develop and implement a menhaden-specific, multi-year coastwide fishery-independent index of adult abundance-at-age with ground-truthing for biological information (e.g., size and age composition). A sound statistical design is essential. Ideally, it should be done coast-wide, but area-specific surveys that cover the majority of the population and are more cost-effective could provide substantial improvements over the indices currently used in the assessment.

2. Continue age-specific studies on spatial and temporal dynamics of spawning (where, how often, how much of the year, batch spawning, etc.)
3. Conduct an ageing validation study, making sure to sample older age classes.
4. Continue to investigate environmental covariates related to productivity and recruitment on a temporal and spatial scale.
5. Consider other ageing methods for the future, such as the use of Fourier transform near infrared spectroscopy (FT-NIRS).

Assessment Methods

Short Term

1. Investigate index standardization to improve CVs and explore methods of combining indices at a regional or coastwide level.
2. Explore the covariance between life history parameters to improve the understanding of uncertainty in the model.
3. Explore the error structure between MCMC and MCB.
4. Perform simulation testing on the Deyle et al. method used in the projections and determine if recruitment is accurately tracked by the method and improve short term projections.
5. Conduct a Management Strategy Evaluation (MSE).

Long Term

1. Continue to monitor model diagnostics given that the model is not robust to anomalous year-classes in the terminal year.
2. Develop a seasonal spatially-explicit model once sufficient age-specific data on movement rates of menhaden are available.

Ecological Reference Point Research Recommendations

The following is the complete list of research recommendations from the ecological reference point stock assessment (SEDAR 2020b).

The Ecological Reference Point Work Group (ERP WG) endorsed the research recommendations laid out in the single-species assessment to improve the understanding of Atlantic menhaden population dynamics, especially the recommendations to develop an Atlantic menhaden-specific coastwide fishery-independent index of adult abundance and to continue to investigate environmental covariates related to productivity and recruitment on a temporal and spatial scale.

In addition, the ERP WG identified a number of research needs to improve the multispecies modeling efforts and the development of ecological reference points for Atlantic menhaden, as well as process considerations to fully implement ecosystem-based fishery management.

Future Research and Data Collection

Short term

1. Expand collection of diet and nutrition data along the Atlantic coast to provide seasonally and regionally stratified annual, year-round monitoring of key predator diets to provide information on prey abundance and predator consumption. This could be done through existing data collection programs.

Long term

1. Improve monitoring of population trends and diet data in non-finfish predators (e.g., birds, marine mammals) and data-poor prey species (e.g., bay anchovies, sand eels, benthic invertebrates, zooplankton, and phytoplankton) to better characterize the importance of Atlantic menhaden and other forage species to the ecosystem dynamics.

Modeling Needs

Short term

1. Conduct a management-strategy evaluation (MSE) to identify harvest strategies that will maximize the likelihood of achieving the identified ecosystem management objectives.
2. Continue development of the NWACS-MICE model to incorporate recruitment deviations (from external models or primary productivity time series) to better capture the productivity dynamics of Atlantic menhaden and other species.
3. Continue development of the VADER model to include bottom-up effects of Atlantic menhaden abundance on key predator species.
4. Continue development of the NWACS-FULL model to bring other species up to date and continue exploring the impacts of fishing on higher trophic level predators like birds and mammals.

Management Process Needs

Short term

1. Develop a coordinated timeline of assessments and assessment updates for Commission-managed species in order to provide the most up-to-date multispecies inputs for the NWACS-MICE model during ERP assessment updates.

Long term

1. Develop a plan to coordinate management of Atlantic menhaden and their predator species across management Boards. This will require changes to the way the Commission has historically operated. These species are currently managed by separate Boards within the Commission, and management objectives, including *F* and *B* targets for each species, are set independently of each other. For successful ecosystem-based fishery management, consistent management objectives for individual species and the ecosystem should be set holistically with the engagement of all managers and stakeholders.