Atlantic States Marine Fisheries Commission

2022 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

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EXECUTIVE SUMMARY

The purpose of this assessment was to update the 2019 Atlantic Menhaden Single-Species Benchmark Stock Assessment (SEDAR 2020a) with recent data from 2018-2021. The stock assessment update reran the peer-reviewed Beaufort Assessment Model (BAM) with a terminal year of 2021 and determined stock status of Atlantic menhaden using the ecological reference points (ERPs) defined in SEDAR 2020b and accepted for management use in 2020. This stock assessment update for Atlantic menhaden adopted the format of a Terms of Reference Report as developed by the Assessment Science Committee.

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 for 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 2021 and 2022 fishing seasons is 194,400 mt. Reduction landings have been steady since the implementation of the TAC, while bait landings have increased particularly in the northern states. For 2018-2021, reduction landings comprised about 70% of the coastwide landings. In 2021, bait and recreational landings were approximately 61,000 mt and reduction landings were approximately 136,700 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 and 2016.

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 2019-2021. The MAD showed high relative abundance in the late 1980s and then variable abundance with peaks in 2014 and 2015. 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 through the terminal year.

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 status. The fishing mortality rate was highest in the 1970s and 1980s and has been declining since approximately 1990. The fishing mortality rate has been relatively stable since the mid-1990s and decreased in 2020 and 2021. Fishing effort in 2020 and 2021 was impacted by the COVID-19 pandemic with several vessels not operating due to restrictions.

Biomass

Biomass has fluctuated over time with a time series high in 1959 to a low in 1973. From 1990 to the present, biomass has increased. Biomass increased at a faster rate than abundance because of the increase in the number of older fish and an increase in weight-at-age.

Fecundity

Population fecundity (i.e., number of maturing ova) 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. In the last decade, fecundity estimates were mostly between the ERP target and threshold with some years exceeding the target.

Stock Status

The fishing mortality rate for the terminal year of 2021 was below the ERP target and threshold and the fecundity was above the ERP target and threshold. Therefore, overfishing is not occurring and the stock is not considered overfished.

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INTRODUCTION

This Terms of Reference (TOR) report describes the update to the single-species stock assessment for Atlantic menhaden (SEDAR 2020a). This assessment extends the fishery-independent and –dependent data for Atlantic menhaden through 2021, reruns the peer-reviewed Beaufort Assessment Model (BAM), and determines stock status of Atlantic menhaden using the ecological reference points (ERPs) defined in SEDAR 2020b and accepted for management use in 2020.

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) through 2021, 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 slowly decreasing over the last few years while the northern reduction landings were increasing, although southern landings were larger than those in the north (Figure 1).

Bait landings from 1955-1984 were compiled from historic records whereas bait landings for 1985-2021 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 landings in the south for the last four years (Figure 2). Several states revised their landings in the beginning of the validated time series (mid-1980s to mid-1990s) which resulted in higher landings than those in the benchmark (Figure 3). States routinely refine their landings as part of their internal data management processes and this updated time series represents the best data available. Particularly in the northern region, the revised landings resulted in a more abrupt change from the pre-1985 landings, which are from historic records and cannot be validated, to the post-1985 validated landings. The revised landings in the northern region did affect the base run of the BAM model and a bridge run has been done as part of TOR 4 to investigate the effects of this change on the results.

The Marine Recreational Fisheries Statistics Survey (MRFSS, 1981-2003) and the Marine Recreational Information Program (MRIP, 2004-2021) 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, although slightly higher in recent years (Figure 4). For use in the BAM, recreational harvest, which comprises less than 1% of coastwide harvest, was added to the bait landings. Reduction landings have remained relatively steady in the last few years with bait landings increasing over time, comprising 30% of coastwide landings in 2021 (Figure 5).

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 Conn method for combining the individual indices into regional or coastwide composite indices can be used on surveys with different time series lengths or missing data and allowed for a terminal year of 2021 despite some surveys not operating during the pandemic.

The coastwide YOY index of relative abundance for Atlantic menhaden indicated high abundance in the 1970s and 1980s, with declines through the 1990s (Figure 6). YOY abundance remained low but slightly higher than the benchmark's terminal year value in 2017 (SEDAR 2020a) which was the lowest value in the time series. The NAD index predicted variable abundance throughout the time series with high abundance occurring in the terminal years of 2019-2021 (Figure 7). There is large uncertainty associated with the high terminal year estimates because all three surveys used in the NAD had at least one year of missing data due to the pandemic. The MAD index predicted high abundance in the beginning of the time series followed by a lower but variable abundance through the late 1990s-early 2010s (Figure 8). 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 but 2021 indicating a mid-range abundance. The SAD index predicted high abundance in 1990 followed by low abundance through the mid-2000s (Figure 9). The index peaked again in 2006 but then decreased and was variable through the terminal year. For the NAD and MAD 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 10). The index increased in the last few years through the terminal year of 2020. Data from 2021 were not available. This index was included in the base run of the assessment model in SEDAR 2020a but was excluded in this update's base run due to issues with model fitting which will be discussed in TOR 4. Additionally, the SAS is recommending that this index is further investigated during the next assessment and included that research recommendation in TOR 7.

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. Two changes were made in the data inputs or structure of the model in this stock assessment update from the benchmark other than adding additional years of data: the exclusion of the MARMAP and EcoMon ichthyoplankton surveys (MARECO) and the exclusion of the 2020 age composition data from the commercial bait fishery in the southern region due to small sample sizes. These changes are discussed in TOR 4 and sensitivity runs were developed to investigate those exclusions. 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) using the same methods as was used for the benchmark.

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.

The benchmark assessment was updated with all available data through the terminal year of 2021. Some changes were made to the updated run from the benchmark assessment, those changes included:

1. Censoring of the 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 and are discussed below under the topics of sensitivity and bridge runs. Briefly, the quality and quantity of data at the end of the time series during the COVID-19 pandemic years caused some problems with estimation of parameters and the determination of year-class strength (recruitment). The 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.

In general, the updated base run assessment is similar to the benchmark assessment. 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*) decreased in 2020 and 2021 and has been relatively stable since the mid-1990s (Figure 11). The recruitment class for 2019 and 2020 appears to be larger (Figure 12). However, the model does have difficulty estimating large year-classes in the terminal year of the model, as evidenced by the benchmark assessment. In addition, the sampling data for 2020 and 2021 are reduced because of the pandemic; thus, the status of the 2019 and 2020 year-classes may not be known until a further update to this assessment. Age-1+ biomass increased during the last three years, showing a steady increase (Figure 13). Finally, fecundity has been stable during the most recent years, but a large increase was estimated for 2021 (Figure 14). That rise in fecundity was due to an increase in fecundity for age-2 individuals, which is linked to a larger estimated year class in 2019. The SAS cautions that the assessment had difficulty during the benchmark estimating recruitment in the terminal years; specifically, the larger recruitment class estimated during the benchmark was estimated to be lower in this assessment. Thus, additional years of data in the next assessment will determine whether the 2019 year class remains larger or not. Until that time, the SAS notes this as an uncertainty.

The SAS evaluated one bridge run for the update assessment to address the changes in the validated northern commercial bait time series of landings which was updated by the states. The landings for this update are the best scientific information available and the most accurate time series of landings data available. Thus, this bridge run was completed for illustrative purposes. The SAS found that the largest difference between the base run results and the bridge run were in mid-1980s estimates of *F* on ages 2-4, as expected. The SAS was satisfied that the change in historical bait landings did not result in significant changes in model fit or a difference in stock status.

A series of sensitivity runs were completed to determine the best approach regarding the 2020 and 2021 data. During 2020 and 2021, the pandemic led to reduced or missing data for some fishery-dependent and –independent sampling programs. With the reduced sample sizes, the data that were collected in 2020 and 2021 did not necessarily reflect the same spatial and temporal extent as past years of data. Thus, the SAS choose to run several sensitivity runs including and excluding the 2020 and 2021 data to determine the impacts on the assessment outcomes. The sensitivity runs included:

1. Censoring all 2020 and 2021 data;
2. Including all 2020 and 2021 data;
3. Including the 2020 and 2021 data except for the commercial bait south 2020 age compositions while also including the MARECO or ichthyoplankton index.

Overall, these sensitivity runs demonstrated that the terminal year age composition data inform terminal year recruitment values. Without those data, the terminal year recruitment values are centered on the mean recruitment values.

A set of sensitivity runs was also completed to investigate the inclusion of the MARECO (the ichthyoplankton index). These sensitivity runs included some of those already described above whereby the index was censored or not in combination with the inclusion or censoring of the 2020 and 2021 data. Additionally, the SAS considered runs whereby the terminal year of data for this index was censored with runs with MARECO data until 2014-2020. When updating the assessment, the MARECO index was causing difficulty for parameter estimation and Hessian inversion for the model, as well as the gradient for the final solution being larger than the criterion. Upon further investigation, the MARECO index did not seem to reflect the population trend as well as other data sources. For example, the pattern of the observed MARECO index was not consistent with estimated spawning stock biomass trends despite being used as an indicator of fecundity in the population (Figure 15). The model was unable to match the increase of the MARECO index given the fits to the other indices, landings, and composition data. These discrepancies could occur for many reasons. First, the MARECO index is an ichthyoplankton index while the other indices directly measure older individuals. Second, mechanisms relating the ichthyoplankton index to the population status are difficult to discern given the unknown drivers between the fecundity/larval abundance stage and recruitment. Many potential biological mechanisms could be considered, but the SAS does not have the data to do so at this time. In addition, 2020 and 2021 data are generally atypical within the assessment, thus the MARECO index may be garnering more weight and influence in the model, which could lead to a larger gradient. During the benchmark assessment (SEDAR 2020a), the SAS noted numerous adjustments that needed to be made in order to develop a reasonable MARECO index including removal of strata, removal of months, and adjustments to account for inconsistencies in the two survey methodologies. Given these previous challenges and the influence of the other data issues created by the pandemic, it is not surprising that the use of this index for the update proved problematic for model convergence. While the MARECO index is dropped for this update, the SAS would like to investigate this topic further in future assessments. One option the SAS could consider is using nonlinear relationships between catchability and the MARECO index.

A retrospective analysis was 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 2021, and the retrospective analysis was run back through a terminal year of 2016. Overall, the retrospective runs fall within the uncertainty bounds from the uncertainty analysis. While the SAS completed a retrospective analysis for this assessment, they urge caution when interpreting the results as 2020 and 2021 data were influenced by the pandemic, as described above.

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. A total of 5,000 runs were completed. Some runs were excluded due to gradients, leaving 4,868 MCB runs for analysis. Overall, the uncertainty was large for all the metrics of interest. A Monte Carlo Markov Chain analysis (MCMC) was completed for the previous benchmark but not run for this update assessment. As noted in the benchmark assessment, while the MCB analysis may overestimate the uncertainty surrounding the base run, the MCMC analysis is an underestimate of the uncertainty surrounding the base run. Hence, the MCB analysis is a more conservative approach and was the preferred uncertainty analysis.

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 - Figure A63), and the retrospective analysis (Figure A64 - Figure A71).

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. Thus, stock status was determined using those benchmarks. The fishing mortality rate for the terminal year of 2021 is below the ERP threshold and target ($F_{2021}/F_{ERPThreshold}$ = 0.28; $F_{2021}/F_{ERPTarget}$ = 0.85; Figure 16), and the fecundity for the terminal year of 2021 is above the ERP threshold and target ($FEC_{2021}/FEC_{ERPThreshold}$ = 1.76; $FEC_{2021}/FEC_{ERPTarget}$ = 1.28; Figure 17). 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 18) and the terminal year fecundity was above the ERP threshold for all of the runs (Figure 19). 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 194,400 mt were provided. At a TAC of 194,400 mt, the fishing mortality rate is below the ERP threshold and target, and the fecundity is above the ERP threshold and target (Figure 20). Further projections based on different removal levels will be analyzed at the Board's request.

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.

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. With that in mind, Congress included a Chesapeake Bay Atlantic Menhaden Abundance provision in the Fiscal Year 2022 Consolidated Appropriations Act (Public Law No: 117-103) encouraging NOAA Fisheries, in partnership with ASMFC and relevant states, to collect Atlantic menhaden abundance data in the Chesapeake Bay. Progress to address this research recommendation was made in 2020 when Wilberg et al. completed a project to evaluate survey designs for a combined aerial-hydroacoustic survey for Atlantic menhaden biomass in the Chesapeake Bay which was reviewed and endorsed by the TC. Regardless, no funding has been attached to the project and it remains unimplemented.

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. For example, biological sampling from the bait and reduction fisheries occurred at lower samples sizes or not at all for 2020 and 2021. There is no expectation that those trends will continue following the pandemic and sampling is likely to increase to pre-pandemic levels. Similarly, an ageing workshop for Atlantic menhaden to assess precision and error among readers has not been initiated, despite plans for it in 2020, due to the pandemic and interest from agers to conduct the workshop in person.

In 2021, responding to the research recommendation to develop a spatially-explicit model for Atlantic menhaden, the Board tasked the TC and Ecological Reference Point Work Group (ERP WG) with identifying data needs and timelines for the development of that model. The TC and ERP WG produced a memo on potential spatially-explicit approaches, which highlighted that completing the task would likely extend the timeline for the next benchmark assessment, currently scheduled for 2025. The Board indicated that completing the benchmark stock assessment in 2025 as planned was the highest priority. Therefore, the next benchmark assessments will focus on refining the ERP approach developed in SEDAR 2020a and 2020b. While some spatial considerations may be incorporated in the process of refining the ERP models, spatial modeling will not be pursued until the 2025 benchmark assessments are completed.

During the next benchmark stock assessment process (scheduled for 2025), 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.

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.

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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)	Sept-lagged Jan	1990-2021
	DB Adult Trawl (1990-2021)		
	NJ Ocean Trawl (1990-1997, 1999-2019)		
MAD	MD Gill Net (1985-1995, 1998-2002, 2005-2021)	March-May	1985-2021
	VIMS Shad Gill Net (1998-2021)		
SAD	NC p915 (2008-2019)	April-July	1990-2021
	SEAMAP (1990-2019)		
	GA EMTS (2003-2021)		
YOY	RI Trawl (1990-2021)	Varies by survey	1959-2021
	CT LISTS (1996-2009, 2011-2017)		
	CT River Alosine (1987-2021)		
	CT Thames River Alosine (1998-2016)		
	NY Juvenile Striped Bass Seine (2000-2021)		
	NY Peconic Bay Trawl (1987-2021)		
	NY WLIS Seine (1986-2021)		
	NJ Ocean Trawl (1990-2019)		
	NJ Striped Bass YOY Seine (1986-2019, 2021)		
	DB Inner Bays (1986-2021)		
	MD Coastal Trawl (1972-1992, 1994, 1998-2021)		
	MD Juvenile Striped Bass (1959-2021)		
	VIMS Juvenile Trawl (1990-2021)		
	VIMS Striped Bass Seine (1968-1972, 1980, 1982, 1985-2021)		
	NC p120 (1989-2021)		
	SC Electrofishing (2001-2021)		

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

	Value(s)
Years in Model	1955-2021
Age Plus Group	6+
Fleets	2 (north and south regions for bait and reduction fisheries)
Fecundity	Time-varying fecundity-at-age
Natural Mortality	Age-varying natural mortality
Maturity	Time-varying maturity-at-age based on length-at-age
Sex Ratio	Fixed at 1:1 for males:females

	Age Group						
	0	1	2	3	4	5	6+
Natural Mortality	1.76	1.31	1.03	0.90	0.81	0.76	0.72

Table 3. Current fishing mortality (*F*) and fecundity (*FEC*) ecological reference points (ERP targets and thresholds) along with terminal year values from the base run of the BAM for the stock assessment update for determining stock status. Fecundity is in billions of eggs.

Reference Point	ERP Value	2021 Value	Stock Status
$F_{THRESHOLD}$	0.57	0.16	Not Overfishing
F_{TARGET}	0.19		
$FEC_{THRESHOLD}$	1,492,854	2,570,080	Not Overfished
FEC_{TARGET}	2,003,986		

FIGURES

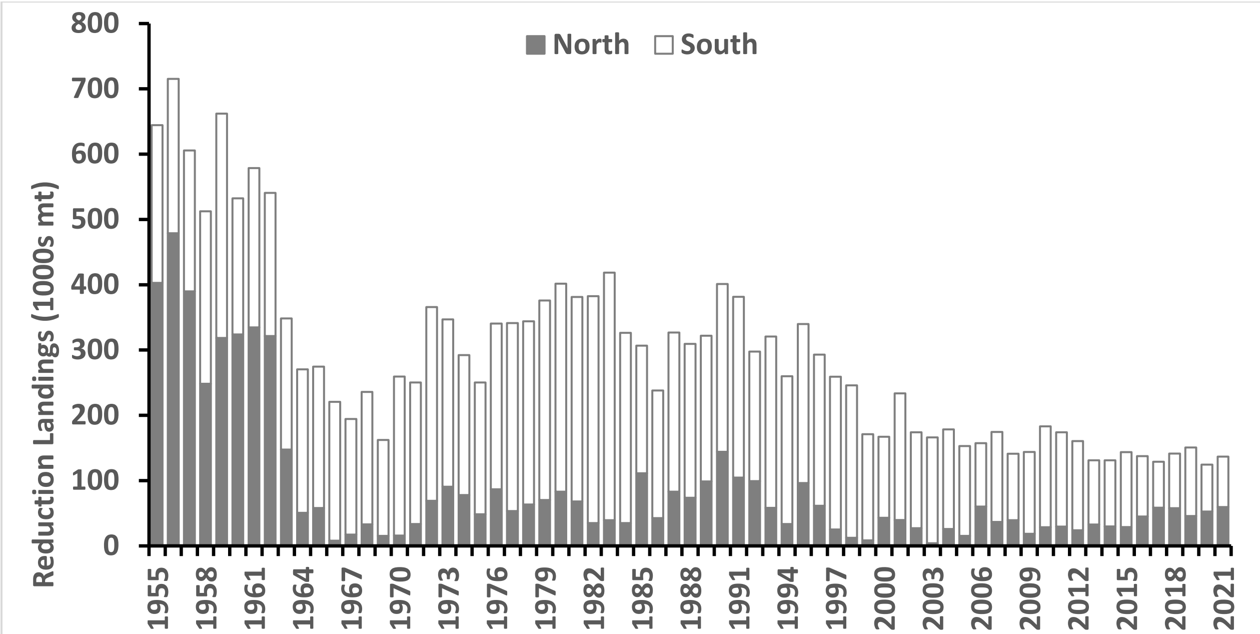


Figure 1. Atlantic menhaden reduction landings (1000s mt) from 1955-2021. The northern region is comprised of landings from north of Virginia Eastern Shore and the southern region is comprised of landings from Virginia Eastern Shore and Chesapeake Bay through Florida (Source: NOAA Fisheries Beaufort).

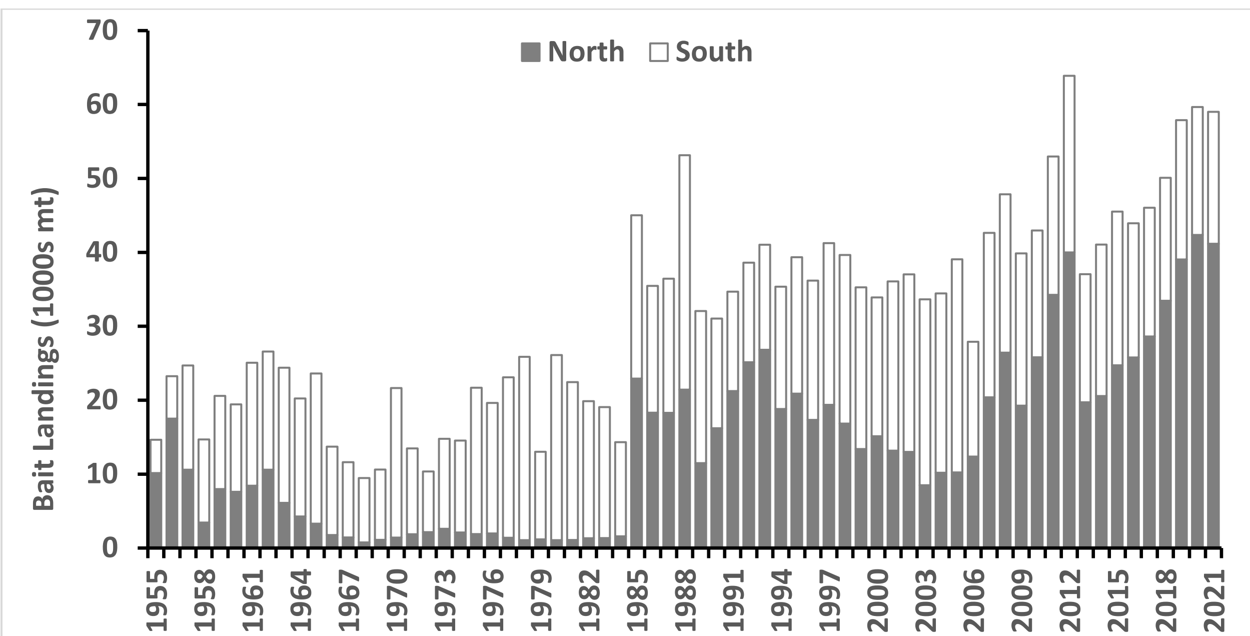


Figure 2. Atlantic menhaden bait landings (1000s mt) from 1955-2021. The northern region includes landings from Maine to Maryland's Eastern Shore, excluding the Chesapeake Bay. The southern region includes landings from the Chesapeake Bay to Florida. Only landings from 1985 on can be validated (Source: ACCSP).

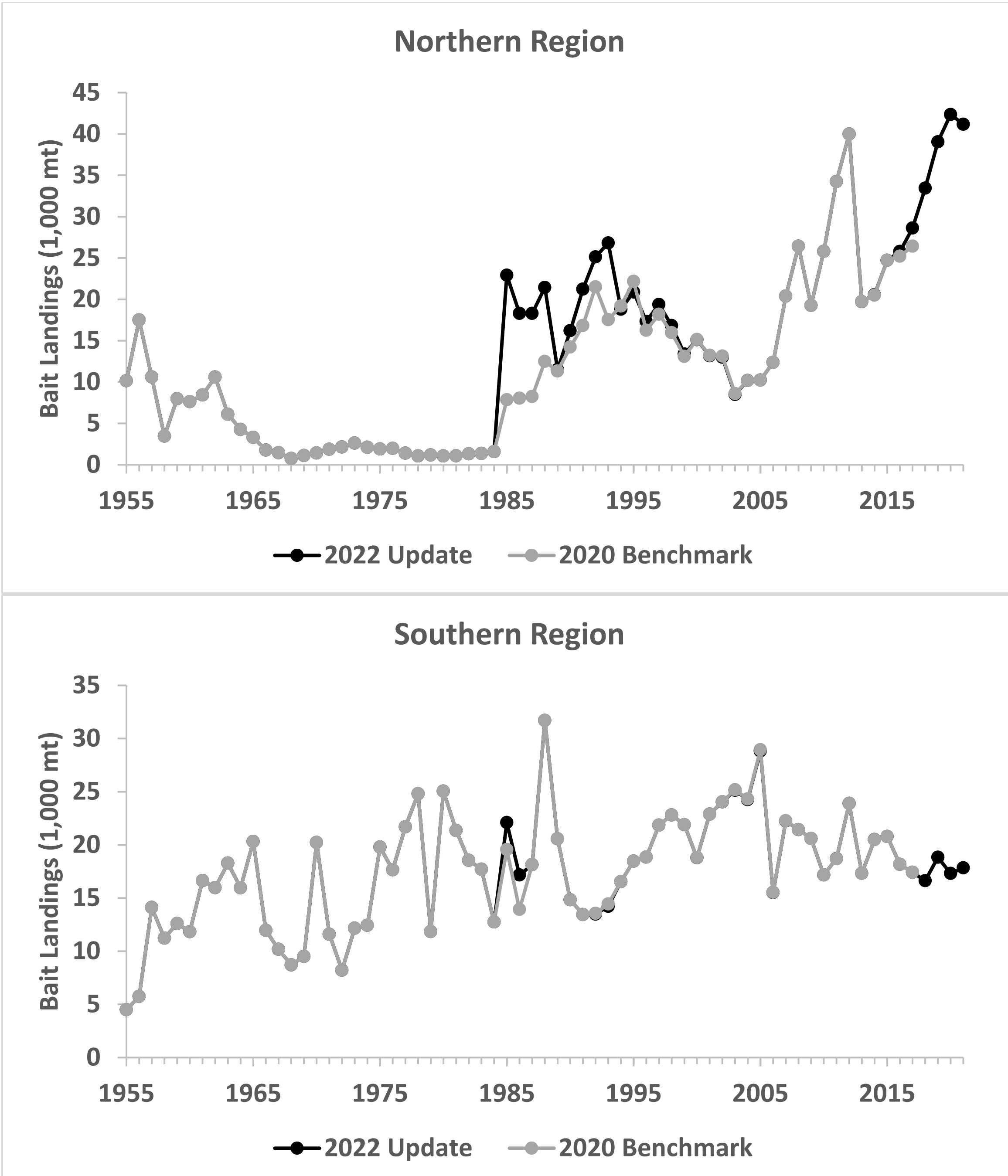


Figure 3. Differences between bait landings from the benchmark and update by region.

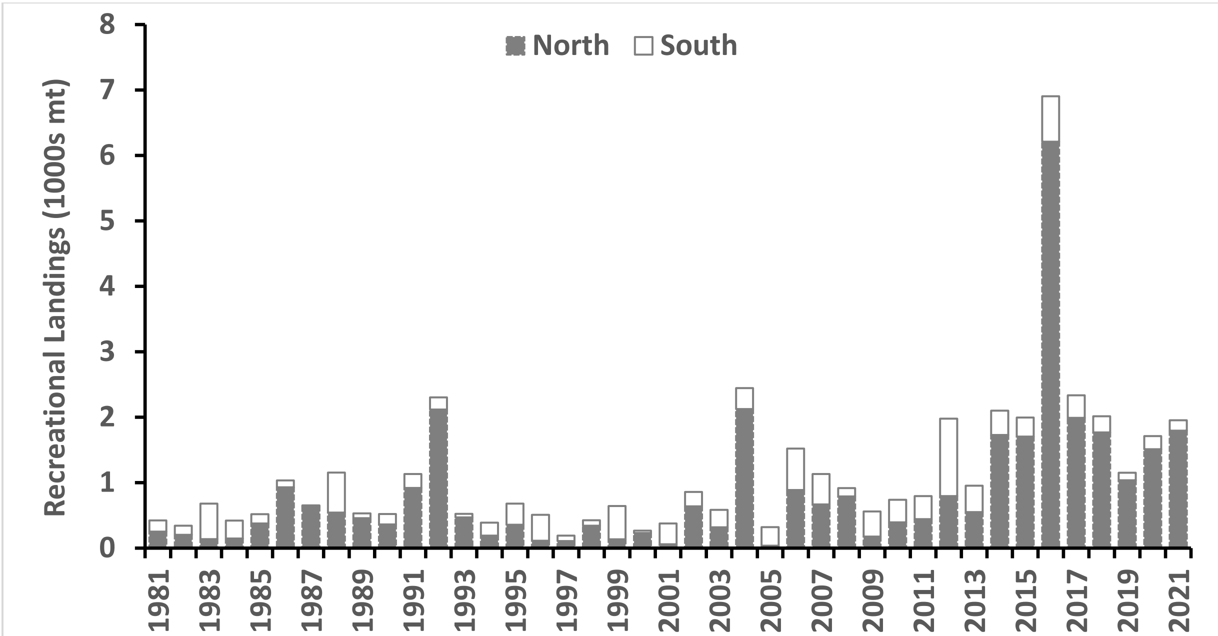


Figure 4. Atlantic menhaden recreational landings (1000s mt) from 1981-2021. The northern region includes landings from Maine to Maryland's Eastern Shore, excluding the Chesapeake Bay. The southern region includes landings from the Chesapeake Bay to Florida (Source: MRIP).

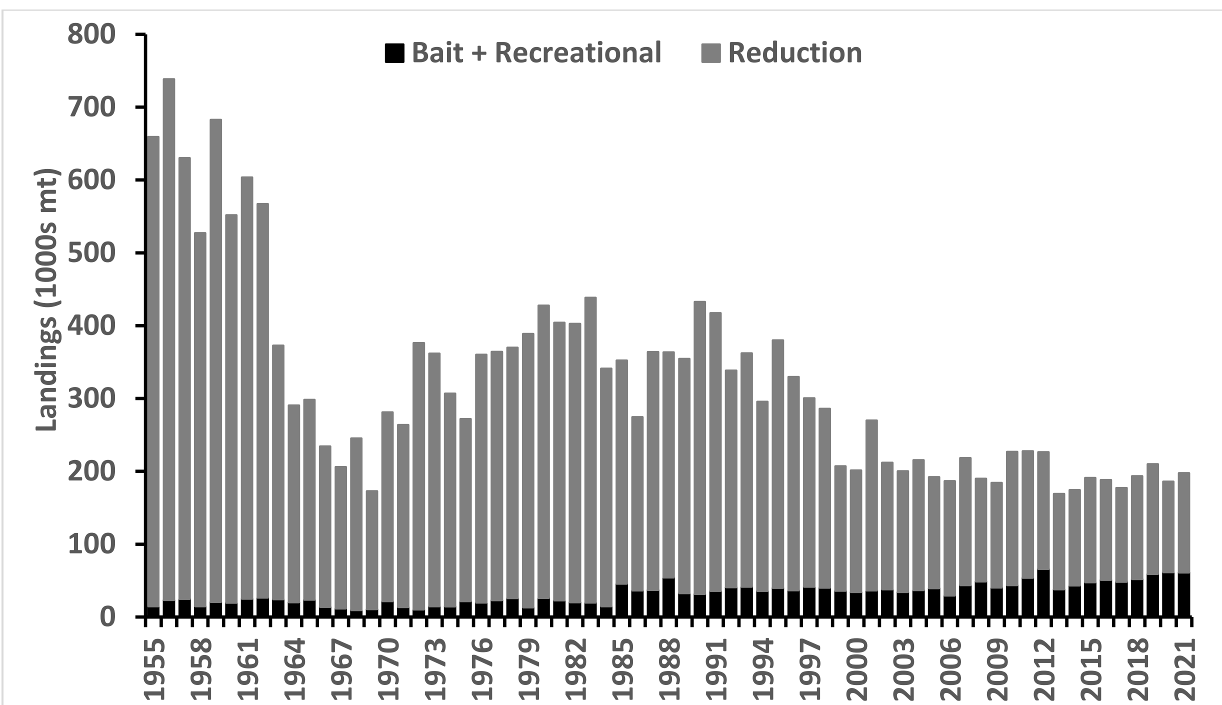


Figure 5. Coastwide Atlantic menhaden landings for the reduction and bait fisheries (1955-2021).

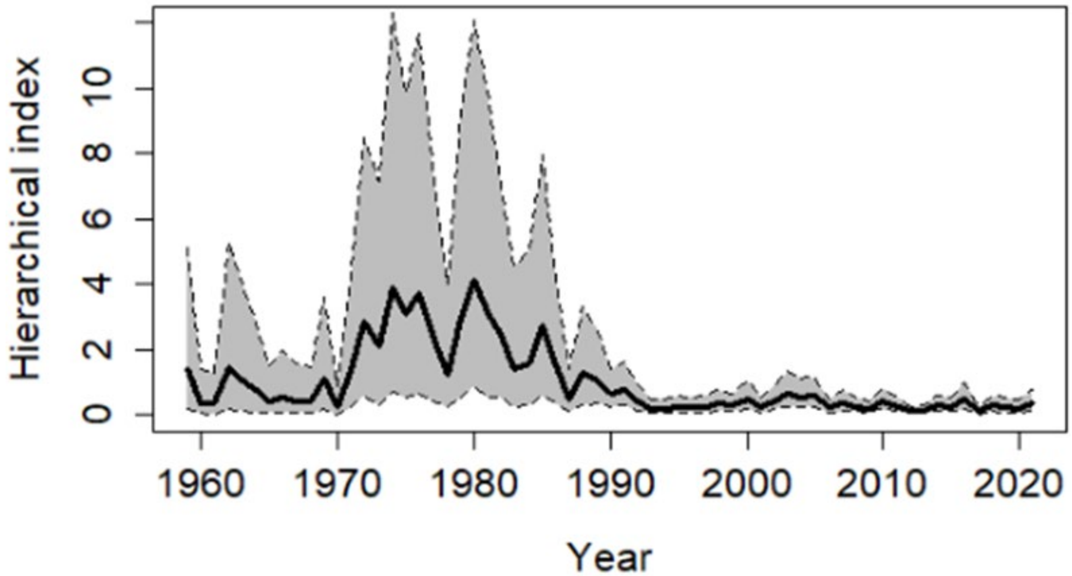


Figure 6. **Time series of the young-of-year (YOY) Atlantic menhaden relative abundance index as estimated from hierarchical analysis (Conn 2010). The black line gives the posterior mean and the grey, dashed lines represent a 95% credible interval about the time series.**

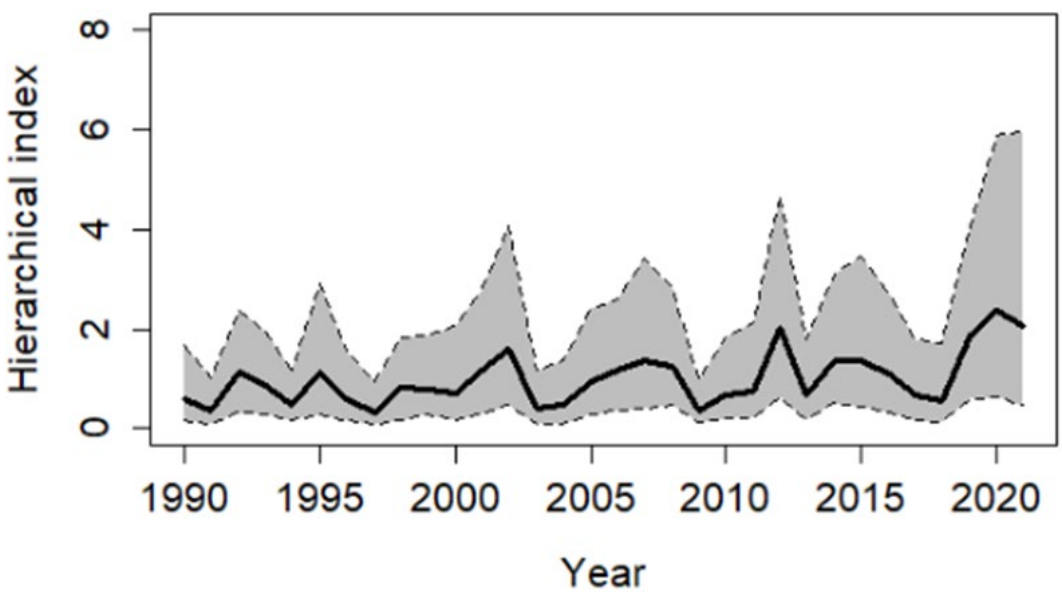


Figure 7. **Time series of the northern adult Atlantic menhaden relative abundance index (NAD) as estimated from hierarchical analysis (Conn 2010). The black line gives the posterior mean and the grey, dashed lines represent a 95% credible interval about the time series.**

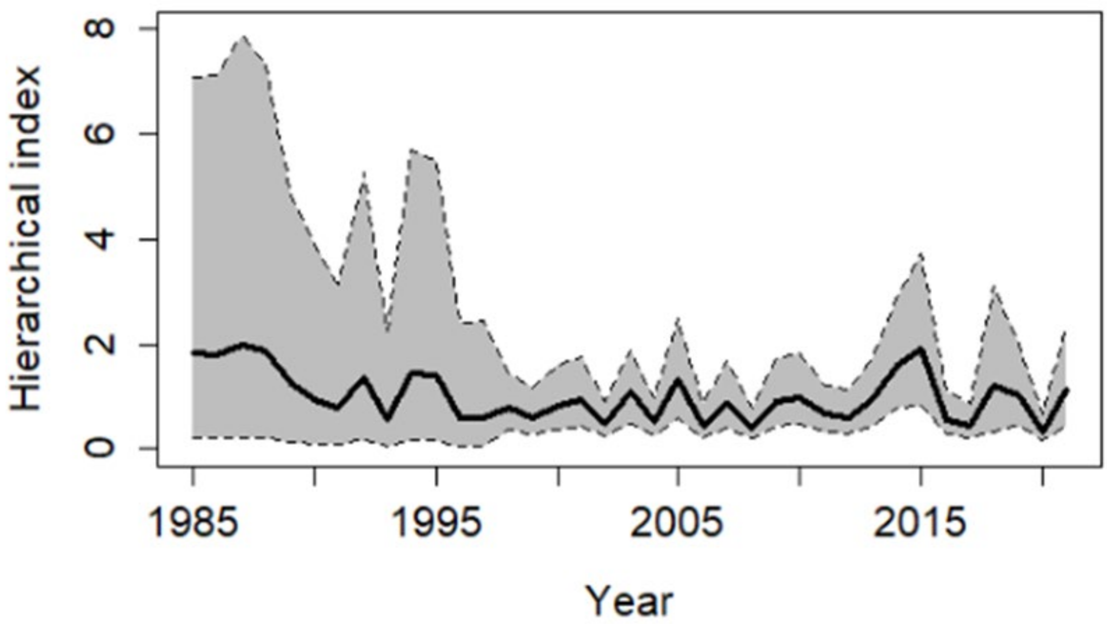


Figure 8. Time series of the Mid-Atlantic adult menhaden relative abundance index (MAD) as estimated from hierarchical analysis (Conn 2010). The black line gives the posterior mean and the grey, dashed lines represent a 95% credible interval about the time series.

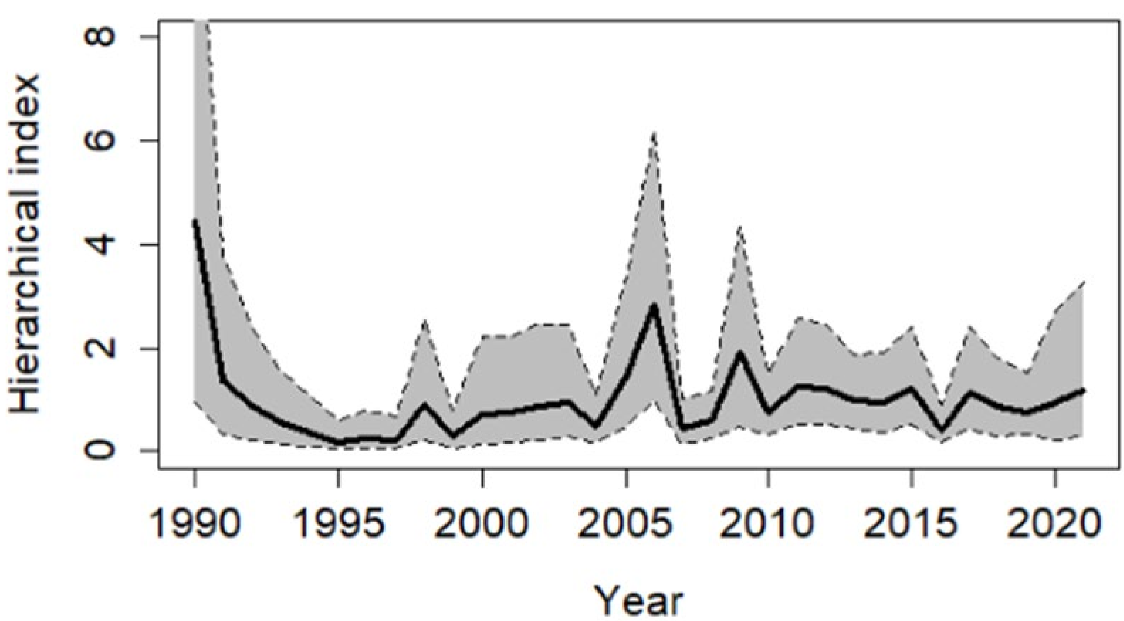


Figure 9. Time series of the southern adult Atlantic menhaden relative abundance index (SAD) as estimated from hierarchical analysis (Conn 2010). The black line gives the posterior mean and the grey, dashed lines represent a 95% credible interval about the time series.

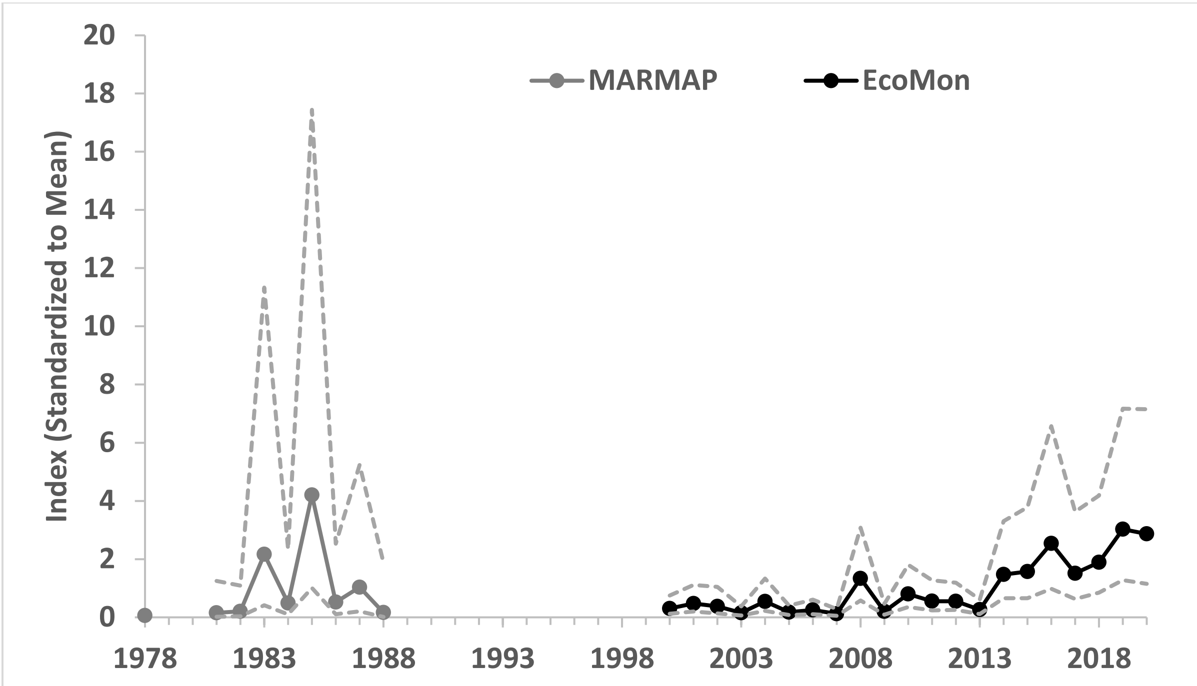


Figure 10. Standardized index of relative spawning stock biomass abundance of Atlantic menhaden developed from the MARMAP and EcoMon ichthyoplankton surveys. Dashed lines represent 95% confidence intervals. The 1978 upper confidence interval has not been included on the graph because of its large value (94).

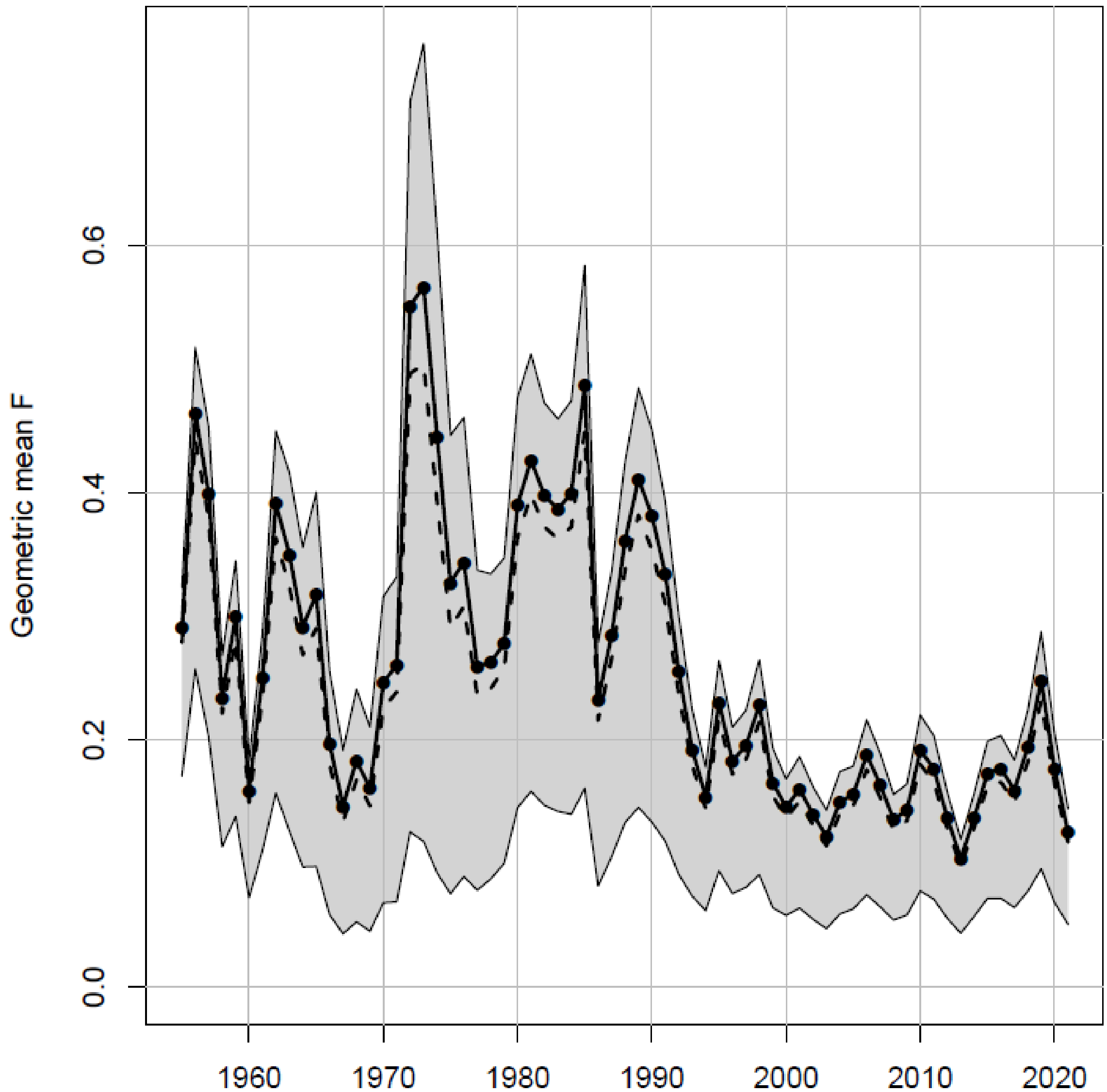


Figure 11. Time series of the geometric mean fishing mortality rate for ages-2 to 4 from 1955-2021 for the Monte Carlo bootstrap runs. The grey represents the 5th and 95th percentiles across the runs, while the black line with closed black circles represents the base run. The dashed line represents the median of the MCB runs.

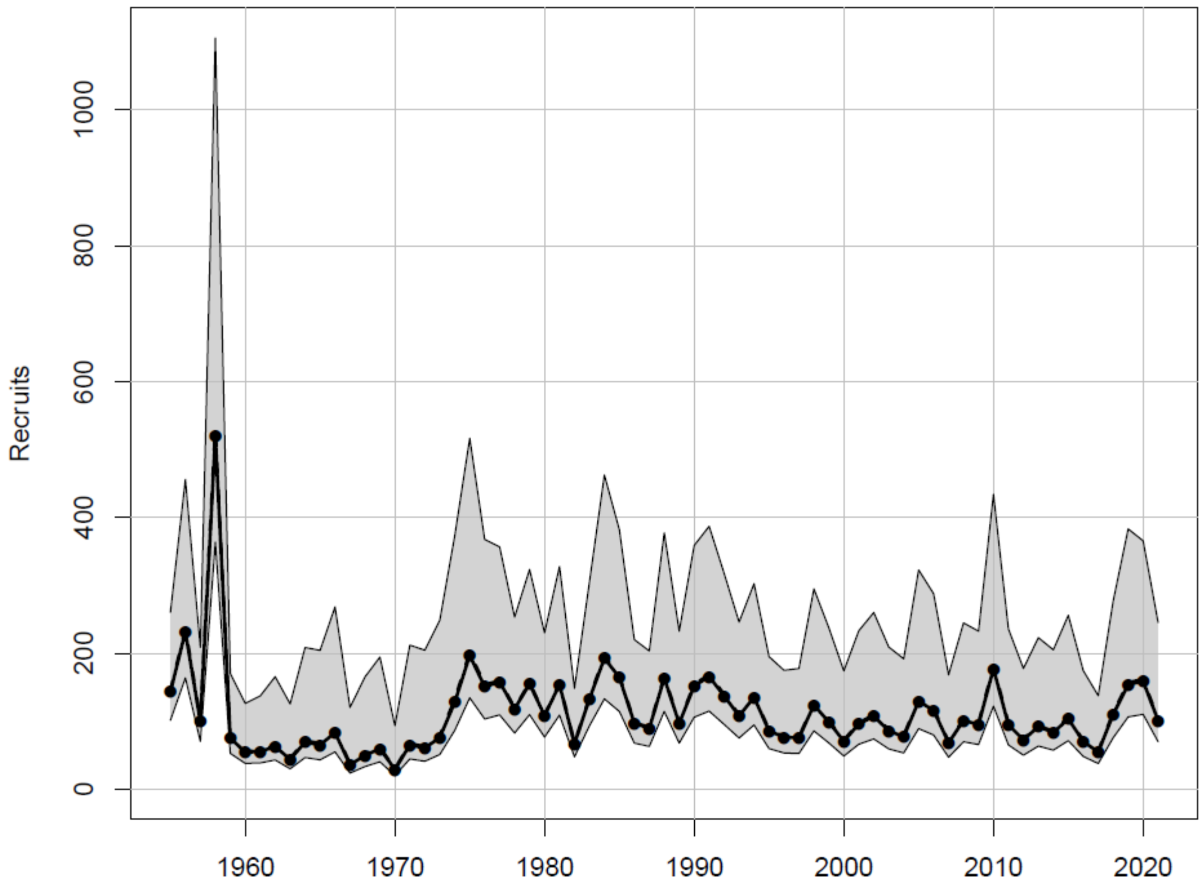


Figure 12. Estimated recruitment over time from 1955-2021 for the Monte Carlo bootstrap runs. The grey represents the 5th and 95th percentiles across the runs, while the black line with closed black circles represents the base run.

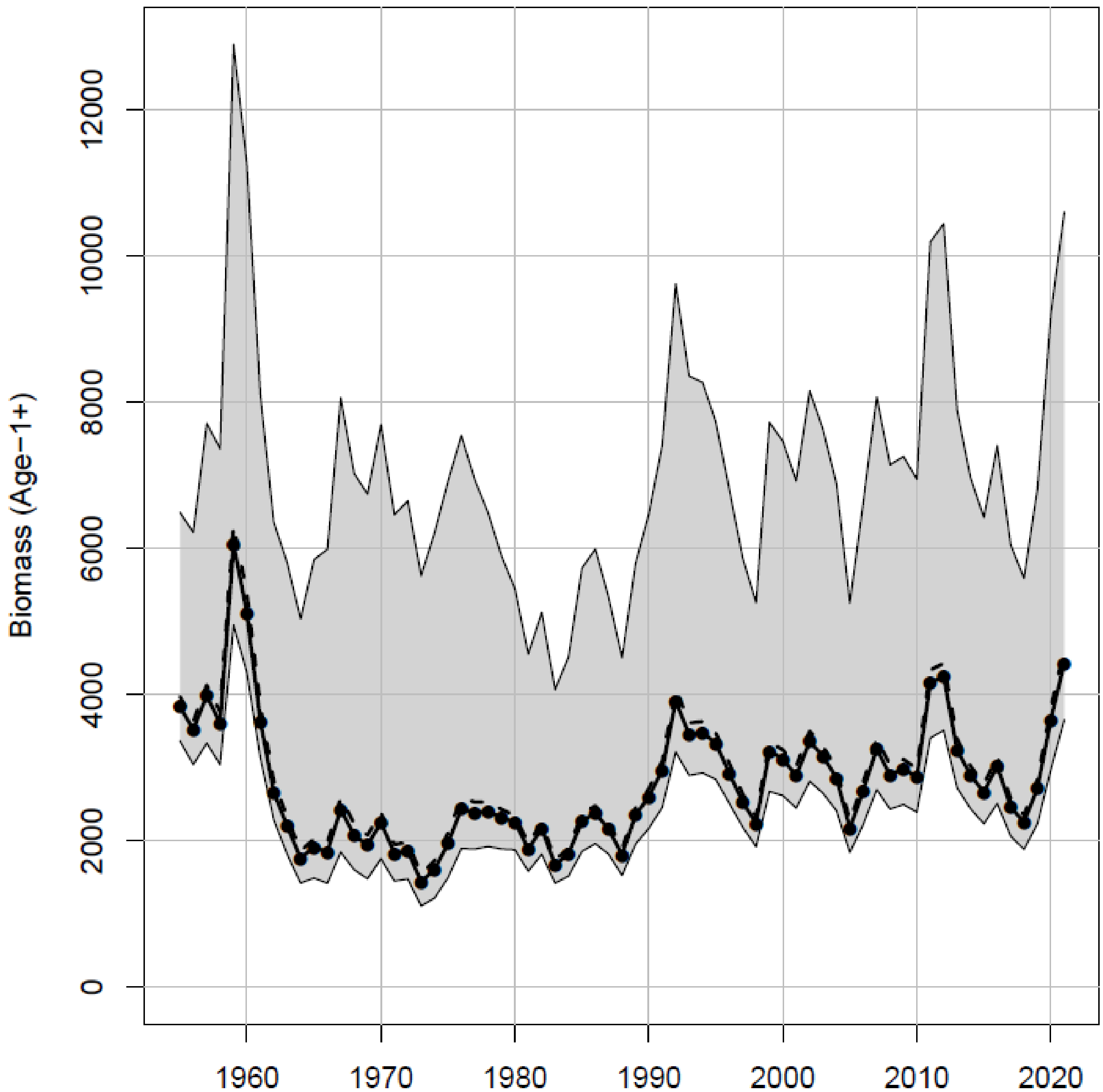


Figure 13. Time series of age-1+ biomass from 1955-2021 for the Monte Carlo bootstrap runs. The grey represents the 5th and 95th percentiles across the runs, while the black line with closed black circles represents the base run. The dashed line represents the median of the MCB runs.

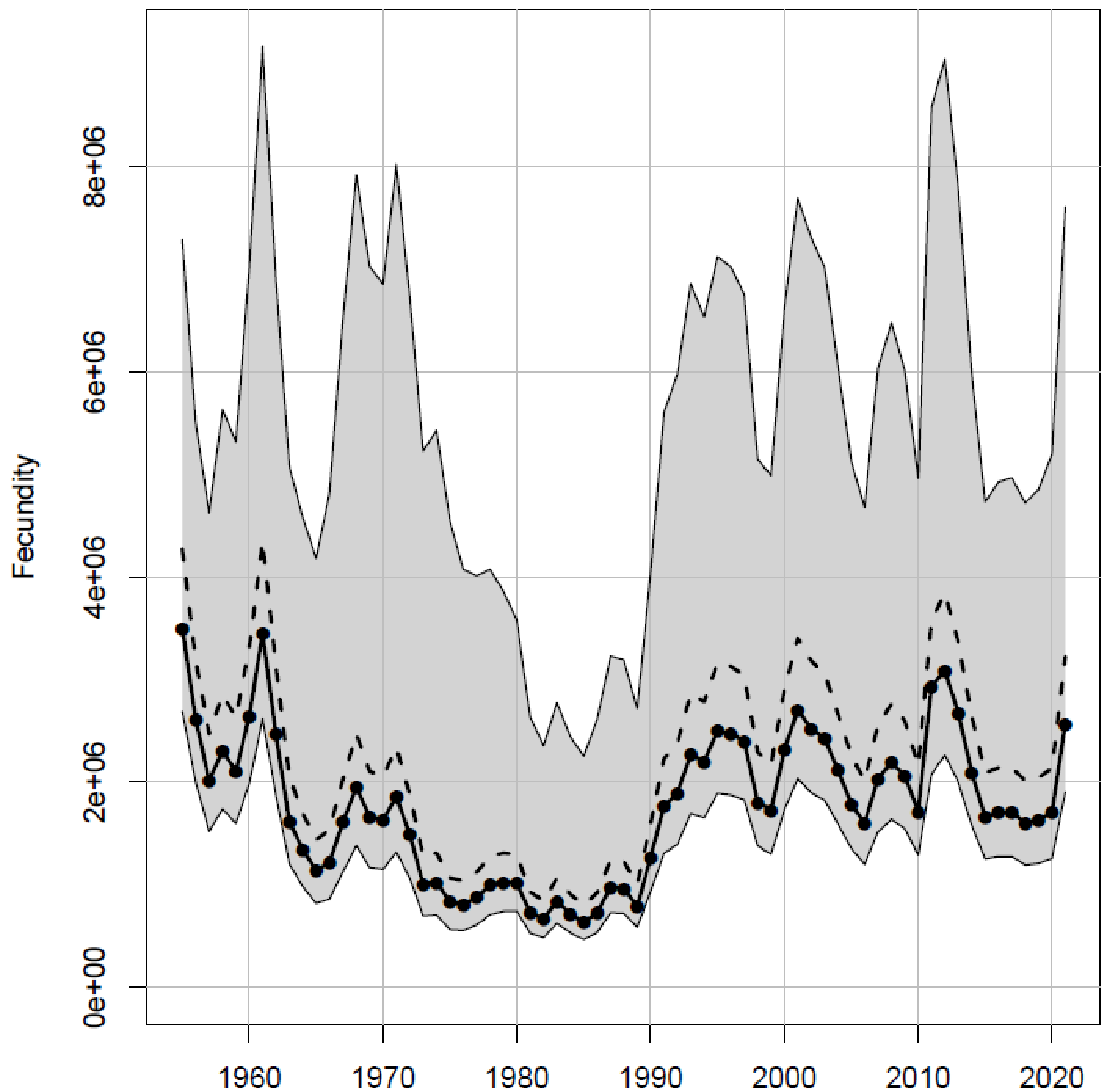


Figure 14. Time series of fecundity from 1955-2021 for the Monte Carlo bootstrap runs. The grey represents the 5th and 95th percentiles across the runs, while the black line with closed black circles represents the base run. The dashed line represents the median of the MCB runs.

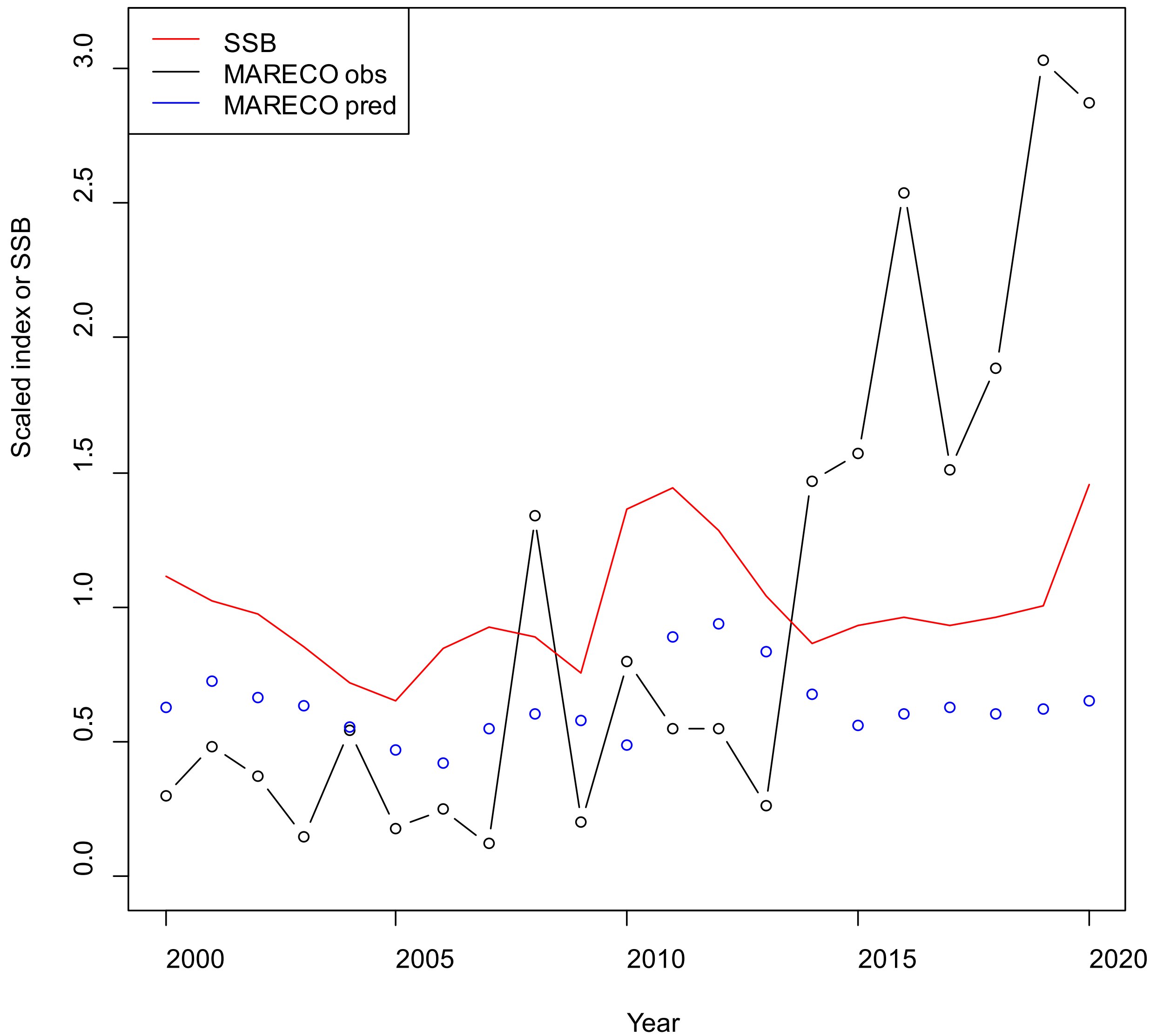


Figure 15. Observed and predicted values for the MARECO index and estimated spawning stock biomass (SSB).

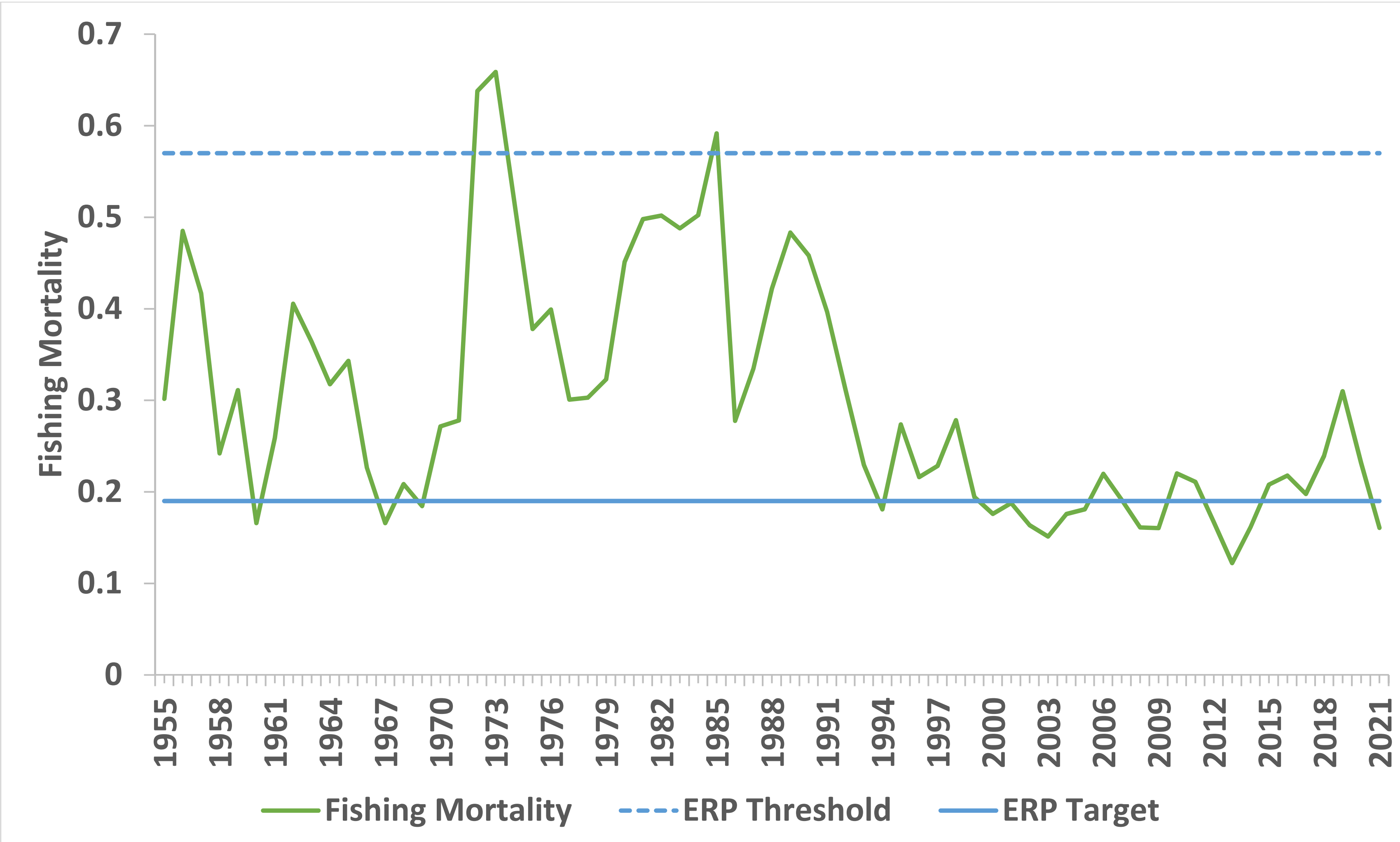


Figure 16. The full fishing mortality rate for 1955-2021 compared to the ecological reference point (ERP) threshold and target for fishing mortality rate. The full fishing mortality is dependent upon selectivity for the fisheries, and thus can represent ages-2 to 4, depending upon the year.

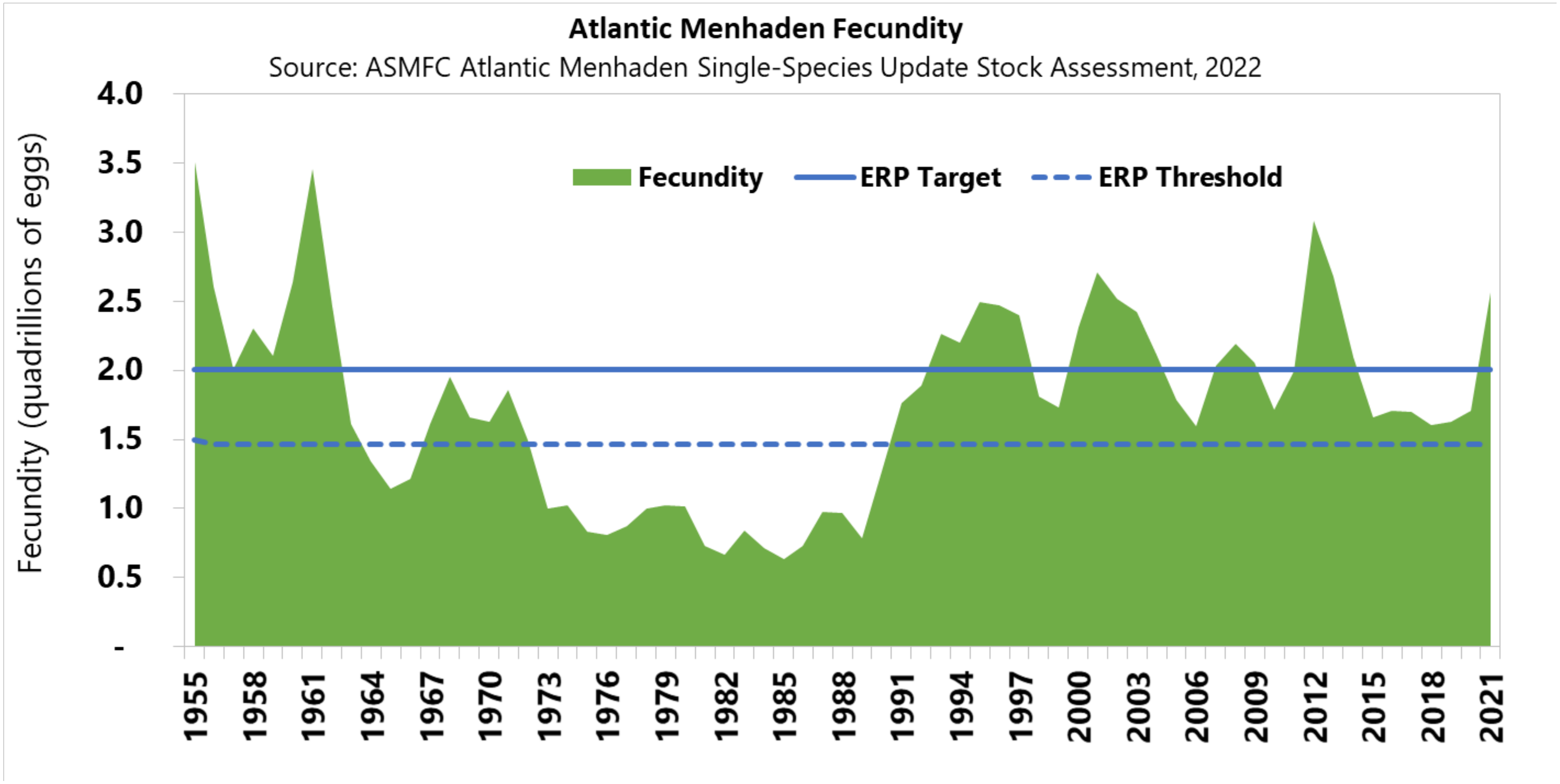


Figure 17. The fecundity for 1955-2021 compared to the ecological reference point (ERP) threshold and target for fecundity.

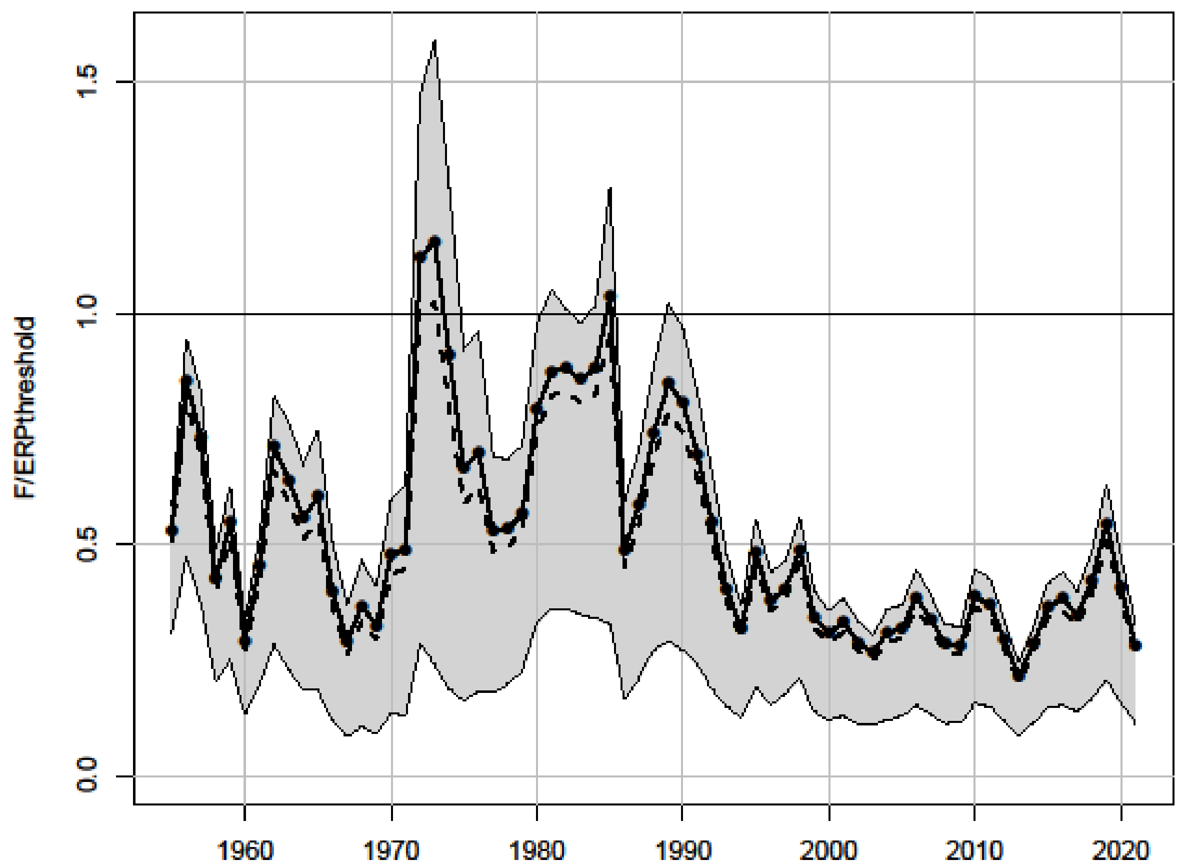


Figure 18. Fishing mortality rate from the MCB analysis over the ERP *F* threshold. The grey represents the 5th and 95th percentiles across the runs, while the black line with closed black circles represents the base run. The dashed line represents the median of the MCB run.

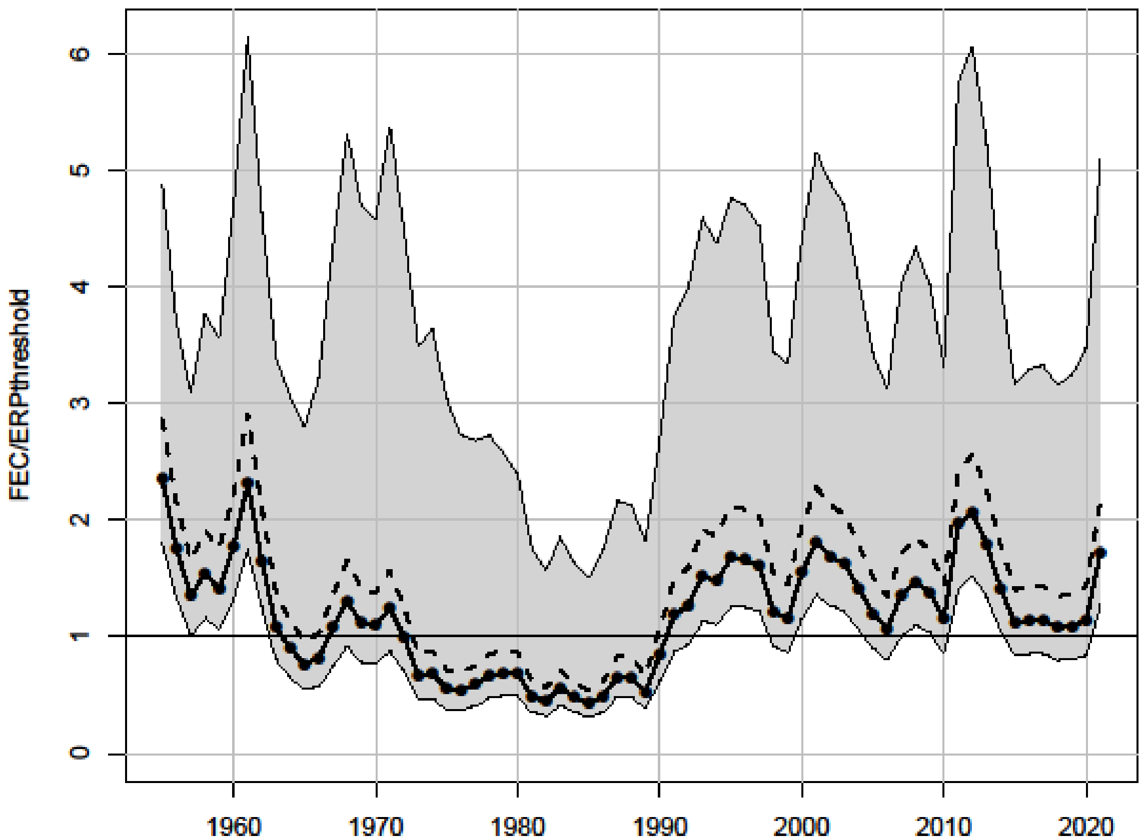


Figure 19. Fecundity from the MCB analysis over the ERP fecundity threshold. The grey represents the 5th and 95th percentiles across the runs, while the black line with closed black circles represents the base run. The dashed line represents the median of the MCB runs.

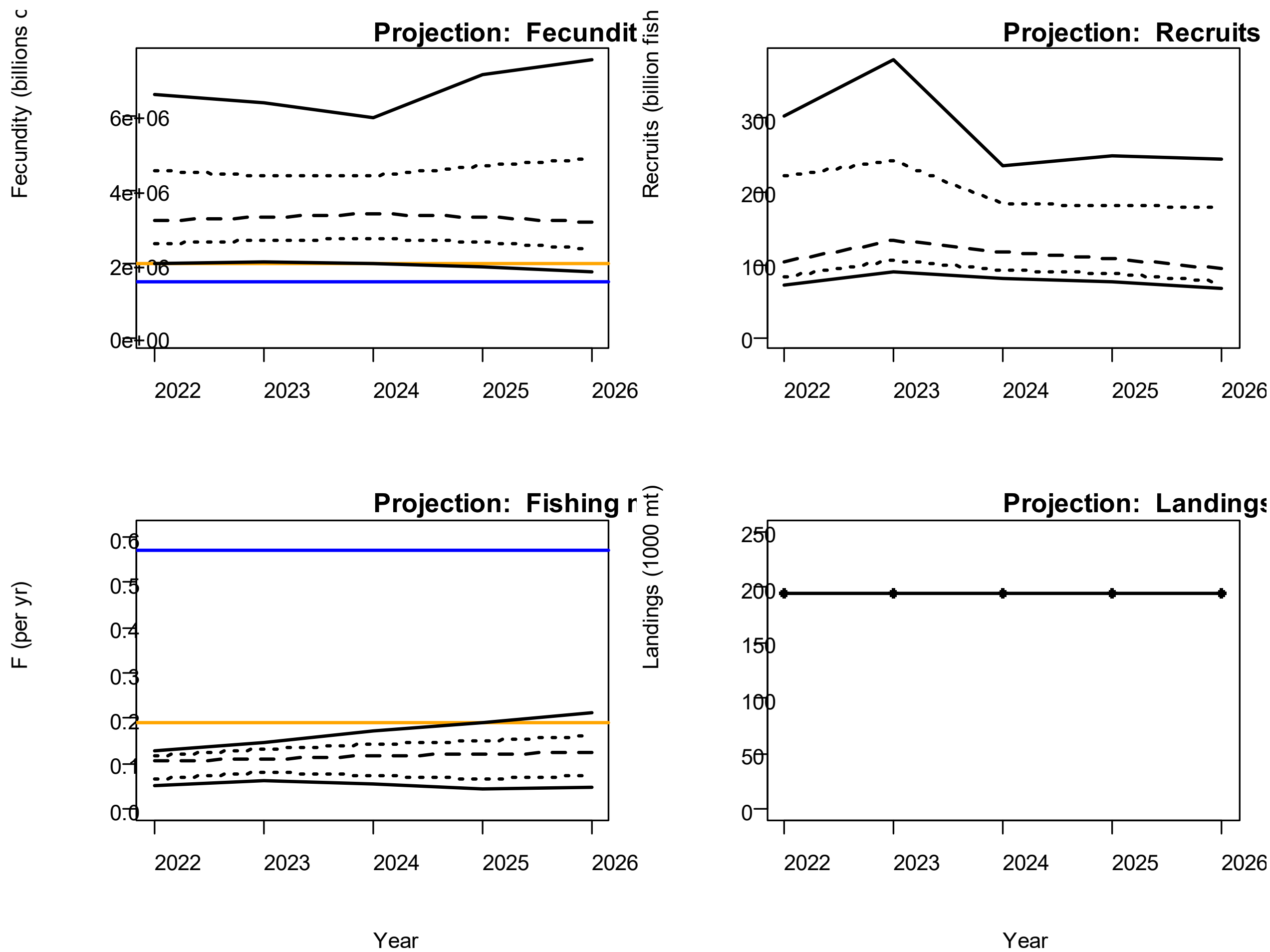


Figure 20. Fecundity, fishing mortality rate, and recruits projected from 2022 to 2026 for a coastwide total allowable catch of 194,400 mt. The orange lines represent the target fishing mortality rate and fecundity for the ecological reference points, while the blue lines represent the threshold fishing mortality rate and fecundity for the ecological reference points.

APPENDIX

Appendix Tables

Table A1. Atlantic menhaden landings (in 1,000s of metric tons) by fishery and region, 1955-2021.

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

Table A1. *Continued*

Year	Reduction Landings			Bait Landings			Recreational Landings			Total Landings
	Total	North	South	Total	North	South	Total	North	South	
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	45.02	22.92	22.10	0.52	0.38	0.14	352.21
1986	237.99	42.57	195.42	35.47	18.30	17.17	1.04	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	21.43	31.70	1.15	0.54	0.61	363.58
1989	322.00	98.82	223.18	32.07	11.49	20.57	0.53	0.46	0.08	354.60
1990	401.15	144.10	257.05	31.04	16.21	14.84	0.52	0.36	0.16	432.72
1991	381.43	104.55	276.87	34.68	21.23	13.45	1.13	0.92	0.21	417.24
1992	297.64	99.14	198.50	38.61	25.13	13.48	2.30	2.12	0.19	338.55
1993	320.60	58.37	262.23	41.04	26.82	14.22	0.52	0.47	0.05	362.16
1994	259.99	33.39	226.60	35.35	18.81	16.54	0.39	0.19	0.20	295.73
1995	339.92	96.30	243.62	39.35	20.88	18.47	0.68	0.36	0.32	379.95
1996	292.93	61.55	231.38	36.19	17.34	18.85	0.51	0.11	0.40	329.62
1997	259.14	25.17	233.98	41.24	19.38	21.86	0.19	0.11	0.08	300.57
1998	245.91	12.33	233.58	39.64	16.83	22.81	0.43	0.34	0.08	285.98
1999	171.19	8.42	162.77	35.27	13.39	21.89	0.64	0.13	0.51	207.11
2000	167.26	43.19	124.08	33.91	15.11	18.79	0.27	0.23	0.04	201.43
2001	233.56	39.62	193.94	36.06	13.17	22.89	0.38	0.06	0.32	269.99
2002	174.07	27.17	146.89	37.04	13.00	24.04	0.86	0.64	0.22	211.96
2003	166.11	4.15	161.96	33.64	8.50	25.14	0.58	0.32	0.27	200.33
2004	178.47	25.91	152.55	34.44	10.19	24.25	2.45	2.12	0.32	215.35
2005	152.85	15.37	137.48	39.06	10.23	28.83	0.32	0.04	0.28	192.23
2006	157.36	60.15	97.21	27.89	12.38	15.52	1.52	0.89	0.63	186.77
2007	174.48	36.63	137.84	42.63	20.39	22.24	1.13	0.67	0.47	218.24
2008	141.14	39.30	101.84	47.87	26.43	21.44	0.92	0.79	0.13	189.93
2009	143.75	18.66	125.09	39.86	19.26	20.60	0.56	0.18	0.39	184.17
2010	183.10	28.67	154.43	42.97	25.80	17.17	0.74	0.39	0.35	226.81
2011	174.02	29.57	144.45	52.96	34.26	18.70	0.80	0.44	0.35	227.78
2012	160.62	23.91	136.71	63.89	39.99	23.90	1.98	0.80	1.18	226.48
2013	131.02	32.70	98.32	37.04	19.72	17.32	0.95	0.55	0.40	169.01
2014	131.10	29.90	101.20	41.06	20.56	20.50	2.10	1.73	0.37	174.26
2015	143.50	28.80	114.70	45.52	24.73	20.79	2.00	1.70	0.29	191.02
2016	137.40	45.00	92.40	43.94	25.78	18.16	6.90	6.21	0.69	188.25
2017	128.92	58.45	70.47	46.04	28.62	17.42	2.33	1.99	0.35	177.29
2018	141.31	57.72	83.59	50.08	33.45	16.63	2.01	1.77	0.25	193.41
2019	150.82	45.78	105.05	57.88	39.05	18.83	1.15	1.04	0.11	209.86
2020	124.60	52.55	72.05	59.66	42.35	17.31	1.71	1.51	0.20	185.98
2021	136.69	59.62	77.07	59.00	41.17	17.83	1.95	1.80	0.16	197.65

Table A2. Catch-at-age for the northern commercial reduction fishery from 1955-2021.

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	0.503	0.407	0.081	0.008	0	0	650
2020								0
2021	0	0.106	0.849	0.045	0	0	0	80

Table A3. Catch-at-age for the southern commercial reduction fishery from 1955-2021.

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

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

Year	0	1	2	3	4	5	6+	# of fish sampled
1985	0	0.010	0.754	0.116	0.093	0.022	0.006	0
1986	0	0.001	0.207	0.563	0.116	0.091	0.023	0
1987	0	0.002	0.215	0.531	0.226	0.016	0.010	0
1988	0	0	0.070	0.521	0.363	0.041	0.004	0
1989	0	0.010	0.216	0.374	0.310	0.089	0.001	30
1990	0	0.003	0.536	0.261	0.143	0.053	0.005	0
1991	0	0.014	0.247	0.543	0.136	0.048	0.011	0
1992	0	0.027	0.359	0.210	0.312	0.074	0.018	0
1993	0	0.008	0.327	0.494	0.099	0.065	0.008	29
1994	0	0	0.111	0.495	0.341	0.050	0.003	401
1995	0	0	0.092	0.471	0.437	0.001	0	190
1996	0	0	0.413	0.442	0.137	0.008	0	203
1997	0	0	0.145	0.324	0.395	0.118	0.018	111
1998	0	0	0.104	0.379	0.420	0.084	0.013	225
1999	0	0	0.147	0.476	0.322	0.044	0.011	201
2000	0	0.004	0.416	0.314	0.229	0.030	0.007	266
2001	0	0	0.112	0.735	0.135	0.014	0.004	678
2002	0	0	0.054	0.553	0.335	0.058	0	524
2003	0	0	0.128	0.663	0.199	0.010	0	101
2004	0	0.007	0.438	0.381	0.161	0.013	0	29
2005	0	0.002	0.188	0.626	0.162	0.022	0	0
2006	0	0.004	0.279	0.566	0.147	0.001	0.004	259
2007	0	0	0.384	0.482	0.125	0.008	0.002	729
2008	0	0	0.262	0.585	0.139	0.013	0	973
2009	0	0	0.204	0.608	0.175	0.013	0	435
2010	0	0	0.365	0.380	0.227	0.025	0.002	466
2011	0	0	0.142	0.486	0.327	0.045	0	449
2012	0	0	0.392	0.468	0.130	0.008	0.002	547
2013	0	0	0.257	0.555	0.159	0.029	0	236
2014	0	0	0.066	0.525	0.387	0.020	0.002	806
2015	0	0.002	0.377	0.522	0.099	0	0	1291
2016	0	0.020	0.390	0.529	0.054	0.007	0	1018
2017	0	0.017	0.565	0.380	0.036	0.001	0	1487
2018	0	0.000	0.272	0.595	0.123	0.010	0	331
2019	0	0.038	0.357	0.445	0.142	0.015	0.004	837
2020	0	0.007	0.688	0.251	0.045	0.007	0.002	754
2021	0	0.030	0.651	0.234	0.082	0.004	0	234

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

Year	0	1	2	3	4	5	6	# of fish sampled
1985	0.004	0.313	0.659	0.016	0.006	0.002	0	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	220
1988	0.004	0.060	0.663	0.232	0.038	0.003	0	10
1989	0.004	0.341	0.577	0.063	0.013	0.003	0	0
1990	0.005	0.061	0.903	0.026	0.003	0.001	0	10
1991	0.012	0.301	0.595	0.084	0.005	0.001	0	78
1992	0.000	0.554	0.446	0.000	0	0	0	70
1993	0.008	0.357	0.530	0.097	0.006	0.003	0	121
1994	0.001	0.142	0.650	0.150	0.052	0.005	0	139
1995	0	0.392	0.374	0.217	0.017	0	0	174
1996	0	0.006	0.757	0.199	0.037	0	0	156
1997	0	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	0.105	0.663	0.174	0.052	0.006	0	338
2000	0.008	0.222	0.659	0.112	0	0	0	270
2001	0.004	0.043	0.658	0.275	0.017	0.004	0	286
2002	0	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	0	328
2004	0	0.066	0.733	0.167	0.031	0.003	0	327
2005	0	0.008	0.515	0.447	0.027	0.003	0	316
2006	0	0.327	0.451	0.197	0.024	0	0	220
2007	0	0.243	0.671	0.067	0.019	0	0	434
2008	0.005	0.044	0.809	0.112	0.017	0.013	0	366
2009	0.004	0.241	0.367	0.341	0.047	0	0	573
2010	0.003	0.306	0.527	0.102	0.059	0.002	0	435
2011	0	0.338	0.470	0.121	0.051	0.020	0	508
2012	0	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	434
2014	0	0.437	0.365	0.138	0.055	0.005	0	559
2015	0.010	0.309	0.589	0.089	0.002	0	0	251
2016	0	0.225	0.423	0.324	0.021	0.007	0	205
2017	0	0.267	0.496	0.229	0.008	0	0	137
2018	0	0.328	0.446	0.166	0.060	0.001	0	280
2019	0	0.580	0.250	0.125	0.039	0.003	0.003	684
2020	0	0.004	0.023	0.973	0	0	0	65
2021	0	0.689	0.307	0.003	0.001	0.001	0	101

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	1.40	1.05						
1960	0.39	1.04						
1961	0.34	1.05						
1962	1.46	1.00						
1963	1.07	1.05						
1964	0.74	1.09						
1965	0.41	1.05						
1966	0.54	1.03						
1967	0.42	1.04						
1968	0.43	0.92						
1969	1.10	0.88						
1970	0.26	0.91						
1971	1.33	0.87						
1972	2.87	0.75						
1973	2.10	0.93						
1974	3.90	0.83						
1975	3.09	0.82						
1976	3.72	0.81						
1977	2.43	0.82						
1978	1.26	0.83						
1979	2.96	0.82						
1980	4.12	0.73						
1981	3.15	0.82						
1982	2.44	0.73						
1983	1.41	0.84						
1984	1.56	0.83						
1985	2.72	0.74			1.82	1.14		
1986	1.50	0.69			1.80	1.15		
1987	0.50	0.68			1.99	1.16		
1988	1.27	0.64			1.89	1.11		
1989	1.09	0.55			1.23	1.15		

Table A6. ***Continued***

Year	YOY		NAD		MAD		SAD	
	Index	CV	Index	CV	Index	CV	Index	CV
1990	0.64	0.49	0.60	0.70	0.96	1.16	4.45	0.66
1991	0.76	0.48	0.36	0.68	0.78	1.17	1.38	0.68
1992	0.43	0.48	1.12	0.49	1.35	1.19	0.87	0.68
1993	0.19	0.54	0.87	0.50	0.56	1.22	0.55	0.72
1994	0.21	0.50	0.48	0.55	1.45	1.11	0.35	0.79
1995	0.26	0.52	1.15	0.60	1.39	1.13	0.18	0.86
1996	0.22	0.52	0.59	0.65	0.60	1.19	0.26	0.79
1997	0.27	0.50	0.34	0.69	0.60	1.18	0.22	0.82
1998	0.36	0.48	0.81	0.54	0.79	0.36	0.91	0.70
1999	0.30	0.49	0.78	0.55	0.60	0.39	0.26	0.79
2000	0.48	0.47	0.69	0.75	0.82	0.39	0.72	0.80
2001	0.26	0.45	1.18	0.56	0.95	0.35	0.76	0.75
2002	0.44	0.43	1.59	0.60	0.46	0.39	0.88	0.69
2003	0.66	0.43	0.40	0.74	1.08	0.33	0.94	0.61
2004	0.57	0.42	0.47	0.72	0.53	0.35	0.46	0.55
2005	0.60	0.41	0.94	0.61	1.33	0.37	1.45	0.52
2006	0.25	0.42	1.18	0.49	0.45	0.37	2.84	0.48
2007	0.38	0.43	1.36	0.60	0.88	0.38	0.42	0.56
2008	0.27	0.42	1.26	0.50	0.40	0.40	0.58	0.41
2009	0.20	0.42	0.37	0.62	0.91	0.37	1.90	0.54
2010	0.41	0.43	0.68	0.64	0.99	0.36	0.75	0.40
2011	0.28	0.42	0.75	0.68	0.66	0.34	1.25	0.42
2012	0.12	0.44	2.02	0.52	0.59	0.39	1.19	0.42
2013	0.15	0.42	0.65	0.68	0.92	0.36	0.97	0.39
2014	0.30	0.42	1.36	0.52	1.61	0.34	0.94	0.42
2015	0.25	0.43	1.35	0.60	1.91	0.40	1.20	0.42
2016	0.49	0.43	1.09	0.60	0.57	0.39	0.41	0.47
2017	0.11	0.44	0.66	0.67	0.44	0.38	1.15	0.45
2018	0.29	0.44	0.56	0.79	1.21	0.61	0.86	0.46
2019	0.25	0.47	1.89	0.48	1.01	0.41	0.76	0.41
2020	0.22	0.48	2.39	0.58	0.33	0.42	0.96	0.71
2021	0.36	0.46	2.07	0.73	1.13	0.45	1.16	0.71

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
Age 1+ Surveys	CT Long Island Sound Trawl	0.96	1.90
	DE Adult Trawl	0.88	0.44
	NJ Ocean Trawl	1.53	1.15
	MD Striped Bass Spring Gill Net	2.23	2.22
	VIMS Shad and River Herring Monitoring	0.24	0.21
	NC Program 915 Pamlico Sound Gill Net	0.92	0.71
	SEAMAP	0.40	0.52
	GA Ecological Monitoring Trawl	0.50	0.73
YOY Surveys	RI Coastal Trawl	2.96	2.94
	CT River Juvenile Alosine Seine	2.50	2.52
	CT Thames River Seine	3.16	3.16
	CT Long Island Sound Trawl	1.34	1.28
	NY Peconic Bay Small Mesh Trawl	3.78	3.58
	NY Western Long Island Seine	2.99	3.10
	NY Juvenile Striped Bass Beach Seine	1.18	2.09
	NJ Ocean Trawl	1.85	1.89
	NJ Delaware River Striped Bass Seine	1.81	1.81
	DE Inland Bays	11.34	4.93
	MD Coastal Bays Trawl	2.17	1.33
	MD Juvenile Striped Bass Seine	1.64	1.44
	VIMS Juvenile Fish and Blue Crab Trawl	1.31	1.22
	VIMS Juvenile Striped Bass Seine	3.05	1.50
	NC Program 120 Estuarine Trawl	0.82	1.00
	SC Electrofishing	0.92	0.97

Appendix Figures

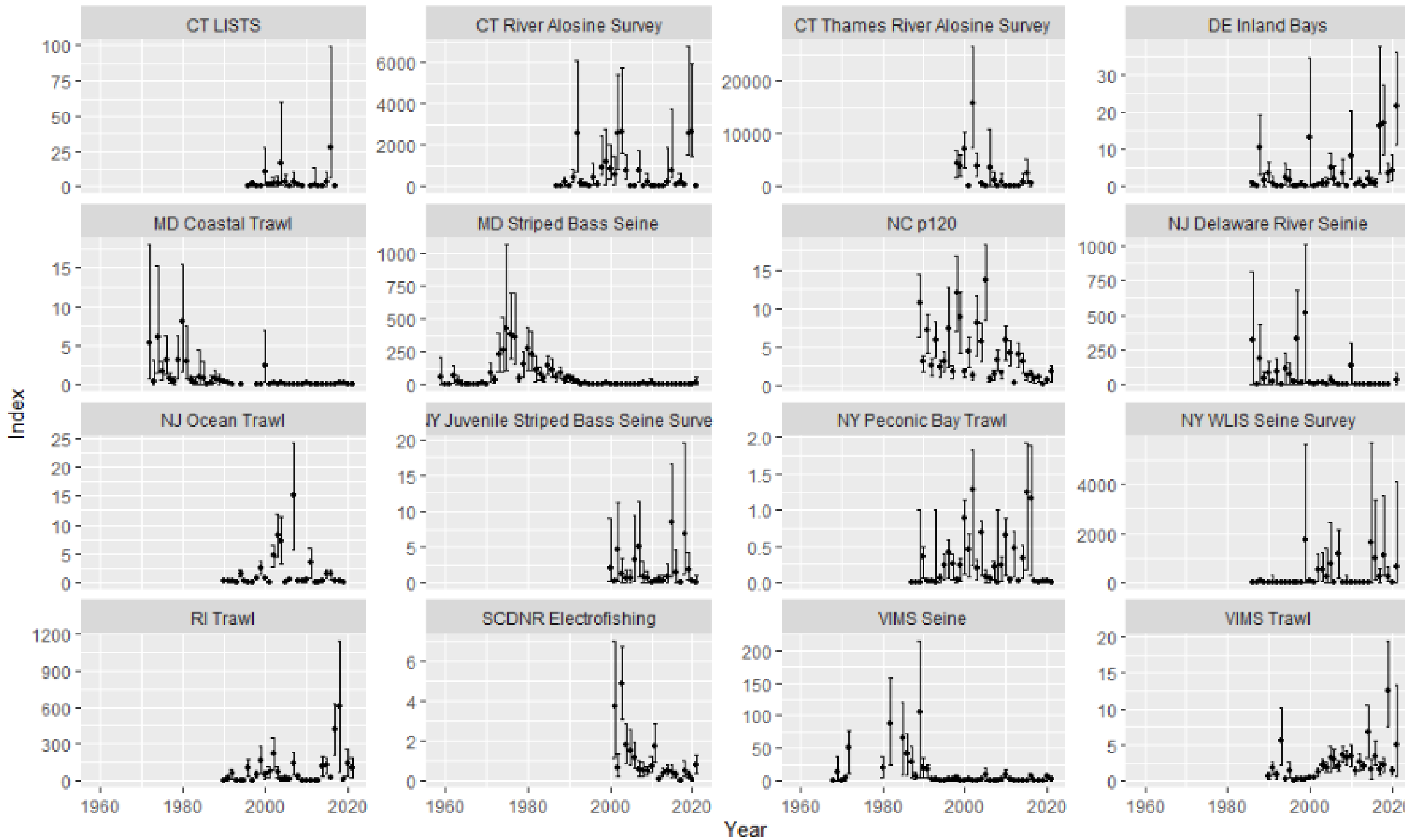


Figure A1. Individual YOY indices with 95% confidence intervals used in the coastwide YOY index.

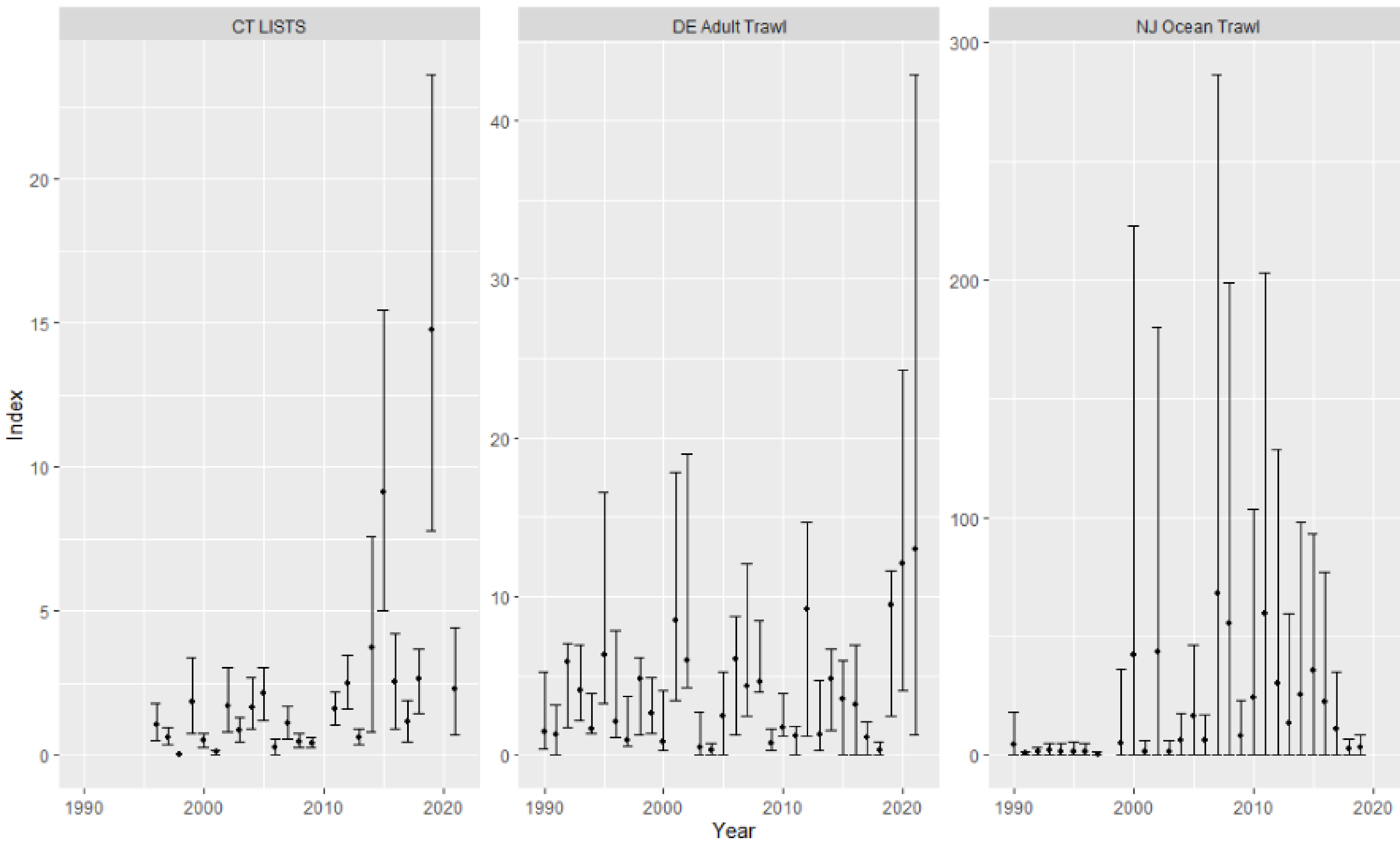


Figure A2. Individual adult indices with 95% confidence intervals used in the NAD index.

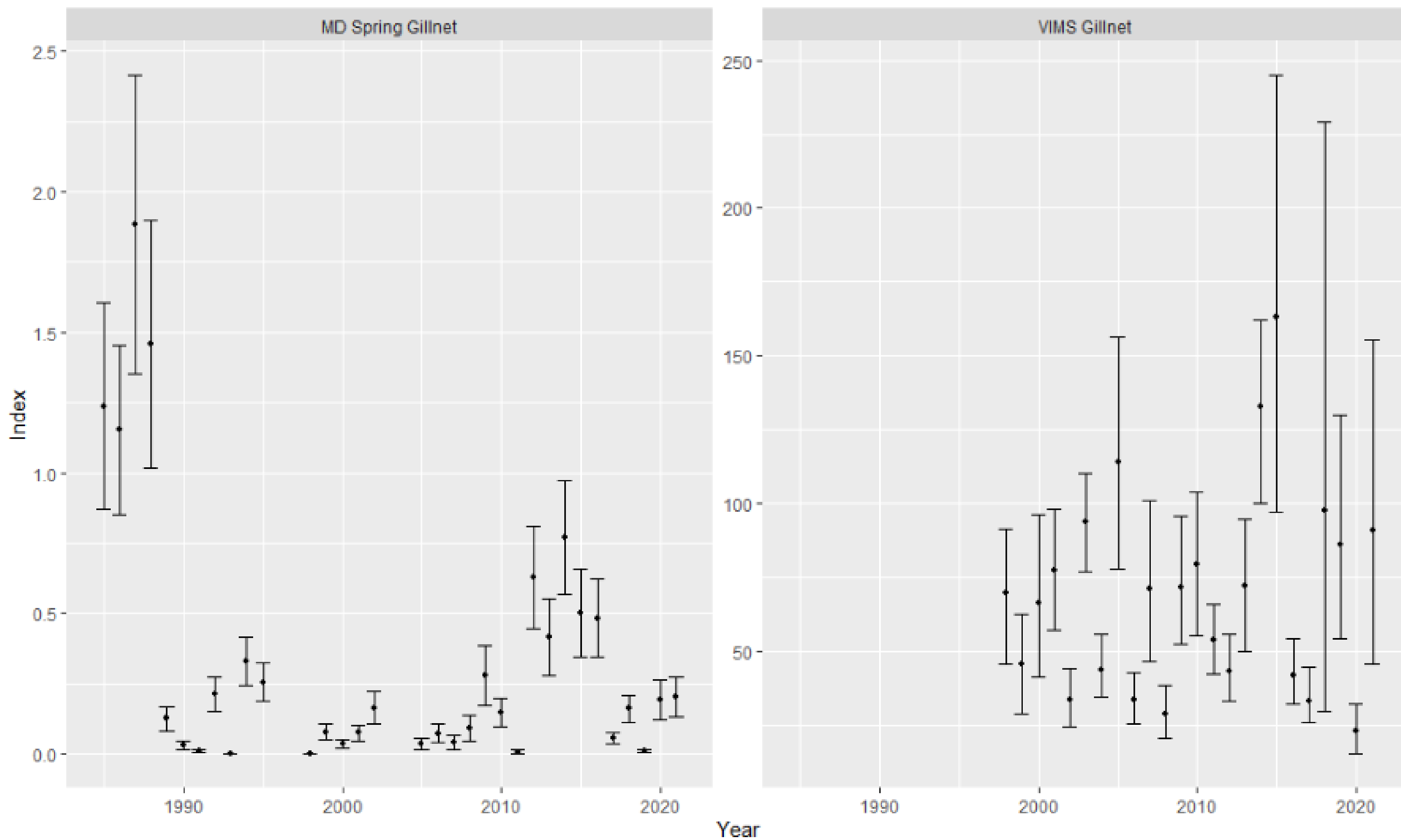


Figure A3. Individual adult indices with 95% confidence intervals used in the MAD index.

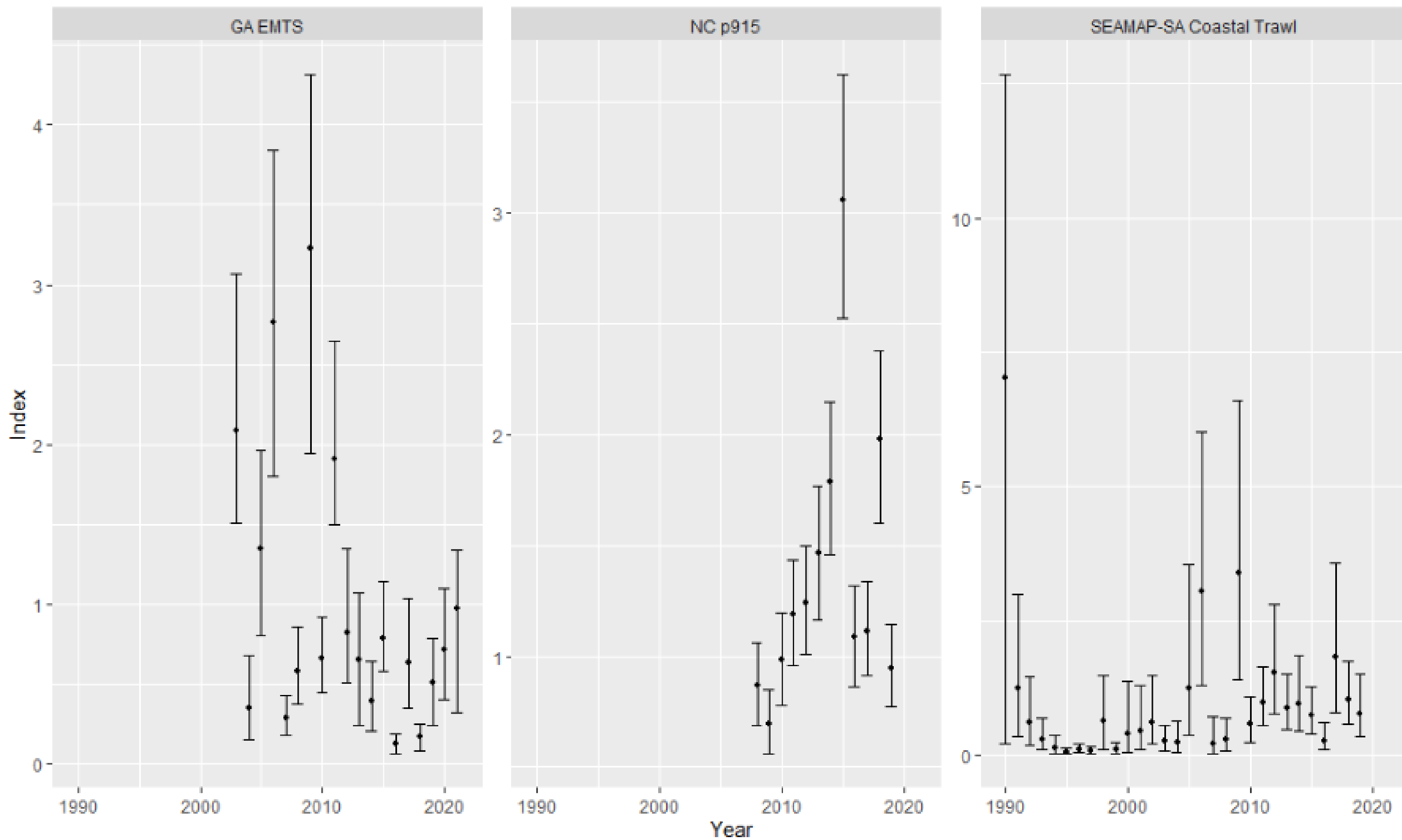


Figure A4. Individual adult indices with 95% confidence intervals used in the SAD index

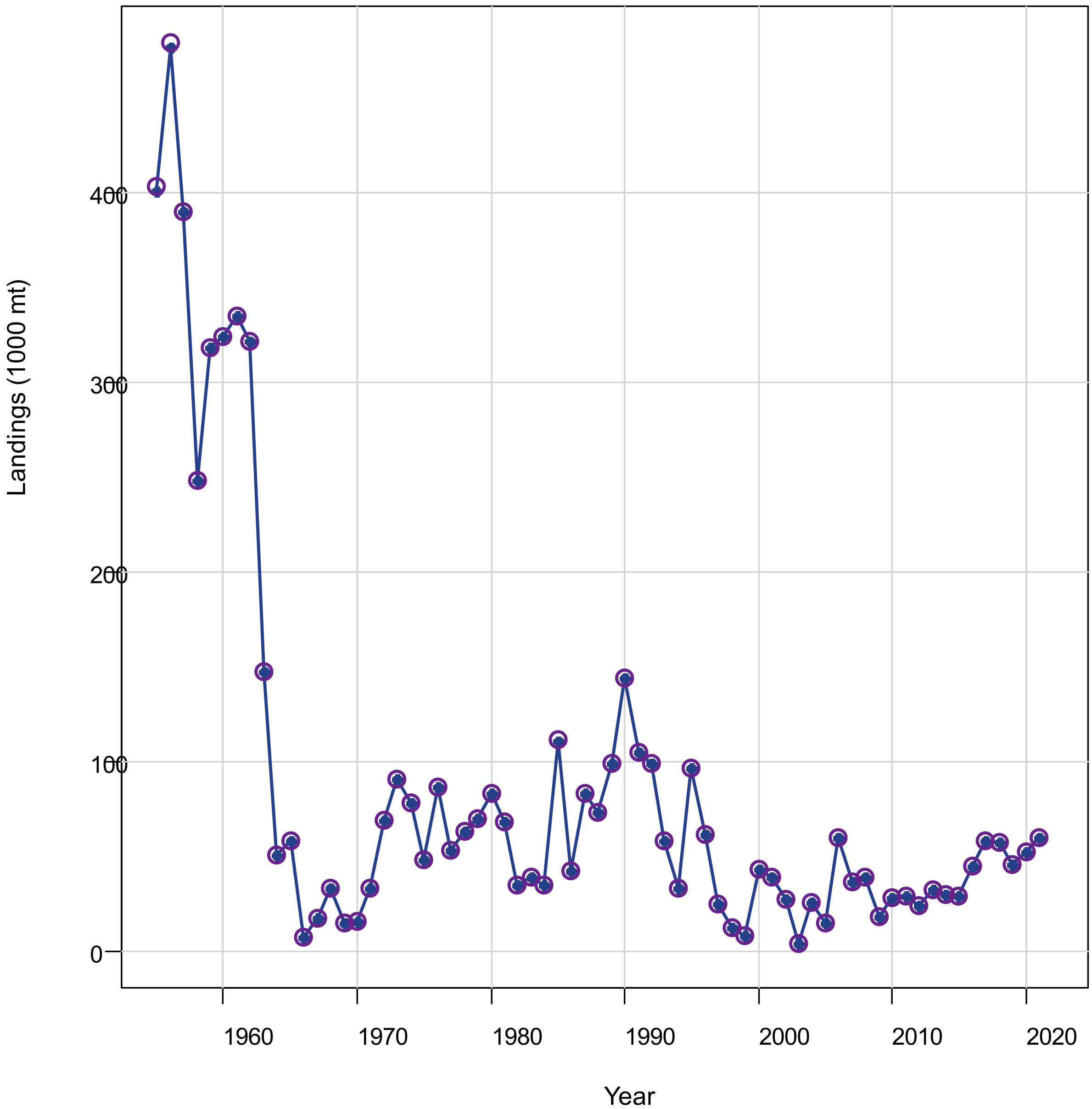


Figure A5. Predicted fit to the observed landings for the commercial reduction north fleet for 1955-2021.

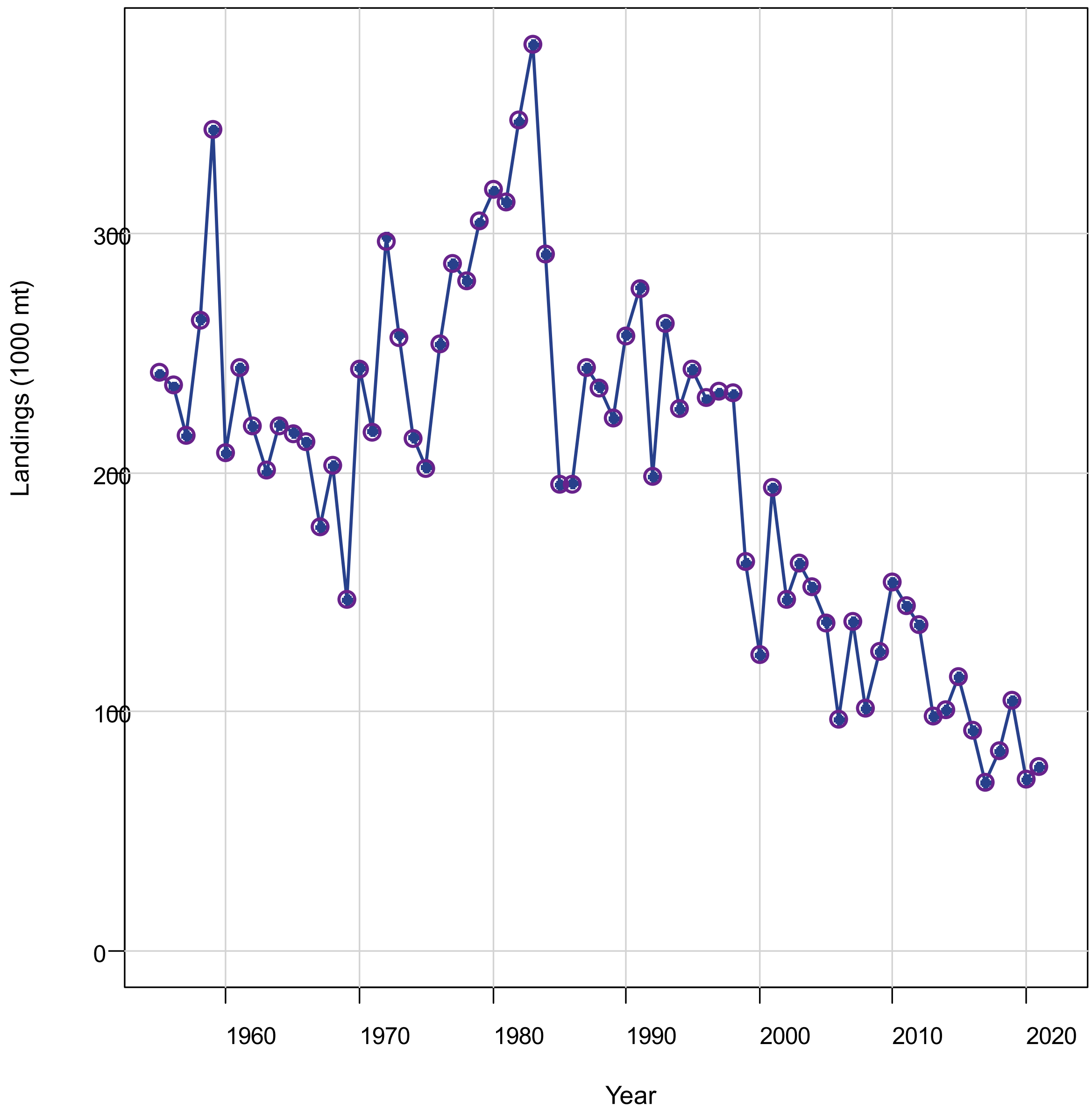


Figure A6. Predicted fit to the observed landings for the commercial reduction south fleet for 1955-2021.

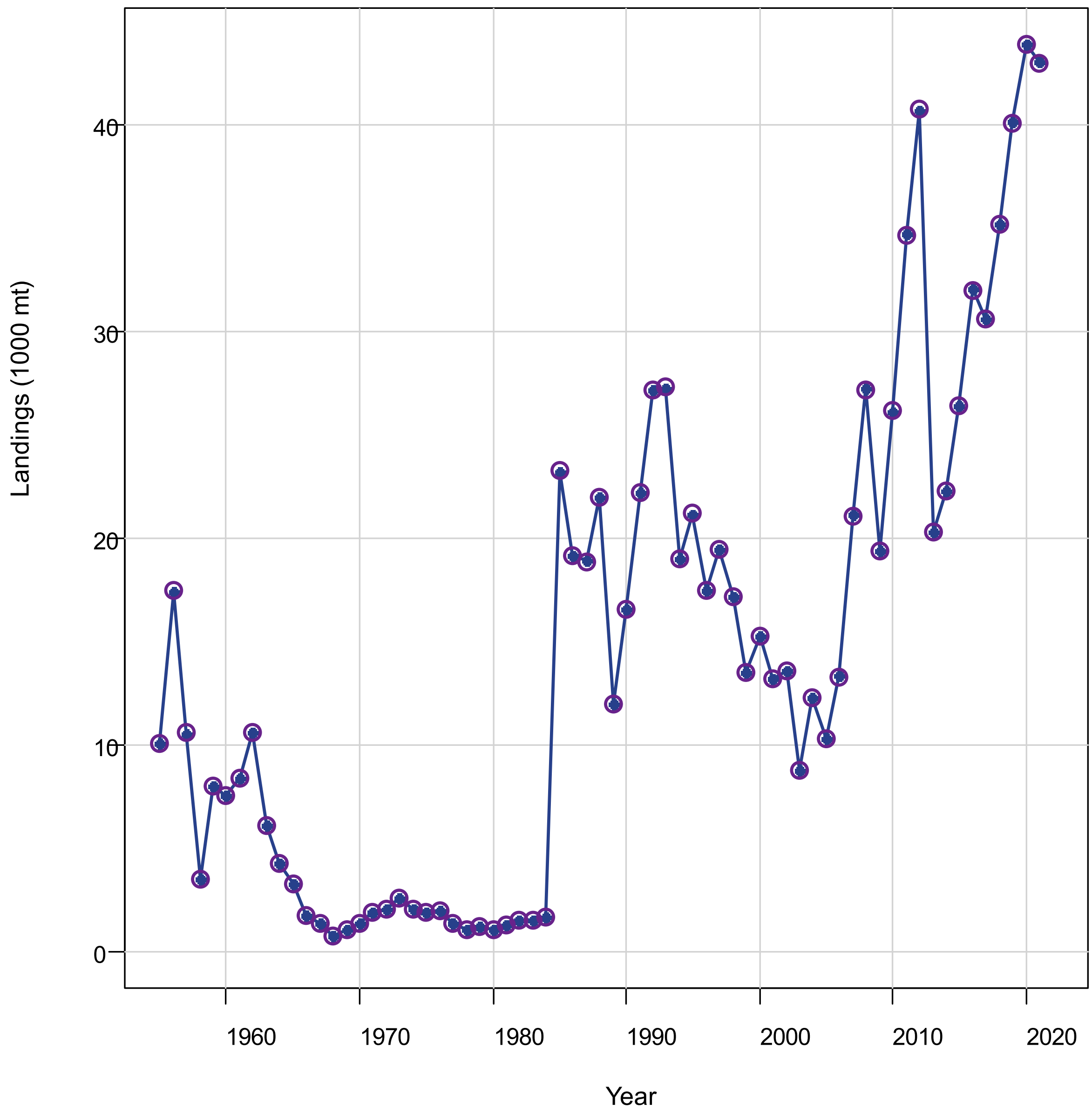


Figure A7. Predicted fit to the observed landings for the commercial bait north fleet for 1955-2021.

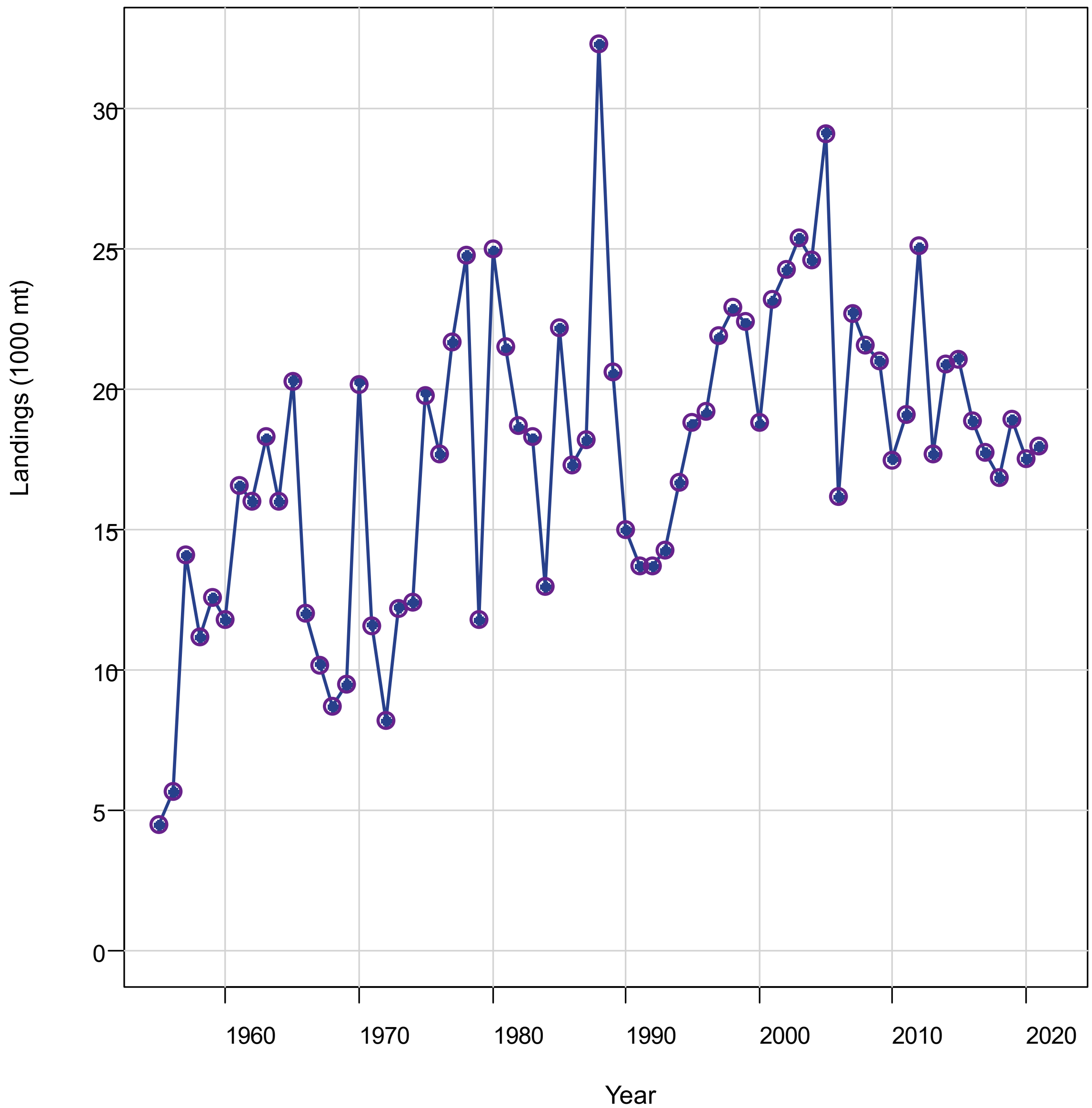


Figure A8. Predicted fit to the observed landings for the commercial bait south fleet for 1955-2021.

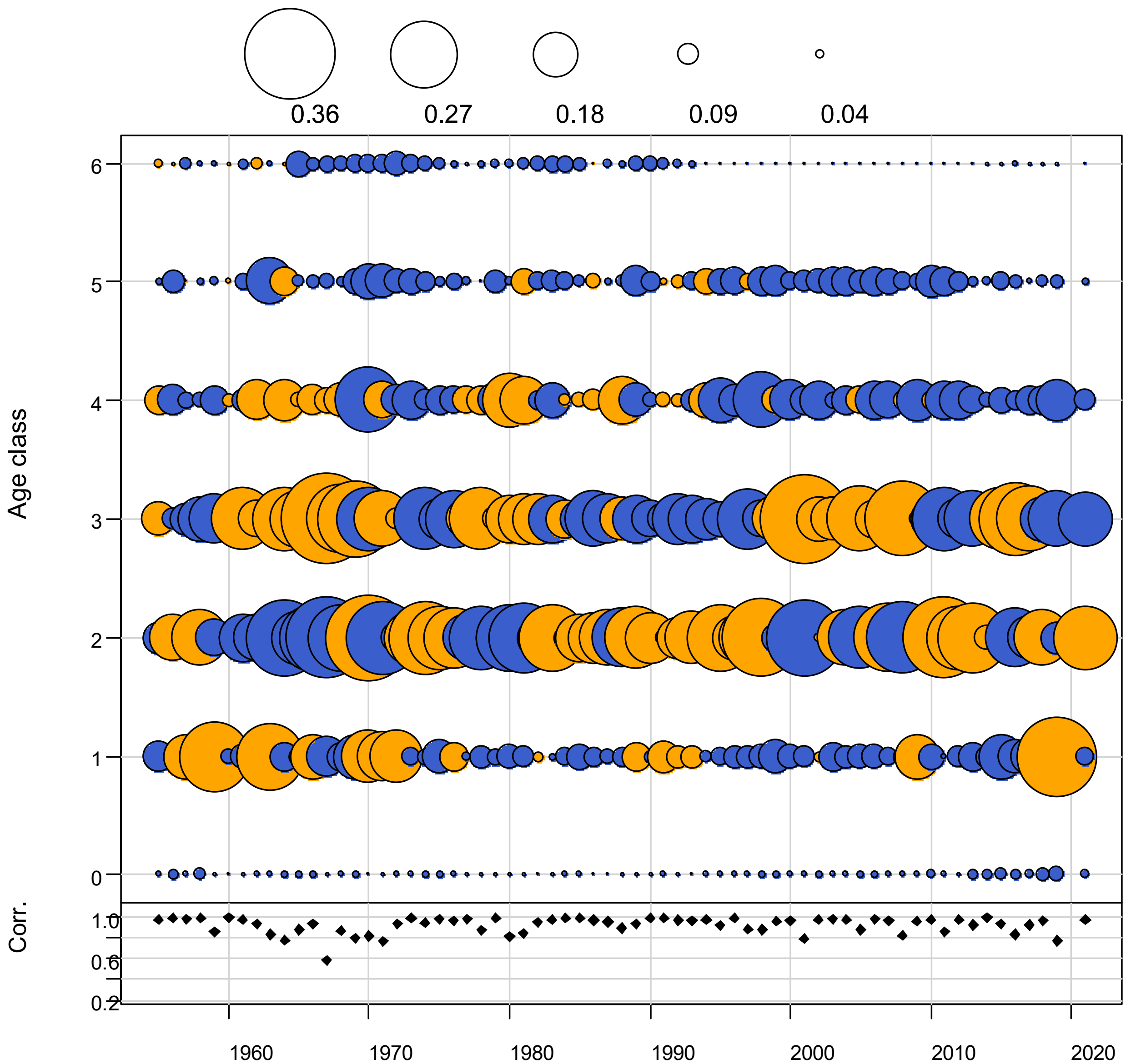


Figure A9. Bubble plot of the fits to the age compositions for the commercial reduction north fleet. Orange indicates an underestimate, while blue indicates on overestimate. The bottom panel indicates the correlation between the observed data and the model prediction.

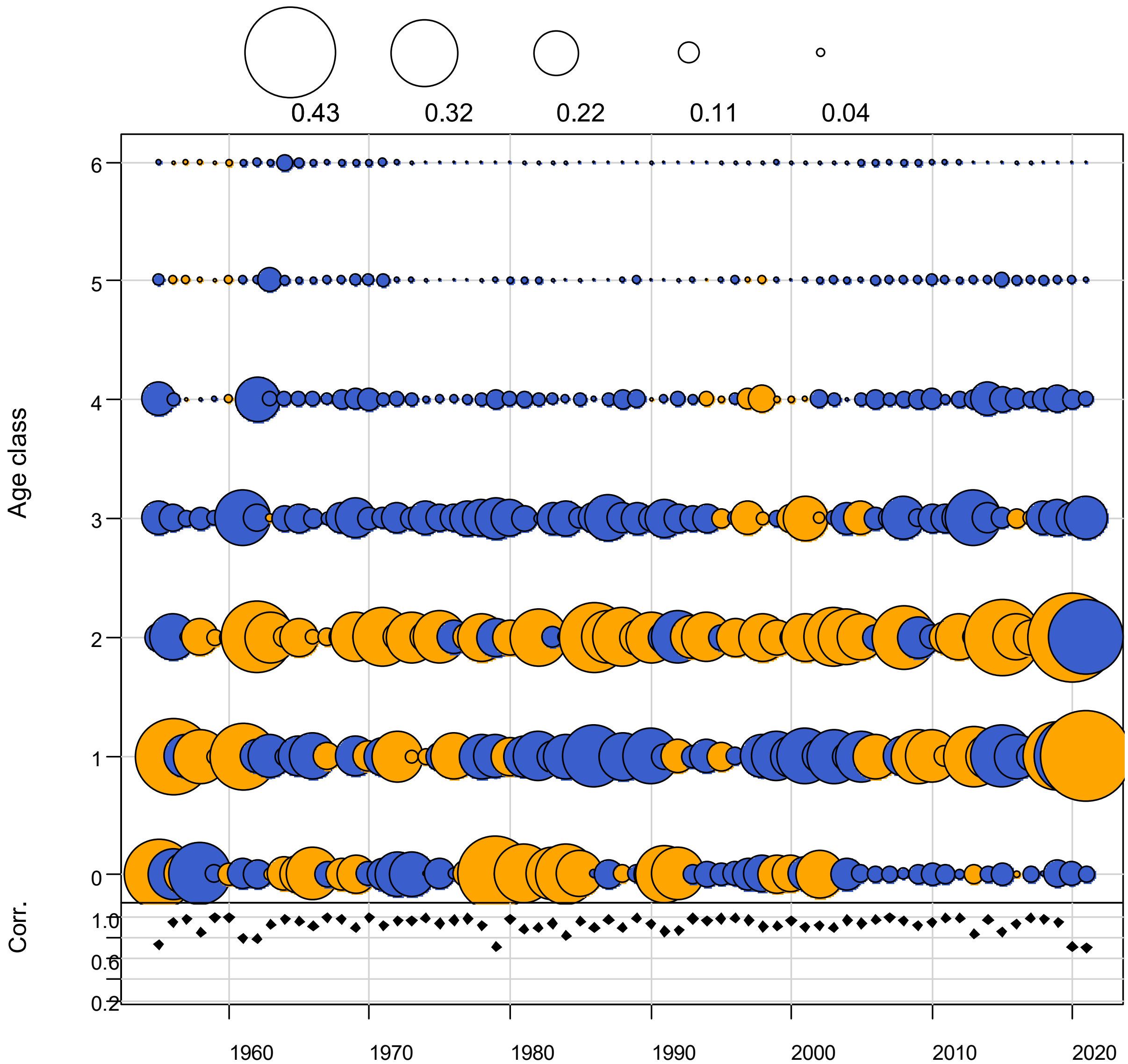


Figure A10. **Bubble plot of the fits to the age compositions for the commercial reduction south fleet. Orange indicates an underestimate, while blue indicates on overestimate. The bottom panel indicates the correlation between the observed data and the model prediction.**

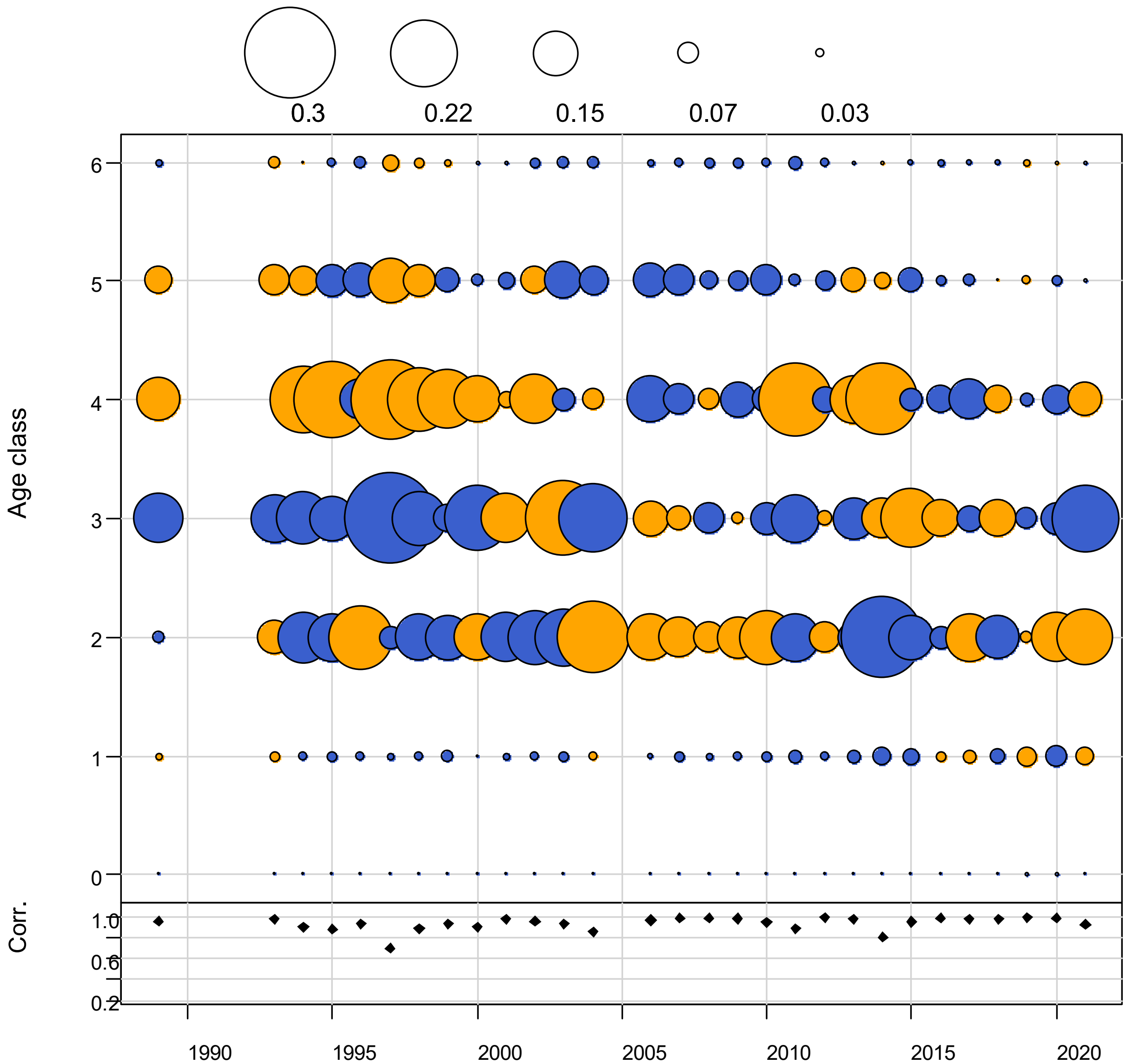


Figure A11. **Bubble plot of the fits to the age compositions for the commercial bait north fleet. Orange indicates an underestimate, while blue indicates on overestimate. The bottom panel indicates the correlation between the observed data and the model prediction.**

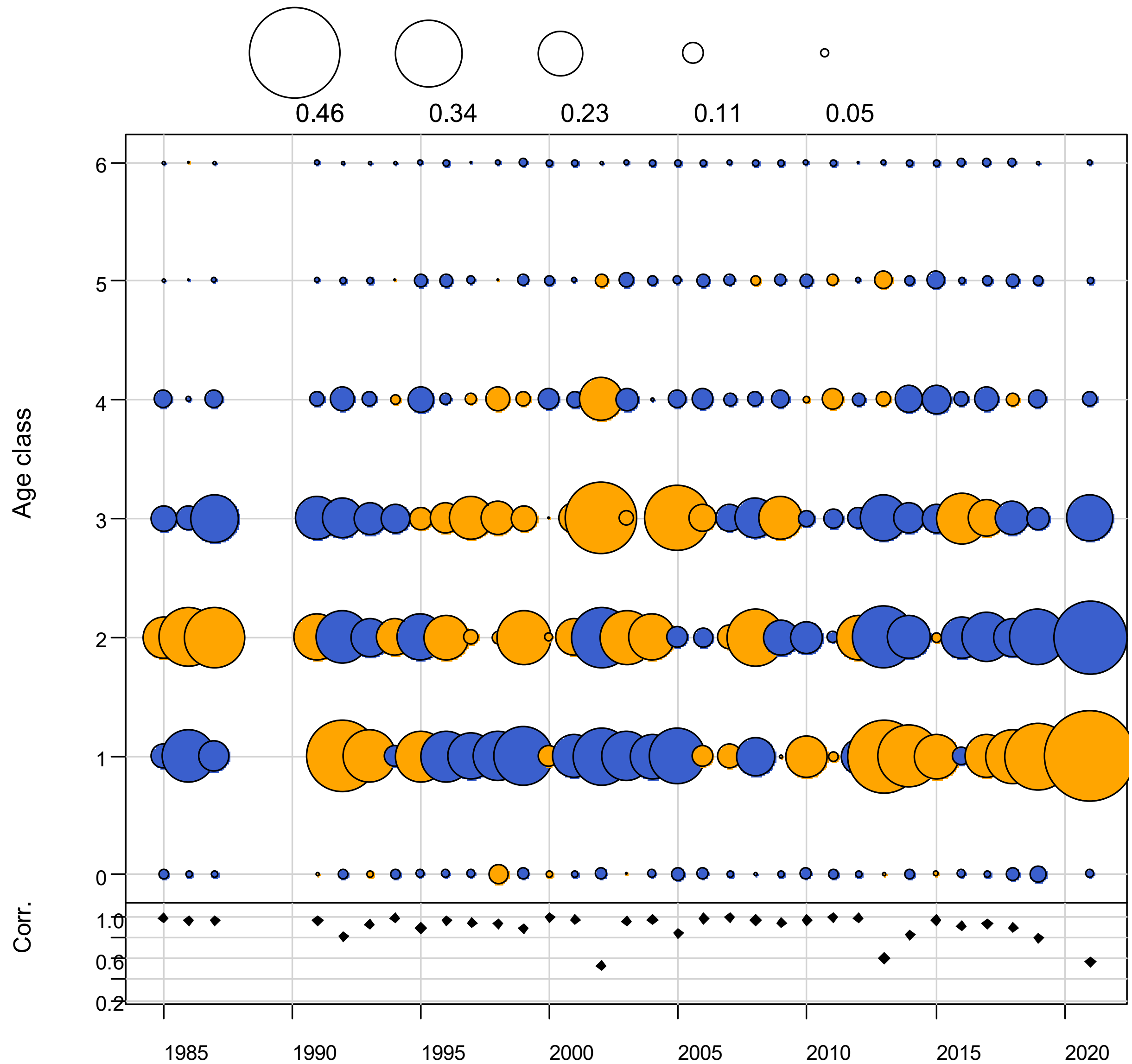


Figure A12. **Bubble plot of the fits to the age compositions for the commercial bait south fleet. Orange indicates an underestimate, while blue indicates on overestimate. The bottom panel indicates the correlation between the observed data and the model prediction.**

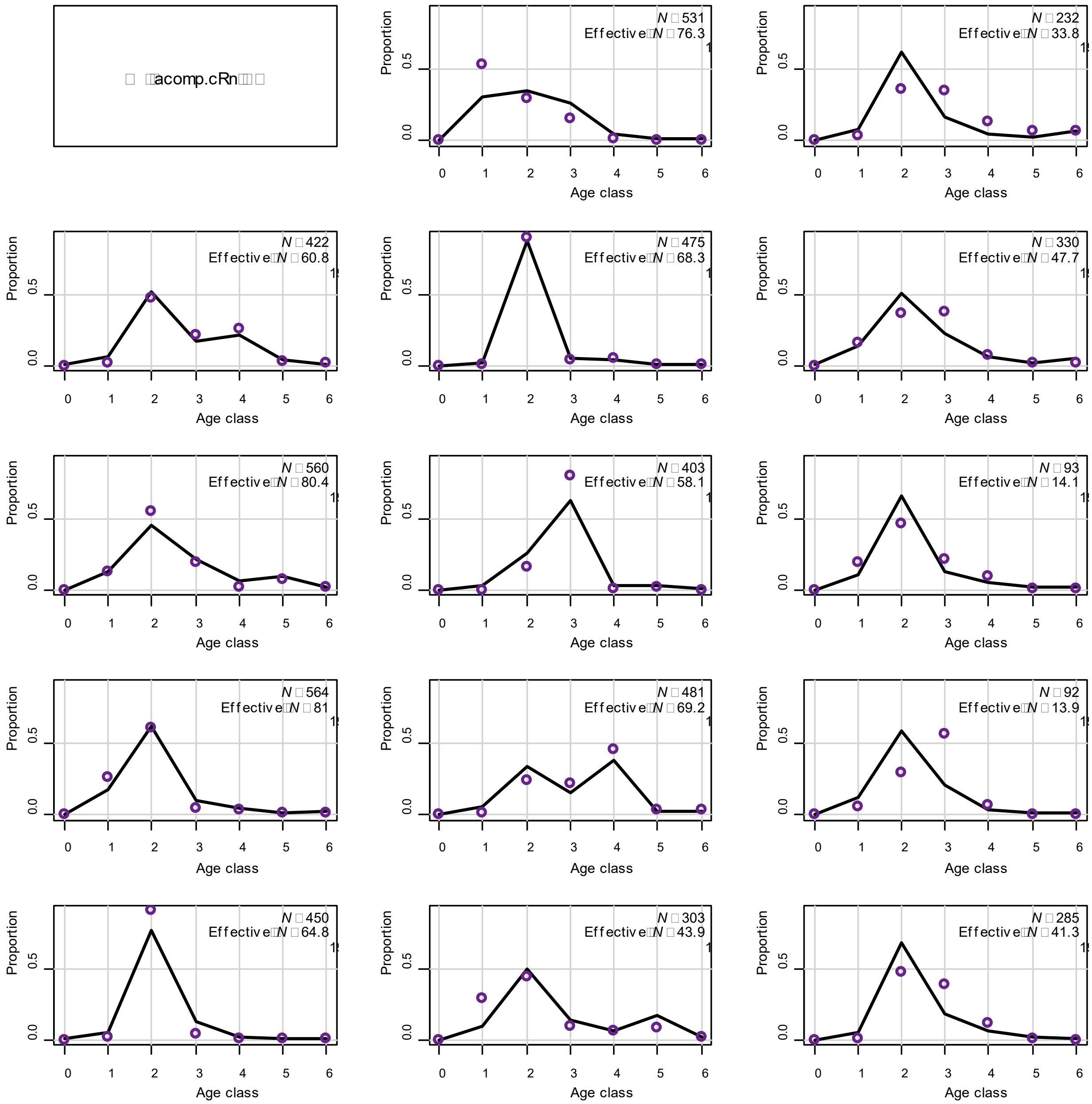


Figure A13. **Annual age composition plots for the commercial reduction north fleet for 1955-2021. Open circles are the observed data, while the line indicates the model fit.**

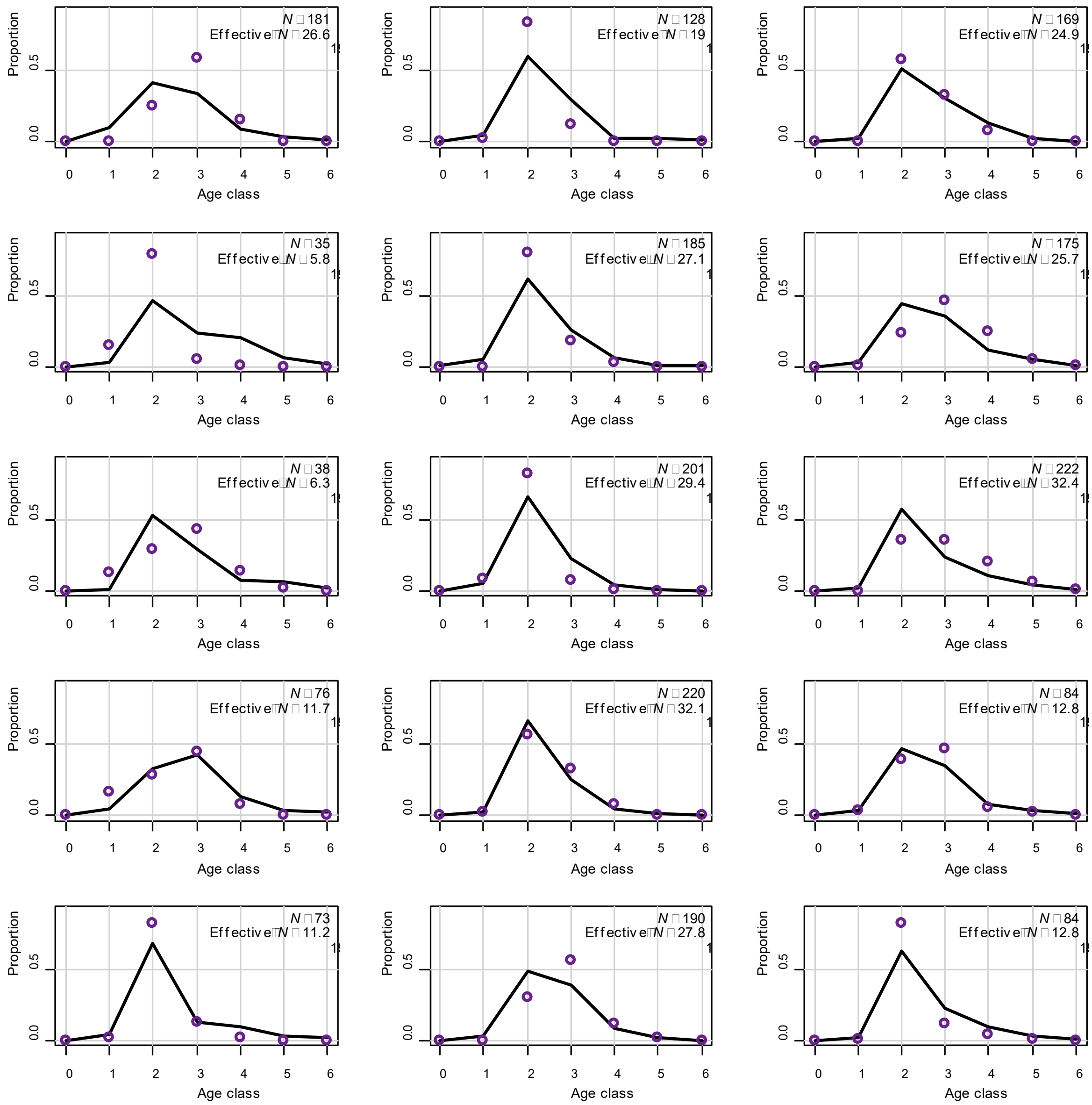


Figure A13. *Continued*

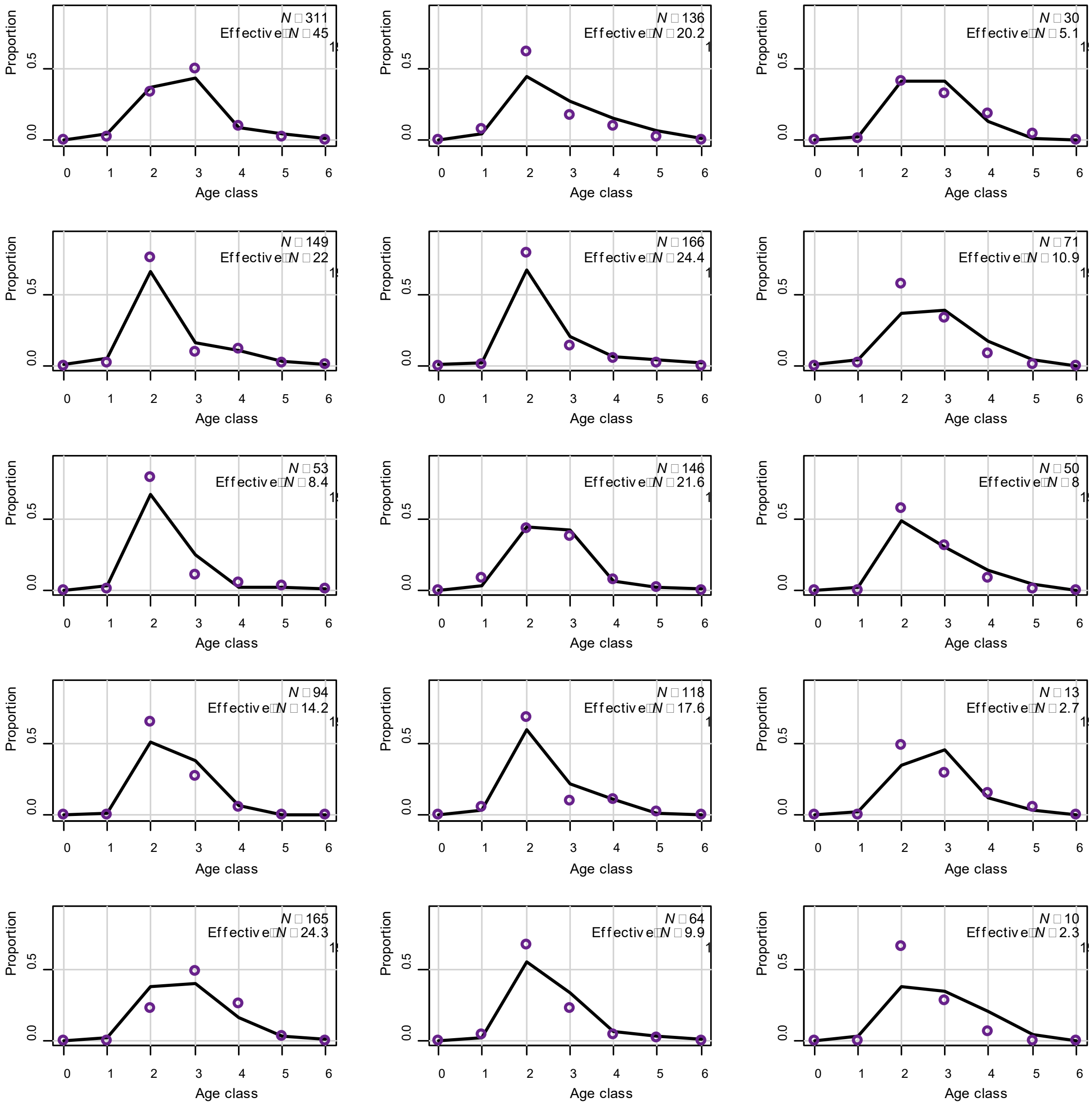


Figure A13. *Continued*

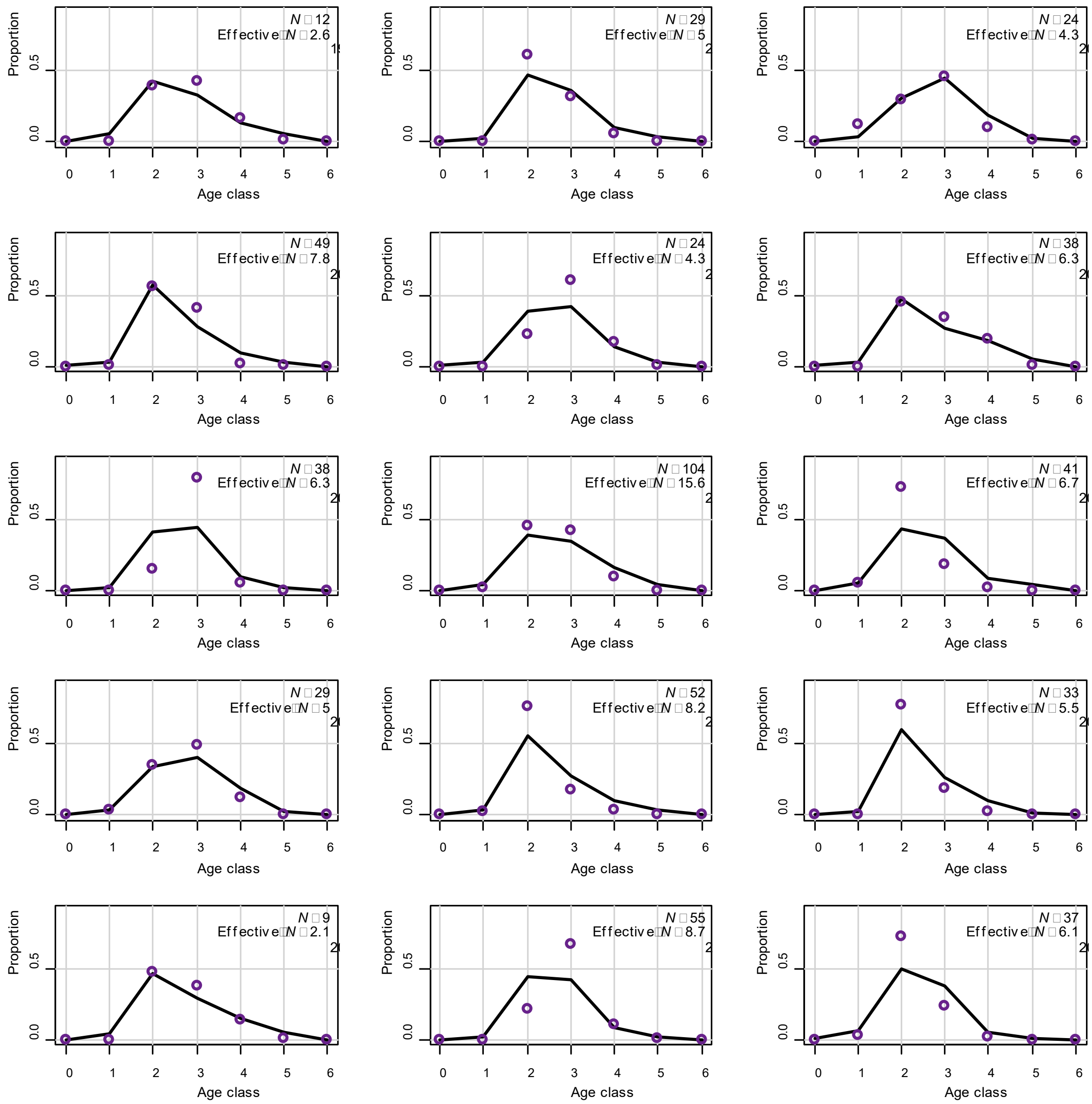


Figure A13. *Continued*

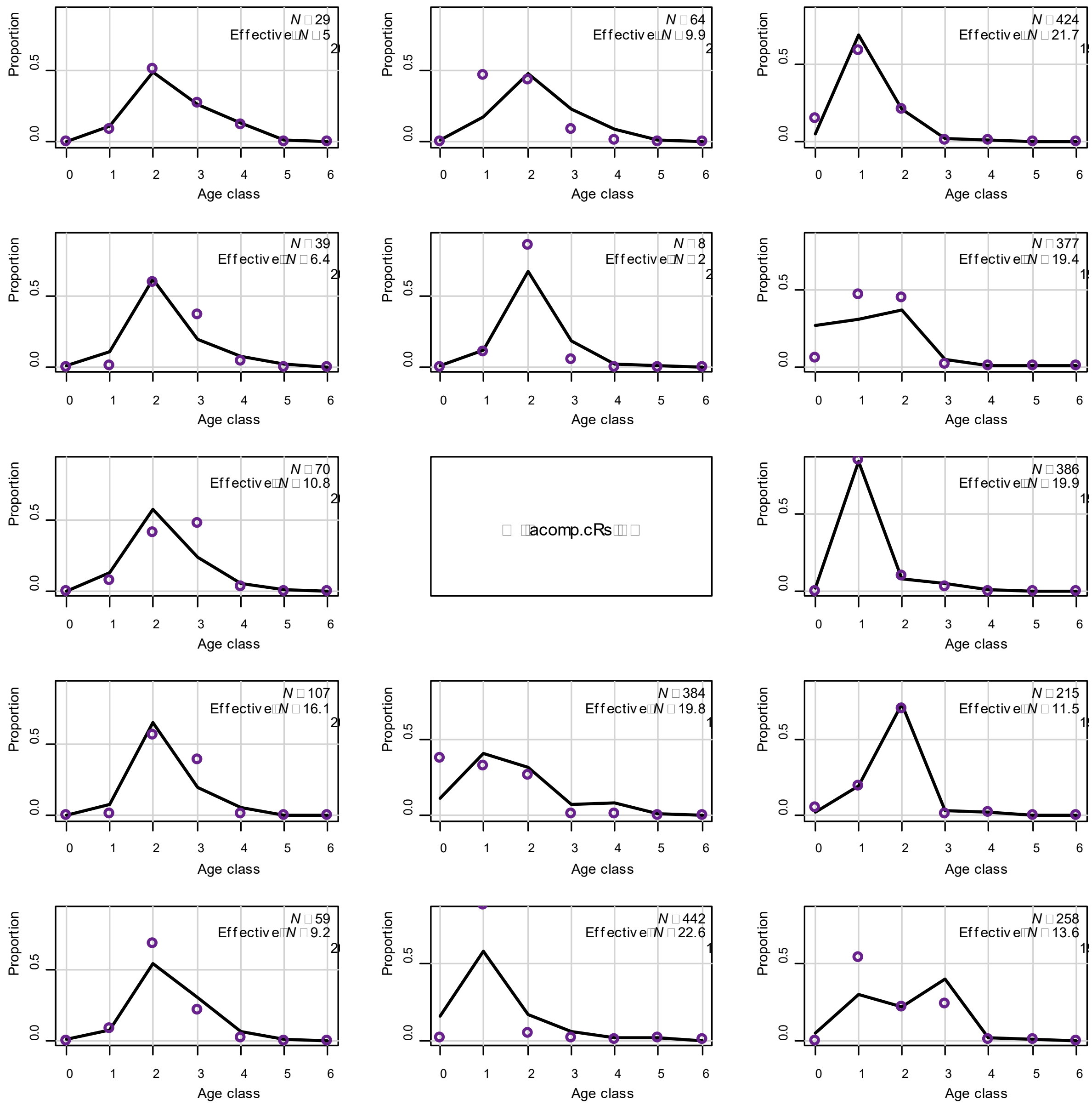


Figure A13. ***Continued***

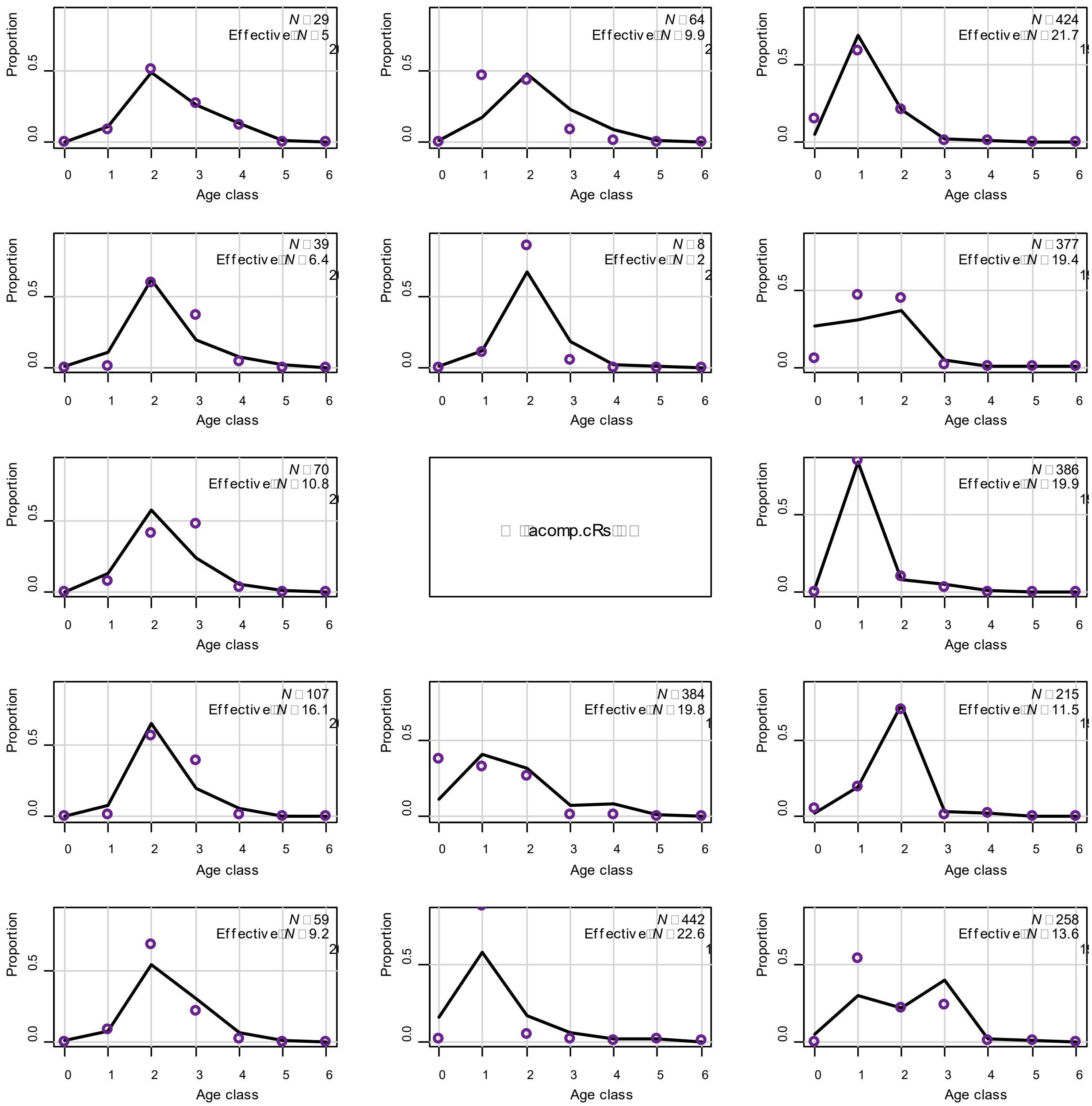
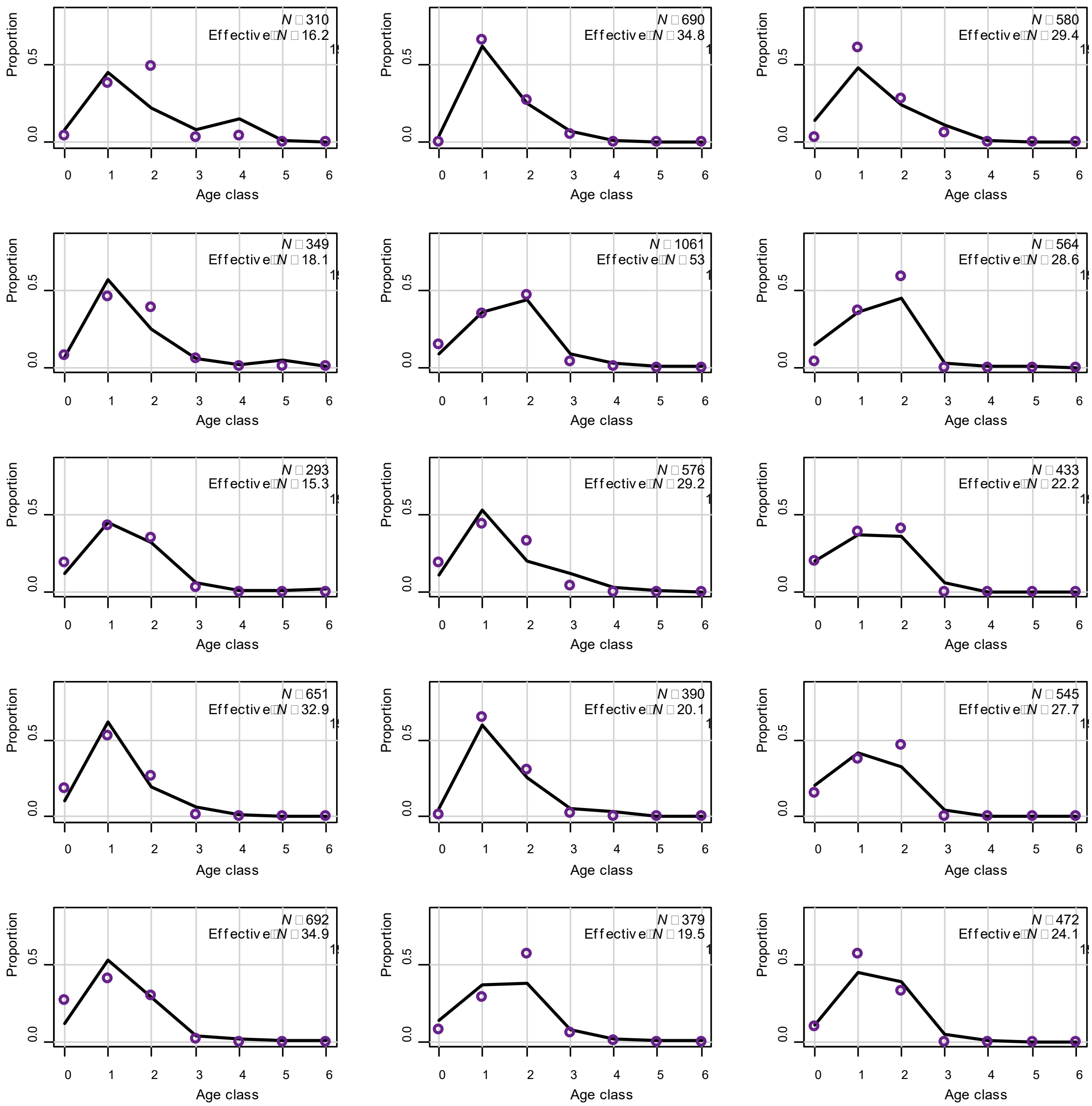


Figure A14. Annual age composition plots for the commercial reduction south fleet for 1955-2021. Open circles are the observed data, while the line indicates the model fit.



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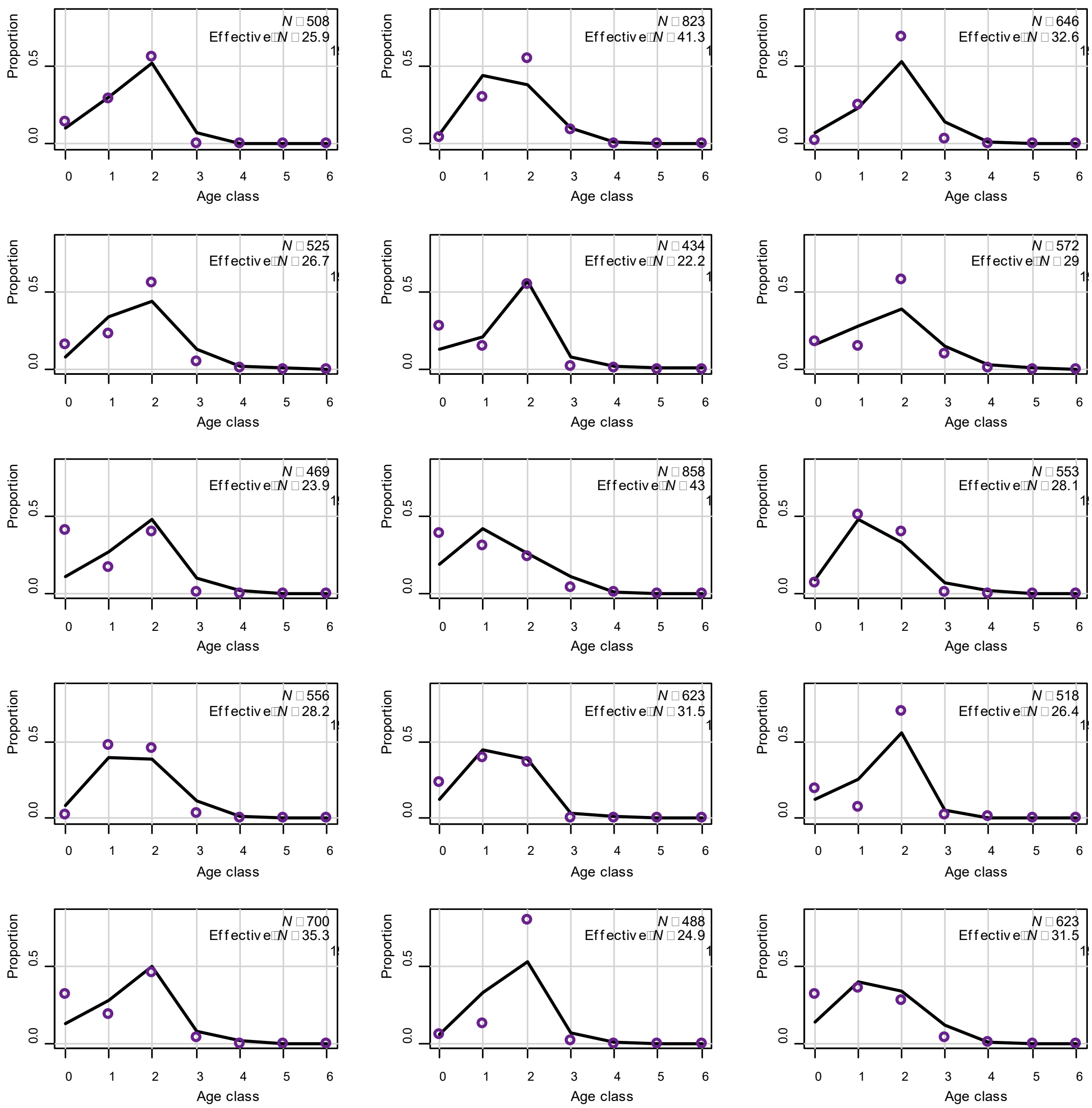

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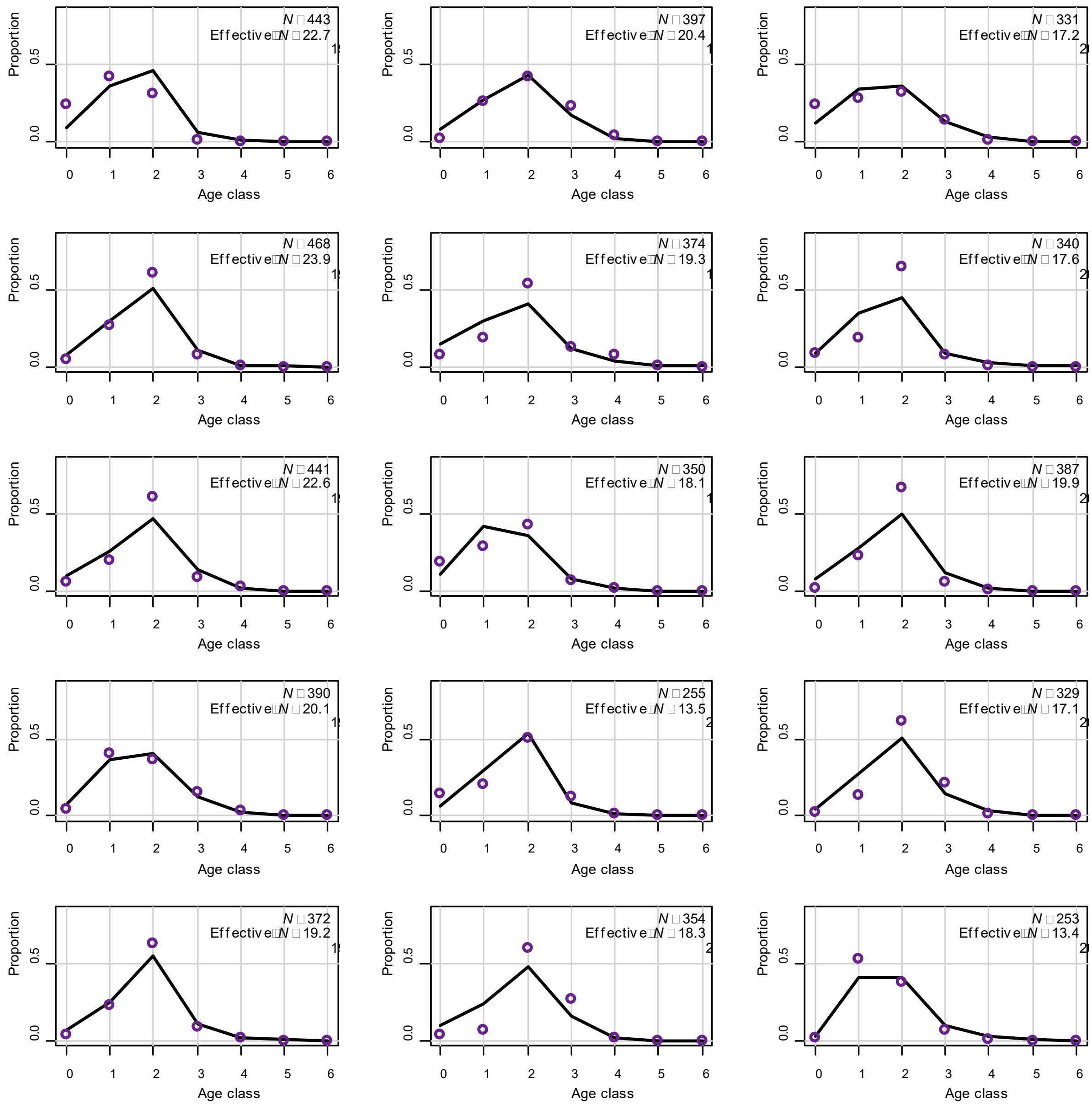

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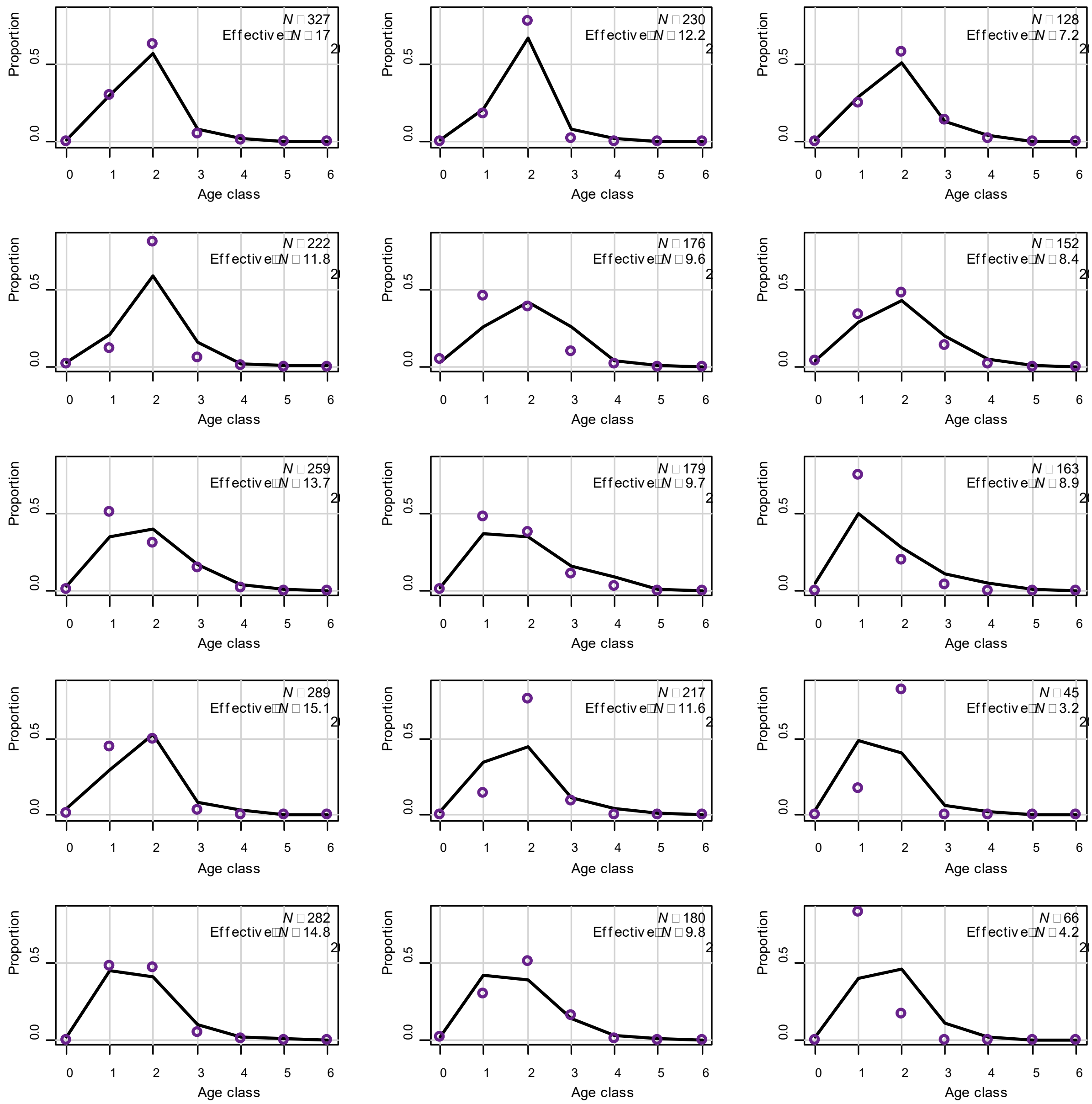


Figure A14. ***Continued***

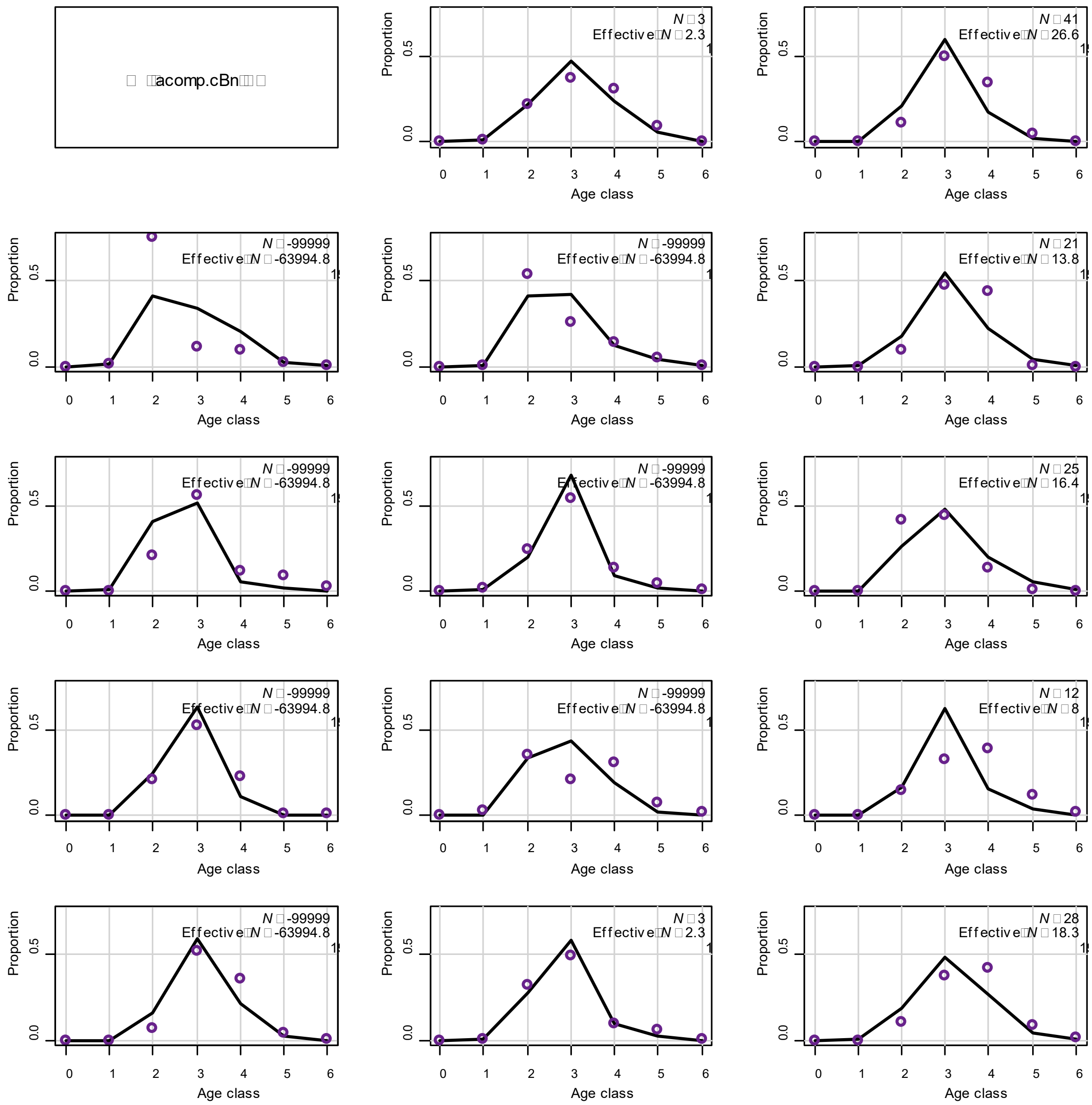
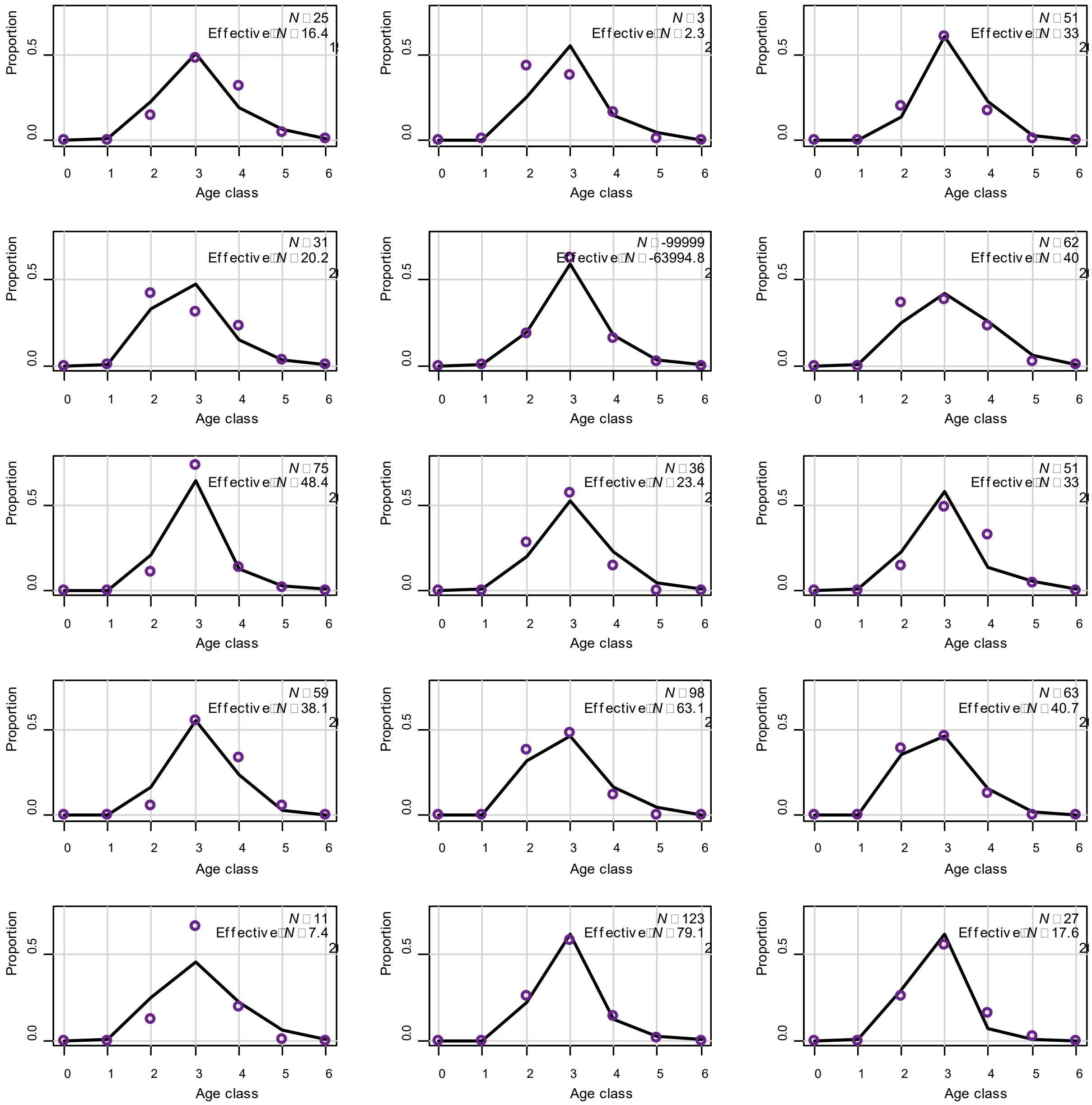


Figure A15. **Annual age composition plots for the commercial bait north fleet for 1985-2021. Open circles are the observed data, while the line indicates the model fit.**



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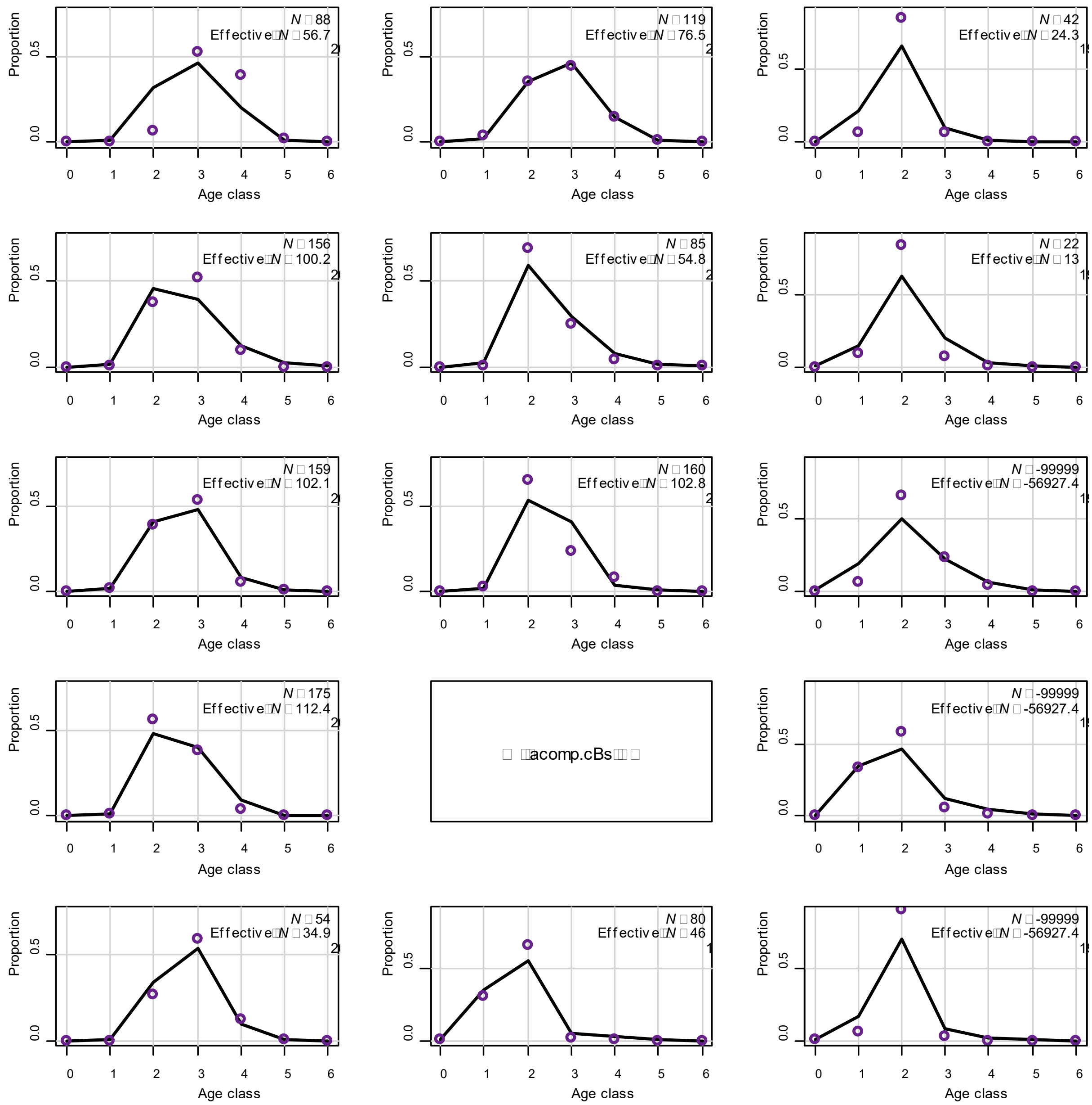

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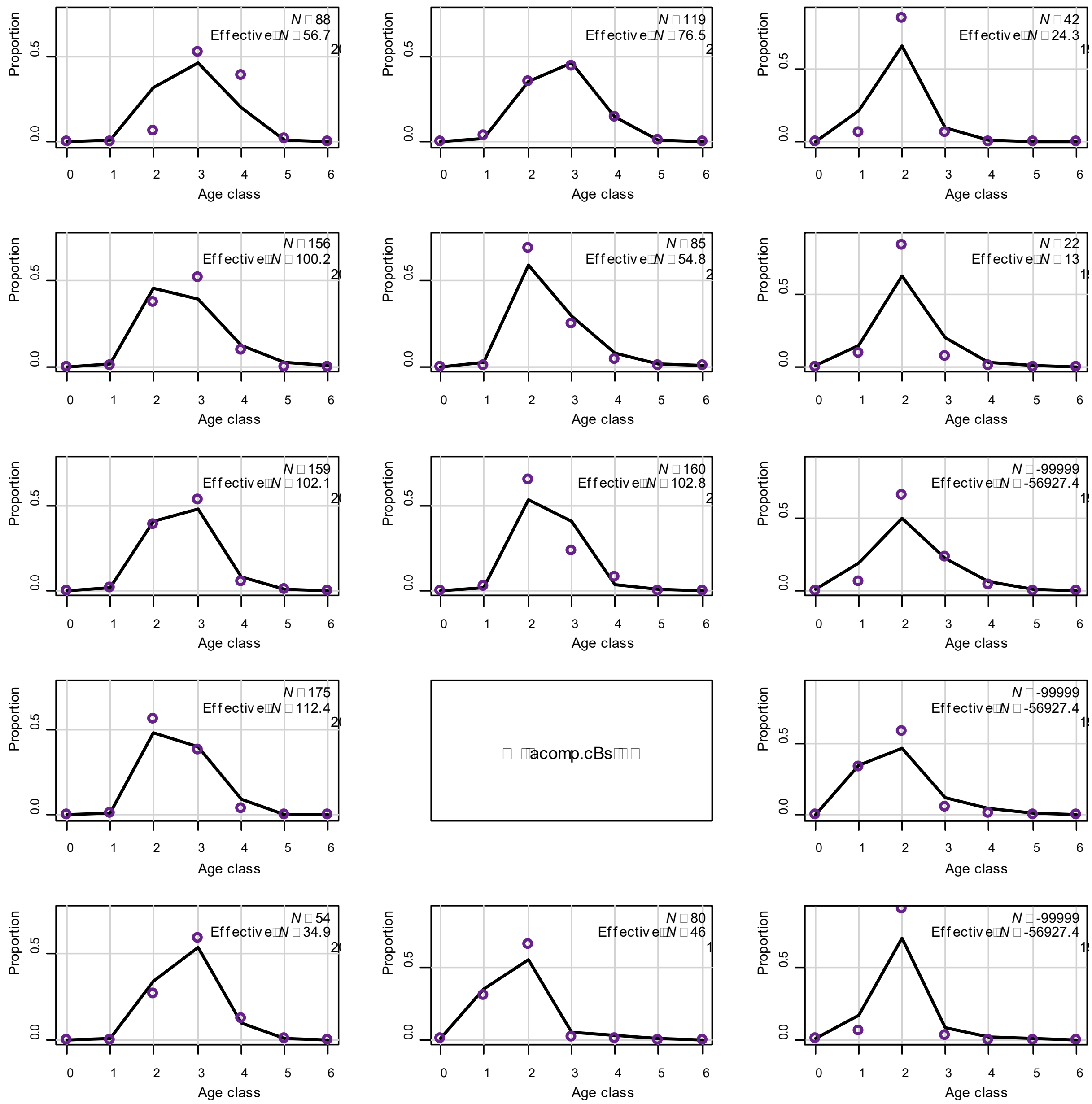
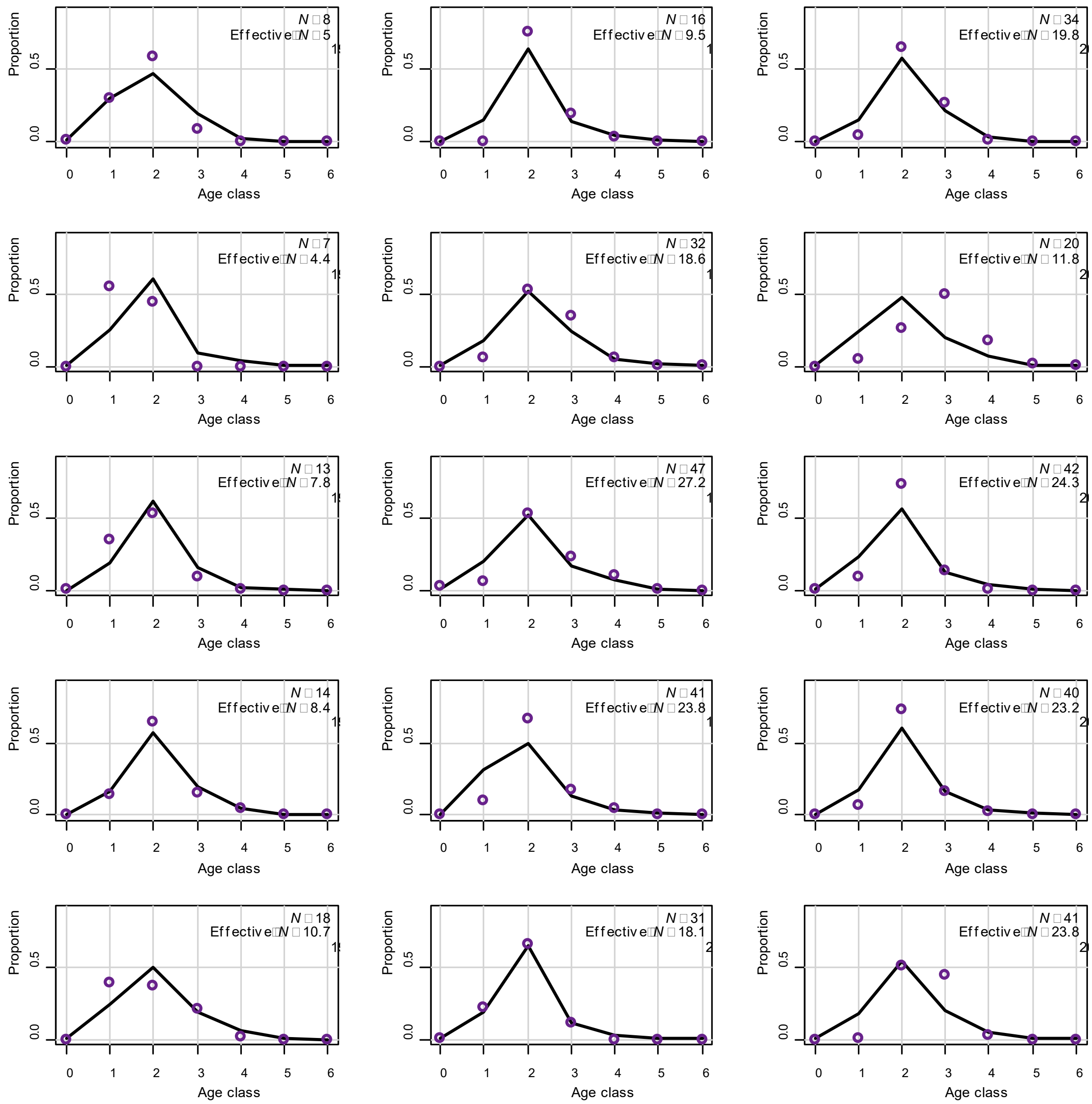


Figure A16. **Annual age composition plots for the commercial bait south fleet for 1985-2021. Open circles are the observed data, while the line indicates the model fit.**



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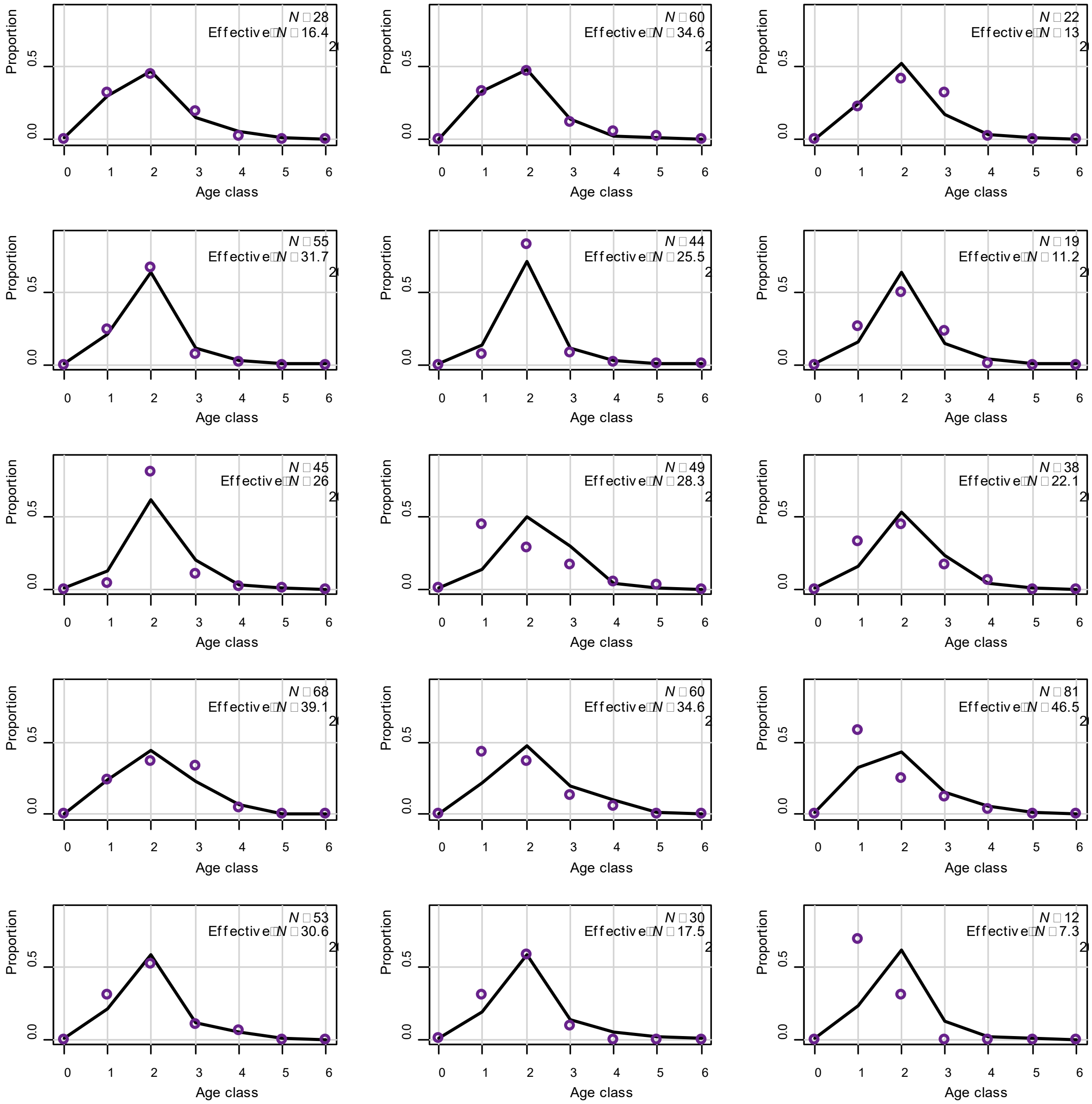

Figure A16. *Continued*

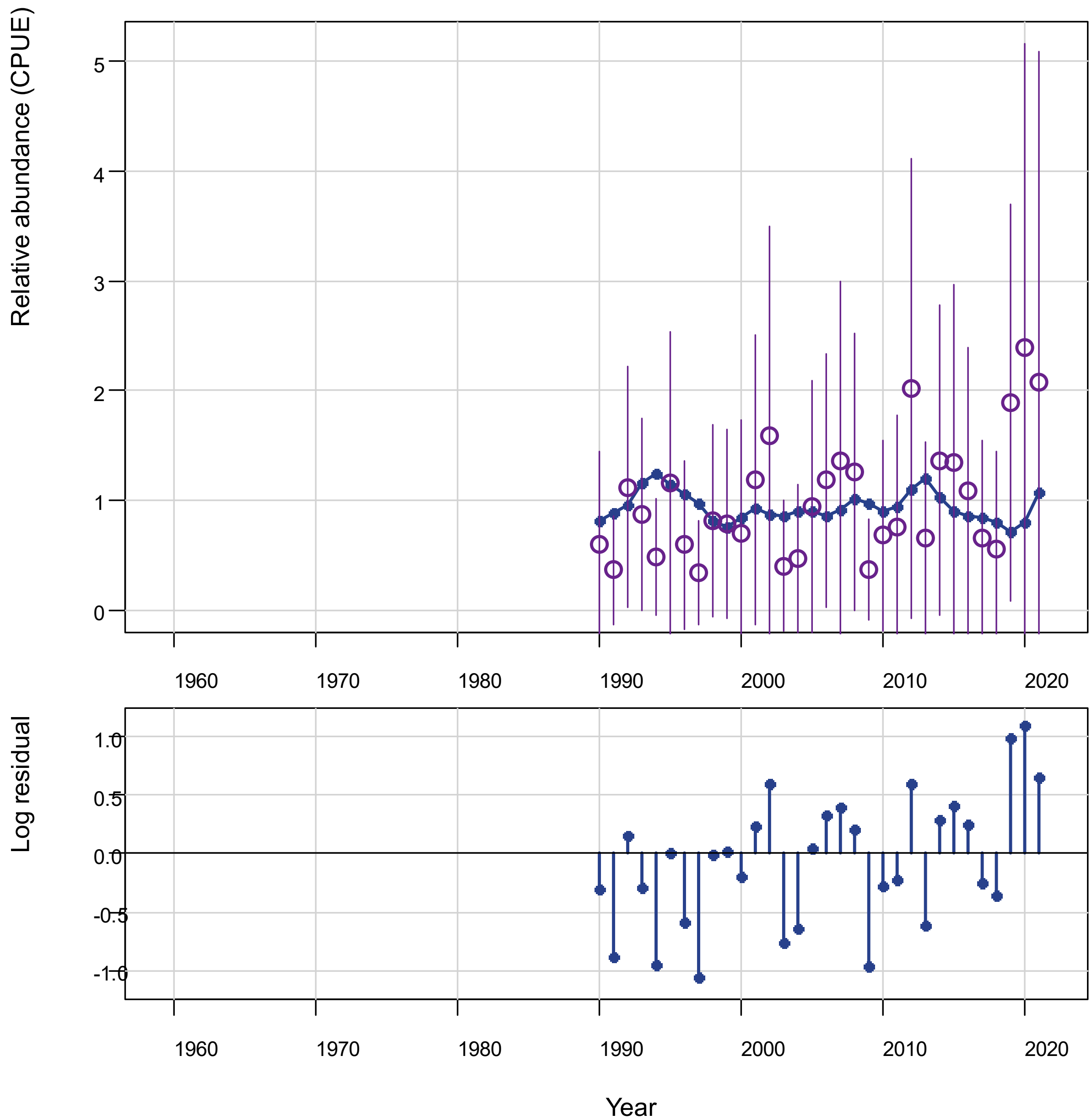

Figure A17. **Predicted fit (blue, closed circle with line) to the observed (open circle) NAD index. The lower panel indicates the residual for each data point.**

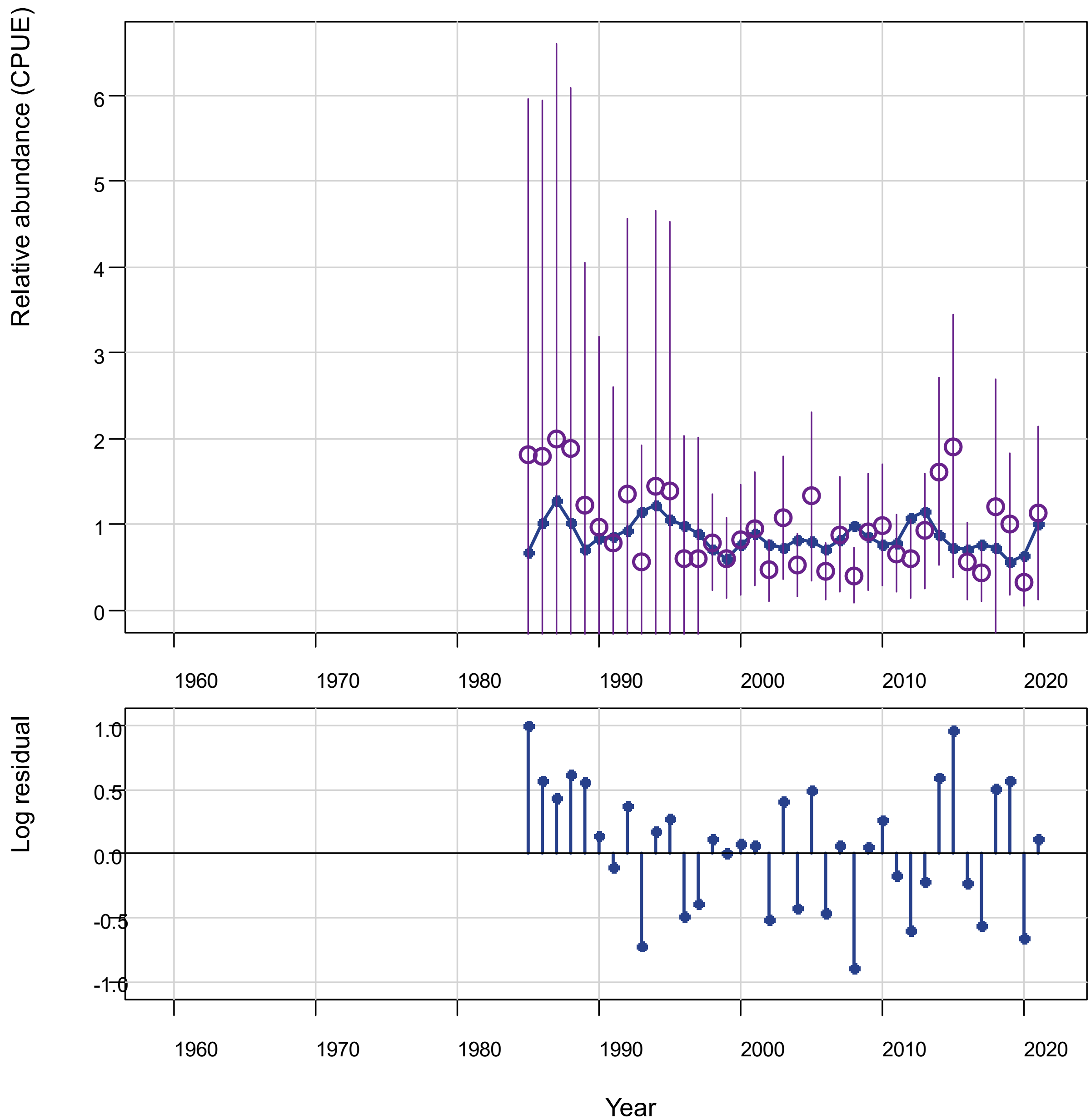

Figure A18. **Predicted fit (blue, closed circle with line) to the observed (open circle) MAD index. The lower panel indicates the residual for each data point.**

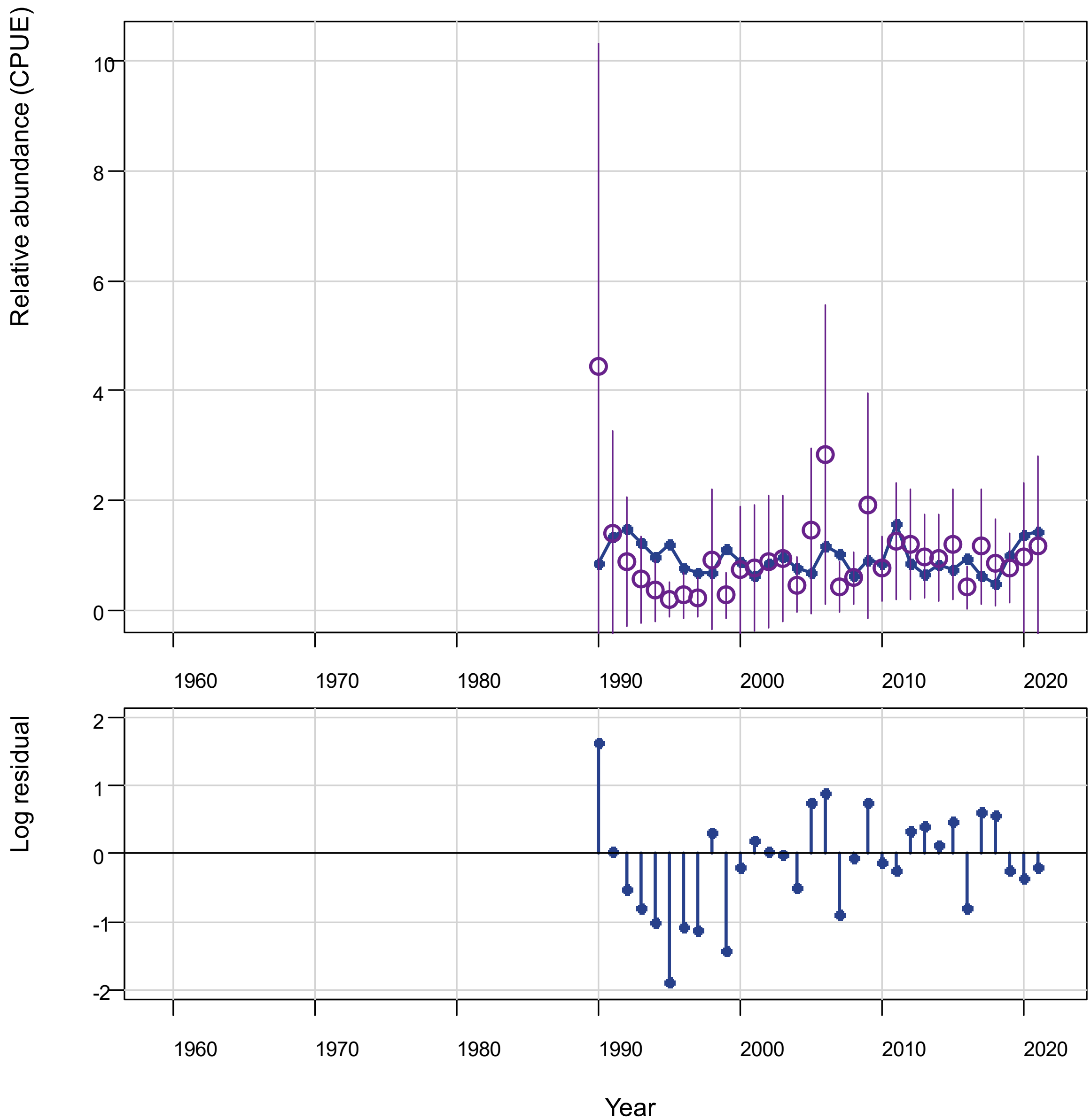

Figure A19. **Predicted fit (blue, closed circle with line) to the observed (open circle) SAD index. The lower panel indicates the residual for each data point.**

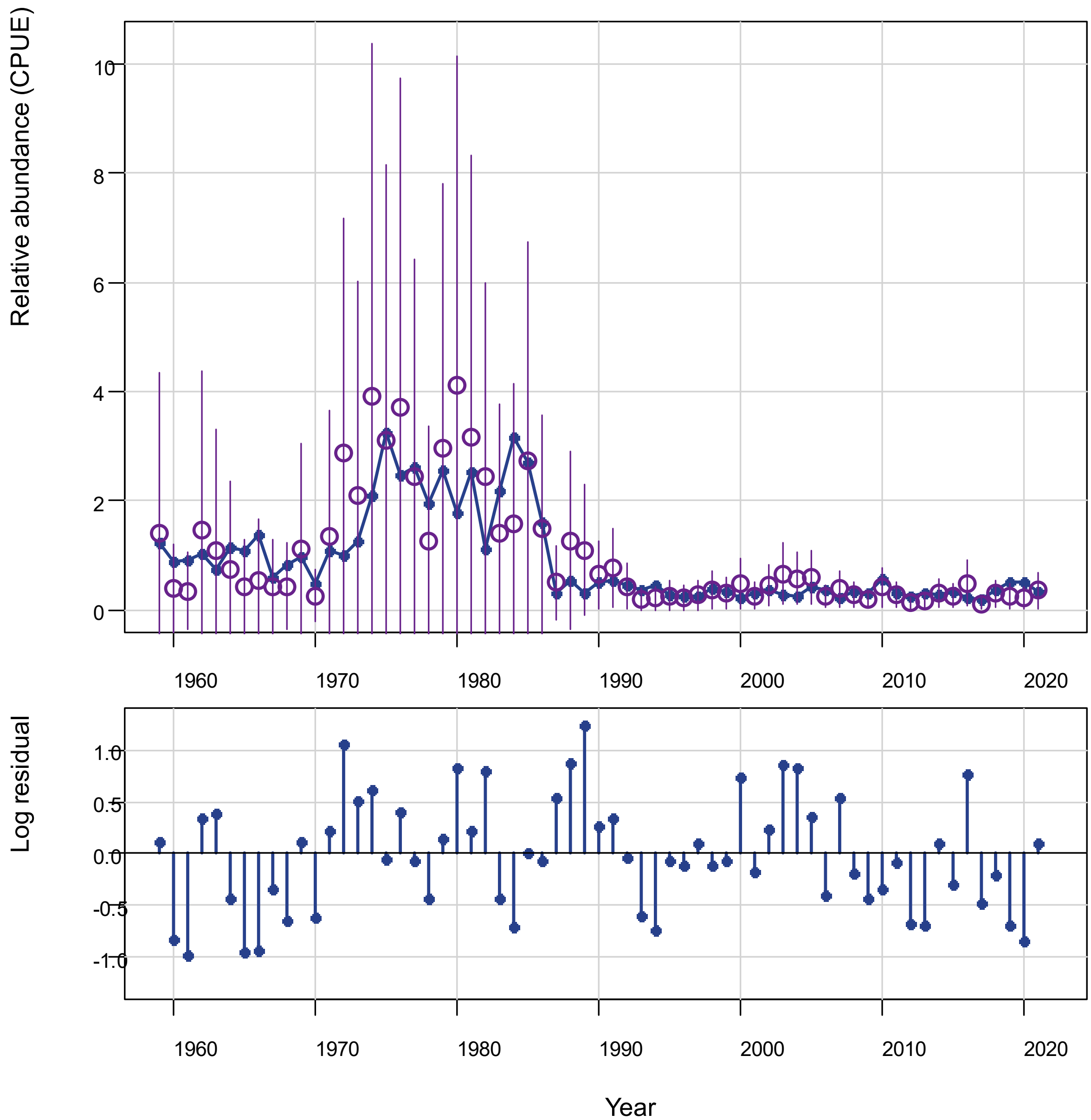

Figure A20. **Predicted fit (blue, closed circle with line) to the observed (open circle) recruitment index. The lower panel indicates the residual for each data point.**

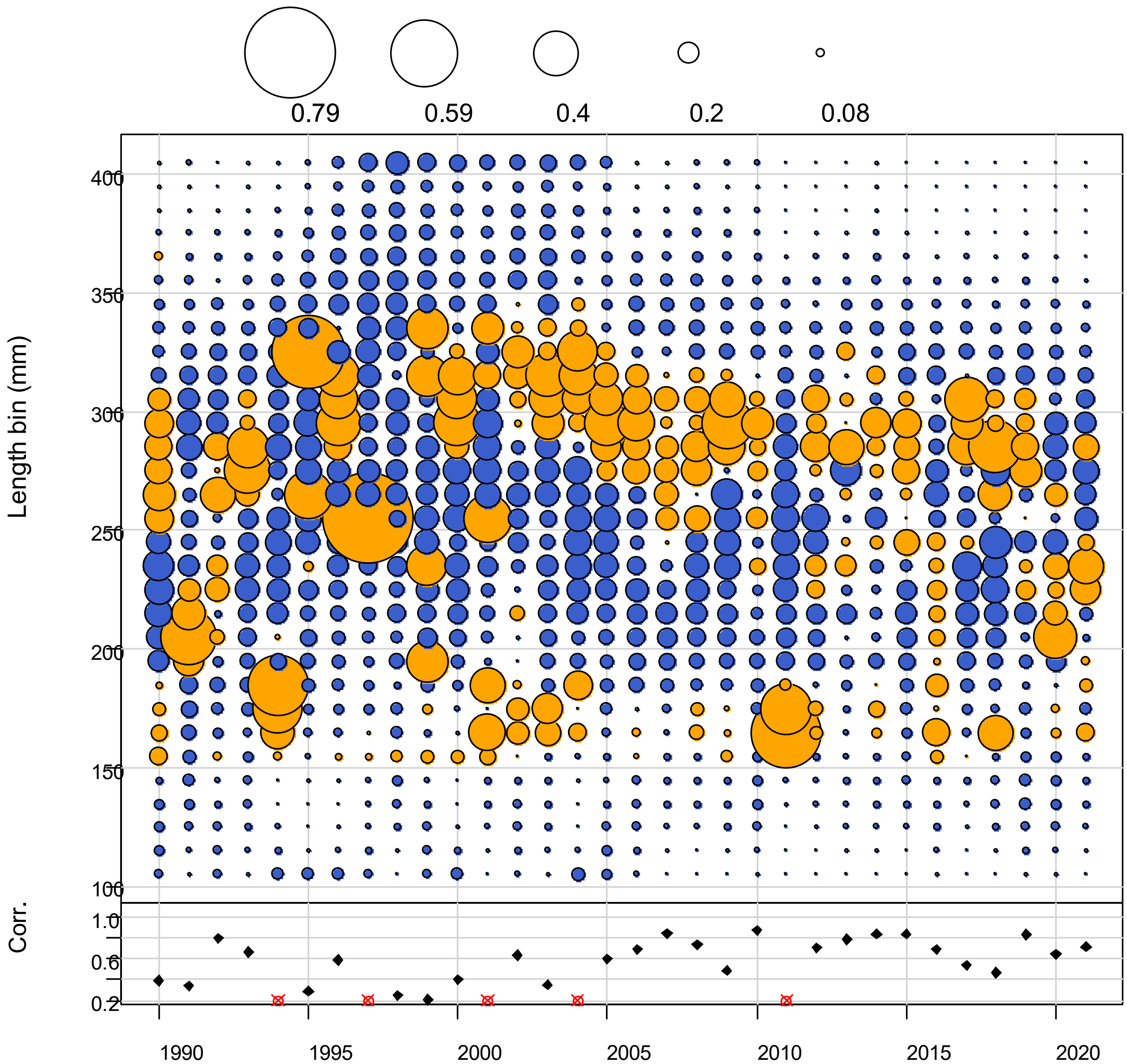

Figure A21. **Bubble plot of the fits to the length compositions for the NAD index. Orange indicates an underestimate, while blue indicates on overestimate. The bottom panel indicates the correlation between the observed data and the model prediction.**

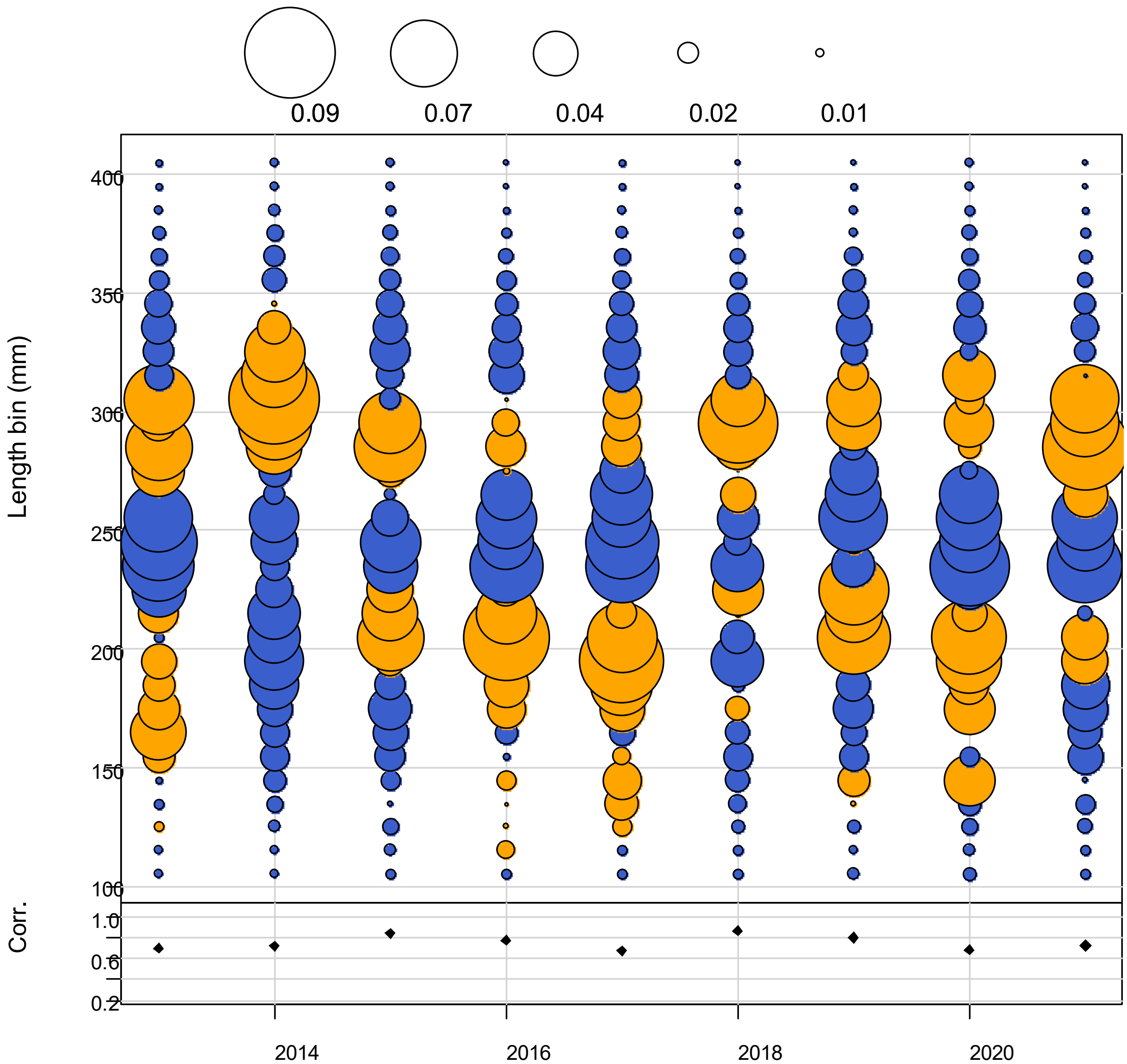

Figure A22. **Bubble plot of the fits to the length compositions for the MAD index. Orange indicates an underestimate, while blue indicates on overestimate. The bottom panel indicates the correlation between the observed data and the model prediction.**

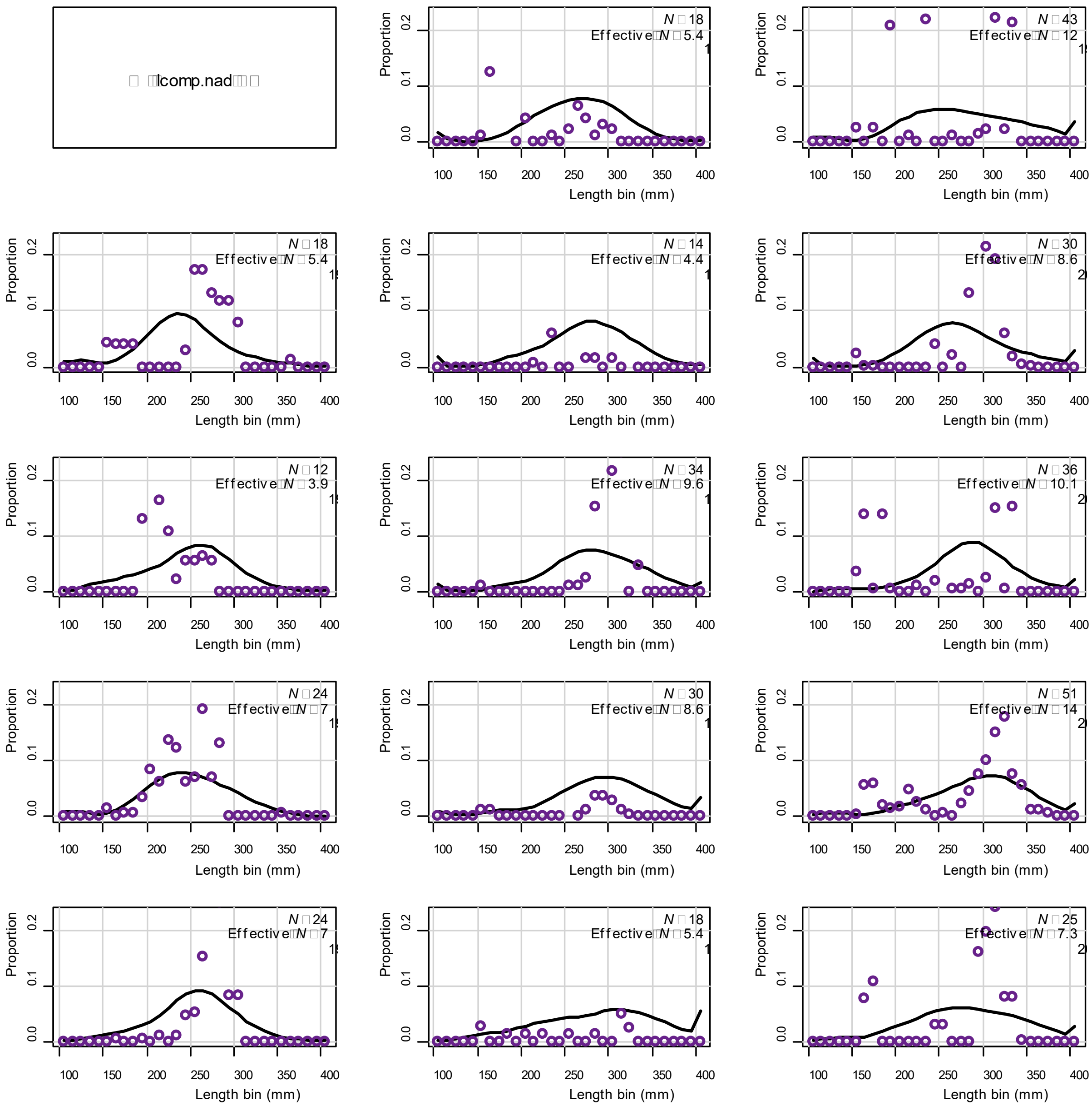

Figure A23. **Annual length composition plots for the NAD index for 1990-2021. Open circles are the observed data, while the line indicates the model fit.**

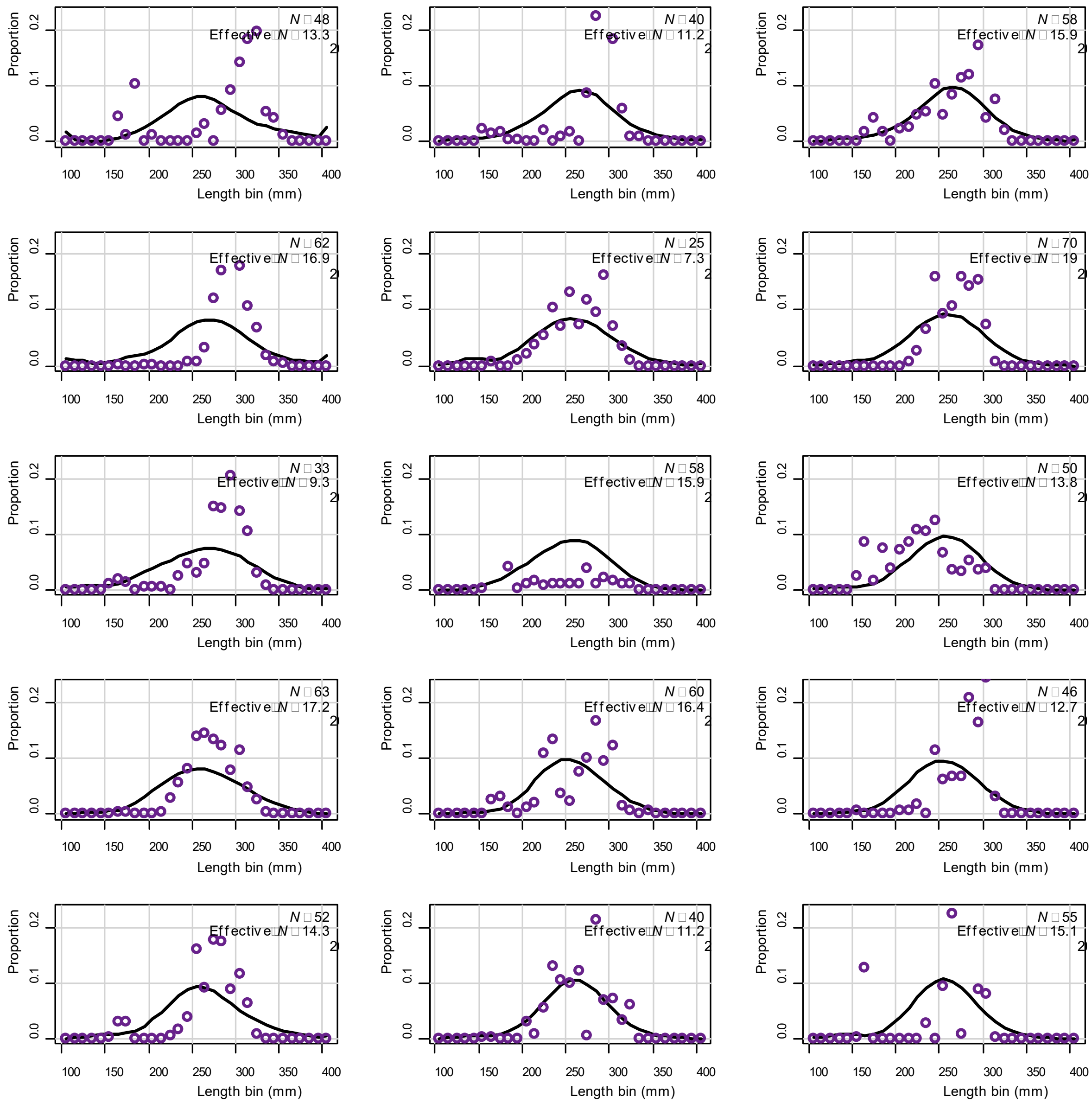

Figure A23. *Continued*

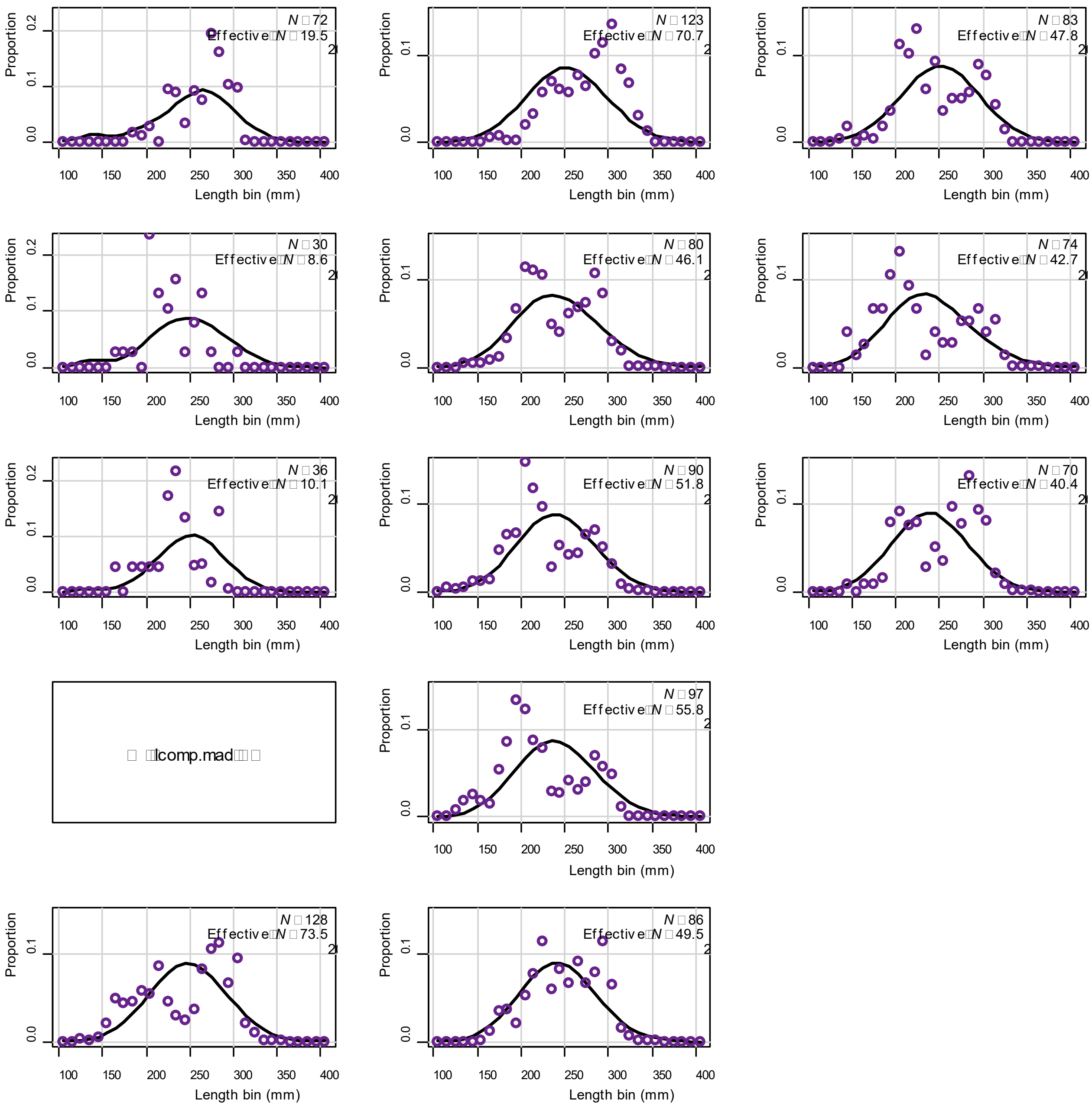

Figure A23. ***Continued***

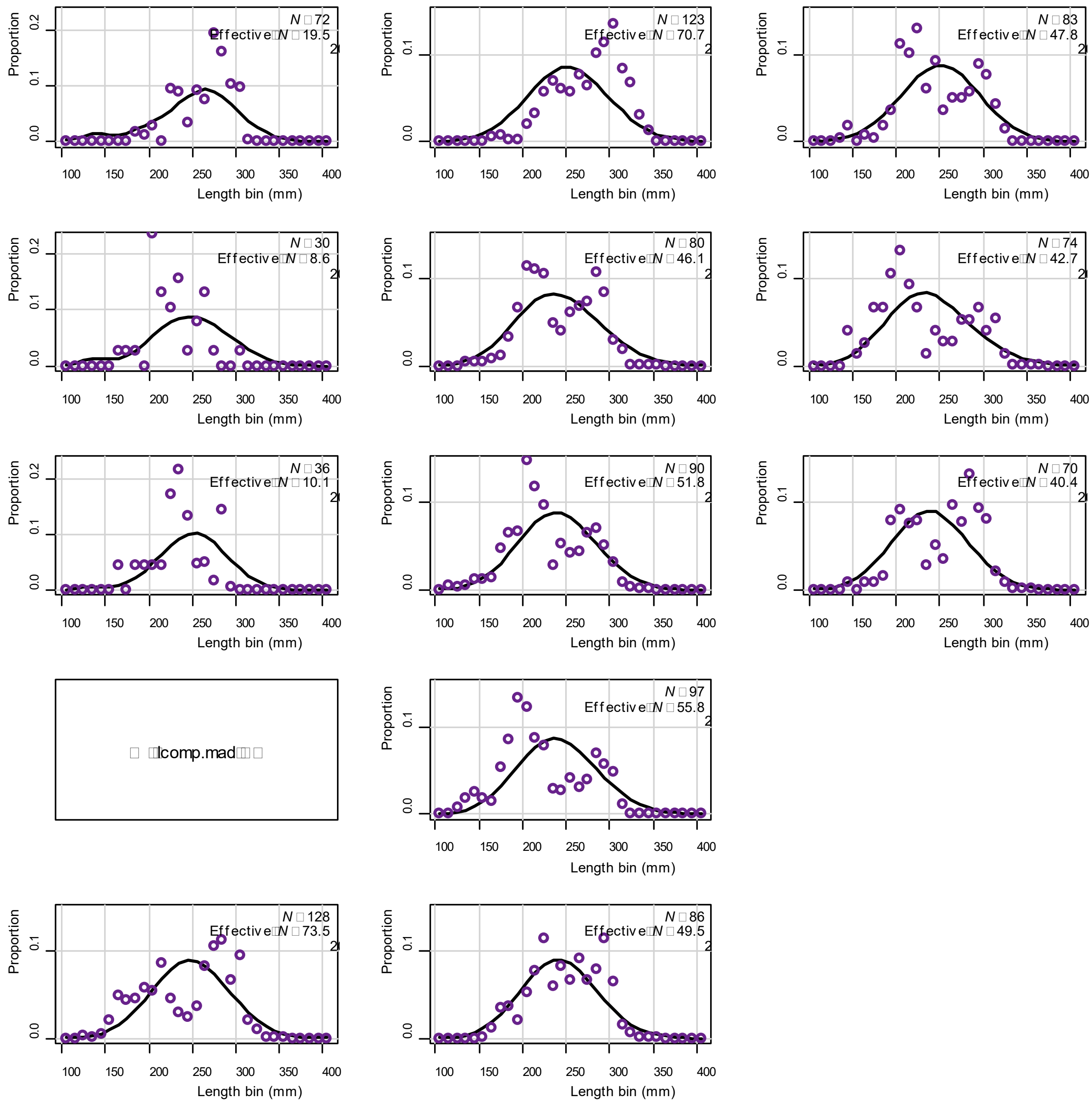

Figure A24. **Annual length composition plots for the MAD index for 2013-2021. Open circles are the observed data, while the line indicates the model fit.**

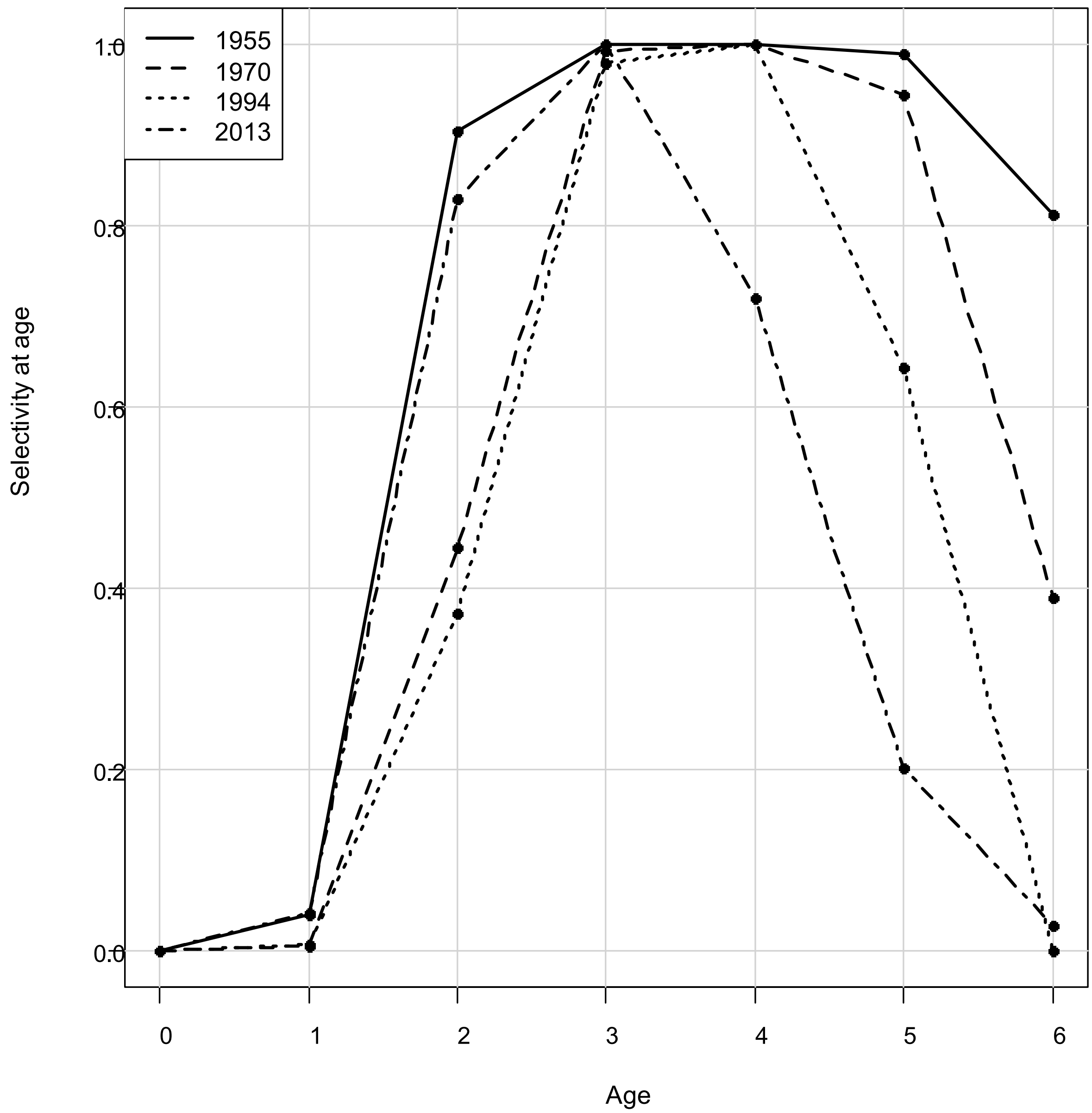

Figure A25. **Estimated selectivity of the northern commercial reduction landings for 1955-1969, 1970-1993, 1994-2012, and 2013-2021.**

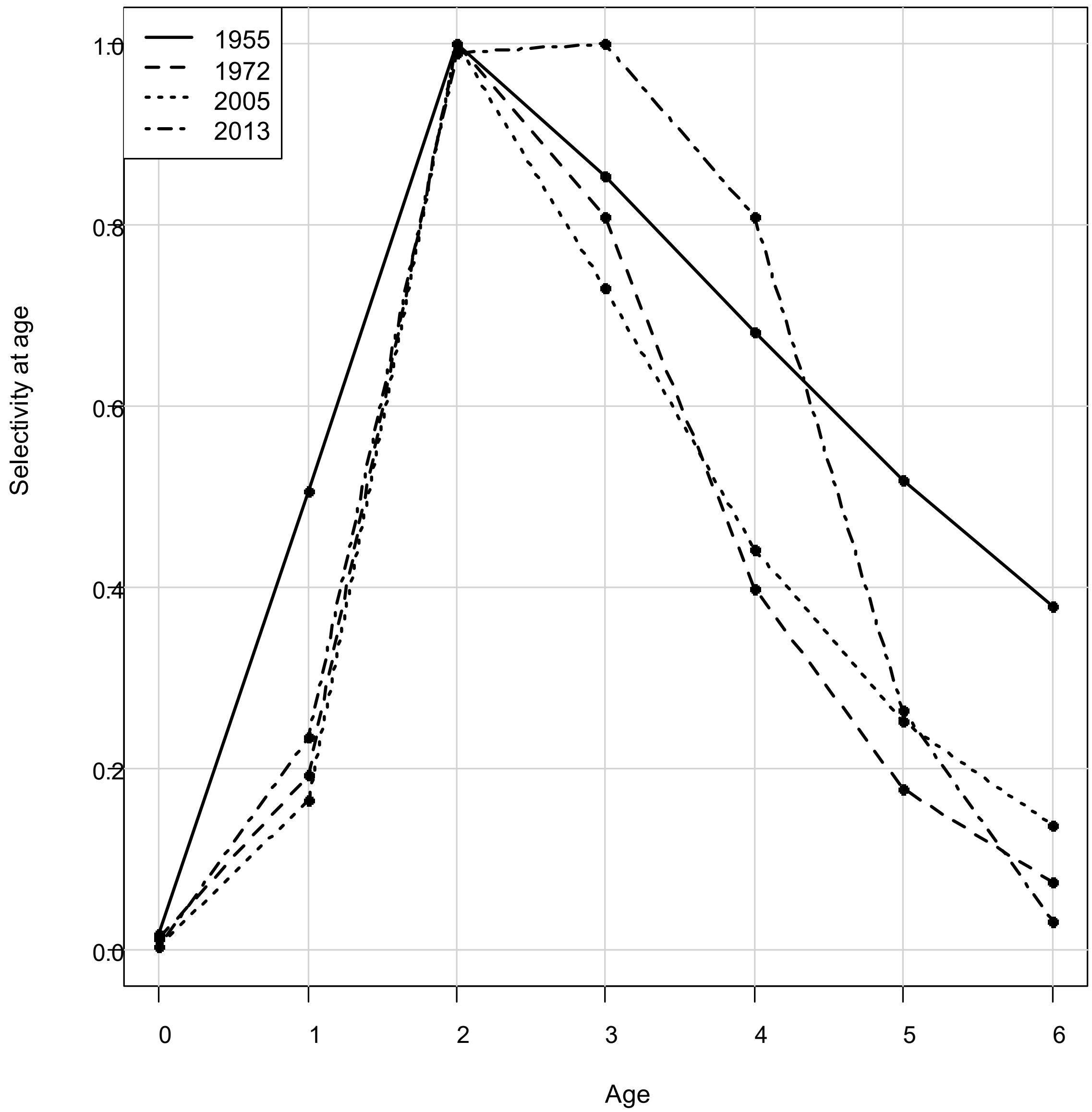

Figure A26. **Estimated selectivity of the southern commercial reduction landings for 1955-1971, 1972-2004, 2005-2012, and 2013-2021.**

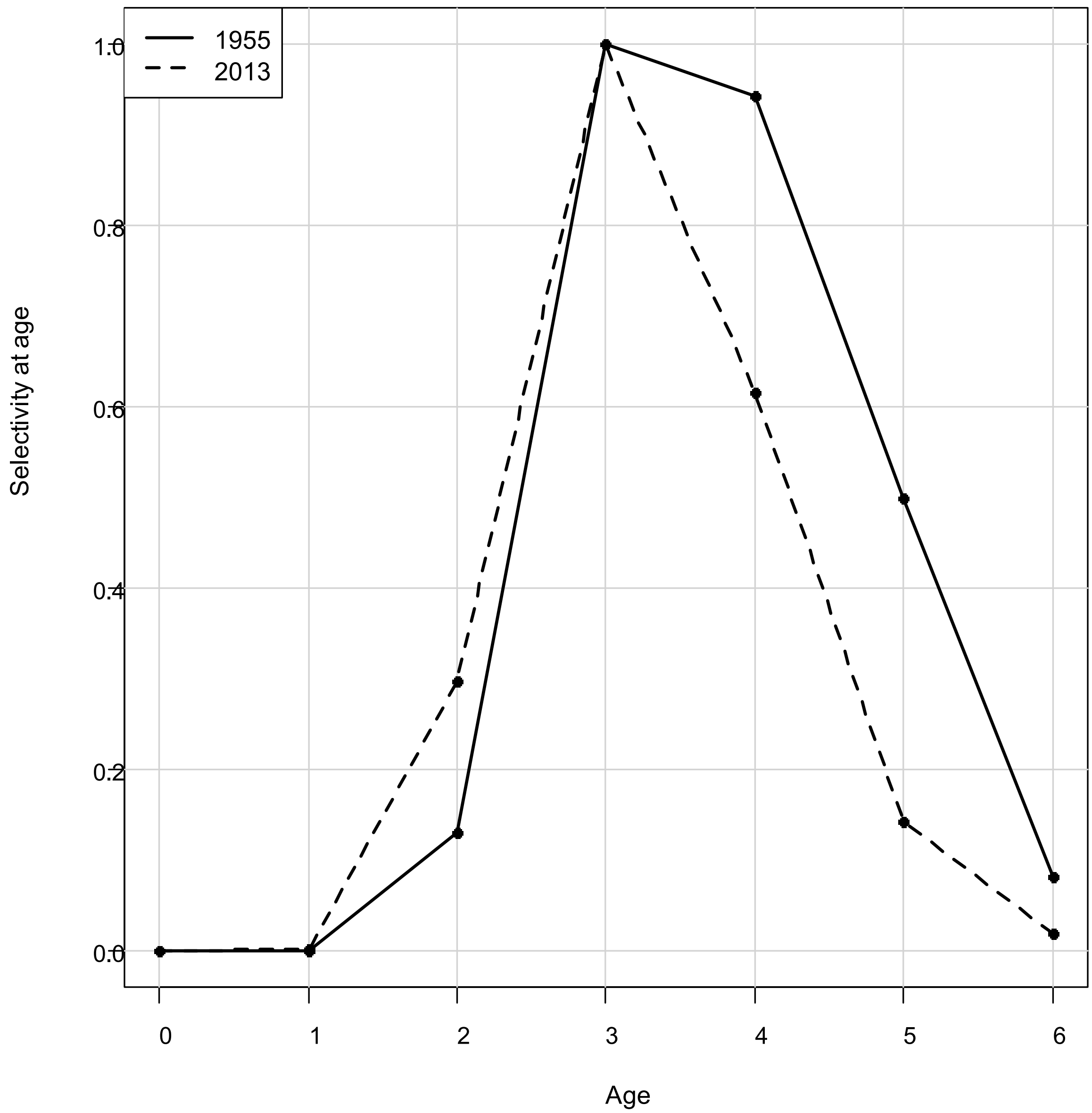

Figure A27. Estimated selectivity of the northern commercial bait landings for 1955-2012 and 2013-2021.

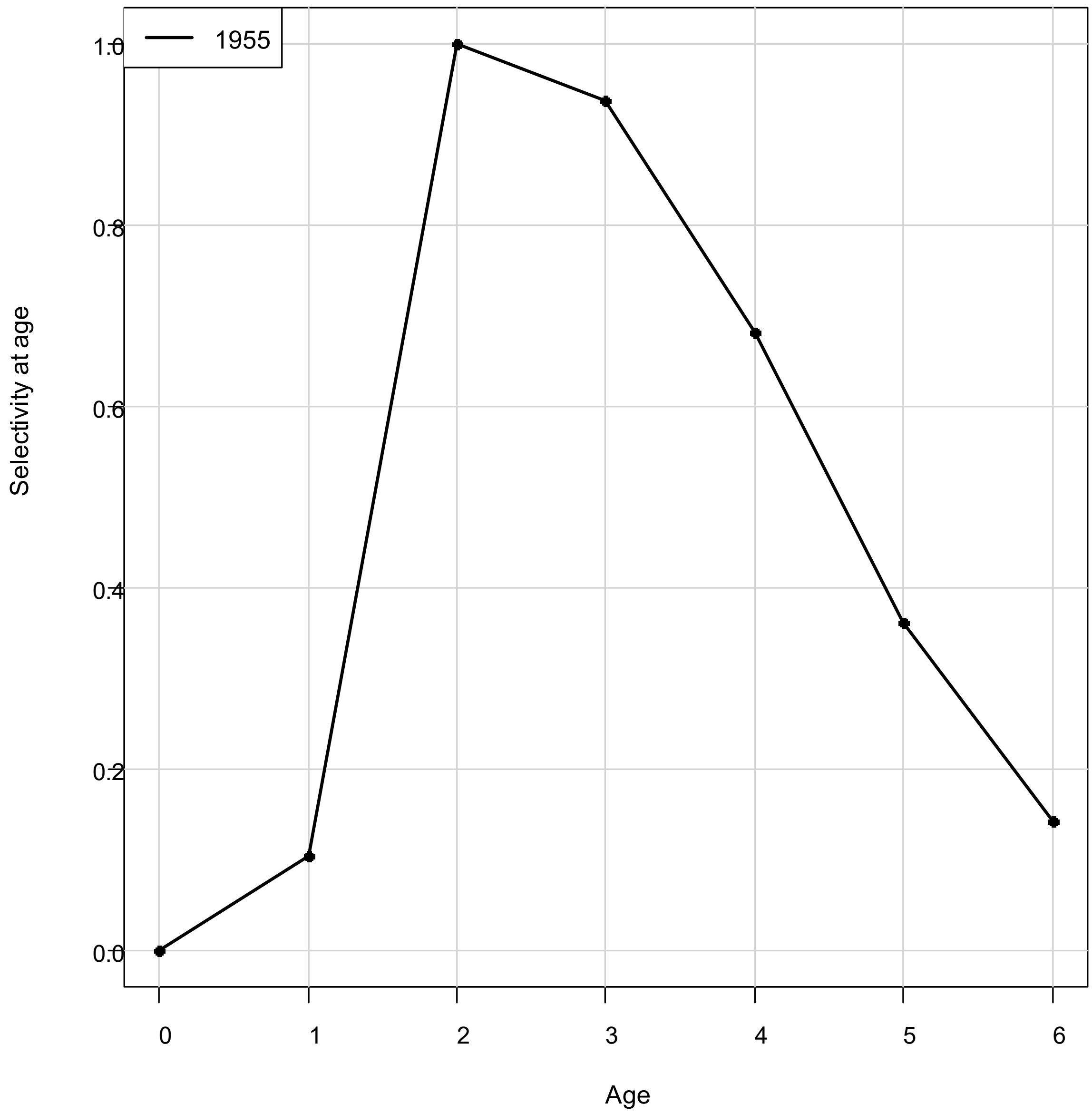

Figure A28. **Estimated selectivity of the southern commercial bait landings for 1955-2021.**

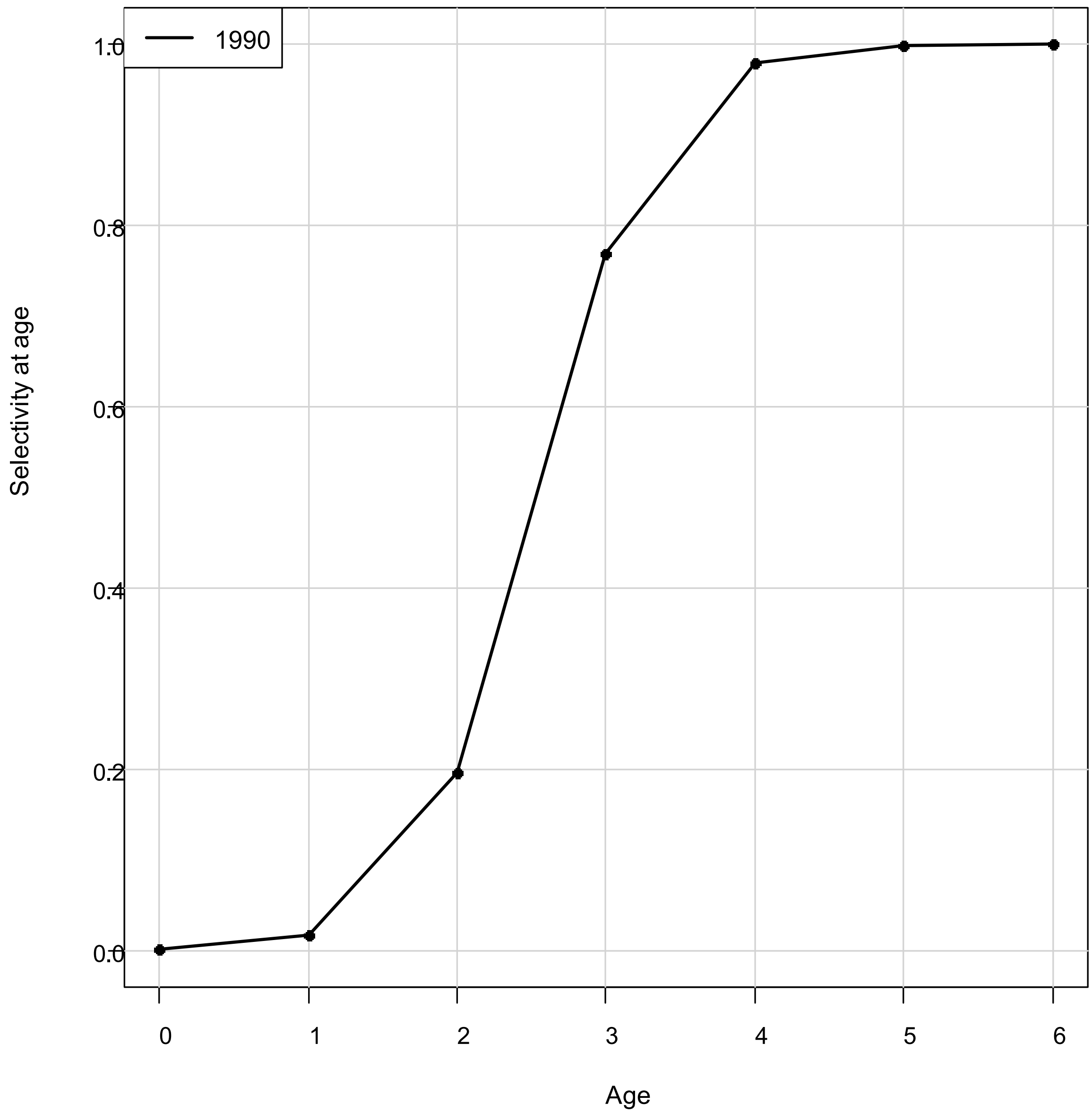

Figure A29. **Estimated selectivity for the NAD index for 1990-2021.**

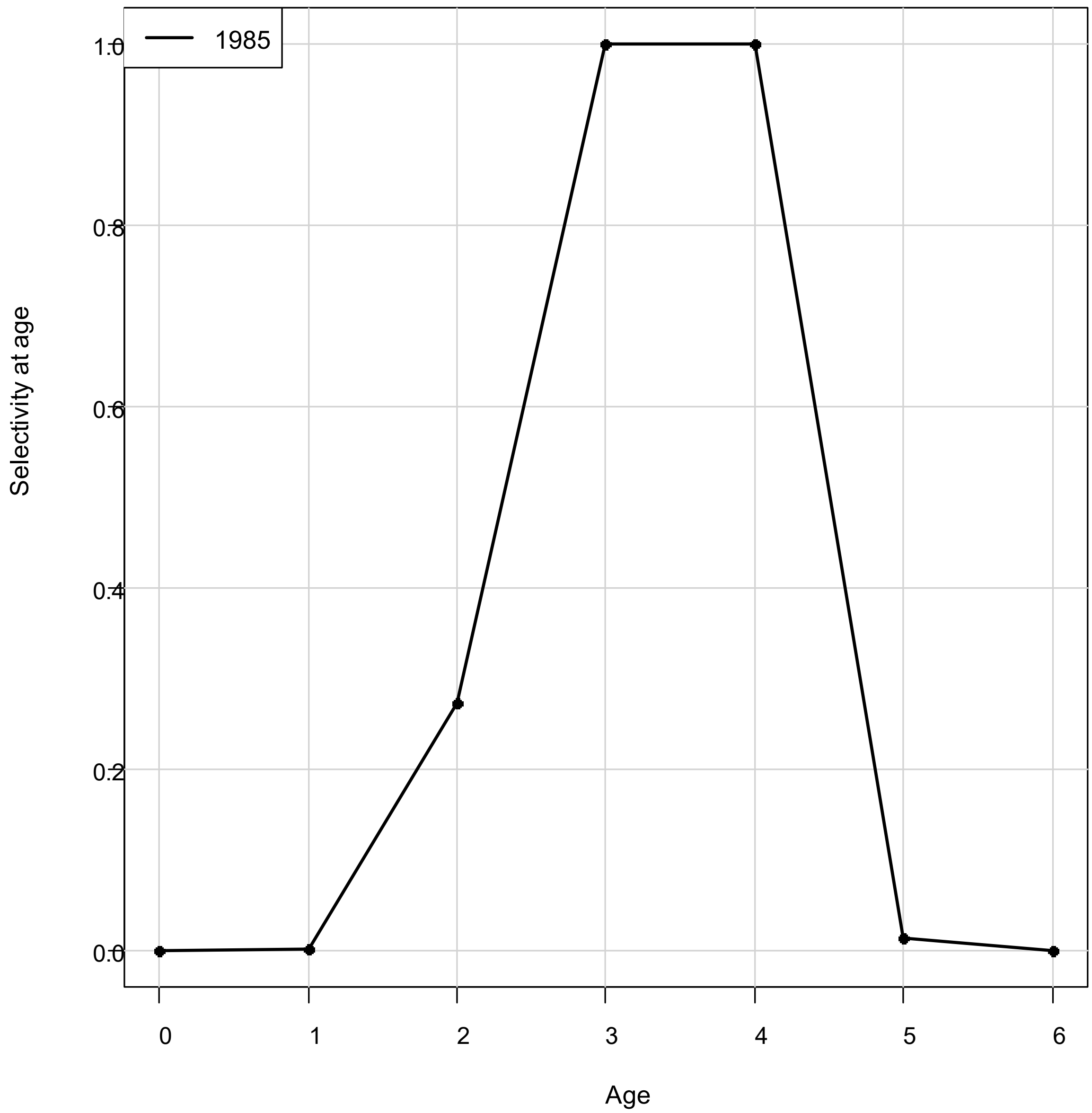

Figure A30. **Estimated selectivity for the MAD index for 1985-2021.**

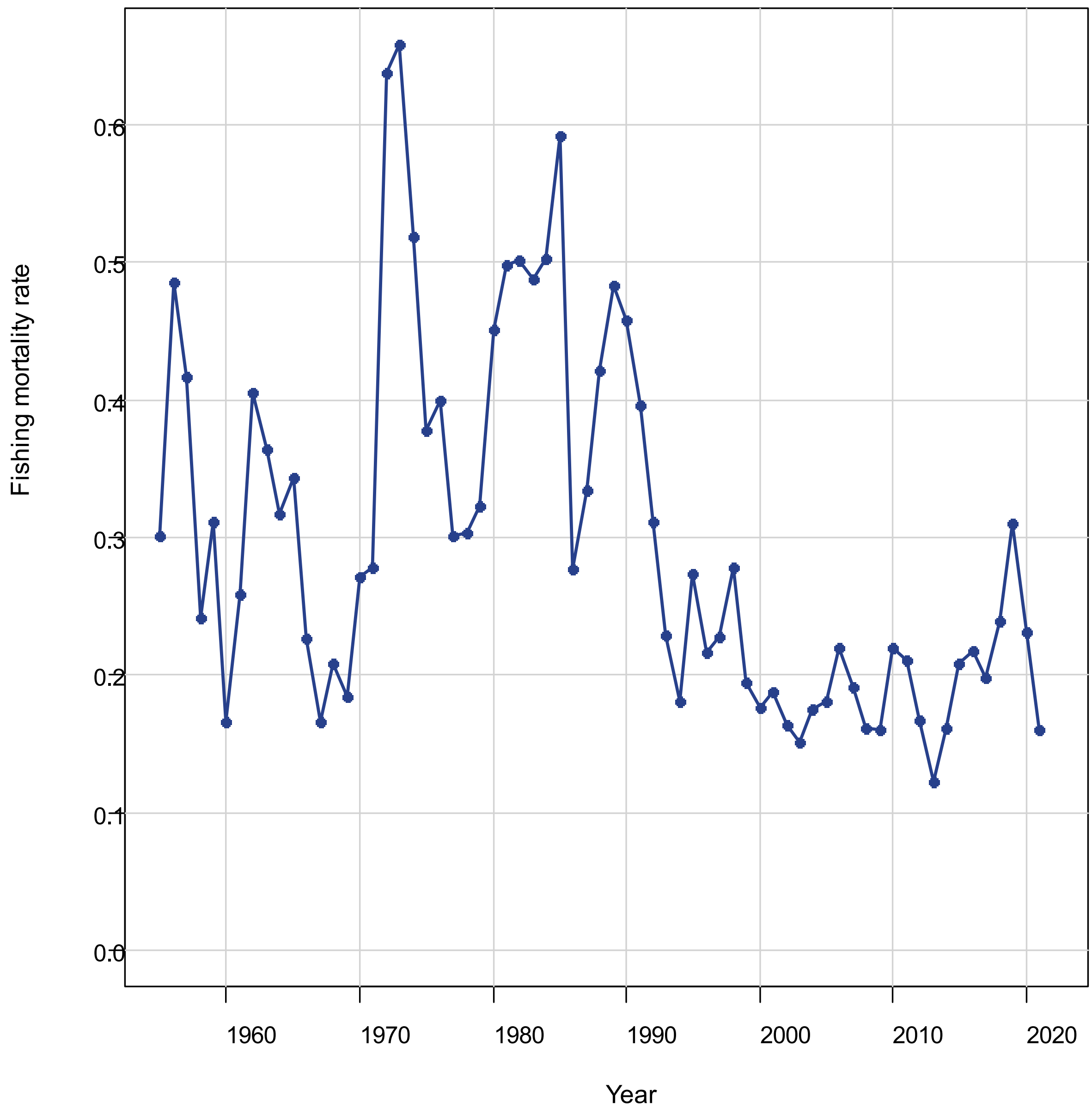

Figure A31. **The full fishing mortality rate for 1955-2021.**

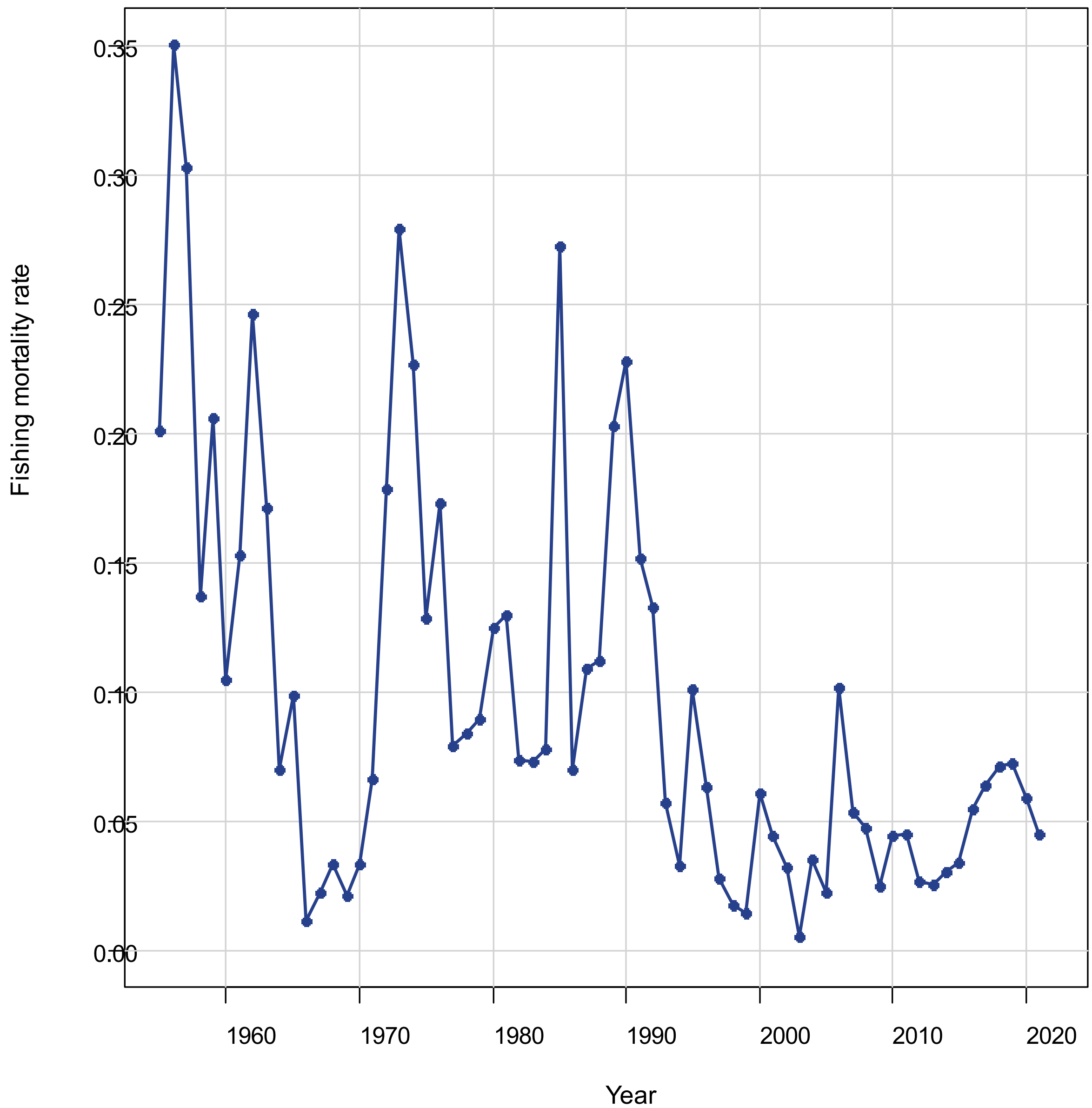

Figure A32. **The fishing mortality rate for the commercial reduction north fleet for 1955-2021.**

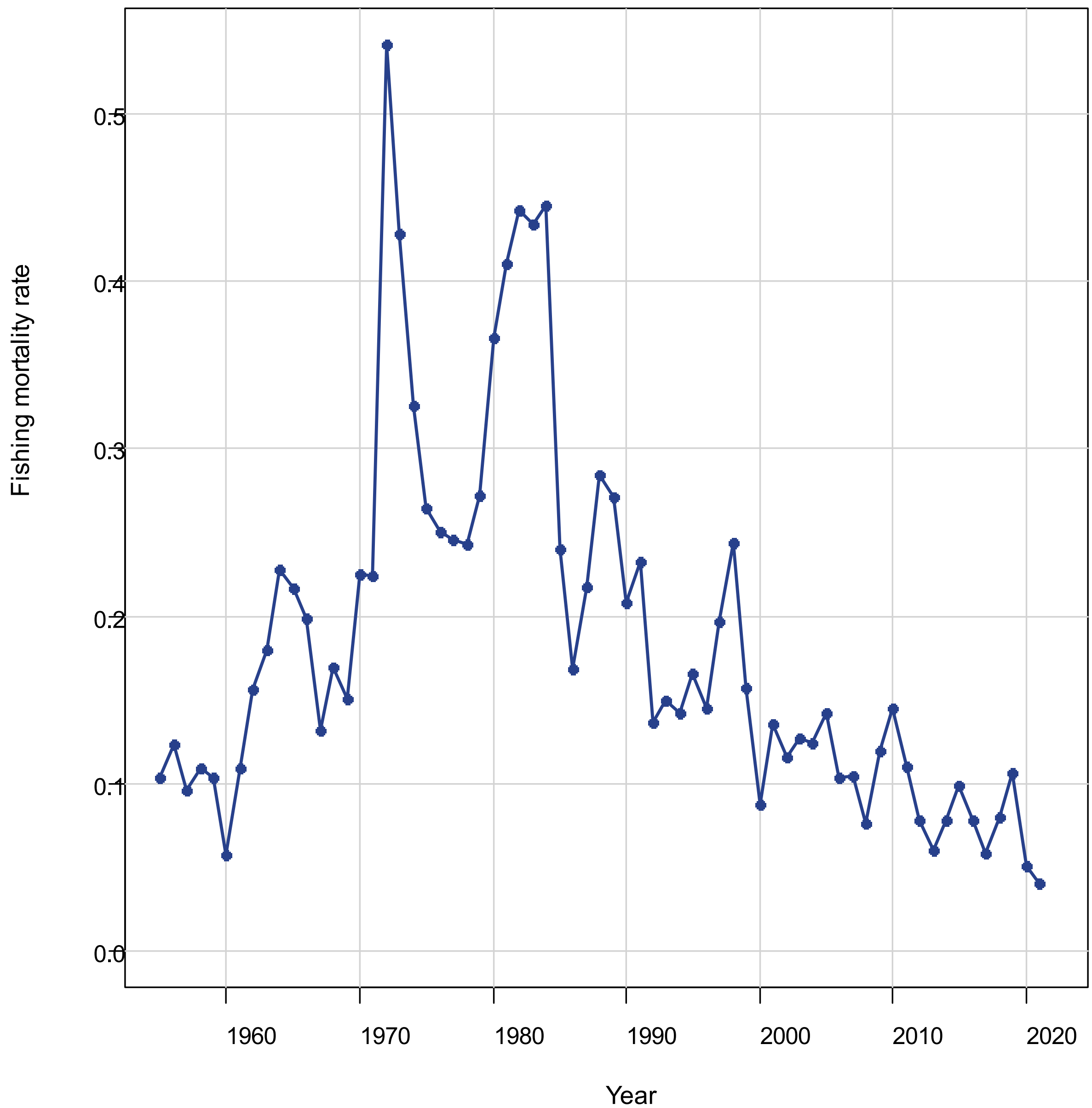

Figure A33. **The fishing mortality rate for the commercial reduction south fleet for 1955-2021.**

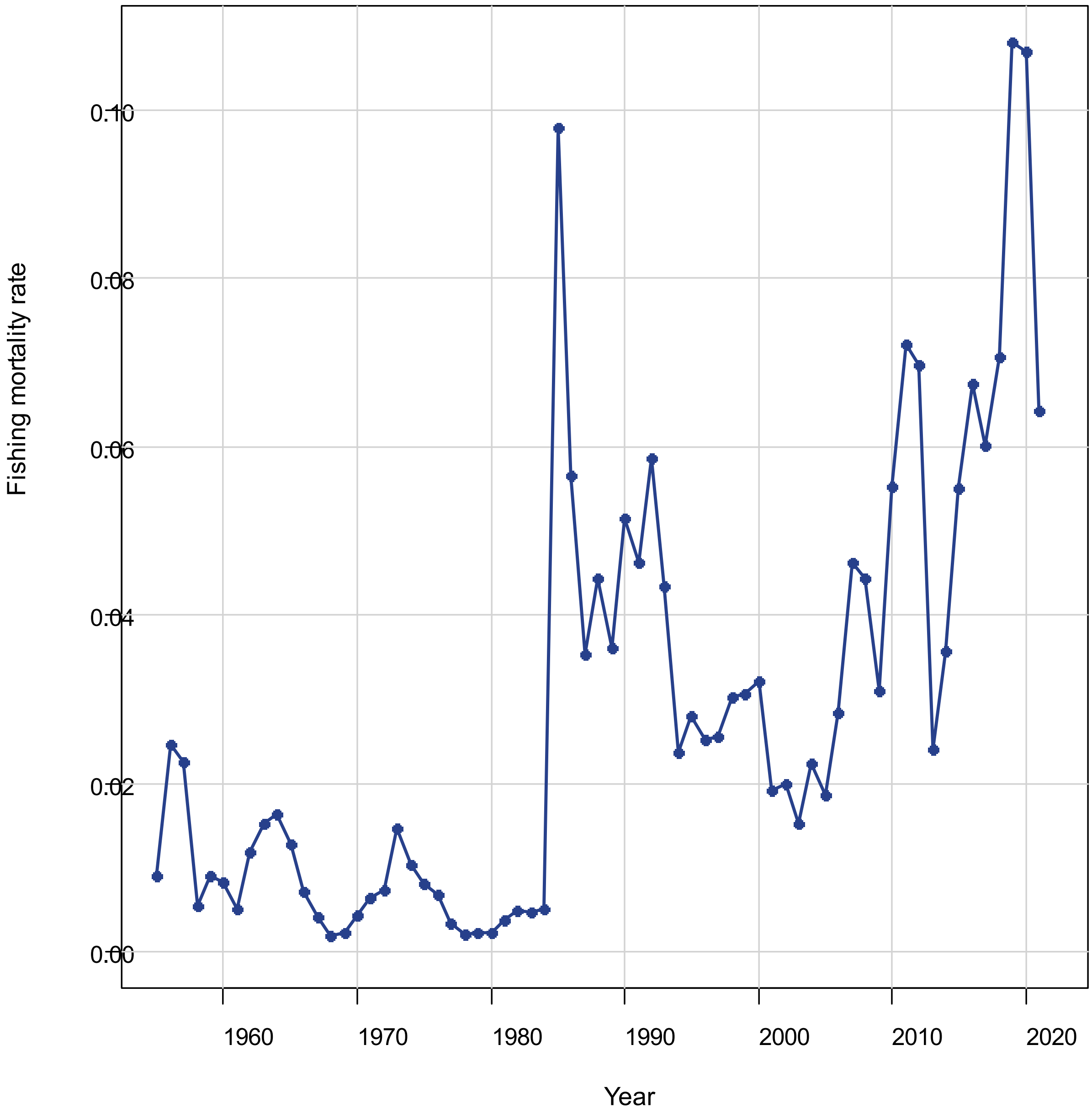

Figure A34. **The fishing mortality rate for the commercial bait north fleet for 1955-2021.**

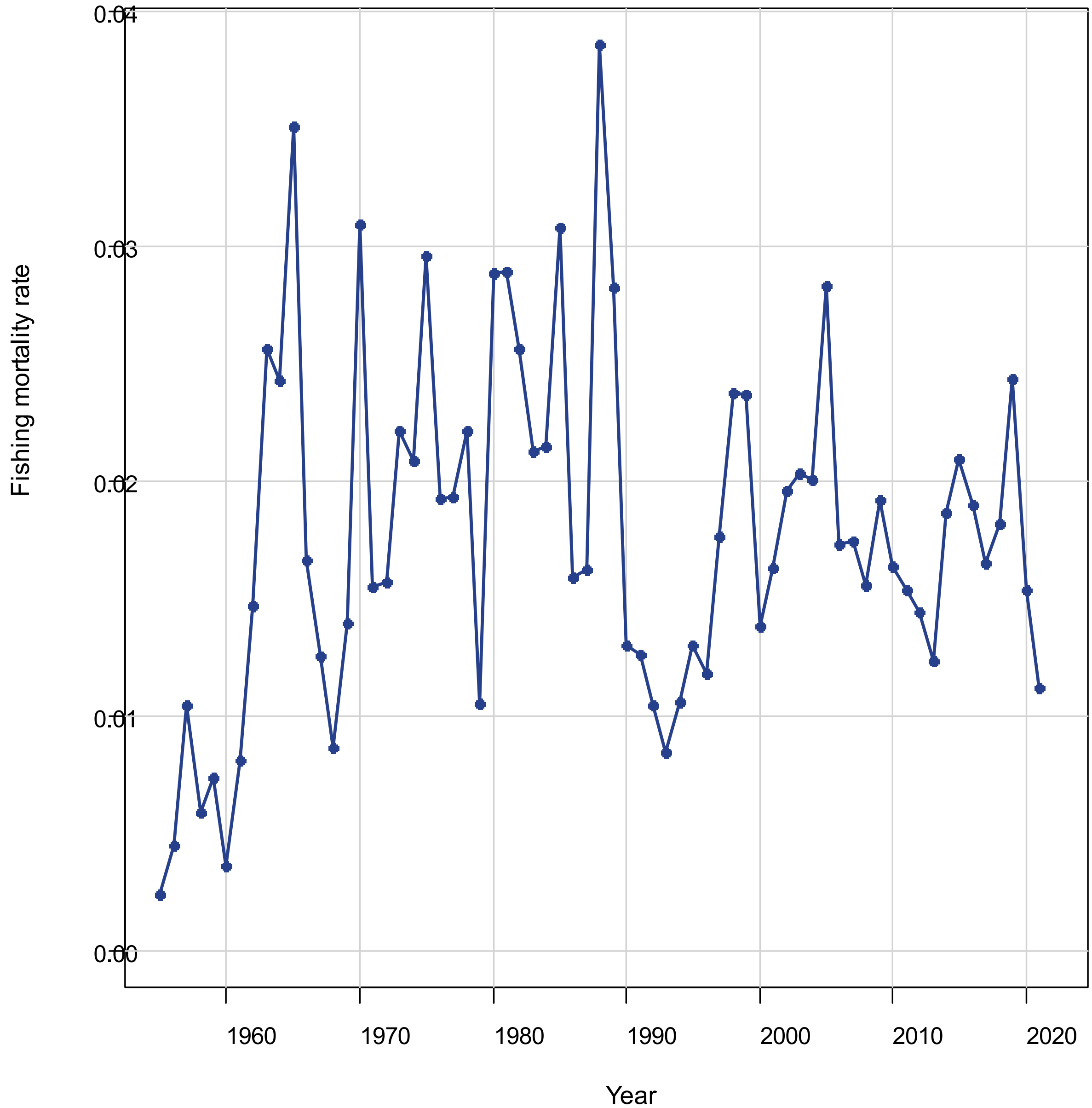

Figure A35. **The fishing mortality rate for the commercial bait south fleet for 1955-2021.**

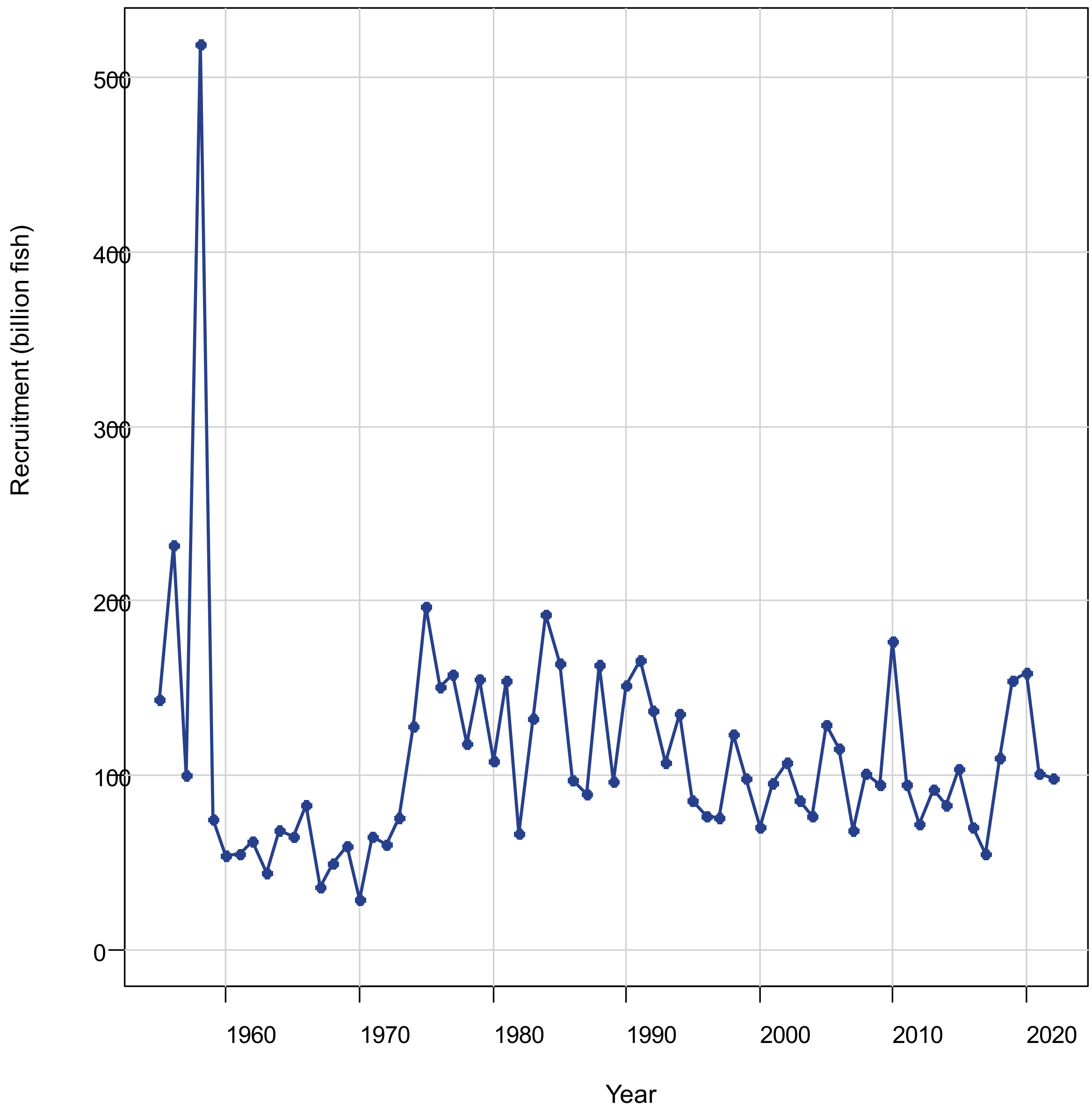

Figure A36. The estimated time series of recruitment for 1955-2021. The 2022 point is a projected recruitment point.

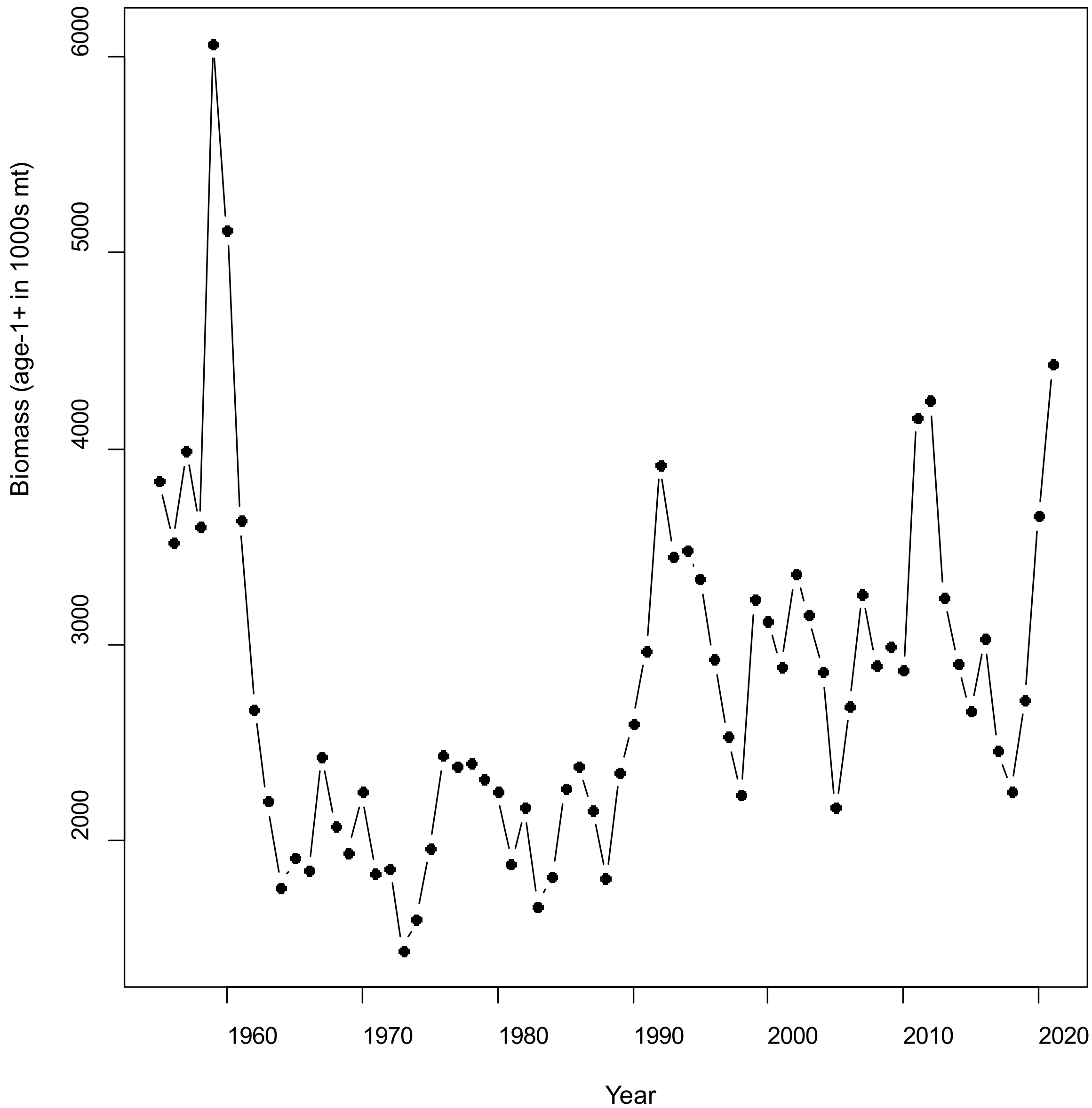

Figure A37. **Age-1+ biomass in 1000s of mt for 1955-2021.**

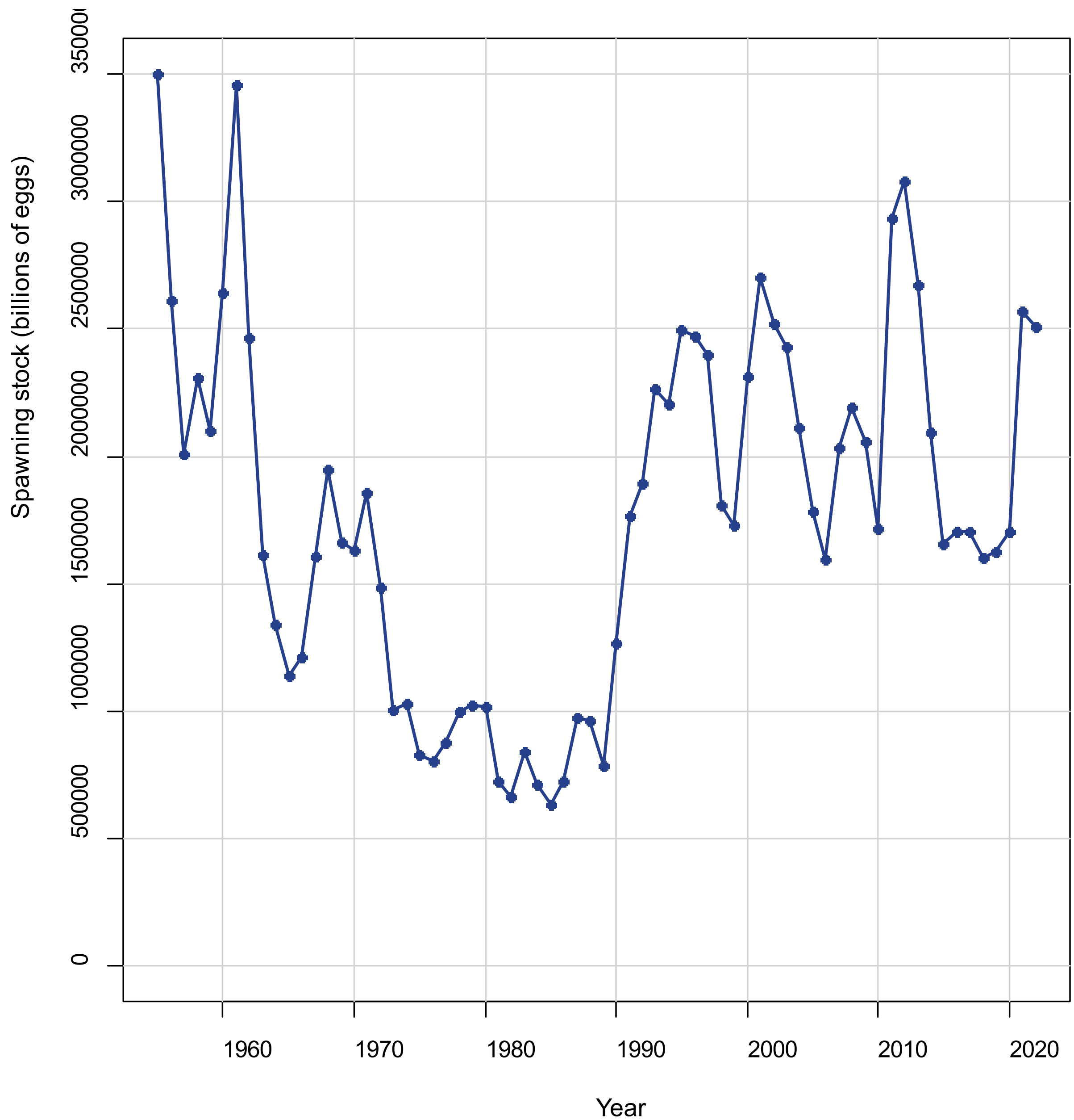

Figure A38. **Fecundity in billions of ova for 1955-2022. The 2022 value is a projection value.**

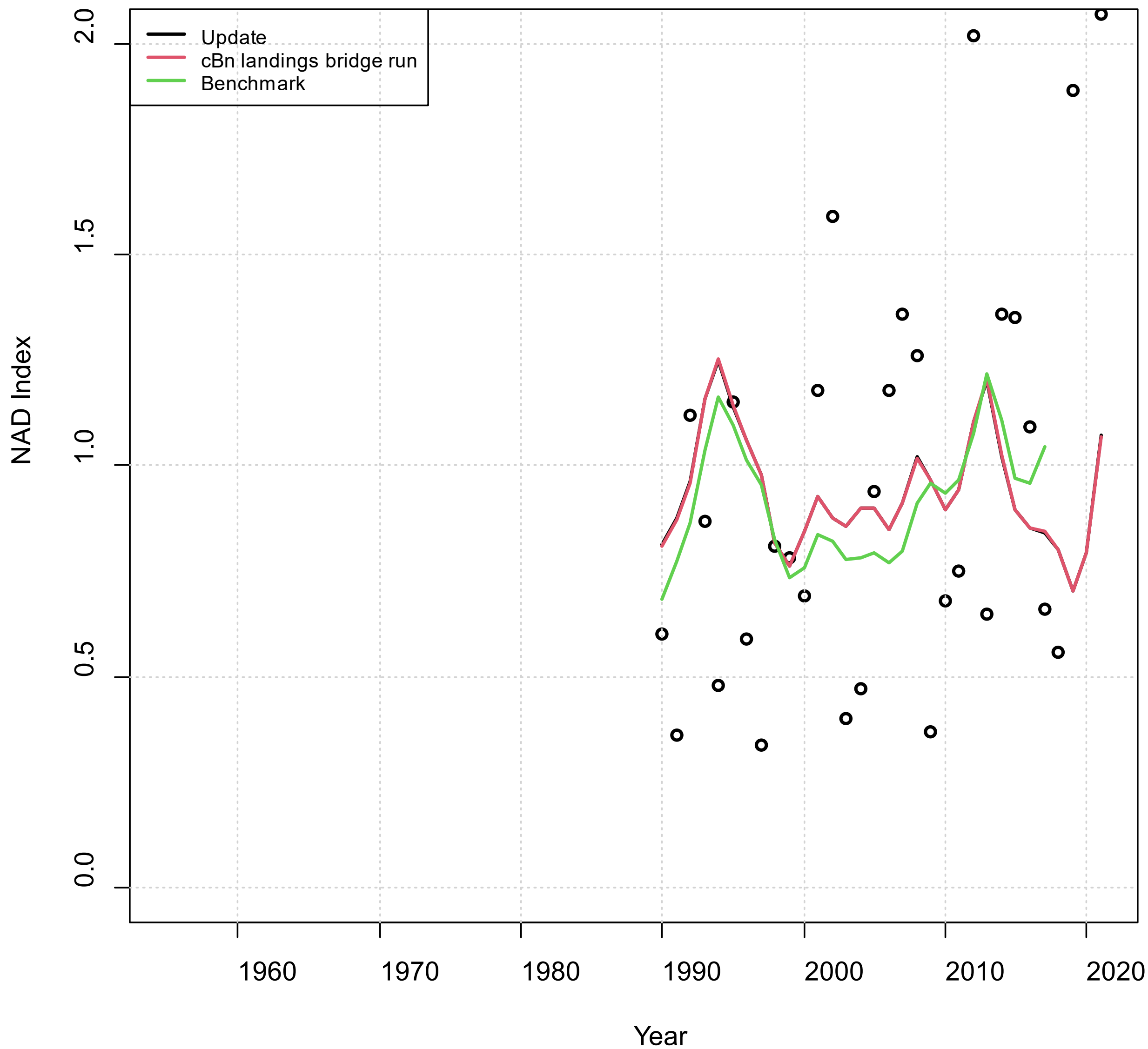

Figure A39. Fit to the observed (open circles) NAD index for the base run for this update assessment, the commercial bait north landings from the last assessment, and the last benchmark assessment.

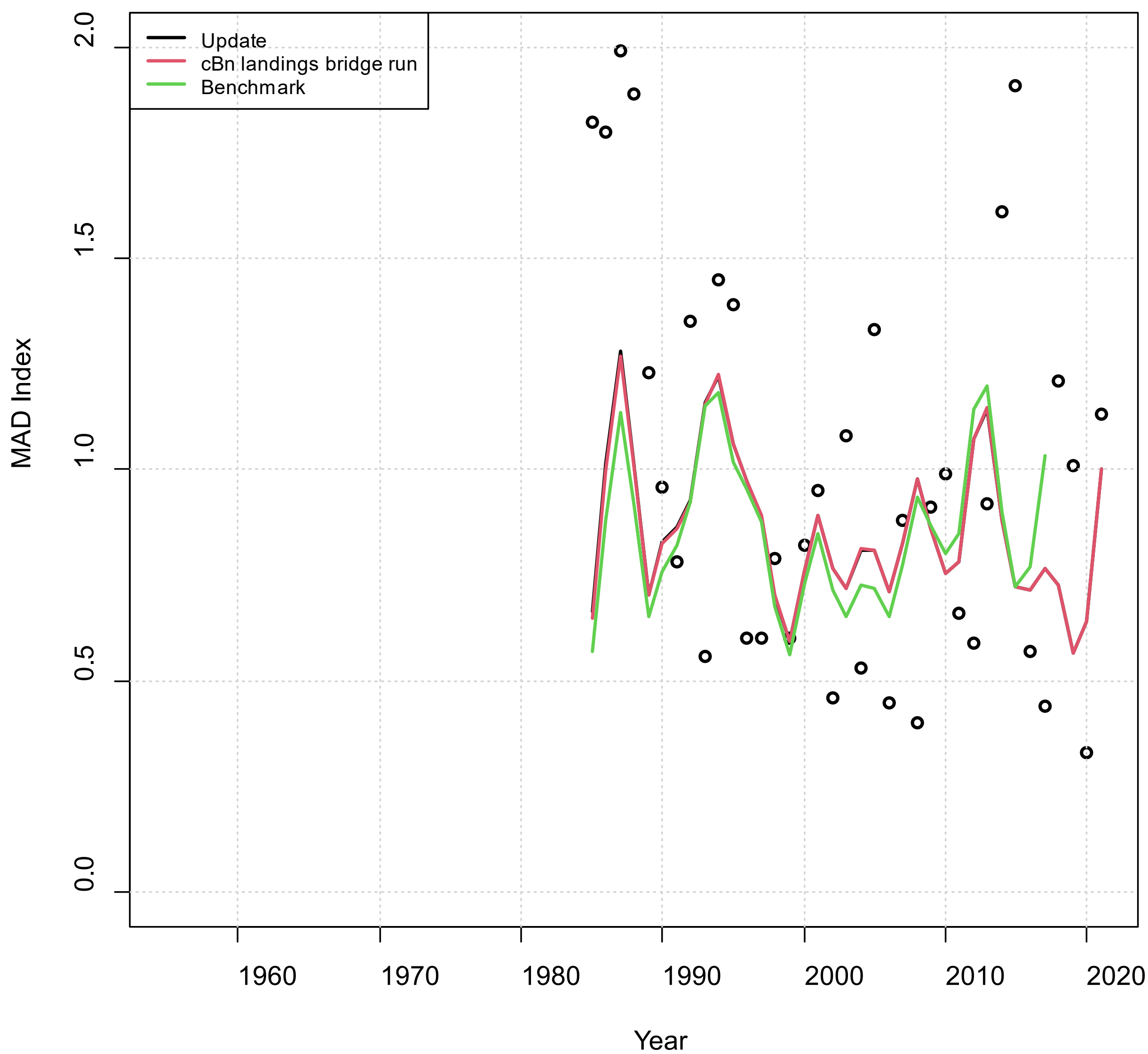

Figure A40. **Fit to the observed (open circles) MAD index for the base run for this update assessment, the commercial bait north landings from the last assessment, and the last benchmark assessment.**

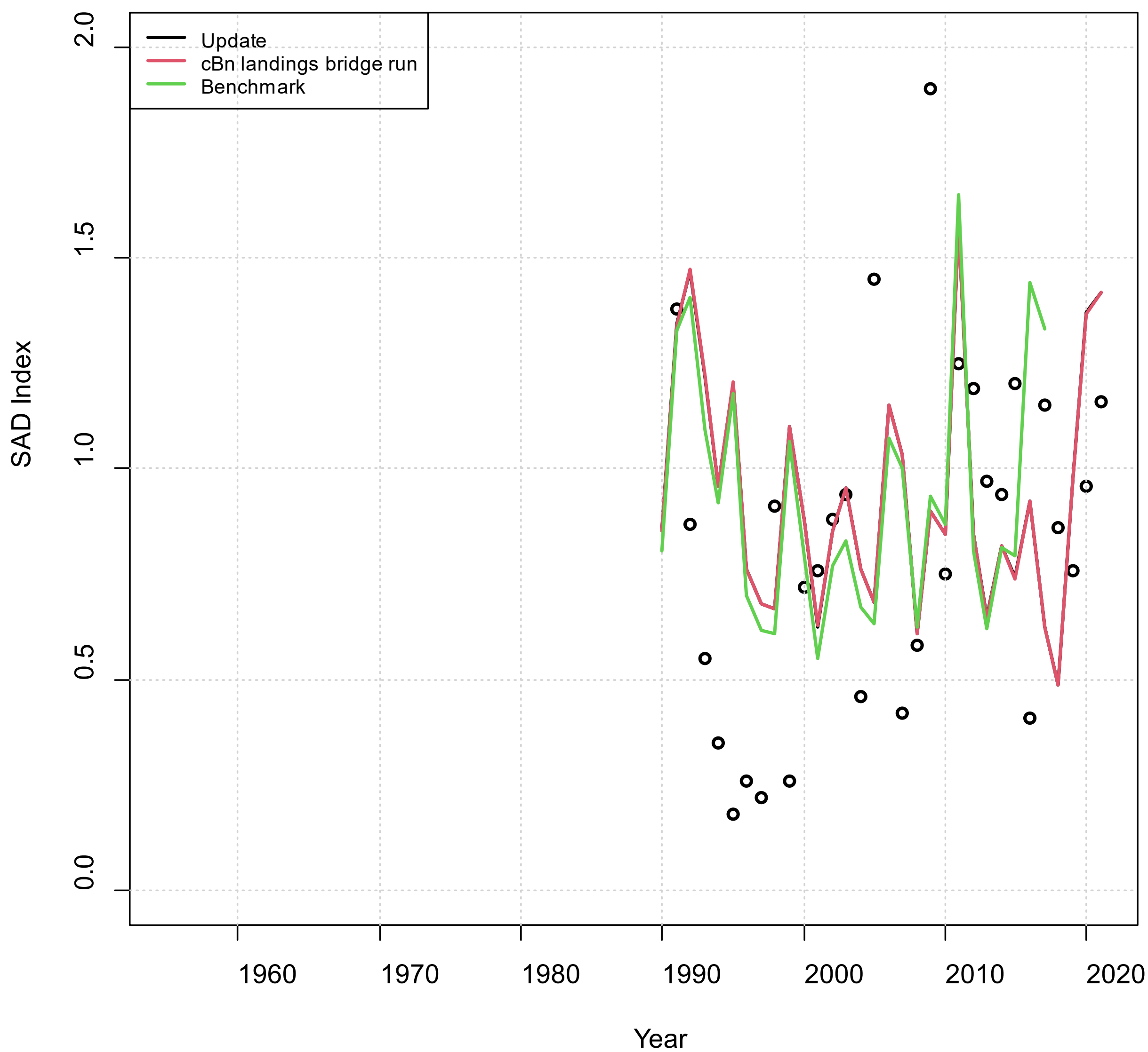

Figure A41. **Fit to the observed (open circles) SAD index for the base run for this update assessment, the commercial bait north landings from the last assessment, and the last benchmark assessment.**

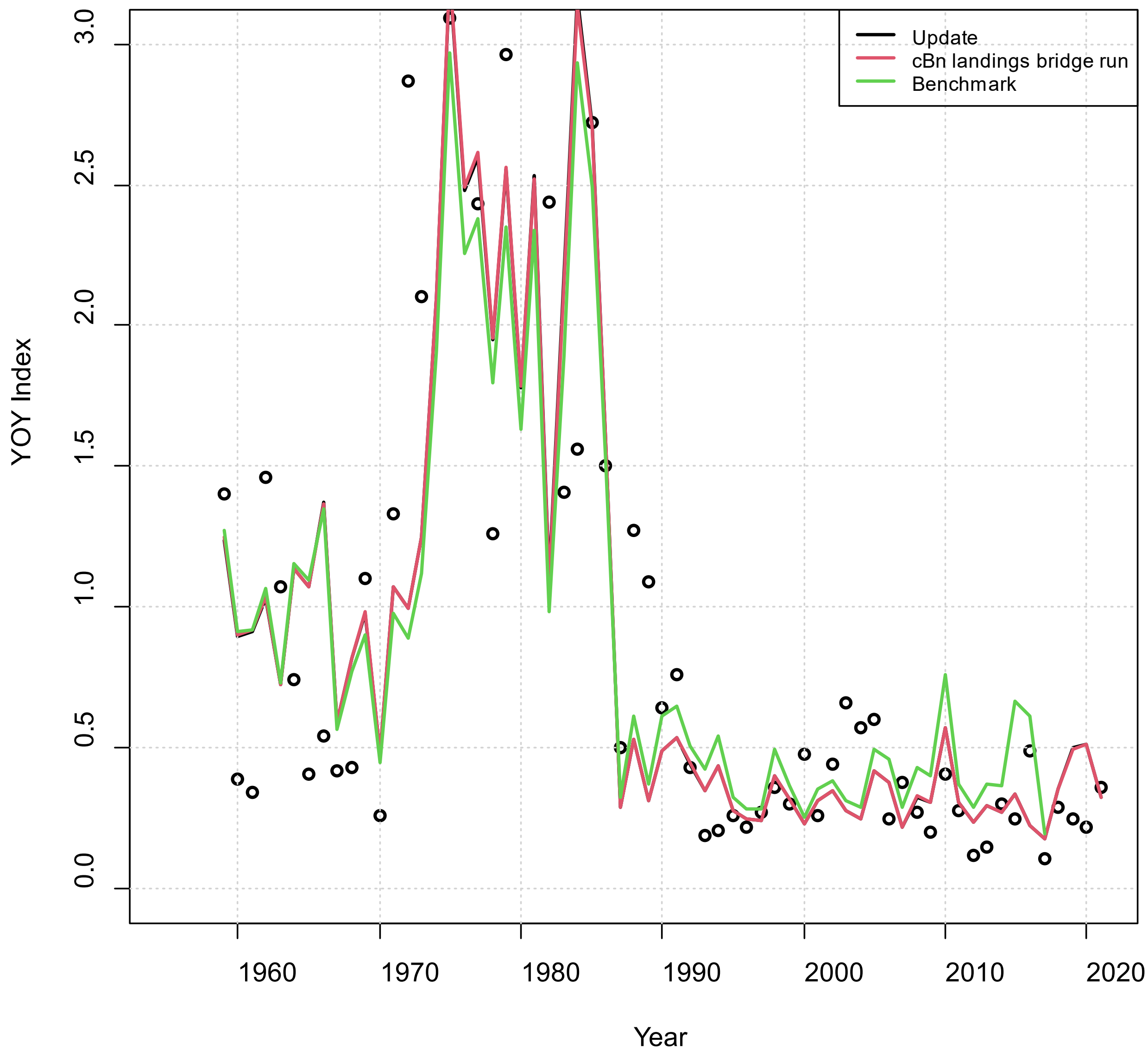

Figure A42. Fit to the observed (open circles) recruitment index for the base run for this update assessment, the commercial bait north landings from the last assessment, and the last benchmark assessment.

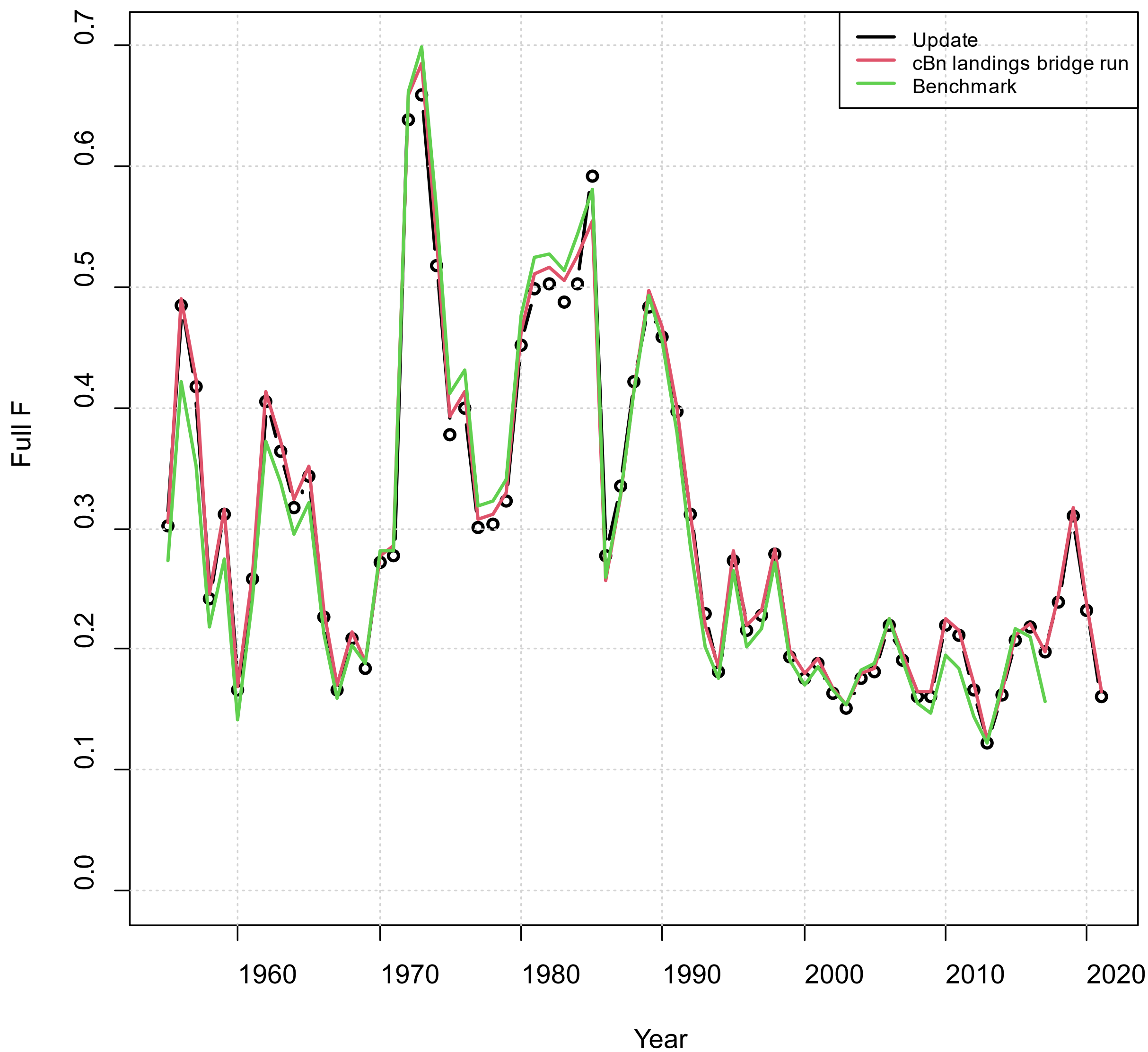

Figure A43. **Estimates of the full fishing mortality rate for the base run for this update assessment, the commercial bait north landings from the last assessment, and the last benchmark assessment.**

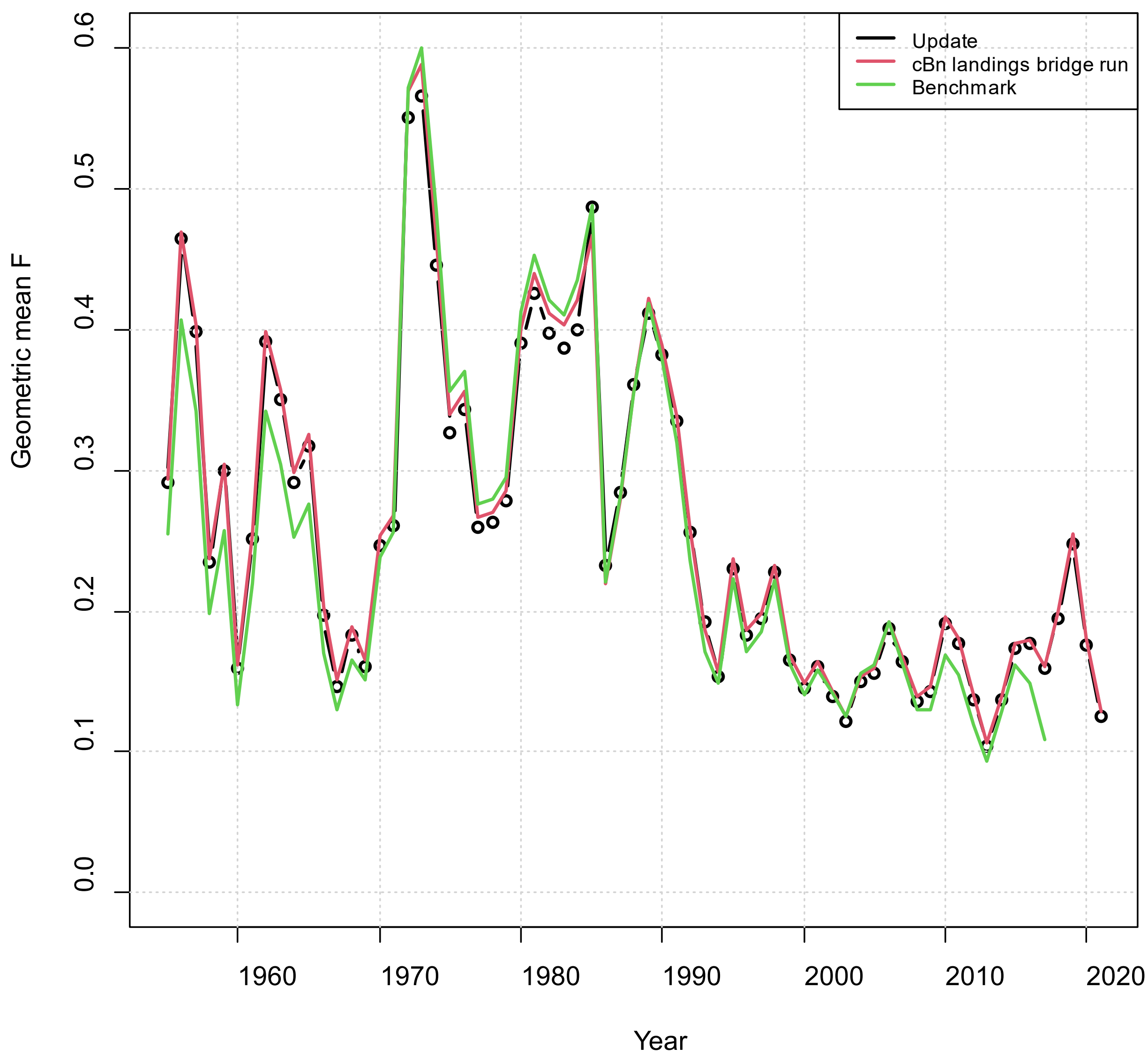

Figure A44. **Estimates of the geometric mean fishing mortality rate for ages-2 to -4 for the base run for this update assessment, the commercial bait north landings from the last assessment, and the last benchmark assessment.**

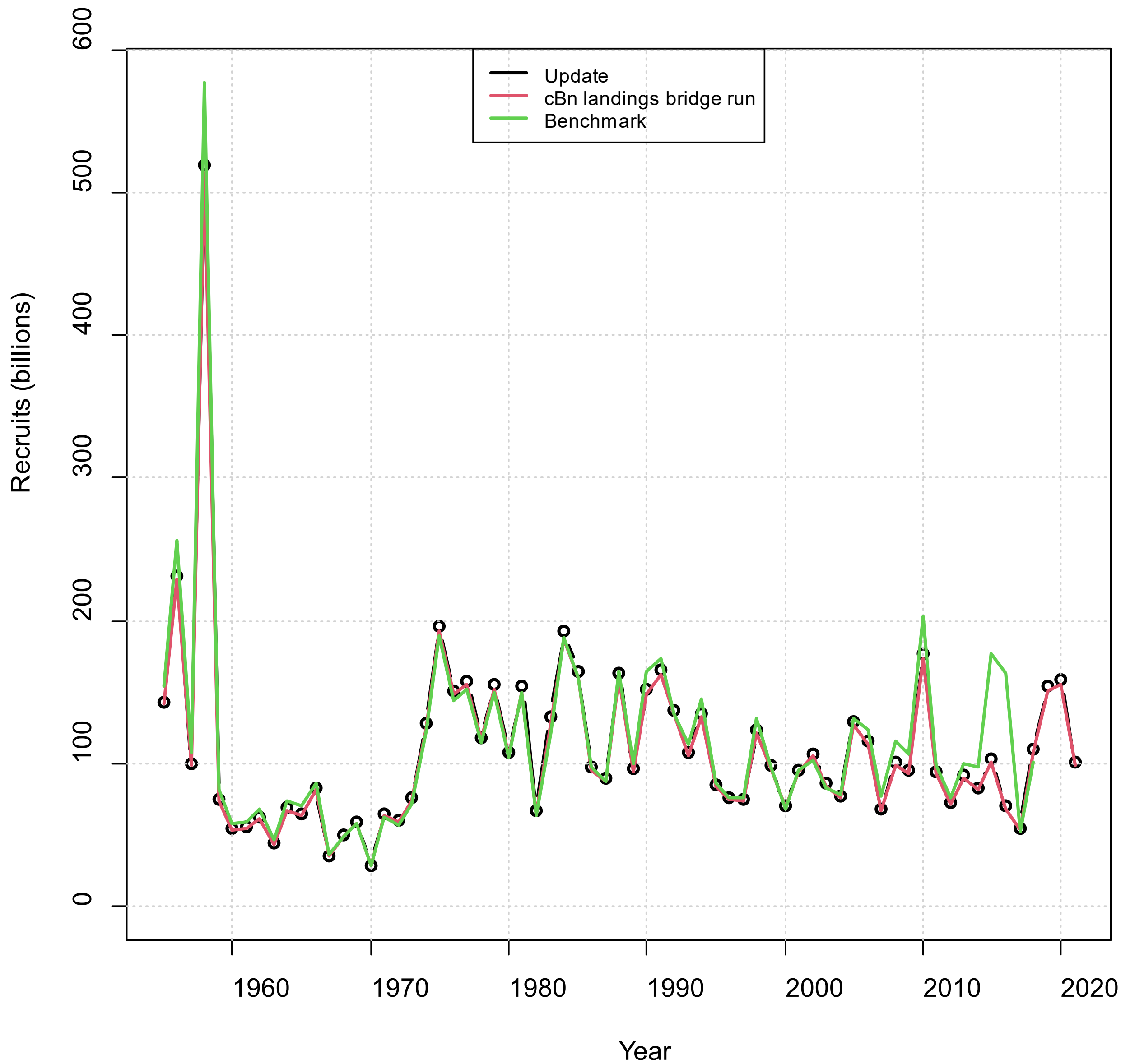

Figure A45. **Estimates of the recruitment time series for the base run for this update assessment, the commercial bait north landings from the last assessment, and the last benchmark assessment.**

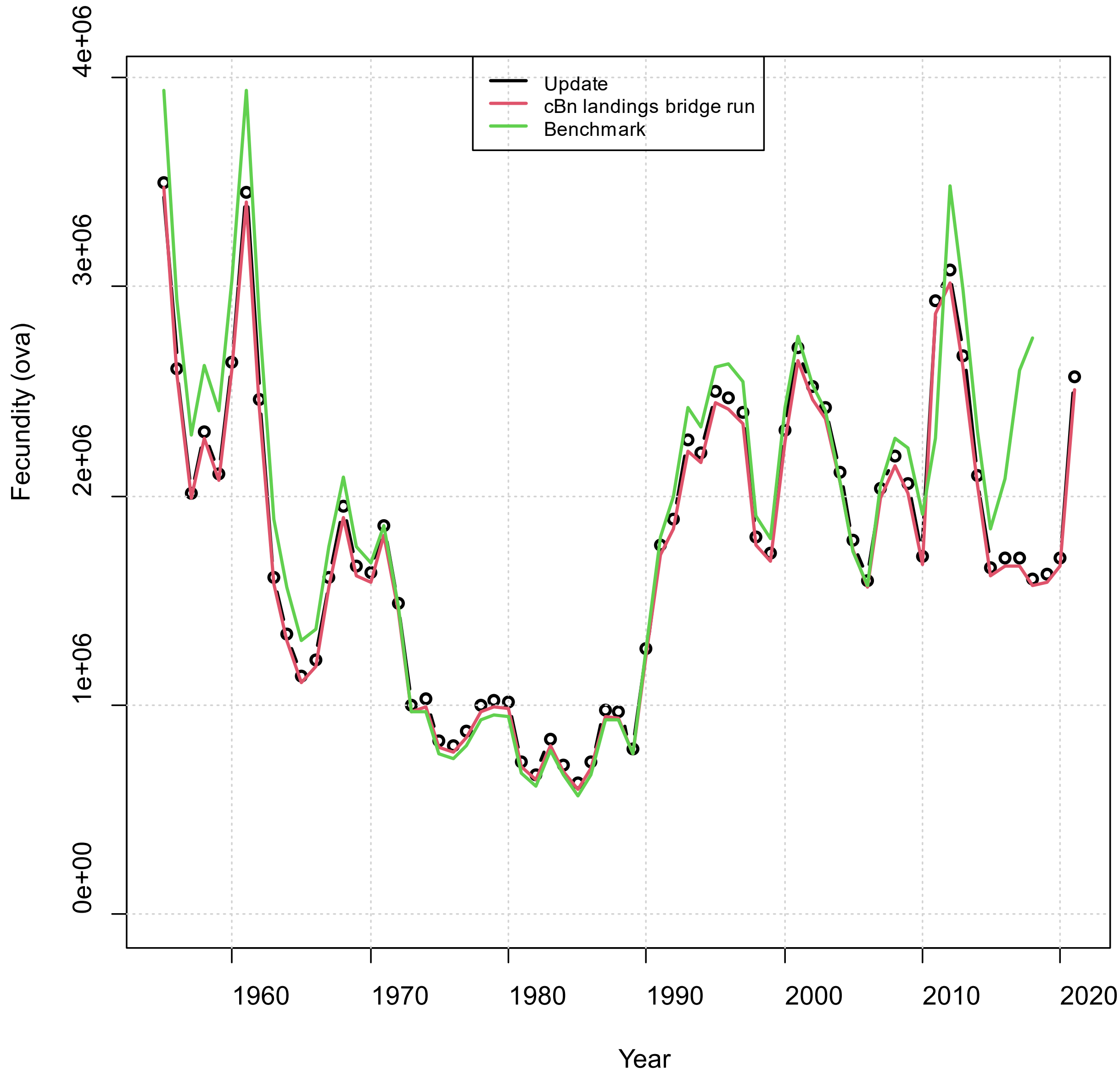

Figure A46. **Estimates of the fecundity for the base run for this update assessment, the commercial bait north landings from the last assessment, and the last benchmark assessment.**

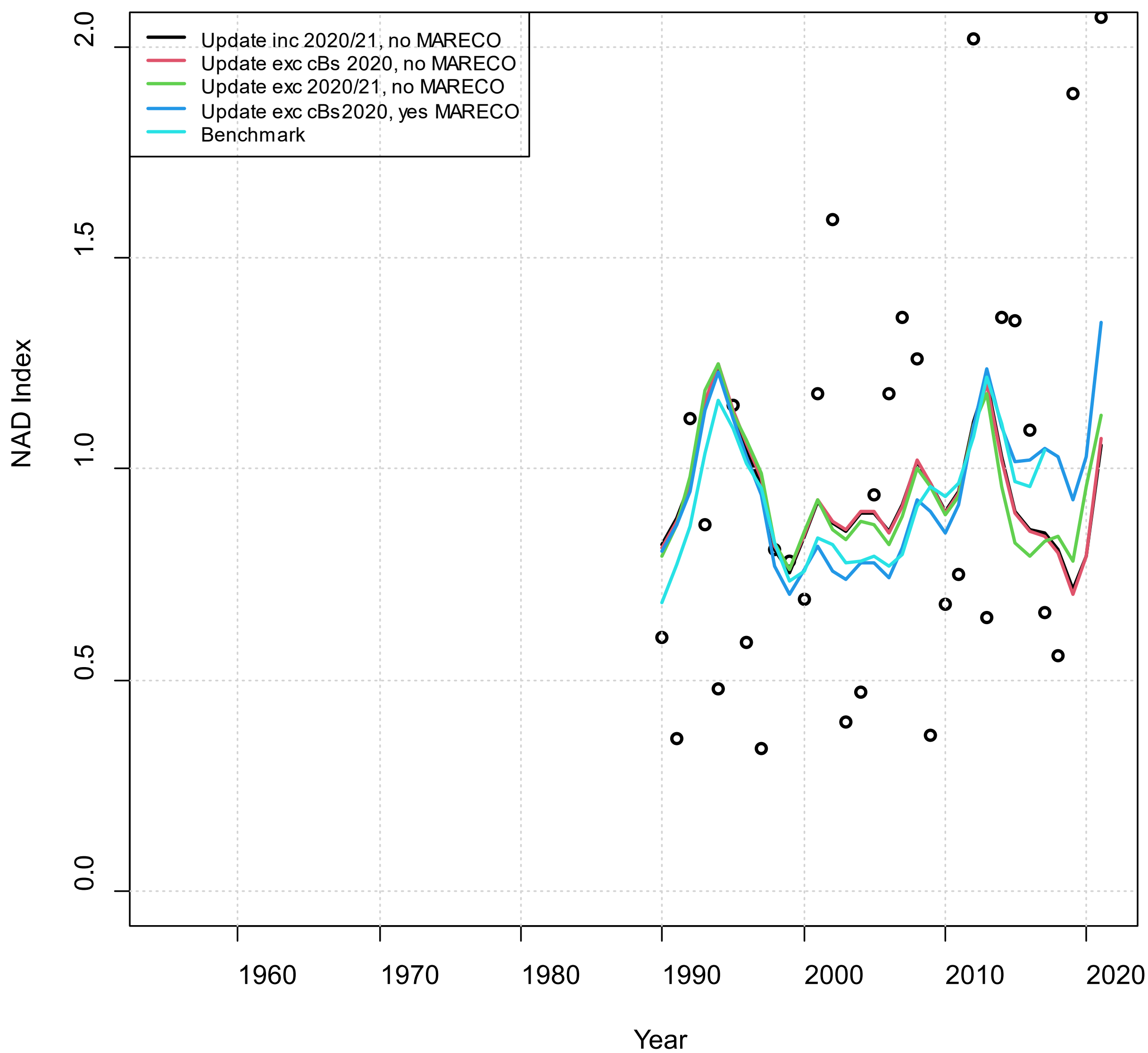

Figure A47. **Fit to the observed (open circles) NAD index for the base run (labeled Update exc cBs 2020, no MARECO) for a series of runs related to the inclusion of the 2020 and 2021 data. The runs either included or excluded the 2020 and 2021 data, excluded the commercial bait south (cBs) data for 2020, or included or excluded the ichthyoplankton index called the MARECO index.**

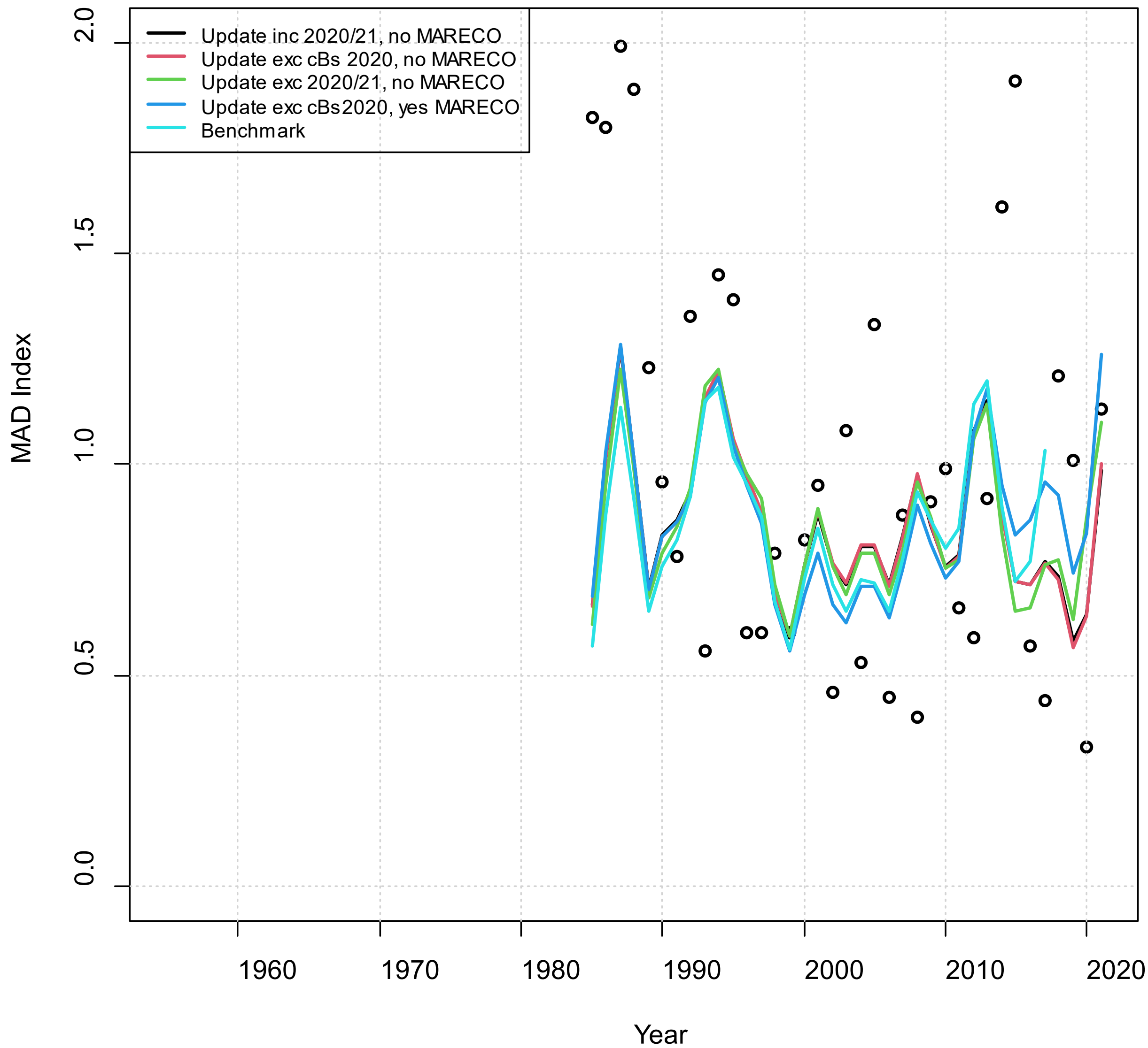

Figure A48. **Fit to the observed (open circles) MAD index for the base run (labeled Update exc cBs 2020, no MARECO) for a series of runs related to the inclusion of the 2020 and 2021 data. The runs either included or excluded the 2020 and 2021 data, excluded the commercial bait south (cBs) data for 2020, or included or excluded the ichthyoplankton index called the MARECO index.**

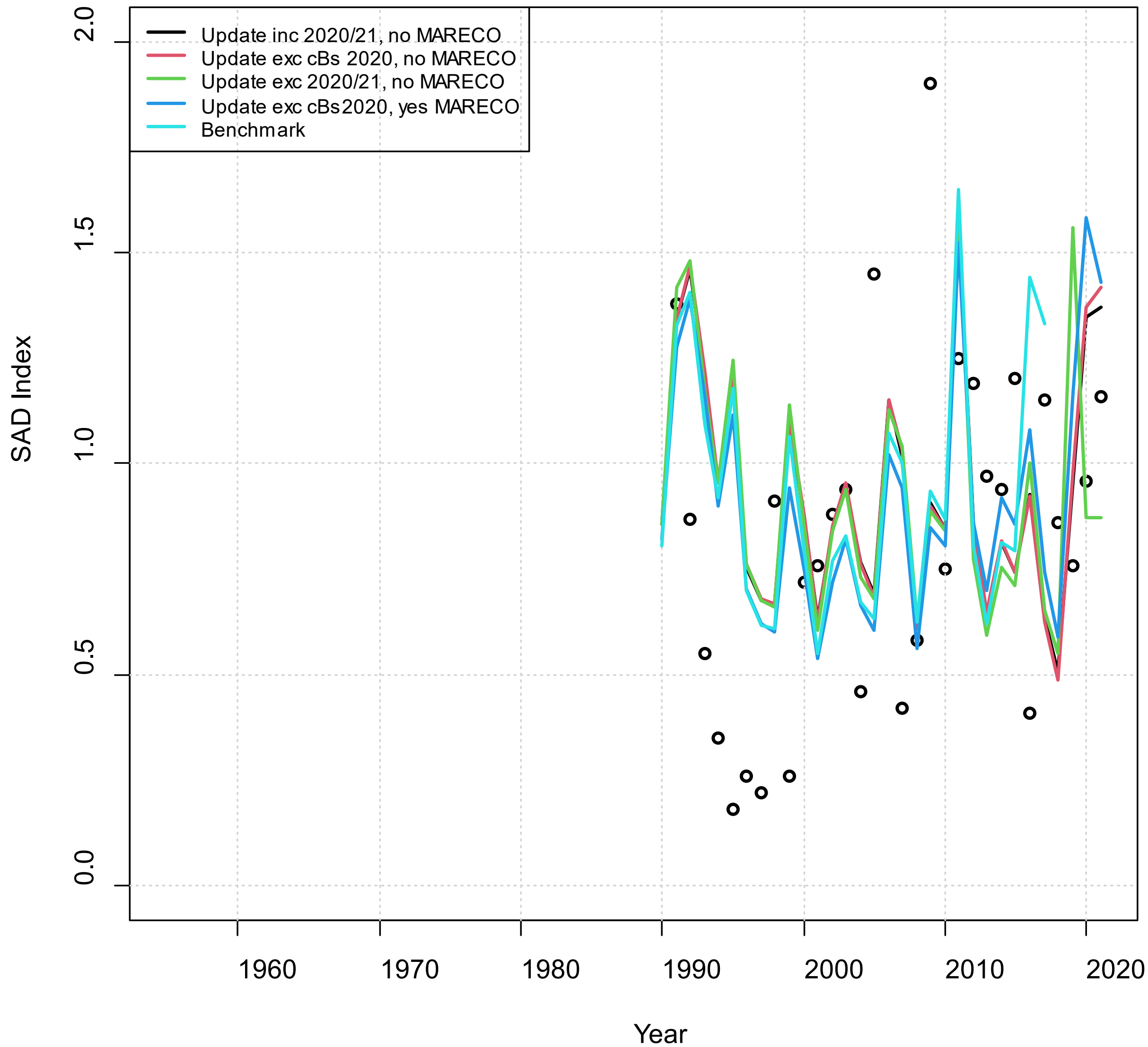

Figure A49. **Fit to the observed (open circles) SAD index for the base run (labeled Update exc cBs 2020, no MARECO) for a series of runs related to the inclusion of the 2020 and 2021 data. The runs either included or excluded the 2020 and 2021 data, excluded the commercial bait south (cBs) data for 2020, or included or excluded the ichthyoplankton index called the MARECO index.**

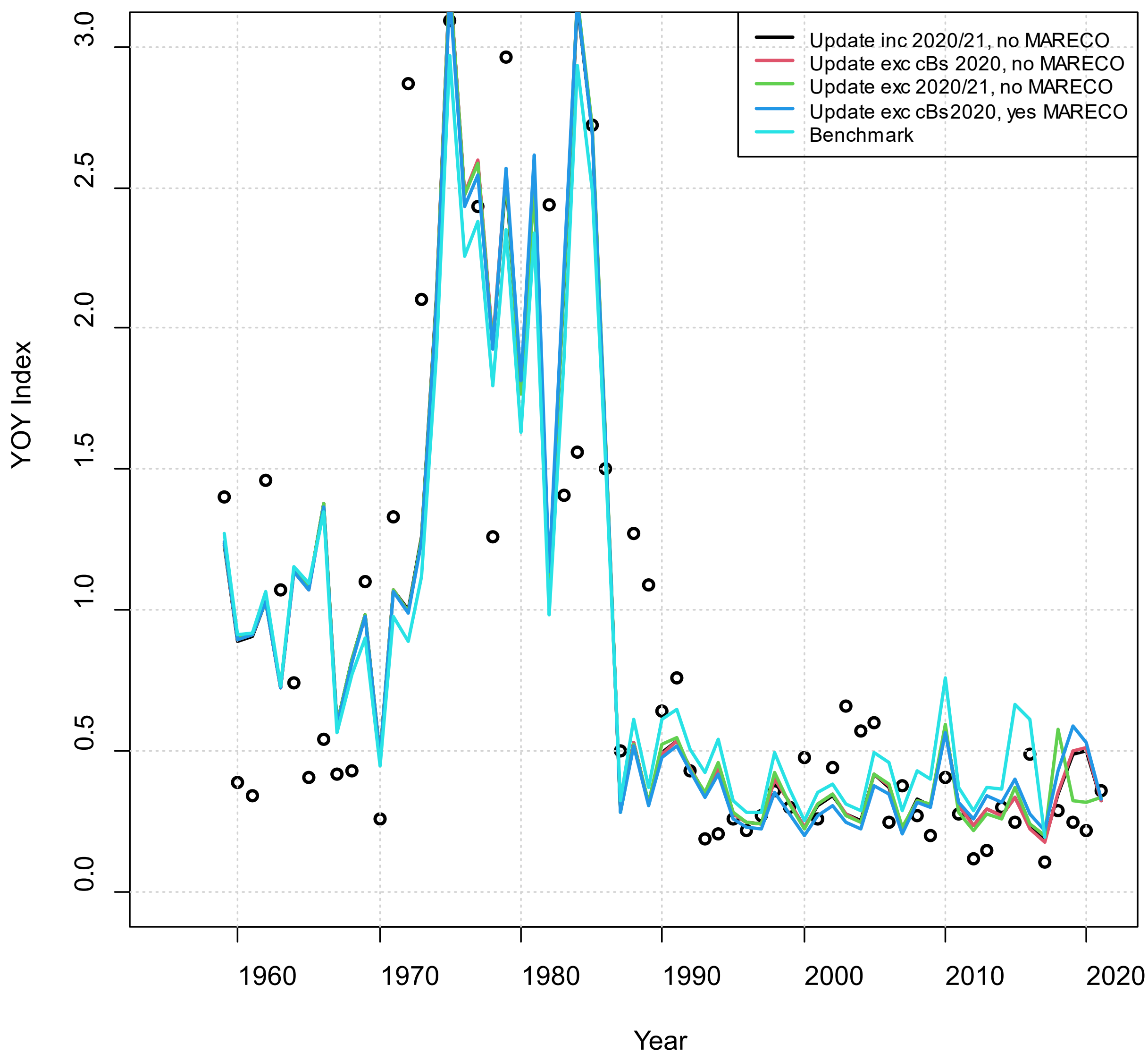

Figure A50. **Fit to the observed (open circles) recruitment index for the base run (labeled Update exc cBs 2020, no MARECO) for a series of runs related to the inclusion of the 2020 and 2021 data. The runs either included or excluded the 2020 and 2021 data, excluded the commercial bait south (cBs) data for 2020, or included or excluded the ichthyoplankton index called the MARECO index.**

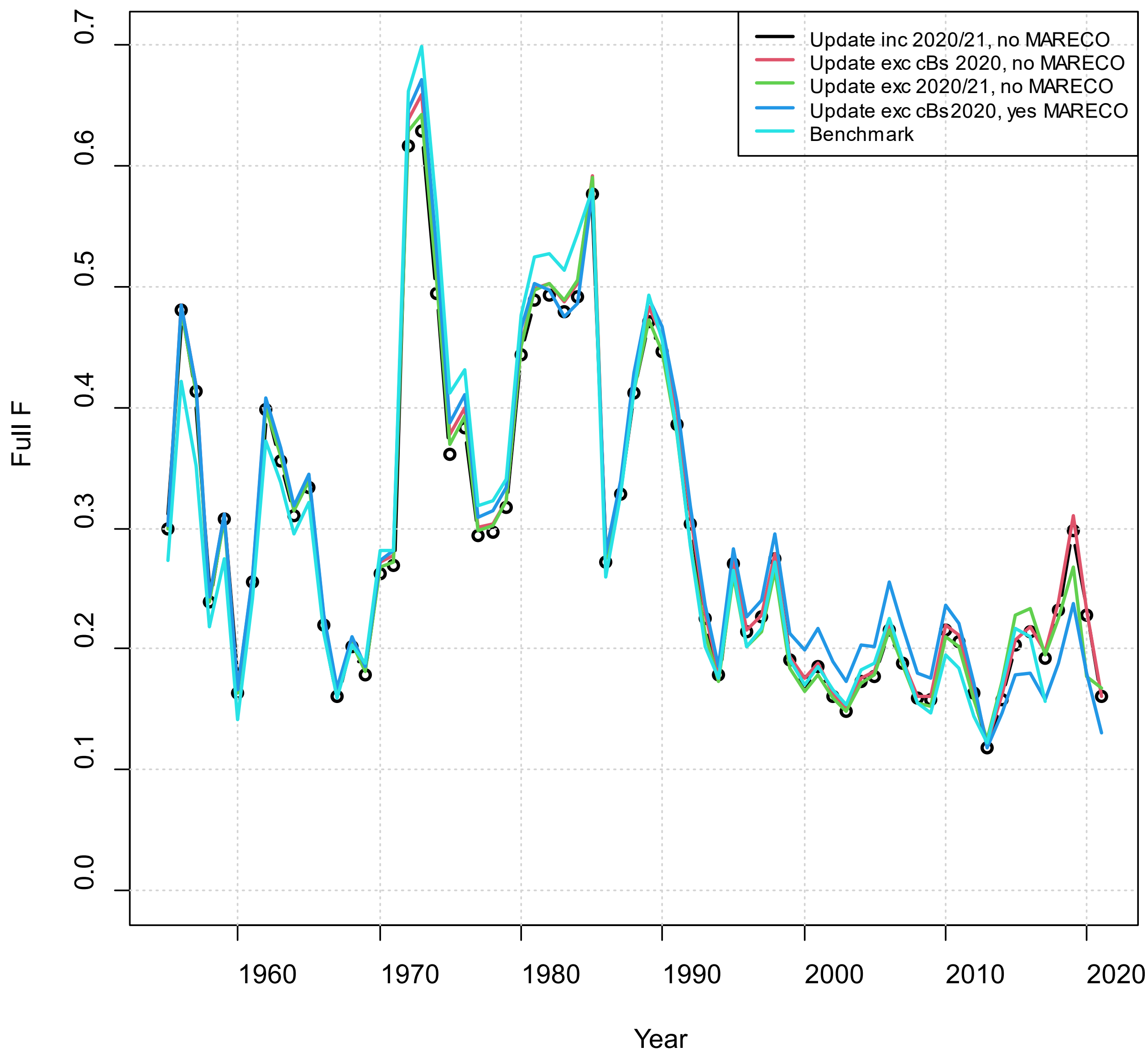

Figure A51. **Estimates of the full fishing mortality rate for the base run for the base run (labeled Update exc cBs 2020, no MARECO) for a series of runs related to the inclusion of the 2020 and 2021 data. The runs either included or excluded the 2020 and 2021 data, excluded the commercial bait south (cBs) data for 2020, or included or excluded the ichthyoplankton index called the MARECO index.**

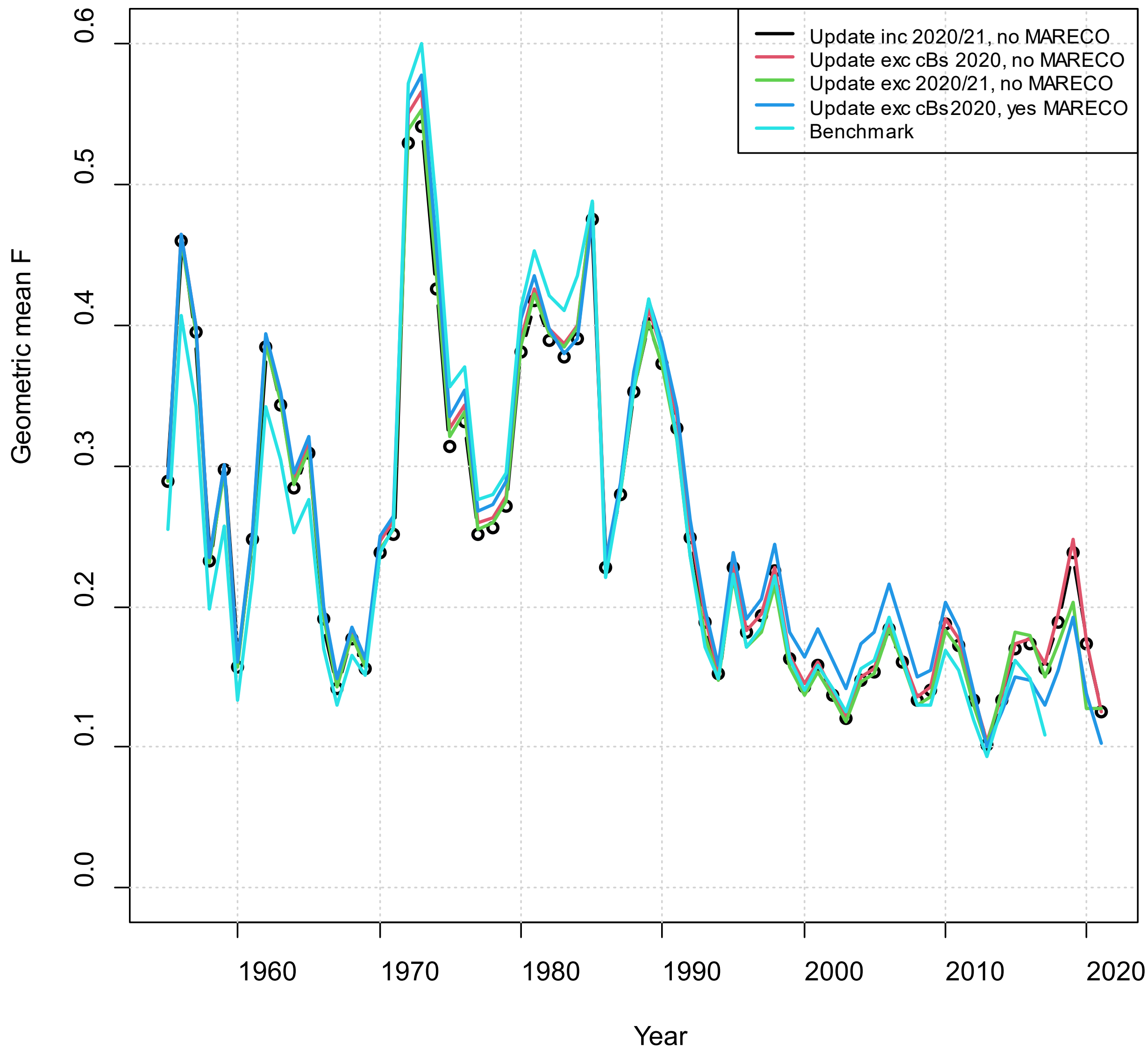

Figure A52. **Estimates of the geometric mean fishing mortality rate for ages-2 to -4 for the base run (labeled Update exc cBs 2020, no MARECO) for a series of runs related to the inclusion of the 2020 and 2021 data. The runs either included or excluded the 2020 and 2021 data, excluded the commercial bait south (cBs) data for 2020, or included or excluded the ichthyoplankton index called the MARECO index.**

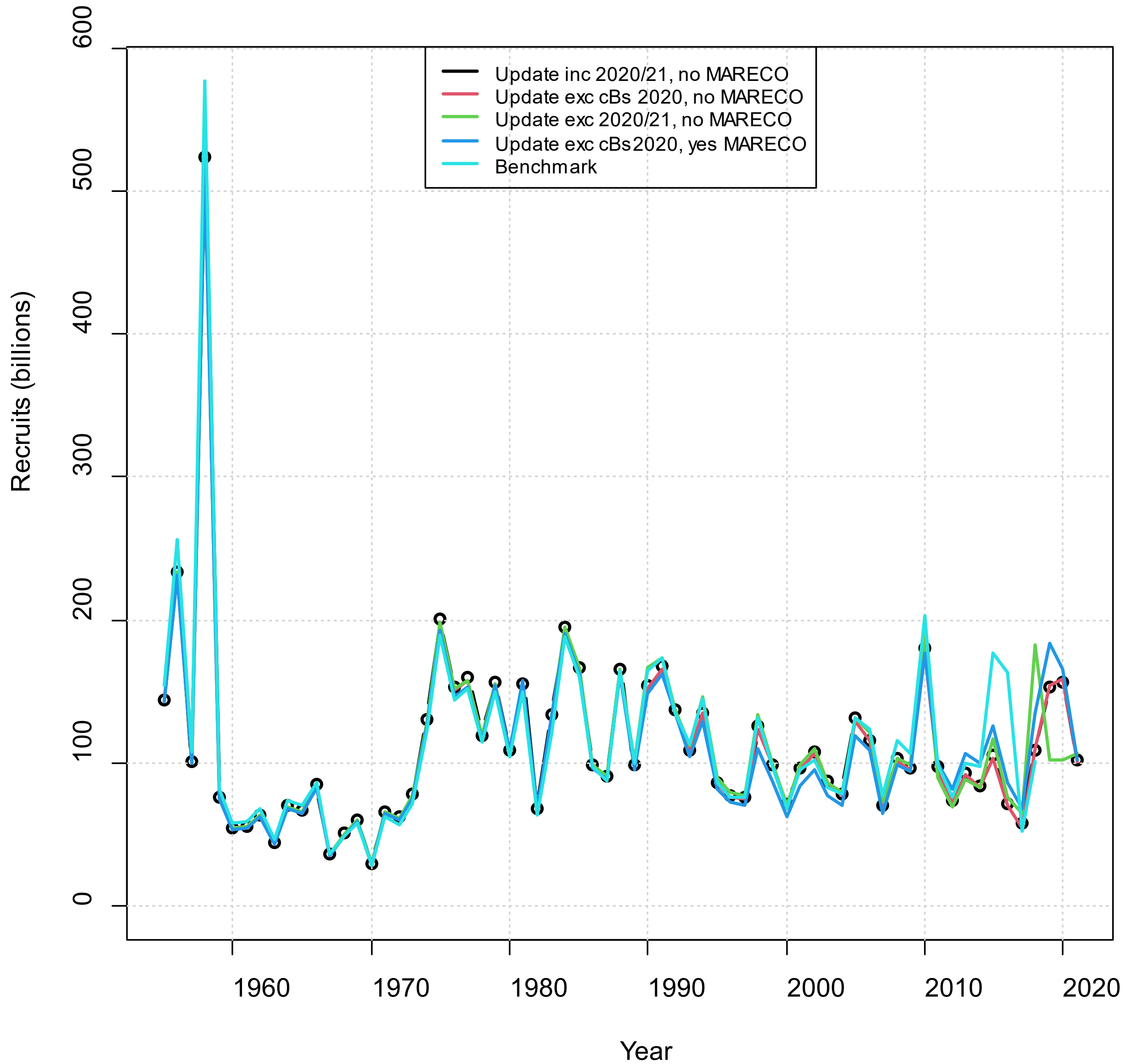

Figure A53. **Estimates of the recruitment time series for the base run (labeled Update exc cBs 2020, no MARECO) for a series of runs related to the inclusion of the 2020 and 2021 data. The runs either included or excluded the 2020 and 2021 data, excluded the commercial bait south (cBs) data for 2020, or included or excluded the ichthyoplankton index called the MARECO index.**

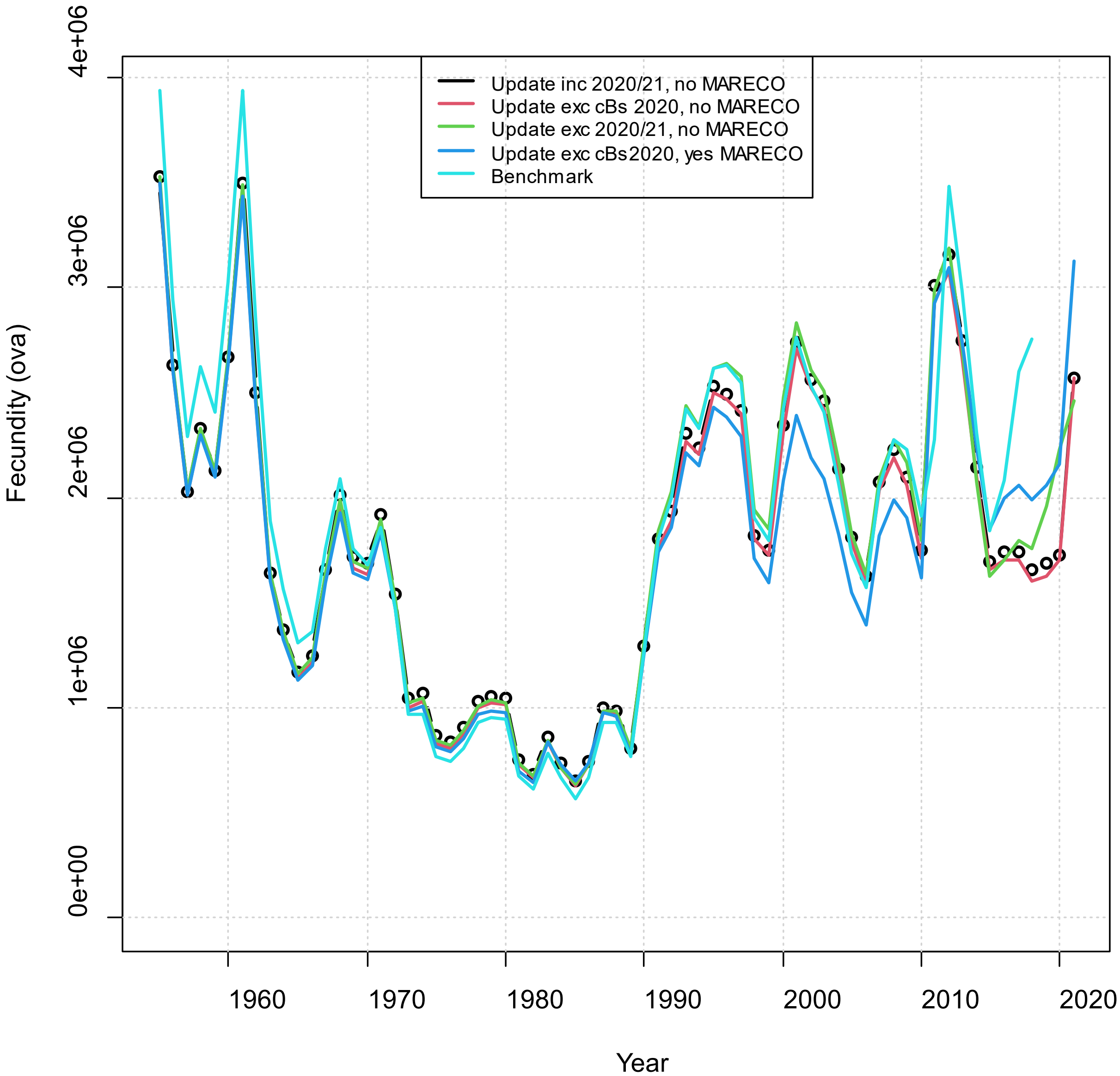

Figure A54. **Estimates of the fecundity for the base run (labeled Update exc cBs 2020, no MARECO) for a series of runs related to the inclusion of the 2020 and 2021 data. The runs either included or excluded the 2020 and 2021 data, excluded the commercial bait south (cBs) data for 2020, or included or excluded the ichthyoplankton index called the MARECO index.**

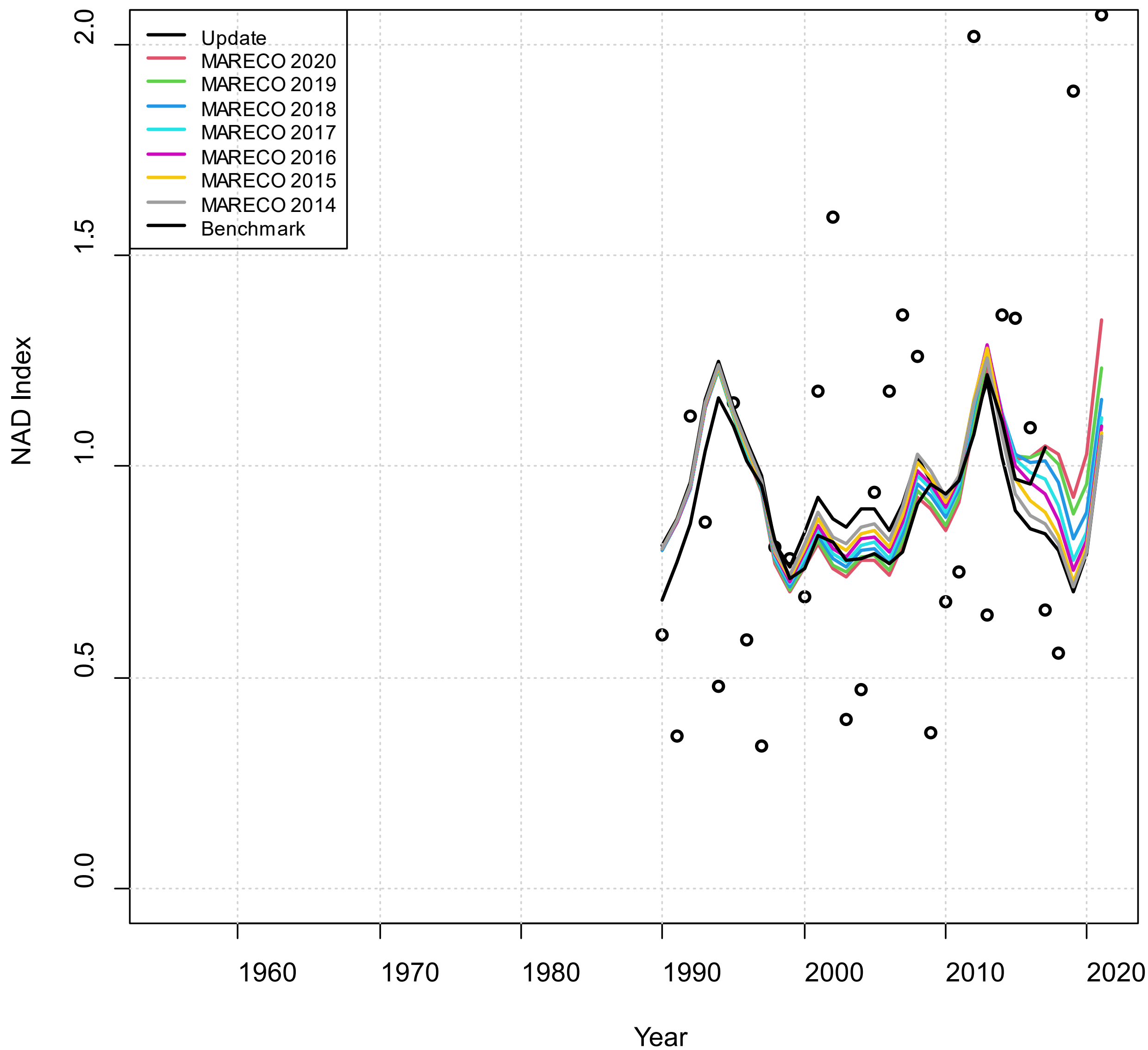

Figure A55. **Fit to the observed (open circles) NAD index for the base run, the last benchmark, and for a series of runs related to the inclusion of the MARECO ichthyoplankton index. The additional runs included the MARECO index with each run indicated by the terminal year of the index (2014-2020).**

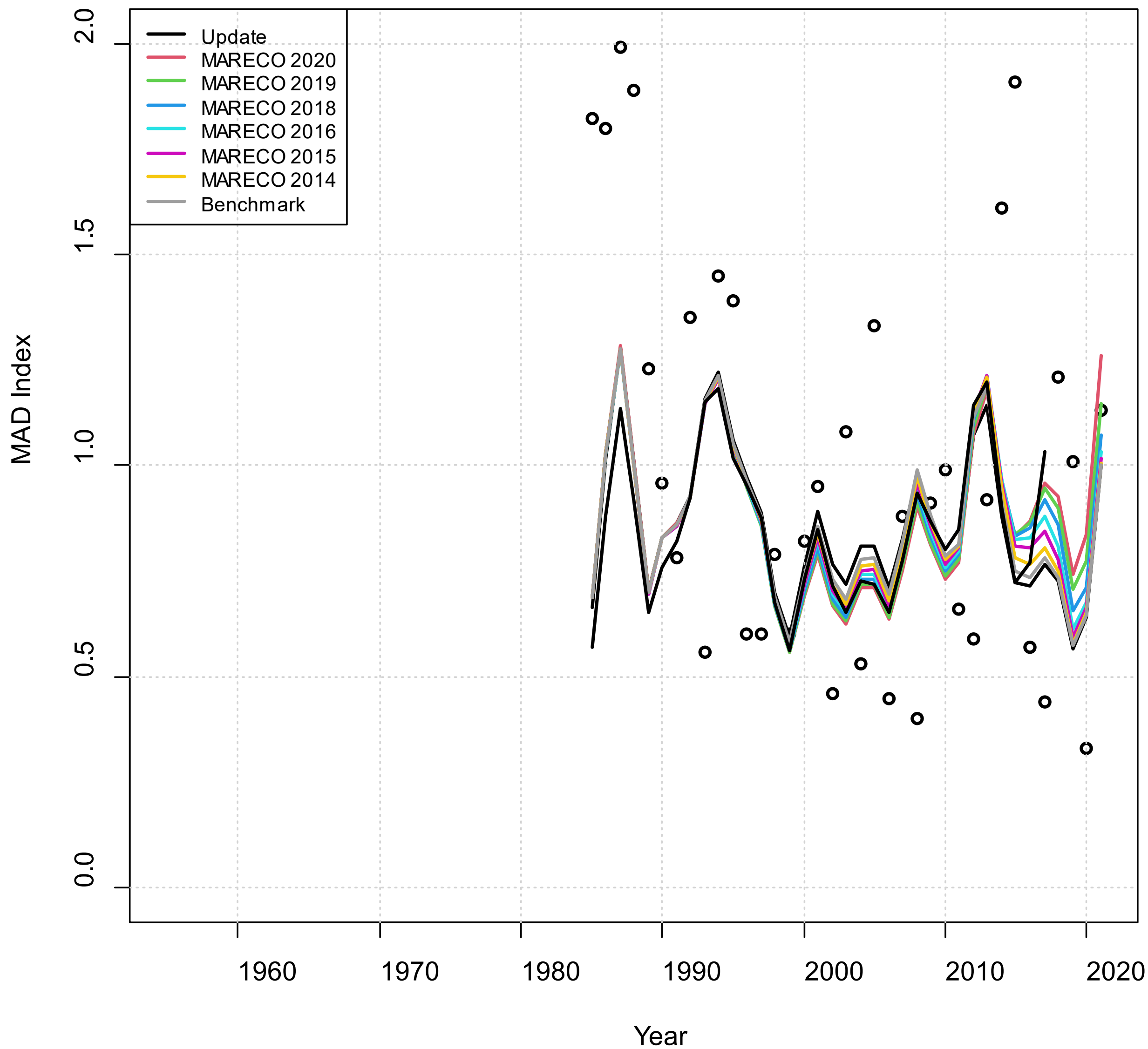

Figure A56. **Fit to the observed (open circles) MAD index for the base run, the last benchmark, and for a series of runs related to the inclusion of the MARECO ichthyoplankton index. The additional runs included the MARECO index with each run indicated by the terminal year of the index (2014-2020).**

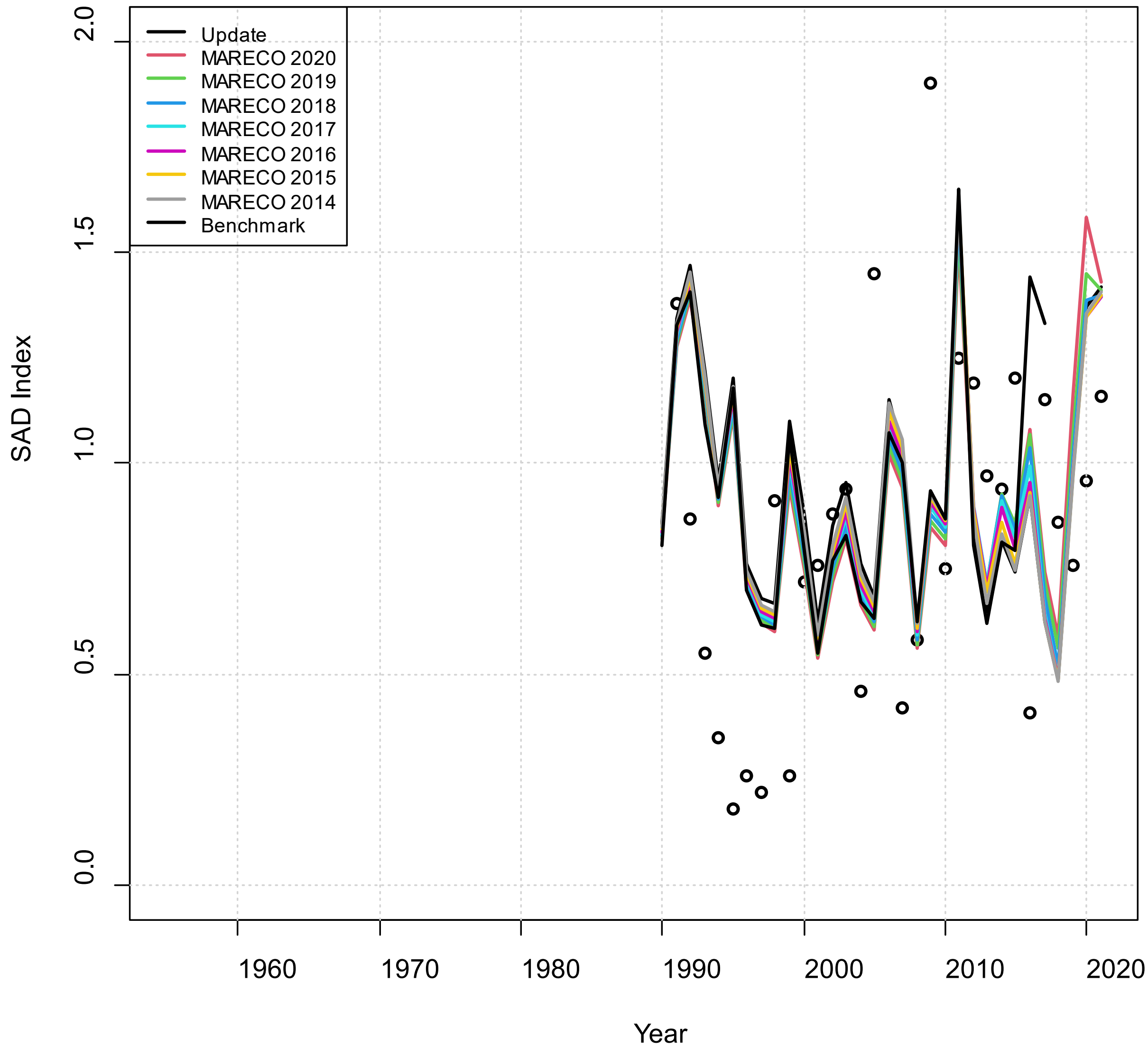

Figure A57. **Fit to the observed (open circles) SAD index for the base run, the last benchmark, and for a series of runs related to the inclusion of the MARECO ichthyoplankton index. The additional runs included the MARECO index with each run indicated by the terminal year of the index (2014-2020).**

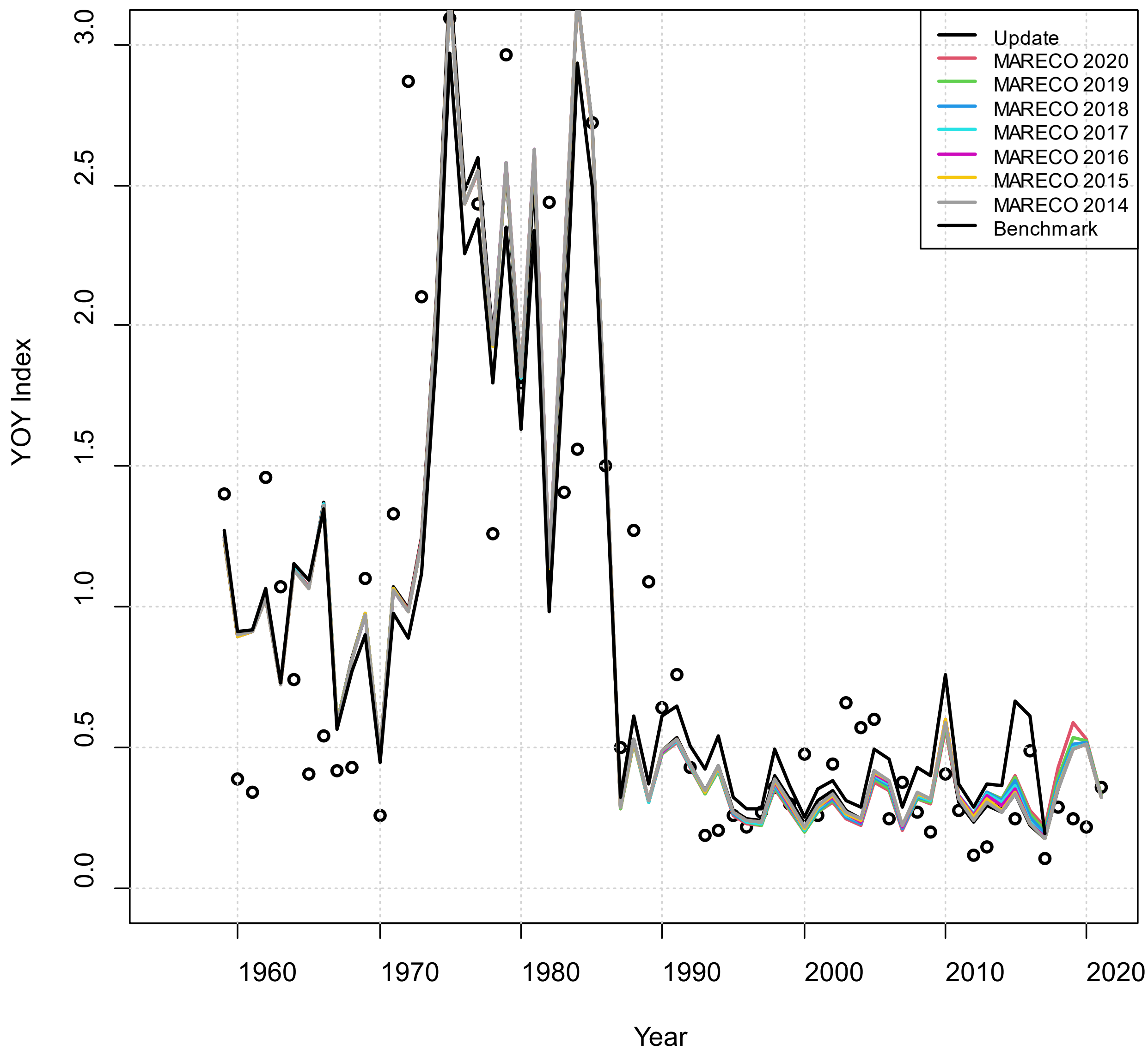

Figure A58. **Fit to the observed (open circles) recruitment index for the base run, the last benchmark, and for a series of runs related to the inclusion of the MARECO ichthyoplankton index. The additional runs included the MARECO index with each run indicated by the terminal year of the index (2014-2020).**

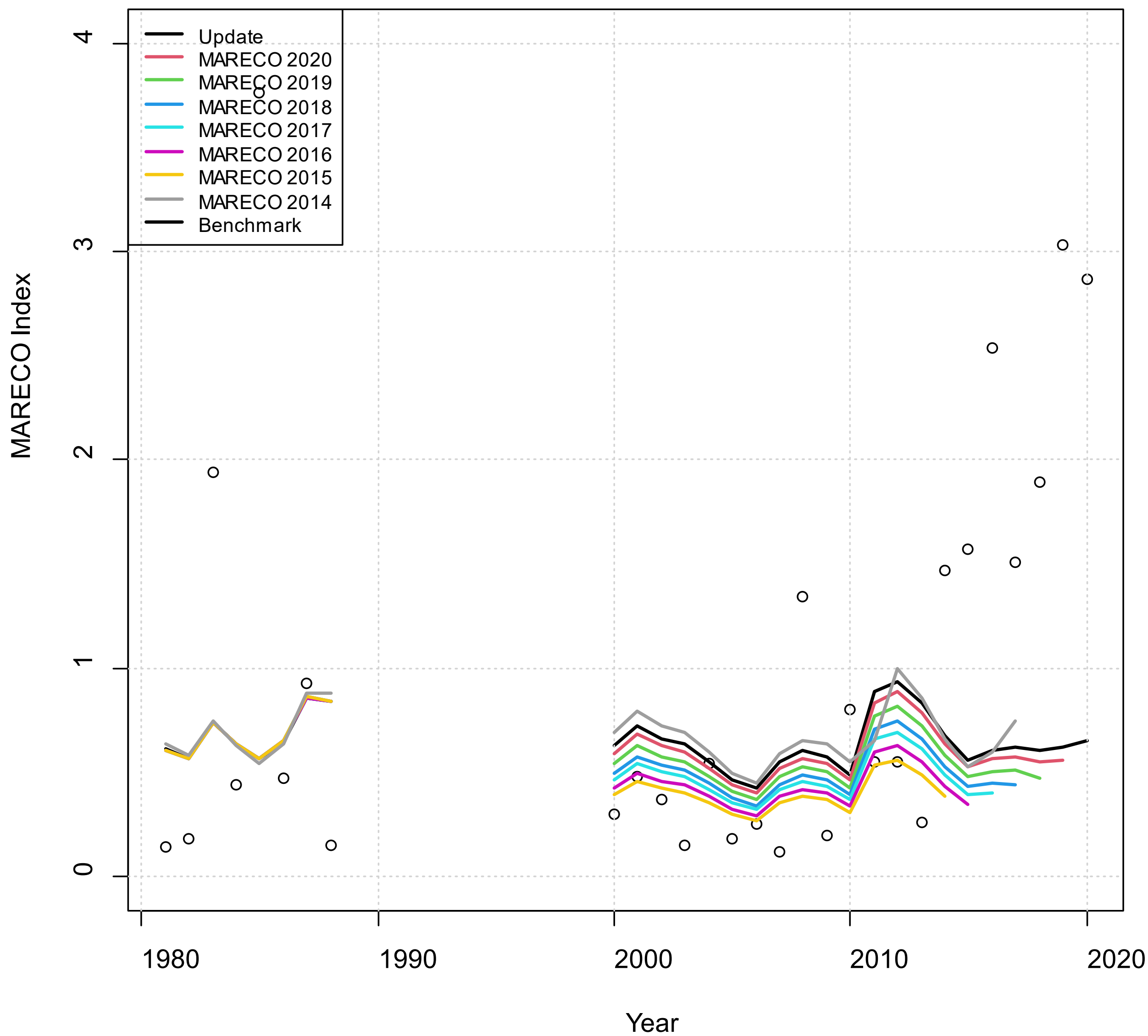

Figure A59. **Fit to the observed (open circles) MARECO index for the base run, the last benchmark, and for a series of runs related to the inclusion of the MARECO ichthyoplankton index. The additional runs included the MARECO index with each run indicated by the terminal year of the index (2014-2020). **Note that the update run is not plotted, as it doesn't include the MARECO index.**

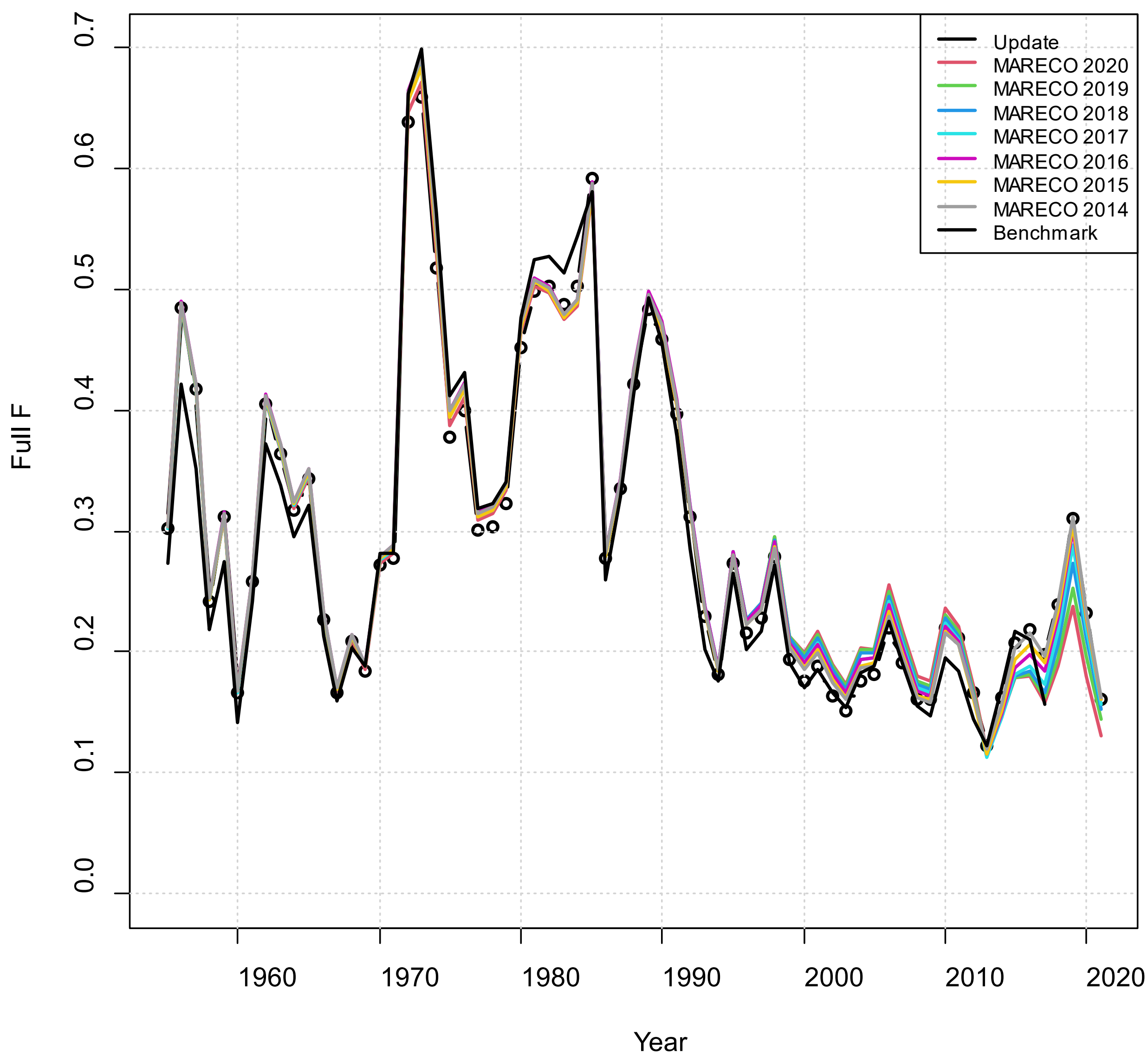

Figure A60. Full fishing mortality rate from 1955-2021 for the base run, the last benchmark, and for a series of runs related to the inclusion of the MARECO ichthyoplankton index. The additional runs included the MARECO index with each run indicated by the terminal year of the index (2014-2020).

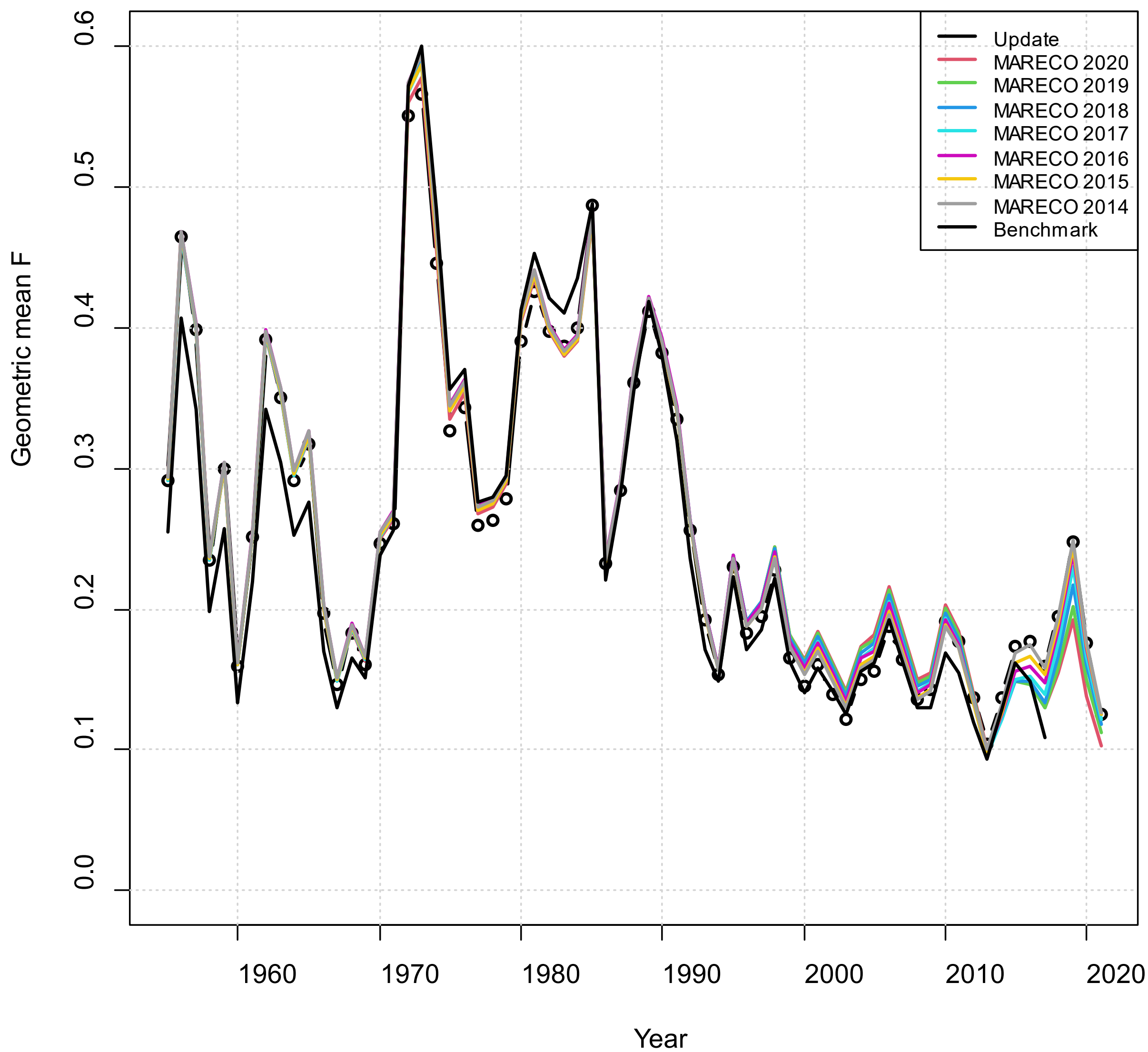

Figure A61. **The geometric mean fishing mortality rate for ages-2 to 4+ from 1955-2021 for the base run, the last benchmark, and for a series of runs related to the inclusion of the MARECO ichthyoplankton index. The additional runs included the MARECO index with each run indicated by the terminal year of the index (2014-2020).**

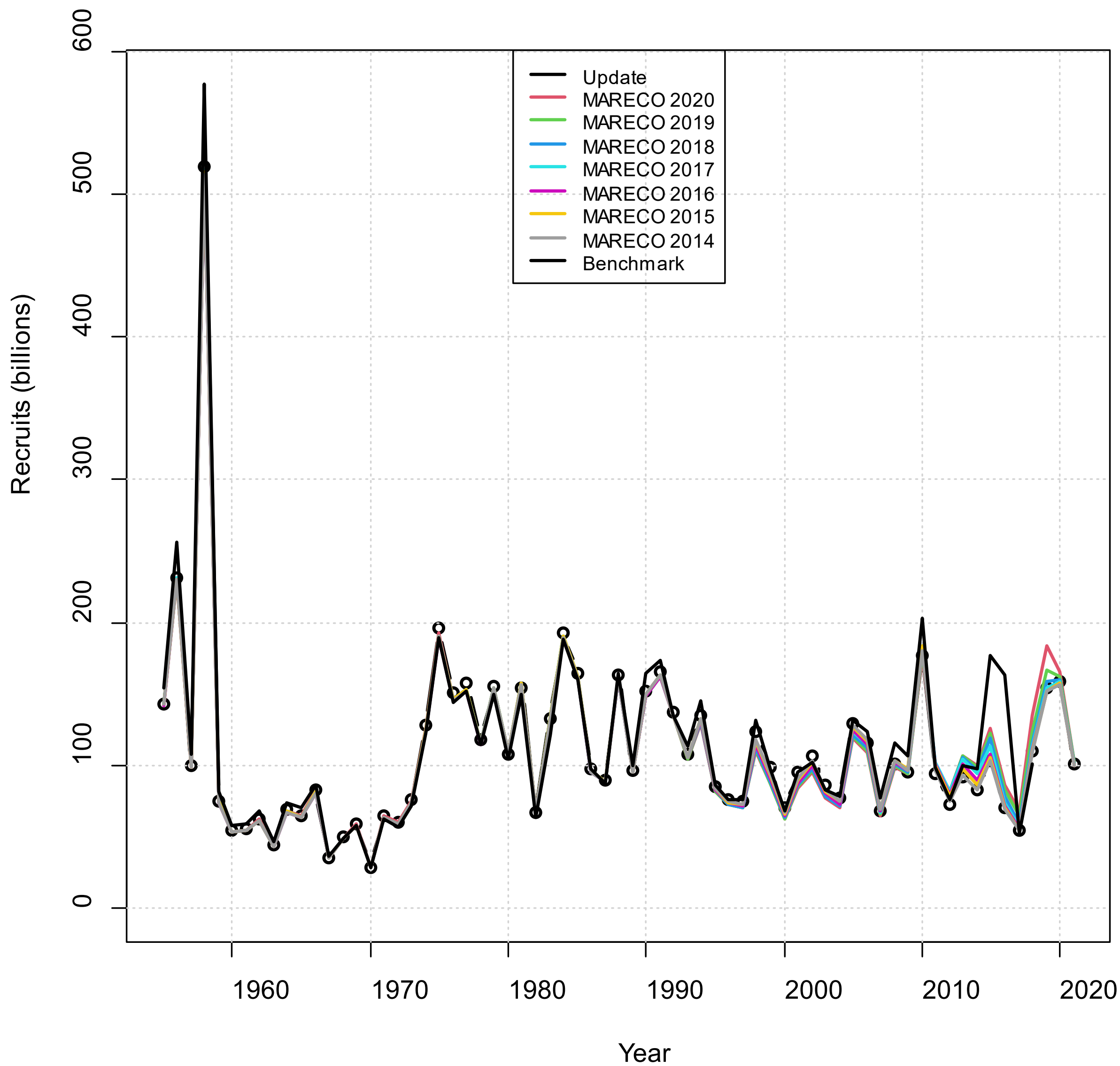

Figure A62. **The recruitment time series from 1955-2021 for the base run, the last benchmark, and for a series of runs related to the inclusion of the MARECO ichthyoplankton index. The additional runs included the MARECO index with each run indicated by the terminal year of the index (2014-2020).**

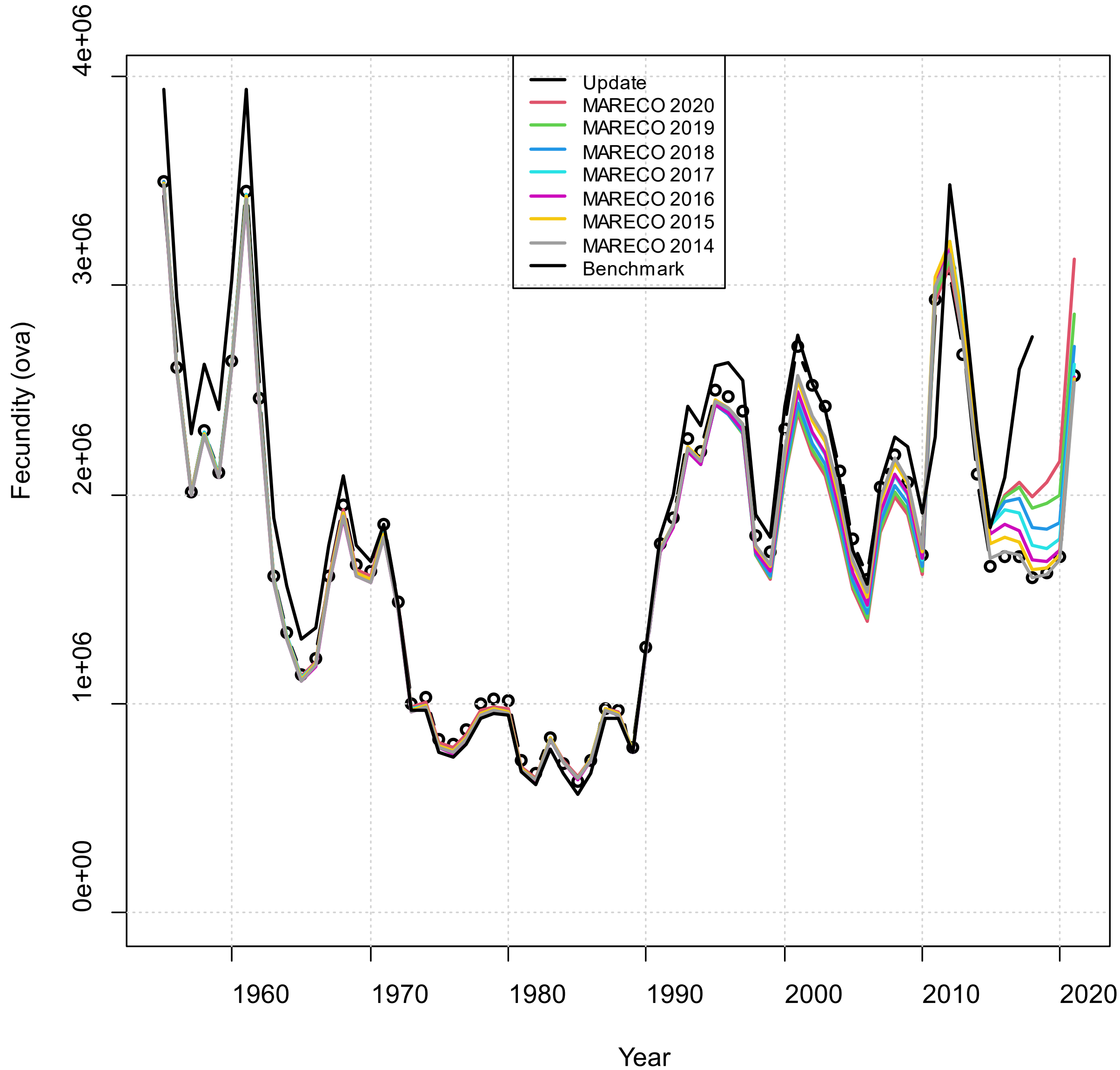

Figure A63. **The fecundity time series from 1955-2021 for the base run, the last benchmark, and for a series of runs related to the inclusion of the MARECO ichthyoplankton index. The additional runs included the MARECO index with each run indicated by the terminal year of the index (2014-2020).**

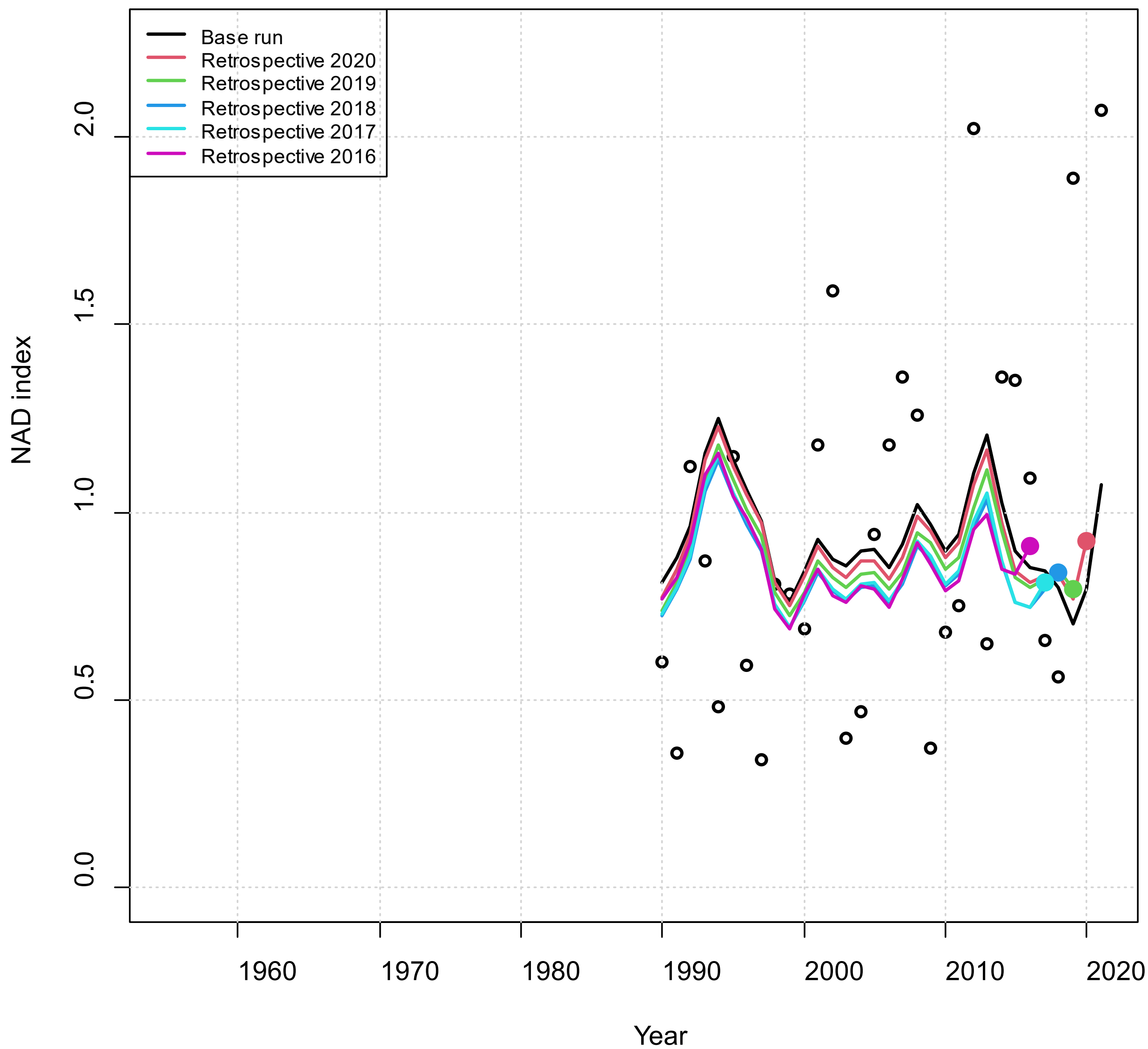

Figure A64. **Fit to the observed (open circles) NAD index for the retrospective analysis with terminal years from 2021 to 2016.**

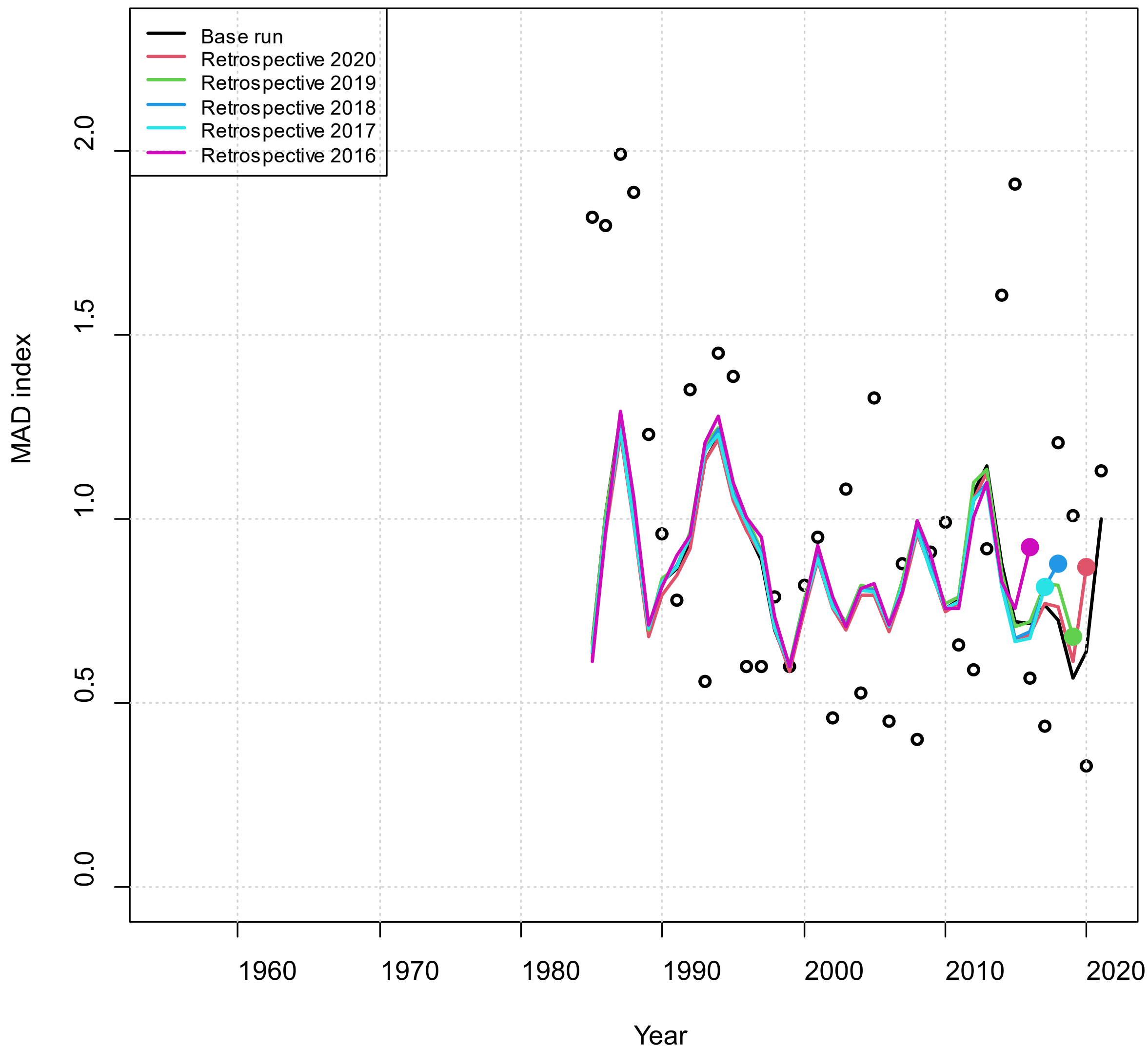

Figure A65. **Fit to the observed (open circles) MAD index for the retrospective analysis with terminal years from 2021 to 2016.**

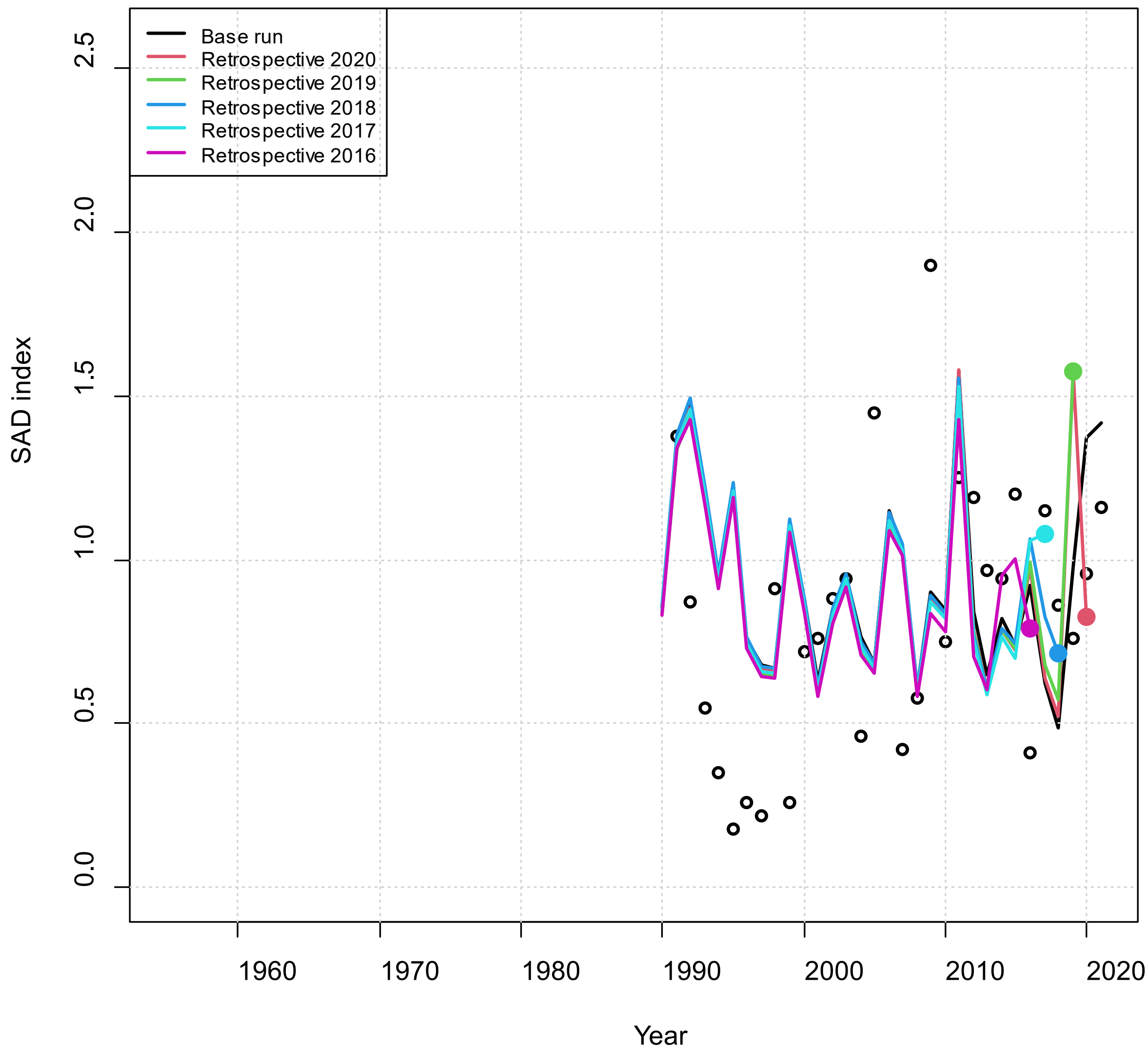

Figure A66. **Fit to the observed (open circles) SAD index for the retrospective analysis with terminal years from 2021 to 2016.**

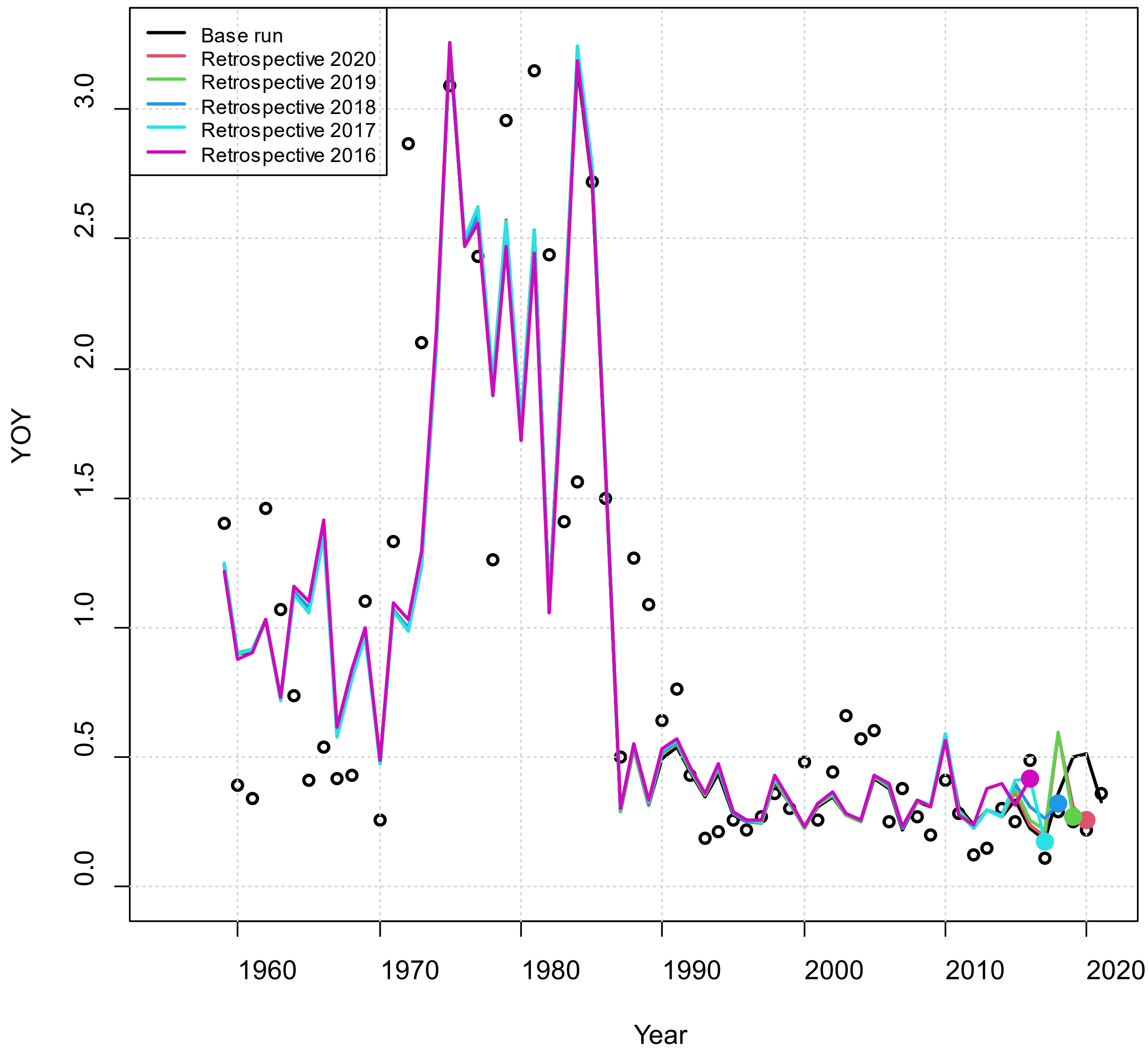

Figure A67. **Fit to the observed (open circles) recruitment index for the retrospective analysis with terminal years from 2021 to 2016.**

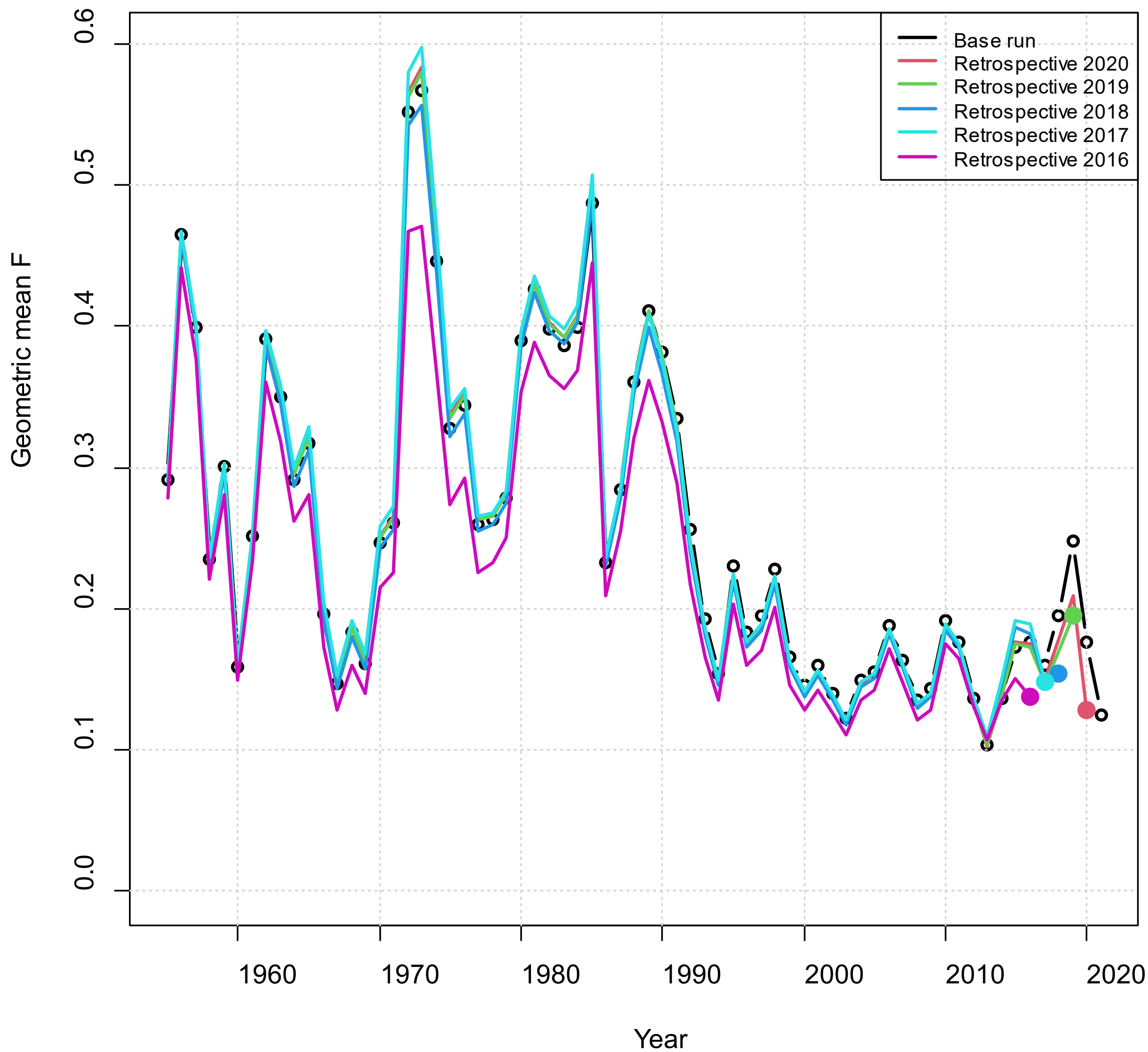

Figure A68. Estimates of the geometric mean fishing mortality rate for ages-2 to -4 for the retrospective analysis with terminal years from 2021 to 2016.

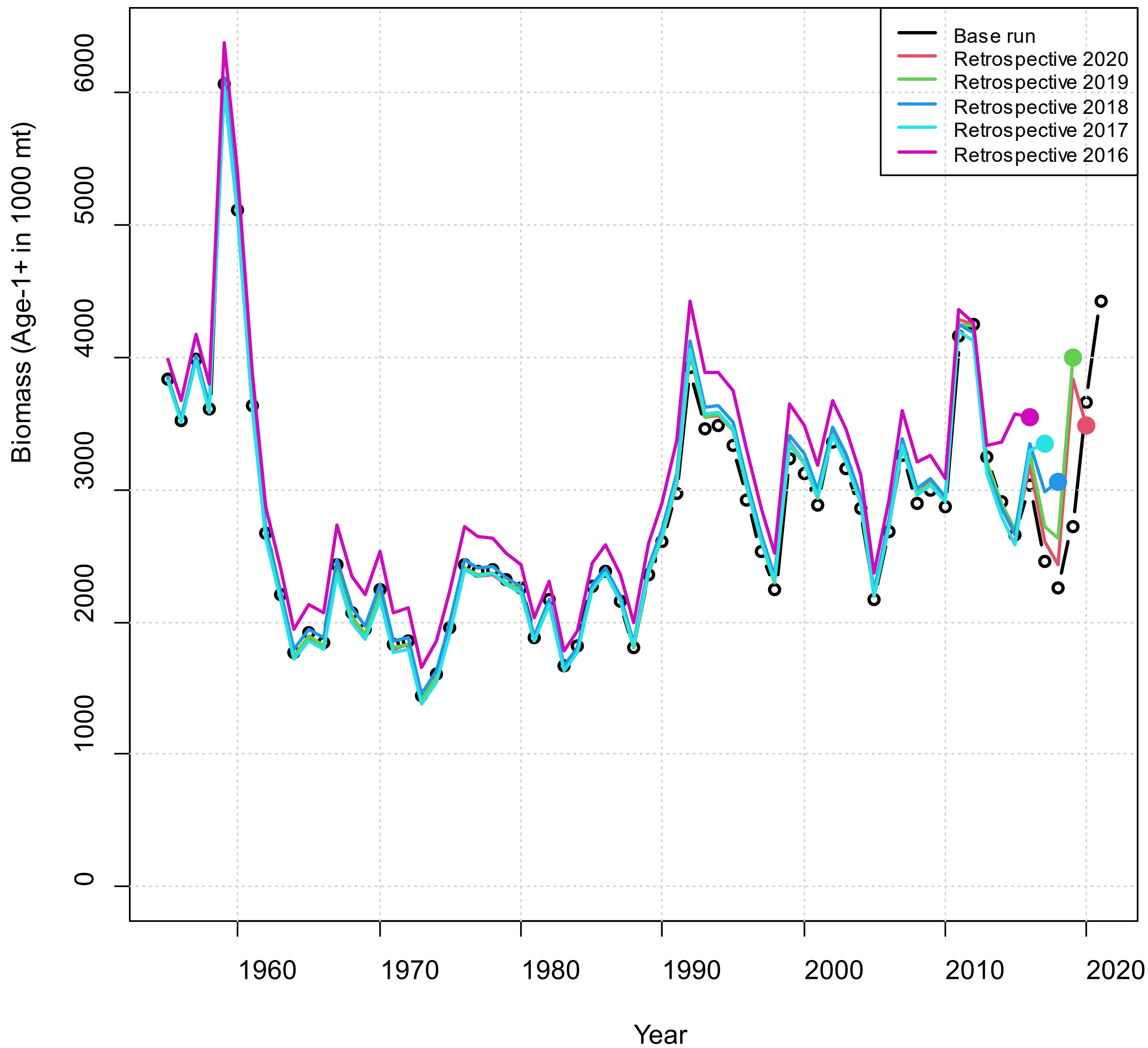

Figure A69. Estimates of the age-1+ biomass for the retrospective analysis with terminal years from 2021 to 2016.

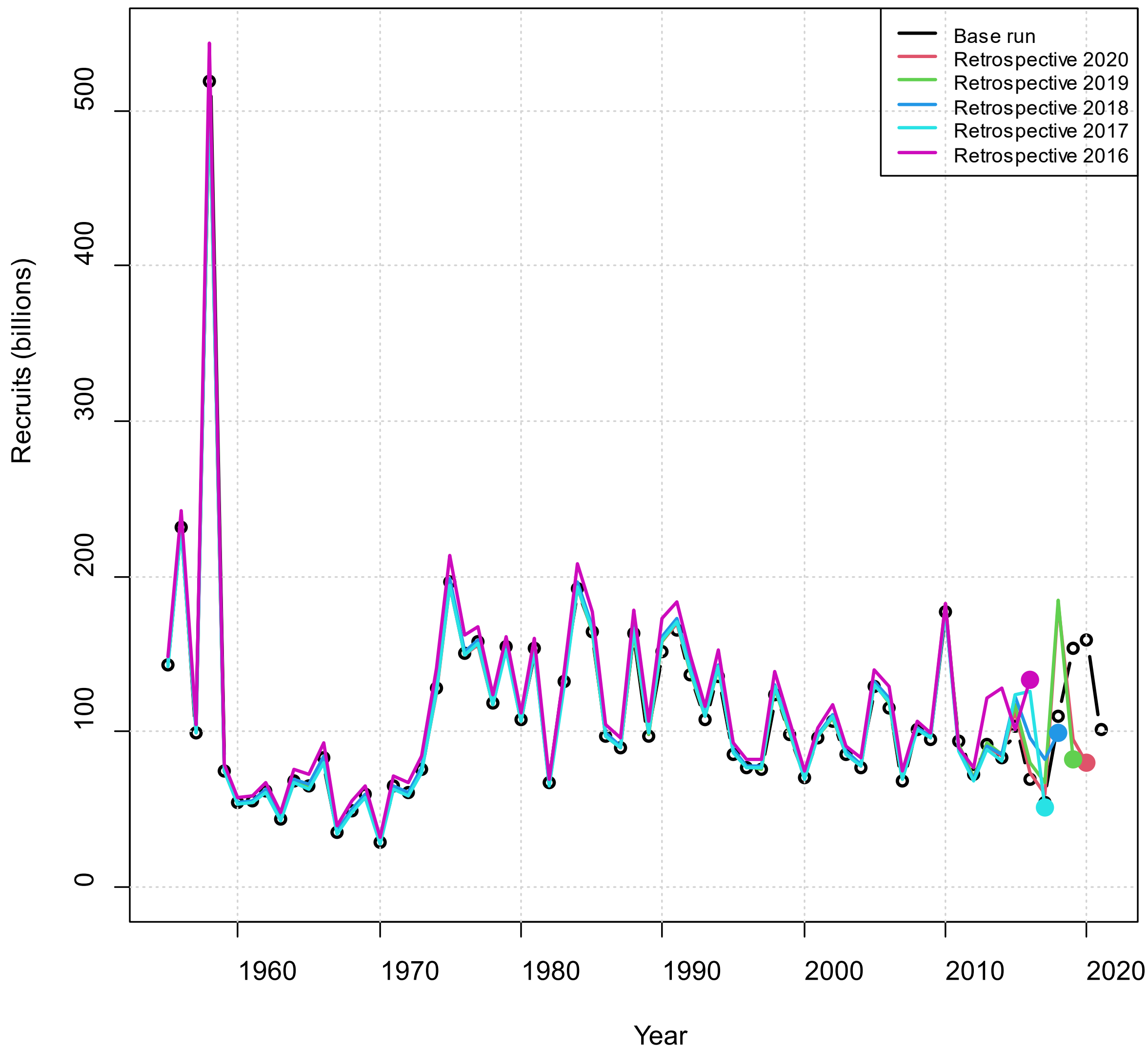

Figure A70. **Estimates of the recruitment for the retrospective analysis with terminal years from 2021 to 2016.**

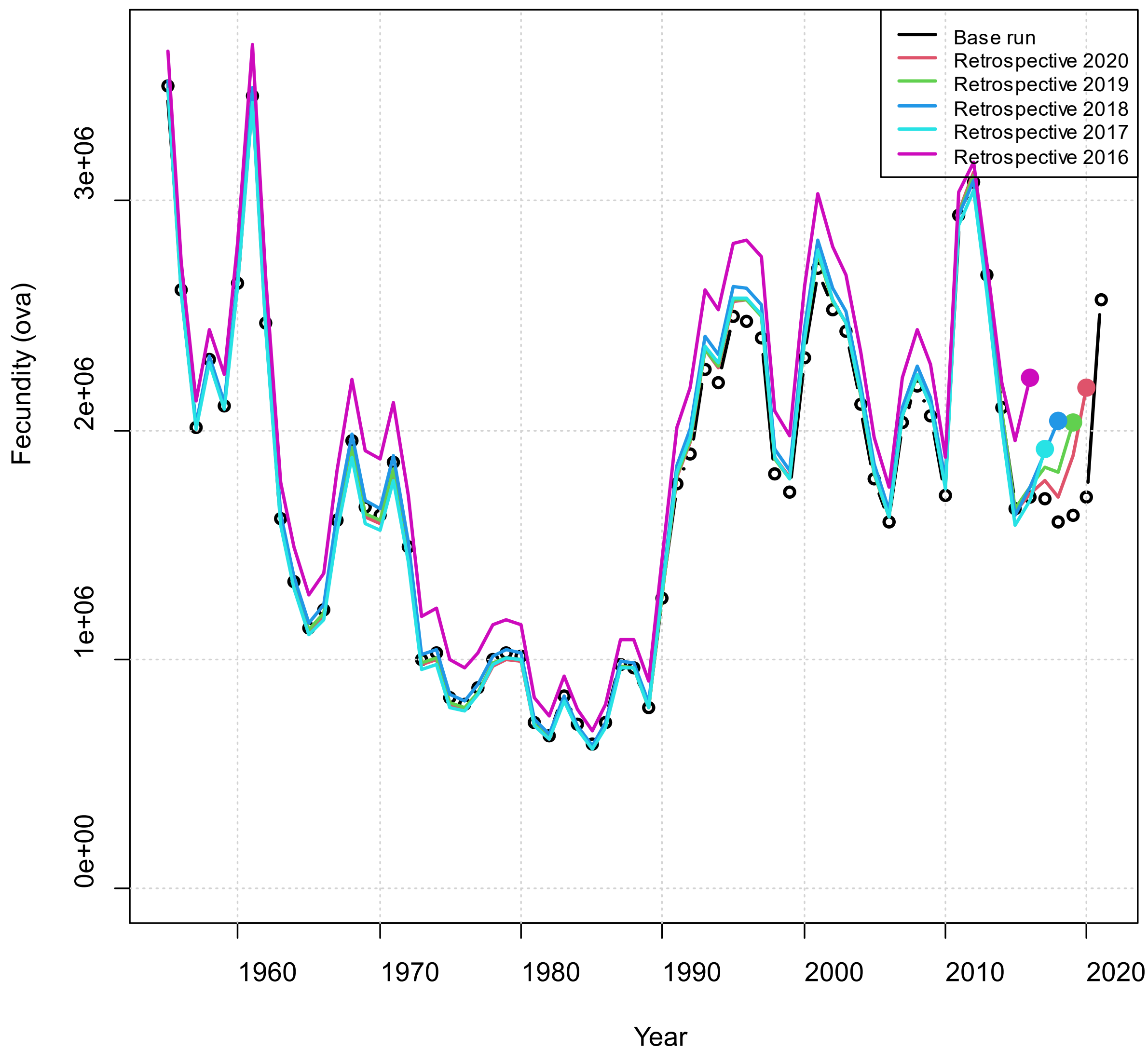

Figure A71. Estimates of the fecundity for the retrospective analysis with terminal years from 2021 to 2016.

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.