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GULF DATA, ASSESSMENT, AND REVIEW

GDAR 04/SEDAR 97
Gulf Menhaden Stock Assessment

2024 Update
Assessment Report

October 2024

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2.0 Executive Summary

This assessment provides an update to the 2018 Gulf Menhaden (*Brevoortia patronus*) benchmark for the Gulf of Mexico (SEDAR 63) and the 2021 Gulf Menhaden update assessment (GDAR 03). The assessment was updated with recent data from 2021-2023. No changes in structure or parameterization were made to the base model run. Changes made to data inputs were minor and are described in the body of this report.

The assessment period was 1977-2023. Updated data included commercial reduction, commercial bait, and recreational landings; age compositions from the commercial reduction landings; the coastwide juvenile abundance index based on seine surveys; the adult abundance index based on a gillnet survey; and length compositions from the gillnet survey.

The primary model, updated here, was the Beaufort Assessment Model (BAM), a statistical catch-age formulation. Additional sensitivity analyses and Monte Carlo bootstrap ensemble runs (MCBEs) were also completed. Stock status was evaluated by measuring the geometric mean 2021-2023 spawning stock biomass (measured as fecundity) and the geometric mean 2021-2023 fishing mortality rate against the respective threshold benchmarks of $SSB_{25\%\text{ at }F=0}$ and $F=M$.

For the base run configuration of BAM, the fishing mortality rate decreased during the 1990s and 2000s and has remained at a lower level since. Additionally, spawning stock biomass (measured as fecundity) has increased steadily since the 1990s and has remained at a higher level since. **The base run configuration of BAM indicates that the Gulf of Mexico Gulf Menhaden stock is not experiencing overfishing and is not overfished.** The sensitivity runs and MCBEs generally support the stock status as indicated by the base run.

The stock status for this updated assessment remained the same as the stock status from the most recent (2021 GDAR 03) update assessment. The update assessment has the same trend and magnitude as both the benchmark and the most recent update assessment.

The Menhaden Advisory Committee (MAC) recommends that the next operational assessment occur in three years (2027); however, if significant new data are available, then a research track or benchmark assessment could be considered.

3.0 Data Review and Updates

In the SEDAR 63 benchmark (2018), the assessment period was 1977-2017, which was extended to 2020 for an update assessment in 2021 (GDAR 03). For this update assessment, data were extended to 2023; making the assessment period 1977-2023. Many of the data sources for the stock assessment remained static, while others were simply updated with the additional three years of data. The recreational data for catch and effort has changed slightly from the previous benchmark in that NOAA has revised the historic estimates.

In this update assessment, the Beaufort Assessment Model (BAM) was fitted to the same data sources as in SEDAR 63 (2018) and GDAR03 (2021) and used the same fixed data:

- Landings: commercial reduction (which include small amounts of commercial bait and recreational landings)
- Indices of abundance: juvenile abundance index based on seine surveys and adult abundance index based on a gillnet survey
- Age compositions of landings: commercial reduction
- Length compositions of indices: gillnet adult survey
- Life history information included:
  - Lorenzen M scaled to tagging data,
  - weights at age for population and fishery, and
  - fecundity, maturity, and sex ratio.

3.1 Life History

Life history inputs from SEDAR 63 (2018) remained the same in this assessment including the length-length conversions, fecundity estimates, and maturity schedule.

The overall weight-length and von Bertalanffy growth relationships remained the same as the benchmark assessment. In SEDAR 63 (2018), several life history based approaches were explored for developing estimates of *M*. We used the same estimates from the benchmark assessment, which used the Lorenzen (1996) method for determining natural mortality (using overall mean weights-at-age; Table 1), which was then scaled to a tagging-based estimate of *M* = 1.10 (Ahrenholz 1981). The estimated value of *M* in Ahrenholz (1981) was supported by a reanalysis of the historical tagging data using current methods (Wilhelm 2023), which estimated a value of *M* = 1.08.

3.2 Landings

Estimates of landings were updated with 2021-2023 data using the methods outlined in SEDAR 63 (2018; Table 2). Commercial reduction landings were updated using the same methods as during the benchmark assessment. As noted above, the recreational landings were updated for the entire time series, although there were only small changes (Figure 1). Commercial bait landings were also updated with 2021-2023 data, including the bait landings for 2020 which were only partial for the last update assessment.

3.3 Indices of Abundance

Both the juvenile abundance index based on state conducted seine surveys from Louisiana, Alabama, and Mississippi, and the adult abundance index based on a gillnet survey conducted by Louisiana were updated with data from 2021-2023 (Figures 2 and 3; Table 3). Each index was standardized using the methods from the benchmark assessment (SEDAR 63 2018). The juvenile abundance index (recruitment) spans from January through June beginning in 1996, while the LA gillnet index spans from April through September beginning in 1988.

3.4 Length Composition

Length compositions were developed from the LA gillnet survey and were updated through 2023 using the same methods as used in the SEDAR 63 benchmark assessment (2018; Table 4).

3.5 Age Composition

Age data were available from the commercial reduction fishery. Ages greater than four were pooled to create a plus group. Fishery age compositions were updated to include 2021-2023 using the same methods as in the last benchmark assessment (SEDAR 63 2018; Table 5).

4.0 Stock Assessment Model and Results

4.1 Model Methods

4.1.1 Overview

The Beaufort Assessment Model (BAM) that was developed for the Gulf Menhaden benchmark during SEDAR 63 (2018) was updated in this assessment. The BAM applies a statistical catch-age formulation (Williams and Shertzer 2015) and was implemented with the AD Model Builder software (Fournier et al. 2012).

4.1.2 Data Sources

The catch-age model included data from two sets of fishery-independent surveys and one fishery fleet, which consisted primarily of the commercial reduction landings but also included small proportions of commercial bait and recreational landings. The data sources used for this assessment were the same as those used for the benchmark assessment. The model was fitted to annual landings, annual age compositions of landings, two indices of abundance (juvenile and adult)), and annual length compositions for the adult abundance index. Data used in the model are described and tabulated in Section 3.0 of this report.

4.1.3 Base Model Configuration

Base model configuration was identical to the base model configuration during the SEDAR 63 benchmark assessment (2018). A general description of the base run configuration follows.

Stock Dynamics: In the assessment model, new biomass was acquired through growth and recruitment, while abundance of existing cohorts experienced exponential decay from fishing and natural mortality. The population was assumed closed to immigration and emigration. The model included age classes 0 to 4+, where the oldest age class 4+ allowed for the accumulation of fish (i.e., plus group).

Initialization: Initial (1977) abundance at age was assumed equal to the equilibrium age structure given initial fishing mortality estimated in the model. The equilibrium age structure was computed for Ages-0 to -4+ based on natural and fishing mortality, where *F* was set equal to the initial fishing mortality rate estimated in the model based on fitting to the available data. Deviations in the initial age structure were estimated with the model.

Natural Mortality Rate: The natural mortality rate (*M*) was assumed constant over time, but decreasing with age. The form of *M* as a function of age was based on Lorenzen (1996). The Lorenzen estimates at age (*a*), M_a, were rescaled such that the Age-2 *M* was equal to the natural mortality estimated from a tagging study (Ahrenholz 1981), as was done in the benchmark assessment.

Growth: Mean size at age of the population (fork length, FL) was modeled with a constant von Bertalanffy growth equation. Weight at age was a fixed input into the model, as was done for the benchmark assessment. For fitting length composition data, the distribution of size at age was assumed normal with the coefficient of variation (CV) of length at age estimated by the assessment model.

Female Maturity: Females were modeled to be fully mature at Age-2, while the proportion mature at Age-0 was fixed at 0.0 and Age-1 was fixed at 0.8.

Spawning Stock: Spawning stock was modeled using fecundity, which is a product of the number of females, the proportion mature, and the mean fecundity at age. For Gulf Menhaden, spawning was considered to occur on January 1, the same date at which the fish turned a year older.

Recruitment: Recruitment to Age-0 was estimated in the assessment model for each year with a set of annual deviation parameters, conditioned about a Beverton-Holt stock recruitment curve, and estimated in log-space. The steepness of the stock-recruitment curve was fixed at 0.99. Annual recruitment variation was informed by annual age composition data during 1977-2023 and an index of abundance for recruitment during 1996-2023. Autocorrelation in recruitment deviations was assumed to be zero.

Landings: The model included a time series of combined landings including the commercial reduction purse seine fleet, commercial bait landings, and recreational landings for 1977-2023. A large portion of the landings, ~99%, are from the commercial reduction fleet. Landings were modeled with the Baranov catch equation (Baranov 1918) and were fitted in units of 1,000s of metric tons (mt).

Fishing Mortality: The assessment model estimated an annual full fishing mortality rate (*F*) for each year of the landings time series. Age specific rates were then computed as the product of full *F* and selectivity at age.

Selectivities: The selectivity curve applied to landings was age-specific, dome-shaped, and fixed for most ages. Age-0 selectivity was fixed at 0.0, Age-2 selectivity was fixed at 1.0, Ages-3 and -4 selectivities were fixed at 0.87, and Age-1 selectivity was estimated during two time blocks (1977-1996 and 1997-2023), as was done during the benchmark assessment. Selectivity for the recruitment index (seine index) was 1.0 for Age-0 and 0.0 for all other ages. Finally, selectivity for the LA gillnet index was estimated as a logistic or flat-topped function with two parameters being estimated.

Indices of Abundance: The model was fitted to two indices of relative abundance: the seine index (1996-2023) and the LA gillnet index (1988-2023). The seine index was considered to represent relative changes in recruitment over time, and the LA gillnet index was considered to represent relative changes in adult abundance over time. Predicted indices were conditional on the selectivity specified or estimated.

Catchability: In the BAM, catchability scales indices of relative abundance to estimated exploitable abundance at large. Following the methodology used in the SEDAR 63 (2018) base run, the update assessment assumed time-invariant catchability for both the seine index and the gillnet index.

Fitting Criterion: The fitting criterion was a total likelihood approach in which total catch, the observed age compositions from the commercial reduction fishery, the observed length compositions from the gillnet index, and the patterns of the abundance indices (both seine and gillnet indices) were fit based on the assumed statistical error distribution and the level of assumed or measured error (see SEDAR 63 benchmark assessment 2018).

Parameters Estimated: The model estimated annual fishing mortality rates, selectivity parameters, catchability coefficients for each index, parameters of the spawner-recruit model, annual recruitment deviations, CV for growth, and the Dirichlet multinomial parameters. All parameters were estimated as described in SEDAR 63 (2018).

4.1.4 Biological Reference Points

As in SEDAR 63 (2018), the *F*-based biological refence points are based on *F=M* for the threshold and *F=0.75M* as the target. The natural mortality associated with the *F*-based reference points was the geometric mean natural mortality for Ages-0 to -2, which is the bulk of the incoming fishery in future years. All equilibrium benchmark calculations were based upon current fishery selectivity, *M*-at-age (which was constant over time), weight-at-age, and fecundity-at-age from the model inputs. Population fecundity (*FEC*, number of maturing or ripe eggs) was used as the measure of reproductive capacity. The *SSB* or *FEC* based metrics were the *SSB* value at 25% and 50% of the equilibrium value when *F*=0.

4.1.5 Sensitivity and Retrospective Analyses

Two sets of sensitivity runs were completed in order to explore new or different data inputs and determine if a retrospective pattern exists. Many sensitivity runs have been conducted with this model formulation during past benchmark and update assessments; thus, the requested sensitivity runs were fewer for this update assessment.

The first set of sensitivity runs considered different formulations of the LA gillnet index. Specifically, LA gillnet survey data was used to provide two different indices of abundance: 1) an index based on mesh size 501 (the smallest mesh; 2-inch stretch, 1-inch bar) and 2) an index based on the other mesh sizes. The 501 mesh is expected to represent Age-1 Gulf Menhaden, and might provide a signal for Age-1 abundance over time. The other mesh sizes might additionally provide a better signal of Age-2+ dynamics without being influenced by the Age-1 data likely present in the 501 mesh. For the first sensitivity run, the LA gillnet index in the base run was replaced with the modified LA gillnet index based on the meshes exluding the 501 mesh. The selectivity was assumed to be logistic for the Age-2+ index. The length compositions were modified to reflect the sizes sampled in the data. For the second sensitivity run, two LA gillnet indices were included in the model, and the index in the base run was replaced. The selectivity for the index excluding the 501 mesh was estimated as logistic, as this index still represented the largest and oldest individuals. The selectivity for the index based on the 501 mesh was estimated as a double logistic or dome-shape in order to account for the 501 mesh sampling smaller sized fish. Two sets of length compositions were included in the model to reflect those sizes sampled in each of the data sets used to create the two indices of abundance.

Finally, a retrospective analysis was completed by sequentially removing the last year of data from the assessment such that the terminal year was 2018, 2019, 2020, 2021, and 2022. This analysis was completed to see how influential additional years of data are on the outcomes of the stock assessment and is a common diagnostic of stock assessments.

List of sensitivity runs:

1. LA gillnet index excludes the 501 mesh
2. LA gillnet index is included as two indices;
    a. an index based on the 501 mesh, and
    b. an index based on the other mesh sizes
3. Retrospective with the terminal year of 2022
4. Retrospective with the terminal year of 2021
5. Retrospective with the terminal year of 2020
6. Retrospective with the terminal year of 2019
7. Retrospective with the terminal year of 2018

4.1.6 Uncertainty and Measures of Precision

Uncertainty was explored using the sensitivity runs described above and a mixed Monte Carlo and bootstrap ensemble procedure (MCBE) described here. MCBE runs were configured as they were configured during the benchmark stock assessment. The MCBEs captured the expectation of uncertainty given the input data, fixed parameters, and life history data.

In this update assessment, the BAM was successively refit to n = 5,000 trials that differed from the original inputs by bootstrapping on data sources and by Monte Carlo sampling of several key input parameters. Runs were trimmed from the final uncertainty characterization using the same criteria in the benchmark assessment. The set-up of the MCBE runs for this update was the same as the specifications described in SEDAR 63 (2018).

The MCBE analysis should be interpreted as providing an approximation to the total uncertainty associated with each output. The results are approximate for two related reasons. First, not all combinations of Monte Carlo parameter inputs are equally likely, as biological parameters might be correlated. Second, all runs are given equal weight in the results, yet some might provide better fits to data than others.

4.2 Model Results

4.2.1 Base Run Results

Measures of Overall Model Fit: Generally, the BAM fit the available data well. The model was configured to fit observed commercial landings closely (Figure 4). The model was configured to fit the observed seine and gillnet indices as closely as possible (Figures 5 and 6) with the gillnet index being upweighted with a weight of 4, as was done in the benchmark assessment. Since the late 2000s and into the early 2010s, the general trend in the gillnet index has been increasing with a flattening out since 2010, although the last couple of years have shown an increase. At the same time, the seine index has indicated several large year classes of recruits occurring in 2011, 2014, and 2018 with the 2023 point being lower than most recent years. Predicted length compositions from the LA gillnet index and predicted age compositions from the reduction fishery were both reasonably close to observed data in most years (Figures 7, 8, and 9).

Stock Abundance and Recruitment: Estimated abundance was higher in the 1970s and early 1980s, decreased to lower levels from the mid-1980s to mid-2000s, and then returned to the levels seen in the 1970s (Figure 10; Table 6). The most recent year, 2023, has one of the lower estimated abundance levels in the time series, likely due to the low value of estimated recruitment in 2023. Annual estimated number of recruits follows a similar pattern to estimated abundance (Figure 11). The model has identified the 2011, 2014, and 2018-year classes as being strong.

Total and Spawning Biomass (Fecundity): Estimated biomass and spawning stock biomass (as fecundity) exhibited similar patterns to that of abundance (Figures 12 and 13; Tables 7 and 8).

Selectivity: The selectivity estimates for Age-1 fish captured in the commercial reduction fishery were similar to the estimates during the last benchmark assessment (Figure 14). The selectivity for all of the other ages was fixed and resulted in dome-shaped selectivity, as was done in the benchmark assessment (SEDAR 63 2018). The LA gillnet index selectivity was logistic or flat-topped and was fully selected at Age-2 (Figure 15).

Fishing Mortality: Estimated fishing mortality rates (*F*) were higher from 1977 to 2000 with the highest fishing mortality rates occurring in the 1990s (Figure 16; Tables 8 and 9). After the 1990s, the fishing mortality rate declined until about 2010. Since 2010, the fishing mortality rate has been variable but stable with the last 4 years (2020-2023) being the some of the lowest fishing mortality rates in the time series. Figure 4 shows total predicted landings in weight. Commercial harvest exceeded 800,000 mt during much of the 1980s, but declined afterwards to stabilize around 400,000 to 500,000 mt for much of the past decade (Figure 4).

4.2.2 Equilibrium Analyses

Spawning potential ratio (SPR) was computed as a function of *F*. These analyses applied the most recent selectivity pattern. Equilibrium landings were computed as functions of *F*. Equilibrium landings for the *F* based benchmarks were 763,458 mt for $F=M$ and 662,989 mt for $F=0.75M$, respectively.

4.2.3 Benchmarks/Reference Points

Stock status for Gulf Menhaden is assessed using fishing mortality compared to the geometric mean of *M* for ages-0 to-2 and using spawning stock biomass (fecundity) compared to percentages of spawning stock biomass (fecundity) at $F=0$ calculated using equilibrium quantities. The current threshold for fishing mortality is $F_{F=M}$, and the current threshold for spawning stock biomass, measured as fecundity, is $SSB_{25\%\ at\ F=0}$. The current target for fishing mortality is $F_{F=0.75M}$, and the current target for spawning stock biomass, measured as fecundity, is $SSB_{50\%\ at\ F=0}$. Estimates of benchmarks are summarized in Table 10.

Point estimates of the benchmarks were $F_{F=M}$ = 1.32, $F_{F=0.75M}$ = 0.99, $SSB_{25\%\ at\ F=0}$ = 1,315,586, and $SSB_{50\%\ of\ F=0}$ = 2,631,172.

4.2.4 Status of the Stock and Fishery

Base run estimates of spawning stock biomass showed no years in the time series were below the threshold (Figure 17; Table 8). Current stock status in the base run was estimated to be $SSB_{2021\text{-}2023}/SSB_{25\%\ at\ F=0}$ = 3.44 (Table 10). MCBE analysis suggests that the stock status determination of being not overfished (i.e., $SSB > SSB_{25\%\ at\ F=0}$) has a low degree of uncertainty (Figures 17 and 18). All of the MCBE runs were greater than $SSB_{25\%\ at\ F=0}$ in the terminal years.

The estimated time series of $F/F_{F=M}$ suggests that overfishing may have occurred historically, prior to the 1990s (Figure 17; Table 8). Current fishery status in the terminal year is estimated in the base run to be $F_{2021\text{-}2023}/F_{F=M}$ = 0.35 (Table 10). This estimate indicates that overfishing is not occurring and appears robust across a majority of the MCBE trials (Figures 17 and 18). Across all MCBE runs, 99% of runs were less than $F_{F=M}$ in the terminal years.

The Gulf Menhaden population is **not overfished** and **overfishing is not occurring**. The base run and all sensitivity runs indicate the same stock status (Figure 19). In addition, most of the MCBE runs indicated the same stock status. In general, there is little risk of overfishing or of being overfished (Figures 17 and 18).

4.2.5 Sensitivity and Retrospective Analyses

Sensitivity runs, described above, are useful to evaluate the implications of decisions that were made during the benchmark assessment (SEDAR 63 2018) and to determine if new data inform the model differently. The sensitivity analyses generally indicated similar stock status to the base run (Figures 20 and 21; Table 11); but, each sensitivity analysis differed from the base run during some time periods of the assessment. Specifically, the sensitivity run that excluded the 501 mesh from the LA gillnet index estimated a different time series during 1980-2010 for fishing mortality rate with the graph being generally flatter than the base run for those years, but looked similar to the base run for SSB. In the most recent time period, the estimates were fairly similar. For the sensitivity run with two indices constructed from the LA gillnet data based on mesh size, during the most recent years, the fishing mortality rate was higher and the SSB was lower when compared to the base run. These sensitivity runs were exploratory in nature. More work needs to be done to explore both the LA gillnet survey data to determine if splitting the data are warranted, as well as configuring the stock assessment model if the LA gillnet index changed in future assessments.

Retrospective analysis generally indicated no pattern in overestimation or underestimation. Fishing mortality rate, biomass, spawning stock biomss, and recruitment show little retrospective pattern (Figures 22, 23, 24, and 25) with differences attributable to the high 2018 recruitment estimate provided the high value of the seine index for that year. The reference point time series do not seem to indicate a pattern in overestimation or underestimation of stock status (Figures 26 and 27). Mohn's rho values were calculated for each retrospective analysis and were as follows: fishing mortality rate 0.18; recruitment 1.32; spawning stock biomass 0.13; and biomass 0.28 (Figure 28).

4.2.6 Comparison with Previous Assessment

This update assessment was congruent with the 2021 update assessment (GDAR03; Figure 29). The differences between the two assessments were minimal and within the bounds of the uncertainty analysis.

5.0 Discussion

5.1 Recommendations for the Next Benchmark Assessment

The MAC recommends that the next operational assessment occur during 2027. Gulf Menhaden are a short-lived species and would benefit from a shorter time between assessments such as 2-3 years.

6.0 Research Recommendations and Priorities

Throughout the course of this assessment update and previous assessments, a number of items were identified as important research topics for future stock assessments. The assessment panel evaluated the various items and developed a consensus priority list. Priorities have equal value in importance whether for single species assessment or ecosystem-based. The shift in the future will be towards ecosystem-based assessments and endeavors should be undertaken towards that shift; however, these efforts should not impinge on the single-species assessment. Several years of side-by-side comparisons of the two assessment types will be informative in the development of ecosystem-based assessments.

TOPIC AREA	DATA ELEMENT	RECOMMENDATION	PRIORITY
Single-Species Assessment			
Biomass Study	FI Adult Winter Survey	Examine the feasibility of an acoustic survey for menhaden populations during winter months to determine spatial distribution and abundance and to estimate an area swept biomass.	Med/High
Modeling	Bootstrap considerations	Evaluate the relationships between the various life history and productivity input parameters, which could be impacting bootstrap results due to the potentially unrealistic combinations of parameters drawn from the specified distributions.	Med/High
Fishery-Independent Adult Index	Fishery-Independent Adult Index	Collect and age Gulf Menhaden from fishery-independent gears (e.g., gillnets) to determine selectivity and possibly track cohorts within the stock assessment. This could be useful when and if large variations in length-at-age are present.	Med/High
Indices of Abundance	Fishery-Independent Indices	Consider the fishery independent survey data specifically the mesh sizes on the gillnet index and what ages/size classes each mesh represents. Explore the relationship between the recruitment indices for each state and the gillnet survey data for each state. Reconsider index configuration, if appropriate.	Med/High
Genetics and Stock Structure	Stock Structure	Evaluate the genetic markers for confirming the meristic identifications of species. We are particularly interested in the periphery of the Gulf Menhaden's range in Texas and Alabama/Florida waters for juveniles and adults.	Med
Legacy Data (FD Surveys)	Legacy Data (FD Surveys)	Process and analyze samples that address the homogeneity of the catch in the hold of the reduction fishery vessels.	Med/Low
Stock Status Benchmarks	Single Species Benchmarks	Continue to evaluate reference points for the stock to ensure long term sustainability while balancing the desires of stakeholders to effectively exploit the stock (Short Term Objective).	Low
Recruitment Evaluation	Recruitment Evaluation	Understand the recruitment drivers for Gulf Menhaden back to the estuary from the spawning grounds (mechanistic understanding of larval migration and movement from offshore to inshore - cues and behavior and general oceanographic events - important for Eco Ref Points) (Long Term Objective).	Low

TOPIC AREA	DATA ELEMENT	RECOMMENDATION	PRIORITY
Ecosystem-Based Assessment			
Predator/Prey	Predator/Prey	Expand understanding of diets of potential Gulf Menhaden predators using a variety of tools including traditional stomach contents analysis, stable isotope analyses for gut contents, and DNA barcoding, Gulf wide across time/seasons - ecosystem critical. (long Term Objective)	High
Stock Status Benchmarks	Ecosystem Benchmarks	Continue to gather more data to populate the existing ecosystem models to move toward assessment benchmarks (e.g., F or proxies) that account for the multiple priorities of ecosystem management that includes predation mortality (Long Term Objective).	Med
Environmental Indices	Environmental Indices	Develop a habitat index to examine the potential shift in the Gulf Menhaden population to more inshore waters as marsh converts to open water from coastal land loss.	Med/Low

Biomass Study

The reviewers of SEDAR 63 (2018) and the MAC recommended that some sort of independent survey be developed to address adult abundance. Utilize new technology such as a combination of down-viewing echosounder and omni-directional sonar to generate biomass estimates in the winter Gulf Menhaden population when they are distributed more offshore for spawning. The work by Liang et al. (2020) proposing a hydro-acoustic project in the northeast could serve as a model for the Gulf. Studies like this are critical to informing the ecosystem-based models by validating the overlap of predators and their prey spatially and seasonally.

Modeling

In general, concern has arisen over the inclusion of related parameters in Monte Carlo bootstrap ensemble (MCBE) analyses, which is not necessarily a menhaden-specific concern or unique to this assessment update. For example, a uniform distribution on one parameter and a uniform distribution on another parameter might not provide realistic combinations of parameters in nature. The uncertainty components currently being modeled in the BAM for Gulf Menhaden are not linked but potentially could be with more information. For example, natural mortality may be correlated with maturity or steepness, so the MCBEs may select potentially unrealistic parameter combinations. This type of analysis has not been conducted but would be valuable to any future stock assessments.

Fishery-Independent Adult Index

The existing state water gillnets remain a reliable source for adult menhaden and ageing of the samples could help determine selectivity and possibly track cohorts within the stock assessment. The gillnets are providing fishery-independent lengths, which are used to estimate an age-based selectivity in the assessment model. Ageing of scale samples from the fishery-independent survey would provide a more direct estimate of selectivity for the adult index.

Indices of Abundance
In addition, creating an index based on the individuals captured in the smallest mesh of the gillnet survey may provide an Age-1 index. The other mesh sizes could then provide an index for adults for Age-2+. More work is needed before this could be considered for use in the next benchmark assessment.

Genetics and Stock Structure
Determining better estimates of natural mortality, migration, and growth could be accomplished through a variety of readily available techniques. These techniques could include mark/recapture and newer methods such as meristic characters and genetics. The use of more recent advances could aid in the understanding of Gulf Menhaden for future assessments.

Considering the overlap of species to the east and west of the traditional harvest grounds, there would be a considerable benefit from using simple genetic techniques such as DNA barcoding to aid species identification, which is currently problematic in peripheral range areas as sampled in the Texas, Alabama, and Florida surveys. Resolution of species identification and any other measures to ensure more consistency across the state surveys that were excluded from the assessment could provide a more representative basis for monitoring abundance.

Legacy Data (FD Surveys)
The reviewers of SEDAR 27 (2011) expressed concern about the potential bias associated with sampling only the last purse-seine set of the trip. The reviewers noted that there could be a sampling bias towards larger/older fish or smaller/younger fish, depending on the proximity to a plant. Therefore, a sampling scheme was devised to sample vessels at dockside and to acquire fish samples from throughout the hold during the vessel unloading operation, not just the top of the fish hold. Fish factory dockside workers at each menhaden plant were asked to sample several vessels seasonally in 2012 as the vessels were unloading their catches retrieving samples periodically during the pumpout process. Samples from the fish stream were not necessarily assumed to represent identifiable purse-seine sets of the fishing trip, rather, they were assumed to be mixed fish from many sets of the given trip. A total of 31 "pumpout events" were sampled with four replicates each (top of the hold and start, middle and end of the pumpout); overall, 1,240 fish were sampled for size/age composition. The sample sizes for this analysis were considered low for some plant locations and across the season. Additional samples have been collected across a greater spatial and temporal domain, but those samples remain unprocessed. The results from the remaining samples could address the question of homogeneity of the catch in the hold of the reduction fishery vessels.

Stock Status Benchmarks (Single Species)
Following the completion of the SEDAR 63 menhaden benchmark assessment (2018), the MAC agreed to begin exploring potential reference points for management. The MAC and a number of invited stakeholders participated in three workshops in New Orleans to look at options for reference points (VanderKooy 2019a, 2019b, 2023). After an extensive review of the options available, the majority of reference points were determined to have many potential issues and a number were rejected outright. The lack of a defined MSY and stock-recruitment relationship resulted in the current reference points from the last benchmark (SEDAR 63 2018) and the 2015 Gulf Menhaden Fishery Management Plan (VanderKooy and Smith 2015) to continue to be the standard. Options exist to adjust the existing

references points should a need be determined.

Recruitment Evaluation

Understanding drivers of recruitment at the fundamental mechanistic level could help scientists to determine future population productivity and levels, especially for a fishery like Gulf Menhaden. These would be informative for both single and multi-species work but narrowing down the critical drivers from the large suite of potential options is problematic. In addition, a lack of overwintering/spawning locations for Gulf Menhaden further complicate the identification of the critical parameters at this time.

Predator/Prey

In order to better describe the ecosystem importance of Gulf Menhaden as a forage species, diet studies are required to better estimate the consumption of menhaden in higher predator species. A better understanding of predator/prey interactions is required to refine the estimate of natural mortality in most EwE models.

Stock Status Benchmarks (Ecosystem and Multispecies)

With the movement towards development of ecosystem benchmarks and use of those benchmarks in management, the MAC suggests continued exploration of multispecies and ecosystem models to determine appropriate ecosystem benchmarks for Gulf Menhaden provided the suite of predator species (de Mutsert et al. 2016, Sagarese et al. 2016, de Mutsert 2017, Berenshtein et al. 2021, Berenshtein et al. 2023).

Environmental Indices

Tracking of environmental indices and habitat changes over time will allow scientists to determine the population level impacts of these changes. Loss of habitat or reproductive capacity could lead to lower levels of overall population productivity.

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8.0 Tables

Table 1. Life history characteristics at age of Gulf Menhaden, including maturity, natural mortality (*M*), fecundity, and weight (g) at spawning.

Age	Maturity	*M*	Fecundity	Weight at spawning
0	0.0	1.67	0	0.0
1	0.8	1.26	164,106	53.4
2	1.0	1.10	404,404	97.5
3	1.0	1.02	744,264	146.7
4+	1.0	0.98	1,149,697	196.4

Table 2. Observed total landings in 1,000s of mt by year for the Gulf Menhaden fishery. Landings include reduction landings, bait landings, and recreational landings.

Year	Landings	Year	Landings
1977	447.73	2001	528.61
1978	820.73	2002	582.84
1979	779.96	2003	524.42
1980	702.63	2004	473.78
1981	554.02	2005	438.19
1982	855.55	2006	467.66
1983	925.24	2007	457.41
1984	985.12	2008	425.61
1985	884.28	2009	457.71
1986	830.83	2010	380.04
1987	912.28	2011	614.26
1988	640.13	2012	580.40
1989	584.11	2013	499.04
1990	539.63	2014	400.98
1991	552.89	2015	540.77
1992	432.88	2016	491.80
1993	551.47	2017	462.55
1994	775.15	2018	529.61
1995	472.04	2019	489.70
1996	491.84	2020	422.45
1997	623.50	2021	362.09
1998	495.79	2022	484.28
1999	694.29	2023	436.53
2000	591.05		

Table 3. Observed indices of abundance and coefficient of variation (CV) from the seine survey and the gillnet survey.

Year	Gillnet	Gillnet CV	Seine	Seine CV
1988	0.87	0.08		
1989	0.49	0.09		
1990	0.54	0.09		
1991	0.54	0.10		
1992	0.40	0.10		
1993	0.32	0.10		
1994	0.57	0.10		
1995	0.46	0.10		
1996	0.52	0.09	1.28	0.26
1997	0.79	0.08	0.51	0.27
1998	0.70	0.08	0.78	0.27
1999	0.65	0.08	0.46	0.28
2000	0.95	0.08	0.70	0.29
2001	1.01	0.08	0.64	0.26
2002	0.80	0.08	0.41	0.26
2003	0.76	0.08	0.64	0.24
2004	0.59	0.08	0.43	0.27
2005	0.92	0.08	0.57	0.26
2006	1.06	0.07	0.74	0.26
2007	0.78	0.08	0.63	0.27
2008	1.96	0.07	0.24	0.27
2009	1.77	0.07	0.87	0.24
2010	0.56	0.08	1.21	0.25
2011	1.34	0.06	3.09	0.25
2012	1.64	0.06	0.95	0.25
2013	1.35	0.09	0.95	0.29
2014	1.64	0.09	1.69	0.31
2015	1.08	0.09	0.95	0.21
2016	1.17	0.10	1.27	0.20
2017	1.33	0.10	0.45	0.22
2018	1.37	0.09	4.34	0.17
2019	1.26	0.09	0.48	0.19
2020	1.14	0.09	1.41	0.19
2021	1.30	0.09	0.82	0.20
2022	1.41	0.08	1.21	0.20
2023	1.95	0.08	0.27	0.20

Table 4. Annual proportion at length from the gillnet survey input to the Gulf Menhaden model. Each column is indicated by the mid-point of the length bin.

Year	Length Bin														
	85	95	105	115	125	135	145	155	165	175	185	195	205	215	225
1996	0.01	0.02	0.01	0.02	0.07	0.16	0.16	0.09	0.11	0.11	0.07	0.05	0.04	0.04	0.02
1997	0.00	0.01	0.00	0.02	0.06	0.14	0.14	0.11	0.11	0.12	0.09	0.07	0.06	0.03	0.02
1998	0.00	0.01	0.01	0.02	0.07	0.17	0.19	0.12	0.11	0.11	0.07	0.04	0.03	0.02	0.01
1999	0.00	0.01	0.01	0.03	0.08	0.16	0.14	0.09	0.11	0.11	0.09	0.06	0.06	0.03	0.02
2000	0.00	0.01	0.01	0.02	0.07	0.14	0.11	0.07	0.07	0.12	0.12	0.08	0.08	0.06	0.03
2001	0.00	0.01	0.01	0.01	0.06	0.11	0.10	0.08	0.12	0.13	0.09	0.08	0.08	0.06	0.04
2002	0.00	0.01	0.01	0.03	0.06	0.14	0.14	0.08	0.09	0.10	0.09	0.06	0.07	0.06	0.03
2003	0.00	0.01	0.01	0.03	0.09	0.19	0.19	0.10	0.09	0.13	0.07	0.02	0.02	0.02	0.01
2004	0.00	0.01	0.02	0.04	0.11	0.18	0.17	0.11	0.10	0.08	0.07	0.04	0.04	0.02	0.01
2005	0.00	0.01	0.01	0.03	0.06	0.15	0.18	0.12	0.12	0.13	0.08	0.04	0.04	0.02	0.01
2006	0.01	0.01	0.01	0.02	0.08	0.16	0.15	0.15	0.10	0.11	0.08	0.05	0.04	0.02	0.01
2007	0.01	0.01	0.01	0.01	0.05	0.13	0.17	0.15	0.14	0.13	0.08	0.04	0.03	0.02	0.01
2008	0.00	0.01	0.01	0.02	0.04	0.12	0.14	0.10	0.12	0.15	0.11	0.08	0.06	0.03	0.01
2009	0.00	0.01	0.01	0.02	0.04	0.09	0.14	0.11	0.11	0.12	0.12	0.08	0.08	0.05	0.02
2010	0.00	0.01	0.01	0.03	0.07	0.14	0.12	0.08	0.09	0.11	0.10	0.08	0.06	0.05	0.02
2011	0.00	0.01	0.02	0.03	0.08	0.16	0.15	0.08	0.08	0.10	0.10	0.06	0.06	0.04	0.02
2012	0.00	0.01	0.01	0.02	0.07	0.17	0.18	0.11	0.11	0.12	0.07	0.05	0.05	0.03	0.01
2013	0.00	0.02	0.01	0.02	0.06	0.12	0.14	0.11	0.14	0.13	0.10	0.05	0.06	0.03	0.01
2014	0.00	0.00	0.02	0.01	0.04	0.13	0.16	0.09	0.09	0.12	0.13	0.09	0.06	0.04	0.01
2015	0.01	0.01	0.01	0.03	0.09	0.18	0.16	0.06	0.06	0.11	0.10	0.07	0.07	0.04	0.01
2016	0.00	0.01	0.00	0.02	0.05	0.12	0.20	0.17	0.13	0.11	0.08	0.04	0.04	0.03	0.00
2017	0.00	0.01	0.01	0.02	0.06	0.17	0.17	0.10	0.11	0.13	0.10	0.04	0.03	0.02	0.01
2018	0.00	0.01	0.01	0.01	0.04	0.13	0.21	0.14	0.11	0.18	0.10	0.03	0.02	0.01	0.00
2019	0.00	0.01	0.02	0.03	0.08	0.19	0.21	0.13	0.09	0.09	0.09	0.03	0.02	0.01	0.00
2020	0.00	0.01	0.02	0.02	0.05	0.15	0.21	0.13	0.12	0.14	0.08	0.03	0.01	0.01	0.00
2021	0.00	0.01	0.01	0.03	0.06	0.15	0.20	0.13	0.11	0.13	0.11	0.03	0.02	0.01	0.00
2022	0.00	0.01	0.01	0.02	0.06	0.13	0.17	0.16	0.12	0.14	0.09	0.04	0.02	0.01	0.00
2023	0.00	0.01	0.01	0.02	0.06	0.23	0.19	0.09	0.09	0.13	0.09	0.03	0.02	0.01	0.00

Table 5. Annual proportion at age from the commercial reduction fishery input to the Gulf Menhaden model.

Year	Age-0	Age-1	Age-2	Age-3	Age-4+
1977	0.000	0.763	0.218	0.018	0.001
1978	0.000	0.708	0.286	0.005	0.001
1979	0.000	0.593	0.363	0.043	0.001
1980	0.009	0.472	0.452	0.060	0.007
1981	0.000	0.763	0.189	0.044	0.005
1982	0.000	0.571	0.366	0.056	0.007
1983	0.000	0.526	0.428	0.043	0.003
1984	0.000	0.697	0.259	0.039	0.004
1985	0.000	0.758	0.218	0.020	0.003
1986	0.000	0.456	0.522	0.019	0.003
1987	0.000	0.603	0.358	0.038	0.001
1988	0.000	0.660	0.319	0.019	0.002
1989	0.000	0.766	0.224	0.009	0.000
1990	0.000	0.668	0.306	0.023	0.002
1991	0.000	0.462	0.487	0.045	0.006
1992	0.000	0.559	0.384	0.050	0.007
1993	0.001	0.666	0.292	0.037	0.004
1994	0.000	0.496	0.437	0.060	0.007
1995	0.000	0.351	0.622	0.026	0.001
1996	0.000	0.391	0.550	0.055	0.004
1997	0.000	0.544	0.403	0.046	0.007
1998	0.000	0.392	0.563	0.041	0.004
1999	0.000	0.544	0.386	0.067	0.003
2000	0.000	0.362	0.564	0.062	0.012
2001	0.000	0.250	0.672	0.074	0.005
2002	0.000	0.317	0.573	0.107	0.003
2003	0.000	0.362	0.571	0.064	0.003
2004	0.000	0.560	0.353	0.080	0.008
2005	0.019	0.394	0.541	0.043	0.003
2006	0.000	0.459	0.470	0.065	0.006
2007	0.000	0.463	0.510	0.024	0.004
2008	0.000	0.266	0.683	0.044	0.006
2009	0.000	0.126	0.731	0.129	0.013
2010	0.000	0.529	0.404	0.061	0.006
2011	0.007	0.632	0.317	0.037	0.007
2012	0.003	0.309	0.658	0.029	0.001
2013	0.002	0.245	0.727	0.025	0.001
2014	0.006	0.258	0.596	0.134	0.006
2015	0.000	0.625	0.309	0.062	0.005
2016	0.006	0.516	0.411	0.062	0.005
2017	0.010	0.657	0.275	0.056	0.001

Year	Age-0	Age-1	Age-2	Age-3	Age-4+
2018	0.017	0.224	0.637	0.113	0.009
2019	0.034	0.566	0.327	0.067	0.006
2020	0.000	0.249	0.668	0.079	0.004
2021	0.001	0.254	0.492	0.230	0.023
2022	0.001	0.159	0.601	0.195	0.043
2023	0.001	0.209	0.490	0.243	0.057

Table 6. Estimated total abundance at age (in billions of fish) at the start of the year.

Year	Age-0	Age-1	Age-2	Age-3	Age-4+
1977	177.15	25.77	2.65	0.44	0.10
1978	156.17	33.34	5.79	0.39	0.10
1979	95.76	29.39	7.07	0.70	0.07
1980	180.84	18.02	6.46	0.96	0.13
1981	175.26	34.04	3.82	0.78	0.16
1982	128.32	32.99	7.88	0.63	0.18
1983	145.39	24.15	7.29	1.10	0.14
1984	212.73	27.37	4.92	0.76	0.16
1985	131.43	40.04	4.99	0.35	0.09
1986	157.25	24.74	8.39	0.58	0.06
1987	89.66	29.60	5.34	1.07	0.10
1988	89.43	16.88	5.92	0.52	0.15
1989	110.52	16.83	3.53	0.68	0.10
1990	80.51	20.80	3.26	0.31	0.09
1991	56.76	15.15	4.28	0.35	0.05
1992	100.16	10.68	3.04	0.43	0.05
1993	127.75	18.85	2.07	0.27	0.05
1994	70.71	24.04	3.43	0.15	0.03
1995	123.37	13.31	4.32	0.23	0.02
1996	127.51	23.22	2.76	0.48	0.03
1997	91.49	24.00	5.33	0.22	0.05
1998	151.22	17.22	5.60	0.48	0.03
1999	143.34	28.46	4.19	0.66	0.08
2000	107.59	26.98	6.45	0.31	0.07
2001	119.21	20.25	6.64	0.82	0.06
2002	79.51	22.44	5.07	0.96	0.15
2003	117.63	14.97	5.40	0.56	0.15
2004	132.64	22.14	3.58	0.58	0.10
2005	93.11	24.97	5.26	0.36	0.09
2006	176.39	17.53	6.29	0.79	0.08
2007	207.48	33.20	4.42	0.94	0.16
2008	34.55	39.05	8.41	0.69	0.21
2009	112.18	6.50	10.39	1.82	0.22
2010	218.14	21.12	1.72	2.13	0.48
2011	171.88	41.06	5.28	0.24	0.45
2012	159.09	32.35	10.19	0.71	0.12
2013	101.91	29.95	8.40	1.87	0.18
2014	151.49	19.18	7.86	1.66	0.47
2015	125.75	28.52	5.09	1.67	0.52
2016	190.12	23.67	7.19	0.77	0.40

Year	Age-0	Age-1	Age-2	Age-3	Age-4+
2017	85.12	35.79	6.08	1.23	0.24
2018	200.39	16.02	9.30	1.13	0.32
2019	86.43	37.72	4.14	1.66	0.31
2020	178.58	16.27	9.62	0.68	0.38
2021	152.66	33.62	4.29	1.97	0.25
2022	248.31	28.74	8.86	0.87	0.53
2023	47.02	46.74	7.56	1.77	0.33

Table 7. Estimated biomass at age (1,000s mt) at start of year.

Year	Age-1	Age-2	Age-3	Age-4+
1977	1375.98	258.27	64.92	20.47
1978	1780.59	564.04	57.19	19.19
1979	1569.64	688.86	102.06	14.35
1980	962.49	629.54	141.35	25.15
1981	1817.64	372.37	113.91	32.03
1982	1761.60	768.25	91.75	36.15
1983	1289.77	710.44	160.70	27.07
1984	1461.33	479.84	112.14	32.13
1985	2138.03	486.35	51.34	17.28
1986	1320.99	818.04	84.66	12.47
1987	1580.55	520.39	157.67	19.85
1988	901.17	576.82	76.81	28.87
1989	898.84	343.93	99.53	18.96
1990	1110.83	317.74	45.42	17.30
1991	809.17	416.92	51.72	10.69
1992	570.53	296.44	62.37	10.13
1993	1006.71	202.26	39.54	10.73
1994	1283.94	334.50	21.52	6.01
1995	710.65	420.81	33.92	3.15
1996	1240.02	269.49	71.00	6.81
1997	1281.55	519.88	32.59	10.70
1998	919.58	546.24	70.25	6.32
1999	1519.91	408.44	97.37	14.77
2000	1440.61	628.53	45.03	14.08
2001	1081.44	647.18	120.96	11.76
2002	1198.19	494.78	140.81	30.41
2003	799.20	526.39	81.94	30.31
2004	1182.32	349.53	84.58	18.94
2005	1333.17	512.40	52.83	16.91
2006	935.91	613.32	115.69	15.92
2007	1772.93	430.63	138.63	30.94
2008	2085.46	820.33	101.06	40.61
2009	347.26	1012.99	266.93	44.00
2010	1127.56	167.29	311.87	95.20
2011	2192.63	514.76	35.87	89.05
2012	1727.61	993.05	104.62	23.15
2013	1599.11	818.75	273.81	35.22
2014	1024.42	766.74	244.16	92.61
2015	1522.71	496.07	244.36	103.00

Year	Age-1	Age-2	Age-3	Age-4+
2016	1264.01	701.26	112.81	78.80
2017	1910.97	592.59	179.78	46.93
2018	855.64	907.10	165.16	62.70
2019	2014.21	404.01	243.98	60.12
2020	868.79	938.16	99.13	75.44
2021	1795.05	418.63	289.25	49.94
2022	1534.49	864.20	128.30	103.31
2023	2495.94	736.62	259.76	64.59

Table 8. Estimated time series of status indicators, fishing mortality, and spawning stock biomass (fecundity). Fishing mortality rate is full *F*. Spawning biomass (SSB, fecundity) is at the start of the year (time of peak spawning).

Year	F	F/FF=M	SSB	SSB/SSB25% at F=0
1977	0.82	0.62	2,451,661	1.86
1978	1.02	0.77	3,559,785	2.71
1979	0.89	0.68	3,659,008	2.78
1980	1.02	0.77	2,920,892	2.22
1981	0.71	0.54	3,389,304	2.58
1982	0.87	0.66	4,097,265	3.11
1983	1.15	0.87	3,545,704	2.70
1984	1.54	1.17	3,169,994	2.41
1985	1.06	0.80	3,817,635	2.90
1986	0.95	0.72	3,571,604	2.71
1987	1.22	0.93	3,480,170	2.65
1988	1.07	0.81	2,583,340	1.96
1989	1.33	1.01	2,126,150	1.62
1990	1.12	0.85	2,190,309	1.66
1991	1.21	0.92	2,021,822	1.54
1992	1.32	1.00	1,503,976	1.14
1993	1.55	1.17	1,788,651	1.36
1994	1.60	1.21	2,344,165	1.78
1995	1.09	0.82	1,841,550	1.40
1996	1.42	1.08	2,283,248	1.74
1997	1.31	0.99	2,767,503	2.10
1998	1.03	0.78	2,459,931	1.87
1999	1.51	1.15	3,005,646	2.28
2000	0.96	0.72	3,229,826	2.46
2001	0.83	0.63	3,012,781	2.29
2002	1.11	0.84	2,945,196	2.24
2003	1.14	0.86	2,370,641	1.80
2004	1.20	0.91	2,448,276	1.86
2005	0.80	0.60	2,884,955	2.19
2006	0.80	0.60	2,762,495	2.10
2007	0.76	0.57	3,514,679	2.67
2008	0.43	0.33	4,640,046	3.53
2009	0.49	0.37	3,333,581	2.53
2010	0.85	0.64	2,802,756	2.13
2011	0.90	0.68	4,114,504	3.13
2012	0.60	0.45	4,516,268	3.43
2013	0.52	0.39	4,461,330	3.39

Year	F	F/FF=M	SSB	SSB/SSB25% at F=0
2014	0.45	0.34	3,739,819	2.84
2015	0.79	0.60	3,821,928	2.91
2016	0.67	0.51	3,524,918	2.68
2017	0.59	0.44	4,171,439	3.17
2018	0.62	0.47	3,535,478	2.69
2019	0.71	0.54	4,108,743	3.12
2020	0.49	0.37	3,485,837	2.65
2021	0.49	0.37	3,954,691	3.01
2022	0.51	0.39	4,306,356	3.27
2023	0.40	0.31	5,443,761	4.14

Table 9. Estimated instantaneous fishing mortality rate (per year) at age.

Year	Age-0	Age-1	Age-2	Age-3	Age-4+
1977	0.00	0.23	0.82	0.71	0.71
1978	0.00	0.29	1.02	0.89	0.89
1979	0.00	0.26	0.89	0.78	0.78
1980	0.00	0.29	1.02	0.89	0.89
1981	0.00	0.20	0.71	0.62	0.62
1982	0.00	0.25	0.87	0.76	0.76
1983	0.00	0.33	1.15	1.00	1.00
1984	0.00	0.44	1.54	1.34	1.34
1985	0.00	0.30	1.06	0.92	0.92
1986	0.00	0.27	0.95	0.83	0.83
1987	0.00	0.35	1.22	1.06	1.06
1988	0.00	0.31	1.07	0.93	0.93
1989	0.00	0.38	1.33	1.16	1.16
1990	0.00	0.32	1.12	0.98	0.98
1991	0.00	0.35	1.21	1.05	1.05
1992	0.00	0.38	1.32	1.15	1.15
1993	0.00	0.44	1.55	1.35	1.35
1994	0.00	0.46	1.60	1.39	1.39
1995	0.00	0.31	1.09	0.95	0.95
1996	0.00	0.21	1.42	1.24	1.24
1997	0.00	0.19	1.31	1.14	1.14
1998	0.00	0.15	1.03	0.90	0.90
1999	0.00	0.23	1.51	1.32	1.32
2000	0.00	0.14	0.96	0.83	0.83
2001	0.00	0.12	0.83	0.73	0.73
2002	0.00	0.16	1.11	0.96	0.96
2003	0.00	0.17	1.14	0.99	0.99
2004	0.00	0.18	1.20	1.04	1.04
2005	0.00	0.12	0.80	0.69	0.69
2006	0.00	0.12	0.80	0.69	0.69
2007	0.00	0.11	0.76	0.66	0.66
2008	0.00	0.06	0.43	0.38	0.38
2009	0.00	0.07	0.49	0.42	0.42
2010	0.00	0.13	0.85	0.74	0.74
2011	0.00	0.13	0.90	0.78	0.78
2012	0.00	0.09	0.60	0.52	0.52
2013	0.00	0.08	0.52	0.45	0.45
2014	0.00	0.07	0.45	0.39	0.39
2015	0.00	0.12	0.79	0.69	0.69
2016	0.00	0.10	0.67	0.58	0.58

Year	Age-0	Age-1	Age-2	Age-3	Age-4+
2017	0.00	0.09	0.59	0.51	0.51
2018	0.00	0.09	0.62	0.54	0.54
2019	0.00	0.11	0.71	0.62	0.62
2020	0.00	0.07	0.49	0.42	0.42
2021	0.00	0.07	0.49	0.43	0.43
2022	0.00	0.08	0.51	0.44	0.44
2023	0.00	0.06	0.40	0.35	0.35

Table 10. Estimated status indicators, benchmarks, and related quantities from the Beaufort catch-age model conditional on estimated current selectivity. Rate estimates (F) are in units of y^{-1}, and status indicators are dimensionless. Spawning stock biomass is measured in total fecundity in billions of eggs.

Quantities	Units	Estimates
$F_{F=M}$	y^{-1}	1.32
$F_{F=0.75M}$	y^{-1}	0.99
$SSB_{25\%\ at\ F=0}$	Billions of eggs	1,315,586
$SSB_{50\%\ at\ F=0}$	Billions of eggs	2,631,172
$F_{2021-2023}$	y^{-1}	0.47
$SSB_{2021-2023}$	Billions of eggs	4,525,923
$F_{2021-2023}/F_{F=M}$	-	0.35
$F_{2021-2023}/F_{F=0.75M}$	-	0.47
$SSB_{2021-2023}/SSB_{25\%\ at\ F=0}$	-	3.44
$SSB_{2021-2023}/SSB_{50\%\ at\ F=0}$	-	1.72

Table 11. Estimated status indicators, benchmarks, and related quantities from the Beaufort catch-age model for each sensitivity run completed and for the retrospective analysis. Rate estimates (*F*) are in units of y^{-1}, and status indicators are dimensionless. Spawning stock biomass is measured in total fecundity in billions of eggs.

Run	$F_{F=M}$	$F_{F=0.75M}$	$SSB_{25\%\ at\ F=0}$	$SSB_{50\%\ at\ F=0}$	$F_{Terminal\ 3\ years}/F_{F=M}$	$F_{Terminal\ 3\ years}/F_{F=0.75M}$	$SSB_{Terminal\ 3\ years}/SSB_{25\%\ at\ F=0}$	$SSB_{Terminal\ 3\ years}/SSB_{50\%\ at\ F=0}$
Base run	1.32	0.99	1,315,586	2,631,172	0.35	0.47	3.44	1.72
LA gillnet index excludes 501 mesh	1.32	0.99	1,430,716	2,861,432	0.38	0.50	2.82	1.41
LA gillnet index divided into 2 indices	1.32	0.99	1,217,222	2,434,444	0.56	0.75	2.48	1.24
Retrospective 2022	1.32	0.99	1,313,998	2,627,996	0.39	0.52	2.83	1.42
Retrospective 2021	1.32	0.99	1,296,954	2,593,907	0.43	0.58	2.91	1.46
Retrospective 2020	1.32	0.99	1,283,098	2,566,195	0.48	0.64	2.69	1.34
Retrospective 2019	1.32	0.99	1,244,853	2,489,707	0.53	0.70	3.15	1.58
Retrospective 2018	1.32	0.99	1,287,588	2,575,176	0.55	0.73	2.59	1.30

9.0 Figures

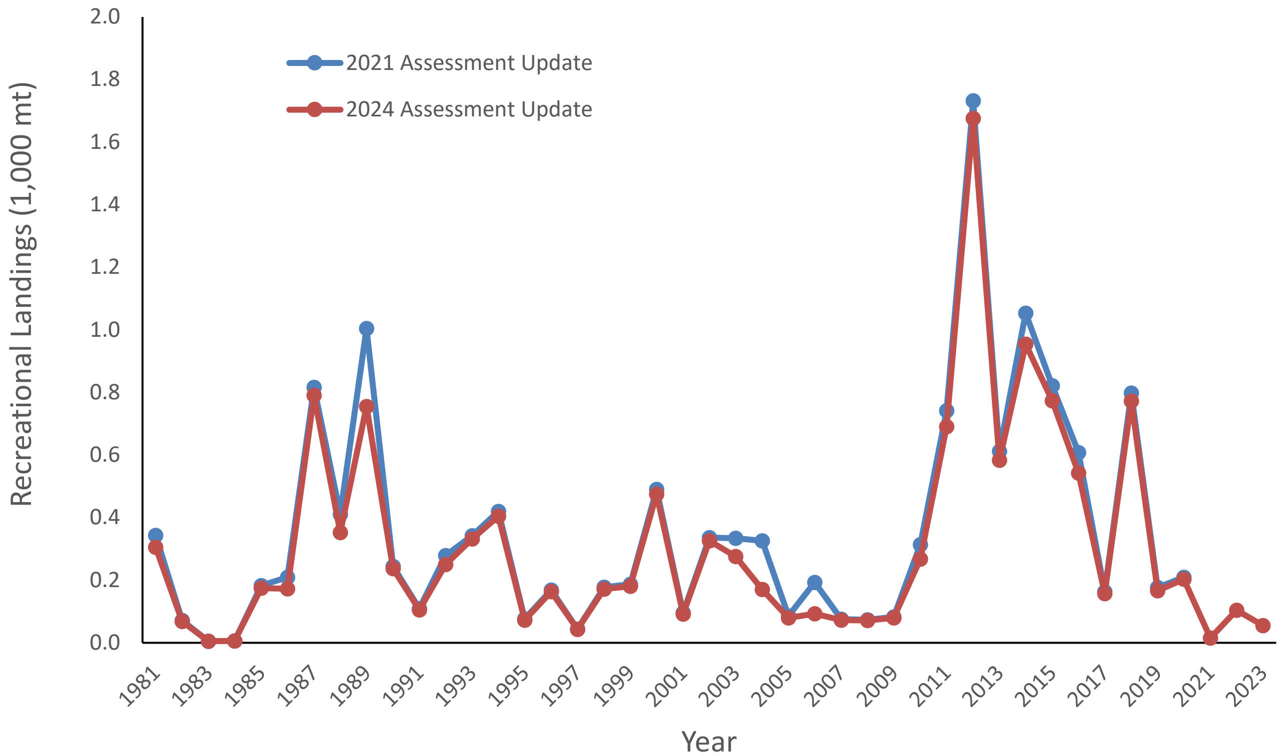

Figure 1. Recreational landings comparison from the the most recent update assessment and this update assessment.

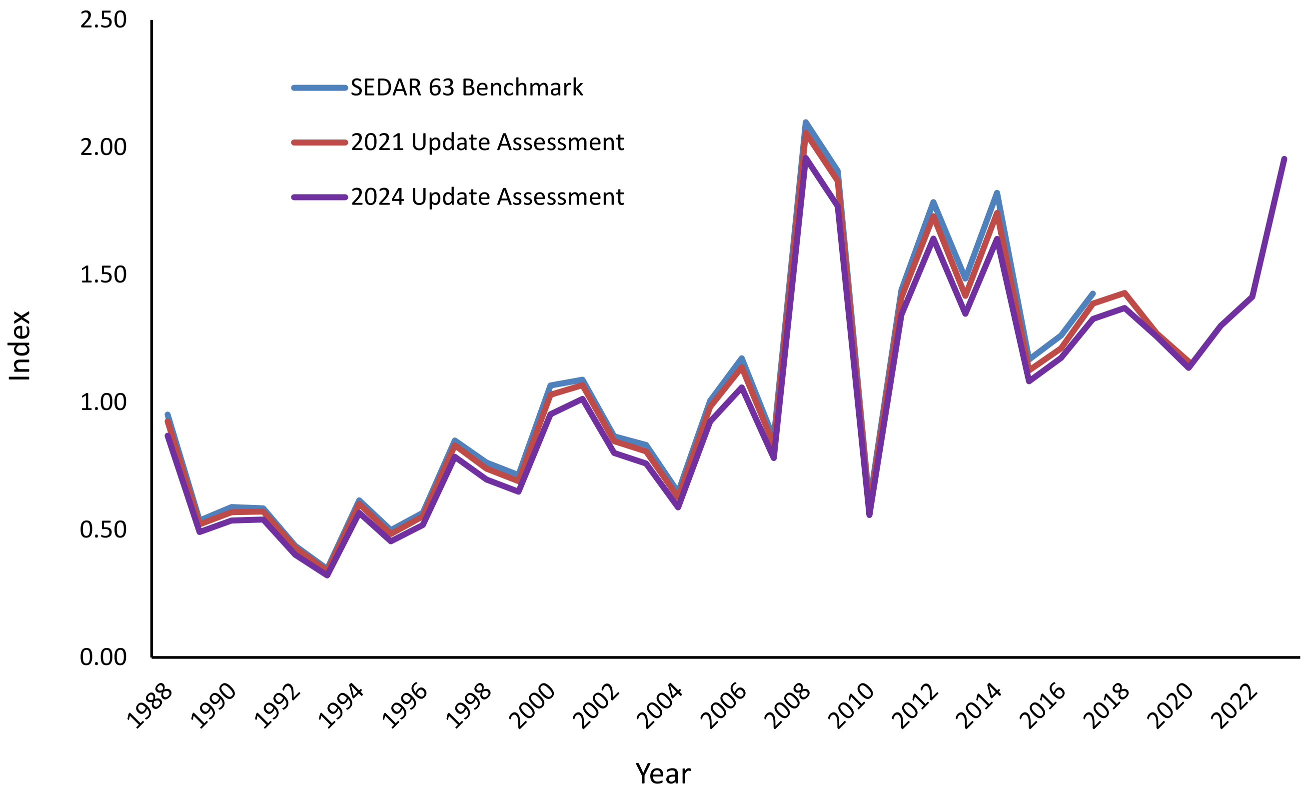

Figure 2. The gillnet index from the benchmark SEDAR 63 assessment, the 2021 update assessment, and updated for the current assessment.

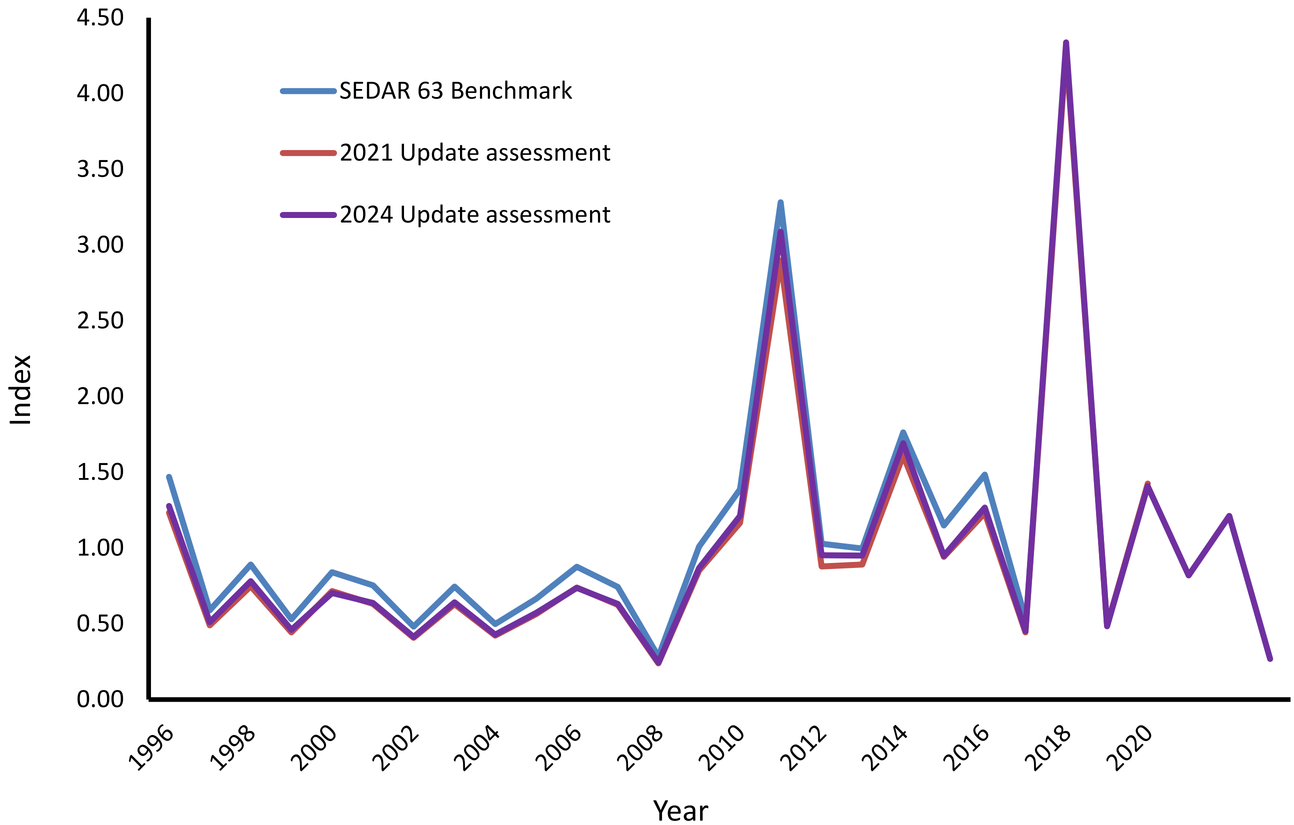

Figure 3. The seine index from the benchmark SEDAR 63 assessment, the 2021 update assessment, and updated for the current assessment.

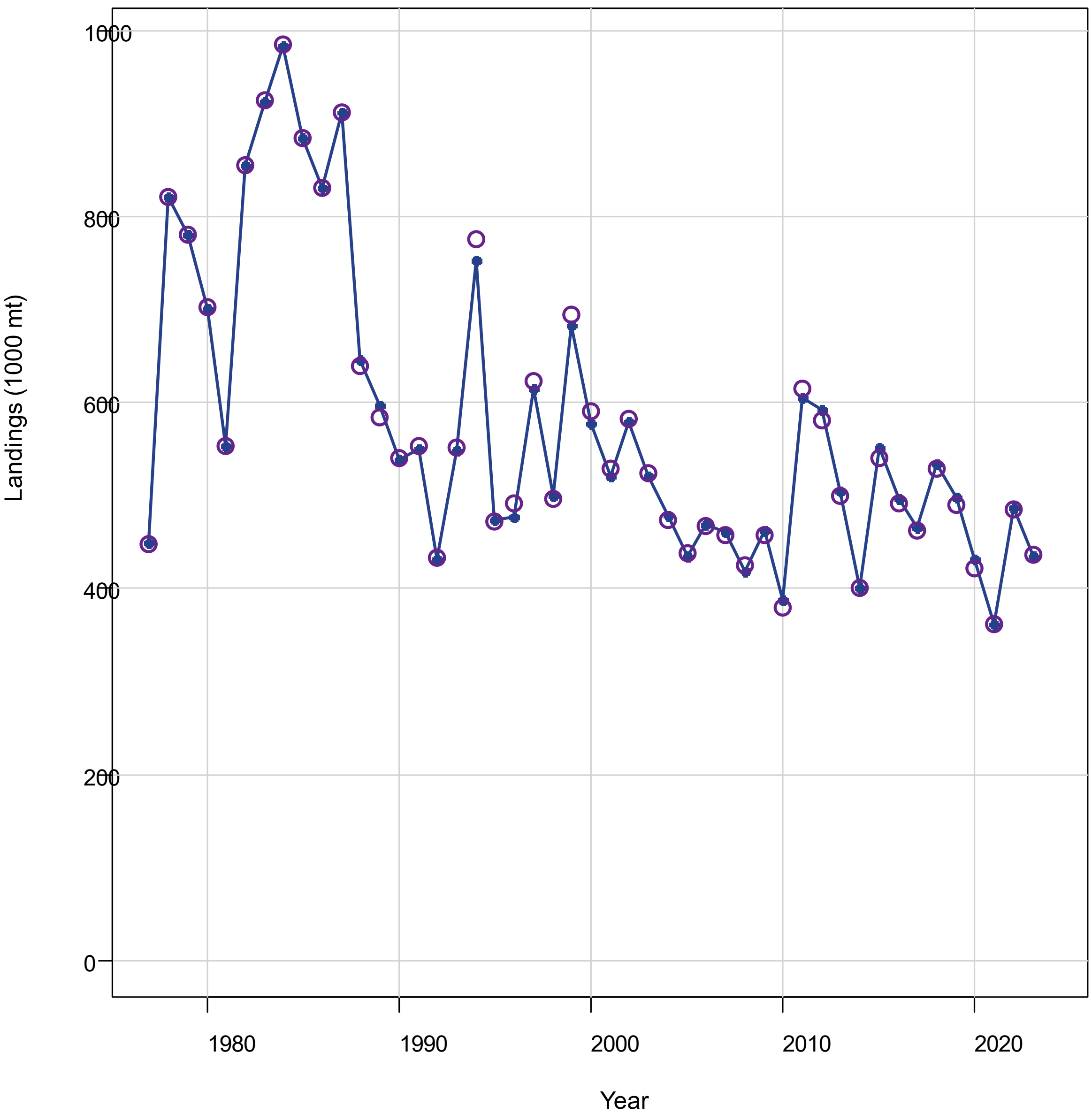

Figure 4. Observed (open circles) and estimated (line, solid circles) commercial reduction, commercial bait, and recreational landings (1,000s mt).

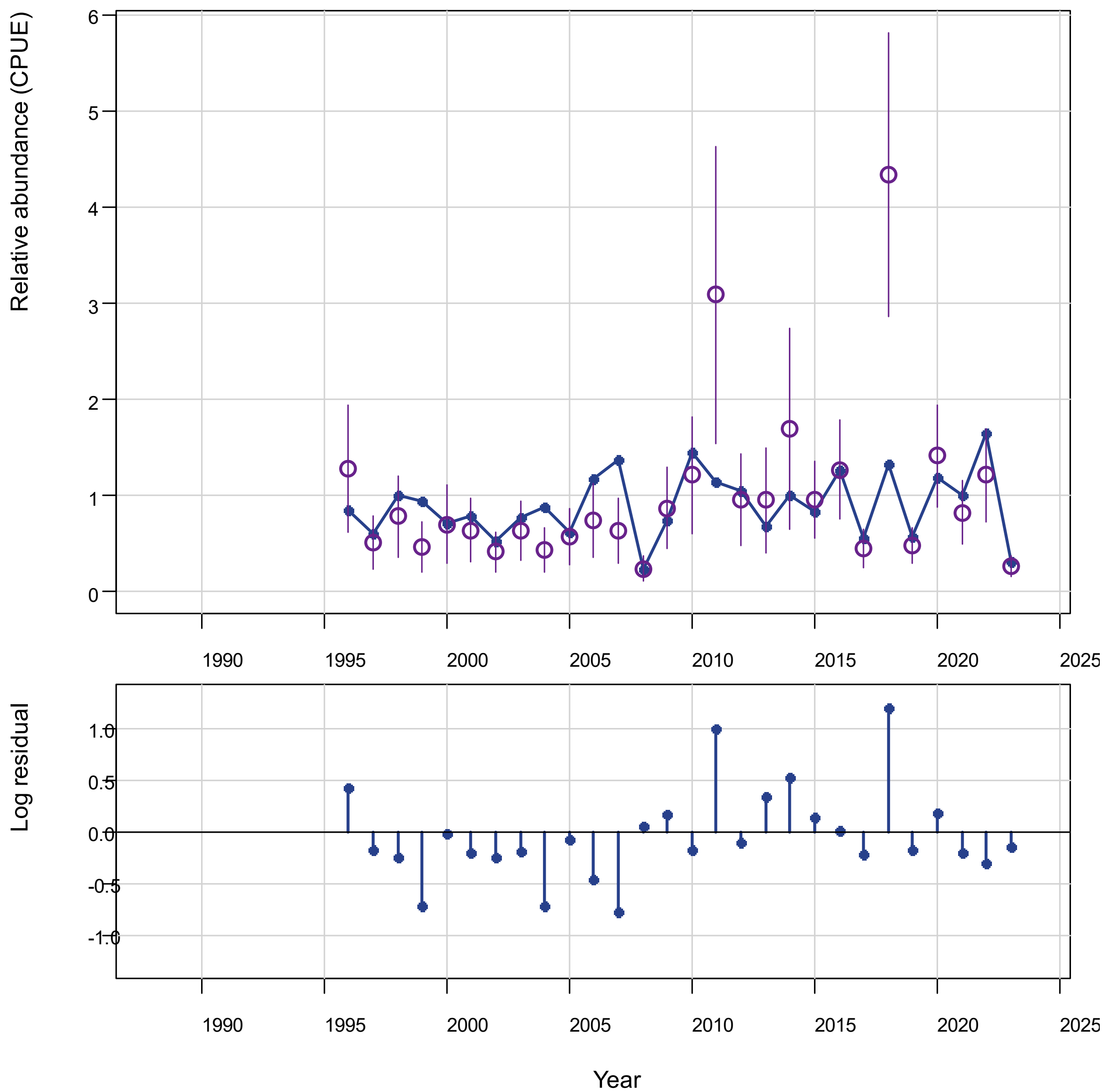

Figure 5. Observed (open circles) and estimated (line, solid circles) index of abundance from the seine surveys in Louisiana, Mississippi, and Alabama.

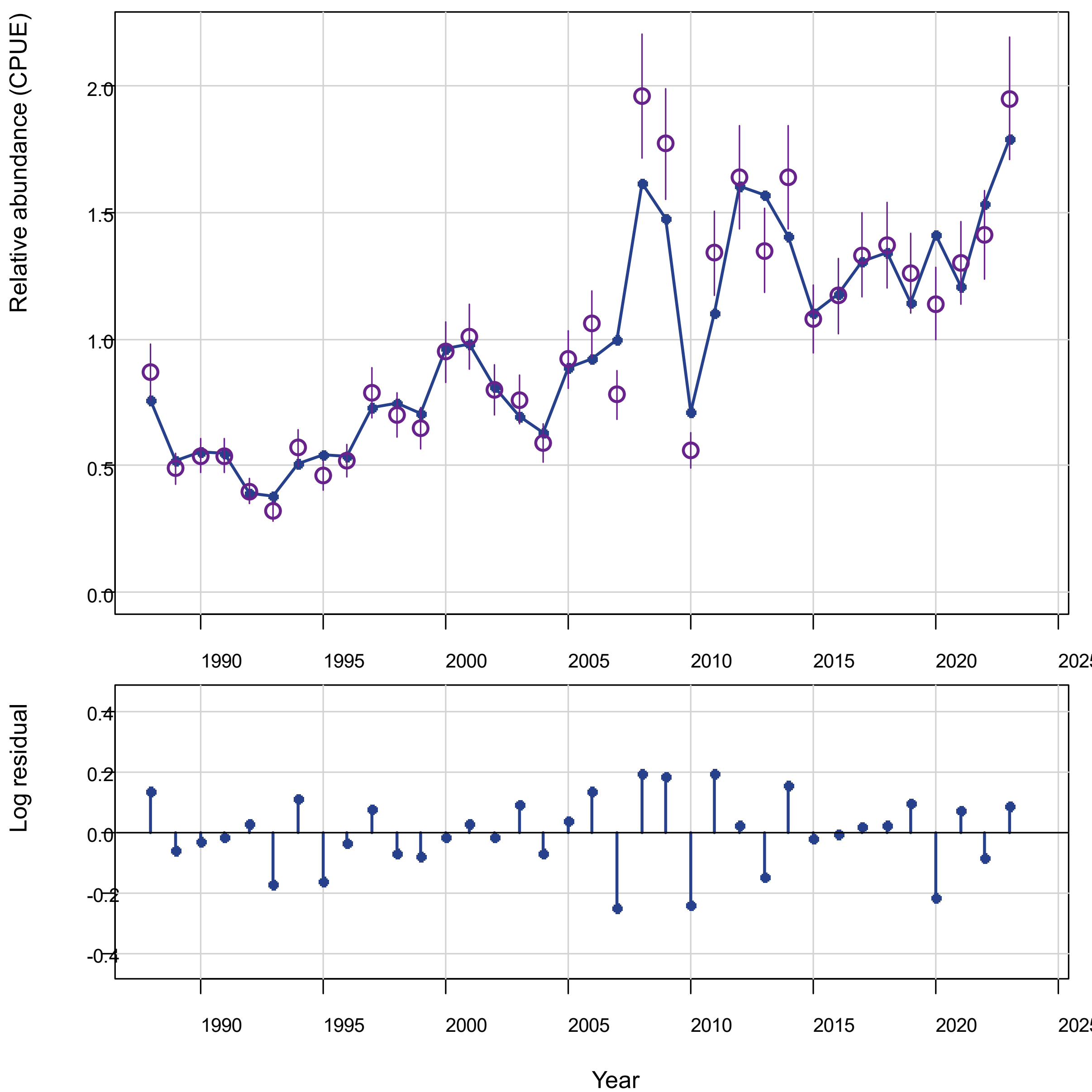

Figure 6. Observed (open circles) and estimated (line, solid circles) index of abundance from the LA gillnet survey.

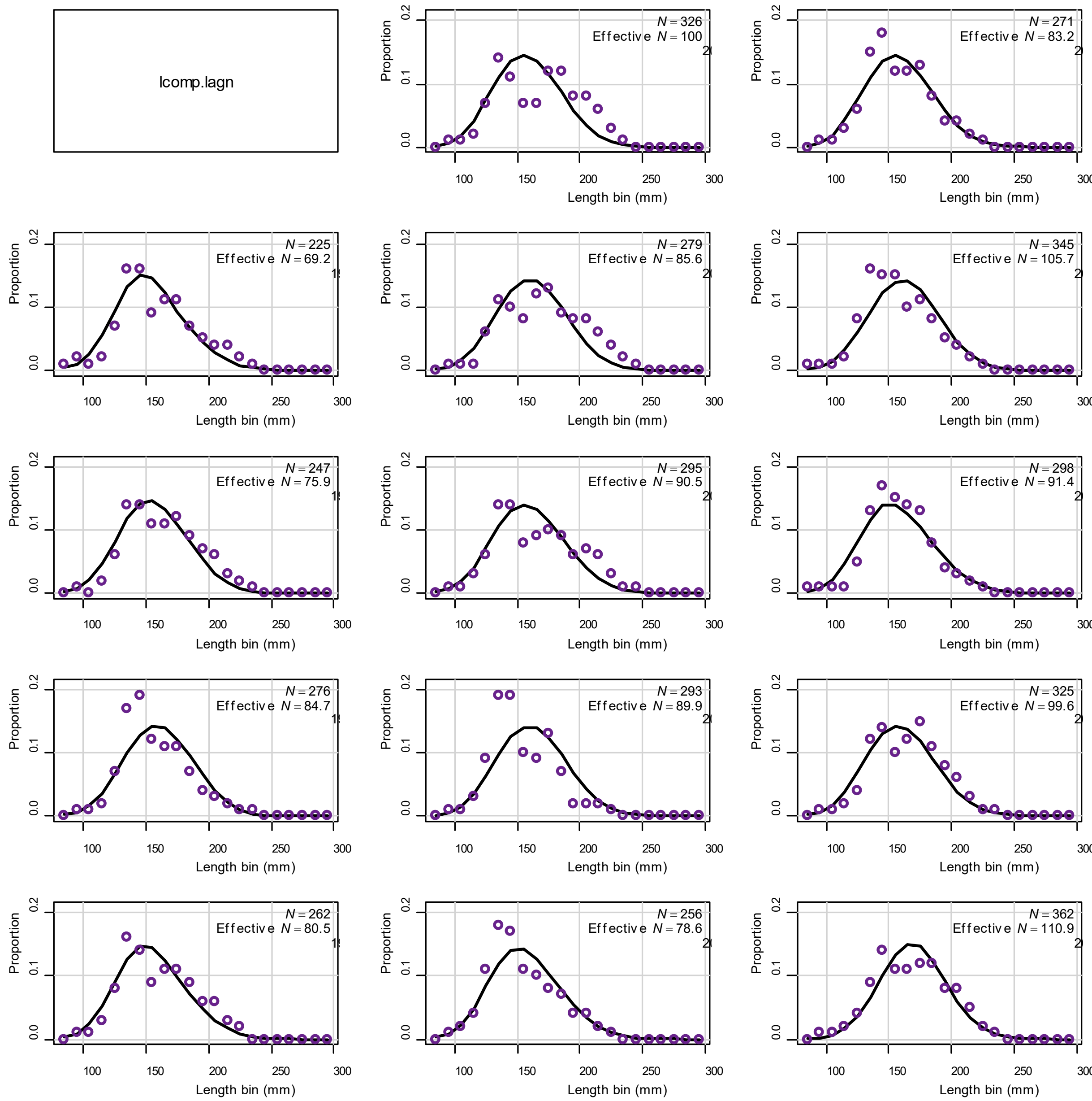

Figure 7. Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, cR to commercial reduction, and lagn to the LA gillnet survey. N indicates the number of trips from which individual fish samples were taken.

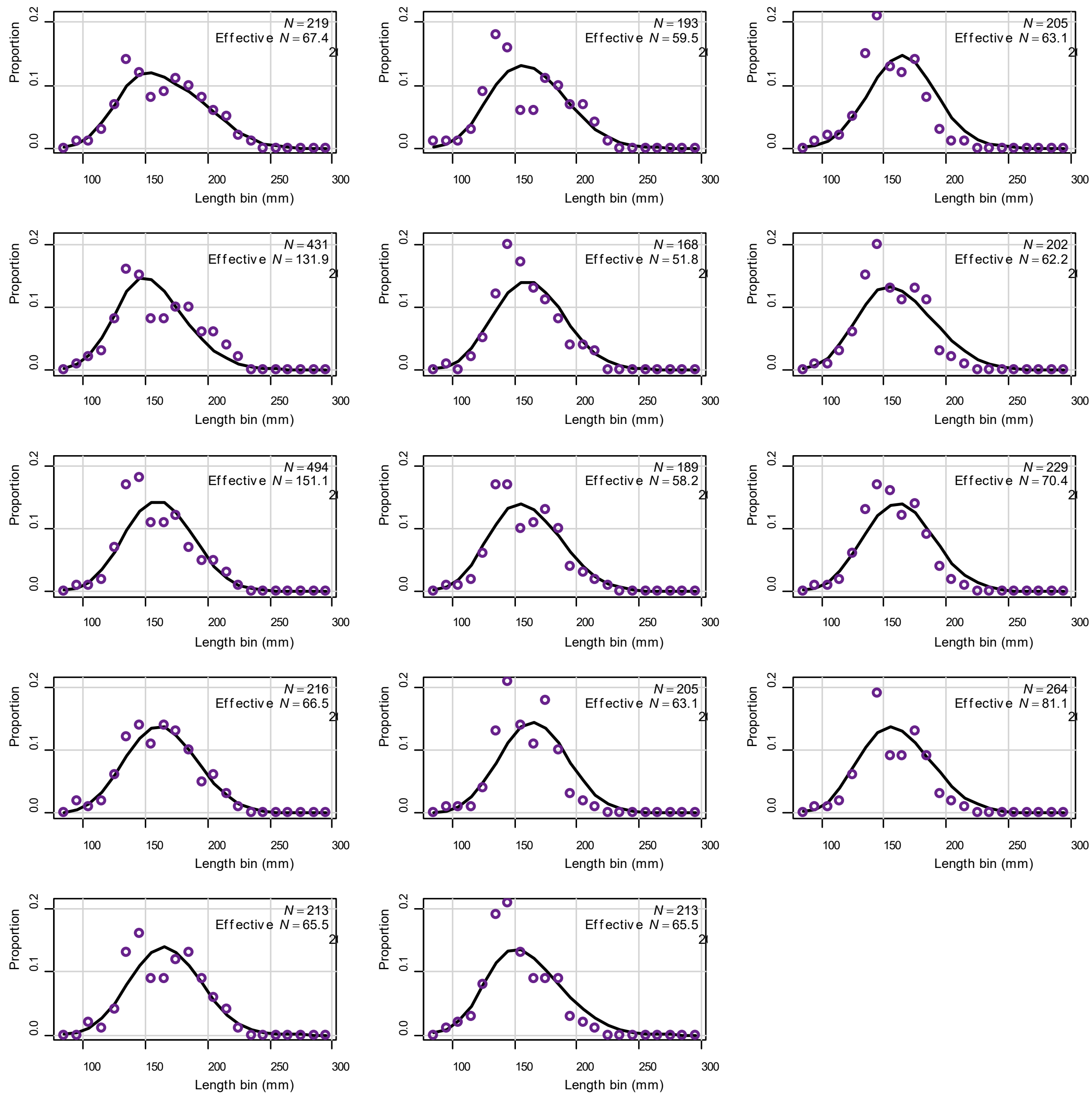

Figure 7. (Continued) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, cR to commercial reduction, and lagn to the LA gillnet survey. N indicates the number of trips from which individual fish samples were taken.

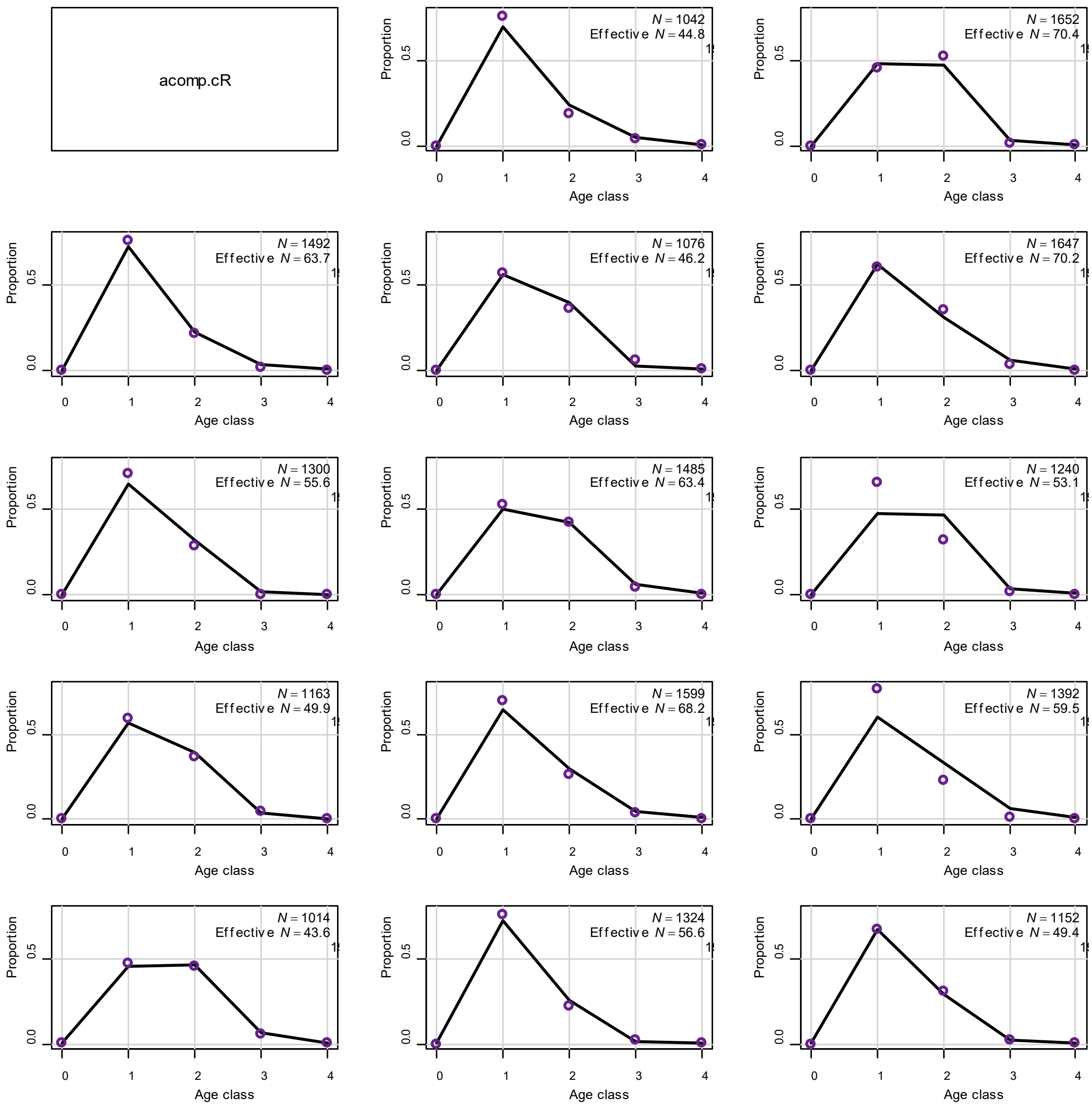

Figure 7. (Continued) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, cR to commercial reduction, and lagn to the LA gillnet survey. N indicates the number of trips from which individual fish samples were taken.

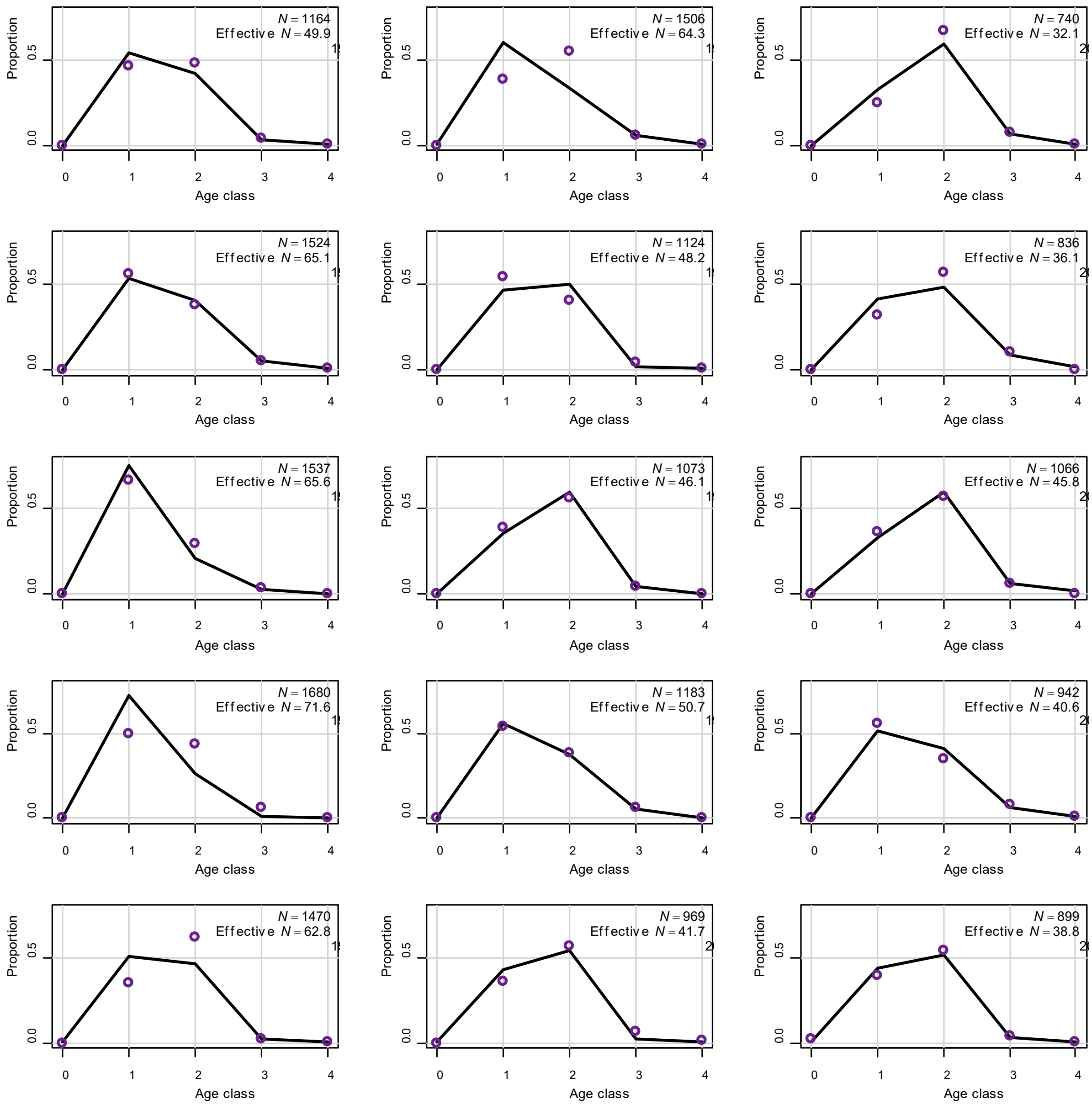

Figure 7. (Continued) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, cR to commercial reduction, and lagn to the LA gillnet survey. N indicates the number of trips from which individual fish samples were taken.

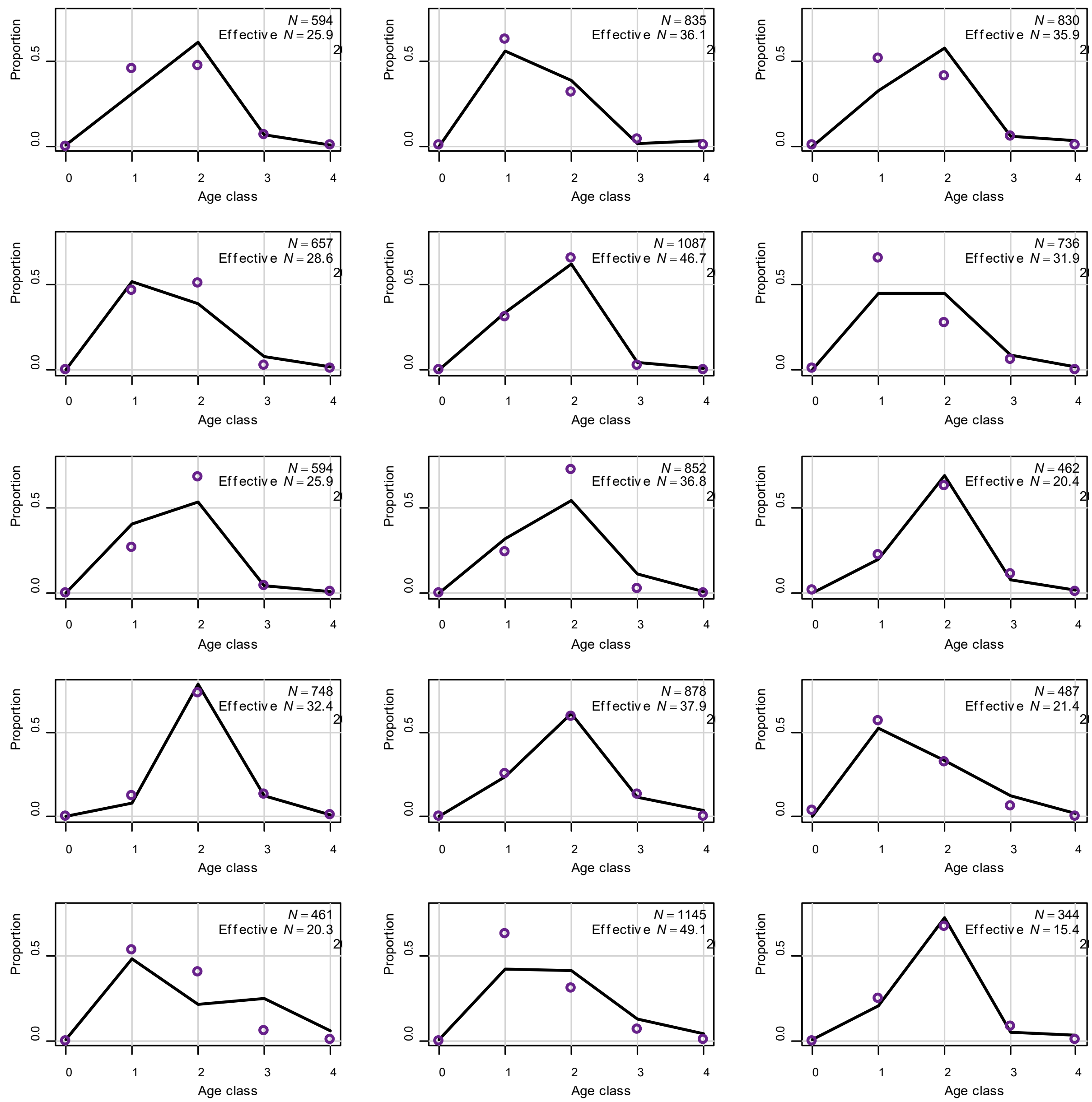

Figure 7. (Continued) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, cR to commercial reduction, and lagn to the LA gillnet survey. N indicates the number of trips from which individual fish samples were taken.

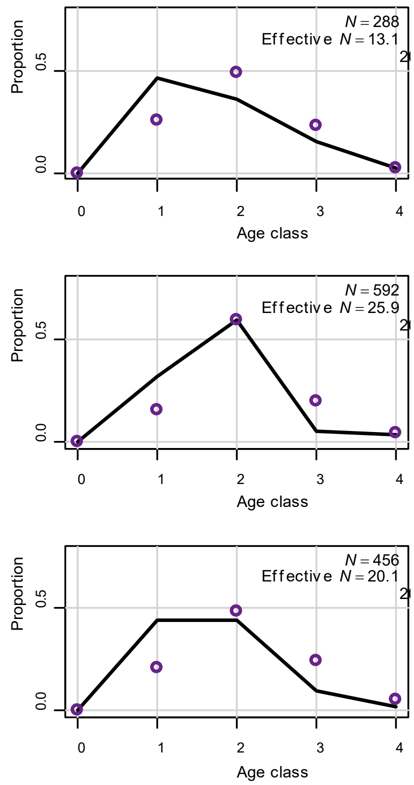

Figure 7. (Continued) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, cR to commercial reduction, and lagn to the LA gillnet survey. N indicates the number of trips from which individual fish samples were taken.

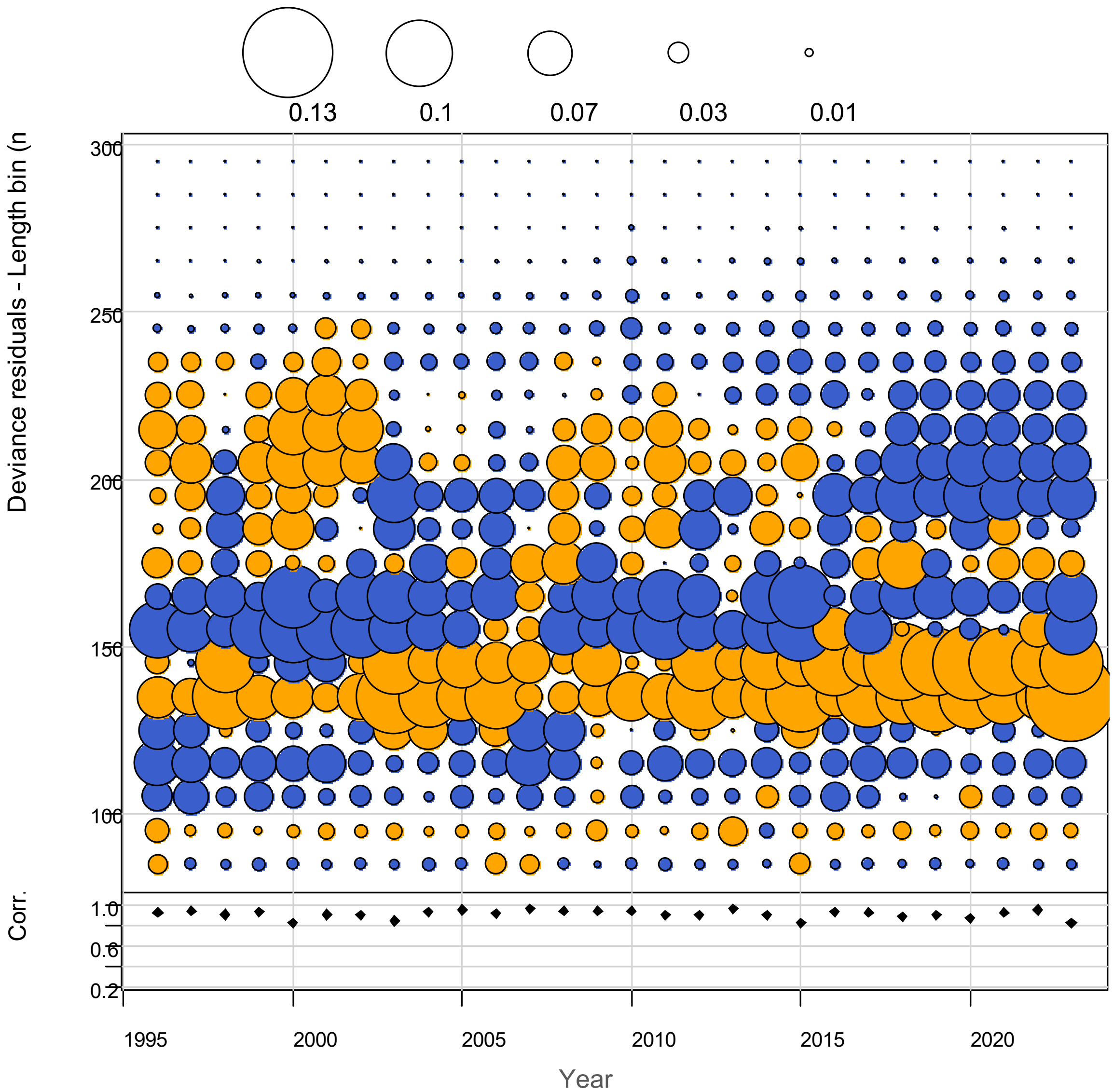

Figure 8. Bubble plot of the LA gillnet index length compositions for 1988-2023. The correlation on the bottom of the figure indicates the correlation between the observed and predicted data.

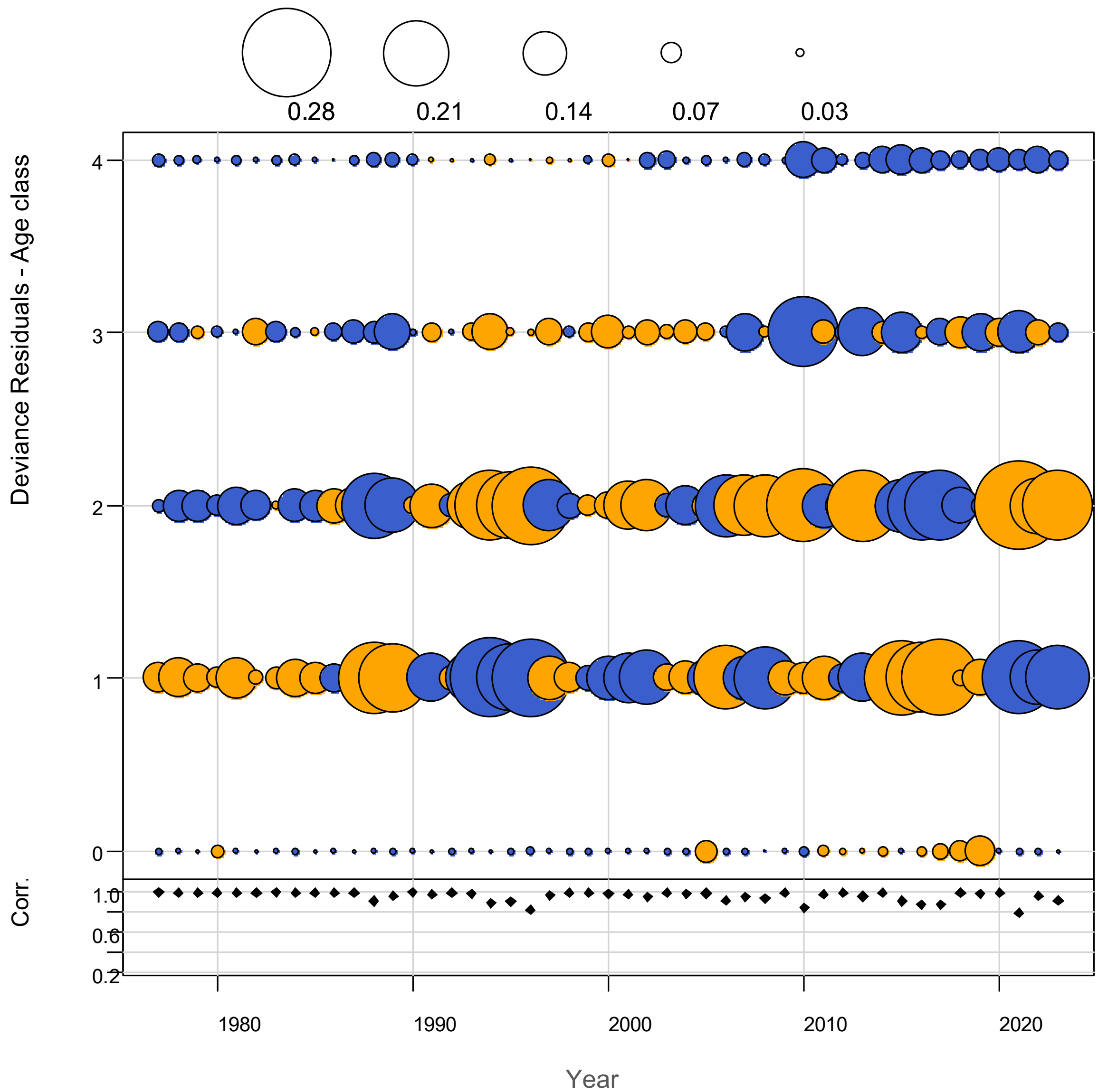

Figure 9. Bubble plot of the commercial reduction fishery age compositions for 1977-2023. The correlation on the bottom of the figure indicates the correlation between the observed and predicted data.

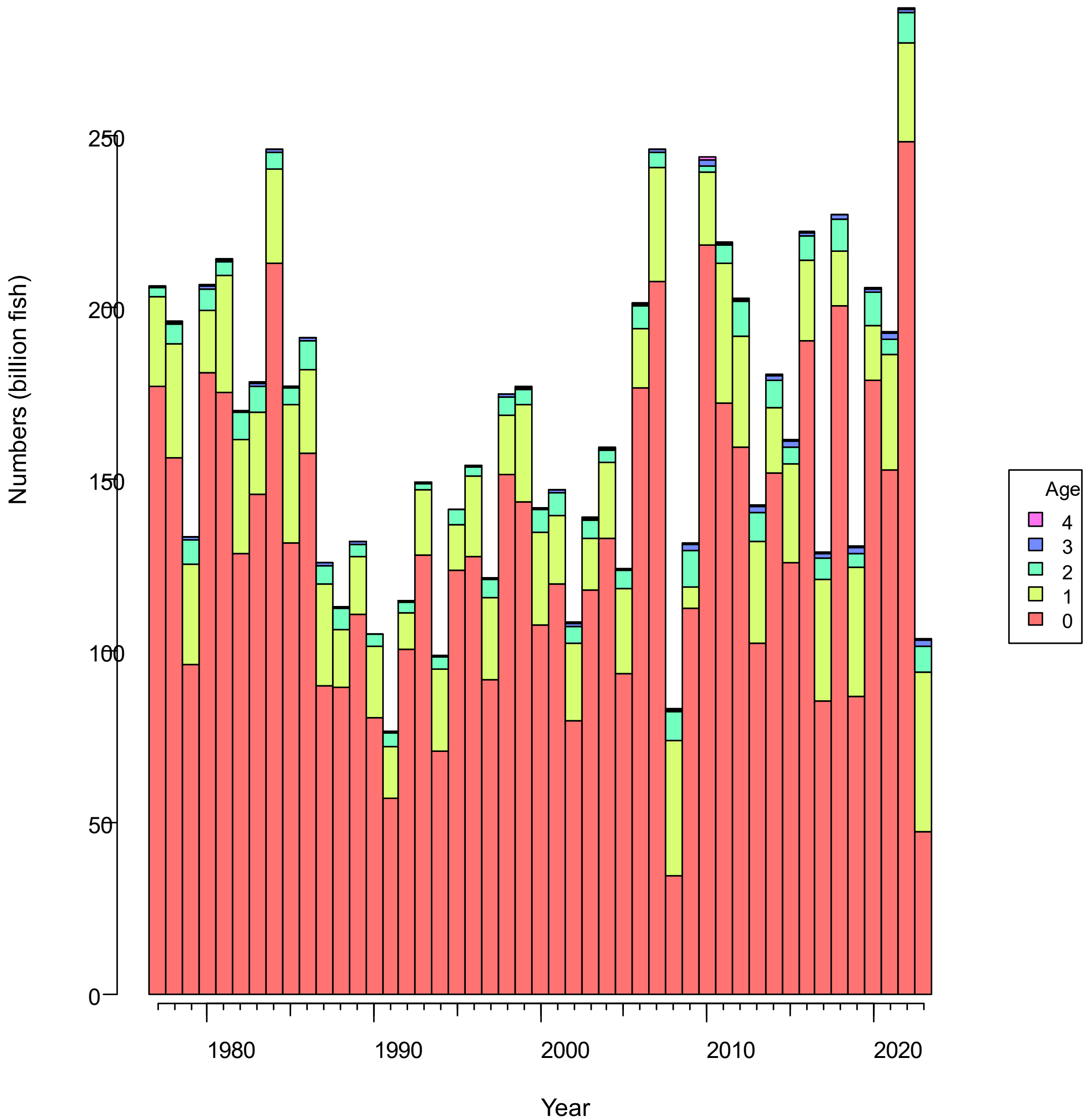

Figure 10. Estimated abundance at age at the start of the year for 1977-2023.

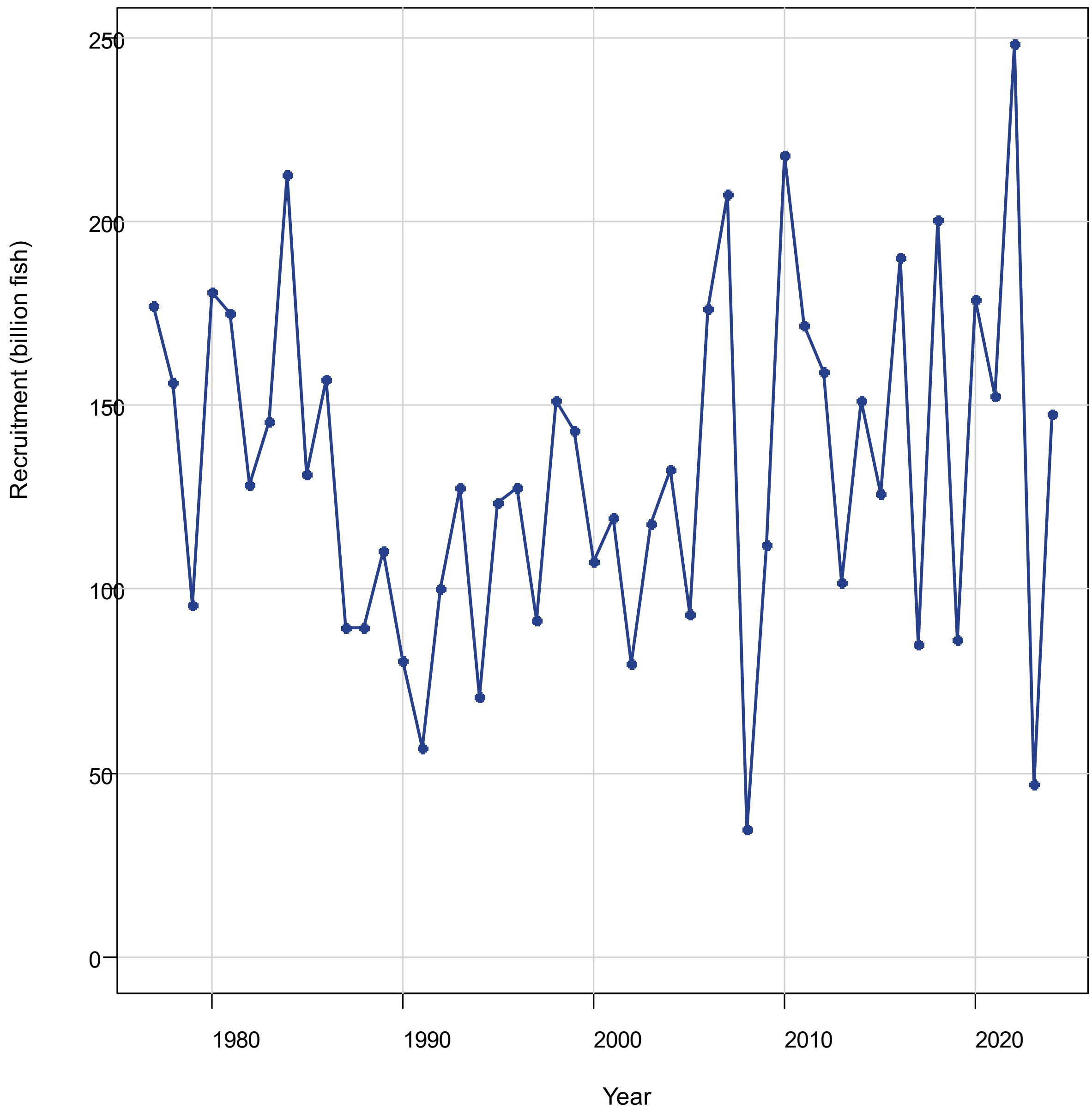

Figure 11. Estimated recruitment of Age-0 fish in billions for 1977-2023, with 2024 being a projection for the year after the terminal year of this update assessment.

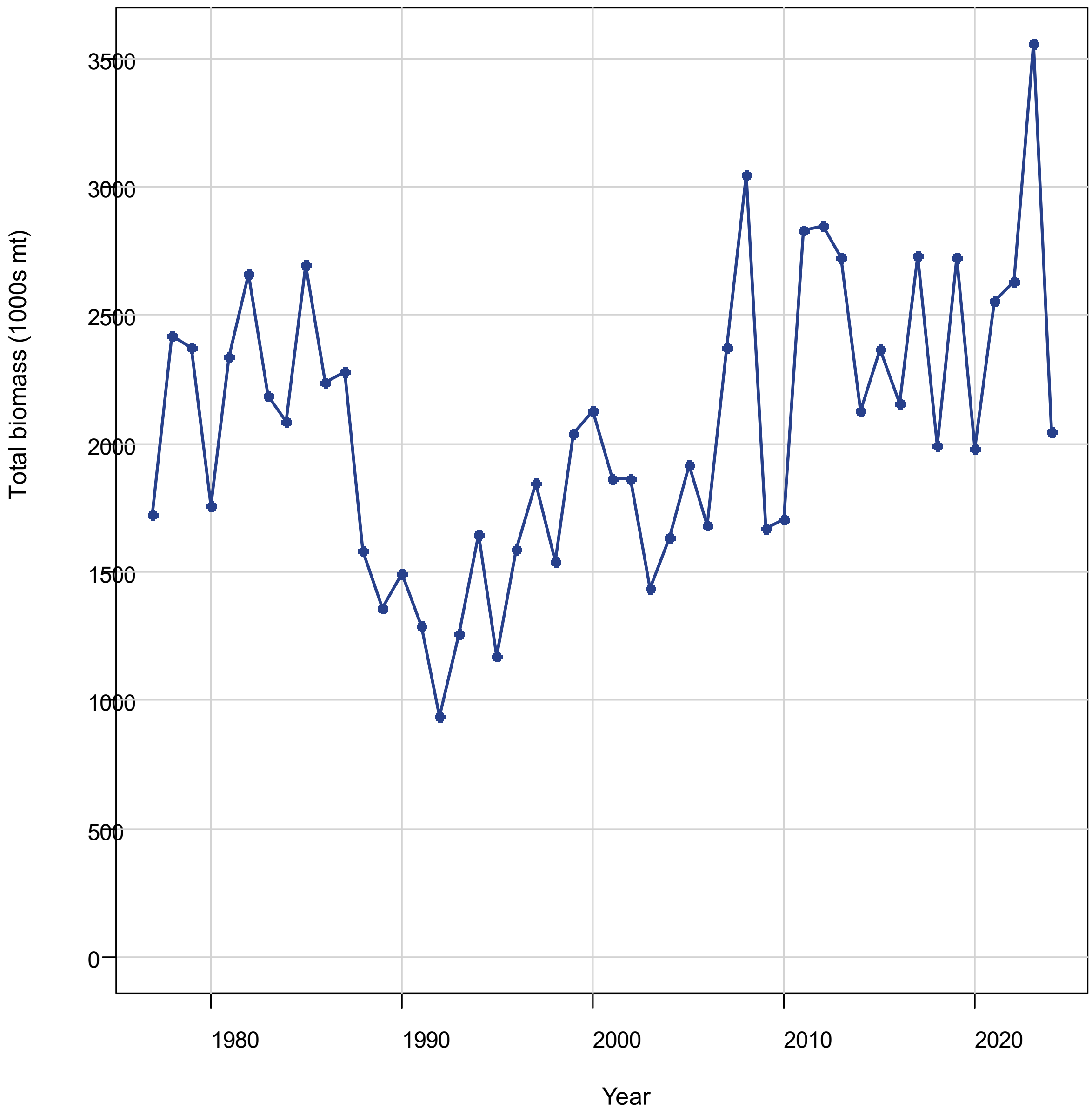

Figure 12. Estimated total Age-1+ biomass (1,000s mt) at start of year for 1977-2023, with 2024 being a projection for the year after the terminal year of this update assessment.

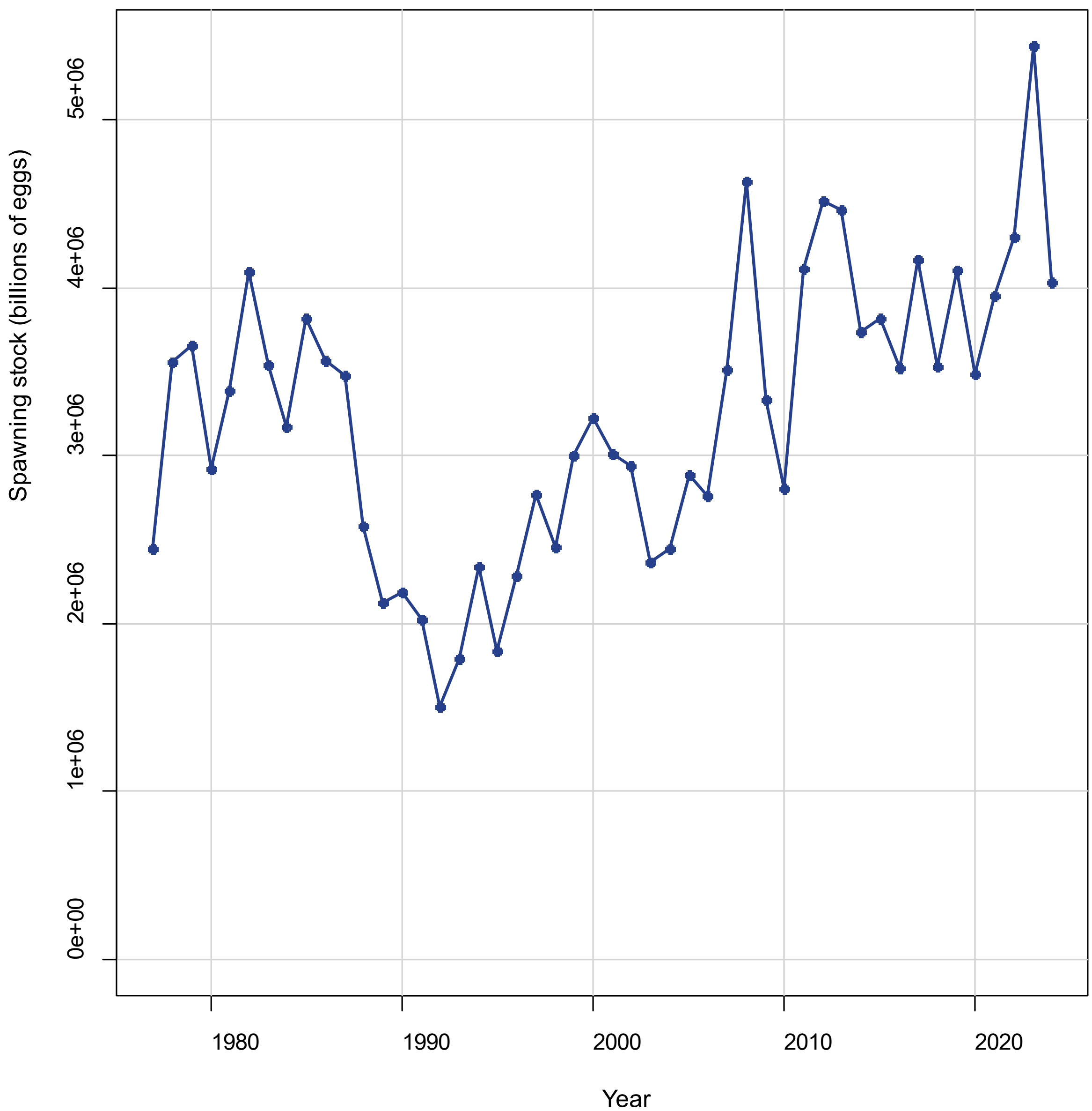

Figure 13. Estimated spawning stock biomass (fecundity in billions of eggs) at time of peak spawning for 1977-2023, with 2024 being a projection for the year after the terminal year of this update assessment.

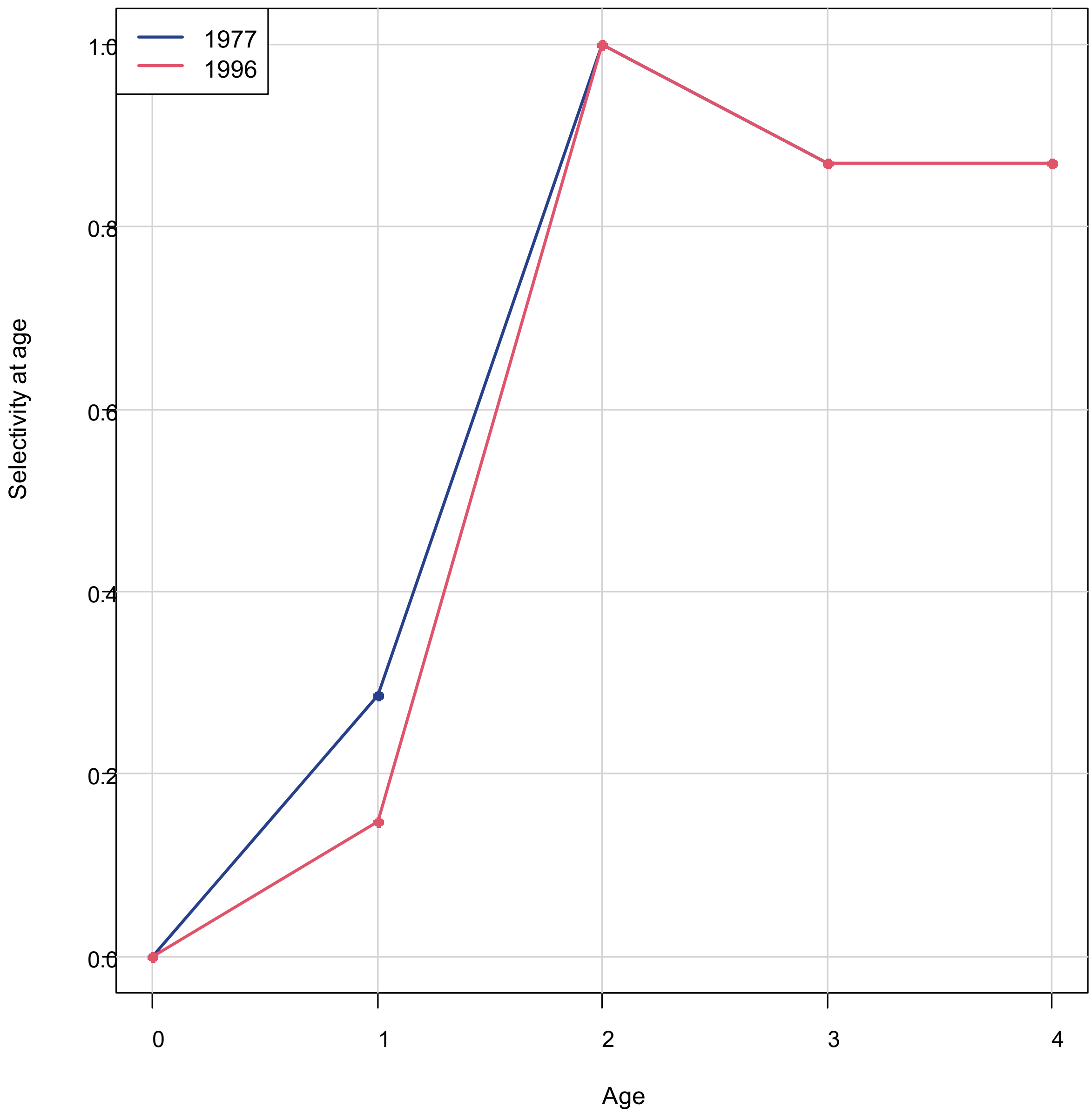

Figure 14. Selectivity of the commercial reduction fleet for 1977-2023 with the blue line being for 1977-1995 and the red line being for 1996-2023.

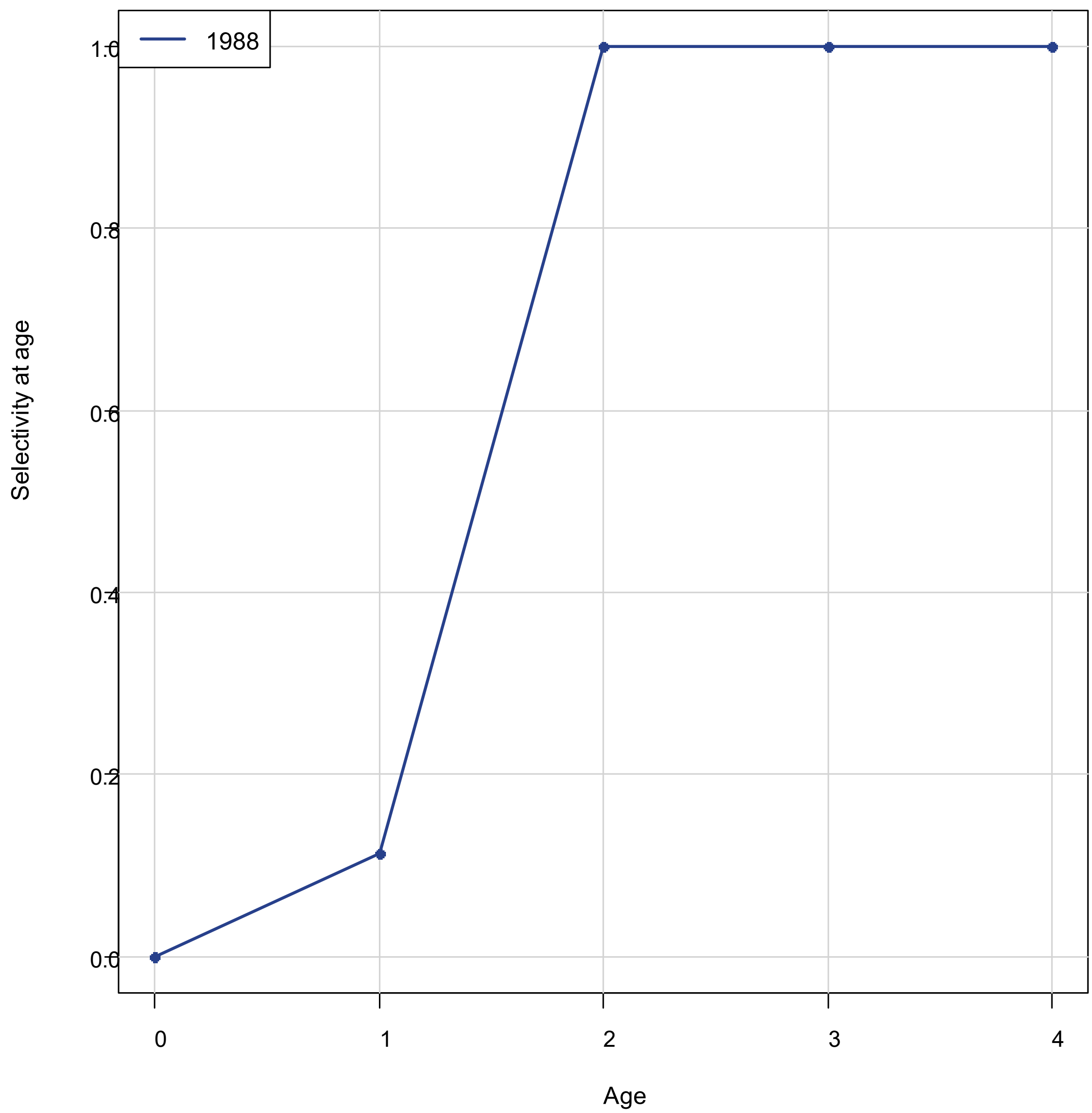

Figure 15. Selectivity of the LA gillnet survey, 1988-2023.

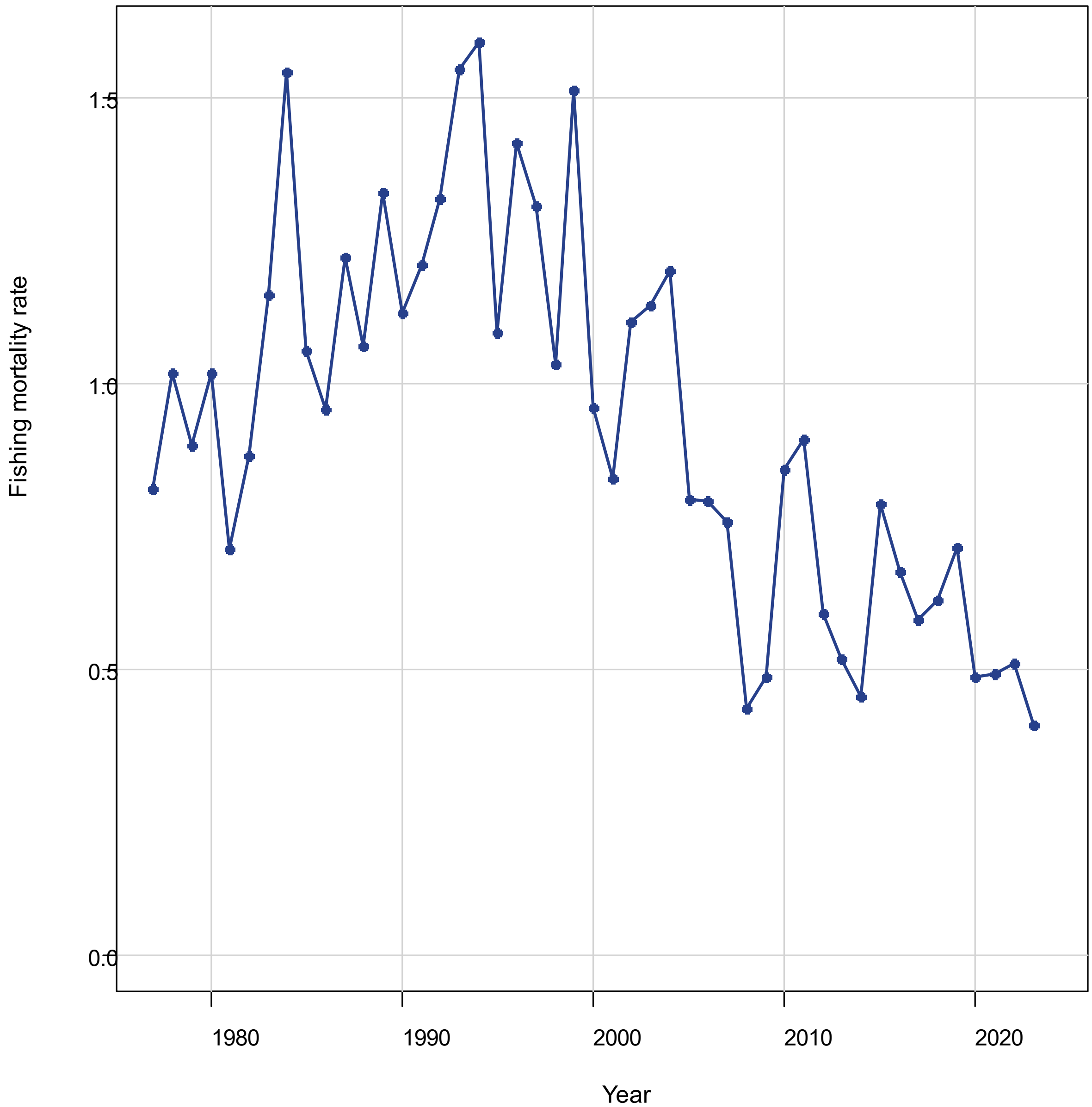

Figure 16. Estimated fully selected fishing mortality rate (per year) for the commercial reduction fishery.

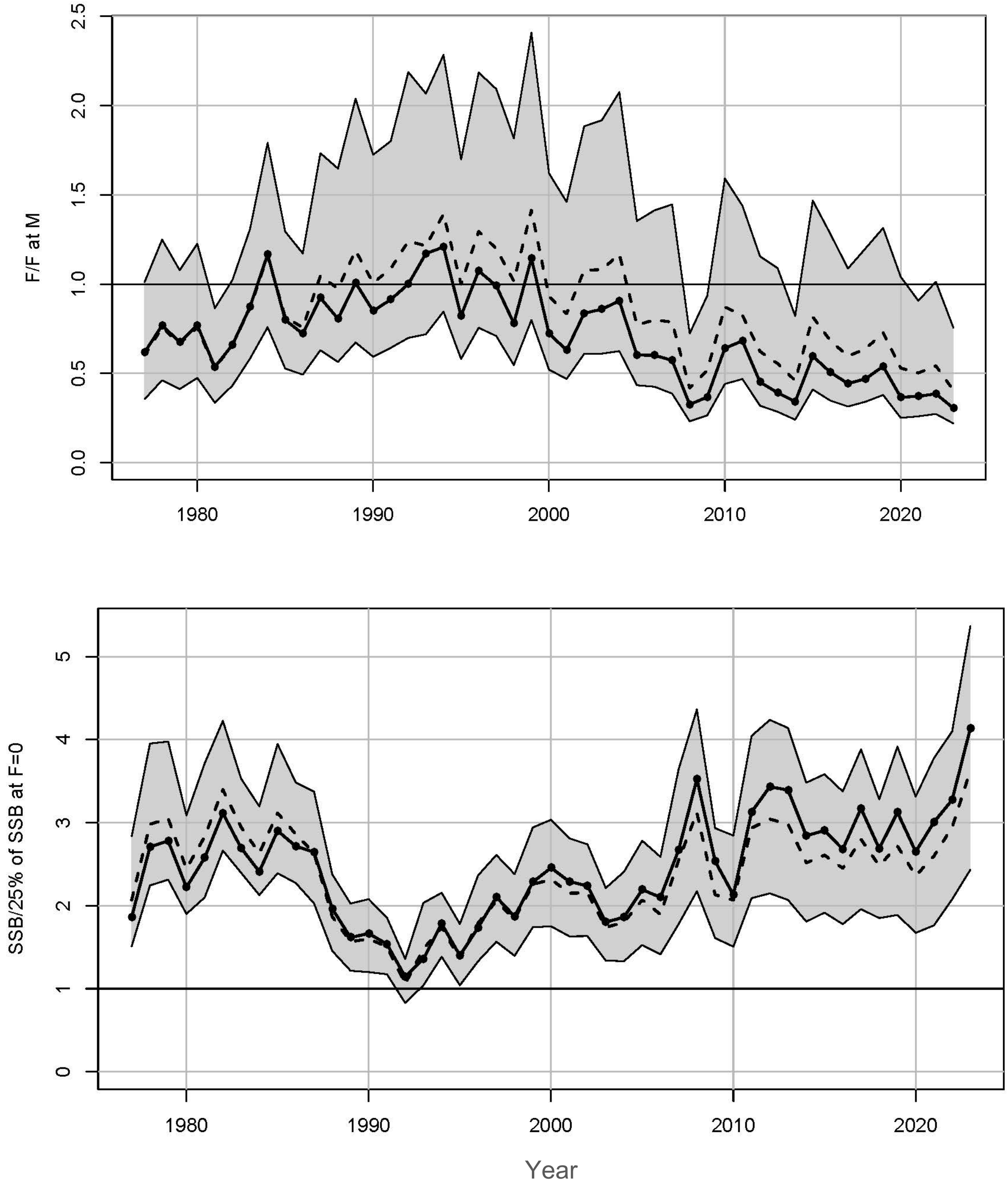

Figure 17. Estimated time series relative to threshold benchmarks. Solid line indicates estimates from base run of the Beaufort Assessment Model (BAM); gray error bands indicate 5th and 95th percentiles of the MCBE runs; dashed line indicates 50th percentile from the MCBE runs. Top panel: F relative to $F_{F=M}$. Bottom panel: spawning stock biomass, measured as fecundity, relative to $SSB_{25\%\ at\ F=0}$.

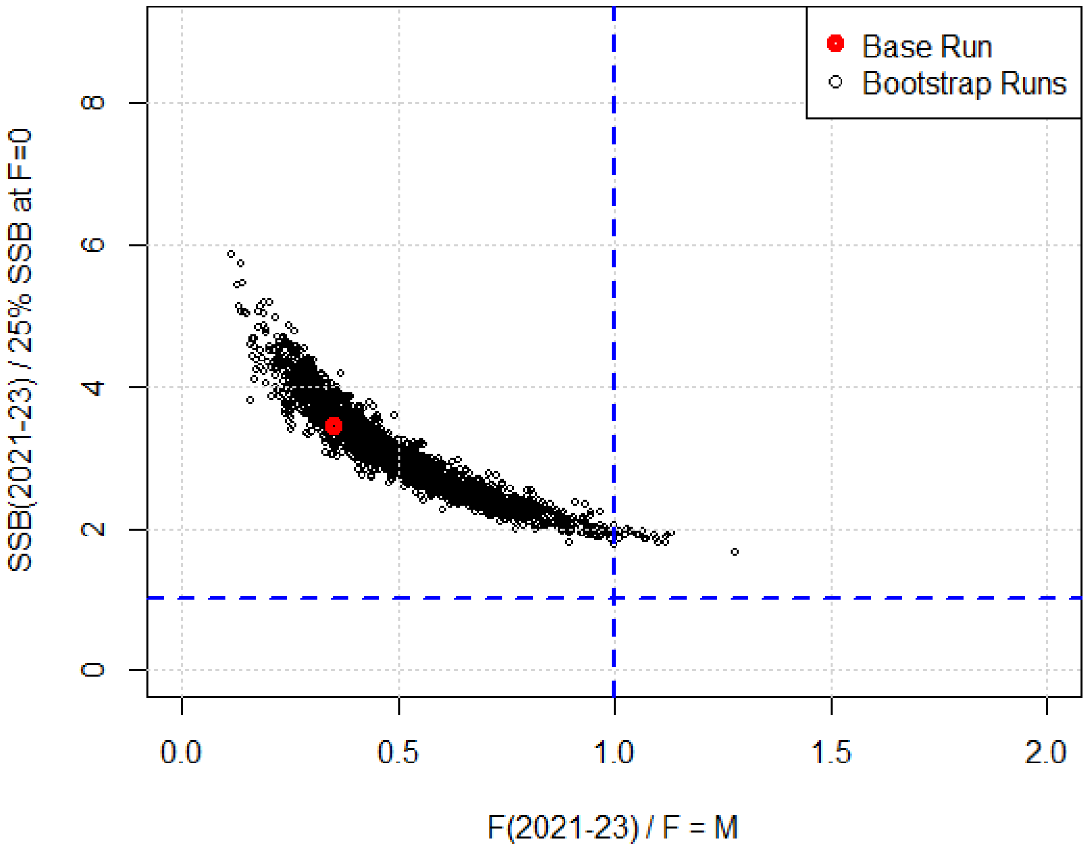

Figure 18. Phase plot of the geometric mean 2021-2023 terminal status estimates from the MCBE analysis of the Beaufort Assessment Model (BAM). The red point indicates estimates from the base run; the black points are individual MCBE runs.

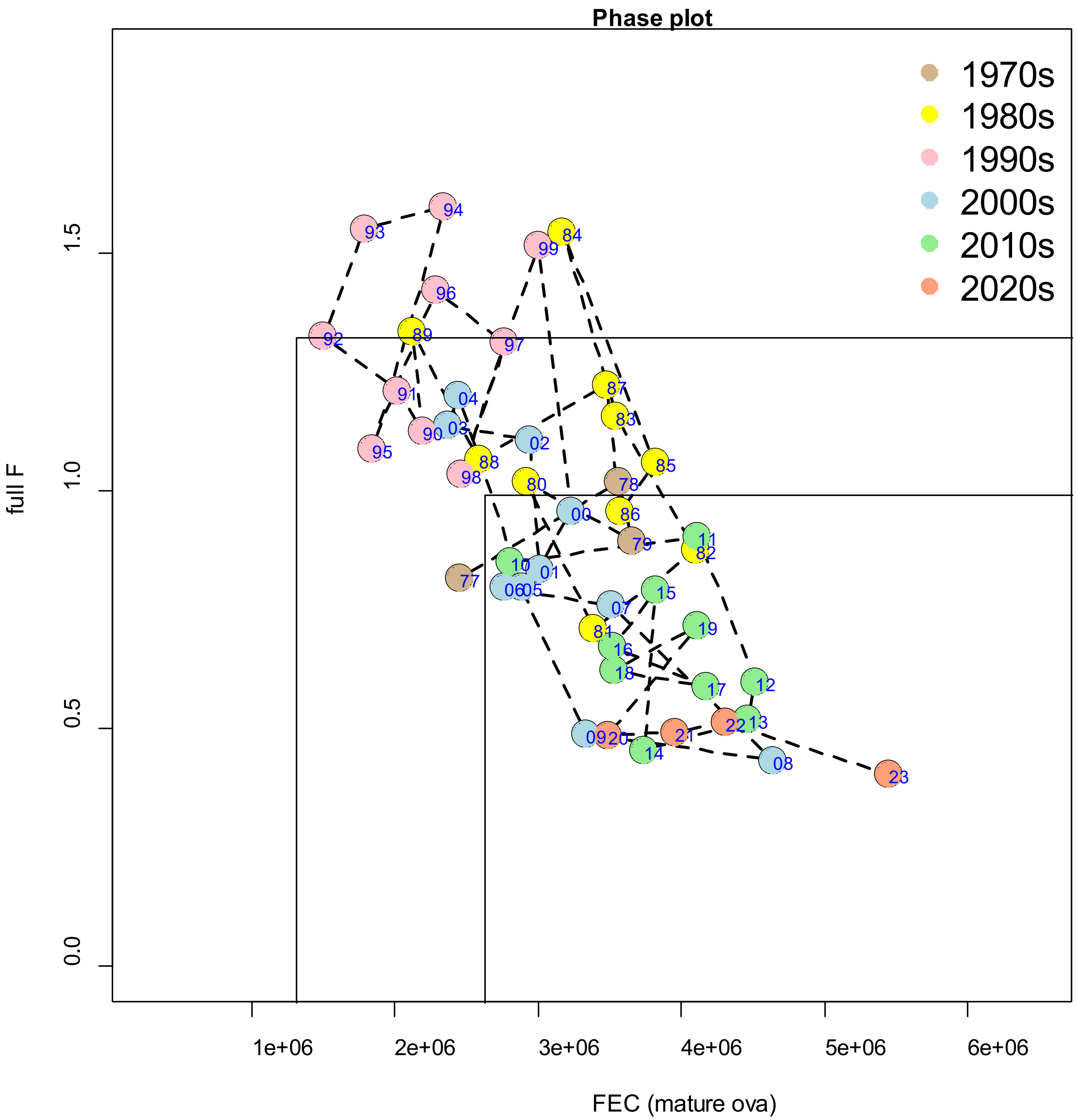

Figure 19. Phase plot of annual estimates of fishing mortality (F) and spawning stock biomass (SSB) or fecundity from the base Beaufort Assessment Model (BAM). Vertical and horizontal lines indicate the reference point thresholds and targets. Each decade has a different color circle.

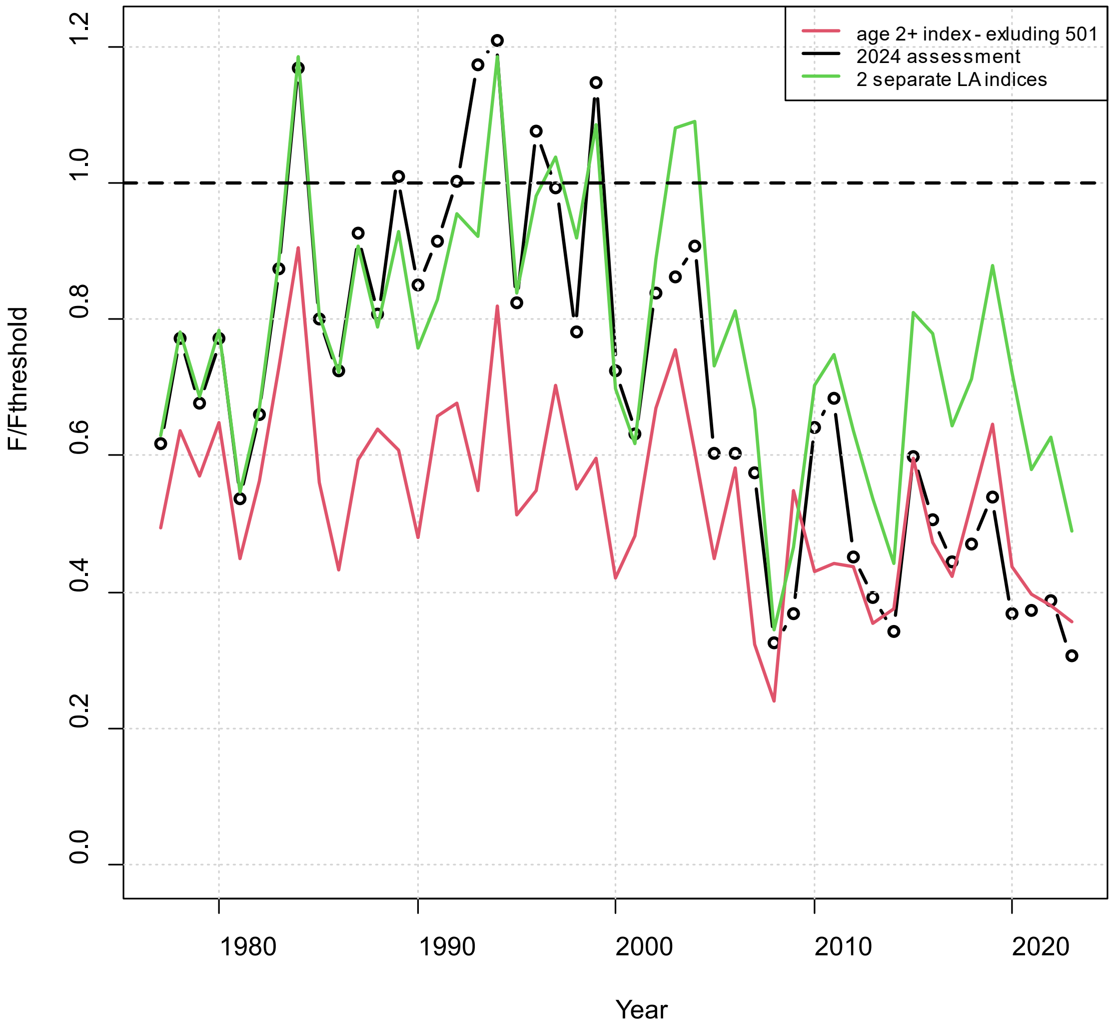

Figure 20. Time series of $F/F_{F=M}$ for the sensitivity runs with the solid black line with open circles being the base run.

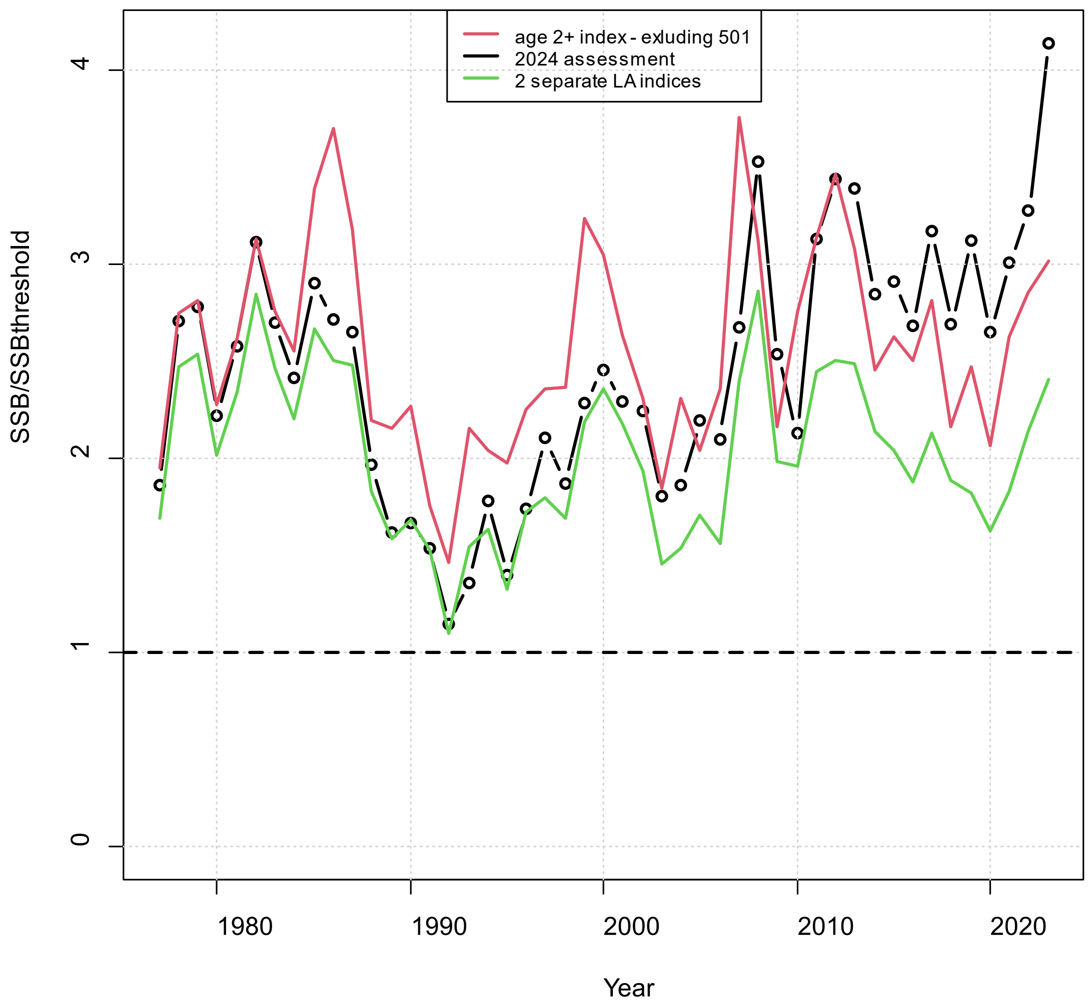

Figure 21. Time series of $SSB/SSB_{25\%\ at\ F=0}$ for sensitivity runs. The solid black line with open circles is the base run.

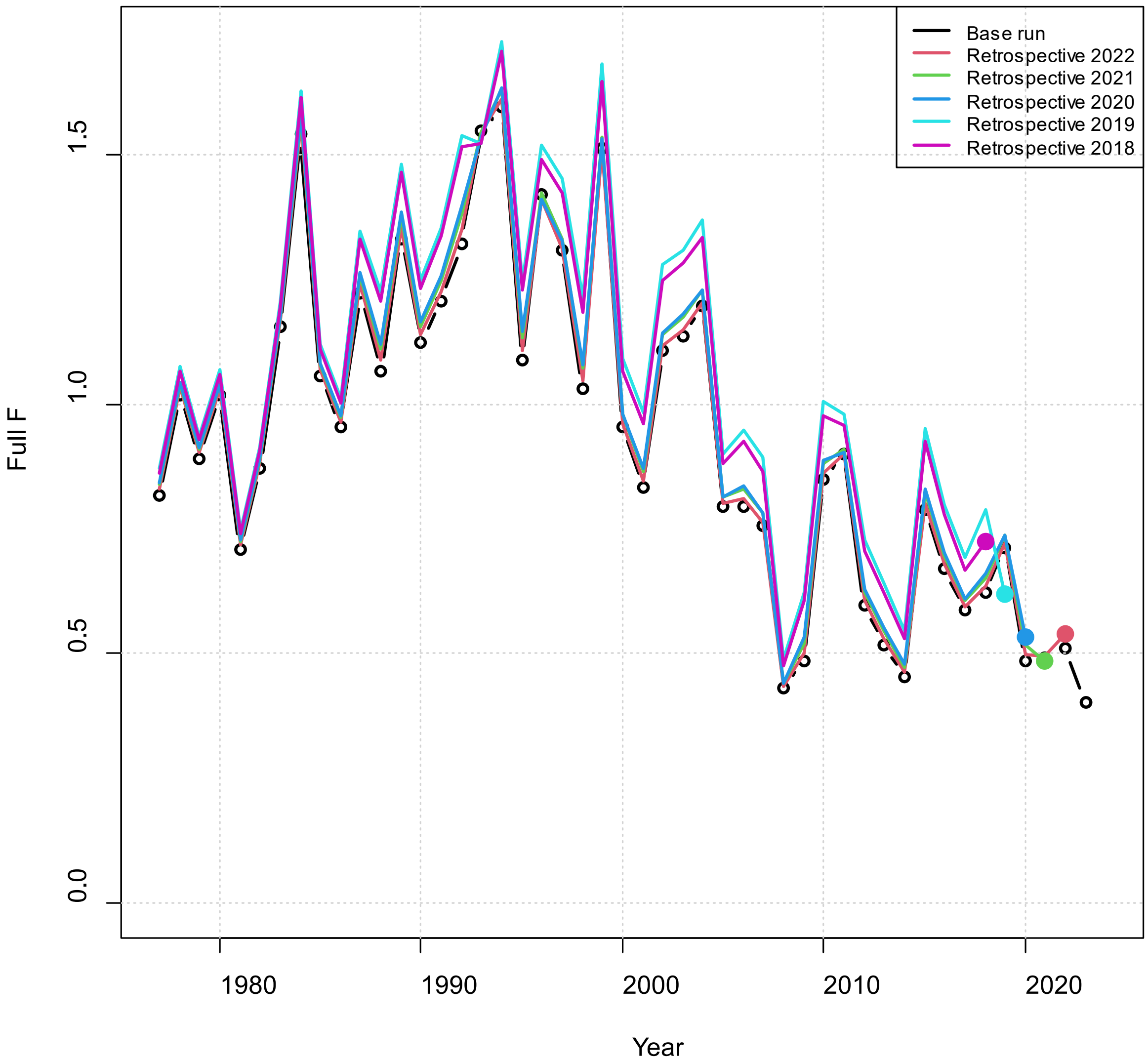

Figure 22. Retrospective analyses. Sensitivity to terminal year of data on the estimation of fishing mortality rate.

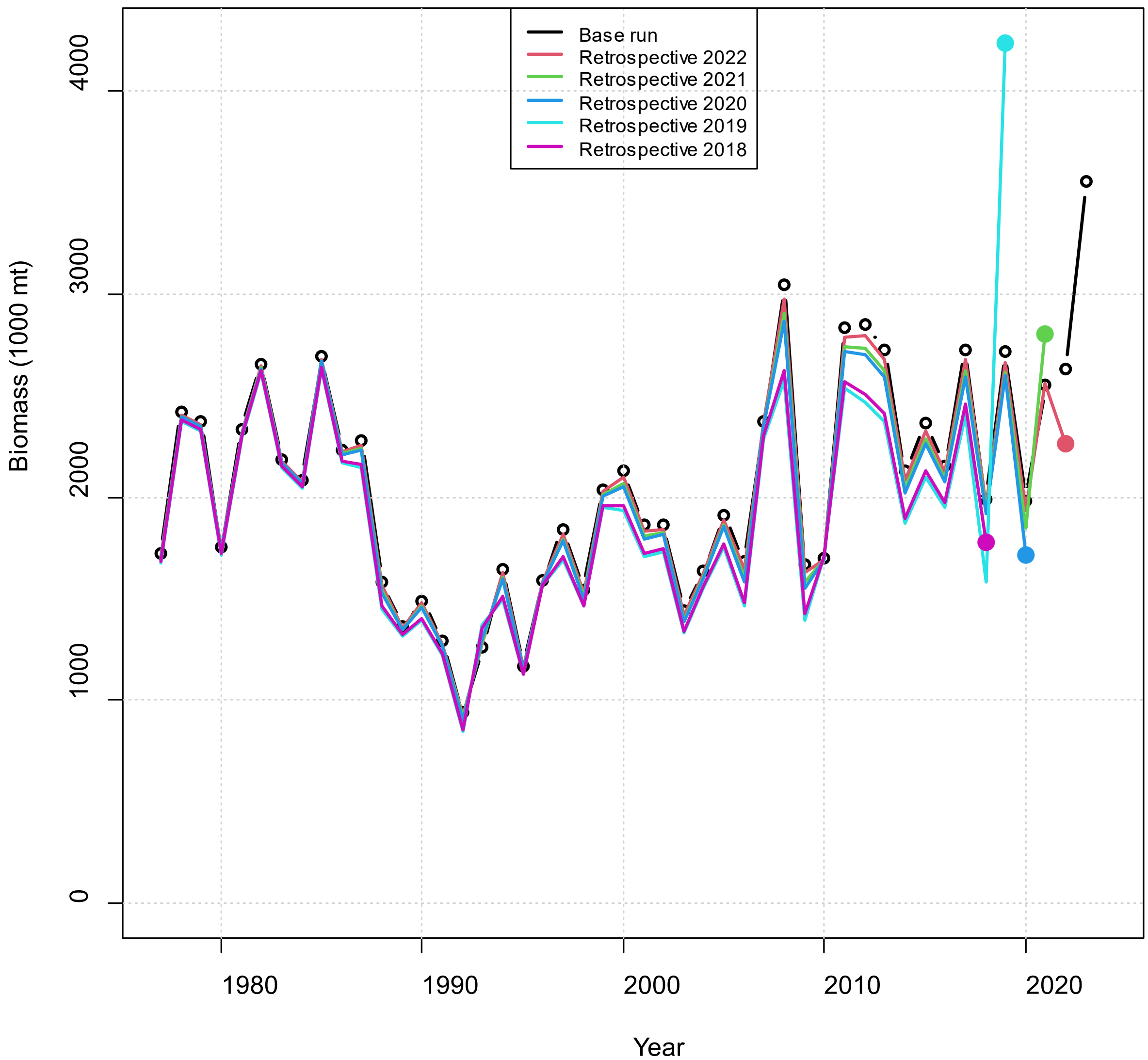

Figure 23. Retrospective analyses. Sensitivity to terminal year of data on the estimation of biomass.

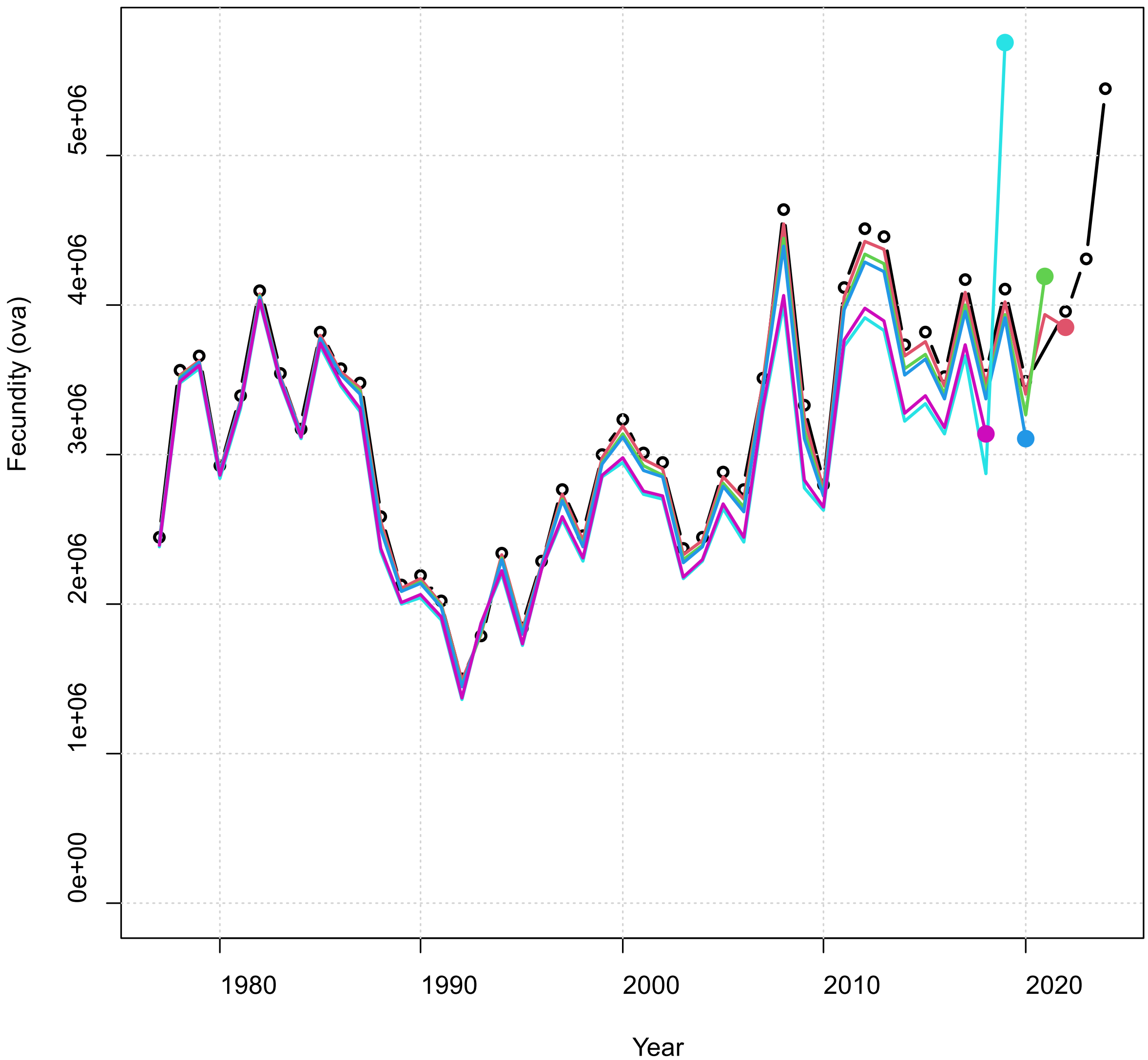

Figure 24. Retrospective analyses. Sensitivity to terminal year of data on the estimation of fecundity.

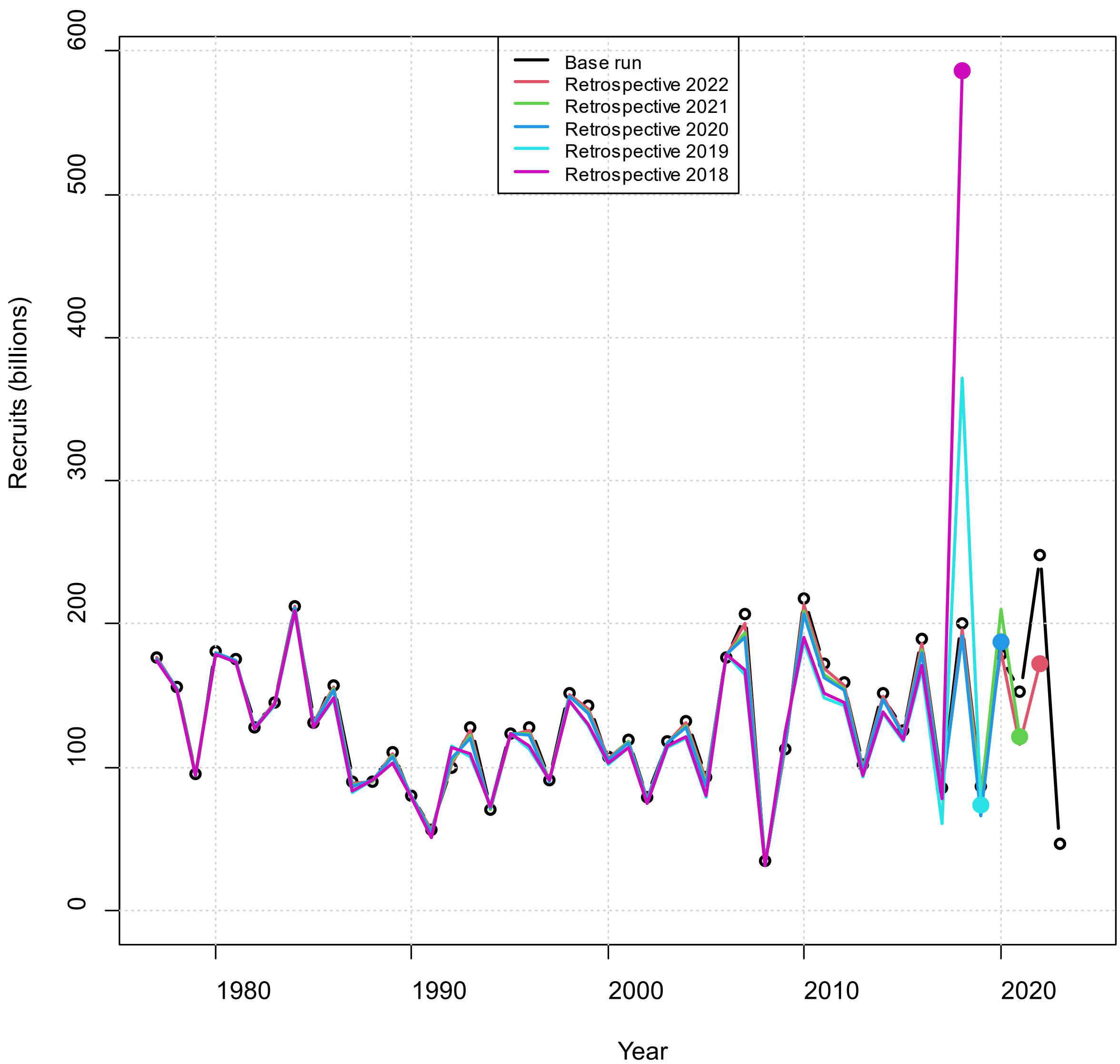

Figure 25. Retrospective analyses. Sensitivity to terminal year of data on the estimation of recruitment.

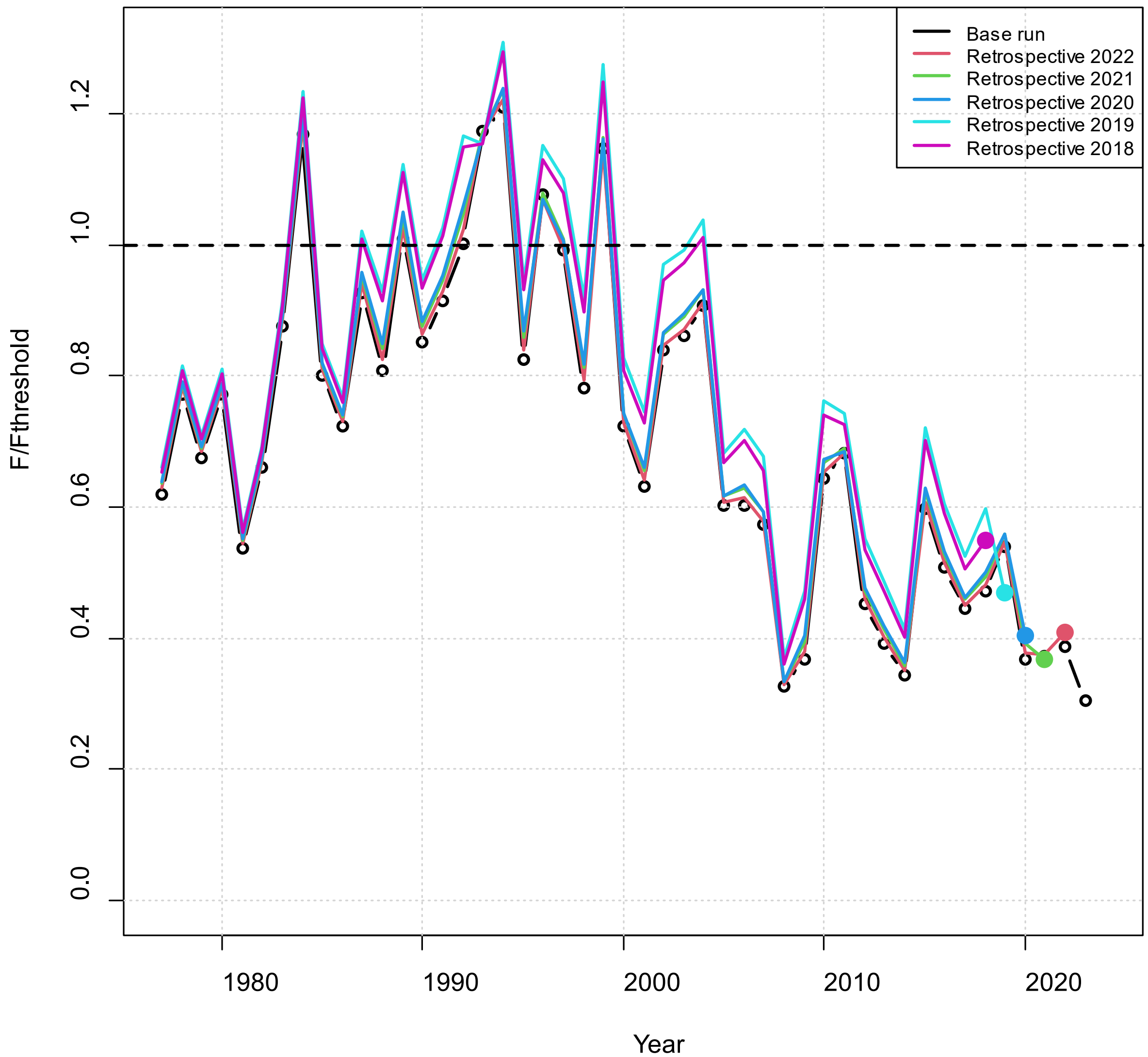

Figure 26. Retrospective analyses. Sensitivity to terminal year of data on the estimation of $F/F_{F=M}$.

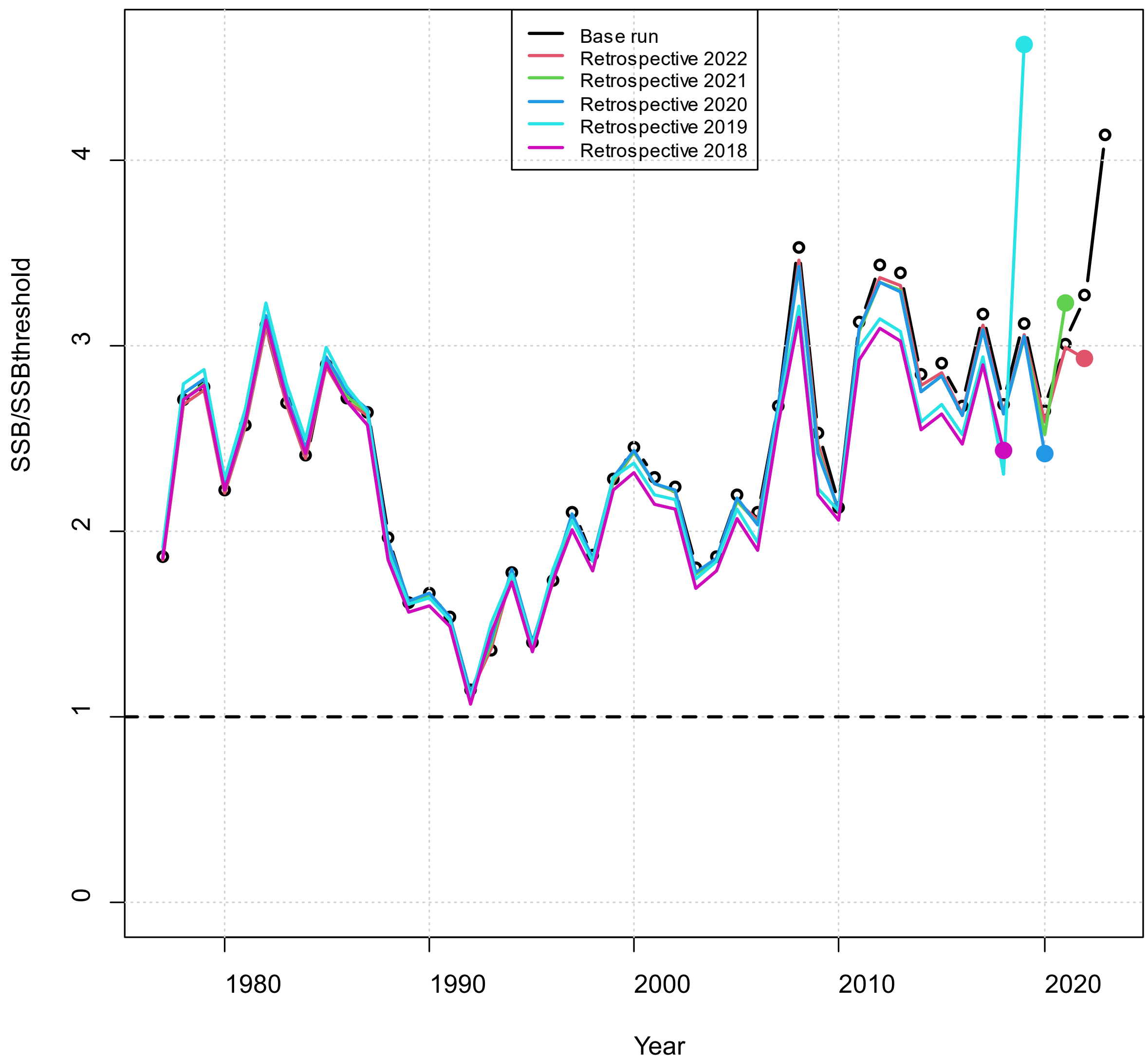

Figure 27. Retrospective analyses. Sensitivity to terminal year of data on the estimation of $SSB/SSB_{25\%\ at\ F=0}$.

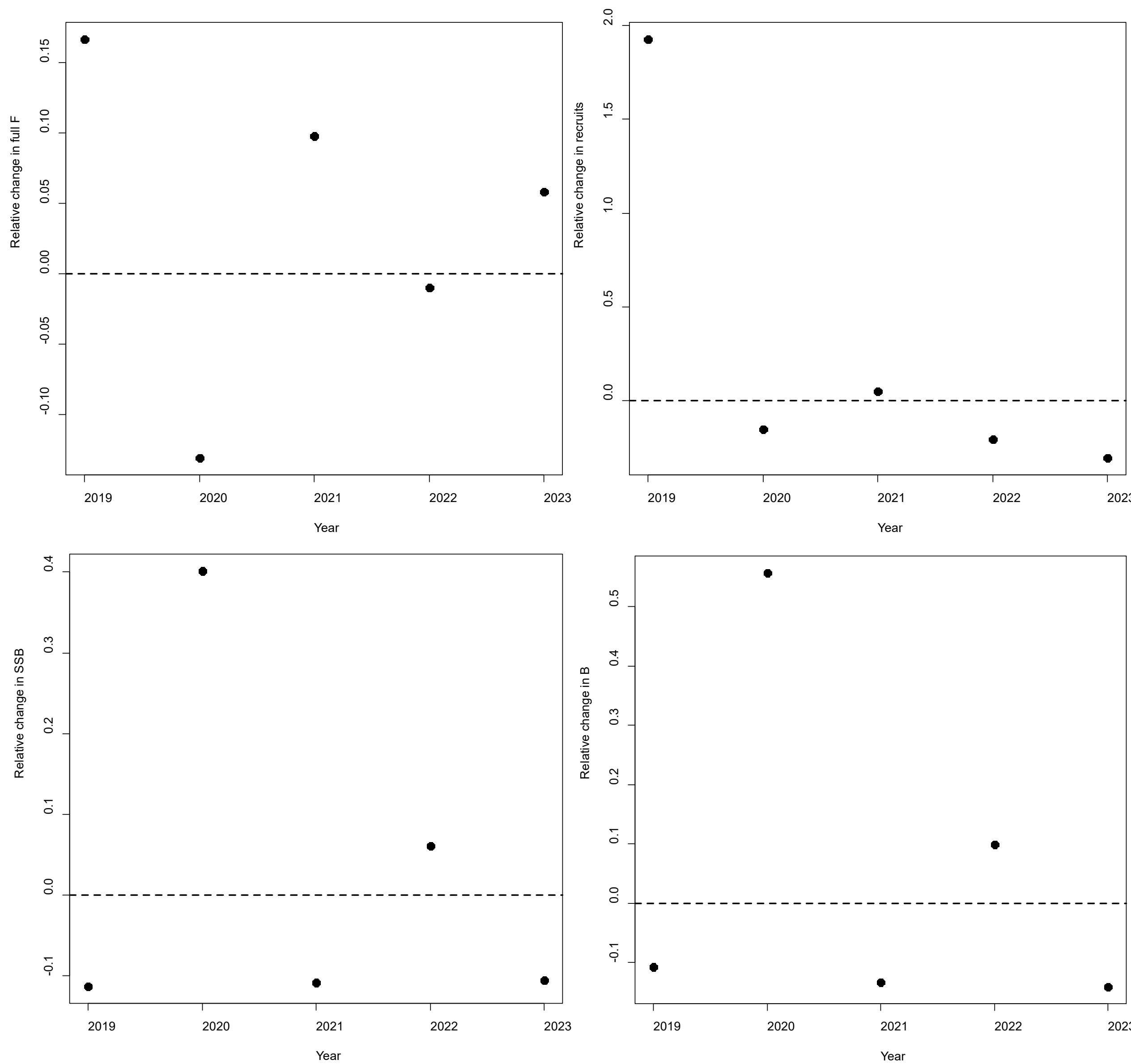

Figure 28. Relative change in fishing mortality, recruitment, spawning stock biomass, and biomass for the retrospective analyses.

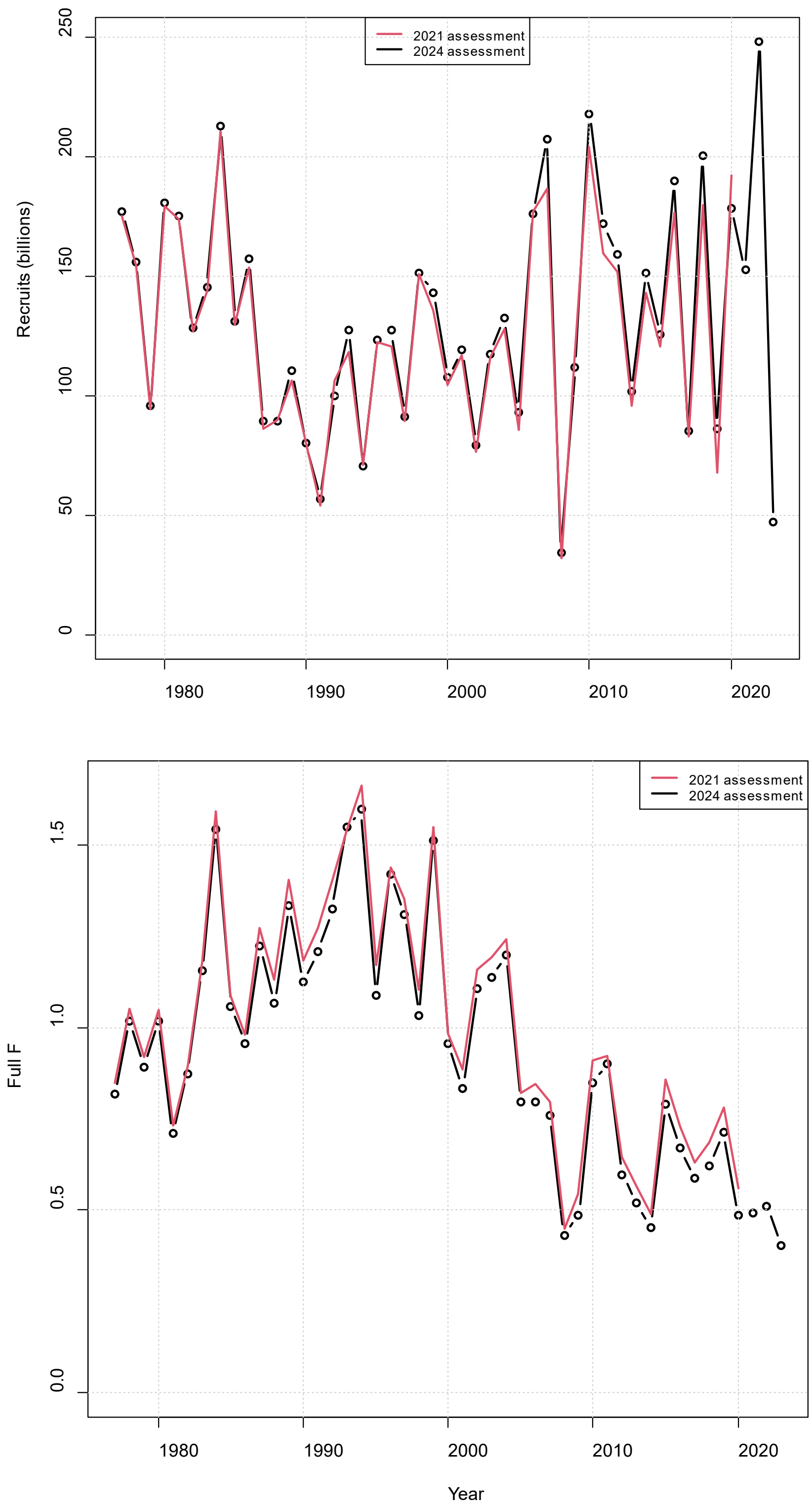

Figure 29. Comparisons of fishing mortality rate and recruitment from this update assessment and the 2021 update assessment.

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