G D A R

GULF DATA, ASSESSMENT, AND REVIEW

GDAR 03
Gulf Menhaden Stock Assessment

2021 Update

October 2021

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Gulf Menhaden Stock Assessment

2021 Update

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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). The assessment was updated with recent data from 2018-2020. 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 1977-2020. 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 2018-2020 spawning stock biomass (measured as fecundity) and the geometric mean 2018-2020 fishing mortality rate against the respective threshold benchmarks of $SSB_{25\%}$ when 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 MCBs generally support the stock status as indicated by the base run.

The stock status for the updated assessment remained the same as the stock status from the benchmark assessment completed during SEDAR 63. The update assessment has the same trend and magnitude as the benchmark assessment.

The Menhaden Advisory Committee (MAC) recommends that the next operational assessment occur in three years (2024), however, if significant new data are available, then a research track assessment could be considered.

3.0 Data Review and Updates

In the SEDAR 63 benchmark, the assessment period was 1977-2017. In this update, the terminal year was extended to 2020; making the assessment period 1977-2020. 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 from the previous benchmark in that NOAA has revised the historic estimates applying two calibrations starting in 2017. The data from 1981 forward were transformed in support of the modified APAIS and new FES, or BASE series.

In this update assessment, the Beaufort Assessment Model (BAM) was fitted to the same data sources as in SEDAR 63 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 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, 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*.

Additional estimates of *M* were derived using the predator-prey interactions modeled in the Ecopath with Ecosim framework (EwE). Two models currently exist, which could be applied to Gulf Menhaden: (1) a U.S. Gulf-wide EwE and (2) a northern Gulf of Mexico (NGOMEX) EwE with Ecospace. Ecosystem based estimates of *M* were deemed not ready for inclusion in SEDAR 63 but are included in this update as sensitivities for the purpose of exploring their potential for use in the future.

The U.S. Gulf-wide EwE model was developed to evaluate potential effects of harvest policies (i.e., both directed and indirect fishing pressures) on marine resources throughout the northern GoM continental shelf and coastline, thus matching the spatial boundaries of management for many economically important finfishes (Berenshtein et al. 2001). A total of 78 functional groups are modeled including marine mammals, seabirds, sea turtles, elasmobranchs, fishes, invertebrates, primary producers, and detritus. Menhaden are key forage fish and are modeled in five age stanzas: 0, 1, 2, 3, and 4+ years old.

The diet matrix is based on an extensive meta-analysis, which relied heavily on Gulf-specific studies, but also incorporated diet studies from outside the region (e.g., Atlantic) as needed (e.g., for larger predators; Sagarese et al. 2016). In the model, 32 functional groups prey on different age classes of menhaden, with top predators including red drum, sea trout, seabirds, inshore coastal piscivores, and mackerels. While the model includes nutrient forcing derived from Mississippi-Atchafalaya River nutrient input, no other environmental drivers (either temporally or spatially) are included in the model.

The NGOMEX model is a very useful tool for describing menhaden dynamics related to predators and their environment because its spatial domain of coastal Louisiana corresponds with Gulf Menhaden's spatial distribution (de Mutsert et al. 2016, 2017). In NGOMEX, menhaden are included as four age stanzas: 0, 1, 2, and 3+ years old. A total of 66 functional groups are modeled including detritus, benthic invertebrates, crustaceans, fishes, mammals, and birds, with diet composition taken directly from Louisiana surveys. Of those, 33 species/functional groups prey on menhaden, with the top consumers including marine mammals, snappers, Spanish mackerel, king mackerel, tunas, birds, lizardfish, seatrout, and Atlantic croaker. Importantly, the NGOMEX model includes species-environmental response functions (e.g., temperature, dissolved oxygen, and salinity) and coupling with a hydro-physical model to drive monthly environmental dynamics, which allows for consideration of environmental impacts on both Gulf Menhaden and their predators.

3.2 Landings

Estimates of landings were updated with 2018-2020 data using the methods outlined in SEDAR 63 (Table 2). Commercial reduction landings and recreational landings were strictly updated using the same methods as during the benchmark assessment. However, as noted above, the recreational landings were updated for the entire time series as the MRIP survey has been recalibrated in support of the modified APAIS and new FES, or BASE series (Figure 1). Commercial bait landings were also updated with 2018-2020 data, which included NOAA gear codes 100 and 125 from the Accumulated Landings System (ALS) database and the GSMFC trip ticket data.

3.3 Indices of abundance

Both the juvenile abundance index based on seine surveys from LA, AL, and MS, and the adult abundance index based on a gillnet survey from LA were updated with data from 2018-2020 (Figures 2 and 3; Table 3). Each index was standardized using the methods from the benchmark assessment. The seine index (recruitment) spans from January through June beginning in 1996, while the 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 2020 using the same methods as used in the SEDAR 63 benchmark assessment (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 2018 to 2020 using the same methods as in the last benchmark assessment (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 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 (ADMB Foundation 2011).

4.1.2 Data Sources

The catch-age model included data from two sets of fishery-independent surveys and one fleet, which consisted primarily of the commercial reduction landings but also included small proportions of commercial bait landings 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 (seine juvenile abundance index and gillnet adult abundance index), and annual length compositions of the gillnet 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. 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, 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 the von Bertalanffy growth equation. Weight at age was fixed and an 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) 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 – 2020 and an index of abundance for recruitment during 1996-2020. Autocorrelation in recruitment deviations was assumed to be zero.

Landings: The model included a time series of landings that was a combination of landings from the commercial reduction purse seine fleet, commercial bait landings, and recreational landings for 1977-2020. 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 1997-2020), 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 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: a seine index (1996-2020) and a gillnet index (1988-2020). The seine index was considered to represent relative changes in recruitment over time, and the 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 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 gill net index, and the patterns of the abundance indices (both seine and gill net indices) were fit based on the assumed statistical error distribution and the level of assumed or measured error (see SEDAR 63 benchmark assessment).

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.

4.1.4 Biological Reference Points

As in SEDAR 63, 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

Four sets of sensitivity runs were completed in order to explore new or different data inputs and determine if a retrospective pattern exists.

First, sensitivity runs were completed with different input data informing selectivity for the gillnet index. Specifically, age composisiton data from the LA gillnet survey from 2016 and 2017 were included as input data, while the length composition data were excluded. Two sensitivity runs were completed: 1) where 2016 and 2017 data were included on an annual basis and 2) where 2016 and 2017 age data were pooled to provide one vector of age compositions.

Second, sensitivity runs were completed considering different input data for natural mortality. Specifically, two sensitivity runs including age and time varying *M* based on EwE models were completed. The first sensitivity run included *M* inputs from the Gulf-wide EwE model (Berenshtein et al. 2021), while the second sensitivity run included *M* inputs from the Northern Gulf of Mexico (NGOMEX) EwE model (de Mutsert et al. 2016, 2017). Each of the time and age varying *M* matrices from the EwE models covered a different range of ages and time periods. The Gulf-wide EwE provided *M* estimates for 1980-2016 and ages 0 to 4, while the NGOMEX EwE provided *M* estimates for 2000-2017 and ages 0 to 3. In order to input a full time series of *M* across all of the ages, the *M* matrices needed to be complete. Filling in the missing years and ages was done by averaging across nearby years or ages. Specifically, for the Gulf-wide matrix, the years 1977-1979 were filled in with the average of 1980-1982 and the years 2017-2020 were filled in with the average of 2014-2016. For the NGOMEX matrix, the years 1977-1999 were filled in with the average of 2000-2002, the years 2018-2020 were filled in with the average of 2015-2017, and age-4 was filled in with the age-3 value for each year. To maintain the scale of *M* the same as the base run and for reference point calculations, the *M* matrices were scaled such that the mean values at age over time were the same as the values from the base run by age. Scaling allowed for exploration of the annual deviations in *M*.

Third, sensitivity runs were completed to consider the impact of COVID-19 on the sampling of the reduction fishery and the resultant age compositions. Sampling for 2020 was compared to sampling for 2018 and 2019 both coastwide and at the plant level. Sampling appeared to be similar to past years, given the cursory inspection. To consider the impact of the 2020 age compositions on the outcome of the assessment, a sensitivity was run which exluded the 2020 age data.

Finally, a retrospective analysis was completed by sequentially removing the last year of data from the assessment such that the terminal year was 2015, 2016, 2017, 2018, and 2019. 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. 2016-2017 LA gillnet age comps
2. Pooled LA gillnet age comps
3. Gulfwide EwE scaled
4. NGOMEX EwE scaled
5. 2020 age comps excluded
6. Retrospective with the terminal year of 2019
7. Retrospective with the terminal year of 2018
8. Retrospective with the terminal year of 2017
9. Retrospective with the terminal year of 2016
10. Retrospective with the terminal year of 2015

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 (MCBEs) described here. MCBEs 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.

The MCBE analysis should be interpreted as providing an approximation to the 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, while at the same time the seine index has indicated several large year classes of recruits occurring in 2011, 2014, and 2018. Predicted length compositions from the 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). 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. The 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. Figure 4 shows total predicted landings in weight. Commercial harvest exceeded 800,000 mt during much of the 1980s, but declined afterwards to stabilize between 400,000 and 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 744,150 mt for $F=M$ and 646,117 mt for $F=0.75M$, respectively.

4.2.3 Benchmarks/Reference Points

Stock status for Gulf Menhaden is assessed using fishing mortality benchmarked based on the geometric mean of *M* for ages-0 to-2 and 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, $SSB_{25\%\ at\ F=0}$ = 1,274,663, and $SSB_{50\%\ of\ F=0}$ = 2,549,325.

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 $SSB_{2018-2020}/SSB_{25\%\ at\ F=0}$ = 2.60 (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 $F_{2018-2020}/F_{F=M}$ = 0.51 (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, 85% of runs were less than $F_{F=M}$ in the terminal years.

The Gulf of Mexico 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 and to determine if new data inform the model differently. The sensitivity analyses indicated similar stock status to the base run (Figures 20 and 21; Table 11); however, the sensitivity analysis with time varying *M* from the NGOMEX model was the most different and warrants future exploration.

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 -0.002; recruitment 2.57; spawning stock biomass 0.70; and biomass 1.03 (Figure 28).

4.2.6 Comparison with Previous Assessment

This update assessment was congruent with the SEDAR 63 benchmark assessment (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 2024. 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 the SEDAR 63 Benchmark Assessment, 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. These efforts should not impinge on the single species assessment. Side-by-side comparisons of the two assessment types will be informative in the development of ecosystem-based assessments.

DATA ELEMENT	DATA ELEMENT	RECOMMENDATION	Priority
Single Species Assessment			
Stock Status Benchmarks	Single Species Benchmarks	Research effort should be focused on determining appropriate reference points for the stock to ensure long term sustainability while balancing the desires of stakeholders to effectively exploit the stock (Short Term Objective).	High
Genetics and Stock Structure	Stock Structure	Use traditional (mark and recapture) and state of the art methods (otolith shape, natural occuring exogenous markers, and potential genetic markers) to determine estimates of natural mortality, migration, and growth.	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/High
Modeling	Bootstrap considerations	Evaluate the relationships between the various life history and productivity input parameters, which could be impacting bootstrap results due to 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
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
Mortality Study	FI Adult Survey	Examine the feasibility of an acoustic survey for menhaden populations during winter months to determine spatial distribution and abundance (singles species) to get at something like an area swept biomass.	Med/Low
Ecosystem Based Assessment			
Predator/Prey	Predator/Prey	Expand understanding of diets of potential Gulf menhaden predators using a variety of tools including traditional stomach analysis, DNA barcoding, and fatty acid profiles Gulf wide - ecosystem critical. (long term objective)	Med/High
Stock Status Benchmarks	Ecosystem Benchmarks	Benchmarks – Develop procedures to establish assessment benchmarks (e.g., *F* or proxies) that account for the multiple priorities of ecosystem management that could include predation mortality and ecological yield separate from other forms of natural mortality (Long Term Objective).	High/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
Recruitment Evaluation	Recruitment Evaluation	Understand the recruitment drivers for Gulf menhaden from the estuary to the spawning grounds. (mechanistic understanding of larval migration and movement from offshore to inshore - cues and behavior and general oceanographic events - important for ecological reference points) (Long Term Objective).	Low

Stock Status Benchmarks (Single Species)

Following the completion of the SEDAR 63 menhaden benchmark assessment, the MAC agreed to begin exploring potential reference points for management. The MAC and a number of invited stakeholders participated in two workshops in New Orleans, the first in February and a second in July 2019, to look at options for reference points and harvest control rules (HCR) for the fishery. The initial workshop developed potential objectives that could be acceptable to all and explored candidate reference points for future consideration to meet those objectives. The second workshop reviewed the results of those candidate reference points applied to the current and historic fishery and tested the robustness of the HCR options. Additional 'extreme circumstances' were suggested by the workshop participants and evaluated by the technical team. The HCR was put forth by Butterworth and Rademeyer included included testing of what the group considered 'exteme' circumstanes such as lower carrying capacity, higher catch rates, and combinations of poor recruitment and increasing natural mortality. The proposed HCR option was successful in reducing impacts from these potential events when compared with no control parameter in place. Management reference points could be applied by the state management agencies and the use of a HCR would aid in buffering impacts on the Gulf menhaden population annually.

Genetics and Stock Structure

Determining better estimates of natural mortality, migration, and growth could be accomplished through a variety of techniques that are readily available. These techniques could include mark/recapture and newer methods such 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.

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. For example, natural mortality may be correlated with maturity or steepness, so the MCBEs may select unrealistic parameter combinations. This type of analysis has not been conducted but would be valuable to any ongoing of 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.

Legacy Data (FD Surveys)

The reviewers of SEDAR 27, expressed concern about the potential bias associated with sampling only the last purse-seine set of menhaden of the tripday. 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.

Mortality Study

The reviewers of SEDAR 63 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 hydro-acoustic survey being proposed in the northeast could serve as a model for the Gulf.

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.

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.

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.

7.0 References

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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	1999	694.29
1978	820.73	2000	591.07
1979	779.96	2001	528.61
1980	702.63	2002	582.85
1981	554.02	2003	524.48
1982	855.55	2004	473.94
1983	925.24	2005	438.20
1984	985.12	2006	467.76
1985	884.28	2007	457.41
1986	830.83	2008	425.61
1987	912.28	2009	457.72
1988	640.13	2010	380.08
1989	584.11	2011	614.31
1990	539.63	2012	580.45
1991	552.89	2013	499.07
1992	432.88	2014	401.08
1993	551.47	2015	540.82
1994	775.15	2016	491.86
1995	472.04	2017	462.56
1996	491.84	2018	529.64
1997	623.50	2019	489.71
1998	495.79	2020	414.73

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	0.93	0.08		
1989	0.52	0.09		
1990	0.57	0.09		
1991	0.57	0.10		
1992	0.43	0.09		
1993	0.34	0.10		
1994	0.60	0.10		
1995	0.48	0.10		
1996	0.55	0.08	1.23	0.26
1997	0.83	0.08	0.49	0.27
1998	0.74	0.08	0.75	0.27
1999	0.69	0.08	0.44	0.28
2000	1.03	0.07	0.72	0.30
2001	1.07	0.08	0.63	0.26
2002	0.85	0.07	0.41	0.26
2003	0.81	0.07	0.63	0.24
2004	0.63	0.08	0.42	0.27
2005	0.98	0.08	0.56	0.26
2006	1.14	0.07	0.74	0.26
2007	0.83	0.07	0.63	0.27
2008	2.06	0.07	0.24	0.28
2009	1.87	0.06	0.85	0.25
2010	0.59	0.08	1.16	0.25
2011	1.41	0.06	2.90	0.25
2012	1.73	0.06	0.88	0.25
2013	1.42	0.09	0.89	0.29
2014	1.74	0.09	1.61	0.31
2015	1.13	0.09	0.94	0.22
2016	1.21	0.10	1.23	0.20
2017	1.39	0.10	0.44	0.22
2018	1.43	0.09	4.29	0.18
2019	1.27	0.09	0.49	0.19
2020	1.16	0.09	1.43	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

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
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

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	175.50	25.43	2.58	0.42	0.10
1978	154.74	33.03	5.69	0.37	0.09
1979	94.50	29.13	6.98	0.66	0.07
1980	179.24	17.79	6.39	0.93	0.12
1981	173.90	33.74	3.76	0.75	0.15
1982	127.19	32.73	7.79	0.60	0.17
1983	144.21	23.94	7.22	1.06	0.13
1984	210.79	27.14	4.87	0.74	0.15
1985	129.94	39.67	4.93	0.33	0.08
1986	153.55	24.46	8.29	0.55	0.06
1987	86.02	28.90	5.27	1.03	0.09
1988	90.13	16.19	5.74	0.49	0.13
1989	106.51	16.96	3.34	0.62	0.09
1990	80.35	20.05	3.25	0.27	0.07
1991	54.09	15.12	4.08	0.33	0.05
1992	106.26	10.18	3.00	0.38	0.05
1993	118.27	20.00	1.95	0.25	0.05
1994	70.96	22.26	3.68	0.14	0.03
1995	122.60	13.36	3.96	0.23	0.01
1996	120.64	23.08	2.73	0.41	0.03
1997	89.68	22.71	5.25	0.22	0.05
1998	151.07	16.88	5.23	0.45	0.03
1999	135.90	28.43	4.04	0.58	0.07
2000	104.57	25.58	6.36	0.29	0.06
2001	116.85	19.68	6.24	0.79	0.05
2002	76.77	21.99	4.87	0.86	0.14
2003	116.29	14.45	5.22	0.51	0.13
2004	127.99	21.89	3.41	0.53	0.08
2005	86.01	24.09	5.13	0.33	0.08
2006	177.24	16.19	6.02	0.75	0.07
2007	186.70	33.36	4.03	0.86	0.14
2008	32.21	35.14	8.37	0.61	0.18
2009	116.68	6.06	9.30	1.78	0.19
2010	204.27	21.96	1.58	1.80	0.44
2011	159.61	38.45	5.42	0.21	0.37
2012	151.82	30.04	9.47	0.72	0.10
2013	96.01	28.58	7.72	1.65	0.17
2014	142.99	18.07	7.43	1.46	0.40
2015	120.61	26.92	4.76	1.52	0.44
2016	176.53	22.70	6.69	0.67	0.34
2017	83.22	33.23	5.76	1.07	0.20
2018	180.09	15.66	8.55	1.02	0.27

2019	67.79	33.90	4.00	1.44	0.26
2020	192.44	12.76	8.53	0.61	0.31

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

Year	Age-1	Age-2	Age-3	Age-4+
1977	1,357.84	251.96	61.95	18.95
1978	1,764.00	554.40	54.09	17.71
1979	1,555.32	680.29	97.12	13.13
1980	949.82	622.65	136.14	23.32
1981	1,801.54	366.56	109.35	29.93
1982	1,748.00	759.95	88.38	33.89
1983	1,278.39	704.16	155.50	25.42
1984	1,449.40	474.79	107.86	30.19
1985	2,118.54	480.26	48.43	15.88
1986	1,306.02	808.33	80.99	11.38
1987	1,543.38	513.56	151.76	18.47
1988	864.56	559.18	72.02	26.50
1989	905.87	325.96	90.37	16.71
1990	1,070.50	316.44	40.14	14.72
1991	807.62	397.67	48.51	8.89
1992	543.68	292.64	55.79	8.84
1993	1,067.94	189.79	35.95	8.91
1994	1,188.66	358.68	20.32	5.41
1995	713.19	385.98	34.05	2.79
1996	1,232.27	265.86	59.91	6.31
1997	1,212.54	511.71	31.63	8.96
1998	901.31	510.11	66.26	5.74
1999	1,518.36	394.08	84.88	13.09
2000	1,365.89	619.90	41.98	11.94
2001	1,051.07	608.13	116.07	10.51
2002	1,174.46	475.15	125.74	27.78
2003	771.63	509.00	74.66	25.94
2004	1,168.82	332.68	77.31	16.21
2005	1,286.36	500.21	48.16	14.74
2006	864.55	587.26	110.25	14.09
2007	1,781.50	393.30	126.50	28.08
2008	1,876.64	816.48	88.92	35.85
2009	323.80	907.13	261.02	38.15
2010	1,172.84	154.24	263.62	87.40
2011	2,053.21	528.27	31.14	72.62
2012	1,604.27	923.00	105.32	18.97
2013	1,526.05	752.47	242.57	33.07
2014	965.10	724.51	213.99	79.15
2015	1,437.35	463.62	222.46	86.90
2016	1,212.33	652.52	98.52	66.41
2017	1,774.40	561.35	157.69	38.45
2018	836.50	834.00	149.54	52.29

2019	1,810.15	389.99	210.73	50.63
2020	681.40	831.45	89.44	61.20

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*	$F/F_{F=M}$	*SSB*	$SSB/SSB_{25\%\ at\ F=0}$
1977	0.85	0.64	2,404,276	1.89
1978	1.05	0.80	3,507,193	2.75
1979	0.92	0.69	3,607,509	2.83
1980	1.05	0.79	2,872,487	2.25
1981	0.73	0.55	3,339,713	2.62
1982	0.90	0.68	4,048,187	3.18
1983	1.18	0.90	3,500,659	2.75
1984	1.59	1.21	3,128,302	2.45
1985	1.09	0.82	3,769,577	2.96
1986	0.98	0.74	3,520,549	2.76
1987	1.27	0.96	3,401,286	2.67
1988	1.13	0.86	2,482,664	1.95
1989	1.40	1.06	2,067,703	1.62
1990	1.18	0.90	2,117,076	1.66
1991	1.27	0.96	1,966,570	1.54
1992	1.41	1.06	1,442,627	1.13
1993	1.54	1.17	1,823,632	1.43
1994	1.66	1.26	2,272,383	1.78
1995	1.17	0.89	1,771,689	1.39
1996	1.44	1.09	2,236,579	1.75
1997	1.35	1.02	2,658,203	2.09
1998	1.10	0.83	2,350,716	1.84
1999	1.55	1.17	2,937,358	2.30
2000	0.98	0.75	3,106,062	2.44
2001	0.88	0.67	2,878,430	2.26
2002	1.16	0.88	2,829,377	2.22
2003	1.19	0.90	2,269,471	1.78
2004	1.24	0.94	2,370,269	1.86
2005	0.82	0.62	2,783,936	2.18
2006	0.84	0.64	2,601,565	2.04
2007	0.80	0.60	3,408,659	2.67
2008	0.45	0.34	4,330,631	3.40
2009	0.54	0.41	3,053,103	2.40
2010	0.91	0.69	2,686,122	2.11
2011	0.92	0.70	3,911,012	3.07
2012	0.64	0.49	4,208,929	3.30
2013	0.57	0.43	4,148,560	3.25
2014	0.49	0.37	3,463,404	2.72
2015	0.86	0.65	3,547,030	2.78
2016	0.73	0.55	3,287,800	2.58

2017	0.63	0.48	3,857,932	3.03
2018	0.68	0.52	3,290,255	2.58
2019	0.78	0.59	3,716,676	2.92
2020	0.56	0.42	2,967,933	2.33

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	0.24	0.85	0.74	0.74
1978	0.00	0.29	1.05	0.91	0.91
1979	0.00	0.26	0.92	0.80	0.80
1980	0.00	0.29	1.05	0.91	0.91
1981	0.00	0.21	0.73	0.64	0.64
1982	0.00	0.25	0.90	0.78	0.78
1983	0.00	0.33	1.18	1.03	1.03
1984	0.00	0.45	1.59	1.38	1.38
1985	0.00	0.31	1.09	0.95	0.95
1986	0.00	0.28	0.98	0.85	0.85
1987	0.00	0.36	1.27	1.11	1.11
1988	0.00	0.32	1.13	0.98	0.98
1989	0.00	0.39	1.40	1.22	1.22
1990	0.00	0.33	1.18	1.03	1.03
1991	0.00	0.36	1.27	1.11	1.11
1992	0.00	0.39	1.41	1.22	1.22
1993	0.00	0.43	1.54	1.34	1.34
1994	0.00	0.47	1.66	1.45	1.45
1995	0.00	0.33	1.17	1.02	1.02
1996	0.00	0.22	1.44	1.25	1.25
1997	0.00	0.21	1.35	1.18	1.18
1998	0.00	0.17	1.10	0.96	0.96
1999	0.00	0.24	1.55	1.35	1.35
2000	0.00	0.15	0.98	0.86	0.86
2001	0.00	0.14	0.88	0.77	0.77
2002	0.00	0.18	1.16	1.01	1.01
2003	0.00	0.18	1.19	1.04	1.04
2004	0.00	0.19	1.24	1.08	1.08
2005	0.00	0.13	0.82	0.71	0.71
2006	0.00	0.13	0.84	0.73	0.73
2007	0.00	0.12	0.80	0.69	0.69
2008	0.00	0.07	0.45	0.39	0.39
2009	0.00	0.08	0.54	0.47	0.47
2010	0.00	0.14	0.91	0.79	0.79
2011	0.00	0.14	0.92	0.80	0.80
2012	0.00	0.10	0.64	0.56	0.56
2013	0.00	0.09	0.57	0.49	0.49
2014	0.00	0.08	0.49	0.43	0.43
2015	0.00	0.13	0.86	0.75	0.75
2016	0.00	0.11	0.73	0.63	0.63
2017	0.00	0.10	0.63	0.55	0.55
2018	0.00	0.11	0.68	0.60	0.60

2019	0.00	0.12	0.78	0.68	0.68
2020	0.00	0.09	0.56	0.49	0.49

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	1,274,663
$SSB_{50\%\ at\ F=0}$	Billions of eggs	2,549,325
$F_{2018\text{-}2020}$	y^{-1}	0.67
$SSB_{2018\text{-}2020}$	Billions of eggs	3,310,900
$F_{2018\text{-}2020}/F_{F=M}$	-	0.51
$F_{2018\text{-}2020}/F_{F=0.75M}$	-	0.68
$SSB_{2018\text{-}2020}/SSB_{25\%\ at\ F=0}$	-	2.60
$SSB_{2018\text{-}2020}/SSB_{50\%\ at\ F=0}$	-	1.30

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	$F_{F=M}$	$F_{F=0.75M}$	$SSB_{25\%\ at\ F=0}$	$SSB_{50\%\ at\ F=0}$	$F_{Terminal\ 3\ years}/F_{F=M}$	$F_{Terminal\ 3\ years}/F_{35\%}$	$SSB_{Terminal\ 3\ years}/SSB_{30\%}$	$SSB_{Terminal\ 3\ years}/SSB_{35\%}$
Base run	1.32	0.99	1,274,663	2,549,325	0.56	0.74	2.79	1.4
2016-2017 LA gillnet age comps	1.32	0.99	1,320,590	2,641,180	0.52	0.69	2.77	1.38
Pooled LA gillnet age comps	1.32	0.99	1,335,451	2,670,902	0.5	0.67	2.78	1.39
Gulfwide EwE scaled	1.32	0.99	1,284,590	2,569,180	0.55	0.73	2.82	1.41
NGOMEX EwE scaled	1.32	0.99	911,452.8	1,822,906	0.56	0.75	3.87	1.93
2020 age comps excluded	1.32	0.99	1,275,327	2,550,654	0.55	0.74	2.8	1.4
Retrospective 2019	1.32	0.99	1,240,673	2,481,346	0.62	0.83	2.42	1.21
Retrospective 2018	1.32	0.99	1,285,142	2,570,284	0.71	0.95	2.62	1.31
Retrospective 2017	1.32	0.99	1,241,641	2,483,281	0.41	0.54	2.54	1.27
Retrospective 2016	1.32	0.99	1,260,141	2,520,282	0.49	0.65	3.03	1.52
Retrospective 2015	1.32	0.99	1,256,415	2,512,831	0.56	0.75	3.08	1.54

9.0 Figures

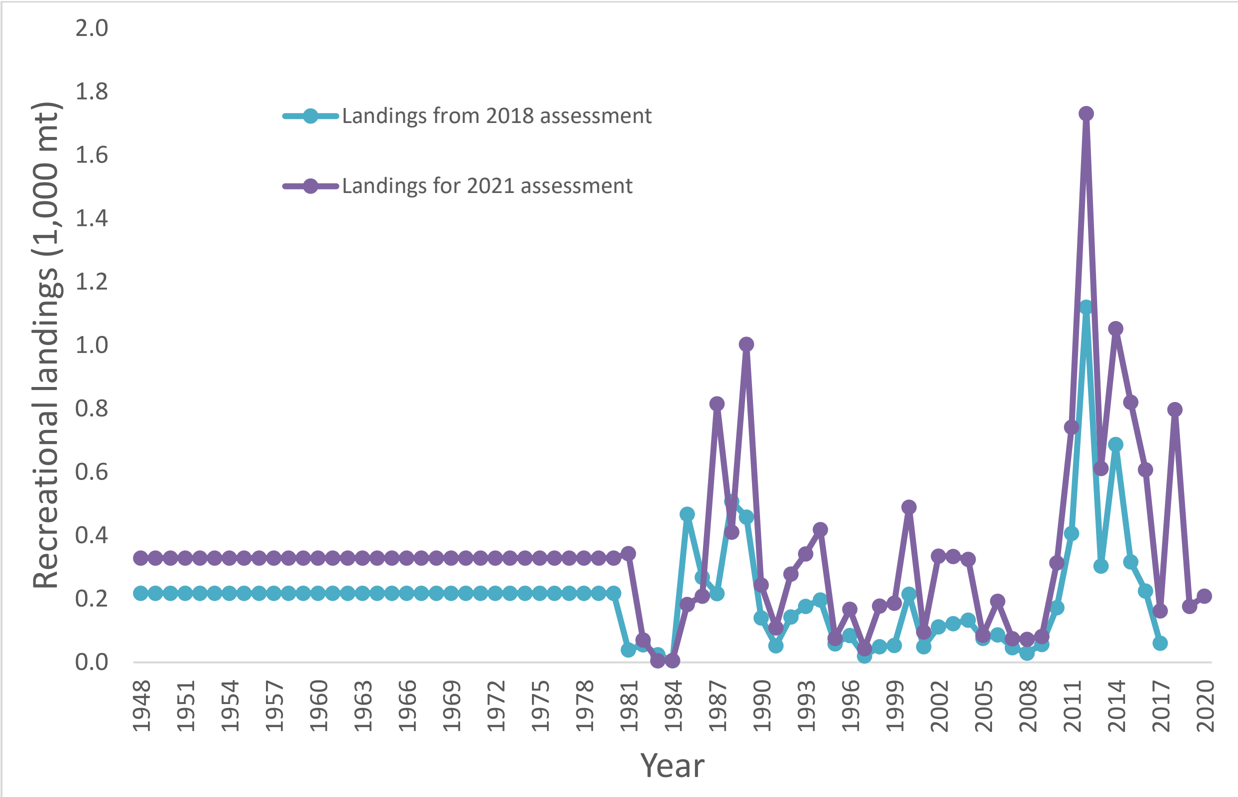


Figure 1. Recreational landings comparison from the SEDAR 63 benchmark assessment and this update assessment. Landings were different due to a change in the methods used by MRIP.

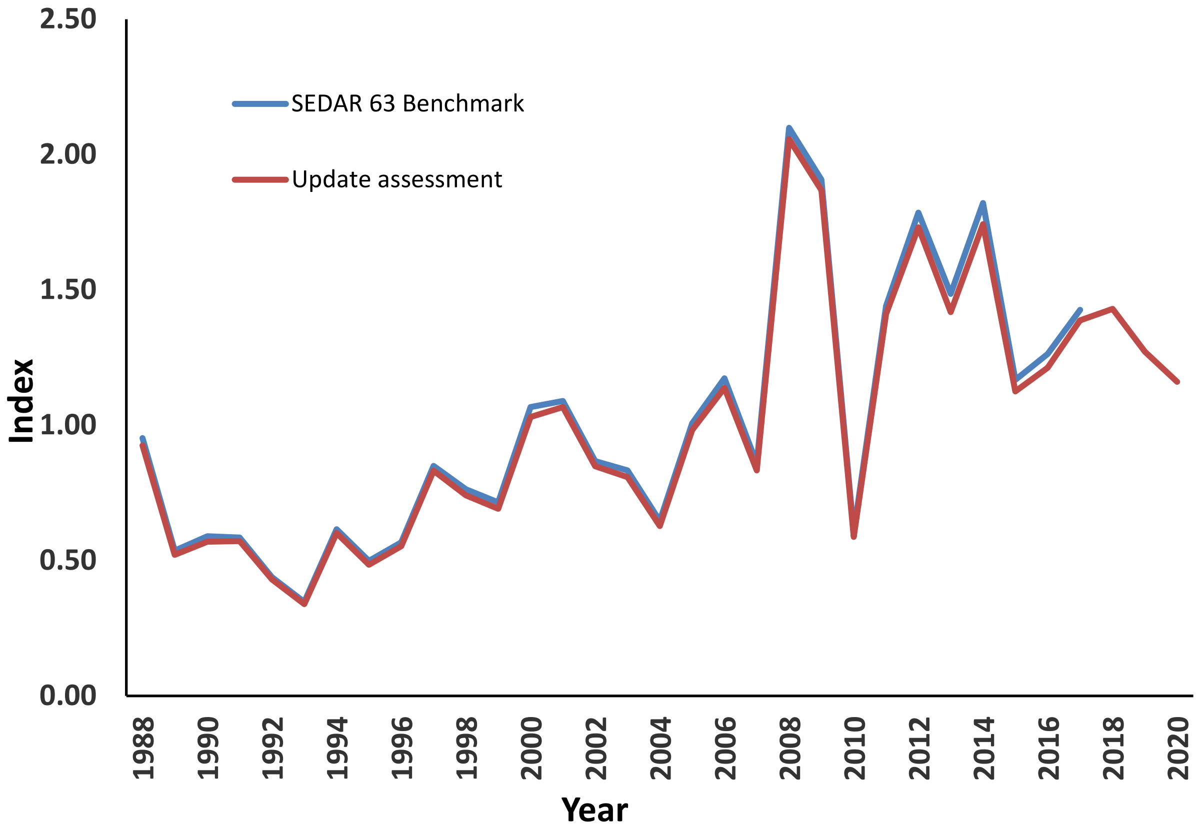


Figure 2. The gillnet index from the benchmark SEDAR 63 assessment and updated for the current assessment.

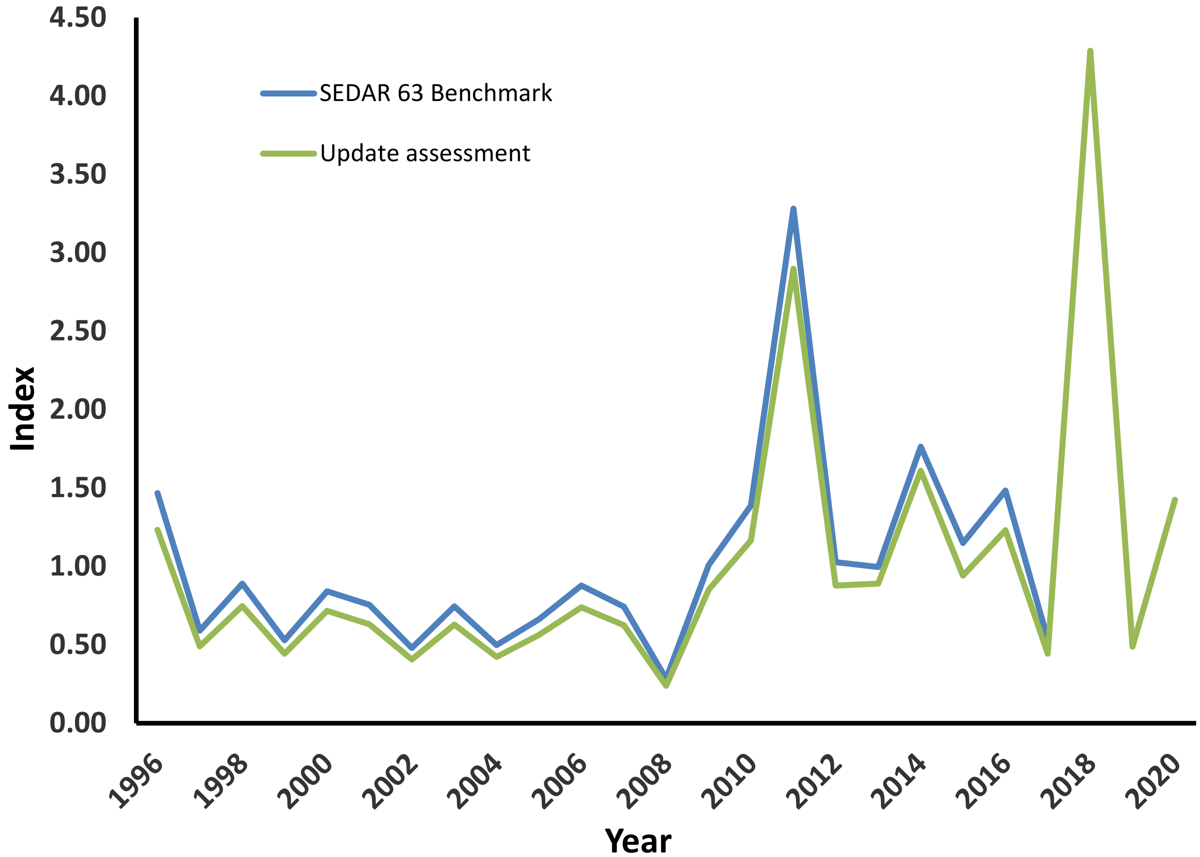


Figure 3. The seine index from the benchmark SEDAR 63 assessment and updated for the current assessment.

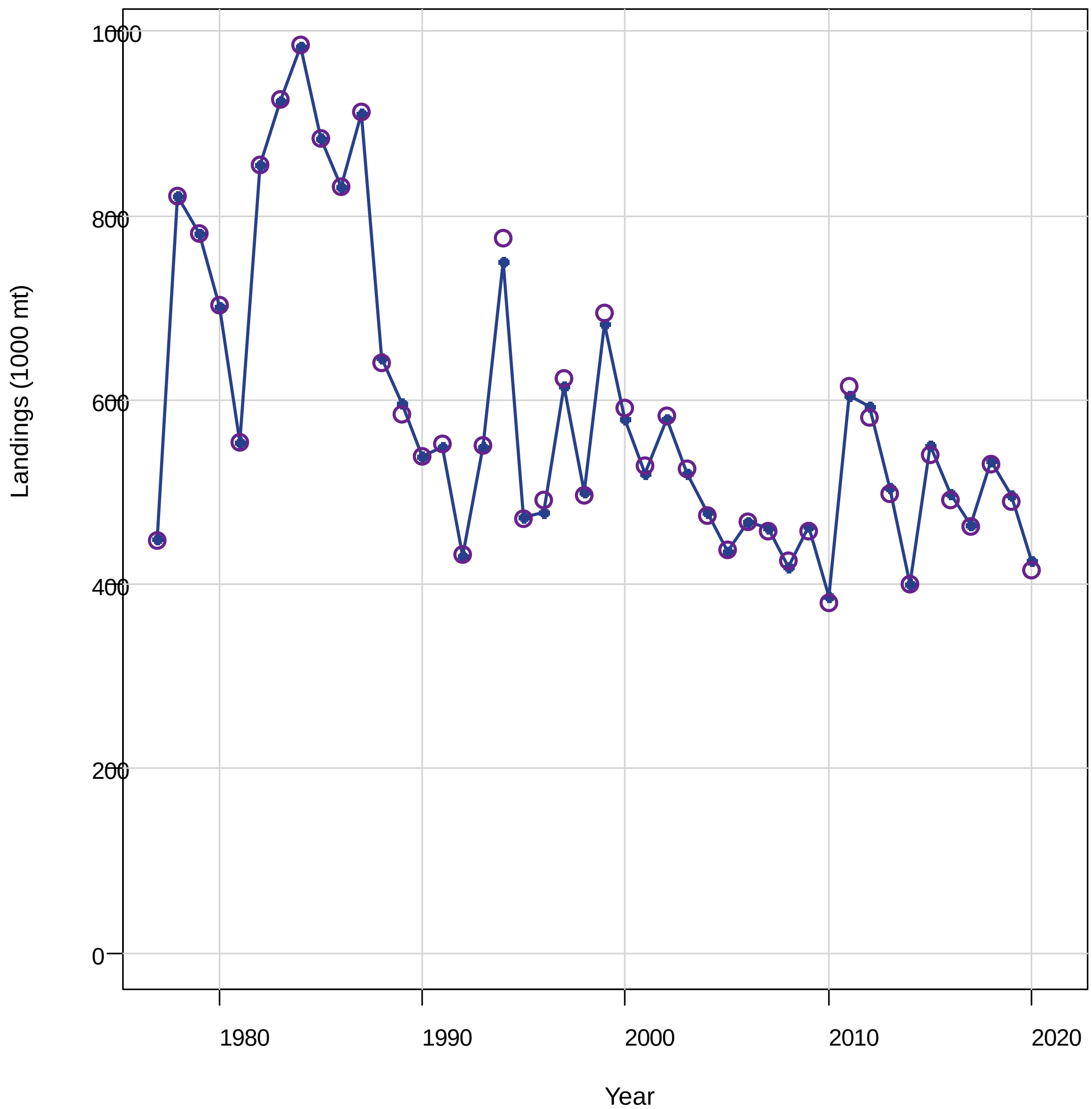


Figure 4. Observed (open circles) and estimated (line, solid circles) commercial reduction, commercial bait, and recreational landings (1,000s mt).

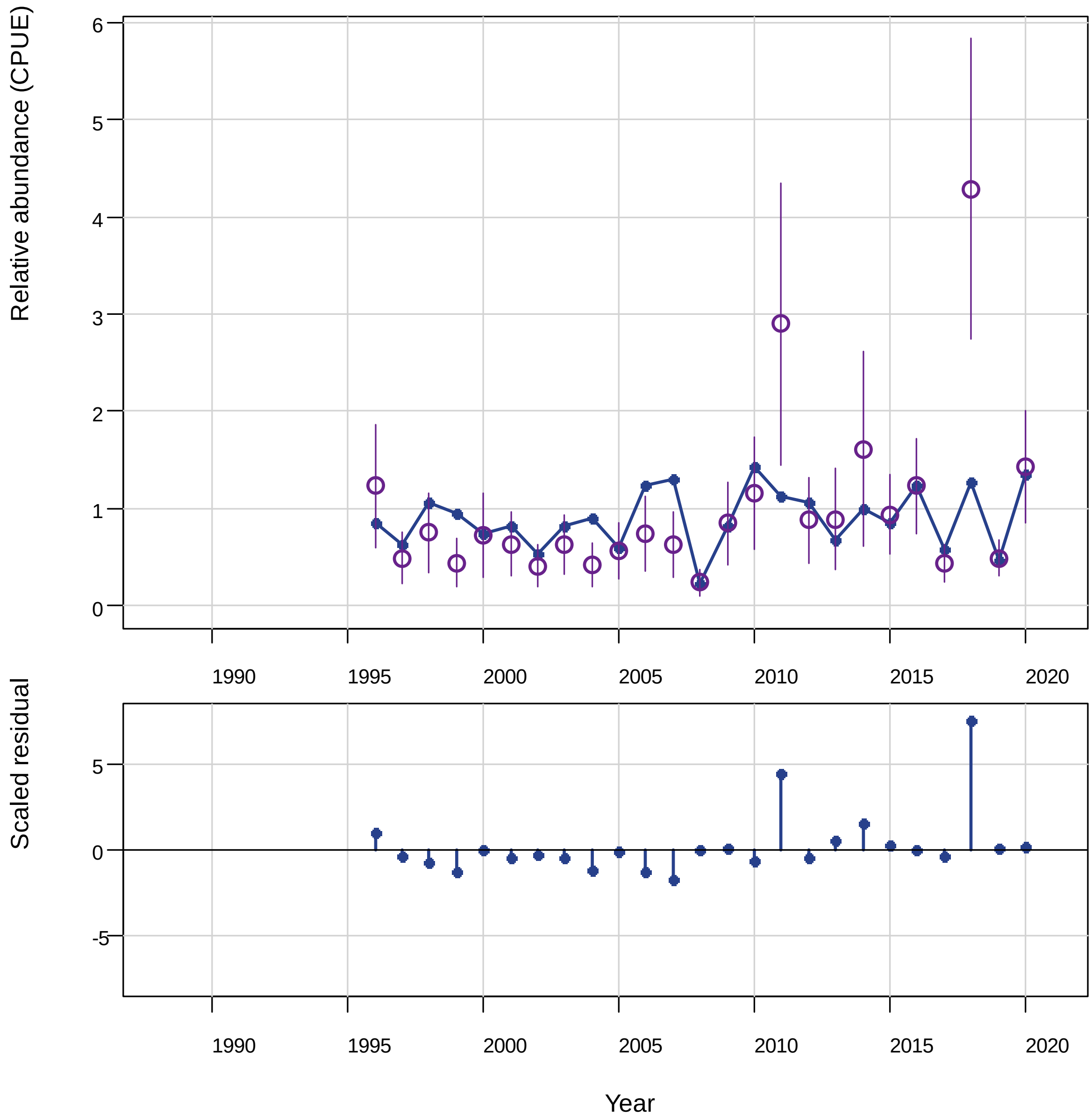


Figure 5. Observed (open circles) and estimated (line, solid circles) index of abundance from the seine surveys in LA, MS, and AL.

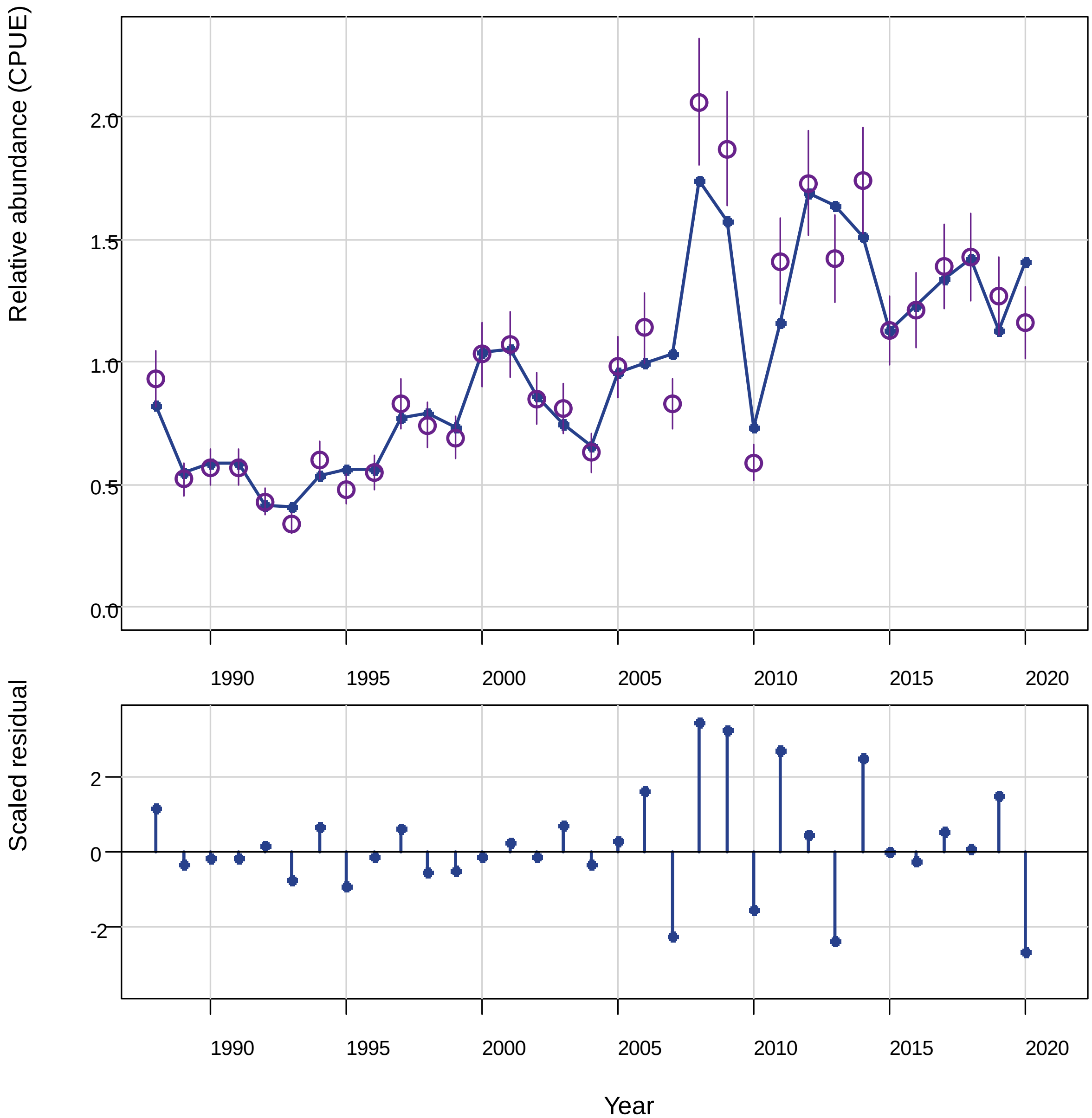


Figure 6. Observed (open circles) and estimated (line, solid circles) index of abundance from the LA gillnet survey.

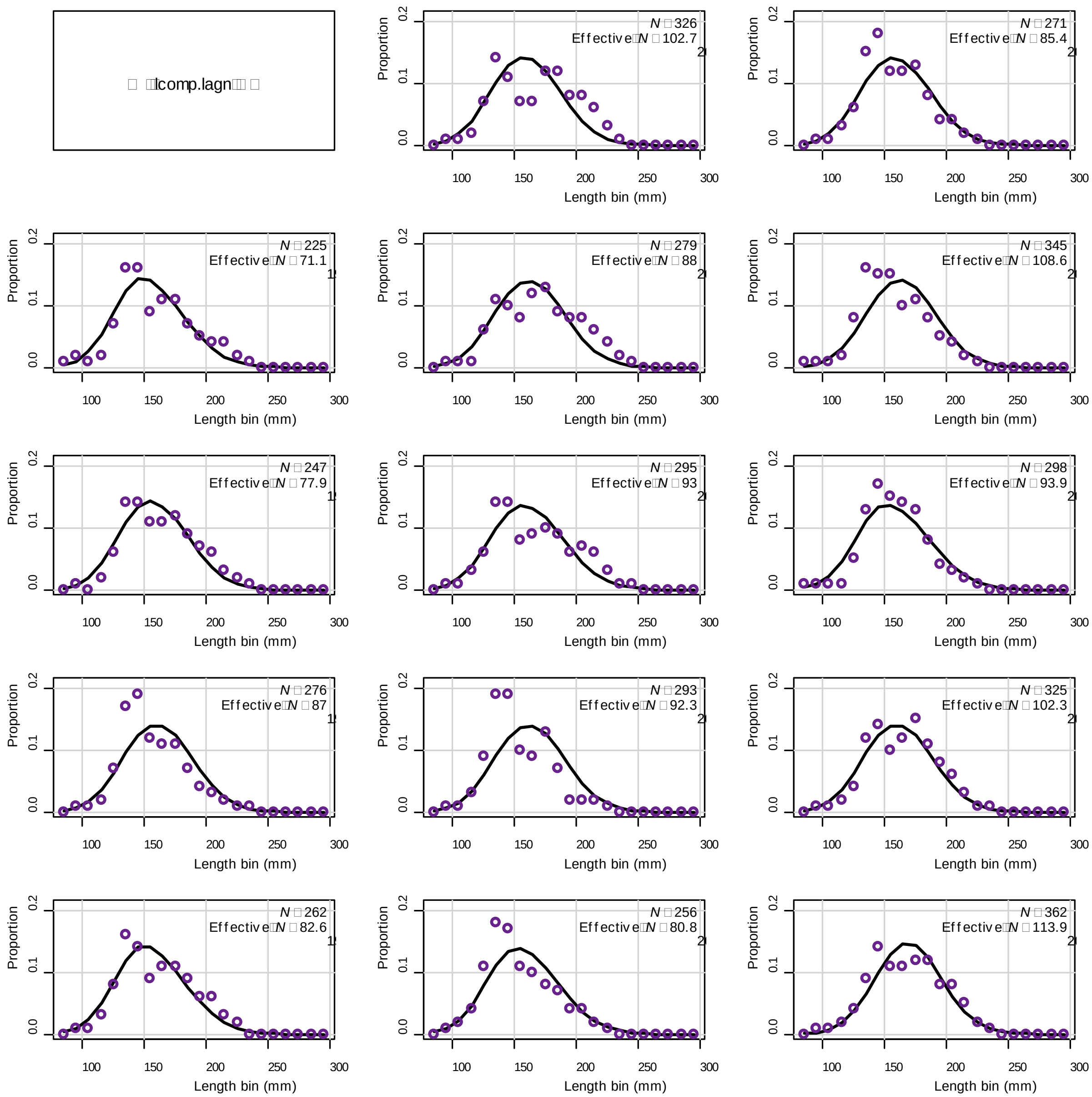


Figure 7. Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, cR to commercial reduction, and lagn to the Lousiana gillnet survey. N indicates the number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

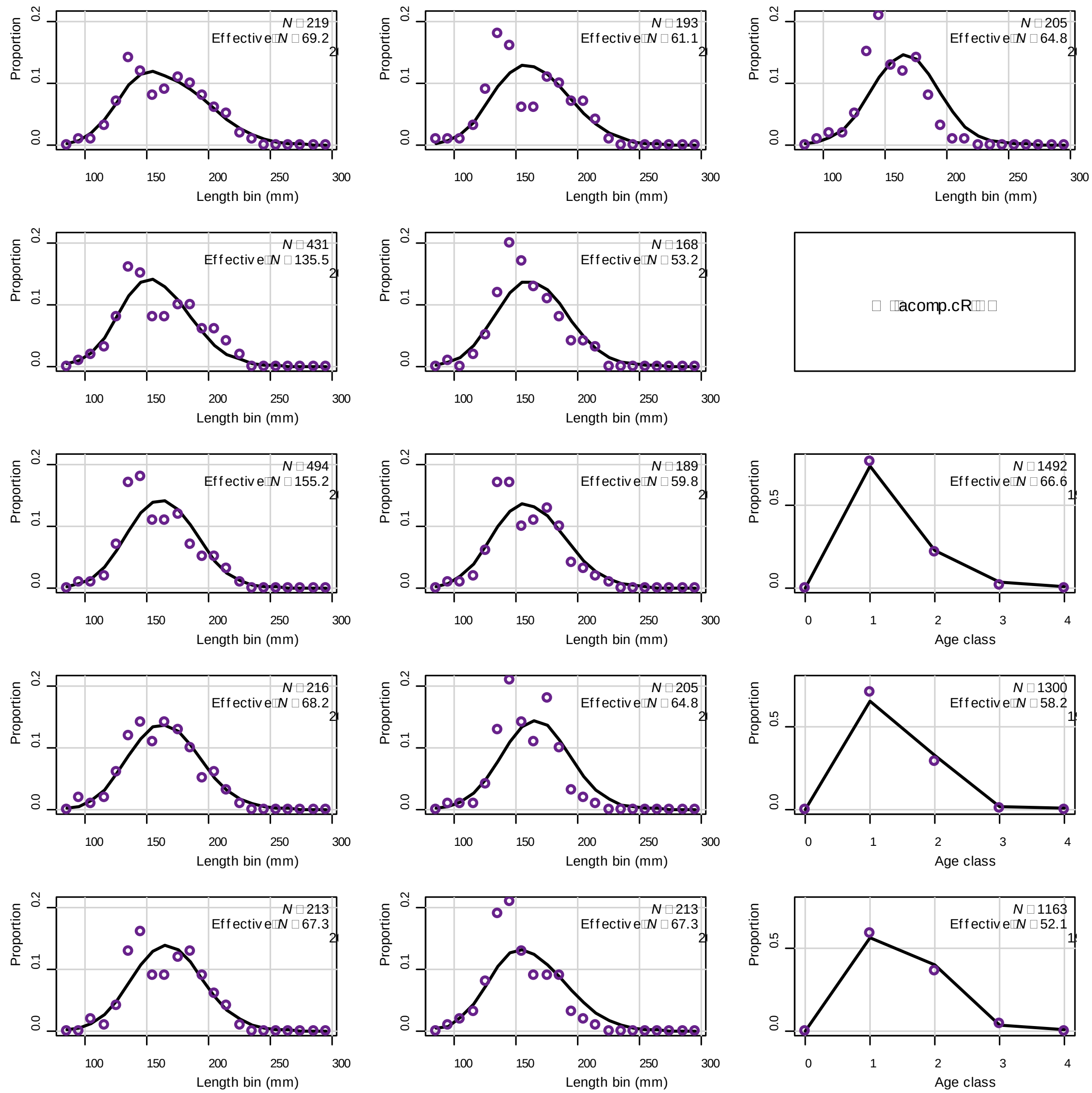


Figure 7. (Continued) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, cR to commercial reduction, and lagn to the Louisiana gillnet survey. N indicates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

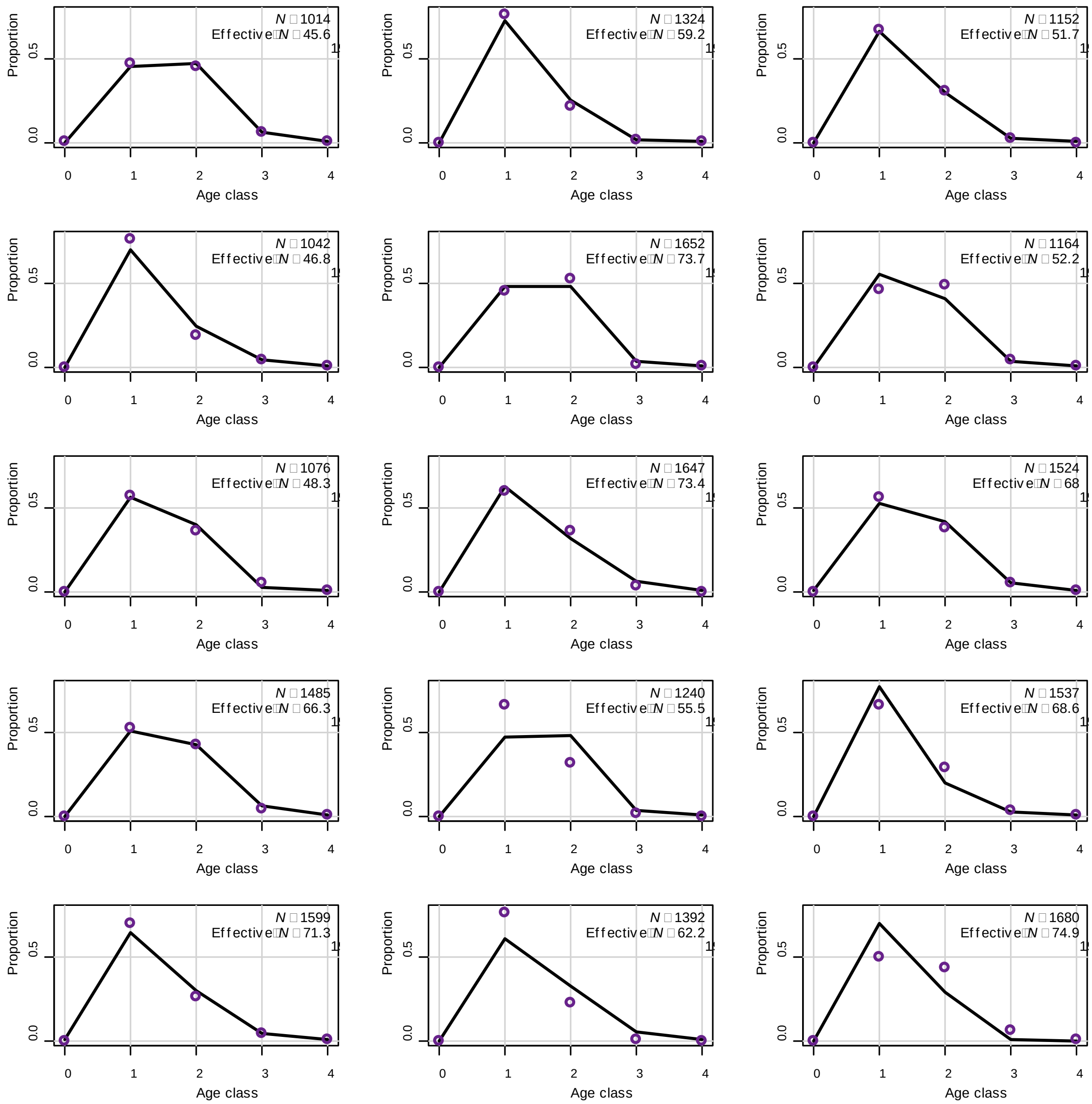


Figure 7. (Continued) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, cR to commercial reduction, and lagn to the Louisiana gillnet survey. N indicates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

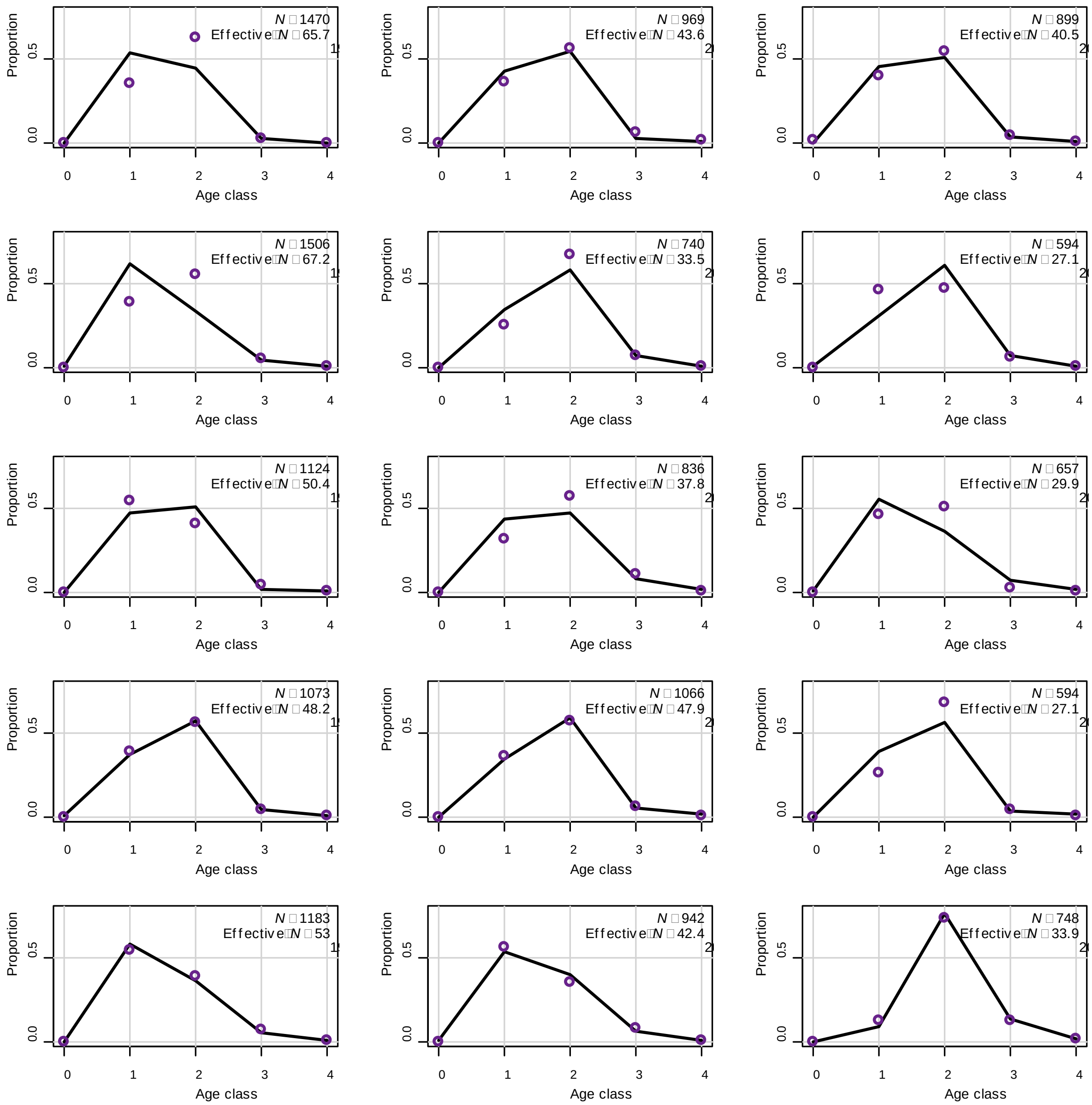


Figure 7. (Continued) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, cR to commercial reduction, and lagn to the Louisiana gillnet survey. N indicates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

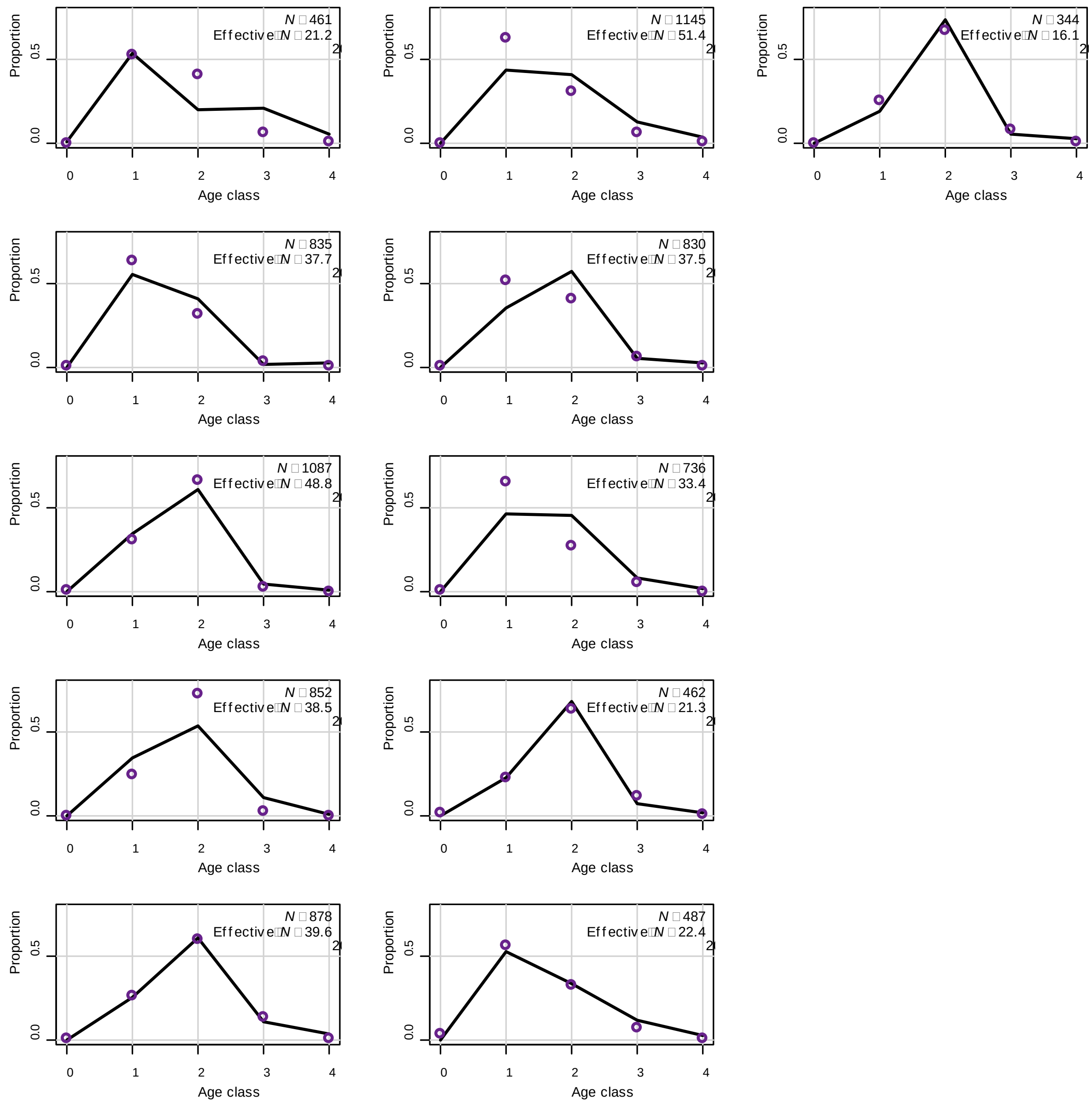


Figure 7. (Continued) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, cR to commercial reduction, and lagn to the Louisiana gillnet survey. N indicates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

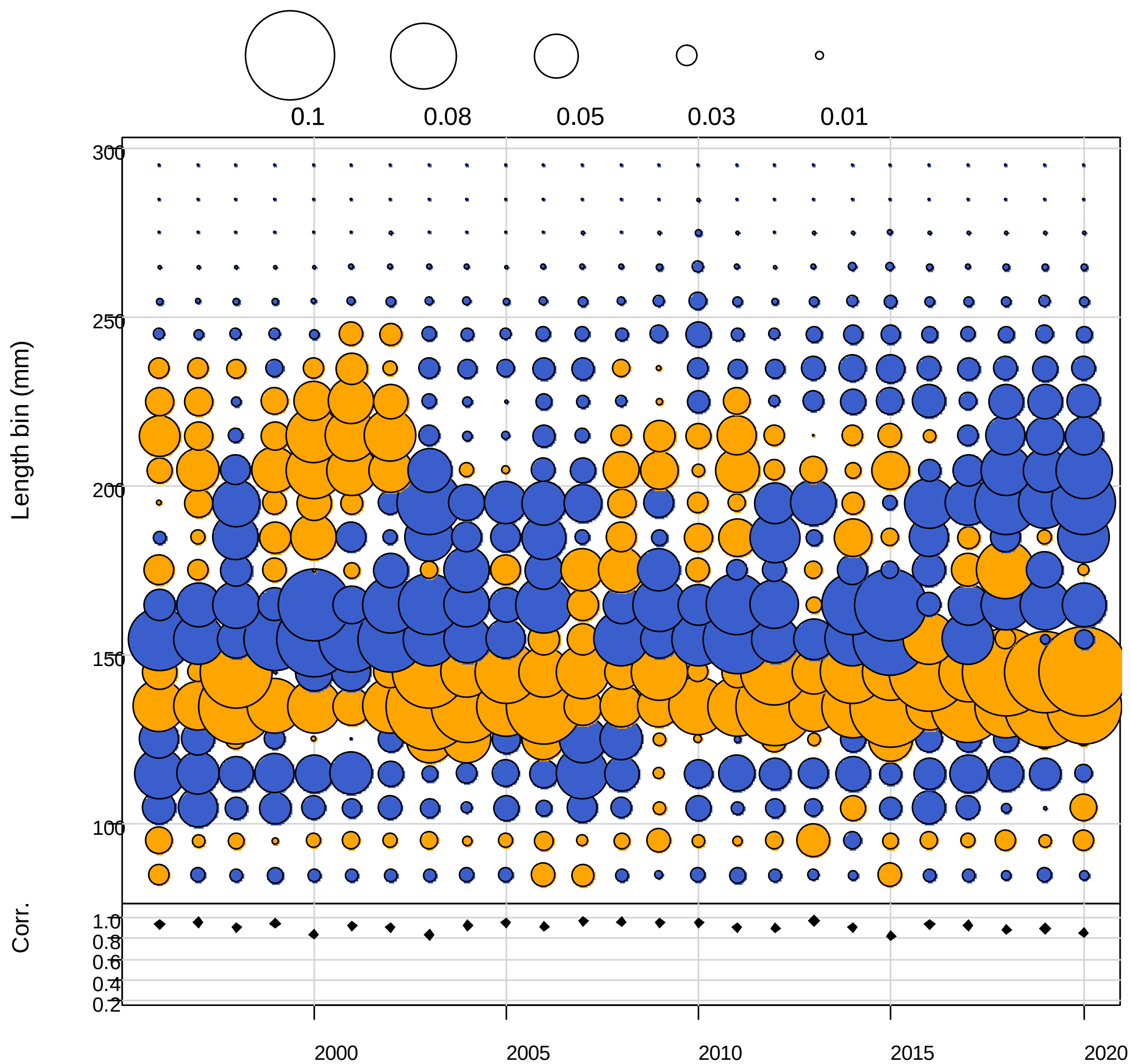


Figure 8. Bubble plot of the gillnet index length compositions for 1988-2020. The correlation on the bottom of the figure indicates the correlation between the observed and predicted data.

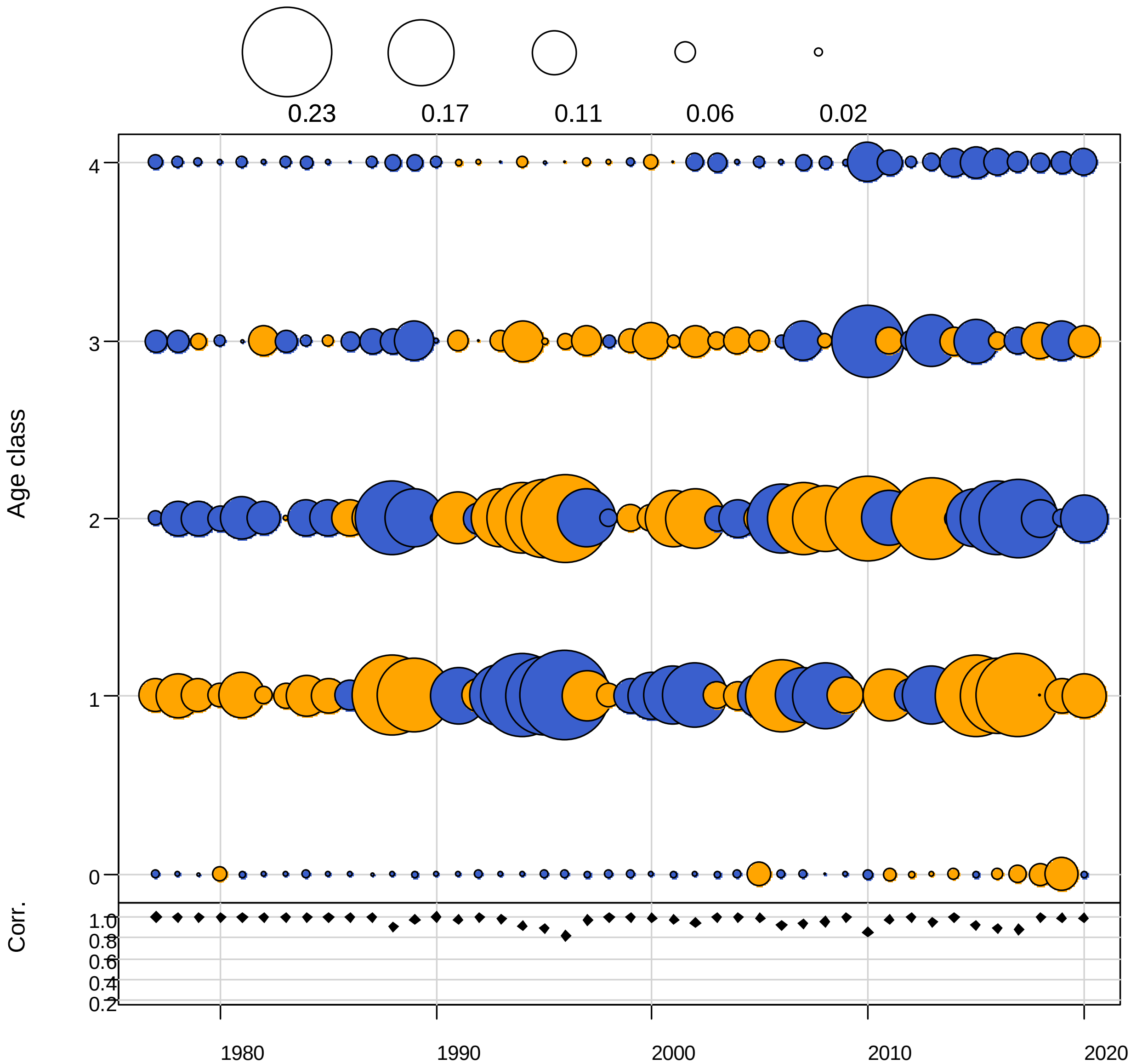


Figure 9. Bubble plot of the commercial reduction fishery age compositions for 1977-2020. The correlation on the bottom of the figure indicates the correlation between the observed and predicted data.

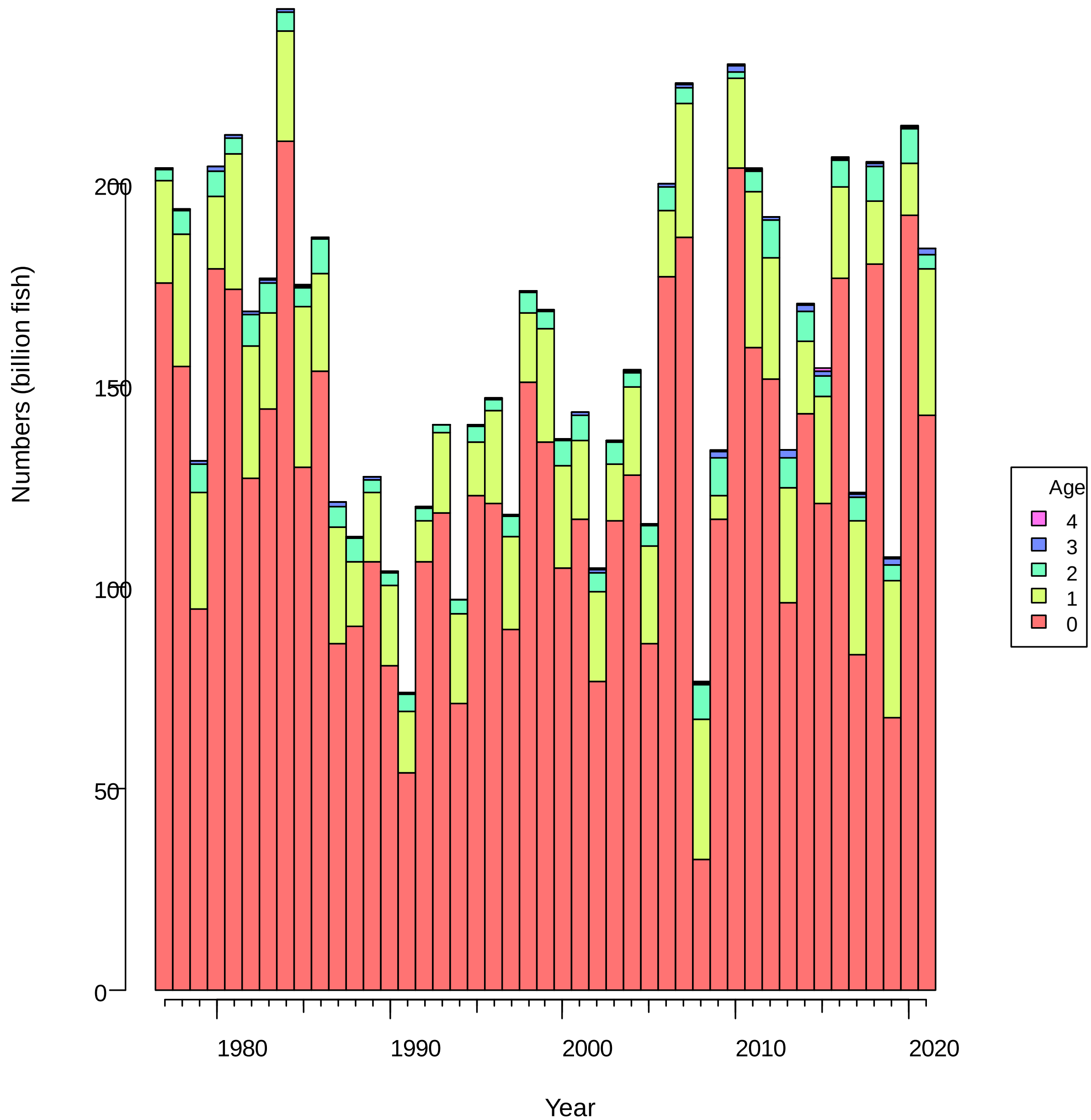


Figure 10. Estimated abundance at age at the start of the year for 1977-2021, with 2021 being a projection for the year after the terminal year of this update assessment.

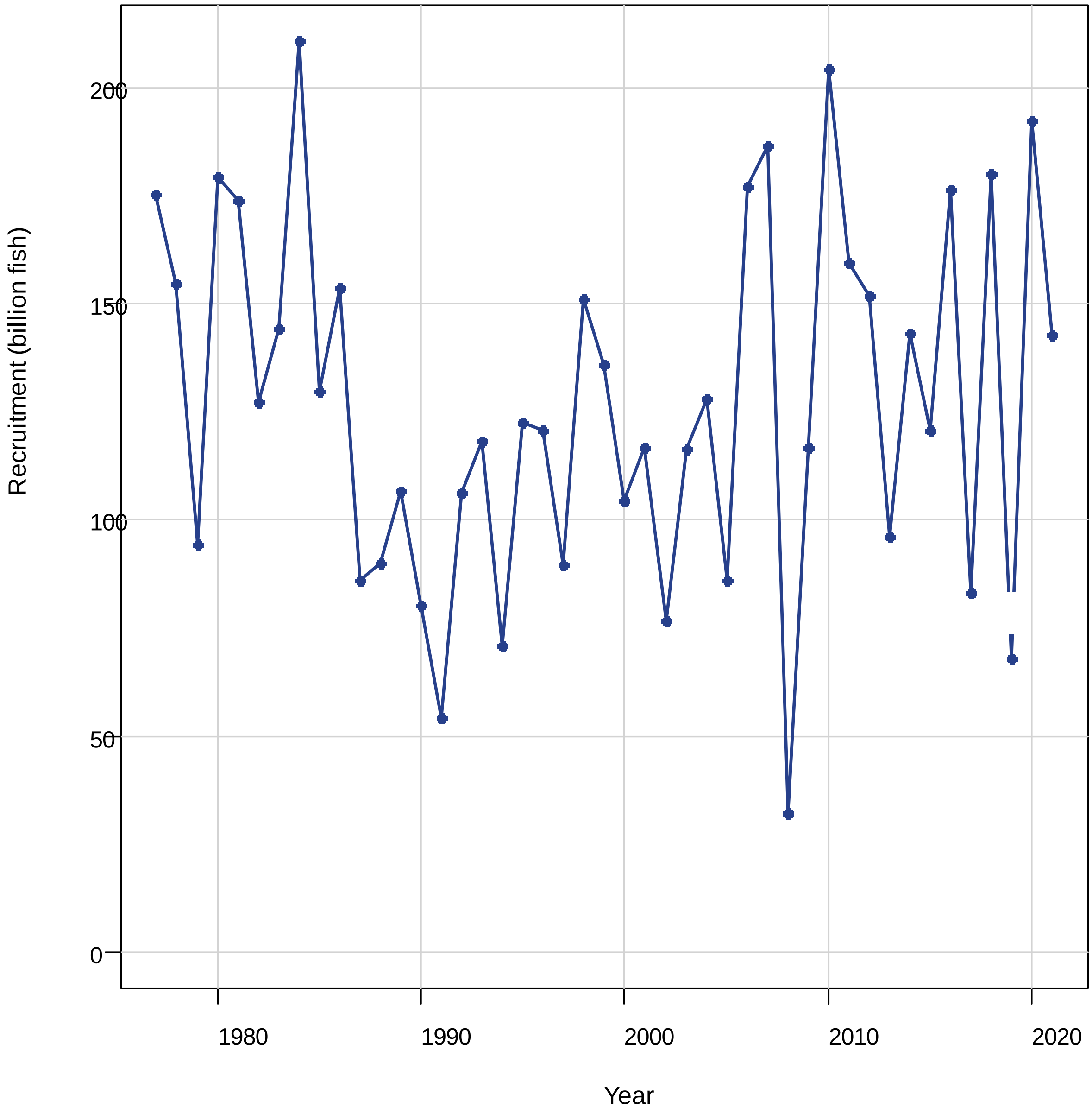


Figure 11. Estimated recruitment of age-0 fish in billions for 1977-2021, with 2021 being a projection for the year after the terminal year of this update assessment.

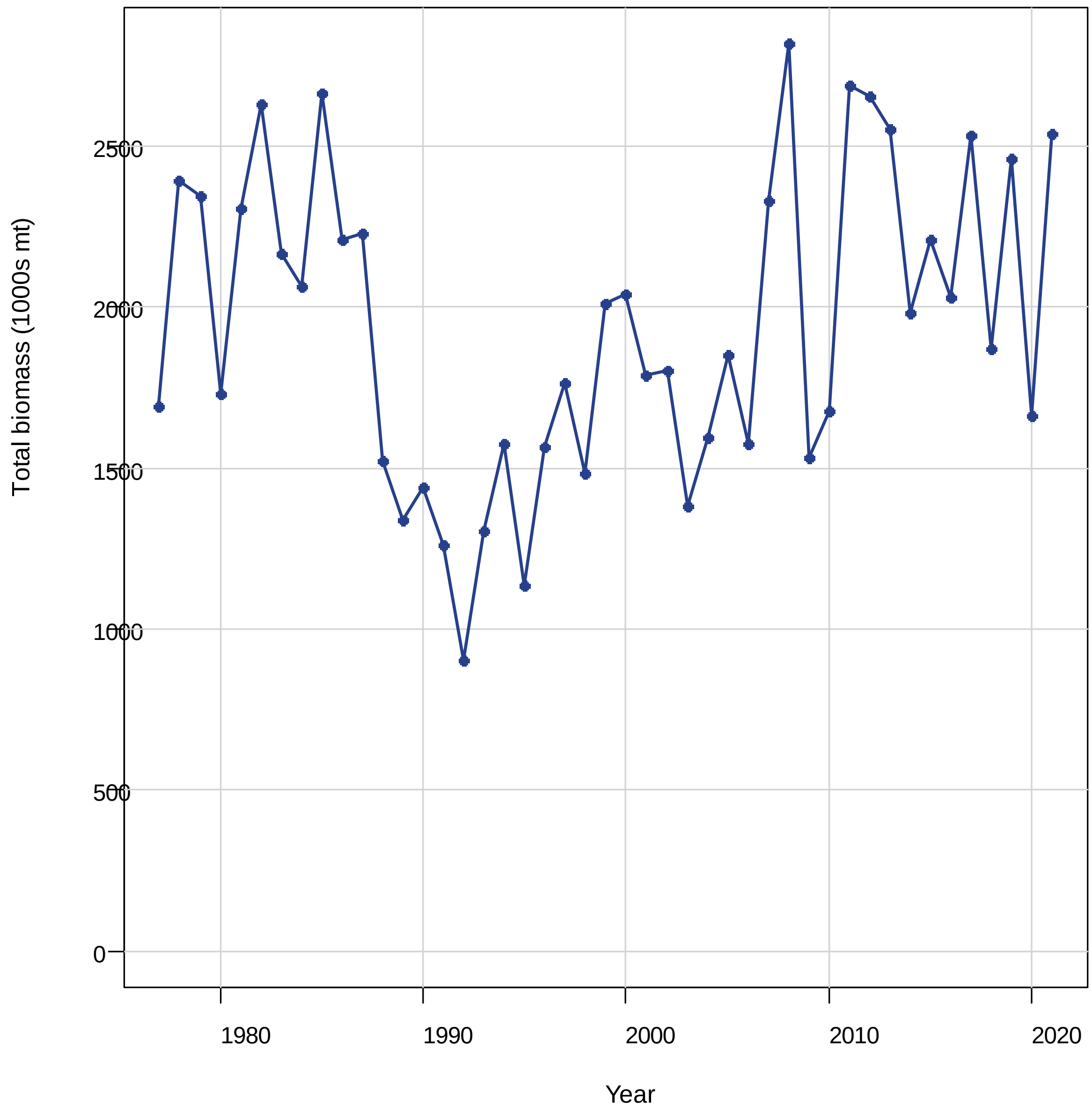


Figure 12. Estimated total age-1+ biomass (1,000s mt) at start of year for 1977-2021, with 2021 being a projection for the year after the terminal year of this update assessment.

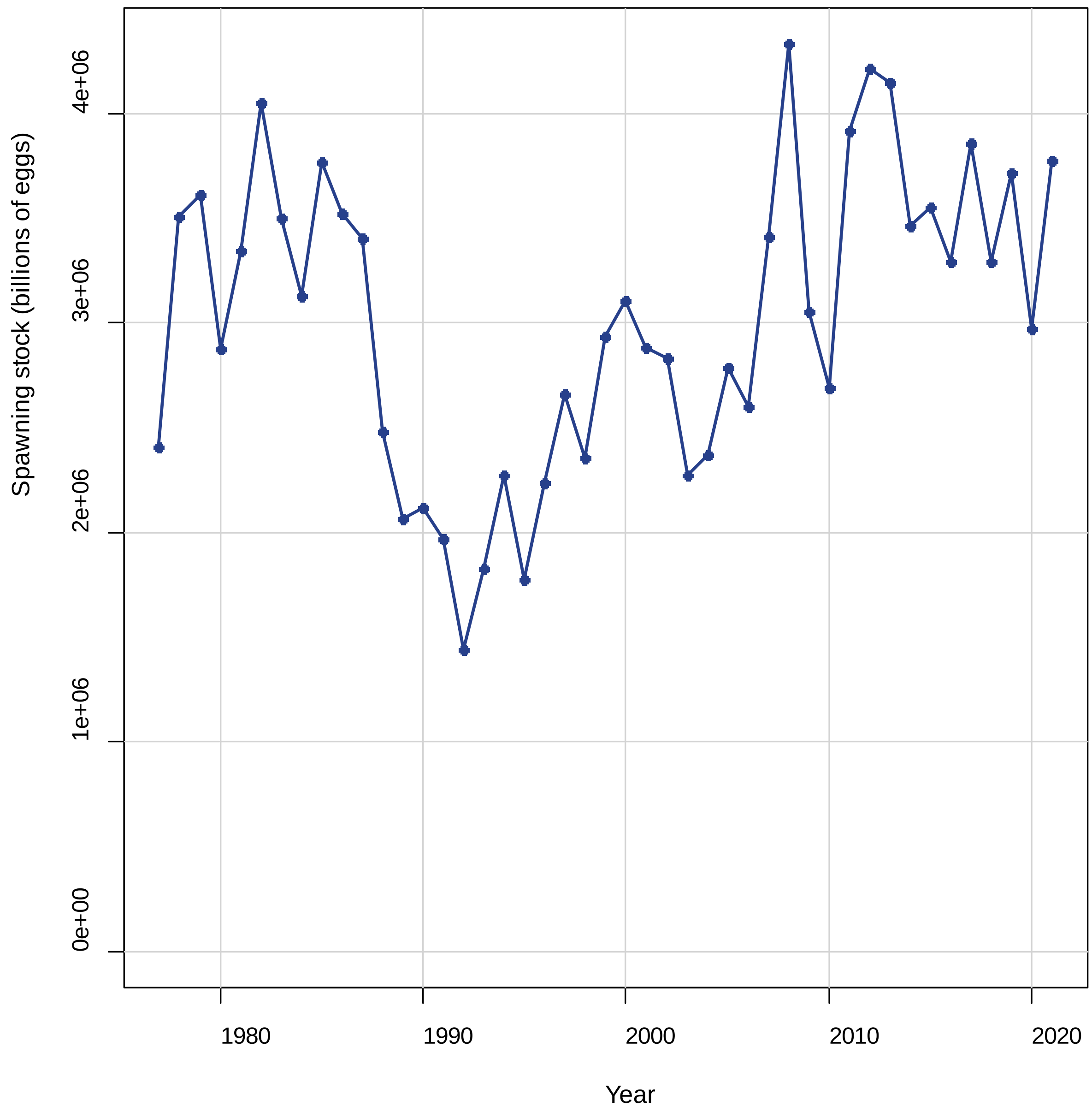


Figure 13. Estimated spawning stock biomass (fecundity in billions of eggs) at time of peak spawning for 1977-2021, with 2021 being a projection for the year after the terminal year of this update assessment.

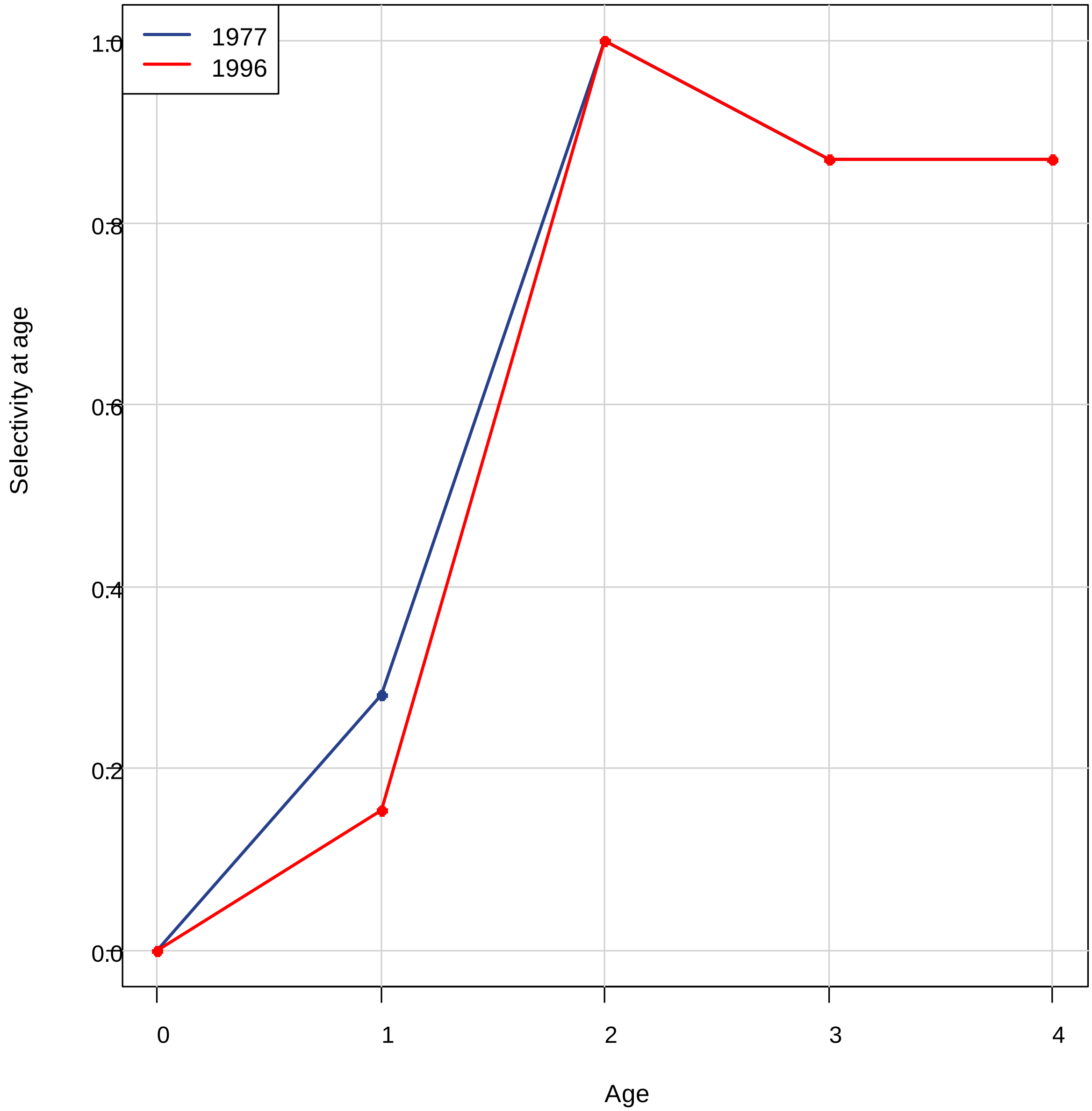


Figure 14. Selectivity of the commercial reduction fleet for 1977-2020 with the blue line being for 1977-1995 and the red line being for 1996-2020.

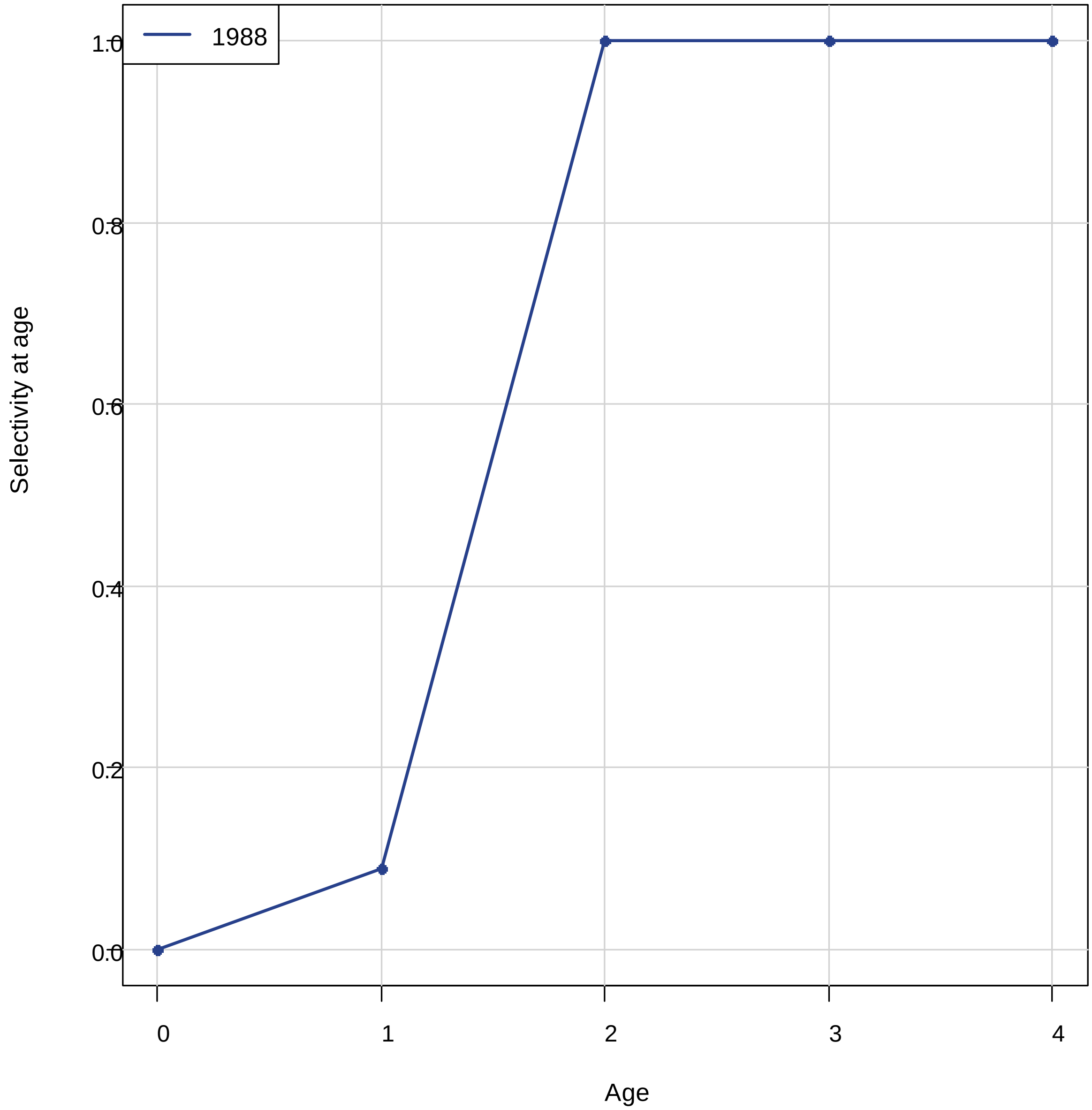


Figure 15. Selectivity of the LA gillnet survey, 1988-2020.

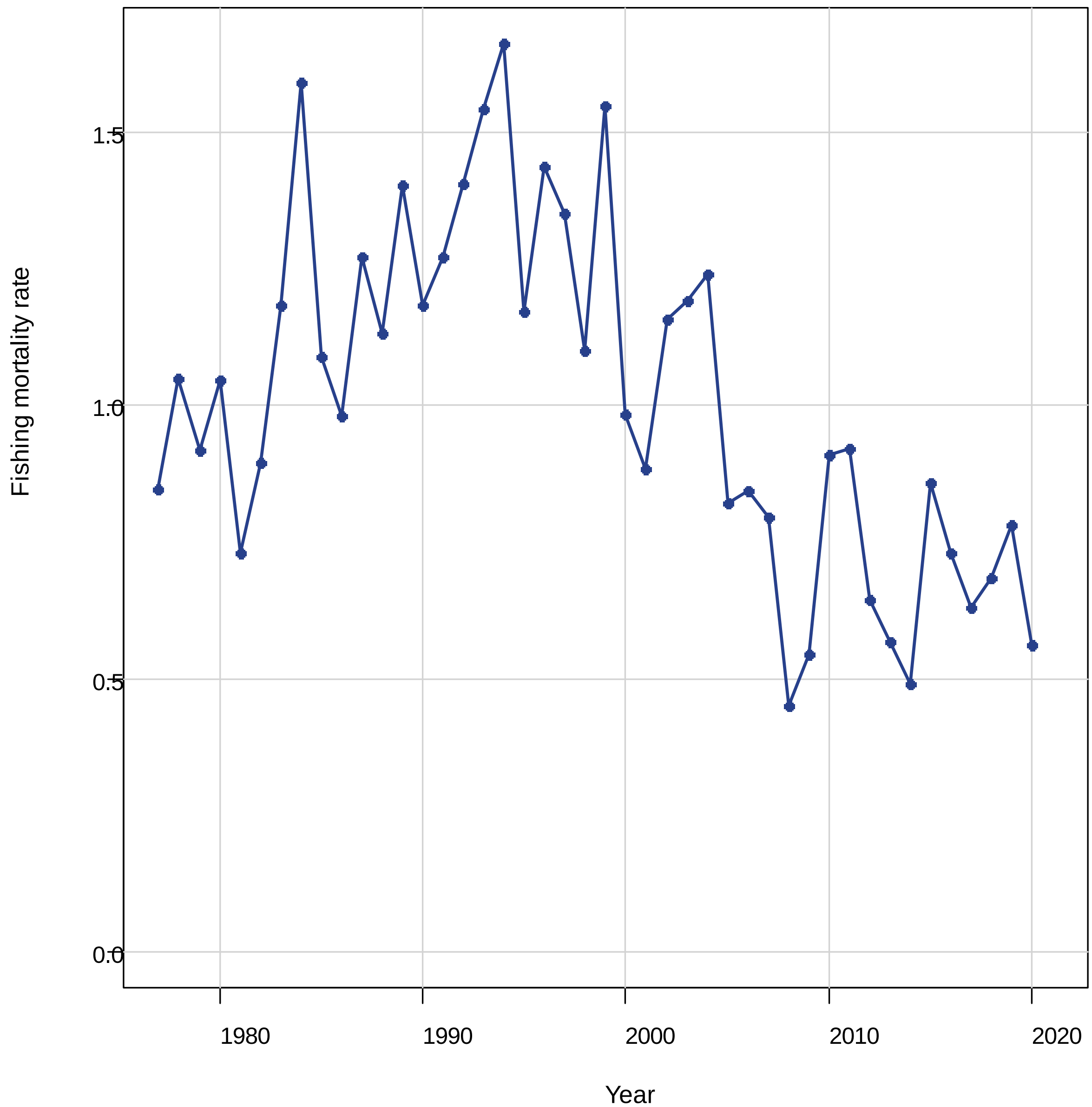


Figure 16. Estimated fully selected fishing mortality rate (per year) for the commercial reduction fishery.

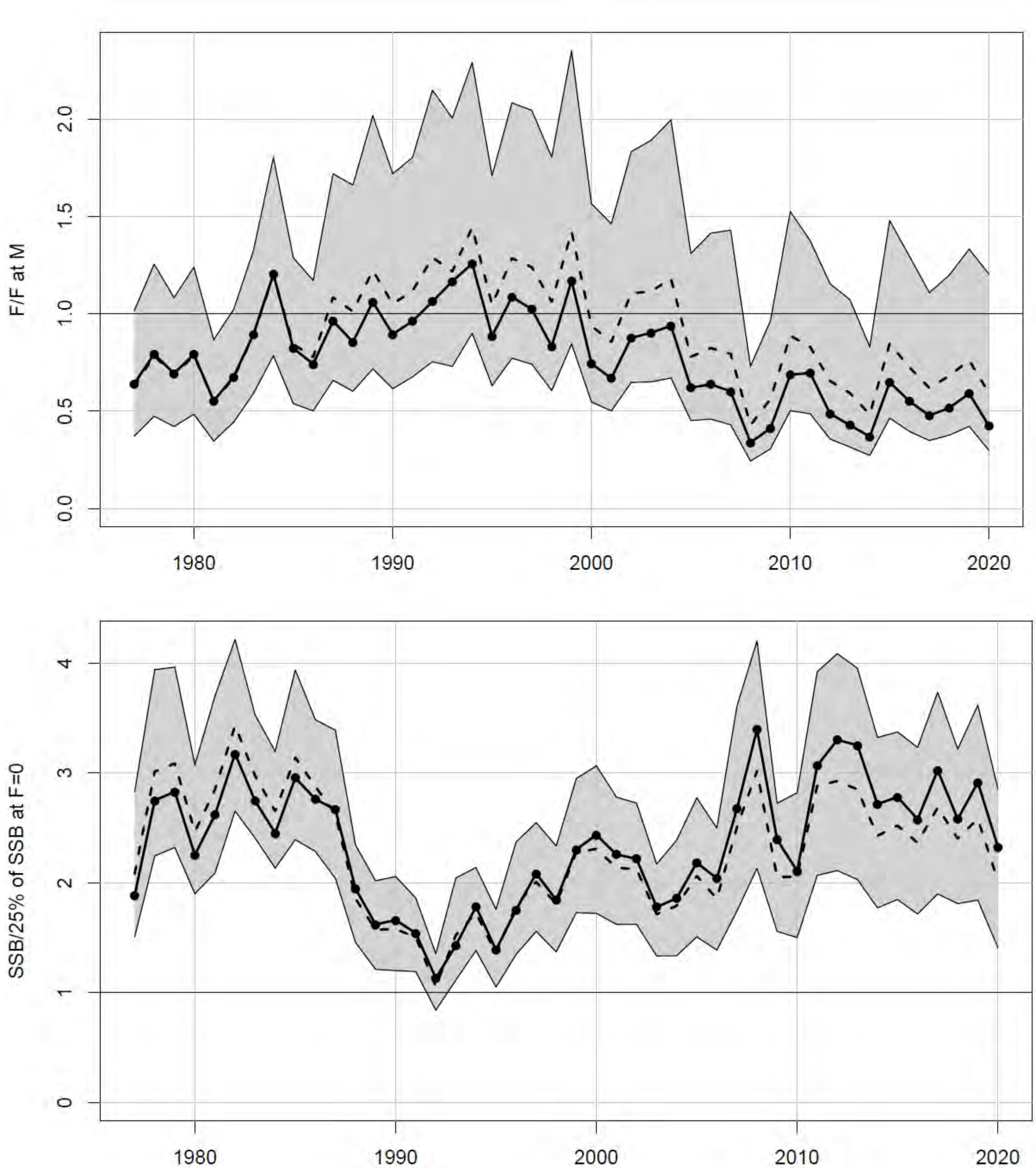


Figure 17. Estimated time series relative to threshold benchmarks. Solid line indicates estimates from base run of the Beaufort Assessment Model; gray error bands indicate 5th and 95th percentiles of the MCBE runs; dashed line indicates 50th percentile from the MCBE runs. Top panel: F relative to $F_{F=M}$.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

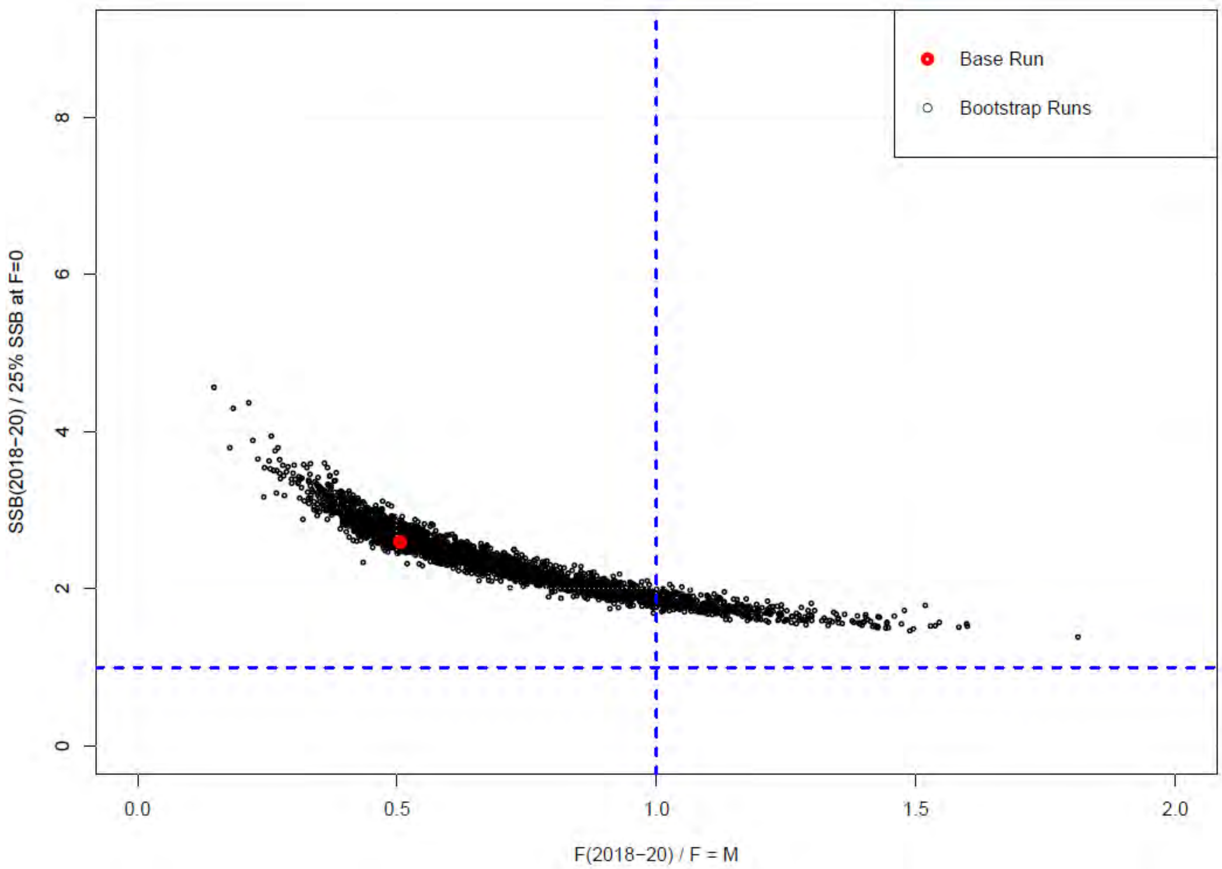


Figure 18. Phase plot of the geometric mean 2018-2020 terminal status estimates from the MCBE analysis of the Beaufort Assessment Model. The red point indicates estimates from the base run; the black points are individual MCBE runs.

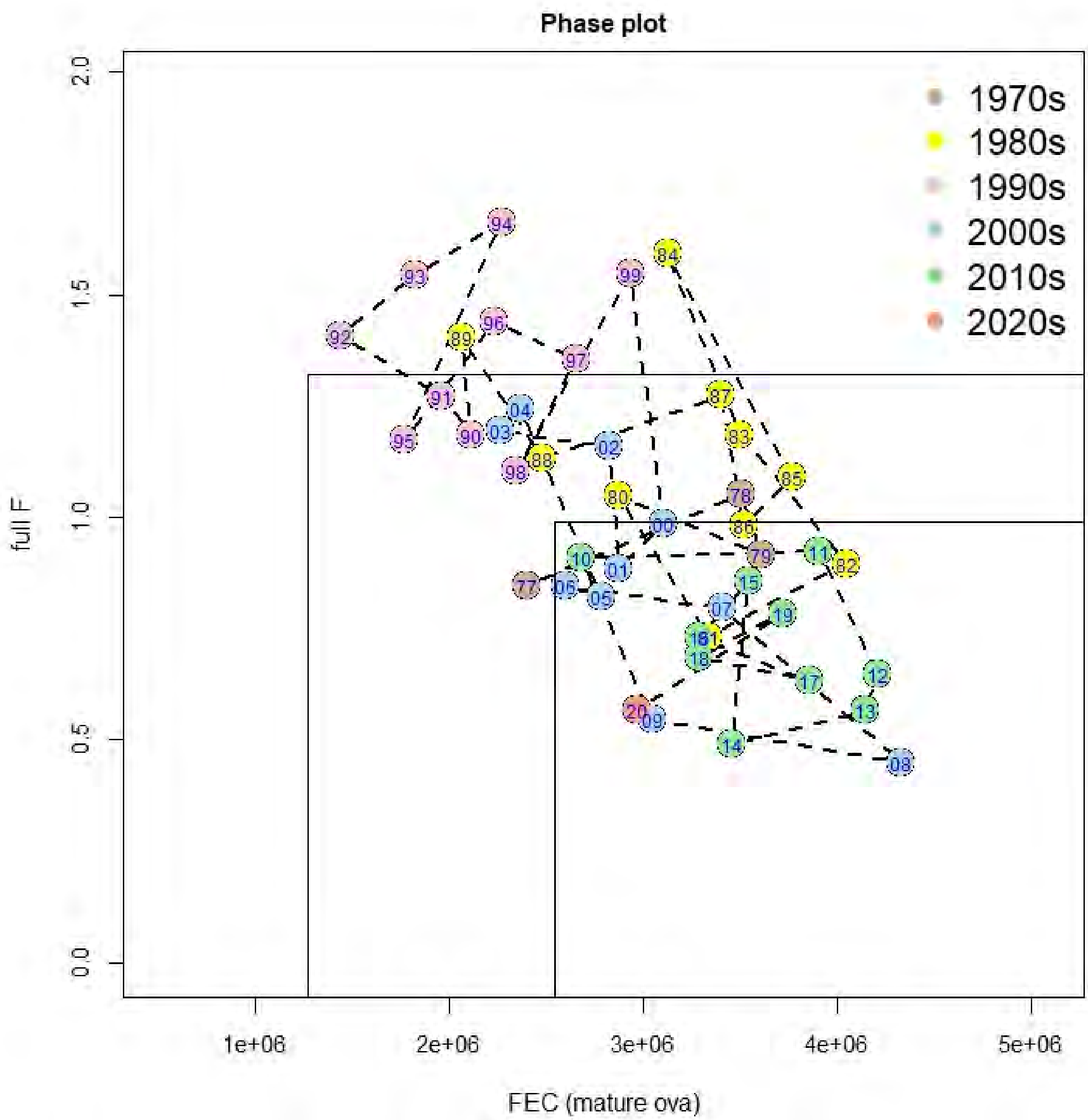


Figure 19. Phase plot of annual estimates of fishing mortality (F) and spawning stock biomass (SSB) or fecundity from the base BAM model. Vertical and horizontal lines indicate the reference point thresholds and targets.

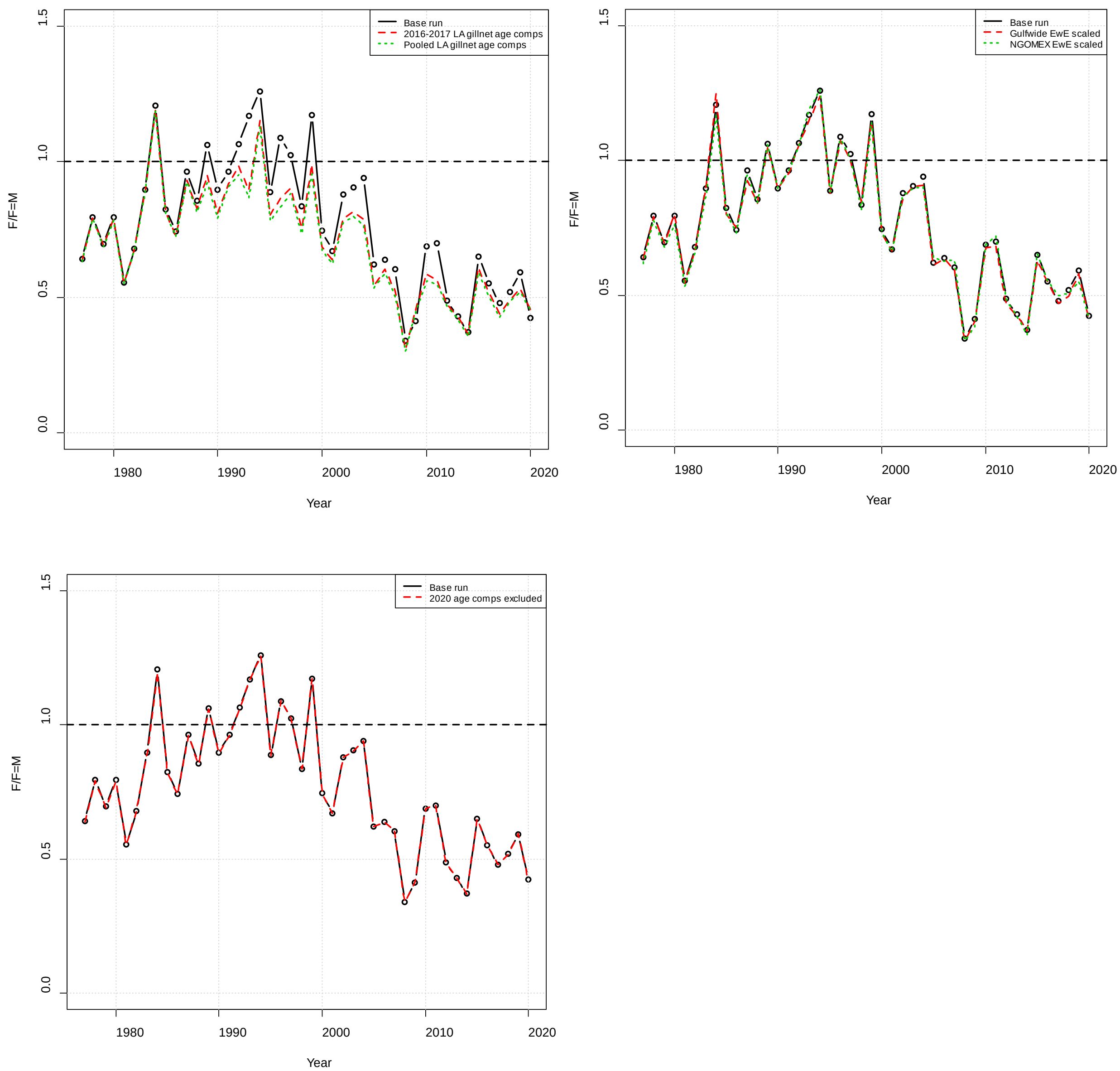


Figure 20. Time series of $F/F_{F=M}$ for the sensitivity runs with the solid black line with open circles being the base run.

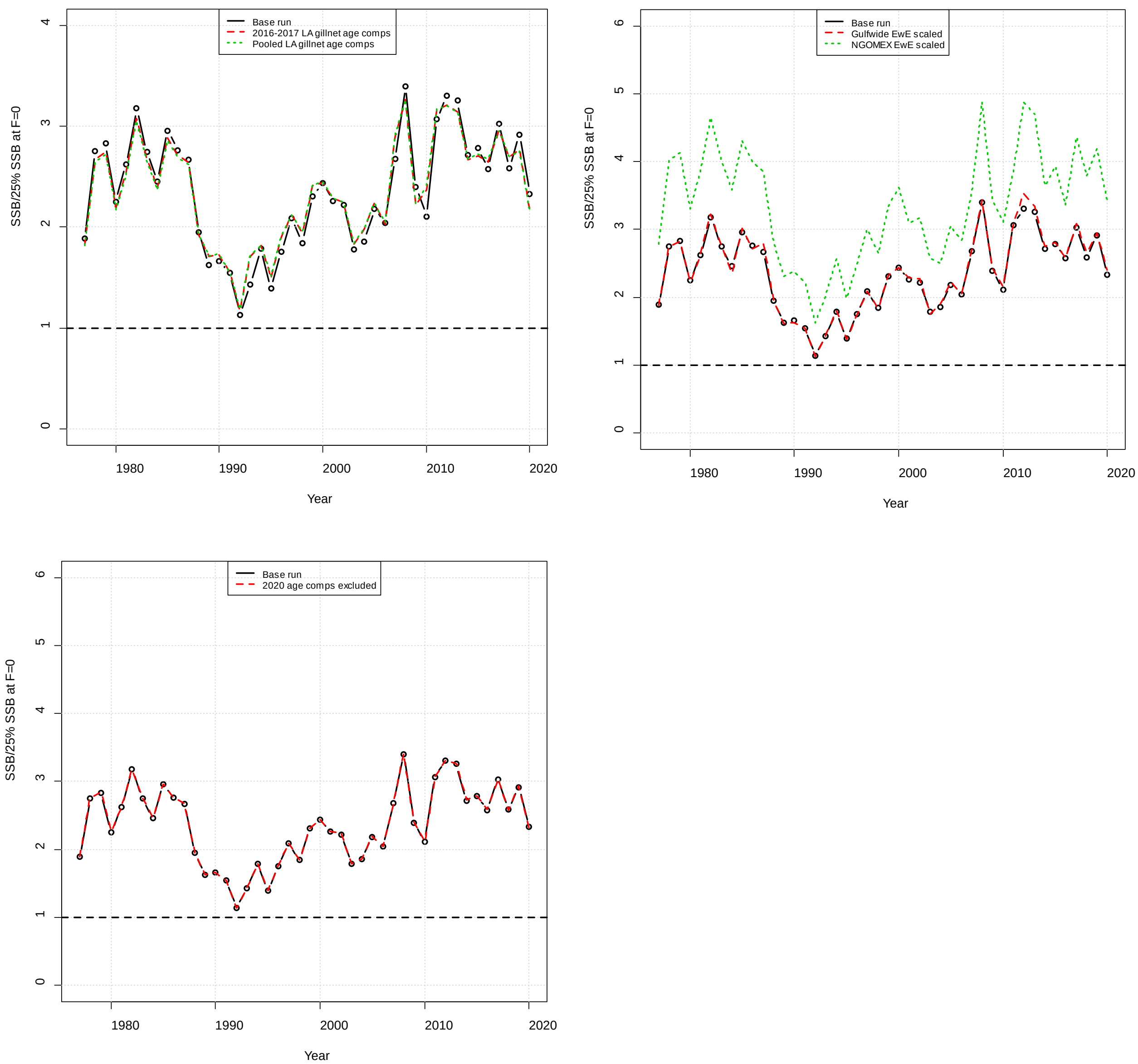


Figure 21. Time series of $SSB/SSB_{25\%\ at\ F=0}$ for sensitivity runs. The solid black line with open circles is the base run.

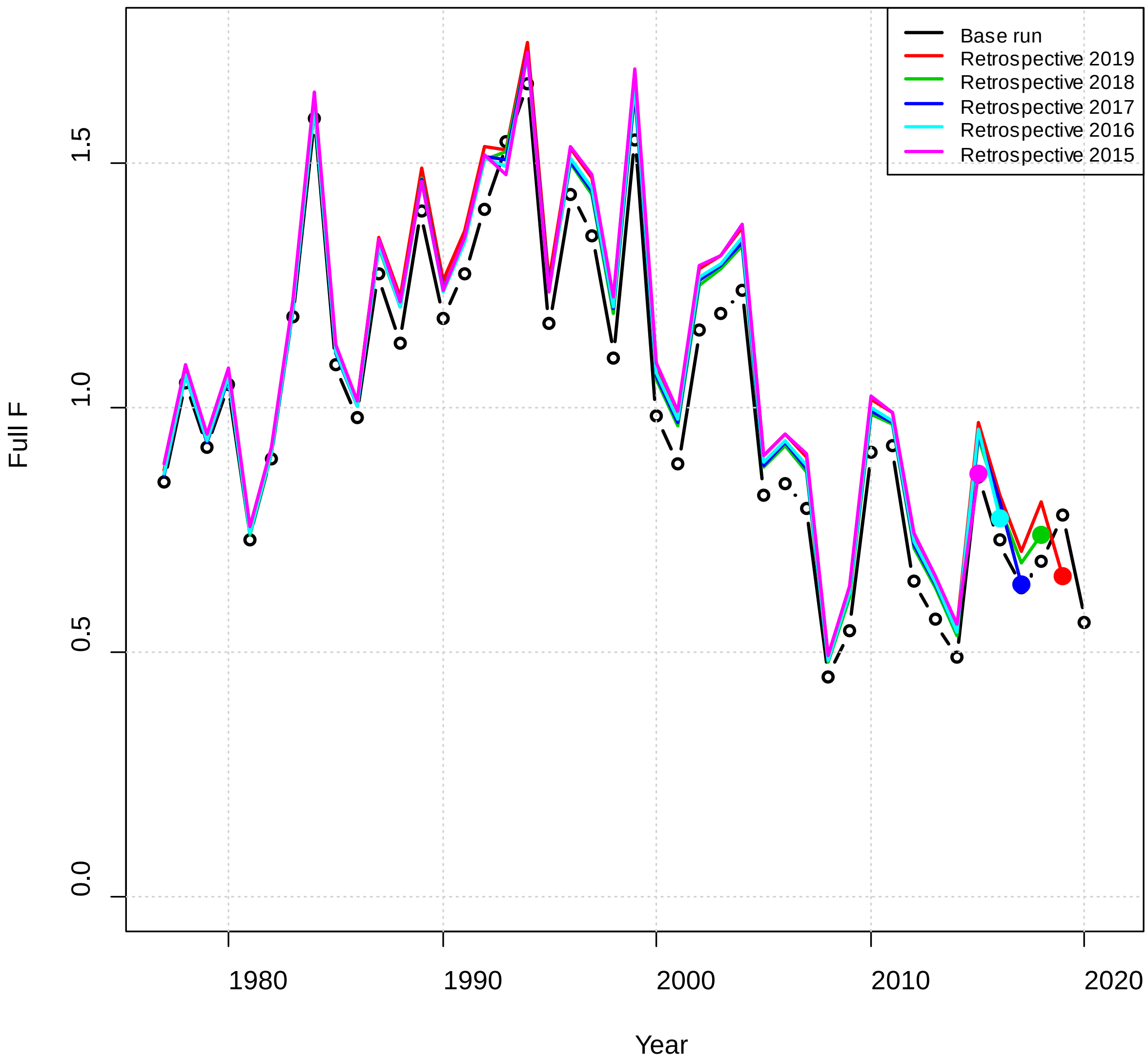


Figure 22. Retrospective analyses. Sensitivity to terminal year of data on the estimation of fishing mortality rate.

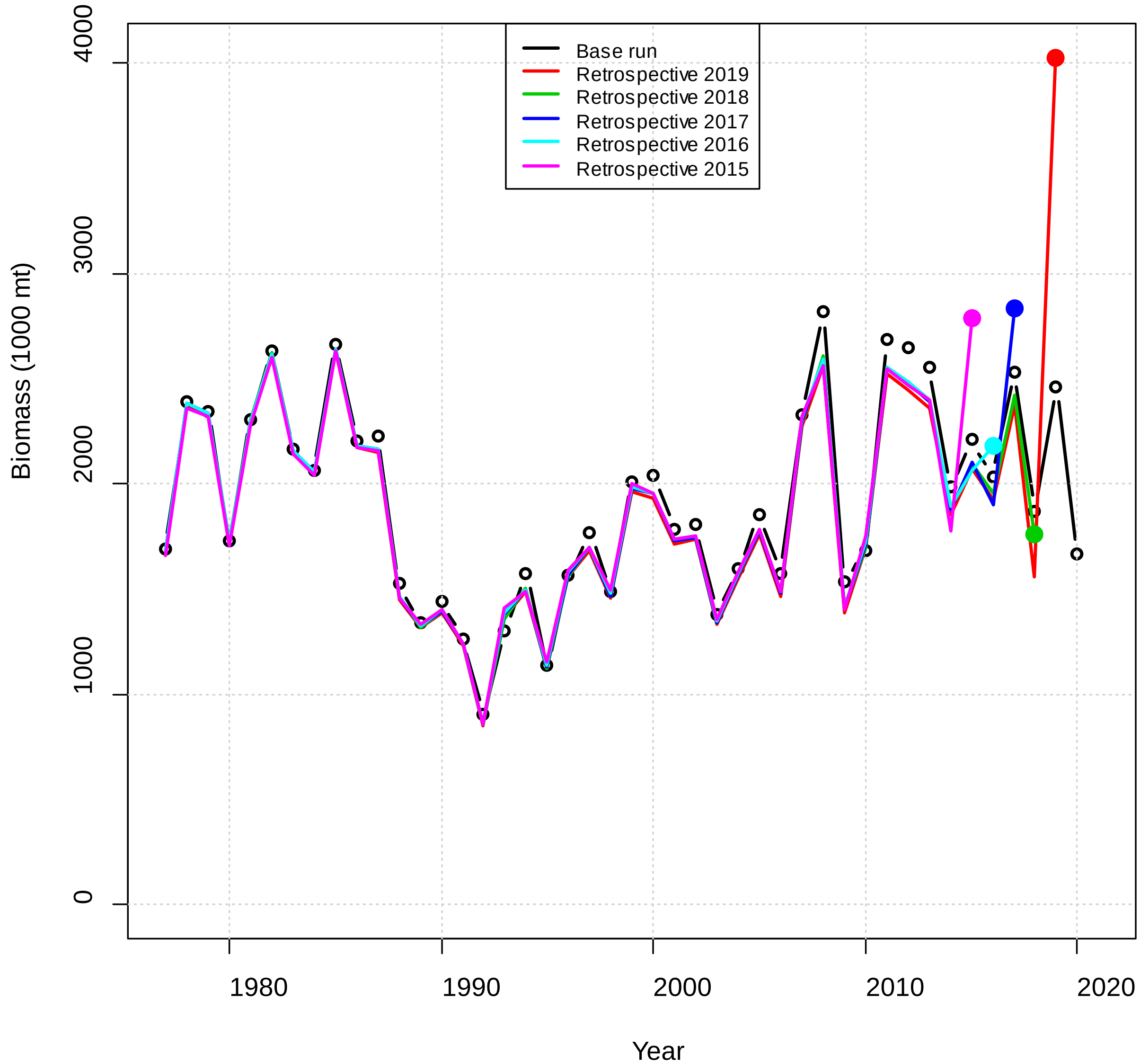


Figure 23. Retrospective analyses. Sensitivity to terminal year of data on the estimation of biomass.

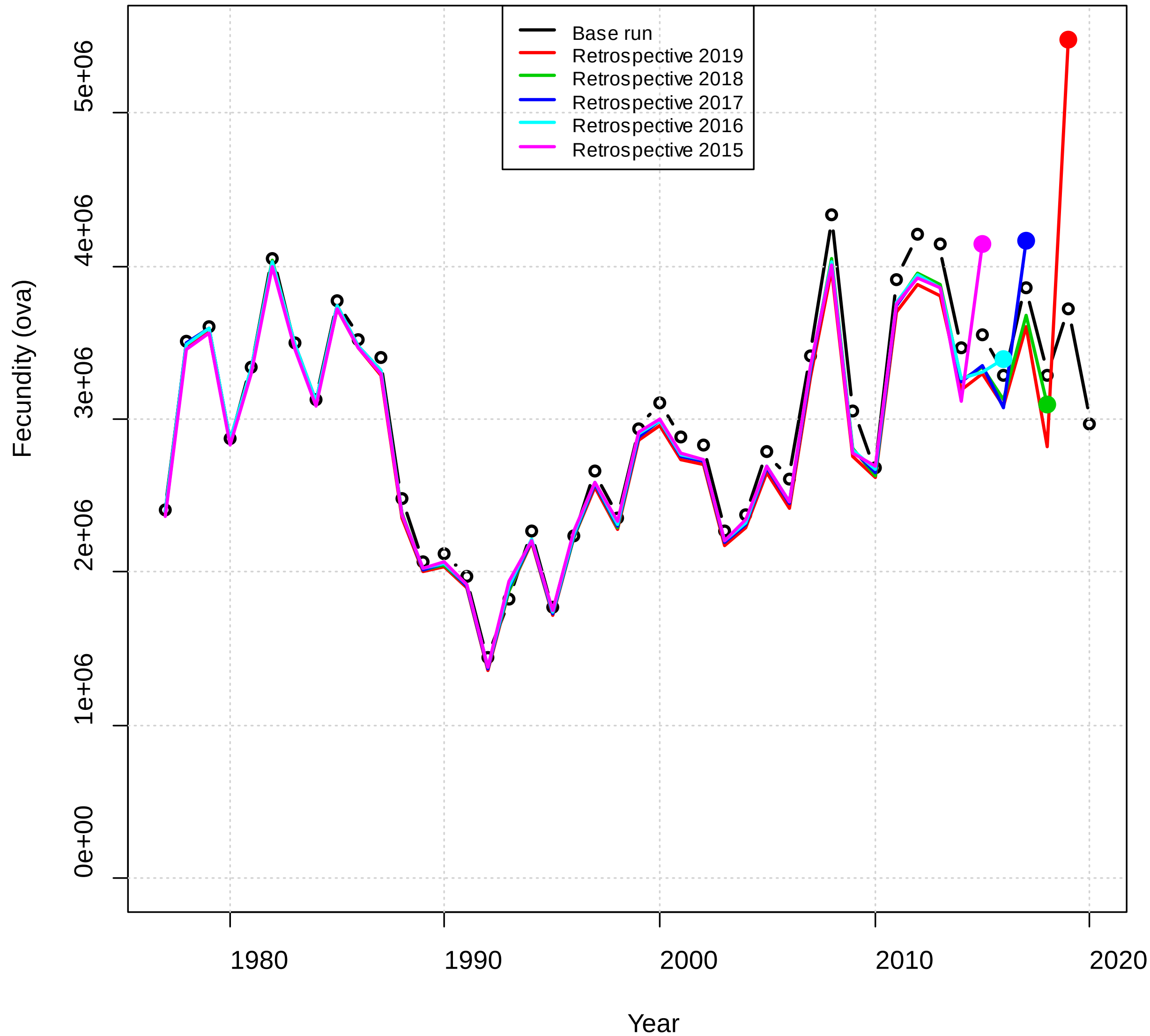


Figure 24. Retrospective analyses. Sensitivity to terminal year of data on the estimation of fecundity.

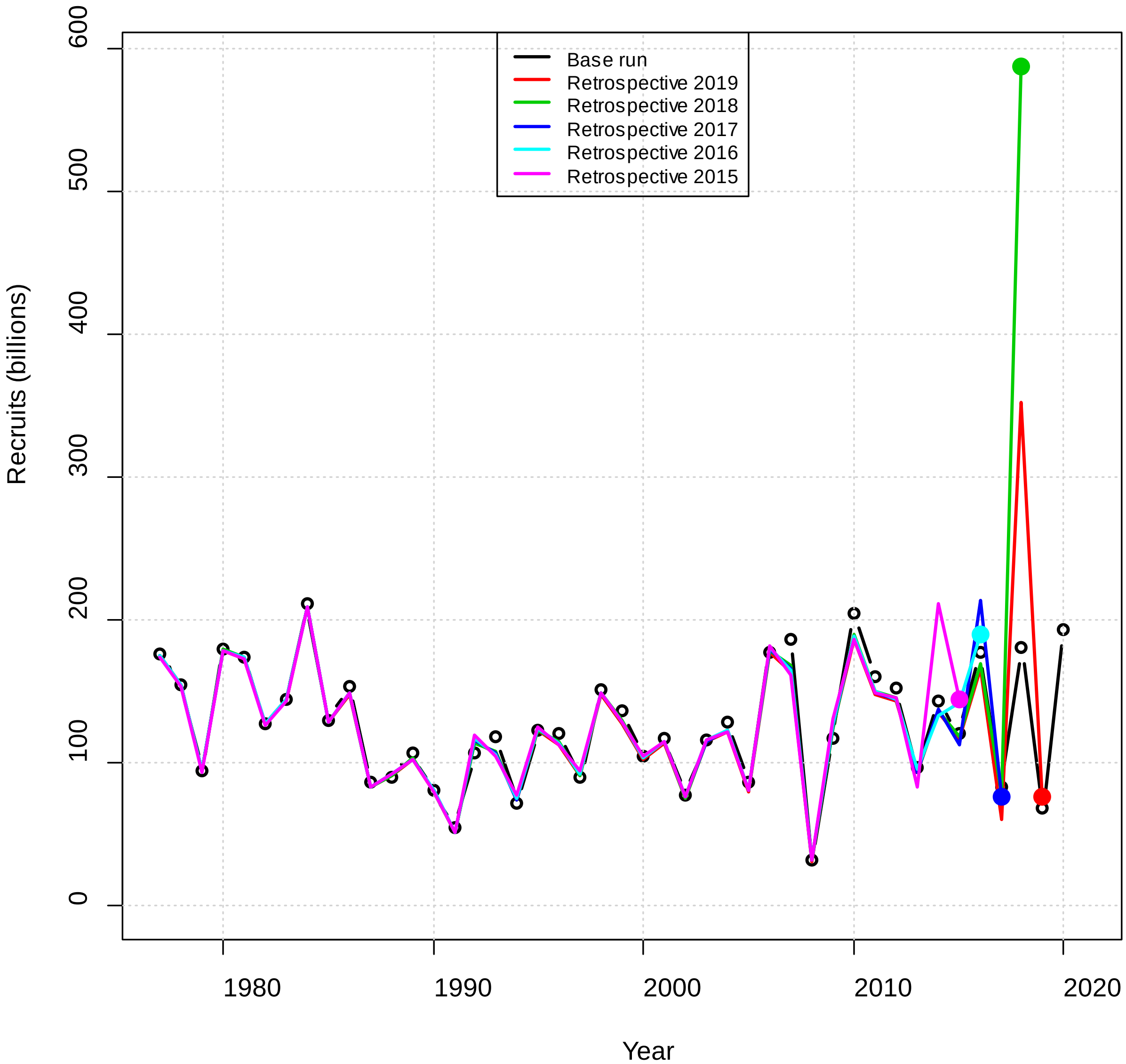


Figure 25. Retrospective analyses. Sensitivity to terminal year of data on the estimation of recruitment.

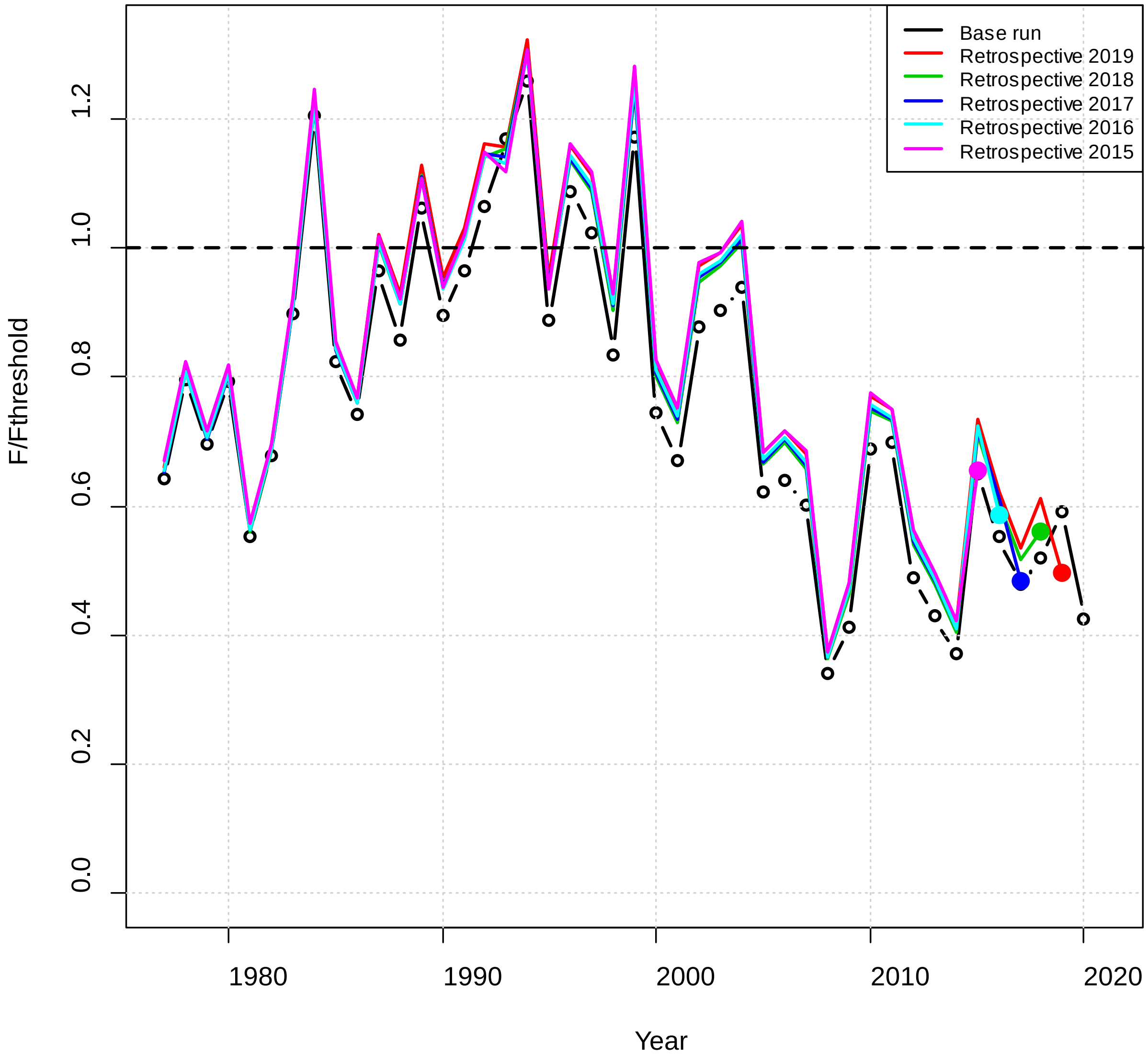


Figure 26. Retrospective analyses. Sensitivity to terminal year of data on the estimation of $F/F_{F=M}$.

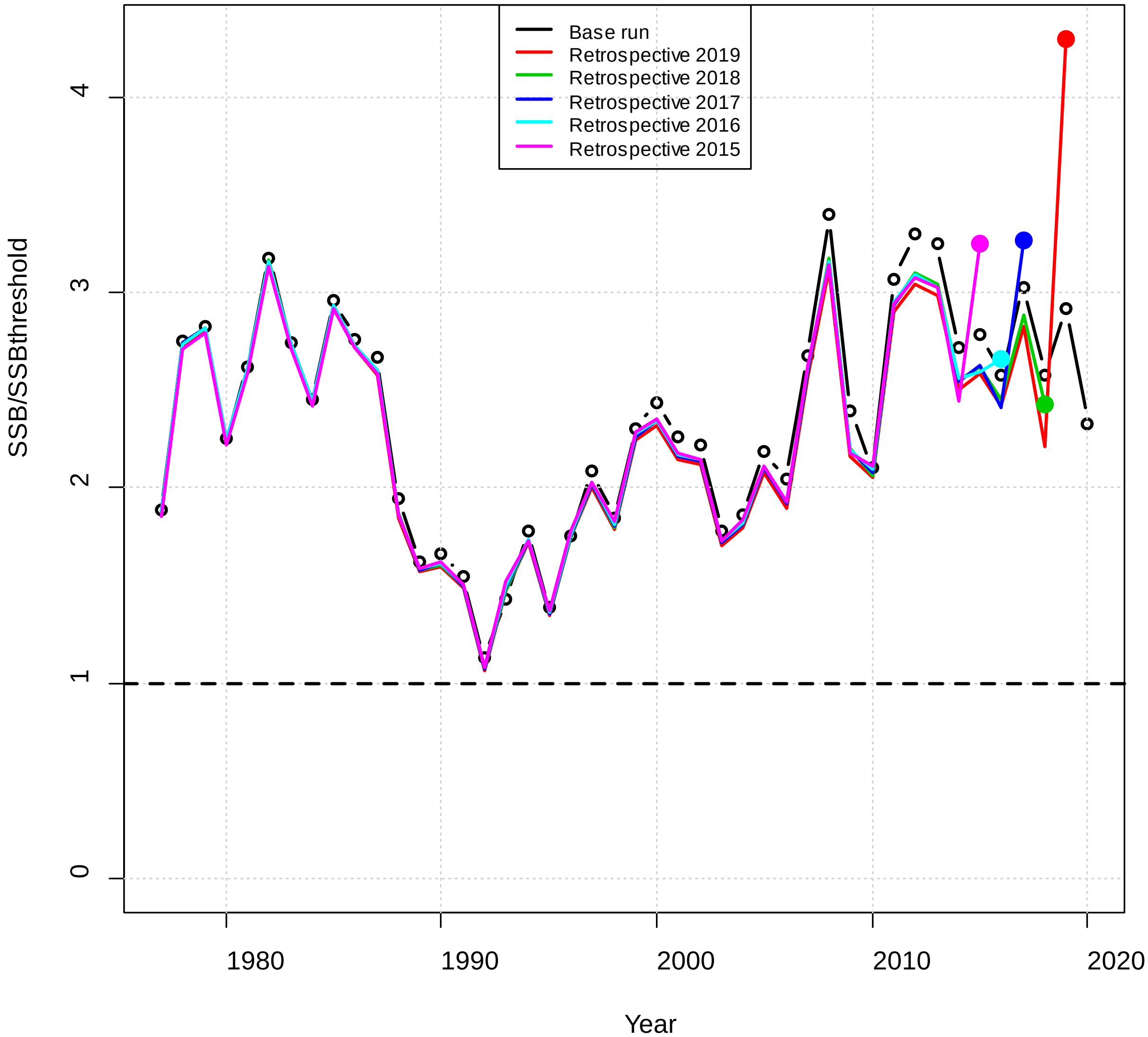


Figure 27. Retrospective analyses. Sensitivity to terminal year of data on the estimation of *$SSB/SSB_{25\%\ at\ F=0}$*.

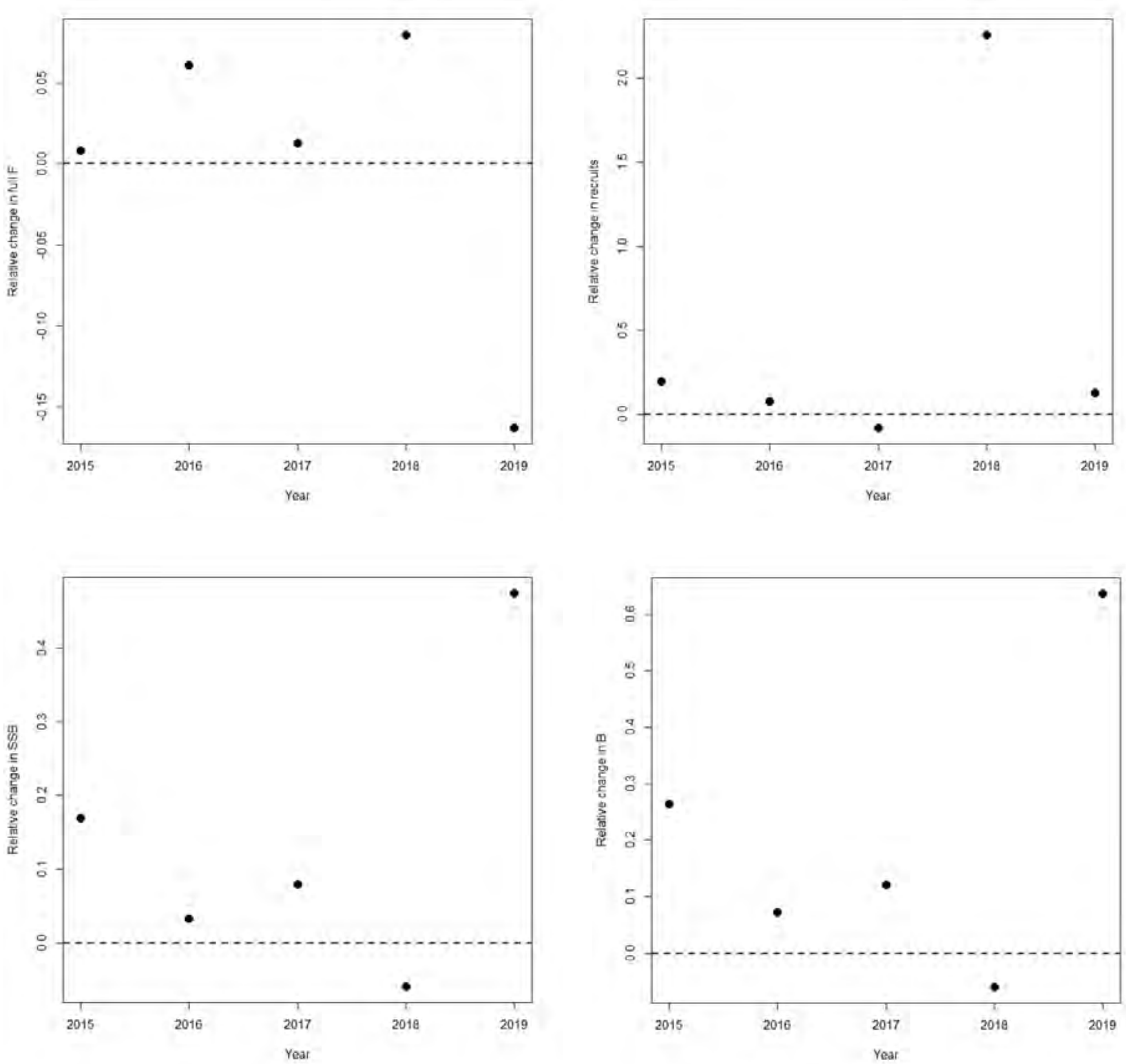
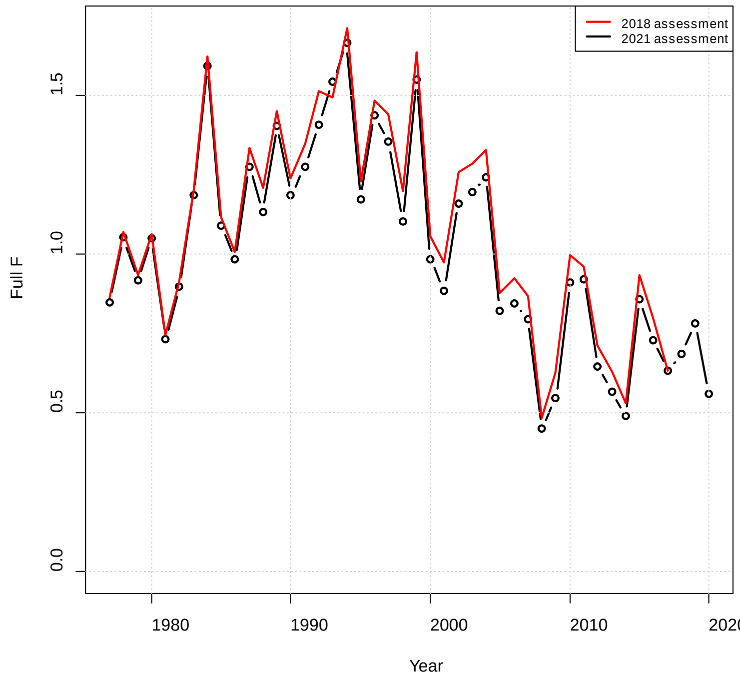


Figure 28. Relative change in fishing mortality, recruitment, spawning stock biomass, and biomass for the retrospective analyses.



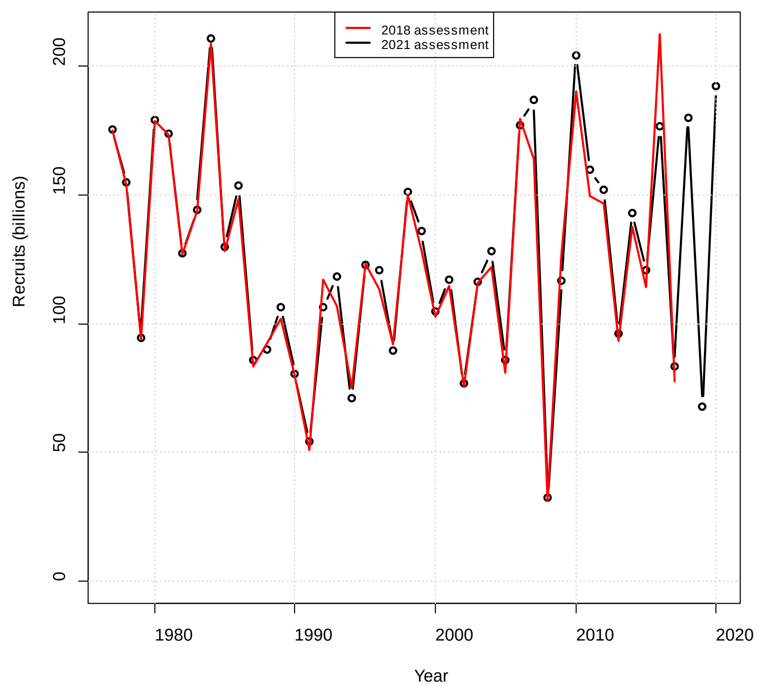


Figure 29. Comparisons of fishing mortality rate and recruitment from this update assessment and the SEDAR 63 benchmark assessment.