# SEDAR
Southeast Data, Assessment, and Review

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# SEDAR 82

# South Atlantic Gray Triggerfish



## SECTION III: Assessment Report

**February 2024**

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# 1 Introduction

## 1.1 Executive Summary

The primary objectives of this assessment were to build on the previous assessment (SEDAR 41, 2016 Benchmark SEDAR41 2016), considering new and existing data sources and analytical methods, and to develop methods to be used for future operational assessments. This assessment was conducted by the Southeast Fisheries Science Center in cooperation with regional data providers, for the assessment period 1982-2021.

Available data on this stock included indices of abundance, landings, discards, and samples of annual length compositions and age compositions from fishery-dependent and fishery-independent sources. A single index of abundance was developed during the SEDAR process and fitted by the model: a fishery independent index combining chevron trap and video data, collected by the Southeast Reef Fish Survey (SERFS). Landings and discard data were available from all significant recreational and commercial sources.

The model used in the previous assessment of this stock—and updated here—was the Beaufort Assessment Model (BAM), an integrated statistical catch-age formulation (Williams and Shertzer 2015). A base run of BAM was configured to provide estimates of key management quantities, such as stock and fishery status. Uncertainty in estimates from the base run was evaluated through a mixed Monte Carlo/Bootstrap Ensemble (MCBE) analysis.

Estimated time series of stock status (SSB/MSST) showed a gradual decline during the assessment period, to a minimum value in the terminal year. Current stock status was estimated in the base run to be $\mathrm{SSB}_{2021}/\mathrm{MSST} = 1.33$, indicating that the stock is not overfished. Through its history, SSB has never dropped below MSST. Results from the MCBE suggested that the estimate of SSB/MSST is rather uncertain, but the stock status is not (Figures 42, 43). The assessment showed that 70.3% of MCBE runs agreed with the stock status result from the base model, that the stock is not overfished in the terminal year.

The estimated time series of $F/F_{40\%}$ from the base model suggests that $F$ has only exceeded $F_{40\%}$ in 2009 and 2010, and in the two most recent years of the assessment (2020 and 2021). However, there is considerable uncertainty in $F/F_{40\%}$ as demonstrated by the MCBE, especially toward the end of the assessment period. Current fishery status in the terminal year, with current $F$ represented by the geometric mean from $2019-2021$ ($F_{\mathrm{current}} = F_{2019-2021} = 0.65$), was estimated by the base run to be $F_{2019-2021}/F_{40\%} = 1.16$. Thus, at the end of the assessment Gray Triggerfish was undergoing overfishing. However, results from the MCBE show that there is a lot of uncertainty in the status of the fishery. The assessment showed that 53.6% of MCBE runs agreed with the fishing status result from the model, and the median value of $F_{2019-2021}/F_{40\%}$ from the MCBE runs (1.06) suggests overfishing. The majority of recent fishing mortality for this stock is from the general recreational landings (Table 12; Figure 33).

### 1.2 Workshop Time and Place

The SEDAR 82 Assessment Process for South Atlantic Gray Triggerfish was conducted via a series of webinars held between March 2023 and January 2024.

### 1.3 Terms of Reference

1. Review any changes in data or analyses following the Data Workshop. Summarize data as used in each assessment model. Provide justification for any deviations from Data Workshop recommendations.
2. Develop population assessment model(s) that are appropriate for the available data.
   a. Provide standard model outputs such as parameter estimates and derived quantities.
   b. Evaluate model diagnostics.
   c. If multiple models are applied, then compare and contrast model performances and appropriateness.
   d. Identify modeling issues encountered.
   e. Comment on the data component weighting used in this stock assessment, if necessary.
3. Recommend biological reference points for use in management.
4. Characterize uncertainty in the assessment and estimated values.
   a. Incorporate uncertainty of appropriate input data.
   b. Provide measures of uncertainty for estimated parameters and derived quantities, including biological reference points and stock status that incorporates appropriate input parameter and data uncertainty.
5. Provide recommendations for future research to improve the assessment. Distinguish between long term research needs and short-term research recommendations that could potentially be implemented for Gray Triggerfish Operational Assessments.
6. Complete an Assessment Workshop Report in accordance with project schedule deadlines.

### 1.4 List of Participants

***Assessment Development Team***

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| Nikolai Klibansky, Lead Analyst | NMFS/SEFSC |
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Mike Schmidtke .......... SAFMC Staff
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### 1.5 Document List

| Document number | Title | Authors | Date Received |
|---|---|---|---|
| | **Documents Prepared for the Assessment Process** | | |
| SEDAR82-AW01 | South Atlantic U.S. gray triggerfish (*Balistes capriscus*) age and length composition from the recreational fisheries | Fitzpatrick 2022*b* | 12/12/2022 |
| SEDAR82-AW02 | South Atlantic U.S. gray triggerfish (*Balistes capriscus*) age and length composition from the commercial fisheries | Fitzpatrick 2022*a* | 12/12/2022 |
| SEDAR82-AW03 | Commercial Discard Estimation of South Atlantic Gray Triggerfish | McCarthy et al. 2022 | 2/21/2023 |
| | **Reference Documents** | | |
| SEDAR82-RD58 | Timing and locations of reef fish spawning off the southeastern United States | Farmer et al. 2017 | 11/30/2022 |
| SEDAR82-RD59 | Virginia Game Fish Tagging Program Annual Report 2021 | Musick and Gillingham 2022 | 12/14/2022 |
| SEDAR82-RD60 | Report of the Working Group on Fish Ecology (WGFE) | ICES 2008 | 12/14/2022 |
| SEDAR82-RD60 | Report of the Working Group on Fish Ecology (WGFE) | ICES 2009 | 12/14/2022 |
| SEDAR82-RD61 | Seaweed, seaweed everywhere | Gower and King 2019 | 1/4/2023 |
| SEDAR82-RD62 | The great Atlantic *Sargassum belt* | Wang et al. 2019 | 1/4/2023 |
| SEDAR82-RD63 | The establishment of a pelagic Sargassum population in the tropical Atlantic: Biological consequences of a basin-scale long distance dispersal event | Johns et al. 2020 | 1/4/2023 |
| SEDAR82-RD64 | Southeast Florida and South Carolina Anglers' Release Practices and Their Attitudes Toward Descending Devices | Responsive Management 2022 | 3/3/2023 |

### 1.6 Comments on Terms of Reference

Note: Original ToRs are in normal font. Statements addressing ToRs are in italics and preceded by a dash (−).

1. Review any changes in data or analyses following the Data Workshop. Summarize data as used in each assessment model. Provide justification for any deviations from Data Workshop recommendations.
   - *See section 2.*

2. Develop population assessment model(s) that are appropriate for the available data.

   a. Provide standard model outputs such as parameter estimates and derived quantities.
   - *See section 4.2.*

   b. Evaluate model diagnostics.
   - *See sections describing results of sensitivity analysis (4.10), an age-structured production model (4.11), and retrospective analysis (4.12).*

   c. If multiple models are applied, then compare and contrast model performances and appropriateness.
   - *See section 4.11 describing results of the age-structured production model.*

   d. Identify modeling issues encountered.
   - *See discussion section 5.1*

   e. Comment on the data component weighting used in this stock assessment, if necessary.
   - *All data components were given equal weight, but see section 3.3.15 for considerations given to data weighting.*

3. Recommend biological reference points for use in management.
   - *See methods sections 3.3.14 and 3.5 and results section 4.8.*

4. Characterize uncertainty in the assessment and estimated values.

   a. Incorporate uncertainty of appropriate input data.
   - *See methods section 3.9*

   b. Provide measures of uncertainty for estimated parameters and derived quantities, including biological reference points and stock status that incorporates appropriate input parameter and data uncertainty.
   - *See results section 4.8*

5. Provide recommendations for future research to improve the assessment. Distinguish between long term research needs and short-term research recommendations that could potentially be implemented for Gray Triggerfish Operational Assessments.

− *See research recommendations section 6*

6. Complete an Assessment Workshop Report in accordance with project schedule deadlines.
   - *This SEDAR 82 Research Track Assessment Report satisfies this ToR.*

## 2 Data Review and Update

In the current SEDAR 82 assessment, data through 2021 were considered. For some data sources, the data were simply updated with the additional years of data (2015-2021) using the same methods as in the prior assessments. However, for some sources, it was necessary to update data prior to 2015 as well. The input data for this assessment are described below, with emphasis on the data that required modification beyond just the addition of years. A summary timeline of data sources fit to in this assessment is plotted in Figure 1.

### 2.1 Data Review

In this research track assessment, the Beaufort assessment model (BAM) was fitted to many of the same data sources as in the SEDAR 41, 2016 Benchmark.

- Landings: commercial handline (south and north), recreational headboat (south), general recreational (south and north)
- Discards: recreational headboat (south), general recreational (south and north)
- Indices of abundance: SERFS trap/video
- Length compositions of discards: recreational headboat
- Age compositions of landings: commercial handline, recreational headboat, and SERFS trap/video survey.

Contrasts to data used in the SEDAR 41, 2016 Benchmark assessment include:

- The SEDAR 82 model time period was 1982 – 2021 in contrast to 1988 – 2014 for the SEDAR 41, 2016 Benchmark.
- Although the basic fleet structure for removals (landings and discards) was the same as in SEDAR 41, 2016 Benchmark, in SEDAR 82 removals were spatially divided along the North Carolina-Virginia line [i.e. the northern boundary of the Southeast Fishery Management Council's (SAFMC) jurisdiction] and modeled separately. Landings or discards from north of this line are referred to as "nort" and those from south of this line are referred to as "south". All indices and composition data are from the southern region that encompasses the SAFMC jurisdiction.
- The age composition data was divided into two time periods (period a, early: 1982 – 2014 and (period b, late: 2015 – 2021) due to improvements in aging methods in the latter period. In the early period ages 1-5+ were used in age compositions while in the late period ages 1-8+ were used.

### 2.2 Data Update

#### 2.2.1 Life History

Some life-history inputs from SEDAR 41, 2016 Benchmark remained the same in SEDAR 82, but several others were updated based on newer data. The length to weight conversion equation, time of peak spawning, and length to batch fecundity equation were the same. Population and fishery growth model parameters, proportions female-at-age, maturity-at-age, number of batches spawned-at-age, maximum observed age, natural mortality constant, and natural mortality-at-age were all updated for SEDAR 82. Primary life-history information is summarized in Table 1. Discard mortality rates also differed from SEDAR 41, 2016 Benchmark.

#### 2.2.2 Landings and Discards

Landings estimates were combined into three fleets: commercial handline, recreational headboat, and general recreational (Table 2). Data providers also provided coefficients of variation (CVs) associated with landings (Table 3), which were not used in fitting the stock assessment model but were used to generate bootstrap data sets during the uncertainty analysis. Commercial landings of Gray Triggerfish were compiled from 1950 through 2021 for the entire U.S. Atlantic Coast, in whole weight (WW). Only landings from 1982 to 2021 were included in this assessment as landings prior to 1982 were minimal. Sources for landings in the U.S. South Atlantic (Florida through North Carolina) included the Florida Trip Ticket program (FTT), South Carolina Department of Natural Resources (SCDNR), North Carolina Division of Marine Fisheries (NCDMF), and the Atlantic Coastal Cooperative Statistics Program (ACCSP).

Commercial handline landings included gear types such as hook and line, bandit reels, and similar hook gear. Landings from other commercial gear types and commercial dead discards were limited and these were included in the commercial handline landings in the assessment. Commercial dead discards were provided to the assessment team in numbers and were converted to weight (1000 lb) during the assessment process. Weight of discards was computed by converting the available recreational discard length compositions to weight with equation 2. Annual mean weights were computed, and then an overall mean weight of a discarded fish as 1.06 lb. Commercial dead discards in numbers were multiplied by that value to compute dead discards in weight. The total weight of commercial dead discards over the assessment period was 12.5 1000 lb.

Commercial handline landings were divided into separate spatial fleets, north and south of the North Carolina-Virginia border (NC-VA border; northern Council boundary). The north landings include any landings north of the northern Council boundary. The south landings extend to the Florida Keys in Monroe County, Florida along US Highway 1 (southern Council boundary). Landings in Monroe County were apportioned by data providers to exclude landings north of the Florida Keys, which are considered part of the Gulf of Mexico (Table 2).

For this assessment, estimates of recreational landings and discards from the private, charter, and shore modes were based on current Marine Recreational Information Program (MRIP) methodology. This included landings from 1981 to 2021, from the Florida Keys to Massachusetts. These removals were combined into general recrational landings and discards, but were divided into separate spatial fleets, north and south of the NC-VA border. For the northern area, headboat mode landings and discards were included with the general recreational landings and discards. In the southern, recreational landings and discards from the headboat mode were provided by the Southeast Region Headboat Survey (SRHS) (Table 2), and were retained as a separate fleet.

In years where landings or discards were estimated to be zero, but were non-zero earlier and later in the time series, these zeros were considered to be missing information and were filled with linear interpolation by the assessment team. A simple method was applied, using the R function `stats::approx` which fills a missing value $t, y_t)$ in a time series by interpolating a straight line from adjacent non-missing values $(t-1, y_{t-1})$ and $(t+1, y_{t+1})$. This method was applied to commercial landings (north) for $1984 - 1989$, general recreational landings (north) for 1981, general recreational discards (north) for 1988, and headboat discards (south) in 1987, 1990, 1993, and 1998.

#### 2.2.3 Indices of abundance

Two indices of abundance were recommended for use in SEDAR 82: SERFS chevron trap (Bubley and Willis 2022) and SERFS video index (Bacheler et al. 2022). These indices were developed from the SERFS which deploys chevron traps with video cameras mounted on them. Trap and video data are paired. The separate indices showed very similar trends and were combined into a single SERFS trap/video index using an averaging approach (Conn Method; Conn 2010). The resulting index and CVs are presented in Table 4.

#### 2.2.4 Length Composition

Length compositions were developed from the recreational headboat discard sampling data from the U.S. South Atlantic. Sample sizes by year and fleet are reported in Tables 5 (number of trips) and 6 (number of fish). Following the methodology of SEDAR 41, 2016 Benchmark and other Beaufort Lab stock assessments, the contribution of each length was weighted by the discards by state.

#### 2.2.5 Age Composition

Age data were available from the commercial handline, recreational headboat, and SERFS sampling programs in the U.S. South Atlantic. The age composition data was divided into two time periods (period a, early: 1982 − 2014 and period b, late: 2015 − 2021) due to improvements in aging methods in the latter period. In the early period ages 1-5+ were used in age compositions while in the late period ages 1-8+ were used. Sample sizes by year and fleet are reported in Tables 5 (trips) and 6 (fish).

## 3 Stock Assessment Methods

This assessment updates the primary model applied during the SEDAR 41, 2016 Benchmark assessment for Gray Triggerfish (*Balistes capriscus*) off the Southeastern United States (hereafter South Atlantic Gray Triggerfish). The methods are reviewed below, and any changes since the SEDAR 41, 2016 Benchmark are emphasized.

### 3.1 Overview

This operational assessment updated the primary model applied in SEDAR 41, 2016 Benchmark (SEDAR41 2016), which was developed using the Beaufort Assessment Model (BAM) software (Williams and Shertzer 2015). BAM applies a statistical catch-age formulation, coded in AD Model Builder (Fournier et al. 2012). BAM is referred to as an integrated model because it uses multiple data sources relevant to population and fishery dynamics (e.g. removals, length and age compositions, and indices of abundance) in a single framework (Schaub et al. 2024). In essence, the catch-age model simulates a population forward in time while including fishing processes (Quinn and Deriso 1999; Shertzer et al. 2008). Quantities to be estimated are systematically varied until characteristics of the simulated population match available data on the real population. The model is similar in structure to Stock Synthesis (Methot and Wetzel 2013) and other stock assessment models used in the United States (Dichmont et al. 2016; Li et al. 2021). Versions of BAM have been used in previous SEDAR assessments of reef fishes in the U.S. South Atlantic, such as Black Sea Bass, Blueline Tilefish, Gag, Greater Amberjack, Red Grouper, Red Porgy, Red Snapper, Snowy Grouper, Tilefish, and Vermilion Snapper, as well as in the previous SEDAR assessment of Gray Triggerfish (SEDAR41 2016).

### 3.2 Data Sources

The catch-age model included data from the fishery independent SERFS trap/video survey, and fleets that landed or discarded South Atlantic Gray Triggerfish: commercial handline, recreational headboat, and the general recreational fleet. The model was fitted to closely to annual landings and dead discards (Table 2) with a CV of 0.05. As noted in section 2 CVs associated with landings (Table 3) were used in the uncertainty analysis, but not the base model. The model was also fitted to the fishery independent SERFS trap/video survey index of abundance (Table 4). The model was also fitted to annual length compositions of headboat recreational discards and annual age compositions from commercial handline and recreational headboat landings, and from the SERFS trap/video survey. Samples sizes associated with composition data are provided in numbers of trips (Table 5) and numbers of fish (Table 6). Data used in the model are described in section 2 of this report, the SEDAR 82 Data Workshop Report (SEDAR82-DW 2023), and Data Workshop working papers (see https://sedarweb.org/assessments/sedar-82).

### 3.3 Model Configuration

Model structure and equations of the BAM are detailed in Williams and Shertzer (2015). The time period for this assessment was 1982 – 2021. A general description of the assessment model follows.

#### 3.3.1 Stock dynamics

In the assessment model, new biomass was acquired through growth and recruitment, while abundance of existing cohorts experienced mortality from fishing and natural sources. The population was assumed closed to immigration and emigration. The modeled population included age classes $1 - 8^+$, where the oldest age class $8^+$ allowed for the accumulation of fish (i.e., plus group).

#### 3.3.2 Initialization

Initial (1982) abundance at age was estimated in the model as follows. The equilibrium age structure was computed for ages 1–8 based on natural mortality and initial fishing mortality ($F_{\text{init}}$). The value of $F_{\text{init}}$ was estimated in the model, with a light normal prior centered at a low value, since landings prior to 1982were very low. The prior was necessary since likelihood profiling conducted during the assessment suggested that the data provided little information to freely estimate $F_{\text{init}}$. Lognormal deviations around the equilibrium age structure were found not to deviate from zero during model development and thus were fixed at zero.



#### 3.3.3 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). As in previous SEDAR assessments, the age-dependent estimates of $M_a$ were rescaled to provide the same fraction of fish surviving from age-5 through the oldest observed age (16 yr) as would occur with constant $M = 0.38$ (SEDAR82-DW 2023). This approach using cumulative mortality is consistent with the findings of Hoenig (1983) and Hewitt and Hoenig (2005). For the MCBE analysis, $M$ was randomly drawn from a uniform distribution from $0.2387 - 0.5313$, and $M_a$ rescaled accordingly.

#### 3.3.4 Growth

Mean length in the population [$l_a$; fork length (FL) in millimeters, (mm)] was modeled with the von Bertalanffy function of age ($a$)

$$l_a = L_\infty(1 - exp[-K(a - t_0 + \tau)]) \tag{1}$$

where $L_\infty = 441$, $K = 0.36$, and $t_0 = -0.94$, are parameters estimated external to the assessment model during the SEDAR 82 process and $\tau = 0.5$, representing a fraction of the year (Figure 2A). Here, $l_a$ is being computed at midyear. All parameters in Eq. 1 were treated as fixed input to the assessment model. For fitting length composition data, the distribution of size at age was assumed normal with coefficient of variation estimated by external fitting ($CV_l = 0.16$). A constant CV, rather than constant standard deviation, was suggested by the size at age data. The population growth model is used in the assessment model to generate a length-age conversion matrix applied to the population and discards (Figure 3A).

A separate growth model, also using Eq. 1,was developed external to the assessment based on fishery-dependent ages and length data, and was applied to the landings. The estimated parameters for this where $L_{\infty,L} = 517$, $K_L = 0.12$, $t_{0,L} = -6.62$, and $CV_{l,L} = 0.11$ (Figure 2B). The fishery growth model is used in the assessment model to generate a length-age conversion matrix applied to the landings (Fig 3B).

### 3.3.5 Age Error

An ageing error matrix was developed for SEDAR 82 using methods developed by Punt et al. (2008) using Agemat software developed by the Northwest Fisheries Science Center (Johnson et al. 2023). Data used to develop the age error matrix were for a set of fish aged using both otoliths and dorsal spines, in an age validation study conducted prior to this assessment. Otoliths ages are considered to be more accurate for this species, but spines are much easier to collect, thus most of the available age data are based on spine ages. All of the age data used in the current assessment were based on spines. Thus, the age-error matrix estimates error for each age between otolith and spine ages. A comparison of models developed using Agemat software showed modeling age error with a consant CV across ages was the most parsimonious approach. The resulting matrix is shown in Figure 4.

### 3.3.6 Weight-Length conversion

Weight at age [$w_a$; WW in kilograms (kg)] was modeled as a power function of $l_a$

$$w_a = \theta_1 l_a^{\theta_2} \tag{2}$$

where $\theta_1 = 2.8e-08$ and $\theta_2 = 2.97$ are parameters estimated external to the assessment model during the SEDAR 41, 2016 Benchmark process and treated as fixed input to the assessment model (Table 1).

### 3.3.7 Spawning stock

Spawning stock was modeled using fecundity measured at the time of peak spawning. For Gray Triggerfish, peak spawning was considered to occur at the end of June (June $29^{th}$; $spawn\_time\_frac = 181/365 = 0.5$. Batch fecundity ($f_{\text{batch}}$; eggs) was computed from fork length ($FL$; mm) with the equation

$$f_{\text{batch}} = c + dL \tag{3}$$

where $c = -1776483$, $d = 8704$. Note that although this equation allows $f_{\text{batch}}$ to be negative at smaller sizes (F¡204mm), these smaller fish would generally be younger than age-1 and are not included in the assessment model (Table 1).

Number of batches spawned ($n_{\text{batch}}$) also vary with age (Table 1). Annual fecundity for each mature female is the product of $f_{\text{batch}}$ and $n_{\text{batch}}$. Spawning stock fecundity per fish, is the product of annual fecundity, proportion female, and proportion of females mature (Figure 5A). Spawning stock fecundity per fish is represented in Figure 5B and Table 1 in the reprod column (in units of $10^{12}$ eggs per fish). In the model, this reprod vector is multiplied by numbers of fish-at-age alive at the time of spawning to compute the spawning stock (i.e. total egg production; the SSB analog) defining stock size. In this report, the terms "spawning stock biomass" and abbreviation SSB are still used because they are customary, but in all cases refer to total egg production.

### 3.3.8 Recruitment

Expected recruitment of age-1 fish was predicted from spawning stock fecundity using the mean recruitment model. This is a slight modification from the approach of SEDAR 41, 2016 Benchmark. That assessment used the Beverton–Holt spawner–recruit model, but because the steepness parameter ($h$) could not be estimated (went to its upper bound), the mean recruitment model was approximated by fixing steepness at $h = 0.99$. Instead, the SEDAR 82 assessment applies the mean recruitment model directly, by estimating the average annual recruitment (here, $R_0$).

This modification was made after initial model explorations, including likelihood profiling on $h$, found that steepness still could not be estimated. This result is not uncommon, as steepness is often difficult to estimate reliably (Conn et al. 2010). The underlying assumption of the mean recruitment model is that recruitment is independent of spawning biomass, which is known to be incorrect for extremely low values of spawning biomass (e.g., zero spawners, zero recruits), unless recruits derive from outside the system. This approach has been applied in other recent Beaufort Lab stock assessments (SEDAR73 2021; SEDAR76 2023) and is recommended as a "null model" by Brooks (2024).

To include annual variability in recruitment, the model estimates lognormal deviations around that average, and estimates the standard deviation ($\sigma_R$) of this lognormal distribution. In early runs of the model, $\sigma_R$ had a tendency to be estimated at the lower bound and thus was initialized at a value of 0.6 from a meta-analysis, and estimated with a normal prior. Annual variation in recruitment was assumed to occur with lognormal deviations for years $1990 - 2018$ only. The first year recruitment residuals were estimated (1990) was the year when age composition data was first available (for the headboat fleet), providing information on year class strength. The last year that recruitment residuals were estimated (2018) was two years prior to the last year of age composition data (for the commercial handline fleet). Gray Triggerfish start to be selected by this fleet around age-3, so year class strength for the 2018 age-1 recruits may be detected in the 2020 age composition data.

### 3.3.9 Landings and Discards

Time series of removals from three fleets were modeled over the $1982 - 2021$ assessment period: commercial handline, general recreational, and recreational headboat. Landings for each fleet over the assessment period were provided by the Data Workshop panel. Commercial discard estimates were only available for the southern area, and were a small proportion of commercial landings. So for the southern area, a discard mortality rate of 0.59was applied to commercial discards, and the estimated dead discards were pooled with commercial handline landings. Headboat discards were also a small proportion of headboat landings, but length compositions of headboat discards were available to inform selectivity, and so headboat landings and discards were modeled separately. General recreational discards were assumed to have the same selectivity as for headboat discards, in part due to insufficient composition data to model a separate selectivity. The same discard mortality rate was assumed for all fleets and for the entire assessment period ($\delta = 0.59$). As noted in section 2.2.2, landings and discards were modeled as spatial sub-fleets (south and north), divided at the NC-VA border, when the data allowed. Removals were modeled with the Baranov catch equation (Baranov 1918) and were fitted in either units of weight (1000 lb whole weight, commercial) or numbers (1000 fish, recreational).

### 3.3.10 Fishing Mortality

For each time series of landings and discard mortalities, the assessment model estimated a separate full fishing mortality rate ($F$). Age-specific rates were then computed as the product of full $F$ and selectivity at age. Apical $F$ was computed as the maximum of $F$ at age summed across fleets.

#### 3.3.11 Selectivities

Selectivity at age was estimated using a two-parameter, flat-topped, logistic model in most cases. Headboat discard selectivity was the exception, which was modeled with a logistic-exponential function, which declines exponentially from 100% selection at age-1. The function has 4-parameters, but three were fixed during the assessment process, such that only the parameter describing the rate of decent of the curve was estimated.

Separate selectivity functions were estimated for commercial handline, recreational headboat landings, recreational headboat discards, as well as for the SERFS trap/video index. Selectivities for general recreational landings and discards were set equal to those estimated for recreational headboat landings and discards, respectively.

In the development of the base model, alternativee functional forms and time blocking of selectivity were investigated extensively in attempts to improve fits to composition data. But these alternative configurations generally increased complexity without improving fits substantially, and the assessment team chose the current configuration in the interest of parsimony. Examples of early configurations which were attempted but rejected include modeling recreational selectivity with a dome-shaped function, modeling separate selectivities for the headboat and general recreational fleets (see sensitivity run S15), and including multiple time blocks for the SERFS trap/video survey.

Consideration was also given to including separate selectivity time blocks for fishery-dependent selectivities associated with size limits, but it was judged that the limits that had been imposed likely had a negligible effect on selectivity. A 12 inch (304 mm) size limit was applied throughout the South Atlantic in 2015 (and Florida before that), but corresponds to age-1 fish not frequently caught by the fishery. A 14 inch (356 mm) size limit, corresponding to age-3 fish, was implemented in Florida from 2015-2020 but did not appear to have an overall effect on the composition data for the entire region.

#### 3.3.12 Indices of abundance

The model was fit to a single index of relative abundance: SERFS trap/video. As noted in section 2.2.3 this index was a combination of separate chevron trap and video indices. The resulting index and CVs are presented in Table 4.

#### 3.3.13 Catchability

In the BAM, catchability scales indices of relative abundance to the estimated vulnerable population at large. The catchability coefficient for the SERFS trap/video index was assumed constant through time.

#### 3.3.14 Biological Reference Points

Because the assessment did not estimate a spawner-recruit relationship, but instead applied the null model, MSY could not be estimated directly, and instead a proxy was used for biological reference points (benchmarks). The proxy used here was based on a proxy for MSY ($L_{\mathrm{F}40\%}$), based on $F_{40\%}$; that is, the fishing rate that would allow a stock to attain 40% of the maximum spawning potential ($SPR_{40}$), which would have been obtained in the absence of fishing mortality. The value of $F_{40\%}$ was chosen here because of its commonality in fishery management and because it has been shown to be an effective proxy (e.g., Legault and Brooks (2013); Hartford et al. (2019)). The proxy of $F_{30\%}$ has been shown to be appropriate only for very resilient stocks (Brooks et al. 2010), and even $F_{40\%}$ might be an aggressive benchmark for some stocks (Clark 2002; Hartford et al. 2019; Zhou et al. 2020). Reference points based on $F_{40\%}$ have also been used in recent assessments for reef fishes in the South Atlantic (SEDAR68 2021). Computed benchmarks in SEDAR 82 associated with $SPR_{40}$ included the fishing mortality rate ($F_{40\%}$), $L_{\mathrm{F}40\%}$, $D_{\mathrm{F}40\%}$ (discards at $F_{40\%}$), total biomass ($B_{\mathrm{F}40\%}$), and spawning stock ($\mathrm{SSB}_{\mathrm{F}40\%}$; Gabriel and Mace 1999). In this assessment, spawning stock measures population fecundity. The minimum stock size threshold MSST was also computed, by scaling $\mathrm{SSB}_{\mathrm{F40\%}}$ by a proportion $p$ which is defined a $(1 - M)$ or 0.5, whichever is greater. Here $p = (1 - M) = 0.62$ and MSST is defined as $0.62 * \mathrm{SSB}_{\mathrm{F40\%}}$. These benchmarks are conditional on the estimated selectivity functions and the relative contributions of each fleet's fishing mortality. The selectivity pattern used here was the effort-weighted selectivities at age, with effort from each fleet estimated as the full $F$ averaged over the last three years of the assessment.

### 3.3.15 Fitting criterion

The fitting criterion was a penalized likelihood approach in which observed landings and discards were fit closely, and observed composition data and the abundance index were fit to the degree that they were compatible. Landings, discards, and index data were fitted using lognormal likelihoods. Length and age composition data were fit using the Dirichlet-multinomial distribution, with sample size represented by the annual number of trips (Table 4), adjusted by an estimated variance inflation factor (i.e. one additional parameter for each fleet's composition data).

The SEDAR 41, 2016 Benchmark fit composition data using the robust multinomial with iterative re-weighting (Francis 2011). Since Francis (2011), additional work on this topic has questioned the use of the multinomial distribution in stock assessment models (Francis 2014), and has recommended the Dirichlet-multinomial as an alternative (Francis 2017; Thorson et al. 2017). A chief advantage of the Dirichlet-multinomial is that it is self-weighting through estimation of an additional variance inflation parameter for each composition component, making iterative re-weighting unnecessary. Another advantage is that it can better account for overdispersion, or, larger variance in the data than would be expected by the multinomial. Overdispersion can result from intra-haul correlation, which results when fish caught in the same set are more alike in length or age than fish caught in a different set (Pennington and Volstad 1994). The Dirichlet-multinomial has been implemented in Stock Synthesis (Methot and Wetzel 2013; Thorson et al. 2017) and in the BAM, and since the SEDAR 41, 2016 Benchmark has become the standard likelihood for fitting composition data in assessments of South Atlantic reef fishes.



The model includes the capability for each component of the likelihood to be weighted by user-supplied values. When applied to landings and indices, these weights modify the effect of the input CVs. In this application to Gray Triggerfish, CVs of landings and discards (in arithmetic space) were assumed equal to 0.05 to achieve a close fit to these data while allowing some imprecision. In practice, the small CVs are a matter of computational convenience, as they help achieve a close fit, while avoiding having to solve the Baranov equation iteratively (which is complex when there are multiple fisheries). In contrast to the SEDAR 41, 2016 Benchmark, iterative re-weighting was not conducted here, in part because the composition likelihoods were self-weighting. Thus, user-supplied data weights were all set equal in the base model, with effective relative weights among data components determined by CVs (landings, discards, index) and the estimated Dirichlet-multinomial variance parameters.

In addition, the compound objective function included several prior distributions, applied to the Dirichlet-multinomial variance inflation factor parameters associated with each set of composition data and the slope parameter for the selectivity function of the general recreational fleet. Priors were applied to maintain parameter estimates near reasonable values, and to prevent the optimization routine from drifting into parameter space with negligible gradient in the likelihood which can result in a non-positive definite Hessian matrix (an indication of incomplete or incorrect parameter solutions).

### 3.3.16 Parameters Estimated

The model estimated a total of 375 parameters including average fishing mortality rates (8 par.) and annual fishing mortality rates (320 par.) for each fleet; annual recruitment deviations (29 par.), selectivity parameters (7 par.), Dirichlet-multinomial variance inflation factors (7 par.), a catchability coefficient associated with each index (1 parameter), the standard deviation of the lognormal recruitment residuals ($\sigma_R$; 1 par.), initial $F$ ($F_{init}$; 1 par.), and virgin recruitment ($R_0$; 1 par.).

### 3.4 Per Recruit and Equilibrium Analysis

Yield per recruit and spawning potential ratio were computed as functions of $F$, as were equilibrium landings and spawning biomass. Equilibrium landings were also computed as functions of biomass $B$, which itself is a function of $F$. As in computation of $F_{40\%}$-related benchmarks (described in section 3.5), per recruit and equilibrium analyses applied the most recent selectivity patterns averaged across fleets, weighted by each fleet's $F$ from the last three years (2019–2021) of the assessment.

### 3.5 Benchmark/Reference Point Methods

A stock-recruit relationship wasn't estimable in this assessment, necessitating a proxy for MSY-based reference points. The quantities $F_{40\%}$, $\mathrm{SSB}_{\mathrm{F40\%}}$, $B_{\mathrm{F40\%}}$, and $L_{\mathrm{F40\%}}$ were estimated here and are recommended as proxies for MSY-based reference points. The value of $F_{40\%}$ is the $F$ that provides 40% SPR. To compute biomass benchmarks, equilibrium recruitment was assumed equal to expected recruitment in arithmetic space (mean unbiased). However, in BAM, spawner-recruit parameters correspond to median-unbiased recruitment. Thus, on average, expected recruitment is higher than that estimated directly from the spawner-recruit model (i.e., $R_0$, when using the mean recruitment model), because of lognormal deviation in recruitment. Therefore, the method of benchmark estimation accounted for lognormal deviation by including a bias correction in equilibrium recruitment. The bias correction ($\varsigma$) was computed from the variance ($\sigma_R^2$) of recruitment deviation in log space: $\varsigma = \exp(\sigma_R^2/2)$. Then, equilibrium recruitment ($R_{eq}$) associated with any $F$ is

$$R_{eq} = \varsigma R_0 \tag{4}$$

where $R_0$ is median-unbiased virgin recruitment. The $R_{eq}$ and mortality schedule imply an equilibrium age structure and an average sustainable yield (ASY). The estimate of $F_{40\%}$ is the $F$ giving 40% of the SPR, and the estimate of $L_{\mathrm{F40\%}}$ is that ASY. The estimates of $\mathrm{SSB}_{\mathrm{F40\%}}$, $B_{\mathrm{F40\%}}$, and $D_{\mathrm{F40\%}}$ follow from the corresponding equilibrium age structure.

Estimates of $L_{\mathrm{F40\%}}$ and related benchmarks are conditional on selectivity pattern. The selectivity pattern used here was an average of terminal-year selectivities from each fleet, where each fleet-specific selectivity was weighted in proportion to its corresponding estimate of $F$ averaged over the last three years (2019–2021). If the selectivities or relative fishing mortalities among fleets were to change, so would the estimates of $L_{\mathrm{F40\%}}$ and related benchmarks.

The maximum fishing mortality threshold (MFMT) is defined here as $F_{40\%}$, and the minimum stock size threshold (MSST) as $(1 - M) * \mathrm{SSB}_{\mathrm{F40\%}}$. Overfishing is defined as $F >$ MFMT and overfished as SSB $<$ MSST. However, if the stock is overfished, the rebuilding target would be $\mathrm{SSB}_{\mathrm{F40\%}}$. Current status of the stock is represented by SSB in the latest assessment year (2021), and current status of the fishery is represented by the geometric mean of $F$ from the latest three years (2019–2021). Generally, South Atlantic assessments have considered the mean over the terminal three years to be a more robust metric than that of a single, terminal year.

### 3.6 Sensitivity Analysis

Sensitivity of results to some key model inputs and assumptions was examined through sensitivity analyses. Sensitivity runs were chosen to address specific questions that arose during the SEDAR 82 assessment process. They were intended to demonstrate directionality of results with changes in inputs or simply to explore model behavior. For several of these sensitivity analyses where a parameter was fixed over a range (e.g. sensitivity to $M$, discard mortality, weight of data sources), results were generated for the runs associated with the lower and upper limits of the range, as well as several runs based on a sequence of values between those limits. In these instances the presentation of results focuses on the runs associated with the limits, and these runs are given identifying numbers (e.g. S1 and S2 associated with low and high values of $M$). These sensitivity model runs vary from the base run as follows.

- S1-S2: Vary initial $F$ ($F_{\text{init}}$) as a fixed value.
  - $F_{\text{init}}$ was fixed over a range from 0.01 (S1) to 0.5 (S2), generating a sequence of 21 runs.
- S3-S4: Vary natural mortality
  - $M$ was fixed over a range from 0.2387 (S3) to 0.5313 (S4), generating a sequence of 5 runs.
- S5-S6: Vary discard mortality rate
  - Discard mortality rate was fixed over a range from 0.364 (S5) to 0.814 (S6) for all discard fleets modeled separately in the base model (i.e. recreational fleets), generating a sequence of 5 runs.
- S07: Assume no age error
- S08: Age comps for all years use age $1 - 8+$
- S09: Assume that batch fecundity is not age-dependent
- S10: Assume that batch number is not age-dependent
- S11: Assume that batch fecundity and batch number are not age-dependent
- S12: Estimate steepness
  - Use a Beverton-Holt stock-recruit relationship and estimate steepness, with an initial value of 0.8
- S13: Smooth general recreational discard value for 2016
- S14: Start SERFS trap/video index in 1990
- S15: Include general recreational (rGN) length compositions and estimate separate selectivity for rGN
- S16-S17: Vary weight of SERFS trap/video index
  - The weighting parameter for the SERFS trap/video index was fixed over a range from 0.2 (S16) to 5 (S17), generating a sequence of 13 runs.
- S18-S19: Vary weight of SERFS trap/video age comps
  - The weighting parameter for the SERFS trap/video age comps was fixed over a range from 0.2 (S18) to 5 (S19), generating a sequence of 13 runs.
- S20-S21: Vary weight of all age comps
  - The weighting parameter for all age comps was fixed over a range from 0.2 (S20) to 5 (S21), generating a sequence of 13 runs.
- S22-S23: Vary weight of all length comps
  - The weighting parameter for all length comps was fixed over a range from 0.2 (S22) to 5 (S23), generating a sequence of 13 runs.



### 3.7 Age Structured Production Model (ASPM)

Age Structured Production Models (ASPM) have been used in past South Atlantic assessments as supplementary analyses to compare with the primary statistical catch-at-age model. Recent research has shown that ASPMs can be informative diagnostics for detecting misspecification in key processes (Carvalho et al. 2017; 2021; Maunder and Piner 2017) Much of the documentation for the ASPM section of this report was originally printed in earlier reports (SFB-NMFS 2016*b*;*a*).

Age structured production models have existed since the advent of catch-at-age models in the mid-1980s (Fournier and Archibald 1982; Hilborn 1990; Kimura and Tagart 1982; Ludwig and Walters 1985; Megrey 1989). ASPMs have been used extensively for highly migratory pelagics, where age collection can be difficult, and other stock assessment analyses as well (Cubillos et al. 2002; Geromont and Butterworth 1999; Nishida et al. 2001; Nishida and Rademeyer 2011; Porch 2003; Restrepo 1997; Restrepo and Legault 1998; Ricard and Basson 2002). ASPMs can be viewed as either a simplified version of statistical catch-at-age models. The simplification from more advanced statistical catch-at-age models is due to the absence of any age or length composition data. Because no age or length data are used in an ASPM, then year class strength is expected to follow a simple production function (i.e. a stock-recruit function; Butterworth and Rademeyer 2008; Field et al. 2008). With this simplification, ASPMs have a greatly reduced number of parameters compared to a full statistical catch-at-age model. Of course with reduced parameters comes simplifying assumptions (e.g. fixed fleet selectivities). In this ASPM, using a mean recruitment model, recruitment is modeled as in the full BAM (statistical catch-at-age model) as an average value, independent of stock size (see section 3.3.8).

The ASPM is a direct modification of the full BAM, where age-structure is still represented but age-dependent processes and dynamics are fixed. In the BAM, much of the age-dependent life history information was already fixed (e.g. growth, maturity, fecundity, natural mortality). In the ASPM, selectivities are fixed at values estimated in the full BAM. The ASPM fits to landings and discards and the SERFS trap/video index, but age and length composition data is not fitted. So without age composition data, Dirichlet-Multinomial parameters were removed from the model. Recruitment deviations were fixed at zero. The parameters that the ASPM estimated were the average $F$ and annual $F$-deviations for each fleet, the catchability parameter for the SERFS trap/video index, and $R_0$. These methods follow the basic workflow described by Carvalho et al. (2021, their section 3.2.2).

### 3.8 Retrospective Analysis

Retrospective analyses were run by reducing the terminal year of the model (2021) one year at a time (new terminal years 2016-2020), thereby trimming all time series accordingly, and rerunning the assessment model. This analysis facilitates investigation of patterns in model results, particularly terminal status estimates, that may occur when recent data are excluded.

Retrospective analyses should be interpreted with caution when data sources are not continuous between 2016 and 2021 (Figure 1). In this case the SERFS trap/video index was not available in 2020 and SERFS trap/video age compositions were not available in 2020 or 2021. The final year of recruitment deviations in each retrospective run was set to the terminal year minus three years to mirror the base run model configuration.

### 3.9 Monte Carlo/Bootstrap Ensemble (MCBE) Analysis

For the base run of the catch-age model (BAM), uncertainty in results and precision of estimates were computed through an ensemble modeling approach (Scott et al. 2016; Jardim et al. 2021) using a mixed Monte Carlo and bootstrap framework (Efron and Tibshirani 1993; Manly 1997). Monte Carlo and bootstrap methods are often used to characterize uncertainty in ecological studies, and the mixed approach has been applied successfully in previous SEDAR stock assessments (Restrepo et al. 1992; Legault et al. 2001; SEDAR68 2021; SEDAR73 2021; SEDAR76 2023). The approach is among those recommended for use in SEDAR assessments (SEDAR Procedural Guidance 2010).

The approach translates uncertainty in model input into uncertainty in model output, by fitting the model many times with different values of “observed” data and key input parameters. A chief advantage of the approach is that the results describe a range of possible outcomes, so that uncertainty is characterized more thoroughly than it could be by any single fit or small set of sensitivity runs. A minor disadvantage of the approach is that computation times can be long, though current parallel computing techniques largely mitigate those demands (i.e. multiple models can be run simultaneously rather than sequentially).

In this assessment, the BAM was re-fit in $n = 2001$ trials that differed from the original inputs by bootstrapping on data sources, and by Monte Carlo sampling of several key input parameters. Of the 2001 trials, 1878 were ultimately retained in the uncertainty analysis. The remaining runs were discarded because of poor model convergence (maximum gradient $\geq 0.1$) or unrealistic values of $F_{40\%}[2019-2021]$ ($\geq 5$) . A check was also conducted to see if any estimated parameters were near bounds (within 1% of the range between bounds from either bound) in each run, to see if they should be removed from the ensemble.

The MCBE 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.

### 3.9.1 Bootstrapping of Observed Data

To include uncertainty in time series of observed landings, discards, and indices of abundance, multiplicative lognormal errors were applied through a parametric bootstrap. To implement this approach in the MCBE trials, random variables ($x_{s,y}$) were drawn for each year $y$ of time series $s$ from a normal distribution with mean 0 and variance $\sigma^2_{s,y}$ [that is, $x_{s,y} \sim N(0, \sigma^2_{s,y})$]. Annual observations were then perturbed from their original values ($\hat{O}_{s,y}$),

$$O_{s,y} = \hat{O}_{s,y}[\exp(x_{s,y} - \sigma^2_{s,y}/2)] \tag{5}$$

The term $\sigma^2_{s,y}/2$ is a bias correction that centers the multiplicative error on the value of 1.0. Standard deviations in log space were computed from CVs in arithmetic space, $\sigma_{s,y} = \sqrt{\log(1.0 + CV^2_{s,y})}$. The CVs used to generate bootstrap data sets of landings and discards were supplied by the data providers (Table 3). The CVs used to generate bootstrap data sets of indices of abundance were the same as those used when fitting the assessment model (Table 4).

Uncertainty in age and length compositions were included by drawing new distributions for each year of each data source, following a multinomial sampling process. Ages (or lengths) of individual fish (Table 6) were drawn at random with replacement using the cell probabilities of the original data. For each year of each data source, the number of fish sampled was the same as in the original data (Table 4).



### 3.9.2 Monte Carlo Sampling

In each successive fit of the model, several parameters were fixed (i.e., not estimated) at values drawn at random from distributions described below.

**Natural mortality** The point estimate of natural mortality ($M = 0.38$) was provided by the SEDAR 82 Workshop Panel with some uncertainty. To carry forward this source of uncertainty, Monte Carlo sampling was used to generate deviations from the point estimate. A new $M$ value was drawn for each MCBE trial from a uniform distribution between 0.2387 and 0.5313. In each run of the ensemble, a drawn value of constant $M$ was then used to rescale natural mortality at age, as described for the base model above.

**Standard deviation of recruitment deviations ($\sigma_R$)** In the base model, the standard deviation of recruitment deviations ($\sigma_R$) was initialized at a value of 0.6 from a meta-analysis, and estimated with a normal prior with $\mu = 0.6$. For each MCBE trial, a new initial value was drawn from a truncated normal distribution defined by $\mu = 0.6$ and $\sigma = 0.15$ truncated to 0.3 to 1.0, and the prior updated to be centered at the randomly drawn value.

**Discard mortalities** Similarly, discard mortalities $\delta$ applied to discard fleets included in the base model (i.e. recreational discards) were subjected to Monte Carlo variation as follows. New values for all sources of discards were drawn for each MCBE trial from a uniform distribution (range [0.364, 0.814]). Recall that in the base model commercial discards were minimal and were combined with commercial landings outside the model. Therefore the discard mortality rate for commercial discards was not randomized in the MCBE process.

### 3.10 Projection Analysis

Projections were run to quantify future stock conditions given different values of fishing mortality rate.The structure of the projection model was the same as that of the assessment model, and parameter estimates were those from the assessment. Any time-varying quantities, such as selectivity, were fixed to the most recent values of the assessment period. A single selectivity curve was applied to calculate landings computed by averaging selectivities across fleets using geometric mean $F$s from the last three years of the assessment period, similar to computation of $L_{\mathrm{F40\%}}$ benchmarks (section 3.5).

Expected values of SSB (time of peak spawning), $F$, recruits, and landings were represented by deterministic projections using parameter estimates from the base run. These projections were built on the estimated spawner-recruit relationship with bias correction, and were thus consistent with estimated benchmarks in the sense that long-term fishing at $F_{40\%}$ would yield $L_{\mathrm{F40\%}}$ from a stock size at $\mathrm{SSB}_{\mathrm{F40\%}}$. Uncertainty in future time series was quantified through stochastic projections that extended the ensemble model fits of the stock assessment model.

#### 3.10.1 Initialization

Although the terminal year of the assessment is 2021, the assessment model computes abundance at age ($N_a$) at the start of 2022. For projections, those estimates were used to initialize $N_a$. However, the assessment has no information to inform the strength of 2022 recruitment, and thus it computes 2022 recruits ($N_1$) as the expected value, that is, without deviation from the spawner-recruit curve, and corrected to be unbiased in arithmetic space. In the stochastic projections, lognormal stochasticity was applied to these abundances after adjusting them to be unbiased in log space, with variability based on the estimate of $\sigma_R$. Thus, the initial abundance in year one of projections (2022) included this variability in $N_1$. The deterministic projections were not adjusted in this manner, because deterministic recruitment was set to mean recruitment.

Fishing rates that define the projections were assumed to start in 2024. Because the assessment period ended in 2021, the projections required an interim period (2022–2024). Fishing mortality during this interim period was set at the estimate of $F_{\mathrm{current}}$ from the assessment model.

#### 3.10.2 Uncertainty

To characterize uncertainty in future stock dynamics stochasticity was included in replicate projections, each an extension of a single assessment fit from the ensemble. Thus, projections carried forward uncertainties in natural mortality and discard mortality, as well as in estimated quantities such as spawner-recruit parameters ($R_0$ and $\sigma_R$), selectivity curves, and in initial (start of 2022) abundance at age.

Initial and subsequent recruitment values were generated with stochasticity using a Monte Carlo procedure in which the estimated recruitment of each model within the ensemble is used to compute expected annual recruitment values ($\bar{R}_y$). Variability is added to the mean values by choosing multiplicative deviations at random from a lognormal distribution,

$$R_y = \bar{R}_y \exp(\epsilon_y). \tag{6}$$

Here $\epsilon_y$ is drawn from a normal distribution with mean 0 and standard deviation $\sigma_R$, where $\sigma_R$ is the standard deviation from the relevant ensemble model run.

The procedure generated 20,001 replicate projections of models within the ensemble drawn at random (with replacement). In cases where the same model run was drawn, projections would still differ as a result of stochasticity in projected recruitment streams. Central tendencies were represented by the deterministic projections of the base run, as well as by medians of the stochastic projections. Precision of projections was represented graphically by the $5^{th}$ and $95^{th}$ percentiles of the replicate projections.

#### 3.10.3 Scenarios

In the projections, management started in 2024, the earliest year possible. Projections were carried forward to 2031. In all scenarios $F = F_{\mathrm{current}}$ from 2022 to 2024:

- Scenario 1: $F = F_{40\%}$ from 2024 to 2031
- Scenario 2: $F = 75\% F_{40\%}$ from 2024 to 2031

## 4 Stock Assessment Results

### 4.1 Measures of Overall Model Fit

The Beaufort assessment model (BAM) generally fit well to the available data. Predicted age compositions from each fishery were reasonably close to observed data in most years. Fits to length compositions for the headboat recreational discards (rHD) were not quite as good (Figure 6,10, 14). The predicted distribution of lengths tended to be more platykurtic than the observed distribution. This is probably due to the fact that about 90% of the headboat discards fall into only three length bins ($240 - 300$ mm), the age-1 selectivity is fixed at 1.0, and the population growth model predicts a broader distribution of lengths at age-1 (Figure 3A). The model was configured to fit observed landings and discards closely (Figures 15, 16, 17, 18, 19, 20, 21, and 22). The fit to the SERFS trap/video index captured the general trend well but not all annual fluctuations (Figure 23).

### 4.2 Parameter Estimates

Estimates of all parameters from the catch-age model are shown in Appendix A. No parameters were hitting bounds. Estimates of management quantities and some key parameters, such as those of the mean-recruitment model, are reported in sections below.

### 4.3 Total Abundance, Spawning Biomass and Recruitment

Total abundance shows an early period of higher abundance prior to 1990. A drop and a pulse of increasing abundance occurs from $1990 - 1995$, followed by a decline to 1998. Abundance is relatively steady for the remainder of the assessment period, punctuated by a second pulse of higher abundance from $2010 - 2016$ (Figure 24 Table 7). The trend in total biomass is similar but shows a more gradual decline and leveling off, punctuated by the same two pulses (25; 8, and 9). These high periods appear to be driven by recruitment (red bars in Figure 24 and 25; Figure 26A), which is following trends in the SERFS trap/video index (Figure 23). The time series of landings, and to a lesser degree discards, tend to be positively correlated with abundance in the stock, showing relative highs similar to predicted biomass and a similar decrease from $1997 - 2000$ (Figures 34 and 35; Tables 18, 19, 20 and 21). Total biomass and spawning stock biomass (SSB) show similar trends, but with major highs and lows shifted one year later for SSB (Figure 27; Table 10). Recruitment has fluctuated during the period when deviations were estimated (1990-2018) ranging from 2,378,084 to 7,138,726 fish with relative lows in 1990, 1997, and 2017 and peaks in 1994, 2012, and 2014. However, there is little evidence of a long term trend (Figure 26A; Table 10). Similarly, recruitment deviations showed fluctuations over this same period with no evidence of a longterm trend (Figure 26B).

### 4.4 Selectivity

Selectivity of the SERFS trap/video index is shown in Figure 28. Selectivities of landings from commercial and recreational fleets are shown in Figures 29 and 30. selectivities of recreational discard fleets are shown in Figure 31. Recall that selectivities for a given fleet were the same for north and south areas. In the most recent years, full selection occurred near age-4 in the recreational fleets, age-5 in the commercial handline fleet, age-5 in the SERFS trap/video. Logistic selectivity functions were used for all landings fleets. Selectivities of discard mortalities had a negative exponential shape, with age at full selection fixed at age-1, an estimated 32% selection at age-2, and $\approx 0\%$ selection at age 3+ (Figure 31).

Average selectivities of landings were computed from $F$-weighted selectivities in the most recent period of regulations (Figure 32). These average selectivities were used to compute point estimates of benchmarks. All selectivities from the most recent period, including average selectivities, are tabulated in Table 11. In the average selectivity, full selection occurred near age-4, like the recreational fleets which are responsible for $> 80\%$ of the total removals in most years (Figures 34 and 35).

### 4.5 Fishing Mortality and Removals

Estimates of total $F$ at age are shown in Table 13 and estimates of landings and discards at age (in numbers and pounds whole weight) are shown in Tables 14, 15, 16, 17. In any given year, the maximum $F$ at age (i.e., apical F) may be less than that year's sum of fully selected $F$s across fleets (e.g. 2016). This inequality exists because full selection occurs at different ages among gears.

The estimated fishing mortality rates ($F$) have generally increased over the assessment period (Figure 33; Tables 10 and 12), with local peaks in 1991, 1997, 2009, 2016, and 2020. The predominant source of fishing mortality is the general recreational fleet, particularly in recent decades. Most of the $F$ is from the area south of the NC-VA border. Although fishing mortality in the north has been variable over time, on average, it has been a fairly steady proportion of total $F$ ($F_{sum}$).

Estimated time series of landings and discards (in number and pounds whole weight) by fleet are shown in Tables 18, 19, 20, 21. The majority of estimated removals were from the general recreational fleet, followed by commercial handline, and recreational headboat (Figures 34, 35; Tables 18, 19). The proportion of total removals attributed to the general recreational fleet has increased over time.



### 4.6 Spawner-Recruitment Parameters

The mean recruit relationship and variability around that mean are shown in Figure 36. Values of recruitment-related parameters were as follows: unfished age-1 recruitment $\widehat{R_0} = 4306649$, and standard deviation of recruitment residuals in log space $\widehat{\sigma}_R = 0.41$ (which resulted in bias correction of $\varsigma = 1.09$). Uncertainty in recruitment quantities were estimated through the MCBE analysis (Figure 37).

### 4.7 Per Recruit and Equilibrium Analyses

Yield per recruit and spawning potential ratio were each computed as functions of $F$. These computations applied the most recent selectivity patterns averaged across fleets, weighted by $F$ from the last three years (2019–2021; Figures 38).

As in per recruit analyses, equilibrium removals and equilibrium spawning biomass were each computed as a functions of $F$ (Figure 39). The equilibrium removals curve (or else equilibrium landings if discards are separated) is the curve from which $F_{\text{MSY}}$ is typically estimated, as the value of $F$ for which removals (landings) are maximized.

### 4.8 Benchmarks/Reference Points

As described in section 3.5, biological reference points (benchmarks) were derived analytically assuming equilibrium dynamics, corresponding to the mean-unbiased recruitment (Figure 36). Reference points estimated were $F_{40\%}$, $L_{\mathrm{F}40\%}$, $D_{\mathrm{F}40\%}$, $B_{\mathrm{F}40\%}$, and $\mathrm{SSB}_{\mathrm{F}40\%}$. Based on $F_{40\%}$, three possible values of $F$ at optimum yield (OY) were considered—$F_{\mathrm{OY}} = 65\% F_{40\%}$, $F_{\mathrm{OY}} = 75\% F_{40\%}$, and $F_{\mathrm{OY}} = 85\% F_{40\%}$—and for each, the corresponding yield was computed. Standard errors of benchmarks were approximated as those from MCBE analysis (section 3.9).

Maximum likelihood estimates (base run) of benchmarks, as well as median values from MCBE analysis, are summarized in Table 22. Point estimates of reference points were $F_{40\%} = 0.56$ ($\mathrm{y}^{-1}$), $L_{\mathrm{F}40\%} = 1865$ (1000 lb), $B_{\mathrm{F}40\%} = 6266$ (mt), and $\mathrm{SSB}_{\mathrm{F}40\%} = 6951918$ ($10^{12}$ eggs). Median estimates were $F_{40\%} = 0.57$ ($\mathrm{y}^{-1}$), $L_{\mathrm{F}40\%} = 1904$ (1000 lb), $B_{\mathrm{F}40\%} = 6389$ (mt), and $\mathrm{SSB}_{\mathrm{F}40\%} = 7.33$ ($10^{12}$ eggs). Note that the $L_{\mathrm{F}40\%}$ values (proxies for MSY) correspond to landings plus the small amount of commercial dead discards pooled with commercial landings. Distributions of these benchmarks from the MCBE analysis are shown in Figure 40.

### 4.9 Status of the Stock and Fishery

Estimated time series of stock status $\mathrm{SSB}/\mathrm{SSB}_{\mathrm{F}40\%}$ showed a steady decline throughout the beginning of the assessment period (Figure 41, Table 10). Base-run estimates of spawning biomass have never been below MSST. Current stock status relative to MSST was estimated in the base run to be SSB/MSST = 1.33 (Table 22), indicating that the stock is not overfished relative to $\mathrm{MSST} = (1 - M)\mathrm{SSB}_{\mathrm{F}40\%}$, where $M = 0.38$. Median values from the MCBE analysis indicated similar results of SSB/MSST = 1.41 in the terminal year. The uncertainty analysis suggested that the terminal estimate of stock status is fairly robust (Figures 42, 43). Of the MCBE runs, 70.3% indicated that the stock was above MSST in 2021. Age structure estimated by the base run showed a steady decline in the proportion of fish in the population at older ages, especially age 6 and older, over the assessment period ($1982 - 2021$), approaching the equilibrium age structure expected at $F_{40\%}$ in recent years (Figure 44). In the terminal year (2021), there were relatively fewer fish in ages $4 - 6$ compared with the equilibrium expectation, driven by average to low recruitment from $2016 - 2018$ (Fig. 26).

The estimated time series of $F/F_{40\%}$ suggests that the fishing rate has been gradually increasing since the beginning of the assessment (1982) with overfishing in only a few years, including the most recent years (Table 10, Figure 41). Current fishery status in the terminal year, with current $F$ represented by the geometric mean from years $2019-2021$, was estimated by the base run to be $F/F_{40\%} = 1.16$ (Table 22). The fishery status was less certain than the stock status (Figures 42, 43). Of the MCBE runs, approximately 53.6% agreed with the base run that the stock is not currently experiencing overfishing.



### 4.10 Sensitivity Analyses

Sensitivity runs, described in section 3.3, may be useful for evaluating implications of assumptions in the base model, and for interpreting MCBE results in terms of expected effects from input parameters. Time series of $F/F_{40\%}$, SSB/MSST, recruitment ($\bar{R}_y$), and SSB are plotted for all runs in each sensitivity analysis. Summarized results presented in Table 23. For analyses where parameters were fixed at a sequence of values, only the runs associated with the lower and upper limits of the sequence are presented in Table 23.

Figures show sensitivity to initial $F$ ($F_{init}$; Figure 45), natural mortality rate (Figure 46), discard mortality rate (Figure 47), age error (Figure 48), using age comps from 1 to 8+ for all years (Figure 49), age-dependent batch fecundity (Figure 50), age-dependent batch number (Figure 51), age-dependent batch fecundity and batch number (Figure 52), estimating steepness (Figure 53), high 2016 value of general recreational discards in the south (Figure 54), start year of SERFS trap/video index (Figure 55), estimating a separate selectivity for general recreational (rGN) landings (Figure 56), weight on SERFS trap/video index (Figure 57), weight on SERFS trap/video age compositions (Figure 58), weight on all age compositions (Figure 59), and weight on all length compositions (Figure 60).

### 4.11 Age Structured Production Model (ASPM)

The fit to the SERFS trap/video index in the ASPM, suggested a gradual decline in abundance over the course of the assessment period, and failed to capture most interannual trend in the index (Figure 61). Comparing this with the base model index fit (Figure 61) suggests that estimation of recruitment deviations is necessary to adequately estimate the trend in the index. Results of the ASPM are presented in Figure 62 and Table 23. Without the influence of age or length composition information, the ASPM estimated a much higher $R_0$ value than the base model, suggesting that the size of the population is much larger. As a diagnostic, this suggests that for Gray Triggerfish, accounting for variability in recruitment is also important for estimating the scale of the spawning stock and the populaiton.

### 4.12 Retrospective Analyses

Retrospective analyses did not suggest any patterns of substantial over- or underestimation in terminal-year estimates of $F/F_{40\%}$, SSB/MSST, recruitment ($\bar{R}_y$), and SSB (Figure 63).

### 4.13 Projections

Projection results with $F = F_{40\%}$ from 2024 to 2031 are shown in Figures 64, 65, and 66 and Table 24. Projection results with $F = 75\%F_{40\%}$ from 2024 to 2031 are shown in Figures 67, 68, and 69, and Table 25. Among all scenarios considered, the probability that SSB exceeds MSST [$P(\text{SSB} > \text{MSST})$] is at least 0.7 in all years of all projections. Thus, under no management prescription considered in the projections thus far is the South Atlantic Gray Triggerfish stock predicted to be overfished.

## 5 Discussion

### 5.1 Comments on Assessment Results

Estimated benchmarks played a central role in this assessment. Values of MSST and $F_{40\%}$ were used to gauge the status of the stock and fishery. Computation of benchmarks was conditional on selectivity. If selectivity patterns change in the future, for example as a result of new size limits or different relative catch allocations among sectors estimates of benchmarks would likely change as well.

The base run of the BAM indicated that the stock is not overfished ($\text{SSB}_{2021}/\text{MSST} = 1.33$), but that overfishing is occurring ($F_{2019-2021}/F_{40\%} = 1.16$). Sensitivity runs and MCBE analyses show that that there is substantial uncertainty in these qualitative results, with considerably more uncertainty in the overfishing status than in the stock status. Almost half of the MCBE runs suggest that overfishing is not occurring. This is partly because the estimated $F$-status indicator $F/F_{40\%}$ is very close to the cutoff value of 1, so much of the distribution around $F/F_{40\%}$ is is below 1. Comparing the MCBE results (Figure 41) with sensitivity to natural mortality (Figure 46), it is clear that much of the uncertainty in this stock assessment was driven by variation in $M$ over the range that was considered ($0.2387-0.5313$). This range was computed based on ranges chosen for other stock assessments in the South Atlantic region, which on average are 38% above and below the base value.

The ASPM diagnostic helped demonstrate that trends in abundance, indexed the SERFS trap/video survey, were not well explained by trends in removals. It was necessary to account for variability in recruitment to adequately fit the index. Similar patterns were presented an exampled provided by Carvalho et al. (2021). Furthermore, in the base model, the trend in recruitment was not well supported by information in the age compositions.

Results of several individual sensitivity runs suggest that stock status might be higher and fishery status might be lower than what is observed in the base run, for example, if there was no ageing error or if age-dependence of fecundity was not taken into account. Such analyses demonstrate the importance of including these relationships in the model, but they are not considered equally valid to the base model.

In this assessment, removals were separated into north and south subfleets, along a management boundary, in the interest of providing separate catch advice for the South Atlantic council area, south of that boundary. The northern removals were not simply excluded because it is hypothesized that they are part of the same biological stock, though further research in population structure is warranted. Gray Triggerfish tends to be a warmer water species and observations of the species north of the North Carolina/Virginia border are more limited than in areas to the south. Seasonal patterns of spring absence and fall presence of juvenile and adult Gray Triggerfish north of 36° N latitude in the Northeast Fisheries Science Center Bottom Trawl Survey and other data sources may suggest immigration from the south during the warmer months. Tagging data exist for Gray Triggerfish caught in Virginia waters, but most recaptured fish were caught after a short period at large, nearly all between June and November. Evidence from mitochondrial (Antoni et al. 2011) and microsatellite (Antoni 2017; Antoni and Saillant 2017) DNA suggest that Gray Triggerfish are genetically homogeneous from the waters off of east Texas in the Gulf of Mexico to South Carolina (i.e. the northern extent of sampling in the western Atlantic) and even shows connectivity with fish collected in France. Long distance movement is suggested by genetic analysis of Gray Triggerfish in other regions, inviting investigation into north and south movement in the US Atlantic as well.

### 5.2 Comments on Projections

As usual, projections should be interpreted in light of the model assumptions and key aspects of the data. Some major considerations are the following:

- In general, projections of fish stocks are highly uncertain, particularly in the long term (e.g., beyond 5–10 years).
- Although projections included many major sources of uncertainty, they did not include structural (model) uncertainty. That is, projection results are conditional on one set of functional forms used to describe population dynamics, selectivity, recruitment, etc.
- Fisheries were assumed to continue fishing at their estimated current proportions of total effort, using the estimated current selectivity patterns. Benchmarks (e.g. $L_{\mathrm{F40\%}}$) are conditional on the estimated selectivity functions and the relative contributions of each fleet's fishing mortality. New management regulations that reallocate harvest in a way that alters proportions of F by fleet or selectivity patterns would likely affect projection results.
- The projections assumed that the estimated spawner-recruit relationship applies in the future and that past residuals represent future uncertainty in recruitment. If future recruitment is characterized by runs of large or small year classes or an overall trend in average recruitment, possibly due to environmental or ecological conditions, stock trajectories will be affected.
- Projections apply the Baranov catch equation to relate $F$ and landings using a one-year time step, as in the assessment. The catch equation implicitly assumes that mortality occurs throughout the year. This assumption is violated when seasonal closures are in effect, introducing additional and unquantified uncertainty into the projection results.

## 6 Research Recommendations

Although it is difficult to estimate the duration of potential research projects, research recommendations have been divided into short and long term groups. Recommendations in the short term group largely suggest further analysis of existing data, and progress may be made relatively quickly. But any of the recommendations could potentially be developed into short or long term projects.

**S**hort term

- Continue to investigate aging methods and aging error: Are spines the best way to age triggerfish? What are the limits of spine based age readings? Increase the number of age samples used to estimate an age-error matrix and consider multiple sources of error. In this assessment, age-error due to differences in aging otoliths versus spines was characterized. But other sources of error, such as error between readers, could also be important.
- Refine estimates of age-dependent reproductive output and associated relationships (i.e. maturity, batch fecundity, and batch number) considering the newest methodologies.
- Investigate methods for standardizing age or length composition data available US South Atlantic Gray Triggerfish, accounting for covariates (e.g. depth, latitude, longitude, time of year).

**L**ong term

- Improve understanding of recruitment, stock structure and potential range shifts in the Atlantic Ocean, including areas outside of SAFMC jurisdiction and outside of the US EEZ.
- Expand fishery independent information to northern areas, maintaining consistent sampling for the SERFS trap/video index of abundance and age compositions.
- Develop direct estimates of natural mortality and associated uncertainty.
- Investigate temporal variation in recruitment and survivorship, considering potential environmental relationships.

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## 8 Tables

*Table 1. Life-history characteristics at age. Variables include size information of fish at midyear: fork length for the population (FL) and landings ($FL_L$) in millimeters (mm), whole weight (WW) in kilograms (kg) and pounds (lb) for the population. Other variables include proportion female ($P_{fem}$), proportion of females mature ($P_{fem.mat}$), batch fecundity ($f_{batch}$) and number of batches ($n_{batch}$) of individual females. Reproductive value (reprod) is an SSB analog in units of million eggs produced per fish in the population. M = natural mortality.*

| Age | $FL_{pop}$ (mm) | $FL_L$ (mm) | WW (kg) | WW (lb) | $P_{fem}$ | $P_{fem.mat}$ | $f_{batch}$ | $n_{batch}$ | reprod | $M$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 256 | 321 | 0.39 | 0.86 | 0.59 | 0.75 | 0.45 | 0.10 | 0.02 | 0.61 |
| 2 | 312 | 343 | 0.70 | 1.55 | 0.55 | 0.93 | 0.94 | 2.10 | 1.01 | 0.51 |
| 3 | 351 | 362 | 0.99 | 2.19 | 0.56 | 0.98 | 1.27 | 3.30 | 2.31 | 0.46 |
| 4 | 378 | 380 | 1.24 | 2.73 | 0.53 | 1.00 | 1.51 | 4.30 | 3.44 | 0.43 |
| 5 | 397 | 395 | 1.44 | 3.17 | 0.55 | 1.00 | 1.68 | 6.30 | 5.81 | 0.41 |
| 6 | 410 | 409 | 1.58 | 3.49 | 0.55 | 1.00 | 1.79 | 6.30 | 6.21 | 0.40 |
| 7 | 419 | 421 | 1.69 | 3.73 | 0.55 | 1.00 | 1.87 | 6.30 | 6.50 | 0.39 |
| 8 | 426 | 432 | 1.77 | 3.91 | 0.55 | 1.00 | 1.93 | 6.30 | 6.69 | 0.39 |

*Table 2. Observed time series of landings (L) and discards (D) for commercial handline landings, south (L.cHLs); commercial handline landings, north (L.cHLn); recreational headboat landings, south (L.rHBs); general recreational landings, south (L.rGNs); general recreational landings, north (L.rGNn); recreational headboat discards, south (D.rHDs); general recreational discards, south (D.rGDs); and general recreational discards, north (D.rGDn). Commercial landings are in units of 1000 lb whole weight. Recreational landings and all discards are in units of 1000 fish.*

| Year | L.cHLs | L.cHLn | L.rHBs | L.rGNs | L.rGNn | D.rHDs | D.rGDs | D.rGDn |
|---|---|---|---|---|---|---|---|---|
| 1982 | 96.64 | 0.10 | 29.50 | 91.17 | 0.51 | 3.32 | 27.53 | 0.10 |
| 1983 | 68.30 | 0.90 | 28.61 | 75.95 | 51.41 | 13.09 | 271.57 | 0.10 |
| 1984 | 73.68 | 0.82 | 26.90 | 221.80 | 3.07 | 5.92 | 45.81 | 0.10 |
| 1985 | 68.42 | 0.75 | 35.60 | 97.94 | 5.72 | 12.94 | 58.86 | 0.10 |
| 1986 | 68.70 | 0.67 | 28.37 | 51.64 | 22.59 | 7.16 | 169.93 | 0.84 |
| 1987 | 73.97 | 0.59 | 29.58 | 75.30 | 70.36 | 21.06 | 138.60 | 4.90 |
| 1988 | 80.95 | 0.52 | 34.93 | 160.64 | 1.85 | 34.97 | 83.68 | 4.44 |
| 1989 | 97.32 | 0.44 | 37.37 | 228.61 | 60.15 | 1.11 | 348.18 | 3.97 |
| 1990 | 191.67 | 0.36 | 71.70 | 184.32 | 50.15 | 1.57 | 60.79 | 37.38 |
| 1991 | 270.91 | 1.24 | 85.53 | 577.08 | 59.06 | 2.04 | 475.37 | 9.94 |
| 1992 | 262.23 | 0.89 | 91.73 | 262.11 | 23.17 | 1.31 | 218.49 | 4.69 |
| 1993 | 324.98 | 4.48 | 107.07 | 215.51 | 64.69 | 1.46 | 69.73 | 9.71 |
| 1994 | 372.84 | 17.97 | 90.39 | 118.10 | 57.09 | 1.61 | 78.17 | 7.53 |
| 1995 | 472.22 | 19.80 | 93.37 | 78.69 | 61.50 | 6.12 | 98.04 | 5.20 |
| 1996 | 433.61 | 16.70 | 89.95 | 118.10 | 118.44 | 1.92 | 118.15 | 48.48 |
| 1997 | 548.83 | 15.15 | 106.17 | 113.83 | 445.10 | 2.65 | 72.85 | 24.44 |
| 1998 | 408.76 | 8.58 | 65.86 | 79.30 | 26.35 | 6.40 | 39.80 | 8.10 |
| 1999 | 272.26 | 10.07 | 37.22 | 119.76 | 1.58 | 10.15 | 89.68 | 1.87 |
| 2000 | 196.18 | 5.17 | 34.09 | 99.51 | 29.21 | 3.67 | 105.49 | 6.52 |
| 2001 | 215.37 | 5.16 | 32.98 | 93.93 | 34.24 | 3.59 | 61.73 | 13.44 |
| 2002 | 192.13 | 15.29 | 57.63 | 191.36 | 71.67 | 17.25 | 142.78 | 8.38 |
| 2003 | 182.85 | 11.43 | 45.75 | 217.29 | 31.52 | 5.83 | 193.19 | 8.94 |
| 2004 | 243.26 | 8.90 | 78.07 | 202.43 | 132.34 | 20.65 | 177.03 | 21.84 |
| 2005 | 267.42 | 5.89 | 63.58 | 143.93 | 111.13 | 26.73 | 163.09 | 2.14 |
| 2006 | 238.18 | 5.05 | 43.15 | 253.24 | 7.00 | 16.03 | 166.61 | 2.84 |
| 2007 | 316.18 | 10.60 | 66.40 | 389.02 | 65.15 | 10.56 | 246.52 | 50.82 |
| 2008 | 320.40 | 5.75 | 44.76 | 322.04 | 14.10 | 6.50 | 173.74 | 1.66 |
| 2009 | 355.47 | 15.92 | 59.94 | 438.06 | 168.09 | 6.15 | 254.21 | 44.02 |
| 2010 | 441.72 | 11.45 | 68.81 | 317.65 | 75.72 | 11.42 | 146.04 | 41.17 |
| 2011 | 481.73 | 17.56 | 53.36 | 214.51 | 27.42 | 6.80 | 79.18 | 8.26 |
| 2012 | 280.64 | 34.38 | 49.10 | 194.69 | 131.39 | 7.47 | 112.11 | 10.82 |
| 2013 | 317.58 | 25.80 | 56.49 | 265.83 | 48.90 | 5.16 | 188.01 | 21.77 |
| 2014 | 275.90 | 10.62 | 53.11 | 410.45 | 161.22 | 7.16 | 247.26 | 12.09 |
| 2015 | 342.50 | 5.14 | 45.97 | 188.92 | 38.11 | 17.83 | 316.73 | 19.05 |
| 2016 | 308.18 | 7.61 | 37.84 | 724.98 | 75.04 | 39.58 | 1470.94 | 32.01 |
| 2017 | 323.64 | 26.31 | 43.36 | 421.06 | 115.93 | 16.83 | 413.00 | 13.36 |
| 2018 | 313.96 | 19.63 | 35.09 | 251.86 | 147.57 | 14.07 | 362.68 | 26.46 |
| 2019 | 321.79 | 12.94 | 35.77 | 304.86 | 147.69 | 15.60 | 283.32 | 26.69 |
| 2020 | 310.72 | 8.24 | 28.14 | 352.51 | 258.50 | 8.55 | 145.70 | 69.69 |
| 2021 | 210.23 | 9.04 | 26.19 | 464.52 | 124.24 | 8.61 | 358.12 | 25.22 |

*Table 3. Observed time series of CVs used in the Monte Carlo/Bootstrap Ensemble (MCBE) associated with landings (L) and discards (D) for commercial handline landings, south (L.cHLs); commercial handline landings, north (L.cHLn); recreational headboat landings, south (L.rHBs); general recreational landings, south (L.rGNs); general recreational landings, north (L.rGNn); recreational headboat discards, south (D.rHDs); general recreational discards, south (D.rGDs); and general recreational discards, north (D.rGDn). These CVs were used to generate bootstrap data sets in the ensemble model analysis only. When fitting to landings and discards the assessment model, CVs of 0.05 were used.*

| Year | L.cHLs | L.cHLn | L.rHBs | L.rGNs | L.rGNn | D.rHDs | D.rGDs | D.rGDn |
|---|---|---|---|---|---|---|---|---|
| 1982 | 0.10 | 0.10 | 0.35 | 0.34 | 0.34 | 0.58 | 0.68 | 0.68 |
| 1983 | 0.10 | 0.10 | 0.39 | 0.39 | 0.39 | 0.54 | 0.71 | 0.71 |
| 1984 | 0.10 | 0.10 | 0.34 | 0.37 | 0.37 | 0.34 | 0.69 | 0.69 |
| 1985 | 0.10 | 0.10 | 0.53 | 0.57 | 0.57 | 0.46 | 0.63 | 0.63 |
| 1986 | 0.10 | 0.10 | 0.52 | 0.35 | 0.35 | 0.78 | 0.52 | 0.52 |
| 1987 | 0.10 | 0.10 | 0.45 | 0.40 | 0.40 | 0.56 | 0.38 | 0.38 |
| 1988 | 0.10 | 0.10 | 0.45 | 0.41 | 0.41 | 0.60 | 0.32 | 0.32 |
| 1989 | 0.10 | 0.10 | 0.53 | 0.35 | 0.35 | 0.54 | 0.27 | 0.27 |
| 1990 | 0.10 | 0.10 | 0.62 | 0.22 | 0.22 | 0.47 | 0.35 | 0.35 |
| 1991 | 0.10 | 0.10 | 0.62 | 0.38 | 0.38 | 0.35 | 0.47 | 0.47 |
| 1992 | 0.10 | 0.10 | 0.58 | 0.24 | 0.24 | 0.27 | 0.22 | 0.22 |
| 1993 | 0.10 | 0.10 | 0.29 | 0.28 | 0.28 | 0.33 | 0.26 | 0.26 |
| 1994 | 0.06 | 0.06 | 0.34 | 0.18 | 0.18 | 0.26 | 0.32 | 0.32 |
| 1995 | 0.06 | 0.06 | 0.33 | 0.19 | 0.19 | 0.24 | 0.27 | 0.27 |
| 1996 | 0.06 | 0.06 | 0.32 | 0.26 | 0.26 | 0.28 | 0.34 | 0.34 |
| 1997 | 0.07 | 0.07 | 0.27 | 0.73 | 0.73 | 0.36 | 0.30 | 0.30 |
| 1998 | 0.06 | 0.06 | 0.31 | 0.31 | 0.31 | 0.31 | 0.25 | 0.25 |
| 1999 | 0.07 | 0.07 | 0.28 | 0.19 | 0.19 | 0.37 | 0.21 | 0.21 |
| 2000 | 0.07 | 0.07 | 0.35 | 0.27 | 0.27 | 0.34 | 0.22 | 0.22 |
| 2001 | 0.08 | 0.08 | 0.42 | 0.21 | 0.21 | 0.25 | 0.20 | 0.20 |
| 2002 | 0.06 | 0.06 | 0.45 | 0.18 | 0.18 | 0.20 | 0.21 | 0.21 |
| 2003 | 0.06 | 0.06 | 0.47 | 0.25 | 0.25 | 0.26 | 0.25 | 0.25 |
| 2004 | 0.05 | 0.05 | 0.48 | 0.23 | 0.23 | 0.17 | 0.22 | 0.22 |
| 2005 | 0.05 | 0.05 | 0.41 | 0.23 | 0.23 | 0.30 | 0.18 | 0.18 |
| 2006 | 0.05 | 0.05 | 0.46 | 0.27 | 0.27 | 0.31 | 0.25 | 0.25 |
| 2007 | 0.05 | 0.05 | 0.42 | 0.16 | 0.16 | 0.31 | 0.18 | 0.18 |
| 2008 | 0.05 | 0.05 | 0.49 | 0.20 | 0.20 | 0.49 | 0.18 | 0.18 |
| 2009 | 0.05 | 0.05 | 0.15 | 0.17 | 0.17 | 0.15 | 0.35 | 0.35 |
| 2010 | 0.05 | 0.05 | 0.16 | 0.18 | 0.18 | 0.16 | 0.23 | 0.23 |
| 2011 | 0.05 | 0.05 | 0.10 | 0.23 | 0.23 | 0.10 | 0.23 | 0.23 |
| 2012 | 0.06 | 0.06 | 0.09 | 0.21 | 0.21 | 0.09 | 0.27 | 0.27 |
| 2013 | 0.05 | 0.05 | 0.10 | 0.18 | 0.18 | 0.10 | 0.29 | 0.29 |
| 2014 | 0.05 | 0.05 | 0.08 | 0.21 | 0.21 | 0.08 | 0.20 | 0.20 |
| 2015 | 0.05 | 0.05 | 0.07 | 0.18 | 0.18 | 0.07 | 0.22 | 0.22 |
| 2016 | 0.05 | 0.05 | 0.06 | 0.37 | 0.37 | 0.06 | 0.35 | 0.35 |
| 2017 | 0.05 | 0.05 | 0.08 | 0.16 | 0.16 | 0.08 | 0.23 | 0.23 |
| 2018 | 0.05 | 0.05 | 0.05 | 0.16 | 0.16 | 0.05 | 0.26 | 0.26 |
| 2019 | 0.05 | 0.05 | 0.06 | 0.21 | 0.21 | 0.06 | 0.25 | 0.25 |
| 2020 | 0.05 | 0.05 | 0.06 | 0.29 | 0.29 | 0.06 | 0.33 | 0.33 |
| 2021 | 0.05 | 0.05 | 0.05 | 0.24 | 0.24 | 0.05 | 0.26 | 0.26 |

*Table 4. Observed index of abundance and CVs from the SERFS trap/video survey (sTVs).*

| Year | sTVs | cv.sTVs |
|---|---|---|
| 1982 | . | . |
| 1983 | . | . |
| 1984 | . | . |
| 1985 | . | . |
| 1986 | . | . |
| 1987 | . | . |
| 1988 | . | . |
| 1989 | . | . |
| 1990 | . | . |
| 1991 | 1.274 | 0.146 |
| 1992 | 0.880 | 0.164 |
| 1993 | 0.777 | 0.142 |
| 1994 | 1.095 | 0.140 |
| 1995 | 1.363 | 0.132 |
| 1996 | 1.690 | 0.130 |
| 1997 | 1.993 | 0.143 |
| 1998 | 1.706 | 0.151 |
| 1999 | 0.893 | 0.180 |
| 2000 | 0.689 | 0.206 |
| 2001 | 0.946 | 0.141 |
| 2002 | 1.403 | 0.160 |
| 2003 | 0.636 | 0.240 |
| 2004 | 1.117 | 0.162 |
| 2005 | 0.768 | 0.151 |
| 2006 | 0.653 | 0.181 |
| 2007 | 0.809 | 0.157 |
| 2008 | 0.871 | 0.172 |
| 2009 | 0.641 | 0.174 |
| 2010 | 0.566 | 0.151 |
| 2011 | 0.834 | 0.110 |
| 2012 | 1.087 | 0.088 |
| 2013 | 1.240 | 0.086 |
| 2014 | 1.213 | 0.086 |
| 2015 | 0.899 | 0.081 |
| 2016 | 1.201 | 0.090 |
| 2017 | 1.196 | 0.081 |
| 2018 | 0.854 | 0.086 |
| 2019 | 0.907 | 0.094 |
| 2020 | . | . |
| 2021 | 0.536 | 0.165 |

*Table 5. Sample sizes (number of trips) for age compositions (ac) or length compositions (lc) for commercial handline, south, early years (cHLsa); commercial handline, south, late years (cHLsb); recreational headboat, south, early years (rHBsa); recreational headboat, south, late years (rHBsb); SERFS trap video survey, south, early years (sTVsa); SERFS trap video survey, south, late years (sTVsb); and recreational headboat discards, south, all years (rHDs). In early years (1982-2014), the assessment fit to ages 1-5+ and in the late years (2015-2021), it fit to ages 1-8+.*

| Year | ac.cHLsa | ac.cHLsb | ac.rHBsa | ac.rHBsb | ac.sTVsa | ac.sTVsb | lc.rHDs |
|---|---|---|---|---|---|---|---|
| 1982 | . | . | . | . | . | . | . |
| 1983 | . | . | . | . | . | . | . |
| 1984 | . | . | . | . | . | . | . |
| 1985 | . | . | . | . | . | . | . |
| 1986 | . | . | . | . | . | . | . |
| 1987 | . | . | . | . | . | . | . |
| 1988 | . | . | . | . | . | . | . |
| 1989 | . | . | . | . | . | . | . |
| 1990 | . | . | 10 | . | . | . | . |
| 1991 | . | . | 21 | . | 56 | . | . |
| 1992 | . | . | . | . | 85 | . | . |
| 1993 | . | . | . | . | 119 | . | . |
| 1994 | . | . | . | . | 151 | . | . |
| 1995 | . | . | . | . | 145 | . | . |
| 1996 | . | . | . | . | 175 | . | . |
| 1997 | . | . | . | . | 185 | . | . |
| 1998 | . | . | . | . | 122 | . | . |
| 1999 | . | . | . | . | 62 | . | . |
| 2000 | . | . | . | . | 90 | . | . |
| 2001 | . | . | . | . | 91 | . | . |
| 2002 | . | . | . | . | 107 | . | . |
| 2003 | . | . | 18 | . | 34 | . | . |
| 2004 | 25 | . | . | . | 79 | . | . |
| 2005 | . | . | 18 | . | 100 | . | 44 |
| 2006 | 87 | . | 30 | . | 68 | . | 42 |
| 2007 | 196 | . | 51 | . | 100 | . | 41 |
| 2008 | 205 | . | 10 | . | 64 | . | 28 |
| 2009 | 178 | . | 26 | . | 79 | . | 49 |
| 2010 | 214 | . | 53 | . | 97 | . | 48 |
| 2011 | 213 | . | 35 | . | 116 | . | 31 |
| 2012 | 111 | . | 46 | . | 190 | . | 36 |
| 2013 | 97 | . | 134 | . | 281 | . | 40 |
| 2014 | 68 | . | 171 | . | 304 | . | 48 |
| 2015 | . | 121 | . | 133 | . | 191 | 70 |
| 2016 | . | 68 | . | 238 | . | 177 | 96 |
| 2017 | . | 55 | . | 165 | . | 195 | 82 |
| 2018 | . | 43 | . | 137 | . | 153 | 79 |
| 2019 | . | 40 | . | 51 | . | 158 | 87 |
| 2020 | . | 33 | . | . | . | . | 10 |
| 2021 | . | . | . | . | . | . | . |

*Table 6. Sample sizes (number of fish) for age compositions (ac) or length compositions (lc) for commercial handline, south, early years (cHLsa); commercial handline, south, late years (cHLsb); recreational headboat, south, early years (rHBsa); recreational headboat, south, late years (rHBsb); SERFS trap video survey, south, early years (sTVsa); SERFS trap video survey, south, late years (sTVsb); and recreational headboat discards, south, all years (rHDs). In early years (1982-2014), the assessment fit to ages 1-5+ and in the late years (2015-2021), it fit to ages 1-8+.*

| Year | ac.cHLsa | ac.cHLsb | ac.rHBsa | ac.rHBsb | ac.sTVsa | ac.sTVsb | lc.rHDs |
|---|---|---|---|---|---|---|---|
| 1982 | . | . | . | . | . | . | . |
| 1983 | . | . | . | . | . | . | . |
| 1984 | . | . | . | . | . | . | . |
| 1985 | . | . | . | . | . | . | . |
| 1986 | . | . | . | . | . | . | . |
| 1987 | . | . | . | . | . | . | . |
| 1988 | . | . | . | . | . | . | . |
| 1989 | . | . | . | . | . | . | . |
| 1990 | . | . | 18 | . | . | . | . |
| 1991 | . | . | 37 | . | 302 | . | . |
| 1992 | . | . | . | . | 165 | . | . |
| 1993 | . | . | . | . | 976 | . | . |
| 1994 | . | . | . | . | 393 | . | . |
| 1995 | . | . | . | . | 568 | . | . |
| 1996 | . | . | . | . | 1142 | . | . |
| 1997 | . | . | . | . | 726 | . | . |
| 1998 | . | . | . | . | 457 | . | . |
| 1999 | . | . | . | . | 181 | . | . |
| 2000 | . | . | . | . | 220 | . | . |
| 2001 | . | . | . | . | 224 | . | . |
| 2002 | . | . | . | . | 313 | . | . |
| 2003 | . | . | 35 | . | 72 | . | . |
| 2004 | 187 | . | . | . | 193 | . | . |
| 2005 | . | . | 66 | . | 337 | . | 110 |
| 2006 | 461 | . | 129 | . | 175 | . | 102 |
| 2007 | 673 | . | 97 | . | 330 | . | 111 |
| 2008 | 734 | . | 18 | . | 272 | . | 89 |
| 2009 | 686 | . | 27 | . | 238 | . | 124 |
| 2010 | 976 | . | 97 | . | 197 | . | 118 |
| 2011 | 1262 | . | 65 | . | 338 | . | 59 |
| 2012 | 760 | . | 137 | . | 451 | . | 61 |
| 2013 | 563 | . | 502 | . | 909 | . | 143 |
| 2014 | 423 | . | 557 | . | 976 | . | 212 |
| 2015 | . | 677 | . | 286 | . | 296 | 378 |
| 2016 | . | 292 | . | 594 | . | 295 | 440 |
| 2017 | . | 191 | . | 404 | . | 299 | 420 |
| 2018 | . | 112 | . | 291 | . | 298 | 358 |
| 2019 | . | 129 | . | 92 | . | 294 | 412 |
| 2020 | . | 104 | . | . | . | . | 50 |
| 2021 | . | . | . | . | . | . | . |

*Table 7. Estimated total abundance at age (1000 fish) at start of year.*

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1982 | 4687.90 | 2504.81 | 1490.38 | 913.82 | 563.16 | 352.53 | 222.81 | 393.32 | 11128.73 |
| 1983 | 4687.90 | 2527.49 | 1494.97 | 915.04 | 563.48 | 352.53 | 222.80 | 393.30 | 11157.52 |
| 1984 | 4687.90 | 2372.84 | 1477.12 | 911.63 | 559.18 | 349.63 | 220.85 | 389.83 | 10968.99 |
| 1985 | 4687.90 | 2513.74 | 1408.55 | 882.65 | 537.18 | 333.88 | 210.74 | 371.77 | 10946.41 |
| 1986 | 4687.90 | 2502.30 | 1494.62 | 861.09 | 541.10 | 334.40 | 209.85 | 369.79 | 11001.05 |
| 1987 | 4687.90 | 2437.69 | 1477.05 | 920.84 | 535.26 | 341.80 | 213.28 | 373.39 | 10987.21 |
| 1988 | 4687.90 | 2445.05 | 1437.36 | 896.36 | 557.50 | 328.82 | 211.99 | 367.50 | 10932.47 |
| 1989 | 4687.90 | 2470.37 | 1445.36 | 867.47 | 537.17 | 338.76 | 201.71 | 359.04 | 10907.79 |
| 1990 | 2981.84 | 2329.30 | 1427.27 | 845.44 | 492.46 | 308.20 | 196.17 | 327.97 | 8908.65 |
| 1991 | 6044.29 | 1561.95 | 1368.21 | 832.38 | 473.73 | 277.96 | 175.51 | 301.45 | 11035.48 |
| 1992 | 5004.72 | 2955.20 | 881.92 | 699.47 | 368.86 | 208.22 | 123.11 | 213.34 | 10454.84 |
| 1993 | 5988.46 | 2580.42 | 1713.74 | 484.49 | 349.00 | 183.35 | 104.32 | 170.24 | 11574.01 |
| 1994 | 7138.73 | 3198.26 | 1513.30 | 940.30 | 238.78 | 170.63 | 90.31 | 136.57 | 13426.87 |
| 1995 | 6086.70 | 3820.31 | 1888.14 | 867.67 | 498.57 | 125.93 | 90.68 | 121.77 | 13499.77 |
| 1996 | 3361.89 | 3239.36 | 2256.17 | 1098.84 | 470.07 | 268.53 | 68.34 | 116.42 | 10879.64 |
| 1997 | 2378.08 | 1733.64 | 1891.75 | 1303.49 | 593.64 | 253.32 | 145.86 | 101.35 | 8401.12 |
| 1998 | 2864.19 | 1232.29 | 1003.05 | 1007.55 | 607.69 | 273.25 | 117.43 | 115.72 | 7221.16 |
| 1999 | 3280.60 | 1521.03 | 728.74 | 593.61 | 567.68 | 342.41 | 155.22 | 133.75 | 7323.06 |
| 2000 | 4458.24 | 1717.85 | 895.35 | 431.35 | 337.34 | 323.76 | 196.95 | 167.86 | 8528.71 |
| 2001 | 4020.58 | 2346.76 | 1012.29 | 528.04 | 244.71 | 192.39 | 186.25 | 211.95 | 8742.97 |
| 2002 | 4198.25 | 2135.51 | 1386.77 | 596.42 | 298.02 | 138.63 | 109.92 | 229.77 | 9093.29 |
| 2003 | 3030.20 | 2174.79 | 1243.86 | 778.94 | 310.50 | 155.16 | 72.77 | 180.09 | 7946.31 |
| 2004 | 3961.96 | 1524.40 | 1256.81 | 706.40 | 414.29 | 165.45 | 83.38 | 137.23 | 8249.91 |
| 2005 | 3813.49 | 2009.55 | 877.78 | 680.98 | 344.04 | 200.71 | 80.78 | 108.78 | 8116.10 |
| 2006 | 3021.48 | 1951.71 | 1163.03 | 483.06 | 338.90 | 170.17 | 100.04 | 95.42 | 7323.80 |
| 2007 | 4964.63 | 1529.96 | 1126.17 | 642.03 | 242.01 | 168.88 | 85.46 | 99.13 | 8858.29 |
| 2008 | 3678.46 | 2490.36 | 868.10 | 559.98 | 264.80 | 97.76 | 68.66 | 75.78 | 8103.89 |
| 2009 | 4942.80 | 1887.83 | 1430.23 | 446.92 | 243.47 | 112.78 | 41.90 | 62.51 | 9168.43 |
| 2010 | 3820.84 | 2482.44 | 1056.82 | 639.64 | 150.19 | 78.63 | 36.59 | 34.20 | 8299.34 |
| 2011 | 6194.81 | 1952.99 | 1411.68 | 507.78 | 238.48 | 53.70 | 28.23 | 25.67 | 10413.34 |
| 2012 | 6785.48 | 3298.55 | 1139.42 | 744.39 | 221.48 | 100.46 | 22.73 | 23.03 | 12335.54 |
| 2013 | 3978.22 | 3599.56 | 1922.35 | 605.23 | 342.84 | 100.38 | 45.84 | 21.08 | 10615.50 |
| 2014 | 7069.02 | 2039.98 | 2084.15 | 1054.53 | 296.04 | 165.79 | 48.89 | 32.91 | 12791.31 |
| 2015 | 6474.52 | 3658.69 | 1177.18 | 1093.54 | 484.60 | 134.80 | 76.06 | 37.90 | 13137.28 |
| 2016 | 4651.25 | 3300.79 | 2127.65 | 677.39 | 587.74 | 259.89 | 72.87 | 62.21 | 11739.80 |
| 2017 | 3264.66 | 1660.94 | 1681.31 | 1061.79 | 287.35 | 246.01 | 109.57 | 57.51 | 8369.13 |
| 2018 | 3336.98 | 1501.23 | 923.58 | 885.12 | 489.66 | 131.11 | 113.08 | 77.55 | 7458.32 |
| 2019 | 4687.90 | 1559.93 | 840.74 | 492.96 | 417.30 | 228.55 | 61.65 | 90.52 | 8379.56 |
| 2020 | 4687.90 | 2330.23 | 882.76 | 418.80 | 204.03 | 169.19 | 93.27 | 62.70 | 8848.88 |
| 2021 | 4687.90 | 2399.08 | 1306.09 | 381.55 | 133.52 | 62.49 | 52.07 | 48.47 | 9071.17 |

*Table 8. Estimated total biomass at age (mt) at start of year.*

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1982 | 1837.67 | 1756.02 | 1480.67 | 1133.50 | 808.50 | 558.38 | 377.37 | 697.55 | 8649.67 |
| 1983 | 1837.67 | 1771.92 | 1485.24 | 1135.01 | 808.97 | 558.39 | 377.35 | 697.51 | 8672.07 |
| 1984 | 1837.67 | 1663.50 | 1467.50 | 1130.79 | 802.79 | 553.80 | 374.05 | 691.37 | 8521.46 |
| 1985 | 1837.67 | 1762.28 | 1399.38 | 1094.84 | 771.20 | 528.84 | 356.93 | 659.34 | 8410.47 |
| 1986 | 1837.67 | 1754.27 | 1484.88 | 1068.09 | 776.84 | 529.67 | 355.41 | 655.82 | 8462.64 |
| 1987 | 1837.67 | 1708.97 | 1467.43 | 1142.20 | 768.45 | 541.39 | 361.22 | 662.21 | 8489.54 |
| 1988 | 1837.67 | 1714.13 | 1427.99 | 1111.84 | 800.37 | 520.83 | 359.04 | 651.76 | 8423.63 |
| 1989 | 1837.67 | 1731.88 | 1435.95 | 1076.00 | 771.19 | 536.58 | 341.64 | 636.76 | 8367.67 |
| 1990 | 1168.89 | 1632.98 | 1417.98 | 1048.68 | 707.01 | 488.18 | 332.25 | 581.65 | 7377.61 |
| 1991 | 2369.38 | 1095.02 | 1359.30 | 1032.48 | 680.11 | 440.27 | 297.26 | 534.62 | 7808.45 |
| 1992 | 1961.86 | 2071.78 | 876.17 | 867.62 | 529.56 | 329.81 | 208.51 | 378.36 | 7223.67 |
| 1993 | 2347.49 | 1809.03 | 1702.58 | 600.96 | 501.04 | 290.42 | 176.69 | 301.91 | 7730.11 |
| 1994 | 2798.40 | 2242.17 | 1503.44 | 1166.34 | 342.81 | 270.27 | 152.96 | 242.21 | 8718.60 |
| 1995 | 2386.00 | 2678.27 | 1875.85 | 1076.25 | 715.77 | 199.47 | 153.58 | 215.95 | 9301.14 |
| 1996 | 1317.87 | 2270.99 | 2241.48 | 1363.00 | 674.86 | 425.34 | 115.75 | 206.48 | 8615.77 |
| 1997 | 932.21 | 1215.38 | 1879.43 | 1616.84 | 852.26 | 401.25 | 247.04 | 179.75 | 7324.15 |
| 1998 | 1122.77 | 863.91 | 996.52 | 1249.76 | 872.43 | 432.81 | 198.89 | 205.23 | 5942.30 |
| 1999 | 1286.00 | 1066.34 | 724.00 | 736.32 | 814.99 | 542.37 | 262.89 | 237.21 | 5670.11 |
| 2000 | 1747.64 | 1204.31 | 889.52 | 535.04 | 484.30 | 512.82 | 333.57 | 297.70 | 6004.92 |
| 2001 | 1576.08 | 1645.22 | 1005.70 | 654.98 | 351.31 | 304.73 | 315.45 | 375.90 | 6229.37 |
| 2002 | 1645.72 | 1497.12 | 1377.74 | 739.79 | 427.85 | 219.58 | 186.17 | 407.50 | 6501.48 |
| 2003 | 1187.84 | 1524.66 | 1235.75 | 966.19 | 445.77 | 245.77 | 123.26 | 319.39 | 6048.64 |
| 2004 | 1553.10 | 1068.69 | 1248.63 | 876.22 | 594.77 | 262.07 | 141.21 | 243.37 | 5988.06 |
| 2005 | 1494.90 | 1408.82 | 872.07 | 844.68 | 493.92 | 317.91 | 136.82 | 192.91 | 5762.02 |
| 2006 | 1184.43 | 1368.26 | 1155.45 | 599.19 | 486.54 | 269.54 | 169.44 | 169.22 | 5402.07 |
| 2007 | 1946.15 | 1072.60 | 1118.84 | 796.38 | 347.44 | 267.50 | 144.74 | 175.80 | 5869.45 |
| 2008 | 1441.97 | 1745.89 | 862.45 | 694.59 | 380.17 | 154.84 | 116.29 | 134.39 | 5530.58 |
| 2009 | 1937.59 | 1323.48 | 1420.92 | 554.35 | 349.54 | 178.63 | 70.96 | 110.86 | 5946.33 |
| 2010 | 1497.78 | 1740.34 | 1049.94 | 793.40 | 215.61 | 124.54 | 61.98 | 60.66 | 5544.25 |
| 2011 | 2428.38 | 1369.16 | 1402.48 | 629.85 | 342.38 | 85.06 | 47.82 | 45.52 | 6350.65 |
| 2012 | 2659.92 | 2312.48 | 1132.00 | 923.34 | 317.97 | 159.12 | 38.49 | 40.85 | 7584.18 |
| 2013 | 1559.47 | 2523.51 | 1909.83 | 750.72 | 492.21 | 159.00 | 77.63 | 37.39 | 7509.76 |
| 2014 | 2771.07 | 1430.15 | 2070.58 | 1308.04 | 425.01 | 262.60 | 82.80 | 58.37 | 8408.62 |
| 2015 | 2538.03 | 2564.96 | 1169.51 | 1356.42 | 695.71 | 213.52 | 128.82 | 67.21 | 8734.19 |
| 2016 | 1823.30 | 2314.05 | 2113.80 | 840.24 | 843.79 | 411.65 | 123.42 | 110.33 | 8580.58 |
| 2017 | 1279.75 | 1164.42 | 1670.36 | 1317.04 | 412.53 | 389.67 | 185.57 | 101.99 | 6521.34 |
| 2018 | 1308.10 | 1052.45 | 917.57 | 1097.91 | 702.98 | 207.68 | 191.52 | 137.54 | 5615.74 |
| 2019 | 1837.67 | 1093.61 | 835.26 | 611.47 | 599.10 | 362.02 | 104.42 | 160.53 | 5604.07 |
| 2020 | 1837.67 | 1633.63 | 877.01 | 519.48 | 292.91 | 267.99 | 157.96 | 111.20 | 5697.86 |
| 2021 | 1837.67 | 1681.90 | 1297.58 | 473.28 | 191.68 | 98.98 | 88.20 | 85.95 | 5755.24 |

*Table 9. Estimated total biomass at age (1000 lb) at start of year.*

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1982 | 4051.30 | 3871.30 | 3264.30 | 2498.90 | 1782.40 | 1231.00 | 831.90 | 1537.80 | 19069.10 |
| 1983 | 4051.30 | 3906.40 | 3274.40 | 2502.20 | 1783.50 | 1231.00 | 831.90 | 1537.70 | 19118.40 |
| 1984 | 4051.30 | 3667.40 | 3235.30 | 2492.90 | 1769.80 | 1220.90 | 824.60 | 1524.20 | 18786.40 |
| 1985 | 4051.30 | 3885.10 | 3085.10 | 2413.70 | 1700.20 | 1165.90 | 786.90 | 1453.60 | 18541.70 |
| 1986 | 4051.30 | 3867.50 | 3273.60 | 2354.70 | 1712.60 | 1167.70 | 783.50 | 1445.80 | 18656.70 |
| 1987 | 4051.30 | 3767.60 | 3235.10 | 2518.10 | 1694.10 | 1193.50 | 796.30 | 1459.90 | 18716.00 |
| 1988 | 4051.30 | 3779.00 | 3148.10 | 2451.20 | 1764.50 | 1148.20 | 791.50 | 1436.90 | 18570.70 |
| 1989 | 4051.30 | 3818.10 | 3165.70 | 2372.10 | 1700.20 | 1182.90 | 753.20 | 1403.80 | 18447.40 |
| 1990 | 2576.90 | 3600.10 | 3126.10 | 2311.90 | 1558.70 | 1076.20 | 732.50 | 1282.30 | 16264.70 |
| 1991 | 5223.50 | 2414.10 | 2996.70 | 2276.20 | 1499.40 | 970.60 | 655.30 | 1178.60 | 17214.50 |
| 1992 | 4325.10 | 4567.40 | 1931.60 | 1912.80 | 1167.50 | 727.10 | 459.70 | 834.10 | 15925.30 |
| 1993 | 5175.30 | 3988.20 | 3753.50 | 1324.90 | 1104.60 | 640.30 | 389.50 | 665.60 | 17041.80 |
| 1994 | 6169.40 | 4943.10 | 3314.50 | 2571.30 | 755.80 | 595.80 | 337.20 | 534.00 | 19221.00 |
| 1995 | 5260.20 | 5904.50 | 4135.50 | 2372.70 | 1578.00 | 439.80 | 338.60 | 476.10 | 20505.30 |
| 1996 | 2905.40 | 5006.60 | 4941.60 | 3004.90 | 1487.80 | 937.70 | 255.20 | 455.20 | 18994.30 |
| 1997 | 2055.20 | 2679.40 | 4143.40 | 3564.50 | 1878.90 | 884.60 | 544.60 | 396.30 | 16146.80 |
| 1998 | 2475.30 | 1904.60 | 2196.90 | 2755.20 | 1923.40 | 954.20 | 438.50 | 452.50 | 13100.40 |
| 1999 | 2835.10 | 2350.90 | 1596.10 | 1623.30 | 1796.70 | 1195.70 | 579.60 | 523.00 | 12500.30 |
| 2000 | 3852.80 | 2655.00 | 1961.00 | 1179.50 | 1067.70 | 1130.60 | 735.40 | 656.30 | 13238.40 |
| 2001 | 3474.60 | 3627.10 | 2217.20 | 1444.00 | 774.50 | 671.80 | 695.40 | 828.70 | 13733.30 |
| 2002 | 3628.20 | 3300.60 | 3037.40 | 1630.90 | 943.20 | 484.10 | 410.40 | 898.40 | 14333.20 |
| 2003 | 2618.70 | 3361.30 | 2724.30 | 2130.10 | 982.70 | 541.80 | 271.70 | 704.10 | 13334.80 |
| 2004 | 3424.00 | 2356.00 | 2752.70 | 1931.70 | 1311.20 | 577.80 | 311.30 | 536.50 | 13201.30 |
| 2005 | 3295.70 | 3105.90 | 1922.60 | 1862.20 | 1088.90 | 700.90 | 301.60 | 425.30 | 12702.90 |
| 2006 | 2611.20 | 3016.50 | 2547.30 | 1321.00 | 1072.60 | 594.20 | 373.50 | 373.10 | 11909.40 |
| 2007 | 4290.50 | 2364.70 | 2466.60 | 1755.70 | 766.00 | 589.70 | 319.10 | 387.60 | 12939.80 |
| 2008 | 3179.00 | 3849.00 | 1901.40 | 1531.30 | 838.10 | 341.40 | 256.40 | 296.30 | 12192.70 |
| 2009 | 4271.60 | 2917.70 | 3132.60 | 1222.10 | 770.60 | 393.80 | 156.40 | 244.40 | 13109.30 |
| 2010 | 3302.00 | 3836.80 | 2314.70 | 1749.10 | 475.30 | 274.60 | 136.60 | 133.70 | 12222.90 |
| 2011 | 5353.60 | 3018.50 | 3091.90 | 1388.60 | 754.80 | 187.50 | 105.40 | 100.40 | 14000.60 |
| 2012 | 5864.10 | 5098.10 | 2495.60 | 2035.60 | 701.00 | 350.80 | 84.90 | 90.10 | 16720.10 |
| 2013 | 3438.00 | 5563.30 | 4210.40 | 1655.00 | 1085.10 | 350.50 | 171.10 | 82.40 | 16556.00 |
| 2014 | 6109.10 | 3152.90 | 4564.80 | 2883.70 | 937.00 | 578.90 | 182.50 | 128.70 | 18537.60 |
| 2015 | 5595.30 | 5654.70 | 2578.30 | 2990.40 | 1533.80 | 470.70 | 284.00 | 148.20 | 19255.40 |
| 2016 | 4019.60 | 5101.60 | 4660.10 | 1852.40 | 1860.20 | 907.50 | 272.10 | 243.20 | 18916.70 |
| 2017 | 2821.30 | 2567.10 | 3682.50 | 2903.50 | 909.50 | 859.10 | 409.10 | 224.80 | 14376.90 |
| 2018 | 2883.80 | 2320.20 | 2022.90 | 2420.50 | 1549.80 | 457.90 | 422.20 | 303.20 | 12380.50 |
| 2019 | 4051.30 | 2411.00 | 1841.40 | 1348.00 | 1320.80 | 798.10 | 230.20 | 353.90 | 12354.70 |
| 2020 | 4051.30 | 3601.50 | 1933.50 | 1145.20 | 645.70 | 590.80 | 348.20 | 245.20 | 12561.50 |
| 2021 | 4051.30 | 3707.90 | 2860.60 | 1043.40 | 422.60 | 218.20 | 194.40 | 189.50 | 12688.00 |

*Table 10. Estimated time series of status indicators. Fishing mortality rate is apical F ($F$; a.k.a. $F_{full}$). Total biomass (B; mt) and spawning stock biomass (SSB; 1e+12 eggs) are at the start of the year. The* MSST *is defined by* $\text{MSST} = (1 - M)\text{SSB}_{\text{F40\%}}$*, with constant* $M = 0.38$*. SPR is static spawning potential ratio and* $R_y$ *is expected annual recruitment.*

| Year | $F$ | $F/F_{40\%}$ | B | $B/B_{\text{unfished}}$ | SSB | $\text{SSB}/\text{SSB}_{\text{F40\%}}$ | SSB/MSST | SPR | $R_y$ |
|---|---|---|---|---|---|---|---|---|---|
| 1982 | 0.059 | 0.105 | 8650 | 0.919 | 14.79 | 2.127 | 3.459 | 0.862 | 4687903 |
| 1983 | 0.071 | 0.126 | 8672 | 0.921 | 14.75 | 2.121 | 3.450 | 0.777 | 4687903 |
| 1984 | 0.106 | 0.189 | 8521 | 0.905 | 14.33 | 2.061 | 3.351 | 0.773 | 4687903 |
| 1985 | 0.064 | 0.115 | 8410 | 0.893 | 14.14 | 2.034 | 3.308 | 0.839 | 4687903 |
| 1986 | 0.050 | 0.089 | 8463 | 0.899 | 14.31 | 2.058 | 3.346 | 0.839 | 4687903 |
| 1987 | 0.078 | 0.138 | 8490 | 0.902 | 14.28 | 2.054 | 3.340 | 0.791 | 4687903 |
| 1988 | 0.089 | 0.158 | 8424 | 0.895 | 14.09 | 2.027 | 3.296 | 0.784 | 4687903 |
| 1989 | 0.146 | 0.261 | 8368 | 0.889 | 13.59 | 1.954 | 3.178 | 0.649 | 4687903 |
| 1990 | 0.163 | 0.291 | 7378 | 0.784 | 12.78 | 1.839 | 2.990 | 0.678 | 2981837 |
| 1991 | 0.415 | 0.738 | 7808 | 0.829 | 10.54 | 1.516 | 2.466 | 0.436 | 6044289 |
| 1992 | 0.291 | 0.519 | 7224 | 0.767 | 9.58 | 1.378 | 2.240 | 0.548 | 5004718 |
| 1993 | 0.308 | 0.549 | 7730 | 0.821 | 9.69 | 1.395 | 2.268 | 0.565 | 5988458 |
| 1994 | 0.232 | 0.414 | 8719 | 0.926 | 10.48 | 1.507 | 2.451 | 0.635 | 7138726 |
| 1995 | 0.211 | 0.377 | 9301 | 0.988 | 12.33 | 1.774 | 2.884 | 0.655 | 6086695 |
| 1996 | 0.211 | 0.375 | 8616 | 0.915 | 13.44 | 1.934 | 3.144 | 0.624 | 3361885 |
| 1997 | 0.369 | 0.657 | 7324 | 0.778 | 12.16 | 1.750 | 2.845 | 0.504 | 2378084 |
| 1998 | 0.166 | 0.295 | 5942 | 0.631 | 10.49 | 1.509 | 2.454 | 0.700 | 2864188 |
| 1999 | 0.153 | 0.273 | 5670 | 0.602 | 9.63 | 1.385 | 2.252 | 0.698 | 3280604 |
| 2000 | 0.153 | 0.272 | 6005 | 0.638 | 8.95 | 1.287 | 2.093 | 0.700 | 4458240 |
| 2001 | 0.160 | 0.285 | 6229 | 0.662 | 9.02 | 1.297 | 2.109 | 0.701 | 4020581 |
| 2002 | 0.245 | 0.436 | 6501 | 0.691 | 9.11 | 1.311 | 2.131 | 0.589 | 4198247 |
| 2003 | 0.221 | 0.394 | 6049 | 0.642 | 9.10 | 1.309 | 2.129 | 0.587 | 3030196 |
| 2004 | 0.317 | 0.565 | 5988 | 0.636 | 8.49 | 1.221 | 1.986 | 0.519 | 3961961 |
| 2005 | 0.296 | 0.528 | 5762 | 0.612 | 7.94 | 1.142 | 1.857 | 0.542 | 3813488 |
| 2006 | 0.289 | 0.514 | 5402 | 0.574 | 7.78 | 1.119 | 1.819 | 0.540 | 3021483 |
| 2007 | 0.500 | 0.891 | 5869 | 0.623 | 6.84 | 0.984 | 1.600 | 0.419 | 4964632 |
| 2008 | 0.448 | 0.797 | 5531 | 0.587 | 6.70 | 0.964 | 1.568 | 0.458 | 3678463 |
| 2009 | 0.726 | 1.293 | 5946 | 0.632 | 6.21 | 0.893 | 1.451 | 0.349 | 4942799 |
| 2010 | 0.625 | 1.112 | 5544 | 0.589 | 6.08 | 0.875 | 1.423 | 0.393 | 3820838 |
| 2011 | 0.460 | 0.819 | 6351 | 0.675 | 6.47 | 0.931 | 1.514 | 0.488 | 6194808 |
| 2012 | 0.385 | 0.685 | 7584 | 0.806 | 7.80 | 1.122 | 1.824 | 0.512 | 6785481 |
| 2013 | 0.320 | 0.569 | 7510 | 0.798 | 9.70 | 1.396 | 2.270 | 0.531 | 3978220 |
| 2014 | 0.379 | 0.676 | 8409 | 0.893 | 9.85 | 1.417 | 2.304 | 0.492 | 7069015 |
| 2015 | 0.215 | 0.383 | 8734 | 0.928 | 10.97 | 1.578 | 2.566 | 0.610 | 6474520 |
| 2016 | 0.464 | 0.826 | 8581 | 0.911 | 11.28 | 1.622 | 2.638 | 0.278 | 4651246 |
| 2017 | 0.378 | 0.672 | 6521 | 0.693 | 9.52 | 1.370 | 2.227 | 0.425 | 3264655 |
| 2018 | 0.355 | 0.632 | 5616 | 0.596 | 8.21 | 1.181 | 1.920 | 0.447 | 3336981 |
| 2019 | 0.497 | 0.884 | 5604 | 0.595 | 6.82 | 0.981 | 1.596 | 0.415 | 4687903 |
| 2020 | 0.779 | 1.387 | 5698 | 0.605 | 5.80 | 0.835 | 1.357 | 0.342 | 4687903 |
| 2021 | 0.717 | 1.276 | 5755 | 0.611 | 5.69 | 0.819 | 1.331 | 0.337 | 4687903 |

*Table 11. Selectivity at age for commercial handline landings (L.cHLs), recreational headboat landings (L.rHBs), general recreational landings (L.rGNs), recreational headboat discards (D.rHDs), general recreational discards (D.rGDs), SERFS trap/video survey index (U.sTVs), selectivity of landings averaged across fisheries (L.avg), selectivity of discards averaged across fisheries (D.avg), and selectivity of total removals (Total = L.avg). All selectivities were estimated from age or length comps from the southern portion of the stock area, so fleet abbrevations have the suffix 's'. These selectivities were also applied to northern portions of the stock area, for which comp data was not available.*

| Age | L.cHLs | L.rHBs | L.rGNs | D.rHDs | D.rGDs | U.sTVs | L.avg | D.avg | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.00 | 0.01 | 0.01 | 1.00 | 1.00 | 0.02 | 0.00 | 0.12 | 0.12 |
| 2 | 0.02 | 0.08 | 0.08 | 0.32 | 0.32 | 0.14 | 0.07 | 0.04 | 0.10 |
| 3 | 0.23 | 0.55 | 0.55 | 0.01 | 0.01 | 0.52 | 0.48 | 0.00 | 0.49 |
| 4 | 0.79 | 0.95 | 0.95 | 0.00 | 0.00 | 0.88 | 0.91 | 0.00 | 0.91 |
| 5 | 0.98 | 1.00 | 1.00 | 0.00 | 0.00 | 0.98 | 0.99 | 0.00 | 0.99 |
| 6 | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 | 0.00 | 1.00 |
| 7 | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 | 0.00 | 1.00 |
| 8 | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 | 0.00 | 1.00 |

*Table 12. Estimated time series of fully selected fishing mortality rates for commercial handline landings, south (L.cHLs); commercial handline landings, north (L.cHLn); recreational headboat landings, south (L.rHBs); general recreational landings, south (L.rGNs); general recreational landings, north (L.rGNn); recreational headboat discards, south (D.rHDs); general recreational discards, south (D.rGDs); and general recreational discards, north (D.rGDn). Also shown is $F_{full}$ (i.e. apical $F$), the maximum F at age summed across fleets, and $F_{sum}$, the sum of all fleet-specific values of fully selected $F$.*

| Year | $F_{\mathrm{L.cHLs}}$ | $F_{\mathrm{L.cHLn}}$ | $F_{\mathrm{L.rHBs}}$ | $F_{\mathrm{L.rGNs}}$ | $F_{\mathrm{L.rGNn}}$ | $F_{\mathrm{D.rHDs}}$ | $F_{\mathrm{D.rGDs}}$ | $F_{\mathrm{D.rGDn}}$ | $F_{\mathrm{full}}$ | $F_{\mathrm{sum}}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1982 | 0.014 | 0.000 | 0.011 | 0.033 | 0.000 | 0.001 | 0.007 | 0.000 | 0.059 | 0.066 |
| 1983 | 0.010 | 0.000 | 0.011 | 0.028 | 0.019 | 0.003 | 0.067 | 0.000 | 0.071 | 0.138 |
| 1984 | 0.011 | 0.000 | 0.010 | 0.084 | 0.001 | 0.001 | 0.011 | 0.000 | 0.106 | 0.119 |
| 1985 | 0.011 | 0.000 | 0.014 | 0.038 | 0.002 | 0.003 | 0.014 | 0.000 | 0.064 | 0.082 |
| 1986 | 0.011 | 0.000 | 0.011 | 0.020 | 0.009 | 0.002 | 0.042 | 0.000 | 0.050 | 0.093 |
| 1987 | 0.012 | 0.000 | 0.011 | 0.028 | 0.027 | 0.005 | 0.034 | 0.001 | 0.078 | 0.118 |
| 1988 | 0.013 | 0.000 | 0.013 | 0.062 | 0.001 | 0.009 | 0.021 | 0.001 | 0.089 | 0.119 |
| 1989 | 0.016 | 0.000 | 0.015 | 0.091 | 0.024 | 0.000 | 0.087 | 0.001 | 0.146 | 0.235 |
| 1990 | 0.034 | 0.000 | 0.030 | 0.078 | 0.021 | 0.001 | 0.022 | 0.013 | 0.163 | 0.199 |
| 1991 | 0.056 | 0.000 | 0.042 | 0.287 | 0.029 | 0.000 | 0.101 | 0.002 | 0.415 | 0.518 |
| 1992 | 0.068 | 0.000 | 0.054 | 0.156 | 0.014 | 0.000 | 0.050 | 0.001 | 0.291 | 0.342 |
| 1993 | 0.091 | 0.001 | 0.060 | 0.120 | 0.036 | 0.000 | 0.014 | 0.002 | 0.308 | 0.324 |
| 1994 | 0.094 | 0.005 | 0.045 | 0.059 | 0.029 | 0.000 | 0.013 | 0.001 | 0.232 | 0.247 |
| 1995 | 0.105 | 0.004 | 0.041 | 0.034 | 0.027 | 0.001 | 0.018 | 0.001 | 0.211 | 0.231 |
| 1996 | 0.083 | 0.003 | 0.034 | 0.045 | 0.045 | 0.001 | 0.036 | 0.015 | 0.211 | 0.262 |
| 1997 | 0.102 | 0.003 | 0.042 | 0.045 | 0.177 | 0.001 | 0.033 | 0.011 | 0.369 | 0.415 |
| 1998 | 0.082 | 0.002 | 0.032 | 0.038 | 0.013 | 0.003 | 0.016 | 0.003 | 0.166 | 0.188 |
| 1999 | 0.061 | 0.002 | 0.021 | 0.068 | 0.001 | 0.004 | 0.032 | 0.001 | 0.153 | 0.190 |
| 2000 | 0.050 | 0.001 | 0.021 | 0.062 | 0.018 | 0.001 | 0.028 | 0.002 | 0.153 | 0.184 |
| 2001 | 0.058 | 0.001 | 0.021 | 0.058 | 0.021 | 0.001 | 0.017 | 0.004 | 0.160 | 0.182 |
| 2002 | 0.053 | 0.004 | 0.034 | 0.112 | 0.042 | 0.005 | 0.040 | 0.002 | 0.245 | 0.291 |
| 2003 | 0.049 | 0.003 | 0.026 | 0.125 | 0.018 | 0.002 | 0.071 | 0.003 | 0.221 | 0.297 |
| 2004 | 0.067 | 0.002 | 0.047 | 0.121 | 0.079 | 0.006 | 0.054 | 0.007 | 0.317 | 0.384 |
| 2005 | 0.081 | 0.002 | 0.043 | 0.097 | 0.075 | 0.008 | 0.050 | 0.001 | 0.296 | 0.355 |
| 2006 | 0.078 | 0.002 | 0.030 | 0.175 | 0.005 | 0.006 | 0.062 | 0.001 | 0.289 | 0.358 |
| 2007 | 0.113 | 0.004 | 0.049 | 0.287 | 0.048 | 0.003 | 0.062 | 0.013 | 0.500 | 0.578 |
| 2008 | 0.131 | 0.002 | 0.037 | 0.265 | 0.012 | 0.002 | 0.053 | 0.001 | 0.448 | 0.503 |
| 2009 | 0.165 | 0.007 | 0.050 | 0.364 | 0.140 | 0.002 | 0.063 | 0.011 | 0.726 | 0.801 |
| 2010 | 0.216 | 0.006 | 0.060 | 0.276 | 0.066 | 0.003 | 0.043 | 0.012 | 0.625 | 0.683 |
| 2011 | 0.221 | 0.008 | 0.042 | 0.168 | 0.022 | 0.001 | 0.016 | 0.002 | 0.460 | 0.479 |
| 2012 | 0.109 | 0.013 | 0.034 | 0.136 | 0.092 | 0.001 | 0.019 | 0.002 | 0.385 | 0.407 |
| 2013 | 0.104 | 0.008 | 0.032 | 0.149 | 0.027 | 0.001 | 0.049 | 0.006 | 0.320 | 0.376 |
| 2014 | 0.073 | 0.003 | 0.026 | 0.200 | 0.078 | 0.001 | 0.043 | 0.002 | 0.379 | 0.426 |
| 2015 | 0.081 | 0.001 | 0.022 | 0.092 | 0.019 | 0.003 | 0.056 | 0.003 | 0.215 | 0.278 |
| 2016 | 0.074 | 0.002 | 0.018 | 0.335 | 0.035 | 0.011 | 0.398 | 0.009 | 0.464 | 0.881 |
| 2017 | 0.080 | 0.007 | 0.022 | 0.211 | 0.058 | 0.006 | 0.154 | 0.005 | 0.378 | 0.543 |
| 2018 | 0.085 | 0.005 | 0.021 | 0.153 | 0.090 | 0.005 | 0.134 | 0.010 | 0.355 | 0.504 |
| 2019 | 0.111 | 0.004 | 0.028 | 0.237 | 0.115 | 0.004 | 0.075 | 0.007 | 0.497 | 0.583 |
| 2020 | 0.152 | 0.004 | 0.027 | 0.343 | 0.252 | 0.002 | 0.037 | 0.017 | 0.779 | 0.835 |
| 2021 | 0.123 | 0.005 | 0.025 | 0.445 | 0.119 | 0.002 | 0.091 | 0.006 | 0.717 | 0.816 |

*Table 13. Estimated instantaneous fishing mortality rate F (per yr) at age*

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1982 | 0.008 | 0.006 | 0.028 | 0.053 | 0.058 | 0.059 | 0.059 | 0.059 |
| 1983 | 0.071 | 0.027 | 0.035 | 0.062 | 0.067 | 0.068 | 0.068 | 0.068 |
| 1984 | 0.013 | 0.012 | 0.055 | 0.099 | 0.106 | 0.106 | 0.106 | 0.106 |
| 1985 | 0.018 | 0.010 | 0.032 | 0.059 | 0.064 | 0.064 | 0.064 | 0.064 |
| 1986 | 0.044 | 0.017 | 0.024 | 0.045 | 0.049 | 0.050 | 0.050 | 0.050 |
| 1987 | 0.041 | 0.018 | 0.039 | 0.072 | 0.077 | 0.078 | 0.078 | 0.078 |
| 1988 | 0.031 | 0.016 | 0.045 | 0.082 | 0.088 | 0.089 | 0.089 | 0.089 |
| 1989 | 0.089 | 0.039 | 0.076 | 0.136 | 0.146 | 0.146 | 0.146 | 0.146 |
| 1990 | 0.037 | 0.022 | 0.079 | 0.149 | 0.162 | 0.163 | 0.163 | 0.163 |
| 1991 | 0.106 | 0.062 | 0.211 | 0.384 | 0.412 | 0.414 | 0.415 | 0.415 |
| 1992 | 0.052 | 0.035 | 0.139 | 0.265 | 0.289 | 0.291 | 0.291 | 0.291 |
| 1993 | 0.017 | 0.024 | 0.140 | 0.278 | 0.306 | 0.308 | 0.308 | 0.308 |
| 1994 | 0.015 | 0.017 | 0.096 | 0.204 | 0.230 | 0.232 | 0.232 | 0.232 |
| 1995 | 0.021 | 0.017 | 0.081 | 0.183 | 0.209 | 0.211 | 0.211 | 0.211 |
| 1996 | 0.052 | 0.028 | 0.089 | 0.186 | 0.208 | 0.210 | 0.210 | 0.211 |
| 1997 | 0.047 | 0.037 | 0.170 | 0.333 | 0.366 | 0.369 | 0.369 | 0.369 |
| 1998 | 0.023 | 0.015 | 0.065 | 0.144 | 0.164 | 0.166 | 0.166 | 0.166 |
| 1999 | 0.037 | 0.020 | 0.064 | 0.135 | 0.152 | 0.153 | 0.153 | 0.153 |
| 2000 | 0.032 | 0.019 | 0.068 | 0.137 | 0.152 | 0.153 | 0.153 | 0.153 |
| 2001 | 0.023 | 0.016 | 0.069 | 0.142 | 0.158 | 0.160 | 0.160 | 0.160 |
| 2002 | 0.048 | 0.030 | 0.117 | 0.223 | 0.243 | 0.244 | 0.245 | 0.245 |
| 2003 | 0.077 | 0.038 | 0.106 | 0.201 | 0.220 | 0.221 | 0.221 | 0.221 |
| 2004 | 0.069 | 0.042 | 0.153 | 0.289 | 0.315 | 0.317 | 0.317 | 0.317 |
| 2005 | 0.060 | 0.037 | 0.137 | 0.268 | 0.294 | 0.296 | 0.296 | 0.296 |
| 2006 | 0.071 | 0.040 | 0.134 | 0.261 | 0.286 | 0.289 | 0.289 | 0.289 |
| 2007 | 0.080 | 0.057 | 0.239 | 0.456 | 0.496 | 0.500 | 0.500 | 0.500 |
| 2008 | 0.057 | 0.045 | 0.204 | 0.403 | 0.444 | 0.447 | 0.448 | 0.448 |
| 2009 | 0.079 | 0.070 | 0.345 | 0.661 | 0.720 | 0.726 | 0.726 | 0.726 |
| 2010 | 0.061 | 0.054 | 0.273 | 0.557 | 0.618 | 0.624 | 0.625 | 0.625 |
| 2011 | 0.020 | 0.029 | 0.180 | 0.400 | 0.455 | 0.460 | 0.460 | 0.460 |
| 2012 | 0.024 | 0.030 | 0.173 | 0.345 | 0.381 | 0.385 | 0.385 | 0.385 |
| 2013 | 0.058 | 0.036 | 0.140 | 0.285 | 0.317 | 0.319 | 0.320 | 0.320 |
| 2014 | 0.049 | 0.040 | 0.185 | 0.348 | 0.377 | 0.379 | 0.379 | 0.379 |
| 2015 | 0.064 | 0.032 | 0.093 | 0.191 | 0.213 | 0.215 | 0.215 | 0.215 |
| 2016 | 0.420 | 0.165 | 0.235 | 0.428 | 0.461 | 0.464 | 0.464 | 0.464 |
| 2017 | 0.167 | 0.077 | 0.182 | 0.344 | 0.375 | 0.377 | 0.378 | 0.378 |
| 2018 | 0.150 | 0.070 | 0.168 | 0.322 | 0.352 | 0.355 | 0.355 | 0.355 |
| 2019 | 0.089 | 0.059 | 0.237 | 0.452 | 0.493 | 0.496 | 0.497 | 0.497 |
| 2020 | 0.060 | 0.069 | 0.379 | 0.713 | 0.773 | 0.778 | 0.779 | 0.779 |
| 2021 | 0.103 | 0.080 | 0.354 | 0.659 | 0.712 | 0.716 | 0.717 | 0.717 |

*Table 14. Total landings at age in numbers (1000 fish)*

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1982 | 0.95 | 7.27 | 32.71 | 38.77 | 26.27 | 16.64 | 10.57 | 18.66 |
| 1983 | 1.14 | 9.00 | 39.97 | 45.15 | 30.14 | 19.05 | 12.10 | 21.36 |
| 1984 | 1.90 | 13.83 | 63.25 | 70.03 | 46.18 | 29.15 | 18.50 | 32.66 |
| 1985 | 1.10 | 8.48 | 35.53 | 41.41 | 27.38 | 17.20 | 10.91 | 19.25 |
| 1986 | 0.81 | 6.25 | 28.30 | 31.14 | 21.43 | 13.40 | 8.45 | 14.89 |
| 1987 | 1.33 | 10.04 | 45.39 | 52.01 | 32.73 | 21.11 | 13.24 | 23.18 |
| 1988 | 1.53 | 11.54 | 50.41 | 57.54 | 38.71 | 23.06 | 14.94 | 25.91 |
| 1989 | 2.53 | 19.56 | 84.28 | 90.18 | 59.99 | 38.19 | 22.85 | 40.67 |
| 1990 | 1.71 | 19.18 | 87.00 | 95.76 | 60.74 | 38.43 | 24.58 | 41.10 |
| 1991 | 8.99 | 33.97 | 209.17 | 218.62 | 133.09 | 78.79 | 49.98 | 85.85 |
| 1992 | 4.98 | 42.33 | 91.88 | 133.71 | 76.70 | 43.76 | 26.00 | 45.06 |
| 1993 | 6.08 | 37.18 | 180.49 | 96.38 | 76.17 | 40.48 | 23.15 | 37.77 |
| 1994 | 4.90 | 30.95 | 111.53 | 142.35 | 40.53 | 29.36 | 15.62 | 23.62 |
| 1995 | 3.47 | 30.56 | 118.29 | 118.66 | 77.61 | 19.90 | 14.41 | 19.35 |
| 1996 | 2.09 | 28.69 | 152.97 | 152.40 | 73.01 | 42.28 | 10.82 | 18.43 |
| 1997 | 2.89 | 30.12 | 237.91 | 303.74 | 151.09 | 65.19 | 37.72 | 26.21 |
| 1998 | 1.30 | 7.85 | 50.22 | 110.19 | 75.67 | 34.55 | 14.93 | 14.71 |
| 1999 | 1.49 | 9.82 | 36.31 | 61.28 | 65.82 | 40.26 | 18.35 | 15.81 |
| 2000 | 2.17 | 11.92 | 47.11 | 45.06 | 39.12 | 38.03 | 23.25 | 19.82 |
| 2001 | 1.98 | 16.44 | 54.09 | 57.11 | 29.54 | 23.54 | 22.90 | 26.07 |
| 2002 | 3.52 | 25.75 | 122.58 | 97.57 | 53.12 | 24.98 | 19.90 | 41.61 |
| 2003 | 2.26 | 23.58 | 99.74 | 116.30 | 50.58 | 25.55 | 12.04 | 29.81 |
| 2004 | 4.31 | 23.96 | 142.93 | 145.78 | 92.75 | 37.43 | 18.95 | 31.20 |
| 2005 | 3.72 | 28.18 | 90.31 | 131.30 | 72.60 | 42.83 | 17.33 | 23.33 |
| 2006 | 2.86 | 26.69 | 116.99 | 91.08 | 69.93 | 35.51 | 20.98 | 20.01 |
| 2007 | 8.39 | 37.28 | 192.77 | 194.08 | 79.01 | 55.68 | 28.31 | 32.84 |
| 2008 | 5.33 | 51.61 | 129.01 | 153.10 | 79.00 | 29.49 | 20.81 | 22.97 |
| 2009 | 12.07 | 66.04 | 337.88 | 179.72 | 105.05 | 49.11 | 18.33 | 27.34 |
| 2010 | 7.35 | 67.89 | 204.02 | 226.32 | 58.02 | 30.71 | 14.36 | 13.42 |
| 2011 | 7.86 | 34.61 | 187.45 | 137.93 | 72.57 | 16.56 | 8.75 | 7.96 |
| 2012 | 8.44 | 58.15 | 145.60 | 178.84 | 58.36 | 26.78 | 6.09 | 6.17 |
| 2013 | 3.94 | 51.01 | 202.14 | 123.27 | 77.14 | 22.86 | 10.49 | 4.83 |
| 2014 | 9.42 | 39.03 | 283.32 | 254.75 | 77.21 | 43.67 | 12.94 | 8.71 |
| 2015 | 4.19 | 33.95 | 83.18 | 155.51 | 76.84 | 21.66 | 12.28 | 6.12 |
| 2016 | 6.63 | 75.07 | 353.80 | 194.46 | 180.85 | 80.71 | 22.74 | 19.41 |
| 2017 | 4.02 | 30.34 | 223.22 | 254.28 | 74.60 | 64.53 | 28.88 | 15.16 |
| 2018 | 3.81 | 25.33 | 114.05 | 200.29 | 120.60 | 32.64 | 28.29 | 19.40 |
| 2019 | 7.83 | 37.66 | 142.88 | 148.10 | 135.43 | 74.91 | 20.30 | 29.81 |
| 2020 | 12.75 | 90.21 | 225.99 | 177.98 | 92.49 | 77.36 | 42.83 | 28.80 |
| 2021 | 11.70 | 86.59 | 315.57 | 153.16 | 57.13 | 26.97 | 22.57 | 21.01 |

*Table 15. Estimated total landings at age in weight (1000 lb)*

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1982 | 1.60 | 14.89 | 79.09 | 107.74 | 82.19 | 57.62 | 39.94 | 76.02 |
| 1983 | 1.92 | 18.44 | 96.64 | 125.50 | 94.30 | 65.96 | 45.72 | 87.02 |
| 1984 | 3.20 | 28.35 | 152.91 | 194.63 | 144.50 | 100.94 | 69.91 | 133.06 |
| 1985 | 1.85 | 17.38 | 85.90 | 115.08 | 85.66 | 59.55 | 41.22 | 78.41 |
| 1986 | 1.36 | 12.80 | 68.41 | 86.54 | 67.05 | 46.38 | 31.92 | 60.65 |
| 1987 | 2.24 | 20.58 | 109.73 | 144.54 | 102.41 | 73.11 | 50.03 | 94.44 |
| 1988 | 2.58 | 23.65 | 121.87 | 159.92 | 121.12 | 79.86 | 56.46 | 105.53 |
| 1989 | 4.25 | 40.08 | 203.76 | 250.65 | 187.70 | 132.24 | 86.33 | 165.69 |
| 1990 | 2.87 | 39.32 | 210.33 | 266.14 | 190.05 | 133.06 | 92.87 | 167.41 |
| 1991 | 15.11 | 69.61 | 505.71 | 607.62 | 416.42 | 272.82 | 188.84 | 349.72 |
| 1992 | 8.38 | 86.75 | 222.13 | 371.63 | 240.00 | 151.54 | 98.24 | 183.56 |
| 1993 | 10.23 | 76.20 | 436.37 | 267.87 | 238.34 | 140.17 | 87.45 | 153.88 |
| 1994 | 8.24 | 63.43 | 269.65 | 395.63 | 126.82 | 101.67 | 59.02 | 96.24 |
| 1995 | 5.84 | 62.63 | 285.99 | 329.78 | 242.84 | 68.92 | 54.43 | 78.82 |
| 1996 | 3.51 | 58.80 | 369.82 | 423.57 | 228.44 | 146.39 | 40.86 | 75.06 |
| 1997 | 4.86 | 61.73 | 575.19 | 844.19 | 472.75 | 225.73 | 142.51 | 106.77 |
| 1998 | 2.18 | 16.09 | 121.41 | 306.25 | 236.77 | 119.62 | 56.39 | 59.92 |
| 1999 | 2.50 | 20.13 | 87.78 | 170.32 | 205.96 | 139.41 | 69.31 | 64.40 |
| 2000 | 3.64 | 24.42 | 113.90 | 125.24 | 122.42 | 131.69 | 87.86 | 80.74 |
| 2001 | 3.34 | 33.70 | 130.76 | 158.72 | 92.43 | 81.50 | 86.53 | 106.18 |
| 2002 | 5.92 | 52.77 | 296.36 | 271.17 | 166.21 | 86.49 | 75.20 | 169.49 |
| 2003 | 3.80 | 48.32 | 241.14 | 323.24 | 158.25 | 88.48 | 45.51 | 121.42 |
| 2004 | 7.24 | 49.10 | 345.55 | 405.17 | 290.21 | 129.60 | 71.61 | 127.08 |
| 2005 | 6.25 | 57.74 | 218.34 | 364.91 | 227.16 | 148.32 | 65.46 | 95.04 |
| 2006 | 4.81 | 54.70 | 282.85 | 253.15 | 218.81 | 122.97 | 79.27 | 81.52 |
| 2007 | 14.10 | 76.40 | 466.06 | 539.41 | 247.21 | 192.81 | 106.96 | 133.77 |
| 2008 | 8.96 | 105.76 | 311.90 | 425.52 | 247.20 | 102.11 | 78.62 | 93.56 |
| 2009 | 20.30 | 135.34 | 816.90 | 499.51 | 328.69 | 170.05 | 69.24 | 111.38 |
| 2010 | 12.36 | 139.13 | 493.24 | 629.00 | 181.55 | 106.34 | 54.25 | 54.68 |
| 2011 | 13.22 | 70.93 | 453.19 | 383.34 | 227.07 | 57.35 | 33.07 | 32.41 |
| 2012 | 14.20 | 119.17 | 352.02 | 497.05 | 182.61 | 92.72 | 23.00 | 25.13 |
| 2013 | 6.62 | 104.54 | 488.71 | 342.60 | 241.37 | 79.17 | 39.64 | 19.66 |
| 2014 | 15.84 | 80.00 | 684.97 | 708.02 | 241.57 | 151.21 | 48.88 | 35.48 |
| 2015 | 7.04 | 69.58 | 201.09 | 432.20 | 240.43 | 74.99 | 46.41 | 24.93 |
| 2016 | 11.15 | 153.84 | 855.38 | 540.47 | 565.87 | 279.46 | 85.90 | 79.07 |
| 2017 | 6.75 | 62.18 | 539.67 | 706.72 | 233.41 | 223.44 | 109.10 | 61.75 |
| 2018 | 6.41 | 51.92 | 275.74 | 556.66 | 377.36 | 113.03 | 106.88 | 79.03 |
| 2019 | 13.16 | 77.17 | 345.43 | 411.62 | 423.74 | 259.40 | 76.70 | 121.43 |
| 2020 | 21.43 | 184.86 | 546.38 | 494.66 | 289.40 | 267.89 | 161.83 | 117.30 |
| 2021 | 19.68 | 177.46 | 762.96 | 425.68 | 178.74 | 93.38 | 85.28 | 85.58 |

*Table 16. Estimated total discards at age in numbers (1000 fish)*

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1982 | 26.18 | 4.68 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1983 | 239.92 | 44.07 | 0.87 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1984 | 44.20 | 7.48 | 0.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1985 | 60.78 | 10.93 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1986 | 150.37 | 27.14 | 0.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1987 | 139.66 | 24.51 | 0.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1988 | 104.45 | 18.32 | 0.35 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1989 | 299.02 | 53.84 | 1.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1990 | 78.67 | 20.67 | 0.41 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1991 | 446.67 | 39.31 | 1.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1992 | 186.90 | 37.16 | 0.35 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1993 | 70.55 | 10.13 | 0.21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1994 | 75.79 | 11.34 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1995 | 90.10 | 18.93 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1996 | 126.45 | 41.15 | 0.93 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1997 | 79.76 | 19.51 | 0.67 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1998 | 47.29 | 6.82 | 0.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1999 | 87.78 | 13.70 | 0.21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2000 | 102.20 | 13.23 | 0.22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2001 | 65.71 | 12.85 | 0.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2002 | 143.33 | 24.55 | 0.51 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003 | 166.57 | 40.63 | 0.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004 | 193.65 | 25.19 | 0.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2005 | 162.61 | 28.92 | 0.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2006 | 151.66 | 33.18 | 0.63 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2007 | 278.21 | 28.93 | 0.65 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2008 | 147.86 | 33.63 | 0.36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2009 | 269.05 | 34.45 | 0.77 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2010 | 162.73 | 35.42 | 0.46 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2011 | 85.11 | 8.93 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2012 | 112.03 | 18.15 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2013 | 164.07 | 50.07 | 0.85 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2014 | 242.32 | 23.45 | 0.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2015 | 295.95 | 56.67 | 0.59 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2016 | 1212.29 | 320.07 | 6.66 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2017 | 374.77 | 66.25 | 2.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2018 | 347.72 | 54.14 | 1.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2019 | 292.42 | 32.93 | 0.55 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2020 | 191.91 | 31.73 | 0.35 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2021 | 333.49 | 57.59 | 0.92 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

*Table 17. Estimated total discards at age in weight (1000 lb)*

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1982 | 22.62 | 7.23 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1983 | 207.34 | 68.11 | 1.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1984 | 38.20 | 11.56 | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1985 | 52.53 | 16.89 | 0.44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1986 | 129.95 | 41.95 | 1.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1987 | 120.70 | 37.89 | 1.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1988 | 90.27 | 28.32 | 0.78 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1989 | 258.41 | 83.22 | 2.26 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1990 | 67.99 | 31.94 | 0.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1991 | 386.02 | 60.76 | 2.35 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1992 | 161.52 | 57.43 | 0.77 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1993 | 60.97 | 15.65 | 0.47 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1994 | 65.50 | 17.52 | 0.38 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1995 | 77.87 | 29.26 | 0.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1996 | 109.28 | 63.60 | 2.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1997 | 68.93 | 30.16 | 1.46 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1998 | 40.87 | 10.54 | 0.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1999 | 75.86 | 21.18 | 0.47 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2000 | 88.32 | 20.45 | 0.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2001 | 56.79 | 19.87 | 0.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2002 | 123.87 | 37.94 | 1.12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003 | 143.95 | 62.80 | 1.64 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004 | 167.36 | 38.93 | 1.44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2005 | 140.53 | 44.70 | 0.88 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2006 | 131.07 | 51.28 | 1.38 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2007 | 240.43 | 44.72 | 1.43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2008 | 127.79 | 51.97 | 0.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2009 | 232.52 | 53.25 | 1.69 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2010 | 140.63 | 54.74 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2011 | 73.55 | 13.80 | 0.44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2012 | 96.82 | 28.05 | 0.43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2013 | 141.79 | 77.39 | 1.86 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2014 | 209.41 | 36.25 | 1.64 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2015 | 255.76 | 87.58 | 1.29 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2016 | 1047.68 | 494.69 | 14.59 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2017 | 323.88 | 102.39 | 4.67 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2018 | 300.50 | 83.67 | 2.33 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2019 | 252.72 | 50.90 | 1.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2020 | 165.85 | 49.05 | 0.76 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2021 | 288.20 | 89.01 | 2.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

*Table 18. Estimated time series of landings (L) in numbers (1000 fish) for commercial handline landings, south (L.cHLs); commercial handline landings, north (L.cHLn); recreational headboat landings, south (L.rHBs); general recreational landings, south (L.rGNs); general recreational landings, north (L.rGNn); and total landings.*

| Year | L.cHLs | L.cHLn | L.rHBs | L.rGNs | L.rGNn | Total |
|---|---|---|---|---|---|---|
| 1982 | 30.61 | 0.03 | 29.51 | 91.18 | 0.51 | 151.84 |
| 1983 | 21.64 | 0.29 | 28.61 | 75.96 | 51.42 | 177.91 |
| 1984 | 23.35 | 0.26 | 26.90 | 221.93 | 3.07 | 275.51 |
| 1985 | 21.70 | 0.24 | 35.61 | 97.98 | 5.73 | 161.25 |
| 1986 | 21.81 | 0.21 | 28.38 | 51.66 | 22.59 | 124.65 |
| 1987 | 23.51 | 0.19 | 29.58 | 75.35 | 70.40 | 199.04 |
| 1988 | 25.73 | 0.16 | 34.94 | 160.96 | 1.85 | 223.64 |
| 1989 | 30.97 | 0.14 | 37.39 | 229.53 | 60.21 | 358.25 |
| 1990 | 61.28 | 0.12 | 71.82 | 185.07 | 50.20 | 368.49 |
| 1991 | 87.24 | 0.40 | 85.72 | 585.95 | 59.15 | 818.46 |
| 1992 | 85.31 | 0.29 | 91.93 | 263.72 | 23.18 | 464.43 |
| 1993 | 108.61 | 1.50 | 107.13 | 215.76 | 64.71 | 497.71 |
| 1994 | 127.36 | 6.14 | 90.32 | 117.98 | 57.06 | 398.88 |
| 1995 | 162.10 | 6.81 | 93.27 | 78.62 | 61.45 | 402.25 |
| 1996 | 148.84 | 5.74 | 89.86 | 117.94 | 118.28 | 480.67 |
| 1997 | 185.80 | 5.13 | 106.11 | 113.76 | 444.06 | 854.87 |
| 1998 | 134.95 | 2.83 | 65.91 | 79.37 | 26.36 | 309.41 |
| 1999 | 87.02 | 3.21 | 37.25 | 120.08 | 1.59 | 249.14 |
| 2000 | 61.86 | 1.63 | 34.11 | 99.67 | 29.23 | 226.49 |
| 2001 | 68.81 | 1.65 | 32.98 | 93.98 | 34.25 | 231.67 |
| 2002 | 63.03 | 5.01 | 57.65 | 191.62 | 71.71 | 389.03 |
| 2003 | 61.00 | 3.81 | 45.77 | 217.75 | 31.53 | 359.86 |
| 2004 | 81.18 | 2.97 | 78.10 | 202.62 | 132.42 | 497.30 |
| 2005 | 88.82 | 1.95 | 63.60 | 144.02 | 111.19 | 409.59 |
| 2006 | 79.32 | 1.68 | 43.14 | 252.93 | 7.00 | 384.07 |
| 2007 | 106.37 | 3.57 | 66.34 | 386.98 | 65.09 | 628.35 |
| 2008 | 109.12 | 1.96 | 44.75 | 321.40 | 14.10 | 491.32 |
| 2009 | 124.46 | 5.58 | 59.94 | 437.56 | 168.02 | 795.55 |
| 2010 | 157.28 | 4.08 | 68.75 | 316.34 | 75.64 | 622.09 |
| 2011 | 172.80 | 6.32 | 53.31 | 213.84 | 27.41 | 473.68 |
| 2012 | 100.54 | 12.31 | 49.11 | 194.95 | 131.51 | 488.43 |
| 2013 | 114.09 | 9.25 | 56.53 | 266.88 | 48.93 | 495.68 |
| 2014 | 98.13 | 3.77 | 53.14 | 412.47 | 161.53 | 729.04 |
| 2015 | 118.81 | 1.78 | 45.98 | 189.04 | 38.11 | 393.72 |
| 2016 | 105.74 | 2.62 | 37.81 | 712.60 | 74.90 | 933.66 |
| 2017 | 110.73 | 9.03 | 43.31 | 416.38 | 115.57 | 695.01 |
| 2018 | 105.08 | 6.59 | 35.07 | 250.56 | 147.12 | 544.42 |
| 2019 | 106.01 | 4.27 | 35.75 | 303.50 | 147.37 | 596.91 |
| 2020 | 105.04 | 2.78 | 28.15 | 353.44 | 259.00 | 748.41 |
| 2021 | 75.20 | 3.23 | 26.19 | 465.75 | 124.33 | 694.70 |

*Table 19. Estimated time series of landings (L) in weight (1000 lb) for commercial handline landings, south (L.cHLs); commercial handline landings, north (L.cHLn); recreational headboat landings, south (L.rHBs); general recreational landings, south (L.rGNs); general recreational landings, north (L.rGNn); and total landings.*

| Year | L.cHLs | L.cHLn | L.rHBs | L.rGNs | L.rGNn | Total |
|---|---|---|---|---|---|---|
| 1982 | 96.65 | 0.10 | 88.21 | 272.62 | 1.52 | 459.09 |
| 1983 | 68.30 | 0.90 | 85.52 | 227.06 | 153.70 | 535.48 |
| 1984 | 73.68 | 0.82 | 80.40 | 663.41 | 9.18 | 827.50 |
| 1985 | 68.43 | 0.75 | 106.29 | 292.49 | 17.09 | 485.04 |
| 1986 | 68.71 | 0.67 | 84.54 | 153.90 | 67.30 | 375.12 |
| 1987 | 73.98 | 0.59 | 88.16 | 224.55 | 209.79 | 597.08 |
| 1988 | 80.98 | 0.52 | 104.16 | 479.82 | 5.51 | 670.98 |
| 1989 | 97.37 | 0.44 | 111.20 | 682.61 | 179.07 | 1070.69 |
| 1990 | 191.96 | 0.36 | 212.75 | 548.26 | 148.73 | 1102.06 |
| 1991 | 271.61 | 1.24 | 252.53 | 1726.21 | 174.26 | 2425.85 |
| 1992 | 262.88 | 0.89 | 266.56 | 764.68 | 67.21 | 1362.22 |
| 1993 | 325.33 | 4.48 | 298.70 | 601.57 | 180.42 | 1410.50 |
| 1994 | 372.47 | 17.97 | 248.55 | 324.68 | 157.03 | 1120.70 |
| 1995 | 471.31 | 19.79 | 255.07 | 215.01 | 168.06 | 1129.25 |
| 1996 | 432.83 | 16.70 | 247.17 | 324.41 | 325.33 | 1346.45 |
| 1997 | 548.25 | 15.15 | 298.92 | 320.47 | 1250.95 | 2433.73 |
| 1998 | 409.44 | 8.58 | 192.24 | 231.51 | 76.88 | 918.65 |
| 1999 | 272.85 | 10.07 | 111.79 | 360.36 | 4.76 | 759.82 |
| 2000 | 196.41 | 5.17 | 102.19 | 298.59 | 87.55 | 689.91 |
| 2001 | 215.50 | 5.16 | 96.68 | 275.46 | 100.38 | 693.16 |
| 2002 | 192.24 | 15.29 | 164.54 | 546.89 | 204.66 | 1123.61 |
| 2003 | 182.99 | 11.43 | 129.65 | 616.79 | 89.31 | 1030.17 |
| 2004 | 243.39 | 8.90 | 221.79 | 575.41 | 376.06 | 1425.55 |
| 2005 | 267.55 | 5.89 | 181.49 | 410.99 | 317.29 | 1183.21 |
| 2006 | 238.12 | 5.05 | 121.70 | 713.48 | 19.75 | 1098.09 |
| 2007 | 315.62 | 10.60 | 185.62 | 1082.75 | 182.11 | 1776.71 |
| 2008 | 320.09 | 5.75 | 123.30 | 885.65 | 38.85 | 1373.63 |
| 2009 | 355.34 | 15.92 | 160.32 | 1170.40 | 449.42 | 2151.41 |
| 2010 | 440.70 | 11.44 | 181.80 | 836.59 | 200.04 | 1670.57 |
| 2011 | 480.06 | 17.55 | 139.90 | 561.12 | 71.93 | 1270.56 |
| 2012 | 280.84 | 34.38 | 129.55 | 514.23 | 346.89 | 1305.89 |
| 2013 | 318.31 | 25.80 | 148.52 | 701.13 | 128.55 | 1322.31 |
| 2014 | 276.20 | 10.63 | 142.28 | 1104.37 | 432.49 | 1965.97 |
| 2015 | 342.67 | 5.14 | 126.06 | 518.31 | 104.49 | 1096.68 |
| 2016 | 307.45 | 7.61 | 103.34 | 1947.97 | 204.75 | 2571.13 |
| 2017 | 322.51 | 26.30 | 120.02 | 1153.91 | 320.27 | 1943.02 |
| 2018 | 313.19 | 19.63 | 100.01 | 714.60 | 419.60 | 1567.03 |
| 2019 | 321.19 | 12.94 | 102.45 | 869.74 | 422.32 | 1728.64 |
| 2020 | 310.98 | 8.24 | 77.53 | 973.57 | 713.43 | 2083.75 |
| 2021 | 210.33 | 9.04 | 68.40 | 1216.29 | 324.68 | 1828.74 |

*Table 20. Estimated time series of discards (D) in numbers (1000 fish) for recreational headboat discards, south (D.rHDs); general recreational discards, south (D.rGDs); general recreational discards, north (D.rGDn); and total discards.*

| Year | D.rHDs | D.rGDs | D.rGDn | Total |
|---|---|---|---|---|
| 1982 | 3.32 | 27.53 | 0.10 | 30.95 |
| 1983 | 13.09 | 271.67 | 0.10 | 284.85 |
| 1984 | 5.92 | 45.82 | 0.10 | 51.83 |
| 1985 | 12.94 | 58.87 | 0.10 | 71.91 |
| 1986 | 7.16 | 170.05 | 0.84 | 178.05 |
| 1987 | 21.07 | 138.70 | 4.90 | 164.66 |
| 1988 | 34.97 | 83.72 | 4.44 | 123.13 |
| 1989 | 1.11 | 348.81 | 3.97 | 353.89 |
| 1990 | 1.57 | 60.80 | 37.38 | 99.75 |
| 1991 | 2.04 | 475.08 | 9.94 | 487.05 |
| 1992 | 1.31 | 218.40 | 4.69 | 224.41 |
| 1993 | 1.46 | 69.72 | 9.71 | 80.90 |
| 1994 | 1.61 | 78.15 | 7.53 | 87.30 |
| 1995 | 6.12 | 98.01 | 5.20 | 109.33 |
| 1996 | 1.92 | 118.13 | 48.48 | 168.53 |
| 1997 | 2.65 | 72.86 | 24.44 | 99.94 |
| 1998 | 6.40 | 39.80 | 8.10 | 54.29 |
| 1999 | 10.15 | 89.68 | 1.87 | 101.70 |
| 2000 | 3.67 | 105.48 | 6.52 | 115.66 |
| 2001 | 3.59 | 61.72 | 13.44 | 78.75 |
| 2002 | 17.25 | 142.76 | 8.38 | 168.39 |
| 2003 | 5.83 | 193.17 | 8.94 | 207.95 |
| 2004 | 20.65 | 177.01 | 21.84 | 219.50 |
| 2005 | 26.73 | 163.06 | 2.14 | 191.93 |
| 2006 | 16.03 | 166.60 | 2.84 | 185.47 |
| 2007 | 10.56 | 246.42 | 50.82 | 307.80 |
| 2008 | 6.50 | 173.70 | 1.66 | 181.85 |
| 2009 | 6.15 | 254.10 | 44.02 | 304.27 |
| 2010 | 11.42 | 146.02 | 41.17 | 198.60 |
| 2011 | 6.80 | 79.17 | 8.26 | 94.24 |
| 2012 | 7.47 | 112.09 | 10.82 | 130.37 |
| 2013 | 5.16 | 188.07 | 21.77 | 214.99 |
| 2014 | 7.16 | 247.27 | 12.09 | 266.52 |
| 2015 | 17.82 | 316.33 | 19.05 | 353.20 |
| 2016 | 39.58 | 1467.43 | 32.01 | 1539.03 |
| 2017 | 16.83 | 412.96 | 13.36 | 443.15 |
| 2018 | 14.07 | 362.39 | 26.45 | 402.92 |
| 2019 | 15.60 | 283.60 | 26.70 | 325.90 |
| 2020 | 8.55 | 145.74 | 69.70 | 224.00 |
| 2021 | 8.61 | 358.17 | 25.22 | 392.00 |

*Table 21. Estimated time series of discards (D) in weight (1000 lb) for recreational headboat discards, south (D.rHDs); general recreational discards, south (D.rGDs); general recreational discards, north (D.rGDn); and total discards.*

| Year | D.rHDs | D.rGDs | D.rGDn | Total |
|---|---|---|---|---|
| 1982 | 3.23 | 26.73 | 0.09 | 30.05 |
| 1983 | 12.74 | 264.52 | 0.09 | 277.35 |
| 1984 | 5.72 | 44.28 | 0.09 | 50.10 |
| 1985 | 12.57 | 57.20 | 0.09 | 69.86 |
| 1986 | 6.96 | 165.31 | 0.82 | 173.09 |
| 1987 | 20.42 | 134.48 | 4.75 | 159.66 |
| 1988 | 33.91 | 81.16 | 4.30 | 119.37 |
| 1989 | 1.08 | 338.96 | 3.86 | 343.90 |
| 1990 | 1.59 | 61.46 | 37.78 | 100.84 |
| 1991 | 1.88 | 438.08 | 9.16 | 449.13 |
| 1992 | 1.29 | 213.84 | 4.60 | 219.73 |
| 1993 | 1.39 | 66.45 | 9.26 | 77.09 |
| 1994 | 1.54 | 74.66 | 7.20 | 83.40 |
| 1995 | 6.04 | 96.62 | 5.13 | 107.79 |
| 1996 | 1.99 | 122.61 | 50.32 | 174.92 |
| 1997 | 2.67 | 73.31 | 24.59 | 100.56 |
| 1998 | 6.10 | 37.98 | 7.73 | 51.81 |
| 1999 | 9.73 | 85.99 | 1.79 | 97.51 |
| 2000 | 3.46 | 99.65 | 6.16 | 109.27 |
| 2001 | 3.51 | 60.39 | 13.15 | 77.05 |
| 2002 | 16.69 | 138.13 | 8.11 | 162.93 |
| 2003 | 5.85 | 193.59 | 8.96 | 208.39 |
| 2004 | 19.54 | 167.52 | 20.67 | 207.74 |
| 2005 | 25.92 | 158.12 | 2.08 | 186.11 |
| 2006 | 15.88 | 165.04 | 2.82 | 183.73 |
| 2007 | 9.83 | 229.44 | 47.31 | 286.59 |
| 2008 | 6.45 | 172.46 | 1.65 | 180.56 |
| 2009 | 5.81 | 240.06 | 41.59 | 287.45 |
| 2010 | 11.29 | 144.38 | 40.70 | 196.38 |
| 2011 | 6.34 | 73.76 | 7.70 | 87.79 |
| 2012 | 7.18 | 107.72 | 10.39 | 125.30 |
| 2013 | 5.31 | 193.36 | 22.38 | 221.05 |
| 2014 | 6.64 | 229.44 | 11.22 | 247.30 |
| 2015 | 17.39 | 308.66 | 18.59 | 344.64 |
| 2016 | 40.04 | 1484.55 | 32.38 | 1556.97 |
| 2017 | 16.36 | 401.59 | 13.00 | 430.95 |
| 2018 | 13.50 | 347.63 | 25.38 | 386.51 |
| 2019 | 14.59 | 265.25 | 24.97 | 304.81 |
| 2020 | 8.23 | 140.32 | 67.11 | 215.67 |
| 2021 | 8.33 | 346.51 | 24.40 | 379.24 |

*Table 22. Estimated status indicators, benchmarks, and related quantities from the base run of the Beaufort catch-age model, conditional on estimated current selectivities averaged across fleets. Also presented are median values and measures of precision (standard errors, SE), 25th and 75th percentiles from the Monte Carlo Bootstrap Ensemble (MCBE). Rate estimates (F) are in units of* $\mathrm{y}^{-1}$*; status indicators are dimensionless; and biomass estimates are in units of metric tons or pounds, as indicated. Spawning stock biomass (SSB) is measured in 1e+12 eggs . The* MSST *is defined by* $\mathrm{MSST} = (1 - M)\mathrm{SSB}_{\mathrm{F40\%}}$*, with constant* $M = 0.38$

| Quantity | Units | Estimate | MCBE Median | MCBE SE | MCBE 25% | MCBE 75% |
|---|---|---|---|---|---|---|
| $F_{40\%}$ | $\mathrm{y}^{-1}$ | 0.56 | 0.57 | 0.22 | 0.42 | 0.77 |
| $85\%F_{40\%}$ | $\mathrm{y}^{-1}$ | 0.48 | 0.49 | 0.18 | 0.36 | 0.65 |
| $75\%F_{40\%}$ | $\mathrm{y}^{-1}$ | 0.42 | 0.43 | 0.16 | 0.32 | 0.58 |
| $65\%F_{40\%}$ | $\mathrm{y}^{-1}$ | 0.37 | 0.37 | 0.14 | 0.27 | 0.5 |
| $F_{30\%}$ | $\mathrm{y}^{-1}$ | 0.89 | 0.91 | 0.39 | 0.65 | 1.26 |
| $F_{40\%}$ | $\mathrm{y}^{-1}$ | 0.56 | 0.57 | 0.22 | 0.42 | 0.77 |
| $F_{50\%}$ | $\mathrm{y}^{-1}$ | 0.37 | 0.38 | 0.13 | 0.28 | 0.5 |
| $B_{\mathrm{F40\%}}$ | metric tons | 6266 | 6389 | 2043 | 5305 | 8322 |
| $\mathrm{SSB}_{\mathrm{F40\%}}$ | 1e+12 eggs | 6.95 | 7.33 | 0.68 | 6.9 | 7.85 |
| MSST | 1e+12 eggs | 4.28 | 4.33 | 0.79 | 3.94 | 4.98 |
| $L_{\mathrm{F40\%}}$ | 1000 lb whole | 1865 | 1904 | 556 | 1586 | 2412 |
| $D_{\mathrm{F40\%}}$ | 1000 lb dead fish | 254 | 256 | 256 | 256 | 256 |
| $D_{\mathrm{F40\%}}$ | 1000 dead fish | 262 | 269 | 269 | 269 | 269 |
| $R_{\mathrm{F40\%}}$ | 1000 fish | 4688 | 4889 | 2877 | 3221 | 7530 |
| $L_{85\%\mathrm{F40\%}}$ | 1000 lb whole | 1770 | 1806 | 530 | 1500 | 2294 |
| $L_{75\%\mathrm{F40\%}}$ | 1000 lb whole | 1683 | 1724 | 510 | 1426 | 2185 |
| $L_{65\%\mathrm{F40\%}}$ | 1000 lb whole | 1578 | 1625 | 484 | 1344 | 2058 |
| $F_{2019-2021}/F_{40\%}$ | — | 1.16 | 1.06 | 0.76 | 0.64 | 1.75 |
| $\mathrm{SSB}_{2021}/\mathrm{MSST}$ | — | 1.33 | 1.41 | 0.69 | 0.91 | 2.03 |
| $\mathrm{SSB}_{2021}/\mathrm{SSB}_{\mathrm{F40\%}}$ | — | 0.82 | 0.86 | 0.29 | 0.62 | 1.1 |

*Table 23. Results from sensitivity runs of the Beaufort Assessment Model compared with the base model. Results of the age structured production model (ASPM; aspm) and retrospective (retro) runs are also presented. Current F represented by geometric mean of last three assessment years ($F/F_{40\%} = F_{2019-2021}/F_{40\%}$). $L_{\mathrm{F}40\%}$ is in 1000 lb weight. Spawning stock biomass (SSB) is measured in 1e+12 eggs. Stock and rebuild status based on terminal year ($\mathrm{SSB}/\mathrm{MSST} = \mathrm{SSB}_{2021}/\mathrm{MSST}$; $\mathrm{SSB}/\mathrm{SSB}_{\mathrm{F}40\%} = \mathrm{SSB}_{2021}/\mathrm{SSB}_{\mathrm{F}40\%}$). Years associated with reference points in retrospective runs differ from other runs. See text for full description of sensitivity, ASPM, and retrospective runs.*

| ID | Description | $F_{40\%}$ | $\mathrm{SSB}_{\mathrm{F}40\%}$ | $L_{\mathrm{F}40\%}$ | $F/F_{40\%}$ | SSB/MSST | $R_0$ (1000$fish$) |
|---|---|---|---|---|---|---|---|
| base | base | 0.562 | 6.95 | 1864.75 | 1.16 | 1.33 | 4307 |
| S01 | F init lo | 0.562 | 6.95 | 1865.19 | 1.16 | 1.33 | 4308 |
| S02 | F init up | 0.562 | 6.95 | 1863.97 | 1.16 | 1.33 | 4302 |
| S03 | M lo | 0.295 | 8.52 | 1384.31 | 3.07 | 0.50 | 1923 |
| S04 | M up | 1.037 | 8.33 | 3292.91 | 0.38 | 2.88 | 11447 |
| S05 | Dmort lo | 0.596 | 6.71 | 1894.14 | 1.10 | 1.37 | 4153 |
| S06 | Dmort up | 0.532 | 7.19 | 1842.94 | 1.22 | 1.29 | 4457 |
| S07 | age error none | 0.429 | 9.23 | 2415.76 | 0.66 | 1.88 | 5790 |
| S08 | age1to8 | 0.625 | 6.36 | 1722.24 | 1.39 | 1.20 | 3983 |
| S09 | fecbatchconstant | 0.802 | 8.78 | 2044.73 | 0.81 | 1.65 | 4307 |
| S10 | nbatchconstant | 1.597 | 9.92 | 2199.59 | 0.41 | 2.15 | 4307 |
| S11 | fecbatchnbatchconstant | 3.000 | 20.50 | 2053.32 | 0.22 | 2.42 | 4307 |
| S12 | steep estimate init0.8 | 0.561 | 6.97 | 1868.96 | 1.16 | 1.33 | 4317 |
| S13 | smooth D rGDs 2016 | 0.562 | 6.85 | 1834.02 | 1.17 | 1.33 | 4241 |
| S14 | styr cpue sTVs 1990 | 0.544 | 7.19 | 1914.11 | 1.06 | 1.41 | 4493 |
| S15 | sel rGN rHB separate | 0.420 | 5.14 | 1473.55 | 1.23 | 1.30 | 3186 |
| S16 | w cpue sTVs lo | 0.570 | 6.63 | 1792.94 | 1.28 | 1.25 | 4092 |
| S17 | w cpue sTVs up | 0.563 | 6.04 | 1654.35 | 1.59 | 1.05 | 3225 |
| S18 | w agec sTVs lo | 0.530 | 7.39 | 1962.77 | 1.01 | 1.46 | 4479 |
| S19 | w agec sTVs up | 0.644 | 6.21 | 1680.09 | 1.44 | 1.15 | 3936 |
| S20 | w agec all lo | 0.563 | 6.87 | 1836.43 | 1.18 | 1.32 | 4160 |
| S21 | w agec all up | 0.573 | 6.38 | 1723.99 | 1.32 | 1.23 | 4041 |
| S22 | w lenc all lo | 0.563 | 6.94 | 1865.59 | 1.16 | 1.34 | 4300 |
| S23 | w lenc all up | 0.561 | 6.96 | 1867.14 | 1.17 | 1.31 | 4266 |
| aspm | aspm | 0.478 | 18.91 | 4560.03 | 0.22 | 3.05 | 12732 |
| retro20 | retro endyr2020 | 0.534 | 7.12 | 1819.52 | 0.87 | 1.59 | 4399 |
| retro19 | retro endyr2019 | 0.488 | 7.06 | 1637.40 | 0.79 | 1.90 | 4384 |
| retro18 | retro endyr2018 | 0.431 | 6.98 | 1413.98 | 1.01 | 1.94 | 4318 |
| retro17 | retro endyr2017 | 0.401 | 7.30 | 1433.82 | 0.84 | 2.00 | 4436 |
| retro16 | retro endyr2016 | 0.424 | 7.02 | 1470.20 | 0.85 | 2.06 | 4259 |

*Table 24. Projection results with fishing mortality rate fixed at $F = F_{40}$ starting in 2025 and projecting forward to 2031. From 2022 to 2024 the fishing mortality rate was fixed at $F_{\text{current}} = 0.65$. R = number of age-1 recruits (1000 fish), F = fishing mortality rate (per year), S = spawning stock (1e+12 eggs), L = landings expressed in numbers (n, 1000 fish) or whole weight (w, 1000 lb), $P(SSB > MSST)$ = proportion of stochastic projection replicates with SSB > $MSST$. The subscript b indicates expected values (deterministic) from the base run; the subscript m indicates median values from the stochastic projections.*

| Year | $R_b$ | $R_m$ | $F_b$ | $F_m$ | $S_b$ | $S_m$ | $L_b$ (n) | $L_m$ (n) | $L_b$ (w) | $L_m$ (w) | $D_b$ (n) | $D_m$ (n) | $D_b$ (w) | $D_m$ (w) | $P(SSB > MSST)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2022 | 4688 | 4477 | 0.65 | 0.61 | 5.80 | 6.26 | 636 | 669 | 1679 | 1755 | 303 | 265 | 294 | 253 | 0.72 |
| 2023 | 4688 | 4473 | 0.65 | 0.61 | 6.07 | 6.44 | 703 | 697 | 1839 | 1839 | 303 | 267 | 292 | 257 | 0.73 |
| 2024 | 4688 | 4504 | 0.65 | 0.61 | 6.26 | 6.50 | 728 | 693 | 1911 | 1835 | 303 | 267 | 292 | 256 | 0.74 |
| 2025 | 4688 | 4488 | 0.56 | 0.56 | 6.49 | 6.63 | 649 | 657 | 1711 | 1745 | 262 | 247 | 253 | 237 | 0.76 |
| 2026 | 4688 | 4454 | 0.56 | 0.56 | 6.72 | 6.74 | 673 | 674 | 1786 | 1795 | 262 | 249 | 254 | 239 | 0.80 |
| 2027 | 4688 | 4476 | 0.56 | 0.56 | 6.85 | 6.84 | 687 | 684 | 1828 | 1826 | 262 | 249 | 254 | 239 | 0.83 |
| 2028 | 4688 | 4477 | 0.56 | 0.56 | 6.91 | 6.90 | 693 | 689 | 1849 | 1841 | 262 | 248 | 254 | 238 | 0.84 |
| 2029 | 4688 | 4455 | 0.56 | 0.56 | 6.93 | 6.92 | 696 | 691 | 1858 | 1848 | 262 | 246 | 254 | 236 | 0.85 |
| 2030 | 4688 | 4499 | 0.56 | 0.56 | 6.94 | 6.92 | 697 | 692 | 1862 | 1852 | 262 | 248 | 254 | 238 | 0.85 |
| 2031 | 4688 | 4490 | 0.56 | 0.56 | 6.95 | 6.93 | 697 | 691 | 1864 | 1852 | 262 | 248 | 254 | 238 | 0.85 |

*Table 25. Projection results with fishing mortality rate fixed at* $F = 75\%F_{40}$ *starting in 2025 and projecting forward to 2031. From 2022 to 2024 the fishing mortality rate was fixed at* $F_{\text{current}} = 0.65$*.* $R$ *= number of age-1 recruits (1000 fish),* $F$ *= fishing mortality rate (per year),* $S$ *= spawning stock (1e+12 eggs),* $L$ *= landings expressed in numbers (n, 1000 fish) or whole weight (w, 1000 lb),* $P(SSB > MSST)$ *= proportion of stochastic projection replicates with SSB >* $MSST$*. The subscript b indicates expected values (deterministic) from the base run; the subscript m indicates median values from the stochastic projections.*

| Year | $R_b$ | $R_m$ | $F_b$ | $F_m$ | $S_b$ | $S_m$ | $L_b$ (n) | $L_m$ (n) | $L_b$ (w) | $L_m$ (w) | $D_b$ (n) | $D_m$ (n) | $D_b$ (w) | $D_m$ (w) | $P(SSB > MSST)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2022 | 4688 | 4510 | 0.65 | 0.61 | 5.80 | 6.23 | 636 | 668 | 1679 | 1751 | 303 | 267 | 294 | 256 | 0.72 |
| 2023 | 4688 | 4506 | 0.65 | 0.61 | 6.07 | 6.41 | 703 | 697 | 1839 | 1837 | 303 | 268 | 292 | 257 | 0.73 |
| 2024 | 4688 | 4489 | 0.65 | 0.61 | 6.26 | 6.48 | 728 | 693 | 1911 | 1836 | 303 | 266 | 292 | 256 | 0.73 |
| 2025 | 4688 | 4512 | 0.42 | 0.42 | 6.75 | 6.90 | 507 | 515 | 1339 | 1369 | 198 | 188 | 191 | 180 | 0.78 |
| 2026 | 4688 | 4456 | 0.42 | 0.42 | 7.36 | 7.46 | 556 | 559 | 1488 | 1499 | 199 | 188 | 192 | 181 | 0.85 |
| 2027 | 4688 | 4484 | 0.42 | 0.42 | 7.75 | 7.79 | 586 | 586 | 1582 | 1586 | 199 | 189 | 192 | 181 | 0.90 |
| 2028 | 4688 | 4456 | 0.42 | 0.42 | 7.95 | 7.97 | 602 | 600 | 1636 | 1635 | 199 | 188 | 192 | 180 | 0.93 |
| 2029 | 4688 | 4510 | 0.42 | 0.42 | 8.06 | 8.10 | 610 | 609 | 1662 | 1661 | 199 | 188 | 192 | 181 | 0.94 |
| 2030 | 4688 | 4472 | 0.42 | 0.42 | 8.11 | 8.13 | 613 | 612 | 1675 | 1674 | 199 | 187 | 192 | 180 | 0.95 |
| 2031 | 4688 | 4478 | 0.42 | 0.42 | 8.13 | 8.17 | 614 | 614 | 1680 | 1682 | 199 | 190 | 192 | 182 | 0.95 |

# 9 Figures

*Figure 1. Timeline of data fit to in this assessment. Date types include landings (L), indices of abundance (index; CPUE), age compositions (comp), and length compositions. Data sources include the commercial (com) handline, recreational headboat and general recreational fleets, and the SERFS trap video survey. Sources of landings and discards are from north and south areas along the US Atlantic coast, divided at the border of Virginia and North Carolina. Age composition data were divided into early (a;$\leq$ 2014) and a late (b; $\geq$ 2015) years.*

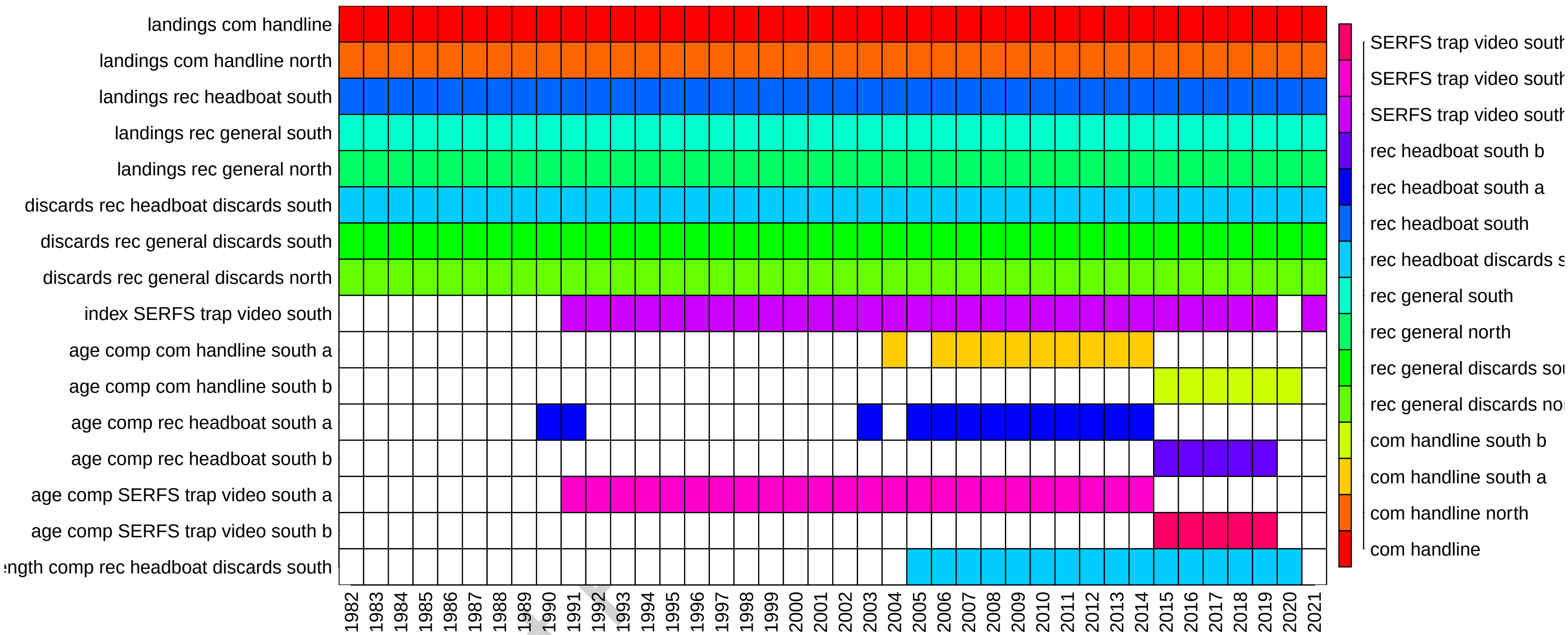


*Figure 2. Fitting of growth models for the (A) population and (B) fishery.*

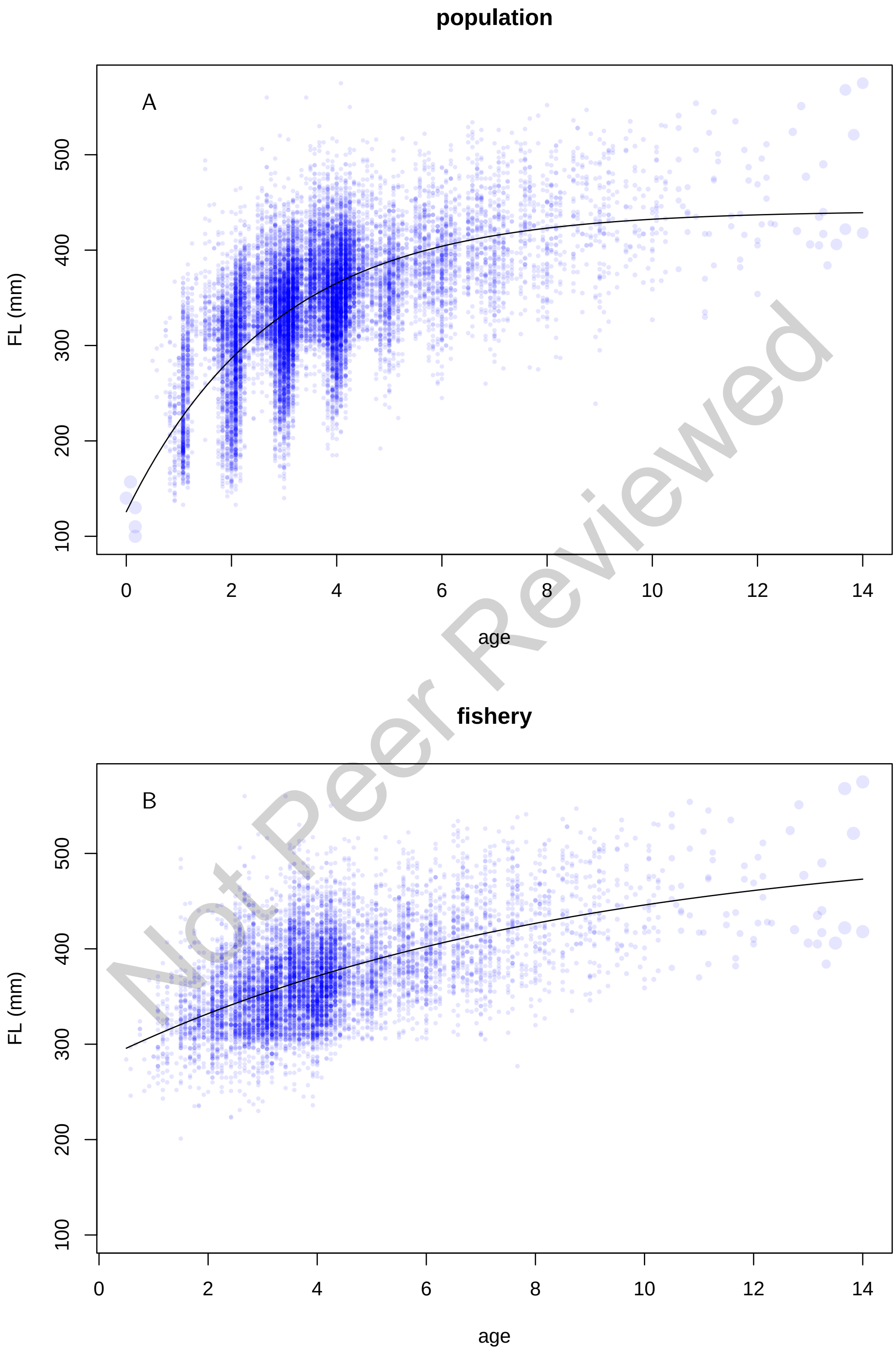
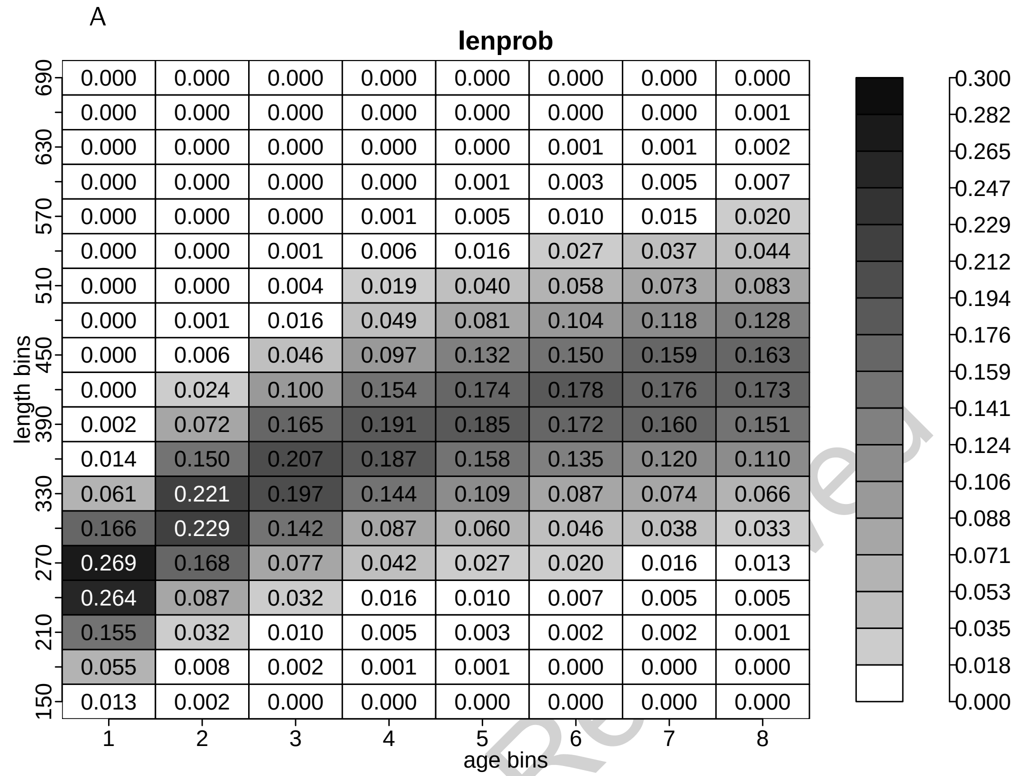


*Figure 3. Length to age conversion matrices for the (A) population and (B) fishery, used in the model.*



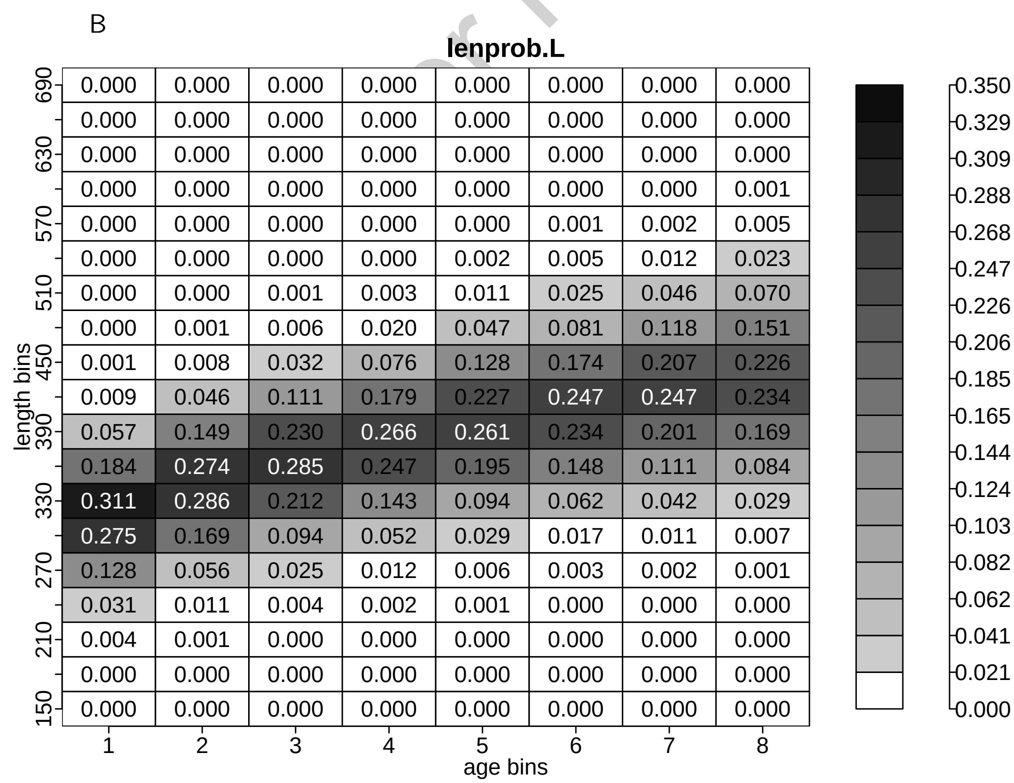



*Figure 4. Aging error matrix used in the assessment, relating true ages to observed (comps) ages.*

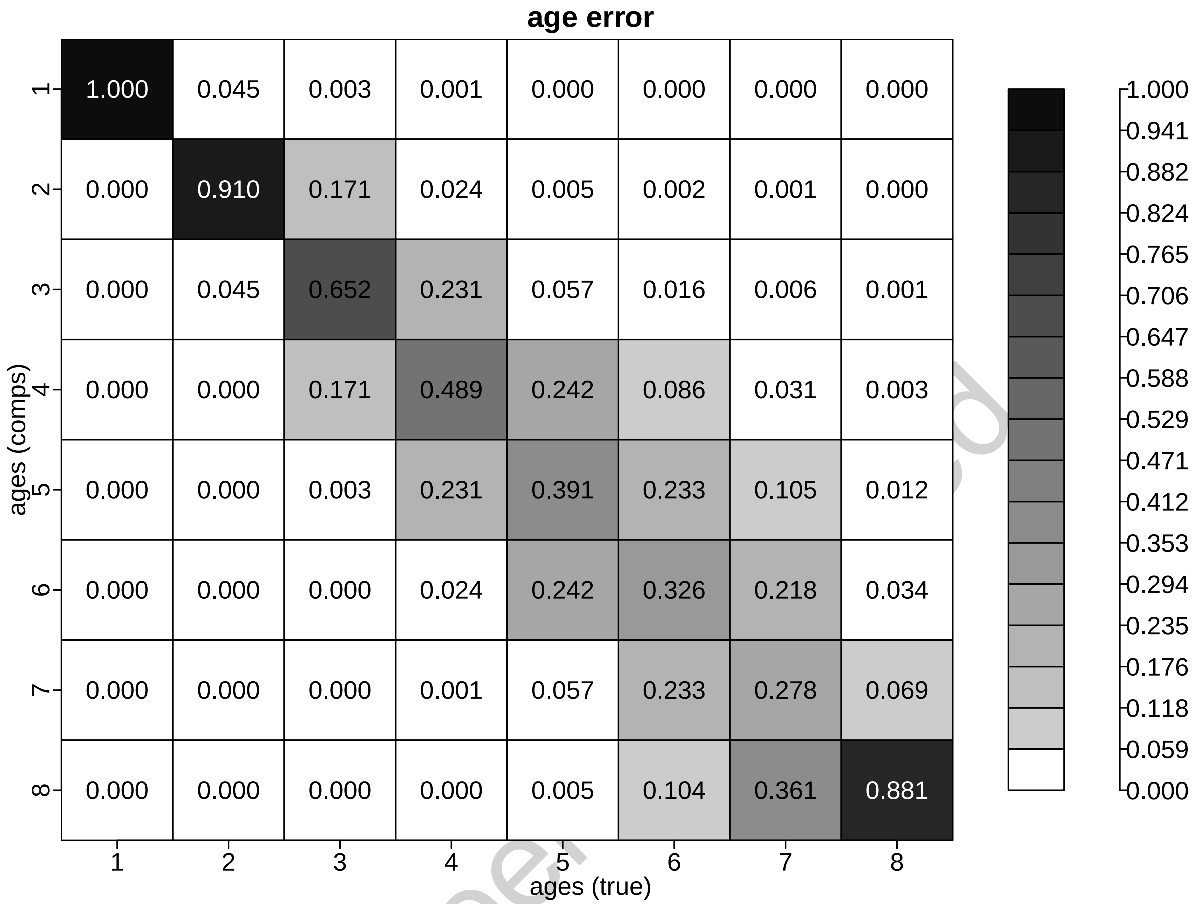


*Figure 5. (A) Female maturity and (B) reproductive output (million eggs) at age.*

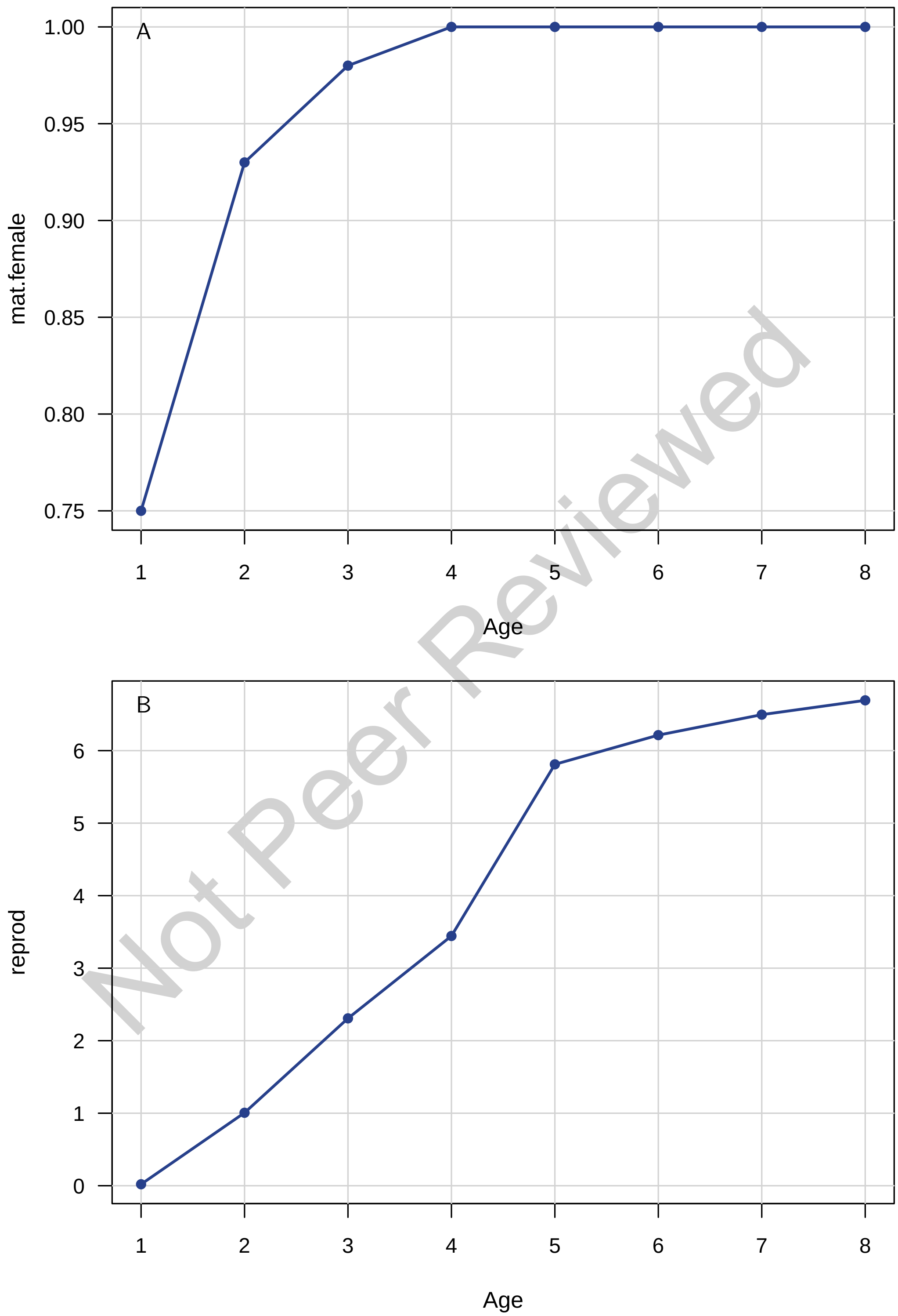


*Figure 6. Observed (open circles) and estimated (solid line) annual age and length compositions by fleet. In panels indicating the data set: acomp = age compositions; lcomp = length compositions; cHLsa = commercial handline, south, early years; cHLsb = commercial handline, south, late years; rHBsa = recreational headboat, south, early years; rHBsb = recreational headboat, south, late years; sTVsa = SERFS trap video survey, south, early years; sTVsb = SERFS trap video survey, south, late years; and rHDs = recreational headboat discards, south, all years.*
*sM = MARMAP longline survey, rA = general recreational. N indicates the number of trips from which individual fish samples were taken. The four digit number in upper right corner of each panel indicates year of sampling (e.g. 1997, 1998).*

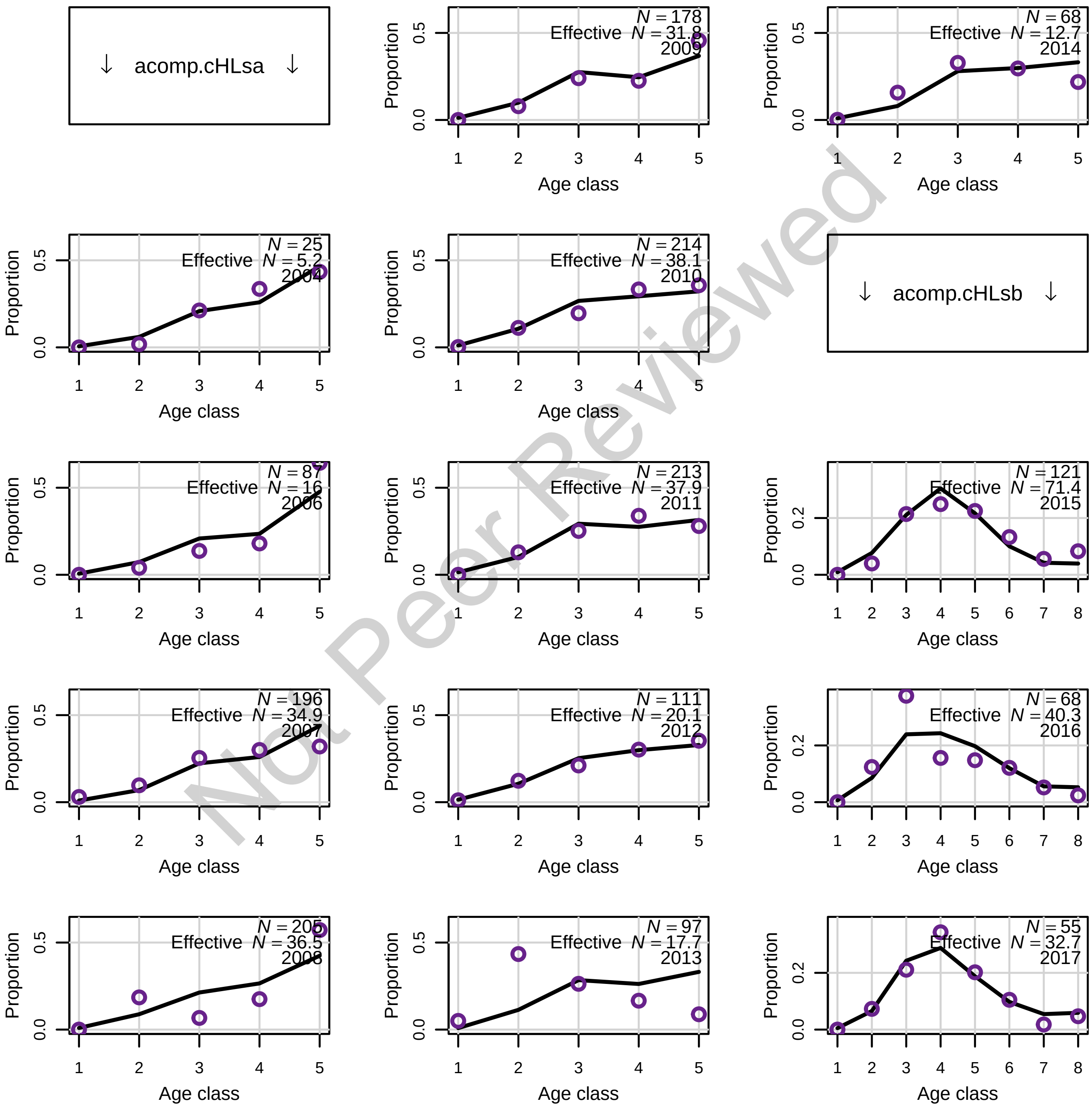


*Figure 6. (cont.) Observed (open circles) and estimated (solid line) annual age and length compositions by fleet.*

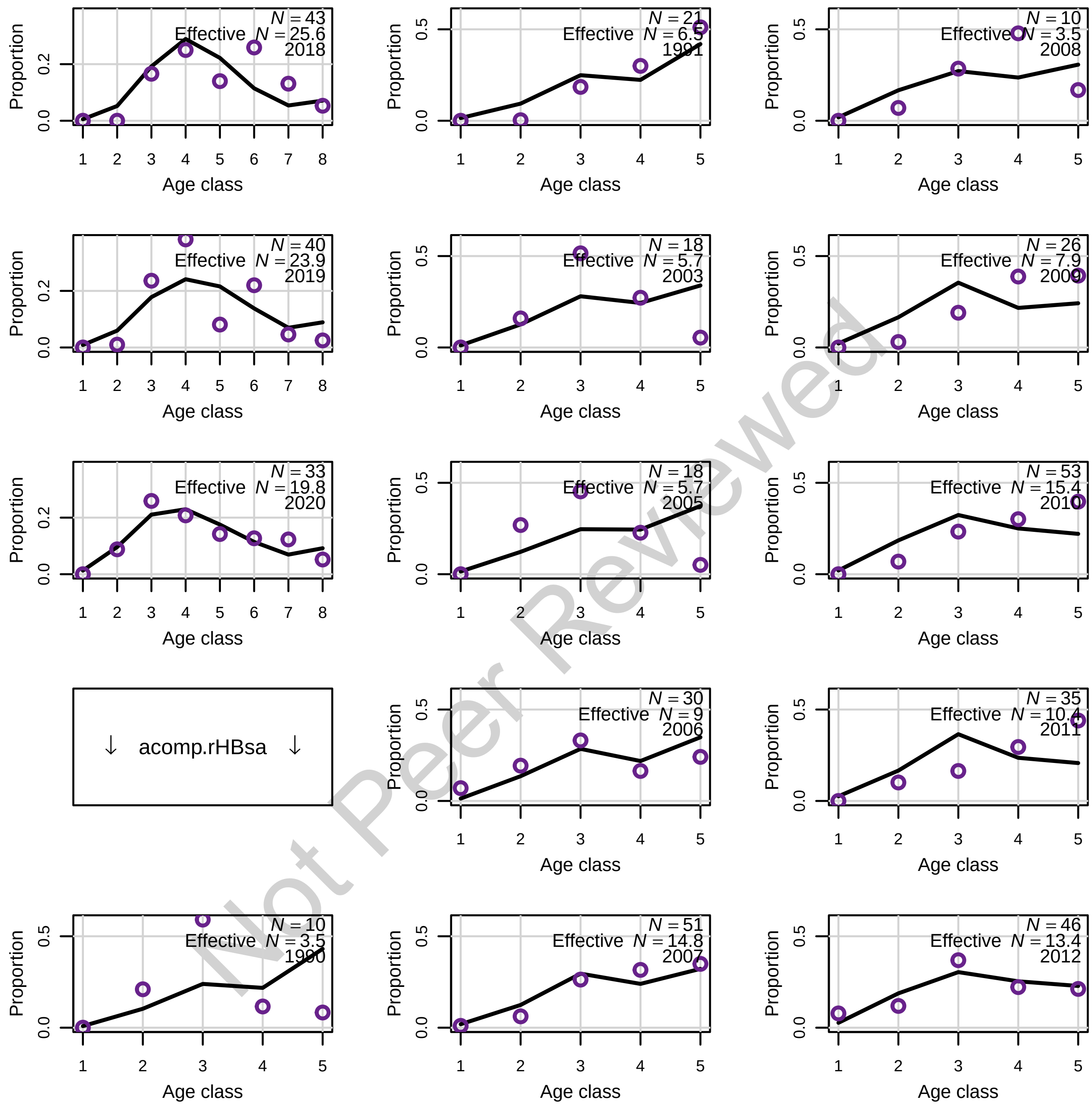


*Figure 6. (cont.) Observed (open circles) and estimated (solid line) annual age and length compositions by fleet.*

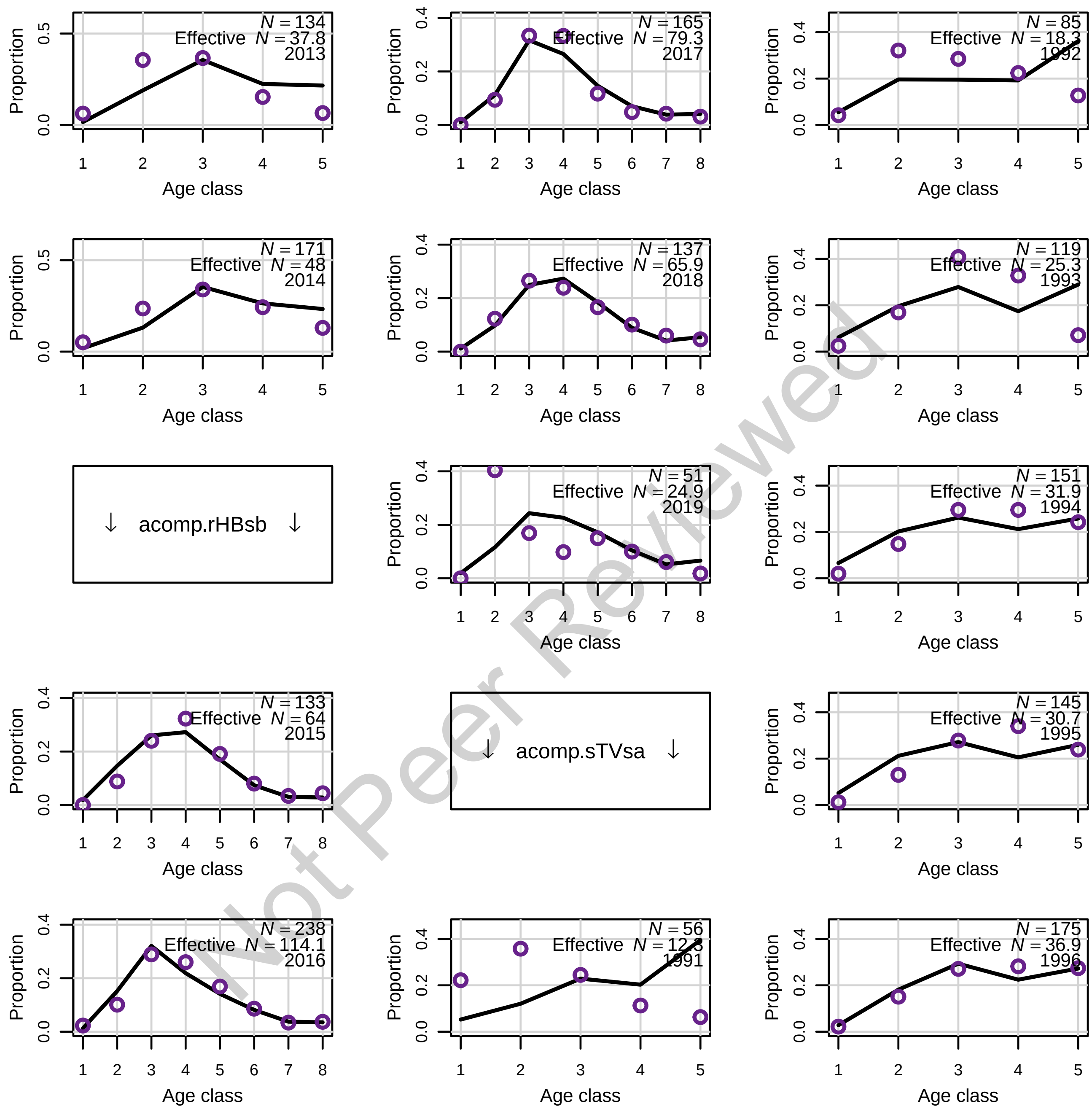


*Figure 6. (cont.) Observed (open circles) and estimated (solid line) annual age and length compositions by fleet.*

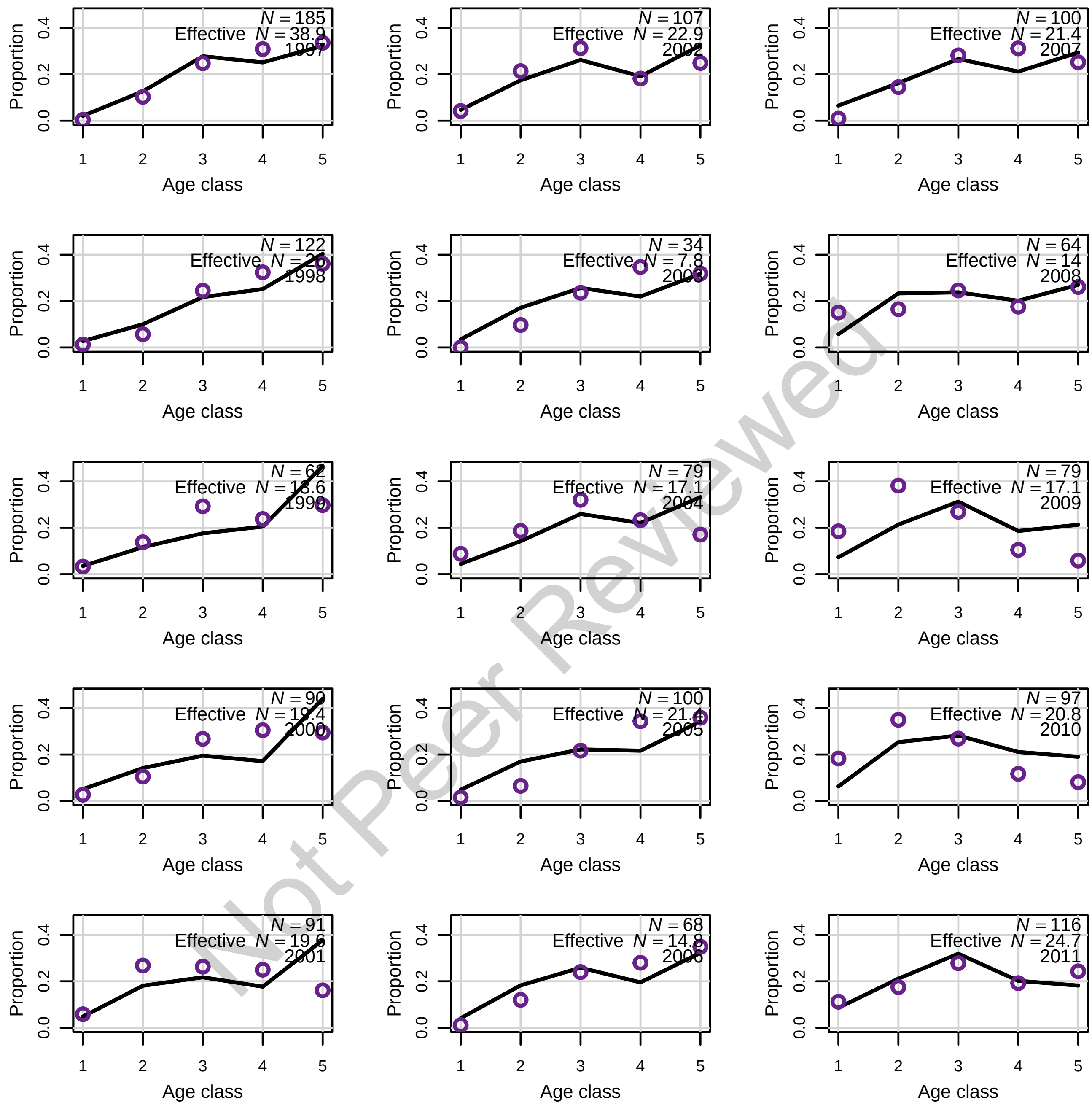


*Figure 6. (cont.) Observed (open circles) and estimated (solid line) annual age and length compositions by fleet.*

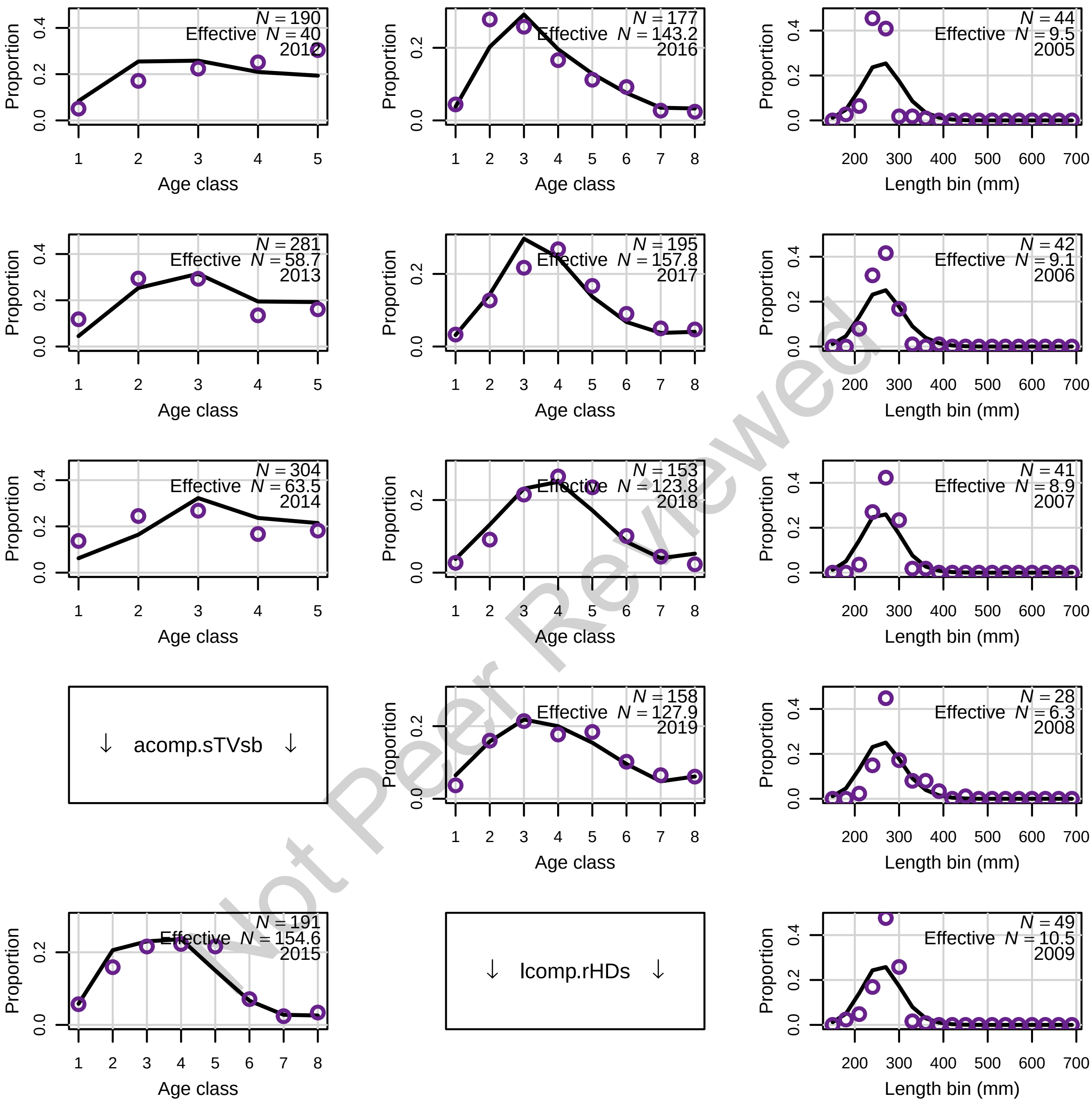


*Figure 6. (cont.) Observed (open circles) and estimated (solid line) annual age and length compositions by fleet.*

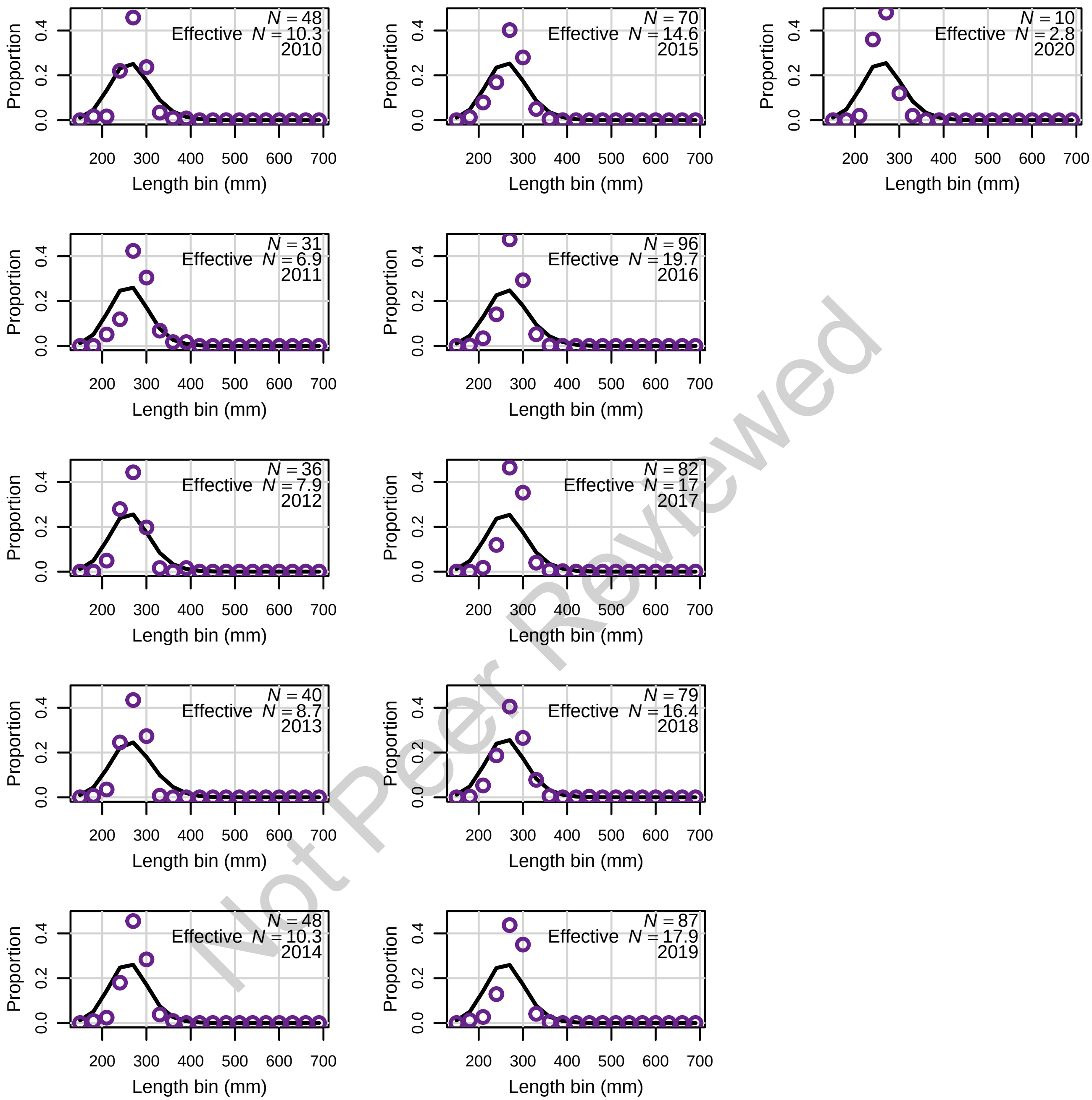


*Figure 7. Observed (open circles) and estimated (solid line) pooled age compositions for commercial handline (south) for early (A; 1990 − 2014) and late (B; 2015 − 2019) periods.*

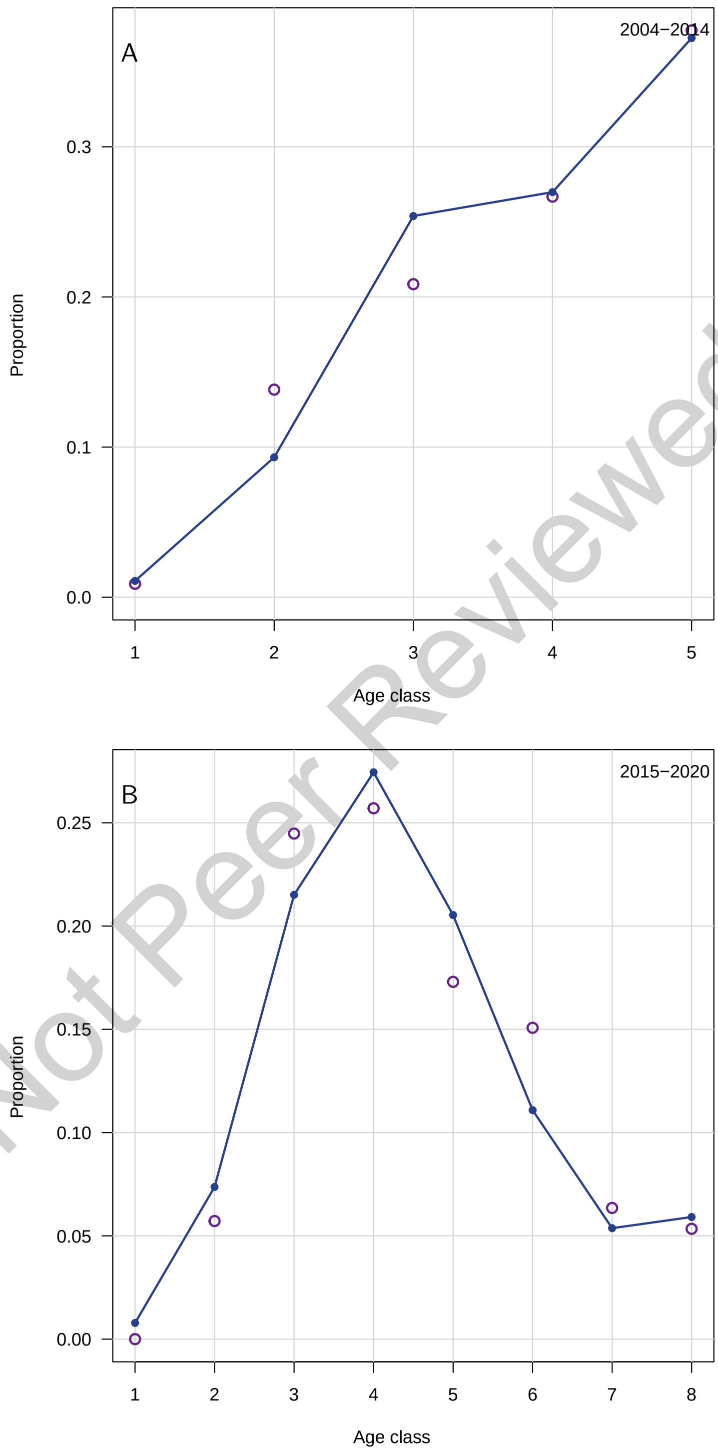


*Figure 8. Observed (open circles) and estimated (solid line) pooled age compositions for recreational headboat (south) for early (A; 1990 − 2014) and late (B; 2015 − 2019) periods.*

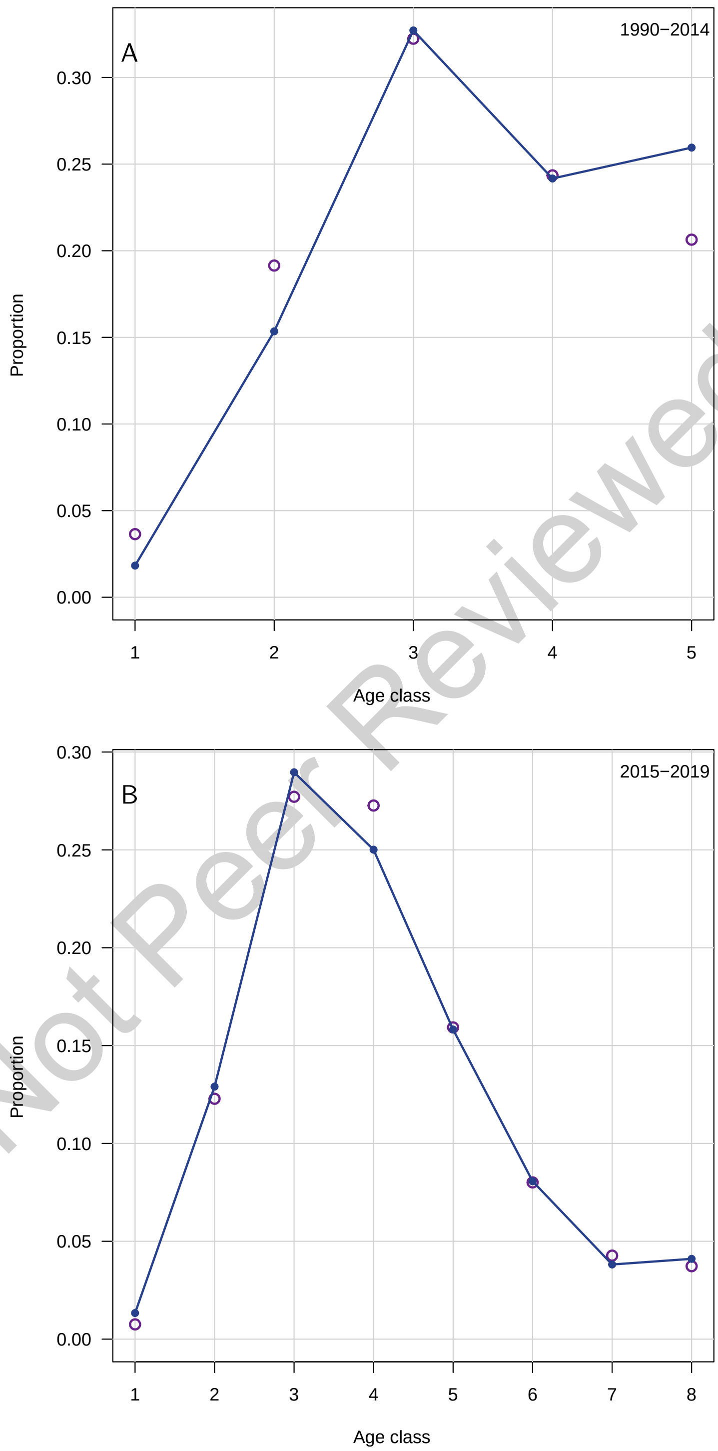


*Figure 9. Observed (open circles) and estimated (solid line) pooled age compositions for the SERFS trap/video survey (south) for early (A;* 1990 − 2014*) and late (B;* 2015 − 2019*) periods.*

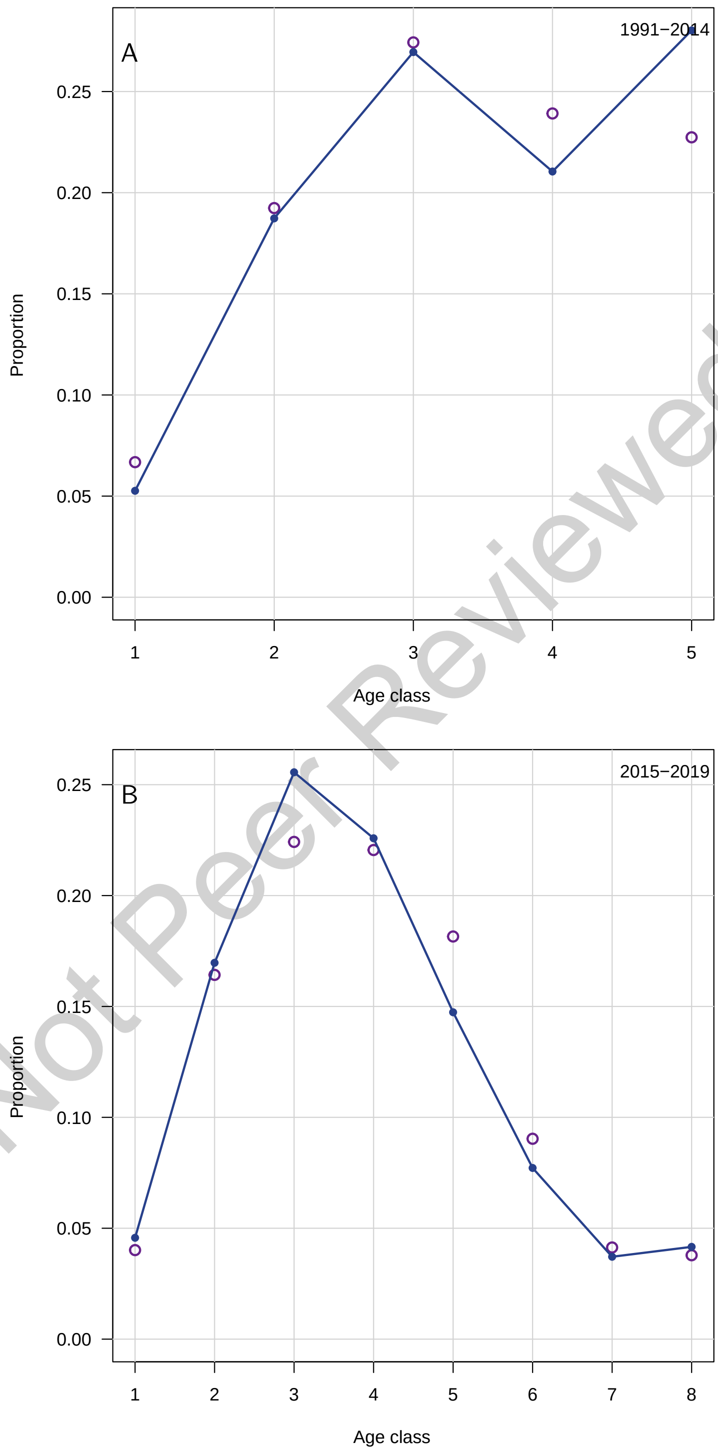


*Figure 10. Observed (open circles) and estimated (solid line) pooled length compositions for recreational headboat discards (south) for all years (2005-2020).*

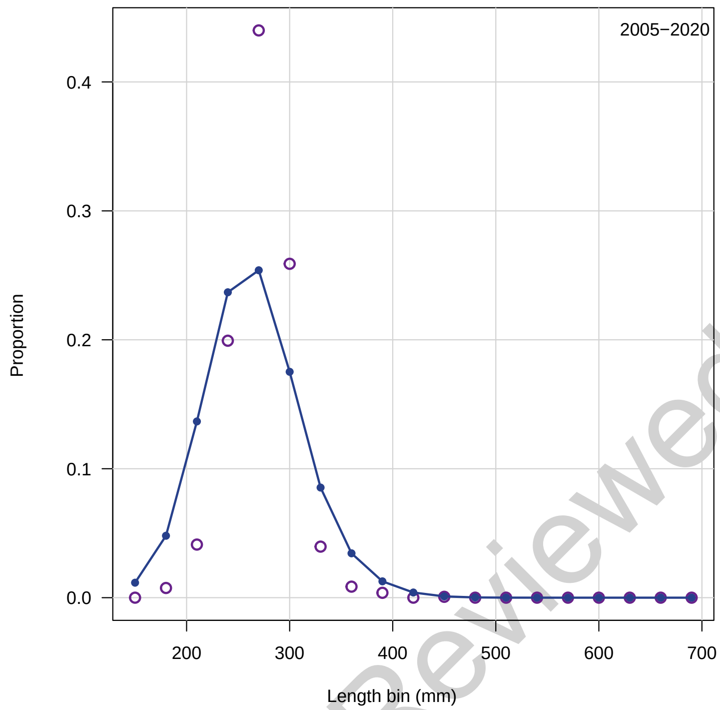
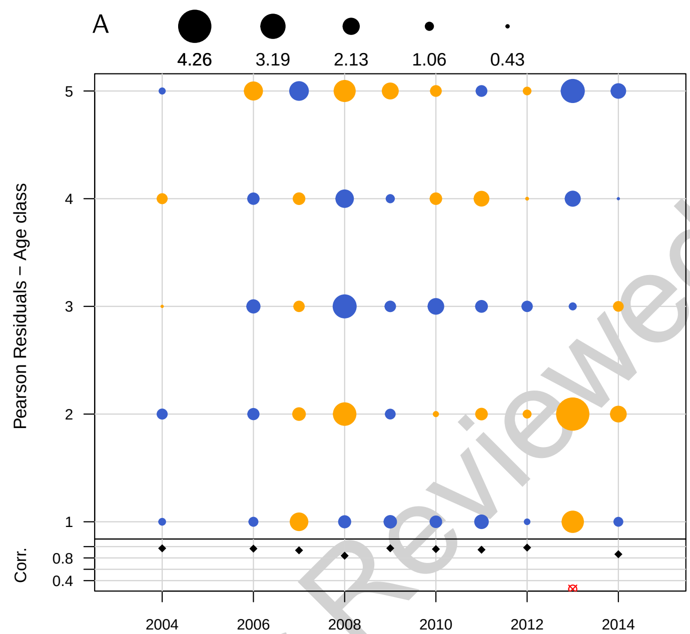


*Figure 11. Pearson residual plots for age compositions for commercial handline (south) for early (A; 1990 − 2014) and late (B; 2015 − 2019) periods. Yellow circles indicate positive residuals. Blue circles indicate negative residuals. The size of circles is scaled uniquely in each panel and is relative to the legend above each panel. Pearson residuals are computed as* $(ob - pr)/sqrt(pr * (1 - pr)/n_{\text{eff}})$*, where ob and pr are observed and predicted proportion at age and* $n_{\text{eff}}$ *is effective sample size.*



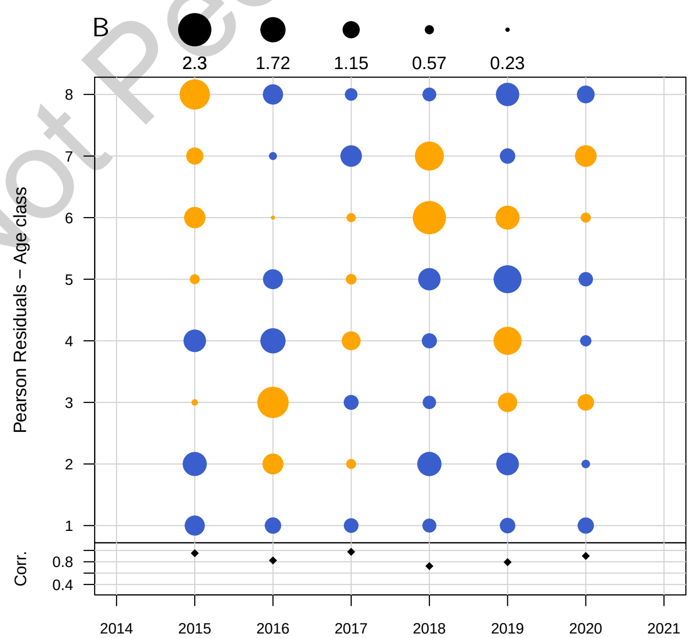
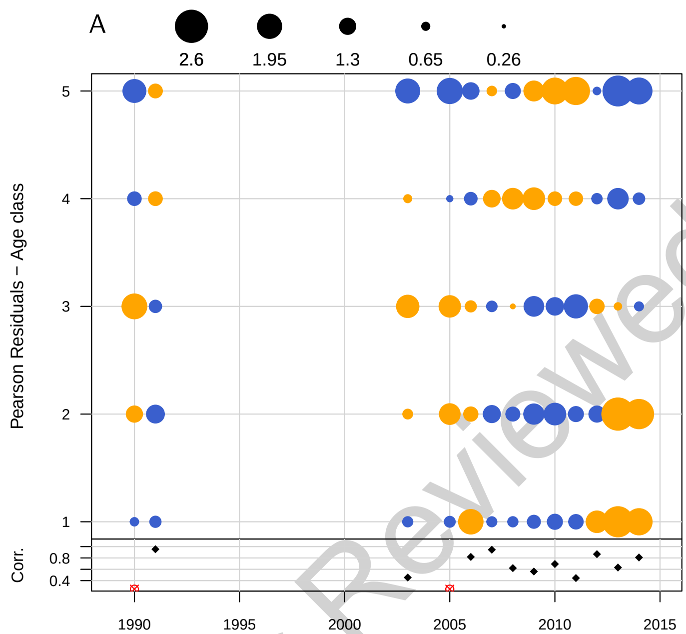



*Figure 12. Pearson residual plots for age compositions for commercial handline (south) for early (A; 1990 − 2014) and late (B; 2015 − 2019) periods. Yellow circles indicate positive residuals. Blue circles indicate negative residuals. The size of circles is scaled uniquely in each panel and is relative to the legend above each panel. Pearson residuals are computed as $(ob - pr)/sqrt(pr * (1 - pr)/n_{\mathrm{eff}})$, where ob and pr are observed and predicted proportion at age and $n_{\mathrm{eff}}$ is effective sample size.*



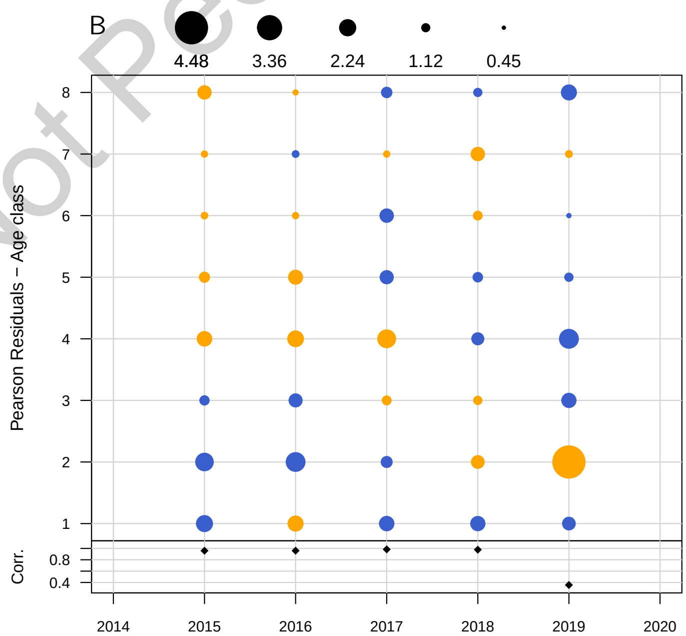
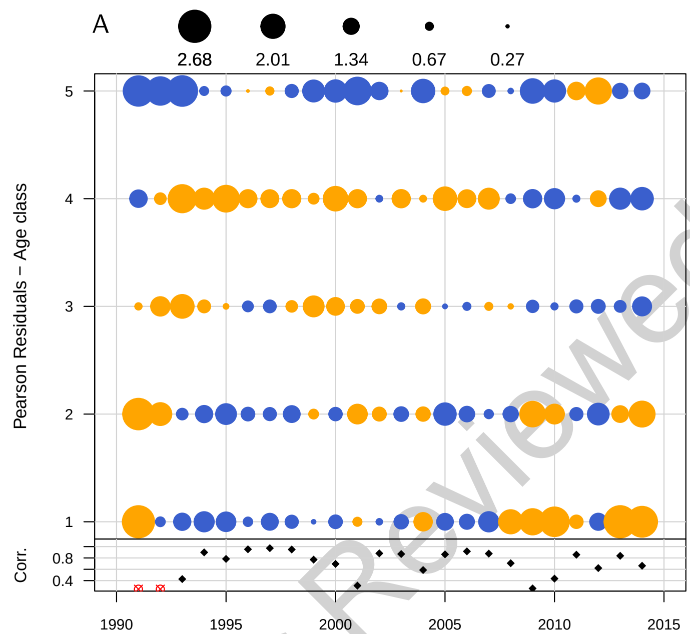



*Figure 13. Pearson residual plots for age compositions for commercial handline (south) for early (A; 1990 – 2014) and late (B; 2015 – 2019) periods. Yellow circles indicate positive residuals. Blue circles indicate negative residuals. The size of circles is scaled uniquely in each panel and is relative to the legend above each panel. Pearson residuals are computed as* $(ob - pr)/sqrt(pr * (1 - pr)/n_{\text{eff}})$*, where ob and pr are observed and predicted proportion at age and* $n_{\text{eff}}$ *is effective sample size.*



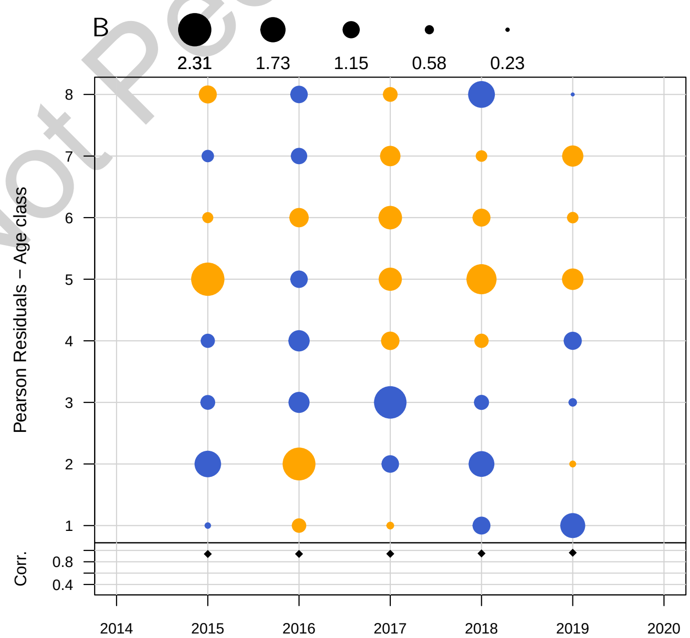



*Figure 14. Pearson residual plots for age compositions for length compositions for recreational headboat discards (south) for all years (2005-2020). Yellow circles indicate positive residuals. Blue circles indicate negative residuals. The size of circles is scaled uniquely in each panel and is relative to the legend above each panel. Pearson residuals are computed as $(ob - pr)/sqrt(pr * (1 - pr)/n_{\text{eff}})$, where ob and pr are observed and predicted proportion at age and $n_{\text{eff}}$ is effective sample size.*

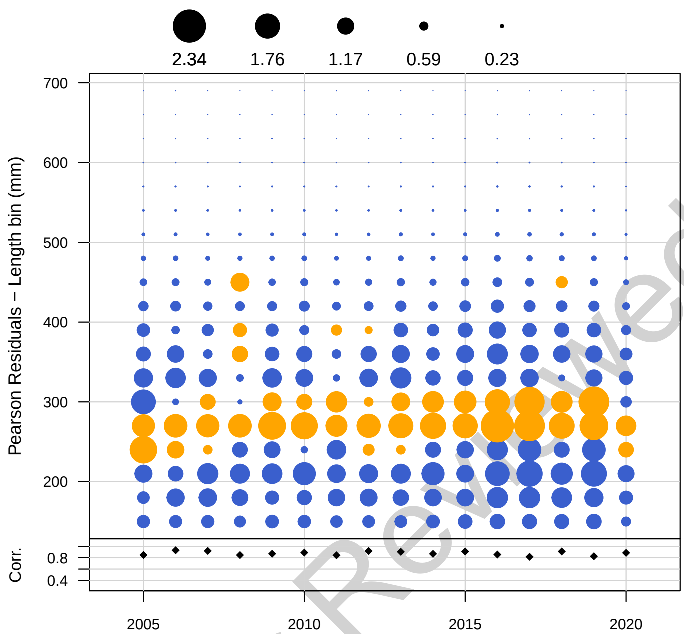


*Figure 15. Observed (open circles) and estimated (line, solid circles) commercial handline (north) landings (1000 lb whole weight).*

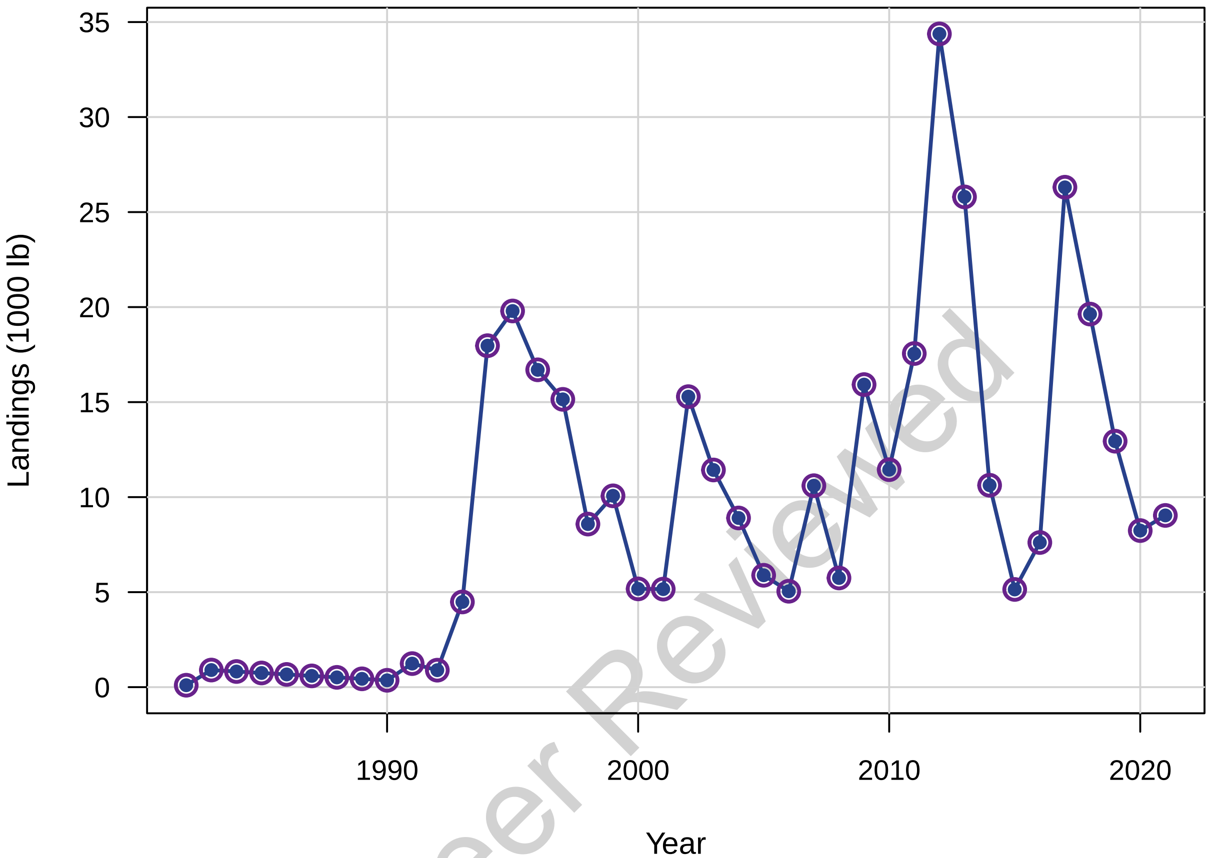


*Figure 16. Observed (open circles) and estimated (line, solid circles) commercial handline (south) landings and dead discards (1000 lb whole weight).*

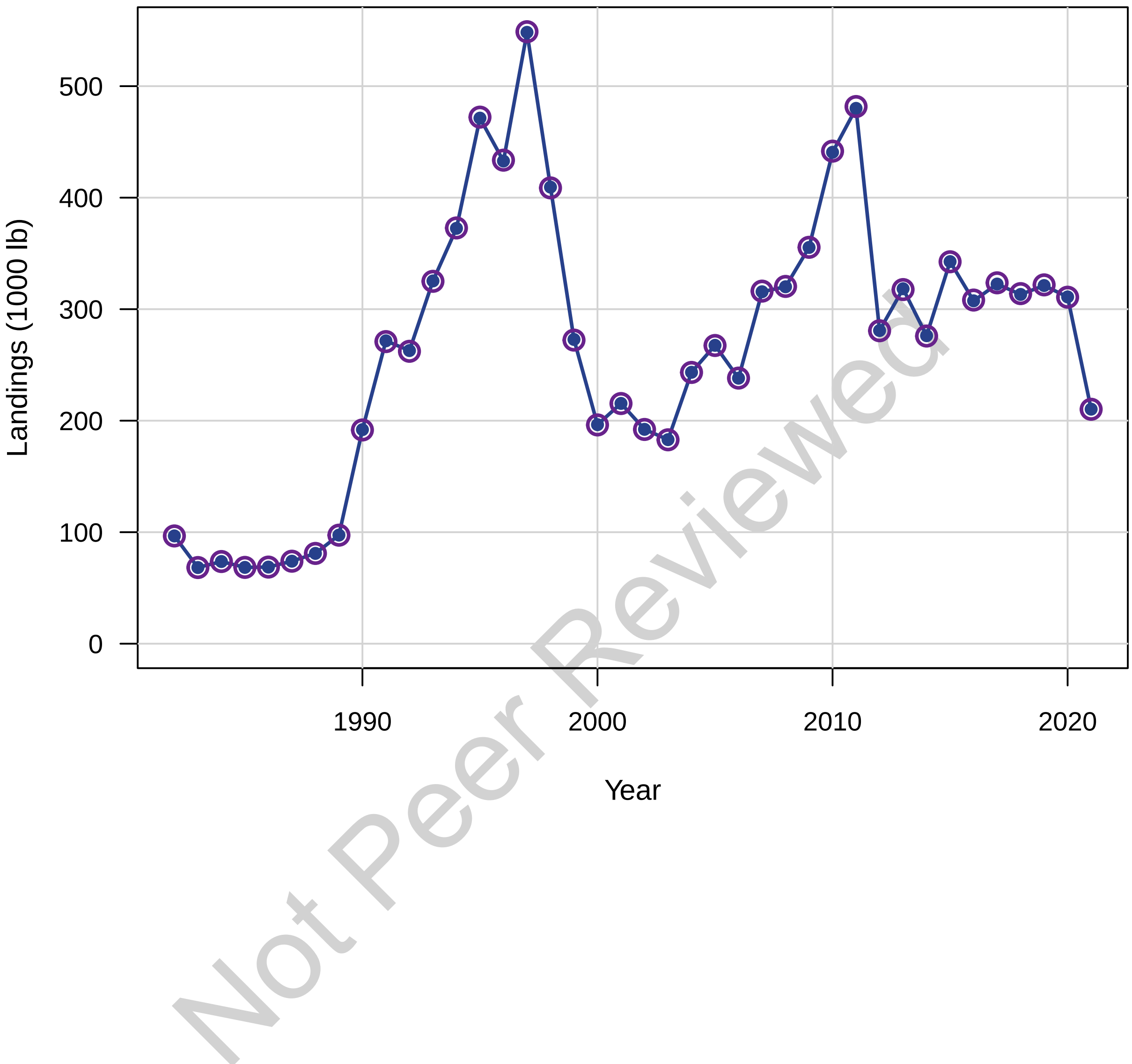


*Figure 17. Observed (open circles) and estimated (line, solid circles) general recreational (north) landings (1000 fish).*

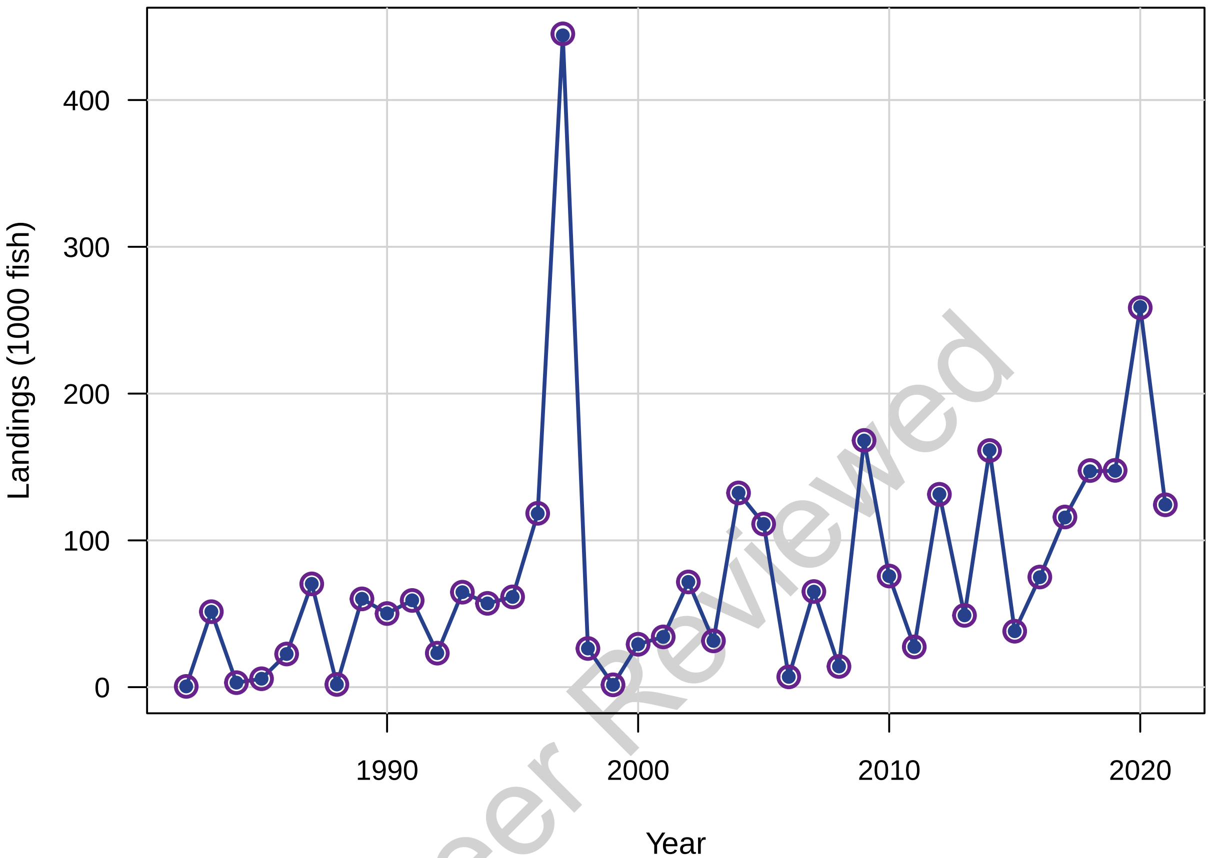


*Figure 18. Observed (open circles) and estimated (line, solid circles) general recreational (south) landings (1000 fish).*

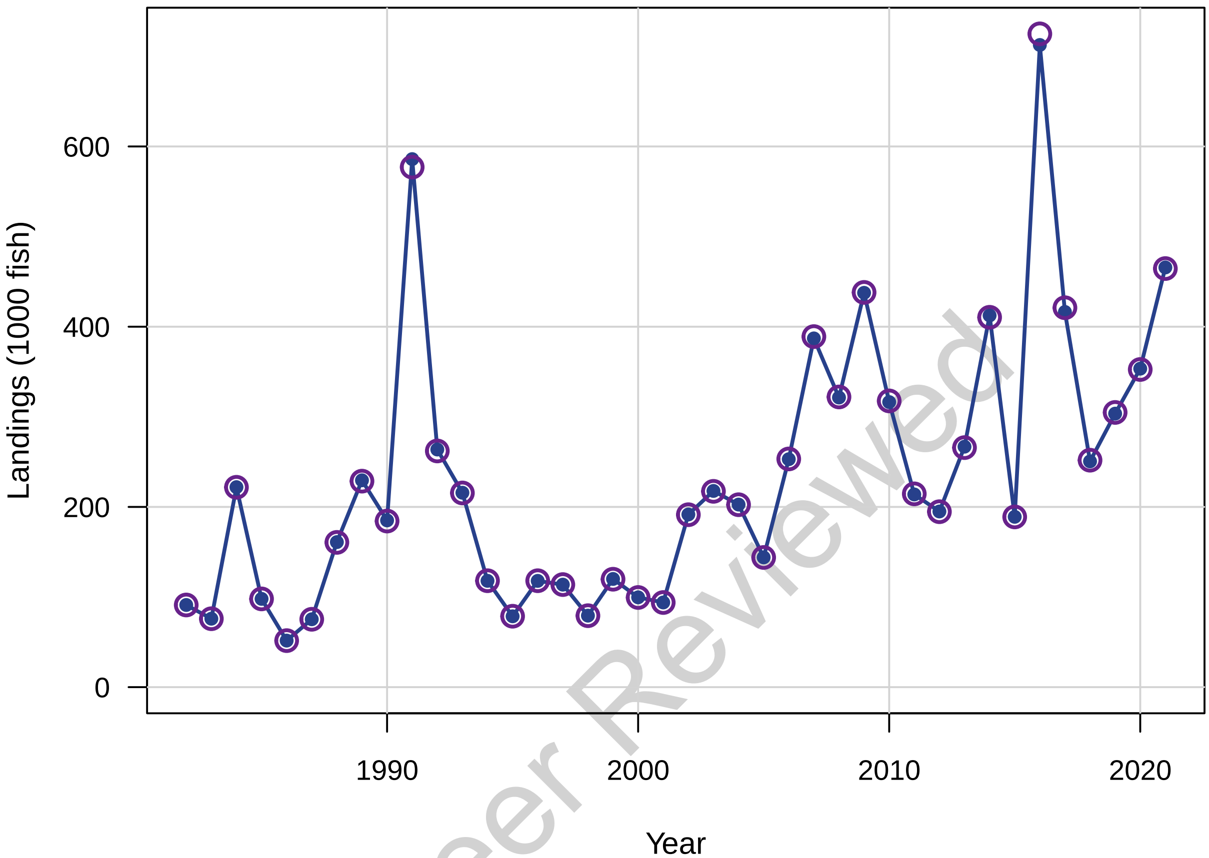


*Figure 19. Observed (open circles) and estimated (line, solid circles) headboat recreational (south) landings (1000 fish).*

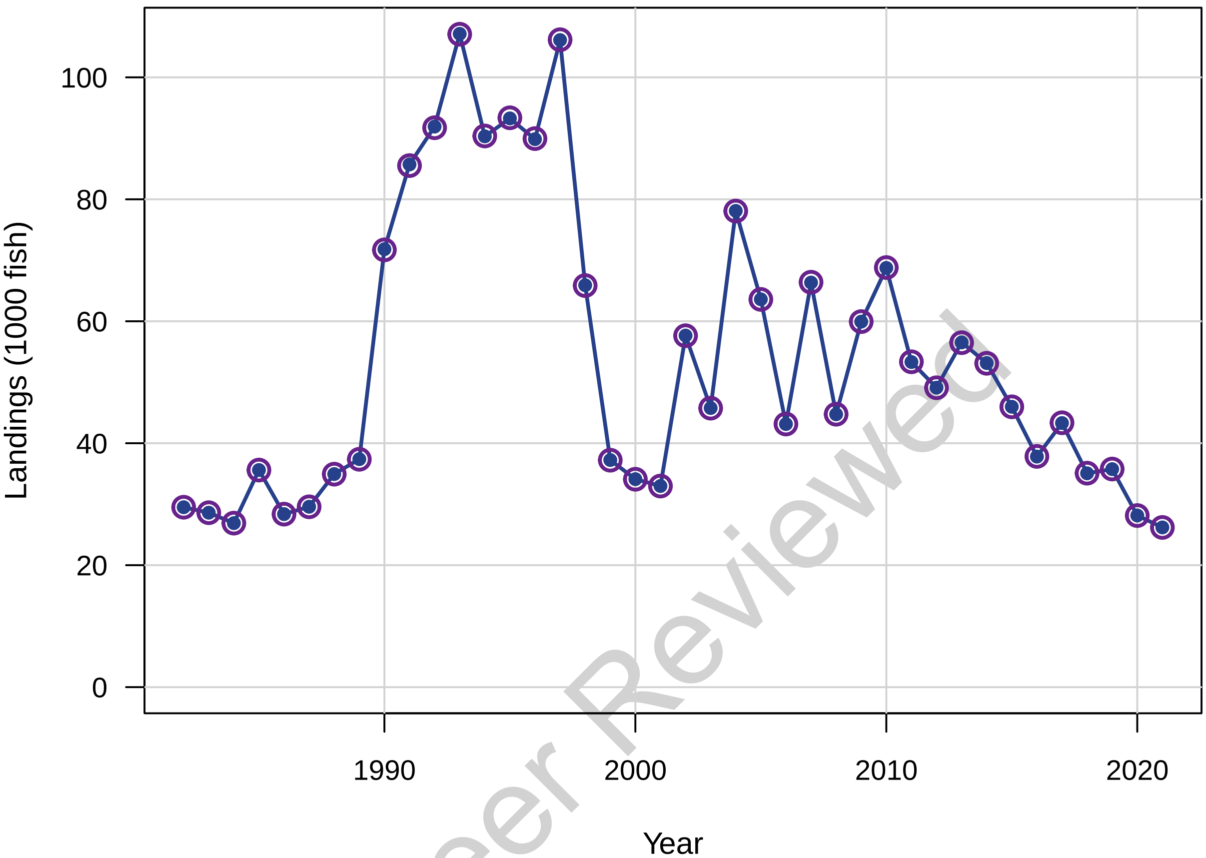


*Figure 20. Observed (open circles) and estimated (line, solid circles) general recreational (north) discards (1000 dead fish).*

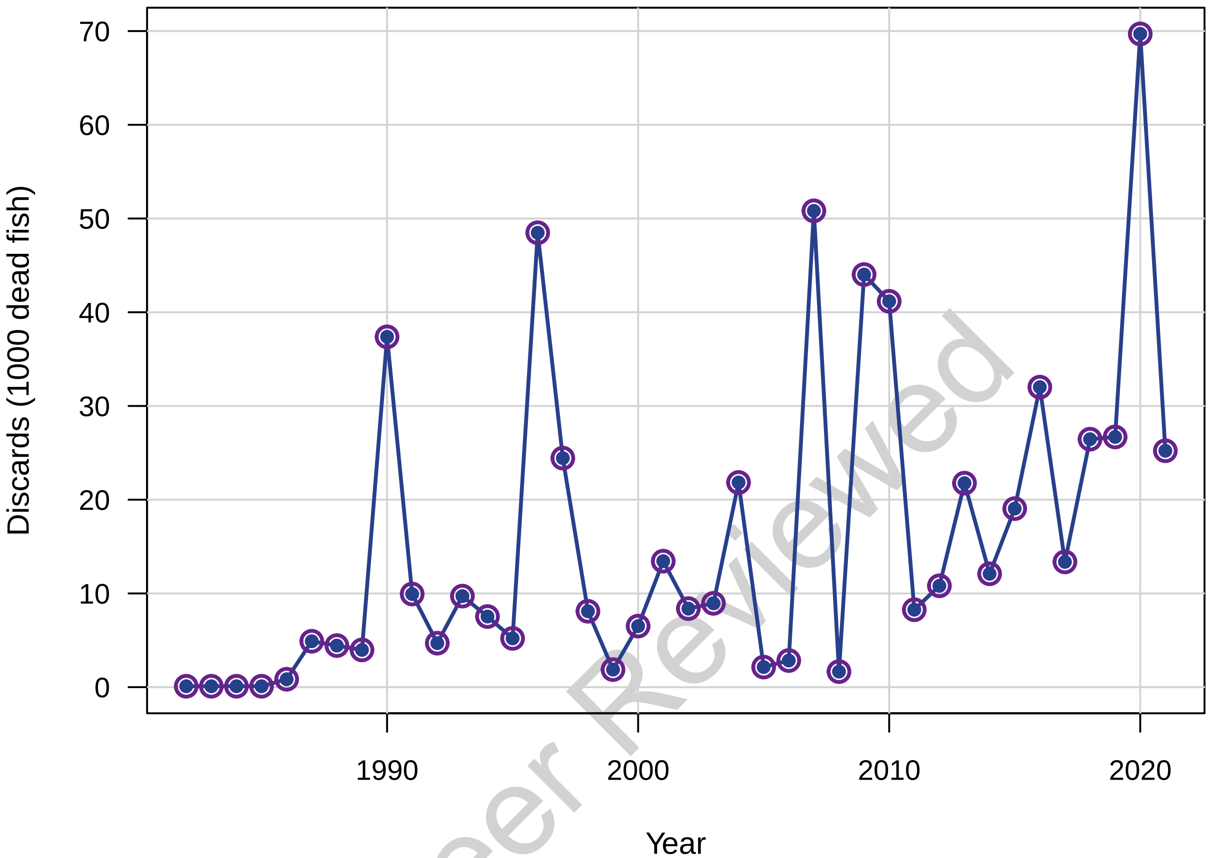


*Figure 21. Observed (open circles) and estimated (line, solid circles) general recreational (south) discards (1000 dead fish).*

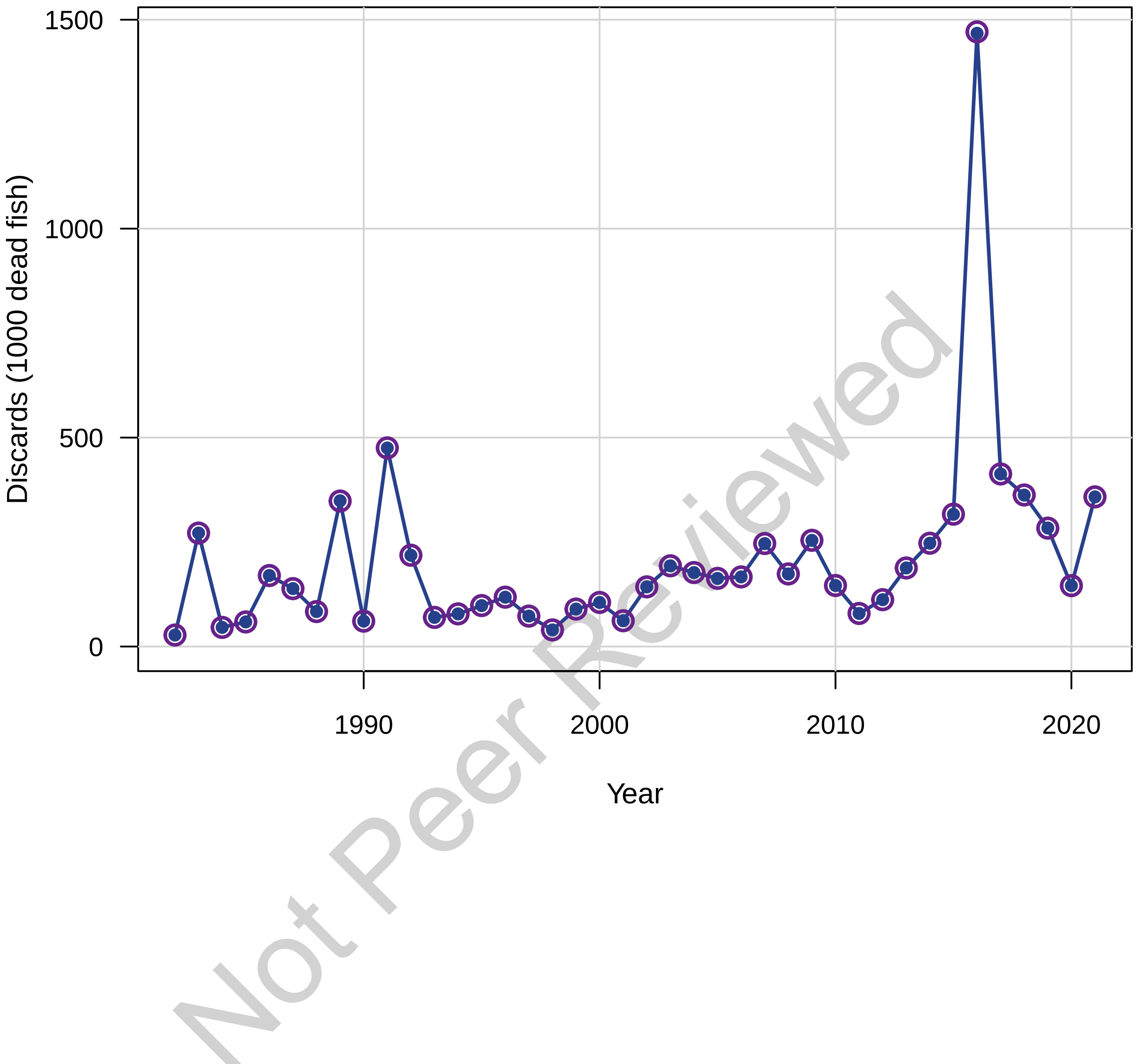


*Figure 22. Observed (open circles) and estimated (line, solid circles) headboat recreational (south) discards (1000 dead fish).*

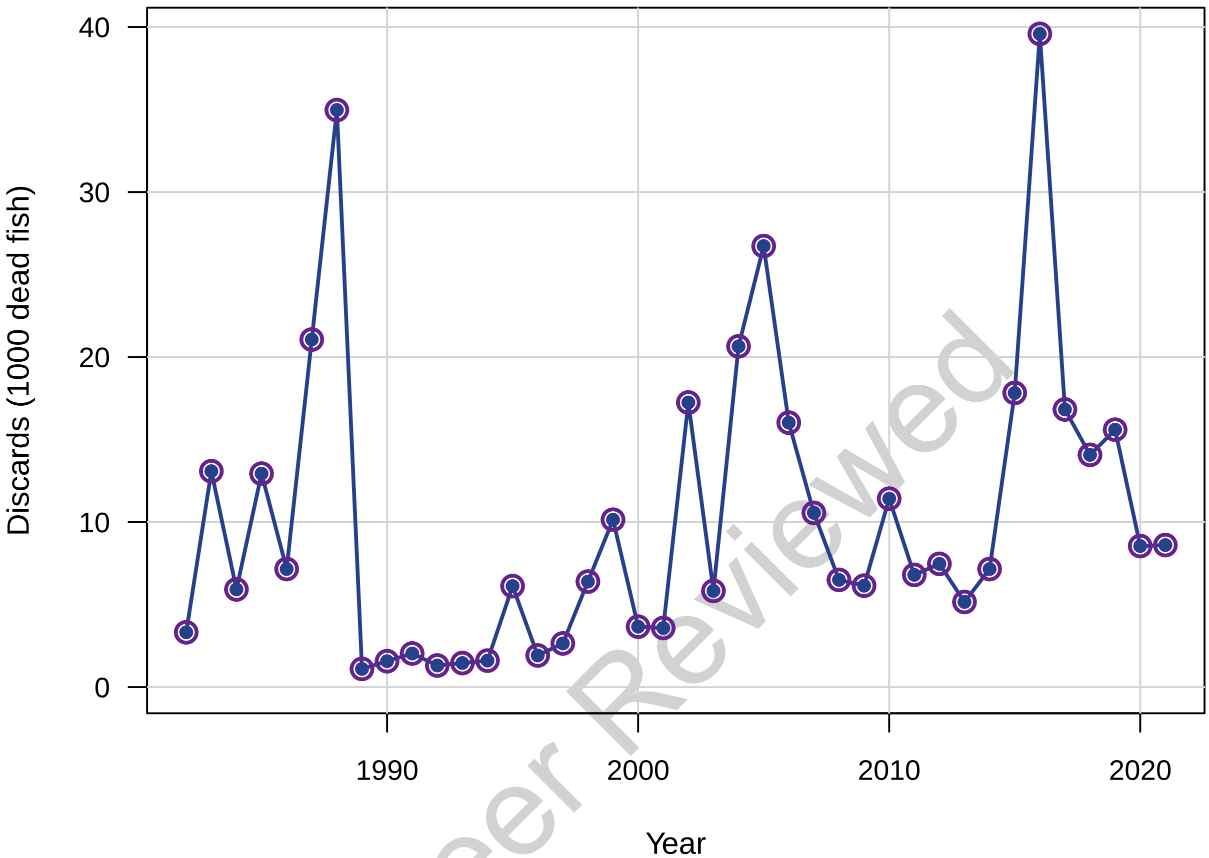


*Figure 23. Observed (open circles) and estimated (line, solid circles) SERFS trap/video index In the upper panel, error bars indicate* $\pm 2$ *standard errors of the observed index* ($U_{ob}$)*. In the lower panel are the log residuals of the fit to the index and the color of the box indicates the p-value of the runs test (green* $> 0.05$*, orange* $\leq 0.05$ *and* $> 0.01$*, red* $< 0.01$*) and the width of the box is 3 times the standard error. Points that fall outside 3 standard errors are plotted in red..*

*Figure 24. Estimated abundance (numbers) at age at start of year.*

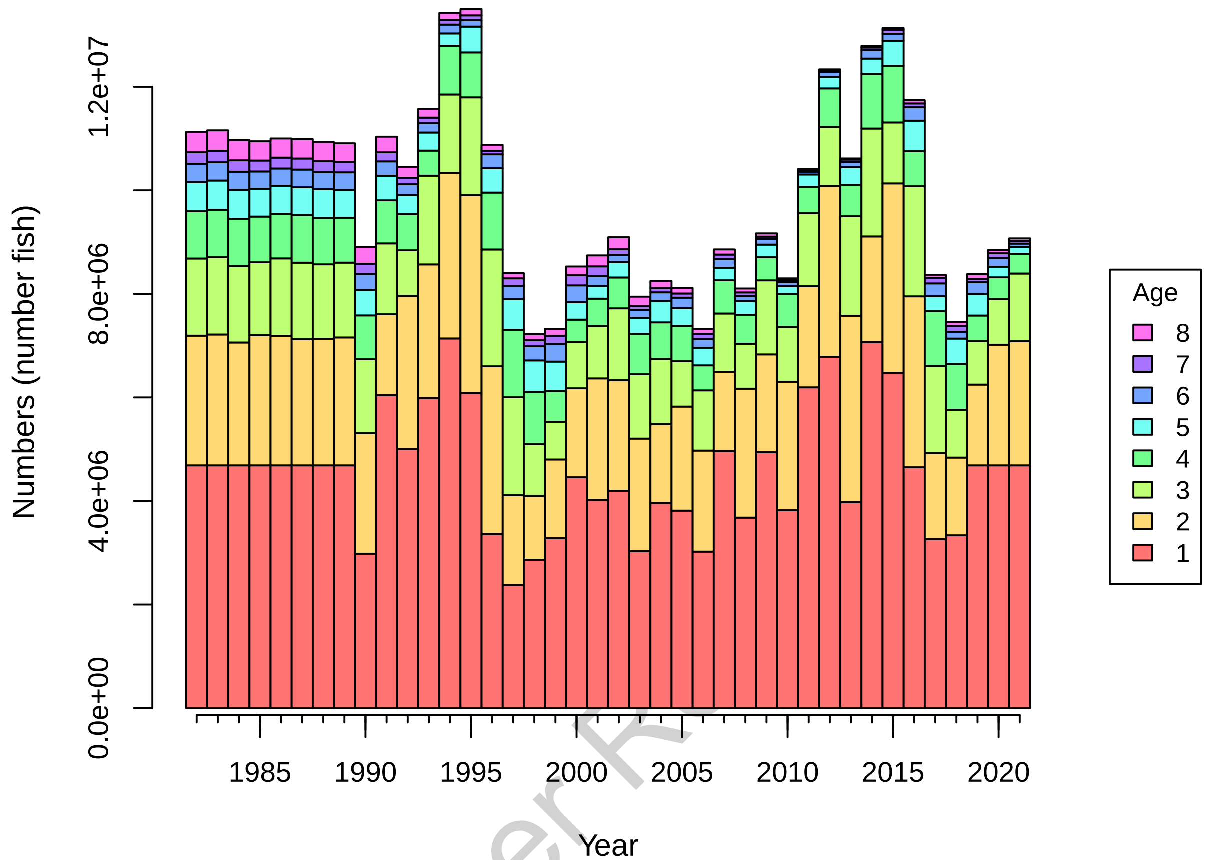


*Figure 25. Estimated biomass at age at start of year.*

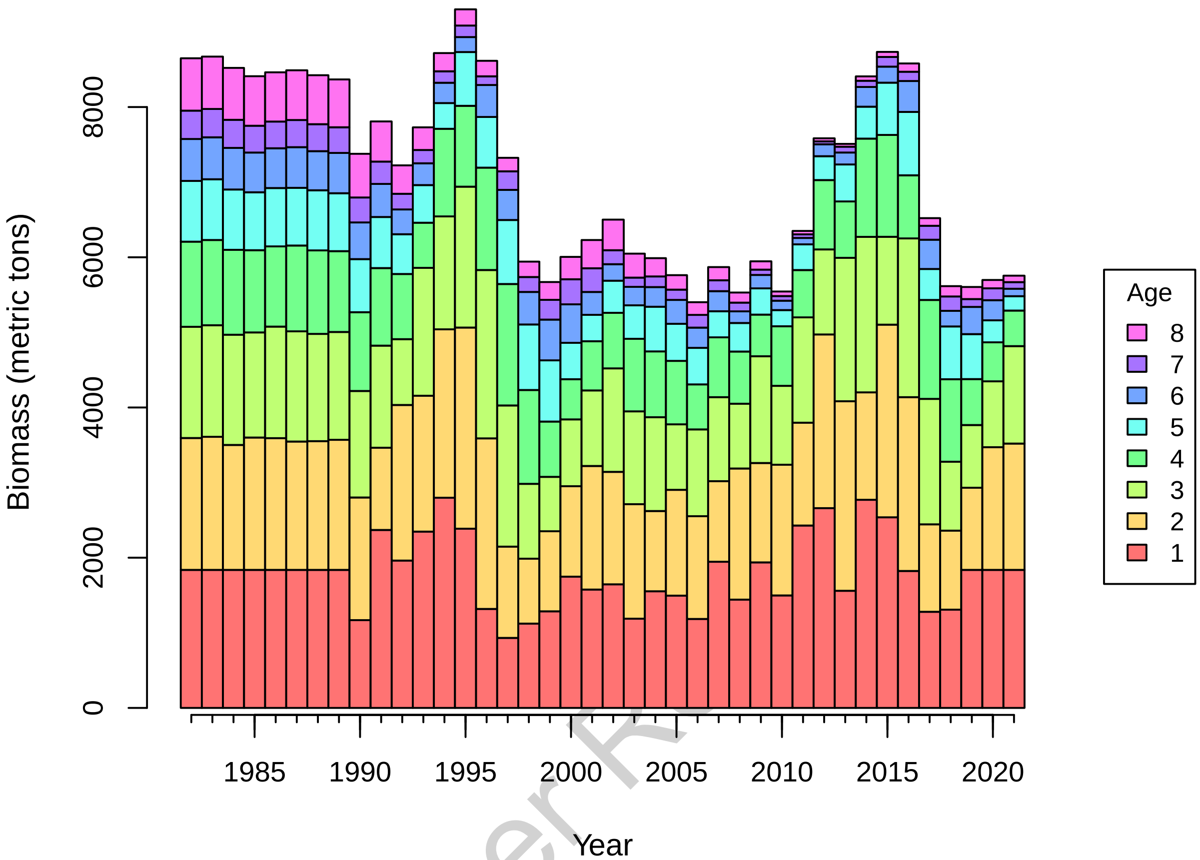


*Figure 26. Estimated recruitment time series. (A) Estimated recruitment of age-1 fish. Horizontal dashed line indicates $R_{F40\%}$. (B) Log recruitment residuals (open circles). These are annual recruitment deviations ($r_y$) estimated within the model. The solid tan line is a lowess smoother fit to the residuals.*

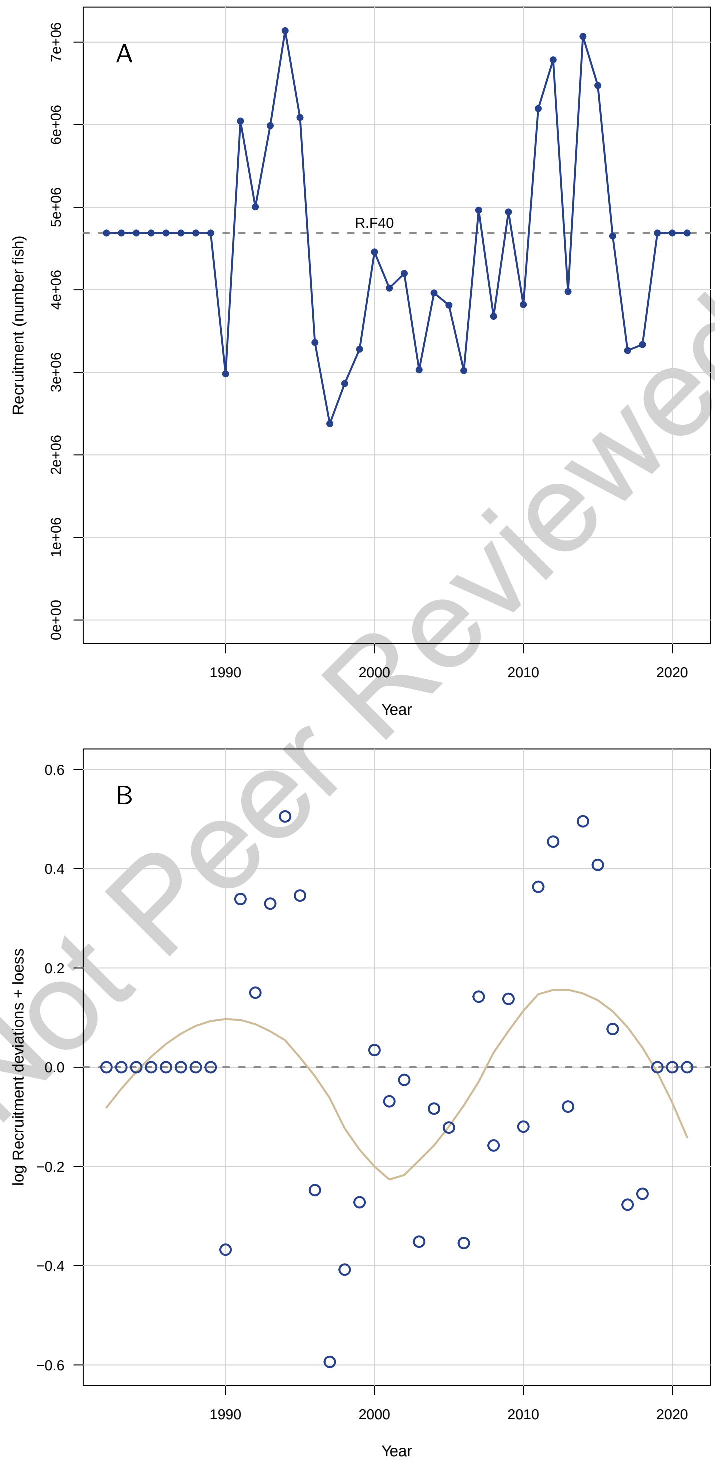


*Figure 27. Estimated total biomass and spawning stock time series. (A) Estimated total biomass (metric tons) at start of year. Horizontal dashed line indicates $B_{\mathrm{F40\%}}$. (B) Estimated spawning stock (million eggs) at time of peak spawning (June $29^{th}$; 0.5 yr).*

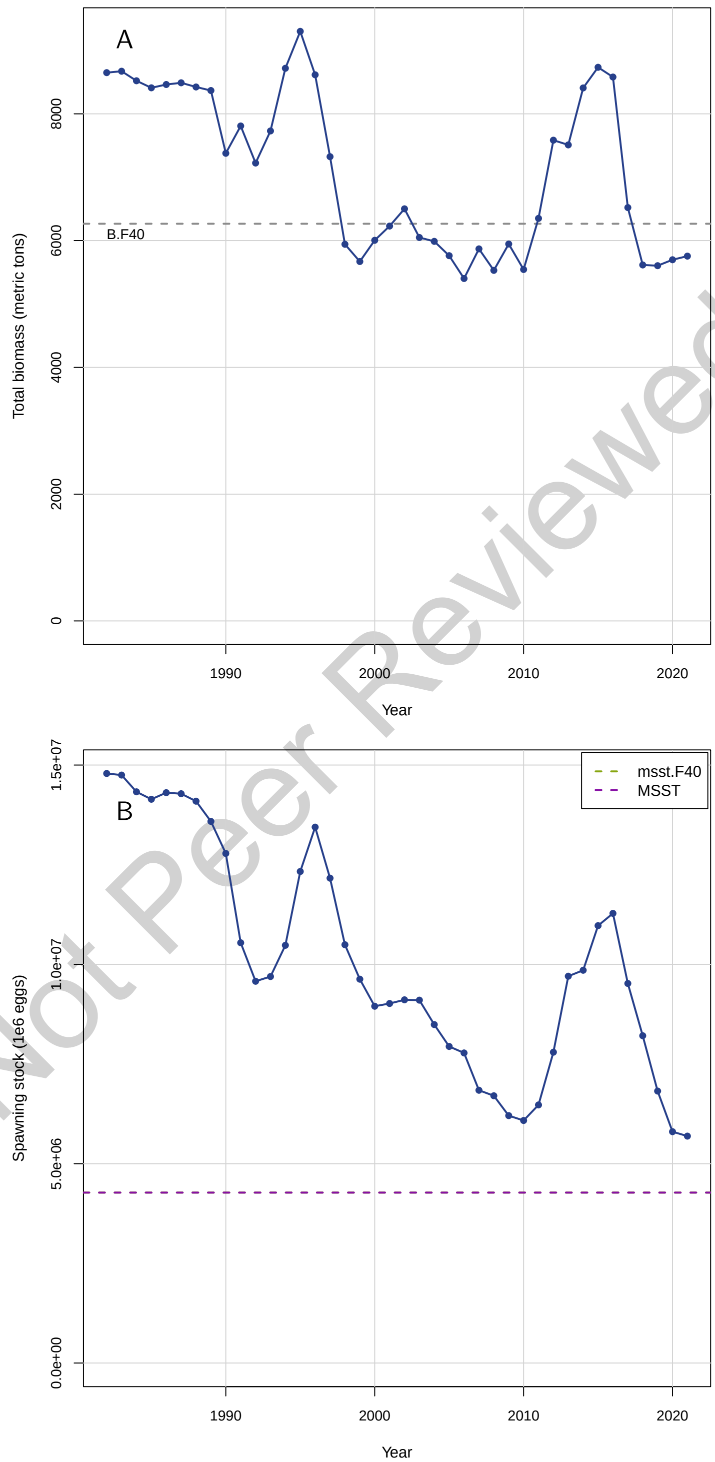


*Figure 28. Selectivity for the SERFS trap/video index. The first year of each selectivity block is indicated in the legend. In this case, there was only one selectivity block.*

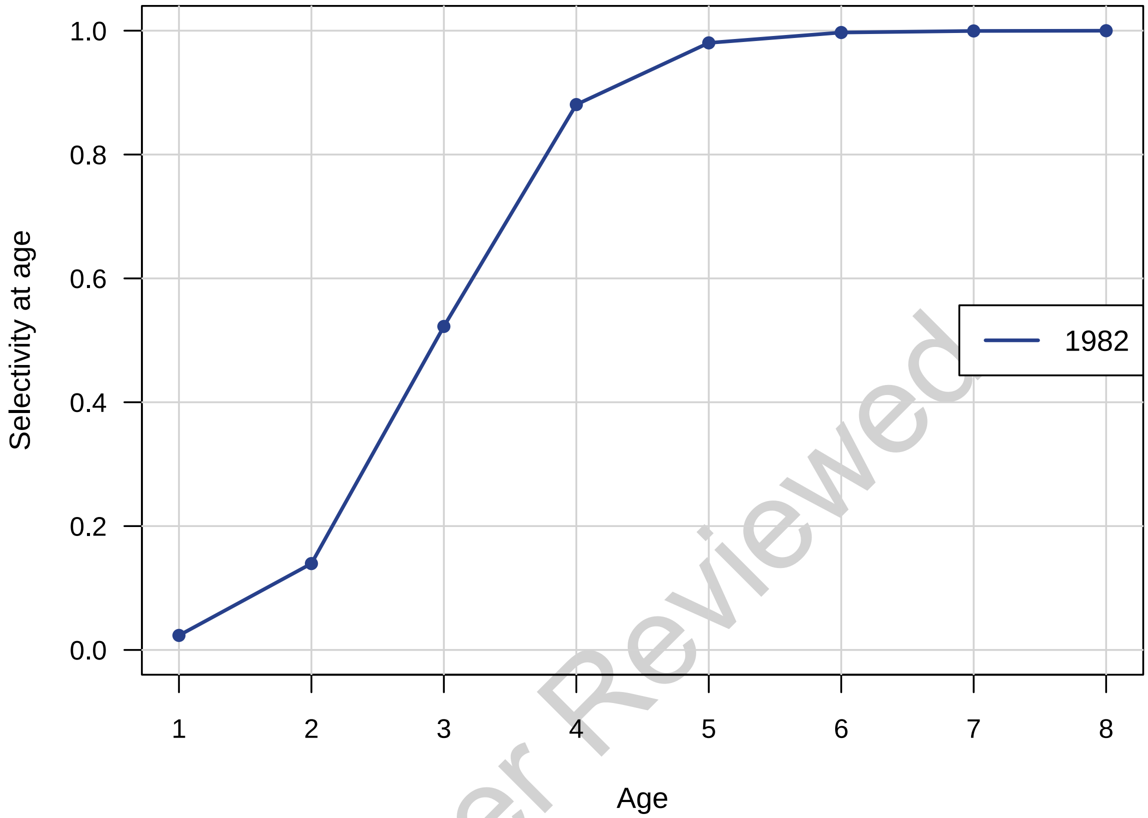


*Figure 29. Selectivity for commercial handline landings. The first year of each selectivity block is indicated in the legend. In this case, there was only one selectivity block. The same selectivity was applied to both north and south areas.*

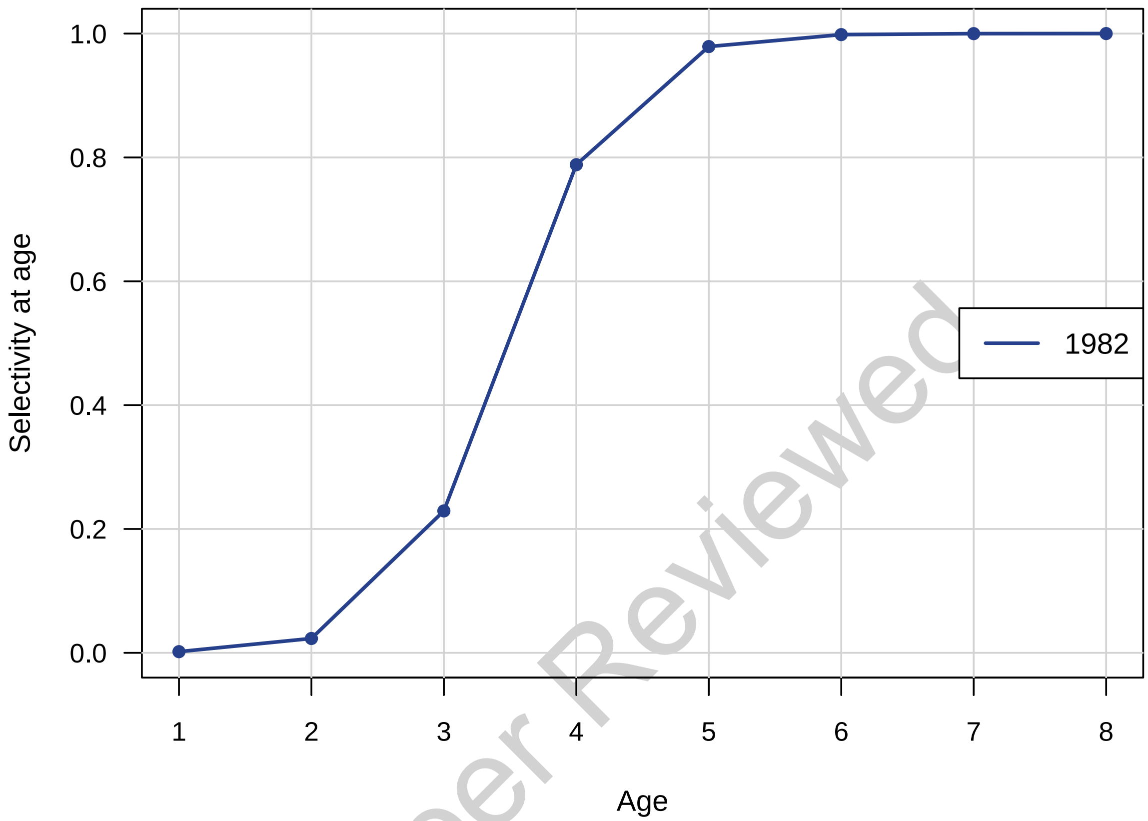


*Figure 30. Selectivity for (A) headboat and (B) general recreational landings. The first year of each selectivity block is indicated in the legend. In this case, there was only one selectivity block. Note that the general recreational selectivity was assumed equal to the headboat selectivity. The same selectivity was applied to both north and south areas.*

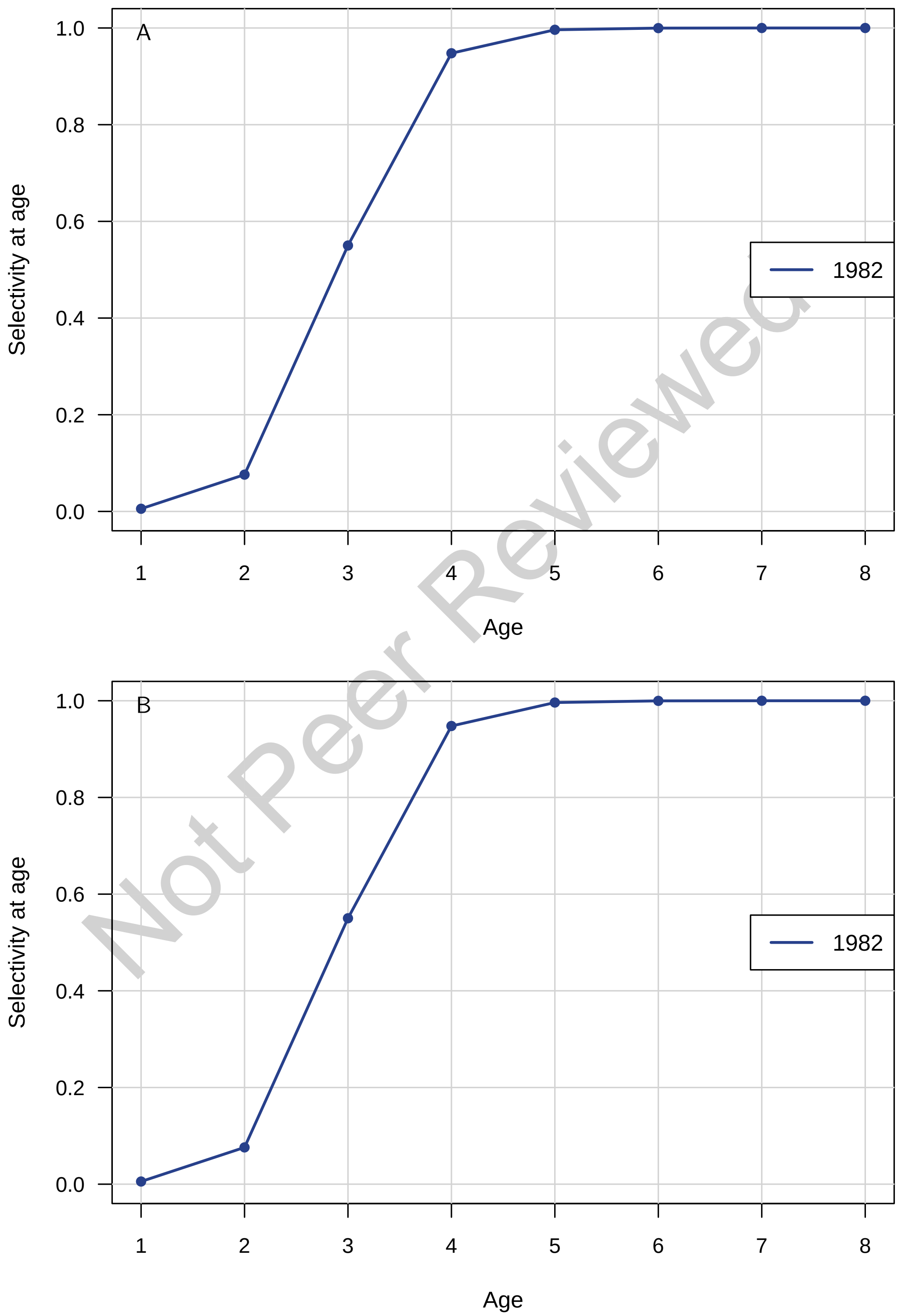


*Figure 31. Selectivity for (A) headboat and (B) general recreational discards. The first year of each selectivity block is indicated in the legend. In this case, there was only one selectivity block. Note that the general recreational selectivity was assumed equal to the headboat selectivity. The same selectivity was applied to both north and south areas.*

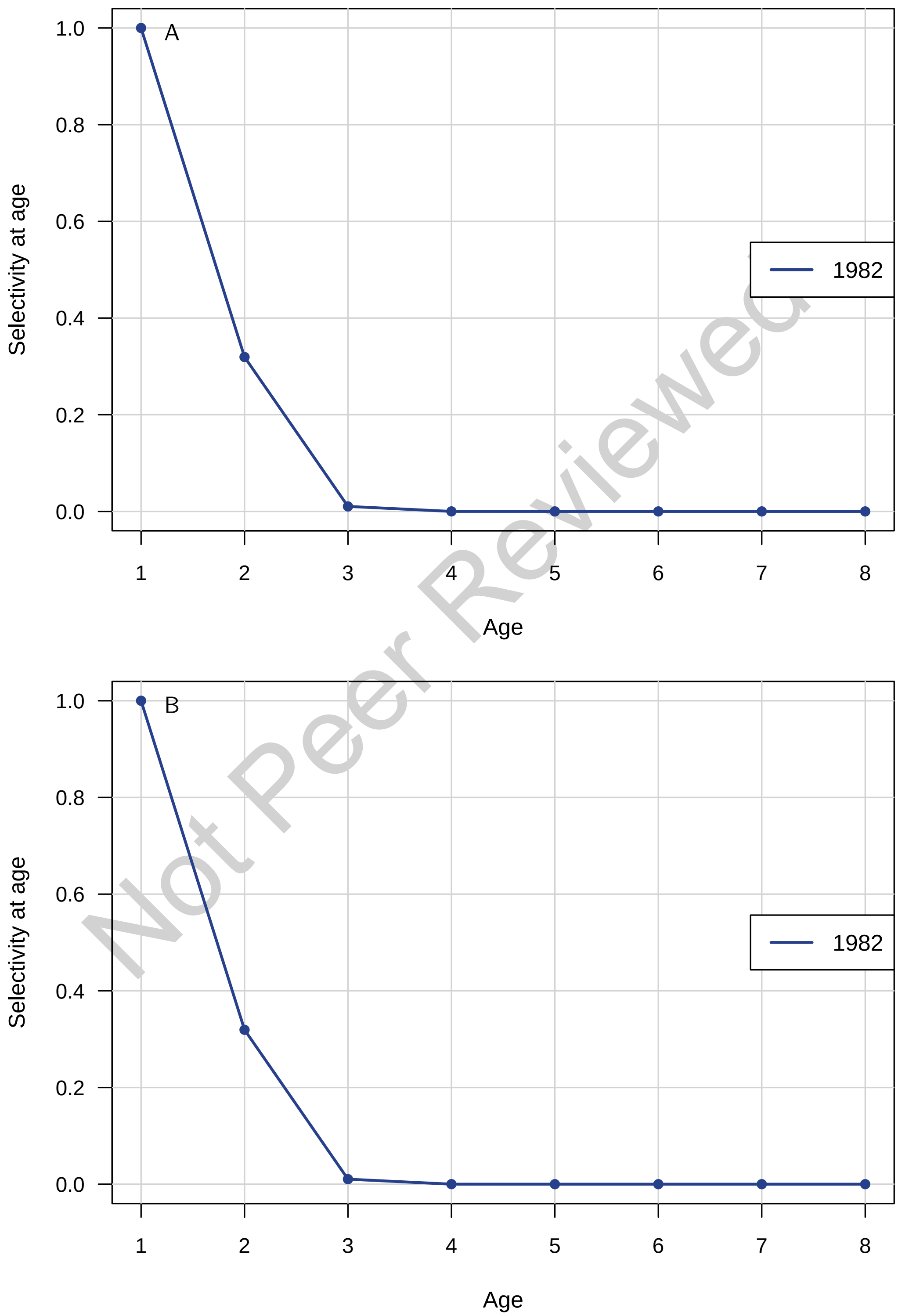


*Figure 32. Average selectivity from the terminal assessment year weighted by geometric mean Fs from the last three assessment years, for (A) landings, (B) discards, and (C) total removals. These selectivities are used in computation of benchmarks and central-tendency projections.*

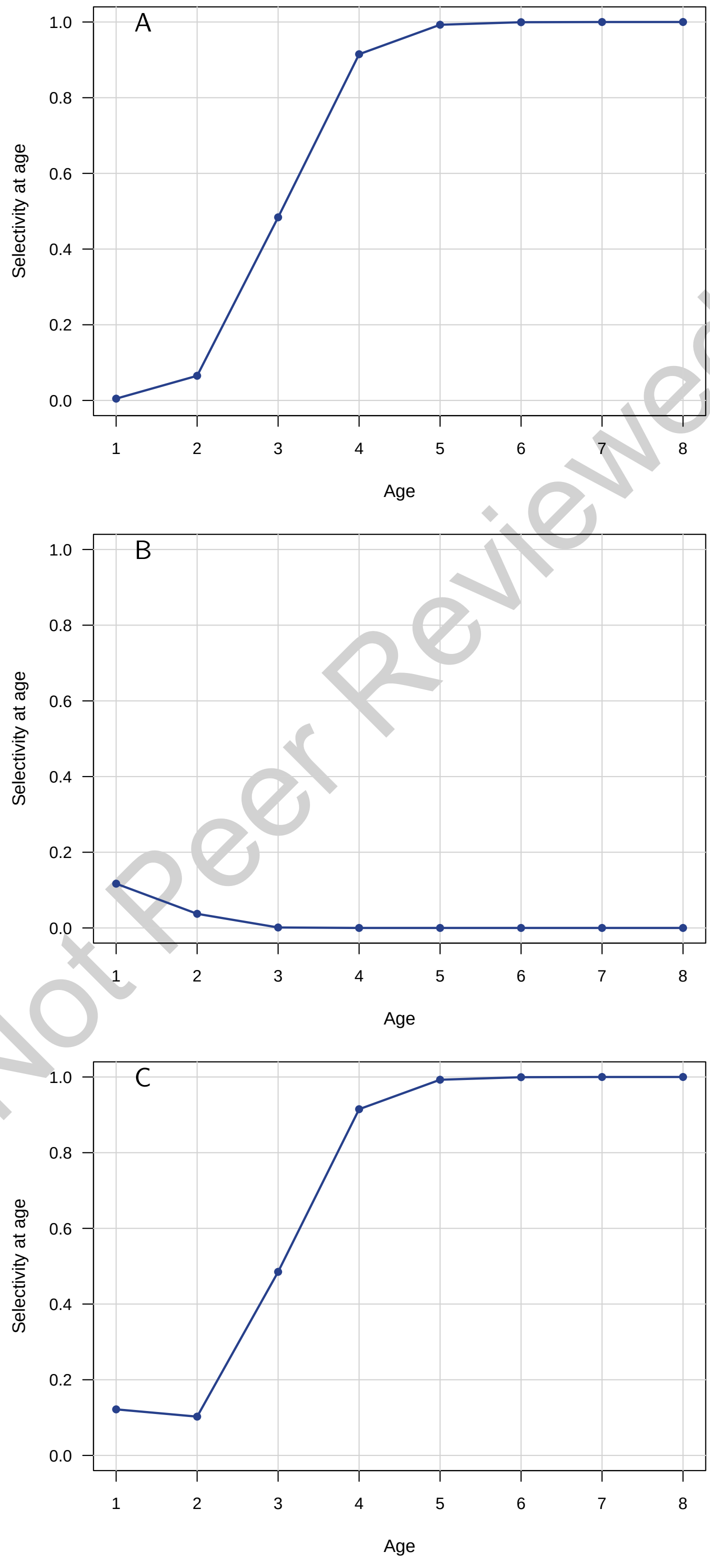


*Figure 33. Estimated fully selected fishing mortality rate (per year) by fleet for discards (D) and landings (L) for general recreational discards, north (D.rGDn); general recreational discards, south (D.rGDs); headboat recreational discards, south (D.rHDs); general recreational landings, north (L.rGNn); general recreational landings, south (L.rGNs); headboat recreational landings, south (L.rHBs); commercial handline landings, north (L.cHLn); and commercial handline landings, south (L.cHLs).*

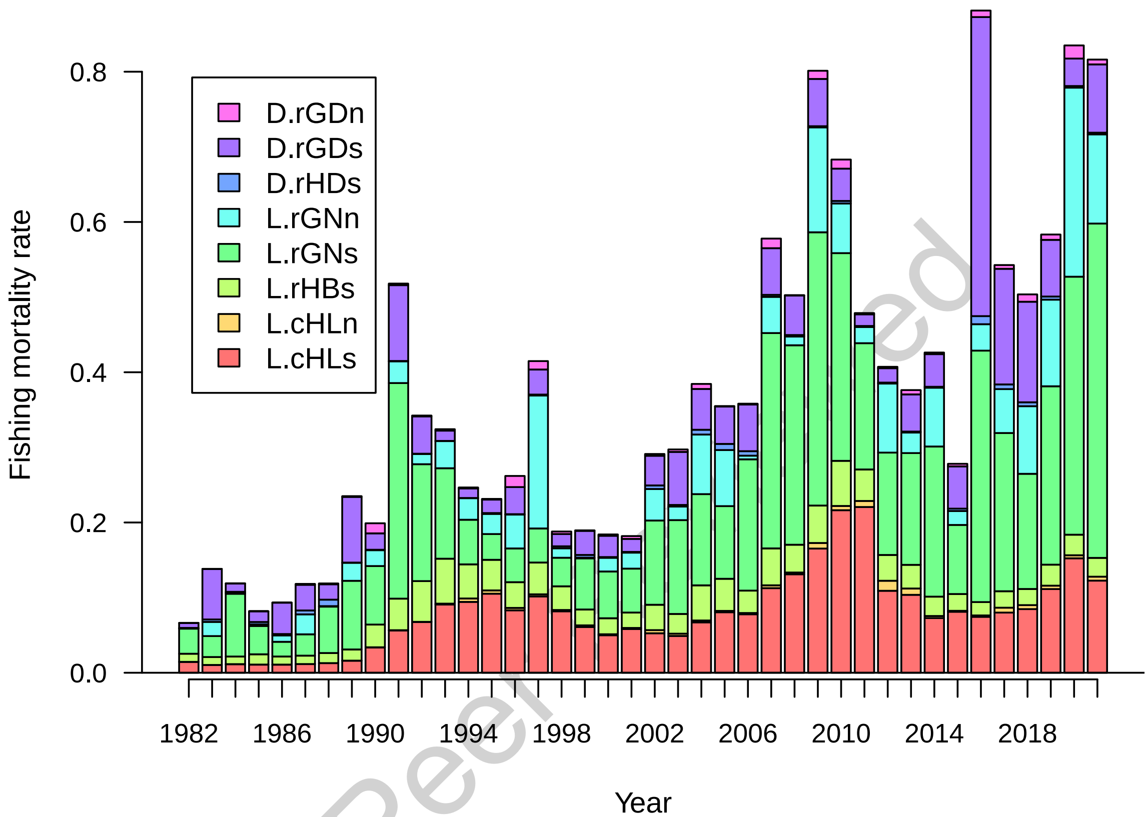


*Figure 34. Estimated landings and discards in (A) absolute numbers and (B) proportion of total numbers by fleet from the catch-at-age model, for general recreational discards, north (D.rGDn); general recreational discards, south (D.rGDs); headboat recreational discards, south (D.rHDs); general recreational landings, north (L.rGNn); general recreational landings, south (L.rGNs); headboat recreational landings, south (L.rHBs); commercial handline landings, north (L.cHLn); and commercial handline landings, south (L.cHLs).*

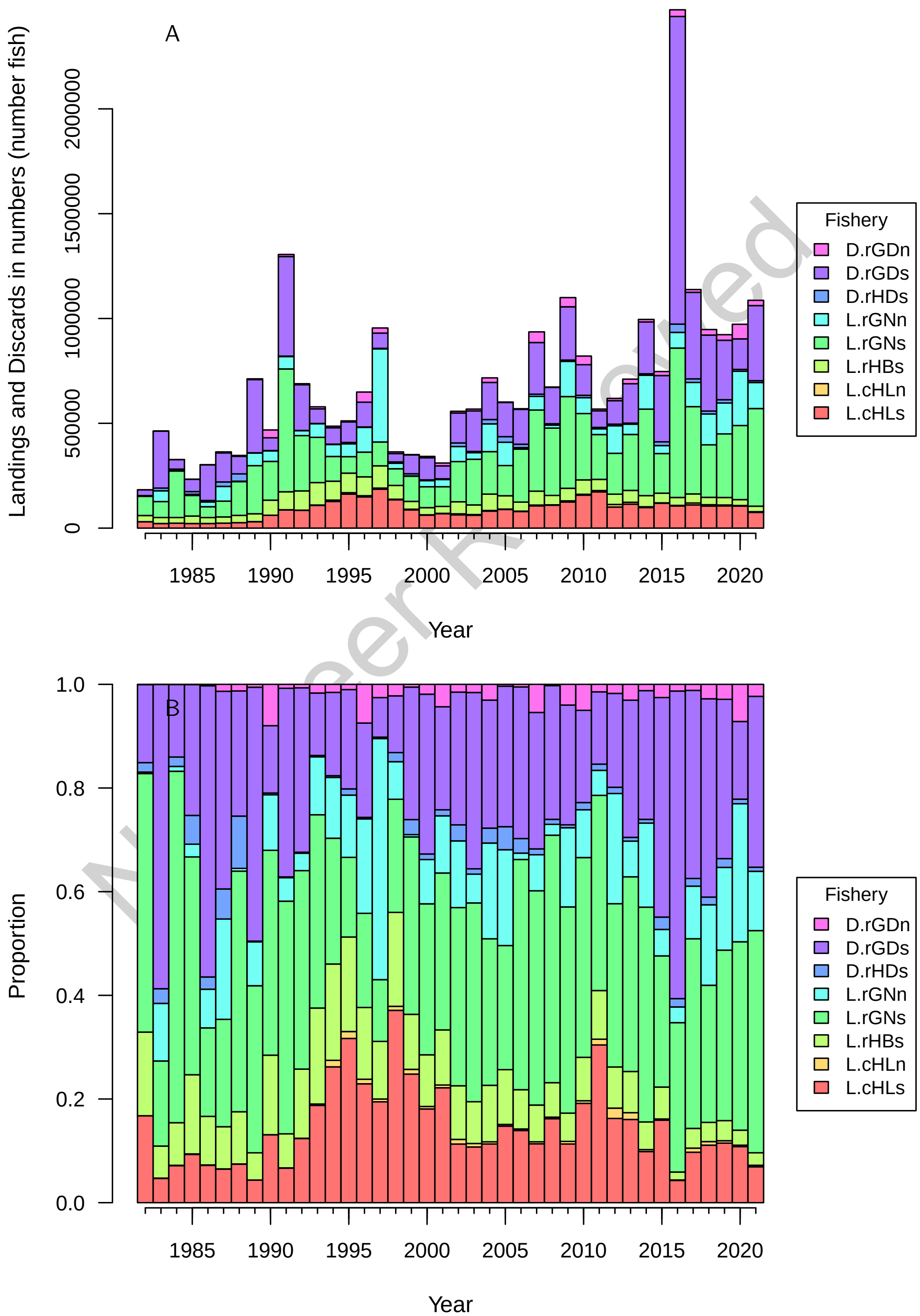


*Figure 35. Estimated landings and discards in (A) absolute weight and (B) proportion of total weight by fleet from the catch-at-age model, for general recreational discards, north (D.rGDn); general recreational discards, south (D.rGDs); headboat recreational discards, south (D.rHDs); general recreational landings, north (L.rGNn); general recreational landings, south (L.rGNs); headboat recreational landings, south (L.rHBs); commercial handline landings, north (L.cHLn); and commercial handline landings, south (L.cHLs).*

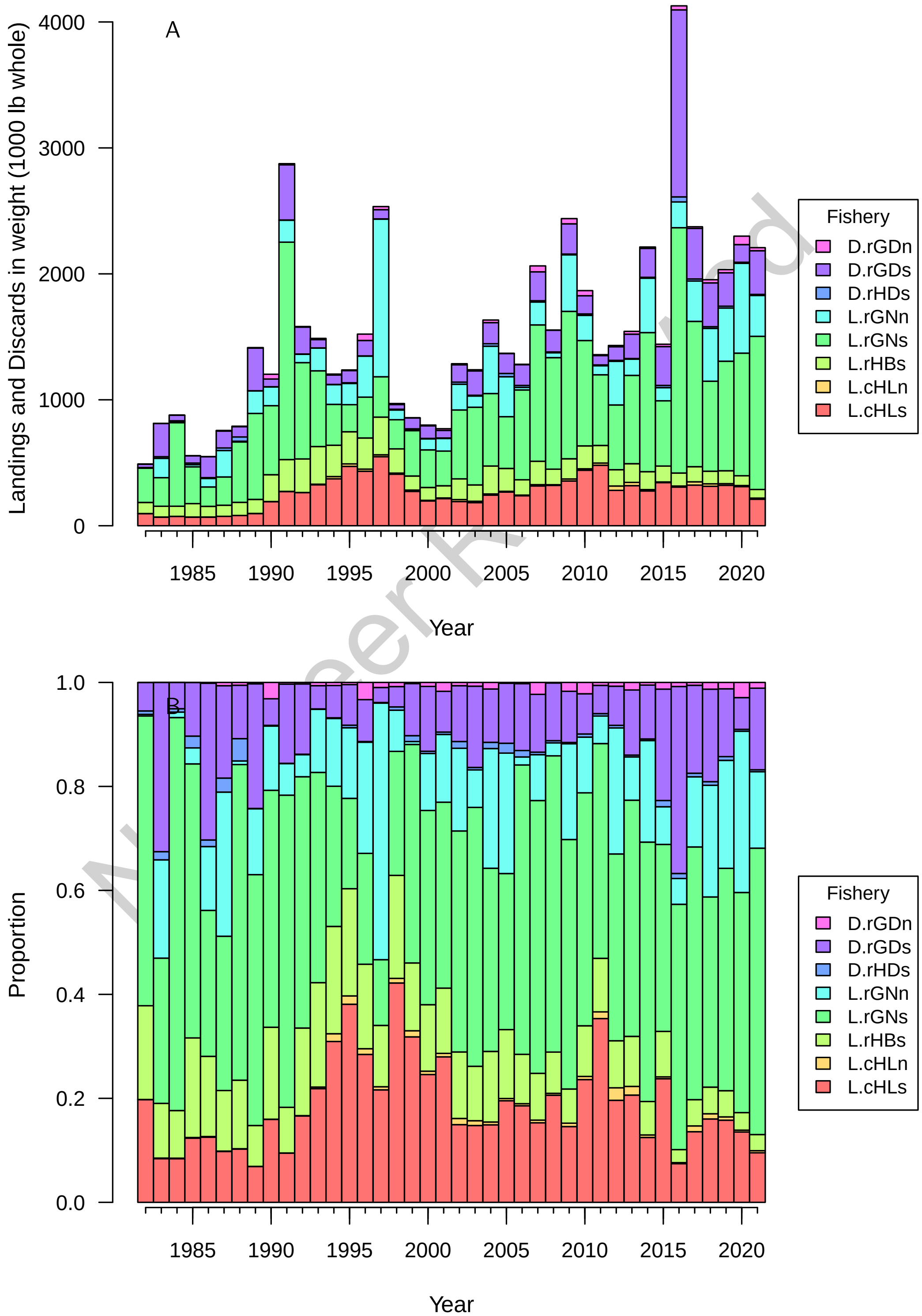


*Figure 36. Spawner-recruit relationship, with and without lognormal bias correction. The expected (mean-unbiased) curve was used for computing management benchmarks.*

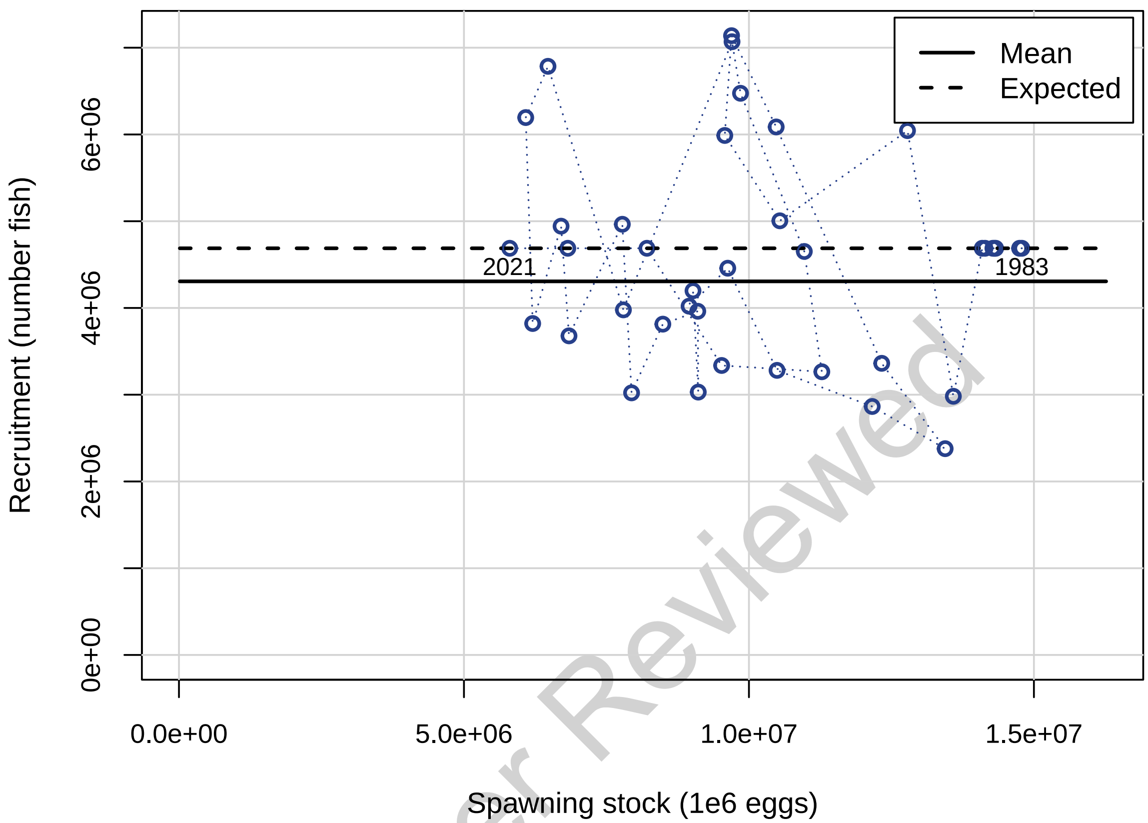


*Figure 37. Probability densities of (A) spawner-recruit quantities R0 (unfished recruitment of age-1 fish), (B) steepness, (C) unfished spawners per recruit, and (D) the standard deviation of the recruitment residuals in log space. Solid vertical lines represent point estimates or values from the BAM base run; dashed and dotted vertical lines represent medians and 95% confidence limits from the MCBE runs, respectively ($n = 1878$). The solid colored lines represent 10 randomly selected simulation runs.*

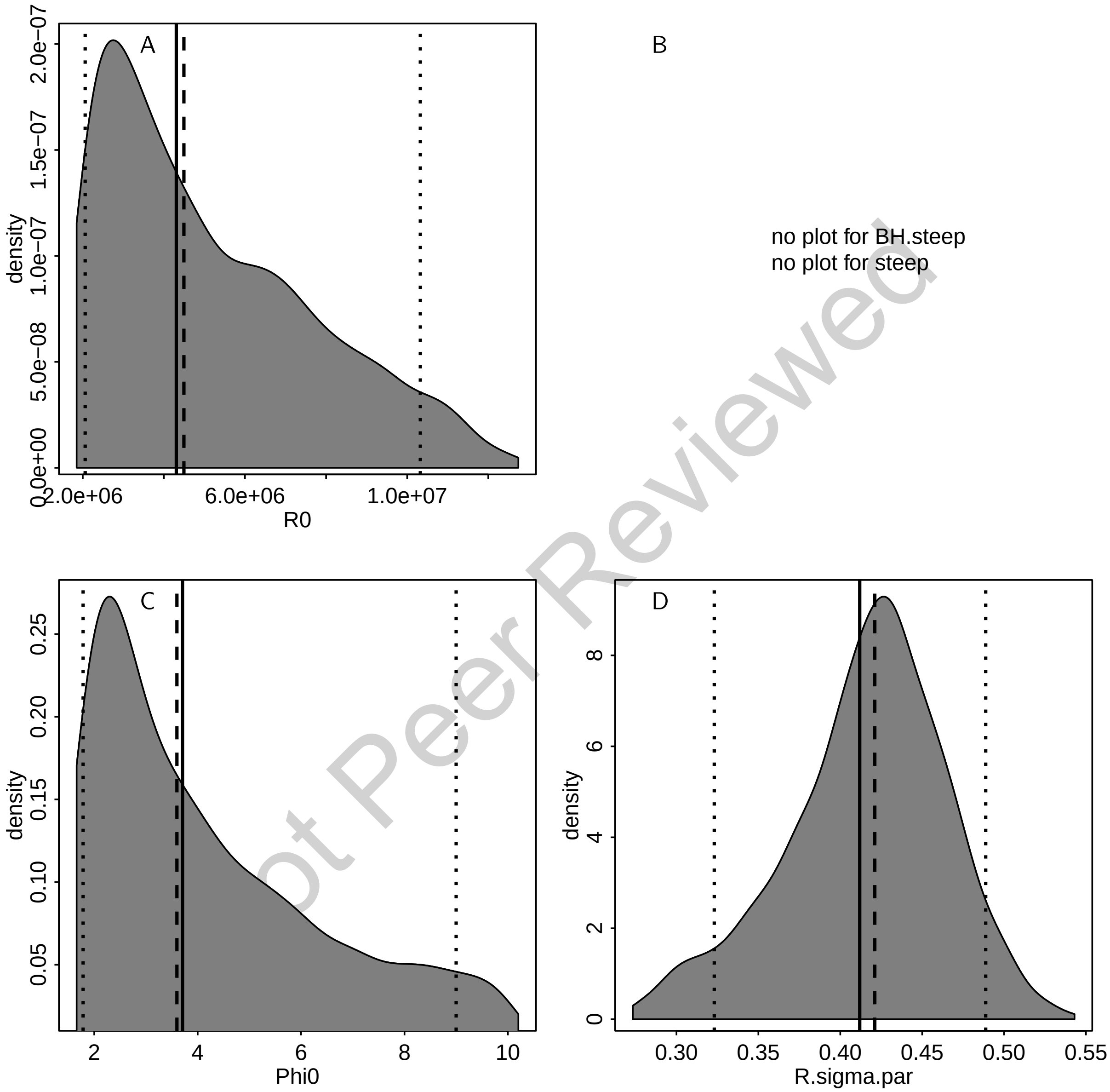


*Figure 38. (A) Yield per recruit (lb) and (B) spawning potential ratio (spawning biomass per recruit relative to that at the unfished level) over a range of F. Both curves are based on average selectivity from the end of the assessment period (see Figure 32).*

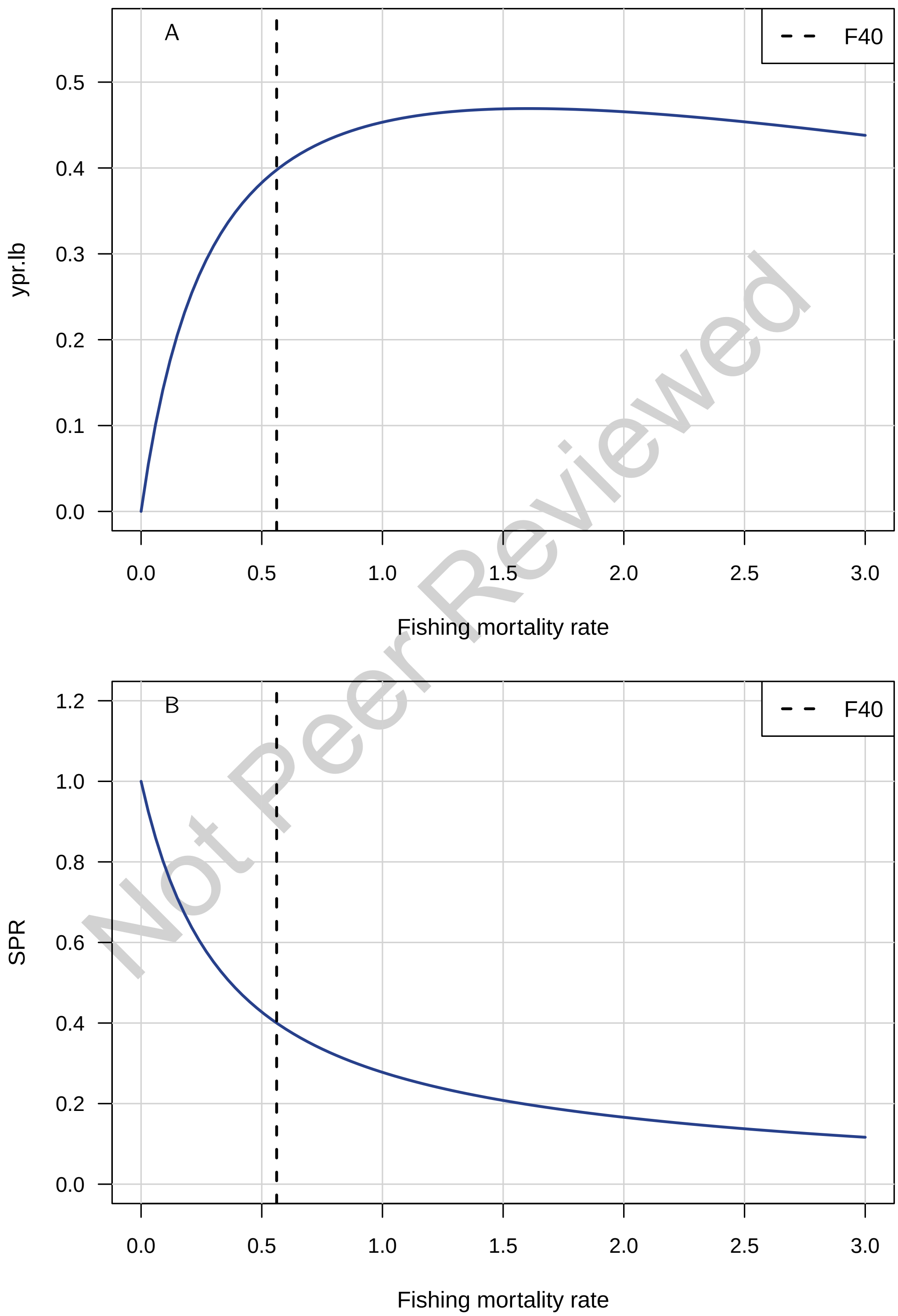


*Figure 39. The top panels shows equilibrium landings at $F$. The peak occurs where fishing rate is $F_{40\%} = 0.56$ and equilibrium landings are $L_{F40\%} = 1865$ (1000 lb). The bottom panel shows equilibrium spawning biomass at $F$. Both curves are based on average selectivity from the end of the assessment period.*

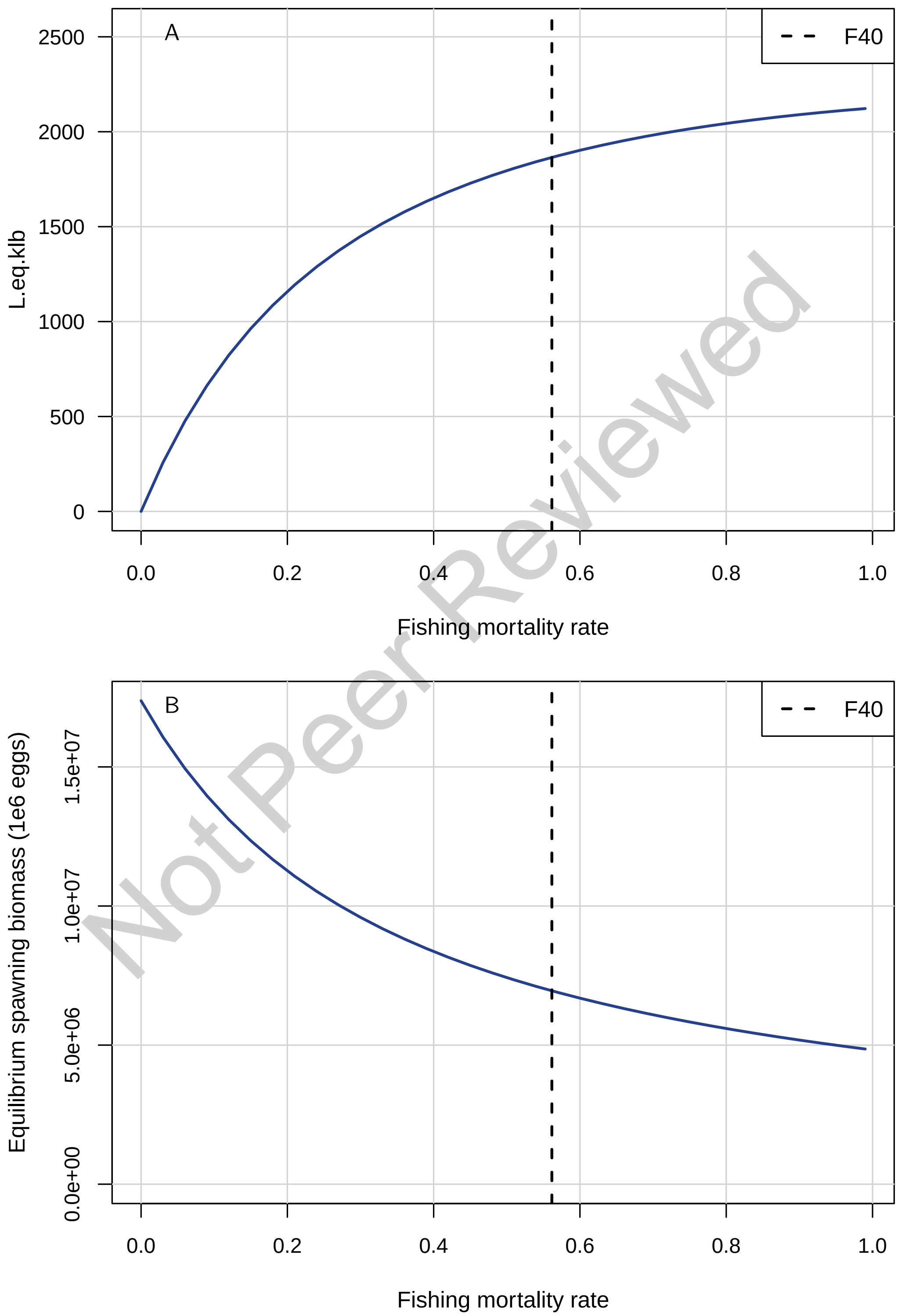


*Figure 40. Probability densities of $F_{40\%}$-related benchmarks (A) $F_{40\%}$, (B) MSST, (C) $L_{F40\%}$, and (D) $B_{F40\%}$ from MCBE analysis ($n = 1878$). Vertical lines represent point estimates from the BAM base run; dashed vertical lines represent medians from the MCBE runs.*

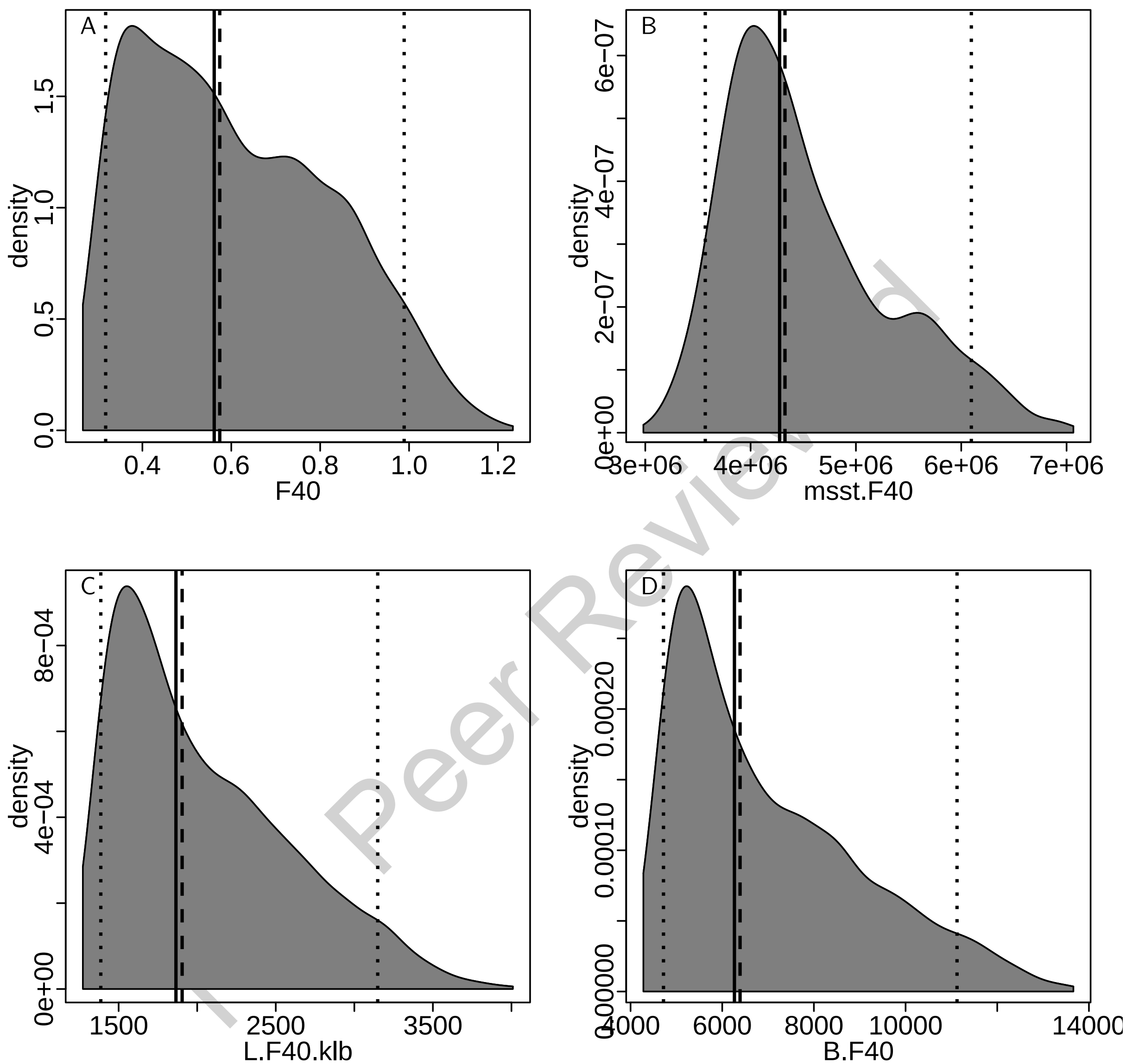


*Figure 41. Estimated time series of* SSB *and* $F$ *relative to benchmarks: (top) spawning biomass relative to the minimum stock size threshold (*MSST*), (bottom)* $F$ *relative to* $F_{40\%}$*. Shaded region represents 95% confidence bands from the MCBE runs (*$n = 1878$*).*

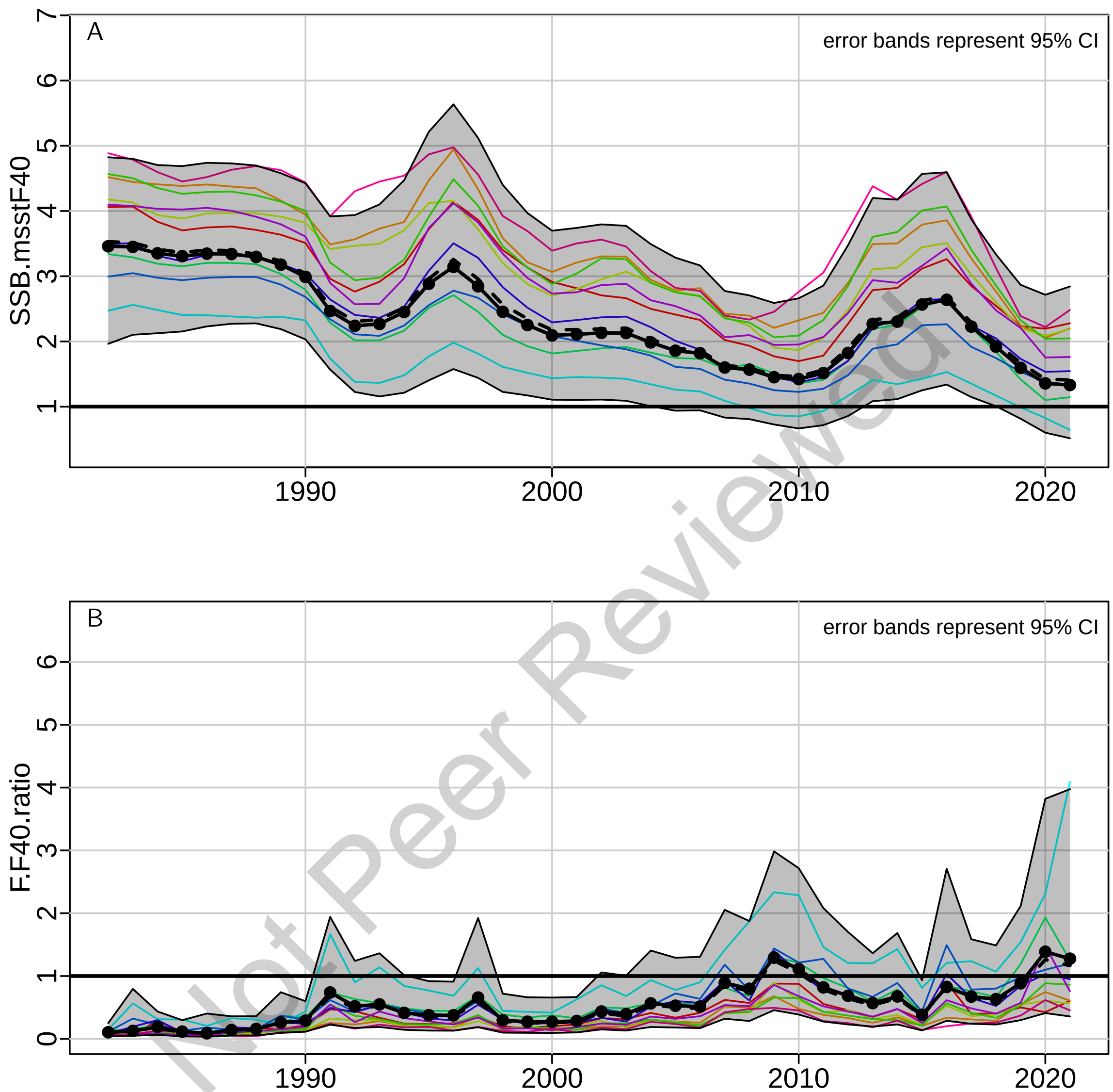
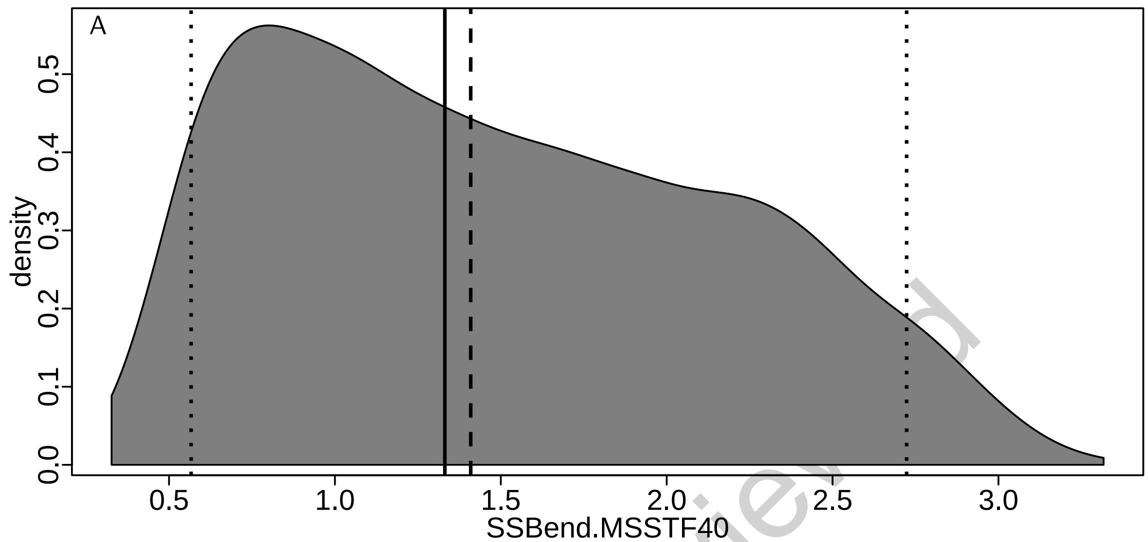


*Figure 42. Probability densities of terminal status estimates from MCBE analysis of the Beaufort Assessment Model ($n = 1878$). Vertical lines represent point estimates from the BAM base run; dashed vertical lines represent medians from the MCBE runs.*



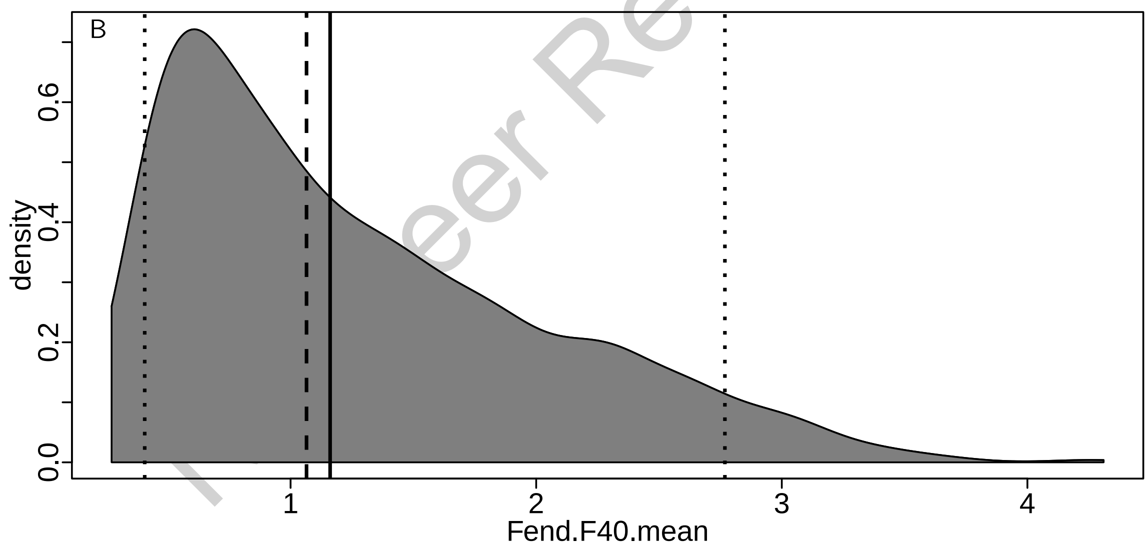



*Figure 43. Phase plot of terminal status estimates from MCBE analysis of the Beaufort Assessment Model (n = 1878). Stock status is plotted along the vertical axis relative to* MSST*. The intersection of crosshairs indicates estimates from the BAM base run; lengths of crosshairs defined by* $5^{th}$ *and* $95^{th}$ *percentiles of MCBE runs.*

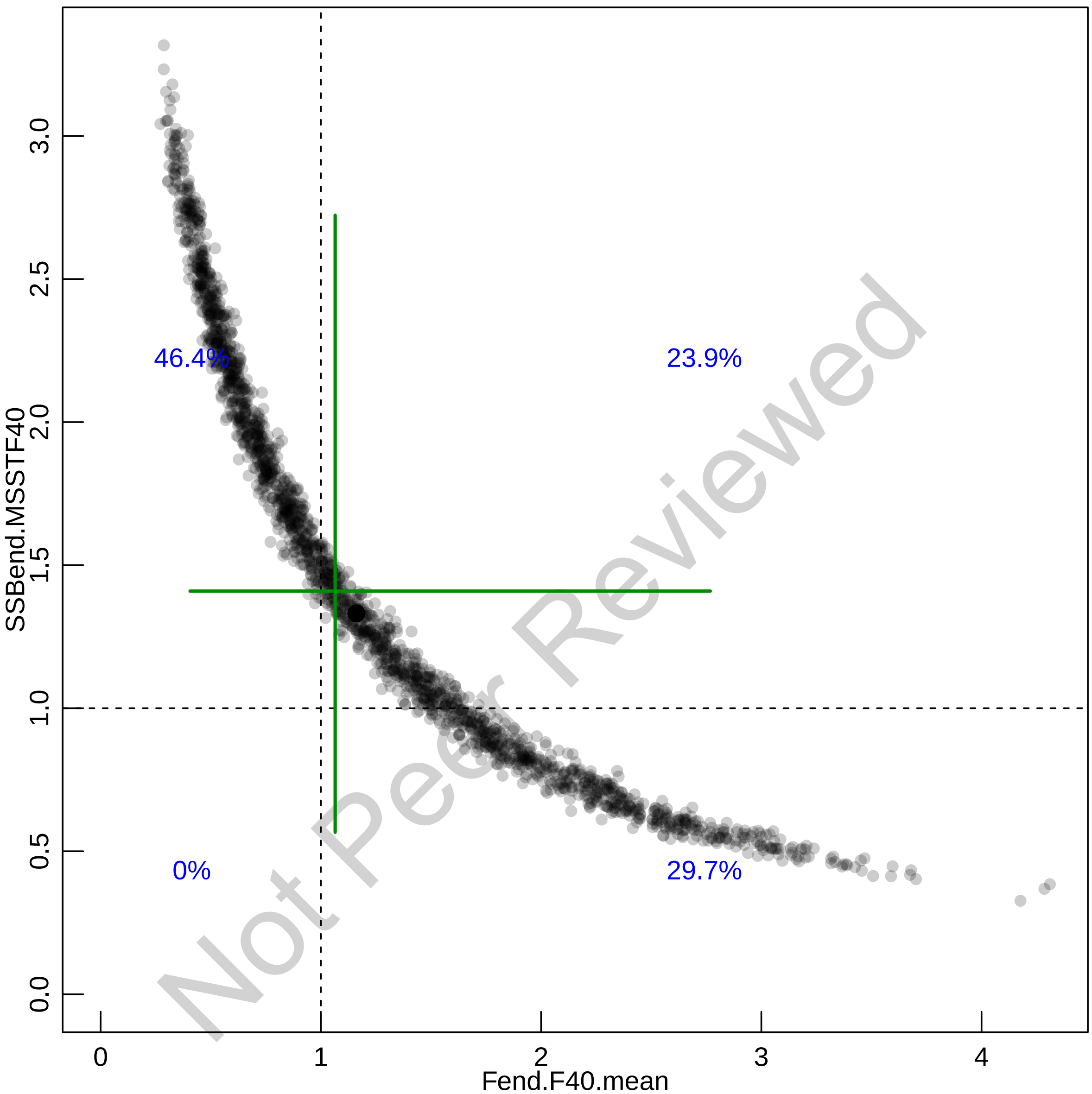


*Figure 44. Estimated age structure from a series of individual years during the assessment, relative to the equilibrium expected at* $F_{40\%}$.

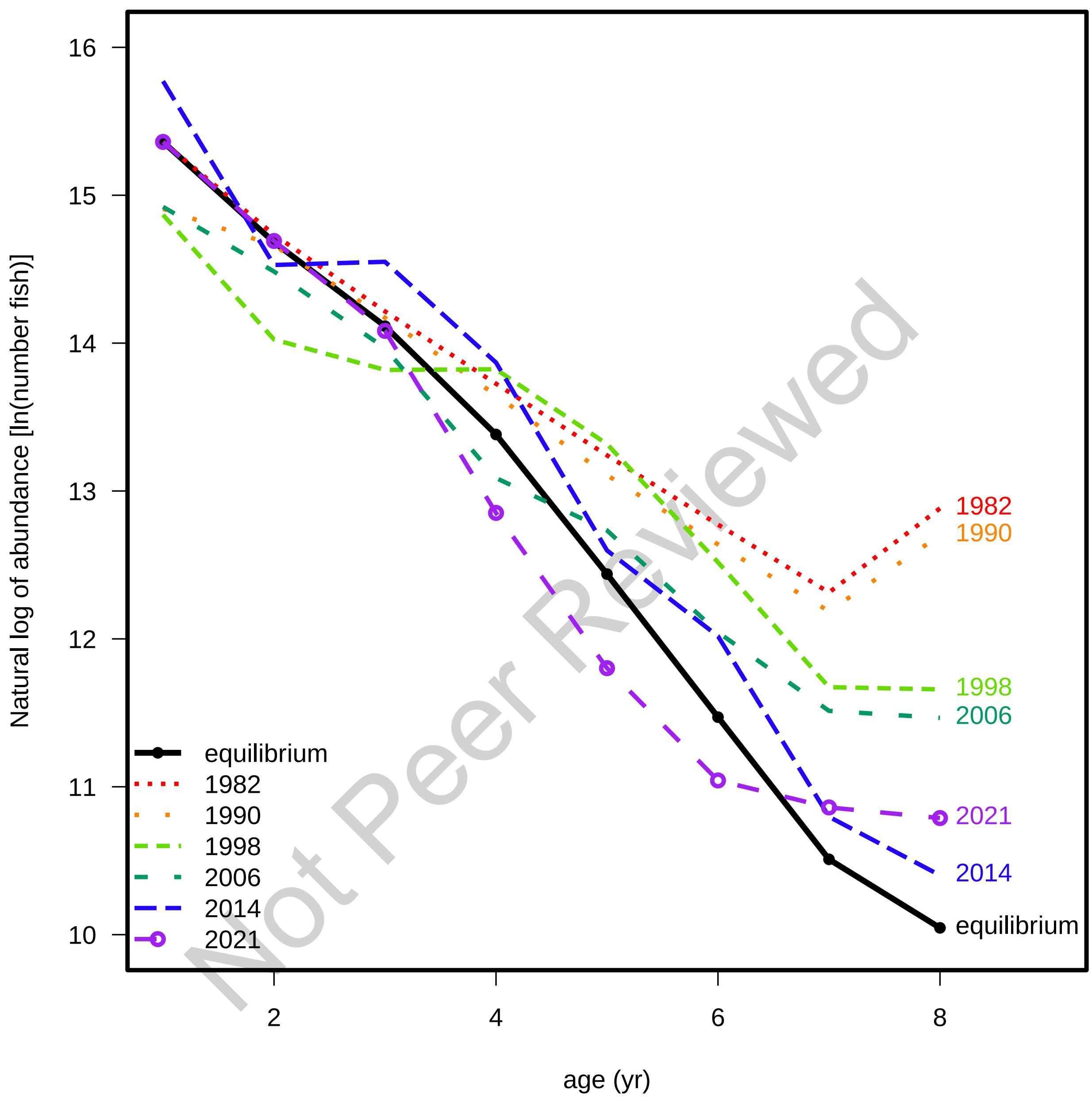


*Figure 45. Sensitivity to initial F ($F_{init}$) (S01-S02). Estimated time series of F and SSB relative to benchmarks ($F_{40\%}$ and MSST), as well as number of age-1 recruits and stock size (*SSB*; million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B)* SSB/MSST, *(C) number of recruits, and (D)* SSB.

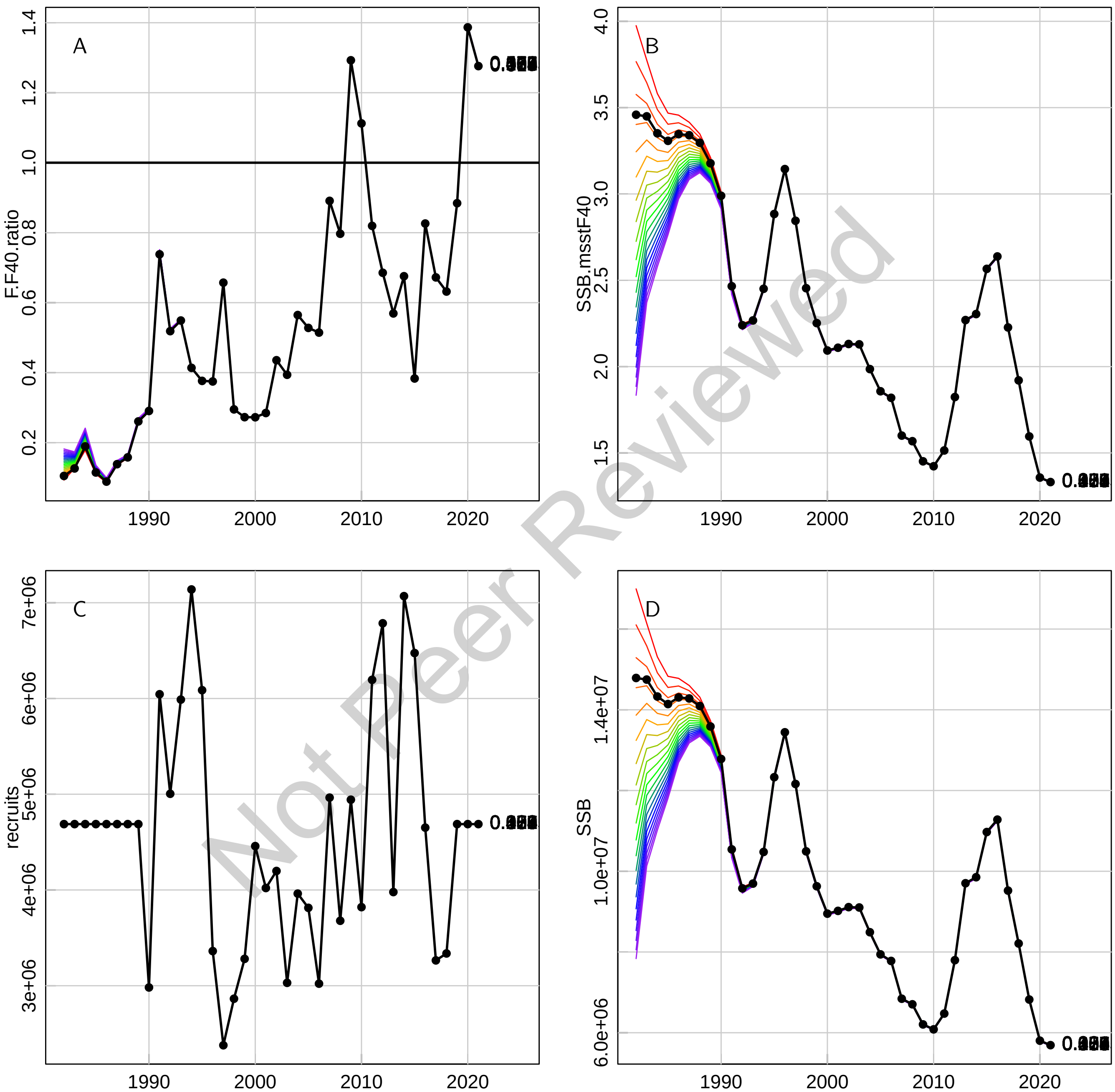


*Figure 46. Sensitivity to fixed values of natural mortality (S03-S04). Estimated time series of F and SSB relative to benchmarks ($F_{40\%}$ and MSST), as well as number of age-1 recruits and stock size (SSB; million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B) SSB/MSST, (C) number of recruits, and (D) SSB.*

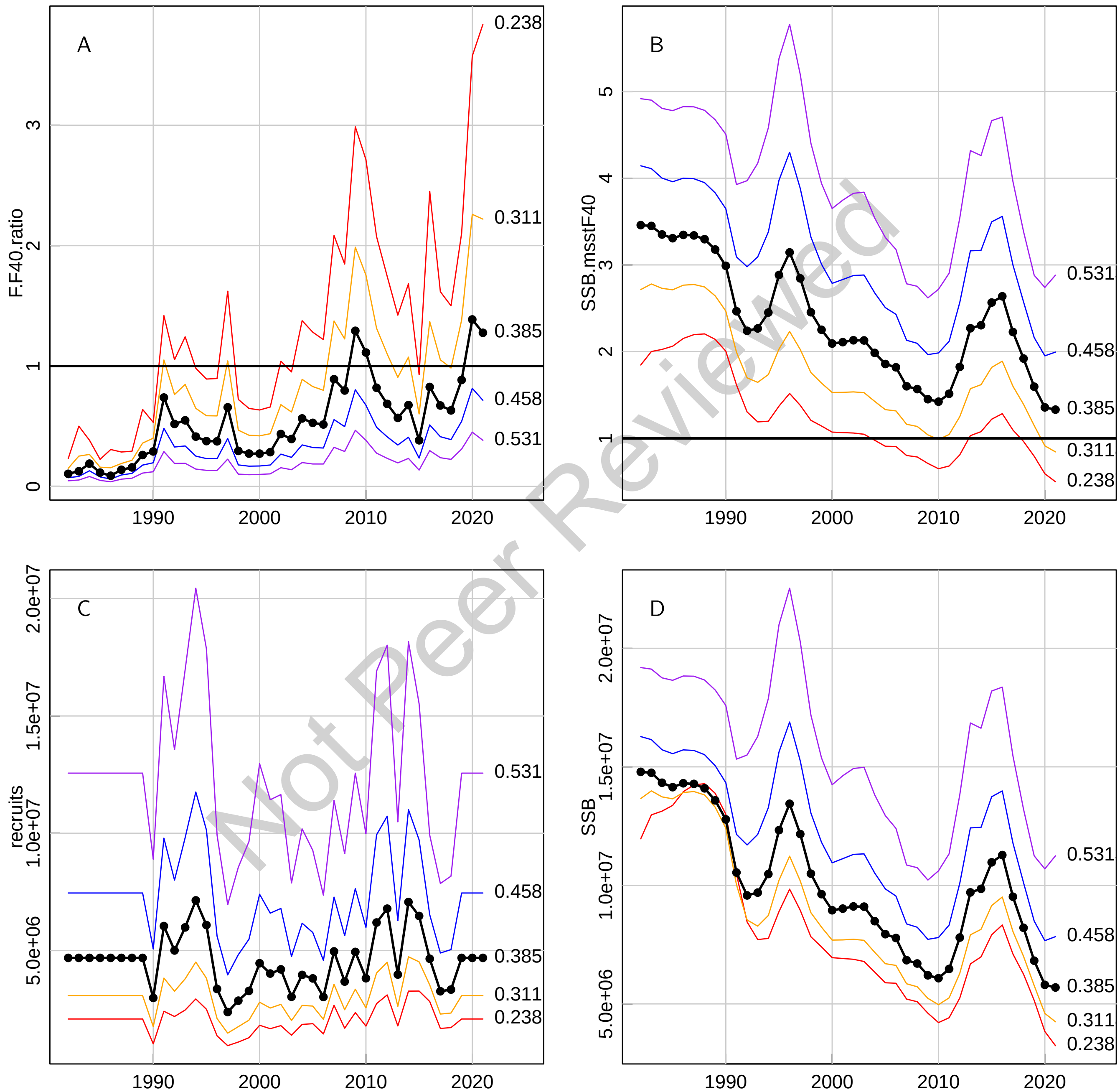


*Figure 47. Sensitivity to fixed values of discard mortality (S05-S06). Estimated time series of $F$ and $SSB$ relative to benchmarks ($F_{40\%}$ and $MSST$), as well as number of age-1 recruits and stock size (SSB; million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B)* SSB/MSST*, (C) number of recruits, and (D)* SSB*.*

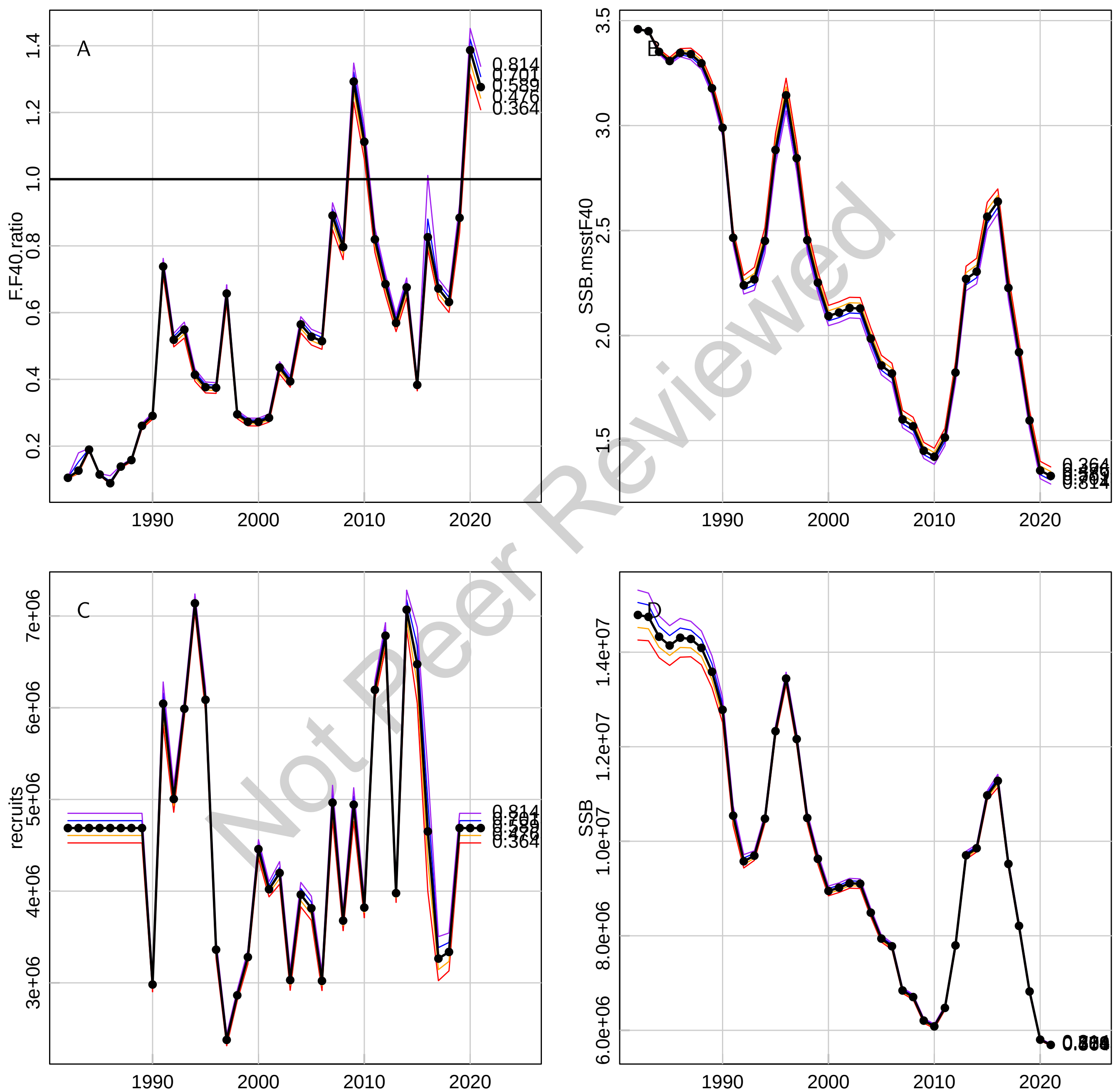


*Figure 48. Sensitivity to excluding age error (S07). Estimated time series of F and SSB relative to benchmarks ($F_{40\%}$ and MSST), as well as number of age-1 recruits and stock size (SSB; million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B) SSB/MSST, (C) number of recruits, and (D) SSB.*

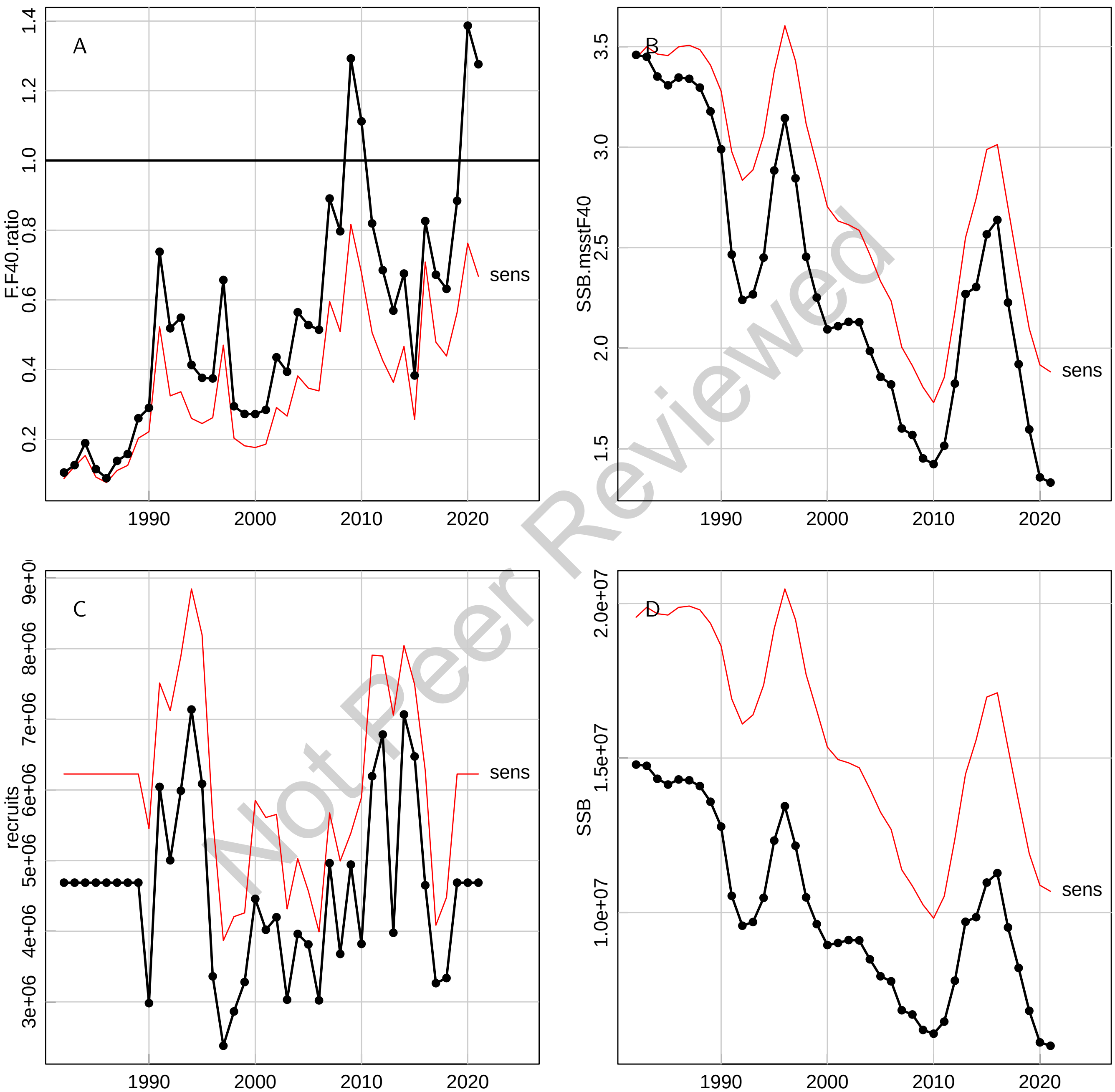


*Figure 49. Sensitivity to using age comps from 1 to 8 for all years (S08). Estimated time series of F and SSB relative to benchmarks ($F_{40\%}$ and MSST), as well as number of age-1 recruits and stock size (SSB; million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B) SSB/MSST, (C) number of recruits, and (D) SSB.*

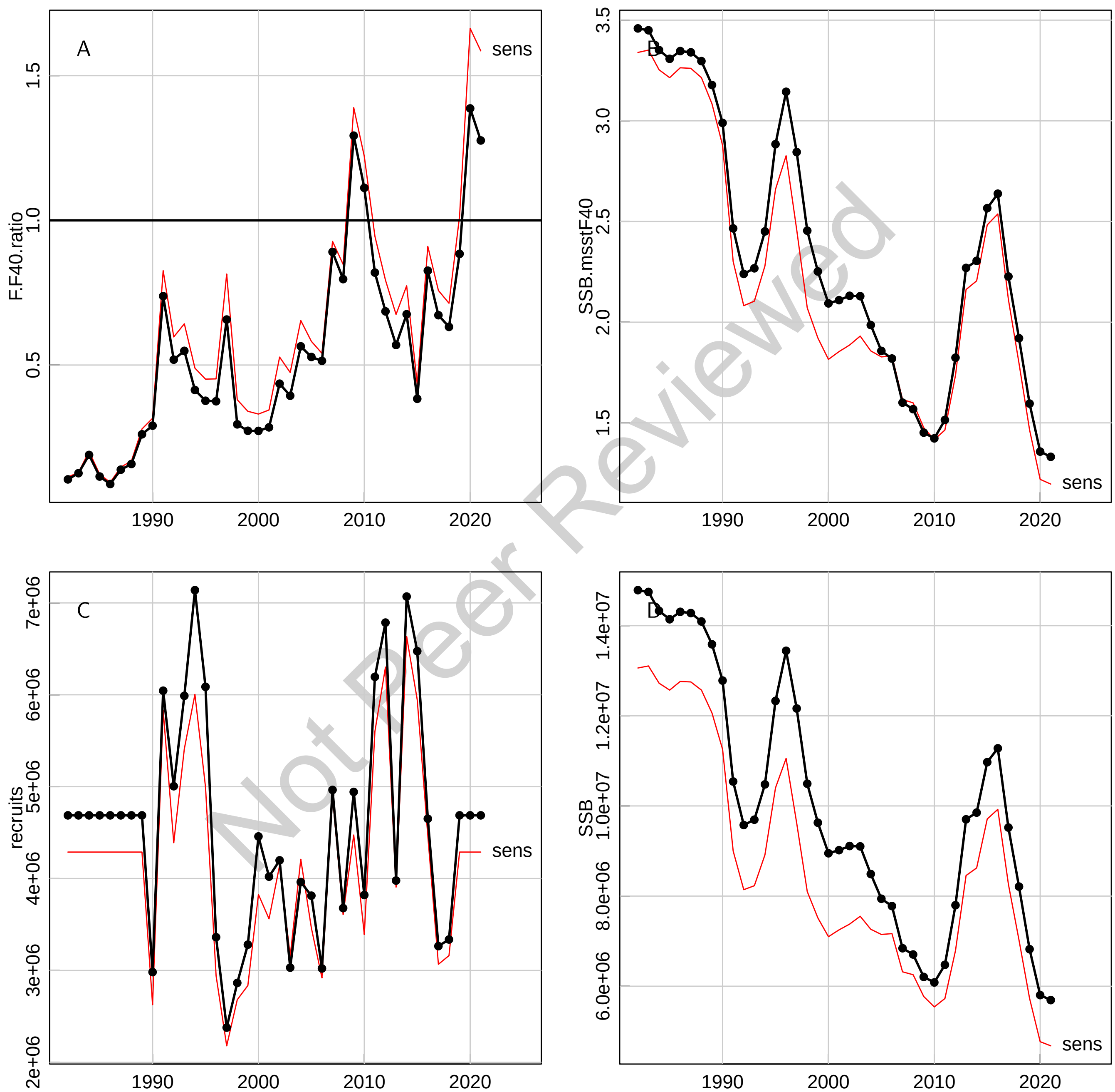


*Figure 50. Sensitivity to age-dependent batch fecundity (S09). Estimated time series of F and SSB relative to benchmarks ($F_{40\%}$ and MSST), as well as number of age-1 recruits and stock size* (SSB; *million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B)* SSB/MSST, *(C) number of recruits, and (D)* SSB.

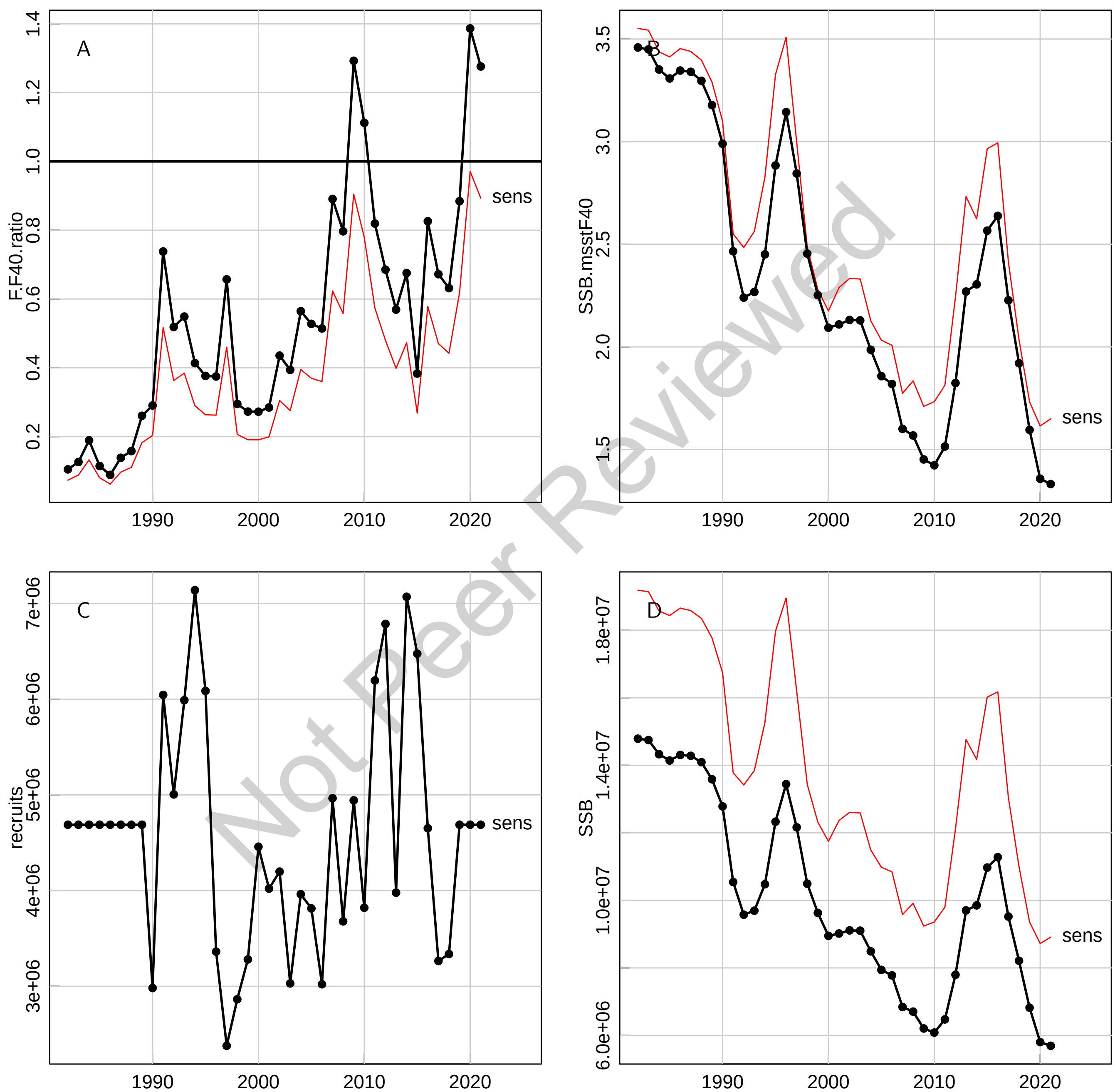


*Figure 51. Sensitivity to age-dependent batch number (S10). Estimated time series of F and SSB relative to benchmarks ($F_{40\%}$ and MSST), as well as number of age-1 recruits and stock size (*SSB*; million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B)* SSB/MSST*, (C) number of recruits, and (D)* SSB.

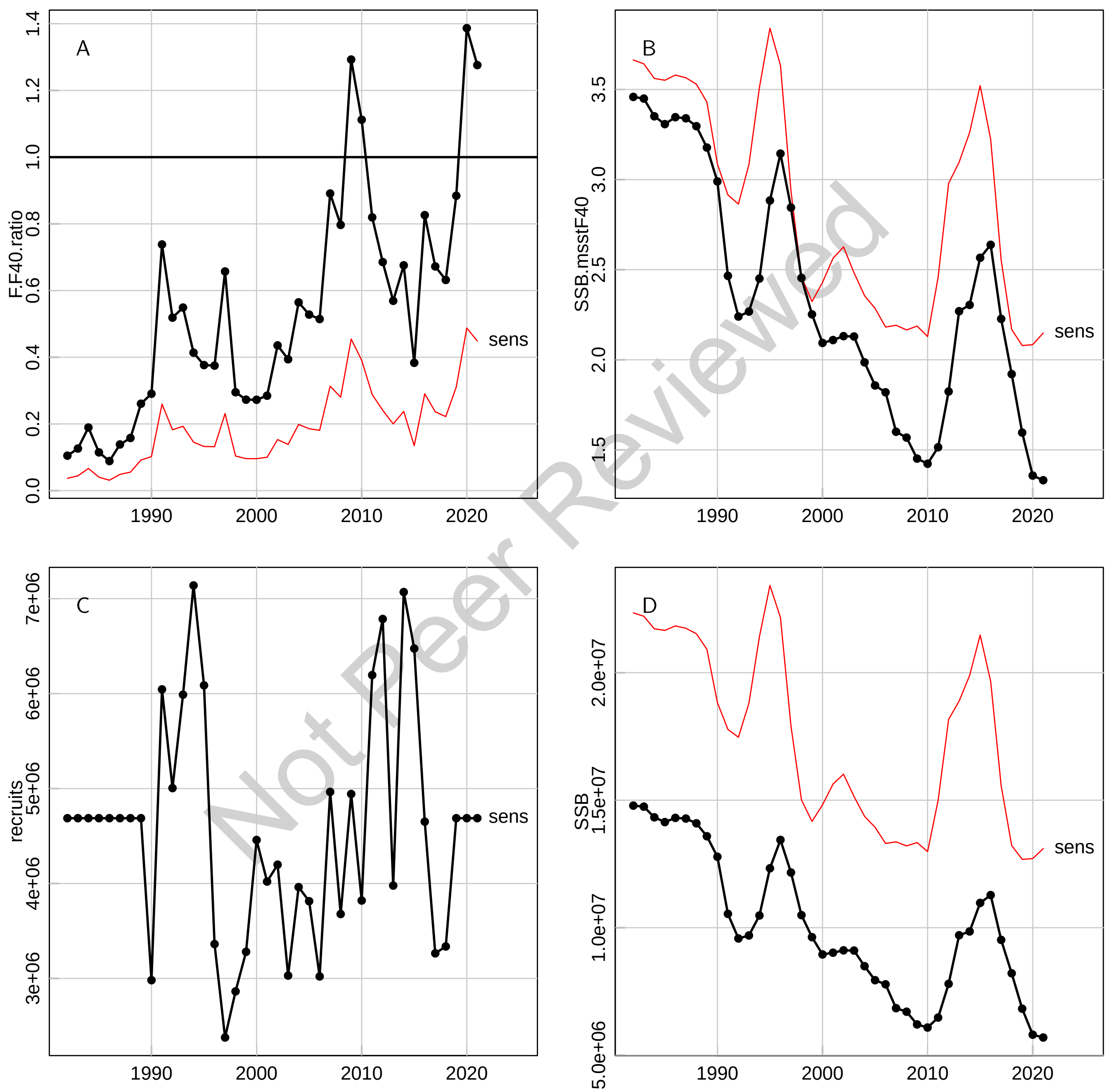


*Figure 52. Sensitivity to age-dependent batch number and batch fecundity (S11). Estimated time series of $F$ and SSB relative to benchmarks ($F_{40\%}$ and $MSST$), as well as number of age-1 recruits and stock size* (SSB; *million eggs*)*. Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B)* SSB/MSST*, (C) number of recruits, and (D)* SSB.

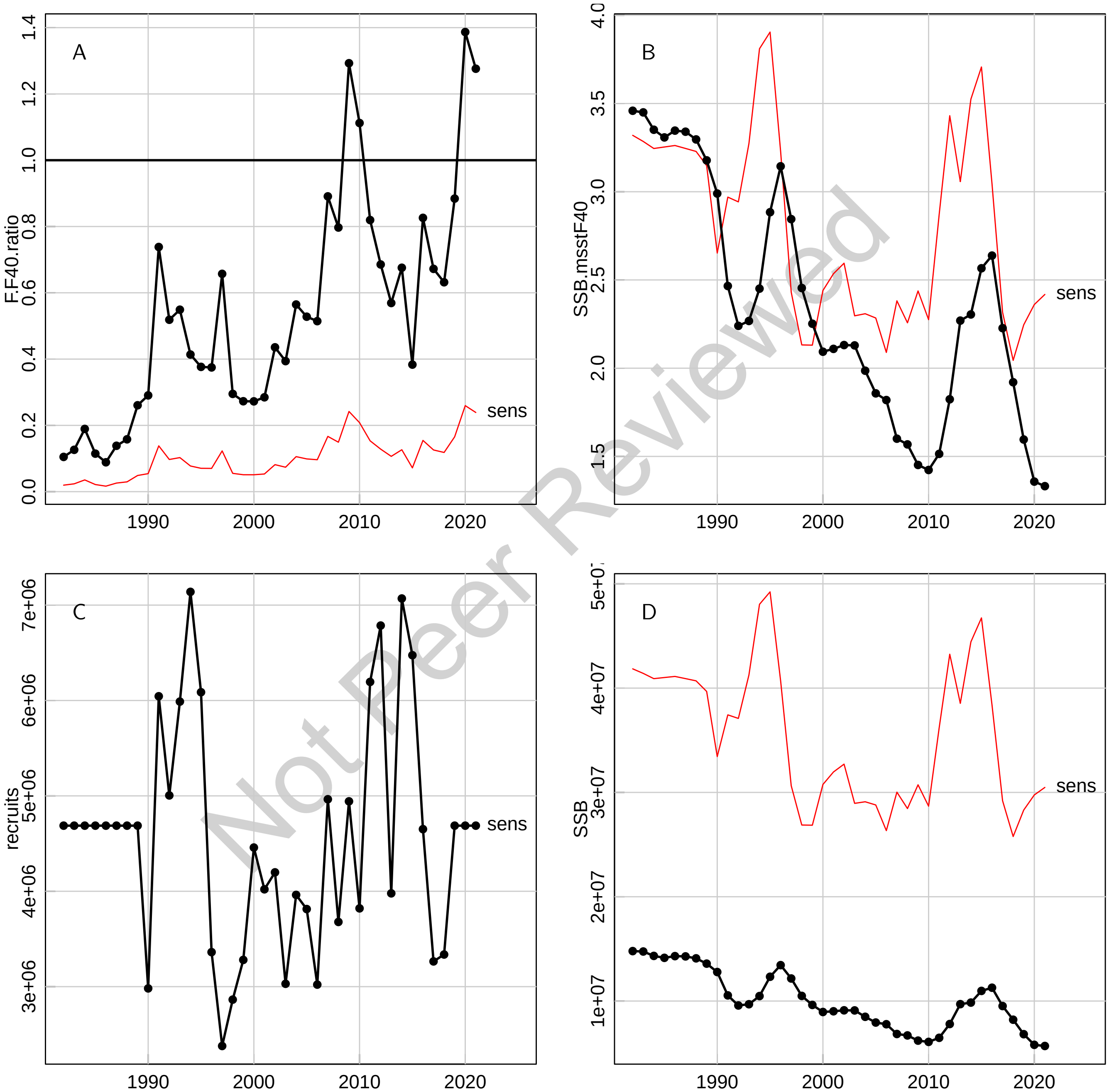


*Figure 53. Sensitivity to estimating steepness (S12). Estimated time series of F and SSB relative to benchmarks ($F_{40\%}$ and $MSST$), as well as number of age-1 recruits and stock size (*SSB*; million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B)* SSB/MSST, *(C) number of recruits, and (D)* SSB.

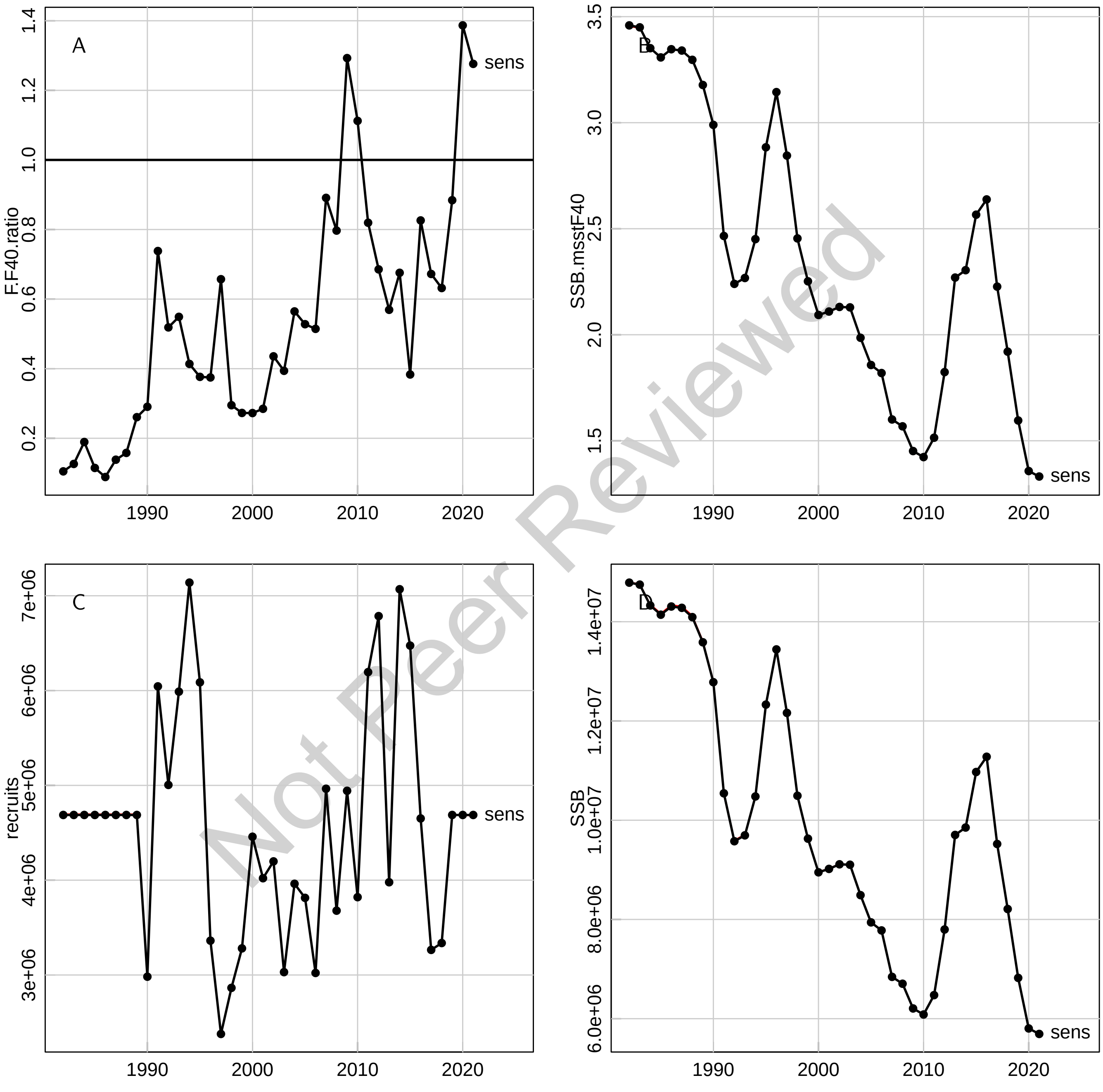


*Figure 54. Sensitivity to high value of general recreational discards (S13). Estimated time series of F and SSB relative to benchmarks ($F_{40\%}$ and $MSST$), as well as number of age-1 recruits and stock size (*SSB*; million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B)* SSB/MSST*, (C) number of recruits, and (D)* SSB*.*

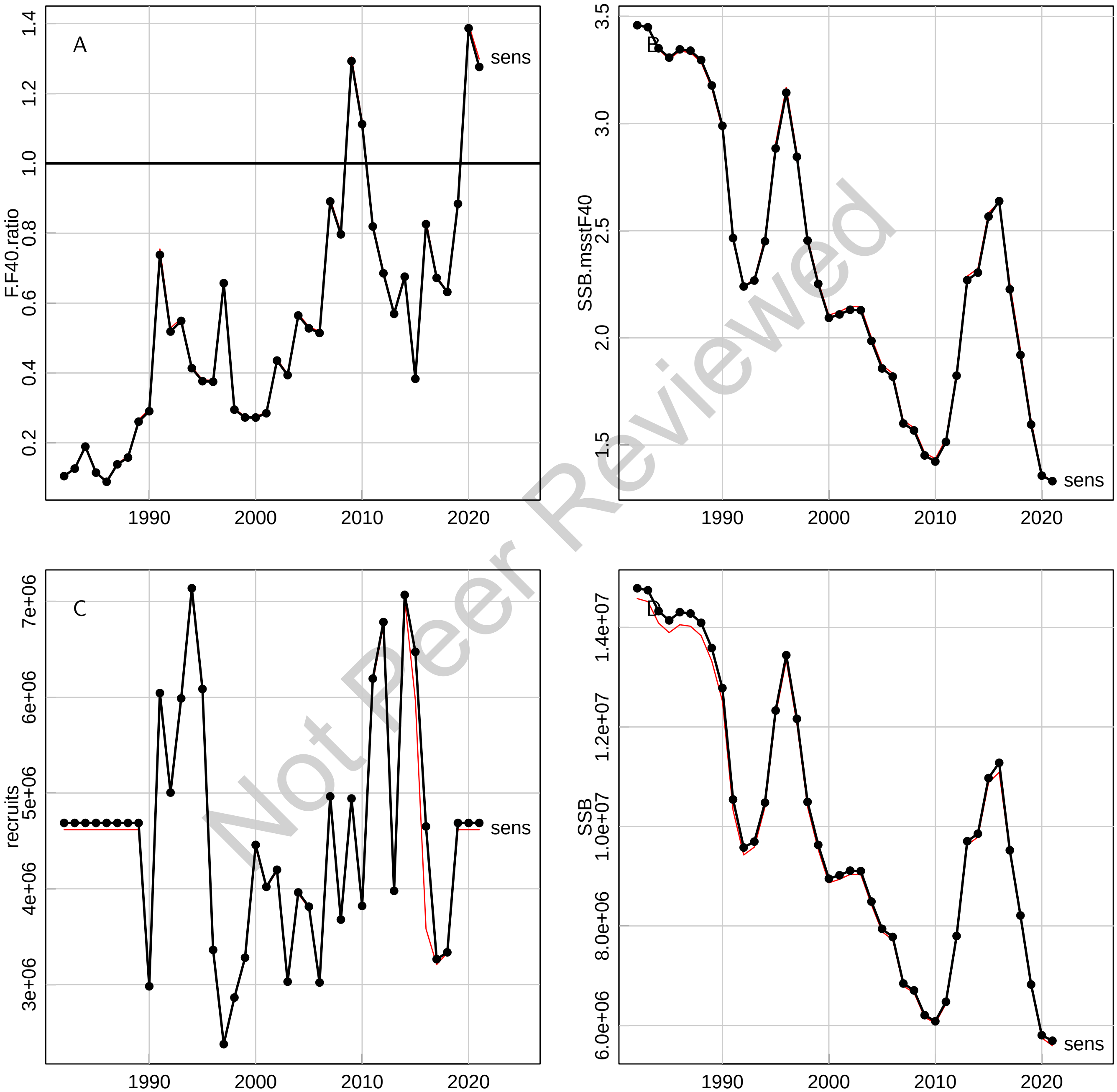


*Figure 55. Sensitivity to start year of SERFS trap/video index (S14). Estimated time series of F and SSB relative to benchmarks ($F_{40\%}$ and $MSST$), as well as number of age-1 recruits and stock size (*SSB*; million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B)* SSB/MSST*, (C) number of recruits, and (D)* SSB.

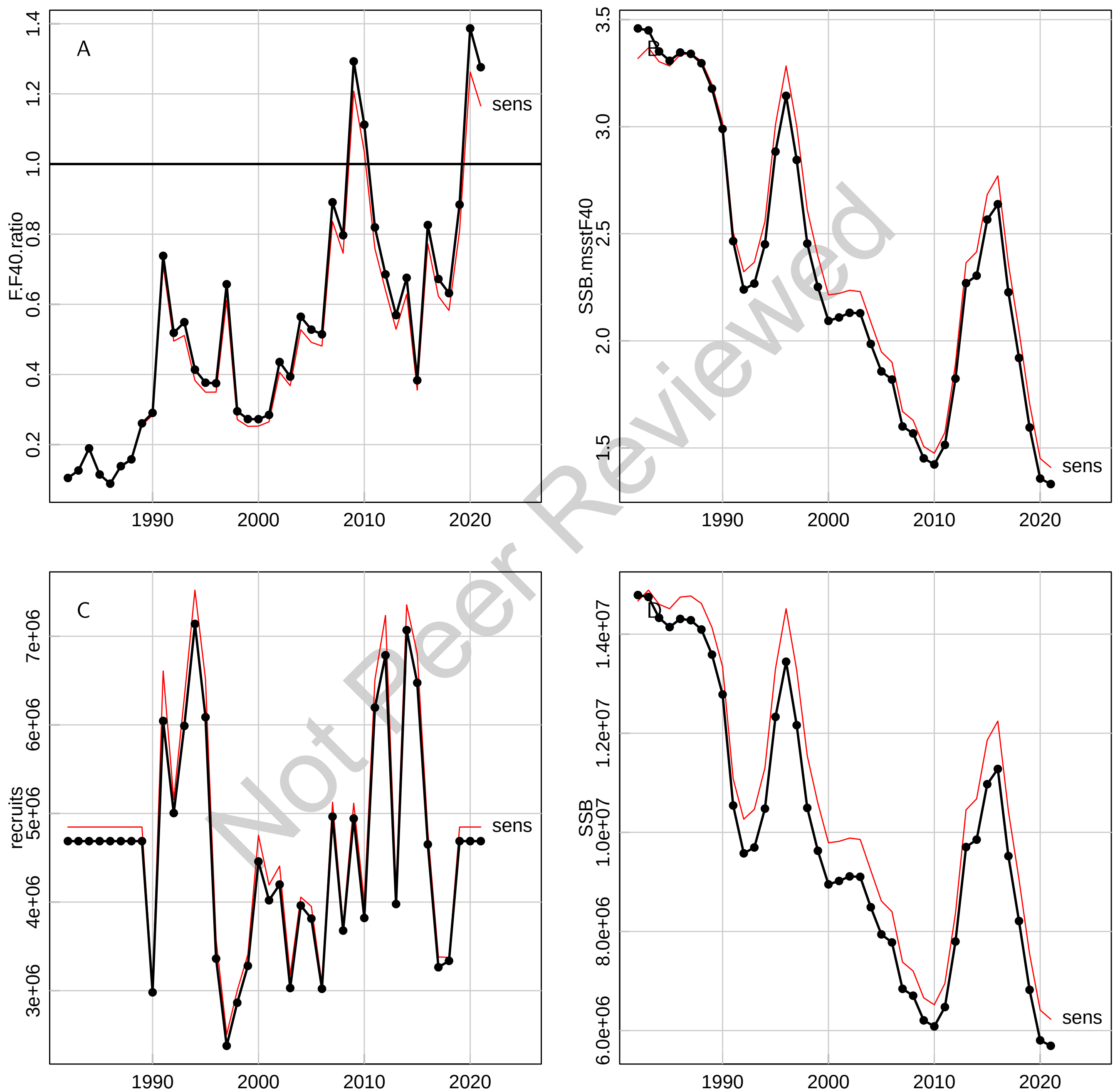


*Figure 56. Sensitivity to estimating selectivity for general recreational (rGN) landings (S15). Estimated time series of $F$ and $SSB$ relative to benchmarks ($F_{40\%}$ and $MSST$), as well as number of age-1 recruits and stock size (*SSB*; million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B)* SSB/MSST, *(C) number of recruits, and (D)* SSB.

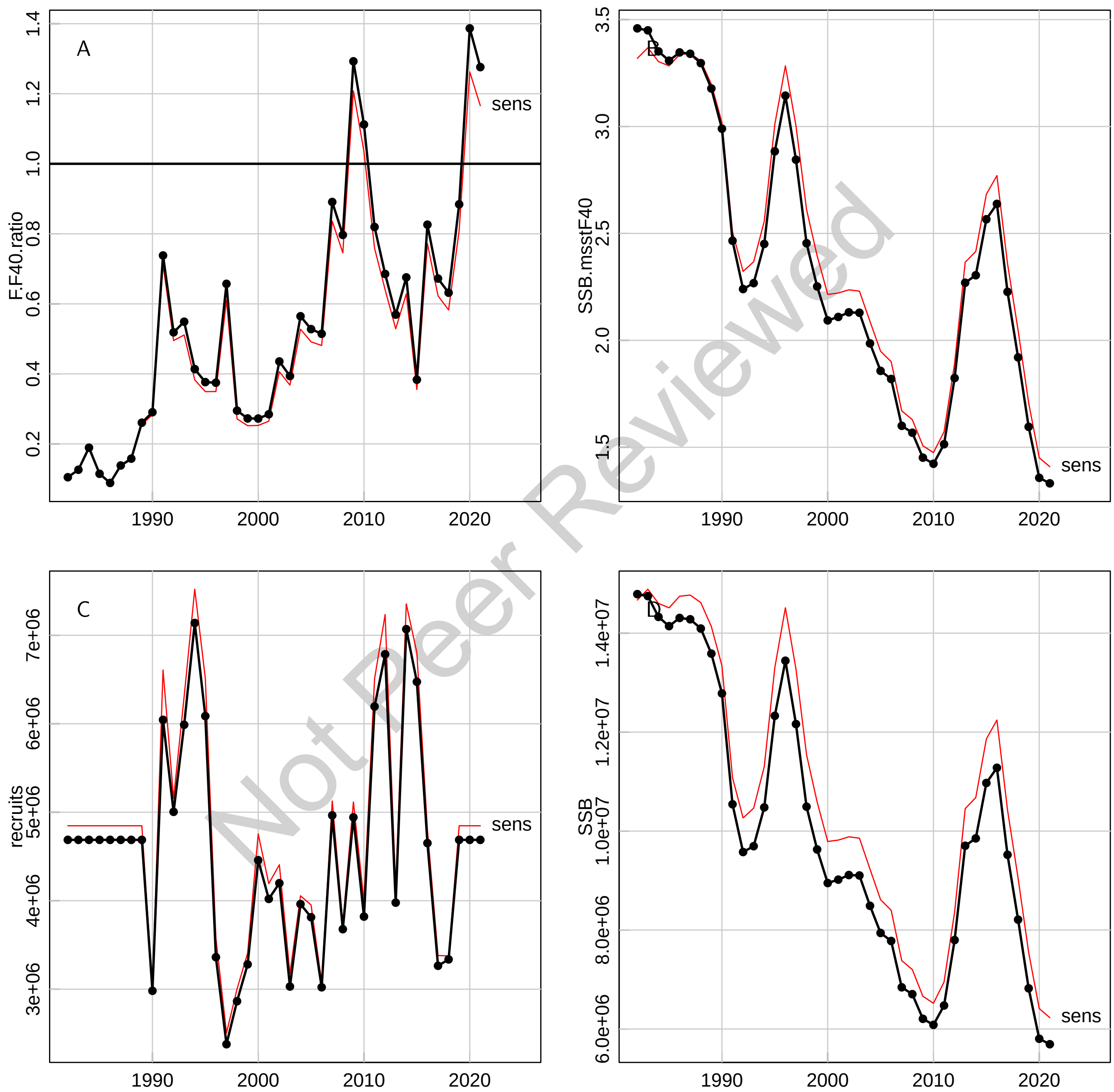


*Figure 57. Sensitivity to weight on SERFS trap/video index (S16-S17). Estimated time series of F and SSB relative to benchmarks ($F_{40\%}$ and $MSST$), as well as number of age-1 recruits and stock size (*SSB*; million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B)* SSB/MSST*, (C) number of recruits, and (D)* SSB*.*

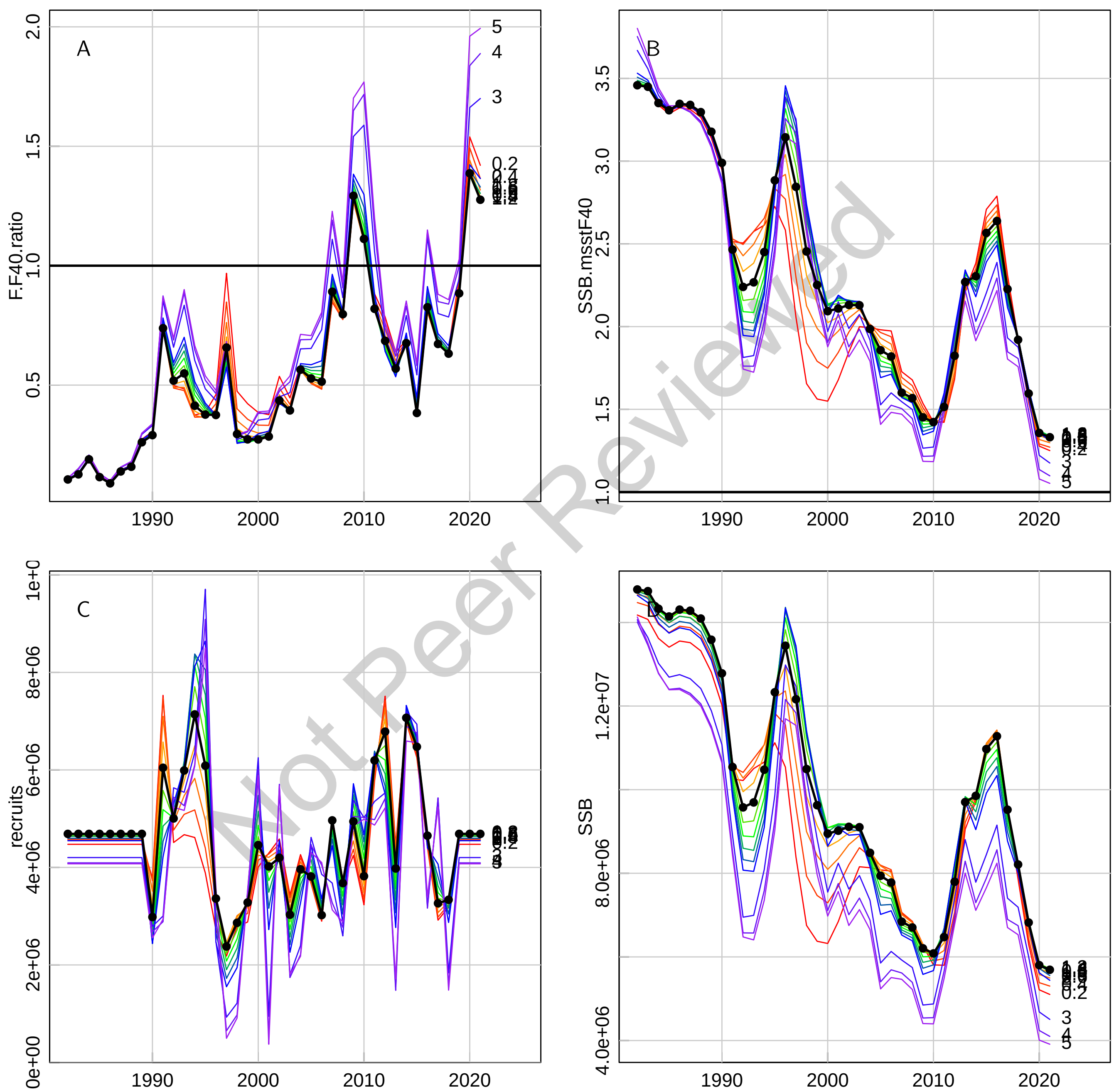


*Figure 58. Sensitivity to weight on SERFS trap/video age comps (S18-S19). Estimated time series of F and SSB relative to benchmarks ($F_{40\%}$ and MSST), as well as number of age-1 recruits and stock size (SSB; million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B) SSB/MSST, (C) number of recruits, and (D) SSB.*

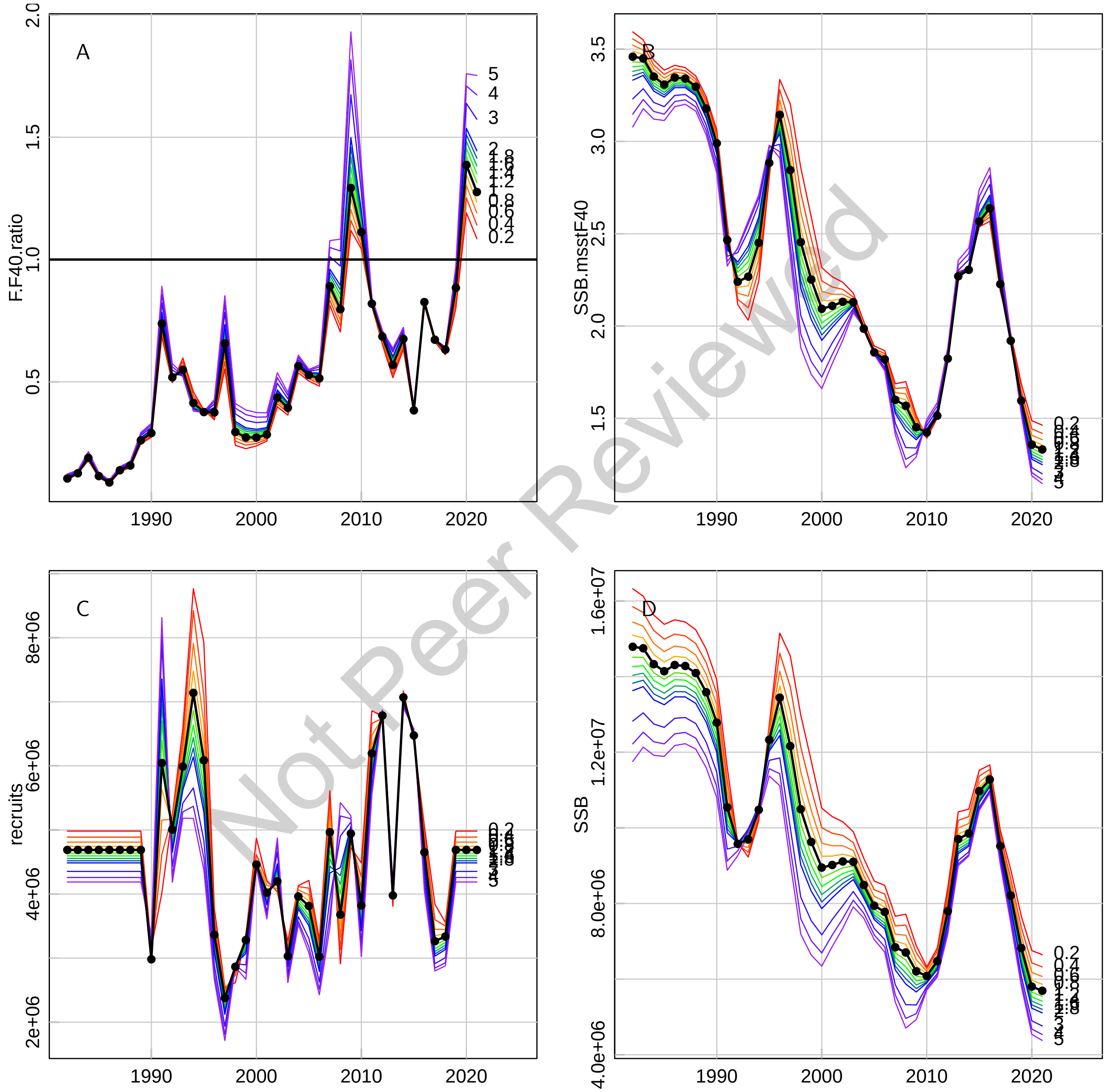


*Figure 59. Sensitivity to weight on all age comps (S20-S21). Estimated time series of $F$ and $SSB$ relative to benchmarks ($F_{40\%}$ and $MSST$), as well as number of age-1 recruits and stock size (SSB; million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B)* SSB/MSST*, (C) number of recruits, and (D)* SSB.

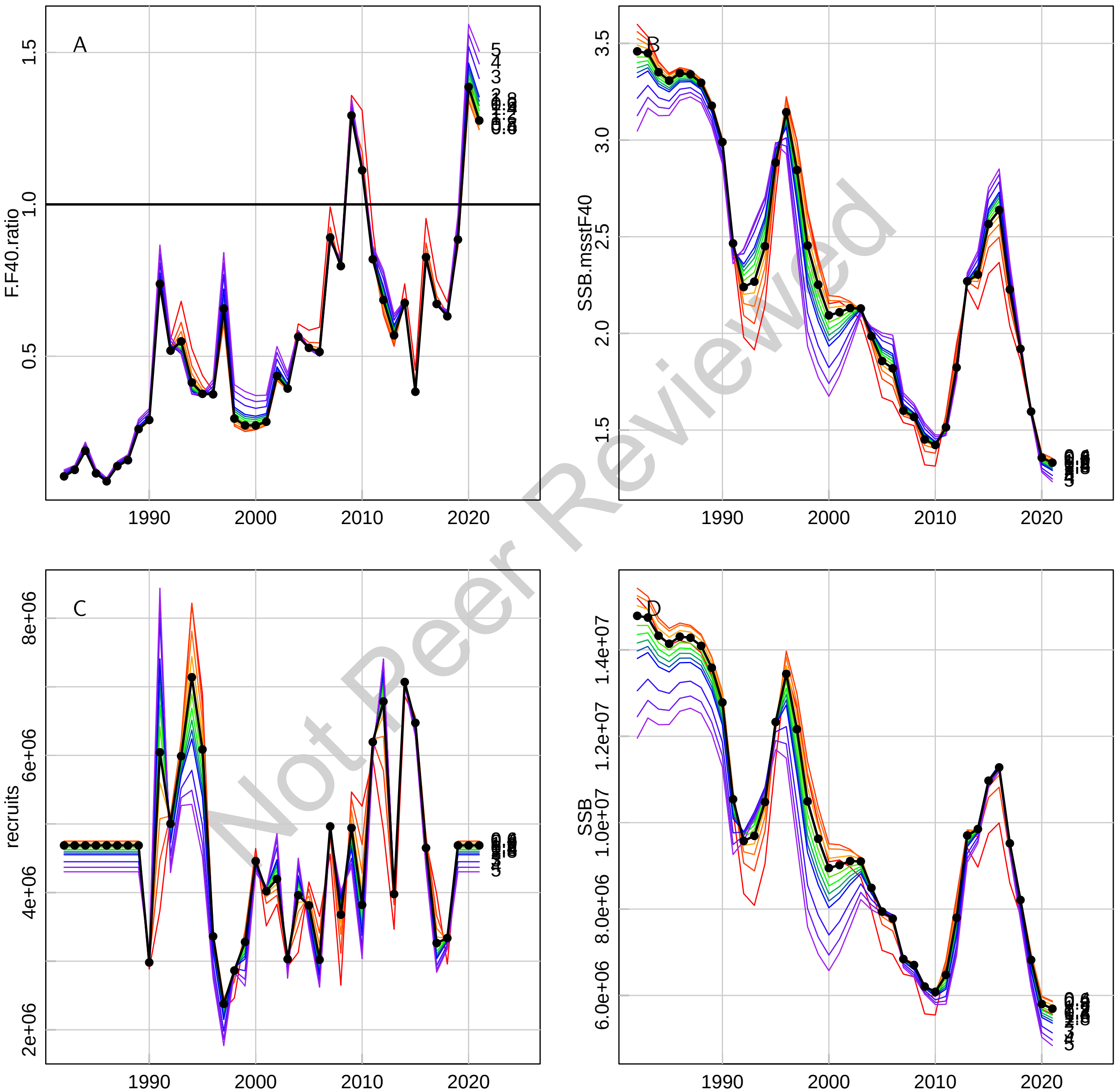


*Figure 60. Sensitivity to weight on all length comps (S22-S23). Estimated time series of F and SSB relative to benchmarks ($F_{40\%}$ and $MSST$), as well as number of age-1 recruits and stock size (*SSB*; million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B)* SSB/MSST*, (C) number of recruits, and (D)* SSB*.*

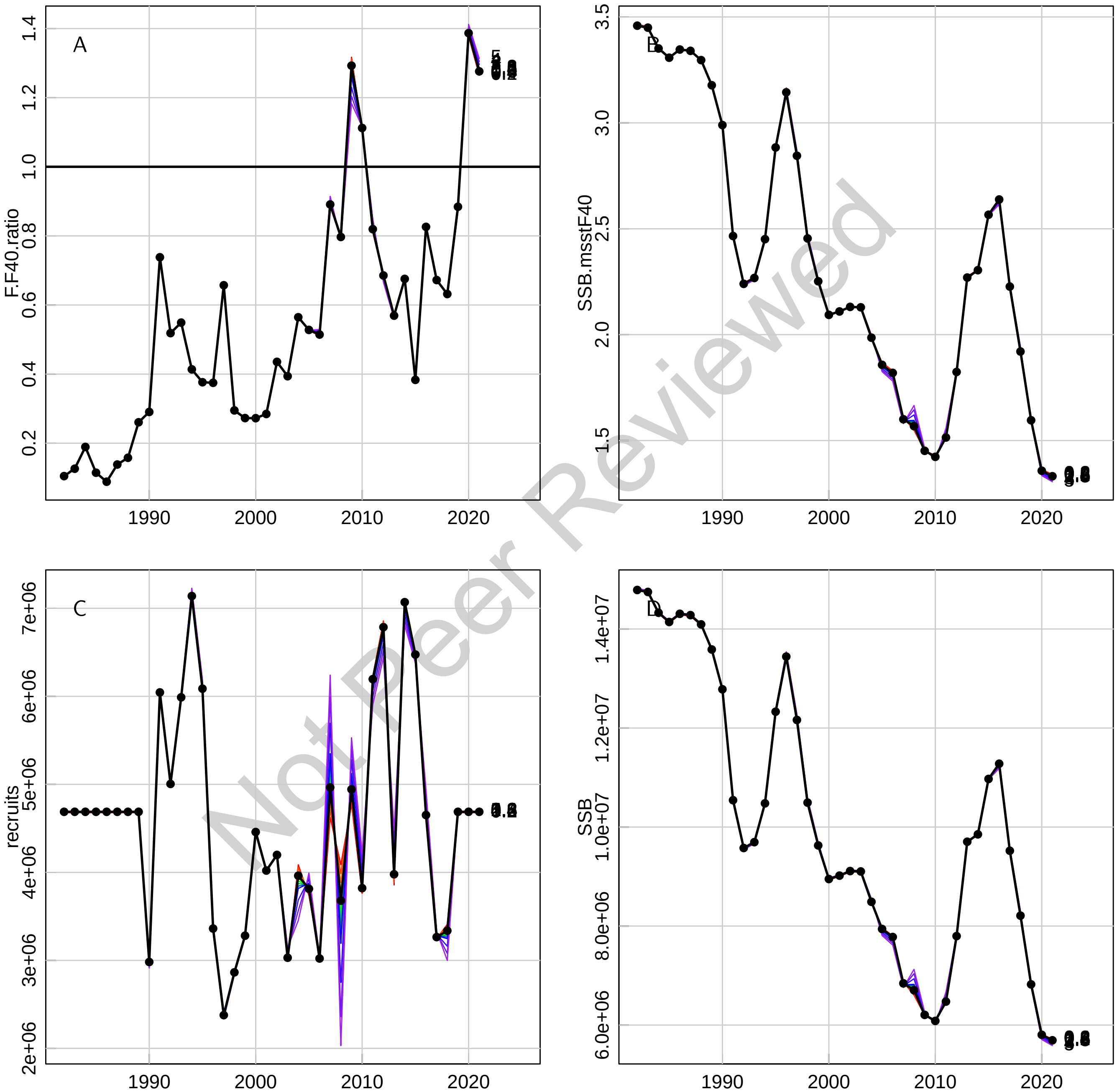


*Figure 61. Observed (open circles) and estimated (line, solid circles) SERFS trap/video index for the Age-Structured Production Model (ASPM). In the upper panel, error bars indicate ±2 standard errors of the observed index ($U_{ob}$). In the lower panel are the log residuals of the fit to the index and the color of the box indicates the p-value of the runs test (green $> 0.05$, orange $\leq 0.05$ and $> 0.01$, red $< 0.01$) and the width of the box is 3 times the standard error. Points that fall outside 3 standard errors are plotted in red..*

*Figure 62. Sensitivity to age structure (age structured production model) (aspm). Estimated time series of F and SSB relative to benchmarks ($F_{40\%}$ and $MSST$), as well as number of age-1 recruits and stock size (*SSB*; million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Sensitivity runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B)* SSB/MSST*, (C) number of recruits, and (D)* SSB.

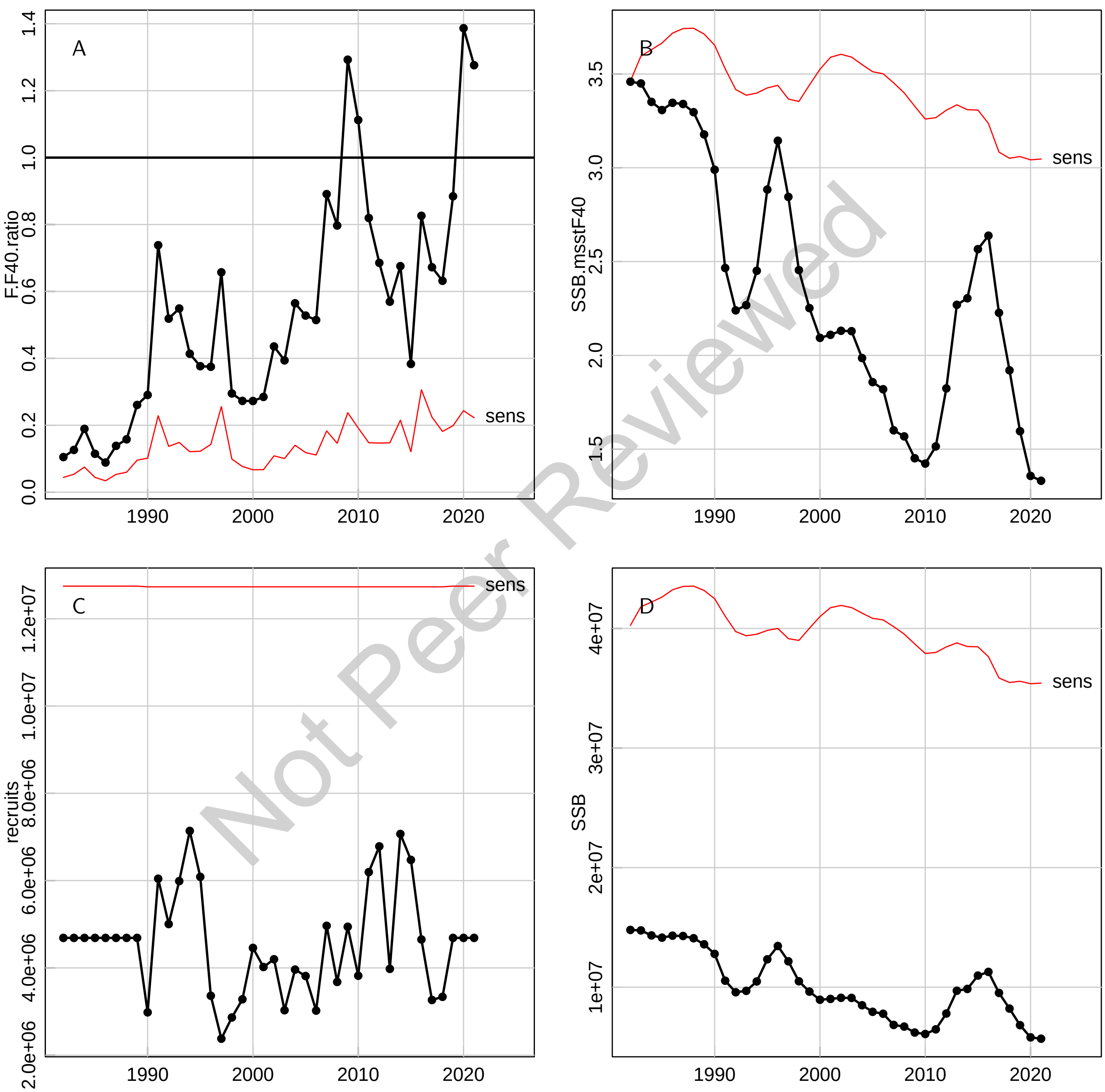


*Figure 63. Retrospective analysis (retro). Estimated time series of F and SSB relative to benchmarks ($F_{40\%}$ and MSST), as well as number of age-1 recruits and stock size* (SSB; *million eggs). Solid black line and solid circles indicate estimates from the BAM base run. Retrospective runs are indicated by colored lines, represented in the legend. Values to the right of each time series indicate which is the sensitivity (sens) run, or indicate a fixed numeric value that was varied in that run. (A) $F/F_{40\%}$, (B)* SSB/MSST, *(C) number of recruits, and (D)* SSB.

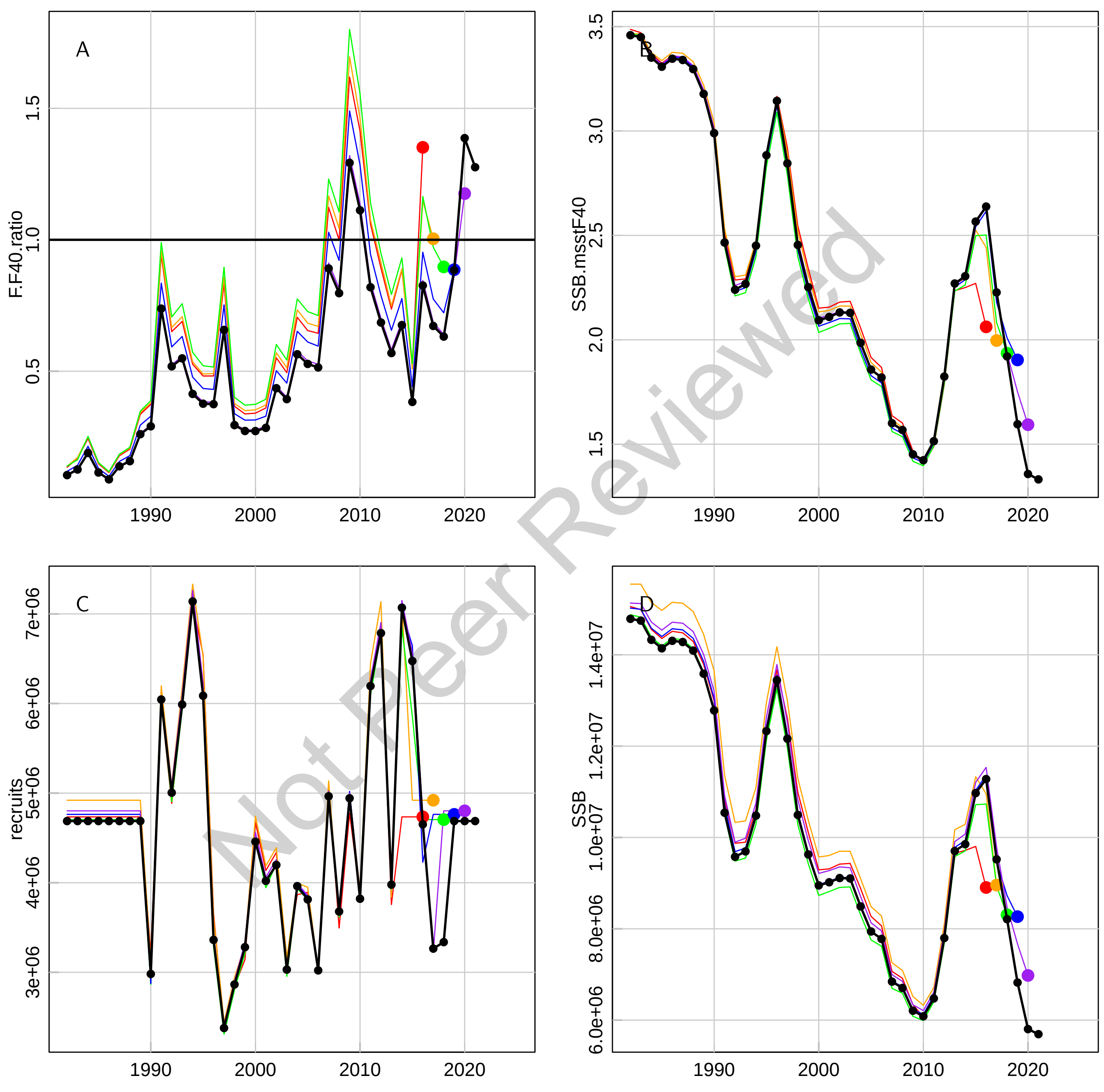


*Figure 64. Plots of (A) $F$, (B) SSB, and (C) recruitment for base years (black lines with gray shading) and projection years (blue lines with light blue shading) with fishing mortality rate at $F_{40\%}$. Expected values associated with the base run (solid time series lines) and medians of stochastic runs (dashed time series lines) are plotted. Shaded bands to $5^{th}$ and $95^{th}$ percentiles of stochastic runs. Solid horizontal green lines mark $F_{40\%}$-related benchmarks; dashed horizontal pink lines represent medians of stochastic runs. The terminal year of the assessment (2021) is indicated by a vertical black line.*

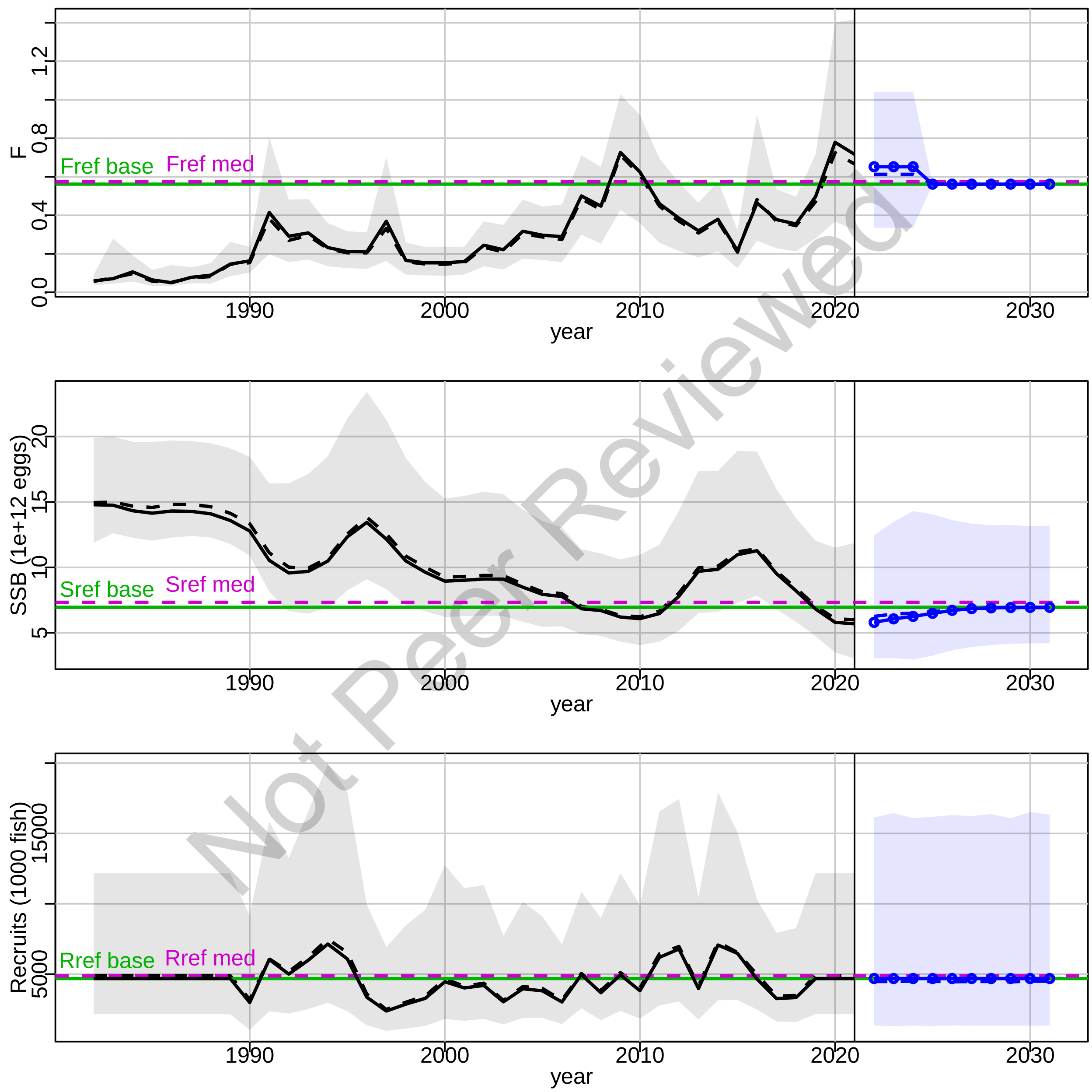


*Figure 65. Plots of (A) landings, (B) discards, and (C) indices for base years (black lines with gray shading) and projection years (blue lines with light blue shading) with fishing mortality rate at $F_{40\%}$. Expected values associated with the base run (solid time series lines) and medians of stochastic runs (dashed time series lines) are plotted. Shaded bands to $5^{th}$ and $95^{th}$ percentiles of stochastic runs. Solid horizontal green lines mark $F_{40\%}$-related benchmarks; dashed horizontal pink lines represent medians of stochastic runs. The terminal year of the assessment (2021) is indicated by a vertical black line.*

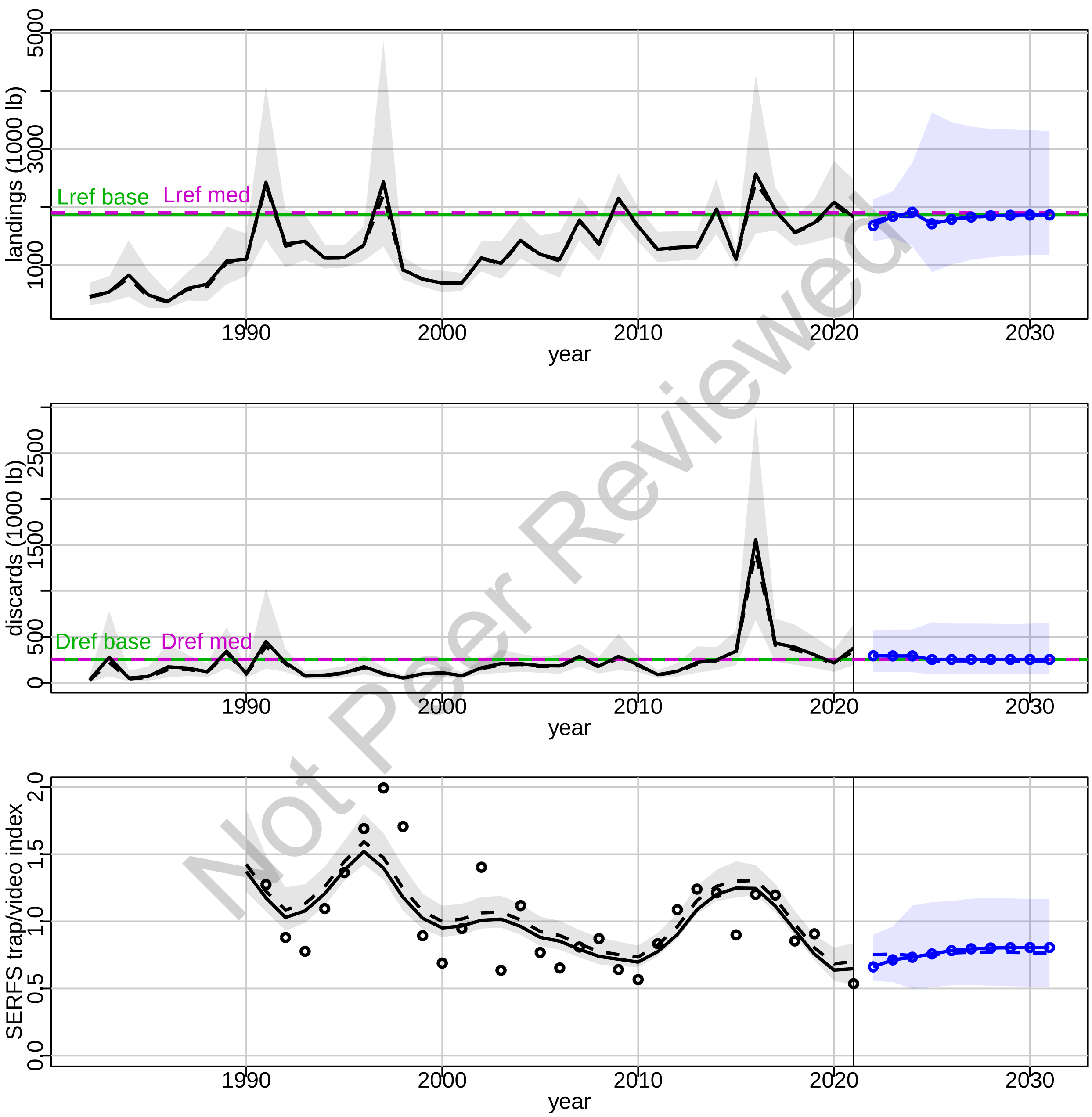


*Figure 66. Plots of probability that* SSB $> MSST$ *for base and projection years (solid line and open circles with fishing mortality rate at* $F_{40\%}$*. The terminal year of the assessment (*2021*) is indicated by a vertical black line. Expected values associated with the base run (solid time series lines) and medians of stochastic runs (dashed time series lines) are plotted. Probabilities 0.5 and 0.7 are indicated by horizontal black lines.*

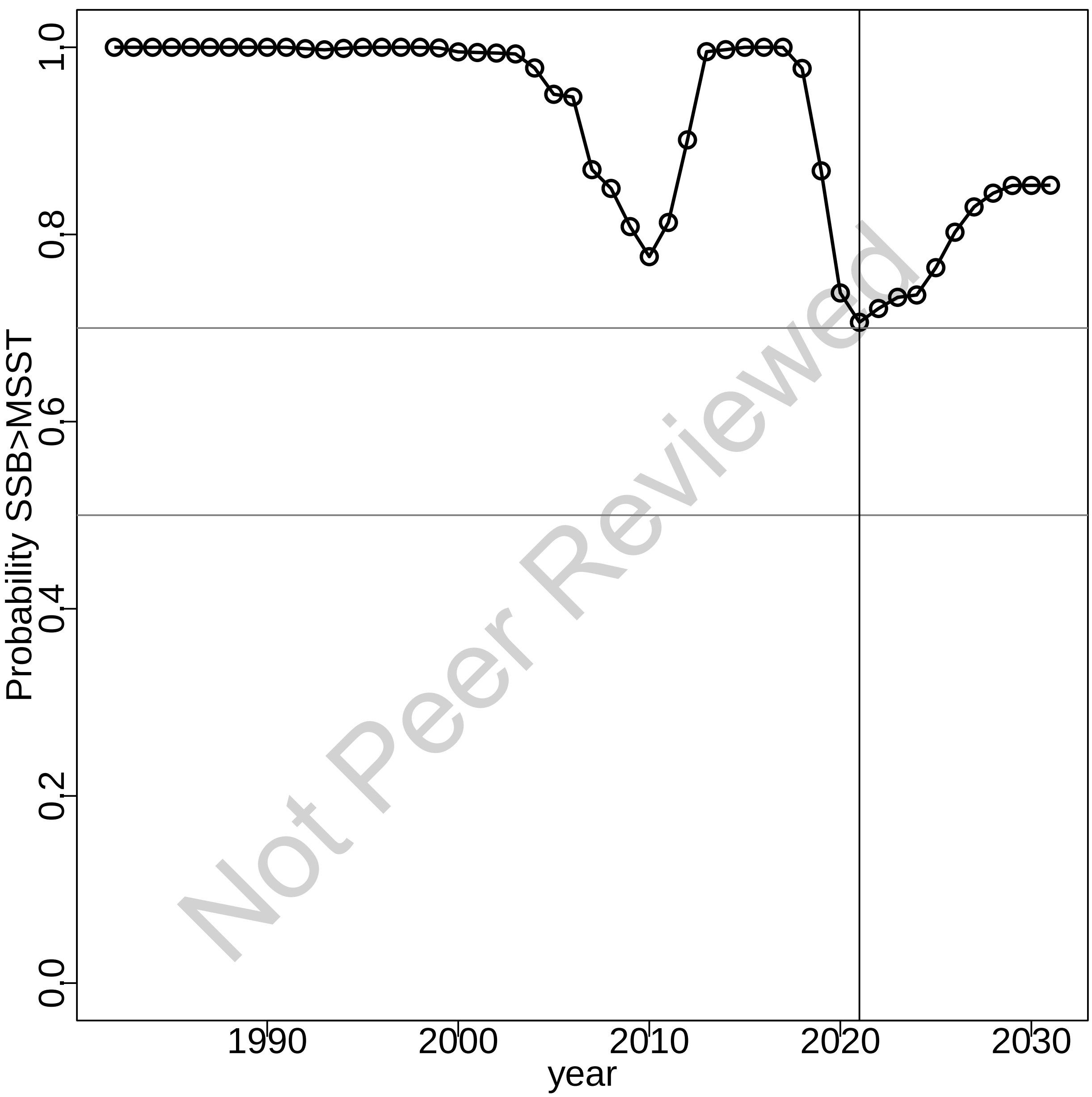


*Figure 67. Plots of (A) $F$, (B) SSB, and (C) recruitment for base years (black lines with gray shading) and projection years (blue lines with light blue shading) with fishing mortality rate at 75%$F_{40\%}$. Expected values associated with the base run (solid time series lines) and medians of stochastic runs (dashed time series lines) are plotted. Shaded bands to $5^{th}$ and $95^{th}$ percentiles of stochastic runs. Solid horizontal green lines mark $F_{40\%}$-related benchmarks; dashed horizontal pink lines represent medians of stochastic runs. The terminal year of the assessment (2021) is indicated by a vertical black line.*

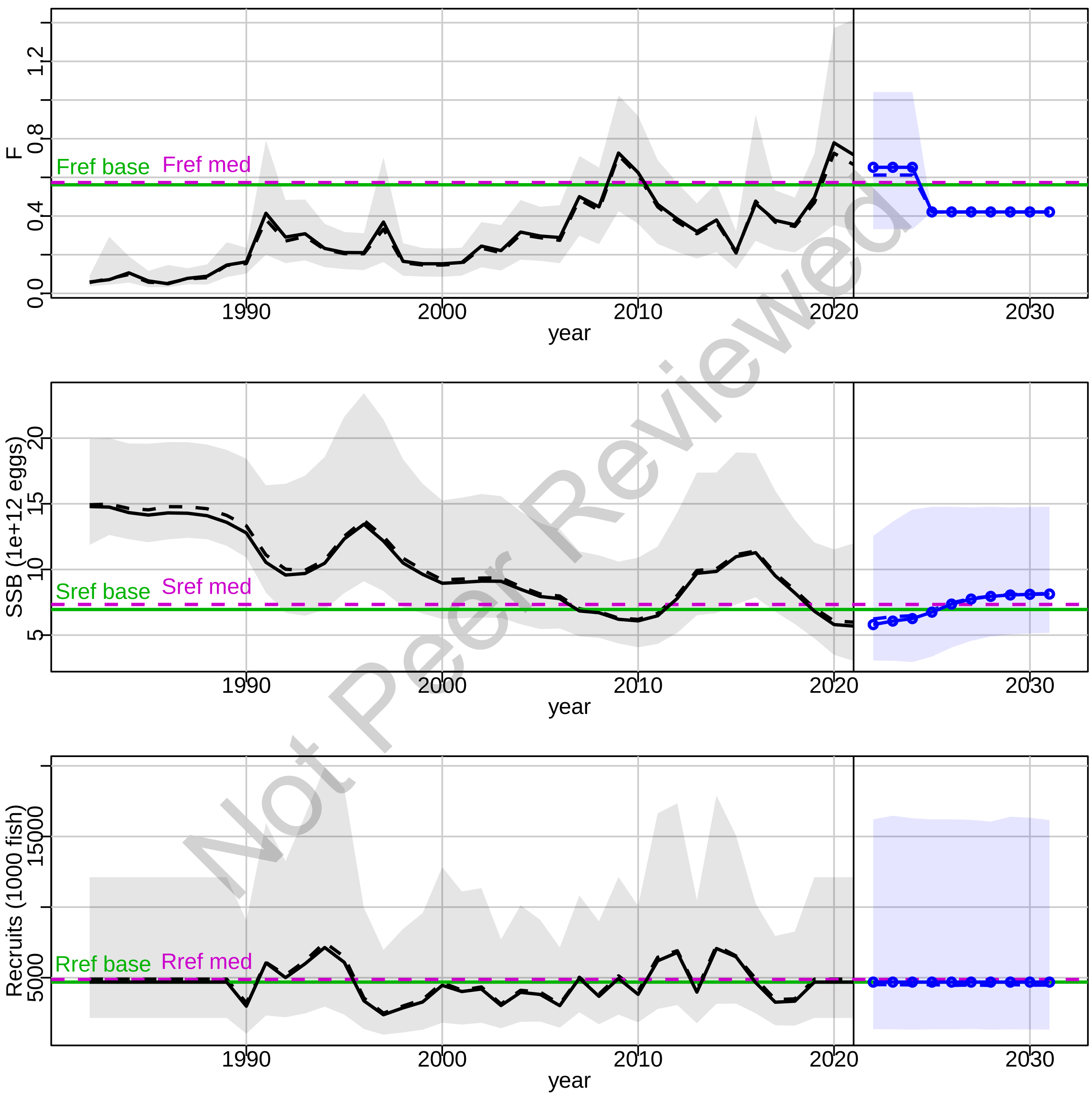


*Figure 68. Plots of (A) landings, (B) discards, and (C) indices for base years (black lines with gray shading) and projection years (blue lines with light blue shading) with fishing mortality rate at* $75\%F_{40\%}$. *Expected values associated with the base run (solid time series lines) and medians of stochastic runs (dashed time series lines) are plotted. Shaded bands to* $5^{th}$ *and* $95^{th}$ *percentiles of stochastic runs. Solid horizontal green lines mark* $F_{40\%}$*-related benchmarks; dashed horizontal pink lines represent medians of stochastic runs. The terminal year of the assessment (2021) is indicated by a vertical black line.*

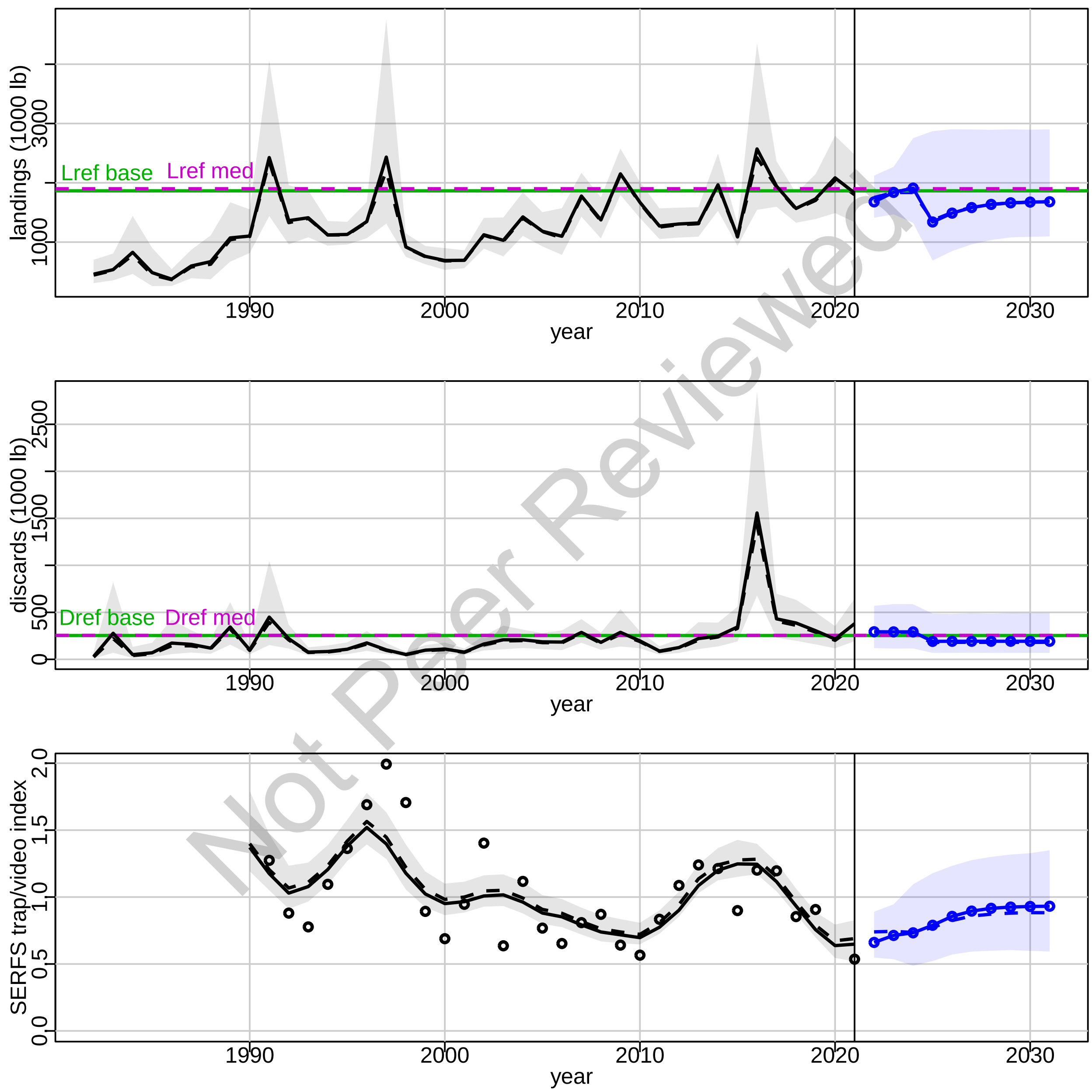
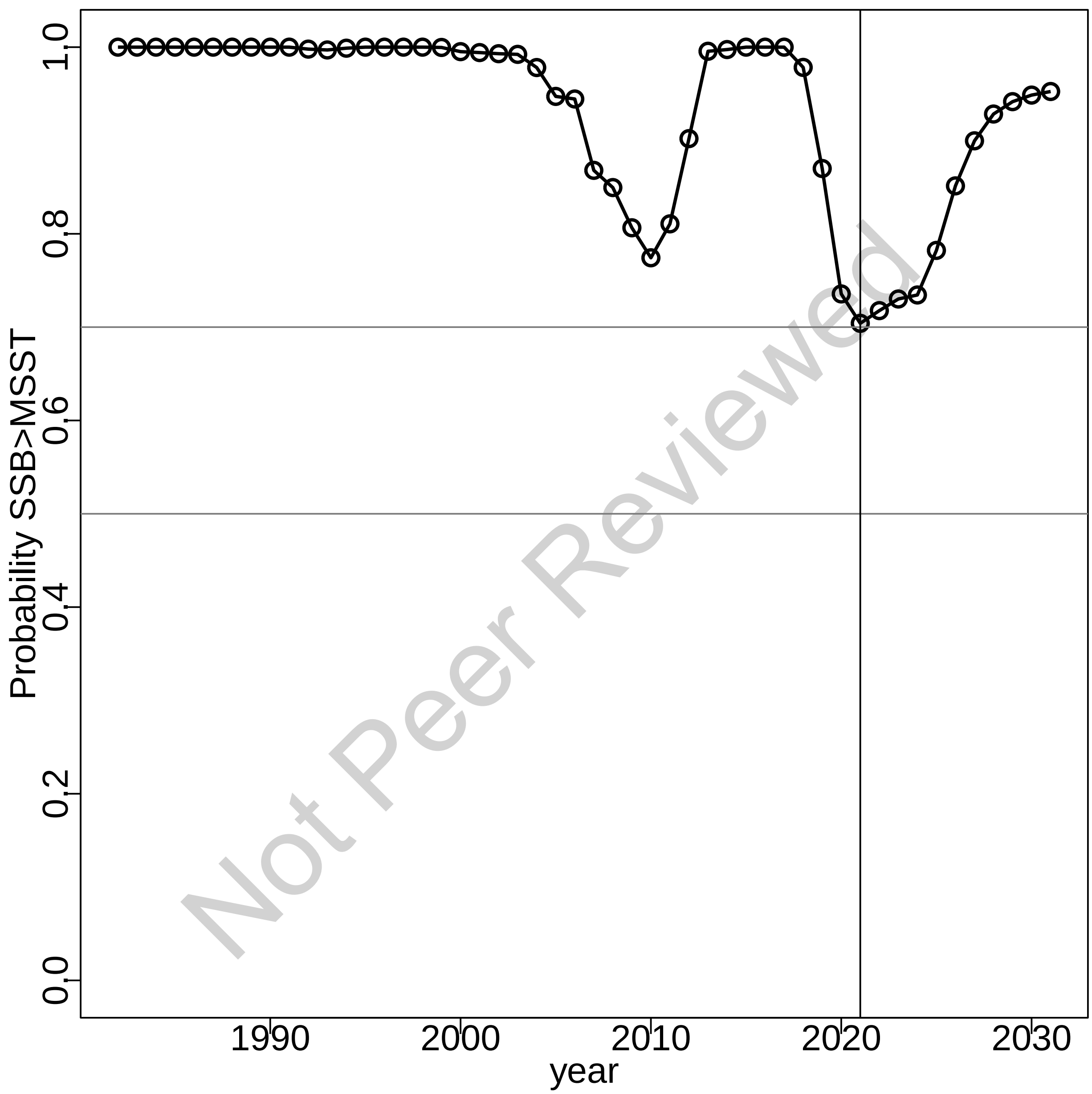


*Figure 69. Plots of probability that* SSB $> MSST$ *for base and projection years (solid line and open circles with fishing mortality rate at* $75\%F_{40\%}$*. The terminal year of the assessment (*2021*) is indicated by a vertical black line. Expected values associated with the base run (solid time series lines) and medians of stochastic runs (dashed time series lines) are plotted. Probabilities 0.5 and 0.7 are indicated by horizontal black lines.*



## Appendix A Parameter estimates from the Beaufort Assessment Model

*Table 26. Names and estimated values of parameters estimated in the base run of the Beaufort Assessment Model.*

| ID | Parameter | Value |
|---|---|---|
| 1 | log.R0 | 15.2760000 |
| 2 | rec.sigma | 0.4118900 |
| 3 | log.dev.rec.1990 | −0.3676200 |
| 4 | log.dev.rec.1991 | 0.3389500 |
| 5 | log.dev.rec.1992 | 0.1502200 |
| 6 | log.dev.rec.1993 | 0.3296700 |
| 7 | log.dev.rec.1994 | 0.5053700 |
| 8 | log.dev.rec.1995 | 0.3459500 |
| 9 | log.dev.rec.1996 | −0.2476600 |
| 10 | log.dev.rec.1997 | −0.5938600 |
| 11 | log.dev.rec.1998 | −0.4078800 |
| 12 | log.dev.rec.1999 | −0.2721300 |
| 13 | log.dev.rec.2000 | 0.0345940 |
| 14 | log.dev.rec.2001 | −0.0687340 |
| 15 | log.dev.rec.2002 | −0.0254930 |
| 16 | log.dev.rec.2003 | −0.3515300 |
| 17 | log.dev.rec.2004 | −0.0834210 |
| 18 | log.dev.rec.2005 | −0.1216200 |
| 19 | log.dev.rec.2006 | −0.3544100 |
| 20 | log.dev.rec.2007 | 0.1421800 |
| 21 | log.dev.rec.2008 | −0.1576600 |
| 22 | log.dev.rec.2009 | 0.1377700 |
| 23 | log.dev.rec.2010 | −0.1196900 |
| 24 | log.dev.rec.2011 | 0.3635500 |
| 25 | log.dev.rec.2012 | 0.4546300 |
| 26 | log.dev.rec.2013 | −0.0793260 |
| 27 | log.dev.rec.2014 | 0.4955600 |
| 28 | log.dev.rec.2015 | 0.4077100 |
| 29 | log.dev.rec.2016 | 0.0769750 |
| 30 | log.dev.rec.2017 | −0.2770100 |
| 31 | log.dev.rec.2018 | −0.2550900 |
| 32 | log.dm.lenc.rHDs | −1.4050000 |
| 33 | log.dm.agec.cHLsa | −1.5572000 |
| 34 | log.dm.agec.cHLsb | 0.3513500 |
| 35 | log.dm.agec.rHBsa | −0.9629300 |
| 36 | log.dm.agec.rHBsb | −0.0911840 |
| 37 | log.dm.agec.sTVsa | −1.3479000 |
| 38 | log.dm.agec.sTVsb | 1.4386000 |
| 39 | selpar.01b01.cHLs | 3.4799000 |
| 40 | selpar.02b01.cHLs | 2.5275000 |

*Table 26.* (continued)

| ID | Parameter | Value |
|---|---|---|
| 41 | selpar.01b01.sTVs | 2.9530000 |
| 42 | selpar.02b01.sTVs | 1.9090000 |
| 43 | selpar.01b01.rHBs | 2.9255000 |
| 44 | selpar.02b01.rHBs | 2.6975000 |
| 45 | selpar.04b01.rHDs | 0.9360000 |
| 46 | log.q.cpue.sTVs | −14.3830000 |
| 47 | log.avg.F.L.cHLs | −2.8340000 |
| 48 | log.dev.F.L.cHLs.1982 | −1.4001000 |
| 49 | log.dev.F.L.cHLs.1983 | −1.7441000 |
| 50 | log.dev.F.L.cHLs.1984 | −1.6436000 |
| 51 | log.dev.F.L.cHLs.1985 | −1.6949000 |
| 52 | log.dev.F.L.cHLs.1986 | −1.6972000 |
| 53 | log.dev.F.L.cHLs.1987 | −1.6304000 |
| 54 | log.dev.F.L.cHLs.1988 | −1.5255000 |
| 55 | log.dev.F.L.cHLs.1989 | −1.2967000 |
| 56 | log.dev.F.L.cHLs.1990 | −0.5515000 |
| 57 | log.dev.F.L.cHLs.1991 | −0.0413440 |
| 58 | log.dev.F.L.cHLs.1992 | 0.1389800 |
| 59 | log.dev.F.L.cHLs.1993 | 0.4344700 |
| 60 | log.dev.F.L.cHLs.1994 | 0.4728800 |
| 61 | log.dev.F.L.cHLs.1995 | 0.5822700 |
| 62 | log.dev.F.L.cHLs.1996 | 0.3467400 |
| 63 | log.dev.F.L.cHLs.1997 | 0.5473900 |
| 64 | log.dev.F.L.cHLs.1998 | 0.3306900 |
| 65 | log.dev.F.L.cHLs.1999 | 0.0345980 |
| 66 | log.dev.F.L.cHLs.2000 | −0.1629100 |
| 67 | log.dev.F.L.cHLs.2001 | −0.0089538 |
| 68 | log.dev.F.L.cHLs.2002 | −0.1113800 |
| 69 | log.dev.F.L.cHLs.2003 | −0.1829400 |
| 70 | log.dev.F.L.cHLs.2004 | 0.1326000 |
| 71 | log.dev.F.L.cHLs.2005 | 0.3154700 |
| 72 | log.dev.F.L.cHLs.2006 | 0.2813600 |
| 73 | log.dev.F.L.cHLs.2007 | 0.6502300 |
| 74 | log.dev.F.L.cHLs.2008 | 0.8021500 |
| 75 | log.dev.F.L.cHLs.2009 | 1.0341000 |
| 76 | log.dev.F.L.cHLs.2010 | 1.3033000 |
| 77 | log.dev.F.L.cHLs.2011 | 1.3227000 |
| 78 | log.dev.F.L.cHLs.2012 | 0.6185100 |
| 79 | log.dev.F.L.cHLs.2013 | 0.5680600 |
| 80 | log.dev.F.L.cHLs.2014 | 0.2133400 |

*Table 26.* (continued)

| ID | Parameter | Value |
|---|---|---|
| 81 | log.dev.F.L.cHLs.2015 | 0.3233400 |
| 82 | log.dev.F.L.cHLs.2016 | 0.2366000 |
| 83 | log.dev.F.L.cHLs.2017 | 0.3091800 |
| 84 | log.dev.F.L.cHLs.2018 | 0.3656300 |
| 85 | log.dev.F.L.cHLs.2019 | 0.6394600 |
| 86 | log.dev.F.L.cHLs.2020 | 0.9524200 |
| 87 | log.dev.F.L.cHLs.2021 | 0.7351800 |
| 88 | log.avg.F.L.cHLn | −6.6874000 |
| 89 | log.dev.F.L.cHLn.1982 | −4.4104000 |
| 90 | log.dev.F.L.cHLn.1983 | −2.2199000 |
| 91 | log.dev.F.L.cHLn.1984 | −2.2847000 |
| 92 | log.dev.F.L.cHLn.1985 | −2.3603000 |
| 93 | log.dev.F.L.cHLn.1986 | −2.4757000 |
| 94 | log.dev.F.L.cHLn.1987 | −2.6051000 |
| 95 | log.dev.F.L.cHLn.1988 | −2.7298000 |
| 96 | log.dev.F.L.cHLn.1989 | −2.8473000 |
| 97 | log.dev.F.L.cHLn.1990 | −2.9742000 |
| 98 | log.dev.F.L.cHLn.1991 | −1.5771000 |
| 99 | log.dev.F.L.cHLn.1992 | −1.6913000 |
| 100 | log.dev.F.L.cHLn.1993 | 0.0033891 |
| 101 | log.dev.F.L.cHLn.1994 | 1.2948000 |
| 102 | log.dev.F.L.cHLn.1995 | 1.2656000 |
| 103 | log.dev.F.L.cHLn.1996 | 0.9451400 |
| 104 | log.dev.F.L.cHLn.1997 | 0.8118200 |
| 105 | log.dev.F.L.cHLn.1998 | 0.3190500 |
| 106 | log.dev.F.L.cHLn.1999 | 0.5885900 |
| 107 | log.dev.F.L.cHLn.2000 | 0.0534340 |
| 108 | log.dev.F.L.cHLn.2001 | 0.1123100 |
| 109 | log.dev.F.L.cHLn.2002 | 1.2104000 |
| 110 | log.dev.F.L.cHLn.2003 | 0.8973000 |
| 111 | log.dev.F.L.cHLn.2004 | 0.6778000 |
| 112 | log.dev.F.L.cHLn.2005 | 0.3525500 |
| 113 | log.dev.F.L.cHLn.2006 | 0.2808200 |
| 114 | log.dev.F.L.cHLn.2007 | 1.1100000 |
| 115 | log.dev.F.L.cHLn.2008 | 0.6355000 |
| 116 | log.dev.F.L.cHLn.2009 | 1.7821000 |
| 117 | log.dev.F.L.cHLn.2010 | 1.5058000 |
| 118 | log.dev.F.L.cHLn.2011 | 1.8675000 |
| 119 | log.dev.F.L.cHLn.2012 | 2.3717000 |
| 120 | log.dev.F.L.cHLn.2013 | 1.9090000 |

*Table 26.* (continued)

| ID | Parameter | Value |
|---|---|---|
| 121 | log.dev.F.L.cHLn.2014 | 0.8089100 |
| 122 | log.dev.F.L.cHLn.2015 | −0.0225270 |
| 123 | log.dev.F.L.cHLn.2016 | 0.3914100 |
| 124 | log.dev.F.L.cHLn.2017 | 1.6561000 |
| 125 | log.dev.F.L.cHLn.2018 | 1.4493000 |
| 126 | log.dev.F.L.cHLn.2019 | 1.2814000 |
| 127 | log.dev.F.L.cHLn.2020 | 1.1752000 |
| 128 | log.dev.F.L.cHLn.2021 | 1.4413000 |
| 129 | log.avg.F.L.rHBs | −3.6175000 |
| 130 | log.dev.F.L.rHBs.1982 | −0.9103200 |
| 131 | log.dev.F.L.rHBs.1983 | −0.9385000 |
| 132 | log.dev.F.L.rHBs.1984 | −0.9754400 |
| 133 | log.dev.F.L.rHBs.1985 | −0.6745700 |
| 134 | log.dev.F.L.rHBs.1986 | −0.9150300 |
| 135 | log.dev.F.L.rHBs.1987 | −0.8781100 |
| 136 | log.dev.F.L.rHBs.1988 | −0.6950100 |
| 137 | log.dev.F.L.rHBs.1989 | −0.5899500 |
| 138 | log.dev.F.L.rHBs.1990 | 0.1182000 |
| 139 | log.dev.F.L.rHBs.1991 | 0.4468700 |
| 140 | log.dev.F.L.rHBs.1992 | 0.7030400 |
| 141 | log.dev.F.L.rHBs.1993 | 0.8004600 |
| 142 | log.dev.F.L.rHBs.1994 | 0.5259900 |
| 143 | log.dev.F.L.rHBs.1995 | 0.4157400 |
| 144 | log.dev.F.L.rHBs.1996 | 0.2424200 |
| 145 | log.dev.F.L.rHBs.1997 | 0.4543900 |
| 146 | log.dev.F.L.rHBs.1998 | 0.1613100 |
| 147 | log.dev.F.L.rHBs.1999 | −0.2400500 |
| 148 | log.dev.F.L.rHBs.2000 | −0.2317700 |
| 149 | log.dev.F.L.rHBs.2001 | −0.2695300 |
| 150 | log.dev.F.L.rHBs.2002 | 0.2282000 |
| 151 | log.dev.F.L.rHBs.2003 | −0.0226600 |
| 152 | log.dev.F.L.rHBs.2004 | 0.5554000 |
| 153 | log.dev.F.L.rHBs.2005 | 0.4641800 |
| 154 | log.dev.F.L.rHBs.2006 | 0.1045000 |
| 155 | log.dev.F.L.rHBs.2007 | 0.6042800 |
| 156 | log.dev.F.L.rHBs.2008 | 0.3196000 |
| 157 | log.dev.F.L.rHBs.2009 | 0.6182000 |
| 158 | log.dev.F.L.rHBs.2010 | 0.8053400 |
| 159 | log.dev.F.L.rHBs.2011 | 0.4451200 |
| 160 | log.dev.F.L.rHBs.2012 | 0.2454800 |

*Table 26.* (continued)

| ID | Parameter | Value |
|---|---|---|
| 161 | log.dev.F.L.rHBs.2013 | 0.1600300 |
| 162 | log.dev.F.L.rHBs.2014 | −0.0419950 |
| 163 | log.dev.F.L.rHBs.2015 | −0.1828700 |
| 164 | log.dev.F.L.rHBs.2016 | −0.4135500 |
| 165 | log.dev.F.L.rHBs.2017 | −0.2037200 |
| 166 | log.dev.F.L.rHBs.2018 | −0.2243700 |
| 167 | log.dev.F.L.rHBs.2019 | 0.0407850 |
| 168 | log.dev.F.L.rHBs.2020 | 0.0183480 |
| 169 | log.dev.F.L.rHBs.2021 | −0.0704270 |
| 170 | log.avg.F.L.rGNs | −2.2503000 |
| 171 | log.dev.F.L.rGNs.1982 | −1.1492000 |
| 172 | log.dev.F.L.rGNs.1983 | −1.3291000 |
| 173 | log.dev.F.L.rGNs.1984 | −0.2322500 |
| 174 | log.dev.F.L.rGNs.1985 | −1.0295000 |
| 175 | log.dev.F.L.rGNs.1986 | −1.6830000 |
| 176 | log.dev.F.L.rGNs.1987 | −1.3103000 |
| 177 | log.dev.F.L.rGNs.1988 | −0.5346500 |
| 178 | log.dev.F.L.rGNs.1989 | −0.1425000 |
| 179 | log.dev.F.L.rGNs.1990 | −0.3023200 |
| 180 | log.dev.F.L.rGNs.1991 | 1.0019000 |
| 181 | log.dev.F.L.rGNs.1992 | 0.3897800 |
| 182 | log.dev.F.L.rGNs.1993 | 0.1334100 |
| 183 | log.dev.F.L.rGNs.1994 | −0.5739800 |
| 184 | log.dev.F.L.rGNs.1995 | −1.1222000 |
| 185 | log.dev.F.L.rGNs.1996 | −0.8527800 |
| 186 | log.dev.F.L.rGNs.1997 | −0.8431500 |
| 187 | log.dev.F.L.rGNs.1998 | −1.0199000 |
| 188 | log.dev.F.L.rGNs.1999 | −0.4366700 |
| 189 | log.dev.F.L.rGNs.2000 | −0.5266700 |
| 190 | log.dev.F.L.rGNs.2001 | −0.5896300 |
| 191 | log.dev.F.L.rGNs.2002 | 0.0621310 |
| 192 | log.dev.F.L.rGNs.2003 | 0.1699000 |
| 193 | log.dev.F.L.rGNs.2004 | 0.1416000 |
| 194 | log.dev.F.L.rGNs.2005 | −0.0856190 |
| 195 | log.dev.F.L.rGNs.2006 | 0.5059700 |
| 196 | log.dev.F.L.rGNs.2007 | 1.0007000 |
| 197 | log.dev.F.L.rGNs.2008 | 0.9241400 |
| 198 | log.dev.F.L.rGNs.2009 | 1.2390000 |
| 199 | log.dev.F.L.rGNs.2010 | 0.9646100 |
| 200 | log.dev.F.L.rGNs.2011 | 0.4670000 |

*Table 26.* (continued)

| ID | Parameter | Value |
|---|---|---|
| 201 | log.dev.F.L.rGNs.2012 | 0.2569800 |
| 202 | log.dev.F.L.rGNs.2013 | 0.3448300 |
| 203 | log.dev.F.L.rGNs.2014 | 0.6400700 |
| 204 | log.dev.F.L.rGNs.2015 | −0.1362400 |
| 205 | log.dev.F.L.rGNs.2016 | 1.1558000 |
| 206 | log.dev.F.L.rGNs.2017 | 0.6924000 |
| 207 | log.dev.F.L.rGNs.2018 | 0.3749700 |
| 208 | log.dev.F.L.rGNs.2019 | 0.8124700 |
| 209 | log.dev.F.L.rGNs.2020 | 1.1815000 |
| 210 | log.dev.F.L.rGNs.2021 | 1.4406000 |
| 211 | log.avg.F.L.rGNn | −3.7878000 |
| 212 | log.dev.F.L.rGNn.1982 | −4.8038000 |
| 213 | log.dev.F.L.rGNn.1983 | −0.1818600 |
| 214 | log.dev.F.L.rGNn.1984 | −2.9755000 |
| 215 | log.dev.F.L.rGNn.1985 | −2.3319000 |
| 216 | log.dev.F.L.rGNn.1986 | −0.9727200 |
| 217 | log.dev.F.L.rGNn.1987 | 0.1591900 |
| 218 | log.dev.F.L.rGNn.1988 | −3.4642000 |
| 219 | log.dev.F.L.rGNn.1989 | 0.0568550 |
| 220 | log.dev.F.L.rGNn.1990 | −0.0694920 |
| 221 | log.dev.F.L.rGNn.1991 | 0.2462100 |
| 222 | log.dev.F.L.rGNn.1992 | −0.5043800 |
| 223 | log.dev.F.L.rGNn.1993 | 0.4666600 |
| 224 | log.dev.F.L.rGNn.1994 | 0.2371300 |
| 225 | log.dev.F.L.rGNn.1995 | 0.1688800 |
| 226 | log.dev.F.L.rGNn.1996 | 0.6875300 |
| 227 | log.dev.F.L.rGNn.1997 | 2.0562000 |
| 228 | log.dev.F.L.rGNn.1998 | −0.5849100 |
| 229 | log.dev.F.L.rGNn.1999 | −3.2267000 |
| 230 | log.dev.F.L.rGNn.2000 | −0.2160000 |
| 231 | log.dev.F.L.rGNn.2001 | −0.0616620 |
| 232 | log.dev.F.L.rGNn.2002 | 0.6167100 |
| 233 | log.dev.F.L.rGNn.2003 | −0.2250300 |
| 234 | log.dev.F.L.rGNn.2004 | 1.2537000 |
| 235 | log.dev.F.L.rGNn.2005 | 1.1931000 |
| 236 | log.dev.F.L.rGNn.2006 | −1.5435000 |
| 237 | log.dev.F.L.rGNn.2007 | 0.7555100 |
| 238 | log.dev.F.L.rGNn.2008 | −0.6651200 |
| 239 | log.dev.F.L.rGNn.2009 | 1.8193000 |
| 240 | log.dev.F.L.rGNn.2010 | 1.0713000 |

*Table 26.* (continued)

| ID | Parameter | Value |
|---|---|---|
| 241 | log.dev.F.L.rGNn.2011 | −0.0497300 |
| 242 | log.dev.F.L.rGNn.2012 | 1.4008000 |
| 243 | log.dev.F.L.rGNn.2013 | 0.1859100 |
| 244 | log.dev.F.L.rGNn.2014 | 1.2401000 |
| 245 | log.dev.F.L.rGNn.2015 | −0.2002200 |
| 246 | log.dev.F.L.rGNn.2016 | 0.4405000 |
| 247 | log.dev.F.L.rGNn.2017 | 0.9481400 |
| 248 | log.dev.F.L.rGNn.2018 | 1.3800000 |
| 249 | log.dev.F.L.rGNn.2019 | 1.6275000 |
| 250 | log.dev.F.L.rGNn.2020 | 2.4081000 |
| 251 | log.dev.F.L.rGNn.2021 | 1.6573000 |
| 252 | log.avg.F.D.rHDs | −6.2890000 |
| 253 | log.dev.F.D.rHDs.1982 | −0.8369800 |
| 254 | log.dev.F.D.rHDs.1983 | 0.5573100 |
| 255 | log.dev.F.D.rHDs.1984 | −0.2489100 |
| 256 | log.dev.F.D.rHDs.1985 | 0.5258800 |
| 257 | log.dev.F.D.rHDs.1986 | −0.0552860 |
| 258 | log.dev.F.D.rHDs.1987 | 1.0271000 |
| 259 | log.dev.F.D.rHDs.1988 | 1.5296000 |
| 260 | log.dev.F.D.rHDs.1989 | −1.9014000 |
| 261 | log.dev.F.D.rHDs.1990 | −1.1896000 |
| 262 | log.dev.F.D.rHDs.1991 | −1.4551000 |
| 263 | log.dev.F.D.rHDs.1992 | −1.8264000 |
| 264 | log.dev.F.D.rHDs.1993 | −1.8683000 |
| 265 | log.dev.F.D.rHDs.1994 | −1.9532000 |
| 266 | log.dev.F.D.rHDs.1995 | −0.5072100 |
| 267 | log.dev.F.D.rHDs.1996 | −1.1529000 |
| 268 | log.dev.F.D.rHDs.1997 | −0.4257600 |
| 269 | log.dev.F.D.rHDs.1998 | 0.3465500 |
| 270 | log.dev.F.D.rHDs.1999 | 0.6692000 |
| 271 | log.dev.F.D.rHDs.2000 | −0.6343700 |
| 272 | log.dev.F.D.rHDs.2001 | −0.6145600 |
| 273 | log.dev.F.D.rHDs.2002 | 0.9441500 |
| 274 | log.dev.F.D.rHDs.2003 | 0.1384700 |
| 275 | log.dev.F.D.rHDs.2004 | 1.2273000 |
| 276 | log.dev.F.D.rHDs.2005 | 1.4788000 |
| 277 | log.dev.F.D.rHDs.2006 | 1.1696000 |
| 278 | log.dev.F.D.rHDs.2007 | 0.3601300 |
| 279 | log.dev.F.D.rHDs.2008 | 0.0587390 |
| 280 | log.dev.F.D.rHDs.2009 | −0.1988200 |

*Table 26.* (continued)

| ID | Parameter | Value |
|---|---|---|
| 281 | log.dev.F.D.rHDs.2010 | 0.5938900 |
| 282 | log.dev.F.D.rHDs.2011 | −0.3282300 |
| 283 | log.dev.F.D.rHDs.2012 | −0.3737800 |
| 284 | log.dev.F.D.rHDs.2013 | −0.3134600 |
| 285 | log.dev.F.D.rHDs.2014 | −0.3902700 |
| 286 | log.dev.F.D.rHDs.2015 | 0.5351300 |
| 287 | log.dev.F.D.rHDs.2016 | 1.7550000 |
| 288 | log.dev.F.D.rHDs.2017 | 1.2168000 |
| 289 | log.dev.F.D.rHDs.2018 | 1.0294000 |
| 290 | log.dev.F.D.rHDs.2019 | 0.8044600 |
| 291 | log.dev.F.D.rHDs.2020 | 0.1440900 |
| 292 | log.dev.F.D.rHDs.2021 | 0.1628700 |
| 293 | log.avg.F.D.rGDs | −3.2367000 |
| 294 | log.dev.F.D.rGDs.1982 | −1.7752000 |
| 295 | log.dev.F.D.rGDs.1983 | 0.5381200 |
| 296 | log.dev.F.D.rGDs.1984 | −1.2552000 |
| 297 | log.dev.F.D.rGDs.1985 | −1.0112000 |
| 298 | log.dev.F.D.rGDs.1986 | 0.0603450 |
| 299 | log.dev.F.D.rGDs.1987 | −0.1405100 |
| 300 | log.dev.F.D.rGDs.1988 | −0.6497900 |
| 301 | log.dev.F.D.rGDs.1989 | 0.7994500 |
| 302 | log.dev.F.D.rGDs.1990 | −0.5873800 |
| 303 | log.dev.F.D.rGDs.1991 | 0.9433200 |
| 304 | log.dev.F.D.rGDs.1992 | 0.2350300 |
| 305 | log.dev.F.D.rGDs.1993 | −1.0558000 |
| 306 | log.dev.F.D.rGDs.1994 | −1.1229000 |
| 307 | log.dev.F.D.rGDs.1995 | −0.7867100 |
| 308 | log.dev.F.D.rGDs.1996 | −0.0861030 |
| 309 | log.dev.F.D.rGDs.1997 | −0.1636100 |
| 310 | log.dev.F.D.rGDs.1998 | −0.8777500 |
| 311 | log.dev.F.D.rGDs.1999 | −0.2038600 |
| 312 | log.dev.F.D.rGDs.2000 | −0.3272200 |
| 313 | log.dev.F.D.rGDs.2001 | −0.8210200 |
| 314 | log.dev.F.D.rGDs.2002 | 0.0052948 |
| 315 | log.dev.F.D.rGDs.2003 | 0.5859600 |
| 316 | log.dev.F.D.rGDs.2004 | 0.3234500 |
| 317 | log.dev.F.D.rGDs.2005 | 0.2350600 |
| 318 | log.dev.F.D.rGDs.2006 | 0.4586500 |
| 319 | log.dev.F.D.rGDs.2007 | 0.4578300 |
| 320 | log.dev.F.D.rGDs.2008 | 0.2919500 |

*Table 26.* (continued)

| ID | Parameter | Value |
|---|---|---|
| 321 | log.dev.F.D.rGDs.2009 | 0.4704400 |
| 322 | log.dev.F.D.rGDs.2010 | 0.0898560 |
| 323 | log.dev.F.D.rGDs.2011 | −0.9264100 |
| 324 | log.dev.F.D.rGDs.2012 | −0.7178600 |
| 325 | log.dev.F.D.rGDs.2013 | 0.2300700 |
| 326 | log.dev.F.D.rGDs.2014 | 0.0998370 |
| 327 | log.dev.F.D.rGDs.2015 | 0.3590500 |
| 328 | log.dev.F.D.rGDs.2016 | 2.3156000 |
| 329 | log.dev.F.D.rGDs.2017 | 1.3650000 |
| 330 | log.dev.F.D.rGDs.2018 | 1.2255000 |
| 331 | log.dev.F.D.rGDs.2019 | 0.6524200 |
| 332 | log.dev.F.D.rGDs.2020 | −0.0724240 |
| 333 | log.dev.F.D.rGDs.2021 | 0.8387400 |
| 334 | log.avg.F.D.rGDn | −6.3196000 |
| 335 | log.dev.F.D.rGDn.1982 | −4.3509000 |
| 336 | log.dev.F.D.rGDn.1983 | −4.3270000 |
| 337 | log.dev.F.D.rGDn.1984 | −4.3404000 |
| 338 | log.dev.F.D.rGDn.1985 | −4.3472000 |
| 339 | log.dev.F.D.rGDn.1986 | −2.1618000 |
| 340 | log.dev.F.D.rGDn.1987 | −0.4012600 |
| 341 | log.dev.F.D.rGDn.1988 | −0.5048600 |
| 342 | log.dev.F.D.rGDn.1989 | −0.5927800 |
| 343 | log.dev.F.D.rGDn.1990 | 2.0089000 |
| 344 | log.dev.F.D.rGDn.1991 | 0.1589100 |
| 345 | log.dev.F.D.rGDn.1992 | −0.5222800 |
| 346 | log.dev.F.D.rGDn.1993 | 0.0558610 |
| 347 | log.dev.F.D.rGDn.1994 | −0.3792800 |
| 348 | log.dev.F.D.rGDn.1995 | −0.6398000 |
| 349 | log.dev.F.D.rGDn.1996 | 2.1061000 |
| 350 | log.dev.F.D.rGDn.1997 | 1.8268000 |
| 351 | log.dev.F.D.rGDn.1998 | 0.6126600 |
| 352 | log.dev.F.D.rGDn.1999 | −0.9910000 |
| 353 | log.dev.F.D.rGDn.2000 | −0.0286440 |
| 354 | log.dev.F.D.rGDn.2001 | 0.7375300 |
| 355 | log.dev.F.D.rGDn.2002 | 0.2527900 |
| 356 | log.dev.F.D.rGDn.2003 | 0.5959100 |
| 357 | log.dev.F.D.rGDn.2004 | 1.3138000 |
| 358 | log.dev.F.D.rGDn.2005 | −1.0141000 |
| 359 | log.dev.F.D.rGDn.2006 | −0.5296800 |
| 360 | log.dev.F.D.rGDn.2007 | 1.9618000 |

*Table 26.* (continued)

| ID | Parameter | Value |
|---|---|---|
| 361 | log.dev.F.D.rGDn.2008 | −1.2776000 |
| 362 | log.dev.F.D.rGDn.2009 | 1.8001000 |
| 363 | log.dev.F.D.rGDn.2010 | 1.9066000 |
| 364 | log.dev.F.D.rGDn.2011 | −0.1035700 |
| 365 | log.dev.F.D.rGDn.2012 | 0.0266660 |
| 366 | log.dev.F.D.rGDn.2013 | 1.1565000 |
| 367 | log.dev.F.D.rGDn.2014 | 0.1648800 |
| 368 | log.dev.F.D.rGDn.2015 | 0.6320000 |
| 369 | log.dev.F.D.rGDn.2016 | 1.5731000 |
| 370 | log.dev.F.D.rGDn.2017 | 1.0170000 |
| 371 | log.dev.F.D.rGDn.2018 | 1.6910000 |
| 372 | log.dev.F.D.rGDn.2019 | 1.3722000 |
| 373 | log.dev.F.D.rGDn.2020 | 2.2728000 |
| 374 | log.dev.F.D.rGDn.2021 | 1.2682000 |
| 375 | F.init | 0.0753210 |

# Appendix B Abbreviations and Symbols

*Table 27. Acronyms and abbreviations used in this report*

| Symbol | Meaning |
|---|---|
| ABC | Acceptable Biological Catch |
| AW | Assessment Workshop (here, for gray triggerfish) |
| ASY | Average Sustainable Yield |
| $B$ | Total biomass of stock, conventionally on January 1 |
| BAM | Beaufort Assessment Model (a statistical catch-age formulation) |
| CPUE | Catch per unit effort; used after adjustment as an index of abundance |
| CV | Coefficient of variation |
| DW | Data Workshop (here, for gray triggerfish) |
| $F$ | Instantaneous rate of fishing mortality |
| $F_{\mathrm{MSY}}$ | Fishing mortality rate at which MSY can be attained |
| FL | State of Florida |
| GA | State of Georgia |
| GLM | Generalized linear model |
| $K$ | Average size of stock when not exploited by man; carrying capacity |
| kg | Kilogram(s); 1 kg is about 2.2 lb. |
| klb | Thousand pounds; thousands of pounds |
| lb | Pound(s); 1 lb is about 0.454 kg |
| m | Meter(s); 1 m is about 3.28 feet. |
| $M$ | Instantaneous rate of natural (non-fishing) mortality |
| MARMAP | Marine Resources Monitoring, Assessment, and Prediction Program, a fishery-independent data collection program of SCDNR |
| MCBE | Monte Carlo/Bootstrap Ensemble, an approach to quantifying uncertainty in model results |
| MFMT | Maximum fishing-mortality threshold; a limit reference point used in U.S. fishery management; often based on $F_{\mathrm{MSY}}$ |
| mm | Millimeter(s); 1 inch = 25.4 mm |
| MRFSS | Marine Recreational Fisheries Statistics Survey, a data-collection program of NMFS, predecessor of MRIP |
| MRIP | Marine Recreational Information Program, a data-collection program of NMFS, descended from MRFSS |
| MSST | Minimum stock-size threshold; a limit reference point used in U.S. fishery management. The SAFMC has defined MSST for gray triggerfish as $(1 - M)\mathrm{SSB}_{\mathrm{MSY}} = 0.7\mathrm{SSB}_{\mathrm{MSY}}$. |
| MSY | Maximum sustainable yield (per year) |
| mt | Metric ton(s). One mt is 1000 kg, or about 2205 lb. |
| $N$ | Number of fish in a stock, conventionally on January 1 |
| NC | State of North Carolina |
| NMFS | National Marine Fisheries Service, same as “NOAA Fisheries Service” |
| NOAA | National Oceanic and Atmospheric Administration; parent agency of NMFS |
| OY | Optimum yield; SFA specifies that OY $\leq$ MSY. |
| PSE | Proportional standard error |
| $R$ | Recruitment |
| SAFMC | South Atlantic Fishery Management Council (also, Council) |
| SC | State of South Carolina |
| SCDNR | Department of Natural Resources of SC |
| SDNR | Standard deviation of normalized residuals |
| SEDAR | SouthEast Data Assessment and Review process |
| SEFIS | SouthEast Fishery-Independent Survey |
| SERFS | SouthEast Reef Fish Survey |
| SFA | Sustainable Fisheries Act; the Magnuson–Stevens Act, as amended |
| SL | Standard length (of a fish) |
| SPR | Spawning potential ratio |
| SSB | Spawning stock biomass; mature biomass of males and females |
| $\mathrm{SSB}_{\mathrm{MSY}}$ | Level of SSB at which MSY can be attained |
| TIP | Trip Interview Program, a fishery-dependent biodata collection program of NMFS |
| TL | Total length (of a fish), as opposed to FL (fork length) or SL (standard length) |
| VPA | Virtual population analysis, an age-structured assessment |
| WW | Whole weight, as opposed to GW (gutted weight) |
| yr | Year(s) |