2018 Stock Assessment Update for Spotted Seatrout, *Cynoscion nebulosus*, in Mississippi

Prepared For:

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Executive Summary

Title: 2018 Stock Assessment Update for Spotted Seatrout, *Cynoscion nebulosus*, in Mississippi

Year: Terminal Assessment Year 2017

Objectives: Provide an annual Stock Assessment for Spotted Seatrout, *Cynoscion nebulosus*, in Mississippi state waters using best available data and model

Analysis: Multiple sources of data compiled from Mississippi Department of Marine Resources (MDMR), Gulf Coast Research Laboratory's Center for Fisheries Research (GCRL CFRD) and NOAA's National Marine Fisheries Service (NMFS) were analyzed in an age-structured stock assessment model to update the status of the Mississippi Spotted Seatrout stock.

Terms of Reference:

1. Describe the assessment model.
2. Report the stock and fishery status relative to the established target reference point, SPR = 20%.
3. Perform forecast projections to determine the potential future fishery and stock status under different levels of fishing mortality corresponding to alternative $F_{\%SPR}$ values.
4. Provide research recommendations for continued sustainable management.

Brief Summary of Results and Status of the Stock:
The 2018 Spotted Seatrout Stock Assessment Update is the second annual update to the initial benchmark assessment completed in 2016. The Mississippi Commission on Marine Resources (MCMR) imposed a regulatory change to the recreational fishery on January 16, 2017 from 13-inches to a 15-inch minimum total length. The recreational bag limit of 15 fish per day remained the same. The commercial sector is managed by a minimum total length of 14-inches and a 50,000 pound quota. This annual update follows the same structure as the 2016 assessment and 2017 update, using an age-structured model, although data input into the model now includes catch and abundance information through 2017, the terminal year for this update. These data include commercial catch, recreational catch-at-age, a fishery-independent age-structured index of abundance, and a fishery-dependent index of abundance. Of note, the fishery dependent data gathered from MRIP for the recreational sector utilized CHTS (Coastal Household Telephone Survey) estimates rather than the new FES (Fishing Effort Survey) estimates. This approach was used as estimates derived from the FES are still being explored and NOAA Fisheries is currently not using the FES estimates for management purposes due to numerous uncertainties. Sensitivity and retrospective analyses were conducted to determine how model inputs affected the estimated stock size, spawning stock biomass (SSB), total stock numbers, fisheries reference points, and fishery stock status. These analyses indicated that the model predictions were generally robust but that some deviations from the base model occurred.

Fisheries reference points are typically used to define acceptable targets and/or limits of fishing mortality and the desired level of harvest to help the sustainability of the stock and to define whether a stock is overfished, experiencing overfishing, and/or if overfishing has occurred in the past. These reference points can include optimum or maximum values of fishing mortality, biomass, or yield. Currently, the MCMR has established a target %SPR of 20 percent. There has been a continued negative trend in the %SPR over the last five years, but the five-year terminal mean estimate has increased relative to that estimated in the 2016 stock assessment (13% SPR in 2016 assessment, 16% SPR in 2017 update assessment). The mean %SPR in the last five years of the assessment is 17.9% with a terminal year estimate of 14.4%. Currently, the fishing mortality rate (F) for Mississippi Spotted Seatrout is calculated as the mean *F* for the last five years, 0.96 y^{-1} and is buoyed by the large terminal year fishing mortality rates in 2016 and 2017. The SSB is calculated using the mean SSB in the last five years of the assessment which is1,139,446 kg.

Using data through the terminal year of 2017, the status of the resource has improved since the initial assessment. However, the historical retrospective analysis indicates a systematic change in $F_{terminal}$ and $SSB_{terminal}$ based on increasing periods of data suggesting that terminal year estimates of fishery and stock status should be treated with caution because of the observed retrospective patterns indicating terminal year estimates may be influencing model predictions. Fisheries staff recommends attentiveness to the management of this resource moving forward and therefore, to continue with current regulations. Staff also recommends maintaining a management target of 20% SPR, to ensure the stock continues to rebuild in future years. To continue to monitor the stock status, staff recommends the addition of a five-year mean 16% SPR threshold. Based on the results of the 2018 update assessment, we conclude that overfishing is not occurring on the Mississippi Spotted Seatrout stock based on stated reference points.

Introduction

1.1 Biological Characteristics

Spotted Seatrout is a popular recreational species found in coastal and estuarine habitats along the Atlantic and Gulf of Mexico (GOM) coasts (Hoese and Moore 1977). The state-specific stock boundaries are supported by the results of genetic analysis (Gold and Richardson 1998) and tagging studies (Hendon et al. 2002). These works indicate that the stock is composed of spatially distinct subpopulations in the GOM. Additional genetic work indicates that there is little or no genetic distinction in Mississippi's coastal waters (Somerset and Saillant 2014). The existence of spatial structure supports the management of Mississippi Spotted Seatrout as a single stock. In this assessment, we define the Mississippi Spotted Seatrout stock as Spotted Seatrout inhabiting and targeted in Mississippi state waters. We recognize that Spotted Seatrout are landed in Mississippi that are caught in neighboring Gulf Coast states' waters – to what extent this is done is not well understood.

Individual Spotted Seatrout length-at-age is highly variable, and the species exhibits sexually dimorphic growth. Females reach greater lengths-at-age through ontogeny (Murphy and Taylor 1990; Dippold et al. 2016). Individual age is estimated by counting annuli on otoliths (VanderKooy 2009); however, for the Mississippi stock, tag-recapture methods have also been used to corroborate length-at-age model parameter estimates (Dippold et al. 2016). Although individual growth is usually described using the von Bertalanffy growth function (VBGF), recent work suggests that a three-parameter logistic length-at-age model is a better model to describe the length-at-age relationship (Dippold et al. 2016).

Spotted Seatrout are "batch spawners" whose spawning season typically occurs from mid-April through September and spawning occurs every four to five days, on average, in Mississippi (Brown-Peterson and Warren 2001). Batch fecundity, defined as the mean number of eggs produced in a spawning event, is positively correlated to standard length (mm, SL) and mean batch fecundity-at-age estimates range from 66,200 ± 8,400 eggs per batch at age one to 354,000 eggs per batch at age five (Brown-Peterson and Warren 2001). Sexual maturity occurs early. Female length at 50% maturity was estimated to be 230 mm SL (10.2 to 10.5 inches TL, less than age-1 y) and 100% of males Brown-Peterson and Warren (2001) were sexually mature at 201 mm SL (9.0 to 9.2 inches TL, less than age-1 y).

1.2 Fishery and Fishery Management Characteristics

Mississippi Spotted Seatrout are harvested by the recreational and commercial sectors; however, harvest is primarily by the recreational fishery (Figure 1.1). Both the commercial and recreational Spotted Seatrout fishery is regulated by a minimum size limit. The commercial sector has a 14-inch TL minimum size limit and a 50,000-pound (22,680 kg) quota. Historically, recreational regulations of the Spotted Seatrout fishery in Mississippi have changed to reflect the evolution of management goals. The current recreational 15-inch minimum TL was implemented on January 16, 2017. The recreational daily bag limit has ranged from 10 to 50 fish but has remained at 15 fish since 1996.

1.3 Assessment Model Description

In this work, which we term the "2018 Spotted Seatrout Update", we perform a quantitative assessment of Mississippi's Spotted Seatrout stock using a statistical catch-at-age model (Age Structured Assessment Program 3 [ASAP]; NOAA Fisheries Toolbox; http://nft.nefsc.noaa.gov) with data through 2017 (terminal year is 2017). We use this age-structured model to assess the current status of the stock and the fishery as well as to predict the outcome of future management decisions, using deterministic projections. The data used in the age-structured model includes total annual harvest for the recreational and commercial sectors, the age-composition of the harvest, and abundance estimates from fishery independent surveys. Model outputs include annual estimates of the annual instantaneous fishing mortality rate (F y^{-1}), associated % spawner per recruit (%SPR) and spawning stock biomass (SSB, kg). Because this work is an update of an accepted, externally peer-reviewed model and model formulation, no alternative models were evaluated.

2.0 Data Sources and Biases

Data for the 2018 Spotted Seatrout Update come from both fishery-independent and fishery-dependent sources. Biostatistical data were provided by CFRD and MDMR. Fishery-independent data from CFRD and MDMR (2009 to 2017) were combined and used to calculate a fishery-independent index of abundance from monthly gillnet surveys conducted at stations along Mississippi's Gulf Coast. These gillnet surveys were conducted using a 750-foot (229 m) multi-mesh gillnet consisting of five 150-ft (46 m) panels (2.0, 2.5, 3.0, 3.5, and 4.0 inch) with a 60-minute soak time. The data gathered from the surveys were used to calculate a fishery-independent index of abundance (IOA) as well as to develop an age-length key, a sex-ratio-at-length relationship, and a three-parameter logistic model of length-at-age. The locations and other specific details of the gillnet survey can be found in the 2016 Spotted Seatrout benchmark assessment.

Fishery-dependent information included data for both the recreational and commercial fishing sectors (1993 to 2017). Information on annual recreational catch was obtained from NOAA Fisheries' Marine Recreational Information Program (MRIP) and the Gulf States Marine Fisheries Commission (GSMFC). Information on the commercial catch was provided by the MDMR and NOAA Fisheries.

3.0 Materials and Methods

3.1 Input parameters

3.1.1 Length-at-age and age length key

The female-specific Spotted Seatrout length-at-age relationship was described using a three-parameter logistic model:

$$L_t = \frac{L_\infty}{1+\alpha(e^{-\beta t})} \,. \quad (1)$$

In this formulation, L_t is the expected TL (inches) at age t (y), L_∞ is the mean maximum TL (inches), α is a scaling coefficient and β (y^{-1}) is the growth rate coefficient. The three-parameter logistic model is used to describe the mean length-at-age relationship. This model had the greatest support among alternative candidate models to describe the length-at-age relationship of

Spotted Seatrout (Dippold et al. 2016). The resulting female-specific mean parameter estimates were L_∞ = 23.8 inches TL, α = 1.74, and β = 0.54 y^{-1}. An age-length key (ALK) was derived from the fishery-independent gillnet data which consisted of the proportion of fish of a given age-at-length (Table 3.1).

3.1.2 Sex Ratio

Because this assessment focuses on the female portion of the Spotted Seatrout population, a sex-ratio-at-length key for the recreational fishery was developed (Table 3.2) and applied to the fishery-dependent catch-at-length data to estimate the female-portion of the recreational catch-at-length. The sex-ratio-at-length relationship was described using the logistic function:

$$p_{fem,l} = \frac{1}{1+e^{(-r(\mathrm{TL}-L_{50}))}}, (2)$$

where $p_{fem,l}$ is the proportion of females-at-length (inches), r is the rate of change and L_{50} is the length (inches) where the proportion of females is equal to 50% (i.e. the inflection point). The mean proportion of females was predicted for one-inch lengths ranging from 8 inches to 27 inches (203 to 686 mm). The resulting mean parameter estimates of the logistic sex-ratio-at-length relationship were r = 0.22 (unitless), L_{50} = 7.28 inches.

3.1.3 Weight-at-length

Weight-at-length was described using the power function,

$$\mathrm{W} = a\mathrm{TL}^b, (3)$$

where W is the weight in grams, a and b are the power function parameters, and TL is total length (inches). The resulting female-specific mean parameters were a = 0.117 and b = 3.108. A single weight at age matrix was used in the update. The weight-at-age vector was determined from combining weight-at-length estimates and length-at-age. The weight-at-age of the age-6+ "plus group" is the weight-at-age of age-6 individuals.

3.1.4 Age-at-maturity

Age-at-maturity estimates used in the assessment were obtained from Brown-Peterson and Warren (2001) who reported 80% of age-1 female fish to be sexually mature. All age classes greater than one were assumed to be 100% mature.

3.1.5 Natural mortality rate

In this update, we assumed a length-specific natural mortality relationship (Lorenzen 2005), where natural mortality is inversely related to length: as length increases, natural mortality decreases. The equation for Lorenzen mortality is:

$$M_L = M_1\left(\frac{1}{L}\right), (4)$$

where M_L is the length-specific instantaneous annual natural mortality, L is the total length (inches), and M_1 is the natural mortality rate-at-length constant. We used a value of 15 y^{-1} at length of 1 cm (0.39 inch) for the M_1 parameter. This is the reported average value for wild fish (Lorenzen 2005). Length-specific natural mortality was converted to age-specific mortality using the female-specific length-at-age relationship (Figure 3.1).

3.2 Input Data

3.2.1 Recreational Sector Length-specific Catch

Length-specific catch for Mississippi (all areas, A + B1) was obtained from the NOAA's MRIP survey (1993 to 2017). To convert these quantities to female-specific age-structured catch we first applied the proportion of the catch comprised of female fish (Table 3.2) and then applied the age-length-key (Table 3.3). The age-length key was determined from MDMR and CFRD gillnet (fishery independent) survey data.

3.2.2 Commercial Catch

Commercial catch in Mississippi is reported as an undifferentiated biomass (no length, age, or sex information, kg, 1993 to 2017). We used the annual length composition of the recreational catch to determine the length-structure of the harvest and the magnitude of the annual age-structured female-only catch (Table 3.1, Table 3.4).

3.2.3 Indices of abundance

Two indices of abundance (IOAs) were used in this update: the first is a fishery-independent index derived from the combination of the CFRD and MDMR gillnet surveys (2004 to 2017). The second is a fishery-dependent IOA calculated from NOAA MRIP recreational catch and effort data.

The index of abundance was determined using a multiple-linear regression model of the combined CFRD and MDMR gillnet surveys (2004 to 2017). The response variable was the log + 1 transformed catch per unit effort (CPUE), where catch is the number of individuals. The independent variables were the station number, the year that the sample was taken, the month that the sample was taken, and the mesh size of the panel in which the fish was collected (2.5, 3.0, 3.5, and 4-inch mesh sizes were used). We note that the biomass (kg) of individuals was also used as a dependent variable in index formulation and the predicted, relative annual abundance was similar. Following step-wise Akaike's information criteria (AIC) evaluation of alternative models, the global model, was accepted as the best fit model:

$$\log(CPUE\ (number\ of\ individuals) + 1) = Month + Year + Station + Panel.$$

We note that each of the independent variables (Month, Year, Station, and Panel) in the analysis are categorical. We used this model to derive predicted annual fishery-independent index for Mississippi Spotted Seatrout for the MDMR gillnet survey (Figure 3.2a), USM's CFRD gillnet survey (Figure 3.2b), and a composite (combined) of MDMR and USM's CFRD gillnet survey (Figure 3.2c).

A fishery-dependent IOA (1993 to 2017) was calculated using the MRIP's directed trips information where the annual number of Spotted Seatrout harvested by the recreational sector in Mississippi's state waters (A + B1) is divided by the number of trips in which Spotted Seatrout are the primary target (number of fish/directed angler trip, Figure 3.3).

3.3 Assessment Model Descriptions

3.3.1 ASAP Base Assessment Model Description

The model used to describe the population dynamics of Spotted Seatrout was the Age Structured Assessment Program (Age Structured Assessment Program 3; NOAA Fisheries Toolbox; http://nft.nefsc.noaa.gov). The ASAP model is a forward projecting statistical catch-at-age model (Fournier and Archibald 1982; Deriso et al. 1985) that separates fishing mortality into year- and age-specific components. The ASAP model is fit using a maximum likelihood framework to the observed recreational catch-at-age, commercial catch-at-age, fishery-independent IOA, and the fishery-dependent IOA.

A Beverton-Holt stock recruitment function is used in the ASAP model to estimate recruitment of the next year (t+1) from the previous years' SSB. SSB is calculated based on the number of individuals-at-age (N_a), maturity-at-age (P_{mat}), the mean weight-at-age (kg, W_a), and the proportion of the total mortality (Z_a) that occurred before spawning (we use ½ year):

$$SSB_y = \sum N_{ay} P_{mat,a} W_a e^{-Z_{ay}(0.5)}, \quad (5)$$

$$\hat{R}_{y+1} = \frac{\alpha SSB_t}{\beta + SSB_t}, \quad (6)$$

$$\alpha = \frac{4\tau\left({}^{SSB_0}/_{SPR_0}\right)}{5\tau - 1}, \quad (7)$$

$$\text{and } \beta = \frac{SSB_0(1-\tau)}{5\tau - 1}. \quad (8)$$

Fishing mortality is modeled as age-, fleet-, and year-specific (F_{agy}, y^{-1}) and is the product of selectivity at age, fleet and year (S_{agy}), and a fleet and year specific fishing mortality multiplier ($Fmult_{gy}$):

$$F_{agy} = S_{agy} Fmult_{gy}. \quad (9)$$

In this assessment, two fleets (recreational and commercial) were modeled such that the total fishing mortality for each age and year ($Ftot_{ay}$) is equal to the age-, fleet- and year-specific fishing mortality. Total mortality at age and year (Z_{ay}, y^{-1}) is therefore the sum of the total fishing mortality at age and year and the natural mortality at age and year (M_{ay}):

$$Z_{ay} = Ftot_{ay} + M_{ay}. \quad (10)$$

Recruitment ($N_{a=1,y}$, assumed to occur at age-1), in the first model year (1993) of age-1 individuals is estimated from the equation:

$$\hat{N}_{a=1,y} = R_y e^{\varepsilon_y}. \quad (11)$$

R_y is calculated from equation 8 and ε_y are recruitment deviations from an assumed lognormal distribution. Abundance for ages greater than one in the first year ($N_{a>1,1993}$) are calculated from the user-defined age-specific abundances and lognormal deviations (e^{v1993}):

$$N_{a>1,1993} = N_{a>1,1993\ input} e^{v_{1993}}. \quad (12)$$

Abundance of age-1 recruits for the remaining years are estimated from equation 11. Abundance-at-ages greater than one (N_{ay}) for all years, after the initial year in the assessment were calculated as (all variables are defined previously):

$$N_{ay} = N_{a-1,y-1}e^{-Z_{a-1,y-1}}, a < A \text{ , (13) and}$$

$$N_{ay} = N_{A-1,y-1}e^{-Z_{A-1,y-1}} + N_{A,y-1}e^{-Z_{A,y-1}} , a = A. \text{ (14)}$$

Catch-at-age by year (C_{ay}) is calculated using the Baranov catch equation:

$$C_{ay} = \frac{N_{ay}F_{agy}(1-e^{-Z_{ay}})}{Z_{ay}}. \text{ (15)}$$

The expected fishery-independent IOA and fishery-dependent IOA (I_{agy}) are calculated as:

$$\hat{I}_{agy} = q_{ind} \sum_a N_{ay} s_{ind,a.} \text{ (16),}$$

where q_{ind} is the catchability coefficient of each index and $s_{ind,a}$ is the survey selectivity-at-age. The estimated proportion-at-age for the fishery-independent index is:

$$\frac{\hat{I}_{agy}}{\sum_a \hat{I}_{agy}} \text{ , (17)}$$

where all variables have the same definition as previously described.

The negative log likelihood objective function used to fit the ASAP model includes multiple components (from the different model components) and penalty terms. Each component is summed in the overall negative log-likelihood function. Each component is assumed to have either a lognormal or multinomial error structure. The two penalties in the objective function are related to the fishing mortality to keep the estimated fishing mortality close to natural mortality during the early minimization process.

3.4 Model Parameterization

3.4.1 ASAP Base Assessment Parameterization

The input data file (file format is .DAT) for the primary base configuration is included as an appendix (Appendix 1). The parameterization of the ASAP base model configuration is described below.

- *Model structure:* The ASAP is a forward-projecting statistical catch-at-age model, and thus provides annual estimates of age, year, and fleet specific stock size, fishing mortality rate, etc.
- *Stock dynamics*: In ASAP, age, year and fleet specific abundances are described using the exponential decay function and catch-at-age is estimated from the Baranov catch equation
- *Stock recruitment*: A reparametrized Beverton and Holt stock-recruitment relationship is used to estimate annual recruitment (Mace and Doonan 1988).
- *Abundance indices*: The model used two indices of abundance: a fishery-independent index and a fishery-dependent index.

- *Fitting criterion*: The ASAP model is fit under the maximum likelihood framework. In the objective function there are likelihood components for each of the assessment sub-models.
- *Estimated parameters*: The ASAP base model in this assessment estimates 86 parameters. The parameters included selectivity parameters, fishing mortality rate multipliers, deviations from the stock-recruitment relationship (for each year), age-specific population abundances in the first year, and the stock-recruitment relationship parameters.

The base model included an age-6 "plus group", one fishery selectivity block, one survey selectivity block and the following levels of error and weighting. A single selectivity block was used to reduce the number of estimated parameters in the model. Fisheries landings (commercial and recreational) were specified with a coefficient of variation (CV) of 0.1 for each year included in the assessment (1993 to 2017). Annual recruitment deviations were specified with a CV of 0.25 and input levels for the abundance indices were specified with CV's of 0.25 for the fishery-independent index and 0.20 for the fishery-dependent index. Lognormal components included in the objective function were equally weighted (all lambda values=1). Input effective sample sizes (ESS) for estimation of fishery and survey age compositions were specified equally for the entire time-series (all ESS=120). Steepness was fixed at 0.99 in the base model.

- 2 fishery selectivity parameters – logistic selectivity A_{50} and slope
- 1 stock-recruitment parameter – (unexploited SSB)
- 2 initial catchability coefficients -1 for the fishery-independent index and 1 for the fishery-dependent index. Catchability was considered constant during the time-series because it was not obvious that changes in either fishery sector warranted the additional parameterization necessary for time-varying, q.
- 5 initial population abundance deviations (age-2, age-3, age-4, age-5, ag3-6+)
- 44 apical fishing mortality rates (F_{mult} in the initial year and 21 deviations in subsequent years for 2 fisheries)
- 25 recruitment deviations (1993 to 2017)
- 4 index (gillnet) parameters

3.5 Model Precision Estimates

3.5.1 ASAP Base Assessment Model Precision Estimates

Monte Carlo Markov Chain (MCMC) is a method of estimating uncertainty in models and was used in this analysis to generate uncertainty estimates around the model outputs. A total of 1,000 MCMC outputs were used to generate uncertainty estimates in estimates of fishing mortality and terminal year spawning stock biomass.

3.6 Sensitivity Analysis

There are two primary ways to evaluate the quality of the models fit to the data: sensitivity analysis and retrospective analysis. Sensitivity analysis is a standard, accepted method to determine how sensitive the model is to the inclusion to alternative data sources and to alternative model parameterization – these are changed singly and model output is evaluated. The specific sensitivity runs are described below.

Additionally, retrospective analyses are used to understand the impact of inclusion of recent years of data on model fit. Retrospective analyses are a standard diagnostic for stock assessment models and are used to diagnose issues of fitting models to data and to ensure that terminal year data are not biasing model predictions.

3.6.1 ASAP Base Assessment Model Precision Sensitivity Analysis

Several sensitivity analyses were presented in previous iterations of the Spotted Seatrout stock assessment (in benchmark and subsequent update). These analyses indicated that the model predictions were generally robust but that some deviations from the base model occurred when mortality, steepness, and discard mortality were altered from the base model formulation. In this report the model had convergence issues in various sensitivity trials. No sensitivity analyses are presented in this report.

3.7 Retrospective Analysis

3.7.1 ASAP Base Assessment Model Retrospective Analysis

A retrospective analysis was performed to evaluate how the inclusion of recent years of data affected the model outputs and the estimation of reference points. The base formulation of the stock assessment model was re-run by omitting, sequentially, the terminal year of data in the assessment. The resulting estimates of fishery reference points, current fishing mortality, and spawning stock biomass were compared to the predictions from the base model. The retrospective analysis included model realizations with the terminal year(s) removed sequentially, beginning in 2017 to 2012. Retrospective analyses are a standard diagnostic for stock assessment models and are used to diagnose issues of fitting models to data and to ensure that terminal year data are not biasing model predictions. The simulated sequential removal of these data provides a diagnostic of the impacts on the model predictions for different durations of time series'.

3.8 Reference Point Estimation – Parameterization, Uncertainty, and Sensitivity Analysis

Fisheries reference points are typically used to define acceptable targets and/or limits of fishing mortality and the desired level of harvest to help the sustainability of the stock and to define whether a stock is overfished, experiencing overfishing, and/or if overfishing has occurred in the past. These reference points can include optimum or maximum values of fishing mortality, biomass, or yield. In January 2017, the Mississippi Commission on Marine Resources (MCMR) set a target %SPR of 20% for the SST fishery in MS state waters.

3.8.1 ASAP Base Assessment Model Reference Point Estimation

Uncertainty of terminal year fishing mortality and SSB were estimated using MCMC.

4.0 Results

4.1 Goodness of Fit

4.1.1 ASAP Base Assessment Model Goodness of Fit

A total of 89 parameters were estimated in the ASAP model. The components of the objective function are displayed in Figure 4.1. The objective function is the sum of the negative log-likelihood of the fit to various model components.

To fit the statistical catch-at-age model, predicted quantities are generated and compared with those that are observed. Overall, the base model provided a generally good qualitative fit to the observed catch data (Figure 4.2). The predicted commercial catch fit the observed data throughout the time series. However, the predicted recreational catch in recent years is underestimated for 2009, 2011, and 2013. The predicted recreational catch is greatly underestimated for 2016. The model-predicted proportions of catch-at-age also generally fit the data well for both the recreational and commercial catch (Figures 4.3a,b). The predominant age class in the fishery are age-2 fish in all years observed. The age-composition of the catch was relatively well estimated (Figures 4.4a,b). In general, both commercial and recreational sectors did not estimate the proportion of age-1 fish well: overestimating (observed catch > predicted catch) those in the recreational catch, especially early in the fishery. The proportion of age-2 individuals in the latter part of the time series are better estimated in the recreational fishery. The model underestimated (observed catch < predicted catch) age-1 in the commercial catch.

The predicted IOA for the gillnet survey did not fit the time-series well – though it does capture the trend of maximum abundance from 2006 to 2011 and a subsequent reduction in stock size (Figure 4.5). The latter part of the time-series has an extremely poor fit, predicting opposite (high) relative abundance than is observed. There was a generally better fit to the fishery-dependent CPUE – though the predicted abundance does not capture the observed variability (Figure 4.5). The predicted abundance is lower than expected in the early part of the time series (2000 to 2008). The index does "track" observations better later in the time series, after 2010.

The estimated recruitment curve, using a fixed steepness of 0.99, was fit to the observed number of recruits (Figure 4.6). Patterning (runs of negative and then positive residual values) is evident in the time-series of recruitment deviations (Figure 4.6).

4.2 Parameter Estimates

4.2.1 ASAP Base Assessment Model Parameter Estimates

Age-structured selectivity is time- and fleet-invariant and is modeled with a logistic function (Figure 4.7). The fishing mortality rate for Mississippi Spotted Seatrout is calculated as the mean *F* for the last five years, 0.96 y^{-1} (Figure 4.8) and are buoyed by the large terminal year fishing mortality rates in 2016 and 2017 (1.2 and 1.18 y^{-1}). The mean %SPR in the last five years of the assessment is 17.9% (Figure 4.8). The spawning stock biomass SSB is calculated using the mean SSB in the last five years of the assessment, 1,139,448 kg (Figure 4.9).

4.3 Biomass and Fishing-Mortality Estimates

4.3.1 ASAP Base Assessment Fishing Mortality, %SPR, Total Stock and Spawning Stock Biomass, and Recruitment.

The fully-selected total instantaneous fishing mortality (unweighted) has ranged from $F = 0.56$ to 1.56 y^{-1} (Figure 4.8). In recent years the instantaneous total annual fishing mortality was variable and reached maximum values in 2014, 2016, and 2017. Similarly, the %SPR, is variable for the times series but never is below 13%. The overall trend in the time series is one of increase in SSB and Total Biomass with drops in both 2012 to 2014 (Figure 4.9). A peak in the number of individuals in the stock and total biomass occurred in 2009 and 2015.

The observed pattern in total biomass and spawning stock biomass indicate that the stock has exhibited an increase in biomass, peaking at 2009 and 2015 (Figure 4.9). After that, the stock biomass has shown variation. The spawning stock biomass reported here is calculated using the mean SSB in the last five years of the assessment, 1,139,448 mt (Figure 4.9).

The phase plot of the times series of recruitment as a function of spawning stock biomass indicates that recruitment is relatively high and there is a linear trend with SSB, coincident with the fixed steepness parameter value used in the base model formulation (Figure 4.10).

4.3.2 ASAP Base Assessment Model Precision Estimates

MCMC estimates of terminal year instantaneous fishing mortality and spawning stock biomass indicate variation around the estimated modal point estimates (Figure 4.11a). Monte Carlo derived uncertainty estimates of annual instantaneous fishing mortality and spawning stock biomass illustrate the range of uncertainty in the time series (Figure 4.11b). The wide intervals around the median indicate that there is considerable uncertainty in the terminal year estimate. These estimates of uncertainty should be considered whenever the interpretation of point estimates (e.g. %SPR) are evaluated.

4.4 Sensitivity Analysis

4.4.1 ASAP Base Assessment Model Biomass and Fishing-Mortality Sensitivity Analysis

No sensitivity analyses are presented in this report – changes to the base model formulation in selectivity and mortality rate resulted in unstable estimates. Such a result indicates that the base model formulation estimates should be interpreted with caution. To understand the impact of the alteration of parameters and input data, the interested reader should consult the previous benchmark and updates submitted by the GCRL/USM and MDMR Stock Assessment Panel.

4.5 Retrospective Analysis

4.5.1 ASAP Base Assessment Model Biomass and Fishing-Mortality Retrospective Analysis

The results of the retrospective analysis indicated the continued presence of a strong retrospective pattern (Figure 4.12). Removal of increasing numbers of the terminal years of data resulted in similar decreasing trends in abundance SSB and increasing fishing mortality, although this pattern was not consistent among all retrospective runs. A notable divergence is that the sensitivity runs with terminal year 2012, 2013, 2014, and 2015 have a much lower predicted spawning stock biomass throughout the time series. Additionally, none of these are

informed by the relatively large increase in abundance (from the fishery independent data) in the terminal year. Because of this retrospective pattern we take the precautionary approach to present terminal year estimates of F y^{-1} and SSB mt as the mean of the final five years of predictions.

4.6 Reference Point Estimation – Parameterization, Uncertainty, and Sensitivity Analysis

4.6.1 ASAP Base Assessment Model Reference Point Estimation

Currently in Mississippi the MCMR has set a target %SPR of 20%. The time-series of %SPR was determined and is reported in Figure 4.8.

5.0 Stock Status

Reference points, set by management, are the basis for determining stock status. The estimated mean %SPR for the terminal five years of the assessment is 17.9% which is below the %SPR target specified by management. We report this, instead of the terminal year estimate because of the presence of what we characterize as the strong retrospective pattern. Thus, we advise the use of the mean terminal year %SPR as a proxy for $\%SPR_{2017}$. We note that %SPR value of 16% is the minimum limit (of the ones presented here) in which the SSB trajectory is positive in the five-year projections (Table 7.1). We propose the use of %SPR value of 16% as a possible limit reference point for management consideration.

5.1 ASAP Base Assessment Model Stock Status

%SPR has varied throughout the observed exploitation period of the stock. The lowest SPR observed was 13.7% and the stock has been over the %SPR target in nine of the 25 years of the assessment.

6.0 Fishery Status

6.1 ASAP Base Assessment Model Fishery Status

The instantaneous fishing mortality rate (F y^{-1}) has varied throughout the observed exploitation period of the stock. The five-year terminal mean estimate is 0.96 y^{-1}.

7.0 Model Projection ASAP Base Assessment Model

Using the ASAP model's projection capabilities, deterministic projections were constructed at a range of fishing mortalities corresponding to %SPR values of 14, 16, 18, 20, and 22 for a five-year projection period (2018 to 2022). We report the projected change in SSB and yield (mt) in Table 7.1 as well at the total percent change in each quantity over the time period.

8.0 Research Recommendations

1. There is currently little effort to assess the sex-, age- or length composition of the recreational sector (other than NOAA's recreational survey, for length composition). There is currently no effort to assess the sex-, age- or length composition for the commercial sector. To increase the precision and accuracy of the assessment model, we recommend statistically sound biological sampling be performed (age, sex, and length composition information) of Mississippi's recreational and commercial harvest.
2. Establish a trawl survey directed towards sampling juveniles.
3. Provide updated studies of fecundity and maturity-at-age. Such an effort would allow sensitivity runs to be evaluated.
4. Understand the dynamic of increasing fishing pressure on the stock from 2009 (estimated fishing intensity has monotonically increased since 2009). A directed-study of stakeholder use of the resource is needed. Although the biological characteristics of the fishery are relatively well known the dynamics of the stakeholders are not. Fisheries are a coupled biological and human interaction – knowledge of the human dimensions of the fishery would serve to inform potential management.
5. Increase and evaluate fishery-independent sampling by adding stations to the gillnet survey.
6. Increase understanding of the stakeholders' motivations and fishing patterns and preferences relative to management in order to set minimum size and bag limits that are coincident with effective management.
7. Determine the retention and discard rates for the recreational and commercial harvest using a variety of fishery-independent and fishery-dependent observations. Targeted dockside interviews and limited charter boat observers could address this need.

9.0 Discussion

There continues to be an increase in the estimated %SPR relative to the five-year mean predictions of %SPR from the 2016 assessment. The USM and MDMR Stock Assessment Panel concluded in their 2016 assessment that the mean %SPR in the terminal three years of the assessment was 9.3%. We have amended and increased this estimate in this work. Given the inclusion of new data, the mean terminal year %SPR is 17.9%. The stock has shown itself to be resilient to fishing and new data implemented into this model has improved our understanding of the capability of the stock for replacement. We emphatically do not use the terminal year estimate ($\%SPR_{2017}$) because of the presence of the reported and described retrospective pattern. The observed increase in abundance, under heavy fishing pressure, indicates the stock is larger and more resilient than was previously predicted.

State-specific Spotted Seatrout management benchmarks vary across the Gulf of Mexico. An 18%SPR is used in some states as a conservation standard. Based on the projection analysis, and considering new data incorporated in the model, the fishery reference point target SPR of 20% is appropriate – it balances an increase in harvest while allowing SSB to increase at moderate levels (Table 7.1). Only after inclusion of data (≥ 2 years) that will allow monitoring of the fishery after the inclusion the new minimum recreational size limit on the stock, can we evaluate the efficacy of this management action.

Although there is recreational and commercial harvest of Spotted Seatrout in Mississippi, the magnitude of the recreational catch and the contribution of the recreational fleet to the total fishing mortality is much greater than the commercial fishing mortality (Figure 1.1). Throughout the time series used in the assessment, the commercial harvest has been relatively low and constant. Management actions and assessment and monitoring (data collection efforts) should primarily be focused on the recreational sector of the fishery.

10.0 Proposed formulation of the 2019 Benchmark Assessment for Spotted Seatrout

In anticipation of a benchmark assessment for mid-2019 Leaf propose the following changes be made for continued assessment.

10.1 Index formulation

The indices used in the assessment, MDMR and GCRL gillnet surveys are treated in aggregate, do not include abiotic variables, and standardized using a general linear model that incorporates some categorical variables. However, given that we now have sufficient data this index needs an alternative standardization approach. Leaf will use a delta-lognormal linear model formulation that incorporates abiotic variables (a standard approach for the treatment of these data).

10.2 Model formulation

I propose to use another age-structured model, "Stock Synthesis version 3 (SS3)" for assessment. This model incorporates the same data sources that are included in the NOAA ASAP model and is one of the standard models (like the one used in this assessment) employed by NOAA Fisheries. However, it is also flexible in its ability to utilize a wide diversity of age, size, and aggregate data from fisheries and surveys – MDMR has provided does have limited age-composition data from surveys of the recreational fishery that could be included in this model. The SS is flexible and allows simple and complex modeling approaches. SS3 represents the state-of-the-art assessment modeling approach.

10.3 Final formulation

Prior to the final model formulation, Leaf will consult with MDMR principals of the stock assessment panel to finalize the schedule, terms of reference, input data, and formulation of the 2019 benchmark stock assessment.

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Table 3.1 Age-length key derived from MDMR and CFRD gillnet sampling. The cells are the proportion of fish of a given age-at-length.

Total Length (in)	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
8	1	0	0	0	0	0
9	0.88	0.12	0	0	0	0
10	0.81	0.18	0.01	0	0	0
11	0.86	0.14	0	0	0	0
12	0.68	0.28	0.03	0	0	0
13	0.41	0.56	0.02	0.01	0	0
14	0.27	0.7	0.03	0.01	0	0
15	0.15	0.72	0.12	0.01	0	0
16	0.07	0.7	0.2	0.03	0.01	0
17	0.06	0.54	0.33	0.07	0	0
18	0.02	0.53	0.41	0.04	0.01	0
19	0.01	0.31	0.58	0.09	0	0.01
20	0	0.22	0.53	0.23	0	0.03
21	0.02	0.09	0.39	0.41	0.09	0
22	0.04	0.07	0.32	0.54	0.04	0
23	0	0.07	0.21	0.5	0.07	0.14
24	0	0	0	0	1	0
25	0	0	0	0	0	1
26	0	0	0	1	0	0
27	0	0	0	0	0	1

Table 3.2 Female-portion of the recreational catch-at-length.

Total Length (in)	Probability of Female
8	0.54
9	0.59
10	0.65
11	0.69
12	0.74
13	0.78
14	0.81
15	0.85
16	0.87
17	0.89
18	0.91
19	0.93
20	0.94
21	0.95
22	0.96
23	0.97
24	0.98
25	0.98
26	0.98
27	0.99

Table 3.3 Age-structured, female-only proportion of recreational catch and total recreational catch for Mississippi (all areas, A + B1) obtained as aggregate catch-at-age and then converted using the age-length key and the portion of the recreational catch-at-length.

	Age (y)						
Year	1	2	3	4	5	6	Catch (Kg)
1993	0.300	0.531	0.137	0.029	0.002	0.002	208,503
1994	0.389	0.475	0.110	0.023	0.002	0.000	135,660
1995	0.244	0.553	0.147	0.032	0.003	0.022	220,171
1996	0.268	0.564	0.130	0.033	0.003	0.001	262,603
1997	0.238	0.570	0.142	0.044	0.006	0.001	228,562
1998	0.268	0.620	0.087	0.023	0.001	0.000	264,848
1999	0.297	0.444	0.163	0.084	0.010	0.003	517,270
2000	0.226	0.564	0.151	0.047	0.007	0.005	326,225
2001	0.226	0.536	0.173	0.054	0.009	0.002	413,383
2002	0.207	0.550	0.182	0.047	0.007	0.007	517,374
2003	0.171	0.606	0.171	0.039	0.011	0.002	281,376
2004	0.279	0.587	0.099	0.025	0.007	0.003	726,476
2005	0.181	0.616	0.164	0.034	0.004	0.001	395,814
2006	0.179	0.605	0.169	0.037	0.006	0.004	594,862
2007	0.191	0.593	0.171	0.040	0.002	0.002	361,462
2008	0.263	0.572	0.136	0.025	0.002	0.001	701,718
2009	0.243	0.554	0.156	0.040	0.004	0.002	1,094,988
2010	0.218	0.510	0.181	0.057	0.016	0.019	858,741
2011	0.186	0.604	0.163	0.038	0.005	0.003	878,389
2012	0.245	0.530	0.182	0.038	0.004	0.001	655,114
2013	0.284	0.597	0.095	0.021	0.002	0.002	789,169
2014	0.247	0.566	0.138	0.043	0.005	0.001	564,698
2015	0.234	0.602	0.136	0.023	0.004	0.000	752,947
2016	0.172	0.579	0.193	0.049	0.004	0.003	2,021,147
2017	0.075	0.577	0.268	0.060	0.012	0.009	951,061

Table 3.4 Age-structured, female-only proportion of commercial catch and total commercial catch for Mississippi obtained as aggregate catch at age and then converted using the length structure of the recreational fishery, the portion of the catch-at-length that is female, and the age-length key.

	Age (y)						
Year	1	2	3	4	5	6	Catch (Kg)
1993	0.205	0.592	0.163	0.036	0.002	0.002	19,542
1994	0.202	0.601	0.158	0.035	0.004	0.000	27,778
1995	0.170	0.600	0.166	0.036	0.003	0.025	27,798
1996	0.197	0.613	0.146	0.038	0.004	0.001	16,579
1997	0.189	0.602	0.153	0.048	0.007	0.001	15,842
1998	0.245	0.639	0.090	0.024	0.001	0.000	15,874
1999	0.169	0.507	0.201	0.106	0.012	0.004	19,633
2000	0.187	0.589	0.161	0.050	0.008	0.005	17,426
2001	0.172	0.567	0.189	0.060	0.010	0.003	16,647
2002	0.151	0.583	0.198	0.051	0.008	0.008	12,619
2003	0.163	0.611	0.173	0.039	0.011	0.002	9,995
2004	0.216	0.634	0.110	0.029	0.007	0.004	11,487
2005	0.145	0.639	0.174	0.037	0.004	0.001	7,294
2006	0.160	0.618	0.174	0.038	0.006	0.004	9,030
2007	0.169	0.607	0.177	0.042	0.002	0.002	10,811
2008	0.201	0.616	0.152	0.029	0.002	0.001	12,743
2009	0.185	0.590	0.172	0.045	0.005	0.003	20,164
2010	0.156	0.542	0.200	0.064	0.017	0.021	16,112
2011	0.164	0.619	0.169	0.040	0.006	0.003	14,902
2012	0.164	0.579	0.207	0.044	0.004	0.002	23,468
2013	0.219	0.648	0.105	0.024	0.002	0.002	19,120
2014	0.202	0.596	0.148	0.047	0.005	0.002	16,285
2015	0.209	0.620	0.141	0.024	0.005	0.000	10,596
2016	0.152	0.590	0.199	0.051	0.004	0.003	19,706
2017	0.075	0.577	0.268	0.060	0.012	0.009	16,530

Table 7.1 Estimated SSB (kg) and Yield (kg) under a range of fishing mortalities corresponding to %SPR values of 14, 16, 18, 20, 22, and 24 for a five-year projection period (2018 to 2022).

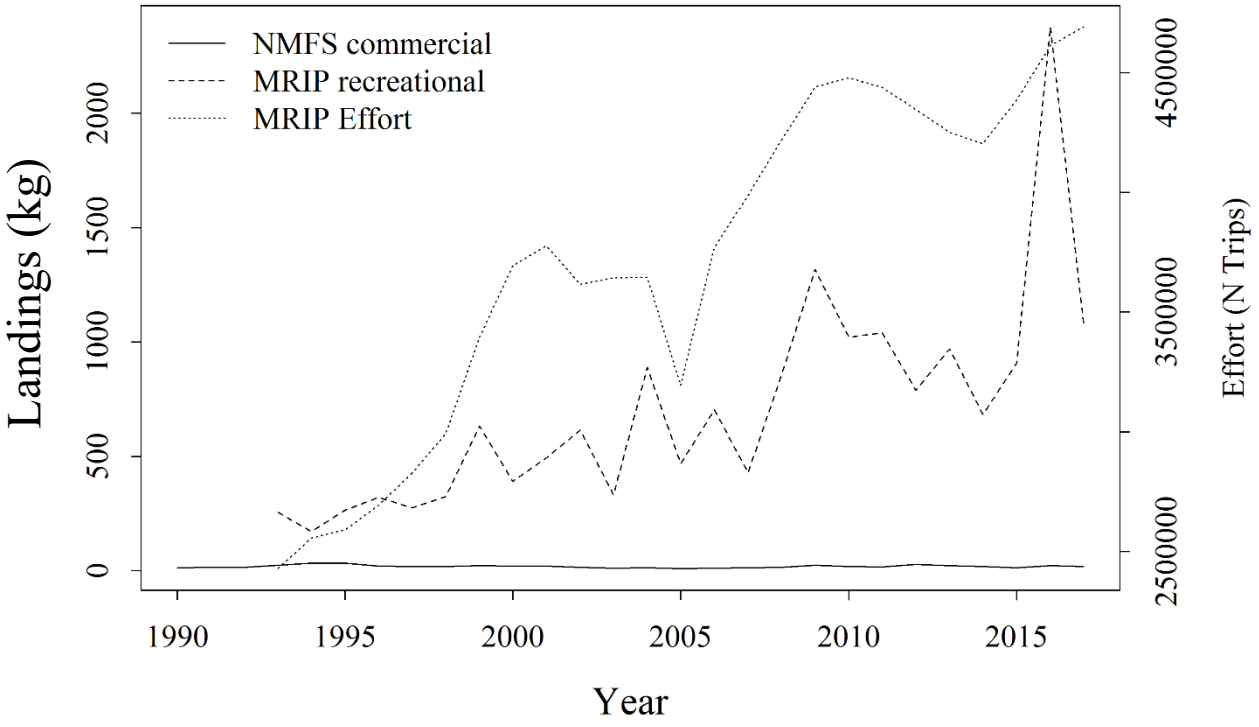
A. SSB

$F_{\%SPR}$ Scenario	2018	2019	2020	2021	2022	Five-year change (%)
14	705,079	693,580	695,381	696,669	696,906	-1%
16	747,398	772,063	788,400	795,258	797,323	6%
18	781,051	841,427	875,916	891,119	896,508	13%
20	808,483	902,893	957,771	983,693	993,988	19%
22	831,316	957,632	1,034,130	1,072,660	1,089,390	24%
24	850,657	1,006,660	1,105,330	1,157,910	1,182,430	28%

B. Yield

$F_{\%SPR}$ Scenario	2018	2019	2020	2021	2022	Five-year change (%)
14	556,549	534,052	536,750	538,486	538,789	-3%
16	498,340	517,992	535,893	543,314	545,526	9%
18	449,501	498,142	529,943	543,873	548,787	18%
20	407,979	476,442	520,118	540,671	548,811	26%
22	372,228	454,075	507,480	534,316	545,942	32%
24	341,090	431,740	492,871	525,400	540,554	37%

Figure 1.1 Time series of recreational (from MRIP) and commercial harvest (time series provided by NMFS and MDMR) for the Mississippi SST stock.



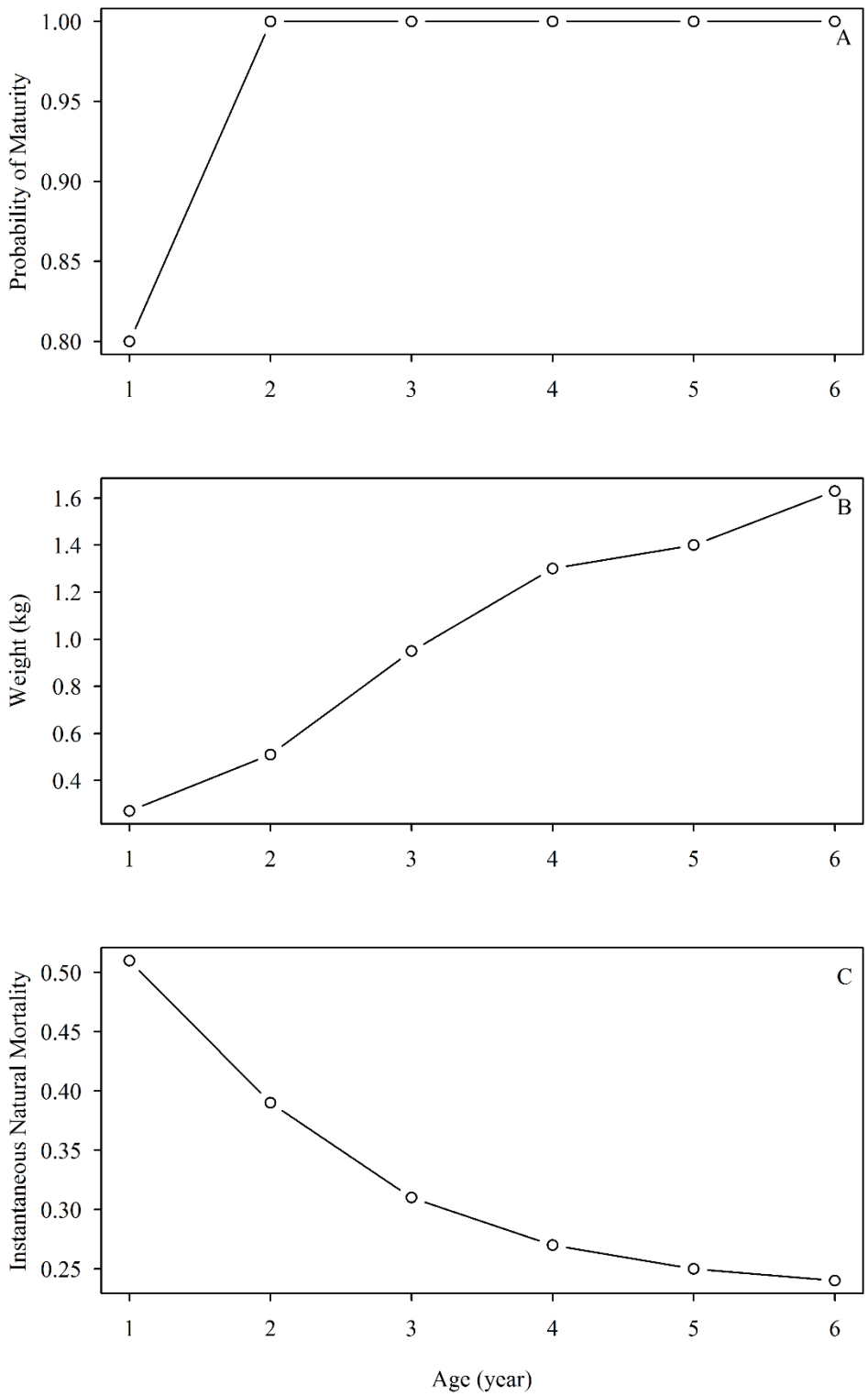


Figure 3.1 Age-specific A) probability of maturity, B) individual weight (kg), and C) instantaneous annual natural mortality for the Mississippi SST stock.

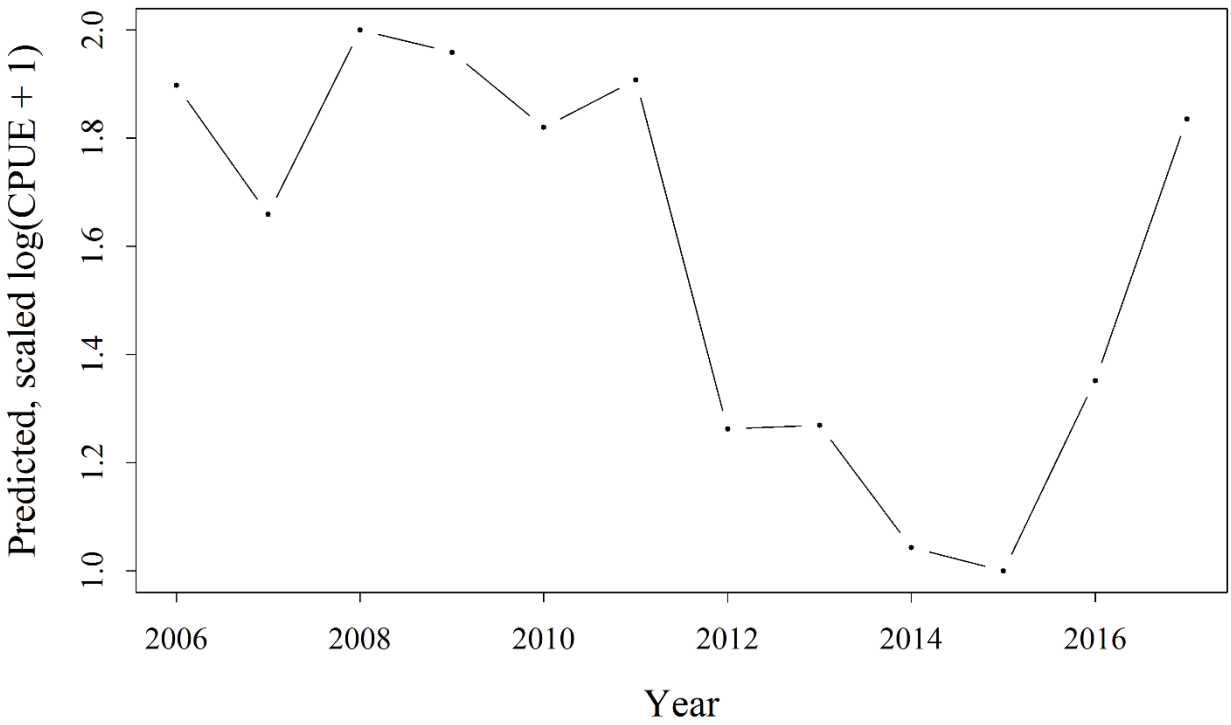


Figure 3.2a Predicted, scaled and log-transformed annual index of abundance derived from multiple linear regression of number of fish sampled by the gillnet sampling performed by MDMR.

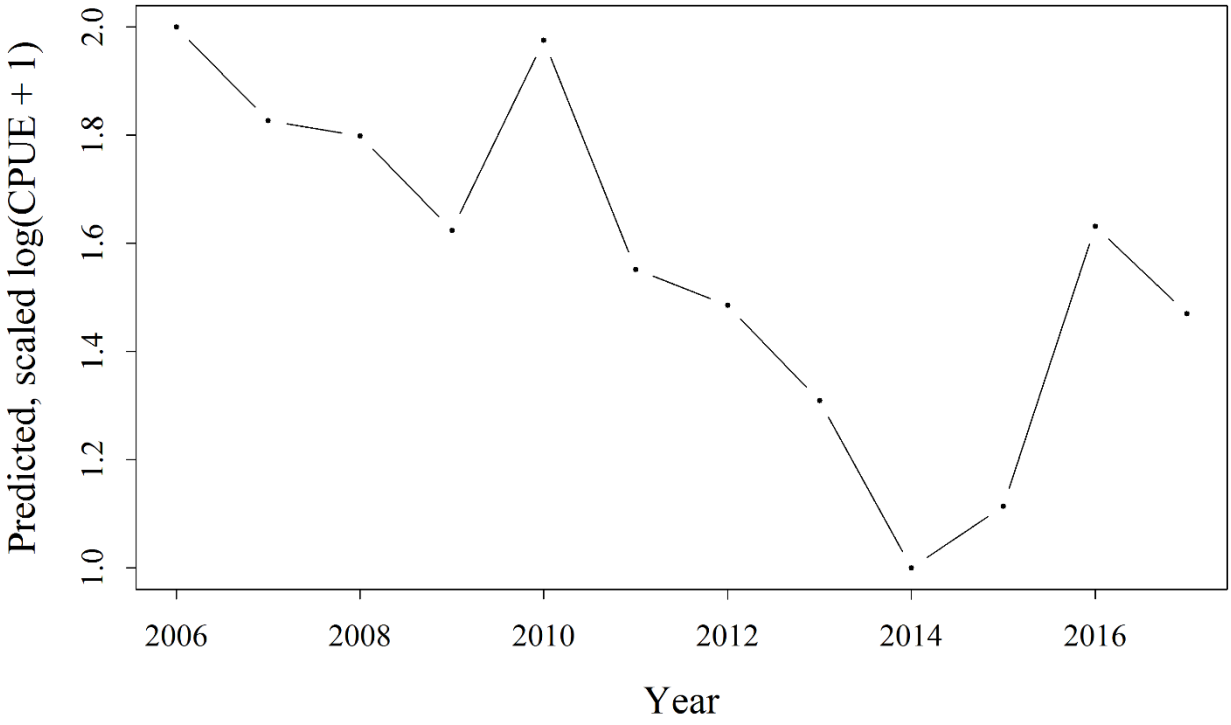


Figure 3.2b Predicted, scaled and log-transformed annual index of abundance derived from multiple linear regression of number of fish sampled by the gillnet sampling performed by USM's Center for Fisheries Research and Development (CFRD).

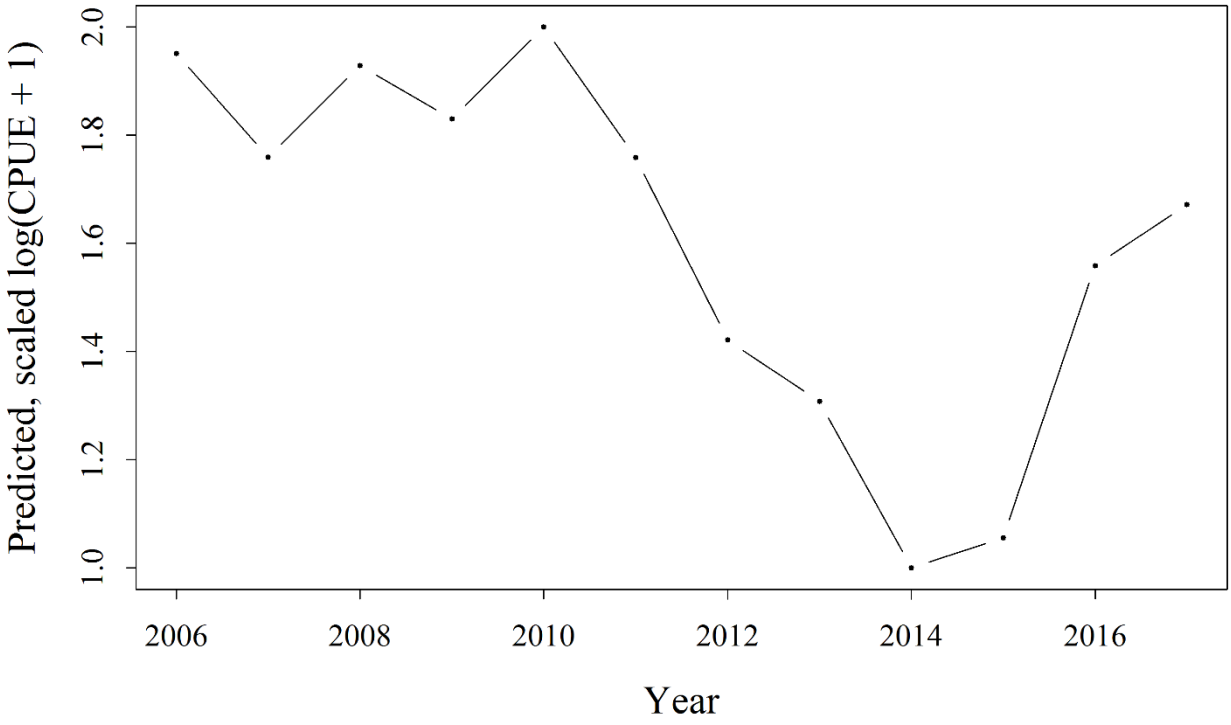


Figure 3.2c Predicted, scaled and log-transformed annual index of abundance derived from multiple linear regression of number of fish sampled by the gillnet sampling performed by combining MDMR and USM's Center for Fisheries Research and Development (CFRD) sampling effort.

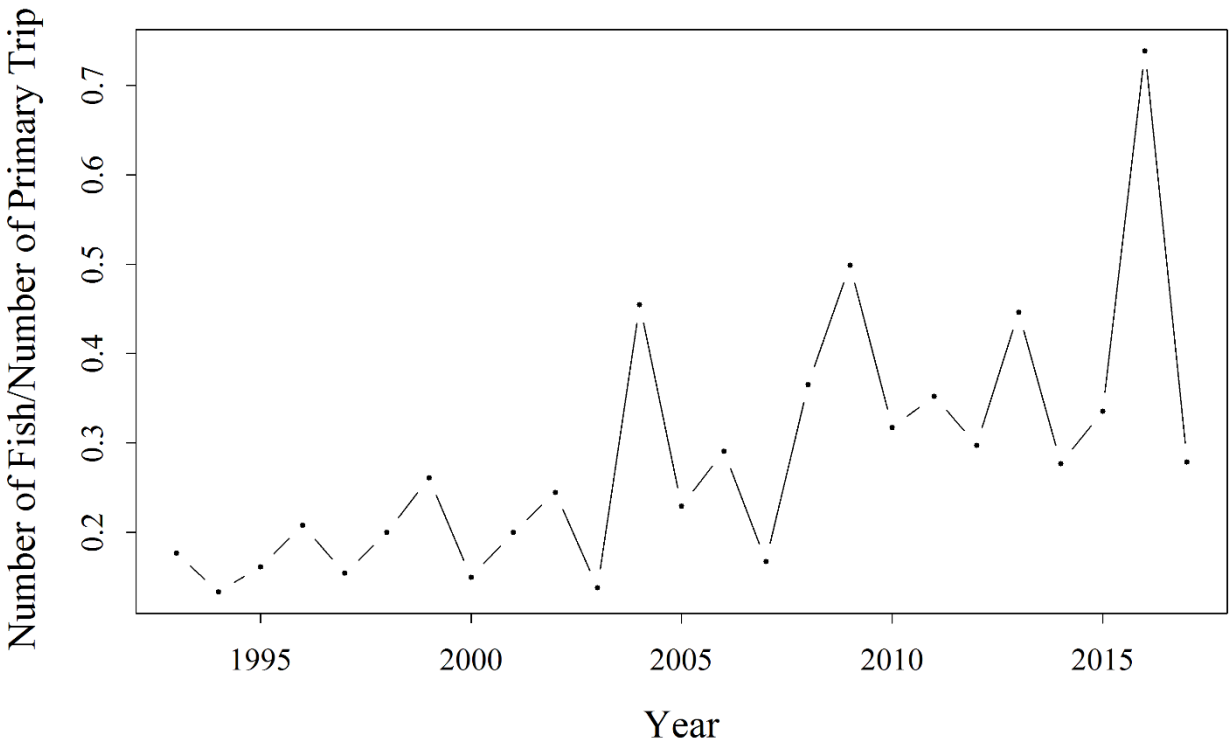


Figure 3.3 Observed number of Spotted Seatrout/Primary Trips from NOAA's MRIP survey.

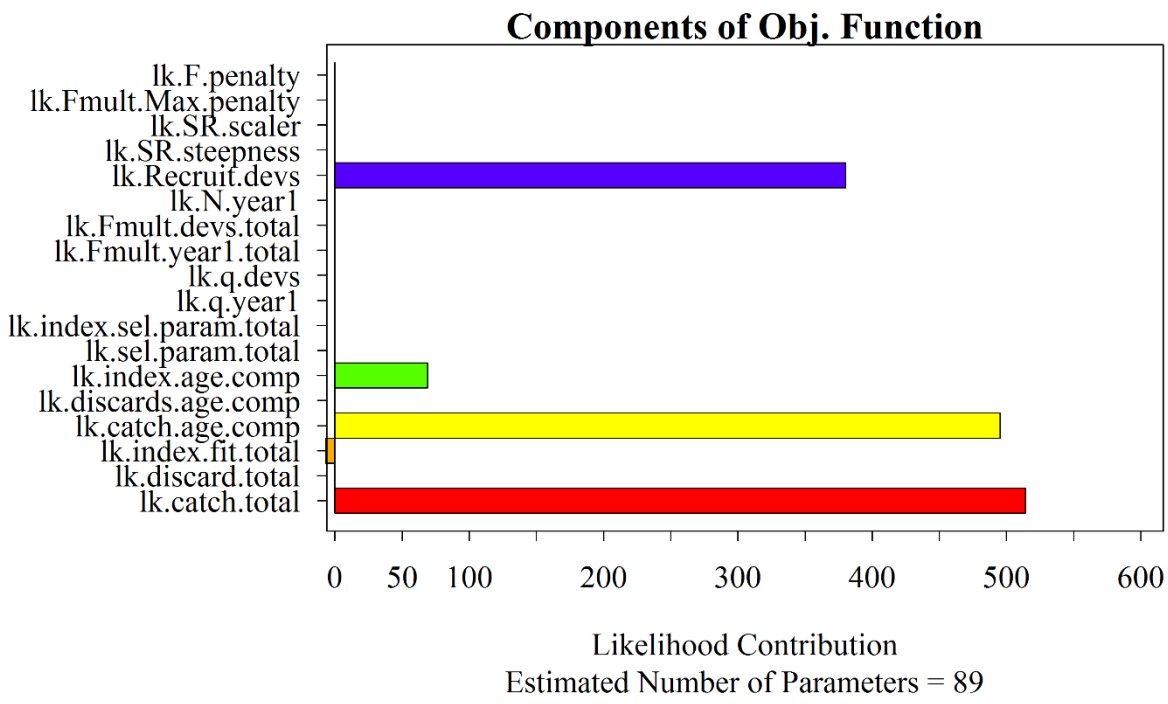


Figure 4.1 Components of the likelihood function for fitting the ASAP model for the Mississippi SST stock. A total of 89 parameters are estimated in the model.

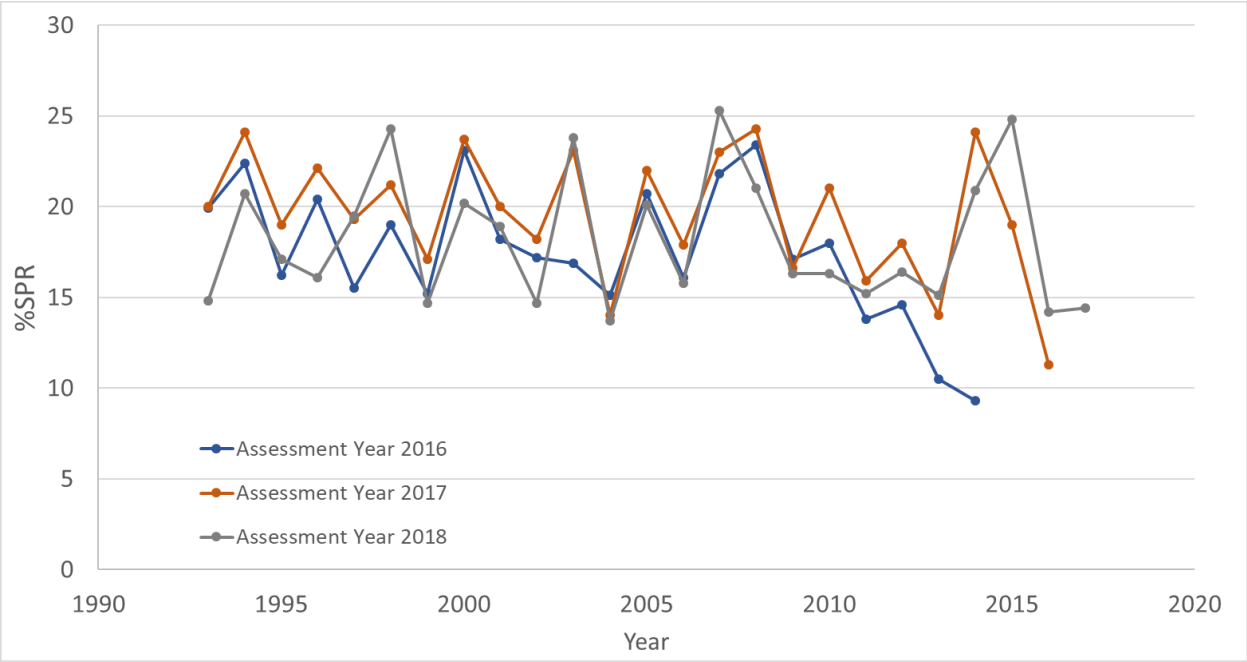


Figure 4.1a %SPR over time from each assessment year

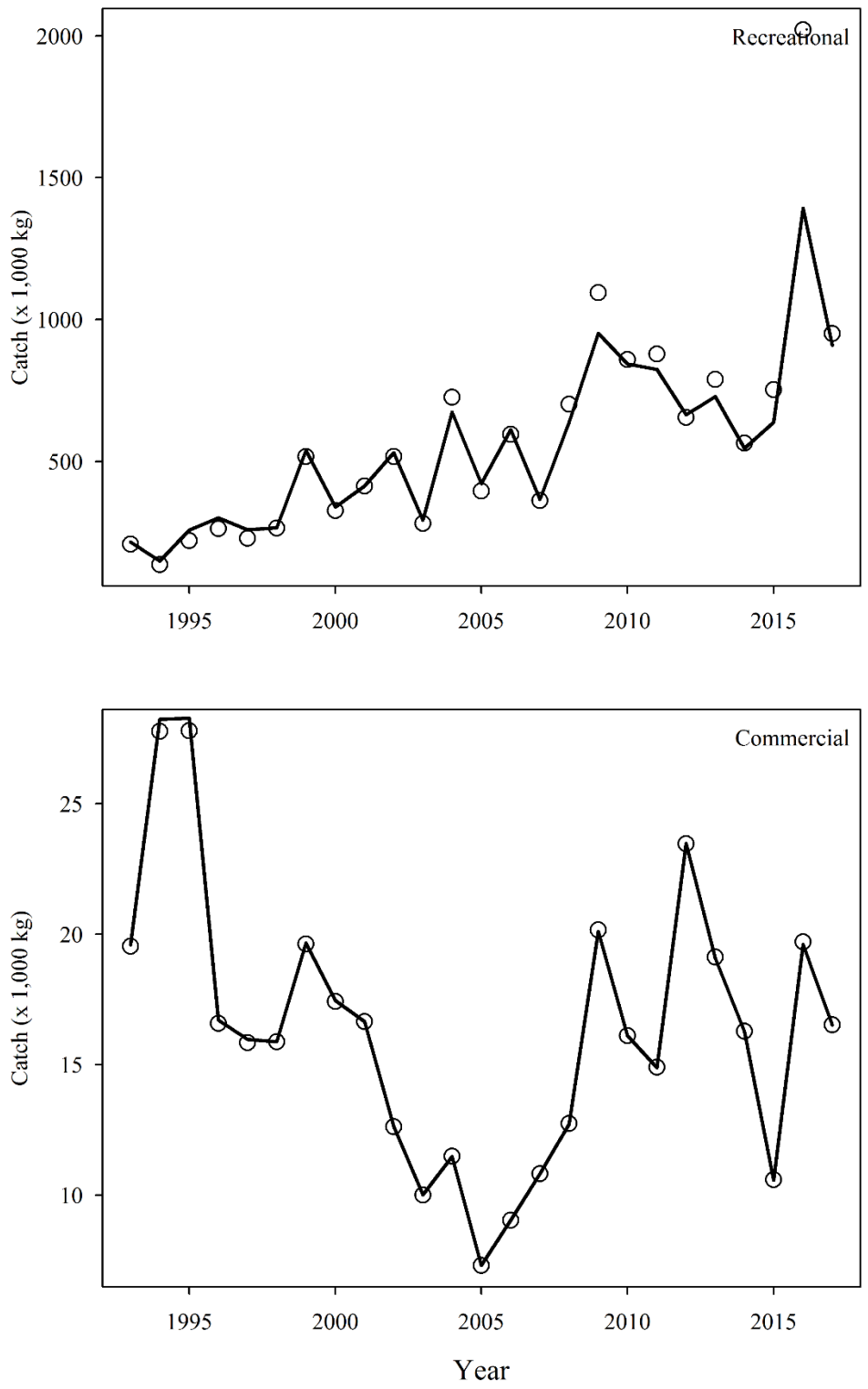


Figure 4.2 Observed (points) and predicted (lines) proportion of catch for the Recreational and Commercial fleets for the Mississippi SST stock from 1993 to 2016.

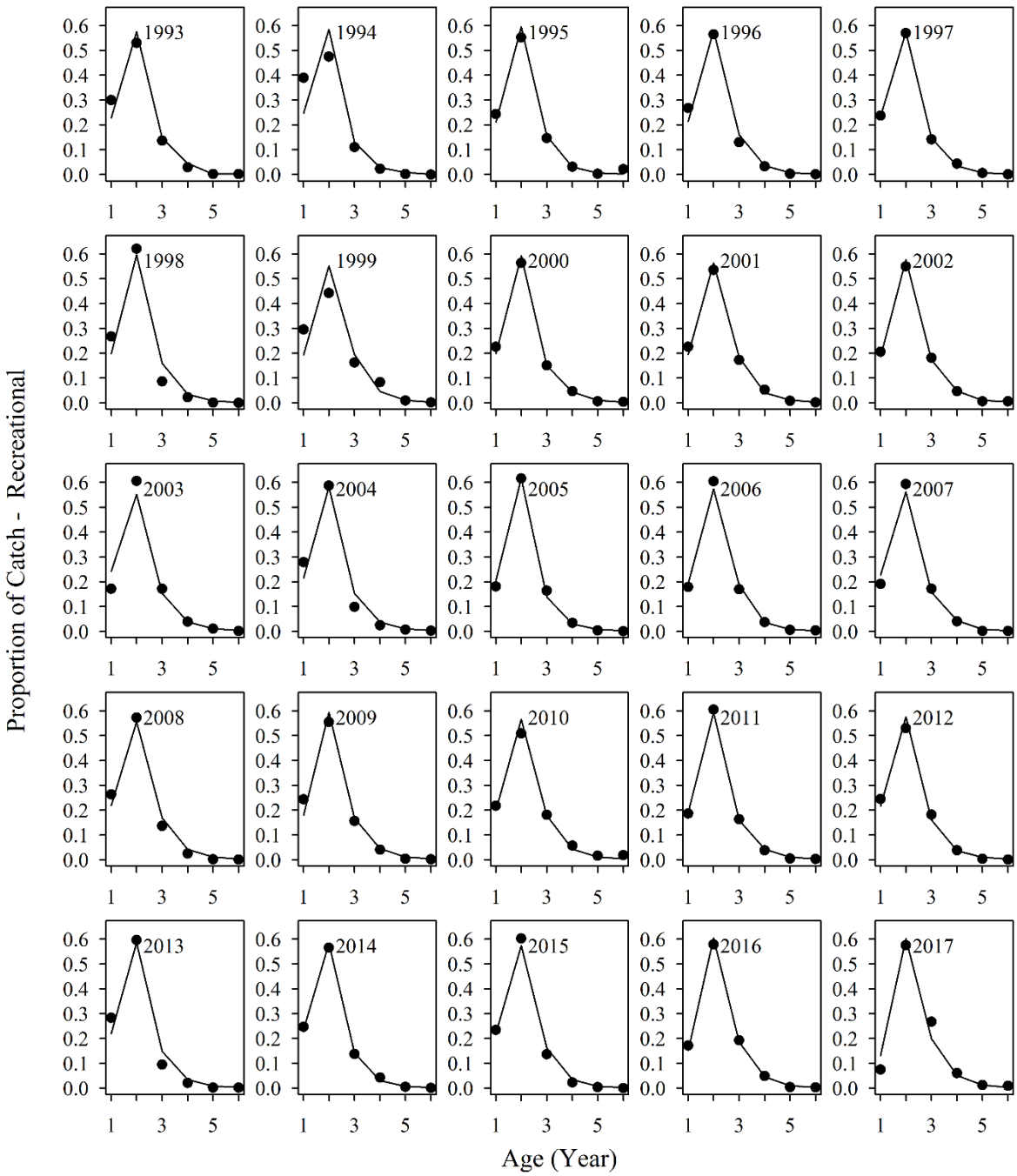


Figure 4.3a The observed and predicted proportion of catch-at-age for the recreational Spotted Seatrout sector.

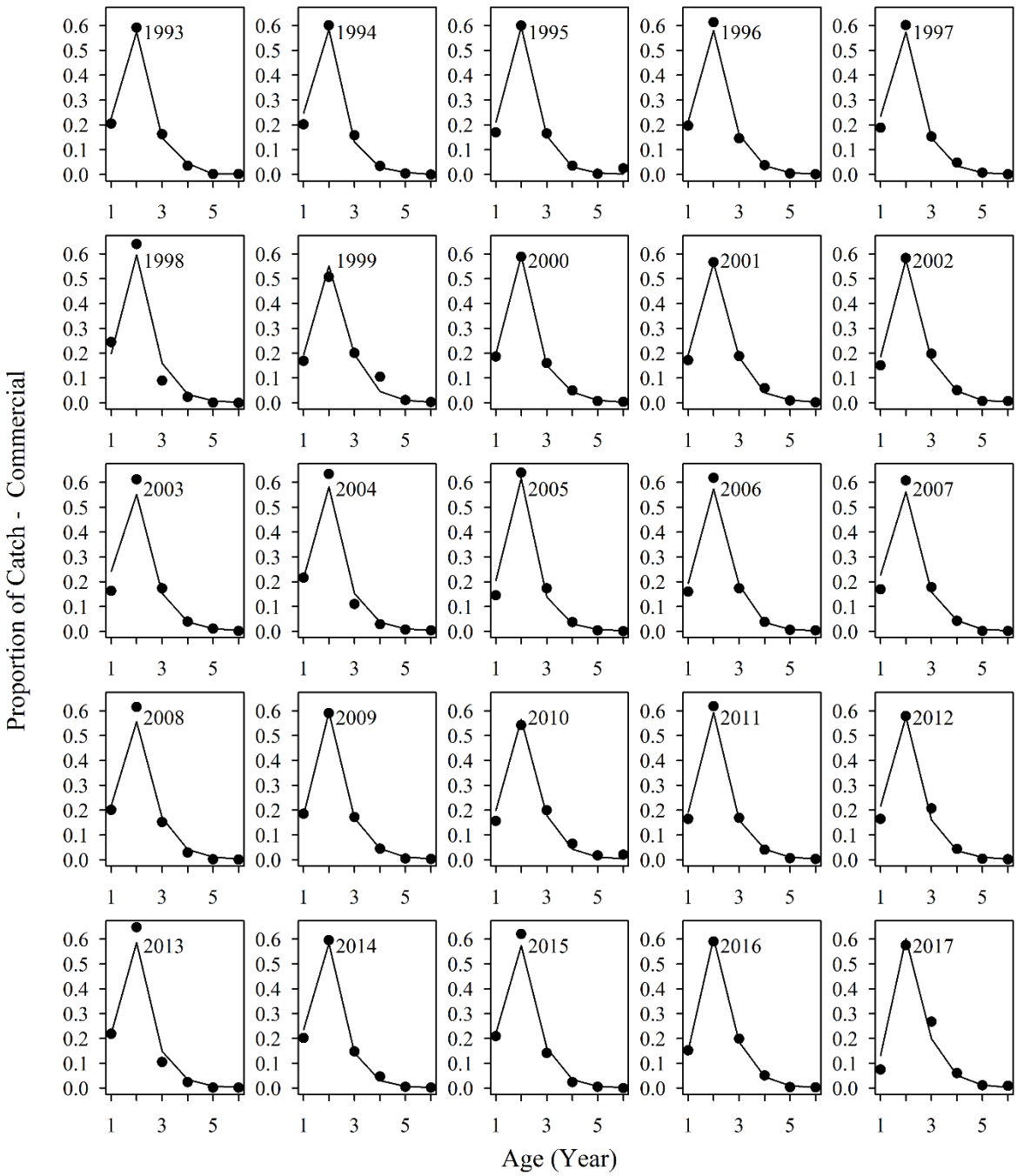


Figure 4.3b The observed and predicted proportion of catch-at-age for the commercial Spotted Seatrout sector.

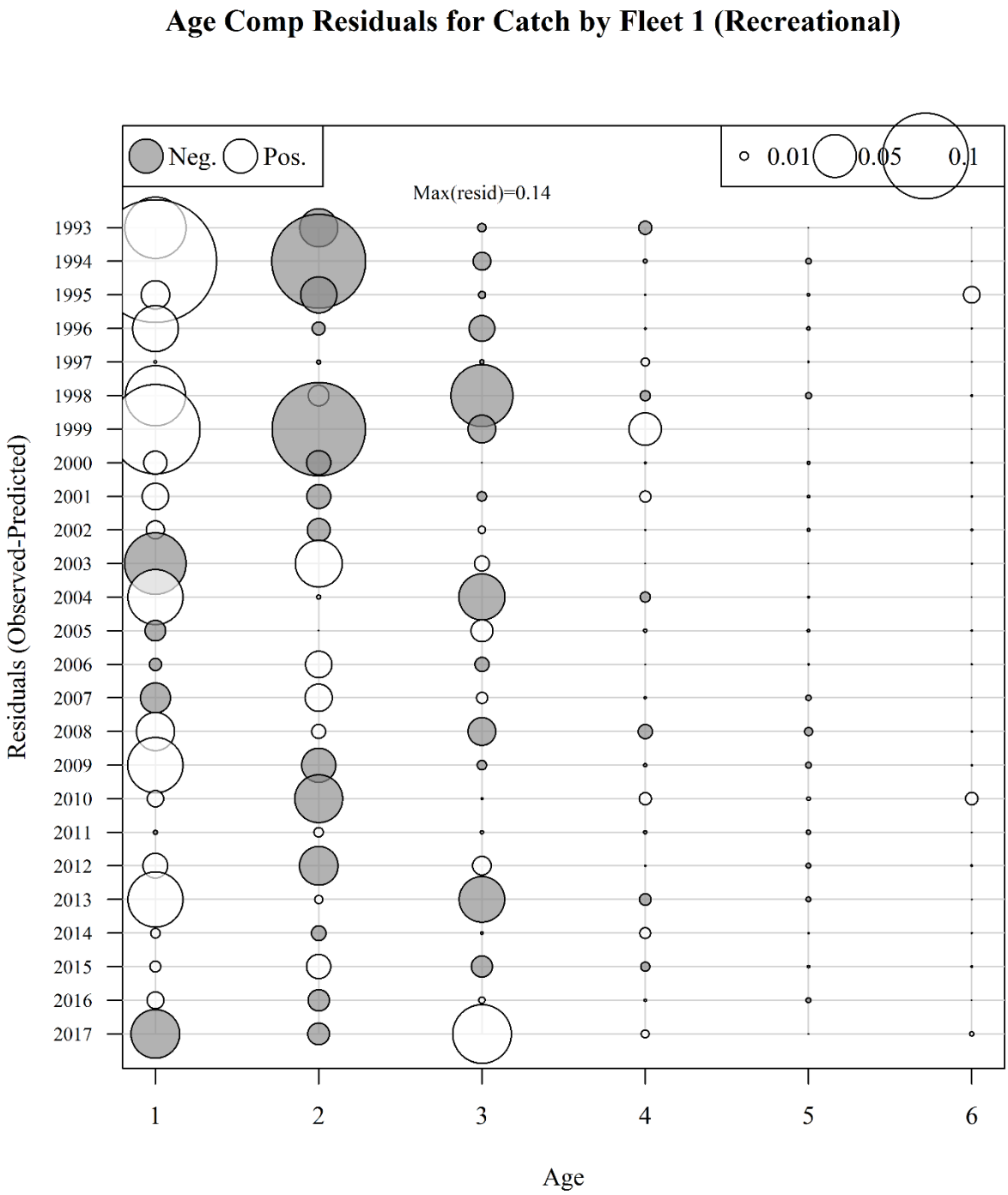


Figure 4.4a Age-specific residuals of the catch at age for the recreational Spotted Seatrout sector.

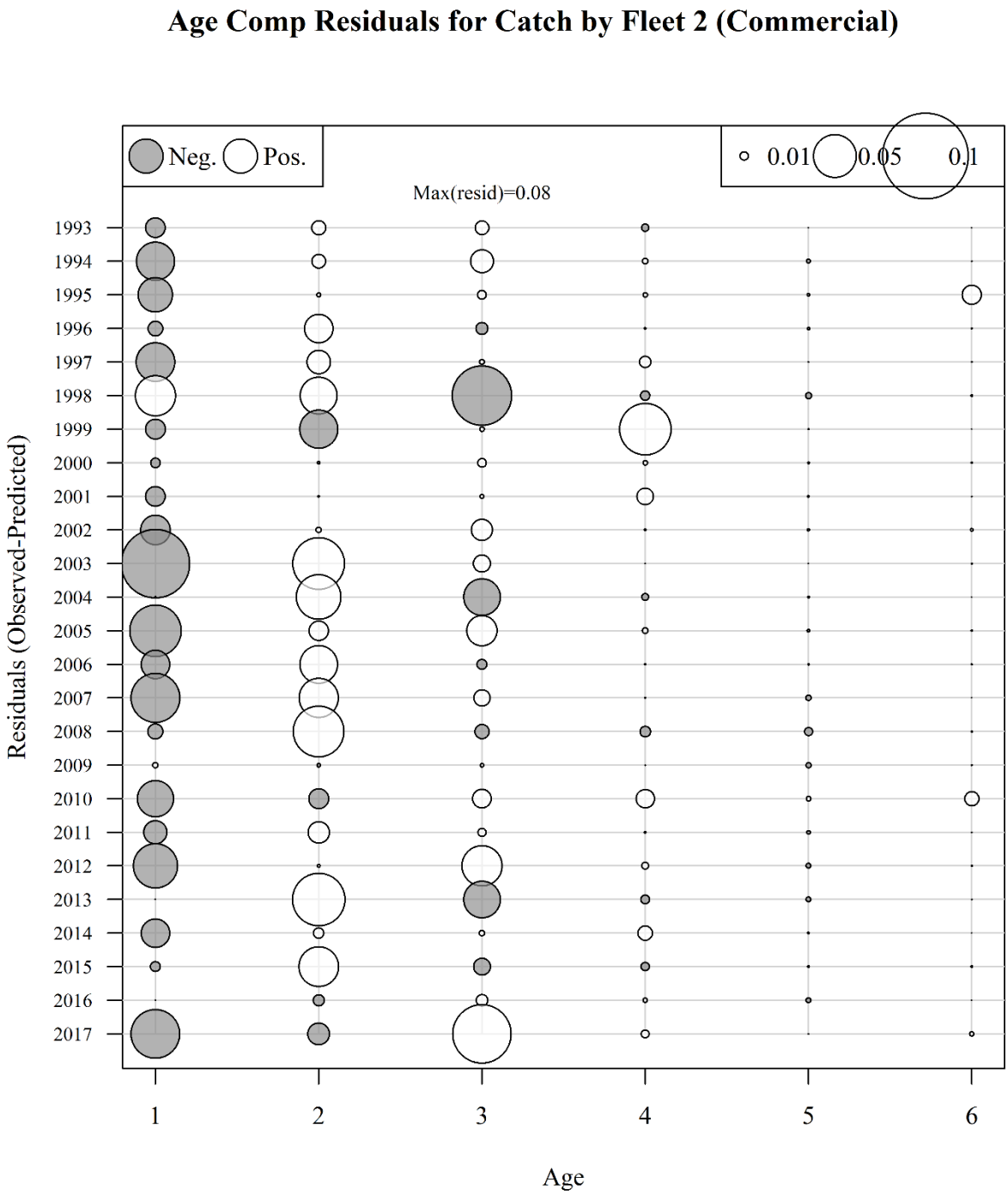


Figure 4.4b Age-specific residuals of the catch at age for the commercial Spotted Seatrout sector.

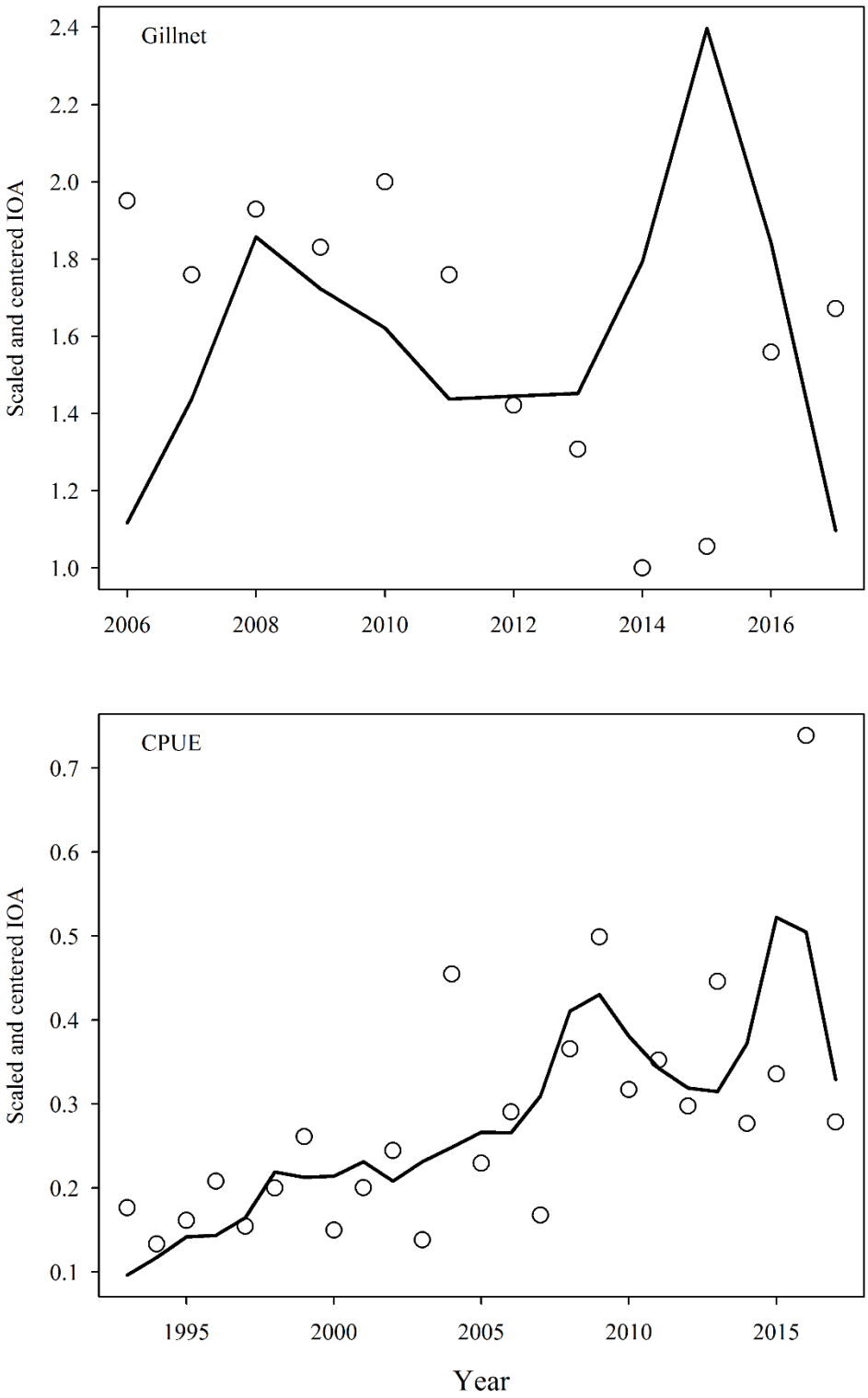


Figure 4.5 Observed (points) and predicted (lines) estimates of relative abundance for the MDMR and CFRD gillnet and MRIP Directed Trips indices.

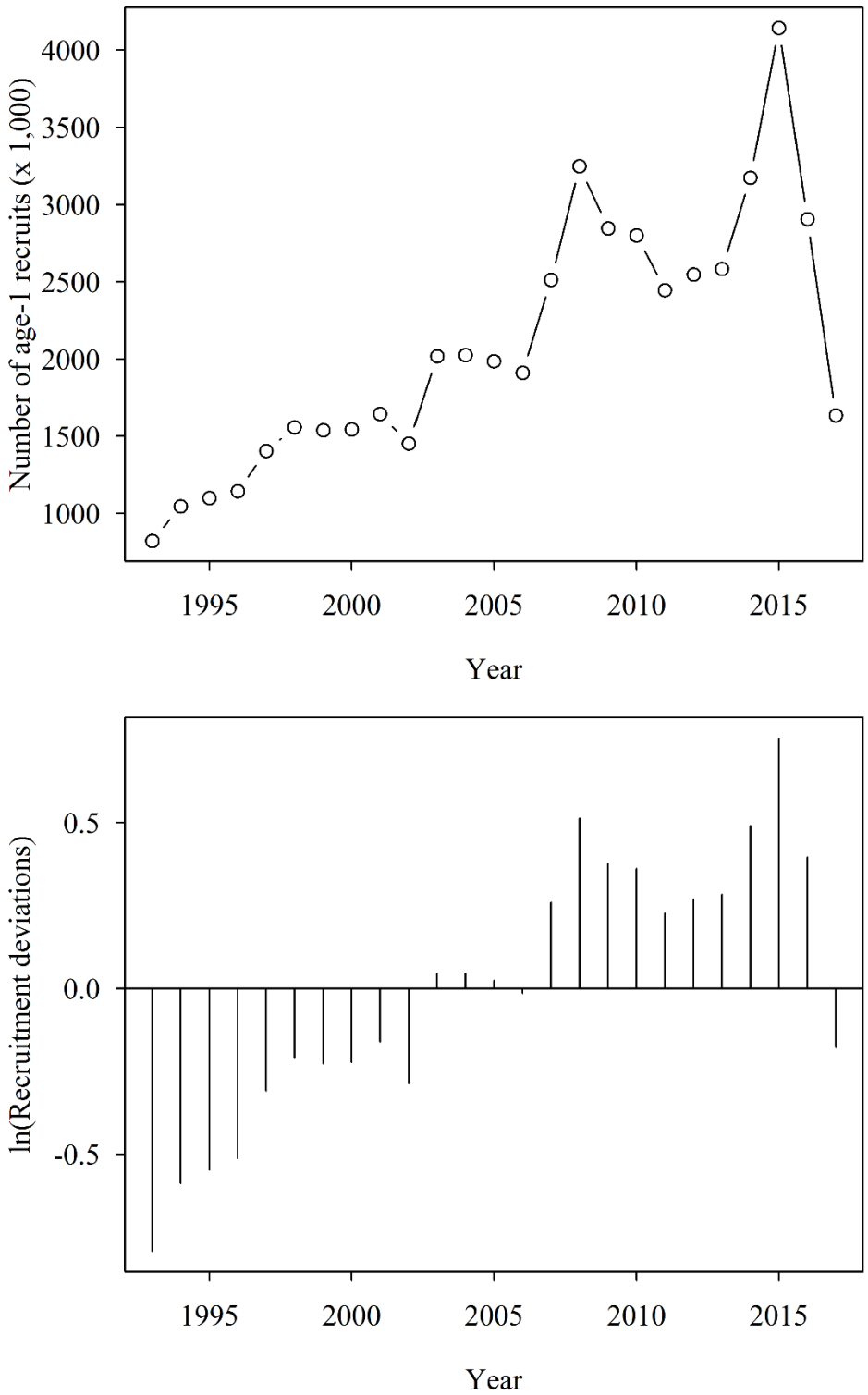


Figure 4.6 Estimated number of age-1 recruits and log transformed recruitment deviations.

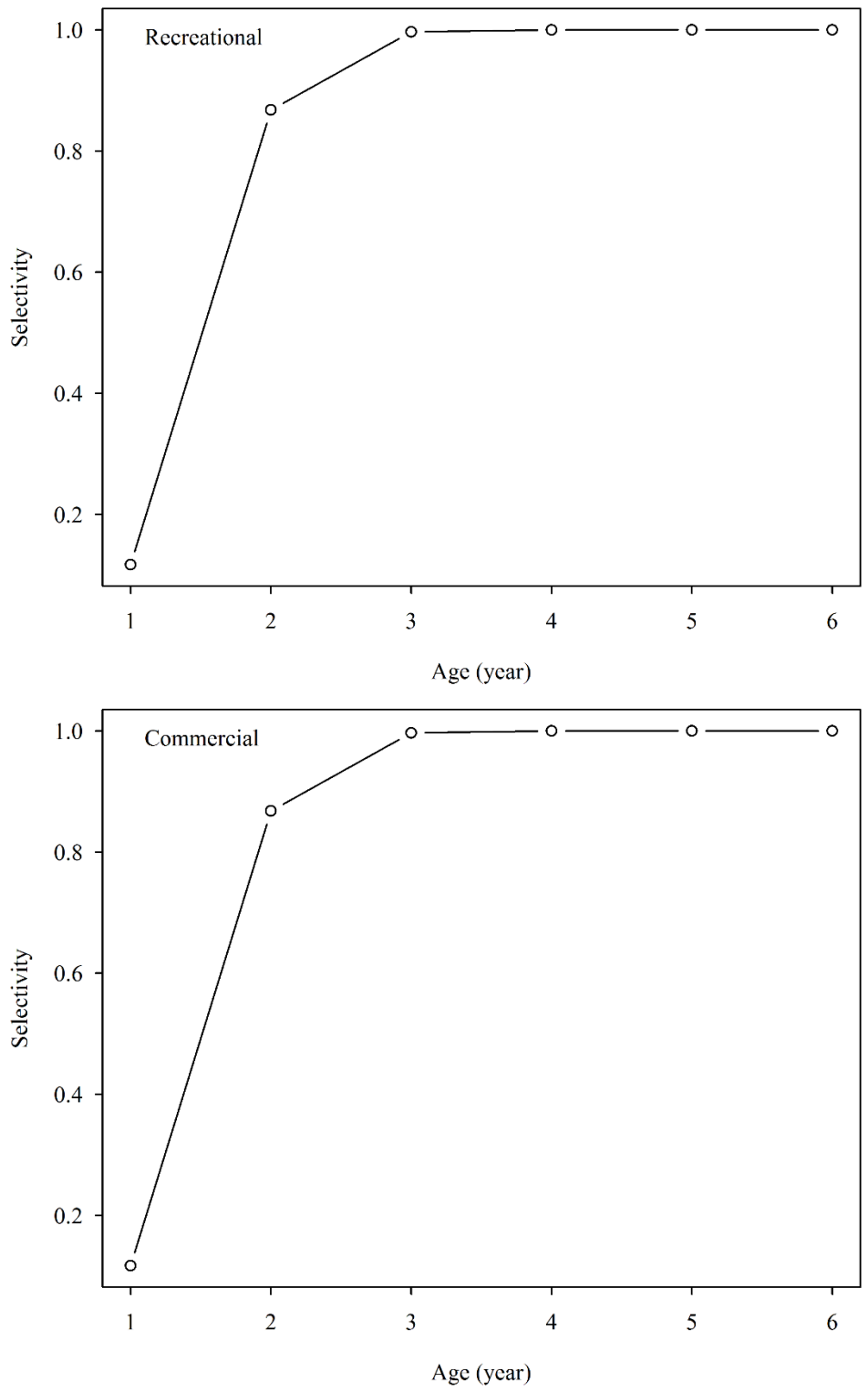


Figure 4.7 Estimated selectivity patterns of the recreational and commercial sectors. These did not vary annually and were identical for both sectors.

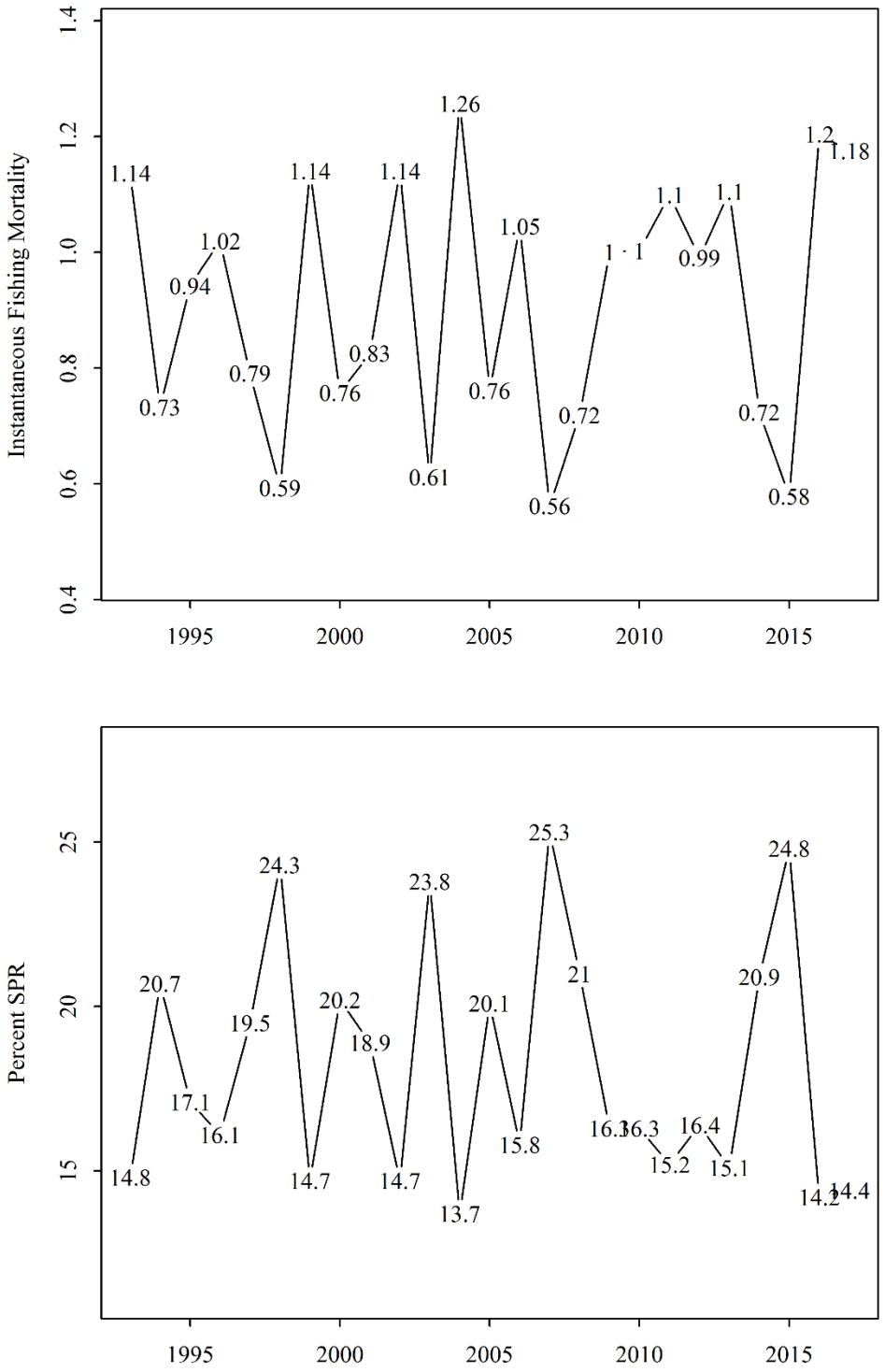


Figure 4.8 Time series of instantaneous fishing morality and percent spawner-per-recruit for the Mississippi SST stock.

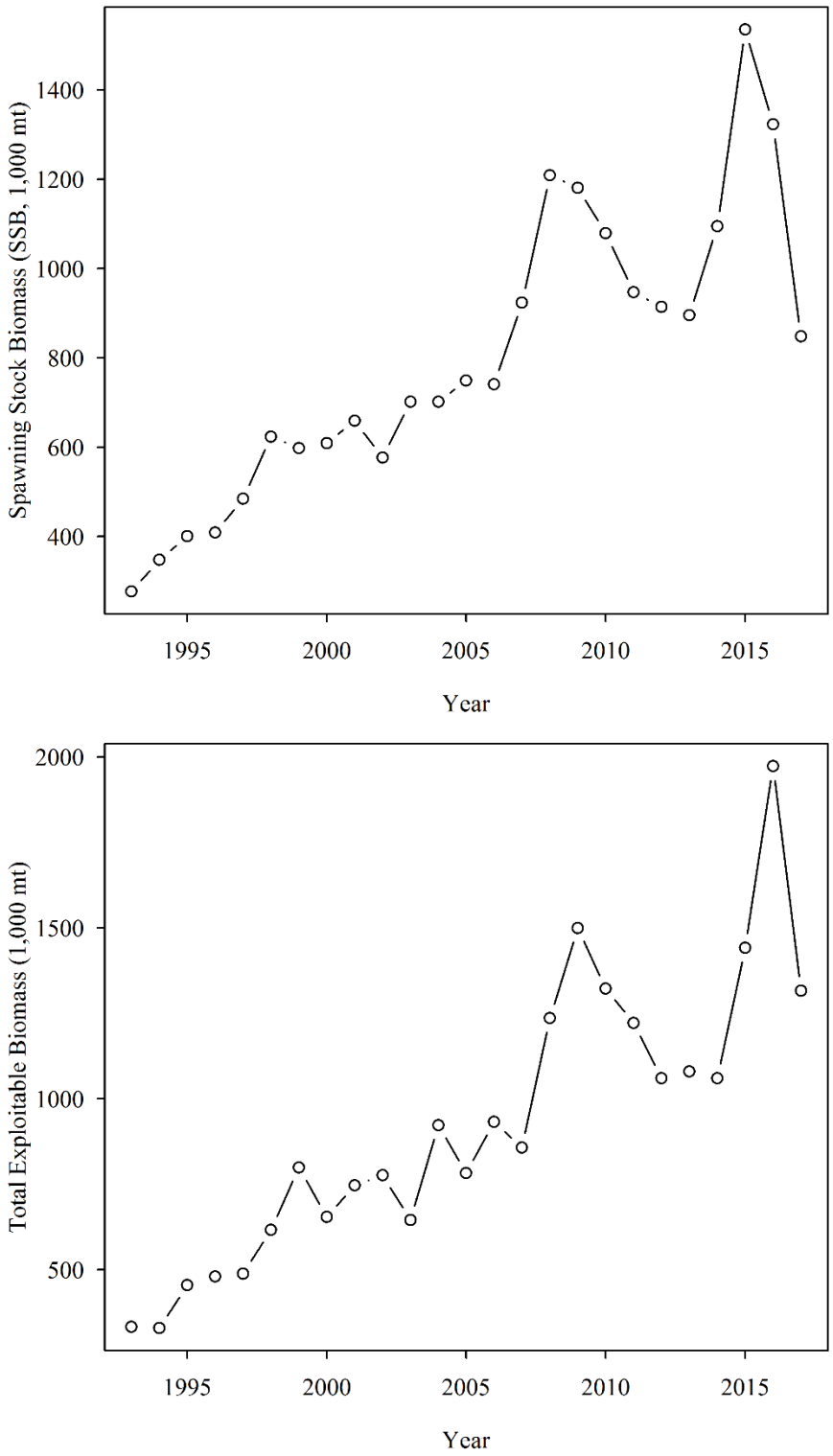


Figure 4.9 Predicted spawning stock biomass and total biomass of Mississippi's spotted seatrout.

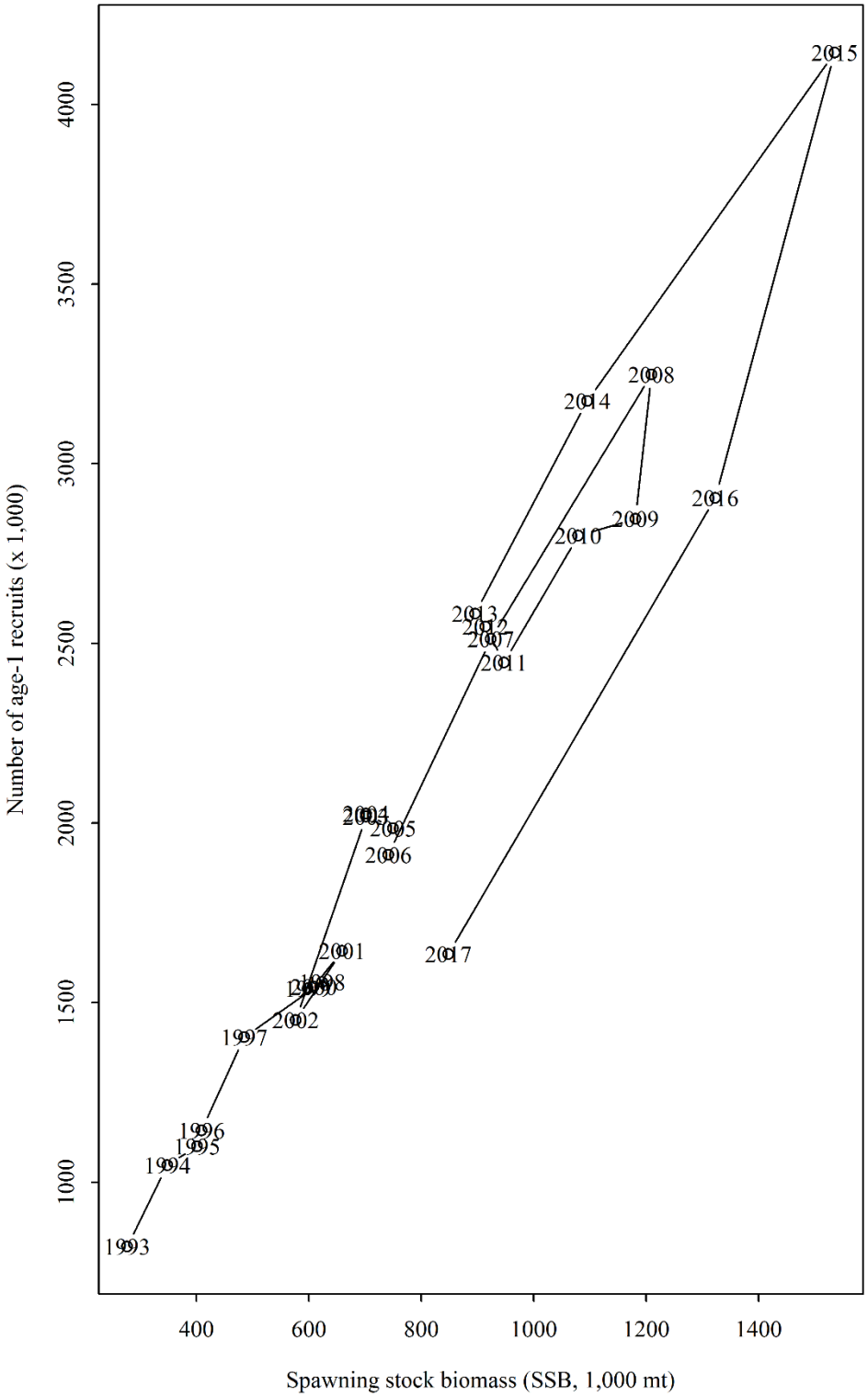


Figure 4.10 Time series of recruitment of age-1 fish as function of spawning stock biomass of the Mississippi SST stock.

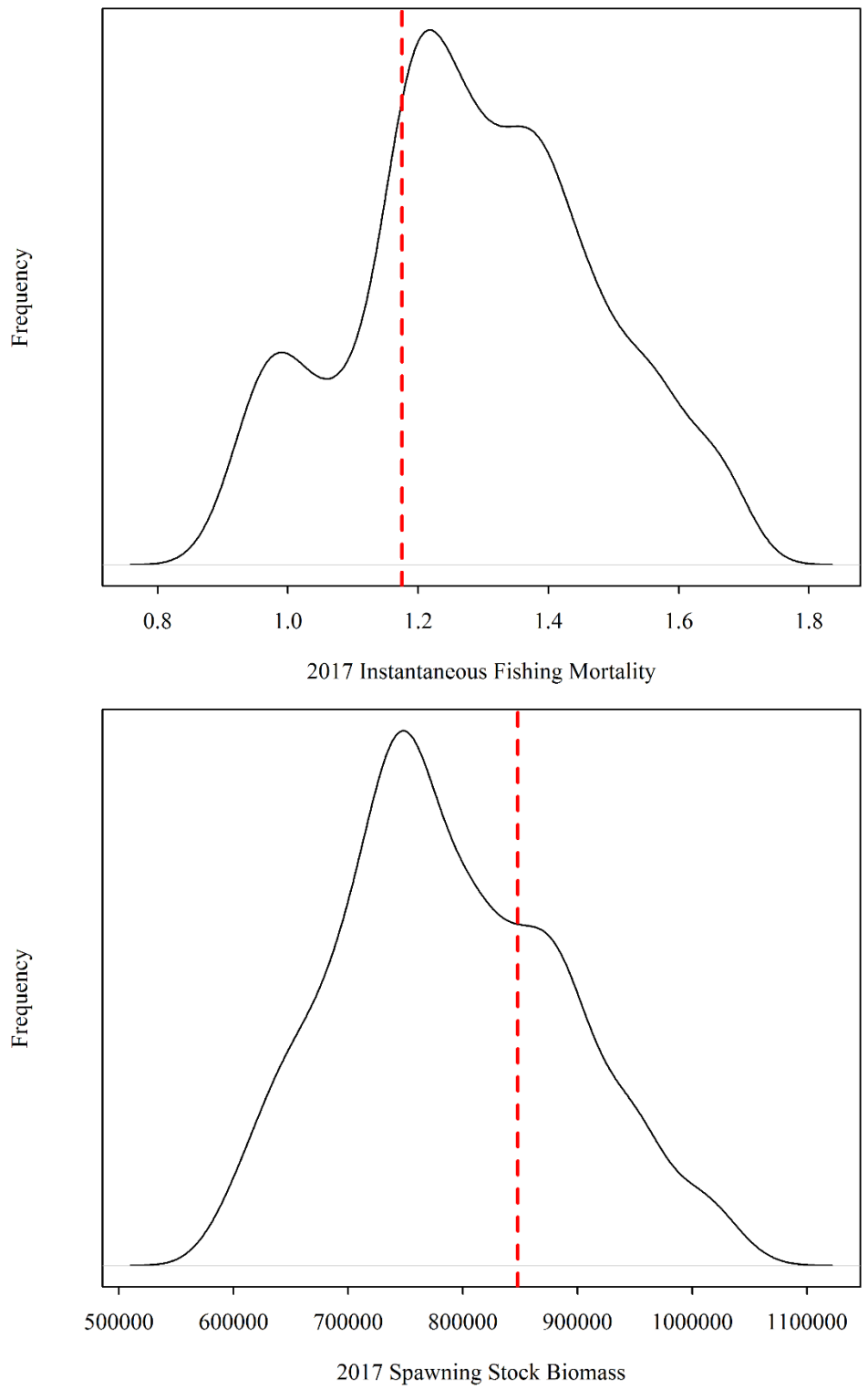


Figure 4.11a Multi-chain Monte Carlo estimates of terminal year instantaneous fishing mortality and spawning stock biomass.

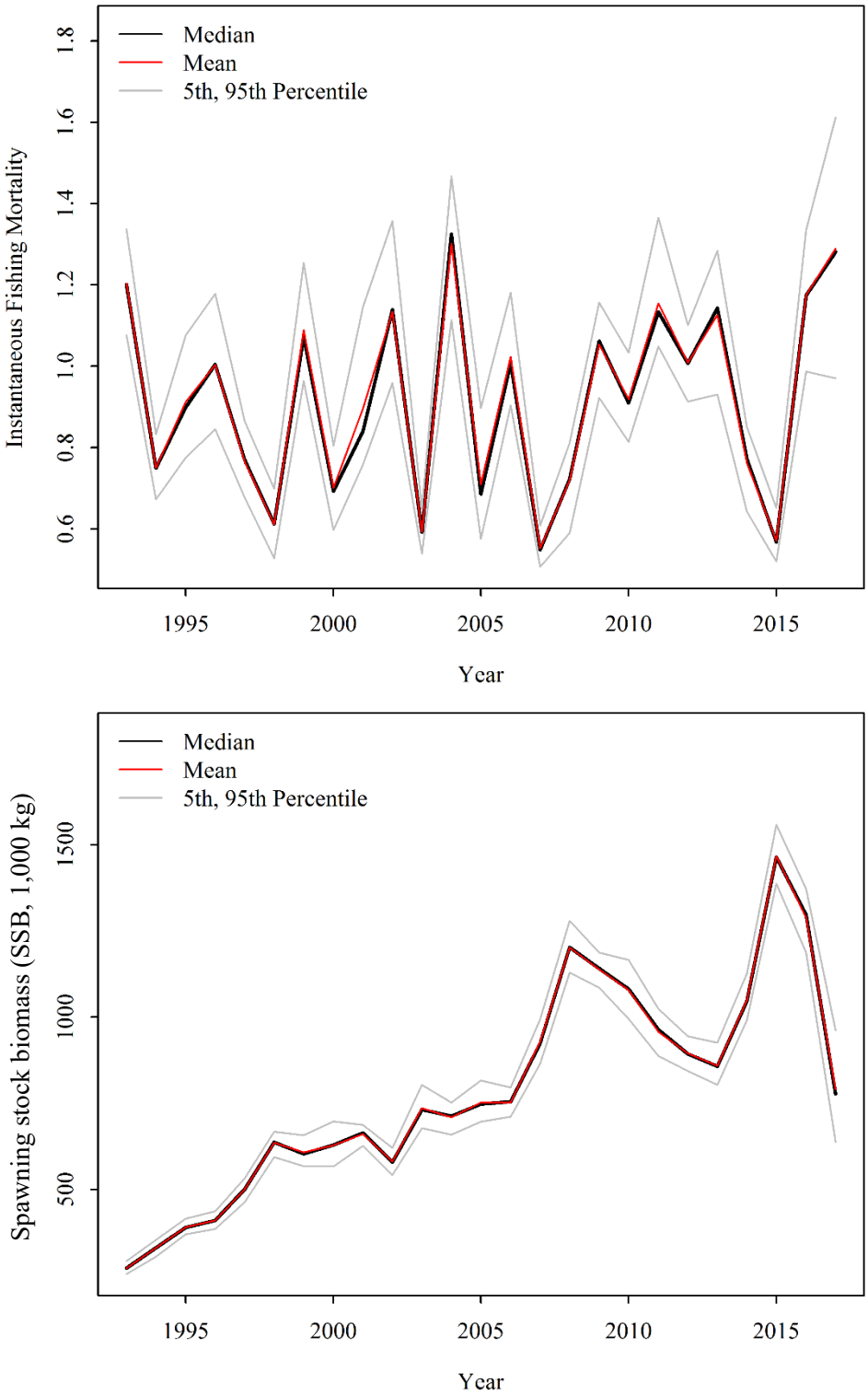


Figure 4.11b Monte Carlo derived uncertainty estimates of annual instantaneous fishing mortality and spawning stock biomass.

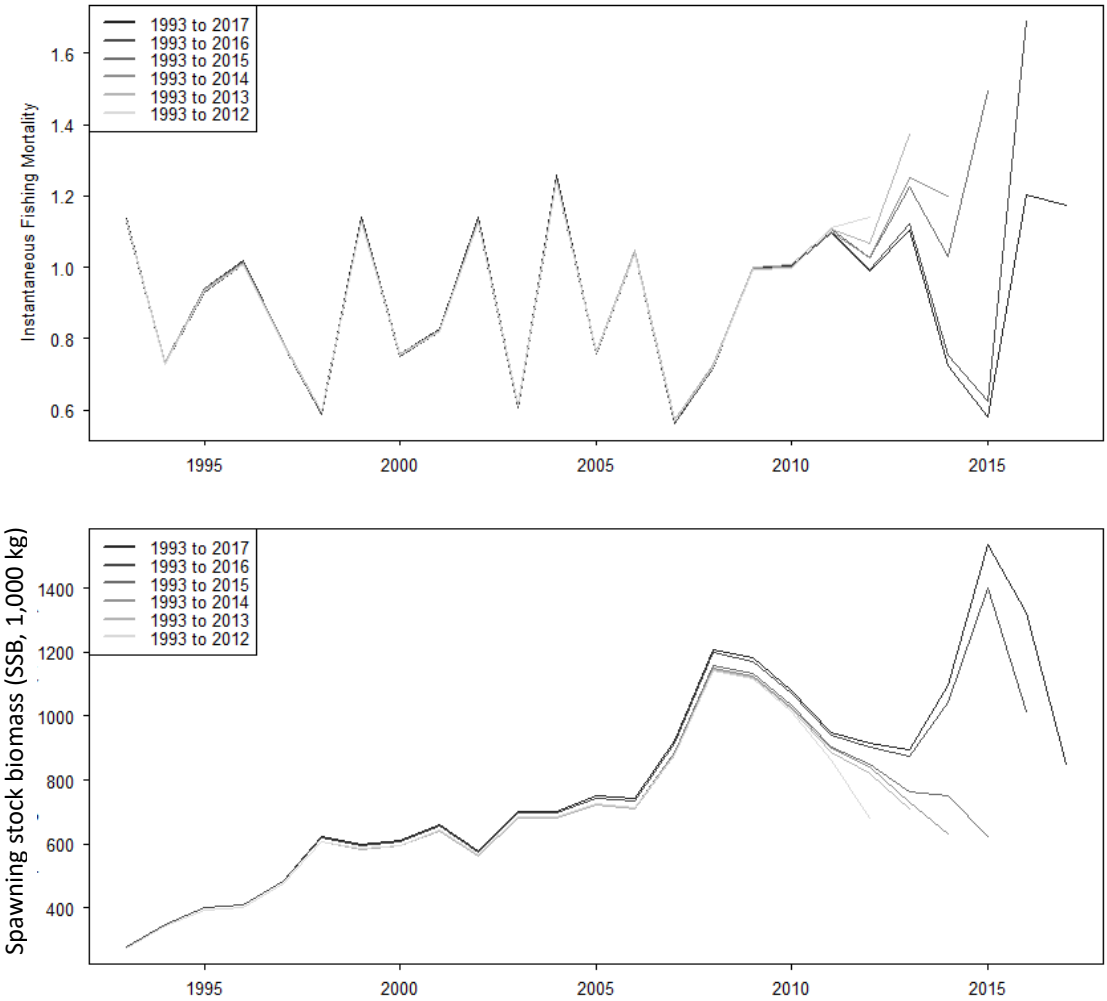


Figure 4.12 Retrospective analysis of the base model. Terminal years are sequentially removed in a series of runs. The time series 1993 to 2017 is the base model prediction.