Assessment of the Albemarle Sound-Roanoke River Striped Bass (*Morone saxatilis*) Stock in North Carolina, 1991–2021

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EXECUTIVE SUMMARY

The North Carolina Fisheries Reform Act requires that fishery management plans be developed for the state's commercially and recreationally important species to achieve sustainable levels of harvest. Stock assessments are the primary tools used by managers to assist in determining the status of stocks and developing appropriate management measures to ensure the long-term viability of stocks.

The Albemarle Sound-Roanoke River (A-R) Striped Bass stock is one of four Striped Bass stocks inhabiting the estuarine and inland waters of North Carolina. The A-R stock is jointly managed by the North Carolina Division of Marine Fisheries, the North Carolina Wildlife Resources Commission, and the South Atlantic Fisheries Coordination Office of the U.S. Fish and Wildlife Service under guidelines established in the Atlantic States Marine Fisheries Commission Interstate Fishery Management Plan (FMP) for Atlantic Striped Bass and the North Carolina Estuarine Striped Bass FMP.

A forward-projecting statistical catch-at-age model was applied to data characterizing landings/harvest, discards, fisheries-independent indices, and biological data collected from the 1991 through 2021 time period to assess the status of the A-R Striped Bass stock. Evaluation of the observed data and review of the predicted trends indicate concerning trends for the stock. Both observed and predicted recruitment have been declining and are relatively low in recent years. Female spawning stock biomass (SSB) has also been declining in recent years. Fisheries-dependent and fisheries-independent data indicate a recent truncation of both length and age structure.

Reference point thresholds for the A-R striped bass stock are based on 35% spawner potential ratio. The estimated threshold for female spawning stock biomass ($SSB_{Threshold}$ or $SSB_{35\%}$) was 125 metric tons. Terminal year (2021) female SSB was 16.1 metric tons, which is less than the threshold value and suggests the stock is currently overfished ($SSB_{2021} < SSB_{Threshold}$). The female SSB target (SSB_{Target} or $SSB_{45\%}$) was 164 metric tons. The assessment model estimated a value of 0.20 for the threshold fishing mortality ($F_{Threshold}$ or $F_{35\%}$). The estimated value of fishing mortality in the terminal year (2021) of the model was 0.77, which is greater than the threshold value and suggests that overfishing is currently occurring in the stock ($F_{2021} > F_{Threshold}$). The fishing mortality target (F_{Target} or $F_{45\%}$) was estimated at a value of 0.14.

This stock assessment represents an update of the benchmark stock assessment that was completed in 2020 and endorsed for management by an external panel of independent experts. Due to the depressed condition of the stock, the population will be monitored through an annual review of data and the stock assessment will be updated if warranted.

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1 INTRODUCTION

1.1 The Resource

The accepted common and scientific names for the species are Striped Bass, *Morone saxatilis* (Walbaum; Robins et al. 1991). In North Carolina it is also known as Striper, Rockfish, or Rock. Striped Bass naturally occur in fresh, brackish, and marine waters from Canada to the Gulf of Mexico. Due to their annual spawning migrations into freshwater, Striped Bass have been the focus of fisheries from North Carolina to New England for several centuries and have played an integral role in the development of numerous coastal communities. Striped Bass regulations in the United States date to pre-Colonial times (circa 1640) when Striped Bass were prohibited from being used as fertilizer (Nelson 2018).

The Albemarle Sound-Roanoke River (A-R) Striped Bass stock is managed jointly by the North Carolina Division of Marine Fisheries (NCDMF), the North Carolina Wildlife Resources Commission (NCWRC), and the South Atlantic Fisheries Coordination Office of the U.S. Fish and Wildlife Service under guidelines established in the Atlantic States Marine Fisheries Commission (ASMFC) Interstate Fishery Management Plan (FMP) for Atlantic Striped Bass (ASMFC 2022) and the North Carolina Estuarine Striped Bass FMP (NCDMF and NCWRC 2020). The Albemarle Sound Management Area (ASMA) includes Albemarle Sound and all of its joint and inland water tributaries, (except for the Roanoke, Middle, Eastmost, and Cashie rivers), Currituck Sound, Roanoke and Croatan sounds and all of their joint and inland water tributaries, including Oregon Inlet, north of a line from Roanoke Marshes Point to the north point of Eagle Nest Bay (Figure 1.1). The Roanoke River Management Area (RRMA) includes the Roanoke River and its joint and inland water tributaries, including Middle, Eastmost, and Cashie rivers, up to the Roanoke Rapids Lake Dam.

Details regarding the life history, habitat, fisheries, and fisheries management of A-R Striped Bass can be found in the previous stock assessment (Lee et al. 2020).

1.2 Previous Assessment (benchmark)

The previous NCDMF assessment of the A-R Striped Bass stock was a benchmark assessment (i.e., peer-reviewed by an external panel of experts) and was completed in 2020 (Lee et al. 2020). That assessment was based on a forward-projecting length-based, age-structured model and was run using the Stock Synthesis 3 (SS3) program (Methot and Wetzel 2013). The model was applied to data collected from 1991 through 2017 and incorporated four fishing fleets and four fisheries-independent survey indices, including one index of age-0 recruitment.

The external peer reviewers worked with the Striped Bass working group to develop a model that the peer review panel endorsed for management use for at least the next five years and agreed the determination of stock status (overfished and overfishing) for the North Carolina A-R Striped Bass in the terminal year (2017) concurred with professional opinion and observations.

The current stock assessment follows the methodology of the 2020 benchmark stock assessment. Any deviations from that methodology are noted in this report.

2 DATA

A complete description of the data sources that were used in the recent benchmark stock assessment and updated for use in this stock assessment can be found in Lee et al. (2020). Estimates of input values were developed following the same methodology as in that recent benchmark stock assessment unless otherwise noted in this report.

The occurrence of COVID-19 in 2020 and 2021 caused disruptions to some of the fisheries-dependent monitoring and fisheries-independent survey programs. The following sections describe how estimates were developed, if developed, if monitoring was interrupted due to COVID-19.

2.1 Fisheries-Dependent

2.1.1 Commercial Landings

No interruption to reporting of commercial landings or sampling of commercial landings occurred in 2020 or 2021.

2.1.2 Commercial Gill-Net Discards

Due to COVID-19 disruptions, NCDMF stopped the Onboard Observer Monitoring Program (Program 466) during March 2020 through 2021.

Note that since the benchmark stock assessment, this program was subject to intensive internal quality control measures to ensure the integrity of the data. This led to a modification to the estimation of commercial estuarine gill-net discards. Similar to the benchmark stock assessment, a generalized linear model (GLM) framework was used to estimate discards based on data collected during 2013 through 2020. A hindcast approach was used to estimate commercial discards for years prior to 2013. The ratio of live or dead discards in numbers to A-R gill-net landings was calculated by year for 2013 to 2020. As these ratios were variable among years, the working group decided to apply the median ratio over 2013 to 2020 separately for live and dead discards. The median ratio for either live or dead discards was multiplied by the commercial gill-net landings in 1991 to 2012 to estimate the live and dead commercial gill-net discards for those years. This was also done for 2021.

2.1.3 Albemarle Sound Recreational Fishery Monitoring

The ASMA striped bass creel survey was discontinued on 27 March 2020 due to Covid-19. The estimates of angler effort, catch, discards, and associated proportional standard errors (PSEs) for the months of January–March 2020 were calculated using the normal methodology as the survey design was not affected by the Covid-19 pandemic. Creel clerks did continue to monitor boat ramps during April 2020 for use in comparison of effort across years. Comparisons of effort and catch statistics were most similar for years 2018 and 2019; therefore, effort and catch statistics for April 2020 were derived from imputing April data during 2018 and 2019. Imputed data for April 2020 were the average of both expanded estimates and PSE values for 2018 and 2019.

2.1.4 Roanoke River Recreational Fishery Monitoring

The Roanoke River Striped Bass Creel Survey was modified in 2020 due to concerns with staff safety related to Covid-19. Normal creel survey methodology was used in the first two periods of the survey during March, and probability-based expansions were used to estimate harvest and discards for March. Angler interviews were not conducted during April or May, but clerks continued to count trailers at Roanoke River boat ramps to document usage as a proxy for effort estimates. Comparisons of trailer count data indicated that usage in April 2020 was most similar to 2015 and 2016. Thus, we used the mean harvest and discard estimates for April of those years as a proxy for April 2020. Discard estimates for May 2020 were not calculated.

Normal methods and estimate calculations resumed in 2021. Due to a reduced TAL in 2021, the harvest season was reduced to a full two months for the entire RRMA to only seven days (10–16 April) in the lower zone and seven days (24–30 April) in the upper zone. Interview sessions were conducted at one location each day of the harvest season, but sampling was conducted four days per week during the closed season (March through 22 May).

2.2 Fisheries-Independent

2.2.1 Juvenile Anadromous Survey (Program 100)

No interruption to sampling occurred in 2020 or 2021.

2.2.2 Striped Bass Independent Gill-Net Survey (Program 135)

No sampling occurred in 2020 due to COVID-19, but sampling resumed in 2021 without deviation from original sampling design or analysis.

2.2.3 Roanoke River Electrofishing Survey

No sampling occurred in 2020 due to COVID-19, but sampling resumed in 2021 without deviation from original sampling design or analysis.

3 ASSESSMENT

3.1 Method

3.1.1 Scope

The unit stock was defined as all Striped Bass within the ASMA and RRMA.

3.1.2 Description

This assessment is based on a forward-projecting length-based, age-structured model. A two-sex model is assumed. The stock was modeled using SS3 text version 3.30.19 software (Methot and Wetzel 2013; Methot et al. 2022). Stock Synthesis is an integrated statistical catch-at-age model that is widely used for stock assessments throughout the world. SS3 was also used to estimate values for established reference points. All SS3 model input files are available upon request.

3.1.3 Dimensions

The assessment model was applied to data collected from within the range of the assumed biological stock unit (ASMA-RRMA).

The time period modeled was 1991 through 2021 using an annual time step based on the calendar year. The year 1991 was selected as the start year because it was the earliest year for which landings from the Albemarle Sound recreational fleet were available (Lee et al. 2020). The terminal year, 2021, was selected because it was the most recent year for which data were available at the start of the assessment update process.

3.1.4 Structure & Configuration

3.1.4.1 Catch

The model incorporated four fishing fleets: ASMA commercial fishery (AScomm), ASMA recreational fishery (ASrec), the RRMA recreational fishery harvest only (RRrecharv), and the RRMA recreational fishery discards only (RRrecdisc). Landings (i.e., "retained" catch) were entered for AScomm (weight), ASrec (numbers), and RRrecharv (numbers; Table 3.1; Figure 3.1). Dead discards (in numbers) were entered for the RRrecdisc fleet (Table 3.2; Figure 3.2). Dead discards (in numbers) were also entered as a component of the AScomm and ASrec fleets. The decision to treat RRrecdisc as separate fleet rather than a component of the RRrecharv was due to difficulties in estimating selectivity for the RRMA recreational fishery when the discards were included (Lee et al. 2020).

3.1.4.2 Fisheries-Independent Survey Indices

Four indices of relative abundance were selected for input into the model. All indices were derived from fisheries-independent surveys (Figures 3.3–3.6). The index derived from the Program 100 Juvenile Trawl Survey (P100juv) was input as an index of age-0 recruitment and so associated biological data (lengths or ages) were not required as inputs into the model. Indices derived from the fall/winter component of the Program 135 Striped Bass Independent Gill-Net Survey (P135fw), the spring component of the Program 135 Striped Bass Independent Gill-Net Survey (P135spr), and the Roanoke River Electrofishing Survey (RRef) were also used.

Changes in indices over time can occur due to factors other than changes in abundance; the fisheries-independent indices were standardized using a GLM approach to attempt to remove the impact of some of these factors (Maunder and Punt 2004). Catchability (q) was assumed to be time-invariant for each survey and was estimated within the model. All indices were assumed to have a nonlinear relation to abundance, requiring an additional parameter to be estimated (survey 'power') for each index.

3.1.4.3 Length Composition

Annual length frequencies were input for each fleet's landings and discards for the years in which lengths were available for the particular fleet. Annual length frequencies characterizing the P135fw, P135spr, and RRef surveys were also input. Where possible, sex-specific length frequencies were used. Length frequencies were input by 2-cm length bins ranging from 10 cm to 130 cm TL.

3.1.4.4 Age Data

Annual sex-specific age data were input for the AScomm landings as well as the P135fw, P135spr, and RRef surveys. The age data were input as raw age-at-length data, rather than age compositions generated from applying age-length keys to the catch-at-length compositions. The input compositions are therefore the distribution of ages obtained from samples in each length bin (conditional age-at-length). This approach is considered a superior approach because it avoids double use of fish for both age and length information, it contains more detailed information about the age-length relationship and so improves the estimation of growth parameters, and the approach can match the protocols of sampling programs where age data are collected in a length-stratified program (Methot et al. 2022). Making the age composition data conditional on length also has the advantage of linking age data directly to the length data (essentially creating an age-length key) and so provides more detailed information about the relationship between length and age, enhancing the ability to estimate growth parameters (Cass-Calay et al. 2014).

Age 15 was treated as a plus group that included ages 15 through 17, the maximum age within the data input into the stock assessment model. Ages were assumed to be associated with small bias and negligible imprecision.

3.1.4.5 Biological Parameters

Natural Mortality

Natural mortality is one of the most important parameters in a stock assessment and one of the most difficult to estimate. Based on a series of sensitivity runs and discussions with the peer review panel during the benchmark assessment, it was decided to assume a value of 0.40 for use in the base run. This value was selected from the range estimated based on the species life history. The value was assumed for both sexes and treated as an age-invariant, fixed input.

Growth

Growth (age-length) was assumed to be sex specific and was modeled using the von Bertalanffy growth curve. In the SS3 model, when fish recruit at the real age of 0.0, their length is set equal to the lower edge of the first population length bin (here, 10 cm; Methot et al. 2022). Fish then grow linearly until they reach a real age equal to a user-specified age (here, age 1). As the fish continue to age, they grow according to the von Bertalanffy growth equation.

Allowing SS3 to estimate the growth curve ensures that the assumptions about selectivity are consistent with other parts of the model and that uncertainty in the growth estimates is incorporated into the estimates of spawning stock biomass, fishing mortality, and reference points (Hall 2013). All age-length growth parameters were estimated for both sexes. The estimated growth parameters for each sex were length at age 1 ($L1$), L_∞, K, coefficient of variation (CV) for $L1$ (CV1), and CV for L_∞ (CV2). Initial values for growth parameter estimates were derived by externally fitting the von Bertalanffy model to the available age-length data by sex (Table 3.3; Figures 3.7 and 3.8). These initial values were treated as informative priors (prior standard deviation=0.05 for $L1$, L_∞, and K; prior standard deviation=0.8 for CV1 and CV2) assuming a normal distribution. Examination of the observed data was used to set reasonable bounds on all growth parameters for males and females.

Parameters of the length-weight relationship were fixed (i.e., not estimated) for both males and females. The assumed values were estimated external to the model (Table 3.4; Figures 3.9 and 3.10).

Maturity & Reproduction

Female maturity at age as estimated by Boyd (2011; Table 3.5) was treated as a fixed input in the model. Reproduction was assumed to occur on January 1 each year.

Fecundity

The SS3 model allows several options for relating fecundity to body size (length or weight). Empirical parameter values describing a linear or non-linear relationship to length or weight can be entered. Alternatively, the user can specify that either eggs or fecundity is equivalent to spawning biomass. Here, the selected fecundity option was that which causes eggs to be equivalent to spawning biomass.

3.1.4.6 Stock-Recruitment

A Beverton-Holt stock-recruitment relationship was assumed. Virgin recruitment, R_0, was estimated within the model. Steepness, *h*, was fixed at 0.9 and the standard deviation of log(recruitment), σ_R, was fixed at 0.6. Recruitment deviations were estimated from 1974 to 2021. The deviations were assumed to sum to zero over this time period. Setting the first year in which to estimate recruitment deviations (1974) earlier than the model start year (1991) allows for a non-equilibrium age structure at the start of the assessment time series (Methot et al. 2022).

3.1.4.7 Fishing Mortality

SS3 allows several options for reporting fishing mortality (*F*). The *F* values reported here represent a real annual *F* calculated as a numbers-weighted *F* (see Methot et al. 2022) for ages 3–5. This age range was selected based on the high selectivity for this age range by the fleets and the large percentage of the total catch this age range comprises.

3.1.4.8 Selectivity

Selectivity can be cast as length or age specific in the SS3 model. As the length data were considered more reliable, the length-specific option was chosen for both fleets and the fisheries-independent surveys. Retention for the fleets was also assumed to be a function of length (the only option for retention parameters in SS3).

Selectivity patterns for the ASrec, RRrecharv, and RRrecdisc fleets as well as the P135spr and RRef surveys were modeled using the recommended double normal curve. The selectivity parameters for the RRrecharv fleet were fixed to match the protective slot limit. Due to the highly skewed sex ratio and different length frequency patterns between female and male Striped Bass observed in the RRef survey, the SS3 model was configured to allow different selectivity patterns for females and males in this survey. Specifically, the male selectivity parameters were modeled as an offset of the female selectivity parameters. Selectivity for the AScomm fleet and the P135fw survey were modeled using the cubic spline. The SS3 model automatically imposes a symmetric beta prior on cubic spline selectivity parameters.

3.1.4.9 Equilibrium Catch

The SS3 model needs to assume an initial condition of the population dynamics for the period prior to the estimation period. Typically, two approaches are used to meet this assumption. The first approach starts the model as far back as necessary to satisfy the notion that the period prior to the estimation of dynamics was in an unfished or near unfished state. For Striped Bass, reliable catch records back to the start of the fishery are not available. For this reason, the model developer recommended use of the second approach, which is to estimate (where possible) initial conditions assuming equilibrium catch (R.D. Methot Jr., NOAA Fisheries, personal communication). The equilibrium catch is the catch taken from a fish stock when it is in equilibrium with removals and natural mortality balanced by stable recruitment and growth.

The SS3 model estimates initial equilibrium catch and initial fishing mortality for each fleet. The initial fishing mortality rates are estimated based on the level of initial equilibrium catch for each fleet. Providing an initial equilibrium catch allows the model to start in a fished state prior to the start year. For all fleets, the starting value provided to the model for initial equilibrium catch was set as half of the minimum observed annual removals over the 1991- to 2021-time period and associated with a standard error, SE, equal to 0.20. The starting value for the initial fishing mortality of all fleets was set at 0.1.

3.1.5 Optimization

The SS3 model assumes an error distribution for each data component and assigns a variance to each observation. The AScomm landings, ASrec and RRrecharv harvests, and RRrecdisc discards were fit in the model assuming a lognormal error structure. These data were assumed precise and assigned a minimal observation error. The standard errors (SEs) of the annual AScomm landings were assumed equal to 0.02 prior to the start of the NCDMF Trip Ticket program (1994) and were assumed equal to 0.01 for the remainder of the time series. As the commercial landings data are derived from a census and recreational data are derived from a survey, a slightly higher standard error was assumed for the annual ASrec and RRrecharv harvest estimates (SE = 0.02). The RRrecdisc discard estimates were based on a hindcast method in earlier years (1991–1995) of the time series and were assumed to have a SE equal to 0.06. Discard estimates from this fleet in subsequent years were assumed to have a SE equal to 0.04.

As dead discards are part of the overall total removals, they were also assumed to be precise, though were assumed to have higher variance than the landings and harvest due to the increased uncertainty in the estimation methods. AScomm discard estimates were based on a hindcast method for 1991 through 2012 and 2021 and were assumed to have a CV equal to 0.08. AScomm discards in the remaining years of the time series were assumed to have a CV equal to 0.04. The CV values for discards from the ASrec fleet were assume equal to 0.04 in all years of the time series. A normal distribution was assumed for the error structure of the discards for each fleet.

Survey indices were fit assuming a lognormal error distribution with variance estimated from the GLM standardization.

Composition information was fit assuming a multinomial error structure with variance described by the effective sample size. For each fleet and survey, the effective sample size was the number of sampled trips and a maximum of 200 was imposed.

Priors were assumed for the von Bertalanffy growth parameters (see section 3.1.4.5). Priors were also assumed for the AScomm fleet and the P135fw survey selectivity parameters (see section 3.1.4.8). Bounds (minimum and maximum values) were established on all estimated parameters to prevent estimation of unrealistic parameter values and convergence problems (Table 3.6).

The objective function for the base model included likelihood contributions from the landings and harvest, discards, survey indices, length compositions, age data, and recruitment deviations. The total likelihood is the weighted sum of the individual components. All likelihood components with the exception of the age data, were initially assigned a lambda weight equal to 1.0. Based on a recommendation from the model developer, the likelihood components for the age data were reduced to 0.25 (R.D. Methot Jr., NOAA Fisheries, personal communication).

The model results are dependent, sometimes highly, on the weighting of each data set (Francis 2011). Francis (2011) points out that there is wide agreement on the importance of weighting, but there is lack of consensus as to how it should be addressed. In integrated models that use multiple data sets, it is not uncommon for the composition data to drive the estimation of absolute abundance when inappropriate data weightings are applied or the selectivity process is miss-specified (Lee et al. 2014). Francis (2011) argues that abundance information should primarily come from indices of abundance and not from composition data. Following the recommendation of Francis (2011), the model was weighted in two stages. Stage 1 weights were largely empirically derived (standard errors, CVs, and effective sample sizes described earlier in this section) and applied to individual data observations. Stage 2 weights were applied to reweight the length and age composition data by adjusting the input effective sample sizes. The stage 2 weights were estimated based on method TA1.8 (Appendix A in Francis 2011) using the SSMethod.TA1.8 function within the r4ss package (Taylor et al. 2021) in R (R Core Team 2022).

3.1.6 Diagnostics

Several approaches were used to assess model convergence. The first diagnostic was to check whether the Hessian matrix (i.e., matrix of second derivatives of the likelihood with respect to the parameters) inverted. Next, the model convergence level was compared to the convergence criteria (0.0001, common default value). Ideally, the model convergence level will be less than the criteria. The values of estimated parameters were checked to see if they were estimated at a bound, which could indicate problems with the data or model structure (Carvalho et al. 2021). The correlation matrix was examined to identify highly correlated (e.g., >0.95) parameter pairs. High correlation among parameters can be indicative of poor model stability. Parameters were examined for excessively high variance (>50% PSE), which is an indication that the associated parameter does not influence the fit to the data.

Model stability was further evaluated using a "jitter" analysis. This analysis is a built-in feature of SS3 in which the initial parameter values are varied by a user-specified fraction. This allows evaluation of varying input parameter values on model results to ensure the model has converged on a global solution. A model that is well behaved should converge on a global solution across a reasonable range of initial parameter estimates (Cass-Calay et al. 2014). Initial parameters were randomly jittered by 10% for a series of 100 random trials. The r4ss package (Taylor et al. 2021) in R (R Core Team 2022) provides tools for automating the jitter analysis and was used for the current stock assessment.

Additional diagnostics included evaluation of fits to landings and harvest, discards, indices, length compositions, mean lengths, and comparison of predicted growth parameters to empirical values. The evaluation of fits to the various data components included a visual comparison of observed and predicted values and calculation of standardized residuals for the fits to the fisheries-independent survey indices, length composition data, and mean lengths. The standardized residuals were first visually inspected to evaluate whether any obvious patterns were present. In a model that is fit well, there should be no apparent pattern in the standardized residuals. If most of the residuals are within one standard deviation of the observed value, there is evidence of under-dispersion. This is indicative of a good predictive model for the data. That is, the model is fitting the data much better than expected, given the assumed sample size.

In a model that is fit well, there should be no apparent trend in the residuals over time. This can be confirmed via the runs test, which was applied to the residuals of the fits to the fisheries-independent survey indices and all estimates of mean lengths using tools in the ss3diags package (Winker et al. 2022). Outliers in the residuals can be detected using the three-sigma limit to identify whether any data point would be unlikely given a random process error in the observed residual distribution if it is further than three standard deviations away from the expected residual process average of zero (see details in Anhøj and Olesen, 2014, cited in Carvalho et al. 2021).

3.1.7 Uncertainty & Sensitivity Analyses

3.1.7.1 Contribution of Fisheries-Independent Data Sources

Uncertainty can also be explored by assessing the contribution of each source of information to the model results (Methot 1990). A data-exclusion technique known as the jack-knife approach was applied in which individual data sources were excluded from the model, which is then rerun with the remaining data. The results give an indication as to whether any single data source is having a strong influence on the model and causing conflicts with other data in terms of estimating parameters. The jack-knife analysis was applied to fisheries-independent data only as the fisheries-dependent data were considered fundamental to stabilizing the stock assessment model. In each jack-knife run, one of the fisheries-independent surveys was excluded from the model; specifically, the index and all associated biological data were effectively removed by changing the weights of the associated likelihood components to 0.0.

3.1.7.2 Alternative Natural Mortality

Natural mortality was assumed to be constant across sexes and ages in the final base run (M = 0.40; section 3.1.4.5); however, natural mortality that varies by sex and age may be more realistic. In one sensitivity run, natural mortality was assumed equal to the values derived using the Lorenzen (1996) approach (assumed sex-specific and age-variable; Table 3.7). Additionally, a run was performed in which natural mortality was assumed equal to the empirical estimate of 0.72 derived from the Harris and Hightower (2017) study (assumed sex- and age-constant). Finally, a run was performed in which natural mortality was assumed equal to 0.30 to provide a run that used a lower range value for natural mortality (assumed sex- and age-constant).

3.1.7.3 Ageing Error and Bias

Ageing error was assumed to be low and constant across sexes and ages in the final bas run (SD = 0.001) with no ageing bias. Given the assessment was built on ageing data from Striped Bass scales, these assumptions could impact the model. Error and bias have been well documented to increase in studies that rely on ages from scales rather than otoliths for many species, including Striped Bass (Secor et al. 1995; Liao et al. 2012; Schlick and De Mutsert 2018). Commonly, scales can bias younger fish with older ages and older fish with younger ages (Liao et al. 2012; Schlick and De Mutsert 2018). When these biases were used in a catch-at-age model, Liao et al. (2012) found that female SSB was underestimated by 19% and F was overestimated by 19%.

Estimates of female SSB and F did not change relative to the base run until the ageing error was increased to a standard deviation (SD) = 0.4 and the model no longer converged at an ageing error of SD = 0.8. Thus, a low medium error of SD = 0.5 and a high error of SD = 0.7 were chosen for this sensitivity analysis. Ageing bias for scales usually occurs with younger fish being overaged and older fish being underaged. This process was mimicked in two runs using an inverted bell curve with the two extremes adding 1 year or 2 years and zero bias around age 7. Also, additional bias runs of +/- 0.5 year and +/- 1 year were also examined. Based on the successful converged error and bias runs, a combination of a medium (SD = 0.5) and high error (SD = 0.7) were paired with varying errors (+/- 0.5 year, +/- 1 year, 1-year inverted bell curve, and 2-year inverted bell curve) to examine confounding impacts from both factors on the model performance.

3.1.8 Results

A summary of the input data used in the base run of the Striped Bass stock assessment model is shown in Figure 3.11.

3.1.8.1 Base Run—Diagnostics

The final base run resulted in an inverted Hessian matrix with a convergence level of 0.000653688. This value was higher than the recommended convergence criteria, which was set at 0.0001. Note that successful model outcomes can be achieved despite larger final gradients (Carvalho et al. 2021). Five of 115 active parameters estimated at their bounds (Table 3.8): CV2 for females, CV2 for males, initial equilibrium F for the RRrec discard fleet, initial equilibrium F for the ASrec fleet, and one of the selectivity parameters for the AScomm fleet (SizeSpline_GradHi). Five parameter pairs were found to be highly correlated (>0.95; Table 3.9). Estimated values of ten parameters were associated with excessively high variance (>50% PSE; Table 3.8).

Seventy-six of the 100 jitter runs successfully converged and forty-three had the same likelihood value as the base run (Figure 3.12). Two jitter runs were excluded due to excessively large likelihood values (>50,000). None of the converged jitter runs resulted in a likelihood value that was lower than the base run, indicating that the model came to a global solution. The majority of the converged runs produced similar trends in female SSB and *F* to the base run (Figure 3.13).

There is near identical agreement between observed and predicted landings and harvest for the AScomm, ASrec, and RRrec fleets (Figure 3.14). This is not unexpected given the small amount of error assumed for these data (section 3.1.5). The SS3 model tended to underestimate discards for the AScomm fleet (Figure 3.15A). For the ASrec discards, the model overestimated in some years and underestimated in others (Figure 3.15B). The RRrec discards were fit well by the model (Figure 3.15C).

Model fits to the fisheries-independent survey indices are fair (Figures 3.16–3.19). While the model captured the overall trends in the observed indices, it failed to capture the interannual variability seen in the observed data. The standardized residuals for the P100juv (Figure 3.16), P135fw (Figure 3.17), and P135spr (Figure 3.18) surveys do not exhibit any significant temporal trends and this was confirmed by the runs test; however, the standardized residuals for the RRef survey were found to exhibit a significant temporal trend over the time series (Figure 3.19). Nearly all of the standardized residuals from the fisheries-independent indices are within the three-sigma limit, with the exception of the 1994 standardized residual for the P135spr survey (Figure 3.18).

The fits to the length compositions aggregated across time appear reasonable for most of the fleets and surveys with the exception of the fit to the AScomm discard lengths (Figure 3.20). This poor fit is likely due, in part, to the small effective sample sizes associated with the AScomm discard length compositions. Examination of the fits to the length composition data by individual year indicates fits ranging from good to poor (Figures 3.21–3.35). Again, the poor fit to the AScomm discard lengths is evident (Figure 3.23). The presence of bimodality in the P135fw survey lengths provided some difficulty in model fitting (Figures 3.30 and 3.31). This was also true for the P135spr survey lengths (Figures 3.32 and 3.33). Residuals from the fits to the length composition data for the different data sources are shown in Figures 3.36–3.44. The length compositions residuals from all data sources demonstrate strong patterns indicating problems with the model fits to the observed data.

Observed and predicted mean lengths were derived from observed and expected length-composition data. Plots of observed and predicted mean lengths along with the associated runs test plots are shown in Figures 3.45–3.51. Fits to the length composition data from the fleets are generally poor and demonstrate significant temporal trends in the residuals (Figures 3.45–3.48). The residuals for the length compositions from the fleets all exhibit at least one residual exceeding the three-sigma limit. The model performed better in fitting the fisheries-independent survey length compositions (Figures 3.49–3.51). Of all the residuals from the fisheries-independent survey length compositions, only those from the P135spr survey failed the runs test (Figure 3.50). Some outliers are also apparent in the P135spr survey length composition residuals (Figure 3.50) and one outlier is evident in the RRef length composition residuals. (Figure 3.51).

Most of the von Bertalanffy age-length growth parameter values estimated by SS3 were similar to those derived empirically (Table 3.10) resulting in nearly identical growth curves derived from the two approaches (Figure 3.20).

3.1.8.2 Base Run—Selectivity and Population Estimates

The predicted selectivity curves are shown in Figures 3.53–3.55 and are considered reasonable.

Annual predicted recruitment is variable among years and demonstrates a general decrease over the time series (Table 3.11; Figure 3.56). Predicted recruitment deviations are shown in Figure 3.57 and show a substantial decrease near the end of the time series.

There is less inter-annual variability in predicted female spawning stock biomass (SSB; Table 3.11; Figure 3.58) than that exhibited in the predicted recruitment values (Figure 3.56). Female SSB values were highest in the late 1990s through the mid-2000s and have generally decreased since. Predicted values of spawner potential ratio (SPR) show a slightly decreasing trend over the time series (Table 3.11; Figure 3.59).

Predicted population numbers at age suggest 75% to 78% of the population has been dominated by fish aged 0 through 2 (Tables 3.12 and 3.13). These predicted numbers at age show an initial decrease in the numbers of older fish followed by an increase in the numbers of older fish through the mid-2000s, followed by a possible truncation of age structure in recent years. Model predictions of population biomass at age also suggests fewer older fish in recent years (Tables 3.14, 3.15). The predictions of landings at age for the AScomm fleet indicate that most (~75%) of the fish captured are ages 3 through 5 (Table 3.16). The majority (63%) of the discards for the AScomm fleet are ages 0 through 2 (Table 3.17). The harvest for the ASrec fleet is dominated (76%) by ages 3 through 5 (Table 3.18). Approximately 73% of the discards for the ASrec fleet are ages 3 and 4 (Table 3.19). The RRrec fleet captures mostly (94%) age-3 to age-5 Striped Bass in the harvest (Table 3.20) while most (62%) of the RRrec discards are age 3 and 4 (Table 3.21).

Model predictions of annual *F* (numbers-weighted, ages 3–5) exhibit moderate inter-annual variability throughout the assessment time series and peaks are observed in 2012 and 2020 (Table 3.22; Figure 3.60). Predicted *F* values range from a low of 0.094 in 1996 to a high of 1.3 in 2012. There is a decline in *F* in the last year of the time series.

3.1.8.3 Contribution of Fisheries-Independent Data Sources

The removal of the different survey data sets had minimal impact on estimates of female SSB and *F* (Figure 3.61).

3.1.8.4 Alternative Natural Mortality

Assuming age-varying natural mortality (Lorenzen *M*) and a lower value of natural mortality (*M* = 0.30) produced estimates of female SSB that were lower than those in the base run while the overall trends were similar (Figure 3.62A). Using the higher empirically derived value of natural mortality (*M* = 0.72) resulted in higher estimates of female SSB than those predicted in the base run. The model that assumed the empirical estimate of natural mortality resulted in lower estimates of *F* relative to the base run (Figure 3.62B).

3.1.8.5 Ageing Error and Bias

Estimates of female SSB in terminal years and estimated *F* had relatively little change relative to the base run for either ageing error sensitivity run (Figure 3.63); however, estimates of female SSB were lower in the mid-range of years of the model (1998–2005) for both of these sensitivity runs.

Also, estimates of female SSB were even lower in the very early years of the model for high error values and estimates of female SSB were higher than those in the base run for early years with medium error.

Adding ageing bias into the model resulted in similar trends in estimates of female SSB and *F*, except when age was underestimated by 1 (+1 year) or younger ages were overaged and older ages were underaged by 2 years (2-year inverted bell curve). The +1-year and 2-year inverted bell curve scenarios resulted in different trends with much lower estimates of female SSB and lower estimates of *F* (Figure 3.64). Underestimating age by half a year (+0.5 year) resulted in female SSB estimates that were lower than the base run estimates, but *F* estimates were higher than the base run estimates. Overestimating the age by 0.5 year (-0.5 year), overestimating by 1 year (-1 year), or when younger ages were overaged and older ages were underaged by 1 year (1 year inverted bell curve) resulted in increased female SSB estimates and decreased *F* estimates relative to the base run.

When combining ageing error and bias into the model together, three of the scenarios tested did not converge (error = 0.5, bias = + 0.5; error = 0.5, bias = - 0.5; error = 0.7, bias = -1). Estimates of female SSB were similar in the terminal years for all runs assuming both ageing bias and ageing error (Figure 3.65A) and trends in *F* were maintained through all converged runs (Figure 3.65B). Estimates of *F* were highest in the base run compared to any of the runs with ageing error and bias combined.

3.2 Discussion of Results

The model diagnostics did indicate some potential issues. Five of the 115 active parameters were estimated near a bound suggesting a problem with the data or model structure (Carvalho et al. 2021). There were five parameter pairs found to be highly correlated (>0.95), which can be indicative of poor model stability. Ten parameters were associated with excessively high variance (>50% PSE) and the variance of eight of these parameters were considered extreme (>1,000% PSE). Such parameters are likely not influencing the model fit to the data. Nine of the ten parameters with excessively high variance were selectivity parameters. Fair fits to the fisheries-independent survey indices and annual length compositions from all sources along with the strong patterns observed in the length composition residuals demonstrate the predictions are not matching the observations.

The current stock assessment for Striped Bass indicates some concerning trends, both observed and predicted. The P100juv survey index suggests observed recruitment has been relatively low for at least the last four years of the stock assessment time series (Figure 3.3). Model-predicted recruitment of age-0 fish has shown a general decline over time and the estimated value in 2021 is about 5% of the value that was predicted for the estimated peak in 2000 (Table 3.11; Figure 3.56). Similarly, predicted female SSB in 2021 is less than 5% of the value predicted for its estimated peak in 2000 (Table 3.11; Figure 3.58). Observed and predicted length and age compositions of striped bass suggest that there are fewer larger and older fish in recent years.

Striped Bass commonly migrate outside the bounds of the A-R management unit, either to other internal waters of North Carolina such as western Pamlico Sound and the Tar-Pamlico, Pungo, and Neuse rivers or by joining the migratory ocean stock. The probability of migration increases with age and has increased over time (Callihan et al. 2014). In the most recent years examined in Callihan et al. (2014), the probability has been most significant for fish age 6 and older (20% or greater). In addition, smaller adults show evidence of density-dependent movements and habitat use, as the likelihood of recapture outside the ASMA in adjacent systems increases during periods of higher stock abundance. When a Striped Bass migrates, it may not return to its natal waterbody; this could be due to harvest outside of the ASMA and RRMA and is not accounted for in the harvest losses here. This loss of fish from the system will likely be interpreted by the model as losses due to natural and/or fishing mortality. Earlier stock assessments of the A-R Striped Bass stock attempted to account for these migration losses by adjusting the natural mortality rate by the probability of migration and fishing mortality occurring in the Atlantic Ocean, thereby creating an estimate of total unobserved mortality that accounted for both natural mortality and losses not attributable to North Carolina fisheries (Mroch and Godwin 2014; Flowers et al. 2016). In this assessment, migration losses were not specifically modeled; this total unobserved mortality was treated as fixed in the modeling process.

The ages in this assessment were derived from scales and were assumed to be associated with small bias and negligible imprecision; however, Welch et al. (1993) found that scales tend to underage Striped Bass for fish that are older than age ten. This suggests that the maximum age assumed for this assessment, age 17, may be an underestimate of the true maximum age. Assuming maximum age that is too young can positively bias the estimates of SPR (Goodyear 1993) and the derived reference points.

4 STATUS DETERMINATION CRITERIA

The General Statutes of North Carolina define overfished as "the condition of a fishery that occurs when the spawning stock biomass of the fishery is below the level that is adequate for the recruitment class of a fishery to replace the spawning class of the fishery" (NCGS § 113-129). The General Statues define overfishing as "fishing that causes a level of mortality that prevents a fishery from producing a sustainable harvest."

The spawner potential ratio (SPR) was deemed an appropriate proxy for developing reference points for A-R Striped Bass. Levels of SPR ranging from 20% to 50% have been found to be appropriate for various stocks, but historical analysis of SPR shows increased risk of recruitment overfishing levels if SPR falls below 30% (Walters and Martell 2004). For this assessment, threshold values were based on 35% SPR and targets were based on 45% SPR.

The target level for female spawning stock biomass (SSB_{Target} or $SSB_{45\%}$) was estimated at 164 metric tons by the SS3 model. The estimated threshold for SSB ($SSB_{Threshold}$ or $SSB_{35\%}$) was 125 metric tons. Terminal year (2021) female SSB was 16.1 metric tons, which is less than the threshold value and suggests the stock is currently overfished ($SSB_{2021} < SSB_{Threshold}$; Figure 4.1).

The fishing mortality reference points and the values of F that are compared to them represent numbers-weighted values for ages 3 to 5 (section 3.1.4.7). The SS3 model estimated a value of 0.14 for F_{Target} ($F_{45\%}$). The estimate of $F_{Threshold}$ ($F_{35\%}$) from the SS3 model was 0.20. The estimated value of fishing mortality in the terminal year (2021) of the model was 0.77, which is greater than the threshold value and suggests that overfishing is currently occurring in the stock ($F_{2021} > F_{Threshold}$; Figure 4.2).

The estimates in the most recent years are often associated with large uncertainty in stock assessment models. Approaching the ending year of the time series, the estimates of the most recent years lack data support from subsequent years during calibration. Nevertheless, stock status is often based on the terminal year estimates of fishing mortality and population size (or a proxy) to address the management needs and interests.

5 RESEARCH RECOMMENDATIONS

The research recommendations listed below are offered by the working group to improve future stock assessments of the A-R Striped Bass stock.

High

- Improve estimates of discard mortality rates and discard losses from the ASMA commercial gill-net fisheries (ongoing through observer program)
- Collect data to estimate catch-and-release discard losses in the ASMA recreational fishery during the closed harvest season
- Investigate relationship between river flow and Striped Bass recruitment for consideration of input into future stock assessment models
- Conduct an age comparison study between scale and otoliths to estimate population-specific age bias and error

Medium

- Transition to an assessment that is based on ages derived from otoliths
- Improve estimates of catch-and-release discard losses in the RRMA recreational fishery during the closed harvest season
- Incorporate tagging data directly into the statistical catch-at-age model
- Improve the collection of length and age data to characterize commercial and recreational discards
- Explore the direct input of empirical weight-at-age data into the stock assessment model in lieu of depending on the estimated growth relationships

Low

- Re-evaluate catch-and-release mortality rates from the ASMA and RRMA recreational fisheries incorporating different hook types and angling methods at various water temperatures (e.g., live bait, artificial bait, and fly fishing)
- Investigate the potential impact of blue catfish on the A-R Striped Bass population (e.g., habitat, predation, forage)

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7 TABLES

Table 3.1. Annual estimates of commercial landings and recreational harvest that were input into the SS3 model, 1991–2021. Values assumed for the coefficients of variation (CVs) are also provided.

	ASMA Commercial		ASMA Recreational		RRMA Recreational	
Year	**metric tons**	**CV**	**numbers**	**CV**	**numbers**	**CV**
1991	49.24	0.02	14,395	0.02	26,934	0.02
1992	45.65	0.02	10,542	0.02	13,372	0.02
1993	49.70	0.02	11,404	0.02	14,325	0.02
1994	46.48	0.01	8,591	0.02	8,284	0.02
1995	39.88	0.01	7,343	0.02	7,471	0.02
1996	40.92	0.01	7,433	0.02	8,367	0.02
1997	43.64	0.01	6,901	0.02	9,369	0.02
1998	56.26	0.01	19,566	0.02	23,109	0.02
1999	73.94	0.01	16,967	0.02	22,479	0.02
2000	97.17	0.01	38,085	0.02	38,206	0.02
2001	99.99	0.01	40,127	0.02	35,231	0.02
2002	101.2	0.01	27,896	0.02	36,422	0.02
2003	146.8	0.01	15,124	0.02	11,157	0.02
2004	124.2	0.01	28,004	0.02	35,481	0.02
2005	105.6	0.01	17,954	0.02	34,122	0.02
2006	84.62	0.01	10,711	0.02	25,355	0.02
2007	77.94	0.01	7,143	0.02	19,306	0.02
2008	34.01	0.01	10,048	0.02	10,541	0.02
2009	43.49	0.01	12,069	0.02	23,248	0.02
2010	90.72	0.01	3,504	0.02	22,445	0.02
2011	61.86	0.01	13,341	0.02	22,102	0.02
2012	52.48	0.01	22,345	0.02	28,847	0.02
2013	31.03	0.01	4,299	0.02	7,718	0.02
2014	32.23	0.01	5,529	0.02	11,058	0.02
2015	51.98	0.01	23,240	0.02	20,031	0.02
2016	55.89	0.01	4,794	0.02	21,260	0.02
2017	34.50	0.01	4,215	0.02	9,899	0.02
2018	52.73	0.01	3,465	0.02	8,741	0.02
2019	62.42	0.01	8,502	0.02	16,582	0.02
2020	56.47	0.01	6,849	0.02	20,376	0.02
2021	12.53	0.01	2,258	0.02	7,795	0.02

Table 3.2. Annual estimates of dead discards that were input into the SS3 model, 1991–2021. Values assumed for the coefficients of variation (CVs) are also provided.

	ASMA Commercial		ASMA Recreational		RRMA Recreational	
Year	**numbers**	**CV**	**numbers**	**CV**	**numbers**	**CV**
1991	4,040	0.08	1,507	0.04	6,281	0.06
1992	3,319	0.08	1,279	0.04	1,517	0.06
1993	3,523	0.08	847.4	0.04	3,635	0.06
1994	1,693	0.08			245	0.06
1995	1,943	0.08			3,373	0.06
1996	1,633	0.08			10,461	0.04
1997	1,561	0.08	1,969	0.04	18,673	0.04
1998	2,289	0.08	5,881	0.04	12,159	0.04
1999	2,912	0.08	2,581	0.04	10,468	0.04
2000	4,132	0.08	5,052	0.04	5,961	0.04
2001	5,923	0.08	3,931	0.04	4,544	0.04
2002	4,709	0.08	3,300	0.04	3,570	0.04
2003	5,886	0.08	1,618	0.04	2,448	0.04
2004	4,088	0.08	2,627	0.04	11,989	0.04
2005	5,124	0.08	1,358	0.04	10,093	0.04
2006	4,165	0.08	605.1	0.04	4,194	0.04
2007	3,454	0.08	870.3	0.04	3,360	0.04
2008	1,383	0.08	2,366	0.04	12,137	0.04
2009	1,906	0.08	2,596	0.04	8,702	0.04
2010	5,116	0.08	1,037	0.04	7,930	0.04
2011	3,405	0.08	1,381	0.04	6,892	0.04
2012	2,908	0.08	1,598	0.04	4,033	0.04
2013	8,245	0.04	1,048	0.04	4,750	0.04
2014	4,393	0.04	1,478	0.04	10,595	0.04
2015	5,472	0.04	3,170	0.04	6,927	0.04
2016	3,228	0.04	662.5	0.04	3,369	0.04
2017	1,898	0.04	1,578	0.04	5,021	0.04
2018	1,950	0.04	1,638	0.04	11,982	0.04
2019	1,994	0.04	2,456	0.04	11,980	0.04
2020	1,119	0.04	3,201	0.04	6,966	0.04
2021	852.7	0.08	498.0	0.04	3,843	0.04

Table 3.3. Parameter values and associated standard errors (in parentheses) of the von Bertalanffy age-length growth curve by sex estimated external to the SS3 model. The function was fit to total length in centimeters.

Sex	n	L_∞	*K*	t_0
Female	30,185	162 (0.67)	0.069 (0.00053)	-0.71 (0.014)
Male	30,129	173 (1.5)	0.055 (0.00075)	-1.2 (0.019)

Table 3.4. Parameter values and associated standard errors (in parentheses) of the length-weight function by sex estimated external to the SS3 model. The function was fit to total length in centimeters and weight in kilograms.

Sex	n	*a*	*b*
Female	24,676	4.8E-06 (7.2E-08)	3.2 (3.3E-03)
Male	27,962	7.9E-06 (1.1E-07)	3.1 (3.3E-03)

Table 3.5. Percent maturity of female Striped Bass as estimated by Boyd (2011).

Age	% Maturity
0	0
1	0
2	0
3	28.6
4	96.8
5	100
6	100
7	100
8	100
9	100
10	100
11	100
12	100
13	100
14	100
15	100
16	100
17	100

Table 3.6. Initial values, bounds (min and max), and prior types assumed for estimated parameters in the base run of the stock assessment model.

Type	Parameter	Initial Value	Min	Max	Prior Type
Growth	L1, female	18.0	10	40	Normal
	Linf, female	162	50	180	Normal
	K, female	0.069	0.01	0.5	Normal
	CV1, female	0.35	0.001	5	Normal
	CV2, female	1.0	0.001	5	Normal
	L1, male	20.0	10	40	Normal
	Linf, male	173	46	180	Normal
	K, male	0.055	0.01	0.5	Normal
	CV1, male	0.35	0.001	5	Normal
	CV2, male	1.0	0.001	5	Normal
Initial Conditions	SR_LN(R0)	10.1	3	31	No prior
	Initial *F*, AScomm	0.1	0	1	No prior
	Initial *F*, ASrec	0.1	0	1	No prior
	Initial *F*, RRrecharv	0.1	0	1	No prior
	Initial *F*, RRrecdisc	0.1	0	1	No prior
Catchability	Catchability, P100	-8.2	-50	25	No prior
	Survey Power, P100	0.6	-25	25	No prior
	Catchability, P135fw	-3.0	-50	25	No prior
	Survey Power, P135fw	-0.54	-25	25	No prior
	Catchability, P135spr	-1.7	-50	25	No prior
	Survey Power, P135spr	-0.74	-25	25	No prior
	Catchability, RRef	1.8	-50	25	No prior
	Survey Power, RRef	-0.37	-25	25	No prior

Table 3.6. **(*continued*)** Initial values, bounds (min and max), and prior types assumed for estimated parameters in the base run of the stock assessment model.

Type	Parameter	Initial Value	Min	Max	Prior Type
Selectivity	SizeSpline_GradLo_AScomm(1)	0.1	-0.001	1	Sym_Beta
	SizeSpline_GradHi_AScomm(1)	-0.001	-1	0.001	Sym_Beta
	SizeSpline_Val_1_AScomm(1)	-5.0	-9	7	Sym_Beta
	SizeSpline_Val_2_AScomm(1)	-3.7	-9	7	Sym_Beta
	SizeSpline_Val_3_AScomm(1)	-2.3	-9	7	Sym_Beta
	SizeSpline_Val_5_AScomm(1)	0	-9	7	Sym_Beta
	SizeSpline_Val_6_AScomm(1)	0	-9	7	Sym_Beta
	Retain_L_infl_AScomm(1)	30	20	100	No prior
	Retain_L_width_AScomm(1)	9.6	0.1	10	No prior
	Size_DblN_peak_ASrec(2)	53	20	100	No prior
	Size_DblN_top_logit_ASrec(2)	0.13	-10	10	No prior
	Size_DblN_ascend_se_ASrec(2)	3.7	-2	9	No prior
	Size_DblN_descend_se_ASrec(2)	3.5	-2	9	No prior
	Retain_L_infl_ASrec(2)	40	20	100	No prior
	Retain_L_width_ASrec(2)	5.1	0.1	10	No prior
	Size_DblN_peak_RRecdisc(8)	51	20	100	No prior
	Size_DblN_top_logit_RRecdisc(8)	0.052	-10	10	No prior
	Size_DblN_ascend_se_RRecdisc(8)	4.4	-2	9	No prior
	Size_DblN_descend_se_RRecdisc(8)	3.5	-2	9	No prior

Table 3.6. **(*continued*)** Initial values, bounds (min and max), and prior types assumed for estimated parameters in the base run of the stock assessment model.

Type	Parameter	Initial Value	Min	Max	Prior Type
Selectivity	SizeSpline_GradLo_P135fw(5)	0.1	-0.001	1	Sym_Beta
	SizeSpline_GradHi_P135fw(5)	-0.001	-1	0.001	Sym_Beta
	SizeSpline_Val_1_P135fw(5)	-5	-9	7	Sym_Beta
	SizeSpline_Val_3_P135fw(5)	0	-9	7	Sym_Beta
	Size_DblN_peak_P135spr(6)	47	20	100	No prior
	Size_DblN_top_logit_P135spr(6)	-0.018	-10	10	No prior
	Size_DblN_ascend_se_P135spr(6)	5.1	-2	9	No prior
	Size_DblN_descend_se_P135spr(6)	3.5	-2	9	No prior
	Size_DblN_peak_RRef(7)	57	20	100	No prior
	Size_DblN_top_logit_RRef(7)	0.014	-10	10	No prior
	Size_DblN_ascend_se_RRef(7)	4.4	-2	9	No prior
	Size_DblN_descend_se_RRef(7)	3.5	-2	9	No prior
	SzSel_MaleDogleg_RRef(7)	59	20	100	No prior
	SzSel_MaleatZero_RRef(7)	7.9	-25	25	No prior
	SzSel_MaleatMaxage_RRef(7)	-6.2	-25	25	No prior

Table 3.7. Estimates of natural mortality at age by sex based on the method of Lorenzen (1996).

Age	Female	Male
0	2.1	1.4
1	0.97	0.84
2	0.66	0.62
3	0.51	0.49
4	0.42	0.42
5	0.36	0.37
6	0.32	0.33
7	0.29	0.30
8	0.27	0.28
9	0.25	0.26
10	0.23	0.24
11	0.22	0.23
12	0.21	0.22
13	0.20	0.21
14	0.19	0.20
15	0.19	0.19
16	0.18	0.19
17	0.18	0.18

Table 3.8. Estimated values, standard deviations (SD), phase of estimation, and status from the base run of the stock assessment model. LO or HI indicates parameter values estimated near their bounds. Standard deviation values marked with an asterisk (*) indicate excessively large (>50%) proportional standard errors.

Type	Parameter	Estimated Value	SD[Value]	Phase	Status
Growth	L1, female	18.1	0.050	2	OK
	Linf, female	162	0.050	2	OK
	K, female	0.065	0.00063	2	OK
	CV1, female	0.18	0.0037	2	OK
	CV2, female	0.001	5.0E-07	2	LO
	L1, male	20.2	0.050	3	OK
	Linf, male	173	0.050	3	OK
	K, male	0.055	0.00058	3	OK
	CV1, male	0.17	0.0036	3	OK
	CV2, male	0.001	6.1E-07	3	LO
Initial Conditions	SR_LN(R0)	6.1	0.041	1	OK
	Initial *F*, AScomm	0.020	0.0050	1	OK
	Initial *F*, ASrec	0.0064	0.0015	1	LO
	Initial *F*, RRrecharv	0.047	0.011	1	OK
	Initial *F*, RRrecdisc	0.00057	0.00013	1	LO
Catchability	Catchability, P100	-6.1	0.56	8	OK
	Survey Power, P100	0.24	0.088	9	OK
	Catchability, P135fw	-1.8	0.23	8	OK
	Survey Power, P135fw	-0.45	0.046	9	OK
	Catchability, P135spr	-0.20	0.25*	8	OK
	Survey Power, P135spr	-0.69	0.045	9	OK
	Catchability, RRef	2.5	0.22	8	OK
	Survey Power, RRef	-0.46	0.051	9	OK

Table 3.8. (***continued***) Estimated values, standard deviations (SD), phase of estimation, and status from the base run of the stock assessment model. LO or HI indicates parameter values estimated near their bounds. Standard deviation values marked with an asterisk (*) indicate excessively large (>50%) proportional standard errors.

Type	Parameter	Estimated Value	SD[Value]	Phase	Status
Selectivity	SizeSpline_GradLo_AScomm(1)	0.15	0.033	3	OK
	SizeSpline_GradHi_AScomm(1)	0.0010	5.9E-05	3	HI
	SizeSpline_Val_1_AScomm(1)	-8.5	0.31	2	OK
	SizeSpline_Val_2_AScomm(1)	-3.8	0.17	2	OK
	SizeSpline_Val_3_AScomm(1)	-2.2	0.14	2	OK
	SizeSpline_Val_5_AScomm(1)	-0.83	0.063	2	OK
	SizeSpline_Val_6_AScomm(1)	-1.9	0.22	2	OK
	Retain_L_infl_AScomm(1)	41.5	0.95	4	OK
	Retain_L_width_AScomm(1)	2.7	0.35	5	OK
	Size_DblN_peak_ASrec(2)	51.0	0.34	4	OK
	Size_DblN_top_logit_ASrec(2)	0.19	196*	4	OK
	Size_DblN_ascend_se_ASrec(2)	3.1	0.12	5	OK
	Size_DblN_descend_se_ASrec(2)	3.5	123*	5	OK
	Retain_L_infl_ASrec(2)	38.6	0.69	4	OK
	Retain_L_width_ASrec(2)	6.5	0.35	5	OK
	Size_DblN_peak_RRecdisc(8)	52.6	0.96	6	OK
	Size_DblN_top_logit_RRecdisc(8)	0.0088	242*	6	OK
	Size_DblN_ascend_se_RRecdisc(8)	4.6	0.12	7	OK
	Size_DblN_descend_se_RRecdisc(8)	3.5	123*	7	OK

Table 3.8. (***continued***) Estimated values, standard deviations (SD), phase of estimation, and status from the base run of the stock assessment model. LO or HI indicates parameter values estimated near their bounds. Standard deviation values marked with an asterisk (*) indicate excessively large (>50%) proportional standard errors.

Type	Parameter	Estimated Value	SD[Value]	Phase	Status
Selectivity	SizeSpline_GradLo_P135fw(5)	0.51	0.099	3	OK
	SizeSpline_GradHi_P135fw(5)	-0.49	0.081	3	OK
	SizeSpline_Val_1_P135fw(5)	-4.3	0.33	2	OK
	SizeSpline_Val_3_P135fw(5)	-1.6	0.23	2	OK
	Size_DblN_peak_P135spr(6)	48.8	1.9	4	OK
	Size_DblN_top_logit_P135spr(6)	-0.023	226*	4	OK
	Size_DblN_ascend_se_P135spr(6)	5.1	0.19	5	OK
	Size_DblN_descend_se_P135spr(6)	3.5	123*	5	OK
	Size_DblN_peak_RRef(7)	55.5	0.86	4	OK
	Size_DblN_top_logit_RRef(7)	0.031	217*	4	OK
	Size_DblN_ascend_se_RRef(7)	4.4	0.074	5	OK
	Size_DblN_descend_se_RRef(7)	3.5	123*	5	OK
	SzSel_MaleDogleg_RRef(7)	60.3	1.4	4	OK
	SzSel_MaleatZero_RRef(7)	7.3	0.76	5	OK
	SzSel_MaleatMaxage_RRef(7)	-9.4	5.2*	5	OK

Table 3.9. Parameter pairs found to be highly correlated (>0.95) in the base run of the stock assessment model.

Parameter 1	Parameter 2	Correlation
Q_power_P100juv(4)	LnQ_base_P100juv(4)	-0.994282
Q_power_P135spr(6)	LnQ_base_P135spr(6)	-0.990604
Q_power_RRef(7)	LnQ_base_RRef(7)	-0.980759
Retain_L_width_ASrec(2)	Retain_L_infl_ASrec(2)	-0.979845
Q_power_P135fw(5)	LnQ_base_P135fw(5)	-0.969508

Table 3.10. Comparison of empirically derived estimates of the von Bertalanffy age-length parameters to those estimated by the base run of the Stock Synthesis model.

Sex	Parameter	Empirical	Stock Synthesis
female	L1 (cm)	18.0	18.1
	Linf (cm)	162	162
	K	0.069	0.065
	CV1	0.35	0.18
	CV2	1.0	0.001
male	L1 (cm)	20.0	20.2
	Linf (cm)	173	173
	K	0.055	0.055
	CV1	0.35	0.17
	CV2	1.0	0.001

Table 3.11. Annual estimates of recruitment (thousands of fish), female spawning stock biomass (SSB; metric tons), and spawner potential ratio (SPR) and associated standard deviations (SDs) from the base run of the stock assessment model, 1991–2021.

	Recruitment		SSB		SPR	
Year	**Value**	**SD**	**Value**	**SD**	**Value**	**SD**
1991	441.9	44	219.1	21	0.28	0.019
1992	388.8	40	209.4	18	0.43	0.019
1993	1,025	65	220.5	16	0.43	0.015
1994	1,035	61	210.7	14	0.50	0.015
1995	1,104	70	204.8	13	0.50	0.014
1996	1,106	63	208.7	12	0.46	0.013
1997	866.6	60	250.4	13	0.48	0.013
1998	1,136	73	296.5	14	0.42	0.011
1999	974.6	78	326.2	15	0.43	0.011
2000	1,438	71	346.1	16	0.32	0.0096
2001	643.3	49	312.9	15	0.30	0.0098
2002	324.2	26	293.0	15	0.31	0.010
2003	193.2	20	290.8	13	0.35	0.0099
2004	355.1	28	315.2	11	0.30	0.0057
2005	818.7	49	256.9	8.1	0.27	0.0050
2006	765.4	44	178.7	6.3	0.24	0.0060
2007	437.1	28	116.4	5.2	0.19	0.0060
2008	204.7	15	92.01	4.8	0.27	0.0083
2009	85.81	9	125.5	5.3	0.29	0.0083
2010	293.4	23	146.3	4.5	0.27	0.0061
2011	740.4	27	125.5	3.1	0.23	0.0041
2012	300.9	21	81.71	2.1	0.10	0.0031
2013	311.0	20	23.06	1.2	0.13	0.0055
2014	349.9	22	37.84	1.9	0.19	0.0057
2015	584.2	22	72.49	2.3	0.16	0.0043
2016	214.8	16	56.29	1.9	0.17	0.0054
2017	133.4	15	47.64	2.2	0.22	0.0080
2018	60.40	12	61.35	2.5	0.21	0.0066
2019	100.9	15	74.67	2.5	0.17	0.0051
2020	14.88	4	49.13	2.1	0.11	0.0066
2021	76.95	22	16.13	2.3	0.12	0.019

Table 3.12. Predicted population numbers at age (thousands of fish) at the beginning of the year from the base run of the stock assessment model, 1991–2021. Values rounded to the nearest integer.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1991	442	323	328	281	47	21	15	15	12	8	5	4	3	2	1	2
1992	389	296	217	219	167	21	8	6	7	6	4	2	2	1	1	1
1993	1,025	260	198	145	139	91	10	4	3	4	3	2	1	1	1	1
1994	1,035	686	174	132	92	76	45	5	2	2	2	2	1	1	1	1
1995	1,104	692	460	117	85	53	40	24	3	1	1	1	1	1	0	1
1996	1,106	739	464	308	75	49	28	21	13	2	1	1	1	1	0	1
1997	867	740	495	310	196	42	25	14	11	7	1	0	0	0	0	1
1998	1,136	580	496	331	198	111	22	13	8	6	4	0	0	0	0	1
1999	975	761	389	331	209	107	55	11	7	4	3	2	0	0	0	0
2000	1,438	652	510	260	210	114	53	27	6	4	2	2	1	0	0	0
2001	643	961	437	341	159	101	47	23	12	3	2	1	1	1	0	0
2002	324	430	644	292	207	74	40	19	10	6	1	1	1	0	0	0
2003	193	217	288	430	179	98	30	17	8	5	3	1	0	0	0	0
2004	355	129	145	193	271	92	43	13	7	4	2	1	0	0	0	0
2005	819	237	86	97	117	126	36	17	5	3	2	1	1	0	0	0
2006	765	547	159	58	58	51	47	14	7	2	2	1	1	0	0	0
2007	437	511	366	106	33	23	17	16	6	3	1	1	0	0	0	0
2008	205	291	342	244	59	11	6	5	5	2	1	0	0	0	0	0
2009	86	137	195	228	146	26	4	2	2	2	1	1	0	0	0	0
2010	293	57	92	130	138	67	10	2	1	1	1	0	0	0	0	0
2011	740	196	38	61	78	61	24	4	1	0	0	0	0	0	0	0
2012	301	494	131	26	35	31	19	8	1	0	0	0	0	0	0	0
2013	311	200	331	86	11	4	2	2	1	0	0	0	0	0	0	0
2014	350	205	134	218	43	2	0	0	0	0	0	0	0	0	0	0
2015	584	233	137	89	123	15	1	0	0	0	0	0	0	0	0	0
2016	215	389	156	91	48	35	3	0	0	0	0	0	0	0	0	0
2017	133	143	260	104	49	14	7	1	0	0	0	0	0	0	0	0
2018	60	89	96	173	60	19	4	2	0	0	0	0	0	0	0	0
2019	101	40	60	63	100	23	5	1	1	0	0	0	0	0	0	0
2020	15	67	27	39	35	31	5	1	0	0	0	0	0	0	0	0
2021	77	10	45	18	17	5	2	0	0	0	0	0	0	0	0	0

Table 3.13. Predicted population numbers at age (thousands of fish) at mid-year from the base run of the stock assessment model, 1991–2021. Values rounded to the nearest integer.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1991	361	265	268	217	31	13	10	10	8	6	3	3	2	1	1	1
1992	318	242	177	174	123	14	6	4	5	4	3	2	1	1	1	1
1993	839	213	162	115	103	64	7	3	2	3	2	2	1	1	1	1
1994	846	562	143	106	70	55	33	4	2	1	1	1	1	1	0	1
1995	904	567	376	94	65	38	29	18	2	1	1	1	1	1	0	1
1996	905	605	379	245	56	35	20	15	10	1	0	0	0	0	0	1
1997	709	606	405	248	148	30	18	10	8	5	1	0	0	0	0	0
1998	930	475	406	263	145	78	16	9	6	5	3	0	0	0	0	0
1999	797	623	318	264	154	75	39	8	5	3	2	2	0	0	0	0
2000	1,176	534	417	204	146	73	35	18	4	3	2	1	1	0	0	0
2001	526	787	357	266	109	63	30	15	8	2	1	1	1	0	0	0
2002	265	352	527	228	143	47	26	13	7	4	1	1	0	0	0	0
2003	158	177	236	342	128	65	20	11	6	3	2	0	0	0	0	0
2004	290	106	119	150	185	58	27	8	5	3	2	1	0	0	0	0
2005	669	194	71	75	78	77	22	11	4	2	1	1	0	0	0	0
2006	625	448	130	44	36	29	28	9	5	2	1	1	0	0	0	0
2007	357	418	299	79	19	11	9	9	3	2	1	0	0	0	0	0
2008	167	238	279	189	40	7	3	3	3	1	1	0	0	0	0	0
2009	70	112	159	177	99	17	3	1	1	1	1	0	0	0	0	0
2010	240	47	75	101	92	40	6	1	1	1	1	0	0	0	0	0
2011	605	160	31	47	49	34	14	2	0	0	0	0	0	0	0	0
2012	245	404	106	17	13	8	6	3	1	0	0	0	0	0	0	0
2013	253	164	269	61	5	1	1	1	0	0	0	0	0	0	0	0
2014	285	168	109	164	25	1	0	0	0	0	0	0	0	0	0	0
2015	477	190	112	65	66	6	0	0	0	0	0	0	0	0	0	0
2016	175	318	127	67	26	16	1	0	0	0	0	0	0	0	0	0
2017	109	117	212	79	31	8	4	0	0	0	0	0	0	0	0	0
2018	49	73	78	132	37	10	2	1	0	0	0	0	0	0	0	0
2019	82	33	48	47	56	11	2	1	0	0	0	0	0	0	0	0
2020	12	55	22	26	13	9	1	0	0	0	0	0	0	0	0	0
2021	63	8	36	12	8	2	1	0	0	0	0	0	0	0	0	0

Table 3.14. Predicted population biomass at age (metric tons) at the beginning of the year from the base run of the stock assessment model, 1991–2021. Values rounded to the nearest integer.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1991	6	25	78	149	45	32	35	47	51	43	32	28	23	16	13	33
1992	5	23	52	116	160	32	18	19	28	31	26	19	17	13	9	26
1993	13	20	47	77	134	140	23	12	13	19	21	17	12	11	9	22
1994	13	52	42	70	88	117	102	16	8	9	13	14	11	8	7	19
1995	14	53	110	62	82	81	91	75	11	6	6	9	9	7	5	17
1996	14	57	111	163	72	75	63	67	54	8	4	4	6	6	5	15
1997	11	57	119	164	188	65	57	45	47	37	6	3	3	4	4	13
1998	15	44	119	175	190	172	50	41	32	33	26	4	2	2	2	10
1999	13	58	93	175	200	165	124	34	28	21	22	17	2	1	1	8
2000	19	50	122	137	202	175	120	86	24	19	14	14	11	2	1	6
2001	8	74	105	180	153	156	108	71	52	14	11	9	8	6	1	4
2002	4	33	154	154	199	114	90	60	40	29	8	6	5	5	3	2
2003	3	17	69	227	172	152	68	52	35	24	18	5	4	3	3	3
2004	5	10	35	102	261	142	97	40	31	21	15	11	3	2	2	3
2005	11	18	21	51	113	195	82	53	23	18	12	8	6	2	1	3
2006	10	42	38	30	56	79	106	44	30	13	10	7	5	3	1	2
2007	6	39	88	56	32	35	38	52	23	16	7	6	4	3	2	2
2008	3	22	82	129	57	17	13	14	22	11	8	4	3	2	1	2
2009	1	10	47	120	140	41	9	7	7	11	6	4	2	1	1	1
2010	4	4	22	69	132	104	24	5	4	4	7	3	2	1	1	1
2011	10	15	9	32	75	94	55	12	3	2	2	4	2	1	1	1
2012	4	38	31	14	34	48	44	25	6	1	1	1	2	1	1	1
2013	4	15	79	46	10	7	5	5	4	1	0	0	0	0	0	0
2014	5	16	32	115	41	3	1	1	1	1	0	0	0	0	0	0
2015	8	18	33	47	118	23	1	0	0	0	0	0	0	0	0	0
2016	3	30	37	48	46	54	6	0	0	0	0	0	0	0	0	0
2017	2	11	62	55	47	21	16	2	0	0	0	0	0	0	0	0
2018	1	7	23	92	58	30	9	7	1	0	0	0	0	0	0	0
2019	1	3	14	33	96	36	12	4	3	0	0	0	0	0	0	0
2020	0	5	6	21	33	48	11	4	1	1	0	0	0	0	0	0
2021	1	1	11	9	17	8	5	1	1	0	0	0	0	0	0	0

Table 3.15. Predicted population biomass at age (metric tons) at mid-year from the base run of the stock assessment model, 1991–2021. Values rounded to the nearest integer.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1991	12	38	98	157	38	24	26	36	40	33	24	22	18	12	9	24
1992	10	35	65	127	152	27	15	16	23	25	21	15	13	11	7	20
1993	27	31	59	84	126	121	19	10	11	16	17	14	10	9	7	17
1994	27	81	52	77	86	104	88	14	7	8	11	11	9	6	5	15
1995	29	81	138	68	80	72	79	64	10	5	5	7	8	6	4	14
1996	29	87	139	178	69	66	54	56	45	7	4	4	5	5	4	12
1997	23	87	148	180	182	57	49	38	39	31	5	2	2	3	3	10
1998	30	68	149	191	179	147	42	34	26	27	21	3	2	1	2	8
1999	26	89	117	192	190	142	104	29	23	18	18	14	2	1	1	6
2000	38	77	153	148	180	139	93	67	18	15	11	11	8	1	1	4
2001	17	113	131	193	134	120	81	54	39	11	9	6	6	5	1	3
2002	9	51	193	166	176	89	69	46	31	23	6	5	4	3	3	2
2003	5	25	86	248	158	122	53	40	28	19	14	4	3	2	2	2
2004	9	15	43	109	228	109	72	30	23	16	11	8	2	2	1	2
2005	22	28	26	54	96	145	60	40	17	13	9	6	4	1	1	2
2006	20	64	48	32	45	55	75	32	22	10	8	5	3	2	1	2
2007	12	60	110	58	24	22	23	34	16	11	5	4	3	2	1	1
2008	5	34	102	137	49	13	9	10	16	8	6	3	2	1	1	1
2009	2	16	58	129	122	31	7	5	6	9	4	3	1	1	1	1
2010	8	7	27	73	113	76	17	4	3	3	5	2	2	1	1	1
2011	20	23	11	34	61	65	38	8	2	1	2	3	1	1	0	1
2012	8	58	39	12	16	16	16	10	3	1	0	1	1	0	0	0
2013	8	23	99	44	6	3	2	2	2	1	0	0	0	0	0	0
2014	9	24	40	119	31	2	1	0	1	1	0	0	0	0	0	0
2015	15	27	41	47	81	12	1	0	0	0	0	0	0	0	0	0
2016	6	46	47	49	32	30	3	0	0	0	0	0	0	0	0	0
2017	4	17	78	57	38	14	10	1	0	0	0	0	0	0	0	0
2018	2	10	29	96	46	19	6	4	1	0	0	0	0	0	0	0
2019	3	5	18	34	69	20	7	2	2	0	0	0	0	0	0	0
2020	0	8	8	19	16	16	4	1	1	0	0	0	0	0	0	0
2021	2	1	13	9	10	3	2	1	0	0	0	0	0	0	0	0

Table 3.16. Predicted landings at age (numbers of fish) for the AScomm fleet from the base run of the stock assessment model, 1991–2021. Values rounded to the nearest integer.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1991	0	0	132	4,107	3,228	2,450	1,987	1,791	1,260	726	398	282	193	115	77	137
1992	0	0	75	2,819	10,748	2,301	968	674	620	467	289	168	123	86	51	96
1993	0	0	63	1,725	8,279	9,413	1,145	398	274	266	215	140	84	62	44	75
1994	0	0	51	1,458	5,144	7,418	4,791	481	165	120	124	105	71	43	32	62
1995	0	0	121	1,150	4,277	4,630	3,830	2,034	200	72	56	61	53	37	22	49
1996	0	0	127	3,145	3,879	4,412	2,739	1,863	969	100	38	31	35	31	22	42
1997	0	0	121	2,827	9,091	3,416	2,213	1,125	748	408	45	18	15	17	16	32
1998	0	0	128	3,179	9,499	9,317	2,013	1,070	531	370	215	25	10	9	10	28
1999	0	1	118	3,743	11,799	10,518	5,882	1,052	551	288	214	131	16	7	6	25
2000	0	1	204	3,812	14,818	13,713	7,004	3,269	579	321	179	140	89	11	5	21
2001	0	1	204	5,817	12,938	13,880	7,139	3,070	1,442	273	162	96	77	50	6	15
2002	0	1	325	5,393	18,306	11,119	6,560	2,840	1,234	621	126	80	49	40	26	11
2003	0	0	205	11,364	23,087	21,398	7,070	3,500	1,537	719	391	84	55	34	28	26
2004	0	0	83	4,044	27,110	15,511	7,856	2,139	1,064	503	255	147	33	22	14	22
2005	0	0	51	2,089	11,819	21,530	6,802	2,918	809	434	222	119	71	16	11	18
2006	0	1	117	1,520	6,904	10,291	10,503	2,904	1,295	391	227	123	69	42	10	17
2007	0	1	436	4,440	6,027	6,651	5,465	5,058	1,508	748	248	154	87	49	30	19
2008	0	0	203	5,246	5,997	1,892	1,047	749	747	250	137	49	31	18	10	10
2009	0	0	100	4,249	12,926	3,971	675	310	224	240	87	50	19	12	7	8
2010	0	0	81	4,199	20,806	16,930	2,866	416	196	154	178	68	41	15	10	13
2011	0	0	28	1,594	9,253	11,955	5,265	763	115	60	51	63	25	15	6	9
2012	0	2	199	1,215	5,689	7,508	5,465	2,231	352	59	34	31	40	16	10	9
2013	0	1	868	7,603	3,548	2,127	1,132	844	445	87	17	11	10	13	5	7
2014	0	1	175	10,100	8,622	697	161	72	63	41	9	2	1	1	2	2
2015	0	1	169	3,778	21,516	4,009	156	30	14	14	10	3	1	0	0	1
2016	0	2	249	5,061	10,878	12,662	1,112	37	8	4	5	4	1	0	0	1
2017	0	0	274	3,914	8,402	3,828	2,121	165	6	2	1	1	1	0	0	0
2018	0	0	123	7,977	12,444	6,378	1,470	691	57	2	1	0	1	0	0	0
2019	0	0	83	3,073	20,506	7,395	1,878	364	182	17	1	0	0	0	0	0
2020	0	0	68	3,160	9,601	12,735	2,260	518	114	66	7	0	0	0	0	0
2021	0	0	67	863	3,221	1,425	756	129	38	10	7	1	0	0	0	0

Table 3.17. Predicted dead discards at age (numbers of fish) for the AScomm fleet from the base run of the stock assessment model, 1991–2021. Values rounded to the nearest integer.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1991	865	53	163	513	113	35	12	4	1	0	0	0	0	0	0	0
1992	651	42	92	352	375	33	6	2	0	0	0	0	0	0	0	0
1993	1,587	34	78	215	289	136	7	1	0	0	0	0	0	0	0	0
1994	1,471	82	63	182	179	107	30	1	0	0	0	0	0	0	0	0
1995	1,408	74	148	144	149	67	24	5	0	0	0	0	0	0	0	0
1996	1,468	83	156	393	135	64	17	4	1	0	0	0	0	0	0	0
1997	1,026	74	148	353	317	49	14	3	1	0	0	0	0	0	0	0
1998	1,425	61	158	397	331	134	12	3	0	0	0	0	0	0	0	0
1999	1,432	94	145	467	411	152	36	2	0	0	0	0	0	0	0	0
2000	2,785	107	250	476	517	198	43	8	0	0	0	0	0	0	0	0
2001	1,456	184	251	726	451	200	44	7	1	0	0	0	0	0	0	0
2002	791	89	399	674	639	160	41	7	1	0	0	0	0	0	0	0
2003	664	63	251	1,419	805	308	44	8	1	0	0	0	0	0	0	0
2004	988	30	102	505	946	224	49	5	1	0	0	0	0	0	0	0
2005	2,360	58	63	261	412	310	42	7	1	0	0	0	0	0	0	0
2006	2,731	165	144	190	241	148	65	7	1	0	0	0	0	0	0	0
2007	2,517	249	535	555	210	96	34	12	1	0	0	0	0	0	0	0
2008	588	70	249	655	209	27	6	2	1	0	0	0	0	0	0	0
2009	213	29	122	531	451	57	4	1	0	0	0	0	0	0	0	0
2010	1,261	21	100	525	726	244	18	1	0	0	0	0	0	0	0	0
2011	2,617	58	34	199	323	172	33	2	0	0	0	0	0	0	0	0
2012	2,219	308	244	152	199	108	34	5	0	0	0	0	0	0	0	0
2013	3,949	215	1,066	950	124	31	7	2	0	0	0	0	0	0	0	0
2014	2,219	110	215	1,262	301	10	1	0	0	0	0	0	0	0	0	0
2015	3,488	117	208	472	751	58	1	0	0	0	0	0	0	0	0	0
2016	1,663	255	306	632	380	183	7	0	0	0	0	0	0	0	0	0
2017	680	61	336	489	293	55	13	0	0	0	0	0	0	0	0	0
2018	377	47	151	996	434	92	9	2	0	0	0	0	0	0	0	0
2019	680	23	101	384	716	107	12	1	0	0	0	0	0	0	0	0
2020	181	69	83	395	335	184	14	1	0	0	0	0	0	0	0	0
2021	557	6	82	108	113	21	5	0	0	0	0	0	0	0	0	0

Table 3.18. Predicted harvest at age (numbers of fish) for the ASrec fleet from the base run of the stock assessment model, 1991–2021. Values rounded to the nearest integer.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1991	0	0	126	3,707	2,221	1,567	1,400	1,519	1,300	875	531	397	278	167	112	200
1992	0	0	50	1,779	5,170	1,029	477	400	447	394	269	165	124	87	52	97
1993	0	0	43	1,113	4,071	4,303	576	242	202	230	204	141	86	65	45	78
1994	0	0	29	787	2,117	2,839	2,019	244	102	86	99	89	61	38	28	54
1995	0	0	69	627	1,776	1,787	1,628	1,041	125	53	45	52	46	32	20	43
1996	0	0	67	1,579	1,484	1,569	1,073	879	556	67	28	24	28	25	18	34
1997	0	0	53	1,168	2,861	1,000	713	437	353	225	27	12	10	12	10	21
1998	0	0	124	2,924	6,657	6,071	1,444	925	559	455	292	36	15	13	15	41
1999	0	0	77	2,309	5,547	4,598	2,832	610	389	237	195	126	15	7	6	24
2000	0	0	231	4,108	12,168	10,471	5,890	3,311	714	462	285	235	152	19	8	37
2001	0	0	234	6,339	10,746	10,719	6,072	3,145	1,797	397	261	162	135	87	11	25
2002	0	0	250	3,949	10,215	5,768	3,748	1,955	1,033	607	137	91	57	47	30	13
2003	0	0	57	3,025	4,684	4,036	1,468	876	468	256	154	35	23	15	12	11
2004	0	0	53	2,432	12,424	6,609	3,685	1,209	732	404	226	138	32	21	13	21
2005	0	0	27	1,023	4,411	7,470	2,599	1,343	453	284	160	91	56	13	9	14
2006	0	0	47	584	2,022	2,802	3,149	1,049	569	201	129	74	42	26	6	10
2007	0	0	122	1,181	1,222	1,254	1,135	1,265	459	266	97	64	37	21	13	8
2008	0	0	148	3,643	3,174	931	567	489	594	232	140	53	35	20	12	12
2009	0	0	68	2,743	6,360	1,817	340	188	166	207	83	51	19	13	7	8
2010	0	0	8	412	1,557	1,178	219	38	22	20	26	10	6	2	2	2
2011	0	0	18	948	4,191	5,034	2,442	426	78	47	45	59	24	15	6	8
2012	0	0	257	1,491	5,322	6,529	5,235	2,574	494	97	61	59	78	32	20	19
2013	0	0	260	2,160	769	428	251	226	145	33	7	5	5	6	3	3
2014	0	0	58	3,156	2,053	154	39	21	23	17	4	1	1	1	1	1
2015	0	0	177	3,752	16,283	2,819	120	28	16	19	15	4	1	1	1	2
2016	0	0	54	1,032	1,690	1,828	177	7	2	1	1	1	0	0	0	0
2017	0	0	80	1,089	1,783	755	460	43	2	1	0	0	0	0	0	0
2018	0	0	19	1,153	1,371	653	166	94	9	0	0	0	0	0	0	0
2019	0	0	28	1,002	5,097	1,708	477	112	68	7	0	0	0	0	0	0
2020	0	0	22	979	2,266	2,794	546	151	40	27	3	0	0	0	0	0
2021	0	0	31	376	1,070	440	257	53	19	6	5	1	0	0	0	0

Table 3.19. Predicted dead discards at age (numbers of fish) for the ASrec fleet from the base run of the stock assessment model, 1991–2021. Values rounded to the nearest integer.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1991	0	0	47	851	330	141	68	36	14	4	1	0	0	0	0	0
1992	0	0	19	408	769	93	23	10	5	2	1	0	0	0	0	0
1993	0	0	16	255	606	388	28	6	2	1	0	0	0	0	0	0
1994	0	0	11	181	315	256	98	6	1	0	0	0	0	0	0	0
1995	0	0	26	144	264	161	79	25	1	0	0	0	0	0	0	0
1996	0	0	25	362	221	141	52	21	6	0	0	0	0	0	0	0
1997	0	0	20	268	426	90	35	10	4	1	0	0	0	0	0	0
1998	0	0	47	671	991	547	70	22	6	2	1	0	0	0	0	0
1999	0	0	29	530	826	414	138	15	4	1	0	0	0	0	0	0
2000	0	0	87	943	1,811	943	287	79	8	2	1	0	0	0	0	0
2001	0	0	88	1,455	1,599	966	296	75	20	2	1	0	0	0	0	0
2002	0	0	94	906	1,520	520	183	47	11	3	0	0	0	0	0	0
2003	0	0	22	694	697	364	72	21	5	1	0	0	0	0	0	0
2004	0	0	20	558	1,849	596	180	29	8	2	1	0	0	0	0	0
2005	0	0	10	235	657	673	127	32	5	1	0	0	0	0	0	0
2006	0	0	18	134	301	253	153	25	6	1	0	0	0	0	0	0
2007	0	0	46	271	182	113	55	30	5	1	0	0	0	0	0	0
2008	0	0	56	836	473	84	28	12	7	1	0	0	0	0	0	0
2009	0	0	25	630	947	164	17	4	2	1	0	0	0	0	0	0
2010	0	0	3	95	232	106	11	1	0	0	0	0	0	0	0	0
2011	0	0	7	217	624	454	119	10	1	0	0	0	0	0	0	0
2012	0	0	97	342	793	588	255	61	5	0	0	0	0	0	0	0
2013	0	0	97	496	115	39	12	5	2	0	0	0	0	0	0	0
2014	0	0	22	724	306	14	2	1	0	0	0	0	0	0	0	0
2015	0	0	66	861	2,425	255	6	1	0	0	0	0	0	0	0	0
2016	0	0	20	237	252	165	9	0	0	0	0	0	0	0	0	0
2017	0	0	30	250	266	68	22	1	0	0	0	0	0	0	0	0
2018	0	0	7	265	204	59	8	2	0	0	0	0	0	0	0	0
2019	0	0	11	230	759	154	23	3	1	0	0	0	0	0	0	0
2020	0	0	8	225	338	252	27	4	0	0	0	0	0	0	0	0
2021	0	0	11	86	159	40	13	1	0	0	0	0	0	0	0	0

Table 3.20. Predicted harvest at age (numbers of fish) for the RRrec fleet from the base run of the stock assessment model, 1991–2021. Values rounded to the nearest integer.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1991	0	0	350	14,863	7,145	2,960	1,136	389	78	9	1	0	0	0	0	0
1992	0	0	70	3,615	8,434	986	196	52	14	2	0	0	0	0	0	0
1993	0	0	65	2,426	7,120	4,423	254	34	7	1	0	0	0	0	0	0
1994	0	0	39	1,527	3,295	2,596	794	30	3	0	0	0	0	0	0	0
1995	0	0	107	1,401	3,187	1,884	738	149	4	0	0	0	0	0	0	0
1996	0	0	101	3,441	2,596	1,613	474	122	18	0	0	0	0	0	0	0
1997	0	0	82	2,636	5,184	1,064	326	63	12	1	0	0	0	0	0	0
1998	0	0	172	5,836	10,667	5,714	584	118	17	2	0	0	0	0	0	0
1999	0	0	124	5,405	10,425	5,076	1,343	91	14	1	0	0	0	0	0	0
2000	0	0	300	7,698	18,305	9,252	2,236	396	20	2	0	0	0	0	0	0
2001	0	0	264	10,319	14,043	8,229	2,002	327	44	2	0	0	0	0	0	0
2002	0	0	396	9,019	18,731	6,215	1,735	285	35	4	0	0	0	0	0	0
2003	0	0	49	3,714	4,616	2,338	365	69	9	1	0	0	0	0	0	0
2004	0	0	79	5,262	21,581	6,747	1,617	167	24	2	0	0	0	0	0	0
2005	0	0	72	3,999	13,846	13,777	2,060	336	27	3	0	0	0	0	0	0
2006	0	0	195	3,464	9,628	7,839	3,783	397	51	3	0	0	0	0	0	0
2007	0	0	517	7,225	6,003	3,618	1,405	493	42	4	0	0	0	0	0	0
2008	0	0	157	5,573	3,900	672	176	48	14	1	0	0	0	0	0	0
2009	0	0	124	7,216	13,433	2,256	181	32	7	1	0	0	0	0	0	0
2010	0	0	58	4,076	12,356	5,492	440	24	3	1	0	0	0	0	0	0
2011	0	0	37	2,899	10,296	7,266	1,514	83	4	0	0	0	0	0	0	0
2012	0	0	500	4,182	11,985	8,635	2,972	460	21	1	0	0	0	0	0	0
2013	0	0	430	5,166	1,478	484	121	34	5	0	0	0	0	0	0	0
2014	0	0	89	7,082	3,703	164	18	3	1	0	0	0	0	0	0	0
2015	0	0	134	4,103	14,304	1,458	27	2	0	0	0	0	0	0	0	0
2016	0	0	237	6,593	8,676	5,520	230	3	0	0	0	0	0	0	0	0
2017	0	0	182	3,559	4,678	1,165	305	9	0	0	0	0	0	0	0	0
2018	0	0	43	3,854	3,680	1,031	113	20	0	0	0	0	0	0	0	0
2019	0	0	54	2,756	11,259	2,219	267	20	3	0	0	0	0	0	0	0
2020	0	0	73	4,675	8,698	6,303	529	46	3	0	0	0	0	0	0	0
2021	0	0	109	1,927	4,405	1,066	267	17	1	0	0	0	0	0	0	0

Table 3.21. Predicted dead discards at age (numbers of fish) for the RRrec fleet from the base run of the stock assessment model, 1991–2021. Values rounded to the nearest integer.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1991	0	13	485	2,553	860	491	403	423	357	239	144	108	75	45	30	54
1992	0	2	65	418	684	110	47	38	42	37	25	15	11	8	5	9
1993	0	5	137	636	1,308	1,118	138	56	46	52	46	32	19	15	10	18
1994	0	1	9	42	63	69	45	5	2	2	2	2	1	1	1	1
1995	0	13	319	514	820	668	559	345	41	17	15	17	15	10	6	14
1996	0	36	848	3,563	1,885	1,612	1,013	802	500	60	25	22	25	23	16	30
1997	0	51	1,283	5,094	7,024	1,985	1,302	770	613	389	47	20	17	20	18	37
1998	0	23	723	3,041	3,896	2,873	628	389	231	187	120	15	6	5	6	17
1999	0	24	458	2,467	3,335	2,235	1,265	263	165	100	82	53	6	3	2	10
2000	0	12	357	1,133	1,888	1,314	679	369	78	50	31	26	17	2	1	4
2001	0	15	252	1,220	1,164	939	489	245	138	30	20	12	10	7	1	2
2002	0	5	296	834	1,214	554	331	167	87	51	11	8	5	4	3	1
2003	0	2	86	807	703	490	164	94	50	27	16	4	2	2	1	1
2004	0	5	230	1,894	5,446	2,343	1,201	380	227	125	70	42	10	6	4	6
2005	0	12	164	1,132	2,746	3,761	1,203	600	200	124	70	40	24	6	4	6
2006	0	19	204	450	876	982	1,014	326	175	61	39	22	13	8	2	3
2007	0	19	508	879	512	424	353	380	136	78	29	19	11	6	4	2
2008	0	30	1,329	5,841	2,865	679	380	317	379	147	89	33	22	13	7	7
2009	0	8	414	2,994	3,906	902	155	83	72	90	36	22	8	5	3	4
2010	0	3	185	1,622	3,447	2,109	361	61	34	31	40	16	10	4	3	3
2011	0	13	96	931	2,318	2,251	1,003	169	31	18	17	23	9	6	2	3
2012	0	47	459	476	955	947	698	331	63	12	8	7	10	4	2	2
2013	0	25	1,519	2,260	453	204	110	95	60	14	3	2	2	3	1	1
2014	0	30	716	7,019	2,571	156	37	19	20	15	4	1	1	1	1	1
2015	0	20	447	1,697	4,143	580	23	5	3	3	3	1	0	0	0	0
2016	0	21	314	1,082	997	872	77	3	1	0	1	0	0	0	0	0
2017	0	11	727	1,762	1,623	556	311	28	1	0	0	0	0	0	0	0
2018	0	13	514	5,660	3,787	1,459	340	186	18	1	0	0	0	0	0	0
2019	0	7	374	2,361	6,758	1,831	470	106	64	7	0	0	0	0	0	0
2020	0	14	215	1,711	2,230	2,222	399	106	28	19	2	0	0	0	0	0
2021	0	3	441	969	1,551	515	277	55	19	6	5	1	0	0	0	0

Table 3.22. Annual estimates of fishing mortality (numbers-weighted, ages 3–5) and associated standard deviations (SDs) from the base run of the stock assessment model, 1991–2021.

	Fishing Mortality	
Year	**Value**	**SD**
1991	0.18	0.012
1992	0.13	0.0070
1993	0.17	0.0083
1994	0.12	0.0064
1995	0.12	0.0063
1996	0.094	0.0046
1997	0.10	0.0043
1998	0.15	0.0059
1999	0.14	0.0052
2000	0.24	0.0098
2001	0.23	0.0099
2002	0.22	0.0097
2003	0.16	0.0052
2004	0.29	0.0065
2005	0.38	0.0094
2006	0.43	0.017
2007	0.36	0.018
2008	0.18	0.0080
2009	0.22	0.0063
2010	0.32	0.0064
2011	0.45	0.0085
2012	1.3	0.052
2013	0.40	0.028
2014	0.25	0.0076
2015	0.57	0.017
2016	0.51	0.022
2017	0.28	0.013
2018	0.28	0.0082
2019	0.57	0.018
2020	1.0	0.086
2021	0.77	0.14

8 FIGURES

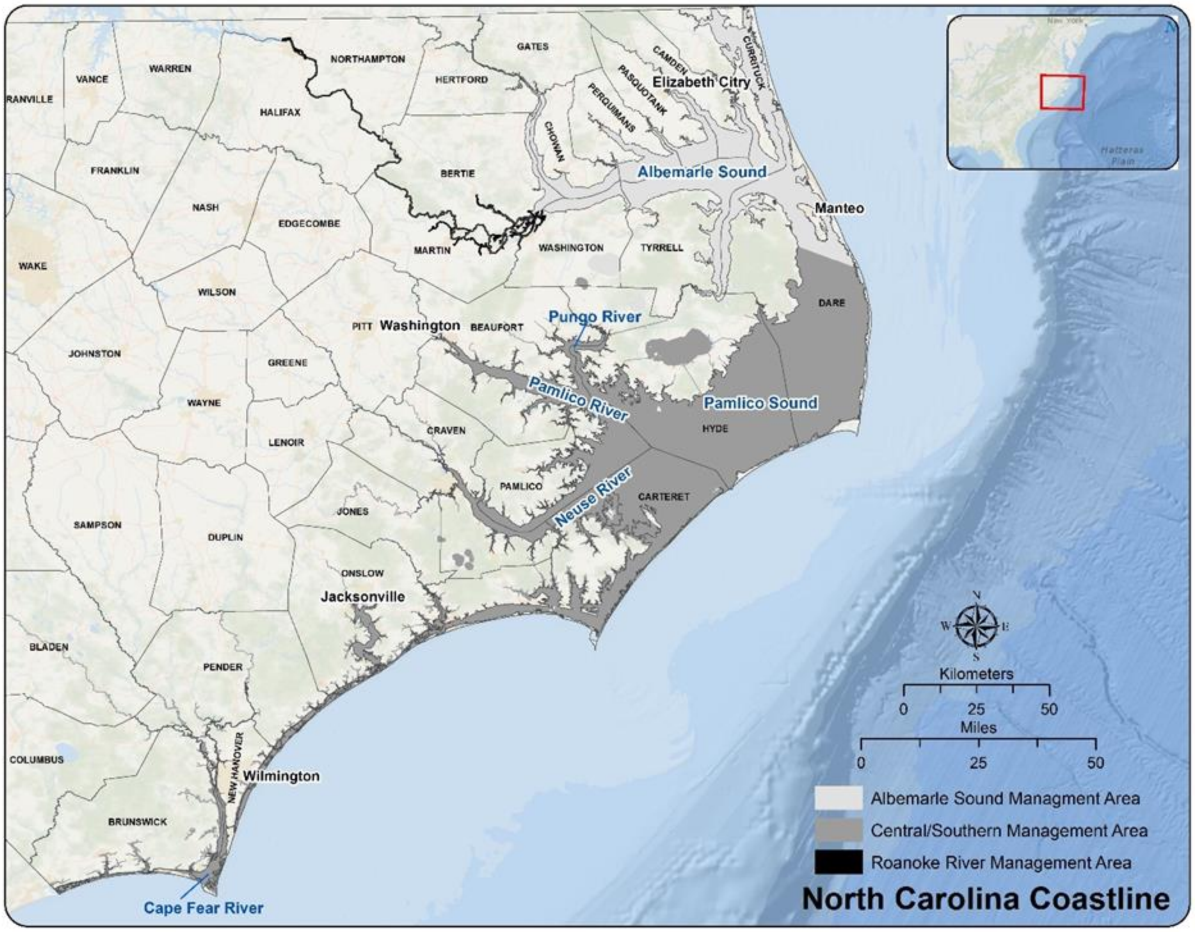


Figure 1.1. Map defining the Albemarle Sound Management Area and Roanoke River Management Area in North Carolina.

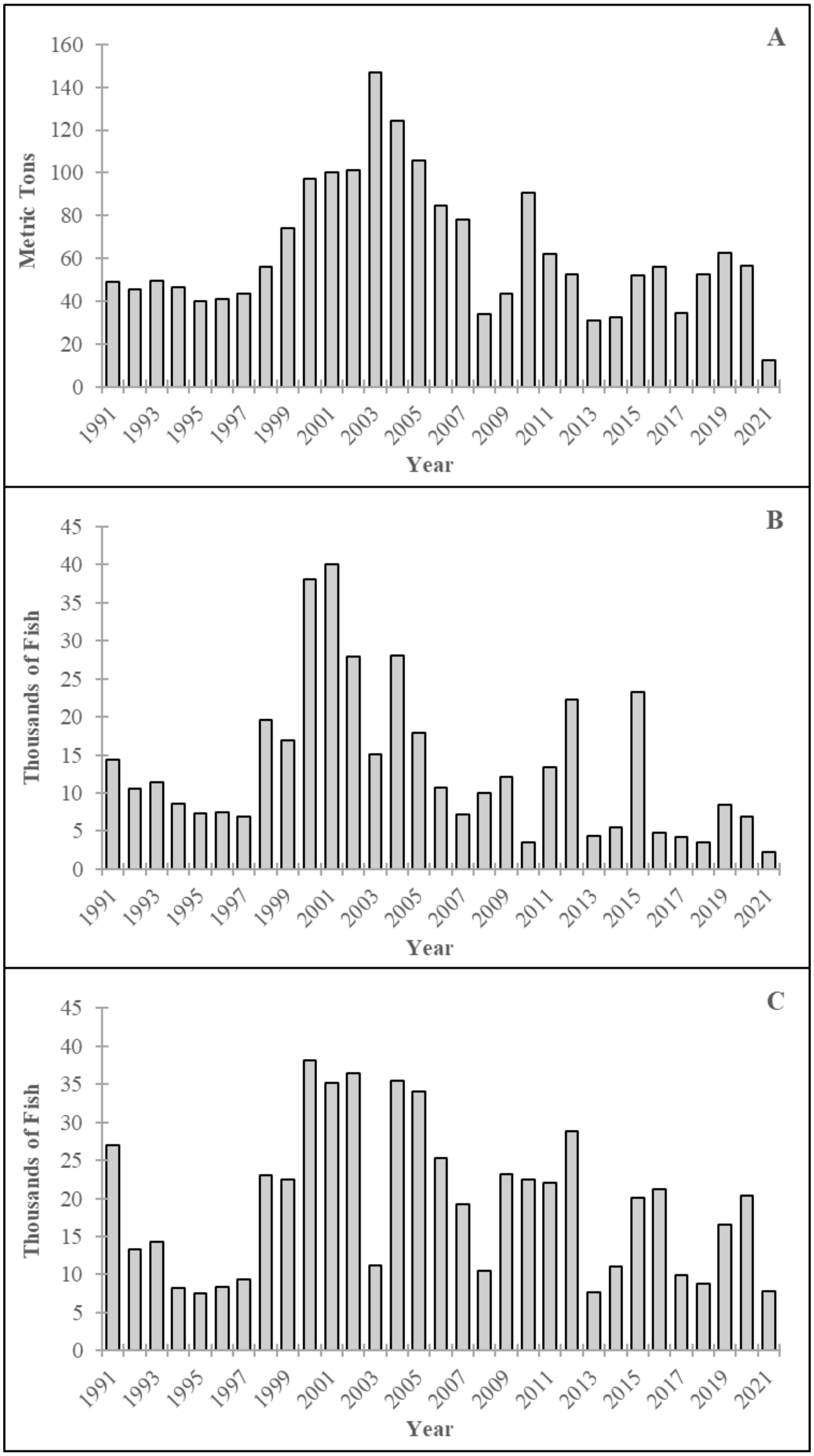


Figure 3.1. Annual (A) AScomm landings, (B) ASrec harvest, and (C) RRrecharv harvest values that were input into the SS3 model, 1991–2021.

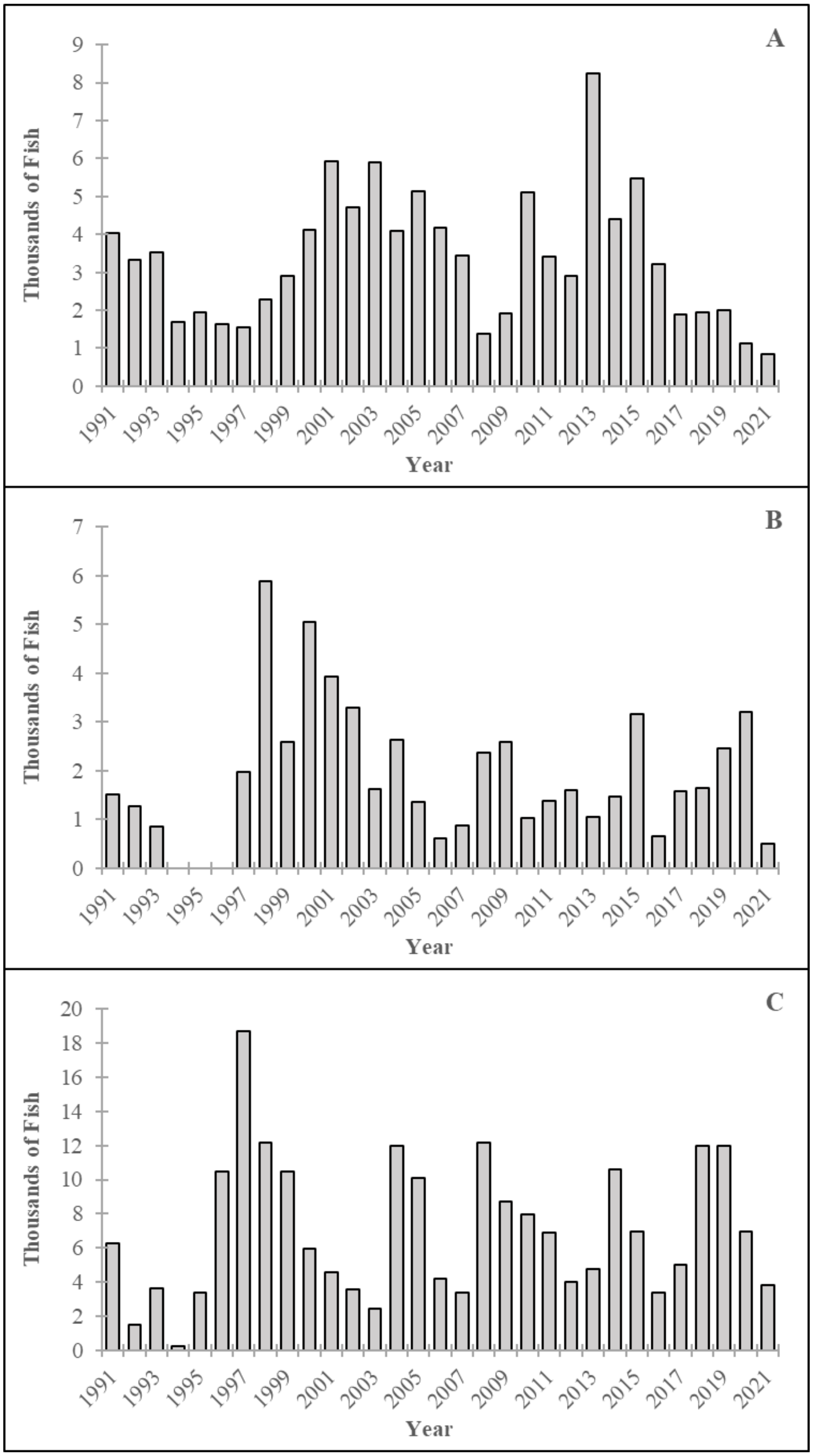


Figure 3.2. Annual (A) AScomm, (B) ASrec, and (C) RRrecdisc dead discards that were input into the SS3 model, 1991–2021.

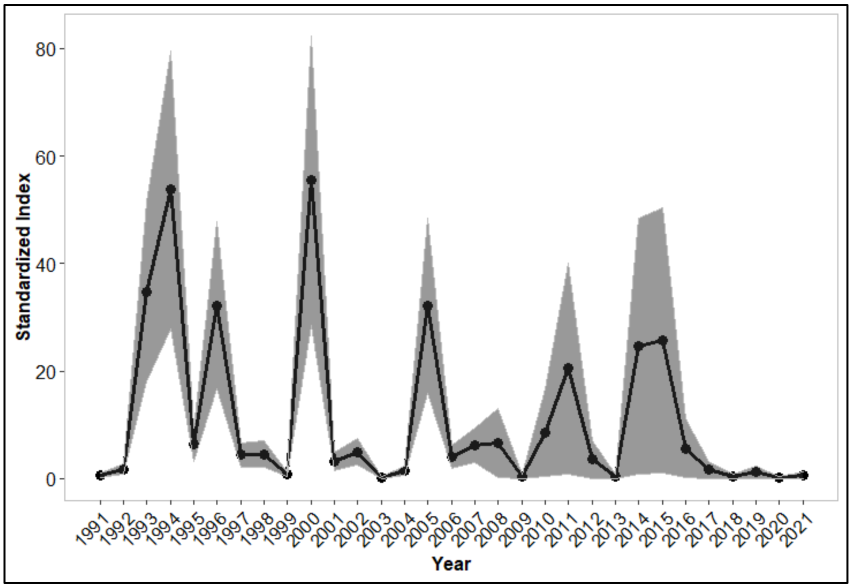


Figure 3.3. GLM-standardized index of relative abundance derived from the Program 100 Juvenile Trawl Survey (P100juv) that was input into the SS3 model, 1991–2021. Shaded area represents ± 2 standard errors.

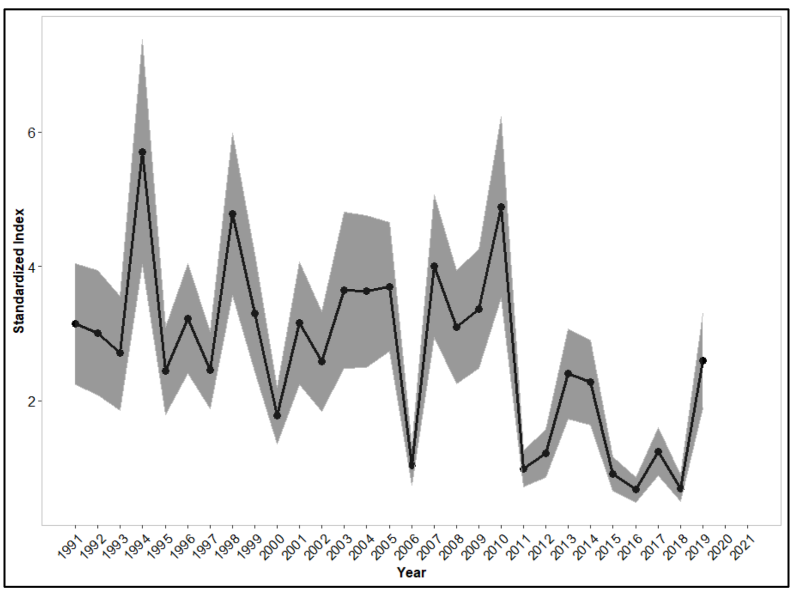


Figure 3.4. GLM-standardized index of relative abundance derived from the fall/winter component of the Program 135 Striped Bass Independent Gill-Net Survey (P135fw) that was input into the SS3 model, 1991–2019. Shaded area represents ± 2 standard errors.

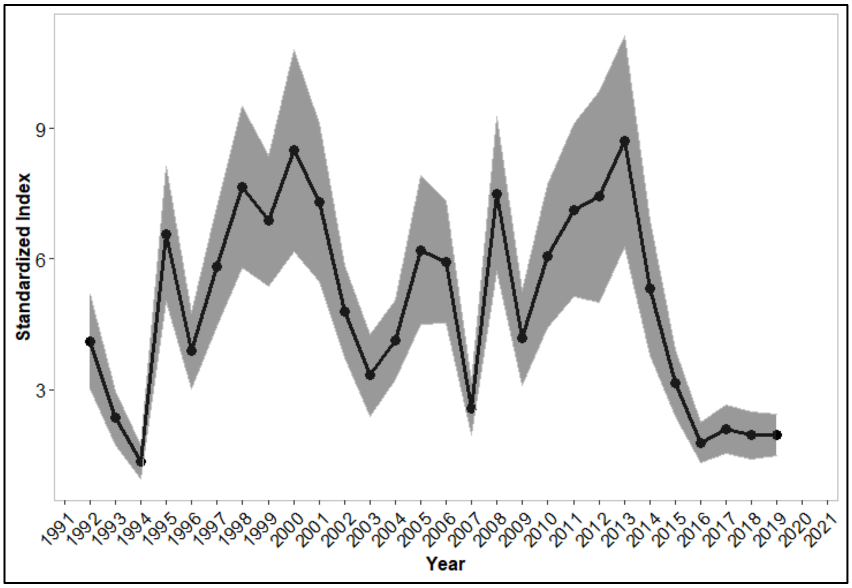


Figure 3.5. GLM-standardized index of relative abundance derived from the spring component of the Program 135 Striped Bass Independent Gill-Net Survey (P135spr) that was input into the SS3 model, 1992–2019. Shaded area represents ± 2 standard errors.

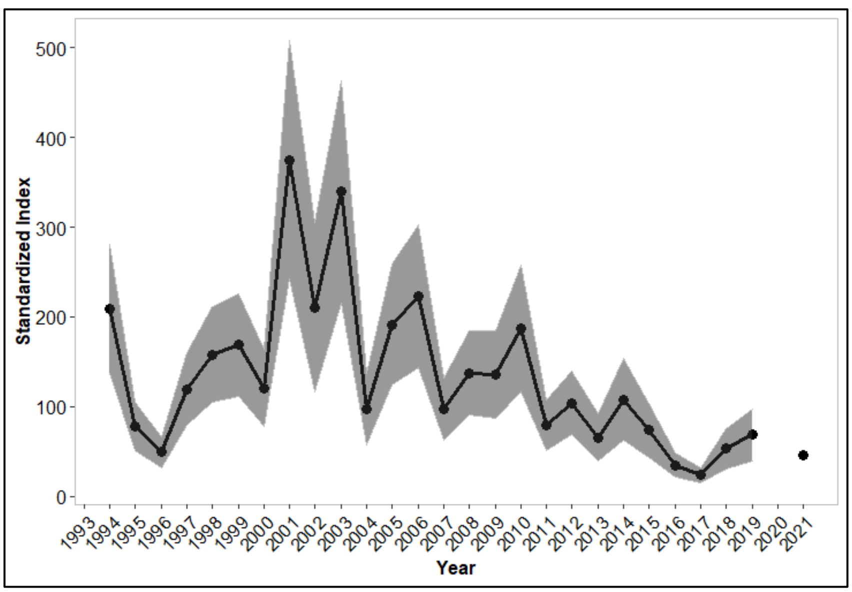


Figure 3.6. GLM-standardized index of relative abundance derived from the Roanoke River Electrofishing Survey (RRef) that was input into the SS3 model, 1994–2021. Shaded area represents ± 2 standard errors.

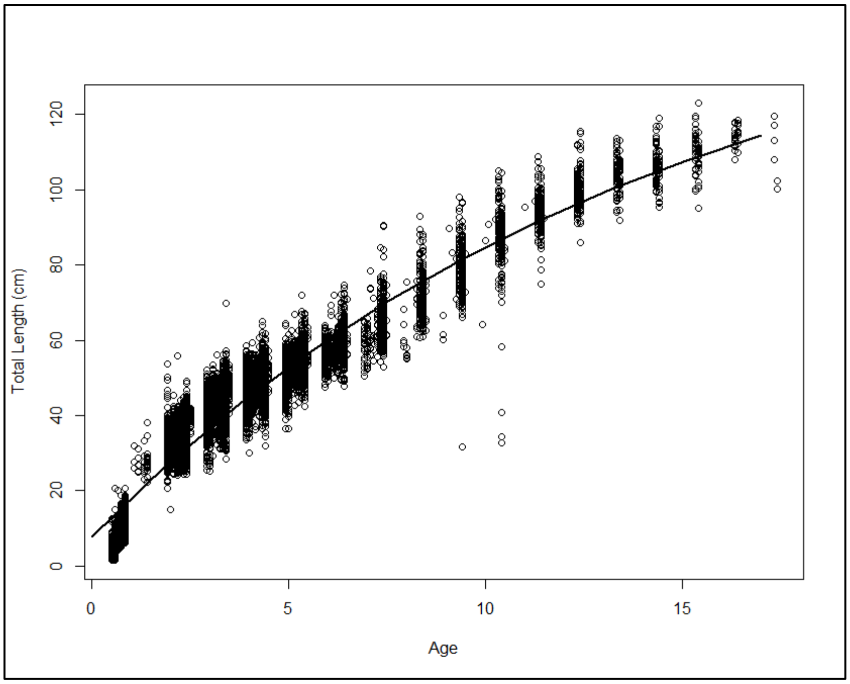


Figure 3.7. Fit of the von Bertalanffy age-length function to available age data (scales only) for female Striped Bass. This fit was perfomed external to the SS3 model.

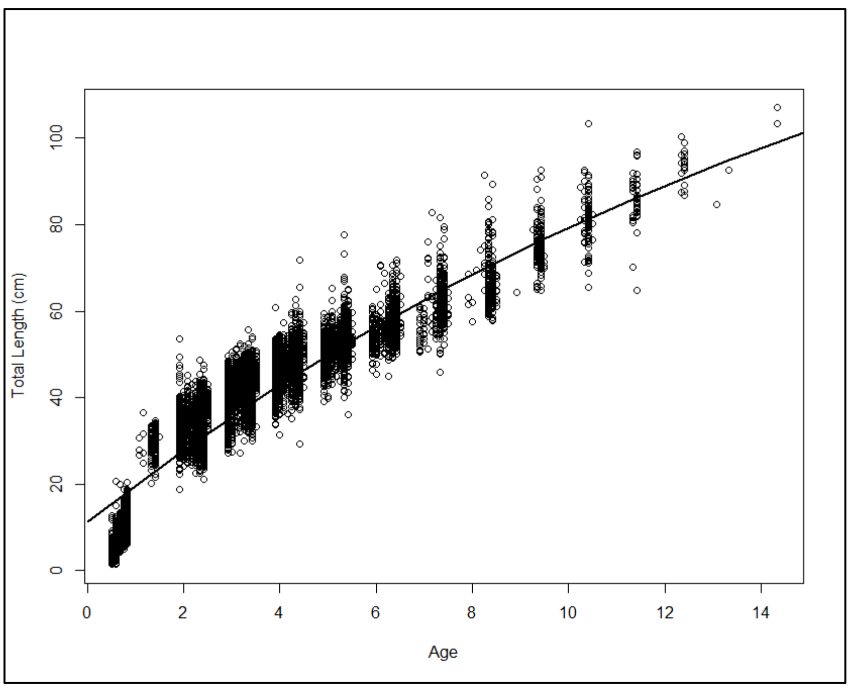


Figure 3.8. Fit of the von Bertalanffy age-length function to available age data (scales only) for male Striped Bass. This fit was perfomed external to the SS3 model.

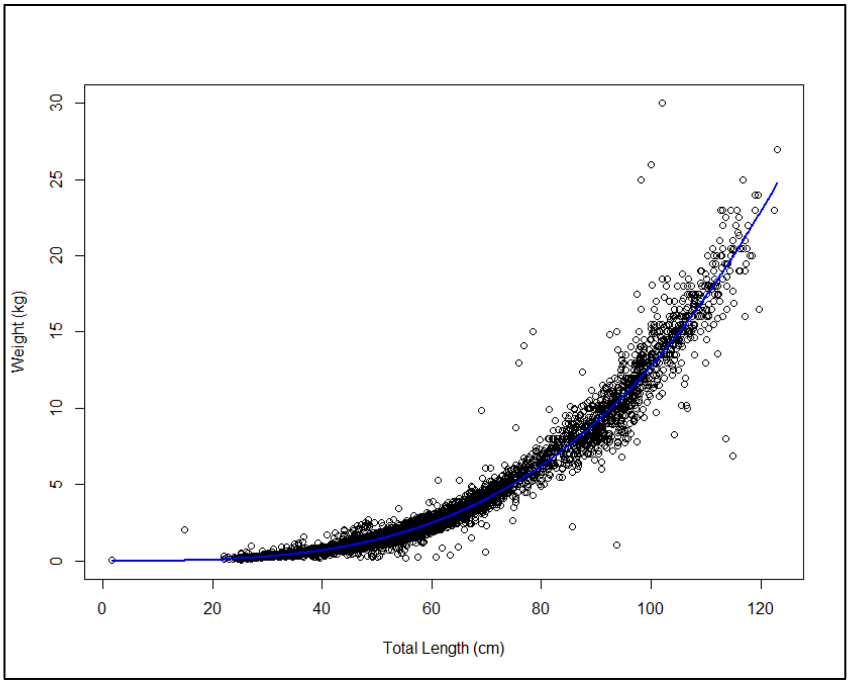


Figure 3.9. Fit of the length-weight function to available biological data for female Striped Bass. This fit was perfomed external to the SS3 model.

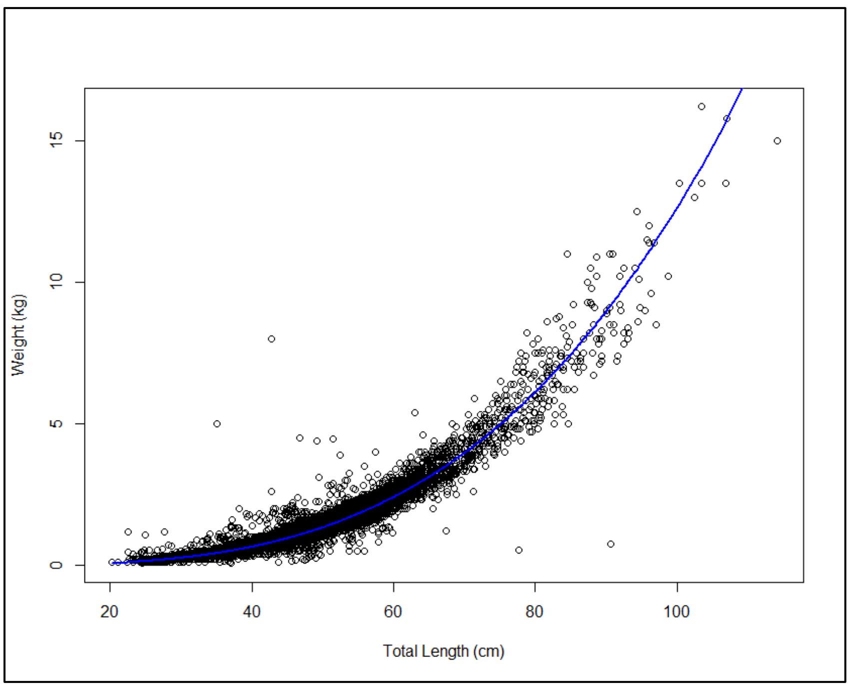


Figure 3.10. Fit of the length-weight function to available biological data for male Striped Bass. This fit was perfomed external to the SS3 model.

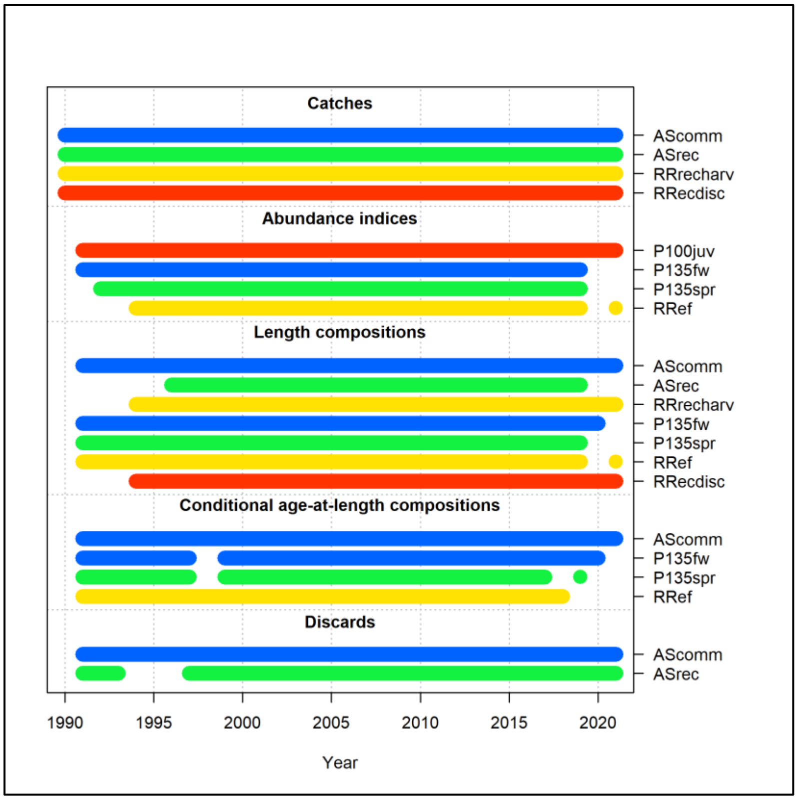


Figure 3.11. Summary of data sources and types used in the base run of the stock assessment for Striped Bass.

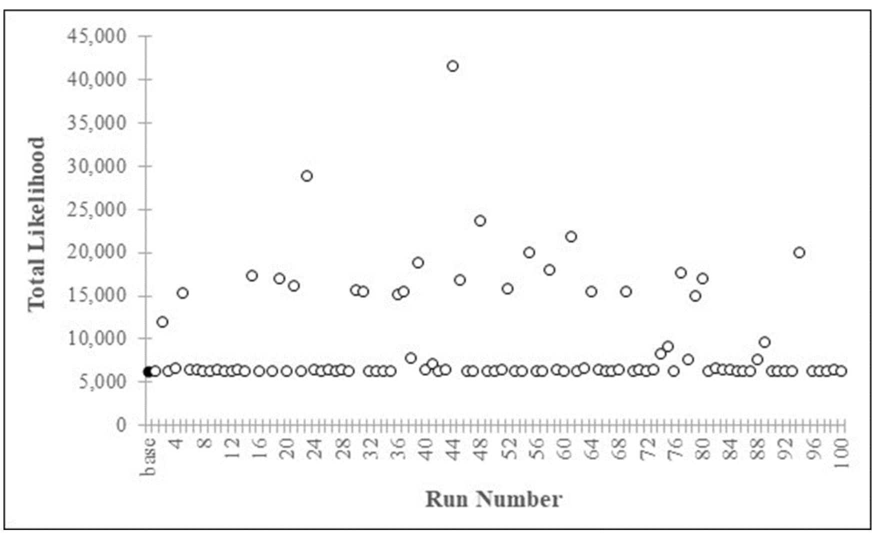


Figure 3.12. Negative log-likelihood values produced from the 100 jitter trials in which initial parameter values were jittered by 10%. The solid black circle is the value from the base run. Runs 17 and 95 not included in plot due to excessively large likelihood values.

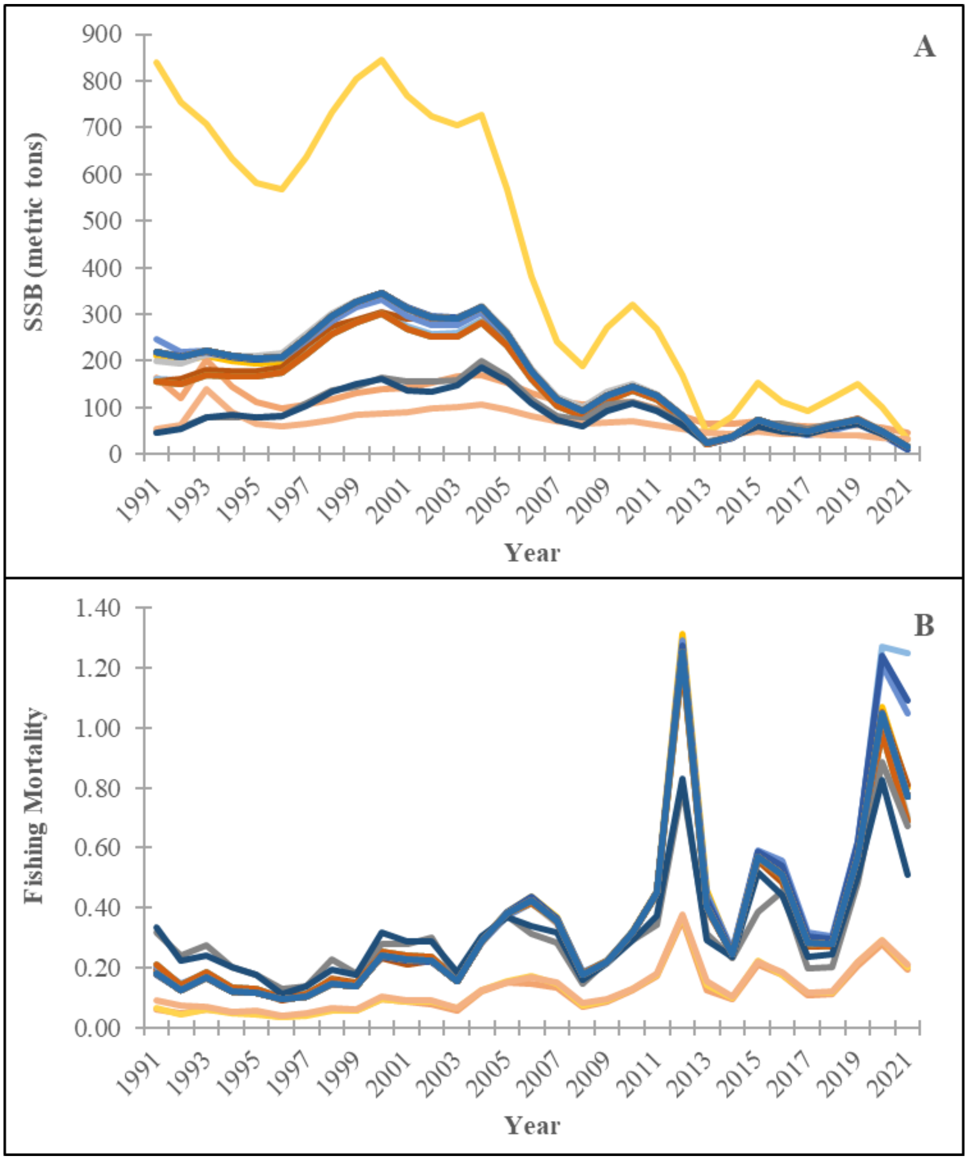


Figure 3.13. Predicted (A) female SSB and (B) *F* (numbers-weighted, aged 3–5) from the converged jutter trails in which initial parameter values were jittered by 10%, 1991–2021. Runs with biologically unrealistic results removed.

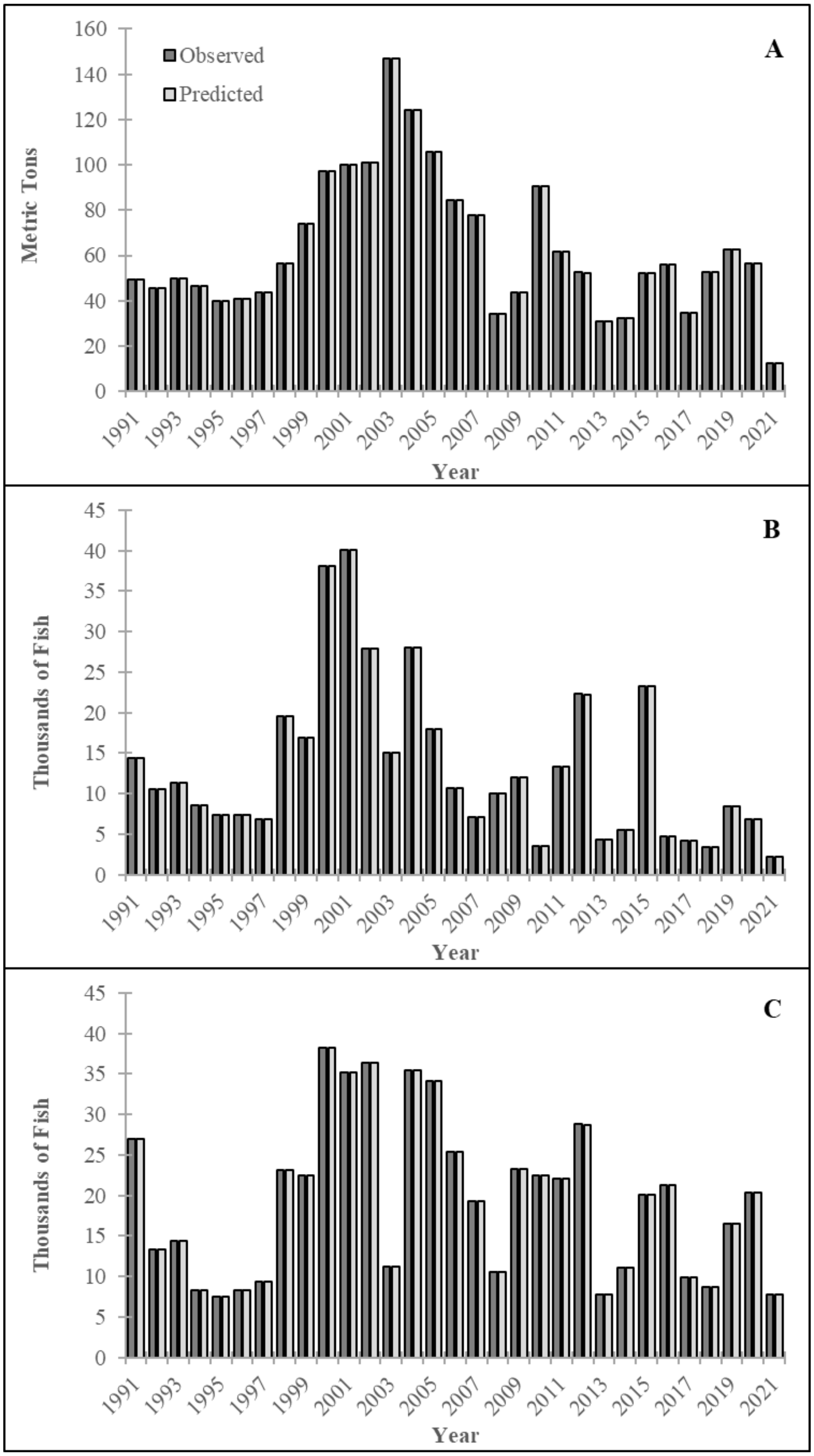


Figure 3.14. Observed and predicted (A) AScomm landings, (B) ASrec harvest, and (C) RRrec harvest from the base run of the stock assessment model, 1991–2021.

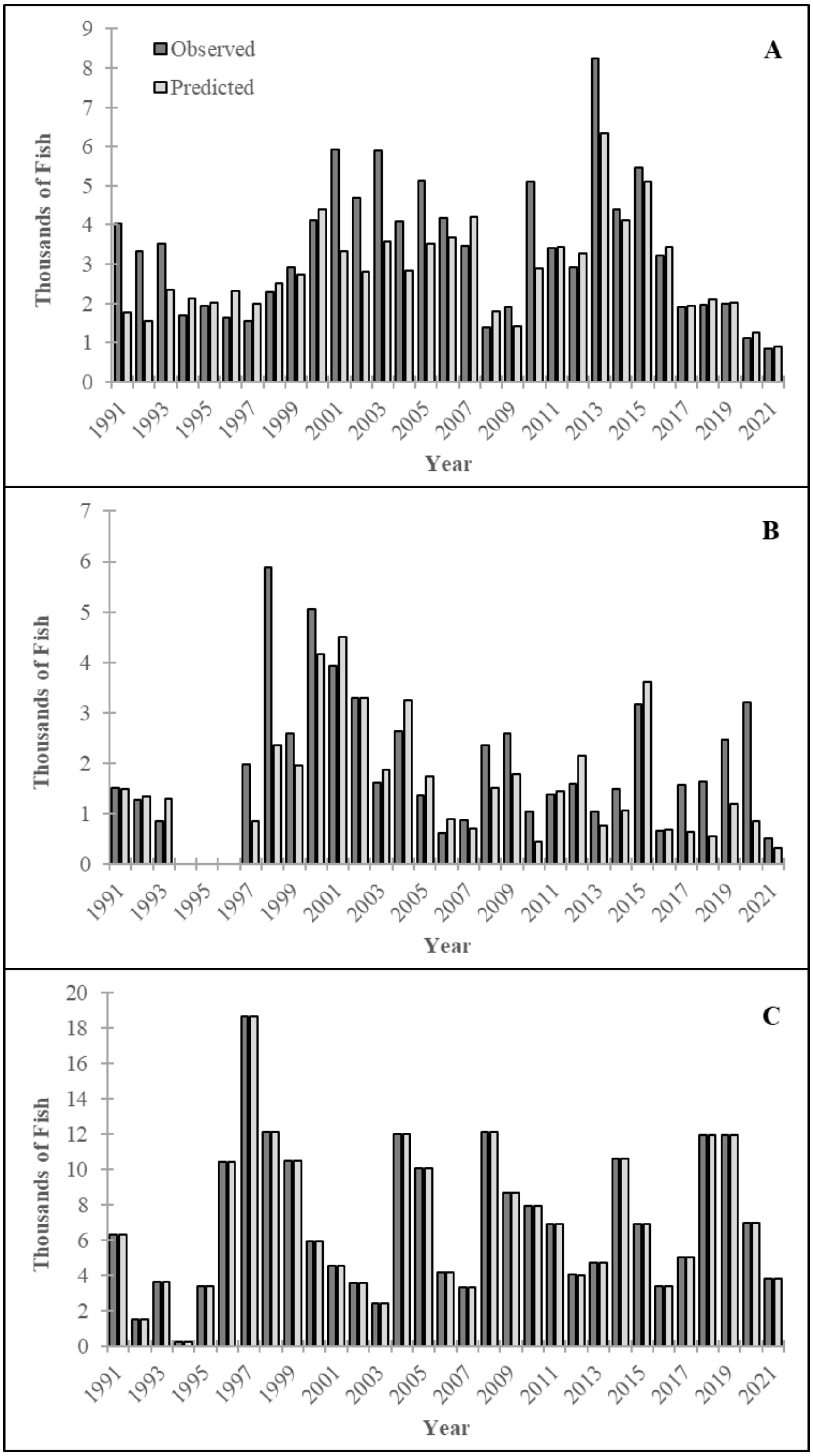


Figure 3.15. Observed and predicted (A) AScomm, (B) ASrec, and (C) RRrec dead discards from the base run of the stock assessment model, 1991–2021.

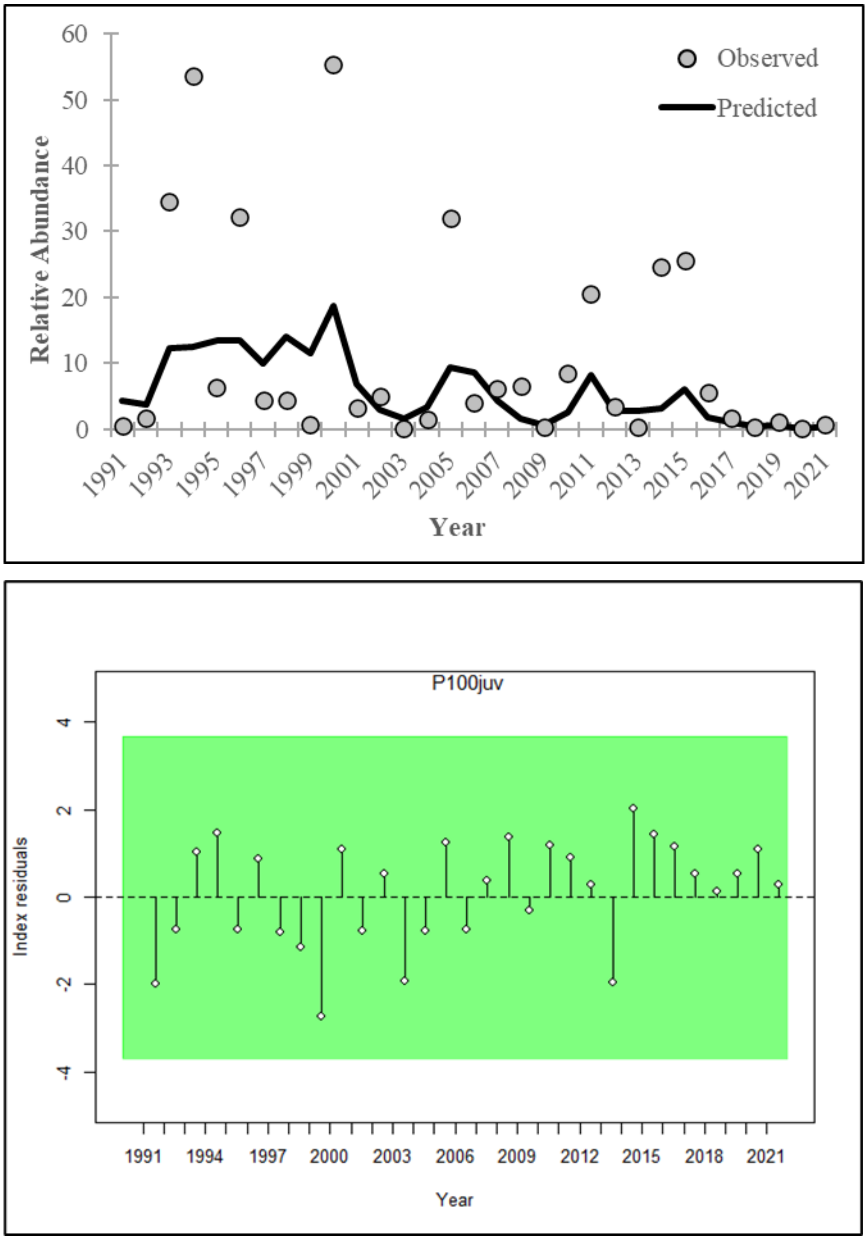


Figure 3.16. Observed and predicted relative abundance (top graph) and standardized residuals on a runs test plot (bottom graph) for the P100juv survey from the base run of the stock assessment model, 1991–2021. Green shading indicates no evidence (α = 0.05) to reject the hypothesis of a randomly distributed time series of residuals. The shaded (green) area spans three residual standard deviations to either side from zero and the red points outside the shading violate the 'three-sigma limit' for that series.

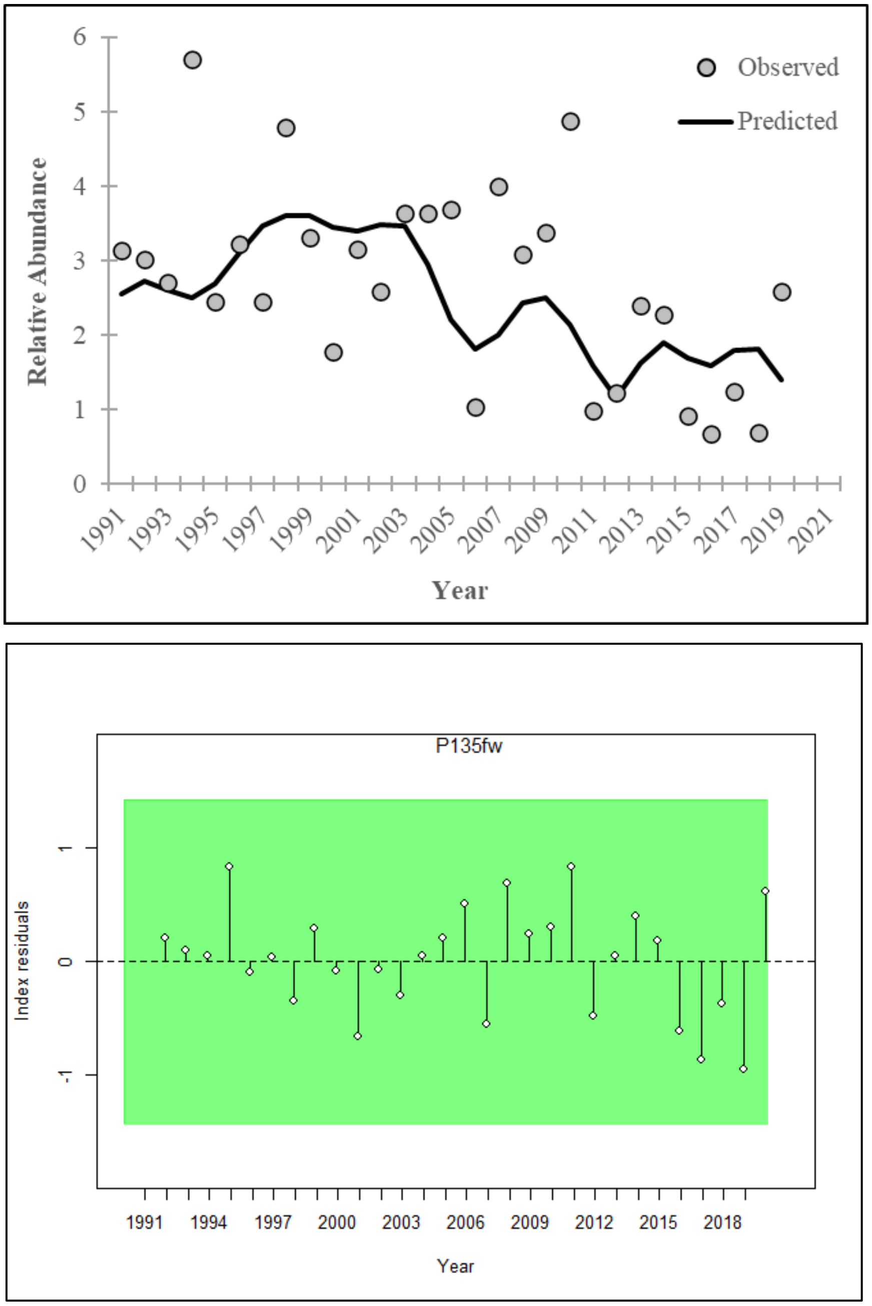
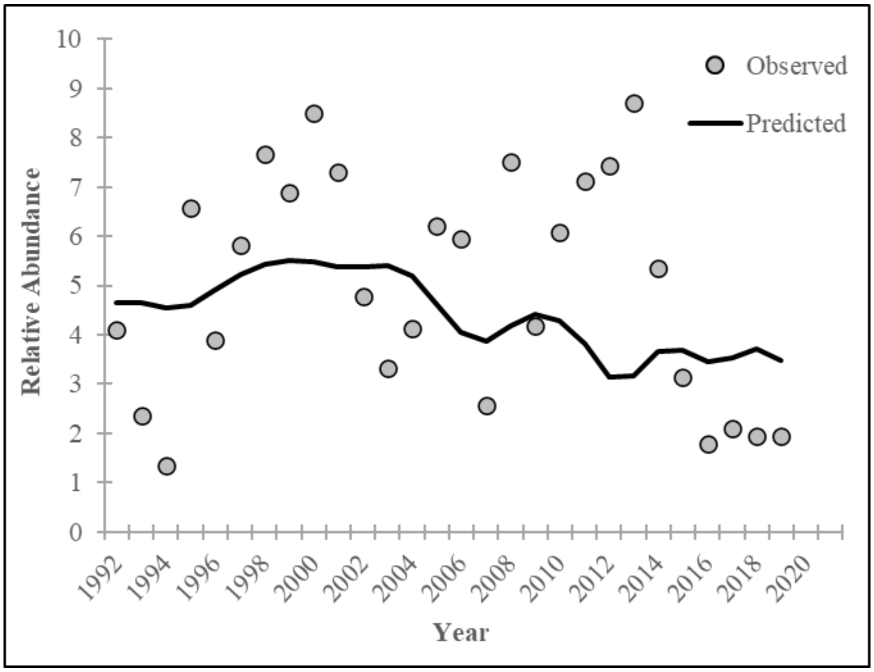


Figure 3.17. Observed and predicted relative abundance (top graph) and standardized residuals on a runs test plot (bottom graph) for the P135fw survey from the base run of the stock assessment model, 1991–2021. Green shading indicates no evidence (α = 0.05) to reject the hypothesis of a randomly distributed time series of residuals. The shaded (green) area spans three residual standard deviations to either side from zero and the red points outside the shading violate the 'three-sigma limit' for that series.



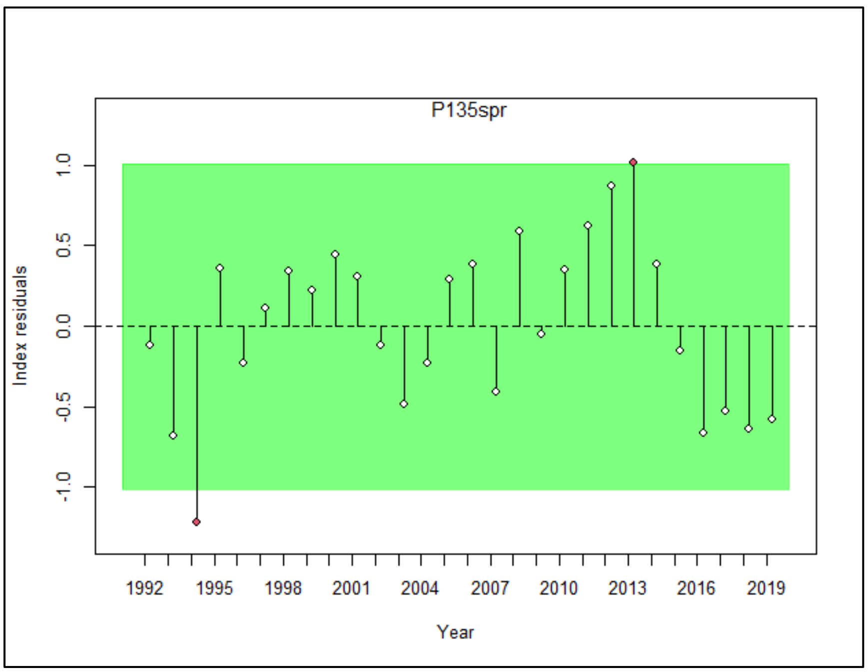


Figure 3.18. Observed and predicted relative abundance (top graph) and standardized residuals on a runs test plot (bottom graph) for the P135spr survey from the base run of the stock assessment model, 1992–2021. Green shading indicates no evidence (α = 0.05) to reject the hypothesis of a randomly distributed time series of residuals. The shaded (green) area spans three residual standard deviations to either side from zero and the red points outside the shading violate the 'three-sigma limit' for that series.

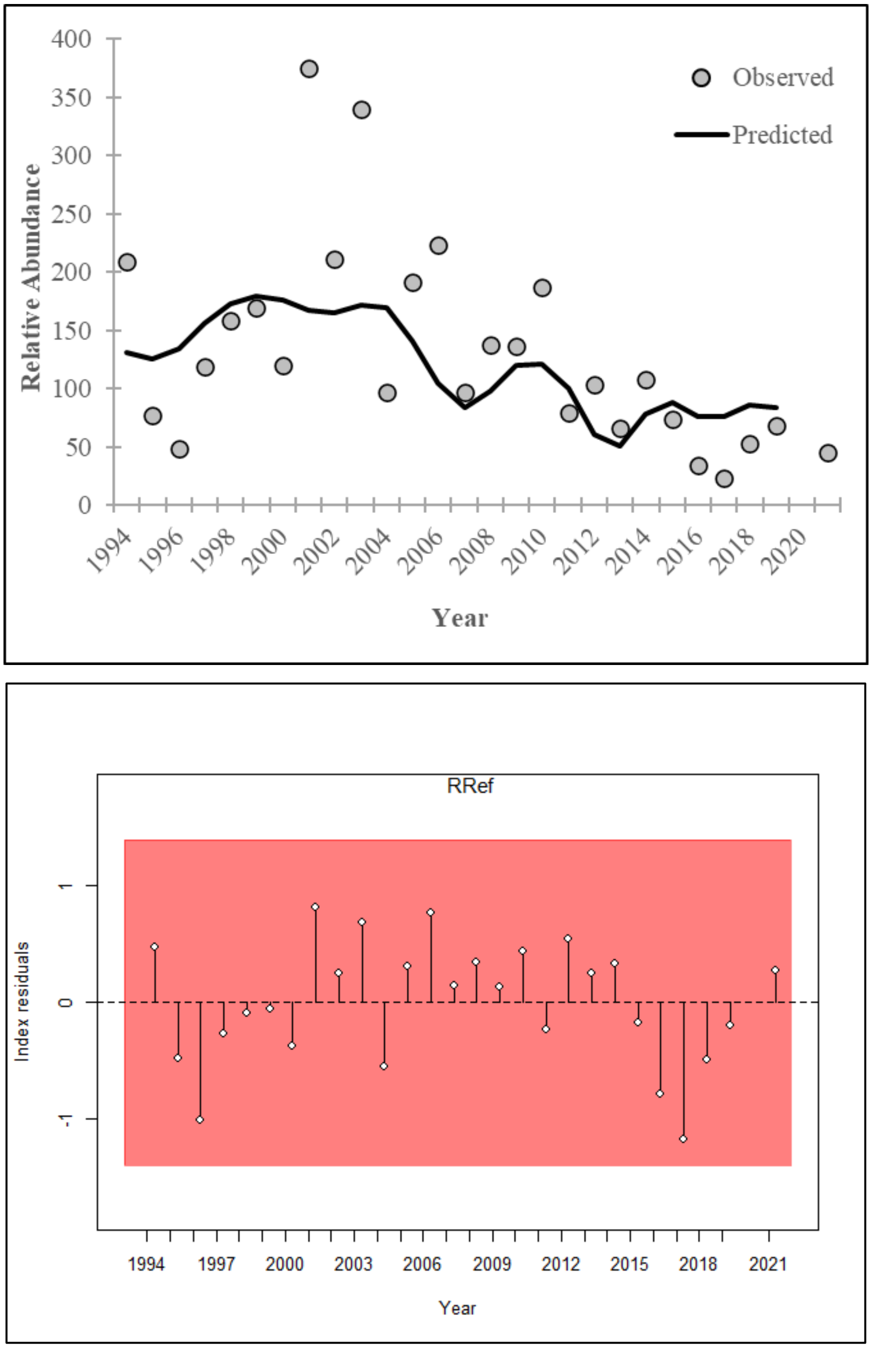


Figure 3.19. Observed and predicted relative abundance (top graph) and standardized residuals on a runs test plot (bottom graph) for the RRef survey from the base run of the stock assessment model, 1994–2021. Red shading indicates there is evidence ($\alpha = 0.05$) to reject the hypothesis of a randomly distributed time series of residuals. The shaded (red) area spans three residual standard deviations to either side from zero and the red points outside the shading violate the ‘three-sigma limit’ for that series.

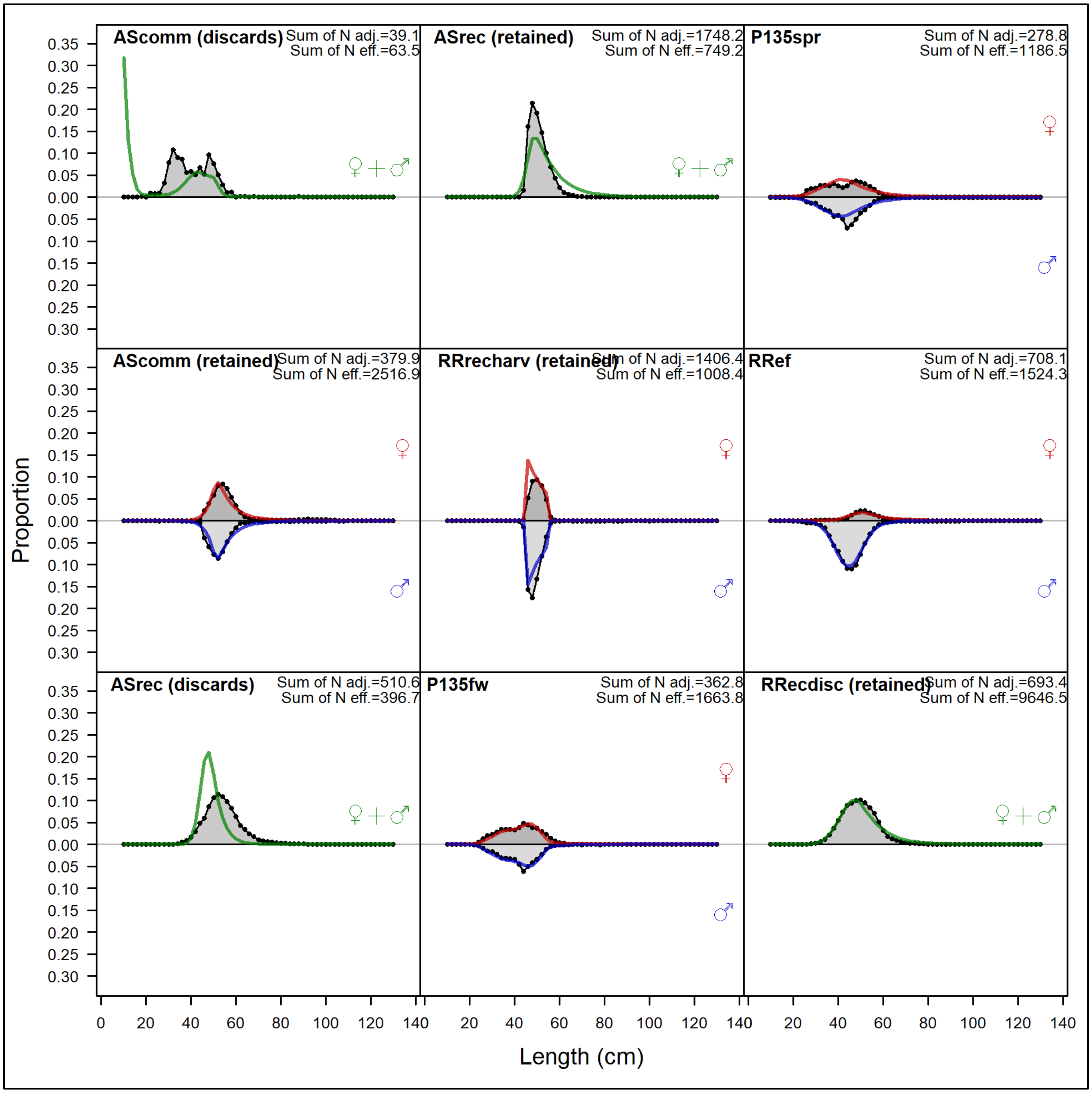


Figure 3.20. Observed and predicted length compositions for each data source from the base run of the stock assessment model aggregated across time. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

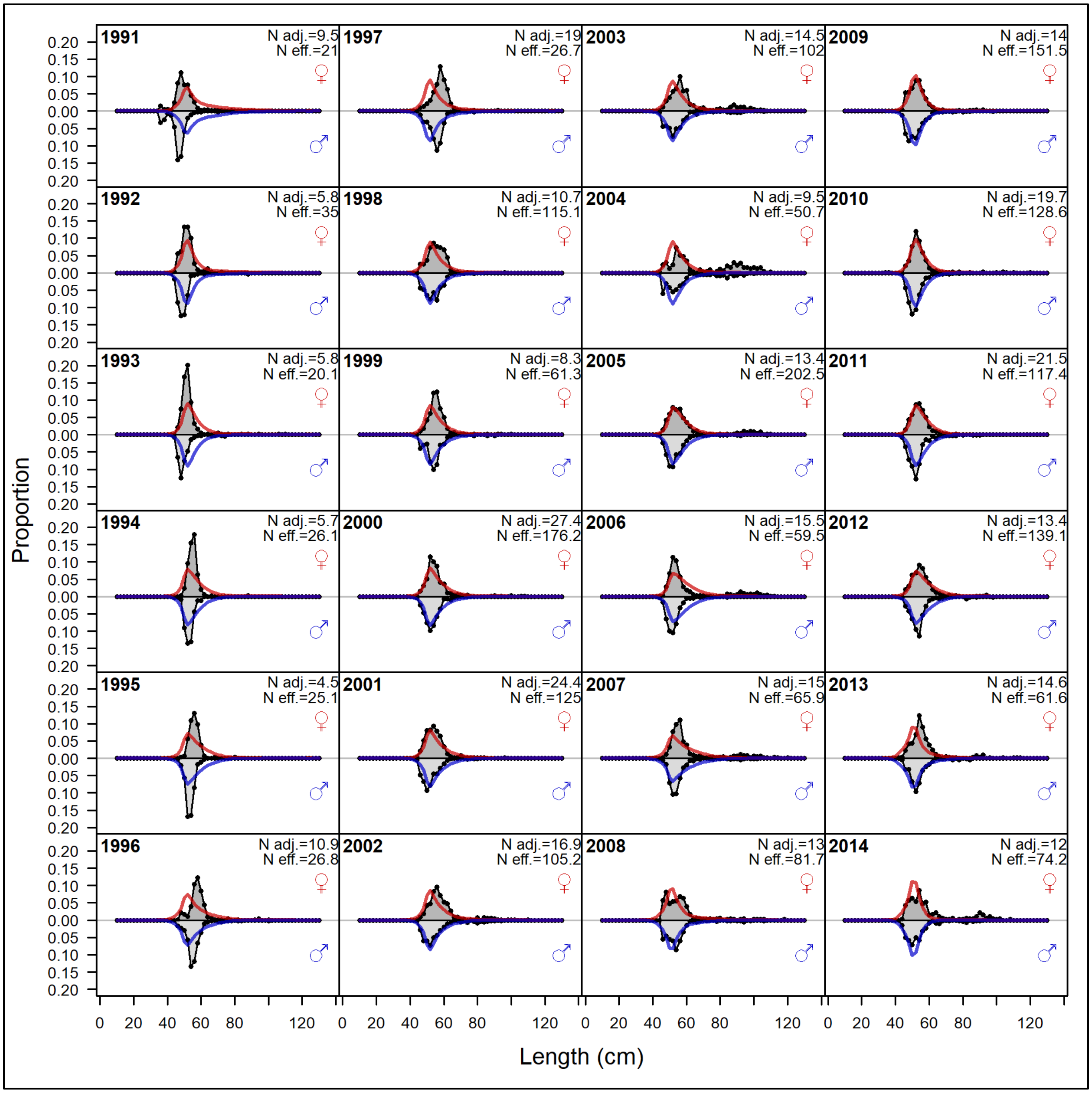


Figure 3.21. Observed and predicted length compositions for the AScomm landings from the base run of the stock assessment model, 1991–2014. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

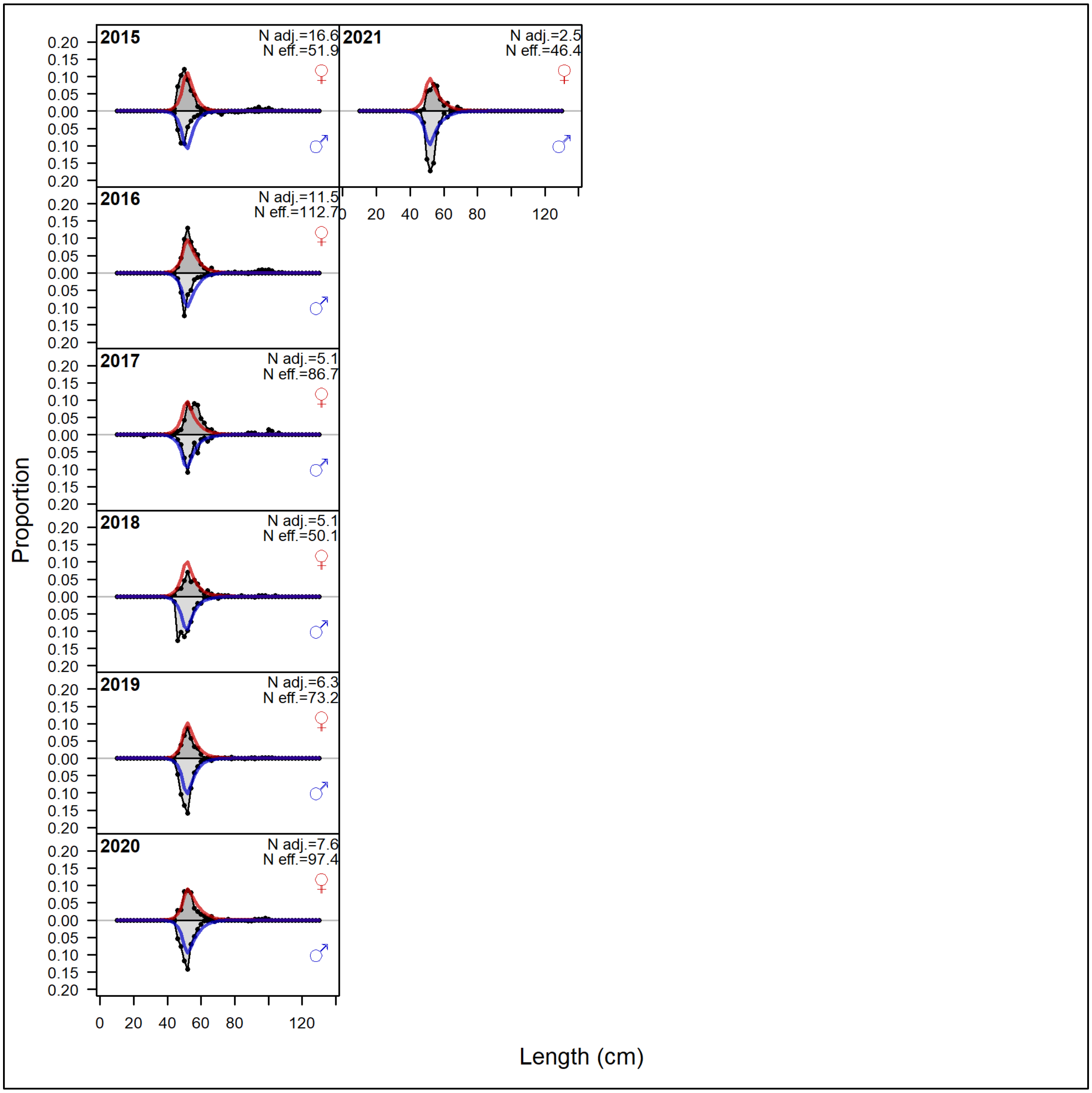


Figure 3.22. Observed and predicted length compositions for the AScomm landings from the base run of the stock assessment model, 2015–2021. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

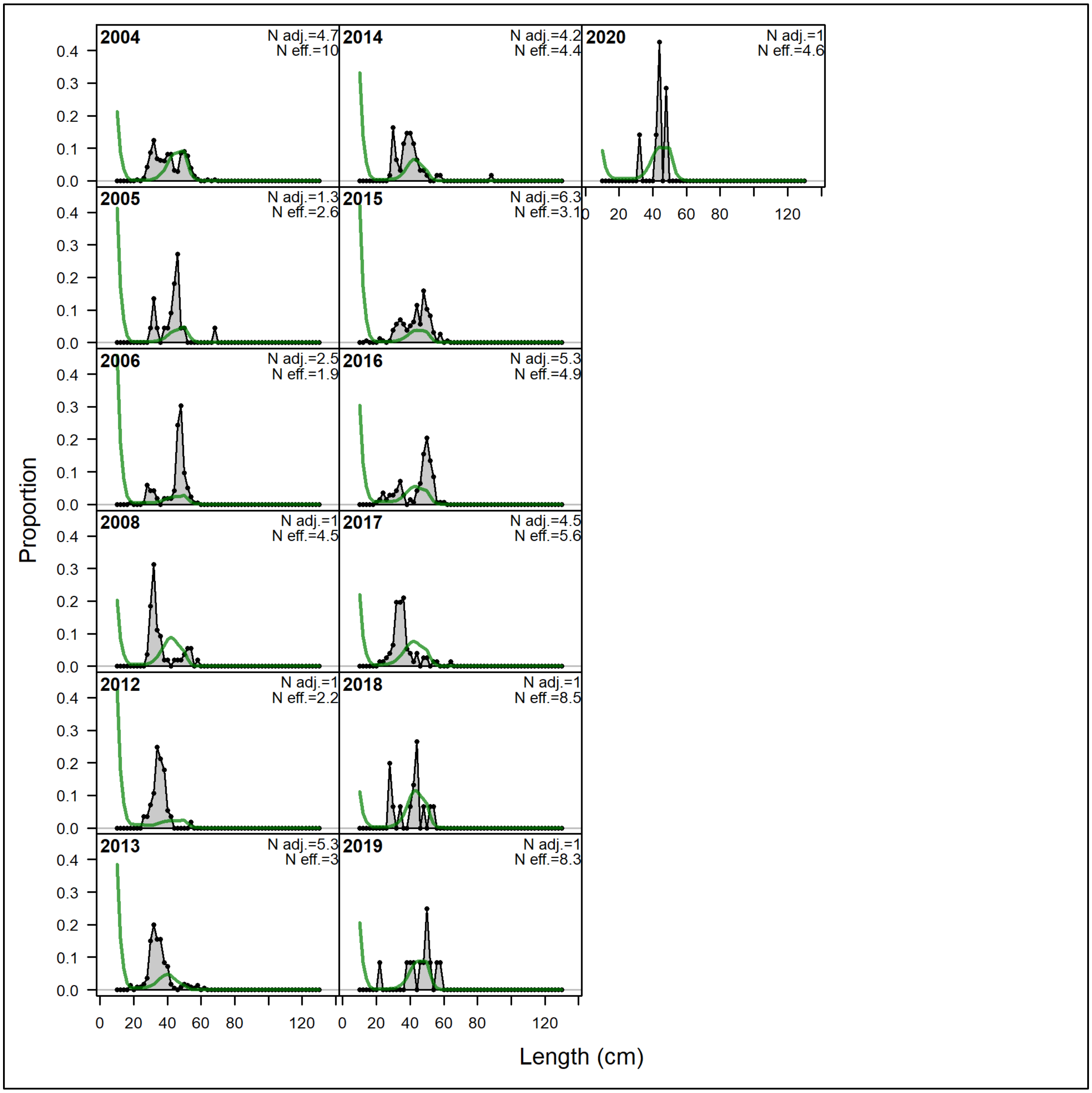


Figure 3.23. Observed and predicted length compositions for the AScomm discards from the base run of the stock assessment model, 2004–2020. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

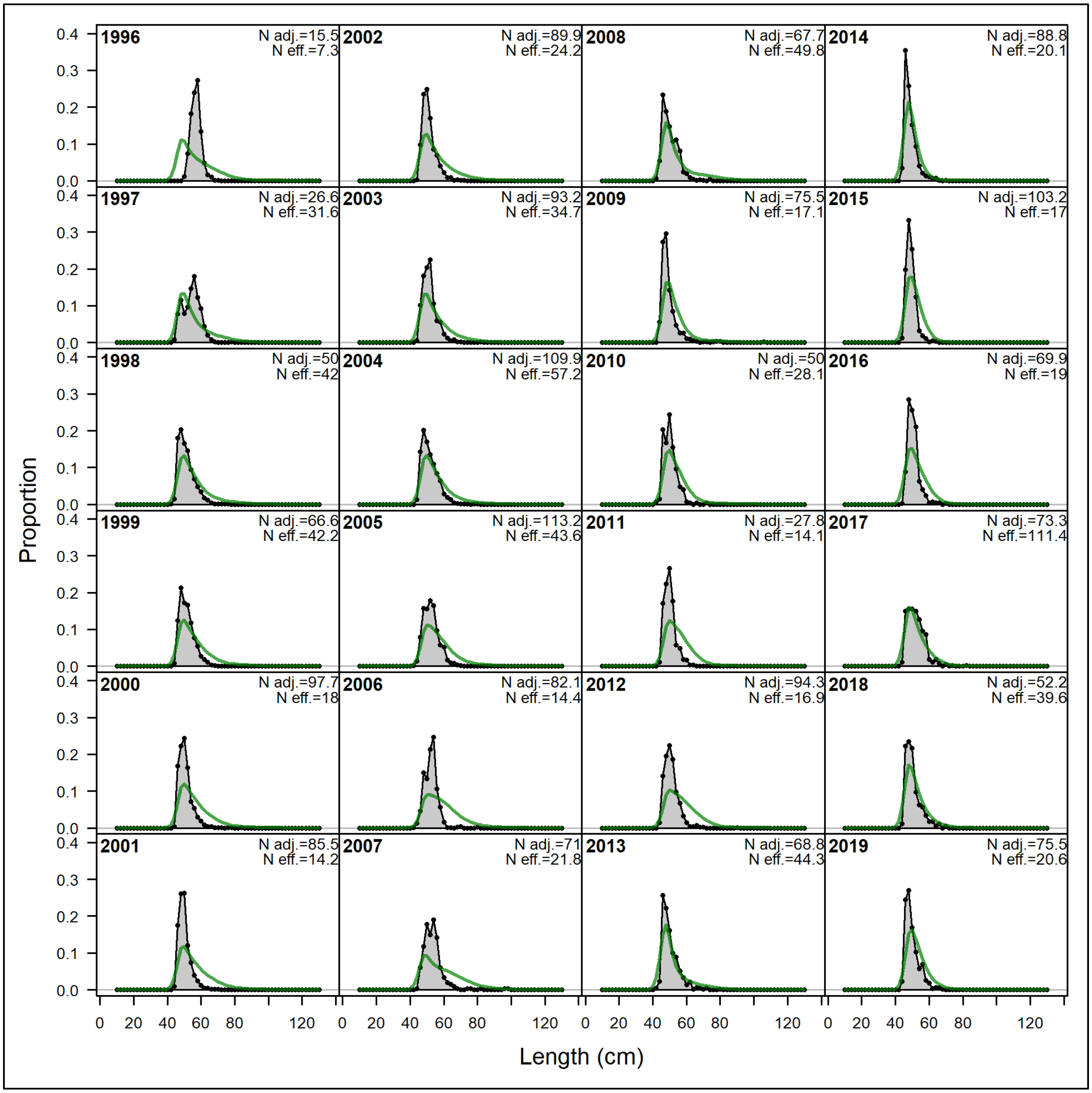


Figure 3.24. Observed and predicted length compositions for the ASrec harvest from the base run of the stock assessment model, 1996–2019. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

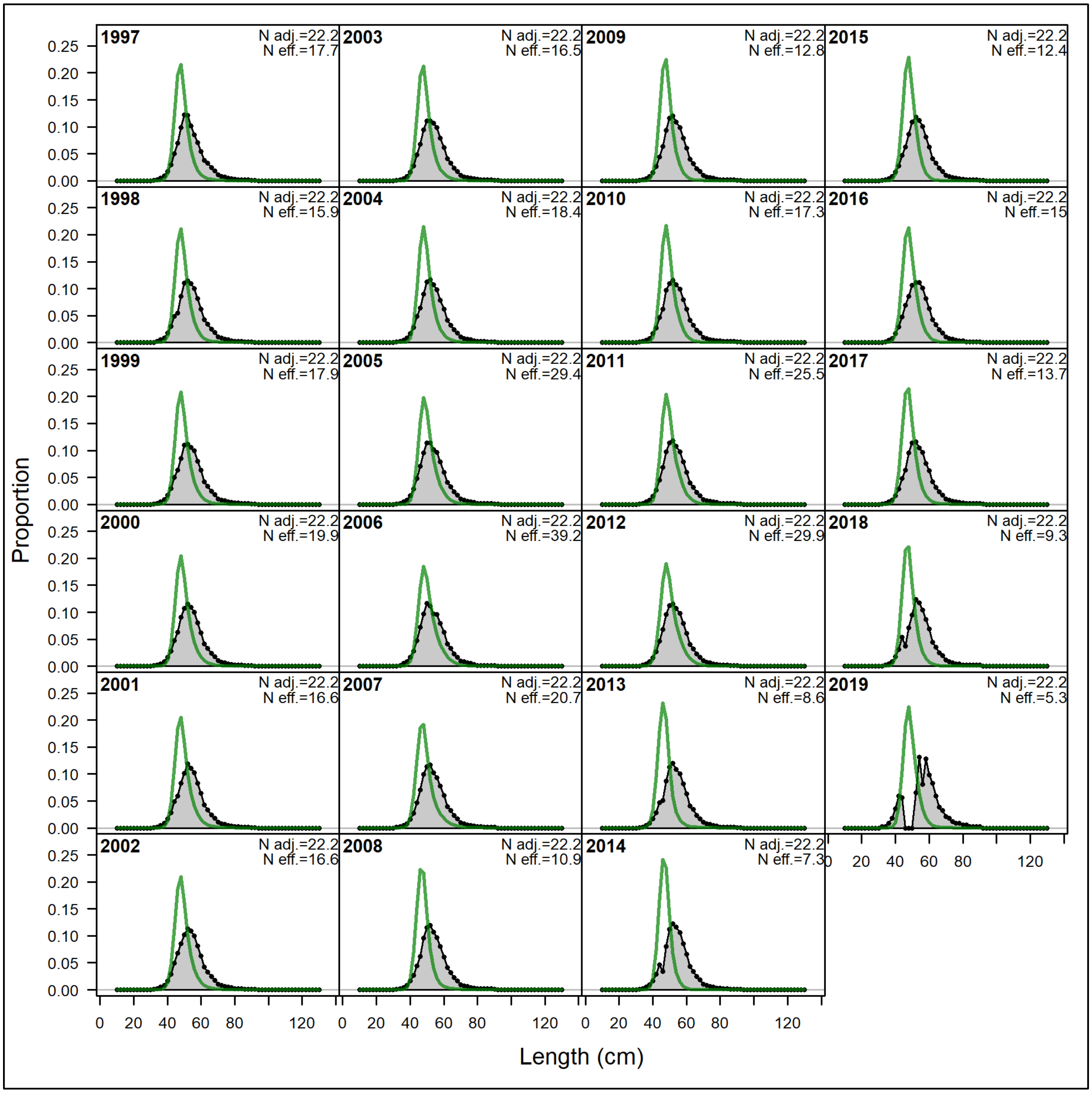


Figure 3.25. Observed and predicted length compositions for the ASrec discards from the base run of the stock assessment model, 1997–2019. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

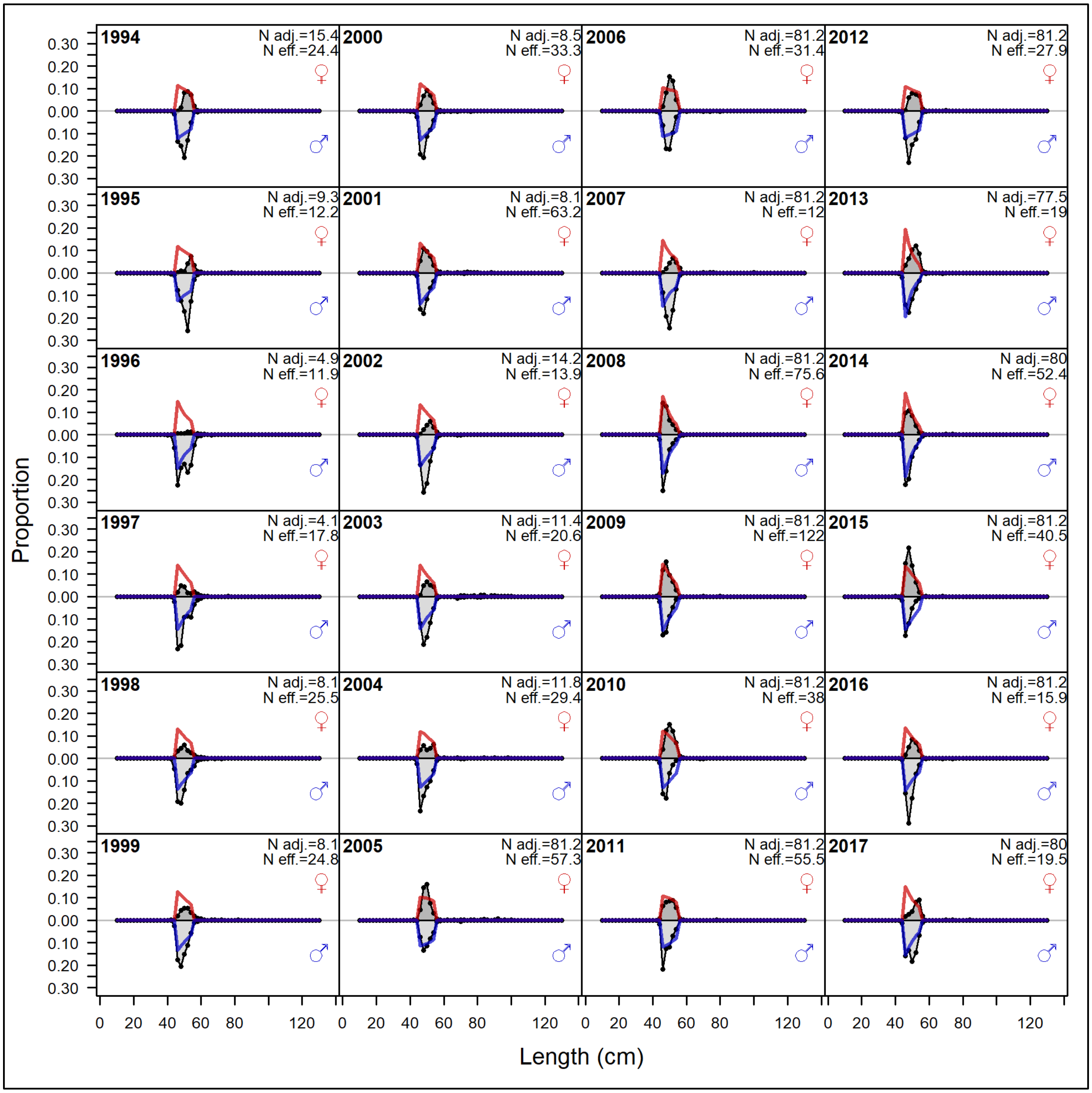


Figure 3.26. Observed and predicted length compositions for the RRrec harvest from the base run of the stock assessment model, 1994–2017. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

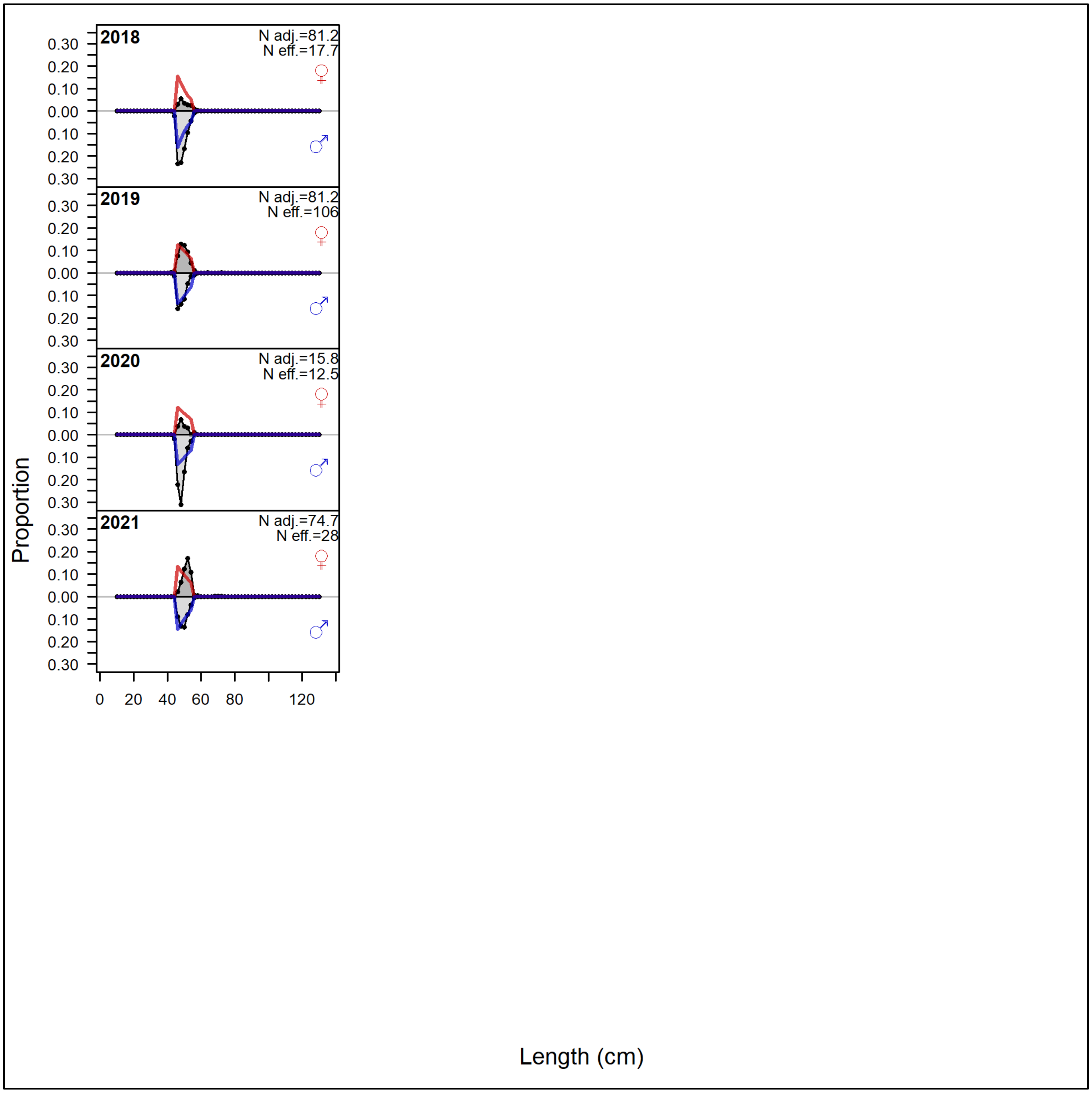


Figure 3.27. Observed and predicted length compositions for the RRrec harvest from the base run of the stock assessment model, 2018–2021. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

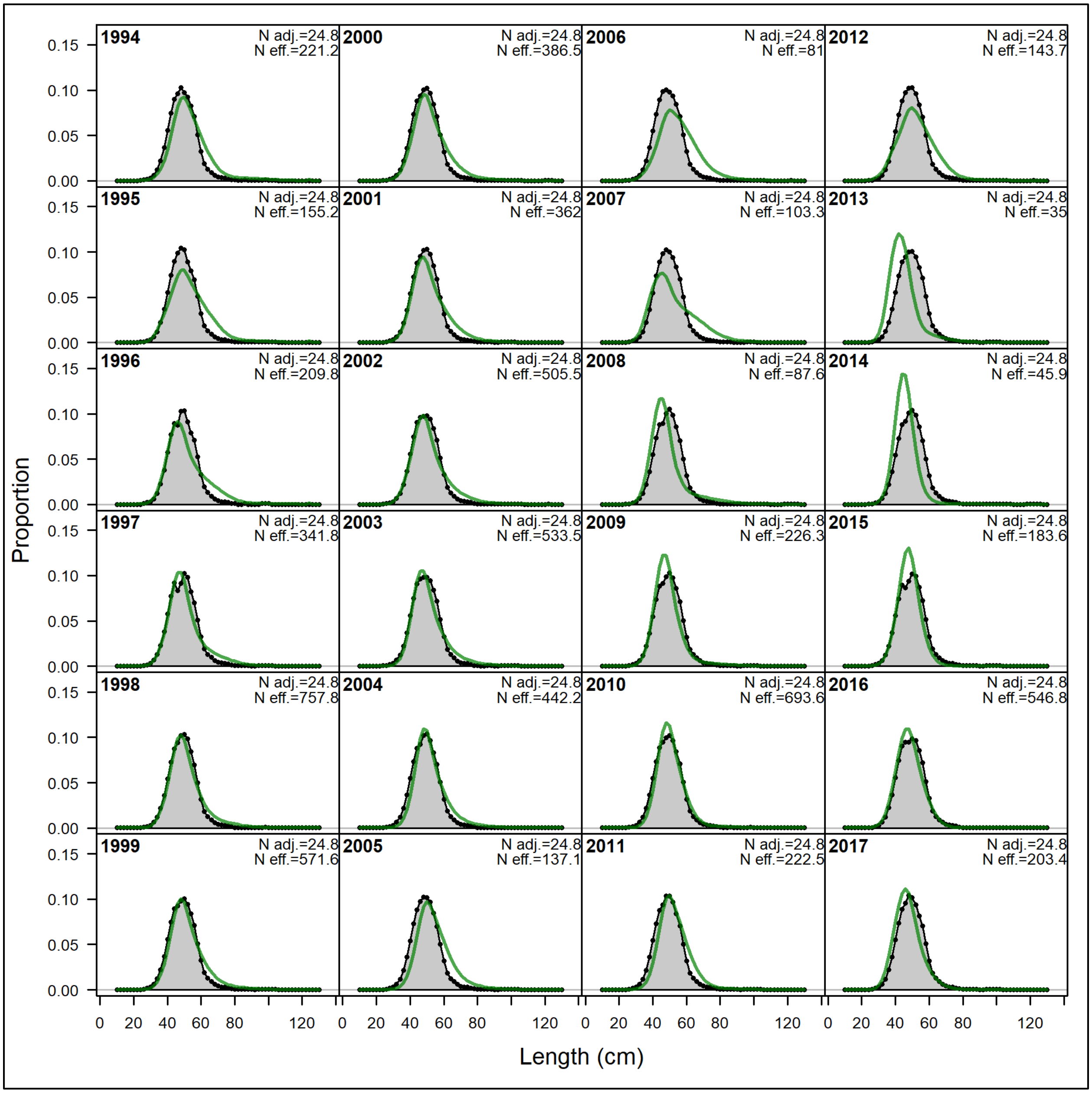


Figure 3.28. Observed and predicted length compositions for the RRrec discards from the base run of the stock assessment model, 1994–2017. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

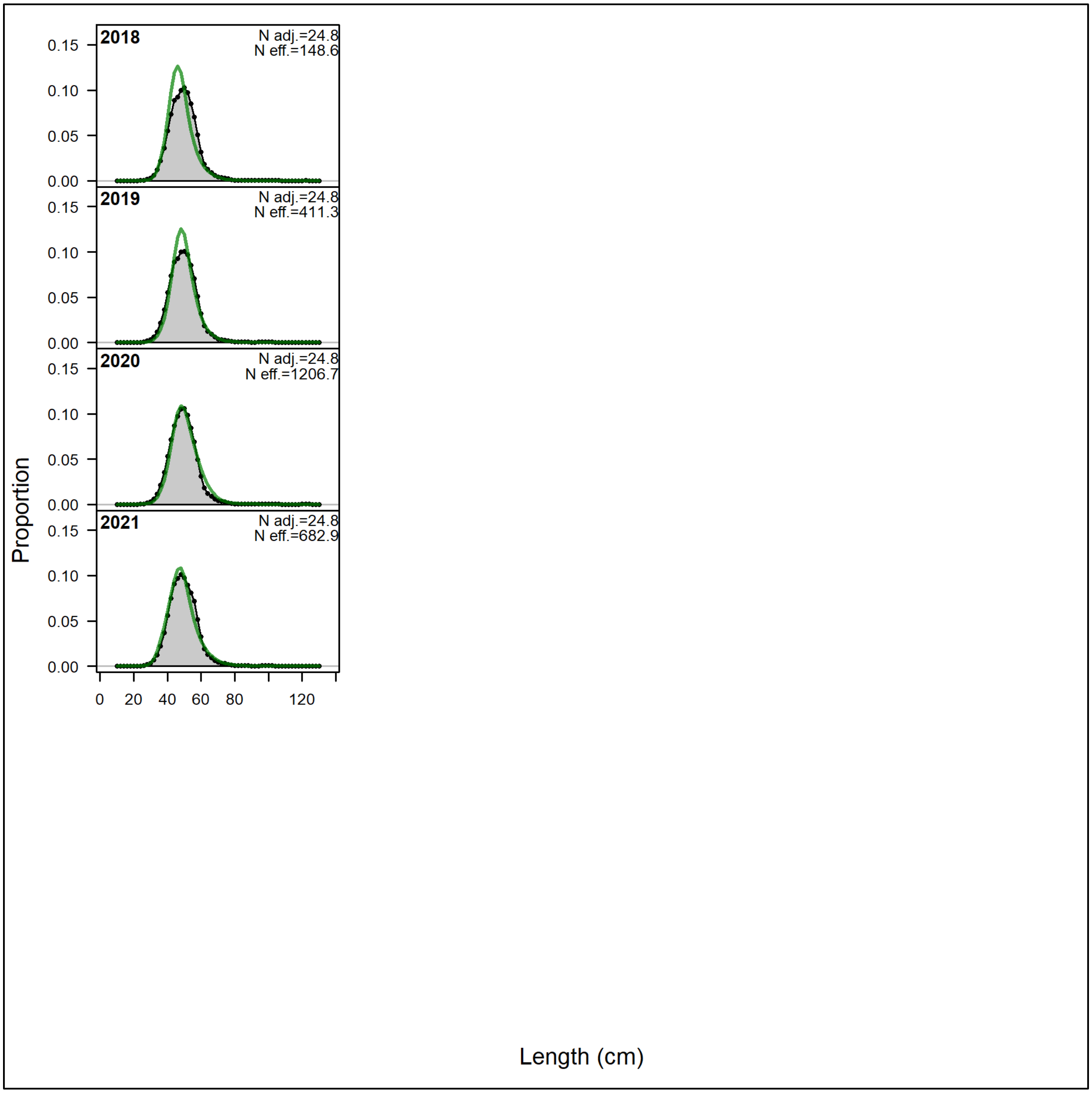


Figure 3.29. Observed and predicted length compositions for the RRrec discards from the base run of the stock assessment model, 2018–2021. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

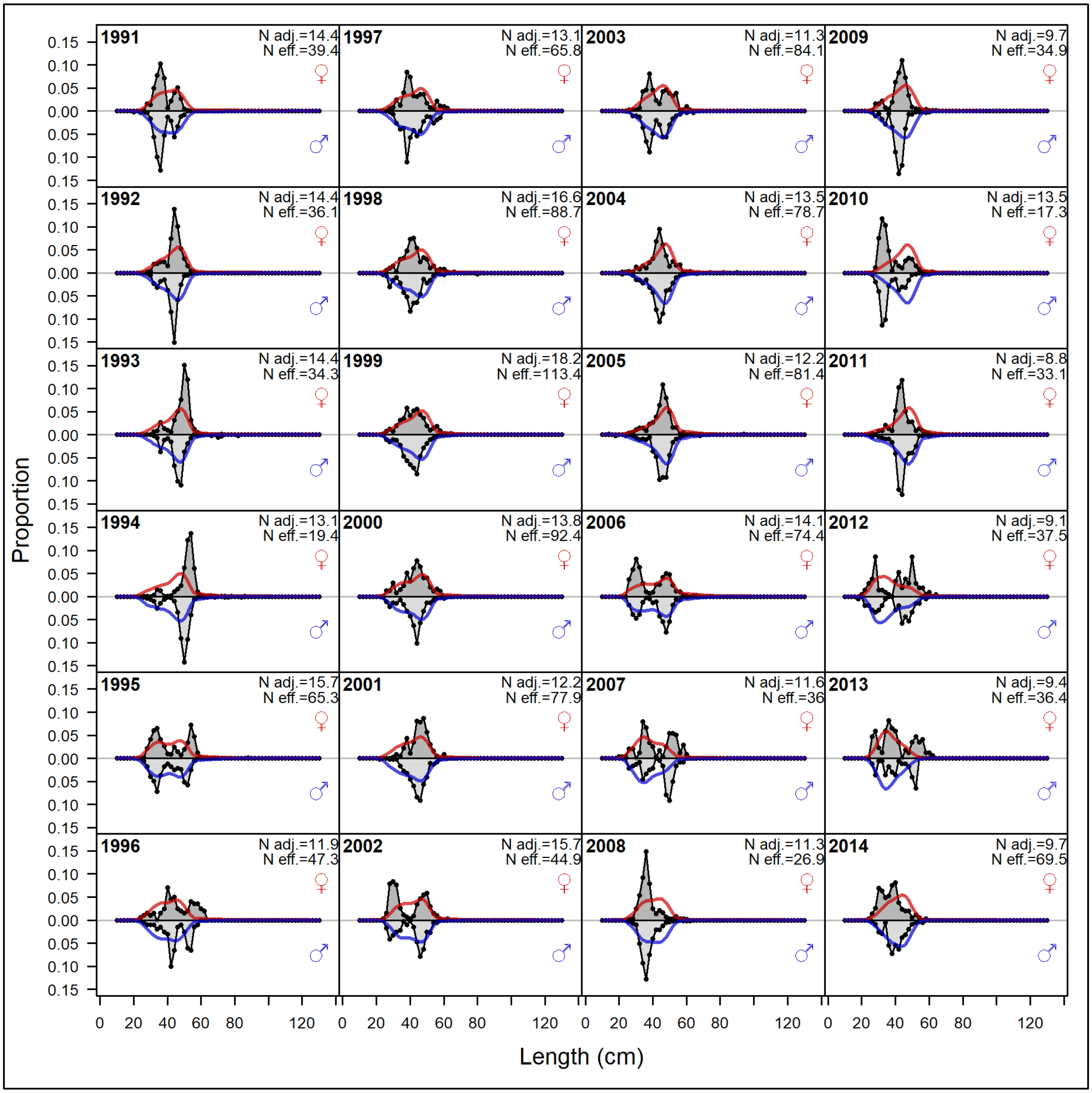


Figure 3.30. Observed and predicted length compositions for the P135fw survey from the base run of the stock assessment model, 1991–2014. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

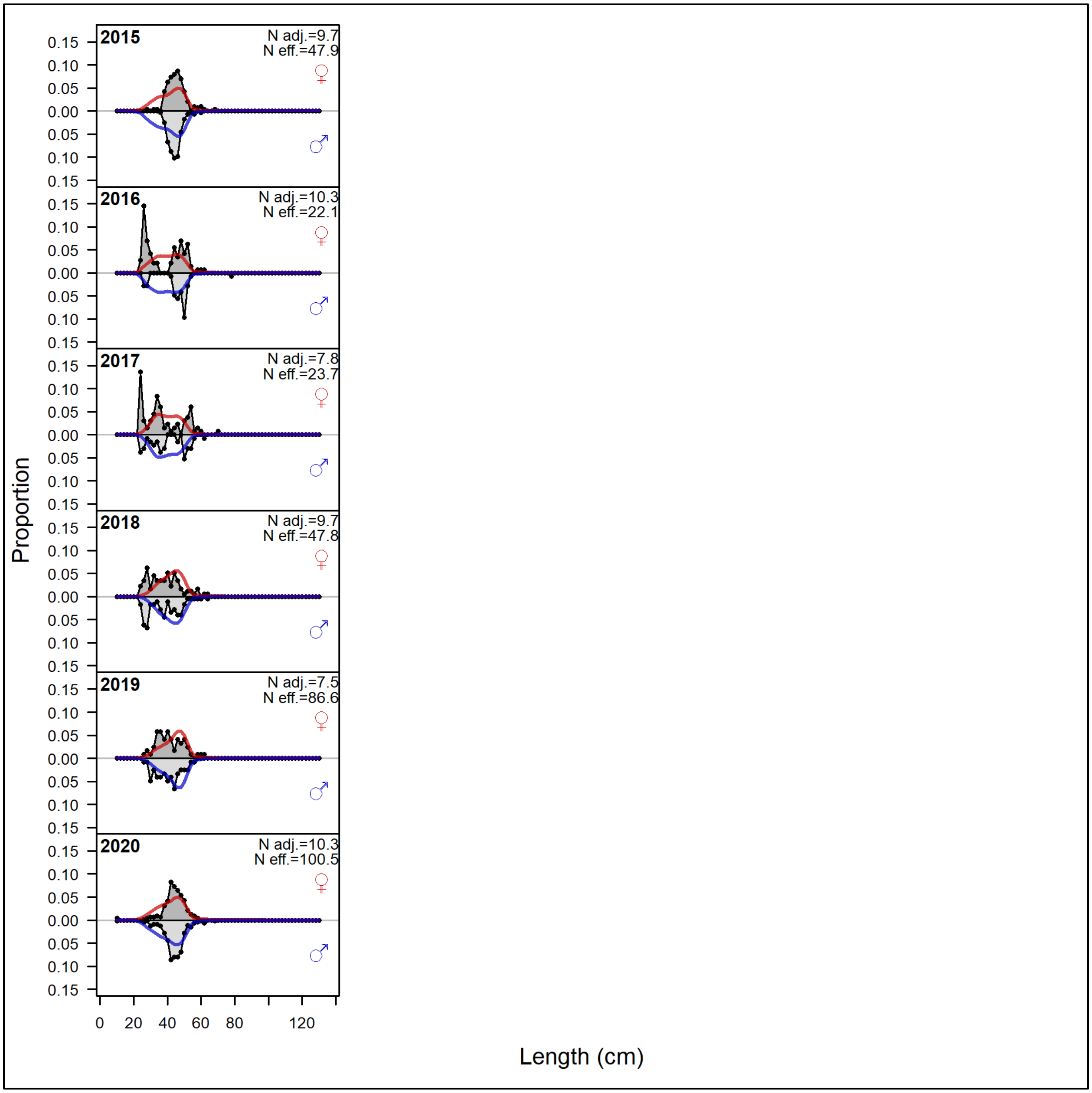


Figure 3.31. Observed and predicted length compositions for the P135fw survey from the base run of the stock assessment model, 2015–2020. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

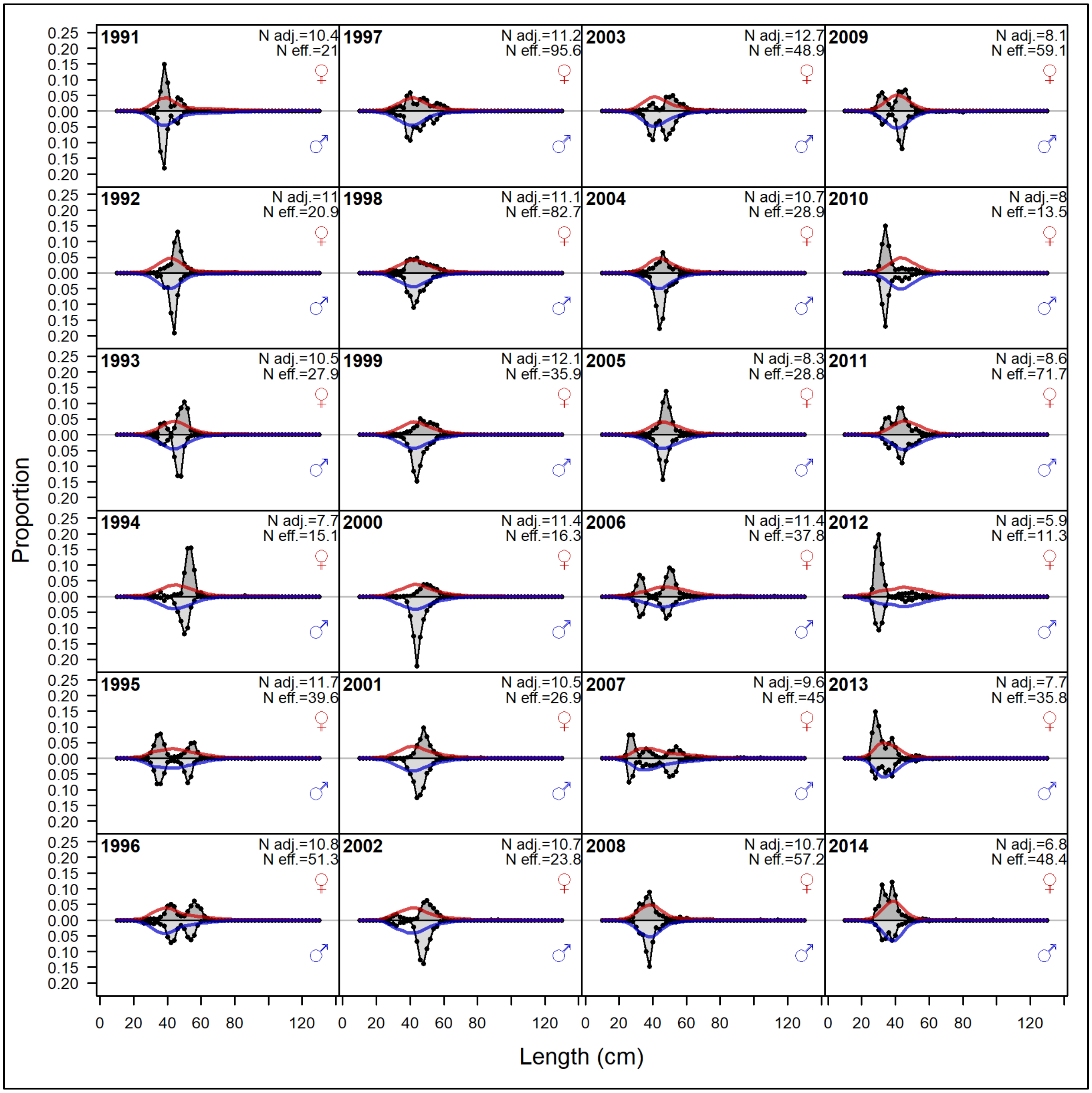


Figure 3.32. Observed and predicted length compositions for the P135spr survey from the base run of the stock assessment model, 1991–2014. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

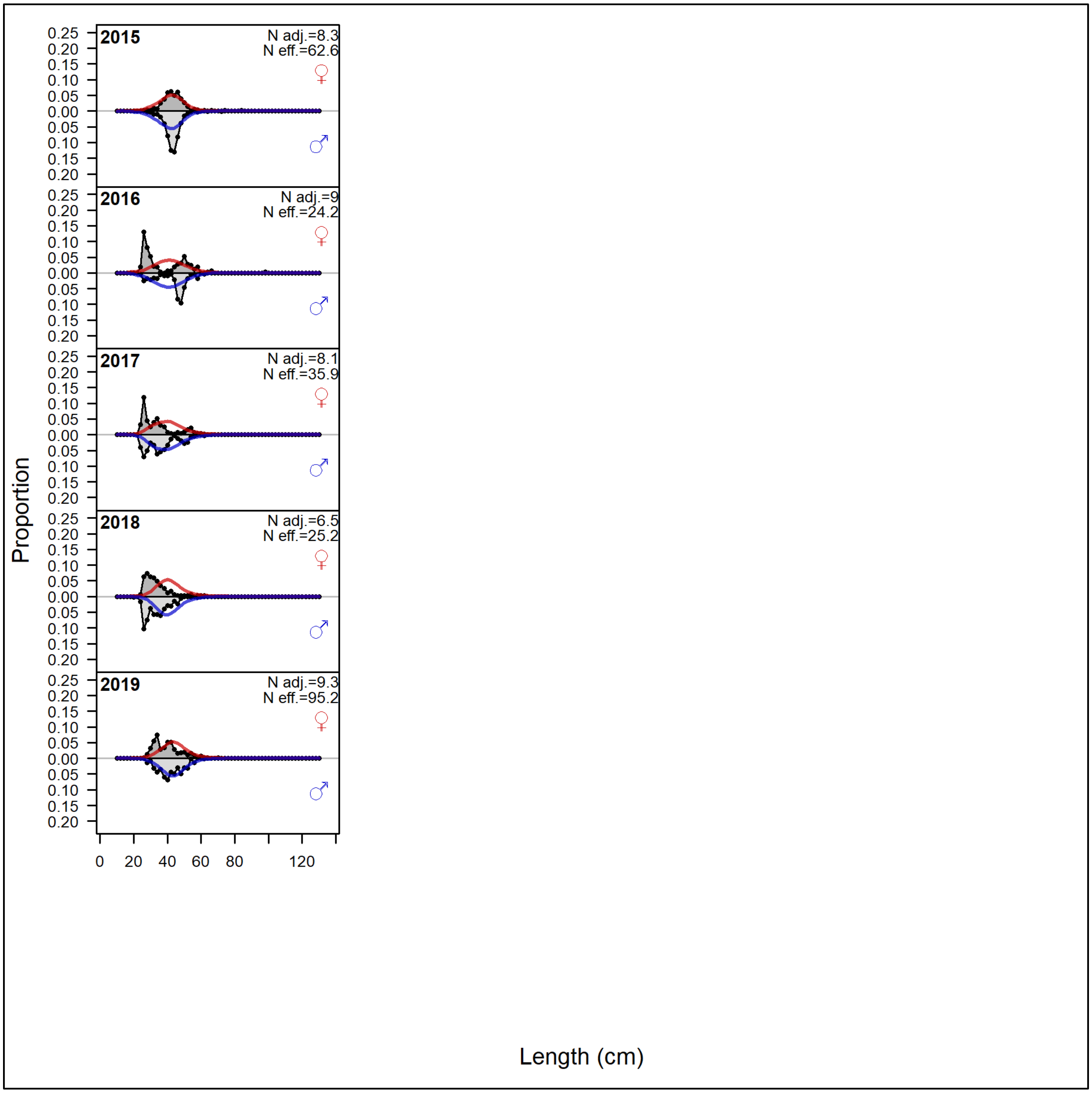


Figure 3.33. Observed and predicted length compositions for the P135spr survey from the base run of the stock assessment model, 2015–2019. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

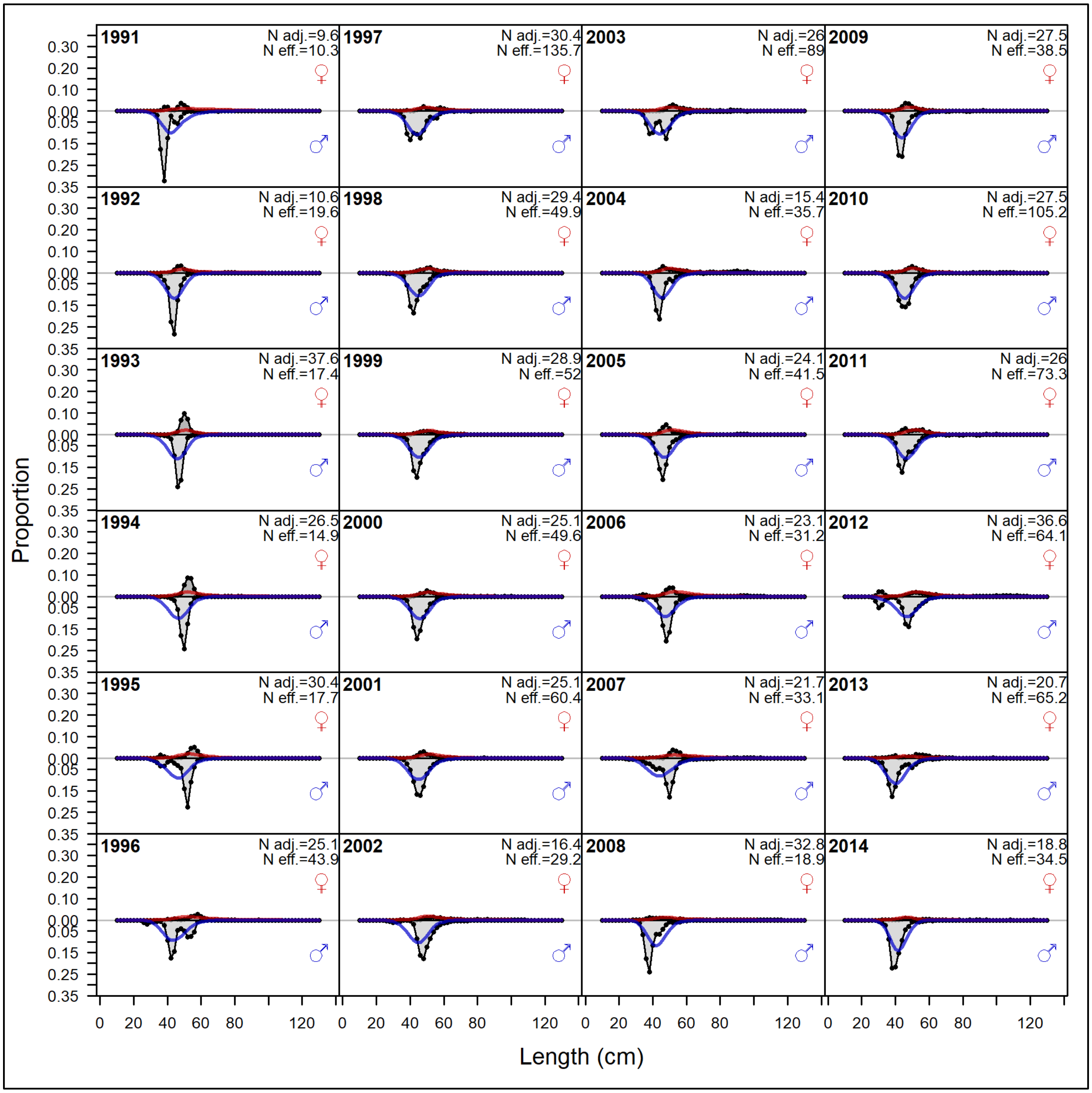


Figure 3.34. Observed and predicted length compositions for the RRef survey from the base run of the stock assessment model, 1991–2014. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

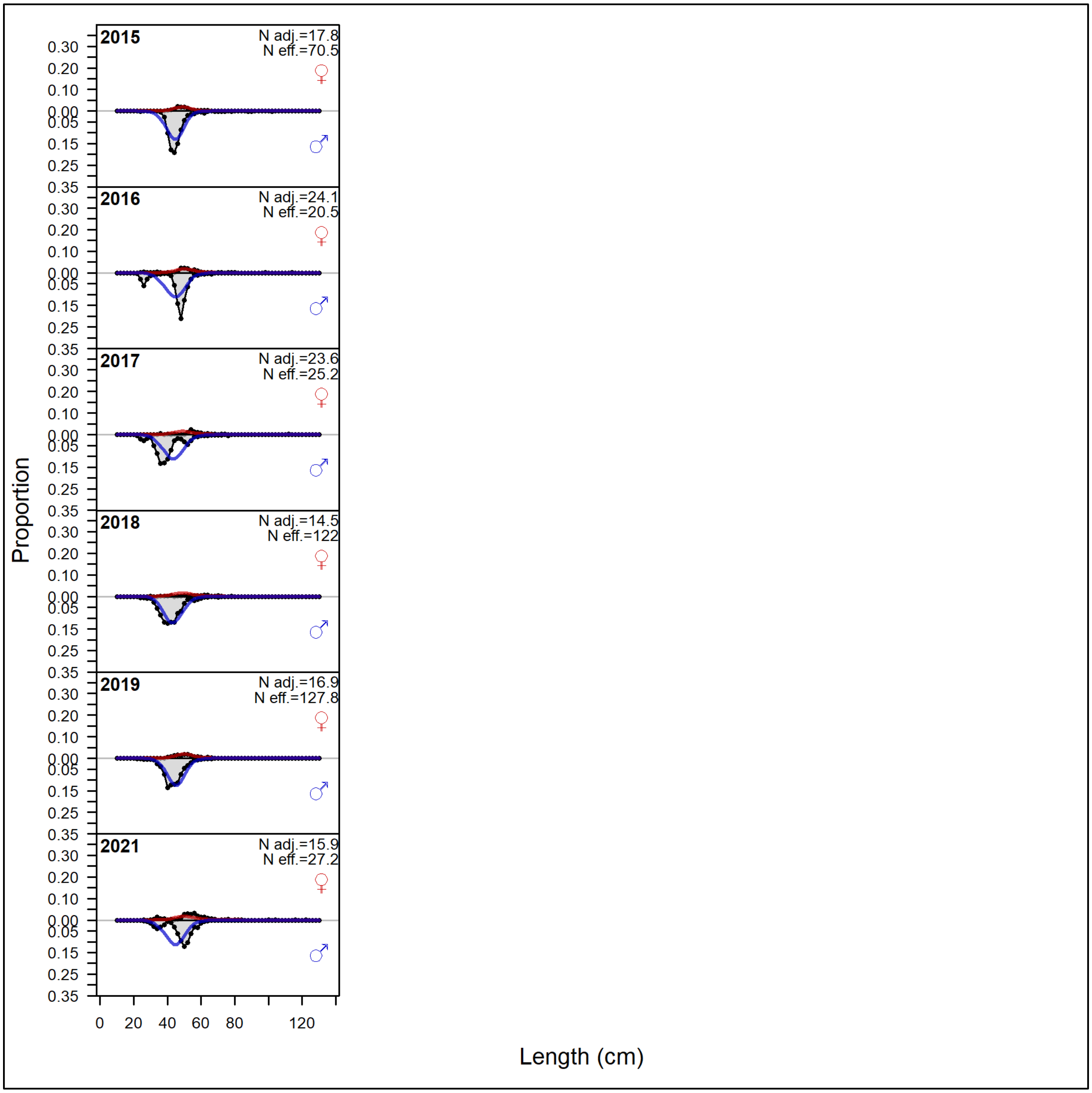


Figure 3.35. Observed and predicted length compositions for the RRef survey from the base run of the stock assessment model, 2015–2021. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

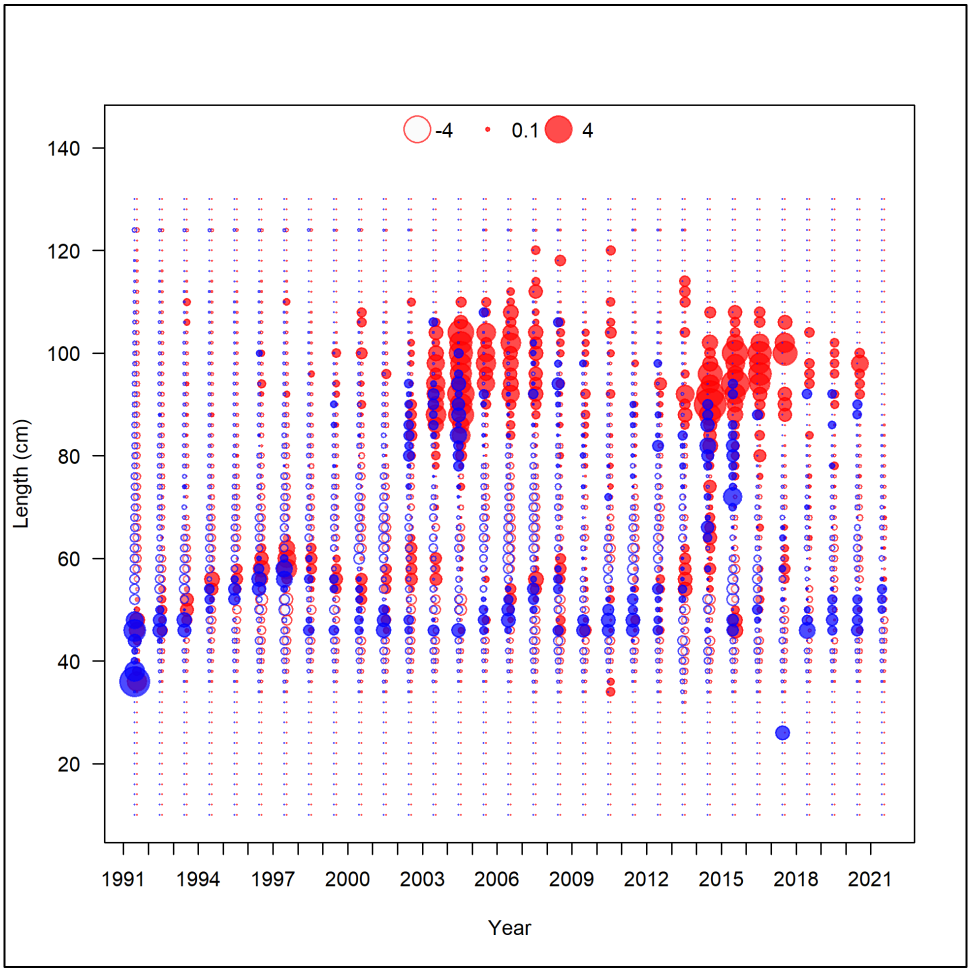


Figure 3.36. Pearson residuals (red: female; blue: male) from the fit of the base model run to the AScomm landings length composition data, 1991–2021. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

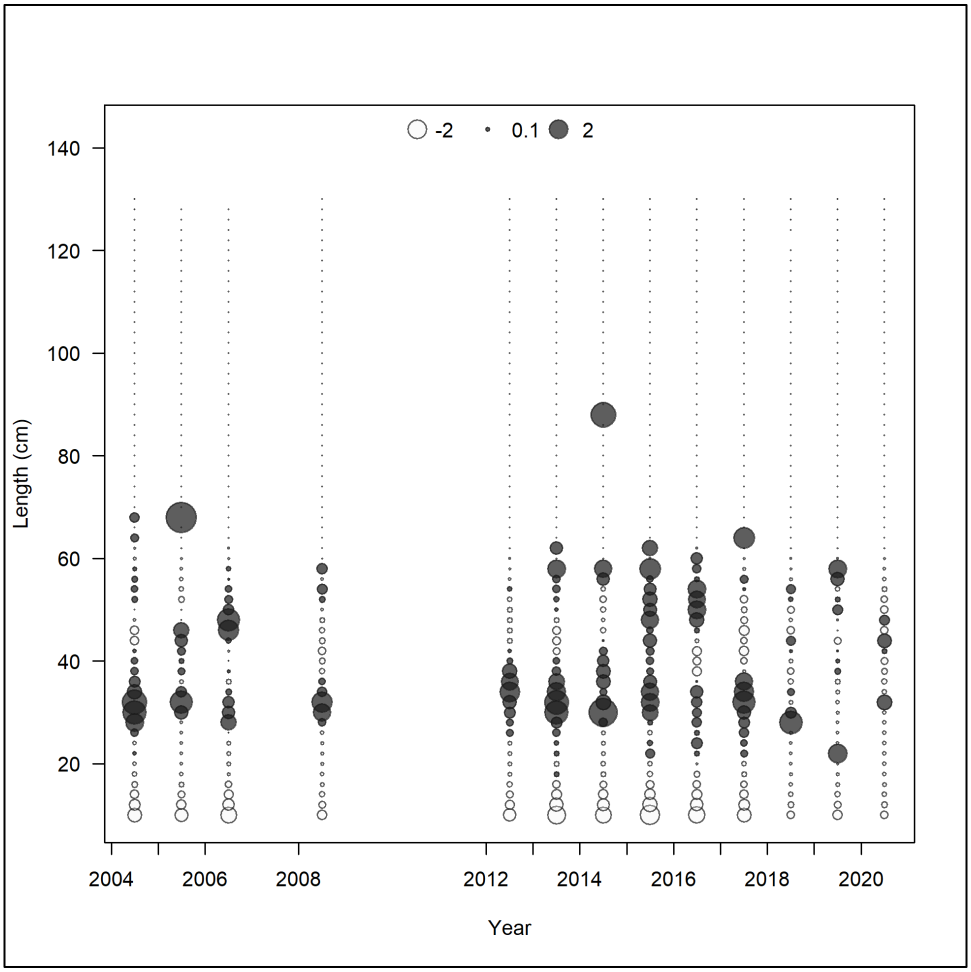


Figure 3.37. Pearson residuals from the fit of the base model run to the AScomm discards length composition data, 2004–2020. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

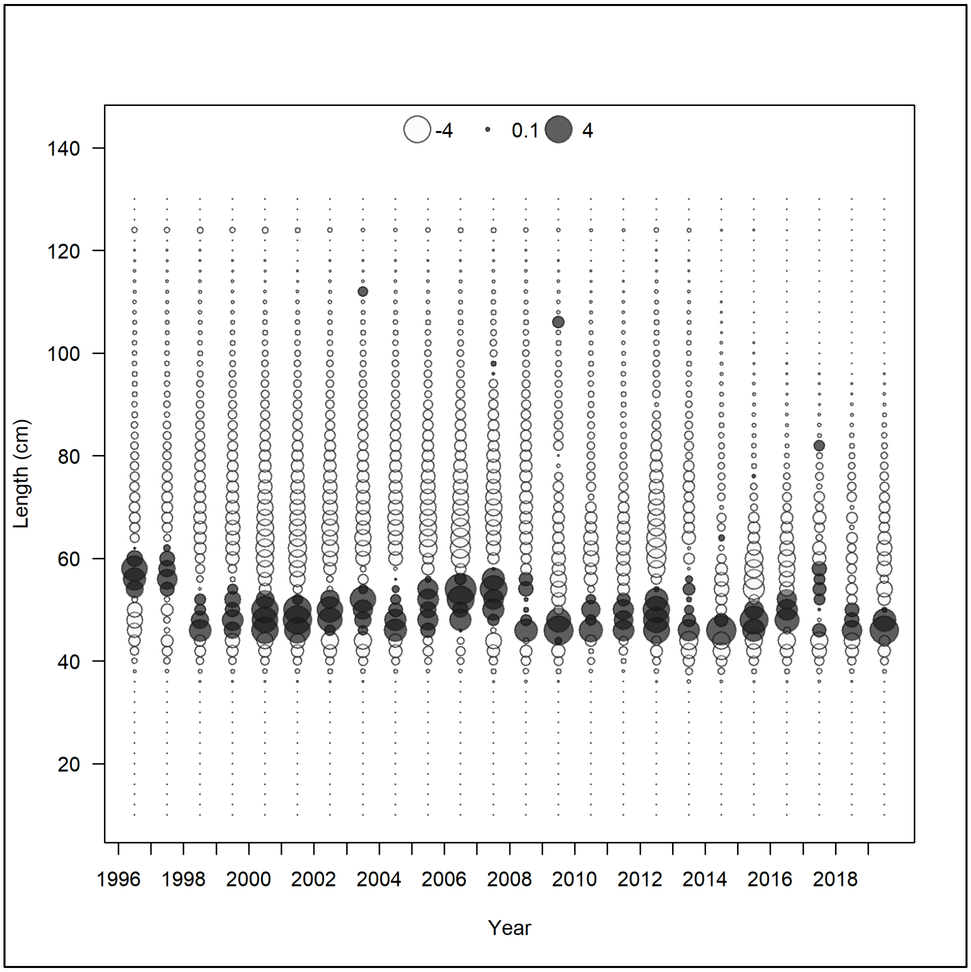


Figure 3.38. Pearson residuals from the fit of the base model run to the ASrec harvest length composition data, 1996–2019. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

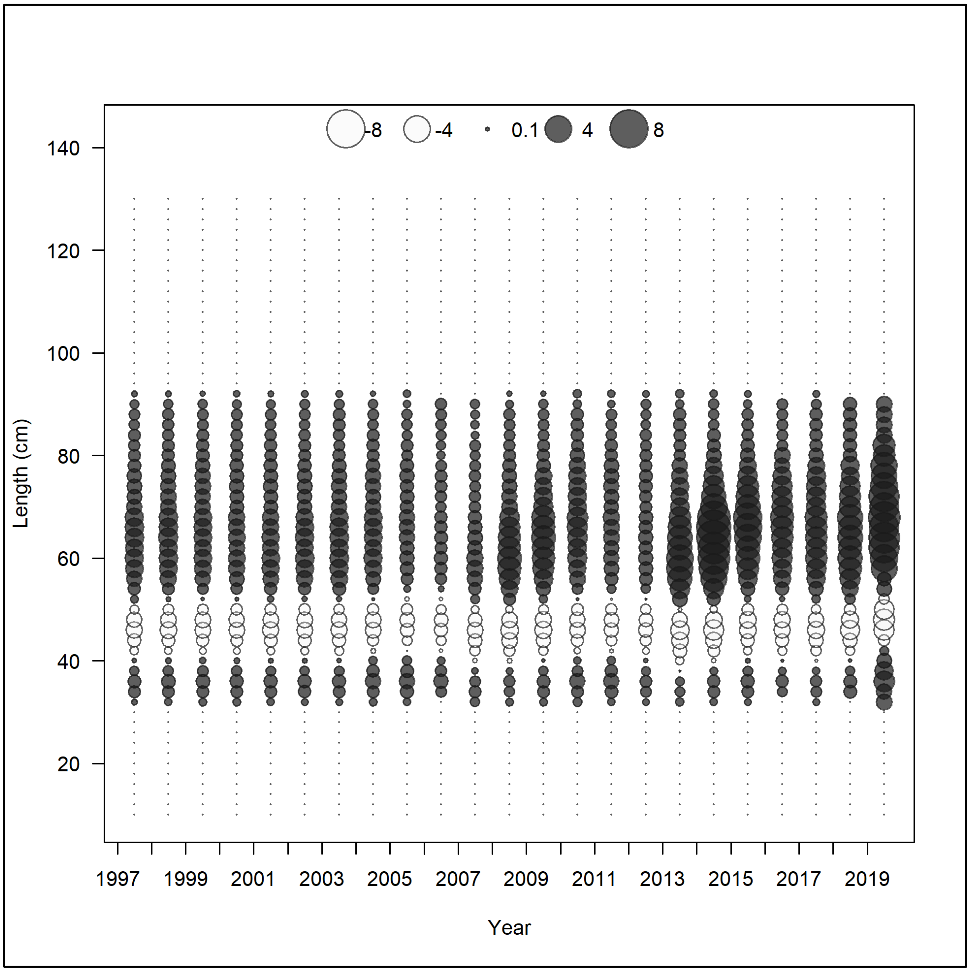


Figure 3.39. Pearson residuals from the fit of the base model run to the ASrec discard length composition data, 1997–2019. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

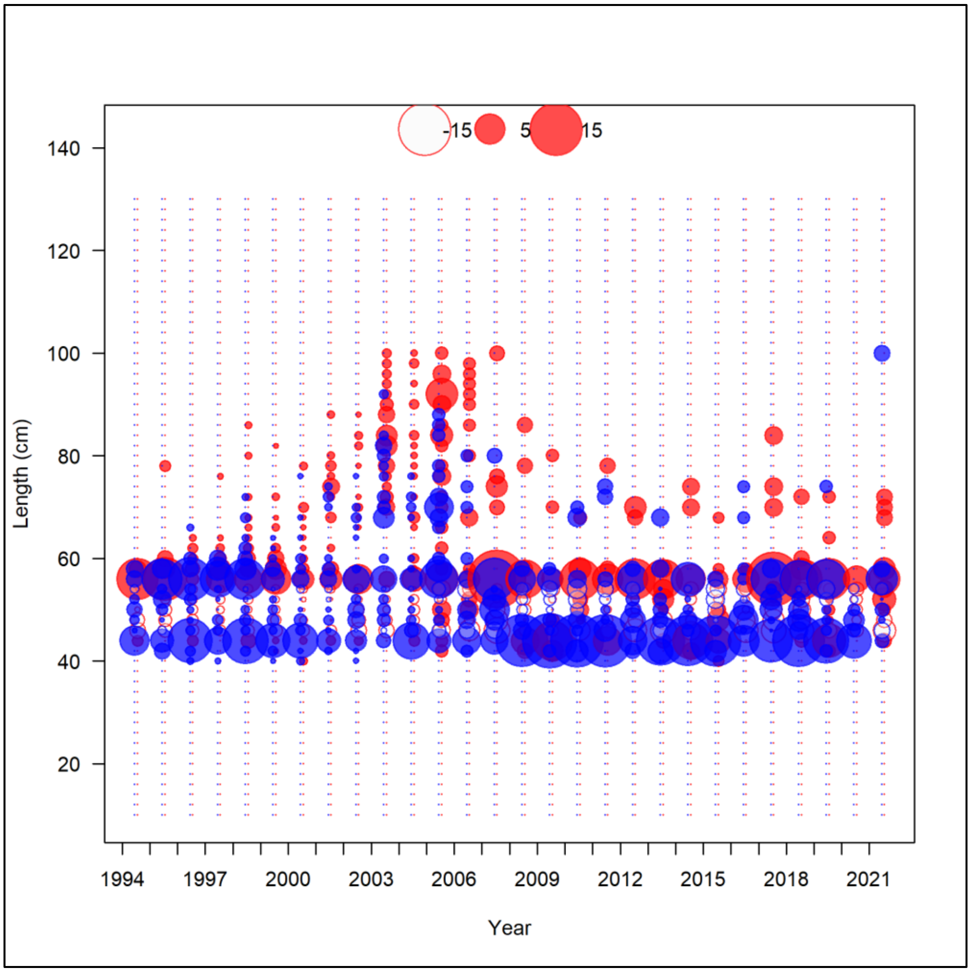


Figure 3.40. Pearson residuals (red: female; blue: male) from the fit of the base model run to the RRrec harvest length composition data, 1994–2021. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

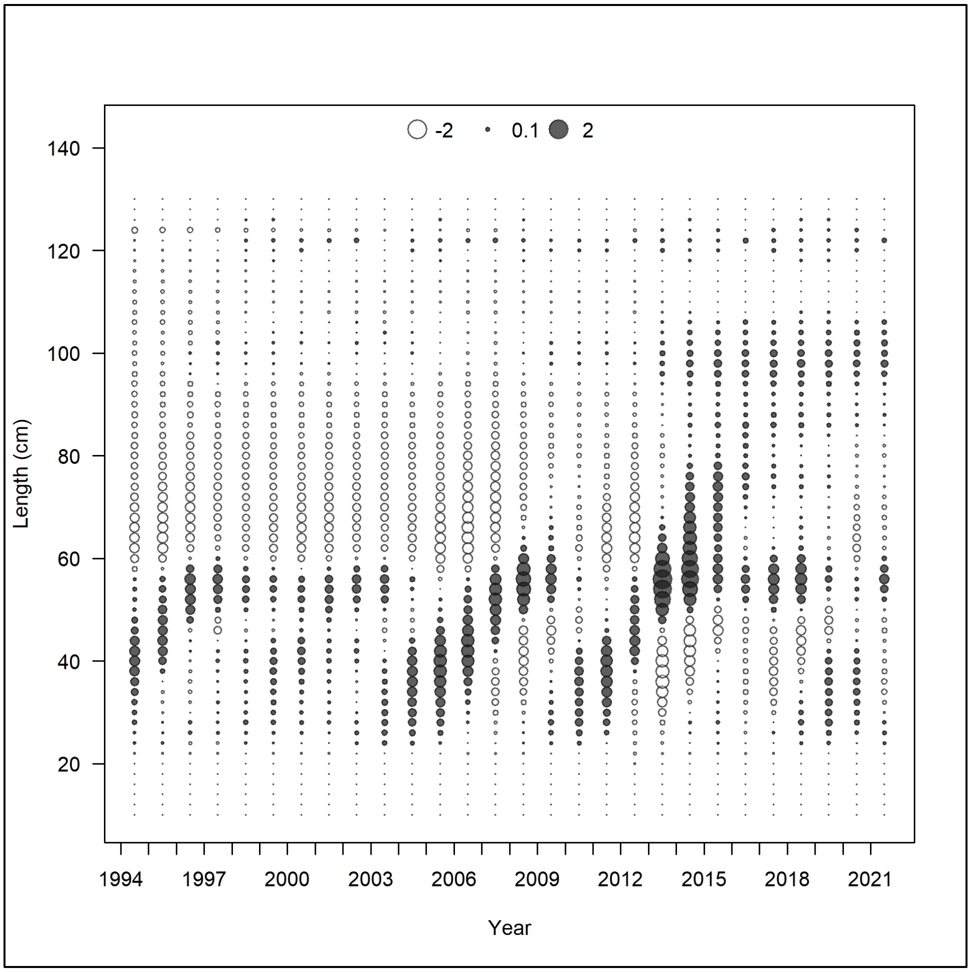


Figure 3.41. Pearson residuals from the fit of the base model run to the RRrec discard length composition data, 1997–2019. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

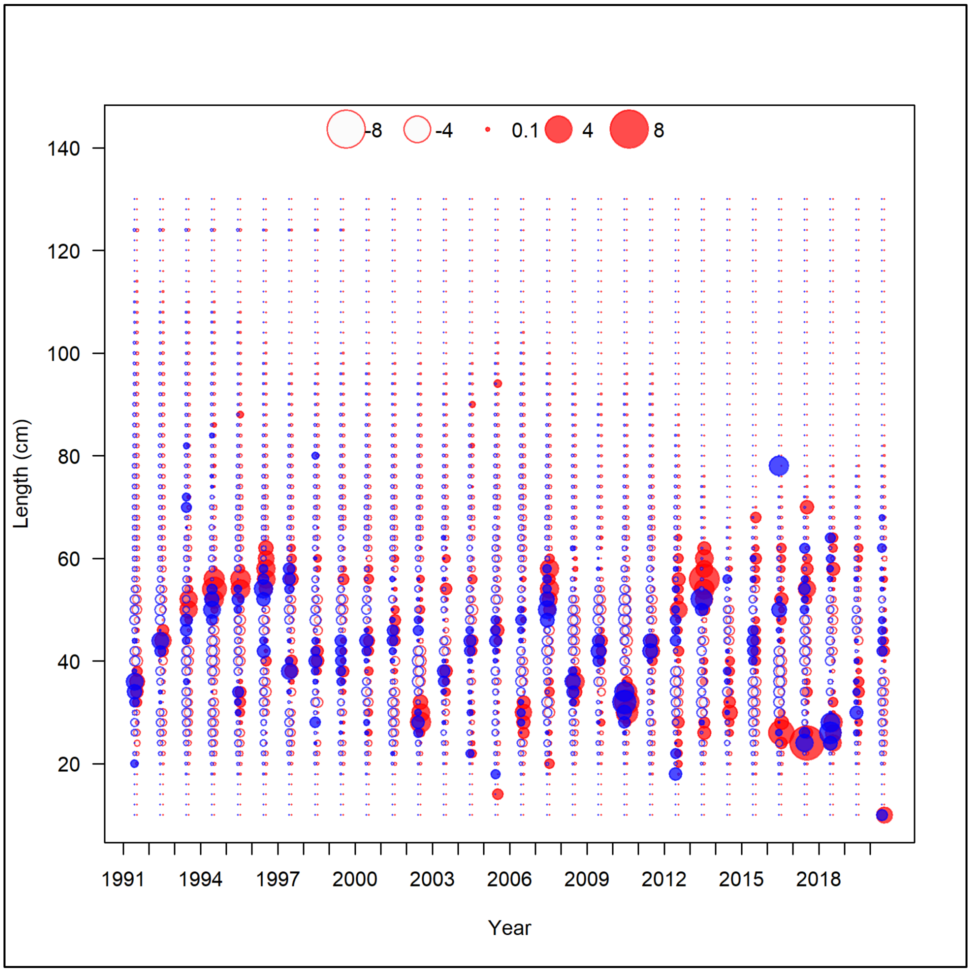


Figure 3.42. Pearson residuals (red: female; blue: male) from the fit of the base model run to the P135fw survey length composition data, 1991–2020. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

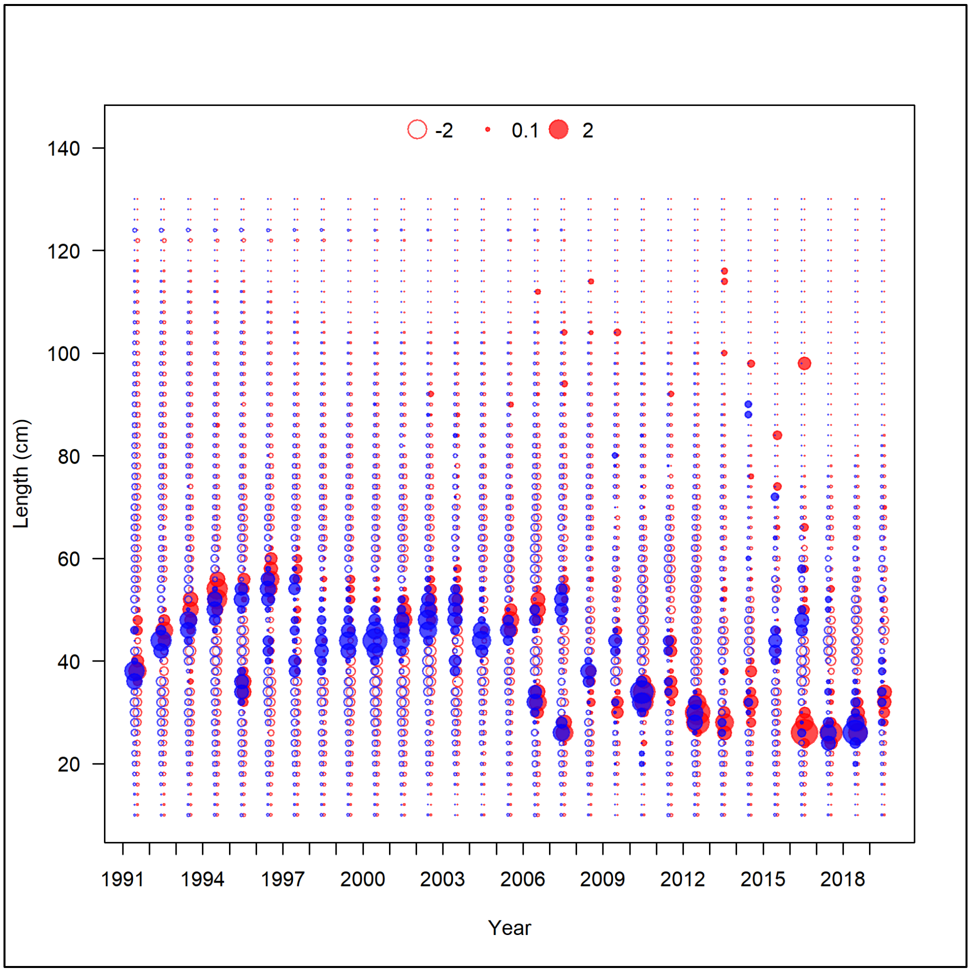


Figure 3.43. Pearson residuals (red: female; blue: male) from the fit of the base model run to the P135spr survey length composition data, 1991–2020. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

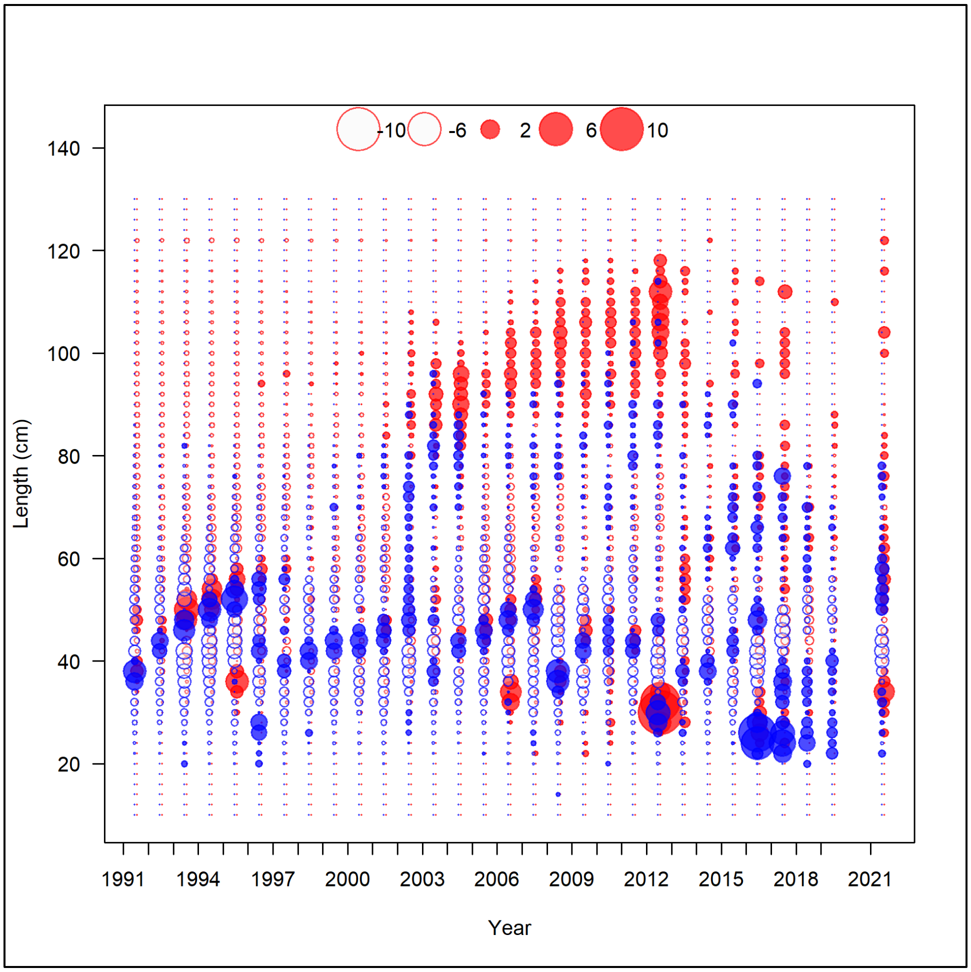


Figure 3.44. Pearson residuals (red: female; blue: male) from the fit of the base model run to the RRef survey length composition data, 1991–2021. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

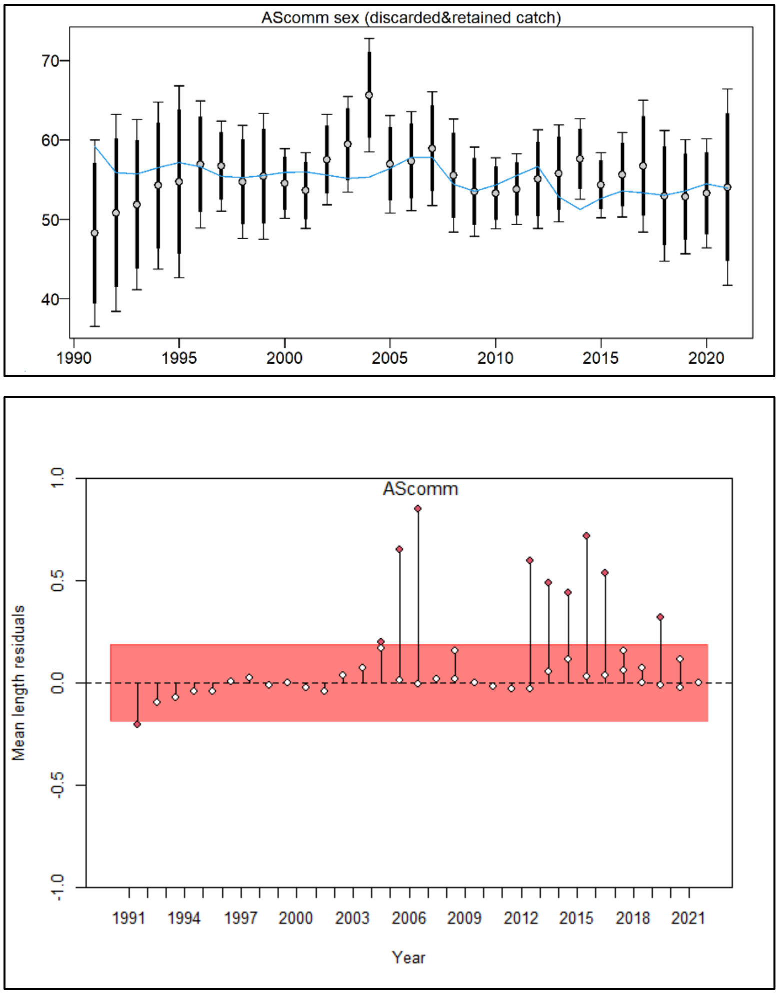
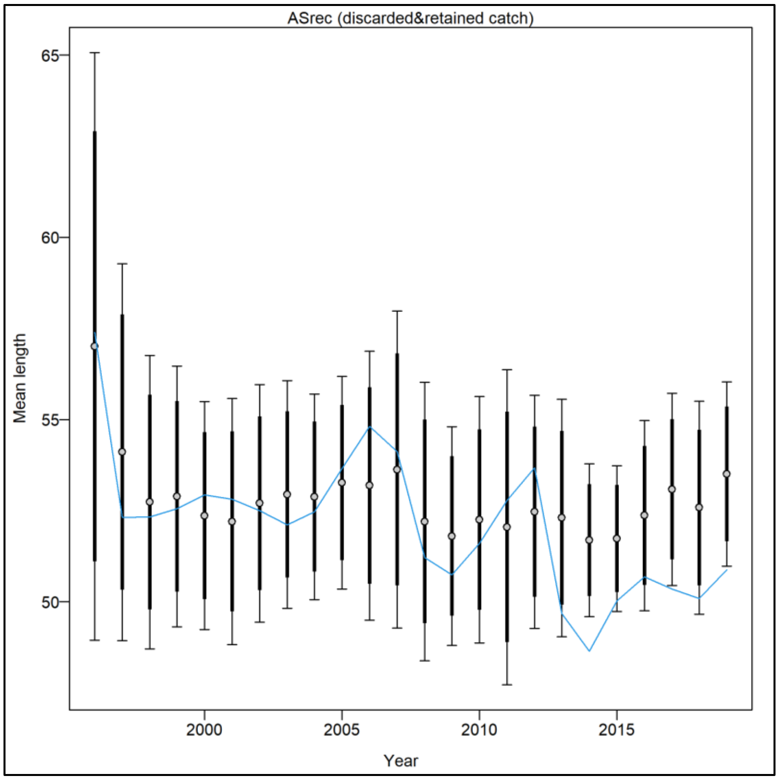


Figure 3.45. Observed and predicted mean lengths (top graph) and standardized residuals on a runs test plot (bottom graph) for the AScomm fishery from the base run of the stock assessment model, 1991–2021. Red shading indicates there is evidence (α = 0.05) to reject the hypothesis of a randomly distributed time series of residuals. The shaded (red) area spans three residual standard deviations to either side from zero and the red points outside the shading violate the 'three-sigma limit' for that series.



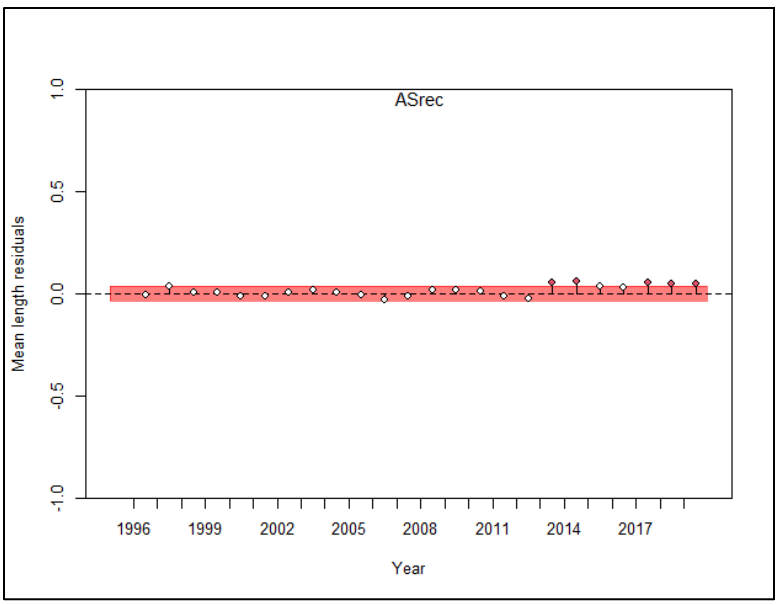


Figure 3.46. Observed and predicted mean lengths (top graph) and standardized residuals on a runs test plot (bottom graph) for the ASrec fishery from the base run of the stock assessment model, 1996–2019. Red shading indicates there is evidence ($\alpha = 0.05$) to reject the hypothesis of a randomly distributed time series of residuals. The shaded (red) area spans three residual standard deviations to either side from zero and the red points outside the shading violate the 'three-sigma limit' for that series.

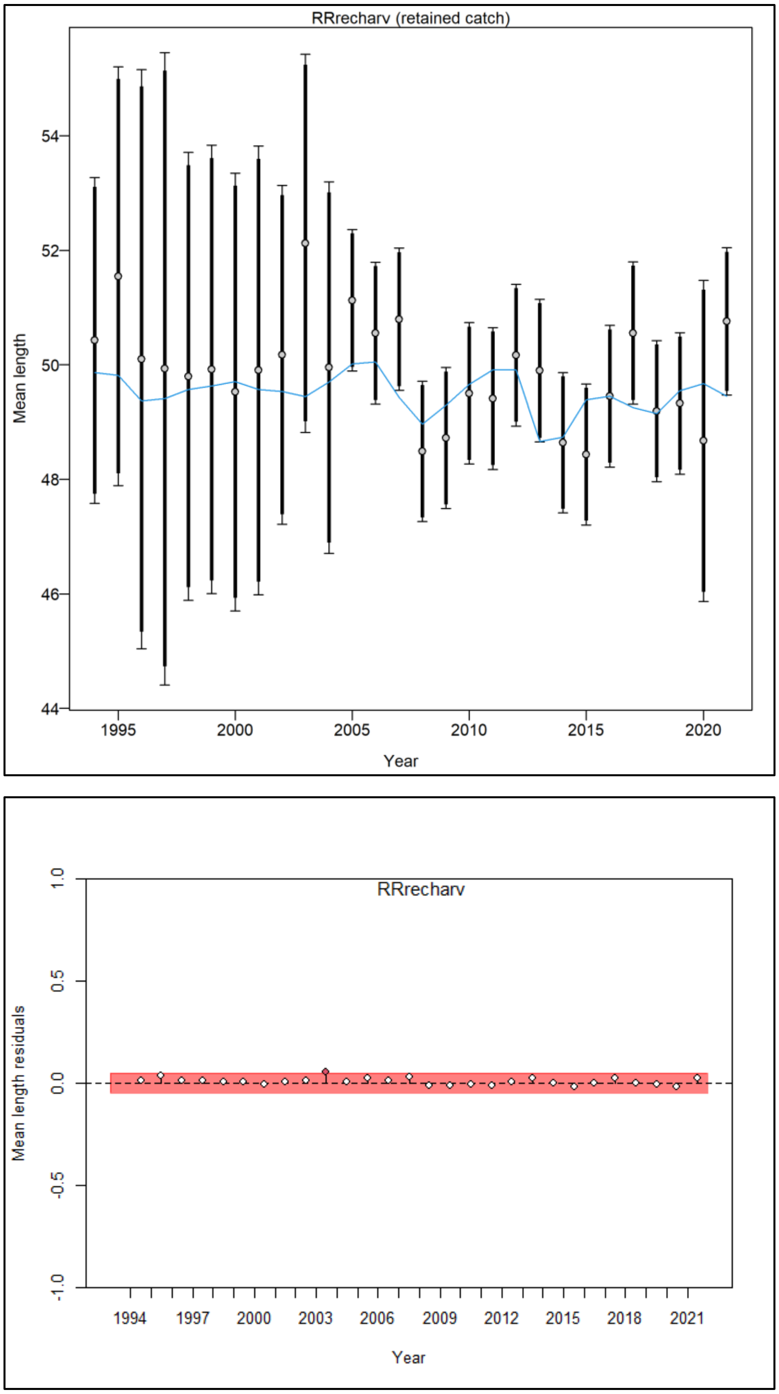


Figure 3.47. Observed and predicted mean lengths (top graph) and standardized residuals on a runs test plot (bottom graph) for the RRrec harvest from the base run of the stock assessment model, 1994–2021. Red shading indicates there is evidence ($\alpha = 0.05$) to reject the hypothesis of a randomly distributed time series of residuals. The shaded (red) area spans three residual standard deviations to either side from zero and the red points outside the shading violate the 'three-sigma limit' for that series.

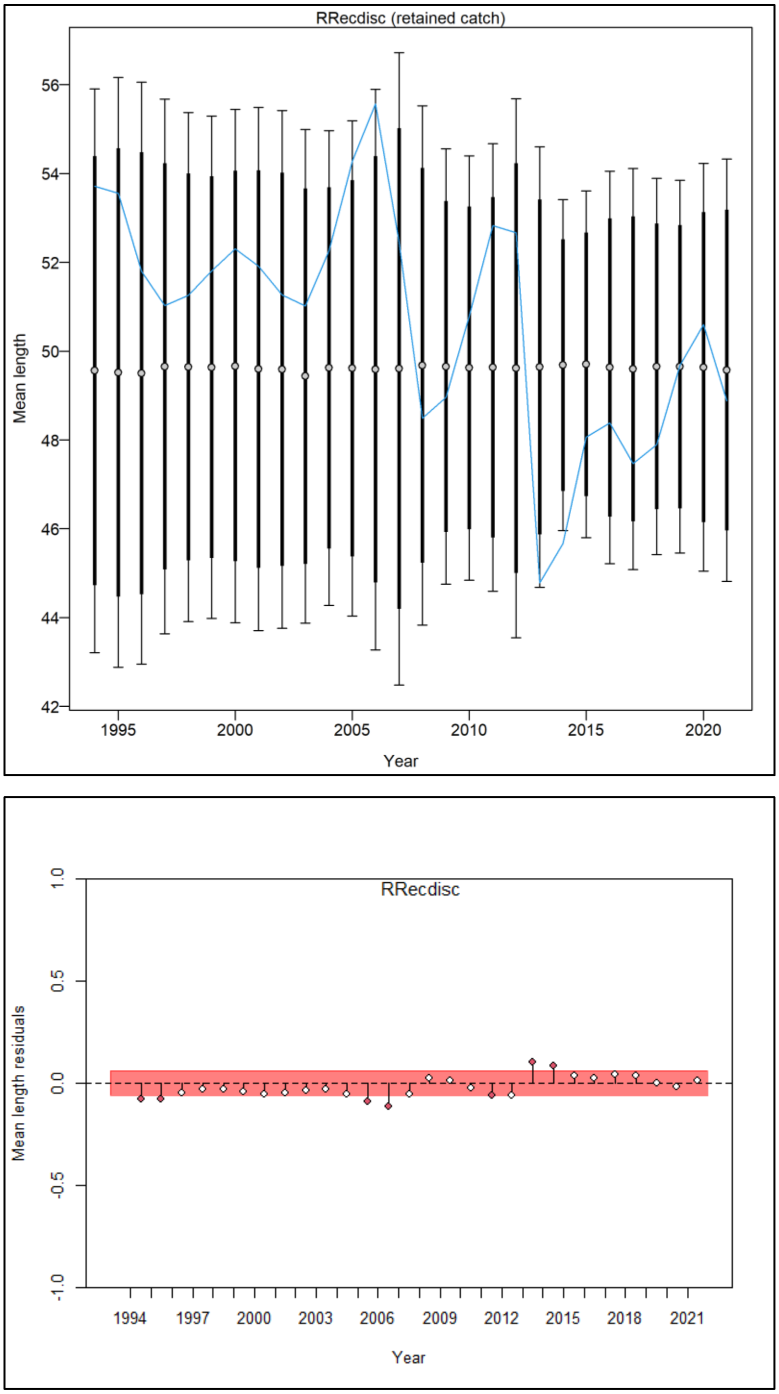


Figure 3.48. Observed and predicted mean lengths (top graph) and standardized residuals on a runs test plot (bottom graph) for the RRrec discards from the base run of the stock assessment model, 1994–2021. Red shading indicates there is evidence ($\alpha = 0.05$) to reject the hypothesis of a randomly distributed time series of residuals. The shaded (red) area spans three residual standard deviations to either side from zero and the red points outside the shading violate the 'three-sigma limit' for that series.

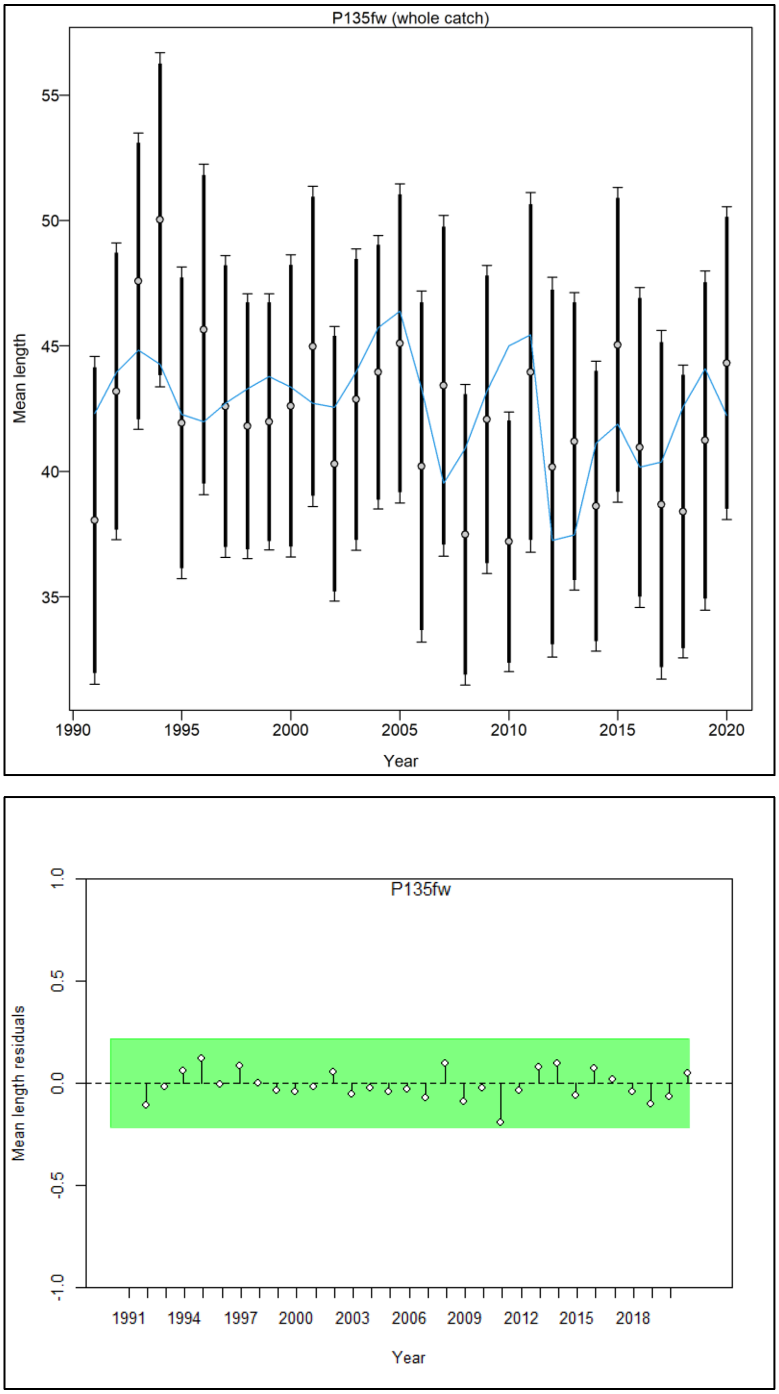


Figure 3.49. Observed and predicted mean lengths (top graph) and standardized residuals on a runs test plot (bottom graph) for the P135fw survey from the base run of the stock assessment model, 1991–2020. Green shading indicates no evidence (α = 0.05) to reject the hypothesis of a randomly distributed time series of residuals. The shaded (green) area spans three residual standard deviations to either side from zero and the red points outside the shading violate the 'three-sigma limit' for that series.

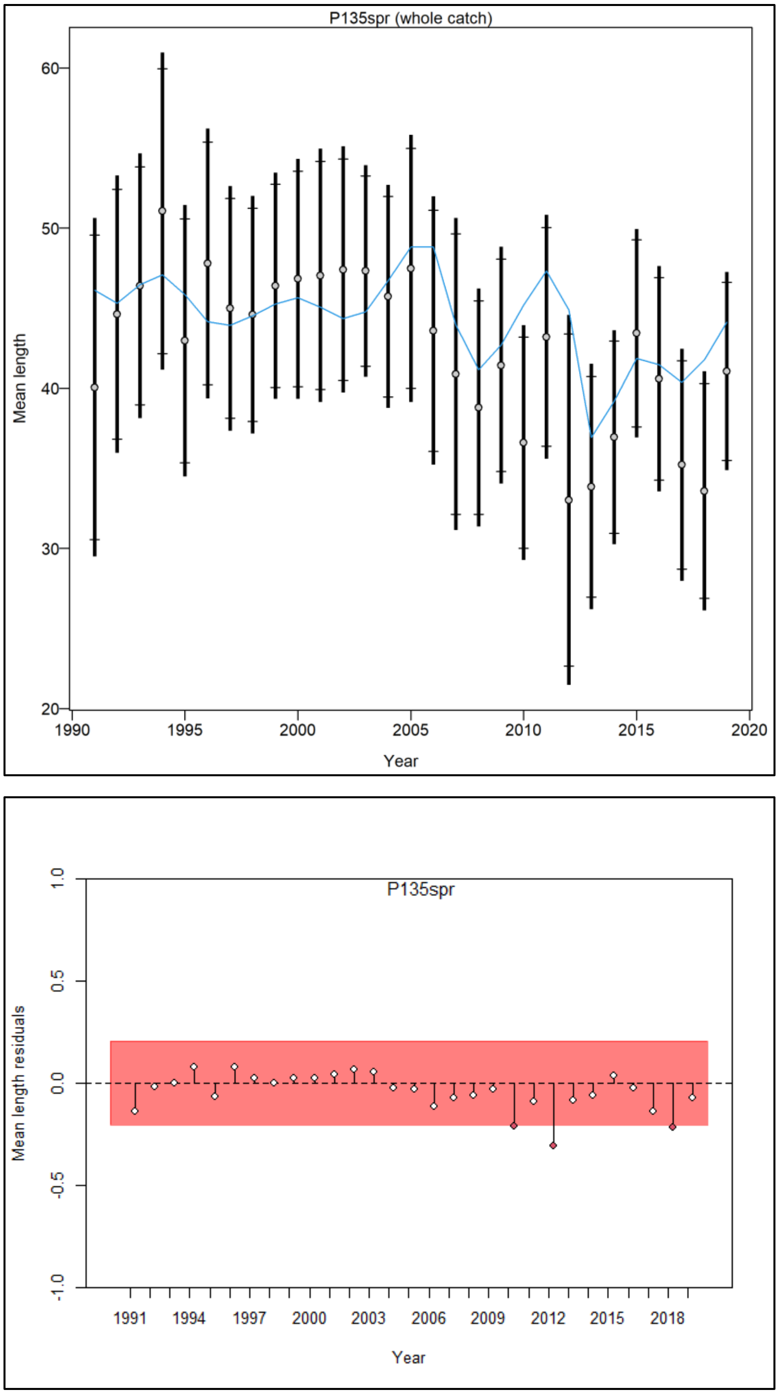


Figure 3.50. Observed and predicted mean lengths (top graph) and standardized residuals on a runs test plot (bottom graph) for the P135spr survey from the base run of the stock assessment model, 1991–2020. Red shading indicates there is evidence ($\alpha = 0.05$) to reject the hypothesis of a randomly distributed time series of residuals. The shaded (red) area spans three residual standard deviations to either side from zero and the red points outside the shading violate the 'three-sigma limit' for that series.

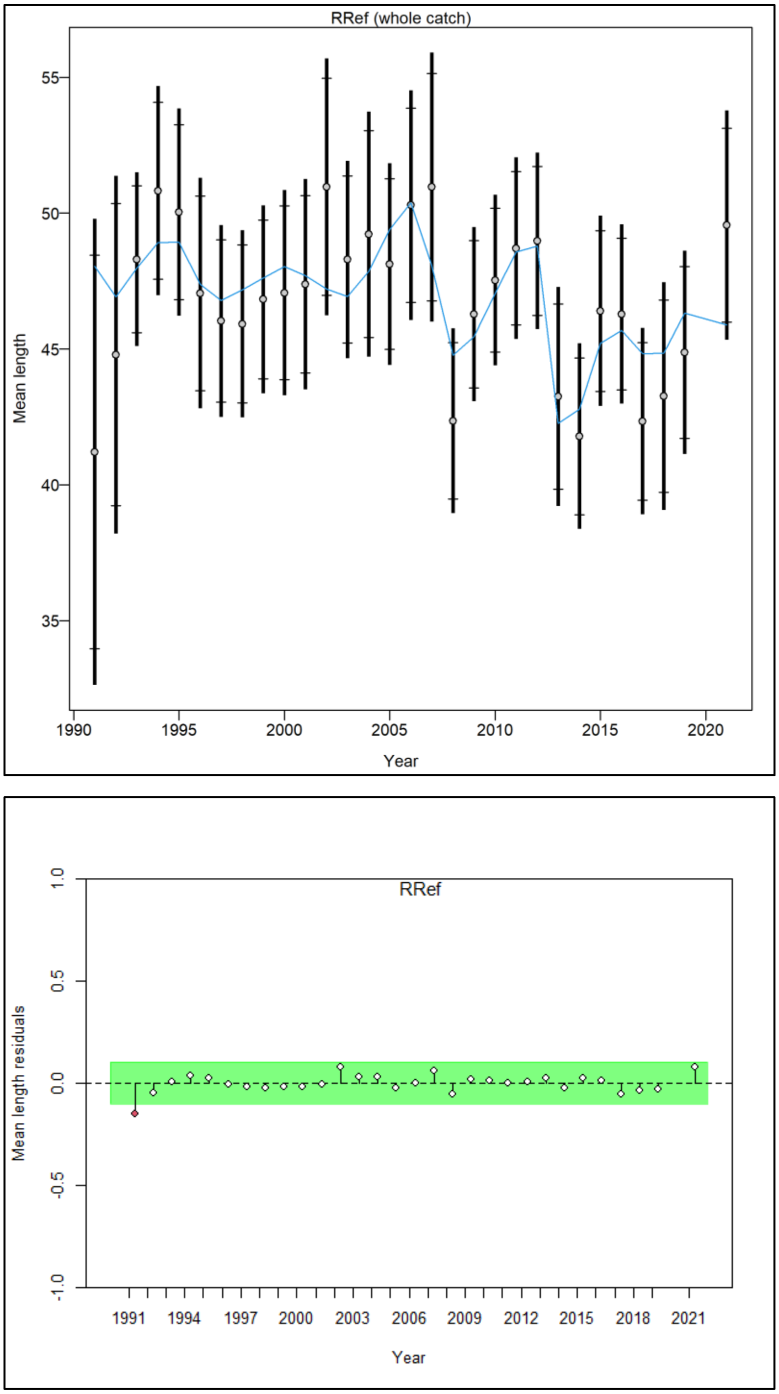


Figure 3.51. Observed and predicted mean lengths (top graph) and standardized residuals on a runs test plot (bottom graph) for the RRef survey from the base run of the stock assessment model, 1991–2021. Green shading indicates no evidence ($\alpha = 0.05$) to reject the hypothesis of a randomly distributed time series of residuals. The shaded (green) area spans three residual standard deviations to either side from zero and the red points outside the shading violate the 'three-sigma limit' for that series.

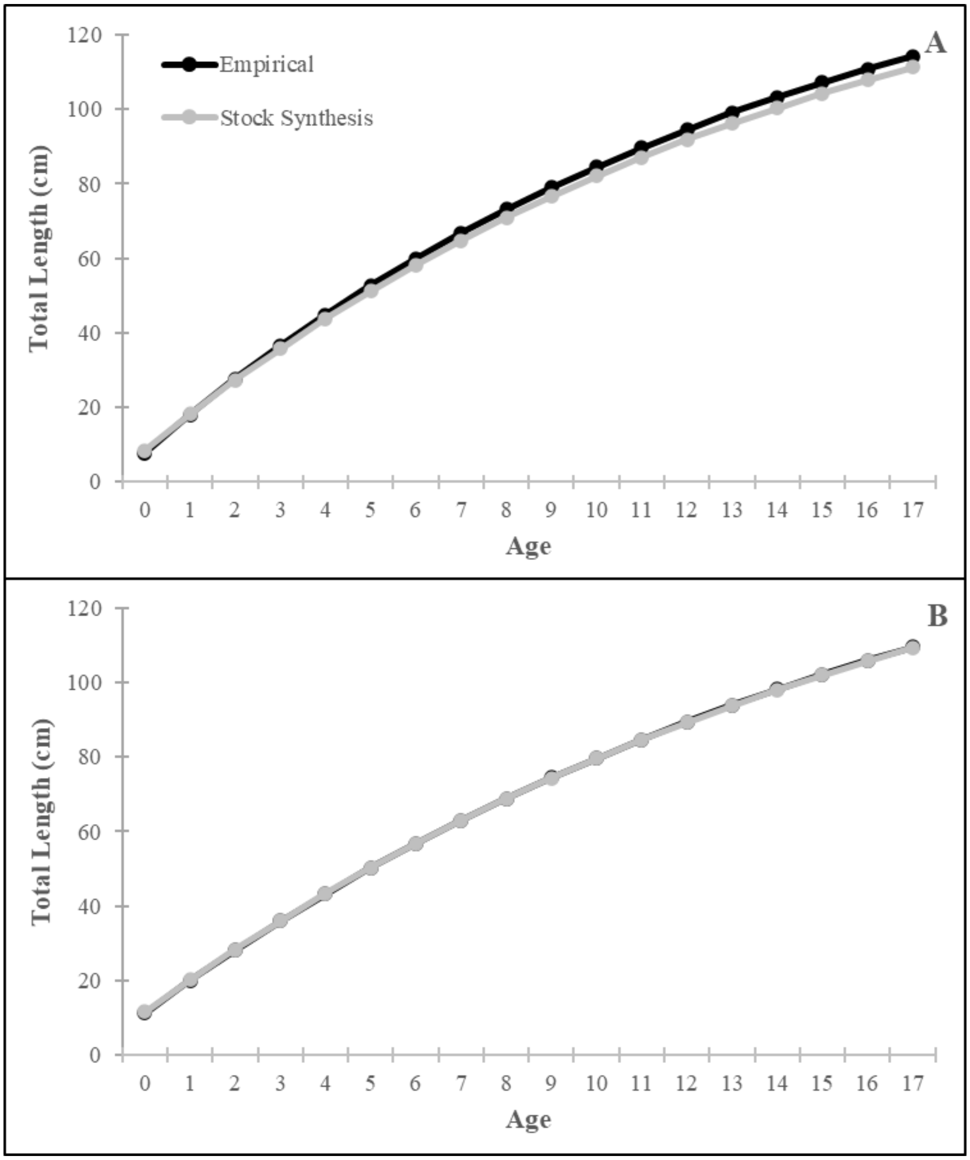


Figure 3.52. Comparison of empirical and model-predicted age-length growth curves for (A) female and (B) male Striped Bass from the base run of the stock assessment model.

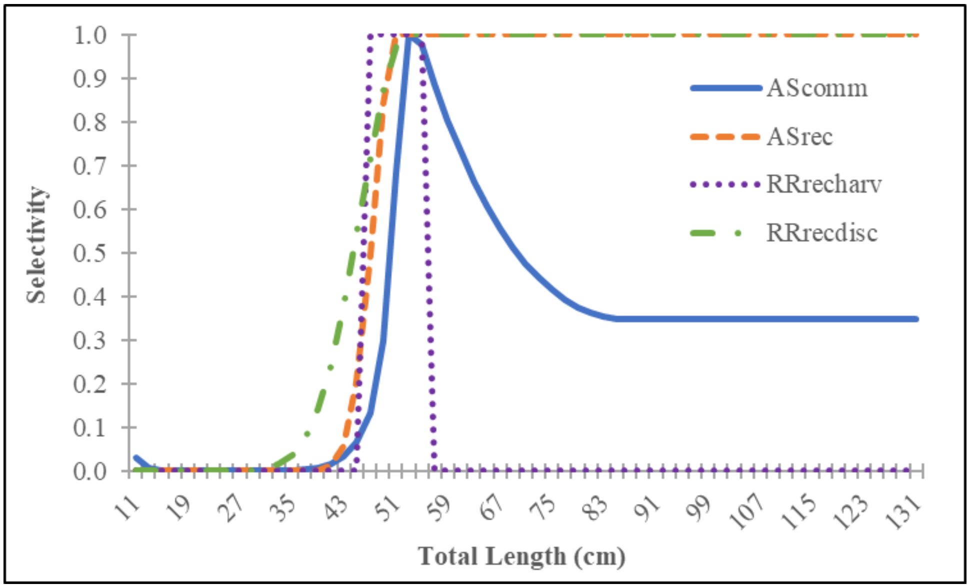


Figure 3.53. Predicted length-based selectivity for the fleets from the base run of the stock assessment model.

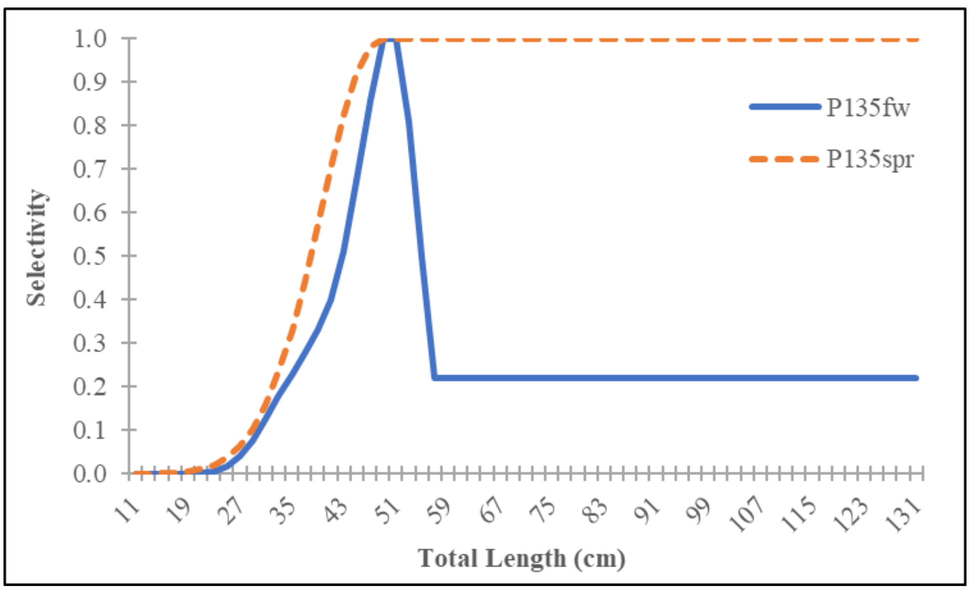


Figure 3.54. Predicted length-based selectivity for the P135fw and P135spr surveys from the base run of the stock assessment model.

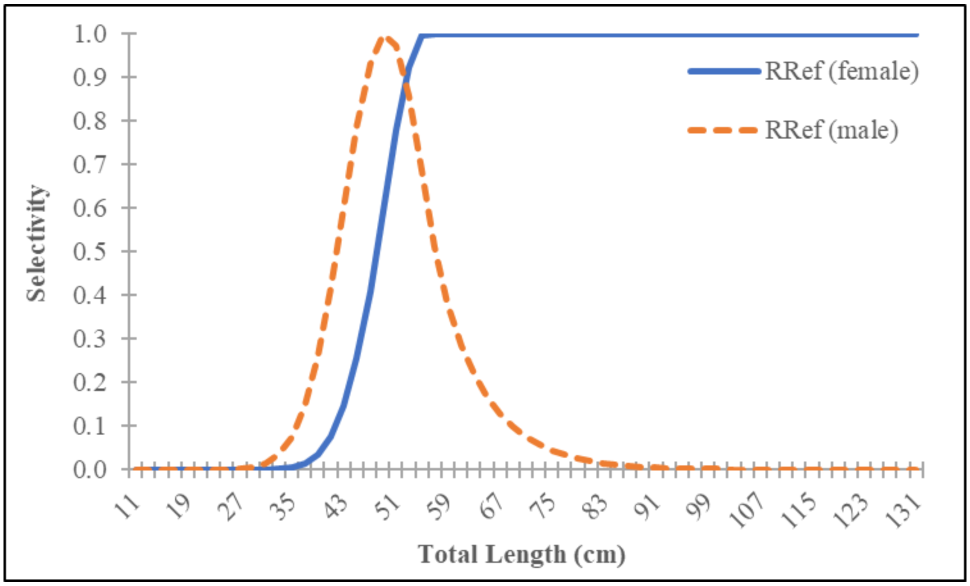


Figure 3.55. Predicted length-based selectivity for the RRef survey from the base run of the stock assessment model.

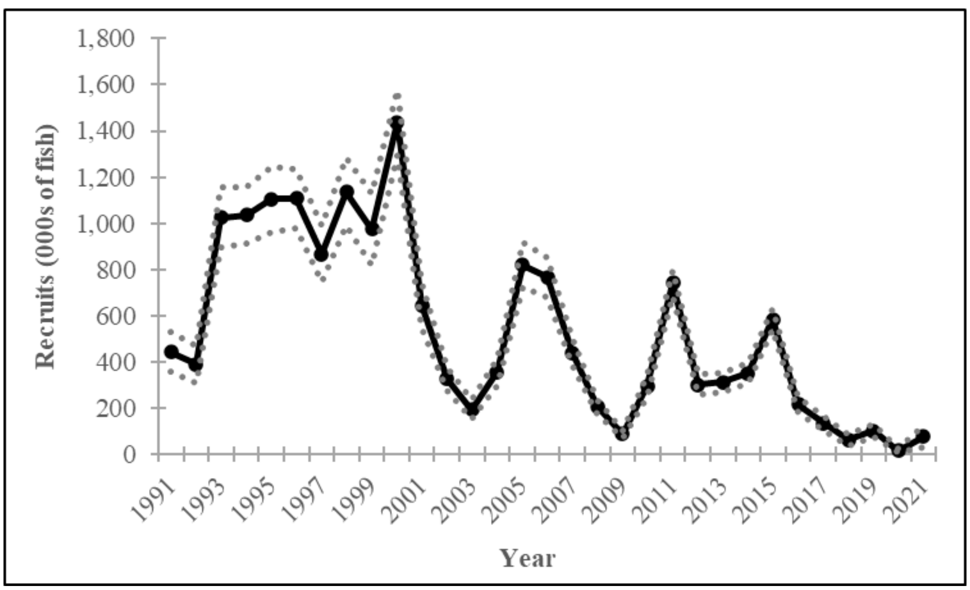


Figure 3.56. Predicted recruitment of age-0 fish from the base run of the stock assessment model, 1991–2021. Dotted lines represent ± 2 standard deviations of the predicted values.

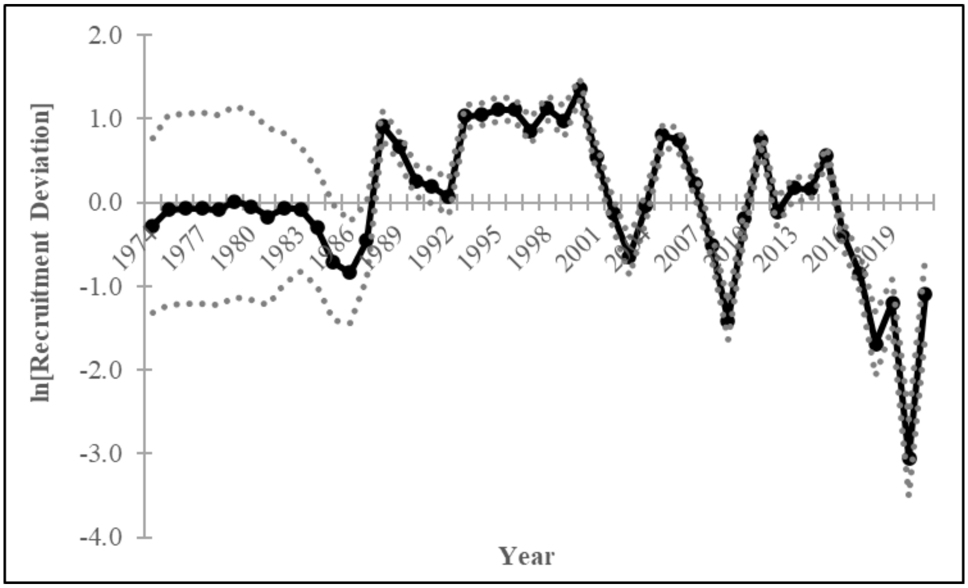


Figure 3.57. Predicted recruitment deviations from the base run of the stock assessment model, 1974–2021. Dotted lines represent ± 2 standard deviations of the predicted values.

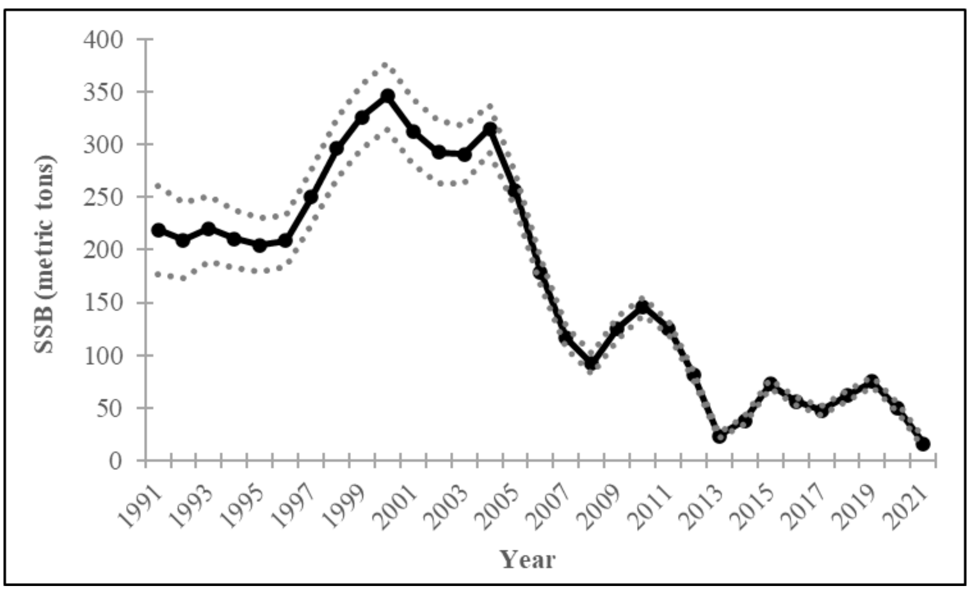


Figure 3.58. Predicted female spawning stock biomass from the base run of the stock assessment model, 1991–2021. Dotted lines represent ± 2 standard deviations of the predicted values.

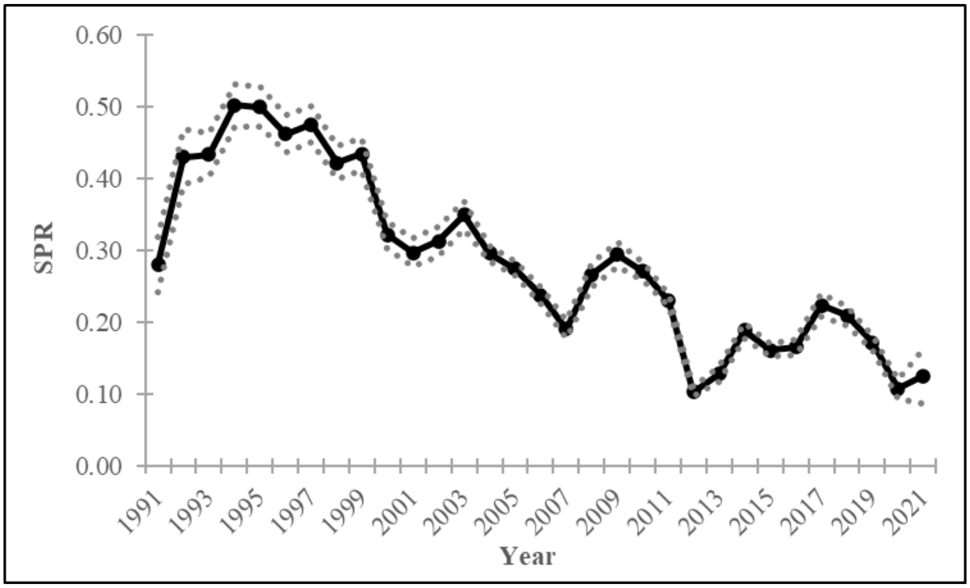


Figure 3.59. Predicted spawner potential ratio (SPR) from the base run of the stock assessment model, 1991–2021. Dotted lines represent ± 2 standard deviations of the predicted values.

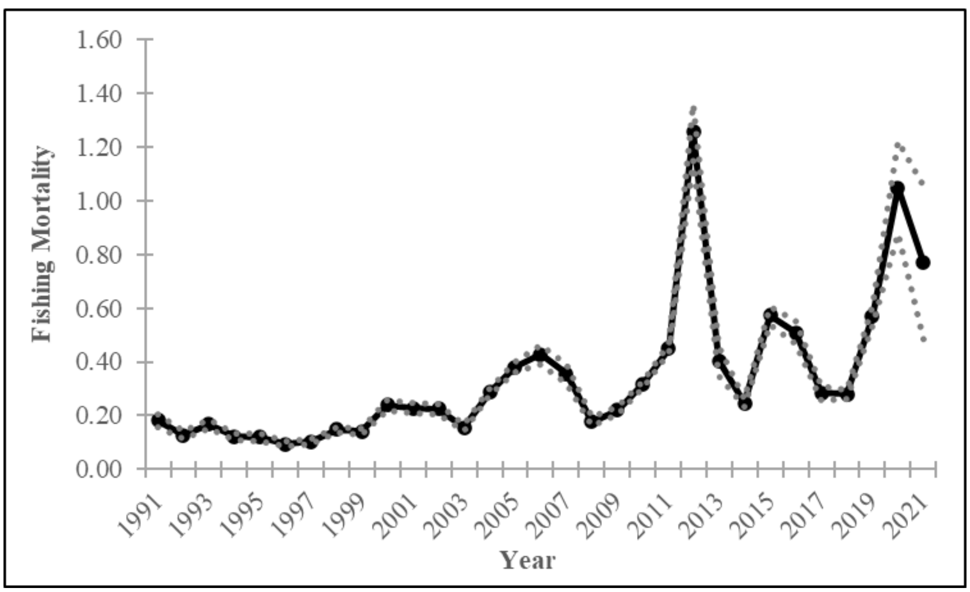


Figure 3.60. Predicted fishing mortality (numbers-weighted, ages 3–5) from the base run of the stock assessment model, 1991–2021. Dotted lines represent ± 2 standard deviations of the predicted values.

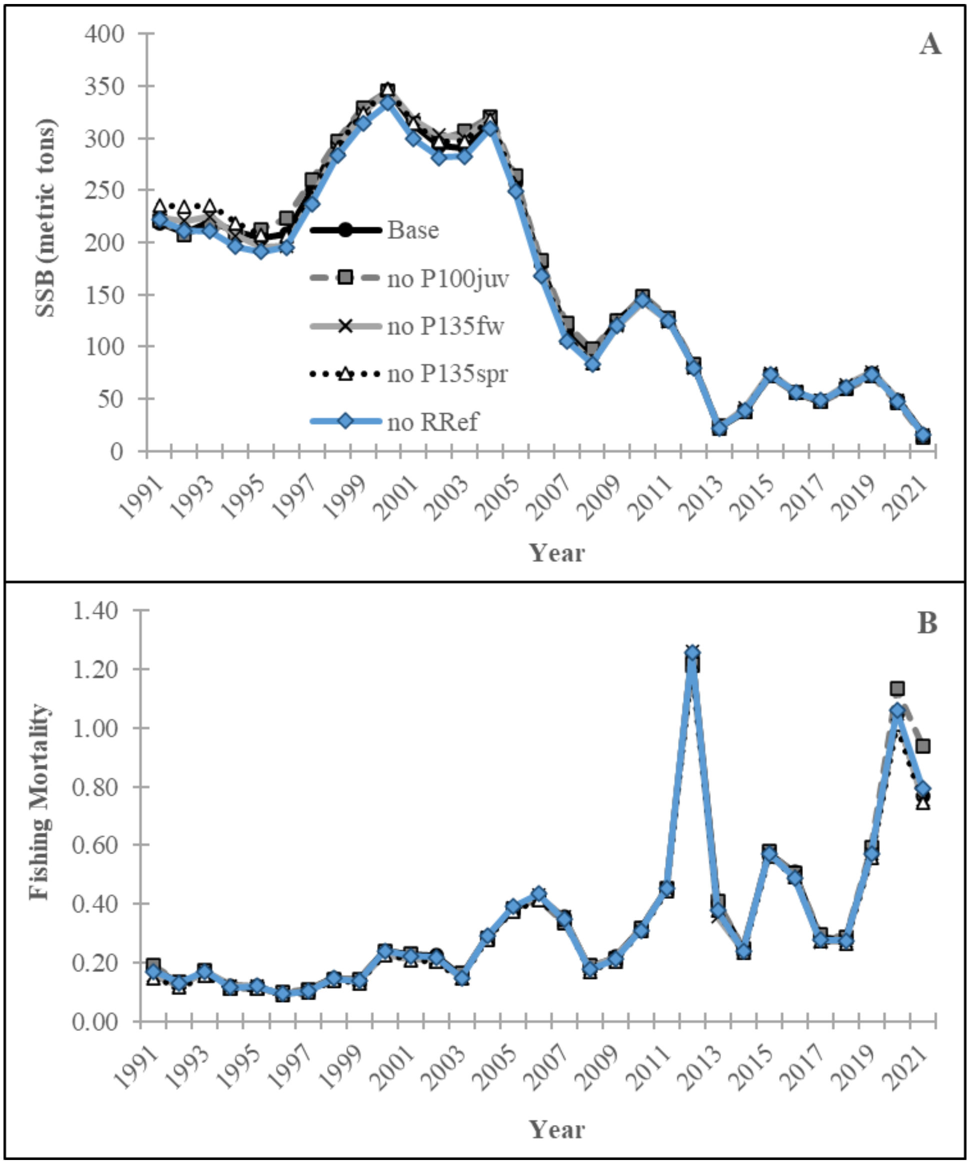


Figure 3.61. Sensitivity of model-predicted (A) female spawning stock biomass and (B) fishing mortality rates (numbers-weighted, ages 3–5) to removal of different fisheries-independent survey indices from the base run of the stock assessment model, 1991–2021.

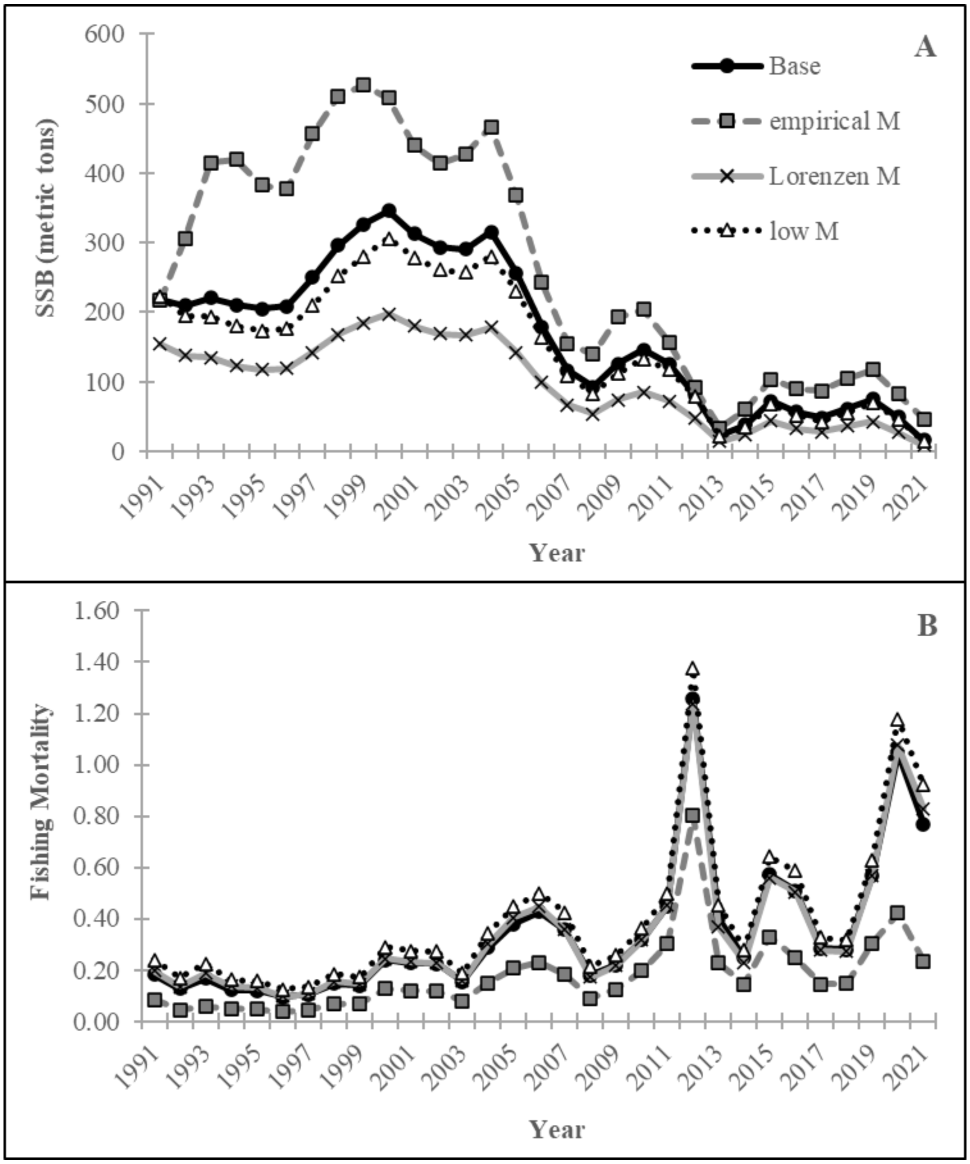


Figure 3.62. Sensitivity of model-predicted (A) female spawning stock biomass and (B) fishing mortality rates (numbers-weighted, ages 3–5) to the assumption about natural mortality, 1991–2021.

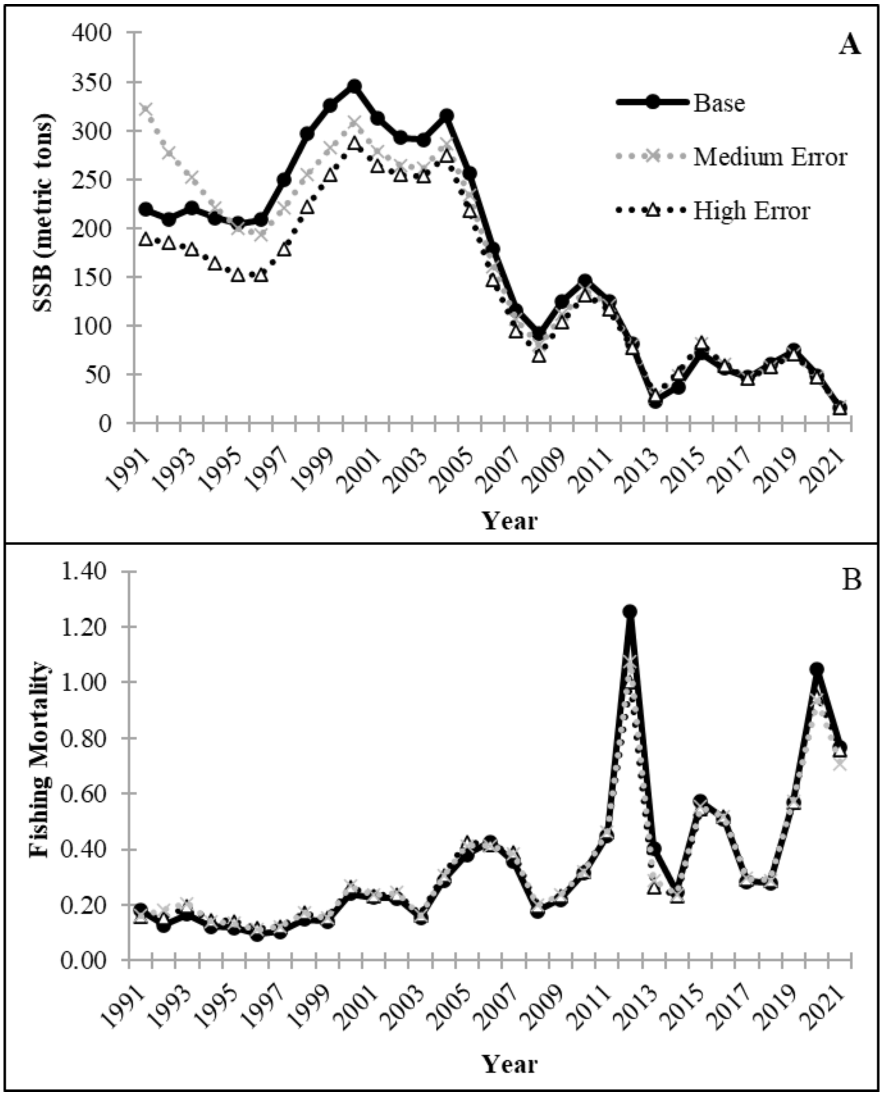


Figure 3.63. Sensitivity of model-predicted (A) female spawning stock biomass and (B) fishing mortality rates (number-weighted, ages 3–5) to the assumption about ageing error, 1991–2021.

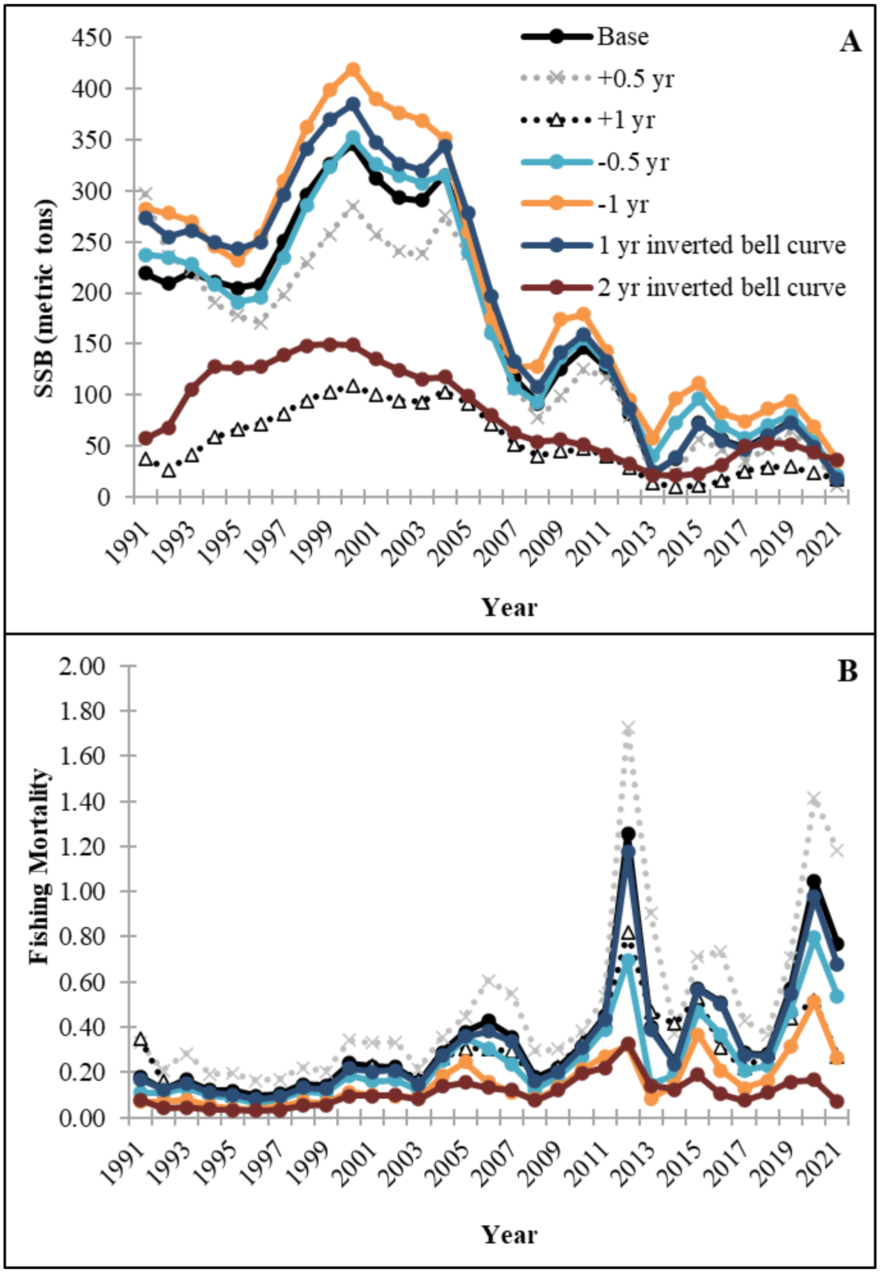


Figure 3.64. Sensitivity of model-predicted (A) female spawning stock biomass and (B) fishing mortality rates (number-weighted, ages 3–5) to the assumption about ageing bias, 1991–2021.

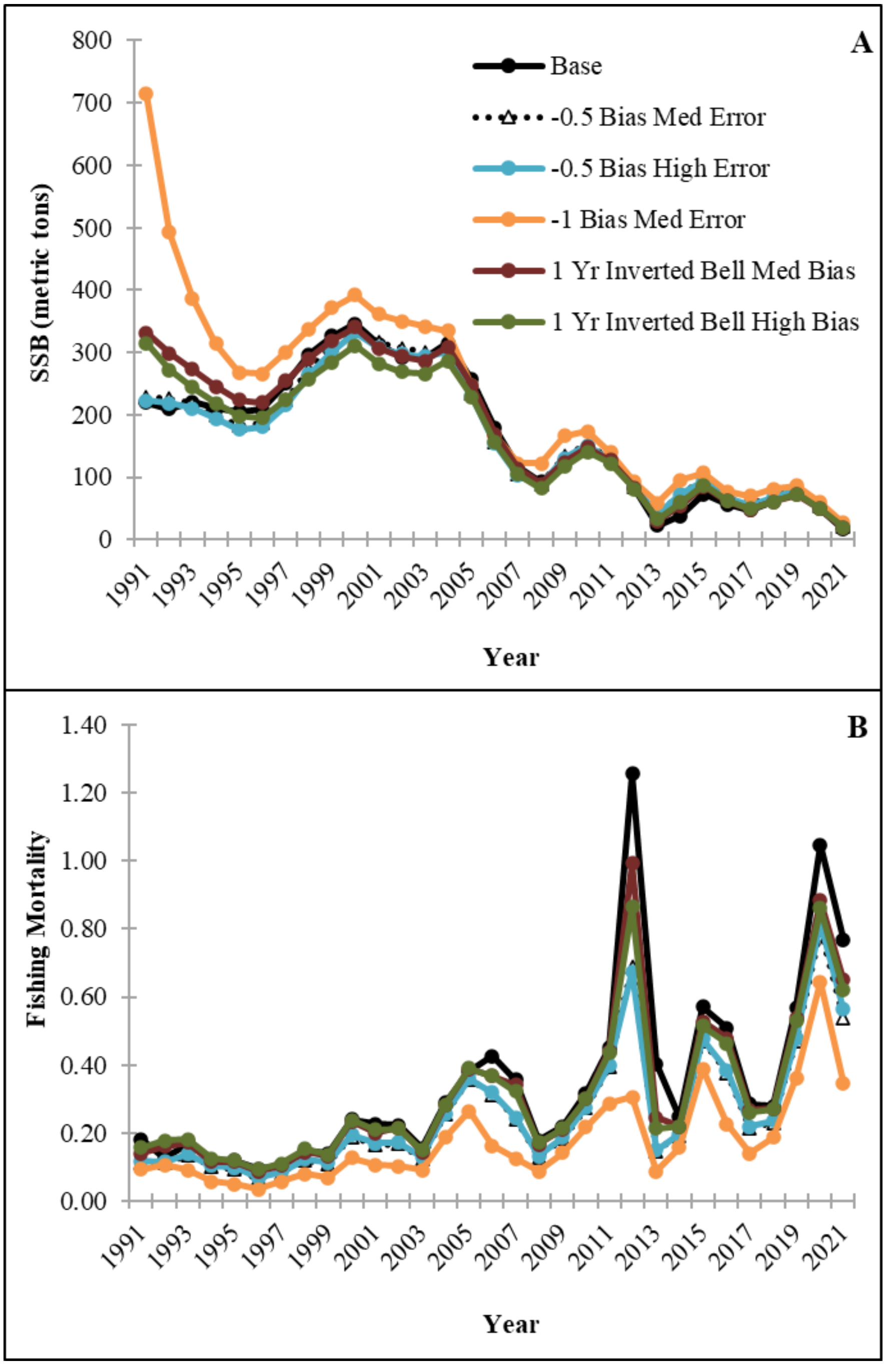


Figure 3.65. Sensitivity of model-predicted (A) female spawning stock biomass and (B) fishing mortality rates (number-weighted, ages 3–5) to the assumption about ageing error and bias combined, 1991–2021.

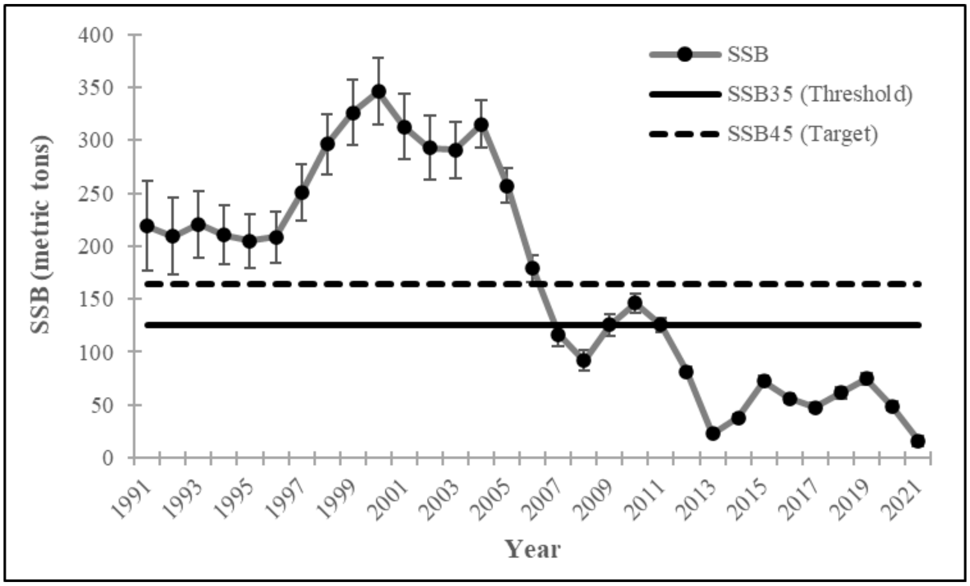


Figure 4.1. Estimated female spawning stock biomass compared to spawning stock biomass target ($SSB_{45\%}$ = 164 mt) and threshold ($SSB_{35\%}$ = 125 mt). Error bars represent ± two standard errors.

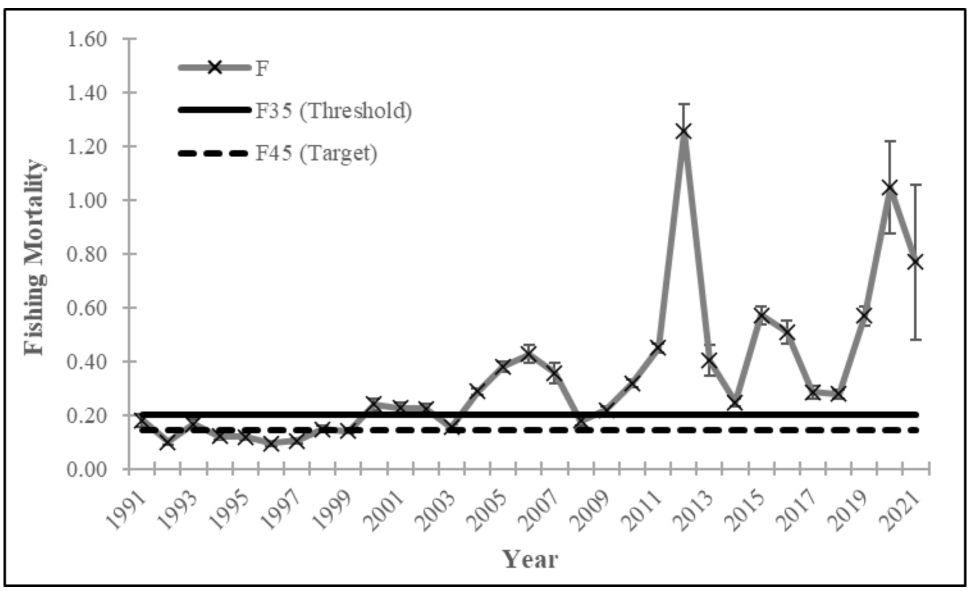


Figure 4.2. Estimated fishing mortality (numbers-weighted, ages 3–5) compared to fishing mortality target ($F_{45\%}$ = 0.14 mt) and threshold ($F_{35\%}$ = 0.20 mt). Error bars represent ± two standard errors.

External Peer Review Report
for the
2022 Stock Assessment Update
of the
Albemarle Sound-Roanoke River
Striped Bass (*Morone saxatilis*) in North Carolina

Jeff Kipp, Atlantic States Marine Fisheries Commission

Rod Bradford, Fisheries and Oceans Canada

Mike Allen, University of Florida

February 2023

Desk Review

EXECUTIVE SUMMARY

The Peer Review Panel (RP) completed a desk review of the 2022 stock assessment update of the Albemarle Sound-Roanoke River Striped Bass stock during January 2023. Specific areas of focus as directed by the peer review terms of reference were handling of data disruptions due to the Covid-19 pandemic, the performance of the stock assessment model, and the overall reliability of the stock assessment model results for advising management of the striped bass stock.

The RP felt that how the data were handled during Covid-19 precautions was a reasonable approach. Though no fault of the Stock Assessment Team (SAT), uncertainty is increased in the assessment due to the inputted/missing data. The SAT noted some model diagnostics indicate potential issues for the updated stock assessment model. These diagnostics indicate some model misspecification, as well as potential overparameterization which impact the assessment by increasing model uncertainty. Despite the results of these diagnostics, the base model estimates agree with the general data trends, notably decreasing recruitment and abundance to low levels, the trends estimated in the benchmark assessment, and trends across sensitivity runs. The RP feels that overall the model results are a credible representation of current stock status, namely that, since the benchmark assessment, Spawning Stock Biomass (SSB) has remained below the threshold (SSB35%), that annual recruitment to the population has not been sufficient to result in any sustained increase in SSB, and that overfishing has occurred and is a contributing factor to the continued depression of SSB. As was the case in the 2020 benchmark stock assessment, drivers of recruitment remain a major uncertainty of the assessment, and alternate hypotheses around environmental drivers warrants future exploration.

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1.3 Do the stock assessment model results represent the most reliable information on which to base management recommendations given our understanding of the life history and the fisheries? Please comment on response. 2

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1 TERMS OF REFERENCE

1.1 Evaluate the development and treatment of data affected by the occurrence of Covid-19. Specifically:

1.1.1 Evaluate the adequacy and appropriateness of methods used to develop estimates of recreational creel statistics for the ASMA and RRMA for the spring of 2020.

- The Peer Review Panel (RP) felt that how the data were handled during Covid-19 precautions was a reasonable approach, by imputing catch based on effort counts of boat trailers at boat ramps. This approach makes sense, but the report didn't provide the trailer count data and it was not clear how much fishing effort actually changed during the pandemic. Further, the imputation of catch data from the incomplete surveys does increase uncertainty in the assessment, but the degree to which this factor influenced uncertainty is not clear. The RP believes the assessment report should acknowledge this uncertainty and seek to quantify the degree to which it influenced the uncertainty of stock status (e.g., through model sensitivity analysis using alternative catch estimates).

- The RP notes that in many locations recreational fishing effort increased substantially during the pandemic (e.g., Midway et al. 2021; Audzijonyte et al, 2022; Trudeau et al. 2022), and thus, were curious as to whether expected fishing effort was higher during this time period than other years. Providing these data on boat trailer counts would be helpful, as well as some text in the report that discusses how fishing effort was expected to change in the time period where the full creel survey was not completed. The assessment update would benefit from showing the expected/estimated fishing effort time series for each system (AS and RR).

1.1.2 Evaluate the treatment of fisheries-independent data affected by Covid-19 as missing in the stock assessment model.

- The periods where fisheries-independent data were not available were treated as missing data, and this had minor effects on stock status determinations. Here the RP had no criticism of the way the data were handled and the effects of the missing data did not change the assessment outcome appreciably.

1.2 Comment on the ability of the model to adequately estimate population parameters within a reasonable degree of uncertainty. Some concerns include recent low recruitment, treatment of data due to Covid-19, and model diagnostics.

- As the Stock Assessment Team (SAT) has described in the stock assessment report, model diagnostics indicate some issues with the base model. These include residual patterns in the data fits (and the odd selectivity pattern for AScomm discards), some parameters being estimated at their bounds and with high uncertainty, patterns in recruitment deviations since the benchmark assessment, and movement in parameter estimates between assessments (Table 1). These diagnostics indicate some model misspecification, as well as potential overparameterization (Carvalho et al. 2021). Poor model diagnostics contribute to model uncertainty and increase risk associated with management based on the assessment model results.

- Although the SAT handled missing index data appropriately, it should be noted in the stock assessment report that uncertainty in terminal year estimates is higher than a typical situation with complete time series (which is already associated with higher uncertainty as was noted by the SAT in the report) because there is very limited abundance information for exploitable-sized fish guiding population estimates. Of six possible data points in 2020 and 2021, only one (RRef in 2021) is available and it shows low abundance similar to the levels at the end of the benchmark stock assessment. This, along with trends from the disrupted surveys prior to the Covid-19 pandemic and the continued low recruitment measured by the P100juv survey during the Covid-19 pandemic, do not provide any indication of significant increases in abundance.
- Despite the results of some model diagnostics, the base model estimates agree with the general data trends, notably decreasing recruitment and abundance to low levels, the trends estimated in the benchmark assessment, and trends across sensitivity runs. Given these consistencies, the model does appear to accurately estimate stock status in the terminal year of the assessment. Further, direction of the retrospective pattern (not included in the stock assessment report) and consistent overprediction of indices of exploitable-sized fish in the last few years, an issue observed in the benchmark assessment, indicate the model may be underestimating the degree of biomass depletion and overfishing, providing additional confidence in the stock status determinations made in the assessment.
- Recommended focal areas for future improvements to the model and reduction of model uncertainty include those identified during the peer review of the benchmark assessment, recruitment drivers and growth, as well as parameterization of index catchability. The model estimates a trend in negative recruitment deviations since the last assessment which could indicate misspecification of the stock-recruitment relationship (i.e., time-varying relationship and/or unaccounted for environmental covariates affecting recruitment). Additional growth analysis by the RP since the benchmark stock assessment shows decreased length-at-age in recent years (Figure 1 and Figure 2) which could also indicate underlying changes to stock productivity, if indeed this is a real biological change occurring. The index catchability parameters are highly correlated, change considerably between assessments, allow the model flexibility not to fit to the interannual variability observed by the surveys, and there is no clear hypothesis for why all fishery-independent surveys would have nonlinear catchability. Removing nonlinear catchability assumptions would constrain the model to fit more closely to the observed indices of abundance and use this information to inform the estimated population dynamics.

1.3 Do the stock assessment model results represent the most reliable information on which to base management recommendations given our understanding of the life history and the fisheries? Please comment on response.

- The RP feels that overall the model results are a credible representation of current stock status, namely that, since the benchmark assessment, Spawning Stock Biomass (SSB) has remained below the threshold (SSB35%) and that annual recruitment to the population has not been sufficient to result in any sustained increase in SSB. The model results support the determination that overfishing has occurred and is a contributing factor to the continued depression of SSB.

- However, the extent to which the current low abundance of spawners can be attributed to overfishing -and therefore the response of the population to additional harvest controls- is not entirely clear because the underlying bases for the continued low recruitment (P100juv survey, assessment report Fig. 3.16) is not understood and the predicted recruitment deviations are currently quite large (assessment report Fig. 3.57).

2 ADDITIONAL COMMENTS

- Overall the RP notes that despite the data stream interruptions given the pandemic, the basic outcome of this assessment is unchanged from the 2020 benchmark assessment. The stock continues to show signs of apparent overfishing based on truncated age structure (i.e., very few fish over age 4 in recent years relative to historical data from 1991-2013, Tables 3.13 and 3.20). All indications are that recruitment has remained very low, and the stock is composed mainly of young fish presumably due to a truncation of the age structure from fishing.
- However, the causes of low recruitment could result not just from recruitment overfishing, and the degree to which environmental factors (e.g., spring river discharge, water quality, estuary temperature and habitat conditions, etc.) are influencing recruitment in this fishery should be a top priority for further analyses. The RP was not convinced that fishing was the primary driver of recruitment, and alternate hypotheses around environmental drivers warrants exploration.
- It may be appropriate to review core assumptions concerning the biological/life-history attributes of the population, specifically whether size (length and weight) at age by sex and maturity at age by sex are sufficiently invariant to justify time invariant growth and maturity parameters.

<u>Minor comments/edits</u>

- Assessment report Figure 3.13 needs a figure legend to describe the colors on these plots.
- Assessment report Figure 3.25 has relatively large differences between observed and predicted length compositions for the ASrec data set in 2008 and later. It is not clear why this occurred and this was not apparent in the RRrec data set (assessment report Figure 3.28).
- Assessment report Table 3.11 shows a time series and would be easier to view if on a plot instead of the table.
- It would be helpful to identify the data points in assessment report tables and figures impacted by Covid-19 disruptions to sampling.

3 LITERATURE CITED

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4 TABLES

Table 1. Comparison of base model parameter estimates between the 2020 benchmark stock assessment and the 2022 stock assessment update.

Type	Parameter	Benchmark (2020)	Update (2022)
Growth	L1, female	17	18
	Linf, female	160	162
	K, female	0.065	0.065
	CV1, female	0.19	0.18
	CV2, female	0.001	0.001
	L1, male	18	20
	Linf, male	161	173
	K, male	0.060	0.055
	CV1, male	0.19	0.17
	CV2, male	0.001	0.001
Initial Conditions	SR_LN(R0)	6.2	6.1
	Initial *F*, AScomm	0.085	0.020
	Initial *F*, ASrec	0.011	0.0064
	Initial *F*, RRrecharv	0.019	0.047
	Initial *F*, RRrecdisc	0.0057	0.00057
Catchability	Catchability, P100	-8.2	-6.1
	Survey Power, P100	0.60	0.24
	Catchability, P135fw	-3.0	-1.8
	Survey Power, P135fw	-0.54	-0.45
	Catchability, P135spr	-1.7	-0.20
	Survey Power, P135spr	-0.74	-0.69
	Catchability, RRef	1.8	2.5
	Survey Power, RRef	-0.37	-0.46
Selectivity	SizeSpline_GradLo_AScomm(1)	0.060	0.15
	SizeSpline_GradHi_AScomm(1)	0.0010	0.0010
	SizeSpline_Val_1_AScomm(1)	-6.1	-8.5
	SizeSpline_Val_2_AScomm(1)	-4.4	-3.8
	SizeSpline_Val_3_AScomm(1)	-2.1	-2.2
	SizeSpline_Val_5_AScomm(1)	-1.1	-0.83
	SizeSpline_Val_6_AScomm(1)	-2.6	-1.9
	Retain_L_infl_AScomm(1)	30	41
	Retain_L_width_AScomm(1)	9.6	2.7
	Size_DblN_peak_ASrec(2)	53	51
	Size_DblN_top_logit_ASrec(2)	0.13	0.19
	Size_DblN_ascend_se_ASrec(2)	3.7	3.1
	Size_DblN_descend_se_ASrec(2)	3.5	3.5
	Retain_L_infl_ASrec(2)	40	39
	Retain_L_width_ASrec(2)	5.1	6.5
	Size_DblN_peak_RRecdisc(8)	51	53
	Size_DblN_top_logit_RRecdisc(8)	0.052	0.0088
	Size_DblN_ascend_se_RRecdisc(8)	4.4	4.6
	Size_DblN_descend_se_RRecdisc(8)	3.5	3.5
	SizeSpline_GradLo_P135fw(5)	0.56	0.51
	SizeSpline_GradHi_P135fw(5)	-0.41	-0.49
	SizeSpline_Val_1_P135fw(5)	-4.6	-4.3
	SizeSpline_Val_3_P135fw(5)	-1.4	-1.6
	Size_DblN_peak_P135spr(6)	47	49
	Size_DblN_top_logit_P135spr(6)	-0.018	-0.023
	Size_DblN_ascend_se_P135spr(6)	5.1	5.1
	Size_DblN_descend_se_P135spr(6)	3.5	3.5
	Size_DblN_peak_RRef(7)	57	56
	Size_DblN_top_logit_RRef(7)	0.014	0.031
	Size_DblN_ascend_se_RRef(7)	4.4	4.4
	Size_DblN_descend_se_RRef(7)	3.5	3.5
	SzSel_MaleDogleg_RRef(7)	59	60
	SzSel_MaleatZero_RRef(7)	7.9	7.3
	SzSel_MaleatMaxage_RRef(7)	-6.2	-9.4

5 FIGURES

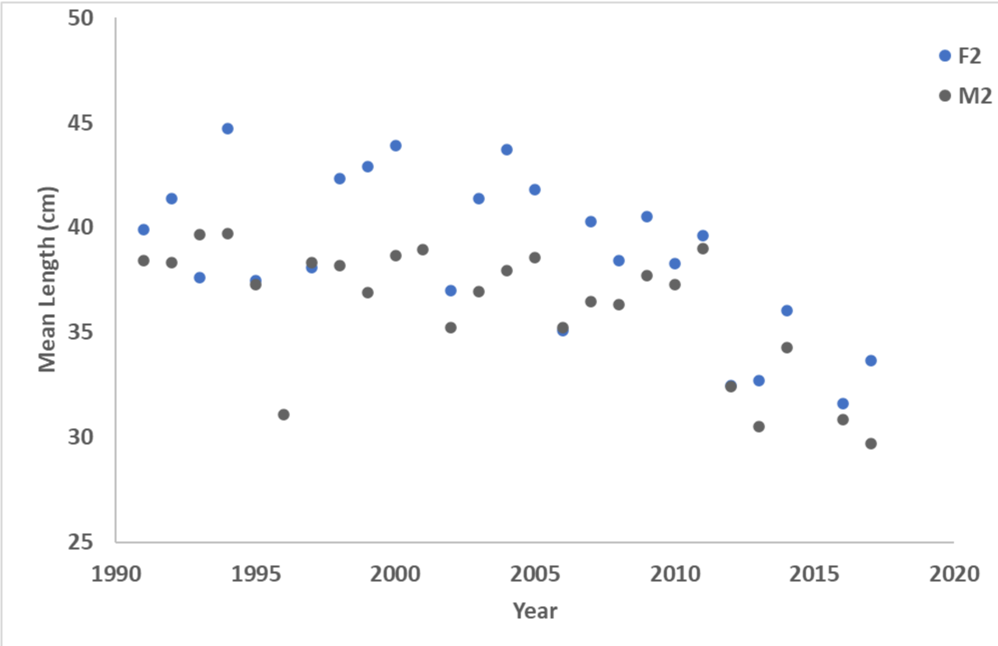

Figure 1. Mean length of age-2 striped bass collected by the RRef survey through time. Blue circles represent females and grey circles represent males.

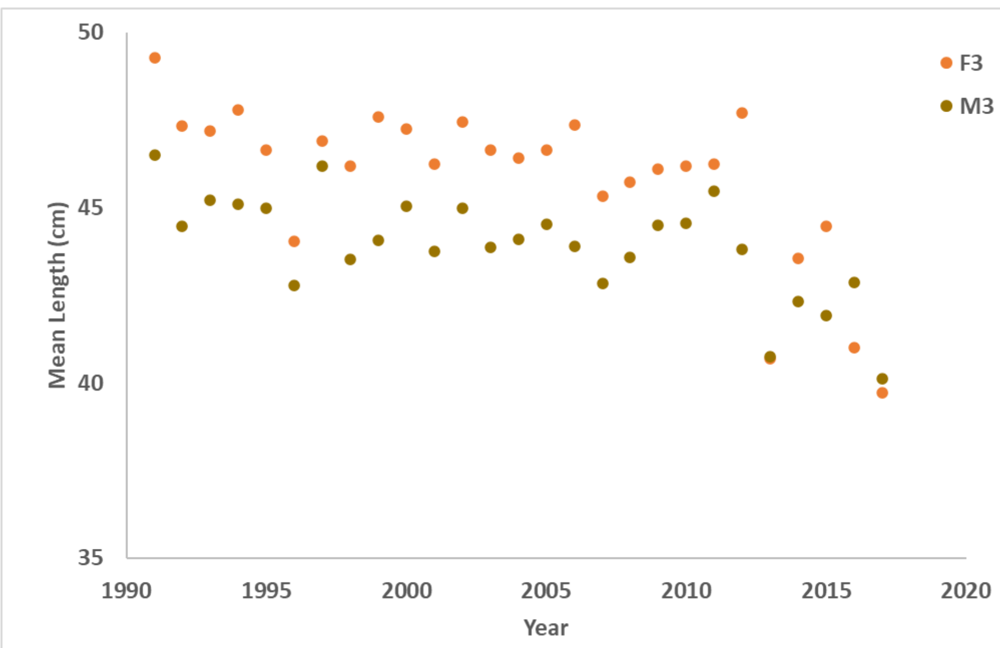

Figure 2. Mean length of age-3 striped bass collected by the RRef survey through time. Orange circles represent females and green circles represent males.