Stock Assessment of Spotted Seatrout, *Cynoscion nebulosus*, in Virginia and North Carolina Waters, 1991–2019

Prepared by

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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 significant species to achieve sustainable 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 their long-term viability.

A seasonal size-structured assessment model was applied to data characterizing commercial and recreational landings and discards, fisheries-independent survey indices, and biological data collected from 1991 through 2019. A nonstationary process was assumed for natural mortality and growth in the model. The seasonal time step and nonstationary natural mortality assumption allows for capturing the cold-stun signals that have been observed for Spotted Seatrout. Both the observed data and the model predictions suggest a shift in population dynamics around the year of 2004 when the survey index data became available. Lower fishing mortality and higher spawning stock biomass and recruitment with greater variation were predicted for the time period after 2004. This trend was also observed in the recreational landing and discards data, with higher values in the time period after 2004.

Reference point thresholds for the Spotted Seatrout stock were based on 20% spawner potential ratio (SPR). The estimated F threshold $F_{20\%}$ was 0.60 per year, and the estimated terminal year (2019) F was 0.75 per year. Thus, the estimated $F/F_{20\%}$ for 2019 is greater than one (1.3), suggesting the stock is currently experiencing overfishing. The estimated SSB threshold ($SSB_{20\%}$) for 2019 was 1,143 metric tons, and the estimated 2019 SSB was 2,259 metric tons. Therefore, the estimated $SSB/SSB_{20\%}$ for 2019 is greater than one (2.0), suggesting the stock is not currently overfished.

An independent, external peer review of this stock assessment recommended the stock assessment for use in management for at least the next five years.

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1 INTRODUCTION

1.1 The Resource

Spotted Seatrout (*Cynoscion nebulosus*), also known as Speckled Trout, are a euryhaline species found from Massachusetts to Mexico (Manooch 1984), inhabiting shallow coastal and estuarine waters throughout their range. Spotted Seatrout is a member of the family Sciaenidae (drums), which includes Weakfish (*C. regalis*), Spot (*Leiostomus xanthurus*), kingfishes or sea mullet (*Menticirrhus* spp.), Atlantic Croaker (*Micropogonias undulatus*), Black Drum (*Pogonias cromis*), and Red Drum (*Sciaenops ocellatus*). This family of fishes is highly sought after in commercial and recreational fisheries. Spotted Seatrout has two other species within its genus found in Virginia and North Carolina waters—Weakfish (Gray Trout) and Silver Seatrout (*C. nothus*). Spotted Seatrout can be distinguished from the other two species by the circular specks or spots on its body, dorsal fin, and caudal fin.

1.2 Life History

1.2.1 Stock Definitions

The unit stock for this assessment consists of all Spotted Seatrout within North Carolina and Virginia waters. Tagging studies in North Carolina and Virginia indicate moderate mixing between the two states (between 6 and 10%; Ellis 2014; NCDMF, unpublished data; Susanna Musick, Virginia Game Fish Tagging Program—VGFTP, personal communication). In contrast, tagging studies in North Carolina and South Carolina suggest Spotted Seatrout rarely move between the two states (<1%; Davy 1994; Ellis 2014; NCDMF, unpublished data). Several genetics studies have been completed in recent years that further investigated Spotted Seatrout stock structure in Virginia, North Carolina, and South Carolina (O'Donnell et al. 2014; Ellis et al. 2019). Overall, genetic data support a single unit stock in Virginia and North Carolina coastal waters (Ellis et al. 2019); however, studies by Ellis et al. (2019) and O'Donnel et al. (2014) both suggest Spotted Seatrout in the Cape Fear, North Carolina region are genetically distinct from Spotted Seatrout found in Bogue Sound, North Carolina northward through Virginia and the New River, North Carolina serving as an area of complex, seasonal mixing and connectivity between these two populations.

In this stock assessment, Spotted Seatrout occurring in the waters between the Cape Fear River and South Carolina state line are included because it is a relatively small area with a low percentage of the total landings (0.5–11.5% of total North Carolina and Virginia landings from 1994 to 2019; NCDMF, unpublished data) and the available tagging data suggest extremely limited movement of Spotted Seatrout between North and South Carolina.

1.2.2 Movements & Migration

As with many estuarine and marine fish in North Carolina, Spotted Seatrout have distinct seasonal migrations. During the winter, Spotted Seatrout migrate to relatively shallow habitats of upper estuaries (Ellis 2014; Ellis et al. 2017b). As the waters warm in the summer, Spotted Seatrout return to oyster beds and shallow bays and flats (Daniel 1988). Movement rates and distance traveled is greatest in spring and fall (Ellis 2014; Moulton et al. 2017). Although Spotted Seatrout seasonally migrate, movements north in the spring and southern movements in the fall, Spotted Seatrout have considerable residency based on tag return studies, with most individuals usually traveling less than 50 km (Music 1981; Brown-Peterson et al. 2002; Ellis 2014; Moulton et al. 2017; Loeffler et al. 2019).

A coast-wide stock assessment of Spotted Seatrout has not been conducted given the largely non-migratory nature of the species (ASMFC 2008). Instead, a list of goals for coast-wide management exist to help guide states that have an interest in the Spotted Seatrout fishery so they can manage their stocks independently (ASMFC 1990).

South Carolina, Virginia, and North Carolina have long-term tagging studies of Spotted Seatrout. South Carolina tagged fish from 1978 to 2009 and less than 1% were recaptured in North Carolina or Virginia (Davy 1994; Wenner and Archambault 1996; Wiggers 2010). Virginia has an ongoing tagging program; from 1995 to 2020, a total of 6.4% of the Spotted Seatrout tagged in Virginia were recaptured outside of the state (mostly in North Carolina, but ranging from Ocean City, Maryland to Savannah, Georgia; Susanna Musick, VGFTP, personal communication). Ellis et al. (2018) collected North Carolina tagging data from 2008 to 2014. Overall, a total of 86% (i.e., 452 fish) of the tagged fish that a recapture location was recorded for were recaptured in North Carolina and 14% (i.e., 71 fish) were recaptured in the Chesapeake Bay. The remaining 0.4% (i.e., two fish) were recaptured in South Carolina. Ellis' (2014) analysis of tagged fish indicated Spotted Seatrout are capable of migrating more than 180 km; however, the majority (56%) of movement based on tag returns is local (<20 km). North Carolina Division of Marine Fisheries' tagging data (2014–2020) indicates a similar pattern (NCDMF, unpublished data). The majority of fish tagged in North Carolina were recaptured in North Carolina waters (91%) although some fish were recaptured in the Chesapeake Bay (Maryland and Virginia waters, 8%) and South Carolina (1%).

1.2.3 Age & Size

Spotted seatrout can reach a maximum size of 1,003 mm (39.5 inches) and 7.92 kg (17.4 lb; FWC 2022). North Carolina's state record was a 5.67-kg (12-lb 8-ounce) fish caught in 2022. The annual average size of Spotted Seatrout landed in the North Carolina recreational fishery between 1991 and 2019 ranged from 361 to 447 mm (14.2 to 17.6 inches); in the commercial fishery, annual average length ranged between 366 and 465 mm (14.4 to 18.3 inches). The maximum observed length in North Carolina's recreational fishery was 927 mm (36.5 inches) while the maximum observed length in the commercial fishery was 836 mm (32.9 inches). The maximum otolith-based age of Spotted Seatrout has been reported to be 10 years old in Virginia (Ihde and Chittenden 2003), 9 years old in North Carolina, 9 years old in South Carolina (Wenner and Archambault 1996), 8 years old in Georgia (GACRD 2003), and 10 years old in Florida (Addis et al. 2018). Although the oldest individual Spotted Seatrout observed in many studies was male (Moffett 1961; Maceina et al. 1987; Colura et al. 1994; Murphy and Taylor 1994; DeVries et al. 1997), both female and male Spotted Seatrout have been aged up to age 9 in North Carolina.

Virginia's state record was a 7.26-kg (16-lb) fish caught in 1977. The annual average size of Spotted Seatrout landed in the Virginia recreational fishery between 1991 and 2019 ranged from 384 to 610 mm (15.1 to 24.0 inches) total length (TL). In the commercial fishery, annual average length ranged between 397 and 537 mm (15.6 to 21.2 inches) TL. The maximum observed length in Virginia's recreational fishery was 770 mm (30.3 inches) TL while the maximum observed length in the commercial fishery was 870 mm (34.3 inches) TL.

1.2.4 Growth

Following the first winter, male Spotted Seatrout attain an average of 246 mm (9.70 inches) in length and females reach an average of 325 mm (12.8 inches) in length (NCDMF, unpublished data). Smith et al. (2008) calculated a growth rate of 1.44 mm/day for juveniles in Chesapeake Bay, which is two to three times higher than growth rates reported in Florida (McMichael and Peters 1989; Powell et al. 2004). Growth rate begins to decrease with age in North Carolina reaching an asymptote by age 4. The predicted average maximum size for Spotted Seatrout in North Carolina is 671 mm (26.4 inches) for males and 775 mm (30.5 inches) for females.

Several studies have examined environmental effects on Spotted Seatrout growth. There is evidence of reduced metabolism of Spotted Seatrout at high temperatures and salinities (temperature-dependent), which may be accompanied by reduced activity and growth (Wuenshel et al. 2004); however, greater Spotted Seatrout growth has also been observed in habitats with both higher salinities and greater seagrass densities (Bortone et al. 2006). Similarly, refuge, better feeding success, and/or habitat complexity were found to be potentially important for relative growth of hatchery-reared late juvenile Spotted Seatrout; Hendon and Rakocinski (2016) found that relative growth of hatchery-raised Spotted Seatrout was significantly greater in submerged aquatic vegetation and non-vegetated shoreline habitats as compared to open water habitats.

1.2.4.1 Age-Length

Available otolith-based annual age data (raw data) from both fisheries-dependent and fisheries-independent data sources in Virginia and North Carolina were fit with a von Bertalanffy age-length model. Data were subset for females (n=14,664) including unknown sex (n=708), males (n=9,014) including unknown sex (n=708), and sex-aggregated (24,386) including unknown sex (n=708). Length at age was modeled using the von Bertalanffy (1938) growth model as:

$$L_{i,j} = L_{\infty,j}\left(1 - \exp\left(-K_j\left(t_{i,j} - t_{0,j}\right)\right)\right)\exp\left(\varepsilon_{L,i,j}\right)$$

$$\varepsilon_{L,i,j} \sim N(0, \sigma^2_{L,j})$$

where j indexes the sex, L_i and t_i are the fork length (mm) and age (fractional age in years) of individual i, respectively, and the parameters to be estimated were the asymptotic length L_∞, the growth coefficient K, and the theoretical age at which a fish has a length of zero t_0. The length $L_{i,j}$ of individual fish sampled was assumed to follow a lognormal distribution.

A Bayesian hierarchical approach was used to estimate parameters with a hierarchical structure for priors on the growth parameters. Growth parameters $L_{\infty,j}$, K_j, and $t_{0,j}$ were assumed to vary by sex and the logarithm of sex-specific parameters were assumed to be multivariate normally distributed (*MVN*), and $t_{0,j}$ was assumed to follow a normal distribution controlled by sex-average parameters:

$$\begin{bmatrix} lnL_{\infty,j} \\ lnK_j \end{bmatrix} \sim MVN\left(\begin{bmatrix} ln\bar{L}_\infty \\ ln\bar{K} \end{bmatrix}, \Sigma\right),$$

$$t_{0,j} \sim N\left(\bar{t_0}, \sigma^2_{t_0}\right),$$

where $\bar{L}_\infty$, $\bar{K}$, and $\bar{t_0}$ are sex-average parameters with uniform distributions and the standard deviation σ_{t_0} was also assumed to be uniformly distributed. The variance-covariance matrix Σ was modeled with an inverse-Wishart distribution (Gelman and Hill 2007) as:

$$\Sigma = \begin{bmatrix} \sigma^2_{L\infty} & \varphi \\ \varphi & \sigma^2_K \end{bmatrix},$$

where σ_{L_∞} and σ_K are standard deviations of lnL_∞ and lnK across sexes and represent variability in growth between sexes; φ is the covariance of lnL_∞ and lnK across sexes. High negative correlation of L_∞ and K have previously been observed in the von Bertalanffy growth model (Kimura 2008; Midway et al. 2015); therefore, in order to improve model convergence, L_∞ and K parameters were modeled jointly with a negative correlation.

Posterior distributions were obtained using the Metropolis-Hasting algorithm using Markov Chain Monte Carlo simulation (Hilborn et al. 1994; Hoff 2009). Three concurrent chains were run with a total of 100,000 iterations for each chain. The first 70,000 iterations were discarded as burn-in and every 10th of the remaining samples from each chain were saved for analysis. The Just Another Gibbs Sampler software (JAGS; version 4.3.0; JAGS Community Team 2021) was used to run the Bayesian analysis.

Estimates of L_∞, K, and t_0 were within the range of estimates from previous studies (Table 1.1). Plots of the observed and predicted values from this study are shown in Figure 1.1.

1.2.4.2 Length-Weight

Parameters of the length-weight relationship were also estimated in this study. The relation of fork length in millimeters to weight in grams (raw data) was modeled for each sex separately based on data collected from both fisheries-dependent and fisheries-independent sources in Virginia and North Carolina. Data were subset as female (n=13,264), male (n=9,249), and sex-aggregated (n=50,612) for the weight-at-length modeling. Sex-aggregated data included unknown sex (n=28,099). Modeling was performed using non-linear least squares. Weight at length was modeled as:

$$W_i \sim a * {L_i}^b$$

where W_i and L_i are the weight (g) and length (mm) of individual i, respectively, and a and b are estimated parameters.

The estimated parameters from this and previous studies are presented in Table 1.2. Plots of the observed and predicted values from this study are shown in Figures 1.2–1.4.

1.2.5 Reproduction

The spawning season for Spotted Seatrout varies depending on location (Texas: Brown-Peterson et al. 1988; Mississippi: Brown-Peterson et al. 2001; Gulf of Mexico estuaries: Brown-Peterson et al. 2002; South Carolina: Roumillat and Brouwer 2004; Florida: Lowerre-Barbieri et al. 2009) and peaks around the full moon (Tucker and Faulkner 1987; McMichael and Peters 1989). Virginia Spotted Seatrout spawn from May through August with peaks in the gonadosomatic index in May and July (Brown 1981). The spawning season in North Carolina is from April to October with a peak in May through June (Burns 1996). The spawning period is generally within the first few hours after sunset (Luczkovich et al. 1999). During this time Spotted Seatrout have been found to acoustically signal spawning using drums, grunts, and staccatos (Montie et al. 2017). During the peak of the season, older Spotted Seatrout (>3 years old) spawn approximately every two days while younger Spotted Seatrout (ages 0 and 1) spawn approximately every four days (Roumillat and Brouwer 2004), though spawning frequency can vary by location and time of year (Brown-Peterson et al. 2001, 2002).

Spawning takes place on or near seagrass beds, sandy banks, natural sand, shell reefs, near the mouths of inlets, and off the beach (Daniel 1988; Brown-Peterson et al. 2002). There is evidence that Spotted Seatrout individuals exhibit strong intra-seasonal and inter-annual spawning site fidelity (Lowerre-Barbieri et al. 2013; Zarada et al. 2019). Estimates of fecundity for Spotted Seatrout range from 3 to 20 million ova per year depending on age, length, and water temperature (Murphy et al. 1999; Nieland et al. 2002; Roumillat and Brouwer 2004; Lowerre-Barbieri et al. 2009); however, fecundity estimates specific to North Carolina and Virginia are not available at this time.

Temperature and salinity have an influence on the reproductive output of female Spotted Seatrout. Temperature and salinity in spawning areas can vary, with temperature ranging from 15 to 31°C and salinity ranging from 18 to 35 ppt (Brown-Peterson et al. 1988; McMichael and Peters 1989; Walters 2005). When water temperatures exceed 30°C, the spawning season can be reduced (Jannke 1971); however, more recent work determined salinity was the most probable factor for differences in spawning season, spawning frequency, and batch fecundity between Gulf of Mexico (GOM) estuaries, particularly low salinity may shorten spawning seasons and decrease spawning frequency and batch fecundity (Brown-Peterson et al. 2002).

The previous North Carolina Division of Marine Fisheries (NCDMF) stock assessment of Spotted Seatrout (NCDMF 2015) applied maturity parameters derived from macroscopic analysis of reproductive tissues. Because this approach relies on visual examination, it is considered subjective and can lead to inaccurate estimates of maturation, which, in turn, can lead to biased estimates of both spawning stock biomass and associated reference points as well as distorting the stock-recruitment relationship (Murawski et al. 2001; Morgan 2008). The NCDMF conducted a maturity study using three different maturity staging methods (macroscopic, whole mount, and histological) to estimate the maturity ogive for Spotted Seatrout and other species in order to improve the accuracy of NCDMF management targets and assessments of fishery stock viability (NCDMF 2021). The histological method is considered more objective, accurate, and reliable of the three approaches (e.g., Vitale et al. 2006; Midway and Scharf 2012). Logistic regression was applied to the maturity samples from female Spotted Seatrout to estimate the length at 50% maturity (L_{50}) and slope. Based on the histological data, the value of L_{50} for females was estimated as 251 mm and the estimated slope was -0.192 (Figure 1.5).

1.2.6 Mortality

1.2.6.1 Natural Mortality

Natural mortality rates are highly variable and are influenced by multiple factors including severe temperatures during the winter months when cold stun events are known to occur and have been documented throughout their range (de Silva, unpublished data; Perret et al. 1980; Johnson and Seaman 1986). Water temperatures below 5°C should trigger concern (Anweiler et al. 2014; Ellis et al. 2017a) as kill events have been found to have population-level impacts (Ellis et al. 2017a, 2018). Spotted seatrout lose equilibrium at ≤ 4°C with no survival after prolonged exposure to 3°C (Ellis at al. 2017a).

Ellis et al. (2018) conducted the first comprehensive Spotted Seatrout conventional tag-return study in North Carolina waters with the objective of quantifying mortality and movement. Estimates of bimonthly natural mortality ranged from 0.062 to 2.5 and varied by season, while annual estimates of natural mortality ranged from 1.1 to 3.8. Ellis et al. (2018) found natural mortality was responsible for 49%–97% of total mortality based on bimonthly estimates and 81% to 92% of total mortality based on annual estimates. The importance of natural mortality compared to fishing mortality was further supported by an acoustic telemetry study. Natural mortality was generally highest during periods of cold temperatures when water temperatures were below 5°C. Estimates of *M* from Ellis et al. (2017b) and Ellis et al. (2018) were particularly high during the winters of 2009/2010 and 2010/2011, periods which coincided with reports of cold-stunned Spotted Seatrout following rapid decreases in temperature throughout the state.

The tag-return model described by Ellis et al. (2018) was adapted to fit to data obtained from two-independent tagging experiments to estimate seasonal natural mortality (Myers and Hoenig 1997; Bacheler et al. 2010). The model was implemented using R statistical software (R Core Team 2021) and JAGS (JAGS Community Team 2021) and fit to tag/recapture data from experiments performed by North Carolina State University (NCSU) during 2008 through 2012 and by the NCDMF during 2014 through 2021. A three-month season time step was used, meaning each year was separated into four seasons: a spring season from March 1st to May 31st, a summer season from June 1st to August 31st, an autumn season from September 1st to November 30th, and a winter season from December 1st to February 28th/29th. Although there was only interest in estimates through February 2020, tag release data from March 2020 to February 2021 were included in the model to lower uncertainty in the final time steps of interest (i.e., the model structure allows for data input from tag-return matrices with more tag-recovery periods than tag-release periods).

Seasonal estimates of median natural mortality (*M*) with 95% lower and upper credibility intervals were obtained for autumn 2008 through winter 2019 (Table 1.3; Figure 1.6). Estimates from winter 2012 to summer 2014 (i.e., the greyed-out time steps in Table 1.3) were disregarded because no tags were released during these time steps. Median estimated *M* ranged from 0.0015 in summer 2017 to 2.4 in autumn 2010 and peaks generally occurred during the winter season, especially during years of known cold stuns (model years 1995, 1999, 2000, 2002, 2004, 2009, 2010, 2013, 2014, 2017). The overall pattern of season *M* was generally similar to the results of Ellis et al. (2018) and aligned with the working groups expectations based on knowledge of cold stun years; however, estimates of *M* in some non-winter seasons were larger than expected (autumn 2010, spring 2012, spring 2017, autumn 2018, and spring 2019). The working group suspects two potential causes: (1) if tag returns occur at a lag, the model becomes less certain as to what season mortality should be assigned and (2) mortality events unrelated to cold stuns can occur from other environmental impacts (e.g., hurricanes and associated poor water quality; Paerl et al. 1998). In one specific instance, the high natural mortality estimate in autumn 2010 is most likely reflective of confirmed high natural mortality in winter 2010 due to a severe cold stun event in December 2010 (Ellis et al. 2018). This error occurred because a large number of tags were released in November 2010 (the autumn time step in this model is September to November) and subsequently were never recaptured. This led the model to conclude there was high mortality in autumn 2010 instead of winter 2010. Overall, credibility intervals were also wider than expected. Sources of uncertainty in the model estimates include multiple time steps in which very few tags were released and allowing the model to assume similar tag loss rates and reporting rates among commercial and recreational sectors between NCSU and the NCDMF data when they most likely differ.

1.2.6.2 Discard Mortality

Commercial

A study in North Carolina (Price and Gearhart 2002) and one in Florida (Murphy et al. 1995) have examined Spotted Seatrout discard mortality associated with commercial small mesh gill nets. Spotted seatrout total discard mortality (at-net plus delayed mortality) in gill nets as reported by Price and Gearhart (2002) were between 66% and 90% depending on mesh size (Table 1.4), whereas Murphy et al. (1995) saw average discard mortalities between 10% and 69% depending on temperature and soak time. In addition, Price and Gearhart (2002), Murphy et al. (1995), and additional NCDMF data from the NCDMF Fisheries-Independent Gill-Net Survey (Program 915; NCDMF 2012a) show that time of year may be a significant factor affecting discard mortality of Spotted Seatrout (Tables 1.5 and 1.6). Mortalities appear higher during spring/summer when water temperatures are warmer and dissolved oxygen levels are lower compared to the fall/winter months. Price and Gearhart (2002) also found differences in delayed mortality between high salinity sites and low salinity sites (Table 1.7).

For the current stock assessment, a commercial discard mortality rate of 30% was assumed because a majority of the Spotted Seatrout commercial effort and landings occur in the late fall and winter when water temperatures are cooler and dissolved oxygen may be higher.

Recreational

Recreational release mortality is likely a significant source of mortality on Spotted Seatrout in North Carolina since Type B2 releases (unobserved or reported live releases) have accounted for an increasing percentage of the overall catch in recent years (between 74 and 97% in the past ten years; National Marine Fisheries Service Fisheries Statistics Division, personal communication). Several hook-and-line release mortality studies have been conducted on Spotted Seatrout throughout the Atlantic and Gulf coasts where estimates of mortality ranged from 4.6% up to 56% (Duffy 1999; Duffy 2002; Gearhart 2002; Hegen et al. 1983; Matlock and Dailey 1981; Matlock et al. 1993; Murphy et al. 1995; Stunz and McKee 2006; Brown 2007; Table 1.8).

Two of the studies were conducted by NCDMF in North Carolina waters: Gearhart (2002) found a hooking mortality rate of 15%, whereas Brown (2007) arrived at a rate of 25%. It was noted that Brown (2007) was limited geographically to the Neuse River and most likely had an inflated release mortality rate due to low dissolved oxygen in the holding pens resulting in deaths not associated with hooking. In comparison, Gearhart (2002) covered a wider geographic range in North Carolina at river (low salinity) and Outer Banks (high salinity) sites from Pamlico, Core, and Roanoke sounds between June 2000 and August 2001. Gearhart (2002) suggested applying separate release mortality rates to fish caught in low versus high salinity areas instead of using the overall release mortality rate, which potentially may overestimate release mortality.

For the current stock assessment, separate rates were applied to fish caught in low versus high salinity areas based on Marine Recreational Information Program (MRIP) data from 1991 through 2019 (see section 2.1.3.5). The MRIP estimates could not be directly separated into regions based on salinity; therefore, raw intercept data from the MRIP survey were used to calculate a ratio of observed catch based on county of landing in low salinity areas (Pamlico, Craven, Hyde, Beaufort, and Currituck counties) versus high salinity areas (Dare, Carteret, Onslow, Pender, New Hanover, and Brunswick counties). The total catch was weighted by the unadjusted mortality rates for low (19.4%) and high (7.3%) salinity sites as reported by Gearhart (2002) and divided by the combined total catch to obtain an overall release mortality rate of 10%. This rate is consistent with the rates used in the previous two Spotted Seatrout stock assessments in North Carolina (Jenson 2009; NCDMF 2015) and Spotted Seatrout stock assessments from South Carolina (Zhao and Wenner 1995), Georgia (Zhao et al. 1997), Florida (Addis et al. 2018), Alabama (Bohaboy et al. 2018), and Louisiana (West et al. 2014).

1.2.7 Food & Feeding Habits

Spotted seatrout have ontogenetic changes in their diet (Holt and Holt 2000). Spotted seatrout less than 38 mm consume copepods as the primary prey. Fish between 38 and 140 mm consume mysids, amphipods, polychaetes, and shrimp. These juvenile Spotted Seatrout have considerable dietary overlap with juvenile Red Drum and tend to inhabit similar areas (Powers 2012; Holt and Holt 2000). Spotted seatrout larger than 140 mm become one of the top predators in estuaries where they feed on a variety of fishes and shrimp (Daniel 1988; McMichael and Peters 1989; Binion-Rock 2018; Binion-Rock et al. 2019).

1.3 Habitat

1.3.1 Overview

Spotted seatrout make use of a variety of habitats during their life history with variations in habitat preference due to location, season, and ontogenetic stage. Although primarily estuarine, Spotted Seatrout use habitats throughout estuaries and occasionally the coastal ocean. Spotted seatrout are found in most habitats identified by the North Carolina Coastal Habitat Protection Plan (CHPP) including water column, wetlands, submerged aquatic vegetation (SAV), soft bottom, and shell bottom (NCDEQ 2016). Protection of each habitat type is therefore critical to the sustainability of the Spotted Seatrout stock.

1.3.2 Spawning Habitat

Spotted seatrout spawning is generally limited to estuarine waters in the late summer and early fall. Peak spawning activity occurs at temperatures between 21 and 29°C and at salinities typically greater than 15 ppt (ASMFC 1984; Mercer 1984; Saucier and Baltz 1992, 1993; Holt and Holt 2003; Kupschus 2004; Stewart and Scharf 2008). Spawning sites have been noted to include tidal passes, channels, river mouths, and waters in the vicinity of inlets with depths of spawning locations ranging from 2 to 10 m (Saucier and Baltz 1992, 1993; Roumillat et al. 1997; Luczkovich et al. 1999; Stewart and Scharf 2008; Lowerre-Barbieri et al. 2009; Boucek et al 2017). Spotted seatrout have been observed to move in the late afternoon or evening to the high intensity spawning sites in an inlet and low-intensity spawning sites within the estuary with larger, older fish being more abundant at the inlet site than the nearby estuary sites (Lowerre-Barbieri et al. 2009; Ricci et al 2017; Zarada et al. 2019). A strong intra-seasonal site fidelity at resident spawning aggregation sites has also been observed in Spotted Seatrout (Lowerre-Barbieri et al. 2013). During the spawning season, studies have found that Spotted Seatrout use SAV habitat as much, if not more, than other spawning sites (Ricci et al 2017; Boucek et al. 2017). Spawning aggregations of Spotted Seatrout have also been found to occur over shell bottom habitats including over subtidal shell bottom (2–5 m) in the lower Neuse River.

In North Carolina, Spotted Seatrout in spawning condition have been collected coast wide (Hettler and Chester 1990; Burns 1996). Spawning Spotted Seatrout were detected using hydrophone and sonobuoy surveys on both the western side of Pamlico Sound including Rose Bay, Jones Bay, Fisherman's Bay, Bay River, and the eastern side of Pamlico Sound near Ocracoke and Hatteras inlets from May through September with peak activity in July (Luczkovich et al. 1999). When Spotted Seatrout aggregations co-occurred with aggregations of Weakfish at Ocracoke Inlet, the habitat was partitioned and each species occupied different depth ranges. Additional hydrophone surveys noted large spawning aggregations of Spotted Seatrout in the Neuse River generally associated with moderate salinities (12–20 ppt), temperatures between 27 and 29°C, saturated dissolved oxygen levels (> 5 mg l-1 O2), and water depths less than 5 m over mud and subtidal shell bottoms (Barrios et al. 2006). Spawning was also reported to occur over both mud and subtidal shell bottoms in these areas. Spawning in Middle Marsh, Back Sound, and Beaufort Inlet has also been confirmed by passive acoustic monitoring.

Eggs of Spotted Seatrout are positively buoyant at spawning salinities allowing for wind- and tidally-driven distribution throughout the estuary (Churchill et al. 1999; Holt and Holt 2003); however, sudden salinity reductions cause Spotted Seatrout eggs to sink, thus reducing dispersal and survival (Holt and Holt 2003). Larval Spotted Seatrout have been collected in surface and bottom waters of estuaries in North Carolina, Florida, and Texas (McMichael and Peters 1989; Hettler and Chester 1990; Holt and Holt 2000). In North Carolina, larval transport studies in the vicinity of Beaufort Inlet indicated that ocean and inlet spawned larvae are dependent on appropriate wind and tidal conditions to pass through inlets and be retained in the estuary (Churchill et al. 1999; Hare et al. 1999; Luettich et al. 1999). Although Spotted Seatrout spawning generally occurs within the confines of the estuary (ASMFC 1984; Mercer 1984; Saucier and Baltz 1992, 1993), spawning aggregations have been located near inlets in North Carolina (Ricci et al. 2017). Therefore, these physical processes appear to directly limit the retention and recruitment success of Spotted Seatrout to high salinity nursery areas (McMichaels and Peters 1989). Behaviors such as directional swimming and movement throughout the water column also provide mechanisms for estuarine dispersal and retention of larvae within the estuary (Rowe and Epifanio 1994; Churchill et al. 1999; Hare et al. 1999).

1.3.3 Nursery & Juvenile Habitat

Wetlands are particularly valuable as nurseries and foraging habitat for Spotted Seatrout (Graff and Middleton 2003). The combination of shallow water, thick vegetation, and high primary productivity provides juvenile and small fishes with appropriate physicochemical conditions for growth, refuge from predation, and abundant prey resources (Boesch and Turner 1984; Mitsch and Gosselink 1993; Beck et al. 2001). Juvenile Spotted Seatrout appear to use estuarine wetlands, particularly the marsh edge habitat of salt/brackish marshes, as nurseries (Tabb 1966; ASMFC 1984; Mercer 1984; Hettler 1989; Rakocinski et al. 1992; Baltz et al. 1993; Peterson and Turner 1994). In North Carolina, juvenile Spotted Seatrout have been found to be abundant in tidal marshes and marsh creeks in eastern and western Pamlico, Bogue, and Core sounds (Epperly 1984; Ross and Epperly 1985; Hettler 1989; Noble and Monroe 1991; Ballie et al. 2015). Additionally, juvenile Spotted Seatrout have been found using salt marsh habitats in the Cape Fear River, although in less abundance than more northern estuaries (Weinstein 1979).

McMichaels and Peters (1989) found that seagrass was the primary habitat for juvenile Spotted Seatrout. In North Carolina, SAV is used extensively by Spotted Seatrout as important nurseries and foraging grounds. Historical data collected by the NCDMF through otter trawl and seine surveys have indicated that juveniles are abundant in high salinity SAV in both Pamlico and Core sounds (Purvis 1976; Wolff 1976; NCDMF, unpublished data). Additionally, meta-analyses indicated that juvenile Spotted Seatrout abundances were found to be greater in SAV than soft bottom and oyster reef and were greater than or equivalent to abundances in wetland habitats (Minello 1999; Minello et al. 2003).

Soft bottom habitats, generally adjacent to wetlands, also function as nursery areas for juvenile Spotted Seatrout (Ross and Epperly 1985; Noble and Monroe 1991; Powers 2012). The benthic microalgae and deposited detrital material provide a rich food base for invertebrates, which are important forage for juvenile Spotted Seatrout (Peterson and Peterson 1979). The primary prey of juvenile Spotted Seatrout (<30 mm in length) consists mainly of benthic invertebrates, including copepods and mysid shrimps; they grow (>30 mm in length), the dominant prey shifts to penaeid and palaemonid shrimps, which remain important in the diet of adults (Peterson and Peterson 1979; Daniel 1988; McMichael and Peters 1989).

Shell bottom habitats have been shown to provide an important forage base of invertebrates and small finfish for juvenile and adult Spotted Seatrout (Coen et al. 1999; ASMFC 2007).

1.3.4 Adult Habitat

Adult Spotted Seatrout use the water column as a migratory corridor and to forage on pelagic fishes and penaeid shrimps with increased importance with increasing size (Lorio and Schafer 1966; ASMFC 1984; Mercer 1984; Daniel 1988; Binion-Rock 2018; Binion-Rock et al. 2019). Adult Spotted Seatrout exhibit a high degree of estuarine fidelity with most movements less than 50 km; however, movements of a few individuals in upwards of 500 km have been noted (Moffett 1961; Iverson and Tabb 1962; Tabb 1966; Overstreet 1983; Callihan 2011; Ellis 2014; O'Donnell et al. 2014).

The Atlantic States Marine Fisheries Commission (ASMFC) lists SAV as a Habitat Area of Particular Concern (HAPC) for Spotted Seatrout (ASMFC 1984). All life stages of Spotted Seatrout have been documented in mesohaline and polyhaline seagrass beds (Tabb 1966; ASMFC 1984; Mercer 1984; Thayer et al. 1984; McMichael and Peters 1989; Rooker et al. 1998). The preferred habitat for Spotted Seatrout is low-flow areas with abundant seagrass and adults have been more commonly associated with soft bottom and SAV than oyster reefs (Tabb 1958; Moulton et al. 2017). SAV provides a safe habitat corridor for Spotted Seatrout and habitat suitability models have indicated that Spotted Seatrout abundance is linearly related to percent seagrass cover until a plateau is reached at 60% coverage (Irlandi and Crawford 1997; Micheli and Peterson 1999; Kupschus 2003).

Spotted seatrout can use shallow flats as migratory refuges from larger predators, which cannot access shallow waters (Peterson and Peterson 1979). Spotted seatrout exhibit conspicuous diel shifts from seagrass to bare substrate and greater rates of movement at night (Moulton et al. 2017). In North Carolina, it has been suggested that a portion of the population moves offshore to deeper marine soft bottom areas and beaches in response to falling temperatures in late autumn (ASMFC 1984; Mercer 1984).

Lenihan et al. (2001) found that adult Spotted Seatrout fed primarily on reef-associated fishes, such as Atlantic Croaker and Silver Perch (*Bairdiella chrysoura*) while inhabiting subtidal oyster reefs in North Carolina. Peterson et al. (2003) found that Spotted Seatrout were documented to use oyster reef habitats as adults; however, data were inconclusive on whether Spotted Seatrout populations were enhanced by the presence of oyster reefs.

1.3.5 Habitat Issues & Concerns

Human activities that alter the preferred environmental conditions of Spotted Seatrout, as well as introductions of excessive nutrients, toxins, and sediment loads can severely impact the habitat value for Spotted Seatrout, especially SAV (NCDEQ 2016; Lefcheck et al. 2018). Excessive nutrient loading in the environment can lead to nuisance algal blooms, increased biological oxygen demand, hypoxia or anoxia, fish kills, and eventually, loss of biodiversity (Paerl 2002, 2018). Much of the nutrient enrichment in North Carolina's estuaries is caused by cultural eutrophication, or the rapid accumulation of nutrients and sediments caused by human land and water use activities (NCDWQ 2000a). Wetland loss and decreasing vegetative buffers can hasten these impacts to the surrounding water (NCDWQ 2000b). The effect of anthropogenic threats on SAV, wetlands, shell bottom, soft bottom, and water quality are summarized in the North Carolina Coastal Habitat Protection Plan (NCDEQ 2016).

Increased loss of wetlands and hydrological modifications due to climate change may cause degraded water quality, fish kills from hypoxia, salinity regime changes, and shoreline erosion resulting in increased sediment and nutrient loading (Meeder and Meeder 1989; Paerl et al. 2001; Mallin et al. 2002; Paerl 2018; Mallin et al. 2019) and higher costs for storm repair (Costanza et al. 2008). Declines in SAV, globally and in North Carolina, due to increased coastal development and decreased water quality, are also altering these ecosystems and their community structure.

Tabb et al. (1962) reported that excessively turbid waters in Everglades National Park following Hurricane Donna resulted in mass mortalities of Spotted Seatrout when their gill chambers became packed with suspended sediments. In 1999, the Pamlico Sound was reported to have salinities reduced by three-fourths, vertical stratification of the water column, bottom water hypoxia, increased algal biomass, displacement of marine organisms, and an increase in the presence of fish disease following hurricanes Dennis, Floyd, and Irene (Paerl et al. 2001). Similar events were observed after hurricanes Matthew (2016) and Florence (2018; Osburn et al. 2019); however, there is no conclusive evidence that hurricanes have a measurable impact on the Spotted Seatrout population in North Carolina (Burgess et al. 2007).

Some simplistic climate change scenario models of Florida Bay have shown that increasing water temperatures may improve habitat suitability for Spotted Seatrout; however, under the same climate change scenarios their prey species show significant decreases which could result in a prey-limited population (Kearney et al. 2015). It has been predicted that hundreds of finfish and invertebrate species will be forced to move northward due to increasing temperatures caused by climate change (Morley et al. 2018).

Generally, Spotted Seatrout overwinter in estuaries, only moving to deeper channels or to nearshore ocean habitats in response to water temperatures below 10°C (Tabb 1966; ASMFC 1984); however, extreme cold waves accompanied by strong winds mix and chill the water column, causing sudden drops in water temperature. The abrupt temperature declines numb Spotted Seatrout and can result in mass mortality. Many estuarine temperature refuges, such as deep holes and channels, are often far from inlets and become death traps as Spotted Seatrout are cold stunned before they can escape (Tabb 1966; Ellis et al. 2017a; McGrath and Hilton 2017). This suggests that the severity and duration of cold weather events can have profound effects on the Spotted Seatrout population in North Carolina's estuaries (Ellis et al. 2017b).

1.4 Description of Fisheries

1.4.1 Commercial Fishery

Virginia

Predominant gears in Virginia's commercial Spotted Seatrout fishery since 1994 have been haul seines (~67%) and gill nets (23.7%). A small amount is also harvested using hook and line and pound net. During more recent years, the commercial haul seine fishery has been targeting Spotted Seatrout during the months of September and October. Virginia currently has between eight and ten haul seine fishermen who target Spotted Seatrout during these months. Gill-net fishermen also target sotted seatrout during this time period. The 2021/2022 commercial season is the first season under the new incidental catch provision and preliminary results show that most incidental catch was harvested by gill nets.

North Carolina

Spotted seatrout have been commercially harvested in North Carolina using a variety of gears, but four gear types are most common: estuarine gill net, long haul seine, beach seine, and ocean gill net. Estuarine gill nets are the predominant gear. Historically, long haul seines (swipe nets) used in estuarine waters were the dominant gear, but effort and landings by this gear have diminished in recent years.

Monthly landings of Spotted Seatrout by estuarine anchored gill nets occur year round but mostly occur during the late fall and winter (October–February) with slight increases in the spring (April–May).

There has been a shift from anchored gill nets to actively fished runaround and strike netting techniques that may have been prompted by expanded fishery rules requiring gill-net attendance for small mesh (<5 inches stretch mesh) beginning in 1998. The importance of runaround gill nets (inclusive of strike netting) in North Carolina has steadily increased since 1972 and a continued surge in the mid-1990s may have been caused by the 1995 gill-net closure in Florida state waters (NCDMF 2006) as some Florida commercial fishermen moved their operations to North Carolina. More jet drive boats, spotting towers, night fishing, and runaround gillnetting were reported by the mid-1990s.

Monthly landings of Spotted Seatrout by estuarine runaround gill nets are highest in November and December. A large spike in the number of positive trips occurs during October without a corresponding spike in catch. This could be indicative of Spotted Seatrout bycatch in other fisheries that are active during October such as the striped mullet (*Mugil cephalus*) fishery.

The long haul season starts in the spring and continues through the fall. The majority of trips occur in July; however, the best catches occur in November and December.

The small mesh beach seine fishery operates predominantly during the spring (April–May) and fall (September–October). Beach seine landings of Spotted Seatrout typically occur during the spring (April–May) and fall (October–November) months. If conditions are favorable, fishermen along the northern Outer Banks particularly target Spotted Seatrout during the full moon in May.

Landings of Spotted Seatrout by ocean set gill nets are most active from October through February, but good catches occur in April and May.

1.4.2 Recreational Fishery

Spotted seatrout are taken by a variety of methods throughout the coastal zone. Depending on the time of year, anglers fish for Spotted Seatrout from the surf, inlets, piers and jetties, bays and rivers, and inland creeks. The fall season produces the largest portion of the catch and offers the most widespread fishing opportunities. Anglers catch Spotted Seatrout using an array of artificial and natural baits. Preferred artificial baits include soft and hard bodied lures of various colors and shapes fished on the bottom, mid-water, and top water. Bottom fishing using natural baits (including peeler/soft crabs, live shrimp, and various finfish) is also a popular and productive method of fishing for Spotted Seatrout.

Spotted seatrout are often selective feeders requiring anglers to use a variety of baits (natural and artificial) and different fishing techniques. While baits and fishing techniques are constantly evolving, the past twenty years have seen significant changes and improvements in artificial baits and other tackle available to anglers that target and catch Spotted Seatrout. There is anecdotal evidence that these improvements have had a positive impact on catch rate and overall fishing success. In the early 2000s, manufacturers introduced scented soft-bodied artificial baits that have become very popular and lead to increased success of anglers targeting Spotted Seatrout. Hard-bodied artificial baits have also undergone design and color pattern changes increasing their effectiveness. Many anglers also attest to better catch rates due to the widespread use of braided fishing lines. Braided lines along with new graphite rod building technology provide increased sensitivity improving strike detections resulting in more fish caught.

In addition to hook-and-line catches, some Spotted Seatrout are taken by gig and recreational commercial gear (gill nets) in North Carolina where permitted (ASMFC 1984; Watterson 2003). In Virginia, gigging is generally impractical, and regulations prohibit recreational use of commercial gear (gill nets) for species that have a commercial quota (including Spotted Seatrout).

1.5 Fisheries Management

1.5.1 Management Authority

The NCDMF is responsible for the management of estuarine and marine resources occurring in all state coastal fishing waters extending to three miles offshore. The Virginia Marine Resources Commission (VMRC) is responsible for tidal waters of Virginia and the ocean waters extending to three miles offshore.

Spotted seatrout have been managed along the Atlantic Coast through an Interjurisdictional Fishery Management Plan (FMP) developed by the Atlantic States Marine Fisheries Commission (ASMFC). The ASMFC Spotted Seatrout FMP was initially approved in 1984 (ASMFC 1984) and has been reviewed annually since 2001. Amendment 1, approved by the ASMFC Policy Board in November 1990, developed a list of goals for coast-wide management but allowed each state that had an interest in the Spotted Seatrout fishery (Florida through Maryland) to manage their stocks independently (ASMFC 1990). The adoption of the Omnibus Amendment 2 (ASMFC 2011) to the Interstate Fishery Management Plan for Spotted Seatrout requires states to comply with Atlantic Coastal Fisheries Cooperative Management Act (1993) and the ASMFC Interstate Fishery Management Program Charter. North Carolina and Virginia are currently in compliance with the minimum size limit for both recreational and commercial sectors and have adopted the recommended 20% spawning potential ratio (SPR) threshold.

1.5.2 Management Unit Definition

The management unit includes Spotted Seatrout and its fisheries in all of Virginia and North Carolina's fishing waters.

1.5.3 Regulatory History

Virginia

Effective July 1, 1992, the VMRC established a 14-inch TL minimum size limit for both the commercial and recreational fisheries, as well as a ten-fish possession limit for the recreational fishery and commercial hook-and-line fishery. In 1995, at a Virginia Finfish Advisory Committee (FMAC) meeting, recreational anglers asked for the commercial fishery of Spotted Seatrout to be regulated by a quota since recreational anglers were held to a ten-fish possession limit. FMAC and staff agreed to a commercial quota of 51,104 pounds. This quota was established using the average landings of Spotted Seatrout from 1993 and 1994 plus 25%. The quota has remained at this level since August 1, 1995, after the VMRC held a public hearing in July 1995 and it was approved and put into regulation. The season runs from September 1 through August 31 of the following year. Effective April 1, 2011, the VMRC lowered the commercial hook-and-line and the recreational possession limit to five fish from December 1 through March 31 and only allowed one fish 24 inches or greater. Effective April 1, 2014, the VMRC established a five fish commercial hook-and-line and recreational possession limit and allowed only one fish 24 inches TL or greater as a year-round regulation. Also, effective April 1, 2014, an 80% trigger was also added to regulation. Once this trigger was hit, then the fishery would move into a bycatch fishery of 100 pounds per vessel (with an equal amount of other species on board) until the quota was landed. Due to directed harvest using large haul seines during the beginning of the season, the 80% trigger has been met by mid-October most years, causing the fishery to switch over to the 100 pounds per vessel per day regulations early in the season. Additionally, language was added to regulation in 2014 to require mandatory buyer reporting from August 1 through November 30 of each year. Effective September 1, 2018, the VMRC established an exemption in the Spotted Seatrout minimum size limit for pound net or haul seine fishermen where the catch of Spotted Seatrout may consist of up to 5.0%, by weight, of Spotted Seatrout less than 14 inches TL.

Because the fishery was getting shut down so quickly after it was opened, harvesters asked staff to consider changes to the regulation in 2021 to cut down on dead discards in the gill-net fishery. Without scientific stock evidence, staff was hesitant to change the overall commercial quota but did change regulation to remove the trigger and bycatch provision and institute an incidental catch provision.

North Carolina

The size limit rule (15A NCAC 03M .0504) for Spotted Seatrout in North Carolina became effective September 1989 (12 inches TL). The first harvest restriction (ten fish recreational bag limit or taken by hook and line) was established through proclamation authority of hook-and-line regulated species (1994). This was put into rule in 1997 by amending 15A NCAC 03M .0504. The rules remained the same until 2009 when the size limit was increased by proclamation (14 inches TL). Rules for Spotted Seatrout management from 1991 to 2009 were that:

(a) it is unlawful to possess Spotted Seatrout less than 12 inches total length.

(b) it is unlawful to possess more than ten Spotted Seatrout per person per day taken by hook and line or for recreational purposes. In 2010, the daily bag limit was reduced to six fish and of those six fish, only two could be greater than 24 inches TL. In 2011, the bag limit was reduced to four fish with a 14-inch TL size limit for recreational fishermen and commercial fishermen using hook and line gear.

The trout rule was repealed in 2012, and Spotted Seatrout was managed under the proclamation authority granted in 15A NCAC 03M. 0512 (Compliance with Fishery Management Plans) until 2017 when the NCDMF re-established the Spotted Seatrout rule 15A NCAC 03M. 0522 due to ASMFC considering retiring the Interstate Spotted Seatrout FMP.

1.5.4 Current Regulations

Virginia

The current regulations in Virginia are a 14-inch TL minimum size limit and five fish commercial hook-and-line and recreational possession limit and allows only one fish 24 inches TL or greater. In addition, the catch of Spotted Seatrout by pound net or haul seine may consist of up to 5.0%, by weight, of Spotted Seatrout less than 14 inches TL. A commercial landings quota of 51,104 pounds is set for each 12-month period of September 1 through August 31 of the following year. As of 2021, when the fishery is predicted to hit 100% of the quota (51,104 pounds) staff will announce a switch over to an incidental catch fishery. When the commission announces that the directed commercial landings quota has been reached, it shall be unlawful for any commercial fisherman to take, harvest, land, or possess more than the daily incidental catch limit for the remainder of the fishing year. The daily incidental catch limit shall be 50 pounds of Spotted Seatrout per licensee aboard the vessel, not to exceed 100 pounds per vessel. In addition, seafood buyers are now required to report daily Spotted Seatrout purchases from August 1 through November 30 until the directed commercial landings quota has been reached.

North Carolina

The NCDMF currently allows the recreational harvest of Spotted Seatrout seven days per week with a minimum size limit of 14-inches TL and a daily bag limit of four fish. Since 2011, the commercial harvest is limited to a daily limit of 75 fish and a minimum size limit of 14-inches TL except for when using hook and line gear. When using hook and line gear, the commercial harvest limit is four fish per day. It is unlawful for a commercial fishing operation to possess or sell Spotted Seatrout for commercial purposes taken from Joint Fishing Waters of the state from midnight on Friday to midnight on Sunday each week; the Albemarle and Currituck sounds are exempt from this weekend closure. In the event of a cold stun, the NCDMF has the authority to close the fishery until the following spawning period. The Spotted Seatrout fishery has been closed three times due to cold stun events. It was closed from January 14 through June 15, 2011, from February 5 through June 14, 2014, and from January 5 through June 14, 2018.

1.6 Assessment History

1.6.1 Review of Previous Methods & Results

The 2015 NCDMF Spotted Seatrout assessment applied a forward-projecting length-based, age-structured model (Stock Synthesis text version 3.24f) and data collected from 1991 through 2012, including tag-recapture data (NCDMF 2015). A two-sex model that accounted for sex specific differences in mortality and growth was assumed. The results of that assessment suggested an expansion of the age structure but also predicted an abrupt decline in estimated recruitment after 2010. Estimates of spawning stock biomass also showed a decline in the final years of the time series. Based on the results of that assessment, the stock was not overfished and overfishing was not occurring in 2015.

1.6.2 Progress on Research Recommendations

Research recommendations put forward in the 2015 NCDMF stock assessment of Spotted Seatrout (NCDMF 2015) are listed below and progress, if any, is discussed.

High

- Histological maturity; fecundity evaluation/batch fecundity

  The NCDMF completed an analysis of histological maturity for Spotted Seatrout in North Carolina (NCDMF 2021). To date, there has been no research into fecundity evaluation or batch fecundity in North Carolina or Virginia.

- Validate juvenile abundance survey; improve juvenile abundance survey through expansion and addition of random stations (or replace fixed design with random or random stratified)

  A Coastal Recreational Fishing License (CRFL) project is currently in progress that is quantitatively analyzing the Estuarine Trawl Survey (Program 120) to identify redundancies, highlight underrepresented habitats, and suggest feasible modifications to their use in identifying fish nursery habitat. Another CRFL project in progress has similar objectives including evaluation of the performance of the current Program 120 survey design in terms of its accuracy, precision, and ability to capture annual variability of juvenile abundance for producing annual recruitment indices and to determine if Program 120 could be optimized using alternative sampling schemes that are more cost-effective and robust to environmental changes.

- Continue and expand tagging studies for estimating natural and fishing mortality, understanding stock structure, and examining migration (e.g., ocean vs. creeks)

  The NCDMF Multispecies Tagging Program (Program 366) is an ongoing tagging program that was started in 2014. Over 9,000 Spotted Seatrout have been tagged between October 2014 and February 2020 throughout coastal North Carolina. Fishing and natural mortality were estimated for a five-year CRFL completion report (Loeffler et al. 2019) and the current stock assessment.

- Collect data to characterize the length distribution of recreational releases

  During August of 2021, NCDMF implemented a new citizen science initiative called “Catch U Later” to collect recreational fisheries-dependent discard data. “Catch U later” is a smartphone and tablet application that allows recreational anglers to report trip and biological data (length frequencies) for flounder species. To date, over 350 flounder records have been submitted. During 2022, “Catch U Later” will be expanded to include additional species including Kingfish, Red Drum, Weakfish, and Spotted Seatrout.

- Conduct further studies to identify appropriate unit stock

  Ellis et al. (2019) conducted a genetic analysis of Spotted Seatrout from Virginia to Florida and identified two separate stocks—one from Virginia to Bogue Sound, North Carolina and a second from the Cape Fear River and southward to Florida. The New River was identified as a mixing area between these two stocks.

- Develop a custom model that allows for incorporation of variable natural mortality rates

  A customized, seasonal, size-structured model was developed in the current assessment. In this model, nonstationary natural mortality and growth were assumed to incorporate the inter-annual variability in natural mortality rates and growth.

- Develop a fishery-independent survey for Virginia waters

  No progress to date.

Medium

- Initiate surveys that assess Spotted Seatrout winter and spawning habitats

  Ellis (2014) and the NCDMF Multispecies Tagging Program (Program 366) both have information on conventionally tagged Spotted Seatrout recaptured from November through March, which would provide information on overwintering areas; however, an analysis has not yet been completed. Ellis et al. (2017b) used telemetry tags to track fish during three consecutive winters while overwintering in North Carolina estuaries.

- Compare maturity ogives between North Carolina and Virginia

  No progress to date.

- Improve discard estimates

  No progress to date.

- Conduct further studies to estimate discard mortality by gear and sector

  No progress to date.

- Investigate relationship between environmental variables and adult and juvenile mortality

  Ellis et al. (2017a) investigated how low temperature and variable salinity impact mortality of adult Spotted Seatrout. Laboratory experiments in this study suggest the temperatures in which Spotted Seatrout become stunned, or experience a complete loss of equilibrium, range from 2 to 4°C; however, Spotted Seatrout begin showing signs of stress at temperatures as low as 7°C. An adult Spotted Seatrout's critical thermal minimum, or the lowest temperature Spotted Seatrout can be exposed to for a short time and still survive, was found to be approximately between 2–3°C. When adult Spotted Seatrout were acclimated and exposed to low water temperatures for an extended period of time, a water temperature of 3°C was found to be 100% lethal to Spotted Seatrout after less than two days. At 5°C, a total of 93% of Spotted Seatrout were still alive after five days, but only 15% survived after ten days. There was high, but not complete, survival (83%) after ten days at 7°C. Ellis et al. (2017a) also observed that Spotted Seatrout subjected to rapid temperature declines in higher salinity were able to withstand lower temperatures before becoming completely stunned compared to fish in lower salinity; the critical thermal minimum was lower by about 1°C in high salinity. In addition, under long term exposure to 7°C water temperatures, several Spotted Seatrout mortalities were observed in lower salinity compared to no mortalities in high salinity at 7°C. Neither effect was statistically significant though, so further research is needed to determine if salinity does influence Spotted Seatrout survival of cold stuns.

- Selectivity of program 915 indices—gear/availability

  In progress. Details not yet available.

Low

- Collect more age and sex samples from the recreational fishery

  The NCDMF Carcass Collection Program, in which fishermen can donate their carcasses to freezers located in select locations throughout coastal North Carolina, has allowed us to collect more age and sex samples from the recreational fishery; however, more age and sex samples from this sector are still needed.

- Evaluate influences of salinity on release mortality

  Gearhart (2002) found differences in delayed mortality in hooking mortality study between high salinity sites and low salinity sites. Price and Gearhart (2002) also found differences in delayed mortality for gill-net caught fish between high salinity and low salinity sites.

- Conduct marginal increment analysis

  No progress to date.

- Conduct an age validation study

  No progress to date.

2 DATA

Note that all data were summarized by fishing year (March to February) to correspond with the life history of the species (a March 1 birth date was assumed). Data were summarized for fishing years 1991 (March 1991) to 2019 (February 2020), where available, to coincide with the time series used in the stock assessment model.

2.1 Fisheries-Dependent

2.1.1 Commercial Landings

2.1.1.1 Survey Design and Methods

Virginia

The VMRC's commercial fisheries records include information on both commercial harvest (fish caught and kept from an area) and landings (fish offloaded at a dock) in Virginia. Records of fish harvested from federal waters and landed in Virginia have been provided by the NMFS and its predecessors since 1929 (NMFS, pers. comm.). The VMRC began collecting voluntary reports of commercial landings from seafood buyers in 1973. A mandatory harvester reporting system was initiated in 1993 and collects trip-level data on harvest and landings within Virginia waters. Data collected from the mandatory reporting program are considered reliable starting in 1994, the year after the pilot year of program. The Potomac River Fisheries Commission has provided information on fish caught in their jurisdiction and landed in Virginia since 1973.

North Carolina

Prior to 1978, North Carolina's commercial landings data were collected by the National Marine Fisheries Service (NMFS). In 1978, the NCDMF entered into a cooperative program with the NMFS to maintain and expand the monthly surveys of North Carolina's major commercial seafood dealers. Beginning in 1994, the NCDMF instituted a mandatory trip-ticket system to track commercial landings.

On January 1, 1994, the NCDMF initiated a Trip Ticket Program (TTP) to obtain more complete and accurate trip-level commercial landings statistics (Lupton and Phalen 1996). Trip ticket forms are used by state-licensed fish dealers to document all transfers of fish sold from coastal waters from the fishermen to the dealer. The data reported on these forms include transaction date, area fished, gear used, and landed species as well as fishermen and dealer information.

The majority of trips reported to the NCDMF TTP only record one gear per trip; however, as many as three gears can be reported on a trip ticket and are entered by the program's data clerks in no particular order. When multiple gears are listed on a trip ticket, the first gear may not be the gear used to catch a specific species if multiple species were listed on the same ticket but caught with different gears. In 2004, electronic reporting of trip tickets became available to commercial dealers and made it possible to associate a specific gear for each species reported. This increased the accuracy of reporting by documenting the correct relationship between gear and species.

2.1.1.2 Sampling Intensity

Virginia

All registered licensees are required to report daily harvest from Virginia tidal and federal waters to the VMRC on a monthly basis.

North Carolina

North Carolina dealers are required to record each transaction with a fisherman and report trip-level data to the NCDMF on a monthly basis.

2.1.1.3 Biological Sampling

Virginia

Field sampling at fish processing houses or dealers involves multi-stage random sampling. Targets are set based on mandatory reporting of harvest data by harvesters from the previous years. A three-year moving average of landings by gear and by month (or other temporal segment) provides a preliminary goal for the amount of length and weight samples to be collected. Real time landings are used to adjust the preliminary targets. Targets for ageing samples (see below for criteria) are tracked and collection updates are done weekly. Sampling data are recorded on electronic measuring boards. Weights of individual fish are recorded on electronic scales and downloaded directly to the electronic boards. A fish identification number unique to each specimen is created as well as a batch number for a subsample from a specific trip.

Subsamples of a catch or batch are processed for sex information (gender and gonadal maturity or spawning condition index). Such subsamples are indexed by visual inspection (macroscopic) of the gonads. Females are indexed as gonadal stage I–V and males I–IV, with stage I representing an immature or resting stage of gonadal development and stages IV (males) and V (females) representing spent fish. Fish that cannot be accurately categorized in terms of spawning condition are not assigned a gonadal maturity stage.

Ancillary data for fish sampled at dealers are collected and include date harvested, harvest area, gear type used, and total catch (recorded if only a subsample was measured). This information would allow for expansion of the sample size to the total harvest reported for a species. Estimates of effort are not typically recorded by this program but can be extrapolated from mandatory harvest reports sent to the VMRC on a monthly basis by harvesters, sometime after a sampling event.

The numbers of Spotted Seatrout lengths sampled from commercial landings by the VMRC are summarized in Table 2.1.

North Carolina

Commercial length-frequency data were obtained by the NCDMF commercial fisheries-dependent sampling program. Spotted seatrout lengths are collected at local fish houses by gear, market grade, and area fished. Random samples of culled catches are taken to ensure adequate coverage of all species in the catches. Length frequencies obtained from a sample were expanded to the total catch using the total weights from the trip ticket. All expanded catches were then combined to describe a given commercial gear for a specified time period.

In cases where the weight of particular species' market grades was included on the trip ticket but were not sampled, an estimate of the number of fish landed for the grade was made by using the mean weight per individual from samples of that species and grade from the same year. Species numerical abundance was calculated by determining the number of individuals/market grade and then summing all the market grades for each species. Catches were analyzed by gear type (i.e., gill nets, seines, and other), month, year, and season (i.e., March–November and December–February).

The numbers of Spotted Seatrout lengths sampled from commercial landings by the NCDMF are summarized in Table 2.2.

2.1.1.4 Potential Biases & Uncertainty

Because trip tickets are only submitted when fish are transferred from fishermen to dealers, records of unsuccessful fishing trips are not available for both the VMRC and the NCDMF. As such, there is no direct information regarding trips where a species was targeted but not caught. Information on these unsuccessful trips is necessary for calculating a reliable index of relative abundance for use in stock assessments.

Another potential bias for NCDMF data relates to the reporting of multiple gears on a single trip ticket. It is not always possible to identify the gear used to catch a particular species on a trip ticket that lists multiple gears and species.

2.1.1.5 Development of Estimates

Annual commercial landings statistics were calculated by year and season (season 1: March 1–November 30, season 2: December 1–February 28/29) for both states combined and separately by state.

Length data were summarized in 40-mm length bins by year and season. Length data were pooled over states and summarized for the commercial fisheries.

2.1.1.6 Estimates of Commercial Landings Statistics

Between 1991 and 2019, total commercial landings for Virginia and North Carolina combined have ranged from 24 to 245.1 mt in season 1 and ranged from 11 to 145.1 mt in season 2 (Table 2.3; Figure 2.1). Annually (March through February), total commercial landings for both states combined have ranged from 38 to 335 mt. Commercial landings of Spotted Seatrout have been consistently higher for season 1 than season 2.

Commercial length-frequency data are summarized in Figures 2.2 and 2.3.

2.1.2 Commercial Discards

2.1.2.1 Survey Design and Methods

The Sea Turtle Bycatch Monitoring Program (Program 466) was designed to monitor bycatch in the North Carolina estuarine gill-net fishery, providing onboard observations to characterize effort, catch, and finfish bycatch by area and season. Additionally, this program monitors fisheries for protected species interactions. The onboard observer program requires the observer to ride onboard the commercial fishermen’s vessel and record detailed gill-net catch and discard information for all species encountered. Observers contact licensed commercial gill-net fishermen throughout the state in order to coordinate observed fishing trips.

2.1.2.2 Sampling Intensity

Trips are observed per management unit based on the average number of trips per month and management unit reported to the trip ticket program for the previous five-year period. Per the sea turtle incidental take permit (ITP; NMFS 2013, 2014), the division is required to observe a minimum of 7% (goal of 10%) of anchored large mesh gill-net trips and a minimum of 1% (goal of 2%) of anchored small mesh gill-net trips by management unit by season. The mesh size categories in the sea turtle ITP (large mesh >= 4-inch inside stretched mesh (ISM), small mesh <= 4-inch ISM) are different than the categories in the trip ticket program (large mesh >= 5-inch ISM, small mesh <= 5-inch ISM).

2.1.2.3 Biological Sampling

Data collected from each species include length, weight, and fate (landed, live discard, dead discard).

2.1.2.4 Potential Biases & Uncertainty

Program 466 began sampling statewide in May 2010. To provide optimal coverage throughout the state, management units were created to maintain proper coverage of the fisheries. Management units were delineated on the basis of four primary factors: similarity of fisheries and management; extent of known protected species interactions in commercial gill net fisheries; unit size; and the ability of the NCDMF to monitor fishing effort. Total effort for each management unit can vary annually based on fishery closures due to protected species interactions or other regulatory actions. Therefore, the number of trips and effort sampled each year by management unit varies both spatially and temporally.

Program 466 data do not span the entire time series for the assessment (no data are available for 1991–2000 and spatially limited data are available 2000–2003). Since 2004, observed trips were sparse for some seasons and management areas for several years despite widespread fishing effort. However, observations were likely adequate to determine whether discards in this fishery were a significant source of removals from the population. Observer data have been collected throughout the Pamlico Sound since 2000 and outside the Pamlico Sound since 2004. Data from 2000 to 2003 were not included due to spatial limitations.

Lastly, observed trips ideally would be random across fishery participants within each sampling stratum; however, participants avoid and occasionally refuse to take an observer. Although anecdotally small, the number of participants who are not observed has not been quantified.

2.1.2.5 Development of Estimates

A generalized linear model (GLM) framework was used to predict Spotted Seatrout discards in North Carolina's estuarine gill-net fishery based on data collected during 2004 through 2019. Only those variables available in all data sources were considered as potential covariates in the model. Available variables were fishing year, season, mesh category (large: ≥5 inches and small: <5 inches), and management unit, all of which were treated as categorical variables in the model. Effort was measured as soak time (days) multiplied by net length (yards). Live and dead discards were modeled separately.

All available covariates were included in the initial model and assessed for significance using the appropriate statistical test. Non-significant covariates were removed using backwards selection to find the best-fitting predictive model. The offset term was included in the model to account for differences in fishing effort among observations (Crawley 2007; Zuur et al. 2009, 2012). Using effort as an offset term in the model assumes the number of Spotted Seatrout discards is proportional to fishing effort (A. Zuur, Highland Statistics Ltd., personal communication).

The best-fitting model for live discards and for dead discards was applied to available effort data from the NCTTP to estimate the total number of live discards and dead discards for the estuarine gill-net fishery. A discard mortality rate of 30% (see section 1.2.6) was applied to the estimates of live discards to estimate those live discards that were not expected to survive. This number was added to the number of dead discards to estimate the total number of dead discards.

Length data were summarized by 2-cm length bins and year.

2.1.2.6 Estimates of Commercial Discard Statistics

The best-fitting GLM for the commercial gill-net live discards assumed a zero-inflated Poisson distribution (dispersion=3.1). The significant covariates for the count part of the model were year mesh and area while the significant covariates for the binomial part of the model were mesh and area. The best-fitting GLM for the dead discards assumed a zero-inflated Poisson distribution (dispersion = 1.4). The significant covariates for the count part of the model were year, season, and area while the significant covariates for the binomial part of the model were season, mesh, and area.

Estimates of dead commercial discards for North Carolina were variable for the gill-net estuarine fishery during 2004 through 2019 (Figure 2.4). Estimates were minimal compared to the magnitude of all fisheries overall. Though estimates of discards from Virginia were not available, they were assumed minimal as well.

Annual length-frequency distributions of commercial gill-net estuarine fishery discards are shown in Figures 2.5.

2.1.3 Recreational Fishery Monitoring

2.1.3.1 Survey Design and Methods

The Marine Recreational Information Program (MRIP) is designed to provide annual and bi-monthly estimates of marine recreational fisheries catch and effort data. Information on commercial fisheries has long been collected by the NMFS; however, data on marine recreational fisheries were not collected in a systematic manner by the NMFS until implementation of the Marine Recreational Fishery Statistics Survey (MRFSS) in 1979. The purpose of the MRFSS was to provide regional estimates of effort and catch from the recreational sector. Importantly, the National Research Council (NRC) identified under-coverage, inefficiency, and bias issues within the MRFSS survey and estimation methodologies (NRC 2006). These deficiencies spurred the development of the MRIP as an alternative data collection program to the MRFSS. The MRIP is a national program that uses several component surveys to obtain timely and accurate estimates of marine recreational fisheries catch and effort and provide reliable data to support stock assessment and fisheries management decisions. The program is reviewed periodically and undergoes modifications as needed to address changing management needs. A detailed overview of the program can be found online at https://www.fisheries.noaa.gov/topic/recreational-fishing-data.

The MRIP uses three complementary surveys: (1) the Fishing Effort Survey (FES), a mail survey of households to obtain trip information from private boat and shore-based anglers; (2) the For-Hire Telephone Effort Survey (FHTES) to obtain trip information from charter boat operators; and (3) the Access Point Angler Intercept Survey (APAIS), a survey of anglers at fishing access sites to obtain catch rates and species composition from all modes of fishing. The data from these surveys are combined to provide estimates of the total number of fish caught, released, and harvested; the weight of the harvest; the total number of trips; and the number of people participating in marine recreational fishing. In 2005, the MRIP began at-sea sampling of headboat (party boat) fishing trips.

The APAIS component was improved in 2013 to sample throughout the day (24-hour coverage) and remove any potential bias by controlling the movement of field staff to alternative sampling sites. The MRFSS allowed samplers to move from their assigned site to more active fishing locations but could not statistically account for this movement when calculating estimates. The MRIP implemented the FES in 2018 to replace the Coastal Household Telephone Survey (CHTS) due to concerns of under-coverage of the angling public, declining number of households using landline telephones, reduced response rates, and memory recall issues.

2.1.3.2 Sampling Intensity

Creel clerks collect intercept data year-round (in two-month waves) by interviewing anglers completing fishing trips in one of four fishing modes (man-made structures, beaches, private boats, and for-hire vessels). Intercept sampling is separated by wave, mode, and area fished. Sites are chosen for interviewing by randomly selecting from access sites that are weighted by estimates of expected fishing activity. The intent of the weighting procedure is to sample in a manner such that each angler trip has a representative probability of inclusion in the sample. Sampling is distributed among weekdays, weekends, and holidays. In North Carolina, strategies have been developed to distribute angler interviews in a manner to increase the likelihood of intercepting anglers landing species of management concern.

The FES mail survey employs a dual-frame design with non-overlapping frames (1) state residents are sampled from the United States Postal Service computerized delivery sequence file (CDS) and (2) non-residents are individuals who are licensed to fish in one of the target states but live in a different state and are sampled from state-specific lists of licensed saltwater anglers. Sampling from the CDS uses a stratified design in which households with licensed anglers are identified prior to data collection. The address frame for each state is stratified into coastal and non-coastal strata defined by geographic proximity to the coast. For each wave and stratum, a simple random sample of addresses is selected from the CDS and matched to addresses of anglers who are licensed to fish within their state of residence. Non-resident anglers are sampled directly from state license databases. The sample frame for each of the targeted states consists of unique household addresses that are not in the targeted state but have at least one person with a license to fish in the targeted state during the wave.

The FES mail survey collects fishing effort data for all household residents, including the number of saltwater fishing trips by fishing mode (shore and private boat). The FES is a self-administered mail survey, administered for six two-month reference waves annually. The initial survey mailing is sent one week prior to the end of the reference wave so that materials are received right at the end of that wave. This initial mailing is delivered by regular, first-class mail and includes a cover letter stating the purpose of the survey, a survey questionnaire, a post-paid return envelope, and a $2 cash incentive. One week after the initial mailing, a follow-up thank you and reminder postcard is mailed via regular first-class mail to all sampled addresses. For addresses that could be matched to a landline telephone number, an automated voice message is also delivered as a reminder to complete and return the questionnaire. Three weeks after the initial survey mailing, a final mailing is delivered to all addresses that have not yet responded to the survey.

2.1.3.3 Biological Sampling

Fish that are available during APAIS interviews for identification, enumeration, weighing, and measuring by the interviewers are called landings or Type A catch. Fish not brought ashore in whole form but used as bait, filleted, discarded dead, or are otherwise unavailable for inspection are called Type B1 catch. Finally, fish released alive are called Type B2 catch. Type A and Type B1 together comprise harvest, while all three types (A, B1, and B2) represent total catch. The APAIS interviewers routinely sample fish of Type A catch that are encountered. Fish discarded during the at-sea headboat survey are also sampled. The headboat survey is the only source of biological data characterizing discarded catch that are collected by the MRIP; however, this number has been negligible (0 Spotted Seatrout headboat discards between 2005 and 2019). The sampled fish are weighed to the nearest five one-hundredth (0.05) of a kilogram or the nearest tenth (0.10) of a kilogram (depending on scale used) and measured to the nearest millimeter for the centerline length. The numbers of Spotted Seatrout measured in Virginia and North Carolina by the MRIP are summarized in Table 2.4.

2.1.3.4 Potential Biases & Uncertainty

The MRIP was formerly known as the MRFSS. Past concerns regarding the timeliness and accuracy of the MRFSS program prompted the NMFS to request a thorough review of the methods used to collect and analyze marine recreational fisheries data. The NRC convened a committee to perform the review, which was completed in 2006 (NRC 2006). The review resulted in several recommendations for improving the effectiveness and use of sampling and estimation methods. In response to the recommendations, the NMFS initiated the MRIP, a program designed to improve the quality and accuracy of marine recreational fisheries data. The MRIP estimation method and sampling design for the APAIS were implemented in 2013, replacing MRFSS. In 2016, the NMFS requested that the NRC, now referred to as the National Academies of Sciences, perform a second review to evaluate how well and to what extent the NMFS has addressed the NRC's original recommendations (NASEM 2017). The review noted the impressive progress made since the earlier review and complimented the major improvements to the survey designs. The review also noted some remaining challenges and offered several recommendations to continue to improve the MRIP surveys. MRIP implemented the FES in 2018 to address the concerns of under-coverage of the angling public, declining number of households using landline telephones, reduced response rates, and memory recall issues of the CHTS.

2.1.3.5 Development of Estimates

The intercept and at-sea headboat data are used to estimate catch per trip for each species encountered. The estimated number of angler trips is multiplied by the estimated average catch per trip to calculate an estimate of total catch for each survey stratum.

Releases of seatrout genus (Spotted Seatrout and Weakfish) are sometimes recorded to the genus (*Cynoscion*) level in the MRIP. Releases are not observed by interviewers and some recreational fishermen are not able to report seatrout to the species level. To estimate the number of Spotted Seatrout released, the proportion of Spotted Seatrout estimated by MRIP as harvested (relative to other *Cynoscion* species) is applied to numbers of reported released *Cynoscion* spp. from the same wave (1–6), mode (type of fishing), and area (inshore vs. ocean). The number of recreational live releases was multiplied by a discard mortality of 10% (see section 1.2.6.2) to estimate the number of dead recreational discards.

The length data from the MRIP sampling of the Type A catch were expanded to total recreational harvest by wave/mode/area strata for each of the states by year and season. The length frequencies were then summed over the states by wave/mode/area strata to provide length frequencies by year and season for the recreational harvest.

2.1.3.6 Estimates of Recreational Fishery Statistics

Recreational harvest (Type A + B1) in terms of weight ranged from 164 to 1,769 mt in season 1 (Table 2.5; Figure 2.6) and from 1 to 716 mt in season 2 (Table 2.6; Figure 2.6) between 1991 and 2019. In terms of numbers, recreational harvest (Type A + B1) in season 1 (Table 2.5; Figure 2.7) has exceeded the recreational harvest in season 2 throughout the time series (Table 2.6; Figure 2.7). Estimates of live releases (Type B2) have increased in recent decades, especially in season 1 (Tables 2.5 and 2.6; Figure 2.8).

Annual length-frequency data for the recreational fishery are presented in Figures 2.9 and 2.10.

2.2 Fisheries-Independent

All the available fisheries-independent data come from North Carolina as there are currently no fisheries-independent sampling programs in Virginia that catch sufficient numbers of Spotted Seatrout to develop a reliable index.

2.2.1 Fisheries-Independent Gill-Net Survey (Program 915)

2.2.1.1 Survey Design and Methods

The Fisheries-Independent Gill-Net Survey, also known as Program 915 (P915), began on May 1, 2001 and originally included Hyde and Dare counties (Figure 2.11). In July 2003, sampling was expanded to include the Neuse, Pamlico, and Pungo rivers (Figure 2.12). Additional areas in the Southern District were added in April 2008 (New and Cape Fear rivers; Figure 2.13) and in the Central District in May 2018 (the White Oak River to Back Sound).

Floating gill nets are used to sample shallow strata while sink gill nets are fished in deep strata. Each net gang consists of 30-yard segments of 3-, 3.5-, 4-, 4.5-, 5-, 5.5-, 6-, and 6.5-inch stretched mesh, for a total of 240 yards of nets combined. Catches from an array of gill nets comprise a single sample; two samples (one shallow, one deep)—totaling 480 yards of gill net—are completed each trip. Gill nets are typically deployed within an hour of sunset and fished the following morning. Efforts are made to keep all soak times within 12 hours. All gill nets are constructed with a hanging ratio of 2:1. Nets constructed for shallow strata have a vertical height between 6 and 7 feet. Prior to 2005, nets constructed for deep and shallow strata were made with the same configurations. Beginning in 2005, all deepwater nets were constructed with a vertical height of approximately 10 feet. With this configuration, all gill nets were floating and fished the entire water column.

A stratified random sampling design is used, based on area and water depth. Each region is overlaid with a one-minute by one-minute grid system (equivalent to one square nautical mile) and delineated into shallow (<6 feet) and deep (>6 feet) strata using bathymetric data from NOAA navigational charts and field observations. Beginning in 2005, deep sets have been made along the 6-ft contour. Sampling in Pamlico Sound is divided into two regions: Region 1, which includes areas of eastern Pamlico Sound adjacent to the Outer Banks from southern Roanoke Island to the northern end of Portsmouth Island; and Region 2, which includes Hyde County bays from Stumpy Point Bay to Abel's Bay and adjacent areas of western Pamlico Sound. Each of the two regions is further segregated into four similar sized areas to ensure that samples are evenly distributed throughout each region. These are denoted by either Hyde or Dare and numbers 1 through 4. The Hyde areas are numbered south to north, while the Dare areas are numbered north to south. The rivers are divided into four areas in the Neuse River (Upper, Upper-Middle, Lower-Middle, and Lower), three areas in the Pamlico River (Upper, Middle, and Lower), and only one area for the Pungo River. The upper Neuse area was reduced to avoid damage to gear from obstructions, and the lower Neuse was expanded to increase coverage in the downstream area. The Pungo area was expanded to include a greater number of upstream sites where a more representative catch of Striped Bass (*Morone saxatilis*) may be acquired.

2.2.1.2 Sampling Intensity

Initially, sampling occurred during all 12 months of the year. In 2002, sampling from December 15 through February 14 was eliminated due to extremely low catches and unsafe working conditions. Sampling in the Pamlico, Pungo, and Neuse rivers did not begin until July 2003. Each of the sampling areas within each region is sampled twice a month. Within a month, a total of 32 samples are completed (eight areas × twice a month × two samples) in both the Pamlico Sound and the river systems.

2.2.1.3 Biological Sampling

All Spotted Seatrout are enumerated and an aggregate weight (nearest 0.01 kilogram (kg)) is obtained for each net (mesh size) fished. All individuals are measured to the nearest millimeter fork length (FL). Specimens are also retained and taken to the lab where age structures (otoliths) are removed, sex, and maturity stage of gonads are determined. The numbers of biological samples collected in Program 915 is summarized in Table 2.7.

2.2.1.4 Potential Biases & Uncertainty

Spotted seatrout are a target species in Program 915. The survey is designed to collect data of fish using estuarine habitats but nearshore ocean areas, which may be used by Spotted Seatrout, are not sampled. In addition, shallow creeks, which are often used by Spotted Seatrout as overwintering habitat and many deepwater areas of Pamlico Sound, potentially used for spawning, are not sampled in Program 915. Despite being used by Spotted Seatrout and being areas of high fishery activity, Albemarle Sound is not sampled. Ellis (2014) noted acoustic tagged Spotted Seatrout seemed to avoid anchored gill nets, indicating catchability of this species using Program 915 gear may be an issue.

While sample design has been largely consistent some adjustments have been made with the goal of reducing sea turtle interactions. In 2005, some deep water grids were dropped in Pamlico Sound, which may have some influence on deep relative abundance prior to this time period. Beginning in 2011, one area strata in eastern Pamlico Sound was not sampled for a three-month period from June through August to reduce sea turtle interactions. This change eliminated 16 samples per year. Excluding these samples from prior analysis had minimal impact on Spotted Seatrout relative abundance and variance.

2.2.1.5 Development of Estimates

Two indices of relative abundance, spring and fall, were developed from the Program 915 data from Pamlico Sound and the Neuse, Pamlico and Pungo rivers. The spring index was based on data from April through June. The fall index was based on data collected from September through November.

The indices were developed using a GLM approach to attempt to remove the impact of factors other than changes in abundance that may be affecting the indices (Maunder and Punt 2004). Because there was some variability in effort (soak time in hours) among hauls, effort was included as an offset variable in the GLM.

Length data were summarized by 40-mm length bins and year. Length data were summarized for each index; that is, they are based on collections from the same months of the associated index.

2.2.1.6 Estimates of Program 915 Survey Statistics

The spring standardized index was modeled using a zero-inflated negative binomial GLM (dispersion=1.0). Significant variables for the presence/absence (binomial) sub-model included depth, temperature, salinity, and distance from shore and the significant variables for the count sub-model included year, depth, temperature, salinity, dissolved oxygen, distance from shore, sediment size, and strata. The fall standardized index was modeled using a negative binomial GLM (dispersion=1.2). Significant variables included year, dissolved oxygen, sediment size, and strata.

The spring and fall standardized indices derived from Program 915 survey data for the northern region indicate a stable or increasing trend in relative abundance from 2003 to 2019 and the standardized indices do not differ dramatically from the nominal indices (Figure 2.14).

Annual length-frequency distributions for the Program 915 survey indices are shown in Figures 2.15 and 2.16.

3 ASSESSMENT

3.1 Overview

3.1.1 Scope

The unit stock for the current assessment is considered all Spotted Seatrout occurring within Virginia and North Carolina waters. The time period covered in this assessment is 1991–2019.

3.1.2 Summary of Methods

The current assessment is based on a seasonal, size-structured model. The model has a seasonal time step to account for seasonal biological processes and fishing patterns. The seasonal time-step may help capture the impact of cold stuns for Spotted Seatrout during cold winters. A size-structured model is used because: (1) size-based data are usually easier to obtain than age-based data and thus are associated with higher accuracy and less uncertainty; (2) management of most fisheries is based on size; and (3) use of a size-based model reduces the uncertainty introduced by age-size conversion during analysis (Quinn and Deriso 1999; Cao et al. 2017).

3.1.3 Current vs. Previous Method

The 2015 NCDMF Spotted Seatrout assessment (NCDMF 2015) used the Stock Synthesis (SS3) model and data collected from 1991 through 2012. The SS model is a length-based, age-structured model that accounts for sex-specific differences in mortality and growth. The model's inability to capture cold stun mortality was one of the major concerns from external peer reviewers in the previous assessment and thus, developing a customized model to account for variable natural mortalities was listed as a research recommendation with high priority. The seasonal, size-structured model was developed for the current assessment. Both the SS3 model and the seasonal size-structured model can incorporate information from multiple sources including fisheries, surveys, and a variety of biological datasets. Both assessments used only fisheries-independent surveys to derive relative abundance indices and used the maximum likelihood estimator through the Automatic Differentiation Model Builder (ADMB) to estimate parameters; however, unlike the previous assessment, this assessment model (1) used a seasonal time step instead of an annual time step to account for cold stun mortality of Spotted Seatrout during winter months; (2) the population dynamics were modeled by size structure instead of age structure; (3) the available data extended through 2019; (4) sexes were combined; (5) natural mortality and growth were assumed nonstationary; (6) the newly calibrated MRIP data were used for the recreational fishery, which are approximately three times the landings and discards used in the 2015 assessment.

3.2 Data Sources

This assessment included data from commercial and recreational fishing fleets that caught Spotted Seatrout in North Carolina and Virginia waters (Table 3.1). The model was fit to data on seasonal landings (in number), discards (in number), and length compositions. Two fisheries-independent indices of abundance and their associated length compositions were included, namely the Program 915 northern spring index (P915NorthSring, April–June, Pamlico Sound and rivers) and the Program 915 northern fall index (P915NorthFall, September–November, Pamlico Sound and rivers).

3.3 Seasonal, Size-Structured Model Configuration

The model developed in this stock assessment was adapted from a seasonal, size-structured model for northern shrimps (*Pandalus* spp.) developed by Cao et al. (2017). The model was coded in the ADMB (Fournier et al. 2012; http://admb-foundation.org).

3.3.1 Population Dynamics

In a size-structured model, the population dynamics of a stock are described in terms of the number of individuals at each size class over time (Sullivan et al. 1990; Cao et al. 2017). With a seasonal time step, the number of fish in size class *k* at the beginning of the season *t* in year *y* is calculated as:

$N_{k,t+1,y} = \sum_{k'} \left(G_{k',k} N_{k',t,y} exp\left(-M_{k',t,y} - \sum_f F_{f,k',t,y}\right)\right) + R_{k,t+1,y}$ for $t < T$ (growing to next season of the same year)

$N_{k,t'=1,y+1} = \sum_{k'} \left(G_{k',k} N_{k',t=T,y} exp\left(-M_{k',t=T,y} - \sum_f F_{f,k',t=T,y}\right)\right) + R_{k,t'=1,y+1}$ for $t = T$ (growing to next year)

where *t* and *t'* index the season, *y* indexes the year, *k* and *k'* index the size class, *f* indexes the fishing fleet, *N* is the population size, *T* is the maximum number of seasons, *G* is a growth transition matrix, $G_{k',k}$ represents the probability of surviving individuals in size class *k'* that grow to size class *k* during one time step (i.e., one season in a seasonal model), *M* and *F* are instantaneous mortalities, and *R* is the recruitment.

In this assessment, a model year began on March 1st and ended on February 28/29th of the following year. For example, the model year 1991 spanned from March 1st, 1991 to February 29th, 1992. Spawning of Spotted Seatrout in North Carolina and Virginia occurs in May–September and peaks in June–July. In the model, spawning was assumed to occur on June 1st. Each year was separated into two seasons, the non-winter season ($t = 1$) from March 1st to November 30th and the winter season ($t = 2$) from December 1st to February 28th/29th. The available length composition data used in this assessment contained lengths from 120 mm to 880 mm. Also, a von Bertalanffy growth model was fit externally using length-age data (section 1.2.4.1) and estimated a mean length of approximately 169 mm for recruits (age 0). Thus, in the model, 19 size classes were used ranging from 120 to 879.9 mm with a 40 mm size bin (i.e., 120–159.9 mm, 160–199.9 mm). The size bins covered in this assessment started at 120 mm to ensure the recruits were included and the length composition data were available for most of the size bins.

3.3.2 Growth

In the assessment model, individuals in a size class grew into the following size classes through a growth transition matrix. The growth transition matrix (*G*) can be determined by assuming growth follows the von Bertalanffy growth curve and the size increment for size class *k* (mm, ΔL_k) follows a normal distribution with mean $E(\Delta L_k)$ and variance $Var(\Delta L_k)$ (Chen et al. 2003; Cao et al. 2017):

$$E(\Delta L_k) = (L_\infty - L_k)\left(1 - exp(-a_t K)\right)$$

$$Var(\Delta L_k) = \sigma_{L\infty}^2\big(1 - exp(-a_t K)\big)^2 + {a_t}^2 (L_\infty - L_k)^2 \sigma_K^2 exp(-2a_t K)$$
$$+ 2\rho a_t \sigma_{L\infty} \sigma_K \big(1 - exp(-a_t K)\big)(L_\infty - L_k) exp(-a_t K)$$

where L_∞ is the asymptotic length (mm), K is the annual growth coefficient (yr^{-1}), ρ is the correlation coefficient between L_∞ and K, L_k is the mid-length of size class k, $\sigma_{L\infty}$ and σ_K are standard deviations of L_∞ and K respectively, and a_t is a scalar for partitioning the growth for season t within a year, where $0 \le a_t \le 1$. The probability of an individual growing from size class k to size class k' within one time step can be calculated as:

$$G_{k,k'} = \int_{k'_{low}}^{k'_{up}} f(x|E(\Delta L_k), Var(\Delta L_k))dx$$

where k'_{up} and k'_{low} are the upper and lower ends of size class k' and $f(.)$ denotes the probability density function of a normal distribution. Negative growth is not permitted and thus, $k' \ge k$ and $\sum_{k'} G_{k,k'} = 1$. The last size class is a plus group with all the individuals staying in the same size class and only subject to mortality.

In this assessment, the growth parameters L_∞ and K were assumed to vary over time and modeled using a random walk process:

$$L_{\infty,y+1} = L_{\infty,y} exp\big(LDev_{y+1}\big)$$
$$K_{y+1} = K_y exp\big(KDev_{y+1}\big)$$

where the growth parameters in year y+1 were determined by the parameters in the previous year y and a multiplicative deviation term in log space (*LDev* and *KDev*). We set $a_1 = 0.75$ and $a_2 = 0.25$ for non-winter season and winter season respectively.

3.3.3 Natural Mortality

Ellis (2014) and Ellis et al. (2018) have demonstrated increasingly high inter-annual variability in natural mortality during periods of cold stuns. Additionally, Ellis et al. (2017) showed high winter natural mortality associated with cold temperature. Thus, to account for the impact of cold stuns in this assessment, the natural mortality was assumed to be constant in the non-winter season but vary by year during the winter season. The natural mortality also varied by size during each season:

$$M_{k,t,y} = M_{t,y} w_k w_y$$

where w_k and w_y are size year scalars respectively and can be pre-specified. In the base model, we set $w_y = 1$ to allow the model to estimate the annual variability in the natural mortality. The size scalar can be determined based on the Lorenzen method (Lorenzen 1996). In this assessment, the Lorenzen M (M_k', in per year) was calculated based on weight (W, in g) with the parameters $M_u = 3.69$ and $d = -0.305$, which are values that were estimated for a wide range of ocean fishes (Lorenzen 1996):

$$M_k' = M_u W_k^d.$$

Then the calculated Lorenzen M values were divided by their average (Avg(M_k')) to generate the size scalar:

$$w_k = \frac{M_k'}{Avg(M_k')}$$

Such a size scalar would scale the Lorenzen *M* values to have an average that equals to the size-constant target natural mortality $M_{t,y}$. The seasonal natural mortality for a given year ($M_{t,y}$) was modeled with a mean ($\bar{M}$) and a deviation term ($MDev_y$):

$$M_{t,y} = \overline{M_t} exp\left(MDev_y\right)$$

where *MDev* is a multiplicative deviation term in log space. In this assessment, the natural mortality for the non-winter season was assumed a fixed constant input, whereas the natural mortality for the winter season was assumed to vary over time and estimated with a deviation. An annual natural mortality of 0.6 was used derived from a meta-analysis (Then et al. 2015; section 1.2.6.1) and then was split into the winter and non-winter seasons based on a ratio of 2:1. As a result, $M_{t=1,y} = \overline{M_{t=1}}$ = 0.2 and $\overline{M_{t=2}}$ = 0.4. Information on how to split the annual natural mortality into seasons were limited, and thus, we tested a series of splitting ratios ranging from 0.2 to 5 (the ratio of winter season relative to non-winter season). The ratio of 2:1 was selected because it produced the lowest total negative log-likelihood. Additionally, a tagging model that was fit externally using tag-recapture data (section 1.2.6.1) estimated a similar ratio (1.78:1).

3.3.4 Female Maturity, Sex Ratio, Fecundity, and Spawning Stock

Female maturity was modeled with a logistic function and the estimated maturity by size was treated as a fixed input to the model. The model was sex combined. The sex ratio was also treated as a fixed input to the model and assumed a 50% female proportion for the first eight size classes (120 mm–440 mm), 70% for the next four size classes (440 mm–600 mm), and 95% for the remaining size classes (600 mm–880 mm). Both female maturity and sex ratio were constant over time. In this assessment, the spawning stock biomass (SSB) was modeled as the population fecundity (number of eggs) and assumed to be equivalent to mature female biomass. Reproduction was assumed to occur once a year on June 1st.

3.3.5 Recruitment

Assuming the age-0 fish represent recruitment, the size-specific seasonal recruitment $R_{k,t,y}$ was modeled as the product of annual recruitment (R_y) and the proportion of R_y that recruits to each season (π_t) and each size (π'_k):

$$R_{k,t,y} = R_y \pi_t \pi'_k.$$

In the base model, $\pi_{t=1}$ = 1 and $\pi_{t=2}$ = 0 because spawning was assumed to only occur in the non-winter season. It was also assumed the fish would recruit to the first seven size classes with the proportion $\pi_{k=1}$ =0.06, $\pi_{k=2}$ =0.11, $\pi_{k=3}$ =0.17, $\pi_{k=4}$ =0.21, $\pi_{k=5}$ =0.20, $\pi_{k=6}$ =0.16, and $\pi_{k=7}$ =0.09, according to the estimates from the von Bertalanffy growth model that was fit externally using length-age data (section 1.2.4.1). These proportions were fixed inputs and assumed constant over time. Recruitment is often driven by environmental factors and spawner abundance often only explains a small amount of the high variation in recruitment. Thus, in the model, the annual recruitment R_y was directly estimated with a deviation term to avoid assuming a fixed spawner-recruitment relationship:

$$R_y = \bar{R} exp\left(RDev_y\right)$$

where *RDev* is a multiplicative deviation term in log space, and its standard deviation was fixed at a value of 0.38 from a meta-analysis (R package FishLife; Thorson et al. 2017).

3.3.6 Landings

Time series (by season) of landings from two fleets were modeled, including the commercial landing fleet and the recreational harvest fleet. Landings were fit in number and were modeled with the Baranov catch equation (Baranov 1918):

$$C_{f,k,t,y} = \frac{F_{f,k,t,y}}{M_{k,t,y} + \sum_f F_{f,k,t,y}} \left(1 - exp\left(-M_{k,t,y} - \sum\nolimits_f F_{f,k,t,y}\right)\right) N_{k,t,y}$$

$$C_{f,t,y}^{pred} = \sum\nolimits_k C_{f,k,t,y}$$

where C is landings. The landings from North Carolina and Virginia were combined for each fleet.

3.3.7 Discards

In this assessment, discards from the commercial and recreational fisheries were modeled as separate fleets, and thus, a total of two discard fleets were included, namely the commercial discard fleet and the recreational discard fleet. The discard fleets accounted for only the dead discards. Commercial discard data were available starting in 2004 for North Carolina (section 2.1.2); commercial discard data were unavailable for Virginia. The recreational fishery data only report those fish that were released, and thus a 10% post-release mortality rate was applied to calculate the dead discards from the recreational discard fleet for North Carolina and Virginia (section 2.1.3). As with landings, the discards were fit in number to the time series (by season) of discards and were modeled with the Baranov catch equation, and the data from North Carolina and Virginia were combined for each fleet.

3.3.8 Fishing Mortality

For each time series of removals (landings and discards), a separate full seasonal fishing mortality ($F_{f,t,y}$) was estimated. The size-specific fishing mortality ($F_{f,k,t,y}$) was then calculated by multiplying the full seasonal fishing mortality with the corresponding fishery selectivity ($S_{f,b,k}$) for each fleet f, time block b (if applicable), and size class k:

$$F_{f,k,t,y} = F_{f,t,y} S_{f,b,k} \ .$$

In this assessment, the annual fishing mortality was represented by the sum of the fishing mortalities across fleets and seasons.

3.3.9 Abundance Index

The model was fit to two NCDMF indices of relative abundance from the Program 915 fisheries-independent survey, the P915NorthSpring and P915NorthFall indices. Both abundance indices were standardized using a generalized linear model (GLM) approach before being input to the model (Maunder and Punt 2004; section 2.2.1.6). The standardization attempts to reduce the impact of other factors, especially environmental factors on the trend of the index timeseries. Predicted indices (I) were conditional on the selectivity of the surveys (S^{survey}) and were computed from abundance (number of fish) at the midpoint of the survey time period ($N_{i,k,y}^{survey}$):

$$I_{i,y}^{pred} = q_i \sum\nolimits_k \left(N_{i,k,y}^{survey} S_{i,k}^{survey}\right)$$

$$N_{i,k,y}^{survey} = N_{k,y} exp\left(\frac{month_i}{12}\left(\sum\nolimits_t \left(-M_{k,t,y} - \sum\nolimits_f F_{f,k,t,y}\right)\right)\right)$$

where q is the survey catchability and i indexes the ith abundance index.

3.3.10 Catchability

In the model, the catchability scales the abundance index to the estimated population abundance, conditional on the survey selectivity. In this assessment, catchability (q) was assumed to be time-invariant for each survey and all abundance indices were assumed to have a linear relationship to the population abundance. The survey catchability was calculated internally as follows:

$$ln(q_i) = \frac{1}{n_y}\sum\nolimits_y ln\left(\frac{I_{i,y}^{obs}}{\sum_k N_{i,k,y}^{survey} S_{i,k}^{survey}}\right)$$

where n_y is the total number of years in assessment time period and $I_{i,y}^{obs}$ is the observed abundance index in year y for survey i.

3.3.11 Selectivity

An asymptotic shaped selectivity was assumed for landing fleets and a dome-shaped selectivity was assumed for discard fleets. The asymptotic-shaped selectivity was modeled using a two-parameter logistic curve and the dome-shaped selectivity was modeled using a six-parameter double-normal curve (Methot and Wetzel 2013).

The minimum size limit for Spotted Seatrout in Virginia has been 14 inches since 1992. The minimum size limit in North Carolina was changed from 12 inches (304.8 mm) to 14 inches (355.6 mm) starting in 2009; however, the length compositions show minimal shift associated with the increase of size limit in 2009. Thus, in the base model, the selectivities of commercial and recreational landing fleets were assumed time-invariant. A model with two time blocks (1991–2008; 2009–2019) for fleet selectivities was included in a sensitivity analysis.

The selectivities of commercial and recreational discard fleets could not be freely estimated because no length composition data were input to the model. Therefore, the selectivities for the two discard fleets were estimated externally and treated as fixed inputs in the model. The selectivity of the commercial discard fleet was estimated based on a length composition from the NCDMF observer data, and the selectivity of the recreational discard fleet was estimated based on a NCDMF tagging study and expert opinions. The selectivities for the winter season mirrored those for the non-winter season, except for the parameter of the first peak in the double normal curve. The value of this parameter for the winter season selectivities was set at a length 15 mm larger than the value for the non-winter season selectivities based on the length information from the observer data.

The selectivity of P915NorthSpring and P915NorthFall surveys were assumed to be asymptotic shaped and time-invariant. Both selectivities were modeled using a logistic function.

3.3.12 Length Composition

The model was fit to four length composition time series (by season), including the length compositions from commercial and recreational landings, and the length compositions from

P915NorthSpring and P915NorthFall surveys. There were no length composition data input for discards fleets.

3.3.13 Initialization

Initial (1991) numbers at size ($N_{k,t=1,y=1}$) were estimated in the model assuming the proportions at size (Pas_k) follows a mixture distribution with three normal distributions (f_1, f_2 and f_3) to account for multiple peaks:

$$N_{k,t=1,y=1} = N_{y=1}Pas_k$$

$$Pas_k = \emptyset_1 f_1(L_k) + \emptyset_2 f_2(L_k) + \emptyset_3 f_3(L_k)$$

where $\emptyset_1 + \emptyset_2 + \emptyset_3 = 1$, and the three normal distributions have different means and variances.

3.3.14 Optimization

Model parameters were estimated using a penalized likelihood approach. In the penalized likelihood approach, each data component is assumed to have an error distribution and each observation is assigned a variance so that the observed removals (landings and discards) are fit closely and the observed compositions and abundance indices are fit to a compatible degree. The objective function is the sum of individual log-likelihood components. In this assessment, removals and abundance indices were fit assuming lognormal likelihood. Landings were assumed precise and assigned a minimal observation error with coefficient of variation (CV) = 0.05 for commercial landings and CV = 0.10 for recreational landings. The discards were assigned a larger observation error, with CV = 0.25 for both commercial and recreational discards. The CVs for abundance indices were estimated from the GLM standardization. Length compositions were fit assuming multinomial likelihood with variance described by the effective sample size. For length compositions, the effective sample size for each fleet and survey was the number of sampled trips and a maximum of 200 was imposed to prevent overfitting to composition data.

The deviations (log-scale) for natural mortality of winter season, recruitment, and growth (L_∞ and K) were modeled assuming normal likelihood with a mean of zero. Normal priors with a CV of 0.15 were applied for growth parameters (L_∞, K, $\sigma_{L\infty}$ and σ_K) to prevent the gradient-based parameter search routine from drifting into parameter space that yields negligible changes in the likelihood. The means of these normal priors were from the von Bertalanffy growth model that was fit externally using length-age data (section 1.2.4.1).

In the objective function, weight can be assigned to each likelihood component to account for data quality. All likelihood components were initially assigned a weight equivalent to one.

3.4 Diagnostics

Multiple measures were applied to assess the model convergence. The Hessian matrix (i.e., matrix of second derivatives of the likelihood with respect to the parameters) was checked to ensure it inverted. The model convergence level was checked to ensure it was less than the convergence criteria (0.0001, common default value). Parameters with estimated values hitting bounds or with excessively high variance (PSE > 50%) were identified. The correlation matrix was evaluated to detect high correlations between parameter estimates. A jitter analysis was performed to evaluate whether the model converged on a global solution (Cass-Calay et al. 2014). In the jitter analysis, initial values for all estimated parameters were randomly jittered by 10% for 100 runs. The total likelihood value, annual estimates of spawning stock biomass and fishing mortality, and stock status (see section 4) from the jitter runs were compared to the base run results.

The model fits were evaluated by comparing the estimates of landings, discards, abundance indices, and length compositions to the observed values via visual inspection. For the fits to the abundance indices, the residuals were calculated and then tested for randomness and normality. The runs test was applied to evaluate whether the residuals are randomly distributed (runs.test function; R Core Team 2021), and the Shapiro-Wilk test was applied to determine whether the residuals are normally distributed (shapiro.test function; R Core Team 2021). A significance level of 0.05 was used for both tests.

A retrospective analysis was also performed to evaluate the consistency of estimates over time, and how recent data changed the perspective of the past (Mohn 1999; Harley and Maunder 2003). Specifically, it evaluates systematic changes in the annual estimates as additional years of data were added (Mohn 1999). The analysis is run by peeling back (removing) one year of data from the end of the time series. The retrospective patterns would not be considered concerning if they are random and do not show a clear bias in any direction. The retrospective error (Mohn's ρ) is used to describe the degree of retrospectivity and is calculated as follows (Mohn 1999; Hurtado-Ferro et al. 2015):

$$\text{Mohn's } \rho = \frac{1}{n_{peel}} \sum_{t=terminal\ year-n_{peel}}^{terminal\ year} \frac{X_t|data\ to\ year\ t - X_t|data\ to\ terminal\ year}{X_t|data\ to\ terminal\ year}$$

where X is the variable of interest and n_{peel} is the total number of years that are "peeled off". Hurtado-Ferro et al. (2015) suggested a range between -0.22 and 0.3 for short-lived species; any values falling outside this range would indicate a concerning retrospective pattern. A positive value of Mohn's ρ for biomass and a negative value for fishing mortality may imply consistent overestimation of biomass and high risk of overfishing. Retrospective patterns may either result from inconsistent or insufficient data or result from natural variation in population dynamics. In this assessment, the base model was run with one year of data removed at a time starting from 2019 until the terminal year reached 2014 ($n_{\text{peel}} = 5$). The estimates of annual fishing mortality and spawning stock biomass (X) were evaluated from each retrospective run. Additionally, a series of sensitivity runs were also developed to explore the robustness of the model to some key model inputs and assumptions (See section 3.6).

3.5 Base Run Configuration

The base run was configured as described above. Uncertainties in point estimates were investigated through sensitivity analyses.

3.6 Sensitivity Analyses

Sensitivity of model outcomes to some key model inputs and assumptions were explored through sensitivity analyses (Table 3.2). Annual estimates of spawning stock biomass, fishing mortality, and recruits were compared to those from the base run.

3.6.1 Data Sources

The contributions of different fisheries-independent surveys were explored by removing the data from each survey one at a time. In each of these runs, the abundance index and length composition data (if applicable) from the survey under evaluation were removed by assigning a lambda weight of 0.0 to their likelihood components.

3.6.2 Initial Year

In the base model, the initial year was set to 1991 when the landing data started; however, the abundance index data were not available until 2003. With no abundance index data extending back to the initial year, the estimates for the early time period, especially the initial year, could become highly dynamic and uncertain. To examine the impact of the initial year on model outcomes, a sensitivity run with 2003 as the initial year was conducted.

3.6.3 Natural Mortality

In the base model, the annual average natural mortality was set to 0.6 based on a meta-analysis. Additionally, two sensitivity runs were performed to explore the impact of the annual average natural mortality on model outcomes, one run with a lower value of 0.4 and the other with a higher value of 0.8. A ratio of 2:1, the same as in the base model, was used to split this annual average natural mortality to the seasonal average natural mortalities for the winter and non-winter seasons in these two sensitivity runs.

3.6.4 Recreational Discards for Non-Winter Season 2018

In the base model, the input value for recreational discards in Season 1 (non-winter season) of 2018 was 1,863.527 thousands of fish. This input value was the highest across the whole assessment time period and approximately three times higher than the average (521.951 thousands of fish) discards within the previous five years (2013–2017). Removal from the recreational fishery dominates the total removal from the Spotted Seatrout stock. The input for 2018 may have affected the estimates for the terminal year 2019 and therefore its stock status determination. Thus, this extremely high input value for 2018 raised concerns over its impacts on model outcomes. A sensitivity run with a lower input value that equaled to 521.951 thousands of fish was conducted.

3.6.5 Time Block Fleet Selectivity

In the base model, no time blocks were set up for fleet selectivity due to no substantial shift in observed size distribution after the minimum size limit was changed in North Carolina in 2009. A sensitivity run with two time blocks was conducted to explore the impacts of time blocks on model outcomes. In the sensitivity run, for each fleet in a given season, its selectivity had two time blocks, i.e., the time block 1991–2008 during which the minimum size limit in North Carolina was 12 inches (304.8 mm) and the time block 2009–2019 during which the minimum size limit in North Carolina increased to 14 inches (355.6 mm). The same as in the base model, all selectivity parameters for landing fleets were free parameters to estimate, and all those for discard fleets were fixed input. The parameter setup for the first time block was the same as in the base model for the fleet in a given season. The parameter setup for the second time block was the same as the first time block except that the parameter controlling the location of the selectivity curve was increased by 50 mm to reflect the increase in minimum size limit. These parameters included the parameter for the length at 50% selection of a logistic curve for landing fleets and the parameter for the first peak of a double-normal curve for discard fleets.

3.7 Results

3.7.1 Base Model—Diagnostics

The base model was considered converged given an inverted Hessian matrix, no parameters hitting bounds or with excessively high variance, no high correlation between parameters, and a reasonably small convergence level of 0.0094. Although this convergence level was higher than the commonly used criteria (0.0001), a value less than one is typically deemed acceptable for such complex models with hundreds of parameters to estimate. Eighty-eight of the 100 jitter runs successfully converged. None of the converged jitter runs resulted in a total negative log-likelihood value that was significantly lower than the base model (Figure 3.1). Although 14 of the 100 jitter runs produced a slightly lower total negative log-likelihood value than the base model, the difference was less than three and thus was not considered statistically significant. This difference in the total negative log-likelihood values was contributed by a slightly better fit to the length compositions of the commercial and recreational landing fleets from these 14 runs. Most of the converged jitter runs predicted similar trends in SSB and F to the base model (Figure 3.2). Overall, the jitter analysis provides evidence that the base model converged to the global solution.

The base model fit the landings and discards well (Figures 3.3–3.6). The fits to the fisheries-independent survey indices were reasonable (Figures 3.7 and 3.8). The predicted indices captured the overall trends in the observed data. The runs test and the Shapiro-Wilk test on the residuals (log-scale) produced non-significant P-values for both P915NorthSpring and P915NorthFall indices at a significance level of 0.05 (Table 3.3). These results suggested the residuals were randomly distributed with no statistically significant temporal patterns or departures from a normal distribution.

The fits to the length compositions were reasonable for most of the fleets and surveys except for RecLanding Season 2 (Figures 3.9–3.14). The fits to the length compositions in individual years appeared reasonable for most of the years. The poor fits to the length compositions for RecLanding Season 2 and for some years in other fleets and surveys were likely due, in part, to the small effective sample size.

3.7.2 Base Model—Predicted Population Dynamics

The predicted selectivities for the landing fleets and the surveys were considered reasonable (Figures 3.15 and 3.16, 3.19 and 3.20). The selectivities for the discard fleets were fixed inputs (Figures 3.17 and 3.18). Overall, fish of the same size were more likely to be selected in Season 1 than Season 2 for most fleets except the recreational landing fleet. The fish smaller than 360 mm were more likely to be caught in Season 2 than Season 1.

Model predictions of annual fishing mortality showed a declining trend over time (Figure 3.21). The predicted fishing mortality was higher and more variable from 1991 through 2004. During this time period, a sharp decrease in fishing mortality estimates occurred in 1998. After 2004, the fishing mortality estimates decreased to a lower level with less variability compared to the earlier time period. An increase in fishing mortality was predicted for the terminal year 2019 with large uncertainty.

The size-averaged natural mortality estimates for the winter season showed great inter-annual variability (Figure 3.22). The model predicted high or rising winter natural mortality in years 1991, 1995, 1999–2000, 2002, 2006–2007, 2009–2010, 2013–2014, 2017, and 2019. This annual trend captured most of the identified cold-stun years except one year (2004). The size-specific natural mortality for individual years showed the winter season had higher natural mortality than the non-winter season and this seasonal difference became more evident for smaller fish (Figure 3.23).

The annual predicted recruitment varied among years and showed a general increasing trend over the assessment time period (Figure 3.24). The predicted recruitment was higher and more variable during the time period after 2004 (2005–2019). The annual predicted spawning stock biomass showed a general increasing trend over the assessment time period (Figure 3.25). Similar to recruitment, higher spawning stock biomass with greater variation was predicted for the time period after 2004. The predicted abundance also demonstrated strong year classes and high abundances through the years after 2004 (Figure 3.26).

The model predicted growth parameters varied moderately among years (Figures 3.27 and 3.28). The predicted L_∞ remained around 1,000 mm. The predicted K averaged around 0.2 with a slow decrease over time. Seasonal growth for individual years showed growth mostly occurred in the non-winter season and the difference in growth between seasons became more evident for smaller fish (Figure 3.29).

3.7.3 Retrospective Analysis

Retrospective analysis showed terminal year fishing mortality was consistently overestimated and terminal year spawning stock biomass was consistently underestimated (Table 3.4; Figure 3.30). The relative bias in terminal year fishing mortality and spawning stock biomass was low when peeling back to 2014, substantially increased when peeling back to 2015– 2017, and became larger when peeling back to 2018. Adding 2019 data seemed to have an essential impact on the predicted fishing mortality and spawning stock biomass, especially during the most recent five years (2015–2019). With 2019 data added, the fishing mortality estimates during 2015–2019 were substantially lowered and the spawning stock biomass estimates during this time period were greatly elevated. The Mohn's ρ values for fishing mortality and spawning stock biomass were 0.762 and -0.284, respectively. Both values are outside the recommended range of -0.22 to 0.3 for short-lived species and suggest a strong retrospective pattern.

3.7.4 Sensitivity Analyses

Removal of either P915NorthFall or P915NorthSpring survey data had minimal impact on predicted fishing mortality, spawning stock biomass, and recruitment (Figure 3.31). Initializing the base model from year 2003 when the survey data become available yielded higher fishing mortality estimates and lower spawning stock biomass estimates during 2004–2010 compared to the base model (Figure 3.32). Otherwise, the predicted fishing mortality and spawning stock biomass after 2010 and the predicted recruitment during the assessment period from this scenario were quite similar to those from the base model.

Changes in natural mortality led to similar trends in outcomes to the base model (Figure 3.33). Increased natural mortality led to lower fishing mortality estimates and higher spawning stock biomass and recruitment estimates.

Overall, a low input value of 2018 Season 1 recreational discards produced almost identical trends in outcomes compared to the base model (Figure 3.34). The predicted fishing mortality during 1999–2002 declined in this scenario compared to an increased trend in the base model.

This discrepancy was likely contributed by the difference in the trends of growth estimates during this time period between this scenario and the base model.

When two time blocks were set up for fleet selectivity, similar trends in outcomes were produced compared to the base model (Figure 3.35). The time block selectivity assumption led to lower fishing mortality estimates than the base model for the time period before 2009 and for the terminal year of 2019. The predicted fishing mortality during 2009–2018 from this scenario was almost identical to that from the base model. The time block selectivity assumption also resulted in higher spawning stock biomass estimates and slightly higher recruitment estimates during the entire assessment period.

3.8 Discussion of Results

Performance of the stock assessment model was considered reasonable in terms of predicting the observed data. The quality of the fits strongly depends on data quality that is reflected by the input variance and effective sample size. The fits to the observed landing and discard data were better than the fits to the survey indices, which was expected given the lower variance assumed for these data sources. The P915NorthFall index was fit better than the P915NorthSpring index due to its 33% smaller variance input on average. The model outcomes were insensitive to the removal of either survey's data, suggesting these two data sources share consistent information. The stock status determination for the terminal year was insensitive to the removal of either survey's data.

The stock assessment model was able to capture the signal from cold-stun events, which was a major concern from both the 2009 and 2015 NCDMF stock assessments and has been one of the major interests for this assessment. Without specifying cold-stun years as inputs in the model, the predicted natural mortality for the winter season was able to track the cold-stun signals for most years. The assumptions regarding the seasonal time step and nonstationary biological processes were essential to allow for the estimation of variation in winter natural mortality in this assessment. This type of modeling practice has not been successfully attempted in the previous assessments of this species or other state-managed species. This model can be easily applied to other species that experience strong seasonal dynamics in fishing and biological processes.

Developing an assessment model that can capture the cold-stun signal was a major interest in this assessment and thus, an extensive effort was attempted to explore alternative approaches. One of the approaches was to directly input the natural mortality estimates from a tagging model. The tagging model was fit externally to the tag-recapture data collected by North Carolina State University (NCSU) and NCDMF from 2008 to 2019. The tagging model was fit using a Bayesian approach and a three-month time step. Several attempts were made to incorporate the tagging model estimates including having tagging estimates as fixed input, incorporating tagging estimates as an environmental factor to guide the estimation of natural mortality deviation, and using tagging estimates to inform the seasonal average natural mortality; however, these attempts were unsuccessful. In these attempts, the assessment model yielded either unrealistic population estimates (e.g., extremely high L_∞ or K) or a collapsed population, which indicated there was conflicting information in the input or the assumptions. Natural mortality estimates for the winter season from the tagging model were extremely variable interannually and had large uncertainty, ranging from 0.002 to 2.346 with an average of 0.9 and a standard deviation of 0.9. These three-month estimates were also extremely high when compared to an annual scale estimate of 0.6 from a meta-analysis for this species. Given such high values of natural mortality and high variability, the population in the model would be difficult to sustain.

The tagging model and this assessment model have different assumptions and use different data sources. For example, the tagging data for Spotted Seatrout covered less than half of the whole assessment time period and only involved fish of certain sizes (280 mm–760 mm). Therefore, the estimated trends from these two types of models may be more comparable than their absolute values. The trends in the winter natural mortality from these two models were consistent. Given that tagging data could provide valuable auxiliary information in stock assessments, future effort may focus on integrating the tagging model as a sub-model into the stock assessment model so that both tagging data and assessment data can inform the population dynamics at the same scale in a coherent system.

Other approaches explored with an attempt to model cold-stun events was to use winter water temperature (cumulative degree days below 5ºC, CDD). One approach was to directly use the CDD as an environmental factor to guide the estimation of natural mortality deviation. Another approach was to predict the natural mortality value for a given winter water temperature based on a linear regression relationship developed by Ellis et al. (2017a) and then use these predicted values as fixed input in the model. These approaches predicted extremely variable and high values of natural mortality and suffered the same problem as with the tagging estimates. Predicting natural mortality solely based on water temperature may not be appropriate because the natural mortality in the model is often a result of a combination of multiple factors, among which cold winter temperature is only one single factor. Other factors may include predation, intra- and inter-species competition, resource availability, habitat quality, and environmental stochasticity such as hurricanes and salinity change. Also, the severity of cold-stun events is variable with some affecting large geographic range and others being more localized and acute (within 24 hours), and thus its impact at population level and annual time scale is still largely unknown and likely variable.

Due to different model structure, assumptions, and data input, it is not possible to compare results from this assessment with the 2015 assessment. The recreational harvest and discards input in this assessment were three times higher than those in the 2015 assessment due to the new MRIP calibration process. Regardless of the differences between these two assessments, the stock status determination for 2012—the terminal year in 2015 assessment—was consistent. The 2012 stock was not overfished, and overfishing was not occurring, but was approaching the threshold.

Trends in predicted fishing mortality, recruitment, spawning stock biomass, and abundance showed a shift in population dynamics around the year of 2004 when the index survey data became available. For example, the fishing mortality shifted from a high level during a time period around 1991–2004 to a low level during a time period around 2005–2019. In this assessment, the model was informed by both fishery and survey data after 2003, before which the model was probably heavily informed by the fishery data only. The fishery data in this assessment, especially the discard data and the recreational landing data, showed such a shift corresponding to the shift in these model results.

Among numerous sensitivity runs, including those in this report, stock status for the terminal year consistently indicates that overfishing is occurring. Although the stock status of being not overfished was determined in most of sensitivity runs, there were a few scenarios suggesting the opposite. For example, in the scenario with initial year of 2003 (Ini2003), the terminal year stock was determined overfished, although the 2019 spawning stock biomass estimate (2,475.647 metric tons) was fairly close to the threshold (2,701.429 metric tons). In the base model, a longer time series of landing and discard data were used, and these data showed a shift around 2004 as discussed above. Excluding these fishery data during the early time period in the Ini2003 scenario led to the data time series being lack of contrast and the model being incapable of capturing the potential shift in population dynamics, and further resulted in different outcomes (e.g., difference in estimated growth, fishing mortality, spawning stock biomass, and stock status).

Although the retrospective analysis in this assessment showed strong retrospective patterns in the predicted fishing mortality and spawning stock biomass, it is less concerning in terms of management risk in this assessment. Based on the results, this assessment model was consistently overestimating fishing mortality and underestimating spawning stock biomass. Thus, theoretically, a lower estimate of fishing mortality and a higher estimate of spawning stock biomass would be expected for 2019 after adding future data, and the management based on this assessment would be more conservative. Management risk caused by strong retrospective patterns has often been more of a concern in cases where the assessment model is consistently underestimating fishing mortality and overestimating spawning stock biomass. In these cases, the stock is most likely to collapse and least likely to meet the management goals if management practices are made based on the results without adjustment for the retrospective patterns (Huynh et al. 2022). Various approaches have been proposed to inform management decisions when strong retrospective patterns emerge in stock assessment, such as the model averaging (Stewart and Hicks 2018) and the adjustment for Mohn's ρ (Miller and Legault 2017); however, the performances of these approaches are mixed on a case-by-case basis (Huynh et al. 2022). Identifying causes of retrospective patterns is challenging due to multiple confounding factors (e.g., nonstationary processes and selectivity assumptions) and insufficient data (Legault 2020; Huynh et al. 2022). The strong retrospective patterns in this assessment were likely partially caused by 2019 data. Before adding 2019 data, the relative biases in the predicted fishing mortality and spawning stock biomass from the other retrospective runs were quite small. The input data showed the recreational harvest for 2019 were historically the highest, and the abundance index values for 2019 were also among the highest values. Given that this fishery is heavily dominated by recreational fishing, such high input values for the 2019 recreational fishery may have led to the high estimate of spawning stock biomass in 2019 even though the stock is undergoing overfishing.

In this type of seasonal, size-structured model, the model behaviors might be complicated by the interaction among the nonstationary natural mortality, the nonstationary growth, size-based selectivity, and the interaction in the dynamics between seasons. Exploratory runs indicate the model could become more robust and predictable with the estimation of growth parameters stabilized and less variable. In this assessment, a small value of 0.04 was selected for the standard deviation of the annual deviation of the time-varying growth parameters through a likelihood profiling, in which a series of values ranging from 0.01 to 0.2 were tested. With such a small value, the estimated growth patterns were able to vary over time while still remaining within a biological meaningful range and make scenarios more comparable.

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 North Carolina Spotted Seatrout FMP defines the stock's thresholds in terms of 20% spawning potential ratio (SPR; NCDMF 2012b). Targets for the stock are based on 30% SPR. These reference points were adopted in this assessment. The base model was used to estimate reference points and to determine the stock status for the stock. The stock is overfished if $SSB/SSB_{20\%}$ is less than one, and overfishing is occurring if $F/F_{20\%}$ is greater than one. In this assessment, the benchmarks are conditional on the estimated selectivity patterns and biological parameters. The selectivity pattern used here was the average selectivity at size across fleets.

Due to the large uncertainty in the terminal year (2019) estimates in this assessment, a weighted average of the estimates over the most recent three years (2017–2019) was used to best represent the terminal year estimate for determination of stock status. The estimates of 2017–2019 from the base model were weighted by the inverse of their CV values before calculating the average. The threshold and target values for the terminal year were also averaged over 2017–2019. The resulting estimated F threshold, $F_{20\%}$, and the F target, $F_{30\%}$, were 0.60 and 0.38 respectively, and the estimated terminal year F was 0.75 (all based on 2017–2019 averages). Thus, the estimated $F/F_{20\%}$ for the terminal year is greater than one (1.3), suggesting the stock is currently experiencing overfishing (Figures 4.1 and 4.2). The stock has been centering around the overfishing threshold from 2007 through 2019. In the base model, the estimated SSB threshold ($SSB_{20\%}$) and the SSB target ($SSB_{30\%}$) for the terminal year (based on 2017–2019 averages) were 1,143 and 1,714 metric tons respectively, and the estimated terminal year SSB was 2,259 metric tons (based on 2017–2019 average). Therefore, the estimated $SSB/SSB_{20\%}$ for the terminal year is greater than one (2.0), suggesting the stock is not currently overfished. The stock has not been overfished since 2007. Overall, results showed the stock had consistently been overfished and overfishing had been occurring until 2007 and has greatly improved since then.

5 SUITABILITY FOR MANAGEMENT

Stocks assessments performed by the NCDMF in support of management plans are subject to an extensive review process. External reviews are designed to provide an independent peer review and are conducted by experts in stock assessment science and experts in the biology and ecology of the species. The goal of the external review is to ensure the results are based on sound science and provide a valid basis for management.

The review workshop allows for discussion between the working group and review panel, enabling the reviewers to ask for and receive timely updates to the models as they evaluate the sensitivity of the results to different model assumptions. The workshop also allows the public to observe the peer review process and better understand the development of stock assessments.

The external peer review panel met with the working group in person August 30–September 1, 2022. The external peer review panel recommended the base model (i.e., the seasonal size-structured model) as the best scientific information available and suitable for management advice for the next five years. The reviewers agreed the determination of the spotted seatrout stock status concurs with professional opinion and observations and suggested using an average of the most recent three years as the best representation of the terminal-year estimates for fishing mortality and spawning stock biomass. The reviewers also agreed that: (1) the justification of inclusion and exclusion of data sources are appropriate; (2) the data sources used in this assessment are appropriate; (3) the base model is a step forward for incorporating nonstationary natural mortality and seasonal variability to capture the cold-stun signal; (4) determination of stock status is overall robust to model assumptions and configurations that have been explored in sensitivity analyses and during the peer-review workshop. The reviewers expressed concerns over the potential overparameterization of the nonstationary growth assumption, the constant live-release mortality assumption for the recreational fishery, and the fixed constant CV input for recreational landings and discards fleets, and the reviewers recommended further investigation in the future. The reviewers also recommended: (1) integration of tagging data in the assessment model being given high priority; (2) exploration of potentially incorporating the P120 juvenile survey data and age composition data in the assessment model; (3) conducting a continuity run with the age-structured model (Stock Synthesis) to compare with this new size-structured base model; (4) improving understanding of live-release mortality and size structure of discards; (5) validating model with existing data. Detailed comments from the external peer reviewers are provided in Appendix.

6 RESEARCH RECOMMENDATIONS

The following research recommendations are offered (ranked by priority) to improve the next assessment of the North Carolina and Virginia Spotted Seatrout stock:

High

- Test and validate the newly developed size-structured model with known data sets and a simulation study that compares this size-structured model with an age-structured model
- Collect data to characterize annual length distributions of commercial discards and recreational releases to inform selectivity parameterization
- Develop a fishery-independent survey for Virginia waters
- Develop a winter-season survey to capture population dynamics in that period, including collection of length composition data
- Integrate tagging data into stock assessment model so both tagging data and other data sources can work together to give a better picture of the population
- Implement a year-round, fisheries-independent juvenile survey
- Improve estimates of recreational discard mortality

Medium

- Conduct a detailed analysis of the existing Program 915 data to determine the extent to which late fall and spring provide insights into overwinter changes in abundance; this analysis could also provide insights into the magnitude of cold-stun events, which could explain differences in the effects observed in tagging and telemetry studies versus survey and fishery monitoring

- Incorporate empirically estimated errors for the recreational landings and live releases, if possible
- Compare maturity ogives between North Carolina and Virginia
- Develop estimates of commercial discards for runaround nets

Low

- Conduct additional work to evaluate more fully the utility of the Program 120 survey; including the recruitment index data may require a higher variance to accommodate the large fluctuations observed in the survey
- Improve estimates of commercial discard mortality
- Conduct an age validation study

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8 TABLES

Table 1.1. Estimated parameter values of the von Bertalanffy age-length model fit to Spotted Seatrout data from this and previous studies, where length is measured in millimeters.

Location	Collection Dates	Gear	Structure	Sex	n	L_∞	K	t_0	Reference
Galveston Bay, Texas	October 1981–September 1982	exp gill nets (most) and hook and line	sectioned otoliths	Female		687	0.512	-0.260	Maceina et al. 1987
Galveston Bay, Texas	October 1981–September 1982	exp gill nets (most) and hook and line	sectioned otoliths	Male		664	0.179	1.939	Maceina et al. 1987
Charlotte Harbor, Florida	February 1986–January 1988	hook and line, seine, gill and trammel nets	sectioned otoliths	Female	1,102	698	0.363	0.39	Murphy and Taylor 1994
Indian River Lagoon, Florida	February 1986–January 1988	hook and line, seine, gill and trammel nets	sectioned otoliths	Female	1,195	839	0.362	0.74	Murphy and Taylor 1994
Apalachicola Bay, Florida	March 1986–January 1988	hook and line, seine, gill and trammel nets	sectioned otoliths	Female	797	818	0.350	0.68	Murphy and Taylor 1994
Virginia/North Carolina	1991–2013	various	sectioned otoliths	Female	10,914	794	0.341	-0.588	NCDMF 2015
Virginia/North Carolina	1991–2013	various	sectioned otoliths	Male	6,764	669	0.314	-0.938	NCDMF 2015
Virginia/North Carolina	1991–2019	various	sectioned otoliths	Female + unknown	14,664	868	0.263	-0.856	This study
Virginia/North Carolina	1991–2019	various	sectioned otoliths	Male + unknown	9,014	677	0.293	-1.11	This study
Virginia/North Carolina	1991–2019	various	sectioned otoliths	Pooled	24,386	885	0.217	-0.975	This study

Table 1.2. Estimated parameter values of the length-weight function fit to Spotted Seatrout data from this and previous studies, where length is measured in millimeters and weight is measured in grams.

Location	Collection Dates	Gear	Sex	n	Length Type	*a*	*b*	Reference
Indian River Lagoon, Florida	February 1986–January 1988	hook and line, seine, gill and trammel nets	Female	1,194	TL	5.75E-06	3.12	Murphy and Taylor 1994
Indian River Lagoon, Florida	February 1986–January 1988	hook and line, seine, gill and trammel nets	Male	605	TL	4.76E-06	3.17	Murphy and Taylor 1994
Apalachicola Bay, Florida	March 1986–January 1988	hook and line, seine, gill and trammel nets	Female	1,229	TL	1.47E-05	2.86	Murphy and Taylor 1994
Apalachicola Bay, Florida	March 1986–January 1988	hook and line, seine, gill and trammel nets	Male	608	TL	1.68E-05	2.81	Murphy and Taylor 1994
southeastern Louisiana coastal areas	January 1975–December 1978	trawl, cast net, hook and line, hoop net, gill net, seine, and trammel net	All	1,208	TL	5.40E-06	3.15	Hein et al. 1980
Virginia/North Carolina	1991–2013	various	Female	10,242	FL	1.07E-05	3.00	NCDMF 2015
Virginia/North Carolina	1991–2013	various	Male	6,909	FL	8.59E-06	3.05	NCDMF 2015
Virginia/North Carolina	1991–2019	various	Female	13,264	FL	1.18E-05	2.98	This study
Virginia/North Carolina	1991–2019	various	Male	9,249	FL	7.79E-06	3.04	This study
Virginia/North Carolina	1991–2019	various	Pooled	50,612	FL	1.23E-05	2.98	This study

Table 1.3. Table of seasonal estimates of median natural mortality (M), lower and upper credibility intervals from the working group's tag-return model (2021). Greyed-out rows below represent time steps in which no tags were released.

Season (time step)	Lower CI	Median M	Upper CI
Autumn 2008	0.000057	0.0035	0.29
Winter 2008	0.00014	0.46	0.94
Spring 2009	0.000068	0.072	0.86
Summer 2009	0.000058	0.0048	0.40
Autumn 2009	0.000055	0.0027	0.24
Winter 2009	0.94	1.5	2.1
Spring 2010	0.000056	0.0037	0.34
Summer 2010	0.000054	0.0017	0.12
Autumn 2010	1.6	2.3	3.1
Winter 2010	0.00021	0.58	1.3
Spring 2011	0.000058	0.0050	0.40
Summer 2011	0.0013	0.34	0.63
Autumn 2011	0.000056	0.0037	0.23
Winter 2011	0.000058	0.0055	0.36
Spring 2012	0.28	0.82	1.2
Summer 2012	0.000072	0.18	1.3
Autumn 2012	0.000063	0.023	1.6
Winter 2012	0.000061	0.020	1.9
Spring 2013	0.000062	0.022	2.1
Summer 2013	0.000060	0.017	2.2
Autumn 2013	0.000060	0.013	2.2
Winter 2013	0.000060	0.012	2.0
Spring 2014	0.000058	0.0079	1.5

Table 1.3. (*continued*) Table of seasonal estimates of median natural mortality (*M*), lower and upper credibility intervals from the working group's tag-return model (2021). Greyed-out rows below represent time steps in which no tags were released.

Season (time step)	Lower CI	Median *M*	Upper CI
Summer 2014	0.000057	0.0058	1.0
Autumn 2014	0.000057	0.0031	0.30
Winter 2014	0.000080	0.48	1.5
Spring 2015	0.000059	0.0095	0.95
Summer 2015	0.000059	0.010	0.97
Autumn 2015	0.000058	0.0067	0.58
Winter 2015	0.00070	1.7	2.6
Spring 2016	0.000068	0.12	2.1
Summer 2016	0.000082	0.24	0.95
Autumn 2016	0.000059	0.010	0.49
Winter 2016	0.000062	0.023	0.79
Spring 2017	0.0028	0.73	1.2
Summer 2017	0.000054	0.0015	0.090
Autumn 2017	0.000071	0.19	1.3
Winter 2017	0.0035	1.7	2.5
Spring 2018	0.000061	0.015	1.4
Summer 2018	0.000055	0.0023	0.19
Autumn 2018	0.58	0.97	1.4
Winter 2018	0.000054	0.0022	0.15
Spring 2019	0.42	0.80	1.1
Summer 2019	0.000071	0.077	0.50
Autumn 2019	0.000058	0.0071	0.33
Winter 2019	0.000063	0.036	2.3

Table 1.4. Total mortality of Spotted Seatrout in commercial gill nets by mesh size reported in Price and Gearhart (2002).

Mesh Size (in)	n	Mortality
2.5	48	90.0%
3.0	70	90.0%
3.5	71	77.0%
4.0	57	67.0%
4.5	29	66.0%

Table 1.5. Total, at-net, and delayed mortality of Spotted Seatrout in commercial small-mesh gill nets by season reported in Price and Gearhart (2002).

	Spring/Summer	Fall/Winter
Total Mortality	82.7%	73.8%
At-Net Mortality	76.2%	61.7%
Delayed Mortality	28.9%	31.7%

Table 1.6. At-net mortality of Spotted Seatrout caught in Program 915 (mesh sizes 3–4.5" combined) by month reported in NCDMF (2012a).

Month	Mortality	n
February	20.0%	15
March	35.0%	31
April	40.0%	95
May	53.0%	185
June	75.0%	134
July	76.0%	110
August	74.0%	99
September	87.0%	224
October	64.0%	198
November	37.0%	186
December	17.0%	63
Total	60.0%	1,340

Table 1.7. Delayed mortality rates of Spotted Seatrout for high salinity (Outer Banks) and low salinity (rivers) areas reported in Price and Gearhart (2002).

	Outer Banks	Rivers
Spring/Summer	41.7%	23.1%
Fall/Winter	36.4%	26.3%

Table 1.8. Summary of recreational fishery release mortality estimates from a review of the literature.

Location	Mortality Estimate	Notes	Reference
Texas	up to 55.6%	artificial and natural baits	Matlock and Dailey 1981
Texas	7.30%	artificial and natural baits	Matlock et al. 1993
Texas	37.0%	artificial and natural baits	Hegen et al. 1983
Texas	11.0%	artificial and natural baits	Stunz and McKee 2006
Florida	4.60%	hook and line	Murphy et al. 1995
Louisiana	17.5%	artificial and natural baits	Thomas et al. 1997
Alabama	14.1%	treble hooks (1994)	Duffy 2002
Alabama	16.3%	single hooks (1994)	Duffy 2002
Alabama	9.10%	treble hooks (1995)	Duffy 2002
Alabama	14.6%	single hooks (1995)	Duffy 2002
North Carolina (River & Outer Banks sites in Pamlico, Core, & Roanoke sounds)	14.8%	artificial and natural baits	Gearhart 2002
North Carolina (Neuse River)	25.2%	artificial and natural baits	Brown 2007

Table 2.1. Number of Spotted Seatrout lengths sampled from Virginia's commercial fisheries by season, 1991–2019. Season 1 is March through November and season 2 is December through February.

Fishing Year	Season 1	Season 2
1991	864	4
1992	311	0
1993	254	0
1994	680	8
1995	257	0
1996	71	9
1997	194	1
1998	537	28
1999	1,379	21
2000	181	2
2001	174	33
2002	491	0
2003	97	0
2004	184	0
2005	228	0
2006	698	114
2007	284	0
2008	205	0
2009	347	1
2010	231	0
2011	483	19
2012	776	0
2013	253	241
2014	646	616
2015	342	10
2016	852	4
2017	1,383	18
2018	876	13
2019	2,104	0

Table 2.2. Number of Spotted Seatrout lengths sampled from North Carolina's commercial fisheries by season, 1991–2019. Season 1 is March through November and season 2 is December through February.

Fishing Year	Season 1	Season 2
1991	1,098	332
1992	1,681	347
1993	1,039	116
1994	598	435
1995	1,328	162
1996	630	30
1997	3,098	362
1998	3,649	698
1999	4,314	1,091
2000	1,701	233
2001	1,142	353
2002	2,575	958
2003	1,032	335
2004	1,638	638
2005	1,324	168
2006	3,969	2,005
2007	4,322	1,692
2008	3,463	740
2009	4,471	2,148
2010	1,546	354
2011	926	200
2012	2,866	2,235
2013	3,041	862
2014	1,758	1,071
2015	885	440
2016	2,237	530
2017	1,543	404
2018	434	99
2019	2,046	996

Table 2.3. Annual commercial fishery landings (metric tons) of Spotted Seatrout by state and season, 1991–2019.

Fishing Year	North Carolina		Virginia		Combined	
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
1991	245.1	89.78	9.28	0.77	254.4	90.55
1992	172.8	45.92	3.93	0.08	176.7	46
1993	152.8	68.34	16.62	0.56	169.5	68.9
1994	123.3	94.07	19.75	0.54	143.1	94.62
1995	141.8	103.6	11.9	1.19	153.7	104.8
1996	45.53	19.21	1.83	0.13	47.36	19.34
1997	77.86	26.09	5.05	0.25	82.91	26.34
1998	114.8	54.29	9.21	0.8	124.0	55.09
1999	161.1	145.1	16.83	0.67	178.0	145.8
2000	57.03	30.12	8.81	0.02	65.84	30.13
2001	29.73	11.04	8.87	0.51	38.6	11.55
2002	54.22	46.77	3.88	0.06	58.1	46.82
2003	42.67	22.68	2.39	0.03	45.07	22.71
2004	38.4	19.4	4.75	0.05	43.15	19.46
2005	40.25	15.97	7.31	0.51	47.56	16.48
2006	101.1	73.79	21.14	1.96	122.2	75.75
2007	105.7	41.82	16.11	0.78	121.8	42.6
2008	90.27	54.16	20.3	0.33	110.6	54.49
2009	93.99	70.57	10.9	0.5	104.9	71.06
2010	38.54	12.58	8.64	0.13	47.18	12.71
2011	24.04	14	6.89	0.71	30.93	14.71
2012	89.17	53.77	52.56	0.01	141.7	53.78
2013	115.3	49.83	17.11	9.89	132.4	59.72
2014	59.87	42.83	30.77	1.63	90.63	44.46
2015	30.89	21.52	2.06	0.13	32.95	21.65
2016	80.55	43.66	7.17	0.06	87.73	43.72
2017	86.07	31.6	24.94	0.38	111.0	31.98
2018	34.25	34.56	7.05	0.97	41.31	35.53
2019	111.3	89.94	45.37	0.44	156.7	90.38

Table 2.4. Numbers of Spotted Seatrout sampled and measured by MRIP by state and season, 1991–2019.

Fishing Year	North Carolina		Virginia	
	n Sampled	n Measured	n Sampled	n Measured
1991	1,306	745	52	46
1992	924	543	59	57
1993	668	485	89	69
1994	1,545	1,076	263	195
1995	1,299	853	170	152
1996	637	307	84	72
1997	897	622	144	109
1998	920	551	48	46
1999	920	699	115	97
2000	512	330	82	75
2001	462	326	18	18
2002	396	283	27	23
2003	204	130	110	80
2004	578	294	77	71
2005	1,051	664	21	17
2006	1,492	706	47	30
2007	1,304	521	168	103
2008	1,133	790	152	108
2009	1,054	779	56	45
2010	444	336	42	32
2011	754	638	86	67
2012	1,418	939	164	85
2013	1,032	865	79	57
2014	546	381	56	45
2015	192	154	6	6
2016	841	647	106	102
2017	1,385	864	202	143
2018	376	274	133	114
2019	2,264	1,574		

Table 2.5. Annual recreational fishery statistics of Spotted Seatrout in North Carolina and Virginia in season 1 (March–November), 1991–2019.

Fishing Year	Harvest (A+B1)				Released Alive (B2)		Dead Discards
	Number	PSE[Num]	Metric Tons	PSE[Mt]	Number	PSE[Num]	Number
1991	1,127,571	11	728	6.77	650,402	13	65,040
1992	1,010,921	15	728	11.03	482,724	27	48,272
1993	788,468	13	589	9.6	576,261	21	57,626
1994	956,829	11	672	7.74	897,975	22	89,798
1995	853,501	13	583	7.03	1,009,116	20	100,912
1996	697,510	22	444	11.21	1,038,455	16	103,846
1997	810,741	13	587	8.71	510,047	13	51,005
1998	755,707	15	566	11.08	258,222	14	25,822
1999	1,311,626	13	1,101	10.34	882,511	20	88,251
2000	846,779	17	616	11.41	528,706	12	52,871
2001	501,885	14	318	10.09	655,730	16	65,573
2002	770,225	25	456	14.28	1,694,938	22	169,494
2003	477,748	14	346	8.49	864,791	24	86,479
2004	492,830	12	307	7.79	889,658	10	88,966
2005	1,381,561	41	724	22.09	3,147,563	34	314,756
2006	1,330,493	18	870	11.97	1,706,549	21	170,655
2007	1,191,955	13	934	7.3	2,038,182	16	203,818
2008	1,407,530	15	1,101	11.86	2,788,068	17	278,807
2009	1,651,295	17	1,158	11.16	4,003,605	29	400,361
2010	634,770	26	587	18.67	8,373,833	13	837,383
2011	920,058	17	833	14.35	7,932,476	15	793,248
2012	1,657,128	9.7	1,256	7.56	4,837,791	8.4	483,779
2013	1,073,405	9.8	877	7.52	3,911,490	11	391,149
2014	629,683	14	512	9.07	3,533,416	14	353,342
2015	203,825	21	164	14.34	3,215,331	17	321,533
2016	1,039,799	10	862	8.79	8,445,350	13	844,535
2017	1,123,038	12	907	8.04	6,991,950	11	699,195
2018	566,162	15	350	10.21	18,635,273	38	1,863,527
2019	2,149,484	12	1,769	8.64	7,850,741	13	785,074

Table 2.6. Annual recreational fishery statistics of Spotted Seatrout in North Carolina and Virginia in season 2 (December–February), 1991–2019.

Fishing Year	Harvest (A+B1)				Released Alive (B2)		Dead Discards
	Number	PSE[Num]	Metric Tons	PSE[Mt]	Number	PSE[Num]	Number
1991	41,005	61	33	35	50,028	99	5,003
1992	1,087	0	0.60	0	3,261	0	326
1993	27,883	0	23	0	19,362	0	1,936
1994	98,823	43	79	29	55,785	62	5,579
1995	217,622	15	177	11	147,337	34	14,734
1996	7,389	23	6.2	8.5	5,889	0	589
1997	105,912	40	89	23	15,050	37	1,505
1998	27,781	0	23	0	6,623	0	662
1999	67,402	26	69	18	90,540	66	9,054
2000	14,245	9.9	18	14	4,256	0	426
2001	26,273	36	10	19	46,462	2.3	4,646
2002	1,802	0	1.5	0	2,859	0	286
2003	41,135	50	23	43	22,454	85	2,245
2004	182,668	35	125	23	135,967	47	13,597
2005	233,449	19	134	10	383,235	21	38,324
2006	181,319	32	145	25	41,727	68	4,173
2007	414,157	19	352	13	840,604	28	84,060
2008	202,212	47	128	18	342,387	12	34,239
2009	266,973	38	197	27	1,008,131	19	100,813
2010	65,895	49	49	32	1,895,812	74	189,581
2011	482,267	8.6	490	6.3	3,110,866	24	311,087
2012	401,412	18	311	13	1,238,806	21.1	123,881
2013	135,866	34	183	33	1,381,484	15	138,148
2014	192,199	14	165	9.1	1,084,535	18	108,454
2015	21,940	47	11	33	3,004,582	40	300,458
2016	254,412	33	207	23	1,363,890	17	136,389
2017	103,749	30	89	21	688,599	34	68,860
2018	122,938	28	83	20	2,246,592	21	224,659
2019	862,336	21	716	13	2,065,385	18	206,539

Table 2.7. Number of length samples collected in Program 915, 2003–2019.

Fishing Year	Spring	Fall
2003		74
2004	23	65
2005	21	58
2006	115	204
2007	124	127
2008	113	166
2009	216	197
2010	62	126
2011	17	84
2012	129	177
2013	146	144
2014	103	134
2015	47	80
2016	49	152
2017	91	153
2018	35	103
2019	215	358

Table 3.1. Input data overview.

Data	Unit	CV/SE	Availability	Length composition	State
Landings					
ComLanding	Number	0.05	1991–2019	1991–2019	NC and VA
RecLanding	Number	0.1	1991–2019	1991–2019	NC and VA
Discards					
ComDiscard	Number	0.25	1991–2019	NA	NC
RecDiscard	Number	0.25	1991–2019	NA	NC and VA
Indices					
P915NorthSpring	Number per unit effort	Estimate d	2004–2019	2004–2019	NC
P915NorthFall	Number per unit effort	Estimate d	2003–2019	2003–2019	NC

Table 3.2. Overview of the sensitivity analyses.

Scenario	Configurations
P915Srm	P915NorthSpring survey index and length composition were removed
P915Frm	P915NorthFall survey index and length composition were removed
Ini2003	Initial year was set to 2003
LowM	Annual average natural mortality was set to 0.4, lower than the base model (0.6)
HighM	Annual average natural mortality was set to 0.8, higher than the base model (0.6)
Low2018	Season 1 (non-winter, March-November) recreational discards was set to the average of the previous five years (2013–2017; 521.951 thousands of fish), lower than the base model (1,863.527 thousands of fish)
Block	Two time blocks were set up for fleet selectivity, 1991–2008 and 2009–2019

Table 3.3. Results of the runs test for randomness and the Shapiro-Wilk test for normality applied to the residuals of the fits to the fishery-independent survey indices from the base model of the stock assessment. The significance level was set at 0.05.

Survey	Runs test		Shapiro-Wilk	
	Statistic	P-value	Statistic	P-value
P915NorthSpring	-1.553	0.121	0.916	0.148
P915NorthFall	-1.035	0.301	0.954	0.531

Table 3.4. Predicted fishing mortality (per year) and spawning stock biomass (metric tons) from the base model (Base) and the retrospective runs (Retro), the relative bias (RelBias), and the Mohn's ρ value from the retrospective analysis in which the model started with the data from 1991 to 2014, and added one additional year of data at a time up to 2019.

Year	Base	Retro	RelBias
Fishing mortality (per year)			
2014	0.541	0.592	0.094
2015	0.241	0.427	0.772
2016	0.578	1.060	0.835
2017	0.656	0.920	0.402
2018	0.434	1.175	1.706
Mohn's ρ			0.762
Spawning stock biomass (metric tons)			
2014	1,851.341	1,849.510	-0.001
2015	1,870.260	1,314.664	-0.297
2016	2,298.879	1,439.140	-0.374
2017	2,141.867	1,668.463	-0.221
2018	2,350.865	1,117.150	-0.525
Mohn's ρ			-0.284

9 FIGURES

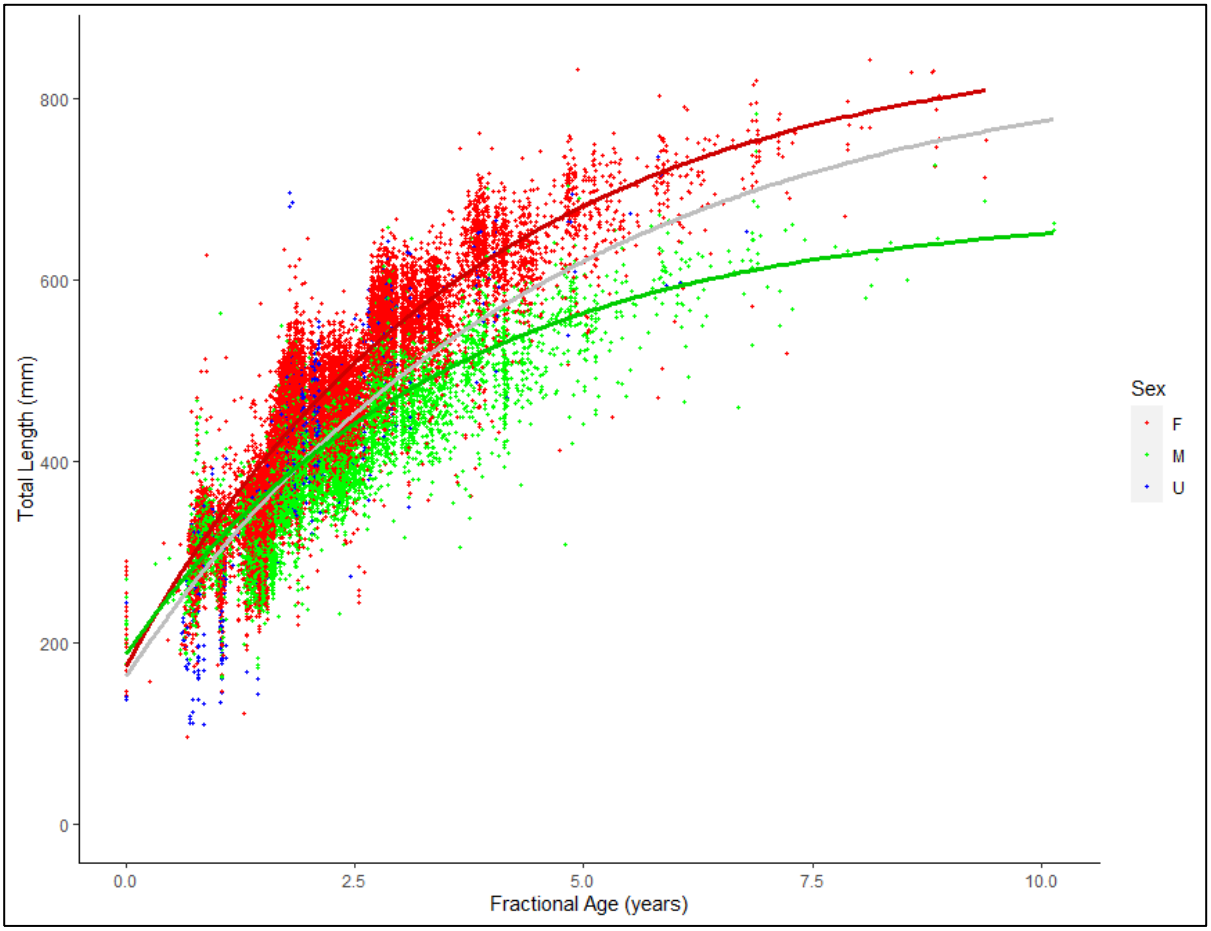


Figure 1.1. Fit of the length-at-age function to available age data for females (red line, n=14,664), males (green line, n = 9,014), and sex-aggregated (grey line, n=24,386) Spotted Seatrout data from Virginia and North Carolina.

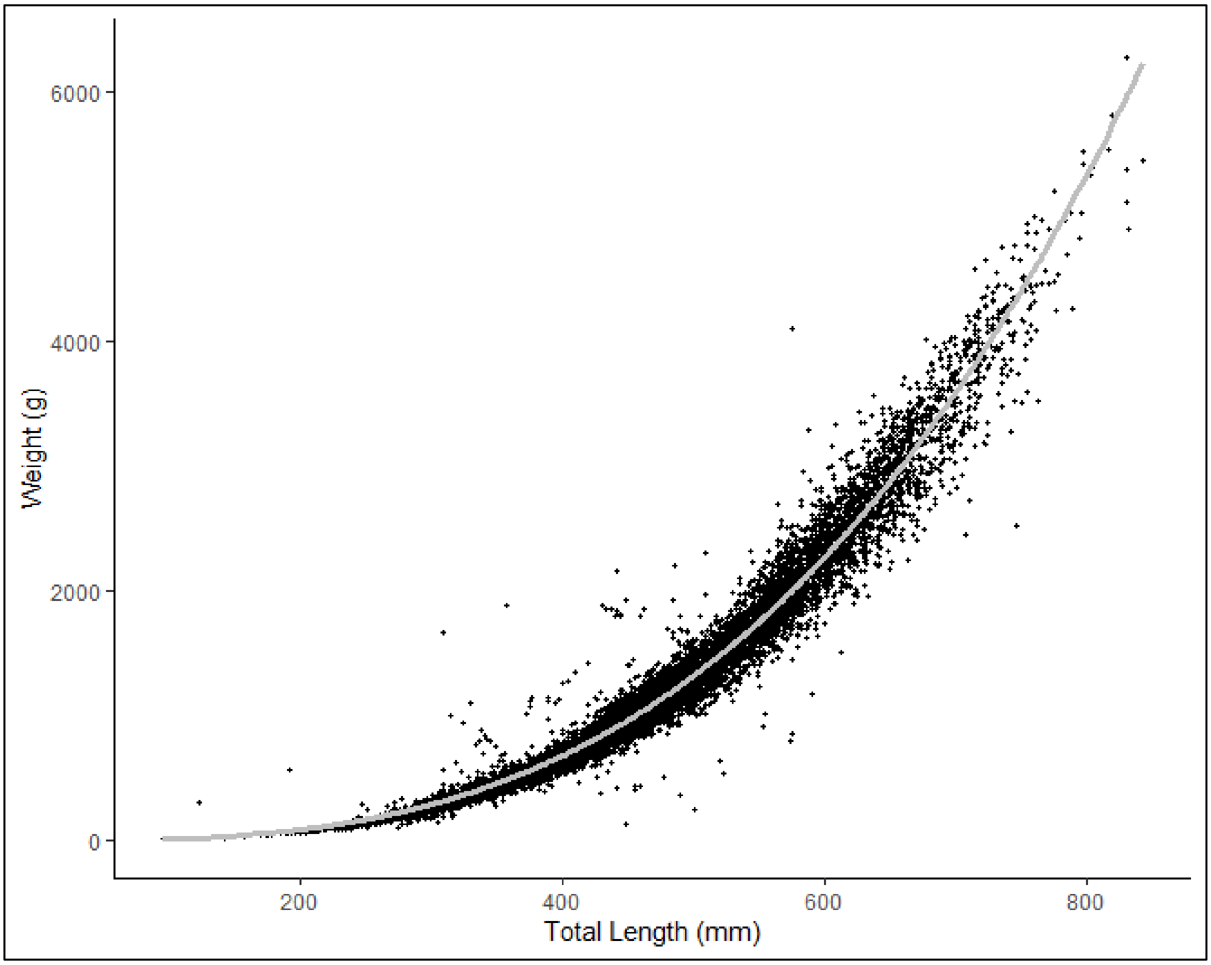


Figure 1.2. Fit of the length-weight function to available biological data for female Spotted Seatrout from Virginia and North Carolina (n = 13,264).

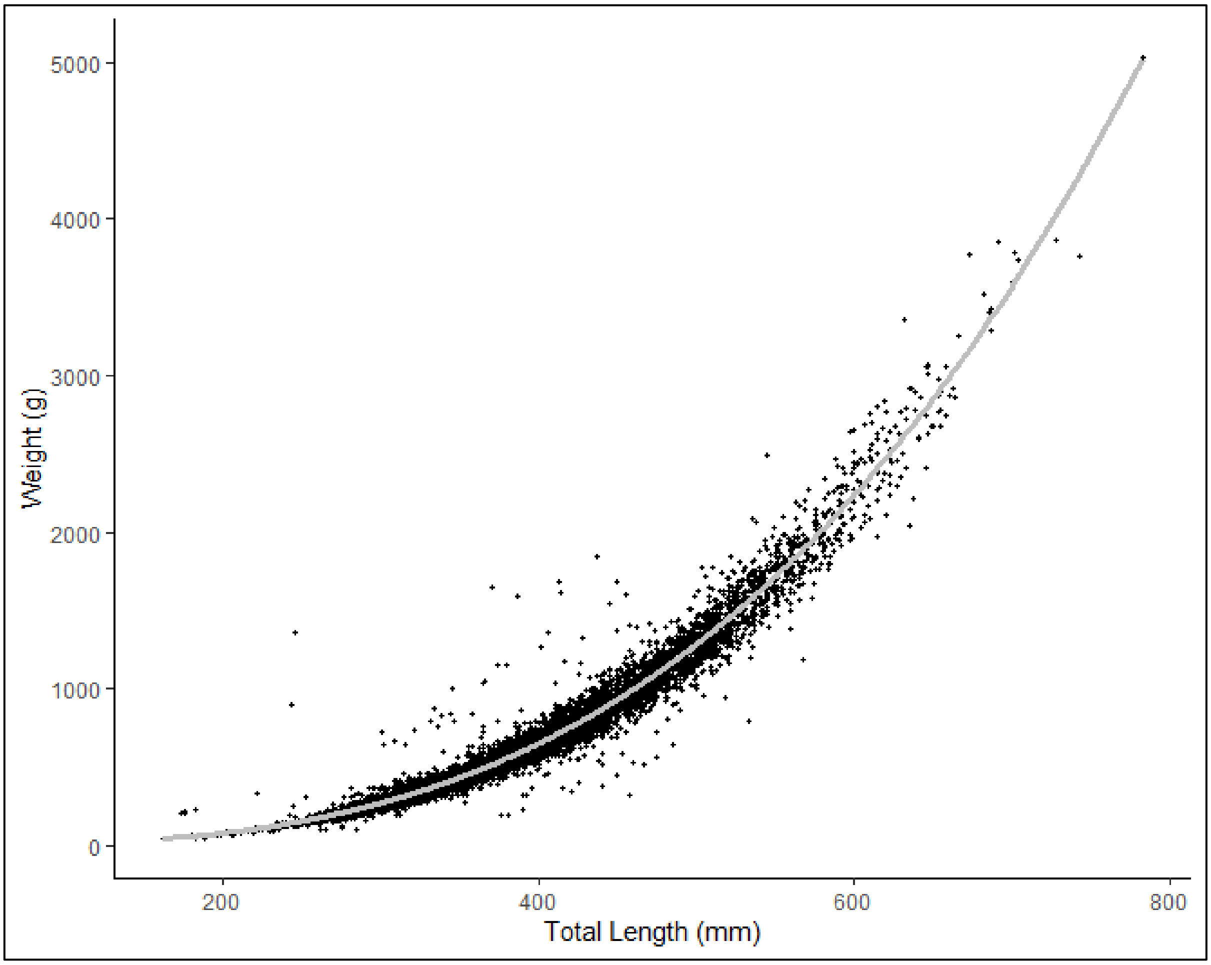


Figure 1.3. Fit of the length-weight function to available biological data for male Spotted Seatrout from Virginia and North Carolina (n = 9,249).

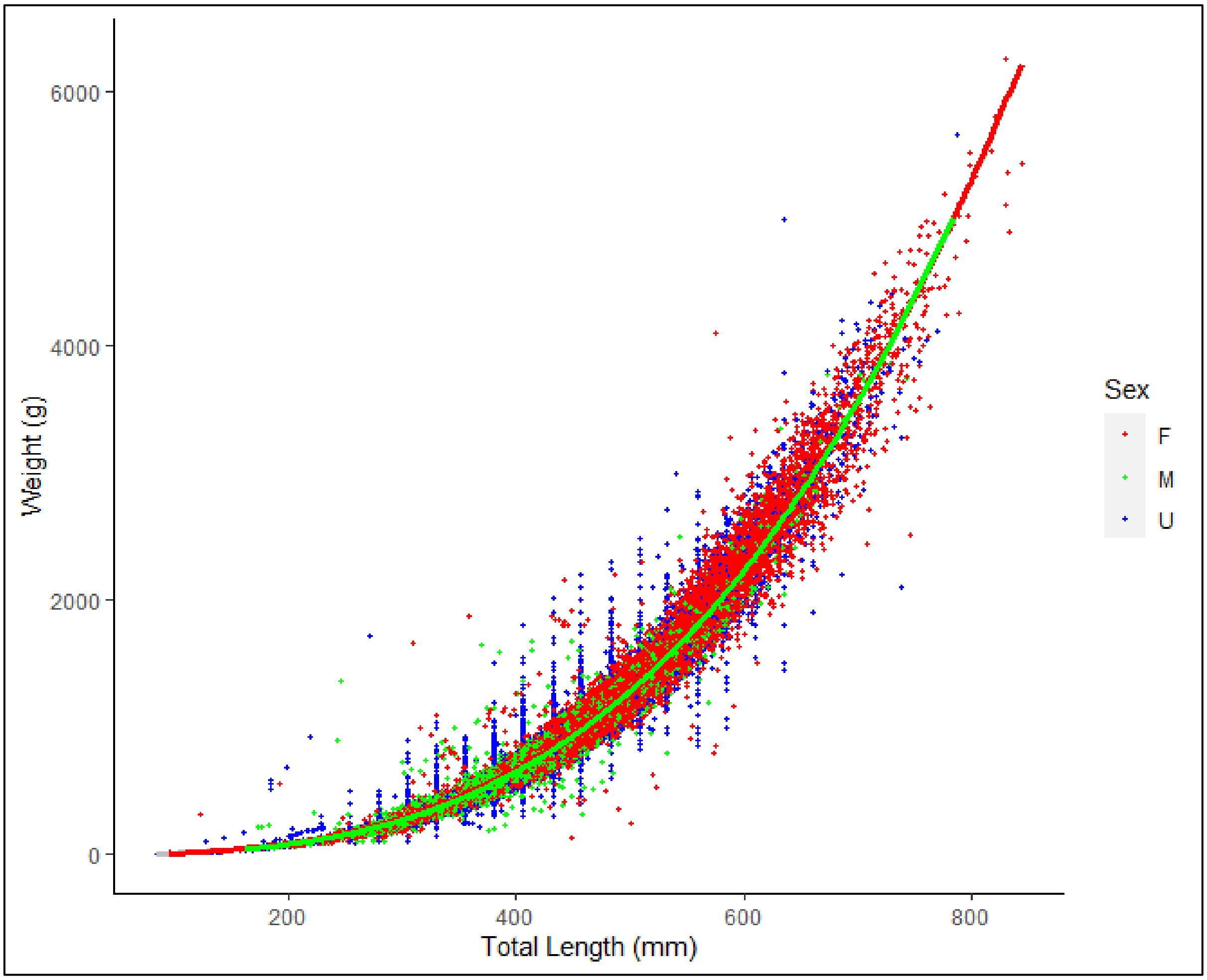


Figure 1.4. Fit of the length-weight function to available biological data for females (red line, n = 13,264), males (green line, n = 9,249), and sex-aggregated including unknown (grey line, n = 50,612) of Spotted Seatrout from Virginia and North Carolina. Sex categories of individual data points include female (F), male (M), and unknown (U).

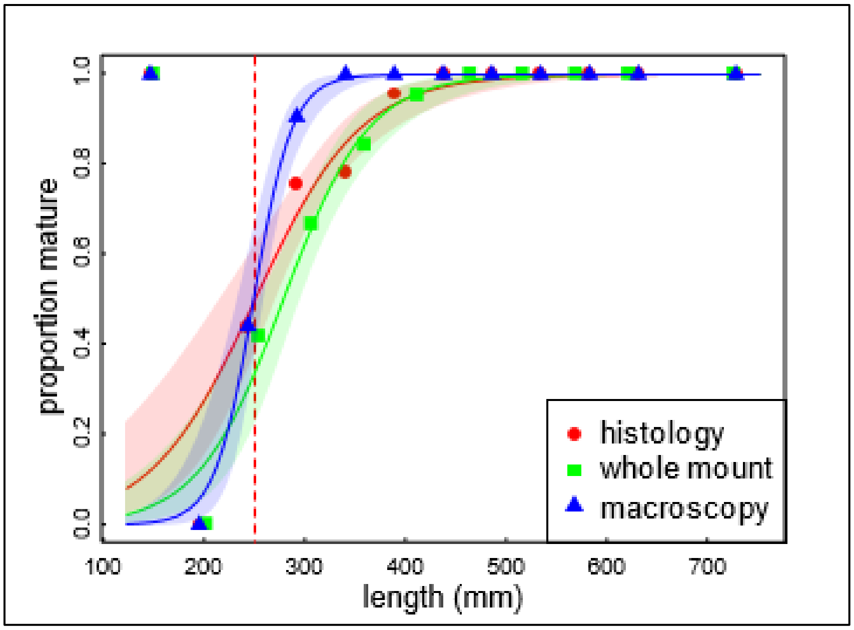


Figure 1.5. Fit of maturity curves to female Spotted Seatrout data collected in North Carolina for three maturity staging methods. The solid lines represent the best-fitting logistic regression and the shaded area represent the 95% confidence bands. The vertical dashed lines represent the predicted length at 50% maturity, L_{50}. The points represent the observed data. (Source: NCDMF 2021.)

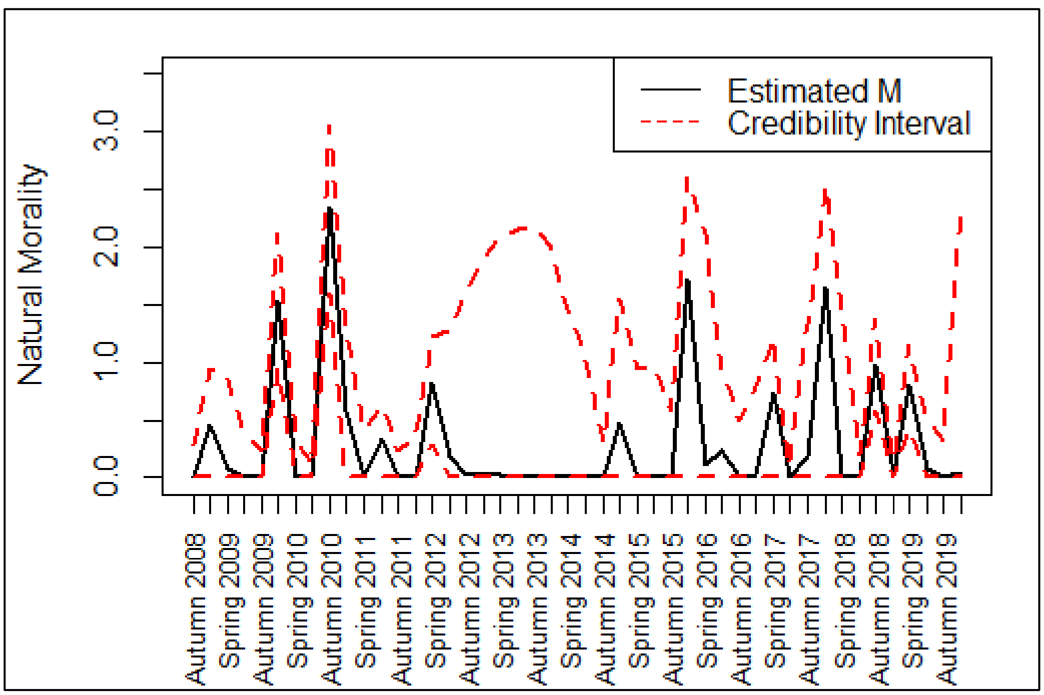


Figure 1.6. Time series plot of seasonal estimates of median natural mortality (black line) and lower and upper credibility intervals (red dashed line) from the working group's tag-return model (2021) from autumn 2008 until winter 2019.

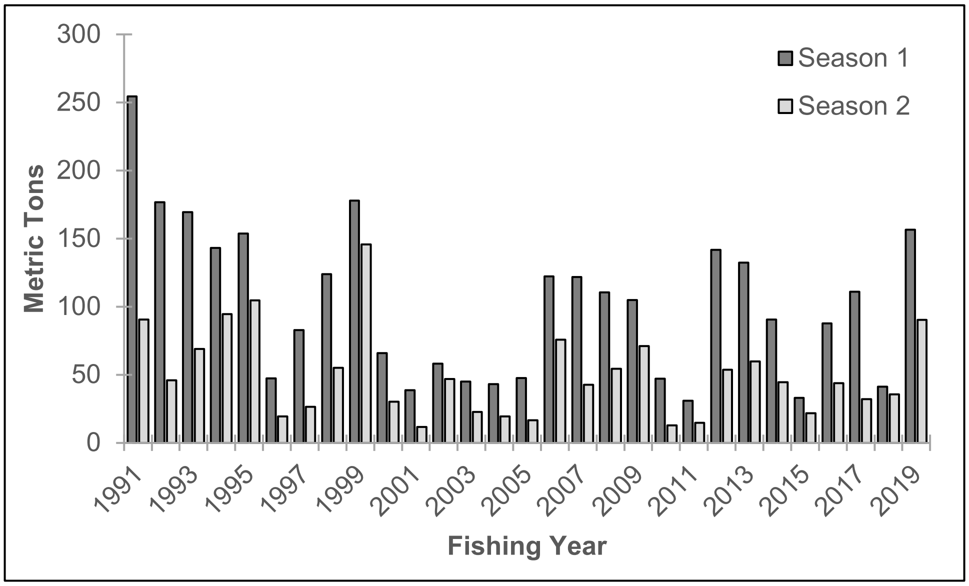


Figure 2.1. Annual commercial landings of Spotted Seatrout in Virginia and North Carolina by season, 1991–2019.

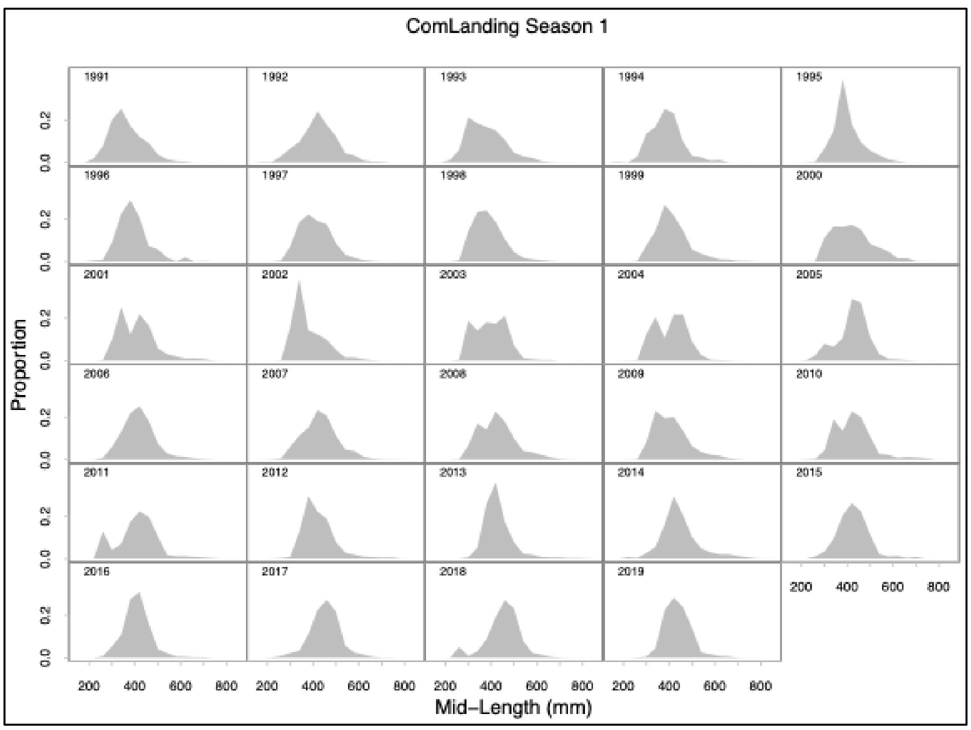


Figure 2.2. Length composition of commercial landings of Spotted Seatrout in Virginia and North Carolina in Season 1 (non-winter season, March–November), 1991–2019.

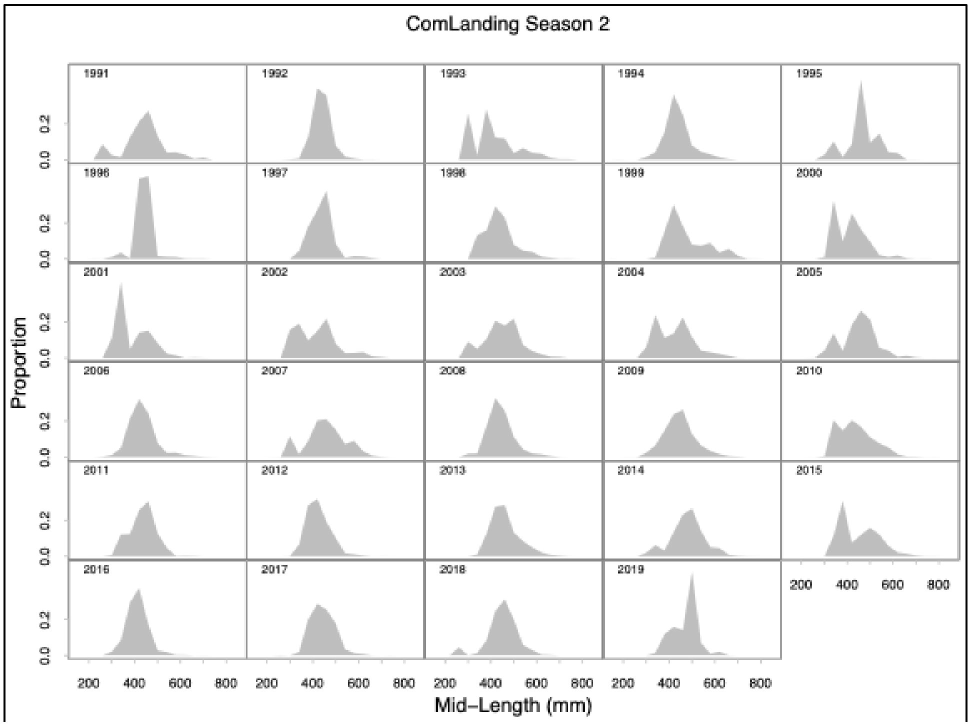


Figure 2.3. Length composition of commercial landings of Spotted Seatrout in Virginia and North Carolina in Season 2 (winter season, December–February), 1991–2019.

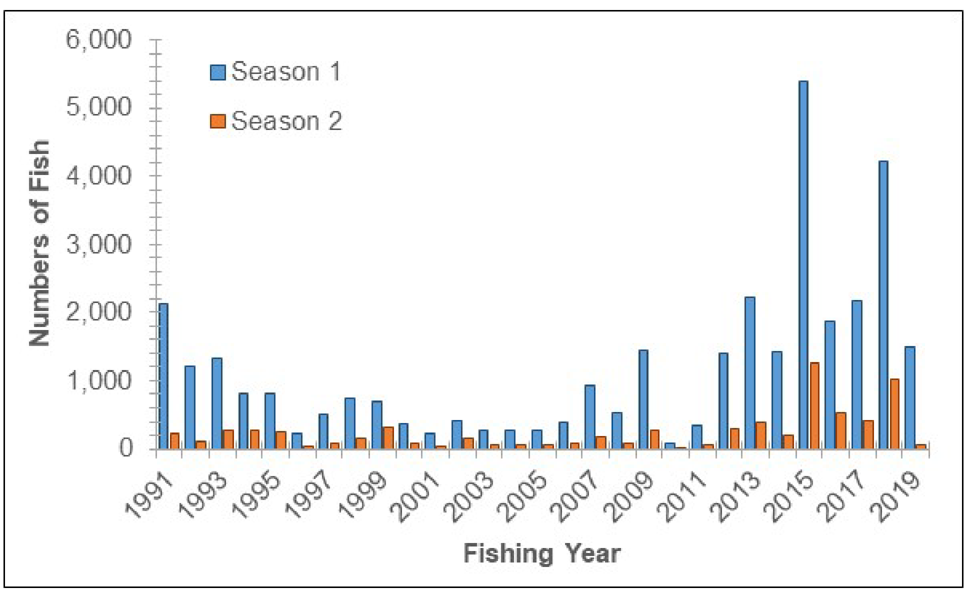


Figure 2.4. Annual commercial gill-net fishery dead discards of Spotted Seatrout in North Carolina by season, 1991–2019.

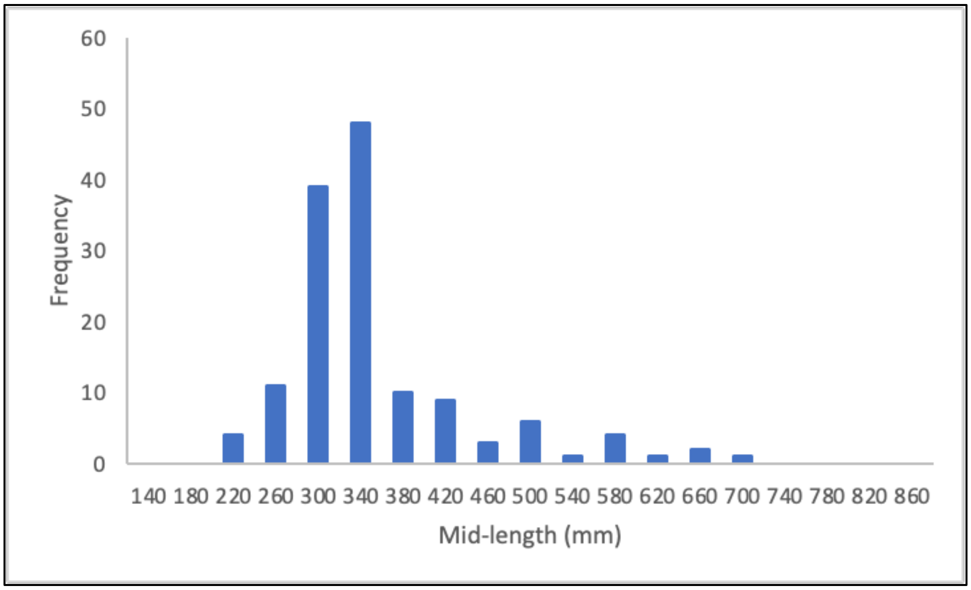


Figure 2.5. Annual length-frequency distributions of Spotted Seatrout sampled from North Carolina commercial gill-net estuarine fishery discards (pooled over years and seasons), 2004–2019.

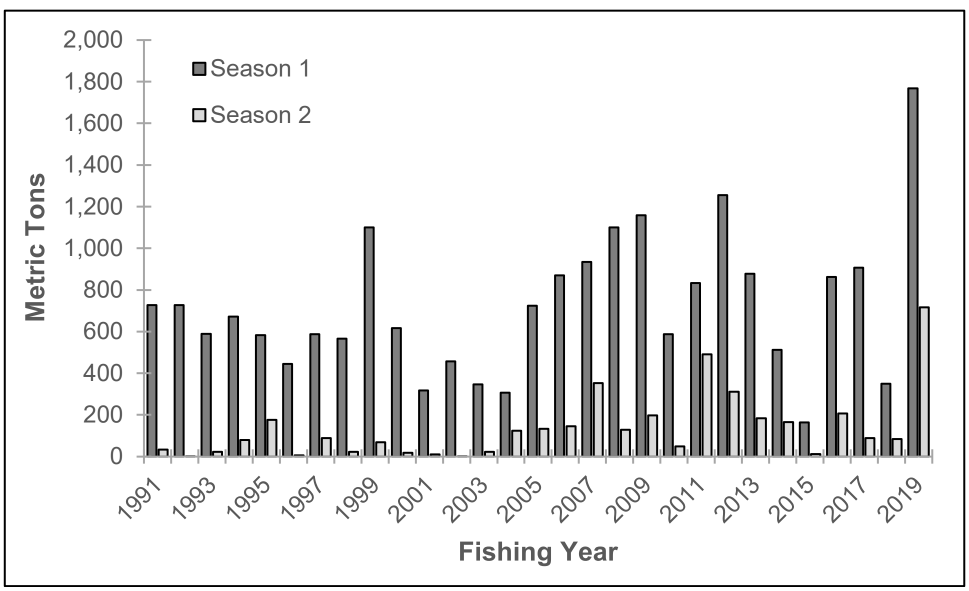


Figure 2.6. Annual recreational harvest (Type A+B1) in weight of Spotted Seatrout in Virginia and North Carolina by season, 1991–2019.

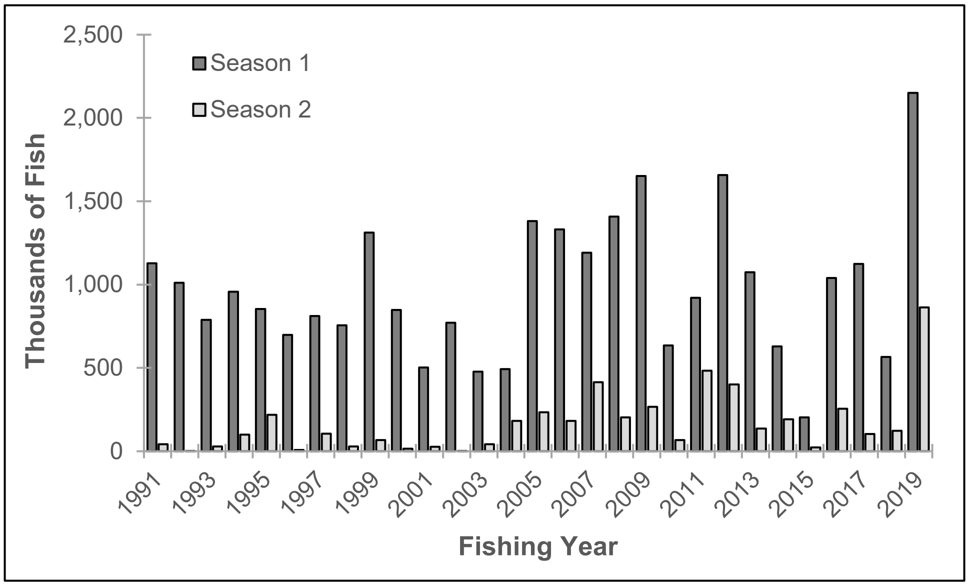


Figure 2.7. Annual recreational harvest (Type A+B1) in numbers of Spotted Seatrout in Virginia and North Carolina by season, 1991–2019.

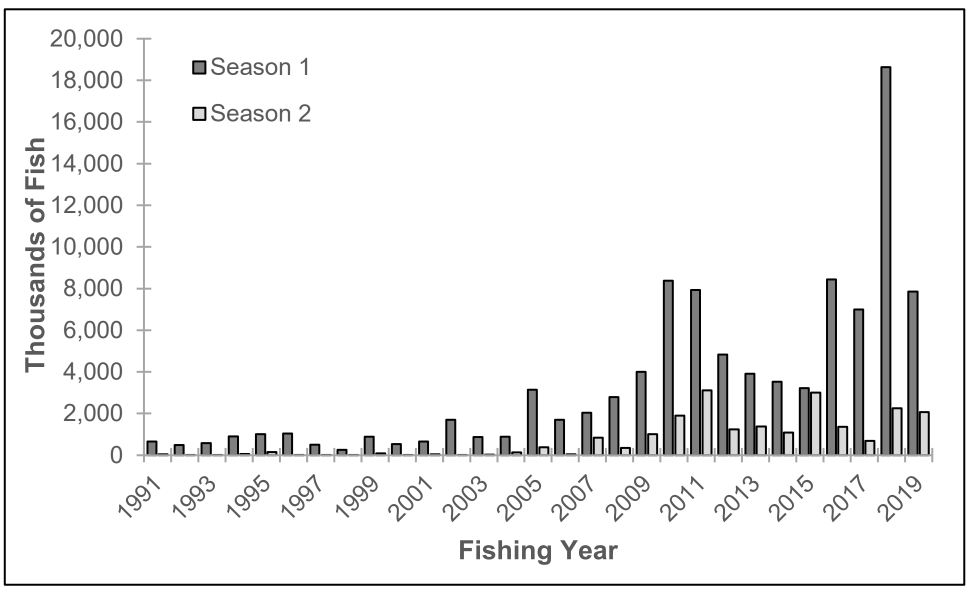


Figure 2.8. Annual recreational live releases (Type B2) in numbers of Spotted Seatrout in Virginia and North Carolina by season, 1991–2019.

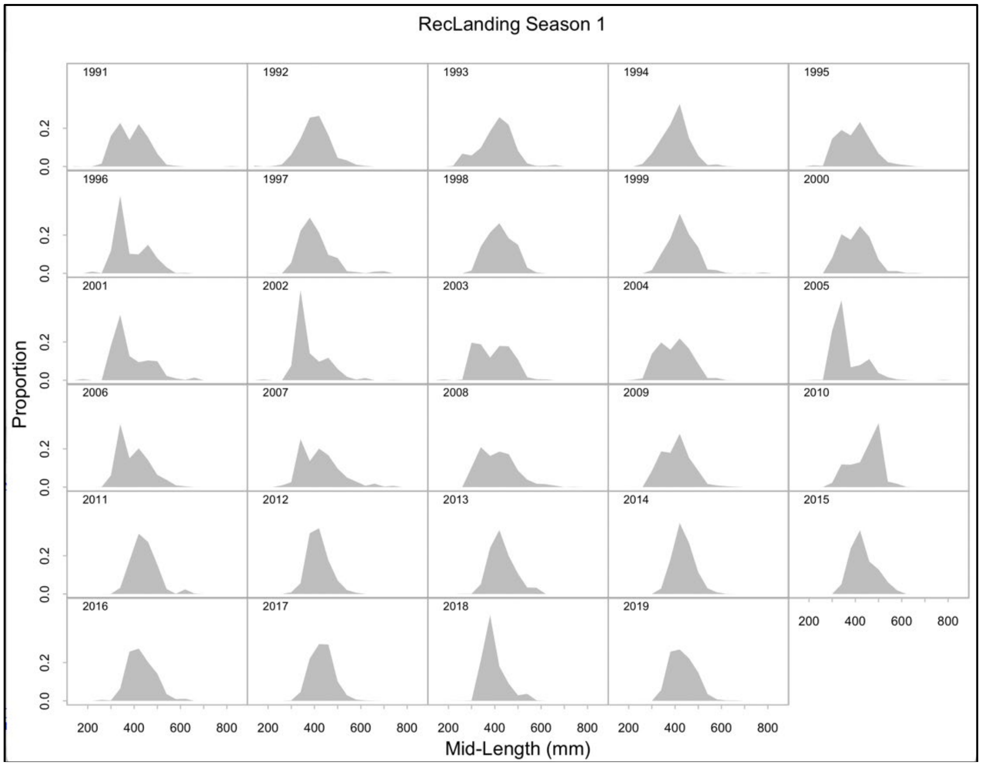


Figure 2.9. Length composition of recreational landings of Spotted Seatrout in Virginia and North Carolina in Season 1 (non-winter season, March–November), 1991–2019.

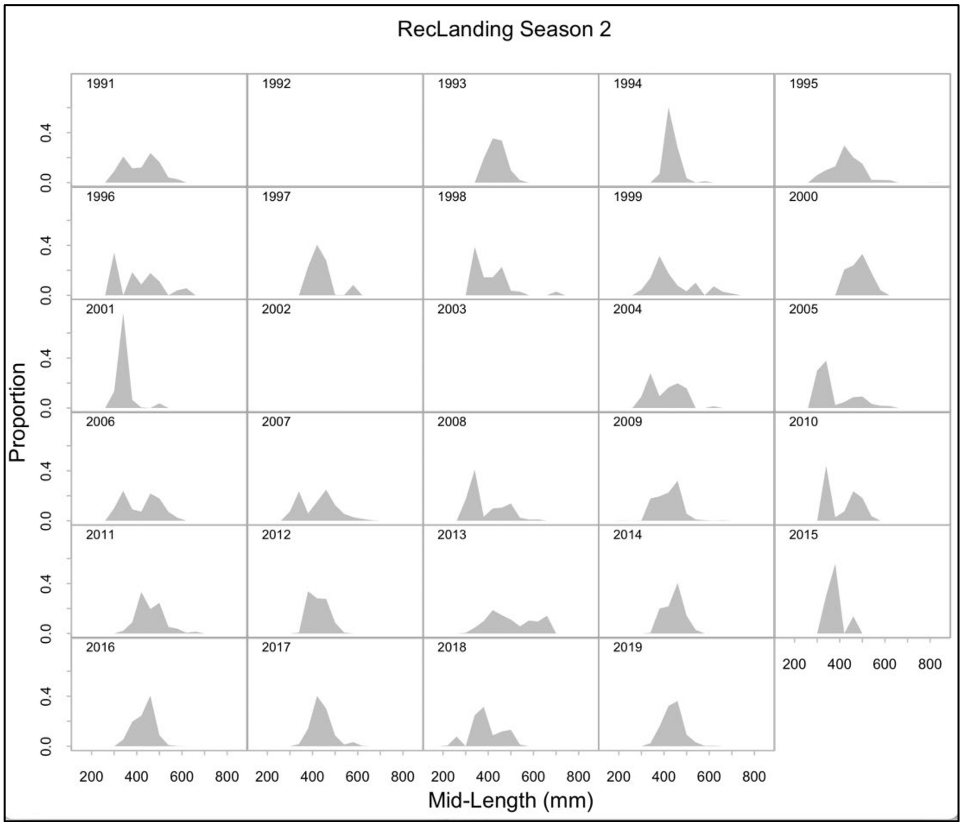


Figure 2.10. Length composition of recreational landings of Spotted Seatrout in Virginia and North Carolina in Season 2 (winter season, December–February), 1991–2019.

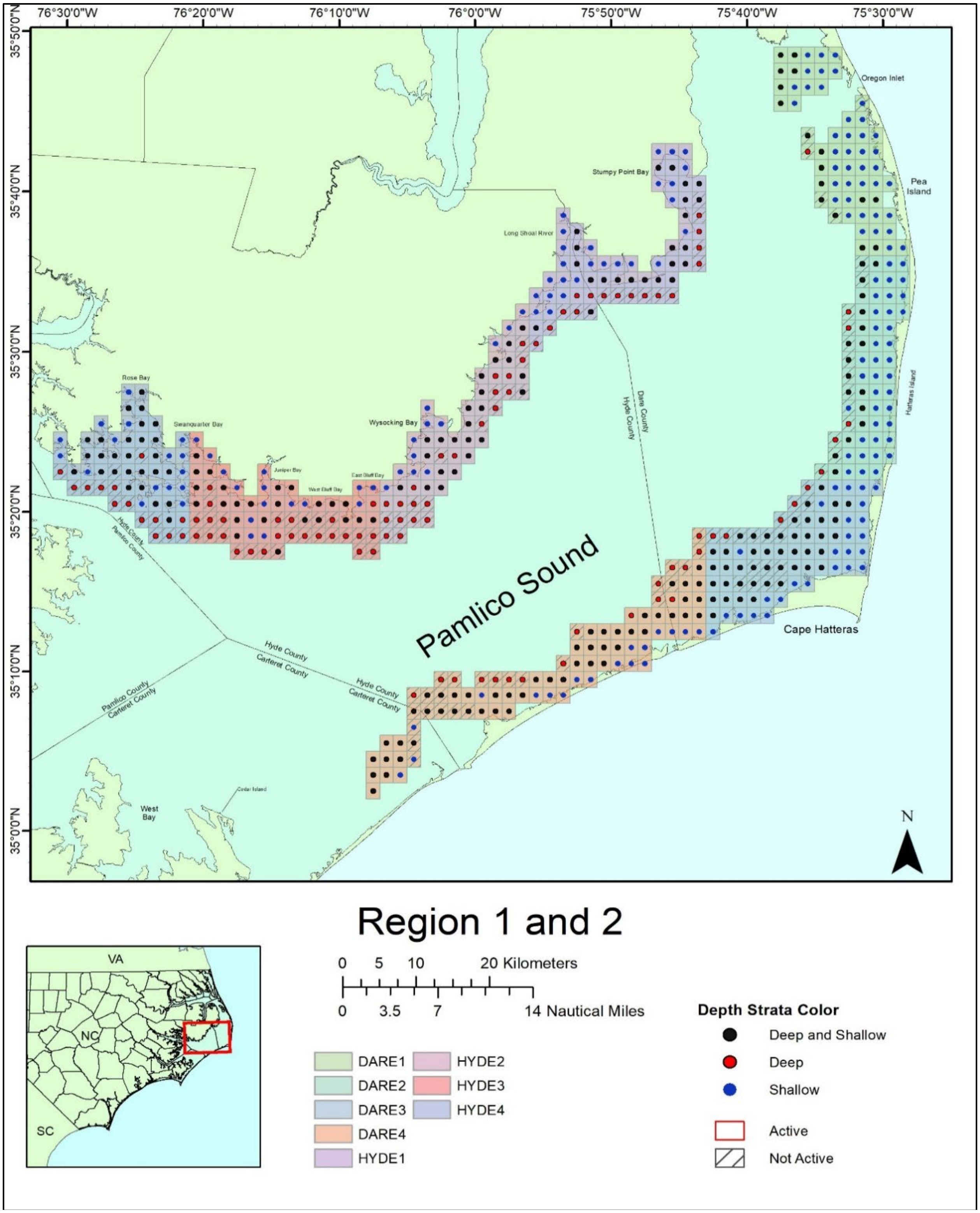


Figure 2.11. The sample regions and grid system for the Pamlico Sound portion of Program 915.

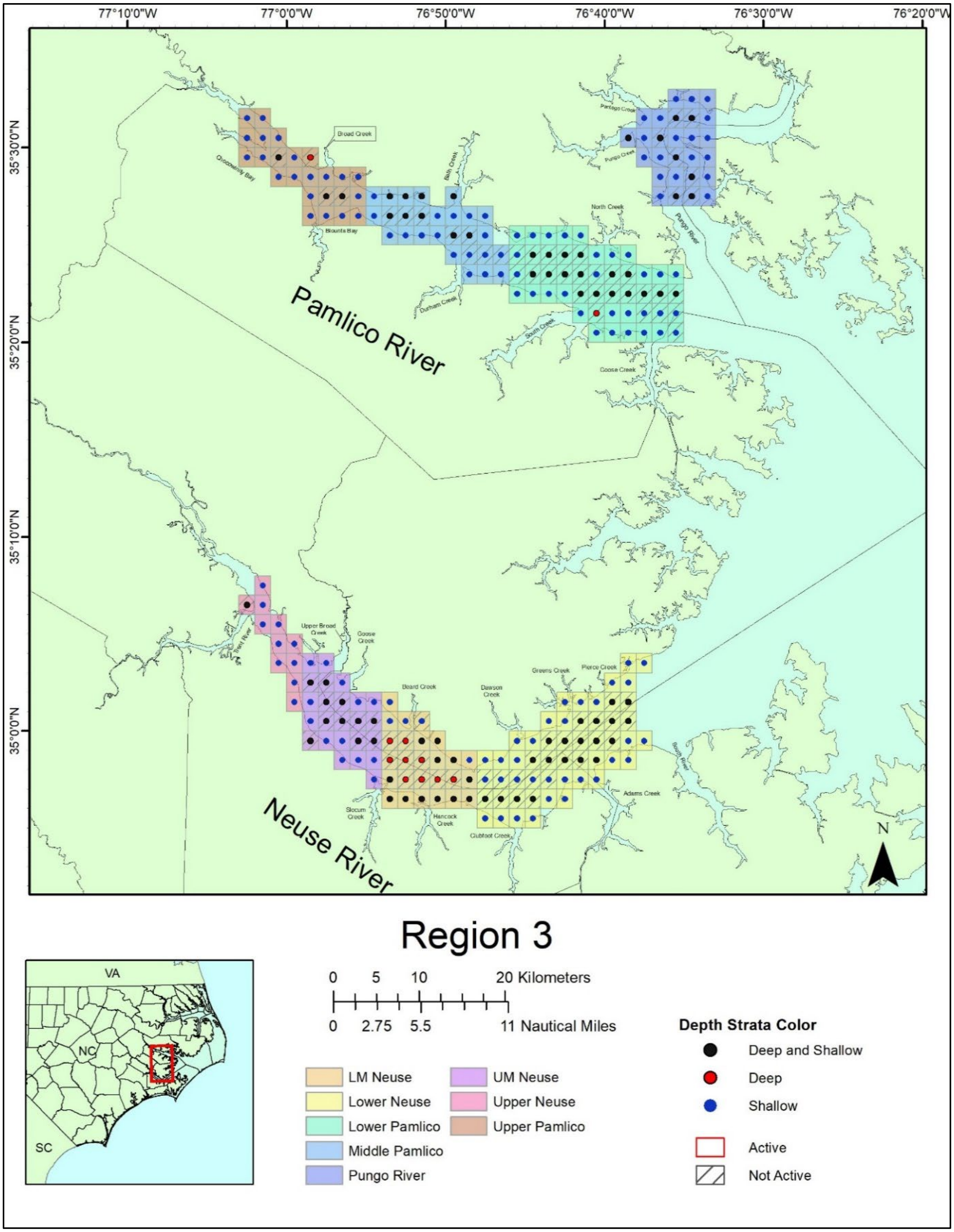
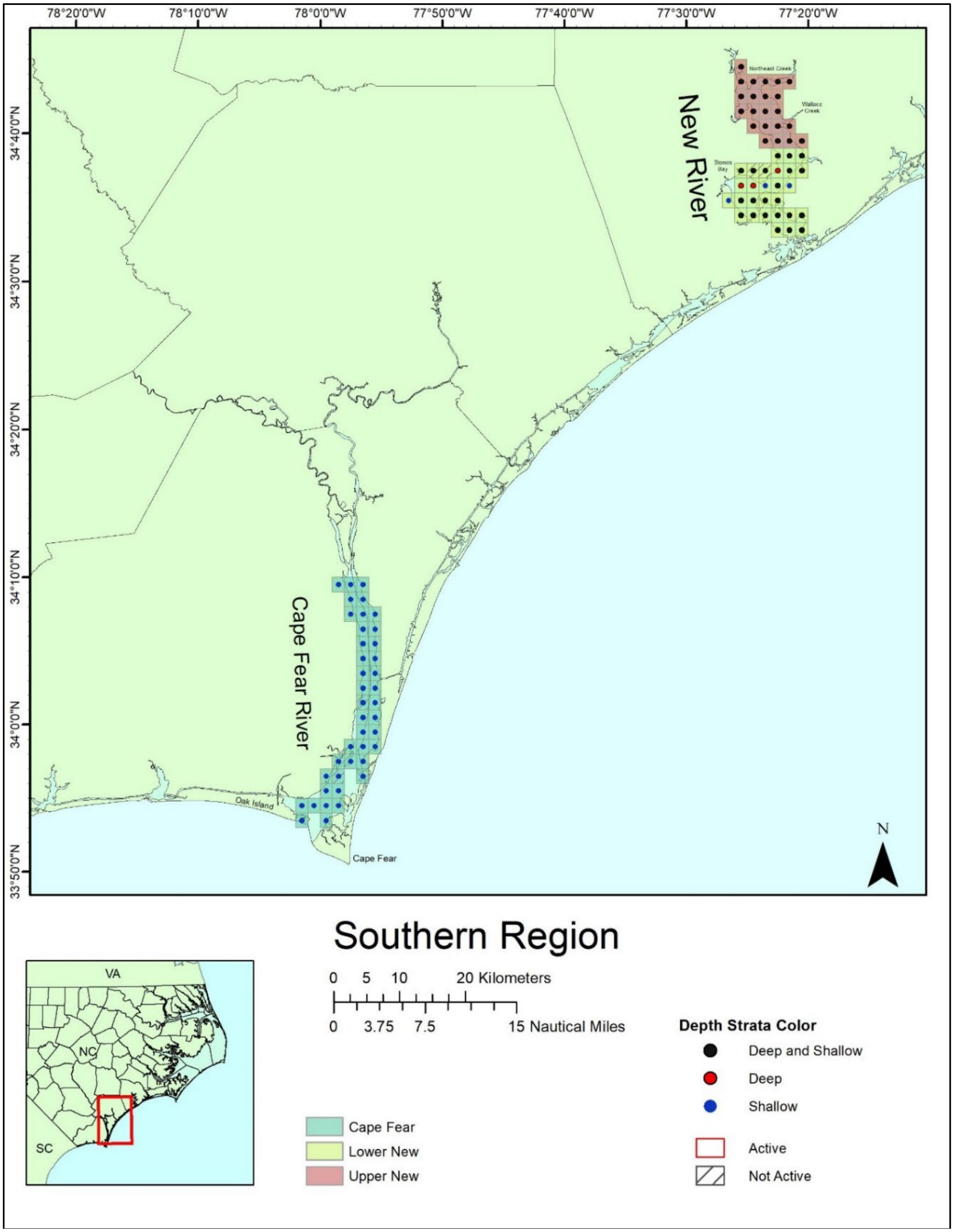


Figure 2.12. The sample regions and grid system for the Neuse, Pamlico, and Pungo rivers portion of Program 915.



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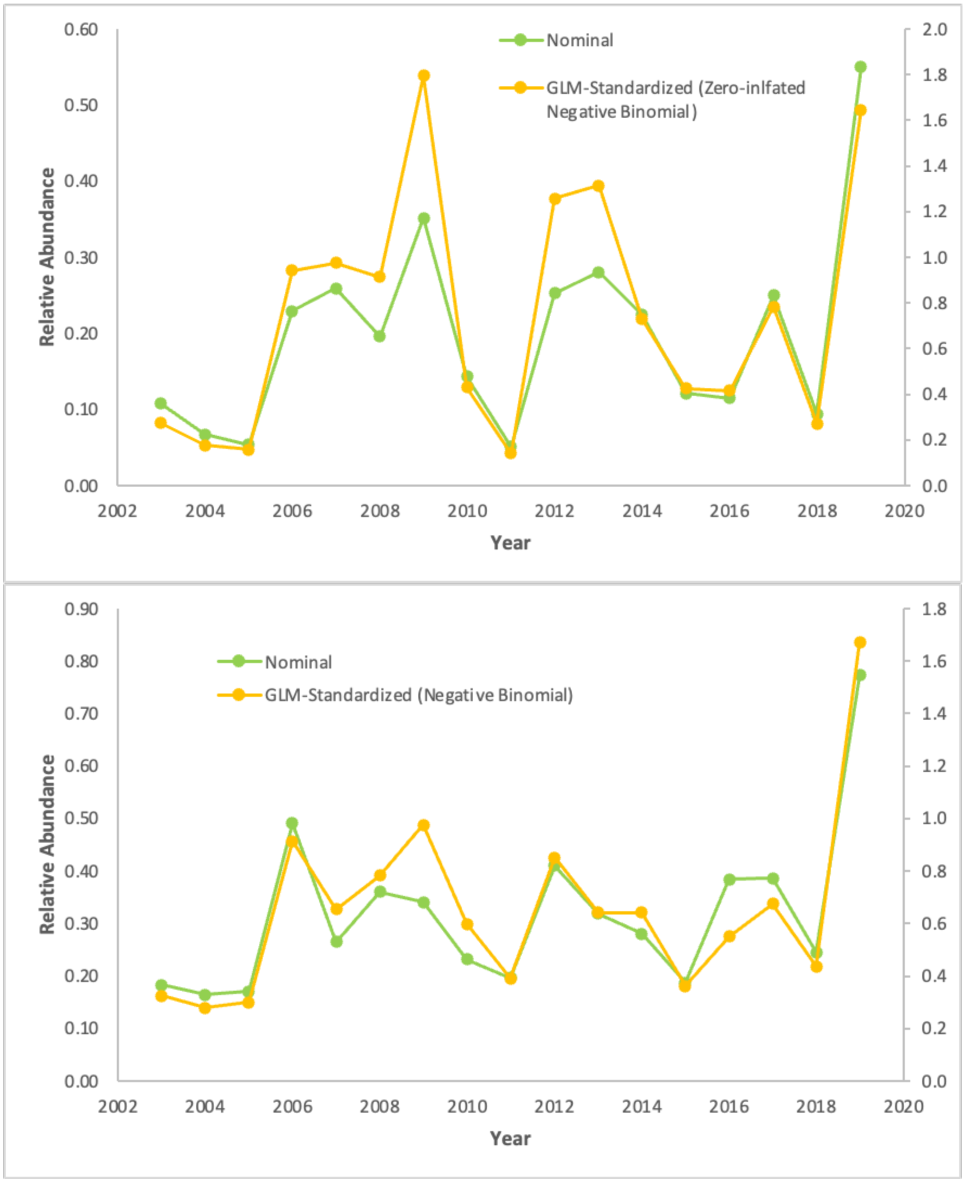


Figure 2.14. Nominal and standardized abundance indices of Program 915 spring (top) and fall (bottom) surveys, 2003–2019.

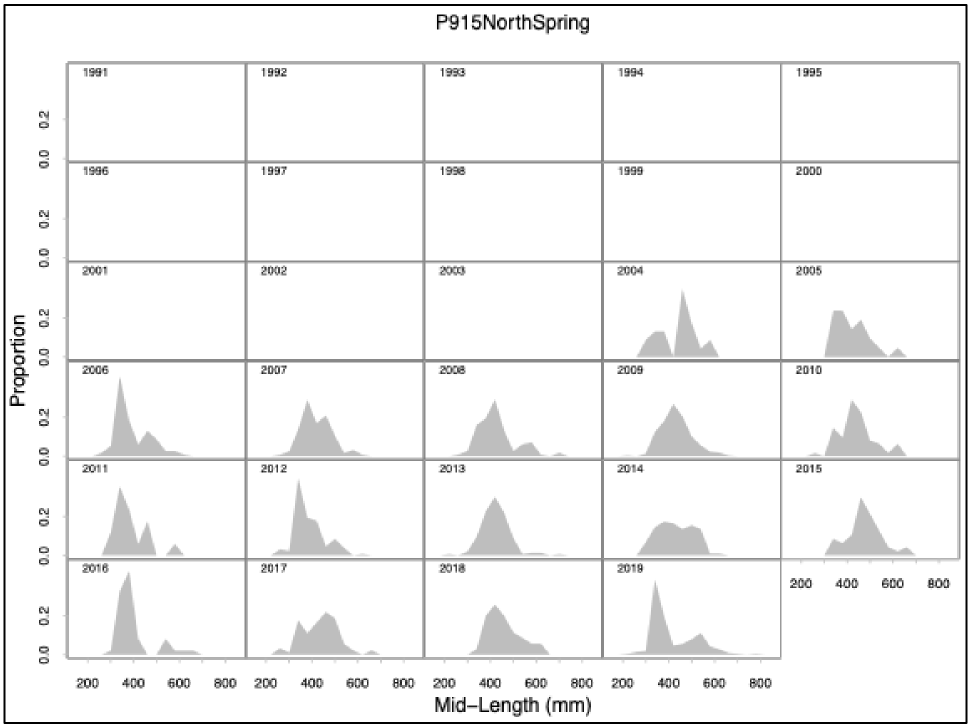


Figure 2.15. Length composition of Program 915 spring survey of Spotted Seatrout, 2004–2019.

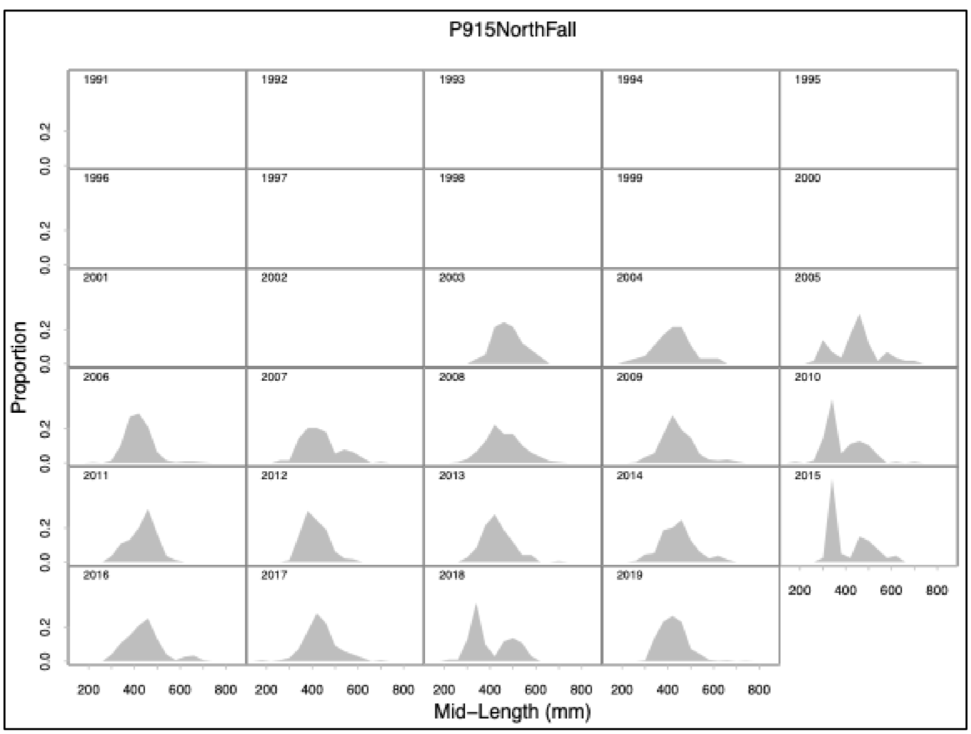


Figure 2.16. Length composition of Program 915 fall survey of Spotted Seatrout, 2003–2019.

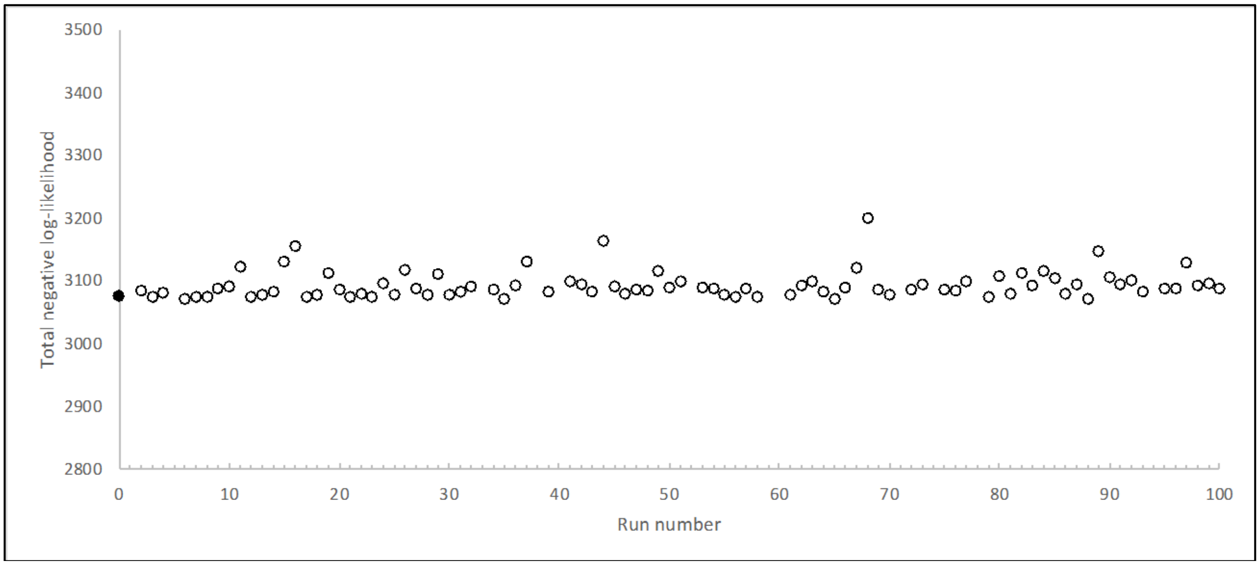


Figure 3.1. Negative log-likelihood values produced from the 100 jitter runs in which initial parameter values were jittered by 10%. The solid black circle is the value from the base model. Figure only shows values from the converged runs.

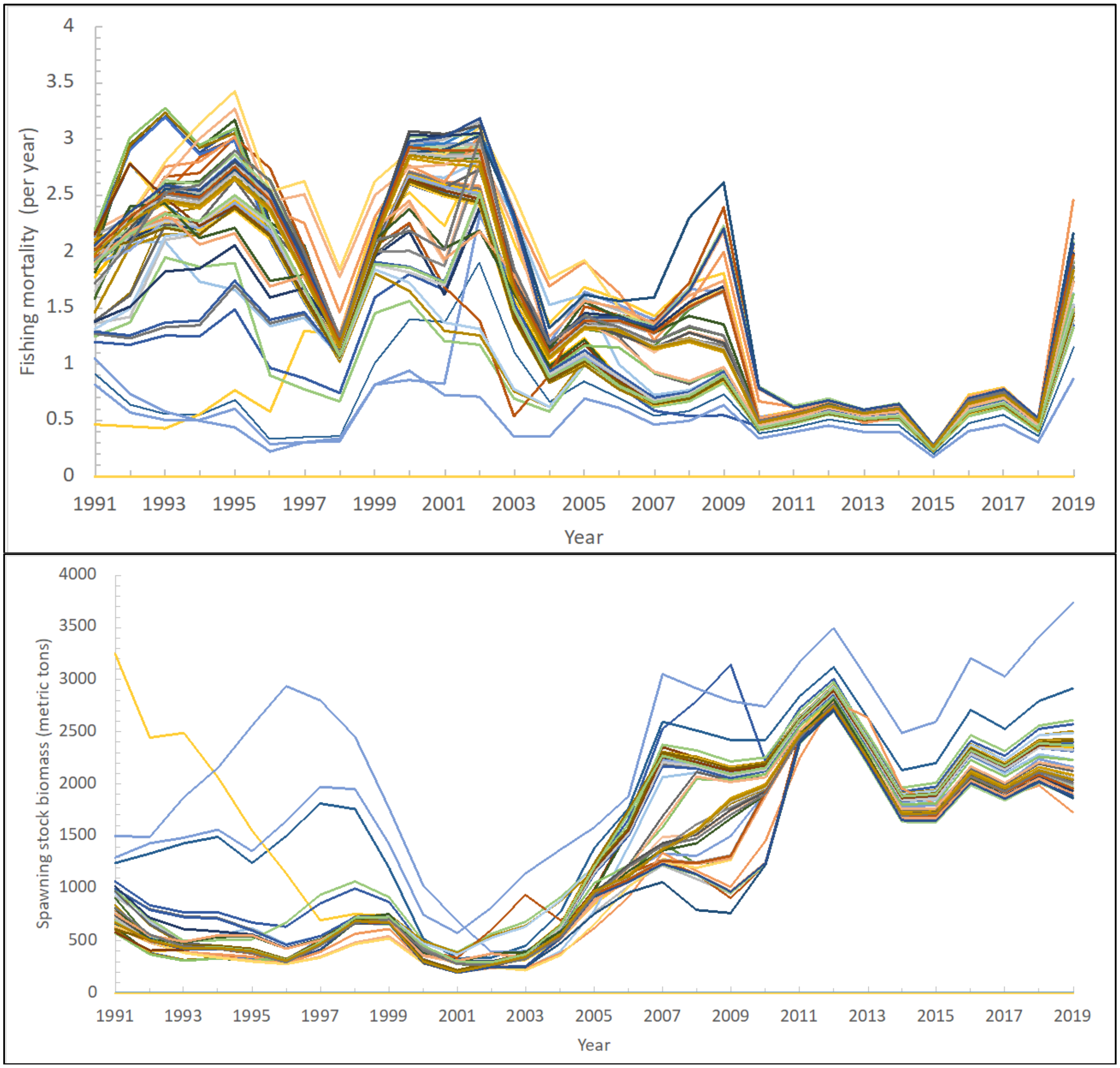


Figure 3.2. Predicted fishing mortality (per year; top panel) and spawning stock biomass (metric tons; bottom panel) from the converged jitter runs in which initial parameter values were jittered by 10%.

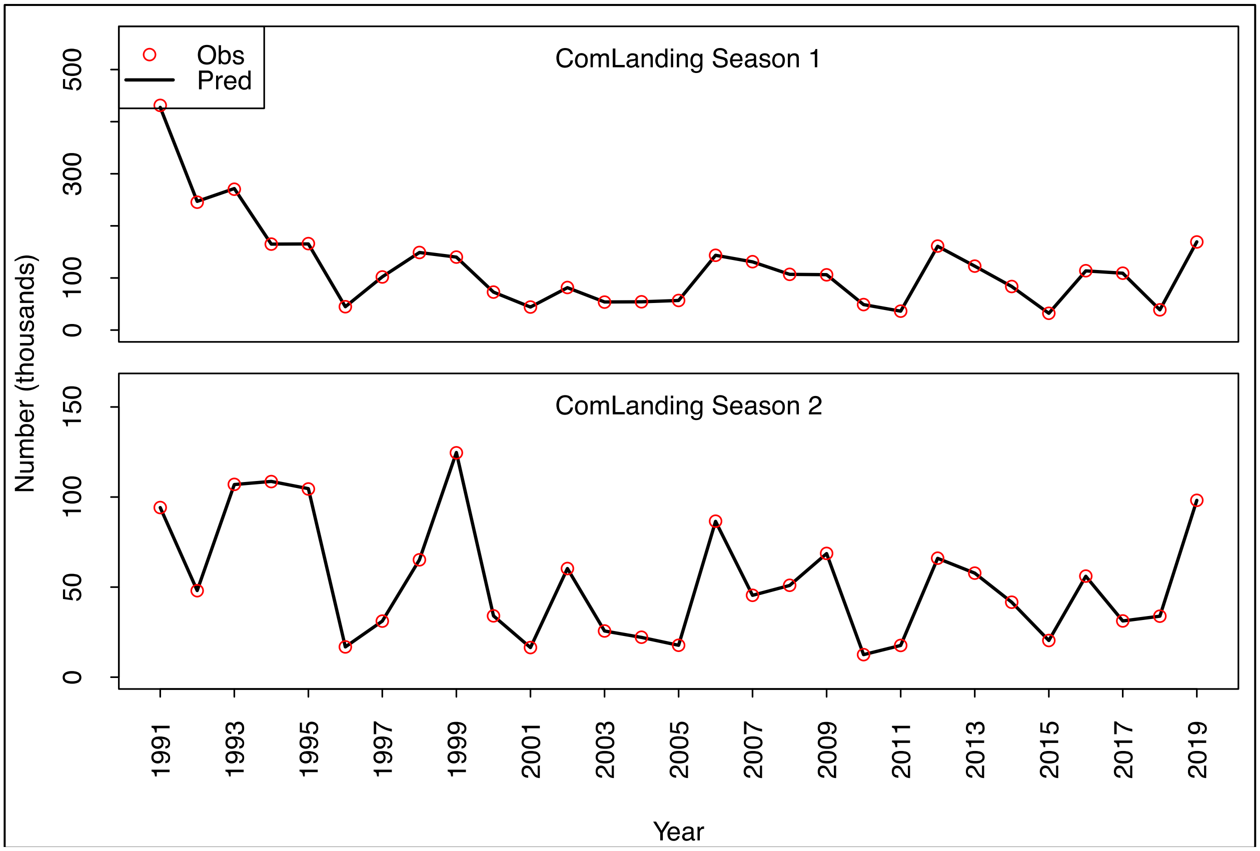
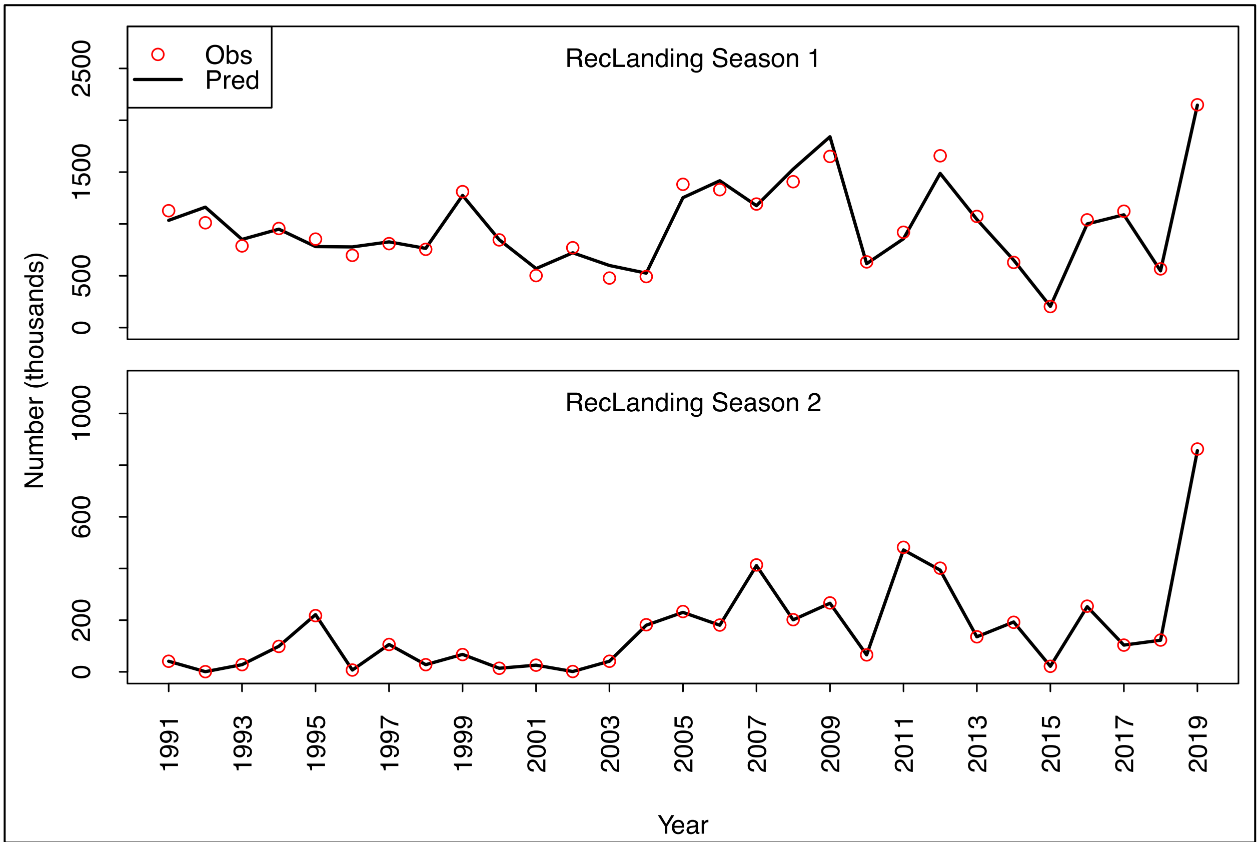


Figure 3.3. Predicted (line) and observed (circle) commercial landings (thousands of fish) of Spotted Seatrout from the base model of the stock assessment, 1991–2019. Season 1—non-winter season, March–November; Season 2—winter season, December–February.



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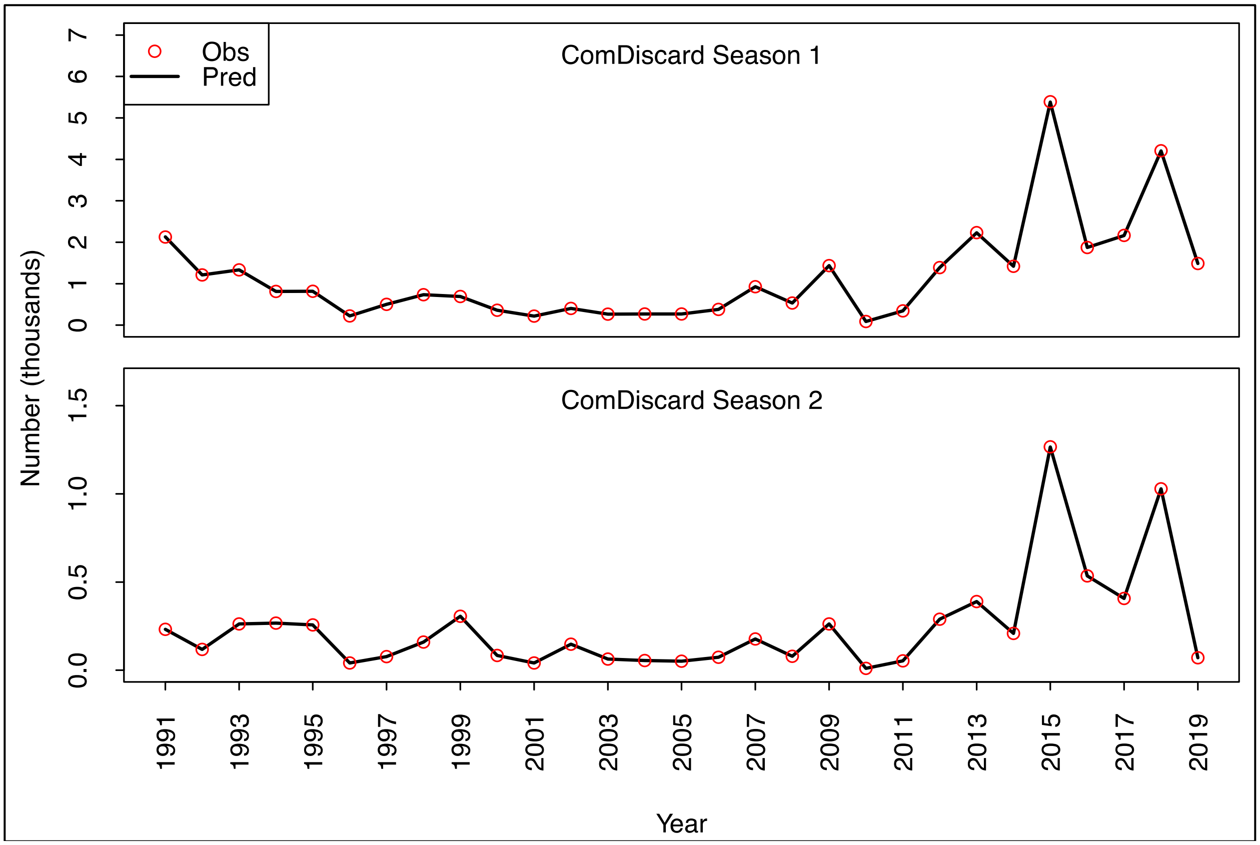


Figure 3.5. Predicted (line) and observed (circle) commercial discards (thousands of fish) of Spotted Seatrout from the base model of the stock assessment, 1991–2019. Season 1—non-winter season, March–November; Season 2—winter season, December–February.

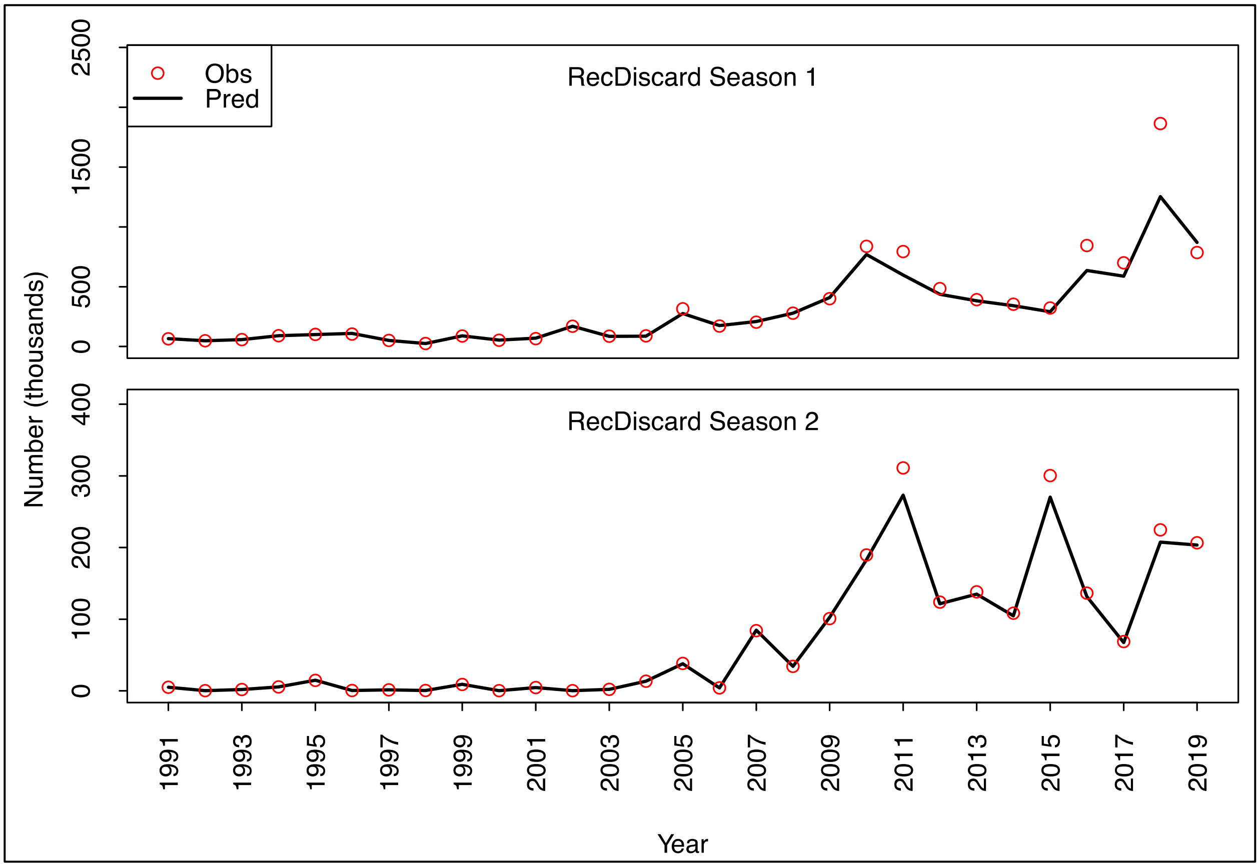


Figure 3.6. Predicted (line) and observed (circle) recreational discards (thousands of fish) of Spotted Seatrout from the base model of the stock assessment, 1991–2019. Season 1—non-winter season, March–November; Season 2—winter season, December–February.

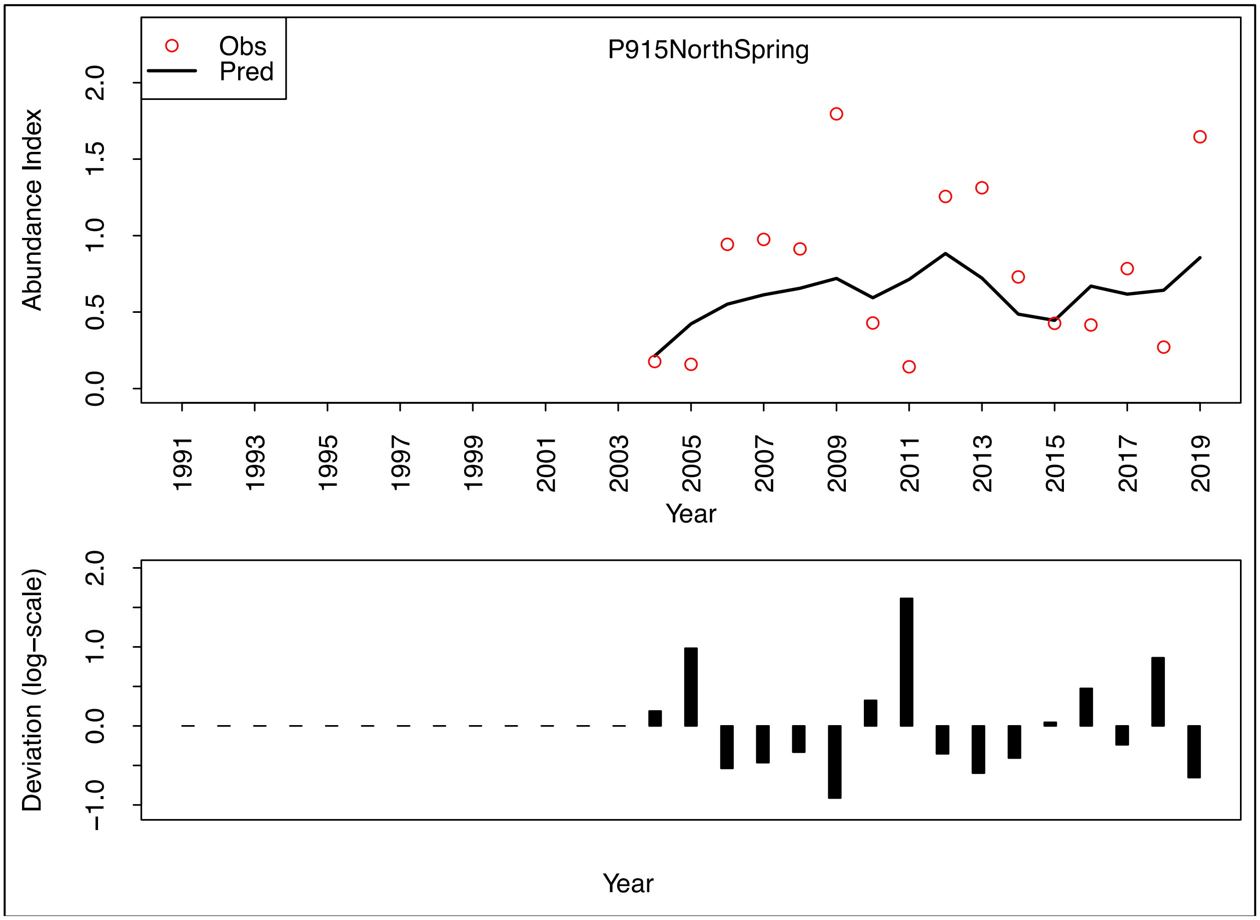


Figure 3.7. Predicted (line) and observed (circle) abundance index (top panel) and residuals (log-scale; bottom panel) for the P915NorthSpring survey from the base model of the stock assessment, 2004–2019.

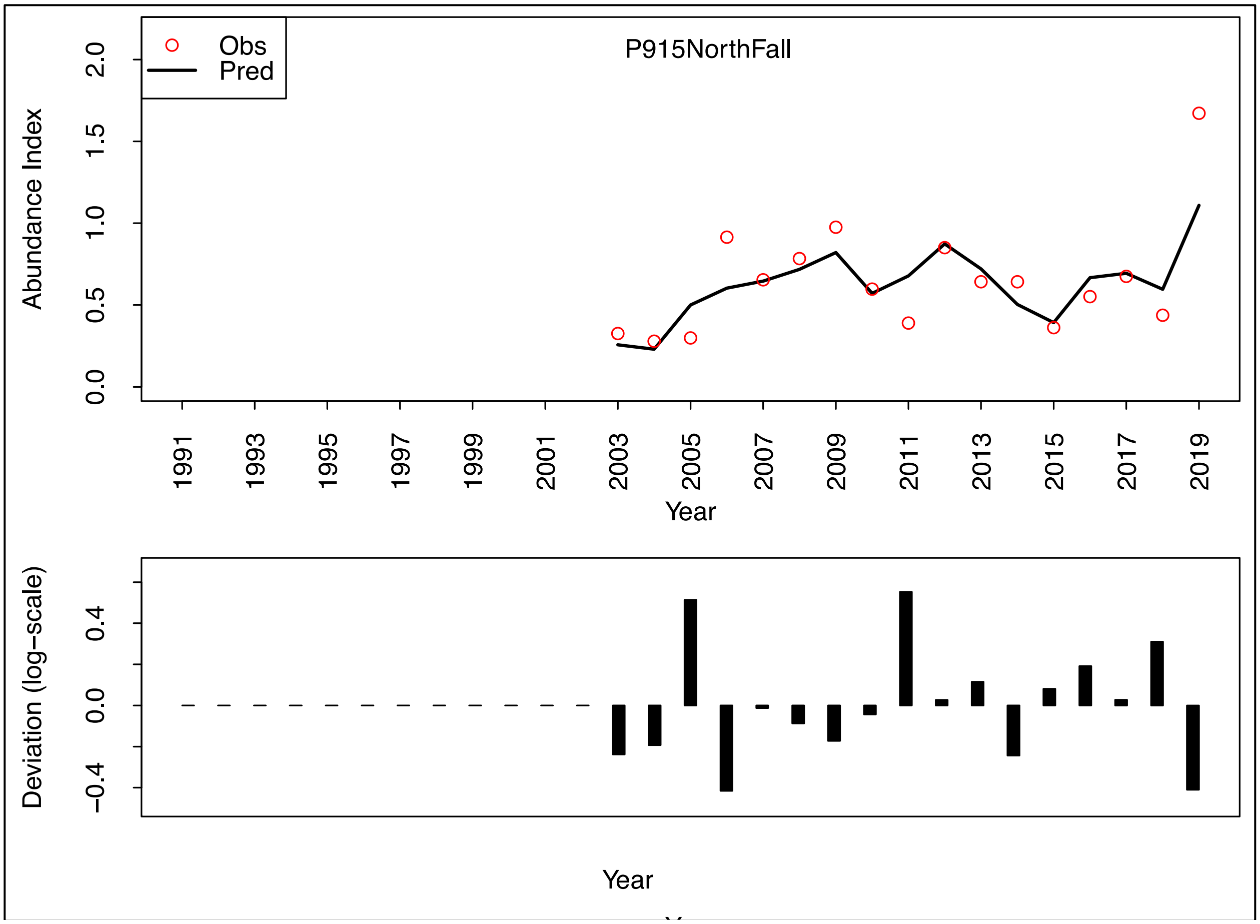


Figure 3.8. Predicted (line) and observed (circle) abundance index (top panel) and residuals (log-scale; bottom panel) for the P915NorthFall survey from the base model of the stock assessment, 2003–2019.

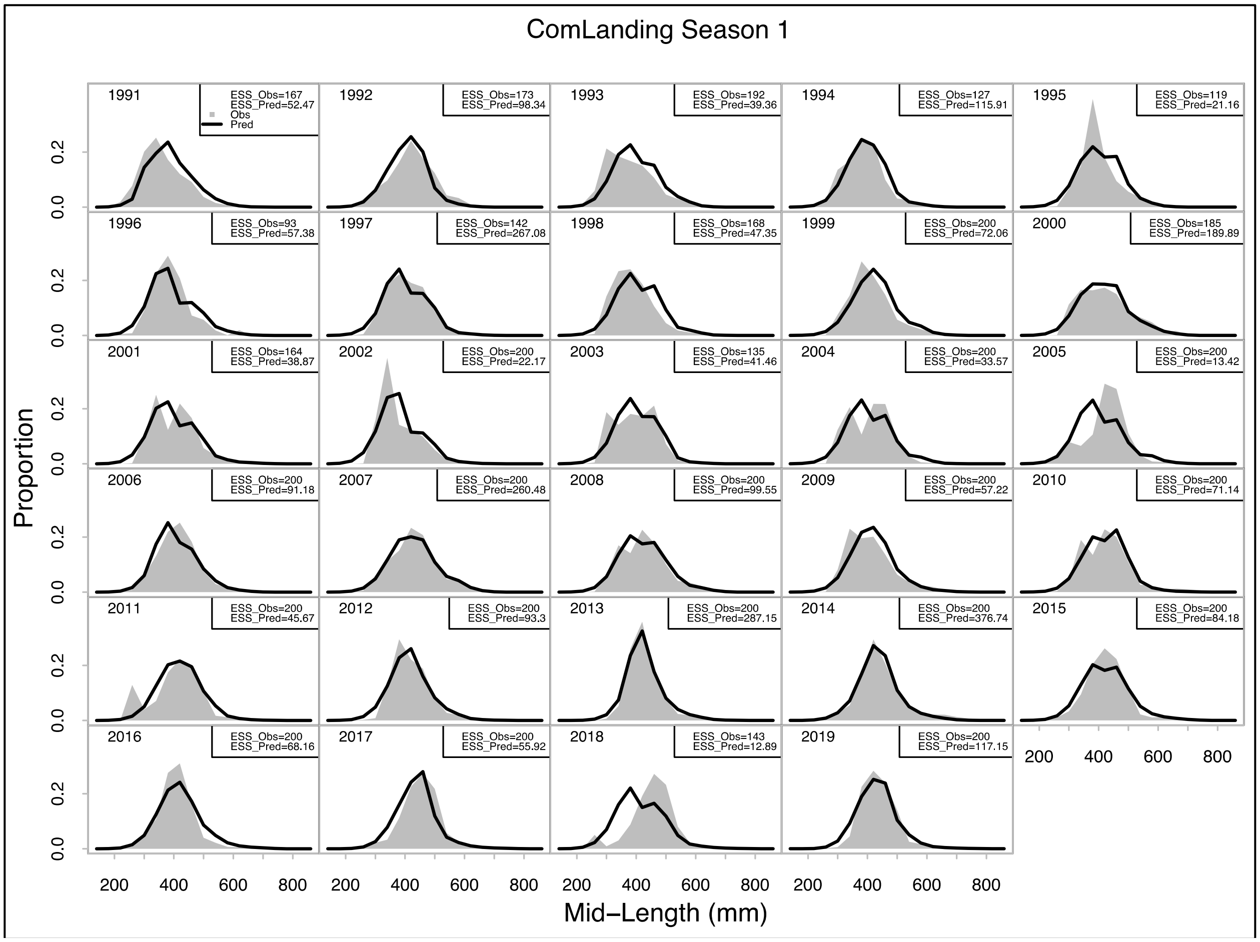


Figure 3.9. Predicted (line) and observed (shaded area) length composition for commercial landings of Spotted Seatrout from the base model of the stock assessment, 1991–2019, for Season 1 (non-winter season, March–November). ESS = effective sample size.

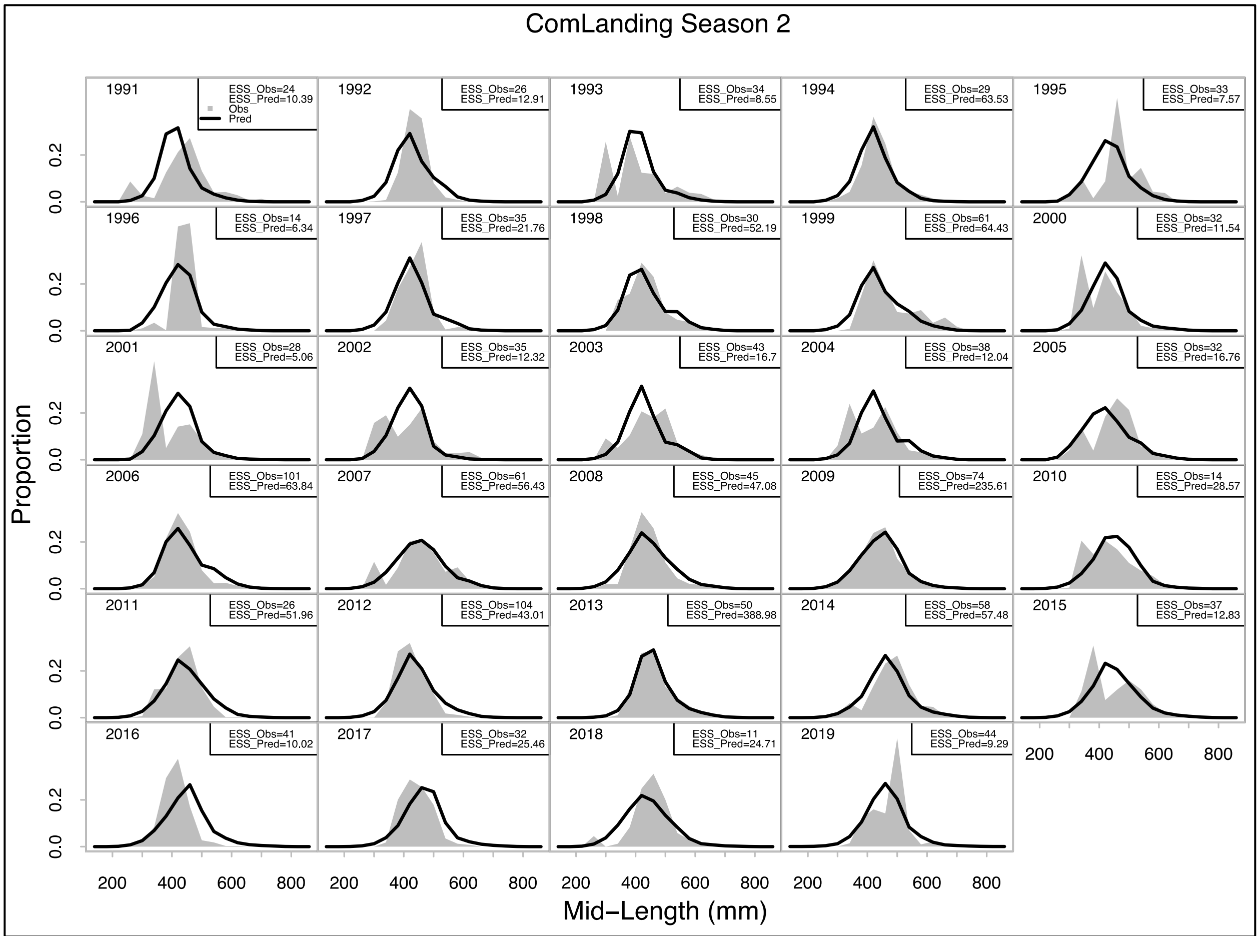


Figure 3.10. Predicted (line) and observed (shaded area) length composition for commercial landings of Spotted Seatrout from the base model of the stock assessment, 1991–2019, for Season 2 (winter season, December–February). ESS = effective sample size.

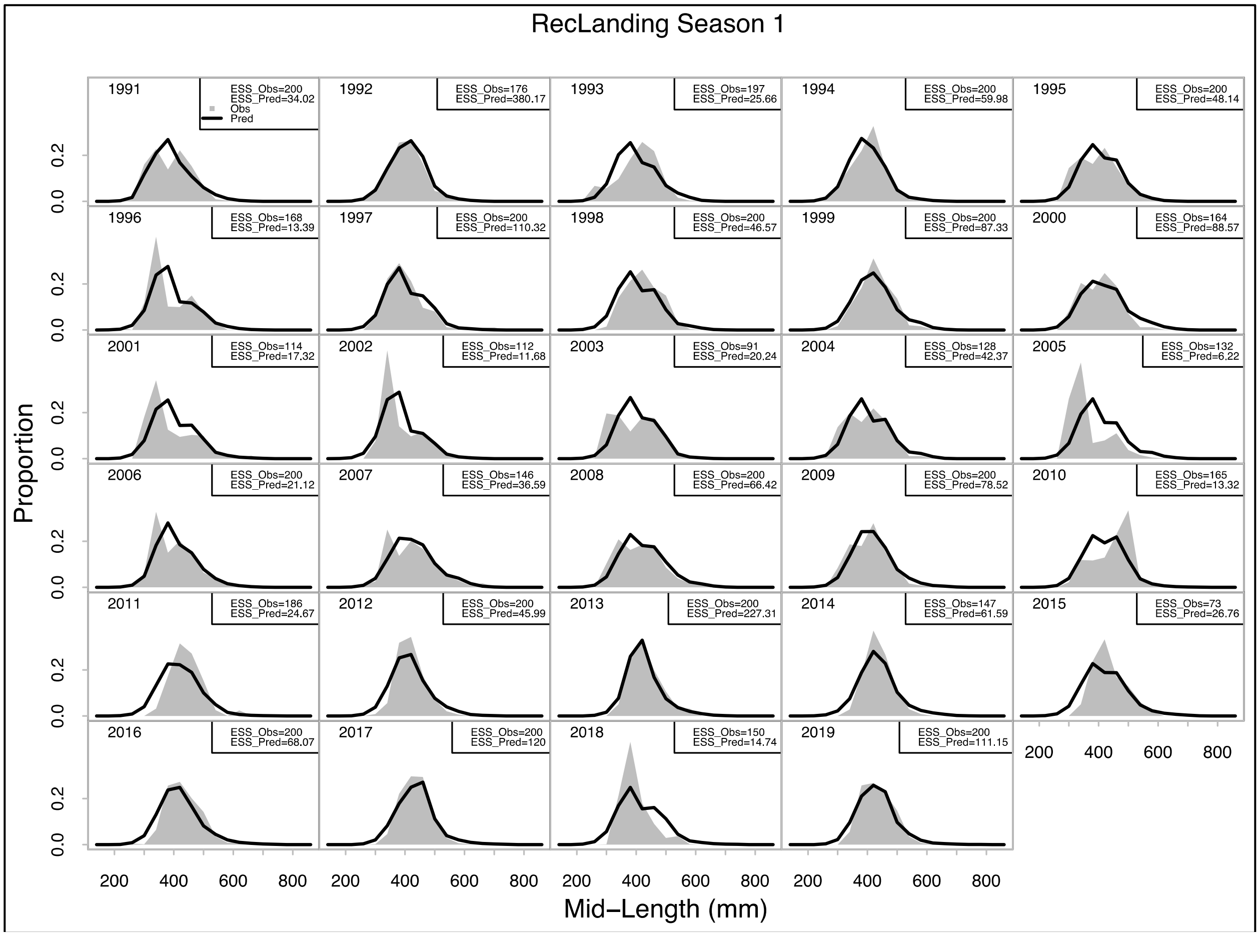


Figure 3.11. Predicted (line) and observed (shaded area) length composition for recreational landings of Spotted Seatrout from the base model of the stock assessment, 1991–2019, for Season 1 (non-winter season, March–November). ESS = effective sample size.

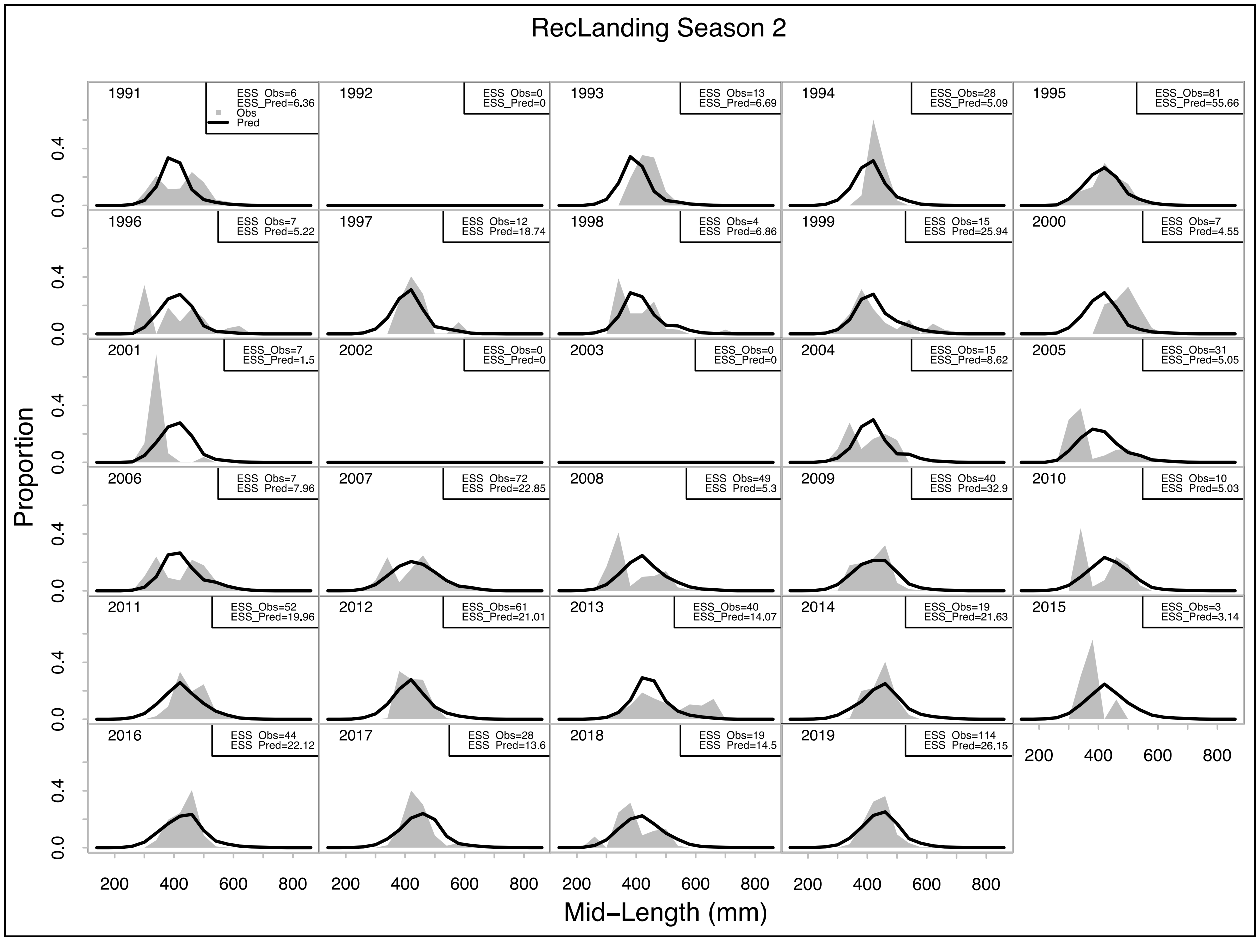


Figure 3.12. Predicted (line) and observed (shaded area) length composition for recreational landings of Spotted Seatrout from the base model of the stock assessment, 1991–2019, for Season 2 (winter season, December–February). ESS = effective sample size. The data in 1992, 2002 and 2003 were removed due to extremely small effective sample size (< 2).

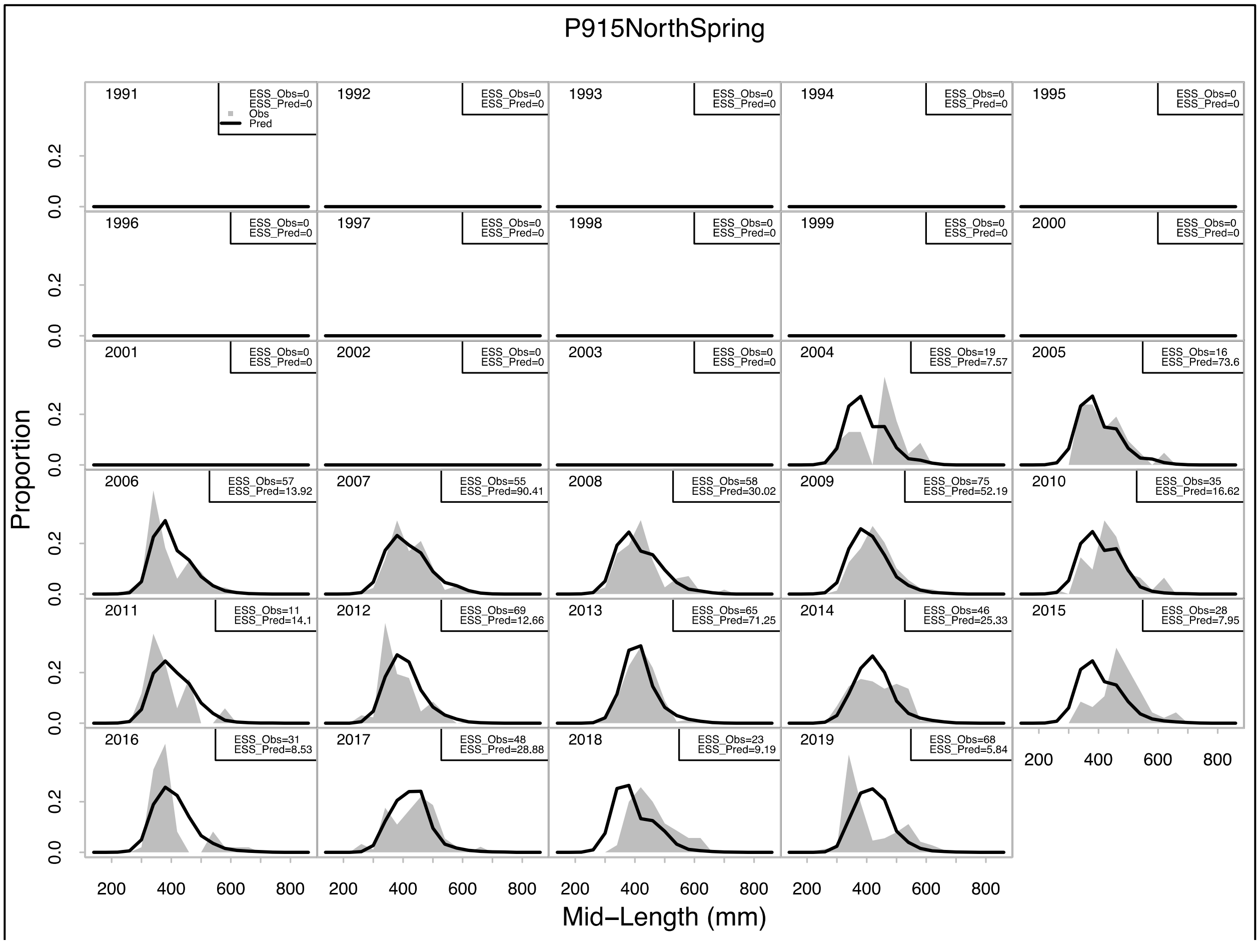
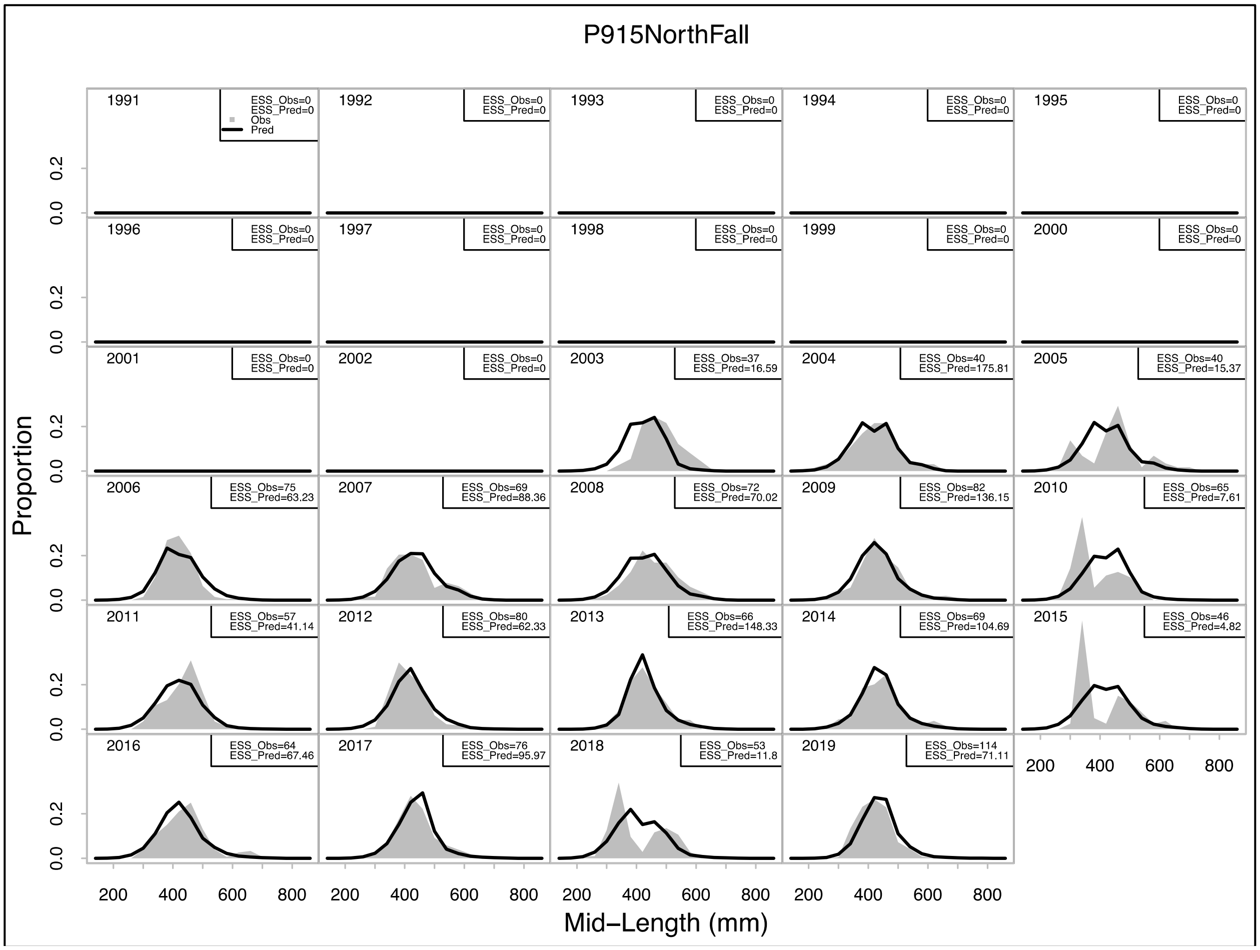


Figure 3.13. Predicted (line) and observed (shaded area) length composition for the P915NorthSpring survey from the base model of the stock assessment, 2004–2019. ESS = effective sample size.



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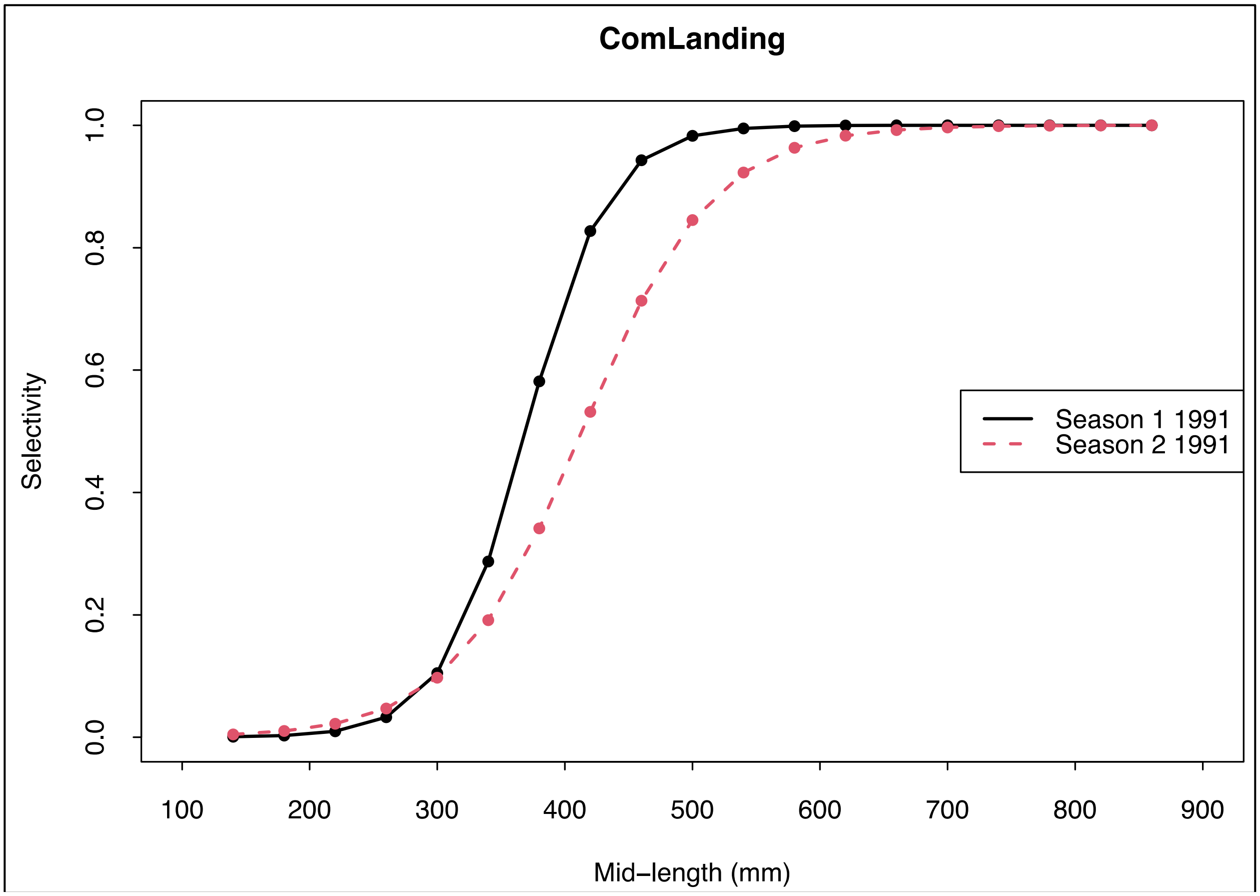

Figure 3.15. Predicted length-based selectivity for the commercial landing fleet from the base model of the stock assessment. Season 1—non-winter season, March–November; Season 2—winter season, December–February.

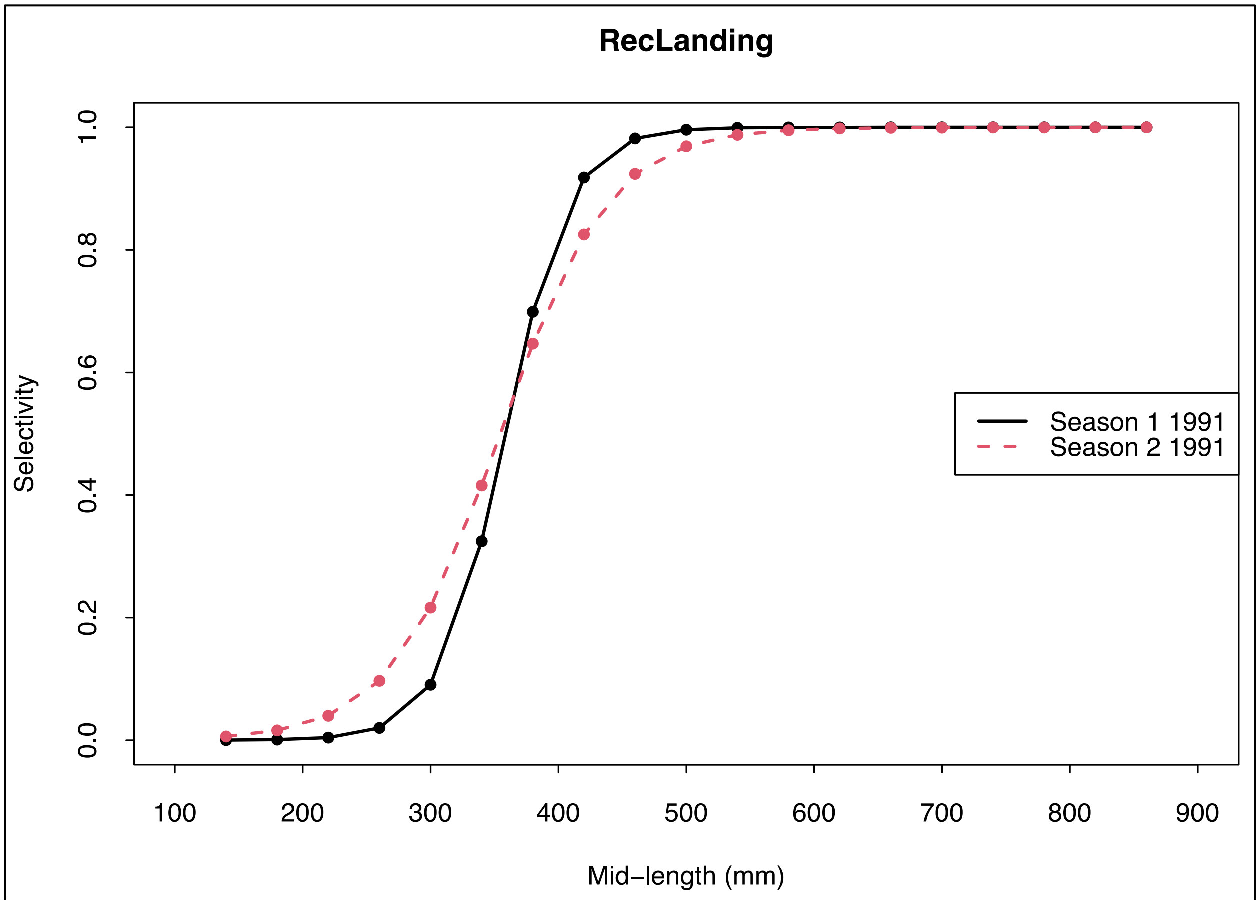

Figure 3.16. Predicted length-based selectivity for the recreational landing fleet from the base model of the stock assessment. Season 1—non-winter season, March–November; Season 2—winter season, December–February.

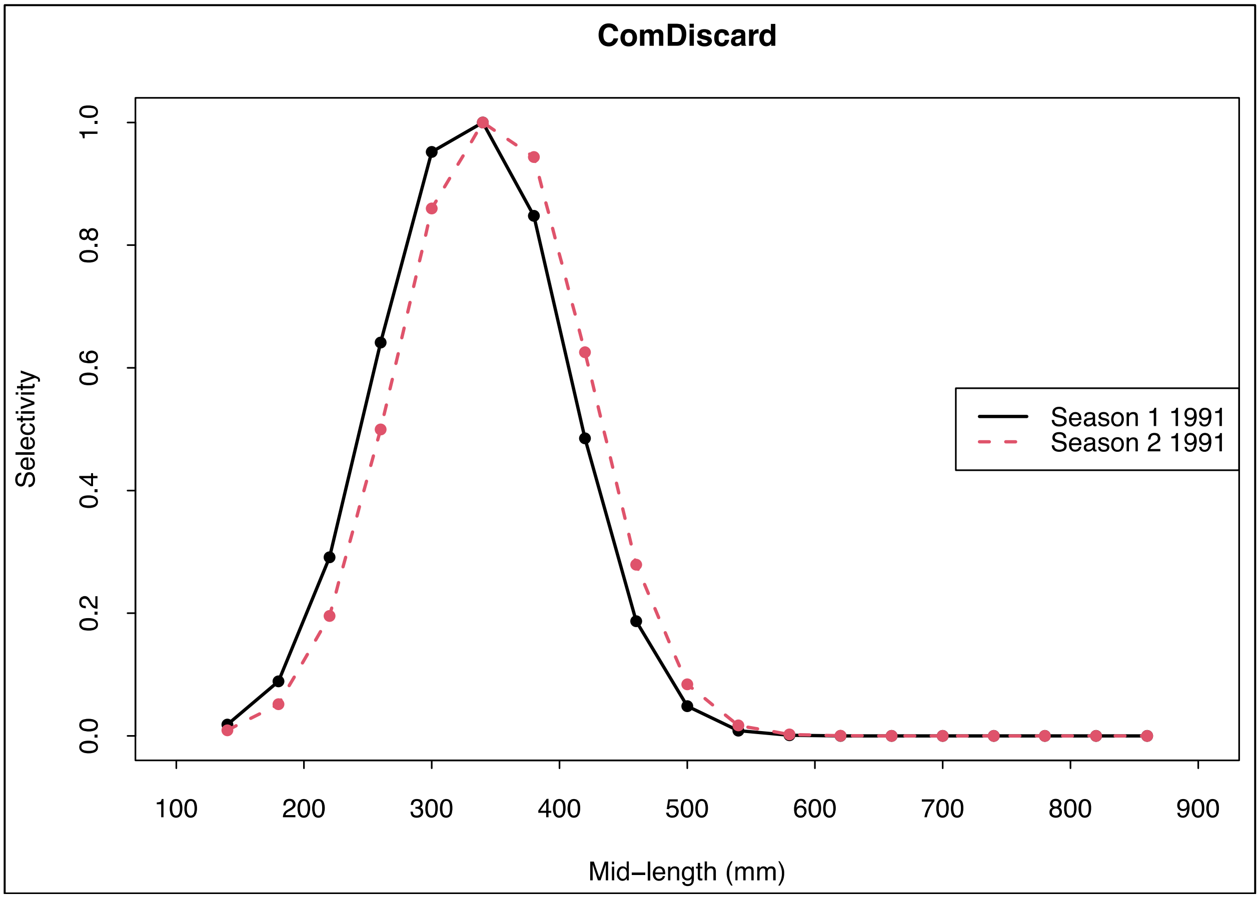

Figure 3.17. Predicted length-based selectivity for the commercial discard fleet from the base model of the stock assessment. Season 1—non-winter season, March–November; Season 2—winter season, December–February.

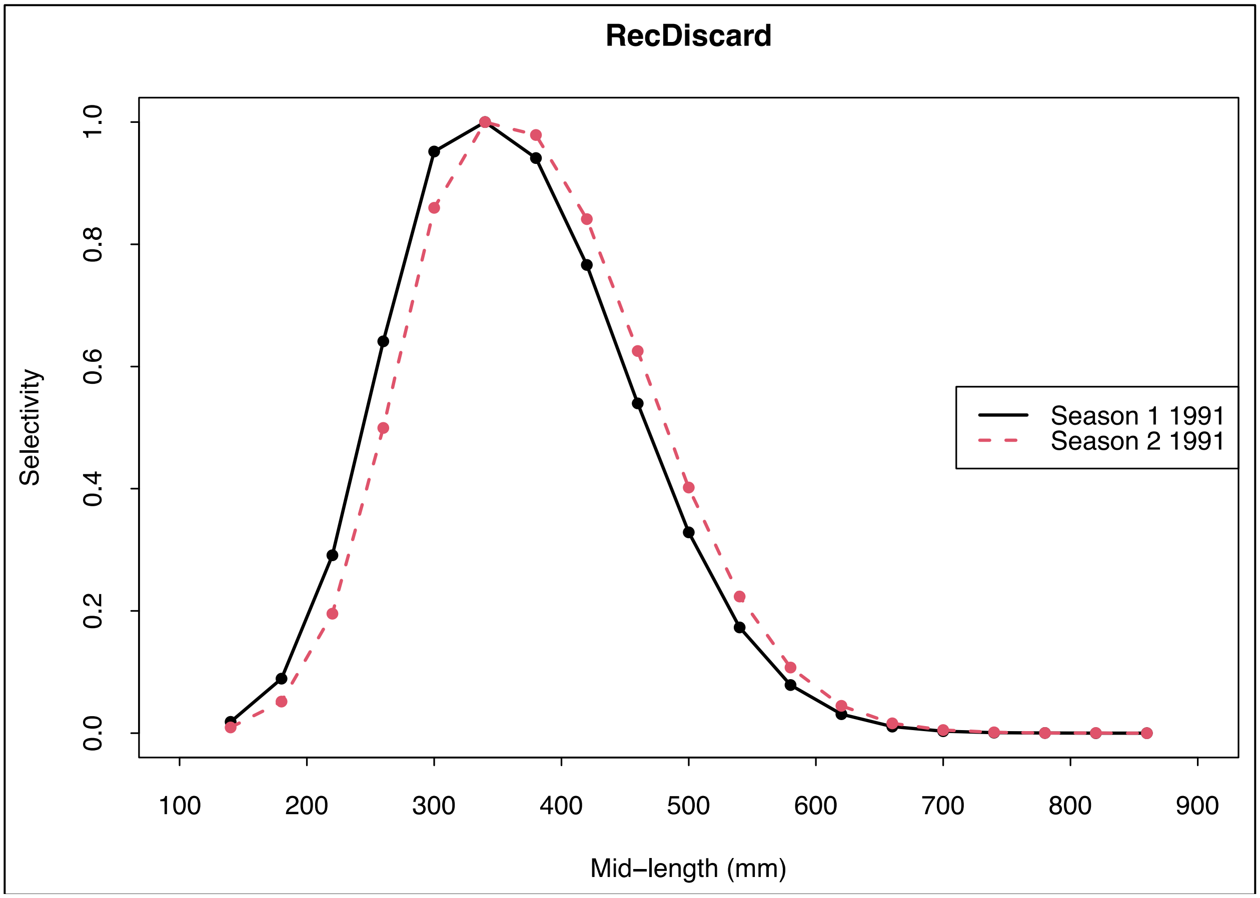

Figure 3.18. Predicted length-based selectivity for the recreational discard fleet from the base model of the stock assessment. Season 1—non-winter season, March–November; Season 2—winter season, December–February.

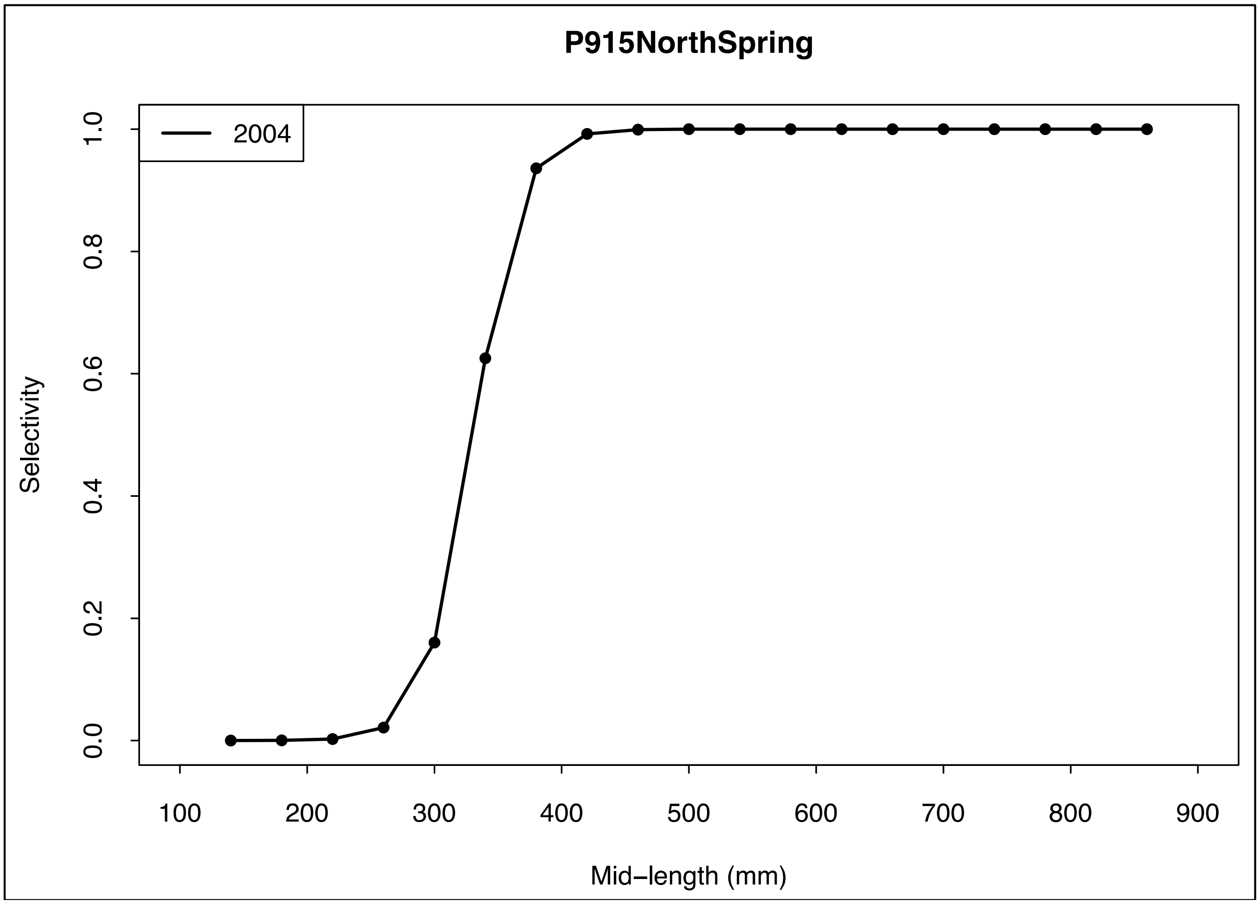

Figure 3.19. Predicted length-based selectivity for the P915NorthSpring survey from the base model of the stock assessment.

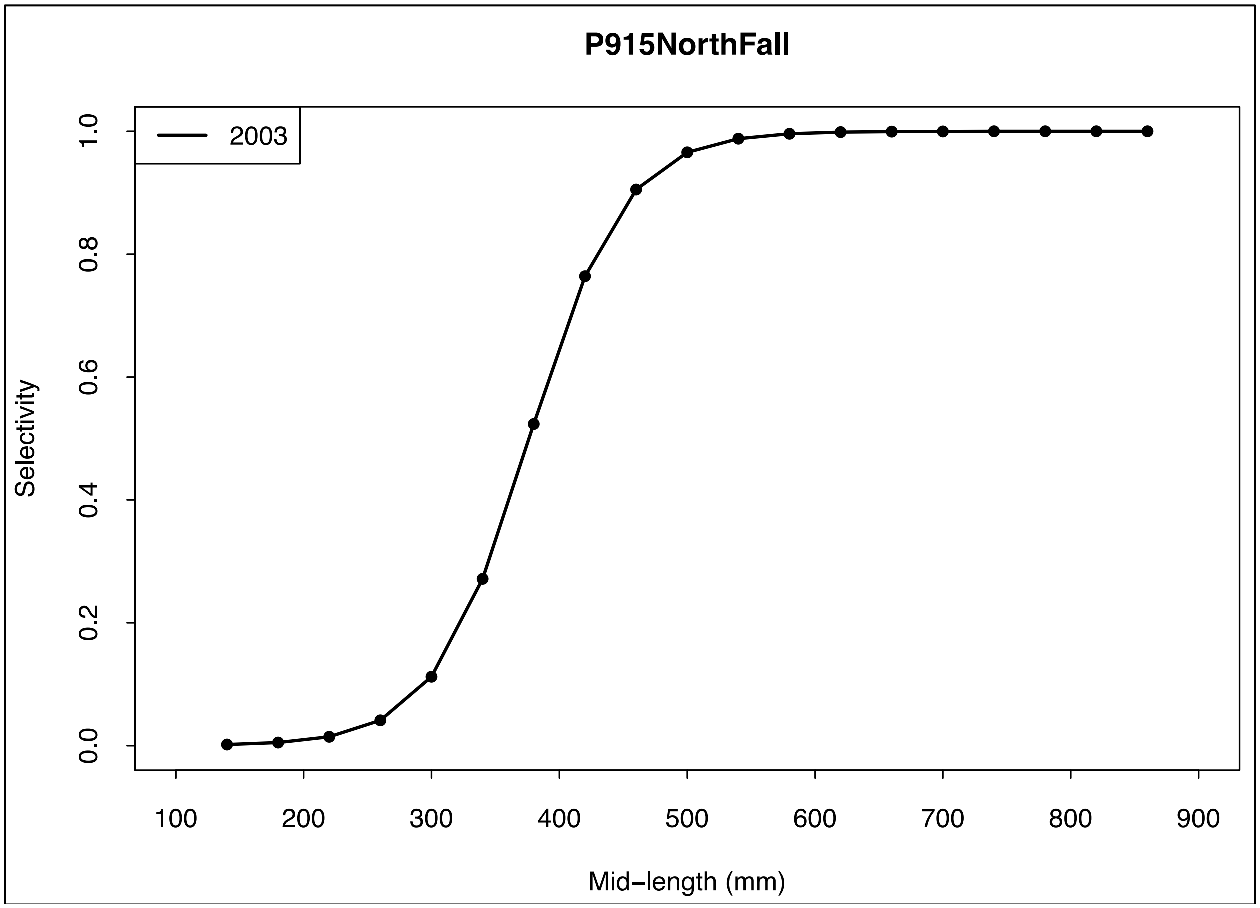

Figure 3.20. Predicted length-based selectivity for the P915NorthFall survey from the base model of the stock assessment.

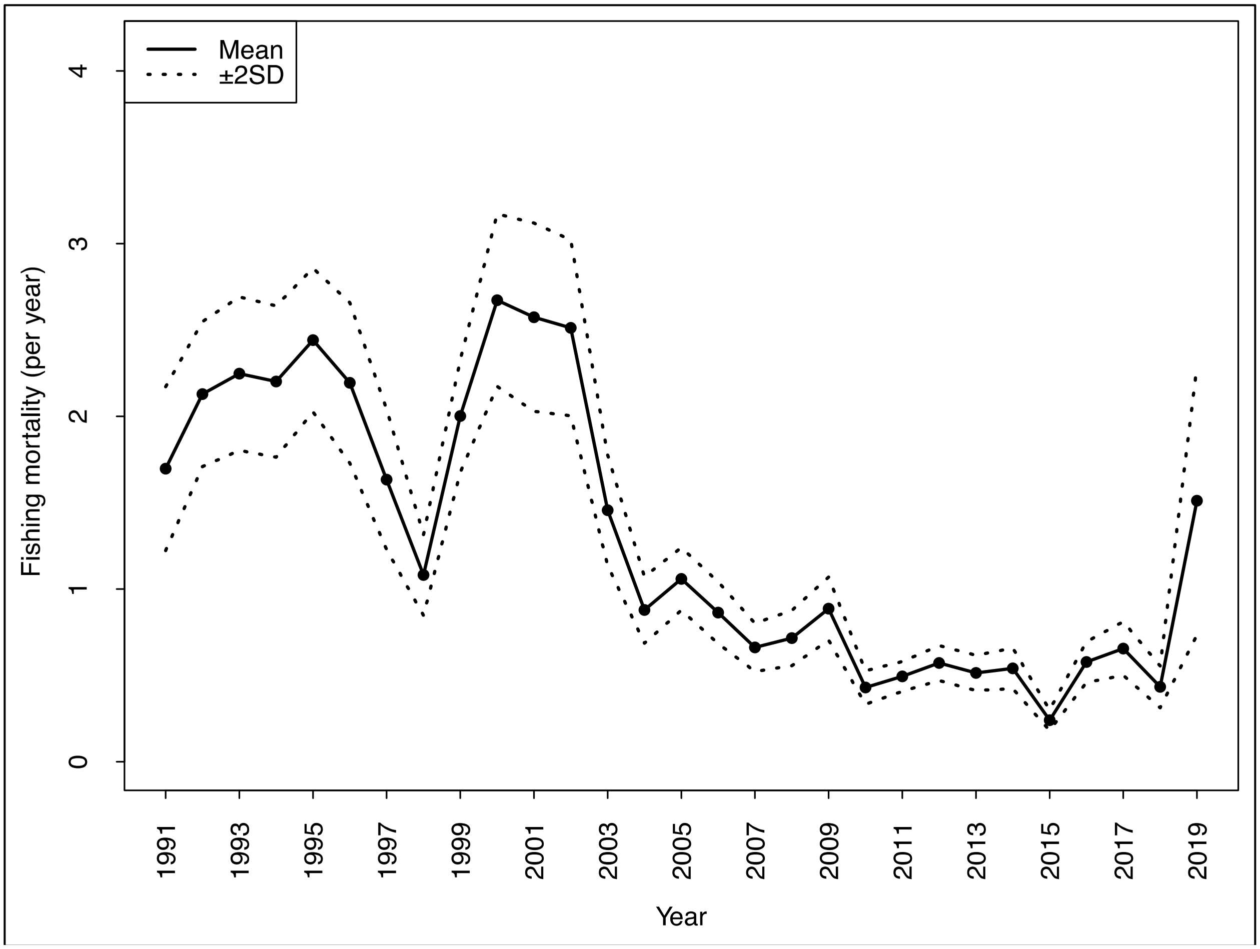

Figure 3.21. Predicted fishing mortality (per year) from the base model of the stock assessment, 1991–2019.

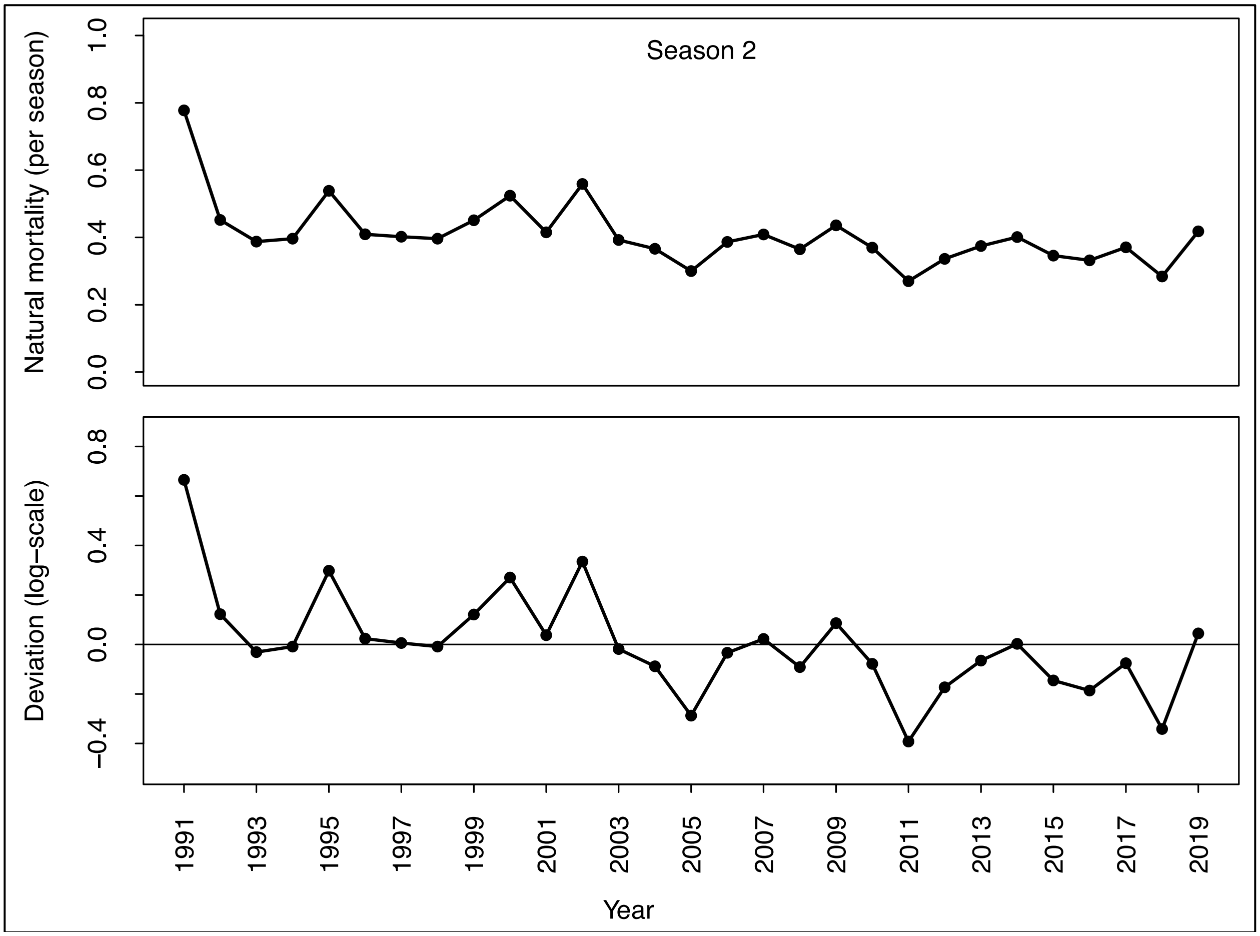

Figure 3.22. Predicted mean natual mortality (per season; top panel) and deviation (log-scale; bottom panel) for Season 2 (winter season, December–February) from the base model of the stock assessment, 1991–2019.

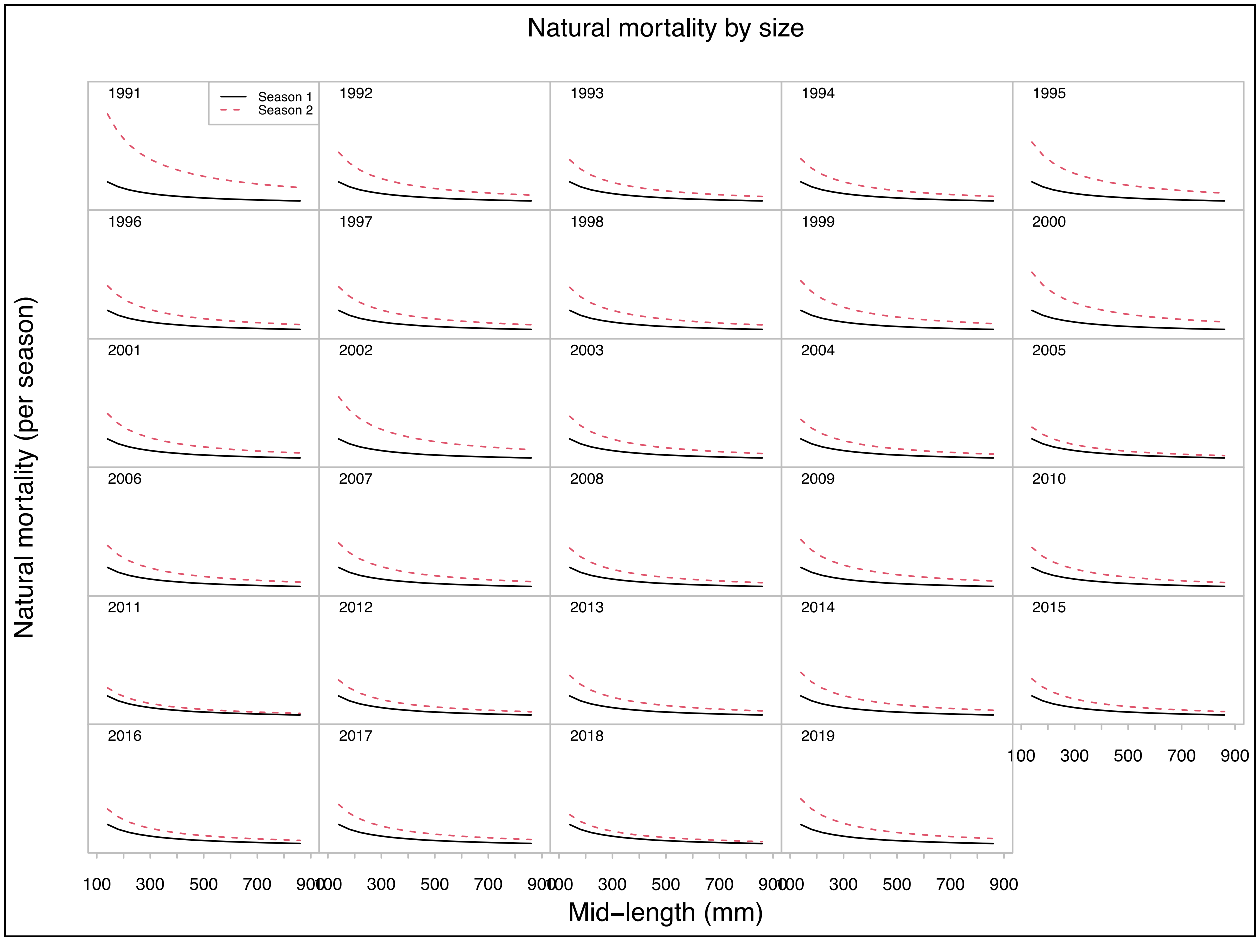

Figure 3.23. Predicted length-based natual mortality (per season) from the base model of the stock assessment, 1991–2019. Season 1—non-winter season, March–November; Season 2—winter season, December–February.

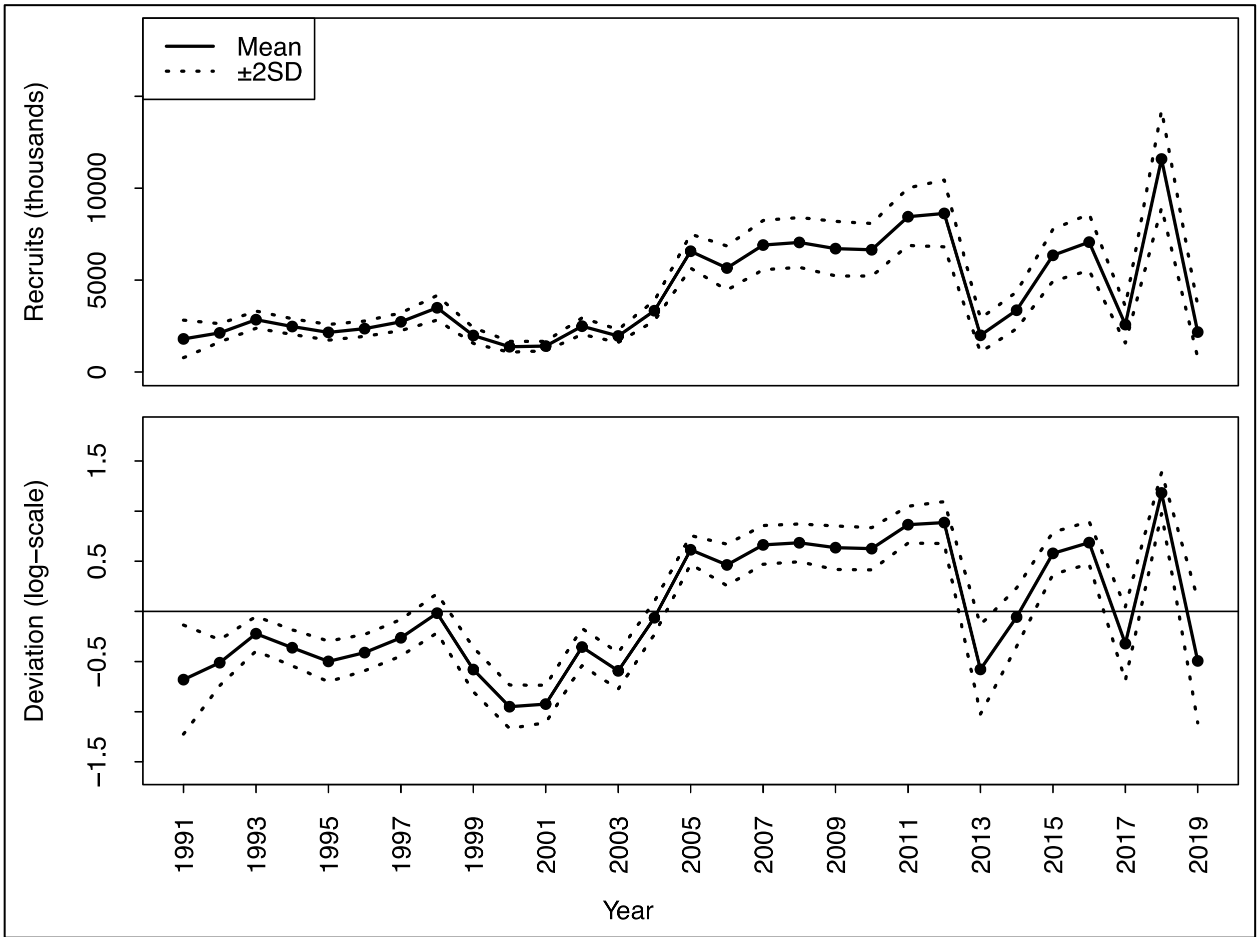

Figure 3.24. Predicted recruits (thousands of fish; top panel) and deviation (log-scale; bottom panel) from the base model of the stock assessment, 1991–2019.

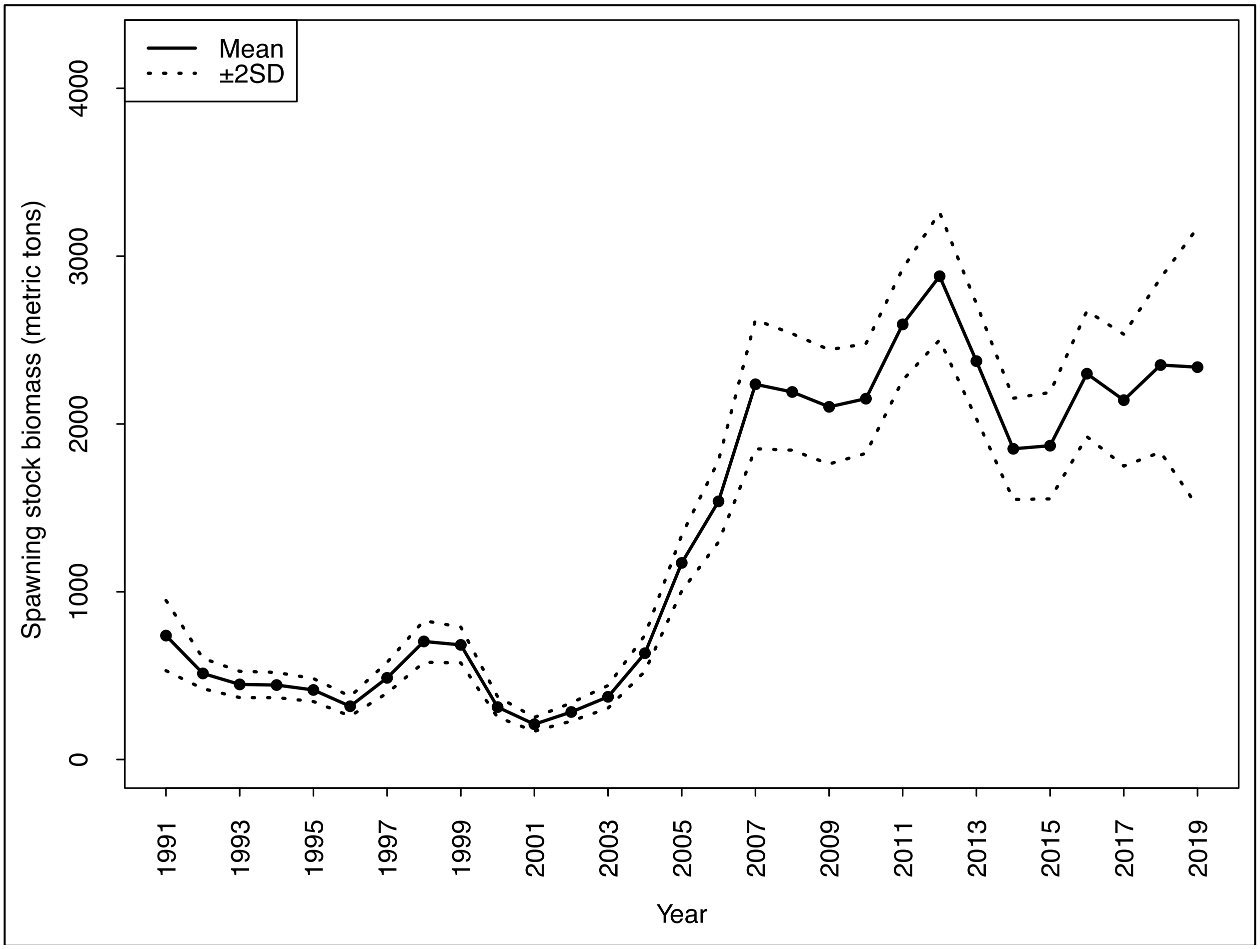

Figure 3.25. Predicted spawning stock biomass (metric tons) from the base model of the stock assessment, 1991–2019.

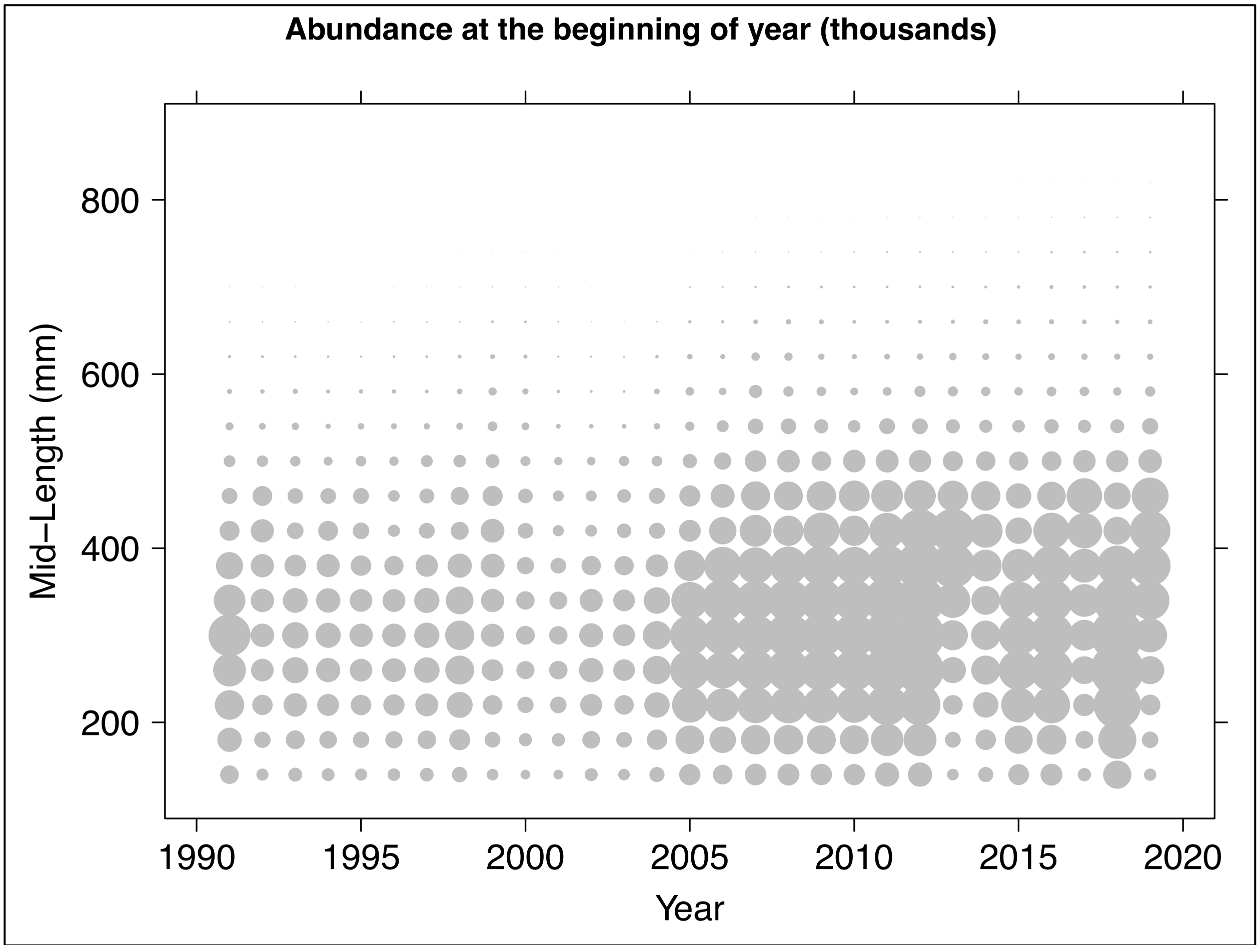

Figure 3.26. Predicted abundance at the beginning of year from the base model of the stock assessment, 1991–2019. The size of the bubble is proportional to the predicted abundance (thousands of fish).

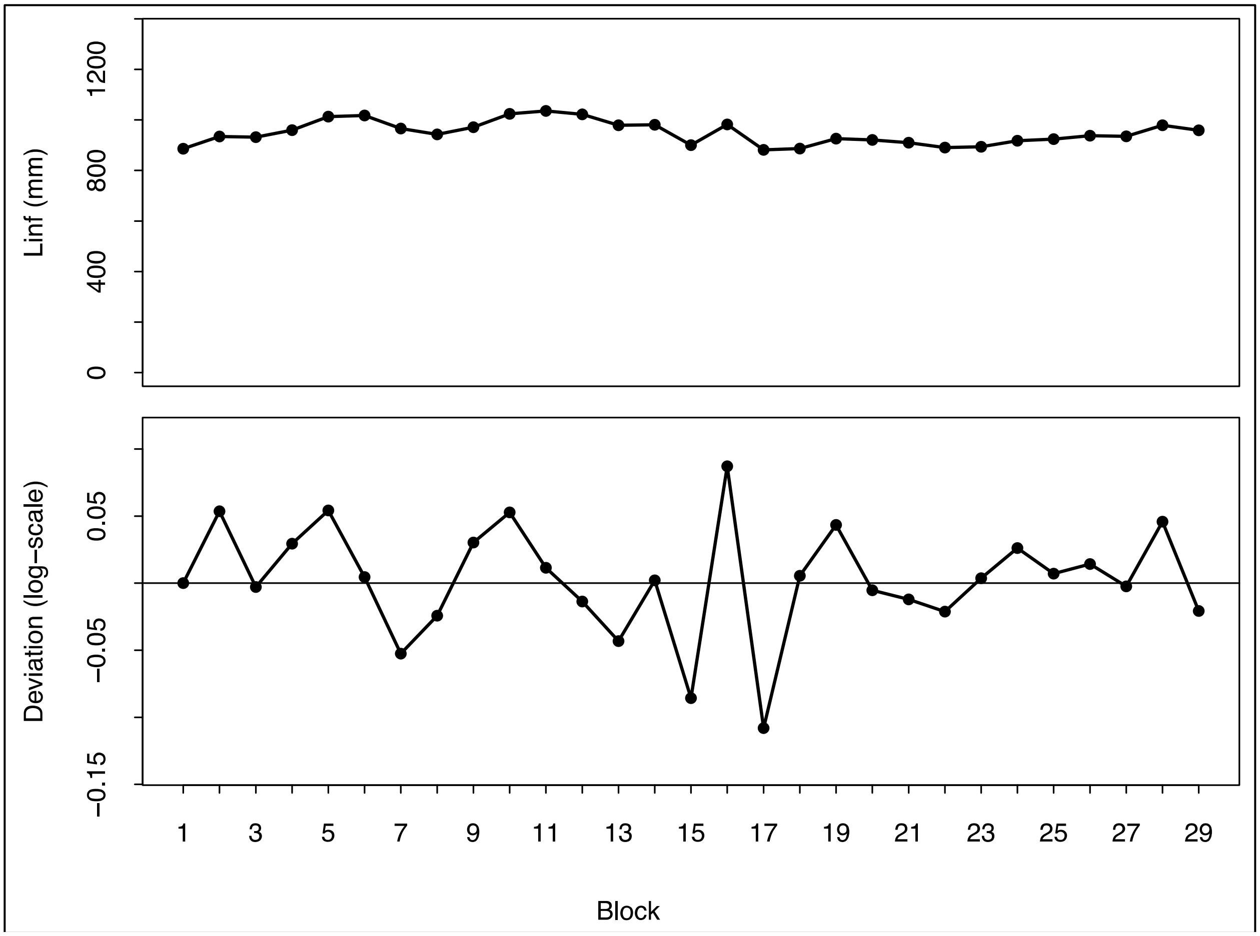

Figure 3.27. Predicted growth parameter L_∞ (mm; top panel) and deviation (log-scale; bottom panel) from the base model of the stock assessment, 1991–2019. Block numbers 1–29 correspond to the year 1991–2019.

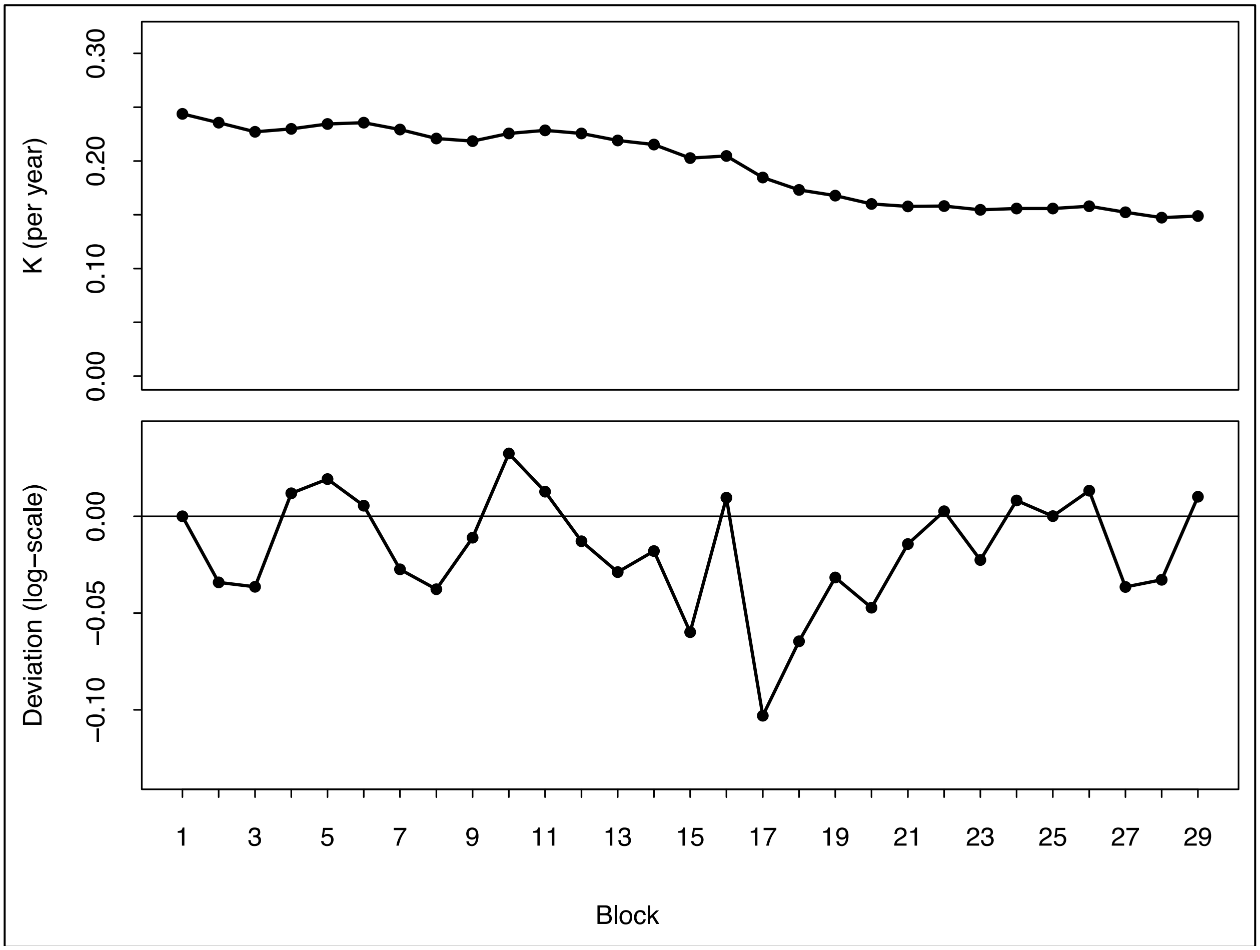

Figure 3.28. Predicted growth parameter *K* (per year; top panel) and deviation (log-scale; bottom panel) from the base model of the stock assessment, 1991–2019. Block numbers 1–29 correspond to the year 1991–2019.

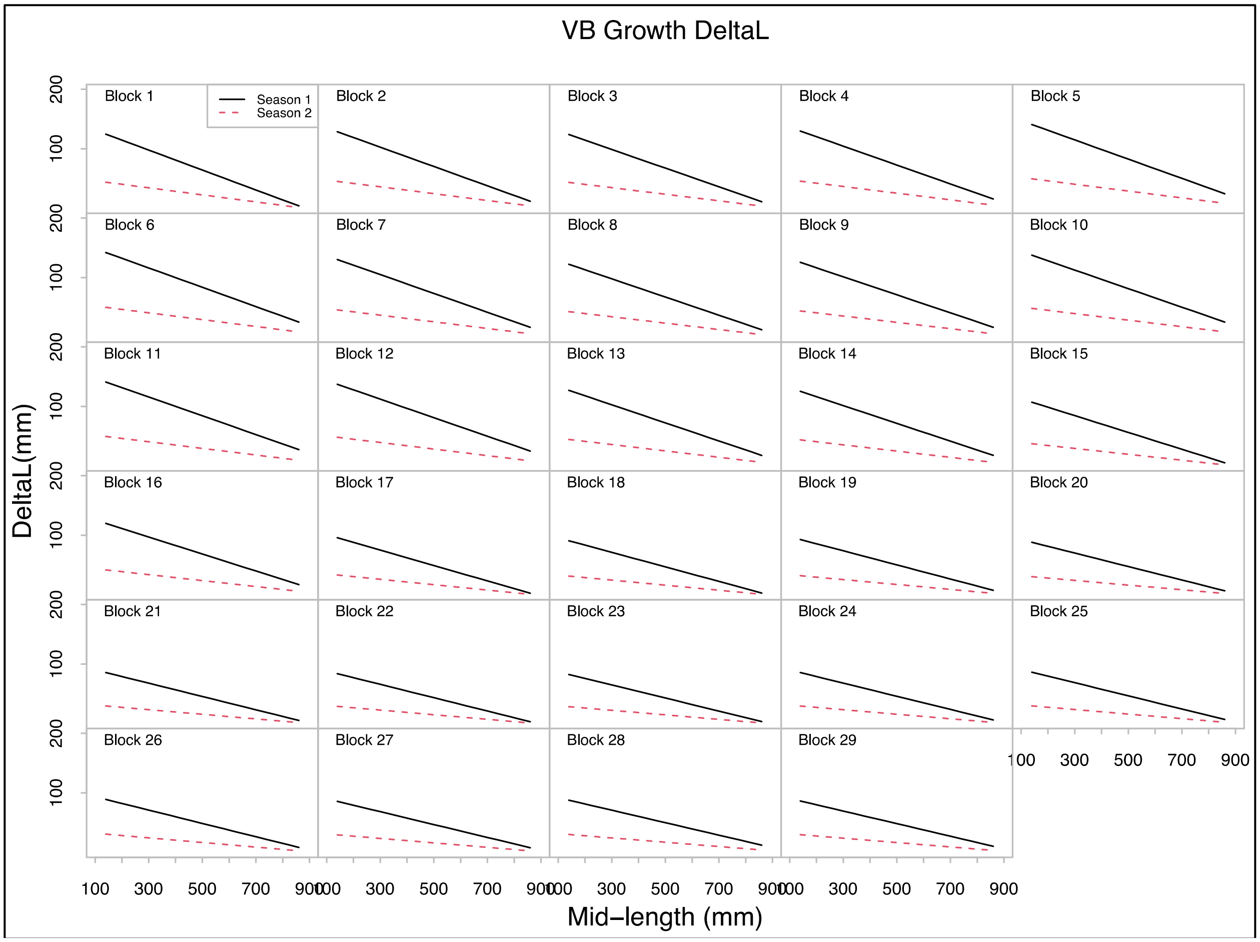

Figure 3.29. Predicted von Bertalanffy growth curve from the base model of the stock assessment, 1991-2019. Season 1—non-winter season, March–November; Season 2—winter season, December–February. Block numbers 1–29 correspond to the year 1991–2019.

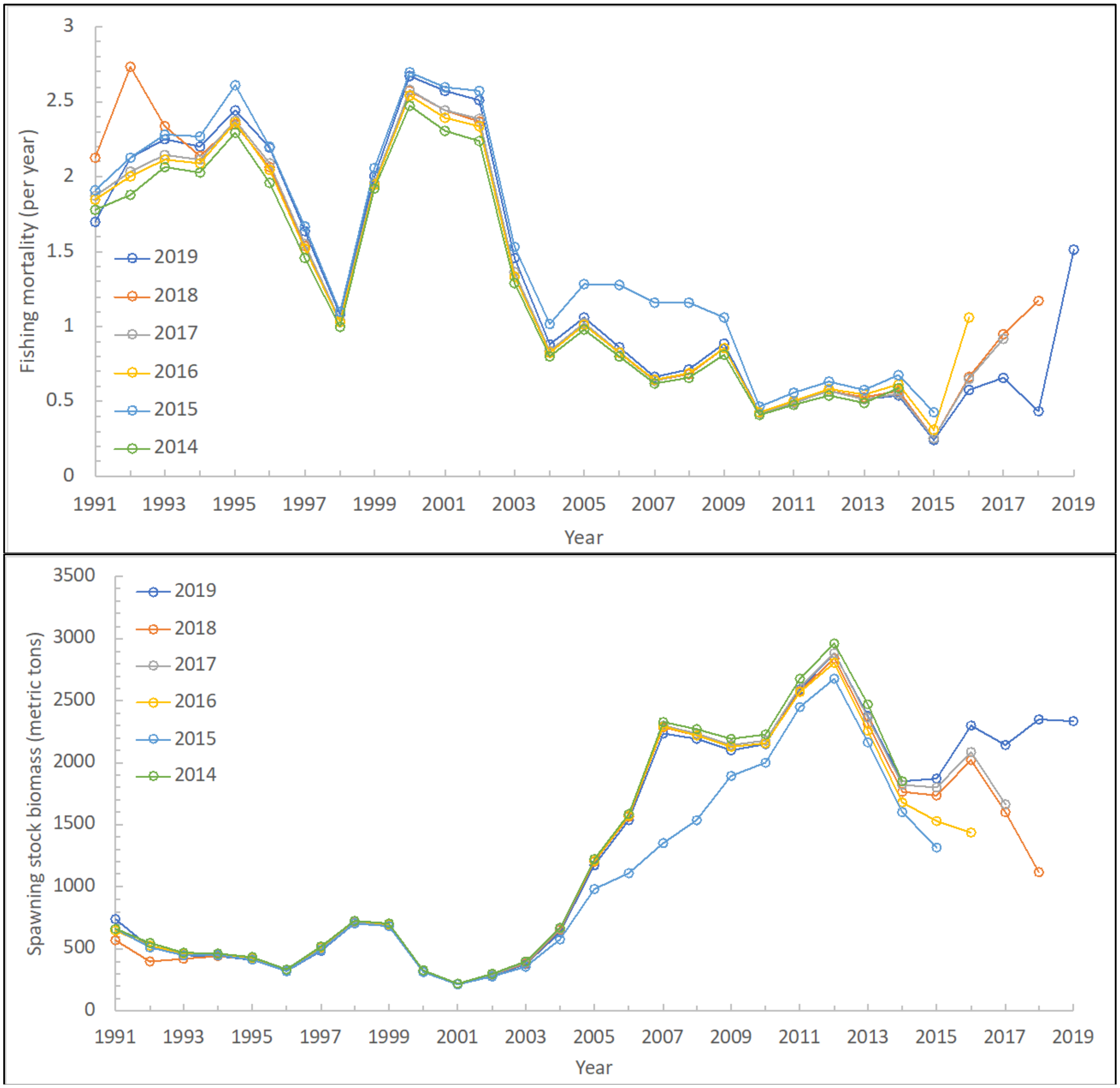

Figure 3.30. Predicted fishing mortality (per year; top panel) and spawning stock biomass (metric tons; bottom panel) from the retrospective analysis in which the model started with the data from 1991 to 2014, and added one additional year of data at a time up to 2019.

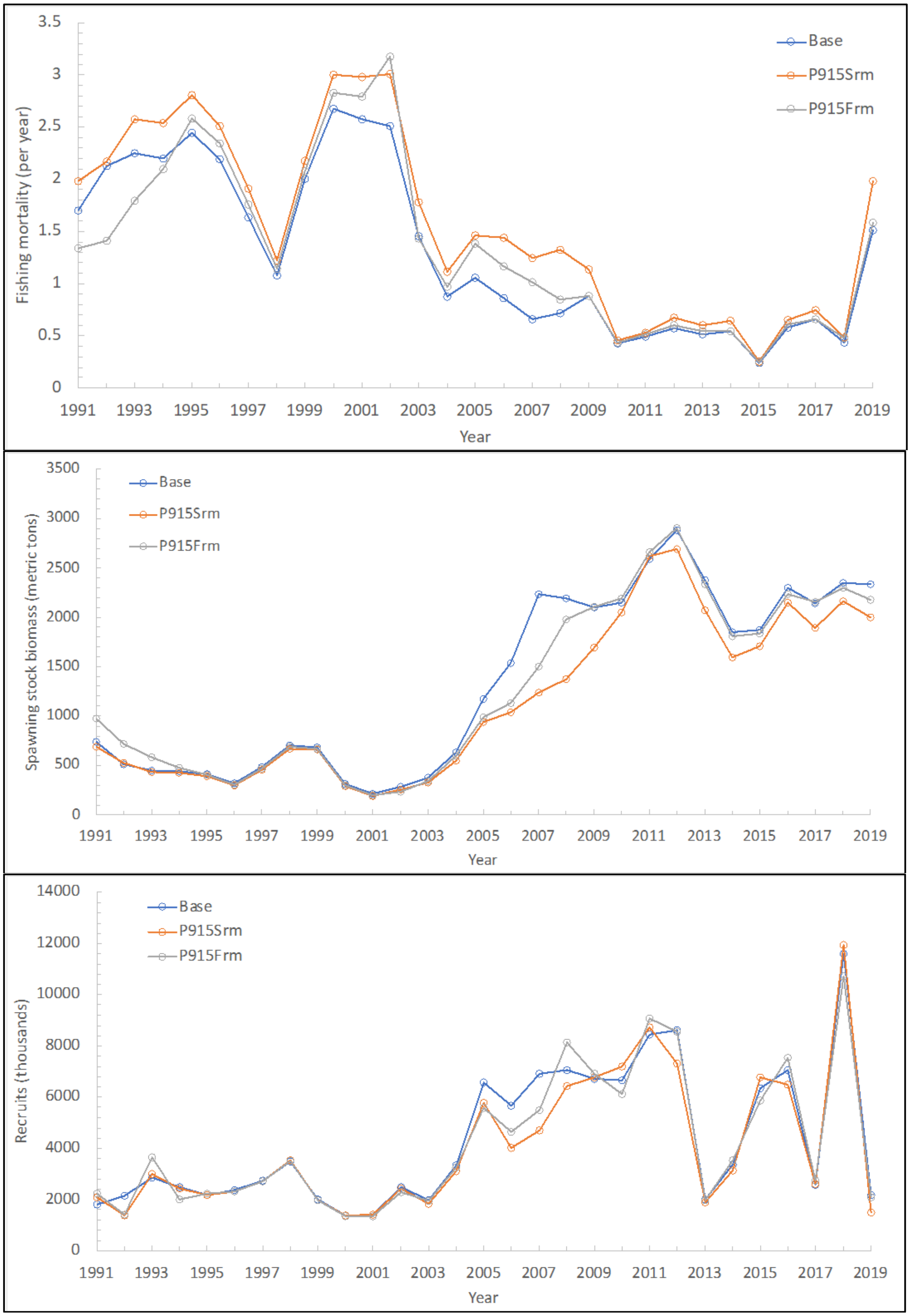

Figure 3.31. Sensitivity of predicted fishing mortality (per year; top panel), spawning stock biomass (metric tons; middle panel) and recruits (thousands of fish; bottom panel) to removal of different fishery-independent survey indices from the base model of the stock assessment, 1991–2019.

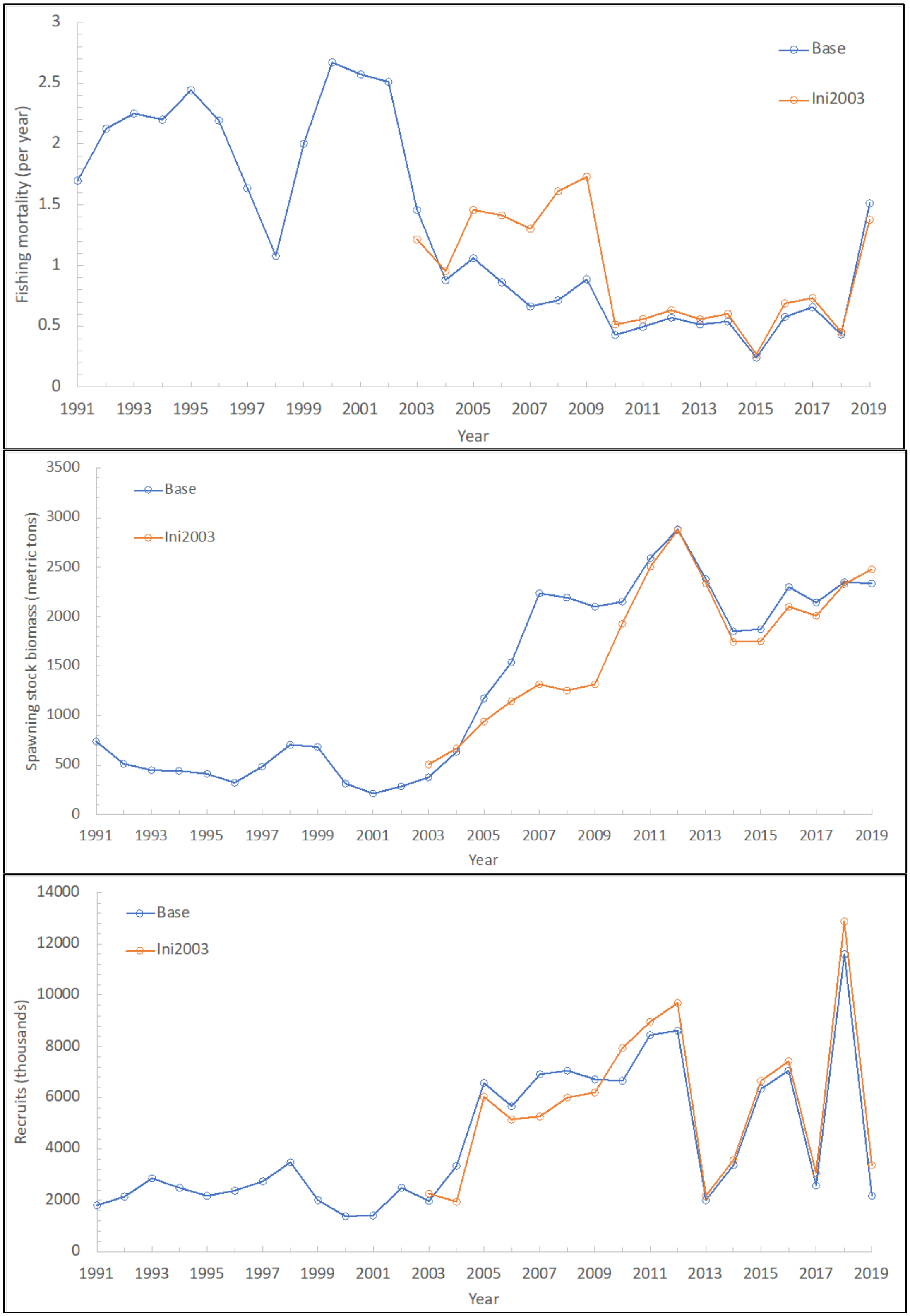

Figure 3.32. Sensitivity of predicted fishing mortality (per year; top panel), spawning stock biomass (metric tons; middle panel) and recruits (thousands of fish; bottom panel) to different initial years.

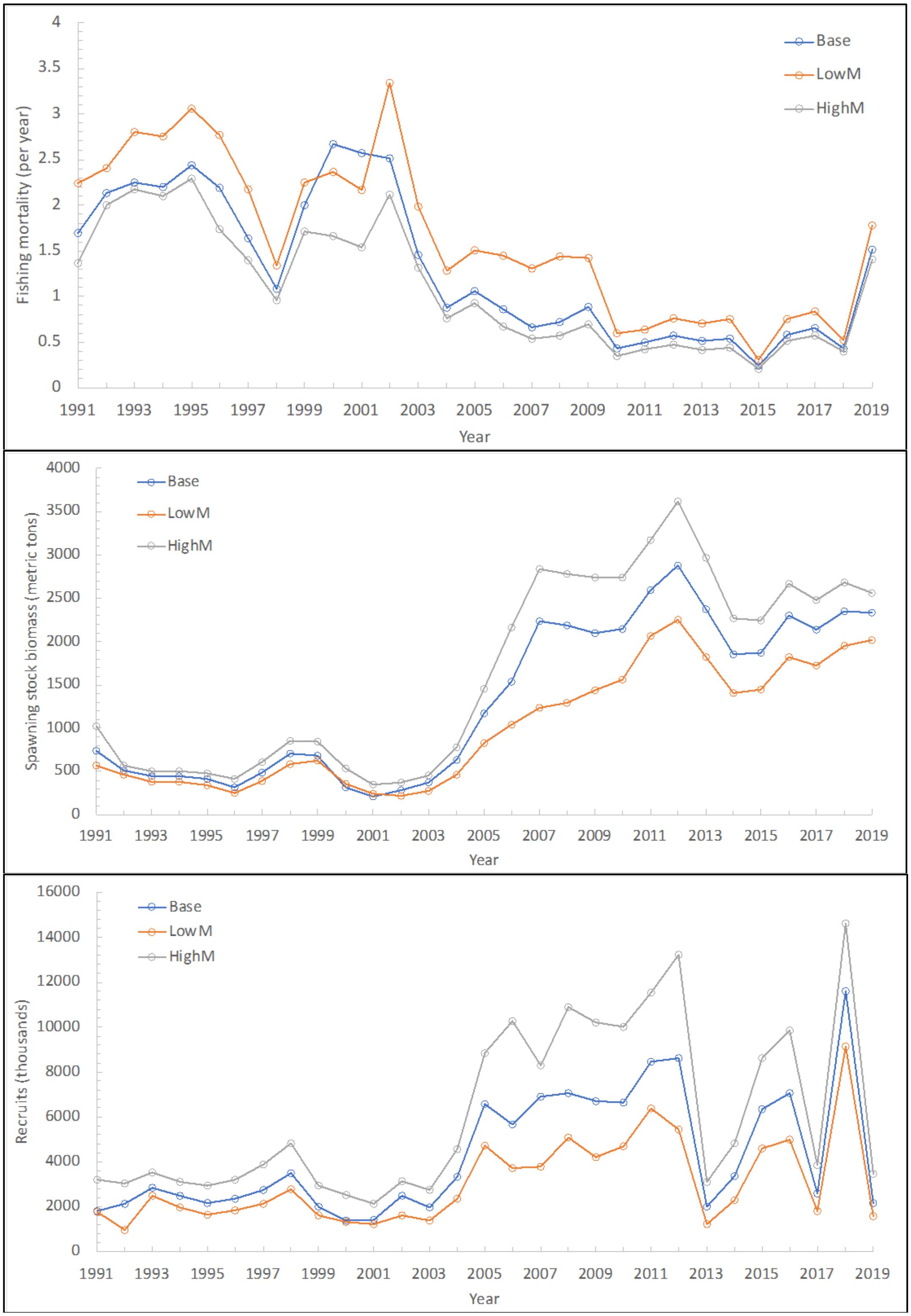

Figure 3.33. Sensitivity of predicted fishing mortality (per year; top panel), spawning stock biomass (metric tons; middle panel) and recruits (thousands of fish; bottom panel) to different annual natural mortality values.

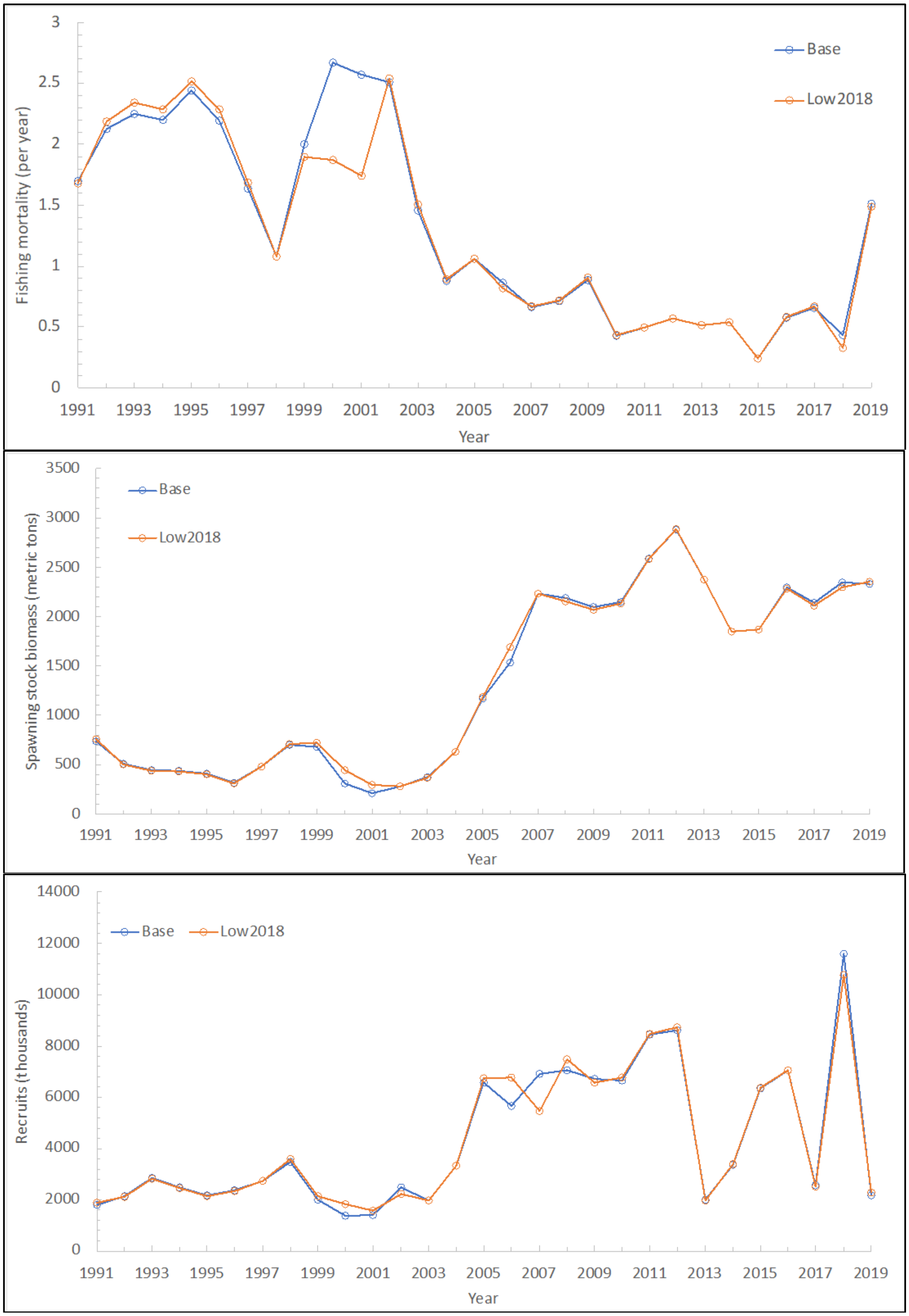

Figure 3.34. Sensitivity of predicted fishing mortality (per year; top panel), spawning stock biomass (metric tons; middle panel) and recruits (thousands of fish; bottom panel) to the 2018 non-winter season recreational discard input.

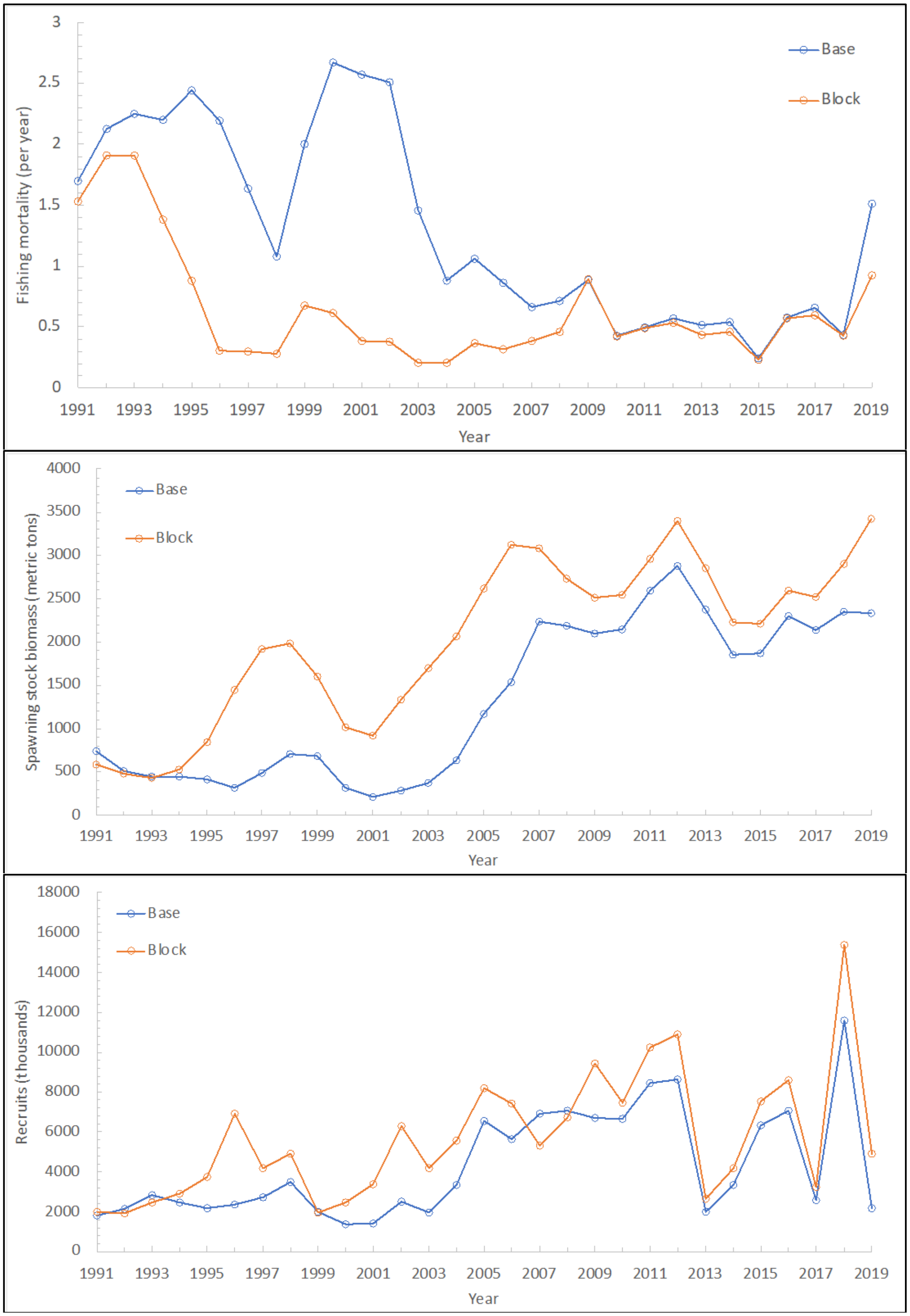

Figure 3.35. Sensitivity of predicted fishing mortality (per year; top panel), spawning stock biomass (metric tons; middle panel) and recruits (thousands of fish; bottom panel) to the assumption on fleet selectivity time block.

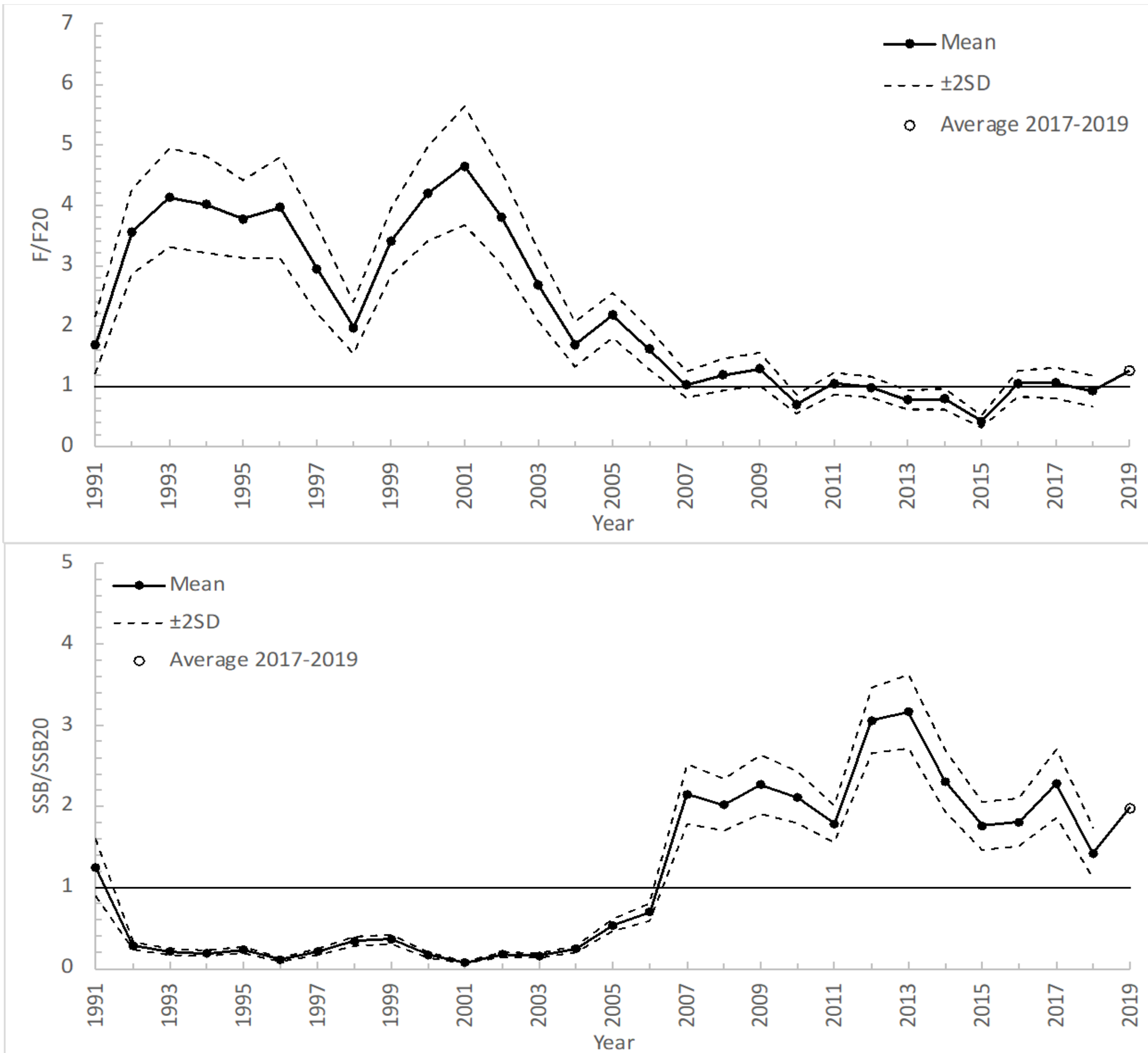

Figure 4.1. Predicted fishing mortality (per year) and spawning stock biomass (metric tons) relative to the fishing mortality threshold (F/F_{20}) and the spawning stock biomass threshold (SSB/SSB_{20}) from the base model of the stock assessment, 1991–2019. The horizontal black line shows a ratio of one. The terminal-year estimate is an average of the most recent three years weighted by the inverse CV values.

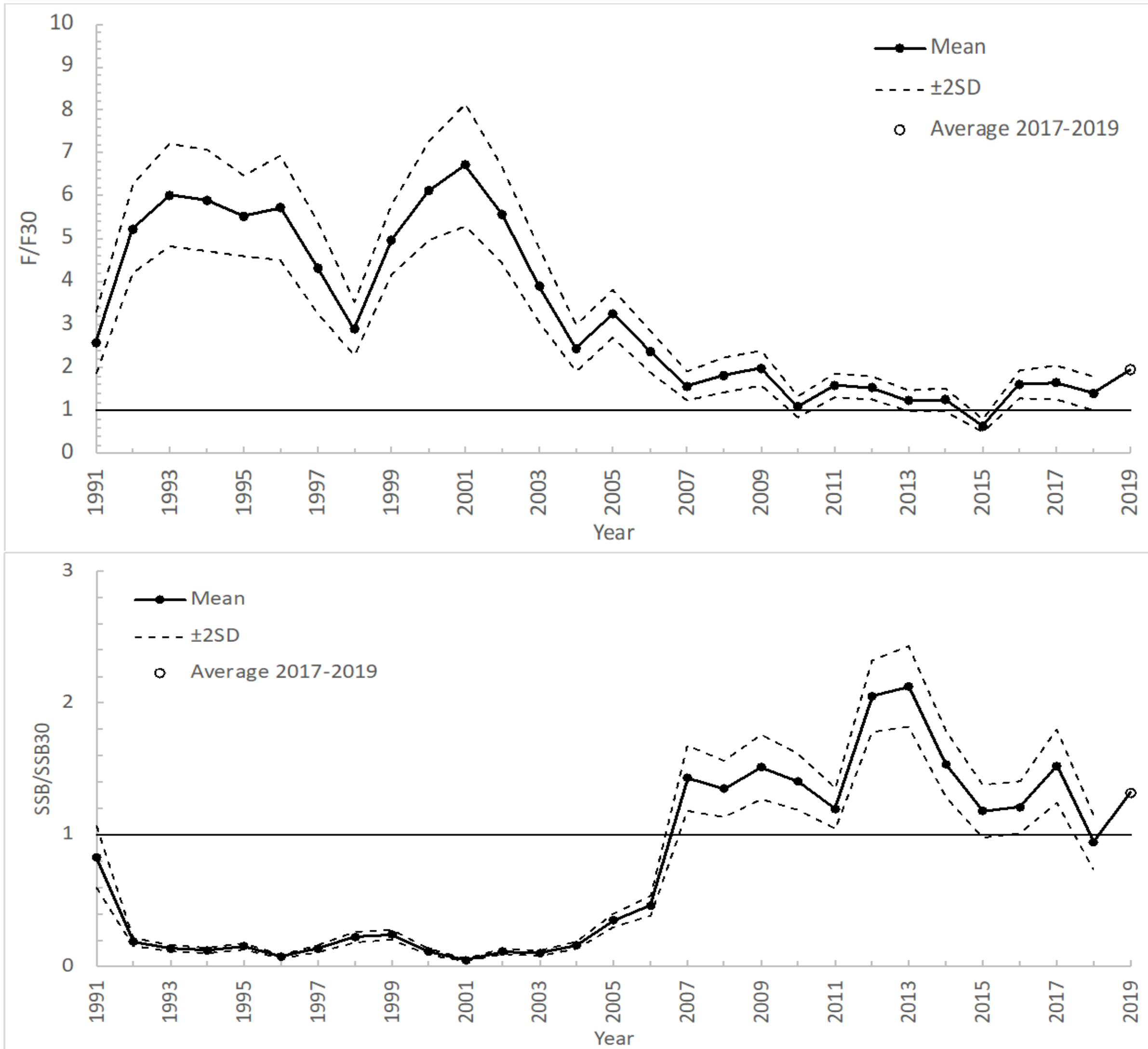

Figure 4.2. Predicted fishing mortality (per year) and spawning stock biomass (metric tons) relative to the fishing mortality target (F/F_{30}) and the spawning stock biomass target (SSB/SSB_{30}) from the base model of the stock assessment, 1991–2019. The horizontal black line shows a ratio of one. The terminal-year estimate is an average of the most recent three years weighted by the inverse CV values.

External Peer Review Report
for the
2022 Stock Assessment
of
Spotted Seatrout in Virginia and North Carolina

External Peer Review Panel

Michael D Murphy(chair) – Retired, Florida Fish and Wildlife Conservation Commission, St. Petersburg, Florida

Joseph E. Hightower -

Emeritus Faculty, NC State University, Raleigh, North Carolina

Mark R. Fisher - Science Director, Texas Parks and Wildlife Department, Rockport, Texas

September 2022

EXECUTIVE SUMMARY

The Spotted Seatrout external Peer Review Panel met in Jacksonville, North Carolina from August 30 - September 1, 2022. Prior to the meeting, the agenda (below) was finalized on July 25, the Stock Assessment Report along with input/output files for the base assessment model were made available (August 1,2), the Terms of Reference for the review were provided to the Panel, and a conference call between the Panelists and the Assessment team was held on August 23. The conference call allowed the Panel to request additional analyses and ask for clarification about data and analyses contained in the Stock Assessment Report. During the meeting North Carolina staff provided presentations on the assessment history, fisheries, and fisheries management during the first day. The spatial and temporal extent of the stock assessment was described. A thorough review of the fishery dependent monitoring for lengths and ages and sex was given as was a presentation of all surveys available for monitoring spotted seatrout. The Panel retired early this day (3:30P) after completion of these presentations and a series of questions and answers. The Panel commends the Assessment team for their concise and comprehensive presentation of the data inputs used in the stock assessment.

On Wednesday the Panel was presented with a thorough description of the assessment model, data inputs and results. The base-run model fit the available data (1991-2019 fisheries landings and length composition, 2003-2019 survey index and length composition) quite well. A strong retrospective pattern was seen in the output suggesting that there could be upward bias in the recent estimates of F and downward bias in the estimated spawning stock biomass. Several alternate data summaries, additional analyses, and model sensitivities were requested and the timely responses greatly facilitated evaluation of the assessment model.

The Panel accepted the base model analyses of spotted seatrout population dynamics as the best scientific information available and suitable for management advice. However, the Panel felt that the terminal-year fishing mortality used in the status determination calculation should be modified to take into consideration the uncertainty inherent in the terminal year estimates. The Panel felt that the Assessment team should utilize an average (e.g., three-year, weighted by inverse of variance) as the best representation of the terminal-year SSB and F estimates.

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1 TERMS OF REFERENCE

The geographic scope of the spotted seatrout considered in the assessment was for fish from all waters of Virginia and North Carolina. Several tag/recapture studies and past genetics analyses indicate little mixing between South and North Carolina but more extensive seasonal movement to and from Virginia. More recent genetic analyses determined that there is a mixing zone between North and South Carolina in the Cape Fear area (O'Donnell *et al.* 2014). Given the infrequent movement of fish between North and South Carolina based on tag recaptures, the relatively small geographic area of mixing, and the relatively low level of spotted seatrout landings made from the mixing zone, the Panel accepted the stock boundaries as defined in the Assessment Report.

1.1 Evaluate the thoroughness of data evaluation and presentation including:

1.1.1 Justification for inclusion or elimination of available data sources

The descriptions of the commercial and recreational fisheries, gears used and seasonality of activity along with fisheries management authority and the history of management actions directed at spotted seatrout in Virginia and North Carolina were adequately described to give context to changes seen in the fisheries over time.

The available recreational and commercial landings and discards data were described, and sources of bias were identified well in the report. The assessment model includes commercial harvest (in number) from VA and NC; commercial discards (relatively minor in magnitude) is only available for NC. Estimates of recreational harvest and discards are available for both Virginia and North Carolina. Recreational discards have increased dramatically in recent years, and estimated dead discards account for a significant fraction of removals. The Panel felt that these data were justified and the best available to account for fishing-induced mortalities. However, the recreational estimates are based on a survey that produces annual error estimates for both seen harvest (Type A) and live releases (Type B2). The Panel accepted the current configuration of the model which utilizes a constant error estimate over time for the recreational fishery harvest and discards but advised more complete use of the survey-estimated errors in the future. The Panel accepted the analyst's estimation schemes used to calculate the commercial live releases and dead discards for the gillnet fishery where direct samples were not available. This fishery is a very small component of the total fishery take.

There are several sampling programs that provide data on the length structure of spotted seatrout seen in the commercial landings and commercial discards. Additionally, the recreational survey (MRIP) provides length composition of landed and kept fish but not of live releases. This was a major data-deficiency for the size-structured assessment model, especially given the increased importance of live-release mortalities to the total fisheries catch in recent years. The Panel accepted the model-based estimation (through a meta-analysis-derived length selectivity function) of this length structure but recommended the future collection of these data through innovative volunteer programs already being initiated by NC staff. Recreational discards size structure and live-release mortality rates were available from proxy observations made from other studies, e.g., tagging. The Panel accepted the current treatment of these data realizing that they need improvement in the future.

The assessment model used spring and fall data from the NCDMF fishery-independent gillnet survey (Program 915, which uses a range of mesh sizes), beginning in 2003. Other surveys, some of which span the entire period of the assessment (1991-2019), either caught few spotted seatrout (NCDMF Program 195, Juvenile red drum survey; NEAMAP, CHESMAP) or catch only age-0 fish below the length range included in the model (NCDMF Program 120). The Panel requested a sensitivity assessment model run that included the Program 120 survey data, but the model was unable to capture the highly variable recruitment dynamics suggested by the trend in spotted seatrout recruit abundance in that survey. More effort should be made to try and incorporate this survey, with the need to possibly increase the amount of variability in recruitment accepted by the model (standard deviation of the recruit deviations).

Fishery-dependent indices were considered but were dropped out of hand over the concerns about the lack of experimental design as used for fishery-independent surveys and the potential for bias from changing catchability over time.

Several life history characteristics were calculated external to the assessment model. A large set (>24,000 fish) of available otolith-based annual age data (raw data) from both fisheries-dependent and fisheries-independent data sources in Virginia and North Carolina were used in an external analysis to provide estimates of von Bertalanffy growth parameters. The Panel judged these data and the analyses as adequate to calculate sex-averaged parameters for asymptotic length (L_∞) and the Brody growth coefficient (K) as needed to estimate the expected mean growth increments for each size class in the initial March-November growth transition matrix.

Available biological data were also used to determine the female size-specific maturity schedule, the maximum age used to estimate a base annual natural mortality rate, and the weight-length relationships. The maturity and weight-length relations were used to calculate the female spawning stock biomass. The Panel questioned the assumed linear relation assumed between the spawning stock biomass and fecundity in this species but accepted it as a measure to be used in the status determination until further information became available from North Carolina. Additionally, the female maturity ogive showed an unusually high level of maturity in one smaller size class that the Panel felt should be checked. The Panel accepted the maturity schedule as estimated.

Habitat and ecological relations were described in a presentation and while pointing out potentials for habitat loss effecting the stock or its dynamics, the only consideration deemed important for inclusion in the assessment model were the changes in natural mortality ascribed to extreme cold events. Many tagging studies were examined to provide information on the variability of natural mortality, often associated with cold kills. This was largely the basis for the decision to use the current size-structure assessment model that can be used to estimate time-varying natural mortality. A base natural mortality was estimated given the observed 9-year maximum age and the cumulative lifetime mortality was distributed across lengths using a weight-based Lorenzen (1996) function. Overall annual estimates of natural mortality (M) were divided into warm (March-November) and cold (December-February) seasons assuming a 1:2 ratio with warm season's M held constant at 0.2. The cold season M was estimated in the model, though constrained through a standard deviation restriction. Assumptions are routinely needed in assessment models to define natural mortality. The Panel accepted the rationale used to define M as used in this assessment model.

1.1.2 Consideration of survey and data strengths and weaknesses (e.g., temporal and spatial scale, gear selectivities, sample size)

The harvest data are assumed to be precise as reflected by the small CVs (0.05, commercial; 0.10, recreational) used in the model. There is considerable (but unknown) uncertainty in the estimated dead recreational discards, obtained as an assumed constant live-release mortality rate (0.10) multiplied by the reported live discards. Discards were fitted using a higher CV (0.25 for both fisheries) to reflect uncertainties associated with those estimates.

The Multiple Panel Gill Net Survey (Program 915) was the sole source of relative abundance indices. These were split into spring (April-June) and fall (September through November) indices. This survey is spatially extensive (within NC) and covers all months except December-February. The spatial extent increased over time and the stock assessment uses a consistent subset of data from 2003 (Fall index) and 2004 (Spring index). Two weaknesses are that the survey covers only the most recent 17 of the 29 years covered by the assessment (1991-2019) and is not conducted in Virginia. The Panel agreed with the development of the standardized indices from these data. The Panel found that the Gillnet survey was well designed for measuring changes in spotted seatrout abundance although its temporal extent only back to 2003 limited its use in guiding the estimation of relative abundance for the entire time series used in the assessment (1991-2019).

1.1.3 Calculation and standardization of indices and other statistics

Generalized linear models were used to adjust for variables that might affect the indices (e.g., temperature or salinity on sampling dates). Nominal and standardized indices showed similar patterns, perhaps due to the relatively intensive and extensive design of the Program 915 survey. The Panel found these analyses to reflect operating standards currently in use in fisheries analyses.

1.2 Evaluate the adequacy, appropriateness, and application of data used in the assessment.

The complete set of available data needed to run the current assessment model and capture all the estimation variability will never be available. However, the Panel found that the available data and estimates were appropriately used and that any assumptions needed to complete the data needed for this analysis, while probably resulting in an underestimate of the overall uncertainty in its findings on fishing mortality and spawning stock biomass, were appropriate and adequate.

1.3 Evaluate the adequacy, appropriateness, and application of method(s) used to assess the stock.

The analysis was based on a size-structured model (Cao *et al*. 2017), modified to allow for time-varying natural mortality (as has been observed in Spotted Seatrout). The model was fitted using maximum likelihood methods and Automatic Differentiation Model Builder software (ADMB; Fournier *et al.* 2012; http://admb-foundation.org). The original size-structured model is peer-reviewed and supports management of northern shrimps (*Pandalus* spp.). Selectivity was estimated for commercial and recreational harvest but fixed at assumed values for discards. The shape of size selectivity was assumed to be logistic for harvest fleets and dome-shaped (double normal) for discards fleets. Natural mortality and growth are time-varying parameters. This provides flexibility to account for temporal changes including cold-stun mortality events.

Likelihood components (landings, discards, survey indices) were given equal weight (1.0). Model diagnostics used to assess fit included presence of estimated parameters at a bound, jitter analysis, evaluation of fits to commercial landings and survey indices, length composition of fisheries and surveys, and retrospective analysis. There were no obvious issues in fit of the base model, including fit to harvest, survey indices and length composition. The Spring survey was relatively uninformative (flat and variable) but precision was higher and the fit was improved for the Fall index. Jitter analysis provided evidence that a global solution had been obtained, but also suggested substantial uncertainty about the final fishing mortality estimate. Model fit showed a change in stock dynamics around the start of the survey data (e.g., fishing mortality: Assessment Report's Figure 3.21; recruitment: Figure 3.24); however, this was also approximately the start of increased recreational harvest.

Time-varying estimates of natural mortality showed some similarity to the temporal pattern from tag-return models, but tag-return models showed substantially higher estimates.

The model has a very large number of parameters (n=367), including time-varying growth and natural mortality. This provides the model with much flexibility but also the potential for overparameterization. Estimates of growth parameters suggested a relatively stable maximum size (L_{∞}) but declining growth rate (K). An independent analysis of age and length data suggested that growth was stable over time (no trend in mean length-at-age). The Panel believes that this discrepancy warrants further investigation, to determine whether the time-varying growth model is overparameterized. Initial sensitivity runs using fixed or estimated time-independent growth parameters showed that estimates of F and spawning stock biomass were sensitive to the growth sub model structure. However, management guidance (F>threshold) was the same for the base run (time-varying) and sensitivity runs (Table 1).

Sensitivity runs were conducted by: (1) omitting one of the two surveys; (2) changing the start of the analysis to 2003 (start of survey data); (3) varying the assumed average natural mortality rate; (4) using a lower value for the (extreme) estimated number discarded in the non-winter season in 2018; and (5) using two selectivity eras for the recreational fishery (based on a 2009 change in minimum length). Results for the more recent period (the focus for management) were relatively insensitive to removal of either survey (suggesting a consistent signal for the two surveys) or changing the starting year of the assessment. Fishing mortality was similar but ending spawning stock varied when the assumed average natural mortality rate was varied. Changing the non-winter discards estimate for 2018 had a negligible effect on recent estimates. Using two selectivity periods to account for the regulation change had a negligible effect on fishing mortality but spawning stock was affected. For model changes that affect complexity (number of estimated parameters, e.g., one versus two selectivity eras), it might be possible to assess whether the increase in complexity was warranted by the improved fit.

There is a strong need for a continuity model to help evaluate how the change from age-structured models that were used in the past to the new size-structured framework has changed the findings. Allowing for cold season variability in natural mortality is a step forward in accurately analyzing spotted seatrout population dynamics in Virginia and North Carolina but it is important to identify other potential biases introduced in this model change.

The time block selectivity model appears to make a difference in early F estimates and stock status. The selectivity-blocked trend in total annual F appears to follow the pattern of total kill taken from the stock (Fig. 1) better than F estimates made from the single time block model. Both the base model and the 2-time-period sensitivity models appear to predict the sizes and number of fish landed, discarded dead, or live-release deaths just as well, thus this sensitivity configuration appeared to have support though with a slight increase in the number of parameters compared to the base model. However, a very strong retrospective pattern emerges from the time-blocked selectivity model results possibly indicating a strong misspecification in the model. The Panel felt that further consideration of this model configuration should be made in the future.

1.4 Reference points

1.4.1 Evaluate the adequacy and appropriateness of recommended stock status determination criteria.

The nonstationary use of M complicated reference point estimation. As currently used the threshold and target fishing mortality and spawning stock biomass are all based on the terminal year (2019) population dynamics. With changing M, accurate benchmark calculations cannot be made unless future natural mortality rates are known (Miller and Legault 2017). Calculations of year-specific benchmarks appear to show that the relative variability of natural mortality does not impart a high degree of variability in the threshold or target values of fishing mortality of spawning stock biomass (Fig. 2). The Panel felt a more important consideration for spotted seatrout is the method used to determine the current state of the fishery in terms of F and SSB and recommended a weighting scheme that considered the terminal-year estimates and their precision.

1.4.2 Evaluate the methods used to estimate values for stock status determination criteria.

The methods appear adequate except for the need to include the variability in the terminal-year dynamics in the calculation.

1.4.3 Comment on the appropriateness of comparing terminal year estimates to stock status determination criteria.

The jitter analysis shows high uncertainty in the terminal year F, as does the estimated variance (which underestimates uncertainty because of fixed parameters and assumptions in the model). The retrospective analysis shows a strong pattern of decreasing F as additional years of data are available. The high terminal-year F was due to very high recreational landings for 2019. The Program 915 survey was not conducted in 2020 and Spring of 2021. All these factors lead to uncertainty about recent status, and suggest a more measured approach (e.g., averaging last few years) to calculating status determination.

The Panel felt that the terminal-year F estimate's variability is large and that it should be incorporated into the calculation of the current stock dynamics, e.g., average last three year's estimates using inverse-variance weighted.

1.5 Do the results of the stock assessment provide a valid basis for management for at least the next five years given the available data and current knowledge of the species stock dynamics and fisheries? Please comment on response.

Yes, the Panel felt that the results adequately capture the recent dynamics of the spotted seatrout stock in North Carolina and Virginia. However, prior to about 2007, there is little information (surveys) to constrain the estimates of abundance or mortality. The sensitivity analyses generally pointed to some consistency in the model estimates of fishing mortality during the period of about 2007 through 2019. The earlier period was highly variable through the different sensitivities.

The sensitivity runs show that the thresholds and targets are highly sensitive to the form of the model, but management guidance (overfished/overfishing) is not sensitive (Table 1). There is however a notable sensitivity to the assessment structure (data, software, assumptions, analyst). Status of spotted seatrout has varied markedly from one assessment to the next, and we recommend against attaching too much significance to a single assessment. Gradual stable management (and regulation change) will be more consistent with the gradual pace of understanding stock dynamics.

The estimates of F from 1991 ~2003 are much higher than in the previous assessment. If accurate, then there should be few fish older than age 3 or 4 observed in the population during those years. The Panel recommends using representative age data from this period to calculate mortality rates that can be used to verify this high of an overall mortality rate.

The Panel recommends that the stock's status relative to threshold and target values calculated for fishing mortality and spawning stock abundance not rely only on the terminal year's estimates but use an average of recent estimates. The Panel believes this would be less likely to inflict wide changes in stock status based on poorly estimated terminal year parameters.

1.6 Evaluate appropriateness of research recommendations. Suggest additional recommendations warranted, clearly denoting research and monitoring needs that may appreciably improve the reliability of future assessments.

Given the large programs dedicated to gathering representative age- and sex-specific information from North Carolina's fisheries and surveys each year, the Panel recommends that there be an effort given to developing an age-structured model that can incorporate temporal changes in natural mortality. At the least, a component of the objective function within the current size-structured model should include a fit to age data.

The size structured model's current configuration did not incorporate estimated errors for the recreational landings and live releases. Though these are available, there was a hesitancy to use other than constant CV's for these data because the model was conditioned on catch and less stable when year/season -specific errors were included.

Re-evaluate the female maturity analysis with consideration of the extreme outlier used in the current assessment.

Spotted seatrout have a protracted spawning season, typically from April-October. A June index of juvenile recruitment will miss a large portion of the later spawn and is incomplete. As a research priority, NC should consider implementing a new fishery-independent juvenile survey, perhaps conducted year-round. It would also be useful for other species.

There is a large increase in the number of removals (all fleets combined) beginning in 2005 (Figure 1). This is a pivotal year for the model results, as well. It would be interesting to understand whether these increases were accompanied by an increase in recreational fishing effort in both Virginia and North Carolina. It is recommended that this be investigated as to whether design changes in the MRIP survey could be responsible for this change.

We suggest a lower emphasis on commercial monitoring for this species, because of the relatively minor impact of commercial fishing on the stock. Recreational discards should be the primary focus (and a high, rather than low, priority) because of the trend and magnitude of recreational catch-and-release. The planned expansion of a Citizen Science initiative to include spotted seatrout may be helpful, if biases related to participating angler reporting can be addressed.

We recommend testing and validating the model with known data sets. It has been used for northern shrimps (which lack age data) but not for fish with information about length and age. Testing can determine the extent to which length composition data can extract stock dynamics for longer-lived, multi-aged fish stocks, and can assess the best way to incorporate the available age data (fishery and survey).

Prior to expanding the Program 915 to winter months (that were initially sampled, then dropped for safety reasons), we recommend a detailed analysis of the existing data. This could determine the extent to which late fall and spring data provide insights into overwinter changes. This analysis could also provide insights into the magnitude of cold-stun events, which could explain differences in the effects observed in tagging and telemetry studies versus survey and fishery monitoring.

We recommend additional work to evaluate more fully the utility of the Program 120 survey, which spans the entire period used for the assessment. Including the recruitment index data may require a higher variance to accommodate the large fluctuations observed in the survey. Initial model results from a sensitivity run suggest that the model is sensitive to inclusion of recruitment data, at least for the early years prior to the start of the Program 915 survey.

We recommend that integration of tagging data be given high priority, given the dramatic difference in results regarding survival rate and natural mortality. Tagging provides an independent look at population dynamics and has different assumptions from analyses of harvest and survey data. Tag returns can also be used to investigate growth (growth increments) that could be compared to the size-based model inferences. An advantage of tagging studies is that key aspects can be tested using auxiliary studies (e.g., double tagging to address tag loss). There is a substantial data set of tags released (2008-2019 for NC; 1995-2018 for VA). Additional field or tank studies might be done to explore the possibility of chronic mortality associated with tagging and telemetry.

Age validation was suggested as a low priority. It is always a worthwhile endeavor but might be removed from the list until age data are being used in the assessment.

1.7 If applicable, recommend recruitment and fishing mortality/catch scenario(s) for projections

N/A

1.8 Recommend timing of next stock assessment for the species

We recommend maintaining the current approach of a five-year cycle. This provides enough additional data to warrant an update. There will be an information gap in the next assessment because of the cessation of sampling during the pandemic. A five-year delay will allow for enough new data to make updating worthwhile. Until the next assessment is done, real-time monitoring using the Program 915 survey and MRIP recreational catch-per-angler-hour could provide insights into the stock's status.

2 ADDITIONAL COMMENTS

3 LITERATURE CITED

Cao, J., Y. Chen, and R.A. Richards. 2017. Improving assessment of *Pandalus* stocks using a seasonal, size-structured assessment model with environmental variables. Part II: Model evaluation and simulation. Canadian Journal of Fisheries and Aquatic Sciences 74(3):1–14

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterised complex non-linear models. Optimisation Methods & Software 27:233–249

Jensen, C. C. 2009. Stock Status of Spotted Seatrout, *Cynoscion nebulosus*, in North Carolina, 1991-2008. North Carolina Division of Marine Fisheries, Morehead City, North Carolina.

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Miller, T.J. and C.M. Legault. 2017.Statistical behavior of retrospective patterns and their effects on estimation of stock and harvest status. Fisheries Research 186(1):109-120.

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Spotted Seatrout Stock Assessment Peer Review Workshop
30 August–1 September 2022
Jacksonville, North Carolina

Final Agenda

DAY 1: TUESDAY, 30 AUGUST 2022, 12:00 pm–5:00 pm

***Day 1 Goals*:** Review purpose and expectations of peer review, gain understanding of fisheries and management history, gain understanding of species biology and ecology, and review and evaluate assessment input data

Preliminaries

- Welcome & introductions (*Steve Poland*)
- Purpose of review workshop & expected products (*Mike Murphy*)
- Review agenda & code of conduct (*Mike Murphy*)

Background

- Presentation: Assessment History (*Laura Lee*)
- Presentation: Fisheries & Management History (*David Behringer*)
- Presentation: Stock Structure & Species Life History (*Lucas Pensinger*)
- Review Panel Q & A

Data

- Presentation: Fisheries-Dependent Monitoring (*Alan Bianchi, Drew Cathey, & David Behringer*)
- Presentation: Fisheries-Independent Surveys (*David Behringer*)
- Review Panel Q & A

DAY 2: WEDNESDAY, 31 AUGUST 2022, 9:00 am–5:00 pm

***Day 2 Goals*:** Review and evaluate assessment model and results, review and evaluate method for estimating reference point values, review and evaluate current stock status, request additional analyses, and review and comment on research recommendations

Seasonal, Size-Structured Model

- Presentation: Model Data Input (*Yan Li*)
- Presentation: Model Structure & Parameterization (*Yan Li*)
- Presentation: Model Results (*Yan Li*)
- Review Panel Q & A
- Identify additional analytical requests

Status Determination

- Presentation: Reference Points & Stock Status (*Yan Li*)
- Review Panel Q & A

- Identify additional analytical requests

Research Recommendations

- Presentation: Research Recommendations (*Yan Li*)
- Review Panel Q & A

DAY 3: THURSDAY, 1 SEPTEMBER 2022, 9:00 am–1:00 pm

Day 3 Goals**:** Recommend best model configuration for assessing stock, recommend best approach for estimating reference point values, recommend whether results provide a valid basis for management, complete draft version of peer review report, and identify any outstanding tasks

Initial Summary

- Review results of additional analytical requests
- Review Panel deliberations (closed session)
- Review Panel reviews initial conclusions with Working Group (closed session)
- Review Panel begins drafting report (closed session)/Working Group session addressing additional analytical requests

Wrap-Up & Next Steps

- Review results of additional analytical requests
- Review Panel deliberations (closed session)
- Review Panel reviews conclusions with Working Group (closed session)
- Review Panel session drafting report (closed session)
- Identify tasks to be completed & timeline

ADDITIONAL INFORMATION

There will be a one-hour break for lunch on Wednesday. Additional breaks will be given at the discretion of the chair.

The order and timing of agenda items is subject to change.

The goals listed for each day are intended for the peer review panel and chair.

During closed sessions, everyone except the peer review panel and chair will be asked to leave the room unless noted otherwise above.

Only the peer review panel and chair participate in the development of the peer review report. The report will not be available to the NCDMF staff, the public, or others until it is considered complete.

Table 1. Biological Reference Points for various sensitivity runs.

Model	TerminalF	TerminalSSB	Fthresh	SSBthresh	Ftarget	SSBtarget
Base	1.512	2337.974	0.691	832.344	0.437	1251.797
P915Srm	1.980	1997.854	0.671	764.102	0.422	1147.740
P915Frm	1.583	2181.306	0.667	834.094	0.422	1252.305
Ini2003	1.376	2475.647	0.525	2701.429	0.359	4025.220
LowM	1.774	2016.808	0.359	1890.147	0.242	2812.434
HighM	1.404	2560.487	1.208	549.635	0.730	824.951
Low2018	1.486	2356.872	0.676	850.583	0.427	1277.680
Block	0.925	3428.873	0.823	1234.601	0.510	1851.404
P120noLag	1.900	2028.298	0.681	795.909	0.432	1193.179
P1201YrLag	1.145	2814.201	0.676	784.001	0.427	1183.223
constGLinfFix	3.635	1125.937	0.549	2268.698	0.374	3429.834
constGLinfKFix	2.503	1577.664	0.559	1394.682	0.374	2094.259
constGLinfKEst	2.048	1936.712	0.500	1415.319	0.330	2127.802
P120NoMissing	0.726	4076.007	0.642	904.110	0.413	1347.701

Model configuration:
Base: default
P915Srm: omission of Program 915 spring gill-net data
P915Frm: omission of Program 915 fall gill-net data
Ini2003: start analysis in 2003
LowM: Annual average natural mortality set to 0.4, lower than the base model (0.6)
HighM: Annual average natural mortality set to 0.8, higher than the base model (0.6)
Low2018: March-November recreational discards set to the average of the previous five years, lower than the base model (1,863.527 thousands of fish)
Block: Two time blocks for fleet selectivity, 1991–2008 and 2009–2019
P120noLag: Inclusion of Program 120 survey data, with no lag
P1201YrLag: Inclusion of Program 120 survey data, with one-year lag
constGLinfFix: Modified growth sub-model with fixed L_∞
constGLinfKFix: Modified growth sub-model with fixed L_∞ and K
constGLinfKEst: Modified growth sub-model with constant but estimated L_∞ and K
P120NoMissing: Inclusion of Program 120 survey data, with 0.01 added to dates with 0 catch

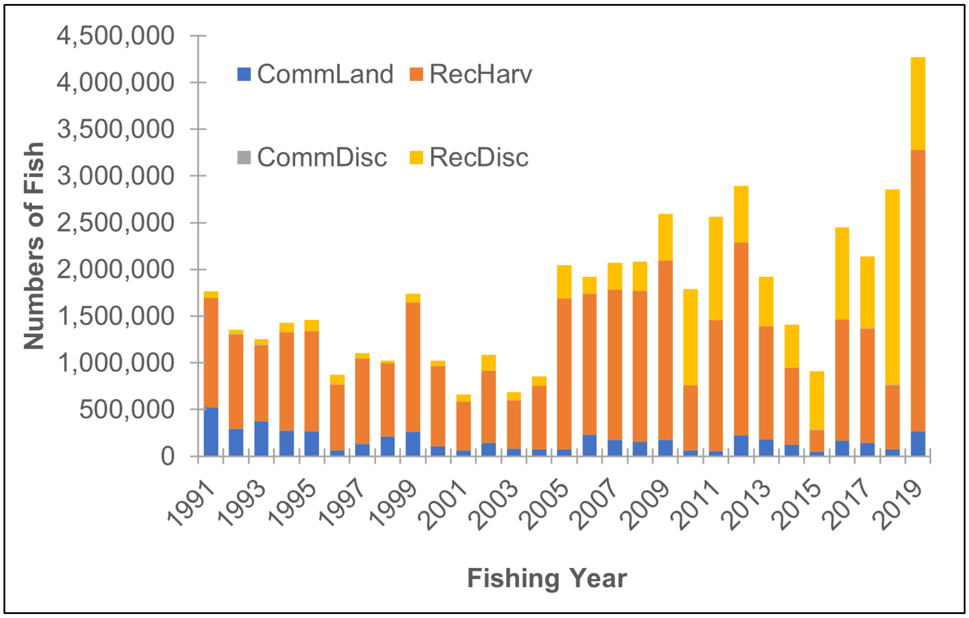

Figure 1. Total kill of spotted seatrout by fishery sector in North Carolina and Virginia during 1991-2019.

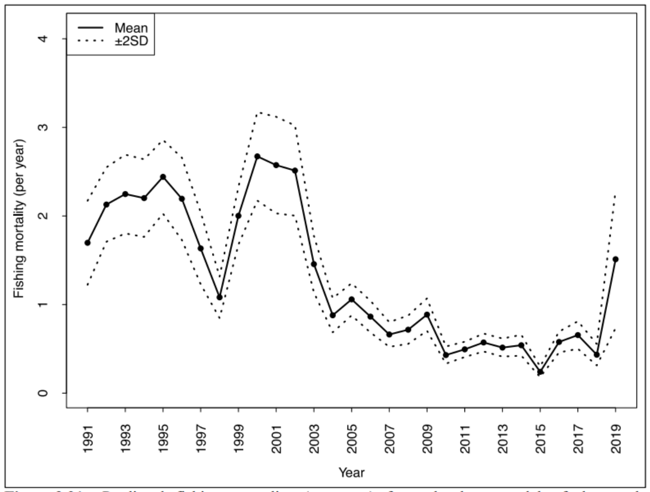

Figure 3.21. Predicted fishing mortality (per year) from the base model of the stock assessment, 1991–2019.

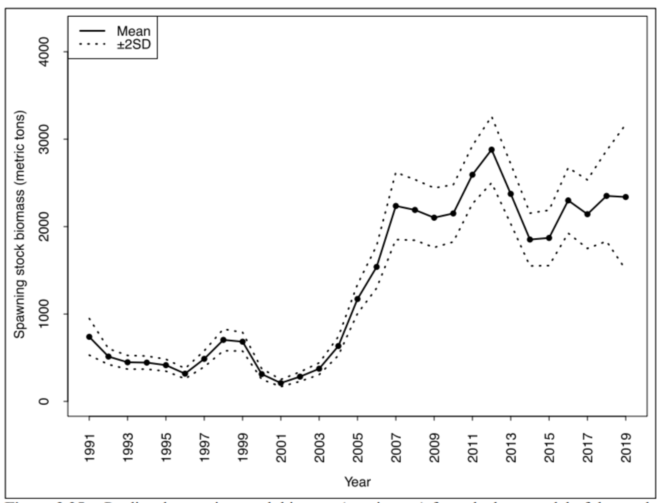

Figure 3.25. Predicted spawning stock biomass (metric tons) from the base model of the stock assessment, 1991–2019.

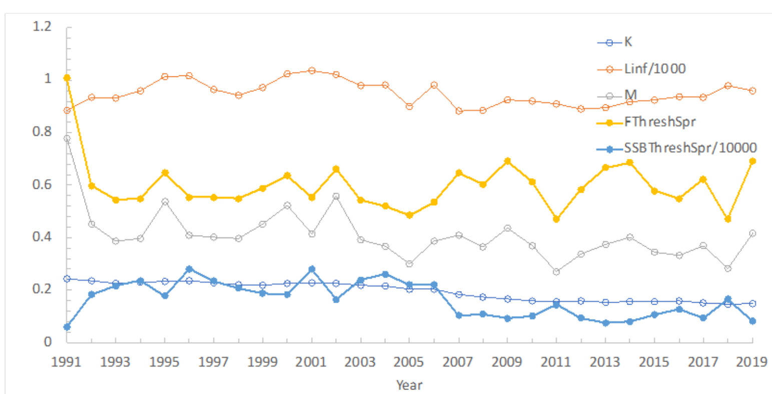

Figure 2. Base model estimates of annual F (Fig. 3.21), spawning stock biomass (Fig. 3.25) and associated estimation error (± 2SD's; dotted lines), and year-specific estimates of F and SSB at the threshold value of 20% spawning potential ratio. Year-to-year changes in thresholds are mostly associated with changes in estimates of annual M.