NEUSE RIVER STRIPED BASS MONITORING PROGRAMS, POPULATION DYNAMICS, AND RECOVERY STRATEGIES

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Abstract.—Between April 15 and May 28, 2014, 316 Striped Bass *Morone saxatilis* were collected from the Neuse River spawning grounds via boat electrofishing. Weekly mean CPUE was 10.1 fish/h, and peaked the week of May 5, 2014 at 23.6 fish/h. Most Striped Bass were collected in upper reaches of the spawning grounds in sites between Smithfield and Raleigh. Abundance of age-6 and older fish was highest on record at 4.6 fish/h, continuing an increasing trend since 2008. Growth continues to be rapid, as Neuse River age-3 fish are approximately the same mean length as age-5 fish collected in 2013 in the Tar and Roanoke rivers. Eight year-classes were represented in the sample (males age 3–9; females age 3–8 and age 10). The 2010 year-class was the most abundant cohort, contributing 34% to the total sample. Catch-curve analysis indicated an annual exploitation rate of 48% ($F = 0.71$). Genetic analysis of fin clips collected in 2014 suggests the 2010 and 2011 year-classes are comprised almost exclusively of hatchery-reared fish. An estimated 39,717 hours of angling effort targeted Striped Bass during the October 1, 2013 through April 30, 2014 recreational season, resulting in an estimated catch of 7,888 fish and harvest of 1,946 fish. However, only 3% of the effort (1,304 h) and 2% of the catch (167 fish) occurred in inland jurisdictional waters. Overall, the low abundance and truncated age-distribution support catch-curve estimates indicating high spawning stock mortality, while preliminary results of parentage based tagging suggest a high proportion of the spawning stock is hatchery-reared. Analysis of spawning potential ratio indicates the stock has likely experienced long-term recruitment overfishing. However, yield-per-recruit analysis suggests stock improvement could be achieved with a reduction in exploitation and implementation of a more restrictive minimum length limit. Cooperation with NC Division of Marine Fisheries will be required to improve the stock, as the population is spatially extant in joint and coastal waters for most of the year.

The North Carolina Wildlife Resources Commission (NCWRC) conducts annual spawning stock assessments of migratory Striped Bass *Morone saxatilis* populations utilizing inland waters within the Central Southern Management Area (CSMA). The CSMA management unit is defined as all internal coastal, joint and contiguous inland waters of North Carolina south of a line from Roanoke Marshes Point across to Eagle Nest Bay in Dare County, to the South Carolina state line (NCDENR 2013). The goal of CSMA Striped Bass assessments is to monitor Striped Bass populations migrating to the spawning grounds within the Tar, Neuse, and Cape Fear rivers. An integral component of this monitoring includes assessing the contribution of hatchery-reared fish to the Striped Bass population in each river.

Striped Bass in the CSMA are considered a stock of concern by the North Carolina Division of Marine Fisheries (NCDMF) due to a “lack of adequate data” and the need for conservative management is supported by “truncated size and age distributions, low overall abundance, and an absence of older fish in spawning ground surveys” (NCDENR 2013). Spawning stock data collected in inland waters by NCWRC will be combined with NCDMF data collected in joint and coastal waters to develop a comprehensive stock assessment model for Striped Bass within the CSMA. Estimates of fishing mortality rates coupled with analyses of basic population trends are critical for determining the appropriate total allowable harvest of Striped Bass from the CSMA Striped Bass fisheries while still allowing for stock preservation and growth. Development and execution of comprehensive inter-agency fisheries management plans are necessary to support the enhancement of Striped Bass populations within coastal North Carolina for the benefit of recreational and commercial anglers (NCDENR 2004, 2013).

In the Neuse River, Striped Bass have been surveyed by NCWRC staff using boat-mounted electrofishing each spring since 1994 to assess spawning stock characteristics. This time series encompasses the 1998 removal of Quaker Neck dam on the main-stem Neuse River at river kilometer (rkm) 225 that blocked access to Striped Bass spawning habitat upstream of Goldsboro, NC (Burdick and Hightower 2006). Due to the removal of this low-head dam, Striped Bass can utilize upper-basin spawning habitat to the base of Milburnie dam (rkm 352) that was previously unavailable (Burdick and Hightower 2006). Analyses of catch data suggest Striped Bass spatial distribution during spawning varies among years since the removal of Quaker Neck dam. Relationships between streamflow and fish abundance suggest access to spawning habitat above Goldsboro is likely restricted at low streamflow (Barwick and Rundle 2005). Because of this restriction, spawning success and year-class production could be negatively affected when spring streamflow is low, particularly less than 800 ft^3/s as measured at USGS gage 02087500 near Clayton, NC (Barwick and Rundle 2005).

Due to low spawning stock abundance and limited Striped Bass recruitment, an annual stocking program has occurred on the Neuse River since 1993. From 1994 to 2011, the Roanoke River was the broodstock source. However, since stocking began there has been little improvement in Striped Bass age-structure or mortality (Dycus et al. 2014). Since 2010, all Striped Bass stocked in the Neuse River can be identified to hatchery broodstock sources through the utilization of genetic marking techniques. In 2012, the stocking program began using Neuse River broodstock to determine if stocking endemic Striped Bass increases spawning stock abundance (e.g., Bulak et al. 2004). Preliminary assessments in 2012 and 2013 indicated very little natural reproduction occurs (NCWRC unpublished data), which was also observed by Barwick and Homan (2008). Understanding contribution of hatchery fish to the Neuse River spawning stock will assist management decisions and assessment of objectives outlined in Amendment 1 to the North Carolina Estuarine Striped Bass Fishery Management Plan (FMP).

This report documents the annual NCWRC Striped Bass spawning stock survey conducted in the Neuse River in 2014. The objective of this spawning stock survey was to quantify Striped Bass spawning stock characteristics by estimating relative abundance, size-structure, age-structure, mortality, and contribution of hatchery fish to the spawning stock. Additionally, estimated recreational fishery statistics collected during the NCDMF Neuse River creel survey will be reported.

Methods

Spawning Stock Assessment

NCWRC field staff collected Striped Bass in the Neuse River from April 8, 2014 through May 28, 2014 during concurrent sampling for American Shad *Alosa sapidissima*. Directed Striped Bass sampling began April 15, 2014 at two fixed sites in Goldsboro, NC and continued weekly during optimum spawning temperatures (18–22°C). Additional sites in Goldsboro, Raleigh, and Smithfield were sampled weekly as Striped Bass catches increased (Figure 1). An additional experimental site (Neuse canal) adjacent to the Goldsboro Beaverdam site was sampled once. Sampling at all sites was contingent upon adequate streamflow to allow boat access (Table 1). Sampling ceased when Striped Bass spawning appeared complete. Striped Bass were collected using a boat-mounted electrofishing unit (Smith-Root 7.5 GPP) with 1 dip netter. To minimize size selection during sampling, fish were netted as they were encountered, and electrofishing time (seconds) was recorded for each sample site. Mean daily water temperature (°C) was recorded at each sample site. Mean daily discharge (ft^3/s) was recorded from the U.S. Geological Survey gaging station (02087500) near Clayton, NC.

Each Striped Bass was measured for total length (TL; mm) and weighed (g). Sex was determined by applying directional pressure to the abdomen toward the vent and observing the presence of milt (male) or eggs (female). Scales were removed for aging purposes from a subsample of fish during each sampling event (15 fish per 25-mm size-class by sex) on the left side of the fish between the lateral line and the dorsal fins (NCWRC and NCDMF 2011). To estimate contribution of hatchery fish to the spawning stock using parentage based tagging (PBT), a partial pelvic fin clip was removed from Striped Bass younger than age 5 (<637 mm for males and <654 mm for females) until 200 fin clips were collected and archived.

Before release, untagged Striped Bass were tagged with an individually numbered internal anchor tag as a cooperative effort with the ongoing NCDMF Striped Bass tagging program (Winslow 2010). Recaptured, tagged Striped Bass were identified by tag number, and scales were removed from the right side of the fish if tagging occurred in a previous year. Recaptures from the current sample year were included in the dataset unless the recapture occurred on the same day as tagging.

All field data were recorded using a Trimble Yuma field computer and archived in the NCWRC BIODE database. Relative abundance of Striped Bass for each sample was indexed by catch per unit effort (CPUE; fish/h). Mean CPUE was calculated for all sampling sites during a calendar week. Site-specific CPUE was analyzed to elucidate spatial differences in spawning ground utilization. Daily mean CPUE and peak daily CPUE were calculated to analyze annual trends in abundance. Length-frequency distributions by sex were used to evaluate size structure. Striped Bass scales were examined at 24X and 36X magnification using an EyeCom

3000 microfiche reader, and annuli were counted to estimate age in accordance with standard protocols (NCWRC and NCDMF 2011). A subsample of 15 scales per 25-mm size-class per sex (as available) was aged by one reader, and a 20% verification subsample was aged by a second reader. Differences between readers were resolved to establish 100% reader agreement. Proportions of each age-class within each 25-mm size-class were computed and expanded to the total number of Striped Bass collected within each size-class by sex. Mean lengths at age were calculated for the entire sample as described by Bettoli and Miranda (2001).

The Chapman-Robson estimator was used to elucidate total instantaneous mortality (Z) following the recommendations of Smith et al. (2012). Instantaneous fishing mortality (F) was derived using the Z estimate and assuming an instantaneous natural mortality (M) of 0.15. See Appendix A for detailed catch-curve methodology.

Virtual population analysis (VPA; Allen and Hightower 2010) was used to reconstruct the spawning stock abundance using phase-II stocking as an estimate of recruitment and catch-curve mortality estimates. The relative contributions of recreational harvest and discard, commercial harvest, and natural mortality to total annual mortality were investigated. Detailed methodology, results, and discussion of this analysis are presented in Appendix B.

Yield-per-recruit models were developed to simulate the effects of various harvest regulations on the population. Response variables of interest included yield (kg), fishery harvest, abundance of 30-in fish and larger (approximately age 9+), egg production, and spawning potential ratio (SPR; Goodyear 1993). See Appendix C for detailed yield-per-recruit methodology.

Stocking Program

Broodstock collections and stocking.—Broodstock collections were conducted April 23–24, 2014, independent of the spawning stock survey. Collections were conducted via boat-mounted electrofishing with 2 dip netters. Broodstock were transported to Edenton National Fish Hatchery for propagation and rearing of juveniles, with the goal of producing 100,000 phase-II (125–200 mm) Striped Bass from two brood tanks each consisting of one female and three males. Fin clips for genotyping were collected from all broodstock for future parentage based tagging assessments.

Hatchery contribution.—Genotyping for parentage based tagging analysis was conducted on fin clip samples by the South Carolina Department of Natural Resources (SCDNR) Hollings Marine Lab. Parentage based tagging analysis was available for year-classes stocked in the Neuse River since 2010. Interpretation of hatchery contribution data presented herein should focus on younger cohorts as origin of fish (hatchery or wild) in year-classes produced before 2010 is unknown via parentage based tagging.

Recreational Harvest

NCDMF creel survey.—Recreational fishing statistics from the CSMA were calculated through a non-uniform probability stratified access-point creel survey (Pollock et al. 1994) on the Neuse River from January 1 to December 31. Access sites were partitioned into three zones along the river (lower, middle, upper) and included major tributaries. Site probabilities were set in proportion to the likely use of the site according to time of day, day of the week, and season. Probabilities for this survey were assigned based on observed effort from past years and direct observation of creel clerks. Morning and afternoon periods were assigned unequal probabilities of conducting interviews, with each period representing half a fishing day. A fishing day was defined as the period from 1 h after sunrise until 1 h after sunset. Monthly sampling periods for each zone were stratified accordingly, and all weekend/holiday dates along with two randomly selected weekdays were chosen from each week for sampling. The three zones were covered with one creel clerk per zone. Only preliminary data collected from the creel survey during the open CSMA recreational season are reported here, however creel survey coverage was not temporally uniform throughout the lower, middle, and upper zones. The lower zone was surveyed from October 1, 2013 through April 30, 2014, while middle zone surveys were conducted January 1, 2014 through April 30, 2014 and the upper zone surveys from February 16, 2014 through April 30, 2014.

Returning fishing parties were interviewed by a creel clerk at the selected access point to obtain information regarding party size, effort, total number of fish harvested and/or released, primary fishing method, and location or “intercept”. Harvested fish were identified, counted, measured (nearest mm fork length), and weighed to the nearest 0.1 kg, while information on discarded fish was obtained from the angler(s) to acquire the number and status of discarded individuals. Discard mortality was calculated by multiplying the number of discards by a 6.4% catch-and-release mortality rate (Nelson 1998). Creel survey results documented in this report should be considered preliminary; finalized data will be analyzed in collaboration with NCDMF and presented elsewhere.

Recreational harvest regulations.—The recreational fishery in inland and joint waters of the Neuse River during this stock assessment period was regulated by a daily possession limit and length limits effective July 1, 2008. During the harvest season of October 1, 2013 through April 30, 2014, the daily creel limit for Striped Bass was 2 fish per day with a minimum total length (MLL) restriction of 18 inches (457 mm) and a protective slot of no Striped Bass harvest between 22 and 27 inches (559–686 mm) in joint or inland waters. Similar regulations were in effect for coastal fishing waters managed by NCDMF, but without the protective slot limit.

Results

Spawning Stock Assessment

Field staff collected 316 Striped Bass and 13 Bodie Bass (female Striped Bass *x* male White Bass *M. chrysops)* between April 15, 2014 and May 28, 2014. Three additional Striped Bass were collected on April 8, 2014, but were excluded from CPUE analyses because American Shad and Hickory Shad *A. mediocris* were the primary target species. After adjusting for in-season recaptured fish, male Striped Bass comprised 72% of the sample (*N* = 224), while females accounted for 28% (*N* = 87; Table 2). Weekly mean (SE) CPUE was 10.1 (3.1) fish/h (Table 3). The peak in weekly mean CPUE was 23.6 (8.9) fish/h, occurring May 5–8 with water temperatures measuring 19.7°C (Table 3). Peak Striped Bass catch occurred on May 6 with 134 (CPUE = 56 fish/h) collected near Smithfield, accounting for 42% of the spring 2014 total sample. Mean site CPUE was highest at Booker Dairy and lowest at Quaker Neck (Figure 2). Sampling effort was almost evenly split between upper (13.8 h; Raleigh and Smithfield access) and lower (13.1 h; Goldsboro access) sampling sites. However, 71% of the total sample was collected in upper-sample sites (Figure 2). Mean CPUE in upper sampling sites was 17.8 fish/h, compared to 5.0 fish/h in lower sites (excluding Neuse Canal).

A total of 210 Striped Bass were aged by the primary reader, with a subset of 70 aged by a second reader. Initial agreement between readers was 53%, with 88% agreement ±1 year and 100% agreement ±2 years. One hundred percent reader agreement was attained on a third read of scales previously disagreed upon. One un-aged male could not be assigned an age because total length was not recorded. Length at age was similar between scales that were read by one reader and the subsample of scales that were read by two readers for both males (Figure 3) and females (Figure 4).

Male Striped Bass were represented by 8 year-classes (ages 3–9) with the 2010 year-class (age 4) dominating the electrofishing catch by comprising 26% of the total sample and a CPUE of 3 fish/h (Table 2). Age-3 and age-5 males contributed 21% and 17% to the total sample (Table 2). Males age 6 and older accounted for 9% of the total sample (Table 2) and 12% of the male sample (Table 4). Female Striped Bass were also represented by 8 year-classes (ages 3–8, age 10), with the 2010 year-class (age 4) comprising 30% of the female sample and 8% of the total sample (Table 2). Age-3 and age-5 females contributed 4% and 7% to the total sample. Females age 6 and older represented 9% of the total sample (Table 2) and 32% of the female sample (Table 4).

Both males and females exhibited unimodal size distributions (Figure 5). Males ranged 470–764 mm TL, with the peak occurring in the 526–550 mm size-class. The male size distribution was right skewed. Mean length-at-age analysis suggested males in the peak size-class were age 3. Age analysis determined age-4 males were more abundant; however their size distribution was protracted compared to age-3 males. Of captured males, 105 were harvestable size, representing 47% of males and 34% of the total Striped Bass sample. Females ranged 516–850 mm TL, with the peak occurring in the 651–675 mm size-class. The female size distribution was also slightly right skewed. The peak size-class corresponded with age-5 females, which had a mean length of 652 mm TL (Table 4) and were the second most abundant age-class. Of captured females, 36 were harvestable size, representing 41% of females and 12% of the total Striped Bass sample.

The Chapman-Robson method estimated mortality $Z = 0.86$ (SE = 0.1), which corresponds to a 58% annual mortality rate (*A*; Figure A.1). Spawning stock exploitation was estimated as $F = 0.71$, or a 48% annual exploitation rate assuming a type II fishery (Figure A.2). The estimated mortality rate exhibited high precision, as evidenced by catch-at-age that closely followed the expected catch-at-age based on the underlying geometric distribution of the Chapman-Robson method (Figure 6). See Appendix A for detailed catch-curve analysis.

Virtual population analysis estimated a 2014 spawning stock biomass of 34,334 kg (Table B.2). The analysis indicated a large proportion of total annual mortality is not accounted for in recreational and commercial fisheries monitoring programs (Table B.3). See Appendix B for detailed VPA analysis.

Yield-per-recruit analysis indicates egg production is severely depressed relative to an unfished fishery, with SPR = 0.03 at the 2014 exploitation rate (Table C.2; Figure C.5; Figure C.6). A 26-in MLL was the least restrictive regulation that was predicted to increase egg production to levels attaining the target SPR (SPR = 0.45) at the exploitation target (F_{TARGET} = 0.25). A 26-in MLL at the target exploitation rate was also predicted to increase yield relative to the current fishery (Table C.2; Figure C.3). See Appendix C for detailed yield-per-recruit analysis.

Stocking Program

Broodstock collections and stocking.—Two females (671 and 854 mm) and six males (540–597 mm) were collected via electrofishing and transported to Edenton National Fish Hatchery. Broodstock were euthanized after spawning was complete to prevent future spawning that would confound PBT analyses. Total weight of broodstock removals was 22.9 kg. Fin clip samples were provided to the SCDNR Hollings Marine Laboratory to determine hatchery or wild origin for future sampling collections containing the 2014 year-class. Hatchery-reared progeny were moved to ponds for grow-out to phase-II sizes. Due to projected surplus, phase-I fish (25–50 mm TL) were stocked in Kinston, NC on July 1, 2014 (50,997 fish) and July 22, 2014 (28,867 fish) by hatchery personnel (Table 5). Only one batch of genetically distinct Striped Bass was produced; therefore, future genetic sampling will not be able to differentiate phase-I and phase-II stocking events. Although the phase-II production goal was 100,000 fish, only 78,866 were stocked at the Bridgeton BAA in November and December 2014 (Table 5). Three thousand phase-II Striped Bass were implanted with internal anchor tags prior to release in cooperation with NCDMF.

Hatchery contribution.—Genetic analysis of 200 fin clip samples collected in 2014 was completed in spring 2015 by the SCDNR Hollings Marine Laboratory (O'Donnell et al. 2015). Of the 200 samples, 147 exhibited a genotype indicative of hatchery parentage (74%). The 2010 hatchery-reared year-class was dominant, providing 43% (N = 85) of the total sample. The 2011 hatchery-reared year-class provided 31% (N = 62), while the remaining 53 samples could not be assigned hatchery parentage and were designated as unknown origin; however, hatchery parentage assignment is not available for pre-2010 year-classes (age 5 and older in 2014). The 53 individuals classified as unknown either hatched in the wild or were stocked before 2010. Hatchery fish comprised 97% of the sample less than 575 mm (predominately age 4 and younger, see Tables 6 & 7), while unknown origin fish (likely wild) comprised 3% of the same size-classes (Figure 7).

Recreational Harvest

Preliminary creel survey results indicated an estimated 39,717 h of angling effort resulted in 7,888 landed and 1,946 harvested Striped Bass from October 1, 2013 to April 30, 2014 (Table 8). Angling effort was concentrated in the lower zone of the creel survey (Turkey Quarter Creek landing and further downstream), with 97% of the effort (38,412 h) and 93% of the harvest (1,815 fish) occurring within joint or coastal waters in the vicinity of New Bern, NC. In NCWRC-managed inland waters, the fishery peaked in April in the upper zone (Milburnie dam to NC 111 in Goldsboro) with 836 h of angling effort and 130 fish harvested (Table 8). Inland waters were responsible for 2% of the catch (harvest and discards; 167 fish). Overall, 5,942 fish were discarded in the Neuse River during the open season (Table 8). The majority of discards (64%) were smaller than the minimum length limit, with most discards occurring in March in the lower zone (Table 8). Estimated recreational discard mortality was 380 fish, bringing the total number of Striped Bass removed from the fishery during the open season to 2,326 fish (3,526 kg).

Management Implications

Overall, results of the 2014 Striped Bass spawning stock survey were similar to previous years. The mean daily CPUE of 10.1 fish/h was almost identical to the mean daily CPUE over the time period 1994–2014 (10.7 fish/h; Table 9). No trends in mean daily CPUE are apparent since 1994, despite the removal of Quaker Neck dam in 1998 and implementation of conservative harvest limits in 2008 (Figure 8). Peak daily CPUE in 2014 (56 fish/h) was the greatest since 2009 and the fourth greatest since 1994 (Figure 8). This peak daily CPUE occurred while sampling Fire Dept. Rd and Booker Dairy sites (Figure 1) at a water temperature of 21.2°C and within the optimal temperature range associated with spawning activity (18–22°C). The four peaks of highest magnitude since 1994 (2000, 2003, 2009, 2014) have occurred at sampling locations in the upper-spawning grounds between Smithfield and Milburnie dam. Peaks in 2000, 2003, and 2009 occurred in April, while the 2014 peak occurred in May. Age-3 CPUE declined from 2012 and 2013 levels, possibly indicating a weak 2011 year-class (Figure 9). Age 6 and older CPUE in 2014 was the highest since the sample record began (Table 9), and continued an increasing trend since 2008 (Figure 9). This trend of increasing age 6 and older CPUE could reflect an increase in recruitment following the change in phase-II stocking from biennial to annual stocking events (Table 5). Higher than average streamflow throughout much of the survey (Figure 10) allowed access to upper spawning grounds and likely influenced higher relative abundance in upper sampling sites (Milburnie, Raleigh, Fire Dept. Rd, Booker Dairy) compared to sampling sites near Goldsboro (Figure 2).

Striped Bass in the Neuse River continue to exhibit fast growth. Male mean length at age 3 was the highest since the survey period began (Table 6), while female mean length at age 3 was third highest for the period (Table 7). Age-3 males and females in the Neuse River in 2014 were approximately the same mean length as age-5 males and females collected in the Roanoke and Tar rivers in 2013 (Dycus et al. 2014; McCargo and Dockendorf 2014). Male mean total length in 2014 was highest during the 1994–2014 sampling period (Table 9) and is the result of faster than average growth and higher abundance of age-6 and older fish in 2014. Mechanisms for fast growth in the Neuse River have not been elucidated.

Catch-curve analysis using the Chapman-Robson estimator indicated high spawning stock mortality. Exploitation exceeded the CSMA management target (F_{TARGET} = 0.25) and threshold ($F_{\text{THRESHOLD}}$ = 0.29) mandated by Amendment 1 to the North Carolina Estuarine Striped Bass Fishery Management Plan (Section 4.3.2 in NCDENR 2013). Mortality also exceeded the 1994–2009 mean Z (0.59) reported by the 2010 CSMA Striped Bass Working Group (Section 14.7 in NCDENR 2013), although Z and F estimates were similar to the period 1994–2001 reported by Carmichael and Waters (2003). Regardless of methodology used, Striped Bass mortality in the Neuse River is similar to the total annual mortality that led to the collapse of the Chesapeake Bay Striped Bass stock in the 1970s (Richards and Rago 1999). The collapse of the Chesapeake Bay stock is well documented as having experienced recruitment overfishing that reduced the spawning stock biomass to levels that could not produce dominant year-classes (Richards and Deuel 1987; Richards and Rago 1999).

The high contribution of hatchery-reared fish in size-classes less than 575 mm TL in 2014 suggests stocked fish contribute prodigiously to the 2010 and 2011 year-classes. As age-classes begin to completely overlap in size, fish of unknown origin belonging to pre-2010 year-classes may be sampled more frequently in 2015 and 2016 genetics analyses. The true contribution of hatchery-reared Striped Bass to the Neuse River population will be unknown until the age-structure is comprised exclusively of fish hatched since spring 2010. Given the current truncated age structure, this will likely occur by 2021. Nonetheless, the 74% hatchery contribution in the 2014 Parentage Based Tagging (PBT) analysis is likely a minimum that will increase as additional age-classes of genetically marked fish recruit to the fishery. Evidence of poor wild recruitment has been documented in previous research (Hawkins 1980, Nelson and Little 1991, Barwick and Homan 2008). The determinant of poor wild recruitment to the 2010 and 2011 year-classes has not been identified. However, it is likely that recruitment overfishing is occurring given the high mortality rates present in the Neuse River since at least 1994 (Figure A.1; Figure C.5). Recruitment overfishing has been implicated as a principle factor for Striped Bass recruitment failure (Goodyear et al. 1985; Richards and Deuel 1987; Richards and Rago 1999). Increasing egg deposition on the spawning grounds by increasing the spawning stock biomass and advancing the female age-structure to older individuals may lead to improved wild recruitment (Goodyear 1984).

Yield-per-recruit analysis indicated a 26-in MLL would be required to attain an SPR of 0.45 if exploitation is reduced to the CSMA management target (Table C.2). However, harvest regulations in inland waters are unlikely to affect Neuse River Striped Bass mortality at the current level of angling effort. Less than 3% of the angling effort and 2% of the Striped Bass catch (harvest and discards) occurred in inland waters in 2014. The NCDMF creel survey indicates that almost all recreational Striped Bass landings occur in coastal waters. Commercial and recreational harvest in the Neuse River has been low, yet similar, since 2004 (NCDMF, unpublished data). Given the high spawning stock mortality in 2014 and evidence of long-term recruitment overfishing, more conservative management actions are needed in coastal waters to reduce exploitation.

Management Recommendations

1. Implement a 26-in MLL in inland, joint, and coastal waters of the Neuse River for recreational and commercial fisheries in conjunction with a substantial reduction in exploitation. Maintain current recreational daily creel limit (2 fish/d) and closed season (May 1–September 30). Commercial discard mortality must be reduced to meet the F_{target} specified in the FMP. Protecting the female spawning stock through an increased MLL in conjunction with reduced exploitation is expected to increase SPR to the target (SPR = 0.45) used to create the F biological reference point in the FMP, potentially improving wild recruitment. If actions to reduce exploitation are not implemented, population recovery will not occur and alternative management strategies that improve inland angling opportunities (e.g., put-grow-take, minimized regulations) should be explored.

2. Continue stocking a goal of 100,000 phase-II Striped Bass in 2015 utilizing broodstock collected from the Neuse River. Preliminary results of a NCSU telemetry study of phase-II Striped Bass suggested poor post-stocking survival. Therefore, enhance hatchery fish foraging ability by feeding live forage at least 1% body weight per day for 5 d prior to stocking. Introduce predatory fish before stocking to develop predator avoidance behavior. Culture two unique genetic batches of phase-II fish to evaluate stocking success at inland stocking locations. Inland stocking locations will be chosen based on potential carrying capacity of phase-II fish and potential trophic interactions with resident species.

3. Elucidate mechanisms affecting natural recruitment. Despite evidence of adult spawning, as well as egg and larval collection in previous research, PBT analyses indicates the Neuse River Striped Bass stock remains hatchery dependent. Streamflow, trophic interactions, juvenile nursery habitat, and stock-recruit relationships should be investigated to isolate likely determinants of mortality bottlenecks. In 2015, stock genetically unique Striped Bass larvae in Smithfield to determine if recruitment bottleneck occurs in the egg stage. Beginning in 2016, implement egg and larvae sampling program to estimate egg production, mortality rates, and identify utilization of available nursery habitat. Consider use of in situ egg and larval bioassays to evaluate egg and larval mortality.

4. Quantify economic impacts of the Neuse River Striped Bass stocking program. Economic cost-benefit analyses and biological statistics (e.g., hatchery contribution, discard mortality) should be considered when evaluating the stocking program.

5. Develop NCWRC Boating Access Areas on the Neuse River upstream of Smithfield, NC. Current access is limited for boat angling and NCWRC field sampling, despite the availability of fish habitat during average to above-average spring streamflow.

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Literature Cited

Allen, M. S., and J. E. Hightower. 2010. Fish population dynamics: mortality, growth, and recruitment. Pages 43–79 *in* W. A. Hubert and M. C. Quist, editors. Inland Fisheries Management in North America, 3rd edition. American Fisheries Society, Bethesda, Maryland.

ASMFC (Atlantic States Marine Fisheries Commission). 2013. Striped Bass stock assessment for 2013. 57th SAW Assessment Report. Atlantic States Marine Fisheries Commission, Arlington, Virginia.

Barwick, R. D., and J. M. Homan. 2008. Investigating Striped Bass recruitment in the Neuse River. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-22, Final Report, Raleigh.

Barwick, R. D., and K. R. Rundle. 2005. Annual Striped Bass monitoring in the Neuse River, North Carolina, 2005. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-22, Final Report, Raleigh.

Bettoli, P. W., and L. E. Miranda. 2001. Cautionary note about estimating mean length at age with subsampled data. North American Journal of Fisheries Management 21:425–428.

Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. Fishery Investigations, Series II, Great Britain Ministry of Agriculture, Fisheries and Food 19.

Bulak, J. S., C. S. Thomason, K. Han, and B. Ely. 2004. Genetic variation and management of Striped Bass populations in the coastal rivers of South Carolina. North American Journal of Fisheries Management 24:1322–1329.

Burdick, S. M., and J. E. Hightower. 2006. Distribution of spawning activity by anadromous fishes in an Atlantic slope drainage after removal of a low-head dam. Transactions of the American Fisheries Society 135:1290–1300.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach, 2nd edition. Springer-Verlag, New York.

Carmichael, J.T., and C. Waters. 2003. Catch curve exploitation estimates and fishery management options for Neuse River and Tar River Striped Bass stocks. North Carolina Division of Marine Fisheries, Morehead City.

Dycus, J. C., K. R. Rundle, and B. R. Ricks. 2014. Review of Striped Bass monitoring programs in the Central Southern Management Area, North Carolina–2013. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

Goodyear, C. P. 1984. Analysis of potential yield per recruit for Striped Bass produced in Chesapeake Bay. North American Journal of Fisheries Management 4:488–496.

Goodyear, C. P., J. E. Cohen, and S. W. Christensen. 1985. Maryland Striped Bass: recruitment declining below replacement. Transactions of the American Fisheries Society 114:146–151.

Goodyear, C. P. 1993. Spawning stock biomass per recruit in fisheries management: foundation and current use. Pages 67-71 *in* S. J. Smith, J. J. Hunt, and D. Rivard, editors. Risk Evaluation and Biological Reference Points for Fisheries Management. Canadian Journal of Fisheries and Aquatic Sciences, Special Publication 120.

Hawkins, J. H. 1980. Investigations of anadromous fishes of the Neuse River, North Carolina. North Carolina Division of Marine Fisheries, Special Scientific Report Number 34, Morehead City.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. U.S. National Marine Fishery Service Bulletin 81:898–903.

ICES (International Council for the Exploration of the Sea). 1995. Report of the study group on unaccounted mortality in fisheries, Aberdeen, Scotland, 17–18 April 1995. ICES CM 1995/B:1, Copenhagen, Denmark.

Knight, E., and R. A. Rulifson. 2014. Maturation and fecundity of Tar and Neuse River Striped Bass populations in 2013. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

McCargo, J. W., and K. J. Dockendorf. 2014. Review of Striped Bass fisheries and monitoring programs in Roanoke River, North Carolina–2013. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

NCDENR (N.C. Department of Environment and Natural Resources). 2004. North Carolina Estuarine Striped Bass Fishery Management Plan. North Carolina Division of Marine Fisheries and North Carolina Wildlife Resources Commission, Morehead City.

NCDENR (N.C. Department of Environment and Natural Resources). 2013. Amendment 1 to the North Carolina Estuarine Striped Bass Fishery Management Plan. North Carolina Division of Marine Fisheries and North Carolina Wildlife Resources Commission, Morehead City.

NCDENR (N.C. Department of Environment and Natural Resources). 2014. Summary maps of North Carolina Striped Bass tagging programs. North Carolina Division of Marine Fisheries, Morehead City.

Nelson, K. L. 1998. Catch-and-release mortality of Striped Bass in the Roanoke River, North Carolina. North American Journal of Fisheries Management 18:25–30.

Nelson, K. L., and A. E. Little. 1991. Early life history characteristics of Striped Bass in the Tar and Neuse rivers, North Carolina. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-22-11, Final Report, Raleigh.

North Carolina Wildlife Resources Commission (NCWRC) and North Carolina Division of Marine Fisheries (NCDMF). 2011. Estuarine Striped Bass in North Carolina: Scale ageing methods, Version 3.0. Federal Aid in Sport Fish Restoration. Raleigh. 15pp.

O'Donnell, T.P., D. J. Farrae, and T.L. Darden. 2015. 2014 Striped Bass Genotyping and Parentage Analyses. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

Pollock, K. H., C. M. Jones, and T. L. Brown. 1994. Angler survey methods and their applications in fisheries management. American Fisheries Society Special Publication 25, Bethesda, Maryland.

Richards, R. A., and D. G. Deuel. 1987. Atlantic Striped Bass: stock status and the recreational fishery. Marine Fisheries Review 49:58–66.

Richards, R. A., and P. J. Rago. 1999. A case history of effective fishery management: Chesapeake Bay Striped Bass. North American Journal of Fisheries Management 19:356–375.

Robson, D. S., and D. G. Chapman. 1961. Catch curves and mortality rates. Transactions of the American Fisheries Society 90:181–189.

Slipke, J. W., and M. J. Maceina. 2001. Fishery analysis and simulation tools (FAST), user's guide. Auburn University, Auburn, Alabama.

Smith, M. W., A. Y. Then, C. Wor, G. Ralph, K. H. Pollock, and J. M. Hoenig. 2012. Recommendations for catch-curve analysis. North American Journal of Fisheries Management 32:956–967.

Winslow, S. E. 2010. North Carolina Striped Bass tagging and return summary, January 1980–September 2010. North Carolina Division of Marine Fisheries, Final Report, Morehead C