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 ($F_{THRESHOLD}$ = 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 City.

TABLE 1.—Neuse River discharge requirements for boating access during spring electrofishing surveys.

Sample Site	Access Area	USGS Gage Station	Min Discharge (ft^3/s)	Min Gage (ft)
Milburnie Dam	Anderson Point Park	2087183	500	2.0
Raleigh	Anderson Point Park	2087183	366	1.7
Fire Dept. Rd	Smithfield	2087500	900	2.8
Booker Dairy Rd	Smithfield	2087570	-	6.7
Cox's Ferry	Cox's Ferry BAA	2089000	650	3.5
Beaverdam	Cox's Ferry BAA	2089000	800	4.5
Quaker Neck	Steven's Mill BAA	2089000	650	3.5
Steven's Mill	Steven's Mill BAA	2089000	650	3.5

TABLE 2.—Striped Bass age distributions (percent composition) and relative abundance (CPUE; fish/h) of 8 year-classes collected by electrofishing in the Neuse River, spring 2014. In-season recaptures were excluded from analyses.

Year Class	Age	Percent Composition			CPUE		
		Male	Female	Overall	Male	Female	Pooled
2011	3	20.6	3.9	24.4	2.4	0.4	2.8
2010	4	25.7	8.4	34.1	3.0	1.0	3.9
2009	5	17.0	6.8	23.8	2.0	0.8	2.8
2008	6	4.2	4.5	8.7	0.5	0.5	1.0
2007	7	3.5	3.5	7.1	0.4	0.4	0.8
2006	8	0.3	0.6	1.0	<0.1	0.1	0.1
2005	9	0.6	0.0	0.6	0.1	0.0	0.1
2004	10	0.0	0.3	0.3	0.0	<0.1	<0.1
Totals		72.0	28.0	100	8.3	3.2	11.6

TABLE 3.—Weekly mean CPUE (average CPUE across all sample sites with standard error) of Striped Bass collected by electrofishing on the Neuse River spawning grounds during spring 2014. Pooled CPUE (total catch/total effort) is also provided. Striped Bass collected on 8 April 2014 are excluded.

Sample Week	N	Effort (h)	Catch	Mean CPUE (SE)		Pooled CPUE	Discharge (ft^3/s)	Water temp (°C)
14–15 April	4	2.15	8	4.9	(1.8)	3.7	2,675	16.2
21–22 April	7	4.41	42	7.7	(3.8)	9.5	2,050	15.3
29 April – 2 May	8	5.98	77	14.3	(2.6)	12.9	1,615	18.7
5–8 May	8	5.93	169	23.6	(8.9)	28.5	1,390	19.7
12 May	4	2.14	2	1.2	(0.9)	0.9	585	24.5
19–21 May	6	4.35	9	2.1	(1.3)	2.1	2,963	20.0
27–28 May	4	1.95	9	8.2	(7.4)	4.6	2,700	24.1
Totals and Mean CPUE	41	26.91	316	10.1	(3.1)	11.7		

TABLE 4.— Age composition and mean total length (mm) at age of Striped Bass collected from the Neuse River by electrofishing, 2014. In-season recaptures and fish without a recorded length were omitted from age analyses. Parentheses denote standard error.

						Total Length (mm)		
Year Class	Age	N Aged	N Estimated	N Total	% Composition	Mean	Min	Max
				Males				
2011	3	34	30	64	28.6	539 (4)	470	610
2010	4	37	43	80	35.7	562 (3)	500	640
2009	5	30	23	53	23.7	617 (5)	577	720
2008	6	11	2	13	5.8	674 (10)	626	763
2007	7	10	1	11	4.9	698 (11)	630	764
2006	8	1	0	1	0.5	687 (-)	678	678
2005	9	2	0	2	0.9	725 (13)	703	736
Totals		125	99	224	100			
				Females				
2011	3	11	1	12	13.8	556 (8)	516	618
2010	4	26	0	26	30.0	606 (7)	530	670
2009	5	21	0	21	24.1	652 (9)	558	718
2008	6	13	1	14	16.1	703 (15)	616	798
2007	7	11	0	11	12.6	733 (19)	630	850
2006	8	2	0	2	2.3	775 (37)	738	810
2005	9	0	0	0	-	-	-	-
2004	10	1	0	1	1.1	812 (-)	814	814
Totals		85	2	87	100			

TABLE 5.—Neuse River Striped Bass stockings 1994–2014.

Year	Spawning Hatchery	Grow-out Hatchery	Phase-I	Phase-II
1994	-	-	103,057	79,933
1995	Watha	Watha	99,176	0
1996	Watha		100,000	100,760
1997	Watha		100,000	0
1998	Watha		207,730	83,195
1999	Watha		100,000	0
2000	Watha		121,993	108,000
2001	Watha		103,000	0
2002	Watha	Edenton	0	147,654
2003	Watha		100,000	0
2004[a]	Watha	Edenton	100,000	168,011
2005	Watha		114,000	0
2006	Watha	Edenton	146,340	99,595
2007	Watha	Edenton	172,882	69,953
2008	Watha		313,798	0
2009	Watha	Edenton	100,228	104,061
2010[b]	Watha	Edenton	0	107,142
2011[b]	Watha	Edenton	0	102,089
2012[b,c]	Watha	Edenton	50,180	90,178
2013[b,c]	Watha	Edenton	181,327	113,834
2014[b,c]	Edenton	Edenton	79,864	78,866

[a] Hatchery staff observed phase-II die-off post-stocking; stocking failed.

[b] Broodstock genotypes available.

[c] Neuse River broodstock utilized; Roanoke-source broodstock used 1994-2011.

TABLE 6.— Mean total length (mm) at age for male Neuse River Striped Bass year-classes collected 1994–2014. Only those year-classes with four or more individuals aged are included.

Year Class	Age 1	2	3	4	5	6	7
1992		422	502	543	596	659	721
1993		423	462	537	591	655	
1994		425	499	532	603		
1995		424	483	539	590		
1996		405	494	547	604	664	664
1997		424	508	565	632	656	
1998		431	526	596	584		718
1999		443	529	534	596		
2000		451	519	577	612		
2001		481	506	584			
2002		430	517				
2003		465	503	552			
2004		418	491	532	609		622
2005			441	569	621	631	
2006	237		501	569	579	640	678
2007		435	531	560	621	656	698
2008			529	578	583	674	
2009		425	504	539	617		
2010			505	562			
2011		437	539				
Mean	237	434	504	556	603	654	684
Min		405	441	532	579	631	622
Max		481	539	596	632	674	721

TABLE 7.— Mean total length (mm) at age for female Neuse River Striped Bass year-classes collected 1994–2014. Only those year-classes with four or more individuals aged are included.

	Age							
Year Class	1	2	3	4	5	6	7	8
1992			521	572	631	657		
1993						697	761	
1994			535	582		681		
1995			519	540	621			
1996		425	561	585	634	684	728	
1997		512	551	600		689		
1998					588			
1999				544	614			
2000			540	590	667		857	
2001			571					
2002								
2003				597				
2004			519	565	619	671		
2005			431	578	618	668		736
2006			530	585	637		710	
2007				591		691	733	
2008			521		600	703		
2009				568	652			
2010			518	606				
2011			556					
Mean		469	529	579	626	682	758	736
Min		425	431	540	588	657	710	
Max		512	571	606	667	703	857	

TABLE 8.— Estimated effort, harvest, and discard statistics of Neuse River recreational Striped Bass fishery. Statistics are preliminary and estimated using data collected by the NCDMF creel survey conducted between Oct 1, 2013 and Apr 30, 2014.

Month	Effort		Harvest		Discard	
	Trips	Hours	Number	Kg	Number	kg
			Lower Zone [a]			
Oct	1,649	7,309	538	864	712	513
Nov	604	2,442	181	275	614	442
Dec	1,206	5,733	190	319	501	361
Jan	583	2,605	64	105	109	78
Feb	957	3,119	42	77	230	165
Mar	1,504	7,298	492	984	3,157	2273
Apr	1,512	9,907	309	628	583	420
			Middle Zone [b]			
Jan	0	0	0	0	0	0
Feb	0	0	0	0	0	0
Mar	132	468	0	0	37	26
Apr	0	0	0	0	0	0
			Upper Zone [c]			
Feb	0	0	0	0	0	0
Mar	28	28	0	0	0	0
Apr	398	809	130	265	0	0
			Total			
Lower	8,016	38,412	1,815	3,252	5,906	4,252
Middle	132	468	0	0	37	26
Upper	425	836	130	265	0	0

[a] Turkey Quarter landing downstream; joint and coastal waters.
[b] Seven Springs BAA to Core Creek Landing; inland waters.
[c] Milburnie dam to NC 111 bridge in Goldsboro; inland waters.

TABLE 9.—Summary of Neuse River Striped Bass spawning stock characteristics and mean discharge, 1994–2014. Due to reporting inconsistencies, data were reanalyzed and may differ slightly from annual NCWRC final reports. Discharge measurements are monthly means from USGS gage number 02087500 (Neuse River near Clayton, NC).

Year	Effort (h)	N	Males	Females	M : F Ratio	CPUE (fish/h)					Total Length (mm)			Discharge (ft^3/s)	
						Age 3	Age 6+	Peak Daily	Mean Daily (SE)	Pooled	Male Mean	Female Mean	Max	April	May
1994	7.3	120	91	28	3.3:1	0.5	3.1	29.7	18.6 (4.7)	16.2	559	650	805	1,460	395
1995	11.0	215	183	32	5.7:1	14.4	1.1	33.2	18.4 (6.2)	19.6	519	613	780	360	309
1996	19.3	226	168	58	2.9:1	2.5	1.2	28.0	11.1 (3.3)	11.7	515	603	818	1,075	1,223
1997	21.3	143	114	29	3.9:1	2.2	0.8	16.0	6.4 (1.6)	6.7	515	639	840	1,190	1,845
1998	17.0	221	175	43	4.1:1	3.1	2.0	39.9	13.9 (4.7)	12.8	501	629	940	3,426	625
1999	13.8	292	242	50	4.8:1	12.4	2.0	46.9	19.0 (3.9)	21.2	523	592	840	979	565
2000	20.2	353	242	111	2.2:1	3.9	1.4	60.0	16.7 (4.2)	17.4	502	612	940	1,542	809
2001	17.5	154	131	23	5.7:1	3.8	0.2	28.0	8.4 (2.5)	8.8	550	622	726	2,846	418
2002	20.0	102	84	18	4.7:1	0.3	1.3	12.0	4.3 (1.0)	5.1	538	696	814	635	292
2003	31.7	402	304	98	3.1:1	6.5	2.2	61.9	11.3 (3.2)	12.7	539	606	918	4,813	1,865
2004	11.3	73	54	19	2.8:1	0.7	1.4	12.6	6.4 (1.1)	6.4	581	656	925	864	502
2005	23.2	127	107	18	5.9:1	1.3	1.1	11.6	5.2 (1.4)	5.4	543	714	1140	1,212	422
2006	12.0	58	53	5	10.6:1	0.6	0.5	8.6	3.8 (1.5)	4.8	448	739	874	428	466
2007	19.3	172	140	32	4.4:1	7.5	0.5	28.0	7.7 (2.6)	8.9	498	609	894	1,405	452
2008	25.2	141	110	31	3.5:1	1.2	0.1	16.6	4.8 (1.4)	5.6	514	560	831	1,079	747
2009	18.2	362	330	31	10.6:1	16.6	0.2	57.3	18.0 (7.0)	19.8	501	604	882	1,696	546
2010	14.5	141	122	19	6.4:1	4.8	0.8	22.9	9.5 (2.8)	9.7	556	618	762	821	1,015
2011	15.0	176	115	60	1.9:1	2.2	1.4	20.3	11.8 (2.1)	11.6	516	614	823	720	587
2012	17.6	144	117	27	4.3:1	4.1	1.3	33.1	5.9 (2.4)	8.2	549	596	767	542	761
2013	19.9	322	265	56	4.7:1	5.3	2.9	29.5	13.2 (2.8)	16.2	545	622	931	1,112	1,693
2014	26.9	316	224	87	2.6:1	2.8	4.1	56.0	10.1 (3.1)	11.6	583	650	850	1,957	2,246
Avg.	18.2	203	161	42	3.9:1	4.6	1.4	31.1	10.7 (1.1)	11.5	528	631	862	1,436	847

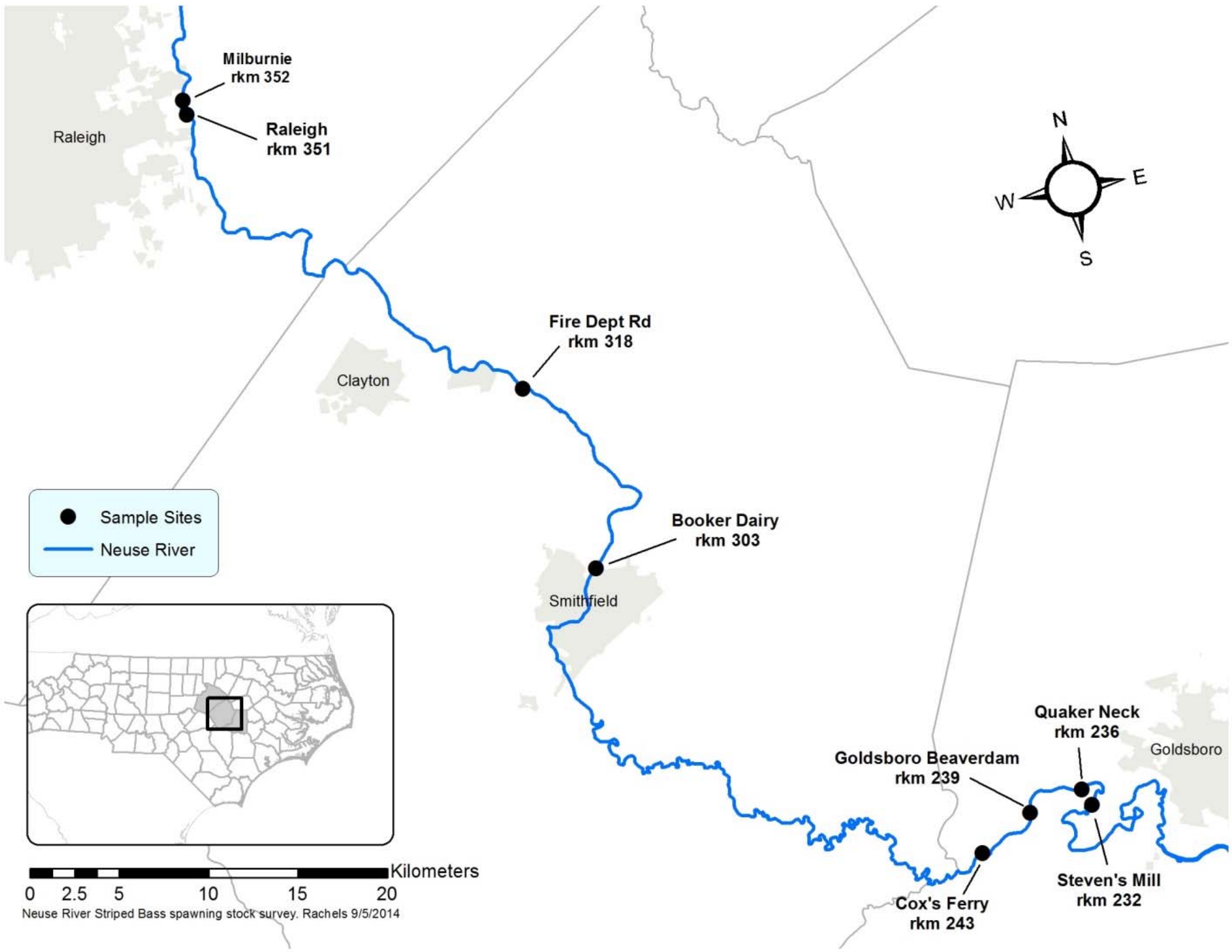

FIGURE 1.—Sampling sites in the Neuse River spawning ground survey, spring 2014.

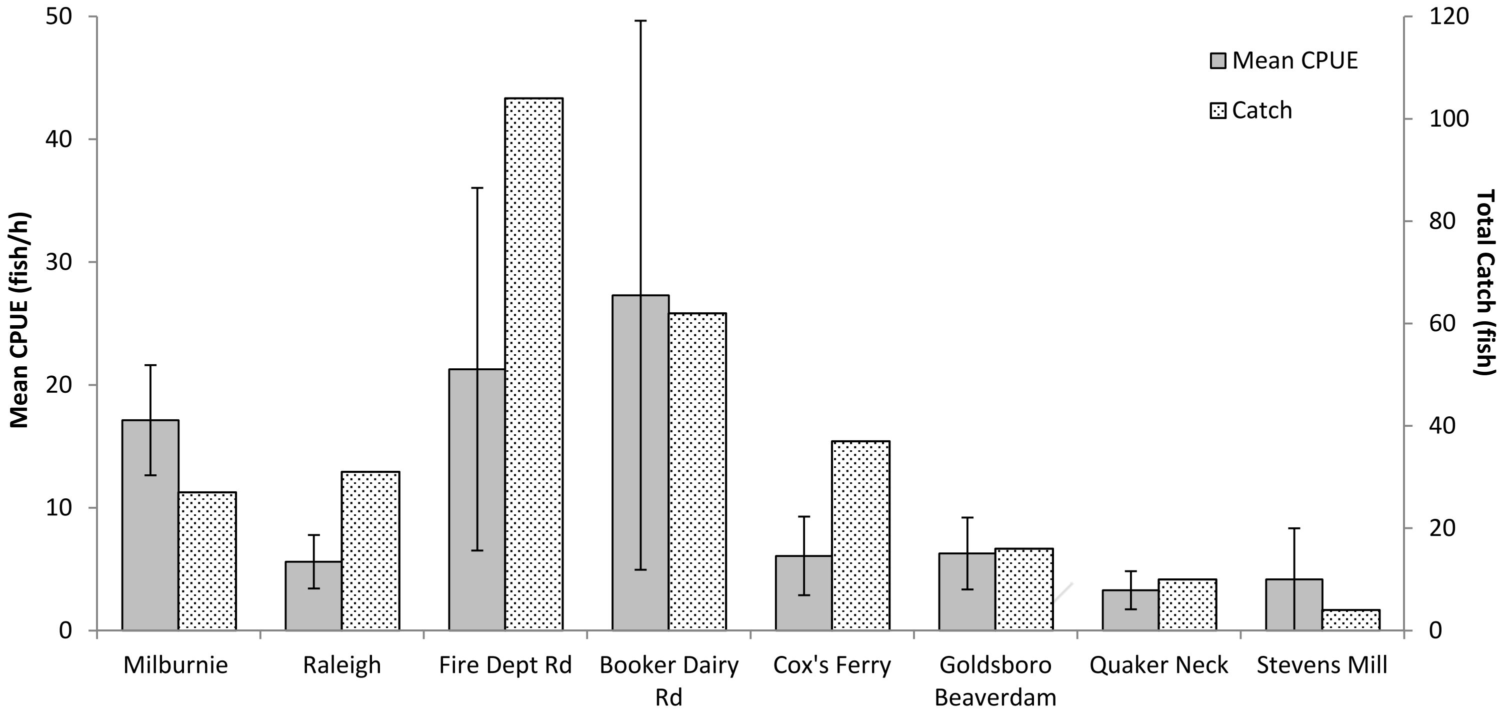

FIGURE 2.—Mean site CPUE (fish/h) and total catch (fish), spring 2014. Sites are ordered left to right from upstream to downstream. Only sites sampled more than once are included. Error bars denote CPUE standard error.

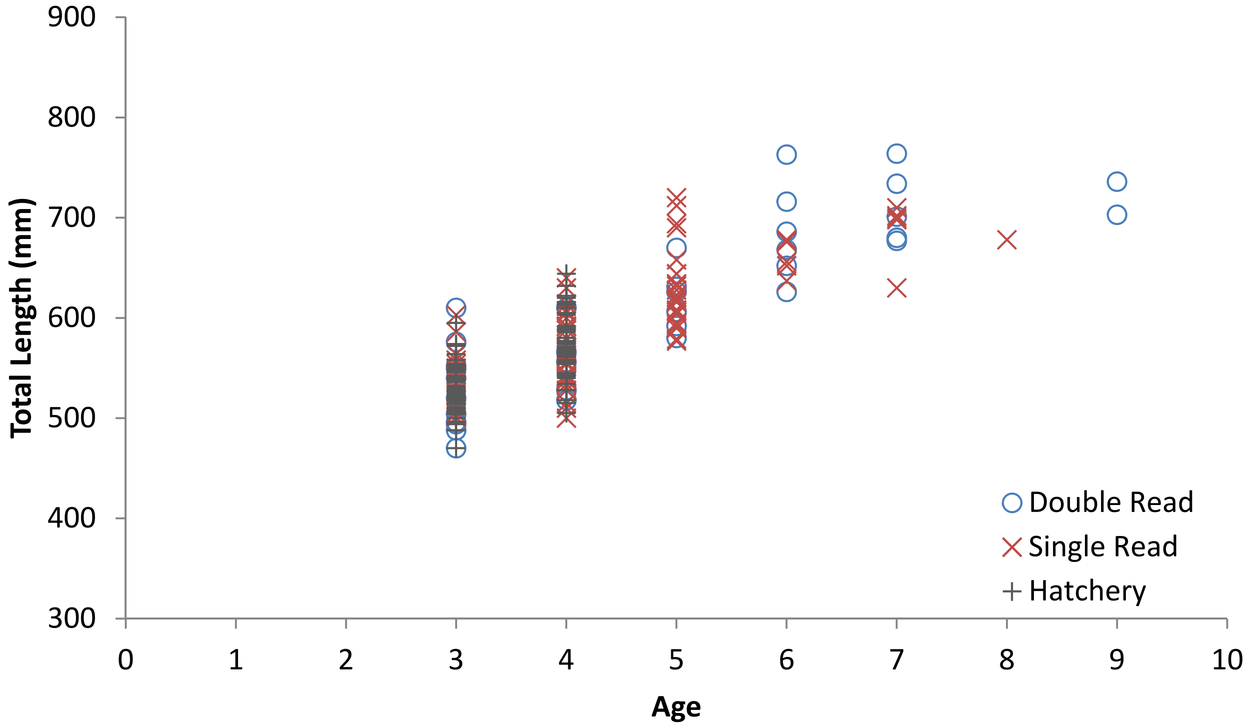

FIGURE 3.—Comparison of male known hatchery-aged fish, single-read, and double-read scale ages collected on the Neuse River, spring 2014.

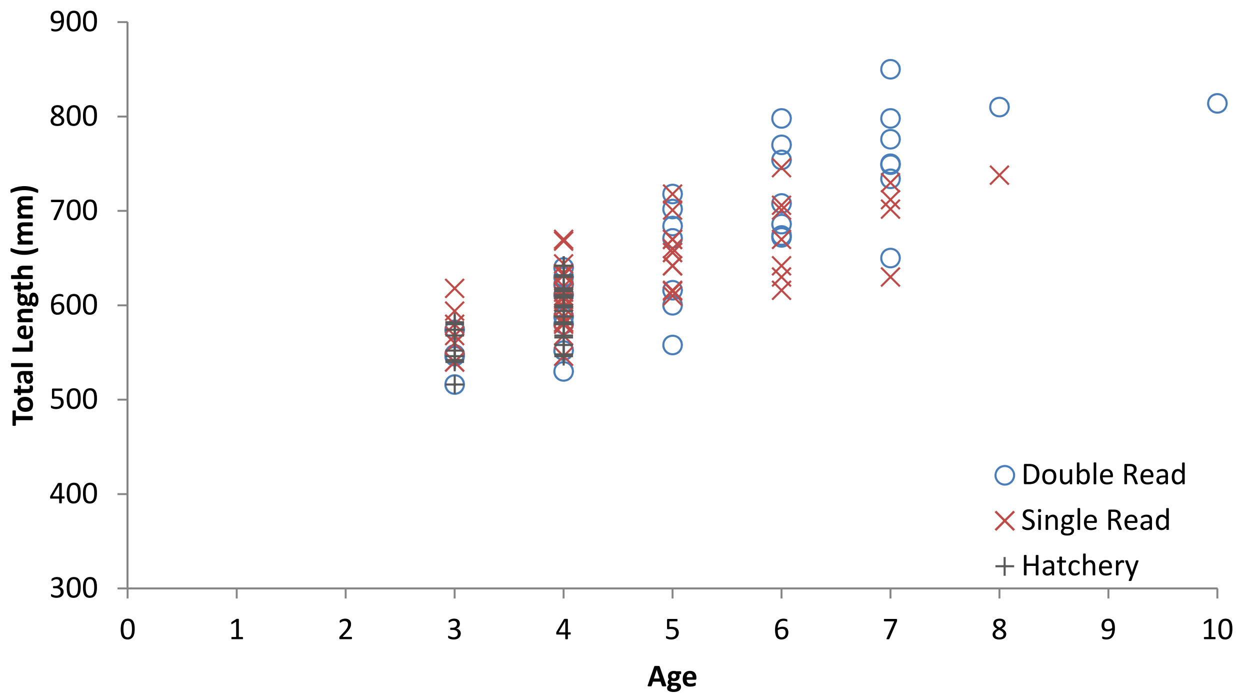

FIGURE 4.—Comparison of female known hatchery-aged fish, single-read, and double-read scale ages collected on the Neuse River, spring 2014.

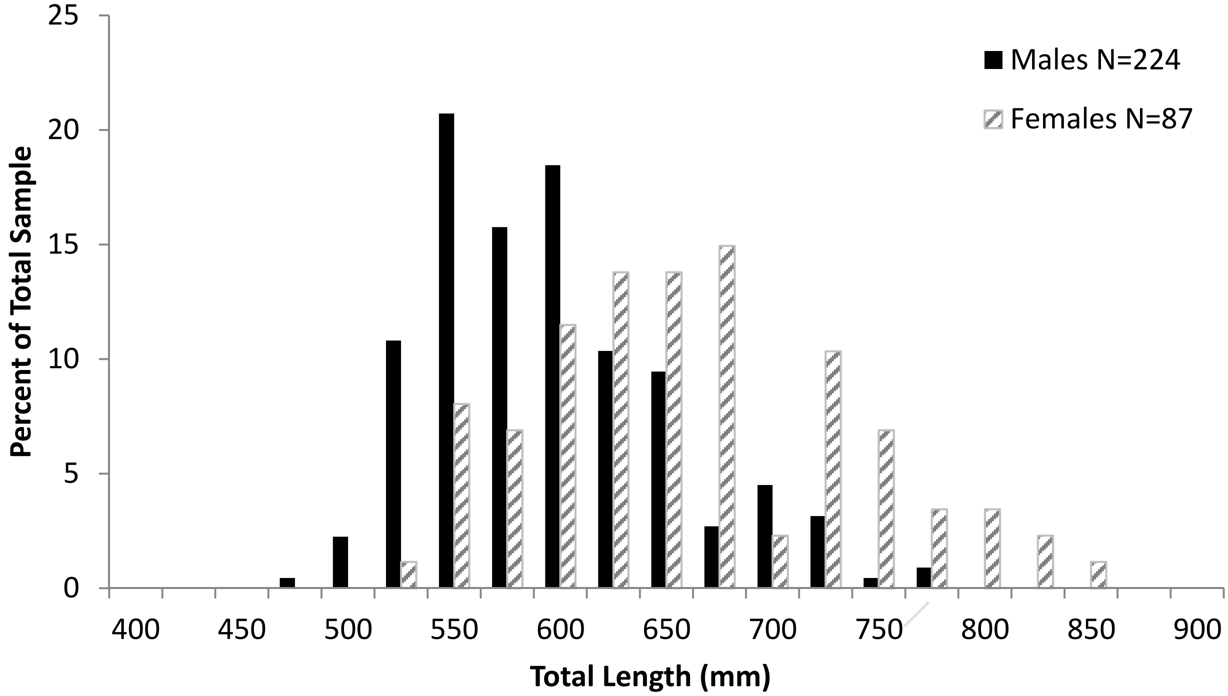

FIGURE 5.—Length-frequency distributions for Striped Bass collected from the Neuse River, spring 2014. In-season recaptures were omitted. Male and female plots sum separately to 100%.

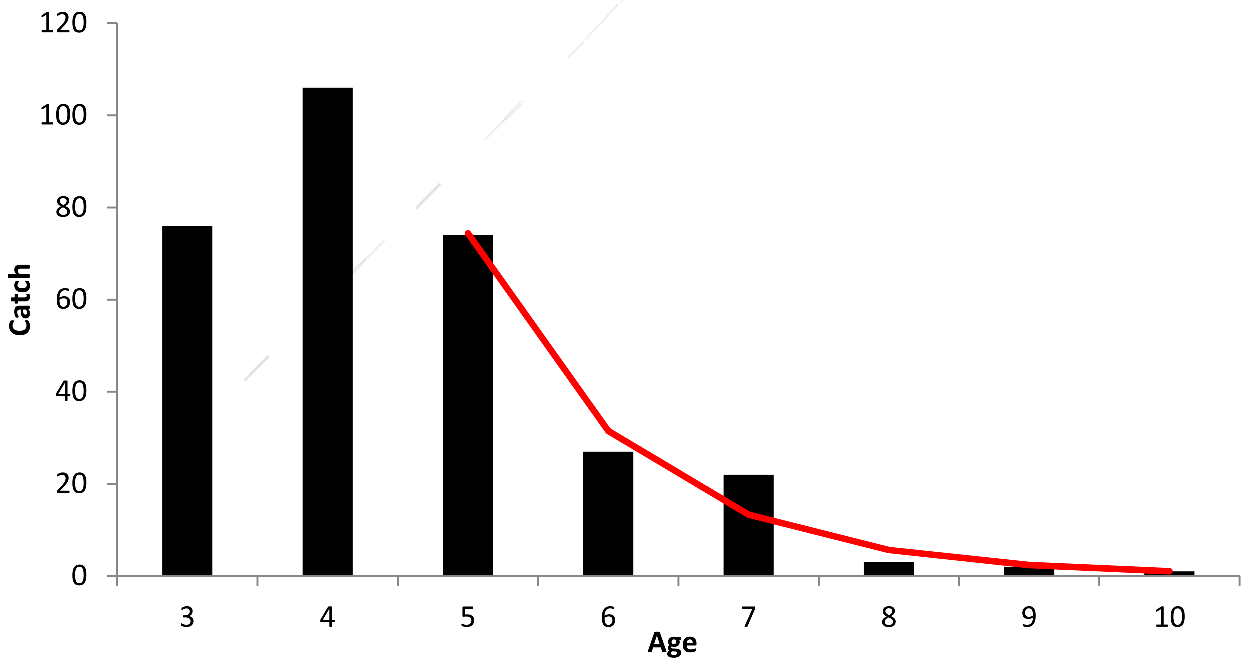

FIGURE 6.—Catch-at-age (black columns) and expected catch-at-age (red line) given a mortality rate based on the geometric distribution. Age at full recruitment (peak catch plus 1 year) occurred at age 5.

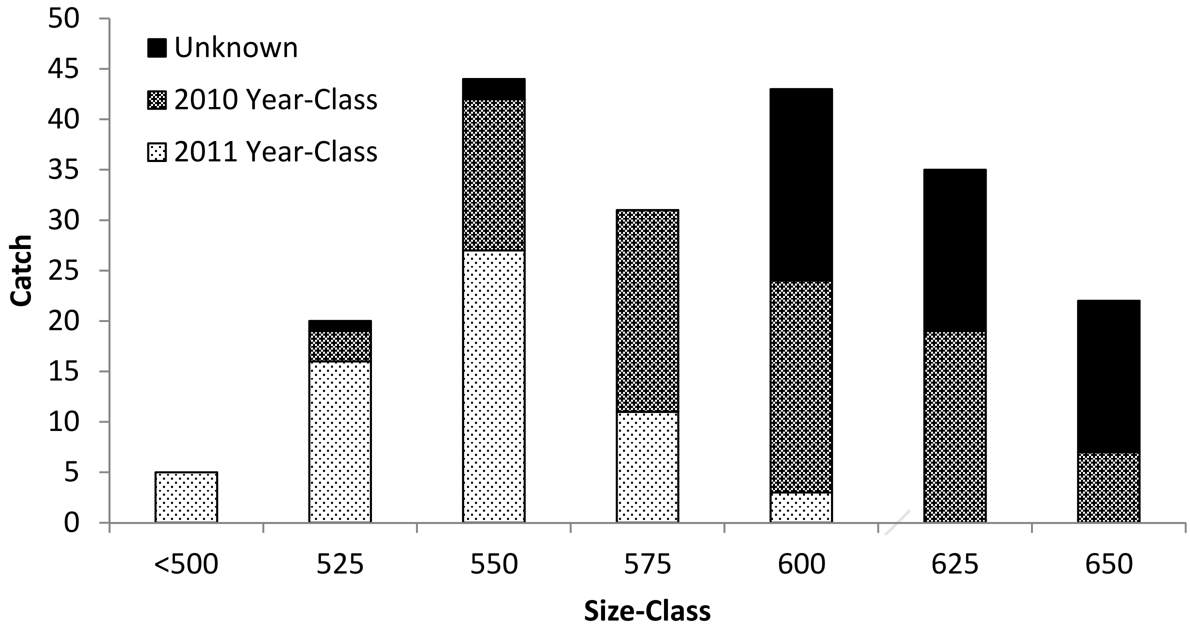

FIGURE 7.—Composition of hatchery and unknown origin fish by size-class from genetic samples collected during the spring 2014 spawning stock survey.

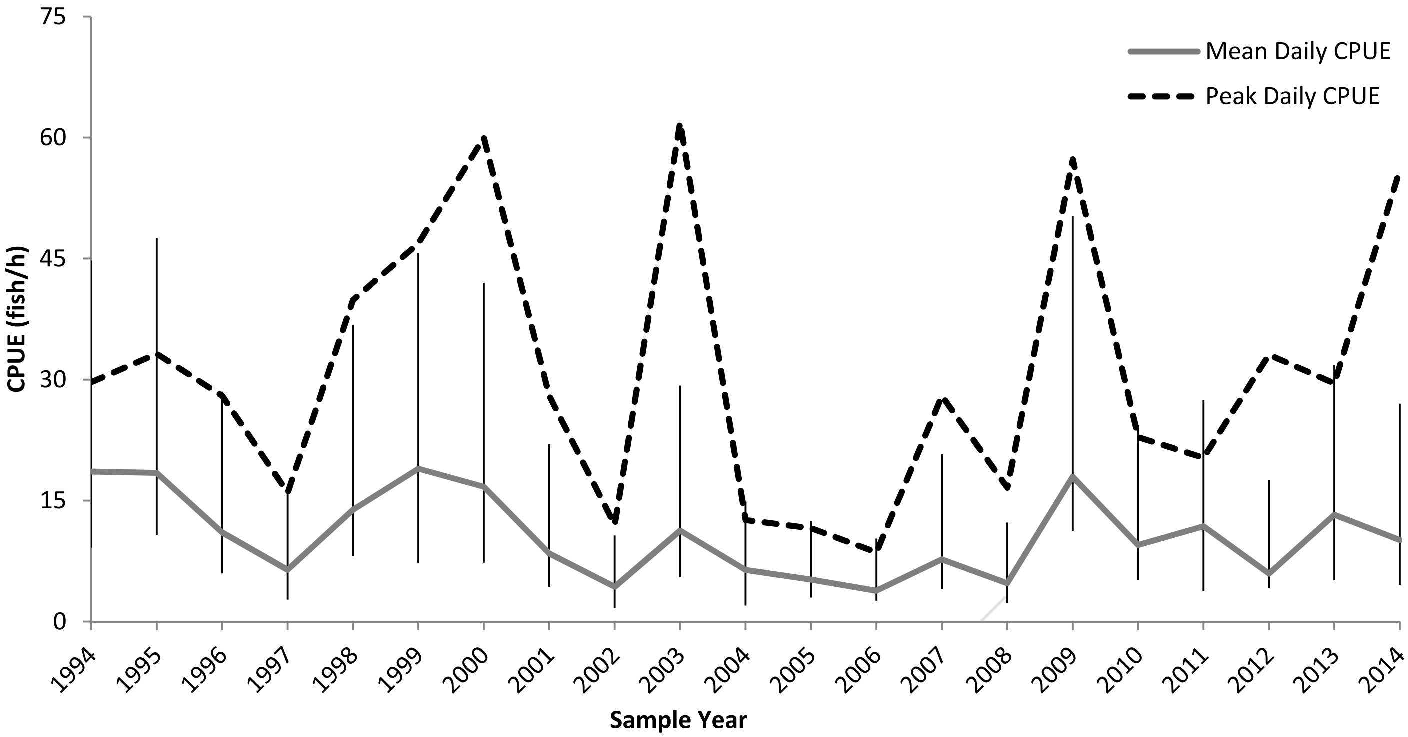

FIGURE 8.—Mean daily CPUE (fish/h) and peak daily CPUE of Striped Bass in sample years 1994–2014. Error Bars denote 95% bootstrapped confidence intervals for mean daily CPUE.

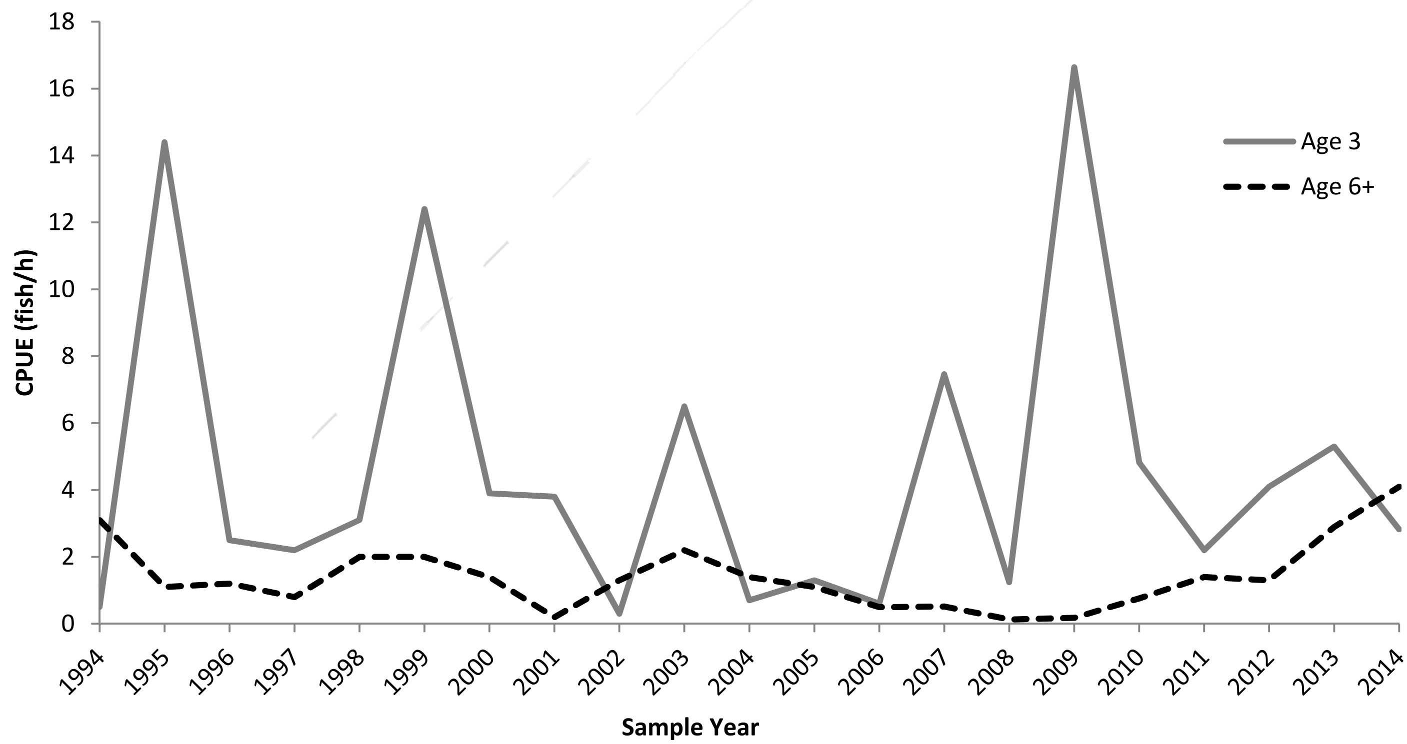

FIGURE 9.—Relative abundance (CPUE; fish/h) of age-3 and age 6+ Striped Bass in sample years 1994–2014.

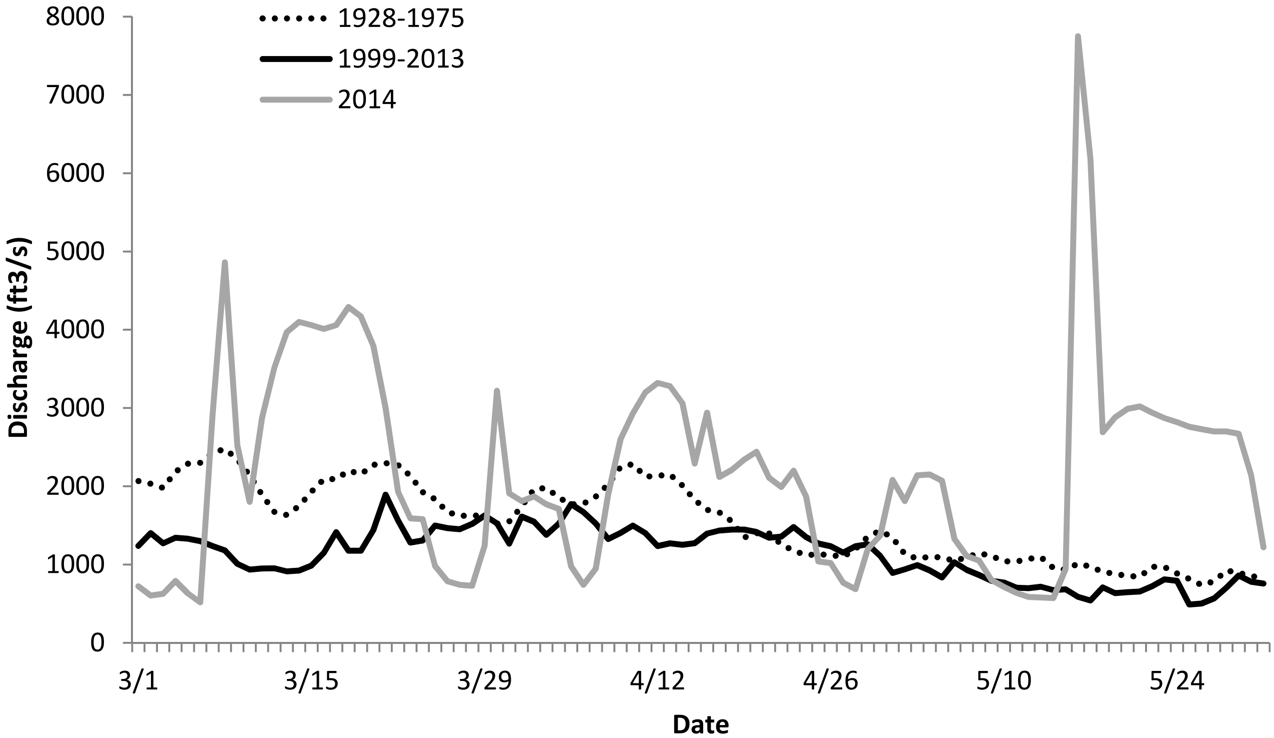

FIGURE 10.—Mean daily discharge from March–May from 1928–1975 (pre-Falls Lake), 1999–2013 (post-Quaker Neck Dam), and 2014 in the Neuse River. Discharge measurements from USGS gage number 02087500 (Neuse River near Clayton, NC).

Appendix A: Neuse River Striped Bass Catch-Curve Analysis, 1994–2014

Stock assessments were conducted in 2003 (Carmichael and Waters 2003) and 2010 (NCDENR 2013) to estimate mortality, derive biological reference points, and evaluate potential management options for the Neuse River and Tar River Striped Bass stocks. Both stock assessments utilized unweighted linear regression catch-curves to assess mortality, resulting in wide confidence intervals around the mortality estimates. These mortality estimates were deemed unsuitable for management use or stock status determination, and resulted in Central Southern Management Area (CSMA) Striped Bass being quantitatively assessed as "unknown" (NCDENR 2013). Albemarle/Roanoke (A/R) biological reference points for fishing mortality of F_{TARGET} = 0.25 and $F_{\mathrm{THRESHOLD}}$ = 0.29 were adopted for CSMA use. These biological reference points were based on spawning potential ratio (SPR) values of 0.45 (F_{TARGET}) and 0.40 ($F_{\mathrm{THRESHOLD}}$).

Recent improvements in catch-curve methodology render unweighted linear catch-curves obsolete. Smith et al. (2012) evaluated several mortality estimators, and provided specific recommendations for their use. For small sample sizes (*N* = 200), Smith et al. (2012) recommended the Chapman-Robson estimator (Robson and Chapman 1961) using an age-at-full-recruitment as the peak catch plus one year, no truncation of older age-classes, and an overdispersion correction for the variance to reduce negative bias. They recommended discontinuing the use of unweighted linear regression catch-curves since they are inferior to the Chapman-Robson estimator and weighted linear regression.

The objective of this analysis was to analyze Striped Bass mortality in the Neuse River using the catch-curve recommendations of Smith et al. (2012). Assessment of mortality rates with updated stock assessment tools will allow better understanding of Striped Bass population dynamics, calculation of biological reference points, and allow development of management strategies that lead to recovery of the stock.

Methods

Age-structure data from 1994–2009 WRC spring electrofishing surveys are from the FMP (Table 5 in Section 14.7; NCDENR 2013). Age-structure data from 2010–2013 were obtained from annual WRC CSMA reports (NCWRC 2011–2014), while age-structure from 2014 is contained within this report (Table A.1).

The Chapman-Robson estimator was applied to each year's catch-at-age data to estimate total instantaneous mortality (*Z*). The Chapman-Robson estimator derives *Z* as

$$CR(\hat{Z}) = \log_e\left(\frac{1+\bar{T}-T_C-\frac{1}{N}}{\bar{T}-T_C}\right) - \frac{(N-1)(N-2)}{N[N(\bar{T}-T_C)+1][N+N(\bar{T}-T_C)-1]}$$

where $CR(\hat{Z})$ is the total instantaneous mortality; $\bar{T}$ is the mean age of fish in the sample greater than or equal to age T_C; T_C is the age at full recruitment; and N is the sample size of fish greater than or equal to age T_C (Smith et al. 2012). The variance for the *Z* estimate was calculated as

$$\widehat{VAR}[CR(\hat{Z})] = \frac{[1-e^{-CR(\hat{Z})}]^2}{Ne^{-CR(\hat{Z})}} \ .$$

Variance overdispersion correction was performed using a variance inflation factor ($\hat{c}$; Burnham and Anderson 2002; Smith et al. 2012). The variance inflation factor was calculated as

$$\hat{c} = \frac{\sum \chi_k^2}{n-1}$$

where $\chi_k^2$is the chi-square goodness-of-fit statistic for catch-at-age k for each age-class greater than or equal to age T_C; and n is the number of age-classes greater than or equal to age T_C. Thus, corrected standard error ($\widehat{SE}_c$) was calculated as

$$\widehat{SE}_c = \sqrt{\hat{c} \ \times \ \widehat{VAR}[CR(\hat{Z})]} \ .$$

Upper and lower confidence limits (α = 0.10) were calculated for *Z* as $CI = Z \ \pm 1.645 \ \times \widehat{SE}_c$. Total annual mortality (*A*) and corresponding upper and lower confidence limits were converted from *Z* as $A = 1 - \ e^{-Z}$.

Annual estimates of instantaneous fishing mortality (*F*) were calculated by subtracting instantaneous natural mortality (*M*) from *Z*. Natural mortality has not been assessed in the Neuse River, therefore *M* = 0.15 was chosen due to its use in previous stock assessments. Since this is an assumed value without a measure of uncertainty, *F* was also calculated using *M* = 0.3. Conditional fishing mortality (*cf*) was calculated assuming natural mortality and fishing mortality coincide (type II fishery), and was estimated as

$$cf = \frac{F \times A}{Z} \ .$$

Results

Total instantaneous mortality and annual mortality exhibited considerable variation throughout the time series (Figure A.1). Annual mortality in 2014 was 57.7% (Table A.1; 90% CI

= 50.4%, 63.8%). However, precision of the mortality estimates was considerably improved over previous stock assessments (see Carmichael and Waters 2003; NCDENR 2013).

Exploitation rates indicate considerable fishing mortality, with F exceeding the FMP F_{TARGET} in 20 out of 21 years (Figure A.2). Instantaneous fishing mortality in 2014 was 0.71; this greatly exceeded FMP F_{TARGET} = 0.25. Exploitation still exceeded F_{TARGET} in 15 years of the 21 year time series using the doubled natural mortality rate (M = 0.30).

TABLE A.1.—Striped Bass catch-at-age from NCWRC Neuse River spring electrofishing surveys, 1994-2014. Shaded age-classes denote data used in mortality estimation.

Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
2	1	0	0	3	2	0	1	0	3	0	0	2	4	4	4	6	0	40	5	10	0
3	16	36	48	27	69	52	75	10	32	46	8	26	33	72	28	133	70	33	72	105	76
4	8	78	40	32	39	89	69	25	9	127	7	25	9	45	38	106	42	48	25	120	106
5	22	51	67	27	40	77	101	51	15	132	27	26	5	30	47	88	18	34	22	51	74
6	37	27	41	26	27	36	63	44	11	43	26	19	4	7	18	28	8	8	12	29	27
7	22	17	14	18	20	20	25	21	17	21	12	10	1	3	3	8	2	7	4	16	22
8	11	11	11	8	13	16	16	4	12	23	6	12	0	4	1	0	1	6	2	7	3
9	3	1	5	1	5	1	5	0	3	7	2	4	0	3	0	0	0	0	2	3	2
10	0	0	0	1	3	1	1	0	0	4	1	0	2	4	2	1	0	0	0	0	1
11	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Catch	120	221	226	143	219	292	357	155	102	403	90	125	58	172	141	373	141	176	144	341	311
Effort	7.3	11.0	19.3	21.3	17.0	13.8	20.2	17.5	20.0	31.2	14.4	23.2	12.0	19.3	23.3	16.4	14.5	15.0	17.7	19.9	26.9
CPUE	16.4	20.1	11.7	6.7	12.9	21.2	17.7	8.9	5.1	12.9	6.3	5.4	4.8	8.9	6.1	22.7	9.7	11.7	8.1	17.2	11.6
Z	1.08	0.73	0.85	0.61	0.45	0.75	0.45	0.52	0.36	0.65	0.78	0.44	0.53	0.63	0.98	0.84	0.94	0.84	0.62	0.75	0.86
90%LCL	0.77	0.58	0.67	0.44	0.37	0.61	0.31	0.32	0.19	0.49	0.59	0.34	0.29	0.46	0.37	0.63	0.75	0.54	0.49	0.62	0.70
90%UCL	1.39	0.88	1.03	0.77	0.53	0.90	0.60	0.73	0.53	0.82	0.97	0.54	0.77	0.80	1.59	1.05	1.13	1.14	0.75	0.87	1.02

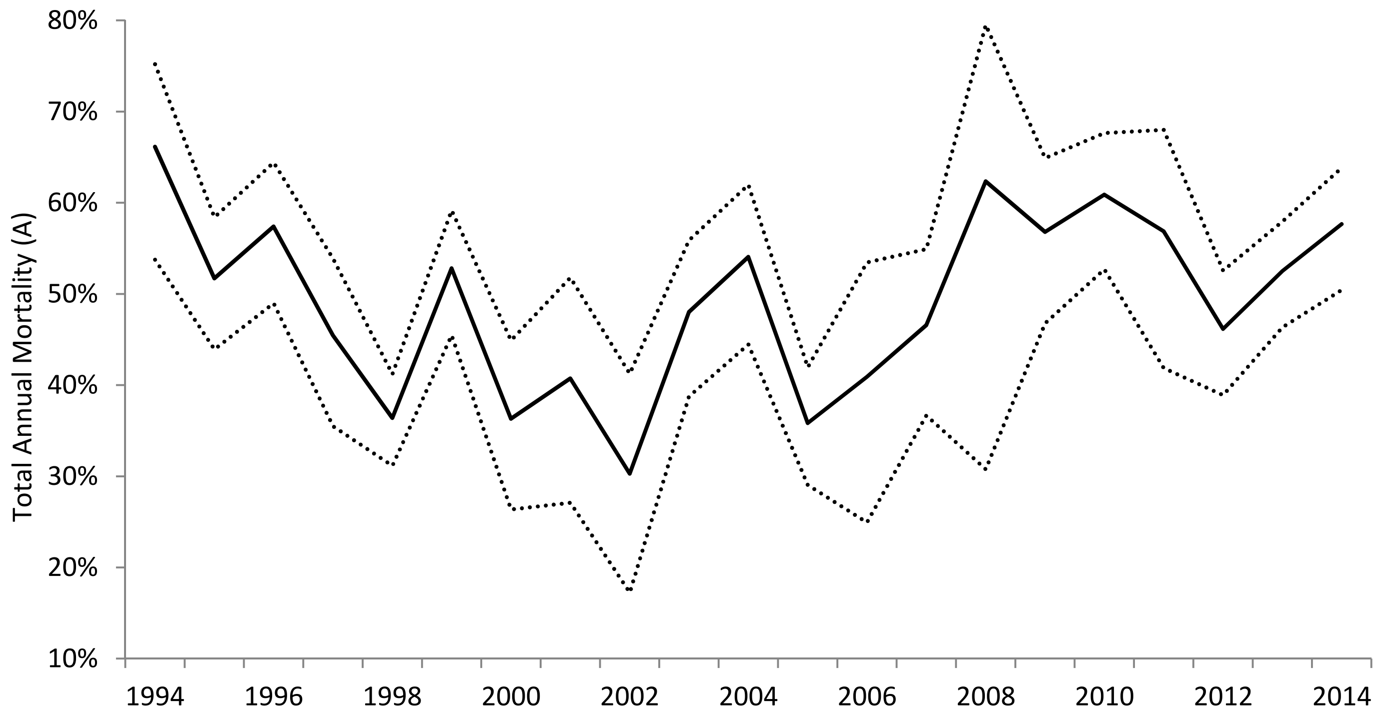

FIGURE A.1.—Striped Bass total annual mortality in the Neuse River, 1994–2014. The dashed lines denote the 90% confidence interval.

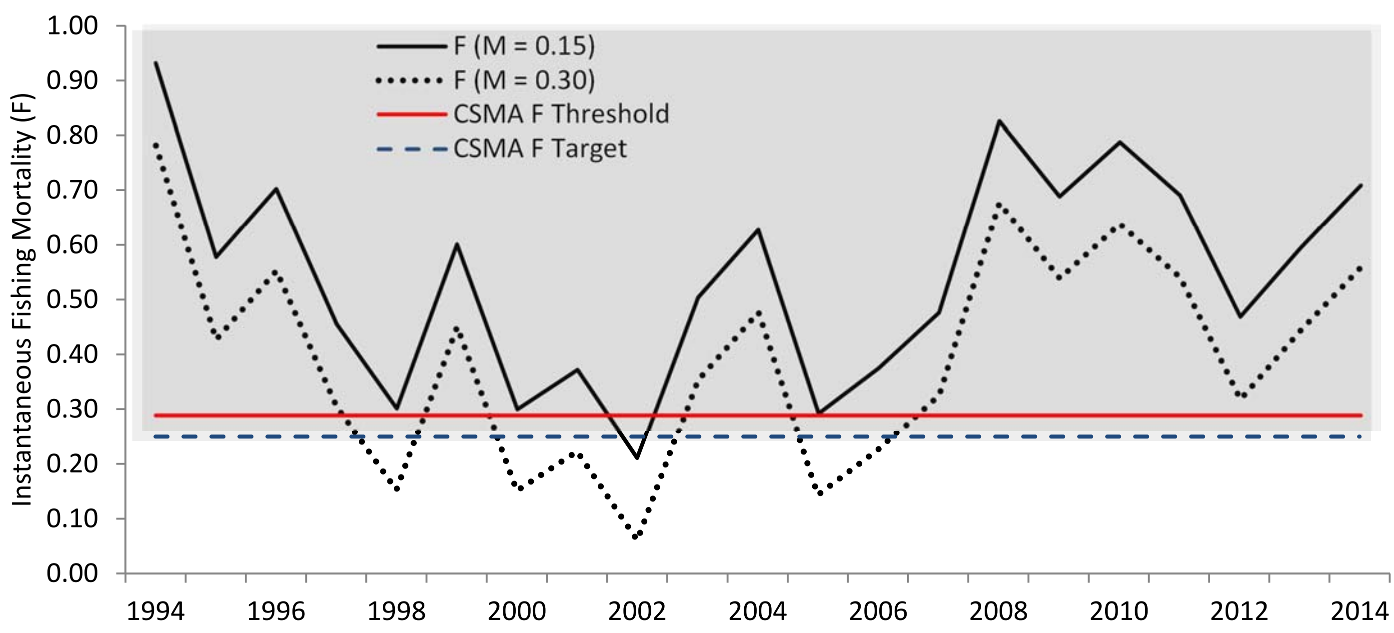

FIGURE A.2.—Striped Bass instantaneous fishing mortality (*F*) in the Neuse River for natural mortality M = 0.15 and M = 0.30. Values in the shaded area exceed the F_{TARGET} specified in Amendment 1 to the North Carolina Estuarine Striped Bass Fishery Management Plan.

Appendix B: 2014 Neuse River Striped Bass Cohort Analysis

Parentage based tagging (PBT) has been used to evaluate contribution of hatchery-reared Striped Bass to the Neuse River Striped Bass population since 2010. Genetic material collected from Neuse River Striped Bass during annual NCWRC spawning stock surveys indicates the population is predominately hatchery origin with few wild recruits. Striped Bass individuals from the 2004–2009 year-classes were collected in the 2014 spawning stock survey and are unable to be assigned as hatchery origin or the product of wild recruitment. Although these year-classes contributed approximately 42% of the 2014 electrofishing sample (Table 2), juvenile sampling indicates the 2013 and 2014 year-classes are 100% hatchery origin. As the 2010–2014 year-classes are almost completely comprised of hatchery-origin fish, it is likely that previous year-classes were mostly hatchery origin.

With a known number of fish stocked each year that are almost completely responsible for recruitment, it is possible to reconstruct the Neuse River Striped Bass population abundance with some degree of confidence using virtual population analysis (VPA; Allen and Hightower 2010). A benefit of this analysis is that since initial recruitment is known, as well as recreational and commercial harvest, it is possible to empirically estimate other sources of mortality given an assumed annual mortality rate. The objective of this analysis was to estimate spawning stock abundance and biomass, as well as investigate which mortality sources drive the high annual mortality observed in catch-curve analyses conducted in Appendix A. The scope of this analysis should be viewed as exploratory due to the relative lack of uncertainty estimates, although statistical methods for estimating VPA uncertainty are developed (e.g., VPA/ADAPT 3.4.5, NOAA Fisheries Toolbox) and should be used in future analyses.

Methods

A life table estimating the 2014 abundance of Neuse River Striped Bass was modeled in Microsoft Excel 2013. Initial recruitment was assumed to equal the number of stocked phase-II fish (modeled as age-1 stockings in January of each year). Although a considerable number of phase-I fish were stocked in previous years, their contribution to recruitment is unknown but likely minimal. Cohort abundance was then estimated using mortality rates to determine the number of individuals still living at the start of the next year. Post-stocking and juvenile mortality rates were unknown, but are currently being assessed through an NCWRC-funded research project conducted by NC State University. Preliminary estimates of post-stocking mortality in 2014 were $A = 0.87$ (J. Rice and C. Bradley, NC State University, personal communication). This estimate of post-stocking mortality was applied to the number of fish stocked in each year from 2001–2011 to calculate age-2 abundance. Age-3 abundance was calculated as the number of age-2 fish minus the number of fish succumbing to natural mortality (assumed $M = 0.15$). Cohorts age-3 and older were considered fully recruited to the fishery and subject to the total annual mortality calculated in Appendix A (Table B.1). Population abundance was calculated as the sum of each cohort's abundance in 2014. Population biomass was calculated by multiplying each cohort abundance by the mean individual weight for that age-class (mean individual weight-at-age observed in 2014 NCWRC spawning stock survey) and summing the biomass of the cohorts. Mean weights for age-classes not present in the sample were calculated as the average individual weight of older and younger cohorts (age-9 females) or were conservatively estimated to weigh the same as the next oldest cohort (age 10+ males and age 11+ females). Male and female contributions to abundance and biomass were estimated using the ratio of males to females in each cohort in the 2014 NCWRC spawning stock survey.

Six scenarios of adult mortality were modeled to explore drivers of high Striped Bass mortality. Adult mortality was modeled at the maximum likely survival rate determined in Appendix A (*S*; 0.423) and the upper and lower 90% confidence intervals (0.496, 0.362). Additionally, natural mortality was modeled at M = 0.15 (cm = 0.14) and M = 0.30 (cm = 0.26) for each *S*. Recreational harvest (kg) was estimated by NCDMF and accessed in the NCWRC Portal Access to Wildlife Systems (PAWS) Creel Survey database. Recreational discard mortality (kg) was estimated by multiplying the number of fish caught and released in 2014 by an assumed mortality rate (14%; J. Rice and C. Bradley, personal communication) and converting from number to weight by multiplying by the average individual weight of fish measured in the creel survey (0.54 kg). Commercial harvest (kg) was obtained from NCDMF as reported by commercial trip tickets.

Results

Virtual population analysis resulted in an estimated 17,655 age-3 and older Striped Bass in the Neuse River in 2014, with a biomass of 34,334 kg (Table B.2). This suggests the Neuse River Striped Bass population is 2–3 orders of magnitude smaller than the A/R population (NCDENR 2013).

Recreational harvest and discard, as well as commercial harvest, contributed modestly to the overall mortality rate (Table B.3). "Cryptic mortality", or mortality not accounted for through reported harvest or natural mortality, was greater than the reported recreational or commercial exploitation in all scenarios. For scenarios using the M = 0.15 rate, cryptic mortality approached or exceeded F_{TARGET} = 0.25 ($F_{TARGET} \approx u$ = 0.22). Cryptic mortality approached the level of recreational and commercial exploitation in only one scenario (Table B.3; high population survival and high natural mortality).

Discussion

The assumptions required to conduct this analysis and the implications of the results merit focused discussion. The largest proportion of adult mortality is unaccounted for in the recreational creel survey and in the commercial trip ticket program. The population loss due to this "cryptic mortality" must occur to explain the observed adult mortality calculated through catch-curve analysis.

Natural mortality has not been empirically estimated for the Neuse River Striped Bass population. Historically, most Atlantic Striped Bass stock assessments used M = 0.15 across all age-classes, which was derived using the Hoenig (1983) method. The most recent ASMFC benchmark stock assessment uses age-specific natural mortality rates derived from tagging studies conducted in Maryland and New York (ASMFC 2013). These age-specific natural mortality rates are highest at age 1 (M = 1.13) and remain above 0.15 until age 7 (ASMFC 2013).

However growth rate of age-2 to age-5 fish in the Neuse River population is considerably faster than the A/R stock, which exhibits similar growth patterns as the northern Striped Bass populations from which age-specific natural mortality was calculated. Since the Neuse River Striped Bass have a larger mean length-at-age, it is probable that age-specific natural mortality is lower that the rates used in the ASMFC benchmark stock assessment. The actual natural mortality rate for Neuse River Striped bass remains unknown, but is likely between 0.15 and 0.30 for the age-classes comprising the spawning stock (age 3+). Therefore, it is unlikely that any significant portion of natural mortality was assigned to cryptic mortality.

The potential for migration to affect cryptic mortality must also be addressed as the Neuse River is an open system allowing fish to swim into Pamlico Sound and other adjacent waterbodies. Emigration of Neuse River Striped Bass would be assigned to cryptic mortality. However, analysis of NCDMF tag-return data indicate very little emigration of Neuse River Striped Bass and few reports of immigration by fish originating from other waterbodies (NCDENR 2014). Therefore, considering the Neuse River a closed system is a tenable assumption.

If cryptic mortality cannot be assigned to natural mortality or migration, it must be assigned to exploitation. Exploitation can be characterized as the “…sum of all fishery-induced mortalities occurring directly as a result of catch, or indirectly as a result of contact with or avoidance of the fishing gear…” (ICES 1995). ICES (1995) formalized the components of exploitation by the equation

$$F = (F_{\mathrm{CL}} + F_{\mathrm{RL}} + F_{\mathrm{SL}}) + F_{\mathrm{B}} + F_{\mathrm{D}} + F_{\mathrm{O}} + F_{\mathrm{A}} + F_{\mathrm{E}} + F_{\mathrm{G}} + F_{\mathrm{P}} + F_{\mathrm{H}}$$

where F is exploitation; F_{CL} represents commercial landing mortality; F_{RL} denotes recreational landing mortality; F_{SL} is subsistence fishing landing mortality; F_{B} represents illegal and misreported landing mortality; F_{D} is discard mortality; F_{O} denotes mortality of fish captured by fishing gear but not landed (drop out mortality); F_{A} represents mortality due to fish who avoid the gear but die from stress or injuries incurred during gear avoidance; F_{E} is mortality resulting from fish contacting but escaping the gear and eventually dying; F_{G} is mortality resulting from “ghost” fishing gears (i.e., abandoned); F_{P} represents predation of fish who escape from or are stressed by fishing gear and would otherwise live; and F_{H} denotes mortality due to fishing gear-induced habitat alterations.

Many of these potential sources of exploitation are likely insignificant for many fisheries, including the Neuse River Striped Bass fisheries. In the Neuse River, F_{CL} and F_{RL} are reported and were included in this analysis, as well as the recreational component of F_{D}. The NCDMF trip ticket program is a direct census of F_{CL}. Since F_{RL} is calculated from survey data and is not a census, F_{RL} parameter uncertainty should be evaluated to explore its effect on cryptic mortality. ICES (1995) suggests F_{B} and F_{D} can have a large influence on exploitation, as well as F_{G} in the case of gillnet fisheries. Therefore, F_{B} , F_{D} , and F_{G} should be investigated as they potentially contribute significantly to the cryptic mortality observed in the Neuse River Striped Bass population.

TABLE B.1.—Projected Neuse River Striped Bass cohort abundance for the 2001–2011 year-classes. Age-1 abundance is considered the previous year's phase-II stocking rate. The survival rate (*S*) acting on each year-class is displayed in the right column.

YEAR CLASS–>	2011	2010	2009	2008	2007	2006	2005[a]	2004	2003	2002	2001	*S*
Age 1	107,142	104,061	0	69,953	99,595	0	0	0	107,654	0	108,000	0.130
Age 2	13,928	13,528	0	9,094	12,947	0	0	0	13,995	0	14,040	0.850
Age 3	11,839	11,499	0	7,730	11,005	0	0	0	11,896	0	11,934	0.423
Age 4		4,864	0	3,270	4,655	0	0	0	5,032	0	5,048	0.423
Age 5			0	1,383	1,969	0	0	0	2,128	0	2,135	0.423
Age 6				585	833	0	0	0	900	0	903	0.423
Age 7					352	0	0	0	381	0	382	0.423
Age 8						0	0	0	161	0	162	0.423
Age 9							0	0	68	0	68	0.423
Age 10								0	29	0	29	0.423
Age 11									12	0	12	0.423
Age 12										0	5	0.423
Age 13											2	0.423

[a] Hatchery personnel observed high post-stocking mortality. Entire year-class assumed lost.

TABLE B.2.—Estimated year-class abundance and biomass in 2014.

Population Characteristic	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Total
Year-class strength	11,839	4,864	0	585	352	0	0	0	12	0	2	17,655
Male abundance	10,064	3,022	0	258	176	0	0	0	6	0	1	13,527
Female abundance	1,775	1,842	0	327	176	0	0	0	6	0	1	4,128
Male biomass (kg)	16,304	5,862	0	899	652	0	0	0	28	0	5	23,749
Female biomass (kg)	3,798	4,606	0	1,298	824	0	0	0	49	0	9	10,585
Total biomass (kg)	20,102	10,468	0	2,196	1,476	0	0	0	77	0	14	34,334

TABLE B.3.—Sources of mortality affecting Neuse River Striped Bass. Cryptic mortality is unobserved or unreported mortality that must exist to explain the catch-curve produced mortality estimates assuming no net migration. Symbology is consistent with Allen and Hightower (2010).

Scenario	*S*	*cm*	Age 3+ Biomass (kg)	Recreational Harvest (kg)	Recreational Discard (kg)	Commercial Harvest (kg)	Natural Mortality (kg)	Cryptic Mortality (kg)	Cryptic Mortality *u*	Commercial Harvest *u*	Recreational Fishery *u* [a]
Likely *S*, normal *cm*	0.423	0.14	34,334	2,534	746	2,807	4,807	8,917	0.26	0.08	0.10
LCL *S*, normal *cm*	0.362	0.14	31,254	2,534	746	2,807	4,376	9,477	0.30	0.09	0.10
UCL *S*, normal *cm*	0.496	0.14	39,354	2,534	746	2,807	5,510	8,238	0.21	0.07	0.08
Likely *S*, high *cm*	0.423	0.26	34,334	2,534	746	2,807	8,927	4,797	0.14	0.08	0.10
LCL *S*, high *cm*	0.362	0.26	31,254	2,534	746	2,807	8,126	5,727	0.18	0.09	0.10
UCL *S*, high *cm*	0.496	0.26	39,354	2,534	746	2,807	10,232	3,515	0.09	0.07	0.08

[a] Includes recreational harvest and discard.

Appendix C: Neuse River Striped Bass Yield-Per-Recruit Analysis

Simulation modeling of population dynamics provides managers the opportunity to evaluate the response of fish populations and their dependent fisheries to various harvest regulations. This approach requires knowledge of recruitment, growth, and mortality in the population. Many population models have been developed and are practiced in fisheries management; the choice of which model to use typically requires a balance between how accurate the model must be along with the type of data required to construct the model.

The yield-per-recruit model (Beverton and Holt 1957) is typically used to evaluate the potential for fishing at a level that reduces the maximum yield per recruit (i.e., growth overfishing; Allen and Hightower 2010). The objective of this analysis was to combine all of the available knowledge of Neuse River Striped Bass population dynamics in 2014 and assess the current status of the fishery and its potential response to alternative harvest strategies. Identification of the best harvest strategy is dependent upon management goals and typically takes into consideration harvest, yield, and protection of the spawning stock.

Methods

Yield-per-recruit models were constructed using FAST 3.0 (Fisheries Analysis and Simulation Tools; Slipke and Maceina 2001). To estimate individual growth rates, males (n = 224) and females (n = 87) captured in the 2014 NCWRC spawning stock survey were combined in the analyses after removing in-season recaptured fish. Recruitment for each model is simply a scaling parameter with no impact on model behavior, therefore it was held constant at an arbitrarily selected value of 10,000. Fecundity information was obtained from Knight and Rulifson (2014). Detailed input parameters are listed in Table C.1. Projected population biomass (kg), abundance (count), abundance greater than 762 mm TL (count of age 9 fish and older), yield (kg), harvest (count), egg production (count), and spawning potential ratio (SPR; Goodyear 1993) was calculated at each combination of natural mortality (*cm*; 0.05, 0.15, 0.25), exploitation (*cf*; 0.1–0.8 by 0.1 increments), and minimum length limit (457–857 mm by 10-mm increments). Several slot and maximum length limits were also evaluated. The analysis produced 991 individual yield-per-recruit models. Models believed to approximate the population dynamics of the fishery in 2014 are presented here. Comparisons are drawn between the current fishery (18-in MLL; *cm* = 0.15; *cf* = 0.5) and the alternative length limits if exploitation is reduced to approximately the FMP F_{TARGET} (*cm* = 0.15; *cf* = 0.2). The effects of the minimum length limits on the response variables suffer some loss in resolution given the slight rounding of minimum length limits to the closest inch (28-in MLL modeled at 707 mm; 28 in = 711 mm) as well as the interval between different exploitation rates (i.e., *cf* modeled at 0.5; 2014 estimated *cf* = 0.48); these errors are not expected to influence management decisions given the magnitude of the differences between the models.

Model outputs were scaled relative to the number of recruits specified. Since management interest in most fishery responses (biomass, abundance, abundance >762 mm, yield, catch, and egg production) was the effect of each harvest scenario on the population, the results were normalized in relation to percent change from the current fishery (18-in MLL; *cm* = 0.15; *cf* =

0.5). The point estimate of SPR is given since it is a ratio that is not affected by the initial number of recruits and it is an indicator of recruitment overfishing.

Results

Yield-per-recruit analysis indicates the 2014 spawning stock had a SPR = 0.03 (Table C.2). At the current level of exploitation, a 28-in MLL would be required to approach the SPR management target (assuming the source of exploitation would be affected by the MLL; Figure C.1). Fishery harvest was maximized with the current 18-in MLL and exploitation rate (Figure C.2). Growth overfishing was evident, with a 26-in MLL maximizing yield for the current exploitation rate of 0.48 (Figure C.3).

Egg production, abundance of age 9+ fish, and SPR increased as the MLL increased (Table C.2). Keeping the 18-in MLL and reducing exploitation to the management target resulted in a 516% increase in egg production, a 7% increase in yield, and a 29% decline in number of fish harvested (Table C.2). A 26-in MLL was the least restrictive regulation that attained the SPR management target, increasing egg production by 1,234% over current conditions (Table C.2). The 26-in MLL allowed exploitation less than maximum yield per recruit, evidenced by a 4% reduction in yield compared to a 22-in MLL (Table C.2).

An 18-in MLL performed poorly for maximizing yield per recruit unless exploitation was less than 0.10 (Figure C.4). When exploitation was 0.1–0.3, the 22-in MLL and 24-in MLL performed similarly (Figure C.4). Yield per recruit was maximized with the 26-in MLL when exploitation approached and exceeded the exploitation observed in 2014 (Figure C.4). While the 26-in MLL was the least restrictive regulation to attain the target SPR at F_{TARGET}, none of the selected length limits attained the target SPR at the 2014 level of exploitation (Figure C.5).

TABLE C.1.—Input parameters for all yield-per-recruit models.

Variable	Value	Method to Derive	Data Source
a	-5.4896	Log_{10} W-L Regression	2014 NCWRC Spawning Stock Survey
b	3.19	Log_{10} W-L Regression	2014 NCWRC Spawning Stock Survey
L_∞	962	Von Bertalanffy	2014 NCWRC Spawning Stock Survey
k	0.129	Von Bertalanffy	2014 NCWRC Spawning Stock Survey
t_0	-3.31	Von Bertalanffy	2014 NCWRC Spawning Stock Survey
Fecundity Intercept	-1132753		Knight & Rulifson 2014
Fecundity Slope	3031		Knight & Rulifson 2014
Age at Maturity	3		Knight & Rulifson 2014
% of Stock Female			2014 NCWRC Spawning Stock Survey
Age 3	15%		
Age 4	25%		
Age 5	25%		
Age 6+	50%		
Max Age	30		A/R Stock Assessment (NCDENR 2013)
Recruits (N_0)	10,000		Arbitrary

TABLE C.2.—Population response to alternative harvest strategies if exploitation is reduced to FMP F_{TARGET}. All models assume *cm* = 0.15. Percentages denote change in response compared to current (2014) fishery.

Regulation [a, b]	Number Harvested	Yield	Abundance 30-in Fish	Egg Production	SPR
Current	0%	0%	0%	0%	0.03
18-in MLL	-29%	7%	2,822%	516%	0.21
20-in MLL	-37%	11%	3,400%	638%	0.25
18-in MLL + 22–27-in Slot	-38%	3%	4,715%	799%	0.31
22-in MLL	-46%	13%	4,180%	795%	0.30
22-in MLL + 26–30-in Slot	-53%	4%	7,375%	1,054%	0.39
22-in MLL + 28-in Max	-54%	-10%	5,742%	1,139%	0.42
24-in MLL	-54%	13%	5,276%	991%	0.37
24-in MLL + 30-in Max	-60%	-5%	5,355%	1,230%	0.45
26-in MLL	-62%	9%	6,890%	1,234%	0.45
26-in MLL + 30-in Max	-69%	-15%	7,011%	1,544%	0.56
28-in MLL	-70%	1%	9,428%	1,517%	0.55

[a] Current fishery represented by 18-in MLL, *cm* = 0.15, *cf* = 0.50.

[b] Slot and max limits include catch and release mortality of *cf* = 0.05 for protected fish

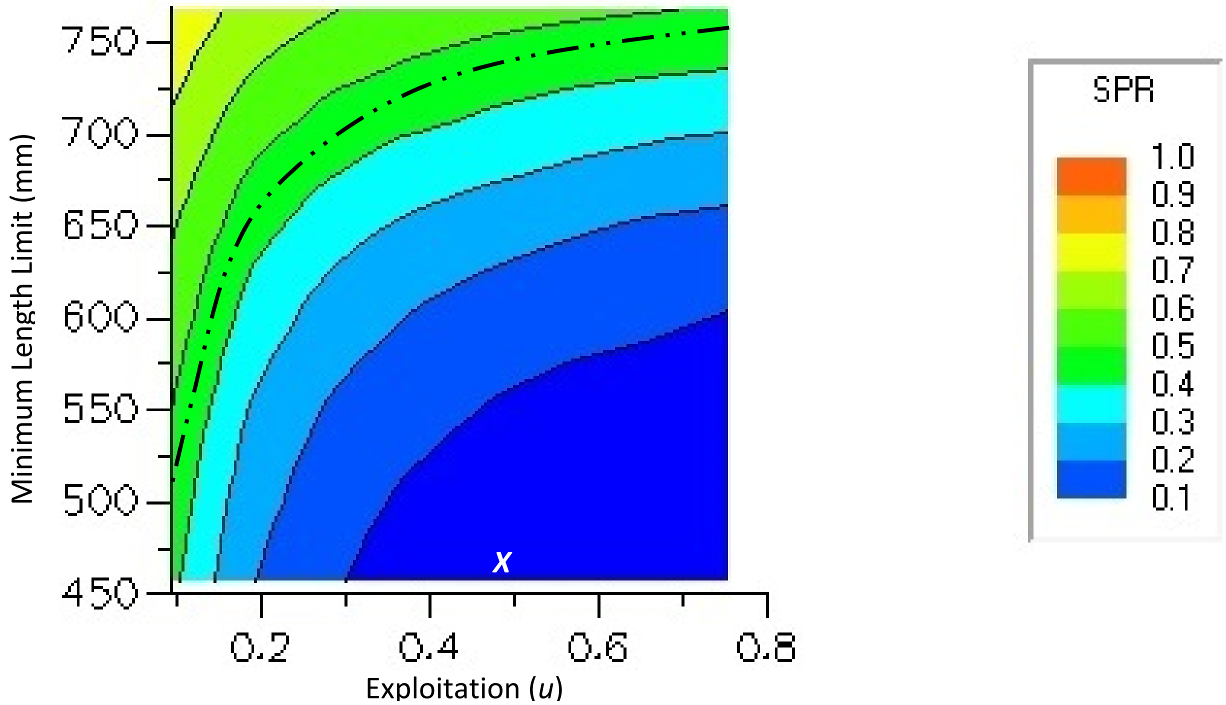

FIGURE C.1.—Spawning potential ratio (SPR) for various minimum length limits (*y*-axis) in relation to exploitation (*x*-axis). Natural mortality was held constant at *cm* = 0.15. The 2014 fishery is denoted by *X*, while the SPR used to develop the FMP F_{TARGET} (SPR = 0.45) is denoted by the dashed line.

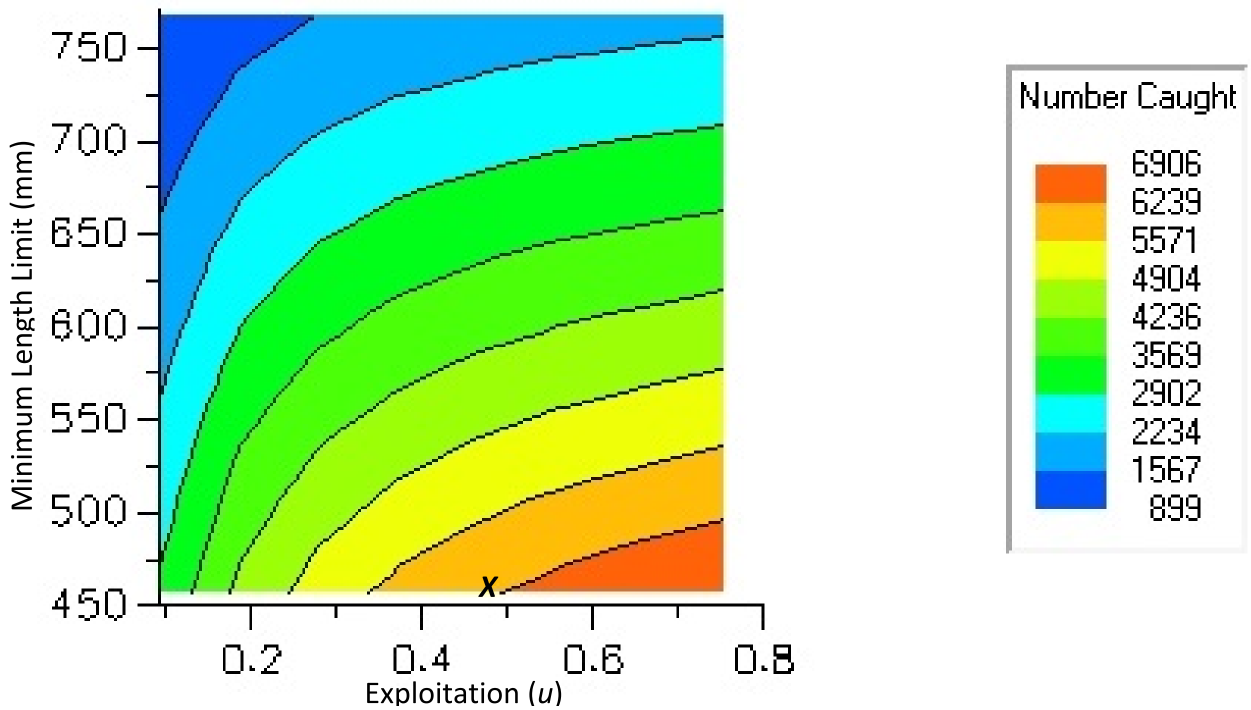

FIGURE C.2.—Fishery harvest for various minimum length limits (*y*-axis) in relation to exploitation (*x*-axis). Values are dependent upon number of recruits (10,000). Natural mortality was held constant at *cm* = 0.15. The 2014 fishery is denoted by *X*.

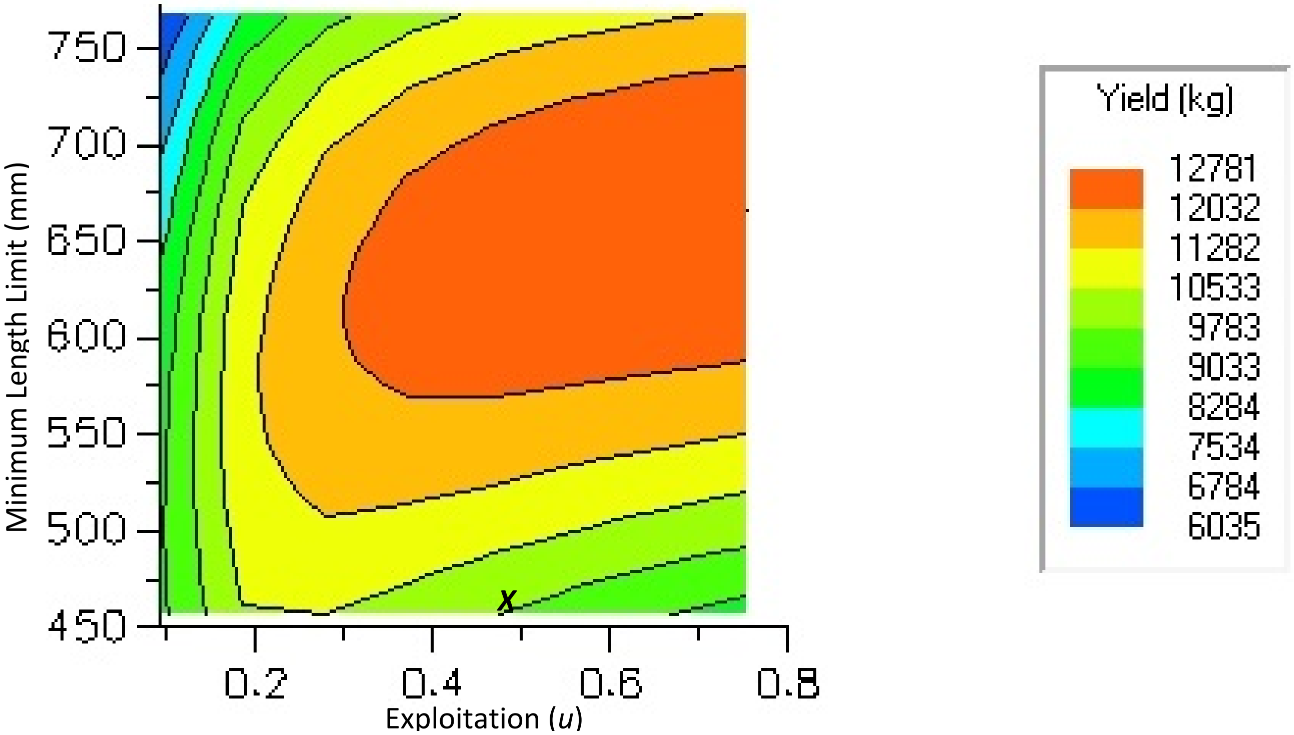

FIGURE C.3.—Fishery yield (kg) for various minimum length limits (*y*-axis) in relation to exploitation (*x*-axis). Values are dependent upon number of recruits (10,000). Natural mortality was held constant at *cm* = 0.15. The 2014 fishery is denoted by *X*.

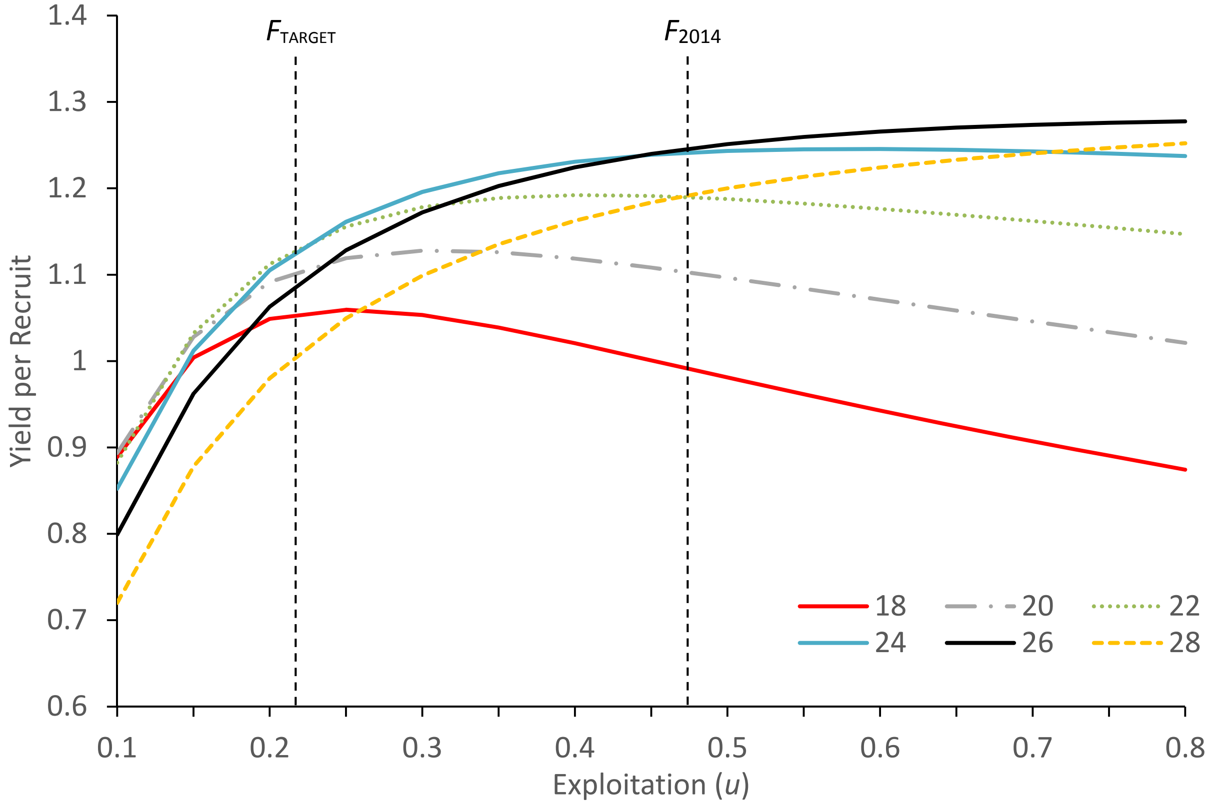

FIGURE C.4.—Relative performance of selected minimum length limits for maximizing yield per recruit. Natural mortality was held constant at *cm* = 0.15. Exploitation to the right of the F_{TARGET} line does not comply with Amendment 1 to the North Carolina Estuarine Striped Bass Fishery Management Plan.

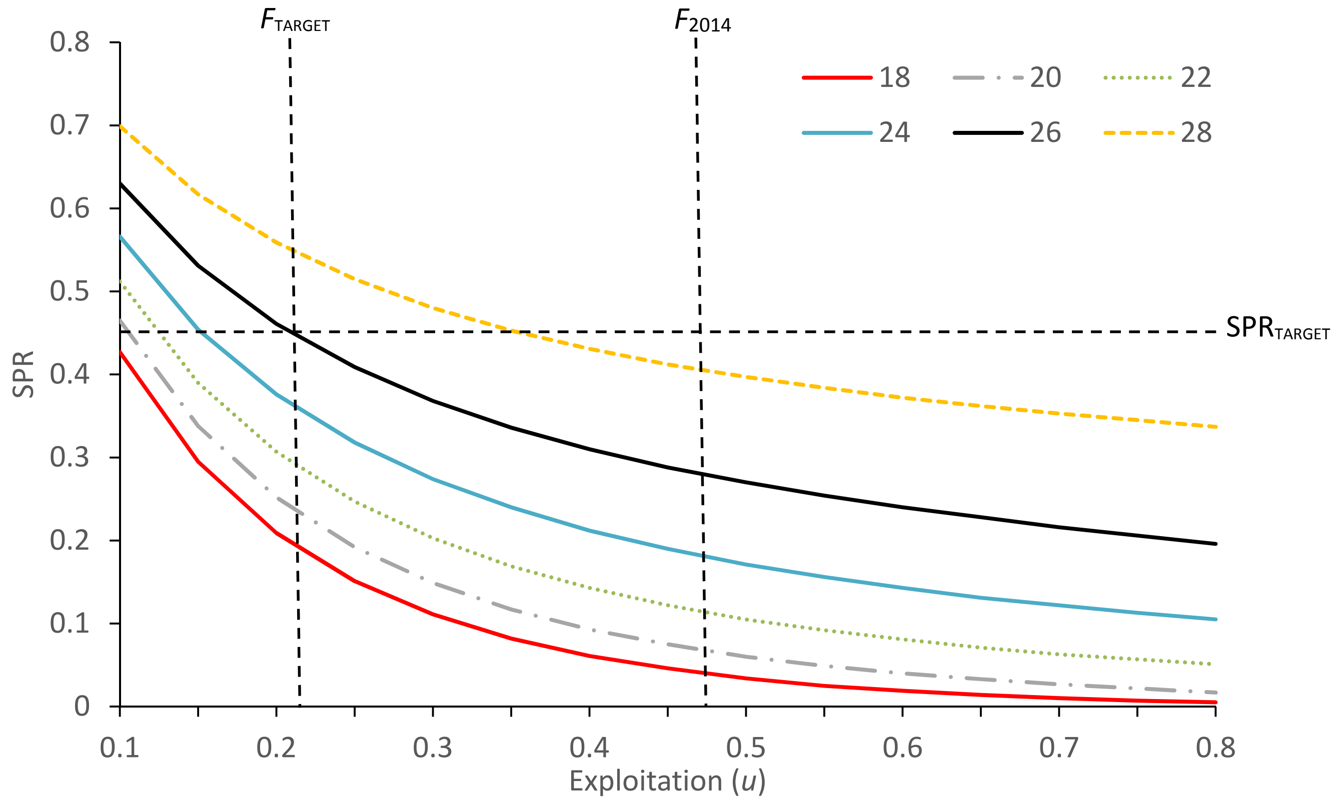

FIGURE C.5.—Relative performance of selected minimum length limits for attaining target SPR. Natural mortality was held constant at *cm* = 0.15. Exploitation to the right of the F_{TARGET} line does not comply with Amendment 1 to the North Carolina Estuarine Striped Bass Fishery Management Plan. Target SPR could not be attained at any level of exploitation with an 18-in MLL.

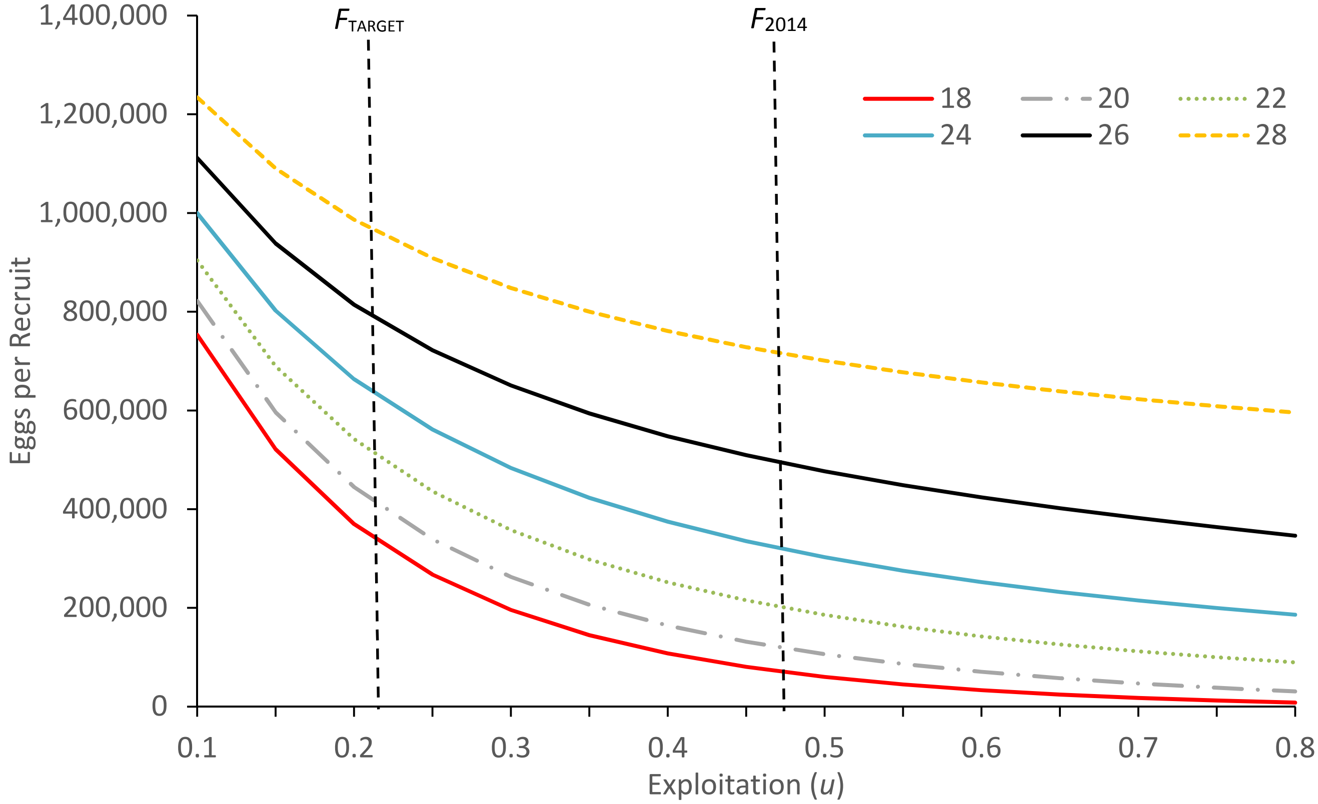

FIGURE C.6.—Egg production for selected minimum length limits. Natural mortality was held constant at *cm* = 0.15. Egg production in 2014 was 1–2 orders of magnitude less than potential egg production at F_{TARGET} for the 26-in MLL and 28-in MLL. Exploitation to the right of the F_{TARGET} line does not comply with Amendment 1 to the North Carolina Estuarine Striped Bass Fishery Management Plan.