NEUSE RIVER AMERICAN SHAD AND HICKORY SHAD MANAGEMENT REVIEW–2015

Federal Aid in Sport Fish Restoration
Project F-108
Report Type: Survey

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Inland Fisheries Division
Raleigh

2016

Keywords: American Shad, Hickory Shad, Neuse River, Electrofishing, Parentage-based tagging

This project was funded under the Federal Aid in Sport Fish Restoration Program utilizing state fishing license money and federal grant funds derived from federal excise taxes on fishing tackle and other fishing related expenditures. Funds from the Sport Fish Restoration Program are used for fisheries management and research, aquatic education, and boating access facilities. The program is administered cooperatively by the N.C. Wildlife Resources Commission and the U.S. Fish and Wildlife Service.

Abstract.—American Shad *Alosa sapidissima* and Hickory Shad *A. mediocris* populations in the Neuse River were sampled using boat electrofishing during spring 2015. Mean catch per unit effort (CPUE) was 19.7 fish/h for American Shad and 9.4 fish/h for Hickory Shad. Catch rates were highest for males of both species. The American Shad age distribution was comprised of age 3–6 males and age 4–7 females. Male American Shad ranged 336–546 mm total length (TL) and female American Shad ranged 447–560 mm TL. Male Hickory Shad ranged 342–412 mm TL and female Hickory Shad ranged 400–554 mm TL. The American Shad stocking program continued in 2015 with 708,045 fry cultured from Neuse River broodfish (*N* = 124; 64 males, 60 females) and stocked into the Neuse River drainage. Genetic parentage analysis of juvenile American Shad resulted in an observed hatchery contribution of 12.6% in 2014 and 1.0% in 2015. Back calculations from the number of fry stocked indicated that stocking added the reproductive equivalent of 9 to 380 additional spawning females depending on the number stocked and fry age at stocking. Abundance of spawning females was estimated to be 2,220 in 2014 and 14,382 in 2015 using the median age at stocking. Abundance estimates indicate the total spawning stock of American Shad in the Neuse River was 7,327 fish in 2014 and 37,393 fish in 2015 using the median age at stocking. Abundance estimates have had unbounded confidence intervals two of the past four years, therefore caution should be used with these estimates. Preliminary creel survey results estimate anglers caught 226 American Shad and 22,604 Hickory Shad; these estimates include fish harvested and released. Management needs include reduced uncertainty of spawning stock abundance and carrying capacity for American Shad, as well as a directed spawning stock assessment of Hickory Shad that includes sites downstream of current sample sites.

The North Carolina Wildlife Resources Commission (NCWRC) has conducted spawning stock assessments of Neuse River American Shad *Alosa sapidissima* and Hickory Shad *A. mediocris* since 2000. American Shad population characteristics from the fisheries-independent sampling program on the Neuse River are summarized each spring and submitted to the North Carolina Division of Marine Fisheries (NCDMF) to update stock assessment models, evaluate performance toward objectives in the American Shad sustainability plan, and be included within North Carolina's annual American Shad compliance report to the Atlantic States Marine Fisheries Commission (ASMFC). Information from ongoing fisheries-independent and fisheries-dependent sampling programs is required under conditions set forth within the fishery management plan for Alosines established for the eastern United States (ASMFC 1985) and associated addendum (ASMFC 2002; ASMFC 2010). Compliance with this plan is necessary to support the enhancement of American Shad populations within coastal North Carolina for the benefit of recreational and commercial fishermen (NCDMF and NCWRC 2012).

Historical evidence suggests the abundance and distribution of American Shad in the Neuse River is currently quite different than pre-1900s levels. Records indicate that American Shad provided a profitable fishery as far upstream as Raleigh, NC (Stevenson 1899), with more than 250,000 fish harvested commercially just in the lower river near New Bern, NC (Yarrow 1874). Further, spawning American Shad could migrate as far upstream as the Eno River near Hillsborough, NC, (Stevenson 1897) before the construction of instream impediments, such as Milburnie Dam, Falls of Neuse Dam, and other obstructions in the Neuse River basin. However, the population declined dramatically and less than 42,000 fish were harvested in 1904 (Cobb 1906). Currently, recreational anglers are limited to one fish per day and commercial harvest of American Shad is not allowed in inland waters. Based on these records, it is likely that the historical spawning stock was much larger than the current spawning stock. Although Stevenson (1897) speculated that the proliferation of commercial fishing in the Neuse River had a greater impact on the decline of American Shad than dam construction, it is likely that both factors are responsible for the depletion of the population.

The first dam on the Neuse River at Milburnie was a wooden structure with an 8-ft drop constructed around 1855 to power a paper mill, although other wooden dams were operated intermittently as far downstream as Smithfield (Swain 1885). The current Milburnie Dam was completed around 1903 with no provisions for fish passage. Therefore, American Shad have been denied access to former spawning grounds for over 100 years. The lowermost dam on the river, Quaker Neck Dam, was built in 1952 and blocked access to approximately 127 km of spawning habitat before it was removed in 1998 (Bowman 2001). Including Contentnea Creek, Swift Creek, and Trent River, approximately 553 km of spawning habitat is currently accessible below Milburnie Dam equating to approximately 6,080 acres of spawning habitat. Hightower and Wong (1997) reviewed abundance estimates of restored American Shad populations to conservatively estimate carrying capacity at a spawning density of 50 fish/acre of spawning habitat. Without future passage upstream, carrying capacity for the Neuse River is approximately 303,000 American Shad. Milburnie Dam will be removed in the future. Upon removal, 24 km of additional American Shad spawning habitat will be added to the Neuse River.

In an attempt to supplement the American Shad population, NCWRC has annually stocked American Shad fry reared at the United States Fish and Wildlife Service (USFWS) Edenton National Fish Hatchery (ENFH) into the Neuse River since 2012. In response to genetic

conservation concerns, endemic American Shad broodfish are used to produce all fry stocked in the Neuse River. To date, Neuse River broodfish have been spawned in circular holding tanks without the use of hormone injections (Evans 2010).

Annual spawning ground electrofishing surveys as well as angler creel surveys are valuable techniques to monitor American Shad population trends, to assess population changes over time, document potential population recovery for a sustainable fishery, and improve opportunities for anglers during anadromous fish migrations in the Neuse River. This report documents the result of NCWRC's American Shad monitoring program and quantifies American Shad and Hickory Shad population metrics as these fish migrate to inland spawning grounds. Preliminary results from an annual creel survey conducted in collaboration with NCDMF are also presented to explore relationships between independent sampling and angler effort, catch, and harvest statistics.

Methods

American Shad and Hickory Shad Spawning Stock Assessments

Spring sampling on the Neuse River for American Shad and Hickory Shad was conducted at three 1-km sites weekly between RKM 250 and RKM 230 near Goldsboro, NC. Once 30 to 40 American Shad were collected in one day at the Goldsboro sites, three sites near Raleigh were added to the weekly sampling regime. Selection of sites was based on river discharge and known spawning locations. Hickory Shad were only targeted at the Goldsboro sites (Figure 1). Directed sampling effort for shad began on March 25, 2015, as water temperatures approached 10°C and ended May 19, 2015, when spawning appeared complete and temperatures exceeded 23°C. Weekly sampling was contingent upon streamflow or gage height measured at USGS gaging stations near sample sites (Table 1). If streamflow and gage height were not adequate for safe and effective sampling, then a site was dropped until water conditions improved. A boat-mounted electrofishing unit (Smith-Root 7.5 GPP; 5000–7000 W, 120 Hz) was used (one dip netter) to capture fish. Surface water temperature (°C), dissolved oxygen (mg/L and % saturation), and conductivity (µS/cm) were measured prior to electrofishing at each site. To minimize size selection during sampling, fish were netted as they were encountered. Electrofishing time (seconds) was also recorded for each site.

Shad were held in an oxygenated live well with circulating water until completion of the sample site. Each fish collected was measured for total length (mm) and weighed (g). Sex was determined for male and female fish by applying directional pressure to the abdomen toward the vent and observing the presence of milt or eggs. Fish with no milt expressed were classified as female. American Shad not utilized for broodfish and all Hickory Shad were released. Hickory Shad collected during the 2015 Neuse River river herring survey were also included in length frequency analysis. Field data was recorded directly into a spreadsheet using a Trimble Yuma field computer. Data were imported into BIODE for further analysis and data archival.

Relative abundance of American Shad and Hickory Shad for each sample site were indexed by CPUE and expressed as number of fish captured per hour of electrofishing effort. Mean weekly CPUE was calculated for all sample sites from a given week. Variation in catch rates occurs naturally due to variability in mortality and recruitment rates in all systems; however,

sampling logistics and limitations due to Neuse River hydrology may also cause variation in annual catch rates. Therefore, caution should be used when relating catch rates to absolute abundance.

American Shad broodfish were sacrificed and otoliths were extracted and aged. Broodfish otoliths were used to supplement a subsample of American Shad from the spawning ground survey of five otoliths per 10-mm size-class per sex as available. Otolith annuli were counted using a stereomicroscope by two independent readers and discrepancies between readers were resolved to establish 100% reader agreement. Mean lengths at age were calculated for the entire sample following methods described by Bettoli and Miranda (2001).

American Shad Restoration Plan and Evaluation of Stockings

Field crews operated boat-mounted electrofishing units to capture American Shad broodfish on April 6–7, 2015. Broodfish collection was independent of the annual spawning ground survey and not included in relative abundance estimates. American Shad were transferred to ENFH in a hauling trailer. The broodfish were tempered from river to hatchery water and given a salt treatment of approximately 0.5‰ after transfer to recover from shock and handling. Hauling mortalities were recorded to report total losses to ASMFC. American Shad fry were cultured without the use of hormones from tank-spawned broodfish at ENFH.

All Neuse River American Shad were stocked at Cox's Ferry near the NC Highway 117 Bridge across the Neuse River near Goldsboro, NC, by ENFH (Figure 1). American Shad were tempered at the stocking location and stocked directly from the hatchery truck. Stocking date, stocking location, and number of fish were recorded.

Beginning in 2012, all American Shad broodfish with potential to contribute to hatchery production were assessed with parentage-based tagging (PBT) techniques at the North Carolina Museum of Natural Sciences (NCMNS). Fin clips were collected from all broodfish at the hatchery and stored in pre-labeled vials with 95% non-denatured, spectrophotometric grade ethyl alcohol. Fin clip procedures followed protocols established by NCWRC personnel that were adapted from the USFWS Warm Springs Conservation Genetics Lab with procedures verified by NCMNS personnel. A strict chain of custody procedure was followed to ensure sample integrity and preservation throughout the entire study. Archived broodfish genetic data was compared to fin clips from potential progeny collected during out-migration in fall 2014 and 2015. Juvenile American Shad fin clips (N = 96) were obtained for PBT analysis from samples collected by NCWRC in the lower Neuse River. Samples were collected during targeted surveys every two weeks and as encountered during sportfish sampling from September 1 to October 13. All fin clips were collected between RKM 64 and 84. After DNA extraction and PBT analysis, percent hatchery contribution was reported. Percent contribution of stocked American Shad in collected samples can be used as an initial metric to annually evaluate stocking success.

To estimate the increase in American Shad reproduction due to the stocking program, the number of American Shad females that would be required to produce the number of fry stocked was calculated for 2012–2015 using methods adapted from Harris and Hightower (2012). American Shad fry were stocked between 5 days post hatch (dph) and 11 dph (S. Jackson, ENFH, personal communication). Since each batch of fry contained larvae with multiple hatch dates, calculations were made for the minimum and maximum possible dph at stocking

and required two different calculations since daily survival rates vary between 0−9 dph larvae and 10−18 dph larvae. The back calculated number of female American Shad that would be required to produce a given fry stocking in a natural spawning event was estimated given a stocking event of 5 dph American Shad fry as:

$$N_{\text{Female}} = \frac{N_{\text{Stocked}}}{F \bullet R_e \bullet R_f \bullet S_h \bullet S_1^{dph}}$$

and for 11 dph fry as:

$$N_{\text{Female}} = \frac{N_{\text{Stocked}}}{F \bullet R_e \bullet R_f \bullet S_h^{3.01} \bullet S_1^{9} \bullet S_2^{dph-9}}$$

where N_{Female} is the estimated number of spawning females, N_{Stocked} is the number of fry stocked in a year, F is the average adult fecundity for the Albemarle Sound American Shad (272,710; Holland and Yelverton 1973), R_e is the egg ripening rate (50%; Sadzinski and Hendricks 2007), R_f is the egg fertilization rate (90%; Sadzinski and Hendricks 2007), S_h is the daily survival rate (29%) at the mean number of days to hatch (3.01 d; Crecco et al. 2007), S_1 is the average daily survival rate from 0−9 dph (78%; Crecco and Savoy 1987), S_2 is the average daily survival rate from 10−18 dph (91%; Crecco and Savoy 1987), and dph is the number of days post hatch.

The methods outlined by Harris and Hightower (2012) were used to estimate abundance of spawning females in the Neuse River in 2014 and 2015. One of several input variables for this model is the age at stocking of American Shad fry. However, the age of American Shad fry at stocking is variable (5–11 dph); therefore, population estimates were calculated for the estimated minimum (5 dph), median (8 dph), and maximum (11 dph) ages at stocking.

Recreational Harvest Regulations and Monitoring

Effective August 1, 2012, regulations were changed on the Neuse River to allow harvest of only one American Shad in the 10-fish combined daily creel limit for American and Hickory Shad. Preliminary results of the 2015 Neuse River creel survey coordinated by NCDMF staff were summarized including angler effort, harvest, and releases of American Shad and Hickory Shad in the Neuse River. This survey covered access areas from Milburnie Dam near Raleigh, NC, to the mouth of the Neuse River and encompassed the entire range of American Shad and Hickory Shad angling in the Neuse River. Following the observations by Millard et al. (2003), a catch-and-release mortality of 1.6% was applied to the number of American Shad released during the 2015 creel survey. Because a discard mortality value for Hickory Shad was not available from the literature, the 1.6% discard mortality observed by Millard et al. (2003) for American Shad was also used to assess Hickory Shad discard mortality. The discard mortality estimate was multiplied by the average weight of fish weighed during the creel survey to calculate an estimate of the total weight of discard mortality.

Results

American Shad Spawning Stock Assessments

Two hundred and twelve American Shad were collected from March 25 through May 19, 2015 (Table 2). Mean CPUE of all sites was 19.7 fish/h, with the peak weekly CPUE occurring April 8, 2015, at 18.2°C (36.1 fish/h; Table 2 and Figure 2). After CPUE peaked, American Shad weekly catch varied between 9.3 fish/h and 24.1 fish/h until sampling ended. Male American Shad comprised 61% of the catch (*N* = 129) while female American Shad contributed 39% (*N* = 83; Table 2). Otolith ages were determined from 20 broodfish and 124 fish collected during the spawning ground survey. Initial agreement between otolith readers was 74% and improved to 100% upon a second concert read. Length at age of these fish was similar to 2010–2014 age data (*N* = 485; Figure 3). A sex specific age-length key was used to assign ages to 64 male and 30 female American Shad from the 2015 sample. One male American Shad (TL = 336 mm) could not be assigned an age because no otoliths were collected from fish of that size bin (Figure 4). Four male cohorts ranged in age from 3 to 6 years and four female cohorts ranged in age from 4 to 7 years (Table 3, Figure 4). Similar to 2014, 90% of the total catch was supported by the 2010, 2011, and 2012 year classes. Size distribution for male American Shad was bimodal with modes at 400 mm and 450 mm, while size distribution for female American Shad was unimodal with a mode of (510 mm; Figure 5). Age 3–5 males and age 4–6 females were most abundant and corresponded to a size-distribution ranging from 352–546 mm for males and 446–554 mm for females. The age distribution suggests that very few American Shad survive over seven years, although American Shad up to ten years old have been documented in the Neuse River (NCWRC, unpublished data). American Shad ranged in length from 336 mm to 560 mm; 95% of all fish 500 mm or larger were females. Although females were larger than males of the same age, annual incremental growth across sexes of adult American Shad returning to the spawning grounds averaged 23 mm per year (range: 1–38 mm per year; Table 3). These values were larger than those observed in 2014 (mean = 15mm/year; Ricks and Rachels 2015).

Neuse River American Shad Restoration Plan – Hatchery Evaluation

The broodfish collection consisted of 60 females and 64 males. Approximately 708,045 American Shad fry were stocked in the Neuse River in 2015 at the NC Highway 117 bridge near Goldsboro, NC (Tables 4 and 5). All broodfish fin clips were sent to the NCMNS where they were genotyped and catalogued for PBT analysis.

In 2014, fin clips from 95 juvenile American Shad collected from the Neuse River were processed to determine hatchery contribution of emigrating juveniles. PBT analysis revealed a conclusive match with hatchery broodfish for 12 of the 95 samples (Table 6). Overall hatchery contribution to the Neuse River out-migration was 12.6% in 2014 (Evans and Wisser 2015). In 2015, fin clips from 105 juvenile American Shad collected from the Neuse River were processed to determine hatchery contribution of emigrating juveniles; PBT analysis revealed a conclusive match with hatchery broodfish for 1 of the 105 samples (Table 6). Overall hatchery contribution to the Neuse River out-migration was 1% in 2015 (Evans and Carlson 2016).

Back calculations from the number of fry stocked to estimate the number of spawning female American Shad that would produce the same number of fry naturally were calculated for fry stocked at 5 dph and 11 dph. Estimated numbers of spawning female American Shad

were much larger when calculated for stockings at 11 dph (179−429 female American Shad) than for 5 dph (56−134 female American Shad; Table 7). Since endemic broodfish that would have spawned naturally were used for Neuse River American Shad fry stockings, the difference between the back-calculated estimates of spawning females and the number of female broodfish used in a given year would indicate the potential benefit of stocking efforts. From 2012 to 2015, stocking efforts equated to adding between 9 and 85 additional females on the spawning grounds if fry were stocked at 5 dph, and between 139 and 380 additional females on the spawning grounds if fry were stocked at 11 dph (Table 7).

Using hatchery contribution and the methods outlined by Harris and Hightower (2012), the abundance of spawning female American Shad in the Neuse River was calculated for 2014 (1,063−3,406 females) and for 2015 (6,882−22,058 females) using the minimum (5 dph), median (8 dph), and maximum (11 dph) age at stocking (Table 8). Spawning female abundance estimates were multiplied by the annual sex ratio to calculate the number of males and estimate the range in American Shad total spawning stock abundance in 2014 (3,506–11,240) and in 2015 (17,893–57,532) for the Neuse River (Table 8). However, the confidence intervals for these estimates were unbounded, indicating a high degree of uncertainty regarding American Shad spawning stock abundance. Approximately 3,843,305 larval American Shad have been stocked in the Neuse River near Goldsboro since 2012 (Table 4). Annual back-calculations from the number of fry stocked to estimate the number of adult female American Shad that would produce an equal number of fry naturally indicate that hatchery stocking has more impact when larval American Shad are stocked between 10−18 dph than at 0−5 dph because fry survival is presumed to be higher at older ages (Crecco and Savoy 1987).

Characterization of Other American Shad Losses

For 2015, USFWS ENFH received 124 American Shad broodfish from the Neuse River. Sixty-four males and 60 females were sacrificed to ensure integrity of genetic markers and extract otoliths for ageing. Seventy-one male and 53 female American shad from the spawning ground survey were also sacrificed for age determination utilizing otoliths. Using an average weight of 0.6 kg for males and 1.2 kg for females, the total weight of losses for Neuse River American Shad were 81.0 kg for males and 135.6 kg for females (Table 9).

Hickory Shad Spawning Stock Assessment

Including Hickory Shad collected during the 2015 Neuse River river herring survey, 75 Hickory Shad were collected in the Neuse River basin from March 3 to April 4, 2015. Only 27 Hickory Shad were collected during the Neuse River American Shad spawning ground survey (Table 10). During routine and exploratory river herring sampling, 13 Hickory Shad from Core Creek, 23 Hickory Shad from Village Creek, 4 Hickory Shad from Mill Creek, and 8 Hickory Shad were collected from the Trent River. Only Hickory Shad collected during routine Neuse River spawning ground surveys were include in CPUE calculations, however; all Hickory Shad collected in 2015 were included in other metrics. Total mean CPUE for all sites was 9.4 fish/h, which was lower than observed CPUE in 2014 (19.2 fish/h; Table 11). In 2015, males comprised 65.3% of the sample (N = 49) while females contributed 38.6% (N = 26; Figure 6). Size

distribution for male Hickory Shad was bimodal and indicated that a dominant year class was entering the spawning stock. The female Hickory Shad size distribution was unimodal. Hickory Shad ranged in length from 310 to 554 mm, with males 310–340 mm the most abundant representing 53% of the sample. Females were consistently larger with 58% of the sample between 400 and 460 mm.

2015 Neuse River Creel Survey Preliminary Results

During the 2015 Neuse River creel survey conducted by NCDMF, American Shad were specifically targeted for 1,203 angler hours during 363 trips from February through May. The majority of anglers, however, did not specify which shad species they targeted; estimated effort by shad anglers was 7,686 trips and 18,657 angler hours. Anglers caught an estimated 226 American Shad and harvested an estimated 94 American Shad. The majority of American Shad effort (56%) was in February. However, the majority of the harvest (69%) was observed during April. Interviewed anglers reported targeting American Shad in May; however, no harvested or discarded American Shad were reported to creel clerks. Catch and release mortality was estimated to be two American Shad (Table 12). Weights of American Shad were not estimated due to low numbers of American Shad observations during the 2015 Neuse River Creel.

An estimated 1,326 Hickory Shad were caught by anglers on the Neuse River in 2015. Hickory Shad were targeted from February through April during 319 trips for a total effort of 1,326 hours. Estimated harvest was 10,418 Hickory Shad weighing 4,632 kg. More anglers were observed targeting Hickory Shad in February (N =192) than in March (N =127); however, effort and harvest in both months were similar. In April, anglers interviewed who reported targeting species other than Hickory Shad released 2,223 fish and harvested 1,398 fish weighing a total of 330 kg. Discard mortality was estimated to be 195 Hickory Shad weighing 89 kg (Table 12).

Discussion

Juvenile American Shad collections during fall out-migration have been conducted each year since 2012. Evaluation of stocking contribution to the adult American Shad spawning stock in the Neuse River began in spring 2015 when adults from the 2012 stocking cohort were expected to first return to the spawning grounds. For both juvenile and adult American Shad, genetic information from fin clips was compared with the corresponding broodfish for Neuse River to determine hatchery contribution to the cohort. Hatchery contribution among juvenile American Shad was 12.6% in 2014 and 1% in 2015. Since this was only the fourth year that PBT techniques were available to determine hatchery contribution, trends in population response as a result of stocking efforts are too early to identify.

Several population outcomes are possible as American Shad management and stocking plans progress for the Neuse River. One scenario is that positive trends in American Shad abundance continue while stocking methodology remains unchanged, resulting in hatchery contribution that would theoretically decrease over time. Under this paradigm, as the American Shad population increases the hatchery contribution would decrease if the number of fry stocked remained consistent. Another outcome could be that American Shad natural recruitment remains relatively stable at or near current levels. Under this scenario, hatchery

contribution would remain generally unchanged provided the number stocked remained constant, and that an increase in stocking rates would result in a subsequent increase in percent hatchery contribution. The last scenario outlines the possibility that both natural recruitment and survival of stocked fish are highly variable; this outcome could confound attempts to evaluate trends in stocking contribution. As PBT results from analysis of hatchery contribution from both juvenile and adult American Shad expand over time to cover all available cohorts, these scenarios will be evaluated and management decisions applied with pertinent success criteria.

Additionally, resource managers need an accurate population estimate of American Shad in the Neuse River to evaluate stocking success. Confidence intervals around the 2012 and 2015 American Shad population estimates were unbounded indicating that uncertainty is high using existing methods. The 2012−2015 estimates provided a basic metric for future comparisons; however, caution should be used with these values because the actual age at stocking is uncertain and greatly influences abundance estimates. Furthermore, it is uncertain if the juvenile American Shad sample was unbiased and accurately characterized the hatchery contribution for the entire population.

The carrying capacity of American Shad in the Neuse River is in excess of 300,000 using the methods outlined for the Roanoke River (number of American Shad/ha; Hightower and Wong 1997). Estimates of tributary spawning habitat are incomplete (e.g., Crabtree Creek, Mill Creek, and Little River); therefore, actual carrying capacity is likely larger. Accurate estimates of tributary spawning habitat in the Neuse River drainage should be assessed to better evaluate potential carrying capacity and abundance of a restored population. It is important for managers to know if a target of 300,000 American Shad in the Neuse River is appropriate, and whether spawning stock abundance is within this potential target. This estimate, while conservative, is reasonable given that in 1873 at least 250,000 American Shad were harvested from the Neuse River before the completion of the spawning season (Yarrow 1874). Despite the need for refined estimates of carrying capacity and population abundance, the 2015 Neuse River American Shad spawning stock was characterized by acceptable growth rates and moderate levels of abundance. A review of catch rates through time indicate that the Neuse River American Shad population is experiencing an increasing trend with the exception of 2015. The 2015 American Shad relative abundance estimates in the Neuse River were lower than previous years (Table 11). This outcome could be due to decreased streamflow in May during peak spawning temperatures when catch rates are typically high. Specifically, the area below Milburnie Dam was not sampled as often in 2015 due to low streamflow. Therefore, lower catch rates observed in 2015 may be an artifact of sampling methodologies and not indicative of a decrease in American Shad spawning stock abundance.

Anglers caught an estimated 94 American Shad in 2015, which was lower than expected based on the number of American Shad observed in the spawning grounds survey. The highest electrofishing catch rates were in April; similarly, creel clerks observed the highest number of American Shad in April. The contrast between angler catch and availability of American Shad on the spawning grounds could be a result of limited angler access on the upper Neuse River as fish remained in the Neuse River into May. Also shad angler effort, regardless of species targeted by anglers, greatly diminished after Hickory Shad abundance decreased. These observations suggest that anglers may not be aware of the abundance of American Shad in the

Neuse River and that outreach efforts are warranted to promote this fishery. Discards from catch and release practices were relatively low. It should be noted that water temperatures in the Neuse River were higher than those observed by Millard et al. (2003) for the Hudson River; therefore, discard mortality rates applied in 2015 may underestimate catch and release mortality for the Neuse River American Shad fishery.

Hickory Shad relative abundance in 2015 was low compared to American Shad CPUE, a trend that has persisted across sample years. This trend could be attributed to sampling logistics as this survey primarily targets American Shad. Reports of angler catches outside the sample area indicate a higher abundance of Hickory Shad downstream in the area around Pitch Kettle Creek. The preliminary NCDMF creel data for the Neuse River suggest that Hickory Shad were in much higher abundance than encountered during the spawning stock survey. Anglers caught 10,418 Hickory Shad, compared to the 75 collected by electrofishing during the spawning stock survey. Catch rates of Hickory Shad have been highly variable since 2002 and could be dependent on streamflow (Table 13). Current electrofishing sampling procedures do not effectively sample Hickory Shad, and could be modified to provide for a more representative sample. Alternatively, Hickory Shad could be dropped as a target species in future surveys since they are not being documented effectively by current methods.

Future work should include exploring new methods to assess population abundance and the relationship between current abundance and carrying capacity for the Neuse River. Stock assessments using hydroacoustic, capture-recapture, or depletion methodologies should be considered. Also, exploratory anadromous surveys have resulted in observations of Hickory Shad and American Shad in locations far removed from the main stem Neuse River such as Contentnea Creek and the Trent River. These populations should be tested against our current genetic database for population-level genetic structuring. Finally, the high variation in catch rates due to factors such as streamflow, temperature, and turbidity necessitate the development of robust metrics and biological reference points, such as sex ratio, proportion of sex-specific catch greater than age 5, proportion of sex-specific catch greater than 500 mm, and NZ50, a probability-based measure of collecting larger fish, (Goodyear 2015), that are resistant to environmental stochasticity.

Management Recommendations

1. Maintain current creel limits to allow no more than one American Shad within the daily creel limit of 10 shad in combination (American Shad and Hickory Shad).
2. Continue the use of endemic Neuse River American Shad broodfish for hatchery production. 2016 American Shad stockings will consist of 1,000,000 fry stocked at Milburnie Dam or Cox's Ferry. However, the benefits of alternate stocking rates or sites should be evaluated. Alternative stocking sites and stocking rates may allow increased resolution into the demographic and genetic effects of the stocking program.
3. Continue the use of parentage-based tagging to determine hatchery contribution to respective cohorts, evaluate temporal and spatial genetic differences within the Neuse River American Shad population, and consult with geneticists to understand genetic implications of a prolonged stocking program.

4. Maintain current American Shad sampling efforts and monitor for changes in spawning stock metrics as a response to hatchery stockings. Develop new biological reference points and analyze over the available time series in the next scheduled final report.
5. Refine estimates of American Shad spawning stock abundance and carrying capacity in the Neuse River. Utilize both metrics to evaluate the utility of stocking hatchery fish and to optimize population recovery targets.
6. Investigate variables that could be a predictor of American Shad year class strength. Additional stations that monitor water quality (e.g., discharge, water temperature, salinity) are needed.
7. Identify opportunities to collaborate with partner institutions to expand knowledge of Hickory Shad population characteristics.
8. Develop NCWRC Boating Access Areas and Public Fishing Areas on the Neuse River between Smithfield and Raleigh, NC.
9. Refine NCDMF creel survey to gather more species-specific shad creel data.
10. Request annual American Shad production report from ENFH such as hauling mortalities, egg production numbers, fertilization rates, hatching rates, and survival rates, similar to annual report provided by Watha State Fish Hatchery.

Acknowledgments

We thank Steve Jackson, Aubrey Olney, Sam Pollock, and Ronnie Smith at Edenton National Fish Hatchery for hatchery culture, stocking logistics and data compilations associated with our hatchery restoration programs. We appreciate the cooperation with Dr. Heather Evans and Kara Carlson at NC Museum of Natural Sciences for processing and analyzing fin clips associated with the American Shad PBT analysis. We appreciate suggestions and comments from Kevin Dockendorf, Jeremy McCargo, and Chad Thomas to previous drafts of this report.

References

ASMFC (Atlantic States Marine Fisheries Commission). 1985. Fishery management plan for the anadromous Alosid stocks of the Eastern United States: American Shad, Hickory Shad, Alewife, and Blueback Herring: Phase II in interstate management planning for migratory alosids of the Atlantic Coast. Washington, D.C. Report 25.

ASMFC (Atlantic States Marine Fisheries Commission). 2002. Addendum I to amendment 1 and technical addendum #1 to the interstate fishery management plan for shad and river herring. Washington, D.C. Report 35b.

ASMFC (Atlantic States Marine Fisheries Commission). 2010. Amendment 3 to the interstate fishery management plan for shad and river herring. Washington, D.C.

Bowman, S. W. 2001. American Shad and Striped Bass spawning migration and habitat selection in Neuse River, North Carolina. Master's thesis. North Carolina State University, Raleigh, North Carolina. Available: http://www.lib.ncsu.edu/resolver/1840.16/2537 (March 2013).

Cobb, J. N. 1906. Investigations relative to the shad fisheries of North Carolina. North Carolina Geological Survey Economic Paper No. 12.

Crecco, V. A., and T. F. Savoy. 1987. Review of recruitment mechanisms of American Shad: the critical period and match−mismatch hypothesis reexamined. Pages 455−468 *in* M. J. Daswell, R. J. Kaluda, C. M. Moffitt, R. L. Saunders, R. A. Rulifson, and J. E. Cooper, editors. Common strategies of anadromous and catadromous fishes. American Fisheries Society Symposium 1, Bethesda Maryland.

Crecco, V., T. Savoy, and J. Benway. 2007. Appendix A: minority report: stock assessment of American Shad in Connecticut. Pages 347−402 *in* ASMFC (Atlantic States Marine Fisheries Commission), editors, American Shad stock assessment report for peer review, volume 2. ASMFC, Stock Assessment Report 07-01 (Supplement), Washington, D. C.

Evans, J. 2010. American Shad fry production report for 2010. North Carolina Wildlife Resources Commission. Federal Aid in Sport Fish Restoration Project F–22. Final Report. Raleigh.

Evans, H., and R. Wisser. 2015. 2014 American Shad Genotyping and Parentage Analysis. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F–108, Final Report, Raleigh.

Evans, H., and K. Carlson. 2016. 2015 American Shad Genotyping and Parentage Analysis. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F–108, Final Report, Raleigh.

Goodyear, C. P. 2015. Understanding maximum size in the catch: Atlantic Blue Marlin as an example. Transactions of the American Fisheries Society 144:274–282.

Harris, J. E., and J. Hightower. 2012. Demographic Population Model for American Shad: Will Access to Additional Habitat Upstream of Dams Increase Population Sizes? Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 4(1):262–283.

Hightower, J. E., and R. Wong. 1997. Potential benefits to anadromous fishes of providing fish passage within the Roanoke River Basin. Report to the U.S. Fish and Wildlife Service and Virginia Power. 30 pp.

Holland, B. F., and G. F. Yelverton. 1973. Distribution and biological studies of anadromous fishes offshore North Carolina. North Carolina Department of Natural and Economic Resources. Division of Commercial and Sport Fisheries. Special Scientific Report 24, Morehead City.

Millard, M. J., J. Mohler, A. Kahnle, K. Hattala, W. Keller, and A. Cosman. 2003. Mortality Associated with Catch and Release Angling of Striped Bass and American Shad in the Hudson River. Report to the New York State Environmental Protection Fund. 38 pp.

North Carolina Division of Marine Fisheries and North Carolina Wildlife Resources Commission. 2012. North Carolina American Shad Sustainable Fishery Plan.

Ricks, B. R., and K. T. Rachels. 2015. Neuse River American Shad and Hickory Shad management report – 2014. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F–108, Final Report, Raleigh.

Sadzinski, R. and M. Hendricks. 2007. Status of Susquehanna River and Susquehanna flats American Shad stock. Pages 46−132 *in* ASMFC (Atlantic States Marine Fisheries Commission). American Shad stock assessment. ASMFC, Stock Assessment Report 07-01 (Supplement), Washington, D. C.

Stevenson, C.H. 1897. The restricted inland range of shad due to artificial obstructions and its effect on natural reproduction. Bulletin of the United States Fish Commission 17:265–271.

Stevenson, C.H. 1899. The shad fisheries of the Atlantic coast of the United States. U.S. Fish Commission Report for 1898. pp. 101–269.

Swain, G.F. 1885. The Southern Atlantic Watershed: IV. The Neuse River and tributaries. Pages 51–55 *in* W. P. Trowbridge, editor. Reports on the water-power of the United States. U.S. Department of the Interior, Washington D. C.

Yarrow, H. C. 1874. Report of a reconnaissance of the shad-rivers south of the Potomac. Report of the Commissioner U.S. Commission of Fish and Fisheries for 1872 and 1873. pp. 396–402.

TABLE 1.—Sampling sites, boating access areas and minimum flow requirements for sampling access on the Neuse River for spring American Shad and Striped Bass surveys.

Sample Area	Access Area	USGS Gageing Station	Minimim CFS	Minimum Gage	Site Status
Milburnie Dam	Anderson Point Park	Falls	500	2	Flows Allowing
Raleigh (Upper part)	Anderson Point Park	Falls	366	1.7	Weekly
Clayton	Smithfield	Clayton/Smithfield	900	2.8/7.0	Flows Allowing
Booker Dairy Rd	Smithfield	Smithfield		6.7	Flows Allowing
Cox's Ferry	Ferry Bridge Road	Goldsboro	650	3.5	Weekly
Goldsboro - Beaverdam	Ferry Bridge Road	Goldsboro	800	4.5	Weekly
Quaker Neck	Stevens Mill	Goldsboro	650	3.5	Weekly
Stevens Mill	Stevens Mill	Goldsboro	650	3.5	Weekly
Seven Springs	Seven Springs	Whitehall		4	Flows Allowing

TABLE 2.—American Shad daily electrofishing effort, catch, male to female ratio, mean CPUE, standard error, number of sites, and mean daily water temperature for Neuse River, 2015. Week date indicates the first day of sampling each week. Logistical limitations introduced varability in the number of sites each week.

Week	Effort (h)	Total Catch	M:F Ratio	Mean CPUE	Total Standard Error	Number of Sites	Mean Water Temp (°C)
03/25/2015	1.13	22	1.2:1	18.9	9.4	4	12.8
03/31/2015	0.90	23	1.1:1	25.4	21.1	3	11.1
04/08/2015	0.90	32	1.3:1	36.1	15.4	3	18.2
04/13/2015	1.70	41	2.4:1	24.1	16.4	6	17.5
04/21/2015	2.30	34	2.1:1	16.2	6.9	7	17.8
04/28/2015	1.00	20	1:1	21.6	10.9	3	16.0
05/04/2015	0.90	8	1.7:1	9.3	5.0	3	16.9
04/11/2015	1.40	15	4:1	10.9	2.8	4	21.2
05/19/2015	0.80	17	0.9:1	17.9	16.0	3	24.6
Total all sites	11.03	212	1.6:1	19.7	3.8	36	

TABLE 3.—Mean total length (mm) at age for American Shad males and females collected from the Neuse River, spring 2015. Not all fish collected could be assigned an age.

Year		Males				Females			
Class	Age	N	Mean	Min	Max	N	Mean	Min	Max
2012	3	49	403	352	442				
2011	4	36	425	354	473	11	482	446	502
2010	5	39	463	380	546	54	515	468	550
2009	6	4	492	474	500	13	515	500	554
2008	7					5	533	514	560

TABLE 4.—American Shad fry produced and stocked into the Neuse River Basin at NC Highway 117 bridge near Goldsboro from 2012 to 2015. Broodfish were processed annually to allow for parentage-based tagging evaluation of juveniles and returning adults.

Year	Edenton National Fish Hatchery
2012	573,582
2013	1,184,303
2014	1,377,375
2015	708,045
Totals	3,843,305

TABLE 5.—Date and number of American Shad fry stocked per trip in the Neuse River Basin in 2015 from Edenton National Fish Hatchery. All fry were stocked at the Highway 117 Bridge at Goldsboro with parental genotype marking.

Date	Number Stocked
04/29/2015	238,200
05/14/2015	349,200
05/26/2015	120,645
Total	708,045

TABLE 6.—Number of juvenile American Shad collected during annual fall electrofishing sampling from the lower Neuse River. Extracted juvenile American Shad fin clips were evaluated for hatchery contribution using parentage-based tagging techniques. Collection start and end dates and the total number of days of the collection period are listed for each year.

Year	Total Collected Genetics Evaluated	Hatchery Origin	Collection Begin Date	Collection End Date	Collection Period (Days)	Mean Water Temperature (C°)
2012	99	2	9/19	11/9	16	24.3
2013	100	6	9/19	11/15	19	23.0
2014	95	12	8/06	10/28	84	19.6
2015	105	1	9/01	10/13	43	23.3

TABLE 7.—Back-calculated number of females on the spawning grounds that would produce the number of fry stocked versus the number of female broodfish collected in the Neuse River by year.

			Estimated Females to Produce Fry		Difference between Estimate and Broodfish	
Year	Broodfish Females	Fry Stocked	5 dph	11 dph	5 dph	11 dph
2012	40	573,582	56	179	16	139
2013	66	1,184,303	115	369	49	303
2014	49	1,377,375	134	429	85	380
2015	60	708,045	69	221	9	161

TABLE 8.—Neuse River back-calculated abundance estimates for spawning females with 95% confidence intervals and total abundance using larval age (days) and annual sex ratio for 2012 – 2015.

Year	Estimated Days Old at Release	Estimated Spawning Females	95% Confidence Interval	Male to Female Ratio	Estimated Total Population
2012	5 (Minimum)	2,788	845–Unbounded	2.1:1	8,641
2012	8 (Median)	5,825	1,716–Unbounded	2.1:1	18,058
2012	11 (Maximum)	8,935	2,547–Unbounded	2.1:1	27,699
2013	5 (Minimum)	1,919	790–8,020	1.9:1	5,564
2013	8 (Median)	4,009	1,547–17,070	1.9:1	11,627
2013	11 (Maximum)	6,149	2,413–30,681	1.9:1	17,832
2014	5 (Minimum)	1,063	504–2,902	2.3:1	3,506
2014	8 (Median)	2,220	932–7,069	2.3:1	7,327
2014	11 (Maximum)	3,406	1,484–11,092	2.3:1	11,240
2015	5 (Minimum)	6,882	845–Unbounded	1.6:1	17,893
2015	8 (Median)	14,382	1,716–Unbounded	1.6:1	37,393
2015	11 (Maximum)	22,058	2,547–Unbounded	1.6:1	57,352

TABLE 9.—Broodfish and spawning ground survey American Shad losses from the Neuse River in 2015.

	Male	Female
Average Weight (kg)	0.6	1.2
Number Spawning Ground Survey	71	53
Number Broodfish	64	60
Total Kilograms	81.0	135.6

TABLE 10.—Hickory Shad daily electrofishing effort, catch, male to female ratio, mean CPUE, standard error, number of sites, and mean daily water temperature for Neuse River, 2015.

Week	Effort (h)	Catch	M:F Ratio	Mean CPUE	Standard Error	Number Sites	Mean Water Temp (°C)
3/25/2015	1.13	22	1.4:1	19.2	2.5	4	12.8
3/31/2015	0.89	5	4.0:1	5.9	4.2	3	11.1
Total for all Sites	2.94	27	1.7:1	9.4	3.1	10	

TABLE 11.—Annual summary of electrofishing effort, sample size, number of males, number of females, male to female ratio, peak site catch rates, overall catch rates with standard error, mean male total length, mean female total length, maximum total length, mean sample temperature, and mean March discharge for Neuse River American Shad spawning ground surveys 2000–2015.

Year	Effort (h)	N	Males	Females	M:F Ratio	Peak Site CPUE	Mean CPUE	(SE)	Mean Male TL (mm)	Mean Female TL (mm)	Max TL (mm)	Mean Sample Temp (°C)	March Mean Discharge (cfs)
2000	20.9	197	122	75	1.6:1	72.0	11.7	(3.0)	446	501	551	17.8	1414
2001	15.1	283	168	115	1.4:1	192.0	26.5	(8.8)	443	502	570	18.5	1429
2002	22.0	286	217	69	3.1:1	118.0	15.0	(3.7)	429	502	557	19.7	422
2003	36.4	738	567	233	2.4:1	137.4	26.3	(4.4)	453	511	575	16.3	3366
2004	16.1	247	140	107	1.3:1	96.0	18.9	(3.8)	446	517	603	18.1	776
2005	23.2	519	342	177	1.9:1	58.0	21.5	(3.5)	417	499	582	17.8	2003
2006	12.0	192	121	71	1.7:1	84.0	16.3	(5.3)	430	473	532	18.4	312
2007	20.0	442	291	151	1.9:1	56.5	21.8	(3.5)	435	490	545	17.3	1534
2008	26.0	559	337	222	1.5:1	70.1	23.9	(3.4)	424	487	566	16.2	525
2009	19.0	387	240	147	1.6:1	191.1	31.7	(10.2)	431	486	564	17.0	2527
2010	15.1	463	346	117	2.0:1	135.5	30.7	(6.4)	434	488	536	15.8	1463
2011	17.2	538	394	143	2.8:1	97.8	29.4	(4.5)	438	494	547	16.7	359
2012	20.3	792	540	252	2.1:1	183.5	37.4	(6.3)	443	497	556	17.9	638
2013	20.2	1086	709	377	1.9:1	144.9	53.9	(5.8)	449	507	560	17.9	1138
2014	21.3	667	338	329	1.0:1	189.0	41.2	(8.4)	450	508	568	17.0	2340
2015	11.0	212	219	83	1.6:1	103.3	19.7	(3.8)	429	510	560	17.4	2368

TABLE 12.—Preliminary creel estimates including angling effort in trips and hours, harvest by number of individuals and weight, and discards over creel and within the legal creel by number and weight from the 2015 NCDMF angler creel survey of the Neuse River.

		Effort		Harvest		Discards				
Month	Species	Trips	Hours	Number	Weight (kg)	Over Creel	Legal size	Total	Mortality Number	Mortality Weight (kg)
February	American Shad	192	670	0	0	0	0	0	0.0	0
March	American Shad	0	0	28		0	30	30	0.5	
April	American Shad	130	378	65		0	120	120	1.9	
May	American Shad	41	154	0	0	0	0	0	0.0	
Total	American Shad	363	1,203	94		0	132	132	2.4	
February	Hickory Shad	192	670	0	0	0	0	0	0.0	0
March	Hickory Shad	127	656	6,908	3,235	1,769	8,194	9,963	159.4	75
April	Hickory Shad	0	0	3,509	1,398	330	1,893	2,223	35.6	14
Total	Hickory Shad	319	1,326	10,418	4,632	2,099	10,086	12,186	195.0	89

TABLE 13.—Annual summary of electrofishing effort, sample size, number of males, number of females, male to female ratio, peak site catch rates, overall catch rates with standard error, mean male total length, mean female total length, maximum total length, mean sample temperature, and March mean discharge for Neuse River Hickory Shad spawning ground surveys 2002–2015.

Year	Effort (h)	N	Males	Females	M/F Ratio	Peak Site CPUE	All Site Mean CPUE (SE)	Mean Male TL (mm)	Mean Female TL (mm)	Max TL (mm)	Mean Sample Temp (°C)	March Mean Discharge (cfs)
2002	2.50	132	112	20	5.6:1	155.8	52.8 (23.9)	371	427	488	15.1	422
2003	12.34	82	65	17	3.8:1	39.4	6.9 (3.3)	395	435	492	13.0	3366
2004	15.78	135	83	52	1.6:1	32.0	6.1 (1.6)	398	442	510	11.9	776
2005	13.01	438	207	231	0.9:1	107.0	33.7 (9.5)	378	441	527	10.0	2003
2006	2.81	68	44	24	1.8:1	131.8	20.7 (9.5)	408	458	495	12.1	312
2007	10.36	240	189	51	3.7:1	141.8	22.5 (5.0)	385	440	514	15.5	1534
2008	10.87	97	63	34	1.9:1	40.0	9.5 (2.3)	386	446	530	13.4	525
2009	11.23	95	79	16	4.9:1	18.6	8.5 (2.1)	378	428	494	10.3	2527
2010	7.96	131	99	32	3.1:1	41.1	19.3 (8.2)	356	401	489	11.6	1463
2011	7.12	42	33	9	3.7:1	40.5	5.7 (2.3)	367	407	457	13.8	359
2012	5.62	197	170	27	6.3:1	271.6	32.5 (27.0)	357	415	480	13.1	638
2013	8.04	251	196	55	3.6:1	114.4	32.4 (9.5)	374	418	487	10.6	1138
2014	5.60	115	80	35	2.3:1	49.9	19.2 (6.3)	348	404	464	12.2	2340
2015	2.94	27	17	10	1.7:1	22.6	9.4 (3.1)	351	422	554	12.0	2368

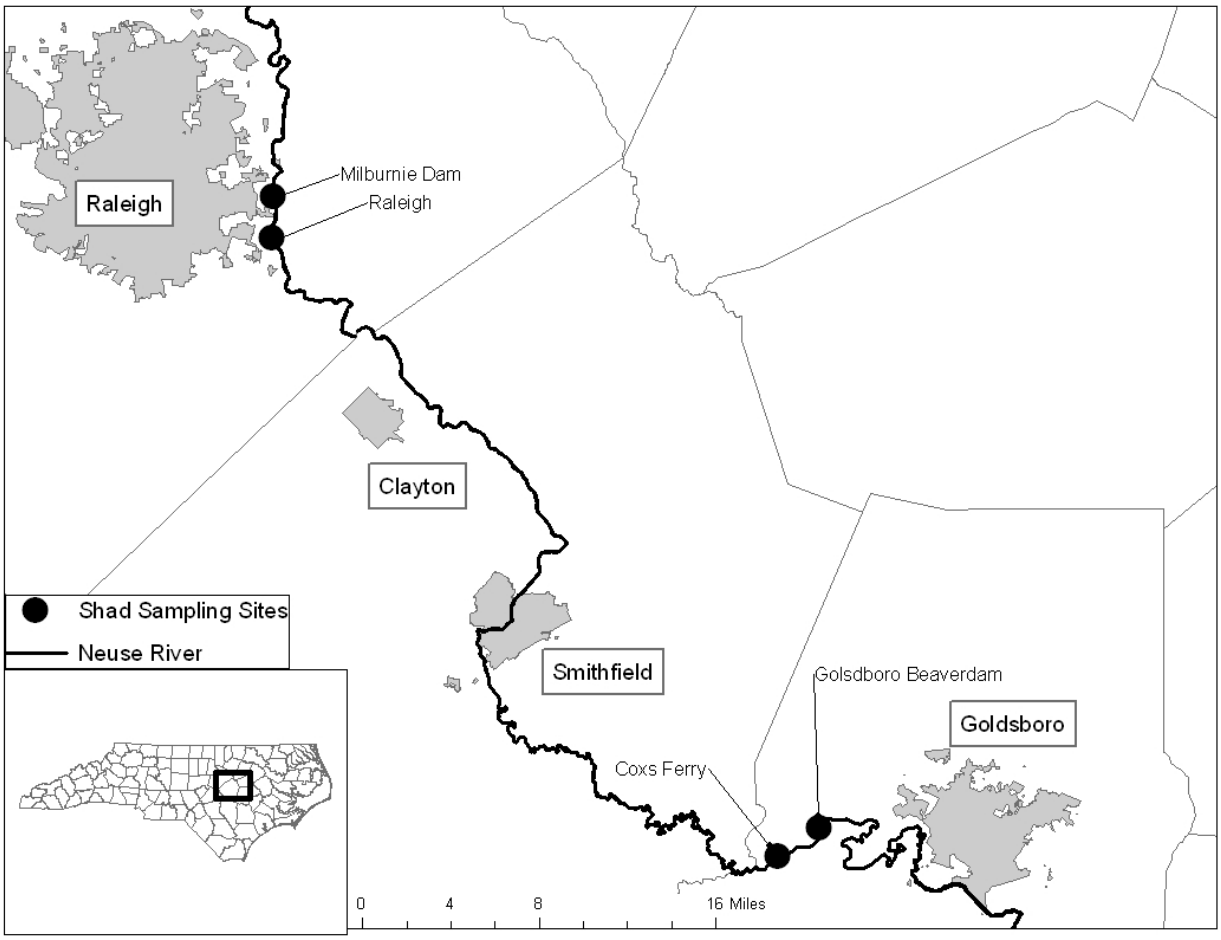

FIGURE 1.—Neuse River American Shad electrofishing sampling sites, spring 2015. American Shad stocking occurred at Cox's Ferry.

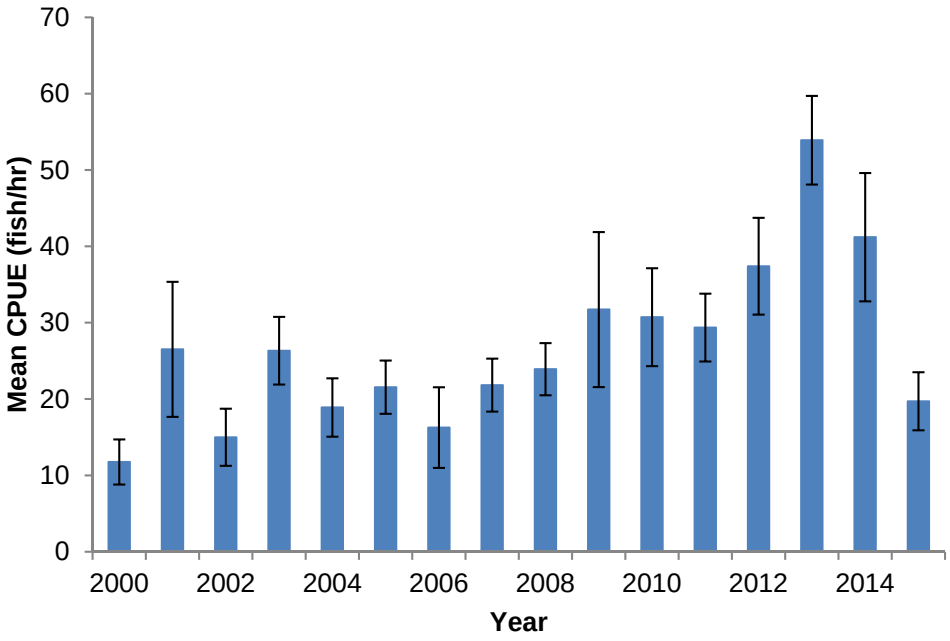

FIGURE 2.—Mean relative abundance (electrofishing CPUE) of American Shad collected from the Neuse River, 2000–2015. Error bars represent standard error.

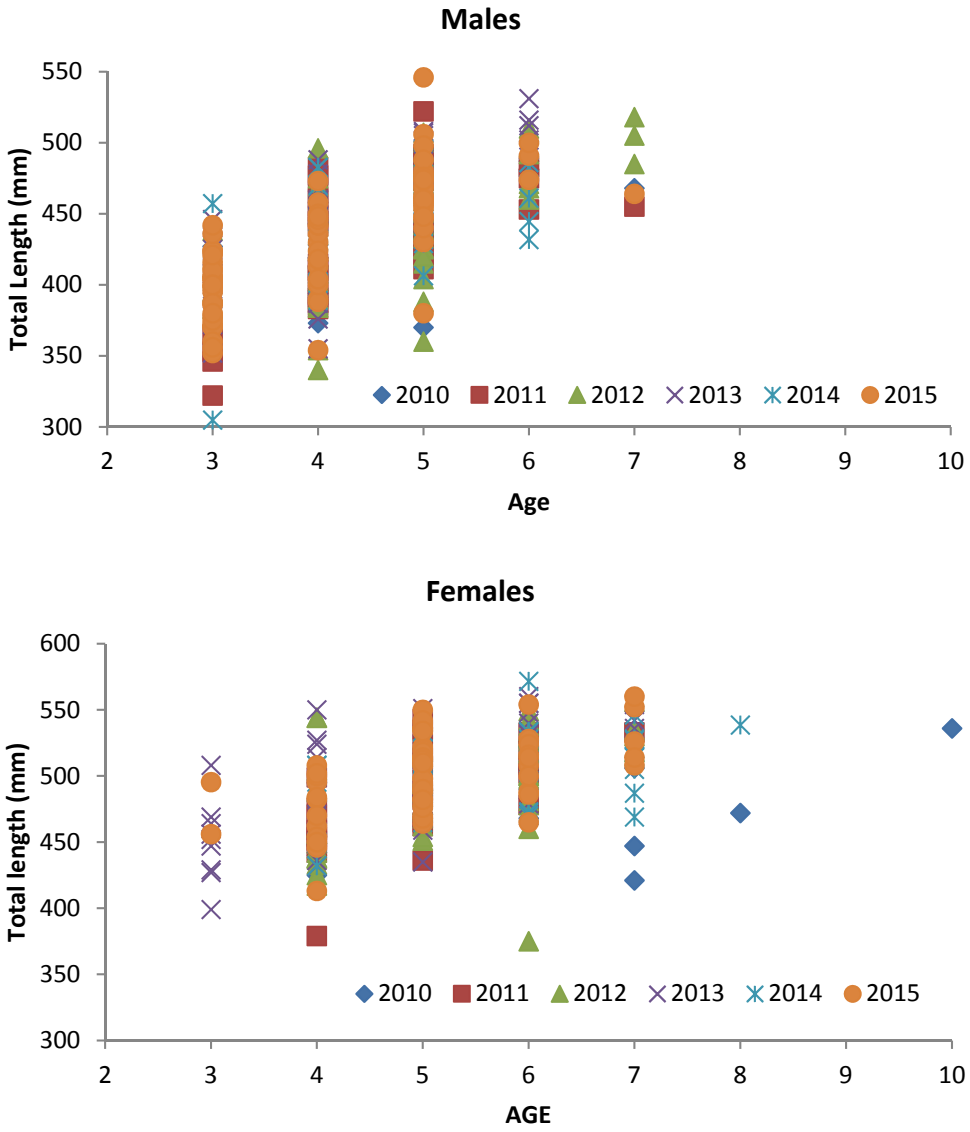

FIGURE 3.—Length at age data from otolith-aged American Shad from 2010–2015. Only broodfish collected in 2014 were aged.

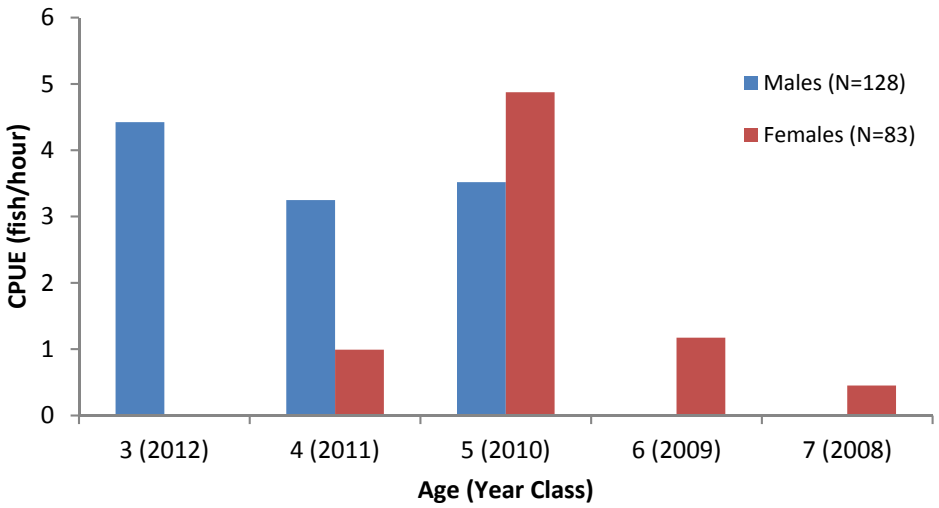

FIGURE 4.—Relative abundance (electrofishing CPUE; fish/hour) of American Shad collected from the Neuse River, spring 2015.

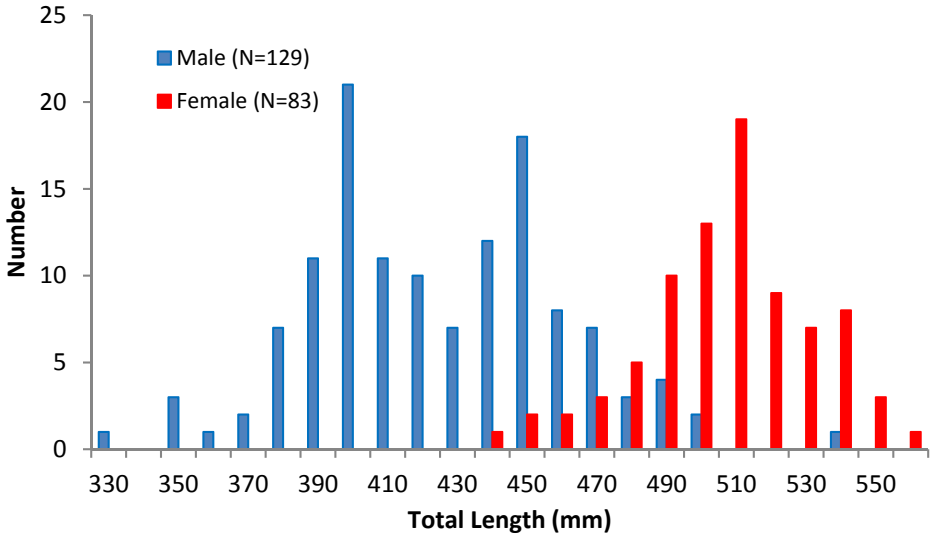

FIGURE 5.—Length-frequency histogram for American Shad collected via boat electrofishing from the Neuse River, spring 2015.

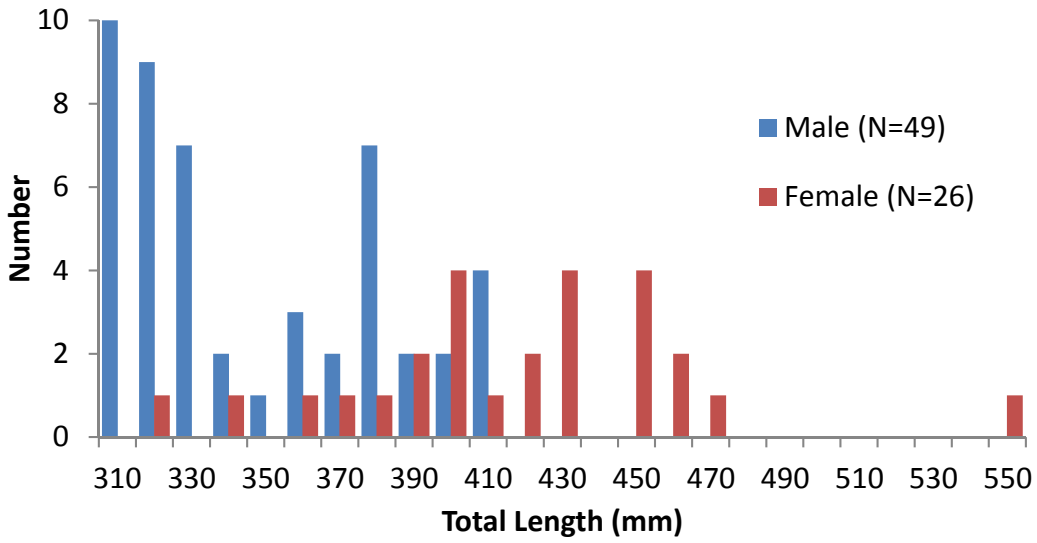

FIGURE 6.—Length-frequency histogram for Hickory Shad collected via boat electrofishing from the Neuse River, spring 2015.