NEUSE RIVER AMERICAN SHAD MONITORING PROGRAM, 2016–2018

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Abstract.— Neuse River American Shad were sampled using boat electrofishing during spring 2016−2018. Mean catch per unit effort (CPUE) was 50.0, 55.6, and 30.6 fish/h from 2016−2018. The age distribution was composed of age 3–7 year-classes with the exception of 2017 when age-7 males and age-3 females were not observed. During the survey period, male American Shad ranged 337–522 mm total length (TL) and female American Shad ranged 386–565 mm TL. The American Shad stocking program produced 1,719,783 fry cultured from Neuse River broodfish and stocked into the Neuse River drainage during this three-year period. Genetic parentage analysis of adult American Shad collected on the spawning grounds resulted in an observed hatchery contribution of 2.2% in 2016, 7.8% in 2017, and 9.3% in 2018. Though the American Shad population in the Neuse River is below historical abundances, population metrics have remained constant since sampling began in 2000 indicating that the population is stable. More refined methods for estimating spawning stock abundance or stock strength and an improved understanding of how these metrics relate to carrying capacity for American Shad in the Neuse River are needed.

The North Carolina Wildlife Resources Commission (NCWRC) has conducted spawning stock assessments of Neuse River American Shad *Alosa sapidissima* 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 and evaluate progress toward objectives in the American Shad sustainability plan (NCDMF and NCWRC 2017). Results of this sampling are also 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 by Amendment 3 to the Interstate Fishery Management Plan of Shad and River Herring for the eastern United States (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 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 including Milburnie Dam (constructed in 1855 and improved in 1903) and Falls of Neuse Dam (constructed in 1981). However, by 1904, the population had declined dramatically, and less than 42,000 fish were harvested (Cobb 1906). 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. Currently, recreational anglers are limited to one fish per day and commercial harvest of American Shad is not allowed in inland waters. Commercial harvest of American Shad is allowed in coastal waters of the Neuse River by the NCDMF.

The lowermost dam on the Neuse 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). Though other early wooden dams were operated intermittently as far downstream as Smithfield (Swain 1885), Milburnie Dam denied access to former spawning grounds for over 100 years until its removal in the winter of 2017. When Milburnie Dam was removed, access to 24 km of historical spawning habitat was regained. Falls of the Neuse Dam currently is the first upstream impediment to American Shad migration on the Neuse River and still limits access to the Eno River.

Including Contentnea Creek, Swift Creek, and Trent River, approximately 577 km of spawning habitat are currently accessible below Falls Dam equating to approximately 6,305 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 as described by St. Pierre (1979). Without future passage upstream, current carrying capacity for the Neuse River is approximately 315,000 American Shad.

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 were used to produce all fry stocked in the Neuse River.

Annual spawning stock electrofishing surveys are valuable for monitoring American Shad population trends, assessing population changes over time, documenting potential population recovery for a sustainable fishery, and improving 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 Neuse River American Shad population metrics as these fish migrate to inland spawning grounds.

Methods

American Shad Spawning Stock Assessments 2016–2018.—Spring sampling for Neuse River American Shad was conducted at a minimum of two 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, a minimum of two sites near Raleigh (RKM 348–352) were added to the weekly sampling regime (Figure 1). Selection of sites was based on river discharge, known spawning locations, and was standardized according to flow (Table 1). Directed sampling effort for shad began in March as water temperatures approached 10°C and ended in May when spawning appeared complete and/or temperatures exceeded 23°C (Table 2). 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 sites in these areas were 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.

American 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. A minimum goal of 200 fin clips was established each year to determine hatchery contribution using parentage-based tagging (PBT) analysis. These fin clips were also used to determine if the Neuse River American Shad population exhibited spatial or temporal genetic differences. Field data were recorded directly into a spreadsheet using a Trimble Yuma field computer. Data were imported into BIODE for further analysis and data archival.

American Shad not utilized for broodfish were released, but a subsample of fish were sacrificed for otolith ageing in 2017. American Shad broodfish were also 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. Ages were assigned with the sex-specific age-length key for unaged fish in 2017 and for all fish in 2016 and 2018. Mean lengths at age were calculated for the entire sample following methods described by Bettoli and Miranda (2001).

Relative abundance of American Shad for each sample site was indexed by CPUE and expressed as the 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 Restoration Plan and Evaluation of Stockings 2016–2018.—Broodfish were collected on 29–30 March 2016, 28–29 March 2017, and 2–3 April 2018. 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‰ to facilitate recovery from electrofishing 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 fry were stocked at the Goldsboro Boating Access near the NC Highway 117 Bridge 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 stocked were recorded (Table 3).

Beginning in 2012, all American Shad broodfish with potential to contribute to hatchery production were assessed with 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 adapted from the USFWS Warm Springs Conservation Genetics Lab and 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 were compared to fin clips from American Shad collected on the spawning grounds from 2016 (N=411), 2017 (N=348), and 2018 (N=246; Table 4). 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. Additional analyses were conducted in 2016 to test for spatial and temporal genetic differences in the Neuse River and in 2017 to test for genetic differences between the Neuse River and two of its major tributaries, Contentnea Creek and Trent River.

Results

2016 Spawning Stock Assessment.—Field staff collected 515 American Shad between 13 March 2016 and 15 May 2016. The male to female ratio was 2:0. Total mean CPUE (SE) was 50.0 (7.4) fish/h (Table 2). The peak in weekly mean CPUE was 91.3 (28.8) fish/h, occurring the week of 10 April 2016 with water temperatures measuring 14.6°C (Table 2). Due to low water levels limiting boat access, the Raleigh area of the Neuse River was sampled less frequently

than the Goldsboro area. Despite more effort in Goldsboro (7.7 h) than in the Raleigh area (2.6 h), 32% of the total sample was collected in the Raleigh area. Mean CPUE in Raleigh sampling sites was 66.9 fish/h, compared to 44.0 fish/h in Goldsboro sites. Including broodfish, 348 male and 171 female American Shad were assigned ages using a sex specific age-length key (Table 5 and Figure 3). Male American Shad were represented by 5 year-classes (ages 3–7) with the 2011 year-class (age 4) dominating the electrofishing catch by comprising 48% of the male sample (Figure 2). Age-5 males were second most abundant and contributed 27% to the total sample (Figure 2). Female American Shad were also represented by 5 year-classes (ages 3–7), with the 2010 year-class (age 5) comprising 43% of the female sample (Figure 2). Age-6 females were second most abundant and contributed 26% to the female sample (Figure 2). The length distributions of male and female American Shad were both unimodal. Males ranged from 364–522 mm, with the peak occurring in the 400–440 mm size-class (Figure 3). Females ranged 386–558 mm TL, with the peak occurring in the 480–500 mm size-class (Figure 3).

2017 Spawning Stock Assessment.—Between 6 March 2017 and 15 May 2017, 597 American Shad were collected. Male American Shad comprised 60% of the sample (N=361), while females accounted for 40% (N=236; Table 6). Mean total CPUE (SE) was 55.6 (11) fish/h (Table 2). The peak in weekly mean CPUE was 126.4 (2.0) fish/h, occurring the week 1 May 2017 with water temperatures measuring 18.3°C (Table 2). Effort varied across sampling areas during the 2017 season due to extreme high and low water events limiting site access. More of the total sampling effort was in the Goldsboro area (8.4 h) than in the Raleigh area (3.1 h). However, 38% of the total sample was collected from the Raleigh area and 62% of the sample was collected in the Goldsboro area. Mean CPUE in Raleigh sampling sites was 98.8 fish/h, compared to 44.0 fish/h in Goldsboro sites. Including broodfish, 119 American Shad were aged by examining otoliths. A sex specific age-length key was used to assign ages to the rest of the sample except for 21 fish which were omitted from age analysis because lengths were not recorded (Table 5). Male American Shad were represented by 4 year-classes (ages 3–6) with the 2013 year-class (age-4) dominating the electrofishing catch by comprising 57.4% of males (Table 5). Age-6 males accounted for less than 1% of males (Table 5). Female American Shad were represented by 4 year-classes (ages 4–7), with the 2012 year-class (age 5) comprising 58.0% of the female sample (Table 5). Age-7 females accounted for 10.6% of the of the female sample (Table 5). Both males and females exhibited unimodal size distributions (Figure 3). Males ranged 370–499 mm, with the peak occurring in the 430–460 mm size-class. Females ranged 449–565 mm, with the peak occurring in the 490–510 mm size-class.

2018 Spawning Stock Assessment.—From 7 March 2018 to 22 May 2018, 481 American Shad were collected. Male American Shad comprised 58% of the sample (N=277), while females accounted for 42% (N=204; Table 6). Mean total CPUE (SE) was 30.6 (3.1) fish/h (Table 2). The peak in weekly mean CPUE was 41.9 (14.7) fish/h, occurring the week of 16 April 2018 with water temperatures measuring 16.4°C (Table 2). The fluctuating nature of spring rainfall limited site access during low flow periods resulting in unequal effort between the Raleigh and Goldsboro sections of the Neuse River. More of the total sampling effort was in the Goldsboro area (11.2 h) than in the Raleigh area (3.7 h). Therefore, 25% of the total sample was collected from the Raleigh area and 75% of the sample was collected in the Goldsboro area. Mean CPUE in Raleigh sampling sites was 29.1 fish/h, compared to 31.2 fish/h in Goldsboro sites. Including broodfish, 275 male and 204 female American Shad were assigned ages using a sex specific age-

length key (Table 5 and Figure 3). Male American Shad were represented by 5 year-classes (ages 3–7) with the 2014 year-class (age 4) dominating the electrofishing catch by comprising 49.8% of males (Table 5). Age-6 males accounted for 1% of the male sample (Table 5). Female American Shad were represented by 5 year-classes (ages 3–7), with the 2013 year-class (age 5) comprising 46.1% of the female sample (Table 5). Age-7 females accounted for 6.4% of the of the female sample (Table 5). Both males and females exhibited unimodal size distributions (Figure 3). Males ranged 337–508 mm, with the peak occurring in the 430–460 mm size-class. Females ranged 435–541 mm, with the peak occurring in the 490–510 mm size-class.

Broodfish collections and stocking.—In 2016, 60 male and 54 female American Shad were used to produce 609,720 American Shad Fry (White and McCargo 2017). In 2017, 71 male and 72 female American Shad were used to produce 440,161 American Shad Fry (White and McCargo 2018). In 2018, 65 male and 80 female American Shad were used to produce 669,902 American Shad Fry. All fry were stocked in the Neuse River at the HWY 117 BAA (Boating Access Area) in Goldsboro, NC (Table 3).

Hatchery contribution.—Hatchery contribution of Neuse River American Shad adults on the spawning grounds increased with each year of the PBT program and was 2.2% in 2016, 7.8% in 2017, and 9.3% in 2018 (Table 4; Evans and Carlson 2017; Evans and Carlson 2018; Evans and McGrady 2019).

Discussion

The 2016–2018 American Shad relative abundance estimates in the Neuse River were within the range from previous years (Table 6; Ricks and Rachels 2015). 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 also cause variation in annual catch rates. Therefore, caution should be used when relating catch rates to absolute abundance.

American Shad population trends in the Neuse River remain consistent. Similar to previous years, total catch for male American shad was supported by age-3, age-4, and age-5 year-classes while the female American Shad catch was supported by the age-4, age-5, and age-6 year-classes. The age distribution suggests that very few American Shad survive over seven years, although fish have been observed to survive up to ten years in rare instances (Ricks and Rachels 2015). Metrics including mean total length at age, the population age structure, and the male to female ratio remained consistent over the time series.

Approximately 5,563,088 larval American Shad were stocked in the Neuse River near Goldsboro since 2012 (Table 3). As expected, hatchery contribution increased throughout the time series as additional cohorts recruited to the fishery, and qualified for genetic analysis. It is difficult to identify significant trends with only 4 years of PBT results and because variation in annual hatchery contribution is likely high. As PBT results from adult American Shad build over the coming years, these scenarios will be evaluated and management decisions will be applied with pertinent success criteria. The efficacy of stocking should be evaluated since the broodfish collected would likely be spawning in the Neuse River naturally. While hatchery practices should yield higher fertilization rates and egg hatching success, the benefits of the restoration program may not make significant increases in the Neuse River American Shad population at

the current stocking levels. Management strategies that include different stocking rates, including years where no fished are stocked, should be evaluated.

The carrying capacity of American Shad in the Neuse River is approximately 315,000 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 315,000 American Shad in the Neuse River is appropriate. This estimate, while conservative, is reasonable given that at least 250,000 American Shad were harvested from the Neuse River before the completion of the spawning season in 1873 (Yarrow 1874). Despite the need for refined estimates of carrying capacity and population abundance, the Neuse River American Shad spawning stock is characterized by an appropriate age structure and moderate levels of abundance.

While the American Shad population in the Neuse River is not at historical levels of abundance, consistent population metrics throughout the monitoring timeframe indicated the population was stable with catch rates trending upward. Future work should explore new methods to assess population abundance and relate it to carrying capacity in the Neuse River. Conducting a DIDSON survey in the Neuse River should be evaluated in the future. Also, exploratory surveys for anadromous fish have resulted in observations of American Shad in locations far removed from the main stem Neuse River such as Contentnea Creek and the Trent River. Genetic analysis of samples indicated that there were no temporal or spatial differences among American Shad collected in the Neuse River basin (Evans and Carlson 2018; Evans and McGrady 2019). American Shad abundance variability could be accounted for by variability in tributary habitat use in a given year, but this has yet to be evaluated. Lastly, due to the high amount of variation in catch rates caused by flow, temperature, and turbidity, other metrics should be developed that are more resistant to environmental changes. Some metrics to consider are sex ratio, ratio of American Shad over age-5, or ratio of American Shad over 500 mm.

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. Temporarily suspend stocking for 3 years as a formal trial. Continue the use of PBT to determine hatchery contribution to respective cohorts and consult with geneticists to understand genetic implications of a prolonged stocking program.
3. 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 using the available time series data.
4. 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.
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. Sites at Fire Department Road, Anderson Point Park, and additional sites owned by Raleigh Parks have been considered. NCWRC should support and facilitate operation of these access areas whenever possible.
6. Replace field computers. An upgrade is needed to avoid data loss and improve efficiency.

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

Sample Area	River Kilometer (RKM)	Access Area	USGS Gage Station	Min Discharge (Ft3/s)	Min Gage (ft)	Site Status
Falls Dam	376	Buffalo Road	2087183	700	2.1	High Flows
Milburnie Dam	352	Anderson Point Park	2087183	500	2.0	Weekly Flows Allowing
Fire Dept Rd	318	Smithfield	2087500	900	2.8	Weekly Flows Allowing
Cox's Ferry	243	Cox's Ferry BAA	2089000	650	3.5	Weekly
Steven's Mill	232	Steven's Mill BAA	2089000	650	3.5	Optional/Brood
Kinston	136	Kinston BAA				Extreme Low Flows

TABLE 2.—American Shad daily electrofishing effort, total catch, male to female ratio, mean CPUE, standard error, number of sites, and mean daily water temperature for Neuse River, 2016–2018. 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	Mean CPUE Standard Error	Number of Sites	Mean Water Temp (°C)
03/13/2016	0.71	12	2:1	17.7	7.3	3	16.6
03/20/2016	0.83	11	1.2:1	12.9	7.2	3	12.7
03/27/2016	1.40	102	1.6:1	75.0	20.4	5	16.7
04/03/2016	0.87	33	1.8:1	36.1	12.5	3	16.6
04/10/2016	1.13	92	1.6:1	91.3	28.8	3	14.6
04/17/2016	0.95	71	2.6:1	76.9	19.0	3	15.7
04/24/2016	1.01	47	1.9:1	50.0	12.9	3	19.9
05/01/2016	0.74	19	1.4:1	24.7	12.5	3	20.5
05/08/2016	1.77	60	3.6:1	34.5	19.4	6	20.7
05/15/2016	0.86	68	3:1	79.0	50.6	3	21.3
2016 Total All Sites	**10.27**	**515**	**2:1**	**50.0**	**7.4**	**35**	
03/06/2017	0.93	52	1.4:1	59.4	11.2	2	13.5
03/13/2017	0.68	19	1.7:1	29.1	15.3	2	7.9
03/20/2017	0.94	60	1.5:1	71.5	38.3	3	11.9
03/27/2017	0.76	39	0.9:1	51	0.2	2	17.8
04/03/2017	0.83	33	1.5:1	41.4	14.4	3	18.4
04/10/2017	0.67	52	1.2:1	78.3	2.1	2	17.2
04/17/2017	0.65	69	1.5:1	111.4	52.5	2	21.2
04/27/2017	1.02	15	1.1:1	12.6	5.3	4	17.9
05/01/2017	0.65	106	1.4:1	201.6	126.4	2	18.3
05/08/2017	3.00	89	2.3:1	28.3	9.1	7	18.8
05/15/2017	1.17	63	2:1	46.7	27.3	4	21.1
2017 Total All Sites	**11.30**	**597**	**1.5:1**	**55.6**	**11.0**	**33**	
03/05/2018	0.62	19	1.7:1	32.9	18.8	2	10.1
03/12/2018	0.70	17	1.8:1	24.5	3.0	2	7.8
03/19/2018	0.73	20	1.5:1	28.9	11.5	2	12.6
03/26/2018	0.65	3	2:1	5.0	2.3	2	10.1
04/02/2018	0.80	21	2.5:1	24.6	13.1	2	14.8
04/09/2018	2.18	97	1.3:1	39.6	11.9	7	13.1
04/16/2018	1.62	76	1.2:1	41.9	14.7	5	16.4
04/23/2018	1.79	63	1:1	32.5	10	5	16.4
04/30/2018	2.18	76	1.7:1	34.6	9.4	6	17.8
05/07/2018	1.19	29	1.2:1	25.5	14.9	3	21.2
05/14/2018	1.38	38	1.5:1	27.7	7.7	4	25.1
05/21/2018	1.02	20	0.8:1	18.1	8.1	4	21.6
2018 Total All Sites	**15.42**	**479**	**1.4:1**	**30.6**	**3.4**	**45**	

TABLE 3.—American Shad fry stocked into the Neuse River Basin at NC Highway 117 bridge near Goldsboro from 2012 to 2018.

Year	Number Fry Stocked
2012	573,582
2013	1,184,303
2014	1,377,375
2015	708,045
2016	609,720
2017	440,161
2018	669,902
Total	5,563,088

TABLE 4.— American Shad adult hatchey contribution on the spawning grounds 2015–2018.

Year	Samples Collected	Samples with Hatchery Origin	Percent Contribution
2015	285	2	0.01
2016	411	9	2.2
2017	348	27	7.8
2018	388	36	9.3

TABLE 5.—Mean total length (mm) at age by sex for Neuse River American Shad year-classes collected 2016–2018. Data includes broodfish and fish collected from the spawning grounds.

	Year		Males				Females			
Year	Class	Age	N	Mean	Min	Max	N	Mean	Min	Max
2016	2013	3	73	408	364	455	6	454	386	500
2016	2012	4	168	424	376	482	34	480	426	542
2016	2011	5	94	442	368	522	74	497	456	552
2016	2010	6	10	471	430	514	44	504	460	558
2016	2009	7	3	462	454	466	13	513	464	558
2017	2014	3	9	390	370	402				
2017	2013	4	201	433	381	480	28	488	449	516
2017	2012	5	138	459	399	499	131	497	457	533
2017	2011	6	2	495	495	495	43	517	473	545
2017	2010	7					24	529	516	564
2018	2015	3	37	413	341	479	4	478	450	503
2018	2014	4	137	432	386	486	44	479	435	520
2018	2013	5	88	451	369	508	94	493	453	541
2018	2012	6	10	461	435	486	49	500	465	539
2018	2011	7	3	461	457	469	13	503	468	530

TABLE 6.—Summary of Neuse River American Shad spawning stock characteristics and mean discharge, 2000–2018.

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
2016	10.3	515	346	169	2:01	177.9	50.0	(7.4)	427	495	558	17.7	1626
2017	11.3	597	361	236	1.5:1	328.1	55.6	(11.0)	441	500	565	17.3	518
2018	15.4	479	276	203	1.4:1	94.3	30.6	(3.4)	436	492	541	16.3	1039

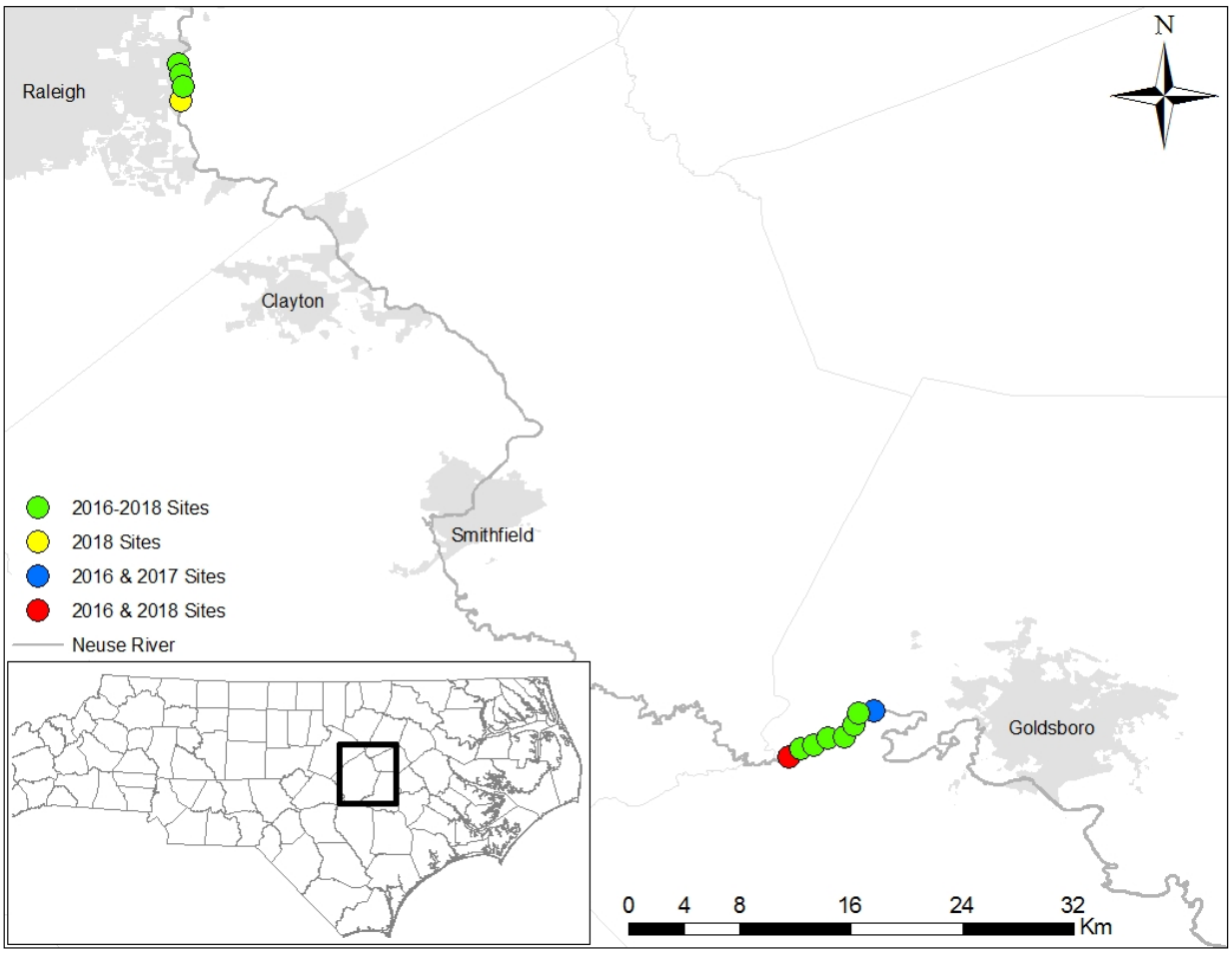

FIGURE 1.— Neuse River American Shad electrofishing sampling sites, spring 2016–2018.

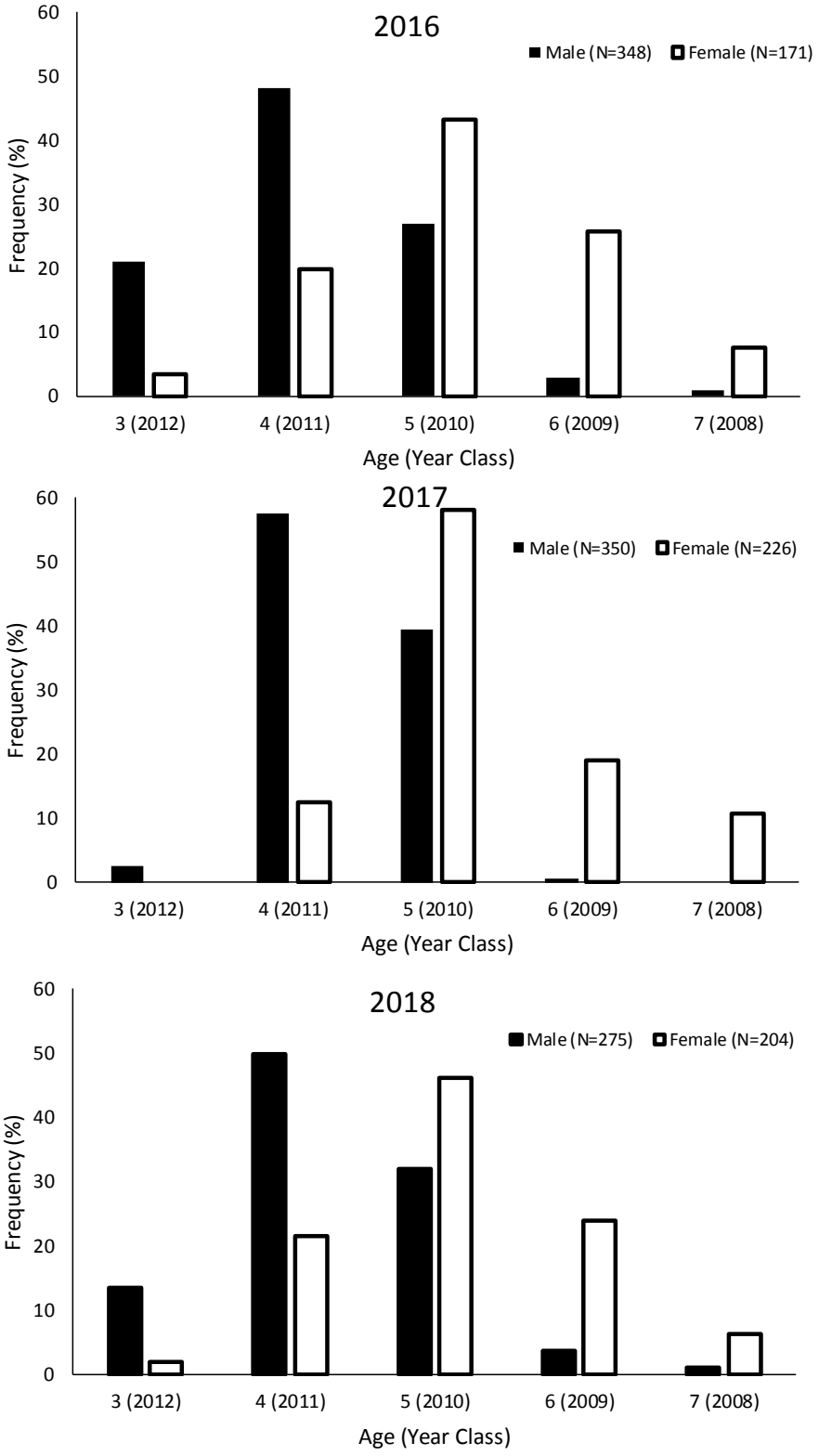

FIGURE 2.—Age-frequency distributions for American Shad collected from the Neuse River, spring 2016, 2017, and 2018. Male and female plots sum separately to 100%.

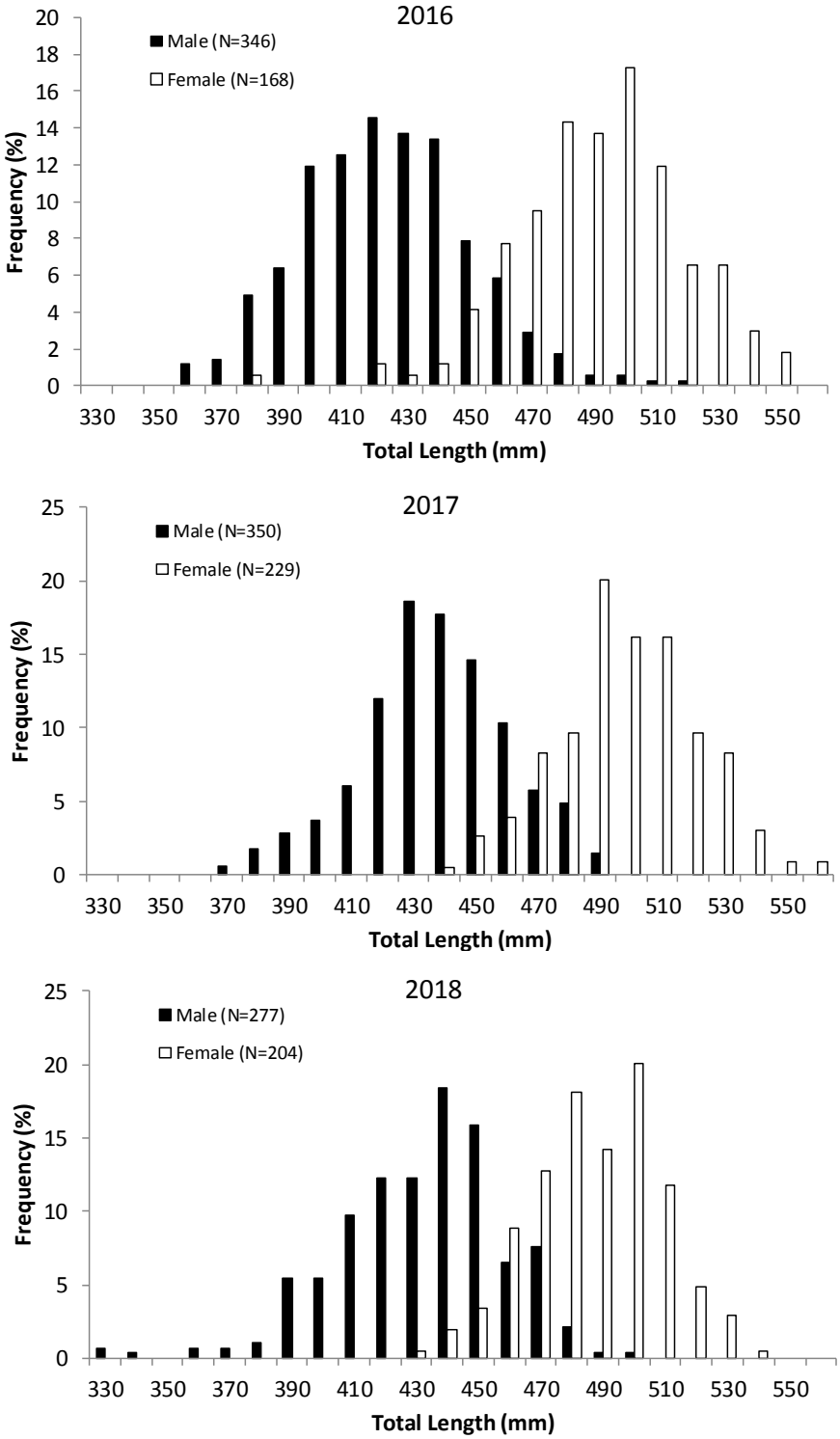

FIGURE 3.—Length-frequency distributions for American Shad collected from the Neuse River, spring 2016, 2017, and 2018. Male and female plots sum separately to 100%. In 2017 length was not recorded for all fish due to logistical limitations.

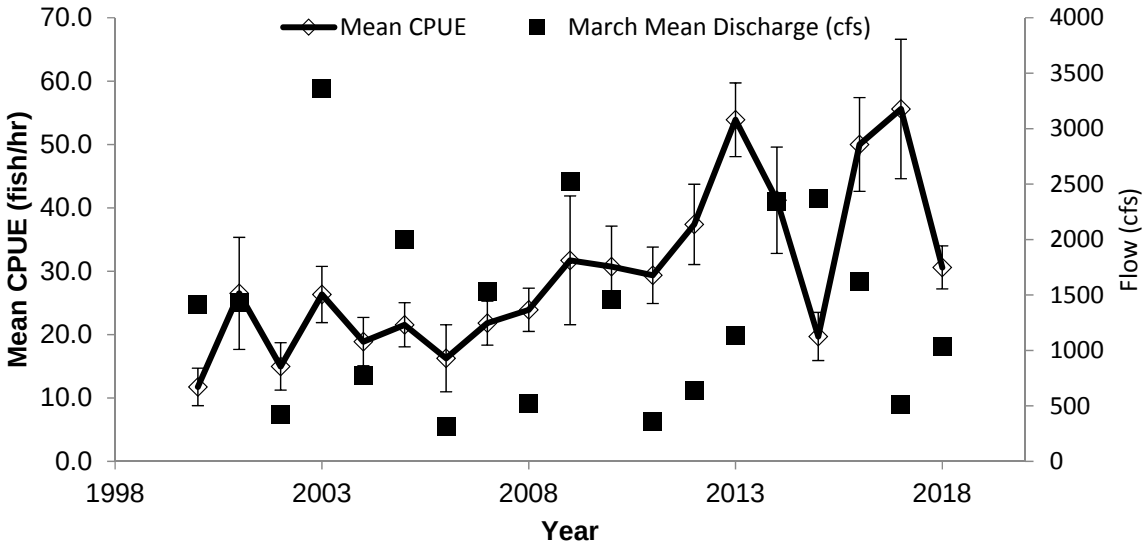

FIGURE 4.—Mean CPUE of American Shad and mean March flows in the Neuse River, 2000–2018.