American Shad Monitoring in the Neuse River, 2021

Federal Aid in Sport Fish Restoration
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Abstract. Neuse River American Shad were sampled using boat electrofishing during spring 2021. Mean catch per unit effort (CPUE) was 26.9 fish/h in 2021. During the survey period, male American Shad ranged 345–496 mm total length and female American Shad ranged 404–542 mm. The age distribution for male American Shad was composed of age 2–7 year-classes while the age distribution for female American Shad was comprised of age 3–8 year-classes. Though the American Shad population in the Neuse River is below historical abundances, population metrics have remained relatively 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 2017).

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). Furthermore, 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 the 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. From 2012 to 2020, commercial harvest of American Shad in the Neuse River has ranged from 109–23,976 pounds and averaged 8,366 pounds annually (NCDMF 2021).

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 not including tributary habitats is approximately 315,000 American Shad.

To supplement the American Shad population, NCWRC annually stocked American Shad fry reared at the United States Fish and Wildlife Service (USFWS) Edenton National Fish Hatchery (ENFH) into the Neuse River 2012–2018. In response to genetic conservation concerns, endemic American Shad broodfish were used to produce all fry stocked in the Neuse River. However, in 2018, American shad fry stocking was suspended due to a low hatchery contribution to the Neuse River American Shad population. Currently, broodfish are collected only to support the North Carolina Museum of Natural Sciences (NCMNS) Shad in the Classroom Program.

Annual spawning ground electrofishing surveys are valuable for monitoring American Shad population trends, assessing population changes over time, and improving opportunities for anglers during anadromous fish migrations in the Neuse River through weekly online fisheries reports summarizing weekly survey observations.

Methods

Study site. Field staff surveyed American Shad spawning grounds on the Neuse River near Goldsboro, NC (RKM 207–245) and Raleigh, NC (RKM 347–376) in 2021 (Table 1, Figure 1). Spring sampling for Neuse River American Shad was conducted at a minimum of two 1-km sites weekly near the Goldsboro, NC spawning grounds. Once 30 to 40 American Shad were collected in one day at the Goldsboro sites, a minimum of two sites near the Raleigh, NC spawning grounds were added to the weekly sampling regime (Table 1, Figure 1). Selection of sites was based on river discharge, known spawning locations, and was standardized according to flow (Table 2). Directed sampling effort for American 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 3). Weekly sampling was contingent upon streamflow or gage height measured at USGS gaging stations near sample sites (Table 1, 2). If streamflow and gage height were not adequate for safe and effective sampling, then sites in these areas were discontinued until conditions improved.

Field collection. A boat-mounted electrofishing unit (Smith-Root 7.5 GPP; 1,000 volts, 4–6 amps, 120-Hz pulsed DC) with one dip netter was used 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 subsample of fish (five per 10-mm size class per sex) were sacrificed for otolith ageing in 2021. A minimum goal of 200 fin clips was established to determine hatchery contribution using parentage-based tagging (PBT) analysis.

Broodfish were collected for the NCMNS Shad in the Classroom Program. All broodfish were transferred to the Watha State Fish Hatchery (WSFH) 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. American Shad fertilized eggs were sent to schools enrolled in the NCMNS Shad in the Classroom Program.

Field data were recorded directly into a spreadsheet using a Trimble Yuma field computer. Data were imported into NCWRC's data repository, BIODE, for analysis and data archival.

Otolith ageing. Once field collection was complete, each American Shad otolith was cleaned by removing organics and allowed to dry. Otolith annuli were counted using a stereomicroscope by two independent readers, and discrepancies between readers were resolved to establish 100% reader agreement (Elzey et al. 2015).

Fin clip procedure. Fin clips were collected 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. After DNA extraction and PBT analysis, percent hatchery contribution was reported. Percent contribution of past stocked American Shad in collected samples can be used as a metric to annually evaluate past stocking success.

Data analyses. Relative abundance of American Shad for each sample site was indexed as catch per unit effort (CPUE; fish/h). Weekly CPUE was calculated for all sample sites from a given week. Length-frequency distributions (10-mm size-classes) of American Shad by sex were used to evaluate size structure. Ages were assigned with a sex-specific age-length key for unaged fish and mean lengths at age were calculated for the entire sample following methods described by Bettoli and Miranda (2001). Fin clips were processed for parentage-based tagging (PBT) analysis by NCWRC geneticists at NCMNS and summarized in a separate report.

Results

During the 2021 American shad spawning grounds survey in the Neuse River, mean water temperature ranged 9.2°C to 22.5°C (Table 3). Field staff collected 355 (160 males, 195 females) American Shad between March 23 and May 11, 2021 (Tables 3, 4). Male to Female ratio (M:F) in 2021 was 0.8:1.0 (Table 4). Due to low water levels, boat access was limited in many areas of the Neuse River, and the Raleigh area was sampled less frequently (1.1 h) than the Goldsboro area (12.9 h). As a result, 96.1% of the total sample was collected in the Goldsboro area while the remaining 3.9% was collected in the Raleigh area. Total mean CPUE in the Goldsboro area was 26.4 fish/h, compared to 12.7 fish/h in the Raleigh area. Mean weekly CPUE ranged 4.6–46.6 fish/h with the peak mean weekly CPUE occurring the week of April 25, 2021, with a mean water temperature of 17.5°C (Table 3). Total mean CPUE (26.9 fish/h) in 2021 was within the range of total mean CPUE during 2007–2021 (Table 4, Figure 2).

The length distributions of male and female American Shad were both unimodal. Males ranged 345–496 mm, with the peak occurring in the 380–460 mm size-class (Table 5, Figure 3). Females ranged 404–542 mm TL, with the peak occurring in the 440–520 mm size-class (Table 5, Figure 3).

A total of 160 male and 195 female American Shad were assigned ages using otolith annuli counts and a sex-specific age-length key (Table 5, Figure 4). Male American Shad were represented by six year-classes (ages 2–7) with the 2017 year-class (age 4) being the most

abundant comprising 30% of the male sample. Age-5 males were second most abundant and contributed 22% to the total sample (Table 5, Figure 4). Female American Shad were also represented by six year-classes (ages 3–8), with the 2016 year-class (age 5) comprising 32% of the female sample. Age-6 females were second most abundant and contributed 23% to the female sample (Table 5, Figure 4).

Recent PBT analysis indicated that hatchery contribution of Neuse River American Shad adults on the spawning grounds continued to be low and was 8.1% in 2019 and 6.7% in 2020 (Table 6; Evans and McCargo 2021, Ricks and Buckley 2021).

In 2021, 43 male and 54 female American Shad broodfish were sent to the WSFH and used to produce American Shad eggs for the NCMNS Shad in the Classroom Program. The results of this effort are summarized in Pender et al. (2021).

Discussion

American Shad population trends in the Neuse River remain consistent to previous years. The 2021 American Shad relative abundance estimates (26.9 fish/h) in the Neuse River were within range (12–55 fish/h) from previous years (2000–2019). 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.

Population metrics in 2021 including male to female ratio, mean total length at age, and the population age structure were similar to other samples in the time series. 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).

American Shad hatchery contribution in the Neuse River remained low. It is difficult to identify significant trends with few years of PBT results and because variation in annual hatchery contribution is likely high. Since stocking has been discontinued except for the NCMNS Shad in the Classroom Program stocking it is likely that hatchery contribution is expected to decrease.

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. Although the American Shad population in the Neuse River is not at historical levels of abundance, population metrics including relative abundance, male to female ratio, mean total length at age, and the population age structure remained consistent throughout the monitoring timeframe indicating the population is stable. Future work should explore new methods to assess population abundance and relate it to carrying capacity in the Neuse River. 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.

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) for 2022.
2. Maintain current American Shad sampling efforts and monitor for changes in spawning stock metrics.
3. Develop NCWRC boating access areas on the Neuse River upstream of Smithfield, NC. NCWRC should support and facilitate operation of these access areas whenever possible.
4. Discontinue PBT evaluations after 2024 and consider selective subsampling of fin clips to monitor hatchery contribution.

Acknowledgements

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TABLE 1. Sample site information for the 2021 American Shad survey in the Neuse River. Note: All discharge data were recorded on the USGS Clayton, NC, Neuse River gage number 02087500.

Sample date	Boating access area	Discharge (cfs)	Site name	Latitude	Longitude
March 23	Cox's Ferry	1830	NR239	35.3721	-78.1026
			NR241	35.3640	-78.1188
			NR243	35.3570	-78.1364
			NR244	35.3515	-78.1442
March 30	Cox's Ferry	1870	NR238	35.3803	-78.0995
			NR242	35.3592	-78.1280
			NR243	35.3570	-78.1364
April 5	Cox's Ferry	2520	NR242	35.3592	-78.1280
			NR243	35.3570	-78.1364
April 7	Anderson Point	1340	NR352	35.8002	-78.5394
April 14	Anderson Point	1300	NR349	35.7766	-78.5385
			NR350	35.7853	-78.5366
April 20	Cox's Ferry	875	NR241	35.3640	-78.1188
			NR243	35.3570	-78.1364
April 22	Goldsboro	582	NR211	35.3439	-78.0269
			NR213	35.3550	-78.0219
April 26	Cox's Ferry	516	NR240	35.3648	-78.1082
			NR241	35.3640	-78.1188
			NR242	35.3592	-78.1280
			NR243	35.3570	-78.1364
April 27	Goldsboro	471	NR211	35.3439	-78.0269
			NR213	35.3550	-78.0219
			NR215	35.3689	-78.0192
May 3	Cox's Ferry	406	NR241	35.3640	-78.1188
			NR242	35.3592	-78.1280
			NR243	35.3570	-78.1364
			NR244	35.3515	-78.1442
May 6	Goldsboro	479	NR212	35.3497	-78.0248
			NR214	35.3631	-78.0220
May 11	Cox's Ferry	650	NR241	35.3640	-78.1188
			NR242	35.3592	-78.1280
			NR243	35.3570	-78.1364
			NR244	35.3515	-78.1442

TABLE 2. Neuse river discharge requirements for boating access during spring electrofishing surveys.

Site name	River kilometer (rkm)	Boating access area	USGS gage	Minimum discharge (cfs)	Minimum gage (ft)	Site status
Falls Dam	376	Buffalo Road	02087183	700	2	High Flows
Milburnie Dam	352	Anderson Point	02087183	500	2	Weekly Flows
Cox's Ferry	243	Cox's Ferry	02089000	650	3.5	Weekly Flows

TABLE 3. American Shad weekly electrofishing effort, number collected, male to female ratio, mean catch per unit effort (CPUE; fish/h), standard error, number of sites, and mean daily water temperature for the Neuse River American Shad spawning grounds survey, 2021. Logistical limitations introduced variability in the number of sites each week.

Sample week	Effort (h)	Number collected	M:F ratio	Mean weekly CPUE	Mean weekly CPUE (se)	Number of sites	Mean water temperature (°C)
March 21–March 27	1.5	27	1.7:1	18.7	4.0	4	9.2
March 28–April 3	1.2	5	0.3:1	4.6	2.3	3	17.0
April 4–April 10	0.8	26	1.9:1	31.3	10.0	3	14.9
April 11–April 17	0.8	9	3.5:1	13.1	6.9	2	15.5
April 18–April 24	2.6	63	1.3:1	28.6	15.5	4	16.5
April 25–May 1	3.5	134	0.5:1	46.6	12.9	7	17.5
May 2–May 8	2.4	69	0.7:1	27.6	11.4	6	22.5
May 9–May 15	1.2	22	0.5:1	11.4	5.0	4	20.5

TABLE 4. Long-term dataset of the Neuse River American Shad spawning stock characteristics and mean discharge, 2000–2021. Note: Because data were incomplete due to the 2020 COVID-19 stay at home order, results from 2020 should not be compared to other years.

Year	Effort (h)	N	Catch males	Catch females	M:F Ratio	Peak site CPUE	Mean CPUE	Mean CPUE (SE)	Male mean TL (mm)	Female mean TL (mm)	Max TL (mm)	Mean water 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	1,414
2001	15.1	283	168	115	1.4:1	192.0	26.5	(8.8)	443	502	570	18.5	1,429
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	3,366
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	2,003
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	1,534
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	2,527
2010	15.1	463	346	117	2.0:1	135.5	30.7	(6.4)	434	488	536	15.8	1,463
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	1,138
2014	21.3	667	338	329	1.0:1	189.0	41.2	(8.4)	450	508	568	17.0	2,340
2015	11.0	212	219	83	1.6:1	103.3	19.7	(3.8)	429	510	560	17.4	2,368
2016	10.3	515	346	169	2.0:1	177.9	50.0	(7.4)	427	495	558	17.7	1,626
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	1,039
2019	15.9	469	303	166	1.8:1	105.4	28.7	(3.7)	418	478	531	18.8	3,396
2020	1.6	135	92	43	2.1:1	124.1	90.0	(22.1)	438	491	539	16.8	995
2021	14.0	355	160	195	0.8:1	105.9	26.9	(4.5)	428	488	547	17.2	3,378

TABLE 5. Mean total length (mm) at age by sex for Neuse River American Shad year-classes collected from the Goldsboro, NC and Raleigh, NC spawning grounds in 2021.

		Male				Female			
Year class	Age	N	Mean	Min	Max	N	Mean	Min	Max
2019	2	2	394	386	404				
2018	3	37	402	346	459	3	449	448	453
2017	4	61	424	345	456	51	475	404	509
2016	5	44	445	411	495	80	485	439	541
2015	6	15	465	405	496	58	503	469	540
2014	7	1	485	481	481	1	544	542	542
2013	8					1	535	531	531

TABLE 6. American Shad adult hatchery contribution on the Neuse River spawning grounds 2015–2020. American Shad fry stocking was suspended in 2018 due to low hatchery contribution to the Neuse River America Shad population.

Year	Number collected	Number 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
2019	345	28	8.1
2020	135	9	6.7

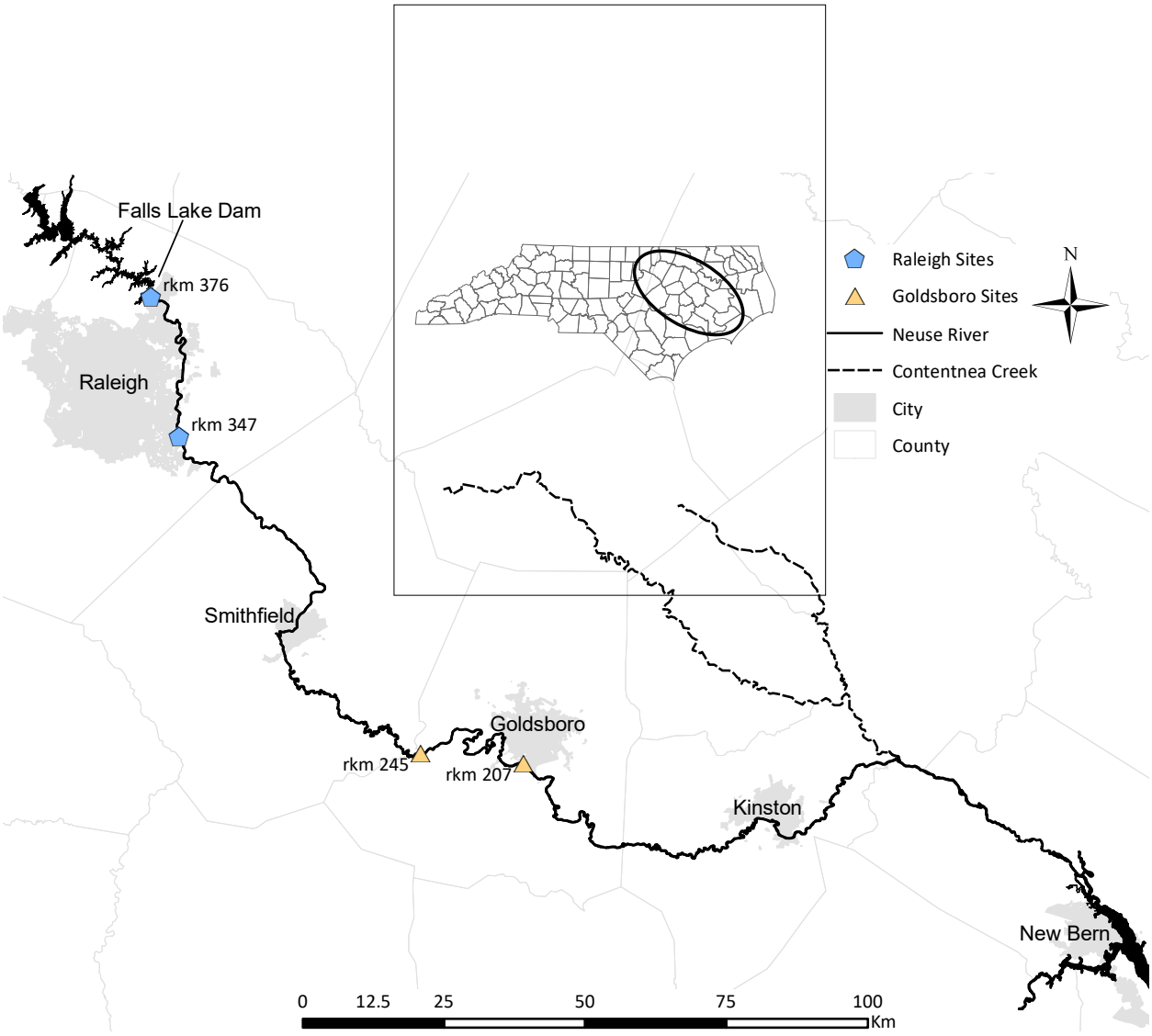

FIGURE 1. Neuse River American Shad electrofishing Goldsboro, NC and Raleigh, NC spawning grounds sampling sites, spring 2021.

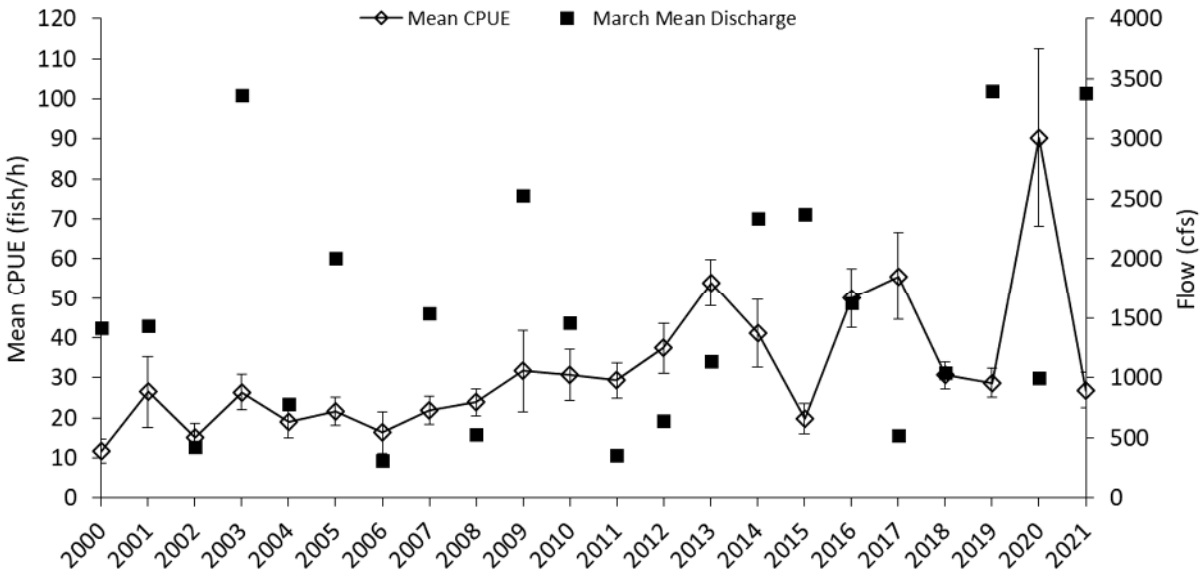

FIGURE 2. Mean catch per unit effort (CPUE; fish/h) of American Shad and mean March discharge in the Neuse River, 2000−2021. Note: Because sampling was incomplete in 2020 due to the COVID-19 stay at home order, results from 2020 should not be compared to other years.

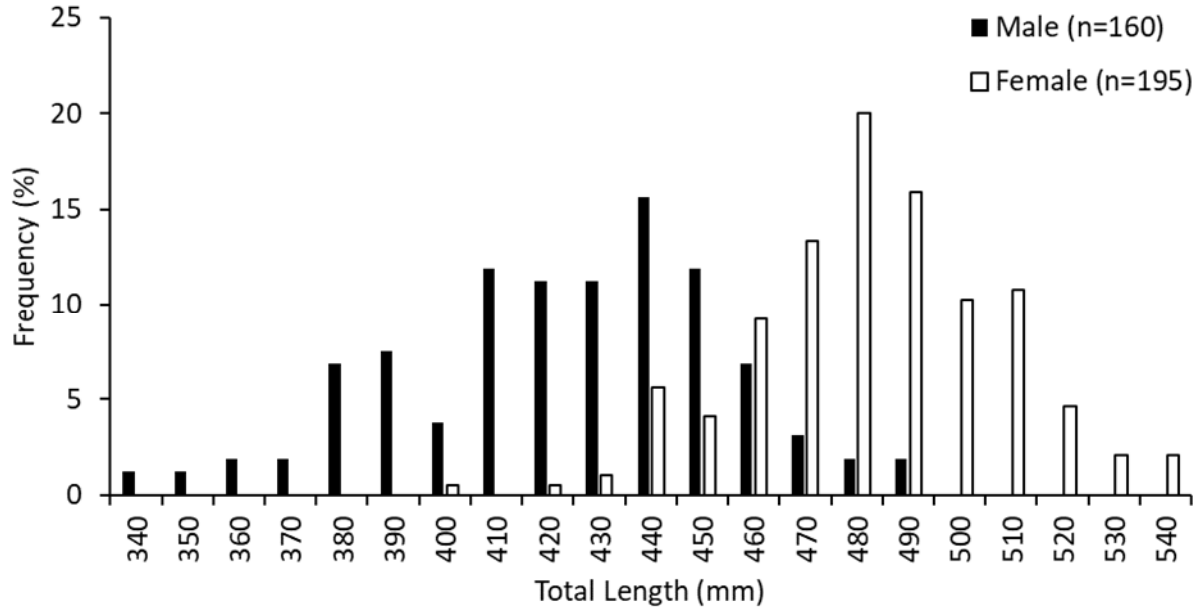

FIGURE 3. Length-frequency distributions for American Shad collected from the Neuse River spawning grounds survey, spring 2021. Male and female plots sum separately to 100%.

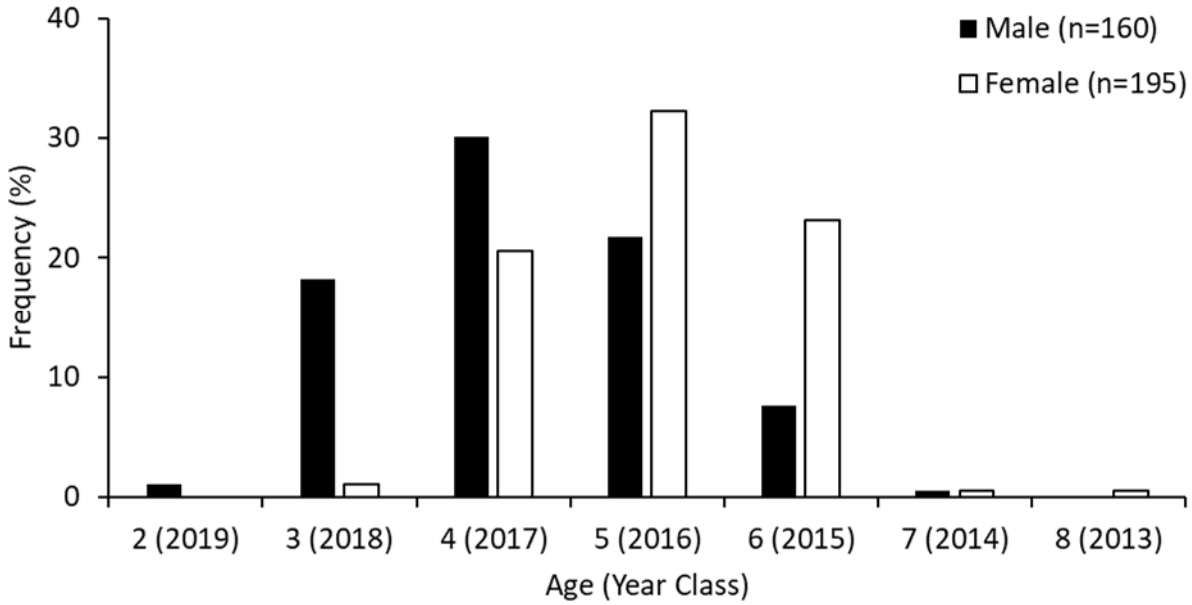

FIGURE 4. Age-frequency distributions for American Shad collected from the Neuse River spawning grounds survey, spring 2021. Male and female plots sum separately to 100%.