AMERICAN SHAD MONITORING PROGRAM IN THE ROANOKE RIVER IN COASTAL NORTH CAROLINA – 2015

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Kathryn M. Potoka

North Carolina Wildlife Resources Commission
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Abstract.—American Shad *Alosa sapidissima* were sampled with boat electrofishing in the Roanoke River at nine survey sites near the Gaston Boating Access Area in spring 2015. A total of 243 American Shad were collected during weekly surveys, and overall catch per unit effort (CPUE) was 34 fish/h. The overall male to female ratio was 1.3:1; with slightly more males (138) collected than females (105). Female American Shad ranged in total length 414–583 mm, while male American Shad ranged 352–531 mm in length. The 2015 age structure of American Shad on the spawning grounds in the Roanoke River was comprised of 3–7 year old males and 4–7 year old females. Our American Shad restoration program continued in 2015 with a total of 4,816,360 fry cultured using Roanoke River broodfish. Fry were stocked by Watha State Fish Hatchery in the Roanoke River at Weldon, NC, in the Staunton River above John H. Kerr Reservoir, and in Gaston Reservoir. Parentage-based tagging (PBT) methods were used to assess hatchery contribution of 118 out-migrating juveniles; 29 were identified as hatchery-origin from the 2015 cohort resulting in 24.6% hatchery contribution. In 2015, 42.6% of at-large adults assessed with PBT methods were determined to be of hatchery origin, representing the 2010, 2011, 2012, and 2013 year classes. These levels of hatchery contribution to the spawning stock and juvenile out-migration indicate the importance of this adaptive management strategy in rebuilding the American Shad spawning stock in the Roanoke River. The abundance estimate of spawning females in 2015 was 1,651 (95% confidence interval: 406–1,851). Current estimates of relative abundance and run size support continued conservation efforts in cooperation with NC Division of Marine Fisheries.

The Roanoke River Basin contains a diverse and dynamic fish assemblage composed of at least 108 resident and diadromous species (Menhinick 1991). Historically, anadromous alosine species including American Shad *Alosa sapidissima,* Alewife *A. pseudoharengus,* and Blueback Herring *A. aestivalis,* were abundant and supported exceptional commercial and recreational fisheries in the Roanoke River. Several factors have contributed to the decline of American Shad populations, primarily, spawning habitat loss, fragmentation caused by the construction of dams, and overharvest (Hightower et al. 1996). Between the 1940s and 1960s at least six major impoundments were constructed on the Roanoke River, with no provisions for fish passage (Harris and Hightower 2012). Currently, the Roanoke River basin contains 16 major reservoirs with a chain of three reservoirs (John H. Kerr Reservoir, Lake Gaston, and Roanoke Rapids Lake) located near the fall line along the Virginia and North Carolina border. These three lower-most dams prevent access of anadromous fishes to approximately 500 miles of potential spawning habitat. Currently only eight river miles comprising approximately 1,000 acres has been delineated as suitable American Shad spawning habitat below these dams. Due to the ecological importance of American Shad in the Roanoke River as well as a focus to provide opportunities for recreational anglers, the North Carolina Wildlife Resources Commission (NCWRC) has invested considerable effort and resources into monitoring and restoring American Shad populations in the Roanoke River.

American Shad spawning stock surveys begin in late spring and continue through early summer until spawning activities appear to cease. Population characteristics of the spawning stock of American Shad in the Roanoke River are summarized each spring and submitted to the North Carolina Division of Marine Fisheries (NCDMF) for use in developing stock assessment models and for inclusion in North Carolina's annual American Shad compliance report to the Atlantic States Marine Fisheries Commission (ASMFC). This information is required of the state of North Carolina as mandated under conditions set forth within the fishery management plan for alosine species established for the eastern United States (ASMFC 1985) and associated amendments (ASMFC 2002; ASMFC 2010). Compliance with this plan is necessary to support the enhancement of American Shad populations within coastal North Carolina. As part of this compliance, a Sustainable Fishery Plan was created to identify and implement management efforts that would rebuild and maintain American Shad populations in North Carolina (NCDMF and NCWRC 2012).

In an attempt to supplement the Roanoke River American Shad population, a hatchery-based stocking program was initiated in 1998. The NCWRC annually collects broodfish that are transferred to Watha State Fish Hatchery (WSFH) and/or Edenton National Fish Hatchery (ENFH) where fry were reared and stocked in the Roanoke River by hatchery staff (Evans 2015). To evaluate efficacy of the stocking program, juvenile American Shad were collected in the fall to characterize hatchery contribution of the juvenile out-migration using parentage-based tagging (PBT) techniques (Evans and Carlson 2016). Additionally, PBT analysis was also conducted on fish collected during spring spawning stock surveys to identify any returning adults of hatchery origin from previously stocked cohorts. Hatchery evaluations using PBT techniques began in 2010 with donor broodfish sources from the Tar, Cape Fear, and Roanoke rivers. In 2011, only endemic Roanoke River American Shad were used as broodfish to reduce concerns regarding genetic conservation and in an attempt to increase hatchery returns. In addition to the restoration program, recreational harvest regulations including a one fish per

day creel limit for American Shad in the Roanoke River are intended to protect the Roanoke River American Shad population on the spawning grounds.

In 2005, state and federal fisheries management agencies in North Carolina and Virginia reached a Settlement Agreement with Dominion/N.C. Power regarding Federal Energy Regulatory Commission (FERC) relicensing of the Gaston and Roanoke Rapids hydroelectric dams in the Roanoke River basin. The relicensing agreement provided for the well-funded and highly coordinated program to restore American Shad in the Roanoke basin. Measures outlined in the restoration effort included improvements in hatchery production of fry, continued intensive monitoring of fry stocking success upstream and downstream of the main stem reservoirs, and annual assessments of American Shad population size to guide decisions regarding construction of upstream passage facilities.

Our objectives were to: 1) describe the population characteristics of the spawning stock in the Roanoke River, 2) evaluate the hatchery contribution of adult American Shad on the spawning grounds, 3) determine the hatchery contribution of juvenile American Shad during the out-migration, and 4) use the best available model to estimate size of the American Shad spawning population. Results from the 2015 spawning stock survey and hatchery evaluation of out-migrating juveniles and returning adults from 2015 are presented in this report.

Methods

Study Area.—From its headwaters in the ridge and valley physiographic province of western Virginia near Blacksburg, the Roanoke River flows southeasterly for approximately 660 km until emptying into the Albemarle Sound in Northeastern North Carolina near Plymouth. More than 18,000 km of tributaries drain approximately 25,600 km^2 in Virginia and North Carolina with nearly two-thirds of the basin occurring in Virginia (NCDWQ 2006; VDEQ 2006). The basin includes portions of 16 counties and 6 cities in Virginia and 15 counties and 42 municipalities in North Carolina. Major tributaries of the Roanoke River include the Dan, Banister, and Smith Rivers. There are three major reservoirs on the Roanoke River near the Virginia and North Carolina border: John H. Kerr Reservoir, Lake Gaston, and Roanoke Rapids Lake. These reservoirs are operated for flood control and hydroelectric generation, and the largest of the three, John H. Kerr reservoir, regulates much of the flow in the North Carolina portion of the river. The portion of river downstream of Roanoke Rapids Lake dam, often referred to as the lower Roanoke River, flows unimpeded through the largest intact and least-disturbed bottomland hardwood forest floodplain in the mid-Atlantic region (NCDWQ 2006).

Spawning Stock Assessment.—American Shad from the Roanoke River were collected weekly with boat-mounted electrofishing gear (Smith-Root 7.5 GPP, 500–1,000V, 3.8–4.0A) between 19 March and 14 May 2015 near the Gaston Boating Access Area (Figure 1). Sampling commenced when water temperatures approached 9^{o}C and continued until low-flow conditions restricted sampling. Electrofishing occurred during daylight hours with one boat driver and two dip netters. Samples were conducted at nine sampling sites once per week during the survey period. Electrofishing commenced at the upstream portion of each 500-m site and continued downstream the entire transect. At each site, electrofishing time (seconds) and water quality parameters were recorded including: water temperature (Celsius), dissolved

oxygen saturation (%), dissolved oxygen concentration (mg/L), specific conductivity (µS/cm), salinity (ppt), pH, and secchi depth (m).

American Shad were held in a circular, 150-gallon live well; water was constantly recirculated and oxygen was diffused through an air stone placed on the bottom of the tank. Upon site completion, each fish was measured for total length (TL mm), weighed (g), and sexed. Sex was determined by applying directional pressure to the abdomen toward the vent and observing the presence of milt or eggs. All American Shad were fin clipped, and a selection of fin clips from males < 480 mm and females < 520 mm were stored in numbered vials containing non-denatured, spectrophotometric grade ethanol for PBT evaluation. Fin clips were recharged with ethanol within one week of collection. Additionally, fin clips observed missing from American Shad in subsequent sampling events allowed for visual identification of recaptures. Relative abundance was calculated each week and for the entire survey period and was indexed by CPUE, expressed as the number of fish captured per electrofishing hour (fish/h). Relative abundance was also calculated weekly for both males and females. American Shad broodfish collections occurred outside of weekly surveys and were not included in CPUE calculations. A weekly male to female ratio was also generated to determine the proportion of female American Shad. A length-frequency histogram was constructed for males and females using 10-mm length groups to categorize the size structure of American Shad on the spawning grounds.

Where possible, a minimum of five otoliths from each 10-mm length group by sex were collected for ageing. Otoliths from all broodfish were used, until five otoliths for each length group were obtained. Otoliths were aged by a primary reader and were photographed using a Wolfe DigiVu CM 2.0 stereomicroscope. A second reader aged all otolith photographs. Otoliths were aged without knowledge of fish sex or length. Differences between readers were resolved with a concert read of digital images until 100% agreement was reached. Ages were assigned to all unaged American Shad separately for each sex using FAMS software (Slipke and Maceina 2014). Age distributions and CPUE by age-class were then calculated. Mean length at age for females and males was calculated for the entire sample, following methods described by Bettoli and Miranda (2001), and von Bertalanffy growth models were calculated.

2015 Hatchery Evaluation.—American Shad broodfish were collected outside of weekly surveys, near the Gaston Boating Access Area between 30 March and 1 April. Broodfish were transported via hatchery truck to WSFH where fish were spawned and fry were reared. When fry were roughly 8 days old, they were stocked by hatchery staff in the lower Roanoke River at Weldon 8 rkm downstream of Roanoke Rapids Dam, in the Staunton River upstream of John H. Kerr Reservoir at Clover Landing, VA, and in Gaston Reservoir at Bracey, VA. (Evans 2015). Fin clips from all broodfish were stored in numbered vials containing non-denatured, spectrophotometric grade ethanol to later be referenced for hatchery origin of out-migrating juveniles and returning at-large adults.

Fin clips from American Shad broodfish were sent to the genetics laboratory at the NC Museum of Natural Science (NCMNS) for PBT analysis to determine any individuals of hatchery origin (Evans and Carlson 2016). Genotyping of discrete batches of broodfish allows specific cohorts to be identified in future surveys and allows for PBT evaluation of hatchery contribution of the juvenile out-migration. With the results of individual origin, hatchery contribution percentages were generated for each stocking cohort. Due to limited information regarding hatchery contributions prior to initiation of PBT techniques in 2010, a length frequency

histogram categorized by fish that were identified as natural origin, hatchery origin, and those only having length information was created using the 2015 PBT results. Additionally, age-length keys were applied to develop an age distribution for fish with processed fin clips in order to determine frequency of hatchery-origin by stocking year.

Juvenile American Shad surveys were conducted near Plymouth, NC, from September to November in 2015. Juvenile shad were collected using boat-mounted electrofishing roughly 30 minutes after sunset. At least one electrofishing transect was completed during each sampling night. Electrofishing transects were on average 420 seconds in duration, and all juvenile shad were collected by a dip-netter and held in a live well. Upon transect completion, fish were identified to species, measured, and fin clips were taken from American Shad. Fin clips were stored in numbered vials containing non-denatured, spectrophotometric grade ethanol. Fin clips were then sent to NCMNS for PBT analysis, to determine hatchery contribution of the 2015 juvenile out-migration.

Abundance Estimate.—Abundance of female American Shad on the spawning grounds in the Roanoke River was estimated for 2015 according to methods described by Harris and Hightower (2012). This method incorporates average fecundity, egg ripening, egg fertilization and fry survival rates with an estimate of juvenile production based on the number of fry stocked and percent hatchery contribution of the out-migrating juveniles to estimate the number of female American Shad present on the spawning grounds in a given year. The number of fry stocked is known, but age at stocking (i.e. days post hatch; dph) can be variable among batches. The model is sensitive to the age at which fry are stocked because fry survival rates vary with age at stocking. Hatchery contribution rates within the juvenile out-migration also influence the estimate of adult female American Shad. In general, a low juvenile hatchery contribution rate will result in a relatively high female abundance estimate, and a high contribution rate will result in a low female abundance. In 2015, the age of American Shad at stocking was estimated between 5 and 12 dph with an average of 8 dph (J. Evans, NCWRC, personal communication); thus, female American Shad abundance was estimated for the minimum, maximum and average dph. The male to female ratio from the spawning stock survey was used to expand the female estimate to total abundance of American Shad on the spawning grounds.

Results

Spawning Stock Assessment.—A total of 243 American Shad were collected from 19 March 2015 to 14 May 2015 from the Roanoke River spawning grounds near the Gaston, NC, boating access area (Figure 1). Visual observations of fins suggested none of these fish were previously collected, indicating a low recapture rate. Males comprised 57% of the sample (N=138), while females accounted for 43% (N=105). In 2015, the male to female ratio on the spawning grounds was 1.3:1 (Table 1). Overall total CPUE was 33.9 fish/h in 2015 (Figure 2). Peak relative abundance of males (33.0 fish/h) occurred on 23 April 2015, and the peak relative abundance of females (30.8 fish/h) occurred on 30 April 2015 (Table 1). The peak weekly CPUE for both sexes combined (61.7 fish/h) occurred on 30 April 2015. In 2015, male mean CPUE (5.6 fish/h) was much lower compared with 2014 (21.2 fish/h), 2013 (39.6 fish/h) and 2012 (34.5 fish/h); similarly, female mean CPUE (3.6 fish/h) in 2015 was lower than in 2014 (17.5 fish/h) and 2013

(15.7 fish/h). Overall, spawning stock size distribution ranged from 352 to 583 mm (Figure 3). Female American Shad lengths ranged from 414 to 583 mm with an average of 517 mm; male American Shad lengths ranged from 352 to 531 mm with an average of 436 mm (Figure 3). The length frequency distribution for males was unimodal with a peak at 420–429 mm. The female length frequency distribution was also unimodal with a peak at 530–549 mm.

Otolith age was determined for 178 individuals obtained from separate broodfish collections (83 females and 95 males). Initial agreement between otolith readers was 68%; however, upon a second concert read, agreement was 100%. The majority of discrepancies were within one year, and the first reader had a tendency to underage by one year. Sex specific age-length keys were created to assign ages to 101 female and 133 male American Shad; five males and four females could not be assigned an age because no fish were aged in their respective size class. Otolith analysis showed an age distribution ranging 3–7 years for males and 4–7 years for females (Table 2 and Figure 4). Male American Shad from the 2011 year class (age 4) were most abundant comprising 51% of total males collected (Figure 4 and Table 2). Female American Shad from the 2009 year class (age 6) were most abundant, comprising 51% of total females collected (Figure 4 and Table 2). Length-at-age analysis indicated mean total length of the most abundant year classes of age-4 males and age-6 females were 420 mm and 523 mm, respectively (Table 2 and Figure 5).

2015 Hatchery Evaluation.—Broodfish collections near the Gaston Boating Access Area occurred from 30 March to 1 April 2015 with 183 male and 184 female adult American Shad transported to WSFH. Hauling mortality was 7% and was similar for females (N=11) and males (N=14; Evans 2015). Hatchery production of American Shad fry in 2015 for all stocking locations was recorded in Table 3. In 2015, 2,584,327 fry were stocked into the Roanoke River downstream of Roanoke Rapids Dam at Weldon, NC; 750,067 fry were stocked upstream of John H. Kerr Dam in the Staunton River near Clover Landing, VA; and 1,481,966 fry were stocked in Gaston Reservoir near Bracey, VA (Table 4; Evans 2015). Hatchery staff stocked a total of 4,816,360 American Shad fry in the Roanoke River system during 16 stocking trips between 16 April and 21 May 2015 (Table 5; Evans 2015).

Broodfish fin clips combined with fin clips collected during weekly samples were collectively referred to as 2015 adult at-large samples. A total of 367 at-large adult fin clips were from broodfish, and 179 fin clips were from weekly samples. PBT analysis confirmed 233 out of 546 at-large adults were of hatchery origin, a 42.6% hatchery contribution on the spawning grounds in 2015. Of the hatchery-identified fish, 66 (27%) were from the 2010 cohort, 141 (67%) were from the 2011 cohort, 23 (10%) were from the 2012 cohort, and 3 (1%) were stocked in 2013. All hatchery origin fish from the 2011–2013 cohorts were identified from Weldon stockings (Evans and Carlson 2016). For the 2010 cohort, PBT analysis for American Shad is limited to hatchery source; all available broodfish fin clips were available to assess hatchery contribution, yet tank designation protocols for specific stocking locations were not available at both hatcheries until the 2011 production season. Thus, stocking location (i.e., Weldon or Clover Landing) cannot be determined for the 2010 cohort.

A total of 101 juvenile American Shad were collected during weekly electrofishing surveys from 3 September to 16 November 2015 and an additional 17 were collected during routine electrofishing surveys in the lower Roanoke River. A total of 118 juvenile fin clips collected from the lower Roanoke River were sent to the NCMNS for PBT assessment. Juvenile out-migration

PBT analysis concluded 29 of the 118 genotyped fish (24.6%) were conclusively matched with hatchery broodfish from the 2015 cohort (Evans and Carlson 2016). Analysis further revealed that all of the recaptured hatchery juveniles were stocked at Weldon in 2015 (Table 6). Total length ranged from 79 mm to 121 mm for juvenile American Shad of hatchery origin and from 61 mm to 182 mm for those of natural origin (Table 7). Overall mean total length for both hatchery origin and natural origin juveniles was 95.4 (SE=1.3).

Abundance Estimate.—Utilizing parameters of 5, 8, and 12 dph at stocking (minimum, average, and maximum values) estimates for 2015 female American Shad were 790, 1,651, and 690, respectively (Table 8). The estimate of spawning females was expanded based on the 1.3:1 sex ratio to estimate the total spawning population in 2015 at 1,817 (5 dph), 3,798 (8 dph), or 1,580 individuals (12 dph; Table 8).

Discussion

Since 2012, a declining trend in overall total CPUE has been observed, which could indicate an overall decline in abundance. Despite the decline in overall abundance, female CPUE was higher in 2015 than in 2012. However, in 2015 sampling was limited by low flows and ended in mid-May rather than June as in previous years. In 2015, sampling results indicated almost equal number of females and males collected on the spawning grounds; 2015 is the second consecutive year a nearly 1:1 male to female ratio has been observed in the Roanoke River. However, female CPUE in 2015 was lower than in 2014. Future surveys will determine if the 1:1 proportion of males to females on the spawning grounds in 2014 and 2015 will produce strong year classes. Two of the three highest CPUE values for American Shad collected on the spawning grounds were observed in 2008 and 2009, which were the two year classes that supported the majority of females on the spawning grounds in 2015. As these two year classes age out of the population, relative abundance of Roanoke River American Shad may continue to decrease in coming years.

Some inconsistencies in relative abundance over time can be attributed to changes in sampling protocol. For example, the depressed overall CPUE in 2010 and 2011 is likely a result of using only one dip-netter and may not be a result of a decline in abundance. A weak year class was suspected in 2010 (Potoka et al. 2015); overall, fewer age-5 males and females were collected in 2015 compared with previous years, contributing to the low CPUE observed in 2015. Similar to 2014, very few age-4 females were observed in 2015, this could indicate that female American Shad in the Roanoke are contributing to the spawning stock at age 5. Additionally, in order to determine if trends in abundance are a result of sampling methods or actual population changes, the same sampling protocol used in 2014 and 2015 should continue to be used in future survey efforts for a minimum of five years. The age distribution showed that the majority of females on the spawning grounds were age 5, 6, and 7 (2010, 2009, and 2008 year-classes). The age distribution of male American Shad was primarily composed of ages 4 and 5 (2011 and 2010 year-classes). All fish less than 4 years old were males. As seen in previous years, males tend to return to the spawning grounds at a younger age than females.

Overall hatchery contribution of at-large adult American Shad was 42.6% in 2015. However, PBT efforts were initiated in 2010; thus, 2015 results did not capture potential hatchery contribution of the 2008 and 2009 year classes, which supported approximately one third

(32.3%) of the collected fish on the spawning grounds. Since PBT analysis was limited to fish stocked from 2010–2015, hatchery contribution by cohort is a more appropriate metric than overall hatchery contribution. The contribution of hatchery-origin fish was relatively high among fish < 500 mm. In 2015, hatchery contribution ranged from 48% for the 2010 cohort to 100% for the 2013 cohort. Overall hatchery contribution will likely be higher in future years as all cohorts become eligible for PBT testing; evaluations should continue in 2016.

In 2015, fewer juvenile American Shad were collected during the out-migration survey than in the previous two years. Hatchery contribution in 2015 (24.6%) was similar to the hatchery contribution observed in 2013 (23%), with roughly 2.5 million fry being stocked in each of those years. All hatchery-origin fish collected in 2015 originated from Weldon stockings. Since 2010, hatchery contribution has been highly variable ranging from 2.8% in 2012 to 44.8% in 2014. However, number of collected American Shad juveniles has also been highly variable, and warrants a more detailed review of relative abundance over the time series.

There was no evidence that fry stocked above the dams were able to pass downstream and complete the out-migration. Additionally, all returning adults of hatchery origin have been from Weldon stockings, further indicating fry stocked above the reservoirs are not contributing to the adult population. Adaptive management strategies have been implemented to identify impediments to passage through the three major dams. These research objectives have been supported by systematically stocking below each of the dams to identify limitations to passage for American Shad fry through each of the impoundments. Upon completion of these investigations, the efficacy of the stocking program will be evaluated to determine the future role of fry stocking as a management technique on the Roanoke River.

Out-migrating juveniles of both hatchery and wild origin were observed in similar numbers throughout the collection period. Thus, timing of out-migration did not differ for hatchery and wild-origin juveniles. There is no indication that hatchery or wild fish have an advantage at the juvenile stage because mean total lengths, timing, and abundance was similar throughout the collection period (Table 7). Future monitoring and continued PBT analysis will help determine if a high hatchery contribution of juveniles translates to a high percent contribution of that cohort in subsequent at-large adult samples.

With 24.6% hatchery contribution in the out-migrating juveniles, abundance estimates for female spawning population and estimated total spawning populations were low compared with carrying capacity of the Roanoke River. In ideal conditions, carrying capacity of American Shad has been described as 50 fish/acre; approximately 1,000 acres of spawning habitat below Roanoke Rapids dam should be able to support 50,000 American Shad (Hightower and Wong 1997). Population estimates ranging from 934–4,257, indicate populations are much lower than this potential carrying capacity. However, given the levels of hatchery contribution, these figures likely underestimate the current abundance of American Shad in the Roanoke River.

Based on previous estimates of the American Shad population size, the American Shad Working Group determined that the Roanoke River American Shad population was not large enough to begin upstream passage of spawning adults in previous years. Results from this study, including low contribution of American Shad fry stocked upstream of the reservoirs to total juvenile American Shad sampled in the lower river and the low population estimate, continue to support the decision to delay design and construction of fish passage facilities at Roanoke Rapids Dam.

Management Recommendations

1) Maintain current creel limits for the Roanoke River to allow no more than one American Shad within the daily creel limit of 10 shad (American and Hickory Shad *A. mediocris*) in aggregate.
2) Continue the use of American Shad broodfish from the Roanoke River for the Roanoke River restoration program. In 2016, stock American Shad fry in the Roanoke River at Weldon and in Roanoke Rapids Lake at the Thelma Boating Access Area with the objective of evaluating passage through Roanoke Rapids Dam.
3) Evaluate the need to continue stocking American Shad fry in the Roanoke Basin.
4) Continue PBT analysis to evaluate hatchery contributions of each eligible cohort through 2016. Collect two fin clips per individual juvenile American Shad to provide additional genetic material to NCMNS. Compile data from spawning stock survey and at-large adult PBT results into a final report, to be completed by 2018.
5) Maintain current American Shad sampling efforts in the Roanoke River in 2016. Promote these efforts via the Coastal Rivers Fishing Reports webpages on www.ncwildlife.org.
6) Complete an analysis of juvenile sampling history and identify trends in relative abundance of juvenile in the out-migration over time and summarize PBT results since 2010. Results will be included in a final report to be completed in 2019.

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TABLE 1.—American Shad weekly electrofishing effort, catch, male to female ratio, mean CPUE, standard error, number of sites, and mean daily water temperature for Roanoke River, 2015 sampling dates. On dates with less than 9 sites, sampling effort was reduced due to low flow limiting access in lower sites.

Date	Sites	Effort (h)	Total Catch (Males, Females)	M:F Ratio	Total CPUE	Male CPUE (fish/h)	Female CPUE (fish/h)	Mean Water Temp (°C)
03/12/2015	9	0.88	0 (0,0)					7.0
03/19/2015	7	0.90	5 (4,1)	4:1	5.6	4.4	1.1	8.7
03/26/2015	5	0.53	19 (9,10)	0.9:1	36.0	17.0	18.9	10.0
04/09/2015	8	0.80	29 (14,15)	0.9:1	36.1	17.4	18.7	13.3
04/16/2015	9	0.81	34 (19,15)	1.3:1	42.0	23.5	18.5	14.9
04/23/2015	9	1.09	63 (36,27)	1.3:1	57.8	33.0	24.7	16.8
04/30/2015	6	0.68	42 (21,21)	1:1	61.7	30.8	30.8	16.1
05/07/2015	9	1.14	48 (34,14)	2.4:1	42.0	29.8	12.3	18.0
05/14/2015	3	0.34	3 (1,2)	0.5:1	8.8	2.9	5.9	19.0
	Mean	1.04	27 (15,12)	1.3:1		17.7	14.6	13.7

TABLE 2.—Mean total length (mm) at age for American Shad males and females collected from the Roanoke River, spring 2015. Five males and four females could not be assigned an age because no fish were aged in their respective size class.

Year Class	Age	Female				Male			
		N	Mean	Min	Max	N	Mean	Min	Max
2012	3	0				7	400	381	415
2011	4	2	453	452	453	68	420	379	477
2010	5	26	497	436	565	40	449	403	501
2009	6	52	522	483	565	17	475	451	500
2008	7	21	533	483	552	1		459	459

TABLE 3.—American Shad fry produced in North Carolina and stocked into the Roanoke River Basin from 1998 to 2015. American Shad broodfish were held in spawning tanks for propagation except in 1998, when eggs and milt were stripped from broodfish in the field and fertilized eggs were cultured in the hatchery.

Year	Edenton National Fish Hatchery	Watha State Fish Hatchery	Total
1998	481,000		
1999	225,000	50,000	275,000
2000	535,000	308,000	843,000
2001	700,000	1,369,000	2,069,000
2002		820,000	820,000
2003	612,000	1,673,629	2,285,629
2004	589,822	1,740,000	2,329,822
2005	1,346,834	1,226,000	2,572,834
2006	1,088,936	1,332,000	2,420,936
2007	772,780	3,540,051	4,312,831
2008	3,126,098	5,093,517	8,219,615
2009	3,665,345	5,132,326	8,797,671
2010	3,729,433	4,153,031	7,882,464
2011	2,741,727	1,715,423	4,457,150
2012		4,800,118	4,800,118
2013		4,570,144	4,570,144
2014		7,504,291	7,504,291
2015		4,816,360	4,816,360
Totals	19,613,975	49,843,890	68,156,865

TABLE 4.—Annual summary of American Shad fry stocked (in millions) by Edenton National Fish Hatchery (ENFH) and Watha State Fish Hatchery (WSFH) at specific stocking locations in the Roanoke River, North Carolina from 2007 to 2015. Daily oxytetracycline (OTC) marking was used 1998–2012, and genetic analyses of hatchery contribution with parentage-based tagging (PBT) were begun in 2010. Age class represents the expected age of stocked American Shad at-large in 2015.

Year	Millions Stocked	Hatchery	Stocking Location	PBT Markers Available	Age Class at-large
2007	2.1	ENFH/WSFH	Weldon, NC	No	8
2008	4.3	ENFH/WSFH	Weldon, NC	No	7
2009	4.5	ENFH/WSFH	Weldon, NC	No	6
2010	6.9	ENFH/WSFH	Weldon, NC	Yes	5
2011	4.0	ENFH/WSFH	Weldon, NC	Yes	4
2012	3.8	WSFH	Weldon, NC	Yes	3
2013	2.4	WSFH	Weldon, NC	Yes	2
2014	3.5	WSFH	Weldon, NC	Yes	1
2015	2.5	WSFH	Weldon, NC	Yes	0
Subtotal	43.6				
2007	2.1	WSFH	Altavista, VA	No	8
2008	3.9	WSFH	Altavista, VA	No	7
2009	4.1	WSFH	Altavista, VA	No	6
2010	0.9	ENFH	Altavista, VA	Yes	5
2011	0.4	ENFH	Clover Landing, VA	Yes	4
2012	1.0	WSFH	Clover Landing, VA	Yes	3
2013	1.3	WSFH	Clover Landing, VA	Yes	2
2013	0.8	WSFH	Bracey, VA	Yes	2
2014	1.4	WSFH	Clover Landing, VA	Yes	1
2014	2.6	WSFH	Bracey, VA	Yes	1
2015	0.75	WSFH	Clover Landing, VA	Yes	0
2015	1.5	WSFH	Bracey, VA	Yes	0
Subtotal	25.2				
Total	68.9				

TABLE 5.—Date, stocking location, hatchery spawning tank, and number of American Shad fry stocked per trip from the Watha State Fish Hatchery in the Roanoke River Basin in 2015.

Date	Location	Number Stocked
4/16/2015	Roanoke River at Weldon	142,491
4/17/2015	Gaston Reservoir at Bracey	136945
4/20/2015	Staunton River at Clover	44,162
4/21/2015	Roanoke River at Weldon	256,049
4/22/2015	Gaston Reservoir at Bracey	352,362
4/24/2015	Roanoke River at Weldon	344,747
4/27/2015	Staunton River at Clover	197,738
4/29/2015	Gaston Reservoir at Bracey	402,202
5/01/2015	Roanoke River at Weldon	392,687
5/04/2015	Staunton River at Clover	244,131
5/05/2015	Roanoke River at Weldon	496,692
5/07/2015	Gaston Reservoir at Bracey	426,137
5/13/2015	Roanoke River at Weldon	89,174
5/19/2015	Staunton River at Clover	264,036
5/20/2015	Roanoke River at Weldon	278,106
5/21/2015	Gaston Reservoir at Bracey	164,230
	Total	4,816,360

TABLE 6.—Number of juvenile American Shad collected during annual fall out-migration sampling from the lower Roanoke River with weekly boat electrofishing during evening hours. Following sampling, juvenile American Shad fin clips were processed with parentage-based tagging (PBT) techniques to assess stocking location and hatchery contribution to the out-migration period. The start and end collection dates and the total number of days of the collection period are also listed for each year.

Year	Total Collected PBT Evaluated	Hatchery Origin-Weldon Stockings	Hatchery Origin-Virginia Stockings	Percent Hatchery Contribution	Collection Begin Date	Collection End Date	Collection Period (Days)
2010	62	9	0	14.5	9/8	11/9	63
2011	82	31	0	37.8	9/29	11/17	50
2012	105	3	0	2.8	9/6	11/15	71
2013	200	46	0	23.0	9/9	11/25	77
2014	299	134	0	44.8	9/2	11/4	64
2015	118	29	0	24.6	9/3	11/16	75

TABLE 7.—Weekly number and mean, minimum and maximum total length (mm) of hatchery- and wild-origin juvenile American Shad collected each week during annual fall out-migration sampling from the lower Roanoke River in 2015.

Date	Hatchery Origin				Wild Origin			
	n	Mean	Min	Max	n	Mean	Min	Max
9/3/15	1	79	-	-	2	86	85	87
9/9/15	1	96	-	-	0	-	-	-
9/17/15	5	91	79	97	7	101	71	102
9/23/15	2	86	82	89	8	89	66	108
9/28/15	5	87	81	98	22	92	79	104
10/7/15	1	96	-	-	1	61	-	-
10/15/15	0	-	-	-	3	88	77	100
10/19/15	0	-	-	-	3	82	75	80
10/21/15	2	108	102	112	4	96	84	108
10/29/15	7	110	100	121	15	95	72	117
11/5/15	0	-	-	-	3	102	95	112
11/10/15	5	102	94	117	9	103	89	119
11/16/15	0	-	-	-	12	102	89	118

TABLE 8.—2015 Roanoke River back-calculated abundance estimates for spawning females with 95% confidence intervals and total estimated populations using age of fry at stocking (days post hatch) according to methods described by Harris and Hightower (2012).

Days Post Hatch	Estimated Spawning Females	95% Confidence Interval	M:F	Estimated Total Spawning Population
5 (minimum)	790	342–1,434	1.3:1	1,817
8 (average)	1,651	406–1,851	1.3:1	3,798
12 (maximum)	690	552–2977	1.3:1	1,586

TABLE 9.—Commercial landings of American Shad in the Albemarle Sound Area, data obtained from NCDMF and NCWRC (2016).

Year	Commercial Landings (lb.)
2007	211,293
2008	79,872
2009	118,020
2010	184,896
2011	160,081
2012	178,002
2013	196,539
2014	109,248
2015	62,114

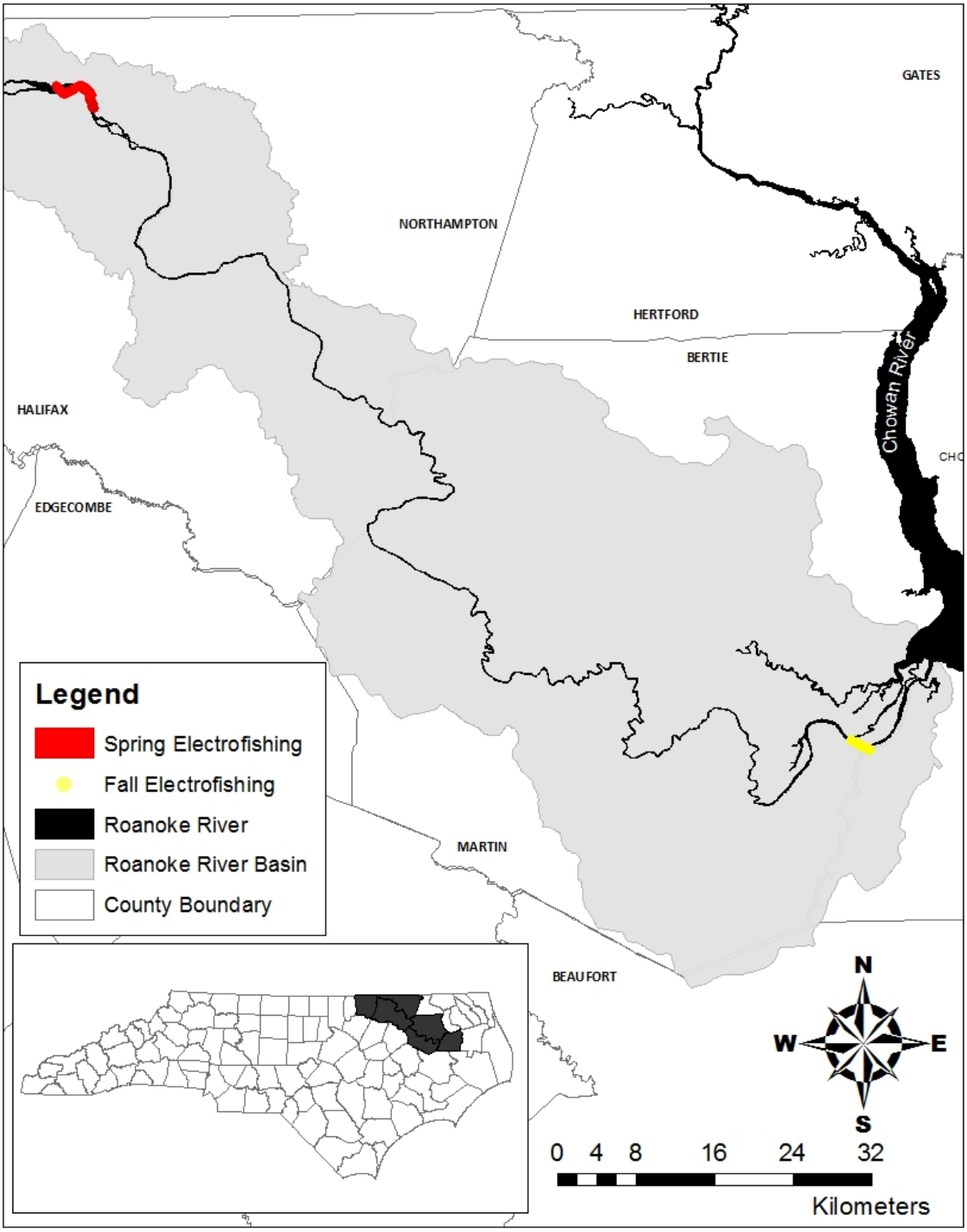

FIGURE 1.—American Shad sampling sites on the Roanoke River in coastal North Carolina, spring 2015.

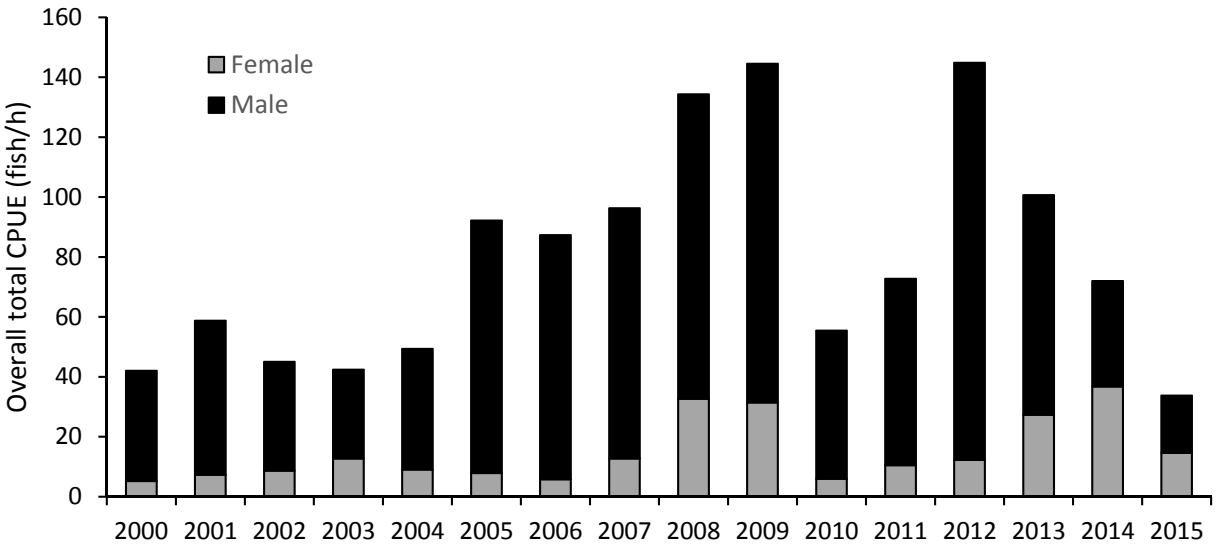

FIGURE 2.—Overall total relative abundance (electrofishing CPUE) of American Shad collected from the Roanoke River, 2000–2015. One dip netter was used from 2000–2004, 2010, and 2011. Two dip netters were used 2005–2009 and 2012–2015. Sampling regime changes occurred in 2013 and 2014.

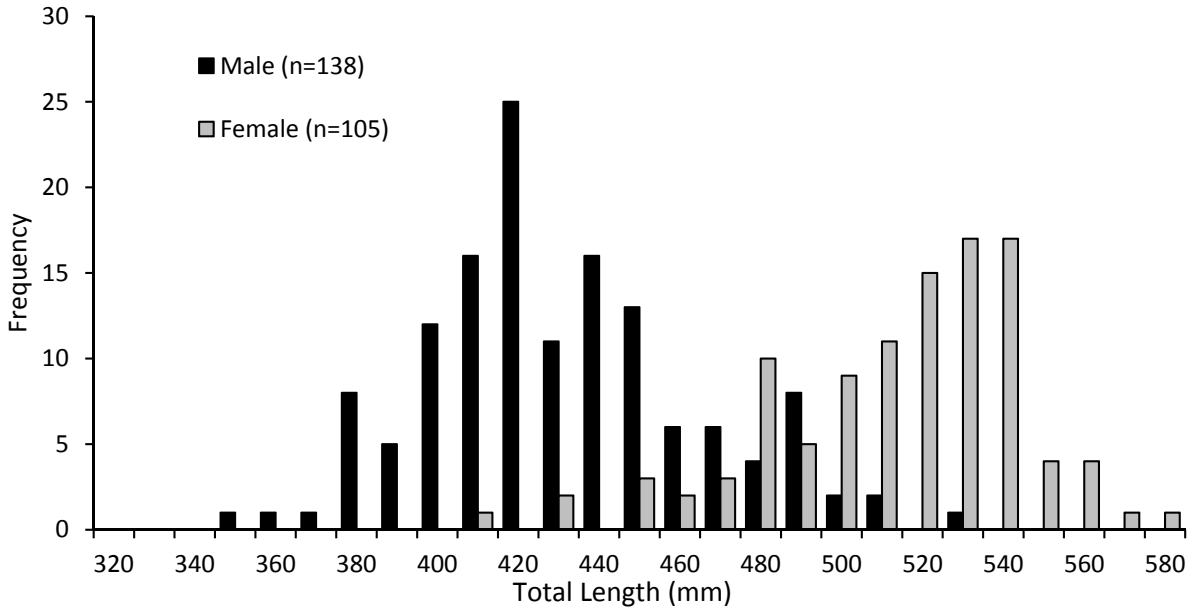

FIGURE 3.—Length Frequency histogram for American Shad collected from the Roanoke River, spring 2015.

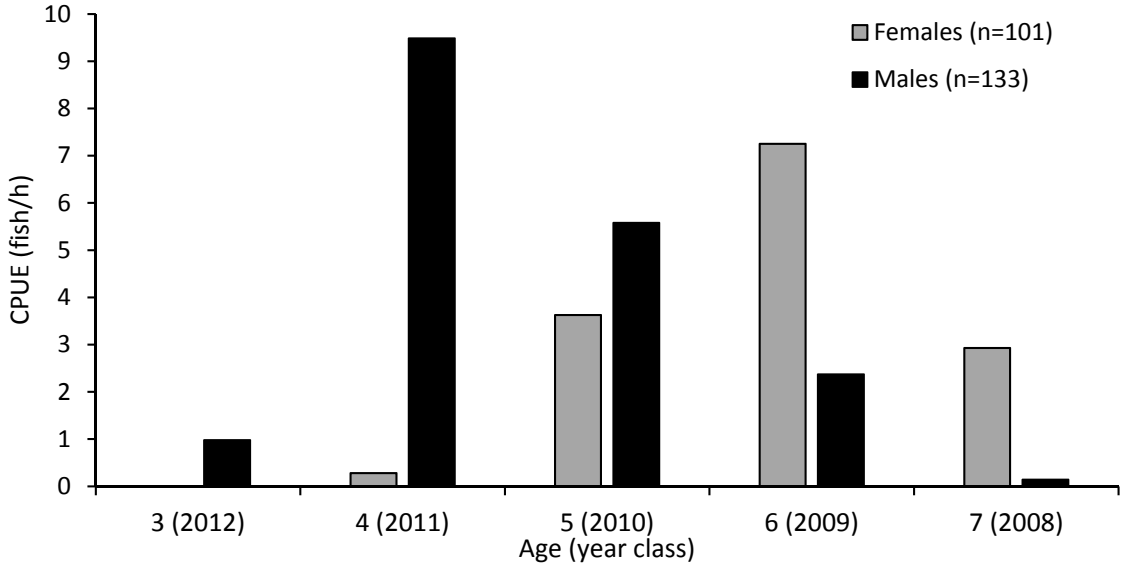

FIGURE 4.—Relative abundance (electrofishing CPUE) of American Shad collected from the Roanoke River, spring 2015.

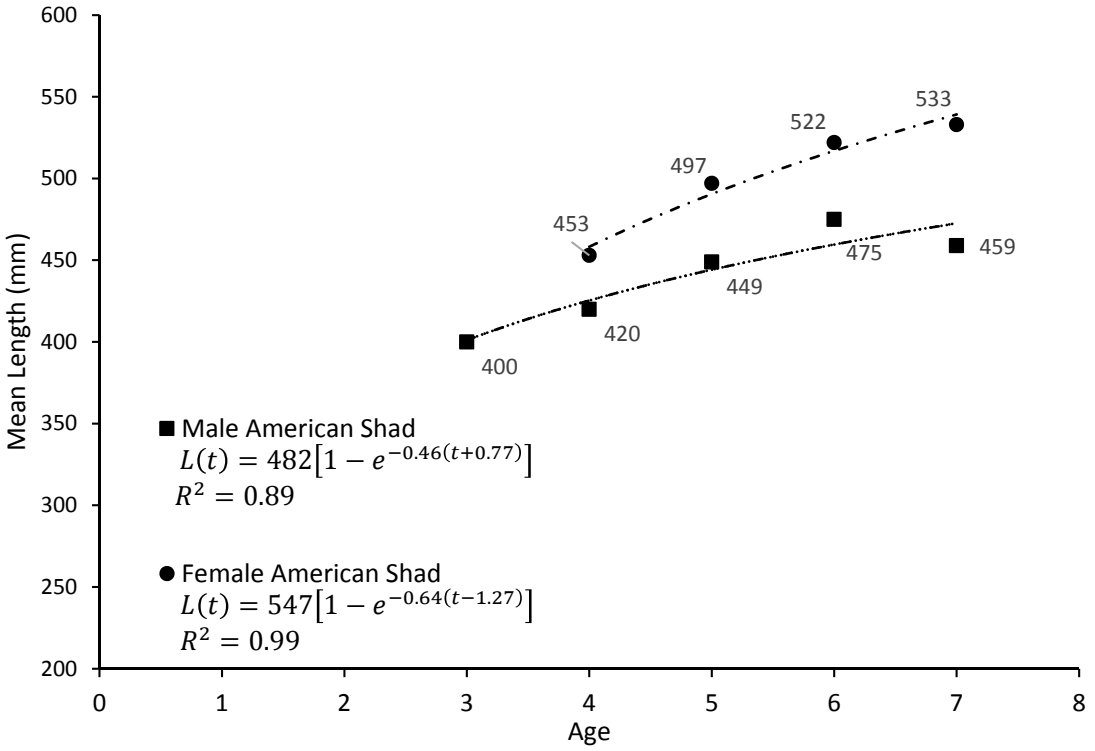

FIGURE 5.—Mean total length at age of American Shad broodfish and individuals from weekly electrofishing surveys, spring 2015. Dashed lines represent von Bertalanffy growth models.

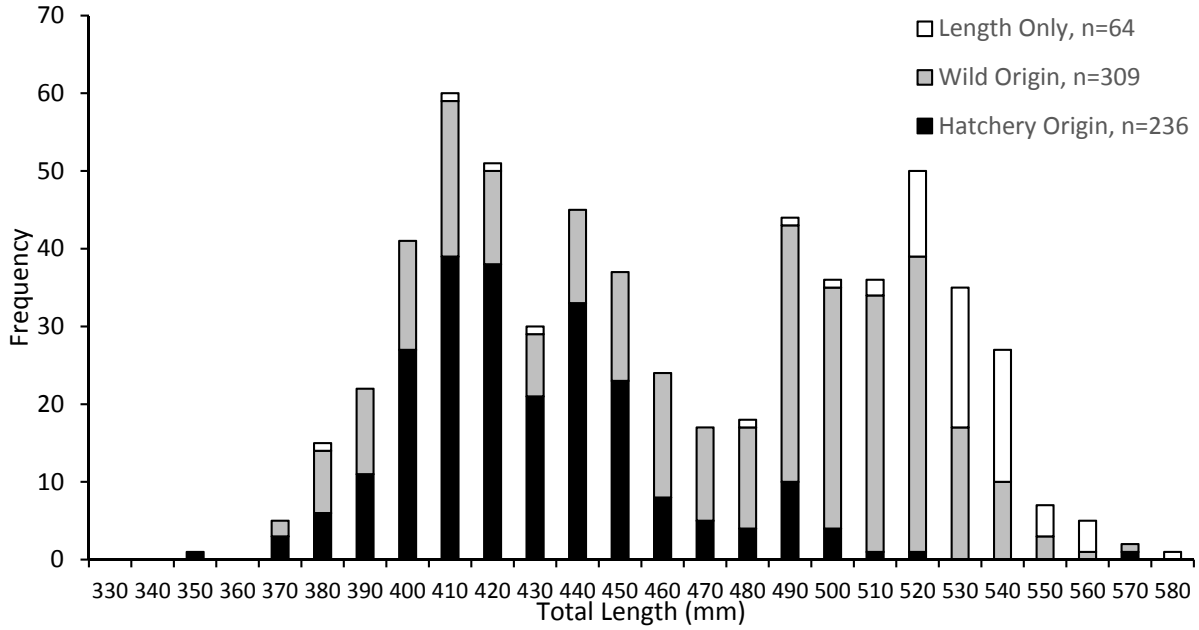

FIGURE 6.—Length Frequency histogram for American Shad of hatchery origin, wild origin, and those with only length data collected from the Roanoke River, spring 2015.

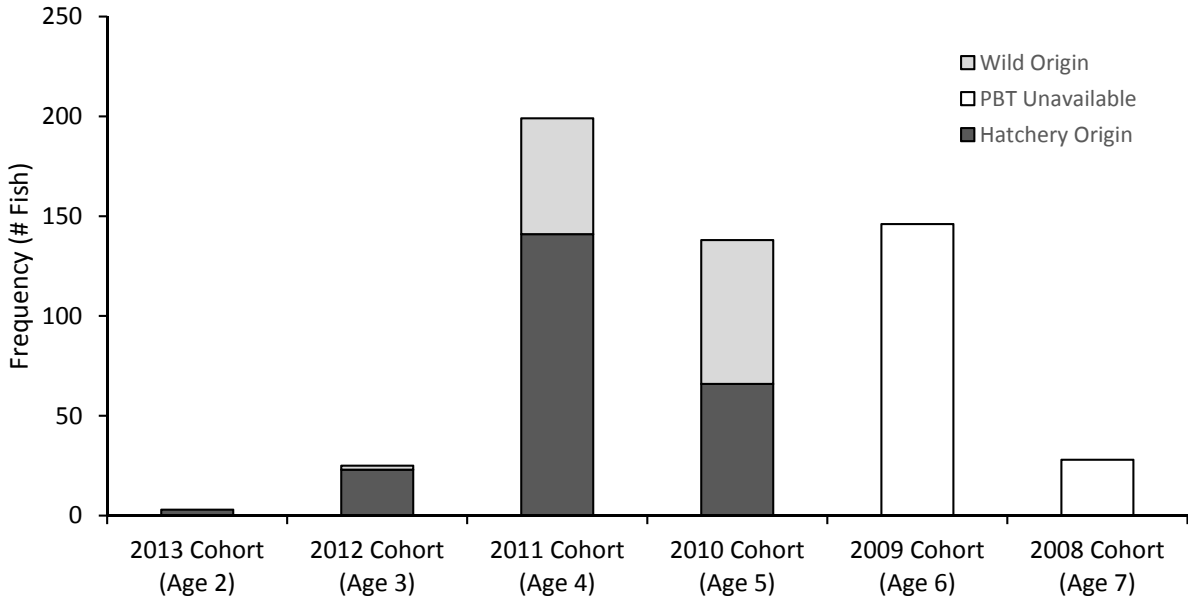

FIGURE 7.—Contribution of hatchery- and wild-origin at-large American Shad for each cohort represented in the 2015 spawning ground survey from the Roanoke River, spring 2015. Parentage-based tagging (PBT) data are only available for 2010–2013 year classes.