The Dynamic Lake James Walleye Fishery

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Abstract.—Lake James, located in Burke and McDowell counties, NC, is the uppermost reservoir in the Catawba River chain of Duke Energy-owned lakes. The North Carolina Wildlife Resources Commission (NCWRC) began stocking Walleye *Sander vitreus* into Lake James in 1949 and established one of the most popular sport fisheries in Western North Carolina. Historical survey results characterized the Lake James Walleye population as having robust natural recruitment, high catch rates of stocked-sized fish, poor to moderate condition, and slow growth. The introduction of White Perch *Morone americana* was verified in Lake James in 2008, and the introductions of Alewife *Alosa pseudoharengus* and Blueback Herring *Alosa aestivalis* were verified in 2010. All three of these invasive species are known threats to Walleye populations. In 2012, the NCWRC initiated a 5-year study to evaluate the impacts of invasive introductions and the potential of stocking Walleye fingerlings (25–75 mm TL) and fry (3–5 mm TL) at three different locations in Lake James to offset a declining population. Parentage Based Tagging (PBT) demonstrated nearly 100% hatchery contribution for Walleyes from the 2012–2015 year classes, suggesting natural recruitment failure, presumably due to ovivory, fry predation, thiamine inhibition, and/or interspecific competition with Alewife, Blueback Herring, and White Perch. Walleyes marked with oxytetracycline hydrochloride (OTC) demonstrated slightly less hatchery contribution for Walleyes from the 2012–2015 year classes at 92%. Furthermore, evidence of spatial differential recruitment was demonstrated by tracking genetically unique cohorts during 2014–2015. Almost 100% of collected Walleyes originated from 2 of the 3 stocking locations as determined by PBT analysis. Walleyes stocked as fingerlings were more successful than fry, as zero stocked fry recruited to gill nets during the single year (2015) fry were evaluated. Survey results suggest the self-sustaining Lake James Walleye population has collapsed; however, stocking appears to be successful and promising. Collectively, these results will help

determine more precise stocking numbers, stocking size, and stocking locations needed to sustain a quality Walleye fishery in Lake James that meets angler expectations.

Background

Walleye *Sander vitreus* is one of the most important sport fishes in North America due to its role in lentic and lotic ecosystems and its socioeconomic value from recreational and commercial fisheries. Walleyes are valued by anglers throughout their native and introduced range for their large size and excellent food quality. In certain parts of the United States and Canada they are the most popular sport fish, and a tremendous amount of management effort by State and Federal agencies is expended on this important fish. Walleyes are believed to be native throughout the Great lakes, Hudson Bay drainages, and the McKenzie River of the Artic drainage. Their native range also includes the Mississippi and Missouri drainages, along with a few unique Gulf Coast populations. Walleyes may also be native to areas on the Atlantic slope from Pennsylvania to North Carolina (NC), but populations further south on the Atlantic slope, and all Pacific drainage populations have been introduced through intensive stocking efforts (Etnier and Starnes 1993; Jenkins and Burkehead 1993; Rider 2006).

The expansive construction of reservoirs throughout the United States beginning in the early 1900s allowed for largescale introductions outside of Walleye's native range. Successful and popular Walleye fisheries have been established in the Midwest and Southeast (Paragamian and Kingery 1992; Vandergoot and Bettoli 2003). In the Mississippi and Gulf Coast drainages of the Southeast where Walleye populations are native to riverine systems, construction of reservoirs slowly eradicated most native populations as Walleye recruitment declined. This caused the extensive stockings of Great-Lakes origin Walleyes in many southeastern reservoirs, both within and outside Walleyes native range (Hackney and Holbrook 1978; Vandergoot and Bettoli 2003). Most native populations in the Southeast have slowly been replaced or mixed with progeny from the Great Lakes (Vandergoot and Bettoli 2003). Self-sustaining populations were established in many waterbodies; however, many resources capable of supporting Walleye populations continue to require stockings to maintain viable fisheries.

Walleyes have been managed in NC since the 1940s. One of the primary targets of these early management efforts was Lake James located in Burke and McDowell counties. Lake James is the uppermost reservoir on the Catawba River chain of Duke Energy-owned lakes. It was created by impounding Catawba River, Paddy Creek, and Linville River by three separate dams in 1923 and covers 2,634 ha at full pool, has 242 km of shoreline, and a watershed area of 984 km^2. The first recorded Walleye stocking in Lake James was in 1949 by the North Carolina Wildlife Resources Commission (NCWRC) consisting of 10,000 fry from New York State (Table 1). By the mid-1950s, over one million fry had been stocked. These early stockings resulted in a robust self-sustaining population, and in 1954 the NCWRC halted Walleye stockings in Lake James. The creation of the Lake James Walleye population was followed by the development of a very popular and important sport fishery.

From the 1950s until the late-1970s, the Lake James Walleye population was sustained by natural recruitment; however, public pressure resulted in sporadic fry stockings in 1977 and 1978, and then a more consistent pattern began in 1981. Approximately 1.5 million fry were stocked annually from 1981–1985. North Carolina Wildlife Resources Commission biologists often questioned the validity and efficacy of these stocking efforts. Beginning in 1986, hatchery production shifted from fry to fingerling Walleyes, and the NCWRC stocked between 30,000–313,659 fingerlings per year until 2004 (Besler 2004; Table 1). Public awareness and emphasis on stocking during this period influenced NCWRC biologists to regularly assess the Walleye population using a variety of field methods.

Baseline data on the Lake James Walleye population was gathered during cove rotenone, gill net, and electrofishing surveys in the early-to mid-1980s. No population data were collected between 1990–1998. In 1999, standardized sampling locations and methods, concurrent with more accurate ageing techniques, were implemented. Early surveys in the 1980s suggested that recruitment was variable, and that anglers realized this by low catch rates during certain years. However, subsequent surveys during 1999–2009 demonstrated constant recruitment (Taylor 2005; NCWRC unpublished data). Biologists were skeptical this pattern of consistent recruitment was due to stocking efforts. Research from various reservoirs suggested stocking was usually unsuccessful in populations with high levels of natural recruitment (Li et al. 1996a, 1996b). In 1999, a research study was initiated evaluating the proportional contribution of stocked Walleyes to the overall Lake James Walleye population (Besler 2004).

Besler (2004) successfully demonstrated that stocking fingerling Walleyes at a rate of 11 fish/ha was unsuccessful in Lake James, and natural reproduction was substantial enough to drive the fishery. During that study, hatchery Walleyes contributed 2.1–3.7% annually to the age-1 Walleye population, which is far below the arbitrary 25% success criterion used to gauge NCWRC stocking success. Based on annual Walleye production costs, combined with the aforementioned rates of hatchery contribution, the estimated cost of an angler-harvested Walleye in Lake James during that period was $16.13 to $28.41 (Yow 2005). This low return per unit cost, in conjunction with high levels of natural reproduction, suggested that stocking was not an efficient way to utilize hatchery resources. Stocking Walleyes halted upon completion of the 2004 study.

Historically, the Lake James Walleye population was described as having high numbers of stock-sized, slow-growing fish in poor to moderate condition, which appeared to be exploited at low levels (Taylor 2005; NCWRC unpublished data). Spawning occurs in the two major tributaries of Lake James, the Catawba and Linville rivers, and possibly in the main reservoir (Brown and Kearson 1986). A short portion of the Linville River is closed to angling from 15 February to 15 April to protect important spawning grounds. Walleyes in Lake James are currently managed under a 381-mm minimum size limit and an 8-fish daily creel limit. Both the length limit and moratoria on the Linville River are unique to Lake James and represent a more conservative management approach when compared to other NC Walleye fisheries. Although the historical population dynamics from 1999–2009 do not give the impression of a destination-type fishery, Lake James Walleye remained a popular target by anglers. Creel surveys conducted in 1987–1988 and 1997–1998 demonstrated that Walleye was second only to black bass as the most sought-after game species in Lake James (Borawa 1989; Yow 2005). Lake James is the most eastern of the mountain reservoirs managed for Walleyes. Its location is convenient to large metropolitan areas in the Piedmont physiographic region of NC making it a very important and popular fishery to local and traveling anglers (Yow 2005). Walleye management efforts in Lake James during this time period remained focused on promoting natural reproduction through length limits and localized angling moratoria and regulations meant to help restrict the introductions of unwanted species.

Introductions of invasive species are a major threat to freshwater ecosystems and can have significant negative impacts on fisheries via habitat alteration, competitive interactions, hybridization, and predation (Vander Zanden 2005; Jelks et al. 2008). Pimentel et al. (2000, 2001) reported that exotic fishes alone cause over one billion dollars annually of economic losses in the United States. Identifying potential threats and solutions is a major focus of invasive research (Vander Zanden et al. 2004). Negative impacts from invasive species are sometimes easy to observe and assess; however, many times the impacts are difficult to determine because the ecological processes affected have high levels of natural variation, like recruitment (Mercado-Silva et al. 2007). Successful invasive species are often trophic generalist, or they are filling an empty niche (Guzzo et al. 2013). Trophic generalists are characterized by their wide ecological tolerances and diets, allowing them to be successful in new environments (Marvier et al. 2004). Once established, invasive generalist can displace wanted species, leading to biotic homogenization and trophic cascades (Bruno and Cardinale 2008). Reservoirs are especially prone to impacts by invasive species. In reservoirs, fish communities are often an assemblage strategically manipulated by resource managers to provide recreational opportunities. These fisheries are often composed of non-native species that do not co-occur in natural settings and are less resilient to invasive impacts. Several species have been heavily studied and determined to have direct negative impacts on Walleye populations. Introductions of Alewives *Alosa pseudoharengus*, Blueback Herring *Alosa aestivalis*, and White Perch *Morone americana* have all been associated with declines in Walleye populations in natural lakes and reservoirs across the country.

Alewives, a planktivorous anadromous clupeid native to the Atlantic Ocean, have been shown to change fisheries by altering plankton communities, impacting lower trophic levels, consuming early life stages of native fish, and by competing with pelagic species during early life stages (Rudstam et al. 2011; Dettmers et al. 2012). Alewives also can cause a condition termed “thiamine deficiency complex” in some predator species. Thiamine is an essential compound during early fish development. Too little thiamine has the potential to cause death or impair function of early life stages. Alewives have high levels of thiaminase, an enzyme that denatures thiamine. It has been postulated that Walleyes with diets heavy in Alewives will experience recruitment issues due to thiamine deficiency (Rinchard et al. 2011). In the Great Lakes, landlocked Alewife populations were established in the late-1800s and early-1900s (Ihssen et al. 1992). These introductions caused ecosystem-level impacts and disrupted trophic dynamics (Dettmers et al. 2012). Walleyes are one of the many species negatively impacted by Alewife introductions in the Great lakes, and a large body of research exists documenting the history and management efforts to ameliorate the invasive impacts. In reservoirs, Alewives have been stocked as additional forage for managed species and have been inadvertently stocked by anglers over time (Vandergoot and Bettoli 2003). Fisheries managers in Tennessee (TN) noticed a decline in Walleye natural recruitment in many reservoirs in the 1980s which coincided with the introductions of Alewives. In the case of Dale Hollow and Watauga reservoirs, TN, Alewives were purposely stocked as forage for Lake Trout *Salvelinus namaycush*. The mechanisms of decline were never identified, and stocking Walleye fingerlings and fry was needed to sustain these populations (Vandergoot and Bettoli 2003).

Blueback Herring is a sympatric species to Alewife and are believed to function similarly upon introduction to natural lakes and reservoirs (Wheeler et al. 2004). Less research has been conducted on Blueback Herring introductions and impacts; however, as they are becoming more common in reservoirs due to intentional and inadvertent introductions, the impacts are becoming clear. Blueback Herring have been shown to have negative impacts on White Bass and Walleye populations in Hiwassee Reservoir, NC. Natural Walleye recruitment declined when Blueback Herring were introduced in 1999. Subsequent studies demonstrated that stocking fingerling Walleyes in Lake Hiwassee was the only way to sustain a viable fishery (Wheeler et al. 2004; Bushon et al. 2009; Wheeler and Bushon 2018).

White Perch is a semi-anadromous estuarine species native to the Atlantic coast (Etnier and Starnes 1993; Jenkins and Burkhead 1993) and are highly successful invaders. They have been shown to expand rapidly after introductions and can have negative impacts on many species, including White Bass *Morone chrysops* (Madenjian et al. 2000) and Walleye (Hurley and Christie 1977). In NC, White Perch have been associated with dramatic declines in White Bass in Lakes Norman and Hickory (Feiner et al. 2013) and have slowly been introduced in many piedmont and mountain reservoirs. Feiner et al. (2013) demonstrated that White Perch occupy a wide trophic niche and use resources shared by Walleyes and White Bass. Feiner et al. (2012) described the ability of White Perch to be phenotypically plastic through its ontogeny and stages of invasion, making it especially adept at invading waterbodies. White Perch may also consume larval and fingerling-sized fish to compound the negative impact on managed fisheries (Schaeffer and Margraf 1987).

In 2008, 35 White Perch were discovered in Lake James during a NCWRC annual Walleye gill-net sample (NCWRC unpublished data). These fish were aged and determined to be introduced as early as 2003. In 2012, NCWRC biologists collected Alewife and Blueback Herring during routine shoreline electrofishing for Largemouth Bass (Wood 2014). By the following year all three invasive species were found in high numbers and observed in Linville and Catawba rivers during the Walleye and White Bass spawning runs (Wood and Goodfred, personal observations). During this same time period, anglers were complaining of low catch rates of Walleyes and White Bass. The NCWRC began stocking 11 fingerling Walleyes/ha (30,000 total) in 2012 as a preemptive attempt to offset any potential recruitment issues. Beginning in Fall 2012, NCWRC began a 5-year gill-net survey to determine invasive impacts and the contribution of hatchery raised Walleyes to the Lake James Walleye fishery. In conjunction with the historical approach of using oxytetracycline hydrochloride (OTC) to batch mark stocked fish (Besler 2004), parentage based tagging (PBT) was used to assign parentage of stocked Walleyes. This approach allows an offspring of hatchery origin to be uniquely assigned to its correct parents. A fish that does not assign to a hatchery parental pair would be considered of wild origin (i.e., the result of natural reproduction in Lake James). Since exact parental origin can be identified using PBT, it allowed researchers to elucidate the differences in recruitment potential among three historical stocking locations [Black Bear Boating Access Area (BAA), Canal Bridge BAA, and Linville Boating Access Area BAA; Figure 1].

This report summarizes a Lake James Walleye gill-net survey conducted from 2012–2016 with comparisons to historical survey results. This report also describes efforts to measure the contribution of stocked fingerling Walleyes to the Lake James Walleye population using OTC and PBT from 2012–2015. Contribution of a single Walleye fry stocking was also evaluated using PBT in 2015. The goal of this study was to determine the impact of Alewife, Blueback Herring, and White Perch on the Lake James Walleye fishery and to evaluate the potential of stocking Walleyes to circumvent any observed recruitment failures.

Specific objectives include:

1- Describe the population structure of the Lake James Walleye fishery since the introductions of Alewives, Blueback Herring, and White Perch;
2- Determine if stocking fingerling and fry Walleyes will contribute to the fishery;
3- Determine if PBT is a suitable methodology for determining proportional contribution of stocked Walleyes to the overall population; and
4- Determine if stocking location influences the ability for stocked Walleyes to recruit.

Methods

Brood stock collections.—Walleye brood stock were collected from known spawning locations in Catawba and Linville rivers directly upstream of Lake James and from Catawba River directly upstream of Lake Rhodhiss during February and March 2012–2016 (Figure 1; Table 2). Fish were sampled via boat-mounted, pulsed direct current electrofishing equipment (4–6 A). Sex was determined in the field, and males and gravid females were collected at a ratio of 3 males to 1 female when possible. All collected Walleyes were transported to Table Rock State Fish Hatchery (TRSFH), Morganton, NC, for strip-spawning.

Tagging and stocking.—Two types of "tagging" methods were employed to test the efficacy of PBT compared to OTC. For PBT, a small anal fin clip was taken from each brood fish and stored in vials containing 95% EtOH until delivered to the North Carolina Museum of Natural Science (NCMNS) Molecular Genetics Lab for genotyping. Female-male combinations were recorded (e.g., Female 1, Male 1,2, and 3; Female 2, Male 4,5,6, etc.; Table 3) each year of the study, and 5–10 fry from each mating pair were collected once hatched and then stored in vials containing 95% EtOH. All fin clips and fry samples were transferred to NCMNS Molecular Genetics Lab for creating a database of all possible parental genotypes from 2012–2016. When all parental broodstock are genotyped as such, then every offspring is genetically "tagged". Although broodstock were genotyped through 2016, the contribution of their offspring to the Lake James Walleye fishery was only determined from 2012–2015 due to a delay in processing samples at the NCMNS Molecular Genetics Lab.

The remaining fry were then transferred to outdoor ponds and reared to approximately 25–75 mm total length (TL; i.e., fingerlings). Each pond was assigned fry from known parents (i.e., each pond had a genetically unique lot of fish). In May 2012–2016, 30,000 Walleye fingerlings were collected from the ponds and transferred to 1.8-m diameter round fiberglass tanks to be marked with OTC. Walleye fingerlings were immersed in a solution of 500 mg/L OTC and 1,000 mg/L sodium chloride, buffered with tris to a pH of 6.5–6.9, for six hours. Although fingerlings were marked through 2016, this report will only describe results from 2012–2015 to coincide and compare with PBT results.

Thirty thousand fingerlings were stocked each year; 10,000 in each of three locations: Black Bear Boating Access Area (BAA), Canal Bridge BAA, and Linville BAA (Figure 1). Beginning in 2014, each location received a genetically unique lot of Walleye fingerlings; thus, stocking location could be determined when subsequently collected and evaluated during fall gill-net surveys. Additionally, during 2015 and 2016 TRSFH produced excess Walleye fry 3–5 mm TL and these were stocked at the same three locations to determine if fry would contribute along with Walleye fingerlings. Each location received a genetically unique lot of Walleye fry; thus, life stage (i.e., fry or fingerling) could be determined from gill-net collected Walleyes. Since Walleyes stocked as fry would be identified using PBT, the contribution of stocked Walleye fry was only determined for the 2015 gill-net survey.

Field sampling.—Twelve historical gill-net locations established during the 1999 survey were sampled in October 2012–2016 on lake points with a moderate slope of 25-45^{o} using a stratified non-random design to represent all areas of the lake (Figure 1). Experimental gill net dimensions were 2.4 x 76.3 m and consisted of five 2.4 x 15.3-m panels with 25-, 32-, 38-, 44-, and 51-mm bar mesh. Gill nets were bottom-set perpendicular to shore in water >3 m depth. The direction of mesh to shore, 25- or 51-mm bar mesh, was randomly chosen annually for the first net set of each day and alternated for each additional set. Nets were checked after 24 h, and water temperatures were recorded at each site.

All fish collected were separated by species. Non-target species were enumerated, then released or discarded. Walleyes were placed in a plastic bag labeled by site, placed on ice, and returned to the Marion State Fish Hatchery. All Walleyes were weighed (g) and measured (TL, mm). Sagittal otoliths were removed from all Walleyes for age determination and OTC mark verification.

Catch-per-unit-effort.—Abundance was indexed as catch-per-unit-effort and expressed as the number of fish collected per net night (24h). Catch-per-unit-effort was determined for all Walleye age classes combined, age-1 Walleyes, and White Perch.

Age and growth.—Sagittal otoliths were mounted on fully-frosted, cytological microscope slides using cyanoacrylate glue and sectioned transversely through the dorsoventral plane into two, 0.5-mm sections using a Buehler Isomet low-speed diamond wheel saw (Allen et al. 2003). Sections then were mounted onto glass microscope slides using Thermo Shandon synthetic mountant, and annuli were counted using a compound microscope (Hoyer et. al. 1985; Heidinger and Clodfelter 1987). Otoliths were read independently by two readers, and any ageing discrepancies between the readers were rectified by jointly reading the otolith section. If the age could not be rectified, the age data were not used in further analyses. Mean TL-at-age values were determined to describe growth patterns.

Size structure.—Length-frequency histograms were developed for each survey year to describe patterns in size distribution. Proportional size distributions (PSDs) were calculated following Anderson and Neumann (1996) and Guy et al. (2007). Length classes were defined as stock (≥ 250 mm TL), quality (PSD; ≥ 380 mm TL), preferred (PSD-P; ≥ 510 mm TL), memorable (PSD-M; ≥ 630 mm TL), and trophy (PSD-T; ≥ 760 mm TL).

Condition.—Relative weight (W_r) values were calculated for Walleyes greater than 250 mm TL via the following equation:

$$W_r = W / W_s \times 100,$$

where W_r is the relative weight, W is the wet weight, and W_s is the length-specific standard weight of an individual. The standard weight equation for Walleye is (Anderson and Neumann 1996):

$$\log_{10} W_s = -5.453 + 3.18 \log_{10} TL.$$

Mortality.—Ages for each survey year were pooled to estimate the annual mortality rate (A) using the Chapman-Robson method. Age classes that contained fewer than five individuals were not used to estimate annual mortality (Robson and Chapman 1961; Ricker 1975; Wheeler et al. 2004).

OTC tagging evaluation.—Walleyes collected during the 2012–2015 gill-net surveys were evaluated to determine origin. If a fish's age was determined to be from the 2012–2015 year classes, the otolith sections were viewed under an epiflourescent microscope to look for an OTC mark. If a mark was present, that fish was considered of hatchery origin.

PBT tagging evaluation.—Anal fin clips were taken from each gill-net collected fish from 2012–2015, placed in a vial with 95% EtOH labeled with a unique ID number and stored until transported to the NCMNS Molecular Genetics Lab to determine origin (i.e., hatchery or wild, and specific female-male combination if hatchery reared). The NCMNS Molecular Genetics Lab used a standardized suite of 13 markers to evaluate contribution of stocked Walleyes as described in Evans and Finan (2015) and Evans and Carlson (2016). Quality control protocols included (1) two independent readers on all chromatograms and (2) 10% of brood stock samples for each tank were genotyped twice for quality control. Known hatchery fry and gill-net collected fish were compared to the brood stock parentage data generated, as well as an "at large" sample of Lake James Walleye not resulting from hatchery stockings. Chromatograms were generated on an ABI 3130XL Genetic Analyzer operated at the NCMNS Molecular Genetics Lab. All parentage analyses were conducted using the likelihood-based parentage analysis program CERVUS. Annual summary reports were completed by the NCMNS Molecular Genetics Lab and included the following components: 1) genetic marker performance and conformance to Hardy-Weinberg equilibrium, 2) indices of genetic diversity between available brood stock batches, 3) feasibility to distinguish juveniles of hatchery origin from wild juveniles, and 4) identify any processing errors related to fin clip collections. Error rates of genotyping scores attributable to strutter-products, large allele drop-out, or null alleles should not exceed 3%.

Hatchery contribution.—Contribution was determined during the 2012–2015 gill-net surveys. The proportion of stocked Walleyes was expressed as the percentage of the total number of Walleyes captured. It was estimated by dividing the number of hatchery origin Walleyes by the total number of Walleyes captured. This analysis was generated using both

OTC and PBT data to compare the two methods. Walleye fingerling stockings were considered successful if the percent contribution for year classes with possible stocked fish (2012–2015) was 25% or greater. This success criterion was selected to be consistent with previous Walleye stocking evaluations in NC (Besler 2004; Bushon et al. 2009).

Results

Brood stock collections.—A total of 899 Walleyes (563 males and 336 females) were captured during the 2012–2016 study while electrofishing for brood stock (Table 2). Walleyes occupied the rivers as early as late February; however, most fish were captured in the first and second week of March each year. A subset of captured fish was collected and transported to TRSFH to be used for hatchery production. A total of 41 females and 125 males were ultimately utilized as brood stock during 2012–2016. Each fish utilized in production was given a unique ID number and female/male pairings were recorded for subsequent parentage determination (Table 3).

Tagging and stocking.—Thirty thousand Walleyes were marked with OTC and stocked in three locations in May 2012–2016 as previously described. Genotypes of all brood stock from 2012–2016 were databased by NCMNS to later establish origin of gill-net collected fish. Additionally, 394,695 and 156,681 Walleye fry were stocked in 2015 and 2016, respectively. Stocking location was also recorded for all fingerling and fry stockings since 2014 (Table 3). Unique genetic lots were stocked at each location since 2014.

Catch-per-unit-effort.—A total of 754 Walleyes were collected in the 2012–2016 gill-net survey. The highest catch rate was recorded during the 2012 survey at 24.0 fish/net night (SE = 4.5), with a steady decrease until 2014 with 10.9 fish/net night (SE = 2.3), representing the lowest catch rate recorded since establishing standardized surveys in 1999. There was a slight increase in 2015 to 14.0 fish/net night (SE = 2.5); however, in 2016 catch rates once again decreased to 12.1 fish/net night (SE = 1.5; Figure 2).

Age-1 Walleyes displayed a similar pattern of low abundance during this study; however, catch rates increased slightly since stocking began in 2012. In 2012, age-1 catch rates were 0.6 fish/net night (SE = 0.6; Figure 3). These fish represent the last year-class (2011 cohort) naturally produced in Lake James prior to initiating stocking in 2012. This low catch rate corresponds with field observations of a rapidly increasing population of Alewives and Blueback Herring in Lake James. This was the lowest recorded age-1 catch rate since establishing standardized surveys in 1999 (Figure 3). The next four lowest catch rates recorded were in 2013–2016. Age-1 Walleyes steadily increased from 2012 until 2015, and then decreased slightly in 2016 (Figure 3). The increase between 2012–2015 coincided with a decrease in White Perch catch rates during the same time period (Figure 4). The subsequent decrease in 2016 may be the result of a substantial fish kill discussed in a later section.

White Perch catch rates increased from 2.5 fish/net night (SE = 0.9) in 2009 soon after they were discovered, to a high of 50.6 fish/net night (SE = 10.9) during this study in 2013. White Perch catch rates declined dramatically to 9.3 fish/net night (SE = 2.3) in 2015, the same year age-1 Walleye catch rates reached their maximum catch rate during the study (Figures 3 and 4).

No abundance data exist for Alewife and Blueback Herring as they do not recruit to the mesh sizes used during this study.

Age and growth.—Walleyes up to age 13 were collected during the gill-net survey. All age classes were collected during most years; however, the distribution of age frequencies shifted towards older fish as the study progressed, indicating few young fish were recruiting to the population. The strongest year class in all but one year of the survey was from 2010 (Figure 5), which corresponds to the first observation of Alewife and Blueback Herring in Lake James. Conversely, the very next year class from 2011 was the weakest during the study. This is one year after biologists first observed Alewife and Blueback herring, and one year before NCWRC initiated stocking efforts (Figure 5).

Mean TL-at-age calculations suggest Walleyes are reaching harvestable size by age 1. Growth is fast until age 3, then slows (Figure 6). The large variation in mean TL-at-age is due to sexual dimorphism as noted by Taylor (2005). Females tend to grow faster and larger than males. Sex was not determined during the 2012–2016 gill-net survey to differentiate growth rates.

Size structure.—Walleyes captured during this study ranged from 236.0 mm TL to 617.0 mm TL. Mean TL ranged from 419.1 mm TL (SE = 6.6) in 2015 to 468.9 mm TL (SE = 4.9) in 2016, with a mean of 439.0 mm TL (SE = 2.1) for the entire survey period. PSD values ranged from 53 in 2015 to 93 in 2012 and 2013. PSD-P values ranged from 6 in 2013 to 16 in 2016. No memorable- or trophy-sized Walleyes were captured during this study (Figure 7; Table 4).

Condition.—Mean W_r values ranged from 88.6 (SE = 0.6) in 2016 to 96.0 (SE = 0.7) in 2015. During previous surveys from 1999–2009 the highest recorded mean W_r was 88.6 in 1999. During this survey W_r values were consistently in the low- to mid-90s, except for the aforementioned value in 2016 (Figures 8 and 9).

Mortality.—Catch-at-age data were combined from 2012–2016 when at least 5 individuals were represented in an age class. Thirteen age classes were represented in the analysis. Estimated annual mortality (*A*) using the Chapman Robson method was 0.22.

OTC tagging evaluation.—A total of 152 gill-net collected Walleyes were determined to be from the 2012–2015 year classes and evaluated for OTC marks. One hundred and thirty seven of the 152 (92%) contained OTC marks. Percentages of individual age classes with OTC marks ranged from 73% in age-2 Walleyes from 2015, to 100% in age-0, -1, -2, and -3 Walleyes from 2013, 2014, and 2015, respectively (Table 5).

PBT tagging evaluation.—All brood stock from 2012–2016 were combined into one dataset and evaluated for Hardy Weinberg equilibrium (HWE), number of alleles, allelic diversity, and the presence of null alleles as implemented in CERVUS 3.0. All 13 markers conformed to HWE and no evidence of null alleles was identified. The combined parent pair non-exclusion probability indicated sufficient power to detect parental matches (Evans and Carlson 2016). Gill-net collected Walleyes from the 2012–2015 year classes were almost 100% derived from hatchery brood stock. A total of 152 gill-net collected Walleyes were determined to be from the 2012–2015 year classes and evaluated for parentage. One hundred and fifty one of the 152 (99%) were matched to hatchery brood stock. The singular non-match was a 1-yr old Walleye collected in 2015. Additionally, in 2014 and 2015 genetically unique lots were stocked at each location. Results demonstrate that almost every age-0 and-1 Walleyes collected during the 2014–2015 gill-net surveys were originally stocked at either Canal Bridge BAA or Linville BAA. Only 2.7% of hatchery-reared fish collected originated from the Black Bear BAA stocking location. The remainder originated in an almost equal proportion from Canal Bridge BAA and Linville BAA stocking locations (Figure 1; Table 6). No fry-stocked Walleyes were collected during the 2015 survey.

Genetic identity analyses demonstrated a loss in genetic variability in the stocked Lake James Walleye population when compared to the "at large" population (i.e., fish that existed prior to stocking). CERVUS revealed six instances of identical microsatellite marker combinations (diplotypes) in 2016. These fish were male brood stock. This suggests decreasing genetic variability and possible allele fixation, which is theoretically the result of a founder effect (i.e., too few fish contributing to the population). Additionally, CERVUS identified ten brood stock as hatchery fish in 2016. Consequently, 10.9% of all 2016 brood stock were from previous stockings, split evenly between the 2012 and 2014 cohorts. Five of the positively identified fish were male and one was a female. Nevertheless, an examination of allelic trends in brood stock reveals a slight increase in genetic variation from 2012–2016. From 2012–2013, genetic variation seemed to be decreasing as indicated by decreasing allele numbers; however, in 2015 and 2016, those trends reversed with the number of alleles increasing. North Carolina Wildlife Resources Commission biologists began using brood fish from the lower Catawba river above Lake Rhodhiss in 2015, and more brood stock were being utilized towards the end of the study. STRUCTURE analysis (Pritchard et al. 2000) did not reveal any genetic difference between the Lake Rhodhiss and Lake James population; however, the fish from Lake Rhodhiss were often large and older fish pre-dating stocking efforts in Lake James, thus, avoiding the use of fish affected by any founder effect.

Hatchery contribution.—Results based on OTC and PBT suggest almost every Lake James Walleye from the 2012–2015 year classes originated from NCWRC stocking efforts (Table 6). One hundred and fifty-two Walleyes were determined to be of the appropriate year classes to analyze for hatchery contribution. Oxytetracycline hydrochloride results were lower than PBT (92% vs 99%); however, both were sufficient methods to describe contribution as very high.

Discussion

The Lake James Walleye population has been substantially impacted by the introductions of Alewives, Blueback Herring, and White Perch. Although the mechanisms were not evaluated during this study, previous research demonstrates that all three species can have ecosystem-level impacts that affect a variety of species. Alewives and Blueback Herring have been shown across the United States to negatively impact Walleye fisheries in both natural lakes and reservoirs from direct ovivory, piscivory on larval fish, competitive interactions among early life stages in pelagic habitats, or through thiamine inhibition (Hurley and Christie 1977; Schaeffer and Margraf 1987; Vandergoot and Bettoli 2003; Rinchard et al. 2011; Rudstam et al. 2011; Dettmers et al. 2012; Feiner et al. 2013). The overall result is recruitment failure and a population completely dependent on hatchery production.

Besler (2004) demonstrated that previous agency attempts at supplemental stocking Walleye fingerlings did not contribute to the Lake James Walleye fishery. Researchers from various parts of the country have experienced similar results from stocking efforts. In most of these studies, Walleye stockings were in systems with established Walleye populations with robust natural reproduction (Ellison and Franzin 1992; Li et al. 1996a, 1996b; Nate et al. 2000; Besler 2004). However, the current situation in Lake James is much different than historical efforts to bolster the population with supplemental stockings. It appears natural recruitment ceased in Lake James after 2010 (Figure 5), which coincides with introductions of Alewife and Blueback Herring. Hatchery efforts are now driving the fishery. This is very similar to the results of Bushon et al. (2009) in Hiwassee Reservoir, NC. Bushon et al. (2009) documented a dramatic decline in Walleyes upon introduction of Blueback Herring in 1999. Stocked Walleyes contributed significantly to the Hiwassee Reservoir population throughout the study period, and their findings suggest the Hiwassee Reservoir population can only be maintained with continued annual fingerling stockings.

The current Walleye stocking approach in Lake James has many issues. Brood stock used for stocking Lake James and other NC mountain reservoirs are still collected from the Catawba River and Linville River upstream of Lake James and the Catawba River upstream of Lake Rhodhiss. This may be sustainable for the time being, but it is inevitable as older fish vacate the fishery, low numbers of younger, stocked Walleyes will be the bulk of the population. This will make collecting the appropriate numbers and size of brood fish difficult. This approach could also exacerbate the loss of genetic variation.

There is cause for serious concern in the genetic variability of the Lake James Walleye population. The stocked portion of the population was founded by very few females leading to a decrease in genetic variation. As these fish become sexually mature and comprise a greater proportion of the overall fishery, the brood stock collected in future years will have originated from stocked fish. Spawning hatchery fish with hatchery fish that originated from a limited number of brood stock is likely to create genetic bottlenecking and allele fixation. This will not only make it difficult to ascertain parental origin when evaluating microsatellites, but it could potentially put the population at risk of a stochastic event (e.g., disease, physical abnormalities, etc.). The recent use of additional Walleye brood stock from Lake Rhodhiss may have temporarily curbed the issue of genetic diversity in Lake James; however, biologists assume the Lake Rhodhiss fishery is the direct result of Lake James and/or TRSFH. Walleyes from Lake James may be moving through the Bridgewater and/or Catawba dams into the Catawba River which feeds Lake Rhodhiss. The fishery may also be inadvertently supplemented from escaped fingerlings and fry from the outflow of TRSFH into Irish Creek, a tributary of Catawba River just upstream of Lake Rhodhiss. If these assumptions are correct, the Lake Rhodhiss Walleye population could experience the same genetic issues as the Lake James Walleye population. The need to introduce genetic variation to the Lake James Walleye population is of paramount importance. Since all NC reservoirs are stocked with fish originating from Lake James and Lake Rhodhiss, this is an issue for all of NC's stocked Walleye fisheries. Due to the need to identify a source of Walleyes that may be used to increase genetic diversity in Lake James, the NCMNS

Molecular Genetics Lab tested "at large" Walleye from Glenville Reservoir, NC, against "at large" Lake James Walleye. STRUCTURE analysis (Pritchard et al. 2000) demonstrated a clear genetic population structure between the two groups; therefore, one possible source of brood stock is Glenville Reservoir.

Although abundance indices and age data demonstrate a declining Walleye population in Lake James, there are a couple promising results. Walleyes in Lake James appear to be taking advantage of the new forage and growing at an increased rate when compared to historical surveys. Total length-at-age data from Taylor (2005) and NCWRC (unpublished data) in 2006–2009 suggested that it took approximately 2 years on average for Walleyes to reach the current harvestable size of 381 mm TL. The 2012–2016 TL-at-age results suggest Walleyes are reaching the same size by age 1. Additionally, contemporary W_r values are higher, indicating fish are in better condition. Mean W_r values from the 2012–2016 survey were often in the mid-90s, while historical mean values were in the mid-80s. Relative weight values historically decreased linearly with increasing TL. Taylor (2005) suggested that the larger Walleyes were less able to compete for forage than other piscivorous fish in the lake, and that the main forage base (Threadfin Shad *Dorosoma petenense* and Gizzard Shad *Dorosoma cepedianum* at the time) often occupied different habitats. The elevated W_r values recorded during the 2012–2016 survey may suggest that larger Walleyes are capable of exploiting Alewife and Blueback Herring and that the three species occupy similar habitats. An alternative hypothesis is that there is less inter- and intraspecific competition, which may have similar results on W_r values. White Bass populations have also significantly declined in Lake James which may increase the available forage for the remaining Walleyes.

Another potential driver of both year-class strength and W_r values is White Perch. Although there is a paucity of research investigating White Perch-Walleye interactions, one researcher focused on NC reservoirs and included Lake James (Feiner et al. 2013). There is evidence from stable isotope analyses indicating a niche overlap between White Perch and Walleye during certain life stages. This is also the case between White Perch and White Bass. Catch-per-unit-effort data from the 2012–2016 gill-net survey suggest that White Perch and Walleye abundances may be linked. White Perch appeared to increase in numbers until 2014 since their first records in 2008, with a dramatic increase from 2013–2014. Then in 2015, White Perch experienced a large decline. This same year, catch rates of all Walleyes and age-1 Walleyes were highest. This may suggest that the Lake James White Perch population reached carrying capacity in 2014 and then began to stabilize as of 2015. This is promising for Lake James Walleye if White Perch are indeed impacting Walleyes as suggested by previous researchers. Along with the biological impacts on the Lake James Walleye population, there appears to also be abiotic impacts worth considering.

In September 2016, NCWRC biologists observed tremendous amounts of Alewives and Blueback Herring in the tailrace below Lake James. These fish were apparently trapped in the hypolimnion of Lake James near the Paddy Creek and Bridgewater dam forebays and entrained through the Bridgewater Hydro Station penstock. One week after this observation many dead adult Walleyes were discovered around the Paddy Creek and Bridgewater dam forebays. Dissolved oxygen (DO)-water temperature profiles conducted by biologists in September 2016 demonstrated DO depletion on the Linville arm of the reservoir (Figure 10). A small lens of oxygen formed at approximately 25-m in depth at the Paddy Creek and Linville forebays. Large numbers of Alewives and Blueback Herring appeared to be trapped in this narrow lens of oxygen. Walleyes may have followed these fish into this oxygen lens, and remained “squeezed” between anoxic waters. Side-scan sonar imagery showed many fish trapped in the area. As oxygen levels further depleted and the lens dissipated, a fish kill occurred. Walleyes and Alewives were the dominant fish species observed (Wood and Goodfred, personal observations). This same phenomenon has been observed in Lake Norman with Alewives and Striped Bass *Morone saxatilis* (Dorsey 2015).

The observed summer and fall DO depletions, and the extent and duration of the events, are most likely influenced by the physical features of Lake James. During the summer the relatively shallow canal connecting the Catawba and Linville arms (~ 10-m deep) of the reservoir only allows warm epilimnetic waters to flow from the Catawba to the Linville arm as water is discharged from the Bridgewater Hydro Station. As cold oxygenated water is removed through the deep penstock for power generation at the Bridgewater Hydro Station, it is replaced by this warm water traveling through the canal. The combined influences of deep water withdrawal and location of the canal apparently resulted in increased mixing in the forebays that prevented distinct thermal stratification on the Linville arm. Based on historical water chemistry evaluations, this has always occurred at some level (Brown et al. 1989). However, now that Alewives and Blueback Herring are occupying the reservoir and searching for colder water during summer months, they are becoming trapped and possibly causing Walleyes to follow. Additionally, in 2012, Duke Energy began remediation on the Bridgewater Hydro Station to comply with the Federal Energy Regulatory Commission’s (FERC) relicensing agreement (Goodfred 2016; Wood et al. 2017). The new license requires an increase in minimum flows from 0.7 m3/sec to 3.5-6.2 m3/sec. This results in larger amounts of cold water removed from the Linville arm during the summer time period, possibly exacerbating the loss of suitable coldwater habitat on the Linville arm. However, there does seem to be a refugia on the Catawba arm of the reservoir where thermal stratification occurs. A pocket of cold, well-oxygenated water was formed in the hypolimnion near the Catawba Dam (Figure 11). This area may act as important habitat during late summer when little habitat exists for coolwater species elsewhere. Additional studies are needed to determine the impact of these summer and fall DO depletions on the Walleye population. If summer fish kills persist, in conjunction with recruitment issues, alternative management approaches for Lake James should be considered.

The Lake James Walleye fishery was stable from the late-1940s until the mid-2000s. Although stocking took place on and off from the 1970s until 2004, it appeared that natural reproduction sustained the fishery. When Alewives, Blueback Herring, and White Perch were introduced to Lake James, the historical self-sustaining fishery was lost. The 2012–2016 study results describe a population that is collapsing; natural reproduction has ceased, and adult fish are slowly vacating the fishery through exploitation and age. The Lake James Walleye fishery is now driven by a precarious stocking program that requires wild brood stock to fulfill programmatic needs. Parentage based tagging proved to be a valuable tool to elucidate the contribution of stocked fish and to help determine where and what life stage has the potential to work in Lake James. Oxytetracycline hydrochloride was still successful and should be considered a viable option as well, especially when the primary goal is simply to determine proportionate contribution. Although contribution percentages of stocked fish using both tagging methods were high, numbers of fish being recruited to the Lake James fishery (estimated by age-1 CPUE) is approximately 1/6 the historical value. One method of increasing recruitment is to only stock fingerling-sized Walleyes at Canal Bridge BAA and Linville BAA since the Black Bear BAA stocking location and fry-sized Walleyes may not recruit to the fishery; however, even with this change, the additional numbers needed to reach historical levels may not be feasible. Currently, TRSFH produces approximately 160,000 Walleye fingerlings each year to supply the NCWRC Walleye program. Almost 3/4 of this total may need to be stocked in Lake James if historical catch rates are ever to be achieved. The current stocking approach is unsustainable and alternatives need to be considered.

Management Recommendations

1- Focus all future Lake James Walleye stockings at Canal Bridge BAA and Linville BAA with fingerling-sized fish (25–75 mm TL) to maximize stocking success.
2- Continue annual Walleye gill-net surveys in 2018 to monitor population trends.
3- Increase Walleye stocking numbers to reach historical age-1 CPUE levels (i.e., levels prior to invasive introductions).
4- Develop alternative Walleye brood stock sources to maintain a suitable level of genetic diversity.
5- Continue to monitor summer water quality in Lake James to determine potential impacts on the Walleye population.

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TABLE 1.—North Carolina Wildlife Resources Commission Walleye stocking records for Lake James, NC, from 1949–2016.

Year	Numbers Stocked	Life stage	Number/ha
1949	10,000	Fry	3.8
1950	30	Adult	0.1
1952	15,000	Fry	379.6
1954	1,000,000	Fry	5.7
1977	200,000	Fry	75.9
1978	1,000	Fry	0.4
1981	1,082,694	Fry	410.9
1982	1,627,980	Fry	617.8
1983	1,000,311	Fry	379.6
1984	1,411,107	Fry	535.5
1985	1,860	Fry	0.7
1986	31,297	Fry	11.9
1988	16,128	Fingerling	6.1
1989	150,158	Fingerling	56.9
1990	313,857	Fingerling	119.1
1991	162,285	Fingerling	61.9
1992	55,000	Fry	20.9
1992	48,738	Fingerling	18.5
1993	121,659	Fingerling	46.2
1994	183,603	Fingerling	69.7
1995	62,943	Fingerling	23.9
1996	71,529	Fingerling	27.1
1997	359,528	Fry	136.4
1997	70,515	Fingerling	26.8
1998	500,000	Fry	189.8
1998	30,000	Fingerling	11.4
1999	30,000	Fingerling	11.4
2000	30,000	Fingerling	11.4
2001	30,000	Fingerling	11.4
2002	41,400	Fingerling	15.7
2003	30,000	Fingerling	11.4
2004	30,000	Fingerling	11.4
2012	30,000	Fingerling	11.4
2013	30,000	Fingerling	11.4
2014	30,000	Fingerling	11.4
2015	394,695	Fry	149.8
2015	30,000	Fingerling	11.4
2016	156,681	Fry	59.4
2016	30,000	Fingerling	11.4

TABLE 2.—Data from Walleye brood stock collections from 2012–2016. Water temperature (Temp °C) is only shown when collected. Lower Catawba is the river reach directly upstream of Lake Rhodhiss. Upper Catawba and Linville are the river reaches directly above Lake James.

Date	Site	Temp °C	Total	Male	Female	Running Females
3/13/2012	Lower Catawba	6.9	51	35	16	6
3/142012	Upper Catawba	7.6	33	26	7	2
3/15/2012	Upper Catawba	7.7	88	48	40	4
3/15/2012	Linville	7.5	7	5	2	2
3/16/2012	Linville	Unknown	2	0	2	2
3/13/2013	Upper Catawba	Unknown	48	36	12	0
3/14/2013	Upper Catawba	Unknown	20	15	5	5
3/15/2013	Upper Catawba	Unknown	4	3	1	1
3/10/2014	Upper Catawba	9.0	39	29	10	0
3/11/2014	Upper Catawba	9.2	36	24	12	0
3/14/2014	Upper Catawba	6.2	81	48	33	4
3/17/2014	Linville	6.6	1	0	1	0
3/18/2014	Upper Catawba	6.5	63	35	28	1
3/19/2014	Upper Catawba	6.7	66	35	31	3
3/21/2014	Lower Catawba	8.0	15	11	4	2
3/9/2015	Upper Catawba	Unknown	10	8	2	0
3/11/2015	Upper Catawba	10.9	43	20	23	3
3/12/2015	Upper Catawba	11.8	45	21	24	4
3/13/2015	Upper Catawba	11.5	37	21	16	2
3/13/2015	Linville	9.9	9	6	3	0
3/17/2015	Lower Catawba	8.5	16	13	3	2
2/29/2016	Upper Catawba	8.1	16	6	10	0
3/4/2016	Upper Catawba	7.0	66	53	13	2
3/9/2016	Upper Catawba	11.3	61	39	22	2
3/14/2016	Upper Catawba	Unknown	42	26	16	0
2/23/2017	Lower Catawba	10.7	9	0	9	0
2/28/2017	Lower Catawba	Unknown	1	1	0	0
3/2/2017	Upper Catawba	11.6	15	6	9	0
3/3/2017	Upper Catawba	9.1	1	1	0	0
3/6/2017	Lower Catawba	Unknown	24	22	2	0
3/7/2017	Upper Catawba	10.5	25	13	12	1
3/7/2017	Lower Catawba	11.6	8	7	1	0
3/8/2017	Lower Catawba	Unknown	29	23	6	1
3/9/2017	Lower Catawba	Unknown	17	17	0	0
3/9/2017	Upper Catawba	12.6	9	8	1	0
3/10/2017	Lower Catawba	Unknown	16	9	7	0
3/14/2017	Lower Catawba	Unknown	12	7	5	2

TABLE 3.—Walleye stock data indicating the year collected, spawning pairs, the identification number for both females and males, life stage stocked, and the locations stocked [one of three Boating Access Areas (BAA)] on Lake James, NC. Fingerling stocking locations are not available (n/a) for 2012 or 2013.

Year	Female	Males	Life stage	Location stocked
2012	1	1,2,3	Fingerling	n/a
2012	2	4,5,6	Fingerling	n/a
2012	3	7,8,9	Fingerling	n/a
2012	4	10,11	Fingerling	n/a
2012	5	12,13,14	Fingerling	n/a
2012	6	15,16,17	Fingerling	n/a
2012	7	18,19	Fingerling	n/a
2013	1	1,2,3	Fingerling	n/a
2013	2	4,5,6	Fingerling	n/a
2013	3	7,8,9	Fingerling	n/a
2013	4	10,11,12	Fingerling	n/a
2013	5	13,14,15	Fingerling	n/a
2013	6	16,17,18	Fingerling	n/a
2014	2	4,5	Fingerling	Canal Bridge BAA
2014	3	6,7,8	Fingerling	Canal Bridge BAA
2014	4	9,10,11	Fingerling	Canal Bridge BAA
2014	7	18,19,20	Fingerling	Black Bear BAA
2014	8	21,22,23	Fingerling	Linville BAA
2014	10	27,28,29	Fingerling	Black Bear BAA
2014	11	30,31,32	Fingerling	Linville BAA
2015	1	1,2,3	Fingerling	Canal Bridge BAA
2015	2	4,5,6	Fingerling	Black Bear BAA
2015	4	10,11,12	Fingerling	Linville BAA
2015	5	13,14,15	Fry	Black Bear BAA
2015	6	16,17,18	Fingerling	Linville BAA
2015	8	22,23,24	Fry	Black Bear BAA
2015	9	25,26,27	Fry	Black Bear BAA
2015	10	28,29,30	Fry	Linville BAA
2015	11	31,32,33	Fry	Linville BAA
2016	2	4,5,6	Fingerling	Canal Bridge BAA
2016	3	7,8,9	Fingerling	Canal Bridge BAA
2016	4	10,11,12	Fingerling	Black Bear BAA
2016	5	13,14,15	Fingerling	Black Bear BAA
2016	6	16,17,18	Fingerling	Black Bear BAA
2016	7	19,20,21	Fingerling	Linville BAA
2016	9	25,26,27	Fry	Linville BAA
2016	10	28,29,30	Fry	Linville BAA
2016	11	31,32,33	Fry	Linville BAA
2016	12	34,35,36	Fry	Linville BAA
2016	13	37,38,39	Fry	Linville BAA
2016	14	40,41	Fry	Linville BAA

TABLE 4.—Proportional size distributions of quality- (PSD), preferred- (PSD-P), memorable- (PSD-M), and trophy- (PSD-T) length Walleyes collected during gill-net surveys since 1999 on Lake James, NC.

Year	PSD	PSD-P	PSD-M	PSD-T
1999	61	1	0	0
2000	48	1	0	0
2001	57	2	0	0
2002	57	2	0	0
2003	56	3	0	0
2004	39	4	0	0
2006	49	3	0	0
2008	54	3	0	0
2009	49	2	0	0
2012	93	7	0	0
2013	93	6	0	0
2014	91	10	0	0
2015	53	10	0	0
2016	83	16	0	0

TABLE 5.—Percent contribution of stocked Walleyes collected during the 2012–2016 gill-net survey on Lake James, NC, using both oxytetracycline hydrochloride (OTC) and parentage based tagging (PBT) methods.

Collection Year	Cohort	Age	N	% OTC	% PBT
2013	2012	1	17	100	100
2013	2013	0	10	70	100
2014	2012	2	11	100	100
2014	2013	1	18	78	100
2014	2014	0	12	92	100
2015	2012	3	5	100	100
2015	2013	2	15	73	100
2015	2014	1	25	88	96
2015	2015	0	39	100	100

TABLE 6.—Number of age-0 and age-1 Walleyes captured that were stocked as fingerlings at three Boating Access Areas (BAA) from 2014–2015 as part of the Walleye stocking evaluation of Lake James, NC.

Collection Year	Age	Total	Black Bear BAA	Canal BAA	Linville BAA
2014	0	12	1	0	11
2015	0	39	0	19	20
2015	1	24	1	19	4
Totals		75	2	38	35

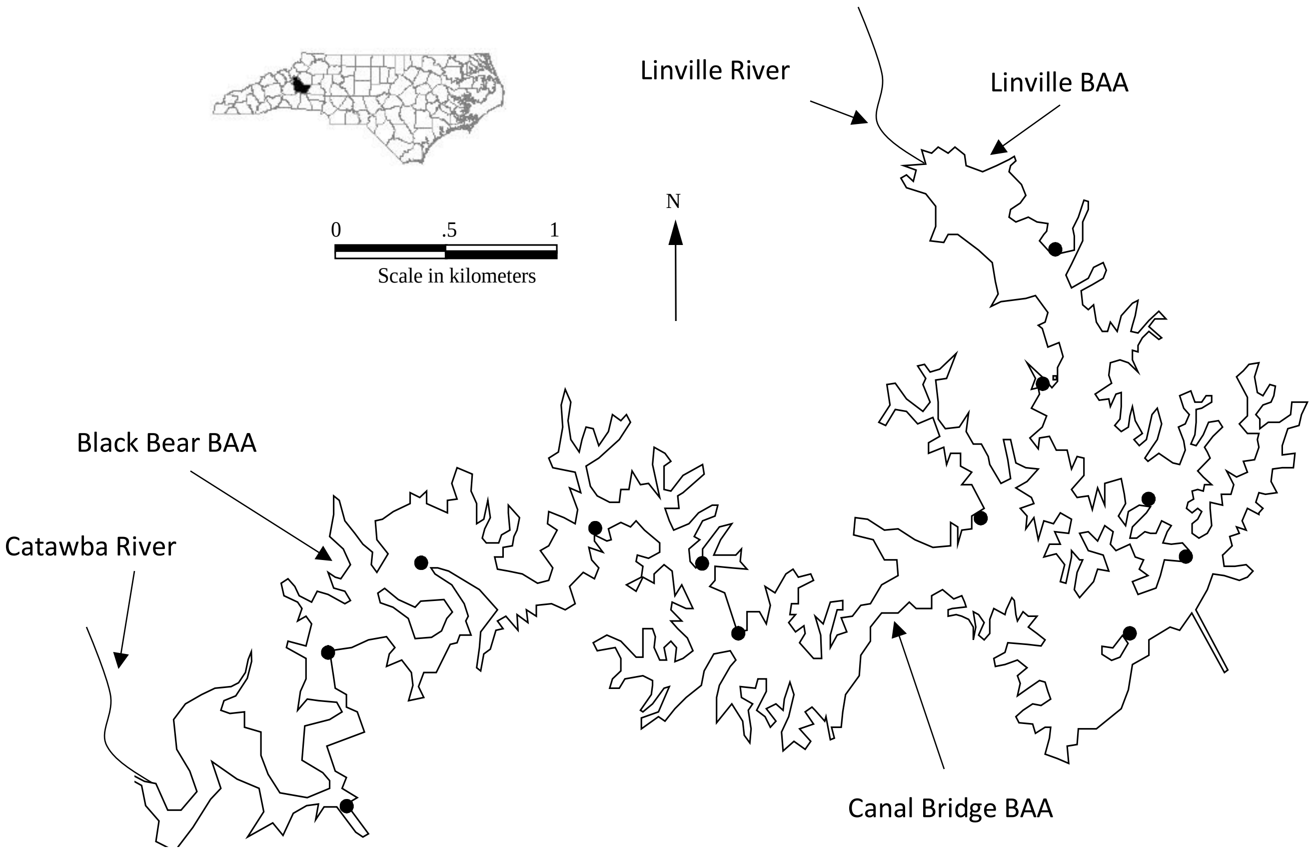

FIGURE 1.—Map of Lake James, Burke and McDowell counties, NC. Black dots indicate 1999–2016 gill-net survey locations. Three North Carolina Wildlife Resources Commission Boating Access Area (BAA) locations are also shown.

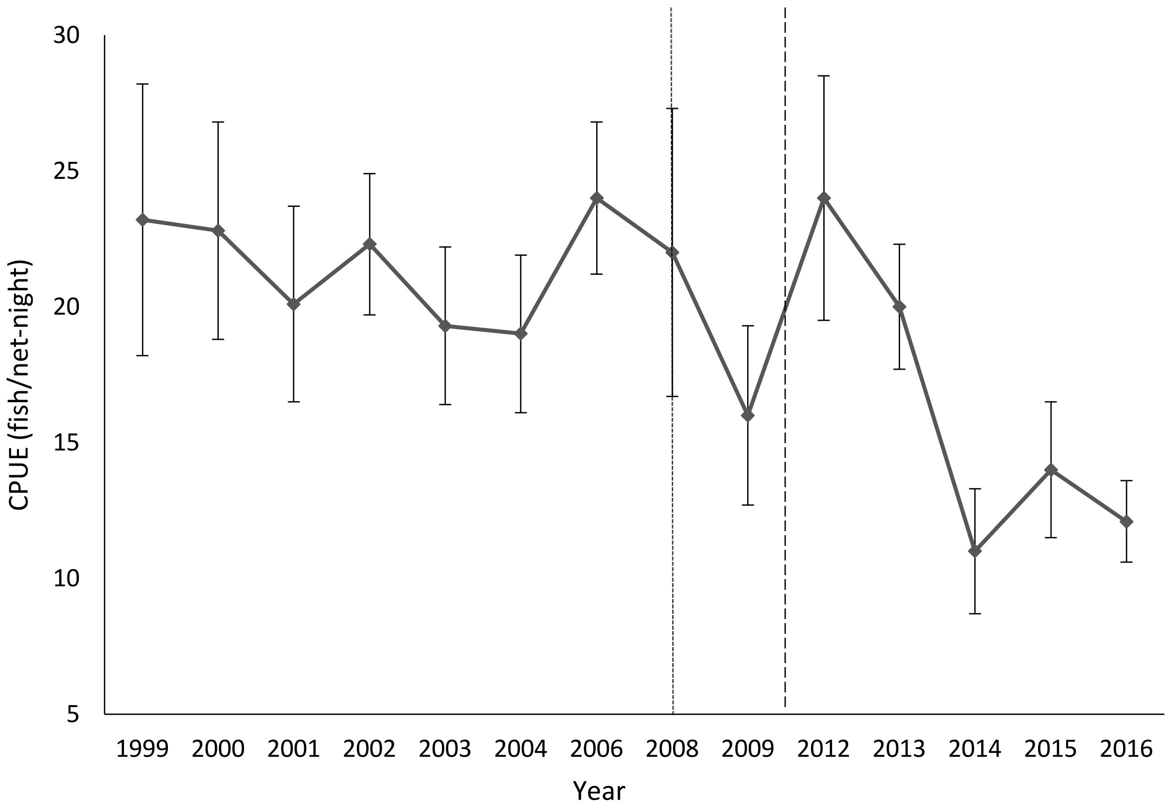

FIGURE 2.—Mean catch-per-unit-effort (CPUE) values for all Walleyes collected during gill-net surveys since 1999 on Lake James, NC. Error bars indicate standard error. The vertical dotted line represents the first observed White Perch in Lake James. The vertical dashed line represents the first observed Alewives and Blueback Herring in Lake James.

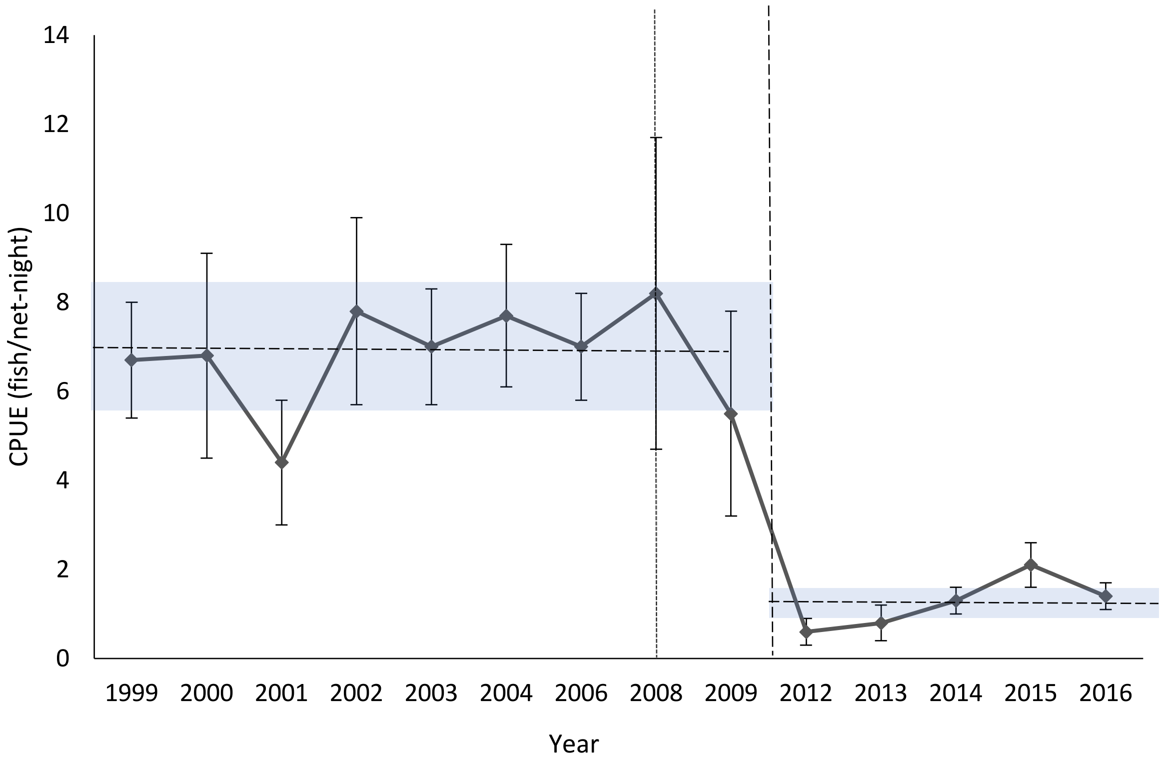

FIGURE 3.—Mean catch-per-unit-effort (CPUE) values for age-1 Walleyes collected during gill-net surveys since 1999 on Lake James, NC. Error bars represent standard error. The vertical dotted line represents the first observed White Perch in Lake James. The vertical dashed line represents the first observed Alewives and Blueback Herring in Lake James. The horizontal dashed lines represent the mean CPUE before and after Alewife and Blueback Herring introductions. The shaded areas represent the 95% confidence intervals associated with mean age-1 CPUE before and after Alewife and Blueback Herring introductions.

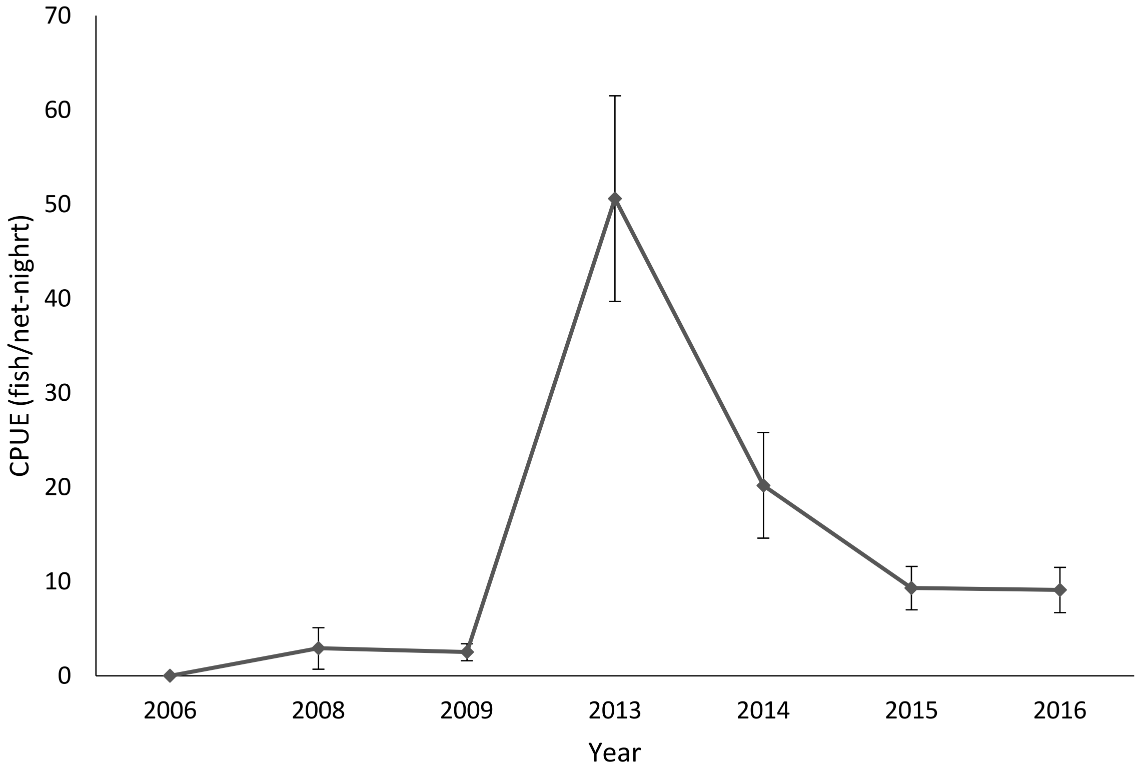

FIGURE 4.—Mean catch-per-unit-effort (CPUE) values of White Perch collected during the 2006–2016 gill-net surveys on Lake James, NC. Error bars represent standard error.

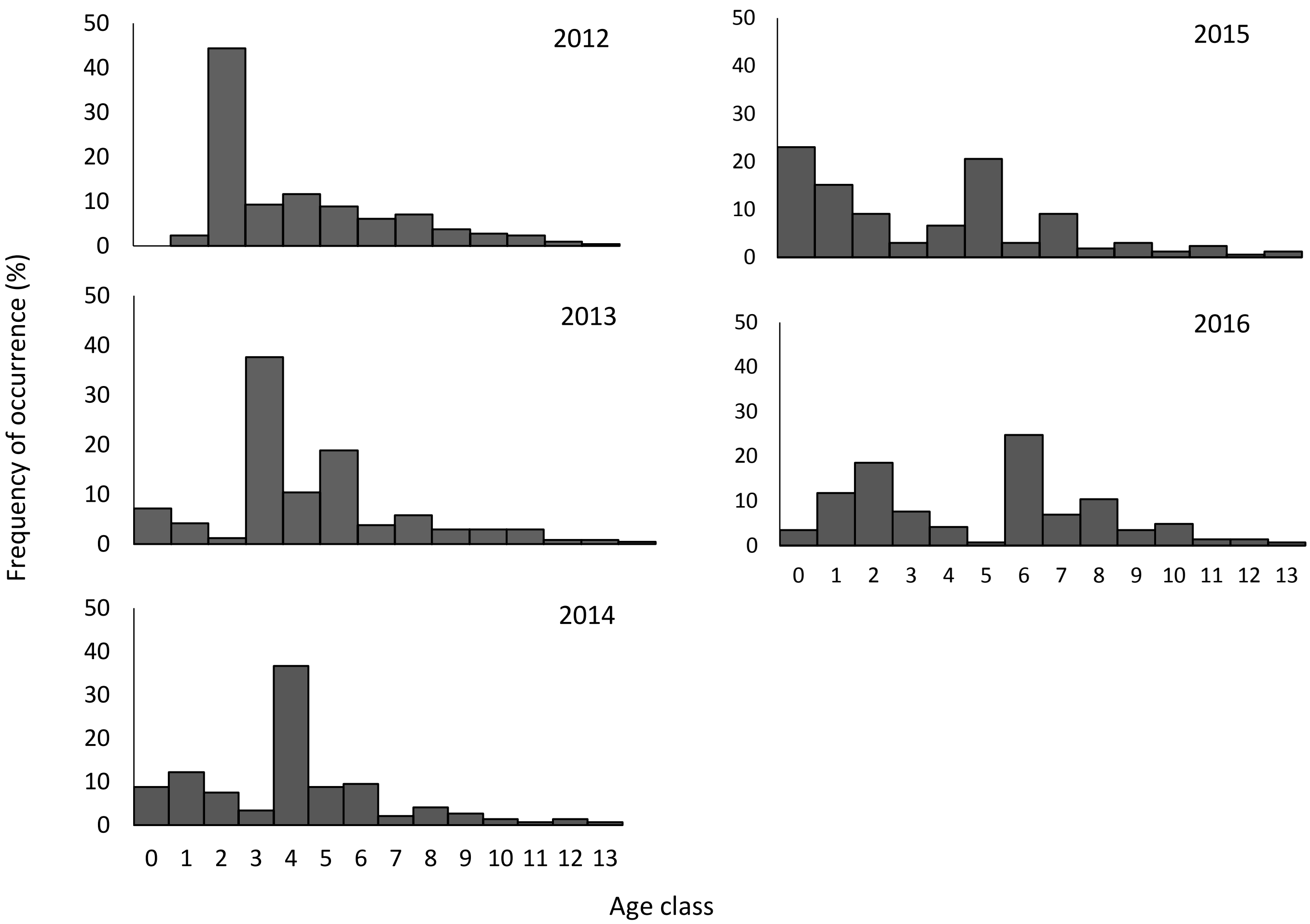

FIGURE 5.—Age-frequency distributions of Walleyes collected during the 2012–2016 gill-net surveys on Lake James, NC.

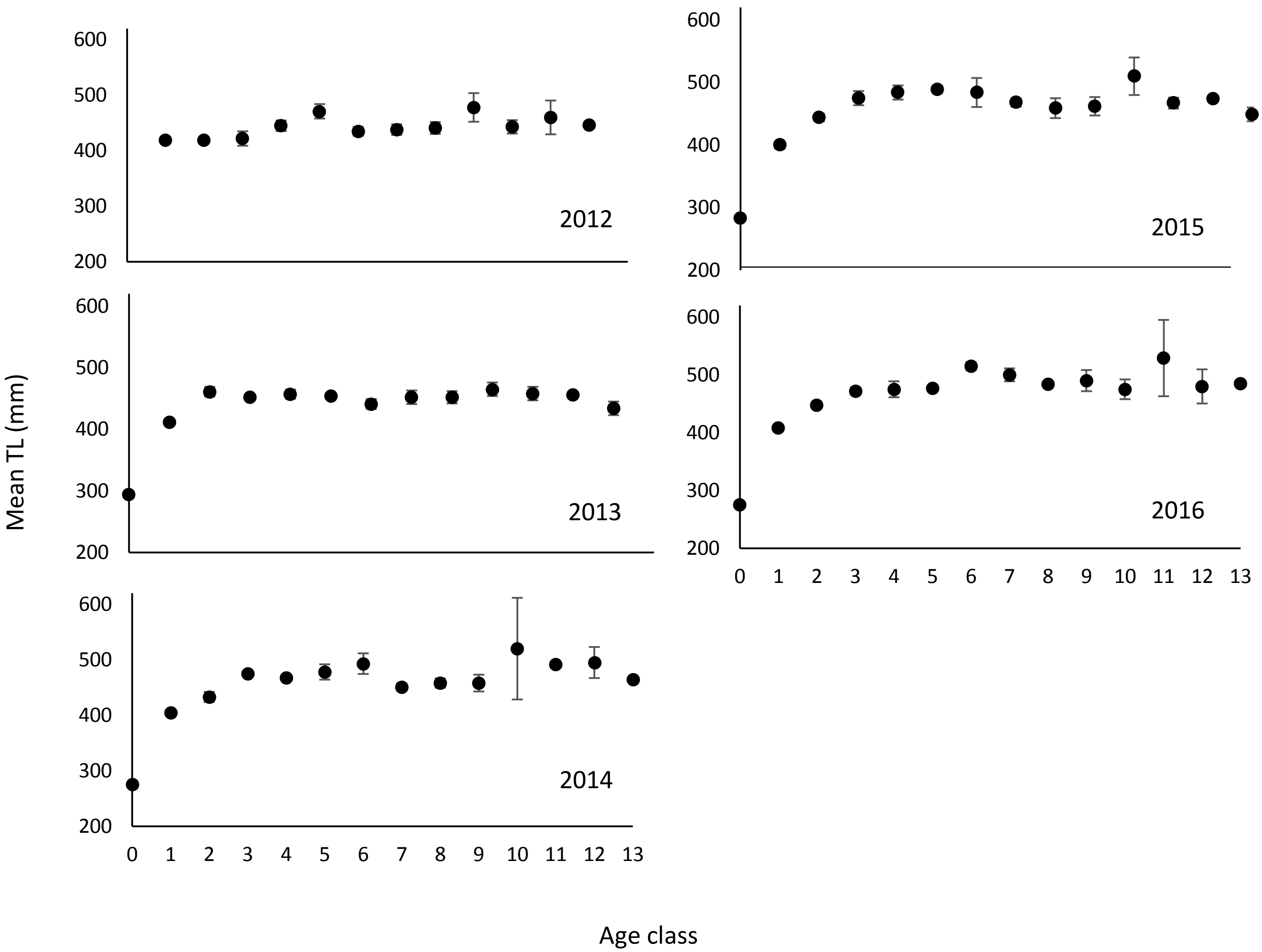

FIGURE 6.—Mean total length (TL)-at-age values for Walleyes collected during the 2012–2016 gill-net surveys on Lake James, NC. Error bars indicate standard error.

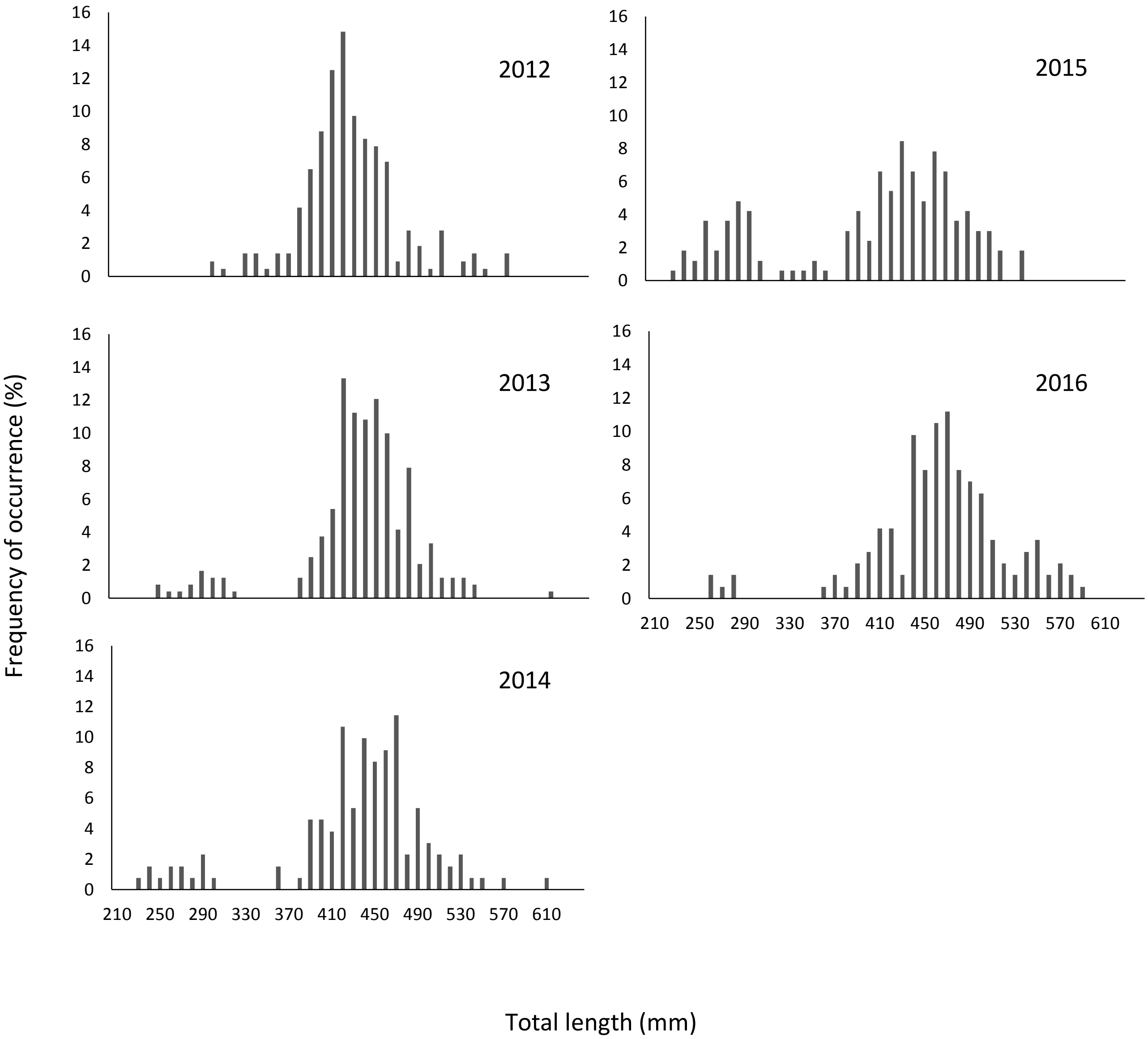

FIGURE 7.—Length-frequency distributions for Walleyes collected during the 2012–2016 gill-net surveys on Lake James, NC. Fish are grouped in 10-mm size classes.

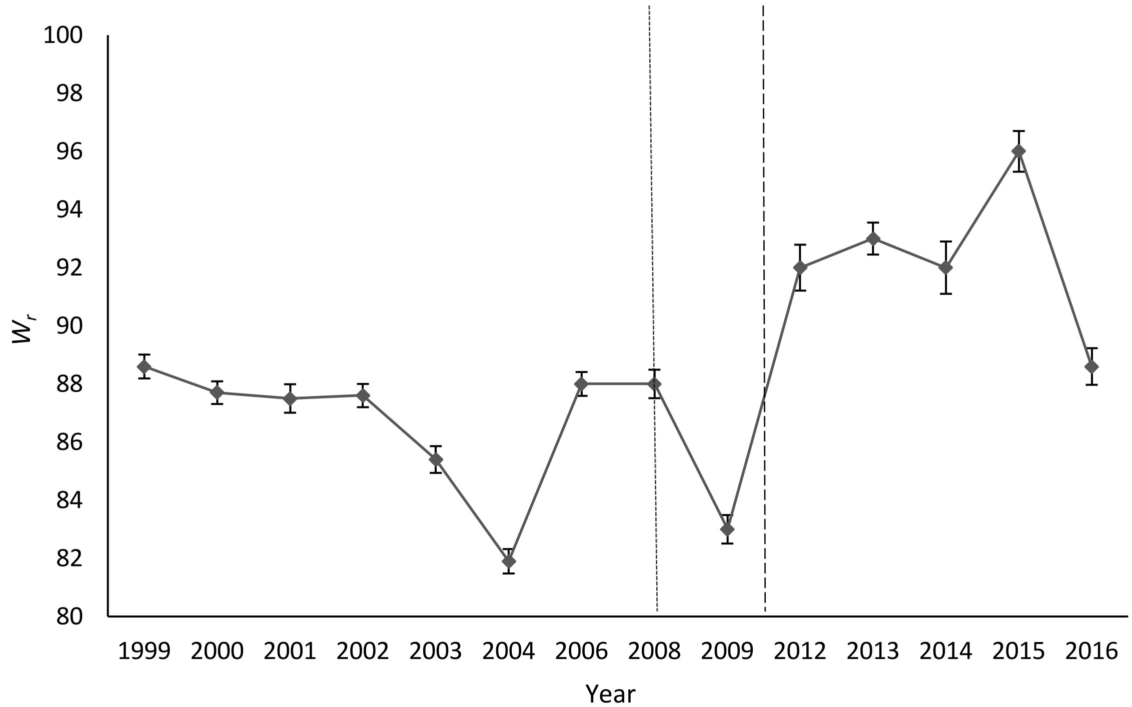

FIGURE 8.—Mean relative weight (W_r) values of Walleyes collected during gill-net surveys since 1999 on Lake James, NC. Error bars represent standard error. The vertical dotted line represents the first observed White Perch in Lake James. The vertical dashed line represents the first observed Alewives and Blueback Herring in Lake James.

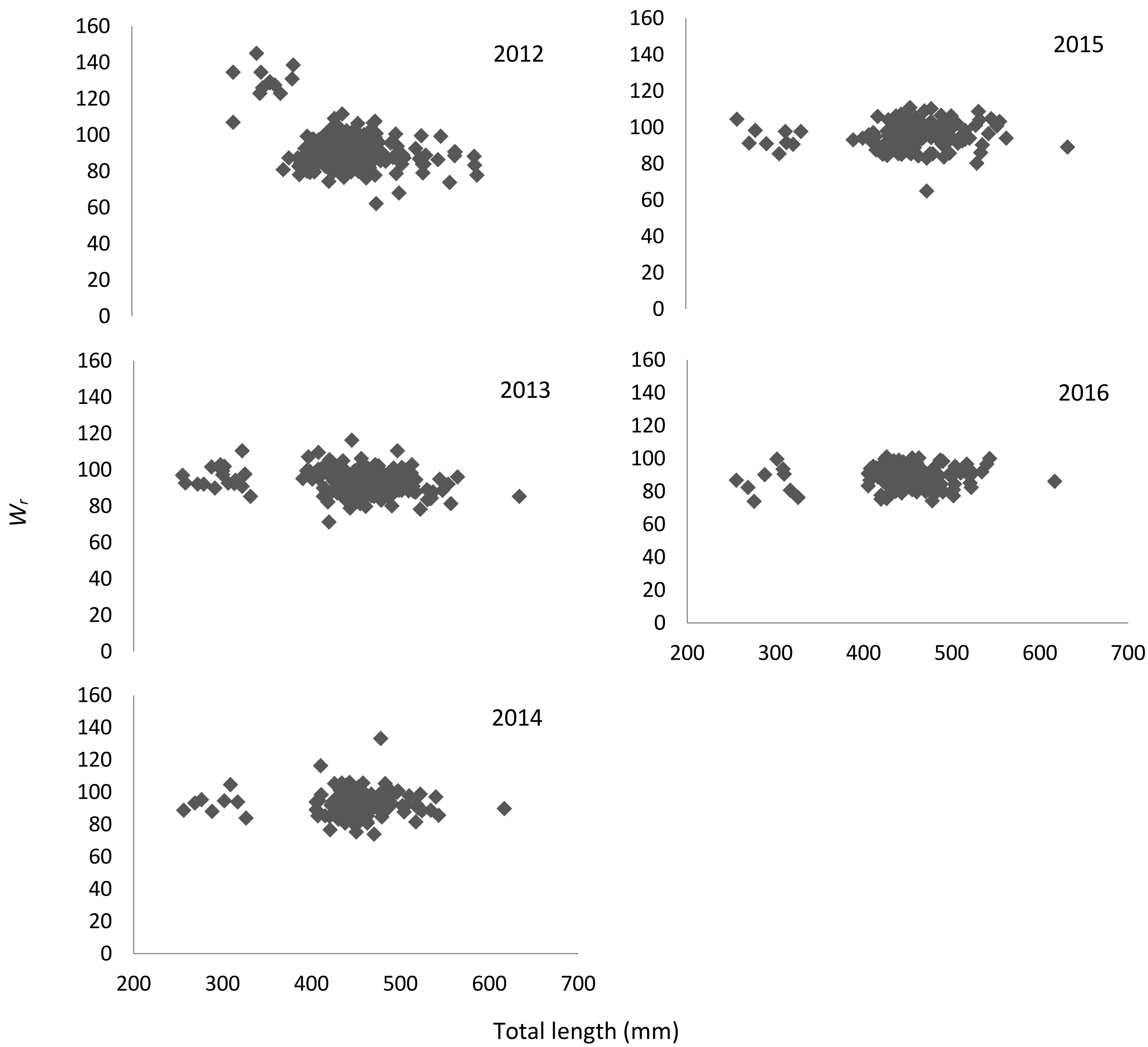

FIGURE 9.—Relative weight (W_r) values for Walleyes collected during the 2012–2016 gill-net surveys on Lake James, NC.

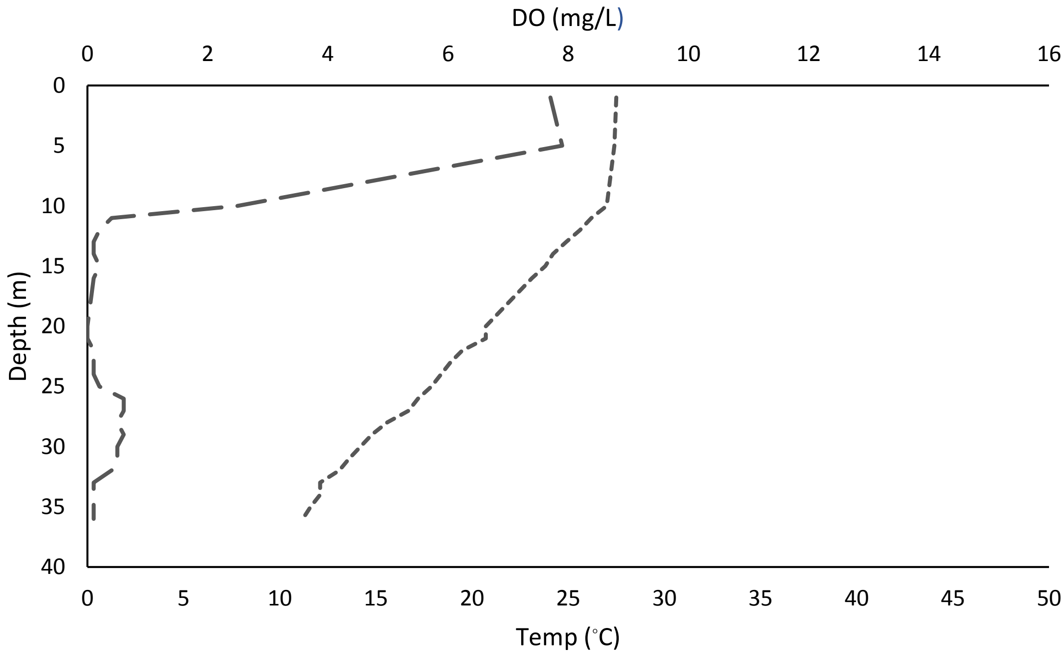

FIGURE 10.—Dissolved oxygen (DO)-water temperature (Temp °C) profiles of Paddy Creek forebay in September 2016. Large dashes represent DO. Small dashes represent temperature.

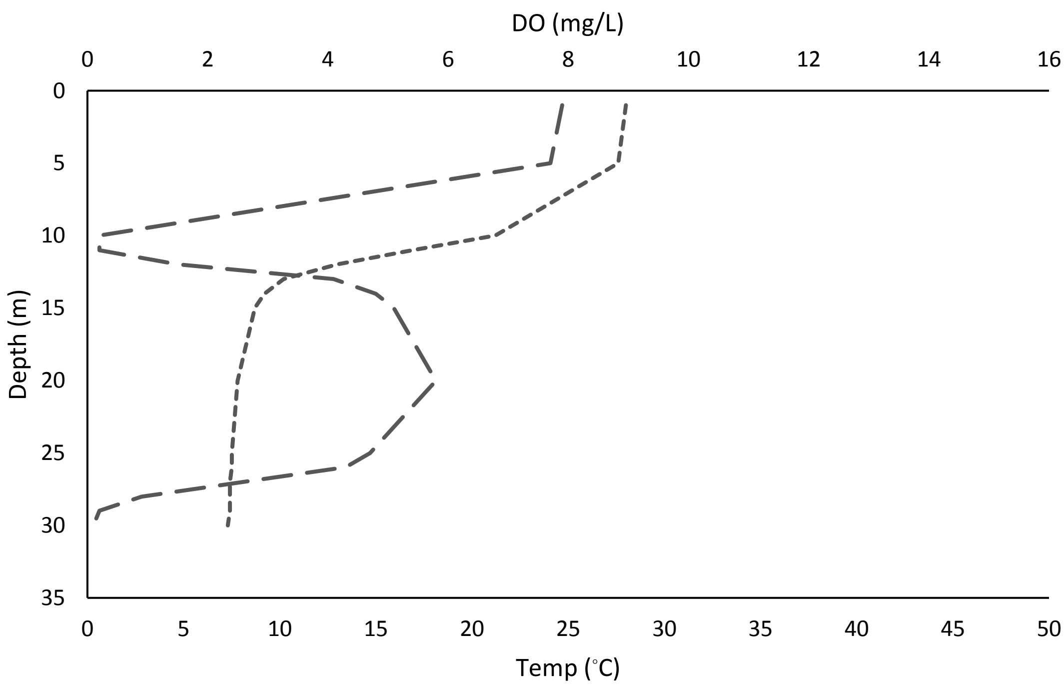

FIGURE 11.—Dissolved oxygen (DO)-water temperature (Temp °C) profiles of Catawba River forebay in September 2016. Large dashes represent DO. Small dashes represent temperature.