Effects of Introduced Alabama Bass on an Existing Largemouth Bass Fishery in Moss Lake, North Carolina

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Abstract: Negative impacts from non-native congener introductions have emerged as an immediate threat to black bass conservation and management. Largemouth bass (*Micropterus salmoides*) historically comprised the sole black bass fishery in Moss Lake, North Carolina. Alabama bass (*Micropterus henshalli*) were illegally introduced into Moss Lake and were first detected during a 2008 electrofishing survey conducted by North Carolina Wildlife Resources Commission biologists. Since this detection, Alabama bass rapidly increased in abundance throughout the reservoir, while largemouth bass abundance declined concomitantly and reached a low equilibrium, except within cove habitat of the upper reservoir. Alabama bass CPUE was generally 2–3 times higher than largemouth bass CPUE during the study, but Alabama bass were overall smaller in size and in poorer condition than largemouth bass. However, Alabama bass mean TL increased through time, corresponding to their expanding population. Alabama bass were smaller than largemouth bass at ages 1–2; however, by age 3, growth rates of both species converged and became similar thereafter. Our findings improve understanding of black bass population characteristics changes following the introduction of Alabama bass on an existing native largemouth bass fishery. Fisheries agencies are encouraged to implement preventative and adaptive control measures to both discourage illegal fish translocations and coordinate unified practical management approaches to the ever-present threat of invasive species expansion.

Key words: invasive species, non-native, growth, CPUE, relative weight

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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). Non-native fishes alone cause over US$1 billion of estimated recurring economic losses annually in the United States (Pimentel et al. 2001, 2005). Invasive species are often trophic generalists with broad ecological tolerances (Marvier et al. 2004), and once introduced and established they can displace desirable species, reduce biodiversity, and disrupt trophic cascades (Bruno and Cardinale 2008). Native species are especially vulnerable to impacts by invasive species in anthropogenically altered environments such as reservoirs (Avise et al. 1997, Bangs et al. 2018).

Negative interactions with translocated non-native congeners are an emerging threat to black bass (*Micropterus* spp.) conservation and management (Shaw 2015, Taylor et al. 2019). Although most management agencies have ceased non-native bass stockings over the last two decades, anglers have continued to illegally translocate species such as Alabama bass (*Micropterus henshalli*) in river basins across the southeastern United States (Pierce and Van Den Avyle 1997, Barwick et al. 2006, Moyer et al. 2014). Many of these introductions have been shown to result in introgressive hybridization between native and introduced congeners (Avise et al. 1997, Pierce and Van Den Avyle 1997, Bangs et al. 2018, Lewis et al. 2021, Peoples et al. 2021). Non-native black bass can also displace or reduce populations of native congeners, especially in situations where environmental conditions have been altered or degraded, favoring more tolerant species (Maceina and Bayne 2001, Sammons and Maceina 2009, Dorsey and Abney 2016). Preservation of genetic integrity is vital to the conservation of endemic black bass taxa (Freeman et al. 2015, Koppelman 2015), but illegal translocations of non-native congeners also present challenges for fisheries managers responsible for ecologically and economically important fisheries (Shaw 2015, Taylor et al. 2019). Although introductions of non-native species rarely produce favorable outcomes (Long and Fisher 2005, Courtenay 2007, Cucherousset and Olden 2011), unauthorized introductions of black bass across the United States continue to expand (Shaw 2015). Consequently, identifying threats, impacts, and solutions remain primary foci of invasive species research and management (Vander Zanden et al. 2004, Lovell et al. 2006).

The potential effects of black bass introduction on a native congener are an important concern at Moss Lake (Kings Mountain Reservoir), a 672-ha impoundment on the upper Broad River in North

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Carolina. Native to the Broad River Basin, the largemouth bass is the only native black bass species in Moss Lake (Silliman et al. 2021). Alabama bass are native to the Mobile River Basin in Alabama, Georgia, Mississippi, and Tennessee (Rider and Maceina 2015) and were first detected in Moss Lake by the North Carolina Wildlife Resources Commission (NCWRC) in 2008 during a shoreline electrofishing survey (Goodfred 2011). This survey was initiated following angler reports of poor largemouth bass fishing and anecdotal reports that anglers from a 2006 recreational bass club tournament hosted at Lake Norman, North Carolina, had introduced Alabama bass into Moss Lake (Goodfred 2011). Dorsey and Abney (2016) reported that Alabama bass were first discovered in Lake Norman during 2001 and caused drastic changes to the black bass fishery. Following evidence of Alabama bass presence, continued recruitment, and accelerated growth in Moss Lake, consistent monitoring was initiated to assess potential impacts to the largemouth bass population (Goodfred 2011). The objective of this study was to describe largemouth bass and Alabama bass population characteristics and trends in Moss Lake following establishment of Alabama bass.

Methods

Impounded in 1963, Moss Lake is the water supply reservoir for the city of Kings Mountain. Moss Lake has a watershed area of 91 km^2, an average depth of 14 m, and a maximum depth of 24 m, and is classified as mesotrophic (NCDEQ 2015). Major tributaries of Moss Lake include Buffalo and White Oak creeks. The watershed consists of rolling hills and rural land with approximately 50 to 70% of developed shoreline (NCDEQ 2015).

Field Collections and Processing

Black bass were collected in Moss Lake during spring of 2008–2010 and 2013–2021, except for 2015 and 2020. Sampling was conducted in littoral habitat during daylight hours in early- to mid-April when surface water temperatures were typically 14–19 C. Five, 300-m fixed transects were established across the reservoir (Figure 1) and sampled each year using a boat-mounted electrofisher (Model 7.5 GPP, Smith-Root, Inc., Vancouver, Washington) operated at 1000 VDC and 120 pulses sec^{-1}. Time (sec) spent electrofishing was recorded at each transect, and all black bass were collected by a single dip netter, enumerated, identified to species, and returned to the Marion State Fish Hatchery laboratory for further processing except for fish collected during 2013, which were measured (TL, mm), weighed (g), and released.

Black bass returned to the laboratory were measured and weighed. Sagittal otoliths were extracted and aged according to methods described by Allen et al. (2003). Two readers independently estimated ages of otoliths (Buckmeier and Howells 2003), and disagreements were examined jointly to reach consensus. Annulus formation was assumed to occur early during the black bass growing season, with each annulus indicating a new growth year (Quist et al. 2012). Early spring collections of temperate fishes usually occurs before the most recent annulus becomes clearly visible (Taubert and Tranquilli 1982); therefore, an additional year was added to final age estimates to account for growth past the final annulus (Sammons and Maceina 2008).

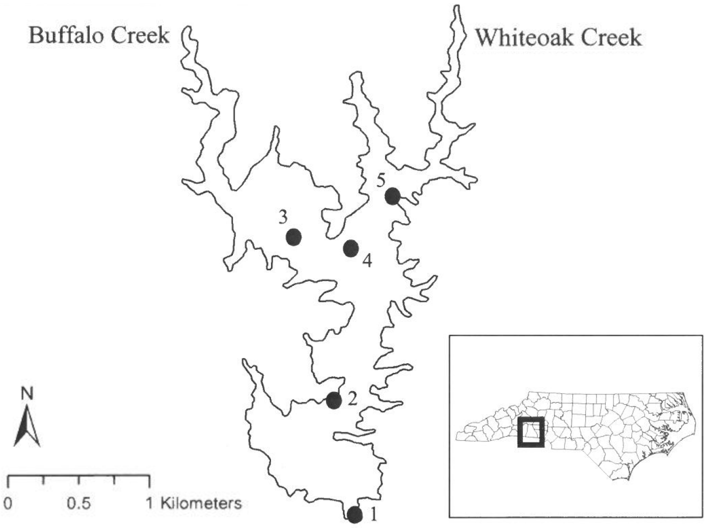

Figure 1. Map of Moss Lake, North Carolina, with 2008–2021 black bass sampling sites. Sites 3 and 4 were along mid-reservoir islands.

Data Analyses

Length frequencies were created using data pooled across years to describe population size structure of each species (Neumann et al. 2012). Differences in length frequencies of fish ≥60 mm TL were examined using a two-sample Kolmogorov-Smirnov test. Relative abundance was indexed by CPUE (fish h^{-1}) of both species per year and by site. Catch rates of each species were log$_{10}$-transformed (log[CPUE + 1]) to improve normality and were examined using a one-way repeated measures ANOVA to determine differences in CPUE across years and sites. Tukey's Honestly Significant Difference (HSD) post-hoc analysis was used to separate means. Within each year, mean CPUE was compared between species using a two-tailed *t*-test. Relative weight (W_r) values were calculated for Alabama bass ≥100 mm TL and largemouth bass ≥150 mm TL using the standard weight equations in DiCenzo et al. (1995) and Neumann et al. (2012). A one-way ANOVA was used to examine differences in mean W_r across years for both species; significant differences were identified using a Tukey's HSD post-hoc test. Within each year, mean W_r and TL were compared between species using a two-tailed *t*-test.

Age data were pooled across years, and a von Bertalanffy (1938) model was used to describe growth of largemouth bass and Alabama bass and to estimate time to reach harvestable size (i.e., 356 mm TL). An ANCOVA was used to compare growth of age 1–6 fish between each species by comparing the slopes of mean TL to $\log_{10}$ age regressions (Bartlett et al. 1984, Sammons et al. 2019). Age frequencies were tabulated for largemouth bass and Alabama bass using data pooled across years to reduce the potential effects of variable recruitment (Miranda and Bettoli 2007, Maceina and Sammons 2016). Because the Alabama bass population was still expanding throughout most of the study and age structure was likely not at equilibrium, we did not calculate total annual mortality. Pooled age frequencies across years for each species of fish age 1 and older were examined using a two-sample Kolmogorov-Smirnov test. All statistical tests were conducted using Real Statistics Resource Pack software (Zaiontz 2020) and were considered significant at $P \leq 0.05$.

Results

Field Collection, Size Structure, Relative Abundance, and Condition

Sampling throughout the study collected 190 largemouth bass and 657 Alabama bass. Length-frequency distributions for each species were generally unimodal, but differed between species. Alabama bass length frequency was skewed towards fish <380 mm TL, whereas almost half (47%) of largemouth bass were ≥380 mm TL (KSa = 0.21, $P < 0.001$; Figure 2). Mean largemouth bass TL was 322–394 mm; no obvious temporal trends were observed, although mean TL was greater in 2009 and 2013 than in 2008 ($F_{9,180} = 2.36$, $P = 0.015$; Table 1). Conversely, mean TL of Alabama bass was 203–360 mm, steadily increased through time, and was 77% greater in 2021 than in 2008. Mean TL of Alabama bass was generally smaller in years prior to 2017 ($F_{9,647} = 13.80$, $P < 0.001$; Table 1). Overall, largemouth bass mean TL was greater than Alabama bass most years ($t = 2.12$–6.03, $P < 0.05$), except in 2017 ($t_{81} = 1.93$, $P = 0.058$), 2018 ($t_{76} = 0.96$, $P = 0.338$), and 2021 ($t_{133} = 1.97$, $P = 0.051$) when mean TL of both species was similar.

Although mean CPUE initially decreased 47% from 2008 to 2009, no obvious temporal CPUE trends were observed for largemouth bass. Mean largemouth bass CPUE was 7.2–44.2 fish h^{-1}; it was greatest in 2008 and least in 2016 ($F_{9,36} = 3.46$, $P = 0.004$; Figure 3). Conversely, Alabama bass CPUE increased approximately 7-fold over this time, ranged from 15.7 to 125.7 fish h^{-1}, and was greater most years after 2010 than before ($F_{9,36} = 7.21$, $P < 0.001$; Figure 3). Largemouth bass abundance was low throughout the reservoir, except in site 5 ($F_{4,36} = 11.96$, $P < 0.001$; Figure 4). Alabama bass abundance was similar throughout the reservoir

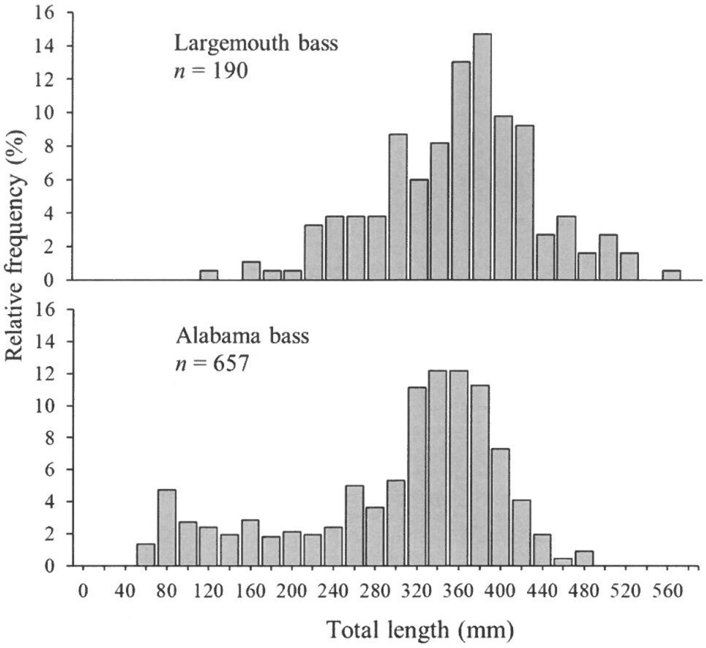

Figure 2. Length-frequency distributions (20-mm length-groups) of largemouth bass and Alabama bass collected during electrofishing surveys in Moss Lake, North Carolina (2008–2021).

Table 1. Mean (SE) total length (TL) and relative weight (W_r) for largemouth bass and Alabama bass collected during electrofishing surveys (2008–2021) in Moss Lake, North Carolina. Means with different letters for each species denote significant differences among years (Tukey's Honestly Significant Difference test; $P < 0.05$).

Species	Year	TL (mm)	W_r
Largemouth bass	2008	322 (10.9)^{b}	89 (1.1)^{a}
	2009	382 (12.3)^{a}	82 (1.3)^{b}
	2010	385 (24.8)^{ab}	82 (2.5)^{b}
	2013	394 (12.6)^{a}	91 (1.9)^{a}
	2014	367 (16.1)^{ab}	88 (1.7)^{ab}
	2016	366 (40.3)^{ab}	87 (3.9)^{ab}
	2017	359 (26.6)^{ab}	89 (2.5)^{ab}
	2018	369 (22.6)^{ab}	94 (2.2)^{a}
	2019	370 (19.1)^{ab}	89 (1.7)^{ab}
	2021	391 (12.4)^{ab}	86 (2.0)^{ab}
Alabama bass	2008	203 (23.2)^{e}	85 (2.2)^{a}
	2009	243 (19.1)^{e}	80 (1.3)^{ab}
	2010	246 (24.5)^{cde}	78 (1.8)^{ab}
	2013	312 (8.2)^{bc}	84 (1.2)^{a}
	2014	261 (15.4)^{de}	79 (0.9)^{b}
	2016	255 (23.9)^{cde}	80 (1.5)^{ab}
	2017	309 (11.2)^{bcd}	79 (0.7)^{b}
	2018	340 (11.3)^{ab}	83 (0.8)^{a}
	2019	326 (7.7)^{ab}	80 (0.5)^{b}
	2021	360 (5.4)^{a}	78 (0.6)^{b}

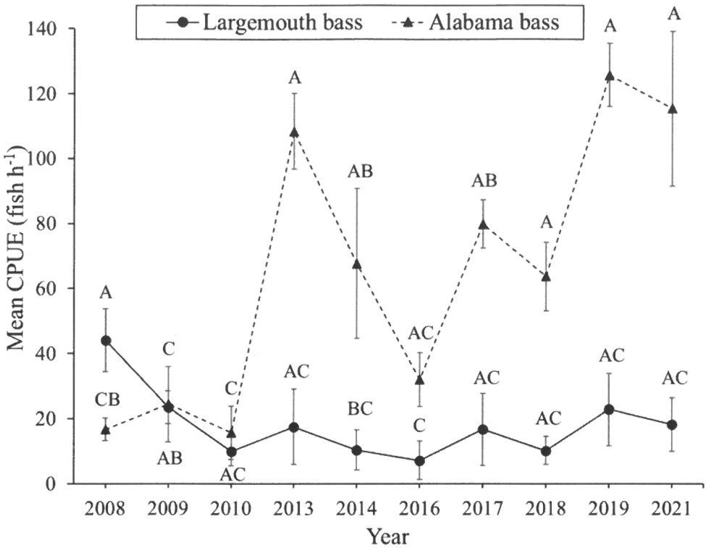

Figure 3. Mean (±SE) catch rate by sampling year of largemouth bass and Alabama bass collected during electrofishing surveys in Moss Lake, North Carolina (2008–2021). Means with different letters for each species denote significant differences among years (Tukey's Honestly Significant Difference test; $P < 0.05$). Letters below 2009 and 2010 means are for largemouth bass.

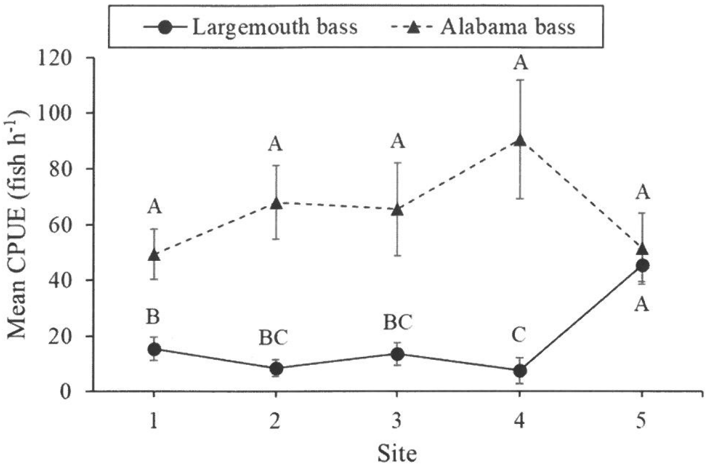

Figure 4. Mean (±SE) catch rate by sampling site of largemouth bass and Alabama bass collected during electrofishing surveys in Moss Lake, North Carolina (2008–2021). Means with different letters for each species denote significant differences among sites (Tukey's Honestly Significant Difference test; $P < 0.05$).

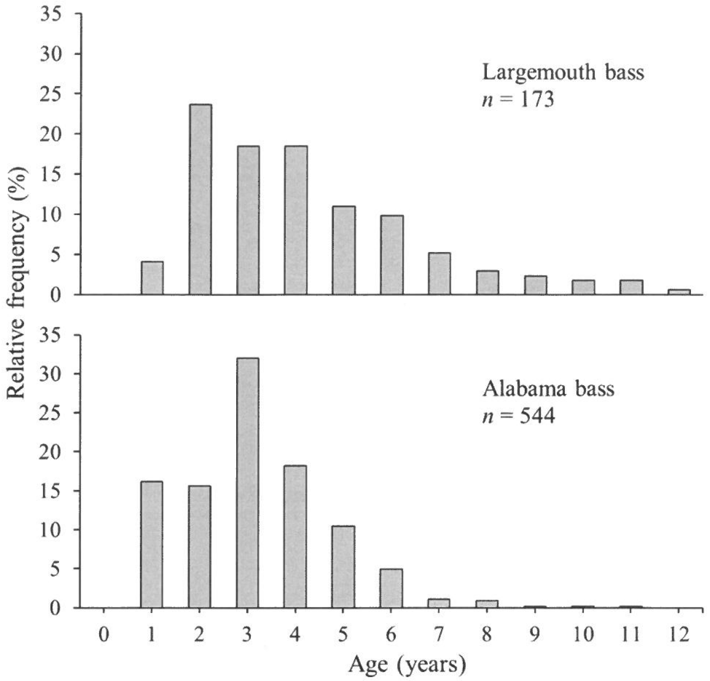

Figure 5. Age-frequency distributions (age 1 and older) for largemouth bass and Alabama bass collected during electrofishing surveys in Moss Lake, North Carolina (2008–2021).

($F_{4,36} = 1.49$, $P = 0.225$) and greater than largemouth bass abundance in all sites ($t = 3.01–5.35$, $P < 0.050$), except site 5 ($t_{10.26} = 0.79$, $P = 0.447$; Figure 4).

Mean largemouth bass W_r ranged from 82 in 2009 and 2010 to 94 in 2018, was greater in 2008, 2013, and 2018 than in 2009 and 2010 ($F_{9,179} = 3.94$, $P < 0.001$; Table 1), and showed no obvious temporal trends. Condition of Alabama bass also did not display temporal trends, ranging from 78 in 2010 and 2021 to 85 in 2008. Mean Alabama bass W_r was greater in 2008, 2013, and 2018 than in 2014, 2017, 2019, and 2021 ($F_{9,607} = 6.13$, $P < 0.001$; Table 1). Condition of largemouth bass was higher than Alabama bass most years ($t = 2.17–6.01$, $P < 0.050$), except during 2008 ($t_{60} = 1.65$, $P = 0.105$), 2009 ($t_{57} = 0.98$, $P = 0.329$), and 2010 ($t_{28} = 1.49$, $P = 0.148$) when mean W_r of both species was similar.

Age and Growth

Ages were estimated for 173 largemouth bass and 544 Alabama bass, corresponding to 12 age classes of largemouth bass and 11 age classes of Alabama bass (Figure 5). Largemouth bass age frequency was skewed towards fish age 6 and older; whereas 97% of Alabama bass age distribution was composed of fish age 6 and younger (KSa = 0.18, $P < 0.001$; Figure 5). Growth of largemouth bass and Alabama bass was similar ($F_{1,9} = 3.02$, $P = 0.116$). Although largemouth bass mean TL was greater than Alabama bass at age 1 ($t_{92} = 4.48$, $P < 0.001$) and age 2 ($t_{124} = 4.02$, $P = 0.001$), the von Bertalanffy model predicted Alabama bass and largemouth bass growth converged sharply by age 3 ($t_{204} = 1.03$, $P = 0.306$) and became similar throughout their lifespan (Figure 6).

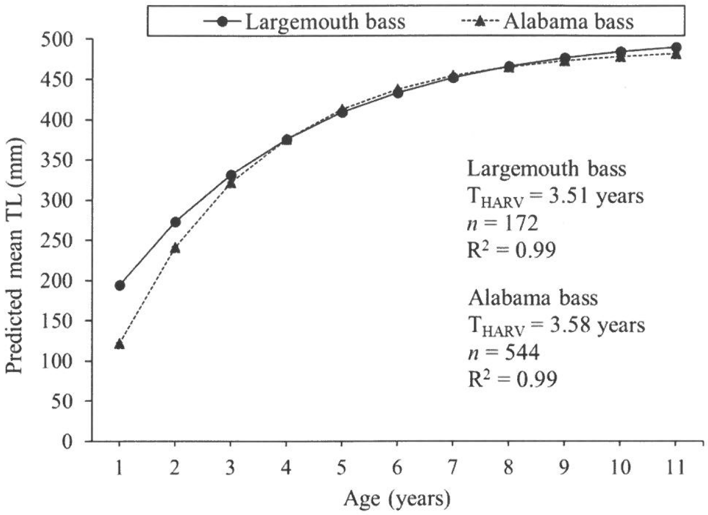

Figure 6. Predicted mean total length (TL) at age from von Bertalanffy growth model for largemouth bass and Alabama bass collected during electrofishing surveys in Moss Lake, North Carolina (2008–2021). Time to reach harvestable size (356 mm TL; T_{HARV}) predicted by growth model is shown for each species.

Discussion

Only two published studies have compared the interactions of introduced Alabama bass on an existing native largemouth bass fishery. Pierce and Van Den Avyle (1997) did not observe any noticeable changes in largemouth bass relative abundance related to Alabama bass introduction in Lake Lanier, Georgia, although the black bass population currently in that reservoir is dominated by Alabama bass (H. Roop, Georgia Department of Natural Resources, unpublished data). Conversely, Dorsey and Abney (2016) reported that largemouth bass CPUE rapidly declined by more than 90% following the discovery of Alabama bass in Lake Norman. Although largemouth bass population characteristics prior to Alabama bass introduction in Moss Lake are unknown, which precludes our ability to accurately detect changes before and after invasion, Alabama bass CPUE was 2–3 times higher than largemouth bass CPUE throughout the study. Our findings improve understanding of how introduced non-native congeners can alter an existing *Micropterus* fishery (Long and Fisher 2005, Stormer and Maceina 2008, Bean et al. 2013).

Population growth of newly introduced species can be rapid (Moyle et al. 1986, Cucherousset and Olden 2011) but also can be mediated by habitat suitability (Greene and Maceina 2000) and competition with existing species (Crooks and Soulè 1999). Alabama bass abundance in Moss Lake remained low for the first three years and then increased dramatically three years later. Dorsey and Abney (2016) reported a similar pattern for introduced Alabama bass in Lake Norman. Although Alabama bass in our study appeared to decline in abundance sooner than in Lake Norman, they also exhibited a substantial secondary CPUE upsurge from 2017 to 2019. Moss Lake experienced a 2.2-m water-level drawdown to assist with dam repairs during 2015 (D. Stewart, City of Kings Mountain, personal communication). Water-level fluctuations can play an important role in regulation of reservoir fish communities in terms of abundance and size structure (Paller 1997, Sammons and Bettoli 2000) and can also reduce catchability (Reynolds and Kolz 2012). Alabama bass may have been impacted by the 2015 Moss Lake drawdown (i.e., lower mean CPUE and smaller mean TL), but low water levels may also have shifted fish more offshore, reducing their vulnerability to the gear. The fact that subsequent samples were characterized by high catch rates and larger mean sizes, whereas largemouth bass CPUE and TL showed little change, tends to support this notion.

Alabama bass CPUE was high throughout Moss Lake; whereas, largemouth bass were more common in the uppermost transect, which primarily occurred in a shallow cove with woody debris. Dorsey and Abney (2016) found that Alabama bass favored main-reservoir habitats in Lake Norman and largemouth bass were more common in coves within the upper reservoir. Alabama bass have been found to dominate lower-nutrient reservoirs with rocky habitats in Alabama reservoirs (Greene and Maceina 2000, Maceina and Bayne 2001). Conversely, largemouth bass are generally found in shallower water (Hunter 2006) and cove habitats with woody debris (Sammons and Bettoli 1999, Rider and Maceina 2015). Given the current mesotrophic status of Moss Lake, established Alabama bass likely will continue to be the dominant black bass fishery. However, given the low number of sample sites in our study, it is unclear if largemouth bass abundance is higher in other upper regions of the reservoir. Additional samples throughout Moss Lake may be warranted to better understand black bass distribution and relative abundance differences within the entire reservoir (Koch et al. 2014).

Similar to abundance, mean size of largemouth bass was consistent throughout our study. This pattern is not surprising given the relatively fewer numbers of young largemouth bass in the population and corresponding low mortality. However, our results differed from the abundance and average size trends of largemouth bass in Lake Norman, where Dorsey and Abney (2016) found an inverse relationship between these two population characteristics following Alabama bass introduction. The rapid increase in Alabama bass mean TL in our study is typical for a relatively newly established population. Goodfred (2011) reported that only 5.7% of the Alabama bass collected in Moss Lake during 2008–2010 were older than age 3 compared to 36% in our study. The observed increasing size structure of Alabama bass in Moss Lake likely reflects an expanding population with more adult fish recruiting through the fishery relative to young fish. Alabama bass mean TL increased by approximately 50 mm TL within three years after discovery in Lake Norman and then continued to increase over the next four years as the population expanded (Dorsey and Abney 2016). Mean TL of largemouth bass and Alabama bass was similar in three of the last four sample years in Moss Lake, which may indicate the Alabama bass population is starting to stabilize. Consistent trends in body condition of each black bass species over time were not observed in Moss Lake; abundance and average size appeared unrelated (Dorsey and Abney 2016). Alabama bass were generally less robust compared to largemouth bass in our study, similar to findings in Lake Norman (Dorsey and Abney 2016), which is likely a product of differing body forms between the species (Ramsey 1975, DiCenzo et al. 1995).

Longevity of largemouth bass appeared higher than that of Alabama bass in Moss Lake; maximum age of Alabama bass was estimated at 11 years in our study, and mortality was high, with most fish age 6 or less. Rider and Maceina (2015) estimated Alabama bass maximum age at 11 years in Alabama reservoirs, and fish ages 9–11 made up <0.5% of the age structure. The age structure of Alabama bass in Moss Lake conferred unrealistically high estimates of total annual mortality compared to those reported in the literature for the species (e.g., 29–42%; Stewig and DeVries 2004, Shepherd and Maceina 2009, Sammons et al. 2013). Thus, our estimated age structure of Alabama bass likely reflected an expanding population yet to reach equilibrium. However, differences in lifespan may also have contributed to patterns we observed, as largemouth bass generally live longer than congeners even under equilibrium conditions in the same waterbody (Novinger 1987, Buynak et al. 1991, Sammons et al. 2019).

Growth was similar between largemouth bass and Alabama bass in Moss Lake despite the latter being >70 mm TL smaller at age 1. DiCenzo et al. (1995) observed similar growth rates for sympatric Alabama bass and largemouth bass populations in Alabama reservoirs. Greene and Maceina (2000) reported age-0 Alabama bass grew faster than age-0 largemouth bass in reservoirs characterized by lower productivity. Estimated growth rates of Alabama bass and largemouth bass in Moss Lake complement those reported for native sympatric populations of these two species in the literature. This may suggest that introduced Alabama bass can be managed under the same minimum length limits as largemouth bass in the same waterbody (Rider and Maceina 2015).

Management Implications

Invasive species introductions are unpredictable, and fisheries managers are constantly adapting management strategies to address introductions of new species within established, long standing, and valued fisheries. Consistent monitoring can facilitate resilient management approaches to address uncertainties in freshwater systems by detecting spatial and temporal changes to fish population metrics resulting from invasive species introductions (Love and Newhard 2012, Dorsey and Abney 2016). In Moss Lake, baseline information for largemouth bass prior to Alabama bass invasion is lacking, which further demonstrates the importance of routine standard sampling of all reservoirs (Miranda and Boxrucker 2009). The standard monitoring design in our study was critical in documenting black bass population characteristics on an existing largemouth bass fishery after introduction of Alabama bass. However, transect selection was restricted to five locations, resulting in low statistical power and unequal spatial coverage throughout the entire reservoir. Given the threat of increasing invasive species introductions, fisheries managers should consider sampling frequency and spatial coverage when designing standard sampling protocols (Miranda and Boxrucker 2009, Koch et al. 2014, Dorsey and Abney 2016).

Although Alabama bass may pose little threat of introgressive hybridization with native largemouth bass in North Carolina reservoirs (Dorsey and Abney 2016; NCWRC, unpublished data), introduction of Alabama bass and subsequent impacts to native largemouth bass populations in Lake Norman and now Moss Lake provide insight for managers and anglers alike about the deleterious competitive effects of translocating Alabama bass across river basins, particularly among southern impoundments. The NCWRC recently has enacted laws that liberalize Alabama bass size and creel limits to encourage harvest, and outreach materials have been crafted to raise awareness of Alabama bass and their impacts within the state and abroad. Clear and effective communication about the negative impacts of unauthorized Alabama bass introductions must be conveyed to the angling public and all beneficiaries of native black bass resources. Fisheries agencies are encouraged to include Alabama bass in aquatic invasive species management plans where the species is considered non-native and poses considerable risks to resident and endemic black bass populations. Mitigation and adaptation measures are vital for any invasive species management approach (Lovell et al. 2006). However, enforcement of unauthorized introductions is notoriously problematic, as public access points provide rapid and unhindered means for introductions (Koppelman 2015). Alabama bass have recently been discovered in numerous reservoirs and rivers across North Carolina (NCWRC, unpublished data), and it is likely that Alabama bass have spread and are impacting riverine and reservoir fisheries elsewhere. A coordinated practical response and acceptance among affected parties is necessary to manage this emerging threat.

Acknowledgments

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