Impacts of Introduced Blueback Herring on Piscivorous Sportfish in a Southeastern U.S. Reservoir

Lee Grove[1], *School of Fisheries, Aquaculture, and Aquatic Sciences, Auburn University, AL 36849*

Ehlana G. Stell, *School of Fisheries, Aquaculture, and Aquatic Sciences, Auburn University, AL 36849*

Chris McKee, *Alabama Wildlife and Freshwater Fisheries Division, District III, 8211 McFarland Blvd., West, Northport, AL 35476*

Russell A. Wright, *School of Fisheries, Aquaculture, and Aquatic Sciences, Auburn University, AL 36849*

Dennis R. DeVries[2], *School of Fisheries, Aquaculture, and Aquatic Sciences, Auburn University, AL 36849*

Abstract: Non-native species have sometimes been introduced to increase forage availability and sportfish production, but such introductions have potential for negative as well as positive effects. In 2010, non-native blueback herring (*Alosa aestivalis)* were found in Lewis Smith Lake, Alabama, due to illegal stocking. Our objective was to quantify food habits and determine potential impacts of blueback herring introduction on body condition and growth of important sportfishes in Lewis Smith Lake. Largemouth bass (*Micropterus salmoides*), Alabama bass (*Micropterus henshalli*), and striped bass (*Morone saxatilis*) were sampled in 2013 and 2014, and diets of these post-blueback herring introduction piscivores were quantified. Relative weight and length-at-age data from these fish were combined with data from Alabama Department of Conservation and Natural Resources and Auburn University collected prior to blueback herring introduction to quantify any changes in relative weights or length at age. Overall, piscivore diets included blueback herring at lower percentages (4.5, 19.5, and 6.6% for largemouth bass, Alabama bass, and striped bass, respectively) than other fish prey (52.2%, 58.7%, and 92.2% for largemouth bass, Alabama bass, and striped bass, respectively). Only summer striped bass diets contained high proportions of blueback herring. Relative weights of all sizes of largemouth bass and Alabama bass and intermediate sized striped bass were significantly higher after blueback herring introduction. This increased condition did not result in increased mean-length-at-age for piscivores age-4 and younger (except age-1 and age-2 striped bass). Blueback herring contributed to piscivore diets and increased body condition of some piscivores, with little change observed in growth. However, long-term effects should be assessed as blueback herring densities increase in the reservoir.

Key words: diet composition, growth, introduced species, relative weight, sportfish

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Native and nonnative prey species have been introduced both legally as part of management efforts and illegally by the public to increase sportfish growth, condition, and abundance (Moyle 1976, Kircheis and Stanley 1981, Ney 1981, Noble 1981, Wydoski and Bennett 1981, DeVries and Stein 1990, Rahel and Smith 2018). Stocking prey species has been used as a management tool to provide additional forage that may allow sportfish to transition to piscivory at earlier life stages, which can provide improved growth and survival of recreationally and economically important species (e.g., Ludsin and DeVries 1997). Introductions can lead to positive, negative, or negligible effects on aquatic communities (Adams 1996, Gozlan et al. 2010). Piscivores that transition to novel prey sources may benefit from these introductions, whereas other species that do not transition to them or are ecologically displaced may decline (Ellis et al. 2011). Although stocking non-native and potentially invasive species has been increasingly scrutinized over time (Jackson et al. 2004, Kolar et al. 2010), illegal introductions by anglers continue to occur (Rahel 2004, Johnson et al. 2009), either to intentionally establish populations or through careless "bait bucket" releases. Introduced prey species can affect established fishes differently across multiple life stages, leading to complex interactions that are difficult to anticipate and predict (Devlin et al. 2017, DeBoer et al. 2018). For these reasons, it is important to fully understand the range of potential impacts an introduced prey may have on fish communities before deciding whether to stock a new species.

Blueback herring (*Alosa aestivalis)* is an anadromous and planktivorous species with a native range from St. Johns River, Florida, to Prince Edward Island, Canada (Loesch 1987, Bozeman and Van Den Avyle 1989) that has been stocked into many inland lakes and reservoirs, to increase forage for piscivorous gamefish. Blueback herring can thrive in landlocked environments; in southeastern U.S. reservoirs where they have been introduced they can establish self-sustaining populations if sufficient cool water thermal refuge

1. Current address: Alabama Wildlife and Freshwater Fisheries Division, District V, 30945 Five Rivers Blvd, Spanish Fort, AL, 36527
2. E-mail: devridr@auburn.edu

is provided (Bulak and Walker 1979, Prince and Barwick 1981, Coutant 1997, Nestler et al. 2002, Winkelman and Van Den Avyle 2002, Grove et al. 2022). However, little is known about the overall impacts of introduced blueback herring in these reservoirs on resident fishes.

The primary positive effect of blueback herring on the growth and abundance of piscivores is attributed to their direct contribution as a high-calorie prey type to predator diets (Bart et al. 2021). Due to both spatial overlap and shared thermal preference between striped bass (*Morone saxatilis)* and blueback herring, striped bass are likely to feed on introduced blueback herring (Rice et al. 2013). Other piscivorous species such as spotted bass (*Micropterus punctulatus*), and Alabama bass (*Micropterus henshalli*) that tend to use deeper water habitats (Hunter and Maceina 2008) might also feed on blueback herring and potentially exhibit increased growth.

Negative impacts of blueback herring introductions are largely attributed to competition with or predation on juvenile piscivores or the resident prey species. However, the evidence for potential negative effects resulting from blueback herring introduction is mixed. Blueback herring may negatively affect resident fish populations by impacting zooplankton communities (e.g., Brooks and Dodson 1965), although some evidence suggests that blueback herring and native prey fishes consume different sizes of zooplankton (Davis and Foltz 1991, Grove et al. 2022). Blueback herring can also have direct negative impacts on other fish populations by consuming eggs and larval fishes (Bulak and Walker 1979, Guest and Drenner 1991, Goodrich 2002, Winkelman and Van Den Avyle 2002, Wheeler et al. 2004). These combined negative effects have been shown to cause declines in sportfish populations. For example, in North Carolina, walleye (*Sander vitreus*) populations in Lake Glenville and Hiwassee Reservoir, and largemouth bass (*Micropterus salmoides*) populations in Lake Norman were reported to decline after the stocking of blueback herring (Wheeler et al. 2004). Although the exact mechanism for the decline was not identified, egg predation was suspected as one mechanism. Lake Burton, Georgia, experienced complete year-class failures of largemouth bass as well as decreased abundances of both black crappie (*Pomoxis nigromaculatus*) and white bass (*Morone chrysops*) following introduction of blueback herring (Wheeler et al. 2004). However, declines in largemouth bass may have been caused more by non-native Alabama bass introductions than blueback herring (Sammons et al. 2023). Regardless, predicting the effects of introducing new species into established systems is complex and full of uncertainty.

Here we examine the influence of introduced blueback herring on piscivorous sportfish diets, growth, and condition in Lewis Smith Lake, Alabama, following their illegal introduction sometime prior to 2010, when they were first identified in the reservoir by Alabama Department of Conservation and Natural Resources (ADCNR) biologists (Jay Haffner, ADCNR, personal communication); they have since spread throughout the reservoir. This project began in 2013 and was the first to study the blueback herring population in the reservoir, focusing on potential impacts of blueback herring introductions on popular sportfishes in these systems that may prey on blueback herring including largemouth bass, Alabama bass, and striped bass. Objectives for this work were to: (1) determine diet composition of three primary piscivores in the system (largemouth bass, Alabama bass, striped bass), including the contribution of introduced blueback herring, and (2) compare relative weights and growth of these piscivores before and after blueback herring introduction.

Study Area

Lewis Smith Lake is a large (8538 ha), mesotrophic reservoir located in north central Alabama (Cullman, Walker, and Winston counties), with three major branches (Ryan, Rock, and Sipsey creeks) characterized by steep banks, rocky substrate, and deep waters (maximum depth > 100 m). The three branches differ in water clarity and primary production, and a thermocline develops in May that usually persists until November (Bayne et al. 1998, Allen et al. 1999, Moss et al. 2003, Grove et al. 2022). The recreational fishery includes several species, with largemouth bass, Alabama bass, and striped bass the most sought-after fishes. A study conducted from 2010–2011 estimated the striped bass fishery was worth US$0.9–1.2 million in yearly revenue (Lothrop et al. 2014).

Methods

Sampling was conducted from January 2013 through November 2014 within the Ryan Creek, Rock Creek and Sipsey Creek branches. Each branch included an upstream and downstream sampling site to account for longitudinal within-reservoir variation in productivity (Bayne et al. 1998, Allen et al. 1999; Grove et al. 2022). Juveniles and adults of largemouth bass, Alabama bass, and striped bass were collected at night by boat electrofishing or gill nets. From January through September 2013, both collection methods were used once per month during the same sampling trip. From October 2013 through November 2014, collection methods alternated monthly. While this meant that striped bass and black basses were primarily collected in alternating months, this did not introduce any bias given that we considered relative weights across fish and diets on a seasonal basis. Electrofishing samples consisted of two 10-min transects at each sampling site using pulsed DC (7.5 GPP, Smith-Root Inc., Vancouver, Washington). Multiple sized gill nets were used to ensure the full size range of striped bass was captured. Gill-net sampling at each site consisted of two gill nets with different mesh sizes (one 38 m × 2.5 m multiple mesh size net with 5–7.6-m panels with mesh sizes ranging from 5 to 15.2 cm, and one 38 m × 2.5 m experimental net with 5–7.6-m panels with mesh sizes ranging from 7.6 to 17.8 cm) that soaked for 6 h. Gill nets were set at the thermocline during summer and nearer the surface after the reservoir was no longer stratified during winter to maximize seasonal catch rates by accounting for fish movement due to temperature tolerances of striped bass (Schaffler et al. 2002, Nestler et al. 2002, Brandt et al. 2009). The thermocline was determined using a YSI 85 multimeter (YSI Incorporated, Yellow Springs, Ohio). Dissolved oxygen and temperature were recorded every 2 m and the thermocline was determined when dissolved oxygen declined rapidly from normoxic to hypoxic.

All fish collected were placed on ice and returned to the lab for further processing the following day. In the lab, fish were measured (TL, mm), weighed (g, nearest 10 g for fish over 5443 g), and stomach contents were removed and frozen (from all largemouth bass and striped bass, and a subsample of 10 randomly selected Alabama bass from each date); sagittal otoliths were removed for aging. Standardized spring electrofishing data for largemouth bass and Alabama bass were provided by ADCNR to supplement post-introduction piscivore length, weight, and age data. Samples were collected during 15 March–30 April in 2016 and 2019, and consisted of 10 sampling sites each year that were selected in a stratified random approach (stratified across morphology of the reservoir) and sampled for 30 min each. All fish were weighed, measured, and had otoliths removed for aging. Pre-blueback herring introduction data were collected from 2005 to 2007 by Shepherd and Maceina (2009) who sampled black bass and striped bass from Ryan and Sipsey creeks and the dam forebay using similar gears as this study. Only fish collected in the spring (approximately at the time of annulus formation) were used in length-at-age analysis. Additional length, weight, and age data collected by ADCNR as described above from 2002 to 2007 were used for pre-introduction largemouth bass and Alabama bass data.

All prey items were identified to the lowest possible taxonomic level and measured (length) under a dissecting microscope, with severely decomposed prey fish identified by otolith morphology. Species-specific length-weight regressions were applied to individual diet items and the total mass estimated by summation was used to estimate consumed prey biomass. Prey species length-weight regressions were taken from published information (Benke et al. 1999). A length-weight regression was generated for blueback herring using intact collected samples of the species from the field. Prey biomass estimates were used to calculate proportional composition by weight for each individual predator, with prey grouped for diet analyses as blueback herring, black bass, threadfin shad (*Dorosoma petenense*), gizzard shad (*Dorosoma cepedianum*), minnows, sunfish (*Lepomis* spp.), crayfish, insects, or other.

Relative weights of largemouth bass, Alabama bass, and striped bass were calculated using equations in Neumann et al. (2012), with the relative weight equation for spotted bass used for Alabama bass. Otoliths were aged independently by two readers, with otoliths from largemouth bass and Alabama bass <5 yr old read whole under a dissecting scope. Otoliths of older black bass and all striped bass were sectioned transversely through the nucleus using a low-speed diamond-bladed saw (South Bay Technologies Model 65, San Clemente, California), then affixed to a microscope slide and read under a compound microscope. If readers did not agree on whole-read otoliths, the otolith was sectioned transversely and reexamined. Otoliths were discarded if readers failed to agree following sectioning. All otoliths were measured from the focus to the posterior-most end of each annulus (nearest 0.001 mm) using an image analysis system. Total length at the *i*th age ($TL_{i;}$) was estimated using the direct proportion method (Le Cren 1947):

$$TL_i = \frac{S_i}{S_c} \times L_c$$

where TL_i is the back-calculated length of the fish at the formation of the *i*th increment, L_c is the length of the fish at capture, S_c is the radius of a sagittal otolith at capture, and S_i is the radius of a sagittal otolith at the *i*th increment (Quist et al. 2012). Growth past the final annulus across seasons was controlled by using back-calculated ages. Shepard and Maceina (2009) data used TL at capture given that all data were derived from spring collections.

Statistical Analysis

Average catch per electrofishing hour (CPE) for largemouth bass and Alabama bass before and after blueback herring introduction were compared using two sample *t*-tests with unequal variance. Diet and relative weight data were categorized into four seasons, defined as Spring (March–May), Summer (June–August), Fall (September–November), and Winter (December–February). Chi-square goodness of fit tests were used to analyze the proportional contributions by weight of diet types in largemouth bass, Alabama bass, and striped bass to determine if the relative contribution of the observed diet categories differed. Relative weights of these piscivorous fishes were compared before (2002–2007) versus after (2013–2019) blueback herring introduction across three size groups (length range within a species divided into thirds) using two-way analysis of variance. Average lengths at age were compared at age-1 through age-4 for piscivore populations pre- versus post-blueback herring introduction using *t*-tests with the fishmethods package (Nelson 2023, R Core Team 2023). All fish used in this analysis from the post-introduction period were from year classes spawned after blueback herring introduction. Statistical tests used $\alpha = 0.05$ to assess significance.

Results

Black Bass CPE and Diets

Mean catch rate of Alabama bass increased from 33.6 fish h^{-1} before blueback herring introduction to 50.7 fish h^{-1} afterwards: ($t_{11} = 2.16$, $P = 0.054$). Conversely, mean catch rate of largemouth bass was similar before (23.3 fish h^{-1}) and after (19.1 fish h^{-1}) blueback herring introduction ($t_{11} = 1.01$, $P = 0.33$).

We collected 495 largemouth bass, 253 striped bass, and 1734 Alabama bass for food-habit analysis. Blueback herring composed a significantly lower proportion of diets than other prey fish (threadfin shad and sunfishes) or crayfish in all piscivore diets that contained fish and crayfish ($\chi^2 = 182.8$, df = 12, $P < 0.0001$; Table 1). For striped bass, threadfin shad (79% of prey biomass) and gizzard shad (12%) accounted for most of the prey consumed when pooled across seasons ($\chi^2 = 353.6$, df = 6, $P < 0.0001$; Table 1). Alabama bass consumed nearly equal proportions of blueback herring (19%), crayfish (21%), and threadfin shad (20%) across seasons. However, diet proportions contributed by blueback herring were much lower for largemouth bass (5%) and striped bass (7%) across seasons. Blueback herring were seasonally important, as they were consumed at disproportionally high rates during the summer for both Alabama bass ($\chi^2 = 115.6$, df = 7, $P < 0.0001$) and striped bass ($\chi^2 = 68.6$, df = 3, $P < 0.0001$).

Relative Weight

We used length categories (TL, mm) of <329 (small), 329–458 (medium), and >458 (large) for largemouth bass. For Alabama bass the small, medium, and large categories were <322, 322–443, and >443, respectively, and for striped bass they were <543, 543–886, and >886, respectively. Relative weights of fish collected post-blueback herring introduction were greater than those collected prior to the introduction for largemouth bass ($F_{1, 2005} = 453.9$, $P < 0.0001$), Alabama bass ($F_{1, 3324} = 532.8$, $P < 0.0001$), and striped bass ($F_{1, 962} = 27.5$, $P < 0.0001$). The size group × time period interaction term was not significant for either largemouth bass ($F_{2, 2005} = 1.8$, $P = 0.16$) or Alabama bass ($F_{2, 3324} = 0.5$, $P = 0.62$), with relative weights greater after introduction for all three size groups for both species ($P < 0.006$; Figure 1). For striped bass, the size group × time period interaction term was significant ($F_{2, 962} = 5.0$, $P = 0.007$), with relative weights of small and large fish similar between time periods but those of medium fish being greater post-blueback herring introduction ($P < 0.0001$; Figure 1).

Table 1. Seasonal and total annual diet percentages (% by biomass, averaged across individuals) for largemouth bass, Alabama bass, and striped bass during 2013–2014 in Lewis Smith Lake, Alabama. Seasons are defined as Spring = March–May, Summer = June–August, Fall = September–November, Winter = December–February. Prey types: BASS = *Micropterus* spp., BBHR = blueback herring, CRAY = crayfish, GIZS = gizzard shad, INST = insects, MINN = minnows, SUNF = sunfish, and THSH = threadfin shad.

			Prey Type								
Species	**Season**	***n***	**BASS**	**BBHR**	**CRAY**	**GIZS**	**INST**	**MINN**	**SUNF**	**THSH**	**Other**
Largemouth Bass	Fall	28	–	–	66.63	–	–	–	22.89	10.48	–
	Winter	91	0.12	1.05	70.04	–	0.00	1.99	20.62	6.19	–
	Spring	42	4.02	19.43	9.67	–	0.78	4.38	35.42	26.31	–
	Summer	71	4.27	0.51	24.63	–	0.44	0.58	59.86	9.69	–
	Total	365	2.20	4.52	43.12	–	0.30	1.82	36.20	11.84	–
Alabama bass	Fall	36	–	16.85	31.48	–	0.01	2.48	20.99	26.32	1.88
	Winter	99	–	9.86	46.18	0.92	0.09	0.74	26.66	15.55	0.00
	Spring	78	4.39	11.04	6.77	6.35	1.73	4.81	51.59	13.30	0.01
	Summer	152	3.62	30.82	2.86	–	3.62	1.51	33.88	23.69	0.01
	Total	232	2.09	19.12	21.39	1.27	1.72	1.87	32.58	19.72	0.23
Striped bass	Fall	50	–	11.99	0.58	12.71	–	–	–	74.73	–
	Winter	35	–	0.26	0.27	0.18	–	–	–	99.30	–
	Spring	26	–	8.85	4.89	75.29	0.02	–	1.15	9.80	–
	Summer	17	15.98	60.57	9.01	0.00	–	–	–	14.44	–
	Total	128	0.68	6.56	1.27	12.05	0.00	–	0.14	79.31	–

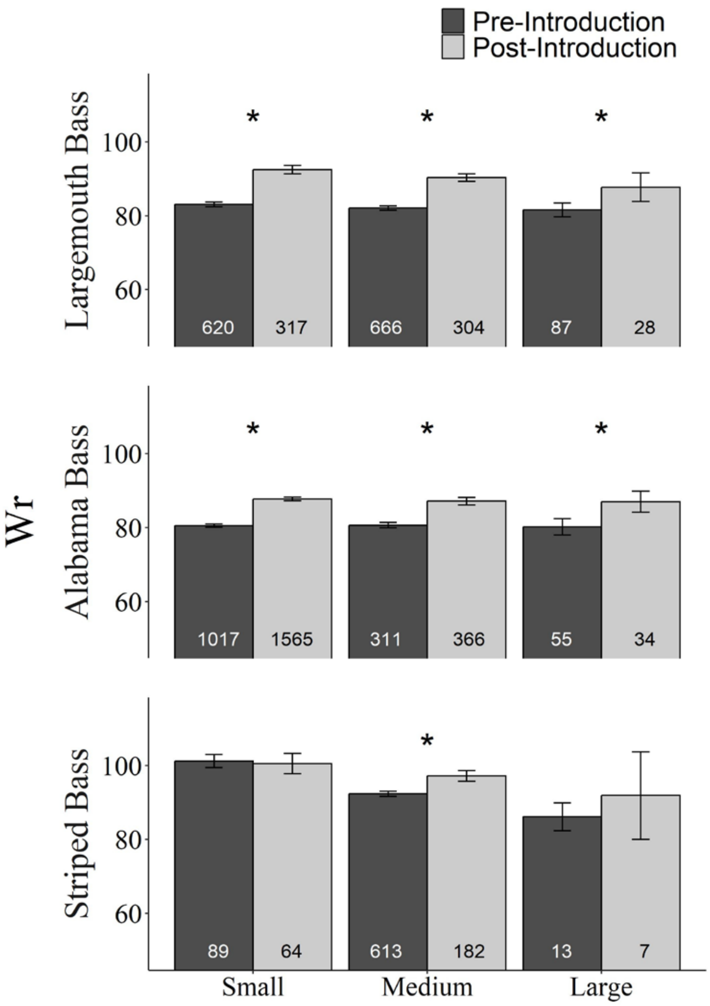

Figure 1. Pre- and post-blueback herring introduction relative weights (Wr; mean ± 95% CI) of largemouth bass, Alabama bass, and striped bass combined across three study areas within Lewis Smith Lake, Alabama. Asterisks indicate significant differences between collections before versus after blueback herring introduction within a species, and sample sizes are listed at the bottom of each bar.

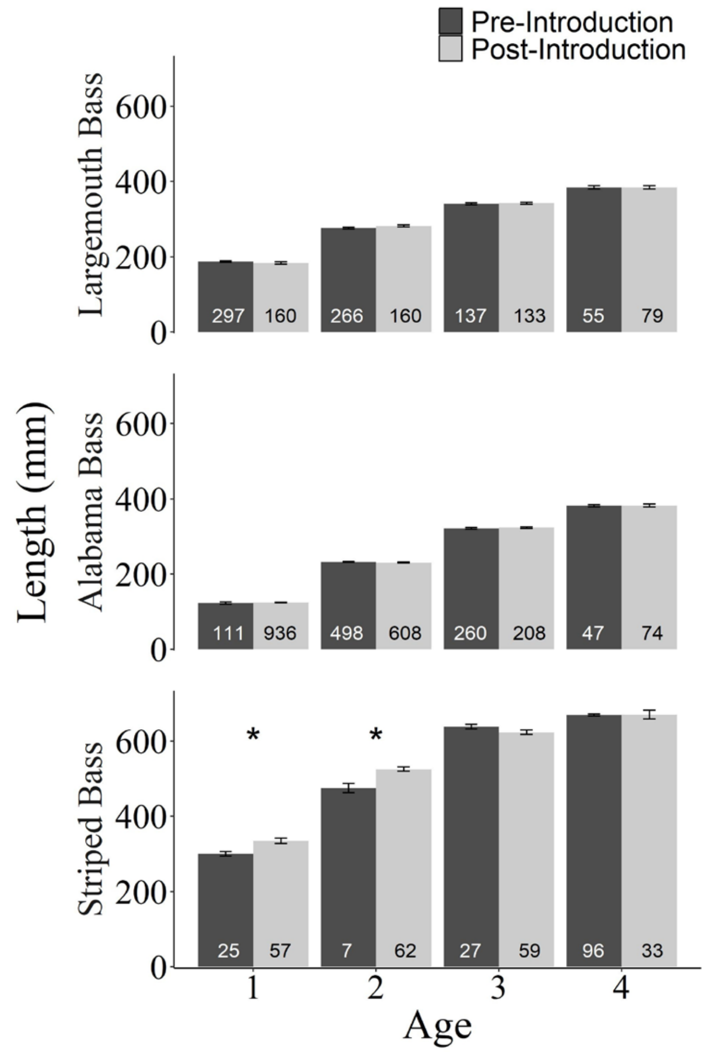

Figure 2. Mean length (mm) at age of largemouth bass, Alabama bass, and striped bass in Lewis Smith Lake, Alabama before and after blueback herring introduction (± SE). Asterisk denotes significant differences in length at age before versus after blueback herring introduction, and sample sizes are listed at the bottom of each bar.

Growth

Mean lengths of age-1 and age-2 striped bass were larger following the introduction of blueback herring (age-1: $t_{73} = -3.61$, $P < 0.0005$; age-2: $t_8 = -3.64$, $P = 0.005$; Figure 2). However, mean lengths by age were similar between time periods for largemouth bass (age-1: $t_{295.0} = 0.94$; age-2: $t_{365.0} = -1.62$; age-3: $t_{268.0} = -0.40$; age-4: $t_{268.0} = -0.049$; $P \geq 0.11$ for all comparisons), Alabama bass (age-1: $t_{122.8} = -0.32$; age-2: $t_{1100.6} = 0.89$; age-3: $t_{432.6} = -0.62$; age-4: $t_{118.7} = -0.12$; $P \geq 0.38$ for all comparisons), and age-3 and age-4 striped bass (age-3: $t_{67.41} = 1.82$, $P = 0.07$; age-4: $t_{35.22} = 0.13$, $P = 0.90$).

Discussion

In this study, we compared condition and growth of three piscivore species in Lewis Smith Lake, Alabama before versus after the introduction of blueback herring and quantified diet composition after blueback herring were established in the reservoir. Existing forage species, including threadfin shad, sunfish, and crayfish contributed the majority of prey biomass for all three of the piscivores in this study despite the introduction of blueback herring. These prey groups provided ~70–90% of biomass of piscivore diets across seasons. However, blueback herring were a seasonally important diet item for some piscivores in the spring and summer. This was apparent for striped bass as their diets were composed of 61% blueback herring in summer compared to 0.3% in winter. Some deep-water reservoirs in the southeastern U.S. provide cool water refuges during the summer for blueback herring and striped bass, which have a cooler thermal maximum limit compared to most native southeastern U.S. fish species found in reservoirs (Nestler et al. 2002, Rice et al. 2013, Sammons and Glover 2013, Bart 2018). Alabama bass differ from largemouth bass in that they prefer deeper, cooler water and are likely using similar thermocline areas during the summer as striped bass and blueback herring (Hunter and Maceina 2008), whereas largemouth bass are commonly found in shallow shoreline areas or coves. This temporary habitat overlap likely explains the greater contribution of blueback herring to the diet of striped bass and Alabama bass during stratification. Given the relatively greater contribution to the diet, previous bioenergetics simulations predicted that Alabama bass and striped bass are most likely to benefit from the introduction of blueback herring (Bart et al. 2021). This increased benefit may be limited to months with the warmest epilimnetic water temperatures and may be leading to the increased relative weight of black basses and medium size striped bass. Further supporting this theory is the increased length-at-age of age-1 and age-2 striped bass.

Any positive effects of blueback herring may be negated if blueback herring were to reduce threadfin shad and gizzard shad populations, which collectively constituted the majority of striped bass diets. If blueback herring outcompete threadfin shad and become the dominant zooplanktivore in the system, the impacts could be potentially negative for striped bass, given the importance of threadfin shad as prey (Shepard and Maceina 2008, Bart et al. 2021), unless striped bass were to increase their consumption of blueback herring to compensate. Already, relative abundance of threadfin and gizzard shad have apparently declined following the introduction of blueback herring (C. McKee, personal observation). Largemouth bass are less likely to be impacted by the introduction of blueback herring because of greater reliance on sunfish and crayfish as prey items but could still suffer direct competition at larval stages or larval and egg predation. Positive impacts on Alabama bass due to the blueback herring introduction might be expected to result in both increased relative weight and individual growth given the level of contribution to their diets compared to largemouth bass and striped bass diets. However, significant increases were only observed for relative weight. Potential reductions in *Dorosoma* spp. abundance may limit impacts to Alabama bass growth as blueback herring replace shad in their diets. Alternatively, the increase in Alabama bass CPE after the blueback herring introduction could indicate that increased energy from blueback herring in Alabama bass diets may be allocated to reproduction rather than growth. However, these changes in CPE may be due to other factors that are changing in the reservoir that confound responses to the blueback herring introduction. As with most introductions, not all impacts are negative. Even though blueback herring are not contributing greatly to piscivore diets, known differences in caloric density compared to native prey may be responsible for the observed increased relative weights in this study (Bart et al. 2021).

Caution should be exercised when considering management activities that could potentially lead to the spread of blueback herring given the potential negative consequences for fish populations, aquatic communities, and ecosystem function (Johnson and Goetll 1999, Ellis et al. 2011, Vivian and Frazer 2021). Unintended consequences could also impact angler success and potentially cause a negative economic impact. For example, the striped bass fishery is an important economic activity for the area surrounding Lewis Smith Lake and negative impacts to the fishery could also result in fewer trips and reduced angler spending (Lothrop et al. 2014). Unfortunately, introductions are sometimes facilitated by individuals who are only interested in the potential positive effect the introduction might have on the species in which they are interested. Clearly a full understanding of the complexity of interactions that can occur when novel and potentially invasive species are introduced is needed (Johnson et al. 2009). In this instance, desired benefits to native predators are not yet manifesting, and the risks associated with blueback herring introductions do not appear to be worth the perceived benefits.

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