

**Evaluating the Potential Impacts of the Introduced Blueback Herring, *Alosa aestivalis*, on
the Aquatic Communities in Lewis Smith Lake, Alabama**

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science
Auburn, Alabama

Auburn, Alabama
May 8, 2016

Keywords: Blueback Herring, diet overlap, age-and-growth

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Abstract

Reservoir food webs are complex, making prediction of the influence of introducing new species difficult. Blueback Herring *Alosa aestivalis* were first discovered in Lewis Smith Lake, Alabama in 2010 and both positive and negative effects are likely to be expressed depending on the species and life stage being affected. Responses elsewhere in the Southeastern U.S. have demonstrated that Blueback Herring can compete with other fishes for zooplankton at multiple life stages. Alternately, introductions might increase prey availability for piscivores and increase piscivore growth and condition. I sampled all life stages of Blueback Herring and resident sport fishes in Lewis Smith Lake over 2 years (2013-2014). High diet overlap between juvenile and adult Blueback Herring and both larval *Lepomis spp.* and adult Threadfin Shad *Dorosoma petenense* for zooplankton prey suggests a potential for competition across multiple life stages. When comparing pre-Blueback Herring data with post-Blueback Herring data, I found significant increases in relative weights of adult Alabama Bass *Micropterus henshalli* and Largemouth Bass *Micropterus salmoides*, and Striped Bass *Morone saxatilis*. Clearly resident fishes will experience a complex mix of positive and negative responses to Blueback Herring introductions, and the overall effect will be some combination of these. Additional research is required to fully quantify these effects and potential effects.

Acknowledgments

I would first like to thank my co-advisors, Dr. Dennis DeVries and Dr. Russell Wright for their guidance and for giving me the opportunity to work under their direction. I would also like to thank my committee member Dr. Matt Catalano for volunteering his time and valuable input on my thesis. I would especially like to thank Tammy DeVries for her invaluable help with lab work and processing countless samples. She definitely helped in more ways than I can name. I would like to thank all of the technicians and fellow graduate students who helped me along the way with fish work-ups and field work: Emily DeVries, Bailey Burdg, Braxton Setzer, Jake Blackstock, Johnathan Wittmann, Adrian Stanfill, Ben Staton, Chris Kemp, Sean Lusk, Nick Feltz, Carl Klimah, and Jeff Buckingham. I would also like to thank Dr. Mike Maceina for generously sharing the historical lake data with me. A special thanks is extended to my wife, Dr. Laura Jay Grove, for her help and support through this process. Lastly, I would thank the Alabama Department of Conservation and Natural Resources for funding this project.

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Introduction

Intentional stocking of freshwater systems with additional prey fish species has historically been a common management practice. The goal of stocking additional forage fish species is to enhance sport fish populations through food web manipulation by increasing available prey to piscivorous fish (Ney 1981; Noble 1981; Wydoski and Bennett 1981; Noble 1986). Stocking of prey fishes can be beneficial to the system, although in reality the results of food web manipulation have proven to be more complex than anticipated, due to varying fish behaviors, size-specific interactions, and diverse life histories (Prince and Barwick 1981; DeVries and Stein 1990). Altering the existing food web in a system can lead to shifts in diet, habitat use, growth and development, increased variation in year-class strength, and eventual alterations in abundance of resident fishes. Further, the introduction of prey species may lead to increased competition among species, which can lead to altered habitat overlap and variable or reduced recruitment. For example, Gizzard Shad *Dorosoma cepedianum* has been introduced into systems to provide additional prey fish for piscivores and has been shown to potentially compete with resident species at larval and juvenile life stages (Davis and Foltz 1991; Stein et al. 1995). Competition across multiple life stages can affect the overall abundance and fitness of both sport fishes and forage fishes.

Ontogenetic shifts in diet make it difficult to predict the effects of prey fish introduction given that timing of diet shifts in piscivores differs among species (Olson 1996; Ludsin and DeVries 1997; DeVries et al. 2009). For example, crappies *Pomoxis spp.*, can take several years to switch from a diet of mostly zooplankton to a diet consisting of mainly fish. In contrast, other piscivorous fish species such as Largemouth Bass *Micropterus salmoides*, and potentially Spotted Bass *Micropterus punctulatus* and Alabama Bass *Micropterus henshalli*, transition to

piscivory relatively quickly (Seaburg and Moyle 1964; Muoneke et al. 1992; Ludsin and DeVries 1997; Jackson and Noble 2000; Pine and Allen 2001; Tuten et al. 2008). The prolonged consumption of zooplankton by crappie species make them more likely to be negatively impacted by an introduced zooplanktivorous prey species due to potential extended dietary overlap during early life compared to other piscivorous fish species that transition to a piscivorous diet more quickly (Guest and Drenner 1989). Species that shift to piscivory more quickly could experience some positive effects from a prey fish introduction.

One particular prey species that has been introduced in many inland lake and reservoirs is Blueback Herring *Alosa aestivalis*. While information from previous introductions of this species is limited, responses in those systems indicate some effects that might be expected. Blueback Herring are anadromous with an endemic range extending from St. Johns River, Florida, to Prince Edward Island, Canada in the northwest Atlantic Ocean (Loesch 1987; Bozeman 1989). Previous research has found that landlocked populations of introduced Blueback Herring are capable of reproducing and developing self-sustaining populations (Bulak and Walker 1979; Prince and Barwick 1981; Nestler et al. 2002). In addition, early work has suggested that even though they may be desirable as additional prey, they have the potential to compete with other fish species in the system as described above for Gizzard Shad (Prince and Barwick 1981). A classic paper by Brooks and Dodson (1965) documented the dramatic effects that landlocked Blueback Herring can have on small landlocked lakes. These authors found that this species had the ability to reduce large zooplankton abundance, leading to an overall reduction in zooplankton size in the system (the “size-efficiency hypothesis”).

Since the seminal study by Brooks and Dodson (1965), Blueback Herring have been introduced (both unintentionally and intentionally) to a number of Southeastern US reservoirs

(Prince and Barwick 1981; Guest and Drenner 1989; Nestler et al. 2002; Kibler 2004). These introductions have had varied impacts on resident fishes. Anecdotal evidence led to the belief that species such as Spotted Bass, Alabama Bass, and Striped Bass *Morone saxatilis* would transition to feeding on Blueback Herring and may exhibit increased growth after Blueback Herring introductions. Lake Burton, Georgia is often used as an example of a successful Blueback Herring introduction. Shortly after the stocking of Blueback Herring, the recreational angling state record for Spotted Bass was caught from the reservoir (Kibler 2004). However, since the catch of the state record occurred before populations of Blueback Herring would have likely contributed significantly to piscivore growth in the lake, it is likely that the state record Spotted Bass and the Blueback Herring introduction were simply co-occurring events with no causal linkage. Also, there is some evidence that Blueback Herring will not compete with the native forage due to consumption of different sized zooplankton individuals (Davis and Foltz 1991).

Even though positive outcomes have been observed after some Blueback Herring introductions, documented effects to date seem to be predominantly negative. Blueback Herring have the potential to directly affect sport fish populations through egg predation and by consuming larval fish (Bulak and Walker 1979; Guest and Drenner 1991; Goodrich 2002; Winkleman and Van Den Avyle 2002; Wheeler et al. 2004). For example, in North Carolina, Walleye *Sander vitreus*, populations in Lake Glenville and Hiwassee Reservoir, and Largemouth Bass populations in Lake Norman were reported to decline after the stocking of Blueback Herring (Wheeler et al. 2004). In Georgia, Lake Burton experienced a complete year-class failure of Largemouth Bass as well as decreased abundances of both Black Crappie *Pomoxis*

nigraomaculatus and White Bass *Morone chrysops* which may have been related to the introduction of Blueback Herring (Wheeler et al. 2004).

The limited studies completed to date on the effects of Blueback Herring on their prey in landlocked systems have found negative impacts. For example, on Lake Theo, Texas, Blueback Herring were found to primarily consume cladocerans having mean lengths greater than the mean lengths found in the lake; however, they did not find community shift from large cladocerans spp. toward smaller cladoceran spp. as expected based the effect observed by Brooks and Dodson (1965). Instead they observed a shift in the system from predominately cladocerans to copepods (Guest and Drenner 1991). Shifts in the zooplankton community from cladocerans to copepods can greatly reduce the available forage for planktivores because copepods tend to be more difficult prey to capture than cladocerans (Drenner et al. 1978).

Blueback Herring may negatively impact resident fishes though indirect and direct competition with other forage species and piscivorous sport fish species. Direct competition with Threadfin Shad *Dorosoma petenense*, Gizzard Shad *Dorosoma cepedianum*, and sunfish *Lepomis spp.* can lead to population reductions (Prince and Barwick 1981; DeVries and Stein 1990; Davis et al. 1991). Given this, increased Blueback Herring abundance can lead to decreased abundance of prey for piscivorous sport fishes like Largemouth Bass and crappies *Pomoxis spp.* This is in part because previous work has shown that Blueback Herring spend more time in the pelagic zone away from typical Largemouth Bass habitat in southern reservoirs and limited habitat overlap reduces the available forage fish for Largemouth Bass and crappie spp. which could result in population declines (Bozeman et al. 1989; Nestler et al. 2002). Furthermore, it has been suggested that other piscivorous species such as the Alabama Bass and Striped Bass may feed on Blueback Herring more effectively than does Largemouth Bass due to

their pelagic feeding tendencies and habitat use. The complexity of competition between forage species and alteration of competition among piscivorous species due to the introduction of Blueback Herring will be unique to each system (e.g., depending on its productivity, morphometry, hydrology, etc.) which makes predicting the overall effects this species will have on a given system difficult (Prince and Barwick 1981; Carpenter 1988; DeVries and Stein 1990; Davis et al. 1991). Given, the diverse outcomes with other species introductions more work is required to investigate the specific interactions of the Blueback Herring introduction into Lewis Smith Lake.

Here I will describe the results of a study designed to quantify the impacts (both positive and negative) that an introduced population of Blueback Herring has on the resident fishes in an Alabama Reservoir. I will quantify their potential interactions at all life stages and with the dominant resident prey and piscivorous species.

Methods

Study Site

Lewis Smith Lake is a large (8,538 ha) mesotrophic reservoir located in north central Alabama, USA (Cullman, Walker, and Winston counties) in the Mobile River Drainage, characterized by three major branches (Ryan Creek, Rock Creek, Sipsey Fork), steep banks, rocky substrate, and deep waters (maximum depth over 100 m; Figure 1). The branches have known differences in abiotic conditions (e.g., water clarity and primary production; see Table 1 in Allen et al. 1999). The lake is home to a number of recreational sport fish species including Largemouth Bass, Alabama Bass, and Striped Bass, all of which are commonly sought by local anglers. The Striped Bass fishery in Lewis Smith Lake has been estimated to have a local economic impact of more than \$2 million (Lothrop 2012). In 2010, Lewis Smith Lake was the

first reservoir in Alabama to document the establishment of Blueback Herring populations. It remains unknown how this species was introduced to the lake; however, it appears that within the few years following the first reported individuals this species has spread throughout the lake.

All sampling was conducted from January 2013 through November 2014 in Lewis Smith Lake. To account for spatial variation in, abiotic and biotic conditions across the reservoir, samples were collected from each of four major areas (Ryan Creek, Rock Creek, Sipsey Fork and the Dam Forebay). To account for longitudinal variation within each sampling area, two sample sites (one downstream and one upstream) were established within each of the three river branches (Ryan Creek, Rock Creek, Sipsey Fork); the Dam Forebay site had a single sampling area due to its smaller size. For consistency throughout this paper, downstream sites are designated with “A” and upstream sites with “B”. The precise locations that were sampled within each sampling site necessarily varied a small amount seasonally to account for fish movement and changes in lake water level. This adjustment to seasonal fish movements was important to accurately evaluate temporal variation in diets of larger predatory fish (Schaffler et al. 2002; Nestler et al. 2002).

Environmental Factors

Water quality data were collected at each site during every sampling trip. Water clarity was measured as Secchi depth (nearest cm) on the shaded side of the boat. Chlorophyll-a samples were collected from just below the water surface in an opaque brown plastic bottle (500 ml), immediately placed on ice, and returned to the lab where they were filtered through a glass fiber filter, extracted using 95% ethanol and chlorophyll-a concentrations quantified with a standard handheld fluorometer (AquaFluor, Turner Designs, Sunnyvale, CA; Welschmeyer 1994). Chlorophyll-a data from March, April, May, and June of 1992 – 1994 (D. DeVries,

unpublished data) were used for historical/pre-Blueback Herring comparisons. The effect of month and year (current and historical) on an abiotic factor (i.e., water clarity or chlorophyll-a) was tested for statistical significance with a one-way, mixed-model repeated measures ANOVA using first order autoregressive error structure where site was the random factor and month was the repeated measure (SAS statistical software, v 9.3). When the ANOVA detected significant differences, a Tukey-Kramer multiple comparisons post-hoc test was used to identify specific differences when main effects differed significantly.

Zooplankton

Two zooplankton samples were collected during daylight hours at each site on every sampling date via a vertical net tow (64- μ m mesh) through the photic zone (measured as approximately twice the Secchi depth to the surface). Samples were immediately preserved in 75% ethanol and returned to laboratory for processing. Zooplankton were counted and identified to the lowest practical taxonomic level. Ten individuals per taxon were measured from each sample. As with the water quality parameters, zooplankton data from 1992 to 1994 (D. DeVries, unpublished data) were used as an historical/pre-Blueback Herring comparison. A one-way mixed-model repeated measures ANOVA, using first order autoregressive error structure where site was the random factor and month was the repeated measure, was used to quantify differences in zooplankton density by site and time period (1992 to 1994 and 2013 to 2014) and a Tukey-Kramer multiple comparisons post-hoc test was used to identify specific differences.

Larval Fish

Larval fish sampling began in February 2013 and continued through September 2014. Larval fish were sampled at each of the 7 sites every other week during spring and summer and sampling continued until larval fish were no longer present each year. Larval fish were sampled

at night during 2013 and during the day in 2014. Time of sampling was changed in 2014 because night collections for diets of larval fish were unsuccessful (i.e., all stomachs were empty) and more full diets have been observed during the day in previous research with clupeids (Dettmers and Stein 1992). Two 5-minute larval fish tows were collected at each of the 7 sites using a 500- μ m mesh net with attached flow meter (General Oceanics, Inc., Miami, FL) towed at a speed of 1 – 1.5 m/sec. Samples were filtered through a 50- μ m sieve and collected larval fish were preserved in 75% ethanol and returned to the laboratory for further analysis.

In the laboratory, all larval fish were counted and identified to the family level, and to the genus and species level if possible. Myomere counts were used to distinguish among Gizzard Shad, Threadfin Shad, and Blueback Herring (Wallus and Simon 2008). Differences in larval fish density ($\#/m^3$) by site and time period (month and year) was assessed with a one-way mixed-model repeated measures ANOVA, using first order autoregressive error structure where site was the random factor and month was the repeated measure, and a Tukey-Kramer multiple comparisons post-hoc test was used to test for differences on specific dates. Diet items of larval crappies, Gizzard Shad, Threadfin Shad, Blueback Herring, and *Lepomis spp.* were identified to the lowest taxonomic rank.

Juvenile and Adult Fish Collection

Juvenile and adult fishes (Largemouth Bass, Alabama Bass, crappies, Striped Bass, Threadfin Shad, Gizzard Shad, and Blueback Herring) were collected at night by electrofishing or with gill nets from January 2013 through November 2014. From January through September 2013 both collection methods were used once per month. Beginning in October 2013, collection methods alternated on a monthly basis for the remainder of the study. Electrofishing samples used of two pulsed-DC (Smith Root 7.5 GPP) 10-minute transects at each sampling site. Gill-net

sampling at each site consisted of three gill-nets with different mesh sizes: a 100' x 8' x 1" mesh net, a 125' x 8' experimental net with 5 – 25' panels with mesh sizes ranging from 2" to 6", and a 125' x 8' experimental net with 5 – 25' panels with mesh sizes ranging from 3" to 7". To maximize seasonal catch rates, gill-nets were set at deeper depths during summer and shallower depths during winter to accommodate fish movement due to temperature tolerances of Striped Bass and Blueback Herring (Schaffler et al. 2002; Nestler et al. 2002; Brandt et al. 2009). Nets soaked for 6 hours, after which all collected fish were removed, placed on ice, and returned to the lab for further processing. All fish collected with gill nets or electrofishing gear were euthanized with MS-222 and immediately stored on ice. In the lab, juvenile and adult fishes were weighed (nearest g), measured (mm), their otoliths removed, and stomachs removed and stored in 95% ethanol.

Hydroacoustic surveys were completed in August 2014 to estimate the relative abundance and size structure of pelagic fishes (Blueback Herring, Threadfin Shad, and Striped Bass). Transects began in the head waters of each major branch and continued to the dam. Single targets were assigned to species based on estimated fish sizes and known thermal tolerances. Abundance and size were estimated through target strength analysis and echo integration. Species were identified using size estimates and known thermal tolerances. Because of the thermal tolerances of Blueback Herring and Striped Bass they were the only fish located below the thermocline, which was validated with gill nets. Estimated size was then used to identify if fish target. We used Echoview software (v 6.1) to analyze the data. Vertical data were processed with 1-m strata from 2 m below the surface to near bottom. Data were manually edited to remove bottom signals or noise. I output single targets that met the following criteria: a -60dB threshold, a pulse length of 0.5 to 1.5 times the transmitted pulse length at -6 dB within 6

dB of the center of the transducer beam, and a standard deviation of the angles (minor and major axis) of all samples within the pulse envelope of <0.6 . Echo integration provided total reflected voltages that were converted to absolute areal abundance through scaling voltages by mean backscattered cross section, conducted separately for vertical data strata (Simmonds and MacLennan 2005). Abundance estimates were obtained for each 250-m transect within the sample/cruise track.

Catch-per-unit-effort (CPUE) for each gear type was calculated for Blueback Herring and Threadfin Shad as the mean number of fish collected per hour of effort. Differences in CPUE across sites and time periods (month and year) were tested with a mixed-model repeated measures ANOVA, using first order autoregressive error structure where site was the random factor and month was the repeated measure, and a Tukey-Kramer multiple comparisons post-hoc test was used to identify specific differences.

Larval, Juvenile and Adult Diet Analyses

Diets of all Largemouth Bass, Striped Bass and crappie spp., were quantified. Given the large number of Alabama Bass, Threadfin Shad, and Blueback Herring collected, diets of 10 individuals were randomly selected for each sample date. Fish diets were examined under a dissecting microscope and lengths of all prey measured. Fish prey were identified to genus (species when possible), larger invertebrate prey (e.g., crayfish) were identified to family, and zooplankton were identified to genus (species when possible).

Severely decomposed prey fish were identified by otolith morphology (unpublished data). To estimate the biomass of prey consumed, species-specific length-weight regressions were applied to the individual diet items and the total mass estimated by summation. Individual species length-weight regressions were taken from unpublished information or generated using

intact collected examples of the species from the field. Prey biomass estimates were then used to calculate diet proportions for each individual predator. All zooplankton in the diet were counted and the first ten individuals from each taxon were measured (body length, nearest mm). Mean zooplankton length in the environment versus what was consumed by Threadfin Shad and Blueback Herring were compared with a one-way ANOVA and a Tukey-Kramer multiple comparisons post-hoc test was used to show specific differences.

Schoener's overlap index was used to evaluate the potential for competition between fish species at larval, juvenile, and adult life stages as follows:

$$overlap = 1 - 0.5 \left(\sum_{i=0}^n |r_{xi} - r_{yi}| \right),$$

where r_{xi} and r_{yi} represent the proportion of prey type i in the diet of species x and y respectively, and n = number of prey types (Schoener 1970). Diet overlap was calculated between adult Blueback Herring versus pelagic larval fishes (crappies and *Lepomis spp.*), juvenile Threadfin Shad, and adult Threadfin Shad. Diet comparisons involving larval clupeids (Threadfin Shad, Gizzard Shad and Blueback Herring) were not possible because all sampled stomachs were empty (see results).

Prey selection by adult Blueback Herring, adult Threadfin Shad, larval sunfishes and larval crappies was quantified using Chesson's alpha for 2013 and 2014 as follows:

$$\alpha = \left(\frac{r_i}{p_i} \right) / \sum_i^m \left(\frac{r_i}{p_i} \right),$$

where p_i = proportion of prey type i in the zooplankton sample, r_i = the proportion of prey type in the predator's diet, and m = number of available prey types. Neutral selection is defined as $\alpha = 1/m$ where a prey type is eaten in proportion to the environmental occurrence (Chesson 1978,

1983). Alpha was calculated for each prey type consumed by an individual fish and a mean for each prey type was calculated for each species.

Biomass in fish diets was calculated for all sampled prey taxa. Prey biomass percentages were calculated for each predator fish species. To account for the consumption of more prey items by larger fish, estimated prey biomass was divided by predator weight. The percent of each prey type consumed was calculated for each individual predatory fish and then averaged across individuals within a species. Prey selection was quantified by season and year for species with piscivorous diets using chi-squared goodness-of-fit analysis that assumed each prey type had equal opportunity of capture.

Growth and Condition

Fish age was estimated for all collected fish from sagittal otoliths. One otolith was independently aged for each fish by two separate readers and if the readers agreed, that age was accepted. If the readers did not agree, the otolith was re-examined by both readers. If an agreement on age was still not reached, the otolith was sectioned transversely using a low-speed diamond bladed saw (South Bay Technologies Model 650) and mounted to a slide where it was re-examined using a compound microscope by both readers. All Striped Bass and Blueback Herring otoliths were particularly difficult to read and required additional processing (see below), and all were read under a compound microscope. Striped Bass otoliths were sectioned and mounted to a slide to increase clarity. Each Blueback Herring otolith was mounted to a slide and sanded from the convex side of the otolith to better reveal the growth rings. All otoliths (whole and mounted) were measured from the focus to the posterior-most end of the 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):

$$L_i = (S_i/S_c) L_c;$$

where L_i is the back calculated length of the fish at the formation of the i th increment, L_c is the length of 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 was estimated with the von Bertalanffy (1938) growth equation using back-calculated length-at-age data (most recent annulus) collected in 2013 and 2104. Maximum likelihood analysis was done in R statistical software (v 3.2.2) with the following equation:

$$L_t = L_\infty(1 - e^{-k(t-t_0)})$$

here L_t = length at time t , L_∞ = maximum theoretical length, k = growth rate, t = time, and t_0 = time when length would be zero.

Body condition was evaluated by calculating relative weight for each species:

$$Wr = (Wt/Ws) * 100;$$

where Wr is the relative weight, Wt is the weight of the fish (g), and Ws is the length-specific standard weight predicted by a length-weight regression fish species (Neumann et al. 2012). Relative weight was calculated for all collected Largemouth Bass, Alabama Bass, and Striped Bass. To evaluate effects of the Blueback Herring introduction on piscivorous fishes, relative weights from fish collected before the Blueback Herring introduction (Sheppard and Macenia, unpublished data) were compared to post-Blueback Herring introduction data (present study) using a one-way ANOVA and a Tukey-Kramer multiple comparisons post-hoc test.

Mortality

A catch-curve analysis was used to estimate total instantaneous mortality (Z) for Largemouth Bass, Alabama Bass, and Striped Bass with the following regression equation:

$$\ln(N_t) = \ln(N_o) - Z(t),$$

where $\ln(N_t)$ is the natural logarithm of the number of fish in a year class at time t , $\ln(N_o)$ is the natural logarithm of the original number of fish in a year class, and Z is the instantaneous rate of total annual mortality. Average annual survival was calculated as

$$S = (N_{t+1}/N_t) = e^{-z},$$

where S is survival and Z is total instantaneous mortality. Total annual mortality (A), was calculated as $A = 1 - S$. This analysis operated under the assumptions of constant recruitment, equal survival between year classes, equal survival between years, natural and fishing mortality being the same each year, and that data are representative of the true age structure (Maceina 1997).

Results

Environmental Factors

Water clarity differed significantly among sample sites ($F_{6, 164} = 10.76$, $P = 0.006$), with upstream sites generally having shallower Secchi depths than downstream sites (the Sipsey Fork branch was the lone exception) (Table 1; Figure 2). Turbidity showed similar patterns (Table 1). In addition, chlorophyll-a concentrations differed significantly across sample sites ($F_{6, 169} = 10.14$, $P = 0.006$), being greatest in the upstream sites in Rock Creek and Ryan Creek. Historical (i.e., pre-Blueback Herring) chlorophyll-a concentrations did not differ from measurements in the current study ($F_{2, 45} = 9.41$, $P = 0.06$; Figure 4).

Zooplankton density differed significantly across sites similar to results for Secchi depth and chlorophyll-a concentration ($F_{6, 74.5} = 5.28$ and $P = 0.0001$), with upstream sites at Rock

Creek and Ryan Creek being greatest (Table 1, Figure 5). Historical (i.e., pre-Blueback Herring) zooplankton densities did not differ from current zooplankton densities at any site (Figure 6).

Larval Fish Density

Eight species/groups of pelagic larval fishes were collected in 2013 and 2014 including, Threadfin Shad, sunfishes, minnows, Gizzard Shad, crappies, catfishes, Brook Silverside, and Blueback Herring. Densities among these groups differed significantly ($F_{8, 818} = 36.88$, $P < 0.0001$). Two general spawning periods were observed. Larvae from early spawners were observed from April to June while larvae from late spawners were present from May to September. Blueback Herring spawned early (April – June) and their larvae co-occurred with larval Threadfin Shad, Gizzard Shad, and crappies. In contrast, larval sunfishes, minnows, catfishes, and Brook Silverside peaked in abundance during summer and experienced relatively little temporal overlap with larval Blueback Herring (Figure 7). Threadfin Shad was generally the most abundant clupeid larval fish collected (Figure 8). During April – June larval Threadfin Shad density (0.06 ± 0.03 fish/m³; mean \pm SE) was significantly greater than larval Blueback Herring density (0.02 ± 0.03 fish/m³, $P = 0.02$) and larval Gizzard Shad density (0.02 ± 0.03 fish/m³, $P = 0.03$). During July-September, Brook Silverside was the most abundant larval fish (0.26 ± 0.03 fish/m³) and had significantly greater ($P < 0.0001$) densities than larval sunfishes (0.05 ± 0.03 fish/m³; Figure 9). Unfortunately, all that was available for the historical comparisons were mean values, so no statistical comparisons could be made with the current results. However, the mean larval fish densities from March to June of 1992, 1993 and 1994 were greater for Threadfin Shad and Gizzard Shad relative to those from the present study (Figure 10).

Blueback Herring and Threadfin Shad CPUE

Both sampling methods (electrofishing gear and gill nets) yielded highly variable CPUE values for Blueback Herring and Threadfin Shad. Overall, Blueback Herring tended to have higher mean CPUEs than Threadfin Shad for both electrofishing and gill netting (Figures 11, 12), but no statistically significant differences were detected ($F_{1,36} = 1.71, P = 0.22$). Hydroacoustic surveys were completed in August 2014 to more accurately quantify the abundance of clupeid fishes. Given the electrofishing and gill net results, we expected that Blueback Herring would be the most abundant clupeid. However, hydroacoustic surveys suggested that Threadfin Shad were more abundant than Blueback Herring (Figure 13).

Zooplanktivore Diets

Larval fish diets were collected from sunfishes, crappies, Gizzard Shad, Threadfin Shad, and Blueback Herring. All stomachs collected from Threadfin Shad, Gizzard Shad and Blueback Herring were empty and will not be considered further. Due to low sample sizes, larval sunfish ($n = 56$) and crappie ($n = 74$) diets were compared across sites and years. Larval sunfishes predominantly consumed *Bosmina* (77% by number) and lesser quantities of cyclopoid copepods (7%), and calanoid copepods (2%). In contrast, larval crappies primarily consumed copepod nauplii (74%) followed by *Bosmina* (15%), cyclopoid copepods (8%), and calanoid copepods (2%; Figure 14).

Adult and juvenile Threadfin Shad and Blueback Herring diets were compared for those dates on which these species co-occurred in my samples (January – June, in both years). Over 98% (by number) of Threadfin Shad and Blueback Herring diets consisted of *Bosmina*, *Daphnia*, calanoid copepods, and cyclopoid copepods. Blueback Herring predominantly consumed

Bosmina (41%) followed by cyclopoid copepods (31%), calanoid copepods (16%) and *Daphnia* (11%). Threadfin shad mainly consumed *Bosmina* (58%) followed by cyclopoid copepods (33%), and *Daphnia* (8%; Figure 15). Overall, Blueback Herring stomachs contained significantly more zooplankton than Threadfin Shad ($F_{1, 1052} = 110$, $P < 0.0001$), as well as more *Bosmina* (mean \pm SE; 1799 ± 678 individuals versus 51 ± 27 individuals; $P < 0.0001$), *Daphnia* (967 ± 637 individuals versus 18 ± 24 individuals; $P = 0.0001$), calanoid copepods (1240 ± 659 individuals versus 1; $P = 0.0016$), and cyclopoid copepods (1294 ± 328 individuals versus 34 ± 31 individuals; $P < 0.0001$; Figure 16).

Blueback Herring selectively consumed larger sizes of zooplankton ($F_{2, 1412} = 119.3$, $P < 0.0001$; 0.39 ± 0.02 mm; mean \pm SE) than either the average size found in the environment (0.27 ± 0.007 mm; $P < 0.0001$) or in Threadfin Shad diets (0.28 ± 0.03 mm; $P < 0.0001$; Table 2), when considering all months and sites. April was the only month during which Blueback Herring and Threadfin Shad diets overlapped and size of zooplankton they consumed did not differ ($P = 0.99$). Only during one individual month (May) did Blueback Herring not consume zooplankton sizes significantly larger than those in the environment ($P = 0.57$); they consumed significantly larger sized zooplankton during all other months. In contrast, Threadfin Shad typically consumed zooplankton sizes that did not differ from those available in the environment (January $P = 1.0$, March $P = 0.71$, April $P = 0.99$ and May $P = 0.34$; Table 2, Figure 17).

Zooplankton size selected by Blueback Herring versus Threadfin Shad varied by prey type and site ($F_{74, 1340} = 56.76$, $P < 0.0001$). Notably, consumption of larger *Bosmina* by Blueback Herring was observed in January at Sipsey Fork A ($P = 0.02$), and in March at both Rock Creek A ($P = 0.03$) and Ryan Creek B ($P = 0.002$). Blueback Herring consumed larger cyclopoid copepods relative to Threadfin Shad at multiple sites including Rock Creek A ($P =$

0.04), Ryan Creek B ($P = 0.002$) and Sipsy Fork B ($P = 0.02$) in March. Larger *Daphnia* were consumed by Blueback Herring versus Threadfin Shad at Rock Creek B in March ($P = 0.02$). Calanoid copepods were found in the diets of Blueback Herring and Threadfin in two samples and were significantly larger in Blueback Herring diets versus Threadfin Shad diets at Rock Creek A in March ($P = 0.0003$). Threadfin never consumed significantly larger zooplankton than Blueback Herring at any site or during any month (Table 3, Figure 18).

Similarly, Blueback Herring generally selected significantly larger zooplankton compared to the mean available in the environment ($F_{6, 1408} = 11.15, P < 0.0001$). In January, larger calanoid copepods were readily selected at most sites including Rock Creek A and B ($P = 0.0002$ and $P < 0.0001$), Ryan Creek B ($P < 0.0001$), and Sipsy Fork A ($P < 0.0001$) while larger *Bosmina* were selected at a single site (Sipsy Fork A, $P = 0.022$). In March, larger *Bosmina* and cyclopoid copepods were both regularly selected at the same sites including Rock Creek A and B (*Bosmina* $P = 0.0031$ and $P = 0.0031$, respectively, and cyclopoid copepods $P = 0.0028$ and $P < 0.0001$, respectively), Ryan Creek B (*Bosmina* $P = 0.0011$ and cyclopoid copepods $P < 0.0001$), and Sipsy Fork B (*Bosmina* $P = 0.0461$ and cyclopoid copepods $P = 0.0005$) while larger *Daphnia* were selected at a single site (Rock Creek B, $P < 0.0001$). In May, larger *Bosmina*, *Daphnia*, calanoid copepods, and cyclopoid copepods were selected from Ryan Creek B ($P = 0.0167$, $P = 0.0212$, $P < 0.0001$, and $P = 0.0007$, respectively; Table 3, Figure 18).

In all months, Threadfin Shad consumed *Bosmina* and calanoid copepods whose sizes did not differ from that in the environment. Threadfin shad only consumed larger zooplankton compared to the environment at a single site (Rock Creek B) during two months. In March, larger *Daphnia* ($P = 0.04$) and cyclopoid copepods ($P = 0.0058$) were consumed and in April, larger cyclopoid copepods ($P = 0.024$) were consumed (Table 3, Figure 18).

Diet Overlap and Prey Selection

Diet overlap was calculated between adult Blueback Herring and both larval *Lepomis* spp. and larval crappies to estimate any potential effects of Blueback Herring on resident fishes; I did this given that all are zooplanktivores and the diets of larval Blueback Herring, larval Threadfin Shad, and larval Gizzard Shad were all empty. Schoener's index was calculated for the period between March and August (2013 and 2014) to include diets of Blueback Herring during spawning. The highest diet overlap and the strongest potential for competition was found between adult Blueback Herring and larval sunfishes (Schoener's index = 0.70); Schoener's overlap between adult Blueback Herring and larval crappies was 0.25 (Figure 19).

Prey selection by adult Blueback Herring, larval sunfishes and larval crappies was quantified using Chesson's alpha. Neutral selection in all cases was always $\alpha = 0.125$. Positive selection was considered when the α value was higher than neutral selection and the error (2 time SE) did not overlap with the neutral selection value. Adult Blueback Herring positively selected multiple zooplankton taxa including *Bosmina* (Chesson's $\alpha = 0.35$), *Daphnia* ($\alpha = 0.19$), cyclopoid copepods ($\alpha = 0.27$), and calanoid copepods ($\alpha = 0.18$). Larval sunfishes positively selected for *Bosmina* ($\alpha = 0.37$) and *Diaphasoma* ($\alpha = 0.23$) while larval crappies positively selected for *Ceriodaphnia* ($\alpha = 0.31$) and copepod nauplii ($\alpha = 0.40$). Chesson's alpha results showed that prey selection patterns were similar for adult Blueback Herring and larval sunfish, while larval crappies positively selected different taxa than both adult Blueback Herring and larval sunfish (Table 4, Figure 20).

Schoener's index was calculated for adult Blueback Herring and adult Threadfin Shad during January through June of both 2013 and 2014 because they co-occurred the most in our gears during this time. Indices were calculated across all sites and we considered three different

time periods: all months (January to June), winter (January – March), and spring (April – June). Overlap values were relatively high in all time periods (Figure 21).

Prey selection by adult Blueback Herring and adult Threadfin Shad was quantified with Chesson's alpha during January to June of both 2013 and 2014 using the three time periods noted above. Neutral selection was always $\alpha = 0.125$. Across all months, Blueback Herring exhibited positive selection for *Bosmina* ($\alpha = 0.41$) and cyclopoid copepods ($\alpha = 0.44$) while Threadfin Shad positively selected for *Bosmina* ($\alpha = 0.18$) and *Daphnia* ($\alpha = 0.68$; Figure 22). From January to March, prey selection patterns of Blueback Herring and Threadfin shad were similar to one another, being positive for both *Bosmina* ($\alpha = 0.43$ and $\alpha = 0.23$, respectively) and cyclopoid copepods ($\alpha = 0.40$ and $\alpha = 0.59$, respectively; Figure 23). During April to June, both adult Blueback Herring and adult Threadfin Shad exhibited positive selected for *Bosmina* ($\alpha = 0.64$ and $\alpha = 0.76$, respectively) and only Blueback Herring positively selected for cyclopoid copepods (0.26; Table 5, Figure 24).

To consider spatial variation in prey selection by adult Blueback Herring and adult Threadfin Shad, Chesson's alpha was compared across both months and sample sites from January through June of both 2013 and 2014. Blueback Herring and Threadfin Shad most frequently selected for *Bosmina* and cyclopoid copepods across multiple month and site. Selection for *Daphnia* occurred less frequently and little pattern in selection was observed. Positive selection for calanoid copepods was more frequent for Blueback Herring than for Threadfin Shad (Table 6; Figures 25 – 31).

Piscivore Diet Selection and Composition

The number of prey in the diets varied by season for adult piscivores (Largemouth Bass $\chi^2_{3, 228} = 39.93$, $P < 0.0001$, Alabama Bass $\chi^2_{3, 258} = 100.48$, $P < 0.0001$ and Striped Bass $\chi^2_{3, 108} = 54$, $P < 0.0001$). During December through February, Largemouth Bass and Alabama Bass tended to consume crayfish disproportionately compared to other prey consumed based on the expected values from the chi squared analysis (66% biomass, $\chi^2_{3, 88} = 87.45$, $P = 0.0002$ and 30% biomass, $\chi^2_{3, 73} = 23.05$, $P < 0.0001$, respectively). While, Striped Bass consumed Threadfin Shad disproportionately to other prey types at 99% of total biomass ($\chi^2_{3, 36} = 54$, $P < 0.0001$). During March through May, Largemouth Bass consumed sunfishes disproportionately to other prey based on the expected values from the chi squared analysis (45% biomass), followed by Threadfin Shad (34% biomass), and Blueback Herring (9% biomass; $\chi^2_{3, 38} = 13.16$, $P = 0.004$; Figure 32). Similarly, Alabama Bass consumed sunfish at disproportional levels (37% biomass) and Blueback Herring (10% biomass; $\chi^2_{3, 42} = 13.24$, $P = 0.004$; Figure 33). During June through August, proportions of prey consumption varied greatly between predator fishes. Largemouth Bass disproportionately consumed sunfish (45% biomass; $\chi^2_{3, 72} = 35.56$, $P < 0.0001$), while Alabama Bass disproportionately consumed Threadfin Shad (28% biomass) and sunfish based on the expected values from the chi squared analysis (13.32% biomass; $\chi^2_{3, 110} = 28.69$, $P < 0.0001$; Figure 32 - 33). Striped Bass consumed similar amounts of Blueback Herring (43% biomass) and Threadfin Shad (48% biomass; $\chi^2_{3, 11} = 7.14$, $P = 0.07$; Figure 34). During September through November, Threadfin Shad and crayfish were consumed at greater frequencies by adult piscivores. Largemouth Bass disproportionately consumed Threadfin Shad (45% biomass) and crayfish (43% biomass; $\chi^2_{3, 30} = 19.87$, $P = 0.0002$), while Alabama Bass consumed crayfish (20% biomass; $\chi^2_{3, 33} = 11$, $P = 0.011$), and Striped Bass mainly consumed Threadfin Shad based

on the expected values from the chi squared analysis (84% biomass; $\chi^2_{3, 52} = 75.85$, $P < 0.0001$; Figure 32 – 34).

Relative Weight

Relative weights differed significantly among sites for both Largemouth ($F_{6, 467} = 10.01$, $P < 0.0001$) Bass and Alabama Bass ($F_{6, 1536} = 10.78$, $P < 0.0001$). For Largemouth Bass, relative weights were high ($Wr > 80$) at all sites and were generally greater upstream (e.g., sites Rock Creek B ($Wr = 94.33$) and Ryan Creek B $Wr = 94.29$) versus downstream (e.g., Forebay $Wr = 87.79$ and Sipsey Fork A $Wr = 85.4$; Figure 35). Alabama Bass relative weights were significantly higher at the upstream sites in Ryan Creek (Ryan Creek B, $Wr = 91.36$) and Rock Creek (Rock Creek B, $Wr = 90.41$) than in all other sites (Figure 36). Relative weights did not differ among sites for Striped Bass (Figure 37). Historic relative weights for Largemouth Bass and Alabama Bass were significantly lower than current relative weights in each major sampling area ($F_{6, 1840} = 108.7$, $P < 0.0001$ and $F_{6, 4292} = 158.4$, $P < 0.0001$, respectively; Table 7, Figures 38 and 39). In contrast, Striped Bass relative weights in the present study were significantly higher at all sites except for sites in Sipsey Fork ($F_{6, 959} = 9.046$, $P < 0.0001$; Table 7, Figure 40).

Growth

Pre- and post-Blueback Herring introduction von Bertalanffy growth curves were generated for Largemouth Bass, Alabama Bass, and Striped Bass. The pre-introduction growth coefficient (k) for Largemouth Bass was higher (k = 0.56) than the post-introduction growth rate observed in the present study (k = 0.23). Similarly, L_{∞} for Largemouth Bass was higher pre-introduction ($L_{\infty} = 565.4$) compared to post-introduction ($L_{\infty} = 424.8$; Figure 41). Alabama Bass showed little change in growth rate (pre k = 0.33 and post k = 0.35) or L_{∞} (pre $L_{\infty} = 527.47$ and

post $L_{\infty} = 506.99$) pre-introduction versus post-introduction (Figure 42). Striped Bass results differed somewhat; L_{∞} was smaller pre-introduction ($L_{\infty} = 817.86$) compared to post-introduction ($L_{\infty} = 891.96$). While growth rate (k) was higher before the Blueback Herring introduction ($k = 0.42$) than after ($k = 0.32$; Figure 43).

Mortality

Mortality was calculated from both historical and current catch-at-age samples for Largemouth Bass, Alabama Bass and Striped Bass. For all three piscivore species, there were no significant changes in historic versus current mortality rates. For Largemouth Bass historical and current total annual mortality values were the same ($A = 0.48$; Figure 44) and for Alabama Bass historical total annual mortality was $A = 0.56$ and current total annual mortality was $A = 0.55$ (Figure 45). Striped Bass showed similar results with total annual mortality being $A = 0.43$ pre-Blueback Herring and $A = 0.42$ in the present study (Figure 46).

Discussion

Blueback Herring have been introduced throughout regions of the United States, both intentionally and unintentionally. Upper thermal tolerances have likely limited the range of their expansion, particularly in the southeastern United States. However, some reservoirs in these warmer regions, such as Lewis Smith Lake, Alabama, are deep enough to provide sufficient cool water thermal refuge and thus can support Blueback Herring, as well as other cool water fishes (Prince and Barwick 1981; Davis and Foltz 1991; Guest and Drenner 1991; Coutant 1997; Nestler et al. 2002; Winkleman and Van Den Avyle 2002; Wheeler et al. 2004; Sammons and Glover 2013). To date, research has been limited relative to the impacts of Blueback Herring introductions; my study represent a holistic effort to quantify the effects of Blueback Herring on

all life stages of the aquatic community in the system. Below, I consider the effects of Blueback Herring on different elements of a southeastern U.S. reservoir (Lewis Smith Lake, Alabama).

Forage Fishes

In the present study, forage fish species were regularly collected throughout the year. CPUE was highly variable (with both gill nets and electrofishing), likely due to the schooling behavior of Blueback Herring and Threadfin Shad which made estimating relative abundance difficult (DeVries et al 1995; Van Den Avyle et al. 1995). Neither electrofishing or gill net CPUE values differed significantly between species; but based on hydroacoustic survey data, Threadfin Shad was more abundant than Blueback Herring during the fall. Hydroacoustic surveys may provide a more accurate representation of clupeid abundance due to the depth and area of the water column sampled combined with fact that I separated fish targets as species (Dennerline et al. 2012). While, there are limitations to hydroacoustic survey data relative to specific fish identification, its utility improves when quantifying thermally restricted fishes that are known to stratify below the thermocline in the warmer months (Nestler et al. 2002; Schaffler et al. 2002; Sammons and Glover 2013).

Diet overlap was relatively high between adult Blueback Herring and adult Threadfin Shad in both winter and spring, which were the only times they co-occurred in our collections. Their prey selection was also similar, with both species consuming large proportions and exhibiting positive selection for both *Bosmina* and cyclopoid copepods. This would further support that the potential for competition to exist between the two species. However, Blueback Herring selected for significantly larger zooplankton than did Threadfin Shad (as well as being larger than the mean size found in the environment). This is likely because Blueback Herring exhibit a particulate feeding mode (Davis and Foltz 1991), while Threadfin Shad typically filter

and pump siphon feed (Holanov and Tash 1978). Although, size-selective predation by one species can reduce the short term potential for competition with a non size-selective zooplanktivore (Davis and Foltz 1991), longer term effects can be negative across multiple trophic levels.

Environmental Parameters

Introduced fish species have been shown to alter environmental parameters in their new systems. For example, following the introduction of Alewife, *Alosa pseudoharengus*, Lake Otsego, New York experienced increased chlorophyll-a density and decreased Secchi depth (Harman et al. 2002). However, in my study there were no significant differences observed between current versus historical chlorophyll-a concentrations or zooplankton density. This lack of effect of Blueback Herring introduction may be because the introduction has occurred relatively recently (2010, 3 years before this study); it is possible that negative impacts on water quality may be observed if their populations continue to expand.

Zooplankton Community

Blueback Herring consumed large amounts of zooplankton and have the potential to cause shifts in both density and community structure of resident zooplankton (Brooks and Dodson 1965; Guest and Drenner 1991; Skov et al. 2002). In my study, I observed Blueback Herring consuming zooplankton in much higher numbers than the dominant resident zooplanktivore Threadfin Shad. In the current study, historical zooplankton densities in Lewis Smith Lake were compared to post-introduction densities but did not differ significantly.

I found Blueback Herring to be size-selective zooplanktivores as has been documented for Alewife, where the zooplankton community dominance shifted from large cladocerans

(*Daphnia*) to smaller cladocerans (*Bosmina*; Brooks and Dodson 1965; Harman et al. 2002). Similarly, in a Texas reservoir Guest and Drenner (1991) observed the zooplankton community to shift from small cladocerans (*Bosmina*) to copepods after the introduction of Blueback Herring. This shift was attributed to both size-selection by Blueback Herring and greater evasiveness of copepods (Guest and Drenner 1991). With the same size selective pressures being exerted on the zooplankton community in Lewis Smith Lake, similar impacts on the zooplankton community would be expected. Even though negative effects of size selection by Blueback Herring in the form of zooplankton density reductions and community shifts have not been observed to date, the potential for negative impacts clearly exists in Lewis Smith Lake. Similar to our findings with environmental parameters, it is possible that zooplankton density and species composition may be affected more if the Blueback Herring population continues to expand. As found in previous studies, it can take several of years for the effects of an introduced zooplanktivore like Blueback Herring to cause observable shifts in zooplankton size and community structure (Brooks and Dodson 1965; Guest and Drenner 1991; Harman et al 2002). This could be particularly true if the zooplankton community was made up of primarily small-bodied forms with less variation in size than in systems where previous introductions of Blueback Herring have been documented.

Larval Fishes

In the present study, larval Blueback Herring overlapped temporally with important sport and forage fishes (crappies, Threadfin Shad, and Gizzard Shad) during the early spring spawning period. The potential for larval Blueback Herring to negatively impact these fishes through direct competition does exist, at least based on temporal overlap. If they do compete with

crappies and forage fishes for zooplankton, there is potential for indirect effects on piscivorous fishes (mediated through reduced availability of other forage).

The time at first feeding is extremely important to larval fish survival and if critical zooplankton resources have been depleted by the presence of a new zooplanktivore, then survival through the larval period may be reduced (Shepard and Cushing 1980; Welker et al. 1994). As has been demonstrated in introductions of both Threadfin Shad and Gizzard Shad, the addition of a new zooplanktivore has the potential to reduce the available zooplankton for all larval fish which can then reduce larval survival and recruitment of other fishes (DeVries et al. 1991; Stein et al. 1995). Blueback Herring also has the potential to cause shifts in the zooplankton community from one that is dominated by cladocerans to one dominated by copepods, as was documented to have occurred with the Blueback Herring introduction into Lake Theo, Texas (Guest and Drenner 1991). Copepods are more difficult for larval fish and older zooplanktivorous fish to capture which can reduce fish feeding potential and their eventual survival (Drenner et al. 1978). Unfortunately, I was unable to empirically estimate competition among larval fishes because diets of all collected larval clupeids were empty. However, the temporal overlap of larval Blueback Herring with larval crappie spp., Threadfin Shad, and Gizzard Shad still leaves competition among larvae of these species a possibility. Full understanding of this potential will require further sampling which is critical to determine the potential for direct competition.

I was able to evaluate the potential for juvenile and adult Blueback Herring to compete with larval crappies and larval *Lepomis spp.*, given the temporal overlap between the species. Diet overlap between adult Blueback Herring and larval crappies was not high, nor did they select for similar zooplankton taxa. These results suggest the potential for competition between

adult Blueback Herring and larval crappies is low. Higher levels of diet overlap were observed between adult Blueback Herring and larval *Lepomis spp.*, and they showed some similarities in prey selection. However, competition between these two groups is likely low because there is little temporal overlap at the time when larval *Lepomis spp.* are present due to thermal restrictions of adult Blueback Herring (Coutant 1997).

Based on anecdotal evidence it is possible that adult Blueback Herring may be consuming larval fish. Anglers who are illegally harvesting Blueback Herring for bait have been reported to use hook-and-line fishing gear (i.e. a sebiki rig) that is intended to mimic larval fish (GLG, personal observation). I did not find any eggs or larval fish in the diets of Blueback Herring, but larval fish and egg predation has been observed on the Jocassee Reservoir in North Carolina (Davis and Foltz 1991). Predation on larval fish may not have occurred in Lewis Smith Lake or they were not evident in diets because of rapid digestion (as documented in Kim and DeVries 2001). Additional sampling would be required to fully document the possibility of larval fish and egg predation.

Piscivorous Fishes

Following the introduction of Blueback Herring, significant increases in relative weights of Largemouth Bass, Alabama Bass, and Striped Bass were observed throughout Lewis Smith Lake. This finding supports that Blueback Herring serves as an additional prey resource to major sportfishes in the reservoir because they were regularly found in the diets of all three species. Although Blueback Herring were found in the diets of Largemouth Bass and Alabama Bass, both still heavily relied on crayfish, sunfishes, and Threadfin Shad. This is particularly true for Striped Bass where Threadfin Shad contributed more than 98% of their annual diet. However, Blueback Herring may be an important prey resource for Striped Bass during summer

when thermal limitations force both of them below the thermocline. Blueback Herring contributed nearly 50% of Striped Bass diets during summer when the water was stratified. Prey resources during this time are limited given that warm water species such as Threadfin Shad and Gizzard Shad remain above the thermocline. The availability of a deep water prey resource may reduce stress and summer mortality of Striped Bass which can lead to increased growth as less prey in ideal temperatures has been found to be more beneficial than more prey in higher than ideal temperatures (Riechert and Tracy 1975).

Little change was observed in growth rate and length-at-age for Largemouth Bass and Alabama Bass pre versus post Blueback Herring introduction. The fact that changes in length-at-age and growth rates were not observed does not necessarily demonstrate a lack of a Blueback Herring effect. It is possible that the effects of the relatively recent Blueback Herring introduction have not yet manifested in older fish that have lived the majority of their life in the absence of Blueback Herring; these pre-Blueback Herring data will continue to influence the results of growth curves. Fish grow most quickly during early life and after the older fish that did not experience early life with Blueback Herring have left the population, a clearer picture should be more apparent (Ludsin and DeVries 1997). Striped Bass theoretical maximum length and growth rate both differed from historic values but also cannot be solely attributed to the introduction of Blueback Herring. Striped Bass is a longer lived species than Largemouth Bass and Alabama Bass in Lewis Smith Lake and were not introduced until the 1990s (Jay Hafner, Alabama Department of Conservation and Natural Resources, personal communication). Historical Striped Bass length-at-age data used to generate growth curves were collected between 2005 and 2007 which would make the oldest possible fish at that time approximately 12 years old, a little more than half the age of the oldest Striped Bass collected during the current study

(21 years old). The larger and older fish collected during the current study are likely responsible for the differences in length-at-age and growth rates and additional data collection through time will help to document this potential effect.

No significant changes were observed in mortality of Largemouth Bass, Alabama Bass, or Striped Bass in Lewis Smith Lake after the introduction of Blueback Herring. If prey availability had been limiting for piscivore survival, I would have expected to see changes in total annual mortality (Adams et al. 1982). For similar reasons as to why I did not see changes in length-at-age (described above), changes in total annual mortality may not be observed until the older fish that experienced their early years of life without Blueback Herring are no longer alive. If Blueback Herring are increasing survival of piscivores by providing an additional prey resource, then decreases in total annual mortality would be expected.

Management Implications

Although it is possible that I may have missed some possible avenues for competition in the form of larval predation and competition between larval Blueback Herring and larval clupeids, there is still potential for negative effects on important fish populations. Not all effects are negative as positive effects were observed for sportfishes in the form of increased relative weight following the introduction. However, the introduction of Blueback Herring only occurred in 2010 a few years prior to the start of this study and it is likely that the population will continue to expand. Recruitment of Largemouth Bass, Alabama Bass, and crappies will need to be further analyzed before it can be definitively said there are no negative effects on the sport fish population. Until the effects of the Blueback Herring introduction are fully understood, the expansion into other naïve systems should be controlled and limited as much as possible.

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Tables

Table 1. Mean (\pm standard error) Secchi depth, turbidity, chlorophyll-a density and zooplankton density by site and across from January 2013 through November 2014.

Site	Secchi Depth (cm)	Turbidity	Chlorophyll-a (ug/L)	Zooplankton Density (#/L)
Forebay	333.47 (20.35)	1.6134 (0.1762)	3.5434 (0.665)	3.3894 (1.8768)
Rock Creek A	294.71 (32.76)	2.2301 (0.4172)	6.0149 (1.2651)	9.3758 (1.8513)
Rock Creek B	257.21 (20.23)	2.4311 (0.5738)	7.6719 (1.6195)	11.7988 (1.8472)
Ryan Creek A	308.15 (15.5)	1.8658 (0.2008)	4.0534 (0.7589)	4.645 (1.8311)
Ryan Creek B	197.88 (20.55)	3.2919 (0.6453)	7.9809 (1.4329)	12.0134 (1.833)
Sipsey Fork A	268.55 (26.29)	2.5136 (0.3718)	3.1501 (0.6729)	2.9017 (1.862)
Sipsey Fork B	267.76 (22.67)	2.3366 (0.3897)	2.8161 (0.5)	2.9604 (1.9051)

Table 2. Mean (\pm standard error) zooplankton sizes in the environment, diets of Blueback Herring (*Alosa aestivalis*) and Threadfin Shad (*Dorosoma petenense*). Significant differences are indicated by letters.

	Blueback Herring	Threadfin Shad	Environment
Total	0.3867 (0.0146) ^a	0.2829 (0.0302) ^b	0.2715 (0.0069) ^b
Month			
1	0.3837 (0.03) ^a	0.2432 (0.0388) ^b	0.2352 (0.014) ^b
2	0.4694 (0.1515) ^a	NA	0.2751 (0.0178) ^b
3	0.4426 (0.023) ^a	0.3221 (0.0429) ^b	0.2775 (0.0122) ^b
4	0.3374 (0.0264) ^a	0.3012 (0.1013) ^{ab}	0.2821 (0.015) ^b
5	0.3152 (0.0392) ^a	0.169 (0.0459) ^b	0.2737 (0.014) ^{ab}

Table 3. Mean (\pm standard error) zooplankton size by site, taxa and month in the diets of Blueback Herring (*Alosa aestivalis*), Threadfin Shad (*Dorosoma petenense*), and the environment. Significance is indicated by letters.

Month	Site	Taxa	Blueback Herring (mm)	Threadfin Shad (mm)	Environment (mm)
January	Sipsey Fork A	Bosmina	0.1719 (0.005) ^a	0.1577 (0.0067) ^b	0.1469 (0.0081) ^b
		Calanoid	0.5724 (0.3393) ^a	NA	0.2739 (0.0082) ^b
		Cyclopoid	0.3854 (0.0695) ^a	0.3054 (0.0437) ^{ab}	0.2346 (0.006) ^b
		Daphnia	0.4152 (0.0982) ^a	0.3215 (NA) ^a	0.2778 (0.0806) ^a
March	Rock Creek A	Bosmina	0.2271 (0.0311) ^a	0.125 (NA) ^b	0.1553 (0.0178) ^b
		Calanoid	0.559 (0.0382) ^a	0.2321 (NA) ^b	0.3546 (0.0323) ^b
		Cyclopoid	0.486 (0.0746) ^a	0.2936 (0.0558) ^b	0.3034 (0.0552) ^b
		Daphnia	0.5526 (0.2424) ^a	0.3304 (0.1607) ^a	0.3222 (0.0886) ^a
	Rock Creek B	Bosmina	0.2178 (0.0185) ^a	0.1716 (0.0229) ^b	0.1584 (0.0097) ^b
		Calanoid	0.5423 (0.0357) ^a	NA	0.3702 (0.0241) ^b
		Cyclopoid	0.5314 (0.0416) ^a	0.5229 (0.0613) ^a	0.3381 (0.0383) ^b
		Daphnia	0.5807 (0.0394) ^a	0.4604 (0.072) ^b	0.328 (0.0814) ^c
	Ryan Creek B	Bosmina	0.1784 (0.0045) ^a	0.1559 (0.0112) ^b	0.1539 (0.0086) ^b
		Calanoid	0.6283 (0.0169) ^a	NA	0.4005 (0.0549) ^b
		Cyclopoid	0.4711 (0.0211) ^a	0.3838 (0.0472) ^b	0.324 (0.0465) ^b
		Daphnia	0.416 (0.036) ^a	0.3282 (0.0748) ^a	0.3355 (0.042) ^a
	Sipsey Fork B	Bosmina	0.1668 (0.0113) ^a	0.1217 (NA) ^b	0.1517 (0.0057) ^b
		Calanoid	0.5857 (0.0638) ^a	NA	0.3094 (0.0265) ^b
		Cyclopoid	0.4295 (0.0562) ^a	0.2375 (NA) ^b	0.2932 (0.0242) ^b
		Daphnia	0.3215 (NA) ^a	NA	0.33 (0.0914) ^a
April	Rock Creek B	Bosmina	0.169 (0.0134) ^a	0.1364 (0.0384) ^a	0.1591 (0.0125) ^a
		Calanoid	0.5559 (0.081) ^a	0.3215 (NA) ^a	0.3943 (0.0315) ^a
		Cyclopoid	0.4142 (0.061) ^{ab}	0.5953 (0.2281) ^a	0.3379 (0.0294) ^b
		Daphnia	0.3833 (0.0572) ^a	NA	0.3522 (0.0765) ^a
	Ryan Creek B	Bosmina	0.1797 (0.0221) ^a	0.15 (0.0036) ^a	0.1643 (0.0188) ^a
		Calanoid	NA	NA	0.3464 (0.0651)
		Cyclopoid	0.3879 (0.0546) ^a	0.3018 (0.0036) ^a	0.2984 (0.0329) ^a
		Daphnia	0.4145 (0.0558) ^a	NA	0.3094 (0.0841) ^a
May	Ryan Creek B	Bosmina	0.1642 (0.0129) ^a	0.13 (0.0179) ^b	0.135 (0.0068) ^b
		Calanoid	0.6483 (0.0107) ^a	NA	0.3418 (0.0176) ^b
		Cyclopoid	0.4399 (0.0738) ^a	0.2899 (0.076) ^b	0.2477 (0.0167) ^b
		Daphnia	0.4718 (0.1079) ^a	NA	0.259 (0.0179) ^b

Table 4. Prey Selection quantified using Chesson's alpha (α) for 2013 and 2014 sampling season (January through June) in Lewis Smith Lake. Chesson's alpha (α), number in parentheses is \pm 95% CL, + = positive selection, - = negative selection, and no exponent = neutral selection.

Taxa	Blueback Herring	Sunfishes	Crappies
Neutral Selection	0.125	0.125	0.125
<i>Bosmina</i>	0.3504 (0.037) ⁺	0.3783 (0.0502) ⁺	0.111 (0.0393)
<i>Ceriodaphnia</i>	0 (0) ⁻	0 (0) ⁻	0.3112 (0.0079) ⁺
<i>Diaphasoma</i>	0.0012 (8.267E-05) ⁻	0.2333 (0.0189) ⁺	0 (0) ⁻
<i>Daphnia</i>	0.1925 (0.0045) ⁺	0.1451 (0.0084) ⁺	0 (0) ⁻
<i>Holopedium</i>	0.0064 (0.0006) ⁻	0.1157 (0.0188)	0 (0) ⁻
copepod nauplii	4.394E-05 (6.955E-05) ⁻	0.014 (0.0266) ⁻	0.4013 (0.048) ⁺
cyclopoid copepods	0.2687 (0.0304) ⁺	0.0683 (0.0332) ⁻	0.1149 (0.0288)
calanoid copepods	0.1807 (0.0225) ⁺	0.0453 (0.0168) ⁻	0.0616 (0.0149) ⁻

Table 5. Prey selection quantified for adult Threadfin Shad and adult Blueback Herring using Chesson's alpha for 2013 and 2014 sampling season in Lewis Smith Lake. Number in parentheses denote \pm 95% CL. + = positive selection, - = negative selection and no exponent indicates neutral selection. THSH = Threadfin Shad (*Dorosoma petenense*) and BBHR = Blueback Herring (*Alosa aestivalis*).

Species	THSH Jan. - June	BBHR Jan. - June	THSH Spring	BBHR Spring	THSH Winter	BBHR Winter
Neutral Selection	0.125	0.125	0.125	0.125	0.125	0.125
Bosmina	0.1816 (0.051) ⁺	0.4113 (2.60E-02) ⁺	0.7562 (0.0682) ⁺	0.636 (0.0384) ⁺	0.4301 (0.065) ⁺	0.2348 (0.0263) ⁺
Ceriodaphnia	0 (0) ⁻	2.116E-05 (2.12E-05) ⁻	0 (0) ⁻	0 (0) ⁻	0 (0) ⁻	3.78E-05 (3.78E-05) ⁻
Diaphasoma	0 (0) ⁻	4.115E-05 (4.12E-05) ⁻	0 (0) ⁻	9.353E-05 (9.353E-05) ⁻	0 (0) ⁻	0 (0) ⁻
Daphnia	0.6776 (0.0353) ⁺	0.0475 (0.01) ⁻	0.0708 (0.0426) ⁻	0.0172 (0.005) ⁻	0.1509 (0.052)	0.0713 (0.0171) ⁻
Holopedium	0 (0) ⁻	0.0004 (0.0003) ⁻	0 (0) ⁻	0.001 (0.0007) ⁻	0 (0) ⁻	0 (0) ⁻
Nauplii	0.0016 (0.0069) ⁻	0.0004 (0.0001) ⁻	0 (0) ⁻	0.0001 (7.86E-05) ⁻	0.0185 (0.0117) ⁻	0.0006 (0.0002) ⁻
Cyclopoid	0.1312 (0.0426)	0.4434 (0.0244) ⁺	0.1595 (0.0545)	0.2553 (0.0311) ⁺	0.3987 (0.0565) ⁺	0.5912 (0.03) ⁺
Calanoid	0.0079 (0.0045) ⁻	0.0969 (0.0143) ⁻	0.0135 (0.0104) ⁻	0.0903 (0.0242) ⁻	0.0018 (0.0018) ⁻	0.1021 (0.0169)

Table 6. Prey selection quantified for adult Threadfin Shad (*Dorosoma petenense*) and Blueback Herring (*Alosa aestivalis*) using Chesson's alpha for 2013 and 2014 by site and month in Lewis Smith Lake. Number in parentheses denote \pm 95% CL. + = positive selection, - = negative selection and no mark indicates neutral selection.

Month	Site	Taxa	Blueback Herring	Threadfin Shad
January	Sipsey Fork A	Neural Selection	0.2000	0.2000
		Bosmina	0.516 (0.1237) ⁺	0.8087 (0.0913) ⁺
		Daphnia	0.0534 (0.0018) ⁻	0.0412 (0.002) ⁻
		Nauplii	0 (0) ⁻	0.001 (0.005) ⁻
		Cyclopoid	0.3405 (0.1071) ⁺	0.1491 (0.0876)
		Calanoid	0.0902 (0.0386) ⁻	0 (0) ⁻
March	Rock Creek A	Neural Selection	0.2000	0.2000
		Bosmina	0.0061 (0.0069) ⁻	0.0189 (0.0208) ⁻
		Daphnia	0.7212 (0.109) ⁺	0.1648 (0.3069)
		Nauplii	0 (0) ⁻	0 (0) ⁻
		Cyclopoid	0.252 (0.1085)	0.7992 (0.2954) ⁺
		Calanoid	0.0207 (0.0105) ⁻	0.0171 (0.0208) ⁻
	Ryan Creek B	Neural Selection	0.1667	0.1667
		Bosmina	0.1067 (0.0694) ⁻	0.5814 (0.0777) ⁺
		Ceriodaphnia	0 (0) ⁻	0 (0) ⁻
		Daphnia	0.0313 (0.0021) ⁻	0.2092 (0.0082) ⁺
		Nauplii	9.664E-05 (9.41E-05) ⁻	0.0001 (0.0005) ⁻
		Cyclopoid	0.0542 (0.0415) ⁻	0.2092 (0.0779)
	Sipsey Fork B	Neural Selection	0.1667	0.1667
		Bosmina	0.2208 (0.0942)	0.2898 (NA)
		Daphnia	0.0121 (0.0003) ⁻	0 (0) ⁻
Holopedium		0 (0) ⁻	0 (0) ⁻	
Nauplii		0.0001 (0.0006) ⁻	0 (0) ⁻	
Cyclopoid		0.4757 (0.0876) ⁺	0.7102 (NA)	
April	Rock Creek B	Neural Selection	0.1667	0.1667
		Bosmina	0.2448 (0.0889)	0.5394 (0.2083) ⁺
		Daphnia	0.0265 (0.0053) ⁻	0 (0) ⁻
		Holopedium	0.0473 (8.64E-05) ⁻	0 (0) ⁻
		Nauplii	0.0001 (0.0002) ⁻	0 (0) ⁻
		Cyclopoid	0.2548 (0.0923) ⁻	0.3007 (0.2135)
	Ryan Creek B	Calanoid	0.4264 (0.0896) ⁺	0.1598 (0.0625)
		Neural Selection	0.1667	0.1667
		Bosmina	0.6452 (0.0786) ⁺	0.9387 (0.0118) ⁻
		Daphnia	0.1071 (0.0059) ⁻	0 (0) ⁻
		Holopedium	0.0296 (0.0003) ⁻	0 (0) ⁻

		Nauplii	0 (0) ⁻	0 (0) ⁻
		Cyclopoid	0.2182 (0.0759)	0.0613 (0.0118) ⁻
		Calanoid	0(0) ⁻	0 (0) ⁻
May	Ryan Creek B	Neural Selection	0.1250	0.1250
		Bosmina	0.6469 (0.1384) ⁺	0.9579 (0.0218) ⁺
		Ceriodaphnia	0 (0) ⁻	0 (0) ⁻
		Diaphasoma	0 (0) ⁻	0 (0) ⁻
		Daphnia	0.0035 (0.0016) ⁻	0 (0) ⁻
		Holopedium	0 (0) ⁻	0 (0) ⁻
		Nauplii	0 (0) ⁻	0 (0) ⁻
		Cyclopoid	0.334 (0.1351) ⁺	0.0421 (0.0218) ⁻
		Calanoid	0.0156 (0.141) ⁻	0 (0) ⁻

Table 7. Relative weights for Largemouth Bass, Alabama Bass and Striped Bass from the present study and from historical data by major branch. The * indicates significant differences between historic and current samples.

	Largemouth Bass		Alabama Bass		Striped Bass	
	Historic	Current	Historic	Current	Historic	Current
Forebay	79.73 (0.69)	87.79 (1.66)*	80.28 (0.52)	87.67 (1.73)*	91.73 (1.50)	98.26 (3.36)*
Rock Creek	NA	93.25 (1.62)	NA	89.62 (0.91)	NA	97.97 (2.16)
Ryan Creek	85.78 (0.75)	93.49 (1.30)*	85.29 (0.52)	90.54 (0.71)*	93.93 (0.95)	99.12 (2.04)*
Sipsey Fork	81.16 (0.70)	86.34 (2.29)*	80.82 (0.49)	86.74 (0.94)*	93.87 (1.65)	92.20 (4.40)

Figures

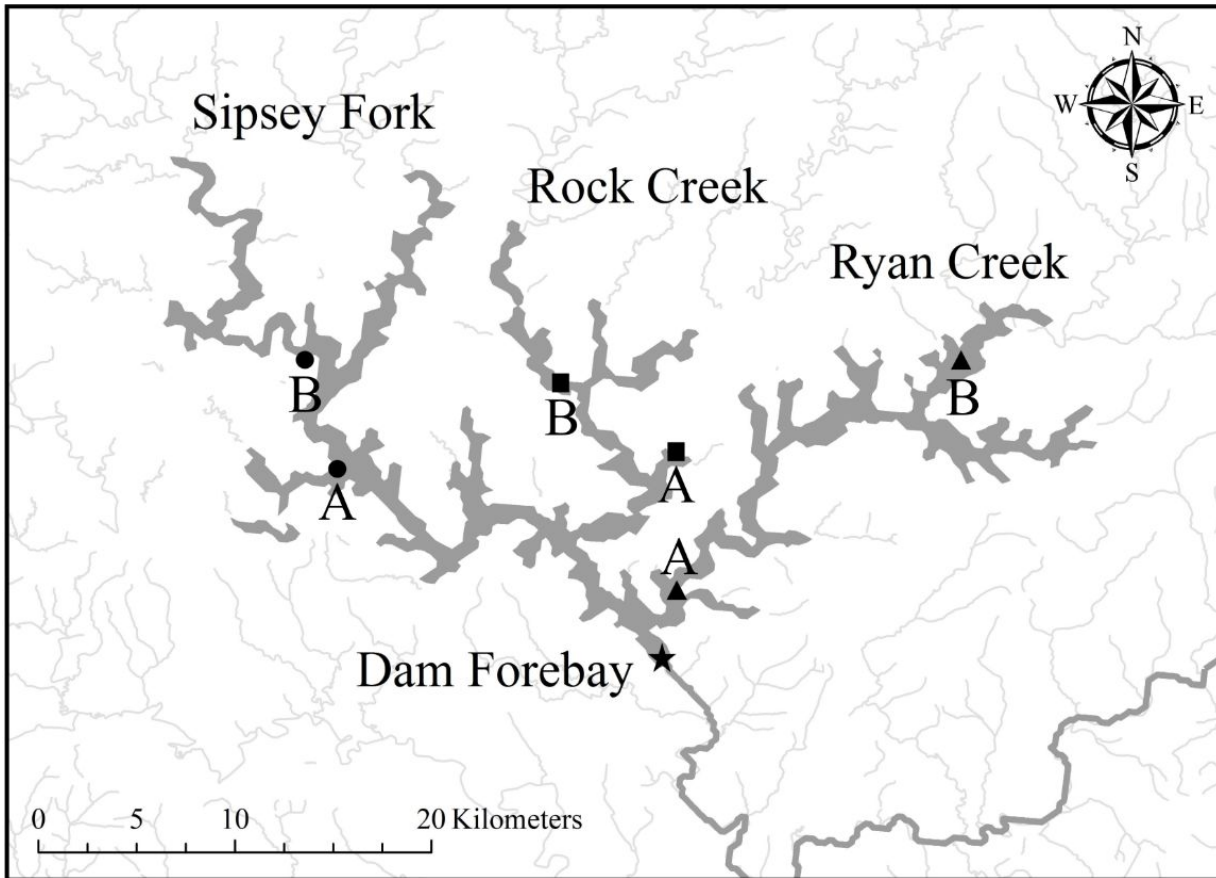


Figure 1. Map of Lewis Smith Lake, Alabama. Sampling sites are labeled with different symbols at Ryan Creek (▲), Rock Creek (■), Sipsey Fork (●), and the Dam Forebay site is indicated by a star. Upstream sites are labeled with the letter B and downstream sites are labeled with the letter A.

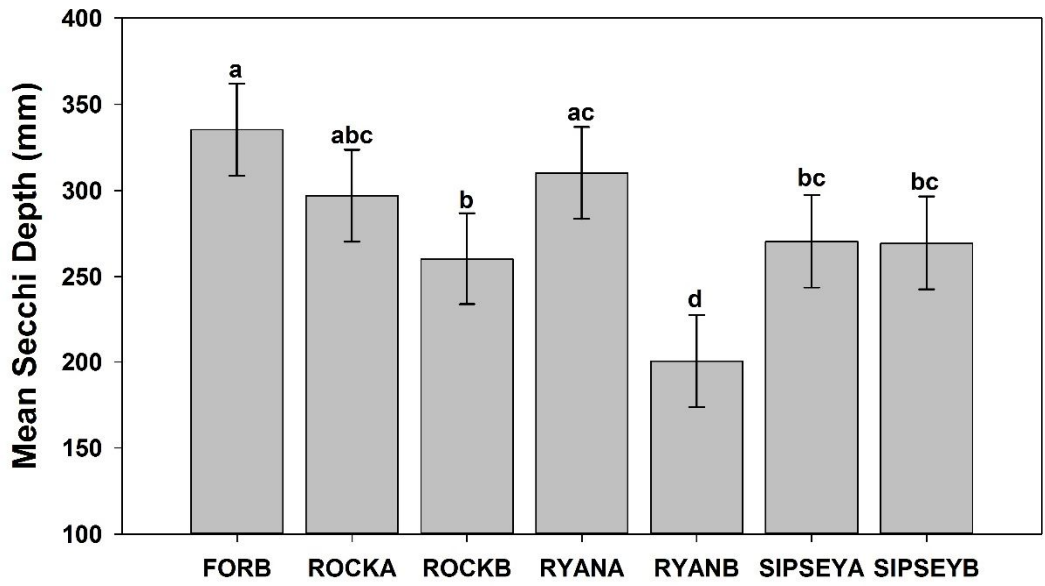


Figure 2. Mean Secchi depth by site and across months collected in 2013 and 2014. Bars with the same letter did not differ.

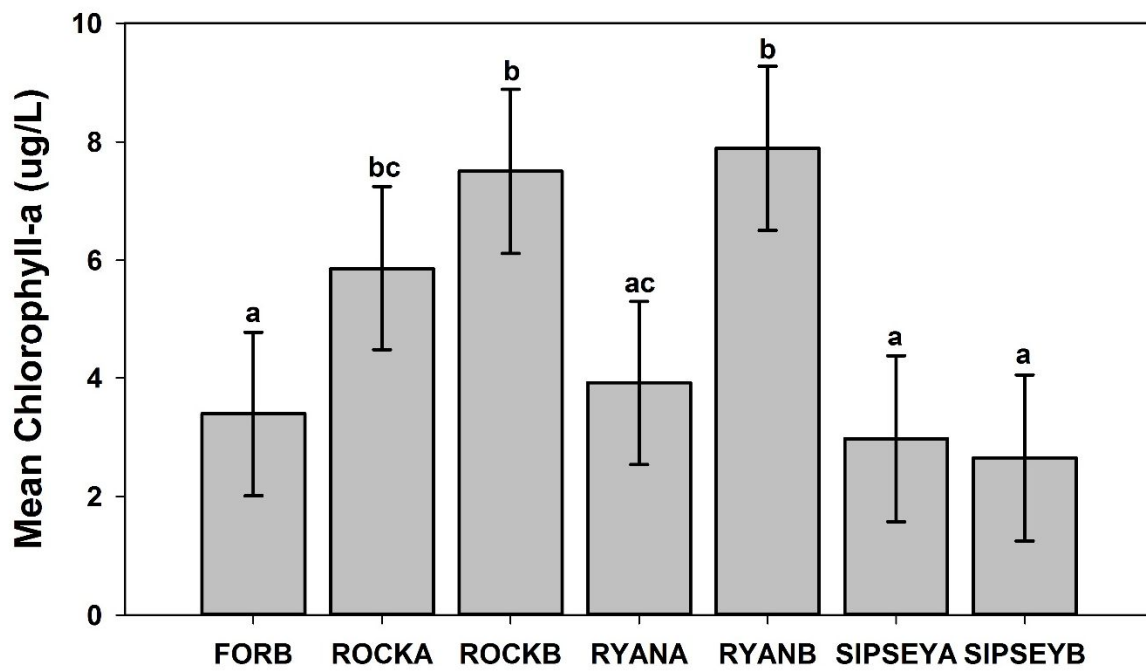


Figure 3. Mean chlorophyll-a concentration by site and across months collected in 2013 and 2014. Bars with the same letter did not differ.

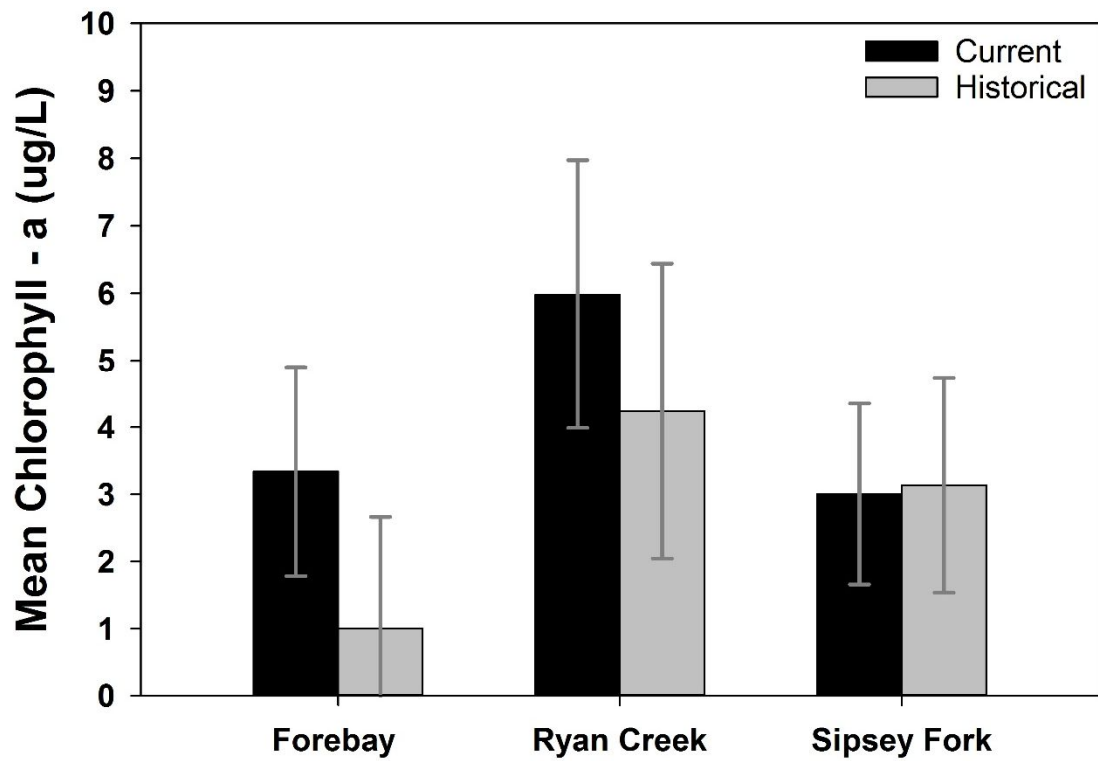


Figure 4. Mean chlorophyll-a densities from the historic samples collected in February through June of 1992, 1993, 1994 and samples from the present study collected during the same months from 2013 and 2014 (no significant differences).

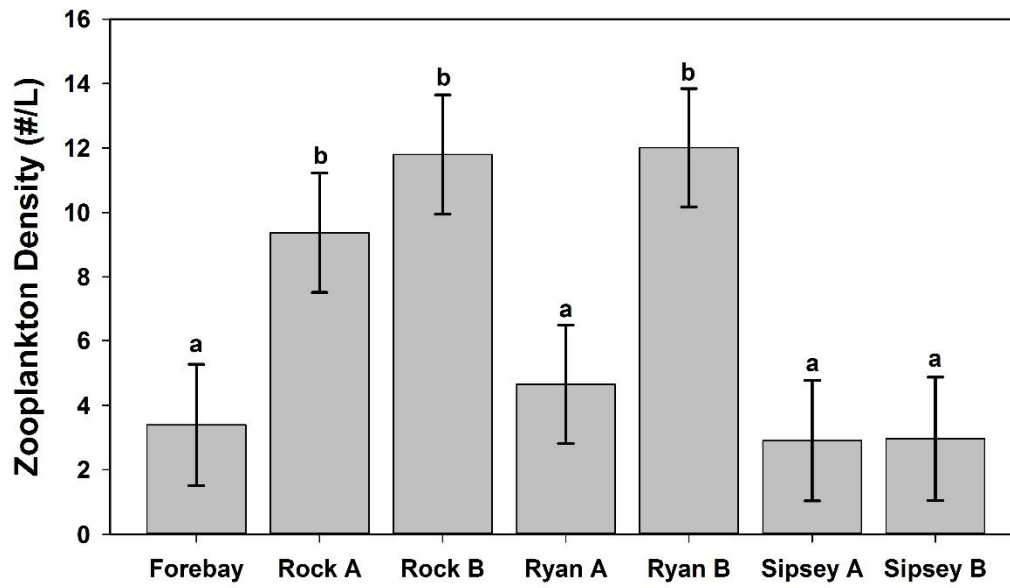


Figure 5. Mean zooplankton density site and across months collected in 2013 and 2014. Bars with the same letter did not differ.

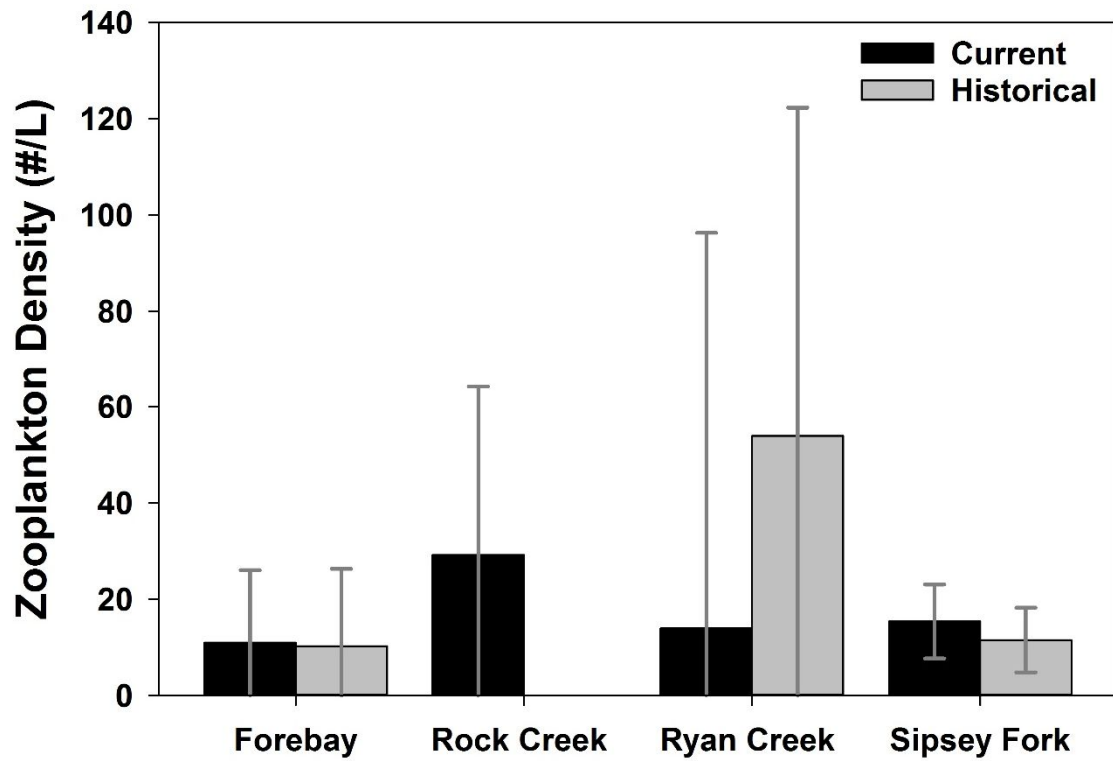


Figure 6. Mean historic and current zooplankton densities for each major creek between March and June. Historic samples were collected in 1992, 1993, and 1994 and current samples are from 2013 and 2014. Black bars indicate current densities and gray bars indicate historic densities (no significant differences).

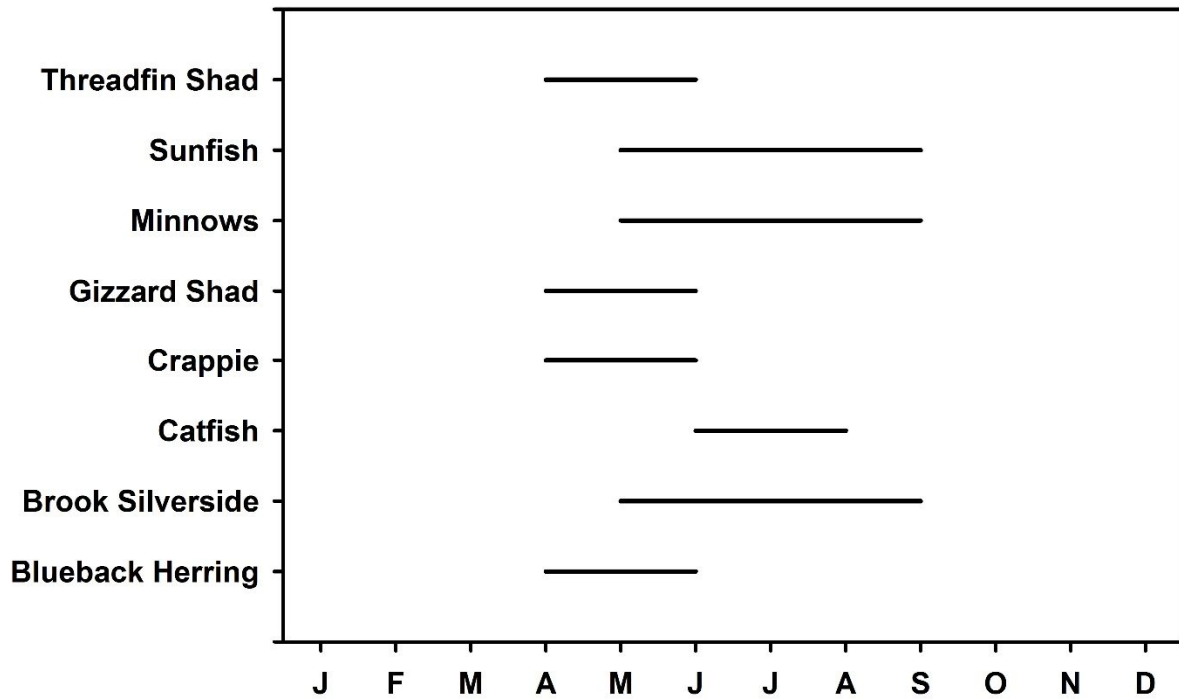


Figure 7. Temporal overlap of larval fishes collected between February and September of 2013 and 2014. Bars indicate the period of time larval were collected in the gear.

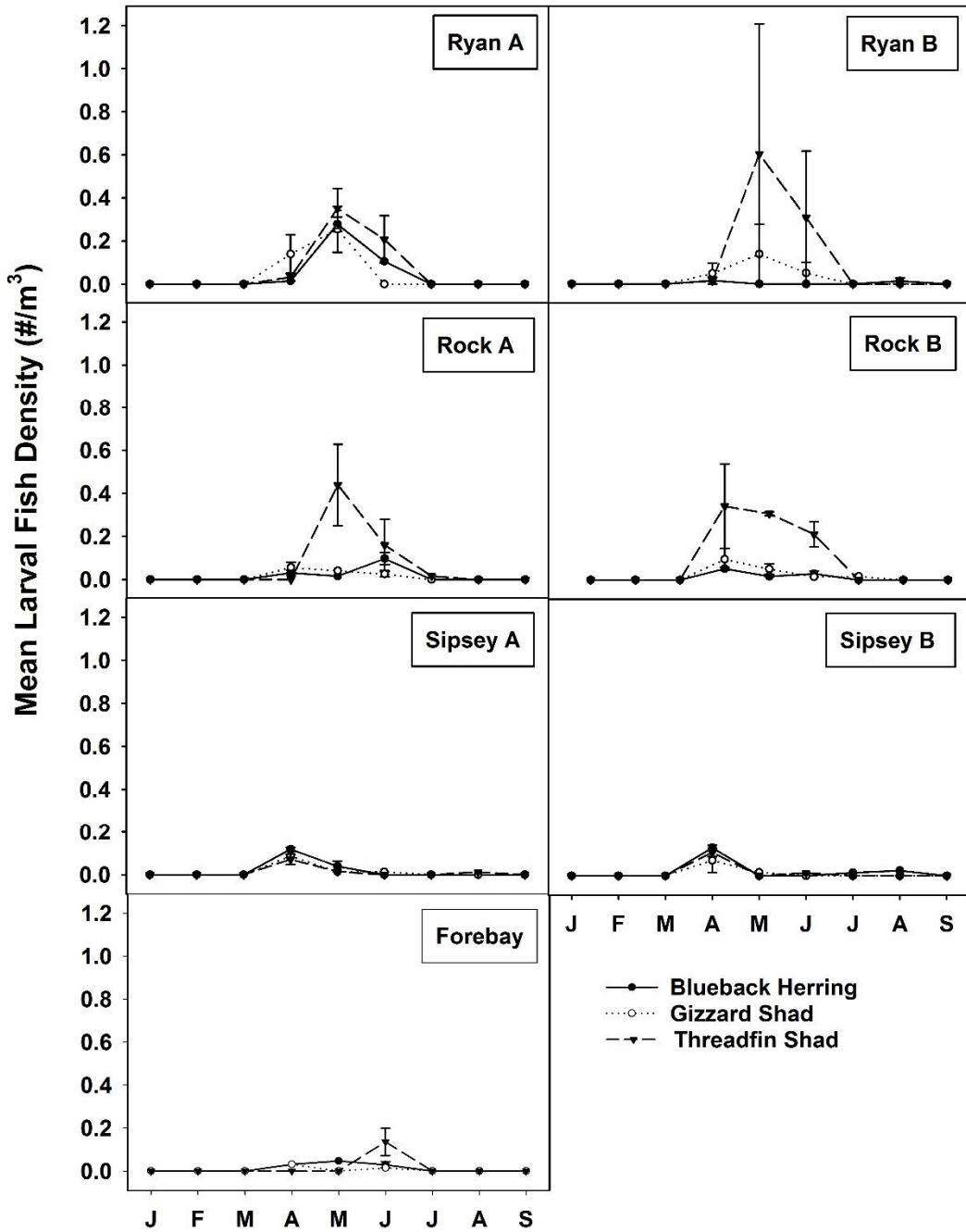


Figure 8. Mean clupeid larval fish densities ($\#/m^3$) at each site from collections in 2014 and 2015 from January to September.

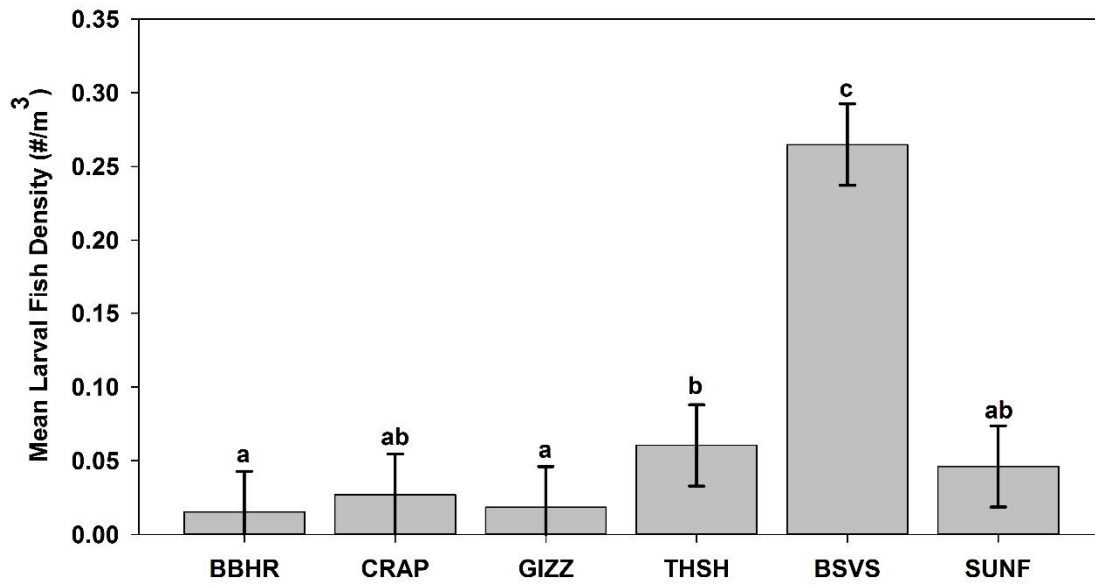


Figure 9. Mean larval fish density ($\#/m^3$) across all sites and sampling dates. Significant differences are indicated by letters.

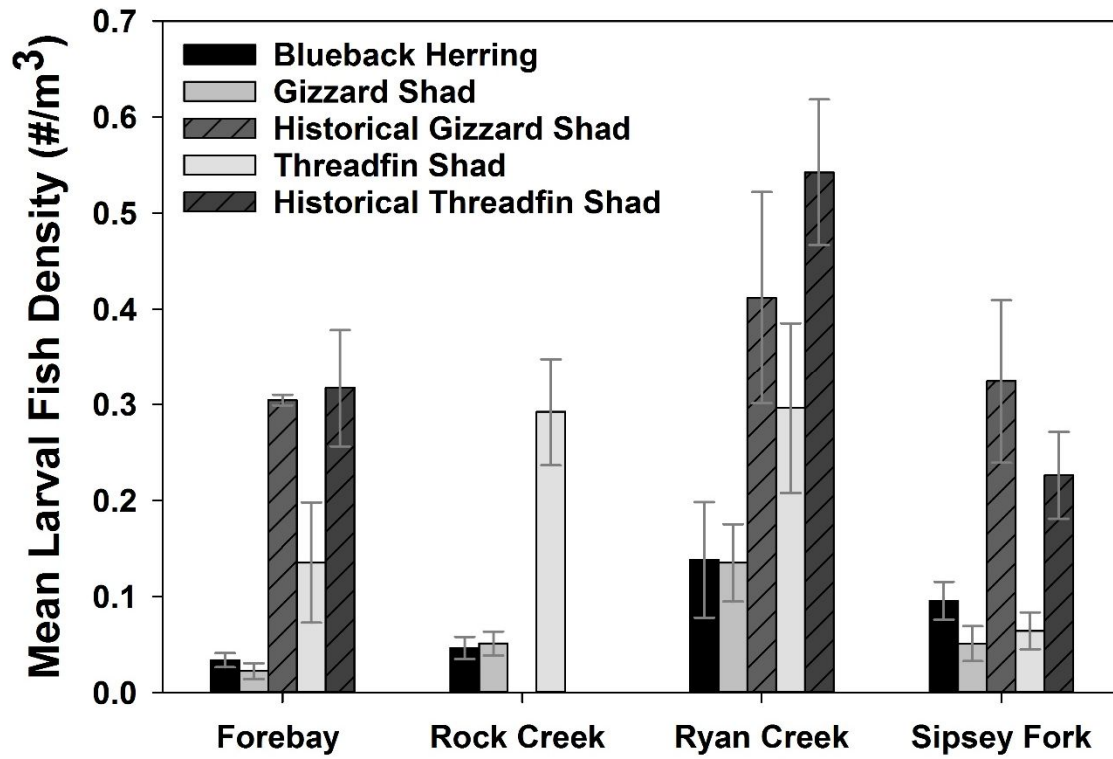


Figure 10. Mean larval fish density (#/m³) for historical samples collected in 1992, 1993, and 1994 between February and June compared to current larval fish densities collected in 2013 and 2014.

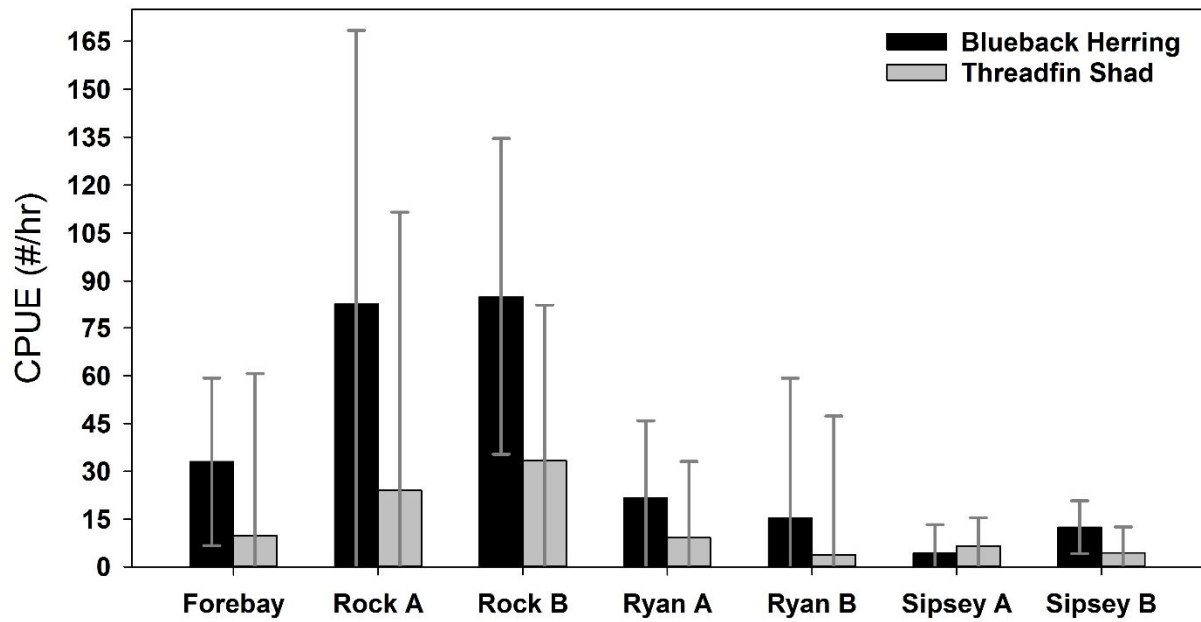


Figure 11. Electrofishing CPUE (#/hr) at each site sites and across month (January – June) collected in 2013 and 2014. No significant differences were observed.

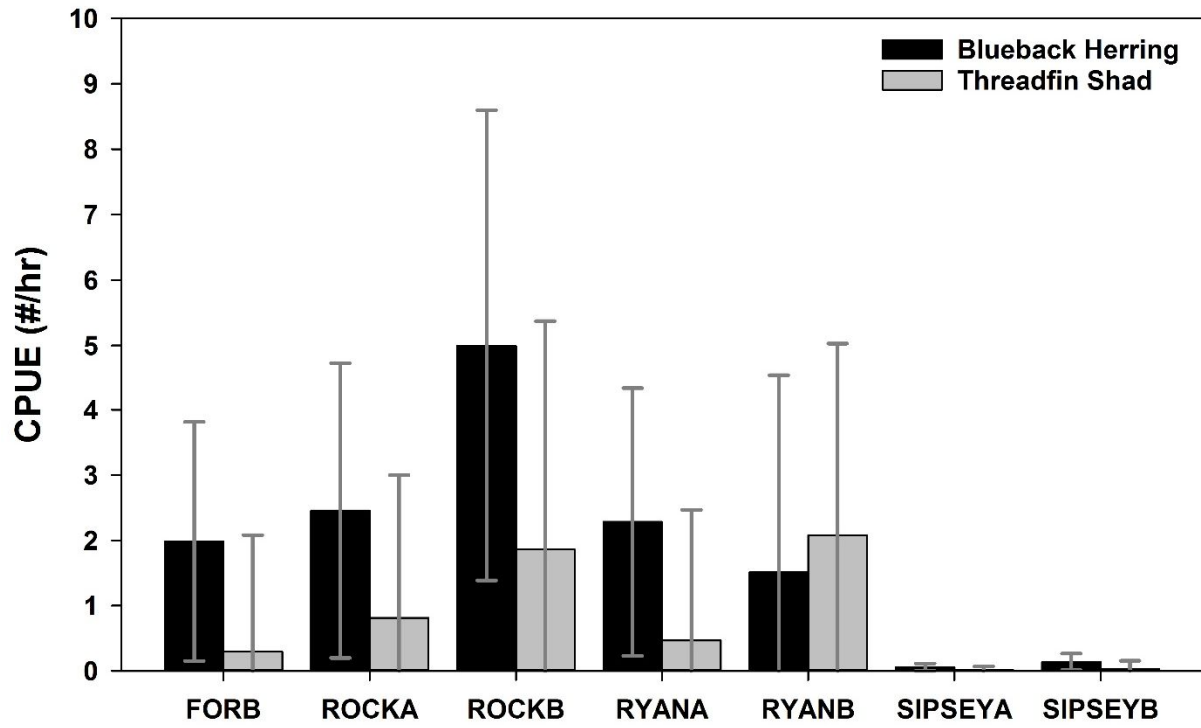


Figure 12. Gill net CPUE (#/hr) at each site sites and across month (January – June) collected in 2013 and 2014. No significant differences were observed.

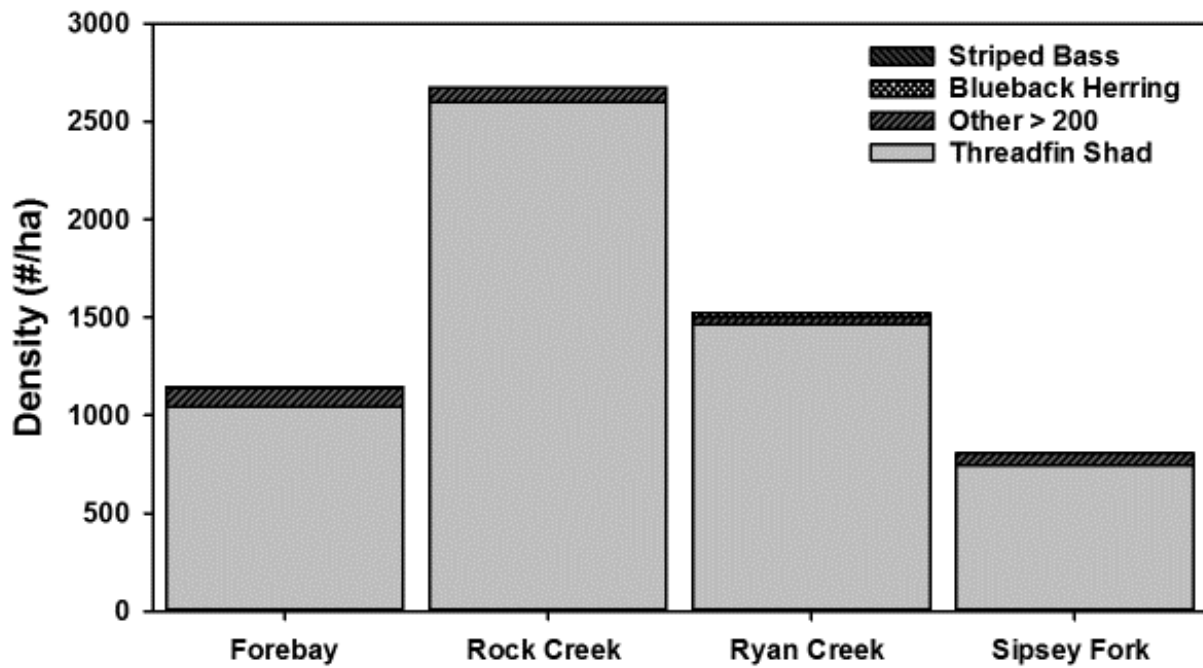


Figure 13. Pelagic fish density (#/ha) estimated from the hydroacoustic data at each site collected in August of 2014.

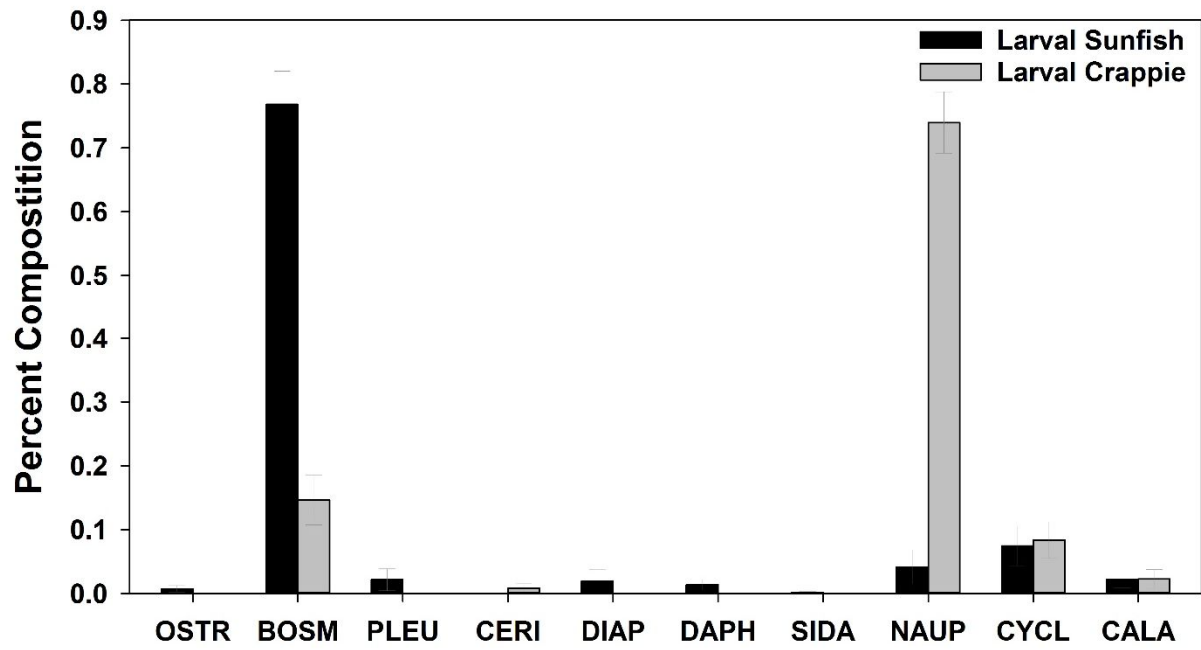


Figure 14. Diet percent composition for larval sunfishes (*Lepomis spp.*) and larval crappies (*Pomoxis spp.*) combined across sites and during the spawning season (March – September) from 2013 and 2014.

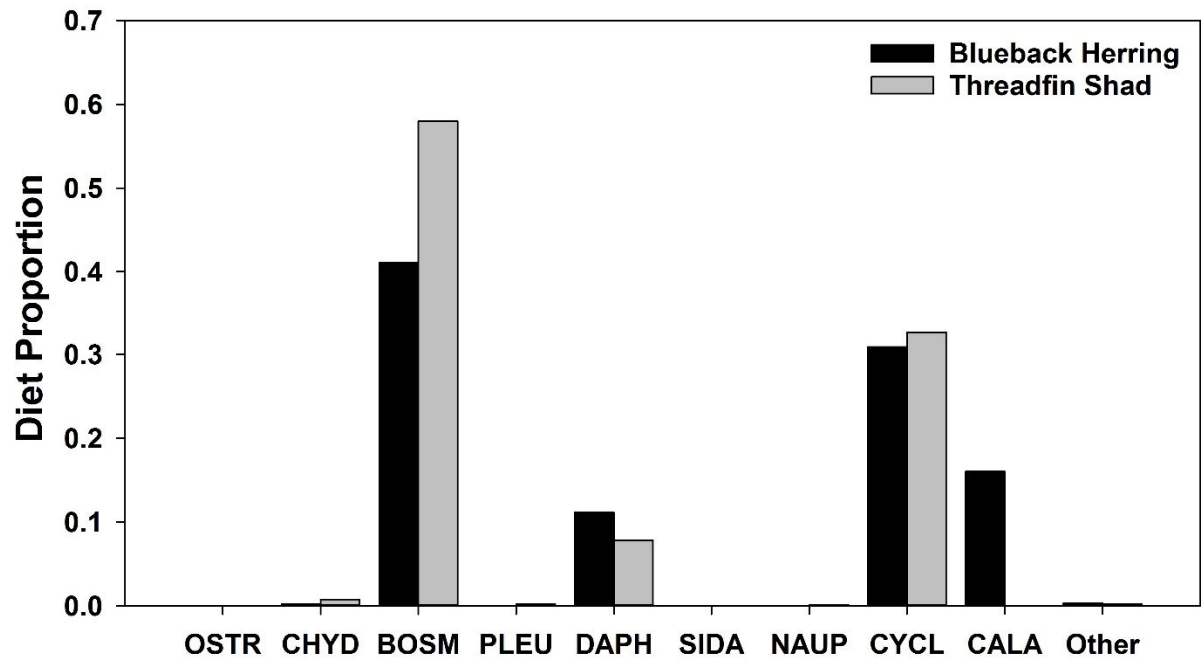


Figure 15. Adult Blueback Herring and Threadfin Shad diet proportions across sites collected from January through June from 2013 and 2014.

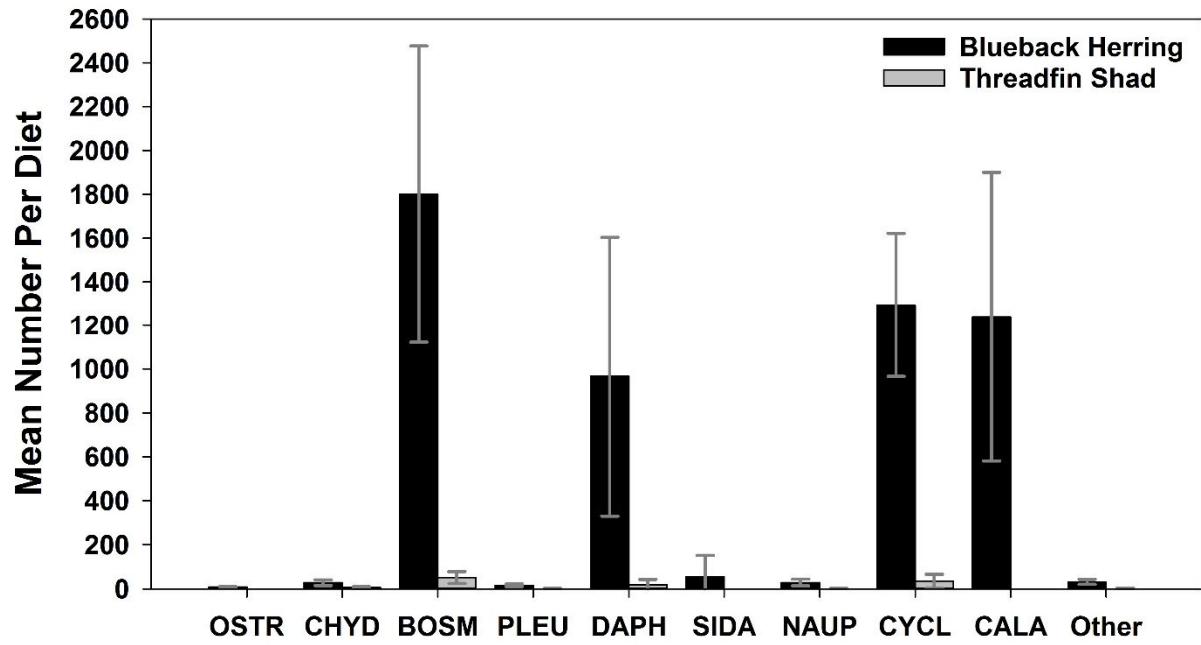


Figure 16. Mean number of zooplankton taxa/groups per diet from Blueback Herring and Threadfin Shad across sites and collected from January through June of 2013 and 2014.

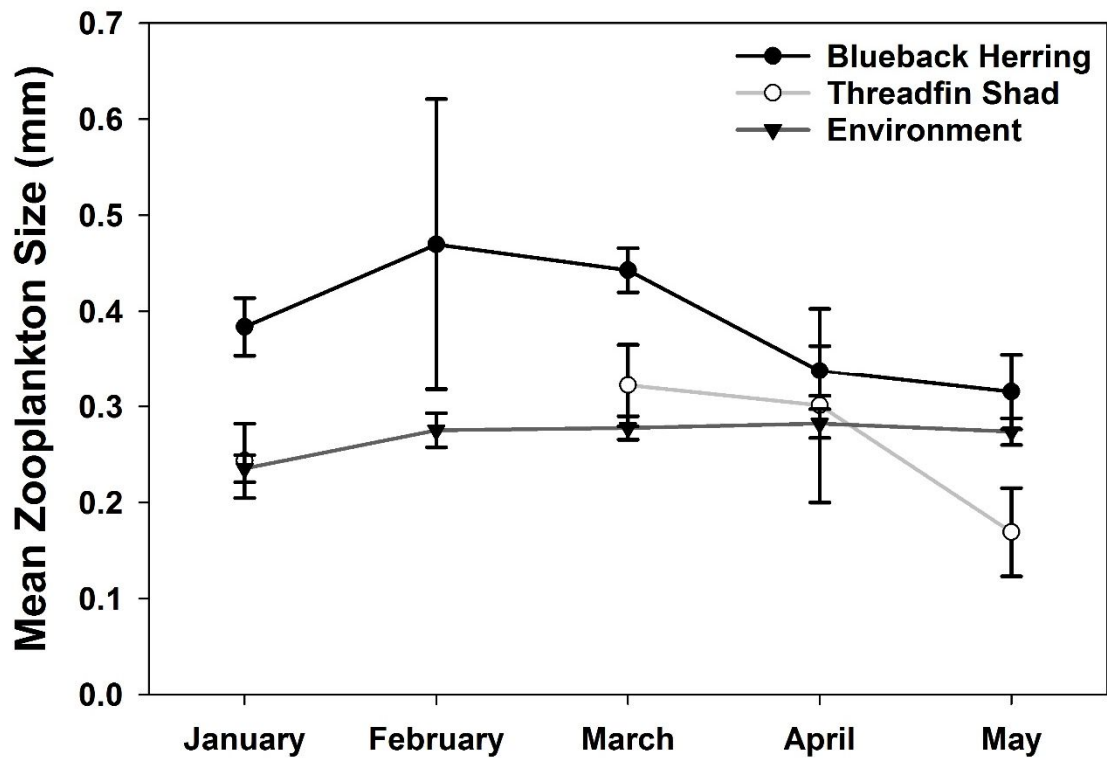


Figure 17. Mean size zooplankton found in the environment and consumed by Blueback Herring and Threadfin Shad from January through June and across sites in 2013 and 2014.

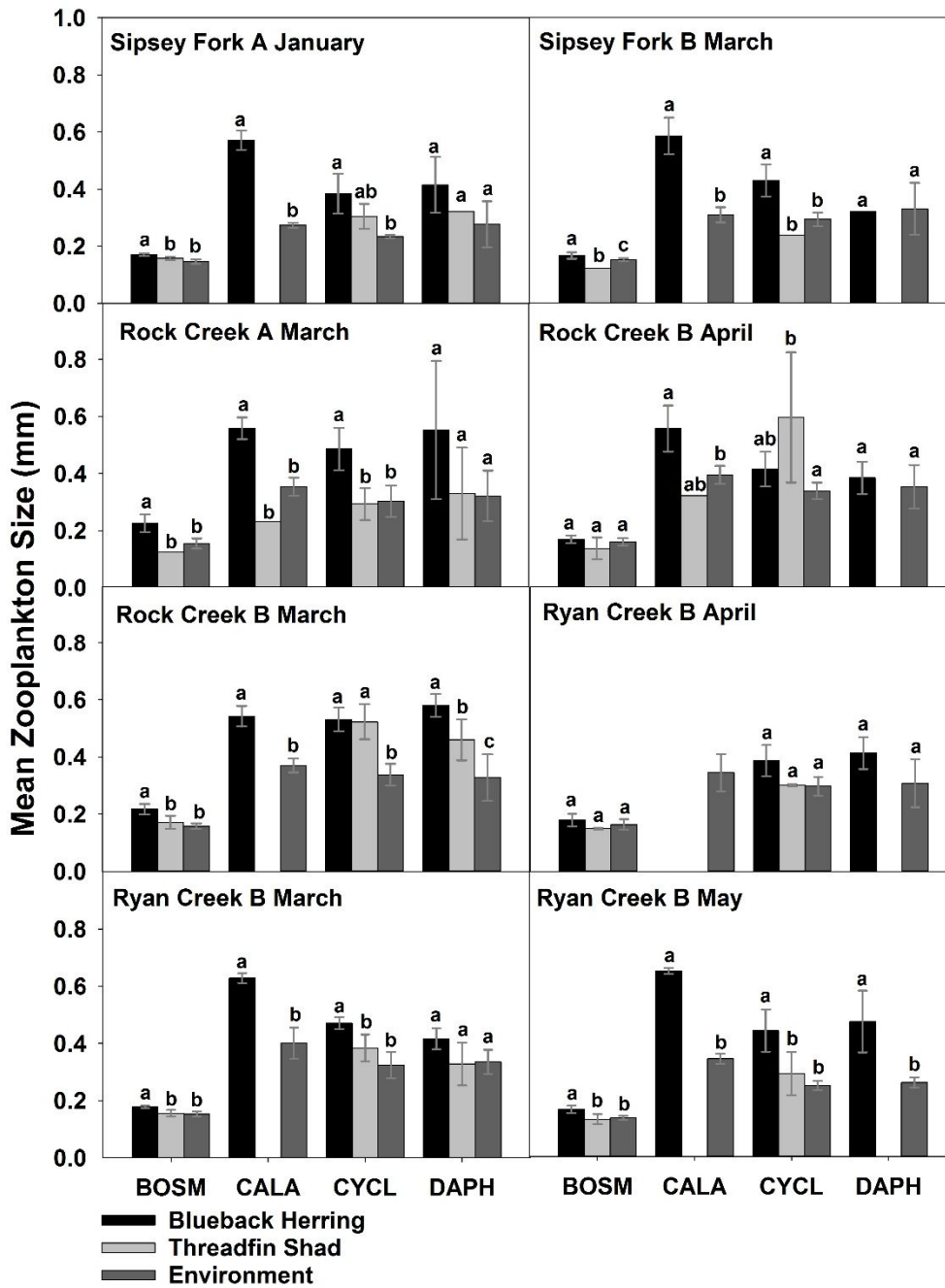


Figure 18. Mean zooplankton size in the environment compared to the diets of Blueback Herring and Threadfin Shad from 2013 and 2014. Bars with the same letter did not differ significantly.

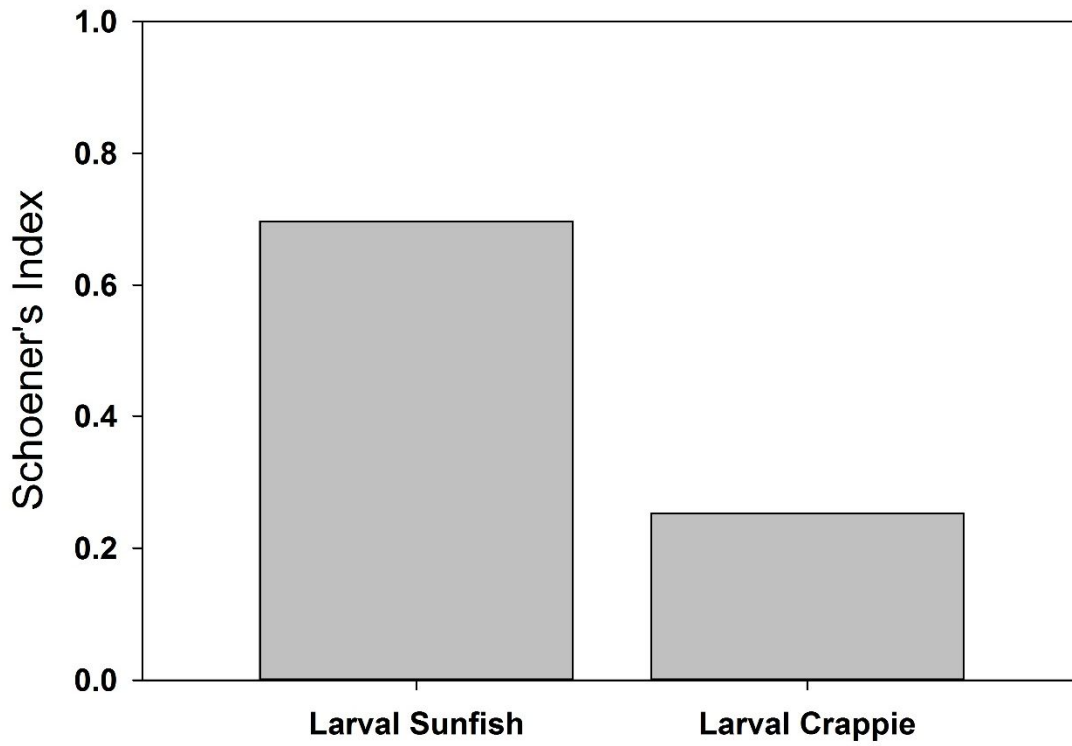


Figure 19. Schoener's Diet Overlap Index between adult Blueback Herring and larval crappies and larval sunfishes across sites and months from 2013 and 2014.

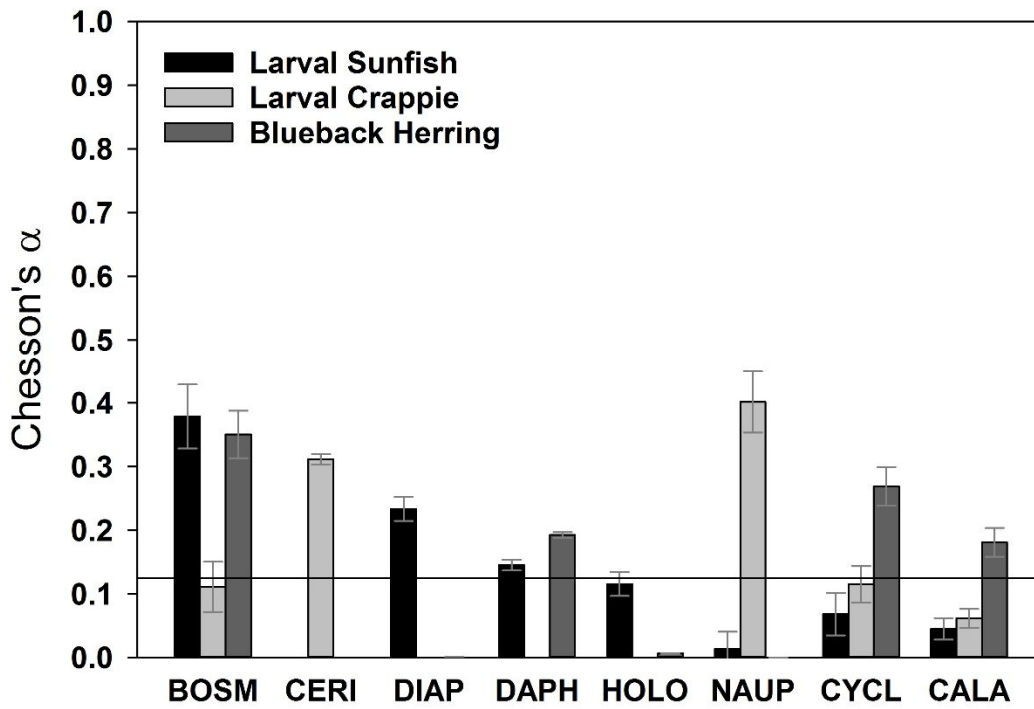


Figure 20. Chesson's α for adult Blueback Herring and larval crappies and larval sunfishes across sites and months from 2013 and 2014. Neutral selection is set at 0.125 given that 8 taxa were available.

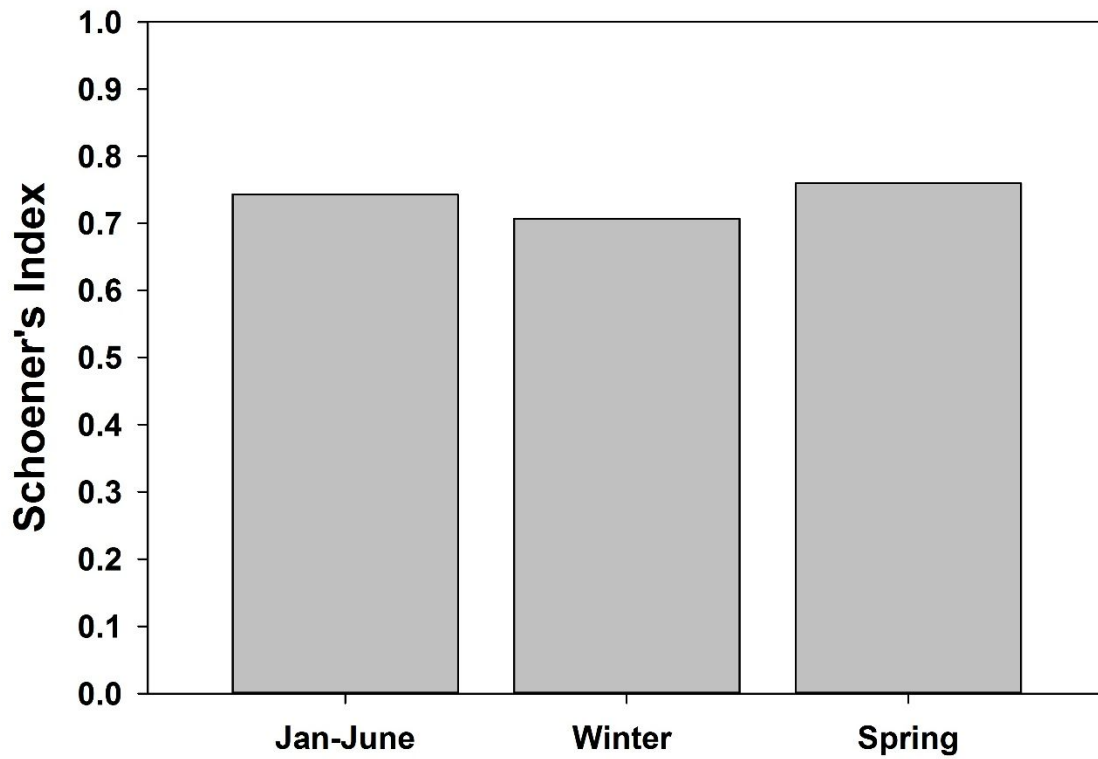


Figure 21. Schoener's Index for adult Blueback Herring and adult Threadfin Shad analyzed at separate time periods, (winter (January – March), spring (April – June) and the combined period (January – June). Samples were combined across sites and years, 2013 and 2014.

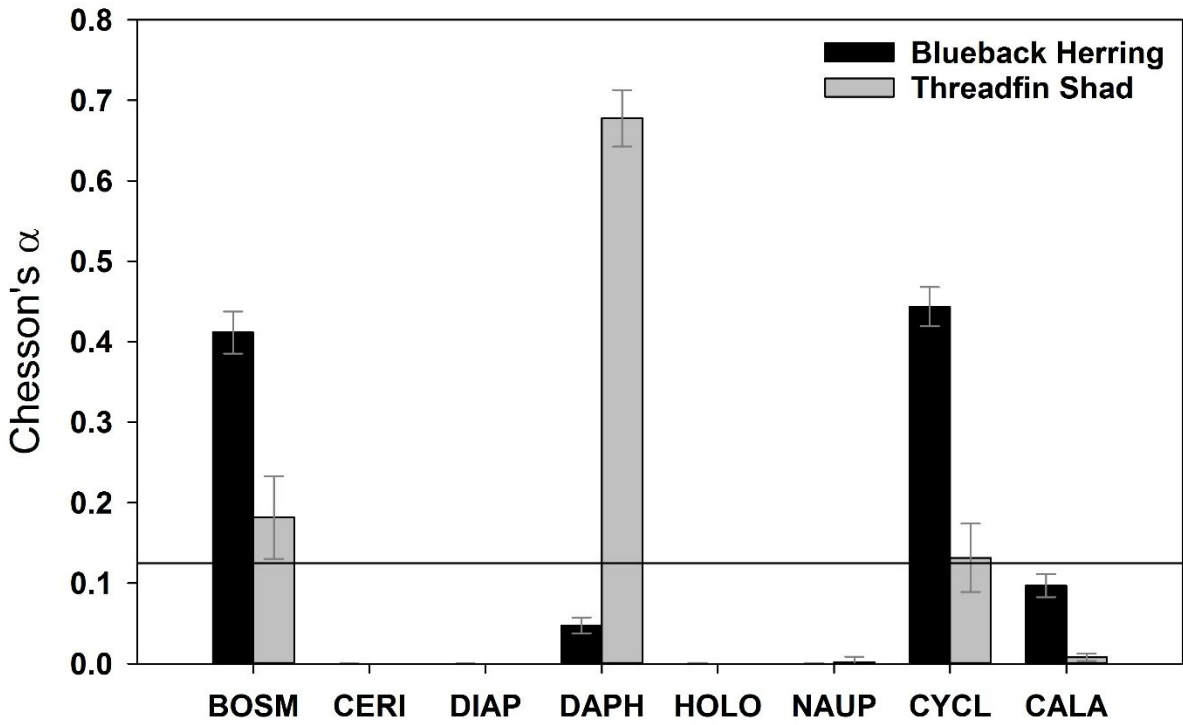


Figure 22. Chesson's α for adult Blueback Herring and adult Threadfin Shad from January to June. Samples were combined across sites and from 2013 and 2014.

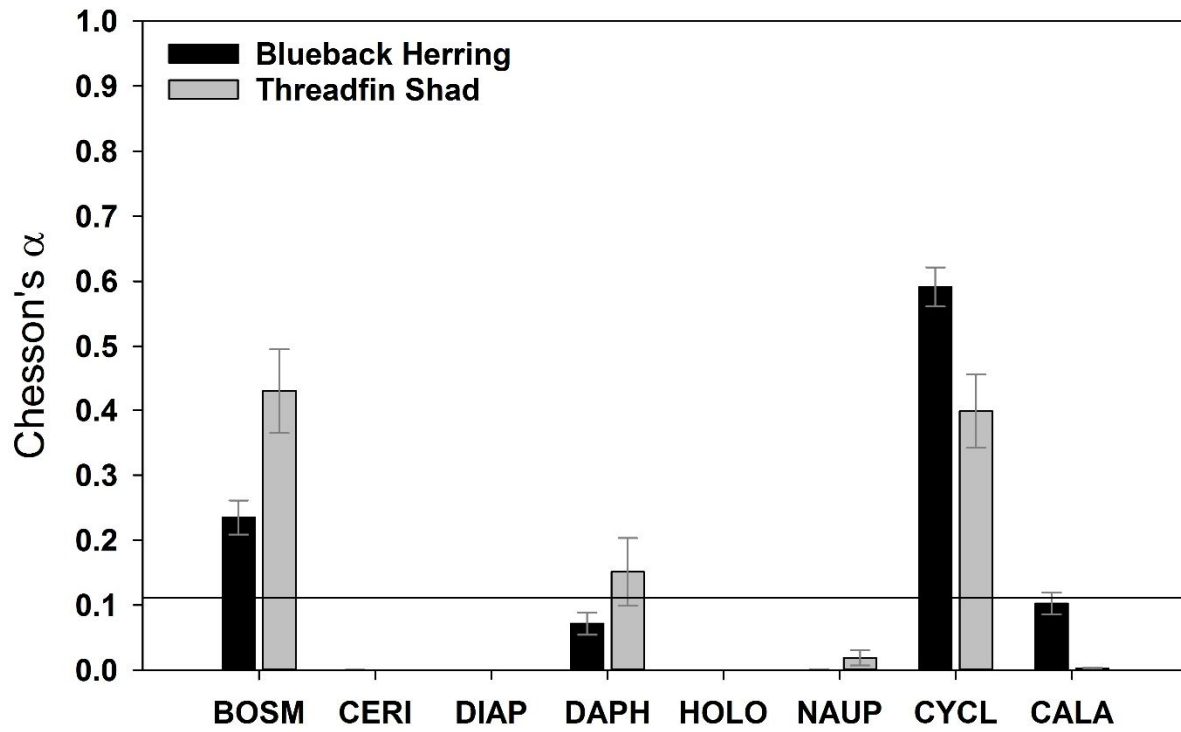


Figure 23. Chesson's α for adult Blueback Herring and adult Threadfin Shad in the winter (January - March). Samples were combined across sites and from 2013 and 2014.

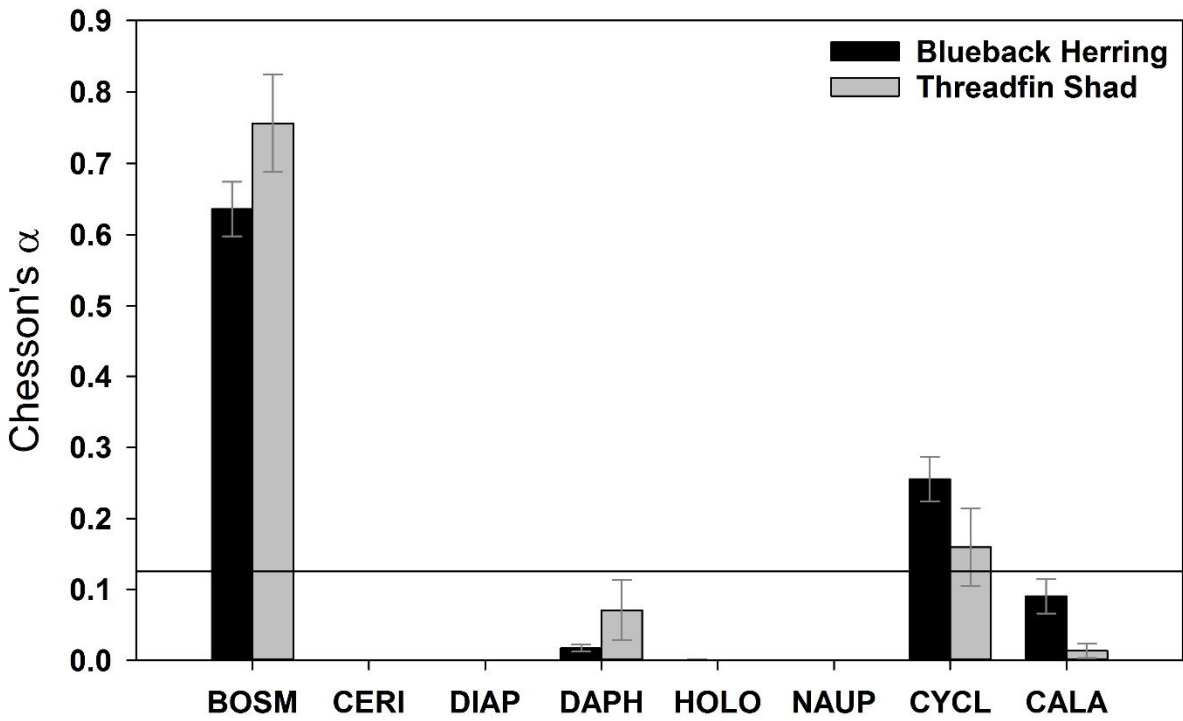


Figure 24. Chesson's α for adult Blueback Herring and adult Threadfin Shad in the spring (April – June). Samples were combined across sites and from 2013 and 2014.

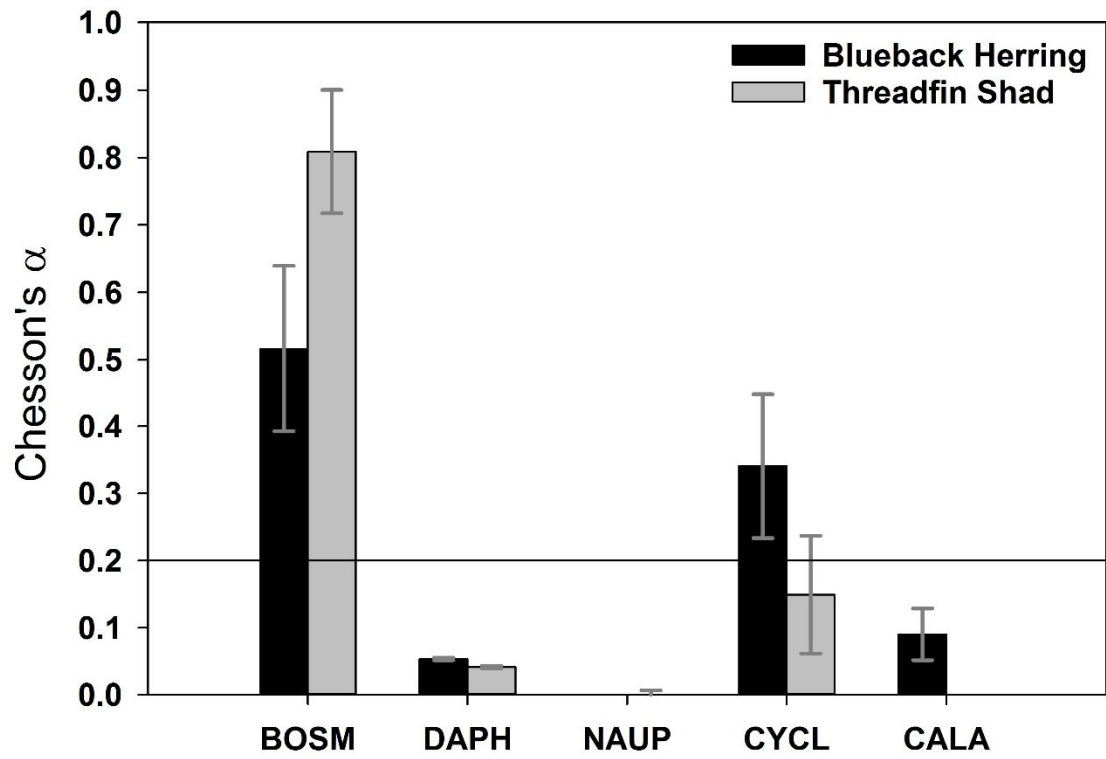


Figure 25. Chesson's α for adult Blueback Herring and adult Threadfin Shad at Sipsey Fork A in January of 2013 and 2014.

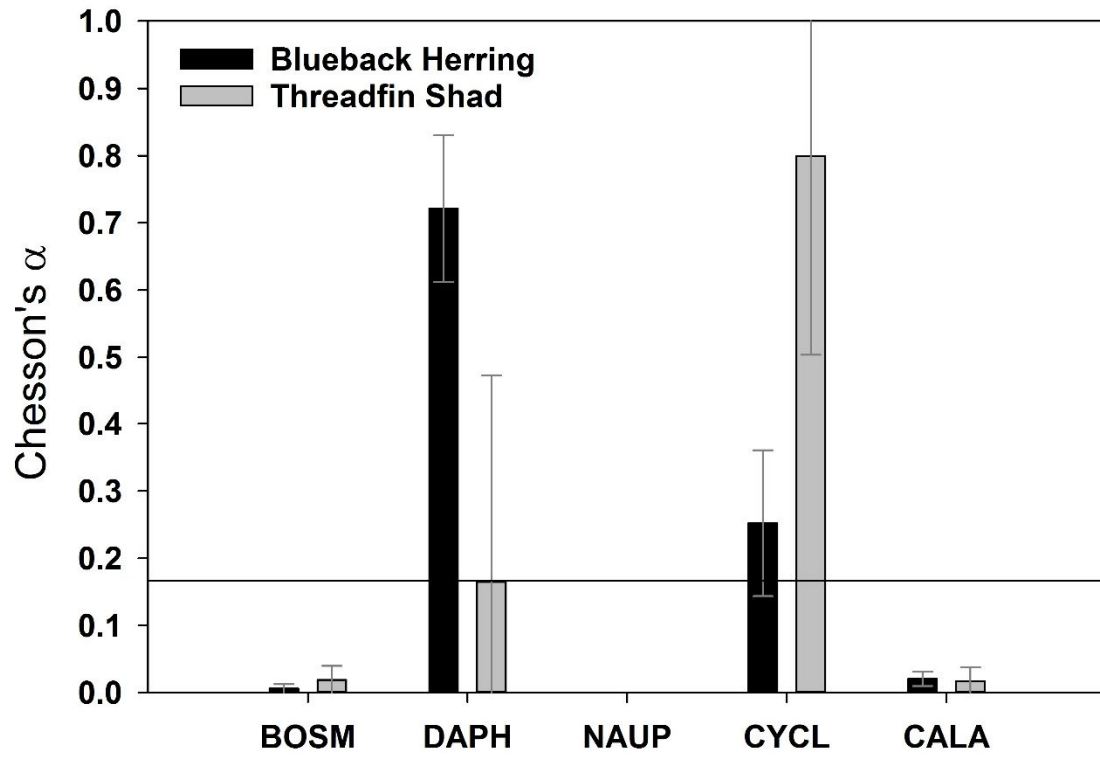


Figure 26. Chesson's α for adult Blueback Herring and adult Threadfin Shad at Rock Creek A in March of 2013 and 2014.

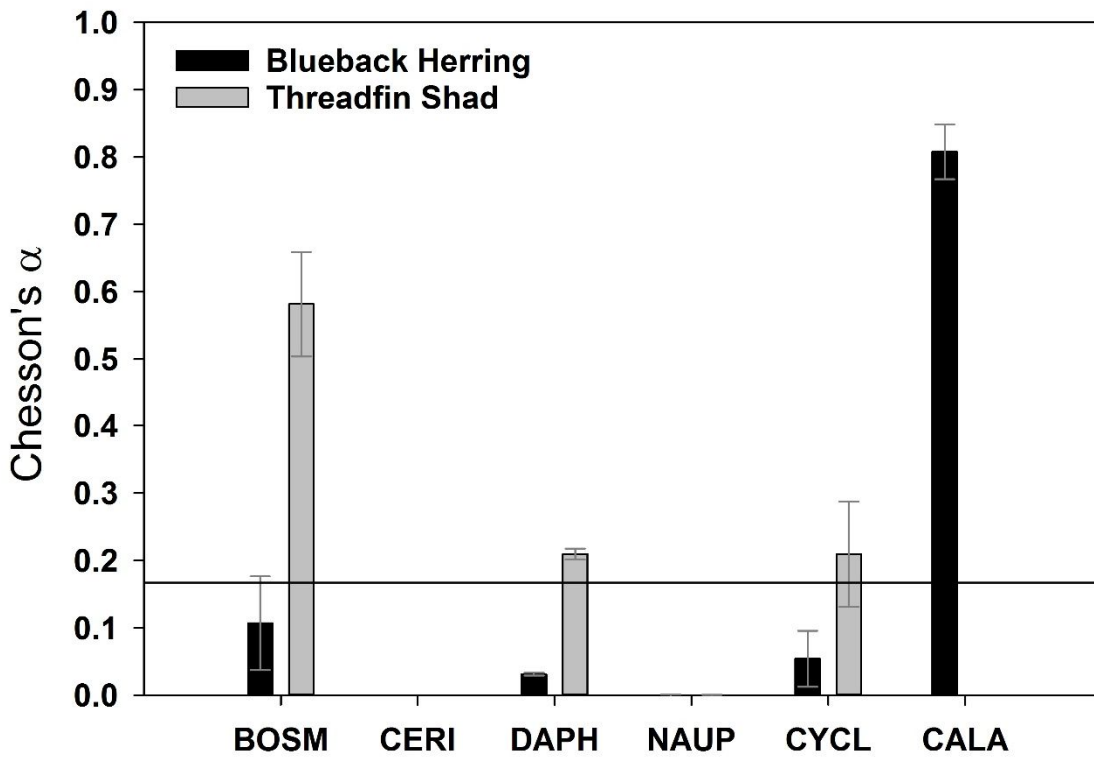


Figure 27. Chesson's α for adult Blueback Herring and adult Threadfin Shad at Ryan Creek B in March of 2013 and 2014.

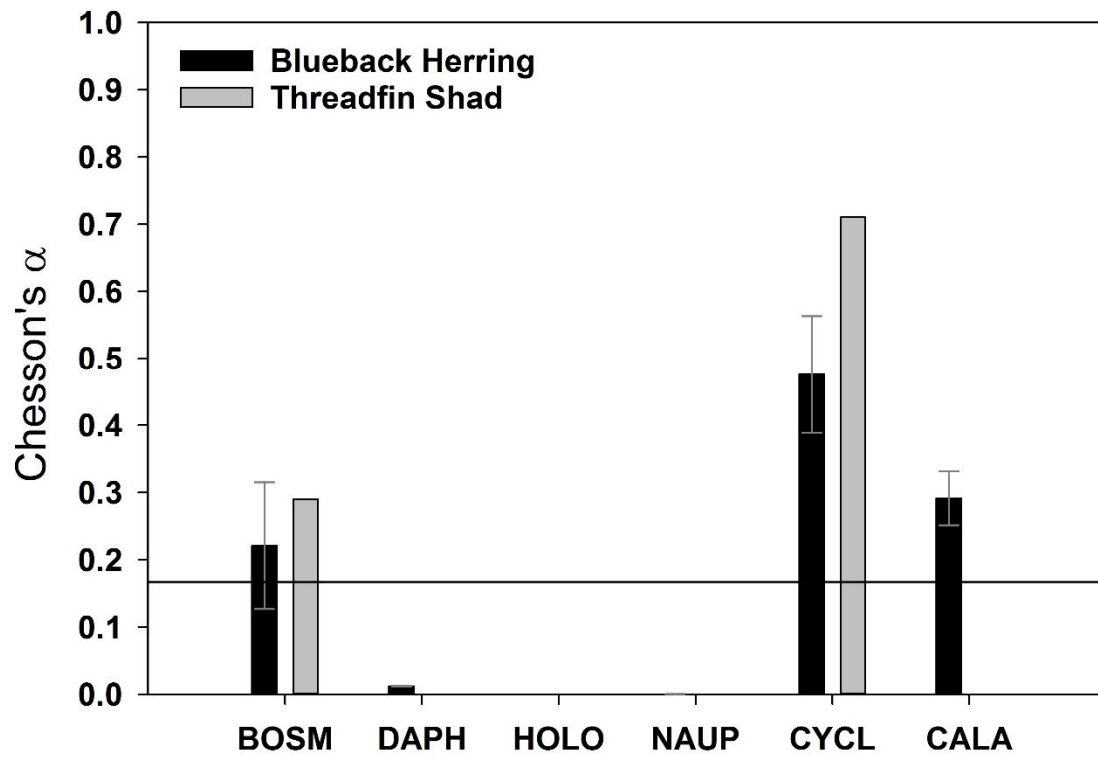


Figure 28. Chesson's α for adult Blueback Herring and adult Threadfin Shad at Sipsey Fork B in March of 2013 and 2014.

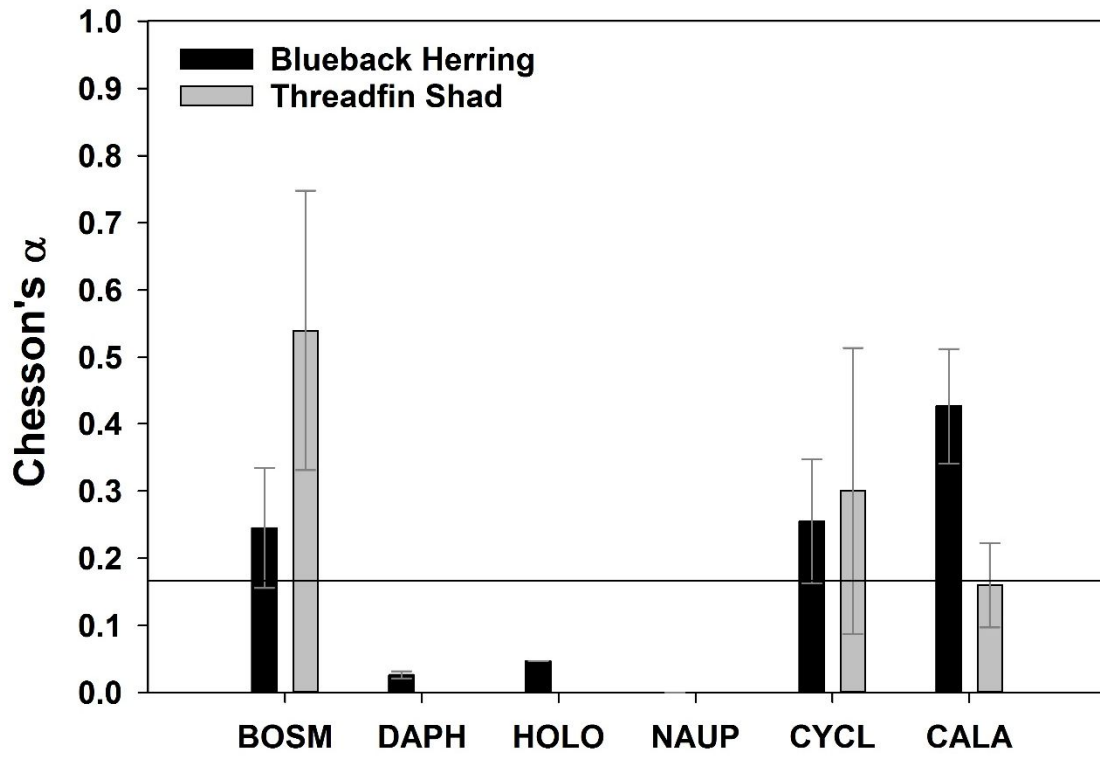


Figure 29. Chesson's α for adult Blueback Herring and adult Threadfin Shad at Rock Creek B in April of 2013 and 2014.

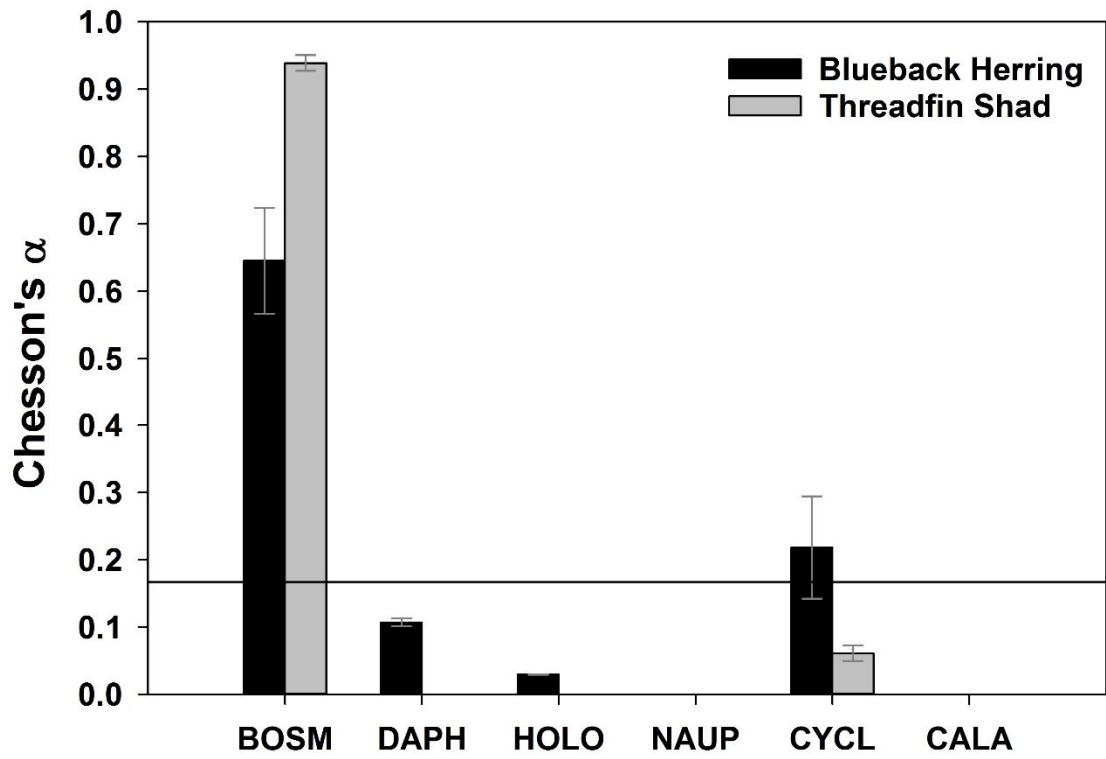


Figure 30. Chesson's α for adult Blueback Herring and adult Threadfin Shad at Ryan Creek B in April of 2013 and 2014.

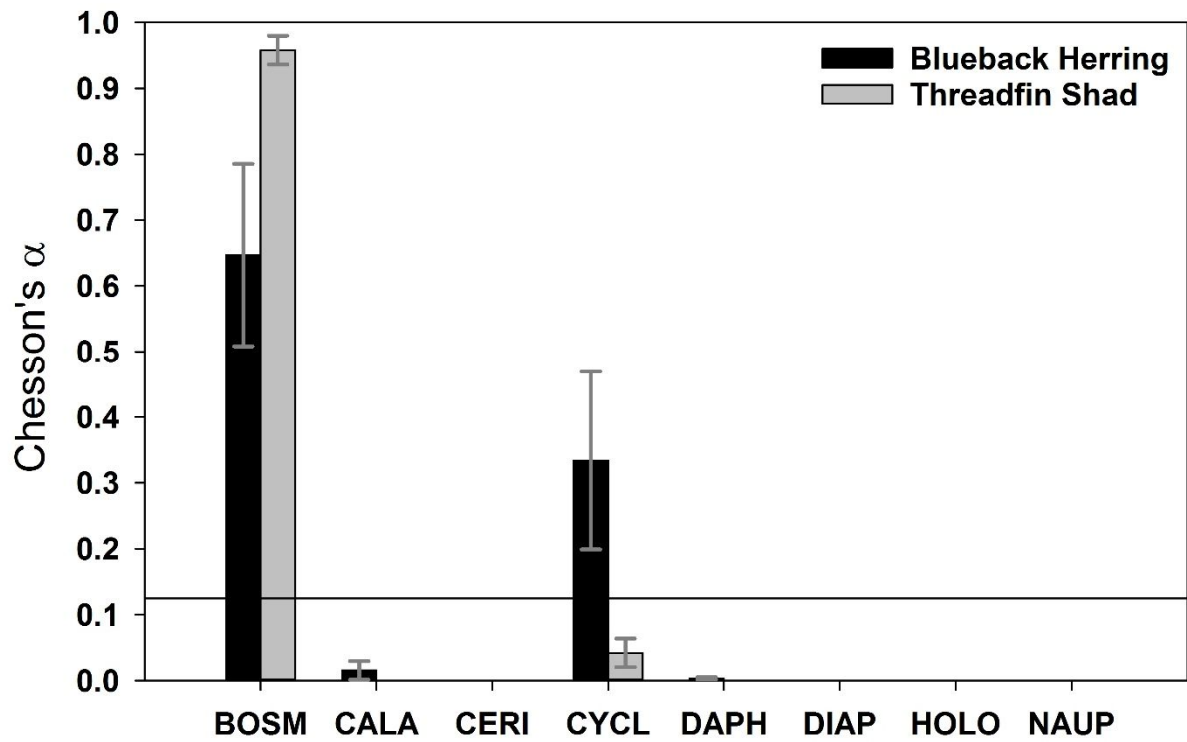


Figure 31. Chesson's α for adult Blueback Herring and adult Threadfin Shad at Ryan Creek B in May of 2013 and 2014.

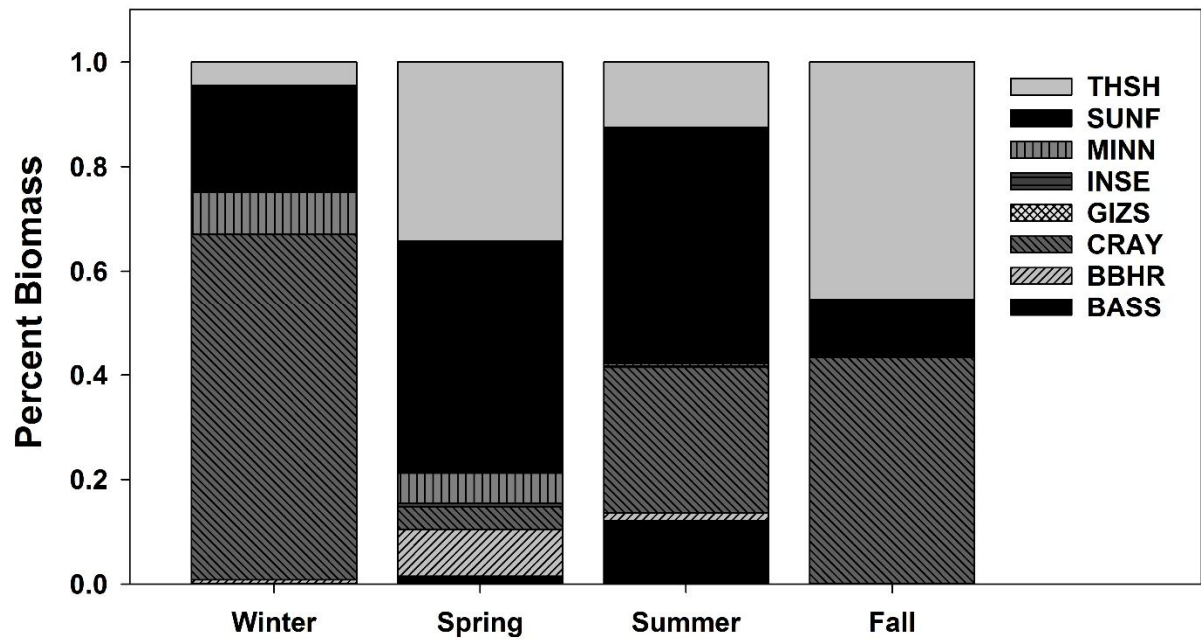


Figure 32. Largemouth Bass diet proportions among seasons and across sites from 2013 and 2014. Prey biomass proportions are calculated as a percent weight of the predator.

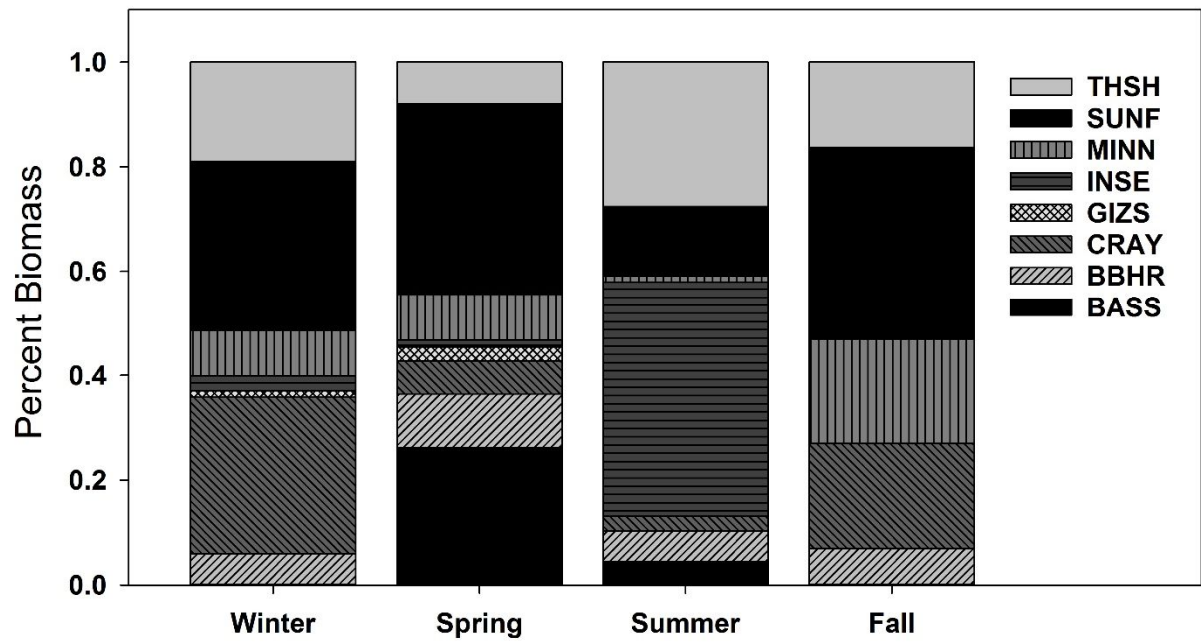


Figure 33. Alabama Bass diet proportions among seasons and across sites from 2013 and 2014. Prey biomass proportion are calculated as a percent weight of the predator.

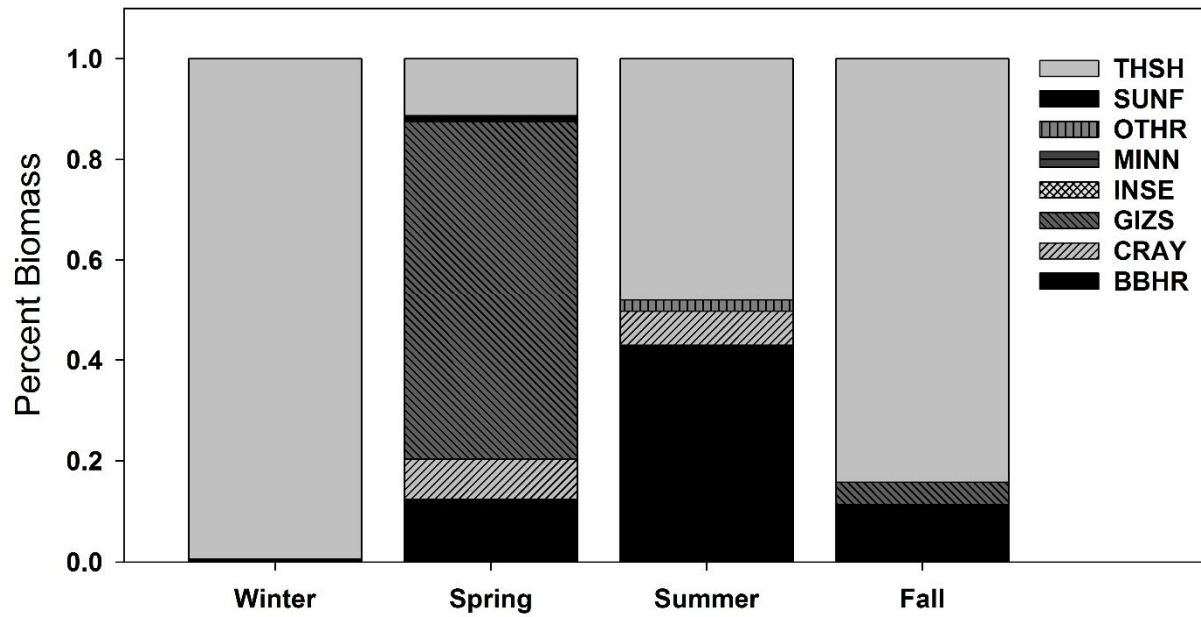


Figure 34. Striped Bass diet proportions among seasons and across sites from 2013 and 2014. Prey biomass proportions are calculated as a percent weight of the predator.

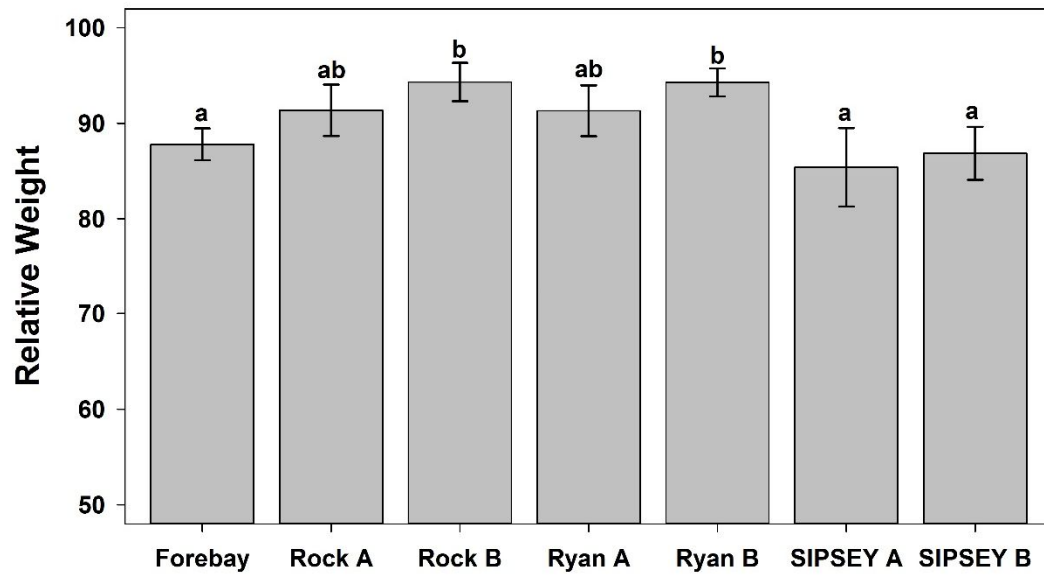


Figure 35. Largemouth Bass relative weights by site combined across months from 2013 and 2014. Bars with the same letter did not differ significantly.

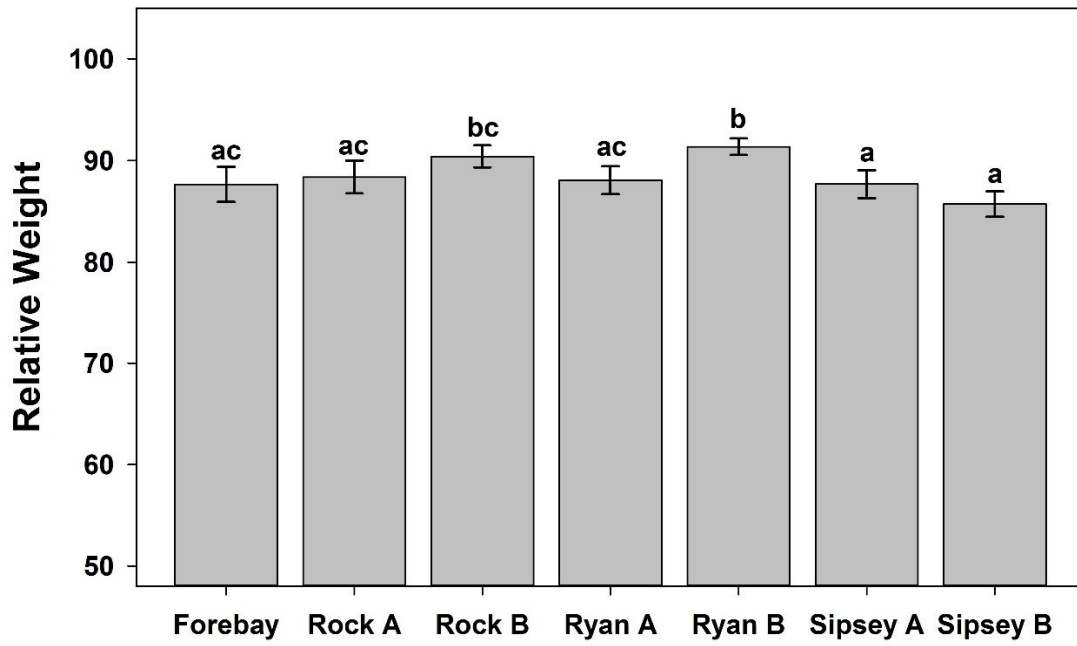


Figure 36. Current Alabama Bass relative weights by site combined across months from 2013 and 2014. Bars with the same letter did not differ significantly.

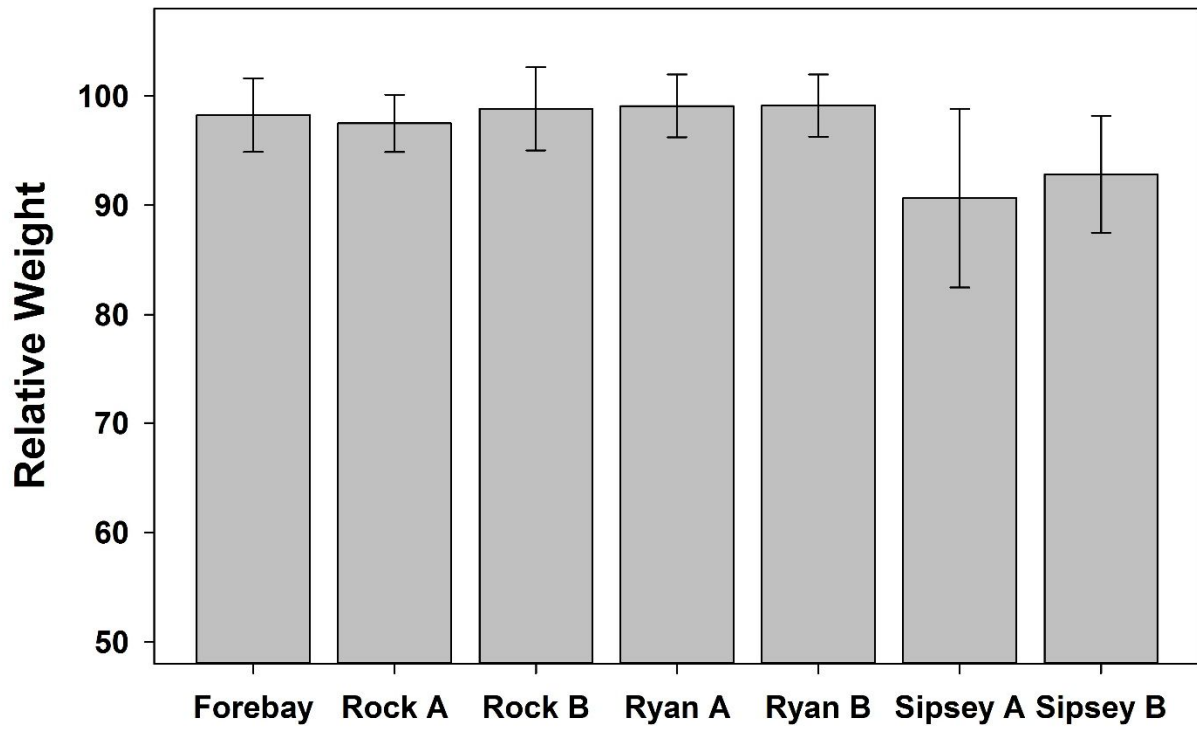


Figure 37. Current Striped Bass relative weights by site combined across months from 2013 and 2014.

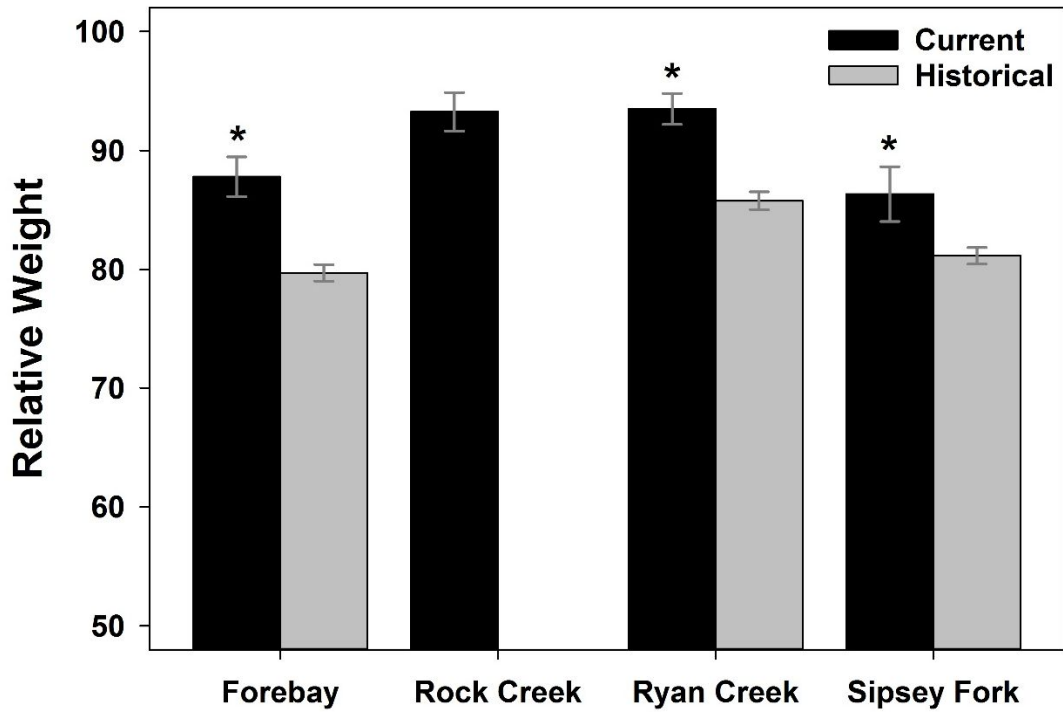


Figure 38. Current and Historic Largemouth Bass relative weights by site combined across months from 2013 and 2014. Significant differences between historical and current values are indicated by (*).

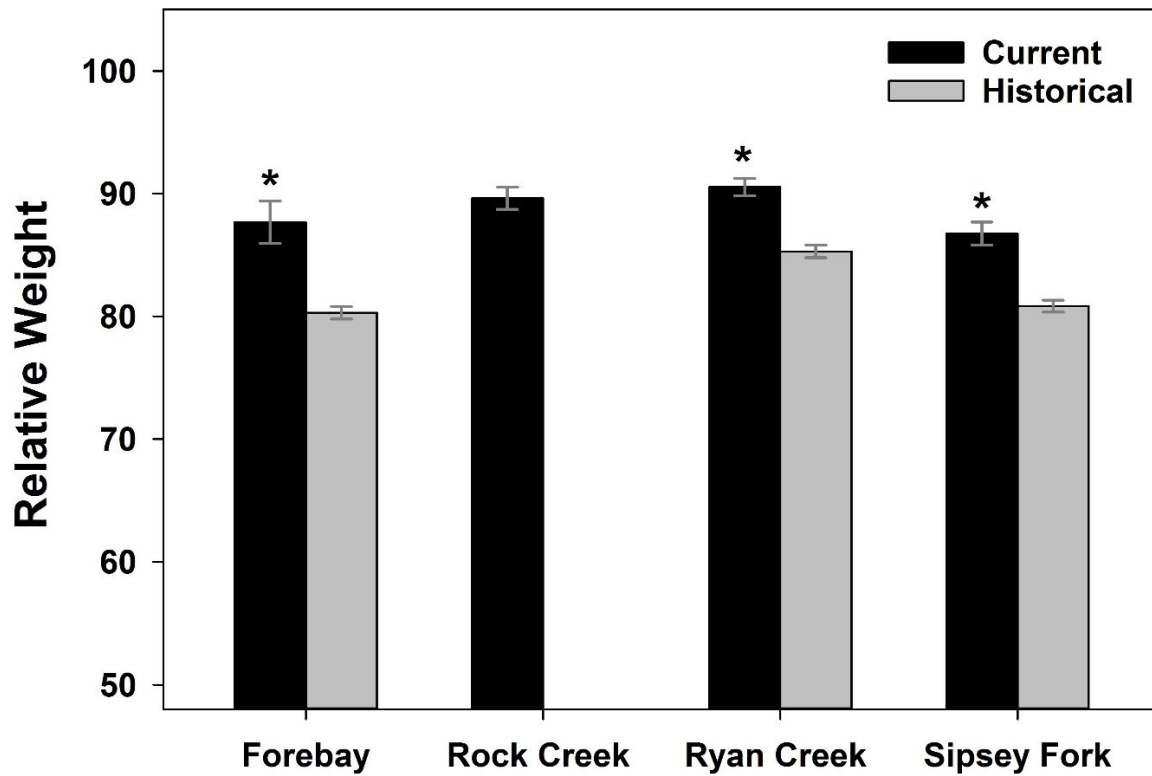


Figure 39. Current and historic Alabama Bass relative weights by site combined across months from 2013 and 2014. Significant differences between historical and current values are indicated by (*).

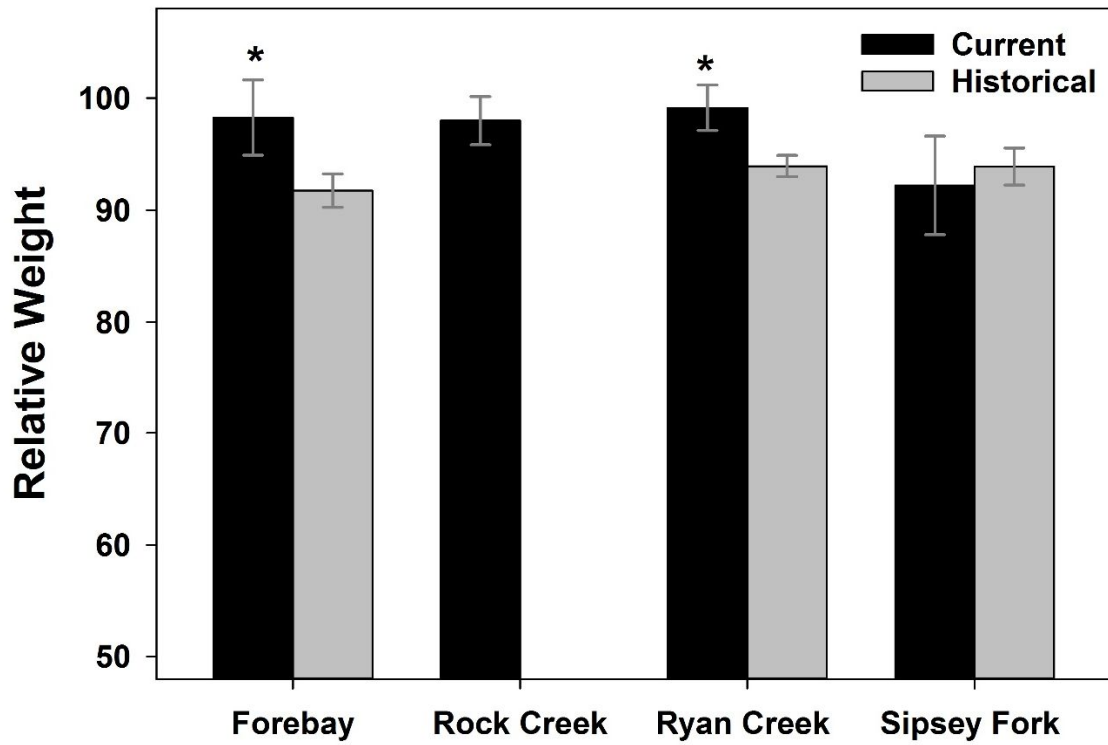


Figure 40. Current and historic Striped Bass relative weights by site combined across months from 2013 and 2014. Significant differences between historical and current values are indicated by (*).

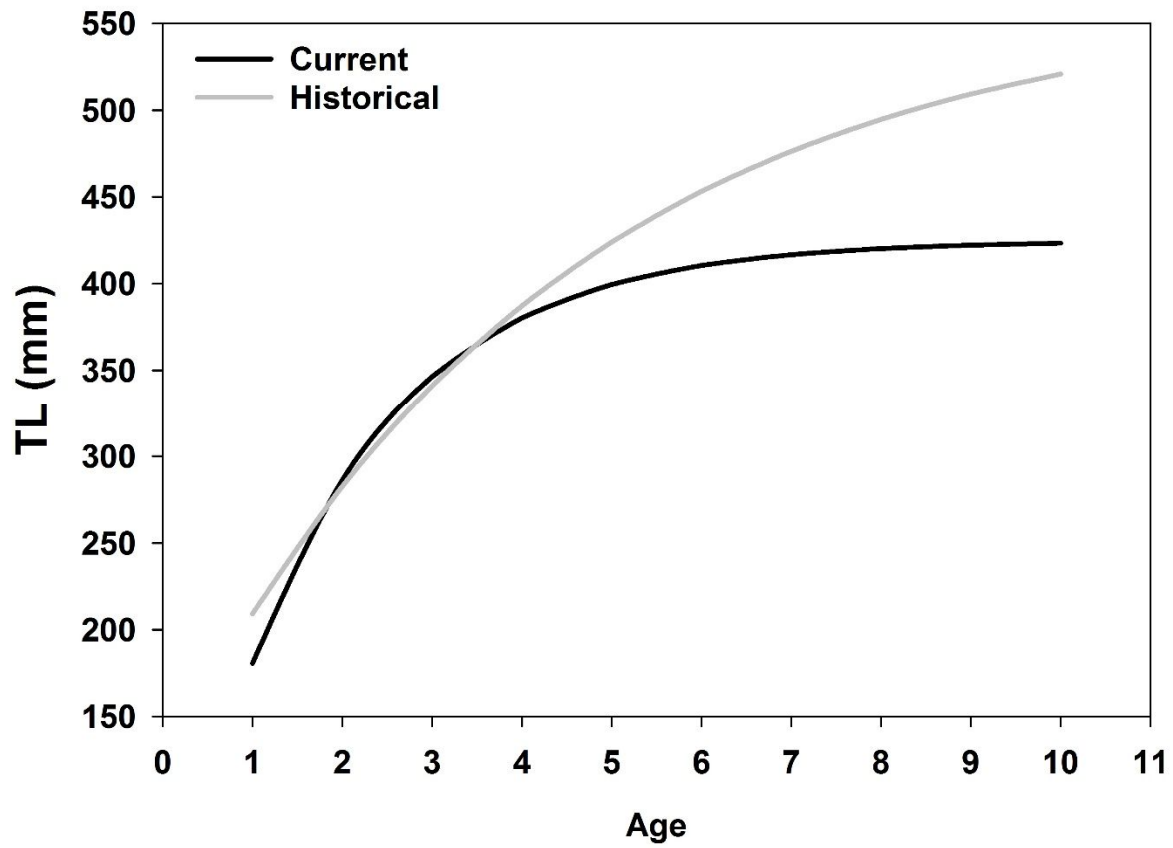


Figure 41. Historical (2005 – 20007) and current von Bertalanffy growth curves for Largemouth Bass across all sites and months form 2013 and 2014.

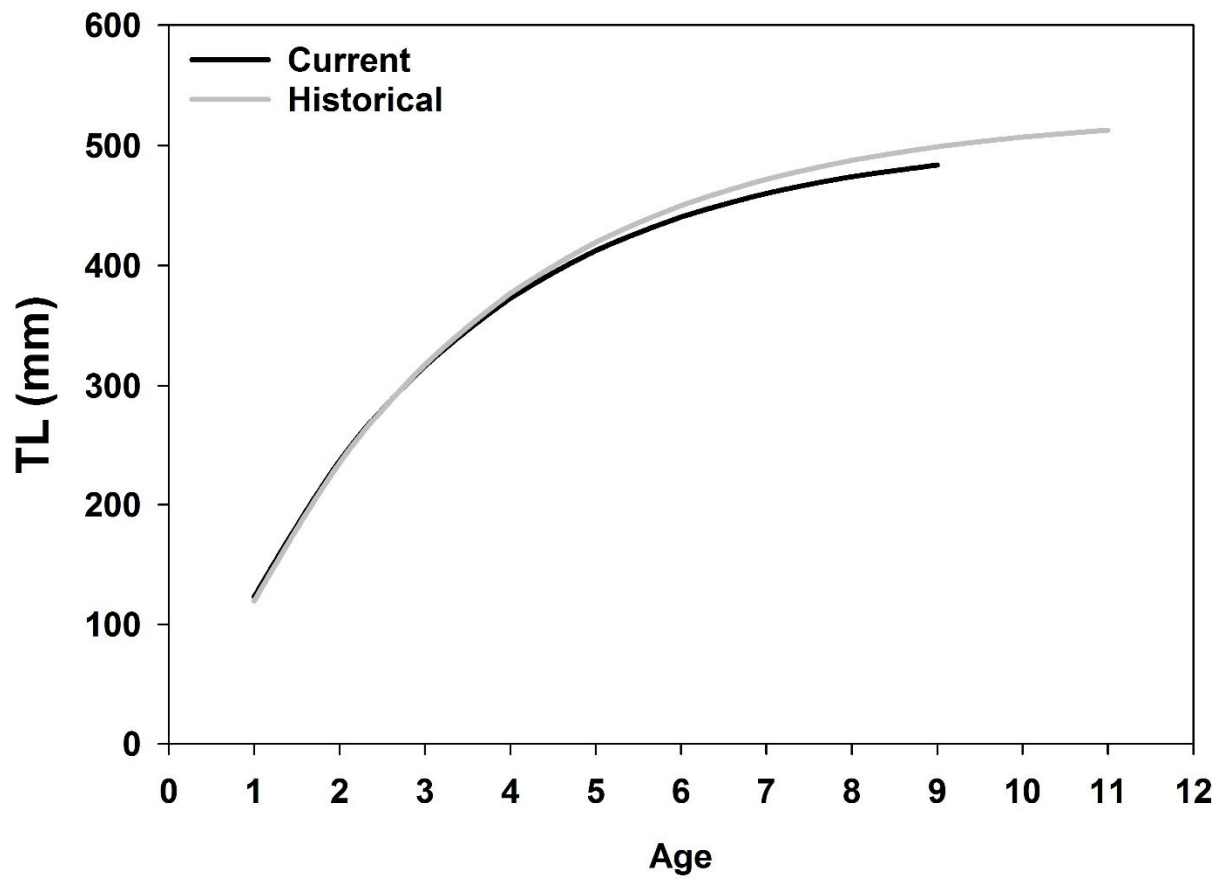


Figure 42. Historical (2005 – 20007) and current von Bertalanffy growth curves for Alabama Bass across all sites and months form 2013 and 2014.

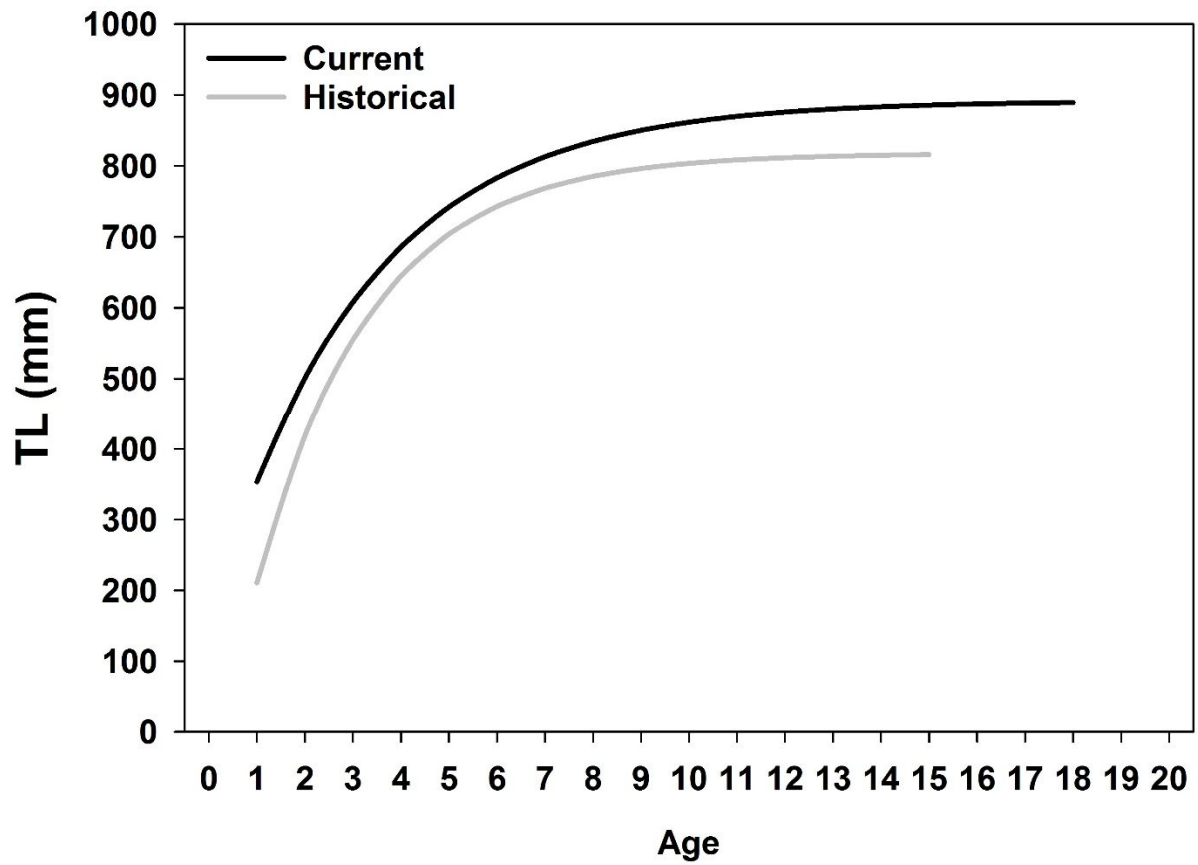


Figure 43. Historical (2005 – 20007) and current von Bertalanffy growth curves for Striped Bass across all sites and months form 2013 and 2014.

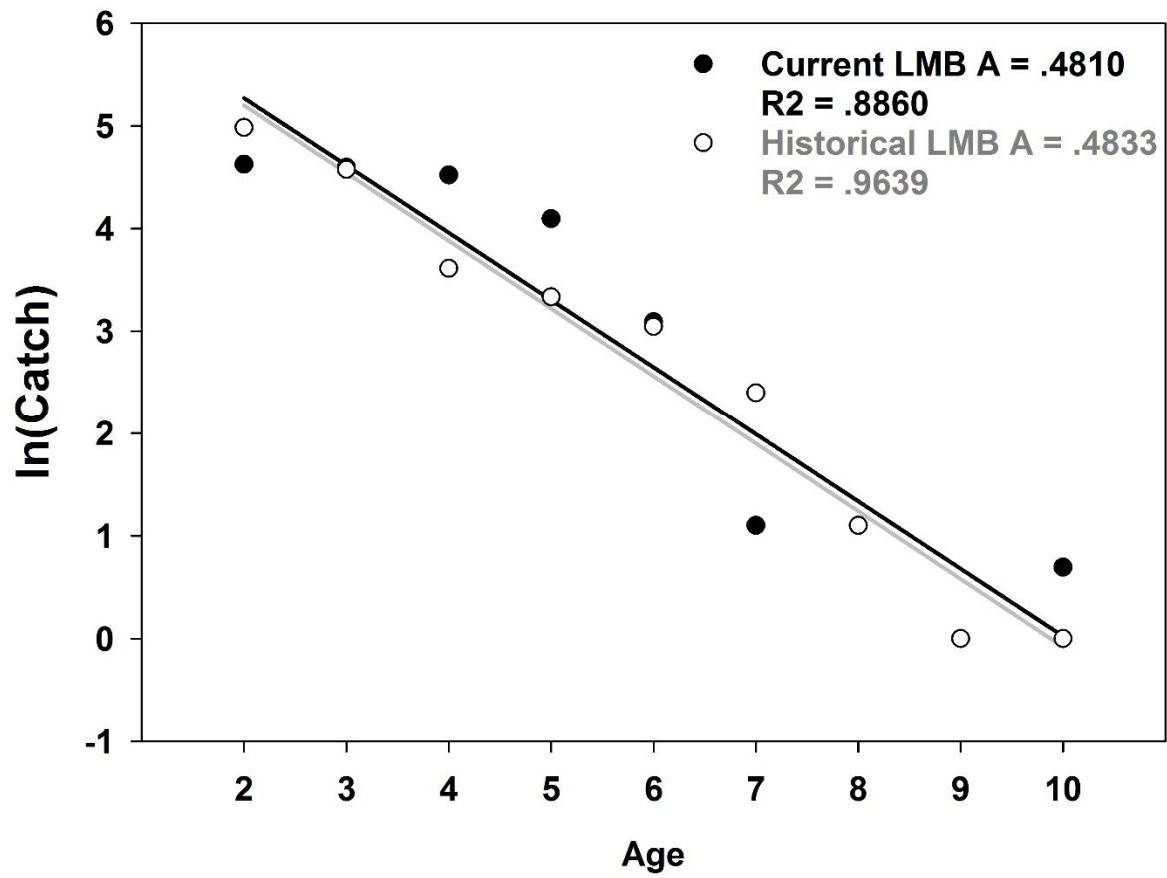


Figure 44. Current and historic Largemouth Bass catch-curve and mortality. Black dots and lines represent current mortality estimates and gray represents the historic samples.

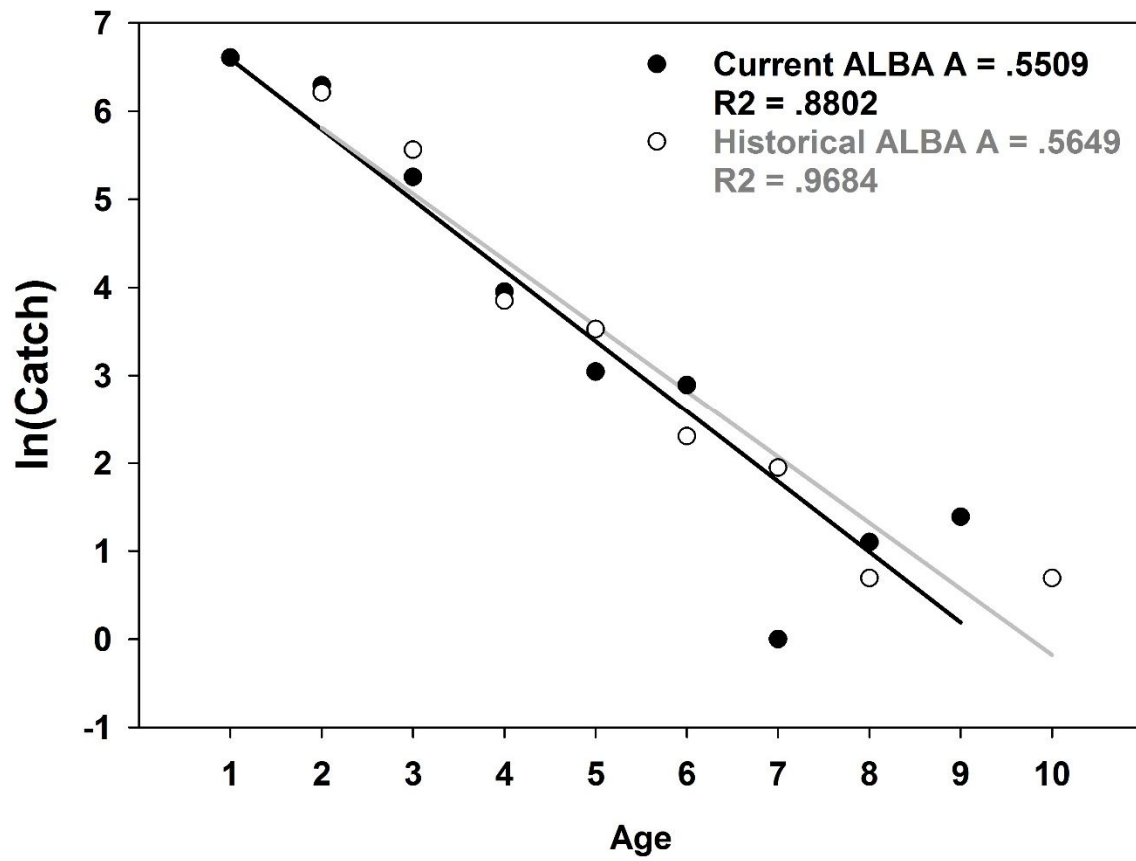


Figure 45. Current and historic Alabama Bass catch-curve and mortality. Black dots and lines represent current mortality estimates and gray represents the historic samples

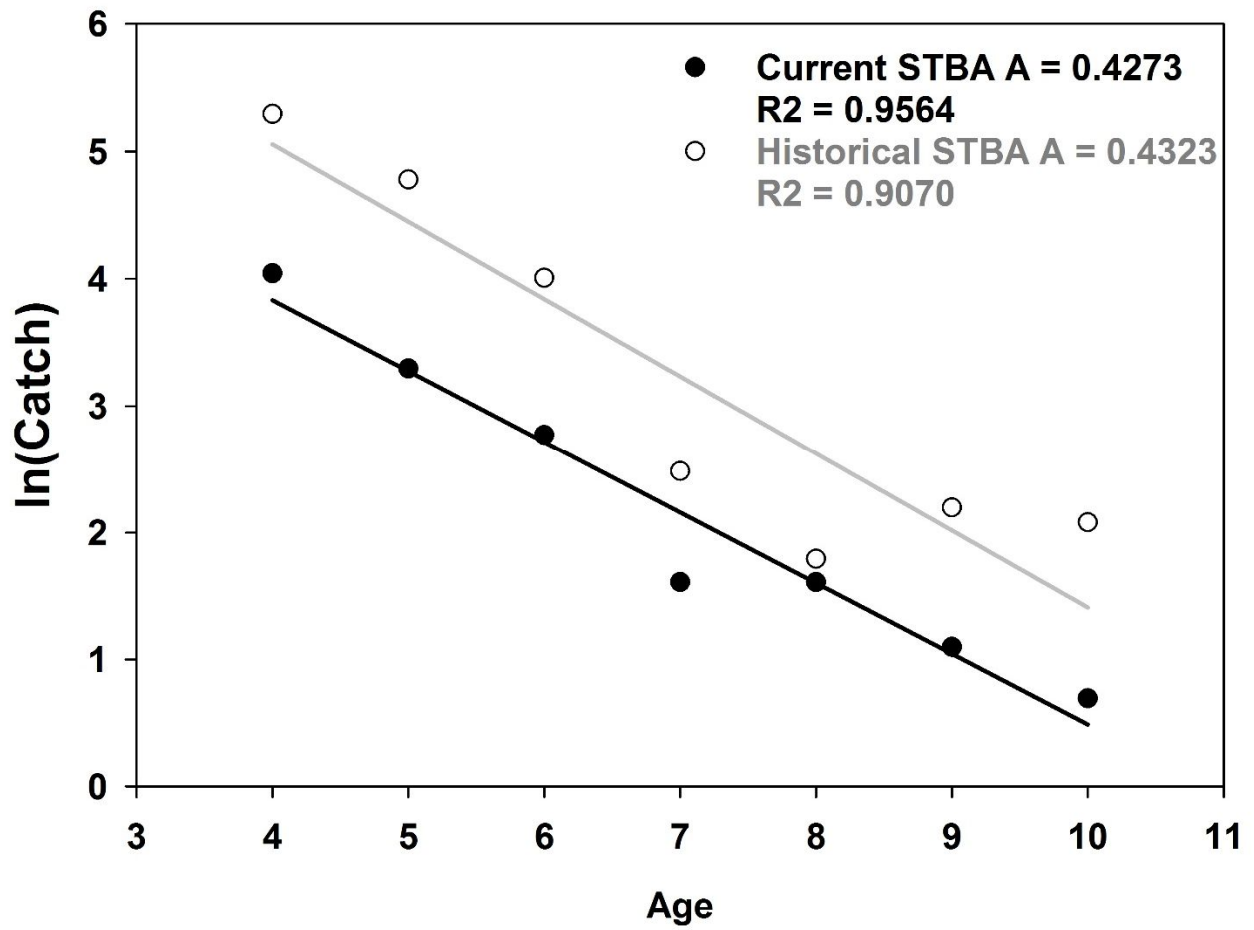


Figure 46. Current and historic Striped Bass catch-curve and mortality. Black dots and lines represent current mortality estimates and gray represents the historic samples.