Evaluating the Effects of Threadfin Shad on Largemouth Bass and Bluegill Populations in Small Impoundments

by

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Abstract

Threadfin Shad are commonly stocked into small impoundments (<40 hectares in surface area) to increase the growth and condition of Largemouth Bass, ultimately to enhance recreational fishing. However, the effects of Threadfin Shad on Largemouth Bass and Bluegill growth and condition in small impoundments are not fully understood. To date, much Threadfin Shad research has focused on large reservoirs with few studies conducted on small impoundments. With over 250,000 small impoundments in Alabama alone, understanding the role of Threadfin Shad in these systems is paramount to providing the best management advice. We evaluated the impacts of Threadfin Shad on Largemouth Bass growth, condition, and diets and Bluegill growth and condition at five recently-stocked and 29 established small impoundments in central Alabama. Results from this study suggest that Threadfin Shad increase the initial growth of Largemouth Bass but do not have significant impacts on Largemouth Bass condition. Largemouth Bass in impoundments recently established impoundments fed primarily on Threadfin Shad whereas Largemouth Bass in established impoundments fed primarily on Bluegill and only supplemented their diet with Threadfin Shad. Threadfin Shad were associated with drastic declines in zooplankton density, low larval Bluegill densities, and low seine catches of age-0 Bluegill in the littoral zone. Bluegill condition was lower in established but not in recently established impoundments. Bluegill growth was not affected by the presence of Threadfin Shad. Results of this study will provide a better understanding of interactions between Threadfin Shad and Largemouth Bass and Bluegill and provide managers with insight on how to better manage small impoundments.

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I. Introduction

A small impoundment is a body of water that is generally less than 40 hectares in surface area (Dauwalter and Jackson 2005) and serves a variety of aesthetic and utilitarian purposes (Renwick et al. 2006). There are an estimated 2.6 million small impoundments in the United States (Smith et al. 2002). Recreational fishing is one of the most popular uses of small impoundments but they are also used for water storage, livestock watering, and aquaculture. A study by the United States Department of the Interior found that 10.6 million anglers (35% of anglers that fish in freshwaters) fish impoundments smaller than 4.2 ha (USDI 1993).

Research in the 1930s and 1940s by Homer Swingle and others at Auburn University experimented with stocking different combinations of fish with the intent of finding a self-sustaining combination of fish for small impoundments (Swingle 1949). Swingle discovered self-sustaining fish communities require a balanced and compatible combination of predators and prey (Swingle 1950), and suggested stocking prey that are vulnerable to predators and have high reproductive rates, to provide predators with ample forage. Swingle also suggested that predators should have high reproductive rates and be able to effectively control prey populations. Swingle's research found that Largemouth Bass *Micropterus salmoides* and Bluegill *Lepomis macrochirus* are the most compatible species for small impoundments in the Southeastern U.S. due to their interaction as predator and prey (Swingle 1950). Largemouth Bass serve as good predators because they effectively feed on Bluegill and have relatively high reproductive success in small impoundments. Bluegill are a good prey resource because they reproduce several times throughout the summer, are vulnerable to predators throughout a large portion of their lives, and their small mouths prevent them from competing with adult Largemouth Bass for forage. However, Bluegill have a variety of defense mechanisms which greatly reduces their predation by Largemouth Bass. These mechanisms include effective predator avoidance behaviors (Werner and Hall 1988), defensive spines, and deep bodies which allow them to outgrow the gape size of Largemouth Bass. Decreased predation on Bluegill can negatively affect both Largemouth Bass and Bluegill populations (Swingle 1956), decreasing the amount of energy Largemouth Bass convert into growth (i.e., weight and length) and reproduction. For Bluegill, decreased predation can result in high densities of Bluegill and high levels of intraspecific competition which reduces growth and condition of Bluegill. Additionally, high densities of Bluegill will feed on Largemouth Bass eggs, further suppressing reproductive success of Largemouth Bass (Swingle 1970). As a result of these potential drawbacks of Bluegill as prey, fisheries managers and biologists have experimented with stocking supplemental prey species.

Additional prey fish species are stocked in impoundments to increase growth, and condition of predators (i.e. Largemouth Bass). A number of supplemental prey species have been used across the United States, including: Golden Shiner *Notemigonus crysoleucas*, Fathead Minnows *Pimephales promelas*, Gizzard Shad *Dorosoma cepedianum,* and Threadfin Shad *Dorosoma petenense*. Supplemental prey species have the potential to have positive or negative impacts on the existing fish community so it is important to consider a few factors before stocking, including: whether the population will be self-sustaining, its potential for overcrowding, its caloric density, and whether adults are vulnerable to predation (Wright and Kraft 2012).

Threadfin Shad is commonly stocked into Southeastern US small impoundments (Haley et. al 2012), and is considered an ideal prey species because they rarely grow larger than 175 mm (Noble 1981), they spawn at early ages, and have no defensive spines. However, Threadfin Shad are pelagic prey and without a pelagic refuge their populations can be quickly decimated by predators. In many regions of the United States Threadfin Shad must be stocked annually because they cannot survive winter water temperatures that drop below 40°F for extended periods of time. Potential positive and negative interactions between Threadfin Shad and existing fish species (i.e., Largemouth Bass and Bluegill) must also be considered. Currently there is a vast amount of research associated with Threadfin Shad and their effects on growth and condition of sport fish such as the Largemouth Bass and Bluegill (DeVries and Stein 1990). However, many of these studies have contradictory results which prevent fisheries biologists and researchers from being able to conclude whether Threadfin Shad ultimately increase or inhibit the growth and condition of Largemouth Bass and Bluegill.

Threadfin Shad have the potential to increase Largemouth Bass growth and condition (May and Thompson 1974; DeVries and Stein 1990). Applegate and Mullan (1967) found that Largemouth Bass had higher growth rates in Beaver Reservoir, Arkansas, with a higher abundance of *Dorosoma spp.* than Largemouth Bass in Bull Shoals Reservoir, Arkansas, which had a lower abundance of *Dorosoma spp.* However, there are also studies that show that Threadfin Shad can negatively impact Largemouth Bass population dynamics (May and Thompson 1974; DeVries and Stein 1990). Keefer (1995) found that Largemouth Bass growth and recruitment increased dramatically after a fish kill dramatically reduced Threadfin Shad and Gizzard Shad populations in Lake Walter F. George, Georgia.

The effects of Threadfin Shad on Bluegill have been well studied, but results of these studies often suggest equivocal results. DeVries et. al (1991) found that Threadfin Shad greatly reduced abundances of zooplankton resulting in a precipitous decline in the survival of Bluegill in Stonelick Lake, Ohio. In the same study, DeVries et. al (1991) found no adverse effects of Threadfin Shad on Bluegill in Clark Lake, Ohio.

In addition to the mixed reviews of stocking shad, there are also many shortcomings in the research to date associated with impacts Threadfin Shad have on the existing fish community. The vast majority of current research is focused on the impacts Threadfin Shad have on adult sportfish. These studies often neglect the interactions between shad and juvenile sportfish. Examining interactions involving juvenile sportfish, in addition to adult sportfish, is important given that negative impacts on juvenile sportfish could ultimately result in reduced recruitment into larger size classes of sportfish, consequently reducing angling success. Von Geldern and Mitchell (1975) found that Threadfin Shad introductions in California initially improved growth of sportfish but ultimately sport fishing success was reduced due to Threadfin Shad competition with juvenile sport fish (Wydoski and Bennett 1981).

Of the recent research associated with interactions between Largemouth Bass, Bluegill, and Threadfin Shad, little have focused on small impoundments. Haley et al. (2012) evaluated several management techniques geared towards enhancing Largemouth Bass and Bluegill fisheries in small impoundments in Alabama. Results of their study found that impoundments with Threadfin Shad generally had Largemouth Bass that were greater in length, growth, and body condition then ponds without Threadfin Shad. In addition, the study found no negative impacts on Bluegill size structure, CPUE, or condition. However, this study did not control for impoundment size, harvest intensity, or system productivity all of which can greatly influence the fish community. Threadfin Shad impoundments sampled in their study were significantly larger than non-Threadfin Shad ponds. This lack of standardization of pond size could have biased their results and masked true impacts that Threadfin Shad have on both Largemouth Bass and Bluegill populations. In general, despite the stocking of Threadfin Shad into small impoundments, their interactions with Largemouth Bass and Bluegill are poorly understood.

Bridging these gaps in research and further understanding these interactions could be invaluable to pond managers who are tasked with enhancing Largemouth Bass growth and condition or ecologists that use small impoundments to study fish community interactions.

The objective of this study is to evaluate the effects of Threadfin Shad on Largemouth Bass and Bluegill population characteristics in small Southeastern US impoundments (<4.2 hectares). More specifically I examined the effects of Threadfin Shad on Largemouth Bass and Bluegill growth and condition in 5 recently established and 29 established impoundments in Alabama (Chapter II). I also examined the effects that Threadfin Shad have on the recruitment of Bluegill in 5 recently established impoundments (Chapter III).

II. Evaluating the Effects of Threadfin Shad on Largemouth Bass and Bluegill Growth and Condition in Small Impoundments

Abstract

Threadfin Shad are commonly stocked into small impoundments in the Southeastern US with the aim of increasing the growth and condition of Largemouth Bass, but the effectiveness of this practice is not well understood. I evaluated the impacts of Threadfin Shad on Largemouth Bass growth, condition, and diets and Bluegill growth and condition in five recently-stocked and 29 established small impoundments in Alabama. Impoundments used for this study were selected based on their similarity in characteristics (i.e., surface area) and management strategies. Electrofishing surveys revealed that Threadfin Shad stocking was associated with higher Largemouth Bass growth rates in established and recently-established impoundments, but condition did not differ. Threadfin Shad had a significant, negative impact on Bluegill condition but had no significant effect on Bluegill growth in established impoundments. In recently established impoundments Threadfin Shad had no effects on Bluegill condition. Results of this study will provide biologists with valuable insight related to the effects of Threadfin Shad on Largemouth Bass and Bluegill populations in small impoundments and will help improve small impoundment management in the Southeastern United States.

Introduction

Small impoundments are a common feature of the Southeastern United States and provide a number of aesthetic and utilitarian purposes (Renwick et al. 2006). Popular uses of these impoundments include cattle watering, irrigation, and recreational fishing. In the Southeastern United States many small impoundments geared towards recreational fishing primarily contain Largemouth Bass (*Micropterus salmoides*) and Bluegill (*Lepomis macrochirus*) fish communities a combination that was popularized through research by Homer Swingle and colleagues at Auburn University in the mid-1900s. Swingle's early research was focused on establishing an impoundment community that would provide a sustainable production of harvestable sized fish, a state generally referred to as balance (Swingle 1950). However, over the past few decades angler attitudes toward recreational fishing have shifted and now place a higher value on catch and release angling (Quinn 1996). Shifting angler attitudes have sparked an interest in alternative management techniques designed to enhance the angling experience by increasing growth and condition of Largemouth Bass and Bluegill. Examples of these management techniques include selective harvest of Largemouth Bass and stocking of supplemental forage.

Supplemental forage may provide Largemouth Bass with an energy rich alternative to Bluegill, which exhibits a series of defense mechanisms to reduce their predation by Largemouth Bass (Werner and Hall 1988; Hambright 1991). Several species have been considered as supplemental forage in small impoundments such as Golden Shiners *Notemigonus crysoleucas*, Fathead Minnows *Pimephales promela,* and Gizzard Shad *Dorosoma cepedianum*. The most commonly stocked supplemental forage species in the southeastern United States is the Threadfin Shad *Dorosoma petenense* (Haley et al. 2012). Threadfin Shad is a desirable supplemental forage species for Largemouth Bass due to their high fecundity, high caloric density, relatively short maximum length (<200 mm), and lack of defensive spines (Eggleton and Schramm 2002; Wanjala et al. 1986). However, Threadfin Shad tend to suffer high winter mortality in many regions of the United States which prevents them from becoming established in regions outside the southeast (Griffith 1978).

Considering the commonality of stocking Threadfin Shad in small impoundments, surprisingly little work has been directed towards evaluating their impacts on Largemouth Bass and Bluegill in small impoundments. Several studies have evaluated the effects of Threadfin Shad on Largemouth Bass and Bluegill but the majority of these studies have focused on large impoundments and to a lesser extent, small impoundments (May and Thompson 1974; May et al 1975; May et al. 1975; Hepworth and Pettengill 1980; DeVries et al 1991). Additionally, many of these studies suggest contradictory impacts of Threadfin Shad on Largemouth Bass and Bluegill. Several studies have shown that Threadfin Shad have positive effects on Largemouth Bass and Bluegill growth and condition (Hepworth and Pettengill 1980; May et al. 1975) whereas other studies suggest negative effects on Largemouth Bass and Bluegill (Wydoski and Bennett 1981; DeVries et al. 1991). A study focused solely on the effects of Threadfin Shad on Largemouth Bass and Bluegill in small impoundments where pond conditions (i.e. size) and management (i.e. fertilization) are controlled would provide valuable insight in examining the effects of Threadfin Shad.

The objective of this study was to better understand how Threadfin Shad affect the growth and condition of Largemouth Bass and Bluegill in established and recently established small impoundments. More specifically my goals were to: 1) assess differences in Largemouth Bass and Bluegill length-at-age in impoundments with versus without Threadfin Shad, 2) compare differences in Largemouth Bass and Bluegill condition in the presence and absence of Threadfin Shad, 3) examine differences in Largemouth Bass and Bluegill size structure between impoundment types, and 4) compare Largemouth Bass diets in impoundments with versus without Threadfin Shad. I hypothesized that Threadfin Shad would have a positive effect on both growth and condition of Largemouth Bass while having no negative effect on Bluegill growth or condition.

Methods

Impoundment Renovation, Stocking and selection

Four of the five impoundments used for this study were located on the North Auburn E.W. Shell Fishery Experiment Station; the fifth impoundment was located on privately owned property in Russell County Alabama (Table 1). All impoundments were renovated during the winter 2013-2014. Fish communities in all impoundments were removed either by chemical rotenone or allowing the impoundment to dry completely. Prior to stocking fish, all impoundments were completely refilled and treated with appropriate quantities of agricultural lime ($CaCO_3$) based on soils tests (Alabama Cooperative Extension System). Fingerling Bluegill were stocked into all five impoundments in March 2014 at a rate of 3700 fish ha^{-1}. Threadfin Shad were stocked into impoundments S-15, S-16 and SB-1 in April of 2014 at a rate of 2,225 fish ha^{-1}. Fingerling Largemouth Bass *Micropterus salmoides* were stocked into all impoundments in June 2014 at a rate of 185 fish ha^{-1}. Largemouth Bass and Bluegill were obtained from the Alabama Department of Conservation and Natural Resources and Threadfin Shad were donated by Southeastern Pond Management. These stocking rates are a combination of recommendations from the Alabama Department of Conservation and Natural Resources (ADCNR), the Alabama Cooperative Extension System (ACES), and private pond consulting companies and represent common stocking combinations used around the southeastern United States. Throughout the spring and summer of both years of this study, water soluble granular fertilizer (10-52-4) was applied to all impoundments to maintain a secchi depth of 45 -60 cm (Boyd 1981). During 2014, these impoundments were sampled once a month from May through December and once every two months from February through October in 2015.

In addition to the five recently established impoundments, an additional 30 privately owned established impoundments were sampled. Established impoundments were defined as bodies of water that had contained Largemouth Bass and Bluegill for at least five years and Threadfin Shad that had been present for at least two years. Established impoundments were selected based on their similarity in surface area (2.95 ± 2.52 ha; mean ± 95% CI), management, and fish community. Required management strategies included fertilizing at recommended rates, liming, and controlling aquatic vegetation. Fish feeders were permitted if less than the recommended feed rate by the ADCNR was used. A study focusing on the effects of fish feeders on Bluegill growth and condition found that there was no significant difference in Bluegill growth and condition between impoundments with versus without feeders if less than the recommended rate of feed was used (Henderson 2014). Fish communities consisted of Largemouth Bass, Bluegill and Threadfin Shad or just Largemouth Bass and Bluegill.

Privately-owned established impoundments were identified via personnel communications with the Alabama Division of Wildlife and Freshwater Fisheries, Alabama Cooperative Extension System, Southeastern Pond Management, Inc., American Sportfish, Inc., and private pond owners. The sampling periods for these impoundments were as follows: shad impoundments = 5 impoundments sampled during summer 2014 and 8 sampled during summer 2015; non-shad impoundments = 8 impoundments sampled during summer 2014 and 8 sampled during summer 2015. These established impoundments were each sampled one time and allowed us to compare differences in growth and condition of Largemouth Bass and Bluegill between impoundments with versus without Threadfin Shad.

Field sampling

Largemouth Bass, Bluegill and Threadfin Shad were collected using a Smith-Root 5.0 GPP pulsed-DC electrofishing boat. During each sampling event, one 20-minute electroshocking transect focused solely on the littoral zone and a second 20-minute electroshocking transect focused on the pelagic zone. During each transect all Largemouth Bass and Bluegill were netted and placed in the boat live well. Upon completion of each transect, all Largemouth Bass and Bluegill were measured (nearest mm, TL) and weighed (nearest g). Beginning in July 2014, 10 Largemouth Bass were randomly selected from each transect from each recently established impoundment during each sampling event and diet contents were removed using acrylic tubes according to methods outlined by Van Den Avyle and Roussel (1980). Removed diets were stored in 95% ethanol, and returned to the lab for analysis. In established impoundments a minimum of 10 randomly selected Largemouth Bass (150-450 mm, TL) and 10 randomly selected Bluegill (70-375 mm, TL) were euthanized and returned to the lab where sagittal otoliths and whole stomachs were removed. A minimum of 10 Largemouth Bass and Bluegill were returned to the lab because in many situations impoundment owners would not allow removal of any more fish than that.

Pond Characteristics

On the same day of sampling, water samples were evaluated by measuring chlorophyll-*a* concentrations, turbidity, alkalinity, hardness and secchi depth (nearest cm). Water samples used for chlorophyll-*a* were collected from the surface of the pond, stored in a dark bottle, and immediately transferred to a refrigerator upon returning to the lab. Chlorophyll-*a* was measured by filtering 500-mL of collected water using a 47-mm diameter glass fiber filter. The filter was frozen and later submerged in 95% ethanol for 24 hours to extract chlorophyll-*a*. Fluorescence of the extracted chlorophyll-*a* was measured using a fluorimeter (µg/L; Turner Designs Aquaflour). Turbidity was measured using a nephelometer (NTU; HG Scientific, Inc.). Alkalinity (ppm) and hardness (mg/L) were measured using LaMotte water test kits (LaMotte Company).

Owners of established impoundments were surveyed at the time of sampling regarding the management of their impoundment including fish harvest (intensity; 0-10, 11-20, 21-30, >30 lbs. · acre^{-1}), fertilization (lbs. · acre^{-1}), control of aquatic vegetation (i.e. grass carp or herbicides), when their pond has been stocked, what species had been stocked and management goals (i.e. balance). Data collected from these surveys were used to ensure that sampled impoundments met the criteria for this study. We later used Google Earth to measure the surface area of each impoundment.

Largemouth Bass and Bluegill Growth and Condition

Sagittal otoliths from Largemouth Bass and Bluegill collected from established impoundments were removed, bottled dry, and stored in 10-mL plastic vials. Prior to aging, all otoliths were mounted in general purpose low viscosity epoxy resin and later sectioned using a low speed diamond wheel saw (South Bay Technology Model 650). Sections were later mounted to microscope slides and aged by two independent readers. Discrepancies in age estimates between readers were resolved by a third reader. Once all estimated ages were agreed upon, the distances between the focus and each annulus and the posterior edge of the otolith were measured (µm) using Nikon NIS-Elements image analysis software (Nikon Instruments INC) to estimate back-calculated lengths at age. Back-calculated total length at age *i* (TL_i) were estimated using the direct proportion method as outlined by Le Cren (1947):

$$TL_i = \frac{si}{sc} \times TL_c,$$

where TL_i is the back-calculated total length at age *i*, L_c is the total length at capture, sc is the distance from the focus to the outer edge of the otolith, and si is the distance from otolith focus to *i*th annuli. A t-test was used to compare differences in mean length at age-2 (MLA-2) of Largemouth Bass and Bluegill in the presence and absence of Threadfin Shad in established impoundments. To compare differences in growth of Largemouth Bass in recently established impoundments, average lengths (TL, mm) and weights (g) were calculated monthly for each impoundment using only the originally stocked cohort. Length-frequency distributions in all impoundments were bimodally distributed which allowed differentiation between recruits and the original stocked cohort within an impoundment. Length and weight data for these analyses were log transformed to meet normality and homogeneity of variance assumptions. Differences in average length and weight between treatments were analyzed using repeated-measures analysis of variance (ANOVA; R Core Team 2014). Monthly averages were fit to a series of fixed- and mixed-effect models where treatment (Shad or Non-Shad) and event (sampling period) were treated as fixed effects and impoundment was treated as a random effect (Table 2). The best model was selected by forward stepwise comparisons of all models using likelihood ratio test.

Largemouth Bass and Bluegill condition were quantified using relative weight (Neuman et al. 2012):

$$W_r = \frac{W}{W_s} \times 100,$$

where W_r is the relative weight, W is the weight of fish, and W_s is standard length-specific weight for each fish species. In established impoundments, relative weights were averaged by impoundment and later analyzed using a t-test to test for a treatment effect. For recently established impoundments, monthly average relative weights were calculated for each impoundment and differences between treatments were tested using repeated-measures analysis of variance (ANOVA; R Core Team 2014) following same procedures used for comparing differences in length and weight.

Largemouth Bass diets

All stomach contents were identified to the lowest taxonomic unit, enumerated, and measured (nearest mm). Lengths of all diet items were later converted to weights using species specific length weight regressions. For diet analysis, items were grouped into the following categories: Bluegill, unidentified fish, macroinvertebrate, Threadfin Shad, zooplankton, crayfish. These diet data were evaluated by computing a percent of body mass (PBM):

$$PBM_i = \sum_{j=1} \left(\frac{W_{ij}}{F_j} \right) \times 100,$$

Where PBM_i is the percent of body mass of prey type *i*, W_{ij} is the weight of prey item *i* in fish *j*, and F_j is the weight of fish *j*. PMB of each prey item was compared using a t-test for established impoundments. In recently established impoundments differences in PBM between treatment types were analyzed using repeated-measures analysis of variance (ANOVA; R Core Team 2014) following same procedures used for comparing differences in relative weight.

*Largemouth Bass and Bluegill Size Structur*e

Differences in Largemouth Bass and Bluegill size structure in established impoundments between treatment types were assessed by calculating the PSD-Q, PSD-P and PSD-M (Guy et al. 2007) for each impoundment and testing for differences between treatments using a t-test. Differences in size structure were further examined by calculating the relative abundance (catch · min^{-1}) of PSD-Q, PSD-P and PSD-M Largemouth Bass and Bluegill and tested for differences using a t-test.

Results

Pond Characteristics

In established impoundments I detected no significant differences in surface area (ha; p = 0.89), harvest intensity (category; p = 0.12), chlorophyll-*a* (µg · liter^{-1}; p = 0.57), secchi depth (M; p = 0.42), hardness (ppm; p = 0.81) or alkalinity (mg · liter^{-1}; p =0.50) between impoundment types (Figure 1). Additionally, there were no significant differences in surface area (ha; p = 0.13), secchi depth (m; p = 0.74), hardness (ppm; p = 0.94), or alkalinity (mg · Liter^{-1}; p = 0.59) between recently established impoundment types (Figure 2).

Largemouth Bass and Bluegill Growth and Condition

Established Impoundments.—Age-2 Largemouth Bass in established shad impoundments were 32.9 mm (±16.52 mm; ± 95% CI) longer than Largemouth Bass in established non-shad impoundments (treatment effect: t = 4.09; df = 26; p <0.01; Figure 3). Relative weights of Largemouth Bass did not differ between established shad and non-shad impoundments (mean difference 2.01± 4.31 (mean ± 95% CI); t = 0.96; df = 27; p = 0.35; Figure 4). Average Bluegill MLA-2 did not differ between established shad and non-shad impoundments (mean difference 11.37 ±20.96 mm (mean ± 95% CI); treatment effect: t = -1.12; df = 24; p = 0.274; Figure 5).

Bluegill in established shad impoundments had relative weights that were 5.32 ± 2.72 percentage points (mean ± 95% CI) lower than Bluegill in established non-shad impoundments (treatment effect: $t = -2.01$; $df = 27$; $p = 0.05$; Figure 6).

Recently Established.— Mean total length in two of the shad impoundments always exceeded the mean lengths of the non-shad impoundments, but the third shad impoundment (Pond S-15) exhibited a pattern that differed from all of the other ponds. During 2014, the size structure of the original stocked cohort of Largemouth Bass in S-15 was bimodally distributed. By September 2014, a portion of the Largemouth Bass cohort in S-15 was roughly 90-140 mm in total length whereas the other portion of this cohort had total lengths more similar to that of Largemouth Bass in the two other shad impoundments. However, in 2015 catch rates for the smaller length group of the original stocked Largemouth Bass in S-15 declined, leaving primarily the larger length group of Largemouth Bass (Figure 7). The best model describing treatment (shad) and month effects on Largemouth Bass length at recently established impoundments was a fixed effect model that included a month main effect (Table 3). Monthly pairwise comparisons indicated that average Largemouth Bass total lengths were significantly higher in shad impoundments than in non-shad impoundments during June (treatment effect: $t = 5.49$; $df = 3$; $p = <0.01$), August (treatment effect: $t = 4.18$; $df = 3$; $p = 0.02$), and October (treatment effect: $t = 4.08$; $df = 3$; $p = 0.03$) 2015.

The best model describing treatment and month effects on Largemouth Bass weight at recently established ponds included a treatment and month main effect (Table 3). Largemouth Bass in shad impoundments had weights that were 49% higher (95% CI: 11 to 101% higher) than Largemouth Bass in non-shad impoundments (treatment effect: $t = 2.79$; $df = 54$; $p = <0.01$; Figure 8). Monthly pairwise comparisons indicated that average Largemouth Bass weight was significantly higher in shad than non-shad impoundments in April 2015 (p = 0.02), June (p = <0.01), August (p = 0.02), and October (p = 0.04) 2015.

The best model describing Largemouth Bass relative weight included a main effect of treatment and month and a random effect of impoundment (Table 3). Impoundments with Threadfin Shad had relative weights that were 8.04 ± 5.7 percentage points (mean ± 95% CI) higher than Largemouth Bass in non-shad impoundments (treatment effect: t = 3.95; df = 49; p = 0.03; Figure 9). Monthly pairwise comparisons indicated that Largemouth Bass in shad impoundments had relative weights that were significantly higher in shad than in non-shad impoundments during April 2015 (p = 0.02).

The best model describing Bluegill relative weight included a main effect of month and a random effect of impoundment (Table 3). There was no significant effect of Threadfin Shad on Bluegill relative weight.

Largemouth Bass diets

Established. —Largemouth Bass in non-shad impoundments had an average PBM of 0.58% (±0.19; ±95% CI; Figure 10). In shad impoundments Largemouth Bass also primarily consumed Bluegill with an average percent of body mass of 0.70% (±0.57; ±95% CI; Figure 11). Average PBM for Threadfin Shad was 0.30% (±0.35; ±95% CI). There were no significant difference in the PBM of Bluegill (p = 0.71), macroinvertebrates (p = 0.81), or zooplankton (p = 0.17) in either treatment type. In established impoundments there was no significant difference in total PBM between treatments (treatment effect: t = 1.367; df = 26; p = 0.18).

Recently Established. —In recently established non-shad impoundments Largemouth Bass primarily consumed Bluegill throughout the duration of this study with an average PBM of 0.18% (±0.12; ±95% CI; Figure 12). Largemouth Bass in Shad impoundments primarily consumed Threadfin Shad with an average PBM of 0.78% (±0.61; ±95% CI; Figure 12). Largemouth Bass in shad impoundments also consumed Bluegill with an average PBM of .43% (±0.34; ±95% CI; Figure 12). There was no significant difference in the PBM of Bluegill (p = 0.21), macroinvertebrates (p = 0.47) or zooplankton (p = 0.62) between treatment types. There was no significant difference in the PBM between treatments (treatment effect: t = 0.81; df = 3; p = 0.42).

*Largemouth Bass and Bluegill Size Structur*e

Established. — The PSD-Q of Largemouth Bass in established shad impoundments was 27.32 (± 15.19; ± 95% CI) percentage points higher than non-shad impoundments (treatment effect: t = 3.70; df = 27; p < 0.01; Figure 13). Largemouth Bass in established shad impoundments also had PSD-P 19.36 (± 12.71; ± 95% CI) higher than PSD-P of Largemouth Bass in non-shad impoundments (treatment effect: t = 6.17; df = 25; p < 0.01; Figure 13). We observed no difference in Largemouth Bass PSD-M between treatments (treatment effect: t = 2.12; df = 8; p = 0.88; Figure 13). Shad impoundments had an average 0.49 catch · min^{-1} (± .47 catch · min^{-1}; ± 95% CI) lower abundance of stock sized Largemouth Bass than non-shad impoundments (p = 0.02), but there was no difference in average catch · min^{-1} of quality (p = 0.18), preferred (p = 0.16), or memorable (p = 0.91) size classes (Figure 14). Bluegill PSD-Q (treatment effect: t = 1.61; df = 27; p = 0.12), PSD-P (treatment effect: t = -1.89; df = 23; p = 0.07), or PSD-M (treatment effect: t = -1.41; df = 11; p = 0.19; Figure 14) did not differ between shad treatments. There was no significant difference in average catch · min^{-1} of stock (p = 0.35), quality (p = 0.31), preferred (p = 0.22), memorable (p = 0.08), or trophy (p = 0.10) sized Bluegill in established impoundments between treatment types (Figure 15).

Discussion

Largemouth Bass and Bluegill Growth and Condition

My study adds to a growing body of evidence that increased Largemouth Bass growth can be associated with the stocking of Threadfin Shad in small impoundments, although body condition may depend on impoundment age. Maceina and Sammons (2015) introduced Threadfin Shad into two established Alabama small impoundments (1.9 and 5.3 ha) and found that Largemouth Bass condition increased for stock- and quality-length fish and size structure improved after introduction. In another study, Haley et al. (2012) selected 66 established small impoundments across the Black Belt region of Alabama and found that Largemouth Bass in impoundments with Threadfin Shad generally exhibited greater length, better size structure, growth, condition, and density when compared to ponds without Threadfin Shad. In a similar study, Henderson et al. (2014) sampled 30 established small impoundments and found that Largemouth Bass in impoundments with Threadfin Shad were significantly larger at age-2 than Largemouth Bass in impoundments without Threadfin Shad; however, there were no significant differences in condition. In both Haley et al. (2012) and Henderson et al. (2014), the surface area of Threadfin Shad impoundments was significantly greater than that of non-shad impoundments, which raised the question of whether the differences in Largemouth Bass lengths at age-2 were attributable to Threadfin Shad or simply a pond size effect. In my study, neither pond size nor any other impoundment characteristic differed between shad and non-shad impoundments, which should have reduced the likelihood for that confounding effect on Largemouth Bass growth. Moreover, my study demonstrated increased Largemouth Bass growth in both recently established and established impoundments which further strengthen the evidence for a positive association between Threadfin Shad and Largemouth Bass growth.

The effects of Threadfin Shad on Bluegill in small impoundments are less clear. In this study Bluegill in established impoundments with Threadfin Shad had significantly lower condition than Bluegill in non-shad impoundments; however, there was no significant difference in Bluegill growth or Bluegill condition in the recently established impoundments. Maceina and Sammons (2015) saw a decline in the condition of quality-length Bluegill after introduction of Threadfin Shad. Conversely, neither Haley et al. (2012) nor Henderson et al. (2014) found significant effects of Threadfin Shad on Bluegill condition. Additionally, Henderson et al. (2014) found no significant effects of Threadfin Shad on Bluegill growth. Lower Bluegill condition in the presence of Threadfin Shad has been observed in other studies (DeVries and Stein 1990) although the mechanism behind this reduced condition is unclear. Density dependence is not likely the reason for the difference in condition as there were no differences in density between impoundment types. The only known difference between impoundments types in this study was the presence or absence of Threadfin Shad suggesting that there is some degree of competition between Threadfin Shad and adult Bluegill. Predation and direct competition for forage are unlikely considering that Threadfin Shad are primarily planktivores and detritivores (Noble 1981, DeVries et al. 1991) whereas adult Bluegill feed primarily on macroinvertebrates, small fish and to a lesser extent zooplankton (Olson et al. 2003; Boschung and Mayden 2004). Therefore, a logical explanation for the reduced condition of Bluegill in the presence of Threadfin Shad is that Threadfin Shad may have a negative effect on the forage base of Bluegill, although this hypothesis needs further study.

In the recently established impoundments Threadfin Shad had a significant effect on Largemouth Bass weight and condition although the bimodal Largemouth Bass size distribution in S-15 during 2014 may have confounded the effect of Threadfin Shad on Largemouth Bass length. Bimodal length distributions in Largemouth Bass cohorts have been well documented and are sometimes attributed to insufficient forage (Timmons and Shelton 1980; Keast and Eadie 1985; Dreves and Timmons 2001). Which leads to increased intraspecific competition and a reduced number of individuals growing to larger sizes, ultimately creating a bimodal length distribution. Bluegill recruitment was negligible in S-15 during both years of this study (Chapter 2, this Thesis). Low abundance of age-0 Bluegill may have resulted in insufficient forage and poor growth for the smaller Largemouth Bass in S-15. These slow growing individuals may have then suffered high winter mortality (Miranda and Hubbard 1994; Ludsin and DeVries 1997) which would explain the dwindling catch of those fish during 2015. Although there was no significant effect of Threadfin Shad on Largemouth Bass length, the bimodal distribution of Largemouth Bass in S-15 introduced additional variation associated with the main effect of treatment (shad) and may have masked the effect of Threadfin Shad on Largemouth Bass length. Nevertheless, during the last three months of this study, Largemouth Bass in shad impoundments were significantly larger (TL, mm) and heavier (g) then Largemouth Bass in the non-shad impoundments. This finding suggests that Threadfin Shad have the potential to positively affect the early growth of Largemouth Bass, but initial growth trajectories may vary across individual impoundments.

Largemouth Bass diets

In established shad and non-shad impoundments, Bluegill were the primary source of forage for Largemouth Bass although Threadfin Shad comprised a significant amount of the diet of Largemouth Bass in shad impoundments. Additionally, Largemouth Bass in shad impoundments had, on average, a higher total percent of body mass then Largemouth Bass in non-shad impoundments. In the presence of Dorosoma spp., studies have shown that centrarchids remain the primary prey for Largemouth Bass (Timmons and Shelton 1980; Bettoli et al. 1992; Irwin et al. 2003). Smaller Largemouth Bass are often too small to feed on Threadfin Shad and remain in the littoral zone feeding on small fish and insects (McConnel and Gerdes 1964; Applegate and Mullan 1967). Larger Largemouth Bass also tend to remain in the littoral zone feeding primarily on centrarchids while intermediate sized Largemouth Bass have been observed in the pelagic zone feeding on Threadfin Shad (Timmons and Shelton 1980; Wanjala et al. 1986). It is likely that Largemouth Bass primarily feed on Bluegill because Largemouth Bass and Bluegill generally occupy similar habitat types (Betsill et al. 1986; Killgore et al. 1989, Smith and Orth 1990; Paukert and Willis 2002) increasing their encounter rates and likely predation rate. However, some Largemouth Bass have been documented selecting limnetic areas over littoral areas (Thompson et al. 2005). In the presence of Threadfin Shad, Colle et al. (1989) observed several Largemouth Bass inhabited primarily offshore areas.

In the recently established impoundments, Bluegill was the primary source of forage for Largemouth Bass in non-shad impoundments, but in shad impoundments they fed primarily on Threadfin Shad and supplemented their diets with Bluegill, which is contrary to previous studies (Timmons and Shelton 1980; Bettoli et al. 1992). Additionally, throughout the duration of this study Largemouth Bass of all sizes primarily consumed Threadfin Shad which differs from previous studies. Wanjala et al. (1986) and Timmons and Shelton (1980) found that shad were not an important prey species until Largemouth Bass grew to 250 mm. The current study suggests that body size is not the sole mechanism behind Largemouth feeding on shad. It is possible that predation risk may also influence Largemouth Bass ability to feed on shad. Young-of-year Largemouth Bass are vulnerable to predation by larger Largemouth Bass and therefore must make a decision between optimal foraging and predation risk (Werner and Gilliam 1984).

To minimize predation risk, smaller Largemouth Bass may remain in near the littoral zone (Dill 1987; Werner and Gilliam 1984) and as a result they are limited to only feed in the littoral zone. Once Largemouth Bass have grown to a size where the risk of predation decreases, their foraging opportunities increase as they are no longer forced to remain in the littoral zone. In the recently established impoundments the original cohort of Largemouth Bass had a wider range of foraging opportunities including pelagic and littoral forage due to low predation risk. As these impoundments age and young-of-year Largemouth Bass have an increased risk of predation, the young-of-year Largemouth Bass might shift their diets away from shad and more towards littoral forage.

Similar to findings in the established impoundments, Largemouth Bass in recently established shad impoundments had total PBMs that were higher than Largemouth Bass in non-shad impoundment. These higher PBMs may be a result of having a larger forage biomass. When designing this study I attempted to best replicate the stocking recommendations for new impoundments which resulted in the impoundments stocked with Threadfin Shad having a larger biomass of forage than non-shad impoundments initially because Bluegill stocking rates were held constant across treatment types. This higher biomass of forage could have contributed to the increased consumption and subsequent growth of Largemouth Bass in the Shad impoundments. Largemouth Bass in recently established shad impoundments consumed more forage relative to their size than Largemouth Bass in non-shad impoundments and they also primarily consumed Threadfin Shad which have a higher caloric density (Wright and Kraft 2012) than Bluegill. It is unclear whether Largemouth Bass grow more rapidly in Threadfin Shad impoundments as a result of feeding on calorie-rich Threadfin Shad, feeding at higher rates than Largemouth Bass in non-shad impoundments, or a combination.

*Largemouth Bass and Bluegill Size Structur*e

There was a higher proportion of both quality- and preferred-sized Largemouth Bass in established shad impoundments when compared to non-shad established impoundments. There was also a higher catch-per-effort of stocked sized fish in non-shad impoundments. These results are consistent with Haley et al. (2012) who found that impoundments with Threadfin Shad had a higher proportion of quality- and preferred-sized Largemouth Bass than impoundments without Threadfin Shad. This difference in the size structure of Largemouth Bass may be a function of Largemouth Bass growing faster from feeding on Threadfin Shad and Threadfin Shad indirectly reducing Largemouth Bass recruitment (DeVries et al. 1991) which could reduce intraspecific competition and increase Largemouth Bass growth. In impoundments with Threadfin Shad and Bluegill, young-of-year Bluegill provide the energy that is essential to the growth of young-of-year Largemouth Bass. Young-of-year Threadfin Shad, which are spawned in the early spring (Gerdes and McConnell 1963), grow very rapidly and outgrow the gape size of young-of-year Largemouth Bass initially (McConnell and Gerdes 1964; Hepworth and Pettengill 1980). As a result of a single spawning event and rapid growth rates of Threadfin Shad, Largemouth Bass rely on young-of-year Bluegill as a preliminary source of energy necessary to grow and survive through the winter (Miranda and Hubbard 1994). Threadfin Shad have the potential to outcompete larval Bluegill which can reduce the forage base for young-of-year Largemouth Bass (DeVries et al. 1991; Chapter 2, this Thesis) and can ultimately negatively affect Largemouth Bass recruitment (May and Thompson 1974). Lower recruitment of Largemouth Bass can increase individual growth rates due to reduced competition for forage. Alternatively, when young-of-year Largemouth Bass have abundant forage, winter survival is high which can result in high intraspecific competition and slowed growth in the future (Oliver et al. 1979; Toneys and

Coble 1979; Garvey et al. 1998). The enhanced growth that Largemouth Bass receive from feeding on Threadfin Shad coupled with the lower abundances of stocked sized fish likely contribute to the higher abundance of quality and preferred Largemouth Bass in established shad impoundments.

Although Threadfin Shad have the potential to reduce larval Bluegill survival (DeVries et al. 1991; Chapter 2, this Thesis), Threadfin Shad may also relieve some predation pressure on Bluegill (Applegate and Mullan 1967; Timmons and Shelton 1980; Wanjala et al. 1986) which might explain the lack of differences in the size structure of Bluegill between impoundment types. In small impoundments without Threadfin Shad, larval Bluegill survival may be higher and many individuals recruit into the littoral zone (Chapter 2, this Thesis). Once in the littoral zone mortality could be increased due to predation and intraspecific competition (Breck 1993; Irwin et al. 2003). In impoundments with Threadfin Shad, larval Bluegill survival in the pelagic zone is low (Chapter 2, this Thesis) but survival in the littoral zone may be higher due to reduced predation and lower intraspecific competition. This tradeoff between mortality in the pelagic zone and mortality in the littoral zone could ultimately result in similar Bluegill size structures between impoundment types.

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III. Evaluating the effects of Threadfin Shad on Bluegill recruitment in recently-stocked small impoundments

Abstract

Many small impoundments across North America have simple Largemouth Bass and Bluegill fish communities a combination that has become prevalent due to the popularity of Largemouth Bass and Bluegill as sportfish and their compatibility as predator and prey. Fisheries biologists have experimented with introducing Threadfin Shad into these simple Largemouth Bass and Bluegill systems; however, the effects of Threadfin Shad on these simple fish communities are not fully understood. In this study I examined the effects of Threadfin Shad on Bluegill in five recently established impoundments located in east-central Alabama. Three of these impoundments were stocked with Largemouth Bass, Bluegill, and Threadfin Shad while the other two impoundments were only stocked with Largemouth Bass and Bluegill. I monitored zooplankton densities and larval fish densities biweekly during spring, summer and fall of 2015 in addition to examining diet overlap and Bluegill recruitment into the littoral zone. Results of this study show that Threadfin Shad is associated with lower zooplankton densities, lower larval Bluegill densities, and lower catches of age-0 Bluegill in the littoral zone. This study provides insight on the effects of Threadfin Shad on Bluegill recruitment and can help fisheries managers make better informed decisions about stocking Threadfin Shad.

Introduction

Bluegill *Lepomis macrochirus* are found throughout North America and have both recreational and ecological value (Davies et al. 1982; Coble 1988). In many regions of the United States Bluegill are a highly valued recreational sportfish, sometimes receiving intense fishing pressure (Coble 1988; Miranda 1999; Paukert et al. 2002; Shroyer et al. 2003; Crawford and Allen 2006). Bluegill also play an important role in aquatic food webs as prey for piscivores (Noble 1981). Bluegill are highly fecund and spawn several times throughout the summer months which provides predators with a variety of sizes of prey throughout the year (Swingle and Smith 1943; Stuber et al. 1982). Essential to the sustainability of their populations, large adult Bluegill are invulnerable to all but the largest of predators (Wright and Kraft 2012). Additionally, the diverse diets and tolerance for a wide variety of environmental conditions by Bluegill adds to their suitability as a target of anglers but also as prey for piscivores (Keast 1978; Mittelbach 1981; Stuber et al. 1982; Dewey et al. 1997).

In small impoundments (<40 hectares in surface area) Bass are highly compatible as predator and prey (Swingle and Smith 1940; Swingle 1950). A key to their compatibility are the relative spawning time. Young Bluegills produced throughout the summer provide young-of-year Largemouth Bass, which are spawned in the spring, with the energy that is critical to their growth, winter survival, and eventual recruitment (Shelton et al.1979; Davies et al. 1982). Swingle and Smith’s (1940) work popularized this simple Largemouth Bass and Bluegill fish community for small impoundments and their stocking recommendations were eventually adopted by the U.S. Soil Conservation Service and the U.S. Fish and Wildlife Service during the 1940s (Regier 1962).

Due to recent shifts in angler values, which place an increased emphasis on catch-and-release fishing (Quinn 1996), fisheries managers have experimented with altering these simple Largemouth Bass and Bluegill fish communities by introducing supplemental forage species. Stocking of supplemental forage is aimed at improving the growth and condition of Largemouth Bass and has become a frequently used technique for enhancement of small impoundment fish communities (Noble 1981). Supplemental forage species such as Golden Shiners *Notemigonus crysoleucas*, Fathead Minnows *Pimephales promela*, and Threadfin Shad *Dorosoma petenense* provide an energy rich alternative food source that could potentially increase growth and condition of Largemouth Bass. In the Southeastern United States, the most commonly stocked supplemental forage species is the Threadfin Shad (Haley et al. 2012), which is a desirable supplemental forage species due to their relatively small maximum length (<200 mm), high caloric density, and lack of defensive spines (Eggleton and Schramm 2002; Wanjala et al. 1986). Despite how commonly Threadfin Shad have been stocked into small impoundments, little work has been devoted to bettering our understanding of how stocked Threadfin Shad may alter the forage base by competing with Bluegill.

Threadfin Shad are planktivorous and have been known to deplete spring zooplankton densities within 1-3 weeks of reaching peak larval densities (Ziebell et al. 1986; DeVries et al. 1991), before transitioning to detritivory (Haskell 1959) and escaping intraspecific competition. Larval Threadfin Shad that appear in the pelagic zone before other species with obligate limnetic larvae, such as Bluegill, can potentially compete with these species via exploitative competition which can negatively affect their recruitment (Kirk et al. 1986; Guest et al. 1990; Garvey and Stein 1998). Year-class strength is often set very early in life (Hjort 1914; Mills and Froney 1981) for many fish species and survival through juvenile stages is critically important to recruitment. Examining interactions at early life stages is important because negative impacts on larval fish could ultimately reduce recruitment to larger size classes, which could negatively affect Bluegill recruitment. In some impoundments, young-of-year Bluegill and Threadfin Shad density are inversely related (DeVries et al. 1991). Bettering our understanding of how Threadfin Shad impact Bluegill recruitment is key in devising best management practices.

The objective of this study was to better understand how Threadfin Shad affect Bluegill recruitment in recently established small impoundments. More specifically my goals were to: 1) assess differences in larval Bluegill and zooplankton densities between newly established impoundments with and without Threadfin Shad, 2) evaluate resource overlap and compare prey selectivity between Threadfin Shad and Larval Bluegill, and 3) quantify Bluegill recruitment into the littoral zone.

Methods

Study Impoundments

The small impoundments used for this study were located on the North Auburn E.W. Shell Fisheries Station and on privately owned property in Russell County, Alabama (Table 1). All impoundments were renovated during winter 2013-2014. Fish communities in all impoundments were removed either by applying rotenone or allowing the impoundment to dry completely. Prior to stocking fish, all impoundments were completely refilled and treated with appropriate quantities of agricultural lime ($CaCO_3$). Fingerling Bluegill were stocked into all five impoundments in March 2014 at a rate of 3700 fish ha^{-1}. Threadfin Shad were stocked into three of the impoundments (hereafter shad impoundments) in April 2014 at a rate of 2,225 fish ha^{-1}. Fingerling Largemouth Bass *Micropterus salmoides* were stocked into all impoundments in June 2014 at a rate of 185 fish ha^{-1}. Grass Carp (*Ctenopharyngodon idella*) were stocked in March

2014 at a rate of 15 fish ha^{-1} to control aquatic vegetation. Largemouth Bass and Bluegill were obtained from the Alabama Department of Conservation and Natural Resources and Threadfin Shad were attained from Southeastern Pond Management, Inc. These stocking rates are a combination of recommendations from the Alabama Department of Conservation and Natural Resources (ADCNR) and private pond consulting companies and represent stocking combinations commonly used around the southeastern United States. Throughout spring and summer of both years of this study, water soluble granular fertilizer (10-52-4) was applied to all impoundments following recommended rates to increase impoundment productivity.

Post-Larval Threadfin Shad Relative Abundance

Post-larval Threadfin Shad (individuals >40 mm, TL) were sampled from the pelagic zone by boat-mounted pulsed-DC electrofishing once per month from April through September 2014 and once per month from March through September of 2015 to assess Threadfin Shad relative abundance. During each sampling event two-20 minute electroshocking transects were conducted, the first focusing on the littoral zone while the second focused on the pelagic zone. During entirety of each transect schools of Threadfin Shad were visually indexed by classifying each school as a category-1 (1-15 individuals), category-2 (16-50 individuals) or a category-3 (>51 individuals). An index of Threadfin Shad abundance was generated by summing the number of each category. The index was used to compare relative abundance between impoundments with Threadfin Shad.

Zooplankton

Zooplankton were sampled from each impoundment once per month from May through September of 2014 and once every two weeks from March through September of 2015. During each sampling period, zooplankton were sampled from the photic zone (approximately twice the secchi depth) using a 0.31-m-diameter zooplankton net (0.91 m long, 50-µm mesh). All collected zooplankton were stored in 95% ethanol and returned to the laboratory. All individuals were later identified to genus for cladocerans and as calanoids, cyclopoids, or nauplii for copepods. The first 10 individuals of each taxon were measured (nearest 0.1 mm). Differences in zooplankton densities between impoundments with and without Threadfin Shad were analyzed using repeated-measure analysis of variance (ANOVA; R Core Team 2014). Data were fit to a series of fixed- and mixed-effect models where treatment (Shad or Non-Shad) and event (sampling period) were treated as fixed effects and impoundment was treated as either a fixed or random effect. The best model was selected by forward stepwise comparisons of all models using likelihood ratio test (Table 2; Table 4). These data were log transformed plus a constant (+1) to meet normality and homogeneity of variance assumptions.

Larval Fish

Larval fish were collected once every two weeks from May through September of 2014 and March through September of 2015. Larval fish were sampled by conducting three replicated daytime surface pushes at 1 m/s using a 0.5-m-diameter ichthyoplankton net (1.5 m long, 500 µm mesh) with a flowmeter installed in the mouth of the net to calculate volume of water sampled. Collected larval fish were stored in 95% ethanol and later identified to species and measured (nearest mm, TL). Larval fish densities were calculated by dividing the number of individuals of each species by the volume of water sampled. Differences in larval fish densities between impoundments with and without Threadfin Shad were analyzed using repeated-measures analysis of variance (ANOVA; R Core Team 2014) following the same model selection procedure used for comparing zooplankton densities. These data were log transformed to meet normality and homogeneity of variance assumptions.

Diet overlap and prey selectivity

Post-larval Threadfin Shad diets were sampled from individuals collected by boat-mounted pulsed-DC electrofishing and larval Threadfin Shad and Bluegill diets were sampled from individuals collected during daytime surface tows. Diets were quantified by removing stomach contents from a minimum of 10 individuals per species per sampling event when possible. All individuals in the diet were identified and counted (following same procedure as zooplankton samples). Potential competition between larval Threadfin Shad, post-larval Threadfin Shad, and larval Bluegill that co-occurred in the pelagic zone, was analyzed using Schoener's Overlap Index (Schoener 1970) which bases resource overlap on similarity of diet composition. Diet composition was calculated for individual fish and then averaged across fish in a particular treatment (i.e. shad or non-shad) and date (Wallace 1981). The equation for this index is:

$$C_{xy} = 1 - 0.5\left(\sum_{i=1}^{n} \left| r_{xi} \cdot r_{yi} \right|\right)$$

where C_{xy} is the overlap index value, r_{xi} is the proportion of prey item i used by species x, and r_{yi} is the proportion of prey item i used by species y, and n is the number of prey items. This index ranges from 0 to 1; where values near 1 represent high overlap and values near 0 represent low overlap. Value ≥ 0.6 indicate a potential for competition if resources are limited (Martin 1984). In this analysis only 7 taxa of zooplankton were included; other taxa that contributed less than 3% of total diet were excluded.

Prey selection was evaluated using Chesson's alpha (Chesson 1978), which bases selection on the availability and consumption of that prey item. The equation for this index is:

$$\alpha = \frac{r_i / p_i}{\sum_i (r_i / p_i)} \quad i = 1,\dots m$$

where α is the selectivity, r_i and p_i are the proportions of prey item i in the diet and environment (i.e. impoundment) and m is the number of prey items in the environment. Values of α equal to $1/m$ indicate that a prey item is being consumed proportional to its abundance in the environment, values $>1/m$ indicate selection for a prey item and values $<1/m$ indicate selection against a prey item. For this analysis, selection was averaged for each taxon across years and sampling events for larval Threadfin Shad, larval Bluegill and post-larval Threadfin Shad. Larval Bluegill were divided into shad and non-shad impoundments. Post-larval Threadfin Shad were divided into "pre" and "post" peak density of larval Threadfin Shad. The number of prey items in the environment used in this analysis was an average of prey items in the environment across impoundment types and sampling events.

Bluegill Recruitment

Bluegill recruitment to the littoral zone was evaluated by conducting quadrat seine hauls (n=3 for July, August and September 2014 and June 2015, n=10 for August and October 2015) using a 4.5 m x 1.7 m seine with 3.2 mm mesh (Swingle 1956). All individuals collected in each seine haul were identified to species, counted and the first 70 individuals of each species were measured (mm, TL). Differences in Bluegill recruitment to the littoral zone between impoundments with and without Threadfin Shad were analyzed by comparing the average number of Bluegill collected per seine haul in each impoundment with repeated-measure analysis of variance (ANOVA, R Core Team 2014) following the model selection procedure that was used for comparing larval fish densities and zooplankton densities.

Results

Post-Larval Threadfin Shad Relative Abundance

Throughout 2014 numerous schools of post-larval Threadfin Shad were observed in all impoundments that were stocked with Threadfin Shad (Figure 16). Peak relative abundances occurred during the late spring and towards the middle of summer then slowly declined through the winter. In 2015 I collected no post-larval Threadfin Shad in S-15 between February and July. After July there was a steady increase in relative abundance of post-larval Threadfin Shad; however, this abundance was still lower than both S-16 and SB-1. In S-16 and SB-1 Threadfin Shad relative abundance increased steadily into the summer and then declined into the winter.

Zooplankton

A total of 22 different taxa of zooplankton were observed in these impoundments in 2014 and 2015. In my analysis all zooplankton were included; however, I report on only 9 taxa (these 9 taxa were the most dominant by number and were collected from the environment throughout the sampling period). In spring 2014, shortly after larval Threadfin Shad densities peaked, zooplankton densities declined in impoundments with Threadfin Shad. In impoundments without Threadfin Shad zooplankton densities peaked in the beginning to middle of summer followed by a decline and eventual stabilization around 50 zooplankton · liter^{-1} (Figure 17). Beginning in June through October 2014, the best model describing treatment (shad) and month effects on zooplankton density in recently established ponds included a treatment main effect (Table 4). Zooplankton densities in shad impoundments were 3.21% (95% CI: 1.34 to 7.65%) of the densities in non-shad impoundments (treatment effect: t = -8.19; df = 25; p = <0.01). Zooplankton densities differed between impoundment types in June (p = <0.01), July (p = 0.04), August (p = 0.03), and October (p = <0.01) 2014. In 2015 zooplankton density peaked in two of the shad impoundments (S-16 and SB-1) in the early spring and then declined shortly after the peak in larval Threadfin Shad density. Beginning in April 2015, after peak densities of larval Threadfin Shad, through September 2015, the best model describing zooplankton density included a treatment main effect. Zooplankton densities (zooplankton · $Liter^{-1}$) in shad impoundments were 20.35% (95% CI: 6.17 to 67.08%) of densities in non-shad impoundments (treatment effect: $t = -2.76$; $df = 25$; $p = 0.01$). Monthly pairwise comparisons indicated that zooplankton densities were significantly less in shad impoundments than in non-shad impoundments during September 2015 ($p = 0.02$). Due to zero catch of larval and post-larval Threadfin Shad in S-15 from January to July 2015, I re-ran the 2015 analysis treating S-15 as a non-shad impoundment. In this additional analysis, the best model included a main effect of treatment and month and a random effect of impoundment (Table 4). Zooplankton densities in shad impoundments were 9.75% (95% CI: 4.17 to 22.75%) of the densities in non-shad impoundments (treatment effect: $t = -5.74$; $df = 25$; $p = <0.01$). Monthly pairwise comparisons indicated that zooplankton densities were significantly less in shad impoundments than in non-shad impoundments during May ($p = 0.02$), June ($p = <0.01$), and July ($p = 0.03$) 2015.

Larval Fish

Larval Threadfin Shad were first detected in all shad impoundments in May 2014 and during this time peak densities were observed in all impoundments (Figure 18). Peak densities varied greatly between impoundments with the highest densities in S-16 (1.26 ± 0.3 fish · $liter^{-1}$) and lowest densities in SB-1(0.21 ± 0.11 fish · $liter^{-1}$). There was also a smaller pulse in larval Threadfin Shad in S-16 (0.04 ± 0.04 fish · $liter^{-1}$) during the early fall. In 2015 larval Threadfin Shad peaked in S-16 (2.73 ± 1.24 fish · $liter^{-1}$) and SB-1(0.49 ± 0.24 fish · $liter^{-1}$) during the mid-spring, however, no larval Threadfin Shad were collected from S-15 during the spring through

July. A large pulse of larval Threadfin Shad in S-15 (1.71 ± 0.37 fish · liter^{-1}) and a smaller pulse of larval Threadfin Shad in S-16 (0.27 ± 0.12 fish · liter^{-1}) were observed in the late summer.

During both 2014 and 2015 larval Bluegill were first collected after peak densities of larval Threadfin Shad. In 2014 there were two pulses of larval Bluegill in S-28 and S-30 with the first peak in abundance during early summer and the second pulse during late summer (Figure 19). There were no comparable pulses of larval Bluegill in 2014 at any of the Threadfin Shad impoundments. During 2014 the best model describing larval Bluegill density included main effects of treatment (shad) and month, and a treatment x month interaction (Table 4). Larval Bluegill densities (Bluegill · liter^{-1}) in shad impoundments were 1.25% (95% CI: 0.23 to 6.97%) of the densities in non-shad impoundments (treatment effect: t = -5.31; df = 35; p = <0.01). Larval Bluegill densities were significantly less in shad impoundments than in non-shad impoundments during June (p = 0.02) and August (p = 0.01). In 2015 there were three pulses of larval Bluegill in S-28 with the first peak during late spring (27.96 ± 9.55 fish · liter^{-1}), the second peak in early summer (13.44 ± 4.13 fish · liter^{-1}) and the third peak in late summer (12.48 ± 3.56 fish · liter^{-1}), whereas S-30 had only two pulses, one during the end of spring (9.06 ± 2.83 fish · liter^{-1}) and the second at the beginning of summer (12.41 ± 6.09 fish · liter^{-1}). In 2015 there were no comparable pulses of larval Bluegill in shad impoundments except for S-15 which had pulses of larval Bluegill in the middle (15.90 ± 3.96 fish · liter^{-1}) and end of summer (14.88 ± 4.99 fish · liter^{-1}). During 2015 the best model describing larval Bluegill density (Bluegill · Liter^{-1}) between impoundment types included main effects of treatment (shad) and month (Table 4). Larval Bluegill densities (Bluegill · liter^{-1}) in shad impoundments were 20.73% (95% CI: 8.02 to 37.17%) of the densities then in non-shad impoundments (treatment effect: t = -5.07; df = 64; p = <0.01). Because no post-larval Threadfin Shad were collected from S-15 from March through

July 2015, I ran an additional analysis on these 2015 data and treated S-15 as a non-shad impoundment. For this additional analysis, the best model describing the density of larval Bluegill included a treatment and month main effect. Larval Bluegill densities (Bluegill · liter^{-1}) in shad impoundments were 11.04% (95% CI: 4.70 to 25.92%) of larval Bluegill densities in non-shad impoundments (treatment effect: t = -5.19; df = 64; p = <0.01).

Diet overlap and prey selectivity

In all impoundments, larval Bluegill and larval Threadfin Shad collected in the pelagic zone consumed only zooplankton during 2014 and 2015 (Table 5). Post-larval Threadfin Shad consumed primarily zooplankton in the spring of 2014 and 2015 before peak densities of larval Threadfin Shad. After larval Threadfin Shad density had peaked, post-larval Threadfin Shad primarily consumed detritus. Larval Bluegill in non-shad impoundments generally selected for *Bosmina*, *Ceridaphnia*, *Diaphanosoma*, copepod nauplii and ostracods. Calanoids, *Chydorida*, cyclopoid copepods and *Daphnia* were negatively selected. Larval Bluegill in shad impoundments selected for *Bosmina*, *Ceridaphnia*, *Diaphanosoma*, and copepod napuplii. All other taxa were negatively selected. Larval Threadfin Shad had positive selection for *Bosmina*, calanoids copepods, cyclopoid copepods, copepod nauplii, and ostracods. All other taxa were negatively selected. Before peak densities of larval Threadfin Shad, post-larval Threadfin Shad selected for *Bosmina*, *Chydorida*, *Diaphanosoma*, and ostracods. After peak densities of larval Threadfin Shad, post-larval Threadfin Shad selected for *Chydorida* and ostracods. All other taxa were negatively selected for.

Schoener's overlap index (Schoener 1970) indicated diet overlap of 0.47 (±0.23; ±95% CI, n = 3 comparisons involving 40 larval Bluegill and 16 larval Threadfin Shad stomachs) between larval Bluegill and larval Threadfin Shad in shad impoundments. Larval Bluegill in shad impoundments and post-larval Threadfin Shad had a mean diet overlap of 0.71 (±0.04; ±95% CI, n = 4 comparisons involving 48 larval Bluegill and 73 post-larval Threadfin Shad stomachs). Overlap exceeded 0.6 for larval Bluegill in shad impoundments and larval Threadfin Shad on 1 date and 4 dates for larval Bluegill in shad impoundments and post-larval Threadfin Shad.

Bluegill Recruitment

I collected a total of 9,308 Bluegill in seine hauls at non-shad impoundments and 1,342 Bluegill at shad impoundments. At shad impoundments, 1,288 of those Bluegill were collected from SB-1, 53 were from S-16 and 1 was collected at S-15. During 2014 the best model describing Bluegill catch rates (Bluegill · seine^{-1}) included a main effect of treatment and a random effect of impoundment. Impoundments with Threadfin Shad had Bluegill catch rates (Bluegill · seine^{-1}) that were 6.25% (95% CI: 0.61 to 63.57%) of larval Bluegill densities in non-shad impoundments (treatment effect: t = -3.71; df = 41; p = 0.03; Figure 20). During 2015 the best model describing Bluegill catch rates (Bluegill · seine^{-1}) included a main effect of treatment. Bluegill catch rates (Bluegill · seine^{-1}) in shad impoundments were 5.48% (95% CI: 0.96 to 31.38%) of larval Bluegill densities in non-shad impoundments (treatment effect: t = -3.60; df = 15; p = <0.01; Figure 20).

Discussion

Post-Larval Threadfin Shad Relative Abundance

Over winter 2014-2015 post-larval Threadfin Shad abundances in S-15 reached a low and did not recover until mid-summer unlike the abundance of post-larval Threadfin Shad in the other shad impoundments which recovered in the spring. One of the major concerns of stocking Threadfin Shad is the possibility of high winter mortality due to low water temperatures (Ellison et al. 1983). Threadfin Shad tend to become disoriented and stop responding to external stimuli as water temperatures rapidly decline or approach 4 °C; below 4 °C mortality sets in (Griffith 1978). Over the course of this study, water temperatures dropped into the single digits for two days over the winter of 2014-2015 although temperature gauges placed in these impoundments indicated that water temperatures never fell below 4 °C. It is unknown why only S-15 had such a low abundance of post-larval Threadfin Shad from December 2014 through June 2015.

Zooplankton

During my study, there was a decline in the density of zooplankton during summer in all impoundments during both years; however, these declines were much more pronounced in impoundments containing detectable abundances of Threadfin Shad. Zooplankton density often varies widely throughout the year (Steiner 2003; Steiner 2004; Rettig et al 2006) and is sometimes influenced by the presence of an omnivorous planktivore (Ziebell et al. 1986; DeVries et al. 1991; Dettmers and Stein 1992; Welker et al. 1994). Declines in the density of zooplankton in impoundments containing shad have been well documented (DeVries and Stein 1992; Hirst and DeVries 1994; Welker et al. 1994) and sometimes occur shortly after densities of larval shad peak in the pelagic zone (Dettmers and Stein 1992; Betsill and Van Den Avyle 1997). DeVries et al. (1991) observed a precipitous decline in zooplankton density following peak abundances of larval Threadfin Shad in the pelagic zone of Stonelick Lake, Ohio. In the present study I also observed declines in zooplankton densities shortly after larval Threadfin Shad densities peaked in the pelagic zone.

Larval Threadfin Shad appeared in the pelagic zone in much lower densities but apparently had a greater impact on zooplankton density than larval Bluegill. This difference in impact on zooplankton may be a function of life history. Throughout the summer there are several waves of larval Bluegill appearing in the pelagic zone, but an individual larval Bluegill only remains in the pelagic zone for a relatively short period of time (Werner and Hall 1988). Larval Threadfin Shad may only appear in a single wave but remain in the pelagic zone for a large percentage of their life. Although in lower densities, juvenile Threadfin Shad exhibit rapid growth rates (Gerdes 1964) and consequently higher absolute individual consumption rates and are likely more capable of reducing zooplankton densities than larvae (Cowan et al. 2000).

Larval Fish

Results of this study suggest that larval Bluegill abundance is negatively correlated with Threadfin Shad. Similar findings have been observed in both small and large impoundments. In a study partly examining the effects of Threadfin Shad on White Crappie, Guest et al. (1990) found that Threadfin Shad was associated with a reduction in both zooplankton and larval White Crappie density. DeVries et al. (1991) also found negative correlations between Threadfin Shad and the density of zooplankton and larval Bluegill. It has been documented that fish suffer high levels of mortality during larval stages (Rice et al. 1987) with one of the main contributors to this mortality being starvation (Houde 1987; Miller et al. 1988). At early life stages first feeding is essential to survival (Hjort 1926) and when food resources are limited at first feeding, starvation can occur resulting in high mortality (Miller et al. 1988; Graeb et al. 2004). During both 2014 and 2015 larval Bluegill appeared in the pelagic zone several weeks after zooplankton densities had declined to less than 1 organism · liter^{-1}. This low density of larval Bluegill in shad impoundments may have resulted from high mortality due to starvation. Threadfin Shad grazing may have been responsible for the decline in zooplankton density and subsequent starvation of larval Bluegill.

Diet overlap and prey selectivity

Despite the similarity of diets between larval Bluegill and larval Threadfin Shad, I observed low diet overlap between larval Bluegill and larval Threadfin Shad. Based on previous work, post-larval Threadfin Shad generally select larger zooplankton and later filter feed for smaller zooplankton once larger zooplankton become rare (Brooks 1968; Holanov and Tash 1978; Ingram and Ziebell 1983). As larvae, Threadfin Shad primarily feed on zooplankton (DeVries et al. 1991; Hirst and DeVries 1994) and then shift their diets towards zooplankton, phytoplankton and detritus as they grow in size and zooplankton become scarce (Haskell 1959; Ingram and Ziebell 1983). This shift in diet allows the Threadfin Shad to mitigate negative effects of intraspecific competition by selecting alternative sources of forage once zooplankton densities have been suppressed. Before the decline in zooplankton abundances, larval Threadfin Shad primarily selected for smaller zooplankton taxa such as copepod nauplii and calanoids copepod whereas post-larval Threadfin Shad generally selected for larger zooplankton such as *Diaphanosoma* and *Chydorida*. Once zooplankton densities were reduced, all Threadfin Shad primarily selected for ostracods and supplemented their diets with detritus. Similar to larval Threadfin Shad, larval Bluegill select for smaller zooplankton early in life such as copepod nauplii (DeVries et al. 1991; Welker et al. 1994). Due to this similarity in diet selection during the larval stage, I expected that diet overlap between larval Bluegill and larval Threadfin Shad would be high in these impoundments. During my study there was only 1 time period during which I observed a relatively higher potential for competition between larval Bluegill and Threadfin Shad. A possible explanation of this low overlap in diets is exploitative competition as a result of the timing of larval appearance in the pelagic zone. Larval Threadfin Shad appeared in the pelagic zone several weeks before larval Bluegill and were able to feed on zooplankton without interspecific competition. Once zooplankton densities had been suppressed and fish had grown to a larger size, Threadfin Shad shifted their diets towards benthic prey. Several weeks later when larval Bluegill appeared in the pelagic zone, they were left to feed on the few remaining zooplankton. As suggested by DeVries et al. (1991) it is likely that Threadfin Shad are negatively associated with larval Bluegill as a result of exploitative competition.

Bluegill Recruitment

Threadfin Shad competition with larval Bluegill in the pelagic zone likely resulted in significantly lower recruitment of young-of-year Bluegill into the littoral zone. During 2014 and 2015 there were significantly lower catch rates of Bluegill in both the pelagic and littoral zone in shad impoundments than in non-shad impoundments. DeVries et al. (1991) observed a similar scenario in Stonelick Lake, Ohio where Bluegill did not recruit into the littoral zone following peak densities of larval Threadfin Shad in the pelagic zone. However, the degree to which Threadfin Shad affect Bluegill recruitment into the littoral zone may vary with impoundment. Through 2014 and 2015, SB-1 was the only shad impoundment that I was able to consistently collect young-of-year Bluegill with a seine. Only a combined 54 young-of-year Bluegill were collected from S-15 and S-16 from seining. Although Threadfin Shad likely have a significant effect on the density of young-of-year Bluegill recruiting into the littoral zone, complex interactions may result in similar densities of adult Bluegill in shad and non-shad impoundments. Hayley et al. (2012) sampled 66 small established impoundments across the Black Belt region of Alabama and found that the abundance of adult Bluegill did not differ between impoundments with or without Threadfin Shad. Similarly, I sampled 29 small established impoundments in Alabama and also found no significant difference in the density of adult Bluegill in shad and non-shad impoundments (see Chapter 1; this Thesis). Understanding how these differences in young-of-year Bluegill densities impact the aquatic ecosystem represents an important next step in furthering our knowledge of how Threadfin Shad affect Bluegill.

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Table 1. Area (ha), maximum depth (m), average depth (m), location and stocked fish community in each study impoundment. E.W. S. = North Auburn E.W. Shell Experimental Fisheries Station, Auburn, AL. SHAD = Largemouth Bass, Bluegill and Threadfin Shad, NON-SHAD = Largemouth Bass and Bluegill.

	Impoundment				
	S-15	S-16	S-28	S-30	SB-1
Impoundment area (ha)	2.3	2.71	1.9	5.3	2.9
Max depth (m)	4.27	1.5	4.27	3.9	5.49
Average depth (m)	1.77	0.6	1.64	1.66	2.19
Location	E.W. S.	E.W. S.	E.W. S.	E.W. S.	Russell County, AL
Fish community	SHAD	SHAD	NON-SHAD	NON-SHAD	SHAD

Table 2. Models fit to Largemouth Bass average total length (mm), weight (g) and condition (Wr). Bluegill and condition (Wr). Larval Bluegill (Bluegill · Liter^{-1}) and zooplankton (zooplankton · Liter^{-1}) density and catch rate of young-of-year Bluegill in the littoral zone (Bluegill · Liter^{-1}). Best model was selected by fitting each model to the data and comparing model fit using forward stepwise selection. Null = null model, Treatment = Shad or Non-shad, Event = sampling period and ε = Random effect of impoundment

Model	Model Formula	Fixed effect	Random effect
1	Null + ε	-	Impoundment
2	Density = Treatment + ε	Treatment	Impoundment
3	Density = Event + ε	Month	Impoundment
4	Density = Treatment + Event + ε	Treatment, Month	Impoundment
5	Density = Treatment + Event + Treatment * Event + ε	Treatment, Month	Impoundment
6	Null	-	-
7	Density = Treatment	Treatment	-
8	Density = Event	Month	-
9	Density = Treatment + Event	Treatment, Month	-
10	Density = Treatment + Event + Treatment * Event	Treatment, Month	-

Table 3. Analysis, best model, effect, coefficient estimate, *P*-value and Chi-square. Best model was determined by forward stepwise comparisons of all models using likelihood ratio test. Models were used to test for differences in recently established Largemouth Bass growth (LMB-TL), weight (LMB-WT) and condition (LMB-CON) as well as recently established Bluegill condition (BLG-CON).

Analysis	Model	Effect	Coefficient	*p*-value	Chi-Square
LMB-TL	8	Month	-	<0.01	217.19
LMB-WT	9	Month	-	<0.01	214.44
		Treatment	1.50	0.01	7.76
LMB-CON	4	Month	-	<0.01	404.23
		Treatment	8.05	0.03	20.16
BLG-CON	3	Month	-	<0.01	415.81

Table 4. Analysis, best model, effect, coefficient estimate, *P*-value and Chi-Square. Best model was determined by forward stepwise comparisons of all models using likelihood ratio test. LARV = density of larval Bluegill (Bluegill · Liter^{-1}), ZOO = density of zooplankton (Zooplankton · Liter^{-1}) and SEINE = density of larval Bluegill (Bluegill · Seine^{-1}). 2014 and 2015 indicate study year. S = S-15 treated as a shad impoundment and NS = S-15 treated as a non-shad impoundment.

Analysis	Model	Effect	Coefficient	*p*-value	Chi-Square
ZOO-2014-S	7	Treatment	0.03	<0.01	67.00
ZOO-2015-S	7	Treatment	0.20	0.01	7.62
ZOO-2015-NS	4	Month	-	0.04	13.21
		Treatment	0.09	0.01	43.48
LARV-2014-S	10	Month	-	<0.01	35.32
		Treatment	0.01	<0.01	28.17
		Treatment x Month	-	0.02	20.79
LARV-2015-S	9	Month	-	0.01	30.37
		Treatment	0.21	<0.01	11.07
LARV-2015-NS	9	Month	-	<0.01	37.24
		Treatment	0.11	<0.01	26.90
SEINE-2014	2	Treatment	0.06	0.03	14.47
SEINE-2015	7	Treatment	0.05	<0.01	12.93

Table 5. Prey selection (estimated by Chesson's alpha; Chesson 1978) by larval Bluegill, larval Threadfin Shad and post-larval Threadfin Shad during 2014 and 2015. Values represent means ± 95% confidence intervals. Values equal to 0.11 (the average reciprocal of the number of prey across impoundments) indicate neutral selection, values greater than 0.11 indicate positive selection and values less than 0.11 indicate negative selection. TFS = Threadfin Shad, PLTFS = Post-larval Threadfin Shad, BLG = Bluegill, PRE = Pre-peak of larval Threadfin Shad density, POST = Post-peak of larval Threadfin Shad density, NS = Non-shad and S = Shad

		Prey Selected								
	N	Copepod nauplii	Bosmina	Calanoid	Ceridaphnia	Chydorida	Cyclopoid	Daphnia	Diaphanosoma	Ostracod
Larval TFS	30	0.54 ± 0.09	0.1 ± 0.05	0.12 ± 0.06	0.05 ± 0.03	0	0.1 ± 0.05	0.05 ± 0.04	0	2.78 ± 2.28
PLTFS-PRE	32	0	0.17 ± 0.05	0.03 ± 0.02	0.01 ± <0.01	0.54 ± 0.07	0.04 ± 0.02	0.05 ± 0.02	0.15 ± 0.04	0.46 ± 0.17
PLTFS-POST	147	0.02 ± 0.01	0.07 ± 0.02	0.05 ± 0.01	0.03 ± 0.01	0.34 ± 0.04	0.01 ± 0.01	0.02 ± 0.01	0.03 ± 0.01	10.47 ± 5.73
BLG-NS	150	0.17 ± 0.03	0.33 ± 0.04	0	0.13 ± 0.03	0.01 ± 0.01	0.03 ± 0.01	0.03 ± 0.01	0.23 ± 0.03	0.19 ± 0.12
BLG-S	86	0.11 ± 0.03	0.26 ± 0.05	0.01 ± 0.01	0.3 ± 0.05	0.01 ± 0.01	0.01 ± 0.01	0	0.15 ± 0.04	0.02 ± 0.02

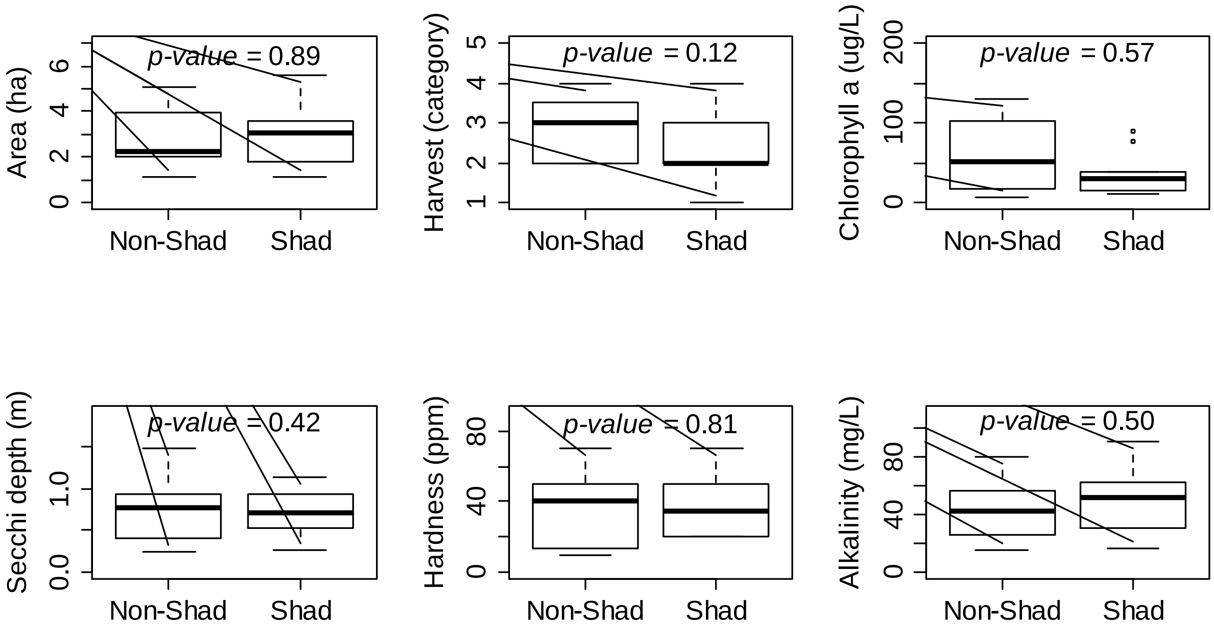

Figure 1. Impoundment characteristic data collected at each of the established impoundments. No significant differences were detected in surface area (ha; p = 0.89), harvest (category; p = 0.12), Chlorophyll-*a* (µg/L; p = 0.57), secchi depth (m; p = 0.42), hardness (ppm; p = 0.81) or alkalinity (mg/L; p = 0.50).

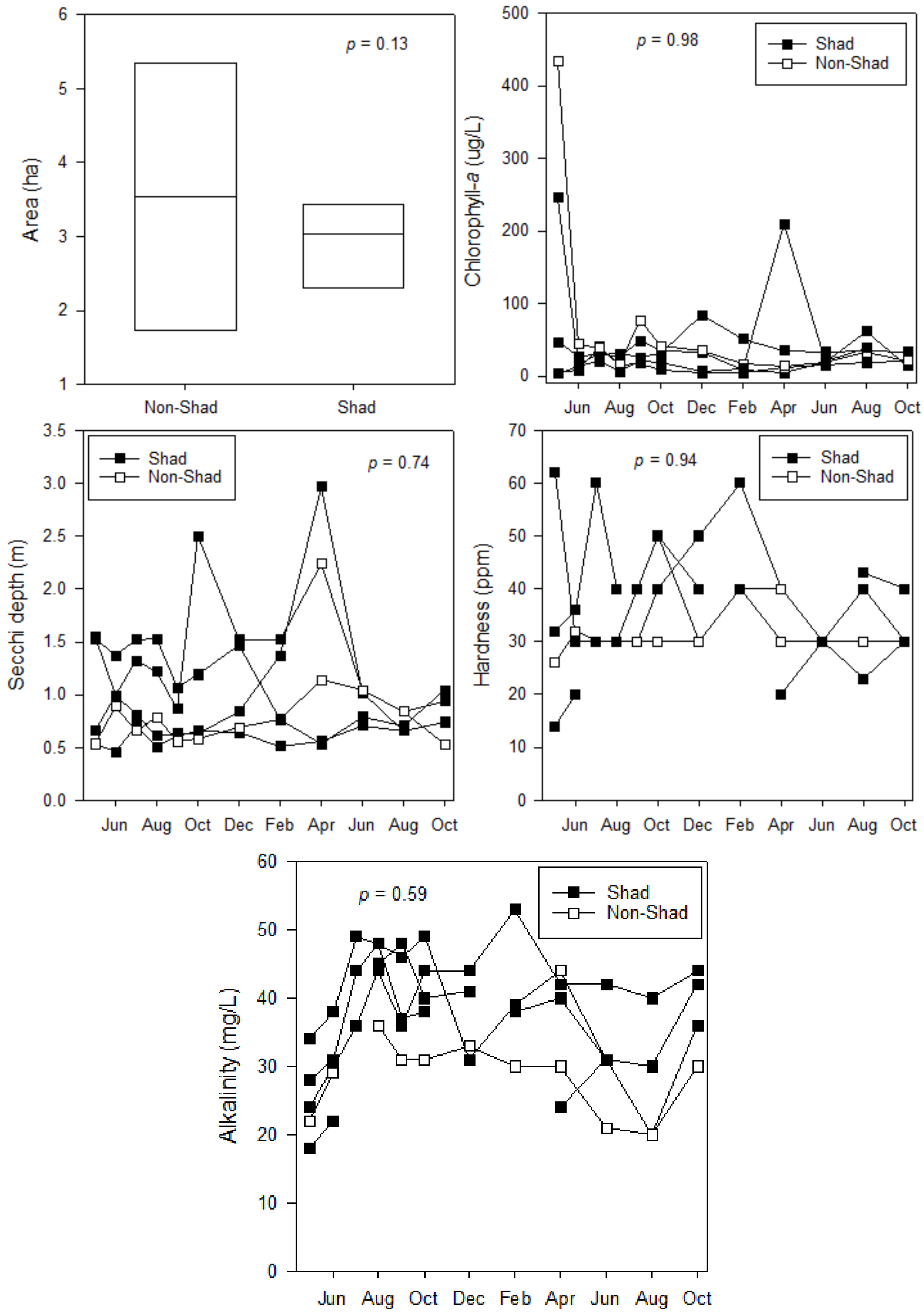

Figure 2. Impoundment characteristic data collected in each of the recently-established impoundments. No significant differences were detected in surface area (ha; p = 0.13), chlorophyll-*a* (µg/L; p = 0.98), secchi depth (m; p = 0.74), hardness (ppm; p = 0.94) or alkalinity (mg/L; p = 0.59).

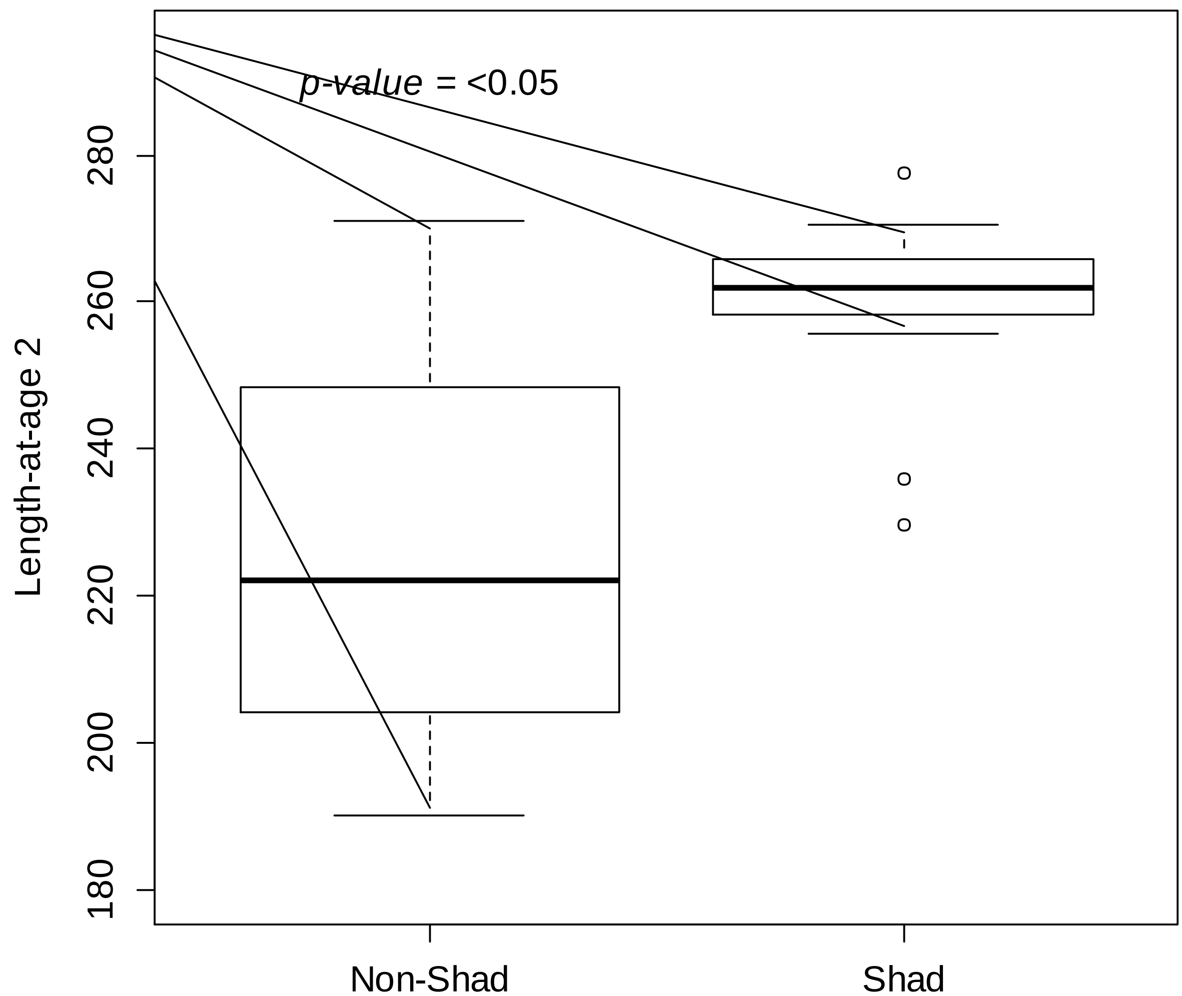

Figure 3. Box plot of average back-calculated length-at-age 2 of Largemouth Bass collected in established impoundments from May 2014 through September 2015.

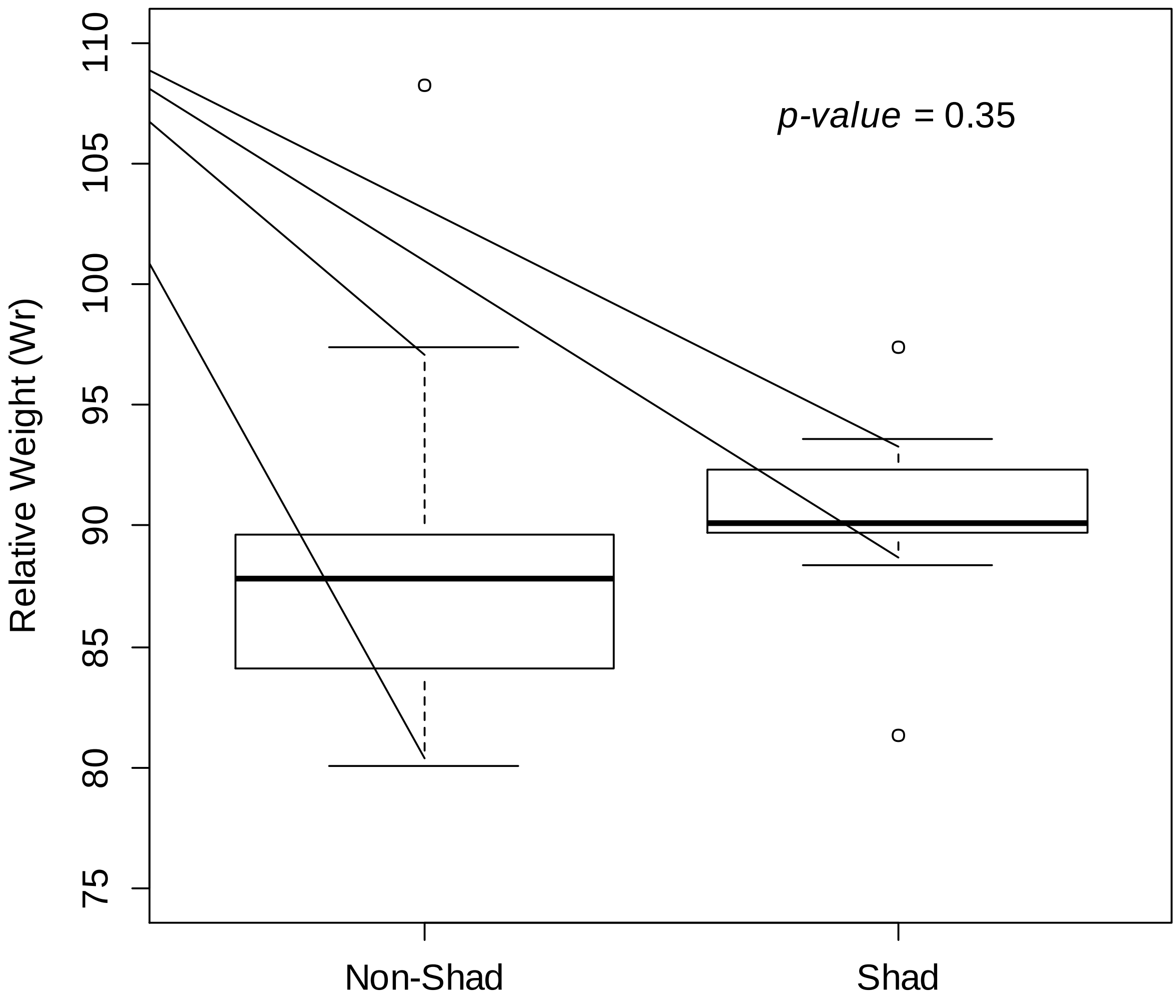

Figure 4. Box plot of average relative weight of Largemouth Bass collected in established impoundments from May 2014 through September 2015.

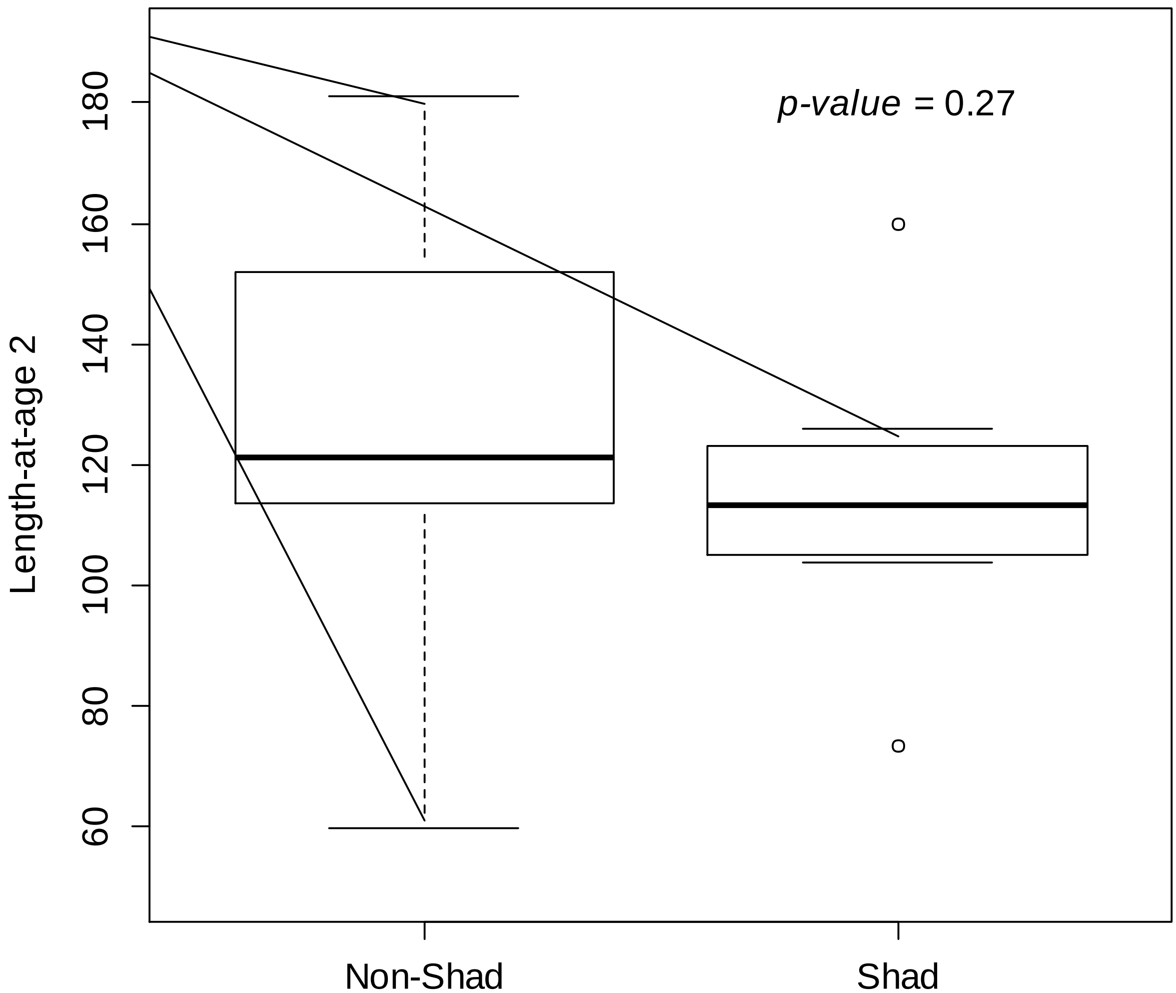

Figure 5. Box plot of average back-calculated length-at-age 2 of Bluegill collected in established impoundments from May 2014 through September 2015.

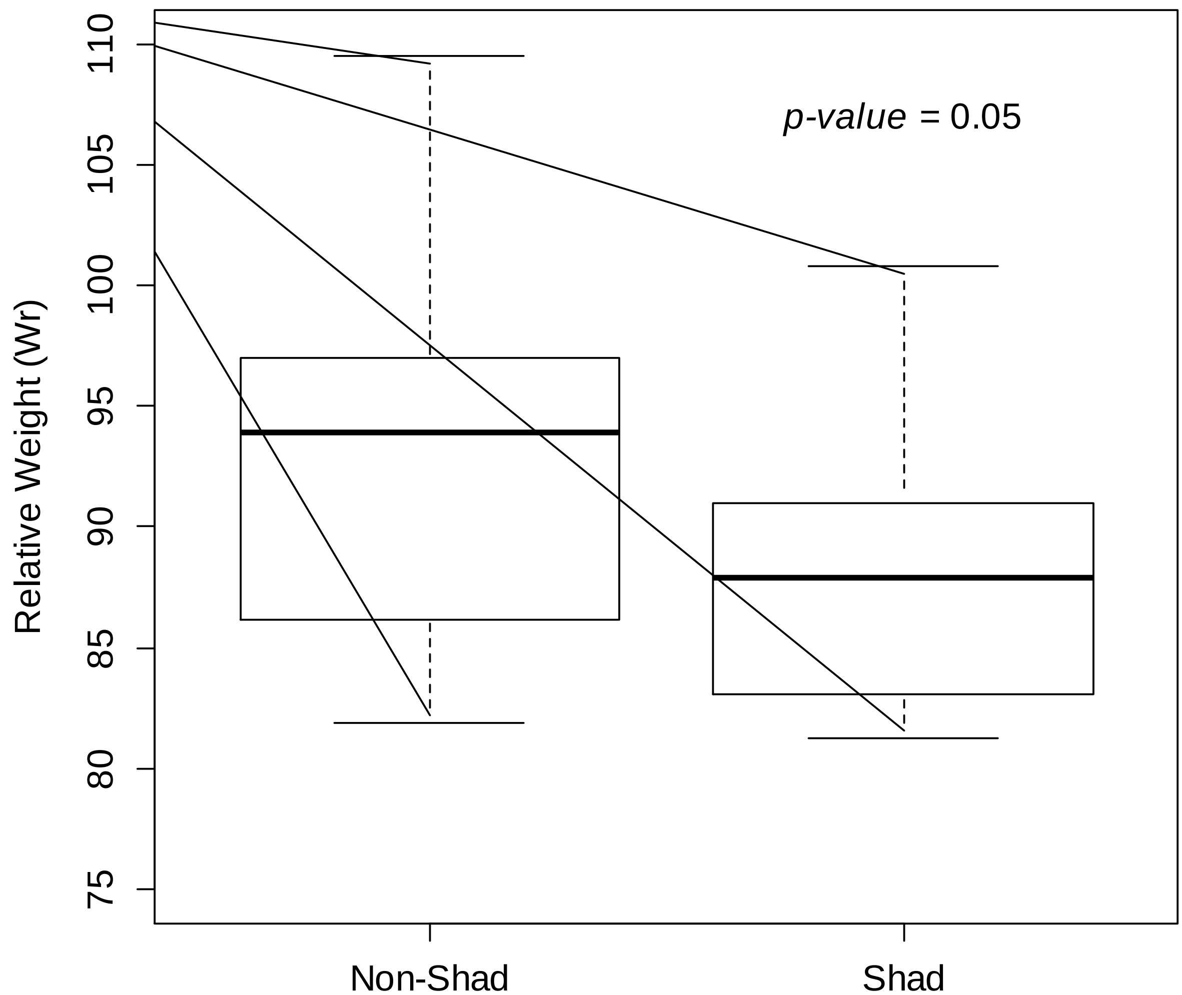

Figure 6. Boxplot of average relative weight of Bluegill collected in established impoundments from May 2014 through September 2015.

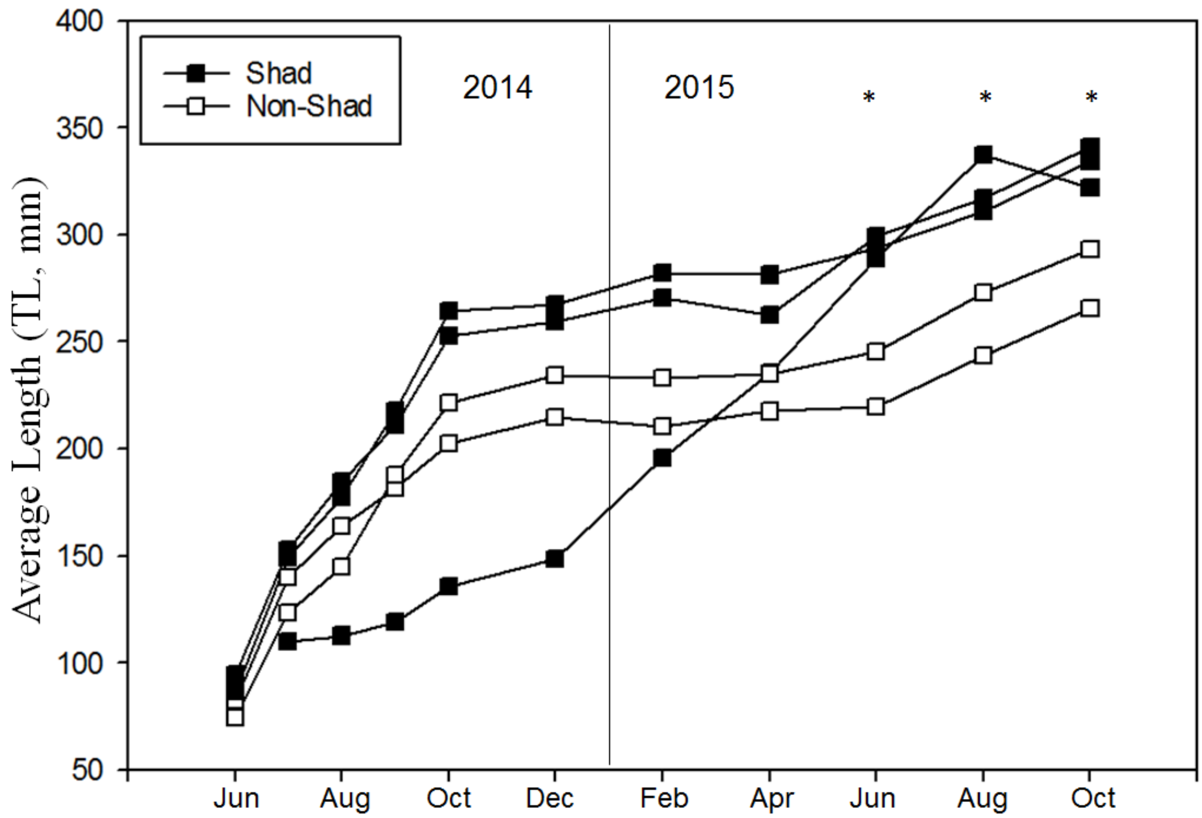

Figure 7. Average length (TL, mm) of Largemouth Bass collected in recently established impoundments from June 2014 through October 2015. Plotted data are not log transformed. Filled squares represent impoundments with shad and non-filled squares represent impoundments without Threadfin Shad. Asterisks indicate months that differed significantly between treatment type.

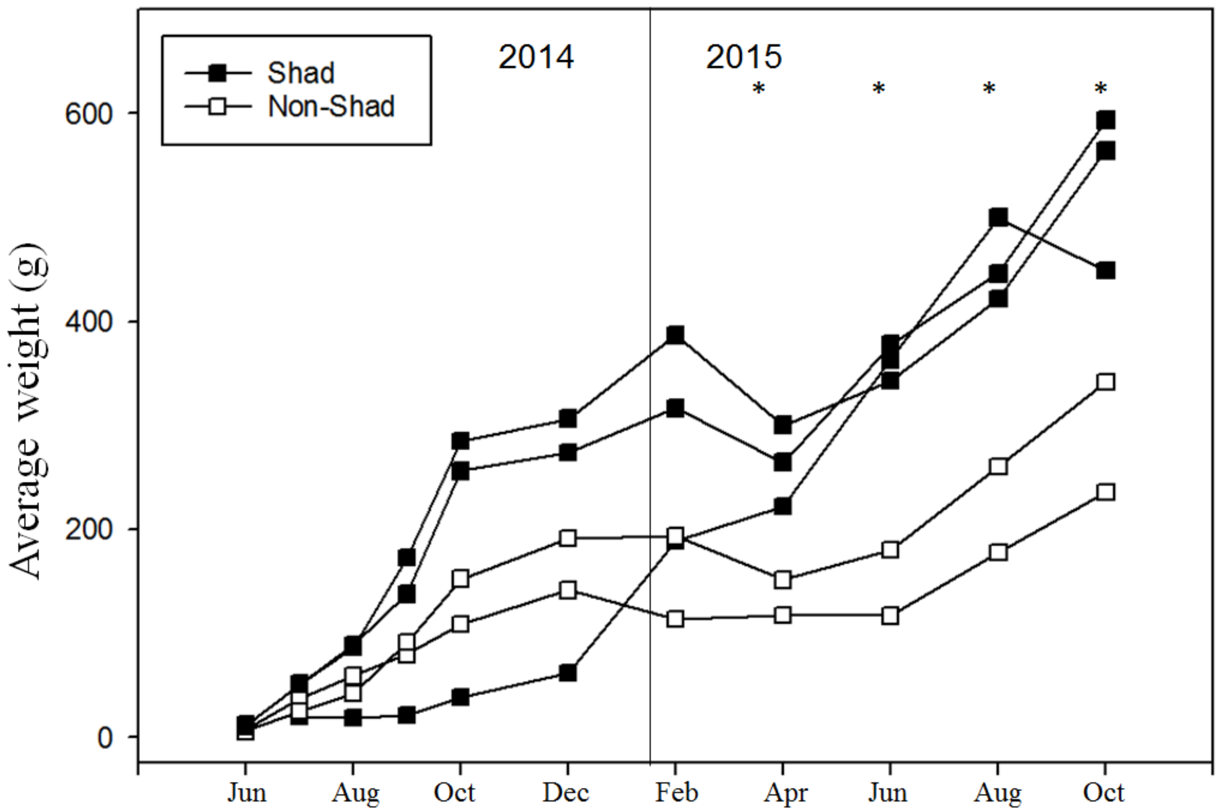

Figure 8. Average weight (g) of Largemouth Bass collected in recently established impoundments from June 2014 through October 2015. Plotted data are not log transformed. Filled squares represent impoundments with shad and non-filled squares represent impoundments without Threadfin Shad Asterisks indicate months that differed significantly between treatment type.

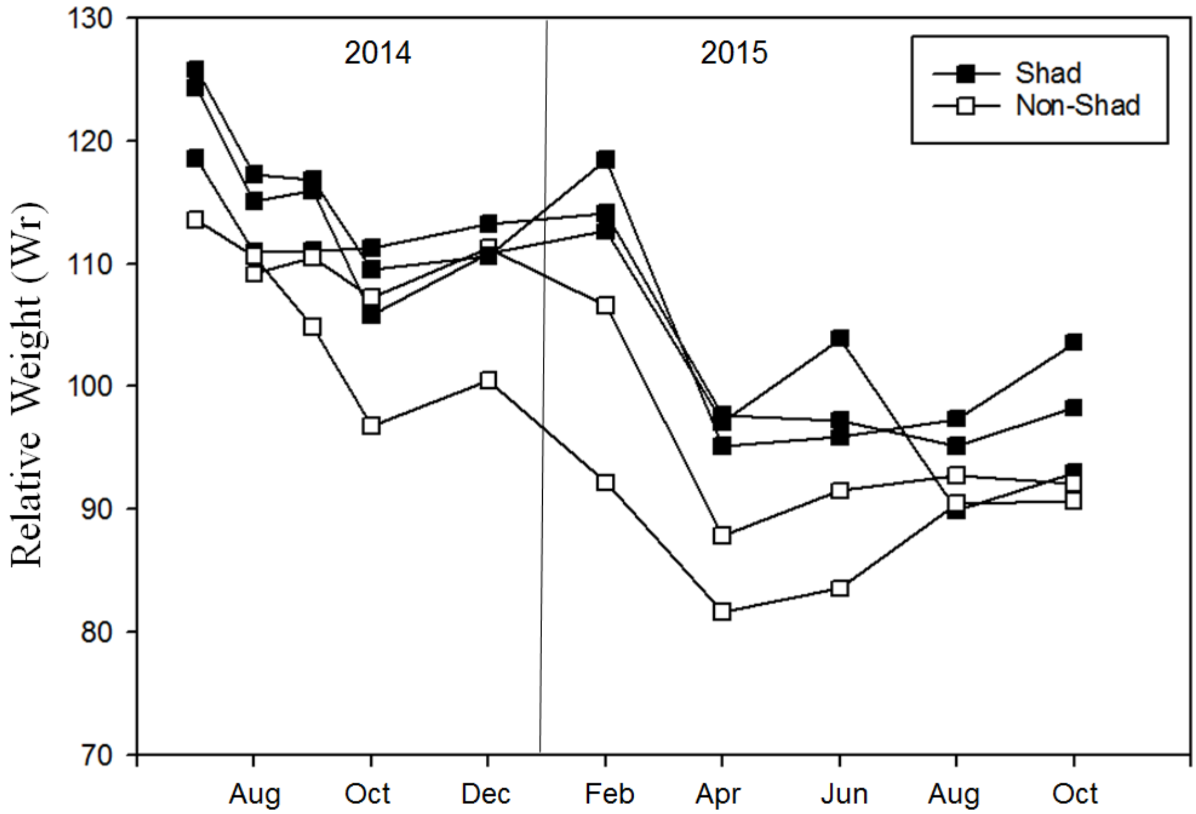

Figure 9. Average relative weight of Largemouth Bass collected in recently established impoundments from June 2014 through October 2015. Filled squares represent impoundments with shad and non-filled squares represent impoundments without Threadfin Shad.

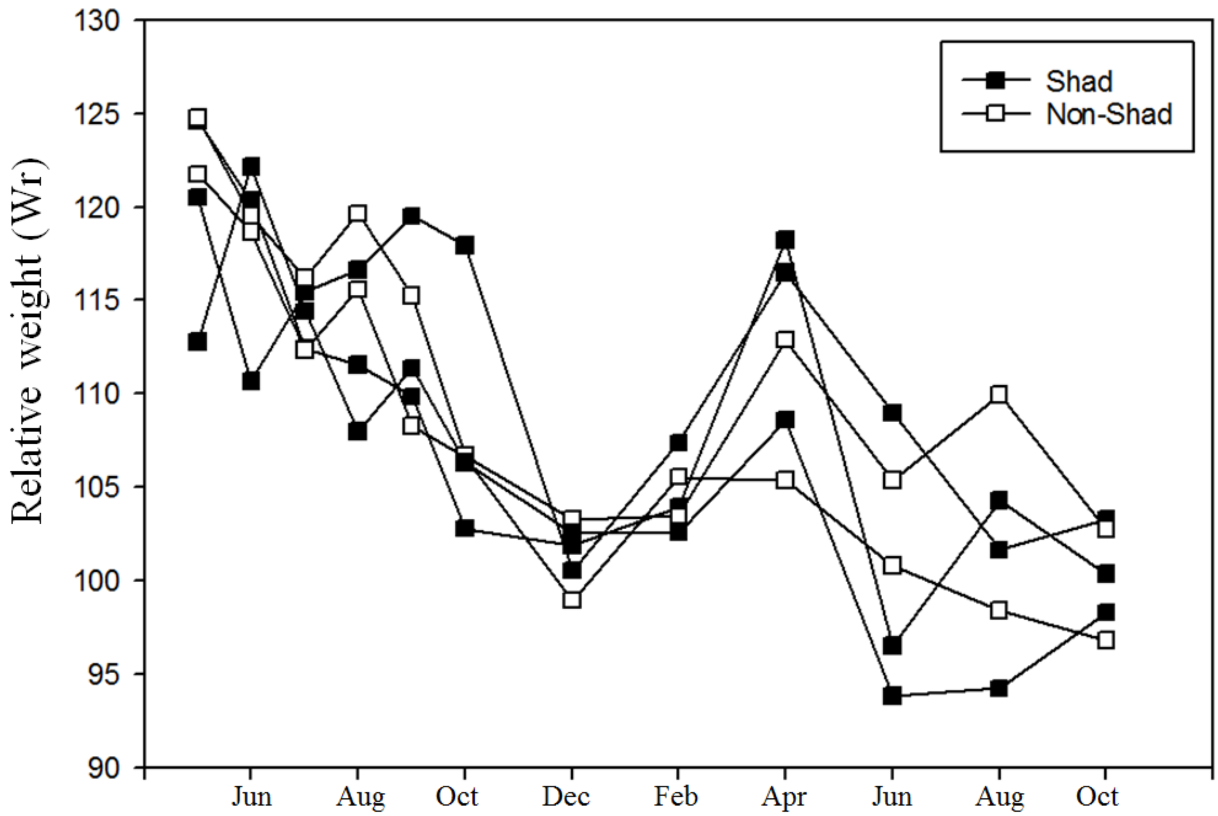

Figure 10. Average relative weight (Wr) of Bluegill collected in recently established impoundments from June 2014 through October 2015. Filled squares represent impoundments with shad and non-filled squares represent impoundments without Threadfin Shad.

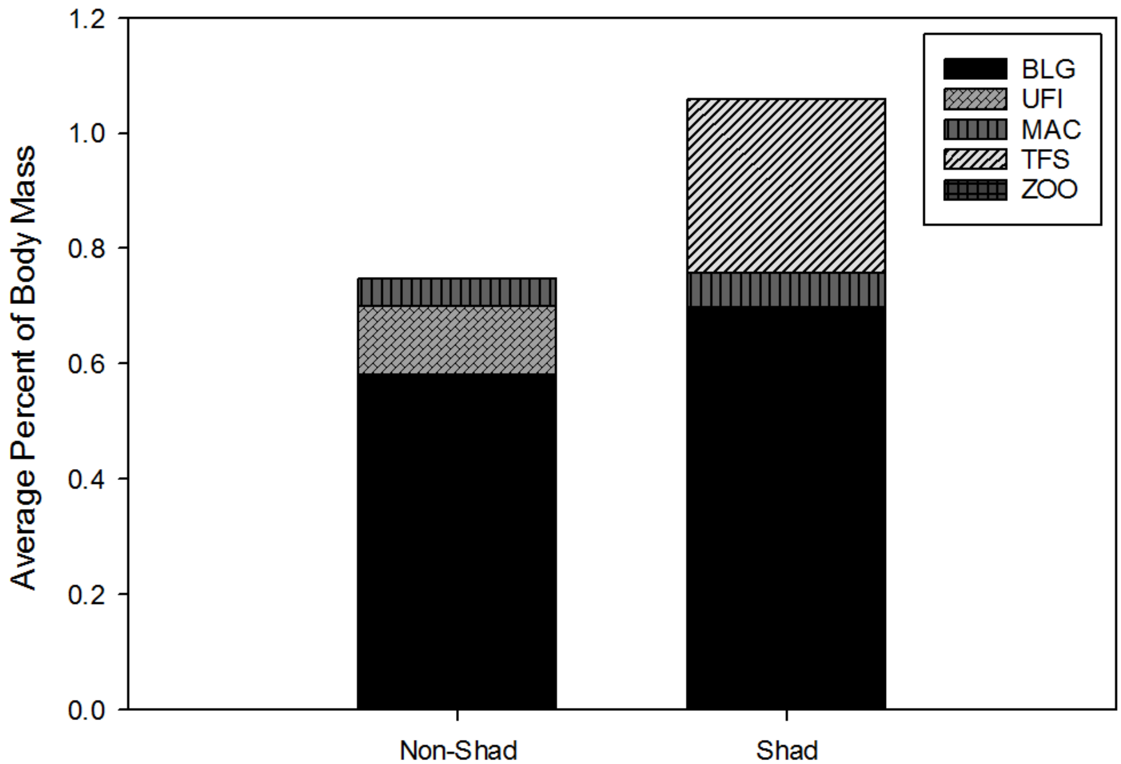

Figure 11. Average percent of body mass for Largemouth Bass in established Shad and Non-Shad impoundments. BLG = Bluegill, FIS = Unidentified fish, MAC = Macroinvertebrates, ZOO = Zooplankton, CRA = Crayfish, and TFS = Threadfin Shad.

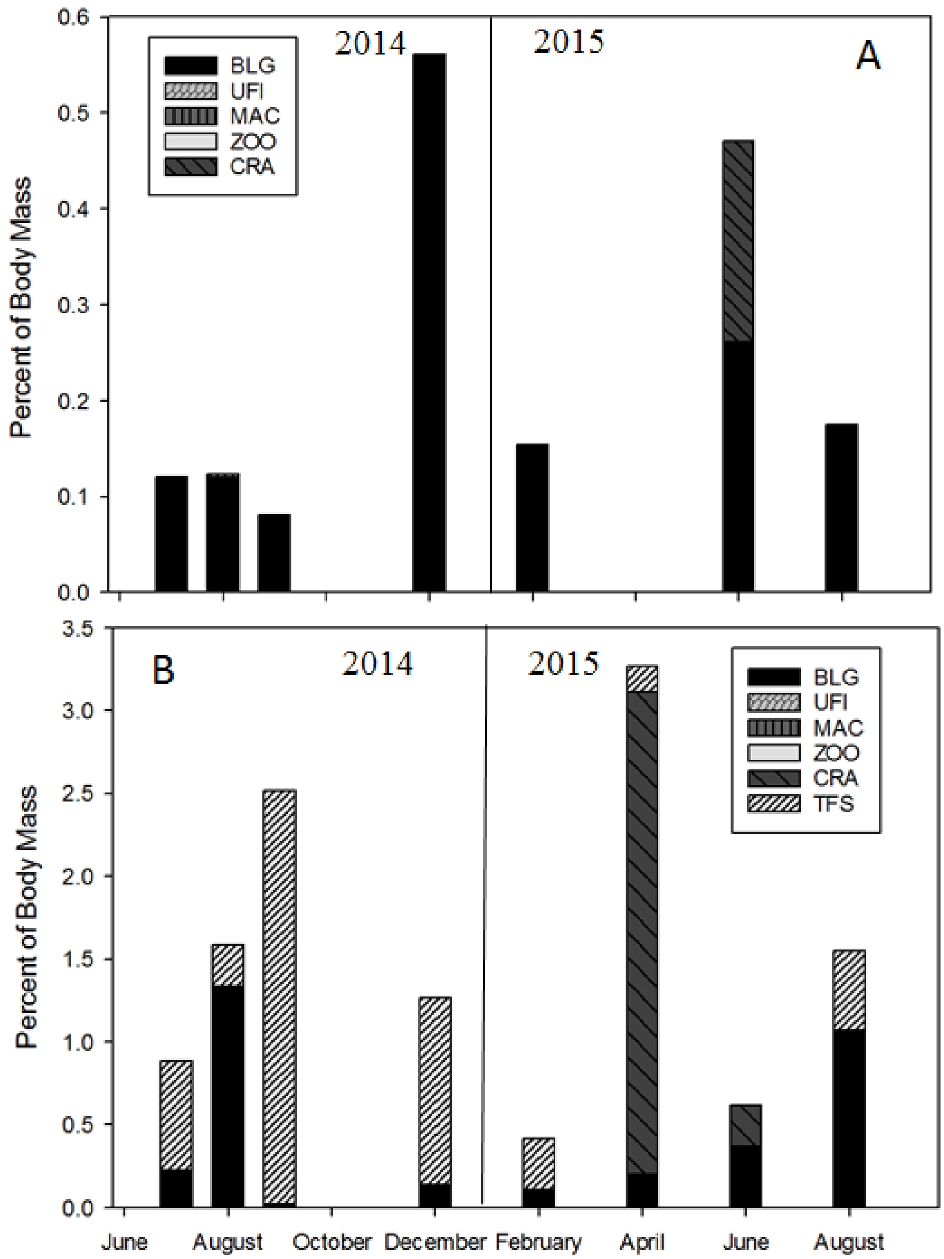

Figure 12. Percent of body mass for Largemouth Bass in Non-Shad (A) and Shad (B) impoundments during 2014 and 2015. BLG = Bluegill, UFI = Unidentified fish, MAC = Macroinvertebrates, ZOO = Zooplankton, CRA = Crayfish, and TFS = Threadfin Shad.

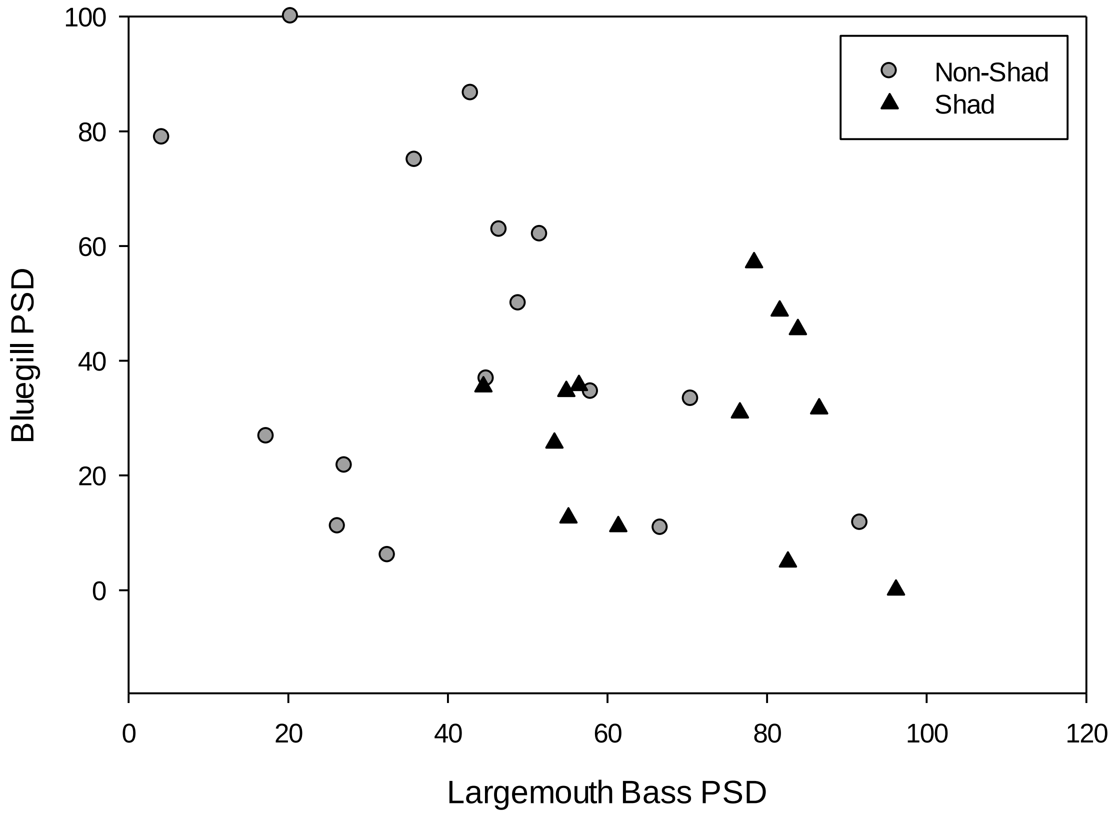

Figure 13. Proportional Size Distribution (PSD) for Largemouth Bass and Bluegill in impoundments with and without Threadfin Shad. Each point represents a single impoundment.

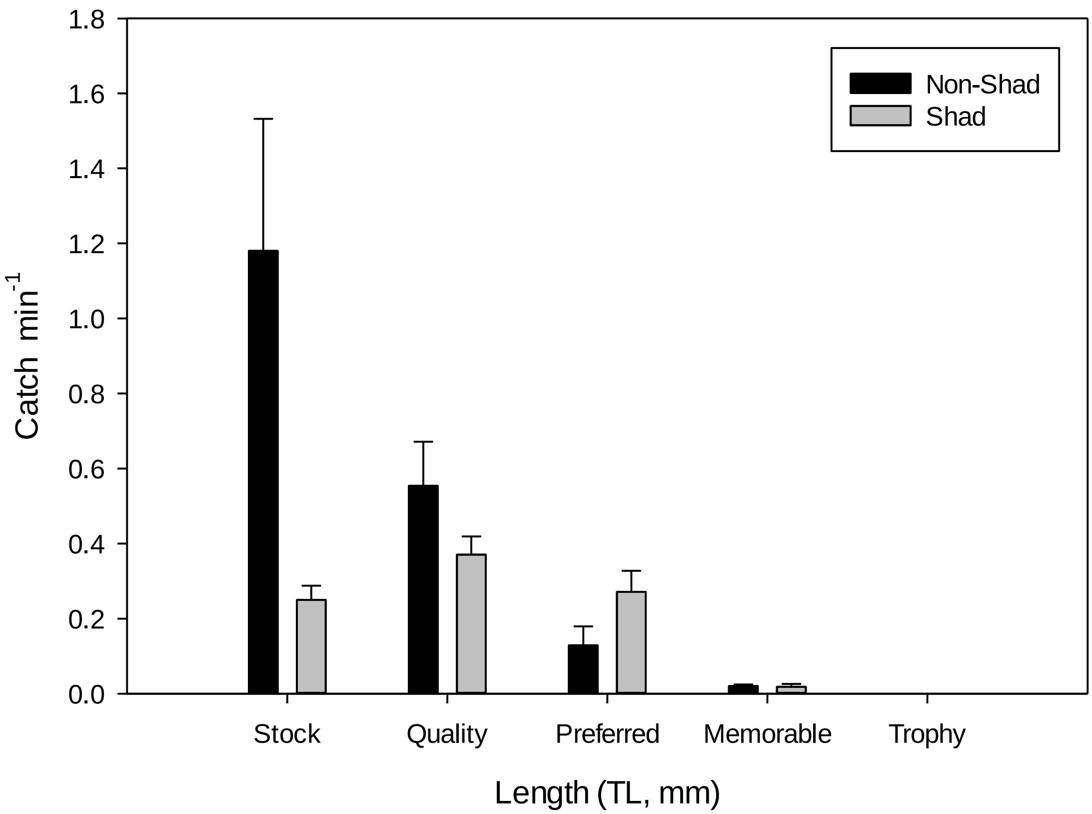

Figure 14. Average CPUE (mean ± SE) of Largemouth Bass collected in established impoundments from May 2014 through September 2015.

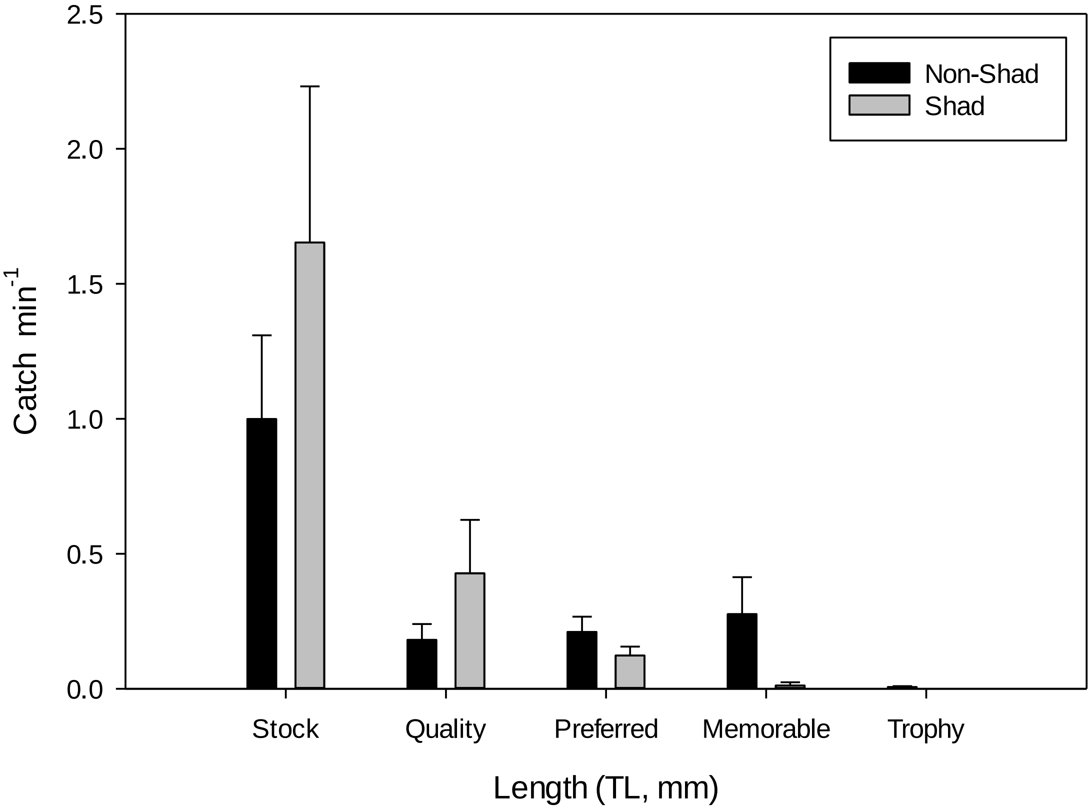

Figure 15. Average CPUE (mean ± SE) of Bluegill collected in established impoundments from May 2014 through September 2015.

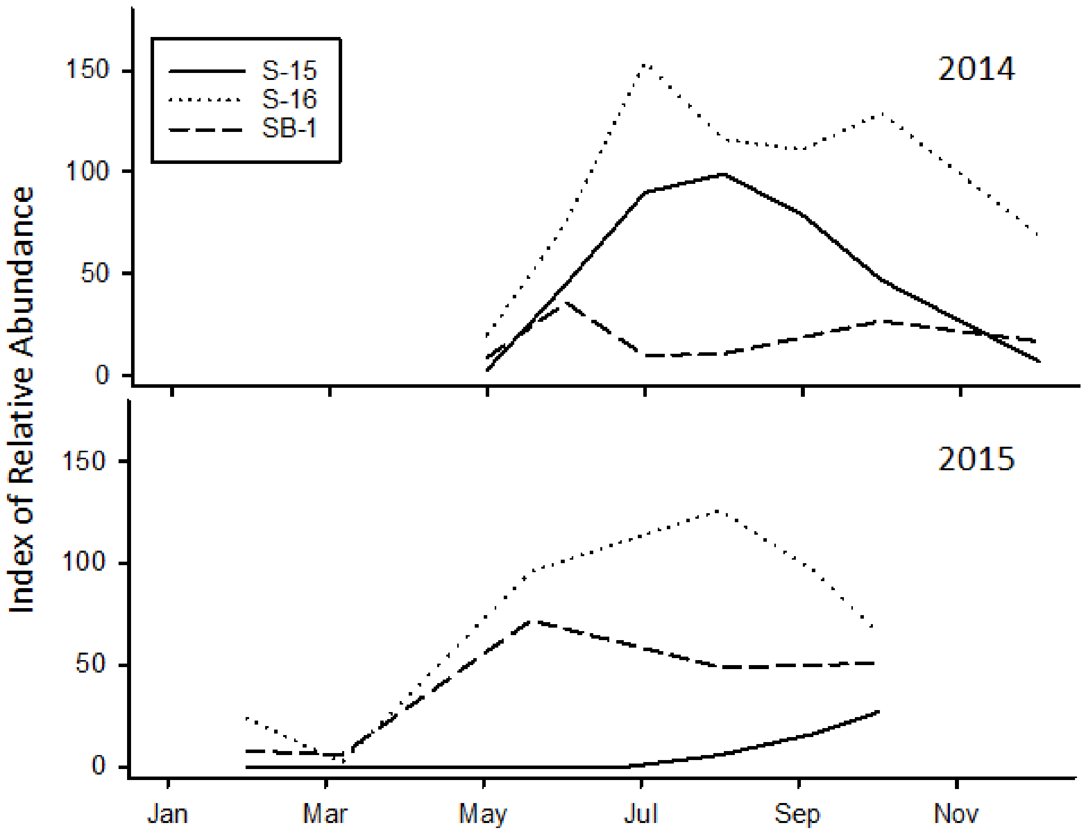

Figure 16. Relative abundance of post-larval Threadfin Shad observed during electroshocking survey in 2014 and 2015. Solid line represents S-15, dotted line represents S-16 and dashed line represents SB-1.

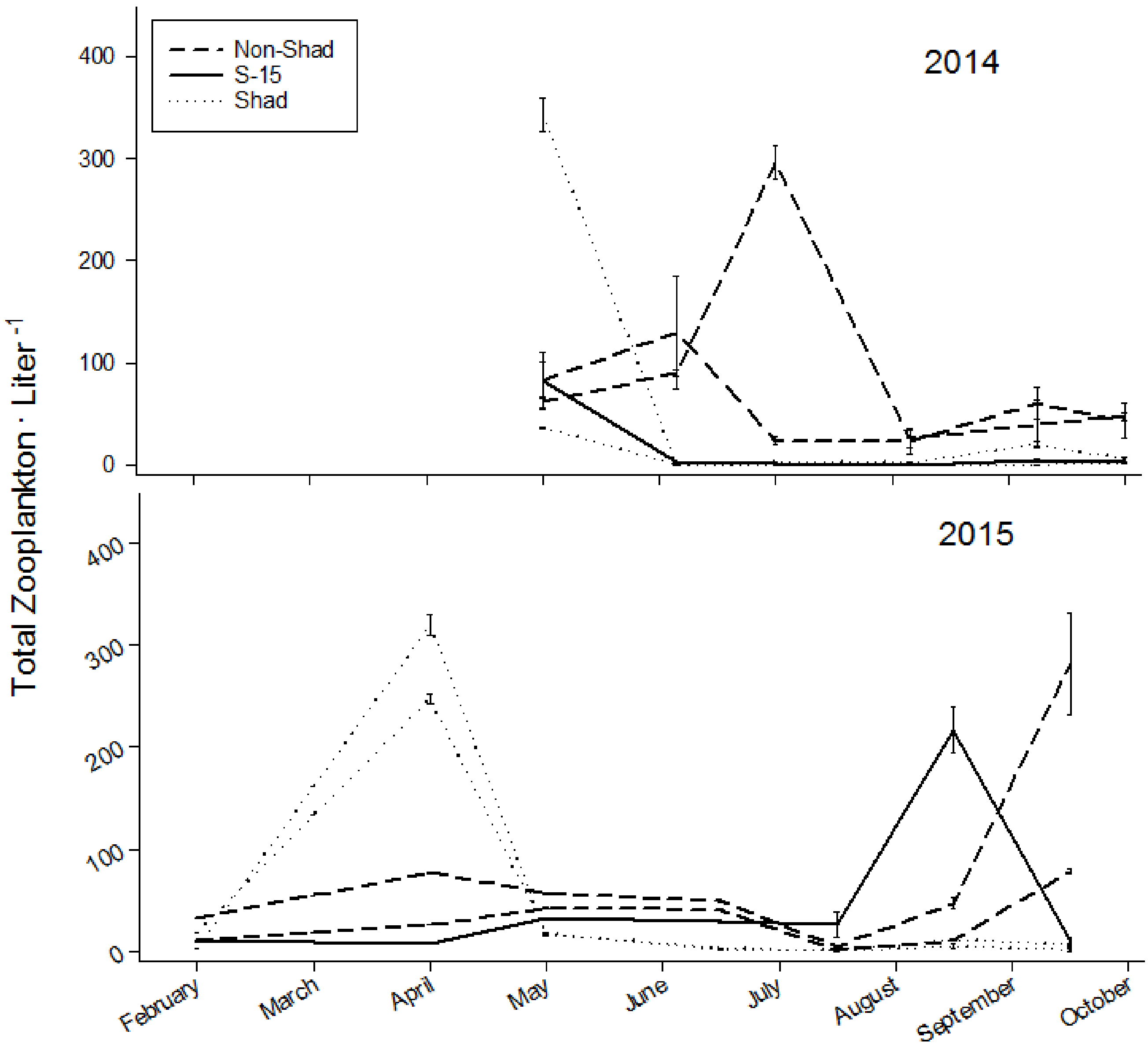

Figure 17. Density (mean ± SE) of zooplankton collected using 0.31-m-zooplankton net from S-15 (solid line), S-16 (dotted line) and SB-1 (dashed line) during 2014 and 2015.

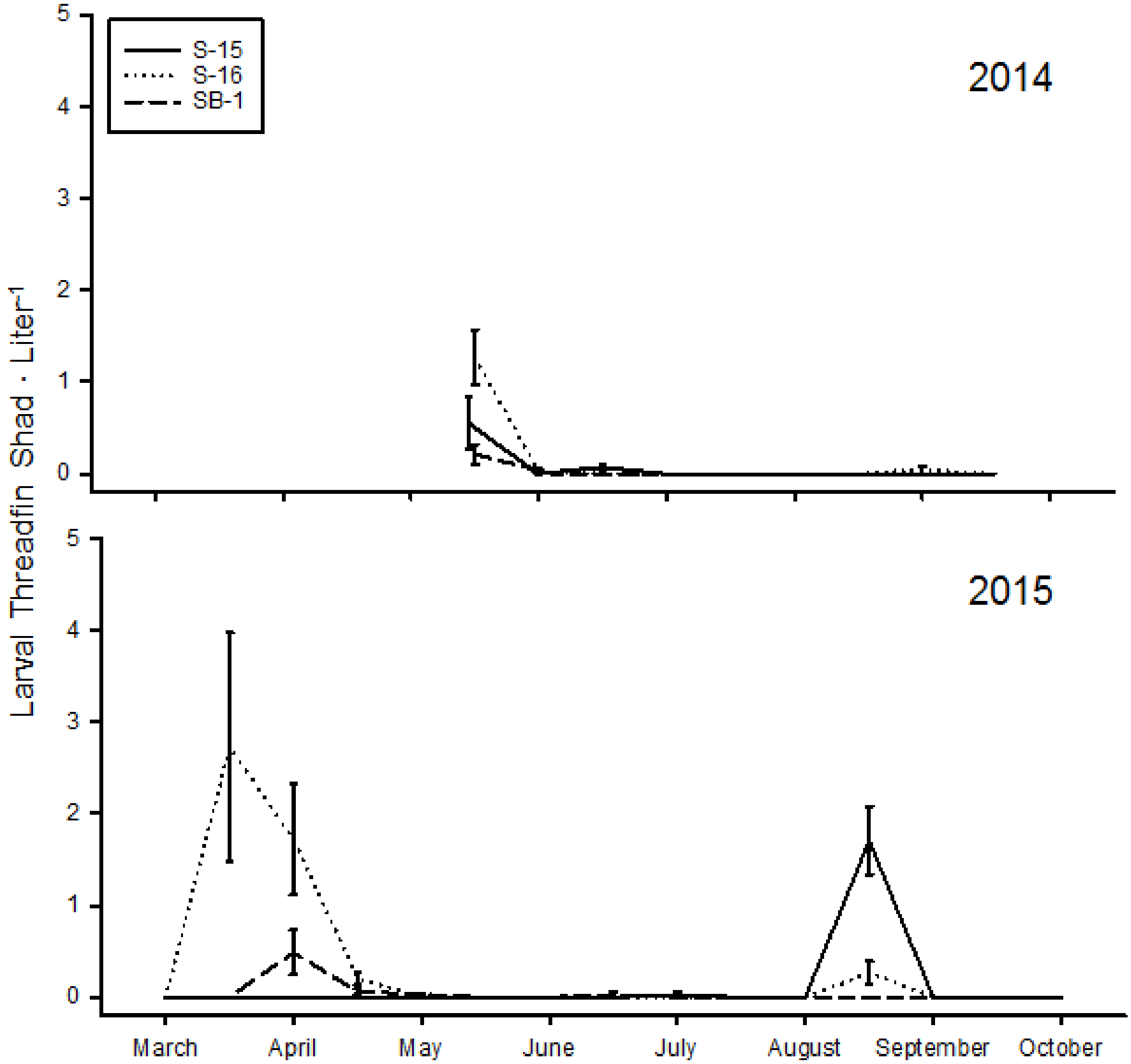

Figure 18. Density (mean ± SE) of larval Threadfin Shad collected from daytime surface tows from S-15 (solid line), S-16 (dotted line) and SB-1 (dashed line) during 2014 and 2015.

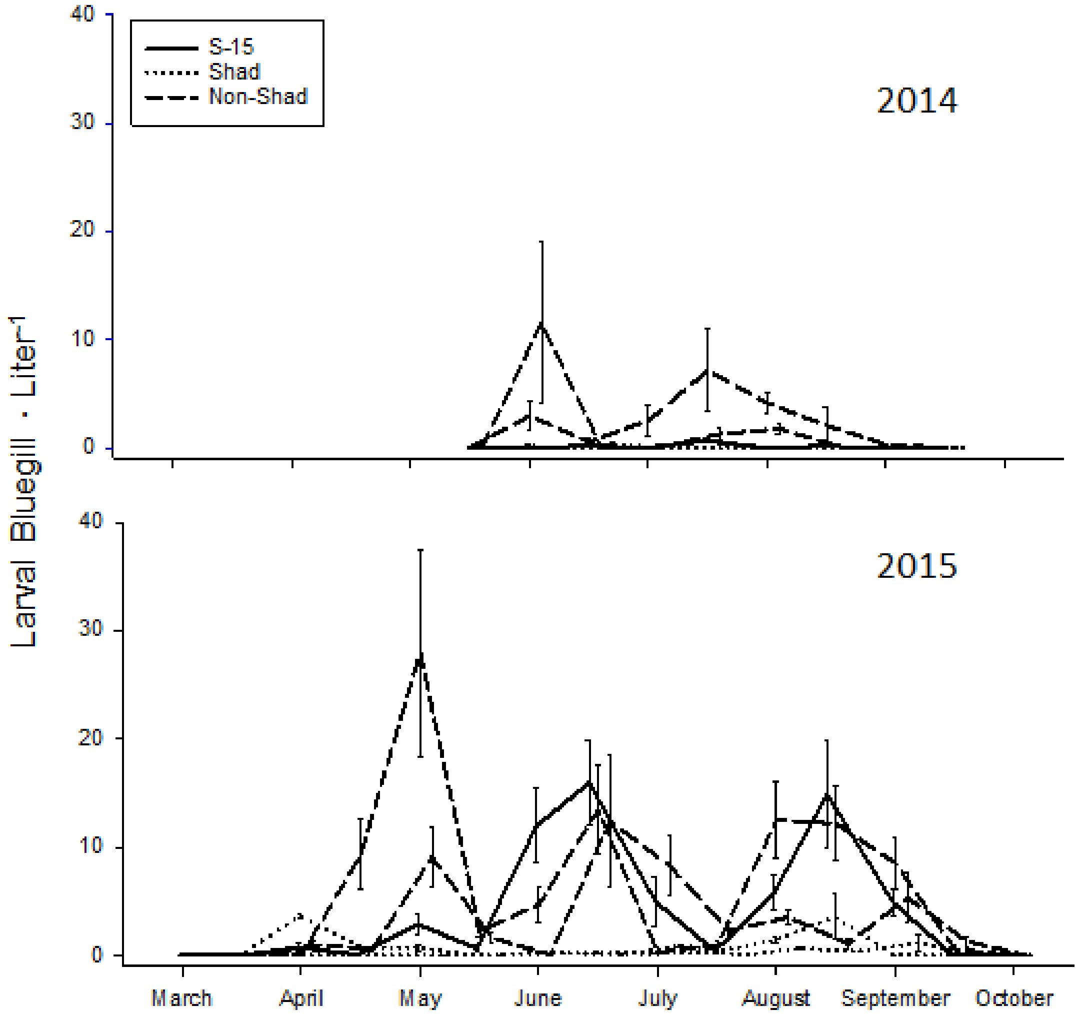

Figure 19. Density (mean ± SE) of larval Bluegill collected from daytime surface tows from S-15 (solid line), shad impoundments (dotted line) and non-shad impoundments (dashed line) during 2014 and 2015.

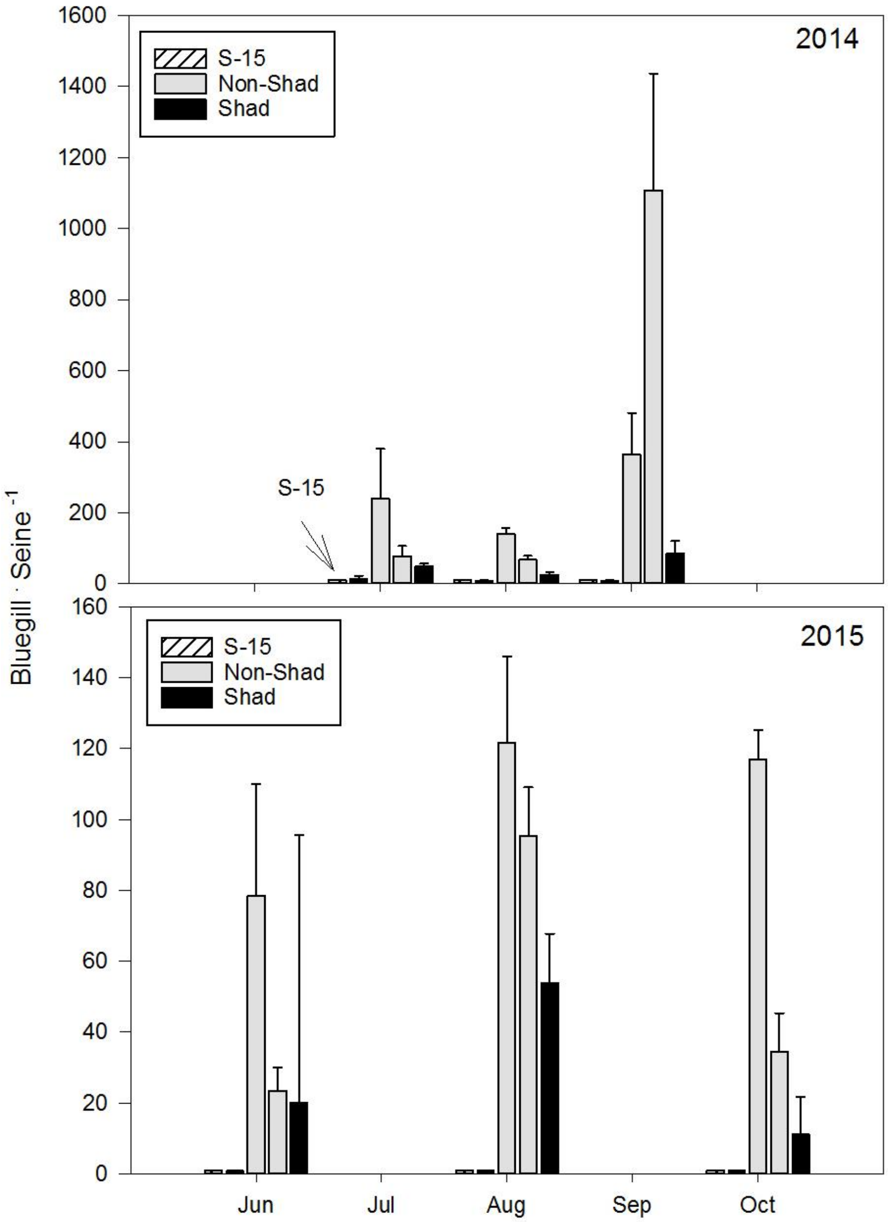

Figure 20. Catch (mean ± SE) of young-of-year Bluegill collected from the littoral zone by seine haul during 2014 and 2015. Shad = S-16 and SB-1, Non-Shad = S-28 and S-30.