Evaluation of a shoreline rotenone application to control Largemouth Bass *Micropterus salmoides* recruitment in small impoundments.

by

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Abstract

Control of Largemouth Bass recruitment would benefit small impoundment recreational fisheries by reducing largemouth population density, which could improve growth rates, body condition, and size structure. I evaluated the efficacy of shoreline rotenone application of the piscicide rotenone to target age-0 Largemouth Bass and reduce Largemouth Bass recruitment in small impoundments. I tested for the effects of shoreline rotenone application on Largemouth Bass and Bluegill density, growth, size structure, and body condition in 20 Alabama small impoundments. Following treatment, Largemouth Bass densities declined, body condition increased, and mean age-1 length increased, whereas Bluegill population indicators were unaffected. My study suggests that shoreline rotenone application may be a useful approach for reducing Largemouth Bass densities in small impoundments, but more study is needed to better assess the effects of impoundment surface area and treatment frequency and duration on the utility of the approach.

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Introduction

Small impoundments (water bodies <200 hectares [ha]) are ecologically, economically, and aesthetically important to the United States. In 2016, 83% of all freshwater anglers (24.6 million) targeted reservoirs, lakes, and ponds (U.S. Department of the Interior, U.S. Fish and Wildlife Service and U.S. Census Bureau 2016). These small impoundments can provide a significant source of income as part of a pay-to-fish operation, for aesthetic value, and as habitat for a broad range of animals (Chaney et al. 2012). The numbers of small impoundments in the continental United States was estimated to be nearly 2.6 million in 1992 (Smith et al. 2002) and as many as 9 million in 2005 (Renwick et al. 2005). Chaney et al. (2012) estimated nearly 280,000 small impoundments in Alabama alone. Small impoundments are used for a variety of reasons, with recreational fishing being the most common (Haley et al. 2012). Due to the importance of recreational fishing in these systems, the development of management strategies that achieve desirable fish population structure for angling is essential.

The most common sympatric stocking of warmwater small impoundment fishes in middle and lower latitudes of North America are Largemouth Bass *Micropterus salmoides* and Bluegill *Lepomis macrochirus* (Smitherman 1975; Novinger and Legler 1978; Brenden and Murphy 2004; Dauwalter and Jackson 2005; Wright and Craft 2012; Haley et al. 2012). The dynamics of this two-species system has been studied extensively (Swingle and Smith 1942; Gabelhouse 1987; Guy and Willis 1990; Shoup and Broderius 2018). The Largemouth Bass is a top-level piscivorous fish that is the most sought, economically significant, and heavily managed species of black bass in North America (Allen et al. 2008; Carlson and Isermann 2010;

Bonvechio et al. 2014; Claussed 2015). Estimates from the 2016 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation show nearly 9.6 million anglers spent 117 million angler-days targeting black basses (U.S. Department of the Interior, U.S. Fish and Wildlife Service and U.S. Census Bureau 2016). Largemouth Bass is self-sustaining, readily catchable via angling, an opportunistic feeder, and rapid grower, making them appropriate for stocking in small impoundments. Bluegill is also a highly sought sport fish, with high diet flexibility, self-sustainability, and high productivity (i.e., spawn multiple times throughout the summer in the southeast) [Wright and Kraft 2012].

Management of small impoundment fish populations is often an exercise in the manipulation of population densities to achieve desirable growth rates. Fish density is typically the object of manipulation because fish populations in these systems exhibit strong density-dependent growth. In this context, density-dependence is defined as a negative relationship between population density and life history traits such as growth, survival, and reproduction. This relationship is referred to as compensatory because it is a negative feedback on population size. The mechanism for compensatory density dependence is intraspecific competition for food and habitat (Heath 1992; Rose et al. 2001). Fishes in small impoundments are known to show a compensatory density-dependent increase in growth after a reduction in overcrowded populations (e.g., Beckman 1941; Swingle and Smith 1942; Beckman 1943; Tiemeier 1957; Tiemeier and Elder 1960; DeAngelis et al. 1991; Aday 2008; Aday and Graeb 2012).

Small impoundment managers typically manipulate relative densities of Largemouth Bass and Bluegill to obtain a “balanced” population that maximizes a desired fish size and production to achieve sustainable harvest for both species over time (Swingle 1950; Geihsler and Holder 1983; Sammons and Maceina 2005). Overharvest of Largemouth Bass was historically one of the most common small impoundment management problems (Funk 1974; Willis et al. 2010). In this case, reduced predation on Bluegill by Largemouth Bass could lead to high Bluegill densities. An overabundance of Bluegill can harm their own population structure (i.e., reduced growth rate and body condition [Willis et al. 2010]), and also interfere with Largemouth Bass recruitment by destroying nests (Smith 1976) or eating eggs and larvae (Swingle and Smith 1942; Bennett 1970; Swingle 1970; Wright and Kraft 2012). Furthermore, similar habitat is occupied by juvenile Bluegill and age-0 Largemouth Bass, potentially resulting in increased direct competition between the two species (Zweiacker and Summerfelt 1974; Werner 1977; Kelso 1983; Brenden and Murphy 2004).

Over the last 30 years across North America, black bass anglers have increasingly adopted catch-and-release fishing due to the desire for trophy sized fish, which has resulted in increases in black bass densities and commensurate density-dependent reductions in their growth in some systems (Quinn 1996; Latona 2005; Sammons and Maceina 2005; Willis et al. 2010; Aday and Graeb 2012; Wright and Kraft 2012; Bonvechio et al. 2014). The fact that Largemouth Bass spawn annually at high rates (2000-7000 eggs per pound of body weight [Moyle 1976; Laarman and Schneider 2004; Claussen 2015]) makes them highly vulnerable to overcrowding and density-dependent growth reductions (Wright and Kraft 2012; Aday and Graeb 2012). Without proper management, consistent annual recruitment of a cohort with high or moderate survival and increased competition limiting food availability may prevent most individuals from growing to a satisfactory size, or potentially result in a stunted body size (Swingle 1950; Deedler 1951; Shelton et al. 1979; Wootton 1990; Allen and Hightower 2010; Aday and Graeb 2012).

Managers of small impoundments use information sources, tools, and techniques to maintain balanced populations of Largemouth Bass and Bluegill (Haley et al. 2012). Swingle and Smith (1942) mentioned draining the small impoundment or poisoning the entire population and then restarting as the simplest treatment for crowded populations, however, this method is costly and time consuming. Other management practices to help solve reduced growth rates and overcrowded populations include control of aquatic macrophyte growth, fertilization, slot length limits (Eder 1984; Gabelhouse 1984b, 1987; McHugh 1990), and heavy harvest of small Largemouth Bass (Swingle and Smith 1942; Gabelhouse 1987). Novinger and Legler (1978) recommend reducing age-0 Largemouth Bass recruitment (age-0 densities) in order to increase Largemouth Bass growth and size structure to correct these bass crowded populations (Aday and Graeb 2012).

Largemouth Bass recruitment is difficult to control directly because common sampling gears (e.g., hook-and-line, electrofishing) are inefficient at capturing age-0 fish, and slot length limits are ineffective because anglers do not typically harvest a sufficient percentage of small individuals (McHugh 1990; Gabelhouse 1984b, 1987). Thus, age 1+ Largemouth Bass are usually targeted for removal, but this is labor intensive and expensive. Few pond owners consistently harvest enough Largemouth Bass from their small impoundments to maintain adequate growth rates, likely due to time and financial limitations (Haley et al. 2012). The concept of catch-and-release fishing has grown substantially in popularity due to increased angler desire for “quality” fishing and personal philosophy, which could also result in inadequate Largemouth Bass harvest (Barnhart 1989). The development and enhancement of methods for controlling Largemouth Bass recruitment would be beneficial to small impoundment management throughout the United States.

One technique used to sample or control fish populations in small impoundments is the application of the piscicide, rotenone (Finlayson et al. 2000). Tropical trees in the genera *Derris* and *Lonchocarpus* produce rotenone naturally in their roots. It has been used for centuries to capture fish where these plants naturally occur: Australia, Oceania, southern Asia, and South America (Bettoli and Maceina 1996; Finlayson et al. 2000). Rotenone is important to fisheries management for many reasons (e.g., see McClay 2000; Finlayson et al. 2000). The most common use of rotenone is the manipulation of fish populations to maintain sport fisheries (McClay 2000). It is extremely effective at targeting fish because the toxin enters the bloodstream directly through the gills and disrupts cellular respiration in the mitochondria. Rotenone is practically nontoxic to nontarget species when using it at the low concentrations needed to affect fishes (Bettoli and Maceina 1996).

Rotenone has been used around the shoreline of small impoundments to reduce Largemouth Bass recruitment on a limited basis (McHugh 1990). However, few studies have experimentally evaluated the effectiveness of this approach. McHugh (1990) used a marginal rotenone treatment paired with electrofishing to reduce Largemouth Bass densities in two 24-28 ha small impoundments and found increased Largemouth Bass growth rate and improvements in Bluegill size structure and Crappie *Pomoxis* spp. recruitment. To date, no studies have evaluated shoreline rotenone treatments targeting Largemouth Bass recruitment in small impoundments ≤10 ha. The overall goal of this study was to evaluate the effect of shoreline rotenone application on Largemouth Bass and Bluegill populations in small impoundments. More specifically, this study (1) evaluated the effectiveness of a shoreline rotenone application at reducing age-0 and age-1 Largemouth Bass densities in small impoundments, (2) investigated compensatory density-dependent responses of Largemouth Bass growth and survival if density reductions occurred, (3) quantified changes in Bluegill population characteristics in small impoundments, and (4) assessed the effect of impoundment surface area on the performance of the approach.

Methods

Study Areas

A total of twenty small impoundments (i.e., impoundments) ranging from 0.7–48 ha in surface area were used for this study (Table 1). Impoundments were located on private, Alabama Department of Conservation and Natural Resources (ADCNR), or Auburn University owned lands ranging across central to southern Alabama (Figure 1). Ten of these impoundments received shoreline rotenone application and the other ten were left as untreated controls. Impoundments were selected so that a control and treatment pair were similar in littoral vegetation coverage, bank depth, surface area (with one exception), and Largemouth Bass and Bluegill densities. The first year of this study included twelve impoundments (i.e., six controls/six treatments) with eight of those (four pairs) being used again in the second year. An additional eight impoundments were added in the second year for a total of sixteen impoundments in the second year, yielding an overall total of twenty impoundments (Table 1).

Summer Rotenone Application

A 5% biodegradable liquid version of the piscicide rotenone was used to target age-0 Largemouth Bass. Juvenile Largemouth Bass recruit to littoral areas of impoundments after they disperse from male-guarded fry schools to escape predation in May (Kramer and Smith 1960; Jackson and Noble 1995), at which time they are highly vulnerable to shoreline rotenone application (McHugh 1990). Treatment impoundments received rotenone application in 2017 only, in 2018 only, or in both years (Table 1). The first application was in May with a follow-up application approximately 21 days later to ensure late spawners were not missed. Liquid rotenone was applied with a boat, two 151 litter (L) tanks, and all required safety gear. One tank was connected to a surface spray wand and the other to a multiport subsurface injector. A single pass was made around the perimeter of each treatment impoundment, applying 0.5 L rotenone per 90-meters (m) of shoreline. A 210,920 kilograms per square meter (kg/m^2) wand was used to apply at the surface and the subsurface injector was a 1.5 m section of chlorinated poly vinyl chloride (CPVC) with five evenly-spaced ports (two-millimeter [mm] diameter) connected to a 3.5 m fiberglass pole. This created a sediment-to-surface curtain of rotenone along the shoreline. The subsurface injector was held 3–5 m off the shoreline while surface application was simultaneously sprayed in between the subsurface injector and shoreline (Figure 2).

Summer Seine Hauls

Each impoundment was seined using a 4.5 X 1.8 m seine net with 3.2 mm knotless mesh at 15 randomly-selected sites within accessible areas of each impoundment. Seining was conducted on five occasions at each impoundment throughout each summer, beginning in May and ending in July. Four of the occasions were before/after samples associated with each rotenone application, and the fifth sample was a mid-summer follow-up. Seine hauls at treatment impoundments were collected beginning at sunrise and immediately before rotenone application on days 1 and 21, and then the seine hauls for the paired control impoundments were collected immediately after shoreline rotenone treatment. The day after each rotenone application (days 2 and 22), treatment and control impoundment seine hauls were collected near the same time of day as the pre-application samples to minimize any daytime effect on seine catch rates. An additional seine haul sample was conducted at each impoundment on day 42 to serve as a mid-summer follow-up cumulative comparison of catch over time (Figure 3). Seine sites were marked with a Garmin eTrex 20x global positioning system (GPS) to ensure the use of consistent sites throughout the summer and over both years (if required). Individual age-0 Largemouth Bass total lengths were recorded, and Bluegill were placed into 25 mm length bins after the first length bin of ≤12.5 mm (i.e., 0–12.5, 12.6–37.5, 37.6–62.5, …) and counted.

Electrofishing

All small impoundments were sampled via electrofishing during March prior to the first treatment and at least once thereafter (Table 1). Sampling included two 15-minute electrofishing transects along the shoreline of the impoundment and all fishes >80 mm were collected. Gear consisted of a Smith-Root 5.0 GPP aluminum boat. During spring electrofishing, a subsample of ten Largemouth Bass per 25 mm length interval for fish between 150–250 mm were collected for aging using otoliths. All fishes captured were measured (nearest mm) and weighed (nearest g). The subsample of Largemouth Bass 150–250 mm was aged by otoliths to determine the appropriate length cutoff for age-1 vs age-2 fish and to quantify and compare mean length-at-age.

All Largemouth Bass collected for aging were measured (nearest mm), weighed (nearest g), and their sagittal otoliths removed. A transverse section of the otolith was mounted to slides using methods of Boehlert (1985) and aged using immersion oil for clarity. Otoliths were aged using a Nikon SMZ800 imaging unit by two independent readers without prior knowledge of ages estimated by the other reader or length and weight of fish. Any differences were addressed by a third party by observing the otolith and discussing as a group to determine the correct age.

During 2018 and 2019 spring electrofishing, stomach contents from up to ten Largemouth Bass between 150–250 mm and 250–350 mm in each impoundment treated or used as a control in summer 2018 (16 total impoundments) were collected. Another electrofishing event occurred in late summer 2018 in an effort to collect stomach contents from ten individuals in each impoundment between 150–250 mm and 250–350 mm. The search for ten individuals in each size group was unsuccessful at some impoundments. Diets were collected in the field. All fish were measured (nearest mm), weighed (nearest g), diets removed, and released if not included in the spring age sample. Stomach contents were removed using a hybrid tubing/gastric lavage technique (Seaburg 1957; Van Den Ayyle and Roussel 1980; Light et al. 1983; Soupir et al. 2000) where three independent bursts of 100 milliliters (ml) of pressurized water created by a 100 ml syringe was used to flush out the gut of the fish through clear acrylic tubing. Contents were stored on ice in plastic bags labeled with the fish identification number. Bags were frozen in the lab until workup. A dissecting microscope was used to identify stomach contents. All food items examined in the diets were identified to family and pooled into major categories as in Chipps and Garvey (2007) and Soupir et al. (2000) (i.e., aquatic insects/decapods, fishes, other prey). Each diet was then categorized as "contains fish" or "contains no fish". The goal was to observe if a higher proportion of Largemouth Bass ate more fish after treatment due to a density-dependent release from intraspecific competition resulting in greater fish prey availability as a potential mechanism for increased growth.

Age-0 Relative Abundance and Mean Length

Two before-after-control-impact (BACI) analyses were used to test for effects of the shoreline rotenone treatment on Bluegill and age-0 Largemouth Bass seine catch rates (Stewart-Oaten et al. 1986). The first analysis compared seine catches from just before (i.e., day-1 and -21) to just after rotenone application (i.e., day-2 and -22) to estimate the immediate effect of the application and if that effect varied with impoundment surface area. Evaluation of a surface area effect was done by including a categorical designation for impoundment surface area (i.e., large [>33 ha] and small [<12 ha]) in this and all following analyses. This analysis was modeled with a generalized linear mixed effects model with a negative binomial sampling distribution in R (R Core Team 2014). There were random effects of impoundment x year intercepts and fixed effects of application (i.e., first: day-1 vs. day-2, and second: day-21 vs. day-22), treatment (control/treatment), time period (before/after), surface area, and all interactions. The treatment x time interaction tests whether catches declined significantly more in treatments compared to controls immediately after treatment for each application.

The second analysis compared the initial pre-treatment (i.e., day-1) seine sample with the mid-summer follow-up sample (i.e., day-42) to estimate the cumulative effect of both rotenone applications compared with natural variation in controls for Bluegill and age-0 Largemouth Bass. This analysis was modeled with a generalized linear mixed effects model with a negative binomial sampling distribution in R (R Core Team 2014). The model included random effects for impoundment x year intercepts and fixed effects of treatment, time period, and impoundment surface area, and interactions. The three-way interaction tested whether the effect of the rotenone application differed between large and small surface area impoundments.

Largemouth Bass age-0 length (MLA-0) in the pre-treatment (i.e., day-1) vs. mid-summer follow-up (i.e., day-42) seine samples were compared using a BACI analysis to estimate initial growth differences between control and treatment impoundments. This analysis was modeled with a linear mixed-effects model via maximum likelihood in R (R Core Team 2014) that included independent random effects of impoundment and year intercepts and fixed effects of treatment, time period, surface area, and all interactions. The analysis was performed on the natural logarithm of MLA-0.

Age 1+ Growth, Recruitment, Survival, Size Structure and Condition

The effect of rotenone treatment on mean age-1 Largemouth Bass length (MLA-1) was estimated using a BACI analysis. Mean length-at-age was obtained from otolith-aged subsamples by taking the weighted average length of each age class, weighted by the sample size in each size class (DeVries and Frie 1996). The analysis fit a linear mixed-effects model to these data via maximum likelihood in R (R Core Team 2014) with independent random effects of impoundment and year intercepts and fixed effects of rotenone treatment (once or twice), impoundment surface area, and rotenone treatment x surface area interaction. The rotenone treatment x surface area interaction tested whether the treatment effect differed between large and small impoundments. The analysis was performed on the natural logarithm of Largemouth Bass MLA-1.

I evaluated the effects of rotenone treatment on electrofishing catch-per-unit-effort (CPUE) of age-1 and age-2+ Largemouth Bass, and stock sized Bluegill (i.e., >80 mm) using the natural logarithmic scale for all three dependent variables in a BACI analysis. Age-1 Largemouth Bass CPUE was assessed to indicate treatment effects on recruitment whereas the age-2+ Largemouth Bass and Bluegill CPUE analyses indicated treatment effects on non-target age classes (2+) and species (Bluegill). For each of these three dependent variables, I fit a linear mixed-effects model via maximum likelihood in R (R Core Team 2014) that included independent random effects of impoundment and year intercepts and fixed effects of rotenone treatment, surface area, and rotenone treatment x surface area interaction.

I tested for compensatory age-0 Largemouth Bass survival after rotenone treatment by calculating an index of Largemouth Bass age-0 survival that was calculated by dividing March age-1 electrofishing catch rates by the mid-summer follow-up seine (day-42) catch rates from the previous year. Differences in the survival index between the number of rotenone treatments applied (i.e., no treatment, one year, two years) was tested using a liner model in R (R Core Team 2014) with fixed effects of rotenone treatment and surface area, and interactions.

Body condition of Largemouth Bass and Bluegill was evaluated using relative weight, which was calculated as:

$$Wr = \left(\frac{W}{Ws}\right) * 100$$

where Wr represents the relative weight, W is the weight of the fish (g), and Ws is a length-specific standard weight predicted by a weight-length regression for that individual species (Murphy et al. 1991; Neumann et al. 2012). Largemouth Bass <150 mm and Bluegill <80 mm were left out of these analyses (Neumann et al. 2012). BACI analyses were conducted for each species by fitting a linear mixed-effects model to data via maximum likelihood in R (R Core Team 2014) with random effects of impoundment and year intercepts and fixed effects of rotenone treatment, surface area, and rotenone treatment x surface area interaction. These analyses were fit to the natural logarithms of relative weights.

Proportional size distribution (PSD), described by Anderson (1978), is a simple index to describe the size structure of fish populations (Neumann et al. 2012). PSD is calculated using:

$$PSD = \frac{number\ \geq minimum\ quality\ length}{number\ \geq minumim\ stock\ length} * \ 100$$

PSD is calculated as the proportion of stock-length fish that are also "quality" length (Gabelhouse 1984a; Gabelhouse 1987; Neumann et al. 2012). Preferred proportional size distribution (PSD-P) is another index to describe the size structure of fish populations (Gabelhouse 1984a; Neumann et al. 2012) and can be calculated using:

$$PSD - P = \frac{number\ \geq minimum\ preferred\ length}{number\ \geq minumim\ stock\ length} * \ 100$$

Largemouth Bass and Bluegill size structures were compared among impoundments through years by calculating PSD and PSD-P (for only Largemouth Bass). I fit linear mixed-effects models to data via maximum likelihood in R for each index and species (R Core Team 2014) on the natural logarithmic scale. The BACI models included random effects of impoundment and year intercepts and fixed effects of rotenone treatment, surface area, and rotenone treatment x surface area interaction which indicates if the treatment effect differs with impoundment size.

Diet Composition

I investigated the effect of rotenone treatment on the probability of occurrence of fish in the diets of Largemouth Bass. I analyzed the frequency of Largemouth Bass ≤250 mm (i.e., 180–250 mm) and >250 mm (i.e., 251–353 mm) containing fish in their diets by using a generalized linear mixed-effects model via binomial family in R (R Core Team 2014). I conducted separate analyses for diets collected from spring and summer electrofishing samples. Within models for spring, I included random effects of impoundment and year intercepts and fixed effects of rotenone treatment and surface area and a rotenone treatment x surface area interaction. Models for summer did not include a year random effect.

Results

Age-0 Relative Abundance and Mean Length

Impoundment surface area and its associated interactions were not significant predictors of the immediate (i.e., 24-hours post-treatment) effect of rotenone treatment on Largemouth Bass seine haul catch per impoundment ($F_{1,72}$=0.12, p=0.74). In addition, the three-way treatment x time period x application interaction was not significant showing that before vs. after (i.e., time period) differences in the responses of treated and control impoundments were similar between the first and second rotenone applications ($F_{1,78}$=0.87, p=0.38). I observed a significant treatment x time period interaction indicating that treatment impoundments experienced an additional 94% (87–97%; ±95% CI) reduction in Largemouth Bass seine catch per impoundment after rotenone applications compared with controls ($F_{1,82}$=51.70, p<0.001; Figure 4). Bluegill seine haul catch per impoundment was unrelated to impoundment surface area and its associated interactions ($F_{1,72}$=0.0025, p=0.96). Furthermore, the three-way treatment x time period x application interaction was not significant showing that before vs. after differences in the responses of treated and control impoundments were similar between the two rotenone applications ($F_{1,78}$=0.92, p=0.34). I observed a significant treatment x time period interaction due to treatment impoundments experiencing an additional 60% (1–78%; ±95% CI) reduction in Bluegill seine catch per impoundment after rotenone applications compared with controls ($F_{1,82}$=10.41, p=0.001; Figure 5).

The analysis of pre-treatment (i.e., day-1) vs. the mid-summer follow-up (i.e., day-42) seine catch rates indicated that there were no significant effects of impoundment surface area and its associated interactions on Largemouth Bass catch per impoundment ($F_{1,24}$=0.22, p=0.65). Catch rates were similar initially in treatment and control impoundments ($F_{1,26}$=5.91, p=0.92) but by day 42 had declined by 74% (44–88%; ±95% CI; $F_{1,26}$=62.15, p<0.001) in control impoundments and 95% (88–98%; $F_{1,26}$=62.15, p<0.001) in treatment impoundments. The treatment x time period interaction was significant ($F_{1,26}$=8.59, p=0.006; Figure 6) and represented an additional 79% (36–93%; ±95% CI) post-treatment decrease in seine catch per impoundment in treated impoundments compared with the controls. Changes in Bluegill catch rates from day-1 to day-42 were unrelated to impoundment surface area ($F_{1,24}$=0.62, p=0.44), and the treatment x time period interaction was not significant demonstrating Bluegill catch rates were not impacted by the rotenone treatment over this time period ($F_{1,26}$=0.11, p=0.75). Baseline (i.e., pre-treatment) Bluegill catch rates were higher in treatment impoundments than in controls ($F_{1,26}$=14.90, p<0.001) but did not change over time in both impoundment types ($F_{1,27}$=0.63, p=0.43; Figure 7).

Largemouth Bass mean age-0 length was unrelated to surface area ($F_{1,27}$=0.18, p=0.68). The treatment x time period interaction was not significant ($F_{1,31}$=0.83, p=0.83) demonstrating that density-dependent responses in age-0 growth were not evident by mid-summer after two rotenone applications (Figure 8). Largemouth Bass MLA-0 on day-42 in the treatments was 63 mm (51–76 mm; ±95% CI) and in the controls was 58 mm (48–71 mm; ±95% CI). However, due to low abundance in treated impoundments, I was unable to capture age-0 Largemouth Bass at six of the treated impoundments; thus no length observations were available from a substantial proportion of treated impoundments.

Age 1+ Growth, Recruitment, Survival, Size Structure and Condition

Mean age-1 Largemouth Bass length was significantly related to rotenone treatment ($F_{2,25}$=15.23, p<0.001) and marginally significant to impoundment surface area ($F_{2,31}$=2.52, p=0.10). Mean age-1 Largemouth Bass length in treated impoundments was 21% (12–32%; ±95% CI) larger than in controls after one summer of rotenone application ($F_{2,34}$=15.23, p<0.001) and 27% (13–42%; ±95% CI) larger after 2 years of applications ($F_{2,22}$=15.23, p<0.001), but the different treatments (i.e., one or two years) were not dissimilar from one another ($F_{2,33}$=15.23, p=0.49). The treatment x surface area interaction was marginally significant ($F_{2,31}$=2.52, p=0.10), which provided some evidence that the treatments were less effective in large impoundments (Figure 9).

Age-1 Largemouth Bass CPUE was significantly higher in large impoundments ($F_{1,48}$=21.18, p<0.001) and there was a significant rotenone treatment effect ($F_{2,41}$=11.37,

$p<0.001$; Figure 10). The treatment x surface area interaction was marginally significant ($F_{2,48}=2.71$, $p=0.080$) and the time series plots (e.g., Figure 10) revealed that CPUE did not decline substantially in large impoundments whereas small impoundments exhibited reductions (Figure 10). Largemouth Bass age-1 CPUE was 80% (59–90%; ±95% CI) lower than controls after a single rotenone treatment ($F_{2,42}=11.37$, $p<0.001$) and 73% (26–90%; ±95% CI) lower than controls after a second treatment ($F_{2,42}=11.37$, $p=0.015$) in all impoundments. Rotenone treatments (i.e., one or two years) were not significantly different from one another ($F_{2,36}=11.37$, $p=0.64$). Age-2+ Largemouth Bass CPUE was 223% (30–700%; ±95% CI) greater in large impoundments ($F_{1,19}=6.39$, $p=0.020$) but was marginally related to rotenone treatment ($F_{2,36}=2.48$, $p=0.10$). The surface area x rotenone treatment interaction was marginally significant ($F_{2,41}=2.96$, $p=0.063$) and Figure 11 revealed that CPUE declined in small impoundments whereas large impoundments exhibited declines only after the second year of treatment. Bluegill CPUE (>80 mm) was unrelated to rotenone treatment ($F_{2,37}=2.39$, $p=0.11$), impoundment surface area ($F_{1,18}=2.50$, $p=0.13$), or their interaction ($F_{2,35}=2.24$, $p=0.33$; Figure 12). The Largemouth Bass age-0 survival index was not significantly related to impoundment surface area ($F_{1,24}=0.47$, $p=0.50$) or rotenone treatment ($F_{2,25}=1.31$, $p=0.23$), which indicated a lack of compensatory survival following rotenone treatment.

Largemouth Bass relative weight was affected by rotenone treatment ($F_{2,44}=5.18$, $p=0.0095$) but not by impoundment size ($F_{2,46}=0.77$, $p=0.47$; Figure 13). Pre-treatment relative weights were 5% (2–9%; ±95% CI) greater in large impoundments ($F_{1,47}=7.85$, $p=0.0074$) when compared with small-sized impoundments. Impoundments treated once had a 7% (3–11%; ±95% CI) greater mean relative weight after treatment than the controls and this difference was significant ($F_{2,47}=5.18$, $p=0.0024$); however, after two consecutive treatments, Largemouth Bass relative weights were not significantly different than controls ($F_{2,48}$=5.18, p=0.28) nor single treatments ($F_{2,39}$=5.18, p=0.35; Figure 13). Rotenone treatment ($F_{2,29}$=0.53, p=0.60), impoundment surface area ($F_{1,20}$=0.39, p=0.54), and their interaction ($F_{2,38}$=0.83, p=0.45) were not statistically significant predictors of Bluegill relative weight (Figure 14).

Largemouth Bass PSD was 73% (2–193%; ±95% CI) higher in large vs. small impoundments ($F_{2,44}$=0.89, p=0.42), but was not related to rotenone treatment ($F_{2,44}$=2.40, p=0.10) or to its interaction with impoundment surface area ($F_{2,44}$=0.89, p=0.42; Figure 15). Largemouth Bass PSD was 16 (12–22; ±95% CI) in small impoundment controls vs. 28 (17–46; ±95% CI) in large impoundment controls (Figure 15). Largemouth Bass PSD-P was unrelated to rotenone treatment ($F_{2,43}$=2.75, p=0.080), surface area ($F_{1,15}$=2.02, p=0.17), and their interaction ($F_{2,35}$=1.12, p=0.34; Figure 16). Bluegill PSD was significantly related to rotenone treatment ($F_{2,48}$=22.21, p<0.001), but was unrelated to surface area ($F_{1,48}$=0.054, p=0.82) and their interaction ($F_{2,47}$=0.16, p=0.85; Figure 17). Bluegill PSDs were 88% (3–242%; ±95% CI) greater after one treatment compared to controls ($F_{2,48}$=22.21, p=0.044). However, Bluegill PSDs declined by 93% (83–97%; ±95% CI) after two consecutive treatment years ($F_{2,46}$=22.21, p<0.001).

Diet Composition

The proportion of Largemouth Bass ≤250 mm diets containing fish during spring sampling was unrelated to surface area ($F_{1,12}$=3.80, p=0.051), rotenone treatment ($F_{1,13}$=1.20, p=0.26), or their interaction ($F_{1,12}$=0.52, p=0.47). For Largemouth Bass >250 mm, the proportion of diets containing fish was significantly greater after one treatment ($F_{2,32}$=15.85, p<0.001) and significantly lower after two years of treatment ($F_{2,32}$=15.85, p<0.001), but surface area ($F_{1,31}$=2.21, p=0.14) and the surface area x treatment interaction ($F_{2,29}$=0.0082, p=0.91) were not significant (Figure 18).

The proportions of Largemouth Bass ≤250 mm diets containing fish during summer could not be analyzed because no Largemouth Bass of that size range were collected from treated impoundments after rotenone application (i.e., I had nothing to compare vs. controls). For Largemouth Bass >250 mm during summer, the proportion of diets containing fish was unrelated to rotenone treatment ($F_{1,14}$=1.24, p=0.27), surface area ($F_{1,13}$=0.049, p=0.83), or their interaction ($F_{1,12}$=0.82, p=0.37).

Discussion

Understanding responses of Bluegill and age-0 Largemouth Bass after summer shoreline rotenone application is critical to determining the effectiveness of this approach. Long-term success of Largemouth Bass populations, along with other species, are influenced by mechanisms related to individual size and population density during early life stages (May 1974; Houde 1987, 1989; Townsend 1989; Swingle and Swingle 1989; Feminella and Resh 1990; Louda et al. 1990; Mitzner 1991; Tonn et al. 1994; Ludsin and DeVries 1997; Pine et al. 2000) which this application directly affects. In my study, seine haul catch rates of Bluegill and age-0 Largemouth Bass in treatment impoundments declined significantly 24-hours after rotenone applications while those in controls did not change significantly, similar to observations made by McHugh (1990) following marginal rotenone application at Fayette and Lamar County Lakes in Alabama. Bluegill seine haul catch per impoundment did not change significantly from day-1 to day-42 in both controls and treatments. This is most likely due to the fact that Bluegill spawn additional times during summer (Cargnelli and Neff 2006; Bartlett et al. 2010) minimizing the overall rotenone treatment effect. In contrast, age-0 Largemouth Bass catch rates declined in both control and treated impoundments by mid-summer (i.e., day-42), but declines were significantly greater in the treatments. It is likely that the decline in age-0 Largemouth Bass catch rates by day-42 was at least partially attributable to reduced vulnerability of larger individual fishes to capture (Jackson and Noble 1995; Willis and Murphy 1996; Garvey and Stein 1998; Pine et al. 2000; Reynolds and Kolz 2012). In addition, natural mortality of age-0 Largemouth Bass is likely high during this period, which would also contribute to reduced seine catches. Bluegill seine catch per impoundment was probably less affected by temporal changes in vulnerability because of their slower growth (in comparison to Largemouth Bass) combined with multiple spawning events by Bluegill (which may have offset losses due to natural and rotenone application mortality).

Largemouth Bass recruitment to age-1 was significantly lower in treatment impoundments, as was the case with age-0 fish the previous summer. These reductions were more pronounced in impoundments with small surface area but were less clear in large sized impoundments. Larger impoundments tended to have more complex littoral habitats (e.g., structure, depths, islands, fingers) that may have affected the efficiency of the rotenone treatment by providing temporary refuge for young-of-year Largemouth Bass. Moreover, these complex littoral habitats such as thick emergent vegetation, shallow backwaters, and overhanging terrestrial vegetation made it more difficult to achieve good rotenone spray coverage. Sampling variation may have also played a role in the larger impoundments. Electrofishing covered nearly the entire shoreline of some of the small-sized impoundments, but in larger impoundments electrofishing only covered a small percentage of the shoreline, which could lead to more variable catchability depending on the distribution of habitat patches containing Largemouth Bass in large impoundments.

It has been reported that small age-0 Largemouth Bass have high overwinter mortality rates in southeastern U.S water bodies leading to a survival bottleneck (Aggus and Elliot 1975; Miranda and Hubbard 1994; Ludsin and DeVries 1997). There could also be a cumulative interaction between multiple abiotic and biotic factors (e.g., water temperature, water level, predation, starvation) that lead to recruitment failure or low survival to older ages (Kramer and Smith 1962; Busch et al. 1975; Clady 1976; Houde 1987; Rice et al. 1987; Freeberg et al. 1990; Reinert et al. 1997; Ludsin and DeVries 1997; Mion et al. 1998; Garvey et al. 1998; Pine et al. 2000). Survival bottlenecks can lead to compensatory density-dependent survival, which could offset density reductions due to rotenone treatment. My survival index analysis showed no compensatory density-dependent survival response due to rotenone treatment, suggesting that overwinter survival bottlenecks may be weaker in these impoundments than in other systems (Garvey et al. 1998; Fullerton et al. 2000; Garvey et al. 2000). Another possibility is that the survival index was too imprecise to detect compensatory survival given that it was constructed as the quotient of two independently noisy observations – electrofishing CPUE (Hangsleben et al. 2013) and seine CPUE (Pine et al. 2000). Therefore, it is plausible that high sampling variation may have confounded detection of changes in survival.

Density-dependent growth refers to a negative relationship between growth and population density such that increased population density results in reducing individual consumption rates due to intraspecific competition for prey resources (Rose et al. 2001; Heath 1992). The reduced age-0 Largemouth Bass densities following rotenone treatment in my study provided an opportunity to test for density-dependent growth. I found that mean age-1 length increased in treated impoundments, particularly in those impoundments with small surface area. McHugh (1990) found similar results from marginal rotenone application during the summer combined with spring electrofishing Largemouth Bass removal where the mean length of age-3 fish before treatment were comparable to age-2 fish after treatment. Beckman (1941) also concluded that age-1 Rock Bass *Ambloplites rupestris* grew faster due to a rotenone application density reduction of the population, which agrees with my findings. I observed weaker growth responses in large-sized impoundments which was consistent with weaker density reductions at those impoundments. More study is needed to more definitively assess the differences in growth responses as a function of impoundment size following rotenone treatment. Although age-1 mean Largemouth Bass length increased following rotenone treatment, I found no effect on age-0 mean length in mid-summer seine hauls. I speculate that size selective sampling bias of the seines against collection of larger age-0 fish may have masked treatment effects, or perhaps density-dependent growth responses would require more time for cumulative growth differences to emerge. Another important caveat of this finding is that no age-0 Largemouth Bass were captured in mid-summer seine hauls at six of the treated impoundments. Thus, the mean length samples may not have been representative because they were obtained from only a subset of the treated impoundments.

Considering the increases in mean age-1 length after rotenone treatment, I expected corresponding increases in relative weight to reflect improvements in body condition. Largemouth Bass relative weight increased following density reduction, but these increases were small (<10%). Schindler et al. (1997) found a negative correlation between Largemouth Bass body condition and population size, which is consistent with our results showing post-treatment increases in relative weight. No treatment effect on Bluegill relative weight in impoundments during spring electrofishing years was observed. Similar to Bluegill CPUE, the treatment effect may be masked by natural variation in Bluegill reproduction and overwinter survival.

Despite rotenone treatment effects on mean length and relative weight observed in Largemouth Bass, neither PSD nor PSD-P were significantly influenced by rotenone application. Results of McHugh (1990) showed that Largemouth Bass PSD increased after treatment and electrofishing; although, his two impoundments were large and contained crappie populations. According to Bennett's (1970) classification, Largemouth PSD would have ranged from poor to average condition before and after my rotenone applications (Neumann et al. 2012). Bluegill PSD from electrofishing in spring of 2017 through 2019 after one treatment was much higher than controls and PSD after two treatments was lower than controls. Sample size is important when assessing fish populations using PSD (Willis et al. 1993; Neumann 2012). My samples for PSD-P of Largemouth Bass contained 37% zeros due to lack of preferred length fish captures.

It is well known that prey availability and suitable prey size both affect growth in fishes (Kimsey 1958; Applegate et al. 1967; Aggus and Elliott 1975; Rainwater and Houser 1975; Jenkins and Morais 1978; Shelton et al. 1979). With less intraspecific competition and large numbers of juvenile Bluegill still present after treatment, prey availability for Largemouth Bass should be great. Largemouth Bass growth increased due to treatment (discussed above); therefore, I expected to observe greater proportions of Largemouth Bass consuming fishes after treatment. Wet weight energy values (j/g) of fish prey for Largemouth Bass is nearly 500 j/g higher than more common diet items (Leonard 2008). However, proportions of Largemouth Bass >250 mm in the summer and ≤250 mm in both spring and summer containing a fish item (e.g., otolith, spine, carcass) in diets did not differ between controls and treatments. This is not uncommon as Schindler et al. (1997) observed adult Largemouth Bass diet composition did not change as bass density increased greater than threefold. The proportion of Largemouth Bass >250 mm diets containing fish in spring did increase after a single rotenone treatment but was not significantly different from controls after two treatments. Thus, the effects of rotenone application on Largemouth Bass diets remains unclear and needs further investigation.

An important consideration associated with selective application of rotenone is potential effect on non-target species and/or life stages of fish. Largemouth Bass age-2+ spring electrofishing CPUE was not impacted by the shoreline rotenone application. This finding indicates that shoreline application of rotenone in early to mid-summer may be selective for age-0 fish thereby minimizing negative effects on older age classes of Largemouth Bass (Wildhaber and Neill 1992). Avoiding high rotenone-related mortality of age 2+ Largemouth Bass would be a desirable feature of this method so that recruitment can be controlled without reducing the abundance of catchable sized fish. McHugh (1990) reported small numbers of non-target fishes (e.g., larger Bluegill and Largemouth Bass, Grass Carp *Ctenopharyngodon idella*) were killed after shoreline rotenone treatment. However, no attempt was made to quantify these numbers directly after treatment. I reported no treatment effect on Bluegill CPUE in spring electrofishing samples. This could be due to natural variation in Bluegill reproduction and overwinter survival that could offset or obscure treatment effects. It is well known that Bluegill transition from littoral and pelagic zones of impoundments as they grow older (Werner and Hall 1988). When Bluegill fry move from the pelagic into the littoral zone, they become vulnerable to shoreline rotenone application like age-0 Largemouth Bass. However, adult Bluegill can spawn multiple times throughout the summer and fry have different "swim-up" (i.e., transition from pelagic to littoral zone) dates. Therefore, my treatment coule have missed a considerable amount of Bluegill fry in the environment, agreeing with my seine haul catch rates.

Management Implications

Shoreline rotenone application appears to reduce recruitment of Largemouth Bass in small impoundments, but the efficacy of the approach may depend on the size of the small impoundment. This application improved Largemouth Bass growth rates and body condition while not impacting Bluegill population dynamics in Alabama small impoundments. These improvements were evident after one year of rotenone application, but an additional year of rotenone application resulted in no further improvements. Large impoundments seemed to be less affected by treatment (e.g., MLA-1, Bluegill electrofishing CPUE); however, light inference can be made due to small sample sizes of large treatment impoundments (N = 3 for one year of treatment; N = 1 for consecutive treatments). This type of application seems to best suit smaller small impoundments with Largemouth Bass and Bluegill (and possibly other *Lepomis* spp.) communities to limit interspecific interactions and competition (McHugh 1990). McHugh (1990) found that his impoundments that had been impacted by shoreline rotenone and electrofishing fish removal began to return to their pre-impact state a few years after impact, and for this reason the application may need to be repeated every 2–4 years. Future studies could evaluate the effect of shoreline rotenone application interval on Largemouth Bass and Bluegill population responses.

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Table 1.

The impoundments sampled along with surface area (ha), the years in which spring electrofished occurred, and the years in which shoreline rotenone was applied, if any (i.e., "CONTROL").

Impoundment	Size (ha)	Year Electrofished	Year Treated
Lee County Lake	48	2017, 2018	CONTROL
Anderson	2.8	2017, 2018	CONTROL
Barbour County Lake	34	2017, 2018	2017
Washington County Lake	38	2017, 2018	2017
Dale County Lake	36	2017, 2018, 2019	CONTROL
AE1	1.6	2017, 2018, 2019	CONTROL
Big Pit	11	2017, 2018, 2019	CONTROL
FP3	0.7	2017, 2018, 2019	CONTROL
Monroe County Lake	34	2017, 2018, 2019	2017, 2018
Little Pit	4	2017, 2018, 2019	2017, 2018
S3	4	2017, 2018, 2019	2017, 2018
Horseshoe	1.3	2017, 2018, 2019	2017, 2018
Drummond3	8.8	2018, 2019	CONTROL
Meriwether	3.4	2018, 2019	CONTROL
Williams	3.3	2018, 2019	CONTROL
Promise	1.9	2018, 2019	CONTROL
Drummond1	8.7	2018, 2019	2018
Britton	2.2	2018, 2019	2018
Zachry	5.3	2018, 2019	2018
Dead	2.2	2018, 2019	2018

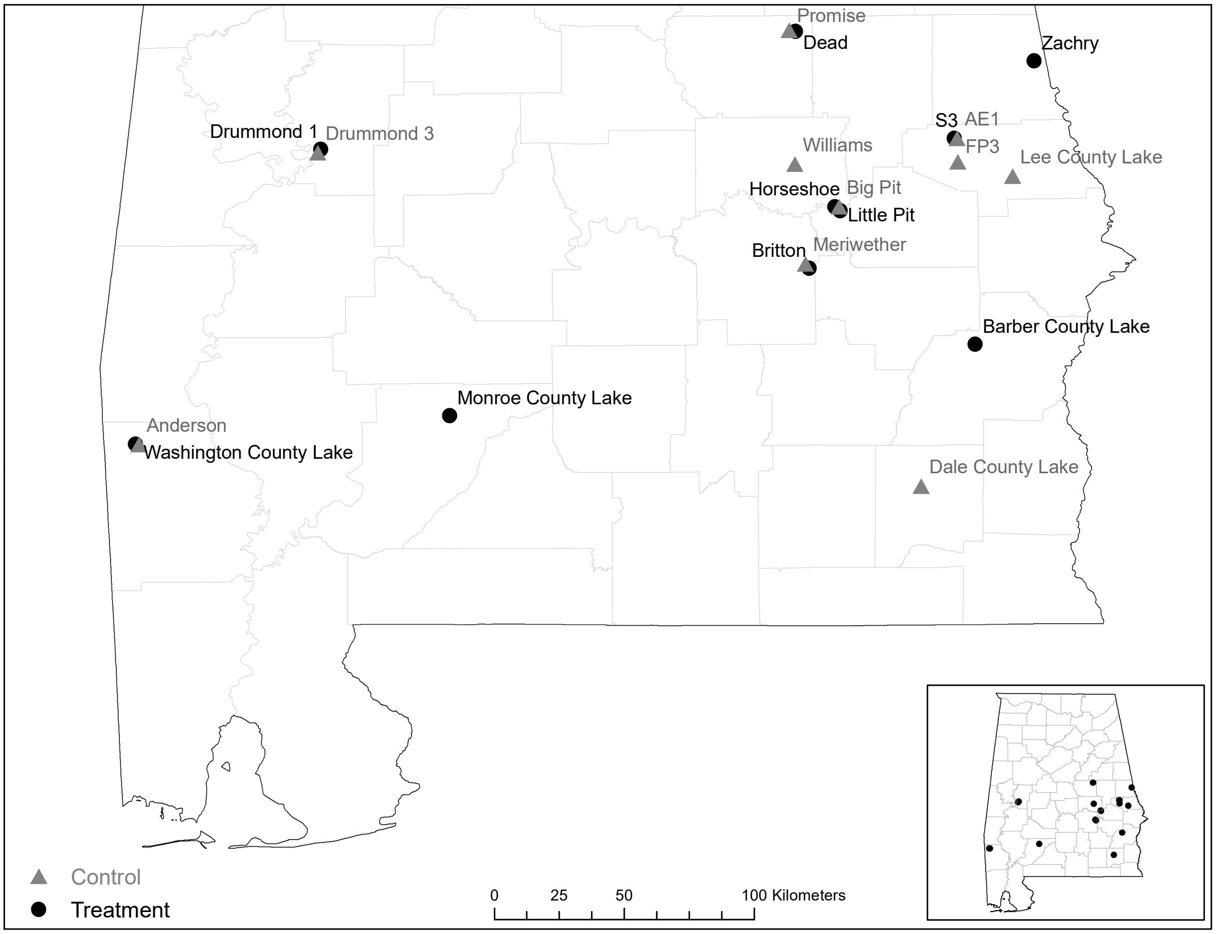

Figure 1.

Map of study small impoundments. Controls are grey triangles, treatments are black circles.

Figure 2.

Shoreline application of rotenone via simultaneous surface spray (surface wand left) and multi-port subsurface injection (subsurface injector right).

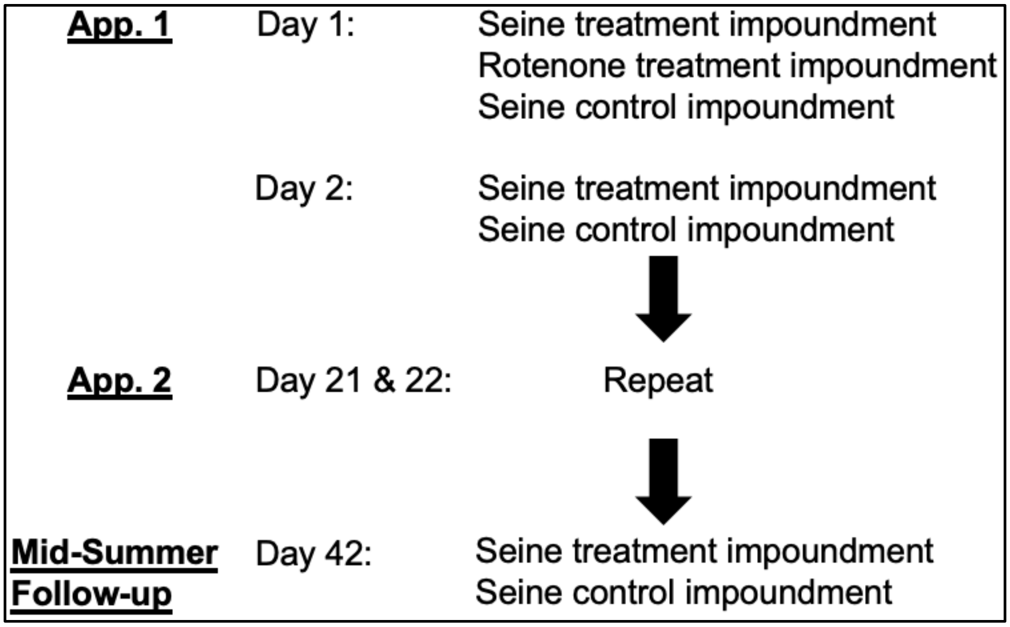

Figure 3.

Overview of summer 2017 and 2018 seining schedule (day-1, -2, -21, -22, -42) and rotenone applications (App. 1 and App. 2).

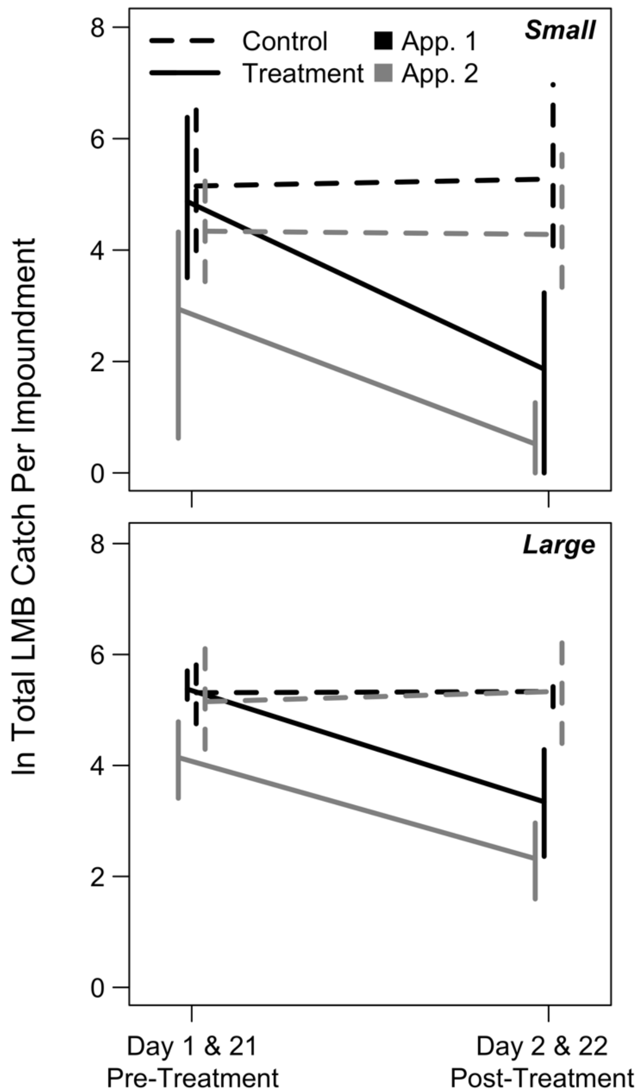

Figure 4.

Largemouth Bass $\log_e$ total seine catch immediately before (days 1 and 22) and after (days 2 and 23) the first (app. 1, black lines) and second (app. 2, grey lines) shoreline rotenone applications in impoundments with small (<12 ha; upper panel) and large (>33 ha; lower panel) surface area (ha). Solid lines denote treated impoundments and dashed lines denote controls. The observations were pooled across years (2017 and 2018) and the error bars represent the 10th and 90th percentiles of data.

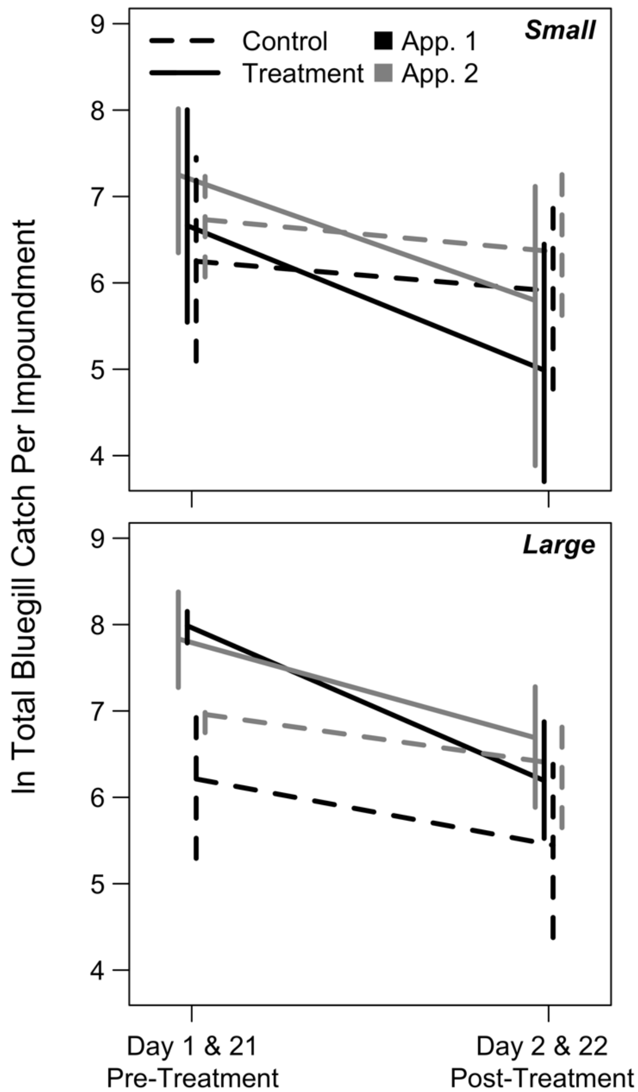

Figure 5.

Bluegill $\log_e$ total seine catch immediately before (days 1and 22) and after (days 2 and 23) the first (app. 1, black lines) and second (app. 2, grey lines) shoreline rotenone applications in impoundments with small (<12 ha; upper panel) and large (>33 ha; lower panel) surface area (ha). Solid lines denote treated impoundments and dashed lines denote controls. The observations were pooled across years (2017 and 2018) and the error bars represent the 10^{th} and 90^{th} percentiles of data.

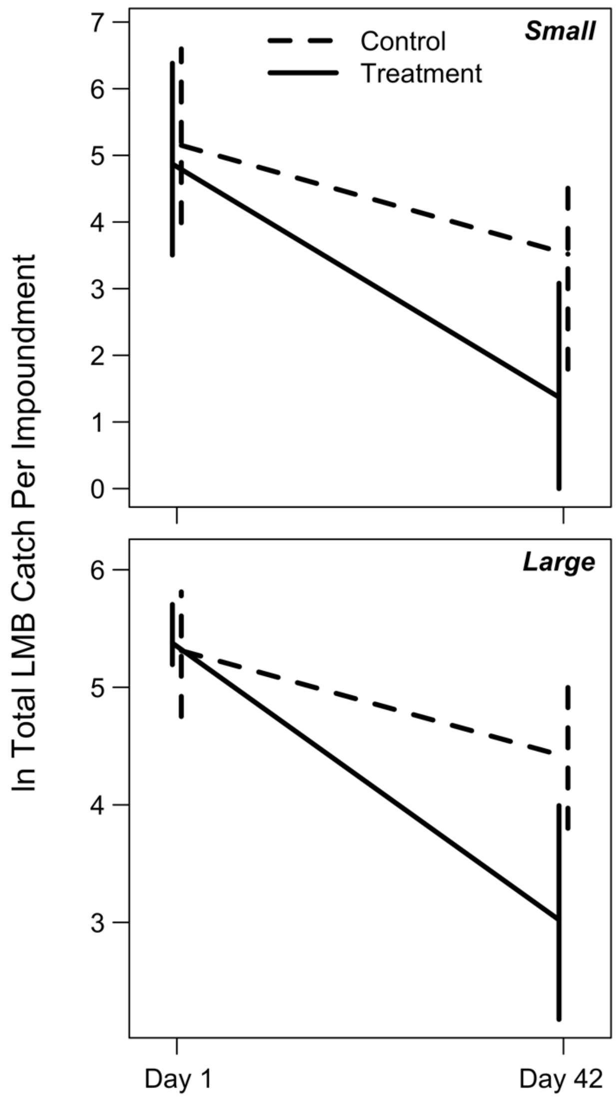

Figure 6.

Largemouth Bass $\log_e$ total seine catch in impoundments of small (<12 ha; upper panel) and large (>33 ha; lower panel) surface area immediately before (day 1) rotenone application and at mid-summer (day-42) after both rotenone applications in 2017 and 2018. Solid lines denote impoundments that received shoreline rotenone treatments and the dashed lines denote controls. The data were pooled across years and error bars represent the 10th and 90th percentiles of data.

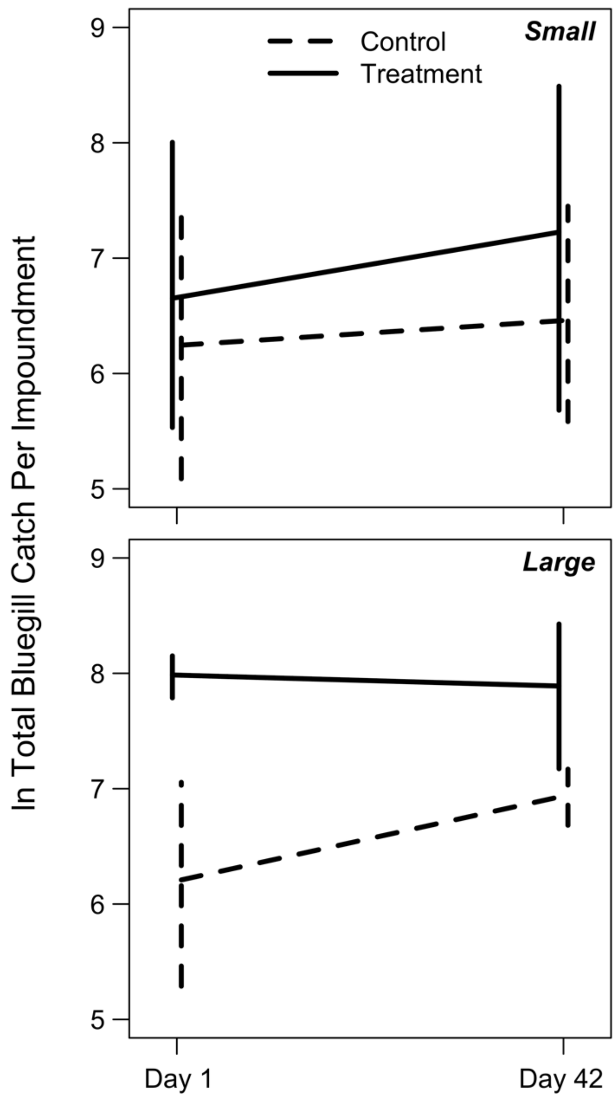

Figure 7.

Bluegill $\log_e$ total seine catch in impoundments of small (<12 ha; upper panel) and large (>33 ha; lower panel) surface area immediately before (day 1) rotenone application and at mid-summer (day-42) after both rotenone applications in 2017 and 2018. Solid lines denote impoundments that received shoreline rotenone treatments and the dashed lines denote controls. The data were pooled across years and error bars represent the 10^{th} and 90^{th} percentiles of data.

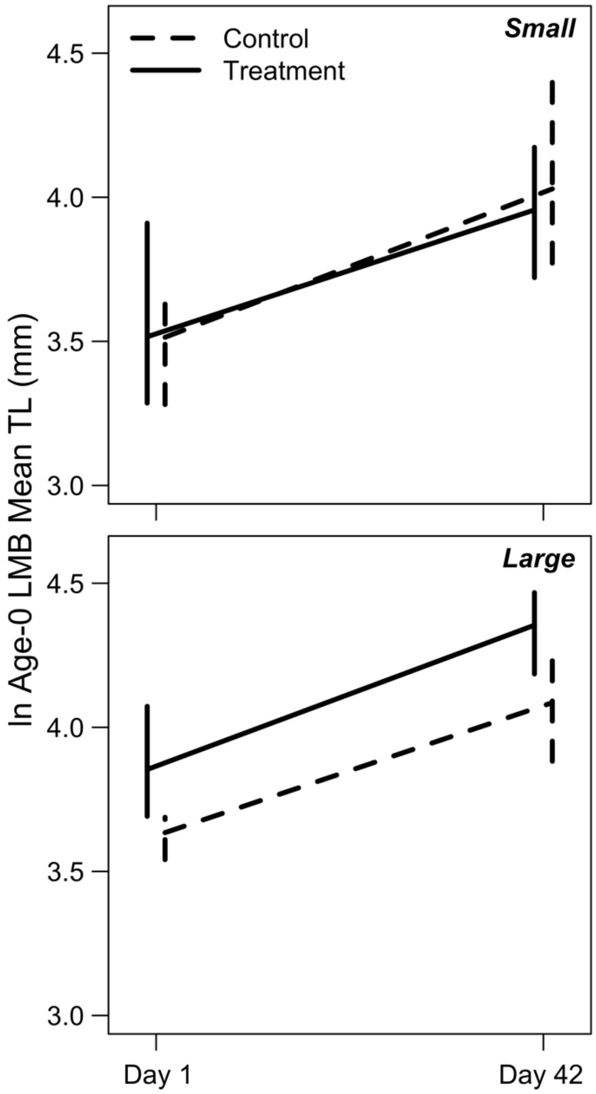

Figure 8.

Largemouth Bass $\log_e$ mean age-0 total length (mm) in impoundments of small (<12 ha; upper panel) and large (>33 ha; lower panel) surface area immediately before (day 1) rotenone application and at mid-summer (day-42) after both rotenone applications in 2017 and 2018. Solid lines denote impoundments that received shoreline rotenone treatments and the dashed lines denote controls. The data were pooled across years and error bars represent the 10th and 90th percentiles of data.

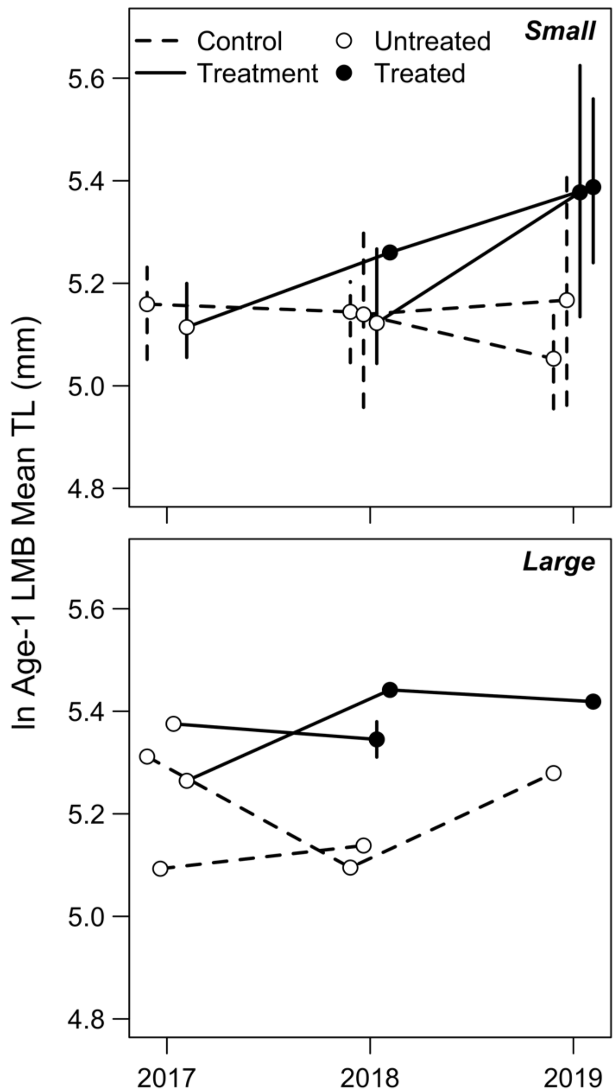

Figure 9.

Largemouth Bass $\log_e$ mean age-1 total length (mm) from annual spring 2017-2019 electrofishing in impoundments of small (<12 ha; upper panel) and large (>33 ha; lower panel) surface area. Solid lines represent impoundments that received shoreline rotenone applications and dashed lines represent controls. Open circles indicate that the impoundment did not receive rotenone treatment the previous summer, whereas closed circles denote prior year rotenone treatment. Multiple lines of the same type indicate groups of impoundments with different years of entry into or exit out of the study. Error bars represent the 2.5th and 97.5th percentiles of data.

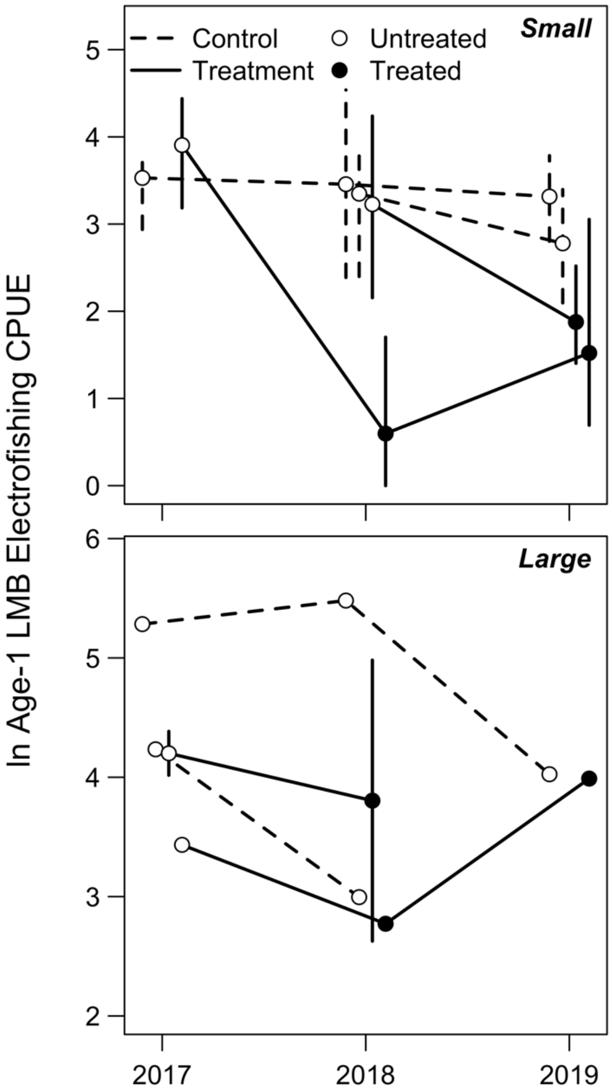

Figure 10.

Largemouth Bass $\log_e$ age-1 CPUE from annual spring 2017-2019 electrofishing in impoundments of small (<12 ha; upper panel) and large (>33 ha; lower panel) surface area. Solid lines represent impoundments that received shoreline rotenone applications and dashed lines represent controls. Open circles indicate that the impoundment did not receive rotenone treatment the previous summer, whereas closed circles denote prior year rotenone treatment. Multiple lines of the same type indicate groups of impoundments with different years of entry into or exit out of the study. Error bars represent the 2.5th and 97.5th percentiles of data.

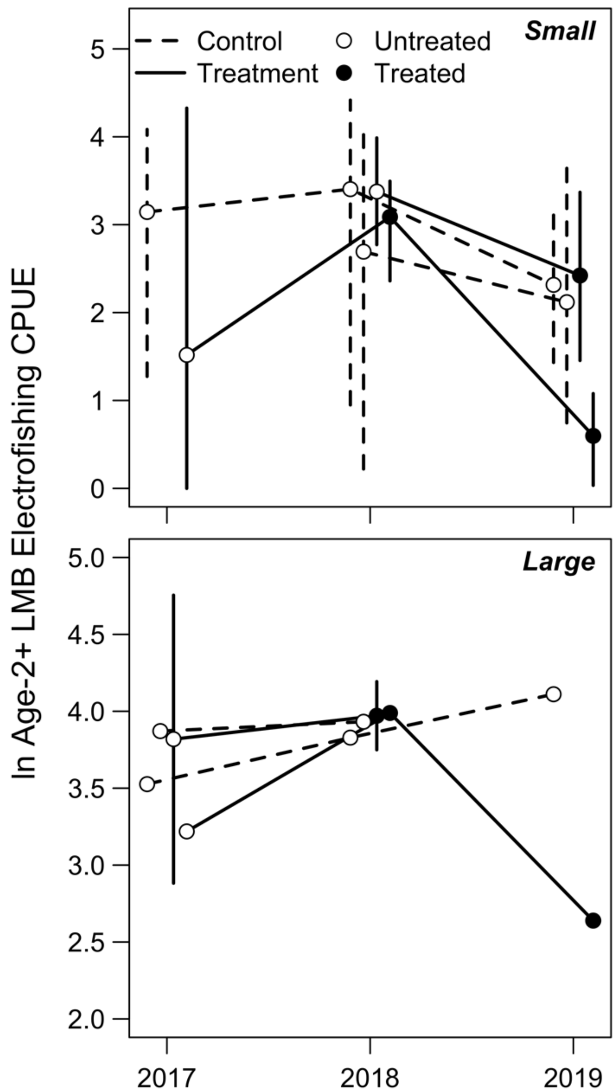

Figure 11.

Largemouth Bass $\log_e$ age-2+ CPUE from annual spring 2017-2019 electrofishing in impoundments of small (<12 ha; upper panel) and large (>33 ha; lower panel) surface area. Solid lines represent impoundments that received shoreline rotenone applications and dashed lines represent controls. Open circles indicate that the impoundment did not receive rotenone treatment the previous summer, whereas closed circles denote prior year rotenone treatment. Multiple lines of the same type indicate groups of impoundments with different years of entry into or exit out of the study. Error bars represent the 2.5th and 97.5th percentiles of data.

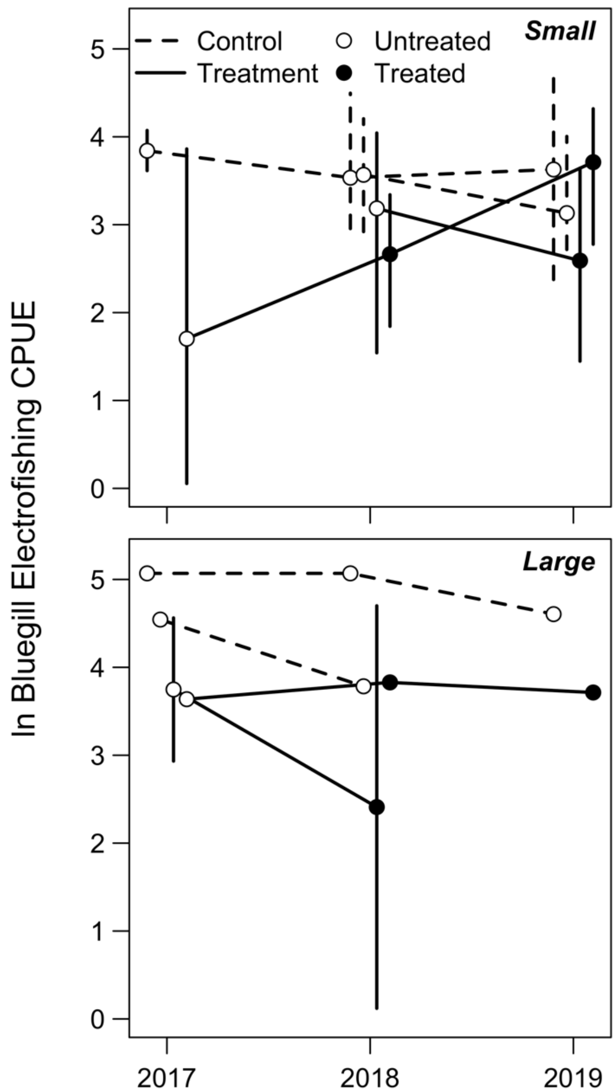

Figure 12.

Bluegill $\log_e$ CPUE from annual spring 2017-2019 electrofishing in impoundments of small (<12 ha; upper panel) and large (>33 ha; lower panel) surface area. Solid lines represent impoundments that received shoreline rotenone applications and dashed lines represent controls. Open circles indicate that the impoundment did not receive rotenone treatment the previous summer, whereas closed circles denote prior year rotenone treatment. Multiple lines of the same type indicate groups of impoundments with different years of entry into or exit out of the study. Error bars represent the 2.5th and 97.5th percentiles of data.

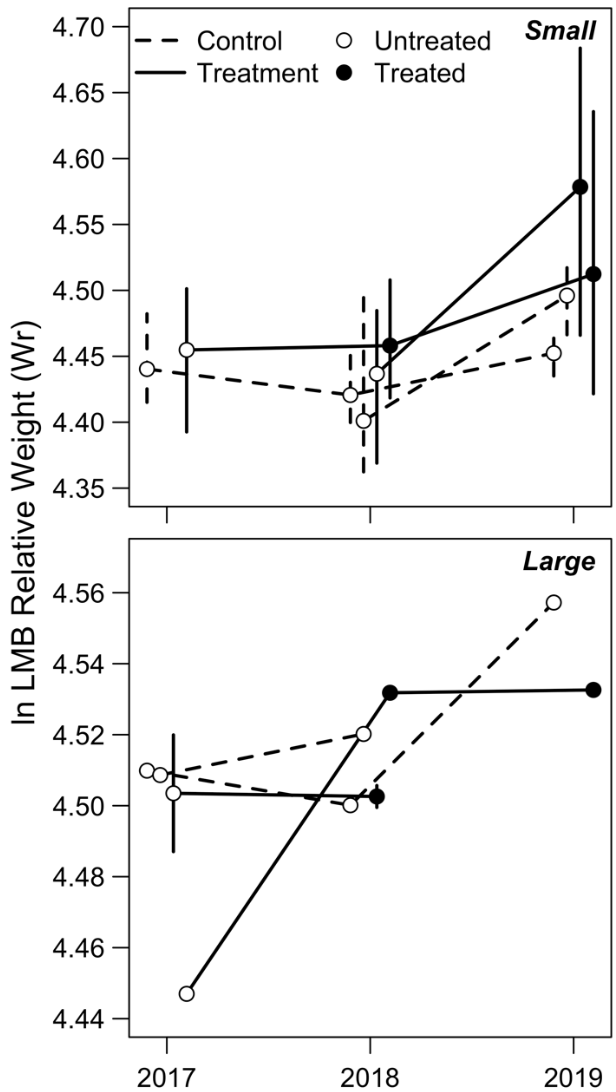

Figure 13.

Largemouth Bass $\log_e$ relative weight from annual spring 2017-2019 electrofishing in impoundments of small (<12 ha; upper panel) and large (>33 ha; lower panel) surface area. Solid lines represent impoundments that received shoreline rotenone applications and dashed lines represent controls. Open circles indicate that the impoundment did not receive rotenone treatment the previous summer, whereas closed circles denote prior year rotenone treatment. Multiple lines of the same type indicate groups of impoundments with different years of entry into or exit out of the study. Error bars represent the 2.5th and 97.5th percentiles of data.

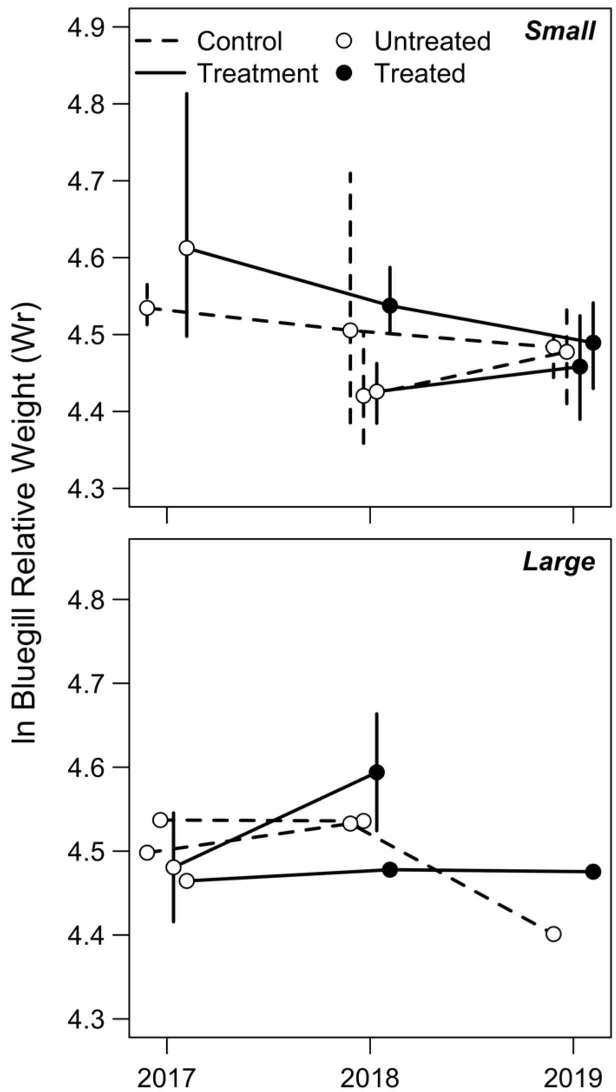

Figure 14.

Bluegill $\log_e$ relative weight from annual spring 2017-2019 electrofishing in impoundments of small (<12 ha; upper panel) and large (>33 ha; lower panel) surface area. Solid lines represent impoundments that received shoreline rotenone applications and dashed lines represent controls. Open circles indicate that the impoundment did not receive rotenone treatment the previous summer, whereas closed circles denote prior year rotenone treatment. Multiple lines of the same type indicate groups of impoundments with different years of entry into or exit out of the study. Error bars represent the 2.5th and 97.5th percentiles of data.

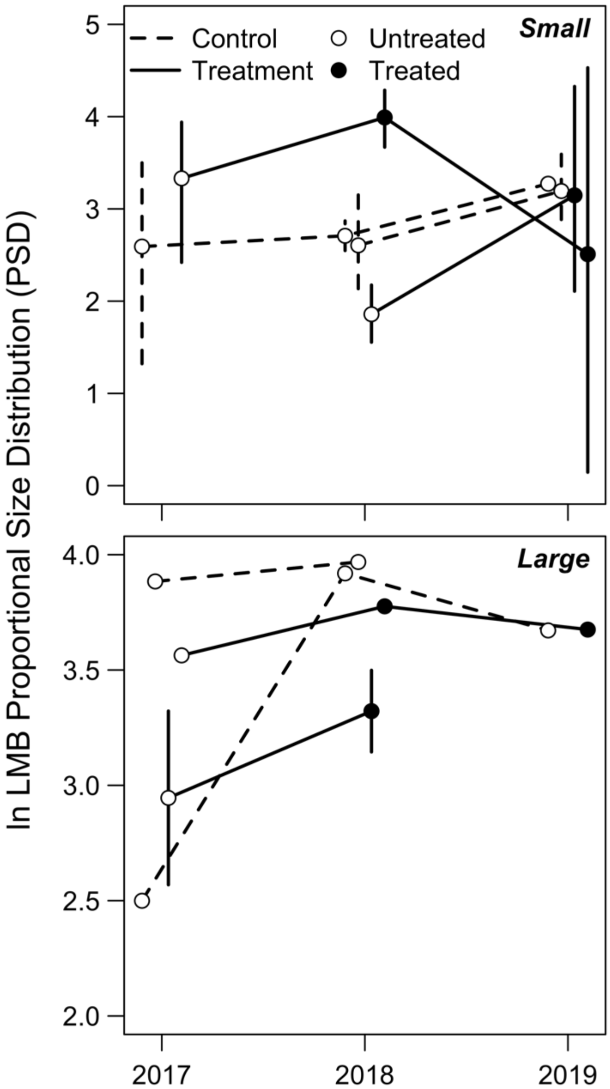

Figure 15.

Largemouth Bass $\log_e$ PSD from annual spring 2017-2019 electrofishing in impoundments of small (<12 ha; upper panel) and large (>33 ha; lower panel) surface area. Solid lines represent impoundments that received shoreline rotenone applications and dashed lines represent controls. Open circles indicate that the impoundment did not receive rotenone treatment the previous summer, whereas closed circles denote prior year rotenone treatment. Multiple lines of the same type indicate groups of impoundments with different years of entry into or exit out of the study. Error bars represent the 2.5th and 97.5th percentiles of data.

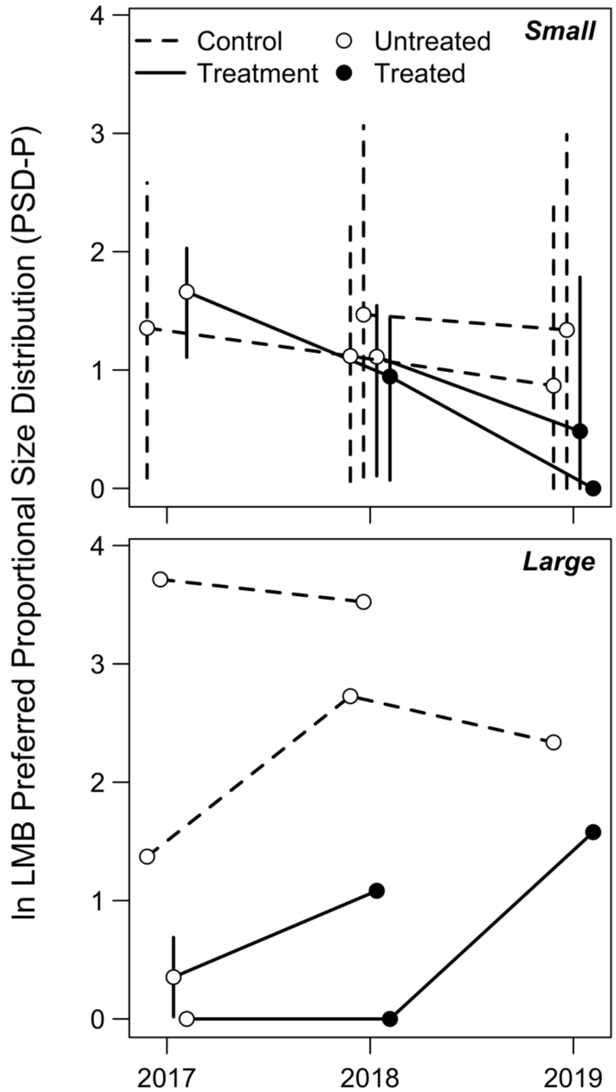

Figure 16.

Largemouth Bass $\log_e$ PSD-P from annual spring 2017-2019 electrofishing in impoundments of small (<12 ha; upper panel) and large (>33 ha; lower panel) surface area. Solid lines represent impoundments that received shoreline rotenone applications and dashed lines represent controls. Open circles indicate that the impoundment did not receive rotenone treatment the previous summer, whereas closed circles denote prior year rotenone treatment. Multiple lines of the same type indicate groups of impoundments with different years of entry into or exit out of the study. Error bars represent the 2.5^{th} and 97.5^{th} percentiles of data.

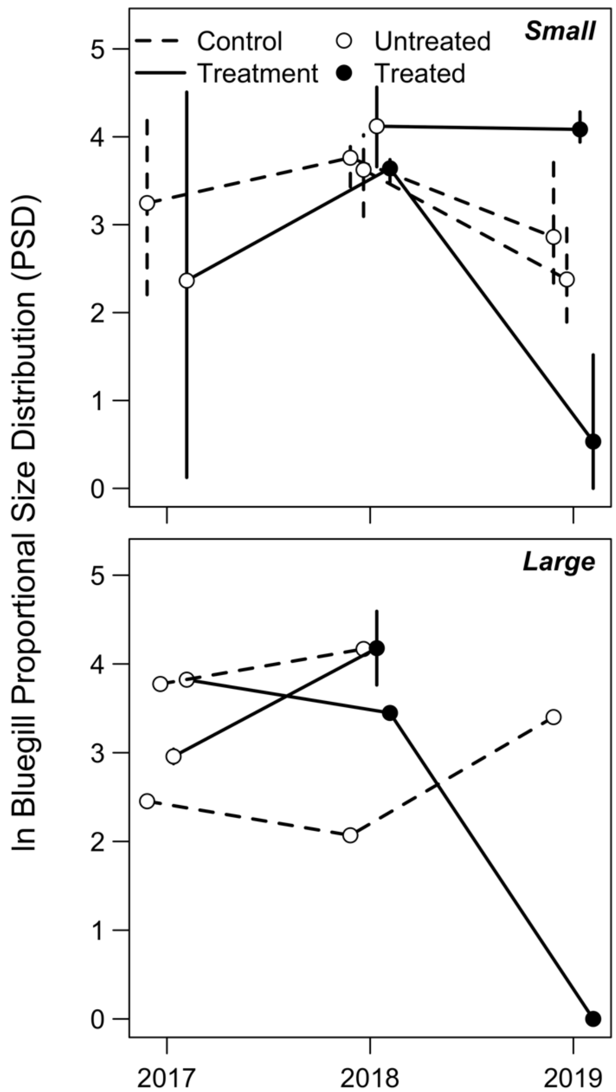

Figure 17.

Bluegill $\log_e$ PSD from annual spring 2017-2019 electrofishing in impoundments of small (<12 ha; upper panel) and large (>33 ha; lower panel) surface area. Solid lines represent impoundments that received shoreline rotenone applications and dashed lines represent controls. Open circles indicate that the impoundment did not receive rotenone treatment the previous summer, whereas closed circles denote prior year rotenone treatment. Multiple lines of the same type indicate groups of impoundments with different years of entry into or exit out of the study. Error bars represent the 2.5th and 97.5th percentiles of data.

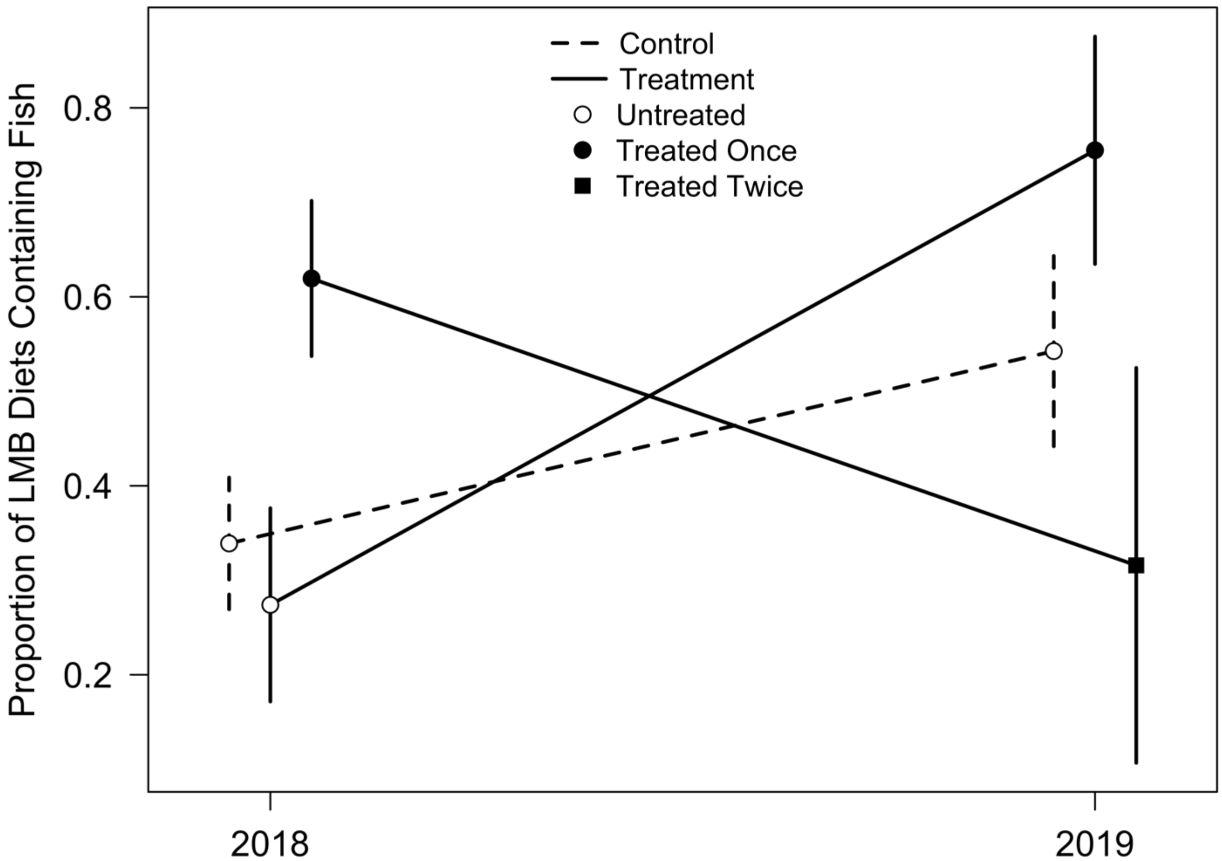

Figure 18.

Proportion of Largemouth Bass >250 mm diets containing fish from spring electrofishing in 2018 and 2019. Solid lines represent impoundments that received shoreline rotenone applications and dashed lines represent controls. Open circles indicate that the impoundment did not receive rotenone treatment the previous summer, whereas closed circles denote prior year first rotenone treatment and closed squares represent prior year second rotenone treatment. Error bars represent the 2.5th and 97.5th percentiles of data.