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Title: **Evaluation of shoreline rotenone application to control Largemouth Bass**

***Micropterus salmoides* recruitment in small impoundments**

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## Abstract

Controlling Largemouth Bass recruitment could benefit recreational fisheries in small impoundments by reducing bass population density, which could improve <sup>individual</sup> growth rates, body condition, and size structure. We tested this hypothesis by evaluating the effects of shoreline rotenone application on Bluegill and age-0 and age-1 Largemouth Bass density, growth, and survival in 20 Alabama small impoundments. Following treatment, Largemouth Bass age-0 densities declined and mean age-1 length increased, whereas Bluegill populations were seemingly unaffected. Our study suggests that shoreline rotenone application may be a valuable method for reducing Largemouth Bass recruitment and increasing Largemouth Bass age-1 growth in small impoundments. However, further research is needed to understand the effects of treatment on non-target fishes and better assess the effects of <sup>factors such as</sup> impoundment surface area and treatment frequency and duration on the <sup>ultimate? overall?</sup> utility of the approach.

## Introduction

Small impoundments (water bodies <200 hectares [ha]) are ecologically, economically, and aesthetically important in the United States. In 2016, 24.6 million U.S. freshwater anglers (83%) targeted reservoirs, lakes, and ponds (USDOI 2018). Recreational fishing is the most common use of the nearly 9 million small impoundments in the continental United States (Renwick et al. 2005), which generate significant revenue via pay-to-fish operations (Haley et al. 2012) while providing aesthetic values and habitats for an array of animals and plants (Chaney et al. 2012). As such, it is important to develop effective small impoundment management

does "bass" = LMB throughout?

of bass as well as Bluegill?

given that you mention B6 in the next sentence

what would an improve size structure look like?

why the age? "relatively"? Either B6 were affected or they weren't. They shouldn't just "seem to be affected"?

what is this? 83% of all FW anglers fish in small impoundments? Need to clarify.

strategies for attaining fish population parameters (e.g., density, growth, body condition) that are desirable for angling.

Largemouth Bass *Micropterus salmoides* and Bluegill *Lepomis macrochirus* represent a common, often studied (e.g., Swingle and Smith 1942; Guy and Willis 1990; Shoup and Broderius 2018) sympatric stocking combination in small impoundments of middle and lower latitudes of North America (Smitherman 1975; Novinger and Legler 1978; Brenden and Murphy 2004; Dauwalter and Jackson 2005; Wright and Kraft 2012). The Largemouth Bass is a top-level piscivore that is the most sought-after, economically significant, and heavily managed fish in North America (Allen et al. 2008; Carlson and Isermann 2010; Bonvechio et al. 2014; Claussen 2015), attracting nearly 9.6 million anglers in 2016 (USDOI 2018). Largemouth Bass and Bluegill are opportunistic feeders that are widespread and highly productive, making them popular sport fish for anglers (Wright and Kraft 2012).

Fisheries management in small impoundments often involves manipulating population densities to achieve desired growth rates. Fish density is typically the object of manipulation because fish populations in these systems often exhibit compensatory density-dependent growth (Swingle and Smith 1942; Gabelhouse 1987; Aday and Graeb 2012) involving intraspecific competition for food and habitat (Heath 1992; Rose et al. 2001). Small impoundment managers commonly manipulate densities of Largemouth Bass and Bluegill to obtain “balanced” populations that optimize fish size and production to achieve sustainable harvest for both species (Swingle 1950; Geihlsler and Holder 1983; Sammons and Maccina 2005). Overharvest of Largemouth Bass was historically one of the most common small impoundment management problems because it reduced predation on Bluegill and <sup>led to</sup> increased Bluegill densities (Funk 1974; Willis et al. 2010). An overabundance of Bluegill can reduce their growth rate and body

condition (Willis et al. 2010) and interfere with Largemouth Bass recruitment via nest destruction (Smith 1976) or consumption of eggs or larvae (Swingle and Smith 1942; Bennett 1970; Swingle 1970; Wright and Kraft 2012). Furthermore, juvenile Bluegill and age-0 Largemouth Bass occupy similar habitats, <sup>resulting in the potential for</sup> ~~which can increase~~ competition between these species <sup>why increase?</sup> (Zweiacker and Summerfelt 1974; Werner 1977; Kelso 1983; Brenden and Murphy 2004).

Over the last 30 years, Largemouth Bass anglers across North America have increasingly adopted catch-and-release fishing, which has <sup>led to</sup> increased bass densities and caused density-<sup>in bass</sup> dependent growth reductions in some systems (Quinn 1996; Sammons and Maceina 2005; Wright and Kraft 2012; Bonvecchio et al. 2014). Largemouth Bass spawn annually at high rates <sup>are their fecundities "high"?</sup> (900—3200 eggs/kg body weight; Moyle 1976; Laarman and Schneider 2004; Claussen 2015), making them highly vulnerable to overcrowding and density-dependent growth reductions (Aday and Graeb 2012; Wright and Kraft 2012). Methods used to regulate Largemouth Bass density and maintain balanced populations of <sup>not the species name here, so not capitalized</sup> Bass and Bluegill include aquatic macrophyte control, fertilization, length limits, recruitment reduction, and fish removal via poisoning or impoundment draining (Swingle and Smith 1942; Eder 1984; Gabelhouse 1987; McHugh 1990). However, time and financial limitations can constrain the suitability of these management approaches (Haley et al. 2012), catch-and-release fishing can make <sup>management via</sup> length limits less effective for Largemouth Bass (Gabelhouse 1987; McHugh 1990), and common sampling gears (e.g., hook-and-line, electrofishing) are inefficient at capturing age-0 bass to reduce recruitment. Moreover, consistent annual recruitment of Largemouth Bass can increase density and intraspecific competition and prevent most individuals from growing to an adequate size (Swingle 1950; Shelton et al. 1979; Allen and Hightower 2010; Aday and Graeb 2012). Thus,

small impoundment managers across the United States would benefit from the development and enhancement of methods for controlling Largemouth Bass recruitment.

One technique used to sample or control fish populations in small impoundments is rotenone application (Finlayson et al. 2000; McClay 2000). For <sup>example?</sup> instance, McHugh (1990) used shoreline rotenone treatments and electrofishing to reduce Largemouth Bass densities in two 24–28 ha impoundments, which <sup>led to</sup> increased Largemouth Bass growth and improved Bluegill size structure and Crappie *Pomoxis* spp. recruitment. To date, no studies have evaluated shoreline rotenone treatments targeting Largemouth Bass recruitment in impoundments  $\leq 10$  ha. As such, our objectives were to (1) assess the effectiveness of shoreline rotenone application in reducing age-0 and age-1 Largemouth Bass densities in small impoundments, (2) investigate compensatory density-dependent responses of Largemouth Bass growth and survival, (3) quantify changes in Bluegill density, and (4) evaluate the effect of impoundment surface area on the efficacy of shoreline rotenone application.

## <A> Methods

*Study site.*—We used 20 small impoundments ranging from 0.7–48 ha for this study; <sup>we</sup> ~~grouping~~ <sup>ed</sup> impoundments into “small-sized” (< 12 ha) and “large-sized” (> 33 ha; Table 1), hereafter referred to as simply small and large impoundments, respectively. Impoundments were located across central to southern Alabama on private lands <sup>those owned by</sup> of those owned by the Alabama Department of Conservation and Natural Resources (ADCNR) or Auburn University (Figure 1). Ten impoundments received shoreline rotenone application; the remaining ten impoundments <sup>served as?</sup> were untreated controls. We selected impoundments so that control and treatment systems were similar in littoral vegetation coverage, bank depth, surface area (with one exception), and Largemouth Bass and Bluegill densities. <sup>we sampled during</sup> We sampled a total of 20 impoundments from spring

through 2017 to spring 2019 for this study; electrofishing each spring and applying rotenone treatment in the summers of 2017 and 2018, which we referred to as treatment periods (Table 1). We included twelve impoundments (i.e., six controls/six treatments) in the first treatment period, with eight of those (i.e., four controls/four treatments) being included again in the second treatment period. We added eight more impoundments the second treatment period for a total of sixteen impoundments that period (Table 1).

*Summer rotenone application.*—We used 5% biodegradable liquid rotenone to target age-0 Largemouth Bass. Juvenile Largemouth Bass recruit in littoral areas of impoundments after dispersing from male-guarded fry schools in late spring (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 in 2017 only, in 2018 only, or both years (Table 1). Two applications were used each year; The first application was in May, with a follow-up application approximately 21 days later to ensure that progeny of late-spawning fish were not missed. We applied liquid rotenone with a boat, two 151-L tanks, and standard safety gear (e.g., nitrile gloves, eye protection, respirator, hazmat suit). We connected one tank to a surface spray wand (210,920 kg/m<sup>2</sup>) and the other to a multiport subsurface injector composed of a 1.5-m section of chlorinated polyvinyl chloride with five evenly spaced ports (2 mm diameter) fixed to a 3.5 m fiberglass pole. Together, the surface spray wand and subsurface injector created a sediment-to-surface curtain of rotenone along the shoreline. We held the subsurface injector 3–5 m off the shoreline and sprayed the surface application simultaneously between the subsurface injector and shoreline. We made a single pass around the perimeter of each treatment impoundment, applying 0.5 L rotenone per 90 m of shoreline.

*Summer seining.*—We seined each impoundment using a 4.5 X 1.8-m seine net with 3.2-mm knotless mesh at 15 randomly selected sites. In summer 2017 and 2018, we seined each impoundment on five occasions, beginning in May and ending in July. Four occasions were immediately before/after rotenone application, and the fifth sample was a mid-summer follow-up. On days 1 and 21, we seined treatment impoundments at sunrise (i.e., immediately before rotenone application) and control impoundments immediately after we treated the treatment impoundment. The day after each rotenone application (days 2 and 22), we seined in the treatment and control impoundments at similar times of day as the pre-application samples to minimize time-of-day effects on seine catches. On day 42, an additional seine sample was collected at each impoundment at the same time of day as previously sampled to compare catches over time. We marked seine sites with a Garmin eTrex 20x global positioning system to ensure that the same sites were sampled consistently over time. We recorded age-0 Largemouth Bass total lengths and enumerated Bluegill in length bins (0–12.5mm, 12.6–37.5mm, 37.6–62.5mm, etc.).

*Electrofishing.*—We sampled all impoundments via electrofishing (Smith-Root 5.0 GPP aluminum boat, 50–60 Hz, 4–5 ms pulse width, 300–400 V) during March before the first treatment and at least once thereafter (Table 1). Sampling included two 15-min shoreline electrofishing transects in which we collected all fishes >80 mm. We measured (nearest mm) and weighed (nearest g) all fishes captured and collected a subsample of 10 Largemouth Bass per 25-mm length interval (for fish 150–250 mm) for ageing using sagittal otoliths. We also used this subsample to determine the appropriate length cutoff for age-1 vs. age-2 fish to quantify and



compare mean length-at-age. We mounted otolith transverse sections on slides using methods of Boehlert and Yoklavich (1985) and aged slides using immersion oil for clarity. Two readers aged otoliths without prior knowledge of fish length, weight, or the other reader's age estimates.

When different ages were assigned to individual fish, we recruited a third reader to have a group discussion to reach a consensus age. *Was consensus reached for all otoliths?*

*Age-0 relative abundance and mean length.*—We used R (R Core Team 2022) <sup>for</sup> ~~to run~~ all analyses. We used two before-after-control-impact (BACI) analyses to test for effects of shoreline rotenone treatment on Bluegill and age-0 Largemouth Bass seine catches in both small and large impoundments (Stewart-Oaten et al. 1986). The first analysis compared seine catches immediately before (i.e., day-1 and -21) and after (i.e., day-2 and -22) rotenone application to evaluate the short-term effect of the application. We conducted this analysis with a generalized linear mixed-effects model with a negative binomial sampling distribution. There were random effects for impoundment x year intercepts and fixed effects of application (first: day-1 vs. day-2, and second: day-21 vs. day-22), treatment (control/treatment), time period (before/after treatment), and all interactions. The treatment x time interaction tested whether catches declined significantly more in treatments than controls.

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 to natural variation in controls) on Bluegill and age-0 Largemouth Bass populations for both large and small impoundments. We used a generalized linear model and generalized linear mixed-effects model with negative binomial sampling distributions for small and large impoundments, respectively. The model for small

impoundments included random effects for impoundment x year intercepts and fixed effects of treatment, time period, and their interaction, while the <sup>smaller</sup> ~~lower~~ large impoundment sample size (Table 1) prevented the use of a random effect.

We compared Largemouth Bass mean length-at-age (MLA)-0 in the pre-treatment and mid-summer follow-up seine samples using a BACI analysis, estimating initial growth differences between controls and treatments for both large and small impoundments. We conducted this analysis using a linear mixed-effects model and natural-log-transformed mean total length data for each impoundment each year to meet the assumption of normality. We included independent random effects of impoundment and year intercepts and fixed effects of treatment, time period, and their interaction.

*Age-1 growth, recruitment, survival, and size structure.*—We estimated the effect of rotenone treatment on Largemouth Bass MLA-1 for both large-sized and small-sized impoundments using a BACI analysis. For this entire section, the effect of rotenone treatment is represented as (1) a control or pre-treatment, (2) treated one year, or (3) treated two years. We obtained MLA from otolith-aged subsamples by taking the average length of each age class, weighted by the sample size in each size class (DeVries and Frie 1996). For small impoundments, we used a linear mixed-effects model via maximum likelihood with an independent random effect of impoundment intercepts—we could not use a random effect of year because our sample size led to a singular fit (e.g., see Table 1)—and a fixed effect of rotenone treatment on the natural logarithm of MLA-1 to meet the assumption of normality. We used a linear mixed-effects model via maximum likelihood with an independent random effect of year intercepts—we could not use a random effect of impoundment because of our sample size (Table 1) resulting in a singular

fit—and the same fixed effect of rotenone treatment on the natural logarithm of MLA-1 to meet the assumption of normality for large impoundments.

We evaluated the effect of rotenone treatment on natural-log-transformed electrofishing catch-per-unit-effort (CPUE) of age-1 Largemouth Bass and stock-sized Bluegill (i.e., >80 mm) to meet the assumption of normality using a BACI analysis for both large and small impoundments. We added a ~~one~~ <sup>1</sup> to all age-1 Largemouth Bass CPUE values to <sup>allow for</sup> log-transform <sup>ing</sup> the data with zeros, <sup>given that</sup> as the Bluegill data did not contain any zeros. We analyzed effects of rotenone application on Largemouth Bass recruitment using age-1 CPUE, and effects on non-target fish for rotenone application (i.e., stock-sized Bluegill) using Bluegill CPUE. For each dependent variable in small impoundments, we fit a linear mixed-effects model via maximum likelihood with an independent random effect of impoundment intercepts—we could not use a random effect of year because of our sample size (Table 1) resulting in singular fit—and a fixed effect of rotenone treatment (control, once, or twice) on the natural logarithm of CPUE. We fit a linear mixed-effects model via maximum likelihood for each dependent variable in large impoundments with an independent random effect of year intercepts—sample size limitation (Table 1)—and the same fixed effect of rotenone treatment on the natural logarithm of CPUE.

We tested for compensatory age-0 Largemouth Bass survival after rotenone treatment using an index of Largemouth Bass age-0 survival. The survival index was calculated by dividing March age-1 electrofishing catches by the mid-summer follow-up seine (day-42) <sup>age-0</sup> catches from the previous year, reducing our sample size by almost half from the previous analyses described above. We tested for differences in the survival index as a function of rotenone treatment frequency (i.e., no treatment, one year, two years) by fitting models on the natural logarithm of the survival index to meet the assumption of normality for both large and

small impoundments. For small impoundments, we fit a linear mixed-effects model via maximum likelihood with an independent random effect of year intercepts with a fixed effect of rotenone treatment. The large impoundment sample size allowed us to fit a linear regression via maximum likelihood with the same rotenone treatment fixed effect.

#### <A> Results

*Age-0 relative abundance and mean length.*—Largemouth Bass seine haul catches three-way treatment x time period x application interaction was not statistically significant: differences in catches between treated and control impoundments before and after rotenone treatment were similar between the first and second rotenone applications in small ( $F_{1,57}=0.38$ ,  $p=0.57$ ) and large ( $F_{1,15}=0.0023$ ,  $p=0.96$ ) impoundments. In small impoundments, treatment impoundments experienced an additional 96% (89–99%;  $\pm 95\%$  CI) reduction in Largemouth Bass seine catches the day following rotenone application (i.e., day 1 to day 2) compared to control impoundments ( $F_{1,61}=44.57$ ,  $p<0.001$ ; Figure 2). Similarly, in large impoundments we observed an additional 86% (56–96%;  $\pm 95\%$  CI) reduction in Largemouth Bass seine catches in treatment compared to control impoundments ( $F_{1,19}=11.62$ ,  $p<0.001$ ; Figure 2) the following day. Bluegill seine haul catches were also unrelated to application and its associated interactions in small ( $F_{1,57}=0.50$ ,  $p=0.48$ ) and large ( $F_{1,15}=0.59$ ,  $p=0.45$ ) impoundments. We observed a statistically significant treatment x time period interaction in small ( $F_{1,61}=7.48$ ,  $p=0.0070$ ) impoundments where treatments experienced an additional 62% (23–81%;  $\pm 95\%$  CI) reduction in Bluegill seine catches the day after rotenone applications compared with controls (Figure 3). However, in large impoundments, a statistically significant treatment x time period interaction was not evident ( $F_{1,19}=2.91$ ,  $p=0.092$ ) in Bluegill seine catches even though an additional 54% (-13–82%;  $\pm 95\%$

CI) reduction was observed one-day post treatment in treatment impoundments compared to controls (Figure 3).

Pre-treatment (i.e., day 1) Largemouth Bass seine catches were similar initially in treatment and control small ( $F_{1,19}=11.22$ ;  $p=0.56$ ) and large ( $F_{1,5}=3.55$ ;  $p=0.97$ ) impoundments. When observing day-1 compared to the mid-summer follow-up (i.e., day-42), we found the treatment x time period interaction was statistically significant in small impoundments ( $F_{1,19}=6.73$ ;  $p=0.017$ ) and represented an additional 86% (38–97%;  $\pm 95\%$  CI) post-treatment decrease in small treatment impoundments compared to small controls (Figure 4). <sup>The</sup> Large impoundments ~~treatment x time period interaction~~ was not statistically significant ( $F_{1,5}=3.53$ ;  $p=0.061$ ), <sup>but did</sup> ~~however,~~ presented an additional 71% (-5–92%;  $\pm 95\%$  CI) post-treatment decrease in large treatment impoundments compared to large controls (Figure 4). Bluegill seine catches were similar initially in treatment and control small impoundments ( $F_{1,19}=5.69$ ;  $p=0.24$ ), but different in large impoundments ( $F_{1,5}=21.059$ ;  $p<0.001$ ; Figure 5). The treatment x time period interaction in small ( $F_{1,19}=0.39$ ;  $p=0.55$ ) and large ( $F_{1,5}=0.41$ ;  $p=0.52$ ) impoundments was not statistically significant, presenting no change in catches of Bluegill from day-1 to day-42 in treatments compared to controls (Figure 5). <sup>Why bold + italic?</sup>

Age-0 Largemouth Bass were not captured in six of the treated impoundments. In <sup>from which</sup> impoundments they were captured, Largemouth Bass MLA-0 in the seine catches pre-treatment (i.e., day 1) were similar in the treatment and control small ( $F_{1,19}=0.025$ ;  $p=0.94$ ) and large ( $F_{1,5}=3.81$ ;  $p=0.16$ ) impoundments. In small impoundments, the treatment x time period interaction did not indicate any additional age-0 growth from day-1 to day-42 in the controls and treatments ( $F_{1,14}=0.024$ ;  $p=0.88$ ). Likewise, large impoundments did not experience additional age-0 growth due to treatment ( $F_{1,5}=0.38$ ;  $p=0.56$ ; Figure 6). Among both impoundment sizes,

MLA-0 on day 42 was 63 mm (51–76 mm;  $\pm 95\%$  CI) in the treatments and 58 mm (48–71 mm;  $\pm 95\%$  CI) in the controls.

*Age-1 growth, recruitment, survival, and size structure.*—Largemouth Bass MLA-1 in small impoundments significantly increased on average by 27% (16–40%;  $\pm 95\%$  CI) after one year of treatment ( $F_{1,24}=19.15$ ;  $p<0.001$ ) and by 31% (16–48%;  $\pm 95\%$  CI) after two consecutive years of treatment ( $F_{1,24}=19.15$ ;  $p<0.001$ ) compared to the controls. However, there was no difference between one ~~and~~ <sup>versus</sup> two years of treatment ( $F_{1,24}=19.15$ ;  $p=0.69$ ) in small impoundments (Figure 7). In large impoundments, Largemouth Bass MLA-1 increased on average 17% (3–33%;  $\pm 95\%$  CI) after the first treatment ( $F_{1,7}=3.83$ ;  $p=0.050$ ) and 20% (-2–45%;  $\pm 95\%$  CI) after two consecutive treatments ( $F_{1,12}=3.83$ ;  $p=0.099$ ). There was no difference between bass MLA-1 after one ~~compared to~~ <sup>versus?</sup> after two rotenone treatments in large impoundments ( $F_{1,9}=3.83$ ;  $p=0.84$ ; Figure 7).

In small impoundments, we found Largemouth Bass recruitment declined 87% (74–93%;  $\pm 95\%$  CI) and 84% (58–94%;  $\pm 95\%$  CI) more than the controls after one ( $F_{1,19}=22.21$ ;  $p<0.001$ ) and two ( $F_{1,19}=22.21$ ;  $p<0.001$ ) years of rotenone application, respectively (Figure 8). We detected no difference between one ~~and~~ <sup>versus</sup> two years of treatment ( $F_{1,19}=22.21$ ;  $p=0.73$ ). We did not identify any difference in Bluegill CPUE in the controls ~~and~~ <sup>versus</sup> after one ( $F_{1,19}=2.021$ ;  $p=0.31$ ) ~~or after~~ <sup>versus</sup> and two ( $F_{1,19}=2.021$ ;  $p=0.16$ ) years of treatment, nor between one ~~and~~ <sup>versus</sup> two years of treatment ( $F_{1,19}=2.021$ ;  $p=0.056$ ) in small impoundments (Figure 9). In large impoundments, we detected no difference in Largemouth Bass recruitment across ~~all~~ <sup>any</sup> treatment comparisons (Figure 8): control ~~and~~ <sup>versus</sup> one year of treatment ( $F_{1,7}=0.89$ ;  $p=0.21$ ), control ~~and~~ <sup>versus</sup> two years of treatment ( $F_{1,7}=0.89$ ;  $p=0.79$ ), one year ~~and~~ <sup>versus</sup> two years of treatment ( $F_{1,7}=0.89$ ;  $p=0.60$ ). Likewise, Bluegill CPUE in large impoundments did not experience a times-treated effect among any group comparison

(Figure 9): control <sup>versus</sup> and one year of treatment ( $F_{1,12}=1.50$ ;  $p=0.11$ ), control <sup>versus</sup> and two years of treatment ( $F_{1,12}=1.50$ ;  $p=0.67$ ), one year <sup>versus</sup> and two years of treatment ( $F_{1,12}=1.50$ ;  $p=0.56$ ).

In small impoundments, we failed to detect any change in Largemouth Bass survival rates between the controls <sup>versus</sup> and one year of treatment ( $F_{1,15}=1.86$ ;  $p=0.47$ ), controls <sup>versus</sup> and two years of treatment ( $F_{1,15}=1.86$ ;  $p=0.071$ ), and one year <sup>versus</sup> and two years of treatment ( $F_{1,15}=1.86$ ;  $p=0.25$ ). We observed the same trend in bass survival rates in large impoundments, where controls <sup>versus</sup> and one treatment year ( $F_{2,4}=0.13$ ;  $p=0.67$ ), controls <sup>versus</sup> and two treatment years ( $F_{2,4}=0.13$ ;  $p=0.97$ ), and one <sup>versus</sup> and two treatment years ( $F_{2,4}=0.13$ ;  $p=0.73$ ) did not differ from one another.

#### <A> Discussion

Evaluating responses of age-0 Largemouth Bass and Bluegill to shoreline rotenone application in small and large impoundments is critical for identifying how this approach can be used to inform freshwater impoundment fisheries management. Long-term population success <sup>for both</sup> regarding Largemouth Bass and Bluegill is influenced by mechanisms related to individual size and population density during early life stages (Ludsin and DeVries 1997; Rogers and Allen 2009) that are directly affected by rotenone application. In the present study, seine <sup>haul</sup> catches of age-0 Largemouth Bass and Bluegill in treatment small impoundments significantly declined 24 hours after rotenone applications, whereas catches in control small impoundments did not significantly change. In large impoundments, seine haul catches of age-0 bass also significantly declined 24 hours after rotenone applications, while Bluegill seine catches did not significantly differ 24 hours post-treatment. These results are similar to observations made by McHugh (1990) following <sup>combined</sup> rotenone application and targeted removal via electrofishing <sup>in</sup> Alabama lakes. In <sup>ow?</sup> small impoundments, age-0 Largemouth Bass seine catches declined in both controls and

treatments by day 42, with a significantly greater decline in treatment impoundments. In large impoundments, age-0 bass seine catches also declined in both controls and treatments by the mid-summer follow-up, <sup>numerically?</sup> ~~however, there was no significant difference in the decline~~, <sup>although the decline was not significant,</sup> unlike <sup>in</sup> small impoundments. In addition to rotenone mortality, this decline is likely partially attributable to reduced vulnerability of larger individual fish to capture with a seine (Jackson and Noble 1995; Willis and Murphy 1996; Reynolds and Kolz 2012). Moreover, natural mortality of age-0 Largemouth Bass is likely <sup>important?</sup> ~~meaningful~~ during the summer months (Rogers and Allen 2009), also contributing to reduced seine catches. In contrast, Bluegill seine catches did not change significantly from day 1 to day 42 in both small and large, control and treatment impoundments. Bluegill catches were likely less affected by temporal changes in gear vulnerability than Largemouth Bass because of their slower growth combined with multiple spawning events (Cargnelli and Neff 2006; Bartlett et al. 2010), which may have offset losses due to natural and rotenone mortality. good!

We did not detect a rotenone treatment effect on Bluegill CPUE in spring electrofishing samples, perhaps reflecting natural variation in Bluegill reproduction or overwinter survival that could offset or obscure treatment effects. Research shows Bluegill move from pelagic to littoral habitats as they grow ~~older~~ (Werner and Hall 1988). When Bluegill fry move from pelagic to littoral areas, they become more vulnerable to shoreline rotenone application. However, adult Bluegill can spawn multiple times throughout the summer, and fry transition from pelagic to littoral habitats at different times. As such, Bluegill <sup>the overall? population?</sup> may have had inherently low vulnerability to rotenone treatments in the present study. <sup>Alternatively</sup> On the other hand, if Bluegill were impacted by rotenone treatment the previous summer, density-dependence could cause over-winter survival of Bluegill to increase, in turn reducing the effect on Bluegill CPUE the following spring. ?



Largemouth Bass recruitment to age-1 was significantly lower in treatments than controls for small impoundments—regardless of being treated once or twice—<sup>Similar to findings for</sup> ~~like~~ age-0 bass the previous summer in seine catches. However, bass recruitment reductions in large impoundments were not pronounced. Larger impoundments tended to have more complex littoral habitats (e.g., thick emergent vegetation, overhanging terrestrial vegetation, shallow backwaters) that may have affected the efficiency of the rotenone treatment by providing temporary refuge for young-of-year Largemouth Bass. Ensuring rotenone spray coverage was also more difficult in complex littoral habitats. Moreover, whereas electrofishing sampling covered nearly the entire shoreline of small impoundments, it only covered a small percentage of the shoreline in large impoundments, potentially contributing to more variable electrofishing catchability and lower catches in large impoundments.

Research shows that age-0 Largemouth Bass in the southeastern U.S. experience a survival bottleneck via high overwinter mortality rates (Aggus and Elliott 1975; Miranda and Hubbard 1994a; Ludsin and DeVries 1997). Low survival may also be caused by cumulative interactions between abiotic and biotic factors (e.g., water temperature, water level, predation, starvation; Kramer and Smith 1962; Miranda and Hubbard 1994b; Ludsin and DeVries 1997; Garvey et al. 2002). Survival bottlenecks can lead to compensatory density-dependent survival, which could offset density reductions due to rotenone application. Our survival index analysis showed an absence of compensatory density-dependent survival in response to rotenone treatment, suggesting that overwinter survival bottlenecks may be weaker in these impoundments than in other systems. Alternatively, the survival index may have been too imprecise to detect compensatory survival given that it was constructed as the quotient of two independent and relatively noisy observations—electrofishing CPUE (Hangsleben et al. 2013) and seine catches

(Jackson and Noble 1995). Therefore, it is plausible that sampling variation from spring electrofishing and late-summer seine catches 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 intraspecific competition for prey resources and slower growth (Heath 1992; Rose et al. 2001). Reduced age-0 Largemouth Bass densities following rotenone treatment provided us an opportunity to test for density-dependent growth. In the present study, we found rotenone treatment <sup>led to</sup> increased Largemouth Bass MLA-1 post-treatment, particularly in impoundments <12 ha. McHugh (1990) found similar results from <sup>combined</sup> rotenone application and targeted electrofishing removal wherein Largemouth Bass MLA-3 before treatment was comparable to MLA-2 after treatment. Similarly, Beckman (1941) concluded that growth of age-1 Rock Bass *Ambloplites rupestris* increased due to a rotenone application used to target juveniles. We observed weaker growth responses in impoundments >33 ha, which was consistent with smaller density reductions in those impoundments. Further research is needed to assess differences more definitively in growth responses as a function of impoundment size following rotenone treatment. Although Largemouth MLA-1 increased following rotenone treatment, we found no effect on MLA-0 in mid-summer seine catches. We speculate that seines were biased against collection of larger age-0 bass (Jackson and Noble 1995), thereby masking treatment effects, or perhaps density-dependent growth responses require more time for cumulative growth differences to emerge. Moreover, no age-0 Largemouth Bass were captured in mid-summer seine hauls at six of the treatment impoundments, so mean lengths may not have been representative of all impoundments.

Prey availability and size also affect fish growth (Shelton et al. 1979; Allen and Hightower 2010). With <sup>reduced</sup> ~~less~~ intraspecific competition and large numbers of juvenile Bluegill still present after rotenone treatment—as we found no rotenone effect on Bluegill densities in the mid-summer seine catches—Largemouth Bass prey availability <sup>should be?</sup> is plentiful. Age-1 Largemouth Bass growth increased <sup>after</sup> ~~due to~~ rotenone treatment (discussed above); therefore, future studies should assess if stock-size Bluegill and age-2+ Largemouth Bass growth, condition, and diet differences exist after rotenone applications in different-sized impoundments. It is important to consider effects of rotenone application on non-target species and life stages. For instance, McHugh (1990) reported that small numbers of non-target fishes (e.g., larger Bluegill and Largemouth Bass, Grass Carp *Ctenopharyngodon idella*) were killed <sup>during this?</sup> after shoreline rotenone treatment. In the present study, we <sup>did</sup> ~~do~~ not assess age 2+ Largemouth Bass responses to <sup>the</sup> ~~this~~ rotenone treatment; however, ~~we wish to know the~~ effects on older Largemouth Bass age classes. <sup>would be of interest in determining the overall value of this approach</sup> Avoiding high rotenone-related mortality of age 2+ Largemouth Bass in efforts to reduce recruitment is desirable given that these fish are catchable sized.

#### <A> Management Implications

Shoreline rotenone application can be used to reduce recruitment of Largemouth Bass in small and large impoundments, but the efficacy of this approach depends on impoundment surface area. <sup>We found</sup> ~~Shoreline~~ rotenone application <sup>to</sup> improved age-1 Largemouth Bass growth rates without impacting Bluegill densities in <sup>our</sup> ~~the~~ impoundments ~~studied herein~~. This improvement was evident after one year of rotenone application, while an additional year of rotenone application resulted in no further improvement. Fish population parameters observed here were less affected by rotenone treatments in impoundments >33 ha, although relatively small sample sizes ( $N =$

three large impoundments with one year of treatment; N = one large impoundment with consecutive treatments) must be considered when interpreting these findings. Shoreline rotenone application appears to be best suited for enhancing Largemouth Bass populations in impoundments <12 ha. An important subject for future research <sup>would be to assess</sup> is assessing the effects of this shoreline rotenone application on non-target species population parameters (e.g., age-2+ Largemouth Bass growth, condition, and diets, and stocked-size Bluegill condition). Additionally, McHugh (1990) found that shoreline rotenone applications and targeted removal via electrofishing impacted fish populations for a few years after initial application. As such, our shoreline rotenone application technique may need to be repeated at regular intervals (e.g., 2–4 years), another important subject for future research in impoundment management.

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Table 1.

Impoundments sampled, surface area (ha), years of spring electrofishing, and year(s) of shoreline rotenone application, if any (i.e., <sup>C.F.</sup>~~ie~~ "CONTROL").

Impoundment	Size (ha)	Years Electrofished	Year(s) 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

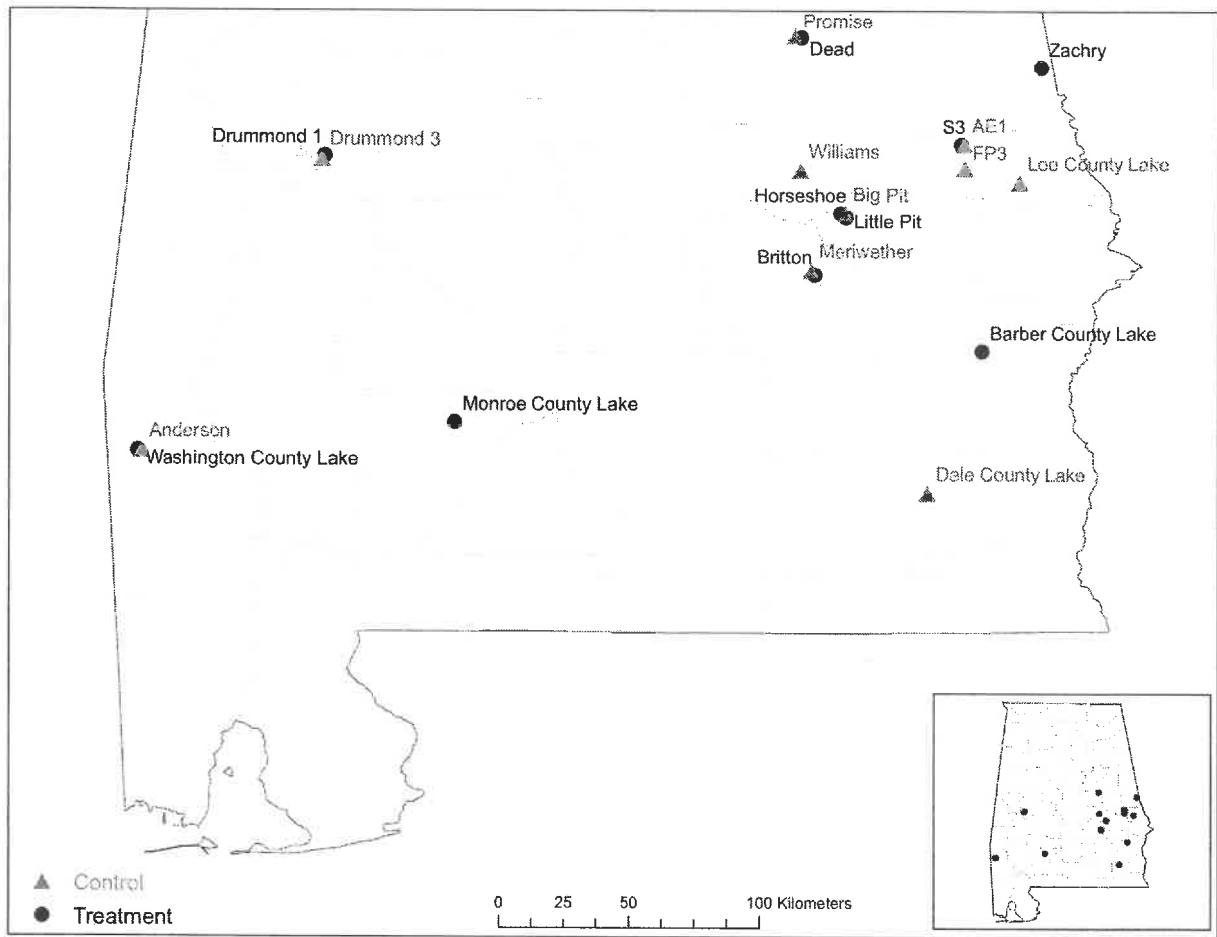


Figure 1.

Map of small impoundments studied. Controls are grey triangles and treatments are black circles. All names ending with “County Lake” represent the large-sized impoundments, while all the other names are the small-sized impoundments.

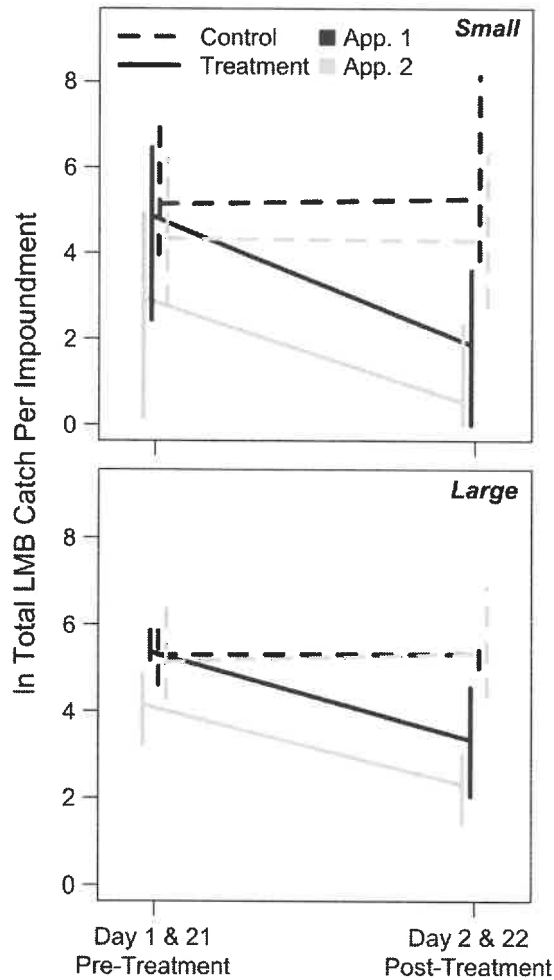


Figure 2.

Largemouth Bass  $\log_e$  total seine catch immediately before (days 1 and 21) and after (days 2 and 22) the first (“App. 1”; black lines) and second (“App. 2”; grey lines) shoreline rotenone applications in small (<12 ha; upper panel) and large (>33 ha; lower panel) sized impoundments. Solid lines denote treated impoundments and dashed lines denote controls. Observations were pooled across years (2017 and 2018) and error bars represent the 2.5<sup>th</sup> and 97.5<sup>th</sup> percentiles (95% confidence intervals).

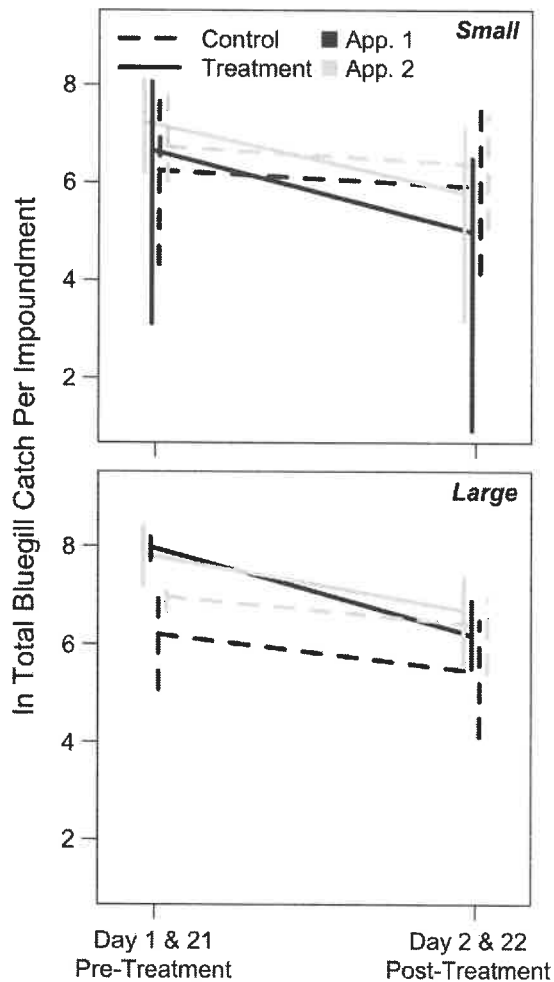


Figure 3.

Bluegill log<sub>e</sub> total seine catch immediately before (days 1 and 21) and after (days 2 and 22) the first ("App. 1"; black lines) and second ("App. 2"; grey lines) shoreline rotenone applications in small (<12 ha; upper panel) and large (>33 ha; lower panel) sized impoundments. Solid lines denote treated impoundments and dashed lines denote controls. Observations were pooled across years (2017 and 2018) and error bars represent the 2.5<sup>th</sup> and 97.5<sup>th</sup> percentiles (95% confidence intervals).

*you might be able to get by with saying "Data are presented as in Figure 2"*

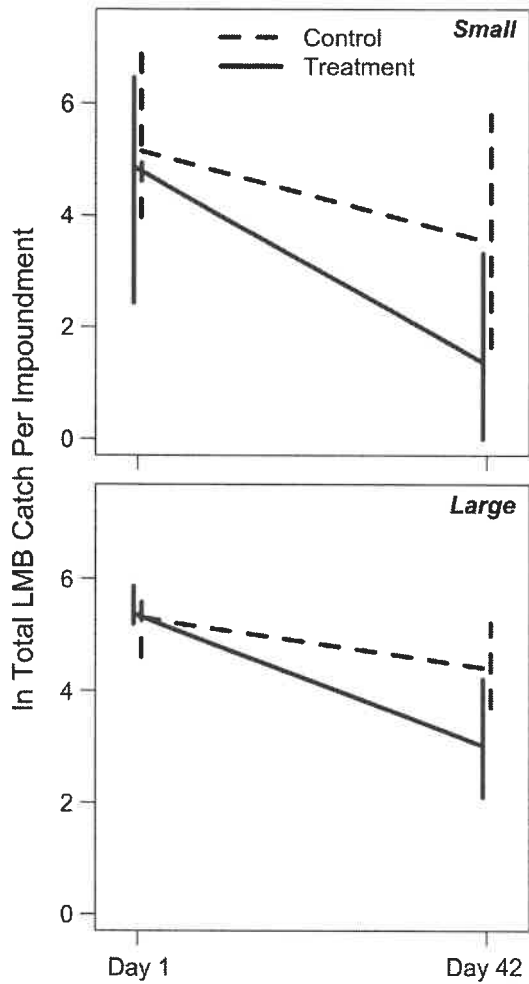


Figure 4.

Largemouth Bass  $\log_e$  total seine catch in small (<12 ha; upper panel) and large (>33 ha; lower panel) impoundments immediately before rotenone application (day 1) and at mid-summer after both rotenone applications (day 42). Solid lines denote impoundments that received shoreline rotenone treatments, and dashed lines denote controls. Data were pooled across years (2017, 2018) and error bars represent 95% confidence intervals.

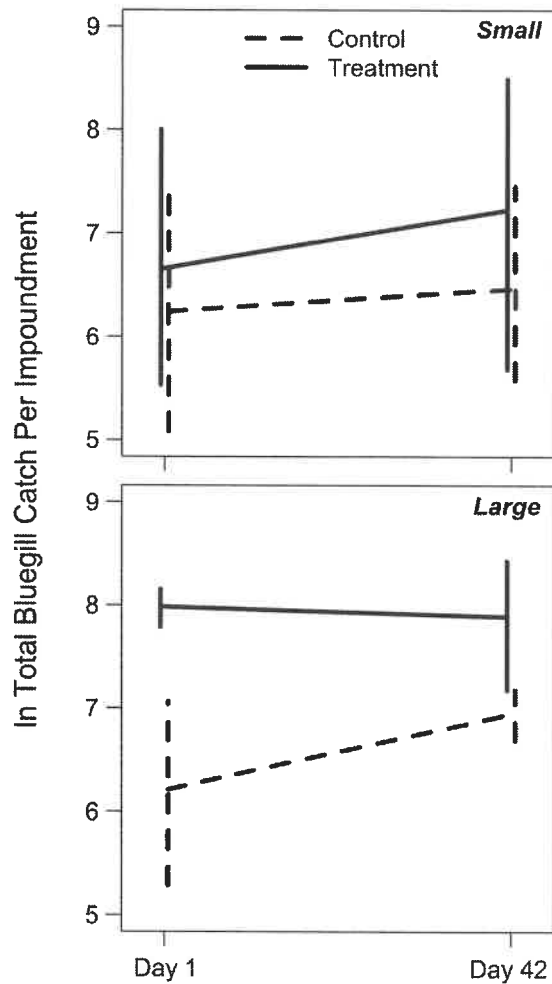


Figure 5.

Bluegill  $\log_e$  total seine catch in small (<12 ha; upper panel) and large (>33 ha; lower panel) impoundments immediately before rotenone application (day 1) and at mid-summer after both rotenone applications (day 42). Solid lines denote impoundments that received shoreline rotenone treatments, and dashed lines denote controls. Data were pooled across years (2017, 2018) and error bars represent 95% confidence intervals.

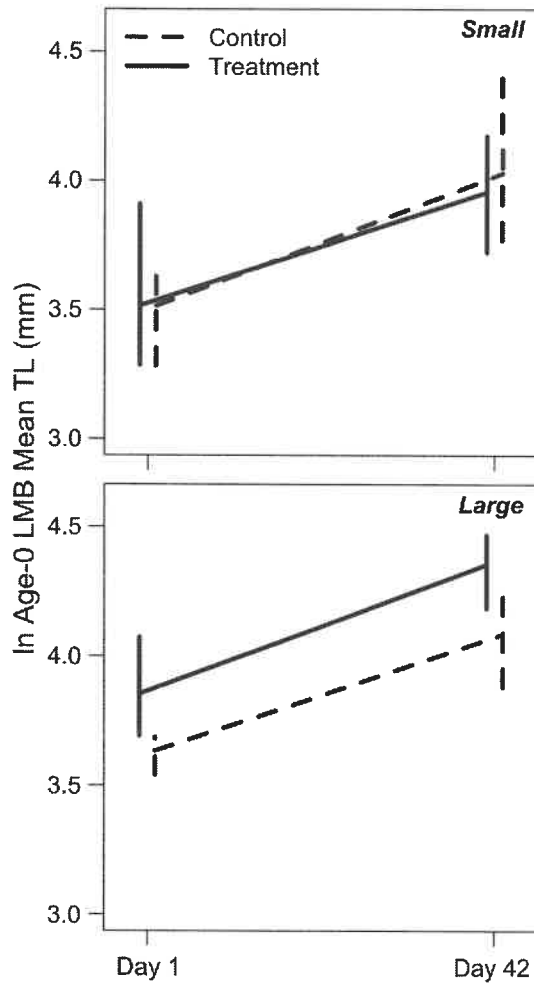


Figure 6.

Largemouth Bass  $\log_e$  MLA-0 in small (<12 ha; upper panel) and large (>33 ha; lower panel) impoundments immediately before rotenone application (day 1) and at mid-summer after both rotenone applications (day 42). Solid lines denote impoundments that received shoreline rotenone treatments, and dashed lines denote controls. Data were pooled across years (2017, 2018) and error bars represent the 2.5<sup>th</sup> and 97.5<sup>th</sup> percentiles (95% confidence intervals).

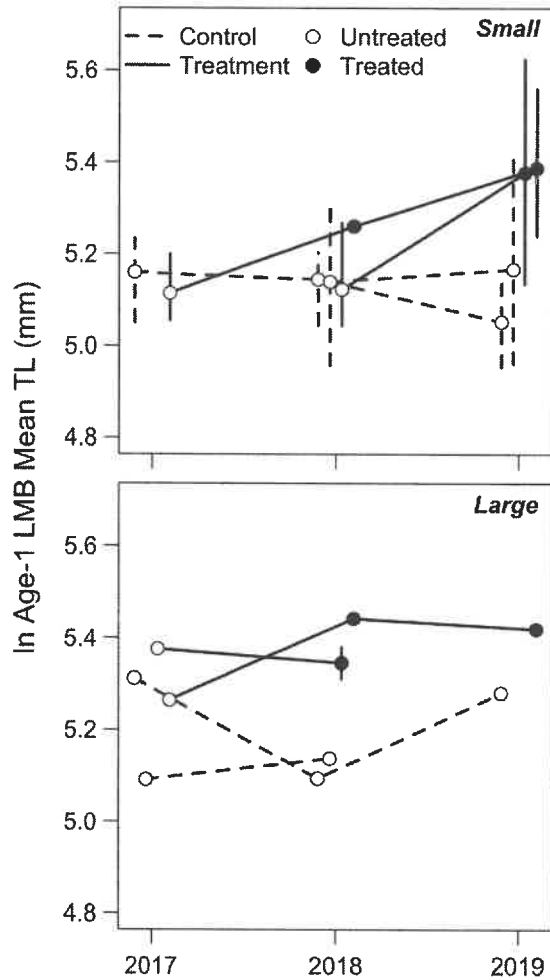


Figure 7.

Temporal trends in Largemouth Bass  $\log_e$  MLA-1 in small (<12 ha; upper panel) and large (>33 ha; lower panel) impoundments in controls (dashed lines) and treatments (solid lines). Open circles denote untreated impoundments, while closed circles denote treated impoundments. Solid lines leading from a closed circle to another closed circle represent the impoundments that were treated twice (e.g., see Table 1). Times treated (untreated control, once, twice) was the variable of interest in our model, and this portrays how the model compared those different levels of treatment. Error bars represent the 95% confidence intervals of the data when the sample size for that year was greater than two impoundments.



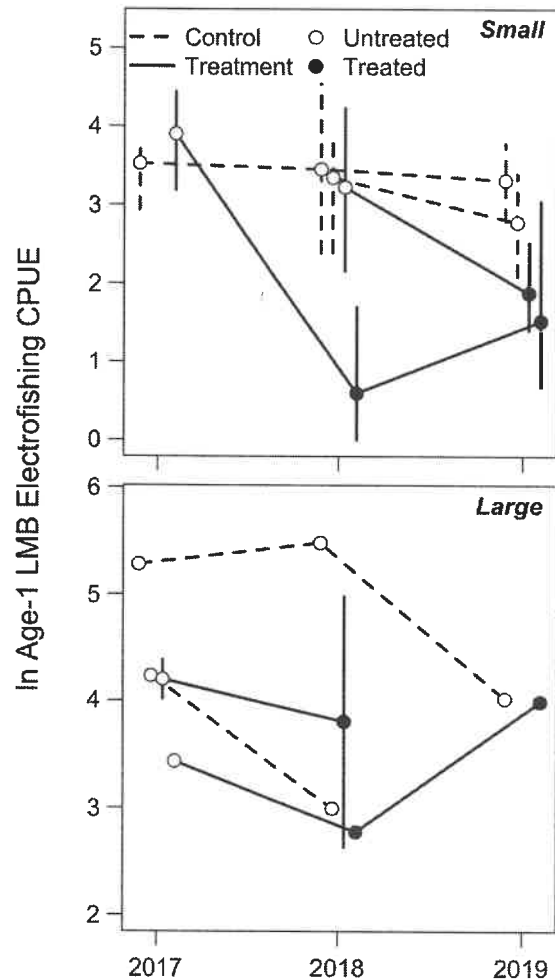


Figure 8.

Temporal trends in age-1 Largemouth Bass  $\log_e$  CPUE—as a proxy for recruitment—in small (<12 ha; upper panel) and large (>33 ha; lower panel) impoundments in controls (dashed lines) and treatments (solid lines). Open circles denote untreated impoundments, while closed circles denote treated impoundments. Solid lines leading from a closed circle to another closed circle represent the impoundments that were treated twice (e.g., see Table 1). Times treated (untreated control, once, twice) was the variable of interest in our model, and this portrays how the model compared those different levels of treatment. Error bars represent the 95% confidence intervals of the data when the sample size for that year was greater than two impoundments.

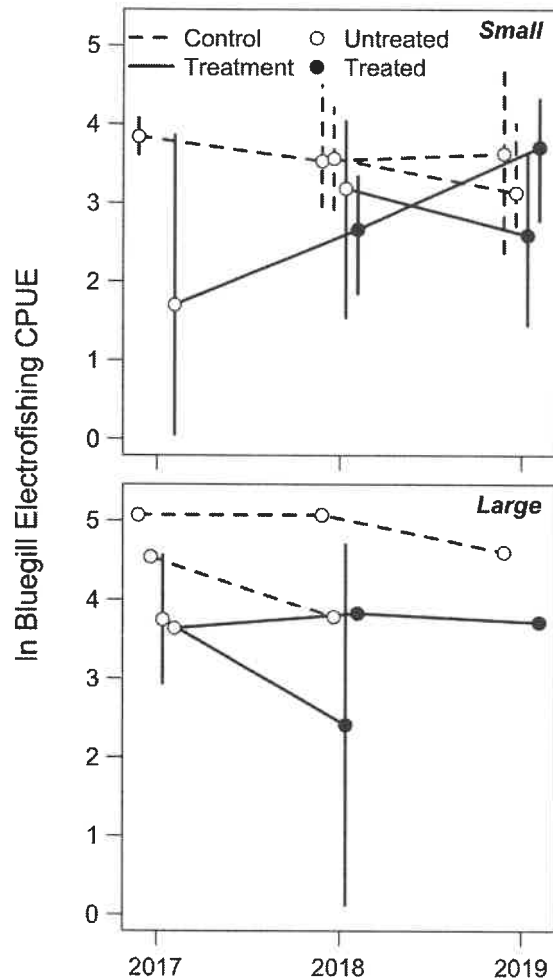


Figure 9.

Temporal trends in Bluegill (>80 mm) log<sub>e</sub> CPUE in small (<12 ha; upper panel) and large (>33 ha; lower panel) impoundments in controls (dashed lines) and treatments (solid lines). Open circles denote untreated impoundments, while closed circles denote treated impoundments. Solid lines leading from a closed circle to another closed circle represent the impoundments that were treated twice (e.g., see Table 1). Times treated (untreated control, once, twice) was the variable of interest in our model, and this portrays how the model compared those different levels of treatment. Error bars represent the 95% confidence intervals of the data when the sample size for that year was greater than two impoundments.