Sportfish Population Characteristics Following Mechanical Largemouth Bass Removal in Two Small Public Fishing Impoundments in South Carolina

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Abstract: Declining angler harvest rates of largemouth bass (*Micropterus salmoides*) have increasingly led to small impoundments containing overcrowded largemouth bass populations. Various methods to correct or prevent crowded largemouth bass populations have been used by fisheries managers, with mixed results. We removed largemouth bass from two small impoundments in South Carolina using boat electrofishing over two consecutive years, with targets of removing 40–50% of the largemouth bass populations each year. We used relative weight (*Wr*) as the removal criterion, such that all largemouth bass displaying condition $Wr < 95$ were removed. Largemouth bass population sizes were estimated using mark-recapture in each impoundment for large (≥200 mm TL) and small (<200 mm TL) largemouth bass length groups. A total of 1641 largemouth bass (162.5 fish ha^{-1}) were removed from Jonesville Reservoir (10.1 ha) and 1022 largemouth bass (63.1 fish ha^{-1}) were removed from Lake Oliphant (16.2 ha) in 2020 and 2021. Proportions removed approached the 40–50% removal targets for both length groups at both impoundments in 2020 but fell short of removal targets in 2021 at Jonesville Reservoir. Improved bluegill (*Lepomis macrochirus*) catch rates and reduced largemouth bass catch rates at Lake Oliphant removals in 2020 led to reduced removal efforts in 2021. Catch rates, estimated population sizes, and estimated biomass (kg ha^{-1}) of large largemouth bass declined from 2020 to 2022 at both impoundments, but results for small largemouth bass were variable. Largemouth bass condition increased at both impoundments and size structure increased at Lake Oliphant. Bluegill catch rates increased at Lake Oliphant but remained low at Jonesville Reservoir. Bluegill condition and size structure declined at both impoundments from 2020 to 2022. We speculate that the presence of an established threadfin shad (*Dorosoma petenense*) population contributed to more successful efforts at rebalancing the fishery at Lake Oliphant than at Jonesville Reservoir, which does not have a threadfin shad population. To achieve management goals, removal efforts likely would need to be repeated at both impoundments at regular intervals in the future, raising the question of whether these populations should be renovated and restocked using modified stocking rates or other innovative options to meet management goals more efficiently.

Key words: pond management, bass crowded, relative weight, electrofishing

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There are between 2.6 million and 9.0 million ponds in the continental United States (US), with the greatest densities in the Great Plains and southeastern regions (Renwick et al. 2005, Willis and Neal 2012). Such ponds include small public fishing impoundments, which offer quick and inexpensive fishing opportunities to anglers who may otherwise have limited options. In 1991, around 35% of the 30.2 million freshwater anglers spent time fishing in ponds smaller than 4.2 ha (USFWS and USCB 1993), the last year when freshwater angling survey data were separated by lakes, rivers, and ponds. Freshwater fishing trip and equipment expenditures totaled US$29.9 billion in 2016 (USFWS and USCB 2018), highlighting the potential economic importance of small impoundments. Additionally, fisheries management actions are easier to implement and evaluate on small impoundments compared to larger, more complex waterbodies (Willis et al. 2010, Schramm and Willis 2012).

Ponds and small impoundments are commonly stocked with largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*) (Swingle 1949, Dillard and Novinger 1975, Modde 1980, Dauwalter and Jackson 2005), with bluegill providing an abundance of appropriately sized prey for largemouth bass of all sizes when their populations are balanced (Wright and Kraft 2012). However, this balance is challenging to maintain. Largemouth bass typically reproduce at high rates and relatively small sizes in ponds

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(Willis et al. 2010, Wright and Kraft 2012). Additionally, the popularity of catch-and-release angling has increased substantially for black bass (*Micropterus* spp.) over the past four decades (Quinn 1996, Noble 2002, Allen et al. 2008, Myers et al. 2008, Isermann et al. 2013). High rates of reproduction and decreased fishing mortality rates frequently combine to cause ponds to become overpopulated with largemouth bass, typically resulting in density-dependent reductions in largemouth bass condition, growth rates (i.e., stunting), and size structure (Swingle 1956, Gabelhouse 1984, McHugh 1990, Hill and Willis 1993, Willis et al. 2010, Fox and Neal 2011, Aday and Graeb 2012, Wright and Kraft 2012). Concurrently, increased predation reduces bluegill recruitment and contributes to an unbalanced bluegill size structure dominated by large individuals that can spawn multiple times throughout the summer, providing enough prey for stunted largemouth bass to survive but not enough to grow to larger sizes (Swingle 1956, Guy and Willis 1990, McHugh 1990, Aday and Graeb 2012, Schramm and Willis 2012). Stunted bass populations are particularly problematic given the increasing demand by largemouth bass anglers for trophy-sized fish (Wilson and DiCenzo 2002, Dutterer et al. 2014, Bonvechio and Rydell 2015, Maceina et al. 2016).

Fisheries managers have limited options to manipulate stunted largemouth bass populations in small impoundments to produce more balanced populations or meet trophy-bass management objectives, short of performing a full population renovation (Willis et al. 2010, Schramm and Willis 2012). The usual management approach is to remove abundant small largemouth bass to reduce density-dependent effects (Aday and Graeb 2012), but compensatory recruitment by largemouth bass can reduce the effectiveness of this method (Allen et al. 2011, Shaw and Allen 2016). Fisheries managers routinely have used boat electrofishing as a means of mechanical removal of largemouth bass (Gabelhouse 1987, Willis 2010, Beaman 2021, Holt 2021). Annually removing 62–91 largemouth bass per ha in the 200–300 mm TL class from a Kansas pond produced minor improvements to largemouth bass size structure, growth rates, and condition after five consecutive years of removals, but less than 25% of the original estimated number and less than 33% of the estimated biomass of small largemouth bass were removed (Gabelhouse 1987). In a South Dakota pond, three years of removal events were necessary before desired size structure and condition shifts were achieved (Willis 2010). Holt (2021) observed improved size structure and condition of largemouth bass and increased prey fish availability for three years following two years of removing approximately 20% of the largemouth bass biomass annually at Cerrillos Reservoir, Puerto Rico. Beaman (2021) removed 0–83% of largemouth bass <356 mm TL from 11 Alabama ponds for two consecutive years; most population metrics of both largemouth bass and bluegill experienced no significant changes in treatment ponds compared to controls. Collectively across studies, mechanical removal has produced mixed results that seem to be system specific and short-lived, with routine removal events potentially necessary to maintain any substantive population changes and prevent the system from returning to a predator-crowded scenario (Willis 2010, Beaman 2021, Holt 2021). Hindering the ability to draw broad conclusions, most studies evaluating effects of mechanical removal of largemouth bass have been conducted on single systems <10 ha in size (Gabelhouse 1987, Willis 2010, Beaman 2021, Holt 2021).

Mechanical largemouth bass removal studies generally have used fish length as the removal criterion (Gabelhouse 1987, Willis 2010, Beaman 2021, Holt 2021). An alternative method that uses fish condition (relative weight [W_r]) to determine which fish to remove has been used with increasing frequency by private lake consultants (Anderson 1980; Schramm and Willis 2012; W. Bales, Quality Lakes Inc., personal communication). Removing poor-condition fish of any length increases resources available to largemouth bass in better condition, potentially resulting in faster growth rates and larger maximum lengths and weights for the remaining largemouth bass (Schramm and Willis 2012; W. Bales, Quality Lakes Inc., personal communication). However, positive correlation between largemouth bass condition and growth rates in small southern US impoundments has been difficult to confirm under experimental conditions (Blackwell et al. 2000, Schramm and Willis 2012).

The challenges of managing small-impoundment fisheries are of direct concern to the South Carolina Department of Natural Resources (SCDNR), which manages 18 small impoundments as part of the State Lakes Program. These impoundments are owned or leased by SCDNR and are managed to provide easily accessible public fishing opportunities. Although sportfish population management is similar among these 18 impoundments, not all produce quality fisheries as desired by SCDNR and the public (Rankin and Breedlove 2018, Stroud et al. 2019). In particular, approximately half of these small impoundments support stunted bass populations (Rankin and Breedlove 2018, Stroud et al. 2019).

In this study, we examined the effects on predator and prey fish populations following the removal of crowded largemouth bass by boat electrofishing at two SCDNR-managed impoundments (10 and 16 ha). We used W_r as the removal criterion to test the performance of this alternative removal method. The objectives of this study were to 1) determine if moderate removal of largemouth bass in poor condition would increase the size structure and condition and decrease the abundance of largemouth bass, and 2) determine if largemouth bass removals would increase the catch rates and decrease the size structure and condition of bluegill. Improving the size structure of largemouth bass to facilitate more quality largemouth bass fishing opportunities was of particular importance.

Study Area

Jonesville Reservoir (10.1 ha) and Lake Oliphant (16.2 ha) are located in north-central South Carolina in the Piedmont ecoregion. Both impoundments receive standard applications of fertilizer and lime with the goal of increasing the abundance of phytoplankton to boost each system's total carrying capacity (Stone et al. 2012). Water transparency levels between 0.7–0.9 m Secchi disk depth are maintained during the growing season with regular additions of fertilizer. Neither impoundment has aquatic macrophytes, and littoral fish habitat generally comprises fallen trees. Offshore habitat is sparse and is mostly restricted to SCDNR fish attractor sites composed of various mixtures of conifers, homemade plastic pipe units, and/or bamboo units. Jonesville Reservoir has a maximum depth of 7.6 m, and an average depth of 3.0 m. Lake Oliphant has a maximum depth of 7.0 m, and an average depth of 1.5 m.

Largemouth bass, bluegill, redear sunfish (*Lepomis microlophus*), black crappie (*Pomoxis nigromaculatus*), and channel catfish (*Ictalurus punctatus*) provide the primary angling targets, but both impoundments were overpopulated with largemouth bass when our study began (Rankin and Breedlove 2018, Stroud et al. 2019). Both impoundments are open to public fishing year-round on two weekdays and one weekend-day per week, and anecdotal evidence indicates both impoundments receive moderate fishing pressure with low harvest rates of largemouth bass (B. Gardner and M. Owens, SCDNR, personal communications). Lake Oliphant has a reproducing population of threadfin shad (*Dorosoma petenense*) that was established by multiple SCDNR stocking events. Jonesville Reservoir does not have threadfin shad. To provide supplemental forage, both impoundments were stocked with various sizes of bluegill and redear sunfish multiple times throughout the study depending on availability from SCDNR's hatcheries system (Table 1). Stocking rates during the study were consistent with numbers of bluegill and redear sunfish that were stocked annually at both impoundments prior to initiation of removal efforts.

Table 1. Number of fish stocked and stocking rate (fish ha^{-1}) by size group each year during stocking efforts to provide supplemental forage for largemouth bass in two South Carolina impoundments. Size groups for bluegill and redear sunfish averaged approximately 450 fingerlings per kg, 45 advanced fingerlings per kg, and 5 phase II per kg. Threadfin shad were approximately 50–75 mm TL when stocked.

Impoundment	Year	Species	Fingerling	Adv. Fingerling	Phase II	Rate
Jonesville	2020	Bluegill	0	9992	0	989.3
	2020	Redear sunfish	0	2500	0	247.5
	2021	Bluegill	22,559	6221	2816	3128.3
	2021	Redear sunfish	0	0	2505	248.0
	2022	Bluegill	0	9316	0	922.4
	2022	Redear sunfish	0	5661	0	560.5
Oliphant	2020	Bluegill	0	0	536	33.1
	2020	Redear sunfish	0	0	504	31.1
	2020	Threadfin shad	0	17708	0	1093.1
	2021	Bluegill	0	0	529	32.7
	2021	Redear sunfish	0	0	642	39.6
	2022	Redear sunfish	33,749	0	0	2083.3

Methods

Field Sampling and Population Estimates

Closed-population mark-recapture sampling was performed at both impoundments annually in the spring to estimate largemouth bass abundances. Population sizes were estimated at the beginning of the project in 2020, mid-study in 2021 in case adjustments needed to be made to removal targets after the first year of removals, and at project end in 2022 to provide a post-removal estimate. Daytime boat-mounted electrofishing was standardized using 60 pulses sec^{-1} DC settings, with output between 3–5 mean amps. Usually, two people netted off the bow of the boat but personnel restrictions due to COVID-19 limited effort to one netter for all samples in 2020. Electrofishing transects were not standard in distance covered or effort expended but continued until livewells became full of fish, whereupon all fish were processed and electrofishing pedal time was recorded for each transect. Additional transects were sampled until the entire shorelines of both impoundments and any available offshore habitat were sampled during each mark-recapture sampling event.

Marking events occurred in May each year. All largemouth bass and bluegill were measured (TL, mm) and weighed (g). All largemouth bass were marked by removing about 75% of one pelvic fin or the anal fin before release. Left and right pelvic fin marks were used in 2020 and 2021, respectively, and the anal fin was marked in 2022. Post-marking mortality for all fin clip locations was assumed to be zero (Pine et al. 2012). Recapture events were conducted two to four weeks after marking events to allow largemouth bass time to disperse before recapture events (Pine et al. 2012). Largemouth bass and bluegill were collected, examined for marks, measured, and weighed. Because electrofishing is size-selective and underrepresents small fish (Reynolds 1996), separate population estimates were calculated for largemouth bass <200 mm TL and ≥200 mm TL. Largemouth bass population sizes of each length group were estimated using Chapman's modified Lincoln-Petersen model (Chapman 1951, Seber 1982), with variance estimates and confidence intervals determined following Pine et al. (2012). Chapman's modified Lincoln-Petersen population estimates were continually updated as additional largemouth bass were sampled and percentage of the population removed was also tracked in real time so that we knew when removal goals had been reached.

Beginning with the first recapture event, largemouth bass in poor condition ($W_r < 95$) at time of capture were removed from the impoundments, based on Anderson's (1980) recommended W_r range of 95–105 for balanced largemouth bass populations. Relative weights of largemouth bass were calculated on site with standard weight equations given in Neumann et al. (2012) so that removal versus release determinations could be made in real time. Any largemouth bass in good condition ($W_r \geq 95$) were not removed and received a caudal fin clip before release. Marking non-harvested fish with caudal fin clips allowed removal events to also serve as additional recapture sampling events to improve the accuracy and precision of population estimates. Uniquely marked largemouth bass that displayed good condition and were released would at most be counted once during multiple recapture events, allowing the use of the simple Lincoln-Petersen estimator by combining multiple recapture events into a single census. This method performed well in similar removal studies where immigration was not a strong influence (Skalski and Robson 1982, Pollock 1991). Top and bottom caudal fin clips were alternated between 2020 and 2021 for non-harvested largemouth bass released during removal events. Additional removal events occurred until the number of fish removed reached targets of 40–50% of estimated population sizes. Largemouth bass were removed from both impoundments in 2020 until removal targets were achieved. Following the first year (2020) of removals, only a limited number of additional largemouth bass were removed from Lake Oliphant due to positive results in the predator and prey fish population metrics in spring 2021. Additional largemouth bass were removed from Jonesville Reservoir in 2021 until the removal target of 40–50% of estimated population size was achieved. No additional largemouth bass were removed from either lake in 2022.

Population Metrics

Populations were assessed annually using only data collected during the marking and the first recapture events to standardize timing of assessments. Catch rate (CPUE) was calculated as the number of fish collected per hour (fish h^{-1}) of electrofishing for each sampling transect and was used as a measure of relative abundance for bluegill and largemouth bass. Largemouth bass and bluegill *Wr* were calculated using equations given in Neumann et al. (2012). Proportional size distributions (PSD) by length classes were used to characterize size structure of the largemouth bass and bluegill populations and were calculated using standard methods (Gabelhouse 1984, Guy and Brown 2007, Neumann et al. 2012, Ogle et al. 2022). Biomass (kg ha^{-1}) of each impoundment was estimated by multiplying the estimated largemouth bass population size by the mean total weight for each year. All population metrics were calculated with program R (R Core Team 2022) and the Simple Fisheries Stock Assessment Methods (FSA) package (Ogle et al. 2022).

Statistical Analyses

Differences in CPUE and *Wr* of largemouth bass and bluegill were assessed among the three study years in each impoundment. Assumptions of normality were checked using histograms of residuals, quantile-quantile plots (QQ-plots), and Shapiro-Wilk tests (R Core Team 2022). Homogeneities of variance were checked using Bartlett's tests. Due to non-normality that was not improved by $\log_{10}$- and square-root transformations, Kruskal-Wallis ANOVA tests were conducted on untransformed CPUE and W_r values for all four impoundment and species combinations from 2020–2022 (R Core Team 2022). Significance of any changes in size structure of largemouth bass and bluegill were determined by using chi-square tests to compare differences in the frequencies of various PSD length groups (stock, quality, preferred, and memorable length) at each impoundment for fish collected during the 2020 and 2022 population assessments (Neumann et al. 2012, Ogle et al. 2022, R Core Team 2022). A significance level of $\alpha = 0.05$ was used for all statistical tests.

Results

Population Estimates

The estimated population size of large largemouth bass remained high after the first year of removals but declined sharply in 2022 at Jonesville Reservoir (Table 2). The estimated population size of small largemouth bass in Jonesville Reservoir declined by over half from 2020 to 2021 but returned to close to the 2020 estimate in 2022. Biomass of large largemouth bass decreased each year, but biomass of small largemouth bass only declined from 2020 to 2021 before increasing in 2022 to close to the 2020 estimate (Table 2). At Lake Oliphant, estimated population size of large largemouth bass declined by over half from 2020 to 2021 and remained low in 2022 (Table 2). Conversely, estimated population size of small largemouth bass showed a lesser decline from 2020 to 2021 but doubled from 2021 to 2022. Biomass of large largemouth bass at Lake Oliphant declined by over half from 2020 to 2021 and remained low in 2022, whereas biomass of small largemouth bass was low and similar among study years (Table 2). Precision

Table 2. Mark-recapture population parameters and estimates for large (≥200 mm TL) and small (<200 mm TL) largemouth bass, including number of fish marked (*M*), number censused (*C*), number recaptured (*R*), estimated population size ($\hat{N}$; 95% CI in parentheses), total biomass estimate (kg; 95% CI), biomass estimate (kg ha^{-1}; 95% CI), number removed, and percent (%) of estimated population size removed for each year at two South Carolina impoundments.

Impoundment	Size	Year	*M*	*C*	*R*	$\hat{N}$	Total Biomass	Biomass	Number Removed	Percent Removed
Jonesville	≥200 mm	2020	205	718	120	1223 (127)	446 (46)	44.1 (4.6)	699	57.2
		2021	213	526	85	1310 (195)	311 (46)	30.8 (4.6)	448	34.2
		2022	115	62	13	521 (219)	169 (71)	16.8 (7.0)	0	0
	<200 mm	2020	139	437	57	1056 (192)	55 (10)	5.4 (1.0)	416	39.4
		2021	109	85	33	277 (60)	19 (4)	1.9 (0.4)	78	28.2
		2022	103	61	7	805 (472)	51 (30)	5.0 (3.0)	0	0
Oliphant	≥200 mm	2020	247	833	108	1897 (248)	776 (101)	47.9 (6.3)	718	37.8
		2021	141	124	27	633 (182)	290 (83)	17.9 (5.1)	54	8.5
		2022	71	69	9	503 (256)	317 (161)	19.6 (10.0)	0	0
	<200 mm	2020	56	259	28	510 (121)	24 (6)	1.4 (0.3)	228	44.7
		2021	50	36	5	314 (200)	19 (12)	1.2 (0.7)	22	7.0
		2022	35	43	1	791 (851)	25 (27)	1.5 (1.6)	0	0

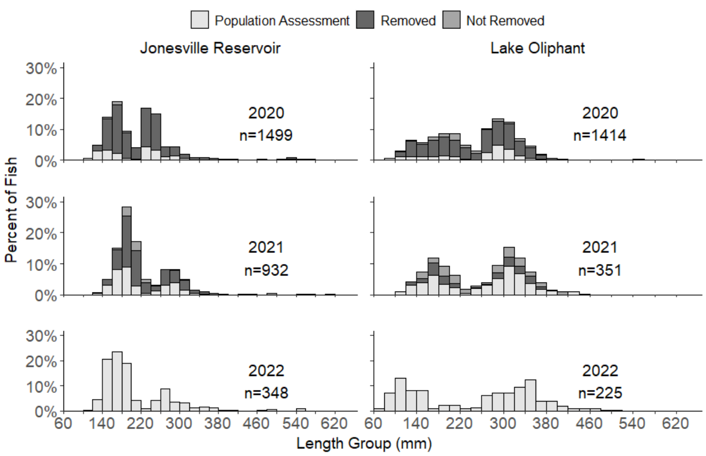

Figure 1. Length frequency histograms showing the distribution of largemouth bass that were collected during population assessment events (light gray) or were collected during removal events and either harvested (dark gray) or released (medium gray) at two small impoundments in South Carolina.

of abundance estimates in both impoundments decreased in 2022 due to fewer recapture events and numbers of recaptures.

Removals

Annual removal totals approached targets of removing 40–50% of estimated population sizes of both length groups at both impoundments in 2020 but fell short at Jonesville Reservoir in 2021 (Table 2). At both impoundments, nearly all largemouth bass over 400 mm TL had good *Wr*, resulting in nearly all removal effort being focused on smaller fish (Figure 1). At Jonesville Reservoir, six removal events, during which the entire shoreline and available offshore habitat were sampled at least once, and usually two or three times, occurred in June and July 2020. This removal-event electrofishing effort totaled 15.4 h of active pedal time, resulting in median CPUE (±95% CI) of 72 (±24) largemouth bass h^{-1}. Of 1155 largemouth bass collected in 2020, 699 large fish and 416 small fish were removed (Table 2). Six removal events also occurred in 2021 at Jonesville Reservoir, producing a total of 20.0 h of electrofishing effort in June and July and median CPUE of 22 (±7) fish h^{-1}. Removal events captured 611 total largemouth bass in 2021, with 448 large fish and 78 small fish removed (Table 2). Cumulatively, during 2020 and 2021, 1765 largemouth bass were collected during removal events and 1641 were removed from Jonesville Reservoir.

Eight removal events occurred in June and July at Lake Oliphant in 2020, for a total electrofishing pedal time of 20.3 h. Removal efforts captured 1092 largemouth bass (median CPUE 51 [±27] fish h^{-1}), with 718 large fish and 228 small fish removed (Table 2). Positive results observed during population assessment events in spring 2021, including nearly a three-fold increase in catch rates of bluegill, decreased catch rates of largemouth bass, high proportions of largemouth bass with condition over the *Wr* removal threshold, and reduced largemouth bass population estimates of both size groups, resulted in the decision to not remove additional largemouth bass from Lake Oliphant. Before the decision had been made, a single removal event occurred in 2021 during which the entire shoreline was sampled once, resulting in 3.0 h of electrofishing effort. Only 160 largemouth bass were collected in 2021 (median CPUE 52 [±23] fish h^{-1}), with 54 and 22 large and small fish removed, respectively (Table 2). Cumulatively, during 2020 and 2021, 1252 largemouth bass were collected during removal events in Lake Oliphant, of which 1022 were removed.

Population Metrics and Statistical Comparisons

Median CPUE of largemouth bass and bluegill varied across years at both impoundments (Figure 2). A total of 11 h of electrofishing effort was expended during population assessments at Jonesville Reservoir in May and June from 2020–2022. Median largemouth bass catch rates declined 40% from 2020 to 2021 and remained low in 2022 (Figure 2). Median bluegill catch rate was higher in 2021 than 2022 but both years were similar to 2020. At Lake Oliphant, a total of 10.3 h of electrofishing effort was expended during population assessments from 2020–2022. Median catch rates of largemouth bass declined by half from 2020 to 2021 and remained low in 2022. Median catch rates of bluegill more than doubled from 2020 to 2021 but were similar between 2020 and 2022 (Figure 2).

Median *Wr* of largemouth bass in Jonesville Reservoir increased 11% between 2020 and 2021, declined 3.1% in 2022, and differed among all three years ($|Z| \geq 3.251$, $P \leq 0.0003$; Figure 3). Median relative weights of bluegill at Jonesville Reservoir were similar between 2020 and 2021 ($Z = 2.053$, $P = 0.120$) and between 2021 and 2022 ($Z = 1.271$, $P = 0.611$), but were 2.7% higher in 2020 than 2022 ($Z = 3.042$, $P = 0.007$). Median relative weights of largemouth bass at Lake Oliphant increased 5.2% from 2020 to 2021 ($Z = -7.897$, $P < 0.001$) and 7.5% from 2020 to 2022 ($Z = -8.253$, $P < 0.001$) but were similar between 2021 and 2022 ($Z = -1.692$, $P = 0.272$). Median relative weights of bluegill in Lake Oliphant increased 4.0% from 2020 to 2021 before declining in 2022 to the lowest value observed during the study ($|Z| \geq 2.842$, $P \leq 0.013$; Figure 3).

Largemouth bass size structure (frequencies of various PSD length groups) did not change at Jonesville Reservoir between 2020 and 2022 (Table 3). Changes in bluegill size structure occurred at Jonesville Reservoir from 2020–2022, primarily driven by a sharp decline in PSD-Q and PSD-P from 2020 to 2022. Largemouth bass size structure changed at Lake Oliphant from 2020 to 2022. This was driven by substantial increases in PSD-Q (64 in 2020 and 79 in 2022) and PSD-P (7 in 2020 and 21 in 2022). Size structure of bluegill also saw significant differences between 2020 and 2022 at Lake Oliphant, mostly driven by declines in PSD-Q and PSD-P (Table 3).

Discussion

Small impoundments with overcrowded largemouth bass populations are a widespread issue (Wright and Kraft 2012). Such crowded impoundments do not meet the goals of many angling groups, particularly because the desire to catch trophy largemouth bass has increased (Wilson and DiCenzo 2002). Across several single-impoundment studies, reducing the abundance of stunted largemouth bass generally has not led to long-term rebalancing of

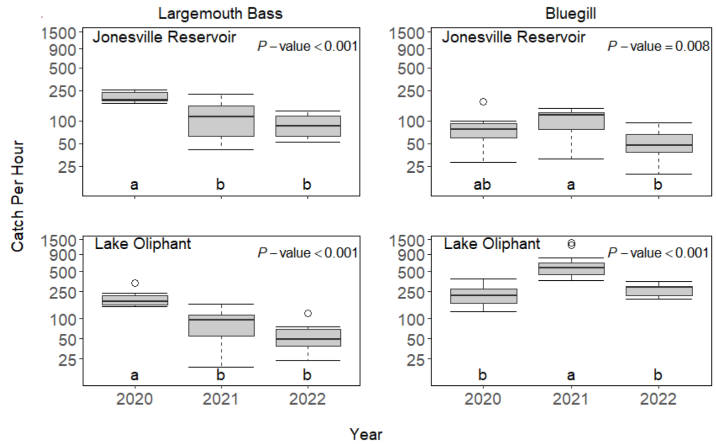

Figure 2. Boxplots illustrating the catch-per-hour (CPUE) of largemouth bass and bluegill during population assessments at Jonesville Reservoir and Lake Oliphant in South Carolina from 2020–2022. *P*-values from Kruskal-Wallis tests are given in the upper right corner of each plot. Shared letters denote similar CPUE values between years in year-by-year pairwise comparisons using Dunn's Test for multiple comparisons for each lake and species.

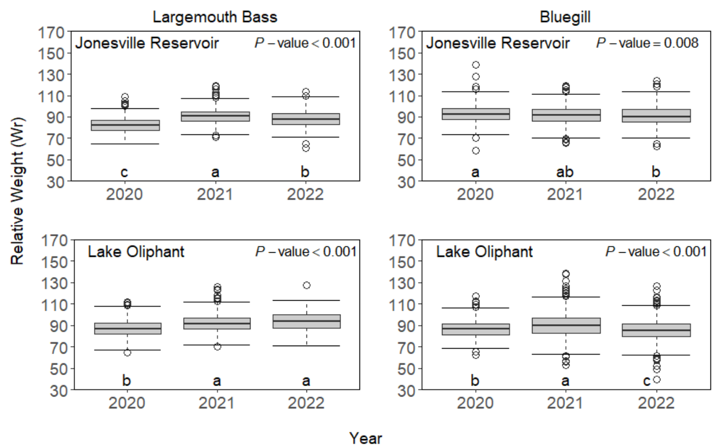

Figure 3. Boxplots illustrating the relative weight (*Wr*) of largemouth bass and bluegill during population assessments at Jonesville Reservoir and Lake Oliphant in South Carolina from 2020–2022. *P*-values from Kruskal-Wallis tests are given in the upper right corner of each plot. Shared letters denote similar W_r values between years in year-by-year pairwise comparisons using Dunn's Test for multiple comparisons for each lake and species.

Table 3. Proportional size distributions (PSDs) for quality (PSD-Q), preferred (PSD-P), and memorable (PSD-M) length largemouth bass (LMB) and bluegill (BLG) and associated chi-square test results comparing changes in length distribution for each impoundment and species from 2020 to 2022 for two South Carolina impoundments.

Impoundment	Species	Year	PSD-Q	PSD-P	PSD-M	X^2(df)	P
Jonesville	LMB	2020	26	8	5	1.78 (3)	0.619
		2022	27	7	3		
	BLG	2020	60	32	1	47.43 (3)	<0.001
		2022	31	8	0		
Oliphant	LMB	2020	64	7	1	27.89 (3)	<0.001
		2022	79	21	1		
	BLG	2020	22	4	0	64.47 (2)	<0.001
		2022	8	1	0		

largemouth bass-bluegill populations (Gabelhouse 1987, McHugh 1990, Willis 2010, Holt 2021). In our study, removal of largemouth bass at moderate rates appeared to be more successful at rebalancing the largemouth bass and bluegill populations at Lake Oliphant than at Jonesville Reservoir. Jonesville Reservoir maintained higher densities of large and small largemouth bass throughout the study than Lake Oliphant, even though it experienced a second year of intense removal efforts in 2021 that did not occur at Lake Oliphant. Although Jonesville Reservoir's large largemouth bass population size declined by nearly half after the second year of removals, bluegill catch rates and largemouth bass size structure did not increase as observed at Lake Oliphant. Higher bluegill catch rates, improved largemouth bass condition and size structure, and greatly reduced largemouth bass catch rates all suggested that removal efforts resulted in progress towards rebalancing the largemouth bass and bluegill populations at Lake Oliphant.

Changes in estimated population sizes of large and small largemouth bass indicated similar trends between the two impoundments. The population size of large fish eventually declined substantially at both impoundments, although Jonesville Reservoir required a second year of intense removal efforts to produce a decline comparable to that observed at Lake Oliphant following only one year of removals. Jonesville Reservoir had greater densities of all sizes of largemouth bass than Lake Oliphant throughout the study (Table 2), likely contributing to the need to perform the second year of intense removal efforts at Jonesville Reservoir in 2021. Holt (2021) found that consecutive years of 20% largemouth bass biomass removals at Cerrillos Reservoir, Puerto Rico, resulted in increased abundance and biomass after the second year of removals, attributing this to improved size structure which opened a wider breadth of potential prey to the population. However, while population sizes and biomass of small largemouth bass declined at both of our study impoundments after the first year of removals, these metrics returned in 2022 to levels similar to those observed in 2020, potentially indicating that compensatory recruitment began to affect both populations (Allen et al. 2011, Shaw and Allen 2016).

Removal events came close to removing targets of 40–50% of the estimated population sizes at both impoundments in 2020 but fell short in 2021 at Jonesville Reservoir. Catch rates declined precipitously at Jonesville Reservoir as the summer went on in 2021, and biologists' time constraints combined with decreased efficiency forced the ending of removal efforts before they had reached removal targets. Similar plummets in catch rates were observed as removal events continued at Lake Oliphant in 2020, which provided hope that adequate largemouth bass removals had been achieved by the end of the second removal season at Jonesville Reservoir. Beaman (2021) encountered similar issues with diminished returns in largemouth bass catchability that resulted in falling short of removal targets, particularly at impoundments with the highest removal targets of 70% or 90% of the estimated population sizes.

We selected $Wr = 95$ as the removal threshold because it was the bottom of the range suggested for balanced fish populations by Anderson (1980). However, the selected threshold was likely too high for a robust evaluation of this technique. Most largemouth bass at Lake Oliphant had relative weights in the 90–95 range prior to removal efforts, and at both impoundments the selected threshold resulted in most largemouth bass encountered during removal events being removed (93% at Jonesville Reservoir and 82% at Lake Oliphant). Conversely, lower *Wr* thresholds would have removed too few fish from the population to trigger population responses of bluegill and largemouth bass. Further, almost every largemouth bass ≥400 mm TL had *Wr* above the threshold at both impoundments, resulting in nearly all removals being of fish <400 mm TL. Thus, we cannot determine the efficacy of utilizing relative weight as a removal threshold. A more robust study with control populations conducted over a longer period of time with a lower removal threshold would likely be needed to fully determine this removal method's effectiveness. It would also be beneficial to estimate growth rates of largemouth bass prior to any subsequent removal experiments so that evidence of stunting can be combined with condition values to confirm that removal of largemouth bass in poor condition removes slow-growing, stunted individuals.

Catch rates of largemouth bass during annual population assessments declined sharply at both impoundments after the first year of removals and remained low in 2022. This would be expected if removal efforts were successful. Catch rates of bluegill were unexpectedly low throughout the study at Jonesville Reservoir, and only increased for one year in Lake Oliphant. This is contrary to what would be expected following a large reduction of predators (Schramm and Willis 2012), but could be due to interactions with other prey fishes (e.g., threadfin shad; Maceina and Sammons 2014) or an artifact of size-selective sampling efficiency (Reynolds 1996).

Largemouth bass median relative weights improved after the first year of removals at both impoundments and remained high at Lake Oliphant but declined slightly at Jonesville Reservoir from 2021 to 2022, similar to results from other studies (Gabelhouse 1987; Willis 2010; Holt 2021). These results differ from those observed by Beaman (2021), as only one length group (254–356 mm TL) experienced improved body condition and not for the entire duration of the removal project. Relative weight values of bluegill declined in both reservoirs from 2020 to 2022, although they increased in Lake Oliphant from 2020 to 2021 before ultimately declining in 2022. Reduced bluegill body condition values were expected from successful rebalancing attempts due to expected increases in bluegill abundance. Bluegill abundance remained low at Jonesville Reservoir throughout this study, making interpretation of the decline in bluegill relative weights difficult. These observations further implicate sampling efficiency issues affecting our ability to assess changes in bluegill CPUE.

Removal efforts restructured the largemouth bass size distribution, in terms of PSD-Q and PSD-P, at Lake Oliphant but not at Jonesville Reservoir. Jonesville Reservoir's lack of size structure improvements is consistent with Willis (2010), who did not see improvements in largemouth bass size structure until year 5 of his removal study. Conversely, Beaman (2021) observed improvements in largemouth bass size structure in treatment ponds after the second year of removal efforts compared to control ponds, similar to our results at Lake Oliphant. However, most improvements in largemouth bass size structure observed by Beaman (2021) resulted mainly from declines in size structure in control ponds rather than strong improvements in treatment ponds, differing from our study results. Bluegill PSD values declined sharply after the first year of largemouth bass removals at both reservoirs. As prey abundance increased following the reduction in predator fish abundance, prey fish size structure was expected to decline (Schramm and Willis 2012), but little change was noted in bluegill abundance at Jonesville Reservoir. This further suggests that relative abundance of bluegill may not have been adequately indexed during this study.

Reasons behind the inconsistent results of largemouth bass removals between the study impoundments are unclear. Beaman (2021) found similar inconsistencies when conducting removals of varying intensities across 11 ponds in Alabama. It is apparent that Jonesville Reservoir was more severely crowded than Lake Oliphant, given that densities of large and small largemouth bass remained greater at Jonesville Reservoir than Lake Oliphant throughout the study. Greater densities of largemouth bass and evidence of possible compensatory recruitment effects could have combined to offset the effects of the largemouth bass removals at Jonesville Reservoir. Jonesville Reservoir (mean depth 3 m) is deeper than Lake Oliphant (mean depth 1.5 m). Quick access to deep water from shoreline areas could have reduced largemouth bass catchability at Jonesville Reservoir, perhaps leading to inaccurate estimates of population sizes and, therefore, underestimating the proportions of the population removed each year. Stocking of supplemental forage in the form of additional bluegill and redear sunfish did not seem to impact results as sunfish were stocked into Jonesville Reservoir at much higher rates than Lake Oliphant. The presence of threadfin shad at Lake Oliphant could a be key factor, as pelagic prey fish may have resulted in a significant subpopulation of pelagic largemouth bass that were not subject to removals (Wanjala et al. 1986). Removal efforts were focused on littoral zones due to limitations of boat electrofishing in deep water. Largemouth bass that specialized in preying on bluegill in shallow water were likely removed at proportionally higher rates than those dwelling in pelagic zones to feed on threadfin shad (Wanjala et al. 1986, Ward and Neumann 1998), potentially reducing largemouth bass predation on bluegill (Maceina and Sammons 2014) and leading to the increase in bluegill abundance observed after the first year of removals. Additionally, stocking threadfin shad into small impoundments has been shown to increase largemouth bass growth (Haley 2009), *Wr*, and size structure (Maceina and Sammons 2014). Threadfin shad stocked into two largemouth bass-crowded impoundments restructured the largemouth bass populations to be skewed towards larger fish with high *Wr* values even though there were no largemouth bass removals (Maceina and Sammons 2014). With an established threadfin shad population present, a single year of intense largemouth bass removals appeared to successfully restructure the largemouth bass and bluegill populations at Lake Oliphant.

Regardless of the reasons for inconsistent responses between our two impoundments, these results illustrate the difficulty of predicting the efficacy of largemouth bass removals. Removal efforts likely need to be continued annually or at least every other year to successfully rebalance or to maintain balanced predator and prey fish populations, given decreases observed in angler harvest of largemouth bass (Myers et al. 2008, Willis 2010, Beaman 2021, Holt 2021). Population restructuring was achieved with five years of largemouth bass removal efforts at Knox Pond, South Dakota, but seven years after removals ceased the impoundment had returned to largemouth bass-crowded conditions (Willis 2010). Therefore, removal events likely need to occur regularly at both impoundments: to affect the desired restructuring at Jonesville Reservoir and to maintain the progress made towards restructuring the populations during this project at Lake Oliphant. Ultimately, the costs of manpower-intensive, long-term, periodic removal events by electrofishing may not be worth the potential returns, especially when success is not guaranteed and cannot be replicated from one reservoir to the next (Beaman 2021).

Alternatives to performing regular mechanical largemouth bass removals exist. McHugh (1990) found that a combination of a selective application of the fish toxicant rotenone to the margins of ponds and mechanical removal of stunted largemouth bass successfully reduced largemouth bass recruitment to the point where largemouth bass growth and bluegill abundance both increased. However, benefits to the largemouth bass and bluegill populations were short-lived, and it was recommended that rotenone applications be repeated every 2–4 years (McHugh 1990). When possible, complete renovations of ponds and small impoundments typically produce higher quality fishing and have a higher rate of success, at least during the initial 5–7 years after restocking, compared to performing mechanical removals with unpredictable success rates (Slipke and Sammons 2012, Wright and Kraft 2012). Where renovation is an option, restocking the impoundment using the innovative female-only largemouth bass management strategy has proven to be a method that can simultaneously prevent, or at least delay, crowding of largemouth bass and produce excellent trophy bass fishing (Bonvechio and Rydell 2015, Maceina et al. 2016). Renovations using either restocking option (traditional or female-only) are more reliable than removals in restructuring sportfish populations and providing quality angling experiences, but they require several years of downtime while the populations build, often making renovations unpopular with anglers and impoundment managers (Slipke and Sammons 2012). In the past, directed removals were not necessary because angler harvest removed appropriate numbers of largemouth bass to maintain population balance, but this is no longer the case (Parks and Seidensticker 1998, Noble and Jones 1999, Allen et al. 2008, Bonds et al. 2008, Bonvechio et al. 2013). Unless black bass angler behaviors change and harvest rates of largemouth bass in small impoundments experience a dramatic increase, small impoundment managers will continue to struggle with methods to prevent or to rehabilitate largemouth bass-crowded fisheries.

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Literature Cited

Aday, D. D. and B. D. S. Graeb. 2012. Stunted fish in small impoundments: an overview and management perspective. Pages 215–232 *in* J. W. Neal and D. W. Willis, editors. Small impoundment management in North America. American Fisheries Society, Bethesda, Maryland.

Allen, M. S., M. W. Rogers, M. J. Catalano, D. G. Gwinn, and S. J. Walsh. 2011. Evaluating the potential for stock size to limit recruitment in largemouth bass. Transactions of the American Fisheries Society 140:1093–1100.

_____, C. J. Walters, and R. Myers. 2008. Temporal trends in largemouth bass mortality with fishery implications. North American Journal of Fisheries Management 28:418–427.

Anderson, R. O. 1980. Proportional stock density (PSD) and relative weight (Wr): interpretive indices for fish populations and communities. Pages 27–33 *in* S. Gloss and B. Shupp, editors. Practical fisheries management: more with less in the 1980's. American Fisheries Society, New York Chapter, Ithaca.

Beaman, T. T. 2021. Evaluation of mechanical removal rates for rehabilitating over-crowded largemouth bass *Micropterus salmoides* populations in Alabama small impoundments. Master's thesis, Auburn University, Auburn, Alabama.

Blackwell, B. G., M. L. Brown, and D. W. Willis. 2000. Relative weight (Wr) status and current use in fisheries assessment and management. Reviews in Fisheries Science 8:1–44.

Bonds, C. C., J. B. Taylor, and J. Leitz. 2008. Practices and perceptions of Texas anglers regarding voluntary release of largemouth bass and slot length limits. Pages 219–230 *in* M. S. Allen, S. M. Sammons, and M. J. Maceina, editors. Balancing fisheries management and water uses for impounded river systems. American Fisheries Society, Symposium 62, Bethesda, Maryland.

Bonvechio, T. F., B. R. Bowen, J. M. Wixson, and M. S. Allen. 2013. Exploitation and length limit evaluation of largemouth bass in three Georgia small impoundments. Journal of the Southeastern Association of Fish and Wildlife Agencies 1:33–41.

_____ and J. J. Rydell. 2015. Use of a female-only stocking strategy to establish a trophy largemouth bass fishery in a Georgia small impoundment. Journal of the Southeastern Association of Fish and Wildlife Agencies 3:136–143.

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological sample censuses. University of California Publications in Statistics 1:131–160.

Dauwalter, D. C. and J. R. Jackson. 2005. A re-evaluation of U.S. state fish-stocking recommendations for small, private warmwater impoundments. Fisheries 30(8):18–27.

Dillard, J. G. and G. D. Novinger. 1975. Stocking largemouth bass in small impoundments. Pages 459–479 *in* R. H. Stroud and H. Clepper, editors. Black bass biology and management. Sport Fishing Institute, Washington, D.C.

Dutterer, A. C., C. Wiley, B. Wattendorf, J. R. Dotson, and W. F. Pouder. 2014. Trophy catch: a conservation program for trophy bass in Florida. Florida Scientist 77:167–183.

Fox, C. N. and J. W. Neal. 2011. Development of a crowded largemouth bass population in a tropical reservoir. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 65:98–104.

Gabelhouse, D. W., Jr. 1984. A length-categorization system to assess fish stocks. North American Journal of Fisheries Management 4:273–285.

_____. 1987. Responses of largemouth bass and bluegills to removal of surplus largemouth bass from a Kansas pond. North American Journal of Fisheries Management 7:81–90.

Guy, C. S. and M. L. Brown, editors. 2007. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

_____ and D. W. Willis. 1990. Structural relationships of largemouth bass and bluegill in South Dakota ponds. North American Journal of Fisheries Management 10:338–343.

Haley, N. V., III. 2009. Privately-owned small impoundments of central Alabama: a survey and evaluation of management techniques and enhancements. Master's thesis, Auburn University, Auburn, Alabama.

Hill, T. D. and D. W. Willis. 1993. Largemouth bass biomass, density, and size structure in small South Dakota impoundments. Proceedings of the South Dakota Academy of Sciences 72:31–39.

Holt, C. 2021. Effects of reduced predator abundance on the predator-prey community of a tropical reservoir. Doctoral dissertation, Mississippi State University, Starkville.

Isermann, D. A., J. B. Maxwell, and M. C. McInerny. 2013. Temporal and regional trends in black bass release rates in Minnesota. North American Journal of Fisheries Management 33:344–350.

Maceina, M. J. and S. M. Sammons. 2014. Stocking threadfin shad to enhance largemouth bass populations in two Alabama ponds. Journal of the Southeastern Association of Fish and Wildlife Agencies 2:28–34.

_____, _____, and R. P. Phelps. 2016. Evaluation of stocking all female largemouth bass (*Micropterus salmoides*) in Alabama (USA) ponds. Natural Resources 7:315–325.

McHugh, J. J. 1990. Responses of bluegills and crappies to reduced abundance of largemouth bass in two Alabama impoundments. North American Journal of Fisheries Management 10:344–351.

Modde, T. 1980. State stocking policies for small warmwater impoundments. Fisheries 5:13–17.

Myers, R. A., J. Taylor, M. Allen, and T. Bonvechio. 2008. Temporal trends in voluntary release of largemouth bass. North American Journal of Fisheries Management 28:428–433.

Neumann, R. M., C. S. Guy, and D. W. Willis. 2012. Length, weight, and associated indices. Pages 637–676 *in* A. V. Zale, D. L. Parrish, and T. M. Sutton, editors. Fisheries techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Noble, R. L. 2002. Reflections on 25 years of progress in black bass management. Pages 419–432 *in* D. P. Phillip and M. S. Ridgeway, editors. Black bass: ecology, conservation, and management. American Fisheries Society, Symposium 31, Bethesda, Maryland.

_____ and T. W. Jones. 1999. Managing fisheries with regulations. Pages 455–480 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Ogle, D. H., J. C. Doll, P. Wheeler, and A. Dinno. 2022. FSA: fisheries stock analysis. R package version 0.9.3.

Parks, J. O. and E. P. Seidensticker. 1998. Evaluation of a 356–457 mm slot length limit for largemouth bass in 5 Texas reservoirs. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 52:76–85.

Pine, W. E., J. E. Hightower, L. G. Coggins, M. V. Lauretta, and K. H. Pollock. 2012. Design and analysis of tagging studies. Pages 521–572 *in* A. V. Zale, D. L. Parrish, and T. M. Sutton, editors. Fisheries techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Pollock, K. H. 1991. Modeling capture, recapture, and removal statistics for estimation of demographic parameters of fish and wildlife populations: past, present, and future. Journal of the American Statistical Association 86:225–238.

Quinn, S. 1996. Trends in regulatory and voluntary catch-and-release fishing. Pages 152–162 *in* L. E. Miranda and D. R. DeVries, editors. Multidimensional approaches to reservoir fisheries management. American Fisheries Society, Symposium 16, Bethesda, Maryland.

R Core Team. 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria.

Rankin, D. and A. Breedlove. 2018. South Carolina Department of Natural Resources. Annual progress report F-63 July 1, 2017 to June 31, 2018. Columbia, South Carolina.

Renwick, W. H., S. V. Smith, J. D. Bartley, and R. W. Buddemeier. 2005. The role of impoundments in the sediment budget of the conterminous United States. Geomorphology 71:99–111.

Reynolds, J. B. 1996. Electrofishing. Pages 221–253 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Schramm, H. L., Jr. and D. W. Willis. 2012. Assessment and harvest of largemouth bass-bluegill ponds. Pages 181–214 *in* J. W. Neal and D. W. Willis, editors. Small impoundment management in North America. American Fisheries Society, Bethesda, Maryland.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters. Edward Arnold, London, UK.

Shaw, S. L. and M. S. Allen. 2016. Quantifying recruitment compensation in Florida largemouth bass, with implications for fisheries. Transactions of the American Fisheries Society 145:462–475.

Skalski, J. R. and D. S. Robson. 1982. A mark and removal field procedure for estimating population abundance. Journal of Wildlife Management 46:741–751.

Slipke, J. W. and S. M. Sammons. 2012. Pond renovation. Pages 235–250 *in* J. W. Neal and D. W. Willis, editors. Small impoundment management in North America. American Fisheries Society, Bethesda, Maryland.

Stone, N., J. E. Morris, and B. Smith. 2012. Managing the pond environment. Pages 113–152 *in* J. W. Neal and D. W. Willis, editors. Small impoundment management in North America. American Fisheries Society, Bethesda, Maryland.

Stroud, R. M., J. E. Marsik, G. C. Edge, and P. C. Chrisman. 2019. South Carolina Department of Natural Resources. Annual progress report F-63 July 1, 2018 to June 31, 2019. Columbia, South Carolina.

Swingle, H. S. 1949. Experiments with combinations of largemouth black bass, bluegills, and minnows in ponds. Transactions of the American Fisheries Society 76:46–62.

_____. 1956. Determination of balance in farm fish ponds. Transactions of the North American Wildlife Conference 21:298–322.

U.S. Fish and Wildlife Service and U.S. Census Bureau [USFWS and USCB]. 1993. 1991 national survey of fishing, hunting, and wildlife-associated recreation. USFWS and USCB, Washington, D.C.

_____ and _____. 2018. 2016 national survey of fishing, hunting, and wildlife-associated recreation. Report FHW/16-NAT (RV). USFWS and USCB, Washington, D.C.

Wanjala, B. S., J. C. Tash, W. J. Matter, and C. D. Ziebell. 1986. Food and habitat use by different sizes of largemouth bass (*Micropterus salmoides*) in Alamo Lake, Arizona. Journal of Freshwater Ecology 3:359–369.

Ward, S. M. and R. M. Neumann. 1998. Seasonal and size-related food habits of largemouth bass in two Connecticut lakes. Journal of Freshwater Ecology 13:213–220.

Willis, D. W. 2010. A protected slot length limit for largemouth bass in a small impoundment: Will the improved size structure persist? Pages 203–210 *in* B. R. Murphy, D. W. Willis, M. L. Davis, and B. D. S. Graeb, editors. Instructor's guide for case studies in fisheries conservation and management: applied critical thinking and problem solving. American Fisheries Society, Bethesda, Maryland.

_____, R. D. Lusk, and J. W. Slipke. 2010. Farm ponds and small impoundments. Pages 501–544 *in* W. A. Hubert and M. C. Quist, editors. Inland fisheries management in North America, 3rd edition. American Fisheries Society, Bethesda, Maryland.

_____ and J. W. Neal. 2012. Small impoundments and the history of their management. Pages 155–180 *in* J. W. Neal and D. W. Willis, editors. Small impoundment management in North America. American Fisheries Society, Bethesda, Maryland.

Wilson, D. M. and V. J. Dicenzo. 2002. Profile of a trophy largemouth bass fishery in Briery Creek Lake, Virginia. Pages 583–592 *in* D. P. Phillip and M. S. Ridgway, editors. Black bass: ecology, conservation and management. American Fisheries Society Symposium 31, Bethesda, Maryland.

Wright, R. A. and C. E. Kraft. 2012. Stocking strategies for recreational small impoundments. Pages 155–180 *in* J. W. Neal and D. W. Willis, editors. Small impoundment management in North America. American Fisheries Society, Bethesda, Maryland.