Stocking of Advanced-Size Largemouth Bass in Two Estuarine Creeks and a Freshwater Impoundment in Southwest Alabama

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Abstract: The Mobile-Tensaw Delta is an 8231-ha oligohaline, tidal estuary that supports a popular largemouth bass (*Micropterus salmoides)* fishery. This system is productive, with an abundant bass population and above-average recruitment to age-1. But recruitment of the 2004 year-class was poor post-Hurricane Ivan, prompting angler concerns about the population. We considered improvements in the fishery were most likely achieved by stocking advanced-size fingerlings. Larger, older fish reared on live food were expected to provide a competitive advantage over native fish and exhibit higher survival than stocking smaller fingerlings. As this is an expensive venture, we tested this proposal in two tidal watersheds, Byrnes Lake and Threemile Creek, and a freshwater control, Monroe County Lake. During 2010–2014, a total of 16,380 advanced-size (97–354 mm TL) largemouth bass were tagged and stocked at approximately 10 months old. Abundance of wild fish was 5.0–77.5 times higher than stocked fish CPUE among sample areas, season and year. Percent contribution of stocked bass to individual cohorts was low, but highest at age-1, ranging from 2% to 31%. Percent contribution of stocked bass to cohorts decreased considerably after age-1, ranging from 1% to 16% and no tagged individuals were found after age-2 in Monroe County Lake. Length-frequency distributions differed between stocked and wild fish at all study areas pooled across years during spring, but distributions did not differ in the fall. Success of fish stockings are linked to numerous factors, though competition with wild fish, size at stocking, and culture techniques are aspects to consider. This study was initiated well after fish populations had recovered and stocking likely was unnecessary given that fish populations are resilient to climate-induced fish kill events. State agencies should consider existing fish populations before stocking and long term recruitment data should be established prior to considering an extensive stocking program.

Key words: stocking contribution, recruitment, survival, estuary

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State agencies often stock largemouth bass (*Micropterus salmoides*) in efforts to supplement populations with the intent of increasing catch rates for anglers (Hoxmeier and Wahl 2002), to improve fish size through genetic introgression (Maceina et al. 1988, Terre et al. 1993), or to bolster poor recruitment (Mesing et al. 2008). As is often the case, the intent for stocking is often incompatible with the intended results, and failures are as common as successes. Nevertheless, managers are often pressured by angler groups after fish-kill events (e.g., hurricanes) to supplement fish populations, regardless of whether the action is needed.

Bunch et al. (2016) reported that stocking F_1 largemouth bass was successful following prolonged drought conditions that depressed natural recruitment in the Chickahominy River, Virginia. In contrast, fingerling to advanced-size largemouth bass stocked in two North Carolina coastal rivers (Thomas and Dockendorf 2009) as well as adults stocked in Pascagoula River oxbow lakes (Alford et al. 2009), in both cases following hurricanes, exhibited no fishery benefit to their respective populations. Results of both studies revealed largemouth bass abundance had recovered naturally within two to three years.

The Mobile-Tensaw Delta (hereafter "Delta") is an 8231-ha oligohaline, tidal river estuary that drains directly into Mobile Bay, Alabama. This large, brackish water body also supports a popular largemouth bass fishery. Access-point creel surveys conducted by the Alabama Division of Wildlife and Freshwater Fisheries (ADWFF) determined that spring angling effort for largemouth bass was high, composing 45% to 58% of total angler h expended (Armstrong et al. 2006, 2015). Largemouth bass in the Delta historically has been abundant, but size structure was skewed towards small fish (<400 mm TL), typical of other bass populations in brackish, tidal environments along the Atlantic and Gulf of Mexico coasts (Guier et al. 1978, Tucker 1985, Hallerman et al. 1986, Meador and Kelso 1990, DeVries et al. 2015). The ADWFF's Bass Angler Information Team program reveals that from 1986 to 2016,

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only 126 bass ≥2.3 kg have been documented, despite 172,675 h of reported tournament angler effort (Bolton 2017). Thus, this population is not highly desirable for anglers in search of trophy-size fish.

Although the Delta is a productive system and the largemouth bass population is characterized by above-average recruitment to age 1, a poor 2004 year-class was evident (record low fall, age-0 CPUE = 1.0 fish h^{-1}) due to post-storm effects of Hurricane Ivan in September 2004. This storm event was devastating to aquatic fauna within the Delta ecosystem as well, reducing dissolved oxygen levels (13-d post-storm surface average was 1.3 mg L^{-1}), as decaying vegetation was flushed from the system (ADWFF, unpublished data; Park et al. 2007). Following Hurricane Ivan, surveys by ADWFF staff documented large numbers of dead fish, most of which were shad (*Dorosoma* spp.), but some centrarchids were also observed, including largemouth bass (ADWFF, unpublished data). During 2007, anglers reported a decline in catchable-size fish (record low spring, age-3 CPUE = 6.4 fish h^{-1}) and began campaigning for ADWFF to stock largemouth bass to restore the population. Because of the varying effectiveness of this strategy reported in the literature, we wanted to determine the utility of stocking largemouth bass in smaller areas of the Delta before expanding the program.

Study Area

This study was conducted in two areas of the Delta—Byrnes Lake and Threemile Creek—as well as a freshwater impoundment, Monroe County Lake that had been stocked with largemouth bass from the Delta before opening to fishing in summer 2000. Byrnes Lake and Threemile Creek are relatively small watersheds located in the lower Delta which drain directly into the Tensaw and Mobile rivers, respectively (Table 1). Byrnes Lake is a blackwater bayou bordered in part by the Mobile-Tensaw Delta Wildlife Management Area in Baldwin County. Threemile Creek was larger, coursing 22.5 km through an urbanized watershed between the cities of Mobile and Prichard in Mobile County (Dewberry 2014). Both Byrnes Lake and Threemile Creek are subjected to diurnal tidal fluctuations. Monroe County Lake is a small impoundment in southwest Alabama managed by the ADWFF as a public fishing area (Table 1). It is located 130 km northeast of the two Delta areas, draining 294 ha of rural, undeveloped land. Despite their origin, adult bass in Monroe County Lake exhibited greater growth rates compared to fish from the Delta (Figure 1), as predicted by Hallerman et al. (1986). The lake was fertilized April–September to maintain phytoplankton blooms with water visibility ranging from 45–60 cm. Angler harvest of largemouth bass is relatively high (12-year average, 2006–2017 = 32.6 kg ha^{-1}) and has been encouraged to reduce predator density and achieve bass-sunfish population balance.

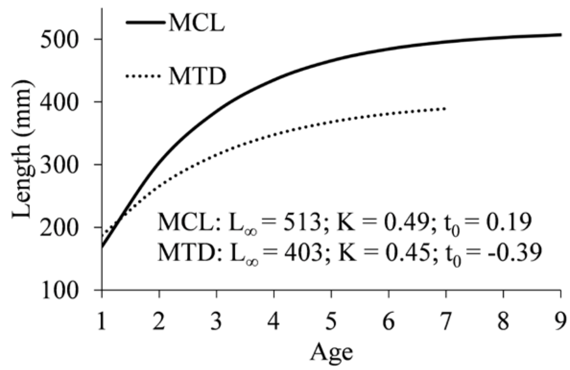

Figure 1. Von Bertalanffy growth curves and equation parameters for largemouth bass in Monroe County Lake (MCL, *n* = 574) and the lower Mobile-Tensaw delta (MTD, *n* = 577) during spring 2008.

Methods

Fish Culture and Stocking

Largemouth bass brood fish were collected from Monroe County Lake, fishing tournaments, and the lower Delta. From 2009 to 2012, we collected and transported 132 largemouth bass (mean

Table 1. Sample area attributes and collection statistics for largemouth bass electrofished (EF) in freshwater Monroe County Lake during spring 2010–2014 and in two tidally-influenced watersheds within the lower Mobile-Tensaw Delta, Byrnes Lake and Threemile Creek. Both Delta areas were sampled during spring 2010–2013, including two annual fall samples during 2010–2012.

					Samples examined (*n*)			
Sample area	Size (ha)	Watershed area (km^2)	Season	Specific conductivity range (µs/cm)	EF transects	Effort (h)	Fish	Otoliths
Monroe County Lake	38	3	Spring	29–45	5	15	2112	490
Byrnes Lake	12	20	Spring	25–148	24	12	945	434
			Fall	31–4,710	36	18	1119	439
Threemile Creek	69	78	Spring	108–877	24	12	952	404
			Fall	87–12,320	36	18	1179	517

Table 2. Stocking rates and subsample information for advanced-size largemouth bass stocked in three sample areas during the study.

				Subsample TL (mm)		
Sample area	Year	Number	Density (*n*/ha)	*n*	Mean (SE)	Range
Monroe County Lake	2010	200	5	200	187 (3.4)	136–285
	2011	470	12	470	202 (0.6)	165–275
	2012	258	7	258	180 (1.5)	135–280
	2013	389	10	389	256 (1.2)	155–354
	2014	500	13	500	239 (0.6)	201–301
Byrnes Lake	2010	671	57	101	138 (0.8)	120–162
	2011	937	80	200	159 (1.1)	135–190
	2012	700	60	57	135 (1.0)	118–155
Threemile Creek	2010	3376	49	101	138 (0.8)	120–162
	2011	4552	66	774	155 (0.5)	103–190
	2012	4298	62	482	139 (0.7)	97–153

weight = 1.89 kg, range = 0.36–4.40 kg) in aerated hatchery trucks for artificial spawning at Marion State Fish Hatchery, Marion, Alabama.

Largemouth bass brood fish were paired to spawn in caged, shallow ponds, and subsequent hatches of fry were routinely collected using dip nets. To reduce naïve feeding attributes, fry were transferred into fertilized 0.20-ha culture ponds ($n = 6–10$) and introduced to live forage (e.g., zooplankton). Each culture pond was also simultaneously stocked one time with 25–30 pairs of adult (>76 mm TL) bluegill sunfish (*Lepomis macrochirus*), and fewer pairs of redear sunfish (*Lepomis microlophus*), which provided a range of suitable-sized forage. Ponds were fertilized on not less than three occasions to maintain productivity (i.e., secchi visibility maintained at 0.5–0.6 m).

Prior to tagging, fingerling largemouth bass were transported from ponds to indoor raceways and held overnight without food. Hatchery staff anesthetized batches of fish from raceways with MS-222 and subsamples of fish (all tagged fish for Monroe County Lake) were measured (TL, mm) and weighed (g) from each raceway to determine range and average size at stocking (Table 2). Fish were tagged using coded wire tags (CWT, Northwest Marine Technology, Shaw Island, Washington) with a Mark IV tag injection system in either the nape or caudal peduncle in alternating years. Tagged fish were held over a second night and stocking took place approximately 48 h after fish were transported from ponds into the hatchery. Target stocking rate in Byrnes Lake and Threemile Creek was 62 fish ha^{-1} during 2010–2012.

Because age-0 largemouth bass in Monroe County Lake were larger and historically sampled at higher densities than those from the Delta, hatchery fish from the largest 10th percentile TL were separated and stocked into Monroe County Lake at a target rate of 12 fish ha^{-1} during 2010–2014. Fish were tagged with passive integrated transponder (PIT) tags (Biomark, Boise, Idaho) during 2010–2013, and during 2014, CWT were used instead of PIT tags. Prior to transport from the hatchery and at each stocking site, staff inspected raceways, trucks, and stocking sites for mortalities; these were noted to adjust stocking rates. Stocking sites in the Delta were located in the upstream-most site of each area and at the boat ramp for Monroe County Lake.

Cage Study

During February 2012, a cage study was conducted at both Delta areas to determine losses due to short-term tagging and stocking mortality. Rectangular, floating cages were constructed with 38-mm PVC plastic frames (1.9 × 1.3 × 1.3 m) and 10-mm plastic mesh. Cages were placed in a water depth of 3 m to maintain water flow and oxygen levels and were left *in situ* for 72 h before being pulled; fish inside were then checked for mortalities.

Field Collections

At Byrnes Lake and Threemile Creek, six fixed sites were located longitudinally in each study area. Sites were sampled once during spring (16 to 45 d post stocking) and twice during fall (202 to 245 d post stocking) to increase tag returns and to examine mortality over time. Each site was sampled for 1800 sec during daylight in a single, nearshore, downstream pass with a boat-mounted electrofisher (7.5 GPP; Smith-Root, Inc., Vancouver, Washington). At all sample areas, we attempted to maintain electrofisher output between 4 and 6 A, varying voltage settings from 170 to 1000 V while maintaining 120 pulses sec^{-1}. From 2010–2014, electrofishing was conducted at Monroe County Lake in similar fashion during spring, 12–84 d post stocking. However, unlike Delta areas, sample starting points were selected randomly and 85% to 100% of the shoreline sampled without replication. Electrofisher pedal time was recorded but no specified sample period was established following ADWFF state lakes sampling policy. At all areas, largemouth bass were measured, weighed and examined for presence of tags. Otoliths were extracted from wild fish by sampling up to 20 individuals within each 2.5-cm length group. Otoliths were read in whole view under a dissecting microscope by two independent readers and disagreements about age were resolved after sectioning using the methods of Maceina (1988). Unaged fish were assigned ages using an age-length key generated by a Microsoft Excel add-in (Slipke 2011). Because of low returns, stocked fish were sacrificed for aging only during the last study year and inspected to confirm tags.

Statistical Approach and Data Analysis

Fixed-sites in Byrnes Lake and Threemile Creek necessitated use of a two-way repeated measures (RM) ANOVA to test for differences in CPUE (Maceina et al. 1994). Our primary objective for this analysis was to compare differences in abundance of stocked and wild fish in each sample area and season. Pearson correlations were used to examine relations among stocking rates and fish abundance. Differences in distribution of fish length were compared between wild and stocked fish using Kolmogorov-Smirnov tests. Pooled data across stocking years were tested within each area and season. Post-stocking mortality of both stocked and wild age-1 fish in the Delta was examined using catch curves to describe the decline in catch of wild and stocked fish through time from stocking through approximately 6 mo in the fall (Luisi and Bettoli 2001). For each year and area, paired sets of data were examined using analysis of covariance (ANCOVA) to evaluate differences in equality of variance and regression slopes.

Prior to analysis, datasets were examined for normality using the Shapiro-Wilk statistic. Dataset variables that did not meet the assumptions of normality were $\log_e (x+1)$ transformed. Significance of all tests were set at $\alpha = 0.10$. Probability values for analyses were further discriminated using Bonferroni corrections. Data analyses utilized Statistix software (Statistix version 10.0, Tallahassee, Florida).

Results

Stocking Mortality, Survival, and Tag Retention

In Byrnes Lake, 50 largemouth bass were placed in the cage and held for 72 h. No mortalities were observed and tag retention was 100%. In Threemile Creek, 105 largemouth bass were placed into the cage; however, fish were not recovered until 6 d later due to a high water event. Upon retrieval, the cage was heavily damaged and 19 individuals had escaped, 29 fish remained alive, and 57 were dead. One fish was missing a tag; we assumed this fish did not immigrate into the cage. Surviving fish were not returned to the stocking area. Combining the two study areas, we observed CWT retention >99% at 3 to 6 d for fish either in cages or during stocking events.

Stocking mortality was not observed at Byrnes Lake; however, 176 fish were retrieved as dead or moribund from a single stocking in Threemile Creek on 16 February 2012. From field examination of dead fish, we suspect these individuals suffered from stress-induced *Aeromonous* spp. infection due to subdermal hemorrhaging. We did not find evidence of similar events on other dates or sites and assumed this was an isolated event; for this one stocking event, the number stocked was adjusted downward to account for this loss. Neither tag nor stocking mortality was assessed formally at Monroe County Lake; however, mortalities were never observed there.

Survival of wild largemouth bass during their first growing season was 2–3 times higher than that of stocked fish during 2011 and 2012 (i.e., 2010 and 2011 cohorts) in Byrnes Lake (Table 3). Similarly, survival of wild largemouth bass was 69 to 229% higher than stocked fish for these same cohorts in Threemile Creek.

Table 3. Catch in three annual samples, instantaneous mortality (*Z*), and interval survival rate of stocked and wild age-1 largemouth bass in two Mobile-Tensaw Delta study areas. Days at large denote the interval from stock date to the third sample date each year.

Sample area	Group modeled	Stock year	Catch spring	Catch fall 1	Catch fall 2	Days at large	*Z*	Survival (%)
Byrnes Lake	Stocked	2010	6	2	5	183	–0.00341	53.6
		2011	25	4	1	168	–0.01299	11.3
		2012	21	2	1	221	–0.01034	10.2
	Wild	2010	69	16	54	183	–0.00454	43.6
		2011	66	30	9	168	–0.00833	24.7
		2012	73	33	22	221	–0.00463	36.0
Threemile Creek	Stocked	2010	42	25	10	204	–0.00526	34.2
		2011	33	17	11	173	–0.00528	40.1
		2012	22	3	3	185	–0.01127	12.4
	Wild	2010	105	27	43	204	–0.00557	32.1
		2011	107	90	61	173	–0.00223	67.9
		2012	82	36	34	185	–0.00484	40.8

In contrast, survival of wild largemouth bass in 2010 (i.e., 2009 cohort) was 19% lower than stocked fish in Byrnes Lake, and virtually identical between the groups in Threemile Creek (Table 3). During 2010, higher numbers of fish were captured during the second series of fall sampling as compared to the first. This was likely due to elevated salinity values that were more than two times higher during the first series of samples compared to the second. Nonetheless, slopes of the catch curves only differed between groups in Threemile Creek during 2012 (2011 cohort; ANCOVA: $F=45.45$, $P=0.0213$); slopes were similar between groups for all other comparisons.

Stocked Fish Contributions

Across study years and areas, 16,380 largemouth bass were tagged and stocked (Table 2), and a total of 353 stocked fish were recaptured (Table 4). Percent contribution of recently-stocked fish was highest at age 1, ranging from 2.0%–30.6% among cohorts. Likewise, spring CPUE of the stocked age-1 largemouth bass at large for 16–84 d was positively associated with stocking rates in all three study areas, however, this relation was not significant ($r=0.6112$, $n=11$, $P=0.0458$). Percent contribution of stocked fish to each year-class declined over time with age-2 fish composing 1.9%–15.5% of each cohort, while age-3 fish composed 2.9%–10.4% of cohorts across years (Table 4). Only three age-4 fish were collected during the study, representing 5% to 12.5% of the 2009 cohort. Stocking contributions were lower in Monroe County Lake, ranging from 1.9% to 3.6% of age-1 fish and 0.8 to 5.4% of age-2 fish. No stocked fish older than age 2 were collected in Monroe County Lake (Table 4).

Field Collections

Data collections during spring 2010 through 2014 stocking years were composed of 125 samples yielding 6307 individual fish (Table 1). Electrofisher output varied across sites and seasons, especially in the Delta, where conductivity varied widely (salinity varied from 0 to 7 ‰); therefore, CPUE analyses were examined within areas and seasons.

Analysis of CPUE between stocked and wild largemouth bass in all three sample areas exhibited identical patterns, with 5–78 times higher abundance of wild fish cohorts compared to stocked fish among sample years each season. Range of mean CPUE values in Byrnes Lake was similar to Threemile Creek during spring, 2010–2013 (Figure 2). Significant differences in CPUE between wild (range = 50.3–103.3 fish h^{-1}) and stocked (range = 1.3–15.7 fish h^{-1}) groups of fish existed in Byrnes Lake ($F=113.1$, df = 1, 10; $P<0.0001$) and Threemile Creek ($F=99.84$, df = 1, 10; $P<0.0001$). Similarly,

Table 4. Total number of tagged (Tag) largemouth bass within each cohort recaptured across all sampling events within each sample year and cohort stocked at Monroe County Lake (Monroe), Byrnes Lake (Byrnes), and Threemile Creek (Threemile).

		2009 Cohort			2010 Cohort			2011 Cohort			2012 Cohort			2013 Cohort		
Sample area	**Year**	**Tag**	**Total**	**% Tag**	**Tag**	**Total**	**% Tag**	**Tag**	**Total**	**% Tag**	**Tag**	**Total**	**% Tag**	**Tag**	**Total**	**% Tag**
Monroe	2010	2	87	2	–	–	–	–	–	–	–	–	–	–	–	–
	2011	2	37	5	15	646	2	–	–	–	–	–	–	–	–	–
	2012	–	–	–	1	79	1	13	358	4	–	–	–	–	–	–
	2013	–	–	–	–	–	–	1	41	2	7	216	3	–	–	–
	2014	–	–	–	–	–	–	–	–	–	1	118	1	7	362	2
	Total	4	124	–	16	725	–	14	399	–	8	334	–	7	362	2
Byrnes	2010	13	152	9	–	–	–	–	–	–	–	–	–	–	–	–
	2011	4	97	4	30	135	22	–	–	–	–	–	–	–	–	–
	2012	4	63	6	7	103	7	24	152	16	–	–	–	–	–	–
	2013	1	20	5	2	42	5	1	53	2	–	–	–	–	–	–
	Total	22	332		39	280		25	205							
Threemile	2010	77	252	31	–	–	–	–	–	–	–	–	–	–	–	–
	2011	18	116	16	61	319	19	–	–	–	–	–	–	–	–	–
	2012	1	35	3	20	147	14	28	180	16	–	–	–	–	–	–
	2013	2	16	13	5	48	10	6	47	13	–	–	–	–	–	–
	Total	98	419	–	86	514	–	34	227	–	–	–	–	–	–	–

there were also significant differences in CPUE among sample years in Byrnes Lake ($F=3.89$, df = 3, 30; $P<0.02$) and Threemile Creek ($F=4.52$, df = 3, 30; $P<0.01$). Analysis of CPUE in Monroe County Lake was not possible due to absence of sample replication. However, abundance of wild largemouth bass was consistently higher (range = 57.0–231.6 fish h^{-1}) than that of stocked fish (range = 0.8–7.5 fish h^{-1}) during spring, 2010–2014 (Figure 2). Both series of fall samples exhibited a wide range of differences in CPUE at Byrnes Lake (stocked range = 0.33–1.67 fish h^{-1}; wild range = 19.3–98.6 fish h^{-1}) and Threemile Creek (stocked range = 3.0–8.3 fish h^{-1}; wild range = 52.7–74.9 fish h^{-1}) during 2010–2012 (Figure 2). Both areas also exhibited significant differences in CPUE between stocked and wild fish during fall, 2010–2012 (range $F=51.2$–340.4, df = 1, 10; all $P<0.0001$). Significant differences in CPUE also existed among years for Byrnes Lake (range $F=8.0$–14.9, df = 2, 20; both $P<0.003$), but not Threemile Creek (range $F=0.3$–1.8, df = 2, 20; both $P>0.19$).

Length-frequency distributions were different between wild and stocked fish (Figure 3) for all study areas during spring sampling (Byrnes Lake: $D=0.38$, $P<0.0001$; Threemile Creek: $D=0.37$, $P<0.0001$; Monroe County Lake: $D=0.38$, $P<0.0001$). Wild fish had larger median lengths than stocked fish for both Delta locations (Byrnes Lake: wild = 222 mm, $n=446$ and stocked = 148 mm, $n=66$; Threemile Creek: wild = 236 mm, $n=514$ and stocked = 164 mm, $n=133$). Conversely, stocked fish at Monroe County Lake had a larger median length (210 mm, $n=49$) than wild fish (181 mm, $n=1924$). Distributions from fall samples did not differ for either Delta area (Byrnes Lake: $D=0.18$, $P=0.56$; Threemile Creek: $D=0.12$, $P=0.29$). During fall collections, median length of wild fish in Byrnes Lake was 239 mm ($n=229$) while stocked fish median length was 222 mm ($n=20$). At Threemile Creek, median length for wild largemouth bass was 291 mm ($n=291$) and 285 mm for stocked fish ($n=85$).

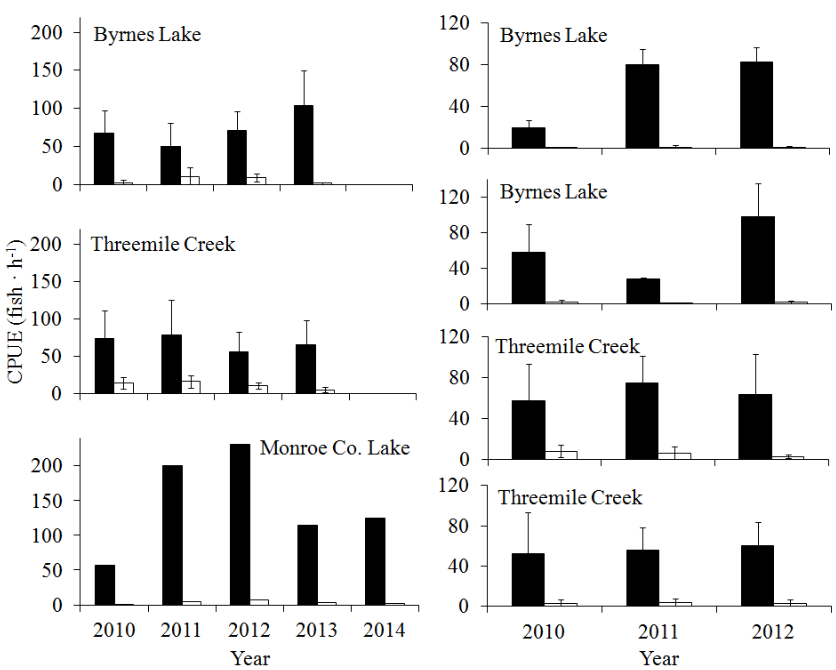

Figure 2. Catch-per-unit effort (CPUE) of wild (black bars) and stocked (white bars) largemouth bass in each area of Byrnes Lake and Threemile Creek, spring 2010 to 2013, and Monroe County Lake, spring 2010 to 2014. Two consecutive series of samples collected during fall in Byrnes Lake and Threemile Creek, 2010 to 2013, are located in the right panels. Histogram bars exhibit total CPUE of values in Monroe County Lake samples without replication (fish hr^{-1}), while those in the Delta exhibit mean values (fish $h^{-1} \pm 95\%$ CI) for six fixed sites in each area. Analyses in Delta areas were performed using repeated measures ANOVA ($P \leq 0.10$) prior to Bonferroni correction.

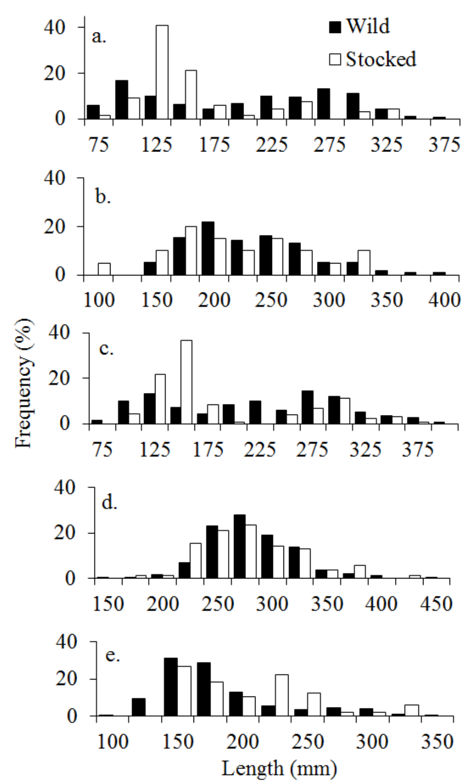

Figure 3. Length-frequency distributions for wild (black bars) and stocked (white bars) largemouth bass using pooled data across years for (a) Byrnes Lake during spring 2010–2013, (b) Byrnes Lake during fall 2010–2012, (c) Threemile Creek during spring 2010–2013, (d) Threemile Creek during fall 2010–2012, and (e) Monroe County Lake during spring 2010–2014. Analysis was performed using Kolmogorov-Smirnov tests ($P \leq 0.10$).

Discussion

Overall, percent contribution of stocked largemouth bass in our study was low across cohorts and years for all areas, especially after age-1. Our results are similar to other coastal river studies that supplemented year-classes after hurricanes where restocking was ultimately ineffective, even when stocking was completed soon after disturbance events (Alford et al. 2009, Thomas and Dockendorf 2009). Though some studies have demonstrated stocking successes, timing of stocking and abundance of native bass populations are important factors to consider when augmenting an already established population. Most successful stockings are usually a product of systems with naturally diminished populations (Bunch et al. 2016) or where natural reproduction is inadequate (Boxrucker 1986, Mesing et al. 2008). Terre et al. (1993) found that the percent contribution of stocked fish within a year-class was inversely related to the relative recruitment of wild fish in Texas reservoirs. In their study, populations with high densities of wild largemouth bass and recruitment had the lowest contribution of stocked fish when compared to populations with low densities of bass and lesser reproduction. In our study, fish were not stocked until after population recovery of largemouth bass had occurred in the Delta and Monroe County Lake was never visibly affected. We found natural reproduction was not diminished and wild fish CPUE was consistently higher than stocked fish in all years and seasons. Though estimated mortality of stocked fish was consistently higher, slopes of most catch-curve regressions up to 221 d post stocking indicated that survival was generally similar between groups during their first growing season.

Conversely, Hoxmeier and Wahl (2002) found that fall abundance of wild, age-0 largemouth bass did not suppress CPUE of stocked fish among 15 study lakes. Even in Delta sites, where stocked largemouth bass initially contributed to the 2010 cohort in Threemile Creek by as much as 31% of all age-1 fish, abundance swiftly declined by fall and these fish did not persist through the study. This scenario was intensified in Monroe County Lake where abundance of wild age-1 bass was higher and stocking rates were lower compared to Delta study areas. Along with significant angler harvest pressure, this combination likely contributed to low percent composition of stocked fish cohorts at age-2 and older. Buynak and Mitchell (1999) documented initial success of stocked adult largemouth bass (29.0–31.5 cm) in Taylorsville Lake, Kentucky, but angler catch of stocked bass also declined after stocking ceased and stocked fish did not contribute significantly after one year of no stocking, which the authors attributed to harvest and other fishing mortality.

Food availability or naïve feeding traits by stocked fish can hinder success of fish stocking programs. We assumed advanced fingerlings in our study could compete for food with wild fish given that they were reared completely on live prey (Heidinger and Brooks 2002). Assuming that large, stocked fish possess equal abilities to compete for food resources, we felt they would further contribute to cohort abundance over time. Pouder et al. (2010) found that stocked Florida largemouth bass had a higher frequency of empty stomachs and higher mortality over 150 d than wild bass of the same cohort, and hypothesized that potential factors were stresses from the stocking process, or an inability to transition to natural prey. Fish used in that study were smaller and younger than those used in our study, and were reared on mosquitofish (*Gambusia* spp.) for only 5 d before stocking. Fish stocked in our study were reared on live forage approximately 10 months, and although we did not examine diets after stocking, we assumed that stocked fish were just as capable as wild fish at capturing live prey.

Diana and Wahl (2009) documented neither stocking mortality nor predation losses for advanced-size (200 mm) largemouth bass, and reported that predation losses were 8% for large-sized (150 mm) fish stocked in Illinois lakes. Mean size of largemouth bass stocked in Monroe County Lake was greater than that of fish examined in the two largest size categories in the Diana and Wahl (2009) study, and although stocking rates in their study were higher than those in Monroe County Lake, they were lower than stocking rates in the Delta. Although mean size of stocked largemouth bass was larger at Monroe County Lake than at Delta sites, it did not result in larger fingerlings outperforming smaller sized fish or improved percent contribution of stocked fish to year classes. We believe that despite the size disparities, overwhelming numbers of wild fish outcompeted and almost certainly preyed upon stocked bass in our study.

Natural resource agencies rarely have surplus largemouth bass ready to stock immediately after extensive fish kills due to the numbers required, timing of kill events, pre-established hatchery production goals, and increasing demands for stocking. Regardless of the lack of expected benefits, stocking programs are popular with anglers and in some cases, have become a panacea for management of a variety of perceived population problems. Despite both angler and agency concerns, sport fish populations often rebound naturally after fish kill events, regardless of stocking efforts. This is likely due to compensatory responses of complex riverine systems, especially those connected to inundated floodplains or expansive estuaries that provide increased spawning and rearing habitat (Alford et al. 2009, Thomas and Dockendorf 2009). In such cases, smaller watersheds may provide a reproduction source for interconnected bodies of water that experience dissimilar effects on recruitment (Ricks and McCargo 2013).

Other studies have documented the importance of spatial location within a basin and its effect on water quality and subsequently, to fish populations. Potoka et al. (2014) found that spatial distribution of fish kills was an important factor when evaluating hurricane effects on fish populations in the Abermarle Sound, North Carolina. In their study, evaluating the effects of Hurricane Irene across a wide expanse in multiple sub-watersheds of the Chowan River system better provided an appropriate scale to evaluate post-storm population effects and recovery of largemouth bass populations. Perret et al. (2010) similarly found that basin location within the Atchafalaya River was an important factor in evaluating sport fish abundance before and their decline after two large hurricanes. They suggested that stable areas within East Grand Lake may have provided oxygen refugia, especially where greater discharge replaced degraded water quality.

Spatial position (Perret et al. 2010, Potoka et al. 2014) within a large, interconnected system (Alford et al. 2009, Ricks and McCargo 2013) may influence the severity of catastrophic storm impacts and subsequent recovery of fish populations. Monitoring data indicated that spatial differences commonly exist in relative abundance of largemouth bass year classes between the upper and lower Delta, and can be traced to environmental influences (i.e., drought mid-1999 to 2001 and Hurricane Ivan in 2004) on the population (Armstrong et al. 2006, 2008 and ADWFF unpublished data). Though effects on upper Delta year classes were detectable years later, the lower Delta bass population was comparatively unchanged and to some extent, may have provided a source for emigrating recruits. In short, the Delta bass population recovered within five years given that tournament data revealed improvements in both angler catch and percent success metrics that met or exceeded the 31-year program average since 2009 (Bolton 2017). Fish populations normally recover naturally over time despite human efforts to intervene and our efforts to augment the largemouth bass population in our Delta study areas following Hurricane Ivan in 2004 were likely unnecessary. Researchers should attempt to gather long-term recruitment data on systems where environmental disturbance events have or could result in expensive or unnecessary population augmentation.

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