Effects of Stocking Adult Largemouth Bass to Enhance Fisheries Recovery in Pascagoula River Floodplain Lakes Impacted by Hurricane Katrina

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Abstract: Following Hurricane Katrina in 2005, hypoxia-induced fish kills occurred throughout the Pascagoula River Basin in southeast Mississippi. We evaluated the effect of stocking adult Florida largemouth bass (*Micropterus salmoides floridanus*; 200–356 mm total length) into Pascagoula River floodplain lakes to enhance fisheries recovery. We stocked 37 fish/ha into five randomly-chosen lakes in December 2006, whereas five additional lakes were left unstocked to serve as a control. Electrofishing catch per unit effort (CPUE: fish/h) and length-frequency distributions of largemouth bass and bluegill (*Lepomis macrochirus*) were not different between stocked and unstocked lakes one year after stocking. Regardless of stocking treatment, largemouth bass and bluegill mean total length increased significantly and length frequencies shifted towards larger size groups from 2006 to 2007, indicating natural recovery of these populations. Non-metric multidimensional scaling of species CPUE revealed that during 2006, planktivorous shads (*Dorosoma* spp.) and brook silverside (*Labidesthes sicculus*) dominated fish assemblage structure in the impacted lakes, but during 2007 it shifted more towards predatory species such as largemouth bass and crappie (*Pomoxis* spp.). Floodplain lakes impacted by hurricane-related fish kills require at least two years of natural recovery to achieve fish population and community characteristics desirable for largemouth bass and bluegill fisheries.

Key words: hurricane, fish kill, supplemental stocking, fisheries recovery, Pascagoula River

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After Hurricane Katrina struck the Mississippi Gulf Coast on 29 August 2005, massive fish kills occurred in floodplain lakes and main channel habitats in the Pascagoula River Basin from 2 to 19 September. Individuals of many fish species and sizes, including those of conservation and recreation concern succumbed to the effects of these hurricane-related events (O'Keefe et al. 2007). Hypoxia resulting from microbial decomposition of organic matter that flushed into the river system from the surrounding watershed during the hurricane caused the fish kill in the Pascagoula River. In the days following Hurricane Katrina, personnel from the Mississippi Department of Environmental Quality (MDEQ) reported fish kills and dissolved oxygen levels were well below 2 mg/L (B. Viskup, MDEQ, personal commununication) at various points in the Pascagoula River Basin. During 2006, sampling of floodplain lakes suggested that largemouth bass (*Micropterus salmoides*) abundance was low and young-of-the-year (YOY) bluegill (*Lepomis macrochirus*) were overabundant, which could potentially lead to undesirable predator-prey balance in these systems (Okeefe et al. 2007, Alford et al. 2008)

As residents of southeast Mississippi began to rebuild their lives, anglers sought relief from psychological distress by fishing water bodies in the Pascagoula River Basin, but many reported very poor fishing success for sunfish (*Lepomis* spp.), crappie (*Pomoxis* spp.), and largemouth bass (Alford et al. 2008). Subsequently, the Mississippi Department of Wildlife, Fisheries, and Parks (MDWFP) fielded many requests to stock sport fishes in order to enhance catches during this difficult time of recovery (J. Rayburn, MDWFP, personal communication).

Development of appropriate response protocols is necessary for effective fisheries management following natural disasters. Supplemental stocking of largemouth bass has been used as a management tool to reduce overabundant forage species, enhance recruitment of wild largemouth bass stocks and establish populations in renovated or reclaimed water bodies (Noble 1981, Smith and Reeves 1986, Boxrucker 1986). Subsequently, our objectives were to evaluate the effect of stocking hatchery-reared adult largemouth bass on the abundance and size-structure of largemouth bass and bluegill populations in Pascagoula River floodplain lakes impacted by a severe hurricane. We also monitored post-hurricane trends in fish assemblage structure to understand short-term recovery dynamics of coastal lake fish communities impacted by hurricane-related fish kills.

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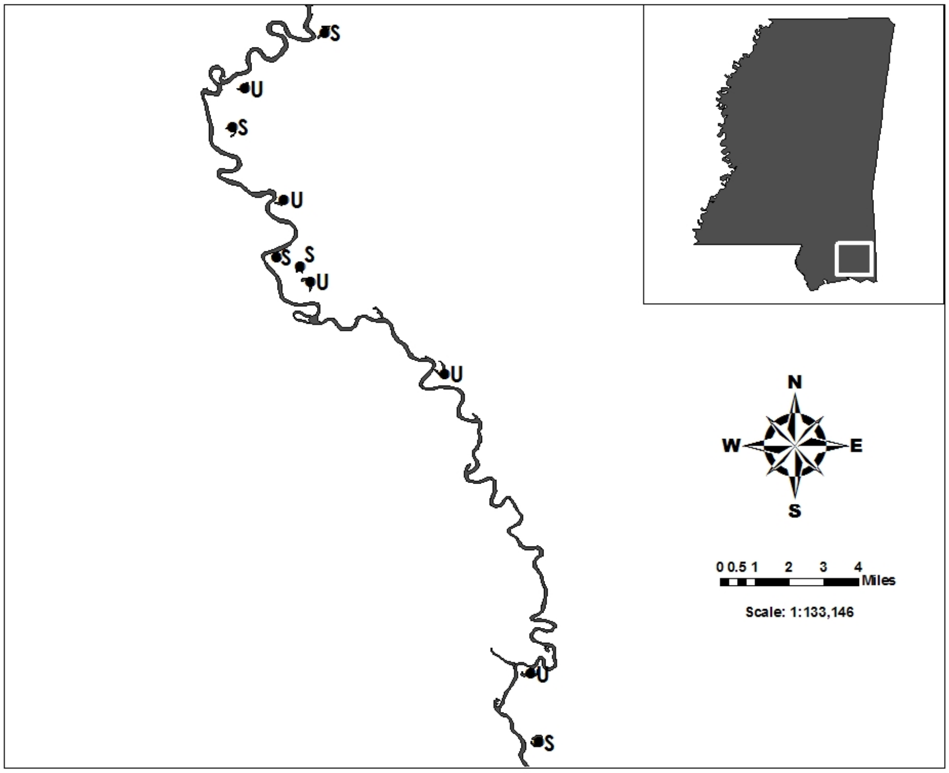

Figure 1. Locations of the 10 Pascagoula River floodplain lakes sampled for this study during fall 2006 and 2007. "S" means the lake was stocked with 37 adult Florida largemouth bass/ha on 12 December 2006. "U" represents a lake that was left unstocked to serve as a control replicate.

Study Area

The Pascagoula River Basin is located in southeastern Mississippi and drains the tributaries of the Leaf and Chickasawhay rivers south to the Gulf of Mexico near Pascagoula, Mississippi (Figure 1). Approximately 42 floodplain lakes of various tidal influence and fluvial connectivity (i.e., permanently or temporarily connected to the main channel via tributaries or overbank flooding) are situated to the east and west of the Pascagoula River main channel. None of the lakes in our study were connected directly to each other.

Methods

We chose 10 lakes impacted by the fish kills as experimental units (Figure 1), because they had similar physical and chemical characteristics, overabundant YOY bluegill and very few or no largemouth bass after the hurricane (see Table 1). We conducted boat electrofishing using 60 Hz pulsed-DC to sample fishes during the pre-treatment period (September through November 2006) as well as the post-treatment period (September through December 2007). Each lake was sampled on a single date by a crew consisting of a boat operator and one netter. Lake shorelines were sampled using two 900-s electrofishing runs. Two runs were conducted in all lakes in both years with the exception of one lake in 2006 because the entire shoreline was sampled during one 900-s run. All lakes were sampled during September through November 2006 to provide pre-stocking data on fish populations as well as physicochemical characteristics at each lake.

Stocked fish were obtained from state hatcheries operated by MDWFP. Five lakes were randomly chosen and stocked with adult (200–356 mm total length [TL]) Florida-strain largemouth bass (FLMB; *M. salmoides floridanus*) at a density of 37 fish/ha on 12 December 2006 (treatment group), and the remaining five lakes were left unstocked and served as the control (Figure 1).

We determined if lakes were physically and chemically similar prior to and after the stocking treatment. We obtained aerial photography from the Mississippi Automated Resource Information System (MARIS, Jackson, Mississippi) and calculated lake area (ha) in ArcMap version 9.0 (Environmental Systems Research Institute, Inc. Redlands, California). We also recorded specific conductance (μS/cm) and surface temperature (C) with a YSI-85 multimeter (Yellow Springs, Inc., Yellow Springs, Ohio), and we measured Secchi disk depth (cm) to assess water clarity. Stocked and control lakes were statistically similar (Table 1) with regard to all physical and chemical characteristics in 2006 and 2007 (repeated measures ANOVA, $F < 1.0$, $P > 0.10$ for year*treatment interactions and main effects). Therefore, we were confident that differences observed in stock characteristics during the post-stocking period would be due to the stocking treatment rather than potentially confounding physicochemical characteristics, which may have influenced electrofishing catchability. We calculated catch per unit effort (CPUE:

Table 1. Physicochemical characteristics and relative abundances (CPUE: fish/h of electrofishing) of largemouth bass (LMB) and bluegill (BG) from 10 experimental Pascagoula River floodplain lakes sampled during fall 2006 and 2007. Numbers in parentheses are standard errors. Five lakes were stocked after the 2006 sample with 37 adult Florida largemouth bass/ha. The other five lakes were left unstocked to serve as a control.

		Lake area (ha)	LMB CPUE (fish/h)[a]	BG CPUE (fish/h)	Secchi disk depth (cm)	Temp. (C)	Specific conductance µS/cm
2006	Stocked	5.9 (0.9)	2.0 (0.9)	54.8 (20.3)	81.0 (13.0)	22.7 (1.4)	54.3 (2.8)
	Unstocked	6.9 (0.9)	5.0 (2.1)	95.2 (35.1)	67.2 (5.1)	22.6 (1.8)	55.1 (2.5)
2007	Stocked	5.9 (0.9)	11.3 (2.9)	83.6 (31.3)	82.0 (14.4)	21.9 (2.5)	49.4 (1.6)
	Unstocked	6.9 (0.9)	27.1 (8.3)	161.7 (57.9)	74.2 (8.3)	18.3 (1.8)	53.0 (1.5)

a. Largemouth bass CPUE was significantly greater in 2007 compared to 2006, regardless of stocking treatment (repeated measures ANOVA; $F=18.07$; $P=0.003$). For all other comparisons, means were not significantly different between stocked and unstocked lakes or from 2006 to 2007 (repeated measures ANOVA, all $P>0.10$).

fish/h) of each species as a measure of relative abundance for each sample. We also measured total lengths (mm) of largemouth bass and bluegill to construct length-frequency distributions for these species.

Experimental Design and Statistical Analyses

A before-after, control-impact design (BACI) was used to assess the effects of stock enhancement and yearly changes in stock-size CPUE, length-frequency distribution and mean total length of stock-sized fish. We used repeated measures analysis of variance (ANOVA) at $\alpha=0.10$ with a Bonferroni correction of $\alpha=0.05$ to test null hypotheses that CPUE and mean total length of largemouth bass and bluegill were not significantly different between stocked and control lakes in 2006 and 2007. Repeated measures ANOVA was chosen to test for the effect of time on largemouth bass and bluegill abundance and size-structure, regardless of stocking treatment. The Bonferroni correction was used to account for any potential statistical relationship between the two dependent variables in the data set (i.e., largemouth bass and bluegill CPUE and length-frequency distribution). We used Chi-square tests of independence at $\alpha=0.10$, also with a Bonferroni correction of $\alpha=0.05$, to test hypotheses that length-frequency distributions of largemouth bass and bluegill were not significantly different between stocked and control lakes in 2006 and 2007 (Neumann and Allen 2007). We also pooled length-frequency data from stocked and unstocked lakes to determine if size-structure of largemouth bass and bluegill changed from 2006 to 2007, regardless of stocking treatment.

We assessed changes in fish assemblage structure in Pascagoula River lakes from 2006 to 2007 using non-metric multidimensional scaling (NMS) on a dissimilarity matrix of Bray-Curtis distances among species CPUE (McCune and Mefford 1999, Miranda 2005). All CPUE data were $\ln(x+1.0)$-transformed to improve normality. We analyzed CPUE data only for species that composed ≥ 1.0% of the overall catch in either the 2006 or 2007 sample, so that "rare" species did not artificially influence the ordination of lakes in fish species space. We used a Monte Carlo randomization procedure to calculate P-values for axes generated by the NMS ordination. Axes were considered statistically significant at $\alpha=0.05$. Stability and stress tolerance values were observed to evaluate the strength of the ordination. Loadings >0.50 of species CPUE on a particular axis were used to determine which species were correlated with a particular axis. We used PC-Ord version 4.2 software (Gleneden Beach, Oregon) to conduct the NMS.

Results

Stocking Effects on Largemouth Bass and Bluegill CPUE

Abundance of stock-size largemouth bass did not differ significantly between stocked and unstocked lakes ($F=3.19$, $P=0.11$). Also, abundance of bluegill was similar between stocked and unstocked lakes ($F=1.87$, $P=0.21$) (Table 1). However, from 2006 to 2007, stock-size largemouth bass CPUE increased significantly ($F=18.07$, $P=0.003$) by an average of 15 fish/hour, whereas stock-size bluegill CPUE remained statistically unchanged from 2006 to 2007 ($F=2.03$, $P=0.19$). All year*treatment interaction effects were not significant ($F<2.99$, $P>0.12$).

Stocking Effects on Largemouth Bass and Bluegill Size-Structure

Length-frequency distribution of largemouth bass in stocked lakes was similar to that in unstocked lakes during 2006 (Chi-square test, $n=117$ fish, $P=0.34$) and 2007 (Chi-square test, $n=124$ fish, $P=0.52$) (Figure 2). Regardless if the lakes were stocked, the largemouth bass length-frequency distribution shifted from predominately small fingerlings with most fish <200 mm TL, to mostly stock-size individuals (TL ≥200 mm) from 2006 to 2007 (Figure 2).

In contrast to largemouth bass, bluegill length-frequency distributions (Figure 3) were significantly different between stocked

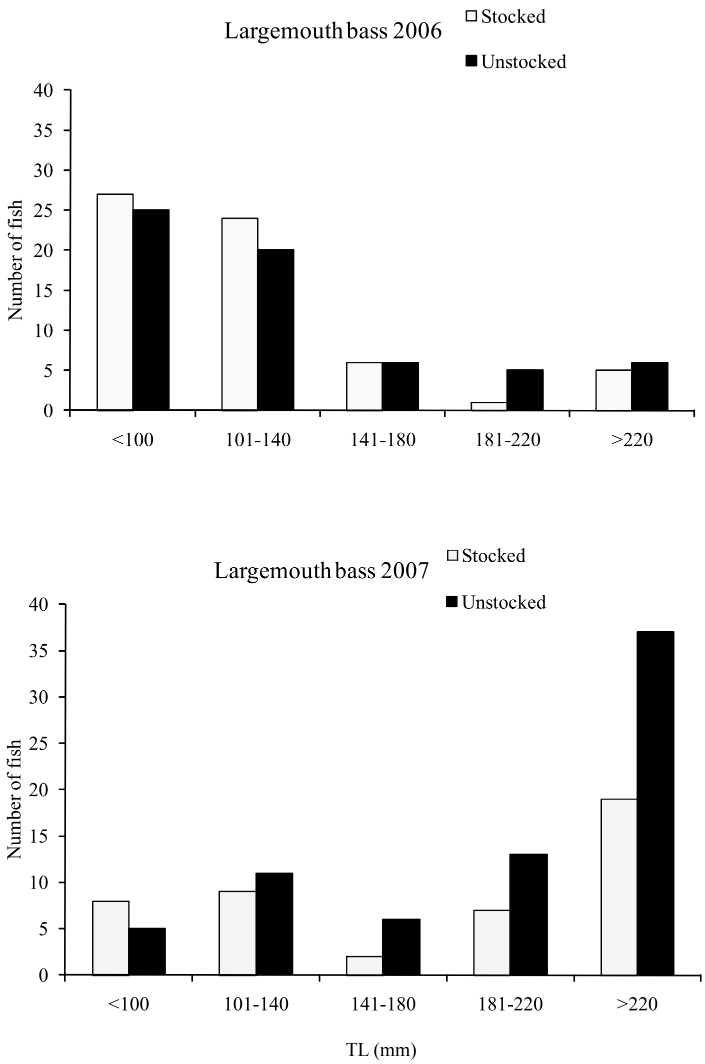

Figure 2. Length-frequency distribution (TL in mm) of largemouth bass from 10 experimental Pascagoula River floodplain lakes sampled by electrofishing during fall 2006 (top) and 2007 (bottom).

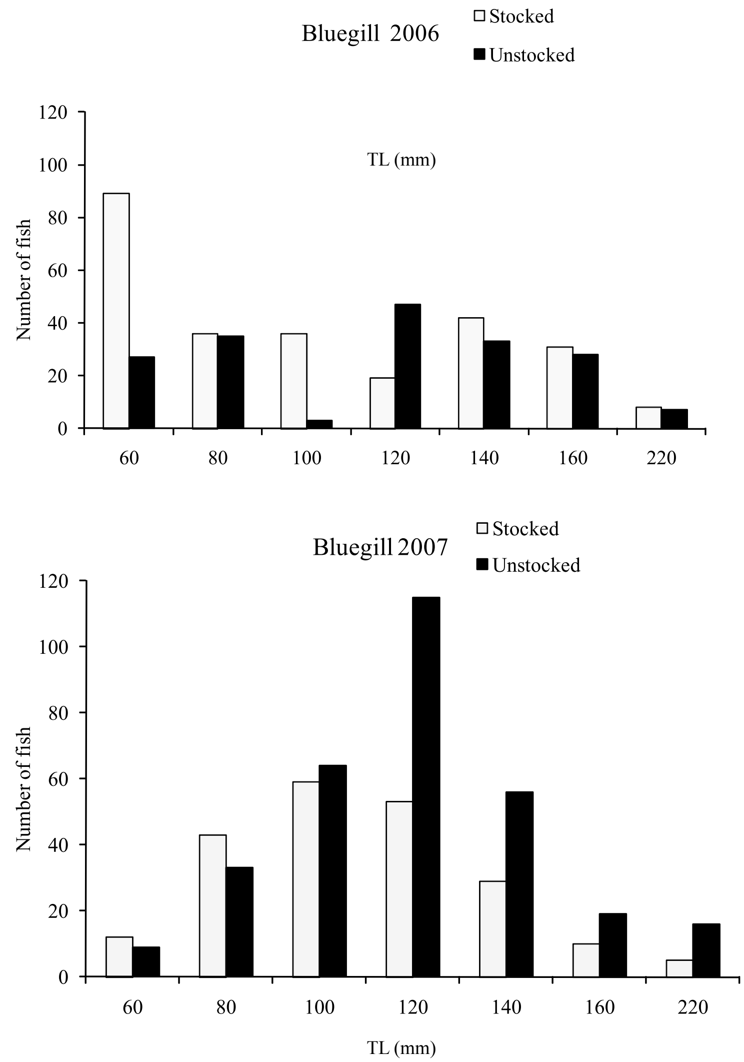

Figure 3. Length-frequency distributions of bluegill from 10 experimental Pascagoula River floodplain lakes sampled by electrofishing during fall 2006 (top) and 2007 (bottom).

and control lakes in 2006 (Chi-square test, $n = 489$ fish, $P < 0.001$) and in 2007 (Chi-square test, $n = 522$ fish, $P < 0.001$). Overall bluegill length-frequency shifted from primarily YOY individuals (i.e., <80 mm TL) in 2006 to mostly intermediate-size individuals (e.g., 90–140 mm TL) in 2007.

Stock enhancement had no effect on mean total length of largemouth bass ($F = 2.02$, $P = 0.16$), and no significant year * treatment interaction for largemouth bass mean total length was detected ($F = 2.2.5$, $P = 0.14$). In contrast, bluegill mean total length was significantly larger ($F = 26.08$, $P < 0.001$) in stocked lakes when compared to control lakes, but only in the pre-treatment period in 2006. Regardless of stocking treatment, largemouth bass and bluegill were significantly larger in 2007 compared to 2006. On average, largemouth bass mean total length increased by an average of 82 mm from 2006 to 2007 ($F = 46.83$, $P < 0.001$), indicating substantial growth from subadult to adult sizes during this period . Mean TL of bluegill increased slightly during 2006–2007 ($F = 27.63$, $P < 0.001$) by an average of 13 mm TL.

Fish Assemblage Changes after Hurricane Katrina

A three-dimensional solution was found for the NMS ordination of species CPUE data (100 runs; stability = 11.5; stress = 0.00001; Monte Carlo test; $P = 0.03$ for axes I–III). The first three axes explained 41% of the variation in the species data (Table 2),

Table 2. Mean CPUE (fish/h of electrofishing) of fish species captured from 10 Pascagoula River floodplain lakes impacted by hypoxia-induced fish kills following Hurricane Katrina. These values were used to describe community structure using non-metric multidimensional scaling. "S" represents lakes stocked with 37 adult Florida largemouth bass/ha on 12 December 2006. "U" represents lakes left unstocked to serve as a control group.

	2006 (*n* = 1,536)		2007 (*n* = 1,046)	
	S	U	S	U
Amia calva	5.2	4.0	5.0	5.6
Dorosoma cepedianum	15.2	5.0	2.4	0.8
Dorosoma petenense	22.0	21.0	0.0	0.2
Labidesthes sicculus	21.6	2.8	0.0	0.4
Lepisosteus oculeatus	4.8	7.6	5.6	9.2
Lepomis gulosus	5.2	3.2	1.8	2.4
Lepomis macrochirus	54.8	95.2	83.6	161.7
Lepomis marginatus	0.6	1.4	0.0	1.6
Lepomis microlophus	4.0	0.8	2.4	5.2
Micropterus salmoides	2.0	5.0	11.3	27.1
Minytrema melanops	3.8	0.8	2.2	2.0
Notemigonus crysoleucus	1.6	0.6	1.4	0.8
Pomoxis annularis	0.8	1.4	2.2	6.2
Pomoxis nigromaculatus	2.4	4.6	3.2	9.8

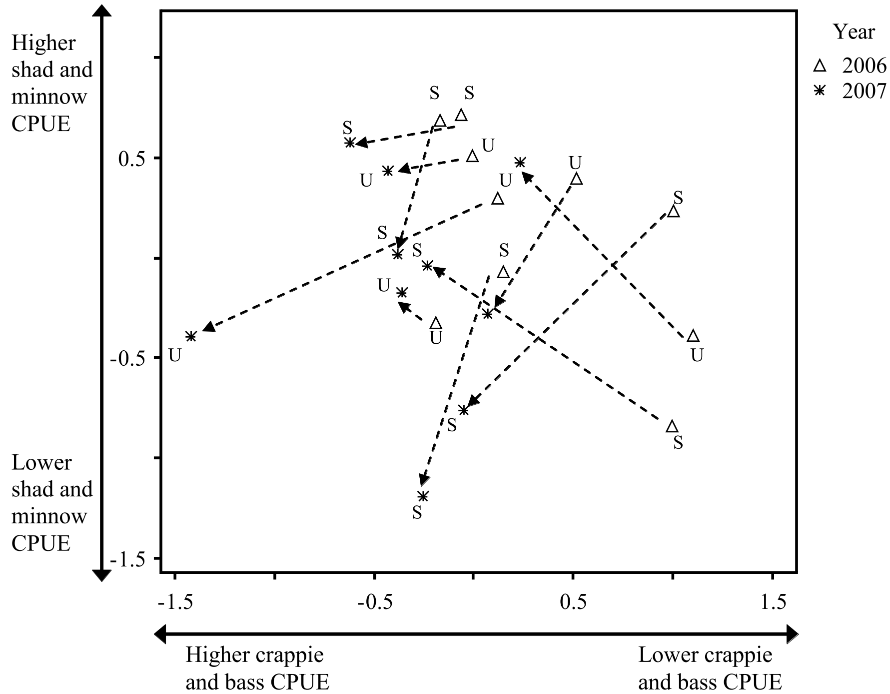

Figure 4. A scatterplot from a non-metric multidimensional scaling ordination of fish species sampled with 60 Hz pps-DC electrofishing from 10 Pascagoula River oxbow lakes during fall 2006 and 2007 (100 runs, stability = 11.5; stress = 0.00001). Axes I and III are shown (Monte Carlo randomization, $P = 0.03$ for both axes). CPUE = catch per unit of effort (fish/h). To interpret the ordination, species loadings for an axis were at least 0.50. Lakes sampled during 2006 are represented by a triangle, while lakes sampled during 2007 are represented by an asterisk. Dashed arrows represent the directional shift in fish assemblage structure by individual lakes from 2006 to 2007. "S" represents stocked lakes and "U" represents unstocked (i.e., control) lakes.

with axes I and III representing most of the variation (37% combined). Community structure was not apparently different between stocked and unstocked lakes, but it shifted from 2006 to 2007 (Figure 4). Structural variation in the fish assemblage in 2006 was explained primarily by gizzard shad (*Dorosoma cepedianum*), threadfin shad (*D. petenense*), and brook silverside (*Labidesthes sicculus*), but in 2007 variation in fish assemblage structure was explained primarily by largemouth bass, black crappie (*Pomoxis nigromaculatus*) and white crappie (*P. annularis*). Axis II explained only 4% of the variation in species data and was defined primarily by bluegill CPUE.

Discussion

Supplemental stocking of largemouth bass has occurred in many aquatic ecosystems to improve predator-prey balance, add to recruitment of wild largemouth bass stocks, and establish populations in renovated or reclaimed water bodies (Noble 1981, Smith and Reeves 1986, Boxrucker 1986). We found that stock enhancement using adult largemouth bass was not an effective management tool to expedite sport fish restoration in Pascagoula River floodplain lakes impacted by Hurricane Katrina. Growth and recruitment of juvenile largemouth bass and bluegill to stock- and quality-sizes (200 mm and 300 mm TL, respectively) was evident from 2006 to 2007 based on observed length-frequency shifts toward larger size classes and increases in mean TL. In addition, predator-prey balance, indicated by declines in YOY bluegill abundance and increases in largemouth bass abundance, improved from 2006 to 2007, but the improvements were not caused by our stocking efforts. If stock enhancement led to improved fish stock characteristics, we would have expected these characteristics in the control (unstocked) lakes to remain the same or decrease. Although not statistically significant, the control lakes appeared to perform better than the stocked lakes with regard to largemouth bass and bluegill abundance and size structure.

Our stocking density (37 fish/ha) of adult largemouth bass could have been too low, but it was larger than that for adult largemouth bass stocked into two Ohio River embayments in West Virginia (21 and 27 adult fish/ha) (Janney 2001), as well as for subadult largemouth bass (TL = 290 – 315 mm) stocked into Carr Creek Lake, Kentucky (25 fish/ha) (Buynak et al. 1999). Janney (2001) found that stocking densities of 21 and 27 adult fish/ha did not effectively enhance largemouth bass stocks in the two Ohio River embayments. Buynak et al. (1999) found that subadult largemouth bass stocked in to Carr Creek Lake did not enhance angler harvest or the largemouth bass population over the long-term.

Our results suggest that natural recovery of largemouth bass and bluegill in floodplain lakes may be more effective than supplemental stocking of adult largemouth bass after hurricane-induced hypoxic events. Other studies have shown that effects of supplemental stocking of largemouth bass on wild largemouth bass populations can be confounded by several factors, including natural growth and recruitment of the wild population, predation on stocked bass, or prey availability (Hoxmeier and Wahl 2002, Mesing et al. 2008, Diana and Wahl 2009). We did not conduct angler creel surveys to determine if angler harvest improved in these lakes after the hurricane. Nonetheless, we feel that potential angler-related impacts to our study results were negligible. The stocking was not publicized, and the number of recreational user days at wildlife management areas where these lakes were located declined by 61% from 2005 to 2006 (Alford et al. 2008).

Based on our results, natural recovery of hurricane-impacted largemouth bass and bluegill stocks require at least two years for populations to reach desirable levels of abundance and size-structure to support recreational fisheries. Similar to our study, McCargo et al. (2008) found that YOY individuals dominated the bluegill stock in the Roanoke River, North Carolina, one year after Hurricane Isabel caused hypoxic fish kills in 2003. Compared to their pre-hurricane electrofishing samples, largemouth bass were much less abundant in their post-hurricane samples and consisted of mostly small individuals (TL<200 mm). After two years, relative abundance and size-structure of largemouth bass and bluegill in the Roanoke River had recovered to pre-hurricane levels.

Following Hurricane Katrina, fish assemblages in Pascagoula River floodplain lakes were structured primarily by planktivorous species such as shad and brook silverside, but more predatory species like largemouth bass and crappie explained most of the variation in fish assemblage structure in 2007. This change in community composition suggests that largemouth bass and crappie capitalized on alternative, soft-finned prey types in addition to bluegill. Thus, although smaller-bodied planktivorous species initially filled the void created by hypoxia-induced fish kills from Hurricane Katrina, larger-bodied predators likely took advantage of this alternative prey source.

Other studies show that hypoxia and other hurricane-induced habitat alterations cause shifts in the physiology, distribution and abundance of larval (Fontenot et al. 2001) and adult sport fishes (Killgore and Hoover 2001, Rutherford et al. 2001) in floodplain river systems. Similar to our study, Rogers and Allen (2008) reported shifts in the Lake Okeechobee fish assemblage following four hurricanes during 2004 and 2005. When macrophyte cover in the lake was uprooted due to intense wave action, the post-hurricane fish assemblage shifted from predominately insectivorous sunfishes (Centrarchidae) and topminnows/killifishes (Poeciliidae and Fundulidae) to planktivorous shads and silversides. McCargo et al. (2008) also found that the post-Hurricane Isabel fish assemblage in the lower Roanoke River was dominated by juvenile shads, eastern silvery minnow (*Hybognathus regius*), bowfin (*Amia calva*), and white catfish (*Ameiurus catus*) following hypoxia-induced fish kills. In 2–3 years, however, these authors reported that the fish assemblage recovered in the Roanoke River, with steady increases in largemouth bass, crappie, and bluegill abundances to pre-hurricane levels.

Hurricanes are naturally occurring phenomena, and coastal ecosystems have endured their impacts for millenia. Aquatic communities that experience hurricanes tend to be resilient following these large-scale pulse disturbances (Dolloff et al. 1994, Paperno et al. 2006). Still, these intense yet relatively infrequent disturbances damage commercially and recreationally important fisheries by physically destroying or altering habitats as well as infrastructure required to capture, transport, and/or process these fisheries. Moreover, ecosystem function and community resilience/resistance to hurricane-related events such as hypoxia (Mallin et al. 2002) can be compromised by land use and hydrological changes to watersheds (Rogers and Allen 2008). Regardless, management agencies are charged with developing appropriate responses to hurricane-related fisheries damage in a timely manner, such that stakeholders are provided with fishing opportunities, including personal, cultural, and economic benefits derived from these opportunities.

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