RECOVERY OF LARGEMOUTH BASS IN THE ROANOKE AND CASHIE RIVERS FOLLOWING HURRICANE IRENE

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Abstract.—Hurricane Irene made landfall in North Carolina on August 27, 2011, creating large areas of hypoxia in the Roanoke and Cashie rivers. From fall of 2011 to the fall of 2014, direct impacts of Hurricane Irene and subsequent recovery of Largemouth Bass *Micropterus salmoides* populations were examined using a boat mounted electrofishing unit. Relative abundance was extremely low in 2011 for both the lower Roanoke River (6.9 fish/h; SE = 1.8) and the Cashie River (3.7 fish/h; SE = 1.7). The paucity of Largemouth Bass was directly related to fish kills caused by hypoxia associated with Hurricane Irene. Recovery of Largemouth Bass populations was first detected in 2012. Although overall relative abundance in both rivers was high in fall of 2012, CPUE for fish >200 mm TL remained low in the lower (9.9 fish/h; SE = 1.6) and middle (16.6 fish/h; SE = 2.73) Roanoke River as well as the Cashie River (5.6 fish/h; SE = 1.6). Large numbers of sub stock-length fish indicated successful spawning in 2013 and 2014 for both rivers. By 2014, the relative abundance of fish >200 mm TL reached the coastal benchmark in the lower Roanoke (27.6 fish/h; SE = 2.9) and Cashie rivers (25.3 fish/h; SE = 6.5). The relative abundance of fish >200 mm TL in the middle Roanoke exceeded pre-hurricane levels as well as the coastal benchmark. If population growth and successful reproduction continue throughout the Roanoke and Cashie rivers, recovery to pre-Hurricane Irene relative abundance levels is likely to occur throughout both river systems.

Estuaries and coastal rivers are frequently affected by hurricanes and large rainfall events. The sudden influx of freshwater flushes the surrounding drainage basins of organic materials and contaminants. As a result, periods of short-term hypoxia (DO < 2 mg/L)) and anoxia (no detectable DO) are often followed by large fish kills. Hurricane-induced hypoxia has been reported from the Chesapeake Bay to Louisiana. Boesch et al. (1976) reported low dissolved oxygen and fish kills in the Chesapeake Bay following Tropical Storm Agnes in 1972. In 1989, Hurricane Hugo dumped a significant amount of rainfall in the Charleston Harbor watershed, resulting in hypoxia and subsequent fish kills (Knott and Mortore 1991; Van Dolah and Anderson 1991). Aided by animal and human waste contamination, Hurricanes Bertha and Fran created large scale hypoxic events in both the Cape Fear and Northeast Cape Fear rivers in 1996 (Mallin et al. 1999). Hypoxic events in these two river systems were also seen following Hurricane Floyd in 1999 (Mallin et al. 2002). Although periodic hypoxia occurred in the Peace River and Charlotte Harbor in Florida, large hypoxic zones and fish kills were reported following Hurricane Charley in 2004 (Stevens et al. 2006; Tomasko et al. 2006). Both Hurricane Katrina and Rita produced hypoxia and associated fish kills that significantly impacted sportfish populations in the eastern Atchafalaya River Basin, Louisiana (Perret et al. 2010). These acute hypoxic events often have significant impacts on fish populations; recovery of these impacted populations usually occurs within months (Knott and Mortore 1991; Van Dolah and Anderson 1991; Stevens et al. 2006). However, several studies have shown that some sportfish populations, including Largemouth Bass *Micropterus salmoides*, could take several years to fully recover following periods of anoxia that extend more than one day (McCargo et al. 2008; Perret et al. 2010; Potoka et al. 2014).

In 2003, Hurricane Isabel caused large-scale fish kills in the Roanoke and Cashie river basins of northeastern North Carolina with the remaining fish assemblage comprised mostly of hypoxia tolerant species (McCargo et al. 2008). During their post-Hurricane Isabel surveys, McCargo et al. (2008) documented improvement in the relative abundance of many species, including Largemouth Bass, and concluded the fish assemblage recovered to pre-hurricane condition nearly three years after landfall of Hurricane Isabel. To assess and facilitate recovery of Largemouth Bass, Thomas and Dockendorf (2009) recommended a hurricane recovery plan for coastal areas in North Carolina following Hurricane Isabel. Immediately following a hurricane, water quality should be monitored to examine the extent of hypoxic events and fish kills. Electrofishing surveys should occur in and around the affected areas as soon as water quality conditions rebounded to determine the status of remaining fish populations. Electrofishing surveys should continue for subsequent years to document recovery of Largemouth Bass populations. Thomas and Dockendorf (2009) also suggested stocking of Largemouth Bass be deferred when the post-hurricane sampling indicates presence of spawning populations and age-0 recruitment. If spawning adults remain absent the spring following a hurricane and young-of-year recruitment is nonexistent, then age-1 Largemouth Bass should be stocked. Thomas and Dockendorf (2009) recommended a stocking density of 1,500 bass/km and timing of stocking should consider recovery of forage species.

Hurricane Irene made landfall near Cape Lookout, NC, on August 27, 2011, and continued northward, passing over the Pamlico and Albemarle Sounds. Along with hurricane force winds and a heavy storm surge, Hurricane Irene inundated eastern North Carolina with 5 to 15 inches of rainfall. In the Albemarle Sound area, documented rainfall ranged from 5 to 10 inches (Avila and Cangialosi 2011). Because of the heavy rainfall and subsequent flushing of organic material from the floodplains and tributaries, portions of the Roanoke and Cashie rivers experienced long-term hypoxic and anoxic events. A rapid reduction in DO occurred on August 28, 2011, and hypoxic and anoxic conditions lasted until September 25, 2011 (Figure 1; USGS 2012). These hypoxic and anoxic events stretched approximately 75 river kilometers (rkm) from the mouth of the Roanoke River to Williamston, NC, and approximately 40 rkm from the mouth of the Cashie River to well above Windsor, NC. Following Hurricane Irene, an estimated 50,000 fish were reported dead or dying near Jamesville and Plymouth, NC, because of anoxic water conditions (NCDENR 2011). The majority of these fish kill reports included Largemouth Bass. The objective of this report was to document impacts to and subsequent recovery of Largemouth Bass populations in the Roanoke and Cashie rivers following the passage of Hurricane Irene in the fall of 2011. Specifically, we compared Largemouth Bass population parameters in the years following Hurricane Irene (2011–2014) to 2010 survey data.

Methods

Study area.—The Roanoke River flows approximately 600 km from the mountains of western Virginia to the Albemarle Sound in eastern North Carolina. The Roanoke River drainage basin is approximately 25,000 km^2, with only a relatively small portion falling within North Carolina. Over 18,000 km of tributaries drain into the Roanoke River from portions of 16 counties in Virginia and 15 counties in North Carolina. Three reservoirs were formed on the Roanoke River for flood control and hydroelectricity: John H. Kerr Reservoir, Lake Gaston, and Roanoke Rapids Lake. Water flow in the North Carolina portion of the river is controlled mainly by the uppermost reservoir in the system, John H. Kerr reservoir. The portion of the Roanoke River below Roanoke Rapids Lake is known as the lower Roanoke. The lower Roanoke is unique in that it flows through the largest intact and least-disturbed bottomland hardwood forest floodplain in the mid-Atlantic region (NCDENR 2006). The Cashie River is located in Bertie County, NC, and is adjacent and connected to the Roanoke River. Sportfish populations in the Cashie and Roanoke rivers are managed as one unit due to the similarity, location, and connectivity of these systems that form a delta that connects to the western Albemarle Sound.

Our study area, the lower Roanoke, was divided into three strata: lower Roanoke, middle Roanoke, and Cashie. The lower Roanoke strata extended from the mouth of the Roanoke River upstream to Williamston, NC. The middle Roanoke strata stretched from Williamston, north to Scotland Neck, NC. The Cashie River stratum was defined as the area below Windsor, NC, to Cashoke Creek near the mouth of the river (Figure 2). Sample sites in each strata were located in tributaries and main stem locations in the Roanoke River and Cashie River (Figure 2). With the exception of 2011, the number of sample sites within each section remained constant between years (Table 1).

Fish sampling.—To monitor Largemouth Bass populations, boat-mounted electrofishing gear (Smith-Root 7.5 GPP; 170–1000 V pulsed DC; 2–4 A) was used to collect fish during each fall from 2011 to 2014, as a part of yearly sportfish monitoring conducted by the North Carolina Wildlife Resources Commission (Commission). Boat electrofishing was conducted during daylight hours by a two-person crew (one netter and one driver) and electrofishing time (s) was recorded at each site. Largemouth Bass were netted as they were encountered and held in a live well until the completion of the sampling site. Individuals were then measured (total length, TL; mm) and weighed (g) before being released.

Data analysis.—Data from the Roanoke River were separated into three strata (lower Roanoke, middle Roanoke, and Cashie River) for analysis. Several population parameters were used to track recovery of Largemouth Bass populations in each section of the Roanoke River. Relative abundance of Largemouth Bass was indexed as catch-per-unit-effort (CPUE; fish/hour) and mean overall CPUE was calculated by averaging the CPUE from all sampling sites in a given section each year. Mean CPUE for fish >200 mm TL was also calculated. To track changes in size structure, length frequency histograms (length bins of 25 mm) were constructed for each section-year combination. Length categories for Largemouth Bass were defined as sub stock-length (<200 mm), stock-length (200–299 mm), quality-length (300–379 mm), preferred-length (380–509 mm), and memorable-length (510–629 mm; Anderson and Neumann 1996).

Results

Lower Roanoke.—Sampling conducted during the fall of 2011 occurred two months after the landfall of Hurricane Irene, with only 13 Largemouth Bass collected. Mean overall CPUE (5.9 fish/h; SE = 1.6) was substantially lower than in 2010 (65.9 fish/h; SE = 9.1; Figure 3). Catch-per-unit-effort ranged from 0.0 to 11.5 fish/h. Relative abundance for fish >200 mm was also lower, with a mean CPUE >200 mm of 5.1 fish/h (SE = 1.6). Lengths ranged from 98 mm to 510 mm TL in 2011. Fish of quality-length or larger made up 92% of the catch, and very few sub-stock, stock, or memorable fish were collected in 2011 (Figure 4). A total of 508 Largemouth Bass were collected in the fall of 2012. Overall relative abundance was high, ranging from 30.1 to 152.5 fish/h with a mean overall CPUE of 72.9 fish/h (SE = 7.9), and a mean CPUE of fish >200 mm of 9.9 fish/h (SE = 1.6), both an increase from 2011. Largemouth Bass collected in 2012 ranged from 60 to 492 mm TL. The length frequency distribution was skewed left, with 96% of the catch being stock-length or smaller. No memorable-length fish were collected. Sampling during fall 2013 yielded 264 Largemouth Bass. Relative abundance ranged from 2.9 to 98.9 fish/h, with a mean overall CPUE of 38.2 (SE = 5.3). Relative abundance of bigger fish continued to increase, with a mean CPUE >200 mm of 25.5 fish/h (SE = 4.1). Lengths ranged from 69 to 527 mm TL. The length distribution continued to be skewed left with peaks in frequency at 125 mm and 250 mm. Quality-length or larger fish made up 12% of the total catch. Relative abundance in 2014 continued to be high, ranging from 20.9 to 123.9 fish/h. Mean overall CPUE in 2014 was 49.3 fish/h (SE = 10.12), and the mean CPUE >200 mm (27.6 fish/h; SE = 2.9) slightly increased from 2013. The Largemouth Bass population continued to be dominated by sub- and stock-length fish (68%), but the number of quality-length or larger fish collected was higher in 2014 than in any of the previous three years.

Middle Roanoke.—Due to sampling priorities related to the Commission hurricane response plan, the middle Roanoke was not sampled in the fall of 2011. A total of 71 Largemouth Bass were collected during the 2012 sampling season. Relative abundance was lower than in 2010 with a mean overall CPUE of 30.3 fish/h (SE = 4.9; Figure 5) and ranged from 18.0 to 57.0 fish/h. Relative abundance for fish larger than stock length was also lower than in 2010, with a mean CPUE >200 mm of 16.6 fish/h (SE = 2.7). Quality-length and larger Largemouth Bass only comprised 24% of the total catch in 2012, and no memorable-length fish were collected (Figure 6). Lengths of fish collected ranged from 46 to 474 mm TL. In the fall of 2013, 83 Largemouth Bass were collected, which was an increase from 2012. Mean overall CPUE in 2013 also increased to 37.4 fish/h (SE = 17.3). Relative abundance among sites ranged from 6.4 to 122.0 fish/h. Mean CPUE >200 mm was 24 fish/h (SE = 9.7). A wide range of sizes were collected (67–437 mm TL), but the majority (80%) was sub-stock length. Memorable-length Largemouth Bass were once again absent from the sample in 2013. Both the number of individuals and relative abundance increased from 2013 to 2014. A total of 203 Largemouth Bass were collected in the fall of 2014. Relative abundance ranged from 26.5 to 201.8 fish/h with a mean overall CPUE of 84.7 fish/h (SE = 25.3), and relative abundance of fish >200 mm was 68.5 fish/h (SE = 25.1). In 2014, Largemouth Bass ranged from 53 to 531 mm TL. The length frequency distribution was unimodal, with the peak occurring at 225 mm. The majority (81%) of fish collected were stock-length or larger. Memorable-length fish were collected but made up less than 1% of the total collection.

Cashie River.—Post-Hurricane Irene sampling yielded only six Largemouth Bass in the fall of 2011. Mean overall CPUE was 3.7 fish/h (SE = 1.9; Figure 7), ranging from 0 to 8.9 fish/h. All six fish collected were of stock to preferred-lengths (range 257–407 mm TL; Figure 8). In the fall of 2012, relative abundance increased from 2011. Mean overall CPUE was 48.9 fish/h (SE = 7.5), and relative abundance ranged from 8.6 to 86.7 fish/h. Relative abundance of stock length or larger fish also increased to a mean CPUE of 5.6 fish/h (SE = 1.6). A total of 144 Largemouth Bass were collected ranging in lengths from 69 to 412 mm TL. The length frequency distribution was skewed left, with the peak occurring at 100 mm. Sub stock-length fish accounted for 89% of the total catch in 2012. Sampling in the fall of 2013 yielded 69 Largemouth Bass. Relative abundance ranged from 8.6 to 37.0 fish/h with a mean overall CPUE of 22.2 fish/h (SE = 3.1). Of the 69 fish collected, 59 (86%) were stock-length or smaller. Mean CPUE >200 mm was 16.1 fish/h (SE = 3.9). In 2013, Largemouth Bass ranged from 90 to 503 mm TL, and memorable-length fish were not collected. Relative abundance increased in the fall of 2014 ranging from 17.9 to 84.6 fish/h. Mean overall CPUE was 36.9 fish/h (SE = 7.5), and mean CPUE >200mm was 25.3 fish/h (SE = 6.5). A total of 118 Largemouth Bass was collected, ranging from 74 to 526 mm TL. The 2014 length distribution was bimodal with peaks occurring at the 100 mm and 300 mm length bins. Of the fish collected, 70% were stock-length or larger. Only two memorable fish were collected in 2014.

Discussion

Hurricane Irene had a significant impact on the Largemouth Bass population in the Roanoke River, especially in the lower Roanoke and Cashie rivers. Pre-hurricane populations were thriving and healthy, with a wide range of sizes and high numbers of quality-length or larger fish throughout the Roanoke and Cashie rivers (Ricks and McCargo 2011). Post-hurricane sampling during the fall of 2011 in the lower Roanoke and Cashie rivers was characterized by the marked reduction in both overall CPUE and CPUE of fish >200 mm TL. Post-hurricane sampling did not occur in the middle Roanoke River, therefore direct impacts of the hurricane could not be evaluated for this section of river. By the end of this study in 2014, relative abundance had markedly improved compared to the fall of 2011 in all river sections. While CPUE did not reach pre-hurricane levels (Ricks and McCargo 2011), relative abundance significantly improved in each of the three river sections, and exceeded the coastal benchmark for healthy populations (25 fish/h >200 mm). Size distributions also indicated that Largemouth Bass populations were represented by several different cohorts of multiple size classes by the end of the study.

Relative abundance in 2011 was significantly lower than the coastal benchmark of 25 fish/h, suggesting a suppressed population in the lower Roanoke River. Following low relative abundance in the spring of 2012 (Commission unpublished data) and interest from local angler groups, over 120,000 Largemouth Bass fingerlings (40–60 mm) were stocked in tributaries of the Roanoke and Cashie rivers (Table 2) near Jamesville and Plymouth. Thomas and Dockendorf (2009) found that stocking of fingerlings and advanced fingerlings had little to no contribution to population recovery following effects of Hurricane Isabel in 2003. Although CPUE of young-of-year fish was higher in stocked sites, relative abundance was also high at unstocked sites indicating that natural reproduction occurred and stocking was not needed (Figure 9). However, in 2012 the overall relative abundance was higher than in both 2010 and 2011 and was driven by numerous substock-length fish. Despite the high overall CPUE, relative abundance of fish > 200 mm remained well below pre-hurricane levels. Recruitment of the strong 2012 year class was observed in the fall of 2013. Relative abundance in 2013 was marginally above the coastal benchmark of 25 fish/h >200 mm for Largemouth Bass and was driven by the 2012 year-class that had reached stock-length. The large proportion of sub stock-length fish indicated successful spawning and recruitment in the spring of 2013. While the Largemouth Bass population in the lower section of the Roanoke River had not reached levels seen in 2010 (Ricks and McCargo 2011), relative abundance of stock-length and larger fish was still above the coastal benchmark when this study concluded in 2014. The proportion of quality-length Largemouth Bass had increased since 2011 and natural recruitment was occurring in the lower section of the Roanoke River. The number of quality-length fish should continue to grow into preferred and memorable length sizes by the fall of 2015.

While the lack of data from the middle Roanoke following Hurricane Irene in 2011 impedes direct quantification, the impacts of Hurricane Irene on habitat conditions in the middle Roanoke did not mirror the impacts in the lower Roanoke. While the majority of the sampling sites did not experience hypoxic conditions (USGS 2012; Gage 02081022), several sites near Williamston may have experienced hypoxic, or even anoxic, conditions. Hypoxia-induced mortality of Largemouth Bass in these several sites may have contributed to the decline in relative abundance of stock-length and larger fish in 2012. It is also possible that Largemouth Bass could have emigrated up-river, where sampling did not occur. Recruitment of young-of-year fish was evident in the fall of 2012, even though the middle Roanoke was not stocked with fingerlings. Successful recruitment of YOY fish was also seen in 2013 and 2014. By the end of this study, relative abundance of adult Largemouth Bass had reached and exceeded 2010 levels (Ricks and McCargo 2011). The large number of stock-length fish found in 2014 should continue to grow, resulting in an expanded length distribution similar to the one observed in 2010.

Similar to the lower Roanoke River sampling area, the Cashie River was also heavily impacted by Hurricane Irene. A significant decline in overall relative abundance, as well as relative abundance of fish >200 mm TL, followed Hurricane Irene's landfall. This reduction in abundance exceeded declines documented in the lower Roanoke River. Sections of the Cashie River, like the lower Roanoke River, were stocked with Largemouth Bass fingerlings in 2012. The large 2012 cohort was visible in 2013 as stock-length fish and in 2014 as quality-length fish. The 2012 cohort likely contributed strongly to reproduction and recruitment in 2013 and 2014. By the end of the study, relative abundance had reached the coastal benchmark of 25 fish/h, but had not reached the 2010 pre-hurricane levels. However, by the fall of 2014 the proportions of stock-length and larger fish were very similar to 2010 (Figure 10). The large number of Largemouth Bass seen in 2014 should continue to grow and reproduce over the next year, thus improving the fishery in the Cashie River assuming habitat and water quality conditions remain favorable.

Although Largemouth Bass were not fully recovered to pre-Hurricane Irene levels by the end of our study period, relative abundance in each section were above the coastal benchmark of 25 bass/h, indicative of a quality Largemouth Bass fishery. Given the growth and reproduction of Largemouth Bass in 2014, it is very likely that populations in the Roanoke and Cashie rivers will reach 2010 quality (as defined by an expanded size and age structure) by 2015. The extended recovery period in this study was congruent with previous hurricane recovery assessments in the Roanoke River (McCargo et al. 2008) and in the nearby Chowan River (Potoka et al. 2014). However, more rapid recoveries have been seen outside of the Albemarle region (Knott and Mortore 1991; Van Dolah and Anderson 1991; Stevens et al. 2006). These rapid recoveries were likely aided by immigration from unaffected areas nearby. A large portion of the Roanoke and Cashie rivers were impacted by hypoxia and thus were not potential sources of immigration. Future research should continue to investigate potential areas of refugia and movement of Largemouth Bass during system-wide hypoxic events. Brown et al. (2015a, 2015b) provided insight on DO thresholds for Largemouth Bass movement and recolonization following hypoxic conditions as well as response to in situ Largemouth Bass displacement to evaluate movement following tournament activity. Continued monitoring of Largemouth Bass populations in the Roanoke and Cashie rivers will increase our understanding of recovery periods following hurricanes and hypoxia-induced fish kills, allowing for better management of Largemouth Bass populations and education of anglers following these unfortunate, yet natural, events.

Management Recommendations

1. Monitor Largemouth Bass populations in the Roanoke River annually and immediately following hurricanes or other large-scale fish kill events. Better understanding the recovery of Largemouth Bass following episodic hypoxia will allow managers to inform anglers of fishery health and possible recovery timelines.
2. Follow the hurricane recovery plan concerning population enhancements. Given improvements in abundance and size structure, no further stockings of fingerlings or transplants of adult fish from other areas or systems are recommended at this time.
3. Conduct a follow-up study to Brown et al. (2015a, 2015b) to tag and release any surviving Largemouth Bass during the initial assessments following an anoxic or hypoxic event. Recapture of tagged fish will help identify possible recolonization effects in response to improved water quality and habitat conditions following anticipated recovery from system wide hypoxic or anoxic conditions.
4. Collect otoliths from Largemouth Bass for an updated age and growth analysis during the fall of 2015. Five fish should be taken from each 10 mm length bin.

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Literature Cited

Anderson, R. O., and R. M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447–481 in B. R. Murphy and D. W. Willis, editors. Fisheries Techniques. 2nd Edition. American Fisheries Society, Bethesda, Maryland.

Avila, L. A., and J. Cangialosi. 2011. Tropical cyclone report, Hurricane Irene, 21–28 August 2011.National Oceanic and Atmospheric Administration, National Hurricane Center, Miami.

Boesch, D. F., R. J. Diaz, and R. W. Virnstein. 1976. Effects of Tropical Storm Agnes on soft-bottom macrobenthic communities of the James and York Estuaries and the lower Chesapeake Bay. Chesapeake Science 17(4):246–259

Brown, D. T., D. D. Aday & J. A. Rice. 2015a. Responses of coastal Largemouth Bass to episodic hypoxia. Transactions of the American Fisheries Society 144:655-666.

Brown, D. T., J. A. Rice, C. D. Suski, and D. D. Aday. 2015b. Dispersal patterns of coastal Largemouth Bass in response to tournament displacement. North American Journal of Fisheries Management 35:431–439.

Knott, D. M., and R. M. Mortore. 1991. The short-term effects of Hurricane Hugo on fishes and decapod crustaceans in the Ashley River and adjacent marsh creeks, South Carolina. Journal of Coastal Research 8:335–356.

Mallin, M. A., M. H. Posey, G. C. Shank, M. R. McIver, S. H. Ensign, and T. D. Alphin. 1999. Hurricane effects on water quality and benthos in the Cape Fear watershed: natural and anthropogenic impacts. Ecological Applications 9:350–362.

Mallin, M. A., M. H. Posey, M. R. McIver, D. C. Parsons, S. H Ensign, and T. D. Alphin. 2002. Impacts and recovery from multiple hurricanes in a piedmont-coastal plain river system. BioScience 52(11):999–1010.

McCargo, J. W., K. J. Dockendorf, and C. D. Thomas. 2008. Fish assemblage response following a hurricane-induced fish kill in the lower Roanoke River, North Carolina. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-22, Final Report, Raleigh.

NCDENR (North Carolina Department of Environment and Natural Resources). 2006. Roanoke River basinwide water quality plan. North Carolina Department of Natural Resources. Division of Water Quality, Basinwide Planning Program, Raleigh.

______. 2011. North Carolina Division of Water Quality annual report of fish kill events 2011. Division of Water Quality, Final Report, Raleigh.

Perret, A. J., M. D. Kaller, W. E. Kelso, and D. A. Rutherford. 2010. Effects of Hurricanes Katrina and Rita on sport fish community abundance in the eastern Atchafalaya River Basin, Louisiana, North American Journal of Fisheries Management 30(2):511-517.

Potoka, K. M., J. W. McCargo, and B. R. Ricks. 2014. Chowan and Meherrin River Largemouth Bass populations response following Hurricane Irene. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

Ricks, B. R., and J. W. McCargo. 2011. Largemouth Bass electrofishing survey on the Roanoke River and Cashie rivers, North Carolina–2010. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-22, Final Report, Raleigh.

Stevens, P.W., D.A. Blewett, and J.P. Casey. 2006. Short-term effects of a low dissolved oxygen event on estuarine fish assemblages following the passage of Hurricane Charley. Estuaries and Coasts 29(6A):997–1003.

Thomas, C. D., and K. J. Dockendorf. 2009. Contribution of stocked Largemouth Bass following hurricane-induced fish kills in two North Carolina coastal rivers. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-22, Final Report, Raleigh.

Tomasko, D. A., C. Anastasiou, and C. Kovach. 2006. Dissolved oxygen dynamics in Charlotte Harbor and its contributing watershed, in response to Hurricanes Charley, Frances, and Jeanne–impacts and recovery. Estuaries and Coast 29(6A):932-938.

USGS (U.S. Geological Survey). 2012. National Water Information System data available on the World Wide Web (Water Data for the Nation). Available: http://waterdata.usgs.gov/nc/nwis/current/?type=flow&group_key=basin_cd. (February 2016).

Van Dolah, R. F., and G. S. Anderson. 1991. Effects of Hurricane Hugo on salinity and dissolved oxygen conditions in the Charleston Harbor Estuary. Journal of Coastal Research 8:83–94.

TABLE 1.—Number of sampling sites per year in the lower Roanoke, middle Roanoke and Cashie rivers.

	2011	2012	2013	2014
Lower	7	21	20	21
Middle	0	7	6	7
Cashie	5	9	9	9

TABLE 2.—Locations and number of Largemouth Bass young of year stocked in 2012.

Location	Stocked Creeks	Number Fish	Fish/kg
Lower Roanoke	Conaby Creek Warren Neck Creek Cow Creek	26,288[a]	375[a]
Middle Roanoke	Gardner's Creek Upper Deadwater Lower Deadwater	68,133	1,934
Cashie River	Cashoke Creek Cashie-Broad Creek Grinnel Creek	26,288[a]	375[a]

[a] Stocking in the Lower Roanoke and Cashie occurred simultaneously and exact number of fish stocked at each location was not recorded, but the number of fish stocked was approximately equal between the two locations.

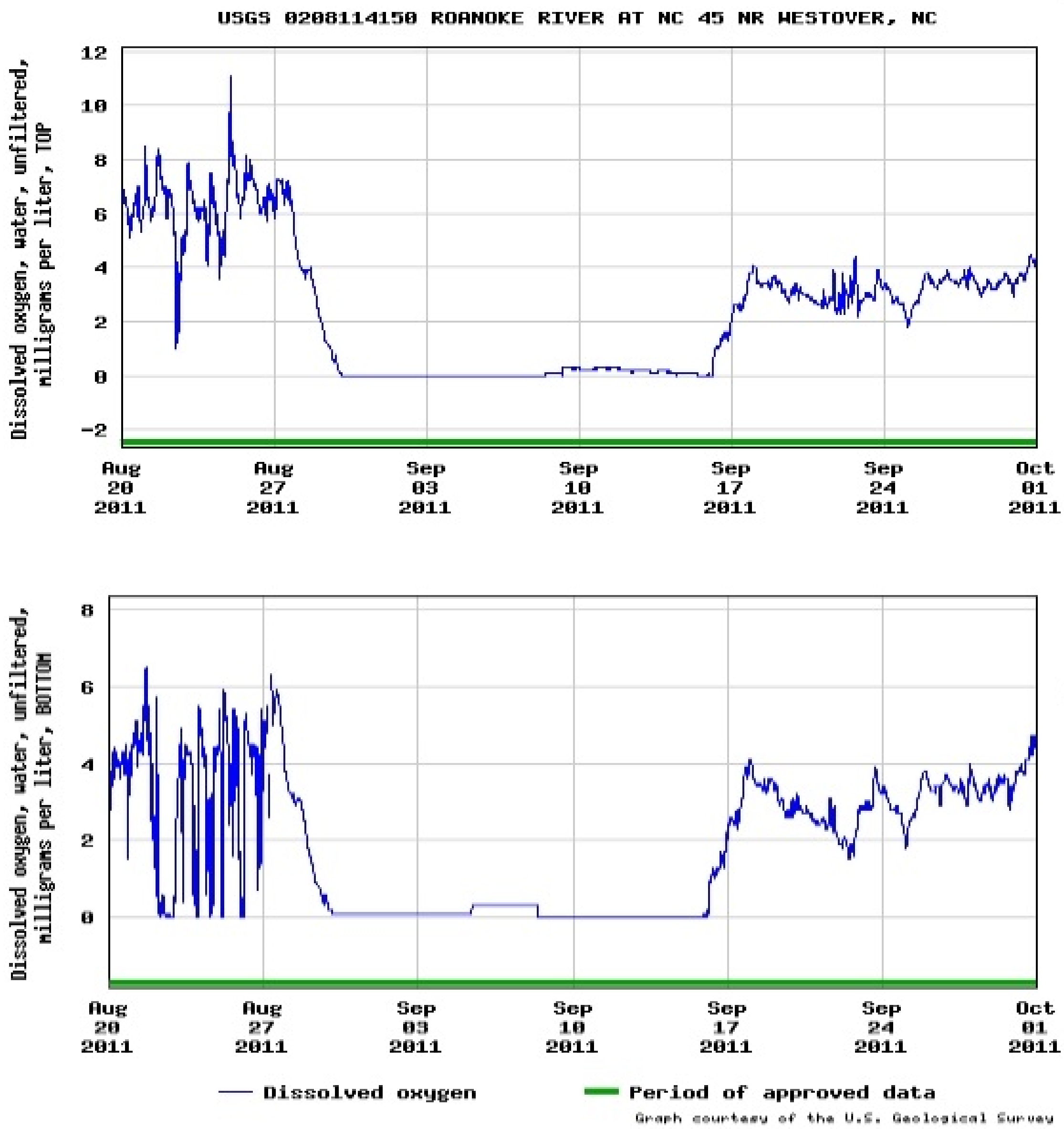

FIGURE 1.—Top and bottom DO readings (mg/L) from the USGS Gage # 0208114150 in the Roanoke River at NC Highway 45. Graphs are courtesy of the U.S. Geological Survey (USGS 2012).

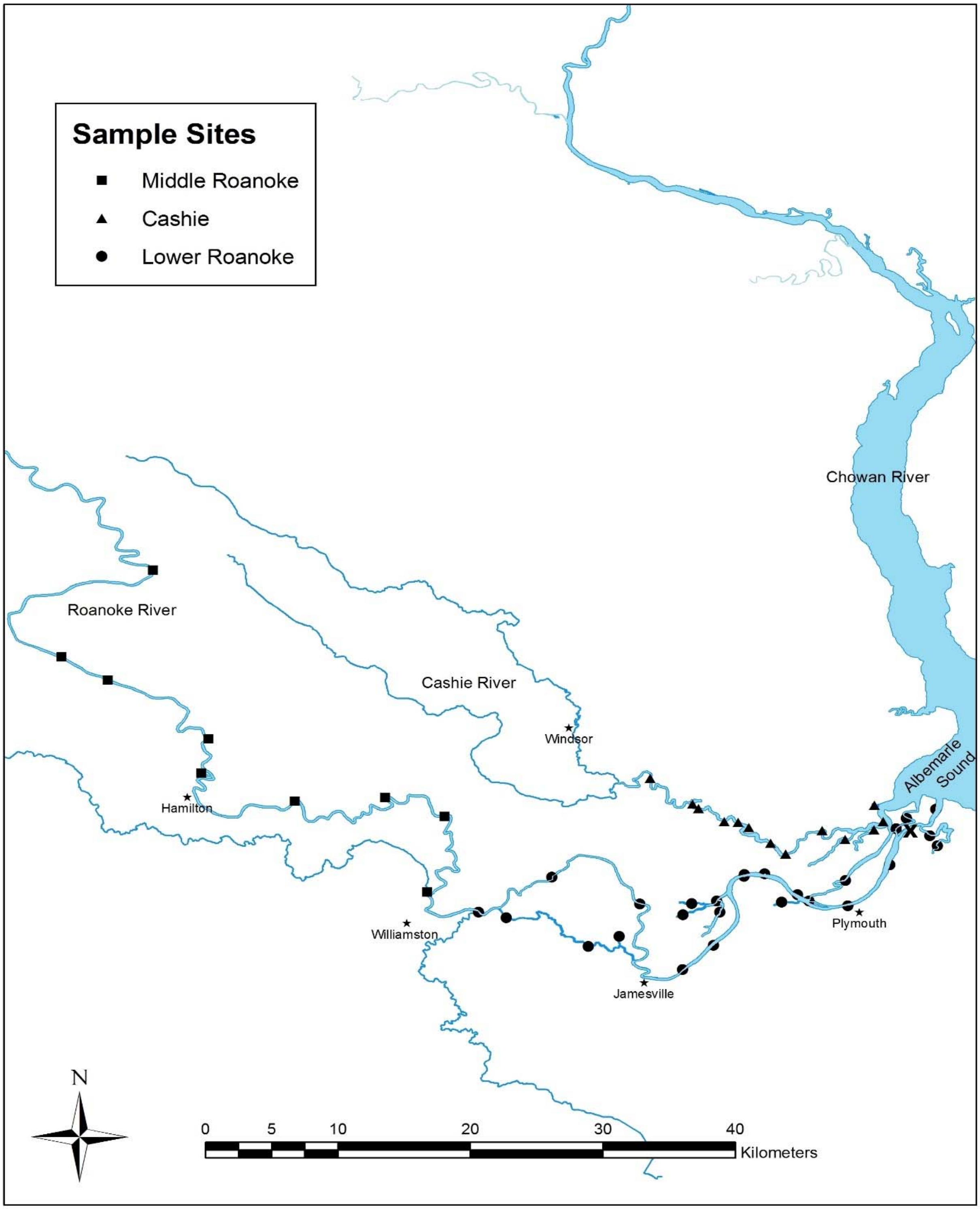

FIGURE 2.—Electrofishing sampling sites utilized from 2011 to 2014 for the Roanoke and Cashie rivers. Stars indicate towns. X indicates relative location of USGS Gage # 0208114150.

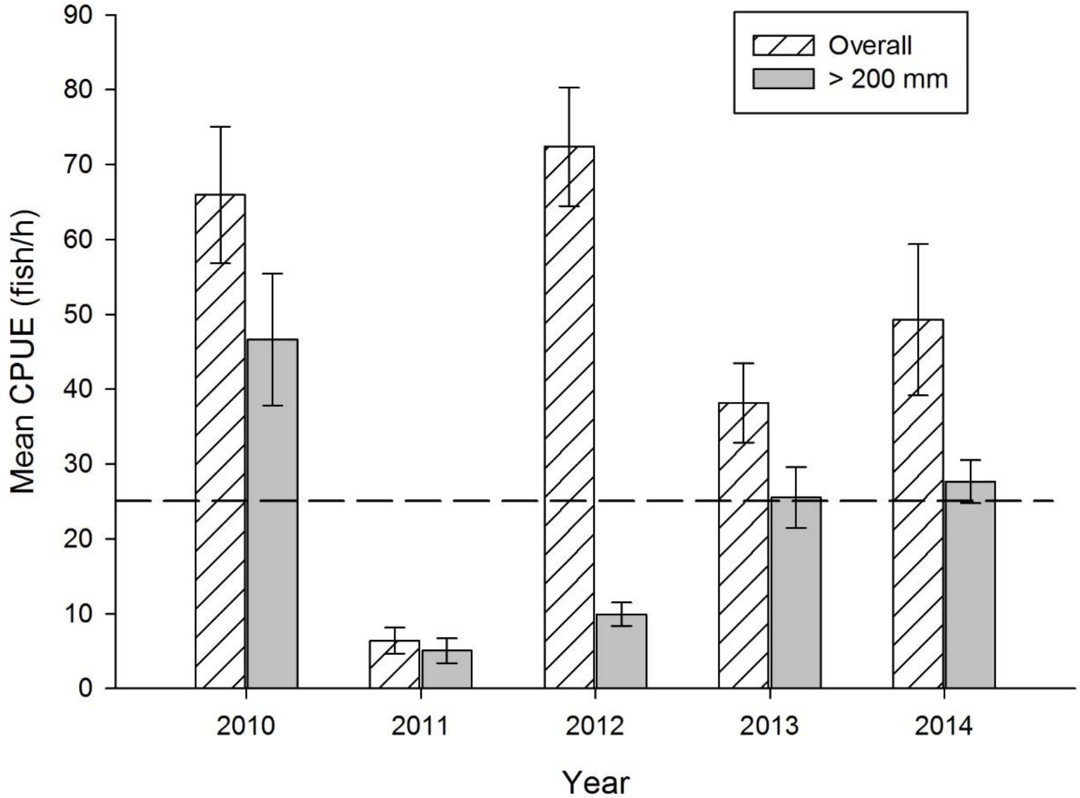

FIGURE 3.—Mean CPUE of Largemouth Bass in the lower Roanoke River. Error bars indicate one standard error. Dashed line indicates the coastal rivers benchmark of 25 fish/h for Largemouth Bass larger than 200 mm. Data from 2010 were obtained from Ricks and McCargo (2011).

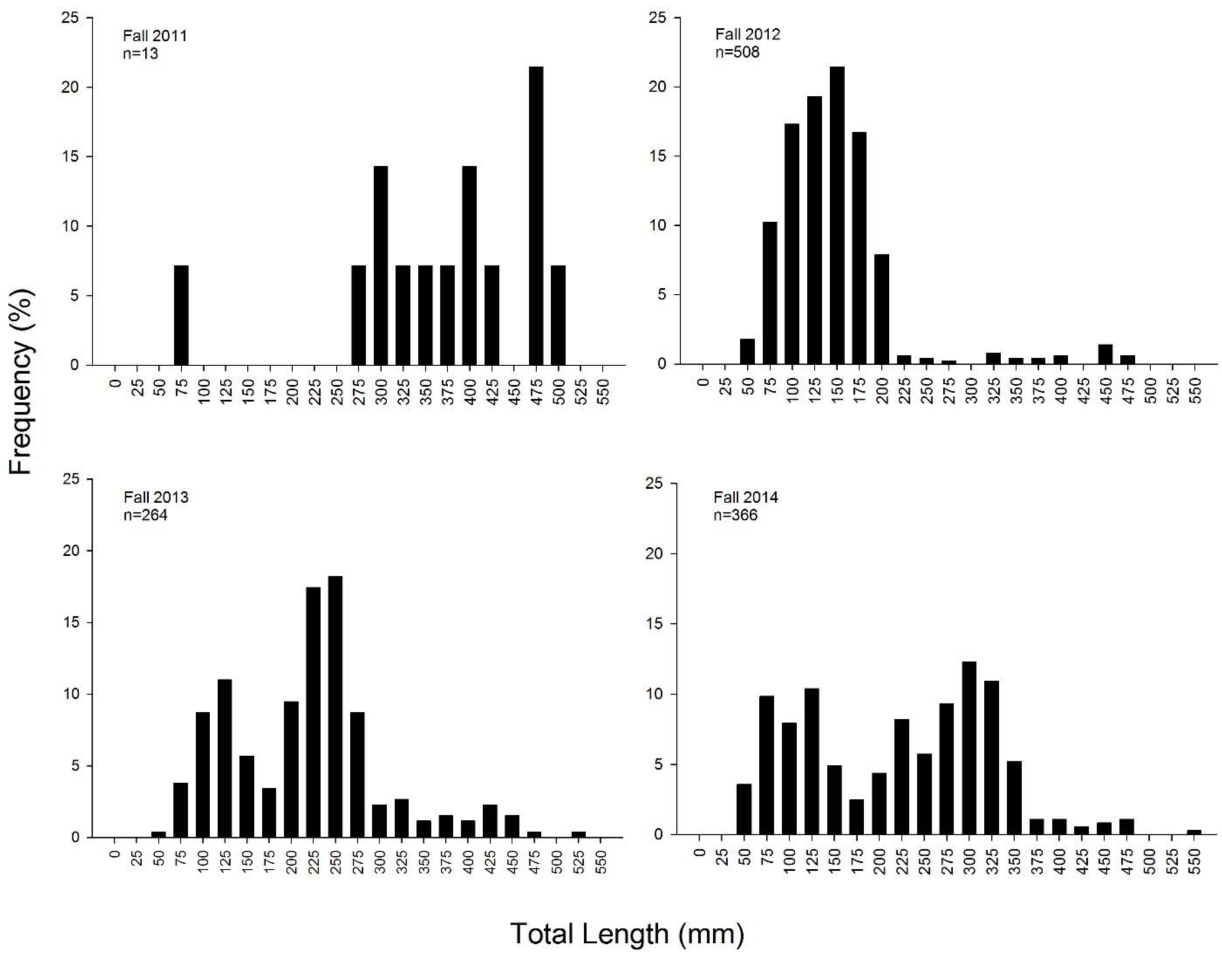

FIGURE 4.—Length frequency distribution for the lower Roanoke from the fall of 2011–2014.

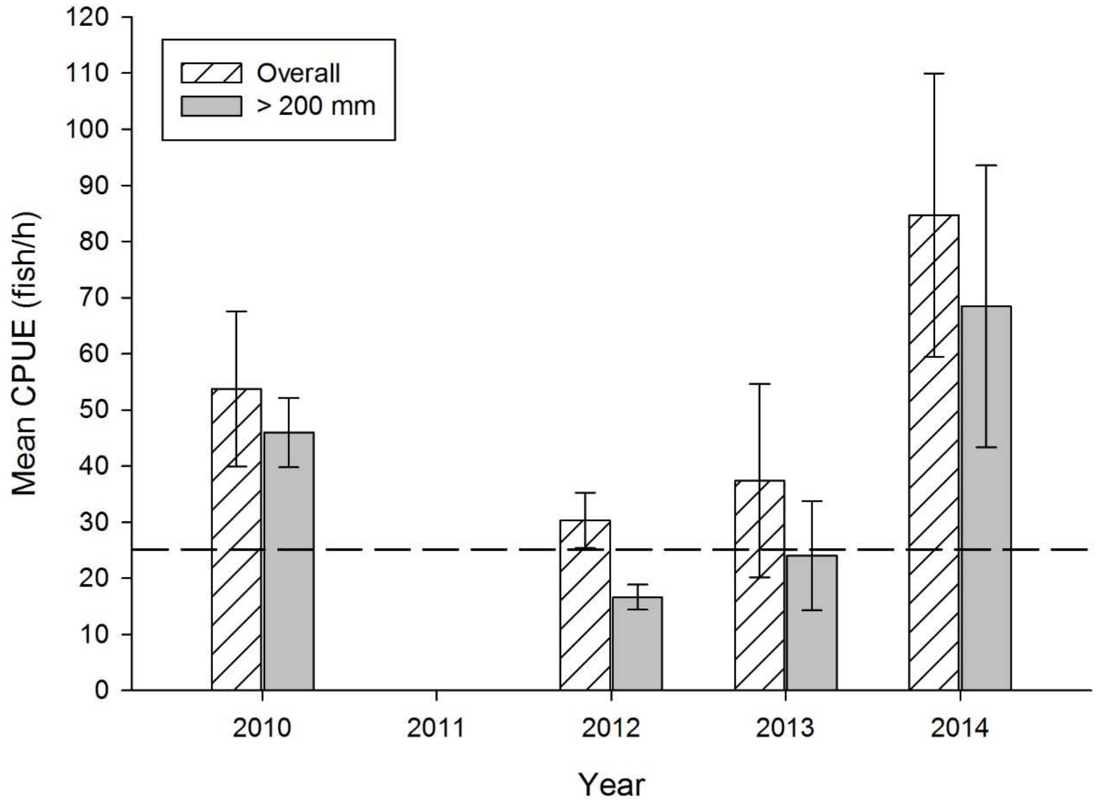

FIGURE 5.—Mean CPUE of Largemouth Bass in the middle Roanoke. Error bars indicate standard error. No data was collected from the middle Roanoke in 2011. Dashed line indicates the coastal rivers benchmark of 25 fish/h for Largemouth Bass larger than 200 mm. Data from 2010 were obtained from Ricks and McCargo 2011.

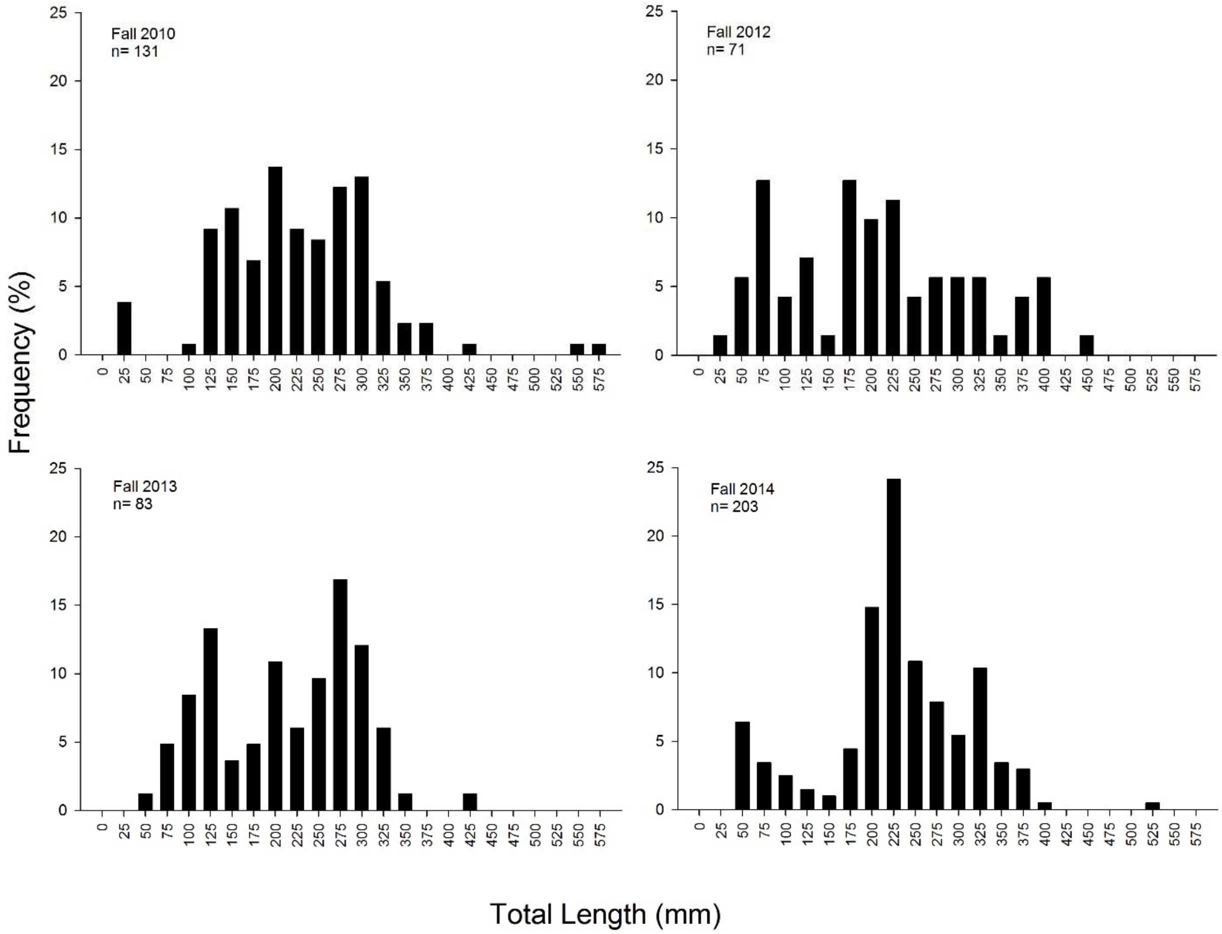

FIGURE 6.—Length frequency distribution for the middle Roanoke from the fall of 2010 and fall 2012-2014. No data was collected from the middle Roanoke in 2011. Data from 2010 were obtained from Ricks and McCargo 2011.

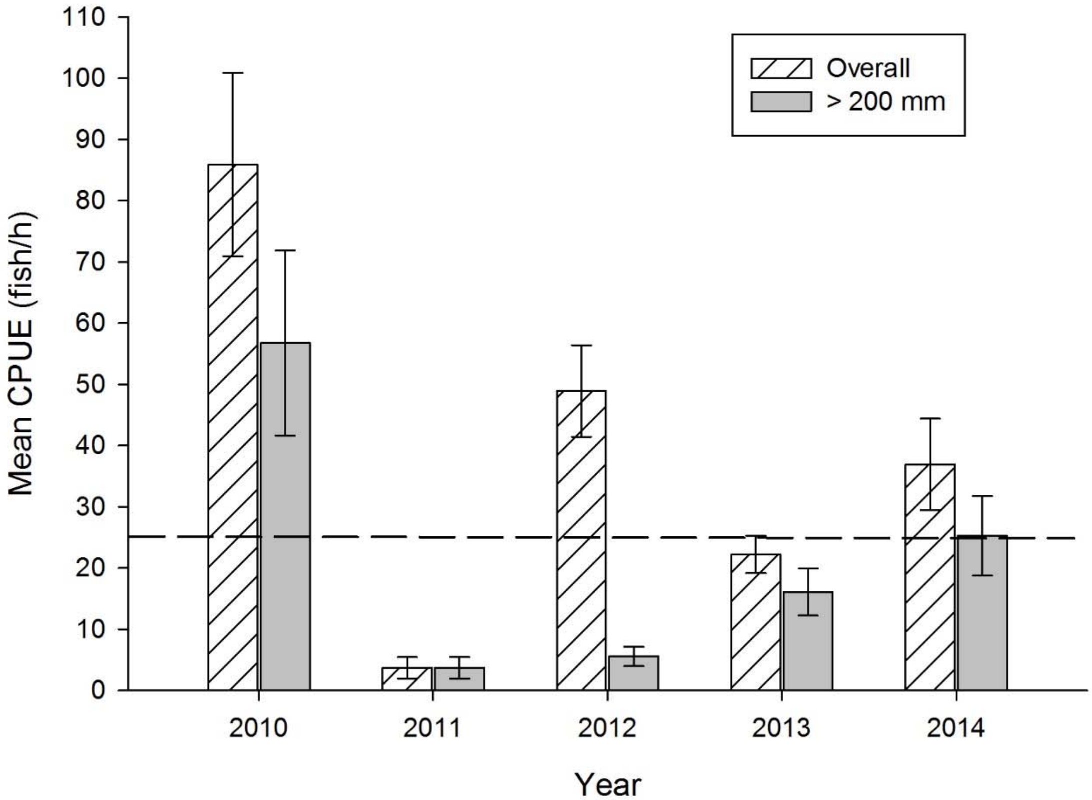

FIGURE 7.—Mean CPUE of Largemouth Bass in the Cashie River. Error bars indicate standard error. Dashed line indicates the coastal rivers benchmark of 25 fish/h for Largemouth Bass larger than 200 mm. Data from 2010 were obtained from Ricks and McCargo 2011.

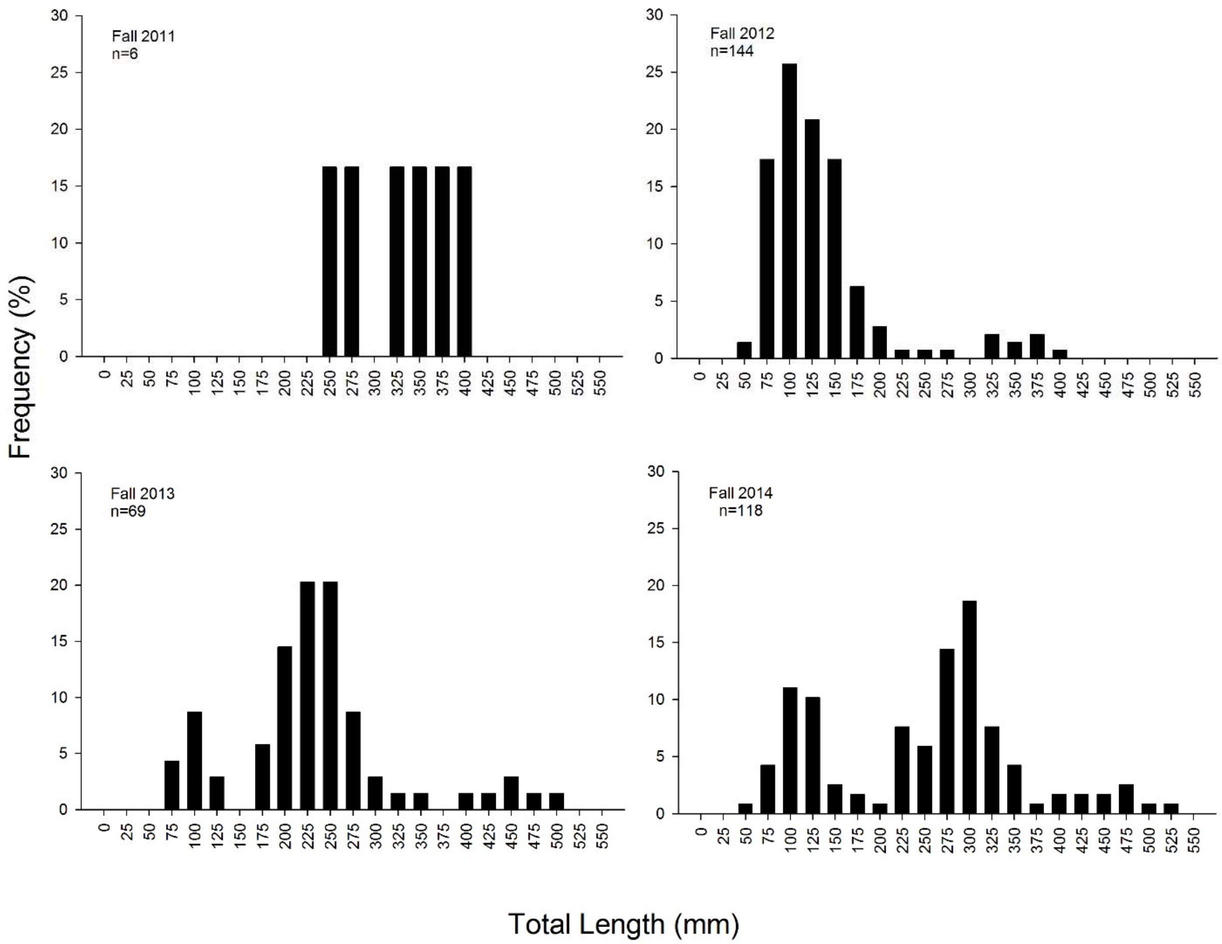

FIGURE 8.—Length frequency distribution for the Cashie River from the fall of 2011-2014.

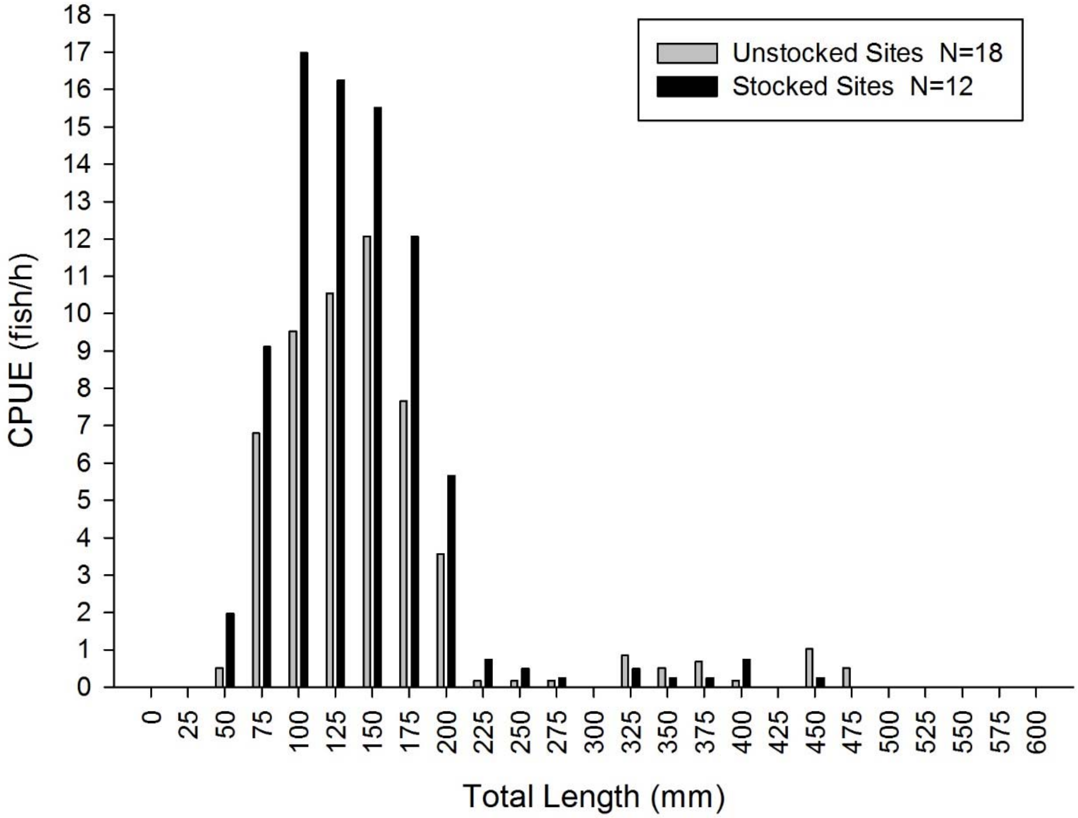

FIGURE 9.—Length distribution from stocked (N=12) and unstocked (N=18) sites in the Roanoke and Cashie rivers during the fall of 2012.

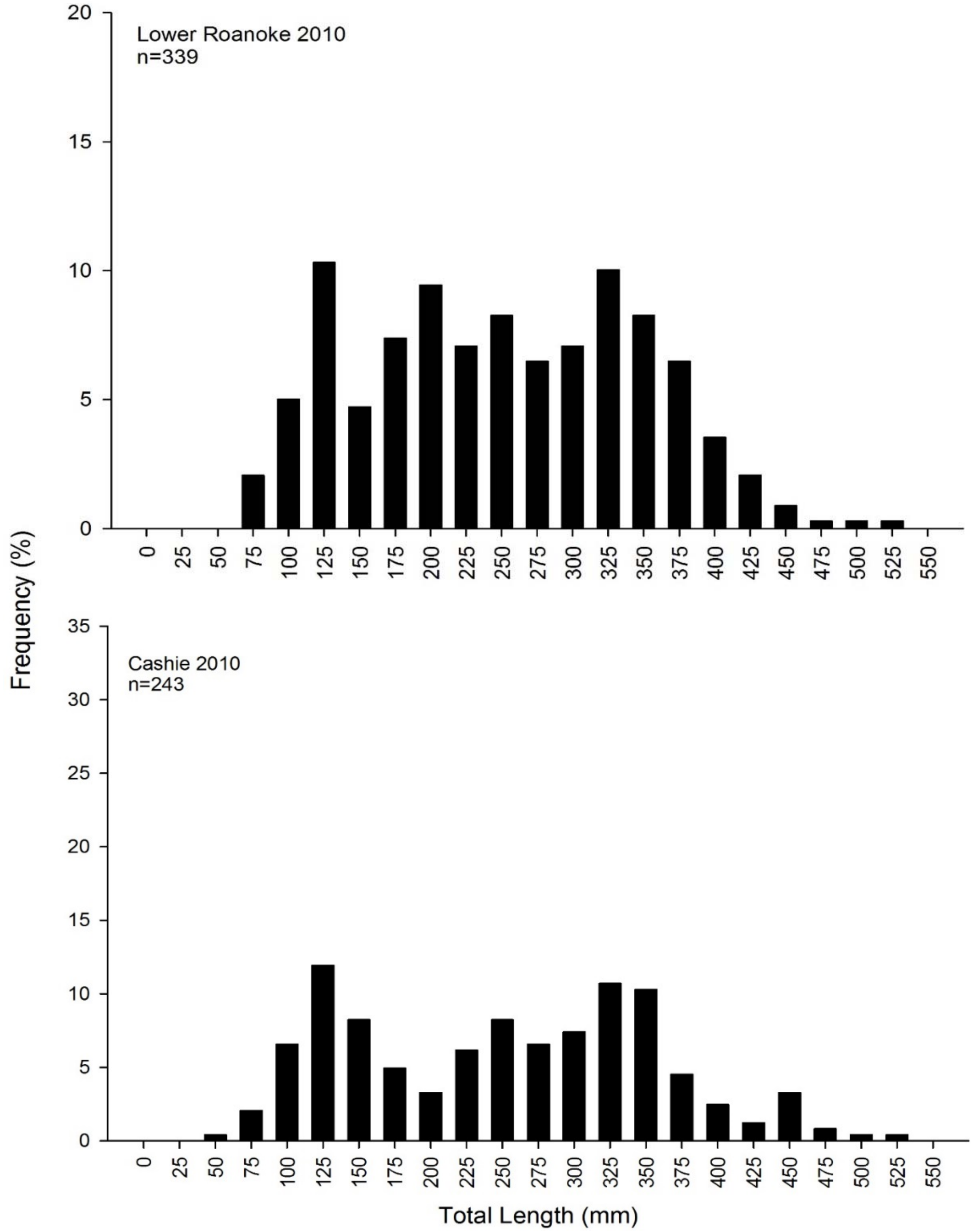

FIGURE 10.—Length frequency distribution for the Lower Roanoke and Cashie rivers from the fall of 2010. Data from 2010 were obtained from Ricks and McCargo 2011.