Fisheries resources of the Cape Fear River

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Abstract. The N.C. Wildlife Resources Commission conducted a baseline survey of fish populations in the Cape Fear River in the summer of 1962. Subsequent surveys focused on sport fish species, Species of Greatest Conservation Need, and anadromous species conducting spawning migrations. A considerable focus of fisheries research in the Cape Fear River has been documenting the behaviors and impacts of Flathead Catfish following their introduction in 1965. A systematic boat-mounted electrofishing survey was conducted in the Cape Fear River in 2015 and 2016 to elucidate the effect of hand-crank electrofishing on introduced catfish populations. The purpose of this report is to summarize data on all collected species and provide comparisons to the 1962 baseline survey. Overall, 2,225 fish representing 34 species were collected, including 13 Inland Game Fish and 9 nonnative species. Two Species of Greatest Conservation Need were observed in 1962 but were not collected in 2015–2016. Eighteen species were collected in this survey that were not observed in 1962. Bluegill, Largemouth Bass, Redbreast Sunfish, and Spotted Bass were the most abundant Inland Game Fish, while Flathead Catfish, Channel Catfish, Blue Catfish, and Longnose Gar were the most abundant nongame fish. White Catfish and other bullheads were historically the most abundant sport fish species; however, these species appear to be extirpated from the Cape Fear River. Although habitat degradation and climate change threaten the Cape Fear River's fisheries resources, introduced species have restructured the fish community and are the greatest challenge to restoring and managing native sport fish species.

The Cape Fear River has been the subject of many fisheries investigations. The earliest reports largely focused on harvest fisheries, principally for anadromous species, but documented abundant populations of catfish and redhorse suckers (McDonald 1887). Smith (1907) later noted that Flat Bullhead *Ameiurus platycephalus* were "very abundant." However, the river's freshwater fisheries remained largely undescribed until the North Carolina Wildlife Resources Commission (NCWRC) surveyed the Cape Fear River in the summer of 1962 as part of a systematic inventory of ichthyofauna in the state's river basins (Louder 1963). Subsequent surveys in the 1960s–1980s focused on anadromous populations (Davis 1967; Baker 1968; Nichols and Louder 1970), black bass management (Guier and Nichols 1977; Nichols 1978; Van Horn and Birchfield 1984; Nichols and Buff 1984; Ashley 1985), and the impacts of Flathead Catfish *Pylodictis olivaris* following their introduction in 1965–1966 (Guier et al. 1984; Ashley and Buff 1987). An index of biotic integrity survey using boat electrofishing was conducted annually from 1997–2006 (NCWRC unpublished data). Excluding the index of biotic integrity survey, most surveys conducted after 2000 targeted sport fish, catfish, or anadromous species (e.g., Rachels and Ashley 2002; Ashley and Rachels 2008; Dycus and Fisk 2014). A comprehensive angler creel survey was conducted 2003–2004 and found that catfish were the most popular sport fish in the Cape Fear River (Ashley and Rachels 2005).

In 2015 and 2016, NCWRC conducted a survey to assess the effects of hand-crank electrofishing on vital rates and abundance of fish populations in Southeastern North Carolina. The primary goal, assessing impacts of hand-crank electrofishing on nonnative catfish populations, was addressed by Fisk et al. (2019). The following report is a general summary of the fisheries resources in the Cape Fear River in 2015–2016. Comparisons are made to the catch composition reported by Louder (1963). Age structure, growth, and mortality are contrasted with other rivers assessed during the 2015–2016 hand-crank electrofishing project.

Methods

Study site. The Cape Fear River is a large coastal plain stream (Strahler Order = 7) that begins at the confluence of the Deep and Haw rivers near Moncure, NC. It flows approximately 312 km to its confluence with the Atlantic Ocean at Bald Head Island, NC. Three U.S. Army Corps of Engineers low head dams are located at river kilometer (RKM; measured from confluence with Atlantic Ocean) 99, RKM 151, and RKM 188 (Figure 1). Additionally, Buckhorn Dam is located at RKM 302 just downstream from confluence of the Deep and Haw rivers. Primary tributaries of the Cape Fear River include the Upper and Lower Little rivers (RKM 265 and RKM 255, respectively), Black River (RKM 67) and Northeast Cape Fear River (RKM 45). Land use in watersheds that drain into the mainstem Cape Fear River upstream of the sample sites (Hydrologic Units 3030002, 3030003, 3030004, and 303005) is 45% forested, 19% agriculture, 14% developed, 12% grassland/shrub, 8% wetland, and 2% open water (USDA 2021). As of 2021, there are 44 active major NPDES permitted discharges in those watersheds (NCDWR 2021). Additionally, there are 45 public municipal stormwater systems rated in fair or poor condition in those watersheds, at least 17 of which have no best management practices in service (NC One Map 2021). The Cape Fear River carries surface water classifications of WS-IV, WS-V, and class C at various locations throughout the study area (NCDENR 2004). Several sections of the main stem Cape Fear River were listed on the 2018 303(d) list of impaired waters, including one section within the study area that spans from the Federal Paper Board Corporation raw water intake (RKM 86) downstream to Bryant Mill Creek (RKM 81; NCDEQ 2019a).

A stratified-random survey design was employed to collect fish in June 2015 and June 2016. Two strata were of interest to the primary goal of the project: a stratum where hand-crank electrofishing is allowed (RKM 95–RKM 190) and a stratum where hand-crank electrofishing is prohibited (downstream of RKM 95 and upstream of RKM 190). A 10-km buffer was maintained between the two strata to minimize the probability of sampling fish that utilize both strata. Five 0.5-km sites were randomly selected in each stratum (10 sites total) to target all fish species. Ten additional 1-km sites were randomly selected in each stratum (20 sites total) to target catfish. For the purpose of this report, strata sampling data were aggregated and were given no further consideration.

Field collection. In the 10 sites targeting all fish species, boat-mounted electrofishing (Smith-Root 7.5 GPP; 120 Hz; 4,000–8,000 W) was utilized along each shoreline (1-km sample). All fish were collected as encountered, and voucher specimens were preserved in buffered formalin if identification could not be ascertained in the field. Low-frequency boat-mounted electrofishing (Smith-Root 7.5 GPP; 15 Hz; 1,800–2,500 W) was used in the 20 sites targeting catfish. A chase boat was employed to increase catch rates. Boats proceeded downstream through the 1-km sample site at 4–8 kph, and all ictalurids were collected as encountered.

For both sampling methods, all collected fish were measured for total length (TL; mm) and weight (g). Otoliths were removed from up to 10 fish per 2-cm size-class for the following species: Flathead Catfish, Blue Catfish *Ictalurus furcatus*, Channel Catfish *I. punctatus*, Bluegill *Lepomis macrochirus*, Largemouth Bass *Micropterus salmoides*, Redbreast Sunfish *Lepomis auritus*, and Redear sunfish *L. microlophus*. Fish in young-of-year size-classes were assumed age 0 following Carlander (1969, 1977). Catfish otoliths were prepared according to Nash and Irwin (1999) and Buckmeier et al. (2002) and read by two independent readers. Centrarchid otoliths were prepared following Long and Grabowski (2017) and were also read by two independent readers. Age disagreements were resolved, or individuals were removed from the age dataset following a concert read. Multinomial age-length keys (Ogle 2015) were constructed, and individual ages were assigned following the method of Isermann and Knight (2005).

Data analyses. Catch of each species was compared to Louder (1963). Relative abundance was indexed as catch-per-unit-effort (fish/h). Density plots were used to summarize size structure for species with five or more collected individuals. Relative frequency plots were used to examine age-class composition.

Growth was modeled using a Bayesian methodology and the von Bertalanffy growth function (VBGF; Beverton and Holt 1957; Doll and Jacquemin 2019). The von Bertalanffy growth function is expressed as

$$L_T = L_\infty\left[1 - e^{-K(T-t_0)}\right],$$

Where L is length, L_∞ is the mean length of the oldest age class (asymptotic length), K describes how quickly mean length at age approaches L_∞, t_0 represents the age when mean fish length is zero, and T denotes age. Informative priors for L_∞ were derived using the NCWRC BIODE database. Specifically, each species had a prior for L_∞ that was Gaussian distributed with a mean and standard deviation calculated from the maximum total lengths of each BIODE project with total length data collected between 2000 and 2014. Projects that did not have sufficient information (i.e., catch of sufficiently large individuals for a given species) were excluded from developing the prior. Priors for the other model estimated parameters (K and t_0) were weakly informative and constant across species [$K \sim$ Cauchy(0.25, 0.25) with a lower bound of zero; $t_0 \sim$ Cauchy(0, 1)]. Growth models were implemented using Stan (Stan Development Team 2019) as interfaced through R package "brms". All growth models used 4 concurrent Markov chain Monte Carlo chains, each with 4,000 total iterations, no thinning, and a 2,000 iteration burn-in period. Models were deemed to have reached approximate convergence if visual examination of trace plots indicated the chains were stationary and mixed, and the potential scale reduction factor ($\hat{R}$) of each estimated parameter was less than 1.1 (Gelman and Shirley 2011; Doll and Jacquemin 2019). The fit of each model was assessed by conducting a posterior predictive check (Doll and Jacquemin 2019).

Poisson log-linear models were used to estimate instantaneous total mortality (*Z*; Millar 2015). Poisson regression is the most robust catch-curve method to assumption violations, which include: recruitment is constant through time, mortality is constant through time and across ages, all fish are equally vulnerable to the sampling gear, and the age composition is estimated without error (Nelson 2019). Age at recruitment to the catch-curve was considered the modal age plus one year (*i.e*., Peak +1; Smith et al. 2012; Nelson 2019). All data analyses were conducted using R 4.0.

Results

Catch. A total of 2,225 individuals representing 34 species were collected (Table 1). Bluegill, Common Carp *Cyprinus carpio*, Largemouth Bass, and Longnose Gar *Lepisosteus osseus* were all collected in 100% of the sample sites in which they were targeted. Bluegill, Largemouth Bass, Redbreast Sunfish, and other *Micropterus* sp. (herein referred to as "Spotted Bass"; see discussion) were the most abundant Inland Game Fish, while Channel Catfish, Flathead Catfish, Blue Catfish, and Longnose Gar were the most abundant nongame fish. Overall, relative abundance of Bluegill, Redbreast Sunfish and Spotted Bass was greatest upstream of RKM 128, while Largemouth Bass did not exhibit a strong spatial gradient (Figure 2). Channel Catfish were most abundant upstream of RKM 128 while Longnose Gar were most abundant downstream of RKM 143. Blue Catfish and Flathead Catfish did not exhibit strong spatial gradients (Figure 3).

The high frequency electrofishing site with the greatest species diversity was RKM 143 with 18 species collected, while RKM 128 and RKM 71 had the fewest collected species (12; Table 2). Diversity in low frequency electrofishing sites was relatively homogenous, except RKM 229 yielded no Blue Catfish and RKM 226 yielded no catch of any ictalurid (Table 3).

Eighteen species were collected that were not present in the 1962 survey by Louder (1963). Among those are six nonnative species, four of which were likely introduced after the 1962 survey (Blue Catfish, Flathead Catfish, Grass Carp *Ctenopharyngodon idella*, and Spotted Bass). Twenty-seven species were observed in the 1962 survey but were not observed in 2015–2016 (Table 1). Many of these species are difficult to sample using boat-mounted electrofishing due to their small size, physiology, or habitat preference. The two Species of Greatest Conservation Need (SGCN) observed in 1962 were absent in 2015–2016 (Table 1). Both SGCN are ictalurids.

Size structure. Eight Inland Game Fish and 10 nongame species had at least 5 collected individuals and were described using density plots. Largemouth Bass were the largest Inland Game Fish, followed by Spotted Bass, Redear Sunfish, and Bluegill (Figure 4). Redear Sunfish were the largest lepomid, followed by Bluegill, Redbreast Sunfish, Pumpkinseed *Lepomis gibbosus*, and Dollar Sunfish *Lepomis marginatus* (Figure 4). Flathead Catfish were the largest nongame fish, followed by Blue Catfish, Longnose Gar, and Common Carp (Figure 5).

Age structure. Bluegill ranged from age 0 to age 7, with age-0 to age-2 fish comprising 71% of the population (Figure 6). Blue Catfish ranged from age 1 to age 21, with age-4 and younger fish comprising 70% of the population (Figure 6). Channel Catfish ranged from age 1 to age 6, but 78% of the population was age 1 (Figure 6). Flathead Catfish ranged from age 1 to age 31 with 73% between age 1 and age 4 (Figure 6). Largemouth Bass ranged from age 0 to age 9, with 82% of the population age 3 or younger (Figure 6). Redbreast Sunfish exhibited a maximum age of 4, but 99% were age 1 to age 2 (Figure 6). Redear Sunfish ranged from age 1 to age 6, with 40% age 1 (Figure 6).

The Flathead Catfish maximum age in this study (31) is the oldest reported age for the species outside of its native range (Fisk et al. 2019) and approaches the maximum age reported in its native range (34; Marshall et al. 2009). The oldest Blue Catfish in this study (21) approaches the maximum age reported from an introduced population (25; Hilling et al. 2018), although it is considerably less than what has been reported from its native range (34; Stewart et al. 2009). The age structure of Largemouth Bass was similar to other coastal NC populations (Potoka and McCargo 2016; Smith and Potoka 2017, 2020; Rachels and Fisk 2021a, 2021b, 2021c). The Bluegill maximum age (7) ties the maximum age previously reported in North Carolina (Richardson and Ratledge 1961). Redear Sunfish maximum age was similar to populations in the Lumber and Waccamaw rivers with a maximum age of 6, although the age distribution was not comparable (Rachels and Fisk 2021b, 2021c). Channel Catfish and Redbreast Sunfish exhibited truncated age structures compared to other southeastern NC populations (Rachels and Fisk 2021a, 2021b, 2021c).

Growth. Approximate convergence was achieved for all von Bertalanffy growth models and graphical posterior predictive checks indicated the models adequately replicated the observed data. The Bluegill and Channel Catfish VBGF models were very precise (Figure 7). The Blue Catfish VBGF was very precise through age 14 (Figure 7). Similarly, the Flathead Catfish VBGF model fit was precise for younger ages with increased uncertainty after age 18 (Figure 7). The combination of L_∞ and *K* suggest the Cape Fear River Flathead Catfish population has the slowest growth among populations in southeastern NC (Table 4 in this report; Rachels and Fisk 2021a, 2021b, 2021c). The Largemouth Bass VBGF was reasonably precise with increasing variability at older ages (Figure 7) but was similar to other populations in southeastern NC (Rachels and Fisk 2021a, 2021b, 2021c). The Redbreast Sunfish VBGF was imprecise (Figure 7) and, due to the relatively small sample size, was likely heavily influenced by the prior probability distributions (e.g., Figure 8). The Redear Sunfish VBGF was also somewhat imprecise and the VBGF parameters may have been driven by the prior distributions (e.g., Figure 8).

Mortality. Blue Catfish and Flathead Catfish mortality estimates were very precise and indicated low total mortality (Table 5). Bluegill total instantaneous mortality was relatively high and approximately the same as the adjacent Black River population (Rachels and Fisk 2021a). Channel Catfish total instantaneous mortality was estimated with reasonable precision and was slightly greater than the adjacent Black River population (Rachels and Fisk 2021a). Largemouth Bass and Redear Sunfish mortality estimates were reasonably precise (Table 5) and comparable to other southeastern NC populations (Rachels and Fisk 2021a, 2021b, 2021c). Although there was considerable uncertainty in the estimate, Redbreast Sunfish mortality was extremely high (Table 5) and greater than the mortality estimated in other southeastern NC populations (Rachels and Fisk 2021a, 2021b, 2021c).

Discussion

The aquatic community in the Cape Fear River has undergone significant change as only 16 species were collected in both the 1962 baseline survey and the 2015–2016 survey. Most notably, no native catfish were collected. Native catfish species are vulnerable to Flathead Catfish predation (Guier et al. 1984; Thomas 1993), and Flathead Catfish appear to have extirpated White Catfish *Ameiurus catus* from the lower Cape Fear River Basin (Rachels 2021).

Comparisons are made between the sample composition in this survey and the 1962 survey by Louder (1963). These comparisons are somewhat tenuous given the different sampling gears utilized by the surveys. Nonetheless, the current survey suggests an overall decline in American Eel and native ictalurids since the Louder (1963) survey. Additional surveys using a broad range of sampling gears, coupled with alternative analytical techniques (e.g., occupancy modeling), may aid in elucidating the current status of American Eel and native ictalurids in the Cape Fear River.

Many issues threaten the Cape Fear River's fisheries resources; however, introduced species have likely had the greatest negative impact in since the 1962 baseline survey. Flathead Catfish, first introduced into the Cape Fear River Basin in 1965, have well-documented negative impacts on native sunfish and catfish (NCWRC 2019). Fourteen years after their introduction, Guier et al. (1984) found that native ictalurid populations had significantly declined and were the most prevalent prey item in Flathead Catfish stomachs. Rachels (2021) examined the long-term changes in the Cape Fear River's ictalurid assemblage and speculated that White Catfish are extirpated from the Cape Fear River and possibly from the entire river basin downstream of Jordan Lake. Other native ictalurids have been collected in some tributaries in the lower Cape Fear River basin that are devoid of Flathead Catfish (Rachels 2021; NCWRC unpublished data); preventing Flathead Catfish expansion should be a priority for native sport fish conservation. Similarly, Blue Catfish were stocked in 1966 but occupy a lower trophic position and are not believed to have affected native sport fish species as significantly as Flathead Catfish (Scharf and Belkoski 2020). Nonetheless, negative impacts from Blue Catfish have been documented in other Atlantic Slope river systems (Orth et al. 2017); continued monitoring of the Cape Fear River Blue Catfish population is necessary to document potential sport fish assemblage changes. Another nonnative species, referred to as "Spotted Bass" in this report, was first stocked in 1978 from Coosa River, AL, source broodfish (Marshall Ray; personal communication; Nichols and Buff 1984) which precludes *Micropterus punctulatus*. The introduction of congeners has caused significant impacts to Largemouth Bass in other waterbodies in North Carolina (e.g., Dorsey and Abney 2016). Additional study is needed in upstream portions of the Cape Fear River to elucidate the current status of *Micropterus* populations and the impacts of introduced black bass species.

Habitat and water quality degradation also threaten the Cape Fear River's fisheries resources. Low head dams have significant negative impacts on fish migration and also affect nutrient transport, sedimentation patterns, and channel morphology (Yeager 1993; Rachels and Morgeson 2018). Timber harvest and land-use changes in areas adjacent to both the river and its tributaries can increase sedimentation and negatively impact the temperature, streamflow, and dissolved oxygen regimes in the river (Filipek 1993). Point-source discharges, especially those that are in poor operating condition and those that discharge emerging chemical compounds, can have negative impacts of unknown magnitude. Many stormwater discharges in the Cape Fear River Basin are in poor condition, and even highly regulated wastewater treatment discharges experience combined sewer overflows during high rainfall events—both can contribute significant nutrient and bacterial loads that negatively impact water quality and dissolved oxygen (Even et al. 2004; Mallin and Corbett 2006). A point-source discharge near William O. Huske Lock and Dam is a producer of per- and polyfluoroalkyl compounds (PFAS; Sun et al. 2016). A class of emerging compounds, various PFAS can cause developmental toxicity and neurotoxicity in fish (Gaballah et al. 2020) and were associated with altered immune and liver function in Cape Fear River Striped Bass (Guillette et al. 2020). The concentration of one PFAS compound in Cape Fear River Striped Bass, PFOS, was among the highest concentrations documented in the literature (Guillette et al. 2020). Population-level effects of PFAS on fish populations in the Cape Fear River are unknown and warrant further investigation.

Finally, climate models project an increase in the frequency of extreme precipitation events in North Carolina, as well as more intense hurricanes (Kunkel et al. 2020), thereby increasing the likelihood of high streamflow events. These events can have significant negative impacts on water quality (Mallin and Corbett 2006; NCDEQ 2019b) and lead to widespread fish kills. Additionally, sea level rise will continue to increase salinity in downstream sections of the Cape Fear River, thereby converting current freshwater habitats into estuarine habitats (Magolan and Halls 2020; NC Climate Risk Assessment and Resilience Plan 2020) and shifting the fish community towards marine species. Fish sampling conducted in areas that are projected to experience habitat regime shifts should be linked with larger monitoring programs and goals to study the effects of climate change on sport fish populations. Additionally, fisheries hurricane response plans should be formalized and broadened to encompass goals that promote long-term resilience and management strategies that proactively reduce the risk of chronic stressors and acute fish kill events.

Management Recommendations

1. Reduce populations of Blue and Flathead catfish by reducing barriers to harvest and investigating novel control techniques.
2. Initiate management actions to restore native catfish populations. Reduced creel limits, hatchery supplementation, and reducing predatory stressors may be required.
3. Within 2 years, conduct biological and genetic surveys in the upper Cape Fear River and tributaries to investigate the impacts of "Spotted Bass."
4. Within 5 years, conduct a creel survey to assess current harvest rates and angling practices.
5. Within 10 years, conduct basin-wide survey of Cape Fear River fish communities.
6. Investigate effects of emerging compounds on sport fish population dynamics.
7. Identify, plan, fund, and support projects throughout the river basin that improve fish habitat and water quality.

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References

Ashley, K. W. 1985. Determination of Spotted Bass population levels and size structures in the Upper and Lower Little rivers. North Carolina Wildlife Resources Commission, Federal Aid in Fish Restoration, Project F-22-9, Final Report, Raleigh.

Ashley, K. W., and B. M. Buff. 1987. Food habits of Flathead Catfish in the Cape Fear River, North Carolina. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 41:93–99.

Ashley, K. W., and R. T. Rachels. 1998. Changes in Redbreast Sunfish population characteristics in the Black and Lumber rivers, North Carolina, 1994–1997. North Carolina Wildlife Resources Commission, Federal Aid in Fish Restoration, Project F-22, Final Report, Raleigh.

Ashley, K. W., and R. T. Rachels. 2005. Cape Fear River Basin recreational angler creel survey, 2003-2004. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-22, Final Report, Raleigh.

Ashley, K. W., and R. T. Rachels. 2008. Cape Fear River Largemouth Bass survey 2008. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-22, Final Report, Raleigh.

Baker, W. D. 1968. A reconnaissance of anadromous-fish runs into the inland fishing waters of North Carolina. North Carolina Wildlife Resources Commission, Federal Aid in Fish Restoration, Project AFS-3, Final Report, Raleigh.

Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. Fishery Investigations, Series II, Marine Fisheries, Great Britton Ministry of Agriculture, Fisheries and Food 19.

Buckmeier, D. L., E. R. Irwin, R. K. Betsill, and J. A. Prentice. 2002. Validity of otoliths and pectoral spines for estimating ages of Channel Catfish. North American Journal of Fisheries Management 22:934–942.

Carlander, K. D. 1969. Handbook of freshwater fishery biology, volume 1, 3rd edition. The Iowa State University Press, Ames (2nd printing, 1970).

Carlander, K. D. 1977. Handbook of freshwater fishery biology, volume 2. The Iowa State University Press, Ames.

Davis, J. R. 1967. Sport fishing significance of anadromous shad runs. North Carolina Wildlife Resources Commission, Federal Aid in Fish Restoration, Project F-16-R, Final Report, Raleigh.

Doll, J. C., and S. J. Jacquemin. 2019. Bayesian model selection in fisheries management and ecology. Journal of Fish and Wildlife Management 10:691–707.

Dorsey, L. G., and M. A. Abney. 2016. Changes in black bass population characteristics after the introduction of Alabama Bass in Lake Norman, North Carolina. Journal of the Southeastern Association of Fish and Wildlife Agencies 3:161–166.

Dycus, J. C., and J. M. Fisk. 2014. American Shad monitoring in the Cape Fear River – 2014. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

Even, S., M. Poulin, J. Mouchel, M. Seidl, and P. Servais. 2004. Modelling oxygen deficits in the Seine River downstream of combined sewer overflows. Ecological Modelling 173:177–196.

Filipek, S. P. 1993. Timber Harvest. Pages 227–244 *in* C. F. Bryans and D. A. Rutherford, editors. Impacts on warmwater streams: guidelines for evaluation. American Fisheries Society, Southern Division, Bethesda, Maryland.

Fisk, J. M. II, C. W. Morgeson, and M. E. Polera. 2019. Evaluation of recreational hand-crank electrofishing on introduced catfish species in Southeastern North Carolina. North American Journal of Fisheries Management 39:150–165.

Gaballah, S., A. Swank, J. Sobus, X. Howey, J. Schmid, T. Catron, J. McCord, E. Hines, M. Strynar, and T. Tal. 2020. Evaluation of developmental toxicity, developmental neurotoxicity, and tissue dose in Zebrafish exposed to GenX and other PFAS. Environmental Health Perspectives 128(4):1–22.

Gelman, A., and K. Shirley. 2011. Inference from simulations and monitoring convergence. Pages 163-174 *in* S. Brooks, A. Gelman, G. L. Jones, and X. Meng, editors. Handbook of Markov Chain Monte Carlo. Chapman and Hall/CRC Press, Boca Raton, Florida.

Guillette, T. C., J. McCord, M. Guillette, M. E. Polera, K. T. Rachels, C. W. Morgeson, N. Kotlarz, D. R. U. Knappe, B. J. Reading, M. Strynar, and S. M. Belcher. 2020. Elevated levels of per- and polyfluoroalkyl substances in Cape Fear River Striped Bass (*Morone saxatilis*) are associated with biomarkers of altered immune and liver function. Environment International 136:1–10.

Guier, C. R., and L. E. Nichols. 1977. A preliminary survey to determine the current status of Largemouth Bass in the Cape Fear River. North Carolina Wildlife Resources Commission, Federal Aid in Fish Restoration, Project F-22-1, Final Report, Raleigh.

Guier, C. R., L. E. Nichols, and R. T. Rachels. 1984. Biological investigation of Flathead Catfish in the Cape Fear River. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 35(1981):607–621.

Hilling, C. D., A. J. Bunch, R. S. Greenlee, D. J. Orth, and Y. Jiao. 2018. Natural mortality and size structure of introduced blue catfish in Virginia tidal rivers. Journal of the Southeastern Association of Fish and Wildlife Agencies 5:30–38.

Isermann, D. A., and C. T. Knight. 2005. A computer program for age-length keys incorporating age assignment to individual fish. North American Journal of Fisheries Management 25:1153–1160.

Kunkel, K. E., D. R. Easterling, A. Ballinger, S. Bililign, S. M. Champion, D. R. Corbett, K. D. Dello, J. Dissen, G. M. Lackmann, R. A. Luettich, L. B. Perry, W. A. Robinson, L. E. Stevens, B. C. Stewart, and A. J. Terando. 2020. North Carolina Climate Science Report. North Carolina Institute for Climate Studies, Raleigh. Available: https://ncics.org/nccsr.

Long, J. M., and T. B. Grabowski. 2017. Otoliths. Pages 189–219 *in* M. C. Quist and D. A. Isermann, editors. Age and growth of fishes: principals and techniques. American Fisheries Society, Bethesda, Maryland.

Louder, D. E. 1963. Survey and classification of the Cape Fear River and tributaries, North Carolina. North Carolina Wildlife Resources Commission, Federal Aid in Fish Restoration, Project F-14-R, Final Report, Raleigh.

Magolan, J. L., and J. N. Halls. 2020. A multi-decadal investigation of tidal creek wetland changes, water level rise, and ghost forests. Remote Sensing 12:1–23.

Mallin, M. A., and C. A. Corbett. 2006. How hurricane attributes determine the extent of environmental effects: multiple hurricanes and different coastal systems. Estuaries and Coasts 29:1046–1061.

Marshall, M. D., M. J. Maceina, and M. P. Holley. 2009. Age and growth variability between sexes of three catfish species in Lake Wilson, Alabama. North American Journal of Fisheries Management 29:1283–1286.

McDonald, M. 1887. The rivers and sounds of North Carolina. Pages 625–637 *in* G. B. Goode, editor. The fisheries and fishery industries of the United States, section V. U. S. Commission of Fish and Fisheries, Washington, D.C.

Millar, R. B. 2015. A better estimator of mortality rate from age-frequency data. Canadian Journal of Fisheries and Aquatic Science 72:364–375.

Nash, M. K., and E. R. Irwin. 1999. Use of otoliths versus pectoral spines for aging adult Flathead Catfish. Pages 309–316 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

NC Climate Risk Assessment and Resilience Plan. 2020. Impacts, vulnerability, risks, and preliminary actions: a comprehensive strategy for reducing North Carolina’s vulnerability to climate change. NCDOT, NCDEQ, NCDPS, NCDNCR, NCDC, NCDHHS, NCDOA, NCDMVA, and NCDIT, Final Report, Raleigh.

NCDENR (N.C. Department of Environment and Natural Resources). 2004. Basinwide assessment report—Cape Fear River Basin, Raleigh.

NCDEQ (N.C. Department of Environmental Quality). 2019a. 2018 NC Category 5 Assessments “303(d) List” Final, Raleigh.

NCDEQ (N.C. Department of Environmental Quality). 2019b. Survey of surface water quality associated with Hurricane Florence, September 2018, Raleigh.

NC One Map. 2021. Public municipal stormwater systems [online dataset]. Available: www.nconemap.gov.

NCDWR (N.C. Division of Water Resources). 2021. NPDES wastewater discharge permits [online dataset]. Available: www.nconemap.gov.

NCWRC (N.C. Wildlife Resources Commission). 2019. 2019 Catfish management plan. North Carolina Wildlife Resources Commission, Raleigh.

Nelson, G. A. 2019. Bias in common catch-curve methods applied to age frequency data from fish surveys. ICES Journal of Marine Science 76:2090–2101.

Nichols, L. E. 1978. Determination of the management potential of Spotted Bass. North Carolina Wildlife Resources Commission, Federal Aid in Fish Restoration, Project F-22, Final Report, Raleigh.

Nichols, L. E., and B. M. Buff. 1984. Evaluation of an introduced Spotted Bass population in North Carolina. North Carolina Wildlife Resources Commission, Federal Aid in Fish Restoration, Project F-22-6, Final Report, Raleigh.

Nichols, P. R., and D. E. Louder. 1970. Upstream passage of anadromous fish through navigation locks and use of the stream for spawning and nursery habitat Cape Fear River, N.C., 1962-66. U.S. Fish and Wildlife Service, Circular 352, Washington, D.C.

Potoka, K. M., and J. W. McCargo. 2016. An evaluation of the Largemouth Bass population in Lake Mattamuskeet and its associated canals, 2014–2015. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

Ogle, D. H. 2015. Introductory fisheries analysis with R. Chapman and Hall/CRC Press, New York.

Orth, D. J., Y. Jiao, J. D. Schmitt, C. D. Hilling, J. A. Emmel, and M. C. Fabrizio. 2017. Dynamics and role of non-native Blue Catfish *Ictalurus furcatus* in Virginia's tidal rivers. Final Report to Virginia Department of Game and Inland Fisheries, Henrico, VA.

Rachels, K. T. 2021. Exploring legacy datasets to infer spatial and temporal trends in the ictalurid assemblage of an Atlantic Slope river. North American Journal of Fisheries Management.

Rachels, K. T., and J. M. Fisk II. 2021a. Fisheries resources of the Black River. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

Rachels, K. T., and J. M. Fisk II. 2021b. Fisheries resources of the Lumber River. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

Rachels, K. T., and J. M. Fisk II. 2021c. Fisheries resources of the Waccamaw River. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

Rachels, K. T., and C. W. Morgeson. 2018. Cape Fear River Striped Bass spawning stock survey and proposed establishment of put-grow-take fishery. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

Rachels, R. T., and K. W. Ashley. 2002. Comparison of 3 electrofishing gear types used to capture catfish. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 56:44–54.

Richardson, F., and H. M. Ratledge. 1961. Upper Catawba River reservoirs and Lake Lure. North Carolina Wildlife Resources Commission, Federal Aid in Fish Restoration, Projects F-5-R and F-6-R, Final Report, Raleigh.

Scharf, F. S., and D. J. Belkoski. 2020. Population demographics and trophic ecology of non-native catfish in southeastern North Carolina. Final Report to the North Carolina Wildlife Resources Commission, Cooperative Agreement DIF-0028.

Smith, C. A., and K. M. Potoka. 2017. Population characteristics of Largemouth Bass and Pumpkinseed in Lake Phelps, 2015–2016. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

Smith, C. A., and K. M. Potoka. 2020. Addressing an 18-year Largemouth Bass trophy regulation at Lake Phelps utilizing boat electrofishing and angler surveys. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

Smith, H. M. 1907. The fishes of North Carolina, volume 2. E. M. Uzzell State Printers and Binders, Raleigh.

Smith, M. W., A. Y. Then, C. Wor, G. Ralph, K. H. Pollock, and J. M. Hoenig. 2012. Recommendations for catch-curve analysis. North American Journal of Fisheries Management 32:956–967.

Starnes, W. C., and G. M. Hogue. 2011. Curating and databasing of voucher collections from the North Carolina Wildlife Resources Commission 1960s statewide surveys of fishes. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-91, Final Report, Raleigh.

Stewart, D. R., G. W. Benz, and G. D. Scholten. 2009. Weight-length relationships and growth data for Blue Catfish from four Tennessee waterbodies. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 63:140–146.

Sun, M., E. Arevalo, M. Strynar, A. Lindstrom, M. Richardson, B. Kearns, A. Pickett, C. Smith, and D. Knappe. 2016. Legacy and emerging perfluoroalkyl substances are important drinking water contaminants in the Cape Fear River watershed of North Carolina. Environmental Science and Technology Letters 3(12):415–419.

Thomas, M. E. 1993. Monitoring the effects of introduced Flathead Catfish on sport fish populations in the Altamaha River, Georgia. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 47:531–538.

USDA (U.S. Department of Agriculture). 2021. National Land Cover Dataset [online dataset]. Available: https://gdg.sc.egov.usda.gov.

Van Horn, S. L., and L. J. Birchfield. 1984. The North Carolina Largemouth Bass catch survey. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 35(1981):453–459.

Yeager, B. L. 1993. Dams. Pages 57–113 *in* C. F. Bryans and D. A. Rutherford, editors. Impacts on warmwater streams: guidelines for evaluation. American Fisheries Society, Southern Division, Bethesda, Maryland.

TABLE 1. Species collected in hand-crank electrofishing survey (2015–2016) and the NCWRC baseline survey (conducted in 1962; Louder 1963). **Bold** denotes Inland Game Fish, *italics* denote Species of Greatest Conservation Need (SGCN), and (◊) denotes nonnative species.

Common name	Scientific name	Catch 1962	Catch 2015–2016	Sites with catch 1962[a]	Sites with catch 2015–2016[b]
American Eel	*Anguilla rostrata*	158	3	67%	20%
American Shad	*Alosa sapidissima*	33	26	33%	40%
Atlantic Menhaden	*Brevoortia tyrannus*	61	0	17%	0%
Atlantic Needlefish	*Strongylura marina*	1	0	17%	0%
Black Crappie	*Pomoxis nigromaculatus*	13	2	67%	20%
◊ Blue Catfish	*Ictalurus furcatus*	0	307	0%	90%
Bluegill	*Lepomis macrochirus*	42	645	67%	100%
Bluehead Chub	*Nocomis leptocephalus*	2	0	17%	0%
Bowfin	*Amia calva*	2	21	17%	60%
Broadtail Madtom	*Noturus n. sp.*	1	0	17%	0%
Brown Bullhead	*Ameiurus nebulosus*	31	0	33%	0%
Chain Pickerel	*Esox niger*	0	1	0%	10%
◊ Channel Catfish	*Ictalurus punctatus*	150	397	67%	93%
Coastal Shiner	*Notropis petersoni*	0	1	0%	10%
Comely Shiner	*Notropis amoenus*	0	4	0%	20%
◊ Common Carp	*Cyprinus carpio*	1	31	17%	100%
Dollar Sunfish	*Lepomis marginatus*	0	15	0%	20%
Eastern Mosquitofish	*Gambusia holbrooki*	1	0	17%	0%
Eastern Silvery Minnow	*Hybognathus regius*	57	0	17%	0%
Flat Bullhead	*Ameiurus platycephalus*	17	0	33%	0%
◊ Flathead Catfish	*Pylodictis olivaris*	0	377	0%	80%
Gizzard Shad	*Dorosoma cepedianum*	794	18	83%	60%
Golden Shiner	*Notemigonus crysoleucas*	13	0	50%	0%
◊ Grass Carp	*Ctenopharyngodon idella*	0	1	0%	10%
Green Goby	*Microgobius thalassinus*	1	0	17%	0%
◊ Green Sunfish	*Lepomis cyanellus*	3	0	17%	0%
Highfin Goby	*Gobionellus oceanicus*	3	0	17%	0%
Hogchoker	*Trinectes maculatus*	34	1	33%	10%
Hybrid Sunfish	*Lepomis sp.*	0	2	0%	20%
Inland Silverside	*Menidia beryllina*	0	2	0%	10%
Largemouth Bass	*Micropterus salmoides*	10	65	50%	100%
Longnose Gar	*Lepisosteus osseus*	2	72	17%	100%
Marked Goby	*Ctenogobius stigmaticus*	64	0	17%	0%
Mummichog	*Fundulus heteroclitus*	1	0	17%	0%
Naked Goby	*Gobiosoma bosc*	2	0	17%	0%
Notchlip Redhorse	*Moxostoma collapsum*	0	1	0%	10%
Piedmont Darter	*Percina crassa*	1	0	17%	0%

TABLE 1. Continued…

Common name	Scientific name	Catch 1962	Catch 2015–2016	Sites with catch 1962[a]	Sites with catch 2015–2016[b]
Pirate Perch	*Aphredoderus sayanus*	8	0	50%	0%
Pumpkinseed	*Lepomis gibbosus*	4	5	33%	30%
Redbreast Sunfish	*Lepomis auritus*	5	54	33%	80%
◊ Redear Sunfish	*Lepomis microlophus*	0	31	0%	80%
Satinfin Shiners	*Cyprinella spp.*	0	1	0%	10%
Sea Lamprey	*Petromyzon marinus*	1	0	17%	0%
Shorthead Redhorse	*Moxostoma macrolepidotum*	3	1	17%	10%
Southern Flounder	*Paralichthys lethostigma*	1	0	17%	0%
Southern Stargazer	*Astroscopus y-graecum*	23	0	17%	0%
Spottail Shiner	*Notropis hudsonius*	233	0	50%	0%
◊ Spotted Bass [c]	*Micropterus sp.*	0	52	0%	80%
Spotted Sucker	*Minytrema melanops*	1	31	17%	60%
Spotted Sunfish	*Lepomis punctatus*	0	1	0%	10%
Striped Mullet	*Mugil cephalus*	0	38	0%	80%
Swallowtail Shiner	*Notropis procne*	9	0	17%	0%
Tadpole Madtom	*Noturus gyrinus*	1	0	17%	0%
Tessellated Darter	*Etheostoma olmstedi*	12	0	33%	0%
◊ Threadfin Shad	*Dorosoma petenense*	0	2	0%	10%
Tidewater Silverside	*Menidia peninsulae*	1	0	17%	0%
Warmouth	*Lepomis gulosus*	3	0	17%	0%
White Catfish	*Ameiurus catus*	343	0	83%	0%
White Perch	*Morone americana*	0	1	0%	10%
Whitefin Shiner	*Cyprinella nivea*	60	14	50%	30%
Yellow Perch	*Perca flavescens*	0	2	0%	20%

[a] Sites 11K-13, 12J-4, 13I-3, 14H-4, 14F-7, and 15E-3 from Louder (1963) as amended by Starnes and Hogue (2011).
[b] Percentages calculated with catfish targeted in all sites (*n* = 30); other species targeted in high-frequency sites only (*n* = 10).
[c] Considered Spotted Bass historically, but species is currently unknown and from Coosa River, AL origin.

TABLE 2. Aggregated catch (2015 and 2016) by high frequency (120 PPS) electrofishing site. The final row gives the number of species captured within each site.

Species	River kilometer									
	71	75	84	128	133	143	173	182	214	223
American Eel	1	2	0	0	0	0	0	0	0	0
American Shad	15	5	2	4	0	0	0	0	0	0
Black Crappie	0	0	0	1	0	1	0	0	0	0
Blue Catfish	1	1	1	1	2	2	25	25	0	6
Bluegill	8	31	60	17	101	69	98	90	86	85
Bowfin	0	4	2	4	8	0	0	2	1	0
Chain Pickerel	0	0	0	0	0	1	0	0	0	0
Channel Catfish	1	0	1	3	5	5	13	18	2	4
Coastal Shiner	0	0	0	0	1	0	0	0	0	0
Comely Shiner	1	0	3	0	0	0	0	0	0	0
Common Carp	1	2	1	1	1	1	3	7	3	11
Dollar Sunfish	0	0	0	0	0	0	0	3	12	0
Flathead Catfish	0	4	1	0	0	0	1	1	0	1
Gizzard Shad	2	0	0	0	6	7	1	1	0	1
Grass Carp	0	1	0	0	0	0	0	0	0	0
Hogchoker	0	0	1	0	0	0	0	0	0	0
Hybrid Sunfish	0	1	1	0	0	0	0	0	0	0
Inland Silverside	2	0	0	0	0	0	0	0	0	0
Largemouth Bass	1	6	9	3	11	4	9	8	9	5
Longnose Gar	9	8	8	23	10	1	2	3	6	2
Notchlip Redhorse	0	0	0	0	0	0	0	0	1	0
Pumpkinseed	0	0	0	0	0	3	0	1	0	1
Redbreast Sunfish	0	1	1	0	4	6	4	4	9	25
Redear Sunfish	0	0	3	4	3	3	5	6	3	4
Satinfin Shiners	0	0	0	0	0	0	0	0	0	1
Shorthead Redhorse	0	0	0	0	0	1	0	0	0	0
Spotted Bass	0	1	0	3	10	7	1	14	3	13

TABLE 2. Continued…

Species	River kilometer									
	71	75	84	128	133	143	173	182	214	223
Spotted Sucker	0	0	0	0	3	12	1	2	4	9
Spotted Sunfish	0	0	1	0	0	0	0	0	0	0
Striped Mullet	3	11	8	3	4	6	1	2	0	0
Threadfin Shad	0	0	0	0	2	0	0	0	0	0
White Perch	0	0	0	0	0	1	0	0	0	0
Whitefin Shiner	0	0	0	0	1	0	0	0	2	11
Yellow Perch	0	0	0	0	0	1	0	0	1	0
Total species	12	14	16	12	16	18	13	16	14	15

TABLE 3. Aggregated catch (2015 and 2015) by low frequency (15 PPS) electrofishing site. The final row gives the number of species captured within each site.

	River kilometer																			
Species	61	64	69	72	76	125	127	135	139	146	153	159	171	179	180	199	218	226	229	232
Blue Catfish	15	3	17	34	23	5	41	17	12	17	6	5	5	1	8	31	2	0	0	1
Channel Catfish	7	1	1	8	4	18	29	29	23	43	21	26	18	1	39	58	8	0	5	6
Flathead Catfish	70	7	17	17	18	15	21	17	35	14	16	25	30	13	14	21	5	0	6	8
Total species	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	0	2	3

TABLE 4. Estimated von Bertalanffy growth parameters. Quantiles represent the median (0.50; most credible estimate) and lower (0.05) and upper (0.95) 90% credible intervals of the joint posterior distribution.

Parameter	Quantiles		
	0.05	0.50	0.95
Bluegill			
L_∞	247	271	297
K	0.16	0.19	0.22
t_0	-1.64	-1.46	-1.28
Blue Catfish			
L_∞	960	1061	1177
K	0.08	0.10	0.12
t_0	-1.27	-0.97	-0.69
Channel Catfish			
L_∞	599	715	847
K	0.14	0.18	0.24
t_0	-0.26	-0.13	0.10
Flathead Catfish			
L_∞	1,048	1,188	1,346
K	0.05	0.07	0.08
t_0	-2.37	-1.84	-1.35
Largemouth Bass			
L_∞	519	566	614
K	0.20	0.25	0.30
t_0	-0.88	-0.61	-0.38
Redbreast Sunfish			
L_∞	200	249	301
K	0.16	0.26	0.40
t_0	-1.57	-0.82	-0.26
Redear Sunfish			
L_∞	252	306	374
K	0.17	0.29	0.46
t_0	-1.12	-0.47	0.04

TABLE 5. Poisson log-linear modeled instantaneous total mortality (*Z*) and discrete annual mortality (*A*). Confidence interval for instantaneous total mortality was modeled using gamma distribution.

Species	Aged otoliths	Max age	*Z* (SE)	*Z* 90% CI	*A*
Bluegill	548	7	1.02 (0.16)	0.77–1.29	64%
Blue Catfish	226	21	0.27 (0.04)	0.22–0.33	24%
Channel Catfish	280	6	0.53 (0.14)	0.33–0.78	41%
Flathead Catfish	305	31	0.23 (0.03)	0.19–0.28	21%
Largemouth Bass	56	9	0.49 (0.10)	0.33–0.67	39%
Redbreast Sunfish	49	4	1.57 (0.47)	0.89–2.43	79%
Redear Sunfish	29	6	0.43 (0.16)	0.20–0.73	35%

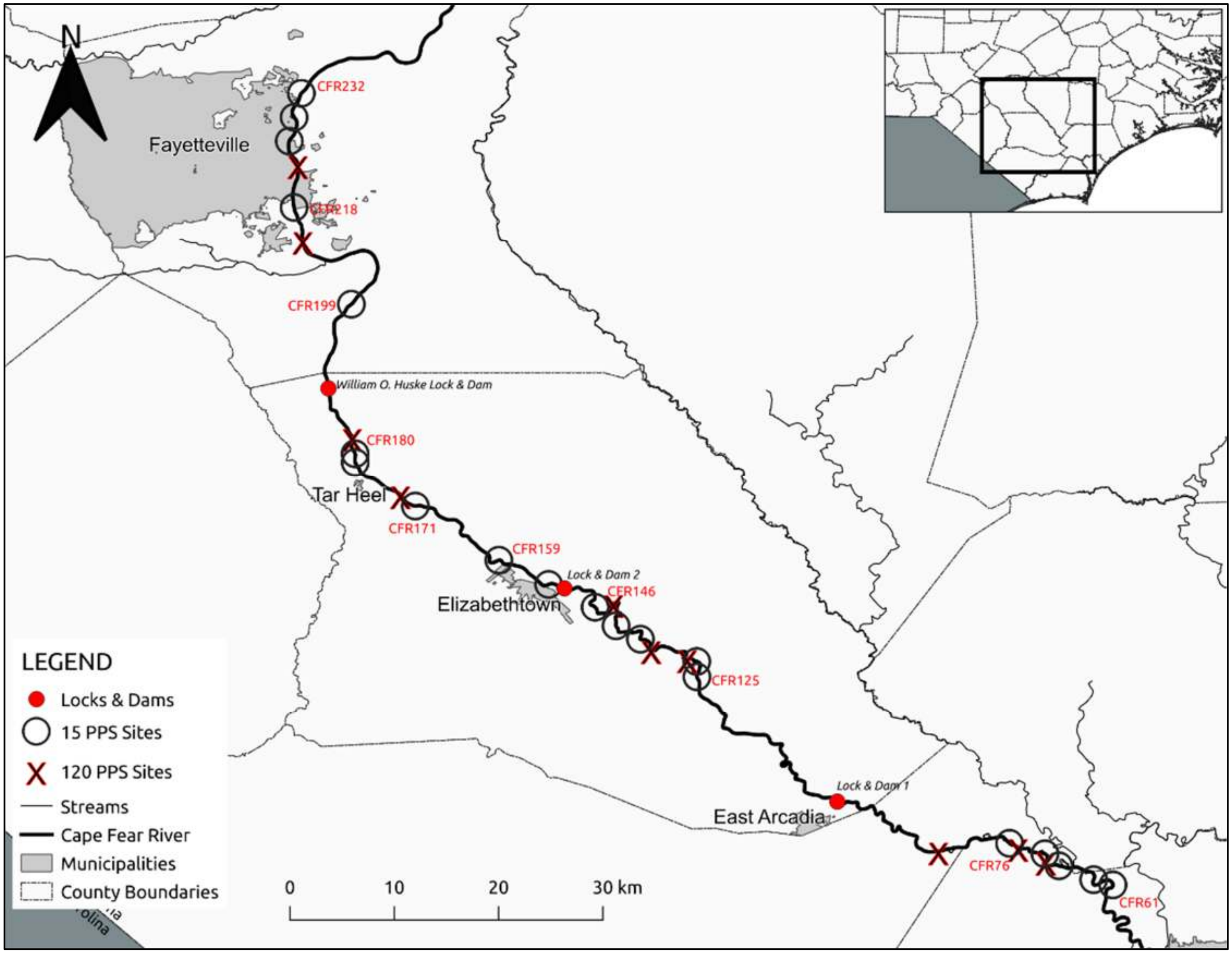

FIGURE 1. Cape Fear River boat electrofishing sites surveyed in North Carolina in 2015 and 2016. Several sites are labeled (red) with their river kilometer.

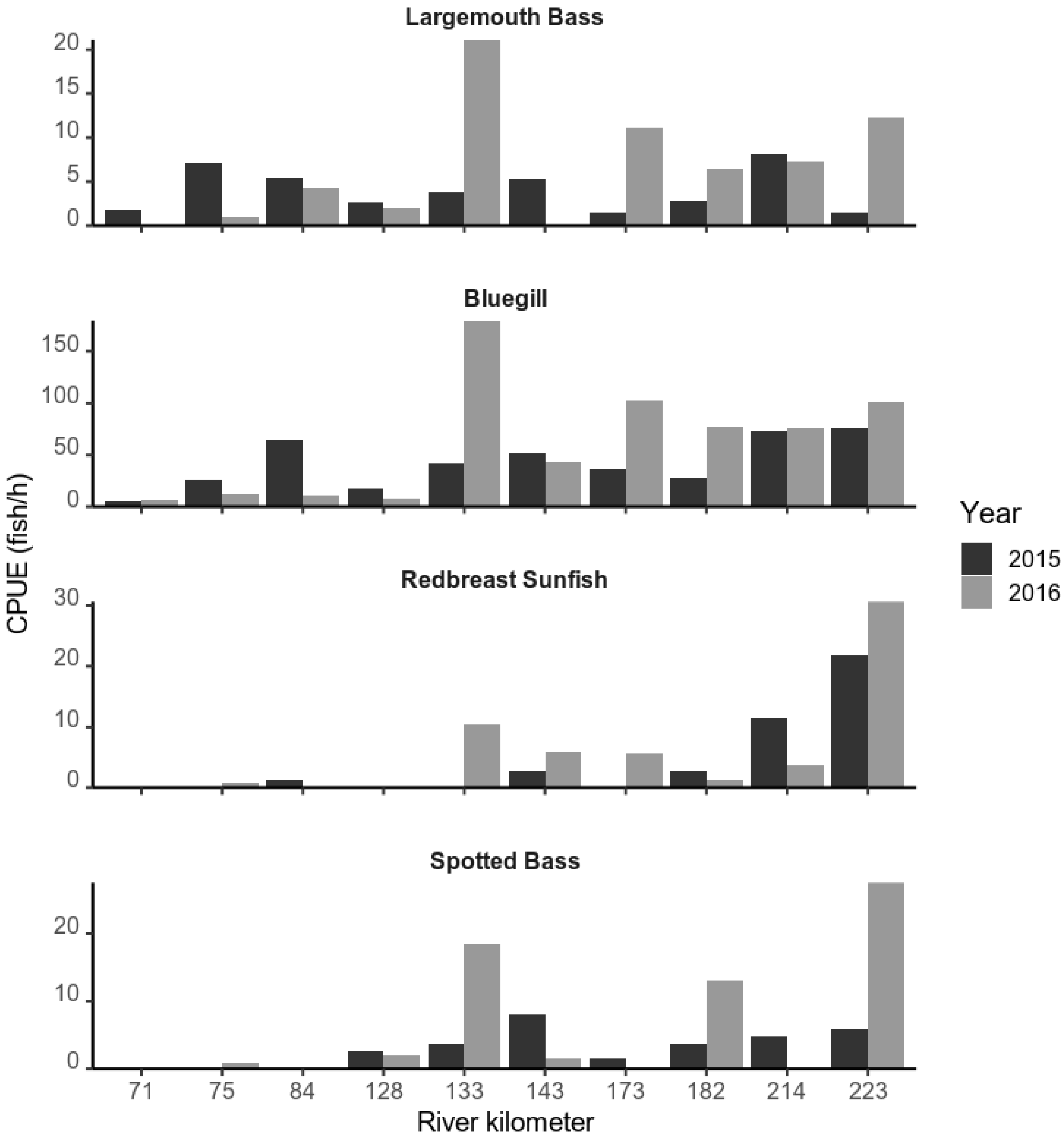

FIGURE 2. Catch per unit effort by site (river kilometer) and year for the four Inland Game Fish with the greatest catch in the high frequency (120 PPS) electrofishing sites. The x-axis is ordered left to right, downstream to upstream.

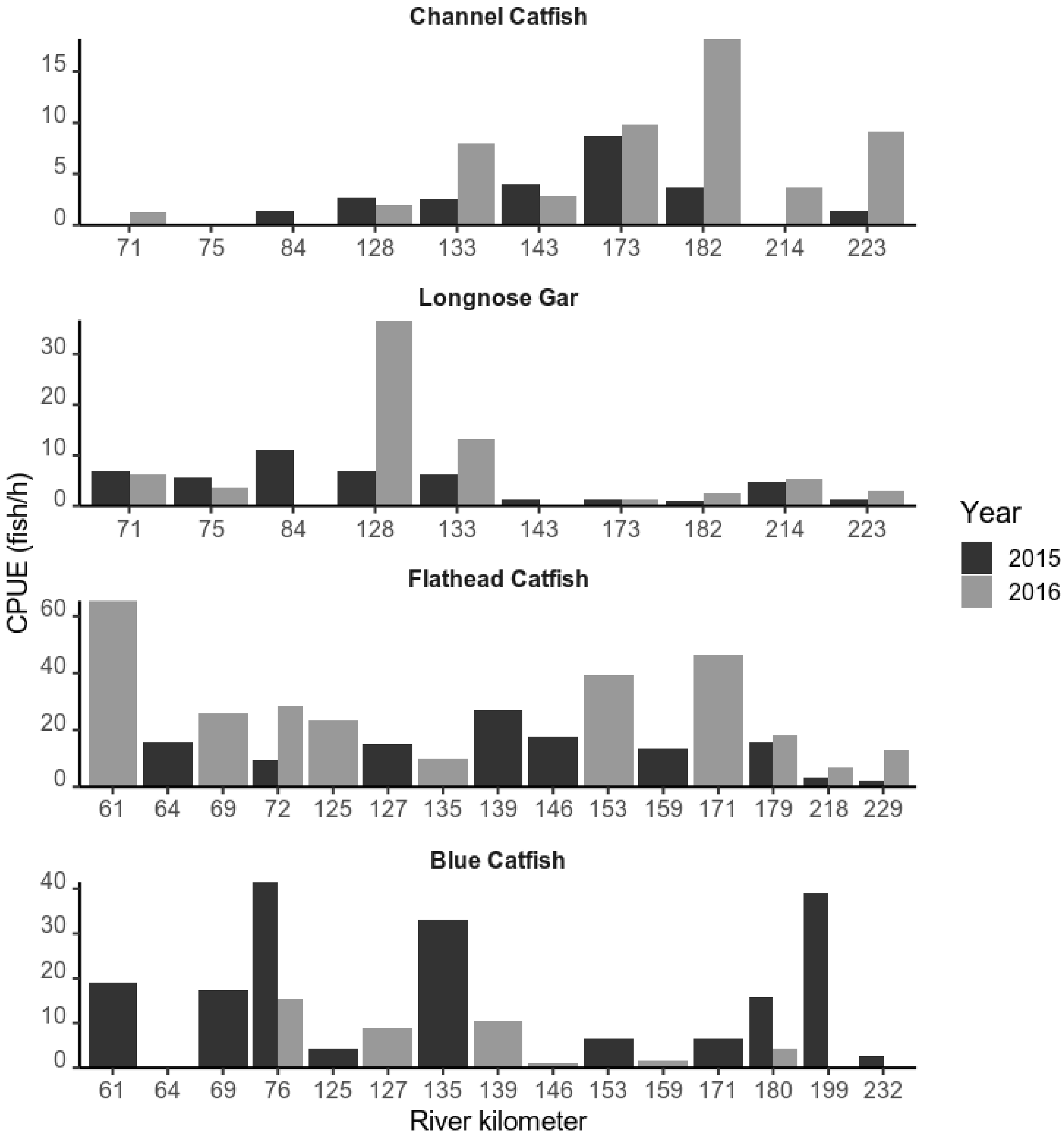

FIGURE 3. Catch per unit effort by site (river kilometer) and year for the four nongame fish with the greatest catch. Blue Catfish and Flathead Catfish sites and effort are from low frequency (15 PPS) electrofishing; other species depict effort from high frequency (120 PPS) electrofishing sites.

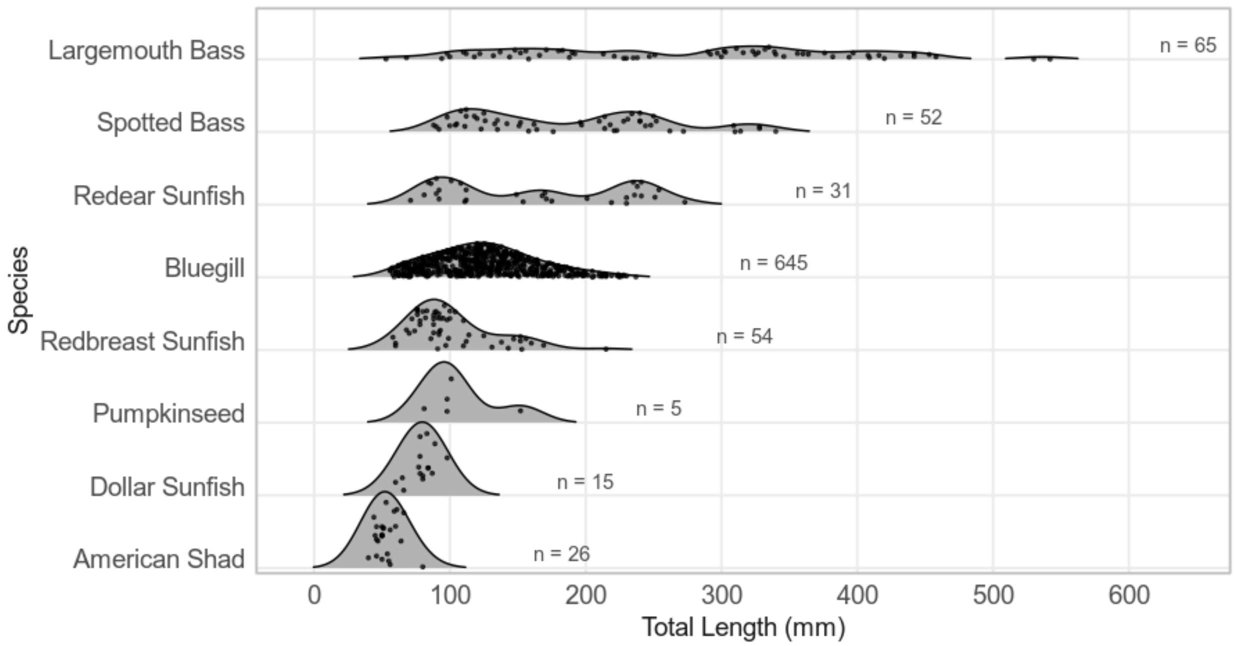

FIGURE 4. Density plots of Inland Game Fish with five or more collected individuals in descending order by maximum size of the largest individual. The sample size is denoted to the right of each size distribution.

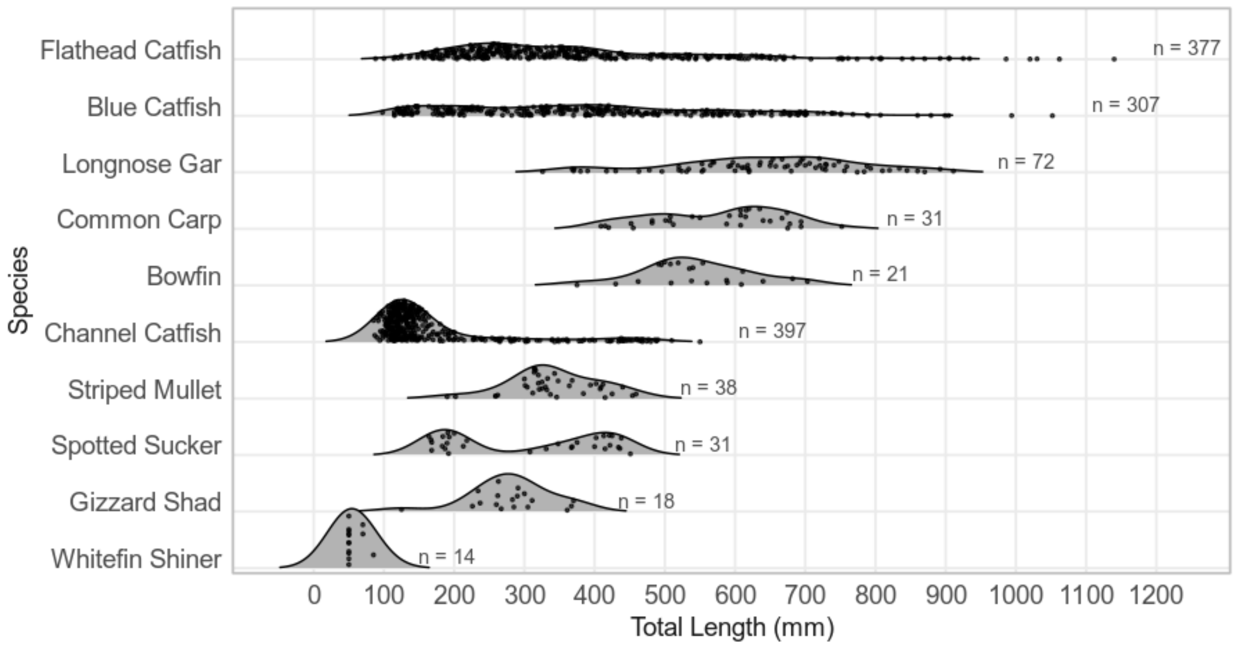

FIGURE 5. Density plots of nongame fish with five or more collected individuals in descending order by maximum size of the largest individual. The sample size is denoted to the right of each size distribution.

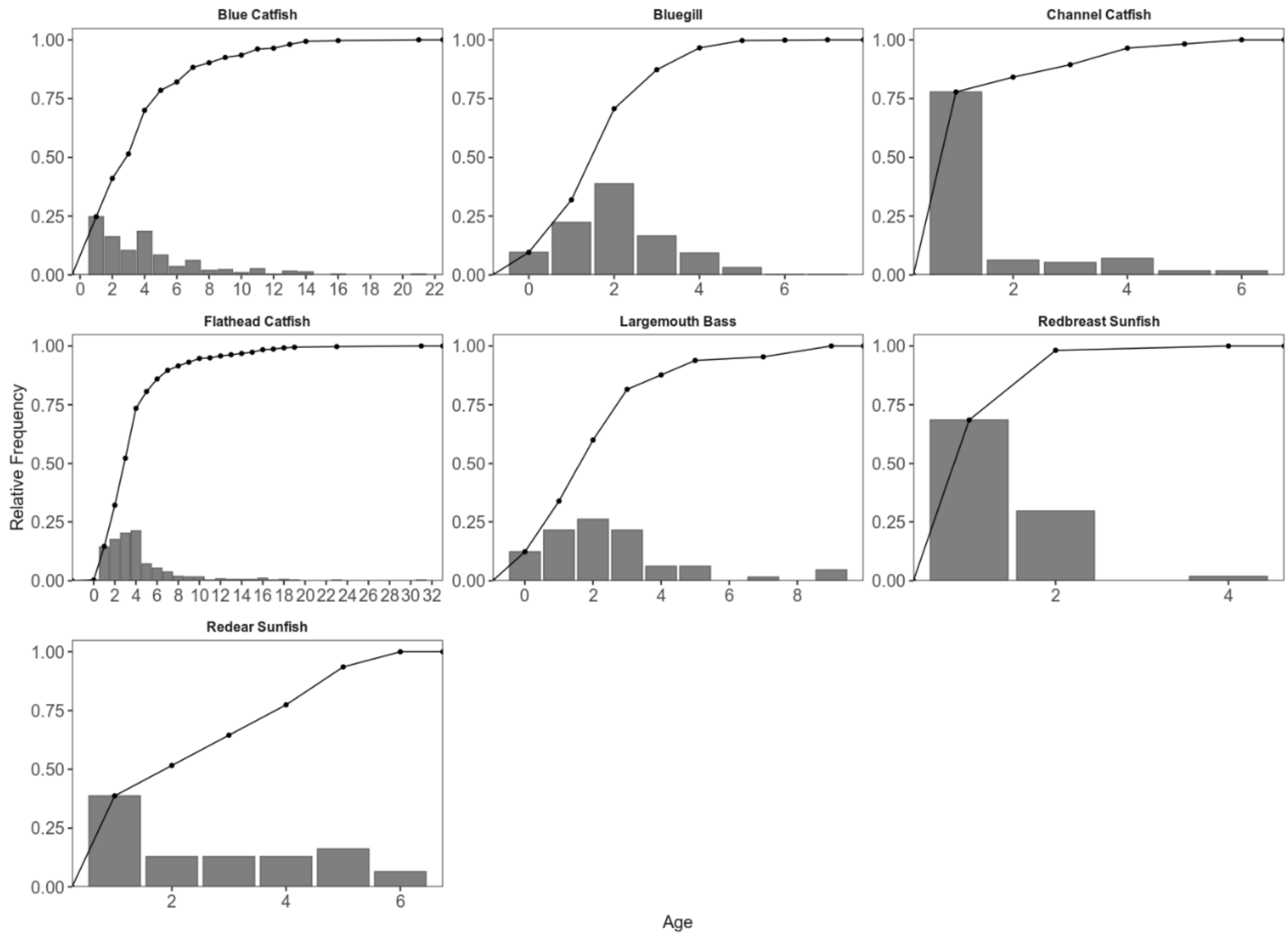

FIGURE 6. Age class relative frequency by species (bars). Line denotes cumulative age frequency.

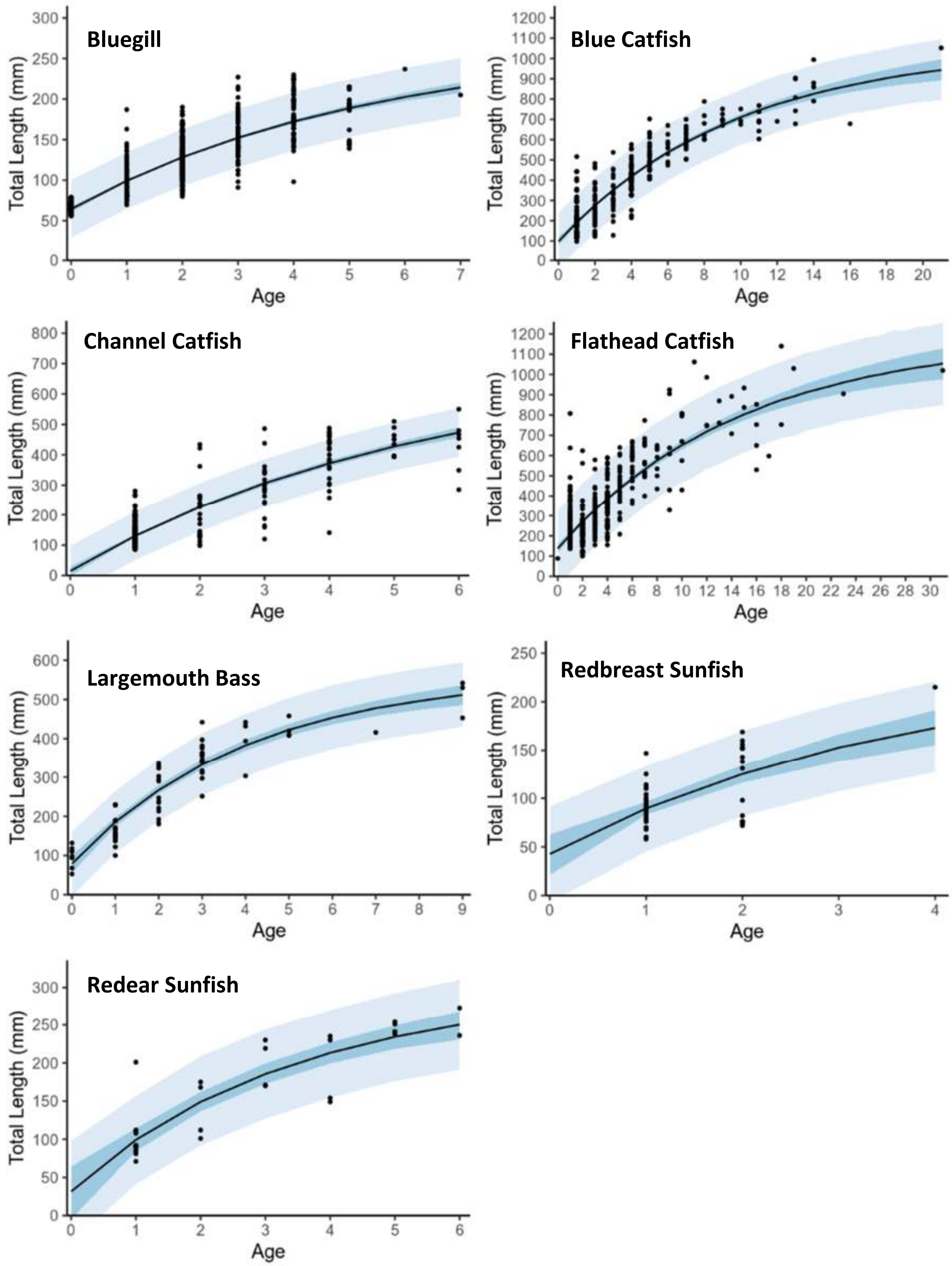

FIGURE 7. Posterior predicted median length-at-age from von Bertalanffy growth models (black line) and observed individuals (point markers). The dark shaded area denotes the 90% credible interval of the model, while the light shaded area denotes the 90% credible interval of the posterior predictive distribution.

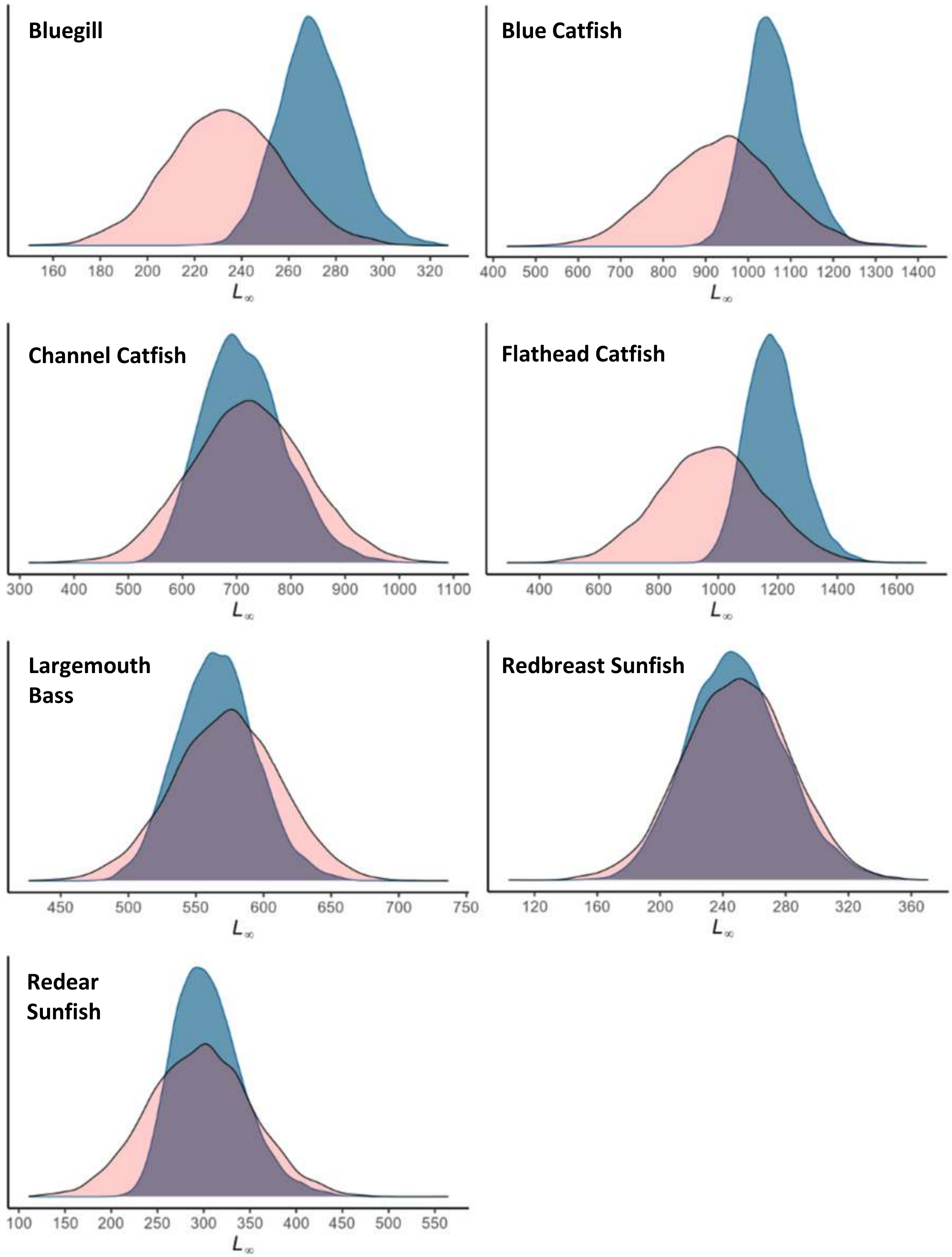

FIGURE 8. Prior (red) and estimated joint posterior (blue) probability distributions for L_∞. All values within the joint posterior distribution are considered credible, while the most credible estimate of L_∞ occurs at the peak of the curve.