Fisheries resources of the Waccamaw River

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Abstract. The N.C. Wildlife Resources Commission conducted a baseline survey of fish populations in the Waccamaw River in the summer of 1961. Subsequent surveys were largely focused on sport fish species or Species of Greatest Conservation Need as identified in the N.C. Wildlife Action Plan. A systematic boat-mounted electrofishing survey was conducted in the Waccamaw River in 2015 and 2016 in both North Carolina and South Carolina to elucidate the effect of hand-crank electrofishing on introduced catfish populations. The purpose of this report is to summarize data collected in North Carolina waters and provide comparisons to previous surveys. Overall, 993 fish representing 31 species were collected, including 19 Inland Game Fish and 5 nonnative species. Three Species of Greatest Conservation Need were observed in 1961 but not collected in 2015–2016. Nine species were collected in this survey that were not observed in 1961. Warmouth, Bluegill, Redear Sunfish, and Largemouth Bass were the most abundant Inland Game Fish, while Flathead Catfish, Bowfin, Longnose Gar, and Channel Catfish were the most abundant nongame fish. Redbreast Sunfish and White Catfish historically supported significant harvest-oriented fisheries; however, high mortality and low abundance indicate these populations are currently depressed. Introduced species and emerging habitat issues require monitoring to mitigate potential negative impacts to the Waccamaw River's fisheries resources.

The Waccamaw River in North Carolina has been the focus of relatively few fisheries surveys. The river's fisheries remained largely undescribed until the North Carolina Wildlife Resources Commission (NCWRC) surveyed the Waccamaw River in the summer of 1961 as part of a systematic inventory of ichthyofauna in the state's river basins (Louder 1962). The only other wide-scale collection of fish in the Waccamaw River was conducted in 1979–1981 (Shute et al. 1981). A creel survey conducted in 1980–1981 documented considerable harvest-oriented fisheries for Bluegill *Lepomis macrochirus*, Redbreast Sunfish *L. auritus*, and White Catfish *Ameiurus catus* (Nichols and Buff 1981). More recently, boat electrofishing index of biotic integrity surveys were conducted occasionally from 1997–2011 (NCWRC unpublished data). Unlike the Waccamaw River, Lake Waccamaw has received considerable directed fisheries investigation due to the number of endemic aquatic species.

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 Waccamaw River in 2015–2016. Comparisons are made to the catch composition reported by Louder (1962). Age structure, growth, and mortality are contrasted with other rivers assessed during the 2015–2016 hand-crank electrofishing project.

Methods

Study site. The Waccamaw River is a free-flowing coastal plain stream (Strahler Order = 6) that begins at a dam on the south shore of Lake Waccamaw in Columbus County, NC (Figure 1). It flows 233 km to its confluence with the Pee Dee River in South Carolina, several kilometers upstream of that river's discharge into Winyah Bay and the Atlantic Ocean. The Waccamaw River watershed (U.S. Geological Survey hydrologic unit 03040206) drains 2,727 km^2 (an additional 1,550 km^2 is in South Carolina) and is 29% wetland, 28% forested, 21% agriculture, 15% grassland/shrub, 5% developed, and 2% open water (USDA 2021). As of 2021, there are 3 major and 6 minor NPDES permitted discharges (NCDWR 2021). Of the 11 public municipal stormwater systems, only 2 are rated in "Good" condition and only 3 utilize best management practices (NC One Map 2021). The Waccamaw River is classified as "Class C, Swamp Waters" for 64 km from its source at Lake Waccamaw downstream to NC 904, and is classified as "Class B, Swamp Waters" from NC 904 to the NC/SC state line near river kilometer (RKM) 155 (NCDENR 2007). Two of the largest tributaries, Grissett Swamp and White Marsh, are listed on the 2018 303(d) list of impaired waters (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 (North Carolina; RKM 233–RKM 155) and a stratum where hand-crank electrofishing is prohibited (South Carolina). 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. As the focus of this paper is the fish community within North Carolina, no further consideration is given to those collections that occurred in South Carolina.

Field collection. In the five 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 10 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 *Pylodictis olivaris*, Blue Catfish *Ictalurus furcatus*, Channel Catfish *I. punctatus*, Bluegill, Largemouth Bass *Micropterus salmoides*, Redbreast Sunfish, 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 (1962). 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) and interfaced through R package “brms”. All growth models used 4 concurrent Markov chain Monte Carlo (MCMC) 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 MCMC 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 993 individuals representing 31 species were collected (Table 1). Bluegill, Bowfin *Amia calva*, Flathead Catfish, Largemouth Bass, Longnose Gar *Lepisosteus osseus*, Redear Sunfish, Spotted Sunfish *L. punctatus*, and Warmouth *L. gulosus* were all collected in 100% of the sample sites in which they were targeted (Table 1). Warmouth, Bluegill, Redear Sunfish, and Largemouth Bass were the most abundant Inland Game Fish, while Flathead Catfish, Bowfin, Longnose Gar, and Channel Catfish were the most abundant nongame fish (Table 1). Overall, relative abundance of the four most abundant Inland Game Fish was variable and did not indicate a strong spatial gradient (Figure 2). Flathead Catfish were most abundant upstream of RKM 170 (Figure 3).

The high frequency electrofishing site with the greatest species diversity was RKM 193 with 22 species collected, while all other high frequency electrofishing sites yielded 15–17 species (Table 2). River kilometer 170 exhibited the greatest catfish diversity with 4 species collected using low frequency electrofishing (Table 3). Flathead Catfish was the only ictalurid captured in all low frequency electrofishing sites (Table 3). A single White Catfish was collected in RKM 189 (Table 3).

Nine species were collected that were not present in the 1961 survey by Louder (1962). Among those are 5 nonnative species, three of which were likely introduced after the 1961 survey [Blue Catfish, Flathead Catfish, and Spotted Bass *Micropterus* sp. (see page 6 for discussion on "Spotted Bass")]. Banded Pygmy Sunfish *Elassoma zonatum*, Banded Sunfish *Enneacanthus obesus*, Eastern Mosquitofish *Gambusia holbrooki*, Eastern Mudminnow *Umbra pygmaea*, Ironcolor Shiner *Notropis chalybaeus*, Lake Chubsucker *Erimyzon sucetta*, Lined Topminnow *Fundulus lineolatus*, Redfin Pickerel *Esox americanus*, Sawcheek Darter *Etheostoma serrifer*, Swamp Darter *E. fusiforme*, Swampfish *Chologaster cornuta*, Tadpole Madtom *Noturus gyrinus*, and Tessellated Darter *E. olmstedi* were present in the 1961 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. All three Species of Greatest Conservation Need (SGCN) as identified in the N.C. Wildlife Action Plan (NCWRC 2015) observed in 1961 were absent in 2015–2016 (Table 1).

Size structure. Twelve Inland Game Fish and 7 nongame species had at least 5 collected individuals and were described using density plots. Chain Pickerel *E. niger* were the largest Inland Game Fish, followed by Largemouth Bass, Brown Bullhead *A. nebulosus*, and Yellow Perch *Perca flavescens* (Figure 4). Redear Sunfish were the largest lepomid, followed by Bluegill and Warmouth (Figure 4). Flathead Catfish were the largest nongame fish, followed by Bowfin, Longnose Gar, and Channel Catfish (Figure 5).

Age structure. Bluegill ranged from age 0 to age 5, with age-1 to age-3 fish comprising 85% of the population (Figure 6). Channel Catfish ranged from age 2 to age 7, but 54% of the population was age 3 (Figure 6). Flathead Catfish ranged from age 1 to age 16 with 90% between age 1 and age 4 (Figure 6). Largemouth Bass ranged from age 1 to age 9, with 81% of the population age 2 to age 3 (Figure 6). Redbreast Sunfish exhibited a maximum age of 3, but 96% were age 0 to age 2 (Figure 6). Redear Sunfish ranged from age 0 to age 6, with 70% age 2 or younger (Figure 6).

This is the first examination of Flathead Catfish age structure in the Waccamaw River. The maximum age (16) was similar to that of other established introduced populations reviewed by Kwak et al. (2006). The age structure of Largemouth Bass was similar to other coastal NC populations (Potoka and McCargo 2016; Smith and Potoka 2017, 2020; Rachels & Fisk 2021a, 2021b, 2021c). The Bluegill maximum age (5) was less than the maximum age reported in North Carolina (age 7 in Richardson and Ratledge 1961 and Rachels and Fisk 2021b) but was identical to the Black and Lumber rivers in 2015–2016 (Rachels and Fisk 2021a, 2021c). Redear Sunfish age structure was similar to the Lumber River population (Rachels and Fisk 2021c) with a maximum age of 6. Similar to the Cape Fear River population, Channel Catfish exhibited a truncated age structure compared to populations in the Black and Lumber rivers (Rachels and Fisk 2021a, 2021b, 2021c). Finally, the Redbreast Sunfish population exhibited the youngest age structure among southeastern NC populations, with a maximum age (3) less than half of what was observed in the Lumber River population (Rachels and Fisk 2021a, 2021b, 2021c).

Growth. Approximate convergence was achieved for all von Bertalanffy growth models. However, graphical posterior predictive checks indicated the models for Channel Catfish and Redbreast Sunfish performed poorly at replicating the observed data. The Bluegill VBGF appeared to be relatively precise (Figure 7) and similar to other southeastern NC populations (Rachels and Fisk 2021a, 2021b, 2021c). The VBGF for Channel Catfish exhibited considerable uncertainty, and given its failure to adequately replicate the observed data using a posterior predictive check, has limited management utility (Figure 7). The Flathead Catfish VBGF model fit was precise for younger ages, although model uncertainty increased substantially after age 9 and the L_∞ was 159 mm greater than the largest observed individual (Table 4, Figure 7). The Largemouth Bass VBGF was reasonably precise (Figure 7) and similar to other southeastern NC populations (Rachels and Fisk 2021a, 2021b, 2021c), although the estimated joint posterior distribution of L_∞ suggests it was significantly influenced by the prior probability distribution (Figure 8). As indicated by the posterior predictive check, the Redbreast Sunfish VBGF failed to adequately replicate the observed data and has limited management utility. The Redear Sunfish VBGF model appeared to exhibit low bias throughout the observed ages (Figure 7) and depicted growth similar to other southeastern NC populations (Rachels and Fisk 2021a; 2021b; 2021c).

Mortality. Bluegill experienced the least mortality of lepomids (Table 5) and the lowest total mortality among southeastern NC populations (Rachels and Fisk 2021a; 2021b; 2021c). The Channel Catfish mortality estimate was imprecise (Table 5) and should be viewed with caution given the small sample size. The Flathead Catfish mortality estimate was also imprecise as only 19 individuals were greater than the age at recruitment to the catch curve (Table 5); however, the broad age-structure lends support to the estimated low mortality rate. The

Largemouth Bass mortality estimate was relatively precise (Table 5) and similar to the Black River population (Rachels and Fisk 2021a). Few Redbreast Sunfish were collected, resulting in an imprecise mortality estimate (Table 5). Indeed, the mortality rate is likely even greater than estimated given the severely truncated age-structure. Few Redear Sunfish greater than the modal age were collected, resulting in an imprecise mortality estimate (Table 5).

Discussion

The aquatic community in the Waccamaw River has undergone significant change since the baseline survey in 1961 and the creel survey in 1981. According to Nichols and Buff (1981), Redbreast Sunfish received over twice as much angling effort (5,534 angler hours) as the next most popular fishery (Largemouth Bass; 2,486 angler hours) and produced an estimated harvest of 1,253 kg annually. Similarly, White Catfish supported the greatest fishery harvest with an estimated 2,181 kg harvested during the 1980–1981 creel survey (Nichols and Buff 1981). Only 24 Redbreast Sunfish were collected in this survey and all were age 3 or younger, indicating low abundance and high mortality. White Catfish were represented by a single individual, suggesting the species is in danger of being extirpated from the Waccamaw River. Both species are vulnerable to Flathead Catfish predation (Guier et al. 1984; Thomas 1993), and Flathead Catfish appear to have extirpated White Catfish from the lower Cape Fear River Basin (Rachels 2021).

Comparisons are made between the sample composition in this survey and the 1961 survey by Louder (1962). These comparisons are somewhat tenuous given the different sampling gears utilized by the surveys. Nonetheless, the current survey suggests an overall decline in SGCN since the Louder (1962) survey. Additional surveys using a broad range of sampling gears, coupled with alternative analytical techniques (e.g., occupancy modeling), may aid in elucidating their current status in the Waccamaw River.

Introduced species are among the most visible threats to the Waccamaw River’s fisheries resources. Flathead Catfish have well-documented negative impacts on native sunfish and catfish (NCWRC 2019). Another nonnative species, referred to as “Spotted Bass” in this report, is of unknown origin but was first stocked in North Carolina in the Cape Fear River in 1978 from Coosa River, AL, source broodfish (Marshall Ray; personal communication; Nichols and Buff 1984) which precludes *Micropterus punctulatus*. It is unknown if the Spotted Bass of the Waccamaw River originated from angler introductions in North Carolina or South Carolina. Nonetheless, the introduction of congeners has caused significant impacts to Largemouth Bass in other waterbodies in North Carolina (e.g., Dorsey and Abney 2016). Although the Spotted Bass population appears to be limited in the Waccamaw River, additional study is needed to elucidate the current status of *Micropterus* populations and the impacts of introduced black bass species.

Habitat and water quality degradation also negatively impact fish populations in the Waccamaw River. 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). Similarly, clearing and snagging activity in the main stem Waccamaw River is occasionally initiated for flood-control purposes but has no long-term utility, increases sedimentation, and greatly diminishes fish habitat (Cobb and

Kaufman 1993). Removal of large woody debris (LWD) in the river through clearing and snagging is especially harmful to Redbreast Sunfish, which prefer LWD habitat for spawning (Davis 1971; Bass and Hitt 1974; Sandow et al. 1974).

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. Potential infrastructure adaptations intended to reduce the impacts of high streamflow on human populations adjacent to the Waccamaw River—adaptations including but not limited to channelization, watershed storage, and flow diversions—would likely negatively impact many native fish species (Bryan and Rutherford 1993). Continued monitoring, and NCWRC engagement in activities proposed to reduce the flood risk of human communities, are necessary to maintain the integrity of fisheries resources in the Lumber River. 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 Flathead Catfish by reducing barriers to harvest and investigating novel control techniques.
2. Initiate management actions to restore Redbreast Sunfish and White Catfish populations. Reduced creel limits, hatchery supplementation, and reducing predatory stressors may be required.
3. Investigate occupancy of native catfish and Redbreast Sunfish.
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 Waccamaw River fish communities.
6. 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., 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 Sport Fish Restoration, Project F-22, Final Report, Raleigh.

Bass, D. G., and V. G. Hitt. 1974. Ecological aspects of the Redbreast Sunfish, *Lepomis auritus*, in Florida. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 28:296–307.

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.

Bryan, C. F., and D. A. Rutherford, editors. 1993. Impacts on warmwater streams: guidelines for evaluation. American Fisheries Society, Southern Division, Bethesda, Maryland.

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.

Cobb, S. P., and J. Kaufman. 1993. Clearing and snagging. Pages 169–180 *in* C. F. Bryans and D. A. Rutherford, editors. Impacts on warmwater streams: guidelines for evaluation. American Fisheries Society, Southern Division, Bethesda, Maryland.

Davis, J. R. 1971. The spawning behavior, fecundity rates, and food habits of the Redbreast Sunfish in Southeastern North Carolina. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 25:556–560.

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.

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.

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.

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.

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.

Kwak, T. J., D. S. Waters, and W. E. Pine III. 2006. Age, growth, and mortality of introduced Flathead Catfish in Atlantic Rivers and a review of other populations. North American Journal of Fisheries Management 26:73–87.

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. 1962. Survey and classification of the Lumber River and Shallotte River, North Carolina. North Carolina Wildlife Resources Commission, Federal Aid in Fish Restoration, Project F-14-R, Final Report, Raleigh.

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.

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.

NCDENR (N.C. Department of Environment and Natural Resources). 2007. Basinwide assessment report—Lumber 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.

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

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

NCWRC (N.C. Wildlife Resources Commission). 2015. North Carolina Wildlife Action Plan. North Carolina Wildlife Resources Commission, Raleigh.

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., and B. M. Buff. 1981. Investigation of the sport fishery in the Waccamaw River. North Carolina Wildlife Resources Commission, Coastal Fisheries Investigations Non-Federal Aid, 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.

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.

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 Cape Fear 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 Lumber River. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

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.

Sandow, J. T. II, D. R. Holder, and L. E. McSwain. 1974. Life history of the Redbreast Sunfish in the Satilla River, Georgia. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 28:279–295.

Shute, J. R., P. W. Shute, and D. G. Lindquist. 1981. Fishes of the Waccamaw River Drainage. Brimleyana 6:1–24.

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, 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.

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.

TABLE 1. Species collected in hand-crank electrofishing survey (2015–2016) and Louder (1962; 1961). **Bold** denotes Inland Game Fish, *italics* denote Species of Greatest Conservation Need (SGCN), and (◊) denotes nonnative species.

Common name	Scientific name	Catch 1961	Catch 2015-2016	Sites with catch 1961 [a]	Sites with catch 2015-2016 [b]
American Eel	*Anguilla rostrata*	2	7	50%	60%
Banded Pygmy Sunfish	*Elassoma zonatum*	9	0	25%	0%
Banded Sunfish	*Enneacanthus obesus*	22	0	50%	0%
Black Crappie	*Pomoxis nigromaculatus*	12	15	75%	60%
◊ Blue Catfish	*Ictalurus furcatus*	0	3	0%	20%
Bluegill	*Lepomis macrochirus*	66	87	100%	100%
Bluespotted Sunfish	*Enneacanthus gloriosus*	116	2	100%	20%
Bowfin	*Amia calva*	1	184	25%	100%
Brown Bullhead	*Ameiurus nebulosus*	1	36	25%	73%
Chain Pickerel	*Esox niger*	8	7	50%	60%
◊ Channel Catfish	*Ictalurus punctatus*	0	24	0%	40%
Coastal Shiner	*Notropis petersoni*	62	9	50%	40%
Creek Chubsucker	*Erimyzon oblongus*	0	1	0%	20%
Dollar Sunfish	*Lepomis marginatus*	18	11	25%	60%
Eastern Mosquitofish	*Gambusia holbrooki*	189	0	100%	0%
Eastern Mudminnow	*Umbra pygmaea*	4	0	50%	0%
Flat Bullhead	*Ameiurus platycephalus*	0	1	0%	7%
◊ Flathead Catfish	*Pylodictis olivaris*	0	198	0%	87%
Flier	*Centrarchus macropterus*	4	3	50%	20%
Golden Shiner	*Notemigonus crysoleucas*	285	3	100%	60%
Hybrid Sunfish		0	1	0%	20%
Ironcolor Shiner	*Notropis chalybaeus*	118	0	50%	0%
Lake Chubsucker	*Erimyzon sucetta*	20	0	25%	0%
Largemouth Bass	*Micropterus salmoides*	33	63	100%	100%
Lined Topminnow	*Fundulus lineolatus*	6	0	50%	0%
Longnose Gar	*Lepisosteus osseus*	35	49	100%	100%
Pirate Perch	*Aphredoderus sayanus*	62	8	75%	80%
Pumpkinseed	*Lepomis gibbosus*	0	14	0%	60%
Redbreast Sunfish	*Lepomis auritus*	37	24	100%	80%
◊ Redear Sunfish	*Lepomis microlophus*	0	83	0%	100%
Redfin Pickerel	*Esox americanus*	7	0	50%	0%
Sawcheek Darter	*Etheostoma serrifer*	14	0	50%	0%
◊ Spotted Bass [c]	*Micropterus* sp.	0	3	0%	40%
Spotted Sucker	*Minytrema melanops*	8	3	50%	40%
Spotted Sunfish	*Lepomis punctatus*	1	25	25%	100%
Swamp Darter	*Etheostoma fusiforme*	43	0	100%	0%
Swampfish	*Chologaster cornuta*	4	0	50%	0%

TABLE 1. Continued…

Common name	Scientific name	Catch 1961	Catch 2015–2016	Sites with catch 1961[a]	Sites with catch 2015–2016 [b]
Tadpole Madtom	*Noturus gyrinus*	62	0	100%	0%
Taillight Shiner	*Notropis maculatus*	69	1	75%	20%
Tessellated Darter	*Etheostoma olmstedi*	21	0	25%	0%
Warmouth	*Lepomis gulosus*	92	99	100%	100%
White Catfish	*Ameiurus catus*	1	1	25%	7%
Yellow Bullhead	*Ameiurus natalis*	9	3	100%	20%
Yellow Perch	*Perca flavescens*	22	25	100%	80%

[a] Sites 13K-5, 13K-7, 13K-9, and 13K-10 in Louder (1962) as amended by Starnes and Hogue (2011).

[b] Percentages calculated with catfish targeted in all sites (n = 15); other species targeted in high-frequency sites only (n = 5).

[c] This species has historically been considered *M. punctulatus* but awaits genetic species identification.

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				
	168	172	188	193	199
American Eel	0	4	1	0	2
Black Crappie	0	2	8	5	0
Blue Catfish	0	1	0	0	0
Bluegill	30	6	25	16	10
Bluespotted Sunfish	0	0	2	0	0
Bowfin	29	37	55	32	31
Brown Bullhead	0	0	1	0	4
Chain Pickerel	1	0	0	3	3
Channel Catfish	0	13	6	1	1
Coastal Shiner	0	0	0	8	1
Creek Chubsucker	0	0	0	1	0
Dollar Sunfish	3	0	0	4	4
Flat Bullhead	0	1	0	0	0
Flathead Catfish	0	9	5	2	0
Flier	0	0	0	3	0
Golden Shiner	1	0	0	1	1
Hybrid Sunfish	0	0	1	0	0
Largemouth Bass	15	11	14	20	3
Longnose Gar	23	6	14	3	3
Pirate Perch	5	1	1	1	0
Pumpkinseed	2	2	0	10	0
Redbreast Sunfish	2	10	0	11	1
Redear Sunfish	63	1	1	12	6
Spotted Bass	2	0	0	0	1
Spotted Sucker	0	0	2	1	0
Spotted Sunfish	4	5	1	9	6
Taillight Shiner	0	0	0	1	0
Warmouth	9	22	52	10	6
Yellow Perch	12	0	6	2	5
Total species	15	16	17	22	17

TABLE 3. Aggregated catch (2015 and 2016) by low frequency (15 PPS) electrofishing site. The final row gives the number of species captured within each site.

Species	River kilometer									
	165	166	170	173	174	189	190	191	195	201
Blue Catfish	0	0	1	0	0	0	1	0	0	0
Brown Bullhead	3	1	7	0	1	3	8	3	4	1
Channel Catfish	0	0	0	0	1	0	0	2	0	0
Flathead Catfish	1	8	2	19	42	20	26	21	20	23
White Catfish	0	0	0	0	0	1	0	0	0	0
Yellow Bullhead	1	0	1	0	0	0	0	0	0	1
Total species	3	2	4	1	3	3	3	3	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_∞	208	233	262
K	0.32	0.47	0.66
t_0	-1.22	-0.78	-0.43
	Channel Catfish		
L_∞	562	693	844
K	0.16	0.30	0.50
t_0	-1.78	-0.24	0.84
	Flathead Catfish		
L_∞	1,022	1,177	1,351
K	0.09	0.11	0.14
t_0	-1.18	-0.75	-0.39
	Largemouth Bass		
L_∞	521	579	640
K	0.15	0.22	0.30
t_0	-2.14	-1.14	-0.34
	Redbreast Sunfish		
L_∞	185	241	299
K	0.11	0.20	0.31
t_0	-1.89	-1.05	-0.47
	Redear Sunfish		
L_∞	290	348	414
K	0.16	0.24	0.34
t_0	-1.41	-0.93	-0.52

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	82	5	0.84 (0.29)	0.43–1.35	57%
Channel Catfish	20	7	0.73 (Inf)	Inf	52%
Flathead Catfish	185	16	0.39 (Inf)	Inf	32%
Largemouth Bass	63	9	0.66 (0.18)	0.40–0.98	48%
Redbreast Sunfish	15	3	0.87 (0.67)	0.12–2.17	58%
Redear Sunfish	80	6	1.07 (0.24)	0.70–1.50	66%

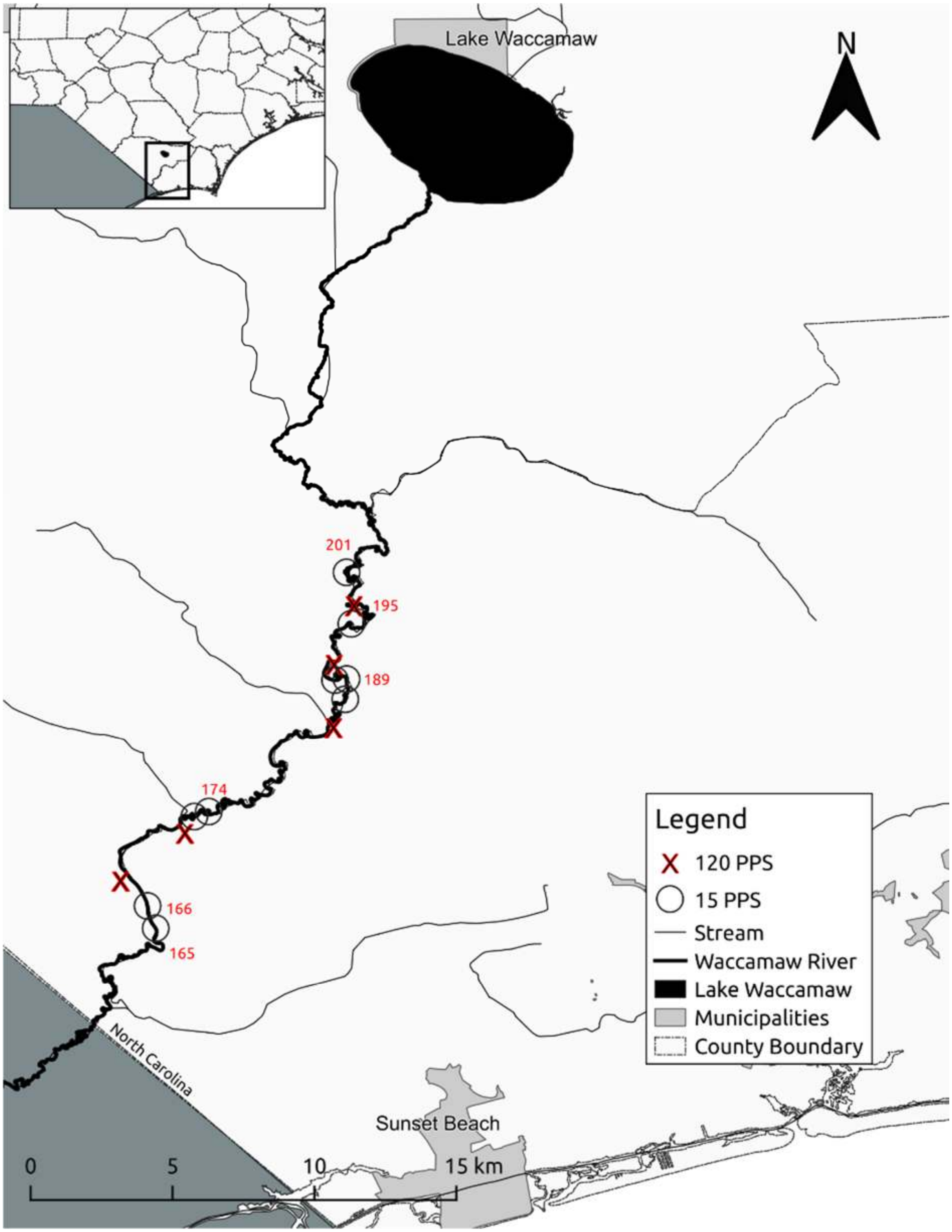

FIGURE 1. Waccamaw River sites surveyed with boat electrofishing techniques in North Carolina in 2015 and 2016. Several sites are labeled (red) with associated river kilometer.

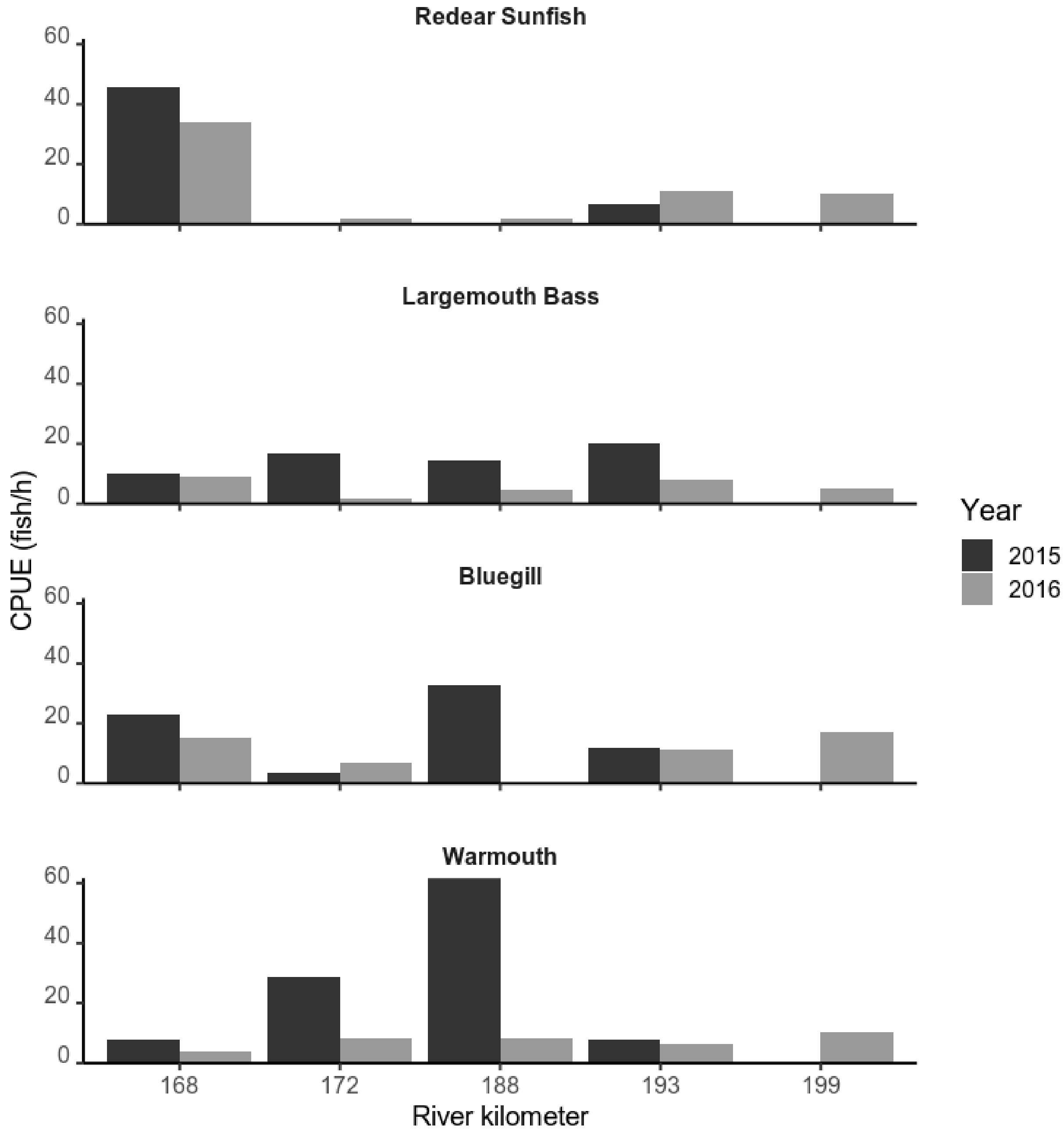

FIGURE 2. Catch per unit effort by site (river kilometer) and year for the four Inland Game Fish with the greatest catch in the high frequency (120 PPS) electrofishing sites. The x-axis is ordered left to right, downstream to upstream.

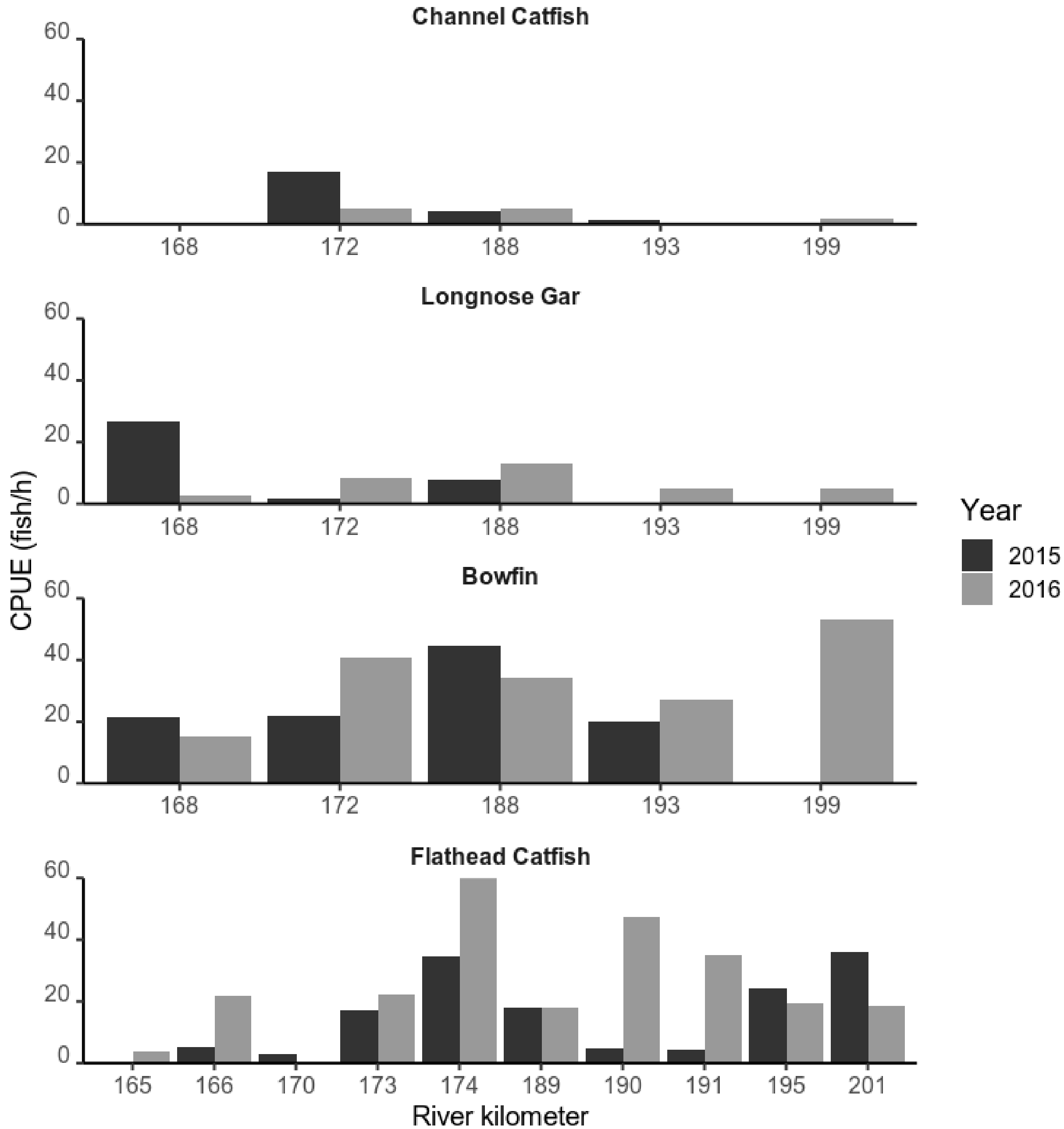

FIGURE 3. Catch per unit effort by site (river kilometer) and year for the four nongame fish with the greatest catch. Flathead Catfish sites and effort are from low frequency (15 PPS) electrofishing; other species depict effort from high frequency (120 PPS) electrofishing sites.

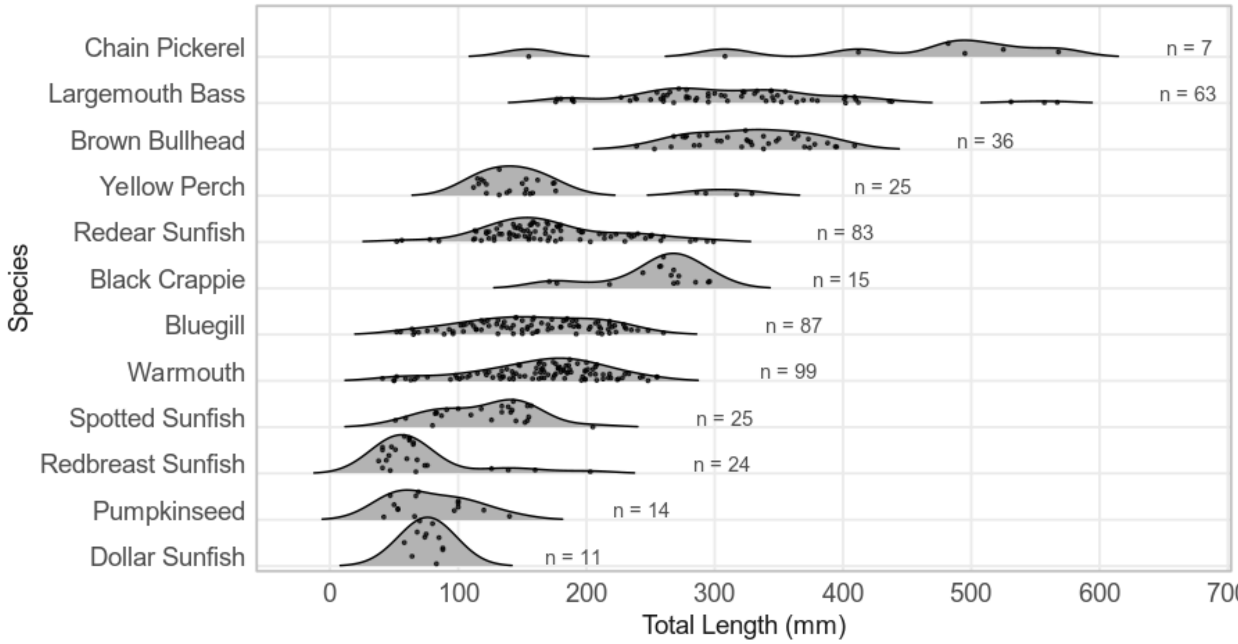

FIGURE 4. Density plots of Inland Game Fish with five or more collected individuals in descending order by maximum size of the largest individual. The sample size is denoted to the right of each size distribution.

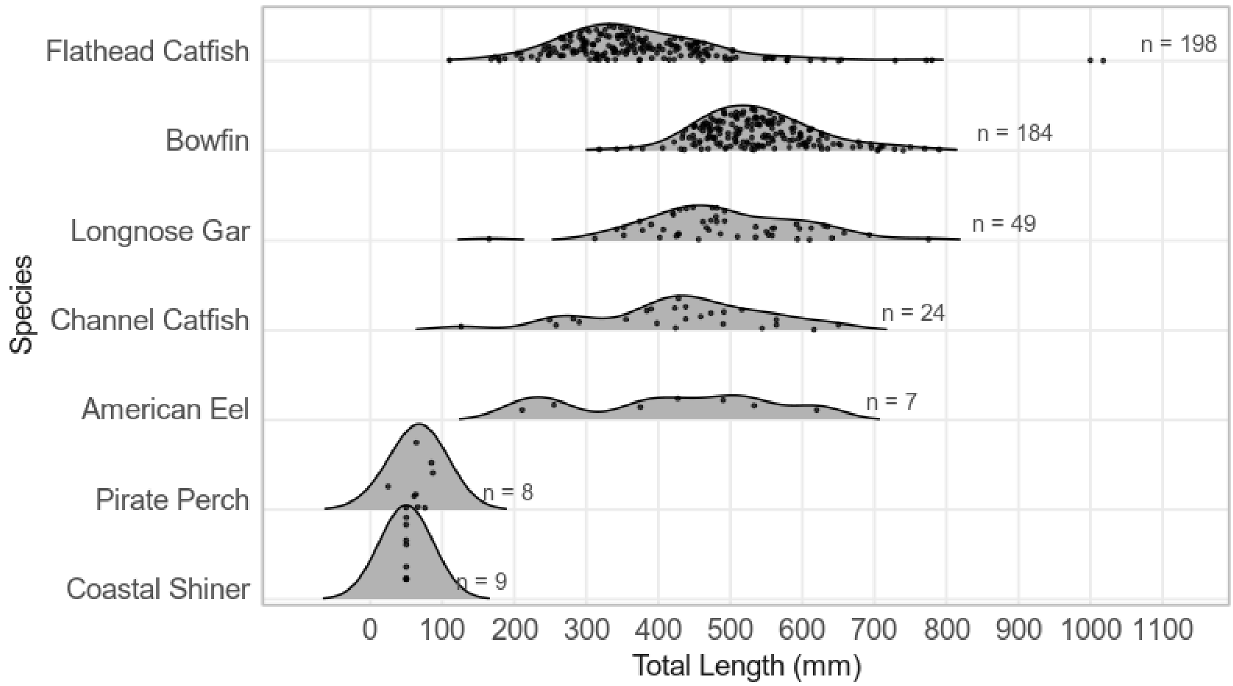

FIGURE 5. Density plots of nongame fish with five or more collected individuals in descending order by maximum size of the largest individual. The sample size is denoted to the right of each size distribution.

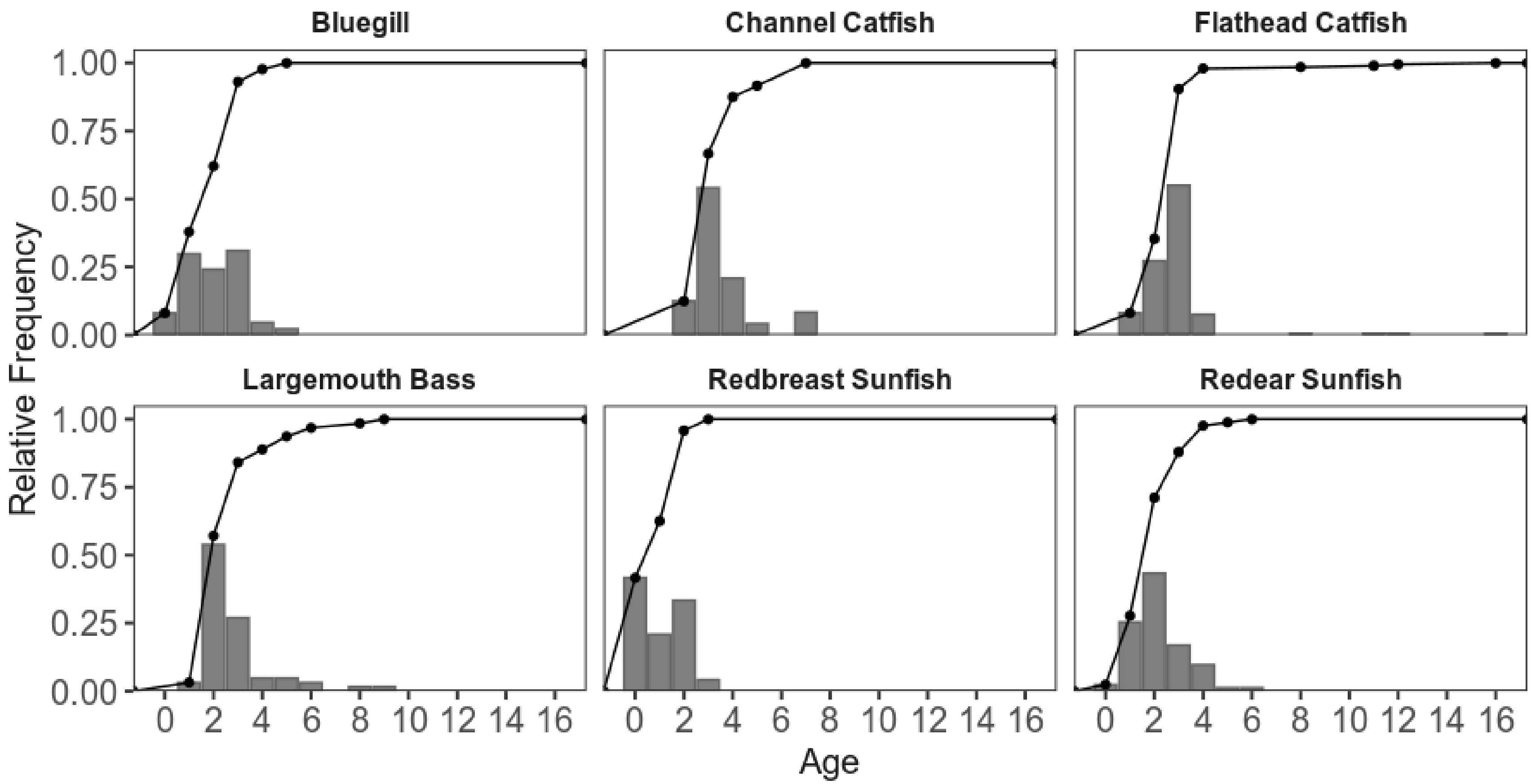

FIGURE 6. Age class relative frequency by species (bars). Line denotes cumulative age frequency.

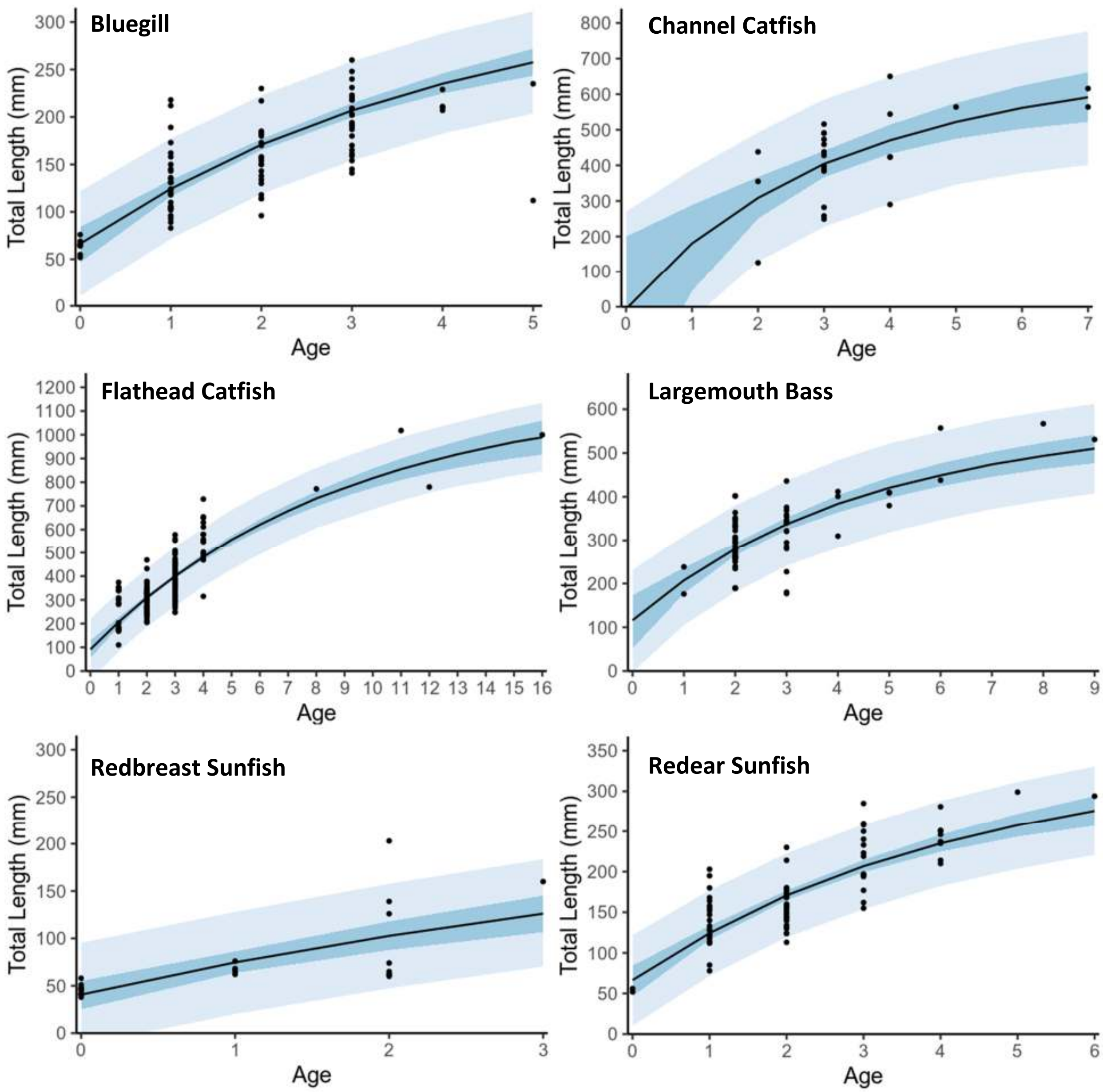

FIGURE 7. Posterior predicted median length-at-age from von Bertalanffy growth models (black line) and observed individuals (point markers). The dark shaded area denotes the 90% credible interval of the model, while the light shaded area denotes the 90% credible interval of the posterior predictive distribution.

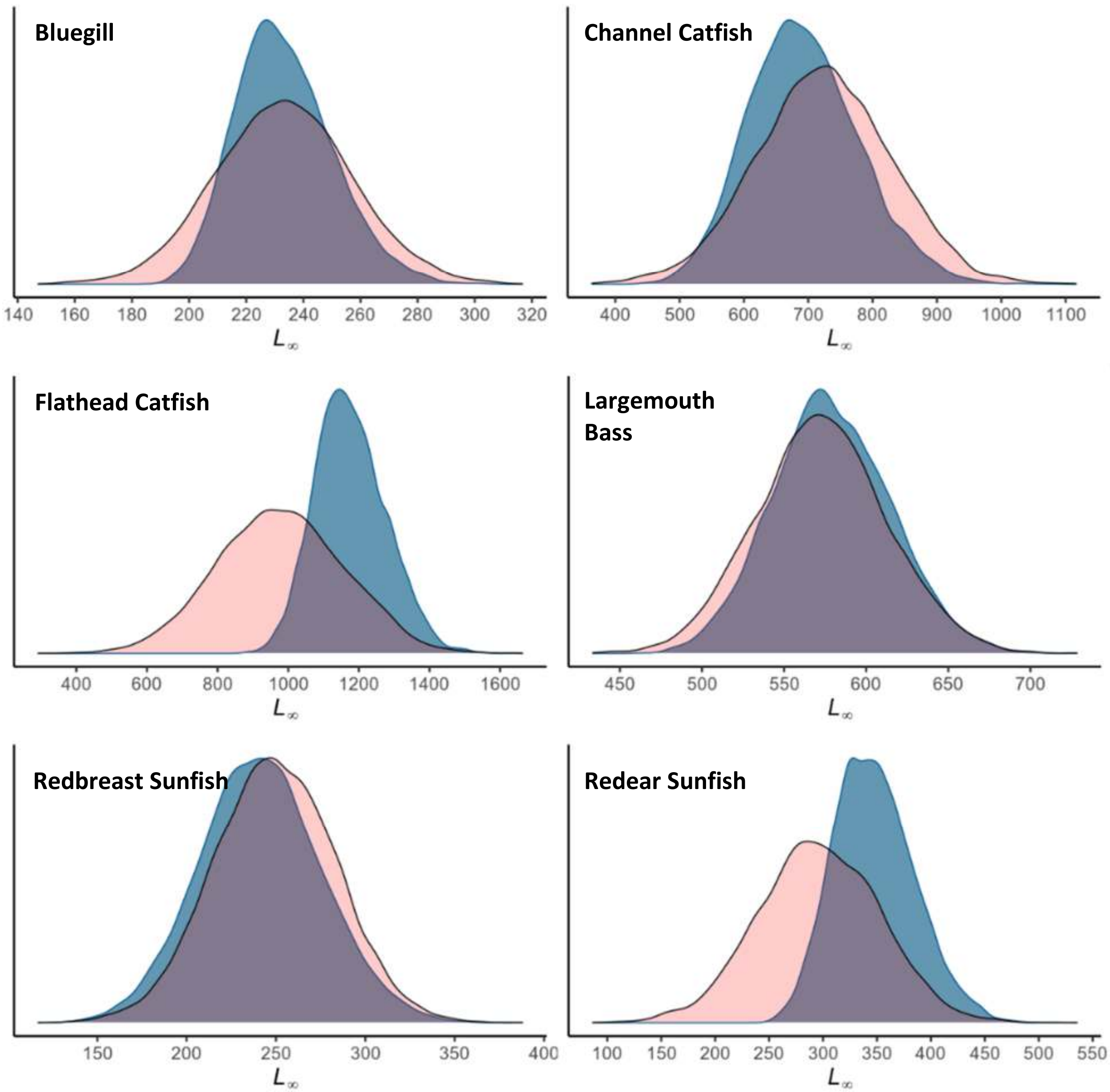

FIGURE 8. Prior (red) and estimated joint posterior (blue) probability distributions for L_∞. All values within the joint posterior distribution are considered credible, while the most credible estimate of L_∞ occurs at the peak of the curve.