Broad River Comprehensive Entrainment Mitigation and Fisheries Resource Enhancement Program

Broad River Aquatic Resources Inventory Completion Report

Submitted by

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EXECUTIVE SUMMARY

1. We evaluated the condition of 312 km of riparian habitat along the Broad River. Approximately 87% of the riparian area was in good condition, 12% was marginal, and only 1% was considered to be in poor condition. Poor bank stability was observed above Parr Shoals Reservoir.

2. We made 181 standardized boat electrofishing collections and 23 catfish electrofishing collections at 10 sites in the Broad River between January 2001 and May 2002. In addition, we made 676 standardized plot samples and 33 shoreline samples with backpack electrofishing gear at 9 sites in the Broad River between fall 2000 and spring 2002.

3. We collected 16,752 fish, comprising 51 species and nine families. No federally-listed threatened or endangered species were collected. Four species (including one hybrid) were not previously documented from the river. The species most commonly collected were redbreast sunfish, whitefin shiner and silver redhorse. Species richness and diversity tended to be higher at downstream locations. Species composition was comparable to that of similar-sized southern piedmont rivers.

4. Based on boat electrofishing collections, dams do not seem to prevent the distribution of resident species throughout the river. Community composition differed between riverine sites and those located near hydroelectric operations.

5. In boat electrofishing collections, a significant relationship was observed between catch rates and distance downstream from a dam. In backpack electrofishing collections, catch rates and species richness were related to physical habitat parameters.

6. The water quality parameters we measured were consistent with those expected for a piedmont river and did not affect species richness, species diversity or catch rates in backpack or boat electrofishing collections.

7. Redbreast sunfish and redear sunfish are long-lived in the Broad River. Growth rates of redbreast sunfish were slower than those reported from other southern rivers. Largemouth bass and smallmouth bass growth and longevity were typical of the region. Snail bullheads in the Broad River grow and live longer than reported elsewhere.

8. We investigated the health of largemouth bass at ten sites. Largemouth bass populations in the Broad River appear to be in good condition; however, our results suggested that condition was adversely affected by industrial effluent.

9. In 1996 Duke Power Company implemented minimum flows in the bypassed section of the Gaston Shoals Tailrace. Analysis of pre- and post-minimum flow fish community data indicated that minimum flows have had a positive impact on the fish community in the bypass. Species diversity was higher and pollution tolerance structure was markedly improved in the post-minimum flow fish community data.

10. We surveyed six sites for freshwater mussels and collected 315 live mussels, representing at least three species. Seven putative species were identified from relic shell collections. The native mussel fauna was more abundant and diverse in the lower section of the river.

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INTRODUCTION

Background

The Broad River Trust Fund was established with money provided by the power companies that own and operate hydroelectric dams on the Broad River. The Trust Fund resulted from an agreement negotiated between SCDNR, USFWS, Duke Power Company, Lockhart Power Company, and South Carolina Electric & Gas Company, as a result of the FERC relicensing process. Funds in the Trust are administered by a board of trustees composed of representatives of each of the entities involved. The funds are intended to be used to enhance the fishery resources of the Broad River. The trustees decided that before any enhancement activity took place, a preliminary survey of the fish community was needed to determine its status and condition. The present study was undertaken to provide that information.

The purpose of this report is to present the findings of two years of baseline fish community, habitat and freshwater mussel data that were collected from the Broad River between October 2000 and September 2002. Objectives were addressed in five distinct study segments, detailed in separate sections of the report.

Objectives

The primary objectives of this study were to: (1) comprehensively inventory the aquatic resources of the Broad River watershed, with emphasis on fishes; (2) compare the fish community along the length of the river, examining the possibility of fish community fragmentation associated with dams; (3) compile habitat and natural resource data obtained in the current study and in previous efforts in a watershed-based database and investigate relationships between the status of the fish community and environmental variables such as dam location, hydrology, water quality and quantity, and adjacent land-use; and (4) use the data collected from this effort to identify opportunities for protecting and enhancing the aquatic resources of the Broad River, with emphasis on the fish community.

In addressing these objectives, we will also: (1) examine the health of largemouth bass along the length of the river; (2) compare the fish community at the Gaston Shoals Bypass before and after the implementation of minimum flows; and (3) perform a qualitative inventory of the Broad River mussel community.

Study Area

The Broad River basin originates in North Carolina and dominates the central Piedmont of South Carolina. Within South Carolina, the river flows approximately 170 km until it merges with the Saluda River to form the Congaree River. The Broad River Basin, within South Carolina, encompasses 9,819 square km. Most of the basin is forested (70%); the remainder of the land is largely agricultural (13%) and urban (8%) (SCDHEC 2001). Average flow of the Broad River approximately 11 km downstream from the North Carolina state line (USGS gage # 1515) was 2,470 cfs, while average flow 16 km below Parr Reservoir (USGS gage #1615) was 6,250 cfs. In the upper part of the basin, where annual rainfall is highest, flows are well sustained and moderately variable; downstream, flows become more variable as rainfall and groundwater support decreases (Snyder et al. 1983). Seven hydropower dams are located on the South Carolina portion of the Broad River; these are Gaston Shoals, Cherokee Falls, Ninety-Nine Islands, Lockhart, Neal Shoals, Parr Shoals, and Columbia. Climatological, hydrological, and limnological differences along the river's course create a variety of habitat types for aquatic organisms residing in the Broad River.

The S.C. Department of Health and Environmental Control (SCDHEC) recently characterized water quality and the associated status of the aquatic community in the Broad

River Basin, including nine assessment sites in the main stem of the Broad River (SCDHEC 2001). At all but one site, aquatic life use was fully supported. Excursions from aquatic life standards for dissolved oxygen and pH were ≤10% and acute aquatic life standards for toxins (heavy metals, priority pollutants, chlorine, and ammonia) were not exceeded. Aquatic life use is not supported in the Columbia Water Plant diversion canal due to the occurrence of copper in excess of the acute aquatic life standards.

Sample Sites

Eleven sites distributed along the length of the river were selected for sampling (Figure 1) based on three primary criteria: access; variety of aquatic habitats (riffle, run and pool); and riverine character. Riverine character was defined as minimally impacted by hydroelectric operations. Most sites (1, 3, 5, 6, 8, and 9) were located far enough from hydroelectric operations that potential impacts from them were minimal. Two sites (2 and 11) that were upstream of dams were close enough to the dams to be influenced by reservoir ponding. Two other sites (4 and 7) were just downstream of dams, where fluctuations in discharge could affect aquatic habitat. Latitude and longitude coordinates of each area sampled are given in Table 1. Site 1, below Bookman Island, is the only site below Parr Reservoir. Sites 2 and 3 are between Neal Shoals and Parr reservoirs. Site 2 is above the confluence of the Enoree River, 22 km above Parr Shoals Dam. Site 3 is above the confluence of the Tyger River, two km below the Sandy River boat access. Site 4 is two km below the Lockhart Power Canal. Sites 5 and 6 are located in the river reach from Ninety-Nine Islands to Lockhart Reservoir. Site 5 is directly below the Pacolet River and Site 6 is at Smiths Ford. Site 7 is two km below the Cherokee Falls Dam. Sites 8, 9, and 10 are located between the Gaston Shoals and Cherokee Falls hydropower dams. Site 8 is directly below Canoe Creek, 5 km above Cherokee Falls Dam. Site 9 is upstream of the confluence with Buffalo Creek, four km below Gaston Shoals Dam. Site 10 is in the Gaston Shoals bypass. Site 11 is 5 km above Gaston Shoals Dam and is influenced by ponding from Gaston Shoals Reservoir.

Table 1. Sites sampled during the Broad River fisheries inventory October 2000 – June 2002.

Site #	Site coordinates	Habitat	Seasoned sampled	Electrofishing gear
1	34E13'46.8", 81E13'84.5"	Riverine	fall and spring	backpack/boat
2	34E43'15.1", 81E41'04.7"	Reservoir	fall and spring	backpack/boat
3	34E55'73.0", 81E42'27.3	Riverine	fall and spring	backpack/boat
4	34E75'89.9", 81E45'52.3"	Tailwater	fall and spring	backpack/boat
5	34E83'72.8", 81E45'80.3"	Riverine	fall and spring	boat
6	34E99'53.5", 81E48'42.2"	Riverine	fall and spring	backpack/boat
7	35E05'33.3", 81E53'82.5"	Tailwater	fall and spring	backpack/boat
8	35E09'96.1", 81E57'36.6"	Riverine	fall and spring	backpack/boat
9	35E11'79.0", 81E57'63.0"	Riverine	fall and spring	backpack/boat
10	35E16'84.6", 81E61'84.7"	Bypass	fall	backpack
11	35E13'73.9", 81E60'08.9"	Reservoir	fall and spring	boat

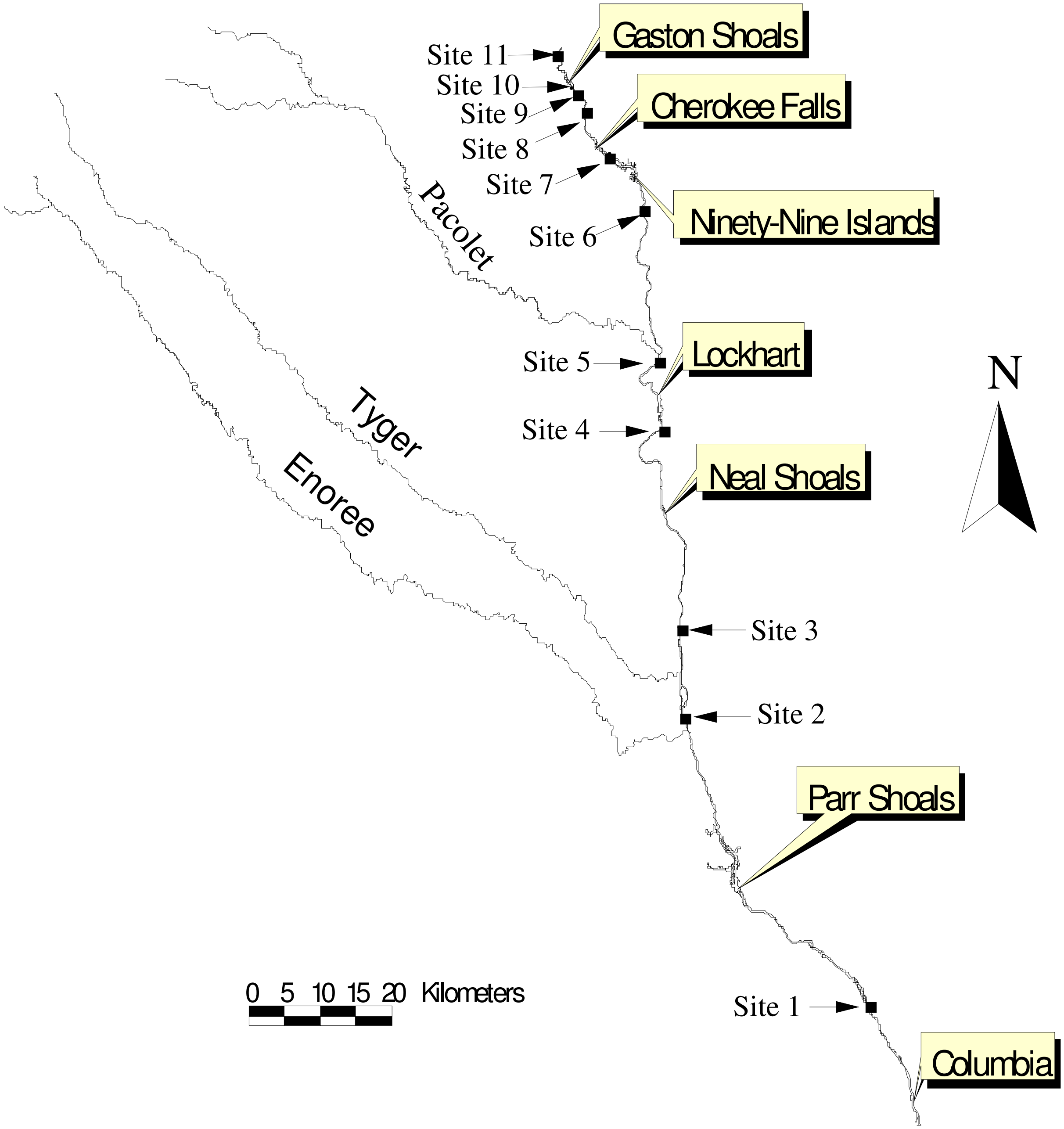


Figure 1. Sites sampled during the Broad River fisheries inventory October 2000 – June 2002. The location and name of hydropower dams is also shown.

HABITAT INVENTORY AND GIS DATABASE CONSTRUCTION

Preliminary reconnaissance of the Broad River was conducted by john boat during low water conditions in spring and summer, 2000, to collect habitat information and identify potential sample sites. Information derived from the survey was compiled in a geographic database using ArcView GIS software. Additional information obtained from a variety of sources was included as layers in the database. Fishery reports from earlier surveys were provided by Duke Power and South Carolina Electric & Gas, water quality monitoring sites and NPDES discharge sites were obtained from South Carolina Department of Health and Environmental Control (SCDHEC), and point locations for USGS gages were digitized from topographic maps.

During reconnaissance, we quantified mesohabitat in the riverine portions of the Broad River. Five categories of mesohabitat were defined: riffle, glide, run, pool, and shoal (Table 2). Upstream and downstream limits of each habitat unit were determined visually and recorded with a Trimble GeoExplorer[3] global positioning system (GPS). We also logged other landscape features, including riparian condition, bank stability, and potential access points using GPS. GPS locations were differentially corrected later using Pathfinder Office software and transferred to ArcView. Mesohabitat data were used to partition a digitized map of the Broad River into appropriate habitat units. We mapped 66 km of approximately 92 km of riverine habitat in the Broad River. Twenty-six km of habitat directly above the Columbia Dam were not mapped. Pools were the most common habitat type, accounting for 51% of the total area inventoried, followed by glides (28%) and shoals (18%)(Table 3). Runs (2%) and riffles (1%) were rare.

Digital orthophoto quarter quad (DOQQ) images downloaded from the SCDNR web page were imported into ArcView to quantify riparian condition. DOQQs were generated from photos taken in 1999. They had a resolution of 1 m, suitable for inventorying riparian vegetation. Riparian corridors were characterized as marginal if they were composed of mature trees but were less than 50 m wide. They were characterized as poor if they had few or no mature trees. Marginal and poor riparian areas on the Broad River were mapped in ArcView and measured. We evaluated 312 km of riparian corridor from the North Carolina state line to the Columbia Dam, excluding 99-Islands and Parr Shoals reservoirs. Approximately 11.5% of the riparian corridor was marginal and 1.3% was poor. Few long sections (>100 m) of riparian corridor in poor condition were identified. Such areas were generally associated with sand dredging operations, but occasionally with agricultural or forestry operations. There were numerous short sections (<100 m) of the riparian corridor in poor condition, however. Most were associated with power line or gas line crossings, or with private access areas (e.g., boat ramps). Almost all of the riparian habitat classified as marginal was associated with agricultural or forestry operations (94%).

The drought conditions during spring and summer, 2000, gave us an excellent opportunity to inventory the mesohabitats of the Broad River at base flows. It is important to recognize that the inventory we conducted was a gross evaluation of mesohabitat types. Shoals were the most complex habitat structure. Within a shoal most of the other habitat types were present, but were not delineated. Habitat classifications are subject to changes in flow. As flow increases the heterogeneous habitat units (i.e., riffles, runs and pools) we observed would likely change to a more homogenous run type habitat (Parasiewicz 2001). The mesohabitat information we collected could be used, with additional chemical and physical habitat data, in a model to predict the impacts of habitat alterations (e.g., impoundment) or the success of species introductions and reintroductions (e.g., robust redhorse and anadromous fish species).

Visual analysis of DOQQs indicated the riparian area along the Broad River is in relatively good condition. We recommend that habitat restoration efforts on the main stem be directed at rehabilitating riparian zones adjacent to sand mining operations, and at educating private landowners regarding the benefits of maintaining riparian buffers. Restoration of riparian areas on the tributaries might be a more effective way to improve conditions for aquatic life in the Broad River.

Sand mining poses other habitat concerns beyond those resulting from riparian zone degradation. Instream sand mining adversely affects physical and chemical habitat and can negatively affect biological communities (Nelson 1993) and recreational uses (Hartfield 1993). Physical impacts on instream habitat include increasing bedload materials and turbidity, changing substrate type and stability, and altering stream morphology (Nelson 1993). Physical habitat alterations associated with sand mining can adversely affect the biological community by impacting the reproduction and survival of fishes (Stuart 1953, Newport and Moyer 1974) and the distribution and composition of aquatic organisms (Buck 1956, Trautman 1957, Newport and Moyer 1974). Our inventory of the Broad River was not designed to evaluate the impacts of sand mining on the aquatic fauna; however, we did observe changes in the physical habitat near sand mining operations. The river downstream of sand mining operations appeared to be much more turbid than it was in areas directly above the activity. Further research to determine the impact of sand mining on the aquatic biota of the Broad River is recommended.

Cursory examination of riverbanks along the Broad River indicated that bank stability was not a major concern in most areas. One notable exception is an area above Parr Reservoir. From the Hwy 34 bridge approximately 7 km upstream the riverbanks are in poor condition with many long sections actively eroding and sloughing. The poor bank stability is probably attributable to fluctuations in water elevations that occur regularly because of Parr's operation as the lower reservoir in a pump storage hydroelectric power complex. Habitat restoration through bank stabilization in this degraded section could benefit aquatic resources.

Table 2. Mesohabitat unit definitions for visual assessment.

Habitat Type	Description
Riffle	Relatively shallow (<0.5m), swift flowing section of river where water surface is broken.
Glide	Relatively shallow (<1m); with visible flow but mostly laminar in nature; minimal observable turbulence; relatively featureless bottom.
Run	Deep (>1m), swift flowing sections with turbulent flow; surface generally not broken.
Pool	Deep (>1m) slow moving sections.
Shoals	Shoal area; which may contain a variety of habitat complexes.

Table 3. Results of the habitat inventory of the Broad River, spring and summer 2000.

Habitat Type	Number of Units	Mean Area (ha)	Total Area (ha)
Glide	71	3.0 (0.4 – 13.9)	214.1
Pool	68	5.7 (0.4 – 38.0)	384.5
Riffle	3	1.9 (0.8 – 3.3)	5.6
Run	8	1.8 (0.1 – 6.8)	14.7
Shoal	52	2.6 (0.2 – 20.3)	134.5
Total	202	3.7 (0.1 – 38.0)	753.3

FISH COMMUNITY

Boat electrofishing collections were made at 10 sites along the Broad River to collect baseline information on the fish community that inhabits pool/run habitat. The objectives of the boat electrofishing were to: (1) describe the fish community inhabiting pool/run habitat along the length of the Broad River; (2) examine the possibility of fish community fragmentation associated with dams; (3) examine the relationship between the fish community and physical and chemical habitat variables; and (4) describe the growth of selected species. Backpack electrofishing collections were made in shoal areas to augment fish community information.

Boat Methods

Fish collection

We conducted boat electrofishing during the winter (10 January – 2 February), 2001, spring (10 April – 3 May), 2001, fall (3 October – 14 November), 2001 and spring (8 April – 30 April), 2002. Boat electrofishing consisted of sampling at least three transects at each sample area: at least one transect along each bank in pool habitat and one mid-channel transect in glide/run habitat. We considered pool habitat to be areas that had little flow and a mean depth of at least one meter. Glide and run habitats were areas that had higher water velocities, more variable depths and were generally located in shoal areas. During the winter, each shoreline transect received ten minutes of continuous electrofishing effort in a downstream direction. Because of concerns about the effectiveness of this method in capturing fish, we modified our shoreline electrofishing techniques for the remaining sampling seasons. During those seasons we fixed the length of the shoreline transects at 150 m and shocked in an upstream direction. Shocking in an upstream direction gave us more control of the boat and allowed us to work the area more thoroughly. Electrofishing output was standardized by electrofishing at a frequency of 60 pulses per second (pps) and varying the voltage to achieve 3.5 – 4.0 amps of output.

At some sites during some seasons we sampled the catfish community with a catfish electrofishing transect. This sampling was conducted to augment fish community information collected with standard electrofishing techniques and to describe the composition of ictalurids in the Broad River. We also wanted to determine if flathead catfish were present in the system. Flathead catfish, a large ictalurid, has the potential to disrupt the aquatic communities of piedmont and coastal streams. Catfish electrofishing transects were conducted by slowly floating down the river mid-channel and operating the electrofisher at a low pulse frequency (7.5 pps).

Each fish collected during sampling was identified to species and, when practical, measured to the nearest mm total length (TL) and weighed to the nearest gram. Occasionally some species were too numerous to measure and weigh individually. In these instances, we enumerated the individuals by species, recorded lengths of 25 randomly selected individuals, and recorded a total batch weight. A reference collection of each species collected was maintained. Species identifications were verified by Fritz Rohde of the North Carolina Division of Marine Fisheries.

To assess age and growth of representative species, we collected otoliths during the spring from largemouth bass, smallmouth bass, redbreast sunfish, and redear sunfish. During the fall we collected the otoliths and opercle bones from silver redhorse and brassy jumprock. We also collected pectoral spines from snail bullheads during fall, 2001, at site 2. Aging structures were removed from individuals selected randomly from within predetermined length-groups. For largemouth bass, redear sunfish, brassy jumprock, silver redhorse, and snail bullheads, we attempted to collect aging structures from at least three individuals per 25-mm length group at each site. For redbreast sunfish, we used a 12-mm length interval. Whole otoliths were viewed in the lab with a microscope, using reflected light. When whole otoliths were difficult to read, they were broken in half near the nucleus, perpendicular to the sulcal groove, sanded smooth, and viewed in cross section microscopically, using a fiber optic light. One-mm sections of snail bullhead spines were cut through the articulating process, proximal to the basal recess. The sections were polished on both sides, mounted on glass slides and viewed under a microscope with transmitted light. To estimate age, two experienced readers read otoliths and spine sections independently. Results were compared. When readers did not agree on an age, they re-read the structure jointly. If agreement could not be reached, the structure was eliminated from analysis. Mean lengths-at-age were calculated for all species when enough data were available. Means for redbreast sunfish and largemouth bass were calculated by site. Means for redear sunfish and smallmouth bass were calculated for the entire river. Means for snail bullheads were calculated for Site 2.

Data obtained from boat electrofishing were used to calculate relative abundance (RA), relative biomass (RB) by family, species diversity (Simpson's diversity index, D), and species richness (total number of species, S) metrics for the fish community at each site during each season. Data collected from catfish electrofishing transects were not included in the calculation of community metrics. Relative abundance was calculated as

$$\mathrm{RA} = \frac{n_i}{N},$$

relative biomass was calculated as

$$\mathrm{RB} = \frac{w_i}{W},$$

and Simpson's diversity index was calculated as

$$D = \sum_{i=1}^{s} \left[\frac{n_i(n_i - 1)}{N(N-1)} \right],$$

where n_i = Number of individuals of species i in the sample
N = Total number of individuals in the sample
S = Number of species in the sample
w_i = Total weight of family i in the sample
W = Total weight of individuals in the sample.

The inverse of Simpson's diversity index (1/D) was used as a test statistic. Mean catch per unit effort (CPUE) was calculated as No./m for each boat electrofishing site during each season and year. Because catfish electrofishing transects were not conducted at every site during each season and year they were not included in calculating mean CPUE.

Water quality and habitat parameters collected

Water quality measurements were collected at each sample site. Water temperature, dissolved oxygen, and conductivity were measured using a YSI Model 85 handheld dissolved oxygen, conductivity, salinity, and temperature meter. pH was measured using a YSI Model 60 handheld pH/temperature meter. Turbidity was measured with a LaMotte 2020 turbidimeter.

Mean depth of each shoreline electrofishing transect was determined. Depth was measured with a wading rod at approximately 10 m intervals along the electrofishing transect with the boat positioned approximately 3 m from the bank.

Statistical Analysis

Differences in species richness were investigated using a two-way ANOVA by site and season. Differences in species diversity and CPUE among sites and seasons were evaluated with independent Kruskal-Wallis tests. Stepwise multiple linear regression was used to investigate the relationship between population and community descriptors such as mean CPUE (log 10) and species richness and habitat and water quality variables. Cluster analysis of relative abundance data was used to investigate longitudinal changes in the fish community and examine the possibility of fish community fragmentation associated with dams. The cluster analysis was performed with the simple average linkage method and the Bray-Curtis distance equation (McAleece et al. 1997). Differences in mean length-at-age, by site, for redbreast sunfish and largemouth bass were assessed using a Kruskal-Wallis test. When conducting non-parametric statistical analyses (e.g., Kruskal-Wallis) pairwise comparisons were not investigated. All statistical comparisons were calculated using SAS (SAS Institute 1989). Tests were considered statistically significant at $\alpha = 0.05$. Winter data were eliminated from all analyses because of the different electrofishing methods used in the winter.

Boat Results/Discussion

Fish sampling

One hundred and eighty-one transects covering approximately 27 km of river were sampled (Table 4). In all, 6,916 fish comprising 44 species were collected from shoreline and mid-channel electrofishing transects (Table 5). Common and scientific names of fishes used in this report are listed in Appendix 1. Overall, redbreast sunfish, bluegill sunfish, and silver redhorse were the most abundant species, comprising more than 50% of the total number of fish collected. Gizzard shad, whitefin shiner, sandbar shiner and brassy jumprock were also relatively common, each comprising more than 5% of all fish collected.

Relative abundance of fish species varied by site (Table 6). Silver redhorse was the only species collected at every site during each season and year. Bluegill and redbreast sunfish were collected at each site during every season and year, except during the winter at site 1. Rare species in the boat electrofishing transects included bluehead chub, fieryblack shiner, flier, green sunfish, golden shiner and rosyside dace; only one individual of each species was collected.

Some species had limited distribution in the river. White perch, white bass, pumpkinseed sunfish, yellow perch, yellowfin shiner, and longnose gar were only collected in the lower half of the river (site 4 and below), while V-lip redhorse and northern hogsucker were only collected in the upper half of the river (site 4 and above).

Twenty-three catfish electrofishing transects were conducted, during which 1,076 ictalurids comprising 5 species were collected (Table 7). Snail bullhead was the dominant species, representing more than 80% of the ictalurids collected at every site. The bullhead catfishes accounted for more than 98% of the ictalurids in the catfish samples. No flathead catfish were collected during our sampling efforts. Future efforts to restore anadromous fish may adversely affect the resident community if flathead catfish are introduced into the Broad River. The flathead catfish is a voracious predator, and has been shown to negatively impact native centrarchid, ictalurid and catostomid communities (Guire et al. 1984, Ashley and Buff 1986, Bart et al. 1994).

Catostomids dominated the boat electrofishing biomass, accounting for 51.2% of the total biomass in shoreline and mid-channel electrofishing samples (Table 8). Members of the centrarchid, cyprinid, and clupeid families were abundant, each comprising more than 11% of the biomass collected. The remaining families contributed little to the total biomass overall, but sometimes were locally important. For instance, ictalurids were an important component of the fish biomass at site 4, and gars were an important component at site 1. Catostomids were the dominant family by weight at every site, comprising 38% to 86% of the total biomass among sites.

Species richness and diversity varied by sample area and season; both tended to be higher at downstream locations (Table 9). Mean species richness among sites ranged from 11.0 to 20.0 and was significantly higher at sites 1-4 than site 11 (ANOVA, P = 0.003). No seasonal differences were detected (ANOVA, P = 0.23). No other significant differences were observed in species richness. Mean Simpson's inverse diversity index ranged from 3.37 to 9.06 among sites. Significant differences in diversity were observed among sites (Kruskal-Wallis, P = 0.05) and between seasons (Kruskal-Wallis, P = 0.05). Diversity was significantly greater during the spring (mean = 6.2) than fall (mean = 4.9).

Mean CPUE varied by season and site, ranging from 0.02 to 0.64 (Table 10). Mean CPUE was typically higher at the downstream sites during both spring and fall. The highest overall mean CPUE (0.61) occurred at site 1 and the lowest (0.20) occurred at site 6. There was a significant difference in CPUE among sites (Kruskal-Wallis, P = 0.04), but not between seasons.

Cluster analysis indicated the most similar sites were sites 8 and 9, and sites 3 and 4 (Figure 2). Two broad clusters were interpreted from the analysis, one containing sites 1, 6, 8, 9 and 5, the other containing sites 2, 3, 4, 7, and 11. There was no indication that dams fragment the current Broad River fish community. Based on cluster analysis, site 1 exhibited more similarity to upstream sites than to downstream sites. If dams fragmented the current Broad River fish community we would have expected the cluster analysis to group lower and upper river sites separately. The two large clusters generated by our analysis did suggest a difference in fish community composition between riverine sites and those impacted by hydroelectric operations. One cluster contained most of the more riverine sites (1, 5, 6, 8, 9) and the other contained sites that were considered tailwater areas (sites 4 and 7) or sites that were influenced from the ponding created by downstream dams (sites 2 and 11). The only site that did not fit this pattern was site 3, a riverine site clustered with those impacted by hydroelectric operations. Although our analysis did not indicate that dams fragment the current fish community, a different community composition might exist in the absence of dams.

During the two spring sampling periods we collected otoliths from 515 redbreast sunfish, 132 largemouth bass, 94 redear sunfish, and 49 smallmouth bass. During the fall we collected otoliths and opercle bones from 117 silver redhorse and 77 brassy jumprock. We also collected spines from 58 snail bullheads during the fall of 2001. Difficulties in determining a suitable method for aging moxostomid species precluded the inclusion of age data for silver redhorse and brassy jumprock in this report.

We aged 496 spring-collected redbreast sunfish, 35-76 per site. Estimated ages ranged from 1 to 8 years. At most sites at least 4 age classes were present. Age classes 2 and 3 predominated at all sites. Fish age-4 and older were more prevalent at upriver sites (sites 7-11). Differences in mean length of redbreast sunfish at ages 1, 2, and 3 were observed among sites (Kruskal-Wallis, $P<0.05$). Age-1 redbreast were longest at sites 6, 2 and 3; age-2 redbreast were longest at sites 6, 2 and 8; and age-3 redbreast were longest at sites 6, 2, and 9 (Table 11). Overall, sites 2 and 6 exhibited the best growth and sites 1, 4, and 7 exhibited the poorest growth over the three age classes. Redbreast sunfish that grew well in their first year generally exhibited good growth in their second and third years (Figure 3).

Redbreast sunfish in the Broad River are long-lived. The age-8 fish we collected equaled the maximum age reported by Carlander (1977) for redbreast sunfish. In surveys of six North Carolina coastal streams, redbreast sunfish did not exceed age-6 (Ashley and Rachels 1998). In the Edisto River, South Carolina, redbreast sunfish did not exceed age-3 (Thomason et al. 1993).

Growth of redbreast sunfish in the Broad River was considerably slower than that reported for other southeastern rivers. Mean total length at age-3 in the Broad River was 130 mm, compared to 175 mm in other southeastern rivers (Ashley and Rachels 1998, Thomason et al. 1993).

We aged 126 spring-collected largemouth bass, 5-29 per site. The oldest individual was 12 years old. At most sites at least 4 age classes were present, but these were often represented by only one or two individuals. Mean length-at-age data are reported in Table 9. Because of the small numbers of fish aged at many sites, and the wide distribution of age classes, between-site comparisons of length-at-age and growth were not statistically meaningful. Largemouth bass at site 2 exhibited the fastest growth rate; mean lengths at ages 1, 2, and 3 were greater there than at any other site. Largemouth bass at sites 4, 6, and 11 exhibited relatively slow growth through age-3 (Table 12).

Life span and growth of largemouth bass in the Broad River was typical for the species in the Southeast. The average life span of largemouth bass in Virginia is 8-10 years (Jenkins 1993); in Tennessee, it's 10-12 years (Etnier and Starnes 1993). Growth of age 1–4 largemouth bass in the Broad River was similar to that reported for the Edisto River, South Carolina (Thomason et al. 1993).

We aged 92 redear sunfish and 42 smallmouth bass collected during spring 2001 and 2002. Numbers of aged fish were insufficient to make meaningful comparisons of growth between sites. Pooled mean lengths at age are reported in Table 13. We aged 54 snail bullheads collected during fall 2001 at site 2. Ten age classes were present. Mean length-at-age data are reported in Table 13.

Smallmouth bass in the Broad River appear to have a moderate life expectancy compared to those in some other Southeastern rivers. The oldest smallmouth bass we aged was 8, but fish as old as 15 have been documented in Virginia rivers (VDGIF, unpublished data). Growth of smallmouth bass in the Broad River was comparable to that of four piedmont rivers in Virginia (VDGIF, unpublished data). Based on growth rates in the Broad River, smallmouth bass could reach quality size (30 cm) in their fourth year, preferred size (35 cm) in their fifth year, and memorable size (40 cm) in their sixth year (Gabelhouse 1984).

Redear sunfish in the Broad River are long-lived; fish up to age-8, the maximum reported age for redear sunfish (Carlander 1977), were observed. Mean length-at-age of redear sunfish in the Broad River is comparable to that reported in Carlander (1977). Based on growth rates we calculated, redear sunfish in the Broad River could reach quality size (18 cm) in their third year, preferred size (23 cm) in their fourth year, and memorable size (28 cm) in their seventh or eighth year (Gabelhouse 1984).

The biology of the snail bullhead has received little attention (Jenkins1994). Snail bullheads in the Broad River, at least at site 2, are long–lived, attaining a maximum age of 9. No other studies that we're aware of have attempted to estimate snail bullhead age. Snail bullheads attain a larger size in the Broad River than reported in other systems. The longest reported snail bullhead had a standard length (SL) of 320 mm (Corcoran 1981); however, we collected numerous specimens longer than 400 mm TL, including one that was 448 mm. Snail bullheads in the Broad River reached approximately 100 mm during their first year and grew an average of 46 mm per year from age-1 through age-6.

<u>Water quality and habitat parameters collected</u>

Water quality and habitat data are reported in Table 14. No longitudinal or seasonal trends in water quality data were observed. Due to equipment problems, pH was only recorded during fall and winter sampling periods. In general, the water quality parameters we measured were consistent with those expected for a piedmont river. Conductivity tended to be lower at site 5, perhaps due to a dilution effect caused by the confluence of the Pacolet River just upstream of our sample site. pH values were somewhat higher than expected at sites 7 and 2, but as isolated data points, they are hard to interpret. During the winter 2001 sampling period, pH recorded hourly at the USGS monitoring station in the Broad River near Carlisle ranged from 6.7 to 8.0. During the fall 2001 sampling period, hourly pH values ranged from 5.1 to 7.6. Readings outside those ranges could have resulted from point or non-point source inputs. The USGS station near Carlisle is located well below site 7 and about 17 km above site 2. Sandy River and Tyger River both enter the Broad River between the gauge and site 2. Mean transect depth among sites ranged from 1.4 to 2.2 (mean = 1.7) m during winter, from 1.3 to 2.3 (mean = 1.7) m during spring, and from 1.0 to 2.2 (mean = 1.6) during fall.

Habitat and community relationship

A significant (P = 0.0001) positive relationship was observed between mean CPUE and distance from a dam and depth. No other variables were significant. Distance from a dam explained 46% of the variation in CPUE and depth explained 11%. There was not a significant relationship (P = 0.13) between species richness and habitat or water quality variables. It's important to recognize that our sampling strategy was not specifically designed to investigate the relationship between distance from a dam and catch rates. One possible explanation for the positive relationship we found is that areas located further from dams generally have more stable habitat and may support more individuals. Another possible explanation is that the relationship we observed was an artifact of our sampling design. The frequency of dams is greater in the upper reaches of the river and less in the in the lower reaches. Therefore, distance from dams was generally greatest at the lower sites. The lower sites may simply have greater catch rates due to the increased productivity one would expect in the lower reaches of a river.

Table 4. Numbers of electrofishing transects, by type, conducted at each site by season and year. Bank transects sampled pool habitat while mid-channel transects sampled glide/run habitat. Catfish transects were conducted in mid-channel using a low pulse frequency.

	2001									2002			
	Winter			Spring			Fall			Spring			
Site	Cat	Bank	Mid	Cat	Bank	Mid	Cat	Bank	Mid	Cat	Bank	Mid	Total
1	1	3	1		3	1		3	1		3	1	17
2	1	3	1		3	1	1	3	1	1	3	1	19
3		3	1		3	1		3	1	1	4	1	18
4		4	1		2	1		3	1	1	3	1	17
5	1	3	1	1	3		1	3	1	1	3	1	19
6		3	1	1	2	1	1	3	1	1	3	1	18
7	1	4	1	1	3	1	1	3	1	1	3	1	21
8		3	1	1	3	1		3	1	1	3	1	18
9	1	3	1		3	1		3	1	1	3	1	18
11	1	3	1	1	3			3	1		3		16
Total	6	32	10	5	28	8	4	30	10	8	31	9	181

Table 5. Relative percent abundance of fish species in Broad River boat electrofishing samples collected during winter, spring, and fall in 2001 and 2002.

Common Name	Winter 2001	Spring 2001	Fall 2001	Spring 2002	Grand Total
Longnose gar	0.8	0.2	0.1	0.2	0.2
Gizzard shad	17.9	4.1	11.2	6.3	8.8
Threadfin shad				0.6	0.2
Rosyside dace	0.1				>0.0
Greenfin shiner		0.6		0.6	0.3
Whitefin shiner	5.8	6.4	4	8.6	6.2
Fieryblack shiner	0.1				>0.0
Common carp	1.7	1.5	0.7	0.8	1.1
Eastern silvery minnow	0.4	0.1	0.1	0.1	0.1
Bluehead chub	0.1				>0.0
Golden shiner				>0.0	>0.0
Spottail shiner	11.8	1.4	0.2	1.2	2.3
Yellowfin shiner		0.1			>0.0
Sandbar shiner	5.6	2.4	4.3	8.5	5.3
Quillback			0.5	1.8	0.7
Highfin carpsucker				0.4	0.1
White sucker	0.1	0.2			0.1
Northern hogsucker	0.6	0.6	0.4	0.4	0.5
Smallmouth buffalo	0.2	0.7	>0.0		0.2
Silver redhorse	18.9	12.7	8.9	12.3	12.2
Shorthead redhorse	1.2	0.7	0.8	0.8	0.9
V-lip redhorse	0.4	0.2			0.1
Striped jumprock	0.2	1.7	1.2	1.2	1.2
Brassy jumprock	6.6	5	5.3	4.5	5.2
Snail bullhead	3.1	3	0.8	0.8	1.7
White catfish		0.1		0.5	0.2
Flat bullhead	0.2	0.6	>0.0	0.2	0.2
Channel catfish	0.1	1.8	1.3	1.2	1.3
Margined madtom		0.1	>0.0		>0.0
White Perch		1.9	2.8	3	2.3
White bass		0.2	>0.0	1.1	0.4
Flier			>0.0		>0.0
Redbreast sunfish	5.7	28.4	26.9	22.1	23.1
Green sunfish			>0.0		>0.0
Pumpkinseed	0.1	0.1	0.1	0.1	0.1
Warmouth		0.2	0.3	0.1	0.2
Bluegill	10.7	14.8	18.4	14.6	15.3
Redear sunfish	1.7	3.3	5.4	3.4	3.8
Smallmouth bass	0.7	1.7	1.3	0.8	1.2
Largemouth bass	4	3.9	3.6	3.0	3.5
Black crappie	0.4	1.0	0.5	0.2	0.5
Tessellated darter			0.1	0.1	0.1
Yellow perch	0.1	0.3	0.4	0.5	0.4
Piedmont darter	0.2	0.1			0.1
Total No. Collected	889.0	1744.0	2158.0	2125.0	6916.0

Table 6. Relative percent abundance of species in Broad River boat electrofishing samples, by site, collected during winter 2001, spring 2001, fall 2001, and spring 2002.

	Site										
Common name	1	2	3	4	5	6	7	8	9	11	Overall
Longnose gar	0.8	0.7	0.2								0.2
Gizzard shad	0.1	23.1	10.6	11.2	0.9	1.9	14.7	3.7	3.4	14.5	8.8
Threadfin shad	0.4	0.7					0.2				0.2
Rosyside dace								0.1			0.0
Greenfin shiner	0.1		0.8	0.2	0.4	0.2	0.6		0.9	0.2	0.3
Whitefin shiner	6.4	2.7	7.4	13.2	5.6	6.1	3.7	4.2	8.8	6.3	6.2
Fieryblack shiner									0.1		>0.0
Common carp	0.1	0.7	0.7	0.5		0.4	1.2	2.3	1.8	5.1	1.1
Eastern silvery minnow	0.1		0.2		0.7	0.4					0.1
Bluehead chub									0.1		>0.0
Golden shiner			0.1								>0.0
Spottail shiner	0.5	6.5	3.2	4.6	1.3	2.1	0.2	0.1	1.6		2.3
Yellowfin shiner	0.2										>0.0
Sandbar shiner	8.3	1.2	0.8	3.0	27.7	11.8		0.4	3.4	1.5	5.3
Quillback		0.1	0.1	0.2	2.0	1.9	4.5	0.4	0.1		0.7
Highfin carpsucker						1.7	0.2				0.1
White sucker						0.6			0.1		0.1
Northern hogsucker				0.9	1.1	0.4	0.8	1.0	1.0	0.2	0.5
Smallmouth buffalo		0.4	0.2	0.2		0.6	0.2	0.6			0.2
Silver redhorse	4.8	14.0	5.3	6.2	16.6	11.0	10.6	18.2	13.3	35.6	12.2
Shorthead redhorse	0.1	1.5	2.6	1.9	0.4	0.8					0.9
V-lip redhorse				0.2	0.2	0.2	0.2	0.1	0.4		0.1
Striped jumprock	0.2		0.3	3.2	0.2	1.9	1.0	1.7	3.6	1.9	1.2
Brassy jumprock	3.6	0.3	5.4	5.6	9.9	10.1	3.1	8.7	7.8	0.2	5.2
Snail bullhead	0.9	0.5	2.0	1.9	0.2	1.7	1.4	3.9	3.9	0.5	1.7
White catfish		1.1									0.2
Flat bullhead	0.6		0.3	0.2		0.4	0.2	0.3	0.3		0.2
Channel catfish	0.2	2.9	2.8	3.3	0.2	0.2	0.6		0.3	0.2	1.3
Margined madtom	0.2					0.2					>0.0
White perch	0.3	13.3	1.5								2.3
White bass	0.1	2.4	0.1	0.2							0.4
Flier	0.1										>0.0
Redbreast sunfish	41.8	8.4	11.3	13.5	22.4	27.4	27.1	31.4	31.6	18.4	23.1
Green sunfish								0.1			>0.0
Pumpkinseed	0.1	0.3	0.2								0.1
Warmouth	0.8			0.2	0.2			0.1	0.1		0.2
Bluegill	16.2	9.8	35.1	17.9	3.6	9.7	19.3	13.0	8.5	9.0	15.3
Redear sunfish	7.5	4.2	5.4	3.2	1.1	2.5	4.1	1.9	1.3	1.9	3.8
Smallmouth bass		0.5		0.9	1.3	2.3	0.6	4.0	3.0	0.5	1.2
Largemouth bass	4.2	3.0	2.6	6.0	3.6	2.3	4.3	2.9	3.6	3.6	3.5
Black crappie	0.4	0.6	0.1	1.4	0.2	0.8	1.2	0.4	0.4	0.2	0.5
Tessellated darter	0.1		0.1		0.4			0.1			0.1
Yellow perch	0.8	1.2	0.4	0.2							0.4
Piedmont darter	0.1		0.1	0.2				0.1			0.1
Total No. fish	1022	1054	974	569	553	474	491	698	668	413	6916

Table 7. Relative abundance of ictalurids collected in catfish electrofishing samples, by site, during winter 2001, spring 2001, fall 2001, and spring 2002.

	Site									
Common Name	2	3	4	5	6	7	8	9	11	Overall
Snail bullhead	93.9	95.6	100.0	92.0	90.2	95.2	99.2	98.7	84.0	95.0
White catfish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.3
Flat bullhead	1.5	4.4	0.0	3.7	3.3	4.8	0.8	0.0	12.0	3.1
Channel catfish	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Margined madtom	1.5	0.0	0.0	4.3	6.6	0.0	0.0	1.3	0.0	1.3
Total No. fish	132	136	70	162	61	125	240	75	75	1076

Table 8. Percent contribution of biomass, by family, at each Broad River boat electrofishing site.

	Site										
Family	1	2	3	4	5	6	7	8	9	11	Total
Catostomidae	49.5	48.9	37.5	38.5	86.1	65.2	53.6	53.3	55.4	45.0	51.2
Centrarchidae	28.2	8.8	10.1	21.7	10.2	15.8	24.2	18.1	15.1	8.8	14.9
Cyprinidae	7.3	12.4	16.1	11.1	0.6	9.4	11.8	16.1	17.2	36.7	14.6
Clupeidae	0.1	14.5	25.0	13.8	1.0	8.5	4.8	10.9	9.6	9.3	11.5
Ictaluridae	3.5	8.9	9.1	14.0	2.1	1.0	5.4	1.6	2.7	0.2	5.3
Lepisosteidae	11.3	1.2	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
Moronidae	0.1	5.0	0.6	0.8	0.0	0.0	0.0	0.0	0.0	0.0	1.2
Percidae	0.1	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Grand Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 9. Species richness and Simpson's inverse diversity index (1/D) for samples collected from the Broad River during 2001 and 2002. Means with similar letters were not significantly different (Tukeys, P> 0.05).

	Species Richness				Simpson's Inverse Diversity Index			
Site	Spring 01	Fall 01	Spring 02	Mean	Spring 01	Fall 01	Spring 02	Mean
1	19	18	18	18.3^{z}	3.5	2.9	6.1	4.17
2	20	13	21	18.0^{z}	10.9	6.0	10.3	9.06
3	19	21	20	20.0^{z}	5.8	4.9	5.8	5.50
4	20	17	18	18.3^{z}	9.6	9.2	6.6	8.46
5	14	17	11	14.0^{zy}	4.5	4.8	5.0	4.77
6	16	14	17	15.7^{zy}	6.2	3.3	9.4	6.30
7	18	15	15	16.0^{zy}	5.0	5.0	5.1	5.03
8	14	13	17	14.7^{zy}	7.2	5.0	4.9	5.70
9	17	14	17	16.0^{zy}	6.9	3.7	6.0	5.53
11	11	13	9	11.0^{y}	3.2	4.1	2.8	3.37
Total	34	33	33		6.3	4.9	6.2	

Table 10. Mean CPUE (No./m) for samples collected from the Broad River with boat electrofishing gear during 2001 and 2002. Winter data were not included in the overall mean or used in the analysis.

Area	Winter 2001	Spring 2001	Fall 2001	Spring 2002	Mean
1	0.05	0.55	0.64	0.63	0.61
2	0.31	0.32	0.44	0.38	0.38
3	0.09	0.45	0.47	0.34	0.41
4	0.09	0.28	0.27	0.26	0.27
5	0.03	0.33	0.33	0.26	0.30
6	0.15	0.18	0.21	0.21	0.20
7	0.03	0.16	0.29	0.31	0.25
8	0.14	0.23	0.25	0.38	0.29
9	0.16	0.30	0.25	0.27	0.27
11	0.02	0.27	0.15	0.32	0.24
Mean	0.11	0.31	0.33	0.33	0.32

Table 11. Mean length-at-age (number of observations in parentheses) of redbreast sunfish, collected by boat electrofishing in the Broad River, by site.

	Age							
Site	1	2	3	4	5	6	7	8
1	63 (4)	85 (29)	120 (31)	158 (9)	140 (3)			
2	83 (5)	102 (20)	141 (10)	136 (1)				
3	84 (5)	98 (19)	136 (18)	147 (2)	161 (2)			
4	64 (3)	88 (10)	119 (17)	137 (3)	143 (2)			
5	60 (7)	96 (16)	130 (21)	135 (1)	173 (3)	190 (1)		
6	85 (4)	103 (21)	140 (16)					
7	59 (4)	87 (10)	121 (19)	146 (5)	164 (3)	141 (1)		
8	66 (7)	100 (18)	132 (15)	154 (10)	172 (2)	183 (1)		
9	56 (3)	95 (26)	137 (27)	157 (11)	137 (2)			
11	59 (1)	93 (14)	128 (17)	146 (8)	166 (5)	148 (2)	146 (1)	185 (1)
Overall mean	69 (43)	95 (183)	130(191)	151 (50)	158 (22)	162 (5)	146 (1)	185 (1)

Table 12. Mean length-at-age (number of observations in parentheses) of largemouth bass, collected by boat electrofishing in the Broad River, by site.

	Age											
Site	1	2	3	4	5	6	7	8	9	10	11	12
1	101 (16)	265 (6)	351 (5)	353 (1)		436 (1)						
2	161 (3)	288 (3)	365 (3)									
3	110 (5)	252 (2)	336 (4)	351 (1)								
4	158 (2)	247 (4)	276 (6)	350 (1)	410 (1)							
5	115 (7)	250 (4)	314 (2)									
6		246 (2)	270 (1)			449 (1)	417 (1)					
7		235 (1)	285 (1)	295 (2)	446 (1)		481 (1)					
8	126 (1)	271 (1)	300 (2)	305 (2)	309 (1)			426 (1)	482 (1)	487 (2)	458 (2)	491 (1)
9	107 (4)	248 (4)	293 (3)	325 (3)	393 (1)							
11	128 (3)		273 (2)	303 (3)				470 (1)				
Overall mean	115 (41)	257 (27)	312 (29)	318 (13)	390 (4)	443 (2)	449 (2)	448 (2)	482 (1)	487 (2)	458 (2)	491 (1)

Table 13. Mean length-at-age (number of observations in parentheses), of redear sunfish (RES), smallmouth bass (SMB), and snail bullhead (SBH), collected from the Broad River by boat electrofishing. RES and SMB were collected during spring 2001 and 2002; SBH were collected during fall 2001.

Age	RES	SMB	SBH
0	--	--	80 (3)
1	74 (4)	129 (19)	111 (2)
2	135 (43)	229 (11)	134 (4)
3	188 (15)	272 (11)	187 (11)
4	234 (13)	298 (3)	255 (7)
5	244 (10)	--	312 (9)
6	264 (5)	432 (2)	340 (6)
7	255 (1)	--	404 (7)
8	301 (1)	465 (1)	405 (3)
9	--	--	397 (2)

Table14. Selected water quality and habitat data collected from the Broad River during boat electrofishing, by sample date in 2001 and 2002.

Date	Season	Site	Temp (C°)	DO (mg/L)	pH	Conductivity (Φhmos)	Turbidity (ntu's)	Mean depth (m)
01/12/01	Winter	1	6.1	11.4	7.7	100	10.4	--
02/07/01	Winter	2	8.8	11.9	8.2	121	8.0	1.8
01/10/01	Winter	3	4.6	13.5	7.8	120	6.6	1.9
01/11/01	Winter	4	3.8	12.3	7.5	97	9.3	1.9
01/23/01	Winter	5	5.5	11.4	6.5	62	15.0	1.4
01/30/01	Winter	6	8.6	12.6	7.9	114	8.7	1.4
01/16/01	Winter	7	8.0	12.2	6.4	130	13.5	1.5
02/06/01	Winter	8	7.7	11.3	7.8	119	24.0	1.4
01/26/01	Winter	9	5.2	12.0	7.4	71	9.9	--
01/25/01	Winter	11	4.6	11.9	7.7	69	9.3	2.2
04/10/01	Spring	1	19.9	10.5	--	98	--	2.0
04/19/01	Spring	2	15.7	8.7	--	90	10.2	1.7
04/18/01	Spring	3	18.8	9.3	--	107	7.7	1.9
04/16/01	Spring	4	20.1	7.4	--	92	11.3	1.9
04/23/01	Spring	5	18.9	7.6	--	80	7.5	1.4
04/24/01	Spring	6	21.4	7.4	--	122	12.0	1.4
04/17/01	Spring	7	16.6	7.9	--	106	11.5	1.6
05/01/01	Spring	8	19.5	7.5	--	136	10.0	1.3
05/03/01	Spring	9	22.8	7.2	--	101	7.2	1.4
04/30/01	Spring	11	18.6	7.4	--	90	3.9	2.3
10/31/01	Fall	1	14.5	8.5	7.8	110	4.9	1.7
11/05/01	Fall	2	15.6	9.1	8.3	133	15.6	1.3
11/14/01	Fall	3	11.3	8.5	7.8	137	--	1.8
10/17/01	Fall	4	17.4	6.8	7.6	136	18.9	1.9
10/18/01	Fall	5	15.6	7.7	7.6	45	14.0	1.0
10/29/01	Fall	6	14.2	11.1	--	129	6.5	1.2
10/03/01	Fall	7	20.7	9.6	8.4	136	14	1.6
10/30/01	Fall	8	12.2	9.2	7.9	118	5.3	1.4
10/16/01	Fall	9	19.6	7.9	7.4	100	10.3	--
10/18/01	Fall	11	11.4	8.8	7.7	88	5.5	2.2
04/08/02	Spring	1	16.5	8.2	--	87	8.6	2.0
04/09/02	Spring	2	16.8	9.0	--	91	11.7	1.6
04/10/02	Spring	3	16.7	8.8	--	93	12.5	1.8
04/11/02	Spring	4	18.5	8.2	--	96	9.8	1.9
04/15/02	Spring	5	18.9	7.6	--	77	10.9	1.3
04/17/02	Spring	6	24.7	8.8	--	92	9.6	1.4
04/16/02	Spring	7	20.9	8.5	--	98	9.9	1.6
04/30/02	Spring	8	20.2	7.8	--	127	9.8	1.3
04/18/02	Spring	9	23.9	8.4	--	76	10.7	1.3
04/22/02	Spring	11	24.2	6.0	--	92	6.2	2.2

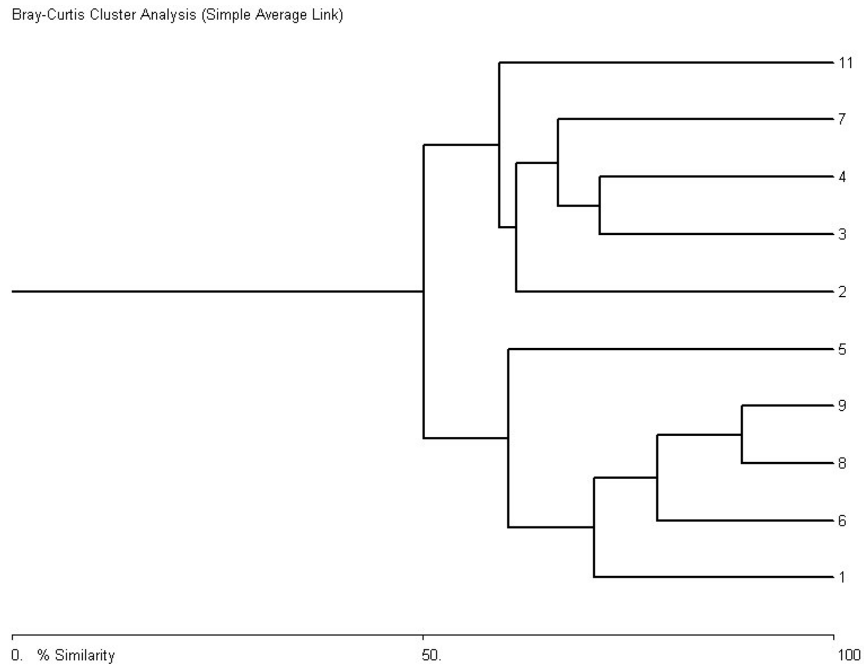


Figure 2. Bray-Curtis simple average cluster analysis of fish community relative abundance data for fish collected from the Broad River during fall 2001, spring 2001 and spring 2002.

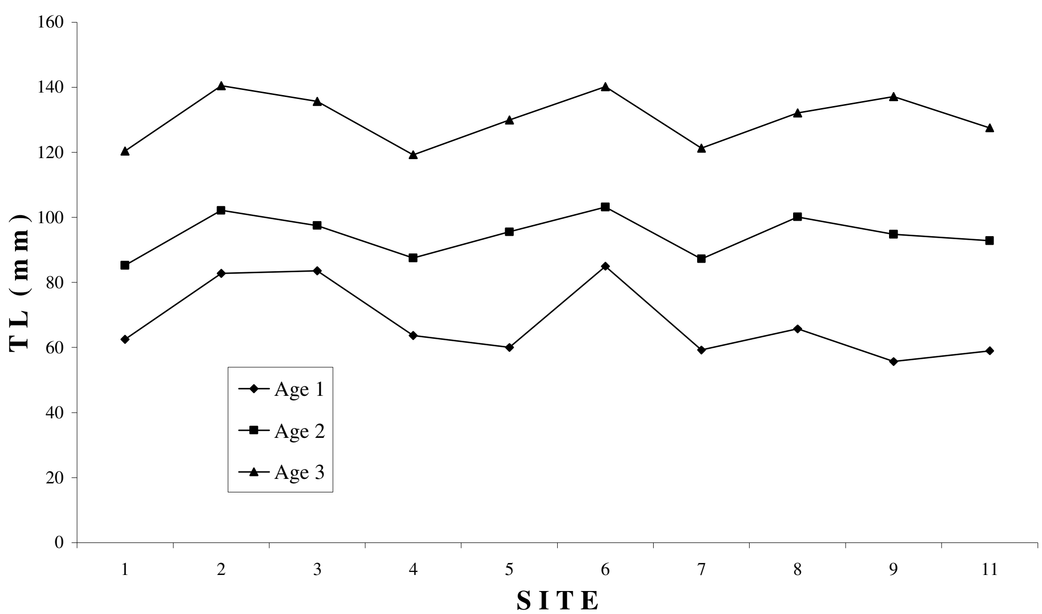


Figure 3. Mean length-at-age of redbreast sunfish collected during spring, 2001 and 2002, Broad River, SC.

Backpack Methods

Fish Collection

We conducted backpack electrofishing during fall 2000, spring and fall 2001, and spring 2002. A modification of the Tennessee index of biotic integrity (TIBI) protocol (TDEC 1995) was used for sampling complex habitat. The sampling protocol was designed to deplete species from dominant habitats (riffles, runs and shorelines). Riffles and runs were sampled until three consecutive units of effort produced no additional species for that habitat. Each unit of effort consisted of sampling a 30 m^2 plot (e.g., 6 x 5 m). A 6-m seine was positioned perpendicular to the current; one person outfitted with a backpack electrofishing unit began shocking 5 m above the seine and shocked downstream into the seine. Stunned fish were collected with dipnets when they were seen, but most fish were captured in the seine. At each sample area, shoreline habitat was sampled by backpack electrofishing a single pass along a 100 m wadeable transect.

Collected fish were identified to species and, when practical, measured (TL mm) and weighed (g). Occasionally some species were too numerous to measure and weigh individually. In these instances, we recorded lengths of 25 randomly selected individuals, then enumerated the fish and recorded a total batch weight by species. Each species collected was assigned to one of three pollution tolerance levels (tolerant, moderately tolerant, and intolerant) and one of five trophic levels (piscivore, insectivore, omnivore, specialized insectivore, and herbivore) (Barbour et al. 1999, NCDENR 2001). Representatives of each species collected were preserved in formalin and maintained in a reference collection. Species identifications were verified by Fritz Rohde of the North Carolina Division of Marine Fisheries.

Data obtained from backpack electrofishing were used to calculate relative abundance (RA), species diversity (Simpson's diversity index, D) and species richness (total # of species) for the fish community at each sample area during each season. Only data from plot samples were included in calculating species diversity and richness. Relative abundance was calculated as

$$\text{RA} = \left(\frac{n_i}{N}\right) \times 100,$$

and Simpson's diversity index was calculated as

$$\text{D} = \sum_{i=1}^{s} \left[\frac{n_i(n_i - 1)}{N(N-1)}\right],$$

where n_i = Number of individuals of species i in the composite sample for each site
N = Total number of individuals in the composite sample
s = Number of species in the sample.

The inverse of Simpson's diversity index (1/D) was used as a test statistic. Mean catch per unit effort (CPUE) was calculated for backpack electrofishing areas (N/plot) by sample area and season. Because only one shoreline section was sampled at each site, only fish collected from riffle and run samples were used in calculating mean CPUE.

Water quality and habitat parameters collected

Standard water quality parameters were measured and recorded at each sample site, as described previously.

Substrate, depth, and flow information were collected at each sample plot. Depth was measured at three points along each of three transects parallel to the seine; transects were at the upstream limit, middle and downstream limit of each sample plot. During fall 2000, substrate and flow were each characterized with a single observation per plot. Primary and secondary substrate components were described using a modified Wentworth scale (Table 15). Flow was categorized as low, moderate or swift. During spring 2001, fall 2001, and spring 2002, substrate and velocity information were collected at each point along each transect along with depth. Substrate was scored using the modified Wentworth scale and velocity was measured with a Marsh-McBirney model 201 flow meter. Percent contribution of each substrate type, mean depth sampled, and mean water velocity were calculated for each sample area. Qualitative data from fall 2000 were not used in these calculations.

Statistical Analysis

Differences in mean species richness and diversity were investigated by site and season with independent Kruskal-Wallis tests. Differences in mean CPUE were investigated using a two-way analysis of variance (ANOVA) by site and season. A logarithmic transformation (base 10) was used to normalize CPUE data. Chi-square analysis was used to evaluate differences in trophic composition and pollution tolerance structure among sites. Stepwise multiple linear regression was used to investigate relationships between normalized CPUE data and habitat and water quality variables. Stepwise multiple linear regression was also used to investigate relationships between species richness and habitat and water quality variables. All statistical comparisons were calculated using SAS (SAS Institute 1989). Tests were considered statistically significant at $\alpha = 0.05$.

Backpack Results/Discussion

Fish Sampling

During the study we made 676 standardized riffle and run backpack electrofishing collections. The mean number of run samples collected per site was 11.2 (range, 5 - 22) (Table

16). The mean number of riffle samples collected per site was 9.3 (range, 4 -15). In addition, one 100 m shoreline section was sampled at each site during each season and year.

A total of 9,836 fish, comprising 38 species, was collected during backpack electrofishing in the 3 habitat types (Table 17). Overall, whitefin shiner and redbreast sunfish were the most abundant species, together comprising more than 44% of the total number of fish collected. Spottail shiner, sandbar shiner, snail bullhead, and thicklip chub were relatively common; each comprised more than 5% of the total number of fish collected.

Relative abundance of fish species varied by site (Table 18). We collected whitefin shiner, snail bullhead, redbreast sunfish, and piedmont darter at every site during each season and year. Redbreast sunfish was the dominant species at sites 1 and 2, whitefin shiner was the dominant species at sites 3-9, and fieryblack shiner was the dominant species at site 10. Most species were relatively evenly distributed among the sites and throughout the river; however, the distributions of some fish were limited. Fantail darter was found only at site 6. Yellowfin shiner and seagreen darter were more common at site 1 than anywhere else. Yellowfin shiner was only collected at sites 1 and 6. Fieryblack shiner was only found above site 3 and was most prevalent at the uppermost sites; at site 10, fieryblack shiner represented 31% of the fish community.

Species richness and diversity computed from plot collection data varied by sample area and season (Table 19). Mean species richness among sites ranged from 10.8 to 16.3, but there were no significant statistical differences among sites (Kruskal-Wallis; $P = 0.06$) or between seasons (Kruskal-Wallis; $P = 0.22$). Mean Simpson's inverse diversity ranged from 3.1 (site 8) to 6.7 (site 1). There was a significant difference in mean species diversity among sites (Kruskal-Wallis; $P = 0.05$), but not between seasons (Kruskal-Wallis; $P = 0.23$). The low diversity of substrate material and the dominance of bedrock at site 8 may have contributed to the poor fish community diversity there.

Mean CPUE varied by site and season (Table 20). Mean catch per plot, among sites, ranged from 4.8 (site 2) to 16.3 (site 9), and there were significant differences among sites (ANOVA; P = 0.01), but not between seasons (ANOVA, P = 0.35). Mean catch per plot was significantly less at site 2 than at sites 4, 7 and 9. No other significant differences in catch per plot were observed. The low catch rates at site 2 may be related to unstable habitat. Site 2 was located at the first shoal area above Parr Reservoir, and may be inundated when the reservoir is at full pool. The frequent inundation of shoal habitat would not be conducive to the nongame communities that were targeted with backpack electrofishing gear.

The most abundant trophic guild in the Broad River was the Insectivores (67.7%), followed by the Specialized Insectivores (16.5%), and the Omnivores (15%). Herbivores and Piscivores were rare. Trophic composition differed among sites (χ^2, P = 0.0001), perhaps attributable to the dissimilar composition displayed at sites 1 and 10 (Figure 4). Insectivores comprised 50% or more of the trophic composition at all sites (Figure 4). In general, the trophic composition of the Broad River is indicative of a well-balanced fish community. Trophic generalists such as Omnivores were minimal at most sites. The paucity of Piscivores is not alarming, given the sampling gear. Backpack electrofishing into a seine in a large river is not very effective at sampling large predators.

The moderate pollution tolerance group was most abundant in the Broad River, comprising almost 80% of the fish collected. Intolerant individuals comprised 17.6% of the fish collected, while tolerant individuals comprised only 2.6%. The distribution of pollution tolerance levels was significantly different among sites (χ^2, P = 0.0001). Moderately tolerant fish dominated the fish community structure at all sites except 1 and 10, where large numbers of pollution-intolerant species were collected (Figure 5). The proportion of moderately tolerant individuals was greatest at site 7 and lowest at site 10. Conversely, the proportion of intolerant individuals was greatest at site 10 and lowest at site 7. Site 10 also had the highest proportion of tolerant individuals. At site 10 the pollution tolerance structure was greatly affected by the dominance of fieryblack shiner, an intolerant species that accounted for 31% of the total relative abundance. At site 1 seagreen and piedmont darters accounted for the increased proportion of intolerant species. Seagreen and piedmont darters accounted for 19% of the fish collected.

<u>Water quality and habitat parameters collected</u>

In general, the water quality parameters we measured were consistent with those expected for a piedmont river. Dissolved oxygen ranged from 6.1 to 9.9 ppm, pH values ranged from 6.3 to 8.5, conductivity ranged from 85 to 262 Φmhos and turbidity ranged from 3.2 to 24.4 NTU. Water quality data are reported in Table 21. No seasonal or longitudinal differences in water quality parameters were noted.

We recorded 4,306 depth and substrate measurements and 3,200 velocity measurements. The percent contribution of substrate types varied by site (Table 22). Overall, gravel, pebble and bedrock were the most common substrates. Gravel was the predominant substrate at sites 2, 3, and 7. Sand was a more important component of the substrate in the lower river than the upper. It dominated the substrate composition at sites 1 and 4. The primary substrate at sites 6 and 9 was pebble, and bedrock dominated the substrate composition at site 8. The average sample site depth ranged from 29 cm to 42 cm and the average water velocity ranged from 0.32 to 0.48 m/s.

Habitat and community relationship

The only habitat and water quality variables that significantly influenced CPUE were mean depth and turbidity ($P = 0.01$), which together explained 40% of the variation. There was a negative relationship between CPUE and depth, which explained 32% of the variation and a positive relationship between CPUE and turbidity, which explained 8% of the variation. The only habitat or water quality variables that significantly influenced the number of species captured were turbidity and depth ($P = 0.004$), which together explained 35% of the variation. A positive relationship between turbidity and species richness was observed that explained 28% of the variation and a negative relationship between species richness and depth, which explained 7% of the variation. The relationships we identified between the fish community and physical habitat parameters may be artifacts of sampling. Backpack electrofishing into a seine was probably more effective in shallow, turbid water than in deep, clear water. Clear water likely made fish more wary and allowed them to spot us more easily, and greater depths provided them the opportunity to avoid capture.

Table 15. Size range of substrate components used for visual assessment, based on a modified Wentworth scale.

Particle type	Diameter
Bedrock	
Boulder	>256 mm
Cobble	65 – 256 mm
Pebble	17 – 64 mm
Gravel	2 – 16 mm
Sand	0.06 – 2 mm

Table 16. Number of plots sampled in the Broad River, by site, using backpack electrofishing, fall 2000 – spring 2002

	No. of riffle samples				No. of run samples				Total
Sample Area	Fall 00	Spring 01	Fall 01	Spring 02	Fall 00	Spring 01	Fall 01	Spring 02	Samples
1	11	11	5	10	10	13	6	7	73
2	11	8	8	10	12	13	12	7	81
3	4	7	8	8	11	11	9	15	73
4	12	10	6	11	5	10	10	11	75
6	11	9	15	9	14	13	12	8	91
7	12	11	9	10	14	12	12	11	91
8	10	6	8	13	18	8	22	17	102
9	11	7	9	9	7	11	8	10	72
10	6				12				18
Total	88	69	68	80	103	91	91	86	676

Table 17. Relative abundance, in percent, of fish collected in Broad River backpack electrofishing samples, by sample period.

Common Name	Fall 2000	Spring 2001	Fall 2001	Spring 2002	Overall
Gizzard shad	0.1	0.1	2.6	0.5	0.8
Threadfin shad				>0.0	>0.0
Greenfin shiner	3.4	5.7	2.4	6.1	4.3
Whitefin shiner	26.7	28.3	19.5	43.5	29.9
Fieryblack shiner	3.9	1.2	1.9	3.6	2.8
Eastern silvery minnow	0.2		0.4	0.1	0.2
Thicklip chub	8.2	7.3	3.4	3.5	5.5
Santee chub				>0.0	>0.0
Bluehead chub	2.4	2.8	4.0	1.3	2.6
Spottail shiner	6	7.6	11.1	10.9	9.0
Yellowfin shiner	0.2	0.3	0.2		0.1
Sandbar shiner	9.7	3	11.4	2.8	7.0
Northern hogsucker	0.6	0.6	1.2	1.3	1.0
Smallmouth buffalo			>0.0		>0.0
Silver redhorse				>0.0	>0.0
Shorthead redhorse	0.2			>0.0	0.1
V-lip redhorse		0.1			>0.0
Striped jumprock	1.2	1.4	1.4	1.3	1.3
Brassy jumprock	0.5	0.1	0.3	0.1	0.3
Snail bullhead	6.5	10.2	4.6	3.8	5.9
White catfish	0.1	0.1	>0.0		>0.0
Flat bullhead	0.7	0.8	0.5	0.4	0.6
Channel catfish	0.5	0.2	0.2		0.2
Margined madtom	4.4	6.1	4.8	1.8	4.1
Eastern mosquitofish	0.4	0.3	0.6	0.1	0.4
White perch				>0.0	>0.0
Redbreast sunfish	15.6	15.6	17.0	10.4	14.5
Green sunfish	0.1				>0.0
Pumpkinseed		0.1			>0.0
Warmouth		0.1	>0.0		>0.0
Bluegill	1.1	1.8	3.4	1.4	1.9
Redear sunfish	0.1	0.4	0.1	0.1	0.1
Smallmouth bass	0.5	1.1	0.7	0.5	0.7
Largemouth bass	0.1	0.1	0.3	>0.0	0.2
Fantail darter	0.2	0.1	>0.0	>0.0	0.1
Tessellated darter	0.9	0.7	1.2	1.1	1.0
Seagreen darter	1.0	0.8	1.9	0.7	1.1
Piedmont darter	4.4	3.0	4.5	4.5	4.2
Total No. of fish	2827	1778	2466	2765	9836

Table 18. Relative abundance, in percent, of fish collected in Broad River backpack electrofishing samples, by site, during fall 2000, spring 2001, fall 2001, and spring 2002.

	Site									
Common Name	1	2	3	4	6	7	8	9	10	Total
Gizzard shad		7.9	1.4	0.1		0.6				0.8
Threadfin shad						0.1				>0.0
Greenfin shiner	0.4	4.7	6.6	2.4	5.7	6.6	2.0	4.8	6.7	4.3
Whitefin shiner	9.0	13.3	21.2	39.6	17.5	43.6	26.9	46.2	17.8	29.9
Fieryblack shiner				0.1	1.7	0.2	8.9	6.5	31.1	2.8
Eastern silvery minnow		0.6	0.2	0.3	0.7		0.1			0.2
Thicklip chub	4.3	0.7	8.5	7.9	10.9	3.6	1.8	5.7	2.2	5.5
Santee chub				0.1						>0.0
Bluehead chub	1.7	0.0	0.1	1.2	7.9	1.4	4.0	3.4	1.1	2.6
Spottail shiner	0.9	11.3	3.2	6.0	10.6	19.8	6.9	8.5	1.1	9.0
Yellowfin shiner	1.3				0.1					0.1
Sandbar shiner	3.2	2.4	10.3	5.7	13.4	3.9	15.0	4.0	0.6	7.0
Northern hogsucker		0.6	0.3	0.4	1.6	2.4	0.7	0.7	1.7	1.0
Smallmouth buffalo					0.1					>0.0
Silver redhorse						0.1				>0.0
Shorthead redhorse		0.8			0.1					0.1
V-lip redhorse						0.1				>0.0
Striped jumprock		0.1	1.3	2.2	2.3	0.9	1.0	1.7	2.8	1.3
Brassy jumprock		0.0	0.7			0.3	0.3		4.4	0.3
Snail bullhead	7.7	6.2	14.0	6.6	4.6	2.2	7.2	2.6	9.4	5.9
White catfish		0.1	0.0		0.1					>0.0
Flat bullhead	1.0	0.8	1.0	0.7	0.9	0.2	0.4	0.2		0.6
Channel catfish	0.1	0.7	0.2	0.8			0.1			0.2
Margined madtom	13.6	6.2	4.8	2.1	8.2	0.5	1.8	1.2		4.1
Eastern mosquitofish			0.1	0.2	0.1	1.6	0.3			0.4
White perch		0.1								>0.0
Redbreast sunfish	35.9	26.3	13.7	11.6	6.9	6.3	17.5	10.7	17.2	14.5
Green sunfish							0.2			>0.0
Pumpkinseed		0.1								>0.0
Warmouth				0.1						>0.0
Bluegill	0.3	5.4	5.1	2.2	2.5	1.8	0.4	0.1		1.9
Redear sunfish		1.0		0.2		0.1		0.1	0.0	0.1
Smallmouth bass		0.4		0.1	0.8	0.9	1.2	1.1	2.2	0.7
Largemouth bass	0.5		0.4	0.4						0.2
Fantail darter					0.8					0.1
Tessellated darter	1.0	2.4	1.6	1.2	0.5	0.8	0.5	0.7		1.0
Seagreen darter	8.3		0.7	0.7	0.0		0.2	0.1	0.6	1.1
Piedmont darter	10.6	7.3	4.1	6.9	2.0	2.1	2.7	1.6	1.1	4.2
Total No. of fish	996	723	979	1445	1179	1723	1125	1486	180	9836

Table 19. Species richness and Simpson's inverse diversity index for plot samples collected with backpack electrofishing gear from the Broad River, SC, during 2000 – 2002.

	Species Richness					Simpson's (1/D)				
Site	Fall 00	Spring 01	Fall 01	Spring 02	Mean	Fall 00	Spring 01	Fall 01	Spring 02	Mean
1	12	13	9	9	10.8	7.8	7.4	5.3	6.2	6.7
2	14	11	11	9	11.3	6.1	6.8	4.8	5.4	5.8
3	9	11	14	14	12.0	5.8	4.6	4.5	7.3	5.6
4	14	12	12	13	12.8	5.5	5.8	2.9	1.9	4.0
6	19	14	19	13	16.3	9.1	5.6	6.6	2.7	6.0
7	13	14	14	18	14.8	2.9	2.5	4.2	2.9	3.1
8	15	6	14	15	12.5	4.2	2.7	5.7	3.5	4.0
9	16	15	16	13	15.0	5.0	3.5	4.9	1.9	3.8
10	14					4.8				

Table 20. Catch per plot for samples collected with backpack electrofishing gear from the Broad River, SC, during 2000 – 2002. Means with the same letter were not significantly different (Tukey, $P > 0.05$).

Site	Fall 00	Spring 01	Fall 01	Spring 02	Mean
1	8.1	6.8	14.8	7.1	9.2^{z}
2	4.4	3.1	6.9	4.9	4.8^{y}
3	6.4	8.7	11.7	8.2	8.7^{zy}
4	25.6	11.2	8.8	14.1	14.9^{z}
6	11.0	4.9	16.0	11.9	10.9^{zy}
7	10.1	12.3	11.2	30.7	16.1^{z}
8	8.6	4.0	7.6	8.7	7.2^{zy}
9	15.6	13.2	13.5	23.1	16.3^{z}
10	8.0				

Table 21. Water quality data collected from Broad River, SC, sample sites during backpack electrofishing.

Date	Season	Site	Temp (C°)	DO (mg/L)	pH	Conductivity (Φmhos)	Turbidity (NTU)
10/24/2000	Fall	1	19.5	8.1	7.1	136.3	5.2
10/25/2000	Fall	2	17.9	8.6	7.1	188.4	6.8
10/02/2000	Fall	3	19.3	8.0	6.7	147.0	--
10/05/2000	Fall	4	21.5	7.7	7.4	177.3	--
10/06/2000	Fall	6	20.7	6.9	7.4	262.0	--
10/10/2000	Fall	7	14.6	9.6	8.1	189.0	--
10/11/2000	Fall	8	15.2	9.2	--	178.0	--
10/26/2000	Fall	9	18.1	7.7	7.8	169.0	7.6
11/15/2000	Fall	10	11.6	9.5	6.3	84.6	11.9
5/08/2001	Spring	1	22.6	9.7	7.9	119.9	6.4
5/09/2001	Spring	2	23.5	8.5	8.4	145.8	5.5
5/14/2001	Spring	3	24.2	7.3	7.7	166.9	8.3
5/15/2001	Spring	4	26.8	7.8	7.8	166.2	7.8
5/16/2001	Spring	6	26.2	7.9	8.0	164.5	13.0
5/24/2001	Spring	7	28.9	7.2	--	143.1	19.7
6/07/2001	Spring	8	26.8	6.1	--	123.6	11.4
6/12/2001	Spring	9	26.8	6.7	7.7	117.1	18.9
9/24/2001	Fall	1	26.8	7.0	8.5	133.3	3.2
10/11/2001	Fall	2	18.7	8.4	8.2	132.0	9.9
10/10/2001	Fall	3	17.2	8.8	7.9	136.5	13.2
10/01/2001	Fall	4	20.5	9.6	8.4	100.0	20.6
10/02/2001	Fall	6	21.5	8.9	8.4	122.3	17.0
10/03/2001	Fall	7	20.7	9.6	8.4	136.0	14.0
10/08/2001	Fall	8	16.3		8.2	171.0	9.8
10/16/2001	Fall	9	19.6	7.9	7.4	99.7	10.3
5/29/2002	Spring	1	26.6	8.1	--	121.1	5.3
5/30/2002	Spring	2	25.4	7.0	8.2	148.5	6.5
6/04/2002	Spring	3	29.6	6.4	8.1	185.0	8.7
5/20/2002	Spring	4	22.3	9.5	--	119.8	11.1
5/22/2002	Spring	6	19.2	9.9	8.3	102.1	9.8
5/28/2002	Spring	7	25.1	6.8	7.7	156.8	24.4
5/23/2002	Spring	8	17.9	8.3	7.7	138.1	23.7
5/21/2002	Spring	9	20.5	7.6	7.7	97.0	15.8

Table 22. Percent contribution of substrate types, by site, with average depth and flow, during backpack electrofishing, 2000 – 2002, in the Broad River, SC.

	Substrate							
Site	Sand	Gravel	Pebble	Cobble	Boulder	Bedrock	Depth (cm)	Flows (ft/s)
1	36	29	12	8	9	7	42	0.42
2	18	27	21	9	11	13	38	0.43
3	18	24	15	8	15	20	40	0.33
4	35	12	17	11	15	10	36	0.42
6	4	17	43	17	6	13	29	0.48
7	7	44	21	2	4	22	37	0.39
8	9	14	10	9	18	41	40	0.32
9	8	17	29	9	18	19	32	0.38
Overall	16	23	21	9	12	19	37	0.39

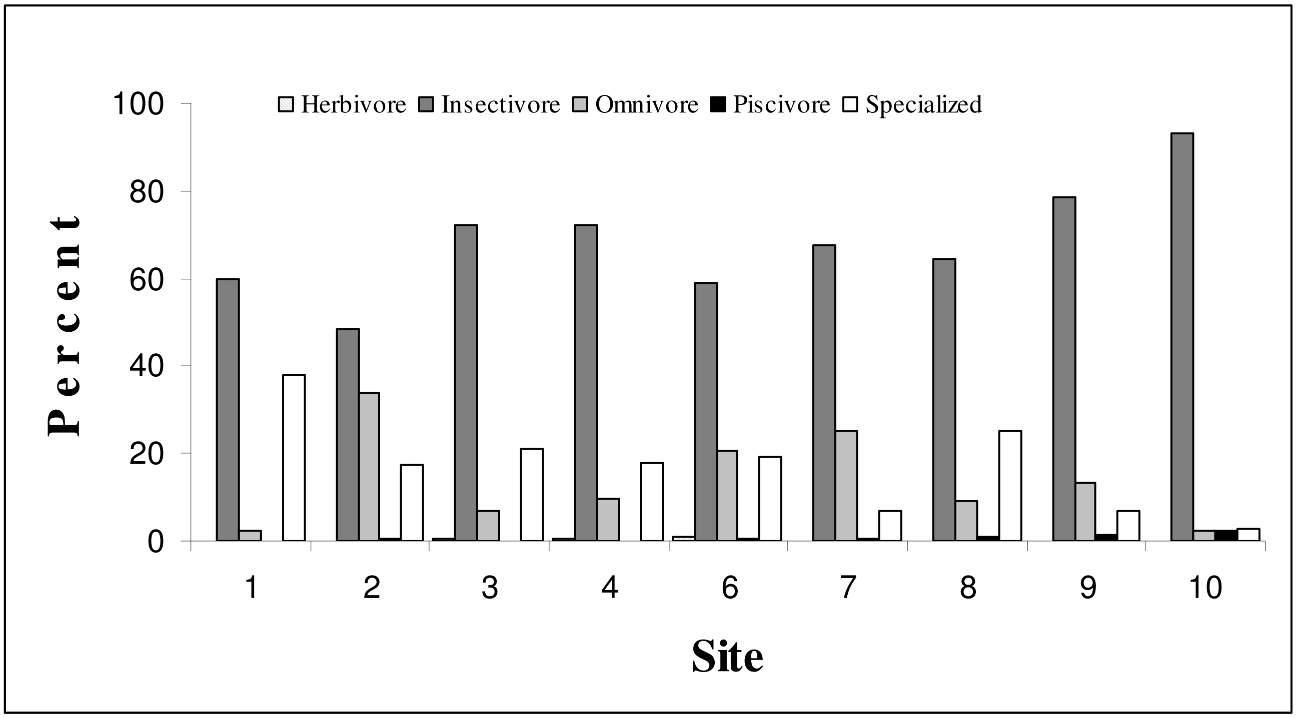


Figure 4. Relative abundance of five trophic groups of fish collected with backpack electrofishing gear from the Broad River, SC.

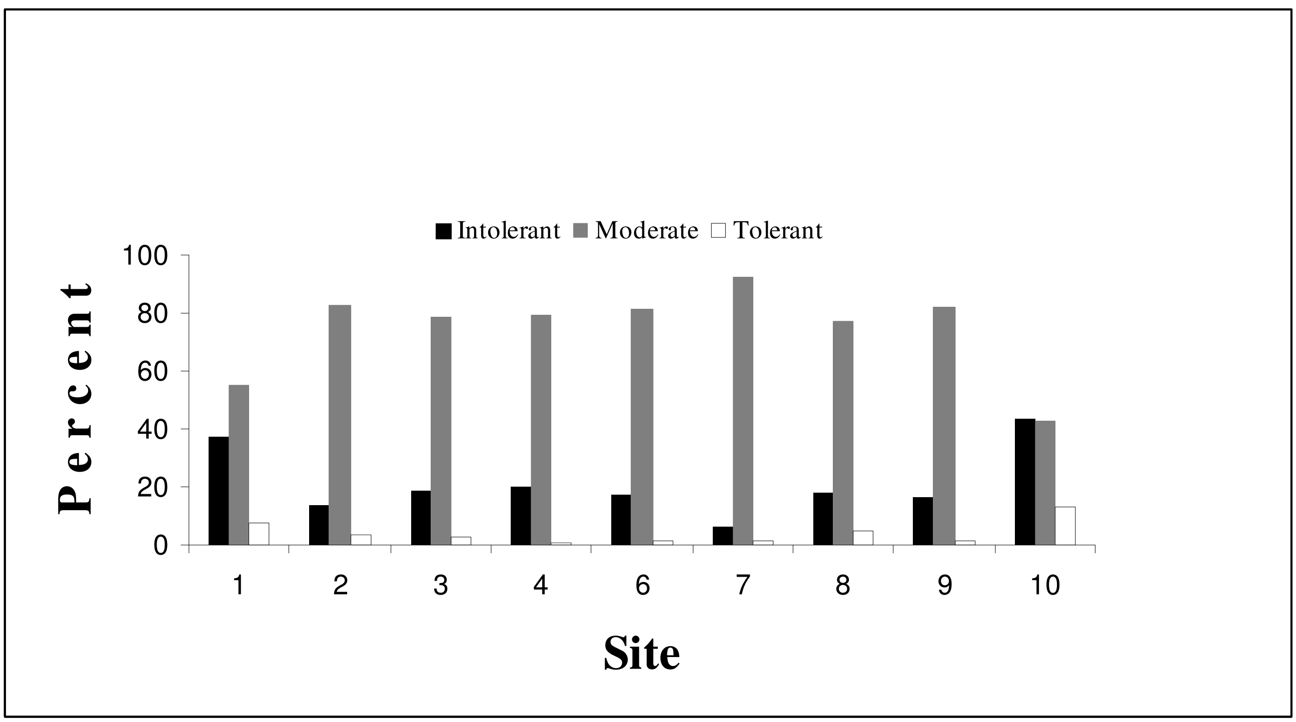


Figure 5. Relative abundance of three pollution tolerance groups of fish collected with backpack electrofishing gear from the Broad River, SC.

Discussion

The Broad River contains a rich and diverse fish community. Fifty-one species of fish representing nine families were collected from the Broad River during the present study (Appendix 1). Forty-seven species of fish were collected with boat electrofishing gear; 34 similar species and 4 additional species were collected with backpack electrofishing gear. We collected three species not previously documented from the Broad River, including an undescribed species similar to highfin carpsucker, smallmouth buffalo, and Santee chub. We also collected hybrid striped bass, not previously documented. The family Cyprinidae contributed the most species (14), followed by Centrarchidae (10 species) and Catostomidae (10 species). Overall, the most commonly collected fish were redbreast sunfish, whitefin shiner and silver redhorse. No federally-listed threatened or endangered species were collected. However, we did collect fantail darter, a species on the South Carolina Heritage Trust list of fishes of special concern.

The current species richness of the Broad River is comparable to what was previously known from the Broad River and similar-sized rivers in South Carolina. Previous sampling, conducted by various researchers (Kleinschmidt Associates 1995, Dames & Moore 1974, Duke Energy unpublished data), identified a total of 77 fish species occurring in the Broad River; however, the identifications of 22 of those species are questionable. Twelve of those 22 were almost certainly misidentified because the Broad River is far outside their known ranges (e.g. pallid shiner and spotted gar) (Appendix 1). A recent survey of the Catawba River documented 39 species (Dewitt 1998) and 59 freshwater fish species were documented in the Edisto River (Thomason et al. 1993).

Species richness and Simpson's inverse diversity index values varied among sites and between seasons. Longitudinal changes in mean species richness and mean diversity were observed in boat electrofishing collections. In general, species richness and diversity tended to be higher at downstream sites. Backpack electrofishing collections also indicated greater diversity at downstream sites, but species richness tended to be lower there. In undisturbed systems species richness normally increases downstream as drainage area increases. It is not clear why backpack electrofishing collections indicated higher mean species richness at upstream sites.

We did not observe any seasonal or longitudinal trends in water quality parameters. Water chemistry did not appear to affect CPUE, species richness or species diversity in backpack or boat electrofishing. Generally, it takes gross changes in water chemistry, such as with heavy pollution, to establish correlations with changes in fish communities (Moyle and Cech Jr. 1988).

Several species of interest were collected from the Broad River including "highfin" carpsucker, V-lip redhorse, and fantail darter. Our collection of "highfin" carpsucker represents only the third time it has been collected from the Atlantic Slope. Previous records for the species on the Atlantic Slope include one individual from the Catawba River, NC and one individual from the Pee Dee River, SC (person. comm., Robert Jenkins). The "highfin" carpsucker is native to the Interior Basin and its taxonomy and distribution along the Atlantic Slope are not known. The SCDNR is now supporting genetics work to investigate the relationship between the "highfin" carpsuckers of the Atlantic Slope and those from the Interior Basin.

The V-lip redhorse was very rare in our collections and was only found at middle and upstream sites. Although this species has been collected previously from the Broad River its occurrence does represent a range extension for the species (pers. comm., Wayne Starnes). It is not clear if there is a reproducing population of V-lip redhorse in the Broad River in South Carolina or if the adults we collected are simply displaced individuals from further up in the basin. The V-lip redhorse may be a candidate for inclusion on the South Carolina Heritage Trust list of fishes of special concern.

The fantail darter was only collected at site 6, a site that had the greatest mean species richness and the second highest mean species diversity in backpack electrofishing samples. Although this species is abundant throughout much of its range outside of South Carolina, we only found one population at one site in the Broad River. The rarity of this fish in our collections support its inclusion on the South Carolina Heritage Trust list of fishes of special concern.

The Broad River supports typical piedmont river sportfishing opportunities, comprising a variety of centrarchid species (e.g. largemouth bass and redbreast sunfish). The Broad River also boasts a smallmouth bass fishery, which is unique to piedmont rivers in South Carolina. Smallmouth bass were introduced into the South Carolina portion of the Broad River by the SCDNR in 1984 to increase and diversify sportfishing. Since their introduction a small but unique fishery has developed that is gaining local and regional attention annually. Based on anecdotal reports from anglers, the fishing for smallmouth bass is generally good. During our study we collected relatively few smallmouth bass; however, growth rates based on our data are comparable to other piedmont systems in the southeast. Additionally, we documented natural reproduction of smallmouth bass at sites 4, 7, and 8. We recommend that further efforts be directed at describing the life-history of the smallmouth bass population in the Broad River and that the economics of the SCDNR smallmouth bass stocking program be evaluated.

LARGEMOUTH BASS HEALTH

Introduction

We investigated the health of the largemouth bass (*Micropterus salmoides*) population in the Broad River, South Carolina, as part of the Comprehensive Broad River Aquatic Resources Inventory. We chose largemouth bass because they were readily available and we believed their condition would reflect the overall health of the aquatic community. The position of largemouth bass in the food chain, as a top predator, should integrate the effects of many biotic and abiotic variables that affect aquatic community health (Adams and McLean 1985). Largemouth bass have been used in Tennessee Valley Authority Reservoirs (Brown and Hickman 1990) and the Catawba River of North and South Carolina (Coughlan et al. 1996) to investigate fish health.

Largemouth bass health was determined by conducting a fish health assessment (FHA), an autopsy-based procedure in which organs, structures and blood parameters of individual fish are assessed and scored based on their deviation from normality (Table 23). Scores for organs, structures and blood parameters of individual fish are summed to calculate a fish health assessment index (FHAI) value. Fish with higher FHAI values are considered to be in poorer health than fish with lower values. The FHA was originally described by Goede and Barton (1990) and has been modified by Adams et al. (1993) and Coughlan et al. (1996).

Methods

Ten sites corresponding to current SCDNR fish community sampling sites were selected for conducting the FHA (Figure 1). Site numbers were assigned longitudinally with the most downstream site being site 1 and the most upstream being site 11. Each site was classified by what were perceived to be the most important anthropogenic impacts. Sites were classified as not impacted (N) or as impacted by industrial effluent (I), municipal/community effluent (M), or hydroelectric facilities (H). Industrial sites were defined as areas with one or more major industrial effluents within 4 km of the sample site. Municipal/community sites were those sites with municipal and community effluent within 4 km of the sample site. Sites classified as impacted by hydroelectric facilities were located within 2 km of an upstream hydroelectric facility.

Fifteen largemouth bass were collected at each site during November, 2001, and processed using the autopsy-based fish health assessment described by Adams (1993). Fish were captured during the day with boat mounted electrofishing gear. After capture, largemouth bass were anesthetized with 10% eugenol (Anderson et al. 1997) and held in an aerated live-well. The peritoneal and pericardial cavities were opened to expose the organs for visual assessment. Because liver coloration and blood parameters can change rapidly after death, liver coloration was evaluated and blood was collected from each fish before the other variables were assessed. Liver color was immediately recorded and blood was collected from the heart with a sharpened micro-hematocrit tube. Fish were then tagged and placed on ice until the other variables could be scored. Otoliths were collected from all fish to estimate age.

FHAI scores were calculated using the Adams scoring methodology (Adams et al. 1993) and the modified method suggested by Coughlan et al. (1996) (Table 23). Comparisons among sites were investigated using a Kruskal-Wallis Test (SAS 1989). Multiple comparisons were investigated using a Nemenyi Test (Zar 1996). Linear regression was used to determine if there was a relationship between average age or weight of fish and mean FHAI scores.

Results

We tried to follow the suggestions of Coughlan et al. (1996) and evaluate only fish that were between 250 mm and 450 mm total length (TL). However, occasionally fish outside the suggested size range were evaluated. Four fish greater than 450 mm TL (range 451-464 mm) and one fish 247 mm TL were scored. Estimated ages of largemouth bass ranged from 1 to 13. Mean estimated ages by site are reported in table 24.

Coughlan-modified FHAI scores (Coughlan et al. 1996) for individual fish ranged from 0 to 125. Mean Coughlan-modified scores by site ranged from 37 to 59 and averaged 45 (Table 25). The highest average scores, 59 and 54, were observed at sites 3 and 8, respectively and the lowest score (37) was observed at sites 1 and 7. The Adams scoring methodology resulted in FHAI scores ranging from 0 to 150 for individual fish. Mean scores by site ranged from 35 to 73 and averaged 57. The highest mean scores, 73 and 69, were observed at sites 3 and 8, respectively and the lowest score (35) was observed at site 6. There were no significant differences in the Coughlan-modified scores among sites (Kruskal-Wallis test; $P = 0.18$); however, there were significant differences among sites using the Adams scores (Table 25)(Kruskal-Wallis; $P = 0.03$). Significant differences were found between site 6 (lowest scoring non-impacted site) and all the sites impacted by industrial effluent (sites 3, 8 and 9). Significant differences were also found between sites 6 and 10, and between sites 3 and 4. There were no significant relationships ($P > 0.05$) between mean age or weight of largemouth bass and FHAI score using either the Adams or Coughlan scoring methodology.

Liver discoloration, poor relative weight (<85%), and skin anomalies were the most frequently observed abnormalities (Table 26). Anomalous livers were observed at every site and in 59% of the fish processed. Most abnormal livers (88%) were scored for moderate general discoloration of the whole liver. The frequency of anomalous livers was greatest at sites 1 and 8 where 12 of 15 fish had discolored livers. Site 6 had the fewest number of fish with anomalous livers (4 of 15). Poor relative weights were observed at every site and in 49% of the fish processed. At sites 4, 7, and 8, 11 of 15 fish had relative weights < 85%. Conversely, at sites 2 and 3 only 2 fish had poor relative weights. Mild hemorrhaging of the skin surface was observed at every site and in 47% of the fish processed. Hemorrhaging of the skin surface was most common at site 7 where 10 of 15 fish had mild hemorrhaging and least common at site 10 where only 3 fish had hemorrhagia on the skin surface.

Abnormalities of the gill rakers, trunk kidney and gills were common (Table 26). Gill raker abnormalities were observed at each site and in 33% of the fish processed. Most (96%) gill raker abnormalities consisted of slightly deformed rakers or gill arches missing 5 or fewer rakers. The frequency of gill raker deformities was rather consistent among sites. Abnormal trunk kidneys were observed in 32% of the fish processed. Most (47 of 48) trunk kidney abnormalities were due to swollen or enlarged trunk kidneys. One fish from site 6 had a trunk kidney that was gray in appearance and contained a milky fluid. The highest frequency of anomalous trunk kidneys was observed at site 3 where 10 of 15 fish had abnormal trunk kidneys. No trunk kidney abnormalities were observed at site 7. Gill abnormalities were observed in 20% of the fish processed and at every site. Most gill abnormalities were due to pale filaments and occasionally missing filaments.

Abnormal blood parameters were observed at each site (Table 27). Twenty-three percent of all fish processed had elevated plasma protein levels. Abnormal plasma protein levels were most common at site 3, where 9 of 15 fish had plasma protein levels above the normal range and least common at site 6 where none of the fish had elevated plasma protein levels. Atypical hematocrit levels were observed in 17% of the fish processed. Most (68%) deviant scores were due to hematocrit levels above the normal range. Atypical hematocrit levels were most frequent at site 4, where 6 of 15 fish had abnormal levels and least common at site 9 where one fish had below normal hematocrit levels. Only one of 150 fish processed had elevated leucocrit levels and it was collected at site 8.

The remainder of the metrics scored contributed little to the FHA. Four fish had mesenteric adhesions that were scored as gross abnormalities. Only three atypical spleens were observed: two were nodular and one was abnormally small; it appeared to be half the size of a normal spleen. We did not encounter an abnormal thymus, pseudobranch or hindgut.

Discussion

Largemouth bass populations in the Broad River appear to be in good condition based on the results of our FHA. Brown (1993) considered sites with average scores >90, using the Adams scoring methodology, to be areas in need of further study. Using the Coughlan-modified scoring method, areas of concern would have average index scores >75 (Coughlan et al. 1996). None of the Broad River sites had mean Adams scores > 73 or Coughlan-modified scores > 59.

Industrial effluent appears to adversely affect largemouth bass health. Sites located near industrial effluent scored higher than nearly all the other sites using both scoring methodologies. The next highest scores were observed at site 10. The high scores (Coughlan 49; Adams 66) at site 10 may have been confounded by the size and age of fish collected. Mean estimated age and weight were greater at site 10 than any of the other sites sampled. Although there was not a significant relationship between age or weight of fish and FHAI score in this study other studies have documented a positive relationship between largemouth bass age and FHAI score

(Coughlan et al. 1996). The other anthropogenic influences identified in this study (municipal impacts and hydropower operations) did not seem to adversely affect the health of largemouth bass.

Although none of the sites warrant further study based on the *a priori* concern levels a relationship between compromised largemouth bass health and industrial sites was identified. Further research is suggested to determine if the trend in largemouth bass health and proximity to industrial sites is consistent annually.

Table 23. Organs, structures and blood parameters scored during the Broad River largemouth bass FHA, associated condition, field designation and values used to calculate index scores using the Adams and Coughlan modified scoring criteria (modified from Adams et al. 1993 and Coughlan et al. 1996).

Tissue or Organ	Condition	Designation	Adams	Coughlan
Liver	Normal. Solid red or light red color.	A	0	0
	"Fatty" liver. Light tan color as "coffee with cream"			
	color moderate[a]	C1	30	15
	color severe	C	30	30
	Cysts/Nodules	D	30	30
	Focal discoloration - change of color in local areas or foci of liver.	E	30	30
	General discoloration of whole liver			
	color moderate[a]	F1	30	15
	color severe	F	30	30
	Other - any observation which does not fit above categories	OT	30	30
Gills	Normal with no apparent aberrations	N	0	0
	Frayed - erosion of tips of lamellae resulting in "ragged" appearing gills	F	30	30
	Clubbed - swelling of gill lamellae tips	C	30	30
	Marginate - light gill margin, discolored lamellar tips	M	30	30
	Pale - light, discolored gills (whole gills)	P	30	30
	Other - any observation which does not fit above categories			
	mild[a]	OT1		10
	moderate[a]	OT2		20
	severe	OT3	30	30
Gill Rakers[a]	Normal			0
	Slightly deformed or missing (<5 rakers)			10
	Moderately deformed or missing (5-10 rakers)			20
	Severely deformed or missing (>10 rakers)			30
Pseudobranch	Normal - flat with no aberrations	N	0	0
	Swollen - convex in appearance	S	30	30
	Lithic - mineral deposits (amorphous white spots)	L	30	30
	Swollen and lithic	X	30	30
	Inflamed	I	30	30
	Other - any observation which does not fit above categories	OT	30	30
Thymus	Normal appearance - no hemorrhage		0	0
	Mild hemorrhage		10	10
	Moderate hemorrhage		20	20
	Severe hemorrhage		30	30
Mesenteric Fat	No fat between pyloric ceca	0		
	Less than 50% of ceca covered with fat	1		
	50% of ceca covered with fat	2		
	More than 50% of ceca covered with fat	3		
	Ceca totally covered with fat	4		
Bile	Straw color, bladder empty	0		
	Straw color, bladder full	1		
	Grass green color, bladder full	2		
	Dark green color, bladder full	3		
Sex	Male	M		
	Female	F		

Table 23. Continued.

Tissue or Organ	Condition	Designation	Adams	Coughlan
Spleen	Normal - black, very dark red, or red	B	0	0
	Granular - rough appearance (normal)	G	0	0
	Nodular - nodules or fistulas of various sizes	N	30	30
	Enlarged	E	30	30
	Other - any observation which does not fit above categories	OT	30	30
Hindgut	Normal - no inflammation or reddening		0	0
	Slight inflammation or reddening		10	10
	Moderate inflammation or reddening		20	20
	Severe inflammation or reddening		30	30
Trunk Kidney	Normal - firm, lying relatively flat dorsally along the ventral surface of the vertebral column	N	0	0
	Swollen - enlarged or swollen, wholly or in part	S	30	30
	Mottled - gray discoloration	M	30	30
	Granular - granular appearance or texture	G	30	30
	Urolithic - white or cream-colored mineral deposits in kidney tubules (nephrocalcinosis)	U	30	30
	Other - any observation which does not fit above categories	OT	30	30
Opercles	Normal - no shortening, gills completely covered			0
	Slight shortening, a very small portion of the gills exposed			10
	Moderate shortening, a small portion of the gills exposed			20
	Severe shortening, a considerable portion of the gills exposed			30
Skin	Normal - no hemorrhagic areas			0
	Mild hemorrhagia on skin surface (<10 %)			10
	Moderate hemorrhagia on skin surface (10 - 60 %)			20
	Severe hemorrhagia on skin surface (>60 %)			30
Fins	Normal - no active erosion		0	0
	Light active erosion		10	10
	Moderate active erosion with some hemorrhaging		20	20
	Severe active erosion with hemorrhaging		30	30
Eye	Normal clear eyes (lens) - no aberrations	N	0	0
	Lenticular opacity (blind)			
	one eye	B1	30	15[a]
	both eyes	B2	30	30
	Exopthalmia - swollen or protruding eye			
	one eye	E1	30	15[a]
	both eyes	E2	30	30
	Hemorrhagic - bleeding			
	one eye	H1	30	15[a]
	both eyes	H2	30	30
	Missing			
	one eye	M1	30	15[a]
	both eyes	M2	30	30
	Other - any observation which does not fit above categories			
	one eye	OT1	30	15[a]
	both eyes	OT2	30	30

Table 23. Continued.

Tissue or Organ	Condition	Designation	Adams	Coughlan
Parasites	No observed parasites		0	0
	Few observed parasites, parasites in just one organ		10	10
	Moderate parasite infestation, parasites observed in several organs		20	20
	Numerous observed parasites, extensive infestation in several organs		30	30
Relative	≥85.00			0
Weight (%)[a]	≥70.00 and <85.00			15
	<70.00			30
Gross	No visible gross abnormalities	N		0
Abnormalities[a]	Tumors visible on external surfaces	E		30
	Tumors visible on internal surfaces	I		30
	Lordosis of vertebral column	L		30
	Scoliosis of vertebral column	S		30
	Skeletal deformities/broken bones of head and jaws	D		30
	Skeletal deformities/broken bones of remaining bony structures	B		30
	Other - any observation which does not fit above categories	OT		30
Hematocrit (%)	Normal range (30 - 45)		0	0
	Above normal range (>45)		10	10
	Below normal range (19 - <30)		20	20
	Well below normal range (<19)		30	30
Leucocrit (%)	Normal range (0 - <4)		0	0
	Above normal range (≥4)		30	30
Plasma	Normal range (3 - 7)		0	0
Protein (g/dL)	Above normal range (>7)		10	10
	Below normal range (<3)		30	30

[a] Parameters used to calculate Coughlan modified scores only.

Table 24. Mean estimated age, range in parentheses, and mean weight for largemouth bass collected from the Broad River during November 2001.

Site No.	Mean estimated age	Mean weight
1	1.9 (1-3)	394
2	3.5 (1-13)	595
3	2.5 (1-7)	647
4	2.7 (2-5)	448
5	2.7 (1-6)	468
6	3.8 (3-8)	586
7	2.7 (2-4)	372
8	2.9 (2-5)	302
9	2.9 (2-5)	390
11	4.1 (2-7)	737

Table 25. Mean Coughlan and Adams fish health assessment index (FHAI) scores and standard deviation for largemouth bass collected from the Broad River, SC, during November 2001. Mean scores with the same letter were not significantly different (Nemenyi Test; P = 0.05).

Site No.	Perceived Impact[a]	N	Coughlan	Adams
1	M	15	37 ± 20	$59^{xy} \pm 29$
2	N	15	39 ± 17	$52^{xy} \pm 29$
3	I	15	59 ± 24	$73^{x} \pm 28$
4	M, H	15	40 ± 20	$46^{yz} \pm 22$
5	N	15	45 ± 26	$60^{xy} \pm 34$
6	N	15	41 ± 34	$35^{y} \pm 39$
7	M, H	15	37 ± 17	$50^{xy} \pm 21$
8	I, M	15	54 ± 35	$69^{xz} \pm 42$
9	I	15	49 ± 20	$65^{xz} \pm 24$
11	N	15	49 ± 31	$66^{xz} \pm 39$
Mean			45 ± 26	57 ± 32

[a]Perceived impacts are classified as: (H) hydroelectric impacts; (I) industrial impacts; (M) municipal impacts; (N) not impacted.

Table 26. Percentage of fish with anomalous tissues, organs, and/or relative weight (Wr), collected from 10 sites in the Broad River, South Carolina during fall 2001.

	Percent atypical in					
Site	Liver	Wr	Skin	Gill rakers	Trunk kidney	Gills
1	80	40	60	13	13	13
2	53	13	40	27	47	7
3	73	13	60	33	67	13
4	60	73	47	33	7	13
5	53	40	47	47	33	33
6	27	60	33	40	33	13
7	47	73	67	40	0	27
8	80	73	60	33	20	20
9	53	60	40	33	47	40
10	67	40	20	27	53	20
All sites	59	49	47	33	32	20

Table 27. Percentage of fish with atypical blood parameters collected from 10 sites in the Broad River, South Carolina during fall 2001.

Site	Hematocrit	Leucocrit	Plasma Protein
1	13	0	33
2	13	0	40
3	20	0	60
4	40	0	0
5	20	0	13
6	13	0	0
7	13	0	7
8	13	7	13
9	7	0	27
10	13	0	40
All sites	17	1	23

GASTON SHOALS BYPASS

Introduction

In 1996 Duke Power Company (Duke) implemented minimum flows for the bypassed section of the Gaston Shoals Tailrace. The bypassed section is an area where water was diverted from the original river channel during dam construction. Before minimum flows were implemented the bypassed section received minimum flows from dam seepage and water running over the spillway during high flow events. We compared data collected before and after minimum flows were initiated to examine the effects of minimum flows on the fish community.

Methods

Pre-minimum flow fish community data were collected by Duke on 6 September 1989. Duke used rotenone and electrofishing to sample two sites located in the bypassed section of the Gaston Shoals Tailrace. Post-minimum flow fish community data were collected on 15 November 2000. Fish were collected with backpack electrofishing gear following the methods described previously.

We pooled the data by sampling year and calculated relative abundance (RA), species richness and Simpson's diversity metrics for the fish community before and after the implementation of minimum flows. Additionally, each species collected was assigned to one of three pollution tolerance levels (tolerant, moderately tolerant, or intolerant) and one of five trophic levels (piscivore, insectivore, omnivore, specialized insectivore, or herbivore) (EPA 1999, NCDENR 2001). We calculated the proportion of each trophic and tolerance group for the two samples.

Results

In 1989 a total of 541 fish comprising 16 species was captured (Table 28). Numerically redbreast sunfish dominated the catch, comprising 43% of all fish captured. The second most abundant species was the whitefin shiner comprising 17% of all fish captured. Bluegill, snail bullhead and greenfin shiner were common, each comprising more than 6% of all fish captured. The rarest fish collected was the tessellated darter; only one individual was collected.

In 2000 eighteen standardized riffle and run backpack electrofishing collections were made and one 100 m shoreline section was sampled. A total of 180 fish comprising 15 species was collected (Table 28). Numerically the most dominant fish was the fieryblack shiner, representing 31% of all fish captured. Whitefin shiner and redbreast sunfish were the second most abundant species, representing 18% and 17%, respectively, of all fish captured. Snail bullhead and greenfin shiner were common, each comprising more than 6% of all fish collected. The rarest fish in the sample included sandbar shiner and seagreen darter; only one of each species was collected.

Simpson's inverse diversity index was higher for the 2000 sample than for the 1989 sample (Table 29). Species richness (total number of species) was slightly higher in 1989 than in 2000.

Percent contribution of tolerance groups varied considerably between pre- and post-minimum flow collections. In the 1989 samples only moderately tolerant and tolerant individuals were collected and they were collected in nearly equal proportions (Figure 6). In the 2000 collections all three tolerance groups were collected. Moderately tolerant individuals were the most abundant followed by intolerant and tolerant individuals. Percent contribution of the five feeding groups did not vary greatly among the pre- and post-minimum flow samples (Figure

7). In both years insectivores were the most dominant trophic group representing more than 90% of the individuals collected. None of the remaining trophic groups represented more than 2% of the population in either 1989 or 2000. The only other notable observations were the slightly higher proportion of specialized insectivores and piscivores and the absence of herbivores in the 2000 collection.

Discussion

The various gear types used during the pre- and post-minimum flow sampling may have influenced the results. Several large bodied species were collected in 1989 that were not collected in 2000, including largemouth bass, silver redhorse and white sucker. The backpack electrofishing techniques used in 2000 are capable of collecting large bodied fish, but not as effectively as the rotenone sampling that was conducted in 1989. The change in species composition suggests that a more diverse community exists in the bypassed reach since minimum flows were introduced. In 2000 we collected four intolerant species: fieryblack shiner, thicklip chub, seagreen darter and piedmont darter. No intolerant species were collected in 1989, but in 2000 they represented 35 % of the fishes collected. The relative abundance of tolerant individuals was reduced during the 2000 sample. During 1989 the three tolerant species (white sucker, redbreast sunfish, and flat bullhead) collected represented 49% of the fish collected. During 2000 only one tolerant species (redbreast sunfish) was collected and it represented only 17% of the total fish collected.

The implementations of minimum flows in the Gaston Shoals bypass appear to have had a positive effect on the fish community residing in the bypass. The change in species composition, species diversity and tolerance composition all suggest a more diverse community residing in a more stable habitat.

Table 28. Number and relative abundance (RA, %) of each species collected for samples collected at the Gaston Shoals bypass before (1989) and after (2000) the implementation of minimum flows.

	1989		2000	
Common Name	No.	RA	No.	RA
Greenfin shiner	43	7.9	12	6.7
Whitefin shiner	93	17.2	32	17.8
Fieryblack shiner			56	31.1
Eastern silvery minnow	7	1.3		
Thicklip chub			4	2.2
Bluehead chub		0.0	2	1.1
Spottail shiner	2	0.4	2	1.1
Sandbar shiner			1	0.6
White sucker	10	1.8		
Northern hogsucker	4	0.7	3	1.7
Silver redhorse	14	2.6		
Striped jumprock	22	4.1	5	2.8
Brassy jumprock	3	0.6	8	4.4
Snail bullhead	33	6.1	17	9.4
Flat bullhead	23	4.3		
Redbreast sunfish	234	43.3	31	17.2
Bluegill	45	8.3		
Smallmouth bass	3	0.6	4	2.2
Largemouth bass	4	0.7		
Tessellated darter	1	0.2		
Seagreen darter			1	0.6
Piedmont darter			2	1.1
Total	541	100.0	180	100.0

Table 29. Species richness and Simpson's Inverse Diversity Index for samples collected at the Gaston Shoals bypass before (1989) and after (2000) the implementation of minimum flows.

Year	1989	2000
Simpson's	4.2	5.8
Richness	16.0	15.0

Figure 6. Percent contribution of three tolerance groups based on data collected from the Gaston Shoals bypass before (1989) and after (2000) the implementation of minimum flows.

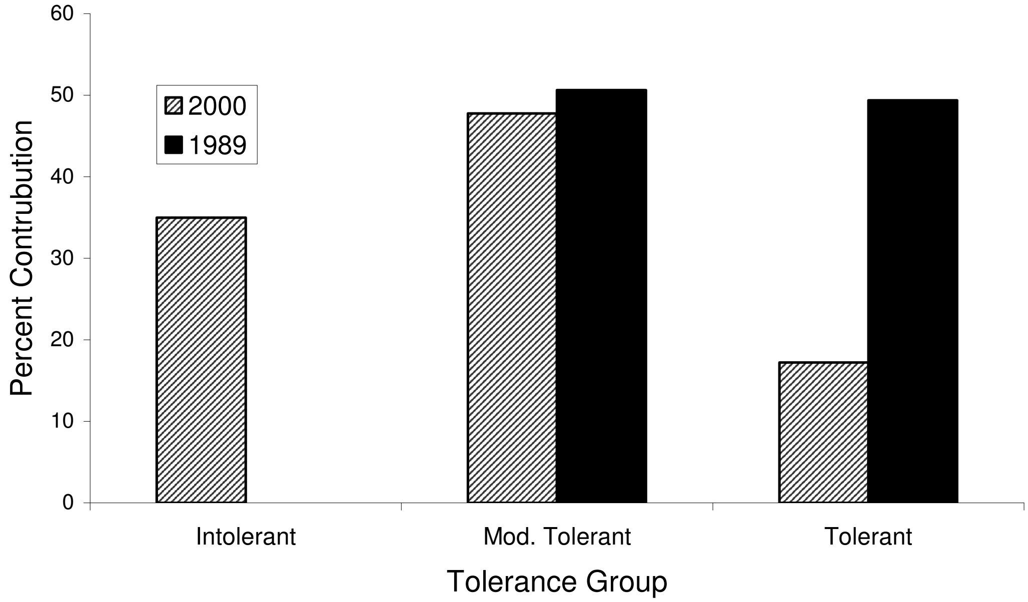
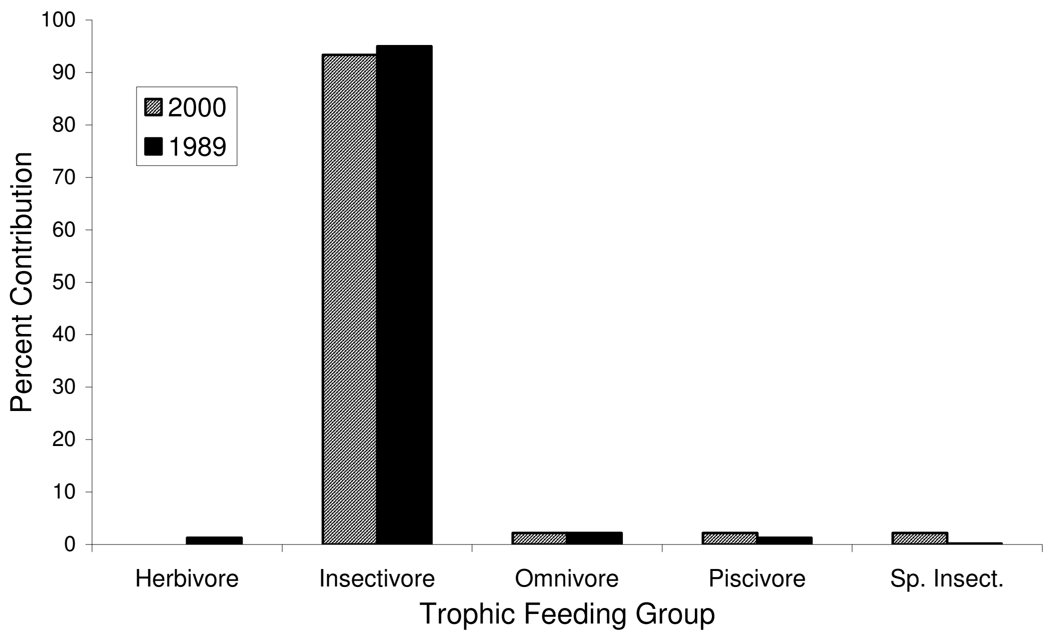


Figure 7. Percent contribution of five trophic groups based on data collected from the Gaston Shoals bypass before (1989) and after (2000) the implementation of minimum flows.



MUSSEL INVENTORY

Methods

We surveyed six sites for mussels during the summer 2002 (Figure 8). We surveyed two sites between Columbia Dam and Parr Shoals Dam, two sites between Lockhart and 99-Islands, and two sites between Cherokee Falls and Gaston Shoals. Latitude and longitude coordinates are provided in Table 30. At each site we conducted a qualitative mussel survey, where two people equipped with view buckets or snorkeling gear visually searched for live mussels. Search time was recorded to the nearest 0.1 hour. All live native mussels encountered were collected and, when possible, identified to species. Species identifications were facilitated with the illustrations and descriptions of Johnson (1970) and with the Workbook and Key to the Freshwater Bivalves of North Carolina (Bogan, 2002). We compiled species lists and computed catch per unit effort (CPUE) as number of live mussels per hour for each site.

Relic shell material was also collected at each site to construct a reference collection and verify species identifications. Relic shells were identified at the North Carolina Museum of Natural Sciences (NCMNS) by Dr. Arthur Bogan (Mussel Curator, NCMNS) using Johnson (1970) and by comparing relic material collected from the Broad River with type specimens held at NCMNS.

Results

At each site two people expended approximately 2 h of effort searching for live mussels (Table 30). We were unable to satisfactorily identify the species of the Elliptio genus in the field and were therefore only able to identify elliptio species as *E. complanata* or as a member of the *E. lanceolata* group. A total of 315 live mussels were collected during the mussel survey. Only two species, *E. complanata* and *Villosa delumbis* and one group of mussels (E. *lanceolata*), were collected. Eighty-seven percent of the mussels collected belonged to the *E. lanceolata* group, 9% were *E. complanata*, and 4% were *V. delumbis*. Catch rate of live native mussels ranged from 0.0 at sites 3 and 4 to 76.7 at site 2 (Table 31). Catch rate of mussels identified as belonging to the *E. lanceolata* group was higher at all sites than the catch rate of *V. delumbis* and *E. complanata*. Additionally, catch rate was much higher at the downstream sites (1 and 2) than the upstream sites.

From the relic shells collected in the Broad River we identified seven shell-forms, which we believe are seven different species (Table 32). Of those seven shell-forms only two, *E. complanata* and *V. delumbis*, could be identified with certainty. Three of the shell-forms likely belong to the *E. lanceolata* group. In that group the shell-forms we collected most resembled *E. gracilentus*, *E. angustata*, and *E. perlatus*. The other two shell-forms collected most resembled *E. icterina* and *Uniomerus carolinianus*.

Discussion

Native mussel fauna were more abundant and diverse in the lower river than in the upper section of the river. The collection gear used may have influenced our results. In the upper section of the river we used view buckets and unaided visual searches to locate live mussels and in the lower section we used snorkel gear. Snorkel gear is likely superior to view buckets and unaided visual searches for locating live mussels; however, it is doubtful that the gear type alone accounted for the differences in mussel catch rates between the upper and lower portions of the river. Physical habitat differences may have contributed to the disparate catch rates. The lower river is generally less turbid and has less silt than the upper sections of the Broad River (personal observation). Agricultural practices and multiple sand mining operations may contribute to the high level of siltation in the upper sections. Silt often causes freshwater mussels to suffocate by clogging their gills (Parmalee and Bogan 1998). Small and juvenile mussels can sink below the surface and suffocate in soft, freshly deposited silt (Williams and Schuster 1989). Silt deposits and shifting sand beds were abundant at sites 3 and 4 where no live native mussels were found. Fine sediment deposits were also common at sites 5 and 6 where few adult mussels and no juvenile mussels were collected. Additionally, the frequency of impoundments, which may have a deleterious effect on the mussel fauna, is greater in the upper section of the river. Dams negatively impact mussel communities by direct loss of habitat due to impoundment, altering flows and temperatures, and changing substrate composition (Parmalee and Bogan 1998).

To our knowledge, this limited mussel survey is the most intensive survey of its type conducted on the South Carolina portion of the Broad River. We identified seven distinct shell forms that we believe are seven different species; however, we are not certain of the identity of five of those species. The *Elliptio* species of the Southern Atlantic slope have received little attention and are among the least known mussels in North America (Arthur Bogan, personal communication). A concentrated study is needed not only in the Broad River, but also throughout the South Carolina portion of the Southern Atlantic slope to better understand the taxonomy and distribution of freshwater mussels in South Carolina.

Table 30. Location of each site sampled, gear used and the amount of effort in man-hours for the Broad River mussel survey, summer 2002.

Date	Site	Latitude	Longitude	Gear	Effort
9/16/2002	1	34 08' 39"	81 08' 46"	snorkel	3.1
9/16/2002	2	34 11' 64"	81 12' 44"	snorkel	2.8
6/20/2002	3	34 54' 38"	81 28' 18"	View bucket	4.0
6/20/2002	4	34 50' 48"	81 27' 11"	View bucket	4.0
9/11/2002	5	35 04' 45"	81 34' 02"	View bucket	4.0
9/11/2002	6	35 05' 18"	81 34' 18"	View bucket	3.9

Table 31. CPUE (No./h) of live mussels collected from six sites in the Broad River during the summer 2002.

	Species			
Site	*E. complanata*	*E. lanceolata group*	*V. delumbis*	All species
1	7.1	21.3	0.0	28.4
2	1.4	71.4	3.9	76.7
3	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0
5	0.3	0.8	0.0	1.1
6	0.5	1.0	0.0	1.5

Table 32. Relic shells collected from six sites in the Broad River during the summer 2002.

	Site					
Species	1	2	3	4	5	6
Elliptio cf gracilentus	x	x			x	x
Elliptio cf angustata		x			x	
Elliptio cf perlatus	x	x				
Elliptio complanata	x	x			x	x
Elliptio cf icterina		x				
Villosa delumbis	x	x				
Uniomerus carolinianus		x				

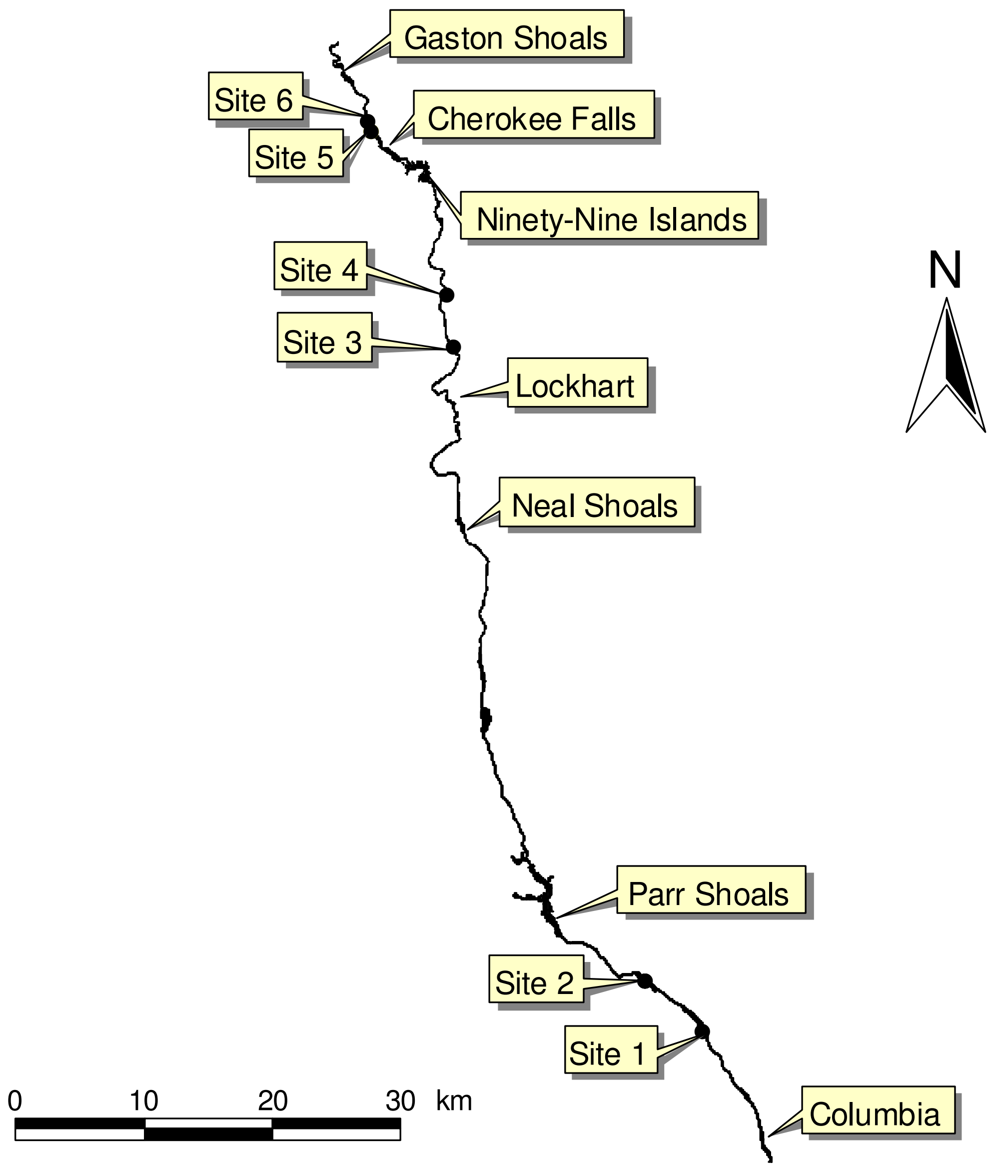


Figure 8. Sites surveyed during the summer 2002 for native mussels.

RECOMMENDATIONS

1. **Habitat restoration:** Aquatic resources in several areas of the Broad River could benefit from habitat restoration. Efforts should be directed at improving riparian areas classified as "poor" and "marginal", and at addressing bank stability issues above Parr Reservoir.

2. **Minimum flows:** Minimum flows have had a positive affect on the fish community in the Gaston Shoals Tailrace. We recommend that minimum flows be implemented at all hydroelectric operations along the Broad River where appropriate.

3. **Sand mining:** Sand mining may have adverse effects on the biotic resources of the Broad River. We recommend that research be conducted to examine the nature and extent of such impacts, and to develop methods to minimize the operational impacts of sand dredging on aquatic biota.

4. **Recreational access:** Although this was not a recreational resource inventory, observations regarding the scenic beauty and the recreational usage and potential of the river were made. Based on those observations, recreational usage would benefit from increased boating access.

5. **Industrial effluent:** Largemouth bass health in the Broad River appears to be adversely affected by industrial discharge. Further research is suggested to examine the effects of point source pollution on fish health.

6. **Fish passage:** Restoration of anadromous fish species to the Broad River could have a tremendous impact on the resident fish community. Although our survey was thorough, we used only one site to describe the fish community in the reach between Parr Shoals Dam and Columbia Dam. Before the installation of a fish passage facility at Columbia Dam, an intensive survey of current fishery resources in that reach is needed. If possible, any fish passage facility installed at Columbia Dam should be designed to prevent the passage of flathead catfish. Also, an intensive fisheries study should be conducted after the fishway has been constructed and has been in operation to determine if any changes in fish communities occur as a result of diadromous fish passage.

7. **Smallmouth bass:** Previous stockings of smallmouth bass have created a small but unique fishery. Creel and length restrictions are needed to protect this limited resource. The SCDNR Smallmouth Bass Management Plan and associated management recommendations are attached in Appendix 2.

8. **Freshwater mussels:** Native mussels in the Broad River are a poorly understood resource. Research addressing taxonomy and distribution may provide information that would be useful in future management decisions, including the potential restoration of robust redhorse.

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APPENDIX 1

Table 33. Fish species reported from the Broad River, South Carolina, during this and previous studies. Site numbers indicate locations where species were collected during our survey. Species not collected (NC) during our survey may have been present but not sampled, or they may have been misidentified originally. The probability that the original identification was correct, based on known species distributions, is characterized as (P) probable, (Q) questionable, or (N) not likely. Common and scientific names follow Robins et al. (1991) except where noted.

Family	Scientific Name	Common Name	Site	Probability
Lepisosteidae	*Lepisosteus oculatus*	Spotted gar	NC	N
Lepisosteidae	*Lepisosteus osseus*	Longnose gar	1-3	
Anguillidae	*Anguilla rostrata*	American eel	NC	P
Clupeidae	*Alosa aestivalis*	Blueback herring	NC	Q
Clupeidae	*Dorosoma cepedianum*	Gizzard shad	1-9 and 11	
Clupeidae	*Dorosoma petenense*	Threadfin shad	1,2 and 7	
Esocidae	*Esox masquinongy*	Muskellunge	NC	P
Cyprinidae	*Campostoma anomalum*	Central stoneroller	NC	P
Cyprinidae	*Clinostomus funduloides*	Rosyside dace	8	
Cyprinidae	*Ctenopharyngodon idella*	Grass carp[b]	1-3	
Cyprinidae	*Cyprinella analostana*	Satinfin shiner	NC	N
Cyprinidae	*Cyprinella chloristia*	Greenfin shiner	1-11	
Cyprinidae	*Cyprinella nivea*	Whitefin shiner	1-11	
Cyprinidae	*Cyprinella pyrrhomelas*	Fieryblack shiner	4 and 6-10	
Cyprinidae	*Cyprinella zanema*	Santee chub[a]	4	
Cyprinidae	*Cyprinus carpio*	Common carp	1-4, 6-9 and 11	
Cyprinidae	*Hybognathus regius*	Eastern silvery minnow	1-6 and 8	
Cyprinidae	*Hybopsis labrosa*	Thicklip chub	1-4 and 6-10	
Cyprinidae	*Nocomis leptocephalus*	Bluehead chub	1-4 and 6-10	
Cyprinidae	*Nocomis micropogon*	River chub	NC	N
Cyprinidae	*Notemigonus crysoleucas*	Golden shiner	3	
Cyprinidae	*Notropis amnis*	Pallid shiner	NC	N
Cyprinidae	*Notropis cummingsae*	Dusky shiner	NC	Q
Cyprinidae	*Notropis hudsonius*	Spottail shiner	1-11	
Cyprinidae	*Notropis hypselopterus*	Sailfin shiner	NC	N
Cyprinidae	*Notropis leedsi*	Bannerfin shiner	NC	N
Cyprinidae	*Notropis lutipinnis*	Yellowfin shiner	1 and 6	
Cyprinidae	*Notropis petersoni*	Coastal shiner	NC	P
Cyprinidae	*Notropis rubescens*	Rosyface chub	NC	N
Cyprinidae	*Notropis scepticus*	Sandbar shiner	1-11	
Cyprinidae	*Semotilus atromaculatus*	Creek chub	NC	P
Catostomidae	*Carpiodes carpio*	River carpsucker[d]	NC	N
Catostomidae	*Carpiodes cyprinus*	Quillback	2-9	
Catostomidae	*Carpiodes sp. cf. velifer*	Highfin carpsucker[a]	2[c], 3[c], 5[c] and 6-7	

Table 33. continued

Family	Scientific Name	Common Name	Site	Probability
Catostomidae	*Catostomus commersoni*	White sucker	6, 9 and 11	
Catostomidae	*Hypentelium nigricans*	Northern hogsucker	2-11	
Catostomidae	*Ictiobus bubalus*	Smallmouth buffalo[a]	2-4 and 6-8	
Catostomidae	*Minytrema melanops*	Spotted sucker	NC	Q
Catostomidae	*Moxostoma collapsum**	Silver redhorse	1-9 and 11	
Catostomidae	*Moxostoma duquesnei*	Black redhorse	NC	N
Catostomidae	*Moxostoma erythrurum*	Golden redhorse	NC	N
Catostomidae	*Moxostoma macrolepidotum*	Shorthead redhorse	1-6	
Catostomidae	*Moxostoma pappillosum*	V-lip redhorse	4-9	
Catostomidae	*Scartomyzon rupiscartes**	Striped jumprock	1-11	
Catostomidae	*Scartomyzon sp.**	"Brassy jumprock"	1-11	
Ictaluridae	*Ameiurus brunneus*	Snail bullhead	1-11	
Ictaluridae	*Ameiurus catus*	White catfish	2, 3, 6 and 11	
Ictaluridae	*Ameiurus melas*	Black bullhead	NC	Q
Ictaluridae	*Ameiurus natalis*	Yellow bullhead	NC	P
Ictaluridae	*Ameiurus nebulosus*	Brown bullhead	NC	P
Ictaluridae	*Ameiurus platycephalus*	Flat bullhead	1-9 and 11	
Ictaluridae	*Ictalurus punctatus*	Channel catfish	1-9 and 11	
Ictaluridae	*Noturus gyrinus*	Tadpole madtom	NC	Q
Ictaluridae	*Noturus insignis*	Margined madtom	1-9	
Ictaluridae	*Noturus leptacanthus*	Speckled madtom	NC	Q
Atherinidae	*Labidesthes sicculus*	Brook silverside	NC	Q
Poeciliidae	*Gambusia holbrooki*	Eastern mosquitofish	3, 4 and 6-8	
Moronidae	*Morone americana*	White perch	1-3	
Moronidae	*Morone chrysops*	White bass	1-4	
Moronidae	*Morone saxatilis*	Striped bass	NC	P
Moronidae	*Morone saxatilis x M. chrysops*	Hybrid striped bass[a]	2	
Centrarchidae	*Centrarchus macropterus*	Flier	1	
Centrarchidae	*Lepomis auritus*	Redbreast sunfish	1-11	
Centrarchidae	*Lepomis cyanellus*	Green sunfish	8	
Centrarchidae	*Lepomis gibbosus*	Pumpkinseed	1-3	
Centrarchidae	*Lepomis gulosus*	Warmouth	1, 4, 5, 8 and 9	
Centrarchidae	*Lepomis macrochirus*	Bluegill	1-9 and 11	
Centrarchidae	*Lepomis marginatus*	Dollar sunfish	NC	P
Centrarchidae	*Lepomis megalotis*	Longear sunfish	NC	N
Centrarchidae	*Lepomis microlophus*	Redear sunfish	1-9, and 11	
Centrarchidae	*Micropterus dolomieu*	Smallmouth bass	2-11	
Centrarchidae	*Micropterus punctulatus*	Spotted bass	NC	Q
Centrarchidae	*Micropterus salmoides*	Largemouth bass	1-9 and 11	
Centrarchidae	*Pomoxis annularis*	White crappie	NC	Q

Table 33. continued.

Family	Scientific Name	Common Name	Site	Probability
Centrarchidae	*Pomoxis nigromaculatus*	Black crappie	1-9 and 11	
Percidae	*Etheostoma flabellare*	Fantail darter	6	
Percidae	*Etheostoma fusiforme*	Swamp darter	NC	Q
Percidae	*Etheostoma olmstedi*	Tessellated darter	1-9	
Percidae	*Etheostoma thalassinum*	Seagreen darter	1, 3, 4, 6 and 8-10	
Percidae	*Etheostoma zonale*	Banded darter	NC	N
Percidae	*Perca flavescens*	Yellow perch	1-4	
Percidae	*Percina crassa*	Piedmont darter	1-4 and 6-10	

[a] Species not previously documented from the Broad River
[b] Species collected with sampling not associated with survey work
[c] Sites where a species was collected with sampling not associated with survey work
[d] Likely confused with *Carpiodes sp. cf. velifer*
* Expected common and/or scientific name change (R. Jenkins, person. comm.)

APPENDIX 2

Smallmouth Bass Management Plan – Broad River Drainage

Prepared by: Richard Christie, Willard "Gene" Hayes,
Hal Beard and Jason Bettinger

Introduction: Smallmouth bass (*Micropterus dolomieui*) were introduced into the South Carolina portion of the Broad River drainage in 1984 to increase the diversity of sport fishing opportunity. This was an experimental stocking of a non-native sportfish species into marginal habitat. The reproductive potential was considered to be low, and discontinuing the stocking program would control any un-anticipated negative impacts this stocking may have on native fish species.

Stocking smallmouth bass appears to have successfully created a small but unique sport fishery on the Broad River. This fishery is gaining prominence annually. Because of this gain in popularity, a management plan and recommended harvest regulations for smallmouth bass in the Broad River are needed to protect this limited resource.

Stocking History: The North Carolina Wildlife Resources Commission (NCWRC) first stocked smallmouth bass in the Broad River basin in May of 1941. They were stocked in a pond in Rutherford County. Stocking continued from the mid 1940's through the late 1960's in streams and ponds in all counties in the basin. Stocking rates are not known, however from 1,000 to 10,000 1-2 inch fingerlings were stocked at each site. Stocking was discontinued in 1985 and NCWRC currently has no plans for future stocking of this species in the Broad River basin.

Smallmouth bass were first introduced to the Broad River drainage in South Carolina in 1984. According to stocking records, 1339 6-inch sub-adults were stocked into several locations in Kings Creek. Since the initial stocking, fish have been stocked in 10 different years at seven different locations (Table 1). A total of 16,500 two-inch fingerlings were stocked just downstream from the Gaston Shoals Hydroelectric plant at Secondary Road 98, and 608 fingerlings were stocked in Bowen Creek. A total of 12,354 six-inch sub-adults were stocked at various bridge crossings on Kings Creek and in the Broad River.

In the summer of 1990, Fisheries District IV personnel surveyed potential stocking sites in tributaries to the Broad River. Sites were evaluated based on access, surface water temperature, turbidity, substrate, and existing sport and forage species. Five sites were identified in York County and seven sites were located in Cherokee County. Since 1990, stocking has been restricted to one or more of those sites and the upper Broad River near Gaston Shoals.

Life History: The following information is summarized from Black Bass Biology and Management, edited by Stroud and Clepper (1975). Smallmouth bass are native to the great Lakes and St. Lawrence River drainages in Canada south to northern Georgia, west to eastern Oklahoma, and north into Minnesota. The species has been introduced, and self-sustaining populations have been established across the United States, Canada, Hawaii, Asia and Africa. Smallmouth bass are found naturally in large, clear water lakes and cool, clear streams having a moderate current and rock substrate. A typical setting would be a stream that supports trout in the colder, upper reaches; smallmouth bass in the mid-section and largemouth bass in the slower, warmer waters. In streams, smallmouth bass usually avoid the stronger currents and inhabit the calmer waters behind structure or near the currents edge. They are not known to be migratory in nature and they have restricted home ranges. Smallmouth bass are active in a wide range of water temperatures but become less active when temperatures dip below 50° F or increase above 85° F. They may lose weight above 95° F. They are spring spawners and move into the spawning grounds when the water temperatures reach 60° F. Soon after they lose their yolksac, bass feed on insect larvae such as midges and mayflies. They are sight feeders, and water clarity is probably an important factor in the success of natural reproduction. Larger fish feed on insects, fish and crayfish. Smallmouth bass exhibit a wide range of growth rates. Smallmouth grow slower than largemouth bass, and age I, II and III fish average 3.7, 6.7, and 9.2 inches, respectively, in total length. One-year old fish grown at the Cheraw Fish Hatchery in South Carolina range from 3 to 7 inches (X=5 inches) and average about 0.1 pounds.

Management: Smallmouth bass were introduced into the Broad River drainage to increase the diversity of sport fishing opportunity. Although habitat is considered to be good in the Kings Creek tributary and satisfactory to marginal in the main river channel, habitat is limited by increased sediment and the resulting impact on turbidity and water temperature. Turbidity is thought to hinder the survival of the eggs by reducing their ability to respire, and to decrease survival of the post sac fry by reducing their ability to see and capture prey. In some years, high water temperature may also impact physiology. Based on limited aquatic surveys, food items do not appear to be a limiting factor in the success of this species. Insects (mayflies and midges), shiners (*Notropis* sp.) and crayfish are abundant in King's Creek but less numerous in the Broad River. Growth rates similar to those reported in the literature are expected. A 12 – 14 inch smallmouth (age V-VI) would be a quality fish and a 16-inch smallmouth would be a memorable fish.

Very little information is currently available regarding the distribution of smallmouth bass to judge the extent at which they will contribute to the sport fishery. A study to evaluate fish species abundance and distribution is ongoing in the Broad river system. Anecdotal information from anglers indicates that the species is concentrated in Kings Creek and above the Lockhart Hydroelectric facility, confined pretty much to where they were stocked. Some anglers have expressed an interest in wanting to "protect" this species before it becomes exploited. We have no estimates of angling effort, harvest, growth rates or mortality from the Broad River population. While the success of this introduction is evaluated, we need to protect smallmouth bass from over harvest. Thus, this proactive recommendation is offered.

Harvest Recommendation: Recommendations are based on the following set of assumptions. 1) the management objective of stocking smallmouth bass in the Broad River is to increase the number of sport species available for recreational fishing. 2) smallmouth bass are often sought by angling "purists" who use ultra-light tackle or fly rods and practice catch and release. A successful trip for most anglers will be determined by numbers of fish caught rather than the quality of the fish. 3) production of quality fish (> 16 in) may be limited by habitat. 4) some smallmouth bass anglers and fisheries managers think that the existing regulation of ten (10) black bass per day with no size limit is too liberal. 5) smallmouth bass handle well and non-harvest fishing mortality is less than 10%. 6) Broad River anglers and enforcement officers can differentiate between largemouth and smallmouth bass. **Based on these assumptions and the current management philosophy, a two (2) fish per day creel limit for smallmouth bass, of which only one may exceed 14 inches in total length, in Game zones 2, 3, and 4, should be imposed.**

Other management recommendations: the following additional recommendations are suggested in the order of their need:

1. Continue to stock smallmouth bass annually. Stocking rates will depend on the availability. Historically, 600-800 sub-adult fish have been stocked in the fall at several locations in Kings Creek. Up to 5,000 fingerlings have been stocked annually in the spring in the Gaston Shoals vicinity of the Broad River. All stocked fish should be marked. Stocking locations should be distributed between Parr reservoir and the Gaston Shoals Hydroelectric plant. Stocking should be confined to that area of the Broad River drainage upstream from Parr Reservoir.
2. Develop an anglers guide to differentiate largemouth and smallmouth bass and provide basic information.
3. Conduct a sport fish creel survey on the Broad River to estimate fishing pressure, harvest, success, and system specific angler information including the quality of fishing for smallmouth bass.
4. Collect life history data to include food habits, age and growth, and reproduction.
5. Establish a Broad River Smallmouth bass advisory council to solicit public input.