Relationships of fish community characteristics to environmental parameters in the Catawba-Wateree Reservoirs

Prepared in partial support of 18CFR4.51, requiring assessment of fisheries resources, for relicensing the Catawba-Wateree Project, FERC #2232

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Metric unit conversions

Metric	Symbol	U.S. Equivalent (approximate)
1 meter	m	3.2808 feet
1 kilometer (1,000 meters)	km	0.62 miles
1 hectare (10,000 m^2)	ha	2.47 acres
1 hectare	ha	0.00386 square miles
1 square kilometer (1,000,000 m^2)	km^2	0.3861 square miles
1 cubic meter	m^3	35.3134 ft^3
1 cubic meter	m^3	1.308 cubic yards
1 cubic meter per day	m^3/day	0.00040872 cfs (cubic feet per second)
1 kilogram	kg	2.2046 lb

Metric measurements are used throughout this report.

INTRODUCTION

Duke Power is currently in the process of relicensing the Catawba-Wateree Project (FERC #2232), which consists of eleven reservoirs and associated hydroelectric structures on the Catawba-Wateree river system. The licensing process requires an assessment of any potential impacts to existing fisheries resources (18CFR4.51). In partial support of this requirement, the objectives of this report are: 1) to provide an overview of the characteristics of the fisheries communities of Catawba-Wateree reservoirs, based on data collected by Duke Power, the North Carolina Wildlife Resources Commission, and the South Carolina Department of Natural Resources; and 2) to examine relationships between environmental parameters and characteristics of the fish communities of Catawba-Wateree reservoirs, in an attempt to identify factors which significantly influence littoral fish standing stock, densities of limnetic forage fish, and sport fish harvest. This investigation is based on 1) spring shoreline electrofishing data collected by Duke Power at 19 sites on the Catawba-Wateree reservoirs from 1993 through 2002; 2) hydroacoustics and purse seine data collected by Duke Power from 1997 through 2003; 3) creel surveys conducted between 1982 and 2002 by the North Carolina Wildlife Resources Commission, the South Carolina Department of Natural Resources, and Duke Power; and 4) cove rotenone data collected between 1980 and 2000 by the North Carolina Wildlife Resources Commission, the South Carolina Department of Natural Resources, and Duke Power.

STUDY AREA

The Catawba River originates in the Blue Ridge Mountains of western North Carolina, at an elevation of approximately 1,158 m-msl. The river flows east and south through the piedmont regions of North and South Carolina, ultimately merging with several creeks south of Great Falls, South Carolina to form the Wateree River. The Wateree River exits the Wateree dam at an elevation of 45 m-msl. Hydroelectric dams built on the Catawba and Wateree Rivers between 1904 and 1963 impounded eleven reservoirs: from upstream to downstream, these reservoirs are Lake James, Lake Rhodhiss, Lake Hickory, Lookout Shoals Lake, Lake Norman, Mountain Island Lake, Lake Wylie, Fishing Creek Reservoir, Great Falls-Dearborn Reservoir, Cedar Creek Reservoir, and Lake Wateree.

Watershed characteristics

From the headwaters of the Catawba River to the Wateree dam, the Catawba-Wateree system drains an area of 12,266 km^2. Discharge from the Wateree dam averages 14.34 million m^3 per day. The headwaters region of the Catawba River basin is characterized by steep topography, deep ravines, and high-gradient streams. Further downstream, topography is characterized by smaller hills and rolling terrain as the river flows through the piedmont region. Land use in the Catawba watershed is summarized in Table 1. The watershed is largely forested in the headwaters area. Agricultural and urban areas become progressively more prevalent downstream, reaching a maximum near the State line. The region below Lake Norman and above Fishing Creek Reservoir encompasses several urban areas, including the major population center of Charlotte, North Carolina, where population density in the Catawba watershed reaches a maximum (Duke Power 2003). In the lower Catawba basin, downstream of Charlotte and Rock Hill, South Carolina, land use and cover are more rural. Approximately 1.5 million people live in the Catawba-Wateree watershed above the Wateree dam, based on the census of 2000. The populated nature of the watershed is reflected in the fact that 473 National Pollutant Discharge Elimination System permits are active in the watershed; the number of permits per subbasin is greatest in the area of maximum population density (Duke Power 2003). Land use, soil characteristics, and physiography of the Catawba watershed have been described in detail by the NC Department of Environment and Natural Resources (NCDENR) (2003) and the SC Department of Health and Environmental Control (SCDHEC) (2004).

Reservoir characteristics

Morphometric and hydrological characteristics of the eleven Catawba-Wateree reservoirs are described in Table 2. Surface areas range from 1.8 to 131.6 km^2, mean depths from 1.4 to 13.5 m, and maximum depths from 10.7 to 43.0 m. Hydraulic retention time, the average time required to discharge a volume of water equivalent to 100% of a reservoir's volume, ranged from less than 1 day to greater than 215 days. This characteristic is also often quantified in fisheries studies as the storage ratio, reservoir volume divided by annual discharge. Storage ratios on the Catawba-Wateree reservoirs ranged from 0.001 to 0.589. Shoreline development ratio, calculated as shoreline length divided by the circumference of a circle having an area equal to lake surface area, is a measure of the degree to which shorelines are dendritic, and may be an indicator of the relative amount of shallow habitat. Shoreline development ratios of the Catawba-Wateree reservoirs ranged from 5.3 on Cedar Creek Reservoir, morphometrically somewhat similar to a river channel, to 23.4 on Lake Norman, a large, highly dendritic reservoir with multiple arms (Table 2).

Morphometric/hydraulic characteristics were generally highly correlated within the set of Catawba-Wateree reservoirs. These reservoirs range along a continuum, from small, fairly shallow reservoirs with short retention times and low shoreline development ratios (Great Falls-Dearborn Reservoir and Cedar Creek Reservoir, for example), to large, deep reservoirs with long retention times and highly dendritic shorelines, such as Lake Norman.

Over the study period (1993-2002), mean surface water temperatures on the Catawba-Wateree reservoirs ranged from 25.9 to 33.9 ^{o}C in summer and from 6.1 to 12.5 ^{o}C in winter (Table 3). All reservoirs remained vertically mixed throughout winter. During the summer, deep, long-retention-time reservoirs maintained fairly stable thermal stratification, while stratification in shallower reservoirs with shorter retention times tended to be transient. Great Falls-Dearborn Reservoir and Cedar Creek Reservoir, small reservoirs with retention times of less than 3 days, did not stratify thermally. All Catawba-Wateree reservoirs with the exception of Great Falls-Dearborn and Cedar Creek exhibited some degree of oxygen depletion in hypolimnetic waters.

Mean summer surface chlorophyll concentrations on the Catawba-Wateree reservoirs ranged from 2.8 to 43.0 µg/L, total phosphorus from 0.009 to 0.184 mg P/L, total nitrogen from 0.201 to 1.051 mg N/L, and turbidity from 0.8 to 13.4 NTU (nephelometer turbidity units) (Table 3). Water quality parameters exhibited significant spatial variation within and among Catawba-Wateree reservoirs. Concentrations of nutrients and turbidity in the forebay regions of these reservoirs were negatively correlated with retention time, suggesting that nutrients and turbidity-causing materials in reservoirs with longer retention times tended to be lost to the sediments prior to reaching the forebay region. Past studies have indicated that primary production in the Catawba-Wateree reservoirs was generally nutrient-limited, with the exception of Great Falls-Dearborn and Cedar Creek Reservoirs, in which primary production appeared to be limited by lack of light penetration and/or washout (Duke Power 2003; Rodriguez 1986).

Water quality in reservoirs is dictated by point- and non-point-source loading of nutrients, suspended sediments, and other materials, as modified by reservoir morphometry and hydrology. Loading varies with population density, and, consistent with the distribution of population in the Catawba-Wateree basin, reservoirs upstream of the North Carolina-South Carolina border tended to be rated oligotrophic or mesotrophic, while those downstream of the border were generally rated eutrophic (North Carolina Division of Water Quality 2000, SCDHEC 2000). The water quality of streams and reservoirs in the Catawba River basin has been described in detail by NCDENR (2003) and SCDHEC (2004).

The fish, phytoplankton, zooplankton, and benthic communities of the Catawba-Wateree reservoirs have been studied extensively by Duke Power, from 1973 to the present, and results of these studies have been described in detail (Duke Power 2000, 2003). Catalogs of reports documenting results of individual studies have been developed as well (Siler 2004a, b, c).

METHODS

Sources of data

Littoral fish biomass - Spring shoreline electrofishing was carried out by Duke Power on all Catawba-Wateree reservoirs in selected years from 1993 through 2002. Electrofishing methods are documented in Duke Power (2003). A total of 19 areas were sampled, including 3 areas per reservoir on Lakes James, Norman, and Wylie, 2 areas per reservoir on Lakes Hickory and Wateree, and one area per reservoir on Lakes Rhodhiss, Lookout Shoals Lake, Mountain Island Lake, Fishing Creek Reservoir, Great Falls-Dearborn Reservoir, and Cedar Creek Reservoir (Figures 1 through 10). In each area sampled, ten transects 300 meters in length were subjected to electrofishing (five transects on Great Falls-Dearborn). Lake areas sampled are identified below, along with years sampled and a code with which these areas are identified in selected tables and figures in this report.

Electrofishing sampling summary, Duke Power

Lake	Area	Site ID	Years sampled
James	Upper Catawba arm	JAM-UC	1994-1997, 2000
James	Lower Catawba arm	JAM-LC	1994-1997, 2000
James	Linville arm	JAM-LIN	1994-1997, 2000
Rhodhiss	Lakewide	RHO	1994-1997, 2000
Hickory	Uplake	HIC-UL	1994-1997, 2000
Hickory	Downlake	HIC-DL	1994-1997, 2000
Lookout Shoals	Lakewide	LOO	1994-1997, 2000
Norman	Marshall Steam Station	NOR-MSS	1993-1997, 1999-2002
Norman	Reference area	NOR-REF	1993-1997, 1999-2002
Norman	McGuire Nuclear Station	NOR-MNS	1993-1997, 1999-2002
Mountain Island	Downlake	MOU	1993-1997, 1999-2002
Wylie	Plant Allen	WYL-PA	1993-1997, 1999-2002
Lake Wylie	Buster Boyd Bridge area	WYL-BB	1993-1997, 1999-2002
Lake Wylie	Catawba Nuclear Station	WYL-CNS	1993-1997, 2000
Fishing Creek	Lakewide	FIS	1993-1997, 2000
Great Falls-Dearborn	Lakewide	GFL	1994-1997, 2000
Cedar Creek	Lakewide	CED	1994-1997, 2000
Wateree	Uplake	WAT-UL	1994-1997, 2000
Wateree	Downlake	WAT-DL	1994-1997, 2000

Limnetic forage fish density - Hydroacoustic sampling was carried out by Duke Power in selected years from 1997 through 2003 to estimate forage fish densities on Catawba-Wateree reservoirs. Lakes Norman, Wylie, and James were divided into zones for hydroacoustic sampling. Zones for Lakes Norman and Wylie are mapped in Figure 11. Zones on Lake James consisted of the Catawba River arm and the Linville River arm. Lakewide sampling was conducted on Lakes Rhodhiss, Hickory, Lookout Shoals, Mountain Island, Fishing Creek and Wateree. Great Falls-Dearborn and Cedar Creek Reservoirs were not sampled. Hydroacoustics methods are documented in Duke Power (2003).

Taxonomic composition of limnetic forage fish community - Purse seine samples were collected in selected years from 1993-2003 on all lakes with the exception of Fishing Creek, Great Falls-Dearborn, and Cedar Creek Reservoirs, in order to characterize the community composition of the forage fish community. Purse seine methods are documented in Duke Power (2003).

Hydroacoustic/purse seine sampling summary, Duke Power

Lake	Zones sampled (hydroacoustics)	Years sampled Hydroacoustics	Years sampled Purse seine
James	Catawba arm, Linville arm	1997, 2000	1993-1997, 2000
Rhodhiss	Lakewide	1997, 2000	1993-1997, 2000
Hickory	Lakewide	1997, 2000	1993-1997, 2000
Lookout Shoals	Lakewide	1997, 2000	1993-1997, 2000
Norman	Zones 1-6 (Figure 11)	1997-2003	1993-2003
Mountain Island	Lakewide	1997, 1999-2003	1993-1997, 1999-2003
Wylie	Zones 1-4 (Figure 11)	1997, 2000	1993-1997, 1999-2003
Fishing Creek	Lakewide	1997, 2000	-
Great Falls-Dearborn	-	1997, 2000	-
Cedar Creek	-	1997, 2000	-
Wateree	Lakewide	1997, 2000	1993-1997, 2000

Sport fish harvest – Sport fish harvest data were obtained from a series of creel surveys carried out by the North Carolina Wildlife Resources Commission (NCWRC), the South Carolina Department of Natural Resources (SCDNR), and Duke Power (Tables 4, 5). Methods are documented in Duke Power (2003). Harvest data were available for all Catawba-Wateree reservoirs with the exception of Lookout Shoals Lake and Great Falls-Dearborn Reservoir.

Water quality - Duke Power carried out a limnological sampling program on the Catawba-Wateree reservoirs quarterly from 1993 through 2002. Water quality data were collected in mid-channel at multiple locations in the larger reservoirs and at the forebays of smaller reservoirs. Parameters sampled included temperature, chlorophyll, nutrients, turbidity, specific conductance, seston dry weight and ash-free dry weight, and densities of zooplankton.

Profile data for water quality parameters were averaged over the top 5 meters of the water column to characterize surface waters. Data to characterize summer conditions were obtained by averaging data collected in July, August, and September; spring data were obtained by averaging data collected in April and May. Stations at which data were collected were coordinated with electrofishing areas and hydroacoustics zones for analysis. Where more than one station was sampled within one electrofishing area or hydroacoustics zone, data were averaged over locations within the area or zone. Finally, data were averaged over the years 1993-2002 (with the exception of total phosphorus – see below). Zooplankton data were treated similarly, but represent zooplankton densities in the top 10 meters of the water column (Table 6).

Reporting limits for nitrogen and phosphorus were standardized as follows prior to averaging data: total phosphorus and orthophosphate, 0.005 mg/L; total Kjeldahl nitrogen, 0.150 mg N/L; ammonia nitrogen and nitrate + nitrite nitrogen, 0.050 mg N/L. Total nitrogen was calculated as the sum of total Kjeldahl nitrogen plus nitrate + nitrite nitrogen. Data for all nutrients with the exception of total phosphorus were averaged over the period 1993-2002. Data for total phosphorus were averaged over the period 1993-2000 only, due to an increase in reporting limit in 2001. Zooplankton data collected from 1993 through 1999 were utilized in this study. Methods are documented in Duke Power (2003).

Morphometry/hydrology - Values for morphometric and hydrologic characteristics of the Catawba-Wateree reservoirs were obtained from Duke Power (2003). Data on shoreline habitat characteristics (Table 7) were collected by Duke Power in July 1998. Shoreline development ratio was calculated as shoreline length divided by the circumference of a circle having an area equivalent to the full-pond surface area of the reservoir. The morphoedaphic index was calculated as mean summer surface specific conductance (µmho/cm) divided by mean depth (m).

Statistical methodology

To prepare electrofishing data for correlation analysis with environmental variables, total fish density (number of fish per kilometer of shoreline) and biomass, as well as the density and biomass of major taxa, were averaged by lake area, over the period 1993-2002. Correlations were initially performed using yearly electrofishing data for each lake section as observations. However, correlations were not better than those performed using data averaged over years. Based on the Shapiro-Wilk test statistic, annual data were less likely to have been normally distributed than data averaged over years, and thus results using data averaged over years were utilized in this report. The percent which each major taxon constituted of total fish density and biomass was calculated for each year for each lake area. These percents were then averaged to obtain the mean percent which each major taxon constituted of total fish density and biomass. To prepare data for correlation analysis with lakewide parameters such as mean depth and retention time, lakewide estimates of littoral fish biomass were obtained by averaging over electrofishing areas within a reservoir.

Forage fish density data were averaged over years for each area sampled, for use in correlation analysis. Where correlations were performed with lakewide parameters such as mean depth and retention time, area-weighted lakewide estimates of forage fish density were used.

Non-parametric analysis of variance (Wilcoxon) was utilized to assess the statistical significance of differences within and among lakes in fish and water quality parameters, using years as replicates.

Variables to be used in correlations of total standing stock and harvest with environmental parameters were subjected to univariate analysis (Shapiro-Wilk statistic) to assess normal distribution. All variables were $\log_{10}$-transformed to attain a normal distribution.

A reference probability of $p<0.0500$ was used to assign statistical significance unless otherwise noted in the text. All statistical analyses were performed using the SAS system of statistical analysis, produced by SAS Institute Inc. of Cary, North Carolina.

OVERVIEW OF THE FISH COMMUNITIES OF CATAWBA-WATEREE RESERVOIRS

Characteristics of the fish communities of the Catawba-Wateree reservoirs have been studied with spring shoreline electrofishing (Tables 8 and 9), hydroacoustics (Table 10), purse seine sampling (Table 11), creel surveys (Tables 4, 5), and summer cove rotenone studies (Table 12). In addition, many investigations of specific aspects of the fisheries of individual reservoirs have been carried out (Table 13).

Management of the fisheries in these reservoirs has included frequent stocking of forage fishes such as threadfin shad and sunfish, and game fishes such as striped and white bass. The stocking history of each of the Catawba-Wateree reservoirs is documented in Tables 14 through 16. Fish kills observed in the Catawba-Wateree reservoirs and their tributaries are documented in Tables 17 and 18.

Based on electrofishing data from all Catawba-Wateree reservoir electrofishing locations, total littoral fish biomass averaged 88.5 kg/km, ranging from 20.3 kg/km in the forebay area of Lake Norman to 191.1 kg/km in the upper Catawba basin of Lake James (Table 9; Figure 12); differences in littoral fish biomass both among and within reservoirs were statistically significant. In terms of taxonomic composition, a total of 56 species, plus hybrid sunfish, were observed in electrofishing samples (Table 19). Black basses (primarily largemouth bass) averaged 37% of total littoral biomass, carps and minnows (primarily common carp) 27%, and sunfish (primarily bluegill, redbreast, and redear) 12% (Table 9; Figure 13). Statistically significant differences in taxonomic composition were observed both among and within lakes, using years as replicates.

Based on hydroacoustics data collected by Duke Power, 1997-2003, mean densities of limnetic forage fish ranged from 887 fish per hectare on the Linville River arm of Lake James to 29,252 fish/ha on Lake Wateree (Table 10; Figure 14). Purse seine sampling conducted by Duke Power from 1993-2003 (Table 11; Figure 15) revealed that both threadfin and gizzard shad were important components of limnetic forage fish communities on Lakes James, Rhodhiss, Hickory, and Lookout Shoals; relative abundance of these species was quite variable among years. On Lake Norman and downstream reservoirs, threadfin shad dominated limnetic forage fish communities. Alewife first appeared in purse seine samples on Lakes Norman and Mountain Island in 1999, presumably as a result of angler ‘bait-bucket’ introduction. The relative abundance of alewife has increased rapidly on Lakes Norman and Mountain Island since 1999 (Table 11), and this species appeared downstream in Lake Wylie purse seine samples in 2001.

Substantial inter-annual variation in forage fish densities and species composition was frequently observed on the upper Catawba-Wateree reservoirs, potentially due to variability in minimum winter temperatures. Threadfin shad become thermally stressed at water temperatures below 9 °C (Griffith 1978; Strawn 1965), and are subject to die-offs during severe winters. The North Carolina Wildlife Resources Commission stocks threadfin shad frequently on the upper Catawba reservoirs to replenish populations (Table 14).

Creel surveys have been conducted on all Catawba-Wateree reservoirs with the exception of Lookout Shoals and Great Falls-Dearborn (Tables 4, 5). Fishes comprising a large percentage of total harvest in terms of numbers included crappie, bluegill, largemouth bass, and channel catfish. In terms of biomass, harvest was dominated by striped bass, largemouth bass, crappie, carp, and channel catfish, with relative percentages varying among reservoirs (Table 5).

A brief overview of the fisheries characteristics of each reservoir follows.

Lake James

The littoral fish community of Lake James was studied from 1994 through 1997 and in 2000, utilizing spring shoreline electrofishing. Three regions were sampled: the upper Catawba River arm, the Linville River arm, and the lower Catawba basin. Mean total fish biomass averaged 191.1 kilograms per kilometer of shoreline in the upper Catawba River arm, 34.4 kg/km in the Linville River arm, and 46.7 kg/km in the lower Catawba basin. Statistically, fish biomass in the upper Catawba River arm was significantly higher than in the lower Catawba basin and the Linville River arm ($p<0.01$).

Thirty-eight species of fish, plus hybrid sunfish, were observed in shoreline electrofishing of Lake James (Tables 20 through 22). In the upper Catawba River arm, littoral fish biomass was dominated by common carp (31%), notchlip redhorse (29%), and largemouth bass (12%). In terms of numbers, the community was dominated by sunfish, primarily bluegill and redbreast, which accounted for 40% of total fish density. Dominance patterns were substantially different in the lower Catawba basin. Black basses accounted for 46% of total biomass on average (largemouth 34%, smallmouth 12%); notchlip redhorse accounted for 19% and common carp for 13%. Sunfish (redbreast, bluegill) were again the most numerically abundant group, averaging 57% of total fish density, while black basses accounted for 25%. In the Linville River arm, black basses averaged 53% of total biomass (largemouth 29%, smallmouth 24%), as compared to 21% for common carp. As with other sections of Lake James, sunfish (redbreast, bluegill) dominated the community numerically, averaging 57% of total fish density, while black basses accounted for 30%.

The littoral fish community of Lake James was also studied from 1983 through 1987, utilizing summer sampling of coves with rotenone (Table 12). Littoral fish community biomass in these studies averaged 141.2 kg/ha. Gizzard shad accounted for 39% of total littoral biomass on average, sunfish for 9%, largemouth bass 4%, crappie 3.5%, yellow perch 3%, walleye 2%, smallmouth bass 2%, threadfin shad 1%, and white bass 1%. Biomass values for carp, minnows, suckers and catfish were not individually reported.

Hydroacoustic sampling (1997, 2000) and purse seine sampling (1993 through 1997 and 2000) were conducted to estimate limnetic densities and composition of forage fish.

Limnetic forage fish densities in Lake James averaged 4,380 fish per hectare in the Catawba River arm and 887 fish per hectare in the Linville River arm (Table 10). Based on purse seine data, gizzard shad accounted for from 0 to 100% of forage fish, averaging 67%; threadfin shad averaged 33% (Table 11). The substantial variation among years in forage fish density and community composition was potentially influenced by thermal stress to threadfin shad during severe winters.

Lake James is unique among the Catawba-Wateree reservoirs in that it supports not only a warm-water fishery but a cool-water fishery as well. Of the Catawba-Wateree reservoirs, smallmouth bass were found only in Lake James, and only Lake James maintained a significant walleye population.

Based on a creel survey conducted jointly by the NC Wildlife Resources Commission and Duke Power in 1997-1998 (Yow 2005), a total of 49,511 fish were harvested on Lake James (18.8 fish/ha/yr, based on surface area at full pond). Sunfish constituted 41% of all fish harvested, crappie 19%, walleye 17%, black basses 15%, and white bass 6% (Tables 4, 5).

The history of fish stocking on Lake James is documented in Tables 14 and 15. Over the past 10 years (1994-2003), largemouth bass were stocked in 1995 and 2000; redear sunfish in 1997; threadfin shad in 1995 and 1997; and walleye annually from 1994 through 2003.

Over the period 1988 through July 2001, the North Carolina Wildlife Resources Commission reported no fish kills on Lake James (Table 17). Although not routinely reported, winter kills of threadfin shad are likely to have occurred frequently, due to the inability of this species to withstand water temperatures below about 9 ^{o}C; average winter water temperatures in the electrofishing areas of Lake James ranged from 6.1 to 7.7 °C, based on data collected 1993-2002 (Table 3).

In addition to the fisheries investigations conducted by Duke Power and other agencies on multiple Catawba River reservoirs, a number of studies were conducted on aspects of the Lake James fishery. Specifically, population dynamics of walleye, white bass and crappie in Lake James have been intensively investigated (Table 13).

Lake Rhodhiss

Spring shoreline electrofishing was carried out by Duke Power on Lake Rhodhiss from 1994 through 1997 and in 2000 (Table 23). Twenty-eight species of fish, plus hybrid sunfish, were observed during electrofishing. Biomass estimates averaged 174.4 kg per kilometer of shoreline, while density averaged 903 fish per kilometer. Biomass was dominated by largemouth bass and common carp, which averaged 40% and 31% of total biomass, respectively. Sunfish (primarily bluegill and redbreast) accounted for an average of 10% of total biomass, and white catfish for 8%. In terms of density, the littoral fish community was dominated by bluegill, which averaged 39% of total density, redbreast sunfish (21%), largemouth bass (16%), and yellow perch (10%).

The distribution of fish in the littoral zone in summer was studied in 1983 by the NC Wildlife Resources Commission, using cove rotenone sampling. Cove rotenone biomass averaged 187.3 kg/ha, of which 32% was gizzard shad, 27% sunfish, 15% catfish, 9% carp, 8% largemouth bass, and 6% yellow perch (Table 12).

Limnetic densities of forage fish in Lake Rhodhiss were estimated with hydroacoustic sampling (1997, 2000) and purse seine sampling (1993 through 1997 and 2000) (Tables 10, 11). Forage fish densities averaged 24,172 fish per hectare. Gizzard shad comprised from 0.3 to 100% of pelagic forage fish, averaging 56%; threadfin shad averaged 44% of pelagic fish density. As with Lake James, the composition of the forage fish community was potentially affected by thermal stress to threadfin shad during severe winters, and by stocking of threadfin by the North Carolina Wildlife Resources Commission.

Based on a creel survey conducted from March 1996 through February 1997 by Duke Power (Baker 2002a), sport fishermen harvested 42,367 fish weighing 16,130 kg on Lake Rhodhiss (11.4 kg/ha/yr based on surface area at full pond) (Tables 4, 5). Striped bass accounted for 44% of total harvest by weight; crappie for 17%, common carp 12%, and largemouth bass 10%. Crappie dominated the harvest numerically, accounting for 52% of all fish harvested.

The fish stocking history of Lake Rhodhiss is documented in Tables 14 and 15. Striped bass have been stocked annually since 1992; threadfin shad were stocked in 1992, 1995, and 1997.

No fish kills on Lake Rhodhiss were reported by the North Carolina Wildlife Resources Commission over the period 1988 through July 2001 (Table 17). However, winter water temperatures on Lake Rhodhiss averaged about 6 ^{o}C (Table 3), below the thermal tolerance limit for threadfin shad, and winter die-offs of this species would be expected.

Several studies specific to Lake Rhodhiss have been carried out in addition to investigations conducted on multiple Catawba River reservoirs. Specifically, these studies investigated population dynamics of crappie and striped bass in Lake Rhodhiss (Table 13).

Lake Hickory

Spring shoreline electrofishing was utilized to study the littoral fish community of Lake Hickory annually from 1994 through 1997 and in 2000 (Tables 24 and 25). Twenty-nine species of fish, plus hybrid sunfish, were observed during electrofishing. Two areas within the lake were sampled: uplake, and downlake in the vicinity of the forebay. Total littoral fish biomass averaged 101.1 kg/km uplake and 94.4 kg/km downlake, a statistically insignificant difference. Littoral fish biomass was dominated by largemouth bass, common carp, and white catfish in both regions of the lake. Numerically, bluegill and redbreast sunfish dominated the community; sunfish accounted for 54% of total fish density uplake and 70% of total fish density downlake.

Characteristics of the littoral fish community in summer were investigated by the NC Wildlife Resources Commission in 1983 using cove rotenone sampling. Cove rotenone data yielded an estimated littoral biomass of 166.3 kg/ha, consisting of 35% sunfish, 28% gizzard shad, 13% largemouth bass, 10% catfish, 8% yellow perch, 3% carp, 2% white bass, and 1% crappie (Table 12).

Duke Power conducted hydroacoustic sampling in 1997 and 2000 to estimate densities of limnetic forage fish in Lake Hickory (Table 10). Purse seine sampling was carried out annually from 1993 through 1997 and in 2000 to characterize the composition of the forage fish community (Table 11). Forage fish densities were estimated to be 30,438 fish/ha in 1997 and 11,173 fish/ha in 2000. The vulnerability of threadfin shad to thermal stress during severe winters was reflected in the extreme variability among years in the composition of the forage fish community. Gizzard shad comprised nearly 100% of fish in purse seine samples in 1994, 1995, and 1996, while threadfin shad accounted for nearly 100% in 1993, 1997, and 2000 (Table 11).

An angler survey was conducted on Lake Hickory from June 1997 through May 1998 (Baker 2002b, Duke Power 2003). Total sportfish harvest was 245,106 fish weighing 132,718 kg (80.0 kg/ha/yr based on surface area at full pond) (Tables 4, 5). By weight, striped bass accounted for 62% of total harvest, catfish for 15%, and crappie for 13%. Numerically, crappie constituted 30% of total harvest, followed by catfish (27%), and sunfish (22%).

The history of fish stocking in Lake Hickory is documented in Tables 14 and 15. Since 1994, striped bass have been stocked every year with the exception of 1996; threadfin shad were stocked in 1995 and 1997.

One fish kill was reported in the Lake Hickory watershed during the period from 1988 through July 2001. Mortality of 250 yellow perch and catfish was observed in the forebay of Lake Hickory in July 2001. No cause was apparent (Table 17). As with Lakes James and Rhodhiss, it is likely that winter die-offs of threadfin shad occurred regularly, as winter surface temperatures averaged 6.7 ^{o}C (Table 3), below tolerance limits for threadfin shad.

In addition to those studies conducted on the Catawba River reservoirs, several investigations specific to the fisheries of Lake Hickory have been carried out (Table 13), including studies of bass and black and white crappie.

Lookout Shoals Lake

Spring shoreline electrofishing was conducted by Duke Power on Lookout Shoals Lake annually from 1994 through 1997 and in 2000 to document the characteristics of the littoral fish community (Table 26). Twenty-seven species of fish, plus hybrid sunfish, were observed during electrofishing. Littoral fish biomass averaged 43.1 kg per kilometer of shoreline. Largemouth bass constituted the largest percentage of biomass, averaging 46%; common carp averaged 17%, sunfish (primarily bluegill, redear, and redbreast) 16%, and white catfish 9%. Total density in the littoral fish community averaged 314.2 fish per kilometer of shoreline, consisting of 41% bluegill, 17% yellow perch, 15% largemouth bass, and 14% redbreast sunfish.

Characteristics of the littoral fish community in summer were studied in 1981 by the NC Wildlife Resources Commission, using cove rotenone sampling (Table 12). Total littoral fish biomass was estimated to be 301.4 kg/ha, which consisted of 20% catfish, 18% gizzard shad, 18% carp, 18% sunfish, and 15% suckers.

Duke Power studied the characteristics of the limnetic forage fish community with hydroacoustic sampling, carried out in 1997 and 2000 (Table 10), and purse seine sampling, conducted annually from 1993 through 1997 and in 2000 (Table 11). Limnetic forage fish densities averaged 7,016 fish/ha. As with the other upper Catawba reservoirs, the composition of the forage fish community was extremely variable among years. Gizzard shad accounted for close to 100% of the community in 1994, 1995, and 1996, while threadfin shad accounted for nearly 100% in 1993, 1997, and 2000. Again, variability in forage fish community composition was potentially due to mortality of threadfin shad at temperatures below 9 °C; winter temperatures on Lookout Shoals Lake averaged 6.6 °C (Table 3).

No creel surveys have been conducted to date on Lookout Shoals Lake and harvest data are not available for this reservoir.

The fish stocking history of Lookout Shoals Lake is detailed in Tables 14 and 15. Striped bass have been stocked sixteen of the past twenty years; threadfin shad were stocked periodically during that time.

No fish kills were reported on Lookout Shoals Lake from 1988 through July 2001 (Table 17). However, as with reservoirs upstream of Lookout Shoals Lake, winter die-offs of threadfin shad were likely to have occurred periodically.

In addition to studies covering multiple Catawba River reservoirs, several studies have been conducted on specific aspects of the Lookout Shoals fishery. Specifically, dynamics of bass and black crappie have been investigated (Table 13).

Lake Norman

Duke Power investigated the littoral fish community of Lake Norman with spring shoreline electrofishing annually from 1993 through 1997 and from 1999 through 2002 (Tables 27, 28, 29). Electrofishing was conducted in an uplake area in the vicinity of Marshall Steam Station; a midreservoir area in the main channel just upstream of the confluence with the Davidson Creek arm; and in the forebay area in the vicinity of McGuire Nuclear Station (Duke Power 2003). Total fish biomass averaged 37.5 kilograms per kilometer of shoreline in the uplake area, 31.7 kg/km in the midreservoir area, and 20.3 kg/km in the vicinity of the forebay. Statistically, fish biomass in the forebay region was significantly lower than in the midreservoir and uplake regions ($p<0.01$).

Thirty-five species of fish, plus hybrid sunfish, were observed during spring electrofishing. Taxonomic composition of the littoral fish community was similar among reservoir regions. Largemouth bass comprised 33 to 39% of total fish biomass, common carp 25 to 35%, and sunfish (primarily bluegill, redbreast, and redear) 14 to 23%. In terms of fish numbers, the community was dominated by sunfish (54 to 60% of total fish density), shiners (17 to 20%), and largemouth bass (9 to 14%).

The characteristics of the summer littoral fish community of Lake Norman were studied annually from 1982 to 1984 with cove rotenone sampling (Table 12). Littoral fish standing stock on Lake Norman averaged 150.4 kg/ha. Gizzard shad accounted for 28% of biomass, carp 23%, sunfish 14%, crappie 9%, threadfin shad 7%, largemouth bass 5%, catfish 5%, yellow perch 4%, and white bass 2%.

The abundance of limnetic forage fish in Lake Norman was estimated by Duke Power with hydroacoustic sampling annually from 1997 through 2003 (Table 10). Sampling was conducted in six zones from headwaters to forebay (Figure 11). Mean densities of forage fish ranged from 2,189 fish/ha in Zone 6, a riverine area in the headwaters of Lake Norman, to 9,636 fish/ha in Zone 5. Statistically, densities in Zone 6 were significantly lower than in all other zones, while densities in Zone 5 were significantly higher than in all zones except Zone 3.

The taxonomic composition of the forage fish community was investigated by Duke Power utilizing purse seine sampling annually from 1993 through 2003 (Table 11). From 1993 through 1998, the forage fish community consisted virtually entirely of threadfin shad; in contrast to reservoirs upstream, mean winter temperatures in some areas of Lake Norman exceed the level at which threadfin shad become thermally stressed (Table 3). In 1999, alewife appeared in Lake Norman purse seine samples for the first time, potentially as a result of angler 'bait-bucket' introduction. From 2000 through 2003, alewife comprised 17% of fish in purse seine samples, on average (Table 11). Anecdotal stories from anglers also mentioned introductions of blueback herring. Though none have been taken in purse seine samples to date, some blueback herring were collected in the Lookout Shoals tailrace during electrofishing studies conducted by Duke Power for the Aquatics 01 fish community survey (D. Coughlan, Duke Power, personal communication).

A creel survey carried out on Lake Norman from March 1994 through February 1995 yielded a total sport fish harvest of 351,098 fish weighing 90,867 kg (6.9 kg/ha/yr based on surface area at full pond) (Baker 1997, Duke Power 2003) (Tables 4, 5). By weight, harvest consisted of 49% crappie, 13% largemouth bass, 13% striped bass, and 12% blue catfish. Numerically, harvest was dominated by crappie (72%), largemouth bass (7%) and white bass (7%).

The fish stocking history of Lake Norman is documented in Tables 14 and 15. Over the past two decades, only striped bass and gizzard shad have been stocked, gizzard shad in 1999, and striped bass annually since 1981. Threadfin shad were introduced to Lake

Norman in 1963 and were successfully established. As noted above, alewife appeared in Lake Norman in 1999, presumably as a result of angler introduction.

Over the period 1988 through July 2001, two fish kills were reported in the Lake Norman watershed (Table 17). In August 1990, mortality of an estimated 150 striped bass was reported on Lake Norman, and in April 1997 a kill of 170 catfish was reported for Lyle Creek, a tributary of Lake Norman, due to a toxic spill from the Conover Northeast waste water treatment plant. In mid-summer 2004, mortality of approximately 2,500 striped bass was reported on Lake Norman (North Carolina Division of Water Quality 2004). The die-off was attributed to trapping of striped bass in the hypolimnion due to low metalimnetic oxygen levels, followed by mortality as oxygen concentrations in the hypolimnion declined to near zero.

Specific aspects of the Lake Norman fishery have been extensively investigated and documented (Table 13). The characteristics of both the entire community and individual populations have been investigated, as have the environmental factors affecting taxa such as black crappie, striped bass, redbreast sunfish, blue catfish, flat bullhead, and others.

Mountain Island Lake

Duke Power (2003) utilized spring shoreline electrofishing to investigate the littoral fish community of Mountain Island Lake annually 1993-1997 and 1999-2002 (Table 30). Twenty-eight species of fish, plus hybrid sunfish, were observed. Mean total fish biomass averaged 45.8 kilograms per kilometer of shoreline. Common carp comprised 40% of total fish biomass, largemouth bass 33%, and sunfish (primarily redbreast, bluegill, and redear) 17%. In terms of numbers, sunfish accounted for 69% of total fish density, and largemouth bass for 21%.

The NC Wildlife Resources Commission conducted cove rotenone sampling of the littoral fish community in summer 1981 (Table 12). Littoral fish standing stock was 81.2 kg/ha. By weight, the littoral community consisted of 33% carp, 28% sunfish, 19% gizzard shad, 9% catfish, 4% yellow perch, 3% largemouth bass, 2% crappie, and 2% suckers.

Duke Power utilized hydroacoustic sampling to estimate limnetic forage fish densities on Mountain Island Lake in 1997, and annually 1999 through 2003 (Table 10). Annual estimates ranged from 998 to 4,554 fish/ha, averaging 3,102 fish/ha. Purse seine sampling was carried out from 1993-2003 (with the exception of 1998) to characterize the taxonomic composition of the forage fish community (Table 11). From 1993 through 1999, threadfin shad accounted for an average of 96% of forage fish in purse seine samples, with the remainder consisting of gizzard shad. Alewife first appeared in purse seine samples in 1999, presumably as a result of downstream movement from Lake Norman, where this species was suspected to have been introduced by anglers. Alewife comprised 12% of the forage fish density on Mountain Island Lake from 2000-2002. In 2003, however, the relative abundance of this species increased dramatically; alewife accounted for 83% of fish in purse seine samples.

Duke Power conducted a creel survey on Mountain Island Lake December 1982 through November 1983 (Cloutman et al. 1988, Duke Power 2003), which yielded an annual harvest estimate of 53,502 fish weighing 10,985 kg (8.4 kg/ha/yr based on surface area at full pond). In terms of weight, harvest consisted of 46% crappie, 17% catfish, 13% sunfish, and 11% largemouth bass (Tables 4, 5).

The fish stocking history of Mountain Island Lake is documented in Tables 14 and 15. For the past two decades, stocking has been limited to striped bass; this species has been stocked nearly annually since 1981.

No fish kills have been reported on Mountain Island Lake (Table 17). Mean winter water temperatures exceeded 9 °C (Table 3), permitting year-round survival of threadfin shad.

Lake Wylie

Duke Power investigated the littoral fish community of Lake Wylie with spring shoreline electrofishing conducted annually from 1993 through 1997 and 1999 through 2002 (Tables 31, 32, 33). Three areas were sampled: an uplake region near Plant Allen, in the South Fork Catawba arm of Lake Wylie just above the confluence with the main Catawba River channel; a midlake region in the vicinity of Buster Boyd Bridge; and a downlake region in major coves on both sides of the main channel, in the vicinity of Catawba Nuclear Station (Duke Power 2003). Total littoral fish biomass averaged 132.0 kilograms per kilometer of shoreline in the uplake area, 122.8 kg/km midlake, and 88.7 kg/km downlake. Statistically, biomass downlake was significantly lower than in mid- and uplake regions ($p \leq 0.01$).

Thirty-eight species of fish, plus hybrid sunfish, were observed during spring electrofishing on Lake Wylie. In terms of biomass, the littoral fish community in the uplake area consisted of, on average, 38% largemouth bass, 19% common carp, 16% white catfish, and 8% bluegill. In the midlake area, biomass was comprised of 47% largemouth bass, 20% white catfish, 9% bluegill, and 8% gizzard shad. Taxonomic composition by weight in the downlake area was generally similar to that observed midlake, consisting of 41% largemouth bass, 23% white catfish, 11% bluegill, and 11% gizzard shad. In terms of numbers, sunfish accounted for 64 to 65% of total fish density lakewide, while largemouth bass accounted for 11 to 14%.

From 1982-1984, the summer littoral fish community of Lake Wylie was assessed with cove rotenone sampling (Table 12). These studies yielded a mean littoral fish biomass estimate of 391.6 kg/ha. Gizzard shad dominated the community in terms of biomass, accounting for 36% of total biomass on average, as compared to sunfish (21%), catfish (20%), suckers (8%), largemouth bass (6%), threadfin shad (5%), and carp (3%).

Duke Power utilized hydroacoustic sampling of four zones on Lake Wylie in 1997 and 2000 to estimate densities of limnetic forage fish (Table 10; Figure 11). Mean densities ranged from 2,402 fish/ha in the South Fork Catawba arm to 8,746 fish/ha downlake. Purse seine samples were collected annually on Lake Wylie from 1993-2003 (excluding 1998) to characterize the taxonomic composition of the forage fish community (Table

11). Threadfin shad constituted greater than 99% of the forage fish community in all years sampled. Alewife first appeared in Lake Wylie in 2001, presumably due to downstream transport of this species from Mountain Island Lake; however, alewife comprised less than 1% of the purse seine catch from 2000 through 2003.

Multiple creel surveys have been conducted to document sportfish harvest on Lake Wylie (Duke Power 2003). The most recent effort was carried out from July 1993 through June 1996 by the South Carolina Department of Natural Resources (SCDNR) and Duke Power (Christie and Stroud 1996, Duke Power 2003). Annual total harvest estimates ranged from 14.8 to 18.9 kg/ha/yr (based on surface area at full pond) (Tables 4, 5). In terms of weight, largemouth bass accounted for 29 to 41% of total harvest, black crappie for 30 to 36%, and channel catfish for 10 to 16%. Numerically, harvest was dominated by black crappie (46 to 51%), largemouth bass (12 to 17%), and bluegill (11 to 15%).

The fish stocking history of Lake Wylie is documented in Tables 14-16. In recent years, stocking has been limited to bluegill and redear sunfish, stocked in 1992, and white bass, stocked in 1998.

Fish kill reports for Lake Wylie and streams in the Lake Wylie watershed are documented in Tables 17 and 18. Winter kills of threadfin shad were occasionally reported during the 1970s and 1980s.

In addition to studies encompassing multiple reservoirs in the Catawba River system, several studies have been conducted on specific aspects of the Lake Wylie fishery (Table 13). These studies include investigations of the population characteristics of largemouth bass, black and white crappie, and bluegill in Lake Wylie.

Fishing Creek Reservoir

The littoral fish community of Fishing Creek Reservoir was characterized through spring shoreline electrofishing, carried out by Duke Power from 1993 through 1997 and in 2000 (Table 34). Total littoral fish biomass averaged 92.7 kilogram per kilometer of shoreline, consisting of 37% largemouth bass, 30% common carp, 11% catfish (primarily white and channel catfish), and 10% sunfish (primarily bluegill). In terms of numbers, the community was dominated by sunfish, which accounted for 53% of total fish density, on average; largemouth bass accounted for 15% of total density, and gizzard shad 12%. A total of 32 species of fish, plus hybrid sunfish, were observed in electrofishing studies.

Limnetic densities of forage fish were assessed by Duke Power utilizing hydroacoustic sampling conducted in late summer-early fall, 1997 and 2000 (Table 10). Forage fish densities were estimated to be 3,163 fish/ha in 1997 and 32,606 fish/ha in 2000. Species composition of the forage fish community was not examined.

A creel survey of the Fishing Creek Reservoir fishery was conducted by SCDNR and Duke Power from July 2000 through June 2002 (Christie and Stroud 2004). Sport fishermen harvested 89,701 fish weighing 28,659 kg in 2000-2001, and 98,652 fish weighing 22,228 kg in 2001-2002; sport fish harvest averaged 18.7 kg/ha/yr, based on surface area at full pond (Tables 4, 5). Black crappie accounted for 49 to 57% of total weight harvested, largemouth bass for 15%, channel catfish 7 to 12%, carp 5 to 14%, and white bass 1 to 10%. In terms of numbers of fish, harvest was dominated by black crappie (54 to 62%), bluegill (11 to 12%), channel catfish (8 to 10%), largemouth bass (7 to 8%), and white bass (2 to 9%).

The fish stocking history of Fishing Creek Reservoir from 1970 through 2002 is documented in Table 16. During this period, stocking was limited to bluegill and redear sunfish, both stocked in 1993.

No fish kills were documented on Fishing Creek Reservoir from 1973 to 2001. Fish kill reports for streams in the Fishing Creek Reservoir watershed are documented in Tables 17 and 18.

Great Falls-Dearborn Reservoir

Spring shoreline electrofishing was carried out annually by Duke Power from 1994 through 1997 and in 2000 to investigate the littoral fish community on Great Falls-Dearborn Reservoir (Table 35). These studies yielded an average total fish biomass estimate of 83.3 kilograms per kilometer of shoreline. Littoral fish biomass consisted of 48% common carp, 18% largemouth bass, 13% sunfish (primarily redear and bluegill), and 10% catfish (primarily white and channel), on average. Average fish density was 267.1 fish per kilometer of shoreline. The community was numerically dominated by sunfish: bluegill accounted for 21% of total density, redear for 14%, pumpkinseed 9% and redbreast 9%. Largemouth bass and gizzard shad were also relatively abundant, averaging 14% and 11% of total density, respectively. A total of 25 species of fish, plus hybrid sunfish, were observed during electrofishing.

No additional fisheries data were available on Great Falls-Dearborn Reservoir, the smallest of the Catawba-Wateree reservoirs, with a surface area of 1.8 km^2.

Cedar Creek Reservoir

The littoral fish community of Cedar Creek Reservoir was investigated by Duke Power utilizing spring shoreline electrofishing, annually from 1994 through 1997 and in 2000 (Table 36). Twenty-eight species of fish, plus hybrid sunfish, were collected. Littoral fish biomass averaged 95.5 kg per kilometer of shoreline, consisting mostly of largemouth bass (48%) and common carp (34%). Total numbers of fish collected averaged 407.1 fish per kilometer of shoreline. Sunfish dominated the catch numerically. Bluegill comprised 36% of total fish density on average, redbreast 8%, pumpkinseed 7%, and redear 4%; largemouth bass were also numerically abundant, constituting 18% of total fish.

The SC Department of Natural Resources and Duke Power conducted a creel survey on Cedar Creek Reservoir from July 2000 through June 2002 (Christie and Stroud 2004). Annual harvest was estimated to be 56,572 fish weighing 16,540 kg in 2000-2001, and 42,453 fish weighing 10,325 kg in 2001-2002, for an average sport fish harvest of 42.0 kg/ha/yr, based on surface area at full pond (Tables 4, 5). Black crappie accounted for 49 to 77% of total harvest by weight, channel catfish 9 to 25%, and largemouth bass 9 to 15%. In terms of numbers, mean annual harvest averaged 155 fish per hectare, consisting of 60% black crappie, 17% bluegill, and 12% channel catfish, on average.

No fish kills have been documented on Cedar Creek Reservoir (Table 18).

Lake Wateree

Duke Power utilized spring shoreline electrofishing to characterize the littoral fish community of Lake Wateree (Tables 37 and 38). Sampling was conducted annually from 1994 through 1997 and in 2000. Two areas were sampled: an uplake region just upstream of the Dutchmans Creek confluence; and a region farther downlake, just upstream of the White Oak Creek confluence (Duke Power 2003). Thirty species of fish, plus hybrid sunfish, were observed during electrofishing. Total littoral fish biomass averaged 80.7 kg/km in the uplake area and 165.2 kg/km in the downlake area. Uplake-downlake differences in total biomass were statistically significant ($p<0.01$).

Taxonomic composition of the littoral fish community was generally similar in the two regions of Lake Wateree. Based on data from both regions, common carp accounted for 42% of total biomass on average, largemouth bass 31%, sunfish (primarily bluegill) 8%, and gizzard shad 7%. In terms of density, the littoral community was dominated by sunfish (primarily bluegill), which accounted for 37% of total fish numbers on average, and gizzard and threadfin shad, which together accounted for an average of 35% of total fish density (Tables 37 and 38).

The SC Department of Natural Resources employed summer sampling with rotenone to characterize littoral populations in coves of Lake Wateree in 1991-1992 and 2000 (Table 12). Fish biomass in these studies averaged 464.8 kg/ha. Dominant taxa included gizzard shad (37% of total biomass), sunfish (13%), threadfin shad (10%), and catfish (10%).

Limnetic forage fish densities in Lake Wateree were estimated to be 7,402 fish/ha in 1997 and 51,102 fish/ha in 2000, based on hydroacoustic sampling carried out by Duke Power (Table 10). Purse seine sampling was utilized on Lake Wateree annually from 1993 through 1997 and in 2000 in order to characterize taxonomic composition of the forage fish community (Table 11) (Duke Power 2003). Threadfin shad constituted from 80.0 to 99.9% of the limnetic forage fish community; gizzard shad averaged 5.7%.

The SC Department of Natural Resources and Duke Power conducted joint creel surveys on Lake Wateree from July 2000 through June 2002 (Christie and Stroud 2004). Annual harvest was estimated to be 735,452 fish weighing 225,767 kg for 2000-2001, and 604,518 fish weighing 213,094 kg for 2001-2002. Harvest averaged 39.6 kg/ha/yr based on surface area at full pond (Tables 4, 5). Black crappie constituted 31 to 47% of total harvest by weight, striped bass 22 to 32%, and channel catfish 10 to 11%. Numerically, harvest averaged 121 fish/ha. In terms of numbers, harvest was dominated by black crappie, which accounted for 33 to 47% of total fish harvested, bluegill (16 to 18%), white perch (10 to 17%), and channel catfish (9 to 10%).

The stocking history of Lake Wateree (Table 16) indicates that striped bass have been stocked at intervals of 1 to 2 years since 1990. Largemouth bass were stocked throughout the mid-1990s; stocking of bluegill and redear sunfish was carried out annually from 1991 through 1993.

Fish kill data for Lake Wateree (Table 18) indicate that winter kills of threadfin shad were occasionally reported during the 1970s and 1980s. Winter water temperatures on Lake Wateree averaged 8.6 °C (Table 3), below the threshold at which threadfin shad experience thermal stress.

RELATIONSHIPS OF FISH COMMUNITY CHARACTERISTICS TO ENVIRONMENTAL PARAMETERS

Littoral fish biomass

Total littoral fish biomass - Mean littoral fish biomass measured with spring shoreline electrofishing at 19 sites on Catawba-Wateree reservoirs, 1993-2002, ranged from 20.3 kg/km at the forebay of Lake Norman to 191.1 kg/km in the upper Catawba basin of Lake James (Figure 12; Table 9). Statistically significant differences in total fish biomass were observed both within and among lakes, based on non-parametric analysis of variance.

Generally, maximum attainable fish production is limited by the availability of food and suitable habitat. Numerous studies have documented relationships between production at the base of the food web and total fish yield, harvest, or standing stock, both within and across geographic regions (e.g., Oglesby 1977; Jones and Hoyer 1982; Downing et al. 1990; Rodriguez and Olmsted 1993). In addition, studies have established positive relationships between fish production and the nutrients which limit primary production (e.g., Hanson and Leggett 1982; Yurk and Ney 1989). Fish harvest, yield, and standing stock have also been extensively investigated in relation to morphometric, hydrological, and other characteristics of reservoirs (e.g., Jenkins 1968; Ploskey 1981; Kimmel and Groeger 1986).

To examine the potential influence of environmental factors on littoral fish biomass, correlation analyses were performed with variables related to reservoir fertility and habitat. Productivity-related factors included mean spring and summer surface concentrations of chlorophyll, total phosphorus, and total nitrogen; specific conductance; spring and summer concentrations of seston ash-free dry weight (volatile solids); and spring and summer densities of zooplankton. Habitat-related factors included shoreline characteristics (percent sand, cobble, etc.) and the shoreline development ratio (ratio of shoreline length to circumference of a circle with an area equivalent to lake area). Shoreline development ratio may provide an indication of the relative amount of shallow, cove habitat (Jenkins 1968). Correlations were also performed with mean depth and retention time, reservoir characteristics which may affect both productivity and habitat (Jenkins 1968); and with the morphoedaphic index (calculated here as specific conductance divided by mean depth), a commonly used and widely investigated predictor of fish abundance (Ryder 1965; Jenkins 1968, 1982; Jenkins and Morais 1971; Oglesby 1977; Ryder 1982).

Total littoral fish biomass was positively correlated with several variables related to reservoir fertility, including spring and summer surface chlorophyll concentration ($r=0.54$ and 0.63, respectively) (Table 39); spring and summer seston ash-free dry weight (volatile solids) ($r=0.67$ and 0.65, respectively) (Table 39); summer specific conductance ($r=0.54$) (Table 39); summer concentrations of total phosphorus ($r=0.57$) and total nitrogen ($r=0.51$) (Table 40); and spring and summer densities of rotifers ($r=0.85$ and $r=0.62$, respectively) (Table 41). No significant correlations were observed between total littoral fish biomass and parameters related to reservoir morphometry, hydrology, or shoreline habitat type. Similarly, the morphoedaphic index was not significantly correlated with littoral fish biomass (Table 42).

The correlation results described above suggest that primary production, i.e. food availability, was an important factor regulating littoral fish biomass in Catawba-Wateree reservoirs. Graphical examination of the relationship between littoral fish biomass and summer surface chlorophyll as an indicator of reservoir fertility indicated that littoral fish biomass tended to increase with increasing chlorophyll, up to chlorophyll concentrations above 25 µg/L (Figure 16). Fishing Creek Reservoir and the uplake area of Lake Wateree exhibited mean summer surface chlorophyll concentrations of 43 and 42 µg/L, respectively, highest among the sites sampled; these reservoirs exhibited the lowest littoral fish standing stock per unit chlorophyll of all reservoir sampling sites. When these two sampling sites were excluded from correlation analysis, the correlation coefficient between total littoral fish biomass and summer surface chlorophyll concentration increased to $r=0.73$ ($p=0.0009$; $N=17$). Thus, based on data from 17 of 19 sites, chlorophyll concentration could potentially account for 53% of variation in total littoral fish biomass (Table 43). Reduced yield of littoral fish biomass per unit chlorophyll on Fishing Creek Reservoir and the uplake region of Lake Wateree suggests that factors other than primary production may have significantly influenced the standing stock of littoral fish at these sites.

Nutrient concentrations have frequently been used to predict fish abundance in reservoirs (e.g., Hanson and Leggett 1982; Yurk and Ney 1989). The underlying basis for the relationship between nutrients and fish abundance is the importance of nutrients in limiting primary production. In the current study, the influence of nutrients on primary production was evident in positive correlations between summer concentrations of chlorophyll and total phosphorus ($r=0.70$), and chlorophyll and total nitrogen ($r=0.70$) (Table 44).

Nitrogen and phosphorus concentrations were strongly correlated with each other ($r=0.95$), indicating that loading of these parameters tended to be linked (Figure 17; Table 44). However, as concentrations of both nutrients increased, nitrogen-to-phosphorus ratios declined (Figure 18), signaling a shift in the relative importance of these nutrients as factors limiting primary production, from phosphorus in less-productive reservoirs to nitrogen in more-productive reservoirs. Smith (1982) indicated that phosphorus was likely to limit algal production at nitrogen-to-phosphorus ratios (by weight) of greater than 17, while at ratios of less than 10, nitrogen was more likely to limit algal production. TN:TP ratios on the Catawba-Wateree reservoirs ranged from greater than 25 on Lakes Norman and Mountain Island, where summer chlorophyll concentrations averaged less than 10 µg/L; to 4.6 on Fishing Creek Reservoir, which maintained the highest mean chlorophyll concentration among Catawba-Wateree reservoirs. Thus, a tendency was evident on Catawba-Wateree reservoirs for the limiting nutrient to shift from phosphorus to nitrogen with increasing eutrophication.

The relationship between nutrients and reservoir productivity was examined in greater detail with regression analysis. Initial regression analyses relating summer surface chlorophyll concentrations to nutrient concentrations identified Great Falls-Dearborn Reservoir as an outlying data point. Regression analyses performed following deletion of the data point for Great Falls-Dearborn Reservoir indicated that variation in total phosphorus concentrations could explain 72% of variation in chlorophyll concentrations, while variation in total nitrogen concentrations could explain 77% (Table 43; Figures 19, 20). The identification of Great Falls-Dearborn Reservoir as an outlier suggests that factors other than nutrients may have been important in influencing primary production in this reservoir. Great Falls-Dearborn exhibited the highest mean concentrations of inorganic (potentially bioavailable) nutrients of all sites sampled on the Catawba-Wateree reservoirs (Table 3), consistent with the idea that nutrients were unlikely to have been limiting primary production. Rodriguez (1986) suggested that algal production on this reservoir may have been limited by a lack of light penetration, and/or by washout (loss of phytoplankton from the reservoir prior to attainment of maximum potential standing stock as dictated by nutrients). Great Falls-Dearborn exhibited the highest turbidity of all sites sampled, and is characterized by a retention time of less than 1 day, shortest among the Catawba-Wateree reservoirs (Table 2).

In correlation analyses relating fish standing stock directly to nutrient concentrations, total littoral fish biomass was significantly, though not strongly, correlated with summer concentrations of both total phosphorus and total nitrogen (Table 40). However, at the four electrofishing sites with the highest nutrient concentrations (Cedar Creek, Fishing Creek, Great Falls-Dearborn, and the uplake section of Lake Wateree), the amount of fish biomass produced per unit of limiting nutrient (in this case, nitrogen), was significantly lower than at other potentially nitrogen-limited locations. Ratios of fish biomass (kg/km) to total nitrogen (mg N/L) at these four sites ranged from 79 to 118, as compared to 245 to 492 at other potentially nitrogen-limited sites (defined here as sites with TN:TP ratios of less than 17).

The reduced yield of fish per unit of limiting nutrient observed at Fishing Creek Reservoir and the uplake section of Lake Wateree is consistent with the observation that fish standing stock per unit chlorophyll at these sites was lower than at other sites, suggesting that factors other than primary production may have been influencing fish standing stock. On Great Falls-Dearborn and Cedar Creek Reservoirs, the reduced yield of fish per unit nutrient was potentially attributable to the influence of washout and/or light limitation on primary production in those reservoirs, leading to a disconnect between nutrient concentrations and fish production. Consistent with this idea, concentrations of inorganic nitrogen, potentially available for algal uptake, were highest on these reservoirs (Table 3).

When data for Cedar Creek, Fishing Creek, Great Falls-Dearborn and the uplake section of Lake Wateree were eliminated from regression analyses of fish biomass and nutrients, variation in total phosphorus concentration potentially explained 70% of variation in fish biomass, and total nitrogen potentially explained 50% (Table 43; Figures 21, 22).

The strong correlation between spring densities of rotifers and mean littoral fish biomass provides additional evidence of the importance of reservoir fertility, indicating that the abundance of both fish and zooplankton tended to vary along a gradient of productivity. Spring rotifer densities were strongly correlated with spring chlorophyll concentrations ($r=0.83$; $p=0.0004$; $N=13$). The lack of observation of significant, positive correlations between fish biomass and densities of crustacean zooplankton is likely attributable to the downward pressure exerted by fish predation on crustacean zooplankton standing stock, particularly predation by clupeids (Rodriguez 1988). In contrast to rotifers, densities of crustacean zooplankton were not significantly correlated with chlorophyll concentration in either spring or summer, consistent with the idea that predation was limiting standing stock.

As noted above, no significant correlations were detected between littoral fish biomass and habitat characteristics such as percent of shoreline consisting of sand, cobble, etc., or with reservoir morphometry or hydrology (Table 42), suggesting again that reservoir fertility was a primary factor influencing fish standing stock. It is important to note, however, that factors such as mean depth, shoreline development ratio, and percent of various types of shoreline (developed, sand, cobble, etc.) represent lakewide estimates. In light of the fact that littoral fish biomass differed significantly among sites sampled within reservoirs, it is less likely that relationships of fish biomass to morphometric and habitat-related factors would be revealed in correlation analyses utilizing lakewide means. In addition, although the overriding influence on fish standing stock may have been reservoir productivity, it is possible that habitat-related factors and other factors such as turbidity may have played a role in modifying the extent of conversion of primary production to fish biomass. Statistically, variability in chlorophyll concentration potentially explained just over half of observed variability in littoral fish biomass (Table 43).

Biomass of selected taxa - Correlation analyses were also carried out relating environmental parameters to mean littoral biomass estimates for selected individual fish taxa (Tables 39, 40, 41). The mean littoral biomass of largemouth bass, sunfish (consisting primarily of bluegill, redbreast, and redear), crappie, and ictalurids (consisting primarily of white and channel catfish) exhibited correlations with environmental parameters that were very similar to those exhibited by total littoral fish biomass, tending to increase with increasing concentrations of environmental parameters related to primary production. Biomass estimates among these taxa were strongly correlated with each other and with total littoral biomass (Table 45). The biomass of cyprinids, however, which consisted almost entirely of common carp, was not significantly correlated with chlorophyll (Table 39), was only weakly correlated with total littoral biomass, and was not significantly correlated with the biomass of other fish taxa (Table 45).

Limnetic forage fish densities

Mean limnetic forage fish densities derived from hydroacoustic sampling on Catawba-Wateree reservoirs ranged from 887 fish per hectare on the Linville River arm of Lake James to 29,252 fish/ha on Lake Wateree (Table 10; Figure 14). Estimates of forage fish density varied substantially among years on some reservoirs, potentially due in part to the susceptibility of threadfin shad to winter die-offs during severe winters (Strawn 1965, Griffith 1978), and to the influence of periodic threadfin shad stocking (Tables 14, 15).

The forage fish community on upstream reservoirs (Lakes James, Rhodhiss, Hickory, and Lookout Shoals) consisted of gizzard and threadfin shad (Figure 15). The relative abundance of these species was extremely variable among years (Table 11), again potentially due to the susceptibility of threadfin shad to winter die-offs.

On Lakes Norman, Mountain Island, and Wylie, threadfin shad comprised nearly 100% of the forage fish community from 1993 through 1999. All of these reservoirs receive thermal discharges which may act as refuge areas for threadfin shad during the winter (Duke Power 2003). Alewife initially appeared in purse seine samples in 1999 on Lakes Norman and Mountain Island, and in 2001 on Lake Wylie (Table 11). The presence of alewife is suspected to be due to angler or 'bait-bucket' introduction on Lake Norman, followed by migration of this species to downstream reservoirs. The relative abundance of alewife has increased rapidly on Lakes Norman and Mountain Island since its introduction. The forage fish community on Lake Wateree consisted primarily of threadfin shad.

Forage fish densities were measured in six zones on Lake Norman, four zones on Lake Wylie, two zones on Lake James, and lakewide on all other reservoirs. Total forage fish densities averaged over years for each of the 18 areas sampled with hydroacoustics were subjected to correlation analysis with environmental variables related to reservoir productivity. Forage fish density was positively correlated with spring and summer chlorophyll concentrations (Figures 23, 24) and with spring rotifer densities (Tables 46 and 47). In contrast, no statistically significant correlations were detected when area-weighted lakewide mean densities of forage fish were subjected to correlation analysis with variables related to habitat, morphometry, and hydrology (Table 48). The observation of positive correlations between forage fish density and measures of plankton abundance suggests that food availability was an important factor regulating total forage fish abundance, and is consistent with the planktonic feeding habit of young clupeids (Manooch and Raver 1988).

Sport fish harvest

Sport fish harvest was calculated as total numbers and weight of fish harvested divided by surface area at full pond. In terms of numbers, harvest ranged from 19 fish/ha/yr on Lake James to 155 fish/ha/yr on Cedar Creek Reservoir (Table 4). Numerically, harvest was typically dominated by crappie and sunfish, as well as largemouth bass and catfish

(Table 5). Walleye constituted a significant component of total fish harvested on Lake James. In terms of weight, harvest ranged from 7 kg/ha/yr on Lake Norman to 80 kg/ha/yr on Lake Rhodhiss. Major components of harvest by weight included striped bass (particularly on Rhodhiss, Hickory, and Wateree), crappie, largemouth bass, and channel catfish.

Total harvest estimates in terms of both density and weight were subjected to correlation analyses with fishing pressure (hr/ha/yr), water quality variables, morphometric and hydrologic variables, and variables quantifying shoreline characteristics (Table 49). Among the variables tested, harvest exhibited strongest correlations with fishing pressure (r=0.77 for harvest in terms of density, and 0.92 for harvest in terms of weight) (Figure 25). Few other significant correlations were detected, potentially due in part to the small number of observations available for analysis.

SUMMARY AND CONCLUSIONS

Spring shoreline electrofishing was carried out at 19 sites on the Catawba-Wateree reservoirs from 1993 through 2002. Based on this study, mean total littoral fish biomass ranged from 20.3 kilograms per kilometer of shoreline in the forebay region of Lake Norman to 191.1 kg/km in the upper Catawba basin of Lake James. Black basses, primarily largemouth bass, constituted 13 to 53% of total littoral biomass, averaging 37%. Cyprinids, primarily common carp, accounted for 2 to 48% of total biomass, averaging 27%. Sunfish (bluegill, redbreast, redear) comprised 12% of total biomass on average, ranging from 5 to 23%, and ictalurids, primarily white and channel catfish, accounted for 1 to 25% of total biomass, averaging 9%. Substantial, statistically significant variability was observed within and among Catawba-Wateree reservoirs in total littoral fish biomass and taxonomic composition.

Correlation analyses were performed in an attempt to identify the environmental factors underlying the observed spatial patterns in littoral fish biomass on Catawba-Wateree reservoirs. Total littoral biomass was positively correlated with summer chlorophyll concentrations ($r=0.62$; $p=0.0045$; $N=19$); this correlation was somewhat stronger when data were limited to the 17 sites where chlorophyll concentrations were less than 25 µg/L ($r=0.72$; $p=0.0010$; $N=17$). Regression analysis based on data from these sites indicated that variability in chlorophyll concentration could potentially explain 53% of variability in littoral fish biomass.

Littoral fish biomass was also positively correlated with both total phosphorus concentration ($r=0.57$; $p=0.0105$; $N=19$) and total nitrogen concentration ($r=0.51$; $p=0.0254$; $N=19$). However, based on concentrations of inorganic (potentially bioavailable) nutrients, and on low production of chlorophyll per unit nutrient, primary production on Great Falls-Dearborn and Cedar Creek Reservoirs appeared to be limited by washout and/or lack of light penetration. In addition, low ratios of littoral fish standing stock to chlorophyll at Fishing Creek Reservoir and the uplake region of Lake Wateree suggested that factors other than nutrient limitation may have been influencing littoral fish biomass at these sites. When these four sites were removed from correlation analyses between nutrients and littoral fish biomass, correlation coefficients increased to 0.84 ($p<0.0001$) for total phosphorus and 0.71 ($p=0.0031$) for total nitrogen, again suggesting that reservoir productivity was an important factor influencing fish standing stock. Consistent with this observation, littoral fish biomass was positively correlated with spring rotifer densities ($r=0.85$; $p=0.0002$; $N=13$) and summer rotifer densities ($r=0.62$; $p=0.0249$; $N=13$), over all sites for which zooplankton data were available. Lack of any significant correlation between crustacean zooplankton abundance and littoral fish standing stock was presumably due to the effect of fish predation on the standing stock of crustacean zooplankton.

The fact that littoral fish biomass in Catawba-Wateree reservoirs tended to vary along gradients related to reservoir productivity suggests that fish biomass was regulated primarily by food availability, particularly in reservoirs exhibiting chlorophyll concentrations at or below about 25 µg/L. These results are consistent with other studies that have documented the influence of primary production and limiting nutrients on total fish yield, harvest, standing stock, and production (Oglesby 1977; Hanson and Leggett 1982; Jones and Hoyer 1982; Downing et al. 1990; Yurk and Ney 1989; Rodriguez and Olmsted 1993).

In contrast to the relationships described above, littoral fish biomass was not significantly correlated with any parameter related to habitat or reservoir morphometry/hydrology, or with the morphoedaphic index. The fact that such correlations were not detected is at least partially attributable to the overriding influence of production at the base of the food web. However, the necessity of using lakewide means for correlations with habitat and morphometry-related factors eliminated within-lake variability from the analyses, reducing the amount of information as compared to that available for productivity-related correlations.

Among individual taxa, biomass of black basses, sunfish, crappie, and ictalurids all tended to increase with increasing reservoir productivity. In contrast, biomass of cyprinids exhibited no significant correlations with environmental variables related to either productivity or habitat. These trends are consistent with those observed in cove rotenone data for reservoirs of North and South Carolina (Rodriguez and Olmsted 1993).

Mean densities of limnetic forage fish on Catawba-Wateree reservoirs ranged from 887 fish/ha on the Linville River arm of Lake James to 29,252 on Lake Wateree. Forage fish densities on some reservoirs varied substantially among years, potentially due to the susceptibility of threadfin shad to winter die-offs during extreme winters, and to the influence of stocking of this species. Inter-annual variability was less evident on those reservoirs with thermal refuge areas, such as Lakes Norman and Wylie.

Both threadfin and gizzard shad were important components of the forage fish communities of Lakes James, Rhodhiss, Hickory, and Lookout Shoals. In Lake Norman and reservoirs downstream, the forage fish community consisted almost entirely of threadfin shad, prior to 2000. In 1999, however, alewife appeared in purse seine samples on Lakes Norman and Mountain Island, presumably as a result of angler 'bait-bucket' introduction on Lake Norman, and by 2001 this species had progressed downstream to Lake Wylie. Alewife accounted for as much as 25% of total annual forage fish density on Lake Norman and 83% of forage fish density on Mountain Island Lake following its initial appearance. According to anecdotal reports and 2004 electrofishing results, blueback herring are also present in Lake Norman.

Limnetic forage fish densities were positively correlated with spring and summer chlorophyll concentrations and with spring rotifer densities, suggesting that food availability was an important factor influencing forage fish standing stock.

Based on creel surveys, total harvest of sport fishes on the Catawba-Wateree reservoirs ranged from 6.9 kg/ha/yr on Lake Norman to 80.0 kg/ha/yr on Lake Hickory. Numerically, crappie constituted the largest percentage of fish harvested on all reservoirs with the exception of Lake James, on which sunfish comprised the largest percentage of harvest. Largemouth bass, channel catfish, bluegill, white bass, and white perch were also numerically important components of harvest; walleye accounted for a significant percentage of total fish harvested on Lake James. In terms of biomass, striped bass were a major component of total harvest on Lakes Rhodhiss, Hickory, and Wateree, and, to a lesser degree, on Lake Norman. Other taxa comprising substantial percentages of total biomass harvested included crappie, largemouth bass, and catfish.

Total sport fish harvest, whether expressed in terms of density or biomass, was strongly correlated with fishing pressure. Few significant correlations were observed with environmental parameters. Lack of detectable correlations between harvest and environmental parameters may have been due in part to the small number of observations available for this analysis, in addition to other factors such as the selective nature of sport fish harvest and the influence of management activities.

Results of these analyses taken as a whole produced a general pattern of increasing standing stock in the littoral and limnetic fish communities with increasing reservoir fertility. Based on the information in this study it would appear that food availability is an important factor influencing fish production in the Catawba-Wateree reservoirs. Undoubtedly environmental characteristics other than those related to productivity play a role in modifying the response of the fish community to trophic conditions, particularly at the species level.

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