Duke Energy.

Bryan J. Dolan
VP, Nuclear Plant Development

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September 17, 2008

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Duke Energy Carolinas, LLC
William States Lee III Nuclear Station - Docket Nos. 52-018 and 52-019
AP1000 Combined License Application for the
William States Lee III Nuclear Station Units 1 and 2
Response to Request for Additional Information
Ltr# WLG2008.09-04

Reference: Letter from J.M Muir (NRC) to B.J. Dolan (Duke Energy), *Request for Additional Information Regarding the Environmental Review of the Combined License Application for William States Lee Nuclear Station Units 1 and 2*, dated August 21, 2008

This letter provides the Duke Energy response to the Nuclear Regulatory Commission's (NRC) requests for the following additional information (RAI) items listed in the reference letter:

RAI 03, Hydrology
RAI 53, Aquatic Ecology
RAI 54, Aquatic Ecology
RAI 65, Terrestrial Ecology

A response to each NRC request is addressed in an enclosure which also identifies any associated changes that will be made in a future revision of the William States Lee III Nuclear Station application.

If you have any questions or need any additional information, please contact Peter Hastings at 980-373-7820.

Bryan J. Dolan
Vice President
Nuclear Plant Development

D079
NRO

Enclosures:

1. Response to RAI 03, Hydrology
2. Response to RAI 53, Aquatic Ecology
3. Response to RAI 54, Aquatic Ecology
4. Response to RAI 65, Terrestrial Ecology

AFFIDAVIT OF BRYAN J. DOLAN

Bryan J. Dolan, being duly sworn, states that he is Vice President, Nuclear Plant Development, Duke Energy Carolinas, LLC, that he is authorized on the part of said Company to sign and file with the U. S. Nuclear Regulatory Commission this supplement to the combined license application for the William States Lee III Nuclear Station and that all the matter and facts set forth herein are true and correct to the best of his knowledge.

Bryan J. Dolan

Bryan J. Dolan

Subscribed and sworn to me on September 17, 2008

Phoebe P. Elliott

Notary Public

My commission expires: June 26, 2011

SEAL

xc (wo/enclosures)

Michael Johnson, Director, Office of New Reactors
Gary Holahan, Deputy Director, Office of New Reactors
David Matthews, Director, Division of New Reactor Licensing
Scott Flanders, Director, Division of Site and Environmental Reviews
Glenn Tracy, Director, Division of Construction Inspection and Operational Programs
Luis Reyes, Regional Administrator, Region II
Loren Plisco, Deputy Regional Administrator, Region II
Thomas Bergman, Deputy Division Director, DNRL
Stephanie Coffin, Branch Chief, DNRL

xc (w/enclosures)

Linda Tello, Project Manager, DSER
Brian Hughes, Senior Project Manager, DNRL

bxc (w/out enclosures):
- Dhiaa Jamil
- Peter Hastings
- Bob Morgan
- Ted Bowling
- Kate Nolan
- Rita Sipe
- Lisa Vaughn

bxc (w/ enclosures):
- Chris Nolan
- Don Silverman
- Kathryn Sutton
- Shelley Kowkabany
- ELL 05P
- File No. WLG 4000.25-04-03

Lee Nuclear Station Response to Request for Additional Information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Number(s): ER RAI 03

NRC RAI:

Submit a discussion of the discharge characteristics of the Broad River (e.g., record used for analysis, average flow, 7Q10, drought years).

Duke Energy Response:

The attached report from Devine, Tarbell and Associates dated July 7, 2008 discusses the discharge characteristics of the Broad River.

Associated Response to the Lee Nuclear Station Combined License Application:

None.

Associated Attachment:

Revised Hydrology Report for Proposed Lee Nuclear Station, July 7, 2008

Devine Tarbell & Associates, Inc.
Consulting Engineers, Scientists, & Regulatory Specialists

John J. Devine, P.E. President
John C. Tarbell, P.E. Sr. Vice President
Richard R. Miller, P.E. CEO
Edwin C. Luttrell, P.E. COO
James M. Lynch, Sr. Vice President

July 7, 2008

Mr. Dale Smith
Nuclear Special Projects
Duke Energy Carolinas, LLC
526 S. Church Street
Charlotte, NC 28202

Subject: **Revised Hydrology Report for Proposed Lee Nuclear Station**

Dear Mr. Smith:

The proposed William States Lee III Nuclear Station (LNS) is located on the Broad River in Cherokee County, North Carolina. Under normal station operations, LNS will withdraw cooling water directly from the Broad River. However, under low river flow conditions, cooling water will be provided by the existing Make Up Pond A and Make Up Pond B at the site. Devine Tarbell & Associates, Inc. (DTA) was commissioned by Duke Energy Carolinas, LLC (Duke) to update and analyze hydrology data regarding low flow conditions and drought frequency.

1.0 Hydrology Database and Annual Mean Flows

The U.S. Geological Survey (USGS) streamflow gauge used for this study was the Broad River at Gaffney, SC (Gauge No. 2153500). This gauge was chosen due to its proximity to LNS located near Gaffney, SC, along the west bank of Ninety-Nine Islands Reservoir. Daily average flows for this gauge were compiled using a combination of actual data from the gauge at Gaffney (1938–1971, 1986–1990) and pro-rated flow data from two upstream USGS gauges on the main stem of the Broad River. The two upstream gauges used were the Broad River near Blacksburg, SC (No. 2153200, 3.1 river miles upstream from the Gaffney gauge), and the Broad River near Boiling Springs, NC (No. 2151500, 16.2 river miles upstream from the Gaffney gauge). During periods where data was not available from the Gaffney USGS gauge, the preference was to use pro-rated data from the Blacksburg gauge. If Blacksburg gauge data was not available, the Boiling Springs gauge was used. Drainage area ratios for the two upstream gauges were used to calculate pro-rated flows, based on drainage area ratios, at the Gaffney gauge for the time periods where flow data was not available. This resulted in an 81-year period of record for the Broad River at the Gaffney gauge location (1926–2006). Table 1 shows the annual mean flows for the entire 81-year period of record and the cumulative annual mean flows in 10-year increments.

DTA

TABLE 1
BROAD RIVER AT GAFFNEY, SC (GAUGE NO. 2153500)
ANNUAL MEAN FLOWS

Year	Annual Mean Flow	Cumulative Mean Flow
1926	1,582	
1927	1,562	
1928	3,225	
1929	3,642	
1930	1,738	
1931	1,802	
1932	2,707	
1933	2,174	
1934	2,407	
1935	2,373	**2,321 cfs**
1936	3,707	
1937	3,279	
1938	1,933	
1939	2,131	
1940	1,812	
1941	1,552	
1942	2,161	
1943	2,398	
1944	2,657	
1945	2,555	**2,370 cfs**
1946	2,760	
1947	2,450	
1948	2,932	
1949	3,608	
1950	2,453	
1951	1,932	
1952	2,543	
1953	1,992	
1954	1,691	
1955	1,489	**2,375 cfs**
1956	1,510	
1957	2,640	
1958	3,001	
1959	2,961	
1960	3,218	
1961	2,942	
1962	2,874	
1963	2,239	
1964	3,662	
1965	2,871	**2,479 cfs**

Year	Annual Mean Flow	Cumulative Mean Flow
1966	2,262	
1967	2,482	
1968	2,234	
1969	2,807	
1970	2,307	
1971	3,117	
1972	2,977	
1973	3,951	
1974	3,409	
1975	4,175	**2,578 cfs**
1976	3,182	
1977	2,564	
1978	2,638	
1979	3,866	
1980	3,021	
1981	1,440	
1982	2,284	
1983	3,208	
1984	3,070	
1985	1,987	**2,602 cfs**
1986	1,680	
1987	2,656	
1988	1,325	
1989	2,346	
1990	3,049	
1991	2,603	
1992	3,001	
1993	3,038	
1994	2,477	
1995	3,439	**2,597 cfs**
1996	2,783	
1997	2,442	
1998	2,644	
1999	1,523	
2000	1,377	
2001	973	
2002	1,180	
2003	3,774	
2004	2,656	
2005	2,693	
2006	1,746	**2,538 cfs**

2.0 7Q10 Calculation

DTA identified the annual 7-day low flow for each year in the period of record using a Log-Pearson Type III (LPIII) distribution to calculate the 7Q10 (i.e., the lowest consecutive 7-day streamflow that is likely to occur in a 10-year period). This is the same methodology recommended and used by the USGS which applies an LPIII non-exceedance analysis for low flow statistics (USGS 1981). DTA calculated the 7Q10 for the Broad River at the Gaffney gauge to be 479 cfs. Table 2 shows annual, 10-year, and cumulative 7Q10 flow for the entire 81-year period of record. Note that the USGS typically uses the longest period of record available when calculating and reporting 7Q10 low flow statistics. This study incorporates the same methodology.

TABLE 2
BROAD RIVER AT GAFFNEY, SC (GAUGE NO. 2153500)
CUMULATIVE 7Q10 FLOWS

Year	7Q1	Cumulative 7Q10
1926	540	
1927	565	
1928	1,330	
1929	1,367	
1930	634	
1931	525	
1932	668	
1933	857	
1934	1,217	
1935	930	**505 cfs**
1936	1,311	
1937	1,380	
1938	936	
1939	772	
1940	569	
1941	566	
1942	994	
1943	931	
1944	967	
1945	918	**555 cfs**
1946	1,142	
1947	893	
1948	1,024	
1949	1,684	
1950	1,172	
1951	729	
1952	867	
1953	682	
1954	387	
1955	533	**533 cfs**
1956	374	
1957	703	
1958	1,133	
1959	1,119	
1960	1,366	
1961	1,077	
1962	1,157	
1963	790	
1964	1,224	
1965	1,227	**540 cfs**

Year	7Q1	Cumulative 7Q10
1966	811	
1967	1,010	
1968	822	
1969	1,311	
1970	913	
1971	1,417	
1972	1,363	
1973	1,533	
1974	1,302	
1975	1,656	**572 cfs**
1976	1,112	
1977	920	
1978	1,039	
1979	1,370	
1980	1,389	
1981	696	
1982	959	
1983	1,163	
1984	1,369	
1985	801	**597 cfs**
1986	394	
1987	770	
1988	567	
1989	934	
1990	1,201	
1991	1,152	
1992	1,243	
1993	845	
1994	1,110	
1995	1,370	**589 cfs**
1996	1,213	
1997	931	
1998	816	
1999	311	
2000	311	
2001	380	
2002	104	
2003	1,652	
2004	1,051	
2005	859	
2006	542	**479 cfs**

3.0 Flow Thresholds and Recurrence Intervals

A minimum continuous flow of 483 cfs was established for Ninety-Nine Islands Hydroelectric Facility for months July through November when low river flow is likely during the Federal Energy Regulatory Commission (FERC) relicensing effort in 1996. LNS will withdraw 78 cfs from the Broad River, with 55 cfs being consumed and 23 cfs used for screen washing and cooling tower blowdown being returned to the river. Two scenarios were considered in a water needs assessment performed for the LNS site. First, based on the minimum continuous flow, LNS was analyzed as if the plant had historically operated from 1926 to 2006. In this case, when the daily average flow rate in the Broad River drops below 538 cfs (483 cfs + 55 cfs consumptive use at LNS), an off-channel storage reservoir would be necessary to supplement consumptive water use needs at LNS. In the second scenario, future water demands were included in addition to plant operations. When the daily average flow rate in the Broad River drops below 588 cfs (483 cfs + 55 cfs consumptive use at LNS + 23 cfs future NC withdrawal + 17 cfs Cliffside Steam Station additional consumptive use + 10 cfs city of Shelby, NC future withdrawal), an off-channel storage reservoir would be necessary to supplement consumptive water use needs at LNS.

Using the 81-year daily average flow record for the Gaffney gauge, 7-day, 30-day, and 90-day rolling averages were plotted using a logarithmic scale. A polynomial trend line was fitted to the 7-day rolling average data and an LPIII distribution was fitted to the 30-day and 90-day rolling average data. Using logarithmic interpolation, the recurrence interval was identified for flows in the Broad River below the withdrawal thresholds based on minimum continuous flows at Ninety-Nine Islands Hydro. The 7-day rolling average flows were analyzed to determine the frequency that LNS would be required to align to an off-channel storage reservoir for a consecutive 7-day period. The 30-day rolling average flows were selected based on the volume of the existing Make Up Pond B reservoir at LNS. The 90-day rolling average flows were analyzed to determine the frequency that LNS would be required to align to an off-channel storage reservoir for a consecutive 90-day period to maintain full station operability. Table 3 identifies the recurrence intervals using the above thresholds and time durations. Figures 1, 2, and 3 (attached to this report) display the three regression curves used in this analysis.

TABLE 3
RECURRENCE INTERVAL RESULTS

Thresholds Based on Minimum Flows at Ninety-Nine Islands Hydro + LNS consumptive use (483 + 55 = 538 cfs)	
Rolling Daily Flow Averages	**538 cfs**
7-day	1.7 years
30-day	12.6 years
90-day	25.3 years
Thresholds Based on Minimum Flows at Ninety-Nine Islands Hydro + LNS consumptive use + future water demands (483 + 55+ 23 + 17 + 10 = 588 cfs)	
Rolling Daily Flow Averages	**588 cfs**
7-day	1.3 years
30-day	8.5 years
90-day	16.6 years

4.0 Frequency Analysis

DTA performed a frequency analysis to find out the number of days that flows at the USGS gauge on the Broad River in Gaffney, SC dropped below the 538 cfs threshold explained in Section 3. The entire 81-year period of record was analyzed on a monthly basis and distinguished in three ways. First, the total number of days in each month that the flow in the Broad River at the Gaffney gauge was below 538 cfs was determined. Next, the number of consecutive days within each month when flows were below 538 cfs was recorded. Lastly, the maximum number of consecutive days that flows were below 538 cfs within each month was recorded. Figures 4 through 11 show this frequency analysis in 10-year increments for the 81-year hydrology database established in this study.

5.0 Low Flow Pond Analysis

DTA built a model to analyze using the existing Make Up Pond A and Make Up Pond B at LNS as supplemental make up water resources during times of low flow in the Broad River. This tool can modify inputs to illustrate different scenarios. Some of these inputs include maximum pumping capabilities from the Broad River, starting reservoir elevations, daily water requirements from LNS, and future water demands. Two cases were studied. The first case is shown in Figures 12 through 14, which illustrate reservoir levels assuming that LNS had operated over the 81-year period of record with the limit of no consumptive withdrawal below the minimum continuous flow of 483 cfs at Ninety-Nine Islands Hydroelectric Facility. The second case is shown in Figures 15 through 17, which illustrate the same constraints as the first case, adding in future water withdrawals as explained in Section 3. These figures also reflect a maximum pumping capacity from the Broad River of 127 cfs and a 55 cfs daily consumptive water use for LNS. Figures 12 and 15 show the entire period of record, while Figures 13 and 16 highlight the 1954–1956 drought, and Figures 14 and 17 highlight the 1999–2002 drought. This

reservoir model reflects that LNS would have been off-line for at least 42 days in 2002 without future water demands, and 48 days in 2002 with future water demands.

6.0 References

U.S. Geological Survey. 1981. "Guidelines for Determining Flood Flow Frequency." Bulletin #17B of the Hydrology Subcommittee. Reston, Virginia.

This report highlights DTA's analysis and results regarding the updated hydrology data, low flow conditions, and drought frequency for LNS. Should you have any questions or require further information, please contact me at (704) 342-7994, liz.gilchrest@devinetarbell.com; or Ty Ziegler at (704) 342-7381, ty.ziegler@devinetarbell.com.

Sincerely,

DEVINE TARBELL & ASSOCIATES, INC.

Liz Gilchrest, E.I.T.	Carey Fraser	Ty Ziegler, P.E.
Associate Engineer	Technical Editor	Environmental Engineering Manager

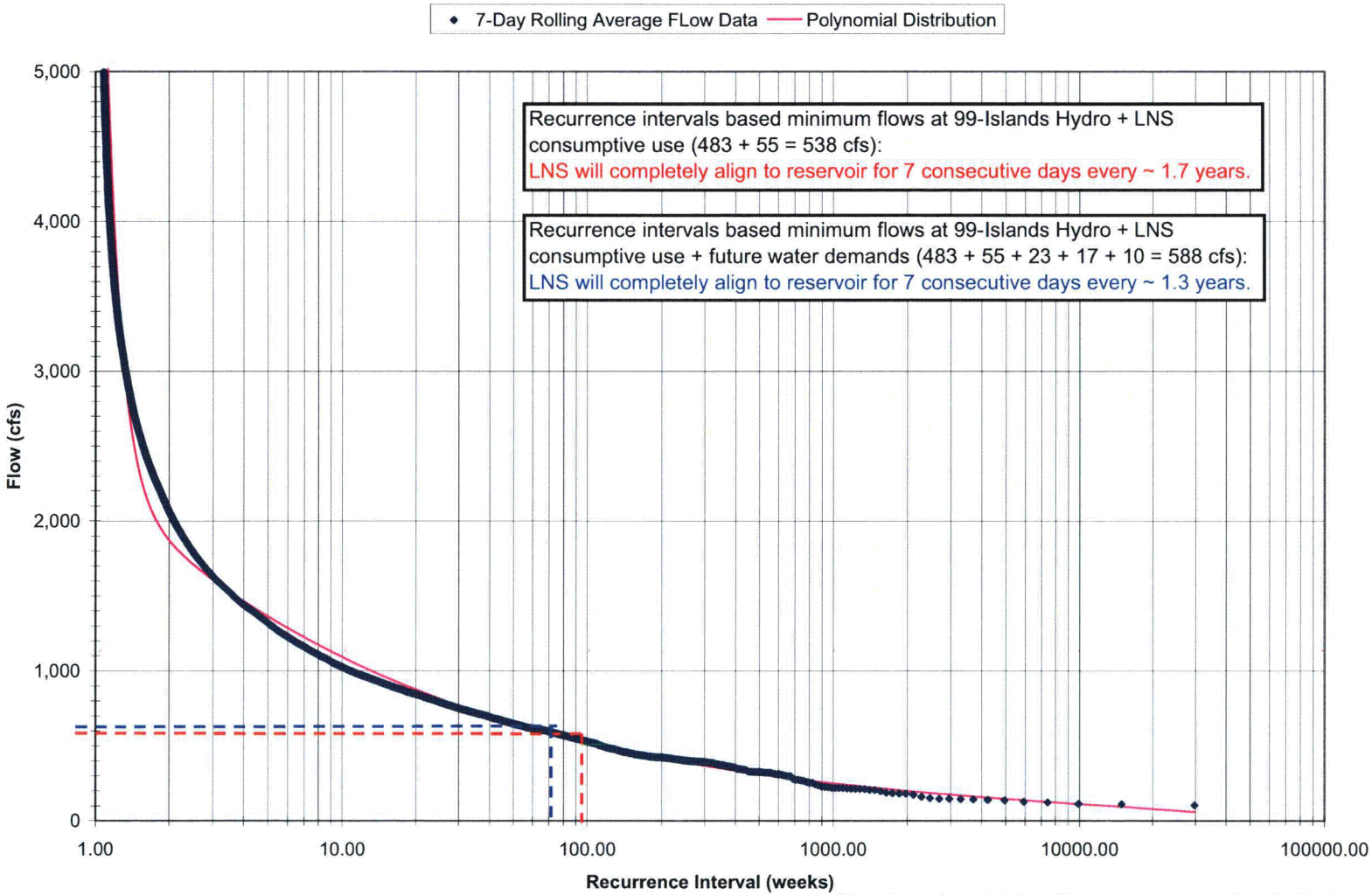
ESG/cef
Attachments

cc: T. Ziegler, DTA
T. Bowling, Duke Energy
J. Thrasher, Duke Energy
File

ATTACHMENTS

FIGURE 1

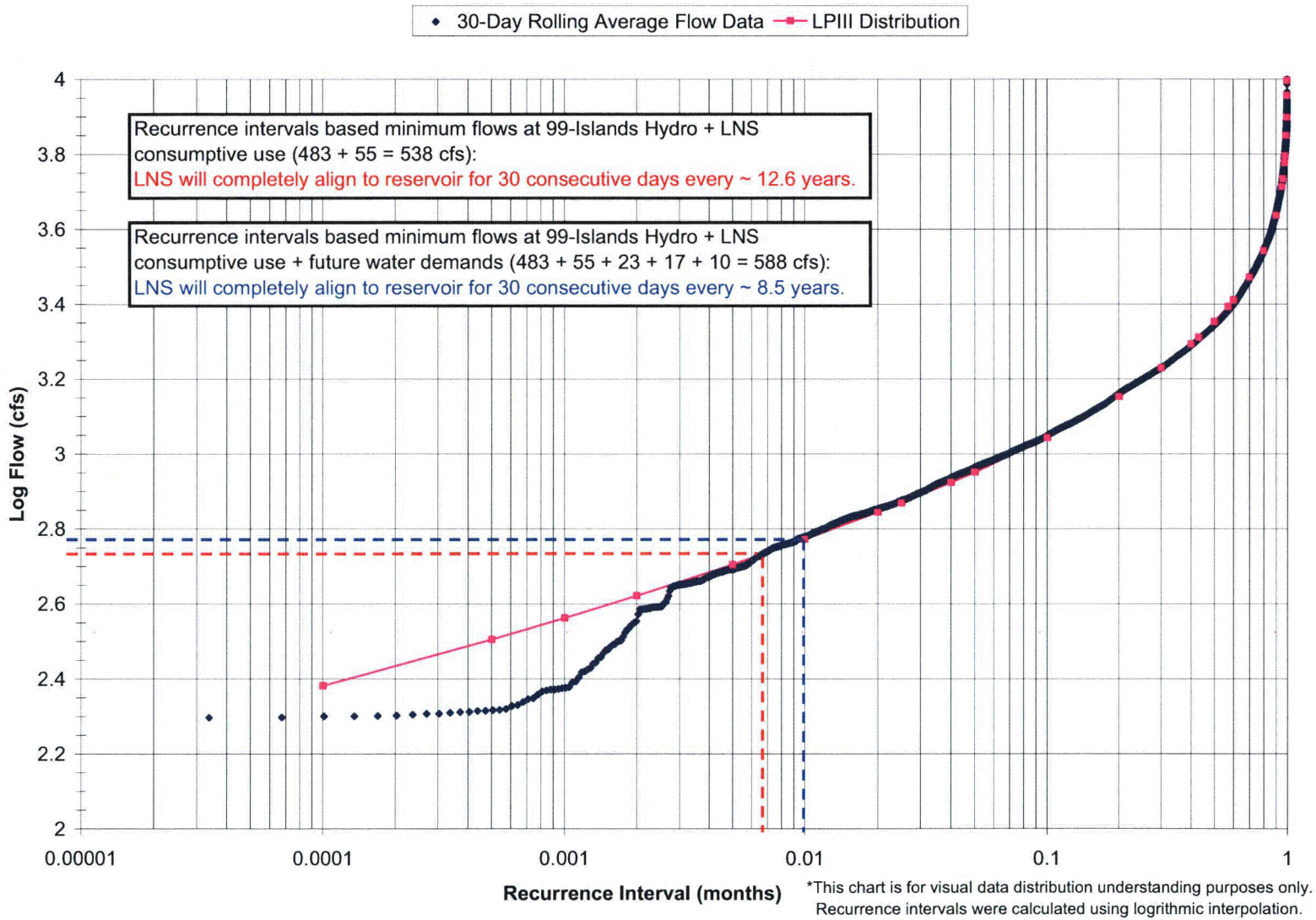
Recurrence Interval for Flows on the Broad River at Gaffney, SC with Polynomial Distribution
7-Day Rolling Average Flow Data (1926-2006)



*This chart is for visual data distribution understanding purposes only.
Recurrence intervals were calculated using a polynomial equation.

FIGURE 2

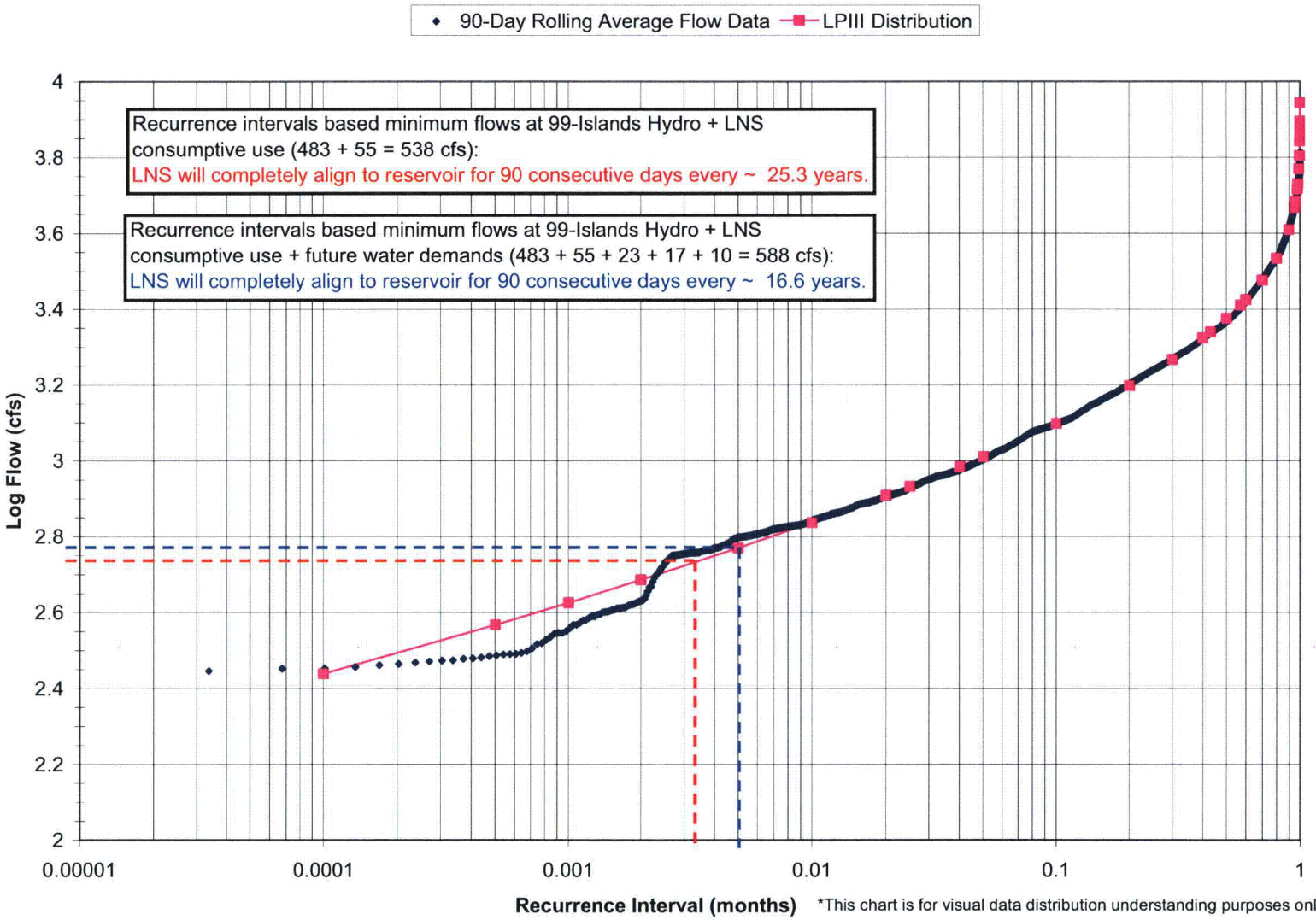
Recurrence Interval for Flows on the Broad River at Gaffney, SC with Log-Pearson Type III Distribution
30-Day Rolling Average Flow Data (1926 - 2006)



*This chart is for visual data distribution understanding purposes only.
Recurrence intervals were calculated using logrithmic interpolation.

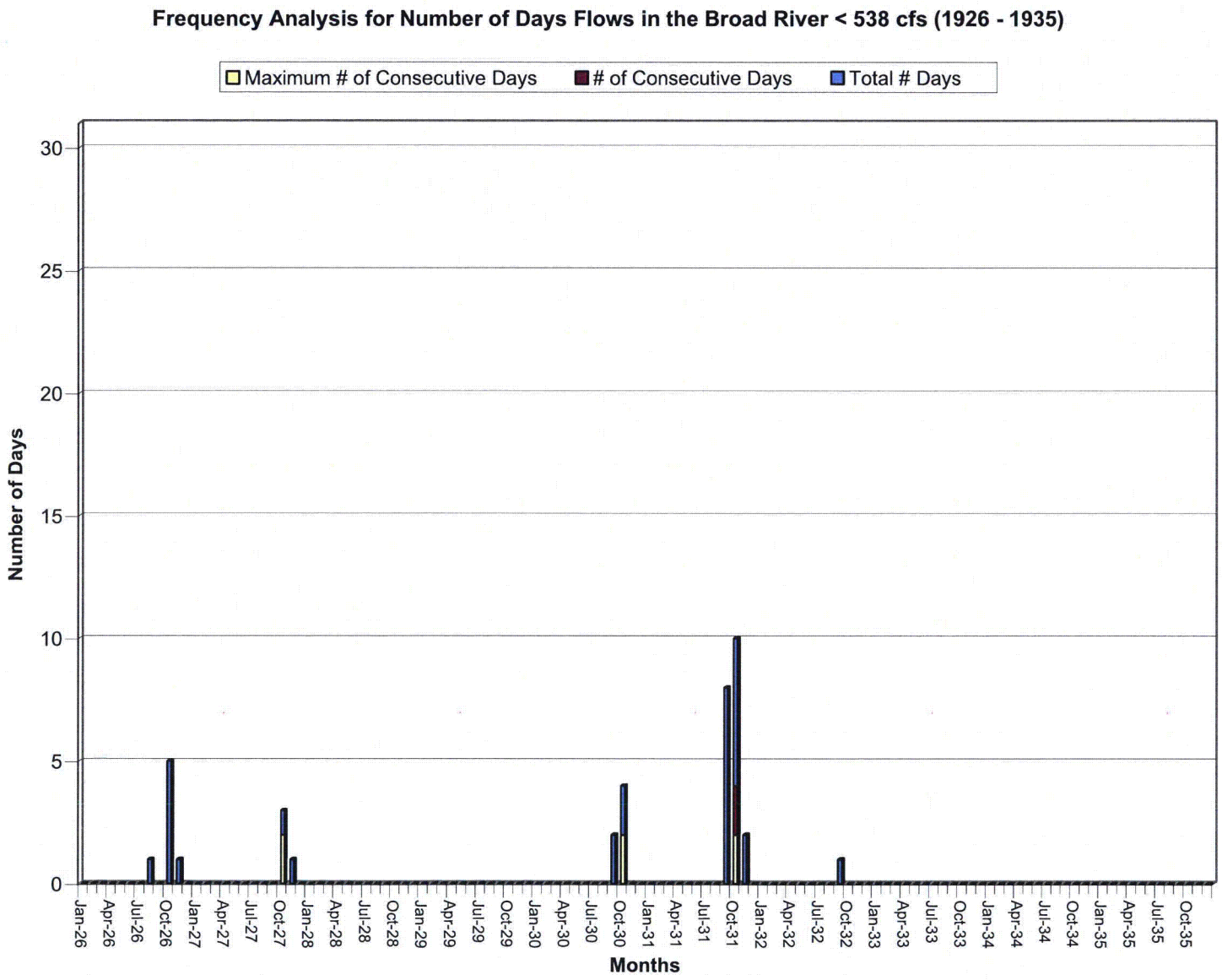
FIGURE 3

Recurrence Interval for Flows on the Broad River at Gaffney, SC with Log-Pearson Type III Distribution
90-Day Rolling Average Flow Data (1926 - 2006)



*This chart is for visual data distribution understanding purposes only.
Recurrence intervals were calculated using logrithmic interpolation.

FIGURE 4


Frequency Analysis for Number of Days Flows in the Broad River < 538 cfs (1926 - 1935)
Maximum # of Consecutive Days
# of Consecutive Days
Total # Days
Number of Days
0
5
10
15
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Months
Jan-26
Apr-26
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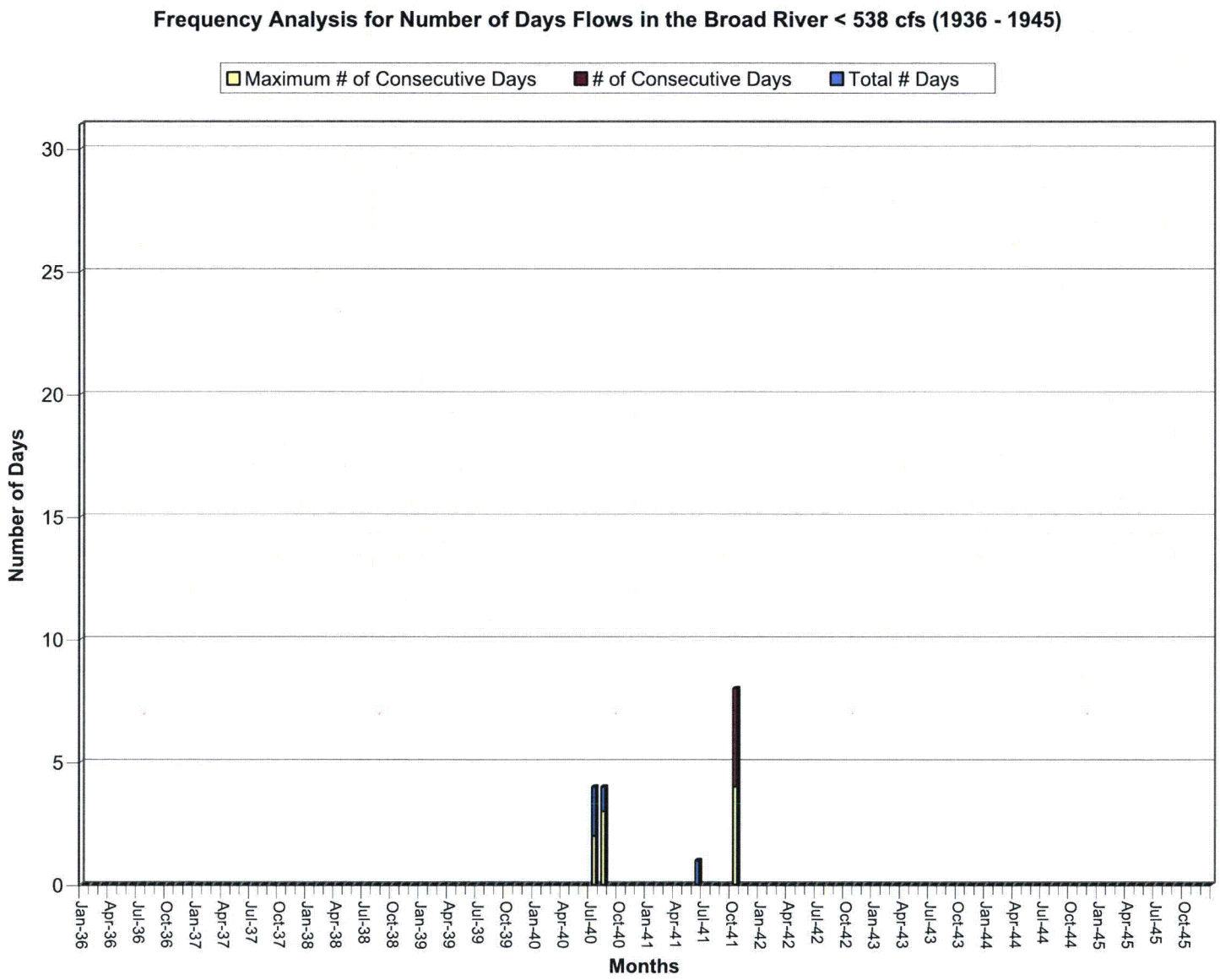
FIGURE 5


Frequency Analysis for Number of Days Flows in the Broad River < 538 cfs (1936 - 1945)
Maximum # of Consecutive Days
# of Consecutive Days
Total # Days
Number of Days
0
5
10
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25
30
Months
Jan-36
Apr-36
Jul-36
Oct-36
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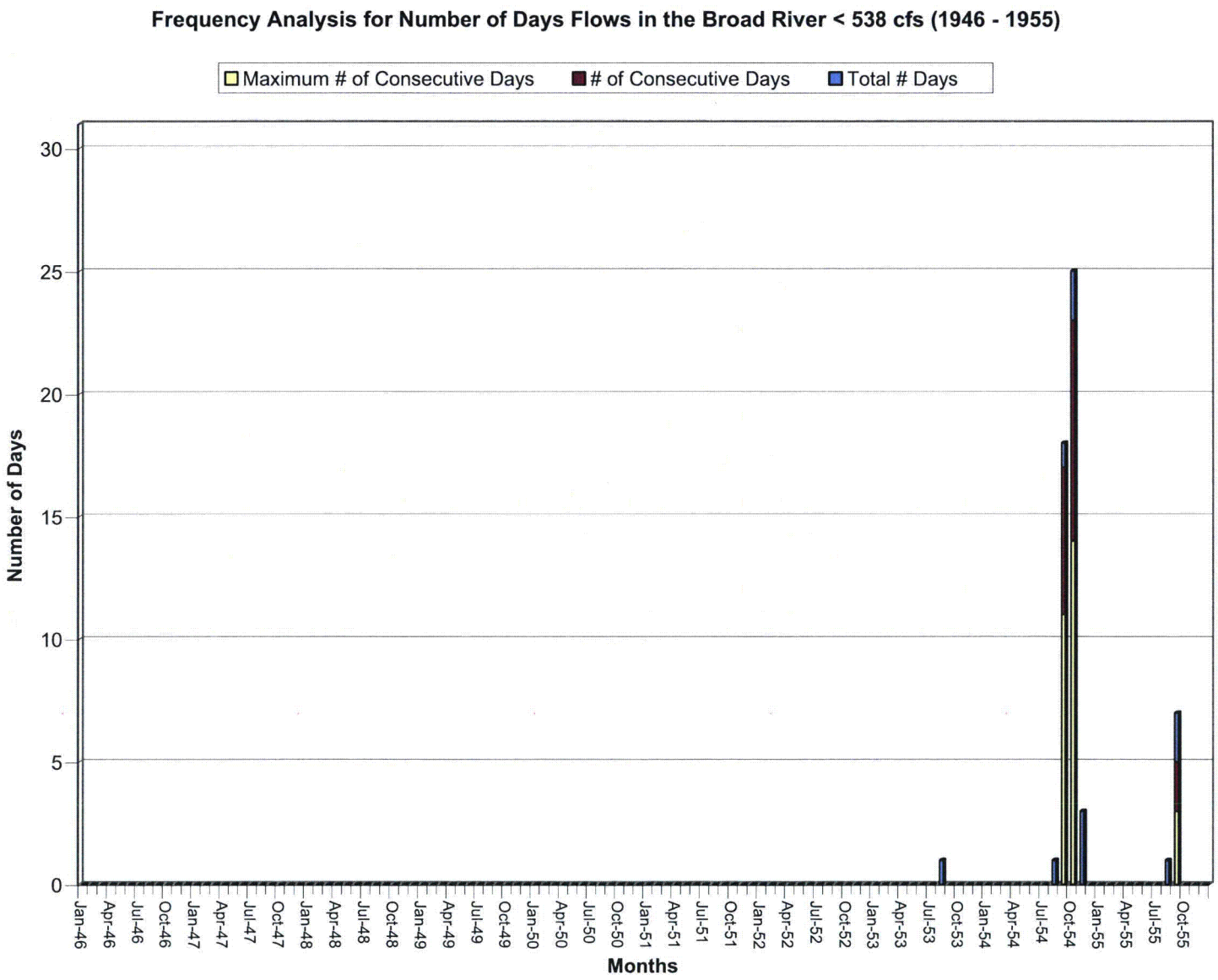
FIGURE 6


Frequency Analysis for Number of Days Flows in the Broad River < 538 cfs (1946 - 1955)
Maximum # of Consecutive Days
# of Consecutive Days
Total # Days
Number of Days
0
5
10
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25
30
Months
Jan-46
Apr-46
Jul-46
Oct-46
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FIGURE 7

Frequency Analysis for Number of Days Flows in the Broad River < 538 cfs (1956 - 1965)

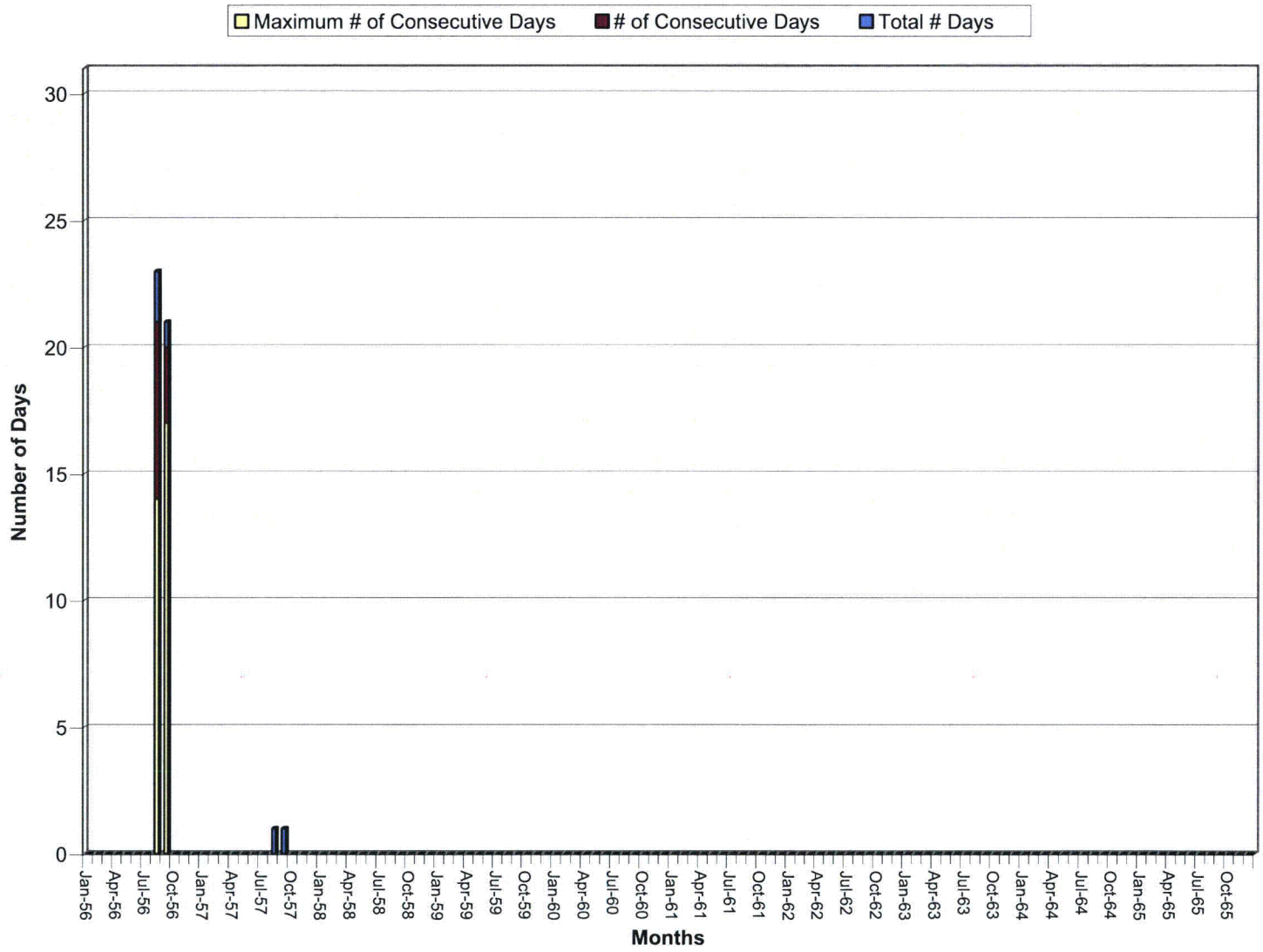


FIGURE 8

Frequency Analysis for Number of Days Flows in the Broad River < 538 cfs (1966 - 1975)

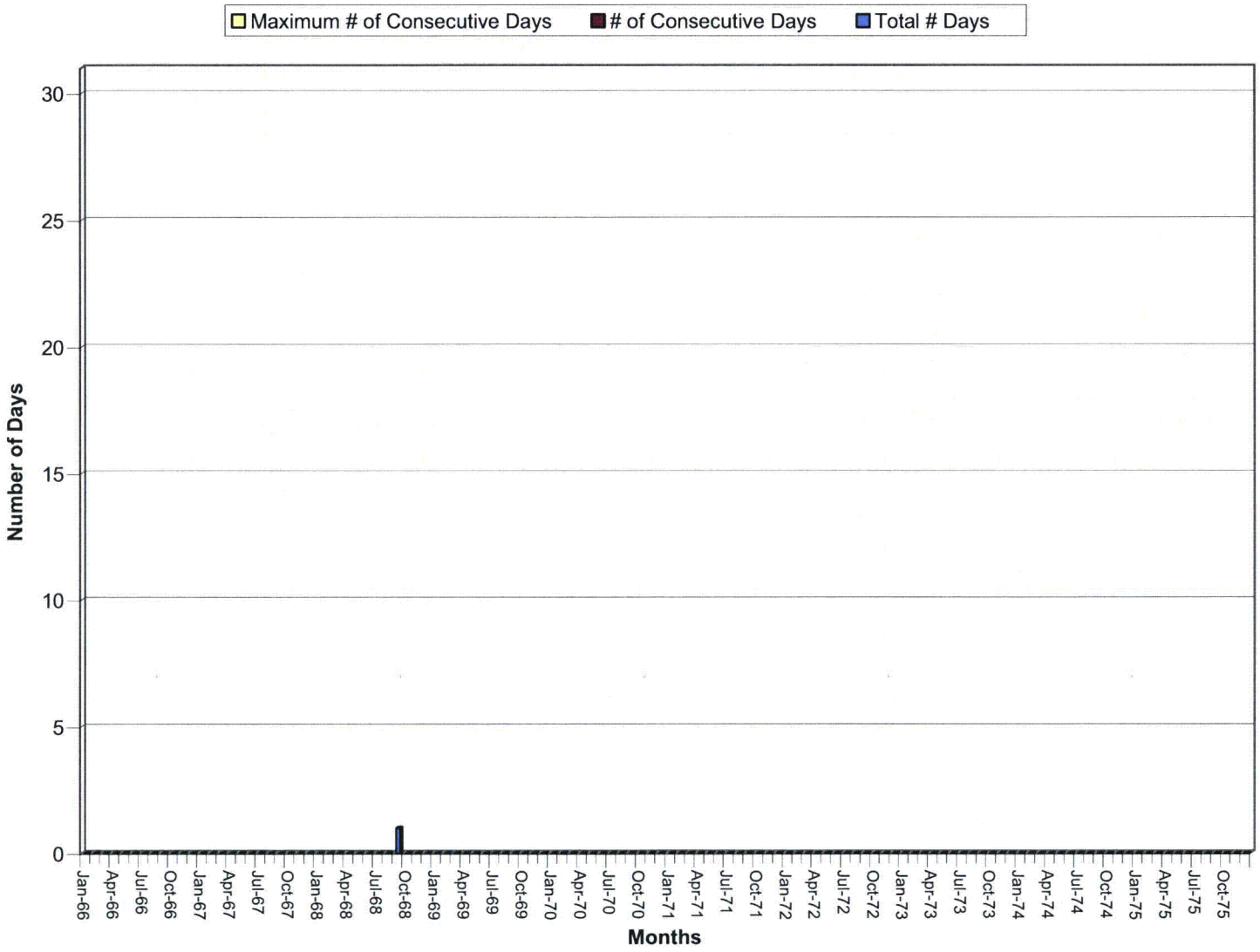


FIGURE 9

Frequency Analysis for Number of Days Flows in the Broad River < 538 cfs (1976 - 1985)

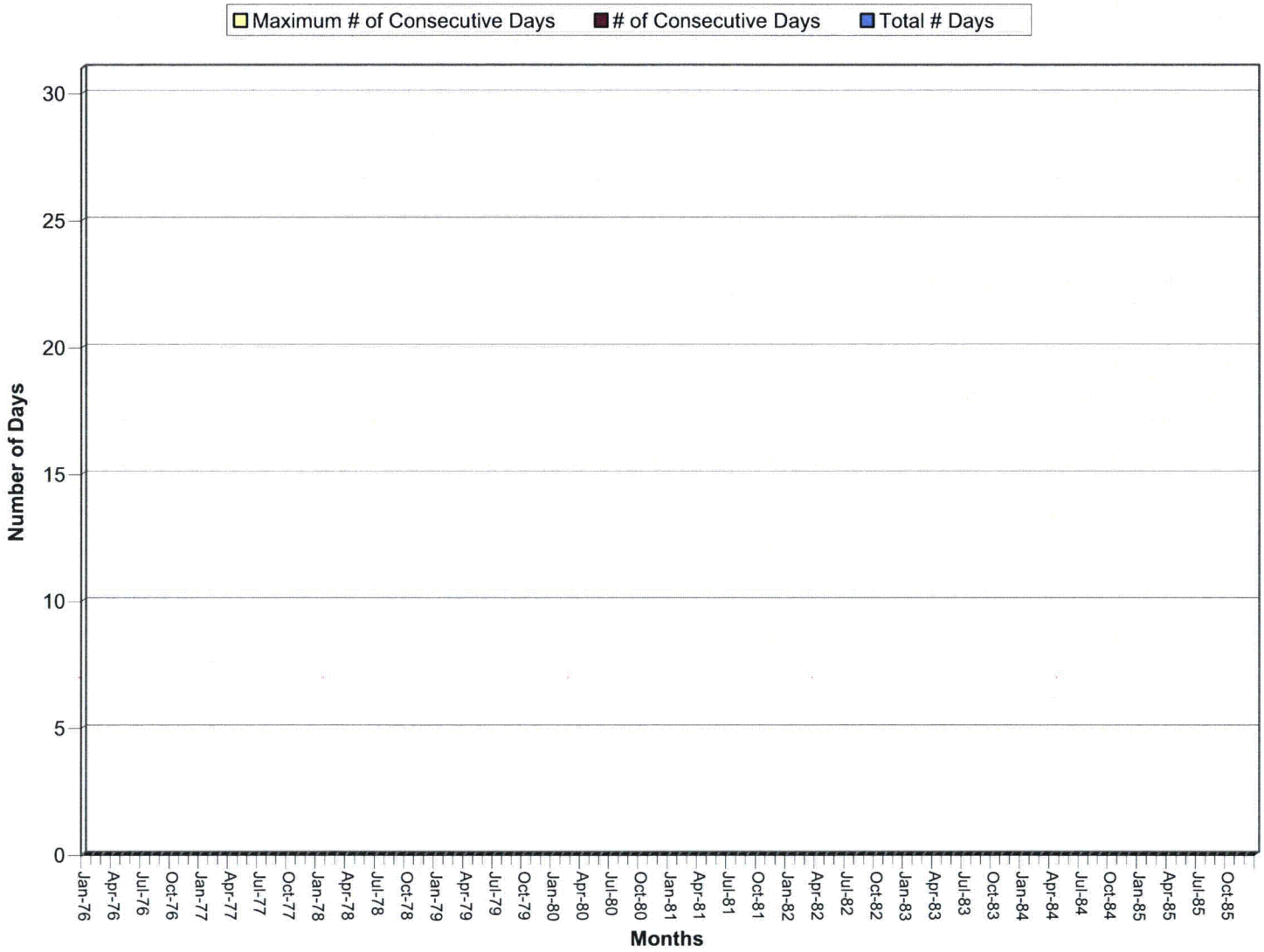


FIGURE 10

Frequency Analysis for Number of Days Flows in the Broad River < 538 cfs (1986 - 1995)

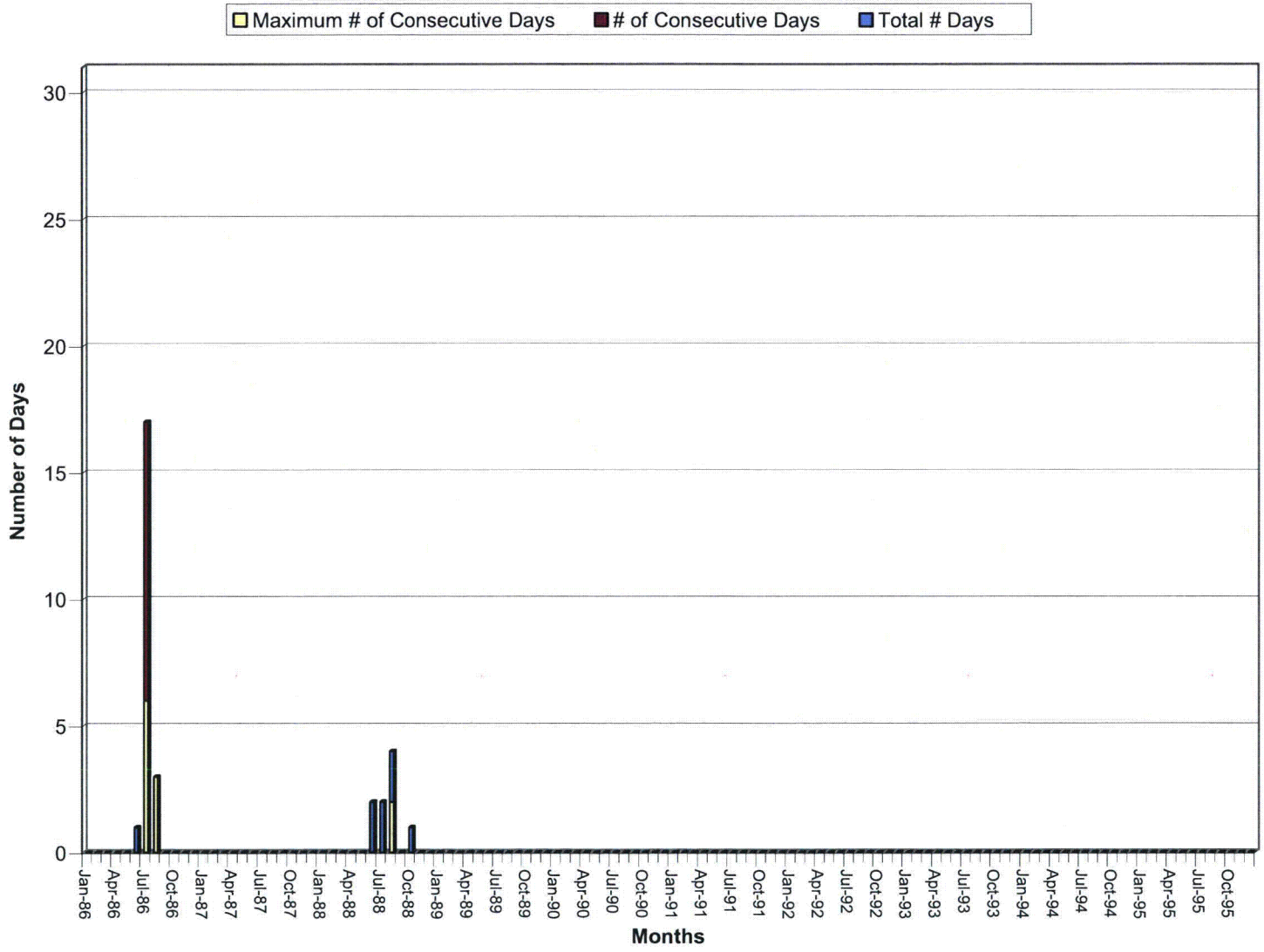


FIGURE 11

Frequency Analysis for Number of Days Flows in the Broad River < 538 cfs (1996 - 2006)

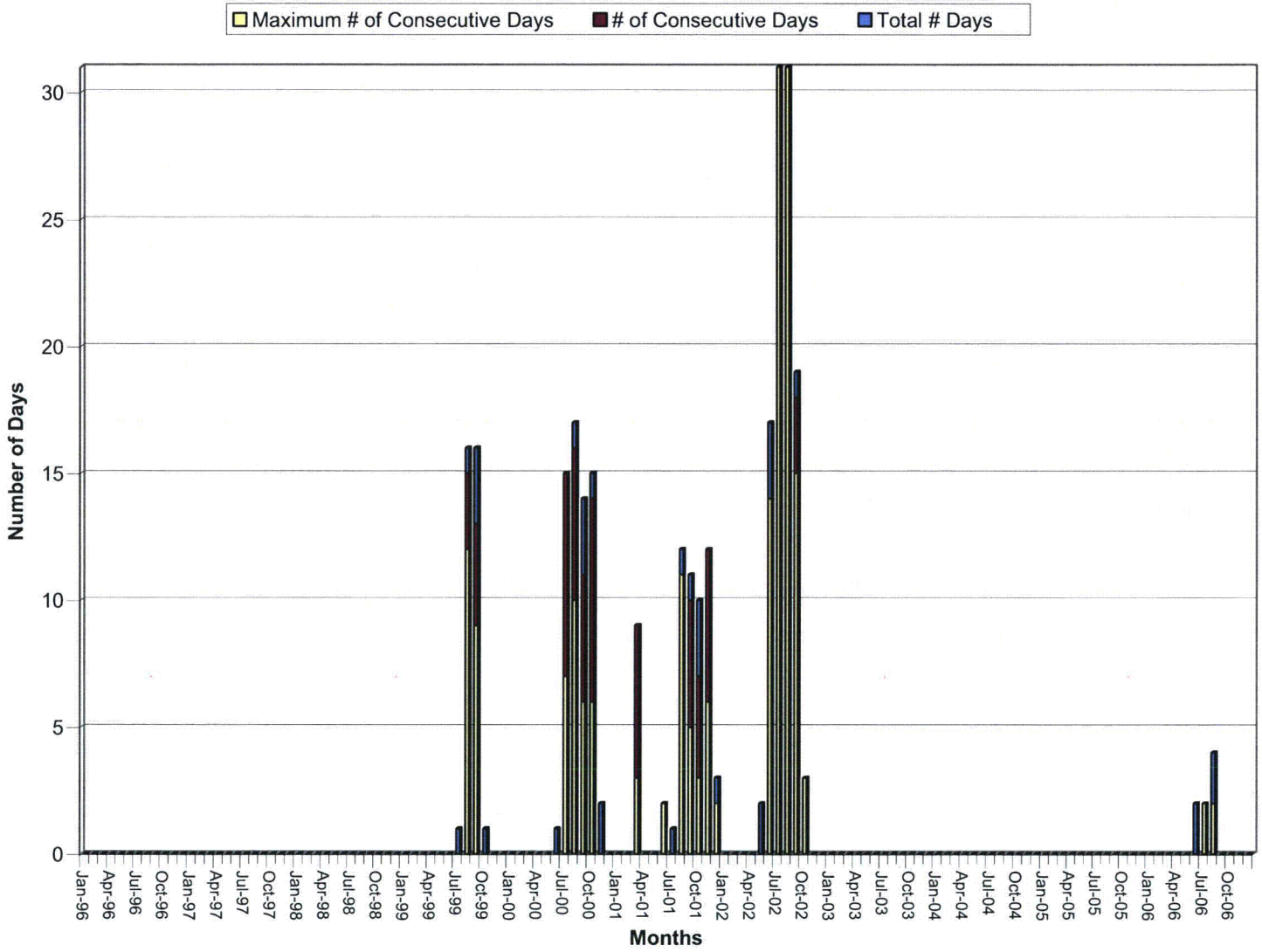


FIGURE 12

Lee Nuclear Station Reservoir Water Surface Elevations with Broad River Pumping (81-year record)
Without Future Water Demands

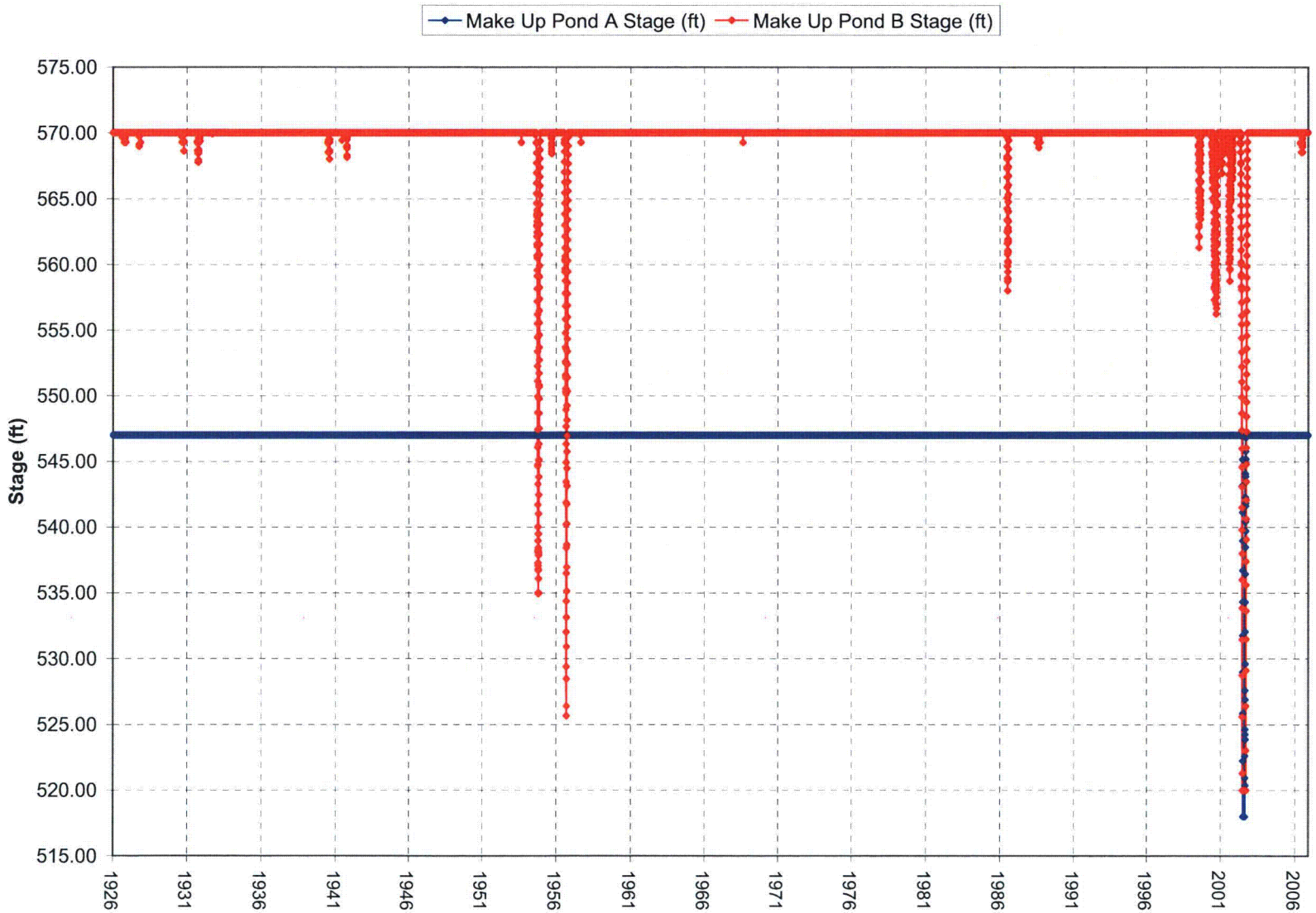


FIGURE 13

Lee Nuclear Station Reservoir Water Surface Elevations with Broad River Pumping (1954 - 1956 drought)
Without Future Water Demands

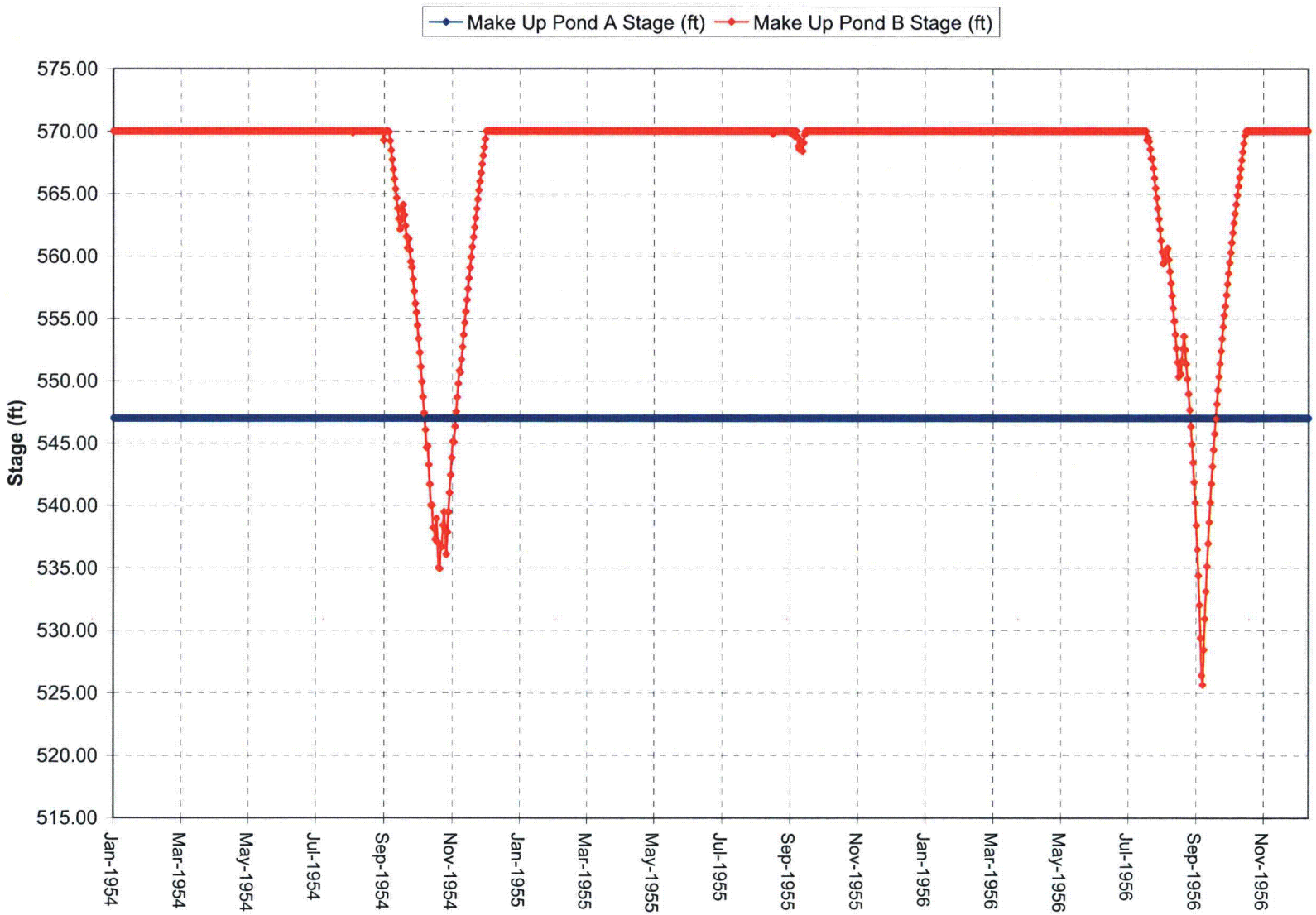
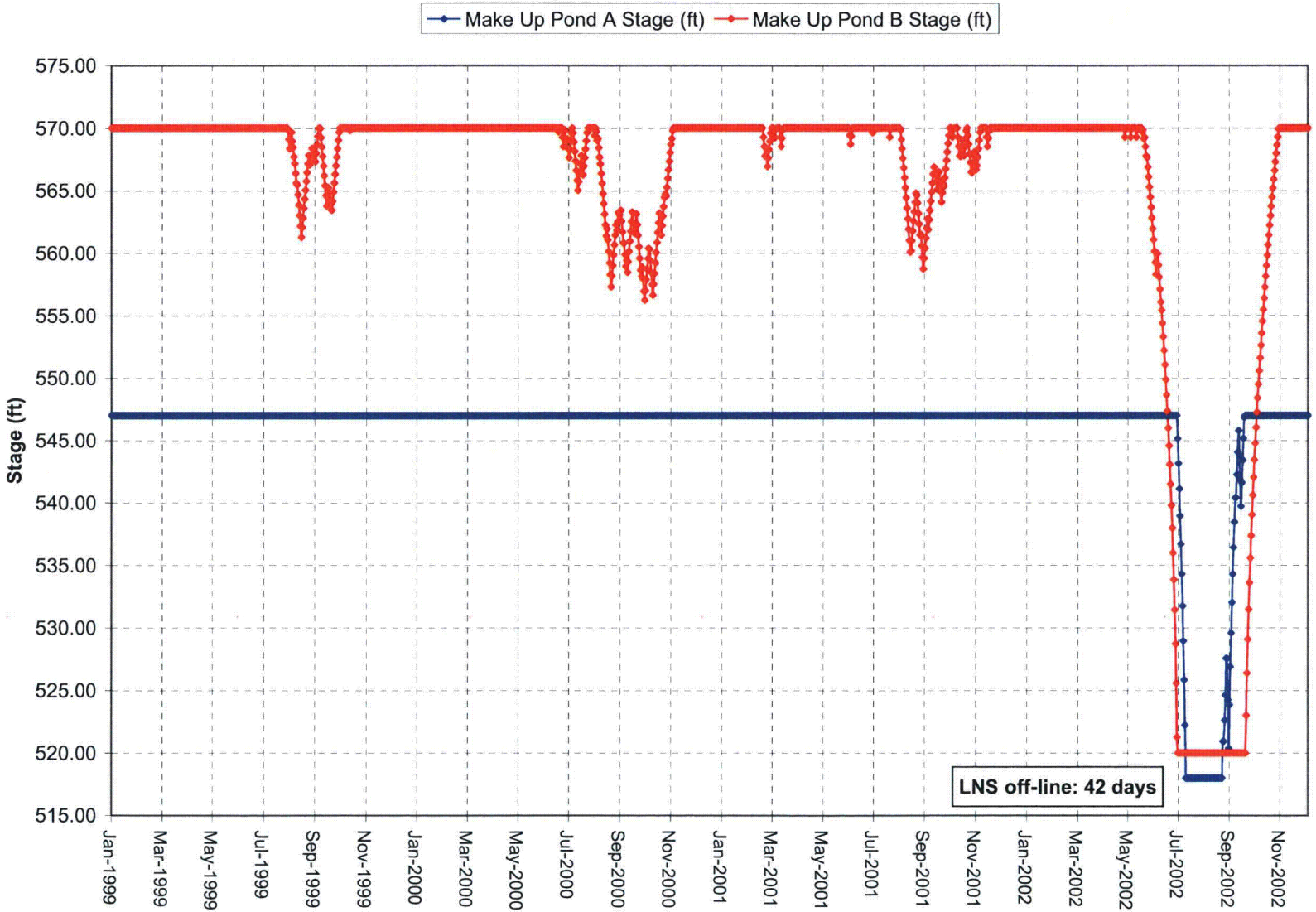


FIGURE 14

Lee Nuclear Station Reservoir Water Surface Elevations with Broad River Pumping (1999 - 2002 drought)
Without Future Water Demands



Lee Nuclear Station Response to Request for Additional Information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Number(s): ER RAI 53

NRC RAI:

Provide the following documents:

1. Barwick, D.H., et al. 2006. Fishery resources associated with the Lee Nuclear Station Site; Cherokee County, South Carolina.
2. Derwort, J.E. and S.F/ McCorkle. 2006. Macroinvertebrate surveys in the vicinity of the proposed Lee Nuclear Station; Cherokee County, South Carolina
3. Data tables associated with Barwick document.

How does the size-class distribution of fish compare with other rivers in the Piedmont region?

Duke Energy Response:

The following documents are provided as attachments to this response:

1. Barwick, D.H., et al. 2006. Fishery resources associated with the Lee Nuclear Station Site; Cherokee County, South Carolina.
2. Derwort, J.E. and S.F/ McCorkle. 2006. Macroinvertebrate surveys in the vicinity of the proposed Lee Nuclear Station; Cherokee County, South Carolina
3. Histograms comparing size-class distribution of fish collected in the 2006 survey with size-class distribution of fish collected in Saluda River, SC studies.

Data tables associated with the Barwick report represent raw data and are available for NRC inspection at our Charlotte, NC office or our contractors' offices in Bethesda, MD and Richland, WA.

Associated Response to the Lee Nuclear Station Combined License Application:

None.

Associated Attachements:

1. Barwick, D.H., et al. 2006. Fishery resources associated with the Lee Nuclear Station Site; Cherokee County, South Carolina.
2. Derwort, J.E. and S.F/ McCorkle. 2006. Macroinvertebrate surveys in the vicinity of the proposed Lee Nuclear Station; Cherokee County, South Carolina
3. Histograms comparing size-class distribution of fish collected in the 2006 survey with size-class distribution of fish collected in Saluda River, SC studies.

FISHERY RESOURCES ASSOCIATED WITH THE LEE NUCLEAR STATION SITE; CHEROKEE COUNTY, SOUTH CAROLINA

by

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15 December 2006

Executive Summary

Seasonal electrofishing and gillnetting of the Broad River in 2006 in areas associated with the future site of the Lee Nuclear Station site resulted in the collection of 41 species of fish representing seven families. Bluegill (*Lepomis macrochirus*) and largemouth bass (*Micropterus salmoides*) dominated catches in the Ninety-Nine Islands Reservoir while spottail shiners (*Notropis hudsonius*), northern hog sucker (*Hypentelium nigricans*), and smallmouth bass (Micropterus dolomieu) dominated catches in the river downstream of the reservoir. The annual gillnet catches in the two Ninety-Nine Islands Reservoir back water areas were dominated numerically by gizzard shad (*Dorosoma cepedianum*) followed by quillback (*Carpiodes cyprinus*) and black crappie (*Pomoxis nigromaculatus*) respectively.

Spring electrofishing of the Broad River upstream of Ninety-Nine Islands Reservoir in the area of the Cherokee Falls Dam targeted spawning sucker populations. Five catostomid species were collected, but only the quillback, brassy jumprock (*Scartomyzon* sp), and notchlip redhorse (*Moxostoma collapsum*) were collected in any abundance.

The three largest ponds on the project site were electrofished once during spring 2006. The fish community in each pond is comprised almost entirely of centrarchids. Bluegill dominated the catch (fish/hr) in the two largest ponds (Low Flow Reservoir and the Sedimentation Basin), while largemouth bass dominated catches in the small Auxiliary Holding Pond.

No endangered, threatened, or species of concern fish were collected during any of the sampling. Additionally, no state or federally listed species are known to occur from this area of the Broad River.

Introduction

The Broad River originates in the Blue Ridge Mountains of North Carolina and after entering the Piedmont of South Carolina then flows some 100 mi. before merging with the Saluda River (near Columbia, SC) to form the Congaree River. The Broad River is generally turbid due to a high sand bedload and suspended particulates. Flows vary from season to season and year to year and averaged 1,239 cubic feet per sec during the period from January 1 – December 5, 2006. The Broad River near the proposed Lee Nuclear Station was impounded in 1910 for hydropower generation. The resulting Ninety-Nine Islands Reservoir is basically a run-of-the river reservoir with two large shallow backwater areas.

The Broad River (including Ninety-Nine Islands Reservoir), along with several onsite ponds. comprises most of the fish habitat in the area associated with the Lee Nuclear Station site. The objective of this study was to survey the fishery resources associated with this site, with special emphasis on endangered, threatened, and species of concern.

Methods and Materials

Fish populations in Ninety-Nine Islands Reservoir (Locations 458, 460, 462, and 463) [Figure 1] were sampled in February, April, July, and October 2006 using a two-man crew (one person collecting fish) and a boat-mounted electrofisher (Smith-Root 3.5 GPP using 120 pulses per second of direct current to produce about 3 amperes of power). Two 100-m segments of shoreline (one on each side of the reservoir or backwater cove) were electrofished (about 1,000 seconds of actual shock time expended on each segment) and all stunned fish were netted. In addition, reservoir fish populations (Locations 458 and 462) were sampled using two experimental monofilament gill nets (30.5 m long x 2.4 m deep) and comprised of five alternating 6.1-m panels of 25-, 38-, 51-, 63-, and 76-mm square mesh). Nets were set perpendicular to the shore in mid to late afternoon at each location and retrieved the next morning.

Fish populations in the Broad River downstream of the Ninety-Nine Islands Reservoir (Location 453) were sampled using the boat-mounted electrofisher (identical to that used in the reservoir) during February and April. As conducted in the reservoir, two 100-m segments of shoreline (one on each side of the river) were sampled (approximately 1,000 seconds of actual shock time expended on each segment). In July and October, water levels at this location were too low to use the boat-mounted electrofisher and a tote barge electrofisher (same equipment and settings as the electrofishing boat) was used instead. The tote barge employed a four-man crew (three people collecting fish). The sampling effort and locations sampled were the same as for the boat-mounted electrofishing.

In addition, catostomid (sucker) populations upstream of Ninety-Nine Islands Reservoir (Location 464 near Cherokee Falls) were sampled in April 2006. This upstream electrofishing used the same boat-electrofisher as used in the reservoir (about 2000

seconds total of actual shock time) and targeted the rocky shoals and riffles that were considered optimal habitat for suckers. Only suckers were collected in this sampling.

The fish populations in the three onsite ponds were also sampled in April 2006. In the 62.3-ha (154-ac) Low Flow Reservoir, seven shoreline segments consisting of approximately 1,000 seconds of actual shock time per segment were selected representing the major habitat types present. Sampling was conducted using a three-man crew (two persons collecting fish) and the same boat-mounted electrofisher and settings described for the reservoir sampling. Additionally, about 1,000 seconds of targeted shock time was expended using low frequency (15 or 20 pulses per second of direct current) to collect ictalurids from selected habitat.

In the smaller Sedimentation Basin (27.5-ha; 68-ac) and in the Auxiliary Holding Pond (1.7-ha; 4.2-ac), the same boat-mounted electrofisher described previously was used to sample four shoreline segments (about 1,000 seconds of actual shock time per segment) and the entire pond perimeter (about 1,000 seconds actual shock time), respectively.

All fish collected at all locations were identified to species, enumerated, and measured for total length (mm). Most fish collected by electrofishing were returned alive in the vicinity of their collection, but a few specimens were preserved and returned to the Duke Energy Environmental Center for taxonomic identification. Fish collected by gill net were released, if alive, or buried.

Results and Discussion

Broad River and Ninety-Nine Islands Reservoir Electrofishing

In 2006, 41 species of fish and 2 hybrid complexes representing 7 families, were collected (Table 1). These results were similar to those noted in the same area in 1974 - 1976 when 36 species of fish representing 8 families were collected (Table 1). The only family not found in 2006 that was collected in 1974-1976 was Poeciliidae, represented by the eastern mosquitofish (*Gambusia holbrooki*). Additionally, the fish community in the Broad River in 2006 in proximity of the Lee Nuclear Station site is similar to other reaches of the Broad River upstream in a North Carolina portion of the river (49 species representing 9 families) and in a large expanse of the Broad River in South Carolina downstream of the Lee Nuclear Station site (43 species representing 9 families) (Table 1).

In 2006, bluegills (*Lepomis macrochirus*) numerically dominated fish populations during all seasons and at all locations in Ninety-Nine Islands Reservoir (Tables 2-5). Generally, largemouth bass (*Micropterus salmoides*) were the second most abundant species at all locations and during all seasons.

Fish populations downstream of the Ninety-Nine Islands Dam (Location 453) were considerably more diverse and abundant than those in the reservoir. These population differences are likely attributable to habitat variables such as rock-rubble substrate as compared to sand-silt in the reservoir. Here fish populations were comprised primarily of cyprinids, catostomids, and ictalurids, depending on the season, but were never

dominated by centrarchids as was the case at all reservoir locations. Additionally, the number of fish species present below the dam (Location 453) was overwhelmingly more diverse than all the reservoir locations with generally twice the number of species as the reservoir locations (Tables 2-5).

Ninety-Nine Islands Reservoir Gillnetting

Gizzard shad (*Dorosoma cepedianum*) dominated gill-net catches at both reservoir sample locations (458 and 462) and were the most abundant species collected during all sample periods except in October, when quillback (*Carpiodes cyprinus*) outnumbered gizzard shad (Table 6). Black crappie (*Pomoxis nigromaculatus*) and channel catfish (*Ictalurus punctatus*) were the only other species collected in any appreciable numbers throughout the year at both locations. However their numbers were always lower than those noted for gizzard shad and quillback. This same trend of gizzard shad and quillback being the preponderate gill net catches in all seasons was also evidenced in 1974-1976 (Duke Power Company 1978).

Catostomid Electrofishing

In order to collect data on catostomids in the Broad River and, in particular, data on rare, threatened, or species of concern, spring electrofishing was conducted downstream of the Cherokee Falls Dam in April 2006 at Location 464 (Figure 1). This area is replete with boulder and cobble habitat interspersed with areas of gravel and sand substrate. The current in this area ranges from moderate to swift. During river reconnaissance trips, this area was identified as the only significant area between Cherokee Falls Dam and the Ninety-Nine Islands Dam that contained any significant sucker spawning habitat. Quillback, brassy jumprock (*Scartomyzon* sp.)[1], and notchlip redhorse (*Moxostoma collapsum*) were the only three species collected in any significant numbers at this location (Table 7).

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[1] At the time of the 1974-1976 Lee Nuclear Station fishery surveys (Duke Power Company 1978), the brassy jumprock was taxonomically classified as *Moxostoma robustum* (Robins and Raney 1956). However, rediscovery of the robust redhorse, which was thought extirpated for over a century, required that the genus name *Moxostoma* and the species name *robustum* revert back to the robust redhorse (Bryant *et al.* 1996; Cooke *et al.* 2005). Thus, the brassy jumprock is currently an undescribed species of the genus *Scartomyzon* sp., but is the same fish reported in the 1974-1976 surveys as *Moxostoma robustum.*

The changing and confusing taxonomy of catostomids does not end with M. robustum. In the 1974-1976 Duke Power study (Duke Power 1978) a species of fish was collected and identified using the taxonomic keys of the day as the silver redhorse (*M. anisurum*). However, today that same species is now known as the notchlip redhorse (*M. collapsum*). It is fair to say that the taxonomic status of several catostomids that are or could potentially occur in the Broad River Basin is questionable. In addition to the robust redhorse and the brassy jumprock, the highfin carpsucker *(Carpiodes velifer*), quillback, and forms resembling the genus Carpiodes on the lower Atlantic slope may even represent undescribed species (Marcy et al. 2005).

In the present study, no robust redhorse were collected near the Lee Nuclear Station and extensive surveys by many researchers in the Broad, Saluda, Catawba, and Wateree rivers of the Santee Basin have failed to yield a wild specimen. The South Carolina Department of Natural Resources has undertaken a program to reintroduce the robust redhorse to the Broad River and this has occurred well downstream of the Lee Nuclear Station site in the reach of the Broad River between Neal Shoals Hydroelectric Station and Columbia, SC.

On-site pond electrofishing

The largest onsite pond, the Low Flow Reservoir, had the most diverse fish population (11 species) of the three onsite ponds sampled, but had the lowest total catch rate (427 fish/hr) (Table 8). The catch rate for bluegill was 273 fish/hr which was nearly double the catch rate of all other species combined. Following the bluegill in catch per unit effort was redbreast sunfish (*Lepomis auritus*), largemouth bass, and redear sunfish (*Lepomis microlophus*) with 55, 36, and 20 fish/hr respectively. The Low Flow Reservoir was the only pond that had any appreciable number of Ictalurids (catfish), with the flat bullhead (*Ameiurus platycephalus*) the dominant species.

The Sedimentation Basin electrofishing produced six species of fish, but only four in any significant number. Bluegill, as was the case in the Low Flow Reservoir, dominated the catch rate (Table 8). The catch rates for the four primary species were bluegill- 499 fish/hr, black crappie-25 fish/hr, warmouth *(Lepomis gulosus)*-15 fish/hr, and largemouth bass-12 fish/hr. The overall catch rate for all species was 555 fish/hr.

The Auxiliary Holding Pond, by far the smallest of the three ponds, had a distinctly different fish community than the other two ponds as only three species were collected (Table 8). The catch rate for largemouth bass was extremely high 217 fish/hr, followed by bluegill (113 fish/hr), and redbreast sunfish (107 fish/hr). The overall catch rate for this pond was 447 fish/hr which exceeded that of the Low Flow Reservoir and approached that of the Sedimentation Basin.

Clearly, the three onsite ponds sampled had appreciable populations of sunfishes (centrarchids). Catch rates for bluegill in the ~300-500 fish/hr range in the two larger ponds and largemouth bass with a >200 fish/hr catch rate in the smallest pond are extremely high. Although no length-frequency distributions were plotted, observations during the electrofishing surveys indicate that although the catch was clearly dominated by small fish, there were also larger fish of all species (indicating different year classes) in the ponds.

During all of the electrofishing and gillnetting activities on the Broad River and Ninety-Nine Islands Reservoir, no endangered, threatened, or species of concern fish were collected. Additionally, no state or federally listed species were discovered in the 1974 - 1976 Duke Power studies (Duke Power Company 1978) or are any listed in the SC Department of Natural Resources Heritage Trust Program (2006).

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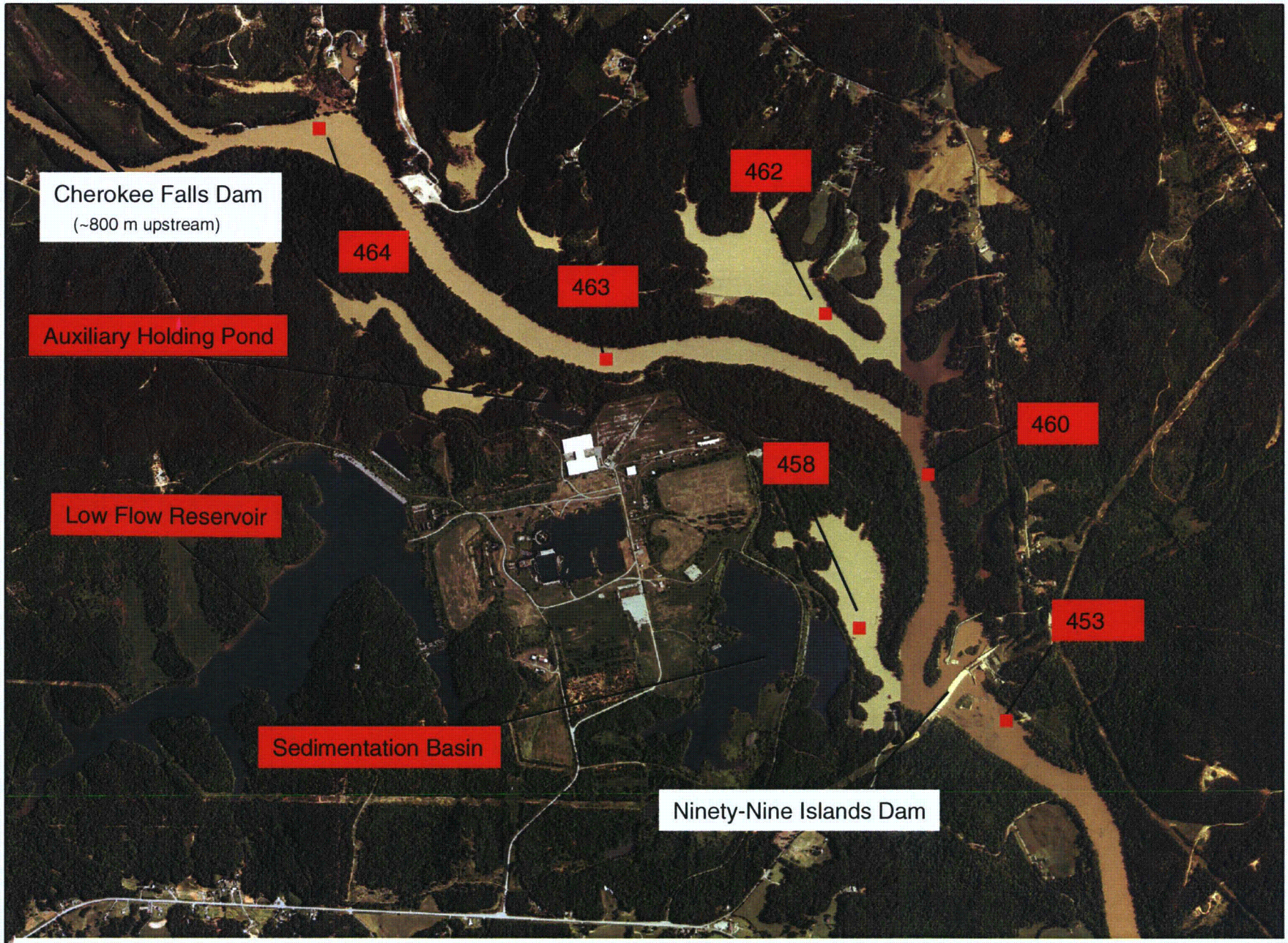

Figure 1. Aerial photograph of the Lee Nuclear Station site, Broad River, SC, and the associated fishery sampling locations (in red).

Table 1. Species of fish collected in the vicinity of the proposed Lee Nuclear Station on Ninety-Nine Islands Reservoir SC, and in the Broad River in NC and SC during the current and previous studies.

Family and scientific name	Common name	In vicinity of proposed Lee Nuclear Station (2006)	In vicinity of proposed Lee Nuclear Station[1] (1974-1976)	Upstream @ Duke Energy Cliffside Station in NC[2] (1989-2001)	SCDNR sampling throughout SC portion of Broad River[3] (2000-2001)
Lepisosteidae					
Lepisosteus osseus	Longnose gar				X
Clupeidae					
Dorosoma cepedianum	Gizzard shad	X	X	X	X
Dorosoma petenense	Threadfin shad	X	X		
Esocidae					
Esox masquinongy	Muskellunge			X	
Cyprinidae					
Campostoma anomalum	Central stoneroller			X	
Clinostomus funduloides	Rosyside dace		X	X	X
Cyprinella chloristia	Greenfin shiner	X	X	X	X
Cyprinella labrosa	Thicklip chub	X	X	X	X
Cyprinella nivea	Whitefin shiner	X	X	X	X
Cyprinella pyrrhomelas	Fieryblack shiner	X		X	X
Cyprinella zanema	Santee chub		X	X	
Cyprinus carpio	Common carp	X	X	X	X
Hybognathus regius	E. silvery minnow		X	X	X
Nocomis leptocephalus	Bluehead chub	X	X	X	X
Notemigonus crysoleucas	Golden shiner	X	X	X	
Notropis hudsonius	Spottail shiner	X	X	X	X
Notropis hypsinotus	Highback chub			X	
Notropis lutipinnis	Yellowfin shiner			X	X
Notropis procne	Swallowtail shiner			X	
Notropis scepticus	Sandbar shiner	X	X	X	X
Pimephales promelas	Fathead minnow			X	
Semotilus atromaculatus	Creek chub	X		X	
Catostomidae					
Carpiodes cyprinus	Quillback	X		X	
Catostomus commersoni	White sucker	X	X	X	X
Hypentelium nigricans	Northern hog sucker	X		X	X
Ictiobus bubalus	Smallmouth buffalo	X			X
Moxostoma collapsum	Notchlip redhorse[4]	X	X	X	X
Moxostoma macrolepidotum	Shorthead redhorse	X	X		X
Moxostoma pappillosum	V-lip redhorse	X		X	X
Scartomyzon rupiscartes	Striped jumprock	X	X	X	X
Scartomyzon sp.	Brassy jumprock[4]	X	X	X	X
Ictaluridae					
Ameiurus brunneus	Snail bullhead	X	X	X	X
Ameiurus catus	White catfish	X	X	X	X
Ameiurus nebulosus	Brown bullhead	X	X	X	
Ameiurus platycephalus	Flat bullhead	X		X	X
Ictalurus punctatus	Channel catfish	X		X	X
Noturus insignis	Margined madtom	X	X	X	X
Poeciliidae					
Gambusia holbrooki	Eastern mosquitofish		X	X	X
Moronidae					
Morone americana	White perch				X
Morone chrysops	White bass	X	X	X	X
Morone hybrid	Hybrid bass	X			

Table 1. Continued.

Family and scientific name	Common name	In vicinity of proposed Lee Nuclear Station (2006)	In vicinity of proposed Lee Nuclear Station[1] (1974-1976)	Upstream @ Duke Energy Cliffside Station in NC[2] (1989-2001)	SCDNR sampling throughout SC portion of Broad River[3] (2000-2001)
Centrarchidae					
Lepomis auritus	Redbreast sunfish	X	X	X	X
Lepomis cyanellus	Green sunfish			X	X
Lepomis gibbosus	Pumpkinseed	X	X	X	X
Lepomis gulosus	Warmouth	X	X	X	X
Lepomis hybrid	Hybrid sunfish	X		X	
Lepomis macrochirus	Bluegill	X	X	X	X
Lepomis microlophus	Redear sunfish	X	X	X	X
Micropterus dolomieu	Smallmouth bass	X		X	X
Micropterus salmoides	Largemouth bass	X	X	X	X
Pomoxis annularis	White crappie	X	X	X	
Pomoxis nigromaculatus	Black crappie	X	X	X	X
Etheostoma flabellare	Fantail darter	X	X		X
Etheostoma thalassinum	Seagreen darter		X	X	X
Perca flavescens	Yellow perch	X		X	X
Percina crassa	Piedmont darter	X	X	X	X
Total Number of Species[5]		41	36	49	43

[1] Duke Power (1978) Baseline environmental summary report on the Broad River in the vicinity of Cherokee Nuclear Station.

[2] Duke Energy (2003) Assessment of balanced and indigenous populations in the Broad River near Cliffside Steam Station.

[3] Bulak et al. (2001) Annual Progress Report F-63, SCDNR.

[4] Common and scientific names have been revised per Jenkins and Burkhead (1994) and Marcy et al. (2005).

[5] Hybrids were not included in the total.

Table 2. Numbers of fish collected by location during electrofishing on Ninety-Nine Islands Reservoir and the Broad River, February 2006.

Family and scientific name	Common name	Locations				
		453	458	460	462	463
Cyprinidae						
Cyprinella labrosa	Thicklip chub	2				
Cyprinella nivea	Whitefin shiner	19		1		12
Cyprinella pyrrhomelas	Fieryblack shiner	6				
Cyprinus carpio	Common carp				5	
Nocomis leptocephalus	Bluehead chub	8				
Notemigonus crysoleucas	Golden shiner		1		3	
Notropis hudsonius	Spottail shiner	111		1		1
Notropis scepticus	Sandbar shiner	41				
Semotilus atromaculatus	Creek chub	1				
Catostomidae						
Catostomus commersoni	White sucker	2				
Hypentelium nigricans	Northern hog sucker	25				
Moxostoma collapsum	Notchlip redhorse	1		1		1
Moxostoma macrolepidotum	Shorthead redhorse	12				
Moxostoma pappillosum	V-lip redhorse	2				
Scartomyzon rupiscartes	Striped jumprock	21				
Scartomyzon sp.	Brassy jumprock	14				1
Ictaluridae						
Ameiurus brunneus	Snail bullhead	4				1
Ameiurus catus	White catfish				4	
Ameiurus platycephalus	Flat bullhead					2
Centrarchidae						
Lepomis auritus	Redbreast sunfish	4		1		7
Lepomis gibbosus	Pumpkinseed		16		5	
Lepomis gulosus	Warmouth				2	
Lepomis hybrid	Hybrid sunfish				1	
Lepomis macrochirus	Bluegill	7	150	38	333	24
Lepomis microlophus	Redear sunfish	1	3	2	8	1
Micropterus dolomieu	Smallmouth bass	6				1
Micropterus salmoides	Largemouth bass		13	8	6	1
Pomoxis nigromaculatus	Black crappie			1	4	
Percidae						
Etheostoma flabellare	Fantail darter					1
Etheostoma olmstedi	Tessellated darter					1
Total number of fish		287	183	53	371	54
Number of species		19	5	8	9	13

Table 3. Numbers of fish collected by location during electrofishing on Ninety-Nine Islands Reservoir and the Broad River, April 2006.

		Locations				
Family and scientific name	Common name	453	458	460	462	463
Clupeidae						
Dorosoma cepedianum	Gizzard shad	6	12		2	
Dorosoma petenense	Threadfin shad				14	
Cyprinidae						
Cyprinella nivea	Whitefin shiner	13				1
Cyprinus carpio	Common carp		5	1	3	2
Notropis hudsonius	Spottail shiner	1				
Catostomidae						
Hypentelium nigricans	Northern hog sucker	12				
Moxostoma collapsum	Notchlip redhorse	6	1	1		
Moxostoma macrolepidotum	Shorthead redhorse	8				
Scartomyzon rupiscartes	Striped jumprock	4				
Scartomyzon sp.	Brassy jumprock	24				
Ictaluridae						
Ameiurus brunneus	Snail bullhead	29				
Ameiurus catus	White catfish		8		3	1
Ictalurus punctatus	Channel catfish	1	1			3
Centrarchidae						
Lepomis auritus	Redbreast sunfish	23		3		5
Lepomis gibbosus	Pumpkinseed					1
Lepomis gulosus	Warmouth		1	1	1	
Lepomis macrochirus	Bluegill	32	110	82	188	58
Lepomis microlophus	Redear sunfish	7	2		2	
Micropterus dolomieu	Smallmouth bass	8				
Micropterus salmoides	Largemouth bass	3	10	5	11	5
Pomoxis nigromaculatus	Black crappie	2	4		4	
Percidae						
Perca flavescens	Yellow perch		1			
Percina crassa	Piedmont darter	4				
Total number of fish		183	155	93	228	76
Number of species		17	11	6	9	8

Table 4. Numbers of fish collected by location during electrofishing on Ninety-Nine Islands Reservoir and the Broad River, July 2006.

Family and scientific name	Common name	Locations				
		453	458	460	462	463
Clupeidae						
Dorosoma cepedianum	Gizzard shad				1	
Dorosoma petenense	Threadfin shad		2		5	
Cyprinidae						
Cyprinella chloristia	Greenfin shiner	2				
Cyprinella labrosa	Thicklip chub	1				
Cyprinella nivea	Whitefin shiner	33				
Cyprinus carpio	Common carp		1	1	1	
Nocomis leptocephalus	Bluehead chub	6				
Notemigonus crysoleucas	Golden shiner				1	
Notropis hudsonius	Spottail shiner	33		1	1	
Catostomidae						
Hypentelium nigricans	Northern hog sucker	41				
Moxostoma collapsum	Notchlip redhorse		2	3		
Moxostoma macrolepidotum	Shorthead redhorse	1				
Scartomyzon rupiscartes	Striped jumprock	5				
Scartomyzon sp.	Brassy jumprock	1				
Ictaluridae						
Ameiurus brunneus	Snail bullhead	82				
Ameiurus catus	White catfish		10			1
Ameiurus platycephalus	Flat bullhead	1				
Ictalurus punctatus	Channel catfish			2	1	
Noturus insignis	Margined madtom	15				
Centrarchidae						
Lepomis auritus	Redbreast sunfish	46		1		3
Lepomis gibbosus	Pumpkinseed		8		1	
Lepomis gulosus	Warmouth		2	1	1	1
Lepomis macrochirus	Bluegill	20	98	26	118	18
Lepomis microlophus	Redear sunfish		2	2	1	2
Micropterus dolomieu	Smallmouth bass	80				
Micropterus salmoides	Largemouth bass	3	9	1	12	2
Pomoxis nigromaculatus	Black crappie				3	
Percidae						
Percina crassa	Piedmont darter	19				
Total number of fish		389	134	38	146	27
Number of species		17	9	9	12	6

Table 5. Numbers of fish collected by location during electrofishing on Ninety-Nine Islands Reservoir and the Broad River, October 2006.

Family and scientific name	Common name	Locations				
		453	458	460	462	463
Clupeidae						
Dorosoma cepedianum	Gizzard shad		5		15	13
Dorosoma petenense	Threadfin shad		1		9	
Cyprinidae						
Cyprinella chloristia	Greenfin shiner	1				
Cyprinella labrosa	Thicklip chub	1				
Cyprinella nivea	Whitefin shiner	107		2		2
Cyprinus carpio	Common carp		5		6	3
Nocomis leptocephalus	Bluehead chub	2				
Notemigonus crysoleucas	Golden shiner				7	
Notropis hudsonius	Spottail shiner	39				
Notropis scepticus	Sandbar shiner	1				
Catostomidae						
Carpiodes cyprinus	Quillback		1			
Hypentelium nigricans	Northern hog sucker	74				
Moxostoma collapsum	Notchlip redhorse	6			1	
Scartomyzon rupiscartes	Striped jumprock	7				
Scartomyzon sp.	Brassy jumprock	14				
Ictaluridae						
Ameiurus brunneus	Snail bullhead	79				
Ameiurus catus	White catfish		2			
Ameiurus platycephalus	Flat bullhead	2	1			
Ictalurus punctatus	Channel catfish			1	1	2
Noturus insignis	Margined madtom	6				
Centrarchidae						
Lepomis auritus	Redbreast sunfish	58		1		5
Lepomis gibbosus	Pumpkinseed		7			
Lepomis gulosus	Warmouth		1	3	3	
Lepomis hybrid	Hybrid sunfish		1			
Lepomis macrochirus	Bluegill	70	194	58	186	40
Lepomis microlophus	Redear sunfish	5	13	5	2	5
Micropterus dolomieu	Smallmouth bass	64				2
Micropterus salmoides	Largemouth bass	3	14	7	14	2
Pomoxis annularis	White crappie		1		3	
Pomoxis nigromaculatus	Black crappie		3		14	
Percidae						
Perca flavescens	Yellow perch				1	
Percina crassa	Piedmont darter	3				
Total number of fish		542	249	77	262	74
Number of species		19	13	7	13	9

Table 6. Total numbers of fish collected during gillnettting at two locations on Ninety-Nine Islands Reservoir in 2006.

		Months and locations								
		February		April		July		October		
Family and scientific name	Common name	458	462	458	462	458	462	458	462	Total
Clupeidae										
Dorosoma cepedianum	Gizzard shad	49	107	62	56	79	50	39	42	484
Dorosoma petenense	Threadfin shad								1	1
Cyprinidae										
Cyprinus carpio	Common carp		3	3	4	1	2		1	14
Notemigonus crysoleucas	Golden shiner	7	1	4	12	2		2	6	34
Catostomidae										
Carpiodes cyprinus	Quillback	4	9	38	26	30	50	62	43	262
Catostomus commersoni	White sucker						1	2		3
Ictiobus bubalus	Smallmouth buffalo						1			1
Moxostoma collapsum	Notchlip redhorse				1					1
Scartomyzon sp.	Brassy jumprock			3						3
Ictaluridae										
Ameiurus brunneus	Snail bullhead		1				1			2
Ameiurus catus	White catfish	6	2		1		1		1	11
Ameiurus nebulosus	Brown bullhead		4	4	1					9
Ameiurus platycephalus	Flat bullhead			3						3
Ictalurus punctatus	Channel catfish	2	7	25	8	11	14	2	2	71
Moronidae										
Morone chrysops	White bass		1							1
Morone hybrid	Morone hybrid	1								1
Centrarchidae										
Lepomis auritus	Redbreast sunfish					1				1
Lepomis gulosus	Warmouth			3						3
Lepomis macrochirus	Bluegill		1	1	4	3	2	1		12
Lepomis microlophus	Redear sunfish		1		4					5
Micropterus salmoides	Largemouth bass	4	4	1	4	2	4	1		20
Pomoxis nigromaculatus	Black crappie	26	35	5	3	19	31	18	18	155
Percidae										
Perca flavescens	Yellow perch		1		1			1		3
Total number of individuals		99	177	152	125	148	157	128	114	1100

Table 7. Numbers of catostomids collected during electrofishing downstream of Cherokee Falls at Location 464 on the Broad River, April 2006.

Scientific name	Common name	N
Carpiodes cyprinus	Quillback	49
Hypentelium nigricans	Northern hog sucker	5
Moxostoma collapsum	Notchlip redhorse	28
Moxostoma pappillosum	V-lip redhorse	1
Scartomyzon sp.	Brassy jumprock	39
Total number of fish		122
Number of species		5

Table 8. Numbers and catch rates of fish collected during electrofishing of three water bodies on the Lee Nuclear Station site, April-May 2006.

		Water body					
		Auxiliary Holding Pond		Sedimentation Basin		Low Flow Reservoir	
Family and scientific name	Common name	No.	No./hr	No.	No./hr	No.	No./hr
Clupeidae							
Dorosoma cepedianum	Gizzard shad					11	5
Cyprinidae							
Cyprinus carpio	Common carp					2	1
Ictaluridae							
Ameiurus brunneus	Snail bullhead					3	1
Ameiurus catus	White catfish			1	1	2	1
Ameiurus platycephalus	Flat bullhead					36	16
Centrarchidae							
Lepomis auritus	Redbreast sunfish	32	107			126	55
Lepomis gibbosus	Pumpkinseed			3	3		
Lepomis gulosus	Warmouth			16	15	36	16
Lepomis macrochirus	Bluegill	34	113	549	499	628	273
Lepomis microlophus	Redear sunfish					47	20
Lepomis hybrid	Sunfish hybrid	3	10				
Micropterus salmoides	Largemouth bass	65	217	13	12	82	36
Pomoxis nigromaculatus	Black crappie			28	25	6	3
Total number		134	447	610	555	979	427
Total number of species*		3		6		11	

*Does not include hybrids

MACROINVERTEBRATE SURVEYS IN THE VICINITY OF THE PROPOSED LEE NUCLEAR STATION; CHEROKEE CO., SOUTH CAROLINA

by

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December 15, 2006

Executive Summary

Macroinvertebrate sampling was conducted on the Broad River in the vicinity of the proposed Lee Nuclear Station site during April, August, and October of 2006. The purpose of the monitoring was to provide macroinvertebrate bioassessment data prior to construction activities at the site.

Total and EPT taxa numbers were highest in April and lowest in August, representing typical seasonal distribution. Spatially, higher total taxa and EPT taxa numbers were recorded from locations well upstream of the site, and below Ninety-Nine Islands Dam. Bioclassification scores well above and below the site were also higher than the three locations in the vicinity of the site, and were always in the "Good/Fair" to "Good" ranges. At the three location in the vicinity of the site, bioclassifications were most often in the "Poor" range, with occasional ratings of "Fair". These variations in total and EPT taxa numbers, as well as bioclassification scores were likely due to variations in habitat, with less suitable habitat at the three locations within the Ninety-Nine Islands Reservoir of the site.

Introduction

The Broad River originates in the Blue Ridge Mountains of North Carolina and continues through the Piedmont of South Carolina where it flows approximately one-hundred miles before merging with the Saluda River to form the Congaree River. The Broad River is turbid due to a high sand and silt bedload with an average annual flow in 2006 of about 1,239 cubic feet per second (cfs). The Broad River was impounded in 1910 to form Ninety-Nine Islands Reservoir which is characterized as a run-of–the river impoundment with two shallow backwater areas.

The objective of this study was to characterize the macroinvertebrate communities at sites upstream, downstream, and in the vicinity of the proposed Lee Nuclear Station site in Cherokee County, SC. Surveys were conducted to provide seasonal information regarding macoinvertebrate community composition and diversity. Macroinvertebrate communities were also used to help characterize ambient water quality prior to construction activities.

Previous macroinvertebrate monitoring was conducted on the Broad River as a part of the baseline study for the proposed Cherokee Nuclear Station during 1974-1977. This historical study included monthly sampling from September 1974 through November 1975, followed by quarterly sampling from the winter of 1976 through the spring of 1977 (Duke Power Company 1978).

Methods and Materials

Macroinvertebrate bioassessment sampling was conducted in the Broad River on April 4 and 5l, August 7 and 8, and October 11 and 13 2006 to provide a baseline assessment of macroinvertebrate communities in the Broad River in the vicinity of the proposed Lee Nuclear Station. Samples were collected at five locations upstream and downstream of the site (Figure 1). Location 465 is well upstream of the site just downstream of Cherokee Falls Dam, Locations 463 and 460 are located in the vicinity of the station above and below the proposed intake, respectively. Location 459 is located in the vicinity of the proposed station discharge, while Location 453 is located downstream of Ninety-Nine Islands Dam, in the vicinity of King's Creek.

Sampling procedures and assessment criteria for benthic communities were determined using the Standard Qualitative Bioassessment Method as outlined in the North Carolina

Department of Environment and Natural Resources (NCDENR) Standard Operating Procedures (SOP) of July 2006 (NCDENR 2006). This protocol is accepted by the state of Couth Carolina. Samples were collected from each major habitat and the organisms were sorted from debris in the field. Organisms were placed into labeled containers, preserved in 95% alcohol, returned to the laboratory, and identified to the lowest practicable taxon. Analysis results in a bioclassification for each location which gives equal consideration to the number of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa present and the biotic index value. The biotic index value is calculated for all taxa collected from a given location. Biologists with NCDENR have assigned biotic index values for benthic taxa based on their relative tolerance to environmental perturbations. A score is assigned to the EPT value and to the mean biotic index. The mean of these two scores is used to assign one of five bioclassifications, from Poor to Excellent (NCDENR 2006). Bioclassifications were determined using Piedmont criteria, with appropriate seasonal corrections, as outlined in the NCDENR SOP. The bioassessment method also requires a visual assessment of the substrate and habitat types at each sampling location. The assessment of the balanced and indigenous nature of the benthic community is determined by comparing both total and EPT taxa abundance which results in the water quality bioclassifications.

Dissolved oxygen, water temperature, and specific conductance were measured at each sampling location. Dissolved oxygen and temperature data were collected *in situ* using a pre-calibrated YSI Model 55 Handheld Dissolved Oxygen System. Water samples for conductivity analysis were collected at each location, placed on ice and returned to the lab. Conductivities were determined within one week of sampling using a calibrated Hydrolab® datasonde.

Results and Discussion

Habitat and Water Quality

Broad River flow rates varied considerably over the course of the study and ranged from less than 250 cfs to nearly 7,000 cfs at the Blacksburg Gauging Station (Figure 2). River flows recorded on sampling dates during 2006 ranged from 202 cfs at the Cherokee Falls Station to 1,080 cfs at the Blacksburg Station (Table 1).

The habitats sampled during 2006 at Locations 465 and 453, were generally similar. Both were located near islands in the river, and consisted of large riffle areas, root masses, leaf

packs, and sand/small cobble substrate. The sampling crew members were able to wade along the banks and into the river at these locations (Table 2). Locations 463, 460, and 459 were also very similar in habitat. All three locations were within the nominal "reservoir" area impounded by the Ninety-nine Islands dam. The habitat at these locations was very limited, with steep banks (sampling was generally conducted from a boat), some root masses along the banks, and organic matter from the river bottom.

The water quality parameters measured varied among all locations. Temperatures varied from as low as 16.7 C (62.1 F) in April, to 31.0 C (87.8 F) during August (Table 3). Dissolved oxygen concentrations ranged from 6.6 mg/l in August to 10.4 mg/l in April. Specific conductance values were lowest in April (84.4 µS/cm - 90.4 µS/cm) and highest during August (132.4 µS/cm - 154.2 µS/cm). Dissolved oxygen concentrations were often slightly higher at the most upstream and downstream Locations 465 and 453, far upstream of the site and below Ninety-Nine Islands Dam, than at the three intermediate locations. Other water quality parameters showed no notable spatial differences. These data were consistent with those observed during the baseline environmental monitoring conducted by Duke Power Company from 1974 into 1977 (Duke Power Company 1978).

Bioassessment

The total number of benthic macroinvertebrate taxa collected during 2006 varied among seasons and locations. The highest number of taxa for all locations combined was recorded in April. The lowest number of taxa for all locations was recorded in August. Taxa abundance increased again in October (Tables 4 through 6, Figure 3). This pattern of seasonal variability was also observed in previous studies on the Broad River (Duke Power Company 1978).

Total taxa numbers and numbers of EPT taxa were consistently higher at Locations 465 and 453 than at Locations 463, 460, and 459 (Tables 4 through 6, Figures 3 and 4). Total taxa ranged from 18 at Location 463 in August, to 86 at Location 465 in April, while numbers of EPT taxa ranged from a single organism each at Location 459 in April and Location 463 in August, to 26 at Location 465 in April.

Bioassessment scores ranged from "Poor" to "Good" at various locations during 2006 (Figure 5). These scores followed the same spatial patterns as total taxa and EPT taxa

numbers, with comparatively high scores at Locations 465 and 453, while Locations 463, 460, and 459 consistently demonstrated considerably lower scores.

Since water quality parameters were generally similar among locations during each season, the variations in total taxa and EPT taxa numbers, as well as bioassessment scores between the upstream and downstream locations as compared to the intermediate locations, were likely due to variations in habitat. Sampled habitats at Locations 465 and 453 were within riffle areas with sand and cobble substrates, as well as abundant leaf packs and root masses. The locations in Ninety-Nine Islands Reservoir (463, 460, and 459) demonstrated substantially less viable habitat. These areas were characterized by steep banks, with little overhang, and mud/silt substrates not conducive to macroinvertebrate diversity.

Comparisons of the baseline benthic studies conducted during 1974-1977 (Duke Power Company 1978) to the current study are problematic because bioassessment methodologies had yet to be developed and the earlier program itself was substantially different in scope. However, some general comparisons can be made. Habitat in areas sampled during the two programs has remained essentially the same. Sites in the reservoir area were then, and still are, limited in diverse habitat for macroinvertebrate taxa. Sites well below the reservoir were characterized by riffles, rock and sand substrates, leaf packs and considerable overhanging vegetation on the banks, thus allowing for far more diverse habitat. Comparisons of taxa collected during the two programs showed that many of the same taxa were present during 2006. These include many species of Diptera (Choronomidae, Chaoboridae) Ephemeroptera (Ephemeridae, Heptageniidae), Plecoptera (Perlidae, Gomphidae), and Tricoptera (Hydropsychidae, Hydroptilidae). This data indicate a comparatively high degree of similarity and stability of macroinvertebrate communities of the study area over time.

Literature Cited

Duke Power Company. 1978. Baseline Environmental Summary Report on The Broad River in The Vicinity of Cherokee Nuclear Station. L. L. Olmsted and A. S. Leiper, eds. Duke Power Company, Charlotte, NC.

North Carolina Department of Environment and Natural Resources (NCDENR). 2006. Standard Operating Procedures for Benthic Macroinvertebrates. NCDENR Division of Water Quality, Section. Raleigh, North Carolina.

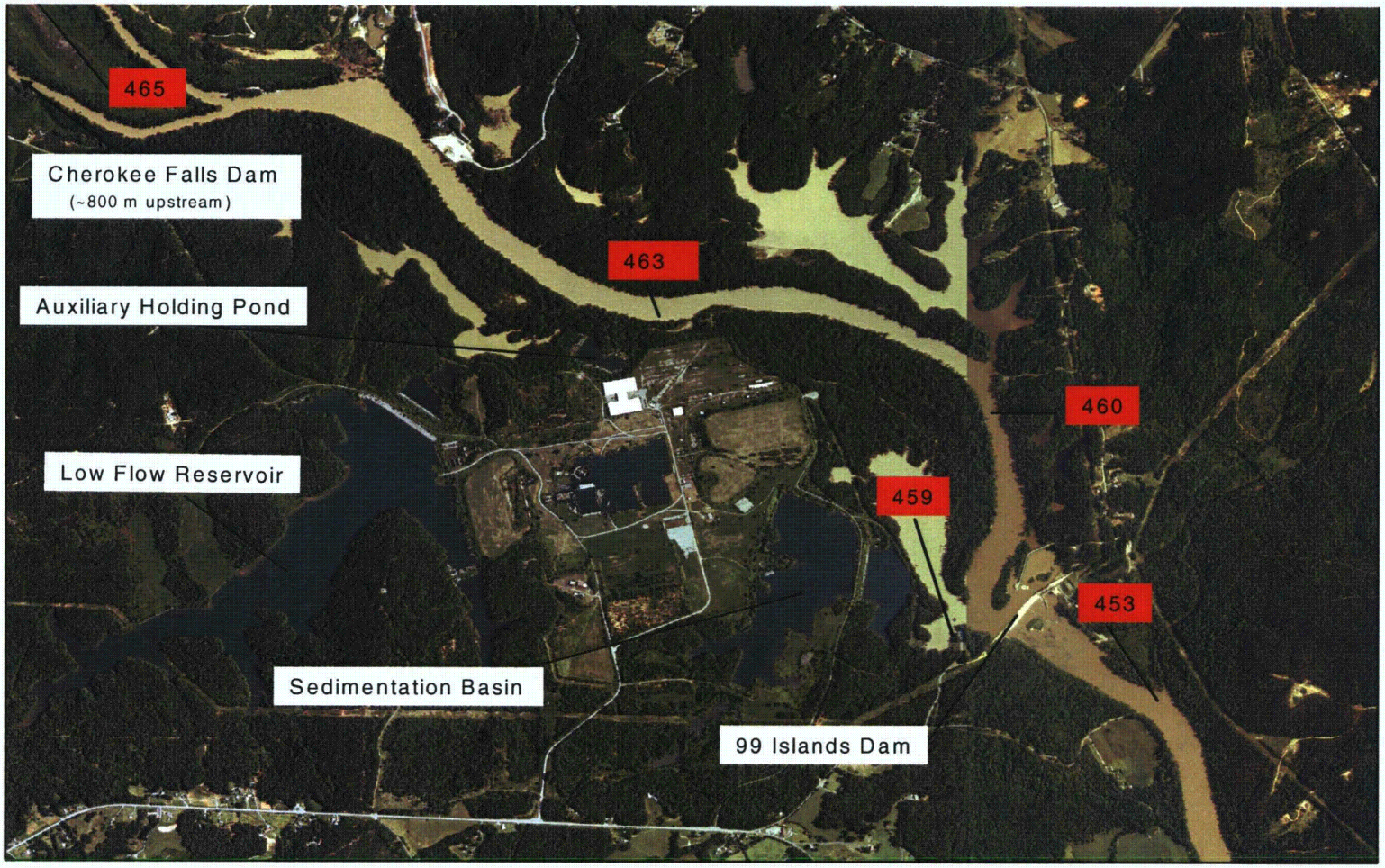


Figure 1. Aerial photograph of the proposed Lee Nuclear Station site, Broad River, SC, and the associated macroinvertebrate sampling locations (in red).

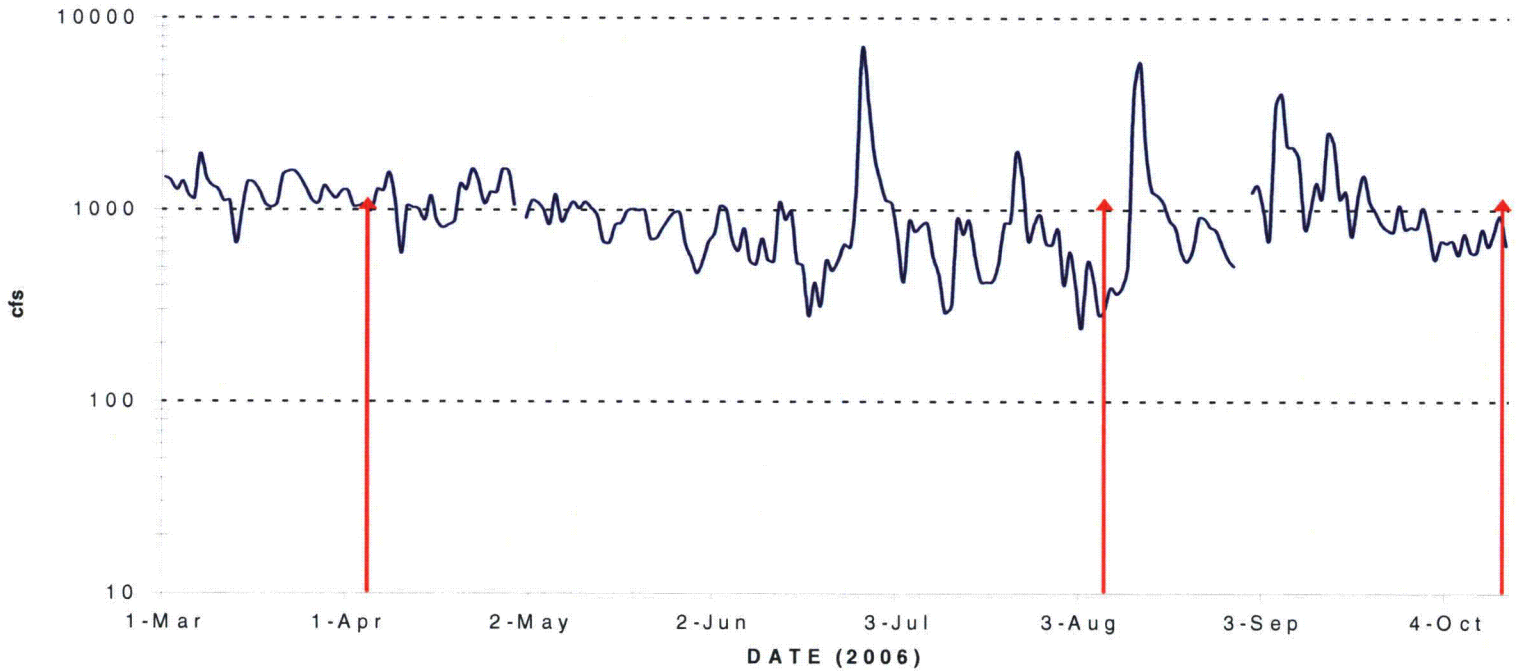


Figure 2. Hydrograph of daily mean flows for the Broad River and associated macroinvertebrate sampling periods (vertical red lines). This plot represents adjusted USGS data from Blacksburg, SC gauge.

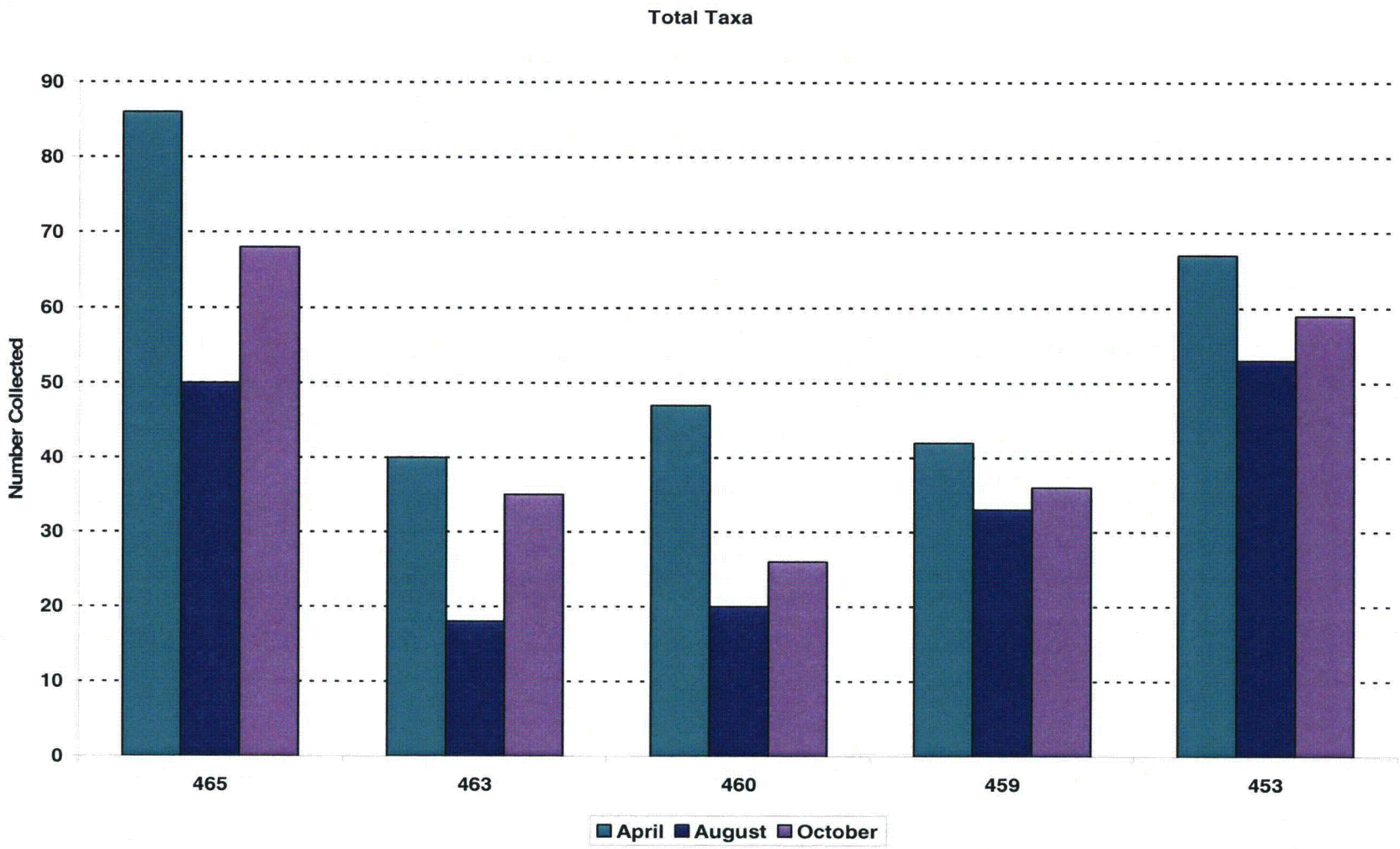


Figure 4. Number of EPT taxa collected from the Broad River during April, August, and October 2006 sampling periods

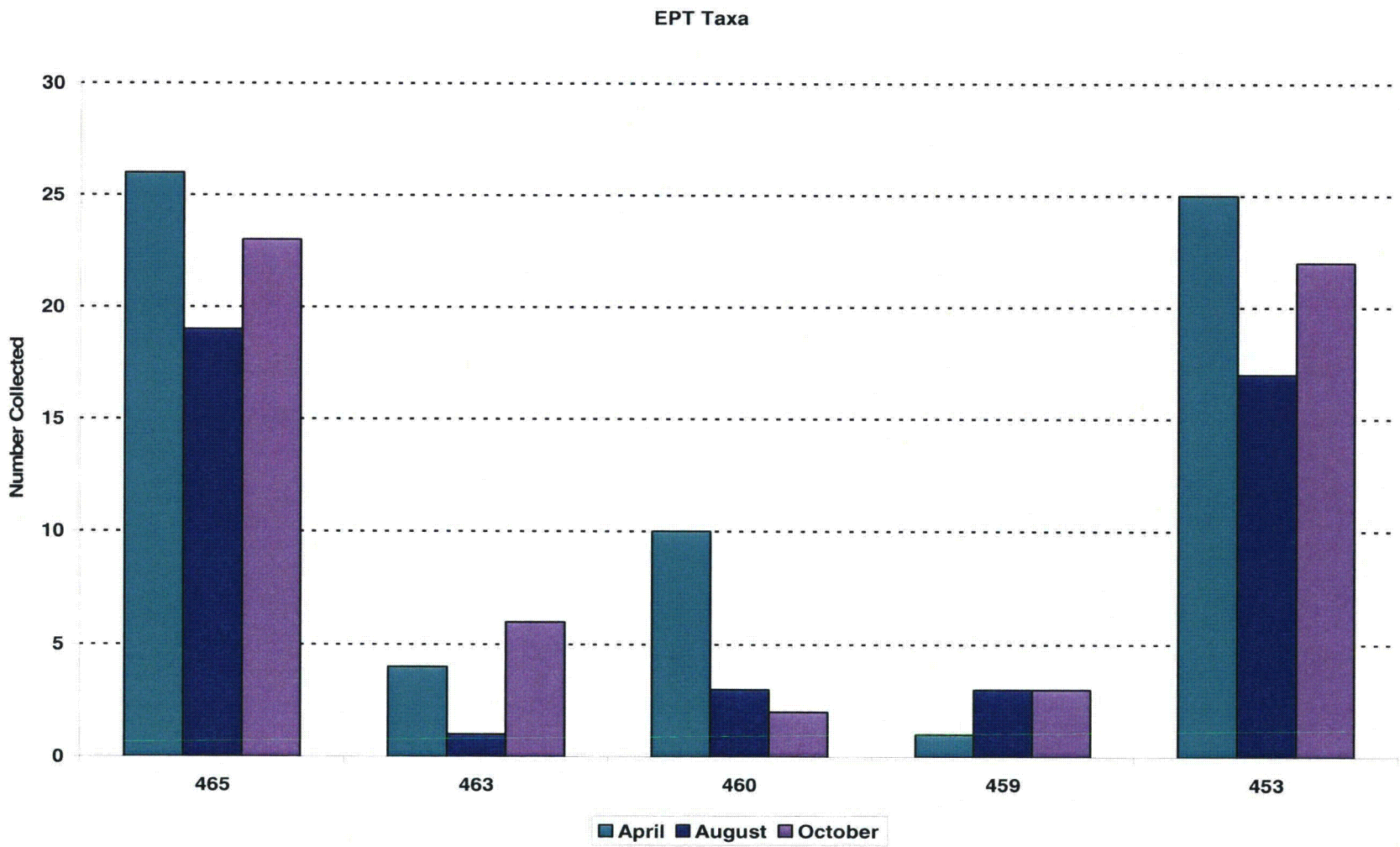


Figure 4. Number of EPT taxa collected from the Broad River during April, August, and October 2006 sampling periods.

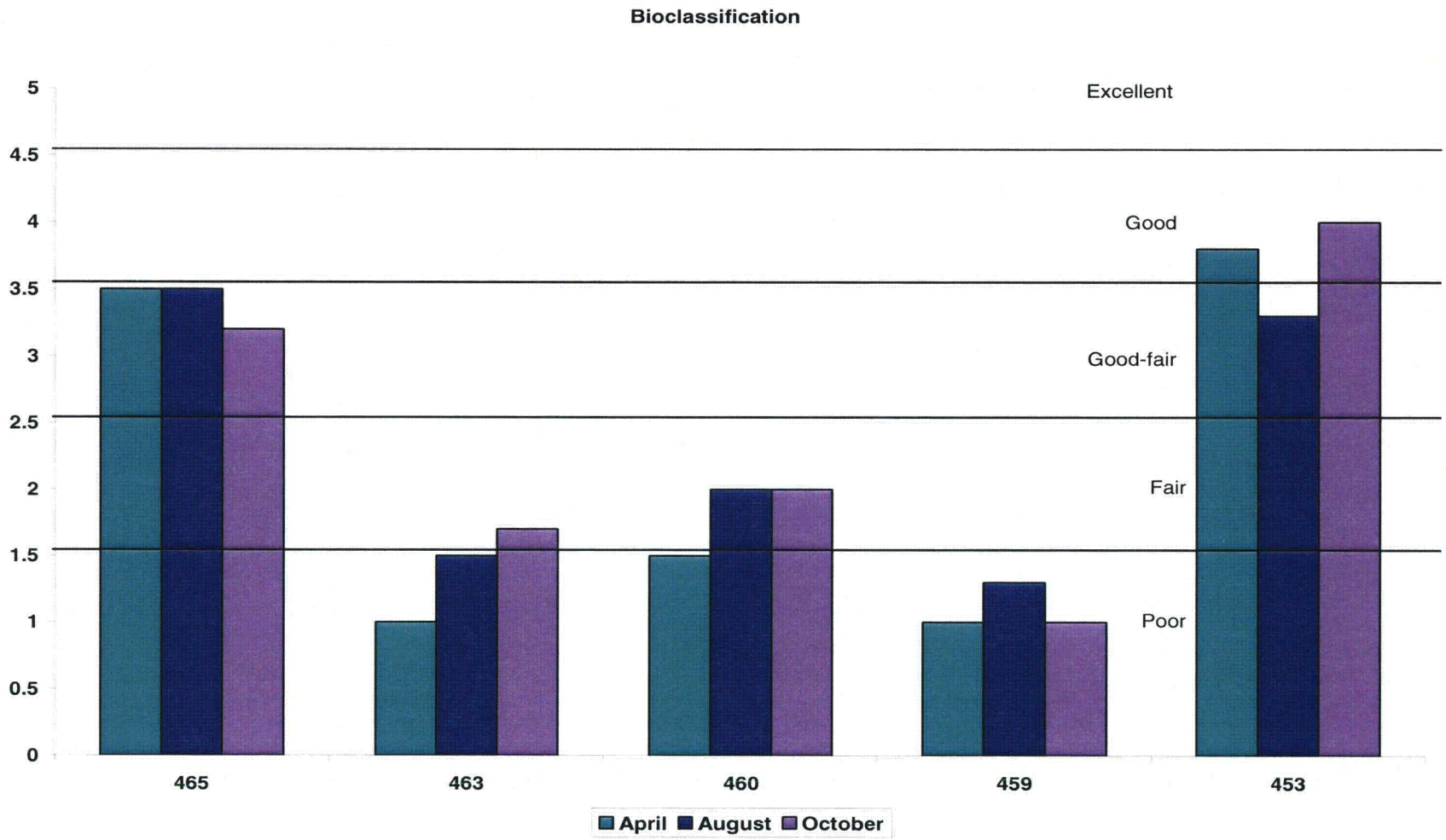


Figure 5. Water quality bioclassifications based on macroinvertebrate collections from the Broad River during April, August, and October 2006 sampling periods.

Table 1. Average daily Broad River flows recorded at the time of macroinvertebrate sample collection. Data were recorded from USGS gauge stations.

Sample Collection Date	Broad River USGS Gage 02153551 Below Cherokee Falls	Broad River USGS Gage 02153200 Near Blacksburg, SC
April 4, 2006	1,050 cfs	1,080 cfs
April 5, 2006	1,030 cfs	992 cfs
August 7, 2006	614 cfs	302 cfs
August 8, 2006	679 cfs	391 cfs
October 11, 2006	202 cfs	645 cfs
October 13, 2006	251 cfs	932 cfs

Table 2. Habitat descriptions of locations sampled on the Broad River in 2006.

Location	Description
465 Upstream Location Below Cherokee Falls	Sampling conducted around an island in the middle of the river. Habitat is comprised of large riffle areas, root mass, leaf packs, and sand/small cobble substrate.
463 Potential LNS Water Intake Area	Sampling conducted from the middle of the river to the shoreline. Habitat is limited and is usually comprised of root mass from bank samples and organic matter taken from the bottom of the river with ponar grabs. This location is located in a reservoir area and is very different from the wadeable upstream (465.0) and downstream locations (453.0).
460 Pick Hill Boat Access Area	Sampling is conducted from the middle of the river to the shoreline. Habitat is limited and is usually comprised of root mass from bank samples and organic matter taken from the bottom of the river with ponar grabs. This location is located in a reservoir area and is very different from the wadeable upstream (465.0) and downstream locations (453.0).
459 Potential LNS Discharge Area	Sampling is conducted from the middle of the river to the shoreline. Habitat is limited and is usually comprised of root mass from bank samples and organic matter taken from the bottom of the river with ponar grabs. When available sticks were washed for chironomids. This location is located in a reservoir area and is very different from the wadeable upstream (465.0) and downstream locations (453.0).
453 Downstream Location Below Ninety-nine Islands Dam	Sampling is conducted around an island in the middle of the river. Habitat is comprised of large riffle areas, root mass, leaf packs, and sand/small cobble substrate.

Table 3. Water quality parameters recorded during the 2006 macroinvertebrate sample collection on the Broad River, SC.

Date	Location	Temperature C (F)	Dissolved Oxygen (mg/l)	Specific Conductance (µS/cm)
April 4, 2006	465	16.7 (62.1)	10.4	84.4
	463	17.6 (63.7)	9.4	87.7
	460	17.2 (63.0)	8.3	91.3
April 5, 2006	459	18.5 (65.3)	9.3	89.2
	453	18.0 (64.4)	10.3	90.4
August 7, 2006	465	29.7 (85.5)	8.1	154.2
	463	30.6 (87.1)	6.7	143.6
	460	30.8(87.4)	6.8	150.3
August 8, 2006	459	31.0 (87.8)	6.6	132.4
	453	29.9 (85.8)	7.7	144.8
October 11, 2006	465	18.7 (65.5)	8.8	102.6
	463	19.4 (66.9)	7.7	111.8
	460	19.6 (67.2)	8.7	107.6
October 13, 2006	459	19.4 (66.9)	7.5	108.0
	453	19.3 (66.7)	8.5	107.7

Table 4. Macroinvertebrates collected from the Broad River at Locations 465, 463, 460, 459, and 453. Samples were collected on April 4 and 5, 2006. "R"= Rare (1-2 individuals collected), "C"= Common (3-9 individuals collected), "A"= Abundant (10 or more individuals collected).

Taxon	**465**	**463**	**460**	**459**	**453**
Annelida					
Oligochaeta					
Haplotaxida					
Tubificida					
Naididae					
Nais behningi	C				
Nais communis				A	
Pristinella osborni	R				
Ripistes parasita	C				
Slavina appendiculata	R				
Stylaria lacustris		R		R	
Tubificidae	R	R			
Branchirua sowerbyi		R		R	
Limnodrilus hoffmeisterei		R	R		
Tubifex harmani		C			
Lumbriculida					
Lumbriculidae	C	R	R	C	C
Lumbriculus variegatus	R			R	A
Arthropoda					
Crustacea					
Amphipoda					
Talitridae					
Hyalella azteca			R	R	
Decapoda					
Cambaridae					
Cambarus spp.			C	C	R
Isopoda					
Asellidae					
Caecidotea spp.		R			C
Insecta					
Coleoptera					
Dytiscidae					
Neoporus spp.			R	C	
Elmidae					
Ancyronyx variegatus	R	R			

Table 4 (Continued).

Taxon	465	463	460	459	453
Macronychus glabratus	C		R		
Stenelmis spp.	R				
Gyrinidae					
Dineutus spp.				A	
Haliplidae					
Peltodytes spp.		A		C	
Hydrophilidae					
Sperchopsis tessellatus	R		R		
Ptilodactylidae					
Anchytarsus bicolor	R				
Diptera					
Ceratopogonidae					
Palpomyia-Bezzia complex	A		C		C
Chironomidae-Chironominae					
Chironomus spp.	R	A	C	C	C
Cladotanytarsus spp.				R	R
Cryptochironomus spp.	C	R	C		
Dicrotendipes neomodestus	C	R	A	C	C
Endochironomus spp.			R		
Glyptotendipes spp.			C	A	
Paralauterborniella nigrohalterale		R			
Paratendipes spp.		R		R	R
Phaenopsectra spp.	C	C	C	R	C
Polypedilum fallax	R	R	R	R	
Polypedilum flavum	A				A
Polypedilum halterale	A	A	C	C	A
Polypedilum illinoiense	A	A	A	A	A
Polypedilum scalaenum		R	R		
Stenochironomus spp.		R	R	R	R
Stictochironomus spp.		C	A		
Tanytarsus spp.	R	R		C	
Tribelos spp.		C	R		
Chironomidae-Diamesinae					
Potthastia longimana gr.	C				
Chironomidae-Orthocladiinae					
Brillia spp.	R		R		
Cardiocladius spp.	A				
Cricotopus annulator	A	R	A		A

Table 4 (Continued).

Taxon	465	463	460	459	453
Cricotopus bicinctus	A	A	A	C	A
Cricotopus cylindraceus					A
Cricotopus infuscatus gp.	A	R	C	R	A
Cricotopus politus	R			R	
Cricotopus sylvestris gp.		C	C	A	R
Cricotopus trifascia	R				A
Cricotopus vierriensis	A		R	R	
Eukiefferiella spp.	C		R		C
Nanocladius spp.	C	R		A	C
Orthocladius obumbratus	A	C	C	C	C
Paratrichocladius spp.	A	C	C		A
Synorthocladius spp.			R		R
Thienemanniella spp.	C				C
Tvetenia spp.	C				
Tvetenia vitracies					C
Chironomidae-Tanypodinae					
Ablabesmyia annulata				C	
Ablabesmyia janta		C	C	C	
Ablabesmyia mallochi	C	R	A		R
Coelotanypus tricolor				R	
Conchapelopia gp.	C	R			R
Nilotanypus spp.	C				
Procladius spp.				C	
Simuliidae					
Simulium spp.	C				C
Tabanidae					
Tabanus spp.				R	
Tipulidae					
Antocha spp.	R				C
Tipula spp.	R				R
Ephemeroptera					
Baetidae					
Acentrella spp.	R				
Baetis intercalaris	A				R
Centroptilum spp.	R		R		
Plauditus dubius grp	C				R
Ephemerellidae					

Table 4 (Continued).

Taxon	465	463	460	459	453
Dannella simplex	A		R		A
Ephemerella dorothea	C				A
Eurylophella versimilis	C	R	C		R
Serratella molita	R				C
Ephemeridae					
Hexagenia spp.		R	R	A	
Heptageniidae					
Heptagenia marginalis	A				A
Stenacron interpunctatum					R
Stenonema exiguum	A		R		A
Stenonema mexicanum	R				
Stenonema modestum	A				A
Stenonema smithae					C
Leptophlebiidae					
Leptophlebia spp.			R		
Neoephemeridae					
Neoephemera purpurea	R				R
Oligoneuriidae					
Isonychia spp.	A		R		A
Hemitpera					
Corixidae					
Sigara spp.				R	
Megaloptera					
Corydalidae					
Corydalus cornutus	C				A
Sialidae					
Sialis spp.				R	
Odonata-Anisoptera					
Aeshnidae					
Boyeria vinosa	R				R
Corduliidae					
Neurocordula molesta	R				
Neurocordulia obsoleta	R				
Gomphidae					
Dromogomphus spp.	C				
Gomphus spp.	R			R	C
Hagenius brevistylus	R				

Table 4 (Continued).

Taxon	**465**	**463**	**460**	**459**	**453**
Ophiogomphus spp.	R				
Stylogomphus albistylus	R				
Libellulidae					
Libellula spp.				C	
Macromiidae					
Macromia georgina	A				
Odonata-Zygoptera					
Calopterygidae					
Calopteryx spp.	C				
Hetaerina spp.	R				A
Coenagrionidae					
Argia spp.	A	R	R		C
Enallagma spp.				C	
Ischnura spp.		R			
Plecoptera					
Perlidae					
Acroneuria abnormis	C				
Neoperla spp.					C
Paragnetina fumosa	A				
Perlesta spp.	A		R		A
Trichoptera					
Hydropsychidae					
Cheumatopsyche spp.	A				A
Hydropsyche incommoda	R				
Hydropsyche phalerata	A				A
Hydropsyche venularis	A		R		A
Macrostenum spp.	R				A
Hydroptilidae					
Hydroptila spp.	R				R
Leptoceridae					
Nectopsyche exquisita	A	C	C		C
Oecetis spp.					R
Triaenodes ignitus	A	R			A
Philopotamidae					
Chimarra spp.					R
Polycentropodidae					
Neureclipsus spp.	R				R

Table 4 (Continued).

Taxon	**465**	**463**	**460**	**459**	**453**
Mollusca					
Gastropoda					
Basommatophora					
Physidae					
Physella spp.		R	R	A	
Limnophila					
Ancylidae					
Laevapex fuscus	R			R	
Mesogastropoda					
Hydrobiidae					
Amnicoloa spp.	C				R
Pleuroceridae					
Leptoxis spp.					A
Pulmonata					
Planorbidae					
Menetus dilatatus			R	R	R
Pelecypoda					
Heterodonta					
Sphaeriidae					A
Heterodontida					
Corbiculidae					
Corbicula fluminea	A		C		
Platyhelminthes					
Turbellaria					
Tricladida					
Planariidae					
Dugesia spp.	R				R
Total Taxa Collected	**86**	**40**	**47**	**42**	**67**
Total EPT Taxa Collected	**26**	**4**	**10**	**1**	**25**
Biotic Index Value	**6.00**	**8.19**	**7.56**	**7.99**	**5.71**
EPT Score	**4**	**1**	**2**	**1**	**3.6**
Biotic Index Score	**3**	**1**	**1**	**1**	**4**
Final Bioclassification	**Good**	**Poor**	**Poor**	**Poor**	**Good**
Total Taxa: All Locations					**130**

Table 5. Macroinvertebrates collected from the Broad River at Locations 465, 463, 460, 459, and 453. Samples were collected on August 7-8, 2006. "R"= Rare (1-2 individuals collected), "C"= Common (3-9 individuals collected), "A"= Abundant (10 or more individuals collected).

Taxon	**465**	**463**	**460**	**459**	**453**
Annelida					
Hirundinea					
Rhynchobdellida					
Glossiphoniidae					
Placobdella				C	
Oligochaeta					
Haplotaxida					
Tubificida					
Naididae					
Nais communis				R	C
Tubificidae		R	R		
Branchirua sowerbyi				R	
Tubifex harmani	C		R		
Tubifex tubifex		R			
Lumbriculida					
Lumbriculidae	C			R	C
Lumbriculus spp.	R				R
Arthropoda					
Crustacea					
Decapoda					
Cambaridae					
Cambarus spp.					C
Insecta					
Coleoptera					
Dytiscidae					
Heichus spp.	R				
Elmidae					
Ancyronyx variegatus	C	R	R		R
Macronychus glabratus	C				C
Stenelmis spp.	A				R
Gyrinidae					
Dineutus spp.	A				A
Diptera					

Table 5 (Continued).

Taxon	465	463	460	459	453
Ceratopogonidae					
Palpomyia-Bezzia complex			R	C	
Chaoboridae					
Chaoborus spp.				C	
Chironomidae-Chironominae					
Axarus spp.			C		
Chironomus spp.				A	R
Cladotanytarsus spp.	R				R
Cryptochironomus spp.	R		R	R	C
Dicrotendipes neomodestus	C			C	A
Glyptotendipes spp.				A	
Phaenopsectra spp.		C			R
Polypedilum beckae			R	A	
Polypedilum flavum	C				
Polypedilum halterale		C		A	R
Polypedilum illinoiense	A	R	C	R	R
Rheotanytarsus spp.	R			R	
Robackia spp.					R
Stenochironomus spp.	C		R	R	C
Tanytarsus spp.	C			C	A
Tribelos spp.	R	A	R	C	
Chironomidae-Orthocladiinae					
Cricotopus annulator					R
Cricotopus politus	A			R	A
Nanocladius spp.		R		R	R
Thienemanniella spp.	R				
Chironomidae-Tanypodinae					
Ablabesmyia spp.	C	C	C	A	C
Ablabesmyia janta			R		
Ablabesmyia mallochi				R	C
Coelotanypus spp.		C	R	C	
Labrundinia spp.			R		
Nilotanypus spp.	R				C
Procladius spp.				R	
Simuliidae					
Simulium spp.					C

Table 5 (Continued).

Taxon	**465**	**463**	**460**	**459**	**453**
Ephemeroptera					
Baetidae					
Baetis intercalaris	C				C
Baetis pluto	R				
Centroptilum spp.	R				
Heterocloeon curiosum	C				A
Caenidae					
Caenis spp.				C	
Ephemeridae					
Hexagenia spp.	R	A			
Heptageniidae					
Heptagenia marginalis	C				
Stenonema exiguum	A				A
Stenonema modestum					R
Stenonema smithae	C				A
Oligoneuriidae					
Isonychia spp.	A				A
Tricorythidae					
Tricorythodes spp.	A				C
Hemitpera					
Nepidae					
Ranatra spp.	R				
Megaloptera					
Corydalidae					
Corydalus cornutus	A				A
Odonata-Anisoptera					
Aeshnidae					
Boyeria vinosa	R	R			R
Corduliidae					
Epicordulia spp.		R		C	
Gomphidae					
Dromogomphus spp.			R	R	R
Gomphus spp.	R	R		C	
Macromiidae					
Macromia georgina	C	R		R	R
Odonata-Zygoptera					

Table 5 (Continued).

Taxon	465	463	460	459	453
Calopterygidae					
Hetaerina spp.	C				R
Coenagrionidae					
Argia spp.	A	C		C	A
Ischnura spp.			R	A	
Plecoptera					
Perlidae					
Acroneuria abnormis					R
Paragnetina fumosa	C				
Trichoptera					
Hydropsychidae					
Cheumatopsyche spp.	C				C
Hydropsyche phalerata	A				A
Hydropsyche venularis	A		R		A
Macrostenum spp.	A		R		C
Hydroptilidae					
Hydroptila spp.			R		C
Leptoceridae					
Oecetis spp.				C	C
Triaenodes ignitus	R				C
Philopotamidae					
Chimarra spp.	R				
Polycentropodidae					
Cyrnellus fraternus				R	
Polycentropus spp.			C		R
Psychomyiidae					
Psychomyia flavida	R				
Mollusca					
Gastropoda					
Basommatophora					
Physidae					
Physella spp.		R			R
Mesogastropoda					
Hydrobiidae					
Amnicoloa spp.	A				A

Table 5 (Continued).

Taxon	**465**	**463**	**460**	**459**	**453**
Pleuroceridae					
Leptoxis spp.					A
Pelecypoda					
Heterodonta					
Corbiculidae					
Corbicula fluminea	C	C	R	C	A
Total Taxa Collected	**48**	**18**	**21**	**33**	**51**
Total EPT Taxa Collected	**19**	**1**	**3**	**3**	**17**
Biotic Index Value	**5.39**	**6.54**	**6.10**	**7.44**	**5.34**
EPT Score	**3**	**1**	**1**	**1**	**2.6**
Biotic Index Score	**4**	**2**	**3**	**1.6**	**4**
Final Bioclassification	**Good/ Fair**	**Poor**	**Fair**	**Poor**	**Good/ Fair**
Total Taxa: All Locations					**83**

Table 6. Macroinvertebrates collected from the Broad River at Locations 465, 463, 460, 459, and 453. Samples were collected on October 11, 2006 and October 13, 2006. "R"= Rare (1-2 individuals collected), "C"= Common (3-9 individuals collected), "A"= Abundant (10 or more individuals collected).

Taxon	**465**	**463**	**460**	**459**	**453**
Annelida					
Hirundinea					
Rhychobdellida					
Glossiphoniidae					
Placobdella spp.				R	
Oligochaeta					
Haplotaxida					
Naididae					
Allonais pectinata				R	
Stylaria lacustris				R	
Tubificida					
Tubificidae		R		R	R
Branchirua sowerbyi			C	R	
Limnodrilus hoffmeisterei		R	R	R	
Lumbriculida					
Lumbriculidae	A			C	A
Lumbriculus spp.	R		R		R
Arthropoda					
Crustacea					
Amphipoda					
Talitridae					
Hyalella azteca				R	
Decapoda					
Cambaridae					
Cambarus spp.	C	C	C	C	R
Insecta					
Coleoptera					
Dryopidae					
Helichus spp.					R
Dytiscidae					
Coptotomus spp.		C			
Elmidae					
Ancyronyx variegatus	C	C	R		R
Macronychus glabratus	C	R	R		C
Stenelmis spp.	C	R	R		

Table 4-6 (Continued).

Taxon	465	463	460	459	453
Gyrinidae					
Dineutus spp.		A			A
Haliplidae					
Peltodytes spp.		A			
Hydrophilidae					
Berosos spp.		R			
Sperchopsis tessellatus	R				
Tropisternus spp.		R			
Diptera					
Ceratopogonidae					
Palpomyia-Bezzia complex		R	R		
Chironomidae-Chironominae					
Axarus spp.			A		
Chironomus spp.			R	R	
Cladotanytarsus spp.	C			R	R
Cryptochironomus spp.	R	R		R	R
Dicrotendipes neomodestus	C		C	C	R
Glyptotendipes spp.				A	R
Phaenopsectra spp.				C	
Polypedium beckae	R			A	R
Polypedilum halterale	C	C			R
Polypedilum illinoiense	C	C	R	A	R
Polypedilum scalaenum					R
Robackia spp.	R				
Stenochironomus spp.	R		R		R
Stictochironomus spp.	R	R			R
Tanytarsus spp.	C	C		R	
Tribelos spp.	R	C	C	C	R
Chironomidae-Orthocladiinae					
Cricotopus annulator	C			R	
Cricotopus bicinctus	A				
Cricotopus infuscatus	A				
Cricotopus politus	A				
Cricotopus trifascia	R				
Cricotopus vierriensis	C				
Eukiefferiella spp.	C				R
Nanocladius spp.				R	
Orthocladius dubitatus	C				

Table 4-6 (Continued).

Taxon	465	463	460	459	453
Orthocladius obumbratus	R				
Paratrichocladius spp.	C				
Rheocricotopus spp.	R				
Thienemanniella spp.	C				R
Chironomidae-Tanypodinae					
Ablabesmyia spp.				R	
Ablabesmyia annulata		C	R		
Ablabesmyia janta		R	R	R	
Ablabesmyia mallochi			R	C	
Clinotanypus spp.		R			
Coelotanypus spp.		C		A	
Conchapelopia gp.	C				
Nilotanypus spp.					R
Simuliidae					
Simulium spp.					A
Tipulidae					
Tipula spp.	R				C
Ephemeroptera					
Baetidae					
Acentrella spp.	C				C
Baetis intercalaris	A				A
Baetis Pluto	C				C
Baetis propinquus	C				
Centroptilum spp.	R	R			
Heterocloeon curiosum	A				A
Caenidae					
Caenis spp.	R	R		R	
Ephemeridae					
Hexagenia spp.		A	A	R	
Heptageniidae					
Heptagenia marginalis					C
Heptagenia pula					R
Stenacron interpunctatum	R				
Stenonema exiguum	A				A
Stenonema mexicanum	R				
Stenonema modestum	A				A
Stenonema smithae	A				C
Oligoneuriidae					

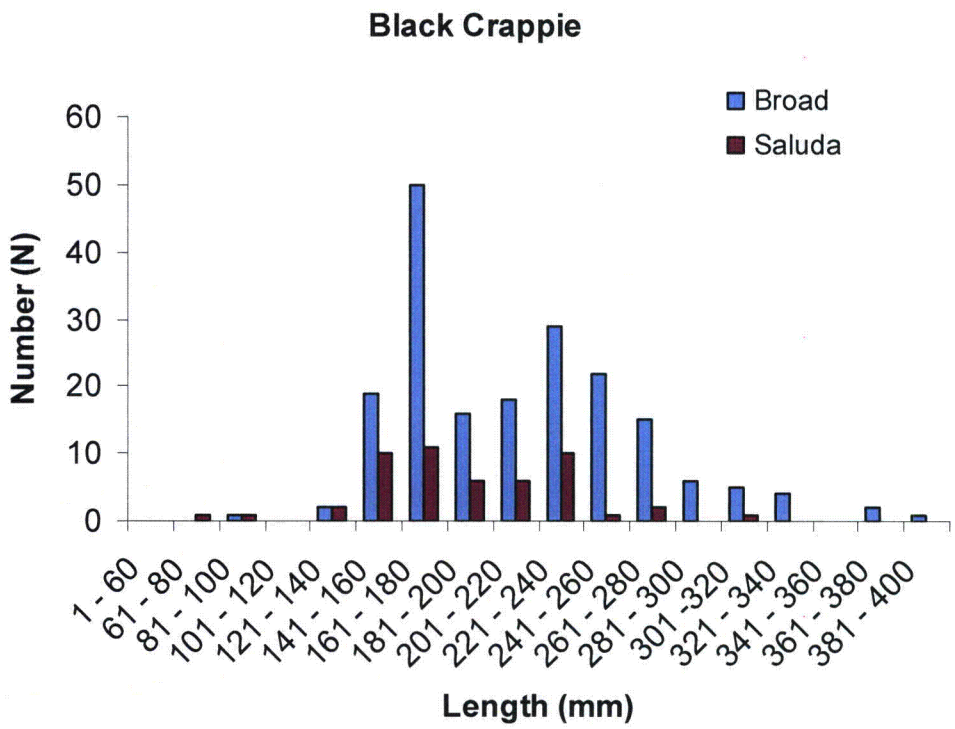
Table 4-6 (Continued).

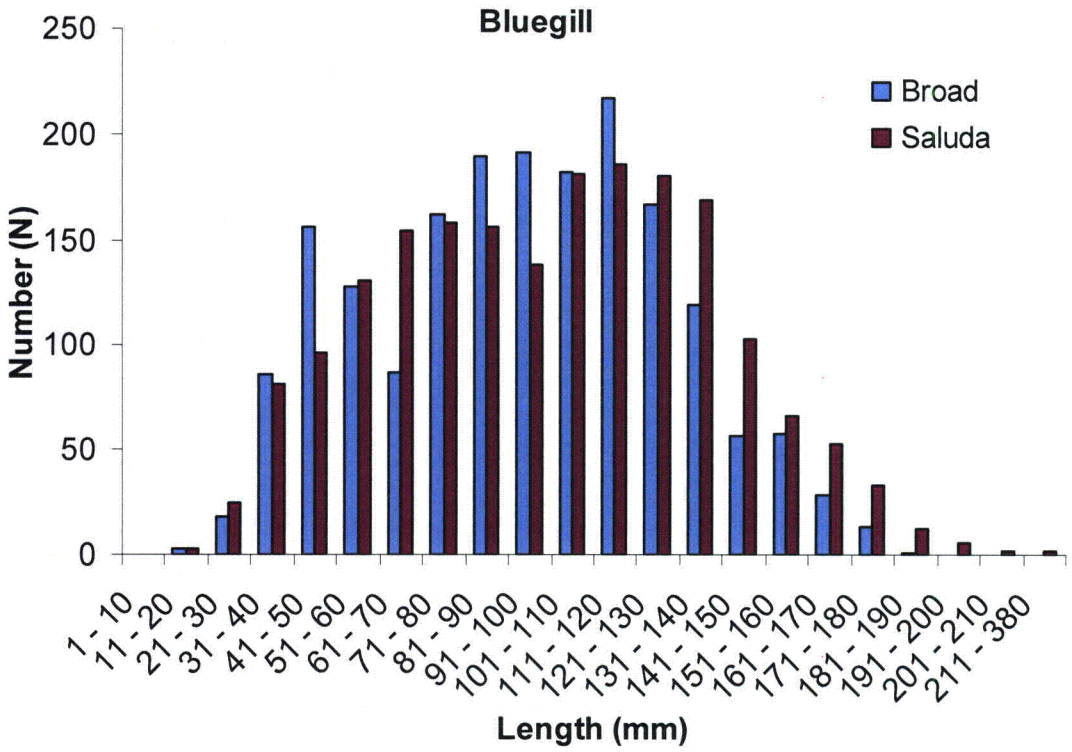
Taxon	465	463	460	459	453
Isonychia spp.	A				A
Tricorythidae					
Tricorythodes spp.	C				R
Hemitpera					
Belosomotatidae					
Belostoma spp.				R	
Megaloptera					
Corydalidae					
Corydalus cornutus	A				A
Odonata-Anisoptera					
Aeshnidae					
Boyeria vinosa	C	C		C	C
Corduliidae					
Neurocordula obsoleta			R	C	
Gomphidae					
Dromogomphus spp.	C		R	R	R
Gomphus spp.	R	C			
Hagenius brevistylus					R
Stylogomphus albistylus					R
Macromiidae					
Macromia georgina	C	C	C		C
Odonata-Zygoptera					
Calopterygidae					
Hetaerina spp.	C				A
Coenagrionidae					
Argia spp.	A	C	R	A	A
Ischnura spp.		R	C	A	R
Plecoptera					
Perlidae					
Neoperla spp.					C
Paragnetina fumosa	C				R
Trichoptera					
Hydropsychidae					
Cheumatopsyche spp.	A				C
Hydropsyche incommoda					C
Hydropsyche phalerata	A				A
Hydropsyche phalerata					C
Hydropsyche venularis	A				A
Macrostenum spp.	C				A
Hydroptilidae					

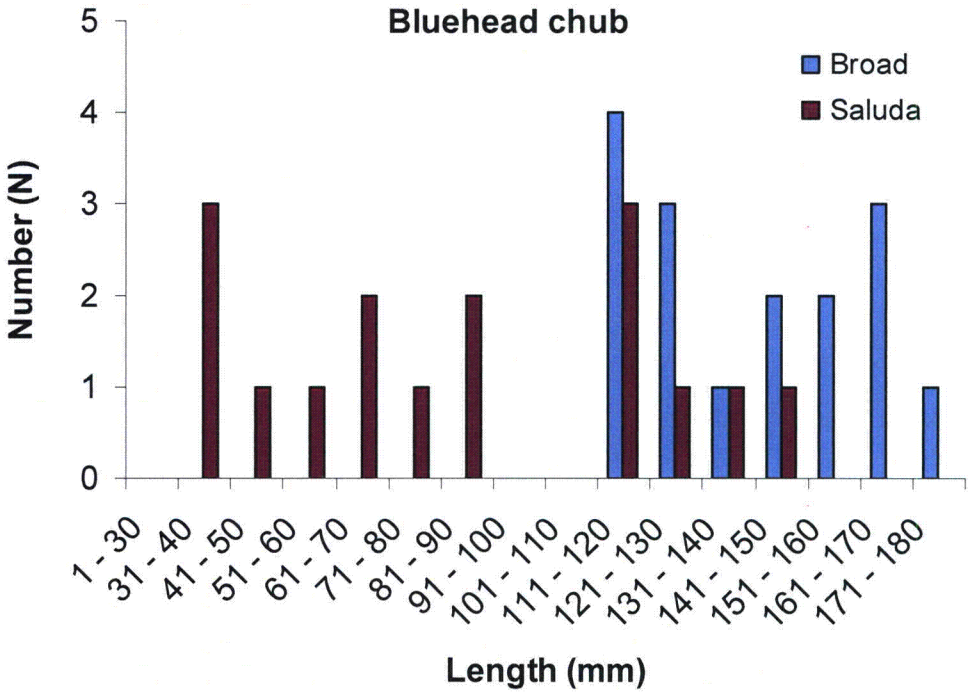
Table 4-6 (Continued).

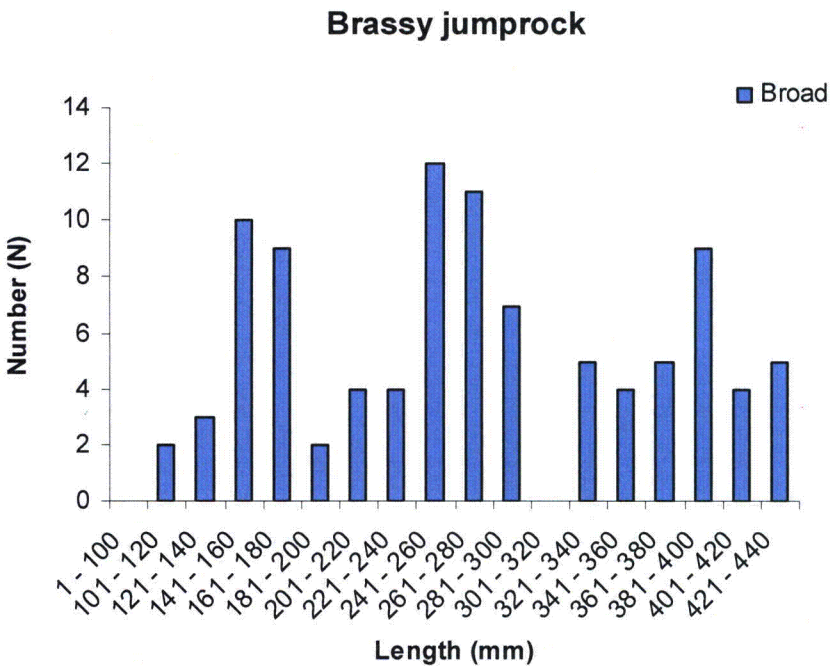
Taxon	465	463	460	459	453
Hydroptila spp.	R				
Leptoceridae					
Ceraclea spp.					R
Cyrnellus fraternus		R			
Nectopsyche exquisita	C	R			C
Neureclipsus spp.	R				
Oecetis spp.				A	
Triaenodes ignitus	C	C	R		
Mollusca					
Gastropoda					
Basommatophora					
Physidae					
Physella spp.	C	A	A	A	
Limnophila					
Ancylidae					
Laevapex fuscus	R				
Mesogastropoda					
Hydrobiidae					
Amnicoloa spp.	R				A
Pleuroceridae					
Leptoxis spp.	R				A
Pelecypoda					
Heterodontida					
Corbiculidae					
Corbicula fluminea	A	R	A		A
Platyhelminthes					
Turbellaria					
Tricladida					
Planariidae					
Dugesia spp.	R			R	R
Total Taxa Collected	**68**	**35**	**26**	**36**	**58**
Total EPT Taxa Collected	**23**	**6**	**2**	**3**	**22**
Biotic Index Value	**5.95**	**6.98**	**6.34**	**7.55**	**5.15**
EPT Score	**3.4**	**1.4**	**1**	**1**	**3.4**
Biotic Index Score	**3**	**2**	**3**	**1**	**4.6**
Final Bioclassification	**Good/ Fair**	**Fair**	**Fair**	**Poor**	**Good**
Total Taxa: All Locations					**110**

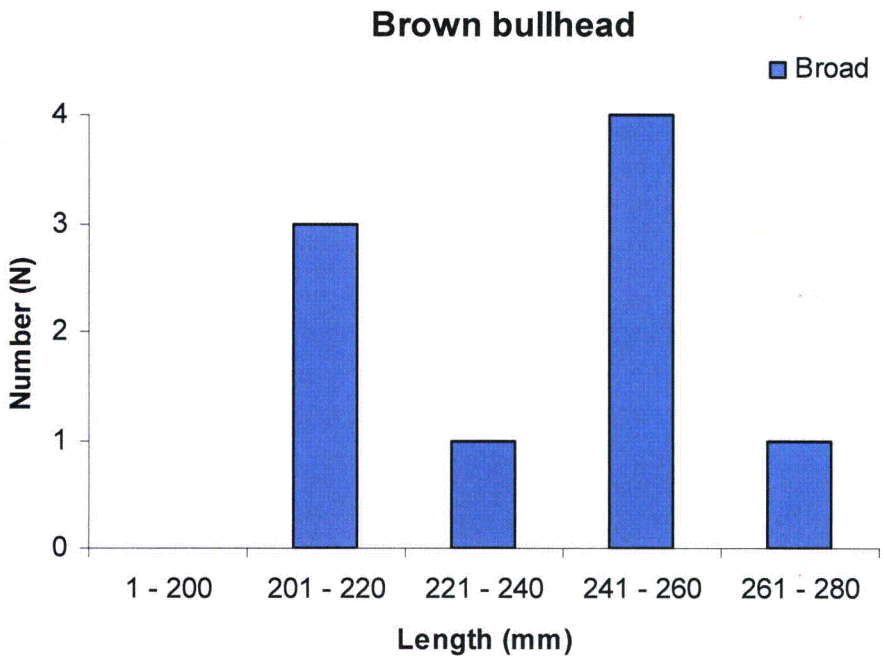
Attachment 3. Size class distribution by species for fish collected during 2006 electrofishing and gill-netting of the Broad River, SC and 2005 – 2006 electrofishing of the Saluda River, SC.

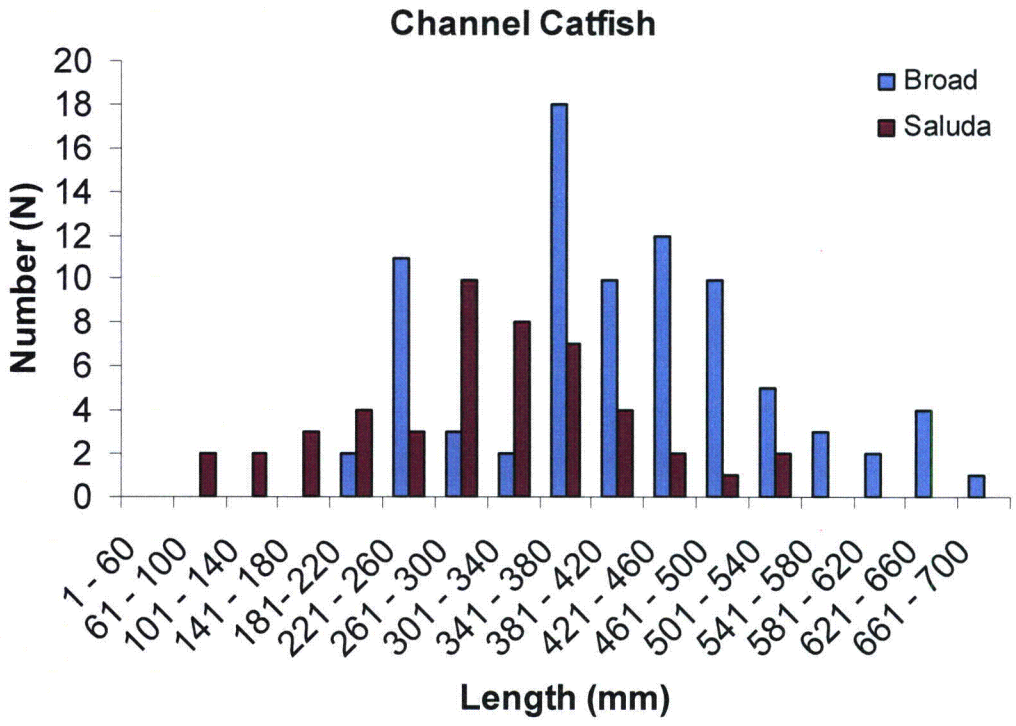


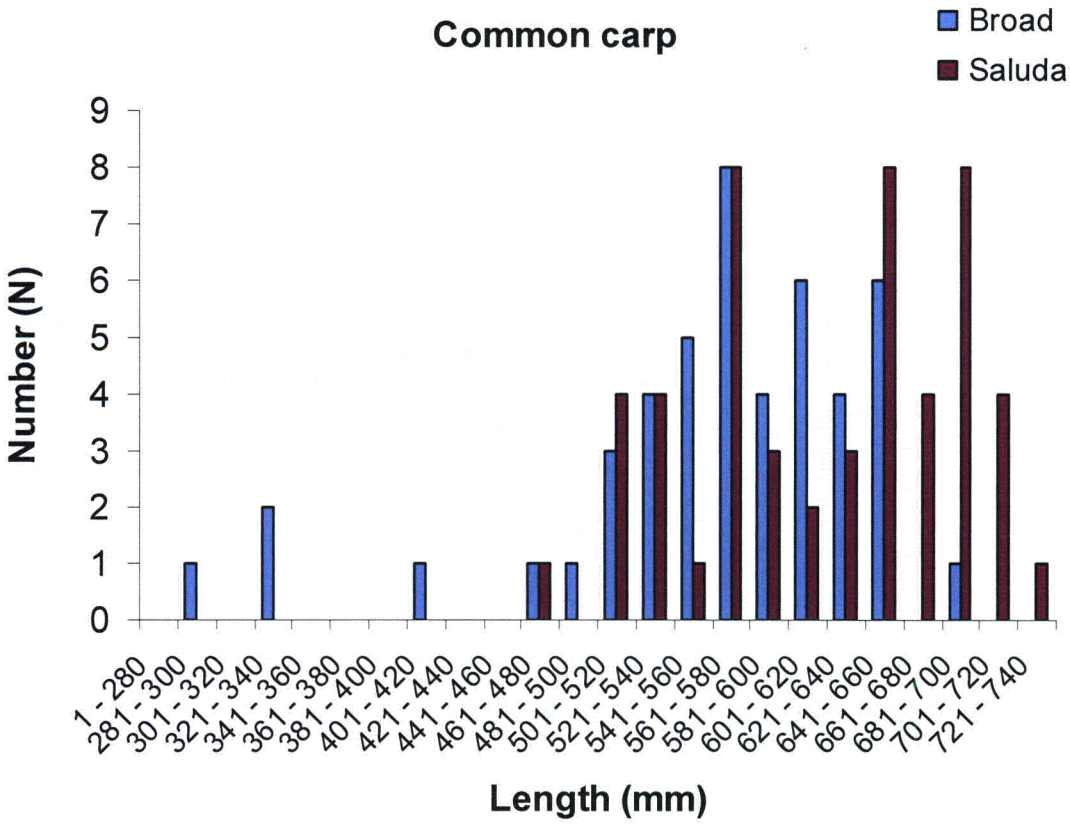



Bluehead chub
Broad
Saluda
Number (N)
0
1
2
3
4
5
1 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
101 - 110
111 - 120
121 - 130
131 - 140
141 - 150
151 - 160
161 - 170
171 - 180
Length (mm)


Brassy jumprock
Broad
Number (N)
0
2
4
6
8
10
12
14
1 - 100
101 - 120
121 - 140
141 - 160
161 - 180
181 - 200
201 - 220
221 - 240
241 - 260
261 - 280
281 - 300
301 - 320
321 - 340
341 - 360
361 - 380
381 - 400
401 - 420
421 - 440
Length (mm)

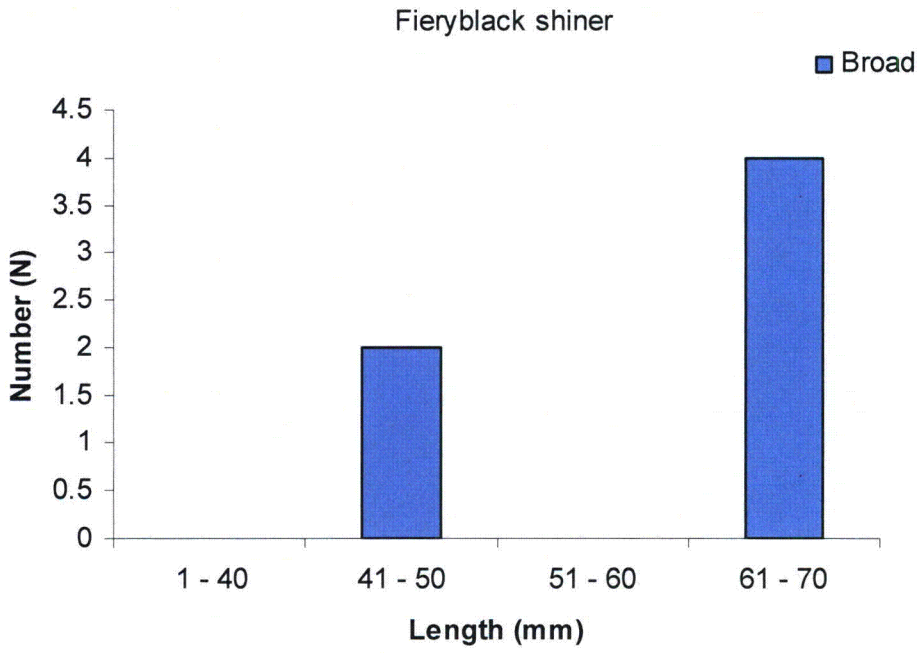

Brown bullhead
Broad
Number (N)
0
1
2
3
4
1 - 200
201 - 220
221 - 240
241 - 260
261 - 280
Length (mm)

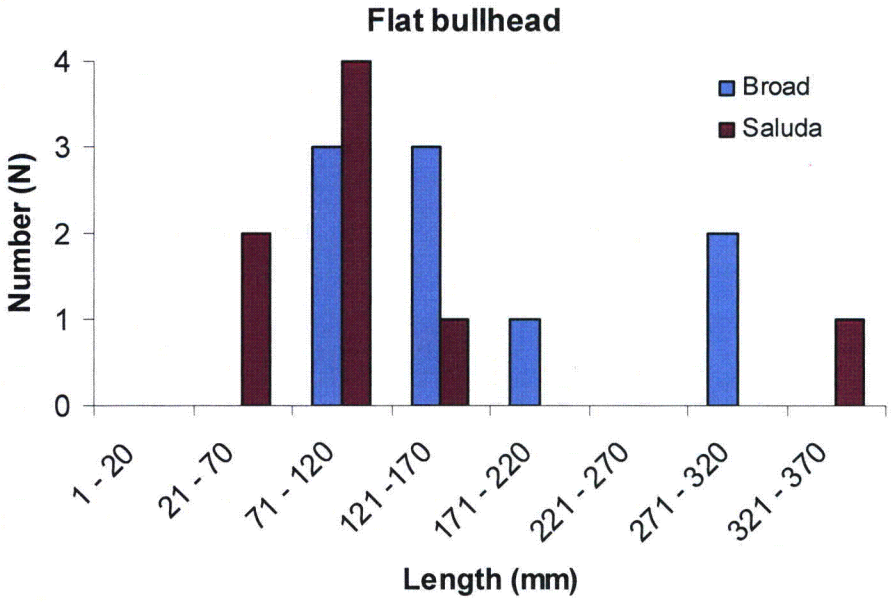

Channel Catfish
Broad
Saluda
Number (N)
0
2
4
6
8
10
12
14
16
18
20
1 - 60
61 - 100
101 - 140
141 - 180
181- 220
221 - 260
261 - 300
301 - 340
341 - 380
381 - 420
421 - 460
461 - 500
501 - 540
541 - 580
581 - 620
621 - 660
661 - 700
Length (mm)

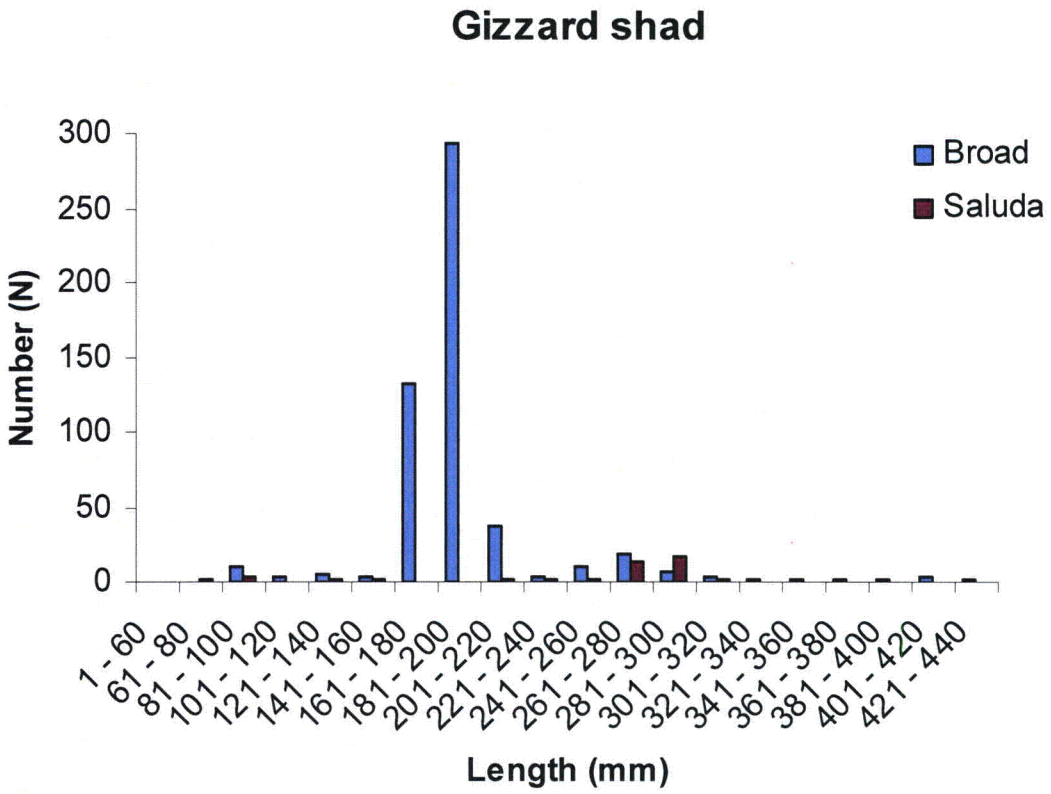


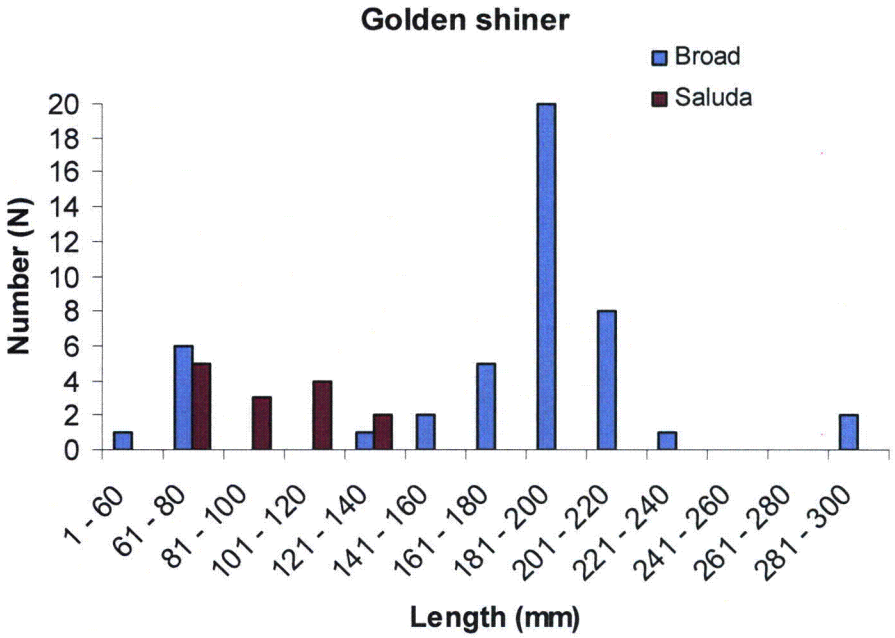
Broad River

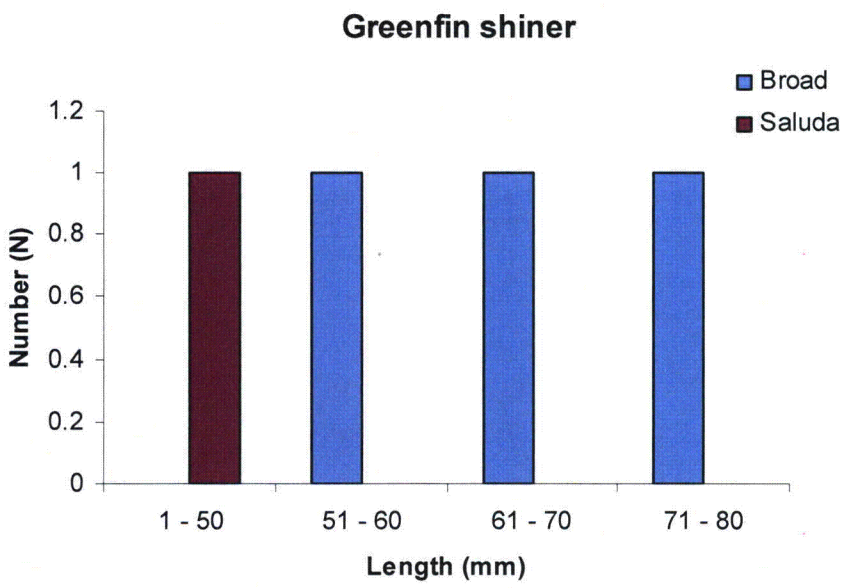
1 Creek chub – 183 mm
1 Fantail darter – 66 mm

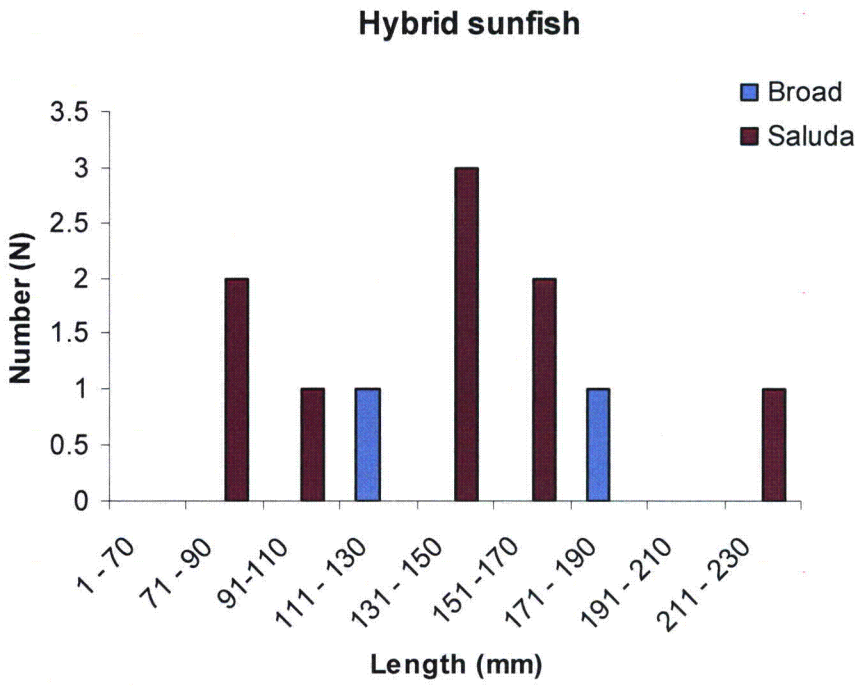

Fieryblack shiner
Broad
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Number (N)
1 - 40
41 - 50
51 - 60
61 - 70
Length (mm)

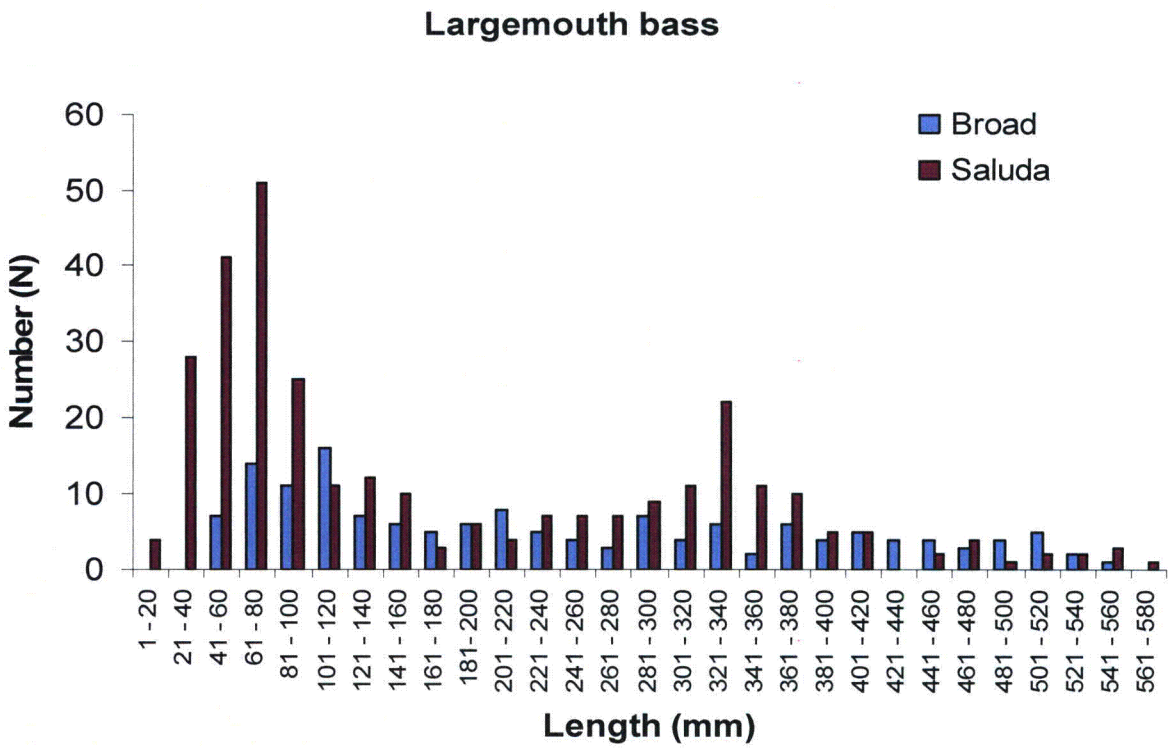

Flat bullhead
Broad
Saluda
4
3
2
1
0
Number (N)
1 - 20
21 - 70
71 - 120
121 - 170
171 - 220
221 - 270
271 - 320
321 - 370
Length (mm)

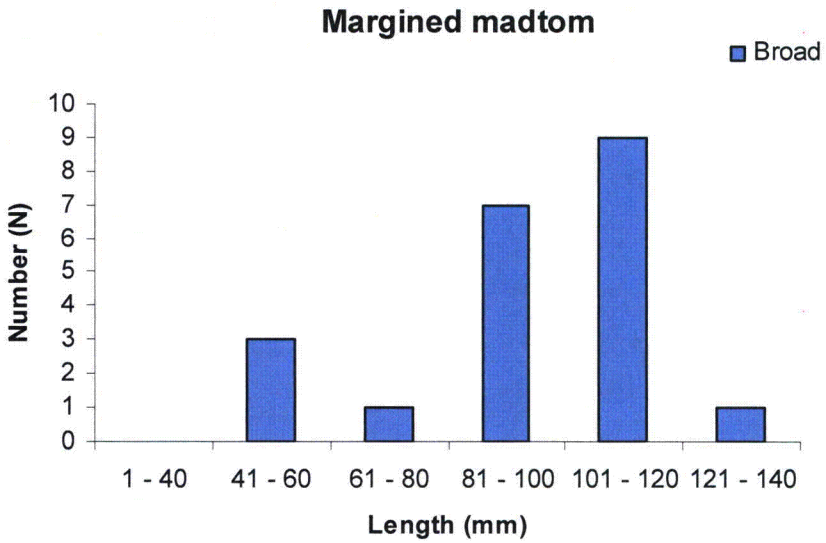

Gizzard shad
Broad
Saluda
Number (N)
300
250
200
150
100
50
0
1 - 60
61 - 80
81 - 100
101 - 120
121 - 140
141 - 160
161 - 180
181 - 200
201 - 220
221 - 240
241 - 260
261 - 280
281 - 300
301 - 320
321 - 340
341 - 360
361 - 380
381 - 400
401 - 420
421 - 440
Length (mm)

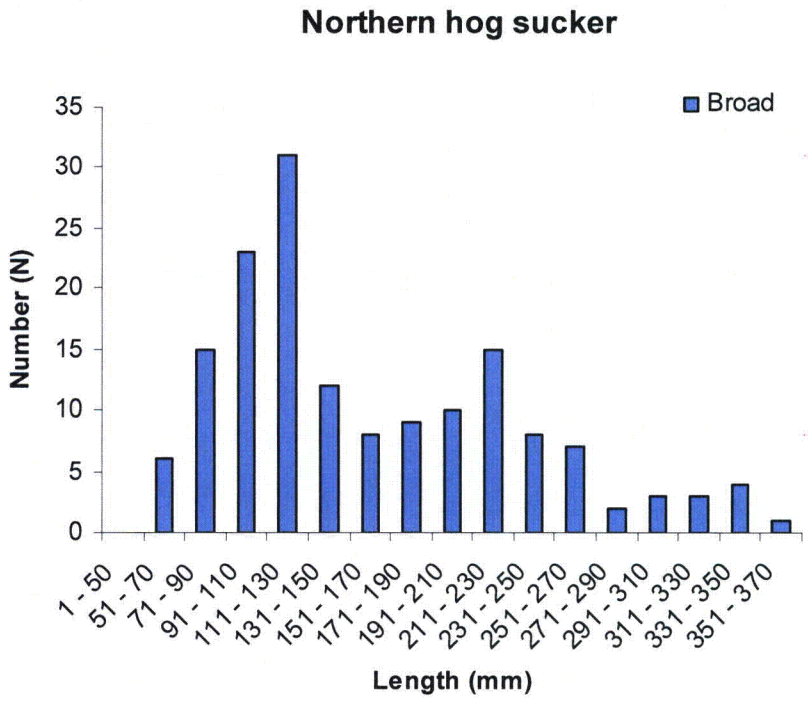

Golden shiner
Broad
Saluda
Number (N)
20
18
16
14
12
10
8
6
4
2
0
1 - 60
61 - 80
81 - 100
101 - 120
121 - 140
141 - 160
161 - 180
181 - 200
201 - 220
221 - 240
241 - 260
261 - 280
281 - 300
Length (mm)

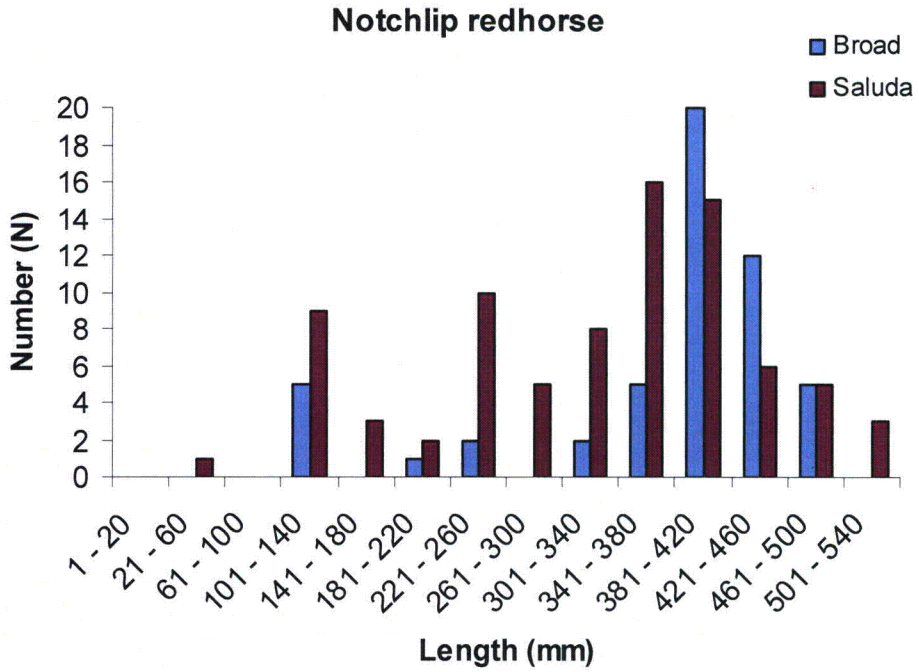

Greenfin shiner
Broad
Saluda
1.2
1
0.8
0.6
0.4
0.2
0
Number (N)
1 - 50
51 - 60
61 - 70
71 - 80
Length (mm)

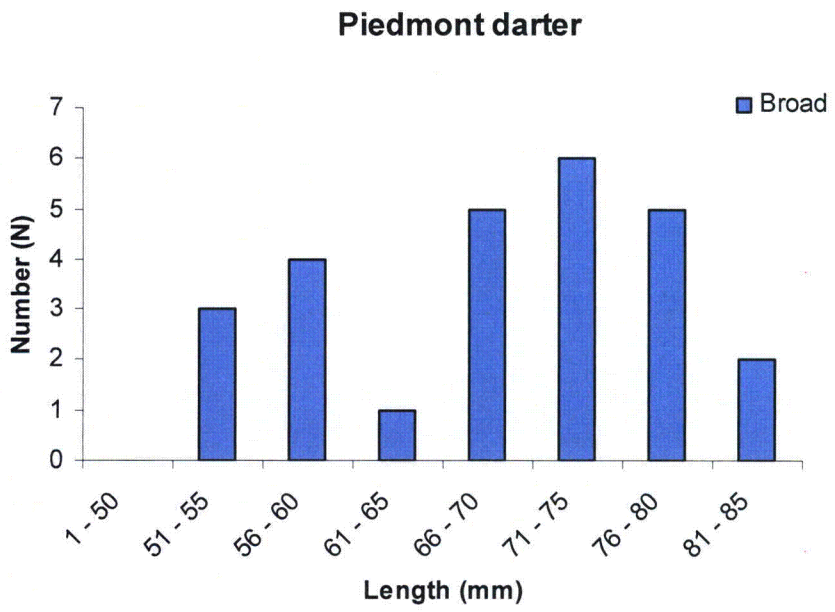

Hybrid sunfish
Broad
Saluda
3.5
3
2.5
2
1.5
1
0.5
0
Number (N)
1 - 70
71 - 90
91-110
111 - 130
131 - 150
151 - 170
171 - 190
191 - 210
211 - 230
Length (mm)

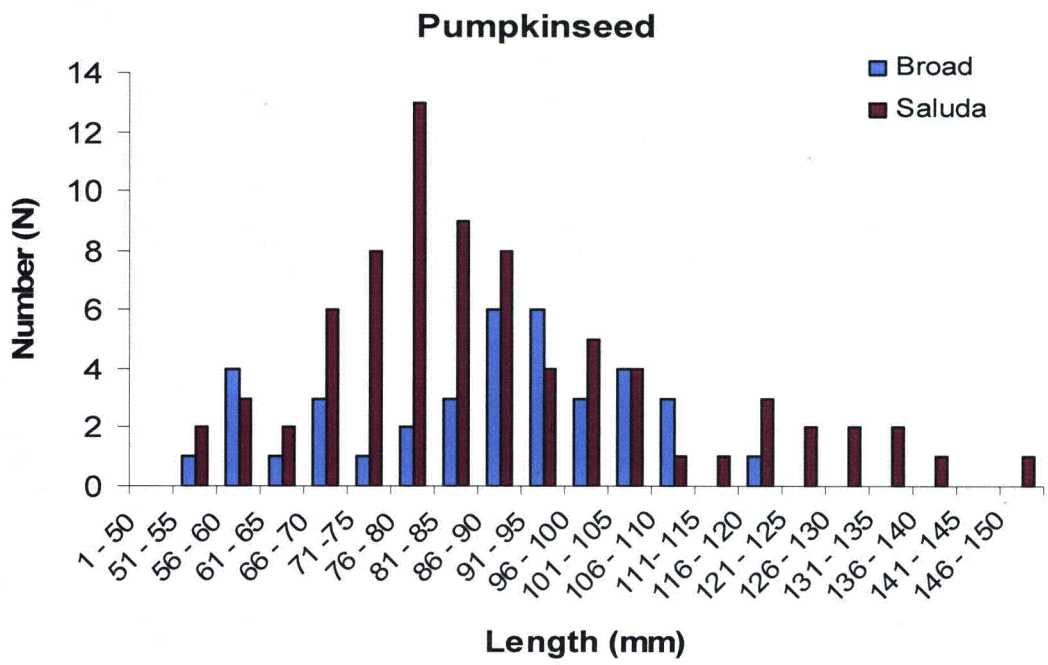

Largemouth bass
Broad
Saluda
Number (N)
60
50
40
30
20
10
0
1 - 20
21 - 40
41 - 60
61 - 80
81 - 100
101 - 120
121 - 140
141 - 160
161 - 180
181- 200
201 - 220
221 - 240
241 - 260
261 - 280
281 - 300
301 - 320
321 - 340
341 - 360
361 - 380
381 - 400
401 - 420
421 - 440
441 - 460
461 - 480
481 - 500
501 - 520
521 - 540
541 - 560
561 - 580
Length (mm)

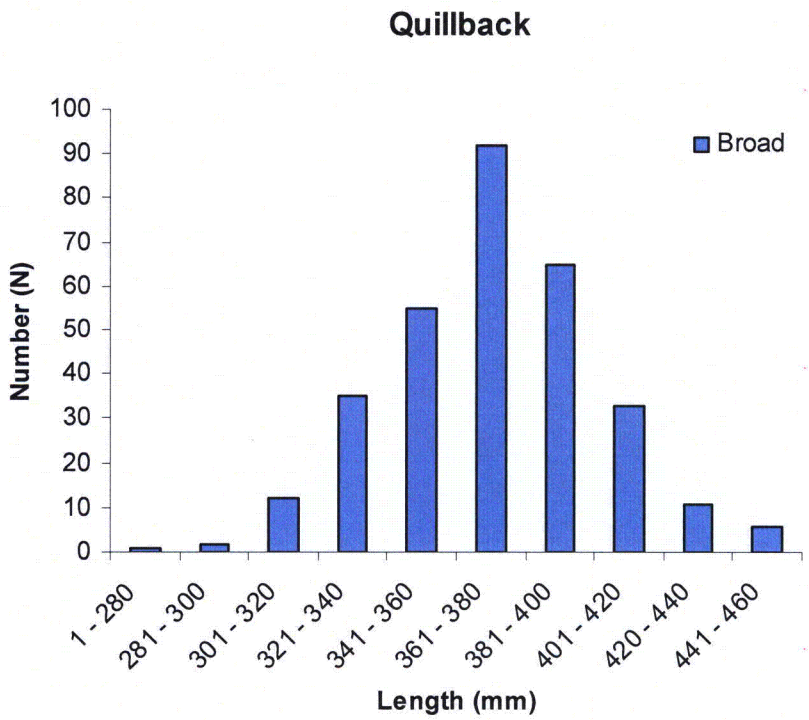

Margined madtom
Broad
Number (N)
10
9
8
7
6
5
4
3
2
1
0
1 - 40
41 - 60
61 - 80
81 - 100
101 - 120
121 - 140
Length (mm)

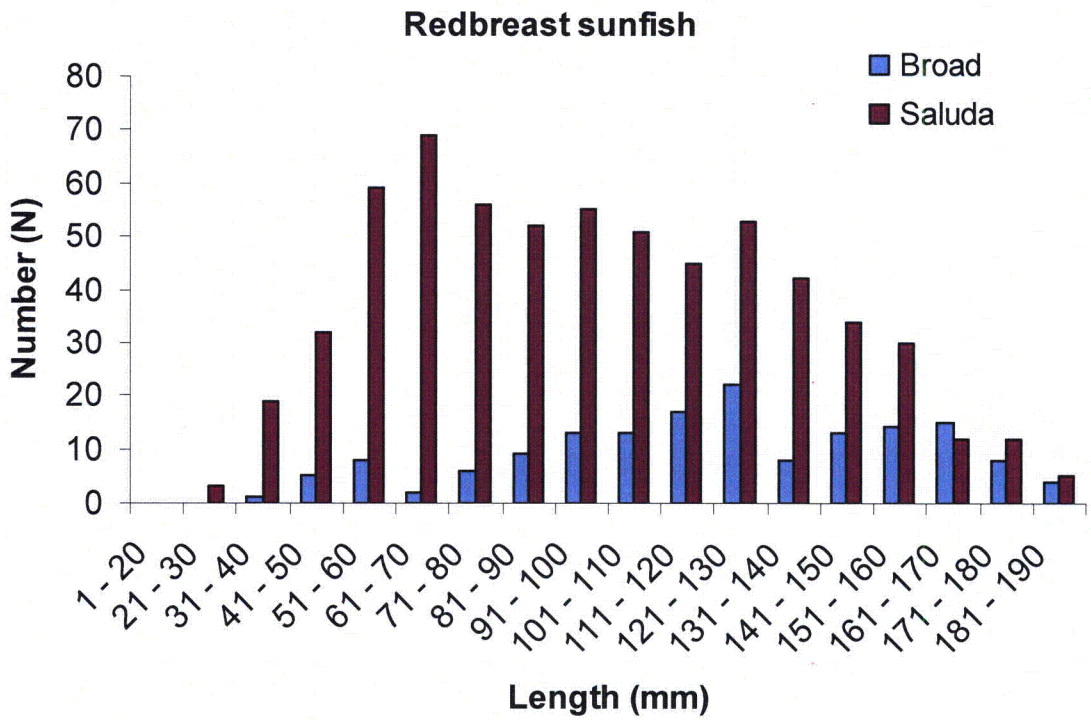

Northern hog sucker
Broad
Number (N)
35
30
25
20
15
10
5
0
1 - 50
51 - 70
71 - 90
91 - 110
111 - 130
131 - 150
151 - 170
171 - 190
191 - 210
211 - 230
231 - 250
251 - 270
271 - 290
291 - 310
311 - 330
331 - 350
351 - 370
Length (mm)

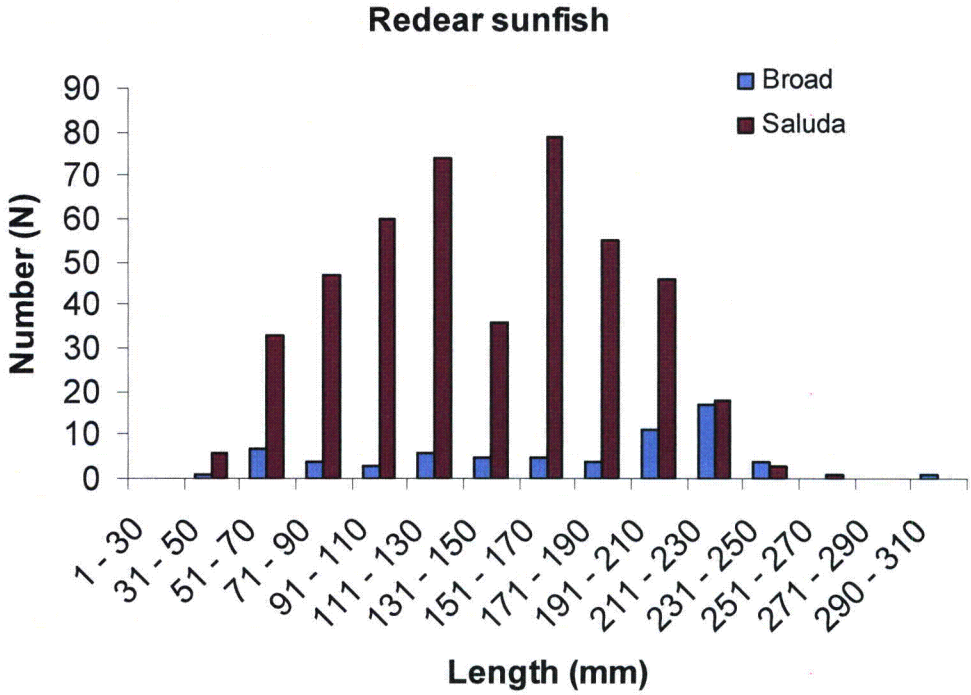

Notchlip redhorse
Broad
Saluda
Number (N)
20
18
16
14
12
10
8
6
4
2
0
1 - 20
21 - 60
61 - 100
101 - 140
141 - 180
181 - 220
221 - 260
261 - 300
301 - 340
341 - 380
381 - 420
421 - 460
461 - 500
501 - 540
Length (mm)

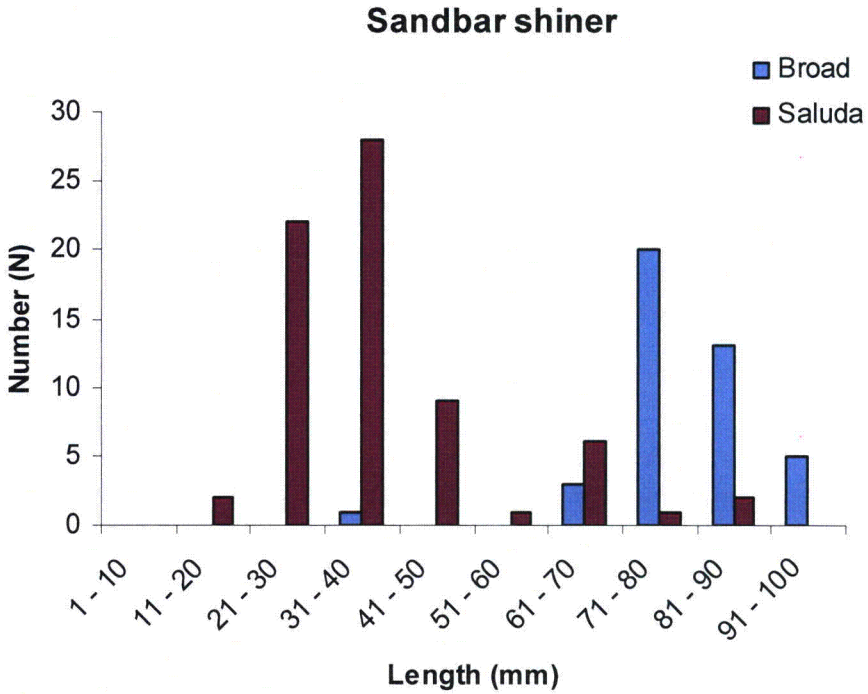

Piedmont darter
Broad
Number (N)
0
1
2
3
4
5
6
7
1 - 50
51 - 55
56 - 60
61 - 65
66 - 70
71 - 75
76 - 80
81 - 85
Length (mm)

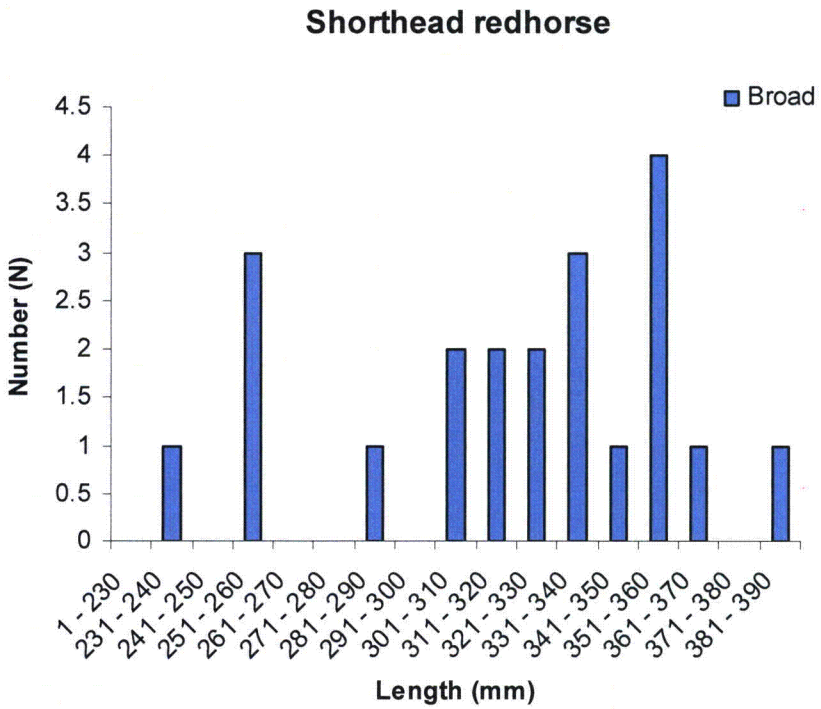

Pumpkinseed
Broad
Saluda
Number (N)
0
2
4
6
8
10
12
14
1 - 50
51 - 55
56 - 60
61 - 65
66 - 70
71 - 75
76 - 80
81 - 85
86 - 90
91 - 95
96 - 100
101 - 105
106 - 110
111 - 115
116 - 120
121 - 125
126 - 130
131 - 135
136 - 140
141 - 145
146 - 150
Length (mm)

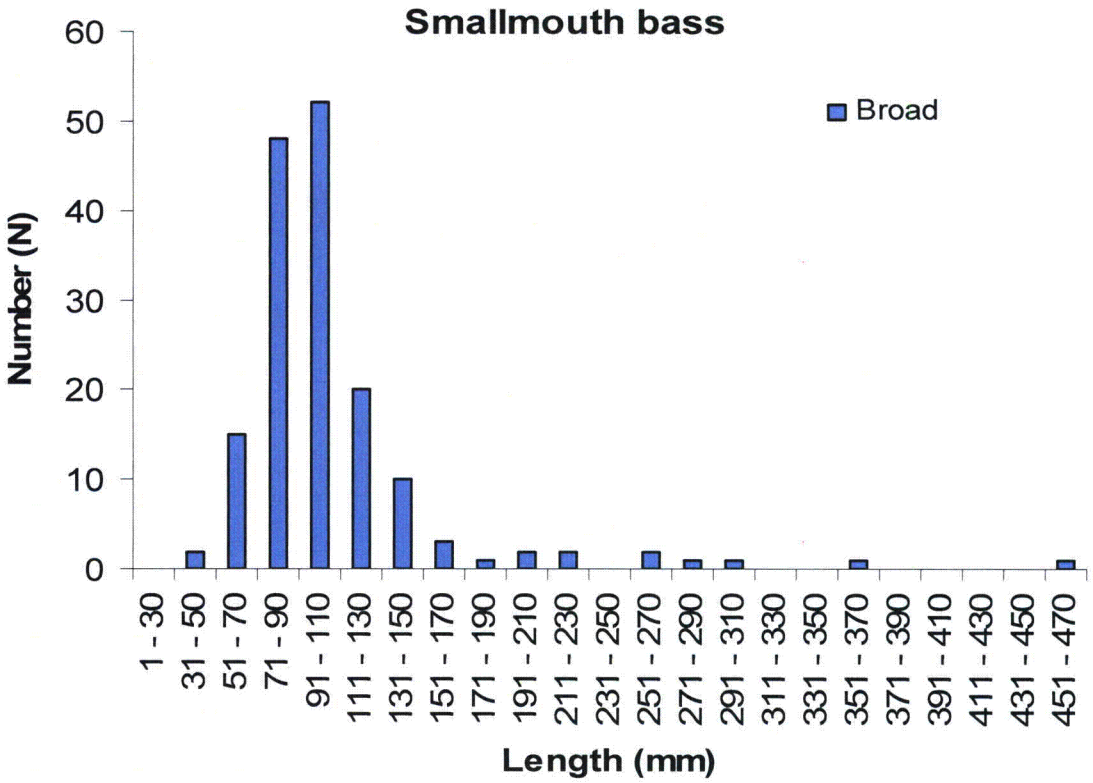

Quillback
Broad
Number (N)
100
90
80
70
60
50
40
30
20
10
0
1 - 280
281 - 300
301 - 320
321 - 340
341 - 360
361 - 380
381 - 400
401 - 420
420 - 440
441 - 460
Length (mm)


Redbreast sunfish
Broad
Saluda
Number (N)
80
70
60
50
40
30
20
10
0
1 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
101 - 110
111 - 120
121 - 130
131 - 140
141 - 150
151 - 160
161 - 170
171 - 180
181 - 190
Length (mm)


Redear sunfish
Broad
Saluda
Number (N)
90
80
70
60
50
40
30
20
10
0
1 - 30
31 - 50
51 - 70
71 - 90
91 - 110
111 - 130
131 - 150
151 - 170
171 - 190
191 - 210
211 - 230
231 - 250
251 - 270
271 - 290
290 - 310
Length (mm)

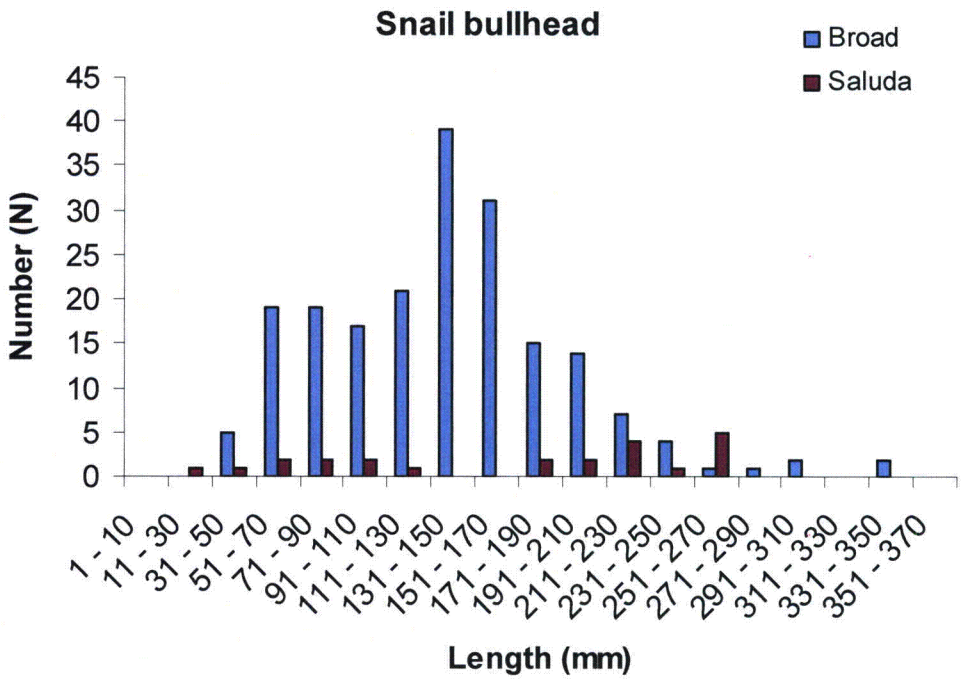

Sandbar shiner
Broad
Saluda
Number (N)
30
25
20
15
10
5
0
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Length (mm)

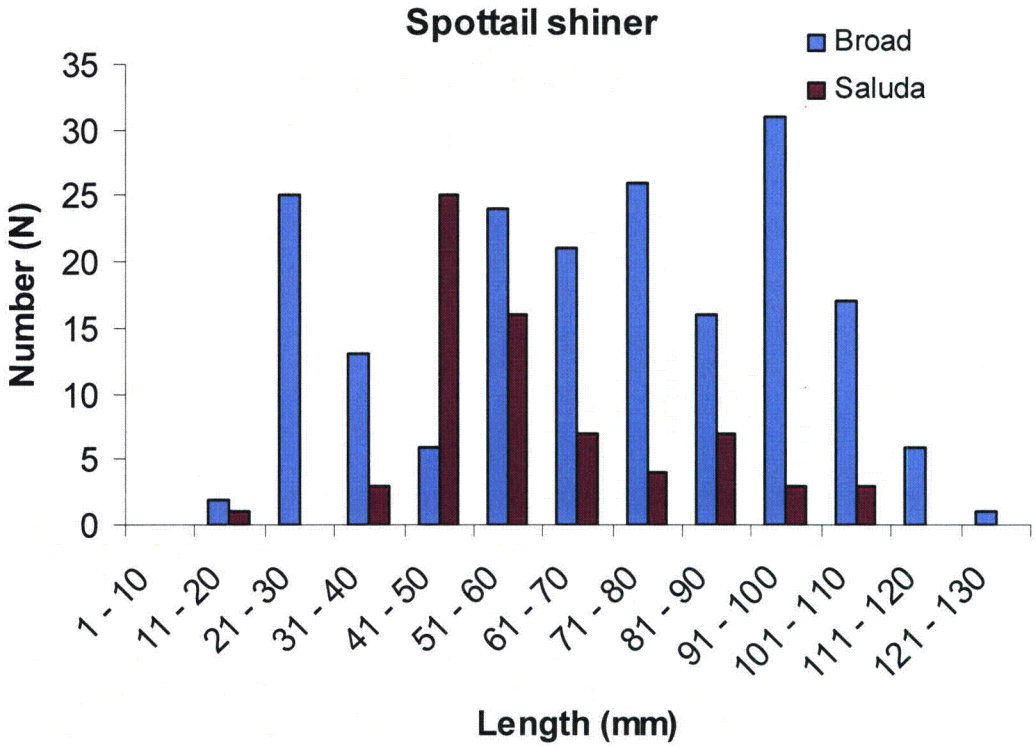

Shorthead redhorse
Broad
Number (N)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1 - 230
231 - 240
241 - 250
251 - 260
261 - 270
271 - 280
281 - 290
291 - 300
301 - 310
311 - 320
321 - 330
331 - 340
341 - 350
351 - 360
361 - 370
371 - 380
381 - 390
Length (mm)

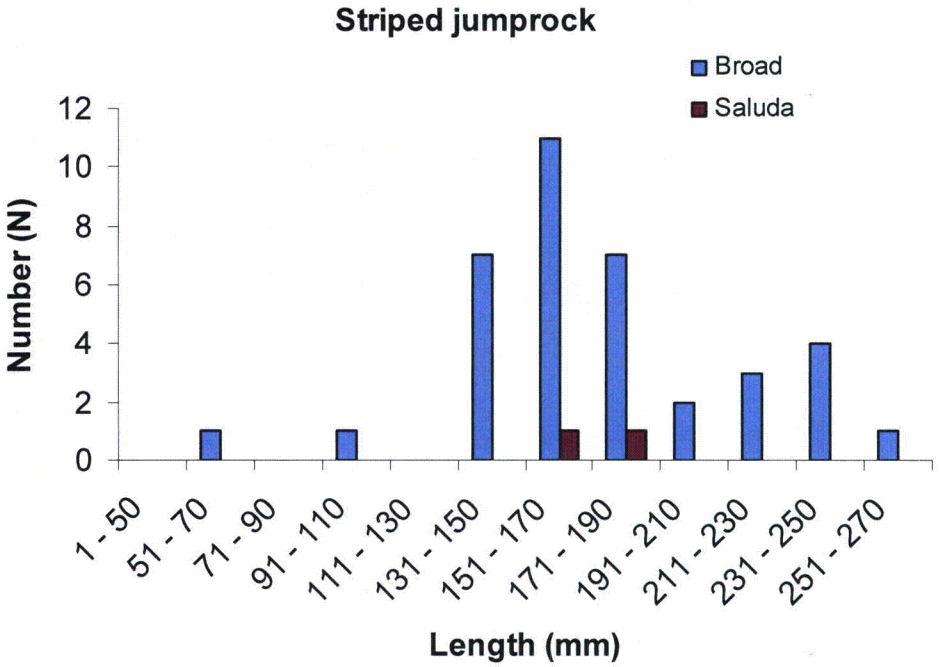

Smallmouth bass
Broad
Number (N)
60
50
40
30
20
10
0
1 - 30
31 - 50
51 - 70
71 - 90
91 - 110
111 - 130
131 - 150
151 - 170
171 - 190
191 - 210
211 - 230
231 - 250
251 - 270
271 - 290
291 - 310
311 - 330
331 - 350
351 - 370
371 - 390
391 - 410
411 - 430
431 - 450
451 - 470
Length (mm)

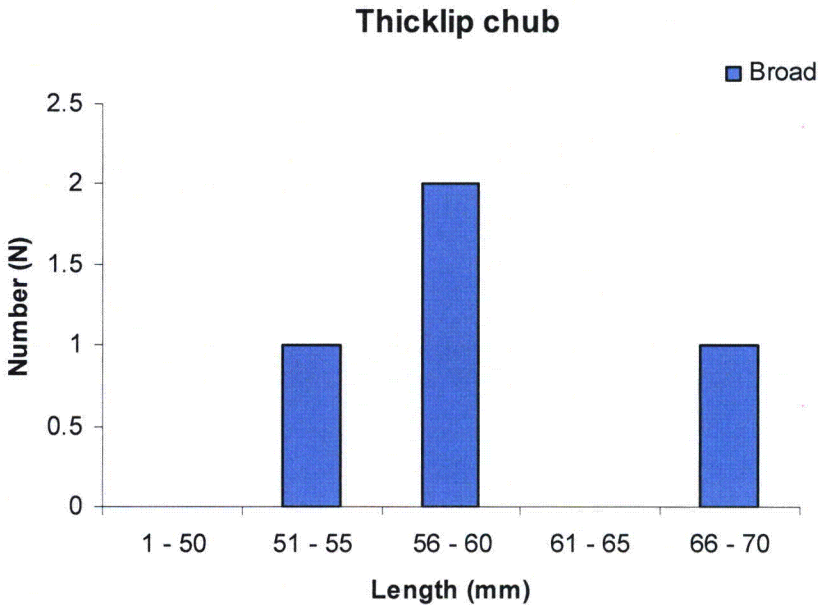
Broad River

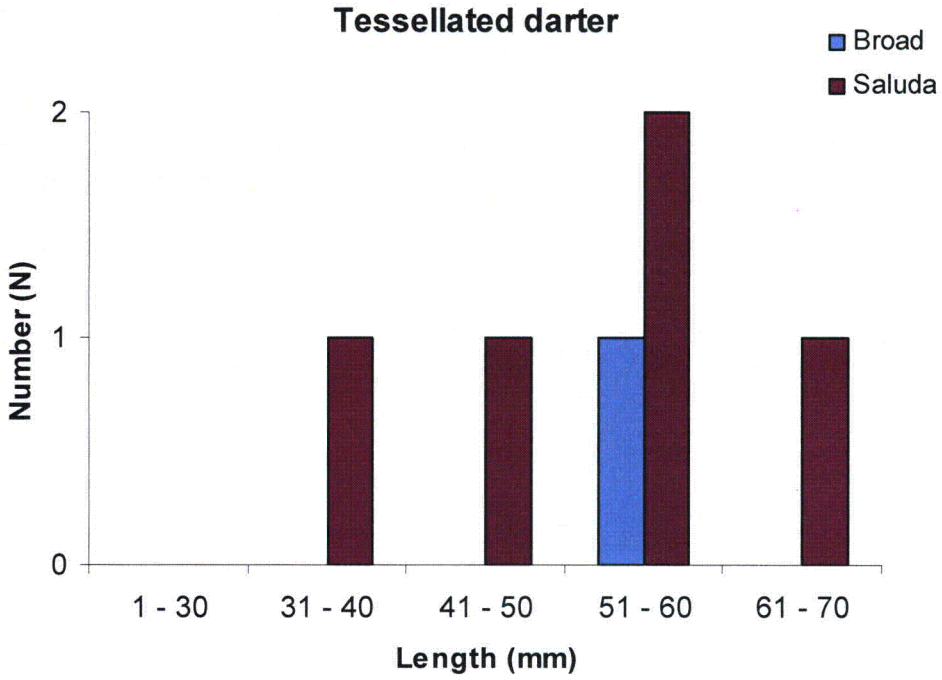
1 Smallmouth buffalo – 455 mm

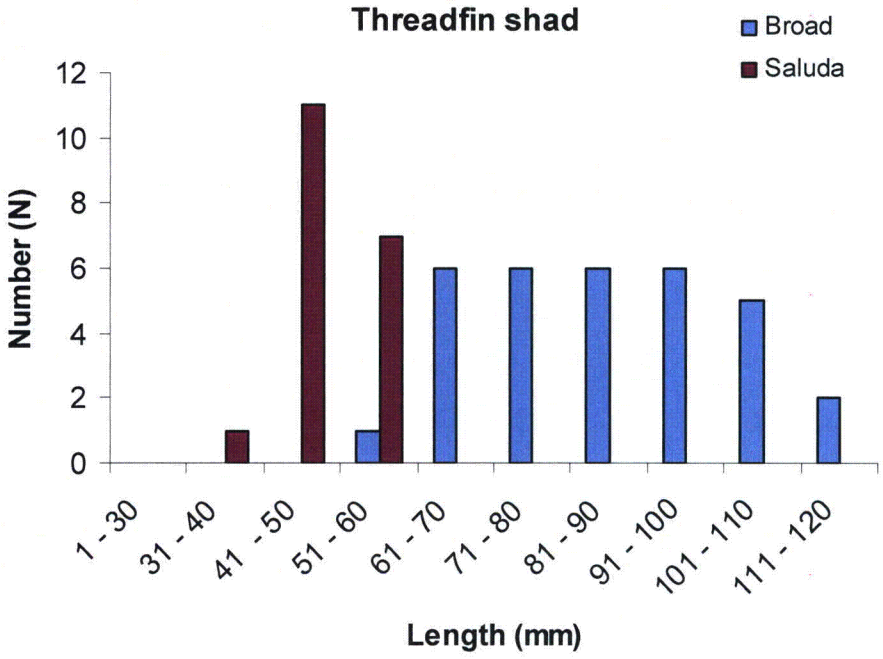


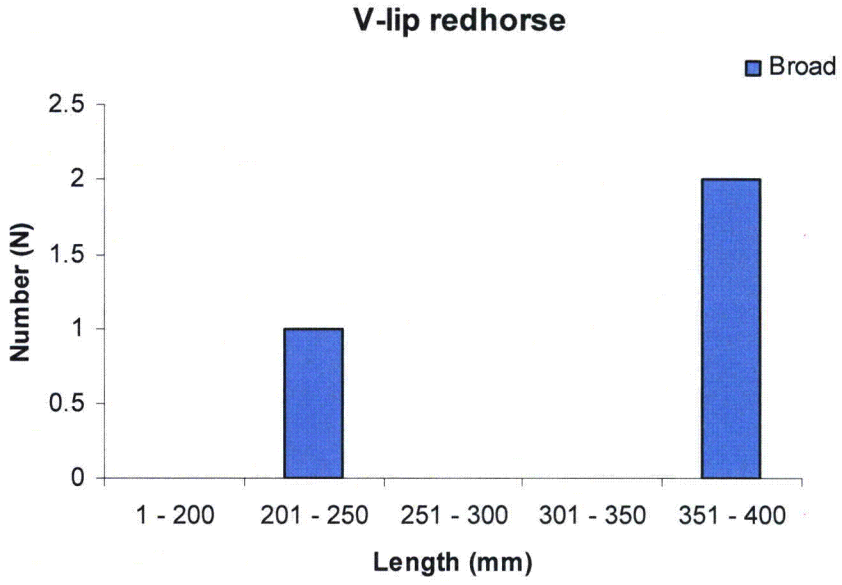

Spottail shiner
Broad
Saluda
Number (N)
35
30
25
20
15
10
5
0
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
101 - 110
111 - 120
121 - 130
Length (mm)

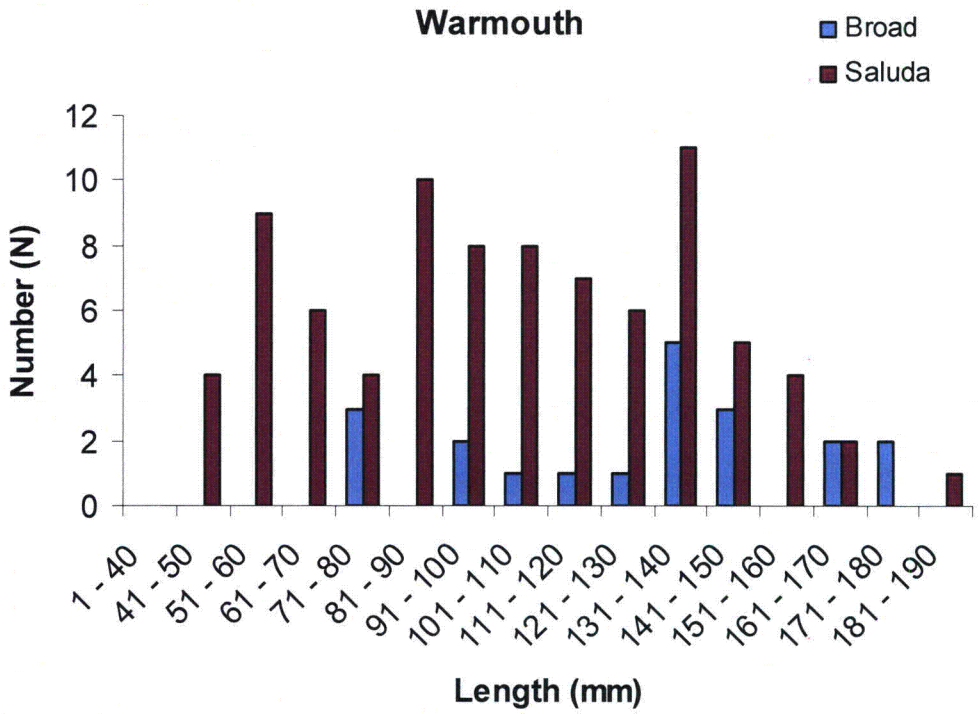

Striped jumprock
Broad
Saluda
Number (N)
12
10
8
6
4
2
0
1 - 50
51 - 70
71 - 90
91 - 110
111 - 130
131 - 150
151 - 170
171 - 190
191 - 210
211 - 230
231 - 250
251 - 270
Length (mm)

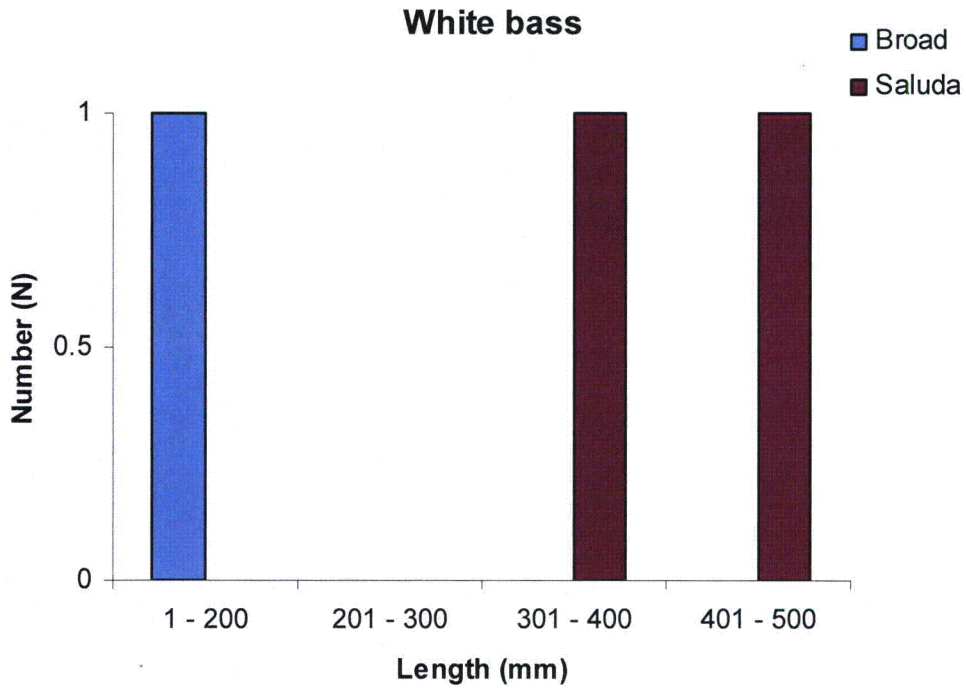

Thicklip chub
Broad
2.5
2
1.5
1
0.5
0
Number (N)
1 - 50
51 - 55
56 - 60
61 - 65
66 - 70
Length (mm)

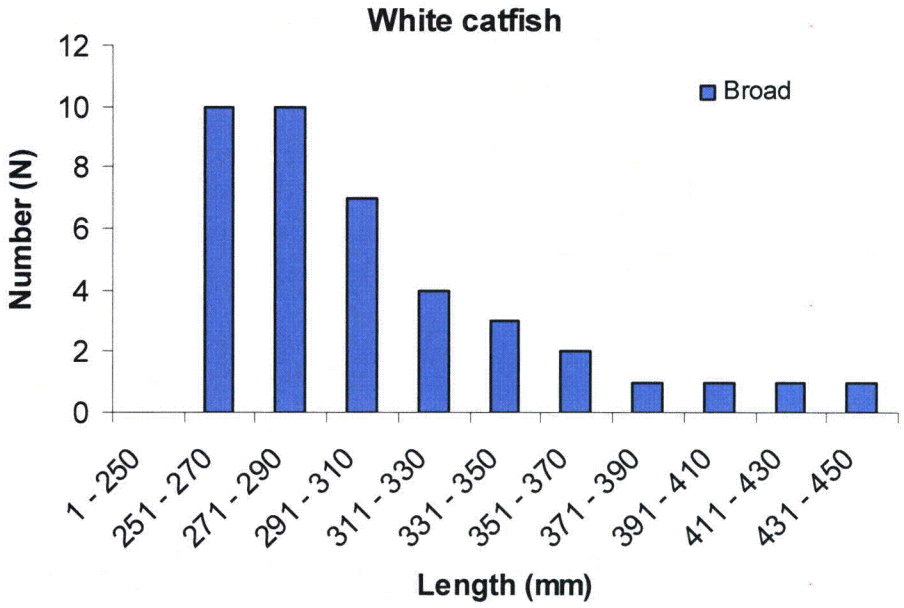

Tessellated darter
Broad
Saluda
2
1
0
Number (N)
1 - 30
31 - 40
41 - 50
51 - 60
61 - 70
Length (mm)

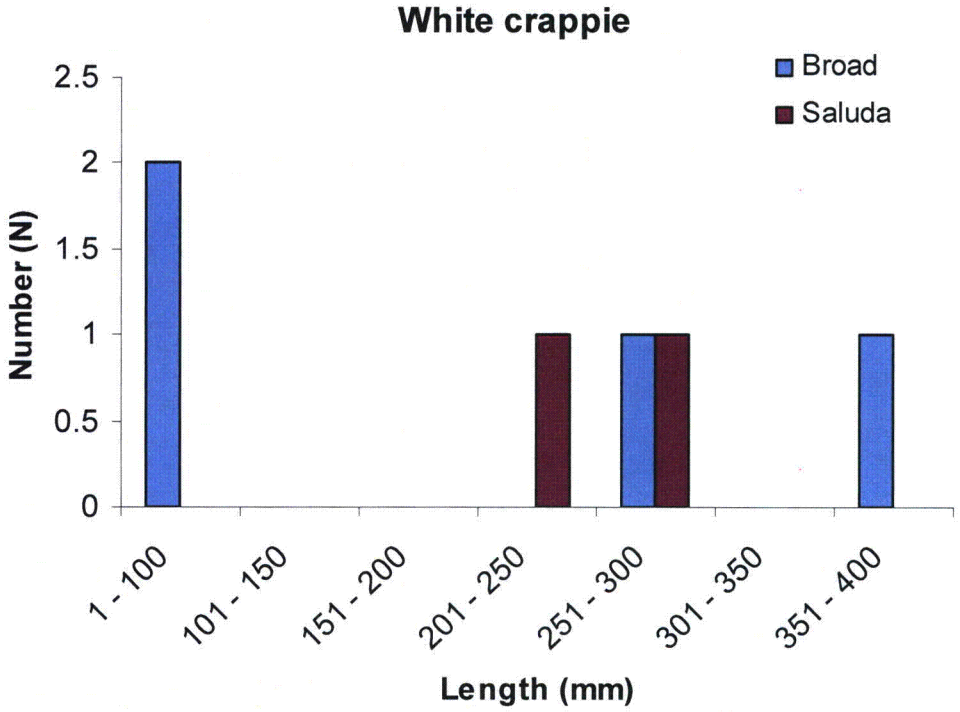

Threadfin shad
Broad
Saluda
Number (N)
12
10
8
6
4
2
0
1 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
101 - 110
111 - 120
Length (mm)

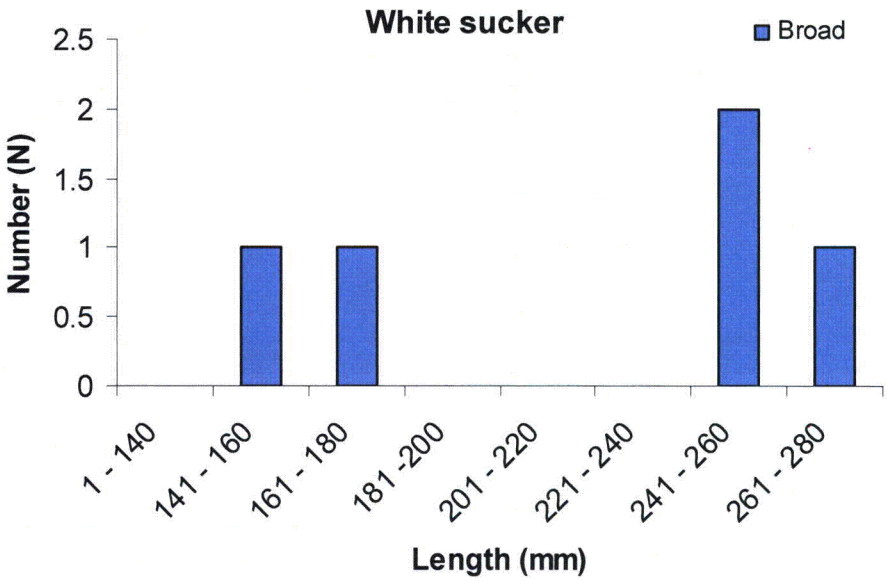

V-lip redhorse
Broad
Number (N)
2.5
2
1.5
1
0.5
0
1 - 200
201 - 250
251 - 300
301 - 350
351 - 400
Length (mm)


Warmouth
Broad
Saluda
Number (N)
0
2
4
6
8
10
12
1 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
101 - 110
111 - 120
121 - 130
131 - 140
141 - 150
151 - 160
161 - 170
171 - 180
181 - 190
Length (mm)


White bass
Broad
Saluda
Number (N)
0
0.5
1
1 - 200
201 - 300
301 - 400
401 - 500
Length (mm)

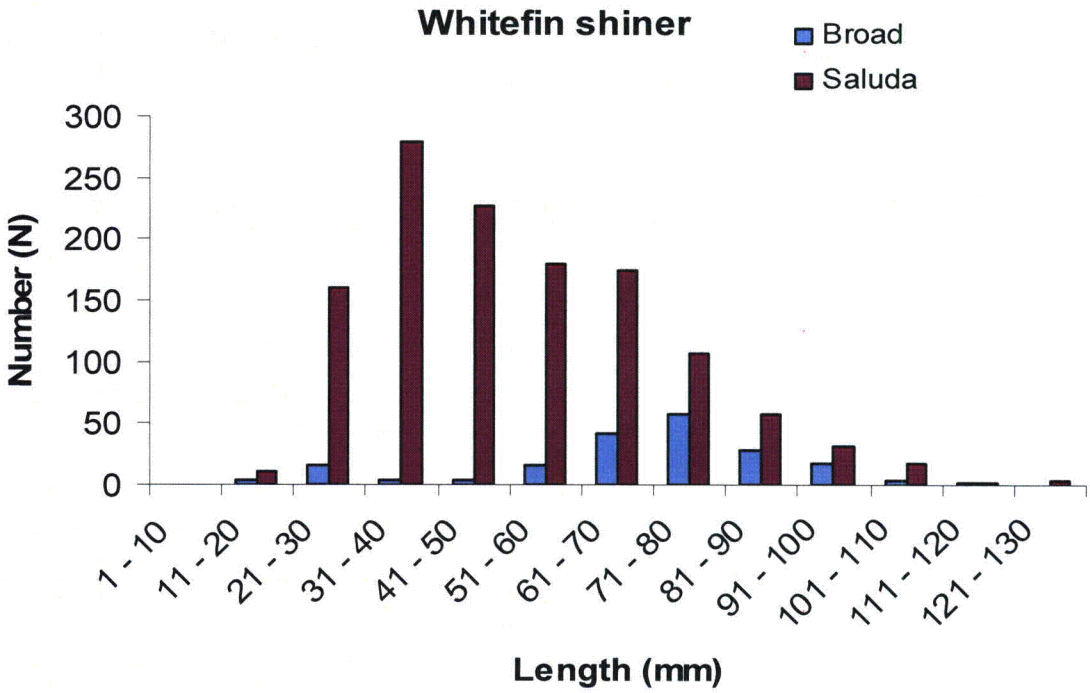

White catfish
Broad
Number (N)
12
10
8
6
4
2
0
1 - 250
251 - 270
271 - 290
291 - 310
311 - 330
331 - 350
351 - 370
371 - 390
391 - 410
411 - 430
431 - 450
Length (mm)

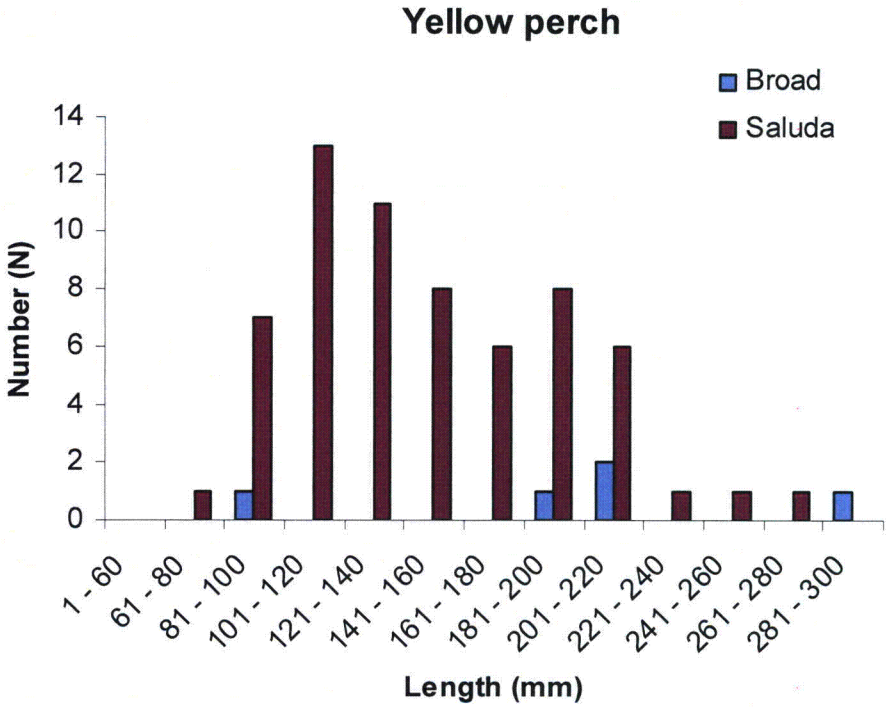

White crappie
Broad
Saluda
Number (N)
2.5
2
1.5
1
0.5
0
1 - 100
101 - 150
151 - 200
201 - 250
251 - 300
301 - 350
351 - 400
Length (mm)



Broad River

1 White bass x Striped bass hybrid – 578 mm


Whitefin shiner
Broad
Saluda
Number (N)
300
250
200
150
100
50
0
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
101 - 110
111 - 120
121 - 130
Length (mm)


Yellow perch
Broad
Saluda
Number (N)
14
12
10
8
6
4
2
0
1 - 60
61 - 80
81 - 100
101 - 120
121 - 140
141 - 160
161 - 180
181 - 200
201 - 220
221 - 240
241 - 260
261 - 280
281 - 300
Length (mm)

Lee Nuclear Station Response to Request for Additional Information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Number(s): ER RAI 54

NRC RAI:

Provide the Cherokee FES 1978 ichthyoplankton data collected from the Broad River from September 1974 through mid June 1975, including the methods and results applied to this particular data collection effort.

Duke Energy Response:

The requested report is provided as an attachment to this response.

Associated Response to the Lee Nuclear Station Combined License Application:

No COLA revisions have been identified associated with this response.

Associated Attachment:

Olmsted, L.L. and A.S. Leiper (ed.), Baseline Environmental Summary Report on the Broad River in the Vicinity of Cherokee Nuclear Station, DUKE PWR/78-06, 1978. (Note: This attachment is provided with text on both sides of the page.)

DUKE PWR/78-06

BASELINE ENVIRONMENTAL SUMMARY REPORT ON THE BROAD RIVER IN THE VICINITY OF CHEROKEE NUCLEAR STATION

EDITED BY
L.L.OLMSTED AND A.S.LEIPER

DUKE POWER COMPANY
1978

EXECUTIVE SUMMARY

1. This report presents the results of an ecological survey of the Broad River System in the vicinity of the Ninety-Nine Islands Hydroelectric Station conducted by Duke Power Company from September 1974 through December 1976. It continues the one-year baseline study performed by a consultant from October 1973 through September 1974 on which the Construction Permit Stage Environmental Report for Cherokee Nuclear Station (CNS) was based.

2. This report, together with quarterly water chemistry data now being gathered, will be used in preparing the Operating License Stage Environmental Report. The reason for evaluating data at this time is to insure that the individuals who actually performed the field work would be directly involved in summarizing and interpreting the results.

3. The Broad River is a turbid Piedmont stream subject to rapid variations in flow. Water temperatures during the study period ranged from 0.1 to 27.5 C, differing little between mainstream stations upstream and downstream from the Ninety-Nine Islands Impoundment. Water temperatures in Kings Creek were similar to those in the mainstream, although those recorded in the east backwater of the impoundment were slightly (ca. 1 C) higher.

4. The Broad River is a softwater bicarbonate system typical of the Carolina Piedmont, with sodium and calcium the major cations. The higher mineral concentrations in Kings Creek had little influence on the Broad River. The average pH was approximately neutral, although low alkalinity allowed wide pH (6.2 to 8.2) fluctuations.

5. Nutrient (nitrogen and phosphorus) concentrations were also characteristic of Carolina Piedmont rivers. With the exception of lower concentrations in Kings Creek, nutrient levels were similar at all sampling stations and relatively consistent throughout the study period.

6. With the exception of a few values of cadmium and mercury, heavy metals were below the EPA recommended limits for the protection of aquatic life.

7. Five major substrate types were encountered during sampling. The backwaters were characterized by a fine, loosely compacted silt with a high organic carbon content. The substrate of the main river channel upstream from and running through the impoundment was primarily coarse sand, which contained little organic carbon. On the west bank of the impoundment near the dam the substrate was a compact silt and clay, with an organic carbon content between that of the main-channel and the backwater. Downstream from the dam the substrate near the shoreline was a mixture of fine sand and silt which contained a much lower organic carbon content than similar sediments in the impoundment. Finally, riffles were formed primarily of bedrock outcrops and rubble.

8. Diatoms and green algae dominated the phytoplankton (drifting algae) of both the Broad River and Ninety-Nine Islands Impoundment. The standing crop of algae was very low throughout the year. The most important factor controlling phytoplankton appeared to be discharge. The small planktonic forms which dominated the algae of both the river and the impoundment apparently succeeded because of their short generation times.

9. The periphyton (attached algae) of the Broad River and Ninety-Nine Islands Impoundment was dominated by diatoms. Green algae were found in abundance only in the backwater. The biomass of periphyton from the mainstream stations was usually highest in the spring and fall, when conditions of sunlight and temperature were apparently most favorable for growth. Densities were temporarily but sharply reduced due to scour during periods of high river flow. The species of periphyton from the impoundment backwater were different from those of the river, consisting primarily of those forms common to still water. Although higher numerical densities occurred in the backwater during the summer, seasonal patterns of biomass were similar in both areas.

10. The zooplankton (small invertebrates suspended in the water) of the Broad River consisted primarily of rotifers (about 76% by number), with lesser numbers of small crustaceans (cladocerans and copepods); this composition is typical of flowing waters. In the impoundment the proportion of crustaceans was considerably greater. Both rotifers and copepods tended to be most abundant in the fall and early spring, although the peaks were short-lived and density differences among stations and sampling periods were often great. It appears that while zooplankton may occasionally be important as a food source (e.g. to larval fish), their densities are too low and too variable for them to be of major trophic significance to the system.

11. The distribution and abundance of the benthos (bottom dwelling fauna) were related to substrate type, organic carbon content of the sediments, and current. The characteristic and most abundanct benthic organisms were midge larvae of the family Chironomidae and small worms of the class Oligochaeta. The riffles, which are ecologically important to rivers because of the diversity of microhabitats, supported the largest and most diverse benthic fauna, including a variety of midges, caddisflies, mayflies, and Asiatic clams (*Corbicula*).

12. Samples of the organic drift (detritus and living organisms carried by the current) indicated that virtually all (99.93% by wet weight) entered the river from the land. This strongly suggests that a major portion of the organic carbon (i.e. the base of the trophic structure) is supplied from outside the system. The findings correspond to the results of a carbon partitioning study conducted in the Yadkin River which showed that less than 0.5% of the organic carbon in that river was present in living tissue. However, it is probable that in the backwaters of the impoundment a larger portion of the organic carbon is present in living organisms.

13. Each of the three major fish habitats (tributary creeks, Broad River mainstream, and impoundment backwaters) contained a distinct assemblage of fishes. Minnows and darters were the most abundant fishes in tributaries; minnows and bluegill dominated the Broad River mainstream; and sunfish, gizzard shad, and quillback were dominant in the backwaters, where total fish densities were much greater than in the mainstream.

14. Growth rates of gizzard shad, white catfish, and largemouth bass were very similar to those reported from other waters. Bluegill, however, showed poor growth. There was no difference in growth rates between sexes except for bluegill (males grew faster) and largemouth bass (females grew faster).

15. Whitefin shiners, white catfish, and bluegill fed on a wide variety of food items, primarily filamentous algae and insects (both aquatic and terrestrial). Largemouth bass fed primarily on fish and crayfish. Differences in food habits were commonly noted between fish of the same species collected from backwater and mainstream areas. These differences were apparently related to the abundance and distribution of forage.

16. Densities of larval fish were much lower in the mainstream of the Broad River than in the backwaters of the Ninety-Nine Islands Impoundment. Mainstream samples were dominated by the larvae of shad, minnows, and catfish, whereas the backwaters yielded mostly shad, sunfishes, and crappie. These differences were related both to the spawning behavior of the adults and the behavior, especially habitat selection, of the larvae. Larvae were present from late April through early September; they tended to be more susceptible to capture during the afternoon and evening than in the morning.

17. The results of this study indicate that the organisms of both the Broad River and Ninety-Nine Islands Impoundment are adapted to large, irregular fluctuations in their physical and chemical environment, and that the trophic structure of the system, especially of the river is based on the input of particulate organic carbon from outside the system.

CHAPTER 1. INTRODUCTION

L. L. Olmsted and A. S. Leiper

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INTRODUCTION

BACKGROUND

Duke Power Company is building Cherokee Nuclear Station (CNS) on the west bank of the Broad River, just upstream from Ninety-Nine Islands Hydroelectric Station in Cherokee County, South Carolina (Fig. 1-1). The station will employ three identical pressurized water reactors to provide heat to three turbine generators, each with a rated net electrical capacity of 1280 MWe. The exhaust steam will be cooled by a flow of water in a closed cycle system incorporating mechanical draft wet cooling towers. Makeup water will be taken from the Broad River upstream from Ninety-Nine Islands Dam; blowdown will be discharged to the Broad River immediately downstream from the dam (Fig. 1-2). Effluents from the various plant wastewater treatment systems will be pumped to the impoundment via a discharge canal from the auxiliary holding pond.

PREVIOUS ENVIRONMENTAL STUDIES

In October 1973 Duke Power Company commissioned a consulting firm to conduct an ecological survey of the Broad River and Ninety-Nine Islands Impoundment. The results of this study, which summarized the physical, chemical, and biological characteristics of the Broad River System upstream and downstream from the proposed CNS site from October 1973 through September 1974, were presented in the Cherokee Nuclear Station Environmental Report (Duke Power Company 1974).

No other ecological studies of this area are known to exist.

REGIONAL SETTING

The CNS site is in the South Carolina Piedmont. Soils in this area are primarily from the Tatum series of the red-yellow podzolic great soil group. These are deep, well-drained soils with moderate permeability, moderately slow infiltration, medium available moisture capacity, low natural fertility, and low content of organic matter.

Farming in Cherokee County is primarily of truck crops and peaches. Dairy cattle, swine, and poultry are also common. Before construction began, much of the site and nearby regions were forested, although no virgin timber stands remained. Due to topographic variation, soil type, land use history, and hydrology of the Broad River, several vegetation types have become established in the area. These include: cattail marsh, alluvial forest, alluvial thicket, mountain laurel-hardwood forest, mixed mesic forest, pine forest, pine scrub, and oak-hickory forest. Considerable acreage in the region is also occupied by successional communities which have developed following logging, farming, or flooding. The plant communities which occur on the CNS site and in the immediate area were described in detail in the Cherokee Nuclear Station Environmental Report (Duke Power Company 1974).

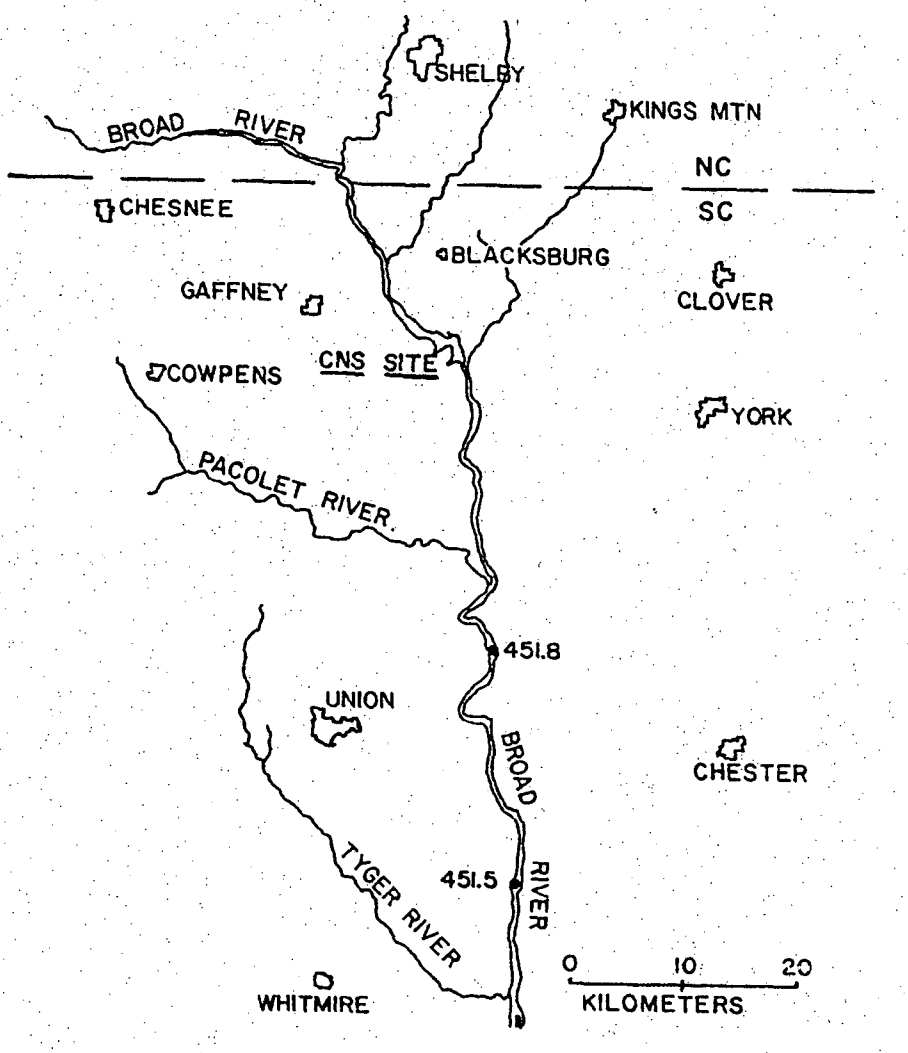

Figure 1-1. Regional map of study area, major tributaries, and locations of Stations 451.5 and 451.8.

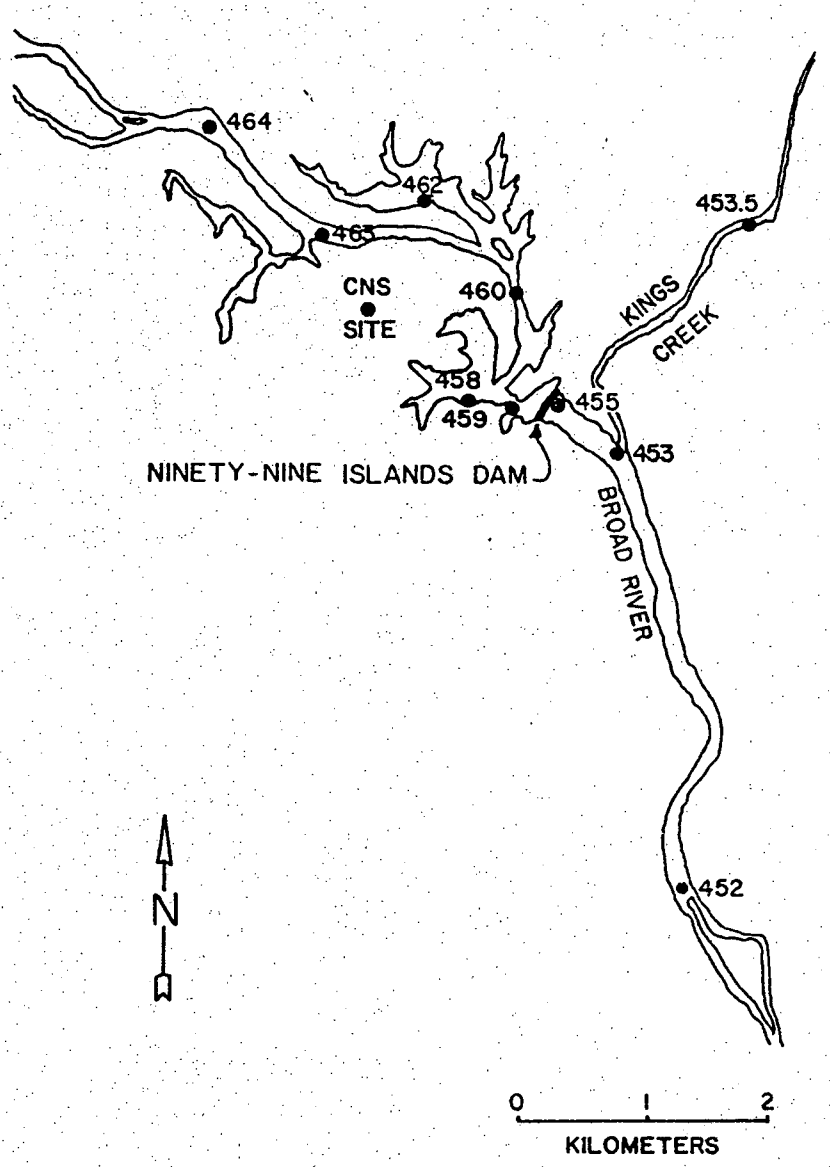

Figure 1.2. Map of Broad River study area showing Cherokee Nuclear Station environmental sampling locations.

Wildlife in the area is dominated by species characteristic of highly interspersed and man-disturbed habitats. Nineteen species of mammals have been observed in the site area, along with 99 species of birds and 27 species of reptiles and amphibians. More than twice this number of species is known to occur in this section of the South Carolina Piedmont (Duke Power Company 1974). Use of the site area by waterfowl is light, and there is no evidence that the Broad River is an important flyway for any species of migratory bird. No rare or endangered species are known to occur in Cherokee County. Several nearby areas (5 to 8 km from the site) are part of the South Carolina Game Management Program and are open to seasonal hunting by the public.

The area surrounding the proposed station is rural. The 1970 population of Cherokee County was 36,791. The two largest nearby towns (Fig. 1-1) are Blacksburg (1970 population approximately 2000) and Gaffney (approximately 13,000). The closest industrial site (250 employees) is at Cherokee Falls, approximately 5 km upstream from the site.

The climate of cool winters and long, warm summers, is typical of the southeastern United States. Monthly average temperatures range from about 6 C (43 F) in January to about 26 C (79 F) in July, with record daily extremes of -15 C (5 F) and 40 C (104 F) (Duke Power Company 1974). Precipitation is fairly uniform from month to month, with annual totals averaging 119 cm. Record maximum and minimum monthly totals are 30.5 cm and 0.1 cm, respectively. The highest recorded 24-hour total was 17.4 cm. Total monthly precipitation and average monthly temperatures for the study period, as measured at the Greenville-Spartanburg Airport (48 km WSW of the CNS site) are listed in Table 1-1. Due to local topography, dispersion factors at the site may differ from those at the airport. However, long-term averages for temperature and rainfall are not likely to differ appreciably.

HYDROLOGY

The Broad River originates in the mountains of western North Carolina and flows southeast to a point near Gaffney, South Carolina. It then flows south to Columbia, South Carolina where it joins the Saluda River to form the Congaree River. The Congaree joins the Wateree forming the Santee River, which enters the Atlantic Ocean near Georgetown. The drainage area of the Broad River at the Ninety-Nine Islands Dam is approximately 4000 km^2.

The Broad River in the study area is generally wide and shallow. The river carries a large bedload consisting chiefly of sand. Mean velocity is approximately 0.8 $m \cdot sec^{-1}$, and mean discharge is 70 $m^3 \cdot sec^{-1}$ (2,472 $ft^3 \cdot sec^{-1}$). Highest flows typically occur during February, March, and April; lowest flows usually occur between July and November. The maximum discharge of record is 3,362 $m^3 \cdot sec^{-1}$), and the lowest 10-year 7-day mean discharge is 13.3 $m^3 . sec^{-1}$ (470 $ft^3 \cdot sec^{-1}$). The mean daily discharge during the study period is given in Fig. 1-3 and App. 1-1.

The Broad River upstream from Ninety-Nine Islands Impoundment is characterized by bedrock (schist) riffles alternating with sand-bottomed pools. Downstream from the impoundment a gneiss bedrock outcrop creates a shallow riffle which is followed by more pools and riffles.

Table 1-1. Total monthly precipitation and average monthly temperatures for January 1974 through August 1976, based on data from the Greenville-Spartanburg, SC airport.

		Total Monthly Precipitation		Average Monthly Temperature	
Year	Month	cm	in	C	F
1974	Jan	10.8	4.24	10.8	51.4
	Feb	12.4	4.90	6.2	43.9
	Mar	8.3	3.26	13.3	55.9
	Apr	10.3	4.06	14.9	58.8
	May	13.8	5.45	20.0	68.0
	Jun	9.6	3.78	22.3	72.2
	Jul	8.2	3.23	25.6	78.0
	Aug	10.2	4.03	25.1	77.2
	Sep	9.6	3.76	21.1	69.9
	Oct	0.6	0.24	14.9	58.8
	Nov	12.2	4.81	9.8	49.6
	Dec	6.4	2.50	6.3	43.4
1975	Jan	13.8	5.42	7.7	45.8
	Feb	14.7	5.78	8.2	46.8
	Mar	21.9	8.64	9.2	48.5
	Apr	2.9	1.14	14.8	58.7
	May	19.8	7.81	21.4	70.5
	Jun	13.7	5.39	23.6	74.4
	Jul	12.2	4.79	24.7	76.5
	Aug	8.2	3.21	25.9	78.6
	Sep	29.6	11.65	21.1	70.0
	Oct	18.9	7.45	17.0	62.6
	Nov	10.1	3.98	11.7	53.0
	Dec	7.8	3.07	5.9	42.7
1976	Jan	11.4	4.49	3.3	38.0
	Feb	5.5	2.15	10.3	50.6
	Mar	18.5	7.30	12.2	54.0
	Apr	1.8	0.69	15.1	59.2
	May	20.6	8.10	17.4	63.3
	Jun	7.1	2.81	21.9	71.4
	Jul	14.6	5.75	25.1	77.2
	Aug	5.3	2.09	24.1	75.3

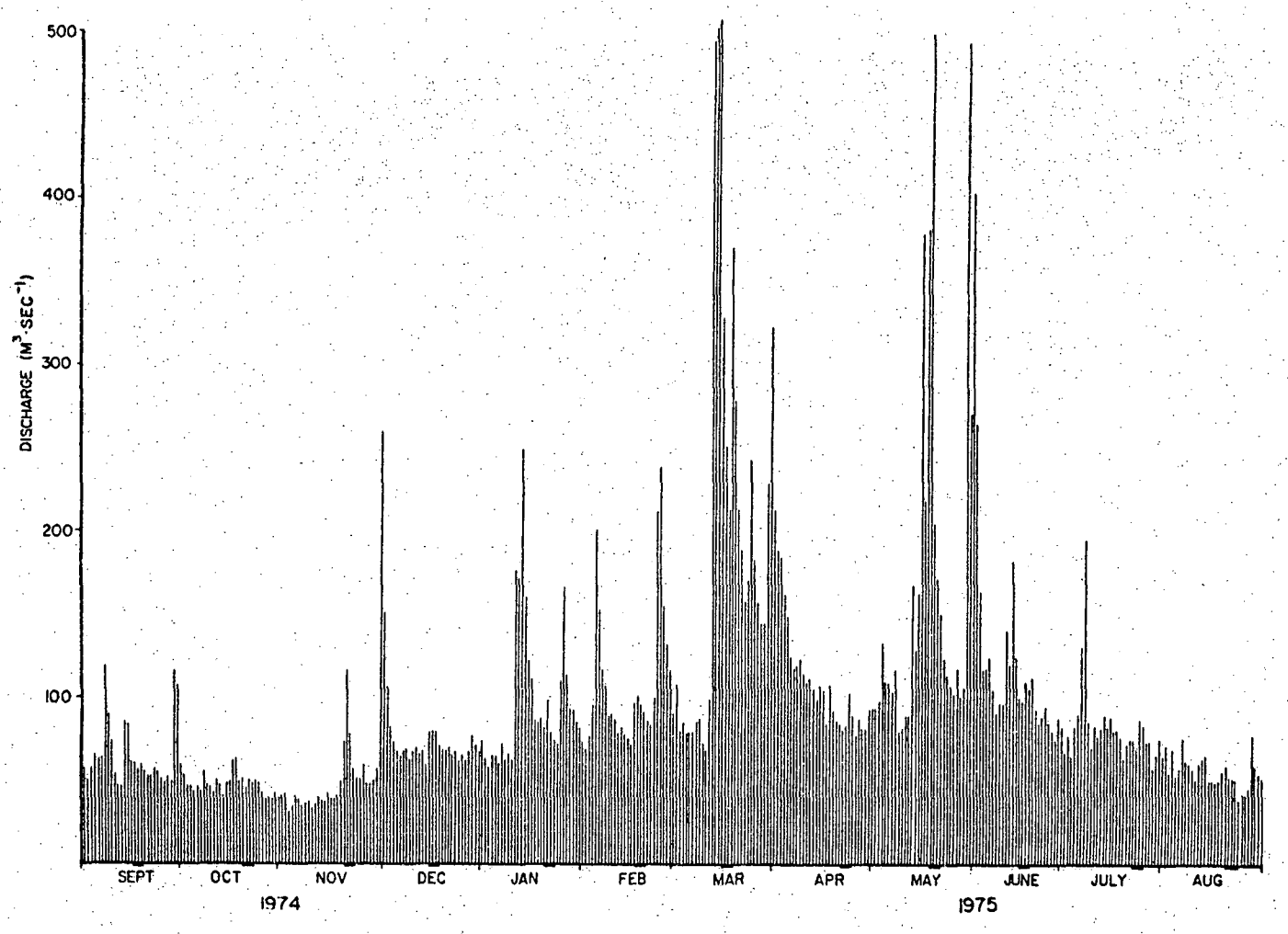

Fig. 1-3. Average daily discharge ($m^3.sec^{-1}$) of the Broad River from September 1974 through August 1976. Data are corrected for Ninety-Nine Islands Dam from data collected at the USGS Boiling Springs, NC gage.

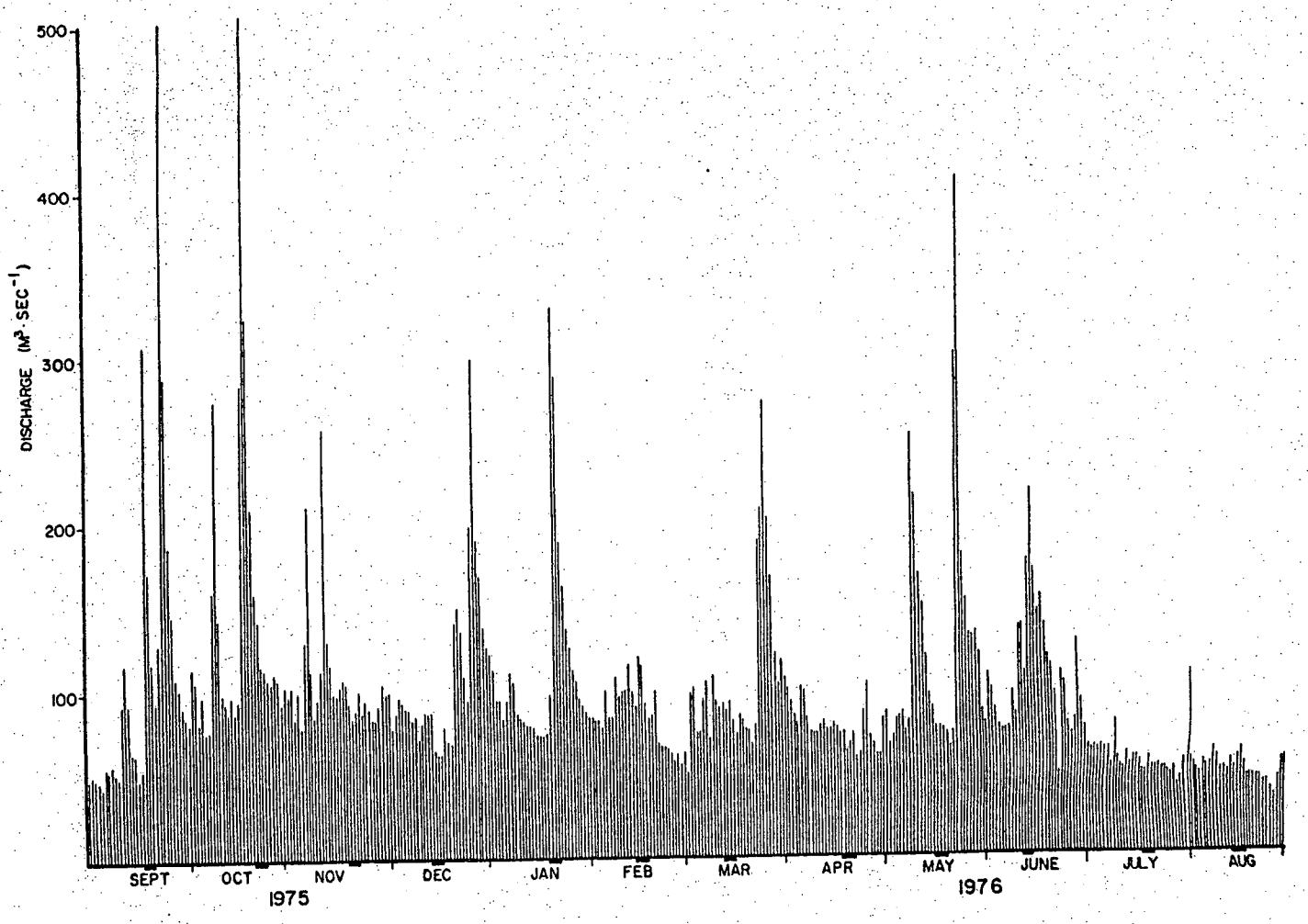
500
400
300
200
100
DISCHARGE ($M^3 \cdot SEC^{-1}$)
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
1975
1976

Fig. 1.3 (cont.)

Ninety-Nine Islands Impoundment has a surface area of approximately 70 ha (175 ac) and a storage volume of 1,850,000 m^3 (1500 acre-ft). The impoundment is characterized by three distinct hydrographic areas: the main channel and 2 major backwater areas (Fig. 1-2). The main channel has a sand substrate and extends through the center of the impoundment between the two backwaters. The main channel generally has a strong current and relatively homogeneous physical-chemical characteristics. The backwaters are little affected by river discharge, and stratify during summer. Stratification may break down when increased river discharge induces mixing.

SAMPLING LOCATIONS

Sampling locations were established on the impoundment and river with greatest emphasis placed on the vicinity of the CNS site. Sampling stations were numbered according to a Duke Power Company format. The three digits to the left of the decimal denote the general sampling location, while the single digit to the right of the decimal indicates the area within the location actually sampled, or the sampling strategy (eg. XXX.0 denotes a sample from midstream at location XXX; XXX.1 indicates a sample taken from near the left (facing downstream) bank; XXX.2 from near the right bank; and XXX.3 a composite sample). Occasionally XXX.4 through XXX.9 are used; the meanings of these variants are given in the chapters where they apply. A description of each location is presented in Table 1-2.

OBJECTIVES

The objectives of this study were to:

1. Document the physical, chemical, and biological characteristics of the Broad River and Ninety-Nine Islands Impoundment; and
2. Develop a sufficient data base to assess the environmental impact of construction and operation of CNS on the Broad River and Ninety-Nine Islands Impoundment.

Table 1-2. Description of sampling locations

Location No.	Location	Substrate	Width (m)	Max. Depth (m)	Remarks
451.5	Broad River at the USGS gaging station, South Carolina Highway 121 Bridge near Carlisle, 55 km downstream from CNS site.	sand, several rocky riffles	55	1.5	Both banks are steep and forested.
451.8	Broad River at South Carolina Highway 49 Bridge, 1.2 km downstream from Lockhart Dam and 32 km downstream from CNS site.	coarse sand	25	3	This station is in a diversion canal which carries water from Lockhart Dam to Lockhart Power Station; both banks are grass-covered levees. The original river bed parallels the canal to the east; it carries virtually no flow except during periods of high river discharge.
452	Broad River at Smith's (also known as Hamrick's) Ford, approximately 6 km downstream from Ninety-Nine Islands Dam	rock, coarse sand and silt	90	2	Both banks are forested.
453	Broad River at its confluence with Kings Creek, approximately 0.7 km downstream from Ninety-Nine Islands Dam	rock and sand	110	2	Both banks are forested.
453.5	Kings Creek at the South Carolina Highway 44 Bridge	sand and gravel	12	1	A clear stream with gravel riffles; banks are lined with fallen trees and brush.

Table 1-2. continued

Location No.	Location	Substrate	Width (m)	Max. Depth (m)	Remarks
455	Broad River in tailrace of Ninety-Nine Islands Hydroelectric Station	scoured rock sand, and gravel	50	2	Banks are steep with sparse vegetation; current variable with operation of hydroelectric station.
458	Backwater of the Ninety-Nine Islands Impoundment to the west of the main channel	silt	150	7	Banks are steep and heavily forested to the water's edge.
459	Ninety-Nine Islands Impoundment on west side of main channel	hard-packed silt	70	6	West bank is heavily wooded; vegetation on east bank is sparse.
460	Broad River, main channel of Ninety-Nine Islands Impoundment	coarse sand	73	2	Both banks are heavily forested; considerable bankside vegetation and brush.
462	Backwaters of the Ninety-Nine Islands Impoundment to the east side of the main channel	silt	149	5	Banks are heavily forested; considerable bankside vegetation and brush.
463	Broad River just below confluence with McKowns Creek	silty	85	1	Both banks are heavily forested.

REFERENCE CITED

Duke Power Company. 1974. Cherokee Nuclear Station. Environmental Report. Vols. I, II, III.

CHAPTER 2. WATER CHEMISTRY

J. C. Perkins

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INTRODUCTION

BACKGROUND

The Broad River is typical of Carolina Piedmont rivers: characteristically brownish-red in color, with fluctuating discharges and turbid conditions that reduce light penetration (Nelson and Scott 1962; Perkins and Caccia 1978). Previous water chemistry studies on the Broad River were limited to physical-chemical data reported by the USGS and the 1973-74 baseline study reported by Duke Power Company (1974).

Local meteorology, hydrology and geology play an important role in determining the physical-chemical characteristics of flowing waters (Golterman 1975; Hynes 1970). During periods of heavy rainfall large amounts of silt are washed into rivers. Analytes such as iron, turbidity, and phosphorus, which are related to silt load, display a direct relationship with discharge. When rainfall is light or absent groundwater is the primary water source of rivers thus, analytes which are related to groundwater (i.e. conductivity) show an inverse relationship to discharge. Water temperatures are controlled primarily by air temperatures. Since dissolved oxygen is inversely related to temperature, highest concentrations are typically recorded during winter, while lowest concentrations occur during summer.

Physical and chemical weathering of soils and bed-rock outcroppings provide the principle source of minerals to rivers (Johnson et al. 1968). The major rock type in the study area is felsic gneiss (granite) however, mafic gneiss, felsic schist, and varying thickness of quartzite have been found (Duke Power Company 1974). Feldspars, plagioclase quartz, and ferromagnesians are the most commonly occurring minerals in the study area. Consequently, higher concentrations of potassium, aluminum, silica, calcium, magnesium, and iron are expected in the study area.

OBJECTIVES

The objectives of this study were to:

1) determine spatial and temporal patterns in physical-chemical variables, of the Broad River in the vicinity of Cherokee Nuclear Station (CNS);
2) ascertain the effects of Kings Creek on the physical-chemical characteristics of the river and;
3) provide baseline data which will be used to predict and assess the impact of CNS on water quality.

MATERIALS AND METHODS

SAMPLING LOCATIONS AND FREQUENCY

To characterize the Broad River in the vicinity of CNS, ten stations (Fig. 1-2) were established. Four stations (464.0, 462.0, 460.0, 459.0) were established upstream of Ninety-Nine Islands Dam. Stations 455.0 (Ninety-Nine Islands tailrace) and 452.0 (Smith Ford) were established downstream from Ninety-Nine Islands Dam.

Two stations were located on Kings Creek, 453.5 and 453.0 (confluence of Kings Creek and the Broad River). Stations 451.8 and 451.5 (32 and 55 km downstream of Ninety-Nine Islands Dam respectively) were sampled quarterly for one year beginning in July 1976.

Water chemistry sampling on the Broad River was conducted at monthly intervals from September 1974 through December 1975. In-situ monitoring of temperature, dissolved oxygen, specific conductance and pH was continued monthly through November 1976 then reduced to quarterly. Beginning in January 1976, sample collection for laboratory analyses was reduced to quarterly.

FIELD PROCEDURES

Temperature, dissolved oxygen, pH and specific conductance were measured in-situ using a Hydrolab Surveyor Model 6D water quality analyzer. Measurements were recorded at the surface of all stations. In addition, a profile was recorded at Station 459.0. The Hydrolab was calibrated before and after each sampling according to manufacturer's instructions.

Duplicate samples were taken for laboratory analyses. Nutrient samples were collected in acid washed linear polyethylene bottles, stored on ice, and returned to the laboratory. Samples for metal analyses were collected in acid washed linear polyethylene bottles containing 0.5% HNO_3 as a preservative.

LABORATORY PROCEDURES

Nutrient samples were filtered in the laboratory and refrigerated at 4°C until analyzed. All analyses were subjected to the standard quality control practices outlined by the USEPA (1972).

The analytes monitored, analytical methods, references, preservation techniques and detection limits employed during the study are listed in Table 2-1.

DATA ANALYSIS

Descriptive statistics (maximum, minimum, mean, frequency analysis) and Pearson correlation coefficients were calculated using Statistical Analysis System of Barr et al. (1976). Only results with $p \leq 0.05$ were considered statistically significant.

In evaluating each analyte's relationship with discharge only mainstream stations (464.0, 460.0, 459.0, 455.0, 452.0) were utilized. Station 453.0 characterized Kings Creek (except where noted).

Table 2-1. Analytical methods, references, preservation techniques and detection limits for physical and chemical monitoring of the Broad River during the study period.

Parameter	Method	Reference	Preservation Technique	Detection Limit
Alkalinity, total	Method 403	A.P.H.A. et al. 1971	4 C	1 $mg \cdot l^{-1}$-$CaCO_3$
Aluminum, total	Atomic Absorption-graphite furnace	Perkin-Elmer Corp. 1973a	HNO_3	0.1 $\mu g \cdot l^{-1}$
Ammonia	Method 98-70W	Technicon Ind. Systems 1972	4 C, filtration	0.02 $mg \cdot l^{-1}$-N
Arsenic, total	Atomic Absorption-graphite furnace	Perkin-Elmer Corp. 1973a	HNO_3	1.0 $\mu g \cdot l^{-1}$
Biochemical oxygen demand	Method 507	A.P.H.A. et al. 1971	4 C	0.5 $mg \cdot l^{-1}$
Cadmium, total	Atomic Absorption-graphite furnace	Perkin-Elmer Corp. 1973a	HNO_3	0.1 $\mu g \cdot l^{-1}$
Calcium, total	Atomic Absorption-direct aspiration	Perkin-Elmer Corp. 1973b	HNO_3	0.01 $mg \cdot l^{-1}$
Carbon, total inorganic	Carbon Analyzer	Ocean Int. Corp. 1974	4 C	0.2 $mg \cdot l^{-1}$
Carbon, total organic	Carbon Analyzer	Ocean Int. Corp. 1974	4 C	0.2 $mg \cdot l^{-1}$
Chloride, soluble	Method 99-70W	Technicon Ind. Systems 1972	none	0.3 $mg \cdot l^{-1}$
Chromium, total	Atomic Absorption-graphite furnace	Perkin-Elmer Corp. 1973a	HNO_3	1.0 $\mu g \cdot l^{-1}$
Conductance, specific	Hydrolab Surveyor 6-D Method 205	Hydrolab Corp. 1973 A.P.H.A. et al. 1971	In situ 4 C	1 $\mu mhos \cdot cm^{-1}$ 1 $\mu mhos \cdot cm^{-1}$
Copper, total	Atomic Absorption-graphite furnace	Perkin-Elmer Corp. 1973a	HNO_3	1.0 $\mu g \cdot l^{-1}$
Iron, total	Atomic Absorption-direct aspiration	Perkin-Elmer Corp. 1973b	HNO_3	0.01 $mg \cdot l^{-1}$
Lead, total	Atomic Absorption-graphite furnace	Perkin-Elmer Corp. 1973a	HNO_3	1 $\mu g \cdot l^{-1}$
Magnesium, total	Atomic Absorption-direct aspiration	Perkin-Elmer Corp. 1973b	HNO_3	0.01 $mg \cdot l^{-1}$
Manganese, total	Atomic Absorption-direct aspiration	Perkin-Elmer Corp. 1973b	HNO_3	0.01 $mg \cdot l^{-1}$
Mercury, total	Flameless Atomic Absorption	U.S.E.P.A. 1974	HNO_3	0.1 $\mu g \cdot l^{-1}$
Nickel, total	Atomic Absorption-graphite furnace	Perkin-Elmer Corp. 1973a	HNO_3	10 $\mu g \cdot l^{-1}$
Nitrate-Nitrite	Method 158-71W	Technicon Ind. Systems 1972	4 C, filtration	0.02 $mg \cdot l^{-1}$-N
Orthophosphate, soluble	Method 155-71W	Technicon Ind. Systems 1972	4 C, filtration	0.005 $mg \cdot l^{-1}$-P
Oxygen, dissolved	Hydrolab Surveyor	Hydrolab Corp. 1973 A.P.H.A. et al 1971	In situ	0.0 $mg \cdot l^{-1}$
pH	Hydrolab Surveyor 6-D Method 442	Hydrolab Corp. 1973 A.P.H.A. et al. 1971	In situ 4 C	0.1 pH unit 0.1 pH unit
Phosphorus, total	Method 00665	U.S.E.P.A. 1974	4 C	0.005 $mg \cdot l^{-1}$-P
Potassium, total	Atomic Absorption-direct aspiration	Perkin-Elmer Corp. 1973b	HNO_3	0.5 $mg \cdot l^{-1}$
Selenium, total	Atomic Absorption-graphite furnace	Perkin-Elmer Corp. 1973a	HNO_3	1.0 $\mu g \cdot l^{-1}$
Silica, soluble	Method 105-71W	Technicon Ind. Systems, 1972	4 C	0.02 $mg \cdot l^{-1}$-Si
Sodium, total	Atomic Absorption-direct aspiration	Perkin-Elmer Corp. 1973b	HNO_3	0.2 $mg \cdot l^{-1}$
Temperature	Hydrolab Surveyor 6-D Method 212	Hydrolab Corp. 1973 A.P.H.A. et al. 1971	In situ In situ	-5.0 C -1.0 C
Turbidity	Monitek Turbidimeter	Monitor Tech. Inc. 1973	4 C	1.0 J.T.U.
Zinc, total	Atomic Absorption-direct aspiration	Perkin-Elmer Corp. 1973b	HNO_3	10 $\mu g \cdot l^{-1}$

RESULTS AND DISCUSSION

GENERAL WATER QUALITY PARAMETERS

TEMPERATURE AND DISSOLVED OXYGEN

Temperature values displayed seasonal patterns typical of Carolina Piedmont streams (Perkins and Caccia 1978). Temperatures ranged from 0.1 to 27.5 C with coldest temperatures December through February and warmest temperatures during July and August (Fig. 2-1). The coldest mean monthly temperature (2.1 C) occurred in January 1976. At this time the lowest single temperature (0.1 C) was recorded at Kings Creek (Station 453.5). Station 462.0, a backwater area, had the warmest temperature in August 1975 (27.5 C). Current in the main channel caused river stations to exhibit cooler temperatures than the backwater area.

Dissolved oxygen (DO) correlated inversely with temperature ($r = -0.89$). Dissolved oxygen, controlled primarily by water temperatures, exhibited highest values in January 1976, ($\sim 15\ mg \cdot l^{-1}$) and lowest in August 1976, ($\sim 7.0\ mg \cdot l^{-1}$) (Fig. 2-1). Depletion of DO did not occur at Location 459.0 where monthly profiles were taken (Appendix 2). Flow at Station 459.0 prevented stratification from occurring. Conversely, depletion of DO probably occurred at the bottom of Station 462.0 where a DO concentration of $0.8\ mg \cdot l^{-1}$ was recorded at the bottom during the 1973-74 Broad River study (Duke Power Company 1974).

pH AND ALKALINITY

The pH of the Broad River ranged from 6.2 to 8.2 with the highest value (8.2) occurring at Station 462.0 in July 1976. Because Station 462.0 supported the highest phytoplankton populations (Chapter 3) a higher pH pulse was expected. The Broad River, typical of Carolina Piedmont waters, is a weakly buffered system and the majority (> 80%) of alkalinity values fell below $20\ mg \cdot l^{-1}\ CaCO_3$. This lack of buffering capacity resulted in highly variable monthly pH values (Fig. 2-1).

Bicarbonate, calculated from alkalinity (Hem 1970), constituted the major dissolved carbon species. Alkalinity correlated inversely with discharge ($r = -0.71$) indicating that runoff diluted bicarbonate concentrations in the Broad River. Higher alkalinity values were recorded in Kings Creek (Table 2-2) and attributed to upstream discharges (Duke Power Company 1974). Little spatial variation in alkalinity existed in the Broad River (App. 2).

TURBIDITY

Turbidity, an indicator of particulate matter, ranged from 15 to 840 JTU and correlated directly with discharge ($r = 0.73$) (Fig. 2-2) indicating runoff and sediment resuspension were sources of turbidity to the river. Turbidity values were similar at all mainstream stations on the Broad River (Table 2-2) except Station 462.0 (backwater area) where they were generally lower. The lower turbidity values at Station 462.0 were due to settling of suspended matter as a result of reduced current.

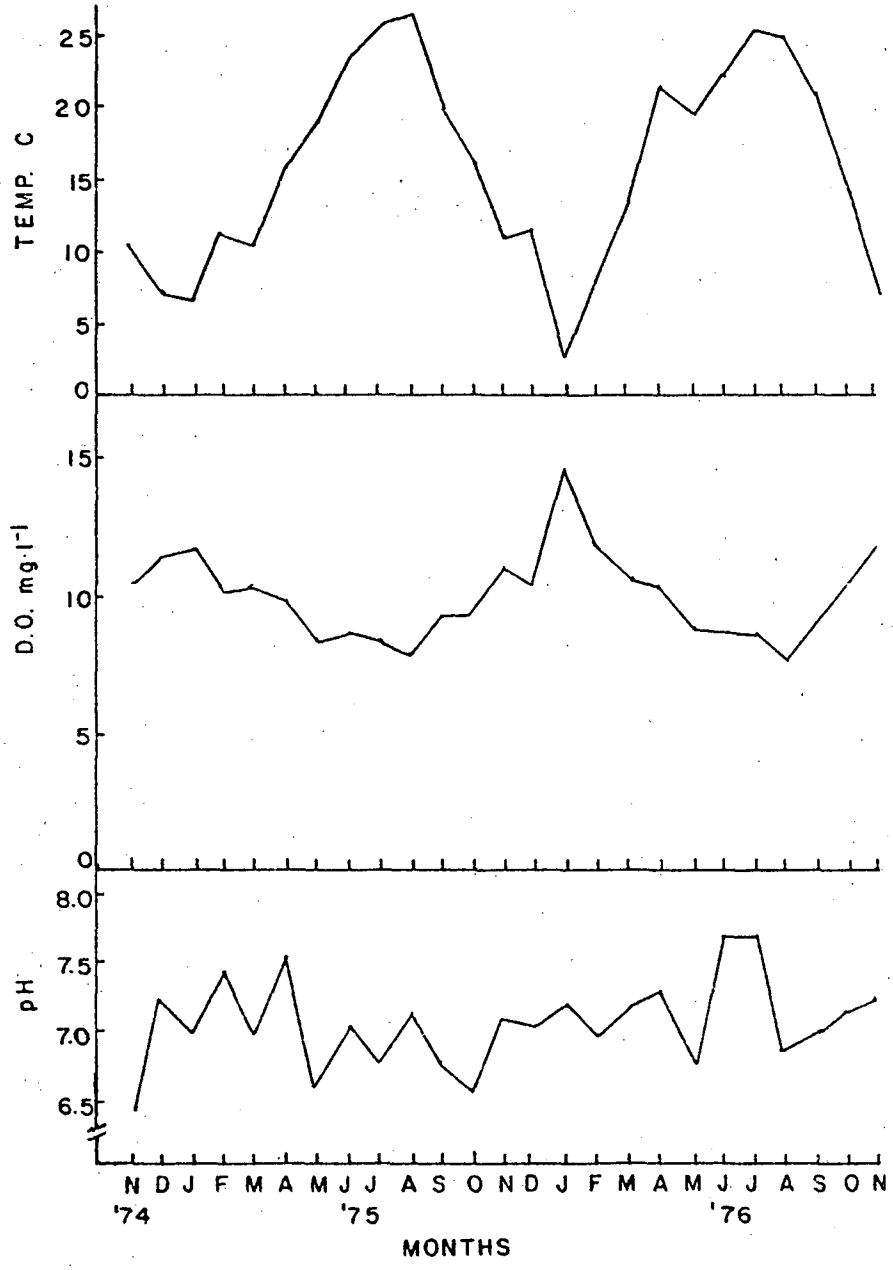

Figure 2-1. Variations of average monthly pH, dissolved oxygen (DO) and temperature on the Broad River from November 1974 through November 1976 combining all stations.

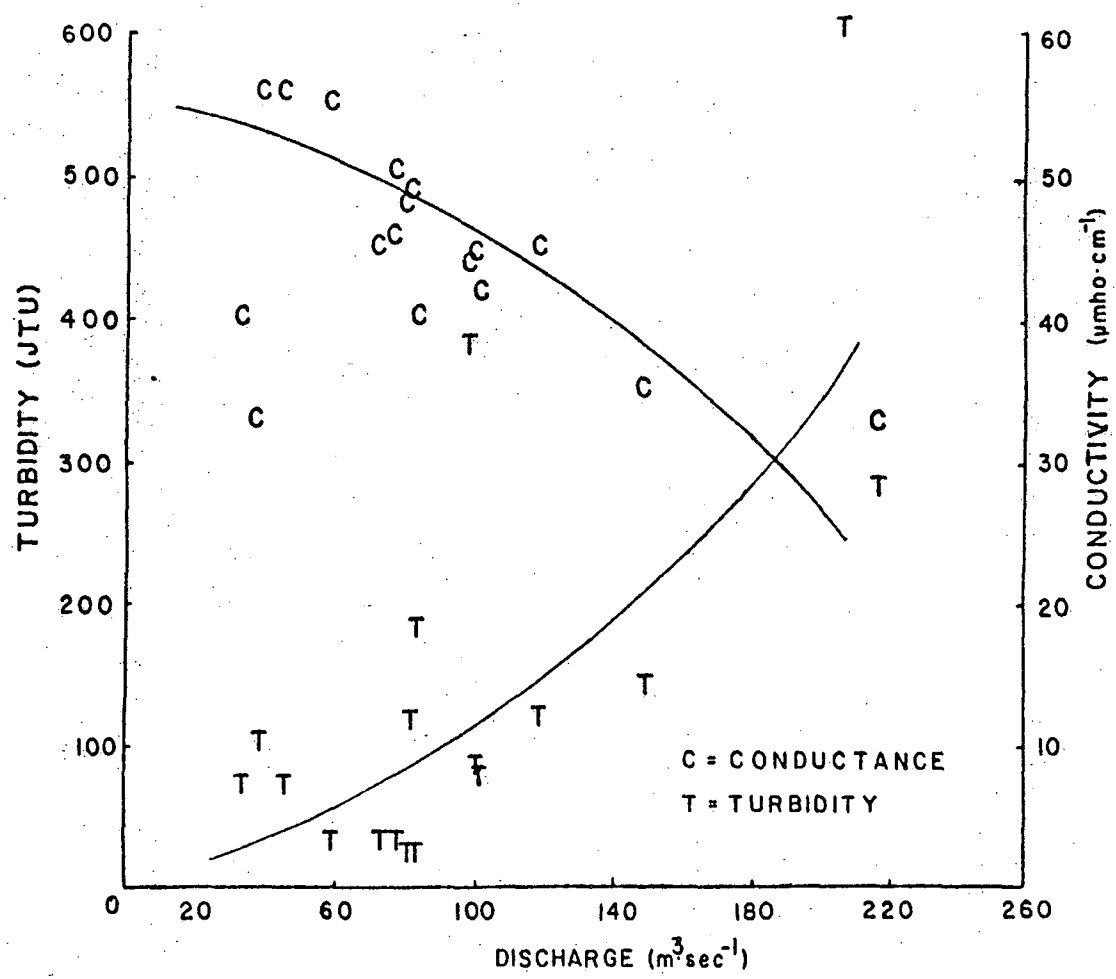

Figure 2-2. Relationship of turbidity and conductivity with flow on the Broad River during the study period.

Table 2-2. Mean and maximum concentrations of selected variables in the study area, November 1974 to November 1976.

Analyte	Locations Upstream of 99 Islands Dam[1]		East Backwater Area[2]		Locations Downstream of 99 Islands Dam[3]		Kings Creek[4]	
	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.
Temperature (C)	14.4	26.0	15.2	27.5	14.5	26.4	14.3	25.6
Dissolved Oxygen ($mg \cdot l^{-1}$)	10.0	7.3[5]	9.9	7.5[5]	9.8	6.3[5]	10.0	7.2[5]
Conductivity ($\mu mho \cdot cm^{-1}$)	38	55	39	55	44	67	73	140
pH	7.0	7.8	7.0	8.2	7.0	7.8	7.2	7.8
Alkalinity ($mg \cdot l^{-1} CaCO_3$)	15	25	15	20.0	16	38	24	37
Turbidity (JTU)	150	670	120	840	150	730	110	480
Chloride ($mg \cdot l^{-1}$)	3.9	5.5	4.3	5.9	4.3	8.2	7.2	43
Nitrate-Nitrite ($mg \cdot l^{-1}$-N)	0.47	1.6	0.39	0.73	0.46	1.5	0.34	0.67
Ammonia (mg·l-N)	0.23	1.7	0.21	0.96	0.19	2.9	0.11	0.30
Orthophosphate ($mg \cdot l^{-1}$-P)	0.03	0.08	0.02	0.07	0.03	0.28	0.04	0.41
Total Phosphorus ($mg \cdot l^{-1}$-P)	0.08	0.21	0.06	0.22	0.09	0.54	0.10	1.4
Silica ($mg \cdot l^{-1}$-Si)	5.5	6.6	5.5	6.4	5.5	6.8	6.0	7.6
Iron ($mg \cdot l^{-1}$)	2.1	8.9	1.9	7.3	2.4	8.0	1.8	5.4
Manganese ($mg \cdot l^{-1}$)	0.05	0.19	0.08	0.28	0.08	0.25	0.11	0.29
Calcium ($mg \cdot l^{-1}$)	2.8	3.6	2.9	3.6	3.3	4.5	6.6	8.2
Magnesium ($mg \cdot l^{-1}$)	1.3	1.7	1.3	1.7	1.4	1.9	2.2	4.3
Aluminum ($mg \cdot l^{-1}$)	3.1	13	2.0	3.7	2.6	6.0	2.2	5.0
Sodium ($mg \cdot l^{-1}$)	4.9	6.1	5.1	6.4	5.0	6.4	6.1	9.4
Potassium ($mg \cdot l^{-1}$)	1.8	3.0	1.8	3.0	1.9	3.3	2.2	3.5

[1] Locations 464.0, 460.0, 459.0
[2] Location 462.0
[3] Locations 455.0, 452.0
[4] Location 453.0
[5] Minimum DO concentration

The highest turbidity value (840 JTU) occurred at Station 462.0 in May 1975 and was the result of a spate that occurred the day before sampling (Fig. 1-3). This spate washed particulate matter into the backwater area from the mainstream of the Broad River while run-off also supplied particulate matter to the area. Settling of particulate matter, especially fine clays, occurs over a period of time (Hynes 1970), consequently settling was still occurring in this backwater area. The substrate (Chapter 5) encounted at Station 462.0 substantiates this conclusion that settling of particulate matter occurs in this backwater area.

Turbidity, exhibited slight correlations with phosphorus forms (orthophosphate $r = 0.29$; total phosphorus $r = 0.49$), while a stronger relationship was observed with iron ($r = 0.84$). This implied that phosphorus and iron values were derived from the same sources (runoff, sediment resuspension).

MINERALS

COMPOSITION

Sodium and bicarbonate represented 50% of the mineral constituents in the Broad River. The overall mineral composition upstream and downstream from Ninety-Nine Islands Dam was similar (Fig. 2-3). However, Kings Creek, due to upstream quarry discharges (Duke Power Company 1974) showed calcium, magnesium and sodium in near equal abundance. The average hardness reflected this difference. The Broad River had a hardness of approximately 30 $mg \cdot l^{-1}$-$CaCO_3$, while that of Kings Creek was 50 $mg \cdot l^{-1}$-$CaCO_3$. Nevertheless, the entire study area can be classified as a soft water system (Hem 1970).

Specific conductance is commonly used as an indicator of dissolved solids concentrations in water. On the Broad River, significant correlations were obtained between conductance and alkalinity ($r = 0.75$) and silica ($r = 0.46$). Specific conductance correlated inversely with discharge ($r = -0.73$) (Fig. 2-2) indicating that the source of dissolved solids was mainly groundwater. This illustrates further that rainfall and runoff, having lower ionic concentrations, had a dilution effect on conductivity values.

CALCIUM AND MAGNESIUM

Calcium and magnesium comprised approximately 13% of the minerals of the Broad River and 26% of the minerals in Kings Creek (Fig. 2-3). The calcium/magnesium ratio was similar at all stations indicating that sources of calcium and magnesium to the study area were mainly geological in origin (Hem 1970). The quarry that existed on a tributary of Kings Creek, although increasing the calcium and magnesium concentration, did not effect the ratio.

Variations in discharge of the Broad River had negligible influence on calcium and magnesium concentrations. Since total calcium and magnesium were analyzed it was not evident which form (dissolved or particulate) was dominant.

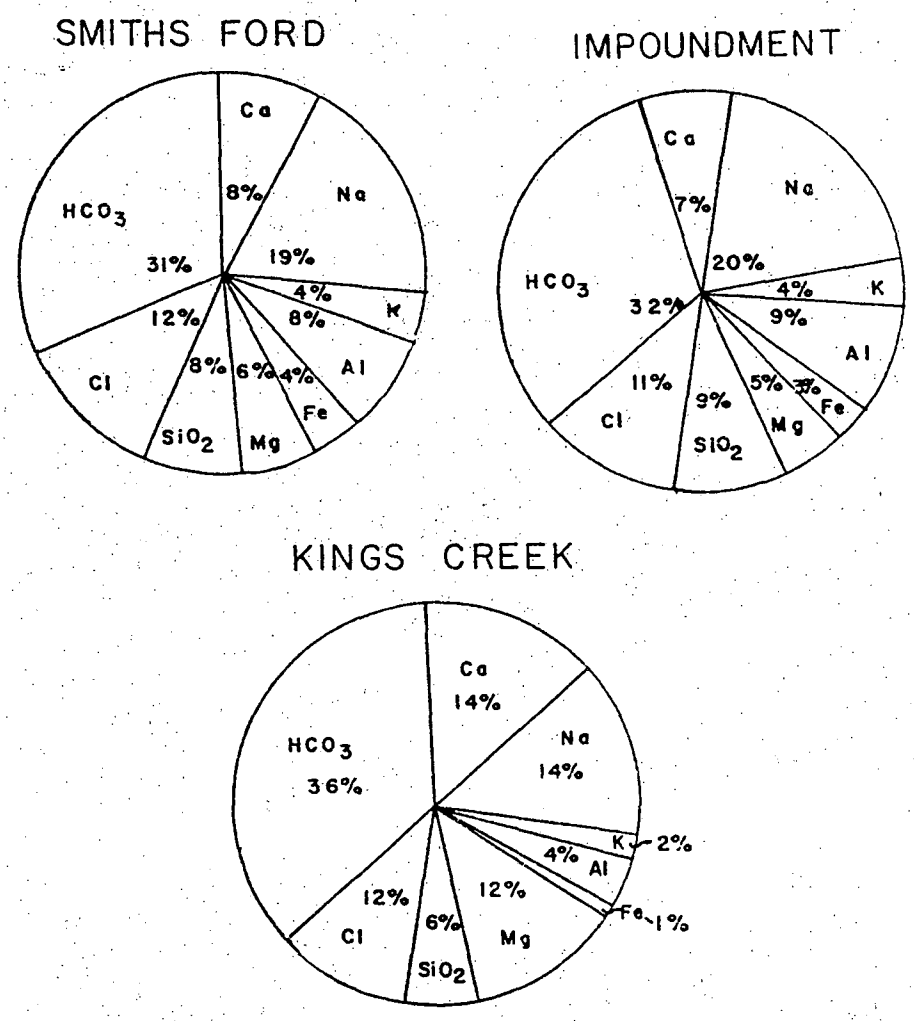

Figure 2-3. Molar percentage of mineral constituents found in the study area from November 1974 to November 1976.

SODIUM AND CHLORIDE

Sodium was the most abundant cation in the study area and chloride was the second most abundant anion (Fig. 2-3) Sodium ($r = -0.84$) and chloride ($r = -0.86$) were inversely correlated to discharge (Fig. 2-4) indicating groundwater was a major source of these two minerals. Two studies on the Missouri River exhibited similar results (Bowling 1974; Delfino and Byrnes 1975).

Spatial variations in sodium and chloride were similar to those of other minerals, with Kings Creek having higher concentrations.

NUTRIENTS

NITROGEN

Nitrate-nitrite concentrations ranged from 0.26 to 1.6 $mg \cdot l^{-1}$ in the Broad River. Nitrate-nitrite concentrations were similar upstream and downstream of the Ninety-Nine Islands Dam (Fig. 2-5; Table 2-2). However Station 462.0, a backwater area, exhibited lower nitrate-nitrite concentrations. Phytoplankton population densities were higher (in summer) in this area (Chapter 3) and could have contributed to the lower nitrate-nitrite concentrations.

Ammonia concentrations exhibited higher variability (0.02 to 1.7 $mg \cdot l^{-1}$) with all stations showing highest values in the fall (Fig. 2-6). These higher concentrations could be the result of: 1) inputs upstream of the study area (Duke Power Company 1974), 2) bottom waters at Station 462.0 approaching anoxia, probably caused surface waters at Station 462.0 to exhibit elevated ammonia concentrations. Kings Creek had lower ammonia concentrations and was not an important source of inorganic nitrogen to the Broad River.

Concentrations of both nitrate-nitrite and ammonia were similar to other Carolina Piedmont rivers (Perkins and Caccia 1978; USGS 1975). Concentrations of inorganic nitrogen, to the Broad River were probably a result of runoff, sediment resuspension, plant decomposition, and precipitation.

PHOSPHORUS

Total phosphorus values ranged from 0.22 to 1.4 $mg \cdot l^{-1}$ with soluble orthophosphate values ranging from 0.006 to 0.41 $mg \cdot l^{-1}$-P. Spatial variations for both orthophosphate and total phosphorus were generally small (Fig. 2-7; Fig. 2-8). Both orthophosphate ($r = 0.53$) and total phosphorus ($r = 0.51$) correlated with discharge, indicating runoff and sediment resuspension were probable sources of phosphorus. The high value of phosphorus observed in Kings Creek in November 1975 probably resulted from upstream non-point inputs. Temporal variations were best depicted by total phosphorus and were highly dependent on discharge.

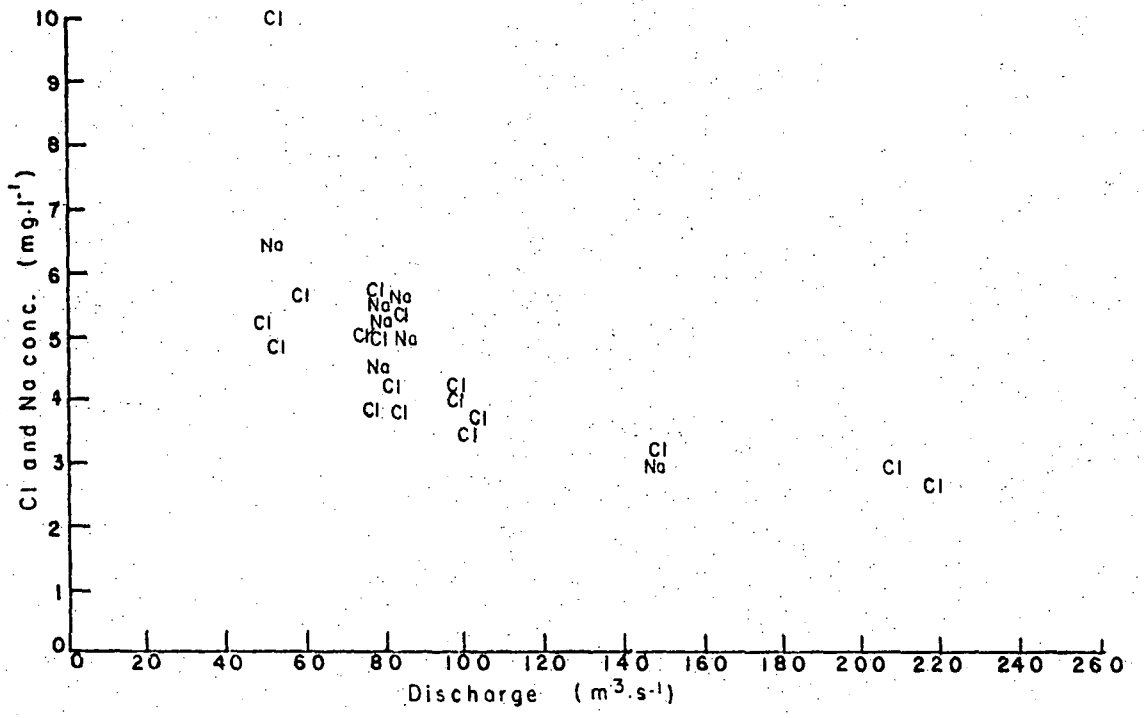

Figure 2-4. Relationship of chloride and sodium with flow on the Broad River during the study period.

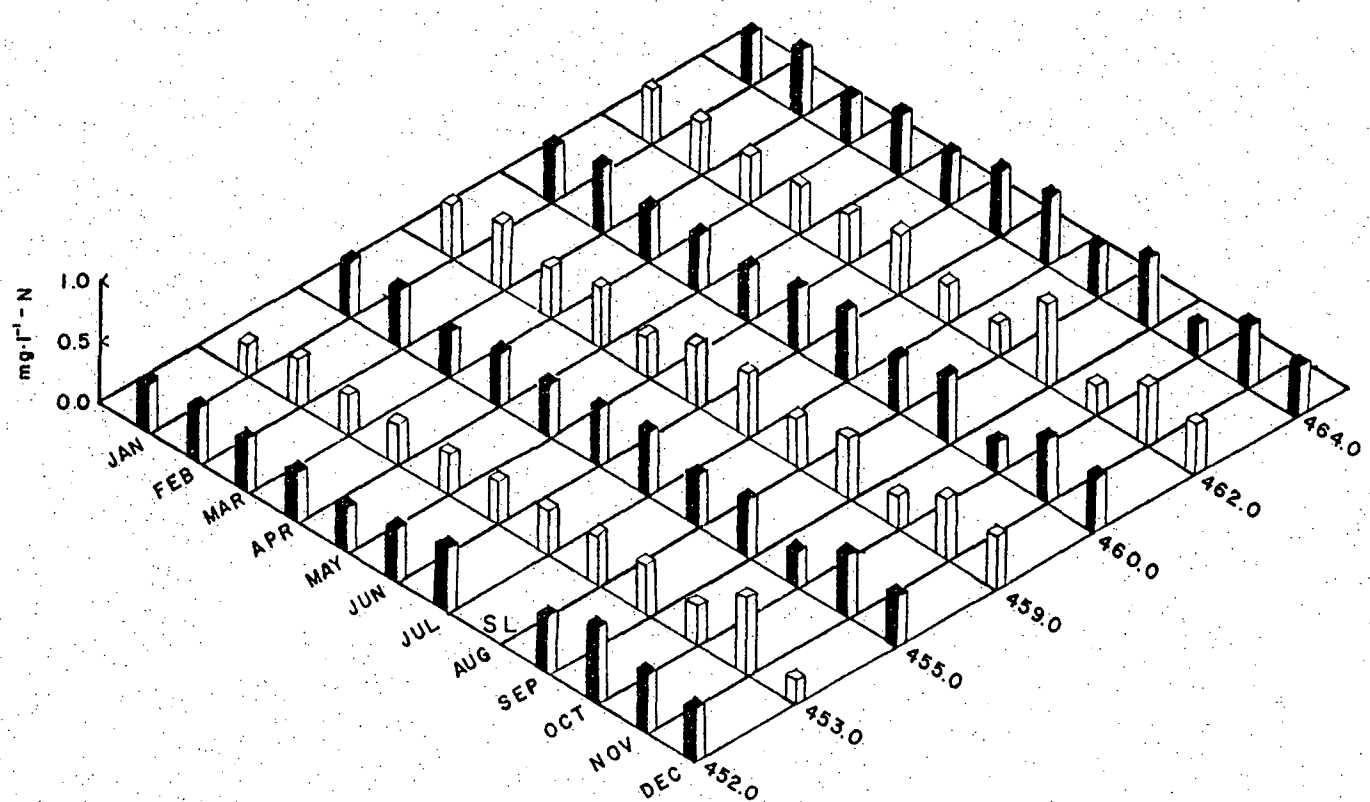

Figure 2-5. Spatial and temporal variation of nitrate-nitrite on the Broad River during 1975. (SL = Sample Lost)

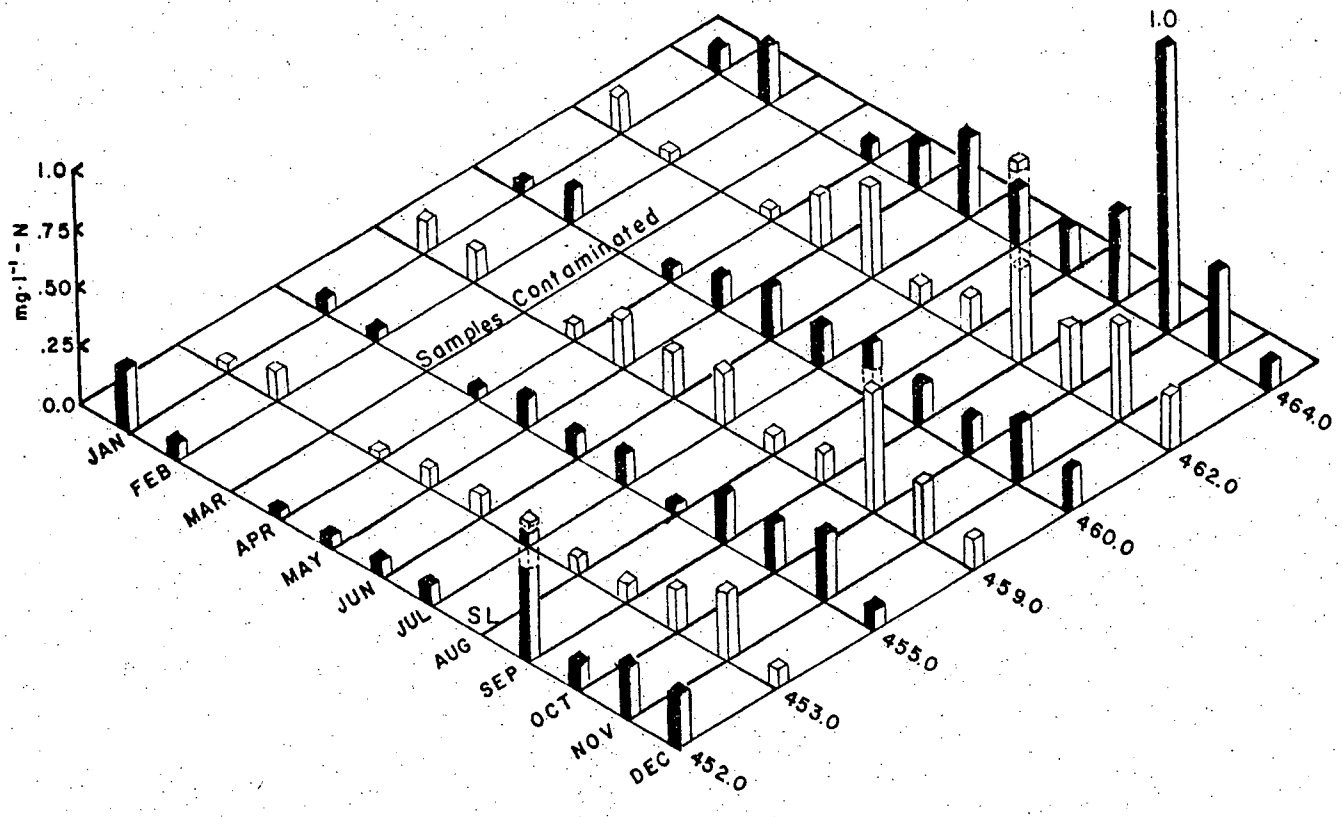

Figure 2-6. Spatial and temporal variations of ammonia on the Broad River during 1975. (SL = Sample Lost)

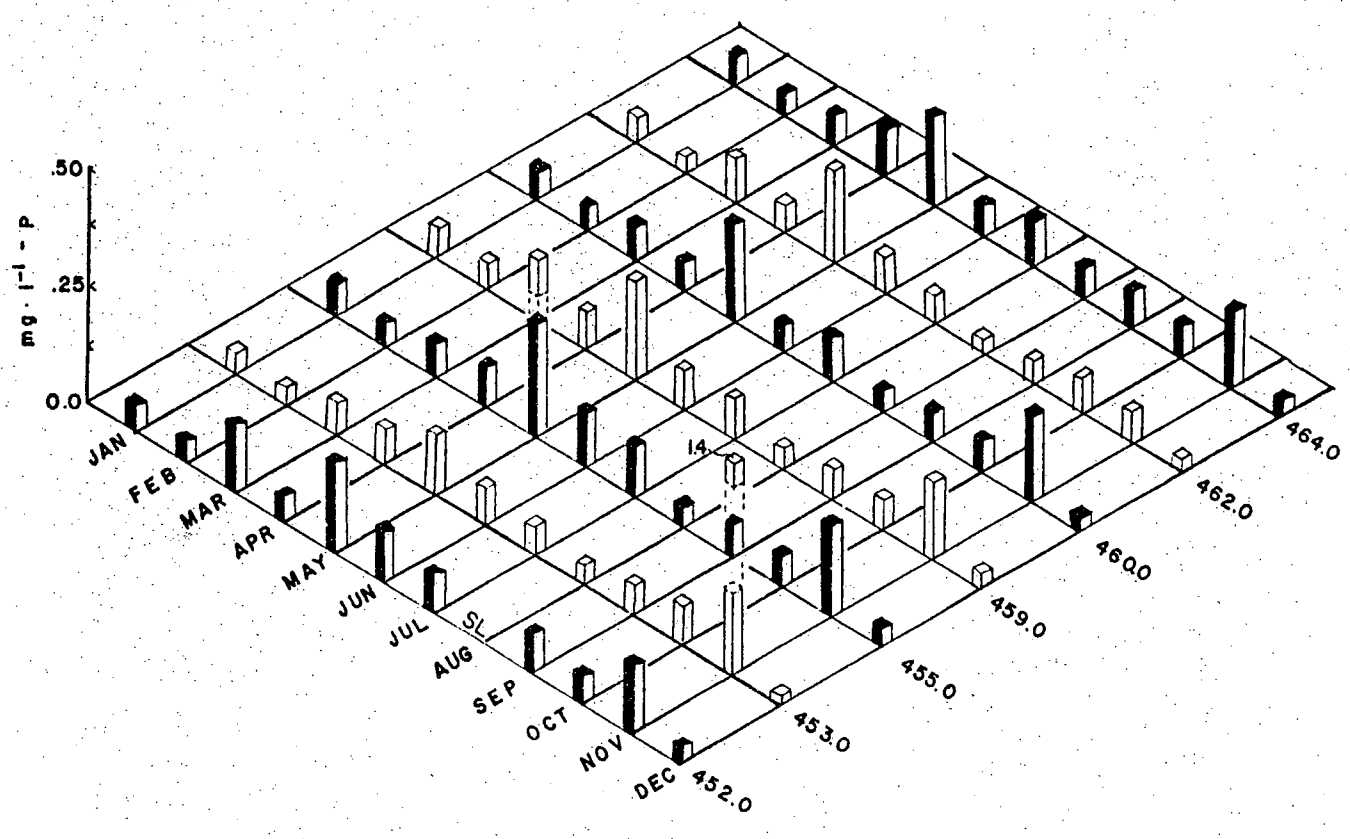

Figure 2-7. Spatial and temporal variations of total phosphorus on the Broad River during 1975. (SL = Sample Lost)

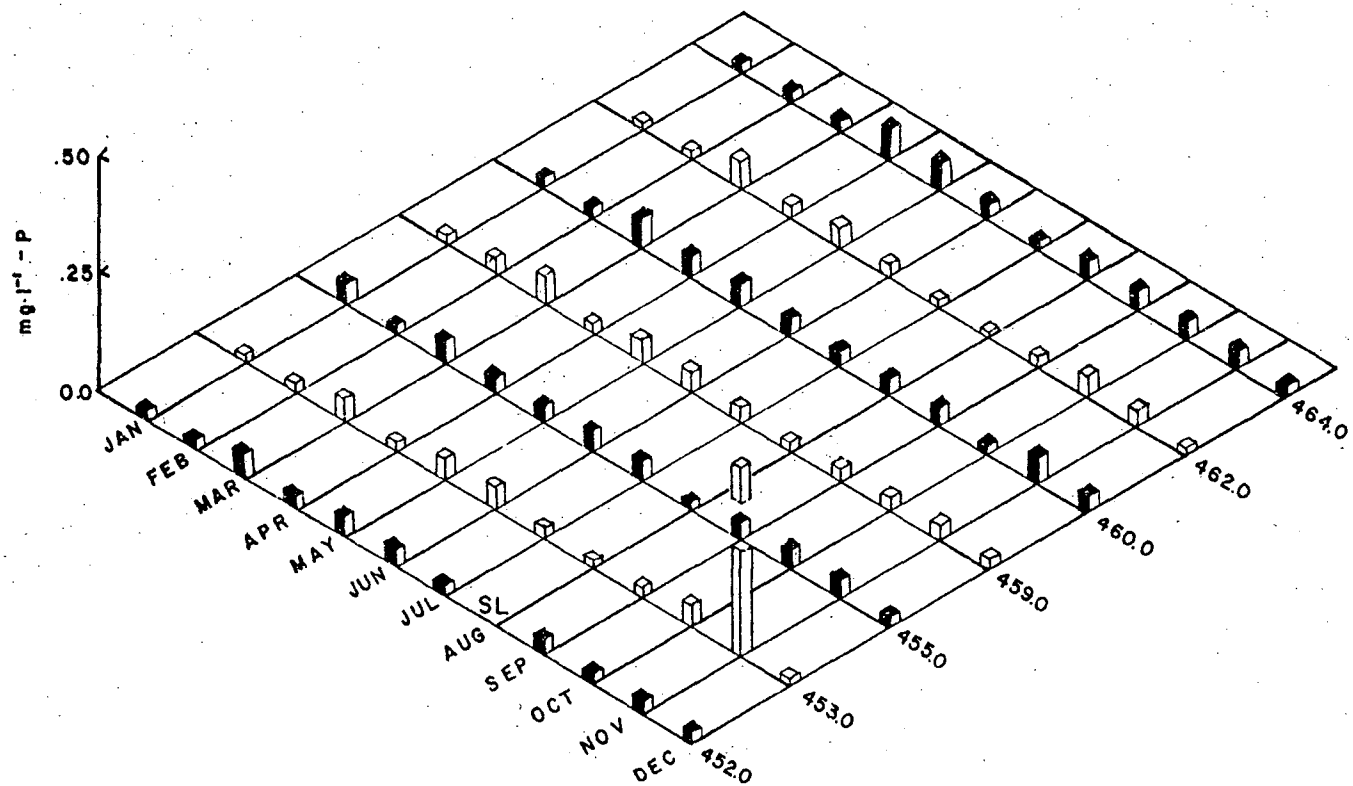

Figure 2-8. Spatial and temporal variations of orthophosphate on the Broad River during 1975. (SL = Sample Lost)

TRACE METALS

The primary sources of trace metals are natural weathering of rock, burning of fossil fuels and discharges of industrial effluents (Leckie and James 1974). All trace metals (Table 2-3) except cadmium and mercury were below recommended USEPA criteria. The USEPA has set cadmium criteria of 0.4 $\mu g \cdot l^{-1}$ (for the preservation of cladocerans and salmonid fishes) and 4.0 $\mu g \cdot l^{-1}$ (for other less sensitive aquatic life). Thirty-six percent of the cadmium values were over the 0.4 $\mu g \cdot l^{-1}$ limit; but, less than two percent were over the 4.0 $\mu g \cdot l^{-1}$ limit.

Of the nine mercury samples analyzed, six had concentrations above the USEPA criterion of 0.05 $\mu g \cdot l^{-1}$ for the preservation of aquatic life. All stations sampled (464.0, 459.0, 452.0) showed elevated mercury concentrations. The highest concentration observed was 0.5 $\mu g \cdot l^{-1}$ at Stations 464.0 and 459.0 in July 1976. Station 452.0 had a concentration of 0.2 $\mu g \cdot l^{-1}$ in July.

Iron and aluminum, although grouped as trace metals were detected in relatively large concentrations (Table 2-3). Both are found in the local lithology (granite). Iron correlated with turbidity ($r = 0.83$) and discharge ($r = 0.80$) indicating that runoff and sediment resuspension were the primary sources. This was also observed on the Yadkin River (Perkins and Caccia 1978). Aluminum correlated moderately with turbidity ($r = 0.37$).

Excluding aluminum, all trace metals showed highest concentrations in Kings Creek (Station 453.0) and at stations downstream of the Ninety-Nine Islands Dam (Table 2-3). This could be due to two factors: (1) settling out of trace metals would be more likely to occur upstream of Ninety-Nine Islands Dam, and/or (2) Kings Creek could be a source of trace metals due to industrial discharges (Duke Power Company 1974).

SUMMARY

The Broad River is a typical turbid Piedmont stream displaying rapid fluctuations in flow. Although the Broad River is circumneutral, wide fluctuations in pH occur as a result of low buffering capacity in the river. Water temperatures (0.1 to 27 C) were similar to other Carolina Piedmont streams with lowest temperatures from December through February and highest in July and August. Dissolved oxygen (6.3 to 15.0 $mg \cdot l^{-1}$) varied inversely with temperature.

Sodium and bicarbonate comprised 50% of the mineral constituents on the Broad River, typical of other softwater Piedmont streams. Geology was the primary source of minerals in the study area, with hydrology in most cases controlling their concentrations. Consequently, increases in discharge resulted in higher concentrations of turbidity, iron, and phosphorus, implying runoff and sediment resuspension as sources for these analytes. Conversely, increased discharge lowered the concentrations of alkalinity, conductivity, silica, chloride and sodium

indicating groundwater was the probable source of these analytes. The mechanism controlling the concentrations of nitrate-nitrite, ammonia, calcium and magnesium were unclear since they exhibited no relationship with discharge.

All analytes except trace metals, showed little variation upstream and downstream from Ninety-Nine Island Dam, indicating the impoundment had little effect on water quality. Both nutrient and mineral concentrations were characteristic of Carolina Piedmont rivers. Kings Creek exhibited higher mineral concentrations and lower nutrient concentrations than the Broad River; however, Kings Creek mineral concentrations had little effect on Broad River concentrations. Trace metals were detectable in the study area with cadmium and mercury being the only trace metals above USEPA criteria.

Table 2-3. Mean and maximum concentrations of trace metals in the study area, November 1974 to November 1976.

Analyte	Locations Upstream of 99 Islands Dam		East Backwater Area		Locations Downstream of 99 Islands Dam		Kings Creek	
	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.
Aluminum ($mg \cdot l^{-1}$)	3.1	13	2.0	3.7	2.6	6.0	2.2	5.0
Iron ($mg \cdot l^{-1}$)	2.1	8.9	1.9	7.3	2.4	8.0	1.8	5.4
Zinc ($\mu g \cdot l^{-1}$)	34	100	26	55	43	100	42	100
Cadmium ($\mu g \cdot l^{-1}$)	0.4	1.8	0.3	0.5	1.0	9.0	2.2	15
Copper ($\mu g \cdot l^{-1}$)	3.8	5.9	3.4	13	5.6	18	6.2	22
Chromium ($\mu g \cdot l^{-1}$)	5.1	10	4.6	10	6.1	12	6.4	10
Mercury ($\mu g \cdot l^{-1}$)	0.2	0.5	—[1]	—[1]	0.1	0.2	—[1]	—[1]

[1]Mercury not sampled in East Backwater Area or Kings Creek.

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CHAPTER 3. ALGAE

L. L. Lawson and D. H. Buetow

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INTRODUCTION

BACKGROUND

The algae of flowing waters may be divided into two groups: periphyton and phytoplankton. Periphyton is attached to various substrates (e.g., rocks, logs, sand grains, plants, the bodies of animals). Phytoplankton are free-floating forms, generally composed of a mixture of lentic algae (euplankton) and detached periphyton (tychoplankton).

Physical variables often control the periphyton and phytoplankton communities in rivers. Substrate type and availability govern the distribution and abundance of periphyton. Rocks and other solid substrates provide a much more favorable habitat for periphytic growth than muddy substrates or shifting sand bottoms (Blum 1956; Nelson and Scott 1962). Higher phytoplankton concentrations are usually observed during low discharge since current is a major factor influencing phytoplankton communities (Eddy 1934). Slower current allows more time for the organisms to replicate if other physical-chemical variables are favorable (Eddy 1934). Increased discharge tends to dilute phytoplankton concentrations. A stable current exerts a positive effect on periphyton communities by constantly renewing nutrients near the cell surfaces of attached algae (Hynes 1970; Ruttner 1953). Turbidity limits the development of periphyton and phytoplankton communities by reducing light penetration (Blum 1956; Patrick 1962). Suspended solids can cause the physical destruction of planktonic and periphytic algae (Chandler 1937; Reif 1939). The effects of temperature on algal growth and production are difficult to separate from those of solar radiation, since both typically follow similar seasonal patterns (Hynes 1970; Lund 1965). Phytoplankton and periphyton data from the Broad River and Ninety-Nine Islands Impoundment indicated that the factors controlling algae distribution were probably stream discharge, streambed substrate, and water temperature (Duke Power 1974). However, chemical factors such as dissolved oxygen, pH, and availability of nutrients and minerals may also, at times, play a role in determining the distribution and abundance of algae in streams (Blum 1956; Hynes 1970).

OBJECTIVES

This report documents the results of a study of periphytic algae and phytoplankton from the Broad River and Ninety-Nine Islands Impoundment. The objectives of this study were to:

(1) quantitatively estimate periphyton and phytoplankton;
(2) determine the seasonal periodicities of periphyton and phytoplankton communities;
(3) determine the major physical and chemical variables influencing periphyton and phytoplankton communities; and
(4) provide baseline data which will be used to predict and assess the impact of Cherokee Nuclear Station on periphyton and phytoplankton.

MATERIALS AND METHODS

PERIPHYTON

FIELD PROCEDURES

Sample Collection

Periphyton in the Broad River was sampled at stations and dates presented in Table 3-1. Descriptions of these stations are found in Chapter 1. Station 462.0 was located in a backwater while all other stations were located in the mainstream. Periphyton samplers were anchored 2 to 3 m from the river bank at each station (Fig. 3-1) for an exposure period of approximately 28 days. Sampler placement during the period of monthly sampling (21 November 1974 through 4 December 1975) was staggered at two-week intervals to provide additional samples if any samples were lost or destroyed during a given month.

Samples were collected using a Periphytometer II™, which consists of a rack holding eight 2.5 X 7.5-cm glass microscope slides oriented vertically and suspended between two floats near the water surface. The use of artificial substrates, in particular glass slides, to quantitatively study periphyton has been reviewed by several authors (Cooke 1956; Patrick et al. 1954; Sladekova 1962; Weber and Raschke 1970).

At the end of each exposure period, the four slides to be used for microscopic analysis were placed in 60-ml wide mouth bottles and preserved in the field with M^3 fixative (Meyer 1971). The four slides to be used for ash-free dry weight determinations were placed in a metal rack and allowed to air dry.

Natural substrate collections (logs, twigs, rocks, and sediment) were made in all seasons for comparison with algae found on glass slides. Tippett (1970) suggested supplementing artificial substrate data with data from natural substrates to obtain a more accurate picture of the periphyton community.

Physical and Chemical Measurements

Subsurface current velocity was measured at the time of phytoplankton sampling with a General Oceanics Model 2030 digital flowmeter (App. 3-1). Discharge data (App. 1-1) were obtained from the U.S.G.S. Boiling Springs, N. C. gaging station located 41 km upstream of the study area (U.S.G.S. 1974, 1975, 1976). Discharge rates obtained from this gage were increased in proportion (1.79) to the increase in drainage area at the Ninety-Nine Islands Dam. Solar radiation data were obtained from Greensboro-High Point, N.C., airport.

LABORATORY PROCEDURES

Population Density

Two of the preserved slides were used for identification and enumeration of algae and two were stored for reference purposes. Periphyton was scraped from the slides with a razor blade or rubber policeman into 60-ml sample bottles where distilled water was added to reach

Table 3-1. Stations and months sampled for periphyton (+) and phytoplankton (0) on the Broad River and Ninety-Nine Islands Impoundment from 1974-1977.

DATE	STATIONS													
	451.5	451.8	452.1	452.2	452.3	453.1	453.2	459.0	460.1	460.2	460.3	462.0	464.1	464.2
1974														
Sep					0	0	0	0			0	0		
Oct					0	0	0	0			0	0		
Nov			+	+	0	+0	+0	0			0	+0	+	+
Dec			+	+	0	+0	+0	0			0	+0	+	+
1975														
Jan			+	+	0	+0	+0	0			0	+0	+	+
Feb			+	+	0	+0	+0	0			0	+0	+	+
Mar			+	+	0	+0	+0	0			0	+0	+	+
Apr			+	+	0	+0	+0	0			0	+0	+	+
May			+	+	0	+0	+0	0			0	+0	+	+
Jun			+	+	0	+0	+0	0			0	+0	+	+
Jul			+	+	0	+0	+0	0			0	+0	+	+
Aug			+	+	0	+0	+0	0			0	+0	+	+
Sep			+	+	0	+0	+0	0			0	+0	+	+
Oct			+	+	0	+0	+0	0			0	+0	+	+
Nov			+	+	0	+0	+0	0			0	+0	+	+
Dec			+	+		+	+					+	+	+
1976														
Jan						0		0			0			
Feb						+	+	+	+	+				
Apr						0		0			0			
May						+	+	+	+	+				
Jul	0	0				+0	+	+0	+	+	0			
Oct	0	0				0		0			0			
Nov						+	+	+	+	+				
1977														
Jan	0	0												
Apr	0	0												

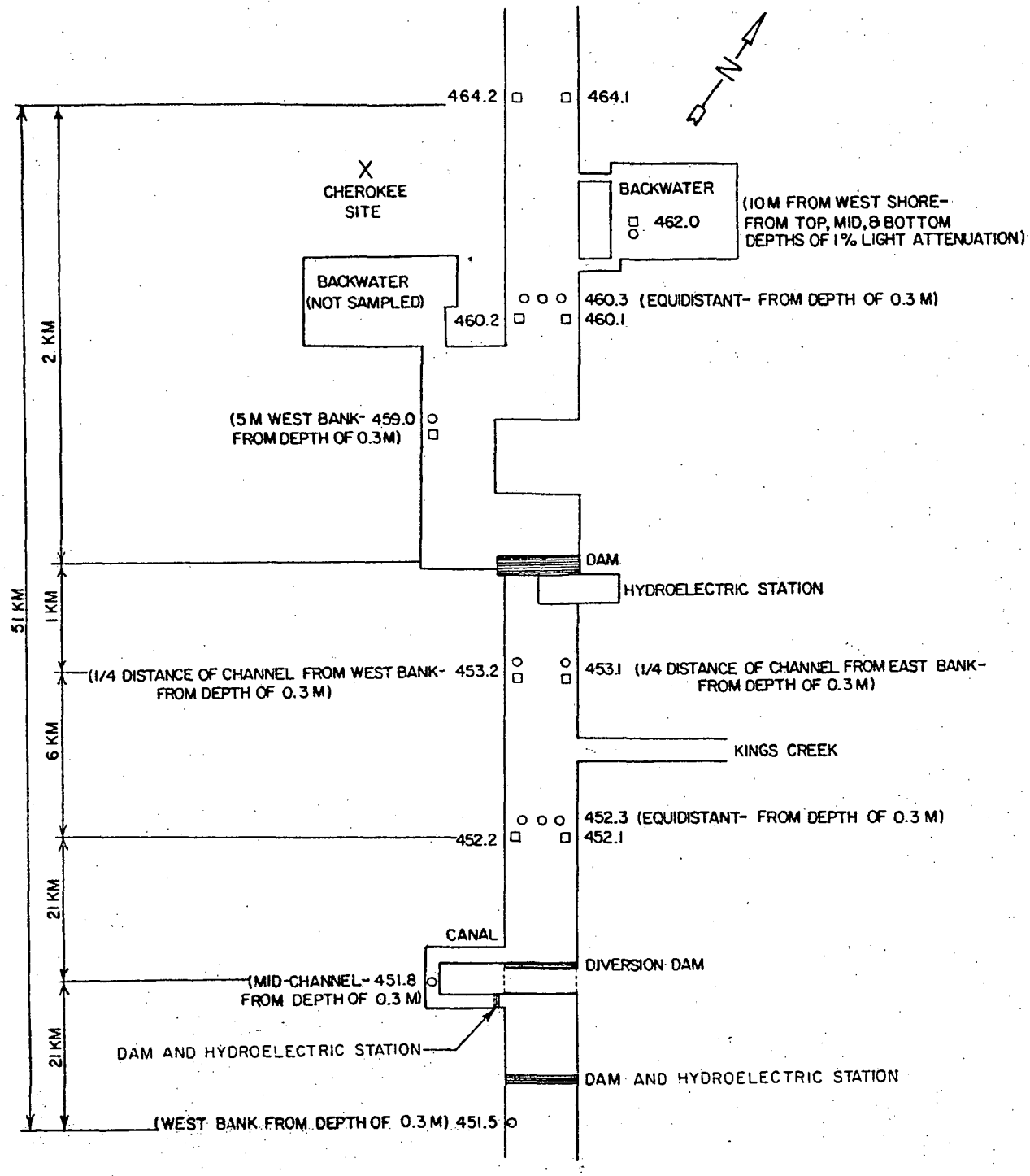


Figure 3-1. A schematic representation of the Ninety-Nine Islands Impoundment and the Broad River showing periphyton (□) and phytoplankton (o) stations, the sampling strategy, and the depths at which phytoplankton samples were taken.

standard volume. After uniformly resuspending the scraped algae, a 0.1-ml aliquot from each sample was placed in a Palmer-Maloney counting slide (Palmer and Maloney 1954) and examined under 500X (phase contrast). All non-diatoms were identified and enumerated at the lowest practicable taxonomic level, while diatoms were enumerated at the class level only. Non-diatoms were counted as cells (for unicellular forms), colonies (for colonial forms) or 18-μm lengths (for filamentous forms). Diatoms were counted as live or dead cells. A total of approximately 500 units (cells, filaments and colonies) was counted and the number of fields or transects noted. Counts of all algae, excluding dead diatom cells, were converted to densities expressed as units per square meter (units/m^2).

As the taxonomy of diatoms is based on characteristics of the cleaned frustule, each sample was treated using the nitric acid cleaning method of Hohn and Hellerman (1963). The cleaned diatom frustules were then mounted in Hyrax and examined under oil immersion at 1250X (phase contrast). Approximately 1000 valves per sample were counted and identified to the lowest practicable taxon. The relative composition of each diatom species to the total number of valves counted was calculated. This proportion was applied to the total density of live diatom cells observed under 500X to obtain the densities of diatom taxa in units per square meter. Natural substrate samples were counted using the same procedures with the exception that only the relative abundance of algal species could be calculated.

Taxonomic keys used for the identification of algae included Cleve-Euler (1953), Cocke (1967), Hustedt (1930), Kim (1967), Patrick and Reimer (1966, 1975), Prescott (1962), Smith (1950), Taft and Taft (1971), Tiffany and Britton (1952), Van Heurck (1896), Weber (1971) and Whitford and Schumacher (1973). Dr. Larry Whitford and Dr. Charles Reimer were retained as consultants to confirm the identifications of non-diatom algae and diatoms, respectively.

Population Biovolume

The species mean biovolume was calculated by applying the average cell dimensions, measured over the period of the study, to the volume formula of an approximate geometric solid. This value was then multiplied by the respective numerical density to obtain the biovolume in cubic millimeters per square meter (mm^3/m^2).

Ash-Free Dry Weights

Ash-free dry weights were determined as described in Standard Methods (A.P.H.A. 1971) with the modification that each slide was placed in a pre-weighed, numbered Pyrex(R) cylinder rather than scraping the periphyton into a crucible. Ash-free dry weights were expressed in grams per square meter (g/m^2).

DATA ANALYSES

A modification of the formula suggested by Lohmann (1908) relating a value to the radius of a circle was used for the graphic presentation of major class density and biovolume data. An index of dominance was calculated for each exposure period using a modified method of Simpson (Simpson 1949, cited in Odum 1971). Species comprising 2% or more of the density at some time during the study, and all classes, regardless of percent composition, were analyzed with the dominance index:

$$C_j = \sum_{i=1}^{n} \left[\left[\frac{N_{ij}}{N_i} \right]^2 \cdot R_{ij} \right] \cdot F^2_j$$

where: n = number of exposure periods

i = exposure period

j = taxon

C_j = index of dominance of j th taxon over all exposure periods.

N_{ij} = density of j th taxon in i th exposure period

$N_i = \sum_{j=1}^{m} N_{ij}$, where m = number of taxa

R_{ij} = inverse rank of $C_{ij} = \left[\frac{N_{ij}}{N_i} \right]^2$ for i th exposure and

F_j = frequency of j th taxon for all exposure periods.

Statistical analyses were performed on data from exposure periods ending 21 November 1974 through 4 December 1975. Homogeneity of variances was tested using Bartlett's test. Data which failed to meet the assumption of homoscedasticity were transformed and retested. Where data transformations were unsuccessful, Friedman's test was employed to detect significant differences between stations. A two-way analysis of variance (ANOVA) was performed on homoscedastic data. If significant interaction was detected, a simple main effects test was used to isolate the sources of interaction. Months with significant simple main effects were further analyzed with Duncan's multiple range test to determine which stations or groups of stations were significantly different from one another. Due to missing values, data from the 24 April 1975 exposure period could not be used in Friedman's or Duncan's Test. Pearson's product-moment correlation coefficients were calculated for total periphyton densities and biovolume, class densities and biovolume, and ash-free dry weights with physical-chemical variables.

The ten-top ranked species by dominance index for densities were evaluated using principle component analysis. This technique summarizes the variability in the data for a group of species into a smaller

number of new components. Each new component represents a progressively smaller portion of the variability in the data, the first two accounting for the two most significant components of variation. Stations and dates with abundances of those species which loaded heavily with respect to a principle component will score high on that component. The score for each station and date on the first two principle components (PC1 and PC2) is plotted on an ordination graph with a cluster analysis of the same data superimposed. Groups of stations and dates with similar species composition will cluster on the graph. In order to relate the position of a cluster on the graph in terms of underlying environmental factors, Pearson's product moment correlation coefficients were calculated for PC1 and PC2 with physical-chemical variables. All statistical analyses were calculated by SAS (Barr et al. 1976).

PHYTOPLANKTON

FIELD PROCEDURES

Sample Collection

Stations and dates which were sampled are presented in Table 3-1. Descriptions of these stations are found in Chapter 1. Station 462.0 was considered a backwater (lentic) station while all others were considered mainstream (lotic) stations.

Three one-liter whole water samples were collected at each station (Fig. 3-1) with a horizontal Van Dorn bottle and pooled in a Nalgene carboy. From this composite sample, a 950-ml subsample for population analysis and a 250-ml subsample for chlorophyll analysis were withdrawn. Duplicate composite samples were collected at each station.

Population Preservation

Each 950-ml population subsample was preserved immediately in the field. From September 1974 through March 1975 all population subsamples were preserved with 10 ml of M^3 fixative. From April 1975 to April 1977 the preservation technique was modified to prevent clumping of suspended particles and algae in the concentrated samples. One milliliter of Cat-Floc T (Calgon Corporation), a cationic polyelectrolyte, was diluted in 10 ml distilled water and added to the 950-ml subsample. To the 10 ml of M^3 fixative, 2g sodium borate ($Na_2B_4O_7 \cdot 10\ H_2O$) was dissolved and the mixture added to the population subsample.

Chlorophyll Preservation

Each 250-ml subsample, was filtered in the field using a Gelman filtering apparatus and a Gelman GF/A glass fiber filter. The glass fiber filter was stored in a darkened centrifuge tube on ice (APHA 1971).

Physical and Chemical Measurements

Water temperature (C) was measured at each station at time of sampling with a mercury bulb thermometer (App. 3-14). Discharge data (App. 1-1) were obtained as outlined in the periphyton field procedures section. Chemical data were collected as described in Chapter 2 and results presented in App. 2.

LABORATORY PROCEDURES

Sample Concentration

The preserved 950-ml composite subsamples were allowed to settle under subdued light at a rate of 4 hr/cm of container height (Weber 1973). The supernatant was aspirated from the sample and the remaining precipitate transferred to a smaller bottle. The original sample bottle was rinsed thoroughly to insure transference of all cells. The settling and aspirating process was continued until the sample was concentrated to a volume of 5 to 25 ml, depending upon the concentration of suspended solids.

Population Density

Organisms were identified to the lowest practicable taxon and counted at a magnification of 500X on a Palmer-Maloney counting cell. Phytoplankton organisms were enumerated in the same units as outlined in the periphyton laboratory procedures. Counts of all algae were converted to densities and expressed as units per cubic meter (units/m^3). The taxonomic references used in identification of the organisms and the consultants retained for confirmation of identifications are cited in the periphyton section.

Population Biovolume

The species mean biovolume was determined by the same methods as outlined in the periphyton laboratory procedures section, except that phytoplankton biovolume, was expressed as cubic millimeters per cubic meter (mm^3/m^3).

Chlorophyll Extraction and Measurement

Chlorophyll a was determined with a Turner fluorometer using methods outlined in Strickland and Parsons (1972). Phaeopigments were determined after acidification of the sample with oxalic acid (Yentsch and Menzel 1963).

DATA ANALYSIS

An index of dominance and ranking was calculated on class density, class biovolume, and species density from monthly samples using the equation as outlined in the periphyton data analysis section.

Statistical analyses were performed on replicate data from monthly sampling. Total density and biovolume, class density and biovolume, chlorophyll a, and phaeopigment data were tested for normality by the Kolmogorov-Smirnov (Lilliefors) test. Two-way analysis of variance was performed to test for significant ($p<0.05$) differences between stations and months. If a significant interaction was detected, a simple main effects analysis was applied to isolate the source of interaction. The least significant differences test (LSD) was used to determine significant differences between stations. Data from March 1975 was not used in the ANOVA analyses since some stations were not sampled that month due to high water.

RESULTS AND DISCUSSION

PERIPHYTON

COMMUNITY COMPOSITION

Two hundred and seventy-seven periphytic algal taxa were identified from artificial and natural substrates in the Broad River and Ninety-Nine Islands Impoundment during the study (Table 3-2). The distribution of taxa among the algal classes were as follows: 223 Bacillariophyceae (diatoms), 32 Chlorophyceae (green algae), 9 Myxophyceae (blue-greens), 6 Cryptophyceae, 4 Chrysophyceae, 2 Euglenophyceae and 1 Dinophyceae. The total number of taxa and distribution among algal classes compares very closely with the two hundred and sixty-four periphytic algal taxa observed from a similar study on the Yadkin River (Lawson et al. 1978).

Diatoms ranked number 1 by annual dominance index for density and biovolume at both river and backwater stations (Table 3-3) and were by far the most abundant and diverse class of algae found during the study. Diatoms comprised such a high proportion of the total community at mainstream stations (94.8% of mean annual density and 98.0% of mean annual biovolume) that the periphyton communities there may be considered primarily as diatom assemblages. A previous study on the Broad River also found the periphyton community to be composed primarily of diatoms (Duke Power Company 1974).

Green algae and blue-green algae ranked number 2 and 3, respectively, by annual dominance index for density and biovolume at both mainstream and backwater stations (Table 3-3). Green algae, however, were generally found in higher abundance at the backwater where they were the number 1 ranked class of algae several months. Green algae contributed 21.9 and 28.2% to the mean annual densities and biovolumes at the backwater station compared to 3.9 and 0.8% of mean annual densities and biovolumes at mainstream stations. Blue-green algae were a minor component of the periphyton community at both the backwater and mainstream stations comprising <2% of mean annual densities and <1% of mean annual biovolumes in either case. This class is of interest as many species are tolerant of high temperatures. All other classes of algae had dominance indices of <0.1 and were considered inconsequential.

Periphyton communities on natural substrates in the mainstream were also composed primarily of diatoms (Table 3-4). However, blue-green algae replaced green algae as the second most abundant class of algae found on natural substrates and comprised 18.8% of mean annual relative abundance and 9.7% of mean annual relative biovolume. Certain blue-green algae do not attach well to glass slides (Lund and Talling 1957) so the use of artificial substrates may underestimate the contribution of blue-green algae to the natural periphyton communities in the Broad River. Only 26 taxa, all of rare occurrence (Table 3-2), were found on natural substrates which were not found on artificial substrates.

Table 3-2. List of periphyton (Peri.) and phytoplankton (Phyto.) taxa observed and their frequency of occurrence from Ninety-Nine Islands Impoundment and the Broad River, SC, from 17 September 1974 to 20 April 1977.

Taxon	Peri. Artificial Substrates	Peri. Natural Substrates	Phyto. Impoundment	Phyto. River
Division: Chlorophyta				
Class: Chlorophyceae				
Acanthosphaera zachariasi Lemm.	*	*	*	R
Ankistrodesmus falcatus (Corda) Ralfs.	R	*	R	R
A. f. var. mirabilis (West & West) G. S. West	R	*	*	*
A. f. var. stipitatus (Chod.) Lemm.	R	*	*	*
A. sp.	R	*	MP	OP
Arthrodesmus sp.	*	*	*	R
Asterococcus limneticus G. M. Smith	*	*	*	R
Carteria globosa Korshikov	*	*	*	R
C. sp.	*	*	*	R
Characium ambiguum Herm.	R	*	*	*
C. sp.	R	*	*	R
Chlamydomonas sp.	R	*	OP	SP
Chlorella pyrenoidosa Chick	*	*	*	R
C. sp.	*	*	R	R
Chlorococcum sp.	*	*	R	R
Chlorogonium sp.	*	*	R	R
Closteriopsis longissima Lemm.	*	*	*	R
C. sp.	*	*	*	R
Closterium dianae var. arcuatum (Breb.) Rabh.	R	*	*	*
C. eboracense Turner	*	*	*	R
C. gracile Breb.	*	*	*	R
C. sp.	*	R	*	R
Coccomonas orbicularis Stein	*	*	R	R
C. sp.	*	*	R	R
Coelastrum proboscideum Bohlin	*	*	R	R
Cosmarium angulosum var. concinnum (Rabh.) West and West	R	*	*	*
C. asphaerosporum var. strigosum Nordst	R	*	*	*
C. impressulum Elfnius	*	*	*	R
C. undulatum var. minutum Wittr.	R	R	*	R
C. sp.	R	R	*	R
Cosmocladium saxonicum Debary	*	*	R	R
C. sp.	*	*	*	R
Cylindrocapsa conferta W. West	*	*	*	R
Crucigenia crucifera (Wolle) Collins	*	*	R	R
C. fenestrata Schmidle	*	*	R	R
C. rectangularis (A. Braun) Gay	*	*	R	*
C. tetrapedia (Kirch.) West and West	R	*	R	R
Dactylococcus infusionum Naeg.	*	*	R	*
D. sp.	*	*	*	R
Dictyosphaerium ehrenbergianum Naeg.	*	*	*	R
D. pulchellum Wood	*	*	R	R
D. sp.	*	*	R	R
Dispora crucigenioides Printz	*	*	R	R
Elakatothrix gelatinosa Wille	*	*	*	R
Euastrum sp.	*	*	R	*
Francia droescheri (Lemm.) G. M. Smith	*	*	*	R
F. ovalis (France) Lemm.	*	*	*	R
Geminella sp.	R	R	*	*
Gloeocystis sp.	*	*	*	R
Golenkinia paucispina West and West	*	*	R	R
G. radiata Chod.	*	*	R	R
Gonium pectorale Muell.	*	*	R	R
Kirchneriella contorta Schmidle	*	*	R	*
K. lunaris (Kirch.) Moeb.	*	*	*	R
K. subsolitaria G. S. West	*	*	R	R
Lagerheimia citriformis (Snow) G. M. Smith	*	*	R	R
L. sp.	*	*	*	R
Micractinium pusillum Fresenius	*	*	R	R
Monoraphidium contortum (Thur.) Fott	R	*	CP	MP
M. setiforme (Nygaard) Komarkova-Legnerova	*	*	R	R
Mougeotia sp.	R	*	*	R
Oedogonium sp.	*	R	*	*
Oocystis sp.	*	*	*	R
Pachycladon umbrinus G. M. Smith	*	*	*	R
Pandorina morum (Muell.) Bory	*	*	*	R
Pediastrum duplex Meyen	*	*	R	R
P. tetras (Ehren.) Ralfs	*	*	*	R
Polyedriopsis spinulosa Schmidle	*	*	*	R
Pteromonas angulosa (Carter) Lemm.	*	*	*	R
Scenedesmus acuminatus (Lager.) Chod.	*	*	R	R
S. dimorphus (Turp.) Kutz.	R	*	*	*
S. quadricauda (Turp.) Breb.	R	R	MP	MP
S. q. var. longispina (Chod.) G. M. Smith	*	R	*	*
S. sp.	R	R	SP	OP
Schroederia setigera (Schroeder) Lemm.	*	*	R	R
Selenastrum minutum (Naeg.) Collins	*	*	SP	SP
S. sp.	*	*	R	R

Taxon	Peri. Artificial Substrates	Peri. Natural Substrates	Phyto. Impoundment	Phyto. River
Sphaerocystis schroeteri Chod.	*	*	R	R
Sphaerozosma granulatum Roy and Biss	*	*	R	R
Staurastrum alterans Breb.	*	*	R	*
S. apiculatum Breb.	*	*	*	R
S. paradoxum Meyen	R	*	*	R
S. p. var. cingulum West and West	*	*	R	R
S. p. var. nodulosum West	*	*	*	R
S. p. var. parvum W. West	*	*	*	R
S. sp.	R	*	R	R
Stichococcus sp.	R	*	*	*
Stigeoclonium subsecundum Kutz.	R	*	*	*
S. sp.	OP	R	*	R
Tetraedron arthrodesmiforme G. S. West	*	*	R	*
T. caudatum (Corda) Hansg.	*	*	R	*
T. gracile (Rein.) Hansg.	*	*	R	*
T. minimum (A. Braun) Hansg.	R	*	R	R
T. trigonum var. gracile (Rein.) DeT.	*	*	R	R
T. sp.	R	*	R	R
Tetrastrum heteracanthum (Nordst.) Chod.	*	*	*	R
T. h. var. elegans (Playfair) Ahlstrom and Tiffany	*	*	*	R
Ulothrix sp.	R	*	*	*
Unidentified coccoid greens	R	*	CP	CP
Unidentified green filament	R	*	R	R
Division: Chrysophyta				
Class: Bacillariophyceae				
Achnanthes deflexa Reim.	CP	CP	R	SP
A. exigua Grun.	R	R	*	*
A. e. var. heterovalvata Krass.	R	*	*	*
A. hauckiana Grun.	*	R	*	*
A. lanceolata (Breb.) Grun.	MP	CP	R	R
A. l. var. apiculata Patr.	R	R	*	*
A. l. var. dubia Grun.	CP	OP	*	*
A. lewisiana Patr.	MP	OP	*	*
A. linearis (W. Smith) Grun.	R	*	*	*
A. l. f. curta H. L. Smith	R	*	*	*
A. lutheri Hust.	*	R	*	*
A. marginulata Grun.	R	R	*	*
A. microcephala (Kutz.) Cl.	R	R	*	R
A. minutissima Kutz.	CP	CP	*	R
A. m. var. macrocephala Hust.	SP	OP	*	*
A. saxonica Krass.	R	*	*	*
A. stewartii Patr.	R	*	*	*
A. sp.	OP	MP	R	SP
Amphipleura pellucida Kutz.	*	R	*	*
Amphora ovalis Kutz.	R	*	*	R
A. o. var. pediculus Kutz.	R	*	*	*
Anomoeoneis serians var. brachysira (Breb.) Cl.	*	R	*	*
A. vitrea (Grun.) Ross	R	R	*	*
Asterionella formosa Hass.	R	SP	SP	OP
Attheya zachariasi J. Brun.	*	*	R	SP
Bacillaria paradoxa Gmel.	R	R	*	*
Biddulphia laevis Ehr.	R	*	*	*
Caloneis bacillum (Grun.) Mer.	R	R	*	*
C. hyalina Hust.	R	*	*	*
C. ventricosa var. minuta (Grun.) Patr.	R	*	*	*
C. spp.	R	R	*	*
Cocconeis fluviatilis Wallace	SP	R	*	*
C. placentula Ehr.	R	*	R	R
C. p. var. euglypta (Ehr.) Cl.	R	*	*	*
C. p. var. lineata (Ehr.) V.H.	CP	OP	*	R
C. sp.	R	*	*	R
Coscinodiscus rothii (Ehr.) Grun.	*	*	*	R
Cyclotella glomerata Bach.	*	*	*	R
C. meneghiniana Kutz.	R	R	*	R
C. pseudostelligera Hust.	R	SP	*	*
C. stelligera (Cl.) V.H.	SP	SP	OP	OP
C. sp.	R	R	R	R
Cylindrotheca sp.	*	*	*	R
Cymbella affinis Kutz.	R	R	*	R
C. aspera (Ehr.) Cl.	R	*	*	*
C. hybrida Grun.	R	*	*	*
C. minuta Hilse ex Rabh.	MP	MP	*	*
C. naviculiformis Aursw. ex Heib.	R	R	*	*
C. sinuata Greg.	R	SP	*	R
C. tumida (Breb.) V.H.	MP	CP	R	SP
C. tumidula Grun.	*	*	*	R
C. turgida Greg.	*	*	*	R
C. ventricosa Kutz.	R	*	SP	SP
C. sp.	R	R	*	R
Denticula elegans Kutz.	R	R	*	*
Diploneis pseudovalis Hust.	R	*	*	*
D. sp.	R	*	R	R
Epithemia zebra (Ehr.) Kutz.	R	*	*	*
E. sp.	*	*	*	R
Eunotia curvata (Kutz.) Lag.	R	R	*	*
E. exigua (Breb. ex Kutz.) Rabh.	R	R	*	*
E. naegelii Migula	*	*	*	R
E. pectinalis (O.F. Mull.) Rabh.	R	R	*	R
E. p. var. minor (Kutz.) Rabh.	R	R	*	R

Taxon	Peri. Artificial Substrates	Peri. Natural Substrates	Phyto. Impoundment	Phyto. River
E. perpusilla Grun.	R	R	*	*
E. tenella (Grun.) Cl.	*	*	*	R
E. tridentula var. perpusilla Grun.	R	*	*	*
E. sp.	R	OP	R	R
Fragilaria intermedia Grun.	R	*	*	*
F. pinnata Ehr.	*	R	*	*
F. vaucheriae (Kutz.) Peters.	MP	CP	*	*
F. virescens Ralfs	*	R	*	*
F. sp.	R	R	R	R
Frustulia rhomboides (Ehr.) DeT.	R	R	R	*
F. r. var. capitata (A. Mayer) Patr.	R	R	*	*
F. r. var. saxonica (Rabh.) DeT.	R	R	*	*
F. vulgaris (Thwaites) DeT.	R	OP	*	*
F. sp.	R	R	*	*
Gomphonema affine Kutz.	R	*	*	*
G. angustatum (Kutz.) Rabh.	SP	R	R	*
G. a. var. producta Grun.	OP	SP	R	*
G. apuncto Wallace	*	R	*	*
G. brasiliense Grun.	R	R	*	*
G. clevei Fricke	R	*	*	*
G. constrictum Ehr.	R	R	*	*
G. c. capitatum (Ehr.) Grun.	R	*	*	R
G. gracile Ehr.	OP	SP	*	R
G. g. var. lanceolata (Kutz.) Cl.	*	*	*	R
G. grunowii Patr.	R	*	*	*
G. intricatum Kutz.	R	R	*	*
G. i. var. vibrio (Ehr.) Cl.	R	*	*	*
G. lanceolatum Ehr.	R	*	*	*
G. olivaceum (Lyngb.) Kutz.	*	*	*	R
G. parvulum Kutz.	CP	CP	R	R
G. sphaerophorum Ehr.	*	R	*	*
G. sp.	MP	CP	R	SP
Gyrosigma acuminatum (Kutz.) Rabh.	*	*	*	R
G. obtusatum (Sull. and Worm.) Boyer	R	*	*	*
G. scalproides (Rabh.) Cl.	R	SP	*	*
G. spencerii var. curvula (Grun.) Reim.	R	SP	*	*
G. sp.	R	R	*	R
Hantzschia amphioxys (Ehr.) Grun.	R	R	*	R
Hydrosera triquetra Wallace	R	R	*	R
Melosira distans (Ehr.) Kutz.	SP	OP	CP	CP
M. d. var. alpigena Grun.	R	*	*	*
M. granulata (Ehr.) Ralfs	R	R	R	SP
M. g. var. angustissima Mull.	R	R	SP	SP
M. italica (Ehr.) Kutz.	R	R	*	*
M. varians Ag.	CP	CP	SP	MP
M. sp.	R	*	*	R
Meridion circulare (Grev.) Ag.	R	R	*	R
M. c. var. constrictum (Ralfs) V.H.	R	*	*	*
Navicula accomoda Hust.	R	R	*	*
Navicula aikenensis Patr.	MP	OP	*	R
N. arvensis Hust.	R	SP	*	*
N. capitata Ehr.	SP	R	*	*
N. clementis Grun.	*	R	*	*
N. cocconeiformis Greg. ex Grev.	R	*	*	*
N. contenta var. biceps (Arn.) V.H.	R	R	*	*
N. cryptocephala Kutz.	CP	CP	*	R
N. decussis Ostr.	OP	MP	*	R
N. elginensis var. neglecta (Krass.) Patr.	R	R	*	*
N. elmorei Patr.	R	*	*	*
N. exigua Greg. ex Grun.	R	R	*	*
N. e. var. capitata Patr.	R	*	*	*
N. globulifera Hust.	R	*	*	*
N. gottlandica Grun.	*	R	*	*
N. graciloides A. Mayer	R	*	*	*
N. gregaria Donk.	R	*	*	*
N. hustedtii Krass.	R	R	*	*
N. lacustris Greg.	*	R	*	*
N. lanceolata (Ag.) Kutz.	R	R	*	*
N. lateropunctata Wallace	SP	SP	*	*
N. luzonensis Hust.	R	R	*	*
N. menisculus var. upsaliensis (Grun.) Grun.	R	*	*	*
N. minima Grun.	OP	MP	*	*
N. mobiliensis var. minor Patr.	OP	MP	*	*
N. mutica Kutz.	R	R	*	*
N. m. var. stigma Patr.	*	R	*	*
N. m. var. tropica Hust.	SP	CP	*	*
N. m. var. undulata (Hilse.) Grun.	R	SP	*	*
N. notha Wallace	OP	OP	*	*
N. obdurata Hohn and Hellerm.	R	*	*	*
N. odiosa Wallace	*	R	*	*
N. paucivisitata Patr.	SP	SP	*	*
N. pelliculosa (Breb. ex Kutz.) Hilse	R	*	*	*
N. pupula Kutz.	R	SP	*	*
N. p. var. mutata (Krass.) Hust.	R	*	*	*
N. radiosa var. parva Wallace	R	R	*	*
N. r. var. tenella (Breb. ex Kutz.) Grun.	R	R	*	*
N. rhyncocephala Kutz.	SP	SP	*	R
N. r. var. germainii (Wallace) Patr.	MP	CP	*	*
N. salinarum Grun.	R	R	*	*

Taxon	Peri. Artificial Substrates	Peri. Natural Substrates	Phyto. Impoundment	Phyto. River
N. s. var. intermedia (Grun.) Cl.	R	OP	*	*
N. schroeteri var. escambia Patr.	MP	CP	*	*
N. secura Patr.	R	*	*	*
N. seminulum var. hustedtii Patr.	R	SP	*	*
N. ventralis var. chilensis Krass.	R	*	*	*
N. viridula (Kutz.) Kutz.	*	R	*	*
N. v. var. linearis Hust.	R	*	*	*
N. v. var. rostellata (Kutz.) Cl.	R	SP	*	*
N. sp.	MP	CP	OP	MP
Neidium affine (Ehr.) Cl.	*	R	*	*
N. affine var. amphirhynchus (Ehr.) Cl.	R	*	*	*
N. a. var. longiceps (Greg.) Cl.	*	R	*	*
N. alpinum Hust.	*	R	*	*
N. bisulcatum (Lag.) Cl.	R	*	*	*
N. sp.	R	R	R	R
Nitzschia acicularis (Kutz.) W. Smith	SP	SP	SP	SP
N. amphibia Grun.	R	R	*	*
N. clausii Hantz.	*	OP	*	*
N. dissipata (Kutz.) Grun.	OP	CP	*	*
N. filiformis (W. Smith) Schutt	R	*	*	*
N. fonticola (Grun.) Grun.	R	*	*	*
N. frustulum (Kutz.) Grun.	SP	OP	*	*
N. f. var. perpusilla (Rabh.) Grun.	R	R	*	*
N. gracilis Hantz.	R	R	*	*
N. hantzschiana Rabh.	R	*	*	*
N. ignorata Krass.	R	*	*	*
N. kutzingiana Hilse	R	*	*	*
N. linearis (Ag.) W. Smith	R	OP	R	R
N. palea (Kutz.) W. Smith	CP	CP	SP	SP
N. paleacea Grun.	*	R	*	*
N. parvula Lewis	R	SP	*	*
N. romana Grun.	R	*	*	*
N. sublinearis Hust.	R	*	*	*
N. tryblionella Hantz.	R	*	*	R
N. t. var. levidensis (W. Smith) Grun.	*	R	*	*
N. t. var. victoriae Grun.	R	R	*	R
N. sp.	MP	CP	MP	CP
Opephora martyi (Herib.)	*	R	*	*
Pinnularia biceps Greg.	R	SP	R	R
P. borealis Ehr.	R	*	*	*
P. braunii var. amphicephala (A. Mayer) Hust.	R	*	*	*
P. caudata (Boyer) Patr.	R	R	*	*
P. hilseana Jan.	R	*	*	*
P. mesolepta (Ehr.) W. Smith	R	*	*	R
P. m. var. seminuda Cl.-Euler	R	*	*	*
P. microstauron (Ehr.) Cl.	R	*	*	*
P. obscura Krass.	R	R	*	*
P. subcapitata var. paucistriata (Grun.) Cl.	R	R	*	*
P. sublanceolata (B. Peters.) Cl.-Euler	*	*	*	R
P. sp.	SP	MP	R	SP
Rhizosolenia eriensis H. L. Smith	R	*	CP	MP
Rhoicosphenia curvata (Kutz.) Grun.	R	SP	R	R
Rhopalodia gibberula var. vanheurckii O. F. Mull.	R	*	*	*
Skeletonema potamos (Weber) G. Hasle	R	*	SP	SP
Stauroneis anceps Ehr.	R	R	*	*
S. kriegeri Patr.	R	*	*	*
S. phoenicenteron (Nitz.) Ehr.	*	R	*	*
S. smithii Grun.	R	R	*	*
S. sp.	R	R	*	*
Stephanodiscus astraea (Ehr.) Grun.	R	*	*	*
S. a. var. minutula (Kutz.) Grun.	R	R	*	*
S. sp.	R	R	*	*
Surirella angustata Kutz.	OP	MP	R	R
S. linearis W. Smith	*	R	*	*
S. ovata Kutz.	SP	OP	*	R
S. o. var. salina W. Smith	R	*	*	*
S. robusta Ehr.	R	*	*	R
S. tenera Greg.	R	*	*	*
S. sp.	R	R	*	R
Synedra acus Kutz.	*	*	SP	SP
S. delicatissima W. Smith	R	*	R	R
S. fasciculata var. truncata (Grev.) Patr.	SP	SP	*	*
S. filiformis Grun.	*	*	R	*
S. pulchella Ralfs ex Kutz.	OP	SP	*	R
S. rumpens Kutz.	SP	SP	R	R
S. r. var. familiaris (Kutz.) Hust.	SP	R	*	*
S. r. var. fragilariodes Grun.	R	*	*	*
S. r. var. meneghiniana Grun.	OP	OP	*	*
S. r. var. scotica Grun.	R	*	*	*
S. socia Wallace	R	SP	*	R
S. ulna (Nitz.) Ehr.	MP	CP	SP	OP
S. u. var. oxyrhynchus f. mediocontracta (Fort.) Hust.	R	*	*	*
S. u. var. ramesi (Herib.) Hust.	R	SP	*	*
S. sp.	OP	MP	SP	OP
Tabellaria fenestrata (Lyngb.) Kutz.	SP	OP	R	SP
T. flocculosa (Roth.) Kutz.	R	R	R	R

Taxon	Peri. Artificial Substrates	Peri. Natural Substrates	Phyto. Impoundment	Phyto. River
Terpsinoe americanum (Bailey) Ralfs	*	*	*	R
Unidentified Centrate Diatom	*	*	R	R
Unidentified Pennate Diatom	*	*	CP	CP
Division: Chrysophyta				
Class: Chrysophyceae				
Chrysococcus sp.	*	*	*	R
Dinobryon bavaricum Imhof	*	*	*	R
D. sp.	*	*	OP	OP
Kephyrion sp.	R	*	*	*
Mallomonas allantoides Harris	*	*	R	R
M. elongata var. americana Bourrelly	*	*	*	R
M. pseudocoronata Prescott	R	*	*	*
M. sp.	R	*	CP	MP
Pseudokephyrion sp.	*	*	R	R
Synura uvella Ehr.	*	*	R	R
S. sp.	*	*	R	SP
Unidentified Chrysophyte Flagellate	R	*	SP	OP
Division: Chrysophyta				
Class: Haptophyceae				
Chrysochromulina cf. parva	*	*	*	R
C. sp.	*	*	*	R
Division: Chrysophyta				
Class: Xanthophyceae				
Ophiocytium capitatum var. longispinum (Moeb.) Lemm.	*	*	*	R
Division: Cryptophyta				
Class: Cryptophyceae				
Cryptomonas ovata Ehr.	R	*	*	*
C. phaseolus Skuja	R	R	*	*
C. reflexa Skuja	R	*	*	*
C. sp.	R	*	MP	CP
Rhodomonas minuta Skuja	R	*	MP	MP
R. sp.	*	*	*	R
Unidentified Flagellate	R	*	R	R
Division: Cyanophyta				
Class: Myxophyceae				
Agmenellum quadriduplicatum (Meneg.) Breb.	*	*	R	R
A. thermale (Kutz.) Drouet and Daily	*	*	*	R
Anabaena sp.	R	R	OP	OP
Anacystis incerta Drouet and Daily	R	*	*	R
A. thermalis (Meneg.) Drouet and Daily	R	*	*	*
A. sp.	*	*	R	R
Coccochloris aeruginosa (Naeg.) Drouet and Daily	*	*	*	R
C. elabans Drouet and Daily	*	*	R	*
C. stagnina Sprengel	*	*	R	*
Cylindrospermum sp.	R	*	*	R
Gomphosphaeria lacustris Chod.	*	*	R	R
Oscillatoria geminata Meneg.	*	*	SP	R
O. tenuis Ag.	R	*	*	*
O. spp.	OP	OP	OP	OP
Phormidium sp.	*	R	*	R
Raphidiopsis curvata Fritsch and Rich	*	*	*	R
Spirulina sp.	R	*	*	R
Unidentified Blue-Green	R	*	*	R
Division: Euglenophyta				
Class: Euglenophyceae				
Euglena sp.	R	*	OP	SP
Lepocinclis sp.	*	*	*	R
Phacus sp.	*	*	SP	R
Trachelomonas sp.	R	*	SP	R
Division: Pyrrophyta				
Class: Dinophyceae				
Glenodinium sp.	*	*	R	R
Gymnodinium sp.	*	*	*	R
Peridinium pusillum (Pen.) Lemm.	R	*	SP	SP

NOTE:
* indicates not present
R indicates rare (1-20% frequency)
SP indicates seldom present (21-40% frequency)
OP indicates often present (41-60% frequency)
MP indicates mostly present (61-80% frequency)
CP indicates constantly present (80-100% frequency)

Table 3-3. Rank of class density and biovolume, based on an index of dominance, for periphyton at mainstream and backwater stations in the Broad River and Ninety-Nine Islands Impoundment, S. C. from 21 November 1974 through 4 December 1975.

		MONTHLY DOMINANCE RANK															
		1974		1975											Annual Dominance Index	Annual Rank	Average Percent Composition
	Main Stream Stations	21 Nov	5 Dec	16 Jan	13 Feb	24 Apr	8 May	5 Jun	3 Jul	31 Jul	28 Aug	29 Sep	24 Oct	4 Dec			
DENSITY INDEX	Bacillariophyceae	1	1	1	1	1	1	1	1	1	1	1	1	1	7459.7	1	94.8
	Chlorophyceae	3	2	2	2	2	2	3	3	3	3	2	2	2	34.7	2	3.9
	Myxophyceae	2	3	3			3	2	2	2	2	3	3	3	6.9	3	1.2
	Cryptophyceae			5			4	4	4	4	4	4		4	<0.1	4	0.1
	Euglenophyceae			4								6			<0.1	5	<0.1
	Chrysophyceae								5			5	4	5	<0.1	6	<0.1
BIOVOLUME INDEX	Bacillariophyceae	1	1	1	1	1	1	1	1	1	1	1	1	1	8132.3	1	98.0
	Chlorophyceae	2	2	3	2	2	2	2	2	2	2	2	2	2	1.6	2	0.8
	Myxophyceae	3	3	4			3	3	3	3	3	3	3	3	0.1	3	0.2
	Cryptophyceae			5			4	4	5	4	4	5		4	<0.1	4	<0.1
	Euglenophyceae			2								4			<0.1	5	<0.1
	Chrysophyceae								4			6	4	5	<0.1	6	<0.1
	Station 462.0																
DENSITY INDEX	Bacillariophyceae	2	2	2	1	*	1	1	1	1	1	1	1	1	3306.2	1	77.0
	Chlorophyceae	1	1	1	2	*	2	2	2	2	2	2	2	2	816.8	2	21.9
	Myxophyceae	3	3		3	*	3		3	3		3	3	3	2.0	3	1.1
	Cryptophyceae	4	4	3		*		3		4	1	4	4		<0.1	4	<0.1
BIOVOLUME INDEX	Bacillariophyceae	1	2	1	2	*	1	1	1	1	2	1	1	1	2927.5	1	71.2
	Chlorophyceae	2	1	2	1	*	2	2	2	2	1	2	2	3	635.7	2	28.2
	Myxophyceae	3	3		3	*	3		3	3		3	3	2	0.1	3	0.6
	Cryptophyceae	4	4	3		*		3		4		4	4		<0.1	4	<0.1

* Sampler Missing

Table 3-4. Average percent class composition by season* and by year of periphyton natural substrate samples collected in the Broad River, S. C. from 7 November 1974 through 4 December 1975. (Number of samples is in parentheses).

Relative Abundance	Winter (8)	Spring (4)	Summer (5)	Fall (3)	Annual Percent Composition (20)
Bacillariophyceae	86.4	85.2	70.3	57.6	77.8
Myxophyceae	13.3	0.0	28.9	41.6	18.8
Chlorophyceae	<0.1	14.6	0.7	0.7	3.3
Cryptophyceae	<0.1	0.0	0.0	0.0	<0.1
Relative Biovolume					
Bacillariophyceae	90.5	95.8	82.8	83.2	88.8
Myxophyceae	8.5	0.0	15.9	15.5	9.7
Chlorophyceae	<0.1	4.1	1.3	1.1	1.3
Cryptophyceae	<0.1	0.0	0.0	0.0	<0.1

* Winter = December, January and February
Spring = March, April and May
Summer = June, July and August
Fall = September, October and November

PERIPHYTON VARIATIONS

Standing Crop

Total periphyton biovolumes and densities for all stations during monthly sampling are presented in Table 3-5. Biovolumes are generally considered better estimates of algal standing crop than densities due to the extreme variation in cell size of individual species (Vollenweider 1974). Cell size of periphytic algal species collected during the study ranged from 11 μm^3 (*Navicula arvensis*) to approximately 220,000 μm^3 (*Biddulphia laevis*). The weights of organic matter or ash-free dry weights (presented in Table 3-6), while at times subject to error in interpretation due to the inclusion of non-algal matter, are also used as a measure of algal standing crop.

Total periphyton biovolumes were generally uniform among stations. The few exceptions occurred among mainstream stations (Table 3-7a and 3-7b). For example the significantly higher biovolume observed at Station 464.1 on 31 July 1975 was due to a high population of *Hydrosera triquetra*, a large filamentous centric diatom (mean cell size 150,000 μm^3). Total periphyton biovolumes at the backwater station were not significantly different from those in mainstream stations any month of the study (Table 3-7a and 3-7b). The yearly mean of total periphyton biovolume at the backwater was 959 mm^3/m^2 compared to 941 mm^3/m^2 at mainstream stations (excluding 24 April 1975 when samples were missing at the backwater). Ash-free dry weights of periphyton assemblages at the backwater were significantly higher than those of mainstream stations ($t = 10.9$, $X^2(0.05)_3 = 7.82$) with stations on opposite sides of the river combined for this analysis. However, ash-free dry weight values were positively influenced, at times, by non-algal matter, principally benthic macroinvertebrates and detritus. As an index of the relative amount of non-algal material present on the slides, the ratios of ash-free dry weights to algal biovolume are presented in Figure 3-2. Large peaks in the ash-free dry weight to biovolume ratio (e.g., 28 August 1975 in backwater) suggest that material other than algae accounted for a large portion of the measured organic weight. Observation of samples from the backwater on 24 August 1975 confirmed the presence of large numbers of chironomid larvae colonizing the slide. In addition, the higher abundance of green algae in periphyton communities in the backwater may also have increased the ash-free dry weight to biovolume ratio. Communities of periphyton consisting mainly of filamentous green algae contain a higher percentage of organic matter in the biomass (~60%) compared to communities composed almost entirely of diatoms (~30-35%) (McIntire 1966). In toto, factors other than an increase in algal biomass probably account for differences in ash-free dry weight values observed between backwater and mainstream stations.

Seasonal patterns of periphyton standing crop in the Broad River and Ninety-Nine Islands Impoundment were not clearly defined (Fig. 3-3 and 3-4). Total periphyton biovolumes at the backwater remained relatively constant throughout the year with the maximum occurring on 4 December 1975 (2840 mm^3/m^2). Biovolumes of total periphyton at mainstream stations

Table 3-5. Total periphytic algal densities (X 10^6 units/m^2) and biovolumes (mm^3/m^2) collected from stations in the Broad River and Ninety-Nine Islands Impoundment, S. C. from 21 November 1974 through 4 December 1975.

ALGAL DENSITIES		MAINSTREAM STATIONS							BACKWATER
Date	Exposure Period (days)	452.1	452.2	453.1	453.2	464.1	464.2	Monthly Mean	462.0
21 Nov 74	29	3100	1780	372	1290	2810	1620	1829	2190
5 Dec 74	28	379	89	85	351	180	739	373	1460
16 Jan 75	28	2270	735	*	1390	184	1144	1144	913
13 Feb 75	28	1230	796	1910	*	1450	*	1347	2730
24 Apr 75	27	*	798	*	*	3020	*	1909	*
8 May 75	28	782	667	512	1250	562	323	683	10400
5 Jun 75	28	3360	561	249	958	48	64	873	8110
3 Jul 75	28	*	479	1940	3000	1040	748	1829	5550
31 Jul 75	28	1710	230	588	539	571	1080	786	5060
28 Aug 75	28	2320	249	649	569	*	1900	1137	3410
29 Sep 75	32	2280	366	3550	2170	2980	3200	2424	6200
24 Oct 75	27	4020	*	1780	1450	856	1790	1979	3310
4 Dec 75	28	2250	1070	2190	1390	*	1100	1600	2400
Mean by station		2155	652	1257	1305	1246	1246	1378	4311
ALGAL BIOVOLUME									
21 Nov 74	29	2380	1610	450	746	3440	2740	1894	1470
5 Dec 74	28	209	68	57	170	132	921	360	1120
16 Jan 75	28	1070	49	*	484	79	440	424	761
13 Feb 75	28	514	285	462	*	419	*	420	1050
24 Apr 75	27	*	1610	*	*	6950	*	4280	*
8 May 75	28	952	488	358	262	314	331	451	740
5 Jun 75	28	436	200	50	267	15	31	166	799
3 Jul 75	28	*	260	1110	815	276	721	636	662
31 Jul 75	28	371	96	643	253	288	5350	1166	590
28 Aug 75	28	1130	169	579	186	*	998	612	424
29 Sep 75	32	1380	142	1860	1010	1480	1570	1240	522
24 Oct 75	27	3050	*	1260	797	455	1100	1332	531
4 Dec 75	28	2400	1830	5310	2750	*	665	2591	2840
Mean by station		1263	567	1104	704	1259	1352	1190	959

* Sampler missing

Table 3-6. Periphyton organic accumulation rates (mg/m^2/day) and in parentheses ash-free dry weights (g/m^2) for stations in the Broad River and Ninety-Nine Islands Impoundment, S. C. from 21 November 1974 through 4 December 1975.

		MAINSTREAM STATIONS														BACKWATER	
Date	Exposure Period (days)	452.1		452.2		453.1		453.2		464.1		464.2		Monthly Mean		462.0	
21 Nov 74	29	96.7	(2.71)	110.9	(3.22)	192.5	(5.58)	145.0	(4.20)	250.9	(7.28)	111.0	(3.22)	151.2	(4.37)	320.6	(9.30)
5 Dec 74	28	16.7	(0.47)	13.3	(0.37)	16.7	(0.47)	10.5	(0.30)	*	(*)	233.4	(6.54)	58.1	(1.63)	232.5	(5.29)
19 Dec 74	28	*	(*)	*	(*)	9.4	(0.26)	*	(*)	18.1	(0.51)	102.0	(2.86)	43.2	(0.95)	109.3	(3.06)
16 Jan 75	28	38.5	(1.08)	27.3	(0.77)	*	(*)	22.4	(0.63)	11.9	(0.33)	69.5	(1.95)	33.9	(1.19)	66.8	(1.87)
30 Jan 75	28	20.7	(0.58)	32.8	(0.92)	*	(*)	*	(*)	13.1	(0.37)	120.8	(3.38)	46.8	(1.31)	55.6	(1.56)
13 Feb 75	28	43.4	(1.21)	11.9	(0.33)	106.6	(2.98)	*	(*)	*	(*)	22.3	(0.62)	46.1	(1.29)	104.8	(2.93)
28 Feb 75	28	111.2	(3.32)	35.2	(1.02)	*	(*)	22.6	(0.66)	44.1	(1.28)	*	(*)	53.3	(1.57)	165.3	(4.79)
24 Apr 75	27	92.0	(2.58)	*	(*)	*	(*)	*	(*)	467.5	(12.62)	93.4	(2.62)	217.6	(5.94)	*	*
8 May 75	28	72.4	(2.03)	68.4	(1.91)	57.9	(1.62)	35.3	(0.99)	57.1	(1.60)	18.0	(0.50)	51.5	(1.44)	65.3	(1.83)
5 Jun 75	28	74.8	(2.09)	84.0	(2.35)	143.0	(4.00)	148.0	(4.14)	97.4	(2.73)	78.5	(2.20)	104.3	(2.92)	139.5	(3.91)
3 Jul 75	28	*	(*)	47.4	(1.33)	216.5	(6.06)	94.9	(2.66)	124.4	(3.48)	174.0	(4.87)	131.4	(3.68)	262.5	(7.35)
31 Jul 75	28	97.5	(2.73)	33.6	(0.94)	47.6	(1.33)	71.9	(2.01)	23.6	(0.66)	64.4	(1.80)	56.5	(1.58)	187.1	(5.24)
28 Aug 75	28	83.6	(2.34)	223.6	(6.26)	33.1	(0.93)	152.5	(4.27)	*	(*)	116.6	(3.26)	121.9	(3.41)	291.5	(8.16)
29 Sep 75	32	90.1	(2.88)	89.2	(2.85)	150.6	(4.82)	86.2	(2.76)	92.3	(2.95)	48.7	(1.56)	92.9	(2.97)	168.8	(5.40)
24 Oct 75	27	112.9	(3.05)	*	(*)	77.7	(2.09)	142.8	(3.86)	39.3	(1.06)	28.8	(0.78)	80.1	(2.17)	134.7	(3.64)
6 Nov 75	28	*	(*)	33.8	(0.95)	257.4	(7.21)	179.2	(5.02)	348.2	(9.75)	22.4	(0.63)	208.2	(4.71)	118.3	(3.31)
4 Dec 75	28	131.3	(3.68)	46.7	(1.31)	296.9	(8.31)	87.4	(2.45)	*	(*)	17.6	(0.49)	116.0	(3.25)	85.5	(2.39)
Mean by station		77.3	(2.20)	61.3	(1.75)	123.5	(3.50)	92.2	(2.61)	93.4	(2.67)	82.6	(2.33)	87.5	(2.41)	175.0	(4.86)

* Sampler missing

Table 3-7a. Results of a two-way ANOVA of total periphyton densities and biovolumes by month for stations in the Broad River and Ninety-Nine Islands Impoundment, S. C. from 21 November 1974 through 4 December 1975.

Densities

Source	DF	Sum of Squares	F
Station	6	1.66×10^{11}	84.01**
Month	10	7.92×10^{10}	24.02**
Interaction	47	3.87×10^{11}	25.01**
Error	50	1.65×10^{10}	

**p<0.01

Biovolumes

Source	DF	Sum of Squares	F
Station	6	1.22×10^{16}	31.38**
Month	10	1.69×10^{15}	2.62*
Interaction	47	7.72×10^{15}	2.54**
Error	50	3.23×10^{15}	

*p<0.05
**p<0.01

Table 3-7b. Results of Duncan's multiple range test of total periphyton densities and biovolumes for months with significant simple main effects for stations in the Broad River and Ninety-Nine Islands Impoundment, S. C. (Means not connected by horizontal lines are significantly different).

Month								
		DENSITIES						
May	Station	462.0	453.2	452.1	452.2	464.1	453.1	464.2
	Mean	1.04×10^6	1.25×10^5	7.83×10^4	6.67×10^4	5.63×10^4	5.12×10^4	3.24×10^4
June	Station	462.0	452.1	453.2	452.2	453.1	464.2	464.1
	Mean	8.12×10^5	3.36×10^5	9.59×10^4	5.62×10^4	2.50×10^4	6.46×10^3	4.80×10^3
July	Station	462.0	452.1	464.2	453.1	453.2	464.1	452.2
	Mean	5.11×10^5	1.71×10^5	1.13×10^5	6.52×10^4	5.78×10^4	5.74×10^4	2.35×10^4
August	Station	462.0	452.1	464.2	453.1	453.2	452.2	
	Mean	3.42×10^5	2.32×10^5	8.32×10^4	6.50×10^4	5.69×10^4	2.50×10^4	
September	Station	462.0	453.1	464.2	464.1	452.1	453.2	452.2
	Mean	6.20×10^5	3.55×10^5	3.20×10^5	2.98×10^5	2.28×10^5	2.17×10^5	3.66×10^4
October	Station	452.1	462.0	464.2	453.1	453.2	464.1	
	Mean	4.03×10^5	3.31×10^5	1.79×10^5	1.78×10^5	1.45×10^5	8.57×10^4	
		BIOVOLUMES						
July	Station	464.2	462.0	453.1	452.1	464.1	453.2	452.2
	Mean	32.0×10^7	6.41×10^7	4.91×10^7	3.72×10^7	2.76×10^7	2.13×10^7	1.02×10^7
October	Station	452.1	453.1	464.2	453.2	462.0	464.1	
	Mean	3.08×10^8	1.28×10^8	1.10×10^8	7.99×10^7	5.33×10^7	4.56×10^7	
December	Station	453.1	462.0	453.2	452.1	452.2	464.2	464.1
	Mean	2.89×10^8	2.05×10^8	1.75×10^8	1.35×10^8	1.07×10^8	7.84×10^7	1.32×10^7

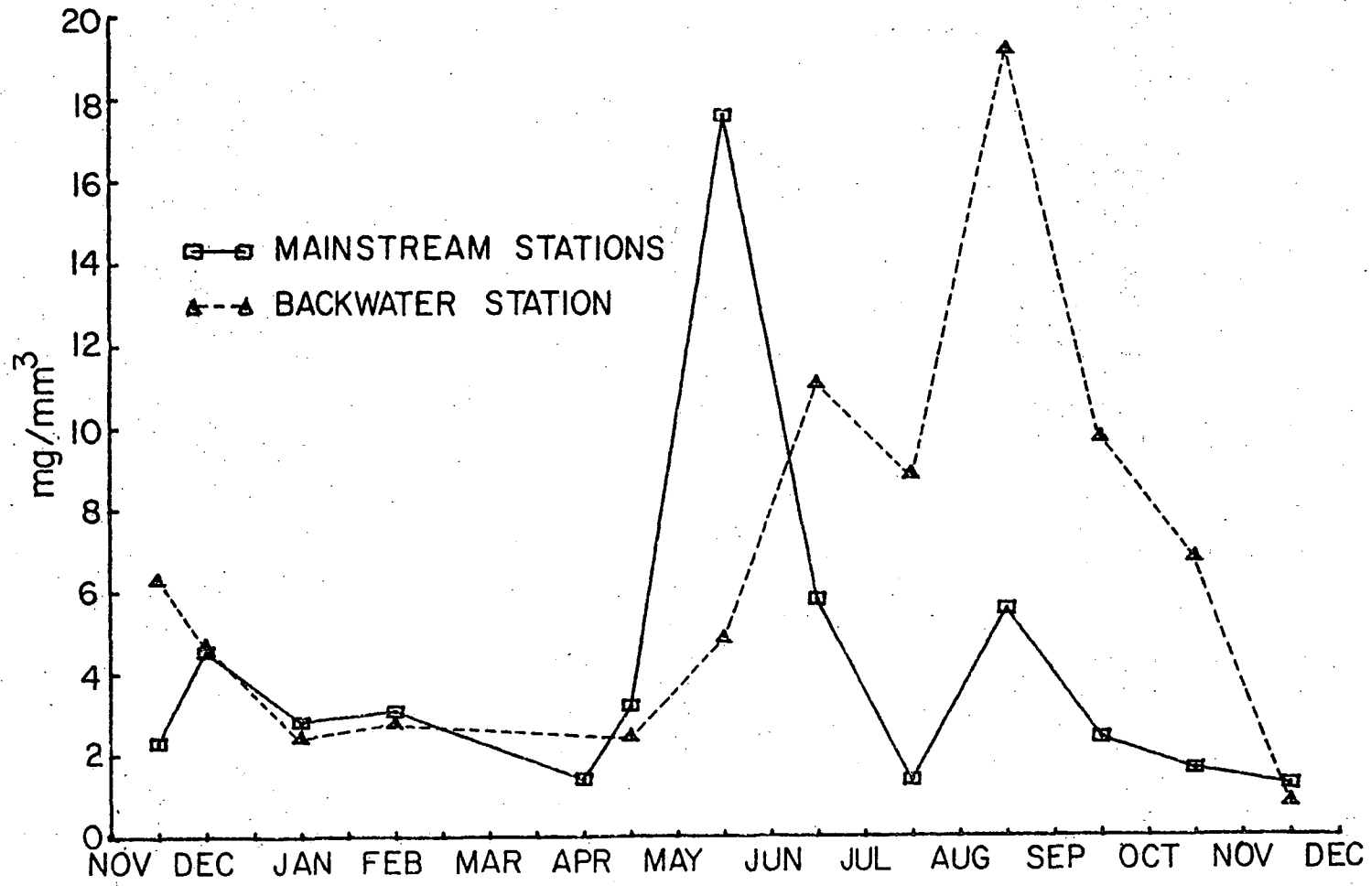


Figure 3-2. Ash-free dry weight to biovolume ratios of periphyton collected at stations in the Broad River and Ninety-Nine Islands Impoundment, S. C. from 21 November 1974 through 4 December 1975.

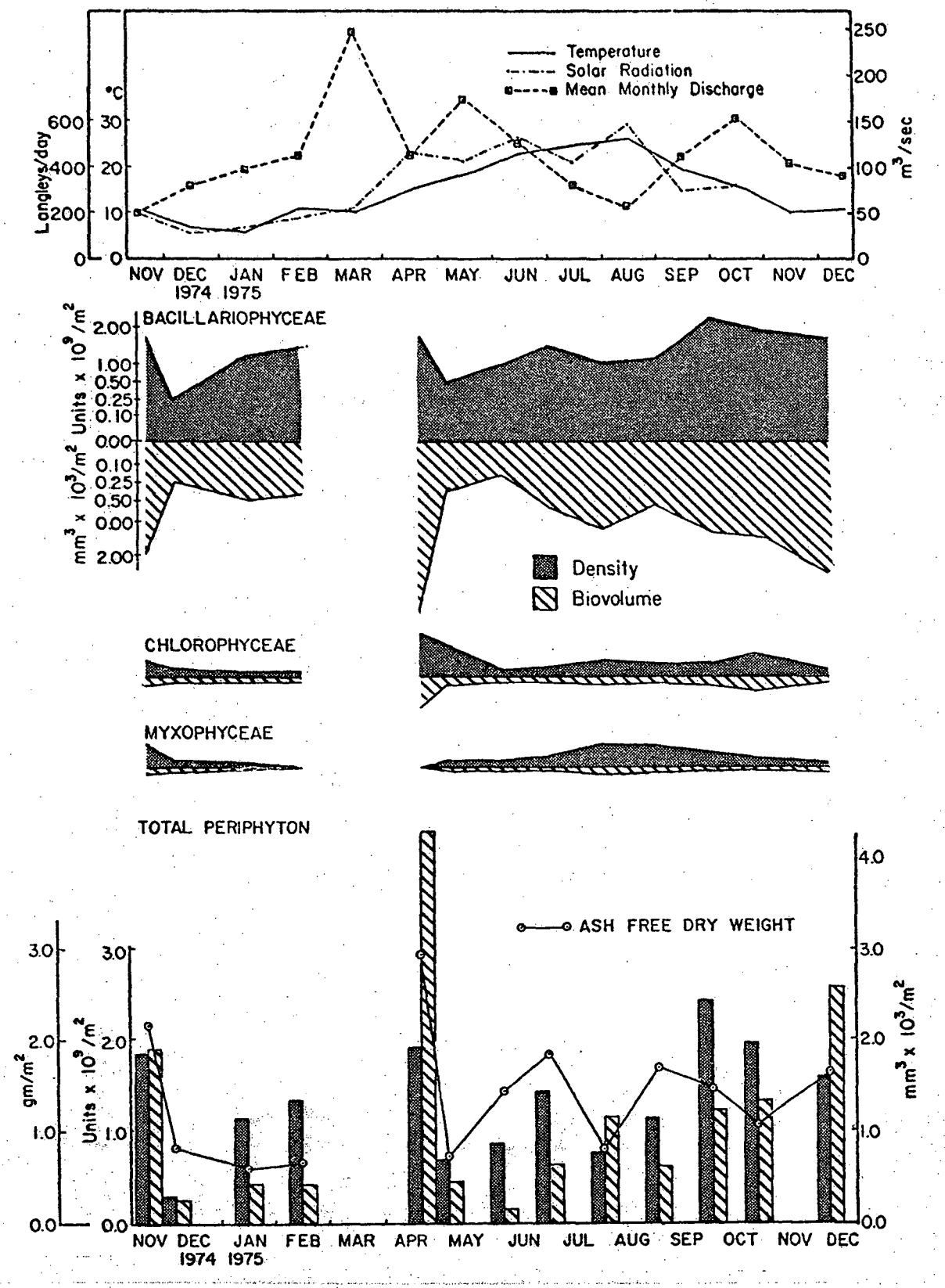


Figure 3-3. Comparisons of mean values of total periphyton densities and biovolumes, class densities and biovolumes, water temperature, solar radiation and discharge at mainstream stations in the Broad River, S. C. from 21 November 1974 through 4 December 1975.

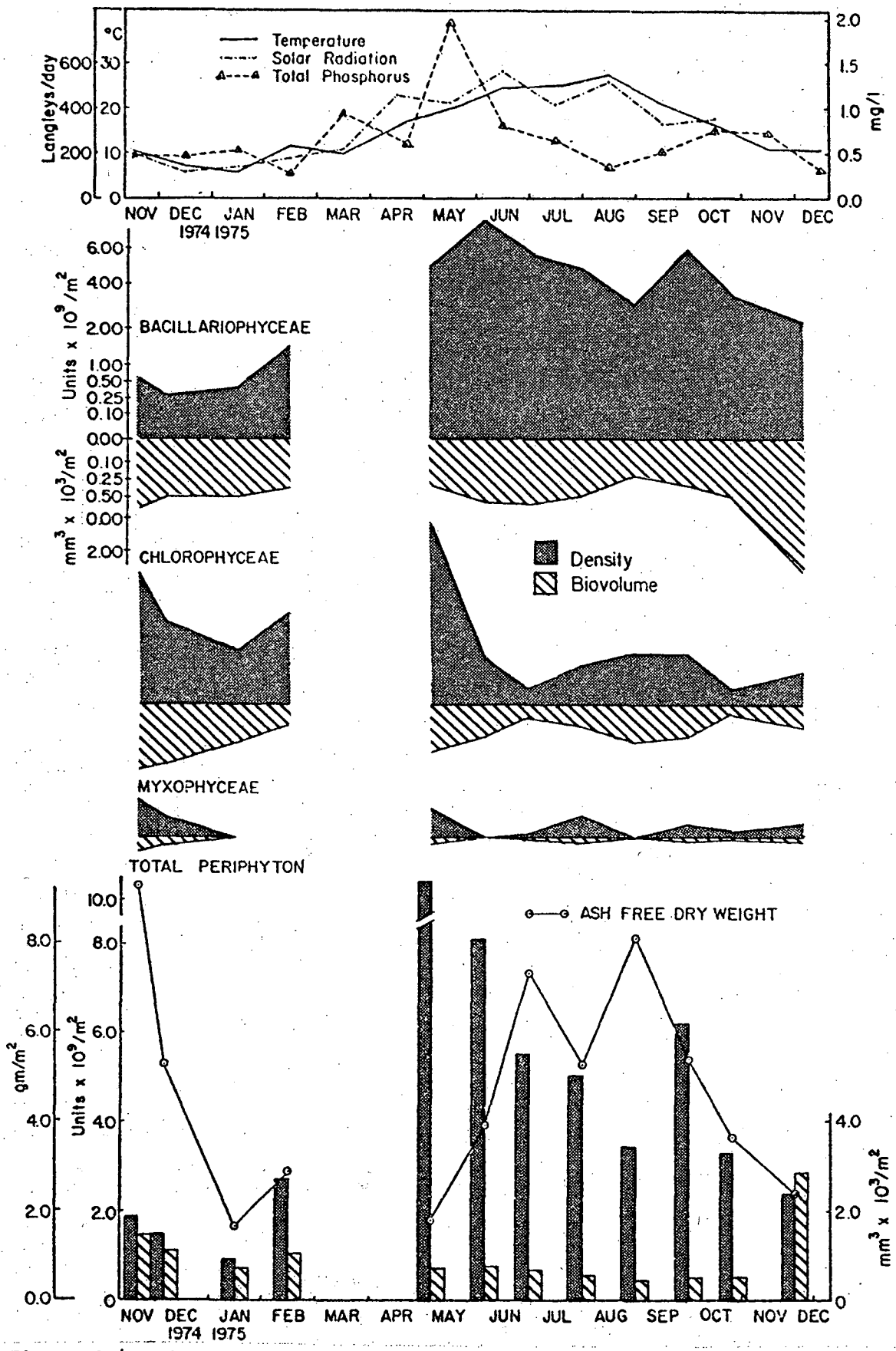


Figure 3-4. Comparisons of total periphyton densities and biovolumes, class densities and biovolumes, water temperature, solar radiation and total phosphorus at Station 462.0 (backwater) in the Broad River, S. C. from 21 November 1974 through 4 December 1975.

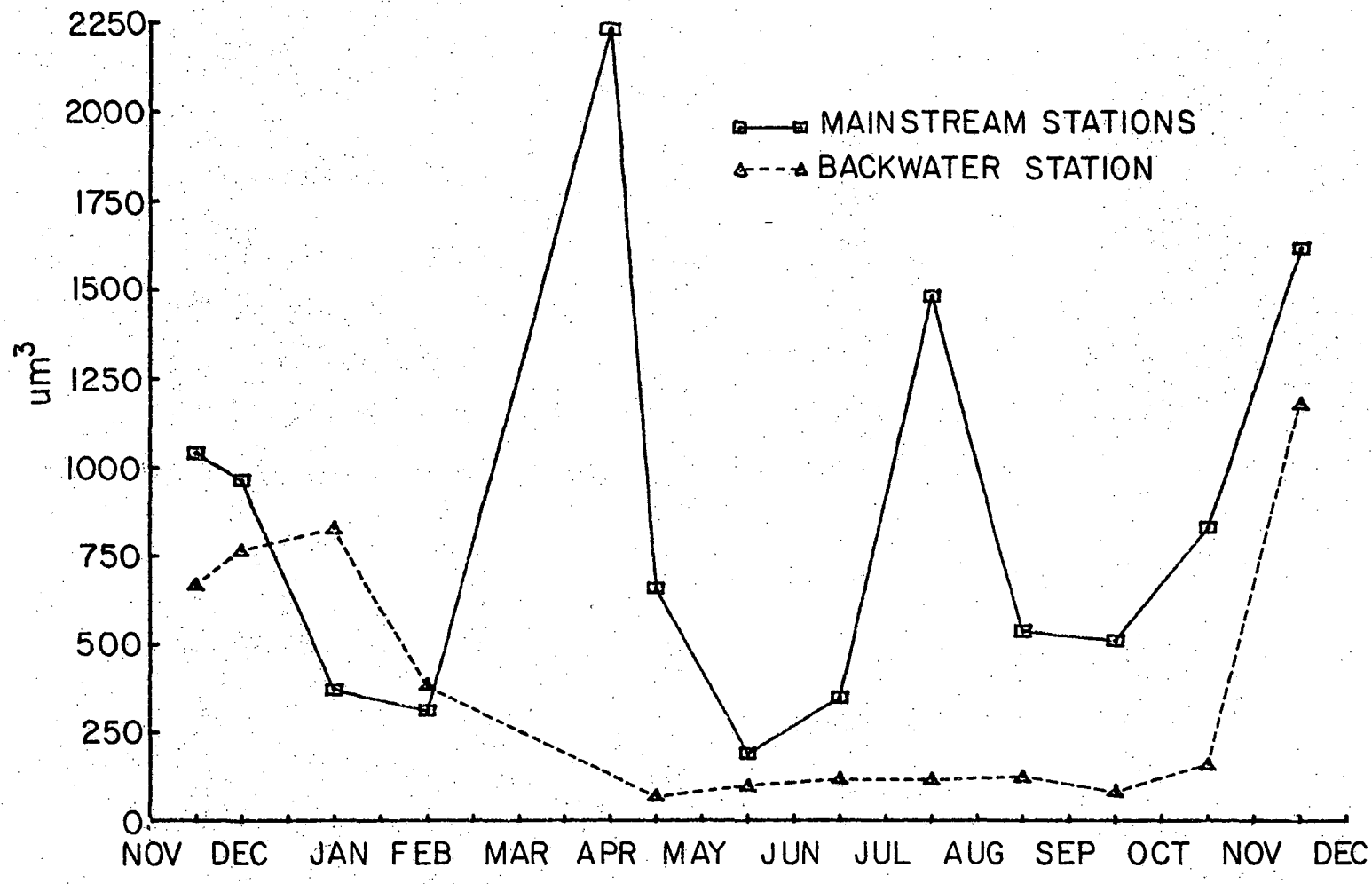


Figure 3-5. Mean cell size of periphyton collected at stations in the Broad River and Ninety-Nine Islands Impoundment, S. C. from 21 November 1974 through 4 December 1975.

exhibited a weak bimodal trend with maxima in spring and fall. Since the periphyton communities at mainstream stations were composed almost exclusively of diatoms and most species of diatoms grow best at temperatures between 15 and 20C (Whitford and Schumacher 1963), spring and fall represent the most favorable seasons for their growth in the Broad River. Light conditions were also favorable during these times. A bimodal pattern of periphyton abundance is typical for periphyton communities in rivers comprised largely of diatoms (Fischer and Sumner 1976; Lawson et al. 1978). Scouring due to high discharge appeared to periodically decrease periphyton abundance at mainstream stations. The extremely low biovolumes observed at mainstream stations on 5 June 1975 (166 mm^3/m^2) were probably related to a sudden increase in discharge a few days prior to sample pickup (Fig. 3-3). Scouring due to increases in discharge, has been shown to reduce periphyton populations in rivers (Starrett and Patrick 1952). Ash-free dry weights at mainstream stations were also low during winter although values observed during other seasons did not correspond well with total periphyton biovolume (Fig. 3-3 and 3-4).

In contrast to standing crops of periphyton which showed no consistent variation between the backwater and mainstream stations, the composition of the periphyton communities differed between the two systems, probably due to the effects of current. Communities of periphyton at stations in the mainstream were constantly subject to current velocities ranging from 0.36 m/sec to 1.26 m/sec. while communities at backwater were exposed to no measurable current (App. 3-1) and developed communities more typical of lakes than rivers. The effects of current velocity on the structure of periphyton communities are well-documented (Hynes 1970; McIntire 1968). Total periphyton densities at the backwater were significantly higher than mainstream stations from May through October (Table 3-7a and 3-7b). The mean total density at the backwater during this period (6006 X 10^6 units/m^2) was nearly 5 times that of mainstream stations (1332 X 10^6 units/m^2). A comparison of mean cell size between backwater and mainstream stations shows that periphyton communities at backwater during summer were made up of small-sized individuals (Fig. 3-5). Achnanthes minutissima, a small (mean cell size 57 μm^3) lentic diatom comprised 81% of total periphyton densities from May through October at the backwater. Green algal densities and biovolumes were significantly higher at the backwater station during November, December, January and February (Table 3-8a and 3-8b). This was also due largely to one taxon, Stigeoclonium sp. (mean cell size 521 μm^3) which is described as a cool water genus in North Carolina streams (Whitford and Schumacher 1963). Similar findings of greater abundance of Stigeoclonium sp. in periphyton communities in slow current have been reported by McIntire (1966). Temperature showed a positive correlation ($r = 0.64$) with total periphyton densities in the backwater (due largely to high populations of Achnanthes minutissima during summer) and a negative correlation ($r = -0.49$) with total periphyton biovolumes (due largely to high populations of Stigeoclonium sp. during winter). The lack of current in the backwater, then apparently acts to cause changes in periphyton species composition towards more typically lentic forms while temperature and presumably light determine the seasonal abundance of these forms.

Table 3-8a. Results of a two-way ANOVA of green algal (Chlorophyceae) densities and biovolumes by month for stations in the Broad River and Ninety-Nine Islands Impoundment, S. C. from 21 November through 4 December 1975.

Densities

Source	DF	Sum of Squares	F
Station	6	6.55×10^{10}	56.32**
Month	10	1.54×10^{10}	7.97**
Interaction	35	4.63×10^{10}	6.83**
Error	43	8.33×10^{9}	

**p<0.01

Biovolumes

Source	DF	Sum of Squares	F
Station	6	1.03×10^{16}	35.94**
Month	10	1.93×10^{15}	4.04**
Interaction	35	6.41×10^{15}	3.82**
Error	43	2.06×10^{15}	

**p<0.01

Table 3-8b. Results of Duncan's multiple range test of green algal (Chlorophyceae) densities and biovolumes for months with significant simple main effects for stations in the Broad River and Ninety-Nine Islands Impoundment, S. C. (Means not connected by horizontal lines are significantly different).

Month		DENSITIES						
January	Station	462.0	452.2	464.1	452.1			
	Mean	4.79×10^{4}	1.06×10^{3}	8.46×10^{2}	4.23×10^{2}			
February	Station	462.0	452.2	452.1				
	Mean	1.31×10^{5}	2.12×10^{3}	4.23×10^{2}				
May	Station	462.0	453.2	452.1	464.1	452.2	464.2	453.1
	Mean	1.68×10^{5}	8.51×10^{4}	3.60×10^{3}	3.39×10^{3}	2.12×10^{3}	1.48×10^{3}	1.27×10^{3}
August	Station	462.0	453.1	453.2	452.1	464.2		
	Mean	4.26×10^{4}	1.21×10^{4}	2.33×10^{3}	1.27×10^{3}	4.23×10^{2}		
September	Station	462.0	453.1	452.2	453.2	452.1		
	Mean	4.23×10^{4}	9.53×10^{3}	4.66×10^{3}	1.06×10^{3}	8.47×10^{2}		
November	Station	462.0	453.1	464.2	452.1	453.2	464.1	
	Mean	1.38×10^{5}	6.35×10^{3}	4.23×10^{3}	3.39×10^{3}	2.12×10^{3}	1.69×10^{3}	
December	Station	462.0	453.2	453.1	452.1	452.2		
	Mean	7.32×10^{4}	6.99×10^{3}	8.47×10^{2}	8.47×10^{2}	8.47×10^{2}		
		BIOVOLUMES						
January	Station	462.0	452.2	464.1	452.1			
	Mean	2.34×10^{7}	5.51×10^{5}	3.40×10^{5}	2.21×10^{5}			
February	Station	462.0	452.2	452.1				
	Mean	6.74×10^{7}	1.10×10^{6}	1.78×10^{4}				
August	Station	462.0	453.1	453.2	452.1	464.2		
	Mean	2.19×10^{7}	2.42×10^{6}	1.12×10^{6}	6.62×10^{5}	4.23×10^{4}		
November	Station	462.0	464.2	452.1	453.1	453.2	464.1	
	Mean	6.86×10^{7}	2.21×10^{6}	1.76×10^{6}	1.33×10^{6}	9.25×10^{5}	8.82×10^{5}	
December	Station	462.0	453.2	453.1	452.1	452.2		
	Mean	3.71×10^{7}	3.64×10^{6}	4.41×10^{5}	4.41×10^{5}	2.63×10^{4}		

Nutrients played only a minor role in the abundance of periphyton during the study. Significant positive correlations were noted between total periphyton densities and total phosphorus ($r = 0.78$) and orthophosphate ($r = 0.47$) at the backwater. However, concentrations of total phosphorus were nearly always above the EPA recommended levels for preventing nuisance algal blooms (0.5 mg/l) and since no similar correlations were noted with total periphyton biovolumes (App. 3-6) it is unlikely that nutrients were limiting to periphyton in the backwater.

Blue-green algae, predominantly Oscillatoria spp., reached their greatest abundance at mainstream stations during summer (Fig. 3-3), a period of high temperatures and stable flow. No significant differences in blue-green algae densities or biovolume were found among stations (App. 3-4).

The grand mean of periphyton ash-free dry weights at mainstream stations in the Broad River was very similar to that study on the Yadkin River, N. C. (2.4 g/m^2 and 2.7 g/m^2, respectively). In contrast, the grand mean of total periphyton densities in the Yadkin River (2723×10^6 units/m^2) was almost twice as high as the Broad River (1378×10^6 units/m^2). This discrepancy is unexplained. However, mean total densities of periphyton during quarterly sampling in the Broad River (3458×10^6 units/m^2) were also higher than during monthly sampling possibly indicating that periphyton densities at mainstream stations were atypically low during 1974-75.

Species Composition

The dominant species at the backwater and mainstream stations are presented in Table 3-9. Throughout the study, periphyton communities in the mainstream exhibited more diversity with respect to species dominance (9 species) compared to the backwater (3 species). With the exception of Stigeoclonium sp., which was especially abundant in the backwater, all of the top ranked species were diatoms. Of the top ten ranked species in terms of numerical abundance, seven were the same as those found in a similar index on the Yadkin River (Lawson et al. 1978).

Differences in species composition between the backwater and mainstream stations were due to the effects of current. Ordination by principle components (Fig. 3-6) indicates that the high densities of the two numerically dominant species in backwater (Achnanthes minutissima and Stigeoclonium sp.) developed in response to a lack of current. Both of these species loaded high on PC1 which had a significant negative correlation with current velocity ($r = -0.58$). With the exception of Melosira varians, a ubiquitous and cosmopolitan species characterized as indifferent to current (Lowe 1974), the dominant species at mainstream stations consisted almost exclusively of rheophilous forms: Achnanthes lanceolata, Cocconeis placentula, Gomphonema parvulum, G. angustatum and Navicula cryptocephala (McIntire 1968). Species composition at the backwater resembled that in the mainstream only during periods when temperatures were less than 15 C (Fig. 3-7)

Table 3-9. Rank of dominant species densities and biovolumes, based on an index of dominance, for periphyton at stations in the Broad River and Ninety-Nine Islands Impoundment, S. C. from 21 November 1974 through 4 December 1975.

	Taxon	MONTHLY DOMINANCE RANK 1974 21 Nov	5 Dec	1975 16 Jan	13 Feb	24 Apr	8 May	5 Jun	3 Jul	31 Jul	28 Aug	29 Sep	24 Oct	4 Dec	Annual Dominance Index	Annual Rank
	Mainstream Stations															
DENSITY INDEX	Achnanthes lanceolata	13	3	2	4	5	3	2	1	1	3	2	1	14	2089.0	1
	Cocconeis placentula var. lineata	5	15	3			15	5	11	2	1	1	2	15	1829.6	2
	Achnanthes deflexa		2	5	6	4	2	1	3	3	6	13	5	5	1062.3	3
	Gomphonema parvulum	6	4	7	7	3	4	3	2	12	15	8	3	1	440.0	4
	Navicula cryptocephala	1	1	4	8	6	5	10	7	16	13		13	4	358.5	5
	Melosira varians	4	6	12		1	6		5	7	14			2	95.3	6
	Gomphonema angustatum		8	1	10	12	20					11		3	80.1	7
	Stigeoclonium spp.	19	7	17	11	2	21	6	14	6	7	10	4		38.6	8
	Navicula arvensis			10	1	10		11							22.5	9
	Achnanthes minutissima	14	10	8	7	7	7	4	4	4	9	7	9	13	19.5	10
BIOVOLUME INDEX	Melosira varians	1	1	1	2	1	1	6	1	2	2	2	1	1	4270.8	1
	Cocconeis placentula var. lineata	6	11	10			10	4	10	3	1	1	2	7	1265.5	2
	Achnanthes lanceolata	4	10	3	4		2	1	2	4	5	3	4		246.4	3
	Cymbella tumida	2	2	5	8		6	9	4	13	6	7	9	2	104.1	4
	Hydrosera triquetra									1	3		7		83.8	5
	Gomphonema angustatum		8	2	1								12	5	54.9	6
	Gomphonema parvulum	15	6	9	7		7	3	3			8	6	4	47.4	7
	Achnanthes deflexa						5	2	7	9					16.9	8
	Synedra ulna	3	9	4	6	3	3		11				5	3	11.5	9
	Stigeoclonium spp.		4	15	11	2		8	12	6	8	9	8		2.2	10
	Station 462.0															
DENSITY INDEX	Achnanthes minutissima	2		3		*	1	1	1	1	1	1	1	1	1202.0	1
	Stigeoclonium spp.	1	1	1	1	*		3		2	2	2			758.5	2
	Gomphonema parvulum	4	9	8	3	*								4	3.7	3
	Melosira varians	6	5	4		*								3	1.5	4
	Navicula arvensis				2	*									0.5	5
BIOVOLUME INDEX	Stigeoclonium spp.	1	1	2	1	*	5	2	4	3	1	2		4	660.2	1
	Achnanthes minutissima					*	1	1	1	1	2	1	2	5	343.1	2
	Melosira varians	2	2	1	2	*							1	1	155.3	3
	Cymbella tumida	3	3	3		*		3	2				3		18.4	4
	Synedra ulna	4			5	*			3	2	3			3	17.0	5

* Sampler Missing

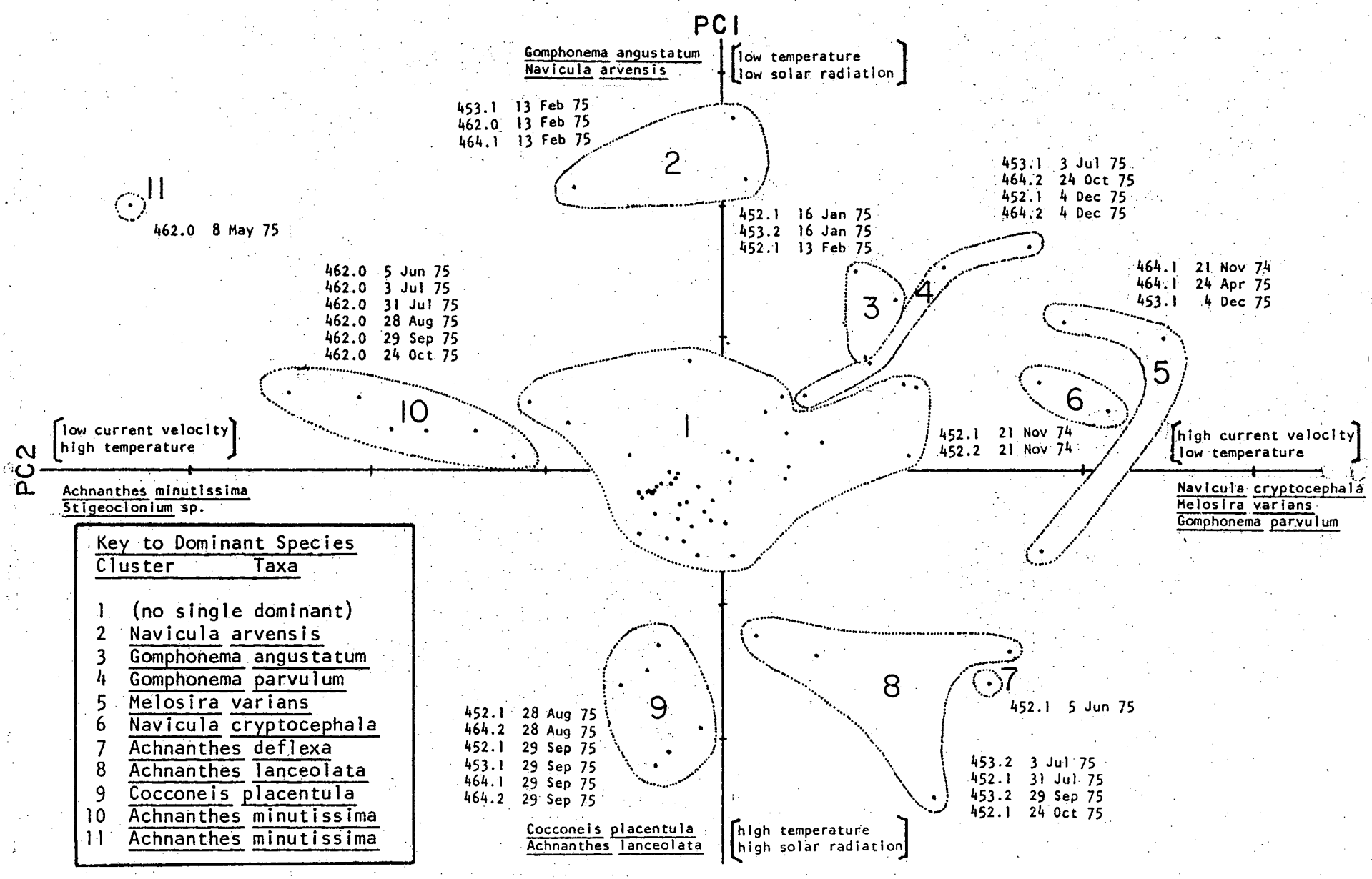
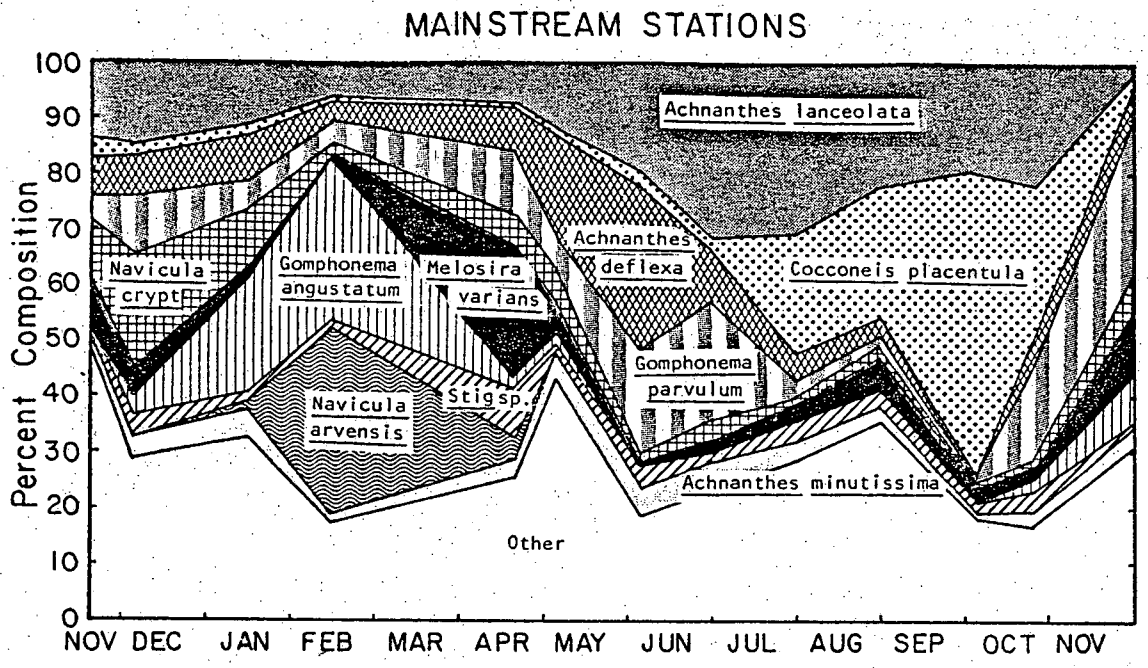


Figure 3-6. Principle components ordination of dominant periphyton species densities at stations in the Broad River and Ninety-Nine Islands Impoundment, S. C. from 21 November 1974 through 4 December, 1975.



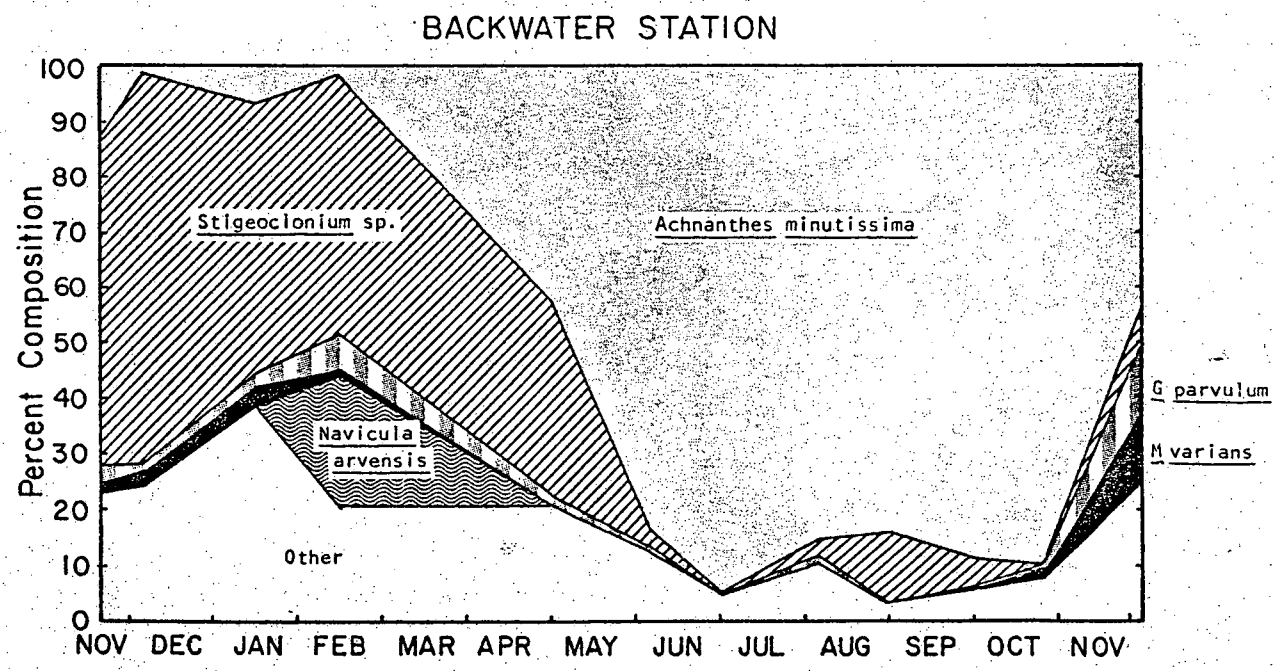


Figure 3-7. Relative abundance of numerically dominant species at stations in the Broad River and Ninety-Nine Islands Impoundment, S. C. from 21 November 1974 through 4 December 1975.

(App. 3-11). A similar observation was reported by Cedergren (1938, cited in Whitford and Schumacher 1963) that most species of algae found in running water are also found in cold still water.

The succession of dominant taxa at mainstream stations appeared to be determined primarily by seasonal variations in temperature and light. On one hand, high densities of Gomphonema angustatum and Navicula arvensis were found only during winter months when temperatures and illumination were low. Stations and dates with these two species as dominant (clusters 2 and 3, respectively) score high on PC2 which showed significant negative correlations with temperature ($r = -0.41$) and solar radiation ($r = -0.43$) (Fig. 3-6). On the other hand, stations and dates where Achnanthes lanceolata and Cocconeis placentula were dominant (clusters 8 and 9, respectively) scored low on PC2 (Fig. 3-6) indicating a positive response to higher temperatures and illumination. Cocconeis placentula, a typically epiphytic species (Lowe 1974), exhibited a distinct maxima in August and September (Fig. 3-7). Both Achnanthes lanceolata and Cocconeis placentula form similar "pavement like" colonies and the dominance of one or the other may be determined by which becomes established first (Patrick 1977). The response of other top-ranked species at mainstream stations to light and temperature regimes in Broad River was less clear cut although Melosira varians, Navicula cryptocephala, Synedra ulna and Cymbella tumida were all found in greater abundance at cooler temperatures. Neither fluctuations in discharge, turbidity, nor nutrients appeared to influence the seasonal variations in periphyton species composition to any extent.

Species composition of periphyton assemblages during quarterly sampling were similar to corresponding months during 1974-75 with the exception that Synedra pulchella replaced Navicula arvensis as the dominant species in February (App. 3-10). The sequence of dominants for the remainder of quarterly sampling was Achnanthes deflexa during May, Achnanthes lanceolata during July, and Gomphonema parvulum during November.

Melosira varians was most often dominant in natural substrate collections, with Oscillatoria spp. the next most frequent dominant (Table 3-10). Species of the genera Nitzschia and Navicula, while commonly found on artificial substrates, were more often abundant in natural substrate collections. Species from these two genera (as well as Oscillatoria spp.) are motile forms, adapted to living on river silt and other soft sediment (Hynes 1970).

PHYTOPLANKTON

COMMUNITY COMPOSITION

Seven classes, 64 genera, and 72 species were identified from the monthly (1974 and 1975) Ninety-Nine Islands Impoundment samples (Station 462.0) (Table 3-2). Nine classes, 102 genera, and 124 species were identified in monthly samples from the five mainstream stations (Table 3-2). Quarterly (1976 and 1977) samples were similar, with one species previously unreported from the monthly samples (App. 3-15).

Table 3-10. Number of natural substrate samples in which a particular taxa was dominant (>50% of the total numbers of biovolume) or abundant (>10% of the total numbers or biovolume) at stations in the Broad River, S. C. from November 1974 through December 1975. (Total number of natural substrate samples = 25).

	Dominant no. of samples ≥50%		Abundant no. of samples >10%	
	Numbers	Biovolume	Numbers	Biovolume
*Melosira varians	3	11	8	22
Oscillatoria spp.	3	0	6	6
*Nitzschia palea	0	0	10	2
*Navicula cryptocephala	0	0	6	0
Navicula schroeteri v. escambia	0	0	3	3
*Cymbella tumida	0	1	1	4
Navicula rhynchocephala v. germainii	0	0	2	1
Nitzschia clausii	0	0	2	1
*Hydrosera triquetra	0	0	0	3
*Achnanthes deflexa	0	0	2	0
Fragilaria vaucheriae	0	0	2	0
Navicula mutica (all varieties)	1	1	1	1
Navicula minima	1	0	1	1
Surirella ovata	0	0	1	1
*Stigeoclonium sp.	0	0	1	1
*Achnanthes lanceolata	0	0	1	0
*Cocconeis placentula	0	0	1	0
*Gomphonema parvulum	0	0	1	0
Nitzschia dissipata	0	0	1	0
Nitzschia sp.	0	0	1	0
Cymbella affinis	0	0	0	1
Gyrosigma spenceri v. curvula	0	0	0	1
Surirella angusta	0	0	0	1

*Species ranked on dominance indices for artificial substrates

The dominant classes, in terms of density and biovolume, in the backwater and the mainstream were the Bacillariophyceae and the Chlorophyceae (Table 3-11 and 3-12). The Chrysophyceae and Cryptophyceae, although usually sparse, were, occasionally abundant and were dominant during some months (Table 3-11 and 3-12).

The composition of the phytoplankton community during the quarterly program was very similar to that of the communities during the monthly sampling program (App. 3-16). Diatoms and green-algae continued to dominate the phytoplankton at mainstream stations throughout the quarterly program.

PHYTOPLANKTON VARIATIONS

Standing Crop

The most notable feature of the standing crop values in both the backwater and the mainstream was the monthly variations (Table 3-13) which appeared to be unrelated to seasonal cycles of incident light and temperature (Fig. 3-8 and 3-9). Summer (June through August) was an exception, however, and the progressive increases in standing crop during summer were in sharp contrast to the remainder of the year (Fig. 3-8 and 3-9). Discharge was primarily responsible for the temporal and spatial variations in standing crop in both the impoundment and the mainstream. The effects of discharge upon phytoplankton communities are well documented (Chandler 1937; Hynes 1970; Reif 1939). Periods of high or fluctuating discharge generally produced low standing crop values in the mainstream and backwater (Fig. 3-8 and 3-9). The linear correlation coefficients of discharge to mainstream total density and chlorophyll a were -0.67 and -0.40, respectively. Periods of low discharge resulted in significant differences among backwater and mainstream stations with respect to total density and chlorophyll a (Table 3-14, 3-15, and 3-16). In addition, periods of low and stable discharge, especially during summer, were generally concurrent with high standing crop values in both systems (Fig. 3-8 and 3-9). Biovolume, however, was statistically similar among stations throughout the monthly study period (Table 3-14). This difference between biovolume, densities, and chlorophyll a was a result of differences in species abundance between the two systems.

Nutrients, incident light, and temperature appeared to be of secondary importance to discharge with respect to phytoplankton abundance. Nutrients were generally high and correlated with discharge or turbidity (Chapter 1). Although phytoplankton abundance was low in both systems, it is doubtful that nutrients were the limiting factor since total phosphate (P) concentrations in the system exceeded EPA levels (0.05 mg/l in streams and 0.025 mg/l in reservoirs) concerning phytoplankton blooms (USEPA 1976). The synergistic effects of incident light and temperature on natural phytoplankton populations are difficult to separate (Lund 1965), however both variables appeared to be important in both systems during summer when discharge was low (Fig. 3-8 and 3-9). Peaks in phytoplankton abundance during summer corresponded with peaks in incident light and temperature and minimal discharge and turbidity.

Table 3-11. Index of dominance and rank of class density and class biovolume of phytoplankton from Ninety-Nine Islands Impoundment, S. C., from 17 September 1974 through 19 November 1975.

CLASS DENSITY

Sampling Date	Bacillariophyceae	Chlorophyceae	Chrysophyceae	Cryptophyceae	Dinophyceae	Euglenophyceae	Myxophyceae
1974							
17 September	(0.0271)[a] [b]3	(0.2437) 1	(0.0014) 4	(0.0009) 5	NP[c]	(<0.0001) 6	(0.0722) 2
24 October	(0.4174) 1	(0.0177) 2	(0.0012) 5	(0.0055) 4	(<0.0001) 6	NP	(0.0114) 3
20 November	(0.7390) 1	(0.0043) 3	NP	(<0.0001) 4.5	(<0.0001) 4.5	NP	(0.0044) 2
18 December	(0.1451) 1	(0.1276) 2	(0.0033) 5	(0.0056) 4	NP	(0.0001) 6	(0.0142) 3
1975							
22 January	(0.3223) 1	(0.0516) 2	(0.0015) 5	(0.0023) 4	NP	NP	(0.0139) 3
19 February	(0.0276) 2	(0.0255) 3	(0.0011) 4	(0.4111) 1	NP	NP	NP
28 March	(0.0144) 3	(0.0738) 2	(0.0058) 4	(0.2762) 1	NP	(<0.0001) 5	NP
23 April	(0.2053) 1	(0.1605) 2	(0.0044) 4	(0.0061) 3	NP	(<0.0001) 5	NP
21 May	(0.0181) 3	(0.3295) 1	(0.0010) 4	(0.0544) 2	NP	(0.0007) 5	NP
18 June	(0.0007) 4	(0.4361) 1	(0.0043) 3	(0.0422) 2	NP	(0.0005) 5	(0.0004) 6
23 July	(0.0080) 5	(0.0167) 3	(0.2478) 1	(0.0252) 2	(0.0002) 6	(<0.0001) 7	(0.0117) 4
20 August	(0.0154) 3	(0.3667) 1	(0.0004) 5	NP	(<0.0001) 6	(0.0096) 4	(0.0223) 2
29 September	(0.0287) 3	(0.1117) 1	(010913) 2	(0.0041) 5	(<0.0001) 6.5	(<0.0001) 6.5	(0.0157) 4
22 October	(0.0115) 5	(0.0323) 4	(0.0671) 1	(0.0528) 2	(<0.0001) 6	(0.0001) 7	(0.0430) 3
19 November	(0.0250) 3	(0.0121) 4	(0.2467) 1	(0.0473) 2	NP	(0.0003) 5	NP
15 Month Study Period Index of Dominance and Ranking	(2336.2298) 2	(2447.8425) 1	(792.1928) 4	(819.5740) 3	(0.0144) 7	(3.7268) 6	(95.9200) 5

CLASS BIOVOLUME

Sampling Date	Bacillariophyceae	Chlorophyceae	Chrysophyceae	Cryptophyceae	Dinophyceae	Euglenophyceae	Myxophyceae
1974							
17 September	(0.0589)[a] 2[b]	(0.1215) 1	(0.0075) 5	(0.0122) 4	NP[c]	(0.0033) 6	(0.0237) 3
24 October	(0.8812) 1	(0.0006) 2	(0.0001) 4.5	(0.0002) 3	(0.0001) 4.5	NP	(<0.0001) 6
20 November	(0.7475) 1	(0.0027) 2	NP	(0.0001) 5	(0.0006) 4	NP	(0.0022) 3
18 December	(0.9157) 1	(0.0018) 2	(0.0001) 4	(0.0001) 4	NP	(0.0001) 4	(<0.0001) 6
1975							
22 January	(0.6333) 1	(0.0080) 2	(0.0040) 3	(0.0020) 4	NP	NP	(0.0001) 5
19 February	(0.0265) 2	(0.0112) 3	(0.0034) 4	(0.4523) 1	NP	NP	NP
28 March	(0.0139) 4	(0.0201) 3	(0.0647) 2	(0.1790) 1	NP	(0.0039) 5	NP
23 April	(0.1320) 1	(0.1077) 2	(0.0429) 3	(0.0074) 4	NP	(0.0002) 5	NP
21 May	(0.0167) 4	(0.0661) 3	(0.0024) 5	(0.0694) 2	NP	(0.0906) 1	NP
18 June	(0.0016) 5	(0.1711) 1	(0.0192) 4	(0.0382) 3	NP	(0.0400) 2	(0.0001) 6
23 July	(0.0258) 3	(0.0241) 4	(0.0528) 2	(0.0570) 1	(0.0153) 5	(0.0007) 7	(0.0041) 6
20 August	(0.0050) 3	(0.0643) 2	(0.0004) 5	NP	(0.0002) 6	(0.3465) 1	(0.0027) 4
29 September	(0.0814) 1	(0.0738) 2	(0.0272) 3	(0.0024) 6	(0.0012) 7	(0.0098) 4	(0.0092) 5
22 October	(0.0118) 6	(0.0148) 5	(0.0225) 3	(0.5565) 1	(0.0050) 7	(0.0354) 2	(0.0155) 4
19 November	(0.0662) 1	(0.0054) 5	(0.0553) 3	(0.0624) 2	NP	(0.0340) 4	NP
15 Month Study Period Index of Dominance and Ranking	(4467.8700) 1	(772.3575) 3	(237.2482) 5	(1517.0596) 2	(1.9350) 7	(370.2600) 4	(20.7700) 6

a Index of Dominance
b Rank
c NP indicates not present in sample

Table 3-12. Index of dominance and rank of class density and class biovolume of phytoplankton from the Broad River stations, S. C., from 17 September 1974 through November 1975.

CLASS DENSITY

Sampling Date	Bacillariophyceae	Chlorophyceae	Chrysophyceae	Cryptophyceae	Dinophyceae	Euglenophyceae	Haptophyceae	Myxophyceae	Xanthophyceae
1974									
17 September	(0.2017)[a] 1[b]	(0.0508) 3	(0.0004) 4	(0.0001) 5	(<0.0001) 7.5	(<0.0001) 7.5	NP[c]	(0.0870) 2	NP
24 October	(0.6956) 1	(0.0061) 2	(0.0002) 6	(0.0010) 3	(<0.0001) 7	(0.0006) 5	NP	(0.0009) 4	NP
20 November	(0.7187) 1	(0.0066) 2	(<0.0001) 5	NP	(<0.0001) 5	NP	NP	(0.0016) 3	(<0.0001) 5
18 December	(0.2355) 1	(0.0451) 2	(0.0038) 5	(0.0128) 4	NP	(<0.0001) 6.5	(<0.0001) 6.5	(0.0145) 3	NP
1975									
22 January	(0.3050) 1	(0.0420) 2	(0.0090) 4	(0.0004) 5	NP	NP	NP	(0.0164) 3	NP
19 February	(0.2410) 1	(0.0733) 2	(0.0010) 4	(0.0265) 3	NP	NP	NP	NP	NP
28 March	(0.1514) 1	(0.1483) 2	(0.0012) 5	(0.0219) 3	NP	NP	NP	(0.0018) 4	NP
23 April	(0.3155) 1	(0.1201) 2	(0.0006) 4	(0.0042) 3	NP	(<0.0001) 5	NP	NP	NP
21 May	(0.1689) 1	(0.1471) 2	(0.0006) 6	(0.0022) 4	(0.0019) 5	NP	NP	(0.0081) 3	NP
18 June	(0.0195) 3	(0.2041) 1	(0.0079) 4	(0.0533) 2	(<0.0001) 7	(0.0002) 6	NP	(0.0048) 5	NP
23 July	(0.0465) 2	(0.0178) 3	(0.1720) 1	(0.0137) 4	(<0.0001) 7	(0.0002) 6	NP	(0.0105) 5	NP
20 August	(0.0588) 4	(0.0257) 1	(0.0902) 3	(0.0024) 5	(<0.0001) 7	(0.0001) 6	NP	(0.1532) 2	NP
29 September	(0.0492) 3	(0.0147) 5	(0.0166) 4	(0.0751) 1	(<0.0001) 6.5	(<0.0001) 6.5	NP	(0.0600) 2	NP
22 October	(0.1245) 2	(0.0057) 5	(0.0109) 5	(0.1354) 1	(<0.0001) 6	NP	NP	(0.0104) 3	NP
19 November	(0.4934) 1	(0.0034) 4	(0.0069) 3	(0.0137) 2	NP	(<0.0001) 6	NP	(0.0011) 5	NP
15 Month Study Period Index of Dominance and Ranking	(5066.8425) 1	(1308.2625) 2	(415.3500) 3	(388.7072) 4	(0.1900) 6	(0.1100) 7	(<0.0001 (8.5)	(347.6837) 5	(<0.0001) 8.5

CLASS BIOVOLUME

Sampling Date	Bacillariophyceae	Chlorophyceae	Chrysophyceae	Cryptophyceae	Dinophyceae	Euglenophyceae	Haptophyceae	Myxophyceae	Xanthophyceae
1974									
17 September	(0.5660)[a] 1[b]	(0.0155) 2	(0.0001) 4.5	(<0.0001) 6.5	(0.0001) 4.5	(<0.0001) 6.5	NP[c]	(0.0082) 3	NP
24 October	(0.7341) 1	(0.0011) 2	(0.0002) 6	(0.0009) 4	(0.0010) 3	(0.0006) 5	NP	(0.0001) 7	NP
20 November	(0.8171) 1	(0.0063) 2	(<0.0001) 5	(<0.0001) 5	NP	(<0.0001) 5	NP	(<0.0001) 5	(<0.0001) 5
18 December	(0.8569) 1	(0.0009) 2	(0.0002) 3	(0.0001) 5	(0.0001) 5	(<0.0001) 7.5	(<0.0001) 7.5	(0.0001) 5	NP
1975									
22 January	(0.4706) 1	(0.0040) 3	(0.0389) 2	(0.0002) 5	(0.0002) 5	(0.0001) 7	NP	(0.0002) 5	NP
19 February	(0.5113) 1	(0.0099) 3	(0.0029) 4	(0.0134) 2	NP	(<0.0001) 6	NP	(0.0001)5	NP
28 March	(0.2268) 1	(0.0494) 2	(0.0091) 4	(0.0333) 3	NP	NP	NP	(0.0006) 5	NP
23 April	(0.5544) 1	(0.0219) 2	(0.0021) 3	(0.0016) 4	NP	(0.0004) 5	NP	NP	NP
21 May	(0.3148) 1	(0.0457) 2	(0.0022) 6	(0.0034) 4	(0.0031) 5	NP	NP	(0.0041) 3	NP
18 June	(0.0108) 3	(0.0172) 2	(0.3391) 1	(0.0064) 4	(0.0004) 6.5	(0.0040) 5	NP	(0.0004) 6.5	NP
23 July	(0.1014) 1	(0.0274) 3	(0.0452) 2	(0.0161) 4	(0.0010) 7	(0.0094) 5	NP	(0.0023) 6	NP
20 August	(0.1575) 1	(0.0449) 2	(0.0063) 4	(0.0023) 6	(0.0012) 7	(0.0051) 5	NP	(0.00248) 3	NP
29 September	(0.3899) 1	(0.0085) 4	(0.0054) 5	(0.0524) 2	(0.0011) 7	(0.0020) 6	NP	(0.0177) 3	NP
22 October	(0.3634) 1	(0.0016) 5	(0.0029) 3	(0.0573) 2	(0.0002) 6	(0.0001) 7	NP	(0.0018) 4	NP
19 November	(0.6571) 1	(0.0002) 5	(0.0027) 3	(0.0046) 2	NP	(0.0022) 4	NP	(<0.0001) 6	NP
15 Month Study Period Index of Dominance	(10105.7400) 1	(284.8050) 3	(671.0288) 2	(216.2475) 4	(1.6850) 7	(11.5765) 6	(<0.0001) 8.5	(55.7032) 5	(<0.0001) 8.5

a Index of Dominance
b Rank
c NP indicates not present in sample

Table 3-13 . Total phytoplankton density (means of replicates expressed as $X10^6$ units/m^3) and total phytoplankton biovolume (means of replicates expressed as $X10^{-3}$ mm^3/m^3) in the Broad River and Ninety-Nine Islands Impoundment, S. C., from 17 September 1974 through 19 November 1975.

Sampling Date	STATIONS 452.3 Density	452.3 Biovolume	453.1 Density	453.1 Biovolume	453.2 Density	453.2 Biovolume	459.0 Density	459.0 Biovolume	460.3 Density	460.3 Biovolume	Monthly Mean Broad River Stations Density	Monthly Mean Broad River Stations Biovolume	462.0 Density	462.0 Biovolume
1974														
17 Sep	970	0.69	940	1.04	490	0.73	1110	0.95	800	0.69	860	0.82	1030	0.43
24 Oct	530	0.63	530	0.54	540	0.43	860	0.35	350	0.51	560	0.49	650	2.04
20 Nov	1000	3.16	1450	3.56	1320	3.64	1120	2.61	1660	6.53	1310	3.90	1640	0.74
18 Dec	200	0.32	260	1.27	200	0.56	200	0.74	160	0.43	200	0.66	290	1.45
1975														
22 Jan	360	0.38	310	0.35	270	0.21	300	0.56	200	0.24	290	0.35	230	0.19
19 Feb	350	0.46	350	0.30	480	0.51	690	0.56	440	0.50	400**	0.47	3210	1.25
28 Mar	*	*	*	*	*	*	140	0.06	120	0.06	130	0.06	570	0.30
23 Apr	860	1.73	840	0.73	870	0.68	2000	0.87	550	0.74	780**	0.95	1620	0.92
21 May	120	0.09	110	0.07	70	0.04	120	0.10	90	0.06	100	0.07	220	0.14
18 Jun	200	0.15	230	0.22	440	0.41	590	0.35	410	1.04	320**	0.43	1110	0.56
23 Jul	410	0.22	520	0.36	680	0.40	1150	0.69	450	0.24	520**	0.38	1370	0.66
20 Aug	760	0.43	1000	0.44	920	0.52	1260	0.54	890	0.57	890**	0.50	2720	2.38
29 Sep	420	0.20	300	0.20	440	0.26	410	0.27	510	0.42	410	0.27	410	0.16
20 Oct	100	0.06	60	0.06	110	0.06	80	0.05	180	0.12	100	0.07	580	0.26
19 Nov	220	0.24	160	0.18	190	0.25	150	0.19	190	0.19	180	0.21	450	0.20
Station Mean	460	0.62	500	0.66	500	0.62	680	0.59	470	2.08	470	0.64	1070	0.78

* Station not sampled due to high water.
** Density from Station 459.0 not included in mean because LSD analysis indicates a significant difference between Station 459.0 and other mainstream stations.

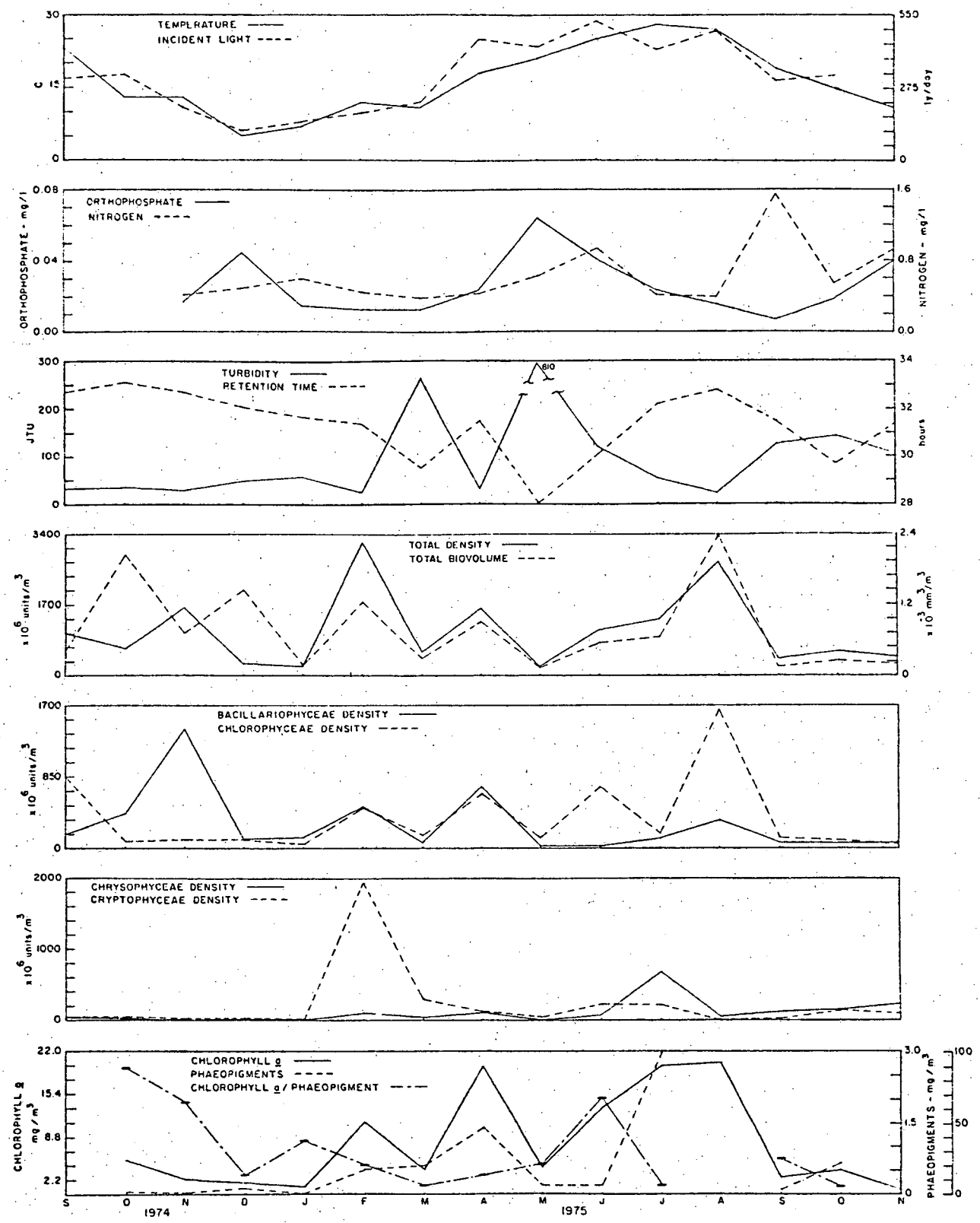


Figure 3-8. Comparisons of water temperature, incident light, orthophosphate, total inorganic nitrogen, turbidity, retention time, total density, total biovolume, Bacillariophyceae density, Chlorophyceae density, Chrysophyceae density, Cryptophyceae density, chlorophyll a, phaeopigments, and chlorophyll a/ phaeopigment ratios at Station 462.0 (backwater) from 17 September 1974 through 19 November 1975.

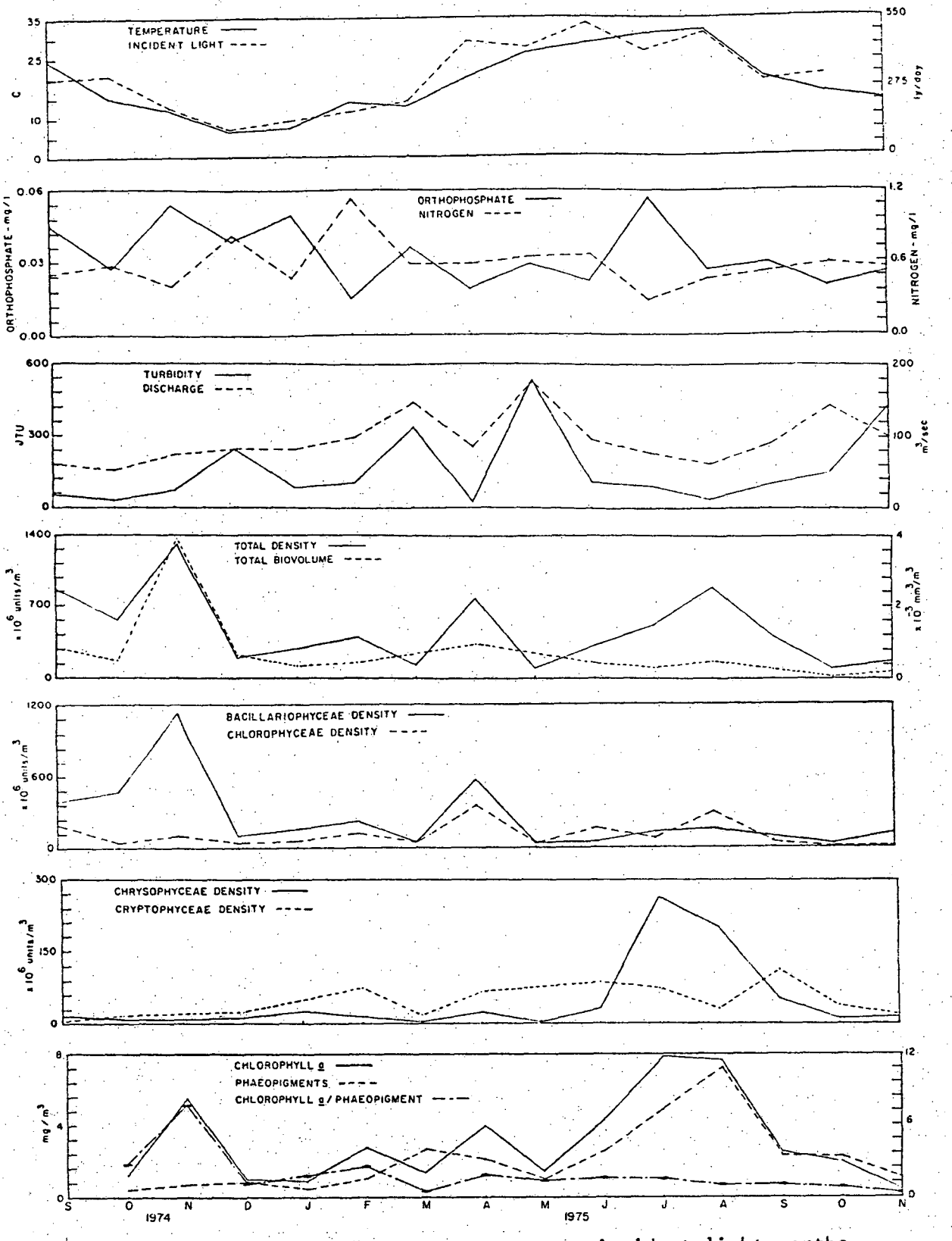


Figure 3-9. Comparisons of water temperature, incident light, orthophosphate, total inorganic nitrogen, turbidity, discharge, total density, total biovolume, Bacillariophyceae density, Chlorophyceae density, Chrysophyceae density, Cryptophyceae density, chlorophyll a, phaeopigments, and chlorophyll a/phaeopigment ratios at mainstream stations from 17 September 1974 through 19 November 1975.

Table 3- 14. Results of two-way analysis of variance of phytoplankton total class density, total class biovolume, chlorophyll a, and phaeopigment concentrations between months and stations for the Broad River and Ninety-Nine Islands Impoundment, S. C., from 17 September 1974 through 19 November 1975.

		Results		
	Source	df	Mean Square	F
Total Density	Month	14	6.21×10^4	13.10*
	Station	5	7.37×10^4	15.54*
	Month × Station	66	8.41×10^3	1.77*
	Error	4844	4.74×10^3	
Total Biovolume	Month	14	1.71×10^{11}	9.76
	Station	5	1.17×10^{10}	0.67
	Month × Station	66	1.59×10^{10}	0.91
	Error	4844	1.75×10^{10}	
Chlorophyll a	Month	13	154.72	159.76*
	Station	5	105.64	108.05*
	Station × Month	62	14.33	14.80*
	Error	81	0.97	
Phaeopigments	Month	13	14.14	22.92*
	Station	5	2.33	3.77*
	Station × Month	62	0.84	1.36
	Error	81	0.62	

*P<.05

Table 3-15. Results of least significant difference analysis of total density (X 10^6 units/m^3) River and Ninety-Nine Islands Impoundment for differences among stations. (Means not connected by horizontal lines are significantly different.)

Sampling Date		Density					
1975							
19 February	Station	452.3	453.1	460.3	453.2	459.0	462.0
	Mean	350	350	440	480	690	3210
23 April	Station	460.3	453.1	452.3	453.2	462.0	459.0
	Mean	550	840	860	870	1620	2000
18 June	Station	452.3	453.1	460.3	453.2	459.0	462.0
	Mean	200	230	410	440	590	1110
23 July	Station	452.3	460.3	453.1	453.2	459.0	462.0
	Mean	410	450	520	680	1150	1370
20 August	Station	452.3	460.3	453.2	453.1	459.0	462.0
	Mean	760	890	920	1000	1260	2720

Table 3-16. Results of least significant difference test of means of chlorophyll a and phaeopigment concentrations ($mg \cdot m^{-3}$) from Broad River and Ninety-Nine Islands Impoundment, SC, for differences among stations. (Means not connected by horizontal lines are significantly different.)

Sampling Date							
				Chlorophyll a			
1974 24 October	Station	452.3	460.3	459.0	453.1	453.2	462.0
	Mean	0.79	1.00	1.16	1.37	1.76	5.27
20 November	Station	462.0	459.0	453.2	452.3	460.3	453.1
	Mean	2.26	3.64	4.08	5.71	6.52	7.75
19 February	Station	452.3	460.3	453.1	453.2	459.0	462.0
	Mean	2.56	2.64	2.98	2.98	4.22	11.22
23 April	Station	453.1	460.3	453.2	452.3	459.0	462.0
	Mean	3.48	3.86	4.22	4.48	7.70	19.73
21 May	Station	453.1	460.3	453.2	459.0	452.3	462.0
	Mean	1.37	1.37	1.42	1.47	1.63	4.23
18 June	Station	452.3	453.2	453.1	460.3	459.0	462.0
	Mean	3.36	3.86	4.47	5.59	6.22	13.26
23 July	Station	452.3	460.3	453.1	453.2	459.0	462.0
	Mean	5.60	5.85	9.98	10.00	17.94	19.79
20 August	Station	452.3	460.3	453.2	453.1	459.0	462.0
	Mean	6.32	6.53	7.75	9.99	14.66	20.27
				Phaeopigment			
1974 20 November	Station	462.0	459.0	460.3	453.1	452.3	453.2
	Mean	1.93	2.50	4.76	5.24	5.71	7.63

Seasonal Succession

Seasonal succession of phytoplankton species was generally not disrupted by fluctuations in discharge. Diatoms typically dominated the phytoplankton during fall and winter while green algae dominated during summer (Fig. 3-8, 3-9, and App. 3-16). Similar findings have been reported by Lawson, et al. (1978) and Whitford and Schumacher (1963) on North Carolina rivers. Blue-green algae, although a minor component of the phytoplankton throughout the year in both systems, reached their maximum abundance during August, a period of low discharge (Fig. 1-3), high temperature, and maximum solar radiation (Fig. 3-8 and 3-9). Total standing crop varied with species composition and discharge. Class dominance was usually determined by one or two species occurring in great abundance relative to the abundance of the other species. For instance, during November 1974 Skeletonema potomos accounted for 67% of the total density at the backwater station (App. 3-16) and, during August 1975, an unidentified species of Euglena accounted for 50% of the total biovolume at Station 462.0 (App. 3-16). Chlorophyll a concentrations at mainstream stations reached high levels when an unidentified species of Chrysophyta became abundant (App. 3-16).

Species Variation

The number of taxa present at the backwater and mainstream stations may have been, in part, a function of discharge. Retention time in the backwater was inversely related to discharge. The estimated retention times were low; approximately 1 to 2 days (personal communication, Wayne Smith, 1978). Short retention times reduce variety and abundance of phytoplankton (Brook and Woodward 1956). This was indicated by the relationship which existed between retention time and the number of species present in the backwater ($r = 0.69$). An inverse relationship existed between discharge and the number of species at mainstream stations ($r = -0.73$).

Nearly twice as many species were identified from mainstream stations as from the backwater. However, 75% of the mainstream species were rarely observed in the samples (Table 3-2). This may indicate that either the mainstream provides a greater diversity of habitat for algae or it may simply result from counting more samples from the mainstream than from the backwater.

The dominant species of the backwater and mainstream stations were nearly identical (Table 3-17). Eight dominant species were shared in common between the two systems. Seven of the eight were of small volume (<400 μm^3). This is in contrast to the dominant periphyton species which were generally of large volume (Table 3-18). Butcher (1946) also noticed the small size of phytoplankton in rivers. Small cells generally have shorter generation times than do larger cells (Findenegg 1965). Small planktonic cells usually have certain morphological features (e.g., relatively large surface areas, spines, setae, ridges, cylindrical shapes, disc shapes, and flattened colonies) which enable them to remain in suspension (Ruttner 1971). The longer retention times and deeper euphotic zone in the backwater may have allowed time for the small phytoplankton cells to develop higher

Table 3-17. Rank and index of dominance of density of the ten dominant species of phytoplankton from Broad River and Ninety-Nine Islands Impoundment, SC, from 17 September 1974 through 19 November 1975.

Taxa	Rank		Index of Dominance	
	Broad River Stations	Impoundment Station	Broad River Stations	Impoundment Station
Bacillariophyceae				
Asterionella formosa	7	-	264.11	-
Melosira distans	8	4	199.87	141.75
M. varians	3	-	986.43	
Rhizosolenia eriensis	-	10	-	9.69
Skeletonema potomos	2	2	1035.72	809.37
Chlorophyceae				
Monoraphidium contortum	9	6	104.17	49.88
Scenedesmus quadricauda	10	8	49.29	38.91
Cryptophyceae				
Cryptomonas sp.	5	3	425.32	216.54
Rhodomonas minuta	1	1	1175.65	1993.68
Myxophyceae				
Anabaena sp.	4	5	467.60	69.12
Oscillatoria geminata	-	9	-	13.12
O. sp.	6	7	402.12	42.88

Table 3-18. Comparison of periphyton dominant species biovolumes with phytoplankton dominant species biovolumes (biovolume expressed as μm^3).

Periphyton Dominant Species	Mean Biovolume	Phytoplankton Dominant Species	Mean Biovolume
Navicula arvensis[1]	10	*Oscillatoria geminata*[2]	60
Achnanthes minutissima	140	*Skeletonema potomos*	70
A. deflexa	160	*Monoraphidium contortum*	70
Nitzschia palea	300	*Melosira distans*	230
Navicula cryptocephala[1]	350	*Scenedesmus quadricauda*	260
Achnanthes lanceolata	500	*Oscillatoria* sp.	270
Stigeoclonium sp.	520	*Rhodomonas minuta*[3]	300
Gomphonema paruulum	570	*Anabaena* sp.	320
G. angustatum	1200	*Asterionella formosa*	450
Cocconeis placentula var. *lineata*	2900	*Cryptomonas* sp.[3]	890
Synedra ulna	4700	*Rhizosolenia eriensis*	1700
Melosira varians	6400	*Melosira varians*[2]	6400
Cymbella tumida	12,500		
Hydrosera triquetra	146,000		

[1] This taxon was a dominant in periphyton density, but was not a dominant in periphyton biovolume.

[2] This taxon is benthic.

[3] A biflagellate organism.

densities than in the mainstream during low discharge. Conversely, similar densities were observed between the two systems when discharge was moderate or high and retention times low (Fig. 3-8 and 3-9).

Autotrophic Condition

The backwater phytoplankton were generally in a better autotrophic condition than mainstream phytoplankton. Chlorophyll a concentrations were typically higher and phaeopigment concentrations generally lower in the backwater than at mainstream stations(Table 3-19). The chlorophyll a/phaeopigment ratios, indicators of the physiological condition of the phytoplankton (APHA 1975), were higher at the backwater station than at mainstream stations (Table 3-19) and there was generally more chloropyll a and less phaeopigment per cell at Station 462.0 than at mainstream stations (Table 3-20). The better physiological condition of backwater phytoplankton may have been due to species composition and the less severe effects of current velocity and turbidity. Although densities and dominant species between the two systems were similar, diatoms accounted for a higher percentage and green algae a lower percentage of the total density at mainstream stations (App. 3-16). Diatoms possess large vacuoles and proportionally have less chlorophyll per cell than the small green algae (Strathman 1967). In addition, the turbulence and turbidity within the river may have stressed the mainstream phytoplankton and/or reduced the photosynthetic capacity of the algae.

PERIPHYTON-PHYTOPLANKTON RELATIONSHIPS

Similar patterns in monthly total density of periphyton and phytoplankton were exhibited in the mainstream (Station 453.1), except during summer (Fig. 3-10). Throughout the study, periphyton densities were 20 to 3,000 times greater than phytoplankton densities on an areal basis. During the summer, however, phytoplankton densities increased due to increases in density of small planktonic green algae while periphyton densities decreased due to decreases in diatom abundance. A high percentage of the total phytoplankton density in mainstream during winter consisted of displaced periphytic species whereas during summer the phytoplankton contained few benthic species. Species most frequently occurring in commom were Achnanthes deflexa, Cyclotella stelligera, Cymbella tumida, Melosira distans, M. varians, Nitzschia acicularis, N. palea, Synedra ulna, Tabellaria fenestrata, and Oscillatoria sp. Blum (1956) and Eddy (1934) reported that in lotic waters the benthic algal communities were the chief contributors to the floating algae. This was found to be generally true in mainstream only during the coldest months when diatoms were the dominant organisms in the phytoplankton (Table 3-12).

Few relationships were evident between periphyton and phytoplankton in the backwater. Monthly patterns in total density between the two communities were not similar (Fig. 3-11). Periphyton densities were 85 to 4,700 times greater than phytoplankton densities on an areal basis. The species composition of the two communities were dissimilar.

Table 3-19. Chlorophyll a and phaeopigment concentrations (expressed as mg/m^3), and chlorophyll a/phaeopigment ratios for Broad River and Ninety-Nine Islands Impoundment, S. C., from 17 September 1974 through 19 November 1975.

	Broad River			Ninety-Nine Islands Impoundment		
Sampling Date	Chlorophyll a	Phaeopigments	Chlorophyll a/ Phaeopigment Ratio	Chlorophyll a	Phaeopigments	Chlorophyll a/ Phaeopigment Ratio
1974						
17 September	a	a	-	a	a	-
24 October	1.22[b]	1.84[b]	0.66	5.27[c]	2.65[c]	1.99
20 November	5.54	5.17	1.07	2.26	1.93	1.17
18 December	1.02	0.77	1.32	1.76	0.41	4.29
1975						
22 January	0.92	1.22	0.75	1.18	1.14	1.04
19 February	2.79[f]	1.74f	1.60	11.22	0.63	17.81
28 March	1.37[d]	0.34[d]	4.03	3.89	0.19	20.47
23 April	4.01[f]	1.26[f]	3.18	19.73	0.42	46.98
21 May	1.45	0.94	1.54	4.23	0.65	6.51
18 June	4.32[f]	1.12[f]	3.86	13.26	2.02	6.56
23 July	7.86[f]	1.06[f]	7.42	19.79	0.20	98.95
20 August	7.65[f]	0.70[f]	10.93	20.27	0.00	e
29 September	2.52	0.72	3.50	2.64	0.75	3.52
22 October	1.98	0.58	3.41	3.74	0.17	22.00
19 November	0.44	0.26	1.69	0.70	0.00	e
Mean	3.08	1.26	3.21	7.85	0.80	19.27

a - Equipment malfunction no data available

b - Mean values of five Broad River stations and replicates

c - Mean values of two replicates

d - Mean values of Stations 459.0 and 460.3 and replicates

e - Undefined

f - Does not include Station 459.0 due to significant differences in LSD analysis between Station 459.0 and other mainstream stations.

Table 3-20. Mean chlorophyll a per cell and mean phaeopigment per cell (expressed as $X10^{-3}$ mg/mm^3) at mainstream and backwater stations.

	Chlorophyll a Per Cell		Phaeopigment Per Cell	
Date	Mainstream	Backwater	Mainstream	Backwater
1974				
24 Oct	2.08	2.58	3.71	1.30
20 Nov	1.42	3.05	1.32	2.61
18 Dec	1.54	1.21	1.17	0.28
1975				
22 Jan	2.63	6.21	3.48	6.00
19 Feb	6.34	8.98	3.95	0.50
28 Mar	22.83	12.97	5.67	0.63
23 Apr	4.13	21.44	1.30	0.45
21 May	20.71	30.21	13.43	4.64
18 Jun	9.39	23.68	2.43	3.61
23 Jul	25.35	29.98	3.42	0.30
20 Aug	15.61	8.52	1.43	0.00
29 Sep	9.33	16.50	2.67	4.69
22 Oct	28.28	14.38	8.28	0.65
19 Nov	2.10	3.50	1.24	0.00

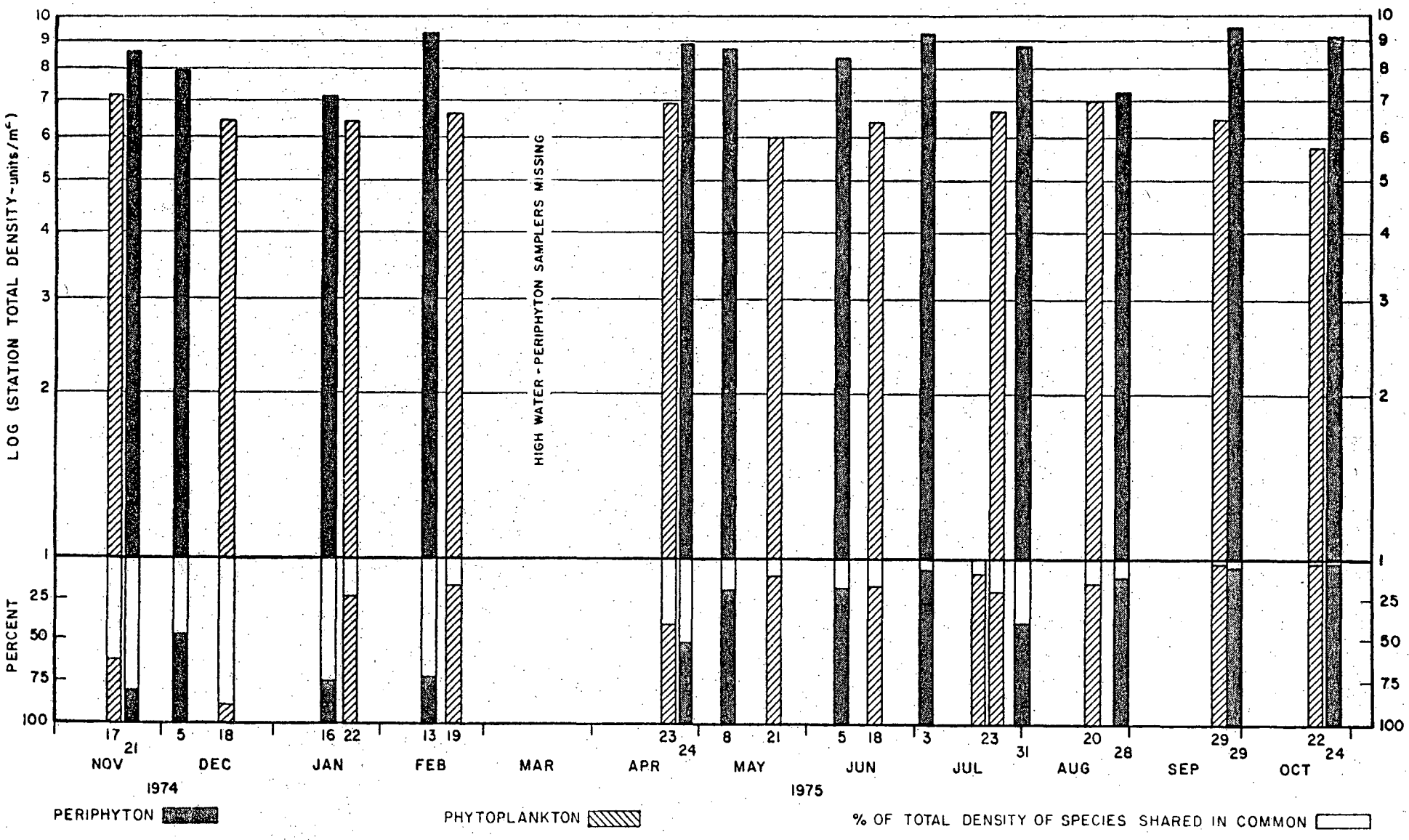


Figure 3-10. Comparisons by month of total density between periphyton and phytoplankton and the percent of the total density of species shared in common at Station 453.1 (Due to missing periphyton samplers at Station 453.1, April comparisons are between Station 452.2 for periphyton and Station 452.3 for phytoplankton, and August comparisons are between Station 452.2

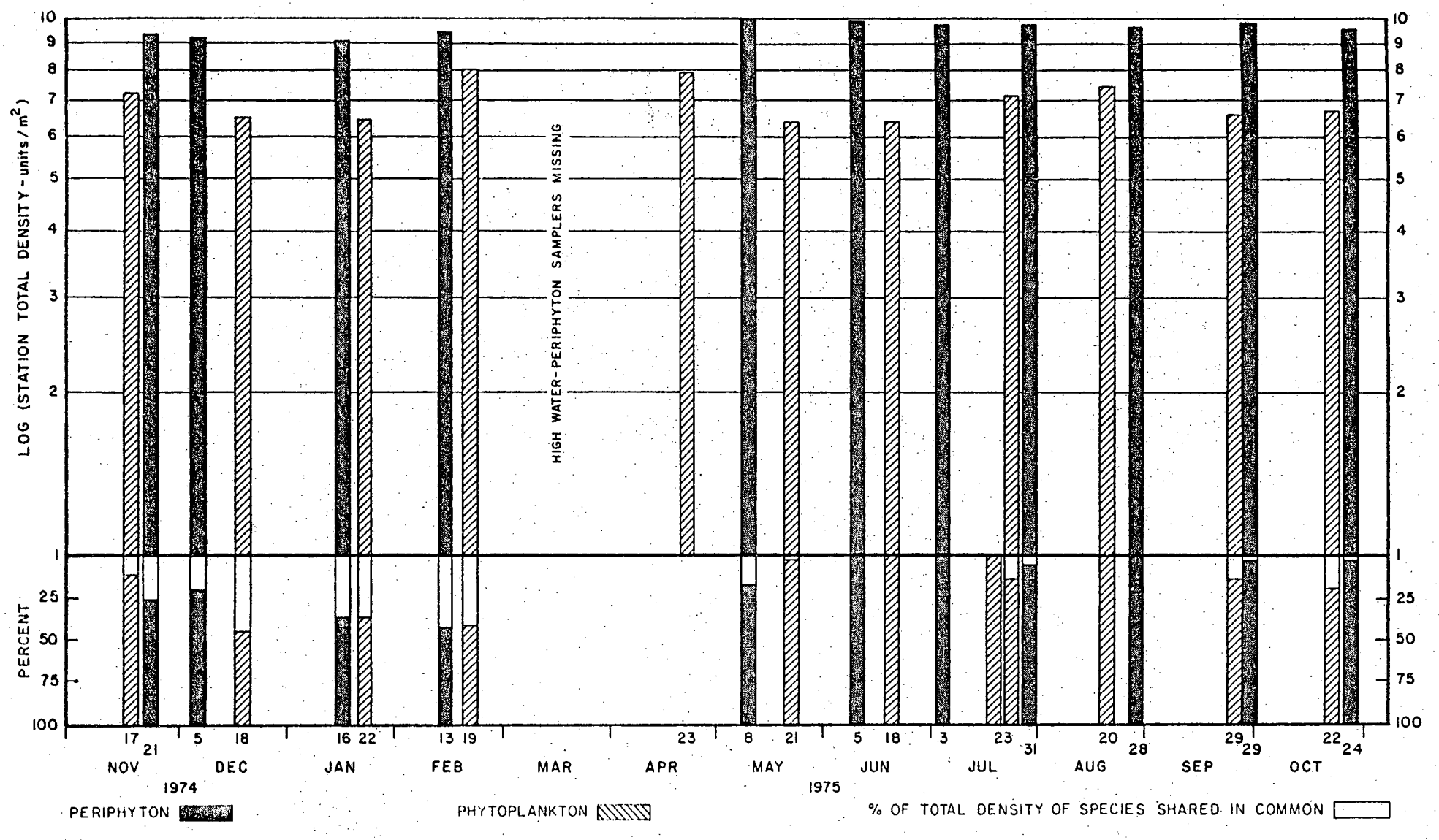


Figure 3-11. Comparisons by month of total density between periphyton and phytoplankton and the percent of the total density of species shared in common at Station 462.0 (backwater).

Both communities were generally dominated by species of small volume (Tables 3-17 and 3-18). However, the periphyton was composed mainly of diatoms, except during winter when it was dominated by a filamentous green algae, Stigeoclonium sp. (Table 3-9). The phytoplankton generally contained few diatoms; however, in winter diatoms were dominant (Table 3-11). The percent of total density of species shared in common was greatest during winter (Fig. 3-11), whereas at other times of the year when the small planktonic green algae and the small flagellated Chrysophytes and Cryptophytes were dominant in the phytoplankton (Table 3-11), the percent of total density of species shared in common was lowest (Fig. 3-11).

SUMMARY AND CONCLUSIONS

PERIPHYTON

The Bacillariophyceae were the dominant class of algae observed from the Broad River and Ninety-Nine Islands Impoundment, comprising >90% of the mean annual densities and biovolumes at mainstream stations and >70% of the mean annual densities and biovolumes at the backwater station. The Chlorophyceae (predominantly Stigeoclonium spp.) were generally found in more abundance at the backwater, and ranked second overall followed by the Myxophyceae. No other classes of algae contributed significantly to the periphyton community at any time.

Total periphyton biovolumes, an indicator of periphyton standing crop, exhibited little spatial variation, and were not significantly different between the backwater and mainstream stations. Significantly higher densities of total periphyton at the backwater station were observed from May through October, primarily due to a shift in species composition to the small lentic diatom Achnanthes minutissima.

Periphyton standing crops at mainstream stations were generally highest in spring and fall. Temperature and solar radiation were of primary influence in determining seasonal patterns of periphyton abundance. Scouring due to fluctuations in discharge periodically interrupted natural cycles of periphyton abundance. Nutrients were not considered to be limiting to the periphyton in the Broad River.

Ash-free dry weights of periphyton generally followed patterns of abundance of densities and biovolumes but were also at times positively influenced by non-algal materials, chiefly benthic macroinvertebrates and detritus. Ash-free dry weights were significantly higher at backwater than at mainstream stations although this may have been due to factors other than an increase in algal biomass.

Distinct differences in species composition between backwater and mainstream stations were due primarily to the effects of current. The dominant taxa at mainstream stations consisted almost exclusively of rheophilous forms; the dominants in the backwater were primarily lentic forms. In addition to current, light and temperature influenced the seasonal succession of species at both backwater and mainstream stations.

Melosira varians, a filamentous centric diatom was the number 1 ranked species by an annual biovolume index at mainstream stations and was most often dominant in natural substrate collections.

Total periphyton densities, biovolumes and ash-free dry weights were higher during quarterly sampling of 1976 than the monthly sampling of 1974-1975.

PHYTOPLANKTON

Sampling of phytoplankton in Ninety-Nine Islands Impoundment and the Broad River was conducted monthly from September 1974 through November 1975, and quarterly into 1977. Mainstream stations did not differ significantly in standing crop and were pooled for data analyses.

Monthly standing crop values, except during summer, exhibited fluctuations which appeared to be in response to changes in discharge. Nutrients, incident light, and temperature were of secondary importance relative to discharge in determining phytoplankton abundance. However, the seasonal succession of the phytoplankton composition was not disrupted by discharge. Diatoms were most abundant during fall and winter, whereas green algae were most abundant during summer. The blue-green algae were a minor component of the phytoplankton throughout the study.

Discharge appeared to determine the number and kind of species present. An inverse relationship existed between discharge and the number of species. Small planktonic species appeared to be most adapted to the habitats within the mainstream and the backwater.

The physiological conditions of the mainstream phytoplankton was lower than the backwater phytoplankton. Species composition, generation times, and discharge appeared to be the principle factors contributing to the differences in the physiological conditions of the two systems.

PERIPHYTON-PHYTOPLANKTON RELATIONSHIPS

The periphyton contributed very little to the phytoplankton in the mainstream or backwater, except during winter. During winter, when diatoms were the dominant algae in both the periphyton and phytoplantkon the percent of total density of species shared in common was greatest in both communities. At other times of the year, when diatoms were replaced by small planktonic algae in the phytoplankton, the percent of total density of species shared in common was lowest.

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CHAPTER 4. Zooplankton

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INTRODUCTION

BACKGROUND

The zooplankton considered in this chapter are microscopic rotifers, copepods, and cladocerans. These organisms are found in both lentic and lotic environments. Although lentic zooplankton communities are well defined (Hutchinson 1967), those of running water have been traditionally thought of as transitory and derived from sources other than the main river channel (Hynes 1970). Large rivers, however, may be capable of supporting stable, reproducing zooplankton communities (Eddy 1932; Hynes 1970; Winner 1975).

Rotifers are usually the numerically dominant zooplankton in rivers, followed in abundance by copepods and cladocerans (Enaceanu 1964 cited by Winner 1975; Williams 1966). Williams (1966) observed a large range of population densities in rivers throughout the United States, but noted that rotifers remained the numerically dominant group. Rotifers have been observed to be the numerically dominant group in the Broad River (Duke Power Company 1974).

Zooplankton population densities are influenced by a variety of factors including temperature, chemical composition of the water, quality and quantity of food, and predation; these and other factors have been extensively investigated (Edmondson 1960, 1965; Hutchinson 1967; Pejler 1957; Reid 1961; Wetzel 1975). Of particular importance in an environment such as the Broad River-Ninety-Nine Islands Impoundment are upstream sources of plankton, floods, current, and silt.

Backwaters, reservoirs, and other lentic areas can significantly contribute to zooplankton populations in rivers (Armitage and Capper 1976; Beach 1960; Eddy 1932; Prins and Davis 1966). Plankton-rich water from these sources is introduced to the main river channel through the action of floods and currents. Hynes (1970) summarized this process, noting that the density of zooplankton in a river increases as increased river current and flooding flush out backwaters and other planktogenic areas. Continued flooding may reduce the zooplankton density of these areas, and after the organisms are washed into the river, the increased flow may dilute the density of plankton.

River current also keeps substances introduced from floods and runoff in suspension. High silt loads have been recorded in the Broad River (U.S.G.S. 1974, 1975, 1976). In a small, shallow reservoir such as Ninety-Nine Islands, silt can also be introduced and retained in the water column through wind-generated wave action on the sediments and shoreline. Silt is a major factor influencing zooplankton populations (Williams 1966), limiting zooplankton density primarily by causing mechanical damage (Pennak 1946) and interfering with feeding (Pennak 1946; Rylov 1940 cited by Winner 1975; Sabaneef 1952 cited by Winner 1975).

OBJECTIVES

The objectives of this study were to:

1) determine the density and species composition of zooplankton in the Broad River and Ninety-Nine Islands Impoundment in the vicinity of the proposed Cherokee Nuclear Station;
2) determine the temporal and spatial distribution of the zooplankton in the study area, and;
3) relate the density, composition, and distribution of the zooplankton to biological and physical-chemical data.

MATERIALS AND METHODS

FIELD PROCEDURES

Stations 451.5, 451.8, 452.3, 453.1, 453.2, 459.0. 460.3, and 462.0 were sampled for zooplankton. The locations and descriptions of these stations are found in Chapter 1. Station 462.0 was considered a backwater station; all other stations were considered as mainstream. Duplicate samples were taken at all stations.

Sampling at all stations except 451.5 and 451.8 began in September 1974 and continued monthly through November 1975. In March 1975, Stations 452.3, 453.1, and 453.2, downstream from the Ninety-Nine Islands Dam, could not be sampled due to high water. Quarterly samples were collected in January, April, July, and October 1976 at Stations 453.1, 459.0, and 460.3. Stations 451.5 and 451.8 were sampled in July and October 1976 and January and April 1977. All samples were taken with an oceanographic style 76-μm mesh plankton net with a mouth diameter of 0.5 m. A flowmeter suspended in the mouth of the net allowed calculation of the volume filtered. Sampling was accomplished by lowering the net into the water and holding it in the current for a measured time (usually 3 to 10 sec depending on the silt load present). The net was towed at Stations 459.0, 462.0, and occasionally 460.2 due to the slow current. The volume of water filtered for all samples ranged from 0.5 to 1.5 m^3.

Zooplankton were washed from the net into vials containing 5 ml of a 1% neo-synephrine (L-phenylephrine HCl) solution. The neo-synephrine relaxed the soft bodied animals (i.e. rotifers) and facilitated their identification. After approximately 15 min the samples were preserved with a sugar-formalin solution (Haney and Hall 1972).

LABORATORY PROCEDURES

Rose bengal stain was added to the samples in the laboratory to facilitate differentiation of the zooplankton from sand particles and detritus. Concentrated samples were diluted to a known volume, usually 250 ml. Subsamples were withdrawn with a Hensen-Stemple wide-bore pipette, placed in a square culture dish, and diluted to fill the dish. All zooplankton in the dish were counted and identified under a dissecting microscope capable of magnification up to 80X. When necessary, organisms were removed from subsamples with an Irwin loop, placed on a depression slide, and identified using a compound microscope. Rotifers were occasionally

placed in sodium hypochlorite (bleach) so that positive identification from the jaw parts (trophi) could be made (Edmondson 1959). Crustaceans were dissected when necessary for identification. All counts were converted to population density estimates expressed as number per cubic meter ($no \cdot m^{-3}$).

Principal taxonomic references used were Ahlstrom (1940, 1943), Bartos (1959), Brooks (1957, 1959), Edmondson (1959), Frey (1961, 1965), Ruttner-Kolisko (1974), Smirnov (1974), Voigt (1956), Wilson (1959), Wilson and Yeatman (1959), and Yeatman (1944, 1959).

PHYSICAL-CHEMICAL MEASUREMENTS

Current velocity, measured with a General Oceanics flowmeter, and temperature, measured with a mercury bulb thermometer, were determined at the time of sampling. Discharge data were obtained from U. S. Geological Survey data from the Boiling Springs gaging station located approximately 41 km upstream from the Ninety-Nine Islands Dam (U.S.G.S. 1974, 1975, 1976). Discharge values obtained from this gage were increased in proportion to the increase in drainage area at the Ninety-Nine Islands Dam. Since zooplankton densities in lotic ecosystems can be influenced by changes in discharge occurring several days prior to sampling (Hynes 1970), the discharge value used in correlation analyses was calculated using the mean of the discharge on the day of sampling and the preceding seven days. Measurements of dissolved oxygen, pH, and turbidity were obtained in the water chemistry study (Chapter 2).

DATA ANALYSIS

Means of replicate samples were calculated for purposes of discussion, calculation of frequency of occurrence, determination of important taxa, and tabular and graphical representations. The frequency of occurrence of a taxon, indicating the percentage of samples in which it was found, was calculated for the monthly samples. A taxon was considered important if its mean density from monthly sampling at a station was greater than or equal to 10% of the mean density of its appropriate group (i.e. rotifers, copepods, or cladocerans) over the same period at the same station.

Statistical analyses were performed on data from the monthly sample period. The backwater Station 462.0 was analyzed separately due to physical differences between it and the mainstream stations. Due to the non-normality and heteroscedasticity of the data, non-parametric analyses were used. Spearman's coefficients of rank correlation (Siegel 1956) were calculated with the Statistical Analysis System (SAS) of Barr et al. (1976). The ANOVA procedure used was Friedman's two-way ANOVA by ranks (Siegel 1956). In order to achieve the complete block design required by this test, data from March 1975 were not included because all stations were not sampled due to flooding.

RESULTS AND DISCUSSION

COMMUNITY COMPOSITION

One hundred fifty-two taxa of rotifers, copepods, and cladocerans were identified and enumerated from the Broad River and Ninety-Nine Islands Impoundment (Table 4-1; App. 4-1, 4-2). Densities of total zooplankton ranged from $226 \cdot m^{-3}$ to $316,760 \cdot m^{-3}$, although densities were usually below $10,000 \cdot m^{-3}$. Rotifers were the most abundant organisms, both in terms of density and number of taxa, usually making up 70 to 80% (range 38.1 to 99.8%) of the total zooplankton densities. Copepods followed in overall abundance usually constituting 20 to 30% of the total zooplankton density. Although more cladoceran than copepod taxa were found, cladocerans were found in the lowest overall densities. Cladoceran densities exceeded 10% of the total zooplankton density in only six samples.

ROTIFERS

Important Rotifer Taxa

Eighty-nine rotifer taxa were found in the monthly samples (App. 4-1); six of these were important (Table 4-2). *Brachionus caudatus*, *Conochilus unicornis*, *Conochiloides* spp., *Keratella* spp., and *Kellicottia bostoniensis* are primarily planktonic rotifers, while the bdelloid rotifers (Class Bdelloidea, Order Bdelloida) are benthic (Edmondson 1959; Ruttner-Kolisko 1974). The rotifer found in the highest density was *Brachionus caudatus* at Station 462.0 in August 1975. This rotifer was not abundant at other stations in August 1975, indicating the isolation of the backwater station during periods of low flow. *B. caudatus* was absent or rare during winter and spring months.

The maximum density of *Conochilus unicornis* was found in September 1974 at Station 459.0. This rotifer also reached relatively high densities in September 1974 and August 1975 at Station 462.0. Densities of *C. unicornis* at mainstream stations downstream from the dam were very low. *C. unicornis* showed a bimodal population distribution with density peaks in fall 1974 and summer 1975.

Conochiloides spp. was usually found in low densities, especially at mainstream stations. The highest densities of this rotifer at all stations were found during the summer of 1975, with the maximum density at Station 462.0 in August 1975. The lowest mean densities of this rotifer were at mainstream stations downstream from the dam.

Keratella spp. and *Kellicottia bostoniensis* were also usually found in low densities. *Keratella* spp. exhibited a pulse in spring 1975 while *Kellicottia bostoniensis* showed density pulses in the fall of 1974 and 1975.

Planktonic rotifer densities were reduced at mainstream stations, increasing the relative importance of non-planktonic rotifers such as bdelloids. Bdelloids were found in higher mean densities at the mainstream

Table 4-1. Taxa collected from the Broad River - Ninety-Nine Islands Impoundment, September 1974-April 1977.

Phylum Rotifera
- Class Bdelloidea
  - Order Bdelloida
    - Unidentified Bdelloida
- Class Monogononta
  - Order Collothecaceae
    - Family Collothecidae
      - Collotheca spp.
  - Order Flosculariaceae
    - Family Conochilidae
      - Conochiloides coenobasis Skorikov
      - C. dossuarius (Hudson)
      - C. natans (Seligo)
      - C. spp.
      - Conochilus unicornis Rousselet
    - Family Flosculariidae
      - Ptygura spp.
      - Unidentified Flosculariidae
    - Family Hexarthridae
      - Hexarthra spp.
    - Family Testudinellidae
      - Filinia limnetica (Ehrenberg)
      - F. longiseta (Ehrenberg)
      - F. spp.
      - Pompholyx sulcata Hudson
      - Testudinella spp.
  - Order Ploima
    - Family Asplanchnidae
      - Asplanchna amphora (Hudson)
      - A. priodonta Gosse
      - A. spp.
    - Family Brachionidae
      - Subfamily Brachioninae
        - Brachionus angularis Gosse
        - B. bennini (Leissling)
        - B. bidentata Anderson
        - B. calyciflorus Pallas
        - B. caudatus Barrois and Daday
        - B. havanaensis (Murray)
        - B. patulus (O. F. Müller)
        - B. quadridentatus Hermann
        - B. urceolaris O. F. Müller
        - B. spp.
        - Euchlanis spp.
        - Kellicottia bostoniensis (Rousselet)
        - Keratella americana Carlin
        - K. cochlearis Gosse
        - K. crassa Ahlstrom
        - K. earlinae Ahlstrom
        - K. quadrata (O. F. Müller)
        - K. spp.
        - Lophocharis salpina (Ehrenberg)
        - L. spp.
        - Macrochaetus subquadratus Perty
        - Mytilina unguipes (Lucks)
        - M. spp.
        - Notholca acuminata Hudson
        - N. labis Gosse
        - N. spp.
        - Platyias quadricornis Ehrenberg
        - Trichotria tetractis (Ehrenberg)
      - Subfamily Colurinae
        - Lepadella ovalis (O. F. Müller)
        - L. patella (O. F. Müller)
        - L. spp.
    - Family Dicranophoridae
      - Dicranophorus forcipatus (O. F. Müller)
      - Encentrum spp.
      - Unidentified Dicranophoridae
    - Family Gastropidae
      - Chromogaster ovalis (Bergendal)
      - Gastropus stylifer Imhof
      - G. spp.
    - Family Lecanidae
      - Lecane flexilis (Gosse)
      - L. haliclysta Harring and Meyers
      - L. hastata (Murray)
      - L. luna (O. F. Müller)
      - L. ploenensis (Voigt)
      - L. spp.
      - Monostyla crenata Harring
      - M. lunaris (Ehrenberg)
      - M. quadridentata Ehrenberg
      - M. stenroosi Meissener
      - M. spp.
      - Unidentified Lecanidae
    - Family Notommatidae
      - Cephalodella spp.
      - Monommata aeschyna Myers
      - M. hyalina Myers
      - Notommata spp.
      - Unidentified Notommatidae
    - Family Proalidae
      - Proales spp.
    - Family Synchaetidae
      - Ploesoma hudsoni (Imhof)
      - P. truncatum (Levander)
      - Polyarthra dolichoptera Idelson
      - P. euryptera Wierzejski
      - P. longiremis Carlin
      - P. vulgaris Carlin
      - P. spp.
      - Synchaeta spp.
    - Family Trichocercidae
      - Trichocerca bicristata (Gosse)
      - T. capucina Wierzejski and Zacharias
      - T. cylindrica (Imhof)
      - T. longiseta (Schrank)
      - T. multicrinis (Kellicott)
      - T. porcellus (Gosse)
      - T. similis (Wierzejski)
      - T. stylata (Gosse)
      - T. spp.
- Unidentified Rotifera

Table 4-1. cont.

Phylum Arthropoda
- Class Crustacea
  - Order Cladocera
    - Family Bosminidae
      - Bosmina longirostris (O. F. Müller)
      - Immature Bosmina
    - Family Chydoridae
      - Alona costata Sars
      - A. guttata Sars
      - A. setulosa Megard
      - Immature Alona
      - Chydorus sphaericus (O. F. Müller)
      - Disparalona acutirostris (Birge)
      - D. rostrata (Koch)
      - D. spp.
      - Kurzia spp.
      - Leydigia leydigi (Leydig)
      - Pleuroxus hamulatus Birge
      - Immature Chydoridae
      - Unidentified Chydoridae
    - Family Daphnidae
      - Ceriodaphnia lacustris Birge
      - C. spp.
      - Immature Ceriodaphnia
      - Daphnia ambigua Scourfield
      - D. parvula Fordyce
      - Immature Daphnia
      - Moina spp.
      - Immature Moina
      - Scapholeberis kingi Sars
      - Immature Scapholeberis
    - Family Macrothricidae
      - Illyocryptus sordidus (Liéven)
      - I. spinifer Herrick
      - Macrothrix laticornis (Jurine)
    - Family Sididae
      - Diaphanosoma brachyurum (Liéven)
      - D. leuchtenbergianum Fischer
      - Immature Diaphanosoma
      - Sida crystallina (O. F. Müller)
    - Immature Cladocera
  - Order Copepoda
    - Sub-Order Calanoida
      - Family Diaptomidae
        - Diaptomus mississippiensis Marsh
        - D. pallidus Herrick
        - D. reighardi Marsh
        - D. spp.
    - Calanoida copepodids
    - Sub-Order Cyclopoida
      - Family Cyclopidae
        - Cyclops nearcticus Kiefer
        - C. thomasi Forbes
        - C. varicans rubellus Lilljeborg
        - C. vernalis Fischer
        - Eucyclops agilis (Koch)
        - E. prionophorus Kiefer
        - Mesocyclops edax (Forbes
        - Paracyclops fimbriatus (Rehberg)
        - Tropocyclops prasinus Fischer
    - Cyclopoida copepodids
    - Sub-Order Harpacticoida
      - Family Canthocamptidae
        - Attheyella illinoisensis (Forbes)
        - Bryocamptus hiemalis (Pearse)
        - B. zschokkei (Schmeil)
        - B. spp.
        - Canthocamptus robertcokeri Wilson
        - Elaphoidella bidens coronata (Sars)
        - Epactophanes richardi Mrazek
        - Moraria cristata Chappuis
        - Parastenocaris spp.
      - Family Phyllognathopidae
        - Phyllognathopus viguieri (Maupas)
    - Harpacticoida copepodids
    - Unidentified Harpacticoida
  - Nauplii

Table 4-2. Important rotifer taxa from the Broad River and Ninety-Nine Islands Impoundment, September 1974-November 1975. Important rotifer taxa are those which had a mean density at any one station greater than or equal to 10% of the mean density of total rotifers at that station.

Taxon	Stations Where Important	Frequency of Occurrence	Maximum Density ($No \cdot m^{-3}$)
Bdelloids	452.3, 453.1, 453.2, 460.3	98.8%	10,192
Brachionus caudatus	453.1, 459.0, 462.0	34.5%	135,644
Conochiloides spp.	462.0	42.5%	125,714
Conochilus unicornis	459.0, 460.3, 462.0	58.6%	65,280
Kellicottia bostoniensis	460.3	75.9%	5,712
Keratella spp.	452.3, 453.1, 462.0	34.5%	135,644

stations than at the backwater station (with the exception of 459.0 which had the least flow of any mainstream station). The higher densities at mainstream stations were probably due to the current washing these rotifers into the water column from their points of attachment in sheltered areas, a process similar to that which Hynes (1970) described in reference to benthic drift. Williams (1966) noted that bdelloid and other benthic rotifers were common in plankton samples from shallow, turbid rivers. Bdelloids were also common in plankton samples from the Yadkin River, N. C. (Edmunds and Carter 1978). Bdelloids in the Broad River and Ninety-Nine Islands Impoundment showed essentially a unimodal density distribution with the highest densities in fall 1974.

Rotifer-Environment Relationships

Significant variations in both temporal and spatial distribution of total rotifer densities were observed (Table 4-3). Population densities of rotifers were essentially bimodal, with major population density peaks in fall 1974 and late winter-spring 1975 (Fig. 4-1). Higher densities of rotifers were found at mainstream stations upstream from the dam than at mainstream stations downstream from the dam (Fig. 4-1). Even though the impoundment had a very short retention time and current was present at both Stations 459.0 and 460.3, conditions at these two stations may have been more favorable for the development of plankton than at the mainstream stations downstream from the dam. The river upstream from the dam in the area of Stations 459.0 and 460.3 was deeper with a much smoother flow than those stations downstream, which were shallow and turbulent, with many riffles and boulders; other studies have noted that obstacles of this type decreased rotifer densities (Beach 1960; Hynes 1970). Another factor contributing to the generally higher densities at mainstream stations upstream from the dam might have been the introduction of plankton from backwater areas. Although Station 462.0 was isolated from the river, as indicated by density differences between this station and Station 460.3 (App. 4-1), areas closer to the river channel could have provided sheltered areas for the production of planktonic organisms, which could then be washed into the river. Such planktogenic areas were absent downstream from the dam.

Rotifer densities at the mainstream stations showed significant negative correlations with velocity, discharge, pH, and dissolved oxygen, and a significant positive correlation with temperature (Table 4-4). Rotifer densities at Station 462.0 showed a significant positive correlation with temperature and a significant negative correlation with dissolved oxygen (Table 4-5). The negative correlations of velocity and discharge with rotifers in the river reflected the physical nature of the river and the role that these factors had in reducing rotifer densities. Station 462.0 had no measurable flow, and rotifers were able to reach higher densities in this sheltered area. However, even this backwater station could have been affected by discharge, as exemplified in late summer 1975. Relatively low discharge in July and August 1975 allowed population increases at all stations, especially at 459.0 and 462.0. September 1975 samples were taken after a period of high discharge, resulting in decreased population densities (Fig. 4-1). Phytoplankton densities showed a

Table 4-3. Results of Friedman's non-parametric analysis of variance by month (degrees of freedom = 13, χ^2 = 22.36) and by station (degrees of freedom = 4, χ^2 = 9.49), Stations, 452.3, 453.1, 453.2, 459.0, and 460.3, September 1974-November 1975.

Variable	Friedman's Test Statistic	
	By Month	By Station
Rotifers	38.83*	15.32*
Copepodites	41.89*	15.48*
Nauplii	47.33*	11.03*
Total Copepods	46.87*	13.32*
Total Cladocerans	38.27*	18.62*
Total Zooplankton	37.39*	12.40*

*Significant, α = 0.05

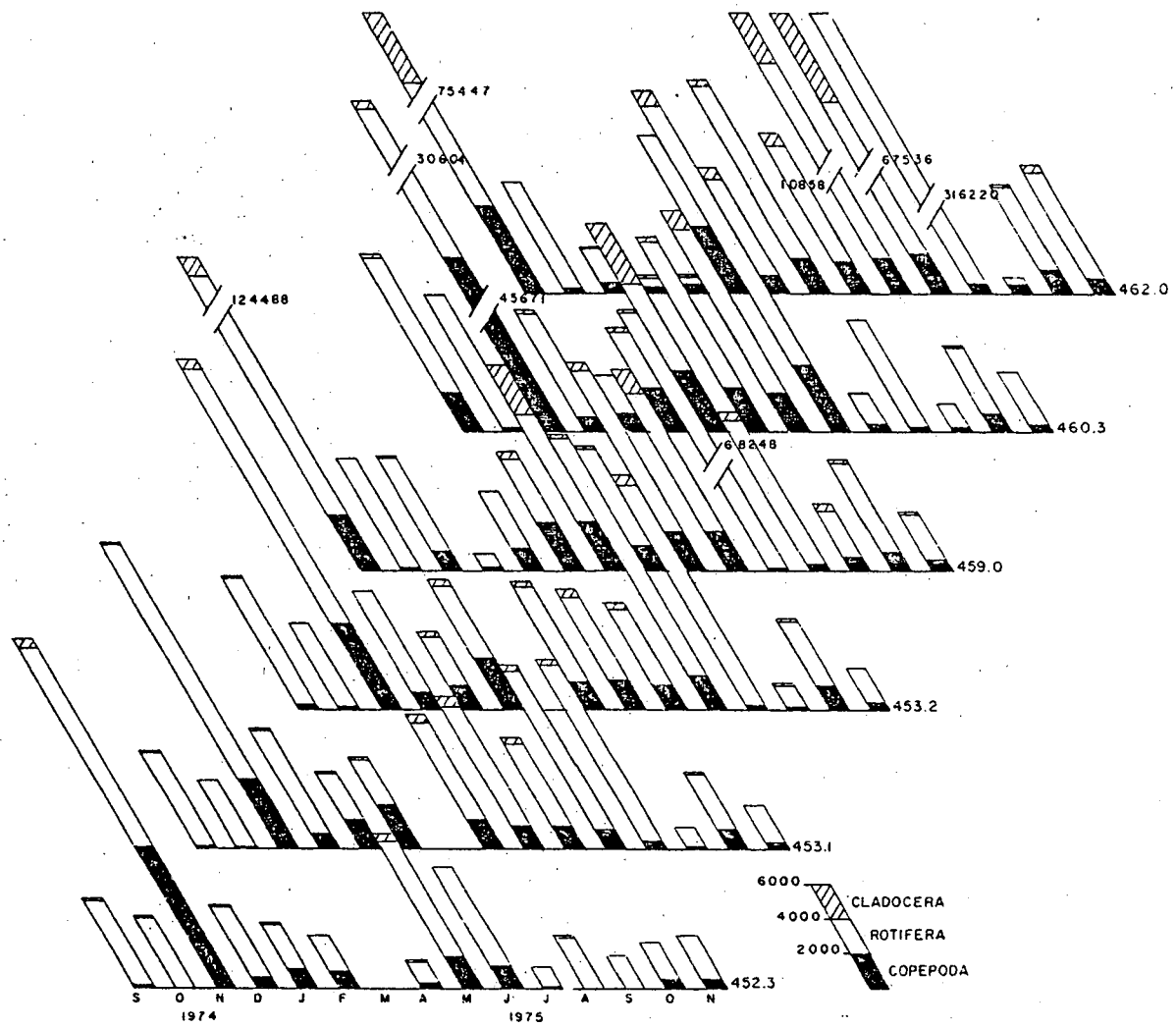

Fig. 4-1. Densities (no·m^{-3}) of rotifers, copepods, and cladocerans from the Broad River and Ninety-Nine Islands Impoundment, September 1974-November 1975.

Table 4-4. Spearman correlation coefficients (upper values) and associated probabilities (lower values) calculated with zooplankton densities and physical-chemical variables, Stations 452.3, 453.1, 453.2, 459.0, and 460.3, September 1974-November 1975.

	Velocity	Discharge	pH	Turbidity	Temperature	Dissolved oxygen
Total Rotifers	-0.40 <0.01	-0.35 <0.01	-0.25 0.04	-0.15 0.22	0.38 <0.01	-0.32 0.01
Copepodites	-0.01 0.96	0.26 0.03	0.03 0.78	-0.07 0.57	-0.08 0.52	0.10 0.43
Nauplii	0.06 0.64	0.08 0.50	0.08 0.51	0.06 0.65	-0.11 0.34	0.14 0.25
Total Copepods	0.05 0.72	0.17 0.15	0.07 0.60	0.10 0.42	-0.13 0.29	0.15 0.24
Total Cladocerans	-0.01 0.95	0.10 0.42	-0.02 0.90	0.04 0.71	0.22 0.06	-0.19 0.12
Total Zooplankton	-0.30 0.02	-0.24 0.04	-0.17 0.15	-0.11 0.39	0.31 0.01	-0.26 0.03

Table 4-5. Spearman correlation coefficients (upper values) and associated probabilities (lower values) calculated with zooplankton densities and physical-chemical variables, Station 462.0, September 1974-November 1975.

	pH	Turbidity	Temperature	Dissolved Oxygen
Total Rotifers	-0.28 0.33	-0.20 0.49	0.83 <0.01	-0.60 0.02
Copepodites	-0.10 0.75	0.17 0.56	0.53 0.04	-0.58 0.03
Nauplii	0.21 0.47	-0.02 0.95	0.24 0.39	-0.18 0.53
Total Copepods	0.22 0.45	-0.03 0.93	0.45 0.10	-0.39 0.17
Total Cladocerans	0.08 0.79	0.40 0.16	0.28 0.31	-0.26 0.38
Total Zooplankton	0.42 0.13	-0.34 0.24	0.76 <0.01	-0.49 0.07

similar pattern during this period (Chapter 3). The decrease in population densities of rotifers at Station 462.0 was nearly 100%. Increased turbidity, although not correlated with rotifer densities, may have contributed to decreases in rotifer densities by such mechanisms as mechanical damage or interfering with feeding (Pennak 1946; Sabaneef 1952 cited by Winner 1975).

In both the river and backwater, temperature showed the highest positive correlation with rotifer densities, reflecting the importance of temperature in influencing population densities of rotifers (Edmondson 1965; Hutchinson 1967). The correlations of dissolved oxygen and pH with rotifer densities were probably not biologically significant due to the narrow range over which these variables were measured, as compared to the ranges in which rotifers may be found (Pejler 1957).

COPEPODS

Important Copepod Taxa

Twenty-eight copepod taxa were identified from the Broad River and Ninety-Nine Islands Impoundment (App. 4-1, 4-2; Table 4-1). Copepod densities were dominated by immature forms, with both nauplii and cyclopoid copepodids important; *Tropocyclops prasinus* was the only important species (Table 4-6).

Nauplii, the initial larval stages of copepods, were found with the highest frequency of occurrence of any copepod taxon, and were the copepod taxon found in the highest densities in all but four samples. The highest densities of nauplii occurred in fall 1974. After June 1975 densities of nauplii were very low. No consistent spatial trends in the densities of nauplii were observed.

Cyclopoid copepodids, which constitute the latter stages (Copepodites I-V) of cyclopoid larval growth, showed a seasonal distribution similar to that of the nauplii. Their densities exceeded $900 \cdot m^{-3}$ in only six samples. Spatial differences in the densities of cyclopoid copepodids were not apparent.

Tropocyclops prasinus, a common planktonic cyclopoid with a cosmopolitan distribution (Yeatman 1959), was the most abundant copepod species and the only one to reach importance. The maximum density of *T. prasinus* was found at Station 460.3 in November 1974 and coincided with the maximum density of nauplii and cyclopoid copepodids. Other stations in November 1974 also had relatively high densities of *T. prasinus*. Densities during the remainder of the study were variable and low, with no clear spatial or temporal trends noted.

Other copepod taxa were, with few exceptions, found infrequently and in low densities. In addition to the important taxa, densities of $150 \cdot m^{-3}$ were exceeded by *Diaptomus mississippiensis*, *Diaptomus* spp., calanoid copepodids, and *Cyclops varicans rubellus*. Adult copepod densities were usually very low and characterized by irregular seasonal and spatial distribution.

Table 4-6. Important copepod taxa from the Broad River and Ninety-Nine Islands Impoundment, September 1974-November 1975. Important copepod taxa are those which had a mean density at any one station greater than or equal to 10% of the mean density of total copepods at that station.

Taxon	Stations Where Important	Frequency of Occurrence	Maximum Density ($No \cdot m^{-3}$)
Nauplii	452.3, 453.1, 453.2 459.0, 460.3, 462.0	97.7%	23,271
Cyclopoid copepodids	451.3, 453.1, 453.2 459.0, 460.3, 462.0	91.2%	11,397
Tropocyclops prasinus	460.3	62.1%	6,152

Copepod-Environment Relationships

Significant station and month differences were found in the densities of nauplii, copepodites (mature and immature copepods, exclusive of nauplii), and total copepods at the mainstream stations (Table 4-3). These differences were probably due primarily to the high densities at Station 460.3 in November 1974 which may have been due to current patterns in the river. The main river current passed along the east bank, resulting in sand deposition in mid-channel and a large backwater on the west bank where no current was noted. Discharge was low for several months and the area may have been stable enough to permit a dense copepod population to become established. Backwater areas such as this have been noted to be significant planktogenic areas (Winner 1975).

Mean densities of copepods at Station 462.0 were similar to the mean densities at the mainstream stations, with the exception of Station 460.3. Brook and Woodward (1956) and Cowell (1967, 1970) found higher densities of crustaceans associated with lentic habitats due to the longer retention times of these areas. In the former study it was determined that retention time must be greater than 18 days for a significant crustacean population to develop. The absence of large spatial differences in copepod densities between mainstream and backwater areas in the present study may have been due to several factors. The sampling technique of surface tows may have underestimated a copepod population that migrated to lower depths in the daytime. The short retention time of the Ninety-Nine Islands Impoundment, typically less than 2 days, probably made it an unstable area for the development of a dense copepod population, resulting in densities similar to the river. Fish predation in the backwater area may have reduced the densities of large copepods, enabling the smaller forms to predominate, as described by Brooks and Dodson (1965). This hypothesis is supported by the absence of large copepods such as *Diaptomus* and the preponderance of smaller *Tropocyclops prasinus* and immature forms.

In general, total copepod densities followed a bimodal distribution with pulses in fall and spring. The low density of copepods relative to rotifers in the Broad River and Ninety-Nine Islands Impoundment is similar to results from the studies of the Yadkin River, N. C. (Edmunds and Carter 1978), and other rivers throughout the world (Hynes 1970; Williams 1966; Winner 1975). Hutchinson (1967) and Schindler and Noven (1971) discussed the dominance of copepods by nauplii and copepodids that was similar to the pattern found in this study. Although the trends were similar, the population densities of copepods reported in the present study were much lower than those reported by these investigators.

Correlations of copepod groups with physical-chemical variables resulted in a positive correlation of copepodites with discharge at the mainstream stations (Table 4-4), while copepodites showed a significant positive correlation with temperature and a significant negative correlation with dissolved oxygen at Station 462.0 (Table 4-5). In view of the work of Brook and Woodward (1956) and Cowell (1967, 1970) discussed previously, the positive correlation of copepodites with discharge was probably spurious.

The correlations of copepodites with dissolved oxygen and temperature reflected, as with rotifers, the inverse relationship between temperature and dissolved oxygen rather than between copepodites and dissolved oxygen.

Both the structure of the copepod population and the physical nature of the Broad River and Ninety-Nine Islands Impoundment suggest that discharge, velocity, and turbidity were detrimental to the establishment of a dense copepod community. The high discharge, velocity, and turbidity, along with the susceptibility of the backwater area to washout, must have affected the density and composition of the copepods, as described by Brook and Woodward (1956), Hynes (1970), and Winner (1975). The low copepod densities, irregular distribution of taxa, and preponderance of immature and small copepods indicated that this was not a favorable system for the development of a large and stable copepod community.

CLADOCERANS

Important Cladoceran Taxa

Of the 33 cladoceran taxa identified during the study, seven were important. These seven taxa, and their frequency of occurrence, were *Bosmina longirostris*, 65.5%; immature *Daphnia*, 35.6%; immature Cladocera, 32.2%; immature *Diaphanosoma*, 25.3%; *Diaphanosoma brachyurum*, 12.6%; *D. leuchtenbergianum*, 16.1%; and *Ilyocryptus sordidus*, 9.2%. The maximum density of total cladocerans was $5,278 \cdot m^{-3}$. The generally low densities of these taxa were emphasized by the fact that they exceeded $1,000 \cdot m^{-3}$ in only nine samples. Densities of all cladoceran taxa were very low, especially when compared to rotifer and copepod densities. In the majority of samples, densities of individual taxa were below $100 \cdot m^{-3}$.

Cladoceran-Environment Relationships

Significant spatial and temporal differences in cladoceran densities were found (Table 4-3). Densities were quite variable and no seasonal trends could be discerned. Spatial differences were distinct, with mean densities ranging from 92 to $981 \cdot m^{-3}$. Mainstream stations downstream from the dam had much lower mean densities (range 92 to $247 \cdot m^{-3}$) than mainstream stations upstream from the dam ($792 \cdot m^{-3}$ at Station 459.0 and $736 \cdot m^{-3}$ at Station 460.3). Station 462.0 was similar to the other upstream stations in composition, but had a higher mean cladoceran density of $981 \cdot m^{-3}$.

Conditions in this system were not conducive to the establishment of a dense cladoceran community, as was also observed with the copepod community. This was probably due to variable discharge and short retention time, as Brook and Woodward (1956) and Cowell (1967, 1970) discussed. No significant correlations between cladocerans and physical-chemical variables were found at either the mainstream or backwater stations (Table 4-4, 4-5).

SUMMARY AND CONCLUSIONS

Six stations in the Broad River and Ninety-Nine Islands Impoundment were sampled monthly from September 1974 through November 1975. Quarterly

sampling was conducted at five stations through 1976 and part of 1977. A total of 152 taxa of rotifers, copepods, and cladocerans was identified and enumerated.

Rotifers were the most abundant organisms, usually constituting 70 to 80% of the total zooplankton density. Important rotifer taxa were Brachionus caudatus, Conochilus unicornis, Conochiloides spp., Keratella spp., Kellicottia bostoniensis, and bdelloid rotifers. All but the bdelloids were planktonic taxa. Large variations in both temporal and spatial distribution of total rotifer densities were observed. The seasonal trend of rotifers was essentially bimodal, with major pulses in fall 1974 and late winter-spring 1975. The highest rotifer densities were found at Station 462.0, a backwater. Higher densities of rotifers were found at mainstream stations upstream from the dam than at mainstream stations downstream from the dam. Velocity, discharge, and temperature appeared to be the most important variables associated with the composition and density of rotifers.

Copepods usually constituted 20 to 30% of the total zooplankton densities. Copepod densities were dominated by immature forms; both nauplii and cyclopoid copepodids were important. Tropocyclops prasinus was the only important mature copepod. Calanoid copepods, which are common in lentic habitats, were found infrequently. Copepod densities generally exhibited a bimodal population distribution with pulses in fall 1974 and spring 1975. With the exception of a high mean density at Station 460.3, mean copepod densities at backwater and mainstream stations were similar. The Broad River and Ninety-Nine Islands Impoundment system, with its flow and turbidity, was apparently unsuitable for the development of a dense copepod community. Cladocerans were found in the lowest total densities, usually constituting less than 10% of the total zooplankton density. Although monthly differences in cladoceran densities were observed, no consistent seasonal trends were found. Mean densities of cladocerans were similar at mainstream stations downstream from the dam but were considerably lower than mean densities at mainstream stations upstream from the dam. The highest mean cladoceran densities were found at the backwater station. Cladoceran densities were probably limited by discharge, turbidity, velocity, and the short or non-existent retention time.

As evidenced by the generally low densities, this system was not favorable for the development of dense zooplankton populations. Although zooplankton occasionally reached relatively high densities, exploiting conditions of low flow and reproducing in sheltered areas, they were always subject to being washed into the main river channel and carried downstream. The river downstream from the dam was an especially harsh area for zooplankton, as it was shallow and turbulent with many large riffles and rocks. The lowest mean densities of rotifers, copepods, and cladocerans were found downstream from the dam.

Although the zooplankton were transitory, they were occasionally able to attain high densities and may have become a significant, although temporary, factor in the biological productivity of this system.

But given the high allochthonous inputs to turbid rivers such as the Broad River and the generally low importance of zooplankton as fish food items in this study (Chapter 6), the zooplankton were probably not a significant factor in the structure of this ecosystem.

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CHAPTER 5. MACROINVERTEBRATES AND SUBSTRATE

Patrick S. Wingo

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INTRODUCTION

BACKGROUND

Many interacting factors influence the distribution and abundance of benthic macroinvertebrates in rivers, the salient features being substrate type, availability of food (Cummins 1973), current velocity, and temperature (Hynes 1970). The importance of substrate type in delimiting the distribution of benthos is well documented (Cummins 1966). Some investigators have suggested that substrate analysis might provide a common denominator in benthic ecology (de March 1976; Sanders 1958; Wene 1940). The relationship between substrate and macroinvertebrate distribution may be direct, owing to the physical properties of the substrate, or it may be indirect, resulting from the distribution of food (Cummins 1962). The amount of allochthonous detritus in rivers has been shown to be a significant limiting factor for macroinvertebrates inhabiting riffles (Egglishaw 1964). Particulate organic matter can represent a major energy source to consumers, provide food for detritivores, and ultimately define the trophic structure of the benthic community (Nelson and Scott 1962).

The drift, or downstream transport of macroinvertebrates and detritus, is a characteristic feature of streams (Muller 1954; Waters 1964). Drift may provide an important source of food for fish (Mundie 1971a) and facilitate rapid colonization or repopulation of denuded substrates (Elliott 1967). Drift densities have been associated with numerous variables, including illumination (Holt and Waters 1967; Waters 1962), water temperature (Muller 1966; Pearson and Franklin 1968), flow (Minshall and Winger 1968), production (Waters 1966), periods of rapid larval growth (Elliott 1967), and age of the larvae (Muller 1966).

OBJECTIVES

This chapter summarizes a baseline investigation on the macroinvertebrates of the Broad River and Ninety-Nine Islands Impoundment from September 1974 through April 1977. Benthos and drift collections, as well as supportive data, were taken from the major habitat types in order to characterize the benthic community and its components.

The objectives of this study were to:

1) describe the temporal and spatial variation in density, biomass, and community composition of aquatic macroinvertebrates in the vicinity of the proposed Cherokee Nuclear Station,
2) characterize the major habitat types of benthic macroinvertebrates,
3) provide life history information, where possible, on the major benthic organisms, and
4) describe the spatial, monthly, and diel variations in density and biomass of invertebrate drift.

MATERIALS AND METHODS

FIELD PROCEDURES

Benthos and drift collections were taken monthly from September 1974 through November 1975, and quarterly from January 1976 through April 1977 (Table 5-1). In addition, a diel study was conducted on 27 and 28 May 1975 in a riffle at Station 452.1. The sampling stations are described in detail in Chapter 1 (Fig. 1-2).

Three replicate grabs were taken at all stations except 453.1 and 452.1 with a lead-weighted modified Petersen grab having a bite of 258 cm^2 (40 in^2). At Stations 453.1 and 452.1, three replicate samples were taken with a standard Surber having a mesh of 1050 µm. A mesh of 471 µm was used in the Surber sampler after September 1975. Kick samples were taken with a circular-frame net in order to characterize qualitatively the riffle benthos downstream from Ninety-Nine Islands Impoundment. With the exception of Station 460.1, all samples were sieved in No. 30 (520-µm) mesh Wildco wash buckets and preserved with 70% ethanol containing 0.25 g/ℓ rose bengal stain. Whole grab samples from Station 460.1 were returned to the laboratory for preservation, because coarse sand sediments would not pass through the 520-µm mesh wash buckets. Temperature and depth of grab samples were recorded at all stations. A fourth grab collected at each station was used for laboratory analysis of total organic carbon and particle size of the sediments.

Duplicate drift samples were collected monthly with a 1.0-m long Nitex net which had a 0.1-m^2 mouth and 471-µm mesh. Samples were timed (usually 10 min), and flow through the net was measured at the mouth with a General Oceanics flowmeter, permitting calculation of the total volume of water filtered.

In diel drift sampling, duplicate plexiglass drift frames were bolted to a heavy steel base. Each frame had a 0.01-m^2 mouth flared back to 0.1 m^2, where 471-µm mesh bags 1.0-m in length were attached. The design permitted prolonged exposure in swift currents with no problem of backwash or clogging of nets. Twenty-four paired samples were taken for 50-min periods from 1100 to 1100 hr EDST. Ten minutes of each hour were required to remove and preserve samples, record flow measurements, and reposition the nets in the river.

LABORATORY PROCEDURES

Invertebrates were hand-picked from preserved samples under a 2X illuminated magnifying lens, identified to the lowest practicable taxon, and counted. Blotted wet weights (to 0.1 mg) were determined for major groups and for the total number of invertebrates. Chironomids were cleared for 24 hr in 10% KOH, dehydrated, and mounted in Euparal prior to identification. The principal references used in taxonomic determinations included Arnett (1968), Beck and Beck (1966, 1969, 1970), Borror and Delong (1971), Brinkhurst and Jamieson (1971), Brown (1972), Chernovskii (1949), Edmondson (1959), Hilsenhoff (1970), Johannsen (1970), Parrish (1975), Peterson (1960), Roback (1953), Ross (1944), Saether (unpublished), Usinger (1971), and Young (1954). Reference specimens were verified by recognized taxonomic authorities. Nymphs and larvae of many aquatic insects could not be

Table 5-1. Macroinvertebrate collection techniques used in the Broad River from September 1974 through April 1977.

	462.0	460.1	459.0	453.2	453.1	452.1	451.8	451.5
1974 Sep 16	*	GD	GD	D	SD	*	*	*
Oct 22	*	GD	GD	D	SD	SD	*	*
Nov 19	*	GD	GD	GD	SD	SD	*	*
Dec 17	*	GDQ	GDQ	GDQ	SD	SDQ	*	*
1975 Jan 23	G	GD	GD	GDQ	SD	SDQ	*	*
Feb 20	G	GD	GD	GDQ	SD	SDQ	*	*
Mar 20	G	GD	GD	GDQ	DQ	SDQ	*	*
Apr 24	G	GD	GD	GDQ	SD	SD	*	*
May 22	G	GD	GD	GDQ	DQ	DQ	*	*
Jun 19	G	GD	GD	GDQ	DQ	SD	*	*
Jul 24	G	GD	GD	GDQ	SD	SD	*	*
Aug 21	G	GD	GD	GDQ	SD	SD	*	*
Sep 18	G	GD	GD	GDQ	SDQ	SD	*	*
Oct 29	G	GD	GD	GDQ	SD	SD	*	*
Nov 20	G	GD	GD	GDQ	SD	SD	*	*
1976 Jan 22	*	GD	GD	GD	SD	*	*	*
Apr 22	*	GD	GD	GD	SD	*	*	*
Jul 22	*	GD	GD	GD	SD	*	D	GD
Oct 21	*	GD	GD	GD	SD	*	GD	GD
1977 Jan 26	*	*	*	*	*	*	GD	GD
Apr 22	*	*	*	*	*	*	GD	GD

G = Modified Petersen grab
S = Surber sample
D = Drift sample
Q = Qualitative (kick net) sample
* = Not sampled

identified to species due to the lack of definite characters in early instars. All specimens were labeled, preserved in 70% ethanol, and stored in two-dram vials.

A subsample of the sediment grab from each station was dried, pulverized, and analyzed for total organic carbon. The remainder of each sediment sample was sent to Duke Power Company's Soils Laboratory, where it was analyzed for grain size according to ASTM (1972) procedures.

DATA ANALYSES

Results from grab and Surber samples are presented as estimated number and biomass (blotted wet weight) per square meter, based on a mean of three replicates per station. The volume of water filtered in drift samples was calculated, and organic drift results are presented as densities (organisms/100 m^3, mg/100 m^3, or g/100 m^3). Results of carbon analyses are presented as percent carbon, based on sediment dry weight. Particle size gradation curves were analyzed according to the Wentworth classification (Wentworth 1922). This consisted of transforming the particle size in millimeters to $-\log_2$, known as phi (ϕ) units. Boulders are $< -8\phi$, cobbles -8 to -6ϕ, and pebbles and granules -6 to -1ϕ, sand -1 to 4ϕ, silt 4 to 8ϕ, and clay $> 8\phi$. Standard statistics in ϕ units, including mean particle size ($M\phi$), phi deviation ($\tau\phi$), and skewness ($\alpha\phi$) were calculated for each sample (Inman 1952).

Bartlett's test was used to test the benthos and drift data for homoscedasticity. Two-way analysis of variance was performed to test for significant differences between stations and months. If a significant interaction was detected, analysis of simple main effects was applied to isolate the sources of the interaction. Duncan's multiple range test was used to determine significant differences between stations within the significant interaction components. Stepwise multiple regression analysis was performed on the drift data and selected biological and physical variables. Pearson's moment-product correlation coefficients were calculated to determine whether selected taxa co-varied with each other. Principal component and cluster analyses were used for the ordination of macroinvertebrate habitats in the Broad River and for comparing the community structure of the Broad River to a similar, concurrent study of macroinvertebrates in the Yadkin River, N. C. (Braatz and Curtis 1978). Densities of eight benthic taxa, representing the dominant macroinvertebrates at similar habitats in both rivers, were ordinated with mean particle size, temperature, and percent carbon. The taxa selected for the analysis were Oligochaeta, Hydropsychidae, *Chironomus* sp., *Orthocladius* spp., *Polypedilum* spp., *Rheotanytarsus* spp., *Robackia* spp., and *Thienemanniella* sp. A heirarchical joiner clustering algorithm using euclidean distance as a measure of station similarity was used to aid in identifying station groups. All statistical analyses were performed using SAS (Barr et al. 1976).

Owing to the disparity of the macroinvertebrate fauna at different stations (App. 5-1), benthic stations were analyzed separately in order to reduce variability and to define organism-substrate relationships. Monthly variation

in macroinvertebrate drift was analyzed on the basis of monthly mean densities of all stations combined.

RESULTS AND DISCUSSION

SUBSTRATE AND ORGANIC CARBON ANALYSES

The backwaters of Ninety-Nine Islands Impoundment (Station 462.0) had a substrate of fine, loosely compacted silt with a high carbon content. The mean particle size was approximately 9.6 µm (6.7ϕ), and sediments consisted of 10% very fine sand, 74% silt, and 16% clay (Fig. 5-1; App. 5-2). The high carbon content (3.92%) suggests that silt and organic material settled out in the backwaters during low flow and constituted a soft, organically enriched substrate. The settling of silt and organic matter accounted for the lower turbidity noted at Station 462.0 (Chapter 2). Sediments of this kind are common in lentic habitats, where the bottom community is often dominated by burrowing detritivores (Wene 1940).

Station 460.1 was characteristic of mainstream areas of the Broad River that had a bottom of coarse sand with a low carbon content (0.08%). The mean particle size was 707 µm (Mϕ = 0.5), and sediments consisted of approximately 20% medium sand, 45% coarse sand, and 35% very coarse sand (Fig. 5-1, App. 5-2). This substrate was similar to mainstream areas of the Yadkin River, which had a mean particle size of 895 µm (Mϕ = 0.16) and a low carbon content (0.06%) (Braatz and Curtis 1978). Turbulence in the mainstream Broad River channel precludes the deposition of finer particles or the accumulation of organic deposits. Coarse sand substrates are generally unstable at velocities of 0.2 m/sec, when particles may begin to slide or roll across the bottom (surface creep) or momentarily bounce above the bottom and travel with the velocity of the water (saltation) (Inman 1949). Coarse sand in the Broad River was well sorted (τϕ = 0.8) due to water velocity causing smaller particles to stay in suspension or be transported by surface creep.

The smallest mean particle size of 8.4 µm (Mϕ = 6.9) was found at Station 459.0, where the sediments consisted of approximately 10% very fine sand, 50% silt, and 40% clay (Fig. 5-1; App. 5-2). This substrate was compact, cohesive,and generally unsuitable for burrowing organisms. Carbon values were intermediate between those in silt and sand substrates (2.05%) and sediment particles were poorly sorted (τϕ = 2.3). Scouring by the current at Station 459.0 was probably responsible for the compact nature of the substrate and its inability to accumulate large organic deposits.

The shoreline of the Broad River (Station 453.2) downstream from Ninety-Nine Islands Impoundment was subject to fluctuating water levels from both river discharge and operation of the Ninety-Nine Islands Hydroelectric Station. Sediments were formed primarily of soils eroded from the river bank and from suspended river load deposited at lower shoreline current velocities. The mean particle size was 165 µm (Mϕ = 2.6) and the substrate consisted of approximately 5% coarse sand, 25% medium sand, 40% fine sand, 18% very fine sand, and 12% silt. This substrate had a relatively lower carbon content (0.17%) and coarser sediments compared to the shoreline of the Yadkin River (Mϕ = 3.6; 0.66% carbon) (Braatz and Curtis 1978), perhaps attributable to periodic increases in discharge caused by hydroelectric generation.

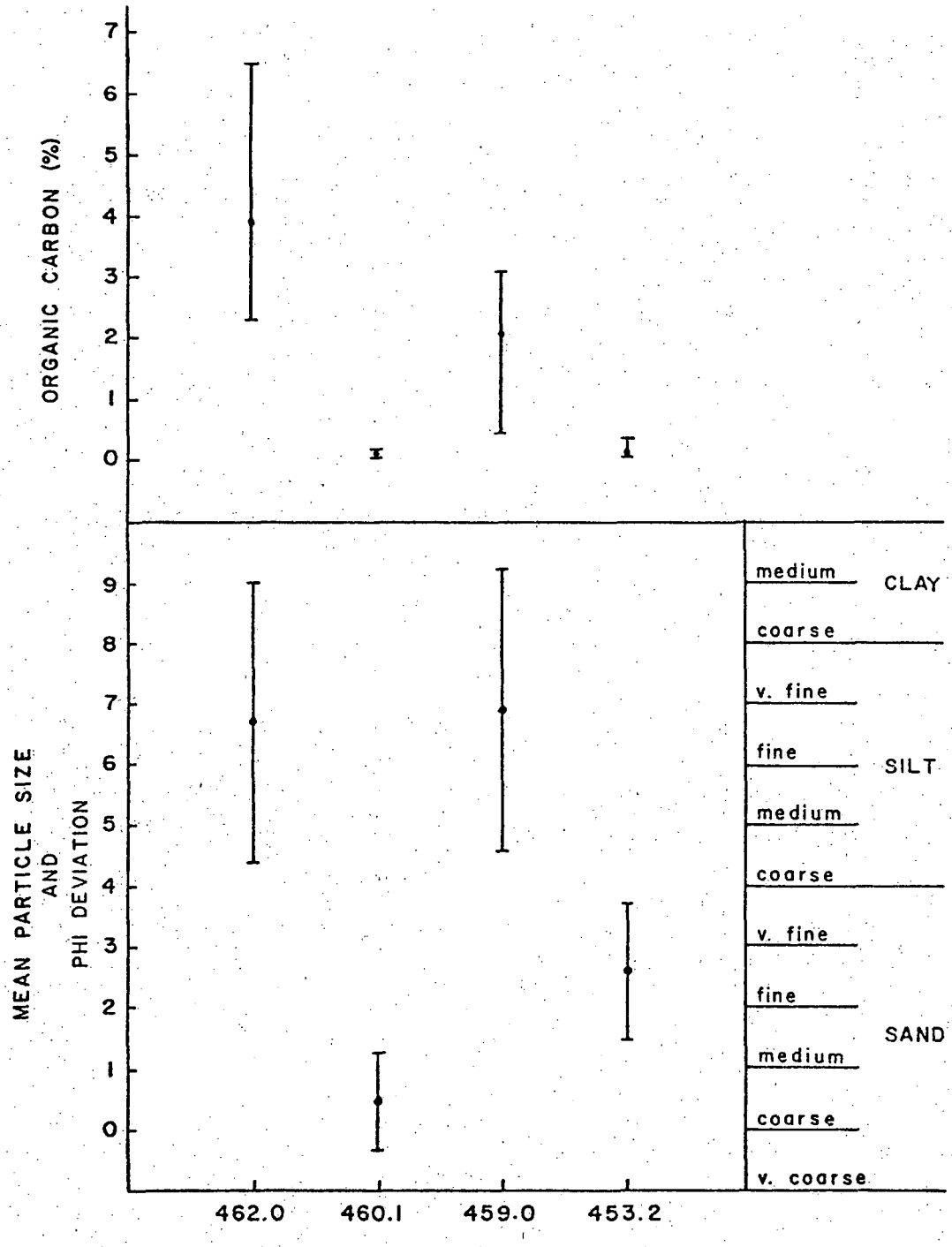


Figure 5-1. Mean substrate particle size and phi deviation (dot equals mean and lines denote range of phi deviation) and mean percent carbon (dot equals mean and lines denote ranges) of Broad River sediments.

Riffles are one of the dominant bedforms of the Broad River (Duke Power Company 1974a). The riffles (Stations 453.1 and 452.1) were characterized by boulders, cobbles, pebbles, gravel, and sand. The bryophyte-covered substrate at Station 453.1 was under water all of the year. Station 452.1 lacked bryophytes and water level fluctuations often left previously sampled areas entirely exposed. Although substrate carbon was not measured at riffles, the macroinvertebrates associated with riffles may derive a substantial portion of their nutrition from the detritus and associated microorganisms trapped behind the stones (Egglishaw 1969; Madsen 1972).

MACROINVERTEBRATE COMMUNITY COMPOSITION

A total of 227 taxa was identified in monthly (1974 and 1975) quantitative and qualitative collections (App. 5-1). Quarterly (1976 and 1977) samples were similar in composition, with eight taxa previously unreported (App. 5-3). The dominant macroinvertebrate groups were Chironomidae, Oligochaeta and Trichoptera (Fig. 5-2). Ephemeroptera and Corbiculidae were never dominant numerically, but did contribute substantially to the biomass. Plecoptera were sparse in the Broad River, and may have been limited by extreme temperatures (27.5 C) in the summer (Chapter 2).

SPATIAL AND TEMPORAL DISTRIBUTION OF MACROINVERTEBRATES

SOFT-SILT FAUNA: STATION 462.0

A total of 29 taxa was collected at Station 462.0 from January through November 1975. Oligochaetes and chironomids constituted 50 and 39%, by number, of the soft-silt fauna, respectively (Fig. 5-2). Other organisms included *Palpomyia* spp., *Chaoborus punctipennis*, and *Hexagenia* spp. (App. 5-4), all of which are typical inhabitants of soft substrates (Wene 1940).

Mean density was lowest in April (363/m^2), presumably a result of chironomid emergence, and highest in September (1,280/m^2) due to an increase in oligochaete density. Mean biomass was lowest in July (536 mg/m^2) and highest in November (7,831 mg/m^2) (Fig. 5-3). Large organisms, such as *Hexagenia* spp., were sometimes responsible for high biomass estimates when density of other organisms was relatively low.

Chironomid and oligochaete densities varied inversely ($r = -0.52$), probably because of a competitive or predator-prey interaction between these two groups (Jonasson and Thorhauge 1976; Loden 1974). *Chironomus* sp., the dominant midge, exhibited a unimodal density pattern, with densities ranging from 0 to 659/m^2. *Procladius bellus*, a predaceous midge (Leathers 1922), had peak densities of 194/m^2 occurring in March and August, suggesting a bivoltine life history.

Ceratopogonids (*Palpomyia* complex) were collected in all but two months. Density was low throughout the winter and spring, gradually increasing to a maximum (233/m^2) in September before declining sharply in October. *Palpomyia* spp. larvae frequently feed on chironomid and ceratopogonid larvae (Chan and Le Roux 1967). They also appear to be tolerant of low dissolved oxygen concentrations, since peak densities occurred during months when stratification and bottom oxygen depletion have been known to occur in the reservoir backwaters (Duke Power Company 1974a).

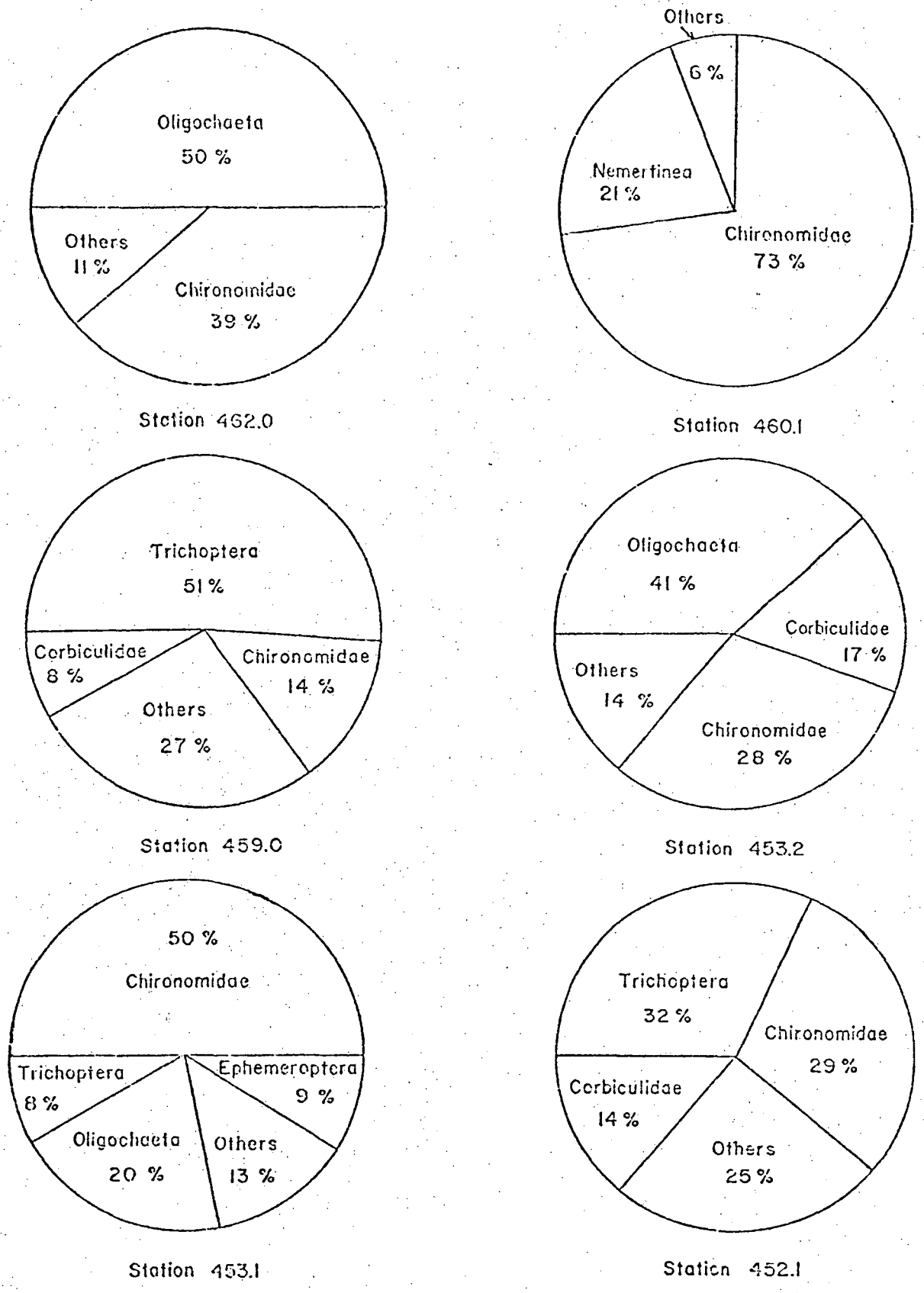
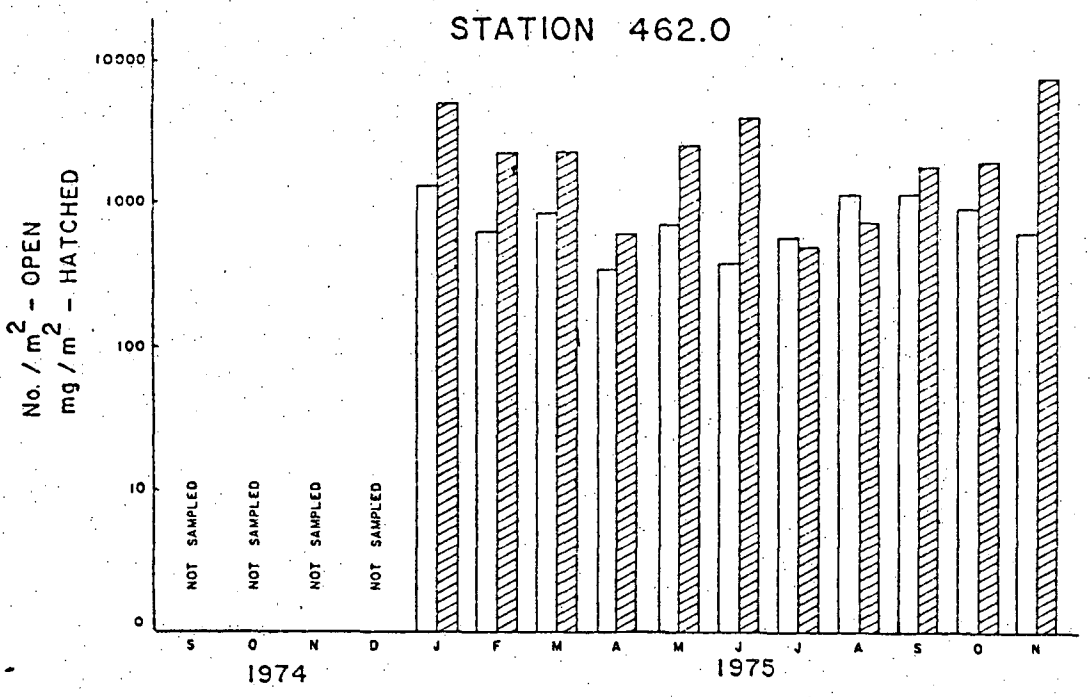


Figure 5-2. Percent composition (No./m^2) of macroinvertebrates collected in benthic samples from the Broad River from September 1974 through November 1975.



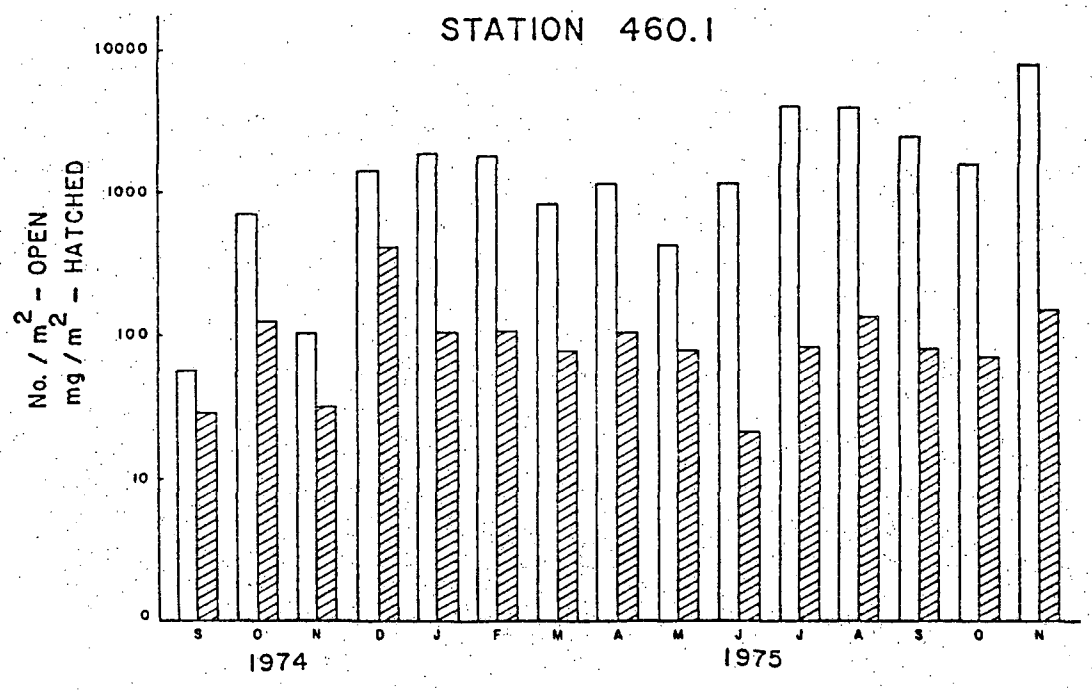


Figure 5-3. Mean density (No./m^2, open bars) and mean biomass density (mg/m^2, hatched bars) of benthic macroinvertebrates at Stations 462.0 and 460.1 from September 1974 through November 1975.

COARSE-SAND FAUNA: STATIONS 460.1 and 451.8

Sixty-one invertebrate taxa were identified from monthly samples at Station 460.1: 46 from quantitative samples, and an additional 15 taxa from qualitative collections (App. 5-1). Quarterly samples from Station 451.8 (Fig. 1-1), indicated a similar substrate and community composition to Station 460.1 (App. 5-3). The habitat and benthic community dominating the midstream of the Broad River also resembled that of the Yadkin River, North Carolina (Curtis and Braatz 1977; Duke Power Company 1974b).

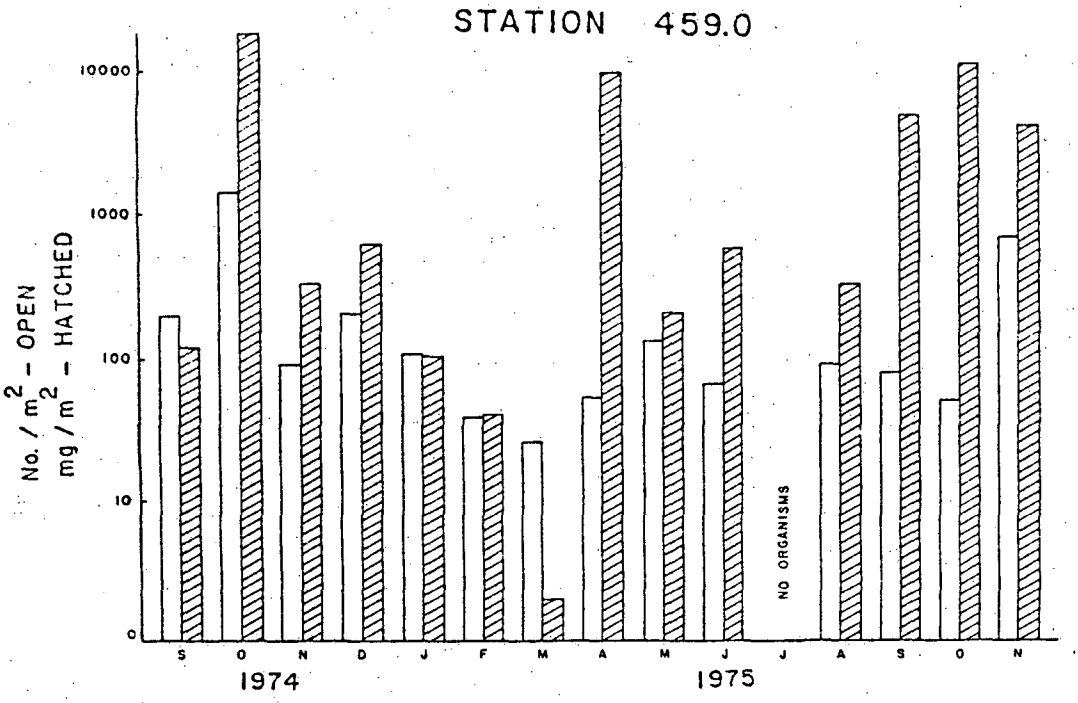
Chironomid larvae dominated the fauna at Station 460.1 (Fig. 5-2). The nemertean worm, Prostoma sp., was also abundant, constituting 21% of the total. Mean density of macroinvertebrates was highest in November 1975 (8,230/m^2), with smaller peaks in July (4,277/m^2) and August (4,030/m^2) (Fig. 5-3). Since many investigators have found coarse sand to be an unsuitable habitat for most benthos (Hynes 1970), these densities are considered high. High densities probably resulted from the fact that coarse sand was not sieved in the field, but whole grab samples were returned to the laboratory for analysis. This method retained small, early instar larvae, and provided a more accurate estimate of the actual population density (Mason et al. 1974; Mundie 1971b). Biomass density was low, with a minimum of 21 mg/m^2 in June 1975 and a maximum of 433 mg/m^2 in December 1974. The low biomass in June resulted from the small size of early instar chironomids, whereas the maximum biomass in December was associated with the overwintering of larger, more mature larvae.

The midge community of Station 460.1 was dominated by Thienemanniella sp., and Robackia spp., all of which are adapted to sandy river habitats (Chernovskii 1949), with specialized adaptations for food searching and attachment to the substrate. Thienemanniella sp. showed a bivoltine life history pattern,with peak densities in January (1,589/m^2) and July (3,463/m^2), and emergence from February through April and August through October. Robackia spp. (R. claviger and R. demeijeri) also exhibited a bivoltine life history, with maximum densities occurring in December 1974 (530/m^2) and August 1975 (698/m^2), and emergence probably occurring from March through May and from September through October. R. claviger pupae were found inside sand-grain cases on the substrate prior to their emergence. Polypedilum spp. and Nilotanypus sp. were also prevalent at Station 460.1, but exhibited random fluctuations in monthly densities (App. 5-5).

COMPACT SILT-CLAY FAUNA: STATION 459.0

The scoured, compact substrate at Station 459.0 supported the least abundant benthic fauna of all stations (Fig. 5-4). Mean densities ranged from 0 in July 1975 to 1,435/m^2 in October 1974 (App. 5-6). The October peak resulted from high numbers of Hydropsyche spp. (633/m^2) and Cheumatopsyche spp. (245/m^2) (Trichoptera: Hydropsychidae). These organisms were collected infrequently and in lower numbers throughout the remainder of the study.

The only other macroinvertebrates able to exploit this habitat were those



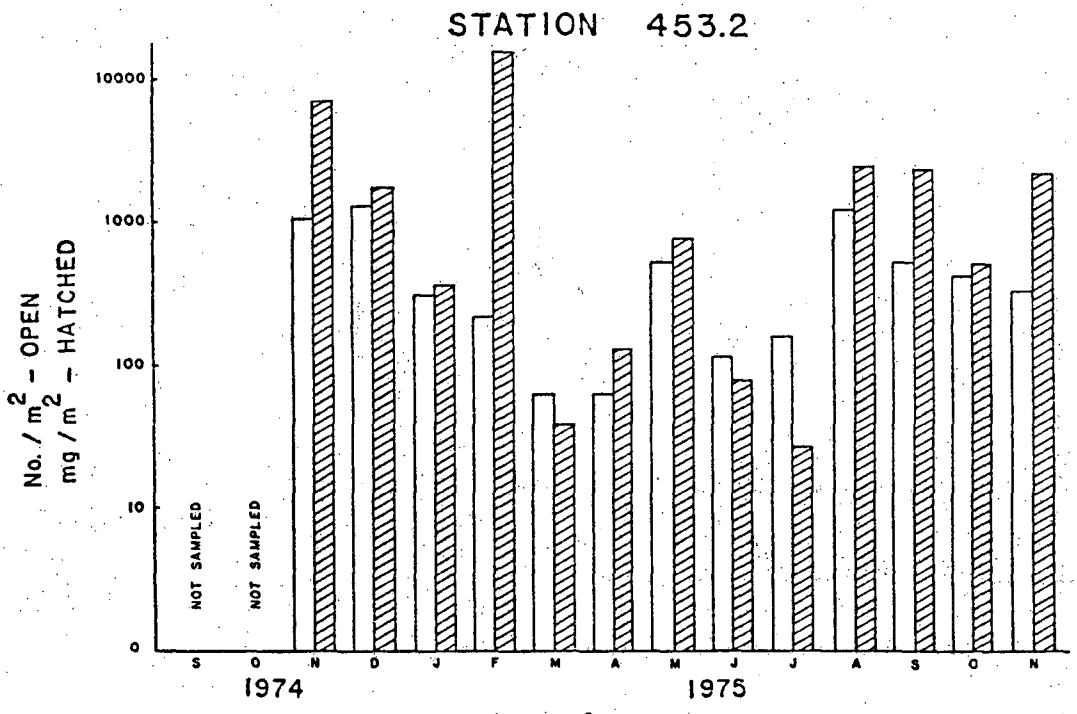


Figure 5-4. Mean density (No./m^2, open bars) and mean biomass density (mg/m^2, hatched bars) of benthic macroinvertebrates at Stations 459.0 and 453.2 from September 1974 through November 1975.

able to attach to the substrate and filter-feed on organic drift, since the substrate did not provide a large variety of food sources. Chironomids comprised 14% of the total numbers at Station 459.0 (Fig. 5-2) but were present in relatively low numbers. Rheotanytarsus spp. were the numerically dominant midges, although collected on only two occasions. Rheotanytarsus spp. are filter-feeders (Bryce and Hobart 1972) and were observed to aggregate on leaves, twigs, or any other substrate suitable for case construction.

FINE SAND-SILT FAUNA: STATIONS 453.2 and 451.5

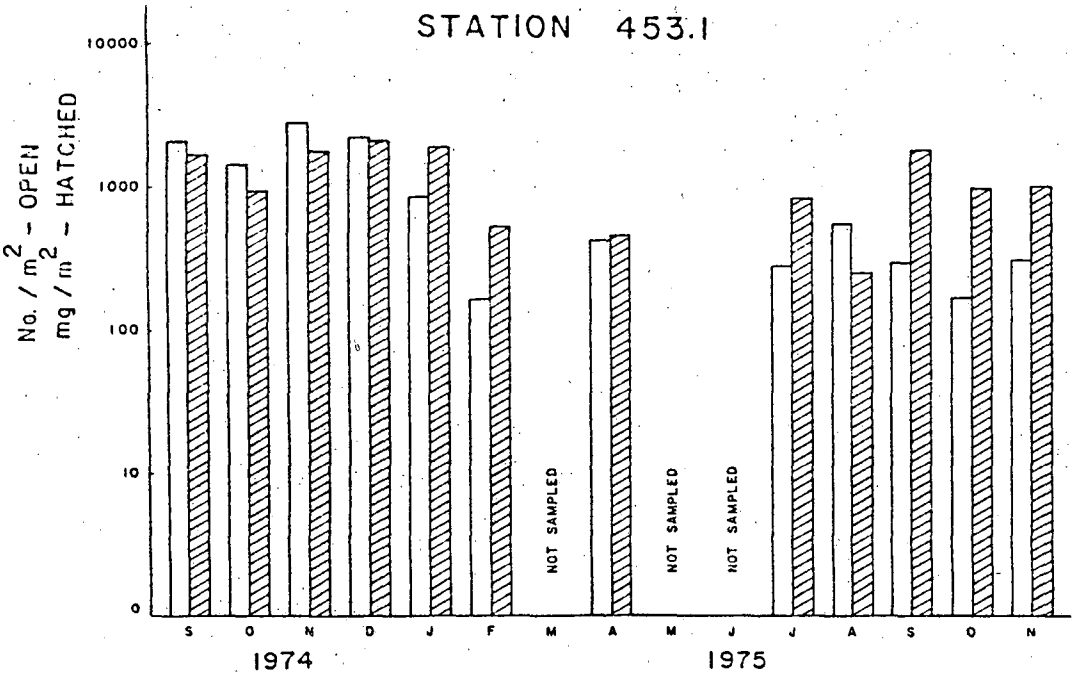
A total of 43 taxa was collected in grabs at Station 453.2 and an additional 70 taxa were taken in monthly kick samples in a riffle approximately 3 m from the shoreline (App. 5-1). Oligochaetes and chironomids were the most numerous benthic organisms, comprising 41 and 28% of the total number of organisms, respectively (Fig. 5-2). The dominance of detritivores along the river shoreline was expected, since fine sand-silt substrates provide both habitat and food for them (de March 1976). Quarterly collections taken at shoreline Station 451.5, 63 km (30 mi) downstream, indicated a similar substrate and community composition to Station 453.2.

Mean density was lowest in March and April 1975 (65/m^2) and highest in December 1974 (1,384/m^2) (Fig. 5-4). Biomass densities were influenced by the collection of large organisms such as Odonata and Pelecypoda, but showed the same general trends as the population densities. Abundance and distribution of the benthos along the shoreline downstream from the dam were affected by water level fluctuations which resulted from river discharge and hydroelectric generation. Many of the organisms probably migrated or drifted toward the shoreline from the adjacent riffle.

Two genera of riffle-dwelling midges, Orthocladius spp. and Cricotopus spp., were abundant in November 1974 and August 1975, but were absent from collections throughout most of the remaining year (App. 5-7). The presence of the midges Odontomesa sp., Paracladopelma sp., and Paralauterborniella sp. was noteworthy, since they were not collected from any other substrate type and may, therefore, select a fine sand-silt habitat.

RIFFLE FAUNA: STATIONS 453.1 AND 452.1

Surber samples at Station 453.1 revealed the greatest macroinvertebrate diversity of any station, with a total of 66 taxa taken in quantitative collections and an additional 16 taxa found in qualitative samples (App. 5-1). Epilithic bryophytes at this riffle may have provided considerable shelter for the benthos, increasing the number of available microhabitats. The evidence for seasonal patterns in density and biomass at Station 453.1 was not complete, because samples could not be taken on three occasions (Fig. 5-5). Total mean density was, however, lowest in February 1975 (167/m^2) and highest in November 1974 (2,821/m^2). Biomass was lowest in August 1975 (251 mg/m^2) and peaked in December 1974 (2,113 mg/m^2). These values reflect the overwintering and emergence of amphibiotic insect groups, particularly chironomids.



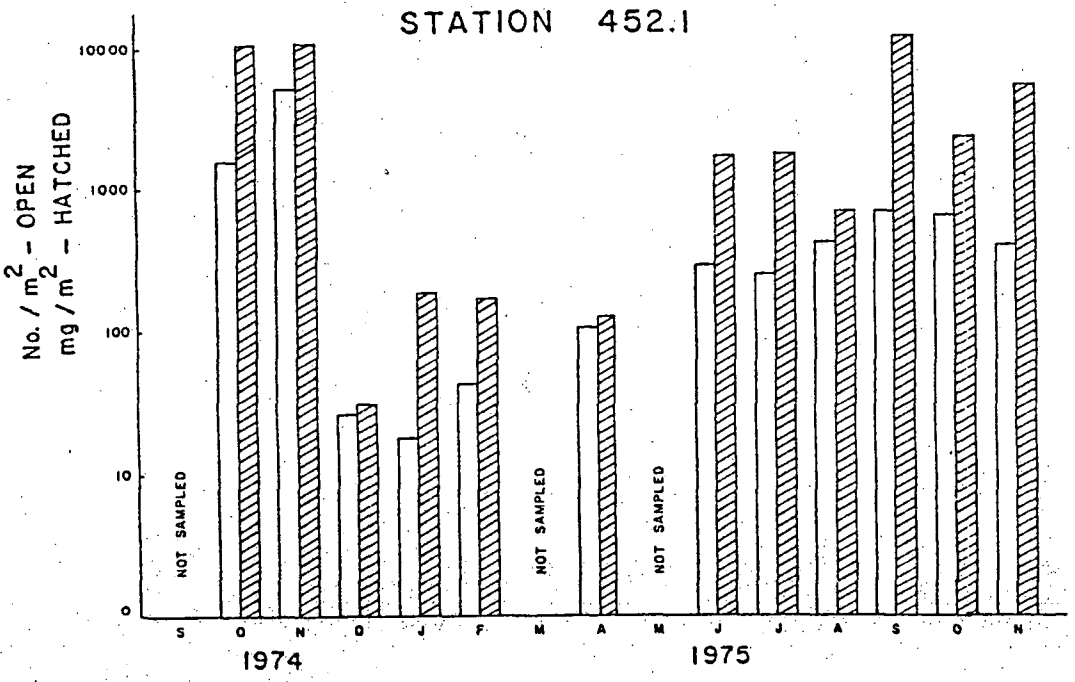


Figure 5-5. Mean density (No./m^2, open bars) and mean biomass density (mg/m^2, hatched bars) of benthic macroinvertebrates at Stations 453.1 and 452.1 from September 1974 through November 1975.

Chironomids were the most abundant organisms at Station 453.1, representing 50% of the riffle benthos (Fig. 5-2). The midges were dominated by Orthocladiinae (81%) and Diamesinae (11%). Mean density of chironomids was highest in November (1,808/m^2) and December (1,667/m^2) 1974, and generally low throughout the remainder of the study. A decrease in density of chironomid larvae in January and February 1975 coincided with an increase in the number of chironomid pupae in the benthos and adult imagoes in the drift (App. 5-8), indicating emergence. Downstream from the dam, midges were observed on the wing during all months of the year; emergence patterns appeared complex, with the Orthocladiinae and Diamesinae emerging in the winter and summer and most of the Chironominae emerging in the spring and summer. This pattern was similar to that of other lotic ecosystems, where many of the Orthocladiinae emerge at low water temperatures (Coffman 1973). The dominant Orthocladiinae at Station 453.1 were Orthocladius spp., Cricotopus spp., and Eukiefferiella spp., which represented 22, 11, and 6% of the riffle fauna, respectively. These midges are typically herbivorous, scraping aufwuchs from the surfaces of rocks and twigs (Kawecka and Kownacki 1974). The only Diamesinae collected, Potthastia longimanus, showed a pattern similar to the Orthocladiinae.

Oligochaetes were abundant at Station 453.1, representing 20% of the fauna (Fig. 5-2). Mean oligochaete density was highest in November 1974 (762/m^2) and lowest in February 1975 (7/m^2). In contrast to the results from Station 462.0, oligochaete densities tended to show a positive relationship to chironomid densities ($r = 0.58$) because of the different species composition and trophic relationship between these two groups in riffles.

Ephemeroptera made up nine percent of the macroinvertebrates at Station 453.1 (Fig. 5-2). Tricorythodes spp., the most abundant mayflies collected, are found in large rivers with moderate to fast currents, and have been reported to emerge in August and September (Hilsenhoff et al. 1972). Stenonema spp. were most abundant during the winter (App. 5-8). These nymphs are carnivorous, and most species are univoltine (Hilsenhoff 1975) and strongly thigmotactic (Berner 1959). Ephemerella spp. were found during the winter and spring, but were absent in warmer months. This genus is thought to be univoltine (Berner 1959) and intolerant of low levels of dissolved oxygen (Nebeker and Lemke 1968; Surber and Bessey 1974). Other mayflies, including Baetis, Pseudocloeon, Caenis, and Heptagenia, were collected infrequently and in relatively low numbers, but probably contributed substantially to the biomass.

Trichoptera, dominated by the net-spinning Hydropsyche spp. and Cheumatopsyche spp., constituted eight percent of the benthos at Station 453.1 (Fig. 5-2). These omnivorous filter-feeders are the most abundant and widespread genera of caddisflies, and are common in most large river systems (Hilsenhoff 1975). They are important in "nutrient spiraling", whereby the excrement from one larva provides a food source for deposit feeders and filter-feeding omnivores. This process repeats itself so that nutrients are cycled among the benthos; the majority of the particulate organic matter, except for that assimilated by the organisms ingesting it, passes through the community (Webster et al. 1976). Filter-feeding caddisflies are dependent upon current for both respiration and feeding; many are unable to construct their nets in the absence of sufficient current (Scott 1958).

Fifty-four taxa of macroinvertebrates were identified from Surber samples at Station 452.1. An additional 21 taxa were identified from qualitative collections (App. 5-1). Total mean density was lowest in January 1975 ($18/m^2$) and highest in November 1974 ($5,082/m^2$) (Fig. 5-5). The data may not represent actual population densities at Station 452.1, since Surber samples were collected at a specified depth of 0.3 m or less, and water level fluctuations often left previously sampled areas exposed. Recently inundated substrates were sometimes sampled when a rise in water level made it impossible to sample at previous locations.

Trichoptera were the most numerous organisms at Station 452.1, representing 32% of the fauna (Fig. 5-2). Larvae of Cheumatopsyche spp. made up 23% of the total, with highest densities in November 1974 ($2,205/m^2$) and relatively low mean densities throughout the remainder of the year. Hydropsyche spp. and Hydroptila spp. had similar seasonal distributions but were less abundant.

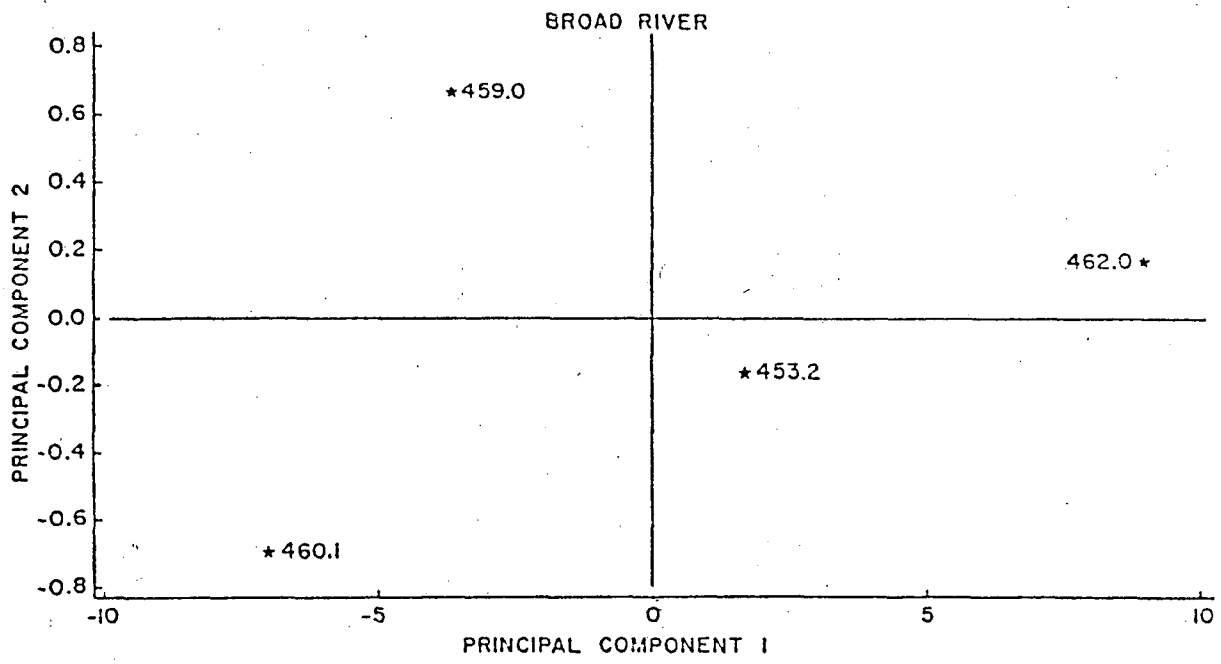
Chironomids comprised 29% of the organisms at Station 452.1 (Fig. 5-2), with highest densities ($1,869/m^2$) in November 1974. Cricotopus spp., Orthocladius spp., and Eukiefferiella spp. were the dominant chironomids, each abundant in November 1974 and declining in density in December 1974 due to emergence. A high density of chironomid pupae in November 1974 supported the conclusion that peak emergence occurred in the winter (App. 5-9).

Corbiculidae, Oligochaeta, and Ephemeroptera comprised 14, 9, and 5% of the organisms at Station 452.1, respectively. Mean densities of these groups fluctuated randomly, with no discernable seasonal patterns.

ORDINATION OF MACROINVERTEBRATE HABITATS

The five benthic habitats sampled in the Broad River and Ninety-Nine Islands Impoundment were relatively distinct in terms of substrate, current velocity, food availability, and dominance of certain benthic organisms. These habitats were characterized by the five substrate types previously discussed. Stations 462.0, 460.1, 459.0 and 453.2 tended to be dissimilar, based on principal component (PC) coefficients and cluster analysis (Fig. 5-6). Principal component coefficients for riffle stations (453.1 and 452.1) were not computed, because particle size and carbon were not measured. The riffles, however, did support a distinct benthic community. Principal component 1 loaded heavily on mean particle size, percent carbon, temperature, and those organisms associated with soft, organic sediments (Chironomus sp. and Oligochaeta). Principal component 1 also loaded inversely on organisms found on coarser, sandy, low-carbon sediments (Robackia spp., Thienemanniella sp., and Polypedilum spp.). Principal component 2 loaded inversely on organisms which were most abundant in riffle habitats (Rheotanytarsus spp., Hydropsychidae, and Orthocladius spp.) and on mean particle size. All remaining PC 2 coefficients were positive, and most were smaller in magnitude (Table 5-2). These data suggest that benthic habitats in the Broad River and Ninety-Nine Islands Impoundment are heterogeneous with respect to sediment type, current velocity, and abundance of the dominant members of each community.

A similar PC loading pattern was exhibited for the same variables in a concurrent study on the Yadkin River, N. C., and for the combined data from both rivers (Fig. 5-7, Table 5-2). Heterogeneity in the distribution



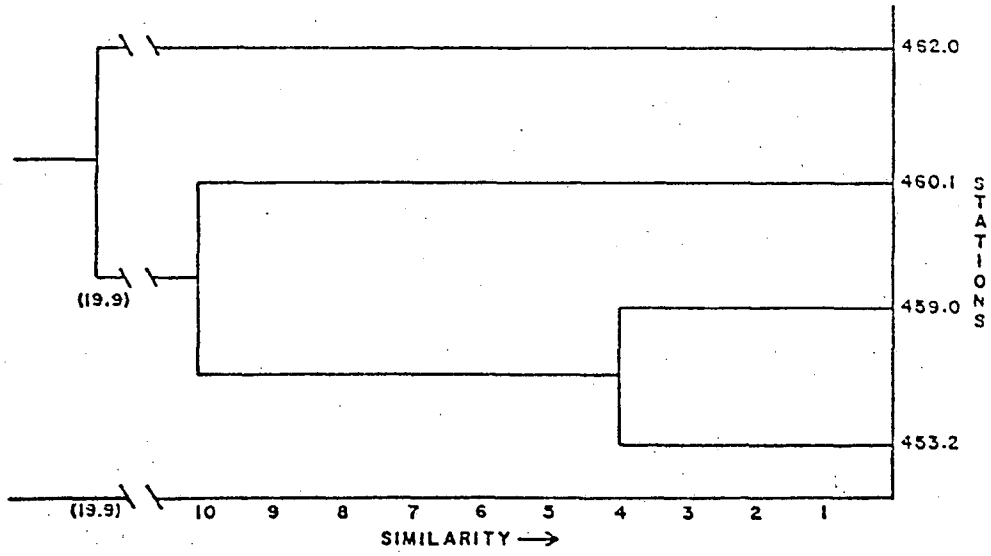
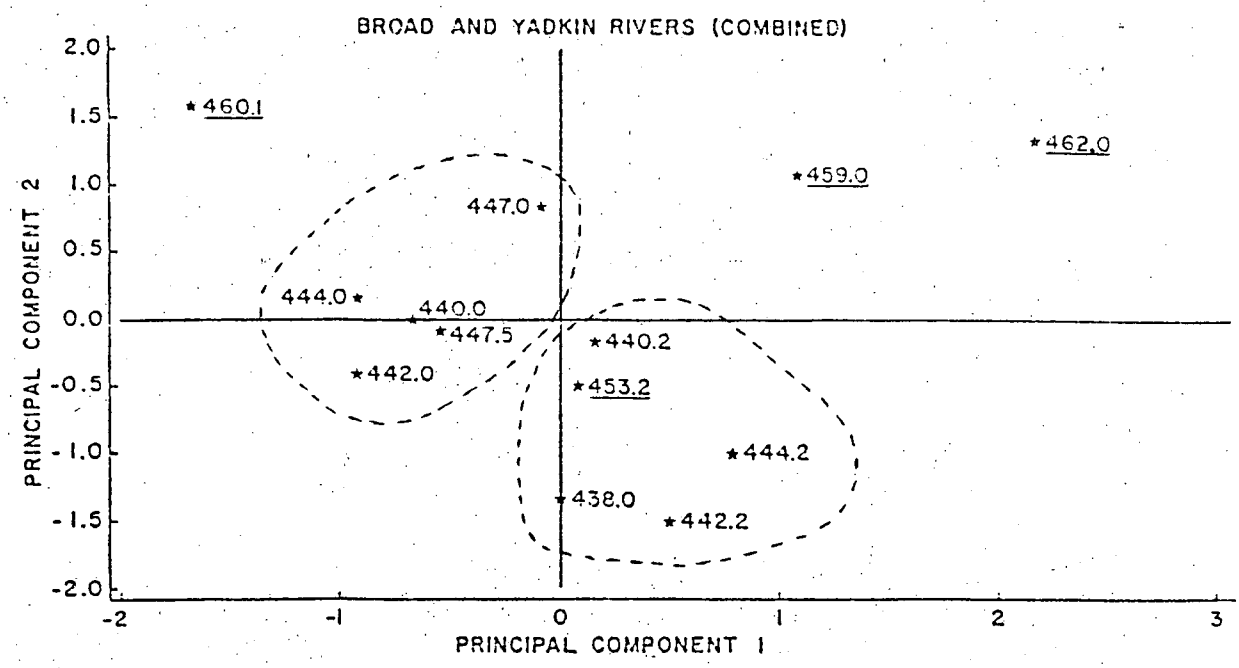


Figure 5-6. Principal components ordination of macroinvertebrate habitats in the Broad River (top) and cluster analysis of sampling stations (bottom). Similarity is measured by euclidean distance.

Table 5-2. Principal component coefficients of selected biological and physical variables calculated from concurrent studies on the Broad and Yadkin Rivers, and summarized for both rivers.

	Broad River Principal Components		Yadkin River Principal Components		Broad and Yadkin Rivers (Combined Data) Principal Components	
	1	2	1	2	1	2
Chironomus sp.	0.76	0.61	0.70	0.48	0.69	-0.05
Hydropsychidae	0.11	-0.92	0.58	-0.50	0.35	0.24
Oligochaeta	0.61	0.54	0.86	0.13	0.53	-0.54
Orthocladius spp.	-0.03	-0.17	0.01	-0.47	-0.10	-0.46
Polypedilum spp.	-0.82	0.54	0.26	0.67	-0.08	-0.56
Rheotanytarsus spp.	-0.17	-0.99	0.60	0.28	0.08	-0.61
Robackia spp.	-0.87	0.40	-0.75	0.38	-0.76	0.38
Thienemanniella sp.	-0.87	0.40	-0.69	0.49	-0.57	0.49
Mϕ	0.85	-0.36	0.83	0.01	0.89	0.20
Temperature	0.82	0.57	-0.07	-0.86	0.40	0.61
% Carbon	0.86	0.15	0.94	0.07	0.86	0.39



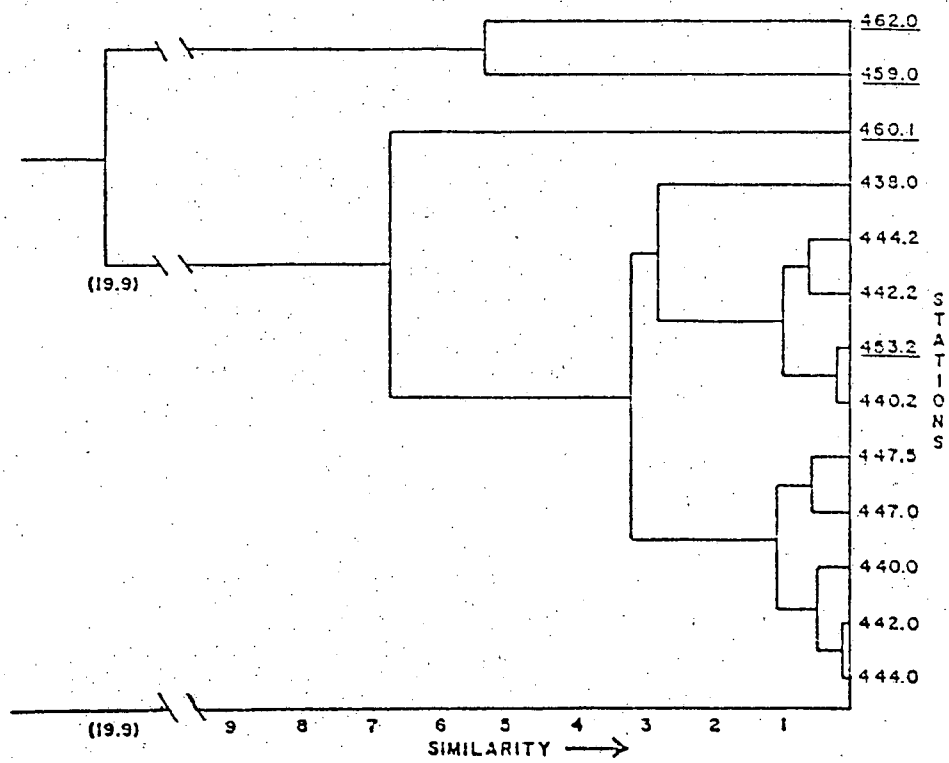


Figure 5-7. Principal components ordination of macroinvertebrate habitats in the Broad and Yadkin Rivers (top) (combined data), and cluster analysis of sampling stations (bottom). Similarity is measured by euclidean distance. Broad River stations are underscored.

and abundance of benthic invertebrates in the Yadkin River was also attributed to substrate type, current velocity, and sediment carbon (Braatz and Curtis 1978). The shoreline, fine sand-silt community of the Broad River (Station 453.2) showed similarity to that of the Yadkin River (Stations 440.2, 442.2, and 444.2). The coarse-sand community of the Broad River (Station 460.1) tended to be dissimilar to that of the Yadkin (Stations 440.0, 442.0, and 444.0), apparently because of greater oligochaete densities in the Yadkin. Particle size and carbon content, however, were not significantly different between the coarse-sand habitats. Riffles in both rivers appeared similar in overall community composition.

ORGANIC DRIFT

DRIFT COMPOSITION

Total Organic Drift

Organic drift (≥471 μm) in the Broad River was comprised of detritus and macroinvertebrates (99.93 and 0.07% by wet weight, respectively). Detritus consisted chiefly of fragmented leaves, twigs, and sticks of terrestrial origin, with mean densities ranging from 21 to 671 g/100 m^3. Mean annual detritus densities were approximately 1,400 times greater than the biomass of aquatic, aerial, and terrestrial organisms combined, indicating the potential importance of detritus to macroinvertebrates in the river. The role of allochthonous organic material in defining the trophic structure of similar lotic ecosystems has been described by many investigators (Egglishaw 1964; Hynes 1963; Hynes et al. 1973; Knight 1978; Minshall 1967; Nelson and Scott 1962).

The macroinvertebrate component consisted of larvae, pupae, and adults of aquatic and terrestrial insects, as well as other invertebrate groups such as worms (Annelida, Nematoda, Nemertinea), snails, and clams (Mollusca). Of 227 taxa identified from Broad River collections, 58% occurred in drift samples and 16% were found exclusively in the drift (App. 5-1, 5-10). Aquatic macroinvertebrates accounted for 72% of all drifting organisms and 70% of the biomass, while aerial and terrestrial groups comprised the remainder. Quarterly drift samples indicated the same general composition and relative abundance as the monthly drift samples (App. 5-3, 5-11).

Aquatic Drift

Larvae, pupae, and adults of the Diptera were consistently the most abundant and frequently collected aquatic invertebrates (Table 5-3) and were represented by 12 families and 60 subordinate taxa (App. 5-1). Chironomidae were the dominant Diptera, comprising 50 taxa in 3 subfamilies. Other important aquatic groups included Ephemeroptera, Trichoptera and Oligochaeta (Table 5-3).

Immature chironomids accounted for 77% of the dipterans and 37% of all drifting aquatic organisms. The most numerous drifting chironomids were *Polypedilum* spp., *Orthocladius* spp., *Rheotanytarsus* spp., and *Cricotopus* spp. Other midges that occurred frequently, but in lower densities, were *Eukiefferiella* spp., *Thienemanniella* spp., and *Robackia* spp. These midge

Table 5-3. Mean density (No./100 m^3) and percent composition of major groups of drifting macroinvertebrates in the Broad River from September 1974 through November 1975.

Order		SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
Ephemeroptera (larvae and adults)	Mean Density	20	6	5	8	9	5	11	10	10	16	11	19	74	5	12
	% of Total	31.3	3.1	3.1	5.4	7.0	4.2	6.7	7.2	4.5	16.0	17.5	12.5	33.9	11.6	14.0
Trichoptera (larvae and adults)	Mean Density	7	9	11	14	12	5	10	18	32	12	15	15	23	8	12
	% of Total	10.9	4.6	6.8	9.5	9.3	4.2	6.1	13.0	14.5	12.0	23.8	9.9	10.6	18.6	14.0
Diptera (larvae, pupae, and adults)	Mean Density	23	135	122	108	85	95	126	68	115	54	27	90	85	23	32
	% of Total	35.9	69.6	52.7	73.0	65.9	80.5	76.8	49.3	52.3	54.0	42.9	59.2	39.0	53.5	37.2
Oligochaeta	Mean Density	13	0	5	4	5	6	4	1	7	3	1	3	5	1	11
	% of Total	20.3	0	3.1	2.7	3.9	5.1	2.4	1.0	3.2	3.0	1.6	2.0	2.3	2.3	12.8

genera were most common in the Broad River drift at the same stations where they were abundant in the benthos. Chaoborus punctipennis (Chaoboridae) was the only other important drifting dipteran. Although C. punctipennis had 53% occurrence by month and a maximum mean monthly density of 87/100 m^3 in March (App. 5-10), large numbers of drifting C. punctipennis were unusual in the Broad River. This species probably originated from the backwaters of the reservoir.

Ephemeropterans were the second most abundant aquatic insects, representing 18% of all drifting aquatic organisms. Mayflies were represented by 10 genera in 7 families (App. 5-10) and constituted between 3.1 and 33.9% of the monthly total (Table 5-3). The most abundant mayflies were Baetis spp., Stenonema spp., Tricorythodes spp., and Ephemerella spp. These genera are common inhabitants of riffles, and occur in most lotic environments (Needham et al. 1972).

Trichopterans, represented by 8 genera in 5 families, made up 14% of the drifting aquatic organisms. The filter-feeding Hydropsyche spp. and Cheumatopsyche spp. were the dominant caddisflies. These genera are active, aggressive, and are common in invertebrate drift samples (Ross 1944; Waters 1962).

Aquatic oligochaetes were present in 93% of the drift collections, with mean monthly densities ranging from 0 to 13/100 m^3 (Table 5-3). Although worms generally inhabit the sediments of rivers and lakes, they are not uncommon in drift collections. They are most often associated with detritus temporarily scoured from the bottom and are not considered active swimmers (Larimore 1974).

Aerial and Terrestrial Drift

Adult dipterans (chiefly chironomids) constituted 84% of the aerial and terrestrial drift. Mean monthly densities of adult dipterans ranged from 2 to 102/100 m^3, with 100% frequency of occurrence by month indicating year-around emergence (App. 5-10). The terrestrial component of the drift was represented by 11 taxa (family level or higher). Homoptera (aphids, hoppers, etc.) were the dominant terrestrials, with mean densities ranging from 26 to 35/100 m^3. Other terrestrial invertebrates were found frequently, but were less abundant. Terrestrial invertebrates are abundant on the vegetation surrounding rivers and often occur in the drift, providing an abundant source of food for fishes (Bailey 1966).

SPATIAL VARIATION

Stations downstream from Ninety-Nine Islands Impoundment generally had the highest mean densities and biomass of aquatic, aerial, and terrestrial organisms as well as highest detritus densities. A two-way analysis of variance revealed significant interaction ($P \leq 0.05$) between stations and months (App. 5-12). An analysis of simple main effects indicated that mean drift densities between stations were significantly different ($P \leq 0.05$) in 9 of 15 months for aquatic invertebrates, in 5 of 15 months for aerials and terrestrials, and in 6 of 15

months for detritus (App. 5-13). Significant differences were also observed on three occasions between mean aquatic biomass and location; downstream stations were responsible for most of the differences. Since the majority of drifting aquatic invertebrates were riffle-dwelling insects, the lower drift densities and biomass upstream from the dam (Stations 459.0 and 460.1) probably reflected the greater distance of these stations from the nearest upstream riffle. Most lotic invertebrates drift in a saltatory fashion (Waters 1965), generally no further than 50 m at a time, and often in a diel or other behavioral pattern (Elliott 1971; McLay 1970). The drift density at any point in the river is, therefore, closely related to substrate type upstream from the sampling location and the time at which samples are taken.

A notable exception to this occurs during "catastrophic" drift conditions (Anderson and Lemhkuhl 1968; Waters 1965), such as caused by high flow or other physical disturbance. In this case, substrate scouring and abrasion cause increased drift densities, overshadowing the "constant" or "behavioral" components (Ryck 1975; Waters 1965). Catastrophic drift was observed at Station 460.1 in March 1975 when mean aquatic drift density and biomass reached 512 organisms/100 m^3 and 805 mg/100 m^3, respectively (App. 5-5). Large numbers (397/100 m^3) of Chaoborus punctipennis, which were washed out of the reservoir backwater, were responsible for this peak. Progressively fewer C. punctipennis were collected with increasing distance downstream. River discharge was the single most important factor in a stepwise multiple regression analysis for total drift density at Station 460.1 ($r^2 = 0.70$), indicating that high discharge washed large numbers of lentic invertebrates out of the backwaters and into the river channel.

Chironomids, caddisflies, and mayflies were the dominant aquatic invertebrates at every station (App. 5-1). Again, the benthic environment appeared to be the most important factor delimiting both the qualitative composition and density of these groups at a given station. Chironomids were abundant at Station 460.1 and at downstream riffles. At Station 460.1, sand-dwelling midges (Robackia spp., Thienemanniella sp., and Polypedilum spp.) were particularly numerous in benthic samples and also accounted for the peak drift density (App. 5-5). Riffle-dwelling midges (Orthocladius spp., Cricotopus spp., and Eukiefferiella spp.) were dominant at downstream stations. Lowest densities of midges, as well as all other macroinvertebrate groups, were observed at Station 459.0 because of the unsuitable benthic habitat provided by hard-packed clay. Caddisflies and mayflies were most abundant at Stations 453.1, 453.2, and 452.1, and least abundant at Stations 460.1 and 459.0, owing to the preference of these organisms for riffles.

Peak abundance and biomass of aerial and terrestrial invertebrates was observed at Station 452.1 (App. 5-14, 5-15, 5-16). Although the factors responsible for spatial differences in drift of aerial and terrestrial invertebrates are not known, the overhanging vegetation along the river shoreline probably provided many of the terrestrials entering the drift. The aerial component of the drift (mostly emerging chironomids) was probably influenced by the location of optimum habitats for immatures.

TEMPORAL VARIATION

Monthly Samples

Peak abundance of total invertebrate drift (219/100 m^3) occurred in May (Fig. 5-9). This was attributed to an increase in numbers of chironomids (larvae and pupae) and caddisflies. Invertebrate drift declined sharply in June, presumably resulting from emergence of these groups. Mean invertebrate biomass was highest in the spring (Fig. 5-6), because of the increased size of mature, later instar aquatic and terrestrial organisms. The peak of 290 mg/100 m^3 was due to large numbers of Chaoborus punctipennis drifting in March (App. 5-10). The lowest mean drift biomass, in October 1975 (18 mg/100 m^3), coincided with the minimum drift density.

Aquatic drift density was highest in September 1975 and lowest in October 1975 (Fig. 5-9). Mean aquatic biomass followed a similar pattern with the peak in March resulting from catastrophic drift. The periods of egg laying, growth, and emergence of amphibiotic invertebrates probably accounted for intermediate fluctuations in aquatic drift. The low density and biomass observed in April, July, and October 1975 probably resulted from sampling selectivity against the small, early instar progeny of emerging species.

Four invertebrate groups, Diptera, Trichoptera, Ephemeroptera, and Oligochaeta (in decreasing order of abundance) accounted for greater than 70% of all aquatic invertebrates collected. Chironomid larvae and pupae were the dominant aquatic drift organisms in every month; caddisflies and mayflies were of secondary numerical importance (Table 5-3). These organisms were dominant food items of whitefin shiners and white catfish in the Broad River (Chapter 6). Chironominae and Orthocladiinae dominated the chironomid drift throughout the year. Polypedilum spp. and Rheotanytarsus spp., the dominant Chironominae, had higher densities in the spring and fall, stemming from increased pre-emergence activity. The most abundant Orthocladiinae were Orthocladius spp., Cricotopus spp., and Eukiefferiella spp. These riffle-dwelling midges were most abundant in winter and spring, again reflecting their emergence periods and sampling selectivity. Thienemanniella sp., a sand-dwelling orthoclad, was abundant only in February, indicating pre-emergence activity (App. 5-10).

Drifting caddisflies were most abundant in May and least abundant in February (Table 5-3). Hydropsyche spp. and Cheumatopsyche spp. were dominant, and emerged in the spring and summer. Maximum seasonal drift of Cheumatopsyche spp. has been shown to correspond to prepupation activity, and their emergence periods are generally sustained throughout the spring and summer months because of brood overlap (Cloud and Stewart 1974a). Maximum seasonal drift of Hydropsyche spp. is thought to correspond to periods of rapid growth of the larvae. A similar "growth-drift" relationship has also been noted for other aquatic insects (Elliott 1967; Radford and Hartland-Rowe 1971).

Peak mayfly abundance occurred in September 1975 (Table 5-3). Baetis spp., Stenonema spp., Tricorythodes spp., and Ephemerella spp. were the dominant mayfly genera. Mayflies generally emerge in the summer and fall,

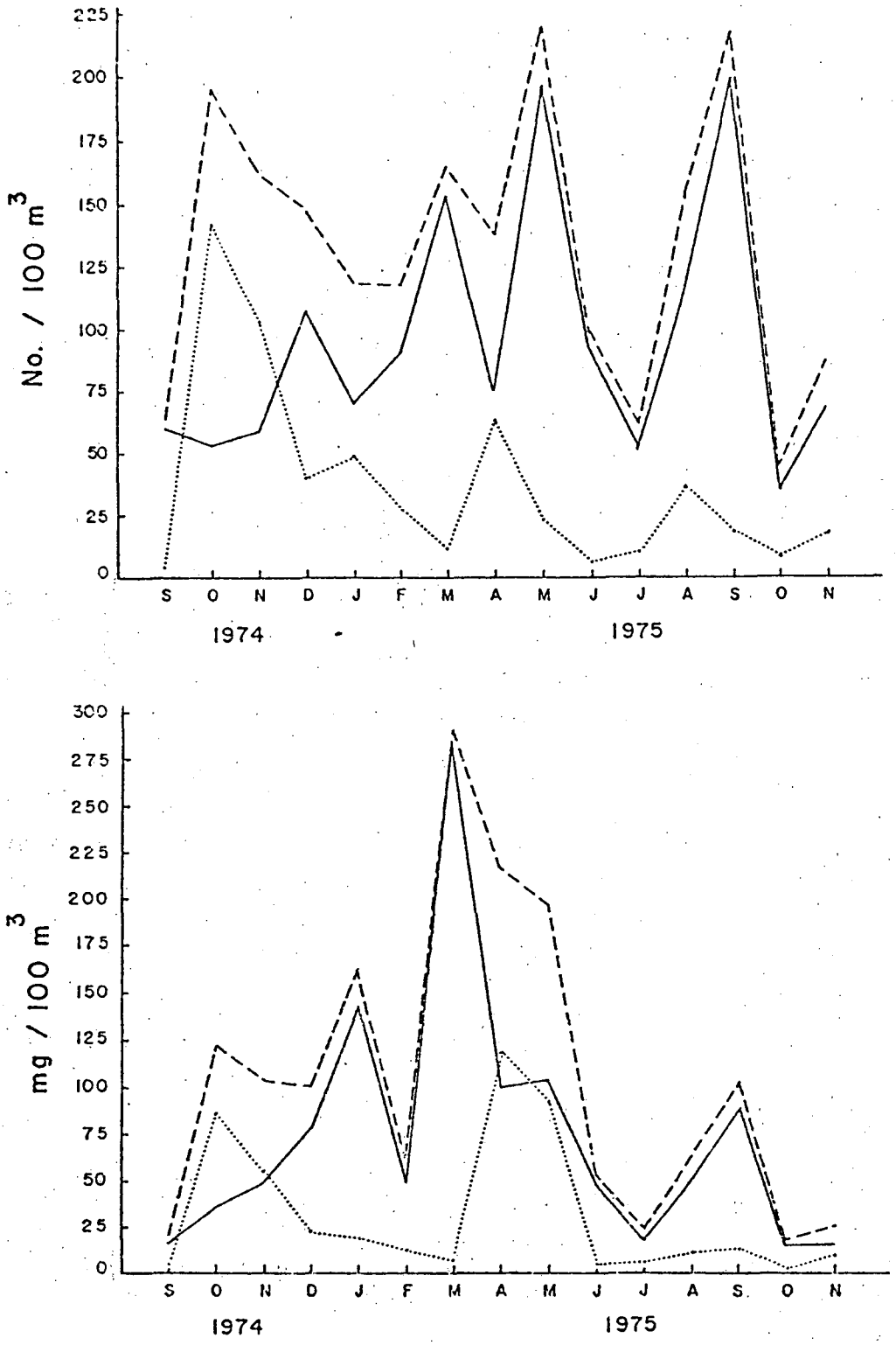


Figure 5-8. Mean monthly densities (No./100 m^3) and mean monthly biomass (mg/100 m^3) of total invertebrate drift (dashed lines), aquatic drift (solid lines), and aerial and terrestrial drift (dotted lines) from September 1974 through November 1975.

and maximum drift densities occur at the time of emergence (Cloud and Stewart 1974b). Most mayflies have one or two generations per year and some undergo diapause during winter, resulting in lower drift densities during the colder months (Needham et al. 1972).

Drift of aerial and terrestrial invertebrates reached peak abundance and biomass in the fall of 1974 and spring of 1975 (Fig. 5-9). The peak density in October 1974 resulted from large numbers of adult dipterans (predominantly chironomids) and homopterans (App. 5-10). A peak in biomass of aerial and terrestrial invertebrates in April 1975 was also attributed to these groups. Overall, the drift of terrestrial invertebrates was probably underestimated due to the use of subsurface nets. Most terrestrial insects float on the surface of the water and their abundance in the drift is often more closely related to meteorological factors such as rainfall and wind velocity than to their abundance in areas surrounding the river (Elliott 1967).

Diel Samples

Maximum density and biomass of aquatic, aerial, and terrestrial drift occurred at night (App. 5-17). A general increase in aquatic drift density and biomass began at 2000 hr, with peak density at 0200 hr and maximum biomass at 0300 hr, when large numbers of caddisflies and phantom midges entered the drift. These peaks were followed by a steady decline until daylight, when drift densities returned to fairly constant levels. This sharp increase in drift density at sunset and the high drift densities throughout the night, coupled with low densities during the day, agreed with diel periodicities described by earlier investigators (Tanaka 1960; Waters 1962, 1968).

Caddisflies were the most abundant aquatic invertebrates collected in diel samples, and densities were 30% higher at night (App. 5-17). The densities of Hydropsychidae peaked at 2100 hr and at 0200 hr. *Hydropsyche* spp. were collected during every hour of the 24-hr period and were most abundant at night, with the maximum at 2300 hr (82/100 m^3) and the minimum at 0500 hr (3/100 m^3). *Cheumatopsyche* spp. were also more numerous at night, with 40/100 m^3 occurring at 0200 hr. The diel drift periodicities of these caddisflies may be related to nocturnal foraging behavior (Elliott 1967; Waters 1962). A major emergence of caddisflies was observed on the night that diel collections were taken, so their high drift densities may also have reflected this increased activity.

Chironomids and chaoborids were also abundant in diel samples, constituting 21 and 12% of the total, respectively. Although chironomids were abundant, no definite diel periodicity was observed for either larvae or pupae. This lack of periodicity was in agreement with earlier findings that chironomid larvae do not drift in a diel pattern (Anderson 1966; Anderson and Lehmkuhl 1968; Holt and Waters 1967). The dominant midges in diel samples were *Polypedilum* spp., *Rheotanytarsus* spp., *Orthocladius* spp., and *Nanocladius* spp.

Chaoborus punctipennis was collected almost exclusively at night, with maximum larval abundance (80/100 m^3) occurring at 0200 hr and maximum pupal abundance (20/100 m^3) at 0100 hr (App. 5-17). The presence of

large numbers of C. punctipennis in the nighttime drift samples was not surprising since they become planktonic at night and graze on lentic zooplankton (LaRow and Marzolf 1970). Chaston (1969) suggested that this night-active feeding behavior may be an adaptation to avoid predators. C. punctipennis were present in the backwaters of Ninety-Nine Islands Impoundment, 3.5 km upstream (App. 5-1) and apparently entered the main river channel after dark. The occurrence of lentic benthos and plankton in stream drift below impoundments has been previously observed (Kubicek 1970; Morris et al. 1968; Swanson 1967). Because of their nocturnal activity and adaptations to lentic habitats, C. punctipennis have the potential to drift great distances in the river and to colonize areas far downstream.

Mayflies were collected during all hours of the day and night; they accounted for 15% of the aquatic diel drift, but did not exhibit a definite diel pattern. Baetis spp., Stenonema spp., Heptagenia spp., Caenis spp., and Ephemerella spp. were most abundant at night, but were also numerous during daylight. Baetis nymphs most often exhibit a bigeminus diel drift pattern, with a major peak occurring just after sunset and a secondary peak prior to sunrise (Cloud and Stewart 1974b; Waters 1968). No such pattern was exhibited by Baetis in the Broad River diel collection. Other mayflies were only moderately abundant and were collected sporadically throughout the 24-hr period.

Peak density and biomass of aerial and terrestrial invertebrates was also observed at night (App. 5-17). Maximum drift density occurred at 2100 hr, with the primary component being adult dipterans (chironomids). Mundie (1971a) and Sprules (1947) also found adult chironomids to be abundant in the drift at night. Aerial and terrestrial drift declined from 2100 to 2400 hr due to fewer adult midges. A slight increase from 2400 to 0100 hr was attributable to increased density of adult chironomids and hemipterans. A continuous decline in aerial and terrestrial drift began at 0100 hr and persisted until 0400 hr, again reflecting lower densities of adult midges. Lower numbers and biomass of aerials and terrestrials were observed during the day.

SUMMARY

Sampling of benthos and organic drift in the Broad River and Ninety-Nine Islands Impoundment was conducted monthly from September 1974 through November 1975, and quarterly into 1977. Results from stations which had different substrate types were analyzed separately in order to elucidate temporal variation as well as organism-substrate relationships. Benthic habitats were heterogeneous with respect to current velocity, substrate particle size, sediment carbon content, and abundance of the dominant members of the community.

The backwater of Ninety-Nine Islands Impoundment (Station 462.0) had a substrate of soft silt with high organic content. The benthic fauna was dominated by burrowing detritivores such as oligochaetes and chironomids. Mean invertebrate density and biomass ranged from 363 to 1,280/m^2 and from 536

to 7,831 mg/m^2, respectively. An inverse relationship was observed between mean densities of oligochaetes and chironomids.

Coarse sand with low organic content (Station 460.1) supported a high density, but low biomass, of small, highly specialized chironomids. Robackia spp. and Thienemanniella sp. were both bivoltine, emerging in the spring and fall. Total population densities and biomass ranged from 57 to 8,230/m^2 and from 21 to 433 mg/m^2, respectively.

The benthic fauna was sparse on the scoured, compact silt-clay substrate at Station 459.0. Filter-feeding organisms (hydropsychid caddisflies and Rheotanytarsus spp. midges) characterized the fauna and probably colonized the area from the macroinvertebrate drift. No stable benthic community was associated with this type of substrate.

The shoreline downstream from Ninety-Nine Islands Impoundment (Station 453.2) was characterized by a fine sand-silt substrate, low in organic content. Oligochaetes and chironomids were dominant components of the benthic fauna, with other organisms migrating or drifting in from the adjacent riffle.

Riffles (Stations 453.1 and 452.1) supported the most diverse benthic fauna, along with the highest biomass density (12,162 mg/m^2 at Station 452.1). Trichoptera, Chironomidae, Ephemeroptera, and Corbiculidae were the dominant groups at both stations. Detrital and algal-feeding midges (Orthocladius spp., Cricotopus spp., and Eukiefferiella spp.) and filter-feeding caddisflies were dominant components of the benthic community at both riffles.

Organic drift samples indicated that the Broad River was a heterotrophic system. Allochthonous detritus was the main component of the drift (99.93% by wet weight), and the invertebrate component (0.07% by wet weight) was approximately 72% aquatic and 28% terrestrial by numbers and 70% aquatic and 30% terrestrial by wet weight.

The dominant drifting aquatic invertebrates were midges (Polypedilum spp., Orthocladius spp., Rheotanytarsus spp., Cricotopus spp., and Eukiefferiella spp.), mayflies (Baetis spp., Stenonema spp., Tricorythodes spp., and Ephemerella spp.), caddisflies (Hydropsyche spp. and Cheumatopsyche spp.), and oligochaetes. Dominant drifting aerial and terrestrial invertebrates were adult dipterans (mostly chironomids) and homopterans.

Spatial differences in aquatic drift were attributed to the varied substrates immediately upstream from the sampling points, and to catastrophic drift caused by high flow which washed many lentic invertebrates out of the reservoir backwaters and into the river channel. Temporal patterns in aquatic drift were interpreted with consideration of the periods of egg laying, growth, and emergence of amphibiotic groups, and of sampling selectivity against early instars.

Diel drift of aquatic, aerial, and terrestrial invertebrates was highest at night, with peaks in density and biomass at 0200 hr and 0300 hr, respectiv The dominant aerial and terrestrial components were adult Diptera. The major aquatic orders in the diel drift were Diptera, Trichoptera, and

Ephemeroptera. Although chironomids were abundant, diel periodicity was not observed. Chaoborids were collected almost exclusively at night because of their nocturnal behavior. Caddisflies were 30% more abundant at night, with peaks at 2100 and 0200 hr. Mayflies were numerous, but did not appear to drift in a diel pattern.

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CHAPTER 6. FISHERIES

Donald G. Cloutman and Thomas J. Edwards

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INTRODUCTION

BACKGROUND

The abundance and distribution of fishes are the products of interaction among fishes and their physical, chemical, and biological surroundings. Environmental factors which influence fishes are numerous, complex, and often interrelated. The major environmental factors which affect stream fishes include water temperature, current, discharge, turbidity, dissolved oxygen, dissolved salts and nutrients, substrate, pollutants, and number and type of predators, competitors, and prey (Lagler 1970). The fishes of the Broad River, a typically turbid and moderately polluted Piedmont stream, are affected to some degree by all of the above factors. Several municipal and industrial discharges flow into the Broad River drainage upstream from Ninety-Nine Islands Impoundment, but no fish kills have been reported from the area (Duke Power Company 1974).

Although comprehensive ichthyological surveys have been conducted in the upper Broad River drainage in North Carolina (Messer et al. 1965), and surrounding portions of the Santee drainage in South Carolina (Derrick 1955, Saluda drainage; Randall 1957, Catawba-Wateree drainage), very little fisheries research has been done in the Broad River drainage in the vicinity of Cherokee Nuclear Station (CNS). A study to monitor the fish community in the Broad River and Ninety-Nine Islands Impoundment during the preconstruction phase of CNS was conducted from September 1973 through August 1974 (Duke Power Company 1974).

OBJECTIVES

This chapter summarizes fisheries monitoring from September 1974 through October 1976 by Duke Power Company. In addition to providing preoperational baseline data for CNS, it provides general information on the ecology and biology of Broad River fishes. The specific objectives of this study were to:

1) document differences in relative abundance and species composition among locations and seasons,
2) determine correlations between electrofishing catches of selected species and selected physical-chemical factors,
3) determine age-growth characteristics and food habits of certain ecologically and/or economically important species, and
4) assess taxonomic composition and spatial and temporal distributions of ichthyoplankton in the Broad River drainage near CNS.

MATERIALS AND METHODS

ELECTROFISHING

Four locations in the mainstream of the Broad River (452, 453, 459, and 460) and two locations in the backwaters of Ninety-Nine Islands Impoundment (458 and 462) were sampled monthly from September 1974 through November 1975 (Fig. 1-2). In addition, several tributary creeks of the Broad River (People Creek, McKowns Creek, Kings Creek, Bells Branch, and Niels Branch) were sampled occasionally to obtain a complete view of the fishery resources in the Broad River drainage near CNS. Locations 453, 458, 459, 460, and 462 were sampled quarterly in 1976.

A boat-mounted Smith Root Mark VI Electrofisher providing 300 to 600 volts and 3 to 4 amps of direct current, depending on conductivity of the water, was used to collect fishes at Locations 458, 459, 460, and 462. Due to shallow water, sampling at Locations 452 and 453 was performed with a gasoline powered Coffelt backpack electrofisher operated from a 3.7-m flatbottom boat. The backpack electrofisher provided 150 to 500 volts of AC current, depending on conductivity of the water. Two 100-m stations (one on each side of the river) were electrofished at each location. At the end of each station, all fishes were identified, counted, and measured to the nearest millimeter. Most fishes were released, but representative specimens for age-growth and food analyses were placed on ice to inhibit digestion of the stomach contents (Doxtater 1963) and brought to the laboratory.

Electrofishing data (expressed as number of fish per 100 m) for total fish, gizzard shad, Dorosoma cepedianum (Lesueur); whitefin shiners, Notropis niveus (Cope); white catfish, Ictalurus catus (Linnaeus); bluegill, Lepomis macrochirus Rafinesque; and largemouth bass, Micropterus salmoides (Lacepede) were analyzed for location and seasonal differences with 2-way analysis of variance (ANOVA). Each 100-m station was designated as a replicate and months were partitioned into four seasons. December through February was designated as winter, March through May as spring, June through August as summer, and September through November as fall. Because of non-normality and heteroscedasticity, data were transformed to meet the assumptions of ANOVA. Homogeneity of variances was tested with Levene's test (Keppel 1973). In the absence of significant interaction, Student-Newman-Keuls (SNK) multiple range tests (Zar 1974) were used to determine which means differed significantly. When the interaction term was significant, a simple main effects test (Keppel 1973) was used to isolate the sources of interaction. Electrofishing data were also correlated with temperature, stream discharge, dissolved oxygen, pH, turbidity, and conductivity using Spearman rank correlation coefficients (Zar 1974).

GILL NETTING

Two 27-m multifilament experimental gill nets with 3-m panels of 2.5, 3.8, and 5.1-cm bar mesh were fished monthly from September 1974 through November 1975, and quarterly during 1976, at Locations 458 and 462. Nets were set during the afternoon following electrofishing and taken in the following morning. Nets were fished approximately 18 hr, which represented one gill net set. Since gill nets were used primarily to obtain supplementary information, no statistical analyses were performed on the catch data.

AGE-GROWTH

Age-growth determinations were made for gizzard shad, whitefin shiners, white catfish, bluegill, and largemouth bass using scales or pectoral spines. These species were selected because of their abundance or economic importance. After the fish were weighed (nearest 0.1 g) and measured (nearest millimeter), scales (excluding white catfish) were removed from the left side immediately posterior to the pectoral fin and below the lateral line. Acetate impressions of scales were examined using a Bausch and Lomb scale projector at constant magnification (23X). The left pectoral

spines of white catfish were removed and sectioned with a jeweler's saw. Sections of white catfish spines were cleared in xylene and examined with a dissecting microscope fitted with an ocular micrometer at a magnification of 30.9X. Annuli were counted, and distance from the scale or spine focus to each annulus was measured.

Total length-scale or spine radius relationships for males and females were determined by stepwise polynomial regression analysis. Coincidental regression tests (Zar 1974) were used to determine if the total length-scale or spine radius relationships for males and females of each species differed significantly. Least squares regressions using logarithmic (Log_{10}) transformations were utilized to calculate total length-weight relationships of males and females of each species.

FOOD HABITS

Viscera for use in food habit analyses were removed from fishes and preserved in 10% formalin. After approximately one week, the viscera were rinsed in water and stored in 40% isopropanol. Stomachs were slit longitudinally and the contents were removed and placed in a petri dish. Food items were examined using a dissecting microscope and identified to the lowest practicable taxon. Food habits were summarized on a seasonal basis by numeric, gravimetric (wet weight), and percent occurrence methods (Hynes 1950). Seasons were the same as those designated for the electrofishing data.

ICHTHYOPLANKTON

During 1975, a circular (0.5 m diameter) nitex net (560-µm square mesh) was used to collect larval fish samples. At Stations 453.1 and 453.2, 5-min drift samples were taken because the river was too shallow to make tows. At Stations 458.0, 459.2, and 460.0 tows ranged from 2.5 to 5 min, depending on the amount of suspended sediment and detritus in the river. Duplicate surface samples were taken during the night (starting just after dusk) at approximately weekly intervals from 19 March 1975 through 29 August 1975.

During 1976, square 0.5-m nitex nets (560 µm square mesh) were used for larval fish collections. The square shape allowed equal sampling effort at all depths within the net. A frame designed to hold three nets simultaneously was mounted to the bow of a 4.9-m aluminum boat. Duplicate push samples and triplicate push samples were taken at Stations 458.0 and 459.2, respectively. Triplicate drift samples were taken at Stations 460.0, 460.1, and 460.2. The boat was held stationary in the river current by attaching to a rope strung across the river and secured on each bank. Drift sampling at Location 460 had several advantages over tow samples. Because the river at Location 460 was shallow in several places, the net sometimes contacted the bottom and filled with sand while being towed. The drift nets allowed more versatility in areas sampled and duration of samples. Also, triplicate samples could be taken simultaneously and at the same location each week. Sampling time was 5 min, and all samples were taken at night (starting just after dusk). Sampling began on 7 April 1976, and continued on an approximately weekly basis from 22 April through 2 August 1976. From 2 August through 21 September 1976, samples were taken biweekly. All samples were taken at the surface.

A diel study was conducted at Stations 459.1, 459.2, 460.0, 460.1, and 460.2 on 13 May 1976 to determine if differences in larval fish densities occurred during different times of the day. Samples were taken at 0300, 0900, 1500, and 2100 hr EST. Stations 459.1 and 460.2 could not be sampled at night due to low water caused by hydroelectric generation at Ninety-Nine Islands Dam. Consequently, these two stations were eliminated from the analysis. Friedman's randomized block analysis of variance by ranks was used to analyze the data. A nonparametric Student-Newman-Keuls (SNK) multiple range test (Zar 1974) was performed to determine at which times the densities were significantly different.

A General Oceanics flowmeter suspended across the net opening allowed calculation of the volume of water filtered in each sample. Larval fish samples were preserved with 10% formalin in the field and brought to the laboratory for analyses. The 1975 samples were sorted in black enamel pans. Because of the large amounts of leaf litter and detritus usually accompanying the samples, rose bengal stain was added to each 1976 sample to facilitate sorting. The 1976 samples were sorted in white enamel pans. Larvae were identified, measured, and stored in 40% isopropanol. Larval fish densities were extrapolated to number per 1000 m^3, based on the volume of water filtered in each sample.

RESULTS AND DISCUSSION

ADULT FISH

SPECIES COMPOSITION AND SEASONAL ABUNDANCE

Forty-three species were collected from the Broad River drainage by electrofishing and gill netting during this study (Tables 6-1 and 6-2 and App. 6-1). Each of the three major habitats (small tributary creeks, the lotic mainstream of the Broad River, and lentic backwater areas of Ninety-Nine Islands Impoundment) had a distinct assemblage of fishes.

Cyprinids (minnows) and percids (darters) were the dominant fishes collected from the small tributaries of the Broad River (Table 6-1). Since these small creeks are out of the area of potential influence of CNS they were not sampled on a regular basis and do not warrant further comment.

Although 35 species were taken from the mainstream of the Broad River (Locations 452, 453, 459, 460) most were present in relatively low abundance (Table 6-1). The five most abundant fishes were the bluehead chub, *Nocomis leptocephalus* (Girard); whitefin shiner; bluegill, fantail darter, *Etheostoma flabellare* Rafinesque; and snail bullhead, *Ictalurus brunneus* (Jordan). Most of the bluehead chubs and fantail darters were taken in a shallow riffle at Location 452, which was destroyed during floods in the spring of 1975. These two species were rarely collected in the Broad River after elimination of the riffle. Differences in abundance of total fish existed among locations and seasons, with Location 459 having significantly greater numbers of fish than the other mainstream locations (App. 6-2). Other locations were not significantly different from each other. The higher number of fish taken at Location 459 was attributed to the location being adjacent to a backwater area. In fact, one station

Table 6-1. Fish species, and their relative abundance and frequency of occurrence in major habitats of the Broad River drainage in the vicinity of Cherokee Nuclear Station, collected with electrofishing gear during September 1974 through October 1976. Relative abundance is expressed as number of fish per 100 m shoreline. Frequency of occurrence is the percent of collections containing the species.

Species	Common Name	Ninety-Nine Islands Backwaters (76 collections)		Broad River Mainstream (140 collections)		Broad River Tributary Creeks (18 collections)	
		Relative Abundance	Frequency of Occurrence (%)	Relative Abundance	Frequency of Occurrence (%)	Relative Abundance	Frequency of Occurrence (%)
Clupeidae							
Dorosoma cepedianum (Lesueur)	Gizzard shad	2.6	68.4	0.6	23.6	0.1	5.6
Dorosoma petenense (Gunther)	Threadfin shad	1.1	13.2	<0.1	1.4	0.0	0.0
Cyprinidae							
Clinostomus funduloides Girard	Rosyside dace	0.0	0.0	<0.1	0.7	13.9	33.3
Cyprinus carpio Linnaeus	Carp	1.5	47.4	0.4	20.7	0.0	0.0
Hybognathus regius Girard	Eastern silvery minnow	<0.1	1.3	0.7	2.1	0.1	5.6
Hybopsis hypsinotus (Cope)	Highback chub	0.0	0.0	0.0	0.0	2.8	38.9
Hybopsis labrosa (Cope)	Thicklip chub	0.0	0.0	0.1	2.1	0.6	16.7
Hybopsis zanema (Jordan and Brayton)	Santee chub	0.0	0.0	<0.1	1.4	0.0	0.0
Nocomis leptocephalus (Girard)	Bluehead chub	0.0	0.0	2.1	9.3	23.7	72.2
Notemigonus crysoleucas (Mitchill)	Golden shiner	0.3	17.1	0.1	5.7	0.0	0.0
Notropis altipinnis (Cope)[1]	Highfin shiner	0.0	0.0	0.0	0.0	0.0	0.0
Notropis chloristius (Jordan and Brayton)	Greenfin shiner	0.0	0.0	0.3	9.3	2.7	44.4
Notropis hudsonius (Clinton)	Spottail shiner	0.0	0.0	<0.1	1.4	0.1	5.6
Notropis lutipinnis (Jordan and Brayton)	Yellowfin shiner	0.0	0.0	0.0	0.0	8.1	55.6
Notropis niveus (Cope)	Whitefin shiner	0.0	0.0	1.5	32.1	0.9	38.9
Notropis procne (Cope)	Swallowtail shiner	0.0	0.0	0.0	0.0	0.8	5.6
Notropis scepticus (Jordan and Gilbert)	Sandbar shiner	0.0	0.0	<0.1	2.1	35.1	50.0
Semotilus atromaculatus (Mitchill)	Creek chub	0.0	0.0	0.0	0.0	1.3	27.8
Catostomidae							
Carpiodes cyprinus (Lesueur)[2]	Quillback	0.0	0.0	0.0	0.0	0.0	0.0
Catostomus commersoni (Lacepede)	White sucker	0.0	0.0	<0.1	0.7	0.2	11.1
Moxostoma anisurum (Rafinesque)	Silver redhorse	0.1	5.3	<0.1	2.9	0.4	5.6
Moxostoma macrolepidotum (Lesueur)	Shorthead redhorse	0.0	0.0	<0.1	0.7	0.0	0.0
Moxostoma robustum (Cope)	Smallfin redhorse	0.0	0.0	<0.1	2.9	0.0	0.0
Moxostoma rupiscartes Jordan and Jenkins	Striped jumprock	0.0	0.0	0.1	1.4	0.6	27.8
Ictaluridae							
Ictalurus brunneus (Jordan)	Snail bullhead	<0.1	1.3	0.8	12.1	0.0	0.0
Ictalurus catus (Linnaeus)	White catfish	1.3	42.1	0.3	9.3	0.2	11.1
Ictalurus nebulosus (Lesueur)	Brown bullhead	0.3	22.4	<0.1	0.7	0.0	0.0
Ictalurus platycephalus (Girard)[2]	Flat bullhead	0.0	0.0	0.0	0.0	0.0	0.0
Ictalurus punctatus (Rafinesque)[2]	Channel catfish	0.0	0.0	0.0	0.0	0.0	0.0
Noturus insignis (Richardson)	Margined madtom	0.0	0.0	0.1	0.7	0.6	11.1
Poeciliidae							
Gambusia affinis (Baird and Girard)	Mosquitofish	<0.1	2.6	<0.1	0.7	0.9	16.7
Percichthyidae							
Morone chrysops (Rafinesque)	White bass	<0.1	1.3	<0.1	0.7	0.0	0.0
Centrarchidae							
Lepomis auritus (Linnaeus)	Redbreast sunfish	<0.1	1.3	0.2	8.6	1.4	44.4
Lepomis gibbosus (Linnaeus)	Pumpkinseed	0.3	11.8	<0.1	2.9	0.0	0.0
Lepomis gulosus (Cuvier)	Warmouth	0.3	22.4	<0.1	1.4	0.0	0.0
Lepomis macrochirus Rafinesque	Bluegill	19.3	89.5	1.2	36.4	0.9	33.3
Lepomis microlophus (Gunther)	Pedear sunfish	1.0	48.7	0.1	5.7	0.1	5.6
Micropterus salmoides (Lacepede)	Largemouth bass	1.6	69.7	0.1	9.3	0.7	27.8
Pomoxis annularis Rafinesque	White crappie	1.6	46.1	0.0	0.0	0.0	0.0
Pomoxis nigromaculatus (Lesueur)	Black crappie	1.6	42.1	<0.1	2.9	0.1	5.6
Percidae							
Etheostoma flabellare Rafinesque	Fantail darter	0.0	0.0	1.1	3.6	5.3	66.7
Etheostoma olmstedi Storer	Tessellated darter	0.0	0.0	<0.1	0.7	4.2	50.0
Etheostoma thalassinum (Jordan and Brayton)	Seagreen darter	0.0	0.0	0.3	1.4	15.4	50.0
Percina crassa (Jordan and Brayton)	Piedmont darter	0.0	0.0	<0.1	0.7	0.0	0.0

[1] Not taken during this study but reported by Duke Power Company (1974)

[2] Not taken by electrofishing, but taken with gill nets (see Table 6-2).

Table 6-2. Seasonal gill net catches (number of fish per overnight gill net set (approximately 18 hr)) from the backwaters of Ninety-Nine Islands Impoundment. Numbers in parentheses are actual numbers of fish collected.

	Location 458				Location 462			
	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer
Gizzard shad	18.9 (284)	0.4 (3)	18.1 (145)	21.5 (172)	1.4 (21)	0.8 (6)	4.3 (34)	2.3 (18)
Carp	0.1 (2)	0.0 (0)	0.0 (0)	0.1 (1)	0.7 (10)	0.4 (3)	2.0 (16)	1.0 (8)
Golden shiner	0.0 (0)	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Quillback	2.9 (43)	0.8 (6)	3.0 (24)	8.1 (65)	9.0 (135)	2.4 (19)	2.8 (22)	6.9 (55)
White sucker	0.0 (0)	0.3 (2)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Silver redhorse	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.1 (1)	0.1 (1)	0.1 (1)	0.3 (2)
Smallfin redhorse	0.0 (0)	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (0)
Snail bullhead	0.2 (3)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
White catfish	0.1 (2)	1.2 (10)	0.8 (7)	0.6 (5)	0.3 (5)	0.8 (7)	1.5 (12)	0.3 (2)
Brown bullhead	0.1 (2)	0.0 (0)	0.4 (3)	0.6 (5)	0.1 (1)	0.4 (3)	0.7 (6)	0.0 (0)
Flat bullhead	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)
Channel catfish	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)
White bass	0.0 (0)	0.0 (0)	0.0 (0)	0.1 (1)	0.1 (1)	0.0 (0)	0.1 (1)	0.0 (0)
Warmouth	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (0)	0.1 (1)	0.0 (0)
Bluegill	0.2 (3)	0.0 (0)	0.1 (1)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.1 (1)
Redear sunfish	0.0 (0)	0.1 (1)	0.0 (0)	0.1 (1)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)
Largemouth bass	0.1 (1)	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
White crappie	0.8 (12)	0.1 (1)	0.3 (2)	1.3 (10)	0.2 (3)	0.1 (1)	0.0 (0)	0.3 (2)
Black crappie	1.5 (22)	0.5 (4)	0.4 (3)	1.3 (10)	0.4 (6)	0.0 (0)	0.1 (1)	0.4 (3)
Total Fish	24.9 (374)	3.5 (28)	23.2 (186)	34.2 (275)	12.4 (184)	5.3 (43)	11.8 (95)	11.6 (91)

(459.1) at Location 459 was in a backwater area which generally yielded more fish than the lotic station (459.2). Significantly more fish were collected during the fall than in other seasons (App. 6-2). This was probably the result of increased collecting efficiency at that time. Discharge during the fall was generally low and the water relatively clear, making it easier to see and net the fish.

Twenty-four species were taken from the backwater areas of Ninety-Nine Islands Impoundment (Locations 458 and 462) by electrofishing and gill netting (Tables 6-1 and 6-2). The two backwater locations had similar species composition. Centrarchids (mainly bluegill) were the most numerous fishes in electrofishing samples, whereas gizzard shad and quillback generally dominated the gill net catches. Most cyprinids and percids, which were common or abundant in the creeks and mainstream of the Broad River, were seldom or never collected in the backwater areas of Ninety-Nine Islands Impoundment. Significant differences in abundance of total fish existed among locations and seasons (App. 6-2). Location 458 yielded significantly higher numbers of fish than Location 462 (App. 6-2). It is difficult to explain the difference in abundance between these two locations because both habitats appeared quite similar. The most obvious difference between these two locations was that Location 458 was deeper than Location 462. Significantly fewer fish were collected by electrofishing during the summer than in other seasons (App. 6-2). Catches in other seasons were not significantly different from each other. Opposite results were obtained from gill net data, which displayed relatively high catches during summer (Table 6-2). These results indicate that fishes were active during the summer, thus susceptible to being caught in gill nets, and generally selected deep cool water, at least during the daytime when electrofishing samples were taken.

Of the physical-chemical factors analyzed, river discharge correlated most significantly with catches of total fish in electrofishing samples (Table 6-3). Greatest numbers of fish were taken in the backwaters of Ninety-Nine Islands Impoundment, and the highest numbers of fish taken in the mainstream of the Broad River were generally collected during periods of low flow, resulting in negative correlation coefficients. Turbidity, which is directly associated with river discharge (Chapter 3), also showed significant negative correlations with catch rates. It is probable that discharge affected both efficiency of collecting and actual abundance of fishes. Fishes were most efficiently collected in clear water during low flow, and most fishes avoided swift water and apparently sought refuge in calm water during periods of high discharge.

Gizzard shad, whitefin shiners, white catfish, bluegill, and largemouth bass were examined separately to determine more specific seasonal and location differences in abundance. These species were selected because of their abundance or ecological and/or economic importance in the study area. Gizzard shad and whitefin shiners were abundant and important forage fishes in the backwaters and mainstream, respectively. White catfish, bluegil and largemouth bass were important sport fishes in the backwaters.

Gizzard Shad

Gizzard shad were generally more abundant in the backwaters of Ninety-Nine Islands Impoundment than the mainstream of the Broad River (Table 6-1).

Table 6-3. Spearman rank correlation coefficients and associated probability values (in parentheses) between electrofishing catches (number of fish per 100 m shoreline) and physical-chemical variables in the mainstream of the Broad River (Locations 452, 453, 459, and 460), backwaters of Ninety-Nine Islands Impoundment (Locations 458 and 462), and all locations combined.

	River Discharge	Turbidity	Dissolved Oxygen	Temperature	Conductivity	pH
Total Fish						
All Locations	-0.71 (<0.01)	-0.33 (<0.01)	-0.08 (>0.05)	0.06 (>0.05)	-0.03 (>0.05)	-0.14 (<0.05)
Backwaters	---	-0.30 (<0.01)	0.10 (>0.05)	-0.26 (<0.05)	0.07 (>0.05)	-0.08 (>0.05)
Mainstream	-0.43 (<0.01)	-0.24 (<0.01)	-0.16 (>0.05)	0.13 (>0.05)	0.09 (>0.05)	-0.09 (>0.05)
Gizzard Shad						
All Locations	-0.37 (<0.01)	-0.06 (>0.05)	-0.02 (>0.05)	-0.01 (>0.05)	-0.18 (<0.05)	-0.11 (>0.05)
Backwaters	---	0.09 (>0.05)	-0.03 (>0.05)	-0.07 (>0.05)	-0.05 (>0.05)	-0.04 (>0.05)
Mainstream	-0.02 (>0.05)	-0.01 (>0.05)	-0.02 (>0.05)	-0.06 (>0.05)	-0.16 (>0.05)	-0.11 (>0.05)
Whitefin Shiner						
All Locations	0.13 (>0.05)	-0.05 (>0.05)	-0.05 (>0.05)	0.02 (>0.05)	0.17 (<0.05)	-0.05 (>0.05)
Backwaters	---	---	---	---	---	---
Mainstream	-0.34 (<0.01)	-0.18 (<0.05)	-0.08 (>0.05)	0.06 (>0.05)	0.16 (>0.05)	-0.11 (>0.05)
White Catfish						
All Locations	-0.39 (<0.01)	-0.29 (<0.01)	0.01 (>0.05)	-0.01 (>0.05)	0.13 (>0.05)	-0.05 (>0.05)
Backwaters	---	-0.32 (<0.01)	0.11 (>0.05)	-0.08 (>0.05)	0.33 (<0.01)	-0.13 (>0.05)
Mainstream	-0.15 (>0.05)	-0.11 (>0.05)	-0.01 (>0.05)	-0.05 (>0.05)	0.15 (>0.05)	0.08 (>0.05)
Bluegill						
All Locations	-0.65 (<0.01)	-0.41 (<0.01)	0.00 (>0.05)	0.05 (>0.05)	-0.05 (>0.05)	-0.06 (>0.05)
Backwaters	---	-0.47 (<0.01)	0.18 (>0.05)	-0.22 (>0.05)	0.15 (>0.05)	0.05 (>0.05)
Mainstream	-0.30 (<0.01)	-0.25 (<0.01)	-0.10 (>0.05)	0.10 (>0.05)	0.04 (>0.05)	-0.04 (>0.05)
Largemouth Bass						
All Locations	-0.54 (<0.01)	-0.11 (>0.05)	-0.05 (>0.05)	0.06 (>0.05)	-0.18 (>0.05)	-0.13 (>0.05)
Backwaters	---	-0.08 (>0.05)	-0.10 (>0.05)	-0.08 (>0.05)	0.08 (>0.05)	-0.22 (>0.05)
Mainstream	-0.02 (>0.05)	0.12 (>0.05)	0.00 (>0.05)	0.04 (>0.05)	-0.11 (>0.05)	-0.05 (>0.05)

Catches of gizzard shad displayed a significant negative correlation with river discharge when all locations were considered, indicating a preference for lentic habitats (Table 6-3). Although a significant negative correlation with conductivity was noted, it is not believed to be biologically significant.

Catches of gizzard shad from the mainstream of the Broad River differed significantly among locations, but not among seasons (App. 6-2). Significantly higher numbers of gizzard shad were present at Location 459 than other mainstream locations (App. 6-2), probably because of the proximity of Location 459 to a backwater area.

Gizzard shad in the backwaters of Ninety-Nine Islands Impoundment were more abundant at Location 458 during the fall than Location 462, but differences during other seasons were nonsignificant (App. 6-2). Reasons for this phenomenon are not known.

Whitefin Shiner

Whitefin shiners were most abundant in the mainstream of the Broad River, but were also taken in large tributary creeks. None were taken in the backwaters of Ninety-Nine Islands Impoundment (Table 6-1). Absence from backwaters and a negative correlation with discharge in the mainstream (Table 6-3) indicate that whitefin shiners select lotic areas with moderate discharge and avoid lentic areas and rivers with high discharge. The significant negative correlation with turbidity in the mainstream was probably the result of decreased electrofishing efficiency under turbid conditions. A significant positive correlation with conductivity when all locations were considered was noted, but is not believed to be biologically significant.

Whitefin shiners were more abundant during the fall than in other seasons (App. 6-2), probably because of increased collecting efficiency due to low discharge and clear water. Abundance did not differ among mainstream locations (App. 6-2).

White Catfish

Although white catfish were collected in a variety of habitats, they were most abundant in the backwaters of Ninety-Nine Islands Impoundment (Table 6-1). Significant negative correlations with river discharge and turbidity were noted (Table 6-3).

No significant differences among locations or seasons occurred in the mainstream or backwaters (App. 6-2).

Bluegill

Bluegill were common in all habitats but were most abundant in the backwaters of Ninety-Nine Islands Impoundment (Table 6-1). Significant negative correlations existed with river discharge and turbidity (Table 6-3).

Abundance of bluegill from the mainstream of the Broad River was significantly different among locations, but not among seasons (App. 6-2). Highest densities occurred at Location 459 and there was a general pattern of decrease in bluegill abundance with increased distance from the backwaters of Ninety-Nine Islands Impoundment (App. 6-2).

Catches of bluegill in the backwaters of Ninety-Nine Islands Impoundment differed among locations and seasons (App. 6-2). More bluegill were collected at Location 458 than Location 462 (App. 6-2). Fewer bluegill were collected by electrofishing during the summer than in other seasons (App. 6-2). It may be that bluegill moved out of the shoreline areas during the summer, possibly to find cooler regions of the reservoir.

Largemouth Bass

The preferred habitat of largemouth bass was the backwaters of Ninety-Nine Islands Impoundment. Abundance of largemouth bass was negatively correlated with river discharge (Table 6-3). Abundance of largemouth bass in the mainstream of the Broad River differed among locations, but not among seasons (App. 6-2). There was a general trend of decrease in largemouth bass abundance with increased distance from the backwaters of Ninety-Nine Islands Impoundment (App. 6-2).

Catches of largemouth bass from the backwaters of Ninety-Nine Islands Impoundment were greater at Location 462 than Location 458 during the winter, but differences during other seasons were nonsignificant (App. 6-2). It may be that largemouth bass avoided the electrofishing gear by selecting deep areas at Location 458 during the winter which were not available at Location 462.

AGE-GROWTH ANALYSES

Gizzard Shad

One hundred-thirty gizzard shad from electrofishing and gill net catches were used for age-growth analysis. Males constituted 46.9% (61), females 37.7% (49), and immatures 15.4% (20) of the gizzard shad examined.

The relationships of total body length to scale radius were established for males, females, immatures, and total fish. These relationships were linear. Based on a coincidental regression test (Zar 1974), the relationship for males and females did not differ significantly ($F = 0.29$, $df = 2,106$), so the equation for all individuals was used. The relationship between total length and scale radius was represented by the linear equation:

$$Y = 29.32 + 2.29X \quad (r^2 = 0.96)$$

where Y represents total length (mm) and X represents scale radius (mm) multiplied by 23 (magnification of the scale projector).

Annulus counts and back-calculated length at each annulus indicated that there was no appreciable difference in life span or growth between males and females, so the data were combined (Table 6-4). Jester and Jensen (1972) also reported insigificant differences in mean total length between males and females. No gizzard shad over six years old were collected in the present study. Growth of gizzard shad in the Broad River and Ninety-Nine Islands Impoundment was most rapid during the first year of life, being at least twice as fast as that of any subsequent year. The growth rate was similar from ages II through V, followed by a decline during age VI.

Table 6-4. Back-calculated total lengths of gizzard shad (sexes combined) collected from the Broad River and Ninety-Nine Islands Impoundment during September 1974 through October 1976 and a comparison of average calculated total lengths of gizzard shad from other waters.

BACK-CALCULATED TOTAL LENGTHS

Age Group	No. of Fish	Avg. Actual Length (mm)	Avg. Actual Weight (g)	Average calculated total length (mm) at each annulus					
				I	II	III	IV	V	VI
I	9	150	27	128					
II	57	185	56	120	171				
III	21	227	117	124	179	212			
IV	11	279	194	120	186	231	258		
V	4	314	244	116	186	231	271	297	
VI	6	364	428	118	190	246	303	338	363
Mean				121	182	230	277	318	363
Weighted Mean				121	176	224	273	322	363
Number of Fish				108	99	42	21	10	6

COMPARISON OF AVERAGE BACK-CALCULATED TOTAL LENGTHS

Locality (Author and Date)	Calculated mean total length at each annulus (mm)										
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Broad River, S.C. (Present Study)	121	176	224	273	322	363					
Elephant Butte Lake, N.M. (Jester and Jensen 1972)	94	151	183	219	254	273	291	324			
Elephant Butte Lake, N.M. (Patterson 1968)	86	128	156	185	214	234	238	260			
Conchas Lake, N.M. (Jester 1962)	76	154	225	284	320	343	360	371	379	387	412
Grand Lake, Okla. (Jenkins 1953)	100	203	260	318	350	383	395				
Tenkiller Reservoir, Okla. (Hall and Jenkins 1953)	140	238	350	385	423	423					
Fort Gibson Reservoir, Okla. (Jenkins 1953)	143	258	325								
Spike Lake, Okla. (Hall 1951)	160	225	305								
Poteau River, Okla. (Hall 1951)	198	228	310	330	358						
Lake Erie (Bodola 1965)	259	366	403	429	467	428					
Foots Pond, Ind. (Lagler and Applegate 1942)	190	248	265	283	348						
Grassy Pond, Ind. (Lagler and Applegate 1942)	193	228	258	283	295						
Crab Orchard Lake, Ill. (Lewis 1953)	101	136	167	170	163						
Beaver Dam Lake, Ill. (Lagler and Van Meter 1951)	240	278	330	375							
Lake Wappapello, Mo. (Patriarche 1953)	103	170	208	230	245	258	273	293	300	293	
Herrington Lake, Ky. (Turner 1953)	110	196	259	311	334						
Lake Newman, Fla. (Berry 1957)	254	317	338								

Growth rates of gizzard shad in the Broad River and Ninety-Nine Islands Impoundment appeared similar to those in other waters (Table 6-4).

Length-weight regressions were derived for males, females, sexes combined, and total fish. A coincidental regression test indicated no significant difference between regression lines for males and females ($F = 1.66$, $df = 2,106$). Therefore, males and females were pooled and the regression equation for total fish was used to express the length-weight relationship:

$$\text{Log } W = -4.9442 + 2.9491 \text{ Log } L \qquad (r^2 = 0.97)$$

where W represents weight (g) and L represents total length (mm).

Jester and Jensen (1972) also reported that differences in the length-weight relationship between the sexes were insignificant in Elephant Butte Lake. Gizzard shad from Elephant Butte Lake were slightly heavier than those from the Broad River and Ninety-Nine Islands Impoundment after attaining a length of 200 mm (Table 6-5).

Whitefin Shiner

Two hundred eighty-five whitefin shiners from the Broad River were used for age-growth analysis. Males constituted 38.6% (110), females 31.2% (89), and immatures 30.2% (86) of the specimens examined.

The total length-scale radius relationship for males was best represented by the second order equation:

$$Y = 16.80 + 1.29X + 0.0092X^2 \qquad (r^2 = 0.93)$$

whereas that of females was best represented by the first order equation:

$$Y = 9.21 + 1.85X \qquad (r^2 = 0.94)$$

where Y represents total length (mm) and X represents scale radius (mm) multiplied by 23(magnification of the scale projector). Therefore separate equations were used to back calculate growth for males and females.

Fastest growth was recorded during the first year, then growth rates generally declined in subsequent years (Table 6-6). Males grew faster than females, especially in the later years of life. Although fish of both sexes were taken through age IV, many more males were in the III and IV age groups than females. The same number of age II males and females were collected. More age I females were analyzed than males, probably because sex could be recognized earlier on females than males. These results suggest that young whitefin shiners had equal sex ratios, but females had higher mortality rates than males in the later years.

Length-weight regressions were derived for males, females, sexes combined, and total fish. A coincidental regression test revealed a significant difference between regression lines for males and females ($F = 22.11$, $df = 2,195$). Therefore, males and females were treated separately (Table 6-7). Comparison of calculated weights showed that females weighed more than males at a given length, presumably because of greater gonadal development.

Table 6-5. Comparison of calculated weights (g) of gizzard shad from the Broad River and Ninety-Nine Islands Impoundment to those from Elephant Butte Lake, New Mexico.

COMPARISON OF CALCULATED WEIGHTS

Length (mm)	Broad River Present Study	Elephant Butte Lake Jester and Jensen (1972)
100	9	9
200	69	69
300	229	234
400	538	557

Table 6-6. Back-calculated total lengths of whitefin shiners collected from the Broad River during September 1974 through October 1976.

BACK-CALCULATED TOTAL LENGTHS

MALES

Age Group	No. of Fish	Avg. Actual Length (mm)	Avg. Actual Weight (g)	Average calculated total length (mm) at each annulus I	II	III	IV
I	16	52	1.1	44			
II	47	69	3.7	42	61		
III	33	85	5.4	41	64	81	
IV	14	98	9.1	42	62	84	97
Mean				42	62	83	97
Weighted Mean				42	62	82	97
Number of Fish				110	94	47	14

FEMALES

Age Group	No. of Fish	Avg. Actual Length (mm)	Avg. Actual Weight (g)	Average calculated total length (mm) at each annulus I	II	III	IV
I	29	46	0.9	40			
II	47	66	2.6	43	61		
III	9	80	4.3	40	62	76	
IV	4	92	7.7	34	57	76	87
Mean				39	60	76	87
Weighted Mean				41	61	76	87
Number of Fish				89	60	13	4

Table 6-7. Length-weight relationships for whitefin shiners from the Broad River during September 1974 through October 1976, and a comparison of the calculated weights (g) for males and females.

LENGTH-WEIGHT RELATIONSHIPS

	n	Equation	r^2
Males	110	Log W = -5.8900 + 3.4259 Log L	0.97
Females	89	Log W = -5.7417 + 3.3627 Log L	0.97
Sexes Combined	199	Log W = -5.7179 + 3.3403 Log L	0.97
Total Fish	285	Log W = -5.9065 + 3.4420 Log L	0.98

COMPARISON OF CALCULATED WEIGHTS

Length (mm)	Males	Females
20	< 1	< 1
40	<1	<1
60	2	2
80	4	5
100	9	10

White Catfish

Ninety-four white catfish from electrofishing and gill net catches were used for age-growth analysis. Males accounted for 44.7% (42), females 44.7% (42), and immatures 10.6% (10) of the white catfish examined.

The relationships of total length to spine radius for males, females, immatures, and total fish were linear. Based on a coincidental regression test, the relationships for males and females did not differ significantly ($F = 0.95$, $df = 2,80$), so the equation for all individuals was used. The relationship between total length and spine radius was represented by the equation:

$$Y = -12.20 + 8.45X \qquad (r^2 = 0.79)$$

where Y represents total length (mm) and X represents spine radius (mm) multiplied by 30.9 (magnification of the dissecting microscope). The intercept value in the equation was low, probably because of a paucity of small fish, and did not yield a reasonable estimate of the length at which the spines formed. The low r^2 value was probably the result of inconsistent spine sectioning.

The oldest male white catfish analyzed in this study were age VI, whereas the oldest female was age VIII. Back-calculated length at each annulus indicated no appreciable difference in growth between males and females, so the data were combined (Table 6-8). Johnson et al. (1978) reported that male white catfish from the Yadkin River, North Carolina, had faster growth than females.

Growth of white catfish in the Broad River and Ninety-Nine Islands Impoundment was about in the middle of the range reported from other waters (Table 6-8).

A significant difference existed between length-weight regression equations for males and females ($F = 17.08$, $df = 2,80$), so males and females were treated separately (Table 6-9). Comparison of calculated weights showed that females weighed more than males at a given length after sexual maturity was reached, probably because of greater gonadal development. Johnson et al. (1978) also observed greater weight in females from the Yadkin River, North Carolina. White catfish from the Broad River and Ninety-Nine Islands Impoundment were generally heavier than those from the Yadkin River.

Bluegill

Two hundred-eleven bluegill from electrofishing and gill net catches were used for age-growth analysis. Males accounted for 41.2% (87), females 32.2% (68), and immatures 26.5% (56) of the bluegill examined.

The total length-scale radius relationships for males and females did not differ significantly ($F = 1.67$, $df = 2,149$), so the equation for all individuals was used. The relationship between total length and scale radius was represented by the equation:

$$Y = 21.95 + 1.91X \qquad (r^2 = 0.94)$$

Table 6-8. Back-calculated total lengths of white catfish (sexes combined) collected from the Broad River and Ninety-Nine Islands Impoundment during September 1974 through October 1976 and a comparison of average calculated total lengths of white catfish from other waters.

BACK-CALCULATED TOTAL LENGTHS

Age Group	No. of Fish	Avg. Actual Length (mm)	Avg. Actual Weight (g)	Average calculated total length (mm) at each annulus							
				I	II	III	IV	V	VI	VII	VIII
I	1	165	41	89							
II	21	198	87	91	167						
III	32	233	145	88	167	220					
IV	15	263	216	84	154	213	254				
V	9	336	479	93	178	220	262	291			
VI	5	345	560	94	156	199	249	292	321		
VII	-	-	-	-	-	-	-	-	-	-	-
VIII	1	475	1360	80	148	215	266	291	334	359	367
Mean				88	162	213	258	291	328	359	367
Weighted Mean				89	165	217	256	291	323	359	367
Number of Fish				84	83	62	30	15	6	1	1

COMPARISON OF AVERAGE CALCULATED TOTAL LENGTHS

	Calculated mean total length at each annulus (mm)											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Broad River, SC (Present Study)	89	165	217	256	291	323	359	367				
Yadkin River, NC males (Johnson et al. (1978)	115	176	223	254	288	319	342					
Yadkin River, NC females (Johnson et al. 1978)	111	164	205	240	310							
Patuxent River, MD (Schwartz and Jochowski 1965)	117	150	185	211	244	264	300	338	378	424	445	508
Sacramento River, CA (Miller 1966)	79	132	175	213	251	292	328	351				
Santee Cooper, SC (Stevens 1959)	81	137	206	272	325	366	399	437	470	472	559	

Table 6-9. Length-weight relationships for white catfish from the Broad River and Ninety-Nine Islands Impoundment during September 1974 through October 1976, and comparison of calculated weights (g) of white catfish from other waters.

LENGTH-WEIGHT RELATIONSHIPS

	n	Equation	r^2
Males	42	Log W = -5.2624 + 3.1288 Log L	0.89
Females	42	Log W = -5.7357 + 3.3245 Log L	0.97
Sexes Combined	84	Log W = -5.5168 + 3.2341 Log L	0.93
Total Fish	94	Log W = -5.0785 + 3.0496 Log L	0.97

COMPARISON OF CALCULATED WEIGHTS

	Broad River Weight Present Study		Yadkin River Weight Johnson et al.(1978)		Alabama Weight Swingle (1965)
Length (mm)	Males	Females	Males	Females	
100	10	8	6	10	12
200	87	82	58	80	99
300	307	316	212	270	336
400	757	822	533	640	798
500	1521	1726	1088	1250	1563

where Y represents total length (mm) and X represents scale radius (mm) multiplied by 23 (magnification of the scale projector).

Growth for both sexes was similar during the first year, but thereafter males grew faster than females (Table 6-10).

Bluegill from the Broad River and Ninety-Nine Islands Impoundment grew slower than those of other waters (Table 6-10). Carlander (1972) reported that both slow and rapid growth of bluegill have been reported from most regions, indicating that population and edaphic conditions may have greater effects on growth than latitude or growing season. However, there does appear to be a trend toward slower growth and longer lifespan in the North than the South.

Length-weight relationships for males and females were not significantly different ($F = 1.10$, $df = 2,151$), so the regression equation for total fish was used to express the length-weight relationship:

$$\text{Log } W = -4.6396 + 2.9286 \text{ Log } L \qquad (r^2 = 0.98)$$

where W represents weight (g) and L represents total length (mm).

Comparison of calculated weights (Table 6-11) and regression coefficients of bluegill from the Broad River and Ninety-Nine Islands Impoundment with those of bluegill from other waters (Carlander 1972) indicates that bluegill from the Broad River and Ninety-Nine Islands Impoundment generally weighed less than bluegill of the same length from other waters.

Largemouth Bass

Fifty-two largemouth bass from electrofishing and gill net catches were used for age-growth analysis. Males constituted 46.2% (24), females 44.2% (23), and immatures 9.6% (5) of the largemouth bass examined. The relationships of total length to scale radius for males, females, immatures, and total fish were linear. The relationships for males and females did not differ significantly ($F = 0.60$, $df = 2,49$), so the equation for all individuals was used:

$$Y = 17.18 + 2.84X \qquad (r^2 = 0.97)$$

where Y represents total length (mm) and X represents scale radius (mm) multiplied by 23 (magnification of the scale projector).

Growth of female largemouth bass from the Broad River and Ninety-Nine Islands Impoundment was faster than that of males (Table 6-12). Previous studies have shown little agreement concerning differential growth rates of sexes of largemouth bass. Beckman (1946) and Stroud (1948) found no difference in growth rates between males and females. Padfield (1951) stated that females generally grew faster than males, especially in environments unfavorable for rapid growth. Faster growth by males was reported by Pardue and Hester (1966) and Olmsted (1974). These results suggest that differences in growth rates between male and female largemouth bass are attributable to environmental rather than genetic factors.

Table 6-10. Back-Calculated total lengths of bluegill collected from the Broad River and Ninety-Nine Islands Impoundment during September 1974 through October 1976 and a comparison of average calculated total lengths of bluegill from other waters.

BACK-CALCULATED TOTAL LENGTHS

MALES

Age Group	No. of Fish	Avg. Actual Length (mm)	Avg. Actual Weight (g)	Average calculated total length (mm) at each annulus I	II	III	IV	V	VI	VII	VIII
I	3	68	5.1	40							
II	7	81	10.1	41	72						
III	10	110	26.0	42	78	102					
IV	36	136	45.2	44	81	106	125				
V	23	151	60.3	45	78	105	128	143			
VI	7	155	69.2	42	74	103	119	137	149		
VII	-	-	-	-	-	-	-	-	-	-	-
VIII	1	185	124.0	45	68	95	117	131	146	162	173
Mean				43	75	102	122	137	148	162	173
Weighted Mean				44	78	105	125	141	149	162	173
Number of Fish				87	84	77	67	31	8	1	1

FEMALES

Age Group	No. of Fish	Avg. Actual Length (mm)	Avg. Actual Weight (g)	Average calculated total length (mm) at each annulus I	II	III	IV	V	VI
I	6	64	4.4	45					
II	16	84	10.1	45	77				
III	24	103	18.0	42	73	93			
IV	12	123	32.2	43	71	98	116		
V	8	148	61.0	47	76	96	119	138	
VI	2	142	51.3	46	68	87	107	126	136
Mean				45	73	94	114	132	136
Weighted Mean				44	74	95	116	136	136
Number of Fish				68	62	46	22	10	2

COMPARISON OF AVERAGE CALCULATED TOTAL LENGTHS (mm)

	I	II	III	IV	V	VI	VII	VIII
Broad River, SC males (Present Study)	44	78	105	125	141	149	162	173
Broad River, SC females (Present Study)	44	74	95	116	136	136		
Yadkin River, NC (Johnson et al. 1978)	54	93	122	146	175			
Potomac River, MD (Sanderson 1958)	56	104	122	147				
Mississippi River, IL (Upper Miss. R. Cons. Com. 1946)	76	135	168	185	198			
Poteau River, Ok (Jenkins et al. 1952)	91	130	152	163	175			
Badin Lake, NC (Tatum 1961)	69	107	140					
Lake of the Ozarks, MO (Montgomery 1956)	43	94	132	155	175			

Table 6-11. Comparison of calculated weights (g) of bluegill from the Broad River and Ninety-Nine Islands Impoundment to those from other waters.

COMPARISON OF CALCULATED WEIGHTS

Length (mm)	Broad River, SC Present Study	Yadkin River, NC Johnson et al. (1978)	Canton Lake, OK Hancock (1955)	Alabama Swingle (1965)
50	2	2	4	2
100	17	16	25	20
150	54	58	78	70
200	126	146	175	171

Table 6-12. Back-calculated total lengths of largemouth bass collected from the Broad River and Ninety-Nine Islands Impoundment during September 1974 through October 1976 and a comparison of average calculated total lengths of largemouth bass from other waters.

BACK-CALCULATED TOTAL LENGTHS

MALES Age Group	No. of Fish	Avg. Actual Length (mm)	Avg. Actual Weight (g)	Average calculated total length (mm) at each annulus I	II	III	IV	V	VI
I	7	179	63	132					
II	5	200	118	122	209				
III	6	296	398	139	220	278			
IV	4	338	591	146	220	269	310		
V	1	340	536	131	188	281	316	335	
VI	1	407	1019	119	179	239	278	333	364
Mean				132	203	267	301	334	364
Weighted Mean				133	212	272	306	334	364
Number of Fish				24	17	12	6	2	1

FEMALES Age Group	No. of Fish	Avg. Actual Length (mm)	Avg. Actual Weight (g)	Average calculated total length (mm) at each annulus I	II	III	IV	V	VI	VII	VIII
I	4	197	71	141							
II	3	218	176	96	208						
III	2	362	674	181	262	337					
IV	3	388	841	176	267	353	383				
V	4	416	1185	171	263	319	364	406			
VI	4	479	1842	134	226	315	377	414	438		
VII	2	527	2799	163	226	311	402	445	477	504	
VIII	1	542	2716	213	321	449	495	520	546	557	566
Mean				159	253	347	404	446	487	531	566
Weighted Mean				152	246	334	387	426	465	522	566
Number of Fish				23	19	16	14	11	7	3	1

COMPARISON OF AVERAGE CALCULATED TOTAL LENGTHS

	Calculated Mean Total Length at each Annulus (mm) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Broad River, SC Males (Present Study)	133	212	272	306	334	364									
Broad River, SC Females (Present Study)	159	246	334	387	426	465	522	566							
Lake Fort Smith, AR (Olmsted 1974)	138	244	310	353	372	426	452								
Center Hill Reservoir, TN (Hargis 1965)	160	295	365	427	451	476									
Claytor Lake, VA (Rosebery 1950)	114	257	345	399	427	452									
Brown's Lake, WI (Hraz and Threinen 1955)	91	170	229	272	305	345	412	452	467	478	498	521	510		
Quabbin Reservoir, MA (McCaig and Mullan 1960)	103	234	325	381	417	445	467	478	489						
Fort Gibson, Reservoir, OK (Houser 1958)	145	259	335	412	478	518	559								
Oklahoma Average (Jenkins and Hall 1953)	140	246	318	379	434	472	506	531	574						
Wisconsin (Bennett 1937)	84	188	267	318	356	384	414	442	460	475	495	506	513	523	533
Beaver Reservoir, AR (Bryant and Houser 1971)	152	277	333	396	462	474									

Male largemouth bass from the Broad River and Ninety-Nine Islands Impoundment generally had slightly slower than average growth but females had generally faster growth than largemouth bass from other waters (Table 6-12). Largemouth bass from northern waters had generally slower growth and longer life spans than those from southern waters. The good growth of females from the Broad River and Ninety-Nine Islands Impoundment can be explained by the abundance of forage-sized gizzard shad and bluegill, but the slow growth of males is unexplained.

Length-weight relationships for males and females were not significantly different ($F<0.01$, $df = 2,49$), so the regression equation for total fish was used to express the length-weight relationship:

$$\text{Log } W = -5.5795 + 3.2826 \text{ Log } L \qquad (r^2 = 0.98)$$

where W represents weight (g) and L represents total length (mm).

Largemouth bass from the Broad River and Ninety-Nine Islands Impoundment weighed more than largemouth bass of the same length from other waters (Table 6-13). Because of the plump condition and abundance of large fish (26.3% of largemouth bass electroshocked were over 400 mm long and 7.1% over 500 mm), an excellent sport fishery for largemouth bass exists in Ninety-Nine Islands Impoundment. However, because of the small size of Ninety-Nine Islands Impoundment, this fishery is limited and could be easily over-fished.

FOOD HABITS

Whitefin Shiner

Whitefin shiners in the Broad River were omnivorous. The stomach contents consisted mainly of organic debris, insect remains, aquatic and terrestrial invertebrates, and plant matter (mostly vascular plant material and filamentous algae) (Table 6-14).

Some seasonal differences in food were noted. The greatest percentage of empty stomachs (42.1%) was observed during the winter, indicating that feeding activities declined during that season. Greatest amounts of filamentous algae were consumed in the fall and smallest in the summer. Most vascular plant matter was eaten during the spring when run-off washed the plants into the river. Aquatic invertebrates (mainly insects) were common in the diet throughout the year. The aquatic insects most often recorded (chironomids, ephemeropterans, and trichopterans) were also predominant in the benthos and organic drift (Chapter 5). Greatest amounts of terrestrial insects were eaten in the spring when run-off swept them into the river. Unidentified insect remains were common in all seasons. Organic debris (including unidentified digested matter) was most prevalent during summer when elevated temperatures increased rates of digestion.

White Catfish

White catfish were omnivorous. Although there were not enough fish during some months to make good seasonal comparisons, food items of white catfish from the mainstream of the Broad River (Table 6-15) were compared with

Table 6-13. Comparison of calculated weights (g) of largemouth bass from the Broad River and Ninety-Nine Islands Impoundment to those from other waters.

Comparison of Calculated Weights

Length (mm)	Broad River, S. C. Present Study	Lake Ft. Smith, Ark. Olmsted (1974) Males	Lake Ft. Smith, Ark. Olmsted (1974) Females	Lewis Smith Reservoir, Ala. Webb and Reeves (1975)
100	10	10	10	13
200	94	88	88	99
300	356	312	315	329
400	916	767	782	772
500	1906	1543	1580	1497
600	3468	2731	2809	2571

Table 6-14. Food of whitefin shiners collected from the mainstream of the Broad River during September 1974 through October 1976.

FOOD ITEMS	FALL Number of Fish = 62 Empty = 20 (32.2%)			WINTER Number of Fish = 19 Empty = 8 (42.1%)			SPRING Number of Fish = 52 Empty = 14 (26.9%)			SUMMER Number of Fish = 144 Empty = 36 (25.0%)			TOTAL Number of Fish = 277 Empty = 78 (28.2%)		
	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.
PLANT MATTER															
Diatoms	-	N	1.6							-	N	0.7	-	N	0.7
Filamentous algae	-	19.6	8.1	-	11.6	10.5	-	5.6	13.5	-	1.5	4.2	-	5.4	7.2
Vascular plant material (r)	-	3.0	9.7				-	44.2	7.7	-	3.7	8.3	-	17.9	7.9
PLANT MATTER (subtotal)	-	22.6	19.4	-	11.6	10.5	-	49.8	21.2	-	5.2	12.5	-	23.3	15.5
AQUATIC INVERTEBRATA															
Bryozoa colonies	-	1.1	3.2	-	2.9	5.3	-	3.9	1.9	-	1.5	2.8	-	2.4	2.9
Cladocera										2.0	N	0.7	1.3	N	0.4
Insecta															
Coleoptera (l)										3.9	0.8	1.4	2.5	0.4	0.7
Diptera															
Chironomidae (l)	18.2	0.8	3.2	28.6	1.0	10.5	36.4	0.3	7.7	5.9	0.1	2.1	13.8	0.3	4.0
Chironomidae (p)	54.5	18.1	1.6	14.3	0.3	5.3	18.2	0.3	1.9				11.3	2.2	1.1
Tipulidae (l)										70.6	13.4	2.1	45.0	6.7	1.1
Ephemeroptera (n)				14.3	4.0	5.3							1.3	0.1	0.4
Ephemeridae (n)										2.0	0.2	0.7	1.3	0.1	0.4
Trichoptera (l)	18.2	1.1	3.2	28.6	10.3	10.5	9.1	0.2	1.9	7.8	2.0	2.1	11.3	1.5	2.9
Leptoceridae (l)							9.1	0.4	1.9				1.3	0.2	0.4
AQUATIC INVERTEBRATA (subtotal)	90.9	21.1	9.7	85.8	18.5	26.3	72.8	5.1	11.5	92.2	18.0	11.1	89.1	13.9	11.9
TERRESTRIAL INVERTEBRATA															
Aranaea				14.3	3.6	5.3	9.1	3.1	1.9				2.5	1.2	0.7
Insecta															
Coleoptera (a)							9.1	2.5	1.9	3.9	2.0	1.4	3.8	1.9	1.1
Diptera (a)										2.0	0.2	0.7	1.3	0.1	0.4
Hymenoptera (a)							9.1	4.5	1.9	2.0	0.5	0.7	2.5	1.9	0.7
TERRESTRIAL INVERTEBRATA (subtotal)				14.3	3.6	5.3	27.3	10.1	5.7	7.9	2.7	2.8	10.1	5.1	2.9
UNIDENTIFIED INSECTA REMAINS	-	24.7	27.4	-	16.8	26.3	-	26.4	28.8	-	19.7	25.0	-	22.6	26.4
OSTEICHTHYES															
Scales	9.1	0.3	1.6										1.3	N	0.4
OSTEICHTHYES (subtotal)	9.1	0.3	1.6										1.3	N	0.4
ORGANIC DEBRIS	-	31.3	50.0	-	49.6	21.1	-	8.4	30.8	-	54.3	59.0	-	35.1	49.1

r = remains
l = larvae
p = pupae
n = nymphs
a = adults
N = negligible amount

Table 6-15. Food of white catfish collected from the mainstream of the Broad River during September 1974 through October 1976.

FOOD ITEMS	FALL Number of Fish = 8 Empty = 6 (75%)			WINTER Number of Fish = 10 Empty = 3 (30.0%)			SPRING Number of Fish = 3 Empty = 2 (66.7%)			SUMMER Number of Fish = 1 Empty = 0 (0.0%)			TOTAL Number of Fish = 22 Empty = 11 (50.0%)		
	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.
PLANT MATTER															
Filamentous algae				-	64.3	10.0							-	58.2	4.5
PLANT MATTER (subtotal)				-	64.3	10.0							-	58.2	4.5
AQUATIC INVERTEBRATA															
Pelecypoda	77.8	33.0	12.5										14.7	3.1	4.5
Decapoda				5.2	21.3	20.0							4.2	18.6	9.1
Insecta															
Coleoptera (l)				1.3	0.2	10.0							1.1	0.2	4.5
Diptera															
Ceratopogonidae (l)				2.6	N	10.0							2.1	N	4.5
Chironomidae (l)				68.8	1.3	30.0							55.8	1.2	13.6
Tipulidae (l)				1.3	0.2	10.0							1.1	0.1	4.5
Unidentified (l)				2.6	0.1	10.0							2.1	0.1	4.5
Ephemeroptera															
Baetidae (n)				2.6	0.2	10.0							2.1	0.2	4.5
Trichoptera (l)				13.0	1.2	10.0							10.5	1.1	4.5
AQUATIC INVERTEBRATA (subtotal)	77.8	33.0	12.5	97.4	24.5	60.0							93.7	24.6	31.8
TERRESTRIAL INVERTEBRATA															
Chilopoda				1.3	0.7	10.0							1.1	0.6	4.5
Insecta															
Coleoptera (a)	22.2	8.7	12.5										4.2	0.8	4.5
Diptera (a)				1.3	0.9	10.0							1.1	0.8	4.5
TERRESTRIAL INVERTEBRATA (subtotal)	22.2	8.7	12.5	2.6	1.6	10.0							6.4	2.2	9.1
UNIDENTIFIED INSECTA				-	2.7	30.0							-	2.4	13.6
ORGANIC DEBRIS	-	58.3	25.0	-	6.9	20.0	-	100.0	33.3	-	100.0	100.0	-	11.8	27.3

l = larvae
n = nymphs
a = adults
N = negligible amount

those from the backwaters of Ninety-Nine Islands Impoundment (Table 6-16). Plant matter was more common in stomachs from the mainstream than backwaters. Aquatic invertebrates were numerous in stomachs from both mainstream and backwater locations, but accounted for a greater portion of the diet in mainstream locations. Chironomid larvae, pelecypods, and trichopteran larvae (in descending order of abundance) were the most abundant aquatic invertebrates in stomachs from mainstream locations, whereas ephemeropteran nymphs, trichopteran larvae, and chironomids were most numerous from backwater locations. The presence of pelecypods in stomachs from the mainstream locations and absence in stomachs from the backwaters was related to their distribution in the benthos (Chapter 5). Terrestrial invertebrates (primarily oligochaetes, arachnids, and insects) accounted for more of the diet in the backwaters than in the mainstream. Fish constituted the greatest portion (by weight) of the food items from the backwater locations but were not found in stomachs from mainstream locations. This was probably the result of lower prey densities and smaller white catfish being taken from the mainstream locations than the backwater locations.

Results reported by Deveraj (1974), Johnson et al. (1978), and Stevens (1959) indicate that white catfish are omnivorous in other waters.

Bluegill

Bluegill from the mainstream of the Broad River and backwaters of Ninety-Nine Islands Impoundment were omnivorous, eating a wide variety of plant and animal items. Differences in food habits were noted between mainstream (Table 6-17) and backwater (Table 6-18) habitats, and among seasons.

More plant matter was consumed at backwater locations (45.7% by weight) than mainstream locations (14.1%). Plant matter (mostly filamentous algae) was most abundant in the diet during the fall in both mainstream and backwater habitats.

Aquatic invertebrates accounted for 81.1% and 93.6% of the number of food items in mainstream and backwater areas, respectively, but only 23.0% and 11.8% by weight, respectively. Bryozoans, gastropods, and pelecypods were minor components of the diet from both mainstream and backwater habitats. Cladocerans, copepods, and ostracods were common in the diet of bluegill from the backwater areas during fall and winter but were rarely eaten in mainstream areas or other seasons. Although they were numerous they contributed a negligible portion by weight to the diet of adults. Planktonic crustaceans were more common in the backwaters than the mainstream, but seasonal trends were difficult to discern because of fluctuations in densities (Chapter 4). Aquatic insects (primarily chironomids) were common in the diet, especially in the fall and winter, in both mainstream and backwater habitats. Chironomids were the most abundant organisms in the benthos and drift (Chapter 5). Aquatic insects generally accounted for a greater percentage of the food by weight from mainstream areas than backwater areas.

Terrestrial invertebrates were 9.8% and 17.0% by weight of the diet in mainstream and backwater bluegill, respectively. Trichopteran adults and formicids were the most common terrestrial invertebrates consumed by bluegill from the mainstream, whereas spiders (Aranaea), oligochaetes,

Table 6-16. Food of white catfish collected from the backwaters of Ninety-Nine Islands Impoundment during September 1974 through October 1976.

FOOD ITEMS	FALL Number of Fish = 11 Empty = 0 (0.0%) % No.	% Wt.	% Occ.	WINTER Number of Fish = 16 Empty = 6 (37.5%) % No.	% Wt.	% Occ.	SPRING Number of Fish = 15 Empty = 5 (33.3%) % No.	% Wt.	% Occ.	SUMMER Number of Fish = 4 Empty = 3 (75.0%) % No.	% Wt.	% Occ.	TOTAL Number of Fish = 46 Empty = 14 (30.4%) % No.	% Wt.	% Occ.
PLANT MATTER															
Filamentous algae				-	2.3	6.3							-	1.2	2.2
Vascular plant (r)							-	4.3	13.3				-	1.5	4.3
PLANT MATTER (subtotal)				-	2.3	6.3	-	4.3	13.3				-	2.7	6.5
AQUATIC INVERTEBRATA															
Bryozoa							-	0.5	6.7				-	0.2	2.2
Decapoda	1.5	5.2	9.1							20.0	7.3	25.0	0.2	0.7	4.3
Insecta															
Coleoptera (l)				5.0	0.1	6.3	1.3	0.8	20.0				1.5	0.3	8.7
Diptera															
Ceratopogonidae (l)				1.7	N	6.3							0.1	N	2.2
Chironomidae (l)	15.7	N	9.1	19.3	N	18.8	10.7	0.4	20.0	60.0	2.6	25.0	11.9	0.2	17.4
Chironomidae (p)	0.7	N	9.1	2.5	N	6.3	1.0	0.1	13.3				1.1	N	8.7
Chaoboridae (l)	0.7	N	9.1	39.5	0.1	12.5	0.1	N	6.7				3.1	0.1	8.7
Tipulidae (l)							0.8	0.9	6.7				0.6	0.3	2.2
Unidentified (l)							0.1	N	6.7				0.1	N	2.2
Ephemeroptera															
Baetidae (n)				0.8	N	6.3	32.9	7.0	26.7	20.0	1.2	25.0	27.6	2.4	13.0
Ephemeridae (n)	0.7	N	9.1				0.1	N	6.7				0.1	N	4.3
Heptageniidae (n)							22.9	4.1	26.7				19.1	1.4	8.7
Unidentified (n)	1.5	2.6	9.1	1.7	N	6.3							0.3	0.4	4.3
Lepidoptera (l)	0.7	1.7	9.1	2.5	0.1	6.3							0.3	0.3	4.3
Megaloptera (l)							0.1	0.6	6.7				0.1	0.2	2.2
Odonata															
Anisoptera (n)							0.2	1.8	13.3				0.2	0.6	4.3
Plecoptera (n)							0.2	N	6.7				0.2	N	2.2
Trichoptera (l)				22.7	0.2	12.5	18.9	6.0	33.3				17.6	2.2	15.2
AQUATIC INVERTEBRATA (subtotal)	21.5	9.5	45.5	95.7	0.5	25.0	89.3	22.2	46.7	100.0	11.1	25.0	84.1	9.3	37.0
TERRESTRIAL INVERTEBRATA															
Oligochaeta							7.2	37.5	26.7				6.0	13.0	8.7
Diplopoda							1.7	1.4	13.3				1.4	0.5	4.3
Aranaea							1.9	0.2	20.0				1.6	0.1	6.5
Insecta															
Coleoptera (a)	0.7	0.1	9.1										0.1	N	2.2
Hymenoptera (a)				1.7	0.1	6.3							0.1	0.1	2.2
TERRESTRIAL INVERTEBRATA (subtotal)	0.7	0.1	9.1	1.7	0.1	6.3	10.8	39.1	26.7				9.2	13.7	13.0
UNIDENTIFIED INSECTA	-	6.5	9.1	-	0.8	12.5	-	9.4	26.7				-	4.6	15.2
OSTEICHTHYES															
Dorosoma spp.	0.7	14.2	9.1	2.5	78.6	18.8							0.3	42.3	8.7
Lepomis macrochirus	1.5	18.7	9.1										0.1	2.6	2.2
Scales	75.4	2.3	18.2				0.1	0.1	6.7				6.5	0.4	6.5
Unidentified remains	-	0.2	9.1	-	16.9	18.8	-	7.8	13.3				-	11.4	13.0
OSTEICHTHYES (subtotal)	77.6	35.4	36.4	2.5	95.5	37.5	0.1	7.9	20.0				6.9	56.7	28.3
ORGANIC DEBRIS	-	48.4	72.7	-	0.7	18.8	-	17.0	46.7	-	88.9	25.0	-	13.1	41.3

r = remains
l = larvae
p = pupae
n = nymphs
a = adults
N = negligible amount

Table 6-17. Food of bluegill collected from the mainstream of the Broad River during September 1974 through October 1976.

FOOD ITEMS	FALL Number of Fish = 52 Empty = 4 (7.7%) % No.	% Wt.	% Occ.	WINTER Number of Fish = 15 Empty = 2 (13.3%) % No.	% Wt.	% Occ.	SPRING Number of Fish = 12 Empty = 1 (8.3%) % No.	% Wt.	% Occ.	SUMMER Number of Fish = 6 Empty = 1 (16.7%) % No.	% Wt.	% Occ.	TOTAL Number of Fish = 85 Empty = 8 (9.4%) % No.	% Wt.	% Occ.
PLANT MATTER															
Filamentous algae	-	22.5	11.5	-	12.7	13.3							-	13.5	9.4
Vascular plant (r)	-	1.1	5.8				-	0.8	8.3				-	0.6	4.7
PLANT MATTER (subtotal)	-	23.6	17.3	-	12.7	13.3	-	0.8	8.3				-	14.1	14.1
AQUATIC INVERTEBRATA															
Bryozoa colonies	-	0.8	1.9										-	0.4	1.2
Gastropoda	1.3	0.7	7.7	5.8	1.9	26.7							1.5	0.8	9.4
Pelecypoda	0.2	0.2	1.9	0.4	N	6.7				3.6	0.5	16.7	0.6	0.1	3.5
Hydracarina				0.4	0.1	6.7							0.1	N	1.2
Cladocera															
Unidentified	0.1	N	1.0										0.1	N	1.2
Copepoda (Cyclopoid)	21.8	N	1.9	24.7	0.1	6.7							17.0	0.1	2.4
Insecta															
Coleoptera (l)	0.6	0.3	1.9	0.4	N	6.7							0.4	0.2	2.4
Diptera															
Ceratopogonidae (l)	0.2	N	1.9	0.4	N	6.7				1.3	0.2	16.7	0.3	N	3.5
Chironomidae (l)	46.7	1.8	30.8	26.5	1.5	60.0	0.5	0.1	8.3	1.3	0.2	16.7	33.6	1.2	31.8
Chironomidae (p)	0.9	0.2	11.5	1.3	0.1	20.0	83.6	5.8	41.7	0.9	0.2	16.7	10.4	1.2	17.6
Stratiomyidae (l)	0.2	0.1	1.9										0.1	N	1.2
Tabanidae (l)	0.1	N	1.9										0.1	N	1.2
Tipulidae (l)	0.1	0.4	1.9	1.3	5.4	6.7							0.2	1.6	2.4
Unidentified (l)	0.2	0.1	1.9				0.9	1.5	8.3				0.3	0.4	2.4
Ephemeroptera															
Baetidae (n)	0.3	0.3	3.8							1.8	0.3	16.7	0.4	0.2	3.5
Ephemeridae (n)	0.1	N	1.9	0.9	9.7	6.7							0.2	2.7	2.4
Heptageniidae (n)	0.1	0.2	1.9	0.9	0.7	13.3							0.2	0.3	3.5
Unidentified (n)	0.1	N	1.9	0.4	N	6.7							0.1	N	2.4
Hemiptera															
Corixidae (a)	3.2	0.3	1.9	2.2	0.7	13.3							2.4	0.3	3.5
Unidentified (a)	2.9	0.6	7.7				4.7	5.2	16.7	1.8	0.2	16.7	2.6	1.3	8.2
Trichoptera (l)	12.5	24.4	15.4	21.1	4.6	26.7				0.4	0.9	16.7	10.7	12.2	15.3
AQUATIC INVERTEBRATA (subtotal)	91.6	30.4	65.4	86.7	24.8	80.0	89.7	12.6	50.0	11.1	2.5	50.0	81.3	23.0	64.7
TERRESTRIAL INVERTEBRATA															
Aranaea				0.9	0.9	13.3							0.1	0.3	2.4
Insecta															
Coleoptera (a)	1.2	1.1	9.6	8.5	0.5	6.7				0.9	0.6	16.7	1.9	0.7	8.2
Diptera (a)				0.9	N	6.7				0.9	0.6	16.7	0.2	0.1	2.4
Homoptera (a)	1.2	0.9	5.8										0.7	0.4	3.5
Hymenoptera															
Formicidae (a)	3.7	1.0	7.7							85.3	19.5	16.7	12.6	2.1	5.9
Unidentified (a)	0.2	0.1	3.8				0.5	0.3	8.3	0.4	1.7	16.7	0.2	0.3	4.7
Lepidoptera (l)	0.2	3.4	5.8										0.2	1.5	3.5
Lepidoptera (a)	0.2	2.0	1.9										0.1	0.9	1.2
Odonata															
Anisoptera (a)				0.4	0.4	6.7							0.1	0.1	1.2
Zygoptera (a)	0.2	0.2	1.9										0.1	0.1	1.2
Orthoptera (a)	0.5	2.1	3.8										0.3	1.0	2.4
Plecoptera (a)	0.1	N	1.9	0.4	N	6.7							0.1	N	2.4
Trichoptera (a)	1.2	1.5	5.8	0.4	0.1	6.7	9.9	7.3	16.7	1.3	2.6	33.3	2.0	2.3	9.4

Table 6-17 (cont.)

FOOD ITEMS	Number of Fish = 52 Empty = 4 (7.7%) % No.	% Wt.	% Occ.	Number of Fish = 15 Empty = 2 (13.3%) % No.	% Wt.	% Occ.	Number of Fish = 12 Empty = 1 (8.3%) % No.	% Wt.	% Occ.	Number of Fish = 6 Empty = 1 (16.7%) % No.	% Wt.	% Occ.	Number of Fish = 85 Empty = 8 (9.4%) % No.	% Wt.	% Occ.
UNIDENTIFIED INSECTA	-	24.1	25.0	-	0.3	6.7	-	44.3	41.7	-	63.0	33.3	-	24.8	24.7
OSTEICHTHYES															
Lepomis macrochirus				1.3	37.4	6.7							0.2	10.3	1.2
OSTEICHTHYES (subtotal)				1.3	37.4	6.7							0.2	10.3	1.2
ORGANIC DEBRIS	-	9.6	36.5	-	22.9	46.7	-	34.6	58.3	-	9.4	33.3	-	18.0	41.2

r = remains
l = larvae
p = pupae
n = nymphs
a = adults
N = Negligible amount

Table 6-18. Food of bluegill collected from the backwaters of Ninety-Nine Islands Impoundment during September 1974 through October 1976.

FOOD ITEMS	FALL Number of Fish = 43 Empty = 2 (4.7%)			WINTER Number of Fish = 22 Empty = 2 (9.1%)			SPRING Number of Fish = 18 Empty = 2 (11.1%)			SUMMER Number of Fish = 14 Empty = 3 (21.4%)			TOTAL Number of Fish = 97 Empty = 9 (9.3%)		
	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.
PLANT MATTER															
Filamentous algae	-	78.5	23.3	-	1.8	9.1	-	2.2	5.6	-	6.9	7.1	-	43.1	14.4
Vascular plant (r)							-	7.3	16.7	-	4.3	14.3	-	2.6	5.2
PLANT MATTER (subtotal)	-	78.5	23.3	-	1.8	9.1	-	9.5	22.2	-	11.2	21.4	-	45.7	19.6
AQUATIC INVERTEBRATA															
Bryozoa															
Statoblasts	32.9	2.4	4.7										18.3	1.3	2.1
Gastropoda	0.1	N	4.7	0.8	1.2	9.1							0.3	0.1	4.1
Pelecypoda	0.1	0.1	4.7	0.7	0.6	4.5							0.3	0.1	3.1
Cladocera															
Alona	0.2	N	2.3										0.1	N	1.0
Bosmina	0.1	N	4.7										0.1	N	2.1
Chydorus				14.6	0.4	4.5							4.1	N	1.0
Daphnia	11.3	N	2.3										6.3	N	1.0
Leptodora	0.2	N	2.3										0.1	N	1.0
Pleuroxus										5.2	0.1	7.1	0.3	N	1.0
Unidentified	0.1	N	2.3	2.9	0.1	4.5							0.9	N	2.1
Copepoda (Cyclopoid)	2.3	0.1	11.6	11.0	0.2	9.1	0.4	N	5.6	0.5	N	7.1	4.4	0.1	9.3
Ostracoda				0.1	N	4.5				0.5	N	7.1	0.1	N	2.1
Insecta															
Coleoptera (l)	0.7	0.4	4.7	0.4	3.1	13.6	1.1	0.2	11.1				0.6	0.5	7.2
Diptera															
Ceratopogonidae (l)	0.1	N	2.3							0.5	N	7.1	0.1	N	2.1
Chironomidae (l)	42.0	4.1	44.2	64.7	14.1	68.2	20.6	0.4	27.8	80.8	2.6	35.7	48.9	3.8	14.4
Chironomidae (p)	5.1	0.8	25.6	1.0	1.0	18.2	17.7	0.9	50.0	9.8	0.5	7.1	5.5	0.8	25.8
Chaoboridae (l)	0.1	N	2.3				0.4	N	5.6	0.5	N	7.1	0.1	N	3.1
Tipulidae (l)	0.5	1.1	2.3	2.2	33.5	18.2							0.9	3.5	5.2
Unidentified (l)	0.9	0.3	7.0				0.4	0.4	5.6				0.5	0.3	4.1
Ephemeroptera															
Baetidae (n)							4.6	1.3	11.1				0.4	0.4	2.1
Ephemeridae (n)							1.1	0.7	11.1				0.1	0.2	2.1
Heptageniidae (n)				0.1	N	4.5	0.4	0.5	5.6				0.1	0.2	2.1
Unidentified (n)	0.3	N	2.3	0.4	0.8	9.1							0.3	0.1	3.1
Hemiptera															
Corixidae (a)				0.1	0.1	4.5	0.4	N	5.6				0.1	N	2.1
Notonectidae (a)	0.2	N	2.3										0.1	N	1.0
Unidentified (a)	0.4	0.2	4.7	0.2	0.1	4.5							0.3	0.1	3.1
Megaloptera (l)				0.1	1.7	4.5	0.4	0.1	5.6				0.1	0.2	2.1
Trichoptera (l)	0.1	N	2.3	0.4	0.4	9.1	0.7	N	11.1				0.2	0.1	5.2
AQUATIC INVERTEBRATA (subtotal)	97.7	9.5	62.8	99.7	57.3	86.4	48.2	4.5	66.7	97.8	3.2	42.9	93.6	11.8	66.0
TERRESTRIAL INVERTEBRATA															
Oligochaeta							13.5	15.1	11.1				1.3	4.8	2.1
Diplopoda							0.4	0.1	5.6				N	N	1.0
Aranaea	0.1	N	2.3				11.3	23.3	16.7				1.1	7.3	4.1
Insecta															
Coleoptera (a)	0.3	0.1	11.6							2.1	68.2	14.3	0.3	4.4	7.2
Hemiptera (a)	1.1	0.1	2.3										0.6	N	1.0
Hymenoptera															
Formicidae (a)	0.1	N	4.7										0.1	N	2.1
Unidentified (a)	0.3	N	9.3	0.1	0.2	4.5							0.2	N	5.2
Neuroptera (l)				0.1	0.4	4.5							N	N	1.0
Orthoptera (a)							0.4	0.9	5.6				N	0.3	1.0

Table 6-18 (cont.)

FOOD ITEMS	FALL Number of Fish = 43 Empty = 2 (4.7%)			WINTER Number of Fish = 22 Empty = 2 (9.1%)			SPRING Number of Fish = 18 Empty 2 (11.1%)			SUMMER Number of Fish = 14 Empty = 3 (21.4%)			TOTAL Number of Fish = 97 Empty = 9 (9.3%)		
	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.
Plecoptera (a)	0.1	0.3	2.3										N	0.2	1.0
Trichoptera (a)	0.1	N	2.3										0.1	N	1.0
TERRESTRIAL INVERTEBRATA (subtotal)	2.1	0.5	30.2	0.2	0.6	4.5	25.6	39.4	16.7	2.1	68.2	14.3	3.7	17.0	19.6
UNIDENTIFIED INSECTA	-	4.2	23.3				-	2.2	16.7	-	0.6	14.3	-	2.9	15.5
OSTEICHTHYES															
Eggs							25.2	1.1	11.1	-	0.1	7.1	2.4	0.3	3.1
Scales							1.4	0.2	16.7				0.1	0.1	3.1
OSTEICHTHYES (subtotal)							26.6	1.3	22.2	-	0.1	7.1	2.5	0.4	5.2
ORGANIC DEBRIS	-	7.1	48.8	-	40.2	54.5	-	43.1	55.6	-	16.7	50.0	-	22.0	51.5

r = remains
l = larvae
p = pupae
n = nymphs
a = adults
N = negligible amount

and coleopterans were most abundant in bluegill from backwaters. Bluegill from mainstream and backwater areas consumed the greatest amounts of terrestrial invertebrates in the summer.

Largest amounts of organic debris in bluegill stomachs from both mainstream and backwater areas were noted in the spring, followed by winter.

Gerking (1962) reported that bluegill in an Indiana pond selected dipteran larvae, particularly chironomids, but Flemer and Woolcott (1966) showed that bluegill in a Virginia stream fed on the most available food source. Johnson et al. (1978) indicated that bluegill in the Yadkin River, North Carolina fed nonselectively on aquatic insects (hydropsychid larvae being most abundant) and organic debris. The fact that bluegill from the Broad River and Ninety-Nine Islands Impoundment fed on a wide variety of food items (Tables 6-17 and 6-18) indicated that they were opportunistic omnivores.

Largemouth Bass

Largemouth bass in the mainstream of the Broad River and backwaters of Ninety-Nine Islands Impoundment were carnivores. Although sample sizes for each season were small, it appeared that largemouth bass fed mainly on fish and crayfish throughout most of the year. In the mainstream areas, the major portion of the diet was evenly divided by weight between crayfish (48.5%) and fish (48.6%) (Table 6-19). In the backwater areas, most of the diet (84.7% by weight) was fish (Table 6-20). These results could be related to the relative abundances of crayfish and forage fish in the mainstream and backwater areas. Crayfish were found in benthic samples only in riffles in the mainstream (Chapter 5). Prey species of fish varied in the diet according to their abundance in each type of habitat. Whitefin shiners were important forage in the Broad River mainstream but were not present in the backwaters of Ninety-Nine Islands Impoundment, whereas shad were the predominant forage fish in the backwaters. Most of the aquatic insects consumed by largemouth bass in the backwaters of Ninety-Nine Islands Impoundment were eaten by young-of-the-year or yearling fish. Other studies such as those reviewed by Olmsted (1974) and Heidinger (1975) make note of the carnivorous (mainly piscivorous) nature of largemouth bass, and the tendency of larger bass to feed on larger prey.

ICHTHYOPLANKTON

TOTAL LARVAE

Samples from the backwaters of Ninety-Nine Islands Impoundment (Station 458.0) had more total larvae than samples from the mainstream of the Broad River (Stations 453.1, 453.2, 459.2, 460.0, 460.1, and 460.2) (Fig. 6-1, App. 6-3), but no significant differences were noted among samples from the different mainstream stations ($\chi_r^2 = 3.73$, $v = 3$, $p>0.05$). Differences in densities between backwater and mainstream locations were related to population densities and spawning behavior of the adults, and behavior and habitat selection of the larvae (Table 6-21). Similar results were obtained by Hess and Winger (In press), who found significantly higher concentrations of larval fish in the Dixon Creek backwater than in the mainstream of the Cumberland River in Tennessee. The ichthyoplankton samples from the mainstream of the Broad River were

Table 6-19. Food of largemouth bass collected from the mainstream of the Broad River during September 1974 through October 1976.

FOOD ITEMS	FALL Number of Fish = 5 Empty = 1 (20.0%)			WINTER Number of Fish = 4 Empty = 1 (25%)			SPRING Number of Fish = 1 Empty = 0 (0.0%)			SUMMER Number of Fish = 3 Empty = 3 (100.0%)			TOTAL Number of Fish = 13 Empty = 5 (38.5%)		
	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.
AQUATIC INVERTEBRATA															
Crustacea															
Cambarus latimanus				50.0	54.4	25.0							20.0	39.7	7.7
Unidentified crayfish remains	50.0	37.6	20.0										20.0	8.8	7.7
AQUATIC INVERTEBRATA (subtotal)	50.0	37.6	20.0	50.0	54.4	25.0							40.0	48.5	15.4
OSTEICHTHYES															
Notropis niveus				50.0	13.3	25.0	100.0	100.0	100.0				40.0	13.1	15.4
Lepomis microlophus	50.0	48.5	20.0										20.0	11.4	7.7
Unidentified fish remains	-	2.2	20.0	-	32.3	25.0							-	24.1	15.4
OSTEICHTHYES (subtotal)	50.0	50.7	40.0	50.0	45.6	50.0	100.0	100.0	100.0				60.0	48.6	38.5
ORGANIC DEBRIS	-	11.7	20.0										-	2.8	7.7

Table 6-20. Food of largemouth bass collected from the backwaters of Ninety-Nine Islands Impoundment during September 1974 through October 1976.

FOOD ITEMS	FALL Number of Fish = 20 Empty = 7 (35.0%)			WINTER Number of Fish = 8 Empty = 0 (0.0%)			SPRING Number of Fish = 5 Empty = 2 (40.0%)			SUMMER Number of Fish = 7 Empty = 2 (28.6%)			TOTAL Number of Fish = 40 Empty = 11 (27.5%)		
	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.	% No.	% Wt.	% Occ.
PLANT MATTER															
Leaf				16.7	1.1	12.5							2.0	0.4	2.5
PLANT MATTER (subtotal)				16.7	1.1	12.5							2.0	0.4	2.5
AQUATIC INVERTEBRATA															
Crustacea															
Cambarus latimanus	30.0	18.3	5.0	16.7	3.5	12.5							8.0	11.5	5.0
Unidentified crayfish remains							50.0	33.8	20.0				2.0	3.1	2.5
Insecta															
Hemiptera															
Corixidae (a)	20.0	N	10.0	16.7	N	12.5				34.4	4.4	42.9	28.0	N	15.0
Gerridae (a)										65.6	3.4	57.1	42.0	N	10.0
Diptera															
Tipulidae (l)				16.7	N	12.5							2.0	N	2.5
AQUATIC INVERTEBRATA (subtotal)	50.0	18.3	15.0	50.1	3.5	37.5	50.0	33.8	20.0	100.0	7.8	57.1	82.0	14.6	27.5
OSTEICHTHYES															
Dorosoma cepedianum	30.0	55.7	10.0										6.0	31.4	5.0
Dorosoma petenense	10.0	4.1	5.0										2.0	2.3	2.5
Dorosoma spp.				33.3	90.4	25.0	50.0	64.3	20.0				6.0	36.2	7.5
Lepomis macrochirus	10.0	N	5.0										2.0	0.1	2.5
Unidentified fish remains	-	21.3	25.0	-	5.0	25.0	-	1.9	20.0	-	92.2	14.3	-	14.7	22.5
OSTEICHTHYES (subtotal)	50.0	81.1	45.0	33.3	95.4	50.0	50.0	66.2	40.0	0.0	92.2	14.3	16.0	84.7	40.0
ORGANIC DEBRIS	-	0.5	10.0										-	0.3	5.0

a = adult
l = larvae
N = negligible amount

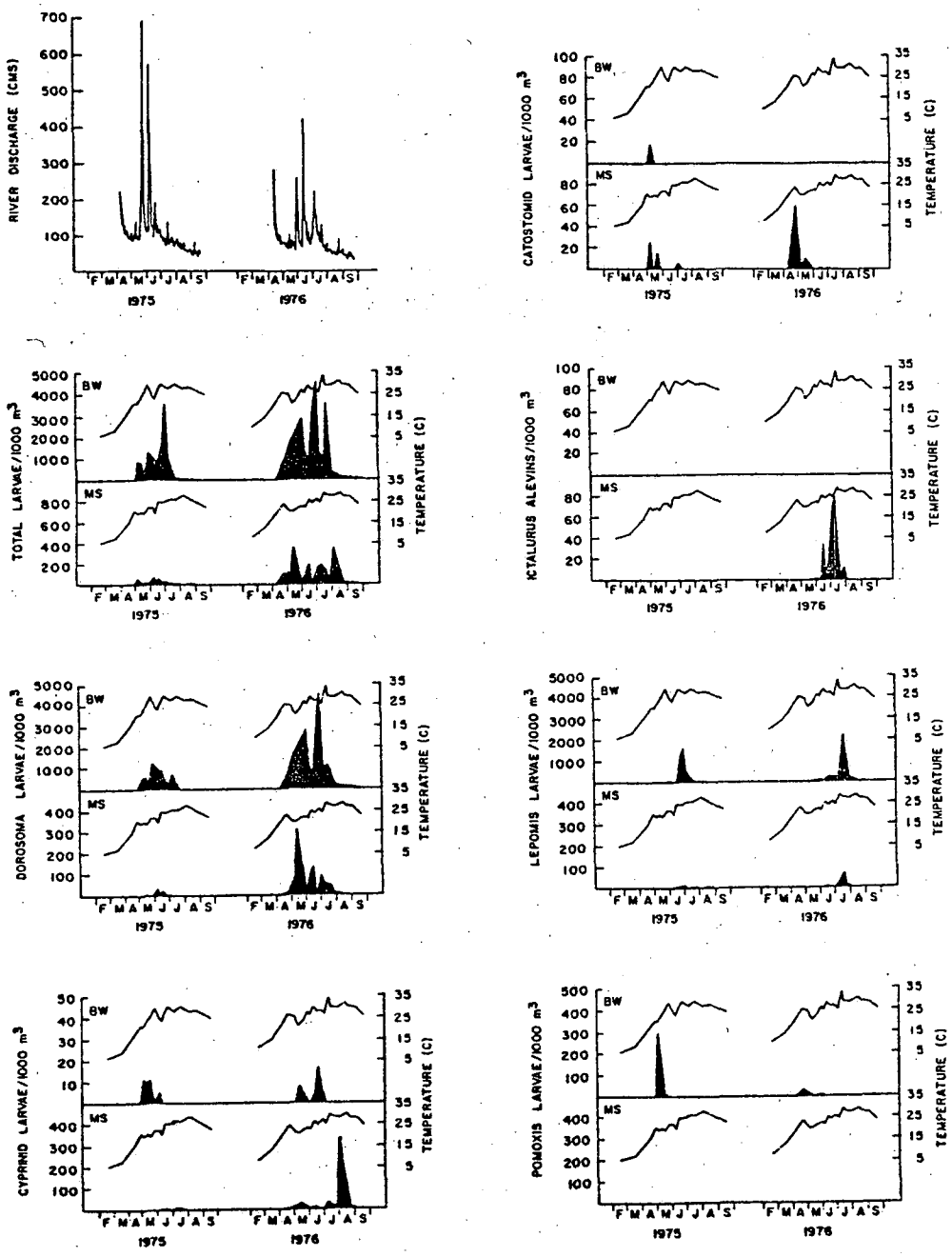

Figure 6-1. Discharge, water temperature, and larval fish densities at the backwaters of Ninety-Nine Islands Impoundment (Station 458.0) and mainstream of the Broad River (Stations 453.1, 453.2, 459.2 and 460.0 during 1975; and Stations 459.2, 460.0, 460.1, and 460.2 during 1976). BW represents backwaters and MS represents mainstream.

Table 6-21. Average adult and larval abundance, reproductive habits, and larval behavior of fishes collected during the 1975 and 1976 spawning seasons in the Broad River and Ninety-Nine Islands Impoundment.

Taxon	Habitat	Average Number of Adults/100m of Shoreline 1975	1976	Average	Average Number of Larvae/1000 m^3 1975	1976	Average	Reproductive Habits and Larval Behavior
Total Fish	Backwater	24.7	27.0	25.9	1117.5	1776.1	1446.8	
	Mainstream	3.1	4.6	3.9	15.3	123.3	69.3	
Dorosoma spp. (Shad)	Backwater	6.4	2.0	4.1	601.0	1390.0	995.5	Scatter eggs in open water or over bottom or vegetation generally in littoral zone of lentic habitats. Some migrate upstream to spawn over shoals or below dams. Eggs are adhesive. Newly hatched larvae stay near the bottom or shore but larger larvae become limnetic (Burns 1966b, Jester and Jensen 1972).
	Mainstream	1.0	0.2	0.6	3.9	52.9	28.4	
Cyprinids (Minnows)	Backwater	0.7	0.0	0.4	3.4	3.5	3.5	Most prefer lotic waters. They may scatter eggs or use nests, depending on species. Some may drift in the current but concentrations have been observed in shallow slack water areas.
	Mainstream	0.8	1.7	1.3	1.3	35.5	18.4	
Cyprinus carpio (Carp)	Backwater	2.1	1.5	1.8	1.0	0.0	0.5	Spawn in shallow areas. Eggs adhere to plants or substrate and are unguarded. Newly hatched larvae rest on or near vegetation for 4 to 5 days until yolk is absorbed, then they move to the bottom. They remain in shallow, weedy areas most of the summer (Burns 1966a).
	Mainstream	0.3	0.4	0.4	5.5	5.0	5.3	
Catostomids (Suckers)	Backwater	0.0	0.0	0.0	2.0	0.0	1.0	Most species migrate upstream and spawn in gravel riffles.
	Mainstream	<0.1	0.0	<0.1	5.1	6.7	5.9	
Ictalurus spp. (Catfish)	Backwater	1.6	1.0	1.3	0.0	0.0	0.0	Spawn in nests in undercut banks or other cover. Larvae remain on the nest guarded by the male for 2 to 7 days, depending on species and temperature (Emig 1966a).
	Mainstream	0.2	0.1	0.2	0.0	14.8	7.4	
Lepomis spp. (Sunfish)	Backwater	11.9	20.8	16.4	356.3	373.4	364.9	Spawn in nests over sand, gravel, brush, or mud. Eggs are adhesive and cling to the substrate. Larvae stay on the nest several days and are guarded by the male. Larger larvae may become limnetic (Emig 1966b).
	Mainstream	1.0	2.0	1.5	5.0	6.5	5.8	
Micropterus salmoides (Largemouth bass)	Backwater	1.9	0.9	1.4	0.0	0.0	0.0	Spawn near shore over sand, gravel, vegetation, or brush. Eggs hatch after 2 to 5 days, depending on temperature. Larvae remain on the nest for 4 to 8 days and are guarded by the male.
	Mainstream	0.1	0.1	0.1	0.0	3.3	1.7	
Pomoxis spp. (Crappie)	Backwater	4.1	0.8	2.5	154.8	9.2	82.0	Spawn in brush or vegetation near the shore. Eggs are adhesive and become attached to the nest or surrounding objects. Incubation ranges from 2 to 4 days, depending on temperature. Larvae remain in the nest 2 to 4 days after hatching and become limnetic when they leave the nest (Siefert 1968).
	Mainstream	0.1	0.1	0.1	0.0	0.0	0.0	
Percina crassa (Piedmont darter)	Backwater	0.0	0.0	0.0	0.0	0.0	0.0	Probably spawn in swift water over gravel. Eggs are probably adhesive (Page and Smith 1971).
	Mainstream	0.0	0.0	0.0	0.0	1.7	0.9	

dominated by shad, minnows, and catfish, with minor occurrence of sunfish, catostomids, carp, largemouth bass, and Piedmont darters. The backwater station samples were dominated by shad, sunfish (Lepomis spp.), and crappie. Low densities of unidentified cyprinids, catostomids, and carp were also present.

Results of this study agreed with Faber's (1967) observations that ichthyoplankton densities can vary from year to year, but that some taxa remain dominant. The 1975 samples contained generally fewer larvae than the 1976 samples (Fig. 6-1). Several factors could have accounted for this trend. High discharge and flooding with rapidly fluctuating water levels were prevalent during the 1975 spawning season, whereas low discharge occurred in 1976. The high discharge in 1975 could have diluted the larvae, and receding waters could have stranded many larvae in the flood plain. Also, the change in sampling techniques between 1975 and 1976 may have increased collecting efficiency, and the use of rose bengal stain in 1976 may have increased the efficiency of sorting larvae from debris in the samples (Mitterer and Pearson 1977).

A significant relationship between time of day and total larval fish densities in diel data from 13 May 1976 was noted ($\chi_r^2 = 23.81$, $v = 3$, $p<0.05$). The nonparametric SNK test revealed that total larval fish densities taken at 1500 hr and 2100 hr did not differ significantly from each other although mean densities were greater at 2100 hr. Densities at 1500 and 2100 hr were significantly higher than densities at 0300 hr and 0900 hr. Densities did not differ significantly between 0300 hr and 0900 hr samples. It appears that larval fish in the Broad River are more susceptible to drift sample collections during the afternoon and evening than during the morning.

SHAD

Shad (Dorosoma spp.) were the most abundant larvae at the backwater station during both years, averaging 601.0/1000 m^3 in 1975 and 1390.0/1000 m^3 in 1976 (Table 6-21). Although differences in shad densities between backwater and mainstream stations were marked (Fig. 6-1), there were no significant differences among the mainstream stations ($\chi_r^2 = 6.43$, $v = 3$, $p>0.05$). In mainstream habitats, shad were third in abundance in 1975 with an average of 3.9/1000 m^3, and first in abundance in 1976 with an average of 52.9/1000 m^3. High densities of larval shad, especially at the backwater station, were attributed to distribution and fecundity of adults, and behavior of larvae. Adult shad were abundant at the backwater station and relatively uncommon at the mainstream stations (Table 6-21). Many larvae would be expected to be produced because the fecundities of the two species involved, gizzard shad; and threadfin shad, D. petenense (Gunther), are normally very high (Baglin 1968; Kilambi and Baglin 1969). Larval shad are limnetic, and thus very susceptible to collection by the gear used in this study.

Spawning occurred earlier in 1976 than in 1975, probably as a result of abnormally warm temperatures in the spring of 1976 (Fig. 6-1). Multiple peaks in abundance during both years could have been the result of multiple spawns or spawning of two species.

Time of day significantly affected larval shad densities in the samples ($\chi^2_r = 20.93$, $v = 3$, $p<0.05$). Larval shad densities taken at 1500 hr and 2100 hr did not differ from each other, but densities at 1500 hr and 2100 hr were significantly higher than densities at 0300 hr and 0900 hr. Densities did not differ significantly between 0300 hr and 0900 hr samples.

CYPRINIDS

Larval cyprinids, excluding carp, were generally more abundant at the mainstream stations than the backwater station. Larval cyprinids were relatively uncommon at the backwater station during both years, averaging 3.4/1000 m^3 in 1975 and 3.5/1000 m^3 in 1976 (Table 6-21). Although the larvae could not be identified, some general observations of larval abundance were related to characteristics of the adult populations. The low densities of larvae in the backwater area were a reflection of low numbers of cyprinid adults (0.4/100 m). Eastern silvery minnows, Hybognathus regius Girard, and golden shiners, Notemigonus crysoleucas (Mitchill), were the only cyprinids other than carp taken in the backwater by electrofishing; therefore, most larvae taken from the backwater were probably these species. No significant difference in abundance of larval cyprinids existed among the mainstream stations ($\chi^2_r = 5.33$, $v = 3$, $p>0.05$). In the mainstream, cyprinids averaged only 1.3/1000 m^3 in 1975, but were second in abundance in 1976 with an average of 35.5/1000 m^3 which was due mainly to a peak in August (Fig. 6-1). The major peak in August is believed to have been mostly whitefin shiners, based on their abundance and time of reproduction, although larvae from the mainstream probably represented several species. Adults of ten species have been recorded from the mainstream (Table 6-1). Electrofishing samples in the mainstream averaged 1.3 adults/100 m (Table 6-21), but based on occasional seine samples, densities were higher than electrofishing samples indicated. Absence of a peak in August 1975 was probably because of the inability to make proper tow samples due to low water.

Although adult carp were generally common to abundant in the Broad River drainage (Table 6-1), and have relatively high fecundity (Carlander 1969), their larvae occurred infrequently in ichthyoplankton samples. Apparently, only a small percentage of the larvae were susceptible to the collection techniques used in this study (Table 6-21). The larvae remain on the bottom, and a cement gland on the snout aids in attachment to the substrate (Balon 1975). During the 1975 spawning season, carp averaged 1.0 and 5.5 larvae/1000 m^3 in backwater and mainstream samples, respectively. In 1976, no larvae were collected from the backwater area, but 5.0 larvae/1000 m^3 were collected in mainstream areas.

Time of day significantly affected larval cyprinid densities in the samples ($\chi^2_r = 18.77$, $v = 3$, $p<0.05$). Larval cyprinid densities taken at 2100 hr were significantly higher than densities from all other times of the day. There were no significant differences among 0300, 0900, and 1500 hr sample densities.

CATOSTOMIDS

Catostomid larvae were relatively uncommon in both backwater and mainstream stations. In the backwater, catostomids averaged 2.0 larvae/1000 m^3 during 1975 but none were taken in 1976 (Table 6-21). In the mainstream, catostomid averaged 5.1 larvae/1000 m^3 in 1975 and 6.7/1000 m^3 in 1976. Although

catostomid larvae could not be identified to species, they could be separated into Ictiobus-Carpoides and Catostomus-Moxostoma groups, based on myomere counts. All catostomid larvae in this study were members of the Catostomus-Moxostoma group. The generally low densities of catostomid larvae appeared to be directly related to low adult densities (Table 6-21), except for quillbacks, Carpiodes cyprinus (Lesueur), which were abundant in the backwaters (Table 6-2). Spawning in 1976 was earlier than in 1975, probably as a result of abnormally warm temperatures during the spring of 1976.

CATFISH

Catfish (Ictalurus spp.) alevins were collected only at the mainstream stations during 1976 (Fig. 6-1), averaging 14.8/1000 m^3 (Table 6-21). Species collected in these samples were snail bullheads; white catfish; flat bullheads, I. platycephalus (Girard); and channel catfish, I. punctatus (Rafinesque). Reasons for absence of alevins in 1975 samples from the mainstream are unknown.

Although densities of adult catfish (mainly white catfish and brown bullheads, I. nebulosus (Lesueur)) were higher at the backwater station than at the mainstream stations (Table 6-1), alevins were not collected at the backwater station. This lack of alevins in backwater collections was probably a manifestation of spawning habits of adults and behavior of alevins (Table 6-21). Catfish generally form nests in undercut banks or some other cover and the male guards the nest. The alevins tend to swarm in the nest under the protection of the male. In backwater areas, the alevins probably do not drift much, so they are not very susceptible to capture with push or tow nets. However; in mainstream areas, alevins may occasionally get swept out of their nests and become incorporated in the drift.

SUNFISH

Sunfish (Lepomis spp.) larvae were abundant at the backwater station during both years, with an average of 356.3/1000 m^3 in 1975 and 373.4/1000 m^3 in 1976, but densities were generally low at mainstream stations with an average of 5.0/1000 m^3 in 1975 and 6.5/1000 m^3 in 1976. This trend was related to distribution and abundance of adults (Table 6-21). Electrofishing data showed that adults averaged 16.4 individuals/100 m of shoreline in the backwater area and 1.5/100 m in the mainstream.

No sunfish larvae were collected at 460.0 and 460.2, but they were present at 459.2 and 460.1. It is possible that these larvae originated in the backwaters of Ninety-Nine Islands Impoundment. Larvae originating in the eastern backwater (Location 462) would tend to drift downstream near the left bank past Station 460.1 and larvae originating in the western backwater (Location 458) would tend to drift down the right bank past Station 459.2.

LARGEMOUTH BASS

Only two largemouth bass larvae were collected during this study. Both specimens (one at Station 459.2 and the other at 460.1) were

taken on 14 June 1976. Although adults were abundant in the backwaters, no larvae were collected there (Table 6-21), apparently because they remain on the nest until they become large enough to avoid the collecting gear.

CRAPPIE

Almost all spawning of crappie (Pomoxis spp.) occurred in the backwaters of Ninety-Nine Islands Impoundment. Crappie larvae were present in the backwaters during both years, with an average of 154.8/1000 m^3 in 1975 and 9.2/1000 m^3 in 1976, but none were found in mainstream samples (Table 6-21). This trend was related to distribution of the adults. In electrofishing samples, 4.1 adults/100 m of shoreline were present in 1975 and 0.8/100 m 1976 at backwater stations. Only 0.1 adults/100 m were found in the mainstream in both years. Higher densities of larvae in 1975 than in 1976 could be related to the higher number of adults present in 1975, or higher water in 1975 could have provided more spawning habitat by inundating the brushy shoreline around the cove. Earlier spawning in 1976 than in 1975 was probably the result of abnormally warm temperatures during the spring of 1976 (Fig. 6-1). One major peak was observed in each of the two years and larvae were collected over a relatively shore time period, indicating that crappie spawned once and had a short spawning season.

PIEDMONT DARTER

Piedmont darter larvae were collected only at the mainstream stations during 1976 (Table 6-12). Piedmont darters were uncommon in the mainstream of the Broad River near the CNS site. No adults were collected by electrofishing during the spawning season (Table 6-21) although a few specimens have been collected on other occasions (Table 6-1). Piedmont darters are typically large stream inhabitants and probably spawn in riffle areas (which are generally absent in the portion of the Broad River immediately upstream from the CNS site).

SUMMARY

Thirty-five species of fishes (predominantly cyprinids and bluegill) were taken from the mainstream of the Broad River, whereas 24 species (mostly centrarchids, gizzard shad, and quillback) were collected in the backwaters of Ninety-Nine Islands Impoundment. Total fish densities were much greater in the backwaters than the mainstream. Catches were generally highest in the fall during low discharge periods. There were significant negative correlations between catch rates of fishes and river discharge.

Age and growth of gizzard shad, white catfish and largemouth bass were within the range reported from other waters. Growth of bluegill was generally slower than that in other waters. No comparisons could be made concerning age and growth of whitefin shiners. Largemouth bass generally weighed more than those from other waters, but there were no noteworthy trends in the length-weight relationship of the other species studied.

Whitefin shiners, white catfish, and bluegill were omnivorous, feeding on a wide variety of plant matter (mainly filamentous algae) and aquatic and terrestrial invertebrates (primarily insects). Largemouth bass were carnivorous, feeding primarily on fish. The plumpness of largemouth bass was probably a manifestation of the large population of forage-sized gizzard shad in Ninety-Nine Islands Impoundment.

Total ichthyoplankton densities were much lower in the mainstream of the Broad River than the backwaters of Ninety-Nine Islands Impoundment. The mainstream samples were dominated by shad, cyprinids, and catfish, whereas samples from the backwaters were dominated by shad, sunfish (*Lepomis* spp.), and crappie. These differences were related to population densities and spawning behavior of adults, and behavior and habitat selection of the larvae. Larvae were present from late April through early September. Larvae were generally more susceptible to capture during the evening and afternoon than the morning.

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Lee Nuclear Station Response to Request for Additional Information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Number(s): ER RAI 65

NRC RAI:

Provide a copy of the technical report "Herpetological Survey for the W.S. Lee III Nuclear Station, South Carolina: Potential Impacts of Operations on Semi-Aquatic Species" by Michael Dorcas, Herpetological Laboratory, Department of Biology, Davidson College, 6 December 2007.

Duke Energy Response:

A copy of the requested report is included with this response.

Associated Response to the Lee Nuclear Station Combined License:

None.

Associated Attachment:

Dorcas, M.E., *Herpetological Survey for the W.S. Lee III Nuclear Station, South Carolina: Potential Impacts of Operations on Semi-Aquatic Species*, Herpetological Laboratory, Department of Biology, Davidson College, December 2007.

Herpetological Survey of the W.S. Lee III Nuclear Station, South Carolina: Potential Impacts of Operations on Semi-aquatic Species

by Michael E. Dorcas

6 December 2007

Herpetology Laboratory
Department of Biology Davidson College

Davidson Herpetology

DAVIDSON

Purpose

This report describes the results of field activities conducted 7 November 2007 to survey for amphibians and reptiles that inhabit aquatic environs of the W.S. Lee III Nuclear Station near Gaffney, South Carolina and provides assessments of the potential impacts alterations in water levels.

Suggested Citation

Dorcas, M. E. 2007. *Herpetological Survey of the W.S. Lee III Nuclear Station, South Carolina: Potential Impacts of Operations on Semi-aquatic Species.* Final Report to Duke Energy Carolinas LLC.

Cover Photograph

Marbled salamander (*Ambystoma opacum*) photographed by John D. Willson. This species was found inhabiting a wetland at the W.S. Lee III Nuclear Station.

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Herpetological Survey of W.S. Lee III Nuclear Station, South Carolina: Potential Impacts of Operations on Semi-aquatic Species

By Michael E. Dorcas

6 December 2007

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EXECUTIVE SUMMARY

This report describes efforts to inventory the amphibians and reptiles inhabiting aquatic habitats of the W.S Lee III Nuclear Station site in South Carolina. Aquatic habitats were searched on 7 November 2007 for amphibians and reptiles and for potential habitat where they likely occur. We documented five species of amphibians and four species of reptiles. One Species of Special Concern in South Carolina (Northern Cricket Frog, *Acris crepitans*) was found to be abundant. We found ephemeral wetland and limited stream habitats that likely support a high-diversity of amphibians and semi-aquatic reptiles. We discuss possible implications of adjustments to make-up pond water levels on species that occur or likely occur.

INTRODUCTION

Despite their prevalence, amphibians and reptiles are vital, albeit often overlooked, components of southeastern ecosystems. Hence, the status of herpetofauna is likely to reveal the environmental well-being of a habitat as well as the consequences of habitat destruction or other forms of environmental degradation (Gibbons 1988, Knutson et al. 1999, Vitt et al. 1990). Comprehensive accounts of regional species composition and diversity are fundamental to initiating meaningful monitoring or research programs applicable to conservation issues and the determination of species richness and diversity is the first step in evaluating status and trends of species in a prescribed area. Documentation of species inhabiting an area can allow predictions of how anthropogenic alteration of habitats will affect them and similar species that may reside there.

The W.S. Lee III Nuclear Station (hereafter referred to as the Lee Nuclear Station) is operated by Duke Energy Carolinas LLC and is located in Cherokee County approximately 8 miles southeast of Gaffney, South Carolina. Development of this nuclear station may require lowering of water levels in two make-up ponds located on the property. The purpose of this report is to provide information that will help to evaluate the potential impacts of lowering the water levels in these make-up ponds on amphibian and reptile populations inhabiting the property.

METHODS

Study Site

Lee Nuclear Station is being licensed by Duke Energy and is located within the Piedmont physiographic province of the Appalachian Mountain system. Habitats on the property include forested areas interspersed with open fields, streams, wetlands, and two large reservoirs; Make-up Pond A (formerly called the Sedimentation Basin) which has a

surface area of 68-ac and the 154-ac Make-up Pond B (formerly called the Low Flow Reservoir) (Fig. 1).

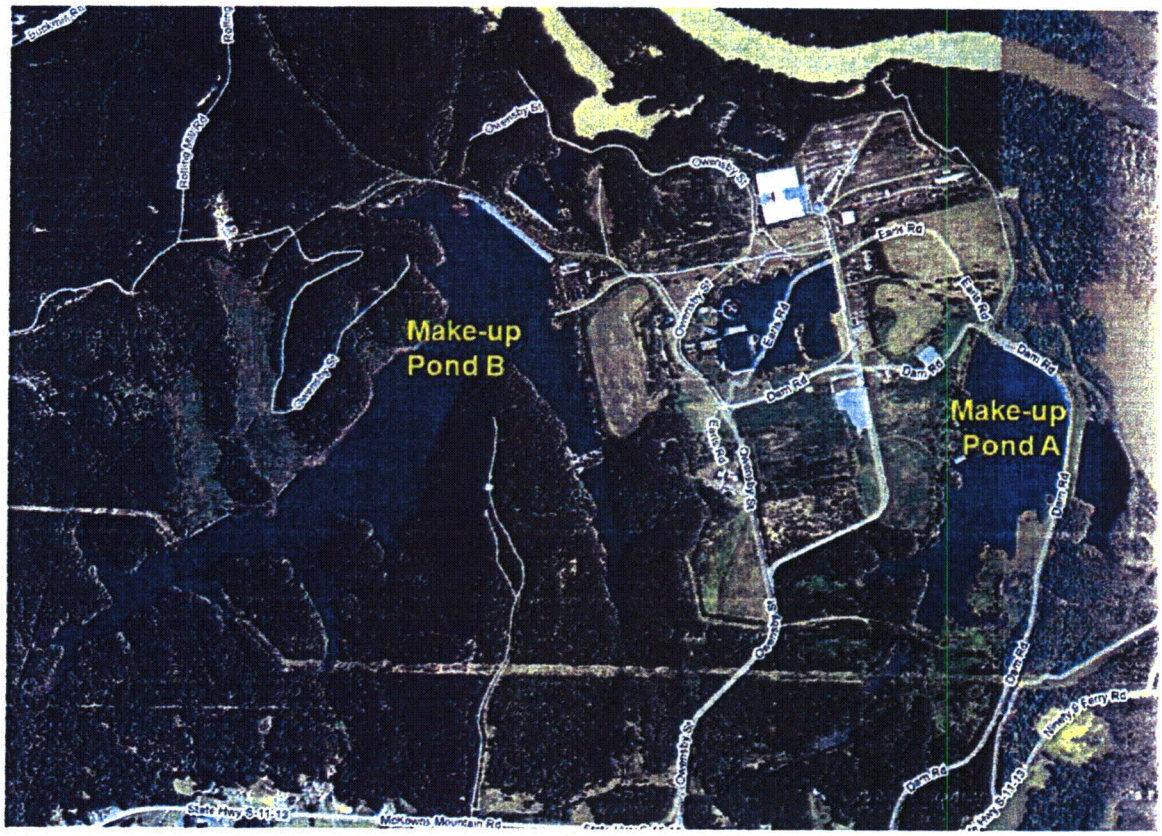

Figure 1. Lee Nuclear Station showing the two make-up ponds sampled.

Potential Species Lists

Unfortunately, there are no publications or documents that provide distribution records for amphibians and reptiles in South Carolina. Therefore, a list of within-range species for the study area was generated based on geographic distribution maps published by Conant and Collins (1998).

Sampling Methods

We visited the site on 7 November 2007 and searched the edges of both reservoirs from a boat for habitats that might harbor amphibians and reptiles. We paid particular attention to areas delineated as wetlands. Shorelines of both reservoirs were scanned using binoculars for suitable habitat and we used previously delineated wetland maps to

make decisions on places to sample. Sampling consisted of searching with binoculars from the boat for basking turtles and snakes, turning cover objects on land and in shallow water, and dipnetting streams and small pools.

All species captured were documented with a voucher photograph to allow for identification to species.

RESULTS AND DISCUSSION

Based on published distributions, 23 amphibian and 40 reptile species potentially occurred within the study area (Table 1). Our sampling was limited to a single day during early November. November is not an optimal time of year for sampling most amphibians and reptiles. Additionally, the drought experienced by much of the southeastern United States in the summer and fall of 2007 likely reduced animal activity further. Consequently, we documented only 4 species of reptiles and 5 amphibian species, excluding some early-stage tadpoles identifiable only to genus (*Bufo*), in puddles at the southern end of Make-up Pond A. These tadpoles are likely either American toads (*B. americanus*) or Fowler's Toads (*B. fowleri*) that bred approximately 2 weeks prior to sampling during a brief rainy period but were too small to allow identification to species. Given the diverse habitats that exist at the study area, numerous other species of amphibians and reptiles likely occur at the Lee Nuclear Station. The presence of marbled salamanders (*A. opacum*) indicates a functioning ephemeral wetland on the southeast side of Make-up Pond A (Fig. 2).

Marbled salamander (*Ambystoma opacum*)

Figure 2. Make-up Pond A showing large ephemeral wetland.

Figure 3. Make-up Pond B showing areas sampled (yellow circles).

This large wetland area that apparently holds water periodically (based on earlier aerial photography) likely supports a high diversity of amphibians such as spotted salamanders (*Ambystoma maculatum*), chorus frogs (*Pseudacris feriarum*), and other amphibians that rely on temporary wetlands. Both of the make-up ponds harbor sliders (*Trachemys scripta*) and likely provide habitat for numerous other semi-aquatic turtles (e.g., snapping turtles, *Chelydra serpentina*) and snakes (e.g., northern watersnakes, *Nerodia sipedon*). Shallow areas of the upper end of Make-up Pond B likely provide habitat for many amphibians and reptiles, especially in areas with emergent aquatic vegetation. One species found in these habitats was the northern cricket frog (*Acris crepitans*), a Species of Special Concern in South Carolina. This species appears to be distributed throughout the study area in appropriate habitats (e.g., muddy, open shorelines and wetlands) and is likely abundant throughout the upper Piedmont of South Carolina. Streams at the upper end (McKowns Creek area) of Make-up Pond B provide important habitat for salamanders (*Desmognathus fuscus* and *Eurycea guttolineata* were detected).

Effects of Water Level Alterations in the Reservoirs

Prediction of the effects of lowering or raising the water levels in the two make-up ponds is somewhat speculative. In my opinion, the primary amphibian and reptile habitats of the Lee Nuclear Station would likely be affected only minimally by lowering of the water levels of the two make-up ponds. Most species of amphibians and reptiles inhabit areas such as wetlands and streams, which are above the existing water levels and thus depend on water sources other than the make-up ponds. If water levels were lowered substantially for extended periods of time, turtles that currently inhabit the make-up ponds would likely leave the area in search for other suitable habitats (e.g., nearby

Broad River). No turtles observed or expected to occur on the property are considered rare, threatened, or endangered.

CONCLUSIONS

The environs of the Lee Nuclear Station contain a diversity of habitats that likely provide resources for a high number of amphibian and reptile species. However, because sampling was conducted during less-than-optimal conditions, our knowledge of species actually occurring on the property is limited. Because most amphibians and reptiles do not rely on the make-up ponds directly, impacts of lowering the water levels, even for extended periods of time, would likely be minimal on all species but turtles. More thorough sampling under better conditions (spring, non-drought) would provide a more thorough understanding of the herpetofaunal diversity of the Lee Nuclear Station property.

Table 1. Potentially occurring and documented amphibians of the Lee Nuclear Station. "*" Denotes Species of Special Concern in South Carolina.

Scientific name	Common name	Status
Acris crepitans	Northern Cricket Frog	Documented*
Bufo americanus	American Toad	Potential
Bufo fowleri	Fowler's Toad	Potential
Gastrophryne carolinensis	Eastern Narrowmouth Toad	Potential
Hyla chrysoscelis	Cope's Gray Treefrog	Documented
Hyla versicolor	Gray Treefrog	Potential
Pseudacris crucifer	Spring Peeper	Potential
Pseudacris feriarum	Upland Chorus Frog	Potential
Rana catesbeiana	Bullfrog	Potential
Rana clamitans	Green Frog	Potential
Rana palustris	Pickerel Frog	Potential
Rana sphenocephala	Southern Leopard Frog	Potential
Scaphiopus holbrookii	Eastern Spadefoot Toad	Potential
Ambystoma maculatum	Spotted Salamander	Potential
Ambystoma opacum	Marbled Salamander	Documented
Desmognathus fuscus	Northern Dusky Salamander	Documented
Eurycea cirrigera	Southern Two-lined Salamander	Potential
Eurycea guttolineata	Three-lined Salamander	Documented
Hemidactylium scutatum	Four-toed Salamander	Potential*
Notophthalmus viridescens	Red Spotted Newt	Potential
Plethodon cylindraceus	White-spotted Slimy Salamander	Potential
Pseudotriton montanus	Mud Salamander	Potential
Pseudotriton ruber	Red Salamander	Potential

Table 3. Potentially occurring and documented reptiles of the Lee Nuclear Station. "*" Denotes Species of Special Concern in South Carolina.

Scientific name	Common name	Status
Apalone spinifera	Spiny softshell turtle	Potential
Chelydra serpentina	Common snapping turtle	Potential
Chrysemys picta	Painted turtle	Potential
Kinosternon subrubrum	Eastern mud turtle	Potential
Pseudemys concinna	Eastern river cooter	Potential
Sternotherus odoratus	Common musk turtle	Potential
Terrapene carolina	Eastern box turtle	Documented
Trachemys scripta	Yellow-bellied slider	Documented
Anolis carolinensis	Green anole	Documented
Cnemidophorus sexlineatus	Six-lined racerunner	Potential
Eumeces fasciatus	Five-lined skink	Potential
Eumeces inexpectatus	Southeastern five-lined skink	Potential
Eumeces laticeps	Broadhead skink	Potential
Ophisaurus attenuatus	Slender glass lizard	Potential
Sceloporus undulatus	Fence lizard	Potential
Scincella lateralis	Ground skink	Documented
Agkistrodon contortrix	Copperhead	Potential
Carphophis amoenus	Worm snake	Potential
Cemophora coccinea	Scarlet snake	Potential
Coluber constrictor	Black racer	Potential
Crotalus horridus	Canebrake rattlesnake	Potential*
Diadophis punctatus	Ringneck snake	Potential
Elaphe guttata	Corn snake	Potential
Elaphe obsoleta	Rat snake	Potential
Heterodon platirhinos	Eastern hognose snake	Potential
Lampropeltis calligaster	Mole kingsnake	Potential
Lampropeltis getula	Eastern kingsnake	Potential
Lampropeltis triangulum	Scarlet kingsnake-milksnake	Potential*
Masticophis flagellum	Coachwhip	Potential
Nerodia sipedon	Northern banded watersnake	Potential
Opheodrys aestivus	Rough green snake	Potential
Pituophis melanoleucus	Pine snake	Potential*
Regina septemvittata	Queen snake	Potential
Sistrurus miliarius	Pigmy rattlesnake	Potential*
Storeria dekayi	Brown snake	Potential
Storeria occipitomaculata	Redbelly snake	Potential
Tantilla coronata	Southeastern crowned snake	Potential
Thamnophis sauritus	Ribbon snake	Potential
Thamnophis sirtalis	Garter snake	Potential
Virginia valeriae	Smooth earth snake	Potential

ACKNOWLEDGEMENTS

Grant Connette assisted with logistics and sampling. Gene Vaughan provided valuable logistical assistance and guidance for nearly every aspect of this project. Funding for this project was provided by Duke Energy Carolinas LLC. All collecting was done under a permit issued by the South Carolina Department of Natural Resources to MED through the University of Georgia's Savannah River Ecology Laboratory.

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