SOME BIOTIC AND ABIOTIC FACTORS AFFECTING THE DISTRIBUTION OF FISHES IN THE UPPER YADKIN RIVER

A Thesis

by

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ABSTRACT

Some Biotic and Abiotic Factors
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An electrofishing survey of the headwater regions of the upper Yadkin River yielded 19 species of fishes. Dissolved oxygen concentration, dissolved carbon dioxide concentration, velocity of flow, volume of flow, pH, and bottom type were the abiotic factors measured in the survey. The range of tolerances that various species of fishes had to the factors and the affect these factors had on the distribution of each species was observed and recorded. Three species of fish, *Semotilus atromaculatus*, *Catostoma commersoni*, and *Hybopsis leptocephala* were found to inhabit much of the survey area. These species were found to have wide tolerances to all the abiotic factors measured and also to be associated with a large number of other species. Those species of fishes found with a limited range over the survey area had a narrow tolerance to one

or more factors. A correlation was found between the volume of water and the number of species present. Under normal conditions the number of species present increased as the volume of water increased. There was also a linear distribution present in the survey area. Linear distribution was found to be affected by the tolerances of each species to the factors measured.

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INTRODUCTION

Vast areas of the southern Appalachians are now undergoing land change and with this change comes the potential for great changes in the environment. The freshwater streams and rivers of the world are fragile ecosystems inhabited by organisms with variable tolerances of abiotic factors. Small changes in these factors can produce drastic effects. For this reason streams and rivers are excellent indicators of the health of the overall environment and man's environment as well (Richardson, 1974). This study is therefore important as a reference for future comparison with environmental data of the region.

Fish are distributed in various regions of streams according to their tolerances to both biotic and abiotic conditions such as: temperature, oxygen concentration, carbon dioxide concentration, bottom structure, pH, rate of stream flow, and other organisms.

Temperature of streams and rivers closely follows the air temperature. Since this study was started in April of 1979 and ended in October of 1979 and because fish were collected from stations only once, temperature was not used as a factor even though it was recorded as ecological data.

Dissolved oxygen concentration, carbon dioxide concentration, bottom structure, pH, and rate of flow are abiotic factors which were considered in this study as possibly affecting distribution.

Certain fish are found together quite often in various interacting relationships. This study, however did not try to determine specific relationships, but only which fish were commonly associated.

The study area was the upper Yadkin River and its tributaries from the headwaters to Patterson, North Carolina. There were 18 sampling stations.

The objectives of this study were as follows:

1. To determine what species of fishes are currently inhabiting the upper Yadkin River and its tributaries.

2. To determine the distribution of each species in the upper Yadkin River and its tributaries.

3. To determine the major icthyological associations existing in the upper Yadkin River and its tributaries.

4. To attempt to determine the tolerances to some abiotic factors of fishes in the study area.

5. To extend the known range of species, if any, which may be found for the first time in the upper Yadkin River and its tributaries.

6. To preserve examples of each species collected for comparison in future distributional studies.

7. To preserve and record data for use as a point of reference for possible environmental changes in the study area.

DESCRIPTION OF THE SURVEY AREA

The Yadkin River is a very large and important river which has its headwaters in North Carolina and its place of discharge in the Atlantic Ocean at Georgetown, South Carolina. The entire length is more than 400 miles and drains an area of 17,000 square miles (Smith, 1907).

The headwaters are in Watauga, Wilkes, and Caldwell counties of North Carolina on the slopes of the Blue Ridge Mountains. The river flows due east to Wilkesboro, then northeasterly to Elkin and then takes a southward course to the Atlantic Ocean. The main headwater streams in the study area are Preston Creek, Bailey Camp Creek, Dennis Creek, and additional small headwater branches.

The soil in the headwater region is alluvial adjacent to the stream and formed originally by podsolization. The average temperature is 65°F. Average precipitation is 40-60 inches per year. The vegetation in the upper part of the survey area has *Quercus rubra* on the ridges, *Tsuga canadensis* in the rough gorges, and *Liriodendron tulipifera* in the rich coves and valleys. The middle of the area has deciduous mixed hardwoods with *Betula lenta, Acer rubrum,* and *Liriodendron tulipifera* present. The lower area is deciduous mixed hardwoods interspersed with crop and pasture land.

Elevation of the study area ranges from approximately 2,950 feet at the headwater branches to approximately 1,100 feet at Patterson, North Carolina, the site of the last sampling station.

REVIEW OF THE LITERATURE

Relatively little work has been done on the interacting factors affecting the distribution of fishes in the rivers of the United States. Some work has been done on the effect of specific factors on fish distribution but little has been done on the multiple factor effect on distribution. Almost no work has been done on the factors affecting distribution of the fishes of the Yadkin River.

Cope (1870) spent several summers in the Appalachians and while there noted only about a score of species in the Yadkin River. Randall (1957) states that Jordan (1889) also spent a summer in 1888 recording the species in the rivers of the Allegheny region, including the Yadkin River. Smith (1907) did a report of the fishes of North Carolina for the North Carolina Geographical Survey. All of these reports added species to the list but none made note of their distribution as affected by common factors. Nothing has been done since then other than regular checks made by the Fish and Wildlife Commission of North Carolina. At the present 77 species are known to exist from the headwaters to the mouth of the Yadkin River.

Hydrogen-ion concentration is known to be one critical factor which affects fish distribution. Each habitat has its own pH range typical of the area and the fish in the area are acclimitized to the range. There is a range where each species does best and also there are lethal pH values regardless of acclimation. There is no definite range where fish are unharmed and outside of which fish are harmed. There is, however, a gradient of habitat deterioration correlated with the degree of variation of pH from the optimal condition. A pH range of 5-9 is not directly harmful to fish, however the toxicity of common pollutants may be affected by pH and cause harmful effects (EIFAC Working Party, 1969).

In an American survey of 409 locations, Ellis (1937) found the pH range of 6.3-9.0 to contain good fish populations but the majority of water courses were between 6.7-8.6. ORSANCO (1955) found that although fish have been found between pH values of 4 and 10, maximum production is found at ranges of 6.5-8.5. Lloyd and Jordan (1964) found fingerlings of Rainbow Trout, *Salmo gairdneri*, to be affected by different pH levels depending on the concentration of free carbon dioxide. No correlation was found between sensitivity to pH and size, however, there was a definite correlation between sensitivity and age. The older the fish, the longer it can survive extreme pH values. Lloyd and Jordan (1964) also found that Brown Trout were more resistant to low pH than Rainbow Trout. Eastern Brook Trout, *Salvelinus fontinalis*, have been found at pH values as low as 4.1 (Creaser, 1930). Menzies (1927) and Campbell (1961) found Brown Trout at pH values of 4.5 and 4.9, respectively. Lloyd and Jordan (1964) found acidemia would set in and cause death in Rainbow Trout at pH values of 3.15. Ness (1949) found that Carp develop a sensitivity to bacteria at pH values of 5.5.

Mountain streams are usually saturated with oxygen due to the contact of water with air in the riffles. Actual oxygen content falls with the lowering of altitude but the oxygen tension does not fall, in fact it does actually rise at lower altitudes (Powers, 1929). This should therefore affect species distribution only in areas of slow water and high temperature, like pools in a stream or slow rivers. Brook Trout are the predominant fish used for oxygen requirement studies because they are considered to have a higher oxygen requirement than many other fish and can survive only in well aerated water (Creaser, 1930). Breder (1927) suggests that this high oxygen requirement might be why Brook Trout are found in cooler waters since this habitat contains more oxygen than warmer waters. Gardner (1926) has published data which shows that for Brook Trout the higher the temperature, the higher the asphyxiation point. Creaser (1930) suggests that the asphyxiation gradient is probably the explanation for temperature control of habitat preference.

Temperature in mountain streams is generally lowest in the high altitudes and highest in the lower altitudes. Temperature also varies with the seasons. Powers (1929) believes it is improbable that temperature is the sole determinant of distribution. He states also the well known fact that fish move upstream and downstream with the changes in temperature brought about by the seasons. Breder (1927) states that Brook Trout have a wide tolerance of temperature variations from 0°C to at least 31°C. This is contradicted by Powers (1929), who states that 19°C is the maximum temperature for Brook Trout waters.

Rate of flow is an important factor in fish distribution. Typical of fast streams are fish whose streamlined bodies offer little resistance to flow such as Blacknose Dace, *Rhinicthys atratulus*, and Brook Trout, *Salvelinus fontinalis*. Fast water habitats have low rates of photosynthesis resulting in heterotrophic conditions and detritus based food chains. Food is swept downstream and fish must be adapted to catching what is swept past in order to survive. As the water slows, the fast water fish are replaced by fish better suited to slow water life. Here also the photosynthesis is low, still causing a heterotrophic way of life. Brook Trout are replaced by Smallmouth Bass, *Micropterus dolomieu*, Blacknose Dace are replaced by shiners, *Notropis* sp. Finally, in the broad rivers where the current is very slow, the Smallmouth Bass is replaced by catfish, *Ictalurus* sp., and Carp, *Cyprinus carpio* (Smith, 1974). In the lotic habitat this type of substrate affects the number and type of fish present.

Gravel and rubble bottoms are the most productive because they offer many places for insects to live.

Bedrock is too exposed to the currents to offer a suitable habitat for either fish or their prey. Silt and sand are the least productive types of substrate. Fish are distributed in relation to which type bottom will produce their preferred food and which is most advantageous for their spawning habits (Smith 1974).

MATERIALS AND METHODS

Collecting Methods

Electrofishing is especially suitable for collecting fish in lotic waters which are difficult to sein or where poisoning is impractical. Current is passed through electrodes and transmitted through the water, temporarily stunning the fish coming into the electrical field. For this study a small DC powered unit was used. The unit was a Coffelt Electronics Company Model BP-3 Lightweight Back-Pack High Voltage Electroshocker with two five foot fiberglass covered aluminum handles with aluminum electrodes on the end. One person was needed to operate the unit while another collected the stunned fish with a dip net.

Volume of stream flow was calculated by the following equation:

$$R = \frac{WDaL}{T}$$

With R= volume of flow in cubic feet per second (cfs)

W= average width of the stream in cm

D= average depth of the stream in cm

L= length of the section measured in cm

T= average time required for a float to travel L three times

a= a constant applied for bottom type (0.8 for rough or 0.9 for smooth)

Rate of flow or speed of the stream was calculated from the following equation: L/T, with L and T designated above. A one inch diameter cork was used as a float.

The pH was determined colorimetrically by the use of Lamotte's color standards.

Dissolved CO_2 was determined by titration with a LaMotte Dissolved CO_2 kit.

Dissolved O_2 was determined by use of LaMotte's Modified Winkler Method.

Temperature was obtained with a standard C°/F° thermometer.

Bottom type was divided into silt, sand, gravel, rocky, boulders, or bedrock. This is important because productivity of a stream is directly related to bottom structure.

Preserving Specimens

Specimens were killed by placing them in a gallon bucket containing ten percent formalin. All specimens were not kept, only enough of each species to make a reliable identification. All others were released unharmed back into the stream. Upon completion of collecting at a station, all large specimens were slit along their right sides penetrating the body cavity to allow the preserving fluid to come into contact with all body tissues. The incision was not made on smaller fish since their small size allowed the solution to reach all their tissues. Specimens were left in the original solution for seven days and then soaked in water for seven days to remove the excess formalin. Water was changed each day during the process. The fish were then placed in a seventy percent solution of ethanol which was the permanent preserving solution.

Fish of each species were placed in separate jars by species after final identification. Attached to each container was a label stating the station numbers where the species was found. The specimen jars were sealed and the entire collection was added to the Appalachian State University Ichthyology collection.

The specimens were identified by using keys and descriptions found in the following works: Eddy (1957); Blair, Blair, Brodkorb, Cagle, and Moore (1957); Menhinick, Burton, and Bailey (1973); Smith (1907); and Trautman (1950).

Field notes containing the survey area, location of collecting site, method of capture, the date, the name of collector, the original preservative, and the ecological abiotic data were made at each station as suggested by Lagler (1956). A list of species by station is provided in Appendix B.

Collecting Stations

The collecting of specimens for this study was undertaken April 19, 1979 and completed October 26, 1979. Specimens were obtained from eighteen different locations in two North Carolina counties. Collecting was done only once at each station. Stations were 1,000 meters in length. A map of the study area is provided in Figure A. A list of the sampling stations is also provided.

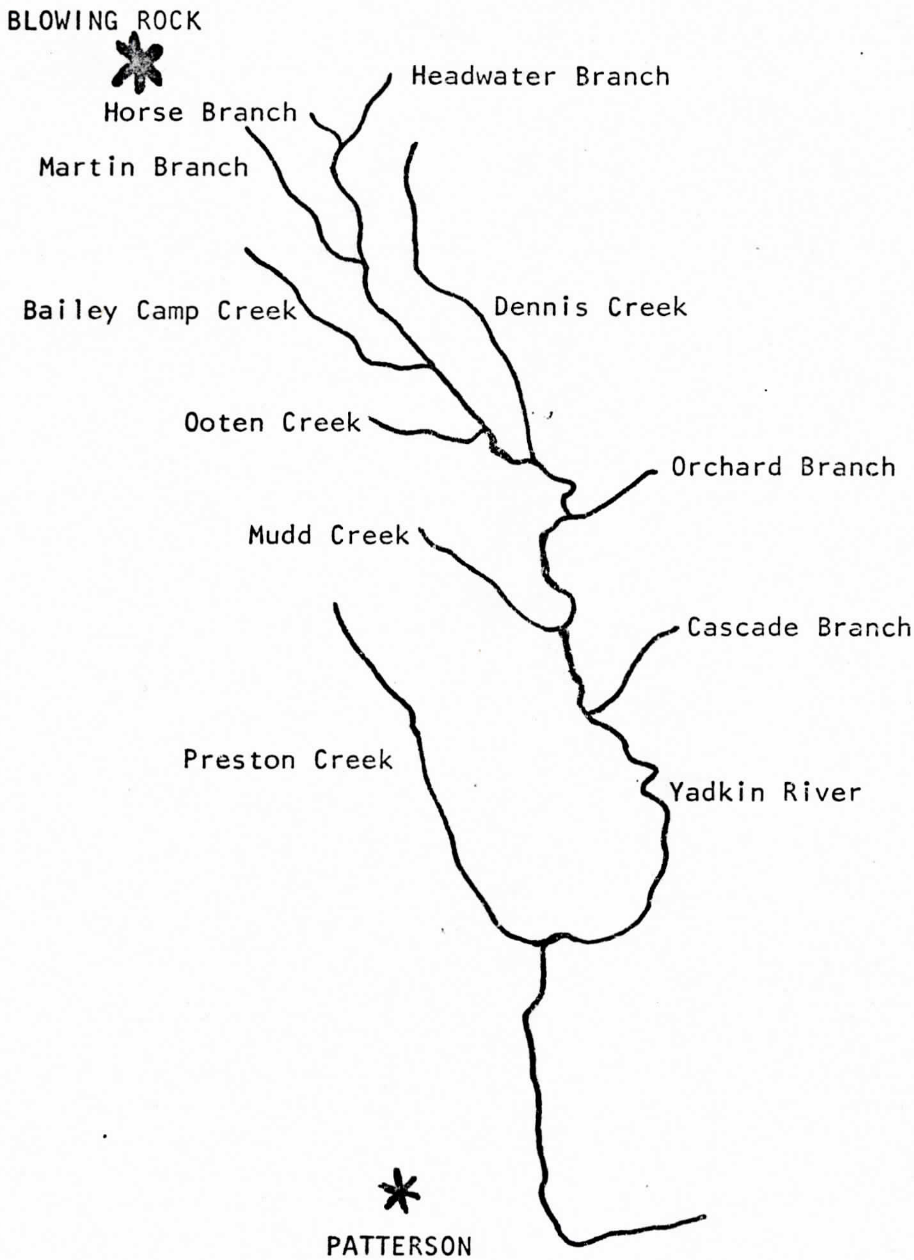

Figure 1: A Map of the Study Area

A LIST OF THE SAMPLING STATIONS

1. Where Highway 268 crosses the Yadkin River in Patterson.
2. Preston Creek at it's confluence with the Yadkin River.
3. Upper Preston Creek beside Nelson's Chapel Baptist Church.
4. The Yadkin River between Cascade Branch and the waterfall.
5. Cascade Branch.
6. The Yadkin River at it's confluence with Orchard Branch.
7. Orchard Branch.
8. The Yadkin River at it's confluence with Mudd Creek.
9. Mudd Creek.
10. Dennis Creek.
11. The Yadkin River at the first bridge below Ooten Creek.
12. Ooten Creek.
13. Bailey Camp Creek.
14. The Yadkin River immediately above Bailey Camp Creek.
15. The Yadkin River at it's confluence with Martin Branch.
16. Martin Branch.
17. Horse Branch.
18. Headwaters Branch

DISTRIBUTION, ASSOCIATIONAL, AND ABIOTIC DATA BY SPECIES

For each species of fish collected in this survey the following information is given in this section: its scientific name, common name, a list of stations where it is found in the survey, the range of values of the abiotic factors of the areas where the species was found, a list of fishes with which it is most often associated, and other pertinent information for each species.

In this study fish are said to be associated if they are found together at the same collecting site. Only those fish which are found associated at least 50% of the time are listed. Associates are listed only for those fish found more than once. The name of each fish listed as an associate is followed by the percentage of association.

Catostoma commersoni (Lacepede)

White Sucker

Stations where species was found: 1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 14

Range of values of abiotic factors of study area:

Water temperature: -2° — +20°C

pH: 5.2 — 7.3

Dissolved CO_2 concentration: 3 — 9 ppm

Dissolved O_2 concentration: 5 — 10.04 ppm

Velocity of flow: 10 — 42.8 cm/sec

Volume of flow: 1.98 — 7.2 X 10^{-2} m^3/sec

Bottom type: silt, sand, gravel, bedrock

Found at least 50% associated with:

Hybopsis leptocephala	91%
Gila vandoisula	58%
Hybopsis labrosa	58%
Lepomis auritus	58%
Notropis lutipinnis	50%

Other pertinent information: *C. commersoni* was most often found in schools, rarely was one found alone. When the species was found in areas with a bottom of bedrock, it was in pools under large overhanging rocks.

Cyprinus carpio (Linnaeus)

Carp

Stations where species was found: 1.

Range of values of abiotic factors of study area:

Water temperature: 20°C

pH: 7.0

Dissolved CO_2 concentration: 4 ppm

Dissolved O_2 concentration: 5.2 ppm

Velocity of flow: 14.7 cm/sec

Volume of flow: 1.98 m^3/sec

Bottom type: silt and sand

Found at least 50% associated with:

This was not computed as this species was found only once.

Other pertinent information: *C. carpio* was found only once, this being in the slow moving water of this station. The fish was caught in an area where the bank was deeply undercut.

Etheostoma flabellare (Rafinesque)

Fantail darter

Stations where species was found: 2, 3, 6, 8, 9.

Range of values of abiotic factors of study area:

Water temperature: -2° — +21°C

pH: 6.4 — 7.3

Dissolved CO_2 concentration: 3.5 — 9.2 ppm

Dissolved O_2 concentration: 5.92 — 10.04 ppm

Velocity of flow: 21 — 31 cm/sec

Volume of flow: 1.37×10^{-1} — 4.2×10^{-1} m^3/sec

Bottom type: coarse sand and gravel

Found at least 50% associated with:

Catostoma commersoni	100%
Hybopsis leptocephala	100%
Lepomis auritus	100%
Hybopsis labrosa	80%
Notropis lutipinnis	80%
Semotilus atromaculatus	80%
Gila vandoisula	60%

Other pertinent information: *E. flabellare* was found only in areas with a substratum of rubble, gravel, or coarse sand. The species was always found in riffles.

Gila vandoisula (Valenciennes)

Rosy dace

Stations where species was found: 1, 3, 5, 6, 9, 10, 11, 13, 14.

Range of values of abiotic factors of study area:

Water temperature: -2° — +21°C

pH: 5 — 7.3

Dissolved CO_2 concentration: 3 — 9.2 ppm

Dissolved O_2 concentration: 5 — 9.2 ppm

Velocity of flow: 10 — 55 cm/sec

Volume of flow: 1.98 — 7.2 X 10^{-2} m^3/sec

Bottom type: silt, sand, gravel, bedrock

Found at least 50% associated with:

Hybopsis leptocephala	100%
Catostoma commersoni	88%
Semotilus atromaculatus	77%
Salvelinus fontinalis	66%
Hybopsis labrosa	55%
Lepomis auritus	55%

Other pertinent information: *G. vandoisula* was found to have a wide habitat range. The species is found most often in the eddies formed by medium to large size rocks.

Hybopsis labrosa (Cope)

Thicklip chub

Stations where species was found: 1, 2, 3, 4, 5, 6, 8, 10.

Range of values of abiotic factors of study area:

Water temperature: -2° — +21°C

pH: 5.2 — 7.3

Dissolved CO_2 concentration: 3.5 — 9.2 ppm

Dissolved O_2 concentration: 5.2 — 10.04 ppm

Velocity of flow: 14.7 — 31 cm/sec

Volume of flow: 1.98 — 7.2 X 10^{-2} m^3/sec

Bottom type: silt, sand, gravel, bedrock

Found at least 50% associated with:

Catostoma commersoni	100%
Lepomis auritus	85%
Notropis lutipinnis	85%
Semotilus atromaculatus	71%
Etheostoma flabellare	57%
Gila vandoisula	57%

Other pertinent information: *H. labrosa* was found most often in slow water or sheltered pools.

Hybopsis leptocephala (Girard)

Bluehead chub

Station where species was found: 1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 13, 14, 15

Range of values of abiotic factors of study area:

Water temperature: -2° — +21°C

pH: 5 — 7.3

Dissolved CO_2 concentration: 1.5 — 9.2 ppm

Dissolved O_2 concentration: 5 — 10.04 ppm

Velocity of flow: 10 — 55 cm/sec

Volume of flow: 1.98 — 8.0 X 10^{-2} m^3/sec

Bottom type: silt, sand, gravel, bedrock

Found at least 50% associated with:

Catostoma commersoni	73%
Gila vandoisula	60%
Semotilus atromaculatus	60%

Other pertinent information: *H. leptocephala* is a species that is present throughout most of the study area, being absent only in the extreme headwater stations. It is usually found in pools, eddies, and slow riffles.

Lepomis auritus (Linnaeus)

Redbreast sunfish

Stations where species was found: 1, 2, 3, 6, 8, 9, 10.

Range of values of abiotic factors of study area:

Water temperature: -2° — +21°C

pH: 6.4 — 7.3

Dissolved CO_2 concentration: 3.5 — 9.2 ppm

Dissolved O_2 concentration: 5.2 — 10.04 ppm

Velocity of flow: 14.7 — 31 cm/sec

Volume of flow: 1.98 — 8.7 X 10^{-1} m^3/sec

Bottom type: mud, gravel, sand

Found at least 50% associated with:

Catostoma commersoni	100%
Hybopsis leptocephala	100%
Hybopsis labrosa	85%
Etheostoma flabellare	71%
Gila vandoisula	71%
Semotilus atromaculatus	71%
Notropis lutipinnis	57%

Other pertinent information: *L. auritus* was usually found in areas of slow water with a silty bottom, submerged roots and overhanging vegetation. The species was never found in mid-stream or in open pools.

Micropterus dolomeiu (Lacepede)

Smallmouth bass

Stations where species was found: 2, 3, 4.

Range of values of abiotic factors of study area:

Water temperature: 13° — 21°C

pH: 5.5 — 7.3

Dissolved CO_2 concentration: 3.5 — 5.5 ppm

Dissolved O_2 concentration: 5.92 — 7.4 ppm

Velocity of flow: 20.2 — 31 cm/sec

Volume of flow: 7.8×10^{-2} — 1.16 m^3/sec

Bottom type: sand, gravel, bedrock

Found at least 50% associated with:

Catostoma commersoni	100%
Hybopsis labrosa	100%
Hybopsis leptocephala	100%
Etheostoma flabellare	66%
Lepomis auritus	66%
Notropis lutipinnis	66%
Semotilus atromaculatus	66%

Other pertinent information: *M. dolomeiu* was found only in rocky pools.

Moxostoma coregonus (Cope)

Redhorse sucker

Stations where species was found: 1.

Range of values of abiotic factors of study area:

Water temperature: 20°C

pH: 7.0

Dissolved CO_2 concentration: 4 ppm

Dissolved O_2 concentration: 5.2 ppm

Velocity of flow: 14.7 cm/sec

Volume of flow: 1.98 m^3/sec

Bottom type: silt and sand

Found at least 50% associated with:

This was not computed as this species was found only once.

Other pertinent information: *M. coregonus* was found only at this lowest station.

Moxostoma rupiscartes (Jordan and Jenkins)

Striped jumprock

Stations where species was found: 1.

Range of values of abiotic factors of study area:

Water temperature: 20°C

pH: 7.0

Dissolved CO_2 concentration: 4 ppm

Dissolved O_2 concentration: 5.2 ppm

Velocity of flow: 14.7 cm/sec

Volume of flow: 1.98 m^3/sec

Bottom type: silt and sand

Found at least 50% associated with:

This was not computed as this species was found only once.

Other pertinent information: *M. rupiscartes* was found only at this station.

Notropis lutipinnis (Jordan and Brayton)

Yellowfin shiner

Stations where species was found: 1, 2, 3, 5, 8, 9.

Range of values of abiotic factors of study area:

Water temperature: 0 — 21°C

pH: 5 — 7.3

Dissolved CO_2 concentration: 3.5 — 8.5 ppm

Dissolved O_2 concentration: 5.2 — 10.04 ppm

Velocity of flow: 10 — 31 cm/sec

Volume of flow: 1.98 — 7.2 X 10^{-2} m^3/sec

Bottom type: silt, sand, gravel, bedrock

Found at least 50% associated with:

Catostoma commersoni	100%
Hybopsis leptocephala	100%
Lepomis auritus	83%
Etheostoma flabellare	66%
Gila vandoisula	66%
Hybopsis labrosa	66%
Semotilus atromaculatus	66%

Other pertinent information: *N. lutipinnis* was found in pools and eddies. It was also observed during breeding season on large redds made of small gravel.

Notropis scabriceps (Cope)
New River shiner

Stations where species was found: 4, 8, 9.

Range of values of abiotic factors of study area:

Water temperature: 0 — 13°C

pH: 5.5 — 6.8

Dissolved CO_2 concentration: 5.5 — 8.5 ppm

Dissolved O_2 concentration: 7.4 — 10.04 ppm

Velocity of flow: 20 — 30 cm/sec

Volume of flow: 1.37×10^{-1} — 4.2×10^{-1} m^3/sec

Bottom type: sand, bedrock

Found at least 50% associated with:

Catostoma commersoni	100%
Hybopsis leptocephala	100%
Lepomis auritus	100%
Semotilus atromaculatus	100%
Etheostoma flabellare	66%
Hybopsis labrosa	66%
Notropis lutipinnis	66%

Other pertinent information: *N. scabriceps* was found in the middle of this survey area. The three stations where it was found are not more than one mile in distance from each other.

Notropis telescopus (Cope)

Telescope shiner

Stations where species was found: 1

Range of values of abiotic factors of study area:

Water temperature: 20°C

pH: 7.0

Dissolved CO_2 concentration: 4 ppm

Dissolved O_2 concentration: 5.2 ppm

Velocity of flow: 14.7 cm/sec

Volume of flow: 1.98 m^3/sec

Bottom type: silt and sand

Found at least 50% associated with:

This was not computed as this species was found only once.

Other pertinent information: *N. telescopus* was found only once at this lowest station.

Noturus insignis (Richardson)

Margined madtom

Stations where species was found: 4

Range of values of abiotic factors of study area:

Water temperature: 13°C

pH: 5.5

Dissolved CO_2 concentration: 5.5 ppm

Dissolved O_2 concentration: 7.4 ppm

Velocity of flow: 20.2 cm/sec

Volume of flow: 1.16 m^3/sec

Bottom type: sand

Found at least 50% associated with:

This was not computed as the species was found only once.

Other pertinent information: *N. insignis* was found along the edge of a large pool formed by a barrier waterfall.

Rhinicthys atratulus (Hermann)

Blacknose dace

Stations where species was found: 7, 10, 14, 15, 16.

Range of values of abiotic factors of study area:

Water temperature: -2° — 19°C

pH: 6.4 — 7.3

Dissolved CO_2 concentration: 1.5 — 5.6 ppm

Dissolved O_2 concentration: 5 — 10.04 ppm

Velocity of flow: 20 — 42.8 cm/sec

Volume of flow: 2.1×10^{-2} — 2.3×10^{-1} m^3/sec

Bottom type: gravel, rocky, bedrock

Found at least 50% associated with:

Salvelinus fontinalis 100%

Hybopsis leptocephala 60%

Other pertinent information: *R. atratulus* was always found in the cold headwater streams.

Salmo gairdneri (Richardson)

Rainbow trout

Stations where species was found: 13.

Range of values of abiotic factors of study area:

Water temperature: 17°C

pH: 7

Dissolved CO_2 concentration: 3 ppm

Dissolved O_2 concentration: 5.44 ppm

Velocity of flow: 55 cm/sec

Volume of flow: 1.33×10^{-1} m^3/sec

Bottom type: gravel, boulders

Found at least 50% associated with:

This was not computed as the species was found only once.

Other pertinent information: *S. gairdneri* is commonly stocked by the North Carolina Fish and Game Commission and as such does not represent a breeding population in the study area.

Salmo trutta (Linnaeus)

Brown trout

Stations where species was found: 11.

Range of values of abiotic factors of study area:

Water temperature: 17.5°C

pH: 7.0

Dissolved CO_2 concentration: 3.5 ppm

Dissolved O_2 concentration: 5.92 ppm

Velocity of flow: 35 cm/sec

Volume of flow: 3.6×10^{-1} m^3/sec

Bottom type: sand, rock

Found at least 50% associated with:

This was not computed as the species was found only once.

Other pertinent information: *S. trutta* is commonly stocked by the North Carolina Fish and Game Commission and as such does not represent a breeding population in the study area.

Salvelinus fontinalis (Mitchill)

Brook trout

Stations where species was found: 5, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19.

Range of values of abiotic factors of study area:

Water temperature: -2° — 19°C

pH: 5.2 — 7.3

Dissolved CO_2 concentration: 1.5 — 8.5 ppm

Dissolved O_2 concentration: 4.6 — 10.04 ppm

Velocity of flow: 10 — 55 cm/sec

Volume of flow: 8.0×10^{-3} — 3.6×10^{-1} m^3/sec

Bottom type: large sand, gravel, bedrock

Found at least 50% associated with:

Hybopsis leptocephala	58%
Gila vandoisula	50%
Rhinicthys atratulus	50%

Other pertinent information: *S. fontinalis* is the species of fish that is found farther upstream than any other fish. This fish was found only in cool headwater streams where it had plenty of cover.

Semotilus atromaculatus (Mitchill)

Stone roller

Stations where species was found: 3, 4, 5, 6, 8, 9, 10, 11, 13.

Range of values of abiotic factors of study area:

Water temperature: -2° — 21°C

pH: 5.0 — 7.3

Dissolved CO_2 concentration: 3 — 9.2 ppm

Dissolved O_2 concentration: 5.44 — 10.04 ppm

Velocity of flow: 10 — 55 cm/sec

Volume of flow: 7.2×10^{-2} — 4.2×10^{-1} m^3/sec

Bottom type: sand, gravel, rock

Found at least 50% associated with:

Hybopsis leptocephala	100%
Catostoma commersoni	88%
Gila vandoisula	77%
Hybopsis labrosa	55%
Lepomis auritus	55%
Salvelinus fontinalis	55%

Other pertinent information: *S. atromaculatus* has a wide habitat range and is found in both riffles and pools.

DISCUSSION

The successful development and maintenance of a population depends upon a harmonious balance between environmental conditions and the tolerance of organisms to variations in one or more of these conditions. This suggests that one or more factors can limit the distribution and density of a population. It is difficult to state which factor from a complex of factors may be designated as limiting due to the fact that utilization of one substance may be regulated by other materials or factors. Minimal requirements of a substance may limit the special distribution of a species. The effect of factors on a population depends primarily on the tolerance of the organisms to a factor or a complex of interacting factors. These ideas are the essence of the law of tolerance. Tolerance to environmental factors varies widely in aquatic organisms. Organisms exhibiting a wide range of tolerance usually have a wide distribution. Tolerance to one factor may be masked or modified by the range of tolerance toward another factor. Many organisms have a wide tolerance to one condition and a narrow tolerance to another. This narrow tolerance may limit distribution of the species (Reid, 1961).

During this ecological and distributional study three important questions became apparent. First, does each species have a narrow or wide tolerance for each of the abiotic factors measured? Second, is there a correlation of the number of species present at a station to the volume of water flowing through the station? Finally, is there a linear distribution of species present in this survey area? This division will attempt to answer these questions.

Tolerances of Abiotic Factors

In this section the tolerances of individual species to the measured abiotic factors will be examined. No attempt will be made to designate limiting factors, only narrow or wide tolerances of the measured factors will be considered.

Seven species were found only once in this study. Two of these were stocked game species, *Salmo trutta*, and *Salmo gairdneri*. The tolerances of these species will not be examined since they do not represent breeding populations in the Yadkin River. *Noturus insignis*, the Margined Madtom, was found below a waterfall in a large natural pool. The waterfall was a natural barrier to further progress upstream for this species and as such no conclusions are drawn as to its tolerances. Four species, *Moxostoma coregonus, Moxostoma rupiscartes, Cyprinus carpio*, and *Notropis telescopus*, were found only once at the last sampling station downstream. This station is a large, wide area with slow moving water and a silty, sandy bottom. This may indicate the upstream limit of their range.

Two species, *Micropterus dolomieu* and *Notropis scabriceps*, were found three times. *Micropterus dolomieu* has a narrow tolerance of CO_2, O_2 and pH. The species is most commonly found in areas where the rate of flow is 20 - 31 cm/sec. The species has a broad tolerance of bottom types. *Notropis scabriceps* has a wide tolerance of bottom types but narrow tolerances of O_2, CO_2, and pH, and is most often found in water moving at speeds of 20 - 30 cm/sec.

Etheostoma flabellare and *Rhinicthys atratulus* were found five times each but in different types of habitat. *E. flabellare* has a broad tolerance of CO_2 and O_2 but a narrow tolerance of pH and bottom type. The species is found only in areas where the bottom is of gravel or small rocks. It is always found in the riffles.

R. atratulus has a narrow tolerance of pH. It has a wide tolerance of CO_2 and O_2 but is most often found in areas with low CO_2 concentrations and high O_2 concentrations. It is found in areas with a substratum of gravel or bedrock with cover. The species tolerates a wide variation in water speed.

Notropis lutipinnis is found in the lower half of the survey area. *N. lutipinnis* has a broad tolerance for all the factors measured except pH and velocity of flow. This species was not found in swift water but in pools and eddies.

Lepomis auritus has a narrow pH range but wide tolerances of the other factors. *L. auritus* is found in areas with abundant cover. It can be found where limbs hang in the water or where the bank is undercut. While the data indicates a large tolerance of water speed, the species was not found in the middle of the stream where the water is swift.

Hybopsis labrosa has a wide tolerance for all the factors measured. The species was found in areas that afford cover.

Gila vandoisula has a wide tolerance of all factors. This species can tolerate swift water but is usually found in pools.

Semotilus atromaculatus is often found over a wide range of values for the factors measured except water volume. Here the range is narrow as the species is not found in areas with very large volumes of water or very small volumes.

Catostoma commersoni is found all over the study area except the headwater regions. It has a broad tolerance for all the factors measured. The species is found in pools, under overhanging rocks, and in the areas where the bank is undercut.

Salvelinus fontinalis has a broad range of tolerances to nearly all factors. It does, however, have a narrow tolerance for variations in volume. The water volume must be small to support this species. It is found where there are pools and places to hide. The species also is found in water with a high O_2 content. It is the only species found either associated with others or alone.

Hybopsis leptocephala is found over a wider range of tolerances than any other species in the study area.

It is absent only in the extreme upper stations. While it may be found in areas of rapid water, it should be noted that when found there, it is found behind or under objects which afford protection from the flow. The species is found most often in pools or eddies.

Water Volume and the Number of Species

Under normal conditions the number of species of fish increases as the volume of water increases. This increase in the number of species may be due to increased food supply, increased breeding habitat, availability of cover, and a number of other factors.

During the study it was observed that there was an overall increase in the number of species as the water volume increased, as is depicted in Figure 2. There were two exceptions to this statement. However, these can be explained since these are both stations in lower altitude regions and, as such, the overall habitat was not greatly different from the main stream. These were broad streams with abundant pools and cover, similar to the farthest sampling station downstream in Patterson, North Carolina. Also three stations appear to have high water volumes in relation to the number of species.

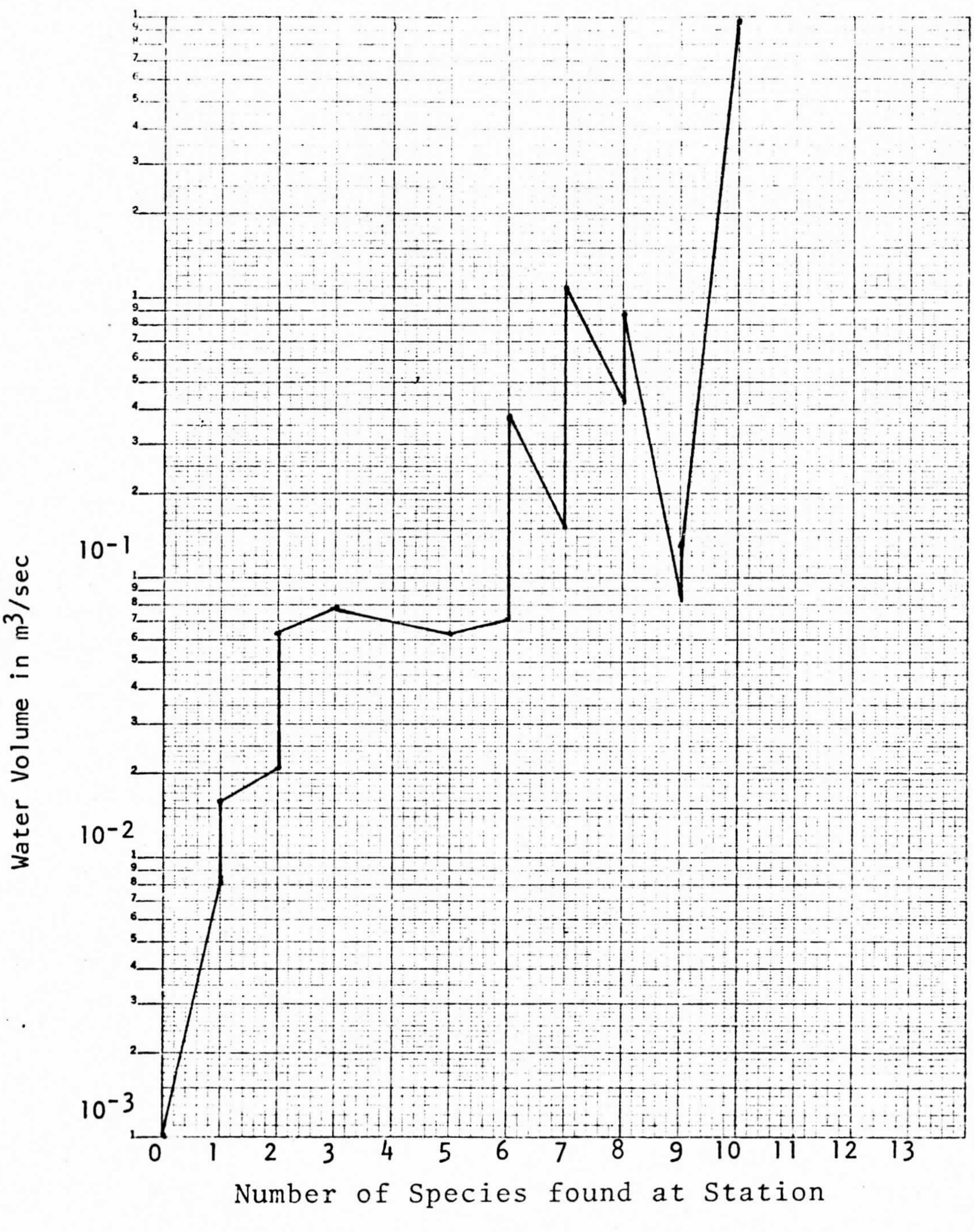

Figure 2. Relation of Number of Species to Stream Volume.

It should be noted that streams may vary in volume due to recent rainfall. At this time the volume does go up but normally not to extreme levels. When this happens flooding may occur. Flooding adversely affects stream life because it often washes organisms downstream temporarily or, rarely, permanently.

Linear Distribution

Linear distribution of species of fishes in streams is a widely accepted principle. A combination of environmental factors influences linear distribution. Species may extend upstream only so far, due to the amount of food, low temperatures, or other factors. Likewise, the species may extend downstream to a point where the oxygen content in the water falls below their tolerance levels, aquatic predators become too numerous, or other factors come into play. No single factor normally defines the upper and lower limites of a species' range, with the exception of natural barriers (Reid, 1961).

In this study it should be noted that several species were found with a wide distribution over much of the study area. These species have wide tolerances to the factors already mentioned in this study. This helps to explain their distribution.

It is possible to arbitrarily divide the study area into three regions characterized by certain species. The uppermost regions of the area can be termed the *Salvelinus fontinalis - Rhinicthys atratulus* section. *S. fontinalis* is found at the uppermost limits of this river. Often associated with this species is *R. atratulus.* Other species found in this region but not native to the study area are *Salmo gairdneri* and *Salmo trutta.* The following species, listed in descending order, are also found in the area but not as far upstream as *S. fontinalis* or *R. atratulus: Hybopsis leptocephala, Gila vandoisula, Lepomis auritus, Cataostoma commersoni, Semotilus atromaculatus,* and *Hybopsis labrosa.*

The next region may be called the *Micropterus dolomieu - Etheostoma flabellare* region. This area is predominantly inhabited by these species and also two species of *Notropis, N. scabriceps* and *N. lutipinnis.* Found here also is *Noturus insignis. N. insignis* was found only once in this survey but no conclusions can be drawn to its distribution due to several facts.

The species is not a large one, normally less than 13 cm long. The particular specimen was found beneath a large waterfall in a large pool. Its upper extent was thus limited by the falls. Also found were *Hybopsis leptocephala*, *Hybopsis labrosa*, *Gila vandoisula*, *Lepomis auritus*, *Catostoma commersoni*, and *Semotilus atromaculatus*.

The final region can be designated the Catostomidae region. The predominate species were members of the sucker family, *Catostoma commersoni*, *Moxostoma coregonus*, and *Moxostoma rupiscartes*. Found here also were *Cyprinus carpio*, *Gila vandoisula*, *Hybopsis leptocephala*, *Hybopsis labrosa*, *Lepomis auritus*, *Notropis lutipinnis*, and *Notropis telescopus*. These species are found in the broad, slow river found here or the large pools.

Nineteen species of fish were found in the study area. A list of the species is provided in Appendix A.

LITERATURE CITED

Blair, W.F., Blair, A.P., Brodkorb, P., Cagle, F.R., & Moore, G.A. (1968). Vertebrates of the United States. New York: McGraw-Hill Book Co. 31-158.

Breder, C.M. (1927). On the temperature-oxygen tolerance of brook-trout. Copeia. 163, 36-39.

Campbell, R.N. (1961). The growth of brown trout in acid and alkaline waters. Salm. Trout Mag. 161, 47-52.

Cope, E.D. (1870). A partial synopsis of the fishes of the freshwaters of North Carolina. Proc. Am. Phil. Soc. 11, 448-495. (Cited after Randall, 1957).

Creaser, C.W. (1930). Relative importance of hydrogen-ion concentration, temperature, dissolved oxygen, and carbon dioxide tension on habitat selection by brook trout. Ecology. 11, 246-262.

Eddy, S. (1957). The Freshwater Fishes. Dubuque, Iowa: Wm. C. Brown Co. 1-253.

EIFAC Working Party. (1969). Water quality criteria for European freshwater fish: extreme pH values for inland fisheries. Water Res. 3, 593-611.

Ellis, H.M. (1937). Detection and measurement of stream pollution. Bull. U.S. Dept. Comm. 27.

Gardner, J.A. (1926). Report on the respiratory exchange in fresh-water fish, with suggestions as to further investigations. Min. Ag. Fish., Fish. Invest., Series 1. 3, No. 1.

Hubbs, C.L. & Lagler, K.F. (1947). Fishes of the Great Lakes Region. Cranbrook Inst. Sci. 26, 1-186.

Jordan, D.S. (1889). Report of explorations made during 1888 in the Allegheny region of Virginia, North Carolina, and Tennessee, and in western Indiana, with an account of the fishes found in each of the river basins of those regions. Bull. U.S. Fish. Comm. 8, 97-173. (Cited after Randall, 1957.

Lagler, K.F. (1956). Freshwater Fishery Biology. Dubuque, Iowa: Wm. C. Brown Co. 294-307.

Lloyd, R. & Jordan, D.H.M. (1964). Some factors affecting the resistance of rainbow trout (*Salmo gairdnerii* Richardson) to acid waters. Int. J. Air Water Pollut. 8, 393-402.

Menhinick, E.F., Burton, R.M., & Bailey, J.R. (1973). An Annotated Checklist of the Freshwater Fishes of North Carolina.

Menzies, W.J.M. (1927). River pollution and the acidity of natural waters. Nature, Lond. 119, 638-639.

Ness, J.C. (1949). Development and status of pond fertilization in Central Europe. Trans. Am. Fish. Soc. 76, 335-358.

ORSANCO. (1955). Aquatic life water criteria. Sewage Ind. Waste 27, 321-331.

Powers, E.B. (1929). Freshwater Studies 1. The relative temperature, oxygen content, alkali reserve, the carbon dioxide tension, and pH of the waters of certain mountain streams at different altitudes in the Smoky Mountain National Park. Ecology 10, 97-110.

Randall, J.F. (1957). The distribution of the fishes of the Catawba-Wateree River drainage basin, North Carolina and South Carolina. Ph.D. thesis. University of South Carolina. 309 pp.

Reid, G.K. (1961). Ecology of Inland Waters and Estuaries. New York: Reinhold Publishing Corp. 263-334.

Richardson, F.R. (1974). Keynote Address. Symposium on Trout Habit at Research and Management. Boone, North Carolina: Appalachian Consortium Press. 7-11.

Smith, H.M. (1907). The Fishes of North Carolina. North Carolina Geological and Economic Survey. Raleigh: E.M. Uzzel and Co. 2, 453 pp.

Smith, R.L. (1974). Ecology and Field Biology. New York: Harper and Row. 614-625.

Welch, P.S. (1948). Limnological Methods. Philadelphia: P. Blakiston's Son and Co. 18, 381 pp.

Appendix A. A list of the Species Inhabiting the Upper Yadkin River

1. *Catostoma commersoni* (Lacepede)
2. *Cyprinus carpio* (Linnaeus)
3. *Etheostoma flabellare* (Rafinesque)
4. *Gila vandoisula* (Valenciennes)
5. *Hybopsis labrosa* (Cope)
6. *Hybopsis leptocephala* (Girard)
7. *Lepomis auritus* (Linnaeus)
8. *Micropterus dolomieu* (Lacepede)
9. *Moxostoma coregonus* (Cope)
10. *Moxostoma rupiscartes* (Jordan and Jenkins)
11. *Notropis lutipinnis* (Jordan and Brayton)
12. *Notropis scabriceps* (Cope)
13. *Notropis telescopus* (Cope)
14. *Noturus insignis* (Richardson)
15. *Rhinicthys atratulus* (Hermann)
16. *Salmo gairdneri* (Richardson)
17. *Salmo trutta* (Linnaeus)
18. *Salvelinus fontinalis* (Mitchill)
19. *Semotilus atromaculatus* (Mitchill)

Appendix B. A List of the Species Found at Each Station

Station 1.

Catostoma commersoni (Lacepede)

Cyprinus carpio (Linnaeus)

Gila vandoisula (Valenciennes)

Hybopsis labrosa (Cope)

Hybopsis leptocephala (Girard)

Lepomis auritus (Linnaeus)

Moxostoma coregonus (Cope)

Moxostoma rupiscartes (Jordan and Jenkins)

Notropis lutipinnis (Jordan and Brayton)

Notropis telescopus (Cope)

Station 2.

Catostoma commersoni (Lacepede)

Etheostoma flabellare (Rafinesque)

Hybopsis labrosa (Cope)

Hybopsis leptocephala (Girard)

Lepomis auritus (Linnaeus)

Micropterus dolomieu (Lacepede)

Notropis lutipinnis (Jordan and Brayton)

Station 3.

Catostoma commersoni (Lacepede)

Etheostoma flabellare (Rafinesque)

Gila vandoisula (Valenciennes)

Hybopsis labrosa (Cope)

Hybopsis leptocephala (Girard)

Lepomis auritus (Linnaeus)

Micropterus dolomieu (Lacepede)

Notropis lutipinnis (Jordan and Brayton)

Semotilus atromaculatus (Mitchill)

Station 4.

Catostoma commersoni (Lacepede)

Hybopsis labrosa (Cope)

Hybopsis leptocephala (Girard)

Micropterus dolomieu (Lacepede)

Notropis scabriceps (Cope)

Noturus insignis (Richardson)

Semotilus atromaculatus (Mitchill)

Station 5.

Catostoma commersoni (Lacepede)

Gila vandoisula (Valenciennes)

Station 5 (cont.).

Hybopsis leptocephala (Girard)

Notropis lutipinnis (Jordan and Brayton)

Salvelinus fontinalis (Mitchill)

Semotilus atromaculatus (Mitchill)

Station 6.

Catostoma commersoni (Lacepede)

Etheostoma flabellare (Rafinesque)

Gila vandoisula (Valenciennes)

Hybopsis labrosa (Cope)

Hybopsis leptocephala (Girard)

Lepomis auritus (Linnaeus)

Semotilus atromaculatus (Mitchill)

Station 7.

Rhinichthys atratulus (Hermann)

Salvelinus fontinalis (Mitchill)

Station 8.

Catostoma commersoni (Lacepede)

Etheostoma flabellare (Rafinesque)

Hybopsis labrosa (Cope)

Station 8 (cont.).

Hybopsis leptocephala (Girard)

Lepomis auritus (Linnaeus)

Notropis lutipinnis (Jordan and Brayton)

Notropis scabriceps (Cope)

Semotilus atromaculatus (Mitchill)

Station 9.

Catostoma commersoni (Lacepede)

Etheostoma flabellare (Rafinesque)

Gila vandoisula (Valenciennes)

Hybopsis leptocephala (Girard)

Lepomis auritus (Linnaeus)

Notropis lutipinnis (Jordan and Brayton)

Notropis scabriceps (Cope)

Salvelinus fontinalis (Mitchill)

Semotilus atromaculatus (Mitchill)

Station 10.

Catostoma commersoni (Lacepede)

Gila vandoisula (Valenciennes)

Hybopsis labrosa (Cope)

Hybopsis leptocephala (Girard)

Station 10 (cont.).

Lepomis auritus (Linnaeus)

Rhinichthys atratulus (Hermann)

Salvelinus fontinalis (Mitchill)

Semotilus atromaculatus (Mitchill)

Station 11.

Catostoma commersoni (Lacepede)

Gila vandoisula (Valenciennes)

Hybopsis leptocephala (Girard)

Salmo trutta (Linnaeus)

Salvelinus fontinalis (Mitchill)

Semotilus atromaculatus (Mitchill)

Station 12.

Catostoma commersoni (Lacepede)

Salvelinus fontinalis (Mitchill)

Station 13.

Gila vandoisula (Valenciennes)

Hybopsis leptocephala (Girard)

Salmo gairdneri (Richardson)

Salvelinus fontinalis (Mitchill)

Semotilus atromaculatus (Mitchill)

Station 14.

Catostoma commersoni (Lacepede)

Gila vandoisula (Valenciennes)

Hybopsis leptocephala (Girard)

Lepomis auritus (Linnaeus)

Rhinicthys atratulus (Hermann)

Salvelinus fontinalis (Mitchill)

Station 15.

Hybopsis leptocephala (Girard)

Rhinicthys atratulus (Hermann)

Salvelinus fontinalis (Mitchill)

Station 16.

Rhinicthys atratulus (Hermann)

Salvelinus fontinalis (Mitchill)

Station 17.

Salvelinus fontinalis (Mitchill)

Station 18.

Salvelinus fontinalis (Mitchill)

Appendix C. Abiotic Data for Each Station

Station 1.

pH: 7.0

Velocity of flow: 14.7 cm/sec

Volume of flow: 1.98 m^3/sec

O_2 concentration: 5.2 ppm

CO_2 concentration: 4 ppm

Bottom type: Sand and mud

Station 2.

pH: 7.1

Velocity of flow: 31 cm/sec

Volume of flow: 1.53×10^{-1} m^3/sec

O_2 concentration: 7.2 ppm

CO_2 concentration: 3.5 ppm

Bottom type: Small gravel and sand

Station 3.

pH: 7.3

Velocity of flow: 22 cm/sec

Volume of flow: 7.8×10^{-2} m^3/sec

O_2 concentration: 5.92 ppm

CO_2 concentration: 4.5 ppm

Bottom type: Small gravel and large sand

Station 4.

pH: 5.5

Velocity of flow: 20.2 cm/sec

Volume of flow: 1.16 m^3/sec

O_2 concentration: 7.4 ppm

CO_2 concentration: 5.5 ppm

Bottom type: Bedrock

Station 5.

pH: 5.2

Velocity of flow: 10 cm/sec

Volume of flow: 7.2×10^{-2} m^3/sec

O_2 concentration: 9.2 ppm

CO_2 concentration: 5 ppm

Bottom type: Rocks and sand

Station 6.

pH: 6.4

Velocity of flow: 30 cm/sec

Volume of flow: 4.2×10^{-1} m^3/sec

O_2 concentration: 8.4 ppm

CO_2 concentration: 9.2 ppm

Bottom type: Gravel

Station 7.

pH: 6.4

Velocity of flow: 35 cm/sec

Volume of flow: 6.4×10^{-2} m^3/sec

O_2 concentration: 10.04 ppm

CO_2 concentration: 5.6 ppm

Bottom type: Rocky

Station 8.

pH: 6.8

Velocity of flow: 30 cm/sec

Volume of flow: 4.2×10^{-1} m^3/sec

O_2 concentration: 10.04 ppm

CO_2 concentration: 6.0 ppm

Bottom type: Rocky

Station 9.

pH: 6.8

Velocity of flow: 21 cm/sec

Volume of flow: 1.37×10^{-1} m^3/sec

O_2 concentration: 9 ppm

CO_2 concentration: 8.5 ppm

Bottom type: Sand

Station 10.

pH: 7

Velocity of flow: 20 cm/sec

Volume of flow: 8.7×10^{-1} m^3/sec

O_2 concentration: 6 ppm

CO_2 concentration: 3.5 ppm

Bottom type: Gravel

Station 11.

pH: 7

Velocity of flow: 35 cm/sec

Volume of flow: 3.6×10^{-1} m^3/sec

O_2 concentration: 5.92 ppm

CO_2 concentration: 3.5 ppm

Bottom type: Rock and sand

Station 12.

pH: 7.2

Velocity of flow: 23 cm/sec

Volume of flow: 7.6×10^{-2} m^3/sec

O_2 concentration: 6.8 ppm

CO_2 concentration: 3.5 ppm

Bottom type: Gravel and boulders

Station 13.

pH: 7

Velocity of flow: 55 cm/sec

Volume of flow: 1.33×10^{-1} m^3/sec

O_2 concentration: 5.44 ppm

CO_2 concentration: 3 ppm

Bottom type: Sand, gravel and boulders

Station 14.

pH: 7

Velocity of flow: 42.8 cm/sec

Volume of flow: 2.31×10^{-1} m^3/sec

O_2 concentration: 5 ppm

CO_2 concentration: 3 ppm

Bottom type: Boulders and gravel

Station 15.

pH: 7.3

Velocity of flow: 25 cm/sec

Volume of flow: 8×10^{-2} m^3/sec

O_2 concentration: 5.12 ppm

CO_2 concentration: 1.5 ppm

Bottom type: Gravel

Station 16.

pH: 7.1

Velocity of flow: 21 cm/sec

Volume of flow: 2.1×10^{-2} m^3/sec

O_2 concentration: 6.6 ppm

CO_2 concentration: 2.5 ppm

Bottom type: Rocky

Station 17:

pH: 7.2

Velocity of flow: 25 cm/sec

Volume of flow: 8×10^{-3} m^3/sec

O_2 concentration: 4.6 ppm

CO_2 concentration: 3.5 ppm

Bottom type: Rock and gravel

Station 18.

pH: 6.4

Velocity of flow: 20 cm/sec

Volume of flow: 1.6×10^{-2} m^3/sec

O_2 concentration: 6.4 ppm

CO_2 concentration: 5 ppm

Bottom type: Rock and gravel

VITA

Roger Eugene Phillips, Jr. was born on March 23, 1956 in Sanford, North Carolina. His parents are Mr. and Mrs. Roger Eugene Phillips of Sanford, North Carolina. He graduated from Sanford Central High School in Sanford, North Carolina in 1974. Upon graduation from high school, he entered Elon College and received the B.A. degree with a major in biology in May, 1978. Upon completion of his undergraduate program, he entered Appalachian State University and began work toward the Master of Science degree in August of 1978.

The typist for this thesis was Mrs. Janice Ashley.