ASSESSMENT OF THE PHYSICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS OF BEECH CREEK USING B.A.S.S. (BASIN AREA STREAM SURVEY)

By

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CHAPTER I

INTRODUCTION

Forestry is one area of natural resource management under strong criticism from the public, especially where streams, water quality, fishing and fish habitat are concerned. Streams are dynamic ecosystems with complex biotic communities. The interactions between land use practices, especially forestry, and water quality, fish habitat, and fish and macroinvertebrate species are complex and not well understood. Researchers and natural resources managers are just beginning to discern those interactions and their impact on how natural resources should be managed. Although there is much to learn about stream ecosystems and the effect of land use practices on streams, government agencies are beginning to establish biological standards and criteria for assessing water quality and pollution in watershed systems. The basis for these standards must come from research that establishes strong links between water quality, physical and habitat parameters, and biological organisms. One study alone can not answer all the questions, but as more information becomes available, natural resource managers will be able to make better decisions regarding the resources they manage.

The importance of classifying lotic systems has been growing due to the increasing development of streamside areas and the increasing demand on lotic systems for drinking water, recreation, and irrigation.

In order for us to maintain healthy lotic ecosystems and rehabilitate impaired lotic ecosystems for all beneficial uses, we must establish guidelines for managing them. Comprehensive classification of streams, characterization of their physical, chemical, and biological features, and re-establishing the range of their natural variability are essential for ecologically sound management. A single classification system for all streams would be difficult to develop and might overlook important regional considerations, but a system of classifications, that can be applied regionally, would provide important information that can be used by natural resource managers. In order to determine what standards should be used, regardless of region, methods for assessing the current status of a stream and it's natural variability must be determined. There are no comprehensive stream classification systems in use in Oklahoma.

Objectives

This study was designed to provide preliminary baseline information on the physical, chemical, and biological structure of an unmanaged forest stream in Southeastern Oklahoma, and to observe differences in physical habitat parameters among pools, runs, and riffles, and differences in biological population characteristics of fish and aquatic macroinvertebrates within and among pool, run, and riffle habitats in the Ouachita National Forest.

The objectives of the study are: 1) to inventory a stream system using B.A.S.S. (Basin Area Stream Survey); 2) to characterize and compare the variation in physical habitat structure within and among pool, run, and riffle habitats; 3) to characterize and compare the variation in community structure and trophic composition in fish and aquatic macroinvertebrate populations within and among pool, run, and riffle habitats.

Definitions

Definitions of terms used in stream ecology and hydrology are provided for a full understanding of concepts in stream and lotic ecosystem research.

Aquatic macroinvertebrates are organisms that have no backbone, are visible to the naked eye, and spend part or all of their life cycle in the water. There are four general functional trophic groups, general categories of organisms based on feeding mechanism, of aquatic macroinvertebrates: collectors, shredders, predators, and scrapers. A collector is an organism that feeds on decomposing fine particulate organic matter (FPOM) (Merritt and Cummins 1984). A shredder is an organism that feeds on living vascular plant tissue, decomposing coarse particulate organic matter (CPOM), or wood (Merritt and Cummins 1984). A predator is an organism that feeds on living animal tissue (Merritt and Cummins 1984). A scraper is an organism that feeds on periphyton, algae, and associated material (Merritt and Cummins 1984).

Fish are also placed in functional groups, based on their feeding mechanism: herbivorous, insectivorous, and piscivorous. Herbivorous fish feed on plant material. Invertivorous fish feed on aquatic and terrestrial insects and other macroinvertebrates. Piscivorous fish feed on other fish. Omnivorous fish feed on plant material, macroinvertebrates, and other fish.

Both macroinvertebrates and fish are used as indicators of water quality, on the premise that if the water is clean a higher abundance of pollution sensitive or intolerant species will be found. As the water becomes more polluted, a shift in types of species will occur, from intolerant to more intermediate pollution tolerant species, and pollution insensitive, tolerant, species. One way of "measuring" whether water is polluted, as indicated by biological organisms, is the Index of Biological Integrity (IBI) (Karr et al., 1986). The IBI uses several parameters to obtain an index, and based on that index, the impairment of the stream can be determined.

An important characteristic of streams is the community structure and function of fish and aquatic macroinvertebrates. Several measurements are used to determine structure: relative abundance, species richness, and species diversity. Relative abundance is a measure of the number or weight of organisms per effort of collection or area of habitat. Species richness is a measure of the number of species in a community (Wetzel 1983). Species diversity is a measure of the number of species (species richness) and how many individuals in each species were observed (relative abundance) (Wetzel 1983). Measurements used to observe function are trophic level composition and environmental tolerance composition. The trophic level is the place in the food web that the organism occupies. Environmental tolerance is an organisms ability to adapt to variability in the environment.

In most stream habitat classification systems three major groups of habitats have been identified, based on velocity of flow, gradient, and depth: pools, riffles, and runs. Pools are generally slow flowing, low gradient, and deep. Riffles are generally fast flowing, low to high gradient, and shallow. Runs are generally fast flowing, low gradient, and deep.

CHAPTER II

LITERATURE REVIEW

Stream Classification

From the onset of stream research, scientists have been trying to develop a stream classification system that can be applied anywhere so that streams of different regions and even different continents can be compared. Researchers have been trying to classify lotic systems for many years but have been restricted by regional considerations (Horton 1945, Kuehne 1962, Harrel and Dorris 1967, Pennak 1971, Bisson et al. 1981, Gorman and Karr 1978, Savage and Rabe 1979, Rosgen 1985, Rohm, Giese and Bennett 1987, McCain et al. 1989, Clingenpeel and Cochran 1992, Overton, Radko and Nelson 1993). Some have attempted to develop one that can be used, with slight modification, in any locality (Pennak 1971). These classification systems have been based on physical, physio-chemical, physio-biotic, and physio-bio-chemical characteristics. Most have successfully developed a regional system but have failed to apply it outside the region for which it was developed.

Physical Characteristics

Stream order. Horton's (1945) method of ranking streams has been a foundation for several stream classification systems. This method of ranking streams, based on branching, ranks extreme headwater streams as first order streams and where two first order streams join as second order streams and so on for higher order streams. Lower order streams flowing into higher order streams do not affect the order designation. He showed that lengths of streams, drainage basin size, and gradient are related to stream order in most drainage basins. Strahler (1957) showed that stream order number is directly proportional to relative watershed dimensions, channel size, and stream discharge.

Other physical measurements. Though stream order shows a strong relationship to basic physical attributes of streams such as discharge and channel size, other characteristics show potential for a more refined classification. In a north-central Oklahoma stream, as stream order increased, drainage area, average pool depth, average pool width, and stream discharge increased, and gradient decreased (Harrel, Davis and Dorris 1967) .

Using order, gradient, pattern of flow, and substrate, Savage and Rabe (1979) classified small streams in natural areas of northern Idaho. Their study defined five stream types among ephemeral, spring, and permanent streams, which are applicable throughout the Rocky Mountain states. Aquatic plants and invertebrates were analyzed and showed definite community associations with the defined stream types.

Rosgen (1985) developed a classification scheme based on measurable morphological features, such as width, depth, discharge, slope, channel material roughness, sediment load, and sediment size. Using this information he developed tables of criteria for stream types and stream sub-types to account for changes in fish habitat, sediment supply, channel stability, etc. Major stream types and sub-types could be determined from aerial photos and topographic maps with fie d checking for validation. This system has many applications from establishing guidelines for riparian areas to stream restoration work.

Physio-Chemical Characteristics

Harrel and Dorris (1967) found strong relationships between stream order and physio-chemical characteristics and structure of benthic macroinvertebrate communities in an intermittent stream system in north-central Oklahoma. They set up 21 collection stations in nine streams, consisting of 3rd, 4th, 5th, and 6th order streams. Physio-chemical fluctuations, turbidity, variation in hydrogen ion concentration, and mean annual water temperature decreased as stream order increased. Volume of stream flow and conductivity increased as stream order increased. Oxygen concentration and alkalinity were variable and influenced by algal activity.

Physio-Biotic Characteristics

Kuehne (1962), using Horton's stream order, as modified by Strahler (1957), collected fish at designated stations to illustrate a relationship between stream order and fish distribution. In a Kentucky stream a progressive increase in average number of species occurred as stream order increased. Harrel, Davis and Dorris (1967) observed a strong positive correlation ($R = .96$) between stream order and diversity of fish in a north-central Oklahoma stream. Gorman and Karr (1978) found the higher the complexity of the habitat by measuring stream depth, substrate type, and current, the higher the fish species diversity.

Integration of Physical, Chemical, and Biological Characteristics

The Environmental Protection Agency (EPA) has established water quality standards (Clean Water Act of 1987) for maintaining acceptable water quality for designated uses in all bodies of water. Designated uses range from municipal drinking water to maintenance of high quality fisheries. Most of the standards are physical or chemical, but biological criteria are being used along with physical and chemical standards to maintain the quality of designated uses and ecosystem-scale health of lotic systems (Pennak 1971, Rohm et al. 1987, Bisson et al. 1981, McCain et al. 1989, Clingenpeel and Cochran 1992).

Stream classification. Pennak (1971) developed a stream classification system, based on 13 physical, chemical, and biological measurements for unpolluted small to large streams, and small to medium rivers. All parameters can be easily measured or quickly estimated and include width, flow, current speed, substrate, dissolved oxygen, rooted aquatics, and streamside vegetation.

Ecoregion classification. Many resource managers support the theory that the U.S. is made up of many ecologically similar units known as ecoregions. The premise is that streams in the same ecoregion will have similar characteristics and streams in different ecoregions will not have similar characteristics. Based on this assumption, a few streams from each ecoregion could be surveyed and serve as the baseline "norm" for that ecoregion.

Rohm et al. (1987) evaluated an ecoregion classification system, based on Omernik's (1987) ecoregion designation , to determine if this approach could help in assessing land use effects on streams or selection of monitoring sites in Arkansas. They collected data from several relatively unimpacted streams within each ecoregion and evaluated the differences among streams to determine if the differences corresponded to the ecoregion classification. Their data included characteristics of fish assemblages, 13 physical, and 12 chemical variables. Fish assemblages and physical variables showed the strongest ecoregion differences. Chemical variables showed fair separation by ecoregion. They concluded that the ecoregion scheme has variables that could account for ecoregion differences in Arkansas and results could be extrapolated regionally.

Habitat classification. Habitat classification incorporates physical, chemical, and biological data to produce results applicable to many fields of stream research. This method can characterize the complexity of lotic systems yet produce data that is manageable when used to assess effects of land use on streams or compare streams. Habitat classification systems were initially used to assess fisheries and fish utilization of habitat, but now encompass a wider scope of use including water quality monitoring and evaluating the effects of land use practices on aquatic ecosystems.

Bisson et al. (1981) developed a habitat classification system to understand habitat utilization by salmonids during low flows in Washington. Three major types of habitats: pools, riffles, and glides, were separated into approximately 10 sub-types. Other measurements such as physical characteristics of the habitat, cover for fish, and water chemistry were also incorporated. A habitat diagram of the stream is developed and compared with other streams. Cited shortcomings include the subjectivity of the cover evaluations and the treatment of cover types.

McCain et al. (1989), used Bisson's system to develop a habitat classification for use in Northern California. They developed 21 habitat types based on velocity of flow, depth, gradient, and position in channel. Habitat information, in conjunction with habitat availability, and fish production can help fishery managers evaluate the potential of the watershed to produce fish.

Clingenpeel and Cochran (1992) used a stream habitat classification system called B.A.S.S. (Basin Area Stream Survey), modified from the system of McCain et al. (1989). B.A.S.S. measures and evaluates the physical, chemical and biological features of a stream. Three unmanaged and three managed watersheds in three ecoregions of Arkansas were compared using B.A.S.S. (Clingenpeel, 1994). The objective was to determine land use effects on stream ecosystems within ecoregions, discern differences among ecoregions, and establish reference streams in different ecoregions for future studies. Physical, chemical, and biological information was collected for 3 years so natural variability could be accounted for. The use of this information can be extended to land managers, fisheries biologists, and used for baseline data on water quality standards.

Habitat classification can be extended with slight modification, nationally, and possibly globally. However, the important variables should be determined regionally. The importance of habitat classification is that useful information can be gathered efficiently and utilized in many fields of study.

Similarities in classification systems. Some common basic physical, chemical, and biological measurements have become incorporated into most classification schemes. Among the most common are substrate type (Savage and Rabe 1979, Rosgen 1985, Beschta and Platts 1986, Sullivan et al. 1987, McCain et al. 1989, Clingenpeel 1994, Rinne 1992), stream order (Horton 1945, Strahler 1957, Kuehne 1962, Harrel et al. 1967, Harrel and Dorris 1967, Savage and Rabe 1979), stream gradient (Savage and Rabe 1979, Rosgen 1985), channel morphology (Beschta and Platts 1986, Sullivan et al. 1987), habitat type (Bisson et al. 1981, McCain et al. 1989, Clingenpeel and Cochran 1992, Overton et al. 1993), pool/riffle ratios (Beschta and Platts 1986, Sullivan et al 1987, McCain et al 1989), woody debris (Bisson et al 1982, Flebbe and Dolloff 1991), fish assemblages (Kuehne 1962, Harrel et al 1967, Gorman and Karr 1978, Bisson et al 1981, Rohm et al 1987, McCain et al 1989, Clingenpeel and Cochran 1992, Overton et al 1993), and macroinvertebrate assemblages (Harrel and Dorris 1967, Savage and Rabe 1979, Clingenpeel and Cochran 1992).

Community Structure of a Stream

Fish

Stream communities in lotic systems are receiving more attention as their importance is recognized. The community structure of biotic organisms can reflect regional stream characteristics and indicate anthropogenic changes that occur in a watershed. Fish are a major component of stream biota, which make them ideal for study.

Distribution in lotic systems. One observable characteristic of fish communities is their distribution within a stream system. Kuehne (1962) observed an increase in the average number of species of fish with an increase in stream order in Kentucky streams. In Idaho streams, Platts (1979) observed an increase in the abundance of fish, width, depth, percent of rubble substrate (summer water space), and available fish habitat in higher order streams.

Schlosser (1990) conducted studies in Illinois that characterized distribution of fish and specific community structure in streams. He found that flow, channel morphology, temperature, and dissolved oxygen gradients within a stream have a major effect on the community structure of fish. From upstream to downstream there are substantial differences in these environmental variables, fish life histories, and seasonal variation in community structure. Upstream sites had higher environmental variability and the fish had shorter life spans, smaller maximum body size, earlier sexual maturity, and exhibited more rapid colonization after a severe disturbance. Schlosser concluded that upstream fish communities are more likely to recover from a disturbance than downstream communities due to their adaptation to more variable conditions.

Grossman et al. (1990) reviewed nine studies on fish community organization and found that there was high variation in fish population and assemblage stability. The variation in fish assemblages was not affected by years of study, familial classification, mean abundance, or time interval between collection. They cautioned that the use of community structure alone for detecting disturbances may be misleading, due to high variability, and addressed the need for long-term data collection on undisturbed streams.

Habitat composition and structure. The ability of fish to utilize microhabitats largely determines their occurrence in a habitat and the community composition. A stream can be broken into consecutively smaller units of classification from watershed basin to stream channel to reach to habitat to microhabitat. To effectively observe community structure, habitat and microhabitat units are most frequently used.

Gorman and Karr (1978) studied streams in temperate and tropical zones to determine if habitat utilization was the same for two climatic regions. They found similar trends in habitat characteristics and community structure of fish.

Depth, bottom type (substrate), and current were three measures of habitat diversity that they used. The habitats types were shallow edges, riffles, shallow pools, pools, and deep pools. Seasonal changes and changing habitat characteristics had a major effect on community structure. There were more diverse and stable communities with an increase in habitat complexity leading them to the conclusion that fish are habitat specialists. The more complex the habitat the more diverse the community.

Foltz (1982) found that there was an increase in diversity of fish downstream due to an increase in heterogeneity and complexity of habitat, less frequent drying, and substrate diversity. He also observed that the presence of stable substrate and substrate colonized by macroinvertebrates positively influenced fish abundance by providing secure habitat and a food source.

McCain et al. (1989) developed a habitat inventory system as a tool for population estimates, production rates, and restoration and enhancement projects for fish. By measuring physical, chemical and biological habitat criteria, critical habitat needs and available habitat can be determined. Clingenpeel (1994) adapted McCain et al.'s system to Arkansas for determining natural variability in stream habitat, stream health for beneficial uses, and to characterize reference streams. With this information, differences in management schemes and regions can be compared.

The use of fish habitat inventories to evaluate the effects of land management practices on aquatic ecosystems provides valuable data for improving land management practices. Overton et al. (1993) conducted habitat inventories on natural and managed sites in Idaho and found differences in habitat structure among sites. Their objective was to ascertain the variables that determine habitat differences and the frequency of sampling required to detect differences. Frequency and maximum depth of pools, and frequency and size of large woody debris were notable habitat variables and sampling 30% of all habitats provided enough sensitivity to detect differences in streams.

Biological integrity and indicator species. Fish community structure is a strong indication of the health of a stream (Karr, 1981). In general, a healthy stream has a more diverse and complex fish community than a polluted stream. A healthy stream has more complex habitats in which more fish are able to utilize. A polluted stream will usually have a few tolerant species that can out-compete less tolerant ones. Because fish are a major component of streams, and sensitive to changes in environment, they are good indicators of disturbances. The advantages of using fish as indicators of "biological integrity" are the extensive information available on fish, fish include a wide range of trophic levels, and are relatively easy to identify, the public can relate to them, and they are typically present in streams (Karr et al, 1986).

The development of the Index of Biological Integrity (IBI) has helped many managers in assessing the effects of land use practices on streams and led the way for more inclusive and comprehensive water quality standards (Karr, 1981). Assuming that a representative group of fish are sampled, the IBI measures species composition and richness, trophic composition, abundance, and presence of disease. Using a rating system, the "health" of a stream can be determined.

Miller et al. (1988) listed modifications in the IBI for different regions. The IBI is founded on community concepts and must be modified for regional application. The scientists of the region determine what criteria need to be changed, but must be careful not to violate the integrity of the index by eliminating or changing important measurements.

Hocutt (1981) suggested that using fish to assess stream "health" can be misleading because of fish mobility, the qualitative nature of the data, differences in interpretation, manpower required to conduct surveys, the difficulty of identification of some fish, and water quality requirement differences between humans and fish.

Aquatic Macroinvertebrates

There is less data available on aquatic macroinvertebrates than for fish. Macroinvertebrates have shorter life cycles, respond to changes very quickly, and require more training to identify. These constraints are some of the barriers for using macroinvertebrate community structure for biological standards. But, macroinvertebrates are useful because they are sensitive to changes, show distinct community structure patterns, and represent a primary level in the food web which effects the levels above.

Distribution in lotic systems. Egglishaw (1969) studied the frequency distribution patterns of benthic organisms in fast-flowing stream habitats and their association with food sources. The most common species showed a non-random frequency distribution and were strongly associated with specific plant detritus types.

Harrel and Dorris (1968) observed seasonal and physio-chemical changes in macroinvertebrate community structure. In intermittent streams in southeast Oklahoma, there was an increase in the number of species with increasing stream order. The maximum number of species and individuals occurred in spring and the minimum number of species and individuals occurred in autumn. Macroinvertebrates showed a more random distribution downstream, along with a more complex and stable community because environmental fluctuations decreased downstream.

In Colorado streams, Allen (1975) observed a relationship between macroinvertebrates and substrate size. Distinct habitat selection was demonstrated by preference for larger substrate. Microhabitats were similar in diversity and substrate composition though not the same species composition. Substrate diversity was strongly related to species richness and was the most important habitat factor.

Matthews et al. (1991) found definite trends in upstream and downstream benthic communities in small streams in Washington. Upstream areas were dominated by more sensitive species and downstream areas were dominated by non-insects and tolerant species.

Habitat composition and structure. The establishment of correlations between habitat characteristics and benthic communities has been difficult and only regional relationships should be considered. Matlock and Maughan (1988) attempted to develop a model based on the relationships of benthic communities with habitat characteristics in Oklahoma. They incorporated physical and chemical measurements but correlations in general were low. They suggest that benthic models not be applied outside the region they were developed.

Biological integrity and indicator species. Macroinvertebrates are useful as indicator species but should be used in conjunction with other criteria. Water Quality Indicators Guide: Surface Waters, a handbook of indicator guides, combines many biological and chemical criteria for assessing water quality (Terrell and Perfetti, 1991). Contained in the handbook is a section of aquatic macroinvertebrate indicator species. Beck's Biotic Index Classes (Beck, 1954), used in the handbook, lists three categories of indicator organisms: intolerant

(Class I), facultative (Class II), and tolerant (Class III). Using a mathematical formula, an index value is derived to determine the pollution level of the stream.

The Environmental Protection Agency's (EPA) Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish (RBPBMF) designates five levels (protocols) of testing from non-intensive to intensive. The protocols for macroinvertebrates are I, II, and III, and the protocols for fish are IV and V. RBPBMF I-III is based on community structure and relative abundance of orders of benthic macroinvertebrates. By ranking certain benthic criteria, Ephemeroptera, Plecoptera, and Tricoptera taxa (EPT), tolerant groups, abundance, and taxa richness, a decision on impairment detection is made. Other factors that influence benthic macroinvertebrate community structure, used in RBPBMF, are periphyton, macrophytes, fish, organic enrichment, toxicants, flow and habitat limitations.

CHAPTER III

THE STUDY AREA

Site Description

Location

The study was conducted on Beech Creek, located in the Beech Creek National Scenic Area of the Ouachita National Forest (ONF), LeFlore Co., Oklahoma. Beech Creek watershed is located in a National Scenic Area (NSA), and a National Botanical Area (NBA) (Figure 1). Beech Creek NSA contains 3,035 ha (7,500 ac) and Beech Creek NBA contains 162 ha (400 ac). The stream survey comprised about 8 km (5 miles) of continuous stream, draining approximately 2,850 ha. There has been no management of any type in this area until a few years ago. According to the management plan for the ONF, Beech Creek NSA is designated as semi-primitive with motorized traffic allowed. Harvesting of trees, prescribed burning, and other vegetation manipulation is allowed for the enhancement of visual quality and wildlife only. All wildfires are suppressed in a timely manner. Beech Creek NBA, which is mainly along the sides of the stream channel, is designated as semi-primitive, no motorized traffic allowed. Vegetation manipulation is allowed only for the enhancement or survival of

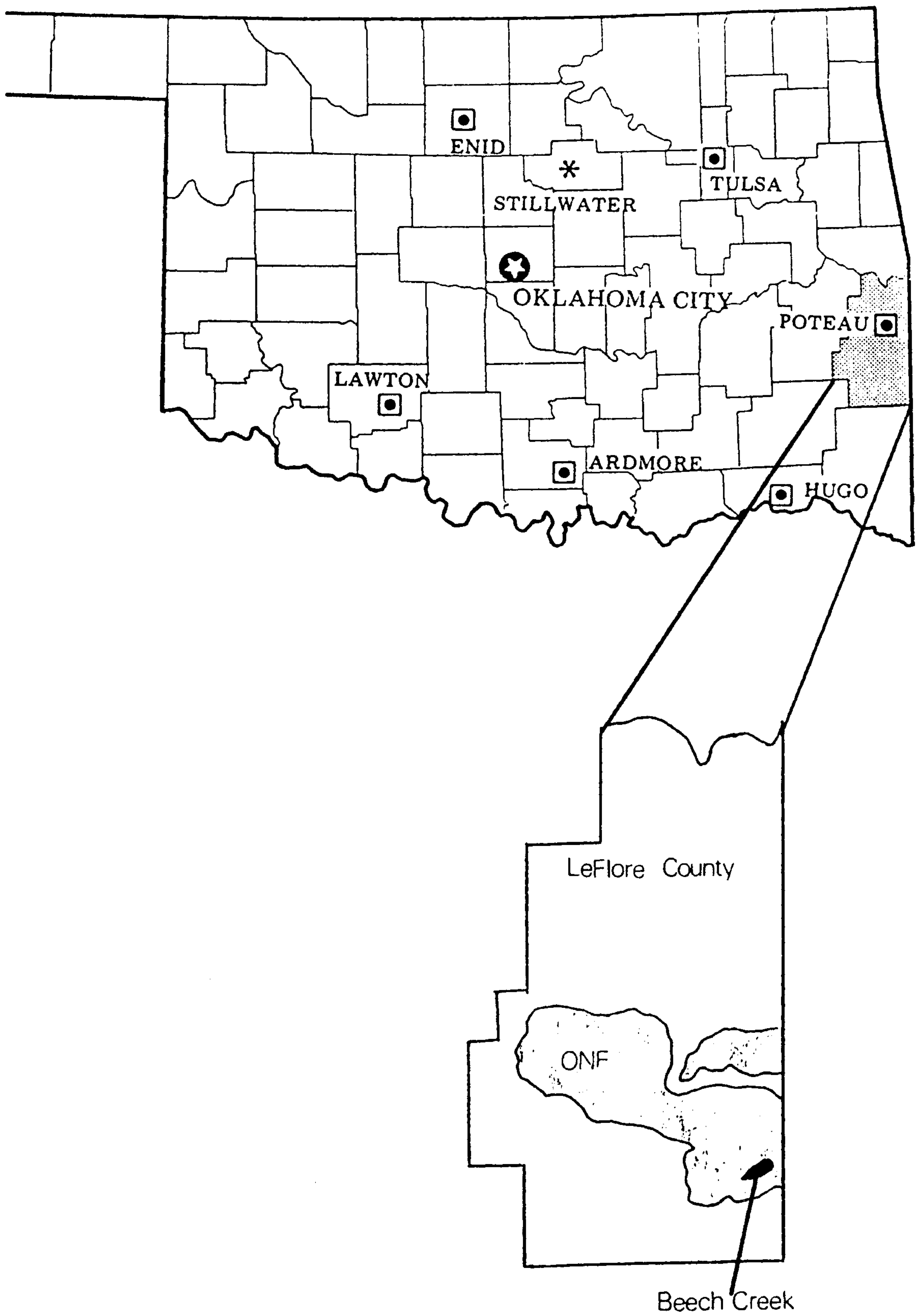

Figure 1. Map of study area.

sensitive plant species and interpretive trails. All wildfires are suppressed in a timely manner.

Soils

Soils on the Beech Creek watershed are classified in three complexes: the Kenn-Ceda, the Carnasaw-Pirum, and the Pirum-Octavia-Panama. The Kenn-Ceda complex is a deep, well drained cobbly loam soil subject to occasional flooding. It is acidic with medium natural fertility, low to medium organic matter content, medium to rapid permeability, and low to medium water capacity. The Carnasaw-Pirum complex is a moderately deep to deep , well drained stony fine sandy loam soil found in the uplands. It is acidic with low natural fertility and organic matter content, moderate to slow permeability, and medium to low water holding capacity. The Pirum-Octavia-Panama complex is a moderately deep to deep, well drained, steep, stony fine sandy loam soil formed from weathered sandstone and shale. It is acidic with low natural fertility and organic matter content, moderate to slow permeability, medium to low water capacity, and a deep root zone (Abernathy and Olszewski 1983).

Climate

Mean annual precipitation from 1951-1974, recorded in Poteau, Oklahoma, was 113.5 cm (Abernathy and Olszewski 1983). Mean annual temperature at Poteau from 1951-1974 was 16.8^{o} C. Annual precipitation (measured at Carter Tower) and evaporation (measured at Broken Bow Dam) from 1988 to 1992 is listed in Table I (compiled from Climatological Data (US Weather Bureau)).

TABLE I

ANNUAL PRECIPITATION AND EVAPORATION FOR SOUTHEASTERN OKLAHOMA, 1988-1992

Year	Precipitation	Evaporation	Maximum Precipitation	Minimum Precipitation
1988	114.5 cm	118.5 cm*	17.0 cm (NOV)	1.1 cm (MAY)
1989	142.3 cm	132.5 cm*	28.7 cm (MAY)	1.2 cm (NOV)
1990	165.0 cm	139.0 cm*	39.7 cm (MAY)	4.7 cm (AUG)
1991	163.1 cm	142.7 cm*	35.9 cm (OCT)	3.0 cm (JUN)
1992	154.1 cm	128.4 cm*	22.3 cm (SEP)	2.3 cm (OCT)

* not a complete year

Monthly precipitation (measured at Smithville) and evaporation (measured at Broken Bow Dam) for 1993 is provided in Table II. Total precipitation for 1993 (Jan - June) was 83.0 cm and total potential evaporation was 45.8 cm (compiled from Climatological Data (US Weather Bureau)).

TABLE II

MONTHLY PRECIPITATION AND POTENTIAL EVAPORATION FOR SOUTHEASTERN OKLAHOMA, JANUARY-JUNE, 1993

Month	Precipitation	Evaporation
January	16.0 cm	NA
February	12.0 cm	5.8 cm
March	12.6 cm	NA
April	17.3 cm	10.8 cm
May	19.3 cm	12.7 cm
June	5.8 cm	16.5 cm

Vegetation Composition

Vegetation on the Beech Creek watershed is composed of upland, bottomland, and riparian tree species. Upland species include shortleaf pine (Pinus echinata), black oak (Quercus velutina), southern red oak (Quercus falcata), and hickory (Carya spp.). Bottomland species include black gum (Nyssa sylvatica), sweet gum (Liquidambar styraciflua), red maple (Acer rubrum) , white oak (Quercus alba), water oak (Quercus nigra), and beech (Fagus grandifolia). Riparian species are dominated by hazel alder (Alnus serrulata), red maple (Acer rubrum), and witch-hazel (Hamamelis virginiana) (Elias, 1980).

CHAPTER IV

MATERIALS AND METHODS

Inventory Procedure

Beech Creek was inventoried using the Basin Area Stream Survey (B.A.S.S.), with a few minor modifications (Clingenpeel and Cochran,1992). The procedures were followed exactly where possible and modifications were made only because of time and cost restraints.

Physical Inventory

A complete (100%) inventory of an approximately 5 mile section of Beech Creek was conducted. Several physical characteristics were measured or ocularly estimated and will be treated separately for clarification (Table III).

Beginning downstream and working upstream, reaches were identified by habitat type (McCain et al 1989). A reach is a continuous stretch of a habitat type. Reaches had a minimum length of 10 meters and no maximum length. A list of habitat type designations is provided in Appendix A. Each reach was flagged and reach number, habitat type number, date, and flag person was written on the flag.

Reach length and water width were measured with a measuring tape to the nearest 0.1 meter. Bankful width was visually estimated to the nearest meter. Depth was measured with a depth rod to the nearest centimeter. Six depth measurements were taken; left bank, right bank, 1/4, 1/2, and 3/4 across, and thalweg (deepest part). Widths and depths were measured at the midpoint of the reach.

Bottom substrate composition was determined as a percent of the reach by taking 10 random measurements across the reach. Substrate was classified as bedrock, boulder (>30 cm), cobble (8-30 cm), gravel (8-1 cm), sand (1-0.5 cm), or fines (<1 mm). Embeddedness was determined by estimating the average percent of cobble-sized material surrounded by fines.

Instream cover, or any structure that provides cover for fish or macroinvertebrates in the stream, was estimated visually and measured as a percentage of the reach. Instream cover consisted of undercut banks, woody debris (logs and rootwads), vegetation overhanging water (height <0.3 m), white water, boulders (diameter > 30 cm), bedrock ledges, vegetation rooted in the substrate, and vegetation clinging on rocks. Instream cover

Bank angle was measured on each bank with a clinometer. The reading was in degrees, where 90^{o} is a vertical bank and $< 90^{o}$ is an undercut bank. Bank stability was estimated as a percent of the bank intact and/or non-erodible for both the left and right banks. Four classes of riparian/terrestrial vegetation were classified; brush, grass, forest, or barren. The dominant vegetation along the stream was the category chosen. Using a spherical densiometer, canopy closure was measured as a percentage of vegetation closure, while facing upstream in the middle of the reach.

TABLE III

PHYSICAL MEASUREMENTS OF THE BASIN AREA
STREAM SURVEY

Measurement	Estimated/Measured
Habitat Type	Estimated - ocular
Length	Measured - nearest 0.1 meter
Bankful Width	Estimated - ocular
Water Width	Measured - nearest meter
Depth	Measured - nearest centimeter
Bottom Substrate	Estimated - percent
Embeddedness	Estimated - average percent
Instream Cover (under-cut banks, terrestrial vegetation overhanging water, white water, boulders, bedrock ledges)	Estimated - percent of habitat area
Riparian Cover (clinging and rooted vegetation, left and right bank angle and stability, canopy closure and terrestrial vegetation)	Estimated - percent of habitat area, bank angle in degrees

All physical habitat data was tabulated and entered into a spreadsheet program. The data was then analyzed using Statistical Analysis System (SAS), (SAS Institute, 1991). A Levene's Test of Homogeneity was performed on the variances of all physical measurements, at a 0.10 significance level, and found to be significant for many variables. All physical variables were analyzed using the nonparametric Kruskal-Wallis procedure, at a 0.05 significance level, to test for significant differences in the mean rank of each physical measure by habitat type. Tukey's Studentized Range (HSD) was performed, at a 0.05 significance level, to determine which habitat types were significantly different in mean rank of each physical measurement. Appendix C lists the statistical output from SAS for Tukey's Studentized Range (HSD) test.

Stream Chemistry

Chemical sampling consisted of six random grab samples, taken approximately every 33 reaches, to determine general chemical conditions of the stream. At the same location as the grab sample, air and water temperature, and dissolved oxygen concentration were measured with a Model 50-B YSI dissolved oxygen meter. The samples were preserved and taken back to the OSU Forest Watershed Laboratory for analysis. The sample analysis included conductivity, pH, alkalinity, and total phosphorus concentration. Statistical analyses were not performed on chemical data due to small sample size, and time and cost constraints.

Biological Sampling

The biological inventory was conducted on approximately 10% of all habitat types. Due to cost and effort of sampling, abundant habitat types were not sampled at 10%. Habitat types 15, 16, 17, 20, and 23 were sampled at less than 10%. Habitat types 5, 6, 7, 8, 21, and 22 were sampled at 100% because of their low occurrence. Habitat types 1, 2, 3, 4, 9, 11, 12, 13, 14, 19, and 24 were sampled more than 10% (Table IV). Habitat types 10 and 18 were not found within Beech Creek. Sample habitat types were randomly stratified along the stream.

TABLE IV

HABITAT FREQUENCY AND SAMPLING FREQUENCY

Habitat Number	Frequency	Number of Samples	Sample Percent
1	12	2	17%
2	3	1	33%
3	3	1	33%
4	4	1	25%
5	1	1	100%
6	1	1	100%
7	1	1	100%
8	1	1	100%
9	4	1	25%
10	0	0	0%
11	7	1	14%
12	18	2	11%
13	5	1	20%
14	2	1	50%
15	17	1	6%
16	71	2	3%
17	13	1	8%
18	0	0	0%
19	4	1	25%
20	15	1	7%
21	1	1	100%
22	1	1	100%
23	17	1	6%
24	2	1	50%

Biological analysis. Relative abundance, species richness, and species diversity was calculated for fish and aquatic macroinvertebrate communities in Beech Creek. Species richness was measured by Menhinick's Index of species richness. Menhinick's Index of species richness (R2) is calculated with the formula

$$R2 = S/\sqrt{n},$$

where S is the total number of species in a community and n is the total number of individuals in a community. Species diversity was measured using the Shannon Diversity Index. The Shannon diversity Index (H') can be calculated with the formula

$$H' = -\Sigma p_i * \ln p_i$$

where p_i, the proportional abundance of the ith species, = (n_i/N), n_i is the number of individuals in species i, and N is the total number of individuals in the community.

All biological data was tabulated and entered into a spreadsheet program. The data was then analyzed using SAS. A Levene's Test of Homogeneity, at a 0.10 significance level, was performed on the variances of the biological measurements and found to be significant for relative abundance and species richness of aquatic macroinvertebrates. Relative abundance and species richness of macroinvertebrates were analyzed using the nonparametric Kruskal-Wallis procedure, at a 0.05 significance level, to test for differences by habitat type. An ANOVA procedure was performed, at a 0.05 significance level, on relative abundance, species richness of fish and species diversity of fish and aquatic macroinvertebrates. Tukey's Studentized Range test was performed, at a 0.05 significance level, to determine which habitat types were significantly different.

Fish sampling. A reach was isolated with block nets at both ends. Fish were collected using the multiple-depletion method with a backpack electroshocker. At the end of each pass, nets were checked for fish. All passes were combined for a single sample per reach inventoried. All sensitive, threatened, and endangered fish were measured in the field and released back to the stream. Identification, weighing, and measuring of fish took place in the field. Species, length, weight, and presence of disease or tumors were recorded. Some fish were preserved in 10% formalin solution and collected for verification. These will be donated to the OSU fish museum. A list of species collected is in Appendix B. Relative abundance of fish was measured in four ways, 1) number of individuals per hour of shocking effort, 2) number of individuals per unit area, 3) total mass (biomass) per hour of shocking effort, and 4) total mass (biomass) per unit area. Species richness was measured using Menhinick Index of species richness. Species diversity was measured using the Shannon Diversity Index. Using the EPA's Rapid Bioassessment Protocols for Use in Stream and River (U.S.E.P.A., 1989) and Assessing Biological Integrity in Running Waters, A Method and Its Rationale (Karr et al., 1986), the fish population was separated into three trophic categories based on feeding behavior; herbivorous, invertivorous, and piscivorous. Using Rapid Bioassessment Protocols for Use in Streams and Rivers (U.S.E.P.A., 1989), the environmental tolerance of fish was separated into three categories; intolerant, intermediate tolerant, and tolerant. The trophic type frequency and environmental tolerance structure of pools, riffles and runs were analyzed.

Aquatic macroinvertebrate sampling. Aquatic macroinvertebrates were collected by three minute traveling kick net samples at the same reaches where fish were sampled after fish were collected. After placing a D-frame dip net downstream, approximately 1 square meter of substrate was vigorously kicked for 3 minutes, then cobbles were scrubbed by hand for a few minutes in the net. The sample was then preserved in 70% ethanol. All samples were later sorted and identified to family, where possible, by personnel in the OSU Forest Watershed Laboratory. A list of species collected is in Appendix B. Relative abundance was measured in two ways, number of individuals per hour of kicking effort, and number of individuals per unit area. Species richness was measured using Menhinick Index of species richness. Species diversity was measured using the Shannon Diversity Index. Using *An Introduction to the Aquatic Insects of North America* (Merritt and Cummins, 1984) and other sources (Lehmkul, 1979; Kaston, 1978; Huggins and Leichti, 1985; Thorp and Covich, 1991; Williams and Abele, 1989) the aquatic macroinvertebrate population was broken into four trophic categories based on feeding behavior; collectors, predators, scrapers, shredders. Aquatic macroinvertebrates were separated into trophic and environmental tolerance groups for analysis.

Aquatic macroinvertebrates were more difficult to separate into tolerance groups than fish. Many scientists have conflicting opinions on the tolerance classification of many organisms. Three grouping schemes, that cover a majority of macroinvertebrate families, were used for this study; the tolerance index developed by Hilsenhoff (1982) used in Pollution and Aquatic Insects as Indicator Organisms, the tolerance indices developed by Hilsenhoff (1988) and Bode (1988) developed used by EPA in Rapid Bioassessment Protocols for Use in Stream and Rivers: Benthic Macroinvertebrates and Fish (RBP), and Beck's Biotic Index (Beck, 1954) used by U.S.D.A. Soil Conservation Service in Water Quality Indicators Guide: Surface Water (WQIG). This indices group most major families of macroinvertebrates into three classes; sensitive or intolerant, facultative, or tolerant. A combination of the three was used for this study (Table V).

TABLE V

INDICES OF ENVIRONMENTAL TOLERANCE OF AQUATIC MACROINVERTEBRATES

Index Used	Range	Intolerant Range or Class	Facultative Range or Class	Tolerant Range or Class
Hilsenhoff, 1982	0-5	0-2	2-3	3-5
Hilsenhoff/ Bode, 1988	0-10	0-3	4-6	7-10
Beck	1-3	1	2	3

Physical/Biological Analysis

Regression analysis (95% confidence level) was used to determine if linear relationships exist between physical and biological characteristics. Fish and macroinvertebrate species diversity, species richness, and relative abundance were regressed with bedrock, boulder, and cobble substrate percentages, volume of water in the habitat, and mean water depth of the habitat, using Microsoft Excel Analysis Tools (linear regression). R-square values and plotted regression lines were observed to determine if linear relationships existed.

CHAPTER V

RESULTS

Physical Measurements

Habitat

The most frequent habitats encountered were step-runs (~35%), bedrock formed lateral scour pools (~10%), runs (~8%), step-pools (~8%), and boulder formed lateral scour pools (~7%) (Figure 2). Data was broken into four groups based on occurrence; very low (< 1%), low (1 to 4%), moderate (4 to 10%), and high (10% <). The very low occurrence habitats were backwater pools (boulder, rootwad, and log formed), trench chutes, log formed lateral scour pools, glides, pocket water, corner pools, and bedrock sheets. The low occurrence habitats were high gradient riffles, cascades, secondary channel pools, plunge pools, dammed pools, rootwad formed lateral scour pools, and channel confluence pools. The moderate occurrence habitats were low gradient riffles, bedrock formed lateral scour pools, runs, mid-channel pools, boulder formed lateral scour pools, and step-pools. Step-runs were the only high occurrence habitats. By separating the inventoried stream into two sections, upper reaches (reaches 100-202) and lower reaches (reaches 1-99) (Figure 4), similar distributions of most habitat types were observed (Figure 3).

Pools

Physical dimensions. The mean depth and width-to-depth ratio among pool habitat types were significantly different based on the Kruskal-Wallis procedure (Table VI). The length , bankful width , and water width among pool habitat types were not significantly different.

The mean depth of step-pools was significantly lower than those of bedrock formed lateral scour pools , plunge pools , rootwad formed lateral scour pools , mid-channel pools, and boulder formed lateral scour pools based on Tukey's test . Table VII shows physical dimensions of pool habitat types found in Beech Creek. The width to depth ratio of step-pools was significantly higher than those of bedrock formed lateral scour pools, secondary channel pools, rootwad formed lateral scour pools, mid-channel pools, and plunge pools. Bankful width , water width , and length were not significantly different among pool habitat types.

TABLE VI

PHYSICAL DIMENSIONS OF POOL HABITAT TYPES AND RESULTS OF THE KRUSKAL-WALLIS PROCEDURE

	Mean Depth (cm)	Width to Depth Ratio	Bankful Width (m)	Water Width (m)	Length (m)
Mean	34.9	0.23	15.9	6.0	37.1
Range	4.8-125.2	0.06-1.13	3.8-55.1	1.6-14.0	10.3-122.1
P value	.0001	.0001	.3104	.5878	.2554
	*	*	ns	ns	ns

N = 90

* statistically significant ($p < 0.05$)

ns Not statistically significant

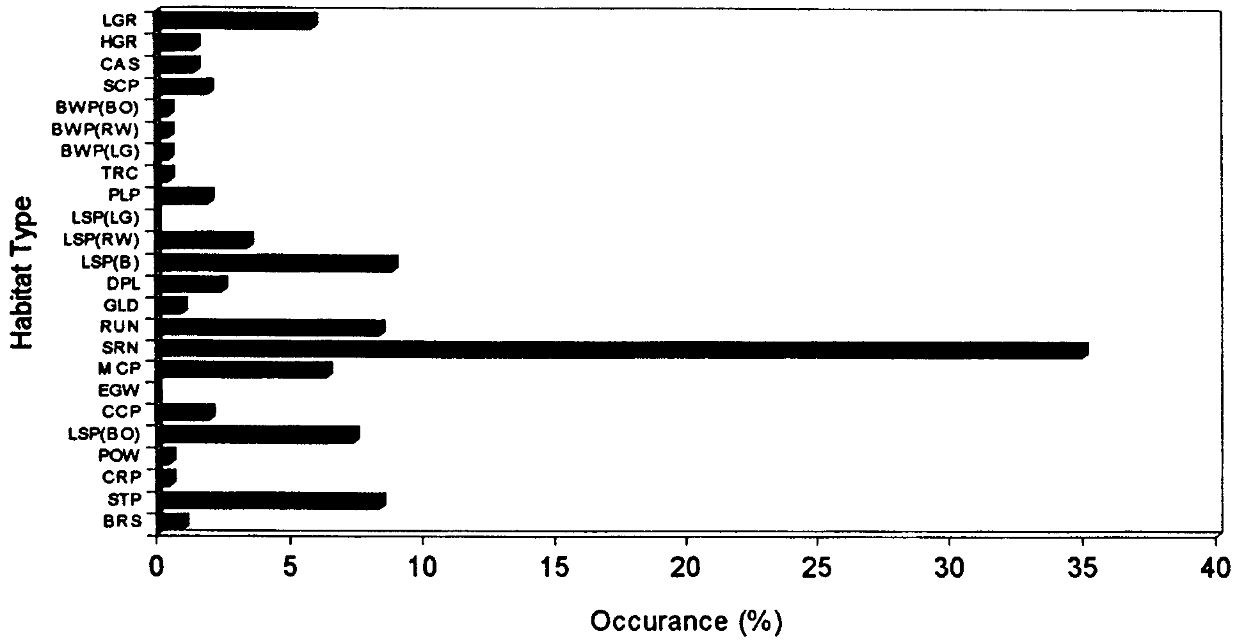

Figure 2. Frequency of habitat types of Beech Creek, summer 1993.

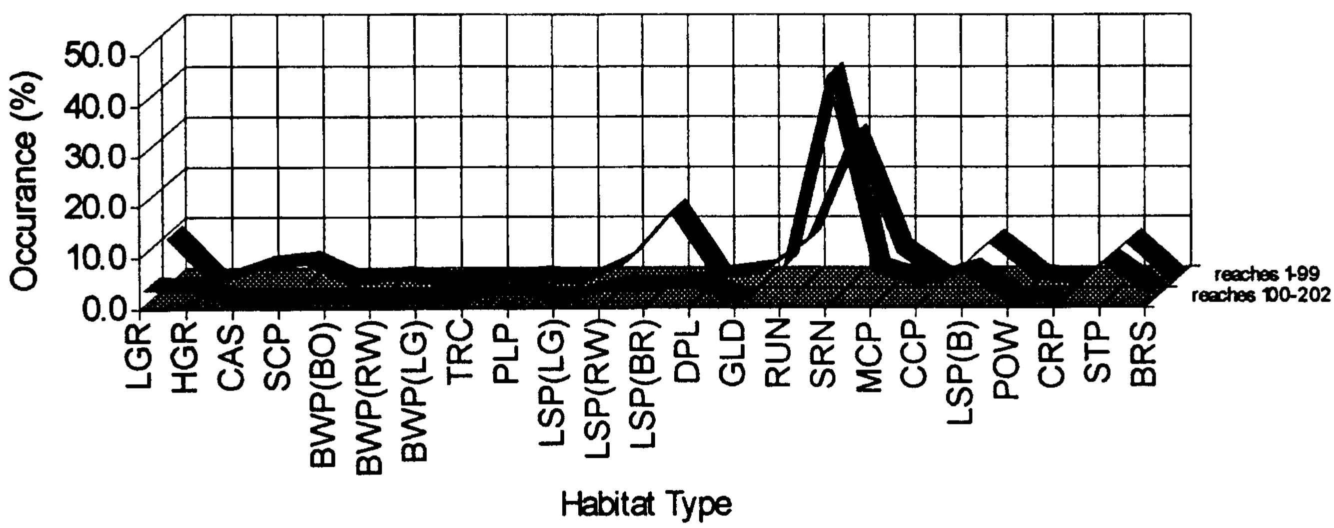

Figure 3. Habitat frequency of Beech Creek, upper reaches (100-202) vs. lower reaches (1-99).

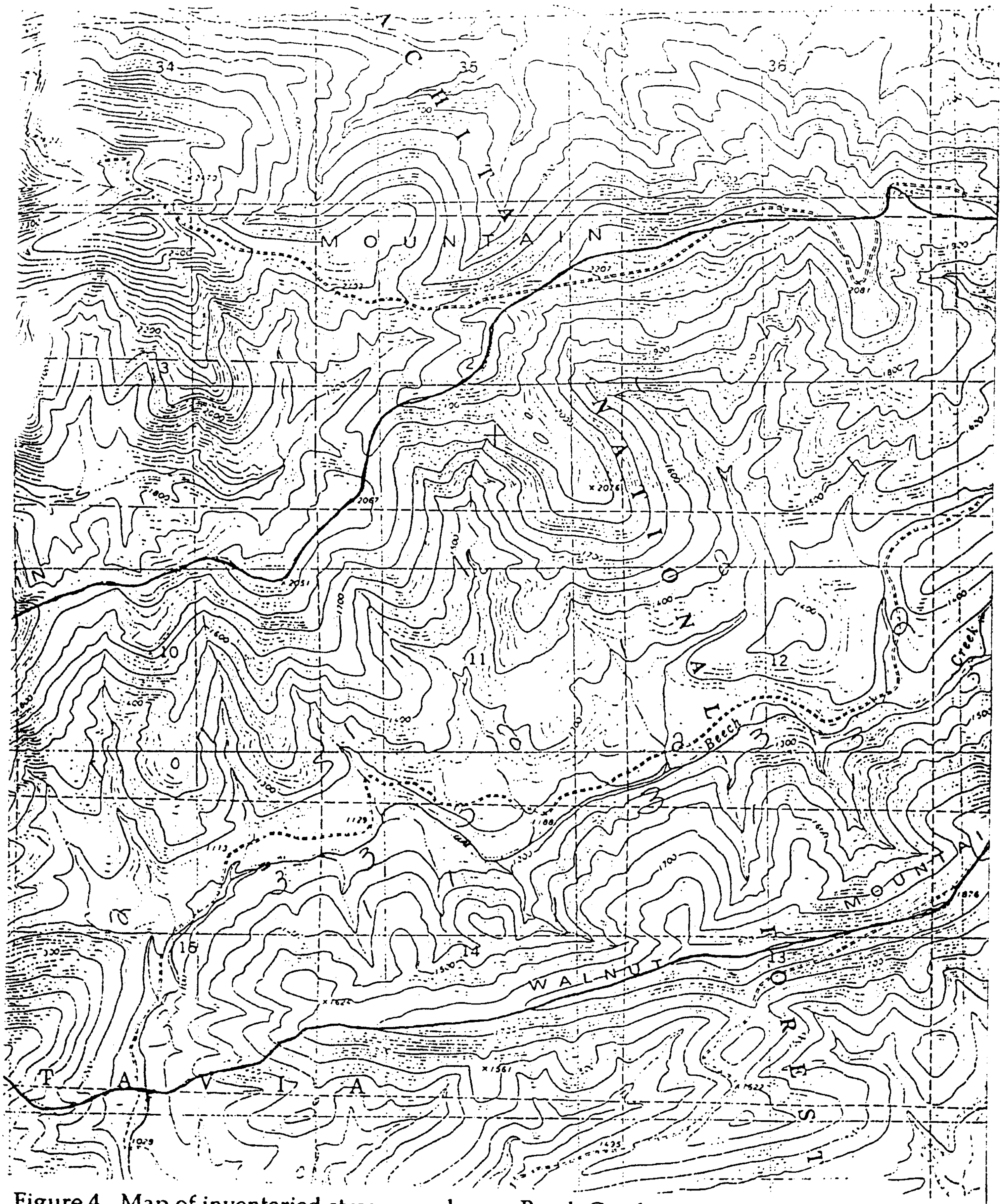

Figure 4. Map of inventoried stream reaches on Beech Creek watershed.

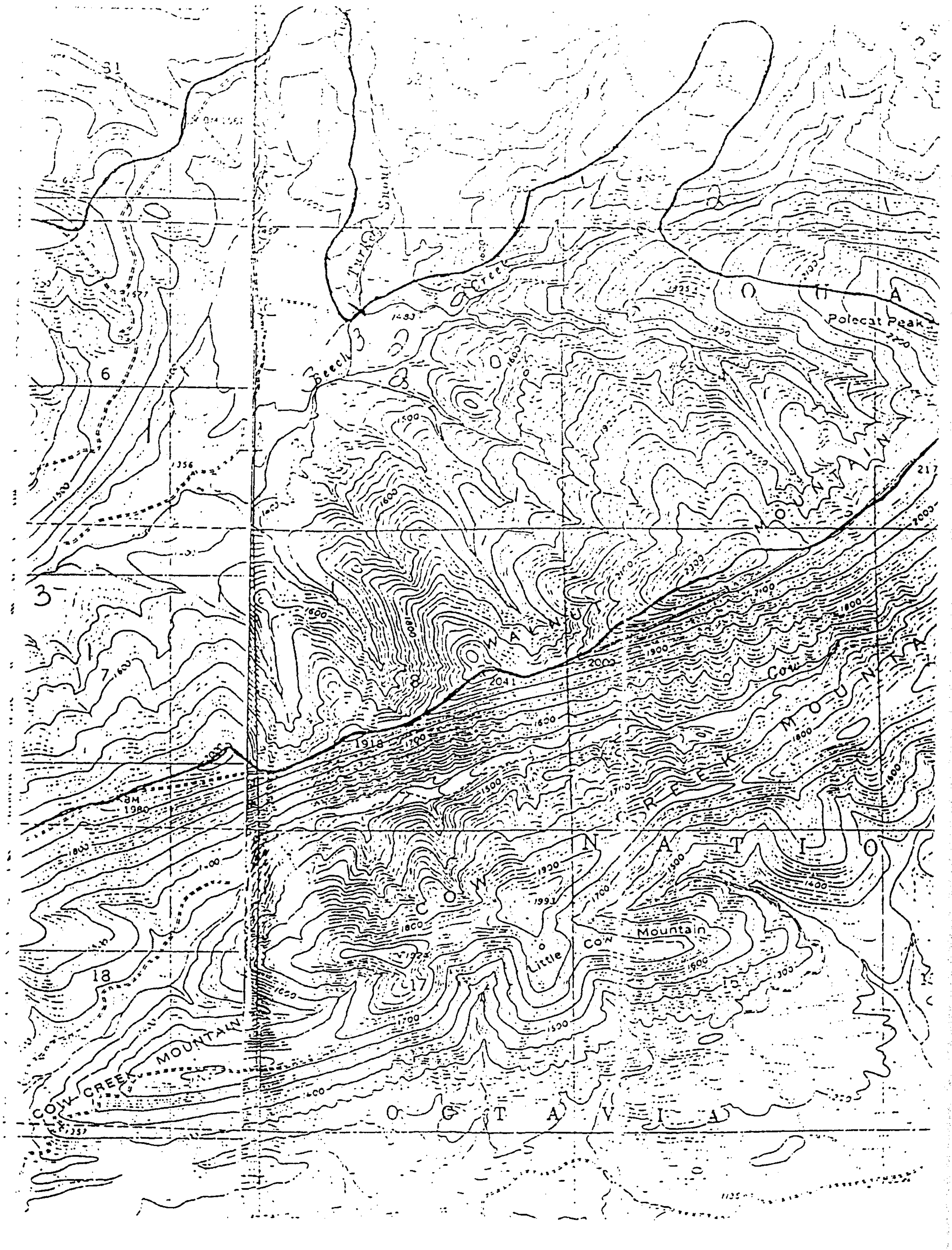
Polecat Peak
Beech
Creek
Little Cow Mountain
COW CREEK MOUNTAIN
1918
2041

TABLE VII

PHYSICAL DIMENSIONS OF BEECH CREEK
POOL HABITAT TYPES

Pool Type	Length (m)	Water Width (m)	Bankful Width (m)	Mean Depth (cm)	Width-to-Depth Ratio
SCP	35.2	4.6	15.1	32.0	.15
BWP	31.6	4.8	19.8	23.5	.22
PLP	13.2	6.5	16.8	46.4	.15
LSP(RW)	34.1	5.2	20.3	34.8	.16
LSP(BR)	49.1	6.7	13.4	47.9	.16
DPL	38.0	6.9	17.1	44.2	.20
MCP	35.2	6.8	15.9	42.5	.18
CCP	20.4	5.9	11.9	45.3	.20
LSP(B)	39.8	5.9	19.0	30.4	.21
CRP	26.6	3.8	20.8	22.7	.17
STP	36.9	5.4	13.4	15.5	.42

Substrate. Mean bedrock, boulder, and cobble substrate composition of pool habitat types were significantly different based on the Kruskal-Wallis procedure (Table VIII). The mean gravel substrate composition was not significantly different for pool habitat types. Sand and fines were not analyzed due to their low occurrence.

The mean bedrock substrate composition of bedrock formed lateral scour pools was significantly higher than those of dammed pools, plunge pools, mid-channel pools, boulder formed lateral scour pools, rootwad formed lateral scour pools, and secondary channel pools based on Tukey's test. The mean bedrock substrate composition of step-pools was significantly higher than the mean rank of bedrock composition of mid-channel pools, boulder formed lateral scour pools, rootwad formed lateral scour pools, and secondary channel pools. Table IX shows the substrate composition of pool habitat types found in Beech Creek. The mean cobble substrate composition of rootwad formed lateral scour pools was significantly higher than those of step-pools and bedrock formed lateral scour pools. The mean cobble substrate composition of mid-channel pools was also significantly higher than that of bedrock formed lateral scour pools. There were no significant differences in the mean gravel substrate composition among pool habitat types.

TABLE VIII

MEAN SUBSTRATE COMPOSITION OF POOL HABITAT TYPES AND RESULTS OF THE KRUSKAL-WALLIS PROCEDURE

	Bedrock (%)	Boulder (%)	Cobble (%)	Gravel (%)
Mean	20	30	44	6
Range	0-100	0-100	0-90	0-60
P-value	.0001	.0694	.0008	.4554
	*	**	*	ns

N = 90
* statistically significant (p< 0.05)
** statistically significant (p< 0.10)
ns Not statistically significant

TABLE IX

SUBSTRATE COMPOSITION OF BEECH CREEK POOL HABITAT TYPES

Pool Type	Bedrock (%)	Boulder (%)	Cobble (%)	Gravel (%)
SCP	0	55	43	3
BWP	13	13	60	13
PLP	8	43	5	0
LSP(RW)	0	30	63	6
LSP(BR)	49	18	29	4
DPL	10	30	52	8
MCP	7	35	54	4
CCP	15	35	43	8
LSP(B)	3	35	50	12
CRP	0	30	60	10
STP	39	26	30	4

Embeddedness. Using the Kruskal-Wallis procedure, the mean embeddedness among pool habitat types was found to be significantly different (Table X).

The mean embeddedness of boulder formed lateral scour pools was significantly higher than that of step-pools based on Tukey's test. Table XI shows the embeddedness of pool habitat types found in Beech Creek.

TABLE X
MEAN EMBEDDEDNESS AND RESULTS OF THE
KRUSKAL-WALLIS PROCEDURE

Variable	Mean	Range	P-value	
Embeddedness	39%	0-65%	.0851	**

N = 90
** statistically significant ($p<0.10$)

TABLE XI

EMBEDDEDNESS OF BEECH CREEK
POOL HABITAT TYPES

Pool Type	Embeddedness (%)
SCP	44
BWP	38
PLP	43
LSP(RW)	41
LSP(BR)	36
DPL	43
MCP	44
CCP	43
LSP(B)	45
CRP	40
STP	26

Instream cover. Using the Kruskal-Wallis procedure, there were statistically significant differences in the mean white water, boulder, and bedrock ledge cover among pool habitat types (Table XII). The mean undercut bank and terrestrial vegetation cover were not statistically significant among pool habitat types.

Using Tukey's test, the mean white water cover of backwater pools was found to be significantly higher than that of mid-channel pools, and white water cover of step-pools was found to be significantly higher than those of boulder, bedrock, and rootwad formed lateral scour pools, damned pools, channel confluence pools, mid-channel pools, and secondary channel pools. The mean boulder cover structure of bedrock formed lateral scour pools was found to be significantly lower than mean rank of boulder cover structure of boulder and rootwad formed scour pools, and damned pools. The mean boulder cover structure of step-pools was found to be significantly lower than that of boulder formed lateral scour pools. The mean bedrock ledge cover of bedrock formed lateral scour pools was significantly higher than the mean ranks of plunge pools, damned pools, boulder and rootwad formed lateral scour pools, mid-channel pools, and secondary pools. Also, the mean bedrock ledge cover of step-pools was significantly higher than that of boulder formed lateral scour pools and mid-channel pools. Table XIII shows the percent of instream cover of pool habitat types found in Beech Creek.

TABLE XII

MEAN INSTREAM COVER PERCENT OF POOL HABITAT TYPES AND RESULTS OF THE KRUSKAL-WALLIS PROCEDURE

	Undercut Banks (%)	Terrestrial Vegetation (%)	White Water (%)	Boulders (%)	Bedrock Ledges (%)
Mean	3	4	1	41	13
Range	0-50	0-30	0-20	0-80	0-75
P-value	.7939	.2010	.0001	.0001	.0001
	ns	ns	*	*	*

N = 90
* statistically significant ($p < 0.05$)
ns Not statistically significant

TABLE XIII

PERCENT OF INSTREAM COVER OF BEECH CREEK POOL HABITAT TYPES

Pool Type	Undercut Banks (%)	Terrestrial Vegetation (%)	White Water (%)	Boulders (%)	Bedrock Ledges (%)
SCP	6	12	0	49	0
BWP	0	0	7	37	17
PLP	2	4	2	53	3
LSP(RW)	5	3	0	52	0
LSP(BR)	6	3	0	22	38
DPL	3	5	0	58	6
MCP	2	7	0	43	4
CCP	2	6	0	43	15
LSP(B)	2	2	0	61	1
CRP	2	3	0	40	0
STP	2	5	2	29	18

Riparian cover. Using the Kruskal-Wallis procedure, statistically significant differences in the mean right bank angle, left bank angle, and left bank stability were found among pool habitat types (Table XIV). The mean rooted vegetation, canopy closure, and right bank stability were not statistically significant among pool habitat types. Clinging vegetation was not analyzed due to its low occurrence.

The mean rooted vegetation among pool habitat types was not significantly different based on Tukey's test. The mean left bank stability of bedrock formed lateral scour pools was found to be significantly higher than those of mid-channel pools and secondary channel pools. Table XV shows the percent of riparian cover for pool habitat types found in Beech Creek.

TABLE XIV

MEAN VALUE OF RIPARIAN COVER OF POOL HABITAT TYPES AND RESULTS OF THE KRUSKAL-WALLIS PROCEDURE

	Rooted Vegetation (%)	Canopy Closure (%)	Right Bank Stability (%)	Right Bank Angle (degrees)	Left Bank Stability (%)	Left Bank Angle (degrees)
Mean	2	66	91	120	91	137
Range	0-40	8-100	75-100	50-180	70-100	40-80
P-value	.7550	.3546	.2129	.0125	.0015	.0528
	ns	ns	ns	*	*	**

N = 90
* statistically significant ($p < 0.05$)
** statistically significant ($p < 0.10$)
ns Not statistically significant

TABLE XV

PERCENT OF RIPARIAN COVER FOR BEECH CREEK POOL HABITAT TYPES

Pool Type	Rooted Vegetation (%)	Canopy Closure (%)	Right Bank Stability (%)	Right Bank Angle (degrees)	Left Bank Stability (%)	Left Bank Angle (degrees)
SCP	8	66	91	120	85	99
BWP	2	59	93	167	90	142
PLP	2	67	90	138	91	109
LSP(RW)	2	76	89	136	91	154
LSP(BR)	3	49	91	110	96	141
DPL	2	75	90	109	90	146
MCP	2	62	88	126	88	140
CCP	1	91	94	154	90	131
LSP(B)	1	70	92	134	90	115
CRP	20	92	85	125	95	175
STP	1	68	93	139	92	156

Riffles

Physical dimensions. Using the Kruskal-Wallis procedure, statistically significant differences in the mean depth and width to depth ratio among riffle habitat types were found (Table XVI). No statistically significant differences were found in the mean length, bankful width, and water width among riffle habitat types.

Tukey's test indicated that the mean depth of cascades was significantly higher than that of bedrock sheets (Table XVII). The mean width to depth ratio of bedrock sheets was found to be significantly higher than that of high gradient riffles. No significant differences were found in the mean bankful width, water width, or length for riffle habitat types .

TABLE XVI

PHYSICAL DIMENSIONS OF RIFFLE HABITAT TYPES AND RESULTS OF THE KRUSKAL-WALLIS PROCEDURE

	Mean Depth (cm)	Width to Depth Ratio	Bankful Width (m)	Water Width (m)	Length (m)
Mean	10.8	.51	19.6	4.8	17.0
Range	2.0-20.5	0.20-2.00	7.1-80.8	1.9-10.5	10-36.8
P-value	.0094	.0717	.1024	.1270	.8181
	*	**	ns	ns	ns

N = 20

* statistically significant ($p < 0.05$)

** statistically significant ($p<0.10$)

ns Not statistically significant

TABLE XVII

PHYSICAL DIMENSIONS OF BEECH CREEK RIFFLE HABITAT TYPES

Riffle Type	Mean Depth (cm)	Width to Depth Ratio	Bankful Width (m)	Water Width (m)	Length (m)
LGR	11.1	.44	25.8	4.7	17.0
HGR	8.8	.32	11.9	2.9	17.8
CAS	15.9	.41	10.7	6.7	19.4
BRS	4.6	1.38	7.8	4.8	12.1

Substrate. Using the Kruskal-Wallis procedure, the mean bedrock and cobble substrate composition for riffle habitat types was found to be significantly different among riffle habitat types (Table XVIII). The mean boulder and gravel substrate compositions were not statistically significant for riffle habitat types. Sand and fines were not analyzed due to their low occurrence.

Using Tukey's test, the mean bedrock substrate composition of bedrock sheets was significantly higher than those of low and high gradient riffles. The mean cobble substrate composition of high gradient riffles was significantly higher than the mean cobble substrate composition of cascades and bedrock sheets. The mean cobble substrate composition of low gradient riffles was significantly higher than that of bedrock sheets. Table XIX shows substrate composition of riffle habitat types found in Beech Creek.

TABLE XVIII

KRUSKAL-WALLIS RESULTS AND MEAN VALUE OF SUBSTRATE COMPOSITION FOR RIFFLE HABITAT TYPES

	Bedrock (%)	Boulder (%)	Cobble (%)	Gravel (%)
Mean	16	22	56	7
Range	0-100	0-60	0-100	0-50
P-value	.0017	.1445	.0054	.2924
	*	ns	*	ns

N = 20
* statistically significant ($p < 0.05$)
ns Not statistically significant

TABLE XIX

SUBSTRATE COMPOSITION OF BEECH CREEK RIFFLE HABITAT TYPES

Riffle Type	Bedrock (%)	Boulder (%)	Cobble (%)	Gravel (%)
LGR	1	23	68	8
HGR	0	13	77	10
CAS	37	40	23	0
BRS	100	0	0	0

<u>Embeddedness</u>. Using the Kruskal-Wallis procedure, the mean embeddedness was found to be significantly different among riffle habitat types (Table XX).

No significant differences in the mean embeddedness among riffle habitat types was found based on Tukey's test. Table XXI shows the embeddedness of riffle habitat types found in Beech Creek.

TABLE XX

KRUSKAL-WALLIS RESULTS AND MEAN EMBEDDEDNESS OF RIFFLE HABITAT TYPES

Variable	Mean	Range	P-value	
Embeddedness	31%	0-55%	.0934	**

N = 20

** statistically significant ($p < 0.10$)

TABLE XXI

EMBEDDEDNESS OF BEECH CREEK RIFFLE HABITAT TYPES

Riffle Type	Embeddedness (%)
LGR	37
HGR	37
CAS	23
BRS	0

Instream cover. Using the Kruskal-Wallis procedure, the mean white water and bedrock ledge cover was found to be significantly different among riffle habitat types (Table XXII). No statistically significant differences were found in the mean undercut bank, terrestrial vegetation, and boulder cover among riffle habitat types. Tukey's test indicated that the mean bedrock ledge cover of cascades was significantly higher than that of low gradient riffles. No significant differences were found in the mean undercut bank, terrestrial vegetation, white water, or boulder cover among riffle habitat types. Table XXIII shows the instream cover of riffle habitat types found in Beech Creek.

TABLE XXII

KRUSKAL-WALLIS RESULTS AND MEAN PERCENT OF INSTREAM COVER FOR RIFFLE HABITAT TYPES

	Undercut Banks (%)	**Terrestrial Vegetation (%)**	**White Water (%)**	**Boulders (%)**	**Bedrock Ledges (%)**
Mean	5	7	16	31	7
Range	0-65	0-40	0-70	0-75	0-70
P-value	.9759	.2159	.0993	.2729	.0285
	ns	ns	**	ns	*

N = 20
* statistically significant (p< 0.05)
** statistically significant (p<0.10)
ns Not statistically significant

TABLE XXIII

INSTREAM COVER OF BEECH CREEK
RIFFLE HABITAT TYPES

Riffle Type	Undercut Banks (%)	Terrestrial Vegetation (%)	White Water (%)	Boulders (%)	Bedrock Ledges (%)
LGR	6	7	15	34	3
HGR	1	10	22	45	0
CAS	3	3	23	28	37
BRS	3	13	1	0	0

Riparian cover. Using the Kruskal-Wallis procedure, the mean clinging vegetation, left bank stability, and right bank stability was found to be significantly different among riffle habitat types (Table XXIV). The mean right bank angle, left bank angle, rooted vegetation, and canopy closure were not significantly different among riffle habitat types. Using Tukey's test, the mean riparian cover types among riffle habitat types were not found to be significantly different. Table XXV shows the riparian cover of riffle habitat types found in Beech Creek.

TABLE XXIV

KRUSKAL-WALLIS RESULTS AND MEAN VALUE OF RIPARIAN
COVER FOR RIFFLE HABITAT TYPES

	Rooted Vegetation (%)	Clinging Vegetation (%)	Canopy Closure (%)	Left Bank Angle (degrees)	Left Bank Stability (%)	Right Bank Angle (degrees)	Right Bank Stability (%)
Mean	4%	3%	61%	154°	93%	156°	94%
Range	0-30%	0-15%	0-100%	60-180°	85-100%	110-180°	90-100%
P-value	.4022	.0349	.3236	.8418	.0631	.4878	.0783
	ns	*	ns	ns	**	ns	**

N = 20
* statistically significant ($p < 0.05$)
** statistically significant ($p < 0.10$)
ns Not statistically significant

TABLE XXV

RIPARIAN COVER OF BEECH CREEK
RIFFLE HABITAT TYPES

Riffle Type	Rooted Vegetation (%)	Clinging Vegetation (%)	Canopy Closure (%)	Left Bank Angle (degrees)	Left Bank Stability (%)	Right Bank Angle (degrees)	Right Bank Stability (%)
LGR	3	1	61	154	93	152	93
HGR	11	7	77	165	90	172	93
CAS	0	3	31	143	97	162	95
BRS	3	8	76	153	98	150	100

Runs

Physical dimensions. The mean depth and length were significantly different among run habitat types based on the Kruskal-Wallis procedure (Table XXVI). No statistically significant differences were found in the mean bankful width and water width for run habitat types.

Based on Tukey's test, the mean length of step-runs was found to be significantly higher than that of runs. The mean depth, width to depth ratio, bankful width, or water width were not significantly different among run habitat types. Table XXVII shows the physical dimensions of run habitat types found in Beech Creek.

TABLE XXVI

KRUSKAL-WALLIS RESULTS AND MEAN VALUE OF PHYSICAL DIMENSIONS FOR RUN HABITAT TYPES

	Mean Depth (cm)	Bankful Width (m)	Water Width (m)	Length (m)
Mean	12.8	14	4.4	46.2
Range	4.5-30.8	3.9-44.4	1.3-11.5	10.0-100.0
P-value	.0063	.8610	.3240	.0010
	*	ns	ns	*

N = 90
* statistically significant ($p < 0.05$)
ns Not statistically significant

TABLE XXVII

PHYSICAL DIMENSIONS OF BEECH CREEK RUN HABITAT TYPES

Run Type	Mean Depth (cm)	Bankful Width (m)	Water Width (m)	Length (m)
GLD	28.3	10.6	4.1	34.7
POW	25.5	14.2	9.2	57.6
RUN	14.7	13.2	4.6	25.7
SRN	11.8	14.3	4.3	51.0

Substrate. The mean bedrock substrate composition was found to be significantly different for run habitat types based on the Kruskal-Wallis procedure (Table XXVIII). The mean boulder, cobble, and gravel substrate compositions were not significantly different for run habitat types. Sand and fines were not analyzed due to their low occurrence.

Using Tukey's test, the mean bedrock substrate composition of glides was significantly higher than those of runs and step-runs. There were no significant differences in the mean boulder, cobble, or gravel substrate composition among run habitats. Table XXIX shows substrate composition of run habitat types found in Beech Creek.

TABLE XXVIII

KRUSKAL-WALLIS RESULTS AND MEAN PERCENT OF SUBSTRATE COMPOSITION OF RUN HABITAT TYPES

	Bedrock (%)	**Boulder (%)**	**Cobble (%)**	**Gravel (%)**
Mean	8	31	55	6
Range	0-80	0-70	10-100	0-40
P-value	.0063	.1006	.2533	.5341
	*	ns	ns	ns

N = 90
* statistically significant ($p < 0.05$)
ns Not statistically significant

TABLE XXIX

SUBSTRATE COMPOSITION OF BEECH CREEK RUN HABITAT TYPES

Run Type	Bedrock (%)	Boulder (%)	Cobble (%)	Gravel (%)
GLD	60	5	35	0
POW	10	30	60	0
RUN	10	27	59	5
SRN	6	33	54	7

Embeddedness. Using the Kruskal-Wallis procedure, no statistically significant differences were found in the mean embeddedness among run habitat types (Table XXX).

Tukey's test indicated that the mean embeddedness was not significantly different among run habitat types. Table XXXI shows embeddedness of run habitat types found in Beech Creek.

TABLE XXX

KRUSKAL-WALLIS RESULTS AND MEAN EMBEDDEDNESS OF RUN HABITAT TYPES

Variable	Mean	Range	P-value	
Embeddedness	40%	0-60%	.5388	ns

N = 90

ns Not statistically significant

TABLE XXXI

EMBEDDEDNESS OF BEECH CREEK RUN HABITAT TYPES

Run Type	Embeddedness (%)
GLD	45
POW	50
RUN	38
SRN	40

Instream cover. Using the Kruskal-Wallis procedure, the mean bedrock ledge, white water, and boulder cover were found to be significantly different for run habitat types (Table XXXII). There were no statistically significant differences in the mean terrestrial vegetation cover. Undercut bank cover was not analyzed due to low occurrence.

Tukey's test revealed that the mean white water cover of step-runs was significantly higher than that of runs. The mean bedrock ledge cover of glides was found to be significantly higher than those of step-runs, runs, and pocket water. The mean terrestrial vegetation or boulder cover were not significantly different among run habitat types. Table XXXIII shows the instream cover of run habitat types found in Beech Creek.

TABLE XXXII

KRUSKAL-WALLIS RESULTS AND MEAN VALUE OF INSTREAM COVER FOR RUN HABITAT TYPES

	Undercut Banks (%)	Terrestrial Vegetation (%)	White Water (%)	Boulders (%)	Bedrock Ledges (%)
Mean	1	3	6	47	3
Range	0-20	0-15	0-33	`0-80	0-60
P-value	------	.2390	.0266	.0666	.0002
	not analyzed	ns	*	**	*

N = 90
* statistically significant (p< 0.05)
** statistically significant (p< 0.10)
ns Not statistically significant

TABLE XXXIII

INSTREAM COVER OF BEECH CREEK RUN HABITAT TYPES

Run Type	Undercut Banks (%)	Terrestrial Vegetation (%)	White Water (%)	Boulders (%)	Bedrock Ledges (%)
GLD	0	4	1	17	43
POW	0	0	1	70	0
RUN	1	2	3	41	0
SRN	0	3	7	49	3

Riparian Cover. Using the Kruskal-Wallis procedure, the mean canopy closure was found to be significantly different among run habitat types (Table XXXIV). There were no statistically significant differences in mean left bank angle and stability, and right bank angle and stability. There were no significant differences in the mean riparian cover among run habitat types based on Tukey's test. Table XXXV shows the riparian cover of run habitat types found in Beech Creek.

TABLE XXXIV

KRUSKAL-WALLIS RESULTS AND MEAN VALUE OF RIPARIAN COVER FOR RUN HABITAT TYPES

	Canopy Closure (%)	Right Bank Stability (%)	Right Bank Angle (degrees)	Left Bank Stability (%)	Left Bank Angle (degrees)
Mean	73	91	146	93	152
Range	8-100	70-100	55-180	85-100	60-180
P-value	.0302	.1193	.6012	.1038	.5008
	*	ns	ns	ns	ns

N = 90
* statistically significant ($p < 0.05$)
ns Not statistically significant

TABLE XXXV

RIPARIAN COVER OF BEECH CREEK
RUN HABITAT TYPES

Run Type	Clinging Vegetation (%)	Rooted Vegetation (%)	Left Bank Angle (degrees)	Left Bank Stability (%)	Right Bank Angle (degrees)	Right Bank Stability (%)
GLD	0	1	158	98	125	88
POW	0	5	115	85	155	80
RUN	1	3	151	93	148	91
SRN	2	3	153	93	146	91

Pools, Riffles, and Runs

Using Tukey's test, significant differences in the mean ranks of many physical variables were found among pools, riffles, and runs. The results are listed in Appendix C.

Physical dimensions. Using the Kruskal-Wallis procedure, the mean length, mean depth, water width, and width to depth ratio among all habitat types were found to be significantly different (Table XXXVI). No statistically significant differences in the mean bankful width were found.

Substrate. Using the Kruskal-Wallis procedure, statistically significant differences were found in the mean bedrock, boulder, and cobble substrate composition among all habitat types (Table XXXVII). No statistically significant differences in the mean gravel substrate composition among all habitat types were found. Figure 5 shows the substrate composition profile of Beech Creek among pools, riffles, and runs.

TABLE XXXVI

KRUSKAL-WALLIS RESULTS AND MEAN VALUES OF PHYSICAL DIMENSIONS FOR ALL HABITAT TYPES

	Mean Depth (cm)	**Width to Depth Ratio**	**Bankful Width (m)**	**Water Width (m)**	**Length (m)**
Mean	22.6 cm	Not Available	15.4 m	5.1 m	39.0 m
P-value	.0001	------	.2965	.0021	.0001
	*	*	ns	*	*

N = 201
* statistically significant ($p < 0.05$)
ns Not statistically significant

TABLE XXXVII

KRUSKAL-WALLIS RESULTS AND MEAN PERCENT OF SUBSTRATE COMPOSITION FOR ALL HABITAT TYPES

	Bedrock (%)	**Boulder (%)**	**Cobble (%)**	**Gravel (%)**
Mean	18	30	50	6
P-value	.0001	.0089	.0001	.5525
	*	*	*	ns

N = 201
* statistically significant ($p < 0.05$)
ns Not statistically significant

Embeddedness. Using the Kruskal-Wallis procedure, the mean rank of embeddedness was found to be significantly different among all habitat types (Table XXXVIII). Figure 6 shows the pattern of percent embeddedness among all habitat types found in Beech Creek.

Instream cover. Statistically significant differences were found in the mean undercut bank, terrestrial vegetation, white water, boulder, and bedrock ledge cover among all habitat types based on the Kruskal-Wallis procedure (Table XXXIX).

Riparian cover. The Kruskal-Wallis procedure indicated that mean clinging vegetation, canopy closure, right bank stability and angle, and left bank stability and angle were significantly different among pool, riffle, and run habitat types (Table XL). No statistically significant differences were found in the mean rooted vegetation of Beech Creek.

TABLE XXXVIII

MEAN EMBEDDEDNESS AND RESULTS OF THE KRUSKAL-WALLIS PROCEDURE AMONG ALL HABITAT TYPES

Variable	Mean	P-value	
Embeddedness	38%	.0372	*

N = 201

* statistically significant ($p<0.05$)

TABLE XXXIX

KRUSKAL-WALLIS RESULTS AND MEAN VALUES OF INSTREAM COVER FOR ALL HABITAT TYPES

	Undercut Banks (%)	Terrestrial Vegetation (%)	White Water (%)	Boulders (%)	Bedrock Ledges (%)
Mean	3	4	5	43	7
P-value	.0052	.0946	.0001	.0001	.0001
	*	**	*	*	*

N = 201
* statistically significant (p< 0.05)
** statistically significant (p< 0.10)
ns Not statistically significant

TABLE XL

KRUSKAL-WALLIS PROCEDURE AND MEAN VALUES OF RIPARIAN COVER FOR ALL HABITAT TYPES

	Rooted Vegetation (%)	Clinging Vegetation (%)	Canopy Closure (%)	Right Bank Stability (%)	Right Bank Angle (degrees)	Left Bank Stability (%)	Left Bank Angle (degrees)
Mean	3	1	69	91	139	92	145
P-value	.6531	.0001	.0519	.0334	.0001	.0001	.0098
	ns	*	**	*	*	*	*

N = 201
* statistically significant (p< 0.05)
** statistically significant (p< 0.10)
ns Not statistically significant

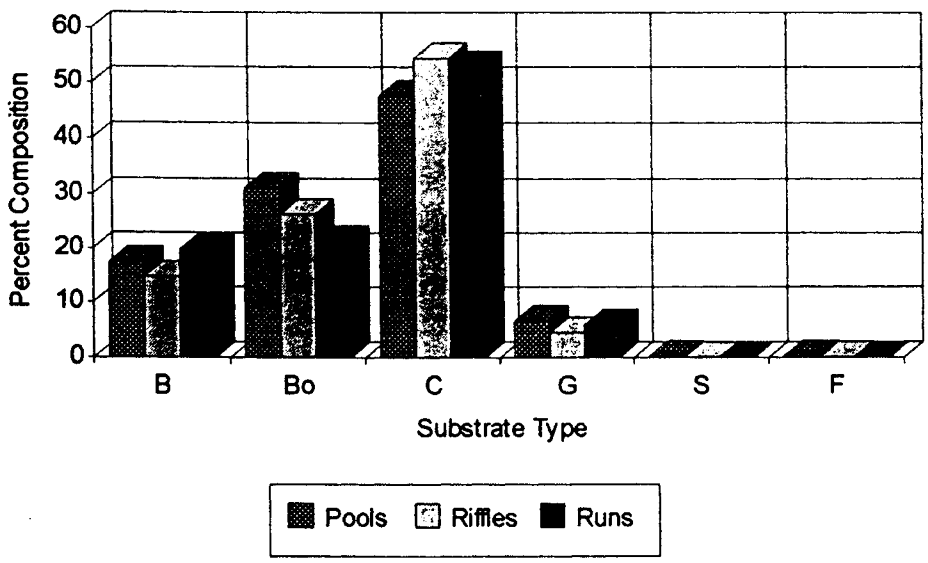

Figure 5. Substrate composition of pool, riffle, and run habitats of Beech Creek. (An average composition percentage was calculated for habitat type).

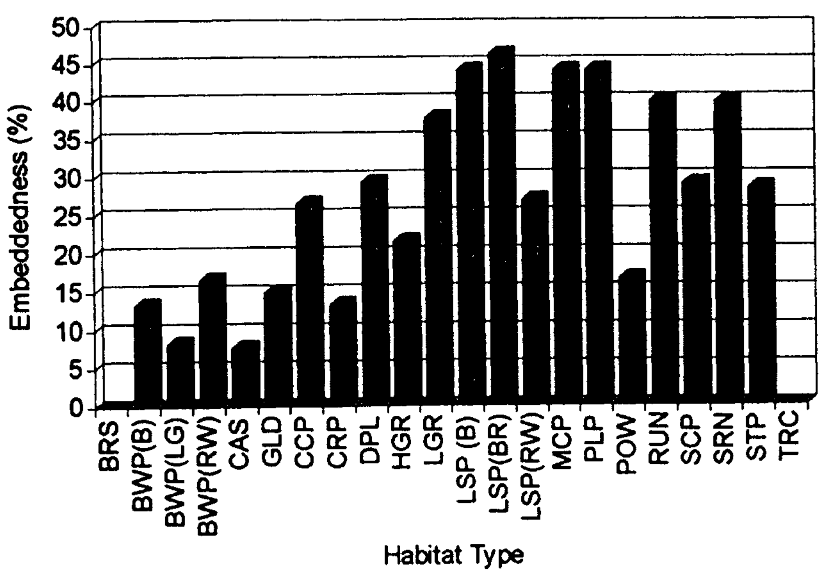

Figure 6. Embeddedness of Beech Creek by habitat type.

Chemical Measurements

Table XLI shows the collection dates of the chemistry samples. The results reported below are only a chemical "snapshot" in time, not an absolute chemical condition (Table XLII).

The Oklahoma Water Resources Board has designated uses of all water bodies in Oklahoma. Beech Creek is designated as public and private water supply, cool water aquatic community, agriculture, primary recreation, and aesthetics. The cool water aquatic community is the primary designation this study is related to.

TABLE XLI

COLLECTION DATES, POSITION IN WATERSHED, AND REACH NUMBER OF CHEMICAL SAMPLES TAKEN FROM BEECH CREEK, SUMMER OF 1993

Reach Number	13	59	77	107	139	186
Position in Watershed	lower	lower	lower	upper	upper	upper
Collection Date	6-28-93	6-30-93	7-7-93	7-9-93	7-13-93	7-13-93

pH

According to Oklahoma's Water Quality Standards, pH (hydrogen ion activity) values shall be between 6.5 and 9.0 for cool water aquatic community designation (OWRB, 1993). The mean pH value of Beech Creek was 6.7, the minimum was 6.5 and the maximum was 7.1. All the pH values were within water quality standards for cool water aquatic communities. Figure 7 shows the trends in pH of Beech Creek sample stations.

Specific Conductance

The mean specific conductance of Beech Creek was 17.2 µS, the minimum was 14.6 µS and the maximum was 20.4 µS. Figure 7 shows trends in specific conductance for Beech Creek sample stations.

Total Phosphorus

The mean total phosphorus concentration of Beech Creek was .025 mg/l, the minimum was .011 mg/l and the maximum was .036 mg/l. Figure 8 shows trends in total phosphorus for Beech Creek sample stations.

Alkalinity

The mean alkalinity of Beech Creek was 0.53 mg/l $CaCO_3$, the minimum was 0.29 mg/l $CaCO_3$, and the maximum was 0.65 mg/l $CaCO_3$. Figure 8 shows the trends in alkalinity of Beech Creel sample stations.

Air and Water Temperature

The air temperature at Beech Creek ranged from 22.7 ^{o}C to 33.0 ^{o}C. The mean air temperature was 28.0 ^{o}C. According to Oklahoma's Water Quality Standards, water temperature values shall be a maximum of 29.0 ^{o}C for summer conditions (6/1 - 10/15) during "other life stages" for cool water aquatic community designation (OWRB, 1993). The water temperature at Beech Creek ranged from 21.6 ^{o}C to 25.4 ^{o}C. The mean water temperature was 23.9 ^{o}C. Figure 9 shows air and water temperature of Beech Creek and the collection dates.

Dissolved Oxygen

The mean dissolved oxygen concentration of Beech Creek was 6.4 mg/l, the minimum concentration was 2.9 mg/l and the maximum was 7.8 mg/l. Figure 9 shows the dissolved oxygen concentration of Beech Creek sample stations. The D.O. lag, measured at reach 139, will be addressed in the discussion section. Oklahoma Water Quality Standards designate a minimum D.O. criteria for cool water aquatic communities as 6.0 mg/l with a 1.0 mg/l D.O. deficit for not more that eight hours during any twenty-four hour period (OWRB 1993). The dissolved oxygen values for Beech Creek, with the exception of reach 139, are within state water quality criteria.

TABLE XLII

CHEMICAL CONDITIONS OF BEECH CREEK, SUMMER 1993

Measurement	Mean	Minimum	Maximum
pH	6.7	6.5	7.1
Specific Conductance (μSeimens)	17.2	14.6	20.4
Total Phosphorus (mg/l)	.025	.011	.036
Alkalinity (mg/l $CaCO_3$)	0.53	0.29	0.65
Air Temperature (°C)	28.0	22.7	33.0
Water Temperature (°C)	23.9	21.6	25.4
Dissolved Oxygen (mg/l O_2)	6.4	2.9	7.8

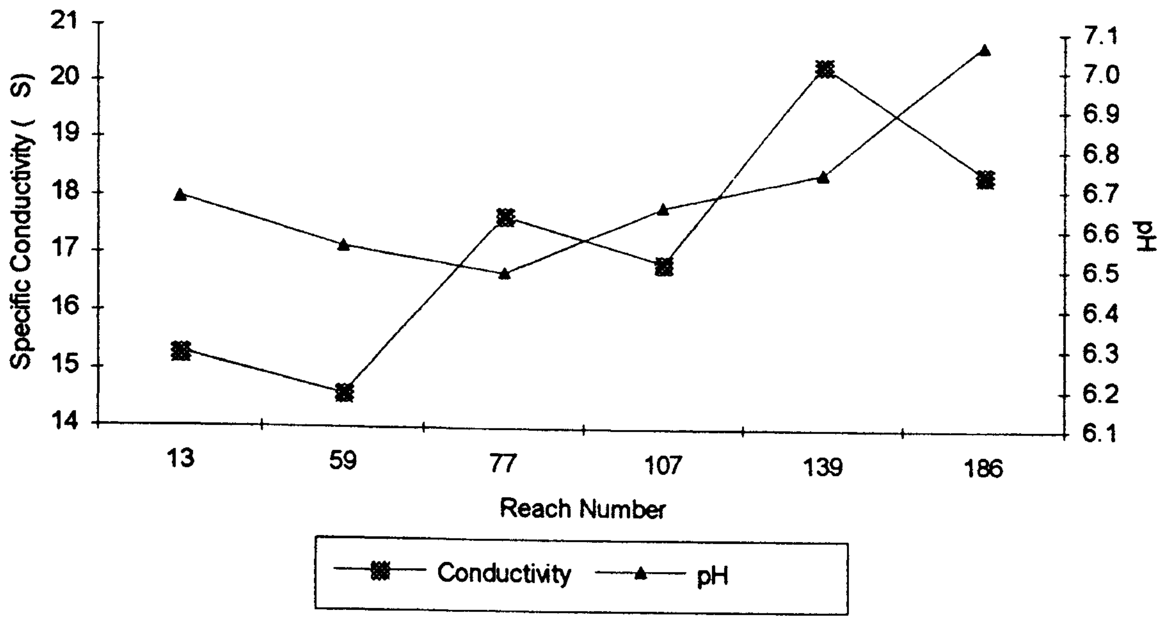

Figure 7. Specific conductance and pH of Beech Creek, Summer, 1993.

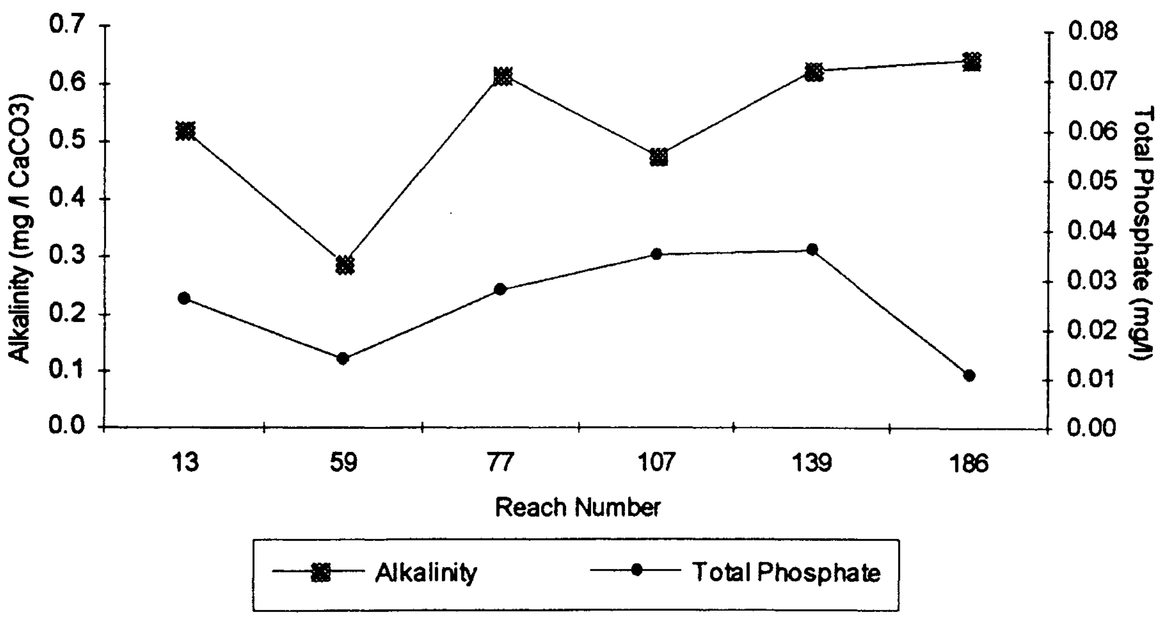

Figure 8. Alkalinity and total phosphate concentration of Beech Creek, summer, 1993.

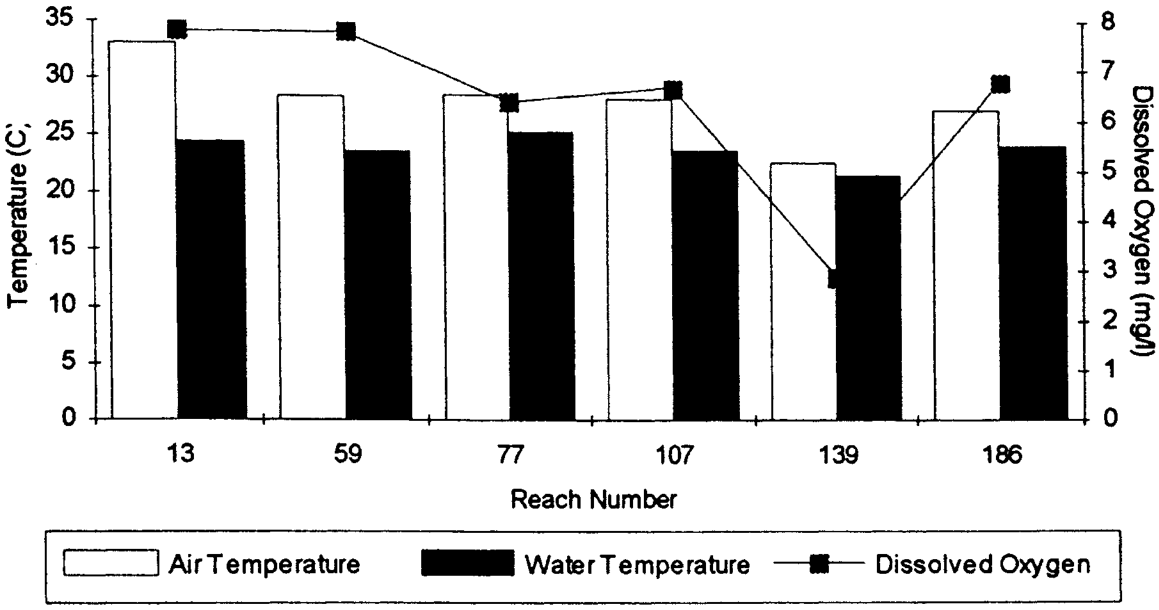

Figure 9. Air and water temperature and dissolved oxygen concentration, Beech Creek, summer, 1993.

Biological Measurements

Fish

Relative abundance. Relative abundance of fish is shown in Table XLIII. The ANOVA procedure indicated no statistically significant differences in the mean relative abundance of fish among pools, riffles, and runs.

Using Tukey's test, no significant differences were found in the mean relative abundance of fish among pools, riffles, and runs.

Species richness. Based on the ANOVA procedure, statistically significant differences were found in Menhinick's Index of species richness ($p < 0.10$). The Table XLIV shows species richness of fish in Beech Creek.

Using Tukey's test, there were no significant differences in species richness of fish among pools, riffles, and runs.

Species diversity. The calculated species diversity of fish for pools, riffles, and runs is listed in Table XLV. The ANOVA procedure indicated no significant differences in species diversity of fish among pools, riffles, and runs.

Species diversity among pools, riffles, and runs was not significantly different based on Tukey's test.

Trophic structure. Within pools, 22% of the fish were herbivorous, 72% of the fish were invertivorous, and 6% of the fish were piscivorous (Figure 10). Within riffles, 21% of the fish were herbivorous, 79% invertivorous, and no piscivorous fish were found (Figure 11). Within runs, 35% of the fish were herbivorous, 63% of the fish were invertivorous, and 2% of the fish were piscivorous (Figure 12).

Among pools, riffles and runs, 56% of herbivorous fish occurred in pools, 16% occurred in riffles, and 28% occurred in runs (Table XLVI). Among habitats, 63% of the invertivorous fish occurred in pools, 19% occurred in riffles, and 18% occurred in runs. Finally, among pools, riffles and runs, 88% of the piscivorous fish occurred in pools, 0% occurred in riffles, and 12% occurred in runs. Table XLVII shows the number of individuals of each trophic category by habitat types.

TABLE XLIII

RELATIVE ABUNDANCE OF FISH AMONG POOL, RIFFLE, AND RUN HABITAT TYPES

	Relative Abundance (#/hour)	**Relative Abundance (#/m^2)**	**Relative Abundance (gm/hour)**	**Relative Abundance (gm/m^2)**
Pools	102.3	0.3	919.7	2.8
Range	5.0-200.0	0.0-1.6	6.0-2296.5	0.0-17.4
Runs	98.0	0.3	504.7	1.3
Range	16.7-168.8	0.0-0.8	0.8-709.7	0.0-3.5
Riffles	94.9	0.7	189.5	1.5
Range	12.5-163.6	0.1-2.2	1.3-362.7	0.0-2.9
P-value	.6329	.8119	.3431	.3970

TABLE XLIV

SPECIES RICHNESS OF FISH AMONG POOL, RIFFLE, AND RUN HABITAT TYPES

	Menhinick Index (R2)
Pools	0.4
Runs	0.6
Riffles	0.5

TABLE XLV

SPECIES DIVERSITY OF FISH AMONG POOLS, RIFFLES, AND RUNS

	Pools	Riffles	Runs
Shannon Index of Species Diversity for Fish	0.79	0.82	1.30

TABLE XLVI

TROPHIC STRUCTURE OF FISH AMONG POOLS, RIFFLES, AND RUNS

	Pools	Riffles	Runs
Herbivores (%)	56	16	28
No. of Herbivores	176	49	91
Invertivores (%)	63	19	18
No. of Invertivores	587	182	165
Piscivores (%)	88	0	12
No. of Piscivores	53	0	7

TABLE XLVII

TROPHIC STRUCTURE OF FISH IN BEECH CREEK
BY HABITAT TYPES

Habitat Type	Herbivorous (# individuals)	Invertivorous (# individuals)	Piscivorous (# individuals)
LGR	27	164	0
HGR	0	1	0
CAS	0	3	0
SCP	20	103	23
BWP(B)	22	124	0
BWP(LG)	11	0	0
LSP(RW)	53	42	1
LSP(BR)	32	81	25
DPL	2	50	0
GLD	70	58	2
RUN	18	24	0
SRN	2	49	0
MCP	0	1	4
CCP	0	62	0
LSP(B)	4	36	0
POW	0	34	5
CRP	0	32	0
STP	32	56	0
BRS	22	14	0

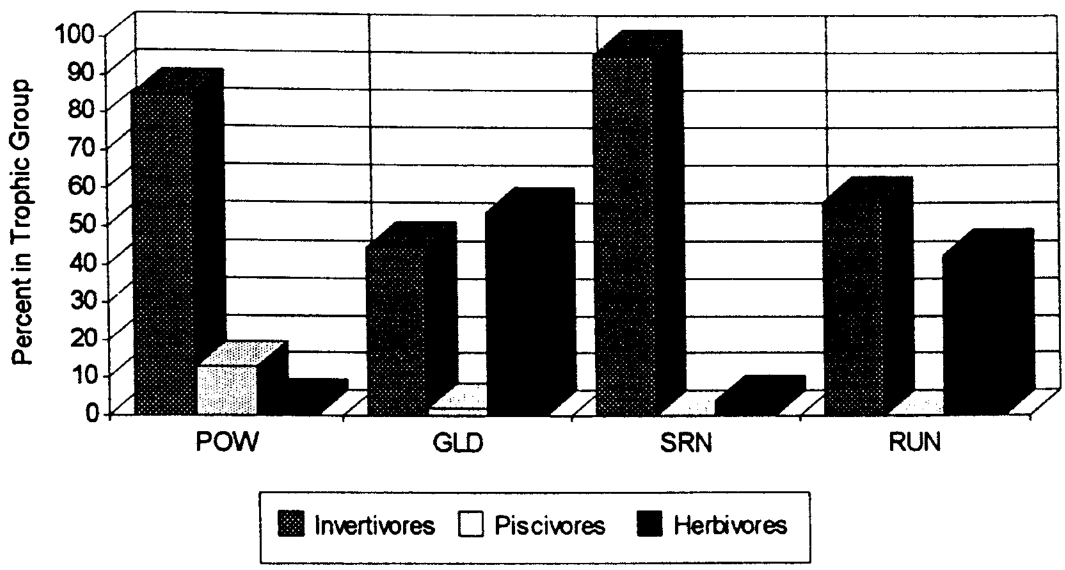

Figure 12. Trophic structure of fish in run habitat types, Beech Creek, summer, 1993.

Environmental tolerance. Within pools, 9% of the fish sampled were intolerant, 35% were intermediate tolerant, and 56% were tolerant (Figure 13). Within riffles, 14% of the fish sampled were intolerant, 78% were intermediate tolerant, and 8% were tolerant (Figure 14). Within runs, 20% of the fish sampled were intolerant, 56% were intermediate tolerant, and 24% were tolerant (Figure 15).

Among all habitat types, 46% of the intolerant fish were in pools, 21% were in riffles, and 33% were in runs. Among all habitat types, 46% of the intermediate tolerant fish were in pools, 30% were in riffles, and 24% were in runs. Among all habitat types, 84% of the tolerant fish were in pools, 4% were in riffles, and 12% were in runs (Table XLVIII). Table XLIX shows the number of individuals in each environmental tolerance group by habitat types.

TABLE XLVIII

STRUCTURE OF ENVIRONMENTAL TOLERANCE OF FISH AMONG POOLS, RIFFLES, AND RUNS

	Pools	Riffles	Runs
Intolerant (%)	46	21	33
Number of Intolerant	72	32	52
Intermediate(%)	46	30	24
Number of Intermediate	279	180	146
Tolerant(%)	84	4	12
Number of Tolerant	441	19	65

TABLE XLIX

ENVIRONMENTAL TOLERANCE STRUCTURE OF FISH IN BEECH CREEK BY HABITAT TYPES

Habitat Type	Intolerant (# individuals)	Intermediate (# individuals)	Tolerant (# individuals)
LGR	32	152	7
HGR	0	0	1
CAS	0	3	0
SCP	49	31	66
BWP(B)	0	51	95
BWP(LG)	0	11	0
LSP(RW)	0	81	14
LSP(BR)	23	47	96
DPL	0	0	0
GLD	37	89	4
RUN	0	22	20
SRN	4	28	19
MCP	0	0	5
CCP	0	3	59
LSP(B)	0	14	27
POW	11	7	22
CRP	0	0	32
STP	0	41	47
BRS	0	25	11

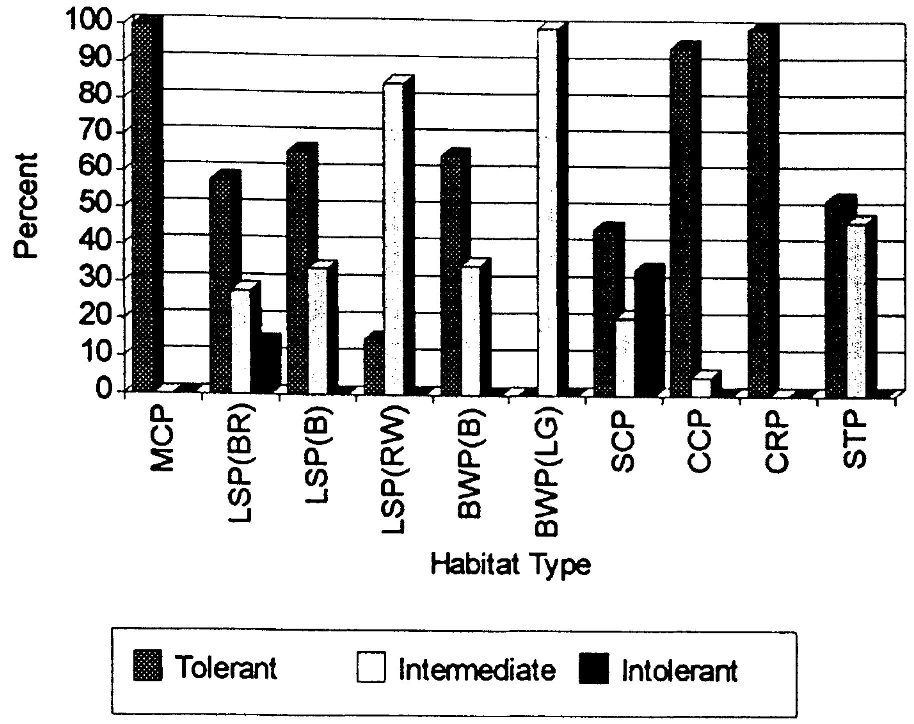

Figure 13. Environmental tolerance of fish in pools, Beech Creek, summer, 1993.

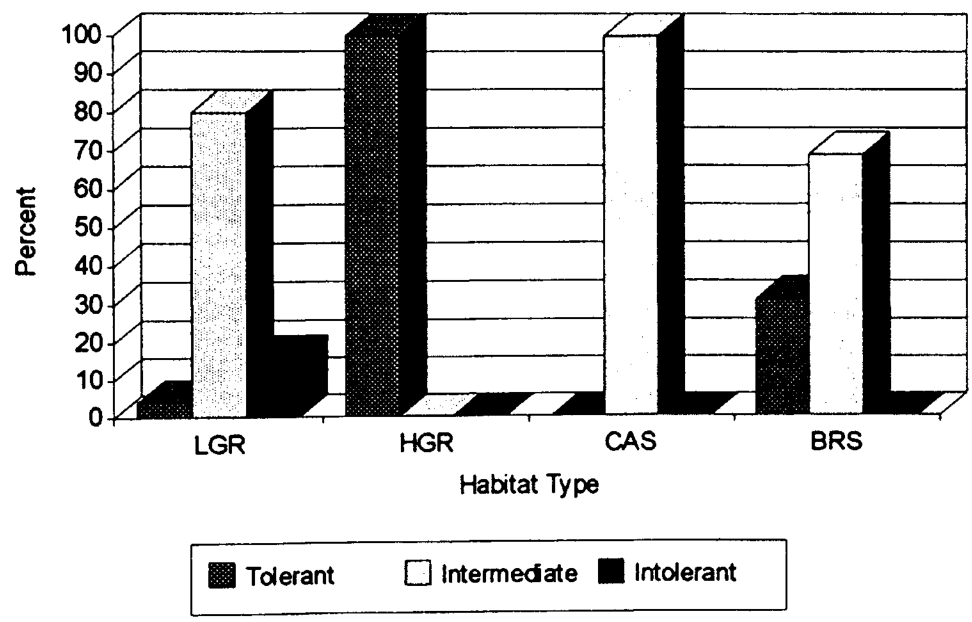

Figure 14. Environmental tolerance of fish in riffles, Beech Creek, summer, 1993.

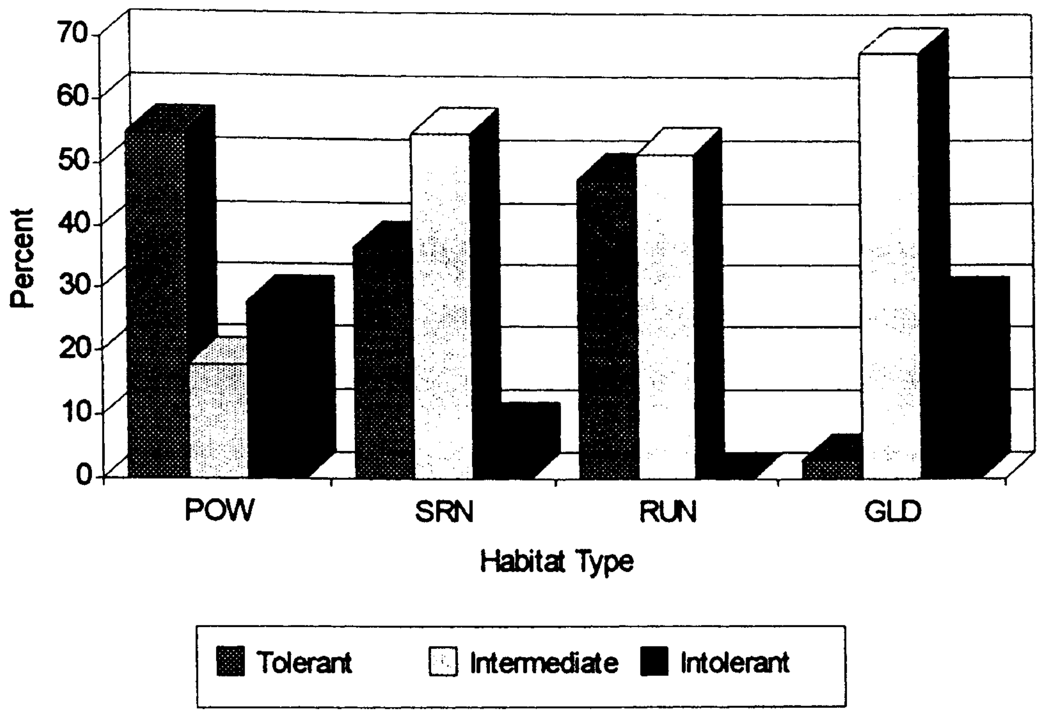

Figure 15. Environmental tolerance of fish in runs, Beech Creek, summer, 1993.

Aquatic Macroinvertebrates

Relative abundance. Table L shows relative abundance of aquatic macroinvertebrates in Beech Creek. Using the Kruskal-Wallis procedure, there were statistically significant difference in the mean relative abundance, as measured by number of individuals per area of aquatic macroinvertebrates, among pools, riffles, and runs. No statistically significant differences in the mean relative abundance, as measured by number of individuals per hour of kicking, was found among pools, riffles, and runs based on the Kruskal-Wallis procedure.

Tukey's test indicated no significant differences in the mean rank of relative abundance of aquatic macroinvertebrates among pools, riffles, and runs.

Species richness. Table LI shows the calculated species richness of macroinvertebrates in Beech Creek. No statistically significant differences in Menhinick's index of species richness (p-value = .4560) for aquatic macroinvertebrates among pools, riffles, and runs were indicated by the Kruskal-Wallis procedure.

No significant differences in Menhinick's index of species richness aquatic macroinvertebrates were found among pools, riffles, and runs based on Tukey's test.

Species diversity. Table LII shows the calculated Shannon species diversity of macroinvertebrate for pools, riffles, and runs. The ANOVA procedure indicated no statistically significant differences in species diversity (p-value = .1539) of macroinvertebrate families among pools, riffles, and runs.

Tukey's test indicated no significant differences in species diversity of aquatic macroinvertebrates among pools, riffles, and runs.

Trophic structure. Within pools, 69% of the macroinvertebrates were collectors, 11% were predators, 19% were scrapers, and 1% were shredders (Figure 16). Within riffles, 61% of the macroinvertebrates were collectors, 23% were predators, 13% were scrapers, and 3% were shredders (Figure 17). Within runs, 47% of the macroinvertebrates were collectors, 14% were predators, 35% were scrapers, and 4% were shredders (Figure 18).

Among pools, riffles and runs, 52% of the collectors occurred in pools, 36% occurred in riffles, and 12% occurred in runs. Among habitats, 32% of the predators occurred in pools, 54% occurred in riffles, and 14% occurred in runs. Among habitats, 46% of the scrapers occurred in pools, 25% occurred in riffles, and 29% occurred in runs. Finally, among pools, riffles and runs, 20% of the shredders occurred in pools, 57% occurred in riffles, and 23% occurred in runs (Table LIII). Table LIV shows the trophic structure, by habitat, of aquatic macroinvertebrates by habitat type.

TABLE L

RELATIVE ABUNDANCE OF AQUATIC MACROINVERTEBRATES AMONG POOL, RIFFLE, AND RUN HABITAT TYPES

	Relative Abundance (#/hour)	Relative Abundance (#/m^2)
Pools	1745.0	0.8
Range	300.0-7,750.0	0.0-13.9
Runs	1336.0	0.6
Range	150.0-2,260.0	0.1-2.0
Riffles	2842.0	4.6
Range	660.0-7,480.0	1.5-12.0
P-value	.4549	.0686
	ns	*

* statistically significant ($p < 0.05$)
ns not statistically significant

TABLE LI
SPECIES RICHNESS OF AQUATIC MACROINVERTEBRATES AMONG POOL, RIFFLE, AND RUN HABITAT TYPES

	Menhinick Index of Species Richness (R2)
Pools	0.8
Runs	1.2
Riffles	1.1

TABLE LII

SPECIES DIVERSITY OF AQUATIC MACROINVERTEBRATES AMONG POOLS, RIFFLES, AND RUNS

	Pools	Riffles	Runs
Shannon Diversity Index for Aquatic Macroinvertebrates	1.5	2.1	1.8

TABLE LIII

TROPHIC STRUCTURE OF AQUATIC MACROINVERTEBRATES AMONG POOLS, RIFFLES, AND RUNS

	Pools (%)	Riffles (%)	Runs (%)
Collectors	52	36	12
Number of Collectors	1446	1026	337
Predators	32	54	14
Number of Predators	221	383	102
Scrapers	46	25	29
Number of Scrapers	405	216	246
Shredders	20	572	23
Number of Shredders	22	62	25

TABLE LIV

TROPHIC STRUCTURE OF AQUATIC MACROINVERTEBRATES IN BEECH CREEK BY HABITAT TYPE

Habitat Type	**Scrapers (# individuals)**	**Collectors (# individuals)**	**Predators (# individuals)**	**Shredders (# individuals)**
LGR	56	307	97	25
HGR	133	103	152	0
CAS	19	35	7	5
SCP	10	32	7	1
BWP(B)	63	55	30	0
BWP(LG)	37	23	21	0
LSP(RW)	32	32	6	1
LSP(BR)	24	459	14	3
DPL	48	31	2	0
GLD	1	13	1	0
RUN	76	38	35	8
SRN	144	169	41	7
MCP	9	16	8	1
CCP	85	36	14	1
LSP(B)	37	39	13	0
POW	25	117	25	10
CRP	44	35	5	2
STP	16	645	101	13
BRS	8	581	127	32

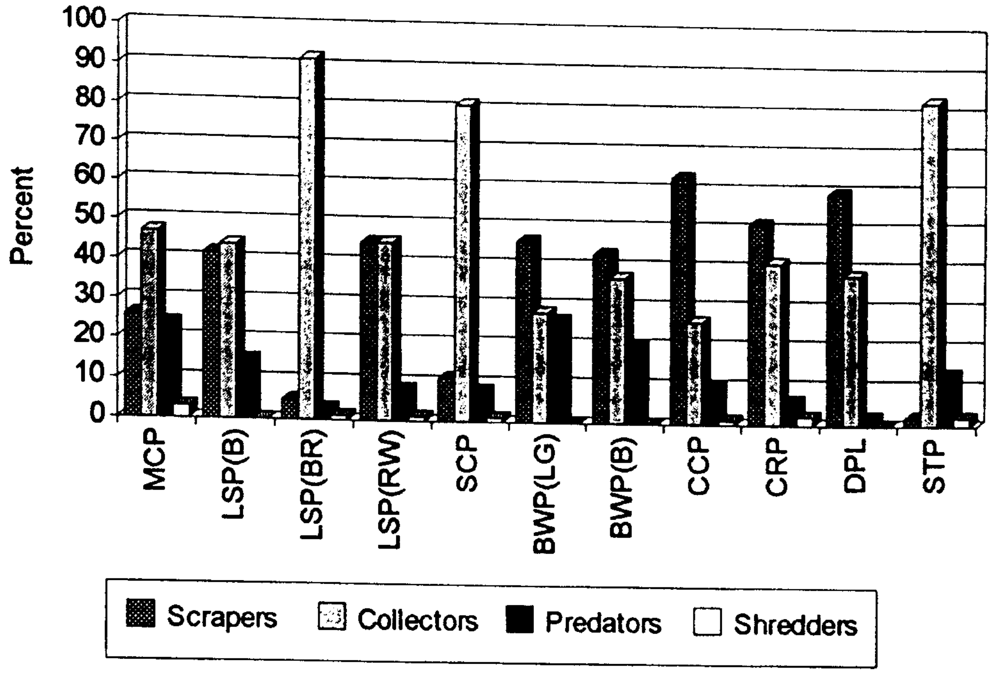

Figure 16. Trophic structure of aquatic macroinvertebrates in pool, Beech Creek, summer, 1993.

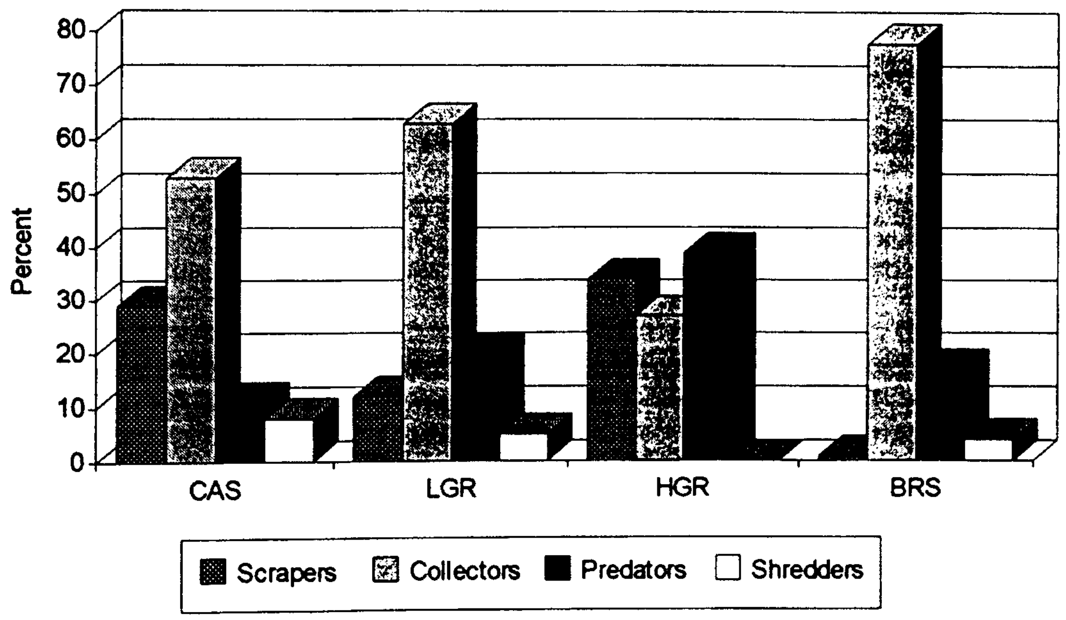

Figure 17. Trophic structure of aquatic macroinvertebrates in riffles, Beech Creek, summer, 1993.

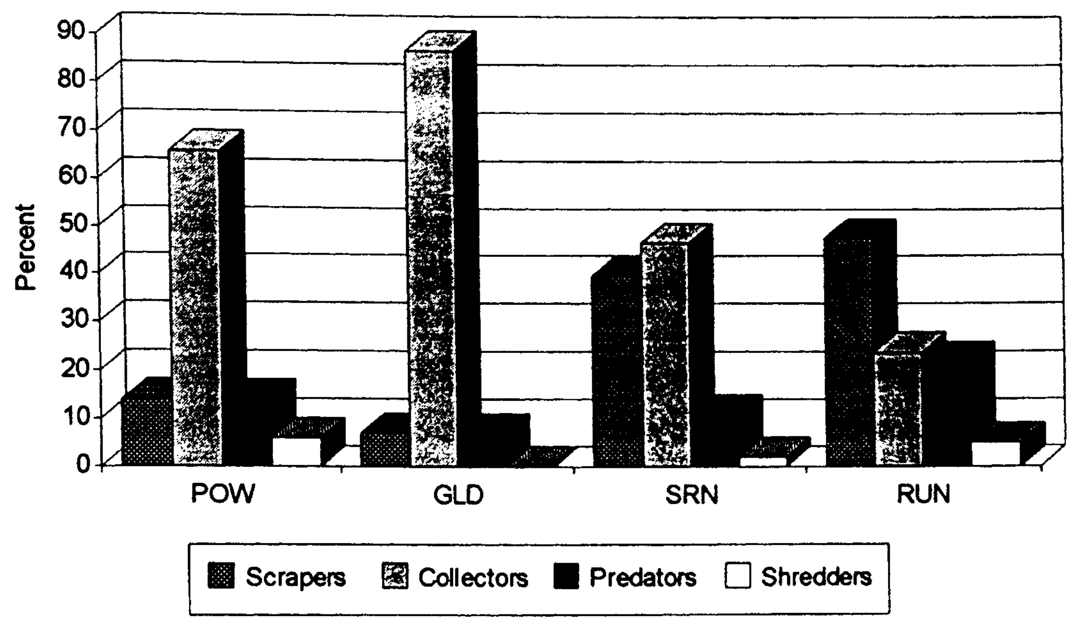

Figure 18. Trophic structure of aquatic macroinvertebrates in runs, Beech Creek, summer, 1993.

Environmental tolerance. Three indices of environmental tolerance (Hilsenhoff, 1977; Hilsenhoff and Bode, 1978; and Beck, 1954) were used in classifying our samples to group as many organisms as possible. Mean tolerance values can be calculated for the habitats sampled and general community characteristics can be described (Figure 19). The mean index values for all three measures of tolerance showed that in all habitats sampled the aquatic macroinvertebrate populations were intolerant or facultative, in general.

Within pool habitat types, 4% of the macroinvertebrates were intolerant, 50% were facultative, and 46% were tolerant (Figure 20). Within riffle habitat types, 26% of the macroinvertebrates were intolerant, 56% were facultative, and 18% were tolerant (Figure 21). Within run habitat types, 16% of the macroinvertebrates were intolerant, 66% were facultative, and 18% were tolerant (Figure 22).

Among pool, riffle, and run habitats, 13% of the intolerant species occurred in pools, 68% occurred in riffles, and 19% occurred in runs. Among habitat types, 41% of the facultative species occurred in pools, 39% occurred in riffles, and 20% occurred in runs. Among habitat types, 68% of the tolerant species occurred in pools, 22% occurred in riffles and 10% occurred in runs (Table LV). Table LVI shows the environmental tolerance structure of aquatic macroinvertebrates by habitat type.

TABLE LV

ENVIRONMENTAL TOLERANCE STRUCTURE OF AQUATIC MACROINVERTEBRATES AMONG POOLS, RIFFLES, AND RUNS

	Pools	Riffles	Runs
Intolerant (%)	13	68	19
Number of Intolerant	99	122	54
Facultative (%)	41	39	20
Number of Facultative	486	186	210
Tolerant (%)	68	22	10
Number of Tolerant	414	92	136

TABLE LVI

ENVIRONMENTAL TOLERANCE STRUCTURE OF AQUATIC MACROINVERTEBRATES IN BEECH CREEK BY HABITAT TYPE

Habitat Type	Intolerant (# individuals)	Facultative (# individuals)	Tolerant (# individuals)
LGR	44	42	13
HGR	40	50	10
CAS	23	32	45
SCP	4	18	77
BWP(B)	19	47	34
BWP(LG)	7	68	25
LSP(RW)	6	50	44
LSP(BR)	4	9	87
GLD	7	13	80
RUN	20	76	4
SRN	15	71	14
MCP	14	41	45
CCP	10	71	19
LSP(B)	14	58	28
POW	12	50	38
CRP	8	60	32
STP	13	64	23
BRS	15	62	24

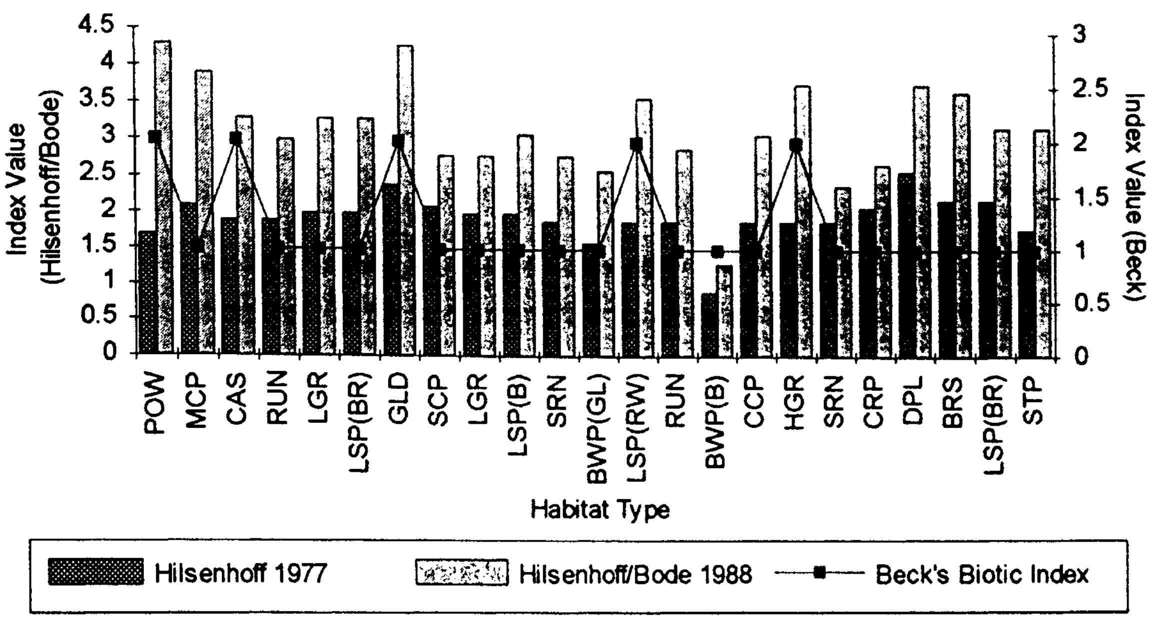

Figure 19. Mean index values for tolerance ratings of aquatic macroinvertebrates by habitat types.

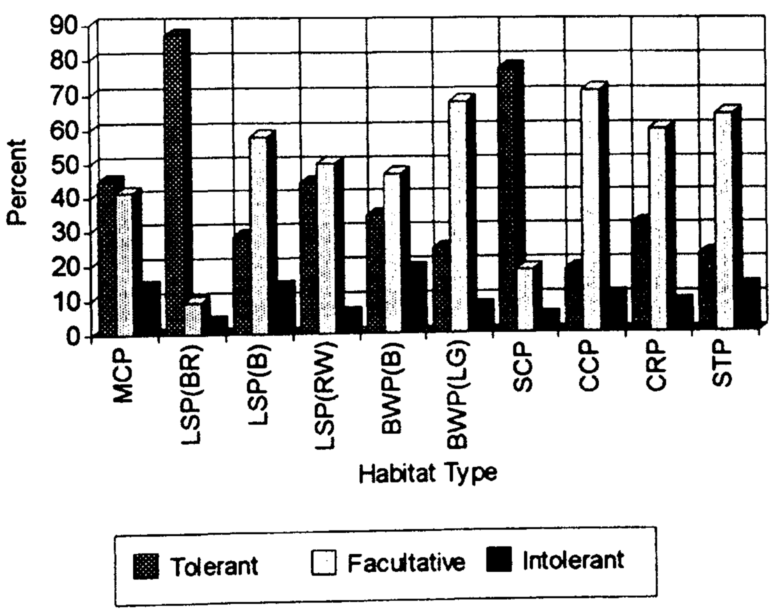

Figure 20. Environmental tolerance structure of aquatic macroinvertebrates in pool habitat types, Beech Creek, summer, 1993.

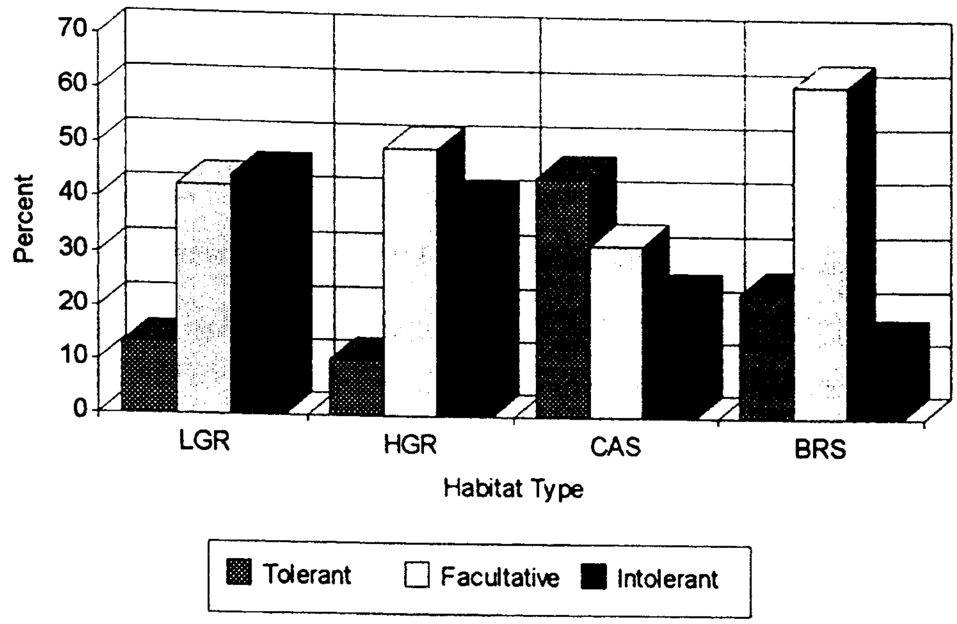

Figure 21. Environmental tolerance structure of aquatic macroinvertebrates in riffle habitat types, Beech Creek, summer, 1993.

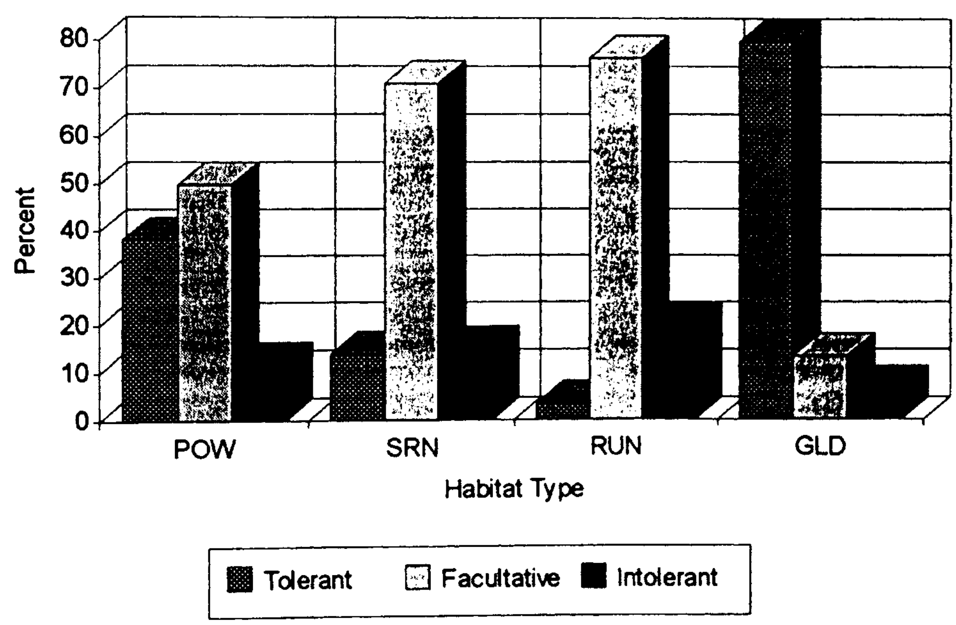

Figure 22. Environmental tolerance structure of aquatic macroinvertebrates in run habitat types, Beech Creek, summer, 1993.

Physical/Biological Relationships

Using regression analysis, no linear relationships were found between physical and biological variables. Table LVII shows the r-square values for all variables that were regressed.

TABLE LVII

REGRESSION ANALYSIS RESULTS OF PHYSICAL AND BIOLOGICAL CHARACTERISTICS OF BEECH CREEK, R^2 VALUES

	Fish Species Diversity	Fish Species Richness	Fish Relative Abundance (#/m^2)	Macroinvertebrate Species Diversity	Macroinvertebrate Species Richness	Macroinvertebrate Relative Abundance (#/m^2)
Bedrock Substrate	0.07	0.00	0.24	0.06	0.09	0.24
Boulder Substrate	0.01	0.01	0.09	0.12	0.01	0.12
Cobble Substrate	0.06	0.05	0.05	.029	0.22	0.05
Substrate Diversity	0.04	0.00	0.03	0.08	0.01	0.25
Water Volume of Habitat	0.07	0.10	0.15	0.00	0.31	0.12
Mean Water Depth of Habitat	0.02	0.05	0.05	0.03	0.19	0.11

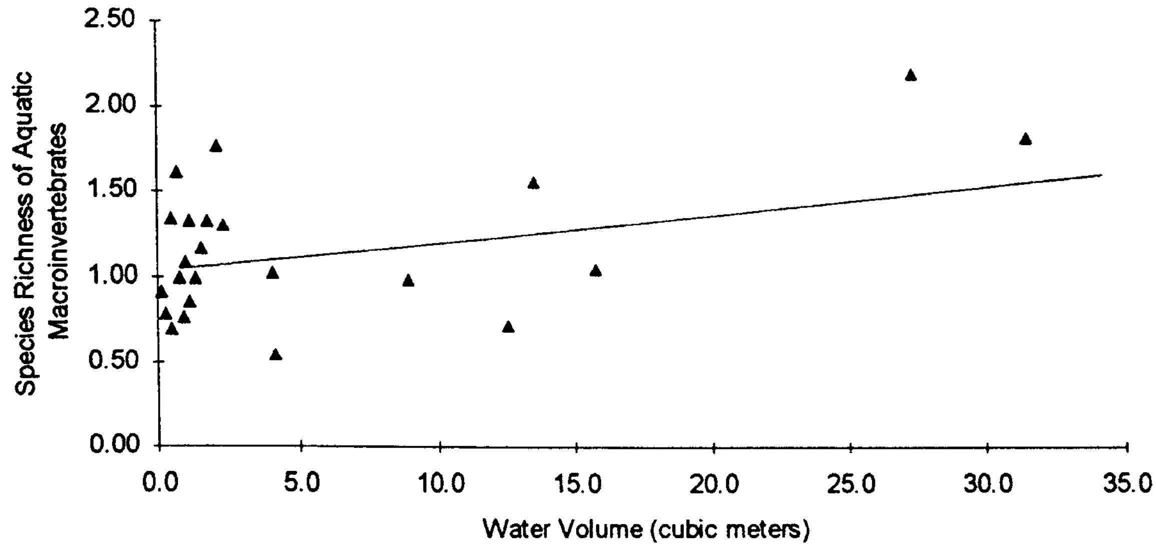

Figure 23. Regresssion line and scatter plot of aquatic macroinvertebrate species richness vs. water volume of habitat, (R^2 = .31).

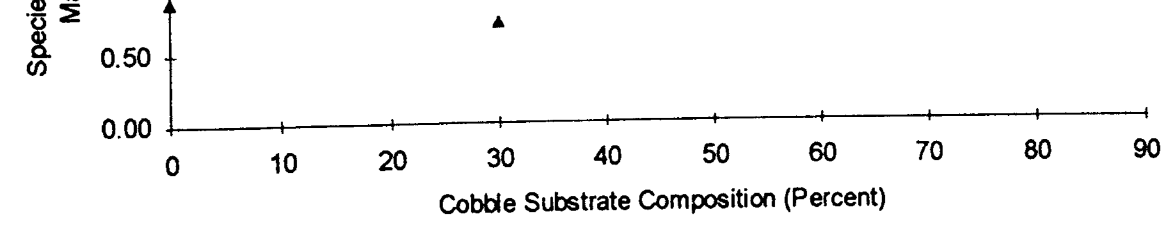

Figure 24. Regression line and scatter plot of aquatic macroinvertebrate species diversity vs. cobble substrate composition, (R^2 = .29).

CHAPTER VI

DISCUSSION

Physical

Habitat Units

Habitat frequency. Clingenpeel (1994) found significant associations ($p<0.01$) with habitat occurrences between years for streams inventoried in Arkansas of comparable size and drainage area to Beech Creek (Table LVIII). He attributed these associations to the flow regimes of the stream and variability in observer classification. In Caney Creek in 1990, he found a high to moderate occurrence of high gradient riffles, step-runs, mid-channel pools, low gradient riffles, bedrock formed lateral scour pools, glides, runs, and pocket water. In 1991, he found a high to moderate occurrence of low gradient riffles, step-runs, mid-channel pools, high gradient riffles, bedrock formed lateral scour pools, and runs. In 1992, he found a high to moderate occurrence of low gradient riffles, bedrock formed lateral scour pools, runs, step-runs, mid-channel pools, and glides. In Brushy Creek in 1990, he found a high to moderate occurrence of low gradient riffles, bedrock formed lateral scour pools, glides, runs, step-runs, mid-channel pools, and pocket water. In 1991, he found a high to moderate

TABLE LVIII

SURVEYED WATERSHED

Stream	Kilometers Inventoried	Drainage Area in Hectares	Ecoregion	Reference Managed
Beech Creek	8	2,850	Upper Ouachita Mountain	Reference
Brushy Creek	9	2,940	Lower Ouachita Mountain	Managed
Caney Creek	14	2,170	Lower Ouachita Mountain	Reference

occurrence of low and high gradient riffles, bedrock formed lateral scour pools, damned pools, step-runs, mid-channel pools, and step-pools. In 1992, he found a high to moderate occurrence of low gradient riffles, bedrock formed lateral scour pools, glides, runs, step-runs, mid-channel pools, and step-pools. In general, Beech Creek (1993) had a similar habitat occurrence pattern as Brushy (1992) and Caney (1992) Creek with a high to moderate occurrence of low gradient riffles, bedrock formed lateral scour pools, runs, step-runs, and mid-channel pools (Figure 25).

The precipitation pattern of Beech Creek from 1988 to June 1993 (Tables I and II) indicates that associations with habitat occurrences between years would be significant if habitat types are attributed to flow regime.

Physical

Pools. The pool habitat types of Beech Creek are moderately long with deep, slow moving stream flow, and wide channels. Bedrock, boulder and

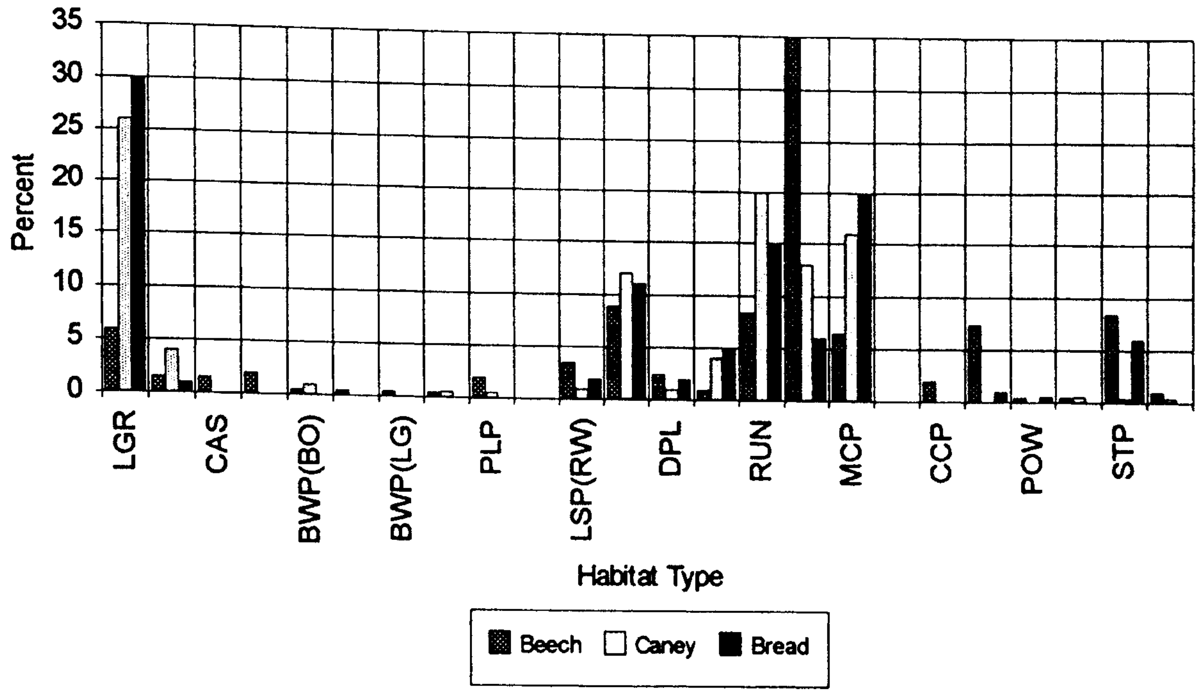

Figure 25. Comparison of habitat distribution between streams in the Ouachita National Forest. (Beech, 1993; Caney, 1992; Brushy, 1992)

cobble substrates comprise the streambed material and boulders and bedrock ledges provide the majority of instream cover. Pool habitat types are very shaded with stable, gently sloping stream banks.

Riffles. The riffle habitat types of Beech Creek are short with shallow, fast moving stream flow, and moderately narrow channels. Cobble substrate dominates the streambed material and boulders and white water provide the majority of instream cover. Riffle habitat types are very shaded with stable, nearly horizontal stream banks.

Runs. The run habitat types of Beech Creek are long with moderately shallow and fast moving stream flow, and narrow channels. Cobble and boulder substrates comprise the streambed material and boulders provide the majority of instream cover. Run habitat types are very shaded with stable, sloping stream banks.

Habitat types of Beech Creek. The habitat types of Beech Creek, in general, are long, with moderately deep stream flow, and wide channels. Boulder and cobble substrates comprise the streambed material, and boulder provide the majority of instream cover. Habitat types are very shaded with stable sloping banks and forest type riparian vegetation. Matthews et al. (1988) reported that upstream locations of the Kiamichi River were high-gradient, and with bedrock or boulder-cobble-gravel bottoms. Platts (1979) reported that 3rd order streams in Idaho were high-gradient, with boulder-rubble bottoms, and are comprised of about half riffles and half pools.

Chemical

Although we did not statistically analyze chemical data, it is an important aspect of the stream ecosystem to consider. The chemical "snapshot" of Beech Creek during the summer of 1993 indicates that the water quality is adequate for biological life (Figures 7, 8, and 9). Beech Creek had neutral pH, high dissolved oxygen concentrations, moderate temperatures, low nutrient concentrations, and low buffering capacity, typical of headwater mountain streams in Southeastern Oklahoma (Matthew et al., 1988). Matthews et al. reported that water quality, at the extreme headwater stations of the Kiamichi River, was well within limits of tolerance for sensitive native fish, with no flow only 32 day per year, dissolved oxygen never below 6.4 mg/l and temperature never above 28.5 C. Harrel and Dorris (1968) reported that physio-chemical conditions of Otter Creek in north-central Oklahoma was highly variable. For 3rd order streams the discharge ranged from 0-.006 m3/sec, dissolved oxygen concentration ranged from 0.6-17.5 mg/l, and the temperature ranged from 2 -39^{o} C.

Biological

Fish

In general, there was no significant differences in relative abundance, species richness, or species diversity in fish among pool, run, and riffle habitat types.

Relative Abundance. Pool habitat types showed the highest relative abundance as measured by number of individuals per hour, biomass of fish per hour, and biomass of fish per square meter of habitat (Table XLIII). Riffle habitat types showed the highest relative abundance as measured by number of individuals per square meter of fish. Pools are areas of refuge for many fish species in headwater streams during low or no flow in dry summer months (Schlosser, 1990). Ouachita Mountain headwater streams typically dry during the summer, leaving only isolated pool habitats for fish and macroinvertebrates.

Species diversity. The value of the Shannon diversity index usually averages between 1.5 and 3.5 (Magurran, 1988). For all habitat types sampled, the species diversity fell well below the average (Table XLV) . Although the Fishes of Oklahoma (Miller, 1973) illustrates about 55 species occurring in the vicinity of Beech Creek drainage, we only collected 11 species in the headwaters. The low species diversity of fish may be a characteristic of Beech Creek though low water conductivity, position in watershed (headwaters, 3rd order), and electroshocking sampling bias may also contribute to the low species diversity. Harrel and Dorris (1968) reported collecting 7 fish species in a 3rd order stream in Oklahoma. Platts (1979) reported collecting only 6 fish species in a 3rd order stream in Idaho. As stream order increased (4th and 5th order) the number of fish species increased to 8 and 6, respectively.

Trophic structure of fish. Within pool, riffle, and run habitat types the majority of fish were invertivorous. This is due to the availability of insect food sources or a deficiency of other food sources in the Beech Creek watershed. The lower occurrence of herbivorous and piscivorous fish support this idea. Herbivorous fish, though lower in occurrence than invertivorous fish, made up approximately a third of the trophic structure. The presence of algae in the stream, confirmed by personal observation, provides an available food source for herbivorous fish. The low occurrence of piscivorous fish would be expected because piscivorous fish are at the top of the trophic pyramid (secondary consumers) and in headwater streams their food source is limited (Wootton, 1992).

The river continuum concept (RCC) proposes that there are definite trophic relationships among fish populations as stream order increases (Vannote et al., 1980). Beech Creek (3rd order stream) falls into the headwaters category from the RCC. In headwater streams (1st to 3rd order), the fish are cool water species, and the majority are invertivores. In medium streams (4th to 6th order), the fish are warm water species, and comprised of invertivores and piscivores. In large streams to rivers (7th order and greater) the fish are warm water species and comprised of invertivores, piscivores, and planktivores.

Beech Creek conforms to the RCC in fish population structure. Piscivores were low in abundance, invertivores were high in abundance, and most species were cool-water species.

Environmental tolerance. Within pools the majority of the fish were tolerant, about a third were intermediate tolerant, and about a tenth were intolerant. Within riffles the majority of the fish were intermediate tolerant, and about a third were either tolerant or intolerant. Within runs about half of the fish were intermediate, a quarter tolerant, and a quarter intolerant. The characteristics of Beech Creek's flow regime cause high variability in physical and chemical conditions especially flow, temperature, and dissolved oxygen. The high occurrence of tolerant and intermediate tolerant fish reflects the variability of conditions. The occurrence of intolerant fish suggests that they have adapted strategies for survival, through microhabitat refuge, migration, or other survival behavior.

Aquatic Macroinvertebrates

Relative abundance. Riffle habitat types showed twice the amount of individuals than in pool or run habitat types (Table L). Riffle habitat types had the highest relative abundance of aquatic macroinvertebrates as measured by number of individuals per hour and number of individuals per square meter. Diverse habitat structure, food transport, i.e. the food comes to them instead of they going to the food, and high dissolved oxygen make riffle habitat types productive for aquatic macroinvertebrates (Ward, 1992).

Species richness. In general, species richness for aquatic macroinvertebrates was higher in riffle habitats than in pool or run habitats (Table LI). Riffle habitat types are diverse with many micro-habitats, therefore more species can exist together (Ward, 1992).

Species diversity. Species diversity for aquatic macroinvertebrates was high in all habitat types (Table LII). Riffle habitats had a higher species diversity than pool and run habitats but they were not significantly different.

Trophic structure. Within pool, run and riffle habitat types the majority of organisms were collectors. Within all habitats a small percentage were shredders and roughly a third were predators or scrapers. Among pool, riffle and run habitat types, riffles had a higher percentage of predators and shredders, and pools had a higher percentage of collectors and scrapers. The other trophic categories among habitat types were fairly evenly distributed. Collectors were, generally, a large part of the macroinvertebrate population.

The (RCC) proposes that there are definite trophic relationships in aquatic macroinvertebrate populations as stream order increases (Vannote et al., 1980). In first , second, and third (headwaters) order streams shredders and collectors are the most abundant trophic groups, predators are fairly abundant, and some scrapers are found. In fourth, fifth, and sixth (medium) order streams, collectors and scrapers are the most abundant, predators are fairly abundant, and some shredders are found. Finally, in seventh (large streams to rivers) order streams and greater collectors are the most abundant, predators are fairly abundant, and few if any shredders or scrapers are found.

Beech Creek does not conform to the RCC in macroinvertebrate composition. The Beech Creek data (Figure 26) shows that collectors were far more abundant than shredders, where according to RCC they should be about equal. Predators and scrapers seemed to conform somewhat to the RCC.

Environmental tolerance. Several indices of environmental tolerance were used for the tolerance structure of the aquatic macroinvertebrate population in Beech Creek. These populations are dynamic and may change weekly, monthly, and definitely seasonally. Within all three habitat types facultative organisms were the highest in abundance. The high occurrence of facultative organisms, and the moderate occurrence of intolerant and tolerant organisms indicates that there is some environmental variability in Beech Creek. The biggest environmental factor is probably flow. During the rainy season there can be large fluctuations in stream flow. Bankful width observations showed that the stream can rise several meters during a storm event. In the summer, especially dry summers, the flow can become very low, and water can be limited to isolated pools. Therefore, majority of organisms must be able to tolerate some environmental variability (Ward, 1992).

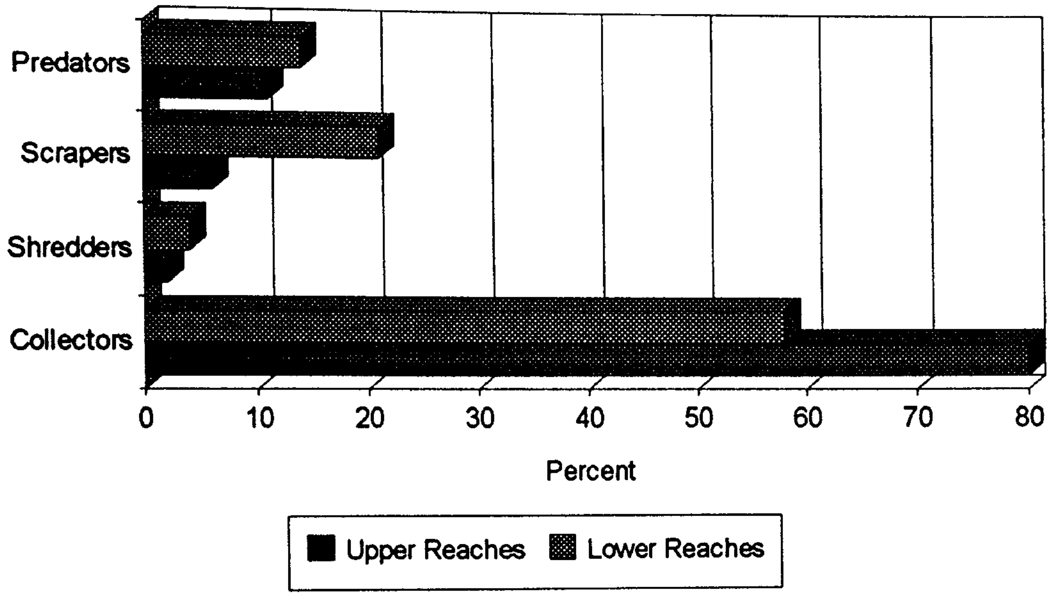

Figure 26. Upper Vs. Lower Reaches, Trophic Structure of Beech Creek, Summer, 1993.

Physical/Biotic Interactions

Gorman and Karr (1978) used regression analysis to predict relationships between habitat structure and fish community structure in small streams. They found that fish species diversity regressed against aspects of habitat structure diversity produced some significant relationships. Current, depth, and combinations of current depth and bottom substrate produced significant regressions ($r = 0.64$ to 0.81). The regression analysis of habitat structure and biotic community structure of Beech Creek did not produce any significant relationships. Correlations of habitat structure with community structure were poor, the r-squares for all variables regressed were below 0.40 (Neter et al., 1989).

CHAPTER VII

SUMMARY AND CONCLUSION

Summary

Beech Creek was inventoried during the summer of 1993, between June and July using B.A.S.S. (Basin Area Stream Survey). Beech Creek watershed is located in a National Scenic Area and a National Botanical Area and may serve as a reference stream in future studies. The inventory included physical, chemical, and biological characteristics.

The objectives of the study were to characterize variation in physical habitat structure within pool, riffle, and run habitat types; to characterize variation in community structure in fish and aquatic macroinvertebrate populations among pool, riffle, and run habitats; and to characterize the trophic composition of fish and aquatic macroinvertebrate populations among and within pool, run, and riffle habitats.

By establishing reference streams in "natural" and "undisturbed" watersheds we can compare unmanaged areas to managed areas to discern if there are beneficial or detrimental effects of land use practices on stream ecosystems and establish more ecologically sound management practices and more inclusive water quality standards for all beneficial uses.

Conclusions and Recommendations

Basin area stream survey (B.A.S.S.) is an efficient method of stream sampling and allows useful data to be collected quickly. A few refinements of this inventory system may improve survey techniques and allow more streams to be inventoried.

Sampling Design

Streams are dynamic ecosystems. Sampling a stream during one season of a single year is merely a "snapshot" in time of possible stream conditions. Stream sampling should be done in several seasons over several years. By sampling in at least two seasons, during high (spring) and low (autumn) flows, and over several years, natural variability can be analyzed and characterized.

Habitat Units

B. A. S. S. contains twenty four habitat designations, 14 pool habitats, 5 riffle habitats, and 5 run habitats. On Beech Creek, twenty one of those were used. An intensive study of the differences in pool, riffle and runs habitat types may lead to a modification in designations without a compromise in the integrity of the inventory system.

Physical Measurements

The physical variables that are measured at each reach are important. Bankful width is an ocular estimate and was not significantly different among pool, riffle and run habitat types in this study. Further studies may suggest that bankful width be modified, measured with a metric tape instead of estimation.

Other physical variable that could be improved on are the instream cover parameters and riparian vegetation parameters. The value depended heavily on the person estimating these parameters. Since instream cover and riparian vegetation are estimated as a percent of the habitat area, a standardized procedure for estimation could be developed to minimize subjectivity.

Chemical

The chemical sampling usually associated with B.A.S.S. is more intensive than this study allowed. A more rigorous sampling of chemical conditions would reveal a clearer picture of diurnal and seasonal changes in stream water chemistry. Since this is the environment in which fish and aquatic macroinvertebrates must adapt to, a clearer understanding of stream chemistry would be beneficial in understanding biotic communities in streams and the dynamics of those communities. Typically, a chemical sample is taken at each habitat that is sampled for fish and aquatic macroinvertebrates and analyzed for more chemical properties than my analysis covered. B.A.S.S. has an appropriate chemical component and should be followed if time and funds allow.

Biological Measurements

The biological measurements of B.A.S.S. are extremely important. The community characteristics of managed and unmanaged streams indicate the impact that land management practices have on stream ecosystems.

Fish sampling. My strongest recommendation for this inventory system is using more than one sampling method for fish collection. Mountain streams characteristically have low specific conductivity which strongly effects electroshocking effort. A combination of electroshocking and seining, or other method, will provide better results and a representative sample of the fish population.

Population characteristics of fish and macroinvertebrates. The use of relative abundance, species richness, species diversity, and trophic structure of fish and macroinvertebrates populations to characterize the community structure of streams is appropriate and useful. In future studies, a more intensive analysis of the correlation of biological organisms with habitat parameters and the interactions of fish and macroinvertebrate populations could characterize community function as well as structure.

Stream ecosystems consist of dynamic and complicated interactions between physical, chemical and biological factors. It is difficult to quantify these interactions and derive some predictive variables to help us understand the structure and function of lotic systems. Further research is needed particularly in the area of biotic interactions. Ideally, data collected from several streams over many years and in different seasons may lend greater insight to the interactions of stream ecosystems.

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APPENDICES

APPENDIX A

HABITAT TYPE DESIGNATIONS

Appendix A. Habitat Type Designations

0	DRY	Dry Channel
1	LGR	Low-gradient Riffle
2	HGR	High-gradient Riffle
3	CAS	Cascade
4	SCP	Secondary Channel Pool
5	BWP(BO)	Backwater Pool (Boulder Formed)
6	BWP(RW)	Backwater Pool (Rootwad Formed)
7	BWP(LG)	Backwater Pool (Log Formed)
8	TRC	Trench/Chute
9	PLP	Plunge Pool
10	LSP(LG)	Lateral Scour Pool (Log Formed)
11	LSP(RW)	Lateral Scour Pool (Rootwad Formed)
12	LSP(B)	Lateral Scour Pool (Bedrock Formed)
13	DPL	Dammed Pool
14	GLD	Glide
15	RUN	Run
16	SRN	Step Run
17	MCP	Mid-Channel Pool
18	EGW	Edgewater
19	CCP	Channel Confuence Pool
20	LSP(BO)	Lateral Scour Pool (Boulder Formed)
21	POW	Pocket Water
22	CRP	Corner Pool
23	STP	Step Pool
24	BRS	Bedrock Sheet

APPENDIX B

FISH AND AQUATIC MACROINVERTEBRATE

SPECIES LIST

Appendix B. Fish and Aquatic Macroinvertebrate Species List

Fish Collected

Common Name	Scientific Name
Black bass	*Micropterus spp.*
Bigeye shiner	*Notropis boops*
Central stoneroller	*Campostoma anomalum*
Creek chub	*Semotilus atromaculatus*
Creek chubsucker	*Erimyzom oblongus*
Green sunfish	*Lepomis cyanellus*
Longear sunfish	*Lepomis megalotis*
Orangebelly darter	*Etheostoma radiosum*
Redfin darter	*Etheostoma whipplei*
Redfin shiner	*Lythrurus umbratilis*
Sunfish hybrid	*Lepomis megalotis x cyanellos*
Yellow bullhead catfish	*Ameiurus natalis*

Aquatic Macroinvertebrates Collected

Scientific Name	Common Name
Arachnida	eight-legged arthropods
Aranea	spiders
Crustacea	
Amphipoda	fresh-water scuds
Gammaridae	shrimp-scuds
Decapoda	crayfish
Cambaridae	
Gastropoda	snails and single shell mollusks
Lancidae	limpets
Hirdinea	leeches
Insecta	insects
Coleoptera	beetles
Elmidae	riffle beetles
Dystacidae	predaceous diving beetles
Carabidae	predaceous ground beetles
Hydrophilidae	water scavenger beetles
Psephenidae	water pennies
Diptera	true flies
Chironomidae	midges
Empididae	dance flies
Simulidae	black flies
Tabanidae	horse or deer flies
Tanyderidae	primitive crane flies
Tipulidae	crane flies
Ephemeroptera	mayflies
Baetidae	
Heptageniidae	
Neoephemeridae	
Oligoneuridae	
Hemiptera	true bugs
Gerridae	waterstriders
Veliidae	broad shouldered water striders
Hymenoptera	wasps
Formicidae	ants
Lepidoptera	moths
Pyralidae	

Scientific Name	Common Name
Insecta	
Megaloptera	alderflies and dobsonflies
Corydalidae	dobsonflies (hellgrammite)
Sialidae	alderflies
Neuroptera	spongillaflies
Sisyridae	
Odonata	dragonflies and damselflies
Anisoptera	dragonflies
Aeshnidae	
Gomphidae	
Zygoptera	damselflies
Coenagrionidae	
Plecoptera	stoneflies
Chloroperlidae	
Perlidae	
Perlodidae	
Tricoptera	caddisflies
Bracycentridae	tube-case makers
Glossosomatidae	saddle-case makers
Helicopsychidae	tube-case makers
Hydropsychidae	net spinner or retreat makers
Hydroptilidae	purse-case makers
Odontoceridae	tube-case makers
Philopostamidae	net spinner or retreat makers
Polycentropodidae	net spinner or retreat makers
Psychomyiidae	net spinner or retreat makers
Oligocheta	aquatic worms
Pelecypoda	clams and mussels
Bivalvia	

APPENDIX C

STATISTICAL OUTPUT FROM SAS PROCEDURES

Tukey's Studentized Range (HSD) Test

Alpha= 0.05 Confidence= 0.95 df= 182 MSE= 2611.794
Critical Value of Studentized Range= 5.048
Comparisons significant at the 0.05 level are indicated by '***'.

Tukey's Studentized Range (HSD) Test for variable: **LENGTH**

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
SRN - RUN	8.922	59.400	109.879	***
SRN - LGR	34.541	91.473	148.405	***
SRN - PLP	13.070	106.806	200.543	***
LSPBR - LGR	9.614	78.387	147.161	***

Tukey's Studentized Range (HSD) Test for variable: **MEAN DEPTH**

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
LSPBR - STP	45.825	90.260	134.694	***
LSPBR - RUN	46.913	92.676	138.440	***
LSPBR - SRN	79.158	114.634	150.110	***
LSPBR - LGR	66.806	116.343	165.880	***
LSPBR - HGR	56.233	138.510	220.787	***
LSPBR - BRS	68.710	166.926	265.143	***
PLP - STP	16.332	88.958	161.584	***
PLP - RUN	17.928	91.375	164.822	***
PLP - SRN	45.815	113.333	180.851	***
PLP - LGR	39.186	115.042	190.897	***
PLP - HGR	36.861	137.208	237.556	***
PLP - BRS	51.842	165.625	279.408	***
LSPRW - STP	18.988	77.512	136.036	***
LSPRW - RUN	20.389	79.929	139.468	***
LSPRW - SRN	49.837	101.886	153.936	***

Tukey's Studentized Range (HSD) Test for variable: **MEAN DEPTH**, cont.

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
LSPRW - LGR	41.109	103.595	166.081	***
LSPRW - HGR	35.097	125.762	216.426	***
LSPRW - BRS	48.836	154.179	259.521	***
SCP - STP	0.957	73.583	146.209	***
SCP - RUN	2.553	76.000	149.447	***
SCP - SRN	30.440	97.958	165.476	***
SCP - LGR	23.811	99.667	175.522	***
SCP - HGR	21.486	121.833	222.181	***
SCP - BRS	36.467	150.250	264.033	***
MCP - STP	25.531	73.353	121.174	***
MCP - RUN	26.711	75.769	124.828	***
MCP - SRN	58.091	97.727	137.363	***
MCP - LGR	46.840	99.436	152.032	***
MCP - HGR	37.449	121.603	205.757	***
MCP - BRS	50.225	150.019	249.814	***
LSPB - STP	17.617	63.550	109.483	***
LSPB - RUN	18.747	65.967	113.186	***
LSPB - SRN	50.589	87.924	125.260	***
LSPB - LGR	38.748	89.633	140.519	***
LSPB - HGR	28.705	111.800	194.895	***
LSPB - BRS	41.313	140.217	239.120	***
CCP - SRN	9.440	76.958	144.476	***
CCP - LGR	2.811	78.667	154.522	***
CCP - HGR	0.486	100.833	201.181	***
CCP - BRS	15.467	129.250	243.033	***
DPL - SRN	13.867	74.658	135.449	***
DPL - LGR	6.431	76.367	146.302	***
DPL - HGR	2.583	98.533	194.484	***
DPL - BRS	17.025	126.950	236.875	***
BWP - BRS	3.979	123.917	243.855	***

Tukey's Studentized Range (HSD) Test for variable: **WATER WIDTH**

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
LSPBR - SRN	9.385	62.147	114.908	***
MCP - SRN	0.536	59.484	118.432	***

Tukey's Studentized Range (HSD) Test for variable: **WIDTH TO DEPTH RATIO**

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
BRS - LSPB	2.428	125.267	248.105	***
BRS - MCP	13.516	137.462	261.407	***
BRS - LSPBR	29.485	151.471	273.456	***
BRS - LSPRW	21.878	152.714	283.551	***
BRS - SCP	14.305	155.625	296.945	***
BRS - PLP	14.930	156.250	297.570	***
CAS - LSPBR	3.782	105.971	208.159	***
LGR - LSPB	13.775	76.975	140.175	***
LGR - MCP	23.845	89.170	154.495	***
LGR - LSPBR	41.653	103.179	164.704	***
LGR - LSPRW	26.814	104.423	182.031	***
LGR - SCP	13.120	107.333	201.546	***
LGR - PLP	13.745	107.958	202.171	***
STP - LSPB	3.301	60.350	117.399	***
STP - MCP	13.151	72.545	131.939	***
STP - LSPBR	31.366	86.554	141.742	***
STP - LSPRW	15.111	87.798	160.485	***
STP - SCP	0.506	90.708	180.910	***
STP - PLP	1.131	91.333	181.535	***
SRN - LSPB	12.206	58.577	104.947	***
SRN - MCP	21.544	70.771	119.999	***
SRN - LSPBR	40.719	84.780	128.842	***
SRN - LSPRW	21.378	86.024	150.670	***
SRN - SCP	5.077	88.935	172.793	***
SRN - PLP	5.702	89.560	173.418	***
RUN - LSPBR	9.007	65.846	122.684	***

Tukey's Studentized Range (HSD) Test for variable: **RIGHT BANK ANGLE**

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
HGR - MCP	0.640	121.718	242.795	***
HGR - LSPBR	19.133	137.510	255.886	***
LGR - LSPBR	11.946	83.218	154.490	***
RUN - LSPBR	4.427	70.270	136.113	***
SRN - LSPBR	14.290	65.331	116.373	***

Tukey's Studentized Range (HSD) Test for variable: **BOTTOM BEDROCK**

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
BRS - RUN	4.189	105.688	207.186	***
BRS - MCP	7.401	110.192	212.984	***
BRS - SRN	16.348	113.380	210.412	***
BRS - LGR	14.347	117.708	221.069	***
BRS - LSPB	21.193	123.067	224.940	***
BRS - LSPRW	21.494	130.000	238.506	***
BRS - HGR	6.460	130.000	253.540	***
BRS - SCP	12.800	130.000	247.200	***
GLD - LSPB	1.193	103.067	204.940	***
GLD - LSPRW	1.494	110.000	218.506	***
LSPBR - RUN	27.285	74.423	121.561	***
LSPBR - PLP	0.279	75.485	150.691	***
LSPBR - DPL	9.086	77.935	146.785	***
LSPBR - MCP	29.066	78.928	128.789	***
LSPBR - SRN	45.574	82.116	118.657	***
LSPBR - LGR	35.419	86.444	137.468	***
LSPBR - LSPB	43.861	91.802	139.742	***
LSPBR - LSPRW	37.960	98.735	159.511	***
LSPBR - HGR	13.988	98.735	183.483	***
LSPBR - SCP	23.529	98.735	173.941	***
STP - RUN	3.133	49.632	96.131	***
STP - MCP	4.879	54.137	103.394	***
STP - SRN	21.612	57.325	93.038	***
STP - LGR	11.218	61.653	112.088	***
STP - LSPB	19.699	67.011	114.323	***
STP - LSPRW	13.663	73.944	134.226	***

Tukey's Studentized Range (HSD) Test for variable: **BOTTOM COBBLE**

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
HGR - STP	8.190	120.972	233.754	***
HGR - LSPBR	15.098	128.353	241.608	***
HGR - BRS	5.404	170.500	335.596	***
LGR - STP	24.030	91.431	158.831	***
LGR - LSPBR	30.623	98.811	167.000	***
LGR - BRS	2.829	140.958	279.088	***
LSPRW - LSPBR	4.919	86.139	167.358	***
RUN - STP	11.114	73.253	135.393	***
RUN - LSPBR	17.640	80.634	143.628	***
SRN - STP	9.049	56.775	104.501	***
SRN - LSPBR	15.323	64.156	112.989	***

Tukey's Studentized Range (HSD) Test for variable: **UNDERCUT BANKS**

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
LSPBR - SRN	2.839	47.926	93.013	***

Tukey's Studentized Range (HSD) Test for variable: **WHITE WATER**

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
HGR - STP	4.299	92.111	179.923	***
HGR - RUN	5.136	93.729	182.322	***
HGR - LSPB	46.376	135.433	224.491	***
HGR - LSPBR	48.633	136.814	224.994	***
HGR - CCP	32.619	140.167	247.714	***
HGR - LSPRW	42.997	140.167	237.337	***
HGR - MCP	49.974	140.167	230.359	***
HGR - DPL	37.332	140.167	243.002	***
HGR - SCP	32.619	140.167	247.714	***

Tukey's Studentized Range (HSD) Test for variable: **WHITE WATER** cont.

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
CAS - STP	0.132	87.944	175.757	***
CAS - RUN	0.970	89.563	178.155	***
CAS - LSPB	42.209	131.267	220.324	***
CAS - LSPBR	44.467	132.647	220.827	***
CAS - CCP	28.453	136.000	243.547	***
CAS - LSPRW	38.830	136.000	233.170	***
CAS - MCP	45.808	136.000	226.192	***
CAS - DPL	33.165	136.000	238.835	***
CAS - SCP	28.453	136.000	243.547	***
LGR - LSPB	37.188	91.725	146.262	***
LGR - LSPBR	40.014	93.105	146.197	***
LGR - CCP	15.160	96.458	177.757	***
LGR - LSPRW	29.489	96.458	163.428	***
LGR - MCP	40.088	96.458	152.829	***
LGR - DPL	21.505	96.458	171.412	***
LGR - SCP	15.160	96.458	177.757	***
SRN - LSPB	39.548	79.562	119.577	***
SRN - LSPBR	42.921	80.943	118.964	***
SRN - CCP	11.933	84.296	156.658	***
SRN - LSPRW	28.512	84.296	140.080	***
SRN - MCP	41.816	84.296	126.775	***
SRN - DPL	19.143	84.296	149.449	***
SRN - SCP	11.933	84.296	156.658	***

Tukey's Studentized Range (HSD) Test for variable: **BOULDERS**

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
LSPB - LGR	2.488	74.008	145.529	***
LSPB - STP	20.518	85.078	149.638	***
LSPB - LSPBR	39.540	104.957	170.374	***
LSPB - BRS	7.622	146.633	285.645	***
SRN - LSPBR	17.391	67.253	117.116	***

Tukey's Studentized Range (HSD) Test for variable: **BEDROCK LEDGES**

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
GLD - LSPB	5.124	96.333	187.543	***
GLD - SRN	11.498	98.373	185.248	***
GLD - LGR	7.042	99.583	192.125	***
GLD - MCP	9.276	101.308	193.339	***
GLD - RUN	11.689	102.563	193.436	***
GLD - SCP	3.068	108.000	212.932	***
LSPBR - PLP	3.755	71.088	138.422	***
LSPBR - DPL	12.246	73.888	135.531	***
LSPBR - LSPB	39.499	82.422	125.344	***
LSPBR - LSPRW	28.532	82.945	137.359	***
LSPBR - SRN	51.745	84.461	117.178	***
LSPBR - LGR	39.988	85.672	131.355	***
LSPBR - MCP	42.754	87.396	132.038	***
LSPBR - RUN	46.447	88.651	130.854	***
LSPBR - BRS	3.512	94.088	184.665	***
LSPBR - SCP	26.755	94.088	161.422	***
LSPBR - HGR	18.212	94.088	169.965	***
STP - LSPB	7.390	49.750	92.110	***
STP - SRN	19.815	51.790	83.765	***
STP - LGR	7.844	53.000	98.156	***
STP - MCP	10.623	54.724	98.826	***
STP - RUN	14.348	55.979	97.611	***

Tukey's Studentized Range (HSD) Test for variable: **CLINGING VEGETATION**

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
BRS - LGR	8.684	98.292	187.899	***
BRS - RUN	12.351	100.344	188.336	***
BRS - DPL	9.340	107.500	205.660	***
BRS - LSPB	19.182	107.500	195.818	***
BRS - LSPBR	19.795	107.500	195.205	***
BRS - CCP	5.895	107.500	209.105	***
BRS - MCP	18.386	107.500	196.614	***
BRS - PLP	5.895	107.500	209.105	***

Tukey's Studentized Range (HSD) Test for variable: **CLINGING VEGETATION** cont.

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
BRS - LSPRW	13.432	107.500	201.568	***
BRS - SCP	5.895	107.500	209.105	***
BRS - BWP	0.399	107.500	214.601	***
BRS - STP	20.052	107.500	194.948	***
SRN - LSPB	1.139	34.479	67.818	***
SRN - LSPBR	2.800	34.479	66.158	***
SRN - STP	3.518	34.479	65.440	***

Tukey's Studentized Range (HSD) Test for variable: **LEFT BANK STABILITY**

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
LSPBR - LSPB	0.899	63.780	126.662	***
LSPBR - MCP	21.515	86.916	152.317	***
LSPBR - SCP	18.377	117.022	215.667	***

Tukey's Studentized Range (HSD) Test for variable: **CANOPY CLOSURE**

HABITAT Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
SRN - LSPBR	1.827	55.783	109.738	***

2

VITA

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