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A comparative bioassessment of rural and urban stream communities

Kenneth Dean Gardner

To the Graduate Council:

I am submitting herewith a thesis written by Kenneth Dean Gardner entitled "A comparative bioassessment of rural and urban stream communities." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

J. Larry Wilson, Major Professor

We have read this thesis and recommend its acceptance:

Jim Drake, Tom Hill

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Thomas K. Hill

J A Dole

Accepted for the Council:

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Date July 30, 1993

A COMPARATIVE BIOASSESSMENT

OF RURAL AND

URBAN STREAM COMMUNITIES

A Thesis

Presented for the

Master of Science

Degree

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Kenneth Dean Gardner

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Abstract

Biological assessments of the resident fish community, using Index of Biotic Integrity (IBI) methodology, and benthic macroinvertebrates were conducted in three East Tennessee streams (of similar size, flow, and morphology) to compare their relative "health" or quality. The streams selected were a highly impacted municipal stream (Second Creek), a marginally impacted stream (Love Creek) on the outskirts of the municipality, and an undisturbed stream (Fisher Creek) in a nearby rural county.

Stream biology assessments indicated that Second Creek (below an industrial site) and Love Creek were in "poor" condition (IBI = 32). Second Creek (below a more rural area) scored 36, placing it in the "poor to fair" range. Fisher Creek, serving as the control stream, had a score of 58, indicating that it was in excellent condition at the time of sampling. These findings were confirmed by macroinvertebrate samples at all but one station. Generally, however, the more pollution-tolerant chironomid and oligochaete taxa dominated in streams considered to be in poor condition, and the less tolerant Ephemeroptera, Plecoptera, and Trichoptera dominated in streams in better condition.

Table of Contents

List of Tables

List of Figures

Chapter 1

INTRODUCTION

Mayor Victor Ashe of Knoxville, Tennessee, initiated a Water Quality Forum in May of 1990. This Forum was composed of a number of different city, county, state and federal offices. Its sole purpose, as designated by the Mayor, was to seek improvement, and subsequent development along the Fort Loudoun Reservoir waterfront within the city limits. The Forum used a document, released by Knoxville's Metropolitan Planning Commission (1990) a month earlier (in recognition of Earth Day) entitled "Environment: Issues, Goals, Objectives and Strategies," as its guide to generating a strategy for this improvement and development.

One of the environmental issues examined in this document was water quality in the streams located within the city limits of Knoxville and its surrounding Knox County, many of which are tributaries to Fort Loudoun Reservoir. As with most streams located in metropolitan areas across the country, Knoxville's streams are subjected to both point source and non-point source pollution.

In an attempt to control these pollution problems and thereby improve the quality of our nations surface waters, the federal government passed legislation mandating that certain actions be taken. The first Act passed in regard to this was the Federal Water Pollution Control Act of 1972 (PL92-500) which was established in order to "... restore and maintain the chemical, physical and biological integrity of the Nation's waters." The Clean Water Act of 1977 (PL95-217) amended the Act of 1972 and broadened the regulations to monitor and improve water quality. This Act defined pollution as "... the manmade or man-induced alteration of the chemical, physical, biological, and radiological integrity of water."

Point source pollution, regulated by the Clean Water Act of 1977, has been broadly defined by the Knoxville Commission as "any pollution that is traceable to a single discharge point such as effluent from industry or wastewater treatment and storage facilities during major storm events." In contrast, the Commission defines non-point source pollution as "something which cannot be traced to a single, discrete location and can be characterized by such things as runoff from roads and parking lots and leaking sewer systems." According to the Commission, Tennessee Valley Authority (TVA), and Tennessee Department of Environment and Conservation (TDEC) officials, non-point source pollution remains one of the most serious threats to Knox County streams. As a result of these perturbations, numerous streams within Knoxville's city limits have been posted by TDEC as unfit for recreational contact.

The goal of improving water quality in the streams, as established by the Commission, "is to clean up and protect local streams which do not meet state standards for recreational and other uses, and protect these streams from degradation." Implicit in achieving this goal are two main objectives: (1) the City of Knoxville must cooperatively evaluate the existing water quality within its tributary stream watersheds and the mainstream Tennessee River along the waterfront; and (2) it must formulate an Action Plan to accomplish water quality improvement within the tributary subwatersheds and the mainstream river.

Working towards these objectives, the Knoxville Water Quality Forum compiled water quality monitoring data from member city, county, state and federal agencies in an attempt to characterize both point source and non-point source pollution impacts. Unfortunately, these data lacked detailed information describing the biological communities resident within Knoxville's tributary streams. The ability of surface waters to support aquatic life has traditionally been determined on a chemical basis in the State of Tennessee (J. West, TDEC, personal communication) as with most states across the country (Ohio EPA 1988). This is accomplished by collecting water samples, conducting chemical analyses, and comparing results with water quality criteria. If specific chemical criteria are surpassed, it is then assumed that the designated use is not being attained. The rationale for emphasizing chemical monitoring is that chemical criteria, developed through toxicological studies of standard aquatic organisms, serves as surrogate measures for monitoring biological integrity (Miller et al. 1988). However, chemical monitoring does not take into account the naturally occurring geographic variation of contaminants (e.g., asbestos, iron, zinc), consider the synergistic effects of numerous contaminants, nor consider sublethal effects (e.g., reproduction, growth) of most contaminants (Karr 1981). Therefore, this approach does not directly measure the biological integrity of surface waters. And as a consequence, biological integrity of the nation's waters has continued to decline because other factors, such as physical habitat, are often limiting (Karr and Dudley 1981). In such cases, biological integrity is unlikely to be improved by controlling chemical pollution (Miller et al. 1988).

Today, the assessment of biological communities is recognized as an increasingly important tool in determining the quality of water in streams. For example, bioassessments are sensitive to changes across a wide array of environmental factors (i.e., they integrate the effects of many man-induced perturbations such as flow alterations and stream habitat and watershed degradation) (Karr 1981; Karr et al. 1986). Biological communities (particularly benthic macroinvertebrates) are also sensitive to low-level disturbances that chemical monitoring may not detect (Chandler 1970). According to the Ohio Environmental Protection Agency (1988), which has adopted bioassessment as part of its water quality monitoring program, numerous attributes of biological communities make them particularly well-suited to define environmental degradation. The Agency's reasoning for this is as follows: (1) some biological communities, particularly fish and many benthic macroinvertebrates, inhabit the receiving waters continuously and, as such, are good indicators of the chemical, physical, and biological history of the receiving waters; (2) these communities reflect the dynamic spatial and temporal interactions of stream flow, pollutant loadings, toxicity, habitat, and chemical quality that are not comprehensively measured by chemical tests alone; and (3) many fish species and macroinvertebrate taxa are relatively long lived (2-10 years and longer in some cases), thus the condition of the biota is an indication of past and recent environmental conditions over a variety of habitat conditions.

Numerous benefits can be gained by monitoring the fish community alone. For example, fish are at the top of the aquatic food chain and therefore often reflect the responses of the entire trophic structure to environmental stress (Berkman et al. 1986). They are typically present in all but the most ephemeral or polluted aquatic habitats, and statements about the fish community can be understood by the general public (Karr 1981). This can also be extremely important in the sense that they are directly consumed by humans, and any bio-accumulation of toxicants can be passed on to the general public directly (Plafkin et al. 1989).

Fish, being mobile, larger and less diverse than macroinvertebrates, reflect "macro-scale" habitat conditions whereas macroinvertebrates are considered to be good indicators of more localized disturbances due to their limited migration patterns and/or sessile mode of life (Berkman et al. 1986). Macroinvertebrates also serve as the primary food source for many recreationally and commercially important fish (Plafkin et al. 1989). Hence, any disturbance that affects their numbers can affect the size of fish populations as well.

To resolve the stated shortcomings in biological data associated with streams within the city limits of Knoxville, and to effectively facilitate remediation of existing problems to Knoxville's urban streams, two studies were developed by the University of Tennessee Department of Forestry, Wildlife and Fisheries, the Tennessee Wildlife Resources Agency (TWRA) (Schacher, 1992), and TVA. In the first study, an assessment of the fish and benthic macroinvertebrate communities was completed in seven urban streams, 0.5 km upstream of their confluence with Fort Loudoun Reservoir (Holdeman 1993, unpublished). These stations were chosen to yield an assessment of the complete stream subwatershed, while minimizing the receiving river's effects on the assessment.

In the second study, with which this document deals, the same fish and benthic macroinvertebrate assessment methodologies were employed. The study was divided into three phases. In the first phase, data on the biota of a relatively unimpacted rural stream in the region were gathered to serve as a control for comparison with the other targeted streams in the study. In the second phase, a bioassessment was conducted in a stream located on the periphery of Knoxville to provide data from a less intensive urban/residential setting. And in the third phase, two stations from a single, heavily impacted, urban stream were assessed to analyze the differences found in biota above and below industry locations (i.e., an upstream/downstream comparison).

The primary purpose of these two studies was to determine the level of point source and non-point source pollution impairment to the biological communities residing within each of the Knoxville stream watersheds (i.e., measure their biological integrity). Once these benchmarks were established, they could be used to prioritize remediation efforts. In addition, it was postulated that the integration of data from these biological surveys with water quality, water chemistry, and sediment analysis data (also collected during the fieldwork) could assist in identifying point source and non-point source pollution problems needing remediation.

Chapter 2

SITE DESCRIPTIONS

Index of Biotic Integrity (IBI) and benthic macroinvertebrate surveys were conducted on three East Tennessee streams for this study. Fisher Creek was chosen to serve as a control for the other targeted streams. Fisher Creek is not an unimpacted stream according to Hughes' (1985) definition, which states that an unimpacted stream is "one with extensive, mature riparian forest, heterogeneous channel morphology and substrate, abundant cover, clear, odorless water, and no local disturbances from roads, livestock, or human refuse." However, for the purposes of this study it was considered to be a suitable representative of a relatively unimpacted stream in the ecoregion, where the only unnatural perturbations were grazing cattle and pastureland which added limited nutrients to the water from feces and run-off. Love Creek was chosen to provide comparison data from a less intensive urban/residential setting. And finally, Second Creek was chosen, as an urban stream, to provide comparable information above and below industry demarcations along a single stream. All sites were of stream order three or four (Osborne and Wiley 1992) and within the Central Appalachian Ridge and Valley Ecoregion (Omernik 1987).

An ecoregion is a relatively homogenous area where boundaries of several key geographic variables more or less coincide (Hughes et al. 1986). Omernik (1987) delineated ecoregions by simultaneously examining patterns in the relative homogeneity of several terrestrial variables. These variables included: land-surface form, soils, potential natural vegetation, and land use. He also incorporated mapped physical, chemical, and biological information into the database for ecoregion delineation.

All of these watershed variables are presumed to have major influences on aquatic ecosystems (Hughes et al. 1986). And for that reason, it was necessary to ensure that all targeted streams were located in the same ecoregion. If not, it would have been impossible to detect impacts due to water quality rather than habitat differences. According to Plafkin et al. (1989), "habitat, as affected by instream and surrounding topographical features, is a major determinant of aquatic community potential."

Fisher Creek

Fisher Creek, a tributary of Big Creek which flows into the Holston River, is located in Hawkins County, Tennessee, approximately 8.9 km north, northeast of the town of Rogersville. At the sampling station (Figure 1), the stream is classified as a small, fourth order, warmwater stream, and has approximately 26.4 sq km of watershed, composed of roughly a 50/50 mixture of woodlots and pastureland. Its elevation is

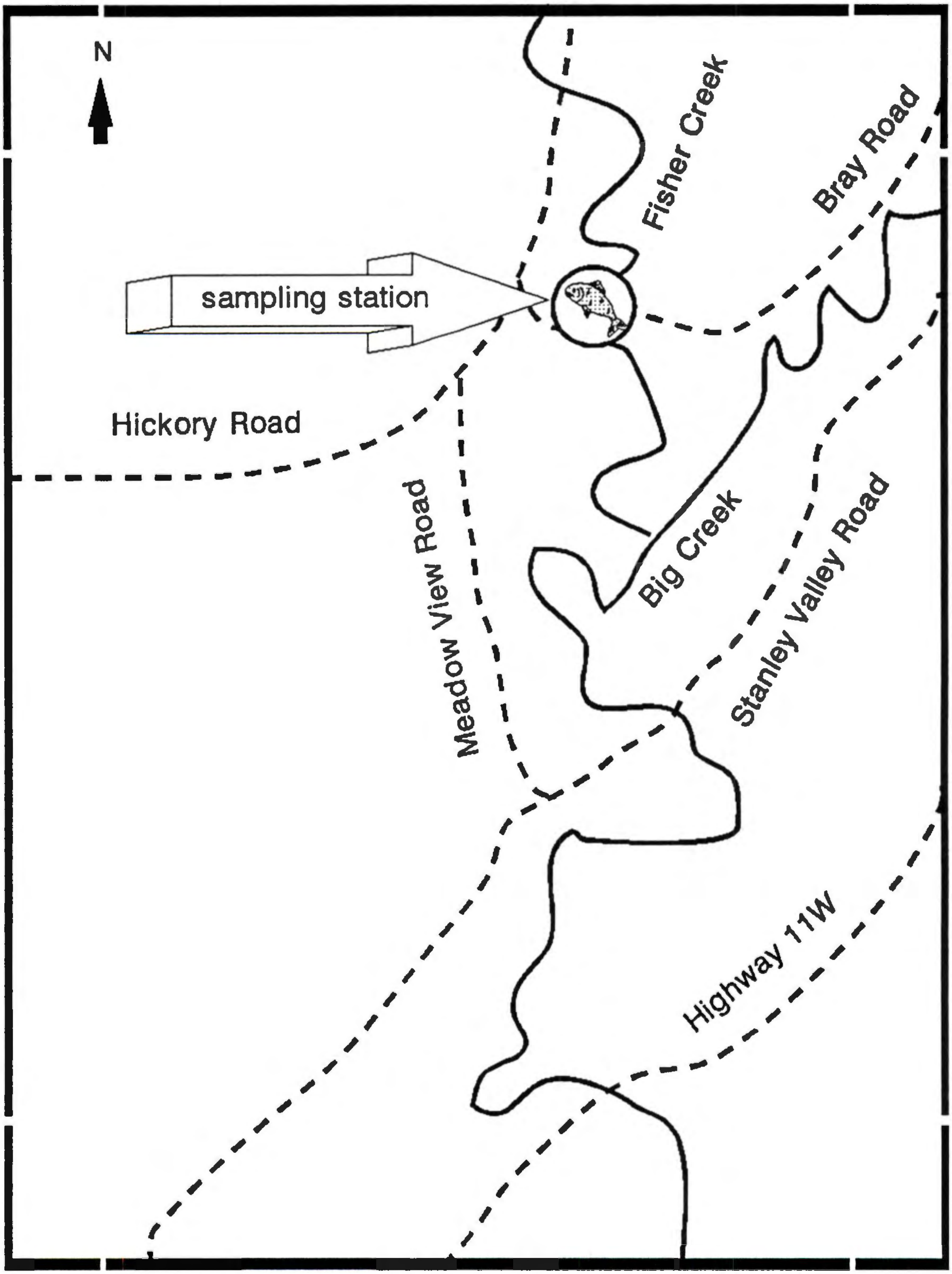

Figure 1. Map showing location of the Fisher Creek sampling station (not to scale).

roughly 0.4 km above sea level, and the encompassing topography is that of rolling hills with mountainous ridges and valleys.

Physical characteristics of the stream include an average width of 3.7 m and average depths of 0.2, 0.5, and 0.8 m for riffles, runs, and pools, respectively. The high water mark (at maximum flow) is approximately 2.1 m. The stream has an 8% gradient and no evidence of dams or channelization. Bottom substrate is primarily composed of a mixture of bedrock in the runs and pools, and gravel in the riffles. Instream cover such as submerged logs, root wads, and undercut banks is plentiful. Only a small amount of siltation was present on the stream bottom at the time of sampling.

The station selected for Fisher Creek was located directly north of Bray Road. It was approximately 0.4 km long and comprised of good pool/riffle, run/bend ratios. The riparian zone, surrounding the station, was predominately trees and nearly 13.7 m wide at the narrowest point. A mixture of canopy cover provided some areas with various degrees of filtered light and other areas with full sunlight. The only access to the stream for cattle was below the station, just south of a bridge on Bray Road. The flow at the time of sampling was 0.1 cubic meters per second (m3/sec).

Love Creek

Love Creek, a tributary of the Holston River, is located in Knox County, Tennessee, east of the City of Knoxville on the outskirts of the municipality. The stream is classified as a large, third order, warmwater stream. Its 14.0 sq km watershed, at the sampling station, is composed of a 30/70 ratio of commercial and residential areas respectively. Its elevation is roughly 0.3 km above sea level. The topography of the area, being somewhat further from the mountains, is relatively gently sloping hills with occasional ridges and valleys.

Physical characteristics of the stream include an average width of 4.3 meters and average depths of 0.2, 0.5, and 0.8 m for the riffles, runs, and pools, respectively. The high water mark is approximately 1.8 m. The stream has a 6% gradient and has been channelized. The bottom substrate is primarily composed of a mixture of rubble and gravel, heavily embedded in silt. Stable instream cover is moderate. Metal barrels, automobile gasoline tanks and tires, shopping carts, as well as other forms of temporary, artificial substrate are scattered in numerous places along the stream.

The station selected for Love Creek (Figure 2) was located directly south of Holston Drive, running parallel to Interstate 40. It was approximately 0.3 km long and comprised of good pool/riffle, run/bend ratios. The entire station

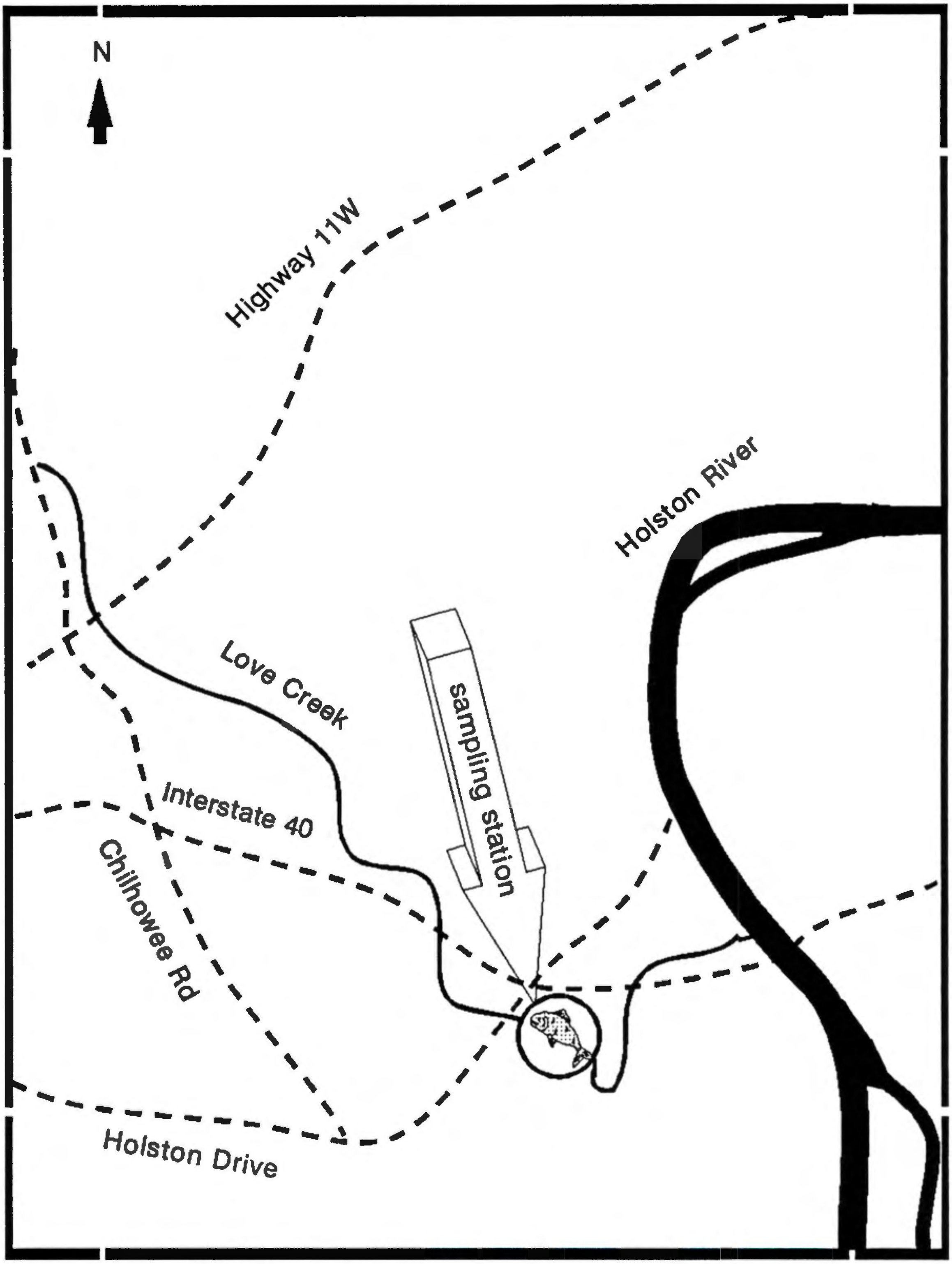

Figure 2. Map showing location of the Love Creek sampling station (not to scale).

was located within an uninhabited woodlot composed predominantly of trees which allowed only filtered light to penetrate through to the water's surface. The narrowest part of the riparian zone (nearly 15.2 km) was on the east side of the stream, between the stream itself and the interstate highway. The flow at the time of sampling was 0.3 m3/sec.

Second Creek (Upper Station)

Second Creek, a tributary of the Tennessee River, is located in Knox County, Tennessee, within the downtown area of Knoxville. It is classified as a third order, warmwater stream. The size of the subwatershed sampled at this station (above an area of the watershed containing several industries) is approximately 8.3 sq km and is composed of a 20/80 ratio of commercial and residential areas, respectively. Its elevation is 0.3 km above sea level. The topography of the area is gently sloping hills with occasional ridges and valleys.

Physical characteristics of this area of the stream include an average width of 2.4 m and average depths of 0.1, 0.2, and 0.6 m for the riffles, runs, and pools, respectively. The high water mark is approximately 1.8 m. The stream has a 4% gradient and has been channelized. The bottom substrate is primarily composed of a mixture of rubble and gravel, moderately embedded in silt. Instream cover is moderate, primarily composed of root wads. The only visible form of temporary, artificial substrate in this area of the stream was a steel "I" beam roughly 3.7 m in length.

The upper station selected on Second Creek (Figure 3) was located south of Inskip Road, running parallel to Interstate 275. It was approximately 0.2 km long and comprised of moderate pool/riffle, run/bend ratios. Approximately 60% of the station was located directly behind a lawn tractor sales and repair shop. The station had a riparian zone width ranging from a minimum of 1.8 m to an area greater than 30.5 m (where a woodlot was located). The other 40% of the station was an open field, fully exposed to the sun. The flow at the time of sampling was approximately 0.2 m3/sec.

Second Creek (Lower Station)

The lower station on Second Creek (Figure 4) was located approximately 3.4 km downstream of the upper station. The size of its subwatershed is roughly 16.8 sq km. This area of the stream's watershed is primarily composed of the following industries: a limestone/crushed rock company, an asphalt shingle manufacturer, a railroad shop, and a steel processing plant. Its elevation is approximately 0.3 km above sea level and the topography is similar to the upper station.

Physical characteristics of this area of the stream include an average width of 3.7 m and average depths of 0.2,

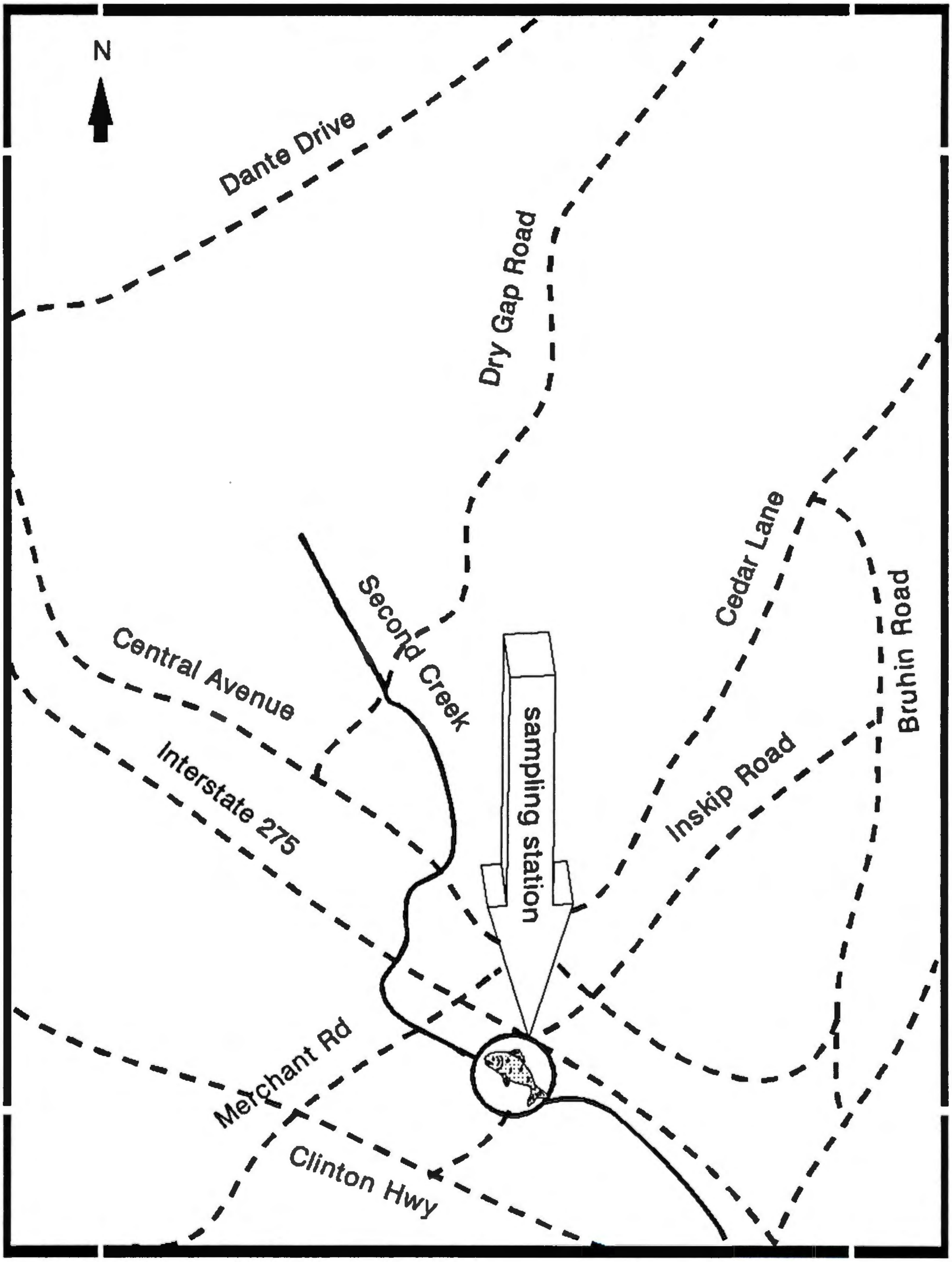

Figure 3. Map showing location of the upper sampling station on Second Creek (not to scale).

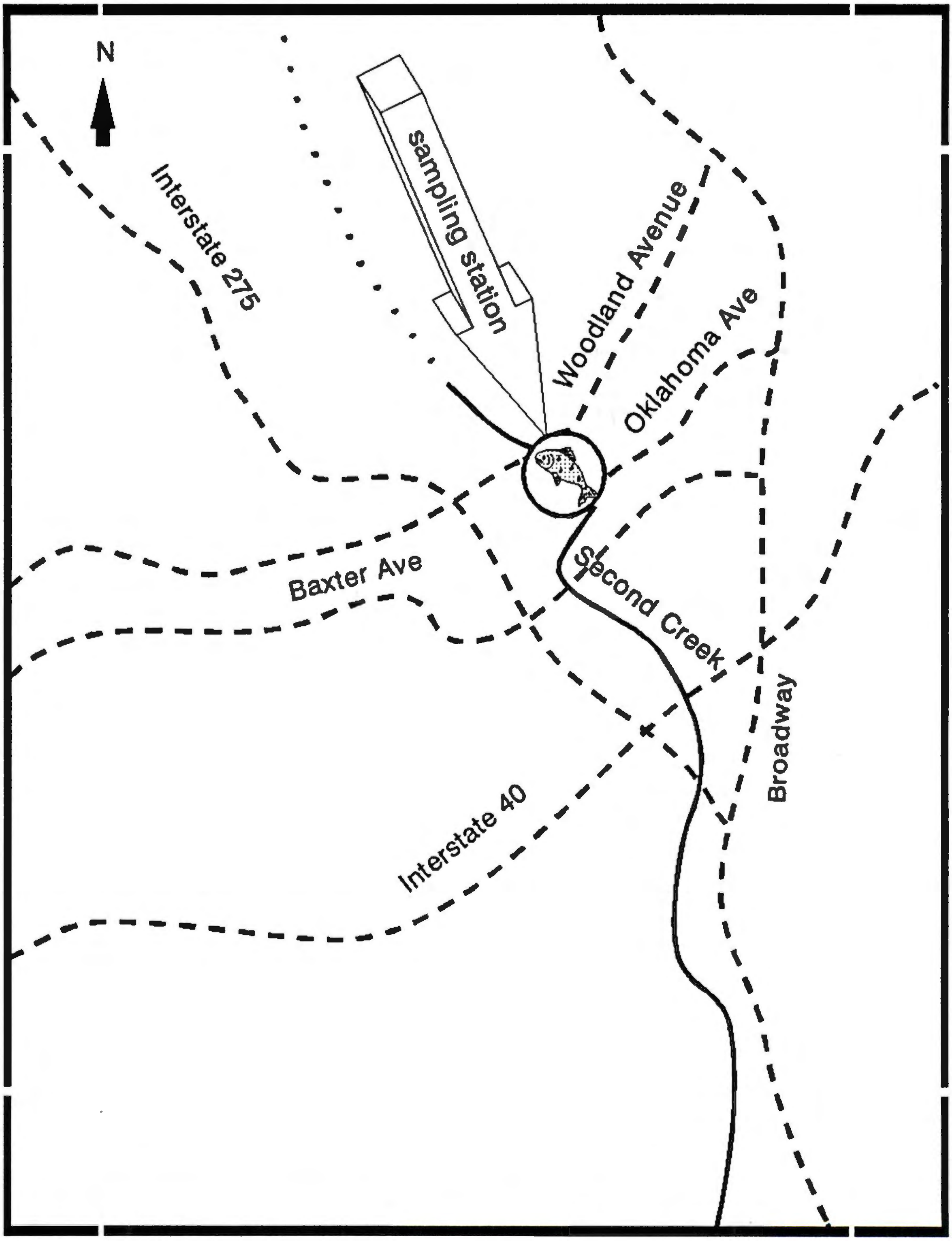

Figure 4. Map showing location of the lower sampling station on Second Creek (not to scale). The dotted line (. . . . .) indicates where the stream is run underground through culverts.

0.3, and 0.5 m for the riffles, runs, and pools, respectively. At the time of sampling, the high water mark was approximately 1.5 m. This area of the stream has a 4% gradient and has been channelized. The bottom substrate is primarily composed of a mixture of rubble and gravel, with veins of bedrock running through it, heavily embedded in silt. Instream cover is moderate, at best, with only an occasional root wad or undercut bank. Automobile gasoline tanks and tires, shopping carts, and other forms of temporary, artificial substrate are scattered along this reach of the stream.

The lower station was approximately 0.3 km long and comprised of poor pool/riffle, run/bend ratios. The area had a riparian zone width of nearly 7.6 m with the entire water surface receiving filtered light. The flow at the time of sampling was 0.1 m3/sec.

Chapter 3

METHODS

Sampling Season

Seasonal changes in the relative fish community abundances can occur during reproductive and migratory periods and under different flow regimes (Gorman and Karr 1978). In order to eliminate as much variability in numbers as possible, mid-summer (mid-June through late July) was chosen as the prime sampling time for all project streams. At this time of year rainfall is at a minimum and therefore flows are low. The resulting loss of variable flows contributes to a more stable environment for fish communities overall. Fewer fish are displaced because of excessive current, and the need to relocate to avoid it is all but eliminated. Although migration can account for some movement during this time of year, fish populations and individuals generally tend to remain in the same areas during the summer months (Funk 1957; Cairns and Kaesler 1971).

Station Selection

The station selections were made in cooperation with TVA, TWRA, and the University of Tennessee. Preliminary reconnaissance was conducted in order to locate stations on the project streams. To ensure general comparability between streams, every effort was made to select stations that represented the best possible conditions on each of the streams. Some of the factors considered in this inspection included: the amount of channel modification (particularly in the urban streams), the condition of the riparian zone, the amount of instream structure, and the presence of comparable gross habitat types. These habitat types consist of riffles, runs, and pools in the Tennessee Valley (Saylor and Ahlstedt 1990). Without an effort to select stations with similar habitats, it would have been difficult to determine whether differences detected in the biotic integrity were due to non-uniformities in habitat or water quality.

To obtain suitable assessments of the cumulative effects of pollutants entering the watershed, stations were chosen near the lower reaches of the streams with the exception of the two stations on Second Creek. On this stream, one station was located above an area of the watershed containing several industries and the other below these industries to ascertain the impacts of point source pollution. To avoid the collection of specimens more typical of larger bodies of water, the other study areas were located no closer than 0.5 km from their confluence with another stream or river (Karr et al. 1986). The approximate length of sampling stations ranged from 160.9 to 402.3 m.

Fish Sampling

In this study, the collection methods were patterned after those developed by TVA aquatic biologists over several years. With extensive knowledge of the stream biota occurring in the Tennessee Valley, and collection techniques which have been tested and proven to provide reliable data from major stream habitats, only a few modifications were made in the collection and analysis techniques employed by the agency.

For quantitative samples of fish in riffles and runs, a generator powered, Smith-Root backpack electrofishing unit (Model 15-B), as well as a 3.1 x 1.5-m seine with 4.8-mm mesh and a dip net were utilized. The seine was stretched across the channel approximately 6.1 m (considered one electrofishing sampling unit) downstream of the electrofishing device. Moving toward the seine, the individual operating the unit attempted to thoroughly cover the area. Another individual, carrying a dip net and accompanying the person electrofishing, collected fish which became trapped in rock crevices and around logs, boulders, undercut banks, and brush piles. The majority of fish, however, were either driven or drifted into the seine. Using this technique, fish were collected from all discernible habitat types within riffle, run, and pool areas (i.e., sand, gravel, rubble, cobble, bedrock, and vegetation). Collection in shallow backwaters, pools, and slow moving runs was accomplished by seine hauls exclusively. Following TVA guidelines "to assure that a high percentage of species present were collected and practical limits on sampling effort were set, predominant habitat types were sampled until a minimum of three consecutive seine hauls or electrofishing runs produced no new species for a given habitat type" (Saylor and Ahlstedt 1990).

Two people were required for qualitative sampling, one to operate the backpack electrofisher and the other to collect fish with a dip net. An area of the stream judged to contain a good representation of the different habitats, and therefore a good representation of the fish species residing in the stream, was sampled for a period of 5 minutes. Additional attempts were made if the area was determined to be less productive than expected.

Upon completion of a sampling effort, the fish were sorted by species, enumerated if captured in a quantitative sample, and recorded. Young-of-year (YOY) fish were omitted from the fish count for two reasons: (1) they were only subjected to stream conditions for a short time and consequently may not show signs of stress; and (2) they were more likely to drift or be displaced than adult fish and therefore affect the accuracy of the IBI by not fully reflecting perturbations (Karr et al. 1986). Occurrence of YOY collections were noted on the record sheets. Voucher specimens from each station were preserved in 10% formalin, appropriately labeled, and their identifications confirmed by

Charles F. Saylor, TVA, Aquatic Biologist (and regional IBI specialist). Prior to release or preservation, each specimen was examined for hybridization, anomalies, disease, and poor condition. In accordance with TVA methodology, fish infested with five or more parasites of Neascus sp. (which appear as black spots on the specimen) were considered diseased and included in Metric 12 of the IBI analysis.

This infestation of parasites is known as black spot disease and is caused by the metacercarian stage of certain trematode parasites; the life cycle has been documented by Steedman (1991). The parasites attach to the intestinal mucosa of piscivorous birds which eat fish infected by metacercariae, and produce eggs within about 4 weeks. The eggs are shed in the birds feces and hatch into miracidia in about 3 weeks. If the miracidia come in contact with the correct intermediate host snail, such as the periwinkle snail (Elimia simplex) found in the degraded streams of eastern Tennessee, they produce sporocysts. These in turn produce cercariae that emerge after about 6 weeks. The free-swimming cercariae penetrate the body musculature of host fish. Black spots appear approximately 3 weeks after infestation; they are produced as the result of pigment deposited by the fish around the encysted metacercariae (Berra and Au 1978).

The Ohio Environmental Protection Agency questions the inclusion of black spot in Metric 12 because their data have shown no clear relationship between black spot and stream degradation. However, TVA biologists continue to incorporate it in the metric because they believe that the occurrence of black spot varies between ecoregions, i.e., it may be more prevalent in some (such as the Eastern Cornbelt Plains Ecoregion of Ohio) than in others (such as the Central Appalachian Ridge and Valley Ecoregion of east Tennessee). The Agency's Valley-wide biomonitoring program, for small rivers and streams, has shown a substantial increase in the occurrence of black spot in degraded streams receiving some sort of cultural enrichment (C. Saylor, TVA, personal communication); therefore, they continue to use it as an index of generalized physiological stress caused by degraded or contaminated habitat. This belief was supported by Steedman's (1988, 1991) research which showed that an increase in the incidence of black spot disease was associated with an increase in the degradation of agricultural and urban streams.

Index of Biotic Integrity Analysis

Karr and Dudley (1981) defined biological (or biotic) integrity as "the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region." The IBI developed by Dr. James R. Karr was chosen as the technique employed in this study to analyze the fish communities and measure the overall "health" or quality of the targeted streams for three reasons: (1) it incorporates both structural and ecological factors which examine 12 attributes (termed metrics) of indigenous fish communities and provides criteria to determine what is excellent or poor (Karr et al. 1986); (2) since these individual metrics differ in their relative sensitivity to various levels of biological condition, they can be used to pinpoint the ecological attributes that have been altered, thereby making it an integrated analysis and reliable indicator of stream conditions (Angermeier and Karr 1986; Leonard and Orth 1986; Angermeier and Schlosser 1988); and (3) professional judgement is incorporated in a systematic and ecologically sound manner unlike other traditional assessment methods such as diversity indices (Miller et al. 1988).

The 12 metrics (Table 1) are divided into three broad categories: Species Composition (Metrics 1-6), Trophic Composition (Metrics 7-9), and Fish Abundance and Condition (Metrics 10-12). Assignment of fish species to these categories was based on their tolerance to pollution, trophic guild, and priority (family) group as designated by Plafkin et al. (1989) and Saylor and Ahlstedt (1990). The priority groupings include Catostomidae (suckers), Centrarchidae (sunfish), Percidae (darters), and a miscellaneous group. For a more detailed explanation of the 12 IBI metrics see Karr et al. (1986) and Plafkin et al. (1989).

The scoring criteria for Metrics 1 through 5, used in

Table 1. Twelve metrics used in calculating the Index of Biotic Integrity (modified from Karr et al. 1986). Ratings of 5, 3, and 1 are assigned to each metric according to whether its value approximates, deviates somewhat from, or deviates strongly from the value expected at a comparable site that is relatively undisturbed.

Metric Number	Metric Description
Species Composition	
Metric 1.	Number of native species
Metric 2.	Number of darter species
Metric 3.	Number of sunfish species (excluding *Micropterus* sp.)
Metric 4.	Number of sucker species
Metric 5.	Number of intolerant species
Metric 6.	Proportion of individuals as tolerant species
Torphic Composition	
Metric 7.	Proportion of individuals as omnivores
Metric 8.	Proportion of individuals as specialized insectivorous minnows and darters
Metric 9.	Proportion of individuals as piscivores
Fish Abundance and Condition	
Metric 10.	Catch rate (average number / unit sampling effort)
Metric 11.	Proportion of individuals as hybrids
Metric 12.	Proportion of individuals with disease, tumors, fin damage, and other anomalies

evaluating the streams, were developed from the number of fish species expected to occur in each of them under unaltered or pristine conditions, in the absence of human influence (Angermeier and Karr 1986). The criteria were calculated by dividing the expected numbers into three equal ranges (allowing for 0.05% error) and then adjusting them for watershed and stream size based on input from TVA biologists, experienced in IBI analysis, and data from similar TVA study areas. The scoring criteria for the proportional Metrics 6 through 9 were based on the numbers of fish actually caught and were calculated in a similar manner. Criteria for scoring catch rate (Metric 10) were based on the average number of fish caught per unit sampling effort (i.e., electrofishing a 6.1 m section of stream or hauling a seine through a pool). Scoring criteria for Metrics 11 and 12 follow those proposed by Karr et al. (1986). Numerical values were then assigned to the three divisions of the metrics based on the degree of comparability to expected values for the streams. They were as follows: 1-deviates strongly from, 3-deviates somewhat from, or 5-approximates the value expected at the site. These numbers for the 12 metrics were then summed, and the total used to assign a classification for the condition of the project streams according to index ranges developed by Karr et al. (1986) (Table 2). The maximum IBI score possible is 60 and the minimum is 12.

Table 2. Index of Biotic Integrity classifications and descriptions used in assessing fish communities (Karr et al. 1986).

Class	Attributes	IBI Range
Excellent	Comparable to the best situation without influence of man; all regionally expected species for the habitat and stream size, including the most intolerant forms, are present with full array of age and sex classes; balanced trophic structure.	58-60
Good	Species richness somewhat below expectation, especially due to loss of most intolerant forms; some species with less than optimal abundances or size distribution; trophic structure shows some sign of distress.	48-52
Fair	Signs of additional deterioration include fewer intolerant forms, more skewed trophic structure (e.g., increasing frequency of omnivores); older age classes of top predators may be rare.	40-44
Poor	Dominated by omnivores, pollution-tolerant forms, and habitat generalists; few top carnivores; growth rates and condition factors commonly depressed; hybrids and diseased fish often present.	28-35
Very Poor	Few fish present, mostly introduced or very tolerant forms; hybrids common; disease parasites, fin damage, and other anomalies regular.	12-23
No Fish	Repetitive sampling fails to turn up any fish.	--

Benthic Macroinvertebrate Sampling

Benthic macroinvertebrates were sampled during the same period as the fish communities in order to supplement and support fish IBI data analysis. However, they have often been used as the only indicator of water quality by state agencies across the country (J. West, TDEC, personal communication). The decision to include macroinvertebrates in this study was based on two reasons: (1) macroinvertebrates, having limited migration patterns and/or sessile states, are well-suited for assessing site-specific impacts such as the upstream and downstream stations on Second Creek (Omernik 1987); and (2), they serve as the primary food source for many fish; therefore, their abundance can affect fish abundance. Macroinvertebrate sampling and analysis also employed many of TVA's techniques.

Quantitative samples were collected in riffle/run and pool habitats in order to determine species abundance in the streams. Quantitative sampling involved the use of Surber and Hess bottom samplers and was limited to those areas no deeper than the height of the sampling units' frames. Another limiting factor was the size of the substrate that could be effectively sampled within the frame of the device. This ranged in size from a mixture of sand and gravel to rubble.

The Surber sampler was used in shallow riffles and around emergent vegetation, while the Hess sampler, a somewhat taller collection device, was reserved for pools and slow moving runs. Sampling with either the Surber or the Hess was conducted in the following manner: (1) it was placed on top of substrate that appeared to be undisturbed, with the funneled net and collection cup downstream of the device's frame; (2) larger pieces of substrate, within the sampling frame, were then lifted up in front of the net and rubbed to dislodge any organisms adhered to their surfaces; (3) larger pieces were removed from the sampling device and the remaining substrate within the frame was physically disturbed to a depth of 5.1 to 10.2 cm in order to dislodge any remaining organisms; and (4), the contents of the collection cup, including detritus, small pieces of substrate and benthic organisms, were then transferred into collection jars containing 10% formalin and appropriately labeled.

Qualitative sampling employed only the use of a D-frame dip net, forceps, and a white enamel pan. Setting a 2-hour time limit at each station, in accordance with TVA methodology, organisms from all habitats within the sampling area were collected. Larger pieces of substrate were hand-picked with the forceps and organisms placed in a labeled jar containing 10% formalin. All other habitats were sampled by kicking into the D-frame dip net, dumping the contents into the white enamel pan, hand-picking the visible organisms, and placing them in a separate, qualitative jar. Any benthic organisms that were discovered in the seine during fish sampling were also retained for the qualitative sample.

Before identifying the organisms collected in the quantitative samples, they had to be separated from the detritus in the collection jars. This was accomplished by first pouring the contents of each jar (individually) into a 270-micron mesh sieve and rinsing it with water to remove the formalin. The contents were then dumped into a white enamel pan. Using a lighted magnifying lens, the macroinvertebrates were removed from the pan using forceps and placed in appropriately labeled vials containing 70% ethanol for later identification.

The benthic macroinvertebrates were enumerated and identifications made to the lowest possible taxon using a stereomicroscope (7 to 70X) and Wiggins (1977), Brigham et al. (1982), and Merritt and Cummins (1984) identification keys. Some specimens were also identified by comparing them to those found in TDEC and TVA aquatic organism collections. For comparative purposes between the project streams, dipteran midge larvae (Chironomidae) were left at the subfamily level. Any questionable identifications were validated by either TDEC or JAYCOR (an environmental consulting company) biologists. Steven A. Ahlstedt (TVA Aquatic Biologist) assisted in identifying the live mussels and snails as well as the relics that were collected.

Benthic Macroinvertebrate Analysis

Impairment of benthic organism communities has often been indicated by four factors: (1) the absence of generally pollution-sensitive macroinvertebrate taxa such as Ephemeroptera, Plecoptera, and Trichoptera (EPT); (2) excess dominance by pollution-tolerant forms such as chironomid and oligochaete taxa; (3) low overall taxa richness; and (4) appreciable shifts in community composition relative to the reference condition (Plafkin et al. 1989). In this study, the total number of EPT taxa and the total number of taxa were used as the primary means for determining benthic community impairment, since they are the most widely accepted techniques for the biomonitoring of benthic organisms (Saylor and Ahlstedt 1990). The reasons for their widespread use are: (1) EPT taxa are considered to be the most sensitive to pollution; and (2) healthy, stable biological communities should have a high species richness and diversity. However, the other indicators were briefly examined as well.

The classification and its corresponding level of impact used in this study are similar to those used by North Carolina Department of Natural Resources (1988) and Saylor and Ahlstedt (1990). Criteria for classification of total number of EPT and total number of taxa are based on data gathered from Fisher Creek (the reference stream). A listing of the scoring system values for total EPT and total taxa appear in Table 3.

Table 3. Scoring system values for total number of EPT taxa and total number of taxa.

Condition	Total EPT Taxa	Total Taxa
Excellent (No Impact)	>21	>46
Good (Slight Impact)	15-21	31-46
Fair (Moderate Impact)	7-14	15-30
Poor (Severe Impact)	<7	<15

Water Quality/Chemistry and Sediment Analysis

Standard water quality parameters were measured using a variety of devices. On Second and Love Creeks, salinity, conductivity, and temperature were measure using a YSI Model 33 S-C-T meter. Dissolved oxygen was measured by a YSI Model 58 DO meter, and pH was measured on an Orion digital Model SA 210 pH meter. On Fisher Creek, all water quality parameters were measured with a Hydrolab Surveyor II. Calibration and operation of the unit followed procedures in TVA's Natural Resource Engineering Procedures Manual, Volume I.. The Robins-Crawford "rapid crude" technique (as described by Orth 1983) was used to estimate flows. After coordinating IBI sampling schedules with TDEC and the Knoxville Utilities Board (KUB), simultaneous grab samples of sediment (collected by TDEC) and water (collected by KUB) were taken. Analyses of these samples were then conducted by TDEC and KUB.

Habitat Assessment

An evaluation of habitat quality is critical to any assessment of ecological integrity. Therefore, a description and evaluation of the riparian habitat and the stream physical habitat for each of the stations was completed using a "Habitat Assessment Field Data Sheet: Riffle/Run Prevalence." Originally described by Plafkin et al. (1989), it was modified by the United States Environmental Protection Agency (USEPA) (1991) to be more appropriate for wadeable streams and rivers having a prevalence of riffles and runs. It was then presented at a Total Maximum Daily Load Workshop sponsored by EPA, Region IV, and TVA in 1991. Information gathered using this sheet provided insight into what organisms may be present, or were expected to occur, and to the presence of stream impacts.

Habitat Analysis

The "Habitat Assessment Field Data Sheet: Riffle/Run Prevalence" used in this study (Figure A-1) was modified from the 9 parameter sheet described by Plafkin et al. (1989) and included three additional parameters: canopy cover, lower bank channel capacity, and riparian vegetative zone width (least buffered side). The 12 parameters evaluated on this sheet are considered to be the most biologically significant, and they are scored by choosing the category (Optimal, Sub-Optimal, Marginal, or Poor) that best fits each parameter description and then assigning it a value based on the ranges provided. These parameters are separated into three principal categories (Table 4). Primary parameters characterize the "microscale" habitat and include characterization of bottom substrate and available cover, estimation of embeddedness, and estimation of flow or velocity and depth regime. According to Plafkin et al. (1989), these parameters have the greatest direct influence on the structure of the indigenous communities and thus have the widest range of possible scores (0-20). The secondary parameters measure the "macroscale" habitat such as channel morphology characteristics and have the next lowest range of possible scores (0-15) (Plafkin et al. 1989). And finally, the least important parameters are the tertiary parameters which evaluate riparian and bank structure and have the smallest range of possible scores (0-10) (Plafkin et al. 1989). Some of these parameters are reviewed in the results portion of this paper. However, for a more thorough interpretation of the specific stream morphological characteristics they examine, see Plafkin et al. (1989), the United States Environmental Protection Agency (Region IV) and TVA's workshop proceedings on "Total Maximum Daily Load" (1991).

Once a total score was obtained for each of the stations on Second Creek, as well as the one on Love Creek, they were

Table 4. Three principal categories of the Habitat Assessment Field Data Sheet (modified from Plafkin et al. 1989) and the associated characteristics of each.

Condition/Parameter	Condition			
	Optimal	Sub-optimal	Marginal	Poor
Primary - Substrate and Instream Cover				
1. Bottom substrate and available cover	16-20	11-15	6-10	0-5
2. Embeddedness	16-20	11-15	6-10	0-5
3. Flow/velocity	16-20	11-15	6-10	0-5
4. Canopy cover	16-20	11-15	6-10	0-5
Secondary - Channel Morphology				
5. Channel alteration	12-15	8-11	4-7	0-5
6. Bottom scouring and deposition	12-15	8-11	4-7	0-5
7. Pool/riffle, run/bend ratio	12-15	8-11	4-7	0-5
8. Lower bank channel capacity	12-15	8-11	4-7	0-5
Tertiary - Riparian and Bank Structure				
9. Bank stability	9-10	6-8	3-5	0-2
10. Bank vegetation	9-10	6-8	3-5	0-2
11. Streamside cover	9-10	6-8	3-5	0-2
12. Riparian vegetative zone width	9-10	6-8	3-5	0-2

compared to Fisher Creek's total score. The ratio between the score for the stations on Second and Love Creeks and the score for Fisher Creek provided a percent comparability measure for each station. Following the percentage ranges established by Plafkin et al. (1989), the station was then classified on the basis of its similarity to the expected conditions, and its apparent potential to support an acceptable level of biological health (Table 5).

Table 5. Habitat similarity to expected conditions, as illustrated by the ratio between the score for the station of interest and the score for the reference stream (Fisher Creek). Score indicates the potential to support an acceptable level of biological health (Plafkin et al. 1989).

Assessment Category	Percent Comparability
Comparable to Reference Stream	≥90
Supporting	75-88
Partially Supporting	60-73
Non-supporting	≤58

Chapter 4

RESULTS AND DISCUSSION

Prior to sampling and analysis of the fish communities, a list of fish species expected to occur in each of the study streams was developed (Table 6). This was necessary in order to make accommodations for the expected differences in the fish communities at each of the sampling stations based on stream and watershed size differences and to adjust IBI scoring criteria accordingly (Karr 1981). Following the establishment of expected species lists, the species were assigned to pollution tolerance groups, trophic guilds, and family groups (Table 7). Both these lists were developed from personal communications with Charles F. Saylor (TVA Aquatic Biologist), records from unpublished TVA surveys of the Tennessee River system (Etnier 1978), TWRA's Annual Stream Fishery Data Collection Report (Bivens and Williams 1991), and ecological information presented by Pflieger (1975), Smith (1979), Lee et al. (1980), and Plafkin et al. (1989).

Fisher Creek

Fish sampling at the station located on Fisher Creek consisted of 12 electrofishing runs, 5 seine hauls, and 4 qualitative samples. Because of the species diversity at this site, neither three consecutive seine hauls nor electrofishing

Table 6. List of expected native fish species (E) developed from personal communications with C. Saylor (TVA, Aquatic Biologist) and the following references: Etnier (1978), Smith (1979), Lee et al. (1980), Plafkin et al. (1989), and Bivens and Williams (1991). Unexpected species that occurred at the sampling stations designated by a "U".

Scientific Name	Common Name	Fisher Creek	Love Creek	2nd Creek (Upper)	2nd Creek (Lower)
Hybopsis amblops	Bigeye chub	E	E	E	E
Semotilus atromaculatus	Creek chub	E	E	E	E
Nocomis micropogon	River chub	E	E	--	E
Rhinichthys atratulus	Blacknose dace	E	E	E	E
Etheostoma jessiae	Blueside darter	--	E	--	E
Etheostoma blenniodes	Greenside darter	E	E	E	E
Etheostoma rufilineatum	Redline darter	E	--	--	--
Etheostoma kennicotti	Stripetail darter	--	E	E	E
Etheostoma simoterum	Snubnose darter	E	E	E	E
Pimephales promelas	Fathead minnow	--	--	U	U
Gambusia affinis	Mosquitofish	--	U	U	U
Moxostoma duquesnei	Black redhorse	U	U	--	--
Cottus carolinae	Banded sculpin	E	E	E	E
Lythrurus ardens	Rosefin shiner	E	--	--	--
Cyprinella spiloptera	Spotfin shiner	E	E	E	E

Table 6. (continued)

Scientific Name	Common Name	Fisher Creek	Love Creek	2nd Creek (Upper)	2nd Creek (Lower)
Notropis chrysocephalus	Striped shiner	E	E	E	E
Notropis telescopus	Telescope shiner	E	E	E	E
Notropis leuciodus	Tennessee shiner	U	--	--	--
Notropis coccogenis	Warpaint shiner	E	E	E	E
Cyprinella galactura	Whitetail shiner	E	E	E	E
Campostoma anomalum	Central stoneroller	E	E	E	E
Ambloplites rupestris	Rock bass	E	E	E	E
Lepomis machrochirus	Bluegill	E	E	--	E
Lepomis cyanellus	Green sunfish	U	--	--	--
Lepomis megalotis	Longear sunfish	E	--	--	--
Lepomis auritus	Redbreast sunfish	U	U	--	--
Lepomis microlophus	Redear sunfish	U	--	--	--
Micropterus sp.	Black bass	E	E	--	E
Hypentelium nigricans	Northern hog sucker	E	E	E	E
Catostomus commersoni	White sucker	E	E	E	E
TOTAL EXPECTED NATIVE FISH SPECIES		21	20	16	20

Table 7. Fish specie totals collected between June 20 and July 25, 1992, at each of the sampling stations.

Scientific Name	Common Name	Fisher Creek	Love Creek	2nd Creek (Upper)	2nd Creek (Lower)
Hybopsis amblops	Bigeye chub	11	0	0	0
Semotilus atromaculatus	Creek chub	0	27	39	53
Nocomis micropogon	River chub	2	0	--	0
Rhinichthys atratulus	Blacknose dace	5	31	225	295
Etheostoma jessiae	Blueside darter	--	0	--	0
Etheostoma blenniodes	Greenside darter	5	0	0	0
Etheostoma rufilineatum	Redline darter	21	--	--	--
Etheostoma kennicotti	Stripetail darter	--	0	0	0
Etheostoma simoterum	Snubnose darter	69	9	0	0
Pimephales promelas	Fathead minnow	--	--	2	--
Gambusia affinis	Mosquitofish	--	3	7	2
Moxostoma duquesnei	Black redhorse	1	1	--	--
Cottus carolinae	Banded sculpin	42	1	0	0
Lythrurus ardens	Rosefin shiner	0	--	--	--
Cyprinella spiloptera	Spotfin shiner	0	0	0	0

Table 7. (continued)

Scientific Name	Common Name	Fisher Creek	Love Creek	2nd Creek (Upper)	2nd Creek (Lower)
Notropis chrysocephalus	Striped shiner	51	5	1	0
Notropis telescopus	Telescope shiner	8	0	0	0
Notropis leuciodus	Tennessee shiner	2	--	--	--
Notropis coccogenis	Warpaint shiner	99	0	0	0
Cyprinella galactura	Whitetail shiner	10	0	0	0
Campostoma anomalum	Central stoneroller	83	20	11	78
Ambloplites rupestris	Rock bass	27	1	0	0
Lepomis machrochirus	Bluegill	8	9	3	3
Lepomis cyanellus	Green sunfish	1	--	--	--
Lepomis megalotis	Longear sunfish	0	--	--	--
Lepomis auritus	Redbreast sunfish	8	2	--	--
Lepomis microlophus	Redear sunfish	1	--	--	--
Micropterus sp.	Black bass	0	0	--	0
Hypentelium nigricans	Northern hog sucker	16	13	0	0
Catostomus commersoni	White sucker	2	23	7	34
TOTAL (SAMPLE SIZE)		478	146	295	466

runs, in combination with a seine, could be completed, for a given habitat type, without the occurrence of a new species. Therefore, sampling was discontinued after 7 hours and 15 minutes. The 17 sampling efforts produced 478 fish (Table 7) representing 16 of the 21 species expected to occur (Table 6). Those not found included creek chub, rosefin shiner, spotfin shiner, longear sunfish, largemouth bass (Micropterus salmoides), smallmouth bass (M. dolomieui), and spotted bass (M. punctulatus). Since any one of the three black bass species could have occurred in the study streams, they were consolidated into one group, black bass, or Micropterus sp. for the purposes of this study. Fish caught, but unexpected, included black redhorse, Tennessee shiner, green sunfish, redbreast sunfish, and redear sunfish. Nineteen of the 21 species caught were native and two were introduced (redear and redbreast sunfish). No hybrid fish were collected at the sampling station.

Priority groups were represented by 3 darter, 3 sunfish, and 2 sucker species (Tables 7 and 8). Two intolerant species were the northern hog sucker and telescope shiner which composed 5% of the total population (Figure A-2). Tolerant species occurring at this station were the river chub, striped shiner, and white sucker which composed 11.7% of the population (Figure A-2).

The IBI score for Fisher Creek was 58 giving it a health or quality classification of "excellent" (Tables 2 and 9).

Table 8. List containing all expected native fish species for the four sampling stations, including their tolerance to pollution, trophic guild, and priority group as assigned by Plafkin et al. (1989) and Saylor and Ahlstedt (1990).

Scientific Name	Common Name	Tolerance*	Trophic Guild**	Group
Hybopsis amblops	Bigeye chub	--	SP	Misc.
Semotilus atromaculatus	Creek chub	TOL	IN	Misc.
Nocomis micropogon	River chub	TOL	OM	Misc.
Rhinichthys atratulus	Blacknose dace	--	IN	Misc.
Etheostoma jessiae	Blueside darter	--	SP	Darter
Etheostoma blenniodes	Greenside darter	--	SP	Darter
Etheostoma rufilineatum	Redline darter	--	SP	Darter
Etheostoma kennicotti	Stripetail darter	--	SP	Darter
Etheostoma simoterum	Snubnose darter	--	SP	Darter
Pimephales promelas	Fathead minnow	--	OM	Misc.
Gambusia affinis	Mosquitofish	TOL	IN	Misc.
Moxostoma duquesnei	Black redhorse	--	IN	Sucker
Cottus carolinae	Banded sculpin	--	IN	Misc.
Lythrurus ardens	Rosefin shiner	--	SP	Misc.
Cyprinella spiloptera	Spotfin shiner	TOL	IN	Misc.
Notropis chrysocephalus	Striped shiner	TOL	OM	Misc.

Table 8. (continued)

Scientific Name	Common Name	Tolerance*	Trophic Guild**	Group
Notropis telescopus	Telescope shiner	INT	SP	Misc.
Notropis leuciodus	Tennessee shiner	--	SP	Misc.
Notropis coccogenis	Warpaint shiner	--	SP	Misc.
Cyprinella galactura	Whitetail shiner	--	IN	Misc.
Campostoma anomalum	Central stoneroller	--	HB	Misc.
Ambloplites rupestris	Rock bass	--	PS	Sun.
Lepomis machrochirus	Bluegill	--	IN	Sun.
Lepomis cyanellus	Green sunfish	--	IN	Sun.
Lepomis megalotis	Longear sunfish	--	IN	Sun.
Lepomis auritus	Redbreast sunfish	--	IN	Sun.
Lepomis microlophus	Redear sunfish	--	IN	Sun.
Micropterus sp.	Black bass	--	PS	Misc.
Hypentelium nigricans	Northern hog sucker	INT	IN	Sucker
Catostomus commersoni	White sucker	TOL	OM	Sucker

*Tolerance - TOL = Tolerant, INT = Intolerant
**Trophic Guild - HB = Herbivore, IN = Insectivore, OM = Omnivore, PS = Piscivore, and SP = Specialized insectivore

Table 9. Analysis of IBI for Fisher Creek at Bray Road, Hawkins County, Tennessee, July 25, 1992 (Tr = Trace value between 0 and 1%).

		Scoring 1992	Scoring Criteria			Observed 1992
			1	3	5	
Metric 1.	Number of native fish species	5	<7	7-13	>13	19
Metric 2.	Number of darter species	5	<2	2	>2	3
Metric 3.	Number of sunfish species (excluding <u>Micropterus</u> sp.)	5	<2	2	>2	3
Metric 4.	Number of sucker species	5	0	1	>1	3
Metric 5.	Number of intolerant species	5	0	1	>1	2
Metric 6.	Proportion of individuals as tolerant species (%)	5	>59	59-30	<30	11.7
Metric 7.	Proportion of individuals as omnivores (%)	5	>45	45-22	<22	11.5
Metric 8.	Proportion of individuals as specialized insectivorous minnows and darters (%)	5	<16	16-32	>32	32.6
Metric 9.	Proportion of individuals as piscivores (%)	5	<1	1-5	>5	5.7
Metric 10.	Catch rate (average number / unit sampling effort)	5	<8	8-16	>16	22.8
Metric 11.	Proportion of individuals as hybrids (%)	5	>1	1-Tr	0	0
Metric 12.	Proportion of individuals with disease, tumors, fin damage, and other anomalies (%)	3	>5	5-2	<2	3.4
	IBI SCORE	58		EXCELLENT		

Metrics 1 through 6, dealing with species composition, and Metrics 7 through 9 concerned with trophic composition each received scores of 5 indicating that they approximated the value expected at the site. The high number of rock bass (11.5% of the population), considered to be a top carnivore, indicated a relatively healthy, trophically diverse community (Karr 1981). Metrics 10 and 11, in the Fish Abundance and Condition category of the IBI analysis, also scored values of 5. Metric 12, dealing with anomalies, was the only metric to lose points in the Fisher Creek analysis. Black spot disease was found on 16 fish (15 striped shiners and 1 telescope shiner). This infestation resulted in a moderate value of 3 for the metric, indicating that it deviated somewhat from the expected value. Karr (1981) found that black spot seemed to be positively correlated with the modification of watersheds. Since roughly half of the watershed has been modified to supply pastureland for cattle, the 3.4% infestation (Figure A-3) was considered to be low.

Benthic macroinvertebrate sampling on Fisher Creek resulted in a mean abundance of 781.3 organisms per sq m, 64 total taxa, 30 EPT taxa, and 1,401 total specimens (Table 10). As mentioned in the Methods chapter of this paper, criteria for classification of total number of taxa, and total number of EPT for the other targeted creeks, were developed from these values. The pollution-intolerant EPT taxa composed 47% of the total taxa, and pollution-tolerant oligochaetes and

Table 10. Quantitative (mean number per square meter) and qualitative benthic macroinvertebrate data from Fisher Creek at Bray Road, Hawkins County, Tennessee, July 25, 1992.

Taxa	Quant.	Qual.
Annelida:		
Oligochaeta	0.6	--
Coleoptera:		
Elmidae / Dubiraphia sp.	2.8	X
Macronychus glabratus	1.1	--
Optioservus sp.	25.6	--
Stenelmis sp.	62.4	X
Psephenidae / Psephenus herricki	14.5	X
Decapoda:		
Cambaridae / Cambarus sp.	4.5	X
Diptera:		
Athericidae / Atherix lantha	0.6	--
Chironomidae / Chironominae	159.4	X
Orthocladiinae	9.5	--
Tanypodinae	46.8	--
Tanytarsini	13.9	--
Empididae / Hemerodromia sp.	5	--
Simuliidae	7.3	--
Tabanidae / Tabanus sp.	0.6	--
Tipulidae / Antocha sp.	1.7	--
Hexatoma sp.	1.1	X

Table 10. (continued)

Taxa	Quant.	Qual.
Ephemeroptera:		
Baetidae / Baetis sp.	1.7	--
Ephemerellidae / Ephemerella eurylophella	0.6	--
Serratella deficiens	63	X
Heptageniidae / Epeorus rubidus / subpallidus	1.1	X
Heptagenia sp.	7.8	--
Stenacron interpunctatum	1.7	--
Stenonema femoratum	3.9	X
Stenonema mediopunctatum	27.9	X
Stenonema terminatum	21.2	X
Leptophlebiidae / Paraleptophlebia sp.	0.6	--
Oligoneuriidae / Isonychia sp.	15.6	X
Siphlonuridae / Ameletus lineatus	3.3	X
Gastropoda:		
Planorbidae	--	X
Pleuroceridae / Elimia clavaeformis (130 relics)	0.6	X
Heteroptera:		
Gerridae / Gerris remigis	--	X
Veliidae / Rhagovelia obesa	--	X
Hydrometridae / Hydrometra sp.	1.1	--
Isopoda:		
Asellidae / Lirceus sp.	3.3	--

Table 10. (continued)

Taxa	Quant.	Qual.
Megaloptera:		
Corydalidae / *Nigronia serricornis*	36.2	X
Sialidae / *Sialis* sp.	--	X
Odonata:		
Aeshnidae / *Boyeria vinosa*	1.1	X
Coenagrionidae / *Argia bipunctulata*	--	X
Cordulegastridae / *Cordulegaster* sp.	0.6	X
Gomphidae / *Gomphus* sp.	--	X
Hagenius brevistylus	--	X
Ophiogomphus mainensis	--	X
Progomphus obscurus	3.3	X
Pelecypoda:		
Corbiculidae / *Corbicula fluminea*	1	--
Unionidae / *Villosa iris* (3 relics)	--	--
Villosa vanuxemensis (24 relics)	--	--
Sphaeriidae / *Sphaerium* sp.	9.5	X
Plecoptera:		
Chloroperlidae	3.9	--
Perlidae / *Acroneuria* c. f. *evoluta*	1.1	X
Agnetina sp.	1.1	--
Eccoptura xanthenes	0.6	--
Perlesta sp.	0.6	--

Table 10. (continued)

Taxa	Quant.	Qual.
Trichoptera:		
Glossomatidae / Glossosoma sp.	7.3	--
Hydropsychidae / Cheumatopsyche sp.	70.8	X
Hydropsyche betteni / depravata	31.8	X
Hydropsyche sp. (early instar)	29	X
Symphitopsyche alhedra	--	X
Leptoceridae / Oecetis sp.	--	X
Triaenodes tardus	--	X
Limnephilidae / Neophylax sp.	23.4	X
Pycnopsyche sp.	0.6	--
Odontoceridae / Psilotreta labida	35.1	X
Philopotamidae / Chimarra sp.	11.1	X
Polycentropodidae / Polycentropus sp.	1.1	X
Rhyacophilidae / Rhyacophila sp.	1.7	X
MEAN ABUNDANCE / SQ M	781.3	
TOTAL (SAMPLE SIZE)	1,401	
TOTAL TAXA	64	
TOTAL EPT TAXA	30	

chironomids composed 27.7% of the total taxa (Figure A-4). Under pristine conditions, the percentage of oligochaetes and chironomids would have most likely been lower. Enrichment due to agricultural practices undoubtedly served to artificially increase this percentage (Saylor and Ahlstedt 1990). The high number of EPT taxa indicated that the degree of degradation due to enrichment was not severe (Table 3), and in fact, had very little impact.

All water quality parameters were normal (Table 11). Bacterial analysis, sampled in the water column, revealed a slightly elevated level of fecal coliform bacteria (280 coliform colonies per 100 ml), associated with human feces, and a relatively high level of fecal streptococcal bacteria (840 fecal streptococcal colonies per 100 ml) (Table 12) which has been associated with wildlife and livestock contamination (Dudley and Karr 1979; TDEC 1991). Typically, TDEC posts streams unfit for recreational contact that have fecal coliform levels greater than 200 coliform colonies per 100 ml. The state considers 1000 fecal streptococcal colonies per 100 ml stressful to the stream biota (J. West, TDEC, personal communication). These elevated bacterial counts gave no evidence of impacting the stream biota; however, it must be remembered that these water samples were grab samples, taken only one time. TDEC (1991) requires a geometric mean be developed from 10 samples taken within 30 consecutive days of each other in order to determine water quality. To date, the

Table 11. Single field parameter measurements for flow (m3/sec), dissolved oxygen (ppm), pH, temperature (degrees Celsius), and conductivity (umhos) on the sampled streams.

Parameter	Fisher Creek	Love Creek	2nd Creek (Upper)	2nd Creek (Lower)
Date	7/25/92	6/29/92	6/20/92	6/20/92
Time	1030	1430	1025	1440
Flow	0.1	0.3	0.2	0.1
DO	7.3	7.9	8.1	8
pH	7.6	7.4	7.6	8
Temperature	20	19.8	18.5	26
Conductivity	319	509	451	327

Table 12. Chemical analysis from water samples taken June 20 to July 25, 1992.

Parameter	Fisher Creek	Love Creek	2nd Creek (Upper)	2nd Creek (Lower)
Al (ppb)	11	132	54	33
Ba (ppb)	50	68	50	62
Cd (ppb)	<5	<5	<5	<5
Cr (ppb)	<5	<5	<5	<5
Cu (ppb)	11	5	2	2
Fe (ppb)	52	203	121	161
Pb (ppb)	2	5	4	5
Mn (ppb)	1	63	49	24
Ni (ppb)	<5	<5	<5	<5
Ag (ppb)	<5	<5	<5	<5
Zn (ppb)	3	7	5	7
N-NH3 (ppm)	<0.2	<0.2	<0.2	<0.2
NO2-NO3 (ppm)	2.8	3.5	3.8	3.8
TKN (ppm)	0.4	<0.2	<0.2	<0.2
COD (ppm)	6	3	7	9
BOD (ppm)	1	1	1	1
Fecal Coliform*	280	670	1,350	5,900
Fecal Strep.*	840	460	400	6,500

*Number of colonies / 100 ml

State of Tennessee has not developed standards for toxic levels of either organic or inorganic substances in the sediment (J. West, TDEC, personal communication). Therefore, only inferences can be made regarding how this analysis compares with the sediment analyses from the other targeted streams.

The habitat assessment score for the station on Fisher Creek was 149 out of a possible 180 points. Although this score may appear low, it falls in line with scores obtained at reference sites used by TVA for warmwater streams (C. Saylor, TVA, personal communication). The station lost points due to the lack of fast, deep habitat, some deposition in pools, infrequent riffles, a slight potential for bank erosion in extreme floods, and dominance of tree form riparian vegetation. Nevertheless, it is a structurally diverse natural stream which, according to Karr and Schlosser (1977), typically has a great deal of buffering capacity because its meanders tend to moderate the effect of floods, its pools offer excellent refuges for fish during dry periods, and its tree shade decreases heat loads and minimizes the oxygen-robbing effect of decomposing and extensive algal blooms. Since Fisher Creek served as the reference stream, the other targeted stream habitats were compared to it in order to assess their potential to support an acceptable level of biological health.

Love Creek

Fish sampling on Love Creek consisted of 17 electrofishing runs, 2 seine hauls, and 3 qualitative samples. Only 2 seine hauls were conducted in pool areas due to an excessive amount of debris which made them difficult to sample effectively with a seine. Therefore, three consecutive seine hauls, without a new species in this type of habitat, could not be completed. The 19 sampling efforts produced 146 fish (Table 7) representing 10 of the 20 species expected to occur (Table 6). Those not found included bigeye chub, river chub, blueside darter, greenside darter, stripetail darter, spotfin shiner, telescope shiner, warpaint shiner, whitetail shiner, and black bass. Fish caught, but unexpected, were black redhorse, mosquitofish, redbreast sunfish, and a hybrid sunfish. Twelve of the 14 species caught were native and 2 were introduced (mosquitofish and redbreast sunfish).

Priority groups were represented by 1 darter, 2 sunfish (excluding the redbreast and hybrid sunfish), and 3 sucker species (Tables 7 and 8). The only intolerant fish species was the northern hog sucker which composed 8.9% of the population (Figure A-2). Tolerant species (excluding the mosquitofish) occurring at this station were the creek chub, striped shiner, and white sucker which composed 37.7% of the population (Figure A-2). Anomalies included: black spot disease which was noted on 7 creek chubs, 2 striped shiners, and 1 white sucker; a lesion was found on a white sucker; and fin rot was found on a rock bass, all of which composed 7.5% of the population (Figure A-3).

The IBI score for Love Creek was 32 giving it a health or quality classification of "poor" (Tables 2 and 13). Trophic Composition was one of the most seriously disturbed components of the IBI analysis for this site. This category is used to evaluate the shift toward a more generalized foraging that typically occurs with increased degradation of the physicochemical habitat (Plafkin et al. 1989). Two of the three metrics included in this category scored poorly. One of these was Metric 8, the proportion of individuals as specialized, insectivorous minnows and darters (6.2%). This is the trophic guild that normally dominates most North American surface waters (Plafkin et al. 1989). "Their relative abundance decreases with degradation, probably in response to variability in the insect supply, which in turn reflects alterations of water quality, energy sources, or instream habitat, " according to Karr et al. (1986). The other Trophic Composition metric that scored poorly was 9, the proportion of individuals as piscivores (0.7%). As mentioned earlier, viable populations of top carnivores are generally considered to be indicative of a healthy, trophically diverse community. Sensitive to habitat alterations (particularly the reduction of pool areas and loss of instream cover) and the reduction of preferred prey, piscivore populations frequently

Table 13. Analysis of IBI for Love Creek at Holston Drive, Knox County, Tennessee, June 29, 1992 (Tr = Trace value between 0 and 1%).

		Scoring 1992	Scoring Criteria			Observed 1992
			1	3	5	
Metric 1.	Number of native fish species	3	<6	6-13	>13	12
Metric 2.	Number of darter species	3	<1	1-3	>3	1
Metric 3.	Number of sunfish species (excluding <u>Micropterus</u> sp.)	5	<1	1	>1	2
Metric 4.	Number of sucker species	5	0	1	>1	3
Metric 5.	Number of intolerant species	3	0	1	>1	1
Metric 6.	Proportion of individuals as tolerant species (%)	3	>59	59-30	<30	37.7
Metric 7.	Proportion of individuals as omnivores (%)	3	>45	45-22	<22	37.7
Metric 8.	Proportion of individuals as specialized insectivorous minnows and darters (%)	1	<16	16-32	>32	6.2
Metric 9.	Proportion of individuals as piscivores (%)	1	<1	1-5	>5	0.7
Metric 10.	Catch rate (average number / unit sampling effort)	1	<8	8-16	>16	7
Metric 11.	Proportion of individuals as hybrids (%)	3	>1	1-Tr	0%	0.7
Metric 12.	Proportion of individuals with disease, tumors, fin damage, and other anomalies (%)	1	>5	5-2	<2%	7.5
IBI SCORE		32		POOR		

decline or disappear in degraded streams (Angermeier 1983). Metric 7 in this category, the proportion of individuals as omnivores, received a moderate score of 3. The percent of omnivores in the community generally increases as the physical and chemical habitat deteriorates.

Another component of the IBI analysis which did not fare well was Fish Abundance and Condition. Typically this category evaluates "such attributes of populations as abundance, age structure, growth and recruitment rates, and fish condition," according to Karr et al. (1989). Two of the three metrics in this category also scored poorly. The catch rate (average number / unit sampling effort), Metric 10, was an extremely low 7. Normally, sites with lower integrity support fewer individuals. The proportion of individuals in poor condition, Metric 12, was greater than the 5% prescribed by the scoring criteria which indicated that both the health and condition of the fish at this site were poor at the time of sampling. The proportion of individuals as hybrids, Metric 11, received a moderate score of 3 (0.7%) indicating that the amount of reproductive isolation or the suitability of the habitat for reproduction may be declining. The percent of hybrids and introduced species generally increases with increasing environmental degradation (Karr et al. 1986; Plafkin et al. 1989).

Four of the six metrics within the Species Composition category of the analysis for Love Creek received moderate scores of 3. This category "assesses the species richness component of diversity and the health of the major taxonomic groups and habitat guilds of fish," according to Plafkin et al. (1989). One of the moderate metrics was 1, the number of native species. The occurrence of 12 native species somewhat approximated the expected number of 20 (Tables 6 and 7). Typically the number of native species will decline with increased environmental degradation, excluding hybrids and introduced species (Karr 1981; Karr et al. 1986). Another one of the metrics with a moderate score was 2, the number of darter species. Only one darter species was caught at the station. Darter species are sensitive to degradation resulting from siltation and benthic oxygen depletion because they feed and reproduce in benthic habitats (Karr et al. 1986; Plafkin et al. 1989). A substantial amount of siltation was present at the station as indicated by the habitat analysis which will be discussed later. The number of intolerant species, Metric 5, was the third metric in this category to receive a moderate score. Intolerant species are typically the first species to disappear following a disturbance of some kind (Plafkin et al. 1989). The proportion of individuals as tolerant species, Metric 6, which distinguishes between low and moderate quality water by evaluating the degree to which typically tolerant species dominate the community, was the last metric in this category to receive a moderate score of 3.

Two metrics in the Species Composition category scored well. One of them was the number of sunfish species, Metric 3. These pool species decrease with increased degradation of pools and instream cover (Gammon et al. 1981). The other metric to score well was 4, the number of sucker species. These species are sensitive to physical and chemical habitat degradation and commonly comprise most of the fish biomass in streams.

Benthic macroinvertebrate sampling at the station located on Love Creek resulted in a mean abundance of 179.3 organisms per sq m, or 602 fewer than Fisher Creek, the reference stream (Tables 10 and 14). There were 33 total taxa, or 31 fewer than the reference stream indicating a slight impact, and 5 EPT taxa, or 25 fewer than the reference stream indicating a severe impact (Table 3). Since some of the more pollution-intolerant EPT taxa were present, yet pollution-tolerant oligochaetes and chironomids did not dominate (Figure A-4), the stream's macroinvertebrate community indicated that it apparently suffers more from acute rather than chronic perturbations. In fact, the slight impact to the overall macroinvertebrate community, yet severe impact to the more sensitive EPT taxa, is indicative of a short-term environmental variation according to Plafkin et al. (1989).

Upon completion of the 1992 field collection, it was hypothesized that because of the macroinvertebrate findings, the low catch rate for fish, and the presence of an intolerant fish species (northern hog sucker), some sort of toxic slug

Table 14. Quantitative (mean abundance per square meter) and qualitative benthic macroinvertebrate data from Love Creek at Holston Drive, Knox County, Tennessee, July 7, 1992.

Taxa	Quant.	Qual.
Amphipoda:		
Gammaridae / Gammarus sp.	19.5	--
Annelida:		
Hirudenia	2.8	X
Oligochaeta	9.5	--
Coleoptera:		
Elmidae / Ancyronyx variegatus	--	X
Dubiraphia sp.	--	X
Optioservus sp.	13.4	--
Stenelmis sp.	51.3	X
Decapoda:		
Cambaridae / Cambarus sp.	2.2	X
Diptera:		
Athericidae / Atherix lantha	0.6	--
Chironomidae / Chironominae	2.8	--
Orthocladiinae	8.9	--
Tanypodinae	0.6	--
Empididae / Hemerodromia sp.	1.1	X
Tipulidae / Antocha sp.	1.1	--
Tipula abdominalis	0.6	X
Tipula sp.	--	X
Ephemeroptera:		
Baetidae / Baetis sp.	--	X
Ephemerellidae / Serratella deficiens	0.6	--

Table 14. (continued)

Taxa	Quant.	Qual.
Gastropoda:		
Pleuroceridae / Elimia simplex (18 relics)	0.6	--
Heteroptera:		
Gerridae / Gerris remigis	--	X
Hydrometridae / Hydrometra sp.	--	X
Veliidae / Rhagovelia obesa	--	X
Isopoda:		
Asellidae / Asellus sp.	0.6	X
Lirceus sp.	0.6	--
Megaloptera:		
Sialidae / Sialis sp.	0.6	X
Odonata:		
Aeshnidae / Boyeria vinosa	--	X
Calopterygidae / Calopteryx sp.	--	X
Coenagrionidae / Enallagma sp.	--	X
Gomphidae / Gomphus sp.	--	X
Pelecypoda:		
Corbiculidae / Corbicula fluminea	20.6	--
Trichoptera:		
Hydropsychidae / Cheumatopsyche sp.	5	--
Hydropsyche betteni / depravata	22.9	X
Hydropsyche sp. (early instar)	13.4	X
MEAN ABUNDANCE / SQ M	179.3	
TOTAL (SAMPLE SIZE)	321	
TOTAL TAXA	33	
TOTAL EPT TAXA	5	

had moved through the station prior to sampling. In support of this hypothesis, the stream has a history of toxic spills. In 1988, a textile factory released wash water into the stream via underground aquifers (R. Parsley, KUB, personal communication), and in 1990 a diesel spill occurred resulting in a fish kill event (W. Schacher, TWRA, personal communication). The presence of northern hog suckers could be explained in one of two ways. Either they found shelter from the toxicant, or they migrated back into the sampling station following the disturbance. The slight impact to the overall macroinvertebrate community, yet severe impact to the more sensitive EPT taxa, was also indicative of a short-term environmental variation according to Plafkin et al. (1989).

A return trip was made on April 27, 1993, to conduct a brief qualitative sample of the fish community in order to determine if this hypothesis could be substantiated. Because of time limitations, neither a complete IBI was conducted nor a sample of the macroinvertebrate community taken. Two riffles, two runs, and two pools were sampled. In the six efforts a total of 139 specimens were collected consisting of 11 species: creek chub, snubnose darter, blacknose dace, banded sculpin, gizzard shad (Dorosoma cepedianum), spotfin shiner, striped shiner, central stoneroller, rock bass, northern hog sucker, and white sucker. The catch rate for this brief analysis was 23.2%. With the catch rate increase of 16.2%, and a history of the prior toxic spills in this stream, it is believed that this evidence supports the hypothesis that the release of some toxic substance preceded the 1992 sample.

All water quality parameters were within the normal ranges (Table 11). Water chemistry analysis revealed a high level of fecal coliform bacteria, 670 coliform colonies per 100 ml (Table 12), indicating that the stream warrants further sampling to determine whether or not it should be posted by the state. Fecal streptococcal bacteria were within acceptable limits. Lead was found in the water column at a concentration of 5 ppb (Table 12). This is 2 ppb higher than the 3 ppb concentration considered acute for fish and aquatic life by TDEC (1991). However, it should be mentioned that the toxicity of this metal is dependent on water hardness, which was not measured in this study. A comparison of sediments from Fisher Creek and Love Creek (Table 15) revealed substantially higher concentrations of aluminum, barium, chromium, copper, iron, lead, manganese, and zinc in the latter. Shineldecker (1992) identified the following industries as possible sources of these types of effluents: metal finishing, foundries, battery manufacturing, porcelain, and aluminum forming. According to Clements et al. (1988), "unlike many forms of organic pollution, particularly nutrient enrichment, in which macroinvertebrate abundance may actually increase owing to dominance by a few tolerant species, heavy metals are usually toxic to most aquatic organisms."

Table 15. Chemical analysis from sediment samples taken between June 20 and July 25, 1992.

Parameter*	Fisher Creek	Love Creek	2nd Creek (Upper)	2nd Creek (Lower)
Al	4,050	7,920	7,980	4,850
Ba	34	146	73	128
Cd	<0.2	1	0.6	3.3
Cr	11	37	19	20
Cu	6.1	12.2	20.9	53.9
Fe	16,200	49,100	14,200	16,800
Pb	8	68	125	202
Mn	371	2,200	695	723
Ni	7	14	10	11
Zn	34	354	243	621
N (ammonia)	36.7	<10	59.7	20
NO2-NO3	3.3	2.1	16.9	1.9
N (T.Kjeld)	340	534	2,080	982
P (Total)	247	378	574	592
COD (sediment)	6,206	41,100	43,100	39,600
BOD (sediment)	296	168**	692	428***
EXTRACT. PET. HYDROCARBONS (ug/kg)	23,900	37,800	197,000	417,000

*All results expressed in mg/kg unless otherwise stated
**Avg. of 207 and 128 at 5 and 4% depletion, respectively
***At 11% depletion

Love Creek scored 88 on its habitat assessment giving it a comparability measure to the reference stream of 59.1%, which is midway between no potential and partial potential to support an acceptable level of biological health (Table 5). The principal parameters of the analysis in which the stream scored the lowest points included: embeddedness, channel alteration, upper bank stability, and bank vegetative protection. Habitat quality undoubtedly contributed to the poor condition of the fish community. Gorman and Karr (1978) and Mendelson (1975) all indicated that stream habitat complexity is correlated with fish species diversity because of their tendency to become habitat specialists. Gorman and Karr (1978) found that natural streams with complex habitats supported fish communities of high species diversity which were seasonally more stable than the lower diversity communities of modified streams with less complex habitats. They list three components of stream environments that are important in the habitat specialization of stream fish: substrate, depth, and current, all of which can be adversely affected after disturbances such as channelization (Gorman and Karr 1978). Siltation, one of the most serious perturbations identified at the station on Love Creek, appeared to be contributing to the decline of benthic macroinvertebrates in the stream. Typically, the number of substrate types is a good predictor of species richness for benthic insects (Allan 1975) and freshwater mollusks (Harman 1972). Because these groups spend their adult life on the substrate, it is not surprising that species richness is correlated with substrate diversity. However, when siltation covers the substrate, its diversity no longer exists, and a more homogeneous environment is created. Lenat (1981) found that as sediment is added to a stream, the area of available rock habitat decreases (where benthic fauna mainly occur), with a corresponding decrease in benthic density.

The highest scores earned in the habitat assessment at this station were in the principal categories of bottom substrate and instream cover and riparian and bank structure (riparian vegetative zone width). The variety of substrate types and instream cover found could provide sufficient habitat to support a healthy community of aquatic organisms had it not been for siltation. The riparian vegetative zone width also provides ample shade, which is necessary to reduce water temperature fluctuations and erratic photosynthetic activity within the stream.

Second Creek (Upper Station)

Fish sampling on Second Creek at the station located above several industries consisted of 12 electrofishing runs, 2 seine hauls, and 1 qualitative sample. The two seine hauls were conducted in slow deep runs, since the station lacked pool habitat. Therefore, three consecutive seine hauls, without a new species in this type of habitat, could not be completed. Seven efforts were required in the run habitats before three could be completed without a new species. Four riffles were sampled before this habitat could meet the same criteria. An additional three runs were electrofished to cover the entire stretch of available habitat. The 14 sampling efforts produced 295 fish (Table 7) representing 5 of the 16 species expected to occur (Table 6). Those not found included bigeye chub, greenside darter, snubnose darter, stripetail darter, banded sculpin, spotfin shiner telescope shiner, warpaint shiner, whitetail shiner, rock bass, and northern hog sucker. Fish caught, but unexpected, were bluegill, mosquitofish, and fathead minnow (introduced). Seven of the 8 species caught were native. The mosquitofish and the fathead minnows caught at this station were excluded from this metric. The fathead minnow was excluded because its range is somewhat ambiguous. Used as a bait fish, it has been introduced to several areas outside its natural range. No darters, 1 sunfish, and 1 sucker species were represented in the priority groups (Tables 7 and 8). No intolerant species occurred. Tolerant species (excluding the mosquitofish) present at this station included: creek chub, striped shiner, and white sucker, which all together composed 15.9% of the total population (Figure A-2). Anomalies consisted of: black spot disease which was noted on 74 blacknose dace, 1 striped shiner, and 1 central stoneroller, and fin rot found on 1 blacknose dace. All together, these anomalies were found on 39.0% of the population (Figure A-3).

The IBI score for the upper station on Second Creek was 36, giving it a health or quality classification midway between "poor" and "fair" (Tables 2 and 16). The Species Composition category of the IBI analysis was adversely affected by the lack of darters and intolerant species (Tables 6 and 7). Zero percentages for Metrics 8 (specialized insectivorous minnows and darters) and 9 (piscivores) indicated that the energy base and trophic dynamics of the community were shifting "toward more generalized foraging that typically occurs with increased degradation of the physicochemical habitat," according to Plafkin et al. (1989). Catch rate approximated the expected conditions as did the zero percentage of hybrids. Unfortunately, the moderately high percentage of anomalies (39%) indicated that the fish community was generally in poor health at the time of sampling.

Benthic macroinvertebrate sampling on the upper station of Second Creek yielded a mean abundance of 710.1 organisms per sq m, or 71.2 fewer than the reference stream (Tables 10 and 17). Fifteen total taxa and no EPT taxa (Table 17) were identified in the samples, both of which indicated that the stream's micro-habitats within the sampling area have been severely impacted (Table 3). Oligochaetes and chironomids dominated the sample with a proportion of 92.9% (Figure A-4)

Table 16. Analysis of IBI for Second Creek (Upper Station) at Inskip Road, Knox County, Tennessee, June 20, 1992 (Tr = Trace value between 0 and 1%).

		Scoring 1992	Scoring Criteria			Observed 1992
			1	3	5	
Metric 1.	Number of native fish species	3	<5	5-10	>10	6
Metric 2.	Number of darter species	1	<2	2	>2	0
Metric 3.	Number of sunfish species (excluding <u>Micropterus</u> sp.)	5	0	-	>0	1
Metric 4.	Number of sucker species	3	0	1	>1	1
Metric 5.	Number of intolerant species	1	0	1	>1	0
Metric 6.	Proportion of individuals as tolerant species (%)	5	>59	59-30	<30	15.9
Metric 7.	Proportion of individuals as omnivores (%)	5	>45	45-22	<22	3.4
Metric 8.	Proportion of individuals as specialized insectivorous minnows and darters (%)	1	<16	16-32	>32	0
Metric 9.	Proportion of individuals as piscivores (%)	1	<1	1-5	>5	0
Metric 10.	Catch rate (average number / unit sampling effort)	5	<8	8-16	>16	19.7
Metric 11.	Proportion of individuals as hybrids (%)	5	>1	1-Tr	0	0
Metric 12.	Proportion of individuals with disease, tumors, fin damage, and other anomalies (%)	1	>5	5-2	<2	39
	IBI SCORE	36	POOR TO FAIR			

Table 17. Quantitative (mean abundance per square meter) and qualitative benthic macroinvertebrate data from Second Creek (Upper Station) at Inskip Road, Knox County, Tennessee, July 11, 1992.

Taxa	Quant.	Qual.
Amphipoda:		
Gammaridae / *Gammarus* sp.	1.1	--
Annelida:		
Oligochaeta	140.5	X
Decapoda:		
Cambaridae / *Cambarus* sp.	1.1	X
Diptera:		
Chironomidae / Chironominae	30.1	X
Orthocladiinae	463.2	X
Tanypodinae	25.6	--
Empididae / *Hemerodromia* sp.	33.4	--
Simuliidae	3.9	--
Tipulidae / *Antocha* sp.	--	X
Tipula sp.	0.6	X
Gastropoda:		
Planorbidae sp. (1 relic)	--	--
Pleuroceridae / *Elimia simplex* (21 relics)	--	--
Heteroptera:		
Gerridae / *Gerris remigis*	--	X
Isopoda:		
Asellidae / *Asellus* sp.	10.6	--

Table 17. (continued)

Taxa	Quant.	Qual.
Odonata:		
Calopterygidae / *Calopteryx* sp.	--	X
Coenagrionidae / *Enallagma* sp.	--	X
Pelecypoda:		
Corbiculidae / *Corbicula fluminea*	--	X
MEAN ABUNDANCE / SQ M	710.1	
TOTAL (SAMPLE SIZE)	1,274	
TOTAL TAXA	15	
TOTAL EPT TAXA	0	

indicating a severe degradation to the stream environment.

All water quality parameters were normal (Table 11) at the time of sampling. Since this stream has already been posted by the state, the high fecal coliform bacterial count of 1,350 fecal coliform colonies per 100 ml came as no surprise (Table 12). Here again, the fecal streptococcal bacterial level was within acceptable limits. Water chemistry analysis indicated that 4 ppb of lead was present in the water column (Table 12) which, at the time of sampling, could be considered an acute concentration to fish and aquatic life depending on water hardness.

A comparison between the reference stream's sediment analysis and the upper station on Second Creek's sediment analysis (Table 15) revealed substantially higher concentrations of aluminum, barium, copper, lead, and zinc in the latter stream. These trace metal effluents have been associated with automobile maintenance facilities by Shineldecker (1992). With 20% of this section of the stream's subwatershed composed of commercial areas, it was speculated that a number of the potential toxicants were introduced by gasoline stations located in the area. The sediment grab sample taken at this station indicated a possible high concentration of extractable petroleum hydrocarbons (197,000 ug/kg) in comparison to the reference stream's (23,900 ug/kg) (Table 15). Shineldecker (1992) also associated this effluent with automobile maintenance facilities. A possible source may have been the lawn tractor repair shop located on the station.

The habitat assessment score for the upper station on Second Creek was 102 giving it a comparability measure of 68.5% which indicated that it has the potential to partially support an acceptable level of biological health at the time of sampling (Table 5). In this portion of the study, the IBI analysis served as a good indicator of the quality of the macro-habitat in comparison to the health of the fish community, since both scored midway between poor and fair condition. The principal parameters of the habitat analysis in which the station scored the lowest points included channel alteration and riparian vegetative zone width. The highest scores were in the canopy cover and bank vegetation parameters. The station had a diversity of shade conditions which was considered optimal (Figure A-1), with different areas of the sampling station receiving direct sunlight, complete shade, and filtered light. The high amount of vegetative coverage on the banks provided sufficient erosion protection.

Second Creek (Lower Station)

Fish sampling on Second Creek, below the area of the watershed containing several industries, consisted of 11 electrofishing runs, 1 seine haul, and 2 qualitative samples. This station, like the upper station, lacked sufficient pool habitat which limited the number of seine hauls that could be conducted. The run habitat was completed with three electrofishing efforts producing no new species. Seven attempts were required in the riffle habitat. The 12 sampling efforts produced 466 fish (Table 7) representing five of the expected species (Tables 6 and 7). Those not found included bigeye chub, river chub, blueside darter, greenside darter, snubnose darter, stripetail darter, banded sculpin, spotfin shiner, striped shiner, telescope shiner, warpaint shiner, whitetail shiner, rock bass, black bass, and northern hog sucker. Collections of unexpected fish during the sampling effort consisted of the mosquitofish and fathead minnow. Excluding the mosquitofish, five of the seven species caught were native. No darters, 1 sunfish, and 1 sucker species were represented in the priority groups (Tables 7 and 8). No intolerant species occurred. Tolerant species (excluding the mosquitofish) present at this station included the creek chub and white sucker which all together composed 18.7% of the total population (Figure A-2).

Pollution-tolerant striped shiners found at the upper station did not occur within the sampling area at the lower station. The loss of a tolerant species which usually dominates in disturbed surface waters could indicate severe degradation, since the proportion of tolerant species (Metric 6) are used to distinguish between low and moderate quality water (Plafkin et al. 1989). Black spot disease was the only anomaly found to occur at this station. It was noted on 35 creek chubs, 283 blacknose dace, 71 central stonerollers, and 3 white suckers. The percentage of anomalies increased from 39% at the upper station to 84.1% at the lower station (Figure A-3). According to Plafkin et al. (1989), anomalies occur more frequently below point sources and in areas where toxic chemicals are concentrated, a fact which was supported by this finding.

The IBI score for the lower station on Second Creek was 32, giving it a health or quality classification of "poor" (Tables 2 and 18). Species Composition deviated strongly from the expected values because of the low number of native species (Metric 1), no darter species present (Metric 2), and no intolerant species occurring (Metric 5). The number of native sunfish (excluding Micropterus sp.) and sucker species, Metrics 3 and 4, scored moderately well, implying that the physical habitat may not be as severely degraded as perhaps the chemical environment. Only 18.7% of the station's fish community was composed of tolerant species (Figure A-2), which is the last metric in the Species Composition category. This indicated that they did not dominate the population. Trophic Composition received low scores for the proportion of individuals as specialized insectivorous minnows and darters (Metric 8) and the proportion of individuals as piscivores (Metric 9). Omnivores dominated the trophic structure of the community. Karr (1981) found that as site quality declines,

Table 18. Analysis of IBI for Second Creek (Lower Station) at Oklahoma Avenue, Knox County, Tennessee, June 20, 1992 (Tr = Trace value between 0 and 1%).

		Scoring 1992	Scoring Criteria			Observed 1992
			1	3	5	
Metric 1.	Number of native fish species	1	<6	6-13	>13	5
Metric 2.	Number of darter species	1	<1	1-3	>3	0
Metric 3.	Number of sunfish species (excluding <u>Micropterus</u> sp.)	3	0	1	>1	1
Metric 4.	Number of sucker species	3	0	1	>1	1
Metric 5.	Number of intolerant species	1	<1	1	>1	0
Metric 6.	Proportion of individuals as tolerant species (%)	5	>59	59-30	<30	18.7
Metric 7.	Proportion of individuals as omnivores (%)	5	>45	45-22	<22	7.5
Metric 8.	Proportion of individuals as specialized insectivorous minnows and darters (%)	1	<16	16-32	>32	0
Metric 9.	Proportion of individuals as piscivores (%)	1	<1	1-5	>5	0
Metric 10.	Catch rate (average number / unit sampling effort)	5	<8	8-16	>16	33.3
Metric 11.	Proportion of individuals as hybrids (%)	5	>1	1-Tr	0	0
Metric 12.	Proportion of individuals with disease, tumors, fin damage, and other anomalies (%)	1	>5	5-2	<2	84.1
	IBI SCORE	32		POOR		

the proportion of individuals that are omnivores increases. "The dominance of these species presumably arises as a result of degradation in the food base, especially invertebrates," according to Karr (1981). This study supported Karr's finding since the mean abundance, total taxa, and total EPT taxa values were all substantially lower than the reference stream's (Table 10). A high catch rate of 33.3 (Table 18), combined with no hybrids (Metric 11) being found at the station, might have indicated that the lower station on Second Creek approximated what would be expected for fish recruitment, mortality, and abundance. However, it must be remembered that species composition was very low, so a large proportion of the population was made up of only a few species and they were in poor condition, which, as mentioned earlier, deviated strongly from what was expected.

Benthic macroinvertebrate sampling on the lower station of Second Creek produced a mean abundance of 49.1 organisms per sq m, or 732.2 fewer than the reference stream (Tables 10 and 19). Fourteen total taxa and no EPT taxa were identified in the samples, indicating that the stream's micro-habitats have been severely impacted (Table 3). Here, as in the upper station, pollution tolerant oligochaetes and chironomids dominated the macroinvertebrate community at 88.6% (Figure A-4).

All water quality parameters were within the normal ranges (Table 11) at the time of sampling. However, there was

Table 19. Quantitative (mean abundance per square meter) and qualitative benthic macroinvertebrate data from Second Creek (Lower Station) at Oklahoma Avenue, Knox County, Tennessee, July 17, 1992.

Taxa	Quant.	Qual.
Annelida:		
Hirudenia	0.6	--
Oligochaeta	18.4	X
Decapoda:		
Cambaridae / Cambarus sp.	--	X
Diptera:		
Chironomidae / Chironominae	5	X
Orthocladiinae	18.4	X
Tanypodinae	1.7	X
Empididae / Hemerodromia sp.	1.7	--
Simuliidae	--	X
Tipulidae / Tipula sp.	--	X
Gastropoda:		
Pleuroceridae / Elimia simplex (1 relic)	--	--
Heteroptera:		
Gerridae / Gerris remigis	--	X
Isopoda:		
Asellidae / Asellus sp.	3.3	--
Odonata:		
Aeshnidae / Boyeria vinosa	--	X
Calopterygidae / Calopteryx sp.	--	X
Coenagrionidae / Enallagma sp.	--	X
MEAN ABUNDANCE / SQ M	49.1	
TOTAL (SAMPLE SIZE)	88	
TOTAL TAXA	14	
TOTAL EPT TAXA	0	

a substantial increase in water temperature between the upper (18.5 C) and lower stations (26 C). Since these stations were sampled on the same day, the large difference in temperature was attributed to thermal discharge from nearby roadways and parking lots. Incredibly high counts for both fecal coliform and fecal streptococcal bacteria (5,900 and 6,500 colonies / 100 ml respectively) were found in the grab water sample (Table 12). Leaking sewer lines on the stream have resulted in continually high fecal coliform counts (J. West, TDEC, personal communication), and Shineldecker (1992) identified the meat processing industry as a source of high fecal streptococcal bacteria counts in urban situations.

Water chemistry analysis indicated 5 ppb of lead present in the water column at the time of sampling (Table 12) which is 1 ppb greater than the upper station, and 2 ppb greater than the level recommended by TDEC (1991). A comparison between the upper and lower stations sediment analyses indicated a lower concentration of aluminum and higher concentrations of barium, cadmium, copper, lead, and zinc at the lower station (Table 15). These trace metals are all industry-related and generally arise from metal finishing (Sax 1979; Shineldecker 1992). As mentioned earlier, a metal processing plant is located within the this station's subwatershed. Extractable petroleum hydrocarbons increased from 197,000 ug/kg to 417,000 ug/kg between the upper and lower stations (Table 15). A large portion of this increase could potentially be traced to the railroad shop located within the this station's subwatershed, since this type of effluent is associated with the railroad industry (Shineldecker 1992). However, it must be remembered that the sediment samples were only taken once. Therefore, only inferences can be made regarding contributors to toxicants in the sediments.

The habitat assessment score for the lower station on Second Creek was 72 giving it a comparability measure of 43.3% (Table 5). This indicated that, at the time of sampling, the station did not have the potential to support an acceptable level of biological health. Here again, the IBI analysis served as a good indicator of the relationship between habitat quality and the health of the fish community, since this station scored poorly on the IBI analysis as well. No excellent scores occurred for any of the parameters. The lowest ("poor") scores in the habitat analysis were achieved in the embeddedness and bank stability parameters (Table A-3). Sub-optimal (or good) scores were earned for the flow/velocity, canopy cover, and streamside cover parameters (Table 4). All other scores were within the marginal or fair range.

Additional Stream Comparisons

Additional comparisons can be made among streams in regards to their health and certain attributes of the biotic communities residing within them. For example, fish species considered to be pollution-intolerant only occurred in Fisher and Love Creeks (Figure A-2), with a larger percentage (8.9%) of the population in Love Creek made up of intolerant species (Figure A-2). A greater percentage (37.7%) of the pollution-tolerant species also comprised the population in Love Creek (Figure A-2), indicating a tendency toward low water quality either preceding the sample or at the time of sampling (Plafkin et al. 1989). However, it must be remembered that Love Creek had a substantially smaller sample size and catch rate (Figures A-2 and A-13), and only one intolerant species occurred in Love Creek (northern hog sucker) while two (telescope shiner and northern hog sucker) occurred in Fisher Creek. No intolerant species occurred at either station on Second Creek (Figure A-2) which differed from the findings of the other study associated with this project located further downstream on Second Creek and closer to the reservoir. Holdeman (1993, unpublished) documented 4 northern hog suckers which could most likely be attributed to either reservoir influence or their proximity to point source discharges. Tolerant species made up less than 25% of the populations on both stations located on Second Creek for this study (Figure

A-2) which agreed with Holdeman's (1993, unpublished) findings. In fact, a majority of the populations in all the study streams were intermediate in pollution tolerance. The dominance of moderately tolerant fish generally indicates that conditions have degraded enough to limit or eliminate intolerant fish, but have not reached a point where tolerant species dominate (Holdeman 1993, unpublished).

The percentage of individuals with poor condition, injury, deformity, disease, and other anomalies (Metric 12) increased substantially from a low of 3.4% at the least impacted station (Fisher Creek), to a high of 84.1% at the most impacted station of the study, the lower station on Second Creek (Figure A-3). The low percentage (7.5%) of anomalies that were found on the fish in Love Creek might also possibly indicate a one-time toxic event preceding the sampling effort (Figure A-3). Karr et al. (1986) and Plafkin et al. (1989) stated that the percentage of omnivores in the community increases as the physical and chemical habitat deteriorates. However, no clear relationship between the level of impact and the percentage of omnivores could be found in this study.

In comparing the benthic macroinvertebrate samples among the study streams, it can be noted that Fisher Creek had more than 4 times the sample size of Love Creek and almost 16 times the most impacted, lower station on Second Creek (Figure A-8). Pollution-sensitive EPT comprised almost half of the taxa in the Fisher Creek samples and almost a third of the taxa in the Love Creek samples (Figure A-4). However, Love Creek had a substantially lower sample size. No intolerant benthic macroinvertebrate taxa occurred at either station on Second Creek. Approximately 95% of the populations at these two stations were composed of pollution-tolerant chironomid and oligochaete taxa (Figure A-4). Their dominance is consistent with Hilsenhoff's (1988) and Wallace's (1990) findings which showed that these two groups exhibit more pollution-tolerance than other benthic macroinvertebrate taxa. Their dominance can most likely be attributed to an increase in soft substrates due to erosion (Holdeman 1993, unpublished). The benthic macroinvertebrate samples for Love Creek indicated a severe impact to the EPT taxa and slight impact to the total taxa, which may also signify a one-time event such as a toxic slug passing down the stream.

As indicated earlier, grab water and sediment samples were taken at all stations. It is probable that the high lead concentrations at both stations on Second Creek and the station on Love Creek contributed to their poor ratings. However, there is an inherent bias associated with grab samples taken along a chemical gradient which is subjected to erratic slugs of chemicals such as those samples taken in Second and Love Creeks (Winner et al. 1980). The frequency with which biologically damaging concentrations of toxic chemicals occurred at each of these stations was probably the most important factor in determining the structure of their fish and benthic macroinvertebrate communities (Winner et al. 1980). The most striking evidence of this was found on Love Creek which has fewer reported spills than Second Creek (J. West, TDEC, personal communication). Here, the pollution-intolerant northern hog sucker was present in the fish community, yet there was a low catch rate, and pollution-intolerant caddisflies (Trichoptera) were present in the insect community, yet the total number of taxa was low.

Man-induced Perturbations

Habitat modifications to the urban stream sampling stations undoubtedly contributed to the loss in species richness and diversity for both the fish and macroinvertebrate communities. According to Gorman and Karr (1978), the ability of stream environments to retain their complexity is reduced by man's modification of the stream habitat to suit his needs. For example, in an attempt to increase drainage efficiency, meanders were removed from sections of the channels on Love and Second Creeks. This increased the stream gradient and resulted in little buffering from floods and droughts and increased their severity to biota in the streams (Gorman and Karr 1978).

Eutrophication (on a seasonal or temporary basis) resulting from the removal of riparian vegetation and the addition of sewage from industrial and municipal sources also affects biota in these streams. Removal of the riparian vegetation, as noted on the upper station of Second Creek, increased the problem associated with the substantial elevation in the number of algal blooms during the summer and their subsequent decomposition in the fall (Gorman and Karr 1978). This, along with sewage discharge, can result in extreme fluctuations in the biological oxygen demand (BOD) of these streams.

The thermal regime was undoubtedly upset in these streams as well. The removal of shade-producing vegetation, such as the area on the upper station of Second Creek, maximizes solar heating of the water on a seasonal basis. This, along with thermal discharges (from storm drains during rain events), can lead to extreme water temperature fluctuations. Water temperatures can change from one section of stream to another and from one time to another more so in urban than in rural streams (J. West, TDEC, personal communication).

The final man-induced habitat modification noted in this study was excavation activities within the Second and Love Creek watersheds and its associated silt pollution. The build-up of silt in the substrate reduced, if not eliminated, those species that directly require silt-free benthic environments, such as the benthic macroinvertebrate community, or indirectly for reproduction and feeding, such as the fish community (Berkman et al. 1986; Karr et al. 1986).

Chapter 5

CONCLUSIONS

Analyses of the taxa data indicate that the composition of the fish and macroinvertebrate assemblages in the impacted and control sites differed considerably. However, as in many studies, it was difficult to separate the causes of the differences because they were numerous, periodic in some instances and often synergistic. According to Hocutt (1981), "Synergistic effects can mask the threshold effect of the 'pollutant' considered limiting." These single samples from the targeted streams in Knoxville, though limited in reliability because of the multi-stressed environments, were thought to be accurate reflections of the relative condition of the biota and the level of point and non-point source pollution impairment to them at the time of sampling. Gammon and Reidy (1981) have shown that, given proper ecological measures such as those used in the IBI, and a thorough sampling of available habitats, a single fish sample can usually rank comparable sites the same regardless of seasonal or annual variations. With this in mind, it is believed that the methods employed in this study gave an accurate representation of the biological communities resident within Knoxville's resident streams at the time of sampling.

Biotic integrity assessments of the fish communities indicated that Second Creek (below an industrial site) and

Love Creek were in "poor" condition (IBI = 32). However, as exhibited by the qualitative re-sampling of Love Creek in 1993, it is believed that its 1992 score may have been artificially lowered due to some sort of toxic event preceding the sampling effort. Second Creek (below a more rural area) scored 36, placing it in the "poor to fair" range. Fisher Creek, serving as the control stream, had a score of 58, indicating that it was in "excellent" condition at the time of sampling.

Data analyses of the benthic macroinvertebrate communities supported the IBI findings very well on all but one station. They identified the upper station on Second Creek as being severely impacted while the IBI analysis identified it as midway between "poor and fair" condition. This may be due, in part, to effluents coming from the lawn tractor repair shop located at the station.

Multi-stressed environments, like those found in the Knoxville streams, have complicated analyses in the past. Because of this, only generalizations can be made concerning the level of impact both point source and non-point source pollution are having on biotic communities. The solution to these water resource problems will not come from better regulation of chemicals or the development of better assessment tools to detect degradation alone. According to Karr and Dudley (1981) and Bedford and Preston (1988), the most critical need is to develop monitoring, assessment, regulatory, and restoration approaches that evaluate not only the biota but the complex dynamics of degradation at local levels as well.

The Metropolitan Planning Commission's goal of improving the water quality in Knoxville's streams is feasible. Restoration of the degraded streams' physical habitats would be the most cost efficient means of achieving this goal. This could include replacing natural stream meanders, heterogeneity of bottom substrate, and pool habitat lost to channelization, as well as dredging the stream bottoms to remove silt. Riparian buffer zones with greenways (such as the one presently under construction on Third Creek) could be established to prevent further erosion and make the project aesthetically pleasing, and more stringent erosion control regulations could be developed.

In conjunction with these physical habitat improvements on the degraded streams, the state, city, and county governments could implement and strictly enforce regulations to help improve water quality. These actions could include: (1) aggressive enforcement of National Pollutant Discharge Elimination System (NPDES) permits issued to industries located in the streams' watersheds, (2) implement and fully fund research related to thermal discharge from non-point source pollution and its effects on urban stream biota, and (3) improve the city's ability to maintain sewer lines and eliminate any remaining storm water and sewer lines that are combined. In order to protect reaches of Knoxville's urban streams, and their tributaries, that have not yet been developed, the city could require riparian buffer zones along the streams and establish minimum distances between paved areas and the streams.

With the benchmarks established by this study, IBI methodology can be used in the future to monitor, regulate, and ensure that restoration efforts are succeeding. It is extremely doubtful that the Knoxville streams could ever reach "pristine" conditions in order to be judged healthy. Therefore, management decisions will have to be based on the amenities that the City of Knoxville desires them to have. It will then become a question of prioritizing these amenities during remediation efforts.

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Appendix

FIGURE PAGE

HABITAT ASSESSMENT FIELD DATA SHEET
RIFFLE/RUN PREVALENCE

Habitat Parameter	Category			
	Optimal	Sub-Optimal	Marginal	Poor
1. Bottom substrate/ instream cover (a)	Greater than 50% mix of rubble, gravel, submerged logs, undercut banks, or other stable habitat. 16–20	30–50% mix of rubble, gravel, or other stable habitat. Adequate habitat. 11–15	10–30% mix of rubble, gravel, or other stable habitat. Habitat availability less than desirable. 6–10	Less than 10% rubble, gravel, or other stable habitat. Lack of habitat is obvious. 0–5
2. Embeddedness (b)	Gravel, cobble, and boulder particles are between 0–25% surrounded by fine sediment. 16–20	Gravel, cobble, and boulder particles are between 25–50% surrounded by fine sediment. 11–15	Gravel, cobble, and boulder particles are between 50–75% surrounded by fine sediment. 6–10	Gravel, cobble, and boulder particles are over 75% surrounded by fine sediment. 0–5
3. ≤0.15 *cms (5 cfs)*— Flow at rep. low	Cold >0.05 cms (2 cfs) Warm >0.15 cms (5 cfs) 16–20	0.03–0.05 cms (1–2 cfs) 0.05–0.15 cms (2–5 cfs) 11–15	0.01–0.03 cms (.5–1 cfs) 0.03–0.05 cms (1–cfs) 6–10	<0.01 cms (.5 cfs) <0.03 cms (1 cfs) 0–5
OR >0.15 cms (5 cfs)— velocity/depth	Slow (<0.3 m/s), deep (>0.5 m); slow, shallow (<0.5 m); fast (>0.3 m/s), deep; fast, shallow habitats all present. 16–20	Only 3 of the 4 habitat categories present (missing riffles or runs receive lower score than missing pools). 11–15	Only 2 of the 4 habitat categories present (missing riffles or runs receive lower score). 6–10	Dominated by 1 velocity/depth category (usually pools). 0–5
4. Canopy cover (shading) (c) (d) (g)	A mixture of conditions where some areas of water surface fully exposed to sunlight, and other receiving various degrees of filtered light. 16–20	Covered by sparse canopy; entire water surface receiving filtered light. 11–15	Completely covered by dense canopy; water surface completely shaded OR nearly full sunlight reaching water surface. Shading limited to <3 hours per day. 6–10	Lack of canopy, full sunlight reaching water surface. 0–5
5. Channel alteration (a)	Little or no enlargement of islands or point bars, and/or no channelization. 12–15	Some new increase in bar formation, mostly from coarse gravel; and/or some channelization present. 8–11	Moderate deposition of new gravel, coarse sand on old and new bars; and/or embankments on both banks. 4–7	Heavy deposits of fine material, increased bar development; and/or extensive channelization. 0–3
6. Bottom scouring and deposition (a)	Less than 5% of the bottom affected by scouring and/or deposition. 12–15	5–30% affected. Scour at constrictions and where grades steepen. Some deposition in pools. 8–11	30–50% affected. Deposits and/or scour at obstructions, constrictions, and bends. Filling of pools prevalent. 4–7	More than 50% of the bottom changing frequently. Pools almost absent due to deposition. Only large rocks in riffle exposed. 0–3
7. Pool/riffle, run/bend ratio (a) (distance between riffles divided by stream width)	Ratio: 5–7. Variety of habitat. Repeat pattern of sequence relatively frequent. 12–15	7–15. Infrequent repeat pattern. Variety of macrohabitat less than optimal. 8–11	15–25. Occasional riffle or bend. Bottom contours provide some habitat. 4–7	>25. Essentially a straight stream. Generally all flat water or shallow riffle. Poor habitat. 0–3
8. Lower bank channel capacity (b)	Overbank (lower) flows rare. Lower bank W/D ratio <7. (Channel width divided by depth or height of lower bank.) 12–15	Overbank (lower) flows occasional. W/D ratio 8–15. 8–11	Overbank (lower) flows common. W/D ratio 15–25. 4–7	Peak flows not contained or contained through channelization. W/D ratio >25. 0–3

Figure A-1. United States Environmental Protection Agency (Region IV) Habitat Assessment Field Data Sheet for riffle / run prevalent situations (modified from Plafkin et al. 1989).

Habitat Parameter	Category: Optimal	Sub-Optimal	Marginal	Poor
10. Bank vegetative protection (d)	Over 90% of the streambank surfaces covered by vegetation. 9–10	70–89% of the streambank surfaces covered by vegetation. 6–8	50–79% of the streambank surfaces covered by vegetation. 3–5	Less than 50% of the streambank surfaces covered by vegetation. 0–2
OR Grazing or other disruptive pressure (b)	Vegetative disruption minimal or not evident. Almost all potential plant biomass at present stage of development remains. 9–10	Disruption evident but not affecting community vigor. Vegetative use is moderate, and at least one-half of the potential plant biomass remains. 6–8	Disruption obvious; some patches of bare soil or closely cropped vegetation present. Less than one-half of the potential plant biomass remains. 3–5	Disruption of streambank vegetation is very high. Vegetation has been removed to 2 inches or less in average stubble height. 0–2
11. Streamside cover (b)	Dominant vegetation is shrub. 9–10	Dominant vegetation is of tree form. 6–8	Dominant vegetation is grass or forbes. 3–5	Over 50% of the streambank has no vegetation and dominant material is soil, rock, bridge materials, culverts, or mine tailings. 0–2
12. Riparian vegetative zone width (least buffered side) (e) (f) (g)	>18 meters. 9–10	Between 12 and 18 meters. 6–8	Between 6 and 12 meters. 3–5	<6 meters. 0–2
Column Totals	___	___	___	___
______ Score ___				

Figure A-1. (continued)

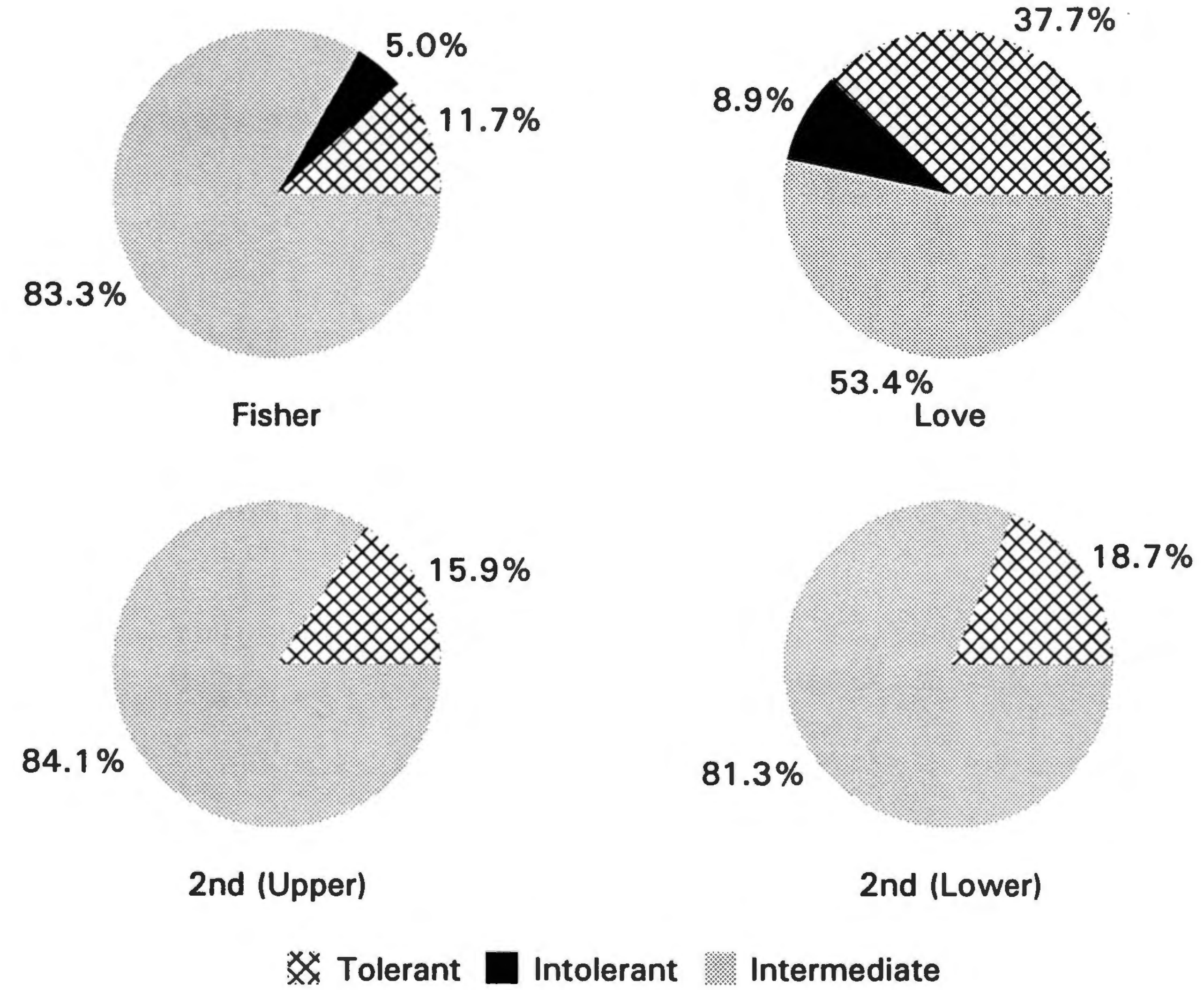

Figure A-2. Percent composition of pollution-intolerant and pollution-tolerant fish in the sampling stations populations.

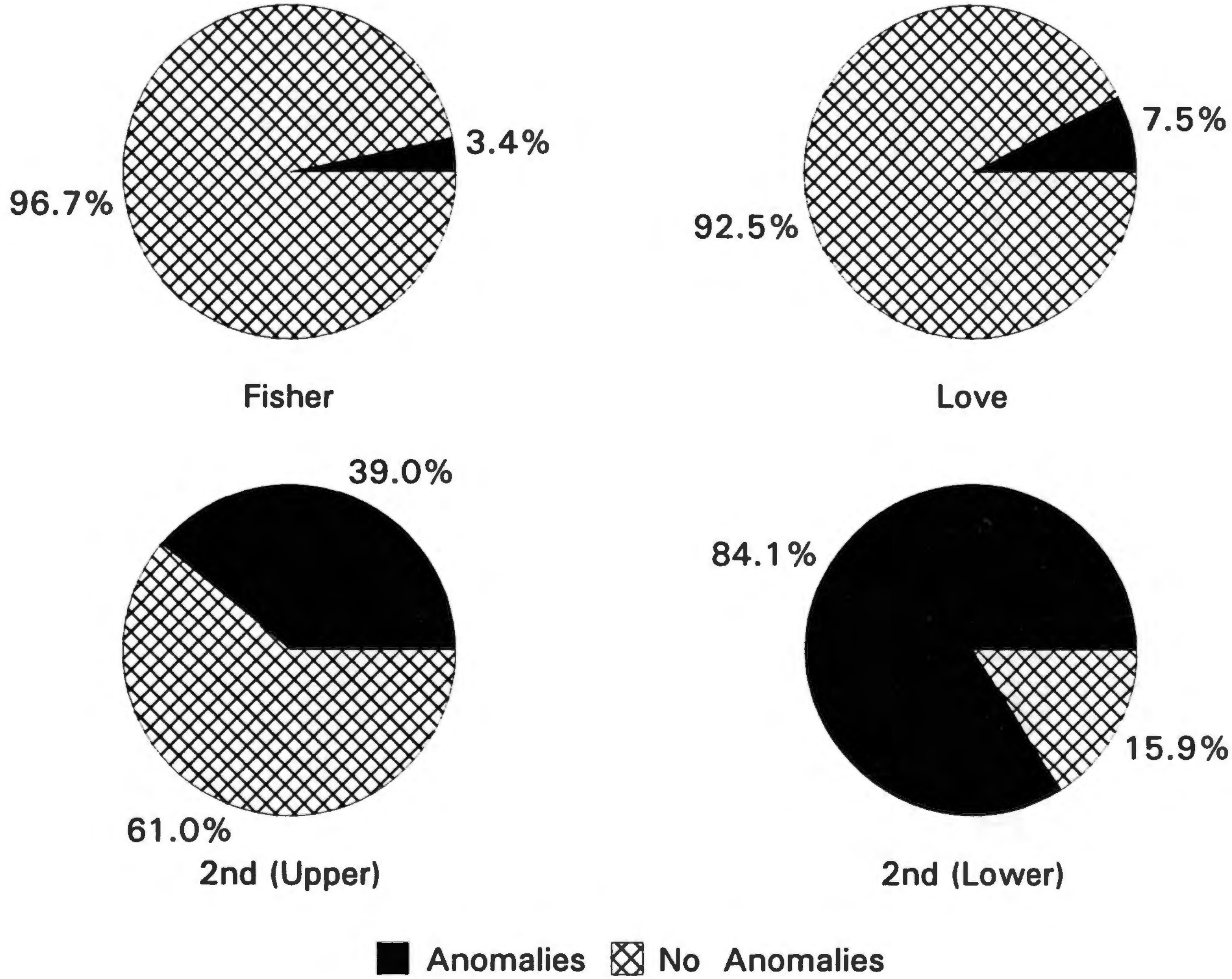

Figure A-3. Percent composition of fish with anomalies and without anomalies in each of the sampling station populations.

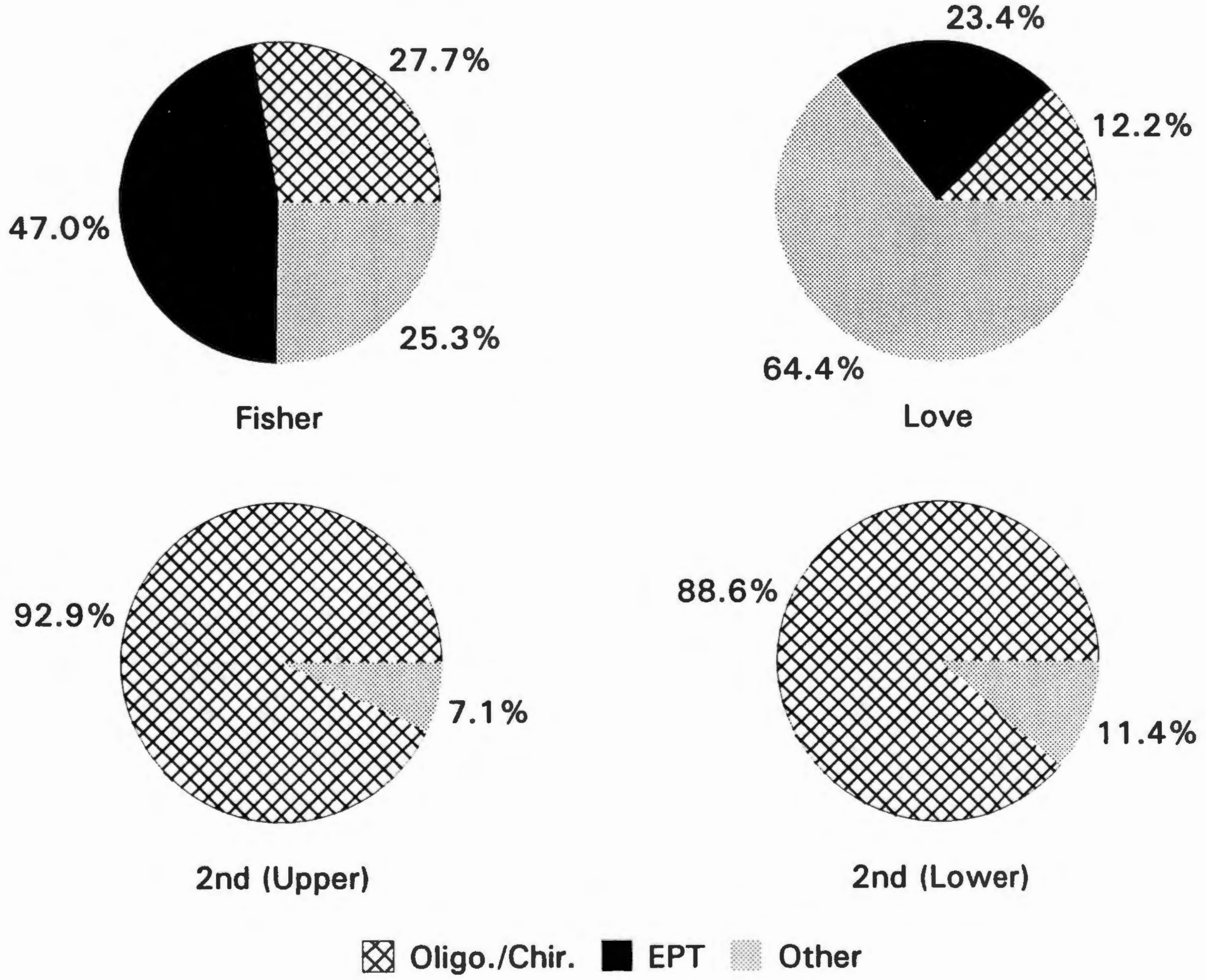

Figure A-4. Percent composition of oligochaete/chironomid and EPT taxa in each of the sampling station populations.

Vita

Kenneth Dean Gardner was born in South Bend, Indiana, on June 22, 1959. He attended elementary school in South Bend and graduated from Clay High School in June of 1977. Upon graduation, he accepted a position as a veterinary technician and attended Indiana University on a part-time basis. In September of 1984, Mr. Gardner moved to Knoxville, Tennessee to attend the University of Tennessee. During his undergraduate years, he worked as a seasonal park ranger for the U. S. Army Corps of Engineers in Hartwell, Georgia. Mr. Gardner received a Bachelor of Science degree in 1988 and was employed by the Corps of Engineers from June of 1988 through October, 1989, in Elberton, Georgia. In November of 1989 he accepted a biologist/technician position with Fish and Wildlife Associates, Inc. and worked for the company through May of 1990 at which time he accepted a temporary biological technician position with the Corps of Engineers in Charleston, South Carolina. In January of 1991, Mr. Gardner returned to the University of Tennessee, as a research assistant, to begin work on an advanced degree. In August of 1993, he was awarded the Master of Science degree in Wildlife and Fisheries Science. Mr. Gardner has been employed by Fish and Wildlife Associates, Inc. since May of 1991.

The author is a member of the honorary fraternity Gamma Sigma Delta. He is also a member of the American Fisheries

Society and the South Carolina Aquatic Plant Management Society.