THE FRESHWATER MUSSELS OF THE STONES RIVER ABOVE J. PERCY PRIEST RESERVOIR, TENNESSEE

A Thesis

Presented to

the Faculty of the Graduate School

Tennessee Technological University

by

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In Partial Fulfillment

of the Requirements for the Degree

MASTER OF SCIENCE

Biology

June 1982

AN ABSTRACT OF A THESIS

THE FRESHWATER MUSSELS OF THE STONES RIVER ABOVE
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Master of Science in Biology

This study investigated the status of the freshwater mussel (naiad) populations of the Stones River. A possible change in species number was anticipated following the impoundment of the lower portion. (22 percent) of the river and the declining water quality in the basin. Thirty-nine, ten, and eight stations were established on the three main tributaries of the stones River to sample naiads and water quality, benthic macroinvertebrates, and fish, respectively. Stations were sampled from April 1980 to March 1981.

The number of naiad species in the Stones River has declined from a reported 45 in 1968 to 30 found in this study. There was an increase in the number of naiad species with distance from each point source of pollution in the East and West Forks. Diversity and evenness values computed for benthic macroinvertebrates were higher upstream and far downstream, than immediately downstream, of each point source. Warm water temperatures, low flows, high BOD effluents, increased nutrients, and gravel dredging are suspected to have caused the decline of the naiad fauna of the Stones River.

ACKNOWLEDGMENTS

I wish to express my gratitude and appreciation to my graduate committee chairman, Dr. R. Don Estes, for his suggestions, advice, and editing of the manuscript. I would also like to thank committee members, Dr. Robert E. Martin and Dr. John A. Gordon, for their advice and editing of the manuscript. Thanks also go to Dr. James A. Gore for his advice with the statistical analysis. A special thanks is extended to Mr. James F. Sharber of the U. S. Army Corps of Engineers, Nashville District, for his assistance in the planning and field stages of this study.

I would also like to thank Mr. H. Joe Cathey and the U. S. Army Corps of Engineers, Nashville District, for making this study possible. The author also appreciates the equipment and facilities furnished by the Tennessee Cooperative Fisheries Research Unit, Tennessee Technological University, and the U. S. Army Corps of Engineers, Nashville District.

Thanks are given to Dr. Paul W. Parmalee and Dr. David H. Stansbery for their help in confirming difficult naiad identifications, to Dr. David A. Etnier for his confirmation of fish identifications, and to Mr. Glenn Johnson for his assistance with water quality analysis. The author would also like to thank his colleagues and fellow graduate students, Randy Clark, Martin Garrett, Robert Karwedsky, Chris O'Bara, and Karen Fitzmayer for their assistance in the field.

Finally, thanks go to my parents for their support and to my wife, Jean, for her assistance in the field and laboratory and for her support and understanding throughout the study.

This study was funded, in part, by the Tennessee Cooperative Fisheries Research Unit. Cooperators of the Unit are: Tennessee Technological University, the Tennessee Wildlife Resources Agency, and the U. S. Fish and Wildlife Service.

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Chapter 1

INTRODUCTION

The Stones River was reputed to have one of the richest populations of freshwater mussels (naiads) in the Cumberland River Basin prior to the impoundment of the lower section in 1968. Much of the remaining portions of the upper Stones River basin, the East, West, and Middle Forks is reported to still support populations of naiads. However, the general feeling among malacologists is that the existing naiad fauna of the system is not as rich as the impounded sections used to be.

This study was initiated to determine the current status of the naiad population in the upper Stones River. A preliminary survey of the naiad population during April 1980 by this researcher revealed that it in fact was not as rich as it used to be (Stansbery 1980; Sharber 1980). Therefore, comparisons were made with the findings of previous investigations and possible reasons for the change in the naiad population were investigated.

There have been many studies on the naiads of various streams in the Cumberland River Basin (Wilson and Clark 1914; Neel and Allen 1964; Stansbery 1969, 1970a; Blankenship and Crockett 1972; Parmalee et al. 1980), but very few have been done on the naiads of the Stones River (Tucker 1972; Wilson and Clark 1914). Several biologists have collected in the Stones River in cooperation with Dr. Stansbery of Ohio State University who conducted a preimpoundment study from 1965 to 1968.

Although he has not published a report of their research, he did provide a species list for comparison with the findings of this study.

Chapter 2

LITERATURE REVIEW

Parchment (1961) did a limnological study of the Stones River including bottom fauna, plankton, and chemical-physical conditions of the river. He concluded that "the Mollusca were the most common organisms based on numbers per square foot" (p. 127) in the Stones River.

Several investigators have collected naiads in the Stones River. Wilson and Clark (1914) conducted an investigation of the Cumberland River and its tributaries. During their study they examined the East Fork at Walterhill and the West Fork at Murfreesboro. They found the river at Walterhill to be shallow and turbid with numerous riffles. Below the ford at Walterhill they found large numbers of a previously undescribed species *Truncilla*(=*Epioblasma*) *walkeri*. They also found many "remarkably large" *Lasmigona costata*. At Murfreesboro they found many *Anodonta grandis* and *L. costata* "of large size on the bank, recently killed by pearlers" (p. 32). Wilson and Clark (1914) described the naiad fauna of the Stones River as being remarkable because it had several species not found in the Cumberland River. They found the genus *Anodonta* nowhere else in the Cumberland River Basin. They also remarked on a peculiar interchange of species between the Stones River and the Cumberland River. *Lampsilis ovata* and *Amblema plicata* of the Cumberland River were replaced by *Lampsilis ventricosa* and *Megalonaias nervosa* in the Stones River.

Stansbery (1980) collected 45 species of naiads in the Stones River and its forks before its impoundment in 1968. Stansbery (1970a) reported that the "last known population of Epioblasma lenoir is now covered by the (J. Percy) Priest Reservoir on the Stones River in Tennessee" (p. 19). Stansbery also reported Epioblasma walkeri to be restricted to the lower Stones River. Stansbery (1966) reported finding Cumberlandia monodonta in the Stones River in 1965.

Tucker (1972), while an undergraduate at Middle Tennessee State University, did a composition and distribution survey of the naiad fauna of the upper Stones River in which he identified 18 genera and 24 species. A more reasonable species list should have only 21 species since four of the species listed were found out of their respective ranges and were probably misidentified and three species were misnamed.

Hargis (1969) conducted an inventory of the lakes, ponds, reservoirs, and streams of Rutherford County. He found the West Fork and Middle Fork to have a sluggish average velocity and subject to farm pollution. The East Fork was found to be subject to moderate flooding, sporadic pollution, and have a sluggish average flow. He found all three streams to lie in a fertilely-rich watershed.

Pelren (1971) conducted the same survey for Cannon County. He found the East Fork to normally be slightly turbid in color and listed gravel dredging and waste disposal as two of the stream uses.

Other investigators have studied the macroinvertebrates of the Stones River. Chandler (1978) used basket samplers to sample the benthic macroinvertebrates of the West Fork. He found Chironomidae present at all stations as well as composing 50 percent of all specimens collected. Maloney and Chandler (1976) did a survey of the leeches of the upper Stones River basin in which they found eight species.

Chantrasorn (1975) did a survey of the stonefly nymphs of Rutherford and Cannon Counties. He recorded 18 species, ten of which were new records in Tennessee. Smith (1973) surveyed the Gerridae (Hemiptera) of the Stones River and other streams in the Tennessee Inner Central Basin.

Several water quality studies have been conducted on the Stones River and J. Percy Priest Reservoir. Galloway (1919) found much of the water in the basin that falls as rain to run into sink holes. Burchett and Moore (1971) surveyed the water resources in the upper Stones River basin. They found the basin's predominately limestone bedrock formations to store little water; most of the water entering streams in the basin came out of solution cavities. The Tennessee Division of Water Quality Control (TDWQC) (1977) and Burdick and Drewry (1973) both assessed the water quality of the Stones River. In both studies, the State's water quality standard for dissolved oxygen was violated below the Murfreesboro sewage treatment plant on the West Fork and below the Woodbury sewage treatment plant on the East Fork. Both groups cited several fish kills on each tributary downstream of each treatment plant.

Chapter 3

AREA DESCRIPTION

In 1968, the U. S. Army Corps of Engineers closed the gates of J. Percy Priest Dam on the Stones River to create J. Percy Priest Reservoir. The remaining free-flowing portions of the Stones River are a short stretch (6.8 miles) downstream of the dam and three main forks upstream of the reservoir--the East, West, and Middle Forks which form the upper Stones River basin. The upper Stones River basin lies in the northcentral portion of the Nashville Basin physiographic region with the Eastern Highland Rim forming its easternmost boundary. Short Mountain (2092 ft. m.s.l.) in eastern Cannon County is the highest elevation in the basin. The lowest point in the upper basin is approximately the level of the reservoir ranging from 480 feet m.s.l. to 504 feet m.s.l. (U. S. Army Corps of Engineers 1978).

The East Fork drops off the Highland Rim flowing westward across Cannon County, meandering 53.3 miles northwestward across Rutherford County and entering J. Percy Priest Reservoir near Smyrna. The Middle Fork flows 14 miles northwestward across southern Rutherford County joining the West Fork near Barfield. The West Fork flows 30 miles northward across southern Rutherford County past Murfreesboro and enters J. Percy Priest Reservoir near Smyrna.

The tributaries of the Stones River are characterized by "many alternating riffles and long pools" (Parchment 1961, p. 11). Hargis (1969) estimated the East, West, and Middle Forks to be 85 percent, 70 percent, and 80 percent pools, respectively. There is good cover along the majority of each tributary and the aquatic macrophyte, *Justicia americana*, is very abundant.

The climate of the Middle Tennessee region is characteristically mild. The temperature rarely drops below -4°C, climbs above 32°C, and usually averages 16°C (Parchment 1961). During July 1980 the temperature was well above 32° (90°F) almost every day. Rainfall in the basin averages 124 cm (46.70 inches) (United States Army Corps of Engineers 1978).

The geology of the Stones River basin is dominated by a 500-foot thick bed of Ordovician limestone. Streams in the basin flow in well-defined channels in the limestone bedrock. The region is characterized by solution cavities which range in size "from a fraction of an inch to several inches high, from several tens of feet to several hundred feet wide, and from a fraction of a mile to several miles long" (Moore et al. 1969, p. 1). Soils in the region average 1.2 m (4 ft.) thick, ranging from 10.6m(35 ft.) in portions of Cannon County to bare rock in parts of Rutherford County.

Approximately 20 percent of the watershed is in timber, 50 percent in pasture, and 30 percent is in cultivation (Hargis 1969).

Chapter 4

MATERIALS AND METHODS

Naiads, benthic macroinvertebrates, fish, and water quality were sampled at various stations on the East, West, and Middle Forks of the Stones River from April 1980 to March 1981 (Figure 1 and Appendix). Data for the upper Stones River basin was also gathered from other sources to aid in defining present and previous land use and water quality conditions in the basin.

This chapter is divided into five major sections. The first four deal with the collection and laboratory procedures and data analysis used for naiads, benthic macroinvertebrates, fish, and water quality collected. The fifth section describes the data obtained from other agencies and how it was obtained.

Naiads

This section deals with station selection, collection and identification, and data analysis procedures utilized to assess the naiad populations of the Stones River.

Station Selection

Thirty-eight stations were established on the three forks to collect naiads. Station selection was based on ease of access, known occurrence of naiads (or habitat), and/or the proximity to a point source of pollution.

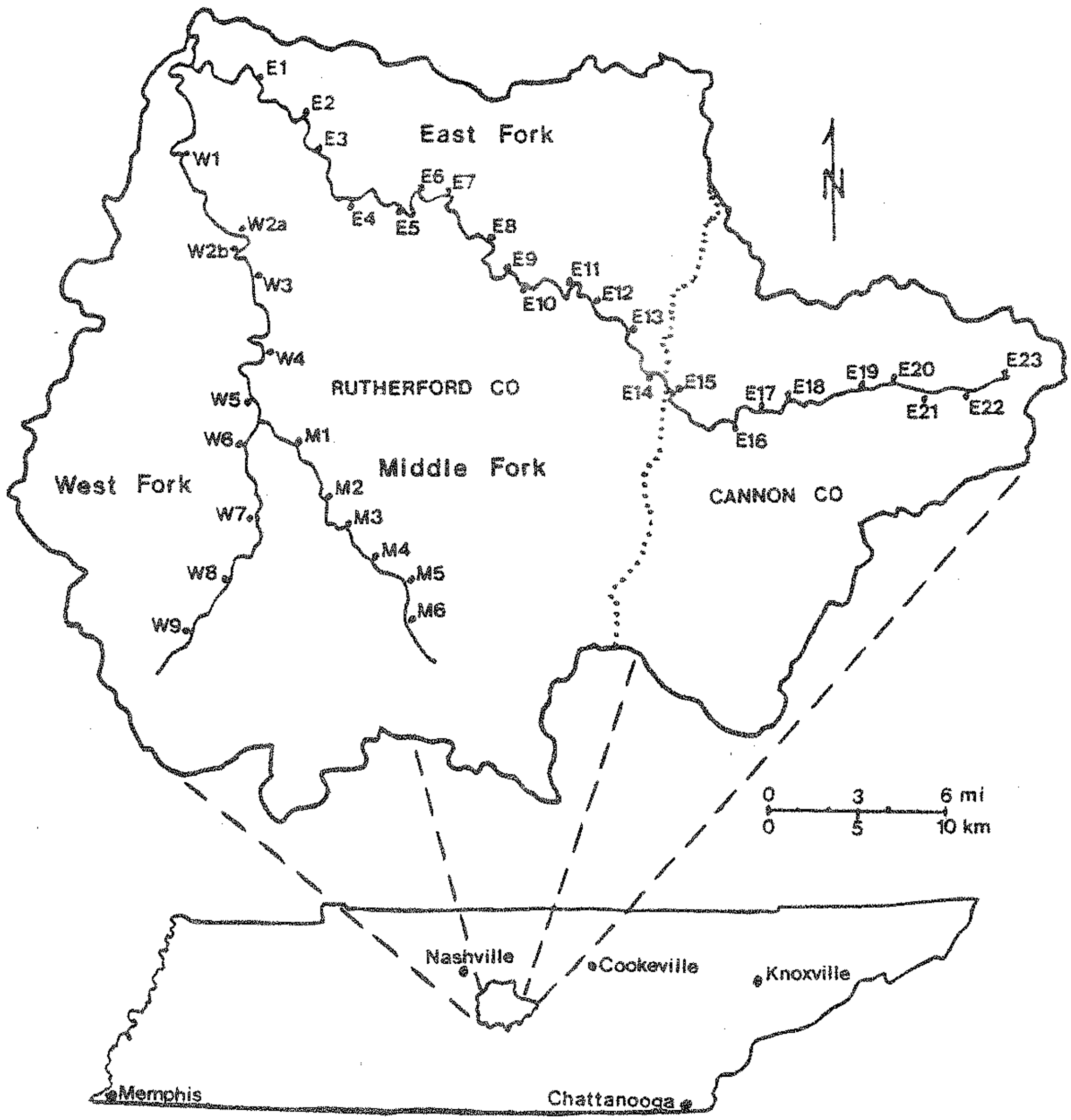

Figure 1. Stations Sampled in the Upper Stones River Basin

Collection and Identification

Each of the 39 stations was visited at least once with most stations having more visits during the 12-month study (Table 1). Stations used and collecting methods employed were very similar to those of Stansbery (1980) in his preimpoundment study. In conjunction with a visit to a station for other purposes (benthic macroinvertebrates, fish, water quality, etc.), the presence of naiads was also noted.

Each site was initially sampled for naiads by walking the banks and wading the shallow areas looking for freshly dead or subfossil shells (Table 2). Shells located in these areas were collected, placed in heavy plastic bags, and labeled for each station. Shells found in these areas were usually washed up in high water or brought up by muskrats and raccoons. The shell piles (middens) made by these mammals are common and often turn up species that are usually found in deep water. Live naiads were located with the aid of an underwater viewing scope. Once located, they were removed from the substrate by hand in shallow water (less than 1 m) or with a modified garden rake. The rake was modified with a wire mesh basket to retain naiads while allowing sand and gravel to pass through.

The majority of live specimens were identified in the field and returned as close as possible to where they were found. Representative and unidentifiable specimens were preserved in the field with 10 percent formalin or 70 percent ethanol, tagged, and brought back to the lab for identification. Occasionally naiads were placed on ice in a cooler, brought back to the lab, cleaned, and then identified. All unidentified specimens collected alive were cleaned and their soft parts removed to aid in identification. Species were identified to the species level

Table 1. Number of Collection Trips Made to Each Station for Naiads, Benthic Macroinvertebrates, Fish, and Water Quality from April 1980 to March 1981

Site	Naiads	Benthic Macroinvertebrates	Fish	Water Quality
E1	8	–	–	4
E2	10	–	–	4
E3	13	2	1	6
E4	2	–	–	–
E5	8	–	–	2
E6	5	–	–	2
E7	6	–	–	2
E8	9	–	1	2
E9	9	–	–	3
E10	3	–	–	–
E11	10	–	–	5
E12	1	–	–	–
E13	5	2	–	3
E14	14	–	–	4
E15	7	–	2	3
E16	7	–	–	3
E17	1	–	–	1
E18	5	2	–	2
E19	9	2	–	4
E20	3	2	–	2
E21	10	–	1	5
E22	6	–	–	4
E23	2	–	–	1
W1	10	2	2	3
W2a	4	2	–	1
W2b	3	2	–	2
W3	4	–	–	1
W4	4	–	–	1
W5	6	–	–	2
W6	6	2*	1	1
W7	6	–	–	2
W8	6	–	1	–
W9	4	–	–	1
M1	3	–	–	1
M2	8	2*	2	2
M3	4	–	–	1
M4	4	–	–	–
M5	4	–	–	1
M6	4	–	–	2
Totals	233	20	11	83

*These stations were dry in the fall.

Table 2. Naiad Specimen Classification (Adapted From Buchanan [1980])

Condition	Condition
Living	Obvious biological functions
Freshly Dead	No soft parts but shell with some luster; periostracum relatively intact
Subfossil	Shell without luster; periostracum peeling off
Fossil	Shell chalky, often brittle; little or no periostracum

using keys and descriptions in Burch (1975), Bogan and Parmalee (1979), Murray and Leonard (1962), and Parmalee (1967). All collected specimens were verified by either Dr. Paul W. Parmalee, Director, McClung Museum, The University of Tennessee, Knoxville, TN, or Dr. David H. Stansbery, Director, Museum of Zoology, The Ohio State University, Columbus, OH.

Data Analysis

All naiad species collected were recorded and listed by station. Comparisons were made with Stansbery's (1980) unpublished data. Each species was discussed in terms of its abundance, distribution, and whether it was threatened or endangered.

Benthic Macroinvertebrates

This section will detail the procedures for station selection, collection and identification, and data analysis for benthic macroinvertebrates.

Station Selection

Ten stations of the 39 stations were sampled for benthic macroinvertebrates during a five-week period in the late spring (May 28, 1980, to July 1, 1980) and during a five-week period in the late fall (November 1, 1980, to December 7, 1980) (Table 1). The purpose for sampling benthic macroinvertebrates was to determine if the known point sources of pollution in the upper Stones River basin were having deleterious effects on the streams. One sample was collected upstream, another immediately downstream, and at three other intervals downstream of the Woodbury sewage treatment plant (STP) on the East Fork Stones River. Samples were collected at three upstream stations, one immediately downstream and one far downstream of the Murfreesboro STP on the West and the Middle Fork (one station) Stones River.

Collection and Identification

Sampling was accomplished with a Surber square-foot bottom sampler. At each station, three samples were taken in either an upstream or lateral direction (Weber 1973) in riffle areas. Care was taken at each station to choose areas that were similar in type of riffle, flow regime, and collectability. Every effort was made to use the same level of effort for each sample taken. Actual sampling began with the sampler resting firmly on the substrate. Then large rocks within the frame were gently scrubbed with a soft vegetable brush in front of the net so dislodged invertebrates would drift into the net. The remaining substrate was then dislodged to a depth of approximately 10-15 cm until little or no turbidity was visible (Surber 1962).

All samples were preserved in the field with 70 percent ethanol and returned to the lab where they were sorted from extraneous matter with the aid of a 3X scanning lens. Specimens were identified to the lowest practical taxonomic level (usually genus) using keys by Usinger (1956), Pennak (1953), Wiggins (1977), Parrish (1968), Williams (1976), Brown (1972), Hobbs (1976), Schuster and Etnier (1978), and Sinclair (1964).

Due to the drought experienced in the region during the summer and fall of 1980, the fall samples were not used. It was felt that these samples were affected by the drought and would not be representative.

Data Analysis

Diversity, evenness, and number of taxa were determined for each station sampled.

Diversity. Diversity indices are a tool for measuring environmental quality and the effect of stress on macroinvertebrate community structure. Most undisturbed environments support relatively large numbers of species with no species in overwhelming abundance (Weber 1973). The higher the diversity, the healthier the community. Kovalik (1981) recommended the Shannon-Weaver index because it is relatively insensitive to sample size, and it is recommended by the U. S. Environmental Protection Agency for the purpose of uniformity (Weber 1973).

Diversity was calculated by the following Shannon-Weaver diversity index formula:

$$H'(\text{diversity}) = \sum_{i=1}^{n} p_i \log_2 p_i$$

where p_i = the proportion of the i^{th} species in the sample.

Evenness. Evenness is also used as a measure of environmental quality. Evenness is defined as how evenly the proportions of the community are distributed. Evenness ranges from 0.0 to 1.0 with high values indicative of healthy systems and low values indicative of stressed systems. A modified version of Pielou's (1975) evenness formula was used.

$$\text{Evenness}(E) = H' \div H'_{max}$$

where $H'_{max} = \log_{10} S \cdot 3.32198$

and S = Number of taxa in the community.

Number of taxa. The number of taxa was determined for each station after all identifications were completed.

Fish

The importance of fish in the life cycle of naiads is well documented (Coker et al. 1921; Stein 1968; Yokley 1972; Mathiak 1978). Fish serve as a host organism for the glochidia or larval stage of naiads. Many naiad species have specific host fish and will not develop on other fish species. Therefore, the availability of the correct host fish species is critical to the maintenance of each naiad species, community, or population. This section will deal with collection and identification and with data analysis for fish species in the Stones River tributaries.

Collection and Identification

To assess whether specific fish hosts were present in the upper Stones River basin, fish were collected at eight of the stations (Table 1) by seining and electroshocking. Collecting was done in riffle and pool areas over substrate favorable to naiads. The net used was a 3.0-by 1.2-meter seine with 3 mm mesh. Electroshocking was accomplished with a portable Honda generator rigged with two AC electrodes.

Most of the game fish collected were identified in the field and released. Other fish collected were preserved in the field with 10 percent formalin solution and brought to the lab for identification. Fish were identified to the species level with the help of keys by Eddy (1969), Pflieger (1975), and Etnier (1981). Dr. David A. Etnier, Department of Zoology, The University of Tennessee, Knoxville, TN, verified all collected specimens.

The presence of game and rough fish species not collected during the study was verified in interviews with fishermen during visits to sampling stations.

Data Analysis

A list of fish species was tabulated for each stream in order to determine if the host fish were present.

Water Quality

This section will deal with the collection, lab, and data analysis procedures employed for water quality assessment during this study.

Collection and Laboratory Procedures

Thirty-four of the stations were sampled for water quality during the study period (Table 1). The majority of this sampling was done in conjunction with naiad or benthic macroinvertebrate sampling at these stations.

Parameters measured in the field were temperature, dissolved oxygen (D.O.), pH, and conductivity. Temperature and D.O. were both measured with a Yellow Springs Instrument (YSI) Model 54 Oxygen meter. An Analytical Measurements, Inc., Model 107 pH meter was used to measure pH. Conductivity was measured using a YSI Model 33 S-C-T meter.

Parameters measured in the lab were alkalinity and hardness. Samples were collected in the field in 1 quart (0.9461 l) Cubitainors. They were then placed on ice in a cooler and transported to the lab where they were later analyzed. Alkalinity was determined by titrating with 0.02N sulfuric acid to a pH of 4.5. Hardness was determined by titrating standard EDTA with Eriochrome Black T indicator to a blue endpoint.

Data Analysis

Water quality data was tabulated by day of collection in an effort to observe water quality trends during the study period.

Data From Other Sources

Data from other sources consists of stream use classification, gravel dredging activities, fishkill activities, agricultural chemical use, farm crop statistics, and water quality and flow data over the last 20 years. This data was obtained from published sources and by personal conversations and correspondence.

Chapter 5

RESULTS AND DISCUSSION

This chapter is divided into four sections. The first section will discuss collection results and data analysis for benthic macroinvertebrates. The second section will report the results of fish collections and discuss naiad/fish host relationships. The third section will report the results of the water quality collections and discuss information gathered from other sources. The fourth section will discuss the collection results and data analysis for naiads.

Benthic Macroinvertebrates

This section will give the results on the quantitative benthic macroinvertebrate collections and then discuss the results of the data analysis made on each sample.

Collection Results

Benthic macroinvertebrates were collected from a total of ten stations--five on the East Fork, four on the West Fork, and one on the Middle Fork. Results of the spring samples appear in the Appendix.

Data Analysis

Figures 2 and 3 illustrate the diversity, evenness, and number of taxa for the ten stations sampled for benthic macroinvertebrates.

According to Wihlm (1970, benthic macroinvertebrate communities from clean water generally have diversity values ranging between 3.0

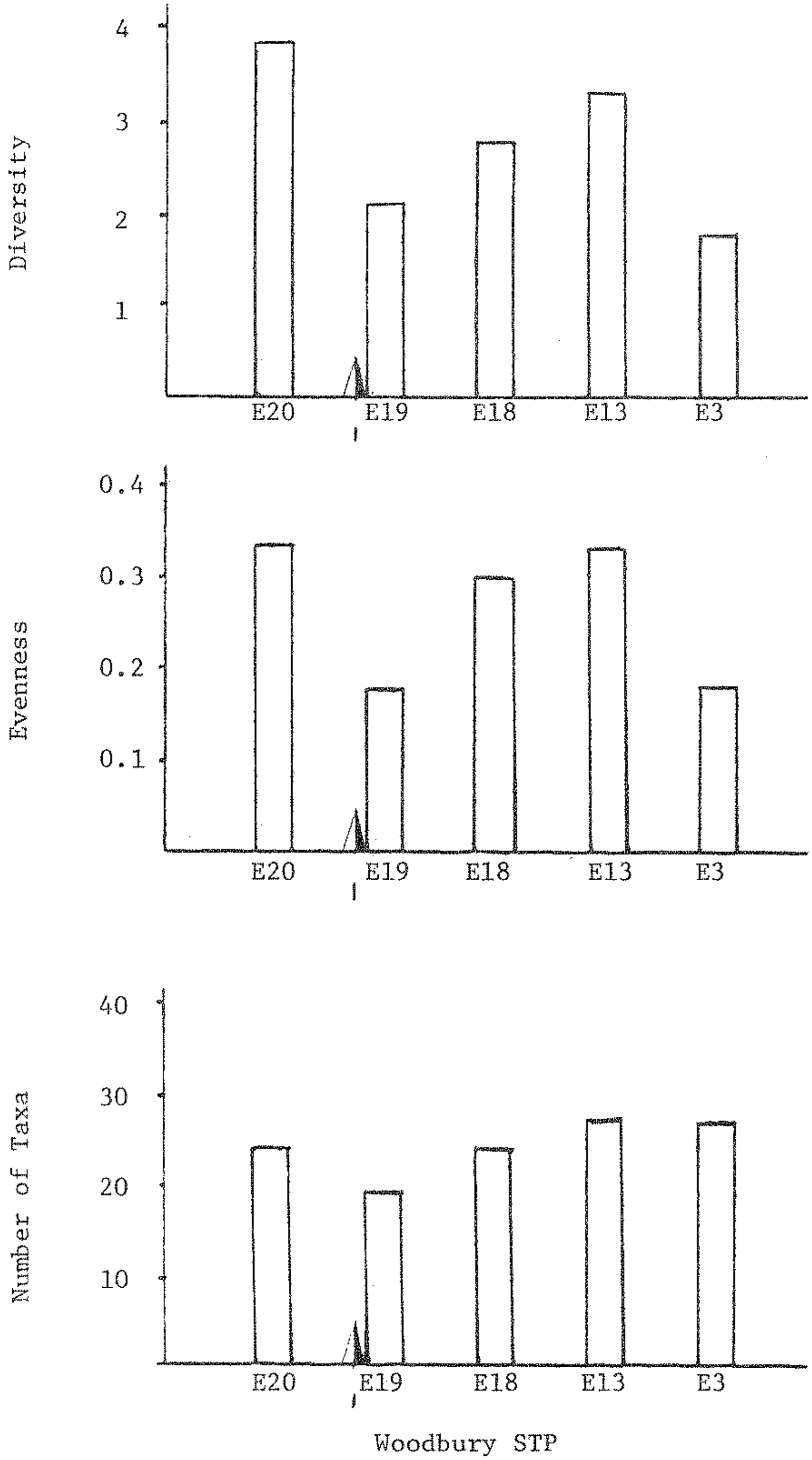

Figure 2. Diversity, Evenness, and Number of Taxa of Macroinvertebrates at Selected Sites on the East Fork of the Stones River

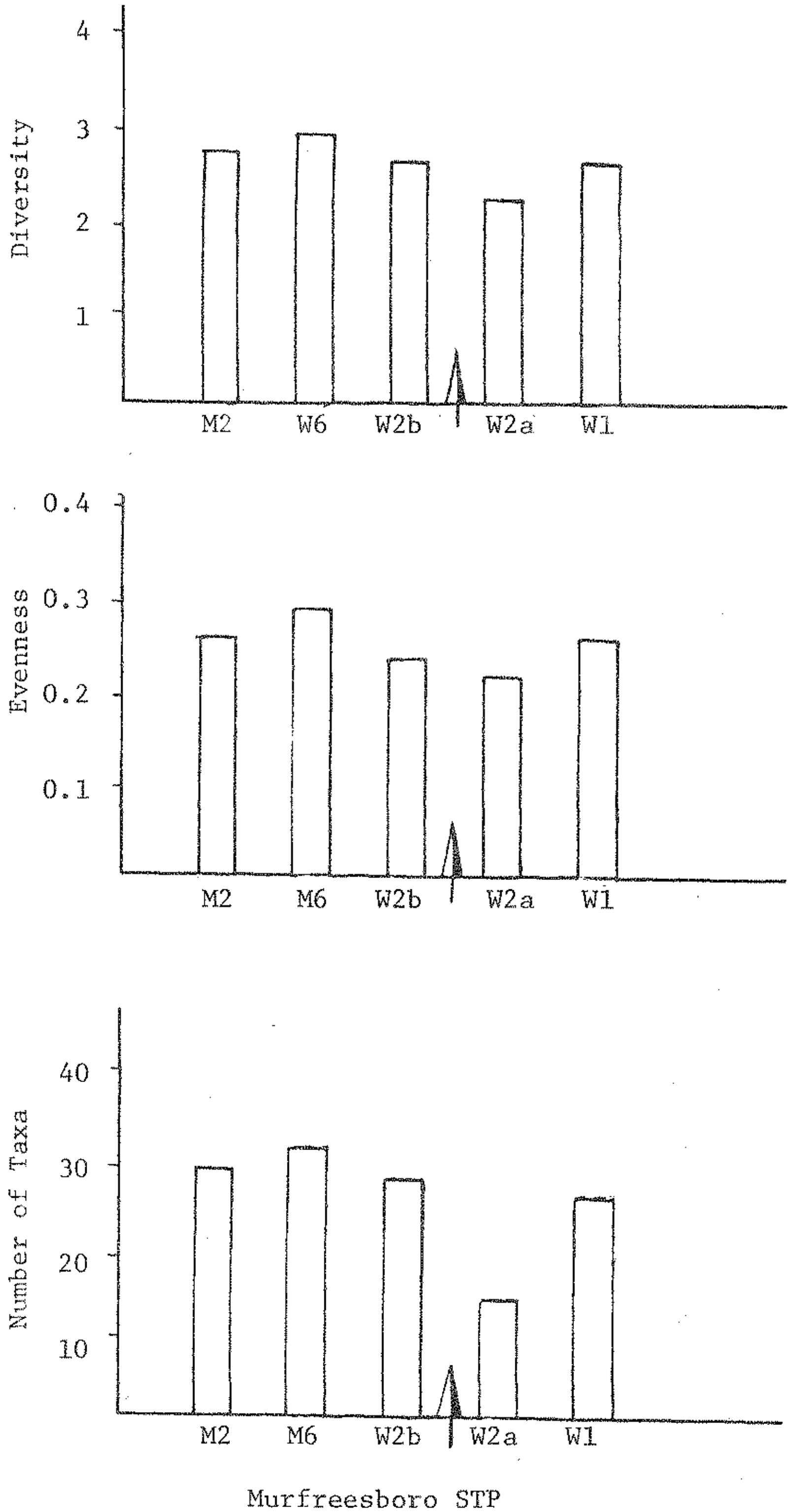

Figure 3. Diversity, Evenness, and Number of Taxa of Macroinvertebrates at Selected Sites on the Middle and West Forks of the Stones River

and 4.0. He also considered diversity values of less than 1.0 to be characteristic of polluted water. Evenness values less than 0.4 indicate a community under stress (Gore 1981). Weber (1973) found streams in the southeastern United States to have evenness values reduced to less than 0.3 even under slight levels of degradation.

In the East Fork, two stations, E20 and E13, had diversity values above 3.0. However, these same stations had evenness less than 0.4. Stress on benthic macroinvertebrate communities was also demonstrated by low diversity and evenness values at the three remaining stations on the East Fork. Values were lowest at Stations E19 and E3 but were still greater than 1.0 (for diversity).

In the West and Middle Forks, diversity and evenness values indicate that every station appeared to be under stress. The lowest values were at Station W2a, immediately below the Murfreesboro STP. Stress at stations upstream of Murfreesboro may be a result of poor water quality due to nonpoint source pollution.

The number of taxa at a station was influenced by the location of the station in relation to the point source of pollution. Numbers were highest above and far below each STP. Immediately below each STP numbers were low but gradually increased with distance downstream. Weber (1973) found number of taxa in a community to be highly sensitive to stress in the environment.

The results of the benthic macroinvertebrate sampling demonstrated the impact the two point sources of pollution were having. Each parameter tested showed a drop in diversity, evenness, and number of taxa below each point source. Parchment (1961) found the Stones River to be relatively clean during his study. He wrote of the "variety of organisms" and the "rare occurrence of scavenger organisms (Tubificidae, Chironomidae)" (p. 112). The dominance of Chironomidae at many stations in this study also indicates that the Stones River is under stress.

Fish

This section is divided into two sections. The first will report the results of the fish sampling. The second will discuss the relationship between naiads and their fish hosts.

Collection Results

Eleven samples of fish were collected from selected stations on the tributaries of the Stones River during the summer and fall of 1980 and the spring of 1981 (Table 1). A total of 45 species were present in the basin (Table 3). There were 39 species collected in the East Fork, 41 species in the West Fork, and 22 species in the Middle Fork.

Naiad-Fish Host Relationships

Many malacologists feel that the presence, absence, or recovery of a naiad species is dependent on the presence of its fish host (Yokley 1976; Ellis 1929; Wilson and Clark 1914; Neel and Allen 1964). Currently, there are 45 species of naiads whose host fish are known or implicated (Fuller 1974). Yokley (1976) felt that host fish concentrating over favorable substrate, either while feeding or spawning, largely determined the presence of a mussel bed. If fish hosts are not available for the glochidia, the naiad communities may die out. Starrett (1971) equated rich fish life with rich naiad populations. Athearn (1967) felt that the practice of eliminating "trash" fish, several of which are known host fish, and restocking with game fish may be a factor in eliminating many mussels.

Table 3. Fish Species Present in the Three Forks of the Stones River, April 1980 to March 1981

Species*	East	Middle	West
Lepisosteus spp.	x		x
Dorosoma cepedianum (Lesueur)	x		x
Campostoma anomalum (Rafinesque)	x	x	x
Cyprinus carpio Linnaeus	x		x
Hybopsis insignis Hubbs and Crowe			x
Nocomis effusus Lachner and Jenkins	x	x	x
Notropis ardens (Cope)	x	x	x
Notropis cornutus (Mitchill)	x	x	x
Notropis galacturus (Cope)			x
Notropis heterolepis Eigenmann and Eigenmann	x		
Pimephales notatus (Rafinesque)	x	x	x
Carpiodes spp.	x		x
Catastomus commersoni (Lacépède)	x		x
Hypentelium nigricans (Lesueur)	x	x	x
Minytrema melanops (Rafinesque)	x		x
Moxostoma dusquensei (Rafinesque)	x	x	x
Moxostoma erythrurum (Rafinesque)	x	x	x
Ictalurus melas (Rafinesque)	x		x
Ictalurus punctatus (Rafinesque)	x		x
Noturus flavus (Rafinesque)	x		x
Pylodictus olivaris (Rafinesque)	x		x
Fundulus catenatus (Storer)	x		
Fundulus notatus (Rafinesque)	x	x	x
Gambusia affinis (Baird and Girard)			x
Labidesthes sicculus (Cope)			x
Morone chrysops (Rafinesque)	x		x
Ambloplites rupestris (Rafinesque)	x	x	x
Lepomis cyanellus Rafinesque	x	x	x
Lepomis macrochirus Rafinesque	x	x	x
Lepomis megalotis (Rafinesque)	x	x	x
Micropterus dolomieui Lacépède	x	x	x
Micropterus punctulatus (Rafinesque)	x		x
Micropterus salmoides Lacépède	x	x	x
Pomoxis annularis Rafinesque	x	x	x
Pomoxis nigromaculatus (Lesueur)	x		x
Percina caprodes (Rafinesque)	x	x	x
Etheostoma atripinne (Jordon)	x	x	x
Etheostoma blennioides Rafinesque	x	x	x
Etheostoma caeruleum (Storer	x	x	x
Etheostoma microlepidum Raney and Zorach			x

Table 3. (Continued)

Species*	East	Middle	West
Etheostoma rufilineatum (Cope)	x		x
Etheostoma squamiceps Jordon	x		
Etheostoma stigmaeum (Jordon)		x	x
Etheostoma virgatum (Jordon)	x		
Aplodinotus grunniens Rafinesque	x		x
Cottus carolinae (Gill)	x	x	x

*All species names are in accordance with Bailey (1970).

Seventeen naiad species not found during this study were found by Stansbery (1980) in his preimpoundment study (Table 4). Table 5 lists the host fish of these species. One naiad species, *Pegias fabula*, has as its only known host the mudpuppy (*Necturus maculosus*), an amphibian (Howard 1914). Mudpuppies are known to live in the Stones River as are all of the fish species listed in Table 5.

The presence of these host fish species would imply that the cause for the decline in the number and abundance of naiad species is not a lack of host fish. However, numerous fish kills in the upper Stones River basin over the years may have cut down on the relative abundance of host fish. Since 1969, four fish kills (Table 6) are known to have occurred on the East Fork Stones River. These fish kills were apparently caused by releases of effluent with high biochemical oxygen demand (BOD) from the Woodbury STP. Eleven fish kills on the West Fork Stones River (Table 7) have occurred--apparently caused by releases from the old Murfreesboro STP. Most of these fish kills were a result of low DO caused by high BOD. These fish kills not only reduced fish host populations in these streams, but the discharged material and resulting water quality were probably injurious to naiad communities downstream.

Water Quality

Naiads, by virtue of being aquatic and relatively sedentary, are dependent on the quality of water in which they live. Major factors affecting the quality of the water in the upper Stones River basin, other than the natural water quality of the stream, include the sewage treatment plants, land use, and gravel dredging operations. This section will discuss the general water quality data collected in the

Table 4. Naiad Species Found by Stansbery During His 1965-1968 Study and the Present Study

Species*	Stansbery	Present Study
Cumberlandia monodonta (Say, 1829)**	x	
Anodonta imbecillis (Say, 1829)	x	x
Anodonta grandis grandis (Say, 1829)	x	x
Strophitus undulatus undulatus (Say, 1817)	x	x
Alasmidonta viridis (Rafinesque, 1820)		x
Pegias fabula (Lea, 1838)	x	
Simpsonaias ambigua (Say, 1825)	x	
Lasmigona complanata (Barnes, 1823)	x	x
Lasmigona costata (Rafinesque, 1820)	x	x
Megalonaias nervosa (Rafinesque, 1820)	x	x
Tritogonia verrucosa (Rafinesque, 1820)	x	x
Quadrula quadrula (Rafinesque, 1820)	x	
Quadrula cylindrica cylindrica (Say, 1817)	x	x
Quadrula pustulosa pustulosa (Lea, 1831)	x	
Amblema plicata plicata (Say, 1817)	x	x
Fusconaia flava (Rafinesque, 1820)	x	x
Cyclonaias tuberculata (Rafinesque, 1820)	x	x
Pleurobema oviforme (Conrad, 1834)	x	x
Pleurobema sintoxia (Rafinesque, 1820)	x	
Pleurobema cordatum (Rafinesque, 1820)**	x	
Pleurobema rubrum (Rafinesque, 1820)**	x	
Elliptio dilatata (Rafinesque, 1820)	x	x
Ptychobranchus fasciolaris (Rafinesque, 1820)	x	x
Obliquaria reflexa (Rafinesque, 1820)	x	x
Actinonaias ligamentina carinata (Barnes, 1823)	x	
Actinonaias pectorosa (Conrad, 1834)	x	x
Plagiola lineolata (Rafinesque, 1820)**	x	
Obovaria subrotunda (Rafinesque, 1820)	x	x
Truncilla truncata (Rafinesque, 1820)	x	x
Truncilla donaciformes (Lea, 1837)	x	
Leptodea fragilis (Rafinesque, 1820)	x	x
Potamilus alatus (Say, 1817)	x	x
Toxolasma parvus (Barnes, 1823)	x	
Toxolasma lividus lividus (Rafinesque, 1831)	x	x
Medionidus conradicus (Lea, 1834)	x	x
Ligumia recta (Lamarck, 1819)**	x	
Villosa iris (Lea, 1829)	x	x
Villosa taeniata taeniata (Conrad, 1834)	x	x
Villosa vanuxemi (Lea, 1838)		x
Villosa lienosa (Conrad, 1834)	x	x

Table 4. (Continued)

Species*	Stansbery	Present Study
Lampsilis teres form teres (Rafinesque, 1820)	x	
Lampsisis ventricosa (Barnes, 1823)	x	x
Lampsilis ovata (Say, 1817)	x	x
Lampsilis fasciola (Rafinesque, 1820)	x	x
Epioblasma brevidens (Lea, 1831)**	x	
Epioblasma lenior (Lea, 1843)**	x	
Epioblasma walkeri (Wilson and Clark, 1914)	x	
Totals	45	30

*All species names are in accordance with Stansbery (1980) (unpublished Ohio State University Museum of Zoology species list for the Ohio River Drainage Basin).

**These species were only collected in the inundated portion of the Stones River (Stansbery 1982).

Table 5. Missing Naiad Species and Their Fish Hosts*

Naiad Species	Fish Host Species (Common Name) Present
Cumberlandia monodonta	Unknown
Pegias fabula	Unknown
Simpsonaias ambigua	Necturus maculosus (mudpuppy)**
Quadrula quadrula	Pylodictus olivaris (flathead catfish)
Quadrula pustulosa	Ictalurus melas (black bullhead)
	Pomoxis annularis (white crappie)
Pleurobema sintoxia	Unknown
Pleurobema cordatum	Notropis ardens (rosefin shiner)
Pleurobema rubrum	Unknown
Actinonaias ligamentina carinata	Morone chrysops (white bass)
	Lepomis cyanellus (green sunfish)
	Ambloplites rupestris (rockbass)
Plagiola lineolata	Aplodinotes grunniens (freshwater drum)
Truncilla donaciformes	Aplodinotes grunniens (freshwater drum)
Toxolasma parvus	Lepomis macrochirus (bluegill)
Ligumia recta	Micropterus salmoides (largemouth bass)
	Pomoxis annularis (white crappie)
Lampsilis teres form teres	Lepisosteus spp. (gars)
Epioblasma brevidens	Unknown
Epioblasma lenoir	Unknown
Epioblasma walkeri	Unknown

*Adapted from Fuller in Hart and Fuller 1974.

**An amphibian

Table 6. East Fork Stones River Fish Kills. Data Obtained From Tennessee Wildlife Resources Agency (1981)

Date	Suspected Cause	Suspected Source	Extent of Kill
10/14-15/69	High BOD, Low DO	Woodbury STP[1]	0.4 miles
6/22/71	High BOD, Low DO	Woodbury STP[1]	0.5 miles
7/22-23/72	High BOD, Low DO	Woodbury STP[1]	3.9 miles
8/27/76	High BOD, Low DO	Woodbury STP[1]	0.5 miles

[1]Woodbury Sewage Treatment Plant located at river mile 45.0 on the East Fork Stones River.

Table 7. West Fork Stones River Fish Kills. Data Obtained From Tennessee Wildlife Resources Agency (1981).

Date	Suspected Cause	Suspected Source	Extent of Kill
7/17/70	High BOD, Low DO	Murfreesboro STP[1]	No data
8/2/70	High BOD, Low DO	Murfreesboro STP[1]	No data
8/19/70	High BOD, Low DO Unspecified toxins	Murfreesboro STP[1]	2.7 miles
9/1/71	High BOD, Low DO	Murfreesboro STP[1]	1.9 miles
10/2/71	High BOD, Low DO, Cr	Murfreesboro STP[1]	1.2 miles
11/22-23/72	High BOD, Low DO, Cn, NH_3, Cr, Ni, Cu, Zn, Cd, Pb	Murfreesboro STP[1]	3.75 miles
7/72	Low DO	Murfreesboro STP[1]	No data
8/27-28/72	High BOD, Low DO	Murfreesboro STP[1]	2.5 miles
9/10-11/73	High BOD, Low DO	Murfreesboro STP[1]	No data
9/10-13/75	Low DO	Murfreesboro STP[1]	No data
6/17-19/78	High BOD, Low DO	Murfreesboro STP[1]	4.3 miles

[1]Murfreesboro Sewage Treatment Plant on Broad Street, located at river mile 15.3 on the West Fork Stones River.

three Stones River tributaries. It will also discuss the major factors affecting the water quality of the streams and how each affects the naiad population.

General Water Quality

The general water quality of the Stones River is determined by the chemical and flow characteristics of each tributary. Commonly, the river water in the basin is relatively high in alkalinity and hardness, and pH is basic. Burchett and Moore (1971), in citing U. S. Geological Survey data for the basin, found median values for alkalinity, hardness, and pH to be 240, 217, and 8, respectively. The median values for alkalinity, hardness, and pH found during this study were 140, 156, and 7.7, respectively.

All of the median values stated above for the water quality of the basin are well within the range necessary for molluscan survival. Twice during the study, however, pH values in the acidic range were recorded. On November 1, 1980, the pH at E15 was 6.8. At the time of sampling, gravel dredging was occurring upstream and the stream was muddy in appearance. On December 7, 1980, a pH of 5.9 was recorded at Station E13, and the conductivity was high (800 μmhos) for an undetermined reason. Upstream at Station E14, pH and conductivity were normal. Matteson (1955) found naiads to stop siphoning, close their valves, and lose weight when exposed to water ranging in pH from 4.4 to 6.1.

On July 22, 1980, D.O. levels dropped as low as 2.9 mg/l at one station (M6) and was below 4.0 mg/l on two other occasions at other stations. Grantham (1969) did not find naiads where D.O. levels dropped as low as 3 mg/l. Imlay (1971) found that a dissolved oxygen above 2.5 mg/l during summer conditions was necessary for survival of naiads.

However, Imlay (1971) found Amblema plicata to survive with no measurable D.O. for several weeks in the lab. Fuller (1974) believes this can be attributed to this species' ability to close its valves tightly and become dormant during periods of stress. Gold (1980) reported that zero flow conditions in the three main tributaries of the Stones River usually occurred during the summer and fall months. Shelton et al. (1978) described the West Fork as a low flow stream in late summer with zero flow occasionally above Murfreesboro. Many stations on the West Fork dried up during the drought in late summer of 1980. Several stations on each fork had no flow at times during the late summer and fall.

Sewage Treatment Plants

The effect the Woodbury and Murfreesboro STPs have had on their two receiving streams has been substantial. Water quality standards in each stream have been violated by discharges from these plants.

The sewage treatment plant at Woodbury has been responsible for several fish kills in recent years (T.W.R.A. 1981). Part of the problem was the old Tennessee Cheese Company in Woodbury. Organic waste spills from this company often overloaded or bypassed the STP, and the result was high BOD effluent entering the East Fork (TDWQC 1977).

The City of Murfreesboro opened a new STP in 1978 that has tertiary treatment capability. Prior to this time, the old Broad Street plant was organically and hydraulically overloaded and did not provide adequate treatment. Additionally, toxic materials from industrial discharges would occasionally disrupt treatment systems (TDWQC 1977). Toxic substances and metals made their way into the Murfreesboro STP through the municipal sewers. Once they enter the plant, these wastes have a twofold effect. First, toxic chemicals reduce the STP's ability to reduce BOD and ammonia nitrogen concentrations in the effluent. Second, the toxic substances plus insufficiently treated wastes pass into the stream where they reduce biological activity and "depress the oxygen profile over a much longer time period than it would if metals were not present" (Burdick and Drewry 1973) (p. 42).

Land Use

Approximately 53 percent of the agricultural land in the upper Stones River basin (94 percent of the total basin) is used for cropland or pasture; the remainder (47 percent) is listed as forest and other uses (TDWQC 1977). Much of the cropland is in the floodplain and lower slopes of the basin.

Increased fertilizer and pesticide use in the basin has caused water quality to decline over the past 20 years. In a study done by Burdick and Drewry (1973), eutrophication was felt to be a significant problem in the basin. In addition, the region is naturally productive, and nutrient levels in the runoff water can be significant (Shelton et al. 1978).

Fertilizer use has increased by 50 percent and 47 percent in Cannon and Rutherford Counties, respectively, in the past thirty years (Ashburn 1981). Pesticide use in the upper Stones River basin has increased considerably in the past ten years. Tables 8 and 9 depict the rates of application and percent acreage treated in the basin.

Part of the reason for the increase in pesticide and fertilizer use has been the increase in the amount of acreage put into row-crops. Despite a reduction of corn acreage by 12,450 acres since 1960, the

Table 8. Agricultural Chemicals Used for Soybeans in the Stones River Watershed of Cannon and Rutherford Counties*

Chemical (Class)	Pounds Active Ingredient per Acre (AI/A)	Estimated Percent of Planted Acreage Treated		
		1960	1970	1980
Trifluralin (organo-nitrogen)	0.75-2.0	0	5	50
Metribuzin (orgnao-nitrogen)	0.5	0	0	40
Linuron (organo-nitrogen)	0.5-1.0	0	0	15
Alachlor (organo-nitrogen)	1.5-2.5	0	0	30
Glyphosate (organo-phosphate)	2.0	0	0	5
Bentazon (organo-nitrogen)	0.5-1.0	0	0	8

*Provided by Dr. Elmer Ashburn, Agricultural Extension Service, University of Tennessee, Knoxville (1981).

Table 9. Agricultural Chemicals Used for Corn in the Stones River Watershed of Cannon and Rutherford Counties*

Chemical (Class)	Pounds Active Ingredient per Acre (AI/A)	Estimated Percent of Planted Acreage Treated		
		1960	1970	1980
Atrazine (organo-nitrogen)	1.2-2.5	5	75	98
Simazine (organo-nitrogen)	1.2-2.5	0	15	10
2, 4-D (chloro-phenoxy)	0.5	5	10	5
Alachlor (organo-nitrogen)	1.5-2.5	0	2	50
EPTC (carbamate)	3.0-6.7	0	0	25
Furadan (carbamate)	7.5-15.0	0	0	20

*Provided by Dr. Elmer Ashburn, Agricultural Extension Service, University of Tennessee, Knoxville (1981).

amount of land utilized for row-crops in the region has increased by 19.250 acres due to a 31,700-acre jump in soybean acreage during this period (Ashburn 1981).

The increasing use of fertilizers and pesticides in the basin can have many indirect effects on naiads. These agricultural chemicals enter the stream by direct runoff, alochthonous input, and underground solution cavities. Approximately 33 percent of the rainfall in the basin runs off into the streams and 12 percent travels through the groundwater (54 percent is evaporated or transpired) (Burchett and Moore 1971). Fertilizers raise the nutrient level of the stream and thus increase the BOD in the water. Starrett (1971) felt that dissolved oxygen concentrations as low as 0.1-0.9 mg/l due to high BOD in the upper Illinois River caused the decline of the naiad populations there.

Gravel Dredging

Krumholz (1970) felt that mechanical dredging was just as destructive to naiad populations as pollution. Ten or more years may pass before naiads become reestablished once removed from an area (Yokley 1976). This is barring any further gravel dredging or other negative impacts to the area. Several unauthorized gravel dredging operations have occurred in the East Fork in the last few years--nine of these are documented in Table 10. Martinez (1981) estimated that at least three times this amount goes unreported.

Only one of the ten naiad species (*Toxolasma parvus*) not collected during this study does not require gravel and sand substrate and riffle habitat. The destruction of this habitat type by gravel dredging may be a reason for the absence of some of these species.

Table 10. Unauthorized Gravel Dredging Operations in the East Fork Stones River

River Mile	Year	Data Source
16.5-16.8	1980	Personal Observation
20.0	1979	Corps of Engineers
24.5	1980	Corps of Engineers
32.1-32.2	1977	Tennessee Wildlife Resources Agency
34.5-34.7	1980	Personal Observation
36.0	1980	Corps of Engineers
37.0-38.0	1980	Corps of Engineers
45.9-46.1	1980	Personal Observation
48.3-48.7	1980	Personal Observation

Gravel dredging can also directly affect naiads by killing the animals and destroying habitat. Indirectly, it uproots the survivors from the substrate. Imlay (1972) conducted several experiments in which he tested naiads' adaptability to artificial displacement. He found that "artificial displacement at any atypical season was too extreme for these animals to adapt to" (p. 78). By an "atypical season" he is referring to the late summer and early fall when flows are generally low. This is also the best time to remove gravel. The high flows of spring can naturally displace naiads. Thus, even if naiads can survive the initial gravel removal operation, they may not recover.

Silt loads in a stream as a result of gravel dredging can be very deleterious to a naiad population downstream. Silt or suspended sediments in the stream can smother mussel beds causing stress and sometimes death. Stansbery (1970b) showed that growth in Amblema plicata was retarded by siltation. Ellis (1931) reported that silt destroys mussel beds by directly smothering the animals, by smothering young mussels even when adults lived, and by blanketing sewage and other organic material which in turn lowers the D.O. in the water. Ellis (1936) reported that suspended silt caused naiads to reduce the amount of water siphoned by 50 percent or more. The effect of reduced siphoning would cause slow starvation and possible suffocation. Cordone and Pennoyer (1960) found silt from a gravel washing plant severely reduced benthic organisms for a distance of 10 miles (16 km) downstream in Cold Creek and the Truckee River, California. Hirsch et al. (1978) determined that tolerance to suspended sediments generally decreased with increasing water temperature or decreasing dissolved oxygen. This is important since most gravel dredging occurs during the summer months when flow in the upper Stones

River basin is low, water temperature is high, and dissolved oxygen is low.

Naiads

This section will be divided into two parts. The first part will report the results of naiad collections and discuss each species as to its abundance, distribution, and its protection status. The second part will discuss the findings of the naiad collections and compare these results with that of Stansbery (1980).

General Collection Results

Thirty species of naiads (Table 4) were collected in the Stones River between April 1980 and March 1981. There were 29 species collected from the East Fork (Table 11), 17 from the West Fork (Table 12), and five from the Middle Fork (Table 13). All species collected in the West Fork, with the exception of *Alasmidonta viridis*, were also present in the East Fork, and all species collected in the Middle Fork were found in the East and West Forks. *A. viridis* and *Villosa vanuxemi* were new records for the Stones River.

Individual Collection Results

Anodonta imbecillis was found at two stations, M4 and E2, during the study. The majority of the specimens were collected at Station M4 while a few were collected at Station E2. This species is rare in the Stones River, but it is not considered threatened or endangered by federal or state standards.

Anodonta g. grandis was one of the most abundant species collected where it occurred. It was most common in the West and Middle Forks where

Table 11. Naiad Species Collected in the East Fork Stones River by Stations

Species	E2	E3	E5	E6	E8	E9	E13	E14	E16
Anodonta imbecillis	x								
Anodonta grandis grandis	x								
Stophitus undulatus undulatus	x								
Lasmigona complanata	x	x							
Lasmigona costata	x	x	x	x	x	x	x		
Megalonaias nervosa	x	x							
Tritogonia verrucosa	x	x		x					
Quadrula cylindrica cylindrica	x			x					
Amblema plicata plicata	x	x	x	x	x				
Fusconaia flava	x				x	x			
Cyclonaias tuberculata	x	x							
Pleurobema oviforme	x								
Elliptio dilatata	x	x	x	x	x	x			
Ptychobranchus fasciolaris	x	x							
Obliquaria reflexa		x							
Actinonaias pectorosa	x								
Obovaria subrotunda	x								
Truncilla truncata	x								
Leptodea fragilis	x								
Potamilus alatus	x								
Toxolasma lividus lividus	x								
Medionidus conradicus	x					x			x
Villosa iris	x								
Villosa taeniata taeniata	x	x	x	x	x	x	x	x	x
Villosa vanuxemi					x	x			
Villosa lienosa	x								
Lampsilis ventricosa	x	x	x	x	x	x			
Lampsilis ovata	x	x	x	x	x	x	x		
Lampsilis fasciola	x		x	x	x	x	x	x	
Totals	27	12	7	9	9	9	4	2	2

Table 12. Naiad Species Collected in the West Fork Stones River by Stations

Species	W1	W2a	W3	W4	W5	W6	W7	W8
Anodonta grandis grandis	x				x		x	
Stophitus undulatus undulatus	x							
Alasmidonta viridis							x	
Lasmigona complanata			x		x			
Lasmigona costata	x	x	x	x	x			
Amblema plicata		x		x				
Cyclonaias tuberculata	x							
Pleurobema oviforme	x							
Elliptio dilatata	x							
Truncilla truncata								x
Potamilus alatus	x							
Toxolasma lividus lividus					x		x	
Medionidus conradicus					x			
Villosa iris	x							
Villosa taeniata taeniata	x		x	x	x	x	x	x
Villosa vanuxemi	x				x			
Villosa lienosa	x							
Totals	11	2	3	3	7	1	4	2

Table 13. Naiad Species Collected in the Middle Fork Stones River by Stations

Species	M2	M3	M4	M5
Anodonta imbecillis			x	
Anodonta grandis grandis			x	
Toxolasma lividus lividus	x		x	
Medionidus conradicus				x
Villosa taeniata taeniata	x	x		
Totals	2	1	3	1

it was found at four stations. Several healthy populations (W5, M4) were found and it is not considered a jeapordized species.

Stophitus u. undulatus was found at two stations (E2, W1) on the East and West Forks. Only a few specimens were collected at each station. This species is rare in the Stones River but is not elsewhere within its range.

The small naiad Alasmidonta viridis is a new distribution record for the Stones River. One small specimen was found at Station W7. This species is not thought to be jeapordized.

Lasmigona complanata was found in low numbers at four stations during the study. Several large specimens (+20 cm) were collected at Stations W2 and W3. The few specimens collected at Stations W3 and W5 were not as large. This species is not considered jeapordized.

Lasmigona costata was one of the more common naiads in the Stones River. It was collected at seven stations in the East Fork and five stations in the West Fork. At most of these stations it ranged second or third in abundance.

Megalonaias nervosa was the largest species collected during the study. Several specimens collected at Stations E2 and E3 measured greater than 25 cm in length. M. nervosa was found only in the East Fork, but it is not considered a threatened or endangered species.

Tritogonia verrucosa was also limited to the East Fork. Many specimens were collected at Stations E2 and E6. One large specimen (+15 cm) was collected at Station E3.

Quadrula c. cylindrica was rarely found during the study. One specimen was found at Station E2 and one at Station E6. Stansbery (1971) considered Q. c. cylindrica an endangered species.

Amblema p. plicata was common at the five stations in the East Fork where it was collected. Only a few specimens were collected at Stations W2a and W4 in the West Fork.

Fusconaia flava was found at three stations in the East Fork. Very few specimens were collected at Stations E2 and E8, but many were collected at E9. It is not a threatened or endangered species.

Cyclonaias tuberculata was collected at three stations in the Stones River. It was very abundant at Stations E2 and E3 and reasonably so at Station W1.

Pleurobema oviforme was rarely collected during the study. Less than five specimens each were collected at Stations E2 and W1. Bogan and Parmalee (1979) felt that *P. oviforme* should be considered for endangered species status.

Elliptio dilatata was very abundant in the East Fork. It was collected at six stations in the East Fork and one in the West Fork. One very large specimen (18 cm long) was collected at Station E3. This species is not considered jeapordized.

Ptychobranchus fasciolaris was found occasionally at two stations in the East Fork, E2 and E3. All of the specimens seen were large. This species is considered by Bogan and Parmalee (1979) deserving of special concern status.

One specimen of *Obliquaria reflexa* was collected at Station E3 in the East Fork. This species was rare in the Stones River but is very abundant elsewhere within its range.

Actinonaias pectorosa was rare in the Stones River. Less than five specimens were found at only one station, E2. Stansbery (1981) collected one of the largest specimens on record at or near this same station during his collections. At this time, A. pectorosa is not considered a jeapordized species.

Obovaria subrotunda was very abundant at one station in the East Fork, E2. It was considered by Bogan and Parmalee (1979) deserving of threatened species status.

Only a few specimens of Truncilla truncata were found during this study. They were collected at Stations E2 and W8. At Station W8, a small community of T. truncata was destroyed when a new, low-water bridge was constructed at the station. This species is not considered jeapordized.

Leptodea fragilis was found only at Station E2 in the East Fork. Only two specimens were collected during the study. Although rare in the Stones River, L. fragilis is not considered a threatened or endangered species.

Potamilis alatus was rare at the two stations, E2 and W1, where it was found. Several large (+20 cm in length) specimens were found at Station E2. P. alatus is not considered a jeapordized species.

Toxolasma l. lividis was found in all three streams. It was not abundant at any station, but due to its small size and fragility, it may have been overlooked occasionally.

Medionidus conradicus was found at five stations (E2, E9, E16, W5, and M5) and in all three streams. Less than five specimens were found at each of these stations. Bogan and Parmalee (1979) suggested that M. conradicus be considered for threatened species status.

Only a few specimens of Villosa iris were collected during this study at Stations E2 and W1. Although not very abundant in the Stones River, this species is not considered jeapordized.

Villosa t. taeniata was probably the most abundant naiad in the Stones River and enjoyed the widest distribution. It was collected at 18 of the 21 stations where naiads were found and in all three streams. Stansbery (1982) described the Stones River as one of the best streams within the species' range to find it.

Villosa vanuxemi was a new record for the Stones River. A total of six specimens were collected from four stations (E8, E9, W1, and W5). Although rare in the Stones River, V. vanuxemi is not considered a jeapordized species.

Villosa lienosa was found in low numbers at two stations (E2, W1) but is not considered jeapordized.

Lampsilis ventricosa was found at six stations in the East Fork. This species was not very abundant, but most specimens collected were large (+10 cm long).

Lampsilis ovata was less abundant than L. ventricosa but was present at seven stations in the East Fork. Neither of these are considered jeapordized.

Lampsilis fasciola was usually abundant at each station where it was present. It was found at seven stations in the East Fork. At Station E8 there was a large population of L. fasciola just downstream of the mill dam.

Data Analysis

Generally, the number of naiad species will increase in a stream as stream order increases. Harman (1974) attributed this to the stream becoming more chemically and physically stable and therefore more habitable to mollusks. The number of species can also increase in a stream recovering from upstream pollution as the effects of pollution become more diluted with distance from the discharge. The East Fork is a good example of increasing species richness with increasing distance downstream (Table 11). There were two species at the most upstream station (E16) and 27 species at the most downstream station (E20) where naiads were collected. The stations between these two showed a relatively steady increase with distance downstream. In the West Fork (Table 12), the trend was not as evident. There was an increase in the number of naiad species downstream of Murfreesboro, but only after the river had flowed past Nices Mill dam at Station W1. Water flowing over the dam is reoxygenated and thus may become a more favorable habitat for naiads. While upstream stations had approximately three species per station, there were 11 species found below the dam.

Stansbery (1980) collected 45 naiad species in the Stones River basin between 1965 and 1968 (Table 4). The majority of his collecting was done prior to the impoundment of the Stones River by the J. Percy Priest Dam in 1968. He found the Stones River to be rich in naiad fauna below Walterhill Dam on the East Fork and downstream of the Route 99 bridge on the West Fork. These two stations were also two of the richest stations sampled during this study (Tables 11 and 12).

Of the 45 species reported by Stansbery (1980), 17 were not collected during this study (Table 4). Seven of these 17 species were not expected to be found since they were previously found only in the flooded portion of the Stones River (Stansbery 1982). Even with the addition of the two new distribution records found in this study, there has been a 22 percent reduction in the number of naiad species in the upper Stones River and a 33 percent reduction in the entire Stones River system since 1968.

Chapter 6

SUMMARY AND CONCLUSIONS

A survey of the naiads of the Stones River above J. Percy Priest Reservoir was made from April 1980 to March 1981. Thirty species of naiads were collected including two new distribution records for the river. Collections made before the Stones River was impounded listed as many as 45 naiad species.

A general trend of increasing number of naiad species with distance from the headwaters was noted in the East Fork. This is usually the case when a stream increases in stream order or recovers from a source of pollution. This trend was not as evident in the West and Middle Forks. In the West Fork, there was a drop in the number of naiad species immediately downstream of the Murfreesboro STP. A sharp increase in species number from three to eleven was noted at a station far downstream. No trends could be seen in the Middle Fork.

Several possible causes for the 33 percent decline in the number of naiad species were investigated. There were point sources of pollution, nonpoint (agricultural) pollution, naiad-fish relationships, and gravel dredging.

Point sources of pollution, the Woodbury and Murfreesboro STPs, were investigated for possible impacts with water quality and benthic macroinvertebrate sampling. Water quality results did not reveal any direct impacts from the two STPs. General water quality within the basin meets all requirements for molluscan survival. Occasionally, the dissolved oxygen concentration did fall to very low levels. Benthic macroinvertebrate results revealed that the communities under the least stress were upstream and far downstream of each STP. Those communities immediately downstream of each STP were under the greatest stress.

Agricultural chemicals use have increased dramatically in an already fertile basin. Record tonnages of fertilizer were applied in 1979-1980. Pesticide use and row-crop acreage has also increased.

Forty-five fish species were collected or their presence verified during the study. Fish hosts for ten of the 17 missing naiads were present in the basin. The fish hosts for the remaining seven are unknown at this time.

Gravel dredging in the basin destroyed four stations during the study. Gravel dredging has been noted in nine locations in the East Fork alone.

A combination of increased BOD and toxic substances from sewage treatment plants and agriculture, gravel dredging, and the abnormal high water temperatures and low flows of the summer of 1980 may have led to the decline of the naiad populations of the Stones River.

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APPENDIX

Table 14. List of Stations Sampled in the Upper Stones River Basin

Station	River Mile	Latitude	Longitude	Site Description
E1	4.2-4.4	35°58 40N	86°25 5W	Deep, slow, pool; approximately 2-4m deep
E2	7.7-7.9	35°57 42N	86°23 25W	Broad riffle, followed by a deep bend and large gravel bar
E3	9.7-10.0	35°56 30N	86°22 42W	Series of riffles and pools, flow generally good
E4	12.4-12.5	35°55 25N	86°21 55W	Slow, deep pool, backed up by Waterhill Dam
E5	15.3-15.5	35°55 7N	86°19 58W	Series of riffles and pools, many beds of Justicia sp.
E6	16.5-16.8	35°55 7N	86°19 34W	Long, shallow pool, many moss-covered rocks, flow good
E7	18.7-18.8	35°55 12N	86°17 16W	Short, high gradient riffle, Bradley Creek enters 100 m upstream
E8	21.7-21.9	35°54 12N	86°16 54W	Just downstream of Brown's Mill; slow, shallow pool then riffle
E9	24.4-24.8	35°53 8N	86°16 12W	Deep pool, limestone ledges, then shallow riffle, good flow
E10	25.4-25.5	35°52 50N	86°15 48W	Cripple Creek enters, good riffle downstream

Table 14. (Continued)

Station	River Mile	Latitude	Longitude	Site Description
E11	27.8-28.1	35°52 30N	86°13 37W	Many gravel bars and islands, deep pool follows
E12	30.3-30.4	35°52 9N	86°13 13W	Shallow gravel ford/riffle
E13	32.1-32.2	35°51 37N	86°12 16W	Shallow gravel and bedrock riffle, many weed beds
E14	34.5-34.7	35°50 14N	86°11 20W	Cement ford/bridge, a deep pool with a gravel riffle below
E15	35.9-36.1	35°49 41N	86°10 36W	Just downstream of Readyville Mill Dam, long shallow riffle
E16	39.7-39.8	35°48 42N	86° 8 17W	Fast riffle, gravel and boulders
E17	40.9-41.0	35°49 14N	86° 7 50W	Deep pool under Route 70S bridge, then shallow riffle
E18	42.3-42.4	35°49 13N	86° 6 55W	Shallow pool and riffle, limestone bedrock substrate
E19	44.9-45.2	35°49 20N	86° 4 56W	Long, shallow pool, gravel and silt substrate, some boulders
E20	45.9-46.0	35°49 46N	86° 4 15W	Long, shallow pool with gravel riffle upstream
E21	48.5-48.7	35°49 43N	86° 1 49W	Shifting gravel on limestone bedrock

Table 14. (Continued)

Station	River Mile	Latitude	Longitude	Site Description
E22	50.9-51.0	35°50 4N	85°59 39W	Shallow, fast, gravel and cobble riffle
E23	53.4	35°50 44N	85°58 30W	Narrow (1 m) bedrock and cobble riffle
W1	6.0-6.3	35°56 27N	86°27 45W	Deep pool below Nice's mill dam, long, shallow riffle
W2a	10.8-11.0	35°54 14N	86°25 39W	Shallow pool, with a long, shallow riffle downstream
W2b	11.4-11.5	35°53 57N	86°25 30W	Shallow pool followed by a narrow gravel and boulder riffle, *Justicia* sp. abundant
W3	14.0-14.2	35°52 42N	86°25 18W	Series of riffles and pools gravel and bedrock substrate
W4	18.3-18.5	35°50 33N	86°24 52W	Shallow pool followed by a gravel and boulder riffle
W5	20.8-21.1	35°49 19N	86°25 8W	Fast riffles through *Justicia*, gravel and sand substrate
W6	22.6-22.8	35°48 6N	86°25 39W	Shallow riffles and pools *Justicia* abundant, sand and gravel substrate
W7	25.7-25.9	35°45 54N	86°24 59W	Gravel and boulder riffle with a shallow pool following

Table 14. (Continued)

Station	River Mile	Latitude	Longitude	Site Description
W8	29.2-29.4	35°43 32N	86°24 6W	Shallow gravel and silt bottomed pool, *Justicia* abundant
W9	32.4-32.5	35°42 11N	86°27 47W	Riffle and pool series over a bedrock substrate
M1	2.1- 2.2	35°48 0N	86°23 41W	Pool with silt and sand bottom
M2	5.3- 5.6	35°46 1N	86°22 34W	Bedrock and *Justicia* riffles with shallow pools
M3	6.6- 6.7	35°45 36N	86°21 9W	Riffle and pool series, gravel substrate, *Justicia* abundant
M4	8.3- 8.5	35°44 50N	86°20 57W	Shallow riffles and pools, many small islands with trees
M5	10.4-10.6	35°43 50N	86°19 44W	Cobble and *Justicia* bed riffle followed by a shallow pool
M6	11.8-11.9	35°42 49N	86°19 54W	Riffle and pool series, bedrock substrate

Table 15. Mean Number of Benthic Macroinvertebrates Per Meter^2 Collected With a Surber Sampler From Selected Stations in the Stones River Basin From June 17 to July 1, 1980

	Density, Number/m^2									
Organisms	E3	E13	E18	E19	E20	W1	W2a	W2b	M2	W6
Planariidae								90	7	7
Oligochaeta		25	7			14		22		4
Hirudinea	4							25		
Lirceus				4					14	
Asellus			11			65		7		
Hyalella azteca						22				18
Gammarus					4					
Orconectes		4	11	14	7	4	7	7	4	4
Ameletus	14	18								
Baetis	129	369	1524	50	97	369	36	3138	2665	775
Caenis	57		18	36	100	7				4
Pentagenia										4
Ephemera								47		
Neoephemera					61					
Potamanthus	54	25			4					
Ephemerella	7									
Ephoron	4	14								
Stenonema	7	79	161	32	111	108	7	1352	100	108
Isonychia	7		14			4		4	11	
Tricorythodes					14	4	36	326		
Neoperla	4	93							18	36
Acroneuria			4		4					
Paragnetina		7								
Leuctra					11					

Table 15. (Continued)

Organisms	Density, Number/m^2									
	E3	E13	E18	E19	E20	W1	W2a	W2b	M2	W6
Agrion	4									
Argia			4	4				11		
Coenagriidae						4				
Hetaerina							14			
Trepobates					4					
Gerridae								4	4	
Homoptera									4	
Saldidae										7
Sialis	4									
Corydalus cornutus		7					14		7	
Micrasema									18	65
Helicopsyche										18
Cheumatopsyche	273	188	165	4	32	1076	29	674	911	104
Hydropsyche	97	789	1879	18	57	298	122	136	1399	136
Symphitopsyche		814	718	4	47					111
Macronema	43							7	57	
Hydroptilidae		18								
Hydroptila	61	29		4		47		61		22
Orthotrichia	11									
Ceraclea	4									
Chimarra		4			4	4		11	25	
Rhyacophila					4					
Leptoceridae								4	4	
Limnephilidae									29	
Nectopsyche										4
Parargyractis	7	4	194			4		68	18	7

Table 15. (Continued)

Organisms	Density, Number/m^2									
	E3	E13	E18	E19	E20	W1	W2a	W2b	M2	W6
Dytiscidae	4									
Optioservus	4		18	11	57					
Stenelmis	11	319	337		54	83	1227	226	721	384
Psephenus herricki	4	39	104	126	172	25		18	197	115
Ectopria										4
Chironomidae	2740	423	692	954	420	1840	1671	2005	384	183
Empididae	190	7	25	32	4	65	280	25	50	22
Simulium	18	14	136			115	925		18	
Tabanidae	7	4								
Antocha			54	14	4					
Hexatoma			11							
Pedicia			7							
Atherix					4					
Ceratopogonidae									4	
Laevapex				7	7					
Physa				7						
Viviparus		305								
Pleurocera		50	54	4		11			122	1628
Corbicula		11								11
Eupera			39	7						18
Sphaerium		29				43		18	14	18
Totals	3769	3688	6187	1332	1283	4212	4368	8286	6805	3817