To the Graduate Council:

I am submitting herewith a thesis written by Stephen J. Fraley entitled "A Baseline Survey of Aquatic Macroinvertebrate Communities at Seven Sites in the Abrams Creek System, Great Smoky Mountains National Park, Blount County, Tennessee." I have examined the final copy of this thesis for form and content and recommend it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Zoology.

David A. Etnier, Major Professor

We have read this thesis
and recommend its acceptance:

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Associate Vice Chancellor and Dean of
the Graduate School

A Baseline Survey of Aquatic Macroinvertebrate Communities at Seven Sites in the Abrams Creek System, Great Smoky Mountains National Park, Blount County, Tennessee

A Thesis

Presented for the

Master of Science

Degree

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ABSTRACT

In 1993, the National Park Service initiated efforts to exclude livestock and improve riparian conditions along Abrams Creek and its tributaries in the Cades Cove area. A baseline survey of aquatic macroinvertebrate communities began in late 1993 and continued through 1995. The purpose of this study was twofold: (1) to provide a baseline bioassessment of conditions during treatment and, (2) provide a detailed inventory of macroinvertebrate taxonomic richness at each of seven sample sites.

Samples revealed a rich macroinvertebrate fauna, with 340 taxa in 90 families identified from all sites combined. Total taxa richness at each site was positively correlated to stream size. However, Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness was lower than expected at two sites downstream of Cades Cove. Biotic index scores (NCBI) also indicated slightly more tolerant communities at these sites. Effects from erosion and possible nutrient enrichment in Cades Cove are implicated. However, other site-specific factors, including lack of habitat diversity, may be significant contributing factors.

TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

I. Introduction

General Introduction

In 1993, the University of Tennessee, Knoxville (UTK) and the National Park Service, Great Smoky Mountains National Park - Resource Management (GSMNP-RSM) entered into a cooperative agreement (sub-agreement to CA-5460-0-9001) to monitor macroinvertebrate communities in Abrams Creek, GSMNP, Blount Co., TN. This monitoring project was initiated after apparent water quality problems (increased sedimentation and excessive algae growth) were observed in Abrams Creek. Increased sedimentation appeared to be the result of stream bank erosion accelerated by cattle and horses having direct access to Abrams Creek and several tributaries in Cades Cove. Potential sources of nutrient enrichment also identified in Cades Cove were livestock wastes and leachates from sewage treatment systems serving park facilities. Projects to stabilize eroding stream banks began in August 1993. This included reducing the number of livestock in the Cove, building and repairing fences along streams, contouring eroded stream banks, and reseeding with native grasses. This work continued through summer 1996.

Macroinvertebrate sampling to establish baseline community data began in December 1993. Seven sites in the Abrams Creek watershed were sampled in winter, late spring, and early fall. This thesis reports the results from the first two years of this monitoring effort (December 1993 - September 1995).

Background

Abrams Creek begins in undisturbed forest on the northern slope of Anthony Ridge and flows west through Cades Cove. Cades Cove is managed by GSMNP as an historic district with open fields maintained by mowing and livestock grazing. Beginning in the early 19th century and continuing until the creation of GSMNP in 1936, small scale row-cropping and livestock grazing was practiced in Cades Cove (Shields 1977). Consequently, soil erosion was recognized by Park Service personnel as a problem in Cades Cove in 1937 (Bratton et al. 1980).In the late 1930s and again in 1946, efforts were made to stabilize stream banks (Bratton et al. 1980). However, shortly after initiating the current management practices of mowing and grazing in 1967, turbidity and siltation resulting from erosion persisted (Kelley 1974). Cattle damage to stream banks was identified as the major source of silt. In the years 1973-75, fencing to exclude cattle access, along with grass and tree plantings were used to stabilize stream banks on some tributaries (Kelley 1974, Bratton et al. 1980).

In 1976-77 thorough surveys were conducted of the Abrams Creek watershed in Cades Cove, including bacteriological, chemical, macroinvertebrate, and fish sampling (Silsbee et al. 1976, Mathews 1978). Surveys identified high levels of fecal streptococcus, nitrates, and orthophosphates in and downstream of areas impacted by livestock. Sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness was lower in these impacted areas. Likewise, relative abundance and biomass of rainbow trout (*Oncorhynchus mykiss*) to "rough fish" were also lower. The conclusion drawn from these studies was that cattle grazing in Cades Cove was having a negative impact on the aquatic systems of Abrams Creek. This prompted GSMNP to reduce the number of cattle permitted from 1200 to 500 head (Mathews 1978).

In 1986, the reintroduction of four native fishes began in lower Abrams Creek. Two madtom catfish species (*Noturus baileyi* and *N. flavipinnis*), spotfin chubs (*Cyprinella monacha*), and duskytail darters (*Etheostoma percnurum*) had, or were believed to have been, extirpated in 1957 during a "reclamation" project designed to improve the rainbow trout sport fishery (Lennon and Parker 1959). Monitoring efforts during this reintroduction project identified some excessive sedimentation and algae growth indicating possible erosion and nutrient enrichment problems (S.E. Moore and J.R. Shute, pers. com.). The most recent attempt to further reduce siltation and nutrient load in Abrams Creek was prompted by the apparent failure of any of the fish reintroductions. At present, it appears that both madtom species and the duskytail darter have been reestablished; there is no indication that the spotfin chub is established (J.R. Shute, pers. com.)

Rationale

To date, intensive studies of aquatic macroinvertebrates across broad spatial and temporal scales, have been rare in GSMNP. The Abrams Creek system supports a rich macroinvertebrate fauna worthy of such studies. Greater knowledge of these aquatic communities will be a valuable addition to the understanding of the biodiversity of GSMNP, Tennessee, and the Southern Appalachians.

Freshwater benthic macroinvertebrate taxa richness and community structure can vary spatially and temporally within the same stream. Factors influencing spatial variability include physical habitat and water quality differences between sites. Temporal variability can be influenced by life history differences among organisms (e.g. temporal succession of active immatures and adult emergence among aquatic insect taxa) and changes in physical habitat and water quality over time. Factors influencing water and habitat quality may be natural or anthropogenic in origin. [see reviews in Resh and Rosenberg (1984) and Ward (1992).]

Taxa richness among the aquatic insect orders Ephemeroptera, Plecoptera, and Trichoptera (EPT index) is a sensitive indicator of stream perturbations, especially non-point source pollution (Eaton and Lenat 1991, Wallace et al. 1996). The EPT index is more strongly correlated with water and habitat quality impacts, and more stable at unimpacted sites, than total taxa richness (Lenat 1996). More specifically, EPT taxa richness is reduced in stream reaches draining poorly managed agricultural areas (Lenat, 1984; see review in Waters 1996). The EPT index is widely used in water quality monitoring by various resource management agencies [Lenat 1988, Plafkin et al. 1989, Tennessee Valley Authority (TVA) 1996].

Biotic indices, based on the relative tolerances of aquatic macroinvertebrate taxa (primarily insects) to various perturbations, have been developed and utilized to assess water quality (e.g. Hilsenhoff 1977 and 1987, Plafkin et al. 1989, Lenat 1993). The North Carolina Department of Environmental Management (NCDEM) used a data set of over 2000 macroinvertebrate stream samples to derive tolerance values and scoring criteria for its biotic index (Lenat 1993). Among these were streams within the same river system as Abrams Creek (Little Tennessee). Thus, the North Carolina Biotic Index for mountain region streams is appropriate for use in assessing water quality in the Abrams Creek watershed.

In this study, sites were selected both upstream and downstream of potential sources of pollution and siltation. Differences in physical habitat exist between these sites that may be attributable to both natural and putative anthropogenic sources (e.g. siltation from eroded stream banks). Treatment to abate siltation was incomplete and ongoing through the second year of sampling. This study should be regarded as a baseline to which future comparisons could be made to evaluate the effects of stream bank stabilization efforts in Cades Cove.

Objectives

The objectives of this study were to qualitatively and semi-quantitatively sample and characterize benthic macroinvertebrate communities and identify any detectable differences and/or changes in communities over two years among seven sites in the Abrams Creek watershed. Questions addressed in this study were:

1. What taxa were present at each site at each time sampled?
2. What was the EPT taxa richness and North Carolina Biotic Index (NCBI) score for each site at each time sampled?
3. Were there differences in species richness, community composition, and/or NCBI score among sites at each time sampled?
4. Were there differences in species richness, community composition, and/or NCBI score at each site among sample periods (i.e. seasons, years)?

5. Were there differences in species richness and/or NCBI scores between the potentially impacted site (Abrams 3) and a site upstream of Cades Cove (Abrams 4) and an unimpacted site of similar size (Mill 2).

II. Materials and Methods

Site Selection

Macroinvertebrate samples were collected from seven sites in the Abrams Creek system -- four sites on Abrams Creek proper, two sites on Mill Creek, and one site on Anthony Creek (Figure 1). Sites were chosen according to four criteria: (1) to sample reaches representative of the Abrams Creek system at various points along the stream continuum (3rd - 5th order); (2) to sample sites both upstream and downstream of potential sources of water quality degradation; (3) to sample a relatively unimpacted site comparable in size to the potentially impacted site; and, (4) site proximity to vehicle access. The two sites on Mill Creek (Mill 1 and Mill 2), the Anthony Creek site, and Abrams Creek site 4 (Abrams 4) are upstream of Cades Cove. Due to its location downstream of pasture fields and associated erosion problems in Cades Cove, Abrams Creek site 3 (Abrams 3) was believed to have the highest potential for detectable impacts to macroinvertebrate communities. Because of their similarity in physical characteristics (i.e. drainage area, flow volume, width, gradient), Mill 1 and Abrams 4 were treated as non-impacted reference sites for Abrams 3. The two lower sites (Abrams 1 and 2) are downstream of the Mill Creek confluence and were considered as downstream recovery sites for any impacts observed at Abrams 3.

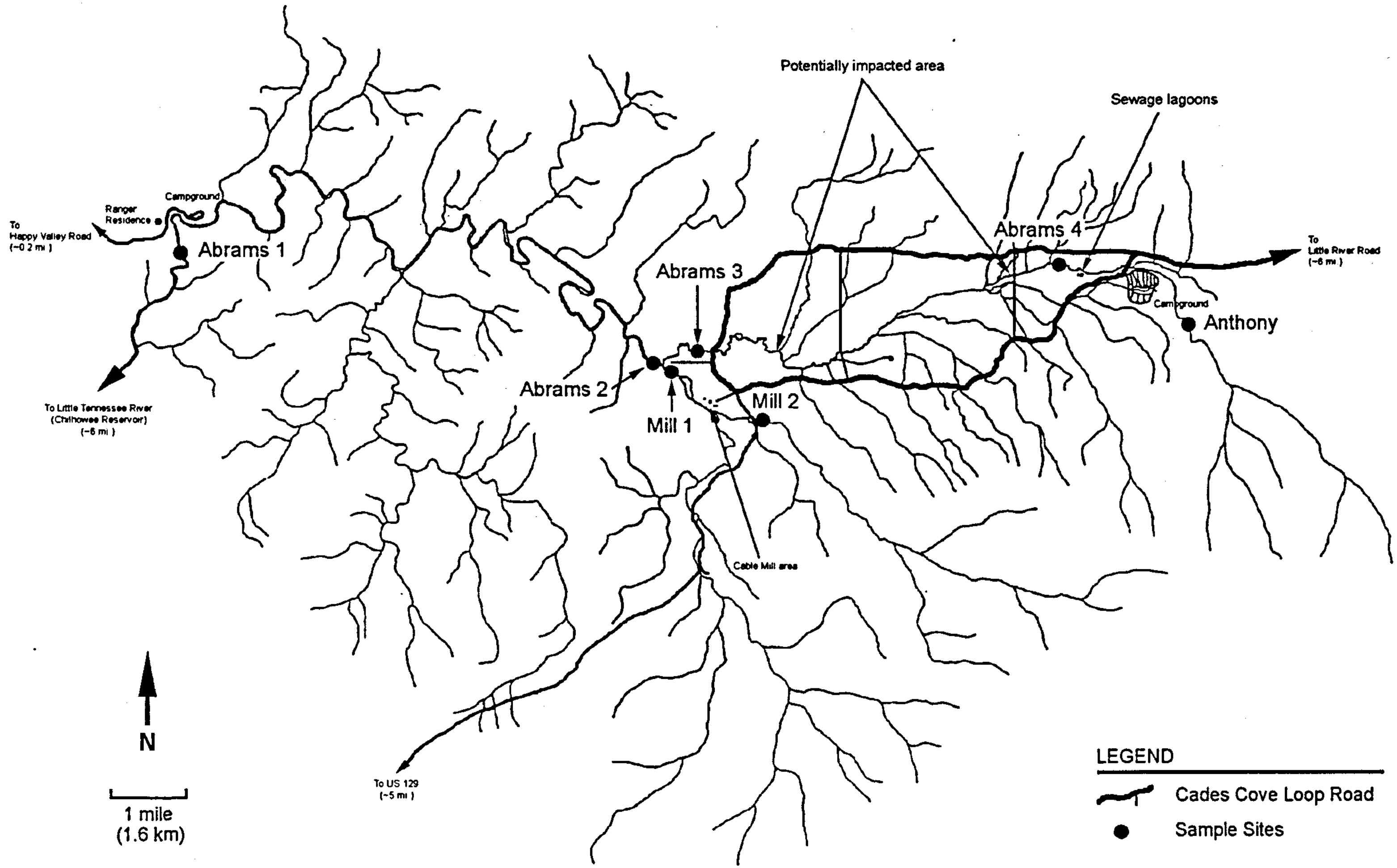

Figure 1. Site localities within the Abrams Creek watershed, GSMNP Blount Co., TN

Sampling Schedule

Sampling began in December 1993 and continued through September 1995. All sites were sampled three times per year: once during winter (late December through early February, as weather permitted), late spring (early May), and early fall (mid September), for a total of six samples per site. Each site was sampled using two techniques: (1) qualitative and (2) semi-quantitative, fixed-number (100 organisms) samples.

Qualitative Sampling Methods

Qualitative samples of 8-14 person-hours (mean=12.24) of effort were taken from each site. Qualitative sampling methods were similar to those described by Lenat (1988), but differed in that they were field "picked" and all individuals collected were not retained in the sample (see below). Composite samples were collected from all habitats represented in the site with the intent of maximizing the total taxa collected at each site.

Sampling gear consisted of large-mesh (1.25mm) kick nets and dip nets. Kick nets were constructed of metallic or nylon window screen approximately 50cm wide by 30cm high and attached at both ends to square wooden strips approximately 3cm wide by 50cm to 1m tall. These were used to sample areas with current sufficient to carry dislodged organisms into the net. These areas included riffles and runs with substrates that varied from fine gravel to bedrock with attached river weed (*Podostemum*). Dip nets were generally used in areas of slower current and where a scooping or sweeping action was required. These areas included overhanging banks with submerged root wads, silty and/or sandy substrates, and leaf and stick packs. Large rocks and woody debris were visually inspected for tightly adhering organisms (e.g. *Nyctiophylax*, *Neophylax* pupae, *Petrophila*, *Blepharicera*, etc.). Decaying woody debris was picked apart and inspected.

Invertebrates were separated from debris in the field using jeweler's forceps and white plastic or enamel trays. Time spent "picking" organisms was included in the total effort. If an organism could be identified to a single taxon in the field, usually no more than 10 individuals were collected. Each collector's observations of abundant field-identifiable taxa were recorded in field notes. Sampling proceeded until all collectors agreed that all available habitats had been representatively sampled and new field identifiable taxa were sufficiently depleted (i.e. no recognizable new taxa in last pan picked).

Semi-quantitative sampling methods

A semi-quantitative, fixed-number sample, similar to the method described by Hilsenhoff (1977), was taken at each site. In year 1, a single semiquantitative sample was taken at each site in each sample period. Two semiquantitative samples were taken at each site in each sample period in year 2. This method entails taking a kick net sample of no fewer than 100 organisms from a shallow, gravel riffle. These samples were collected the same day as, and subsequent to, qualitative sampling. This gave collectors a rough idea of the density of organisms in riffles at each site prior to semiquantitative sampling. Thus, collectors were usually able to limit the number of organisms dislodged into the kick net to approximately 100. The contents of the kick net were transferred to a white enamel pan, and any organisms clinging to the net were picked off and counted. If a sample failed to contain 100 organisms, a second kick was performed with effort sufficient to collect the remaining difference. If a sample contained significantly more than 100 organisms (>110), it was discarded and a second sample collected.

Physical Characteristics

Concurrent with this study, all sites except Mill 2 and Anthony Creek were also sampled for fish populations by GSMNP-RSM and UTK personnel. Mean stream width, discharge, gradient, and dominant substrate type (using a method modified from Platts et al. 1983), were measured by GSMNP-RSM personnel in October 1995, when fish populations were sampled. The dominant (>50%) substrate type within an area 1m in diameter was visually estimated and recorded at 0.25, 0.5, and 0.75 of the total stream width, at ten meter intervals along the sampled reach.

In December 1995, it was discovered that the fish sample sites on upper Mill Creek and Anthony Creek were approximately 100m upstream of where macroinvertebrates were sampled. Physical characteristics were sufficiently different between the two reaches on each stream to warrant gathering additional data specific to the macroinvertebrate sites. Thus, mean stream width, discharge, gradient, and dominant substrate type were measured at Mill 2 and Anthony Creek by the author in October 1996, following the same methodology.

Watershed areas above sites Abrams 1 and Abrams 3 were obtained from a published source (TVA 1970). Watershed areas for all other sites were estimated from U.S. Geological Survey (USGS)1:24,000 scale 7.5 minute topographic quadrangles.

Laboratory Methods and Data Analysis

Identification and Data Tabulation. Samples were preserved and stored in 70% isopropyl alcohol. Most organisms were identified to the lowest taxon possible. Exceptions were the Chironomidae, Simuliidae, and Sphaeriidae (to family level), Trombidiformes (= "Hydracarina", in part) (to suborder), and the Oligochaeta and Gordioidea (to class). Some taxa (e.g. *Acentrella, Tipula*) were identified to genus, but with unique descriptions used to discriminate putative taxa within genera (operational taxonomic units). The primary reference for identification was Brigham et al. (1982), with various supplementary materials used as well (Chapin 1978, Edmunds et al. 1976, Flint 1962 and 1984, Fullington and Stewart 1980, Louton 1982, Merritt and Cummins 1995, Morihara and McCafferty 1979, Parker and Wiggins 1987, Pennak 1989, Schefter and Wiggins 1986, Stark 1986, Stewart and Stark 1988, Wiggins 1977, Wojtowicz 1982). Unless otherwise stated in the following, nomenclature follows Brigham et al. (1982). Other nomenclatural references and taxa to which they apply were: Turgeon et al. (1988), Mollusca; Pennak (1989), all other non-Insecta taxa; McCafferty (1996), Ephemeroptera; Morse (1993), Trichoptera.

Once identified, organisms were systematically tabulated and enumerated. Total and EPT taxa richness were calculated from qualitative samples for each site at each time sampled. However, given the informative limitations of total taxa richness in detecting impacts, some of the subsequent analyses were performed on EPT taxa richness only. Average total and EPT taxa richness per sample at each site was calculated for each sample year and for both years combined. Cumulative total and EPT richness per site were also calculated for each sample year and for both years combined. Additionally, average total and EPT richness per sample and cumulative richness were calculated from annual data for each season at each site. Total cumulative EPT taxa richness was calculated for each season among all sites. A cumulative grand total of all taxa and EPT taxa collected within the entire study area was calculated from all samples at all sites.

When taxa richness was calculated for single samples, all discrete taxa were included in the sum. Early instars of taxa which were identifiable to a lower taxon (e.g. species) in a later instar, were not counted as discrete taxa in individual samples if the sample contained lower taxon-identifiable specimens of the same higher taxon. However, if early instars were the only specimens collected in a given taxon (e.g. genus), then they were counted. Similarly, if adults or late pupae identifiable to species, and larvae identifiable only to the same genus (e.g. some Plecoptera and Trichoptera) were collected in the same sample, then they were treated as the same taxon and counted only once when calculating richness. If, however, two or more putative taxa within the same genus were separated as operational taxonomic units, then only one larval taxon was excluded from the count per species identified from adults or late pupae. The same conservative practices were followed when calculating cumulative richness for sites, seasons, and years; and community similarity coefficients.

Species Composition Similarity. Jaccard's coefficient of similarity (Ludwig and Reynolds 1988) was used to compare EPT communities between seasons and years at each site and between sites. Jaccard's coefficient of similarity is simply the proportion of the total number of taxa collected in two samples, present in both samples. Seasonal EPT community composition was compared at each site by calculating similarity coefficients between individual season samples within each year. Similarity coefficients were also calculated between cumulative total EPT taxa collected in each season from both years at each site. Individual sample EPT community composition within each season was compared between years at each site. Cumulative EPT taxa collected from all samples within each year was also compared between years at each site. Sites were compared by calculating similarity coefficients between total cumulative EPT taxa collected at each site among all sites.

North Carolina Biotic Index. North Carolina Biotic Index (NCBI) scores were calculated from the semiquantitative samples. This index was calculated by assigning a tolerance value between 0 and 10 to each taxon represented, with 0 being least tolerant and 10 most tolerant to water quality perturbations. Thus, index scores are inversely related to water quality (i.e. lower score= higher quality). Tolerance values for most taxa were obtained from published sources [primarily Lenat (1993), with some modified from Hilsenhoff (1977)]. A few taxa collected for which no published value was found were either assigned a value based on the published values of closely related organisms (taxonomically and ecologically, if known), or arbitrarily assigned the median value of all other organisms in that sample. The tolerance value for each taxon was then multiplied by the number of individuals in that taxon collected in the sample. Composite values for each taxon were summed and divided by the total number of all individuals in the sample to arrive at an index score for each site at each time sampled. Fall and winter samples were corrected for seasonal variation as per Lenat (1993). Biotic index scores were compared among sites in three ways: individual sample scores within each year, average annual scores from each year, and average of all samples from both years.

Statistical Analysis. These data are from unreplicated, qualitative and semiquantitative collections, which fail to meet the assumptions of most statistical techniques. However, to further examine apparent trends and relationships, some limited use of statistical techniques was made with caution and qualification. To test for effects of site, season, and year, and interactions between these factors on EPT richness, a three-way analysis of variance (ANOVA) was performed on $\log^{10}$ transformed EPT richness (n+1) (Sokal and Rohlf 1995). Since fall and winter NCBI scores were corrected for seasonal differences (Lenat 1993) to be comparable with spring (=summer, *sensu* Lenat 1993) scores, seasonal samples within each year were treated as replicates at each site. A one-way non-parametric ANOVA (Kruskal-Wallis) was performed on NCBI score mean ranks within year one (n=3) and year two (n=6) separately (Zar 1984). Multiple comparisons were made for significant ANOVA results using Dunn's test.

Taxa richness from summary data was compared among sites as a function of stream size, measured as estimated drainage area, flow discharge, and mean stream width. Coefficients of determination (r^2) were calculated for average and cumulative total taxa and EPT taxa richness from each year and both years combined versus each stream size measure. Coefficients of determination were calculated using data from all sites and all sites excluding Abrams 3. Due to the uniformity of substrate and channel morphology, and the possibility of impacts from Cades Cove [factors known to influence taxa richness, independent of stream size (e.g. Allan 1975, Lenat 1984, Statzner and Higler 1986)] at Abrams 3, its affect on taxa richness to stream size correlations was unknown.

III. Study Area

Great Smoky Mountains

The Appalachian Mountains are oriented in a northeasterly direction from Georgia to Maine. The Unaka Range forms the western front of the Appalachians in eastern Tennessee, rising abruptly from the Tennessee Valley [elevation 287 m (940 ft.) at Maryville, TN] to some of the highest peaks in the eastern U.S. [elevation 2025 m (6643 ft.) at Clingmans Dome]. The Great Smoky Mountains are a further subdivision of the Unaka Range. The Smokies are bordered on the northwest and northeast by the Tennessee Valley and the Pigeon River Gorge, respectively. Maggie Valley and the valleys of the Tuckasegee and Little Tennessee Rivers form the southeastern and southwestern boundaries. Great Smoky Mountains National Park straddles the border between eastern Tennessee and western North Carolina and encompasses most of the Great Smoky Mountains. The portion of the Abrams Creek watershed considered in this study is entirely within GSMNP, Blount County, Tennessee.

Abrams Creek System

Abrams Creek is a fifth order tributary of the Little Tennessee River

(Chilhowee Reservoir) in Blount County, Tennessee. The Abrams Creek watershed drains an area of 227 km^2 (88 $mi.^2$) (TVA 1970). Three arbitrary divisions, or watershed units, within the study area are defined here: 1) Upper Abrams Creek, including Anthony Creek and Abrams Creek upstream of the Mill Creek confluence; 2) Mill Creek, including Forge Creek; and 3) Middle Abrams Creek below the Mill Creek confluence and downstream to Abrams Creek site one. In the descriptions that follow, distances and elevations were obtained from USGS 1:24,000 scale 7.5 minute topographic quadrangles. Forest cover information was obtained from the GSMNP Geographic Information System (GIS) vegetation map.

Upper Abrams Creek. Anthony Creek, the easternmost tributary of Abrams Creek, begins along the crest of the western Great Smokies on Mount Squires (elevation 1511 m [4958 ft.]). From its origin to its confluence with Abrams Creek, it flows a distance of approximately 6.5 km (4 mi.). In that distance it descends nearly 928 m (3000 ft.) with an average gradient of 140 m/km (750 ft./mi.).

Abrams Creek then flows through the valley known as Cades Cove, and the gradient is greatly reduced. From the confluence with Anthony Creek downstream 9.4 km (5.8 mi.) to the Mill Creek confluence (elevation 521 m [1710 ft.]), it descends only 63 m (205 ft.) -- an average gradient of 6.7 m/km (35.3

ft./mi.).

Vegetation and Land Use. The upper elevations are predominantly covered with northern hardwoods. Cove hardwoods cover much of the mid-elevations with mixed mesic hardwood, mesic oak, and tulip poplar stands interspersed. Xeric oak and pine stands dominate the dryer ridgetops and continue down to the lower elevations where they dominate the forested portion of Cades Cove.

Cades Cove is unique in that a large proportion of it is unforested and devoted to agricultural land use. Approximately 730 ha (1800 acres) are cleared and used as livestock pasture and/or mown for hay. This use is associated with the management of Cades Cove as an "historic district." The Park Service manages Cades Cove to preserve the open pastures and other remnants of the farming community which flourished from the early 19th century until the creation of the national park in 1937 (Shields 1977).

The Cades Cove Loop Road is an asphalt paved, single lane road encircling most of the cleared area within Cades Cove. This often heavily traveled road provides access to several historical and natural points of interest and associated parking lots. Two gravel roads, Sparks and Hyatt lanes, cross Cades Cove and Abrams Creek, intersecting the Loop Road at both ends. (see Figure 1)

Disturbance is minimal in the Anthony Creek watershed. The disturbances present include trails which parallel Anthony and Little Anthony Creeks and a developed campground for trail horse riders and their horses. Additionally, a developed campground for tents and recreational vehicles and a picnic area with paved roads are present in the vicinity of the Abrams-Anthony Creek confluence.

Potential Pollution Sources. Most of the potential and actual sources of silt and animal waste input into Abrams Creek occur within the agricultural areas in Cades Cove. Maple, McCaulley, and Oliver branches, tributaries which drain the southeastern portion of Cades Cove, were identified by Park Service personnel as having serious stream bank erosion problems (S.E. Moore, pers. com.). These problems have been exacerbated by livestock having unfettered access to stream banks.

In the summer of 1993, much of the problem on Maple Branch was alleviated. Stream banks were fenced to exclude livestock, and banks were contoured and seeded with native grasses. The following summer, similar work began on McCaulley and Oliver branches. This work continued through summer 1996.

Another potential source of water pollution exists in this portion of the watershed. Alongside Abrams Creek in the upper end of Cades Cove are two sewage disposal lagoons (see Figure 1). These lagoons serve in the treatment of waste water from the campground and other park facilities in upper Cades Cove. The potential exists for leachates from these lagoons to seep into Abrams Creek. Overflow during periods of high sewage input or heavy rains could result in effluent entering the stream.

Geology. The geology of Cades Cove is unique in the Abrams Creek watershed. The highlands surrounding Cades Cove are formed of ancient rock of Precambrian origin. Elkmont sandstone and Metcalf phyllite dominate the upper watersheds of Anthony Creek and the other major tributaries. The Cades Cove valley floor, however, is underlain with younger Jonesboro limestone of Ordovician origin (Moore 1988, Neuman and Nelson 1963).

This unusual situation of younger rock underlying older strata is explained by the tectonic forces that created these mountains. During the Appalachian orogeny (mountain-building) in the late Paleozoic (200 million years ago), the land mass which gave rise to the Great Smokies was thrust up and over the younger land mass of the Tennessee Valley. Cades Cove is a "window" eroded down through this overthrusted mass, exposing the younger limestone beneath (Moore 1988, Neuman 1963).

Mill Creek. The headwaters of Mill Creek and its major tributary, Forge Creek, drain the crest of the Great Smokies from McCampbell Knob (elevation

1354 m [4440 ft.]) to Gregory Bald (elevation 1509 m [4949 ft.]) (see Figure 1). From its origin to the confluence with Forge Creek, Mill Creek descends approximately 823 m (2700 ft.) in 8.2 km (5.1 mi.), with an average gradient of 102 m/km (529 ft./mi.). Likewise, Forge Creek descends approximately 1052 m (3209 ft.) in 8.8 km (5.5 mi.), with an average gradient of 117 m/km (586 ft./mi.).

Vegetation and Land Use. With the exception of a small area near the confluence with Abrams Creek in lower Cades Cove, the entire Mill Creek watershed is forested. Forest cover is similar to the Upper Abrams Creek watershed described above.

Two gravel roads are present within this watershed unit. Forge Creek Road crosses Mill, Wildcat, and Forge Creeks, and parallels Forge Creek for 2.4 km (1.5 mi.). Parson Branch Road enters the watershed for a short distance before intersecting with Forge Creek Road. The Gregory Ridge Trail begins at the end of Forge Creek Road and parallels Forge Creek for 2.9 km (1.8 mi.).

The lower portion of the watershed within Cades Cove is more disturbed. Open hay fields and a restored historic site occupy 6 ha (15 acres). This historic site, the John P. Cable Mill Area, includes several restored historic buildings, as well as a gravel parking lot and rest room facilities to accommodate tourists.

Potential Pollution Sources. Two potential sources of pollution exist within this watershed unit. The potential for pollution from these sources may, arguably, be negligible but they are identified here for completeness.

The sewage from tourist facilities in the Cable Mill Area is disposed of through a septic tank and field bed system. This system is within 100 m of Mill Creek. Leachates from this system could potentially enter Mill Creek, although no indications of this have been observed (unpublished TVA water quality data).

The second potential source comes from the top of the watershed. Along the Appalachian Trail on Mollies Ridge is Mollies Ridge Shelter. This shelter serves as overnight accommodations for hikers on the Appalachian Trail. No rest room facilities are present. The practices of sanitary latrine site selection and burial are left to the discretion of the individual. If waste disposal is not handled properly, raw sewage could be introduced into the headwaters.

Geology. The geology of the Mill Creek and Anthony Creek watersheds is similar. Precambrian Elkmont sandstone and Metcalf phyllite dominate the highlands. A small area of Cades sandstone is present, primarily in the Forge Creek watershed. While lower Mill Creek enters Cades Cove for a short distance, it is not in direct contact with limestone strata as is Abrams Creek. The small portion of Cades Cove drained by Mill Creek is an area of deep alluvium, transported from the surrounding highlands (Neuman 1963).

Middle Abrams Creek. This watershed unit includes the area drained by Abrams Creek and its tributaries from the Mill Creek confluence downstream approximately 16 km (10 mi.) to site Abrams 1 (see Figure 1). In that distance, it descends approximately 186 m (610 ft.) with an average gradient of 11.6 m/km (61 ft./mi.).

Rabbit Creek is the largest tributary within this watershed. Its headwaters arise on Hannah Mountain at an elevation of approximately 850 m (2800 ft). Rabbit Creek and its tributaries drain the majority of the watershed south of Abrams Creek. Several smaller tributaries drain from the north. The majority of these streams head below 610 m (2000 ft.).

Vegetation and Land Use. Except for a small area near site 1 in the lower portion, this watershed is completely forested. While the upper elevations are covered with northern, cove, and mixed mesic hardwoods, the majority of the watershed is dominated by xeric oak, pine, and mixed xeric oak and pine stands.

Minimal disturbance is present within this watershed. The small area near site 1 is the most disturbed. A permanent ranger residence and a small horse pasture [approximately 0.8 ha (2 acres)] are present. In addition, a gravel road is present which provides access to Abrams Creek campground. This road parallels Abrams Creek from site 1 to the campground. The campground is located approximately 800 m (.5 mi.) upstream of site 1.

Another gravel road is present within the Rabbit Creek watershed. Parsons Branch Road parallels the headwaters of Rabbit Creek for approximately 2.4 km (1.5 mi.). This road was severely damaged by flooding in 1994 and remains closed.

Several trails are present within this watershed. The Abrams Falls and Little Bottoms trails parallel Abrams Creek from the Abrams Creek campground upstream to Cades Cove. The Cooper Road and Beard Cane trails are in the northern portion of the watershed. The Rabbit Creek and Hannah Mountain trails are in the southern portion, primarily within the Rabbit Creek watershed.

Potential Pollution Sources. A small potential for pollution exists primarily at the lower end of this watershed. The wastewater from the Abrams Creek campground and the ranger residence is disposed of by separate septic tank and field bed systems. These systems are within 100 m of the stream. Leachates from these systems could potentially enter Abrams Creek.

Geology. The geology of this portion of the Abrams Creek watershed is dominated by Cades sandstone. The Rabbit Creek watershed and watersheds of the northern tributaries upstream of Abrams Falls are in an area dominated by this rock type. Abrams Falls is along the Rabbit Creek Fault, which is the boundary between the Cades sandstone and the Wilhite Formation that underlies the lower part of this watershed. The Wilhite formation is divided into a band of conglomerate and a band of siltstone. This band of conglomerate rock is present from Abrams Falls downstream to the area between Mill Branch and

Buck Shank Branch. From there, the remainder of this watershed unit, and the rest of Lower Abrams Creek, flows through Wilhite siltstone (Neuman 1963).

Site Descriptions

A brief description of each site follows. Complete physical data collected are listed in Table 1. See Figure 1 for graphic representation of site locations.

Site 1 (Abrams 1). Sample site 1 is located on Abrams Creek approximately 16 km (10 mi.) downstream of Cades Cove. Access is through the Abrams Creek GSMNP entrance via Happy Valley Road. The upper end of the site is immediately downstream of the Abrams Creek Ranger Station and approximately 800 m (0.5 mi.) downstream of the Abrams Creek Campground. The area sampled begins at the pool below the Rabbit Creek Trail footbridge and extends to the head of a broad riffle, approximately 250 m (820 ft.) upstream. The dominant substrate constituent is cobble (61%). Mean stream width and percent gradient were 17.7 m (58.1 ft.) and 1.73, respectively. Total flow discharge in October 1995 was 46.8 cubic feet per second (cfs).

The site is dominated by a long, shallow, slow-flowing pool/run, comprising approximately 40% of the total sample area. The margins of this pool are relatively steep with some undercut banks. Most of these banks are overhung with shrubby vegetation (primarily *Cornus* spp.) with submerged root

Table 1. Physical data from the seven sites sampled within the Abrams Creek system. Defined substrate particle size ranges follow GSMNP-RSM modification of Platts et al. (1983). (m= meters, cfs= cubic feet per second, sq. km= square kilometers, mm= millimeters, cm= centimeters)

						Substrate (%)							
Site	Reach Sampled (m)	Mean Gradient (%)	Mean Width (m)	Discharge (cfs)	Watershed Area (sq. km)	Silt (<0.06mm)	Sand (0.06 - 2mm)	Small Gravel (2mm - 2cm)	Large Gravel (2 - 10cm)	Cobble (10 - 30cm)	Small Boulder (30 - 60cm)	Large Boulder (>60cm)	Bedrock
Abrams 1	250	1.7	17.7	46.8	157	0	3	0	3	61	11	8	14
Abrams 2	200	2.7	19.5	34.1	94	0	3	6	0	21	12	3	55
Abrams 3	150	1.6	8.9	13.9	49	4	19	11	44	19	0	0	7
Abrams 4	100	1.6	5.7	10.9	14	0	0	3	6	70	21	0	0
Anthony	100	5.0	5.1	3.1	10	0	3	0	0	21	43	23	10
Mill 1	150	2.8	10.5	22.2	44	0	0	3	13	64	13	0	7
Mill 2	100	2.1	4.7	3.8	12	0	6	6	21	49	15	0	3

wads extending from undercut banks. The substrate in these marginal areas is primarily sand to silty-sand. Within a meter or two of the water's edge, this grades into the cobble-small boulder substrate that dominates the majority of the pool.

The adjacent riparian zone at the site is forested. Canopy cover over the creek, however, is limited to approximately 15 percent. This is attributable to stream width and the apparent early successional stage of the riparian forest.

Site 2 (Abrams 2). Sample site 2 is located on Abrams Creek as it exits Cades Cove, just below the confluence with Mill Creek. Site 2 is approximately 16 km (10 mi.) upstream of site 1. Access is from the Abrams Falls Trail parking lot via the Cades Cove Loop Road. The area sampled begins immediately downstream of the Mill Creek confluence and extends downstream approximately 200 m (656 ft.). Over half of the substrate sampled at site 2 was bedrock (55%). Mean stream width and percent gradient were 19.5 m (64.1 ft.) and 2.7, respectively. Total flow discharge in October 1995 was 34.12 cfs.

An abundance of bedrock ledges nearly perpendicular to the stream course characterize this site. This results in a series of longitudinally narrow pools, divided by shallow bedrock riffles and runs where the ledges near, or break, the water's surface. The lower half of the site is dominated by this habitat type.

Within site 2, a long, slow-flowing pool is present, similar to but not as extensive as at site 1. This pool comprises approximately 35% of the total sample area. Marginal areas of this pool are similar to the lower site in having sand to silty-sand substrates, but they lack dense, overhanging, shrubby vegetation. However, larger rosebay rhododendron (*Rhododendron maximum*) is present and overhanging along much of this site. Undercut banks are rare.

The riparian zone adjacent to this site is forested. While the mean width is actually greater at this site than at site 1, percent canopy cover (approximately 40%) is greater . A later successional stage forest dominated by large hemlocks (*Tsuga canadensis*) is present.

Site 3 (Abrams 3). Sample site Abrams 3 is located on Abrams Creek approximately 840 m (0.5 mi.) upstream of the Mill Creek confluence in lower Cades Cove. Access is from the gravel road leading to the Abrams Falls Trail parking lot, approximately 100 m (330 ft.) from the intersection with Cades Cove Loop Road. The area sampled begins approximately 250 m (820 ft.) downstream of the Cades Cove Loop Road and extends downstream approximately 150 m (490 ft.). Mean stream width and percent gradient were 8.9 m (29.4 ft.) and 1.63, respectively. Total flow discharge in October 1995 was 13.9 cfs.

This site is considerably different from all other sites. Substrate type and water depth are nearly uniform throughout the site. Gravel substrates dominate (56%), with cobble and sand contributing significant proportions (18.5 and 15%, respectively). Additionally, all coarse substrates were moderately to heavily embedded in finer particles (sand and silt). Water depth averaged 0.5 m (1.6 ft.) with little variation. This results in the site being dominated by long, slow pools and runs, occasionally separated by broad gravel riffle/runs.

The riparian zone adjacent to this site is forested. Large tulip poplar (*Liriodendron tulipifera*), buckeye (*Aesculus octandra*), and ironwood (*Ostrya virginiana*) trees provide a high canopy cover of approximately 80%. The meandering stream course here, however, has eroded the banks considerably. Several areas of near vertical, bare soil banks, are present primarily on the outer banks of bends in the stream. Frequent collapse of undercut banks is evident.

A portion of the flow volume at Abrams 3 is contributed by springs. These springs are scattered throughout an area approximately 360 to 720 m (390 yds. to 790 yds.) upstream of this site. During late summer and fall, when flows are at a minimum, much of the flow volume of Abrams Creek sinks into the substrate in an area approximately 960 m (0.6 mi.) upstream of this site (see Figure 1). During these periods, much of the flow volume at site 3 comes from these springs. It is not known whether the water emerging from these springs is the same water which sank upstream, if it comes from other subterranean streams, or is a combination of the two.

Site 4 (Abrams 4). Sample site 4 is located on Abrams Creek, just upstream of the mouth of Crooked Arm Branch, in upper Cades Cove. Access is from the Cades Cove Loop Road. The area sampled begins at the mouth of Crooked Arm Branch and extends upstream approximately 100 m (330 ft.). The upper end of the sample area is approximately 450 m (1500 ft.) downstream of the sewage treatment lagoons. Cobble dominates the substrate within site 4 (70%). Mean stream width and percent gradient were 5.7 m (18.7 ft.) and 1.6, respectively. Total flow discharge in October 1995 was 10.9 cfs.

This site is more typical of a lower gradient montane stream than site 3. Habitat at this site is a complex of riffles, runs, and small pools, with riffles and runs dominating. Larger substrate particles are abundant here with little to no embeddedness.

The riparian zone adjacent to this site is predominately pasture with a single line of trees along the stream bank. Very little shrubby vegetation is present. Grasses and herbs dominate under relatively widely spaced large trees. These trees are predominately large oaks (*Quercus* spp.) and tulip poplars. These provide a high, partially closed canopy over much of the site. However, small portions of the site are open, and due to the large size and scattered distribution of trees, a considerable amount of direct and diffuse sunlight reaches the stream.

Despite livestock having complete access, stream banks are largely stable and uneroded. The root systems of the trees and well established grasses appear to contribute significantly to this stability.

Site 5 (Anthony). Sample site 5 is located on Anthony Creek approximately 1.3 km (0.8 mi.) upstream of the confluence with Abrams Creek. Access is by the gated road/trail leading to the horse camp via the Cades Cove Picnic Area. The area sampled begins approximately 100 m (330 ft.) upstream of the horse camp and extends another 100 m upstream. Substrate is dominated by small boulders (47%). Mean stream width and gradient were 5.07 m (16.6 ft.) and 5%, respectively. Total flow discharge in October 1995 was 3.14 cfs.

This site has the highest gradient among all sites. Habitat is typical of a high gradient montane stream. Pools and runs separated by steep riffles and cascades characterize this site. Substrates are virtually silt free with no embeddedness. Exceptions are small areas in quiet backwaters of pools with light accrual of finer particles and organic matter.

The riparian zone adjacent to this site is forested. Large hemlocks, yellow birch (*Betula alleghaniensis*), and rosebay rhododendron are the dominant species. Canopy cover is near 100%. Where rhododendron is present, canopy cover is very dense, making sunlight penetration minimal. Stream banks at this site appear to be relatively stable over time. However, the high gradient makes banks susceptible to erosion during exceptional flood events. This was apparent following the floods of spring 1994 when the outer bank of a bend within this site was severely eroded.

Site 6 (Mill 1). The downstream end of sample site 6 is located on Mill Creek approximately 190 m (630 ft.) upstream of the Abrams Creek confluence and continues upstream approximately 150 m (490 ft.) to the downstream end of a small island. Access is from the Abrams Falls Trail parking lot via the Cades Cove Loop Road. Substrate is dominated by cobble (63%). Mean stream width and percent gradient were 10.54 m (34.6 ft.) and 2.78, respectively. Total flow discharge in October 1995 was 22.18 cfs.

This is a lower gradient site, similar to Abrams 2 and Abrams 3. However, in contrast to Abrams 2, habitat is predominately broad, shallow riffles and runs and perpendicular bedrock outcrops are absent. Unlike Abrams 3, pools are small and few as are areas with accumulations of finer substrates. Larger substrate particles are virtually silt free with little embeddedness.

The riparian zone adjacent to this site is forested. Tulip poplar, yellow birch, and ironwood are common. Canopy cover is approximately 90% with some areas completely covered. Stream banks appear to be stable. Some undercut banks are present, however, support is provided by dense tree roots and there is no evidence of recent collapse.

Site 7 (Mill 2). Sample site 7 is located on Mill Creek approximately 650 m (710 yds.) upstream of the Forge Creek confluence. Access is from Forge Creek Road via the Cades Cove Loop Road. The sampled reach begins immediately upstream of the Forge Creek Road bridge and extends upstream approximately 100 m (330 ft.). The most frequently observed substrate constituent was cobble (49%). Mean stream width and percent gradient were 4.69 m (15.4 ft.) and 2.1 respectively. Total flow discharge in October 1995 was 3.84 cfs.

At this site, Mill Creek is comparable in size and watershed to Anthony Creek at site 5. While the gradient is less than at site 5, a similar diversity of habitats exists. The difference in gradient results in a higher ratio of pools and runs to riffles and cascades. Areas with accumulations of finer substrates are rare. Larger substrate particles are virtually silt free with little embeddedness.

The riparian zone adjacent to this site is mostly forested. The lower third of the site is bordered on the south by the Forge Creek Road. A few scattered trees and shrubs grow between the road and the stream. The majority of the riparian zone is dominated by yellow birch, maples (*Acer* spp.), and ironwood. With the exception of the lower third, there is near complete canopy closure. Stream banks are stable with no evidence of erosion. Undercut banks are rare, but where present are well supported by tree roots. No evidence of recent collapse of undercut banks was observed.

IV. Results

Taxonomic Resolution

Overall, 340 macroinvertebrate taxa in 90 families were identified (Table 2) during the entire study. Of those, 222 taxa (65%) were identified to species. Fifty-eight additional taxa (17%) were identified to species pairs or groups, or as operational taxonomic units within genera. Fifty-five taxa (16%) were identified to genus. The Chironomidae, Daphnidae, Simuliidae, and Sphaeriidae were identified to family, and the Trombidiformes ("Hydracarina"), Oligochaeta, and Gordioidea were identified to suborder, class, and subphylum, respectively.

Among the total taxa identified, 214 (63%) were from the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT). Of those EPT taxa identified, 148 (69%) were identified to species, 45 (21%) were identified to species pairs or groups, or operational taxonomic units. Twenty-one EPT taxa (10%) were identified to genus only. See Appendix for complete lists of taxa identified from sites on Abrams Creek proper (Table A-1) and Mill and Anthony creeks (Table A-2).

Total Taxa Richness

Year 1. Among qualitative samples from year 1 at each site, lowest single

Table 2. Macroinvertebrate taxa per higher taxon identified from all sites and samples, Abrams Creek system, December 1993-September 1995. (C= class, F= family, G= genus, O= order, OTU= operational taxonomic unit, S= species, SF= subfamily, SG= species group, SO=suborder)

Phylum	Class	Order	Family	Taxa	Resolution
Nematomorpha					
	Gordioidea			1	C
Annelida					
	Hirudinea				
		Rhynchobdellida			
			Glossiphoniidae	1	G
	Oligochaeta			1	C
Mollusca					
	Gastropoda				
		Mesogastropoda			
			Pleuroceridae	2	S
		Limnophila			
			Ancylidae	1	S
			Lymnaeidae	1	G
			Planorbidae	2	S
			Physidae	2	S
	Pelecypoda				
		Schizodonta			
			Sphaeriidae	1	F
			Unionidae	1	S
Arthropoda					
	Arachnoidea				
		*Trombidiformes (="Hydracarina")		1	SO
	Crustacea				
		Amphipoda			
			Gammaridae	1	G
			Talitridae	1	S
		Cladocera			
			Daphnidae	1	F
		Decapoda			
			Cambaridae	3	S
		Isopoda			
			Asellidae	2	G
	Insecta				
		Plecoptera			
			Capniidae	3	G, S

* suborder

Table 2. (continued)

Phylum Class Order Family	Taxa	Resolution
Arthropoda		
Insecta		
Plecoptera (continued)		
Chloroperlidae	5	G, S
Leuctridae	1	G
Nemouridae	4	G, SG, S
Peltoperlidae	1	G
Perlidae	12	G, SG, OTU, S
Perlodidae	16	G, SG, OTU, S
Pteronarcyidae	3	OTU, S
Taeniopterygidae	5	G, OTU, S
Ephemeroptera		
Ameletidae	2	S
Baetidae	14	OTU, S
Baetiscidae	2	S
Caenidae	2	G
Ephemerellidae	23	SG, OTU, S
Ephemeridae	2	G
Heptageniidae	26	SG, OTU, S
Isonychiidae	1	G
Leptohyphidae	1	G
Leptophlebiidae	5	G, SG, S
Siphlonuridae	1	G, OTU
Odonata		
Aeschnidae	5	S
Calopterygidae	2	SG, S
Coenagrionidae	2	G, OTU
Cordulegastridae	3	SG, S
Corduliidae	2	G, S
Gomphidae	12	S
Macromiidae	2	S
Heteroptera		
Belostomatidae	1	S
Corixidae	1	G
Gerridae	2	S
Nepidae	2	S
Veliidae	2	G, S
Megaloptera		
Corydalidae	3	S
Sialidae	1	G
Trichoptera		
Arctopsychidae	2	S
Brachycentridae	10	S
Calamoceratidae	2	S

Table 2. (continued)

Phylum	Class	Order	Family	Taxa	Resolution
Arthropoda					
	Insecta				
		Trichoptera (continued)			
			Glossosomatidae	4	G, S
			Helicopsychidae	1	S
			Hydropsychidae	14	G, SG, OTU, S
			Hydroptilidae	1	G
			Lepidostomatidae	2	G, SG, OTU, S
			Leptoceridae	8	G, OTU, S
			Limnephilidae	12	G, SG, S
			Molannidae	1	S
			Odontoceridae	2	G, S
			Philopotamidae	3	G, S
			Phryganeidae	1	G
			Polycentropodidae	4	G, S
			Psychomyiidae	2	G, S
			Rhyacophilidae	8	G, SG, OTU, S
			Sericostomatidae	2	G, S
			Uenoidae	6	G, SG, OTU, S
		Lepidoptera			
			Pyralidae	1	S
		Coleoptera			
			Carabidae	1	OTU
			Dryopidae	4	S
			Dytiscidae	4	G, OTU, S
			Elmidae	12	G, S
			Eubriidae	1	G
			Gyrinidae	1	G, S
			Hydrophilidae	6	G, S
			Psephenidae	1	S
			Ptilodactylidae	1	S
		Diptera			
			Athericidae	1	S
			Ceratopogonidae	3	G, SG
			Chironomidae	1	F
			Culicidae	1	G
			Dixidae	1	G
			Empididae	1	F, G
			Ptychopteridae	1	S
			Simuliidae	1	F
			Tabanidae	3	G
			Tanyderidae	1	S
			Tipulidae	17	SF, G, OTU

sample total taxa richness was 60, in both the fall sample from Anthony Creek and the spring sample from Mill 2 (Table 3a). The Anthony Creek site also had the lowest average total taxa per sample among year 1 samples [mean=69, standard deviation(SD)=12]. Lowest cumulative taxa richness from year 1 samples was at Mill 2 (107). Site 1 on Abrams Creek had the highest single sample total taxa richness (spring=108), average total taxa per sample (mean=98, SD=15), and total cumulative taxa richness per site among year 1 samples.

Year 2. Year 2 total taxa richness was generally greater than in year 1, with 17 of 21 samples having higher richness in year 2 (Table 4a). Two of the four samples with lower total taxa richness were from Abrams 4, spring and fall samples. Abrams 4 was also the only site at which cumulative total taxa decreased from year 1 to year 2.

Among all year 2 samples, lowest single sample total taxa richness (winter=68) and average total taxa per sample (mean=77, SD=12) was again from Anthony Creek. The Anthony Creek site also had the lowest cumulative total taxa richness in year 2 (122). Highest single sample total richness (spring=124) and cumulative total taxa (179) in year 2 was again from Abrams 1. However, highest average total taxa per sample among year 2 samples was from Abrams 2 (mean=113, SD=3.8).

Table 3. Total macroinvertebrate and Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness from year 1 (1993-94) samples. (W= winter, S= spring, F= fall; SD= standard deviation)

a. Total Taxa

Site	W	S	F	Mean	SD	Cumulative Total
Abrams 1	80	108	104	97.3	15.1	161
Abrams 2	90	95	96	93.7	3.2	155
Abrams 3	77	83	67	75.7	8.1	130
Abrams 4	71	101	82	84.7	15.2	141
Anthony	65	82	60	69.0	11.5	115
Mill 1	77	85	85	82.3	4.6	129
Mill 2	70	60	81	70.3	10.5	107
Mean	75.7	87.7	82.1			134.0
SD	8.1	15.7	15.3			19.8

b. EPT Taxa

Site	W	S	F	Mean	SD	Cumulative Total
Abrams 1	42	61	56	53.0	9.8	94
Abrams 2	59	62	57	59.3	2.5	97
Abrams 3	48	45	32	41.7	8.5	77
Abrams 4	47	68	45	53.3	12.7	94
Anthony	47	61	36	48.0	12.5	87
Mill 1	51	57	52	53.3	3.2	87
Mill 2	46	42	51	46.3	4.5	71
Mean	48.6	56.6	47.0			86.7
SD	5.3	9.5	9.8			9.6

Table 4. Total macroinvertebrate and Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness from year 2 (1994-95) samples. (W= winter, S= spring, F= fall; SD= standard deviation)

a. Total Taxa

Site	W	S	F	Mean	SD	Cumulative Total
Abrams 1	90	124	107	107.0	17.0	179
Abrams 2	116	116	109	113.7	4.0	176
Abrams 3	81	80	76	79.0	2.6	135
Abrams 4	76	88	77	80.3	6.7	129
Anthony	68	91	72	77.0	12.3	122
Mill 1	89	98	81	89.3	8.5	132
Mill 2	83	87	85	85.0	2.0	136
Mean	86.1	97.7	86.7			144.1
SD	15.2	16.3	15.1			23.3

b. EPT Taxa

Site	W	S	F	Mean	SD	Cumulative Total
Abrams 1	52	70	56	59.3	9.5	109
Abrams 2	71	72	64	69.0	4.4	118
Abrams 3	47	48	34	43.0	7.8	78
Abrams 4	47	56	38	47.0	9.0	85
Anthony	49	68	44	53.7	12.7	91
Mill 1	61	63	45	56.3	9.9	91
Mill 2	54	59	53	55.3	3.2	95
Mean	54.4	62.3	47.7			95.3
SD	8.8	8.6	10.5			13.8

Both Years. Lowest average total taxa per sample among all samples from both years came from Anthony Creek (mean=73, SD=12) (Table 5a). Total cumulative taxa richness per site, summed from all samples from both years was lowest at Mill 2 (148). Highest average total taxa per sample among all samples from both years was virtually equal at Abrams 2 (mean=104, SD=11) and Abrams 1 (mean=102, SD=15). Total cumulative taxa richness per site, summed from all samples from both years was greatest at Abrams 1 (214).

EPT Taxa Richness

A three-way ANOVA detected significant interaction (p= 0.05) between both years and seasons and years and sites among $\log^{10}$ transformed EPT taxa richness from all samples (Table 6). No significant interaction between site and season was detected. Since interaction between any of the factors makes tests of each individual factor unreliable, no further statistical tests of the effect of site, season, or year were performed. However, while the ability to detect significant statistical differences is limited, direct comparison of the data reveals some informative patterns, especially in EPT richness among sites.

Year 1. Among samples from year 1 at each site, lowest single sample EPT taxa richness (fall=32) and average EPT richness per sample (mean=42, SD=8.5) were from Abrams 3 (Table 3b). Total cumulative EPT richness,

Table 5. Mean and cumulative total macroinvertebrate and Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness from both years' samples combined. (W= winter, S= spring, F= fall; SD= standard deviation)

a. Total Taxa

	Seasonal Means						Overall		Cumulative Totals Seasons			
Site	W	SD	S	SD	F	SD	Mean	SD	W	S	F	Overall
Abrams 1	85.0	7.1	116.0	2.1	105.5	6.8	102.2	15.3	112	153	132	214
Abrams 2	103.0	18.4	105.5	9.2	102.5	14.1	103.7	11.4	134	140	119	197
Abrams 3	79.0	2.8	81.5	6.4	71.5	2.4	77.3	5.7	104	112	93	167
Abrams 4	73.5	3.5	94.5	3.5	79.5	3.1	82.5	10.7	92	118	104	163
Anthony	66.5	2.1	86.5	8.5	66.0	5.7	73.0	11.5	86	110	84	151
Mill 1	83.0	8.5	91.5	2.8	83.0	4.9	85.8	7.2	107	115	98	150
Mill 2	76.5	9.2	73.5	2.8	83.0	10.4	77.7	10.5	99	95	104	148
Mean	80.9		92.7		84.4				104.9	120.4	104.9	
SD	12.9		16.2		14.8				15.6	19.6	16.1	

b. EPT Taxa

	Seasonal Means						Overall		Cumulative Totals Seasons			
Site	W	SD	S	SD	F	SD	Mean	SD	W	S	F	Overall
Abrams 1	47.0	7.1	65.5	6.4	56.0	0.0	56.2	9.3	67	90	74	134
Abrams 2	65.0	8.5	67.0	7.1	60.5	4.9	64.2	6.2	84	90	74	129
Abrams 3	47.5	0.7	46.5	2.1	33.0	1.4	42.3	7.3	66	66	45	99
Abrams 4	47.0	0.0	62.0	8.5	41.5	4.9	50.2	10.5	60	82	57	112
Anthony	48.0	1.4	64.5	4.9	40.0	5.7	50.8	11.7	64	84	52	115
Mill 1	56.0	7.1	60.0	4.2	48.5	4.9	54.8	6.8	73	76	55	104
Mill 2	50.0	5.7	50.5	12.0	52.0	1.4	50.8	6.0	67	66	69	104
Mean	52		59		47				68.7	79.1	60.9	
SD	7.6		9.2		9.8				7.8	10.2	11.5	

Table 6. Three-way ANOVA, log 10 transformed EPT richness for each sample by site, year, and season. (s=significant, fds=failed to detect significance)

Source of variation	df	SS	MS	MS/MSE	F(*P*=0.05)	
Year	1	0.01094	0.01094	10.648	4.75	s
Site	6	0.09687	0.01614	15.706	3	s
Season	2	0.07432	0.03716	36.152	3.89	s
Year x Site	6	0.01728	0.00288	2.802	3	fds
Year x Season	2	0.00360	0.00180	1.753	3.89	fds
Site x Season	12	0.06613	0.00551	5.361	2.89	s
Year x Site x Season	12	0.01233	0.00103			

summed from all year 1 samples was lowest at Mill 2 (71). Highest single sample EPT richness from year 1 was 68 (spring, Abrams 4). Highest year 1 average EPT richness per sample (mean=59, SD=2.5) and cumulative EPT richness was from Abrams 2 (97).

Year 2. As with total taxa, EPT richness was greater in year 2 samples, with 15 of 21 samples higher in EPT taxa than their counterparts in year 1 (Table 4b). Likewise, cumulative EPT taxa was higher in year 2 at all sites except Abrams 4.

Among samples within year 2 at each site, Abrams 3 again had the lowest single sample EPT richness (winter=34) and average EPT richness per sample (mean=43, SD=8), as well as the lowest cumulative EPT richness (78). Highest single sample EPT richness (spring=72), average EPT richness per sample (mean=69, SD=4.4), and cumulative EPT richness for year 2 were all recorded from Abrams 2.

Both Years. Among samples from both years, Abrams 3 produced the lowest average EPT taxa richness per sample (mean=42, SD=7.3), average spring sample EPT richness (47), and total cumulative EPT richness (99) (Table 5b). Highest average EPT richness per sample among all samples from both years (mean=64, SD=6) and highest average spring sample EPT richness (67) was at Abrams 2. However, total cumulative EPT taxa collected from all samples was greatest at Abrams 1 (134).

Taxa Richness Seasonality

At most sites, EPT taxa richness was greatest in spring samples and least in fall samples from each year and when cumulative taxa collected per season was calculated from both years. Spring samples produced the highest EPT taxa richness at all sites in year 2, and fall samples were lowest at all sites except Abrams 1, where the lowest EPT richness was in the winter sample (Table 4b). In year 1, however, Abrams 3 and Mill 2 had highest EPT taxa richness in winter and fall, respectively (Table 3b). Lowest EPT richness in year 1 occurred in winter at Mill 1 and Abrams 1 and in spring at Mill 2. Consequently, Abrams 3 and Mill 2 were also the exceptions among cumulative taxa collected per season. Abrams 3 had equal numbers in winter and spring (66). Mill 1, however, was highest in fall (69) and lowest in spring (66).

Total taxa seasonality generally followed EPT taxa. Since EPT taxa are included in, and make up the majority of, total taxa richness, this pattern appears to be a result of EPT richness seasonality. Indeed, when examined separately, non-EPT taxa richness seasonal trends were different than EPT richness at each site, with greatest richness generally in fall samples and lowest richness in winter samples (Tables 7 and 8). Exceptions included Mill 2, year 1 and Abrams 1,

Table 7. Non-EPT taxa richness means and cumulative totals from year 1 and 2. (W= winter, S= spring, F= fall, SD= standard deviation)

a. Year 1

Site	W	S	F	Mean	SD	Cumulative Total
Abrams 1	38	47	48	44.3	5.5	67
Abrams 2	31	33	39	34.3	4.2	58
Abrams 3	29	38	35	34.0	4.6	53
Abrams 4	24	33	37	31.3	6.7	47
Anthony	18	21	24	21.0	3.0	28
Mill 1	26	28	33	29.0	3.6	42
Mill 2	24	18	30	24.0	6.0	36
Mean	27.1	31.1	35.1			
SD	6.3	9.9	7.5			

b. Year 2

Site	W	S	F	Mean	SD	Cumulative Total
Abrams 1	38	54	51	47.7	8.5	70
Abrams 2	45	44	45	44.7	0.6	58
Abrams 3	34	32	42	36.0	5.3	57
Abrams 4	29	32	39	33.3	5.1	44
Anthony	19	23	28	23.3	4.5	31
Mill 1	28	35	36	33.0	4.4	41
Mill 2	29	28	32	29.7	2.1	41
Mean	31.7	35.4	39.0			
SD	8.3	10.4	7.8			

Table 8. Non-EPT Taxa richness means and cumulative totals from both years combined. (W= winter, S= spring, F= fall, SD= standard deviation)

	Seasonal Means						Overall		Seasons			
Site	W	SD	S	SD	F	SD	Mean	SD	W	S	F	Overall
Abrams 1	38.0	0.0	50.5	4.9	49.5	2.1	46.0	6.7	45	63	58	80
Abrams 2	38.0	9.9	38.5	7.8	42.0	4.2	39.5	6.3	50	50	45	68
Abrams 3	31.5	3.5	35.0	4.2	38.5	4.9	35.0	4.6	38	46	48	68
Abrams 4	26.5	3.5	32.5	0.7	38.0	1.4	32.3	5.4	32	36	47	51
Anthony	18.5	0.7	22.0	1.4	26.0	2.8	22.2	3.7	22	26	32	36
Mill 1	27.0	1.4	31.5	4.9	34.5	2.1	31.0	4.2	34	39	43	46
Mill 2	26.5	3.5	23.0	7.1	31.0	1.4	26.8	5.1	32	29	35	44
Mean	29.4		33.3		37.1				36.1	41.3	44.0	
SD	7.5		10.0		7.6				9.2	12.8	8.6	

year 2, where EPT and non-EPT richness followed the same seasonal trends. Non-EPT richness data includes some taxa (e.g. Diptera, in part; Oligochaeta) not identified to the specific or even generic level. The possible effect of further resolution of these taxa on observed seasonal trends is unknown.

Taxa Richness vs. Stream Size.

Total Taxa. Overall, total taxa richness was strongly correlated with stream size (Table 9). Mean width explained more of the variation among sites in mean total richness per sample in year 1 and both years combined (r^2= 0.893 - 0.948) and total cumulative richness from year 2 (r^2= 0.872 - 0.875). However, more of the variation among sites in total cumulative richness from both years combined was explained by drainage area (r^2= 0.885). Both mean total richness per sample (r^2= 0.856 - 0.858) and total cumulative richness (r^2= 0.800) from year 1 data were more strongly correlated with discharge. When Abrams 3 was excluded from the calculations, slightly better correlations resulted for mean total richness per sample (e.g. average increase in mean width r^2= 0.039). Little to no increase in correlation coefficients resulted when Abrams 3 was excluded from total cumulative richness calculations.

EPT Taxa. EPT richness was only moderately correlated with stream size (Table 10). Mean width explained more of the variation in mean richness per

Table 9. Coefficients of determination for mean and cumulative total taxa richness vs. drainage area, discharge, and mean stream width from all sites and all sites excluding Abrams 3, for each year and both years combined.

a. Mean Richness per Sample

	Year 1		Year 2		Both Years	
	All	- Abrams 3	All	- Abrams 3	All	- Abrams 3
Drainage Area	0.71	0.73	0.69	0.76	0.74	0.81
Discharge	0.86	0.86	0.77	0.79	0.87	0.89
Mean Width	0.76	0.77	0.89	0.95	0.89	0.94

b. Cumulative Richness

	Year 1		Year 2		Both Years	
	All	- Abrams 3	All	- Abrams 3	All	- Abrams 3
Drainage Area	0.70	0.70	0.85	0.86	0.88	0.88
Discharge	0.80	0.80	0.82	0.82	0.82	0.83
Mean Width	0.73	0.72	0.87	0.87	0.78	0.78

Table 10. Coefficients of determination for mean and cumulative EPT taxa richness vs.drainage area, discharge, and mean stream width from all sites and all sites excluding Abrams 3, for each year and both years combined.

a. Mean Richness per Sample

	Year 1		Year 2		Both Years	
	All	- Abrams 3	All	- Abrams 3	All	- Abrams 3
Drainage Area	0.20	0.32	0.26	0.38	0.24	0.42
Discharge	0.38	0.50	0.33	0.39	0.37	0.52
Mean Width	0.44	0.65	0.51	0.69	0.51	0.82

b. Cumulative Richness

	Year 1		Year 2		Both Years	
	All	- Abrams 3	All	- Abrams 3	All	- Abrams 3
Drainage Area	0.25	0.29	0.46	0.63	0.58	0.73
Discharge	0.39	0.40	0.50	0.58	0.57	0.64
Mean Width	0.38	0.41	0.64	0.81	0.57	0.66

sample from each year and both years combined (r^2= 0.436 - 0.823). Excluding Abrams 3 from calculations had a greater effect on both mean EPT richness (e.g. average increase in mean width r^2= 0.240) and cumulative richness correlations (e.g. average increase in mean width r^2= 0.100), than on total richness. Which stream size measure showed the strongest correlation with cumulative EPT richness depended upon which cumulative total was used (years) and whether Abrams 3 was included in the calculations. Mean width was more strongly correlated with year 2 cumulative richness (r^2= 0.644 - 0.814, with and without Abrams 3) and year 1 cumulative richness, without Abrams 3 (r^2= 0.408). However, with all sites included, more of the variation in cumulative richness from year 1 (r^2= 0.388) and both years combined (r^2= 0.575) was explained by discharge. Cumulative richness from both years combined was strongly correlated with drainage area when Abrams 3 was excluded (r^2= 0.731).

The two largest sites, Abrams 1 and 2, had the highest EPT richness among most summary data. However, Abrams 1, with a >50% larger drainage area, had slightly lower EPT richness than Abrams 2 in all summary data except total cumulative EPT richness. Conversely, the Anthony Creek site with the smallest drainage area among all sites, consistently had higher EPT richness than sites with larger watershed areas (e.g. Abrams 3 and 4).

The overall, relatively low EPT richness observed at Abrams 3 is inconsistent with expectations of a positive correlation between taxa richness and stream size. When compared to the next site upstream (Abrams 4) and the sites most similar in flow discharge (also Abrams 4) and drainage area (Mill 1), Abrams 3 had the lowest EPT richness among all summary data. Moreover, Abrams 3 had lower EPT taxa richness than all other sites among most sample periods (except winter and spring year 1) and summary data (except year 1 cumulative EPT richness), despite having the third largest drainage area and fourth largest flow discharge and mean width among all sites.

Community Similarity

Between Seasons. Jaccard's similarity coefficient was used to compare EPT taxa collected in qualitative samples between each seasonal sample within each year and between cumulative EPT taxa collected in each season from both years at each site.

Year 1. In year 1 at each site, winter and spring samples were generally most similar (mean=0.35, SD=0.08) (Table 11a). Exceptions were at Abrams 2, where winter and spring, as well as fall and winter samples, were equally most similar (0.39), and Abrams 1, where spring and fall samples were most similar (0.39) [winter and spring samples were least similar (0.26)]. Highest similarity coefficient in year 1 was calculated for winter and spring samples from Mill 2

Table 11. Jaccard's Coefficient of Similarity of EPT communities between seasons at each site for year 1, year 2, and cumulative seasonal totals. (W= winter, S= spring, F= fall; SD= standard deviation)

a. Year 1

	W vs. S	S vs. F	F vs. W	Mean	SD
Abrams 1	0.26	0.39	0.32	0.32	0.07
Abrams 2	0.39	0.33	0.39	0.37	0.04
Abrams 3	0.33	0.26	0.23	0.27	0.05
Abrams 4	0.31	0.30	0.28	0.29	0.02
Anthony	0.30	0.29	0.24	0.28	0.03
Mill 1	0.43	0.32	0.32	0.35	0.06
Mill 2	0.47	0.42	0.37	0.42	0.05
Mean	0.35	0.33	0.31		
SD	0.08	0.06	0.06		

a. Year 2

	W vs. S	S vs. F	F vs. W	Mean	SD
Abrams 1	0.27	0.43	0.23	0.31	0.11
Abrams 2	0.32	0.37	0.34	0.34	0.03
Abrams 3	0.28	0.32	0.27	0.29	0.03
Abrams 4	0.32	0.35	0.29	0.32	0.03
Anthony	0.33	0.27	0.29	0.29	0.03
Mill 1	0.33	0.39	0.38	0.37	0.03
Mill 2	0.36	0.35	0.28	0.33	0.05
Mean	0.32	0.36	0.30		
SD	0.03	0.05	0.05		

c. Both Years, Cumulative

	W vs. S	S vs. F	F vs. W	Mean	SD
Abrams 1	0.35	0.50	0.29	0.38	0.11
Abrams 2	0.43	0.40	0.41	0.42	0.02
Abrams 3	0.44	0.36	0.31	0.37	0.07
Abrams 4	0.32	0.35	0.29	0.32	0.03
Anthony	0.41	0.38	0.29	0.36	0.06
Mill 1	0.47	0.42	0.45	0.45	0.02
Mill2	0.43	0.51	0.35	0.43	0.08
Mean	0.41	0.42	0.34		
SD	0.05	0.07	0.07		

(0.47). Lowest similarity coefficient came from fall and winter sample comparisons at both Abrams 3 and Anthony Creek (0.23 and 0.24, respectively). Average seasonal similarity in year 1 was greatest at Mill 2 (mean=0.42, SD=0.05) and lowest at Abrams 3 (mean=0.27, SD=0.05).

Year 2. Among year 2 samples at each site, spring and fall samples were generally most similar (mean=0.36, SD=0.05) (Table 11b). Exceptions were at Mill 2 and Anthony Creek where winter and spring samples were most similar (0.36 and 0.33, respectively). Spring and fall samples at Abrams 1 were most similar (0.43) among all year 2 comparisons. Abrams 1 also had the lowest similarity coefficient between its fall and winter samples (0.23). Average seasonal similarity in year 2 was greatest at Mill 1 (mean=0.37, SD=0.03) and lowest at Abrams 3 and Anthony Creek (mean=0.29, SD=0.03).

Cumulative. Among cumulative EPT taxa collected over both years within each season at each site, winter and spring (mean=0.41, SD=0.05) and spring and fall (mean=0.42, SD=0.07) were generally more similar than fall and winter (Table 11c). Winter and spring were most similar at four sites (Abrams 2 and 3, Mill 1, and Anthony Creek). Spring and fall samples were most similar at three sites (Abrams 1 and 4, and Mill 2). Highest similarity coefficient among cumulative seasonal comparisons came from Abrams 1, spring and fall (0.50). Least similar were fall and winter samples from Abrams 1, Abrams 4, and

Anthony Creek (0.29). Average cumulative seasonal similarity was greatest at Mill 1 (mean=0.45, SD=0.02) and lowest at Abrams 4 (mean=0.32, SD=0.03).

Between Years. Overall, samples from the same season in different years were generally more similar at each site than samples from different seasons in the same year, indicating greater variability in EPT taxa composition between seasons than between years at most sites. A possible exception was at Mill 2 where year 1 winter and spring samples shared nearly the same proportion of EPT taxa (0.47) as did winter samples from each year (0.49) (Table 12a).

Within Seasons. Among annual samples compared within seasons at each site, fall samples were generally most similar (mean=0.54, SD=0.10) (Table 12a). Exceptions were at Abrams 4, where winter samples were most similar (0.57) and fall samples were least similar (0.44), and Mill 2, where spring samples were most similar (0.53) and fall samples were also least similar (0.48). Highest similarity coefficient was between fall samples at Mill 1 (0.71) and lowest was between winter samples at Abrams 1 (0.39). Average annual similarity within seasons was greatest at Mill 1 (mean=0.60, SD=0.10) and lowest at Abrams 3 (mean=0.44, SD=0.03) and Abrams 1 (mean=0.45, SD=0.06).

Cumulative. Over 50% of cumulative EPT taxa collected at all sites within each year were collected in both years (Table 12b.) Cumulative annual

Table 12. Jaccard's Coefficient of Similarity of EPT communities between years within seasons and seasons combined within years at each site. (W= winter, S= spring, F=fall; SD= standard deviation)

a. Between Years, Within Seasons

Site	W	S	F	Mean	SD
Abrams 1	0.39	0.46	0.51	0.45	0.06
Abrams 2	0.55	0.49	0.62	0.55	0.07
Abrams 3	0.44	0.41	0.47	0.44	0.03
Abrams 4	0.57	0.51	0.44	0.51	0.06
Anthony	0.47	0.51	0.52	0.50	0.03
Mill 1	0.52	0.58	0.71	0.60	0.10
Mill 2	0.49	0.53	0.48	0.50	0.03
Mean	0.49	0.50	0.54		
SD	0.06	0.05	0.10		

b. Between Years, Cumulative

Site	
Abrams 1	0.55
Abrams 2	0.65
Abrams 3	0.59
Abrams 4	0.59
Anthony	0.54
Mill 1	0.75
Mill 2	0.57

samples were most similar at Mill 1 (0.75) and least similar at Anthony Creek (0.54).

Between Sites. Both cumulative total and EPT taxa were used in comparing communities between sites. Overall, taxa similarity relationships among sites generally concurred in both data sets. With exceptions, sites similar in size, position in the watershed, and/or in close proximity generally showed higher community similarity.

Total Taxa. Similarity coefficients ranged from 0.29 (Abrams 1 vs. Abrams 4) to 0.61 (Mill 1 vs. Abrams 2) (Table 13a). On average, Abrams 2 generally shared more taxa with other sites (mean similarity=0.49, SD=0.10), being either most similar, or tied for most similar, to four of the other six sites (Abrams 1, 3, 4, and Mill 1). The exceptions were with Mill 2, which was more similar to Anthony and Mill 1, and equally as similar to Abrams 4 as Abrams 2; and Abrams 3 which was equally as similar to Abrams 1 as Abrams 2. Mill 1 (mean similarity=0.48, SD=0.12) and Mill 2 (mean similarity=0.47, SD=0.11) were virtually equal to Abrams 2 in average similarity to all other sites. Abrams 4 was least similar, or tied for least similar, to all other sites (mean similarity=0.32. SD=0.02). The tie was with Anthony Creek, which surprisingly, was equally least similar to Abrams 4 (most proximal site to Anthony) and Abrams 1 (most distant and dissimilar in physical characteristics to Anthony). Abrams 1 was a close

Table 13. Jaccard's Coefficient of Similarity of total cumulative total and EPT taxa between sites. (W= winter, S= spring, F= fall; SD= standard deviation)

a. Total Taxa

Site	Abrams 1	Abrams 2	Abrams 3	Abrams 4	Anthony	Mill 1	Mill 2
Abrams 1		0.43	0.43	0.29	0.33	0.38	0.37
Abrams 2	0.43		0.57	0.34	0.45	0.61	0.54
Abrams 3	0.43	0.57		0.30	0.40	0.51	0.44
Abrams 4	0.29	0.34	0.30		0.33	0.33	0.34
Anthony	0.33	0.45	0.40	0.33		0.45	0.56
Mill 1	0.38	0.61	0.51	0.33	0.45		0.60
Mill 2	0.37	0.54	0.44	0.34	0.56	0.60	
Mean	0.37	0.49	0.44	0.32	0.42	0.48	0.47
SD	0.06	0.10	0.09	0.02	0.09	0.12	0.11

b. EPT taxa

Site	Abrams 1	Abrams 2	Abrams 3	Abrams 4	Anthony	Mill 1	Mill 2
Abrams 1		0.44	0.42	0.30	0.30	0.39	0.35
Abrams 2	0.44		0.55	0.37	0.43	0.58	0.51
Abrams 3	0.42	0.55		0.34	0.44	0.49	0.45
Abrams 4	0.30	0.37	0.34		0.37	0.40	0.42
Anthony	0.30	0.43	0.44	0.37		0.47	0.58
Mill 1	0.39	0.58	0.49	0.40	0.47		0.63
Mill 2	0.35	0.51	0.45	0.42	0.58	0.63	
Mean	0.37	0.48	0.45	0.36	0.43	0.49	0.49
SD	0.06	0.08	0.07	0.04	0.10	0.09	0.10

second (mean similarity= 0.37, SD=0.06) to Abrams 4 in average lowest similarity and they were mutually least similar to each other (0.29).

EPT Taxa. Similarity coefficients ranged from 0.30 (both Abrams 1 vs. 4, and Abrams 1 vs. Anthony) to 0.63 (Mill 1 vs. 2) (Table 13b). As with total taxa, Mill 1 (mean similarity=0.49, SD=0.09), Mill 2 (mean similarity=0.49, SD=0.10), and Abrams 2 (mean similarity=0.48, SD=0.08) were, on average, more similar to all other sites. However, Mill 2 was most similar to three of the other six sites (Abrams 4, Anthony, and Mill 1), with Abrams 2 and Mill 1 most similar to two sites (Abrams 1 and 3, and Abrams 2 and Mill 2, respectively). Abrams 4 (mean similarity= 0.36, SD=0.04) and Abrams 1 (mean similarity=0.37, SD=0.06) were also lowest in average EPT community similarity.

North Carolina Biotic Index

Year 1. All semi-quantitative samples from year 1 produced excellent North Carolina Biotic Index (NCBI) scores (4.18 and below) (Table 14a). Lowest NCBI score per sample (winter=1.37) and average NCBI score per site (mean=1.97, SD=0.71) among year 1 samples, was at Mill 2. Conversely, Abrams 1 had both highest NCBI score per sample (fall=3.92) and highest average NCBI score among year 1 samples (mean=3.67, SD=0.35). Abrams 3 had a close second highest average year 1 score (mean=2.99, SD=1.03). While

Table 14. North Carolina Biotic Index scores from each semiquantitative sample from each year. Mean scores averaged across seasons for each site and sites for each season from each year and both years combined are included. Year 2 includes duplicate samples (1&2). (W= winter, S=spring, F= fall, SD= standard deviation)

a. Year 1

Site	W	S	F	Mean	SD
Abrams 1	3.27	3.81	3.92	3.67	0.35
Abrams 2	2.05	2.39	3.19	2.54	0.59
Abrams 3	3.75	1.82	3.39	2.99	1.03
Abrams 4	2.91	2.30	2.86	2.69	0.34
Anthony	1.60	2.64	2.45	2.23	0.55
Mill 1	1.51	1.60	3.34	2.15	1.03
Mill 2	1.37	1.80	2.75	1.97	0.71
Mean	2.35	2.34	3.13		
SD	0.95	0.75	0.49		

b. Year 2

	W		S		F			
Site	1	2	1	2	1	2	Mean	SD
Abrams 1	3.41	3.59	4.31	4.31	3.85	3.81	3.88	0.37
Abrams 2	1.87	2.63	2.77	2.53	3.11	3.06	2.66	0.45
Abrams 3	0.82	2.90	4.06	4.40	4.14	4.84	3.53	1.47
Abrams 4	2.46	2.05	2.51	2.83	3.32	3.61	2.80	0.58
Anthony	1.96	1.78	2.83	3.09	2.06	1.65	2.23	0.59
Mill 1	3.39	2.36	2.51	2.61	2.15	2.41	2.57	0.43
Mill 2	1.45	1.73	2.87	2.11	2.29	2.02	2.08	0.49
Mean	2.31		3.12		3.02			
SD	0.81		0.79		0.95			

b. Both Years

	Seasonal Means						Overall	
Site	W	SD	S	SD	F	SD	Mean	SD
Abrams 1	3.42	0.16	4.14	0.29	3.86	0.06	3.81	0.36
Abrams 2	2.18	0.40	2.56	0.19	3.12	0.07	2.62	0.46
Abrams 3	2.49	1.51	3.43	1.40	4.12	0.73	3.35	1.30
Abrams 4	2.47	0.43	2.55	0.27	3.26	0.38	2.76	0.49
Anthony	1.78	0.18	2.85	0.23	2.05	0.40	2.23	0.54
Mill 1	2.42	0.94	2.24	0.56	2.63	0.63	2.43	0.65
Mill 2	1.52	0.19	2.26	0.55	2.35	0.37	2.04	0.53
Mean	2.33		2.86		3.06			
SD	0.83		0.85		0.81			

relative NBCI scores among sites is informative, analysis of variance failed to detect statistically significant differences between sites in year 1 (Table 15a).

Year 2. NCBI scores from year 2 were generally very similar to year 1, although there was a slight increase in spring samples overall (year 1 mean=2.34, SD=0.75; year 2 mean= 3.12, SD=0.79) (Table 14b). More importantly, some year 2 samples scored good (range=5.09-4.17, Lenat, 1993) while all samples in year 1 scored excellent. The Abrams 3, fall sample b (4.84), and both spring samples from Abrams 1 (a=4.31, b=4.31), year 2, scored good. All other samples scored excellent (4.18 and below). Analysis of variance detected significant statistical differences among year 2 NCBI scores (p=0.0028) (Table 15b). Multiple comparisons (Dunn's test) identified significant statistical differences between Abrams 1 and both Anthony and Mill 2 (Q=0.05) (Table 16).

Both lowest and highest NCBI scores among all samples came from year 2, Abrams 3, winter sample 1 of 2 (0.82), and fall sample 2 of 2 (4.84), respectively. As in year 1, average NCBI scores at each site among year 2 samples was lowest at Mill 2 (mean=2.08, SD=0.49). Highest year 2 average NCBI scores again came from both Abrams 1 (mean=3.88, SD=0.37) and Abrams 3 (mean=3.53, SD=1.47), with virtually identical averages.

Both Years. Average NCBI score from all samples from both years was lowest at Mill 2 (mean=2.04, SD=0.53) and Anthony Creek (mean=2.23,

Table 15. One-way nonparametric ANOVA (Kruskal-Wallis) on year 1 and year 2 North Carolina Biotic Index score mean ranks. (s=significant, fds=failed to detect significance)

a. Year 1

Source of variation	df	SS	MS	F	P	
Between	6	363.83	60.64	2.09	0.12	fds
Within	14	405.67	28.98			
Total	20	769.50				

b. Year 2

Source of variation	df	SS	MS	F	P	
Between	6	3008.42	501.40	5.55	0.0004	s
Within	35	3160.58	90.30			
Total	41	6169.00				

Table 16. Site comparisons using Dunn's tests on year 2 North Carolina Biotic Index mean ranks. All other sites had mean ranks greater than Mill 1. (s=significant, fds=failed to detect significance)

Sites	Q	Q(0.05)	
Abrams 1 v. Mill 2	3.57	3.04	s
Abrams 1 v. Anthony	3.25		s
Abrams 1 v. Mill 1	2.47		fds

SD=0.54) (Table 14c). Highest average NCBI score from all samples from both years came from Abrams 1 (mean=3.81, SD=0.36) and Abrams 3 (mean=3.35, SD=1.30).

V. Discussion

Site Comparisons

Taxa Richness. The River Continuum Concept (RCC) states that various benthic community characteristics (including species richness) shift in a predictable fashion with progression downstream along a stream continuum (e.g. Allan, 1975; Vannote et al., 1980; Minshall et al., 1985; Grubaugh et al., 1996). Species richness varies with stream size along a log-normal curve, being highest in midorder streams (4th-6th) and lower in headwater streams and higher order rivers. Relative total taxa richness among the seven sites (3rd-5th order) generally followed RCC expectations. For the most part, sites of the same order and similar size had similar total taxa richness, but this varied among the temporal scales by which the data were reported (i.e. individual seasonal samples and mean annual richness vs. annual and overall cumulative richness).

The relationship of EPT taxa richness to stream size was not as clear. Various habitat factors influencing species richness, such as substrate size, flow velocity, and temperature regime, are generally more heterogeneous, both spatially and temporally, in midorder streams. This habitat heterogeneity, rather than stream size *per se*, provides a wider array of habitat optima for more taxa per unit area and over time (Vannote et al. 1980, Minshall 1984, Statzner and

Higler 1986, Ward 1992, Grubaugh et al. 1996). The results of this study suggest that the EPT component of total taxa richness is more closely linked to habitat heterogeneity than are non-EPT taxa. Sites with more homogeneous habitat conditions (Abrams 1, Abrams 3, and to a lesser extent, Mill 1) did indeed have lower than expected EPT richness, while non-EPT taxa richness followed RCC expectations.

The lower than expected EPT richness at Abrams 1 and 3 is clearly related to habitat homogeneity. Abrams 1 is dominated by a long pool/slow run area, known to produce fewer taxa than more heterogeneous riffle areas (e.g. Brown and Brussock 1991, Kerans et al. 1992, Wohl et al., 1995). Some sediment deposition is present, especially along pool margins, but extensive silt covered areas and excessive substrate embeddedness are not evident. The habitat diversity is lower than at Abrams 2 and is most likely why taxa richness is generally lower at Abrams 1 than at Abrams 2.

The substrate at Abrams 3 is dominated by gravel and smaller particles (Table 1). There are areas of silt and sediment accrual in depositional areas (pools and backwaters) and a relatively high degree of embeddedness in erosional areas (riffle/glides and runs). Reduced interstitial spaces and the relative lack of substrate variety caused by erosion and sedimentation reduces EPT taxa richness (eg. Lenat et al. 1981, Lenat 1984, Cooper 1987, Wohl and

Carline 1996). Erosion in Cades Cove undoubtedly contributes to this condition. However, other factors not directly linked to cattle-related problems in Cades Cove also appear to contribute to the high proportion of sand and silt, and the relative habitat homogeneity at Abrams 3.

Local geomorphic characteristics affect substrate conditions at Abrams 3. This reach of Abrams Creek flows through an area of flood plain deposits (Newman and Nelson 1963). Soils are deep, silty, and sandy loams with relatively few large rocks, resulting in a local scarcity of large substrate particles (large cobble and boulders). Abrams 3 also shares the lowest mean gradient among all other sites with Abrams 4 (Table 1). The low gradient, both in the vicinity of Abrams 3 and a good distance upstream, may hinder bedload movement of larger substrate particles into the area. Moreover, instead of the drop in elevation occurring at a few distinct, heterogeneous riffles as at Abrams 4, it is spread evenly over the length of Abrams 3. Due to this gradual slope and the relative lack of larger substrate constituents, flow velocity is apparently more homogeneous over most of the site. Statzner and Higler (1986) found that lesser variation in flow velocity per unit area was correlated with lower taxa richness.

Localized stream bank erosion due to stream meander also contributes sediment to Abrams Creek. This primarily occurs in scattered areas throughout the lower third of Cades Cove. Channelization and stream alignment "adjustments" were performed on Abrams Creek and some tributaries from the 1940s through the early 1970s (Bratton et al. 1980, Matthews 1977). These efforts were apparently implemented to prevent stream meander and subsequent erosion. However, this may be accelerating meander in areas downstream of straightened reaches. Extensive areas of bank erosion and collapse are present in the vicinity of Abrams 3. Matthews (1977) also observed "natural" meander eating away at stream banks within formerly channelized reaches.

Temperature regime, another factor known to influence taxonomic assemblage structure (Ide 1935, Vannote and Sweeney 1980, Hawkins et al. 1997), may have an effect at both Abrams 3 and Abrams 1. While thermal variables were not considered in this study, certain evidence suggests temperature related effects. A complex thermal situation exists at Abrams 3. Abrams Creek and its tributaries within Cades Cove (upstream of Abrams 3) are typically lower gradient, have a relatively high pool to riffle ratio, and reduced riparian shading -- all factors known to increase stream temperature (Brown 1969, Ward 1985, Hawkins et al. 1997). However, the degree of influence on Abrams 3 may be minimal, given that springs immediately upstream contribute much of the flow volume at Abrams 3, especially since Abrams Creek upstream of the springs often goes dry in late summer and early fall, when temperatures would be highest. This spring influence may decrease seasonal temperature variability. Kelly (1974) found Abrams Creek average daily temperatures (measured between Abrams 3 and the Mill Creek confluence) higher than Mill Creek (measured near Mill 1) except during July-September, when the spring influence was greatest. Nonetheless, Abrams 3 and Abrams 1 share several taxa not found at the other sites (*Villosa iris*, *Argia* sp., *Hydropsyche venularis*, *Optioservus trivittatus*, *Gyrinus* sp. *Sperchopsis tessellatus*), possibly suggesting a similar temperature regime. Higher temperatures at Abrams 1 are indicated by a fish community dominated by cool water rather than cold water species (unpublished GSMNP fishery survey data).

Biotic Index Scores. NCBI scores calculated from fixed-number semiquantitative samples generally support EPT richness indications. The higher scores from Abrams 1 and Abrams 3 correspond with lower than expected EPT richness. Since NCBI scores were calculated from samples from a single habitat (shallow riffles) at each site, index scores provide a measure less vulnerable to intersite habitat differences than EPT richness. Unlike EPT richness, Lenat (1993) determined that NCBI scores were not strongly affected by stream width (i.e. position in stream continuum).

Overall, these samples and scoring criteria appear to be fairly robust, discerning relatively slight differences between sites, as indicted by EPT taxa richness. However, a fair amount of variation was seen in scores among seasons and, in year 2, between duplicate samples at each site. While most variation was within individual scoring ranges, duplicate sample scores from Abrams 3 twice fell within different ranges (excellent and good), although the actual numerical variation was small. Given the small subsample of the riffle species assemblage represented in one of these samples, and the variation in scores, multiple or larger samples might yield more precise scoring.

Scores calculated for fall samples may not be as accurate as summer and winter scores. Lenat (1993) warns that stream ratings should be made with caution during late spring and fall. These are periods of high species turnover when species assemblages are in seasonal flux and may produce spurious scores.

Conclusions and Recommendations

All sites sampled within the Abrams Creek system support rich and diverse macroinvertebrate communities. Greatest taxa richness was collected in samples from winter and spring. Relative taxa richness and NCBI scores among sites indicate site specific differences variously attributable to position along the stream continuum, and habitat and water quality differences. In particular, sites Abrams 1 and Abrams 3 had lower EPT richness and higher NCBI scores than might be expected from stream size differences alone. The factors influencing these differences at Abrams 1 and Abrams 3 are at least partially attributable to increased sediment and nutrient loads originating in Cades Cove. However, physical attributes of these sites, some of which are clearly unrelated to perturbations originating in Cades Cove, are also factors in lower than expected EPT richness and NCBI scores.

Treatment of sediment and enrichment sources in Cades Cove should continue. Despite attributes of sample sites that confuse clear-cut assessment of impacts from Cades Cove, there are identifiable effects. In order for the National Park Service to keep its management of Cades Cove as an historic district (which presently includes cattle) compatible with its mission to restore and preserve the natural aquatic communities in Abrams Creek, minimal impacts on the natural zone are essential. Abrams Creek and its tributaries should be completely fenced to exclude cattle and natural riparian vegetation restored. In addition to current efforts, restoration of channelized reaches to a more natural state is also recommended.

Following the completion of all treatments, macroinvertebrate communities should be sampled again. If possible, the same sites and techniques should be used for comparison to this baseline data. In addition to the techniques employed during this study, collection of quantitative data would provide data suitable for more robust statistical and community structure analysis.

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APPENDIX

Table A-1. Total macroinvertebrate taxa collected in all samples at all sites on Abrams Creek proper, December 1993 - September 1995. (W= winter, S=spring F= fall; * denotes taxa recorded as abundant in field notes)

Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
Season	W		S		F		W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Nematomorpha																								
Gordioidea	1					1		2	1			1												
Annelida																								
Oligochaeta	5	4	6	3	4	1	9	18	5	5	11	24	15	13	4	22*	7	13	12	11	9	17*	12	9
Hirudinea																								
Glossiphoniidae																								
Placobdella sp.									2			1			1			1						
Mollusca																								
Gastropoda																								
Ancylidae																								
Ferrisia rivularis	10	2	1	3	4	10*	7	3		4	1	5		3	5	2	3	2						
Lymnaeidae																								
Stagnicola sp.							1																	
Planorbidae																								
Helisoma anceps		1	1			4		1																
Menutus dilatatus						1																		
Pleuroceridae																								
Elimia proxima	1				2	1	18	14	5	12*	8*	14*	6	35	7	46*	16*	33*						1
Leptoxis praerosa	2		6	3	7	1																		
Physidae																								
Physella gyrina		1				3		4		1			5	8	2	10	6							
P. heterostropha							6			1		9		5			2	12						
Pelycypoda																								
Sphaeriidae			2	4		1	2	2						2	1	2	2	2						1
Unionidae																								
Villosa iris	1	1	2		6	2												1						
Arachnoidea																								
Trombidiformes (="Hydracarina", in part)		6	2	12		11		1	1	3	14	7	2				3	18	1	1	2		2	4
Crustacea																								
Amphipoda																								
Talitridae																								
Hyalella azteca															4									

Table A-1. (continued)

Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
Season	W		S		F		W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Crustacea (continued)																								
Cladocera																								
Daphnidae																			11*					
Decapoda																								
Cambaridae																								
Cambarus bartoni			6*	2	1*				3	1	2	1			1		7	7		1	5	2	3	1
C. longirostris					6*	2		2		2	6	4					4			1	2	2	3	3
C. sp. (juvenile, second form male, or female)	2*														3					2			3	
Orconectes erichsonianus					2	2																		
O. sp. (juvenile, second form male, or female)	3*	1	4*	2																				
Isopoda																								
Asellidae																								
Asellus sp.									1				1											
Insecta																								
Plecoptera																								
Capniidae																								
Allocapnia sp.							50	11					10											
A. aurora adults								6											1					
A. recta adults							4						3						3	4				
Chloroperlidae																								
Alloperla sp. 1		2							1					1							1			
A. sp. 2		3												4										
Haploperla brevis										1												1		
Rasvena terna							1																	
Sweltsa sp.		2						21	1		6			4					13	24	5		9	6
Leuctridae																								
Leuctra sp.			1	6	1	1		5		13	12	15		2		1	1	2	1	2	4	29	24	32
Nemouridae																								
Amphinemura delosa/nigritta									6	1					6	5					28	6		
A. sp. (*appalachia*?)																					1	1		
A. sp. (early instars)																								
Prostoia similis																			4					

Table A-1. (continued)

Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
Season	W		S		F		W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																								
Plecoptera																								
Nemouridae (continued)																								
Nemouridae sp. ? (rounded pronotum w/ bristle fringe; foretibia w/ complete fringe; no intercalary setae on cerci; fits no keyed genus)													31											
Peltoperlidae																								
Tallaperla sp.	6	8*	9	6	7	4	43*	18*	17	5	18*	11*	15	7*	2	2	8	8	26	22*	40*	8	10*	12*
Perlidae																								
Acroneuria abnormis	41	25*	61*	44	56*	27*	4	3	8*	15	1	7		7		3	7	9	11	9	14*	5	40	10
A. carolinensis					2		13	3	3	4	1	5							1					
A. evoluta						2																		
A. felicis											1													
Attaneuria ruralis									1															
Eccoptura xanthenes										1		2				1			2	1	3			1
Neoperla sp.	1		4	5	5	5																		
Paragnetina immarginata				2		1	1	1			1	4				1						1	1	
P. media		1	8	11	3	2																		
Perlesta sp. cf. *frisoni*			2																					
P. sp. cf. *nelsoni*				26						1					4						6	1		1
Perlodidae																								
Clioperla clio	4						1	1					18		1						3			
Cultus decisus		2*					11	9	1				9											
Diploperla sp.							9	8	11				2						2	1				
Helopicus subvarians	1	16																						
Isogenoides hansoni							1	9			24	6												
Isoperla bilineata	1	8	6				3	53*	11				11	2	14				104	69	1			
I. holochlora			6	7			9	54*	19	70					2	1					29*	16		
I. sp. cf. *holochlora* (head w/smaller, trident-		6	3				2			3	1				1	1					9			
shaped ant. spot; abd. w/o long. bands)																			2					
I. similis		1																						
I. nana									1															
Isoperla orata																					5			

Table A-1. (continued)

Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
Season	W		S		F		W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																								
Plecoptera																								
Perlodidae (continued)																								
Malirekus hastatus		2					17	28*			6			4			2		34	33			23	3
Remenus bilobatus			1	1						7					8						6	14		
Pteronarcyidae																								
Pteronarcys dorsata	9	4	1		1	6																		
P. (*Allonarcys*) sp. cf. *proteus*				8			16	8*	20	9	7*	3		1					30	8*	44	10	17*	13*
P. (*A.*) sp. cf. *biloba*				2	1	1	8	1		7	1	10	18*	5*	22	12	21*	17						
Taeniopterygidae																								
Strophopteryx fasciata (larvae & adults)	15							9																
Oemopteryx/*Taenionema* sp.														26						1				
Taenionema atlanticum		2					2						2						9					
Taeniopteryx sp. cf. *burksi*								21																
T. sp. cf. *metequi*													1											
T. sp. cf. *parvula*							23*													3				
Ameletidae																								
Ameletus cryptostimulus								1												9	1			
A. lineatus	9	6	4					2					4	7					9	3				
Baetidae																								
Acentrella sp.1 cf. *ampla* (broad & short; cerci <or= body length w/ light setal fringe; ab.terg. w/ long stout setae most numerous near post. margin; palm of tarsal claw broader- teeth longer)	3	11	50*	7	13	9		4	8*	8	21	2									5	10	15	15
A. sp. 2 (slender; cerci as long as body w/mod. fringe; ab.terg. w/ minute setae, 7 & 8 sometimes appear to have 4 dots; fringe of long setae on femur only; palm of tarsal claw more slender-teeth shorter)	4		10*	45	5	10		1	13*	22	24	12			2	1					43*	40	85*	17
A. sp. 3 (broad & short; ab. terg. & pronotum well patterned; gills w/ consp. trachea- pigmented w/ spot near base & area near tip; ab.terg. w/o scales - few small fine setae; surface of terg. alutaceous- post. margins w/o spines)						4																		

Table A-1. (continued)

Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
Season	W		S		F		W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																								
Ephemeroptera																								
Baetidae (continued)																								
A. sp. 4 (ab.terg. 8,9&10 light; males w/ ab.terg 5,6&7 dark, ant. segs mostly light; females w/all terg ant. of 8 dark;dorsum of thorax w/ dense short setae, esp. wing pads, w/ tufts of long setae from inner junction of forewing pad & mesothorax; cerci banded w/ long setal fringe; tarsi w/o long setal fringe)			7		8																			
Baetis/Acentrella? sp. (fairly broad;ab.terg. w/ minute scale-like spatulate setae; legs prop. short, legs w/long setal fringe; gills w/o distinct trachea but w/some median shading appearing to be small spicules; med.caud. fil.= stub; cerci w/mod. setal fringe)	2			4	1	3											2						8	5
Baetis intercalaris			7	52	27*	16					1	2												1
Baetis flavistriga					6*	2			4	13	16	4					5	1			2	36	12*	17
B. pluto			3	17	12*	17				7	18	18									2		9	4
B. tricaudatus		1						15	2						7	1				56		22	28*	
Labiobaetis propinquus				8	3																			
Procloeon sp. 1 (dorsal flaps on gills 1-4, tarsal claws <0.5 tarsi length)			1	1	1	1				1		5		5		2							3	
P. sp. 2 cf. *viridocularis* (gills simple, long slender tarsal claws nearly as long as tarsi)					1	1						2				5		8				1		3
Baetiscidae																								
Baetisca carolina	25*	29*	4	2	5	11*	17	27	9	22	11	15	24*	32*	4	40*	1	10	11	27*	4	4	5	14*
B. gibbera	1																							
Caenidae																								
Brachycercus sp.				3						2						9	1	11						
Caenis sp.				25	16	16						11				1	1	1						
Ephemerellidae																								
Drunella allegheniensis				2	2	5					2	7												
D. tuberculata (=*conestee*)											13	5					1	1					14	3

Table A-1. (continued)

Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
Season	W		S		F		W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																								
Ephemeroptera																								
Ephemerellidae (continued)																								
D. cornuta/cornutella			13*	4					2	49					18	3					40*	136*		
D. longicornis																					3			
D. wayah			1						14	14					6						73*	31*		
Ephemerella catawba									33*	52	5	3									132*			
E. dorothea		7*	204*	6					122*	92			1	2	187	71*					1*			
E. hispida		1						9													8*			
E. invaria/rotunda	27*	93*							1*	3			3			6*						72		
E. rossi									21*	5			2						5		76*			
E. septentrionalis	5	5	1																					
E. subvaria	70*	47*					73	119*					1	25*					285	174*				
Ephemerella sp. cf. *rotunda* (submed. spines on 8 close together ; submed. on 3-9)													1											
E. sp cf *rossi/hispida* (early instar)																						21		
E. sp. (early instar)	29*				1		4			2			10	23*	27	18*		2	89	24*	37*			
Eurylophella doris gr.		72*	52*	50*					24*	26			3		42	53*								
E. funeralis	74*	2*	8*	1	2		6	3	23*	2			3			4*			3	16*	13	18		
E. verisimilis				4																				
E. sp. (early instar)	74*		5*	24							1		4	22*			3		5				12	1
Serratella deficiens			15	13		2				22												37		5
S. serratoides				12	8	5																		
S. spiculosa											5	1												
S. sp. (w/ vivid yellow diagonal bands on pronotum and wing pads)						1																		
S. sp. (early instar)							1																	
Timpanoga lita									1						3	6					4	32		
T. simplex			3	1						37														
Ephemeridae																								
Ephemera sp.			2				1	1	4	4	2	2	1	1		2		1		1	3		2	
Hexagenia sp.				1	1						1													

Table A-1. (continued)

Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
Season	W		S		F		W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																								
Ephemeroptera (continued)																								
Heptageniidae																								
Cinygmula subaequalis			1						37*	25*				1	31				3	16	229	35*		
Epeorus dispar	14		6		7		7		25*				8	6	5	1			96*					
E. sp. cf. *pleuralis*		7*					1	54*		14*					10					121*	88*	21*		
E. rubidus/subpallidus		11*	17	7		5	1	30*	38*	68*	37*	25		11	12	11	15	9		21*	72*	97*	108*	56*
E. sp. (early instar)	6	1*			4														110*	29*			11	
Heptagenia sp. cf. *julia*	4																							
H. sp. cf. *marginalis*					8																			
H. sp. cf. *pulla*				1																				
Heptagenia/Leucrocuta sp. (early instar)						4		1								3								
Leucrocuta juno				1						6		11									14	24*		35*
L. thetis		3									1	5									2		16	
L. sp. cf. *aphrodite*			10		20	24																		
L. sp. cf. *maculipennis*	1			8														1						
Rhithrogena sp. cf. *amica*										7														
R. sp. cf. *exilis*										3														
R. sp. cf. *fuscifrons*										13											2			
R. sp. cf. *uhari*						1		14*												1				
R. sp.							5		3	7									10					
Stenacron carolina																				1			1	
S. interpunctatum			2	21	3																			
S. pallidum	5		3	3	1	2	5	1	8	15	1	8			1	3		2	1	1	2	8*	1	2
S. sp. (early instar)											88													
Stenonema ithaca/modestum	50*	93*	68*	111	58*	40				4			3			2	2							
S. pudicum (*meririvulanum* in part?)	13*	6*	23*	2			173*	136*	65*	91	26	86	97*	72	38	50	85*	26*	188*	79*	102*	73*	26	116*
S. sinclairi																							1	
S. mediopunctatum													1											
S. sp. (early instar)				10														111*	3	64*	9	15*	156	
Isonychiidae																								
Isonychia sp.	24	19	20*	36	32*	51*	30	18*	20*	22	14	26*	3	3	9	13	6	17	33	3*	35*	6	58	73*

Table A-1. (continued)

Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
Season	W		S		F		W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																								
Ephemeroptera (continued)																								
Leptohyphidae																								
Tricorythodes sp.					2	13																		
Leptophlebiidae																								
Habrophlebia vibrans				4												1					3	4		
Habrophlebiodes sp.									3	20		2				2					15	20		1
Leptophlebia sp.		2					2	5					1	8	1				11	8				
Paraleptophlebia adoptiva/mollis		4						60												44				
P. sp. cf. *guttata*											5	8						1					11	31
P. sp. (early instar)							34		2	2			1	1				2	51			3	3	
Siphlonuridae																								
Siphlonurus sp. cf. *quebecensis*															8									
S. sp.		2					1	1						1					1		1			
Odonata																								
Aeschnidae																								
Aeshna umbrosa								1		1	1	1					1	1						
Basiaeschna janata						1																		
Boyeria graffiana				2	1				3	2	2	4*				1					2	1	2	1
B. vinosa	17	4	23*	9	14	4	9	4	7	5	8	10*	7	7	6	15	25	23*	10	3	2	3	16	4
Epiaeschna heros																					1			
Calopterygidae																								
Calopteryx angustipennis			2*	2*		8																		
C. maculata/dimidiata	10	5*	6*	10*	14	3	2	20*	6*	10	6	12	10*	10	12	14	12*	10	4	8	6	12	6	10*
Coenagrionidae																								
Argia sp.			3													1								
Enallagma sp. cf. *divagans*				3																				
Cordulegastridae																								
Cordulegaster erronea							2*		1	4							1				4	2	1	1
C. maculata	4	9*	8*	8*	11	1	11*	21	11	18	10	21	19*	7	26	22*	16	10	4	6	8	5	5	6
C. fasciata/obliqua										1														
C. sp. (early instar)							4*	1			2										1			

Table A-1. (continued)

Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
Season	W		S		F		W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																								
Odonata (continued)																								
Corduliidae																								
Neurocordulia yamaskenensis			1																					
Somatochlora sp.															1			2						
Gomphidae																								
Dromogomphus spinosus									1															
Gomphurus (=Genus A.) *rogersi*	1	4*	10*		3*		11	14	38*	23	25	17*	13*	5	18	9*	10	7*	5	3	5	3	12	6
Gomphus lividus	7	7*	25*	18*	15*	8*	1	1		1		3*	8*	5	21	11*	8	20*						
Hagenius brevistylus	3	2	4	3*	4			1							2	4	2	6*						
Hylogomphus abbreviatus	2																							
H. brevis	1			2																				
H. parvidens	1																							
Lanthus vernalis	3	1	34*	13*			4	11	12*		6	20*		2	2	2		2*	1	17*	31	7	34	14
Ophiogomphus alleghenensis		1																						
O. carolinus				1																				
O. sp. (early instar)	5		2		5	26*	1																	
Stylogomphus albistylus	21	14*	34*	16*	14*	9*	4	7	8	13	7	22*	11	9	6	31*	7	28*	1	1		1	2	1
Stylurus scudderi		1	3	2	2	2		2	4	2			2	2	2	2	5	2*						
Macromiidae																								
Didymops transversa						1																		
Macromia sp. cf. *taeniolata*						3																		
M. sp. (e.i.)	13	1	14*	14	10			5	3		1				1				1				2	2
Heteroptera																								
Belostomatidae																								
Belostoma flumineum		1									1													
Corixidae																								
Sigara sp.															5									
Gerridae																								
Aquarius remigis			1		1	1			6	8	3	6	4	4	1	6	2	5		2	1	3	3	1
Metrobates hesperius					1																			
Nepidae																								
Ranantra nigra																								1

Table A-1. (continued)

Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
Season	W		S		F		W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																								
Heteroptera																								
Nepidae (continued)																								
R. kirkaldyi				1																				
Veliidae																								
Microvelia paludicola						1					1	2								1				1
M. sp.										1														
Rhagovelia obesa				14	11	6					3												1	1
Megaloptera																								
Corydalidae																								
Corydalus cornutus	3	2	8	12	21	11																	1	
Nigronia fasciata										1											20			1
N. serricornis	17	12*	11	18	19*	18	6*	14	15*	17	11	27	14*	9	6	7	15	21	18*	13	2	13	22	22*
Sialidae																								
Sialis sp.	1	1					1																	
Trichoptera																								
Apataniidae																								
Apatania sp.	13	4		33			30*	27	3				2	1	7	1								
Arctopsychidae																								
Arctopsyche irrorata												1												
Parapsyche cardis																					1			
Brachycentridae																								
Brachycentrus lateralis						1																		
B. nigrosoma						1																		
B. spinae	1																							
Micrasema bennetti						23	2	6			23	52*												
M. burksi				1																				5
M. charonis								4	6					5										
M. rickeri	22	21			5	13	5	21*		3	3	6*												
M. rusticum (pupae)			11	6																				
M. scotti												3*												
M. wataga		1	1	21		12			4	33*	1					1								

Table A-1. (continued)

Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
Season	W		S		F		W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																								
Trichoptera																								
Calamoceratidae																								
Anisocentropus pyraloides							1	3*	1			4												
Heteroplectron americanum							1	5*	2		6	2		1	1	1	1						2	
Glossosomatidae																								
Agapetus rossi (male pupae)			18*																					
A. tomus									69	4					102	57*					49			
Agapetus sp.													18*	118*							18*	11		
Glossosoma nigrior (larvae and male pupae)	33	11	4	20	1		3	18	1	11	4	1	13*	5	4		3	3	26	34*	22*	36*	43	6
Matrioptila jeanae																					2			
Goeridae																								
Goera calcarata	7		3	13	3	1	11		6	1		2	1	5		4			1	2	3	6		
G. fuscula							9	8	7	1	1	11	12	6			9	13	7	20			3	
G. sp. (female pupa)															2							2		
G. sp. (empty cases)		1																				9		9
G. sp. (early instar)		1																			2			
Helicopsychidae																								
Helicopsyche borealis						1																		
Hydropsychidae																								
Ceratopsyche alhedra									16*			1												
C. bronta		3	6	7	5	1					2	1						2					1	
C. macleodi												2											3	
C. morosa			1	2	3																			
C. slossonae			8				11	21	22*	45*	21	35	3		11	14*	3	34*	3		3	5	6	16
C. sparna	13	117*	29*	74	42*	63*	3	23		2	4	23		9			4	11*	2	22	2	28*	65	67
C. sp. *alhedra/slossonae*														4						1				
C. sp. *cf. ventura*														2										
Cheumatopsyche harwoodi (male pupae)			2						1														1	
Cheumatopsyche sp.	12	20*	38*	16	21*	22*	19	30	16*	47*	14	20	39*	71	22	102*	62	297*	43	40*	47*	65*	61	124
Diplectrona modesta			4		4		1	2	12*	5	3				4			1	8	10	155*	4	16*	
Hydropsyche betteni/depravata								11			4		2	3	2	1	8	4			1	1		
H. scalaris	4																							

Table A-1. (continued)

Taxa / Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
Season	W		S		F		W		S		F		W		S		F		W		S		F	
Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																								
Trichoptera																								
Hydropsychidae (continued)																								
Hydropsyche simulans			2																					
H. venularis	4	11*	3	26	5	41*												9*						
H. sp. cf. *scalaris*					4	26*																		
H. sp. (early instar)										1														
Hydroptilidae																								
Hydroptila sp.				3		1		11																2
Hydroptila ? (empty sand grain purse case)										1														
Lepidostomatidae																								
Lepidostoma sp.		1	6		1	5	1	4	16	7	3	2		1					2	10	13	17	1	
L. sp. (uniform brown head)				1																				
L. (*Mormomyia*) sp. (light muscle scars on brown head and thoracic nota)				2																				
Leptoceridae																								
Mystacides sepulchralis				2			1			4		2				4	1	5						
Nectopsyche candida	1				1																			
Oecetis sp.			1	2		4																		
O. sp. cf. *inconspicua*												1												
Triaenodes sp. cf. *ignitus*				10	1	6		2	2	1		1					1							
T. sp. cf. *abus/marginatus*																						1		
T. sp. cf. *perna* (brown head w/yellow frontoclypeus.)				3		9																		
T. sp. [black bands at leg joints(*cf. florida*); swimming hairs reduced]				1																				
Limnephilidae																								
Hydatophylax argus								8			4	1	5		2	1	5			1			2	
Ironoquia punctatissima								1					3						1					
Platycentropus radiatus													1		2	1	1							
Pycnopsyche antica (pupae)							1					1											1	
P. lepida		1						3								1		3						
P. guttifer species group	20	9	4	7	2	2	19*	33*	8	8*	1	10*	7	9*		9	5	7	10	9*	1	2		
P. luculenta/sonso	6	4	4	5	1	2	2*	4*	21*	26*	28*	32*	31*	12*	22	16	13	16	19	18*	9	14		10

Table A-1. (continued)

Taxa	Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
	Season	W		S		F		W		S		F		W		S		F		W		S		F	
	Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																									
Trichoptera																									
Limnephilidae (continued)																									
P. sonso (pupae)												2	2											5	
Molannidae																									
Molanna blenda							3	4		5	4	1	3	4	1	2	2		2			1	1		
Odontoceridae																									
Psilotreta frontalis												1	1												
Philopotamidae																									
Chimarra sp.		1	3	19*	16	2	16		1					2	2				3						2
Dolophilodes distinctus				23*	12	5		5	34	6	40	12	2	1		1				29	4	12	58*	12	38*
Wormaldia moesta (adults)																				1					
W. sp.																									
Phryganeidae																									
Ptilostomis sp.							1	2	3						4	2		5							
Polycentropodidae																									
Neureclipsis crepuscularis		1	1		1																				
Nyctiophylax nephophilus (male pupae)																									
N. sp.					8	1	8	8	11	2		3	5						1					2	
Phylocentropus sp.		6			3	5		2	6	1	9	1	3									5	5		
P. sp.			6	3	16		2		3	4	12			1	1					3	10		24	1	
Psychomyiidae																									
Lype diversa									2			1	1	1	1	4		5			1				
Psychomyia flavida		1									3				1		1						9		
P. sp.				1												4						1			
Rhyacophilidae																									
Rhyacophila atrata																					1				
R. carolina																				1		7	2		
R. fuscula			4	2	1	1		8*	38	12	8	4	2	1		1				5	5	16	13	5	2
R. glaberrima											2														
R. vuphipes				2	5		2																		
R. sp. cf. *carolina* gr.			1	6				2	1	1	2					2									
R. sp. cf. *nigrita*									1		1	2													

Table A-1. (continued)

Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
Season	W		S		F		W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																								
Trichoptera																								
Rhyacophilidae (continued)																								
R. sp. (early instar)		1									1								1					
Sericostomatidae																								
Fattigia pele																				1				
Uenoidae																								
Neophylax aniqua																						1		
N. auratus/oligius																			8					
N. auris?																				3				
N. consimilis							7		11*		2							3			1	22		
N. consimilis (male pupae)					8							2					4							
N. consimilis/ornatus													2		3	3								
N. consimilis/oligius										13														
N. mitchelli (larvae & male pupae)					1							1									2	2	8	
N. oligius								8						2										
N. sp. cf. *mitchelli* (no ventral IIIa gills)																					4			
N. sp. (early instar)							6	13					1								1			
N. sp. (early pupae)	1			1								2												1
Lepidoptera																								
Pyralidae																								
Petrophila fulicalis	3	4		4	1	14																		
Coleoptera																								
Carabidae																								
Chlaenius sp.?								1																
Dryopidae																								
Helichus basalis (adults)	5	3	12*	8	6	5	1	6		3	9	27*	1	3	4	2	10	4			2	1	5	4
H. fastigiatus (adults)				5	3	2					3	2*				1		1					2	
H. lithophilus (adults)	1			4	6	6			3	6		2*	1					2						
H. striatus			2																					
Dytiscidae																								
Acilius semisulcatus ?																		1						
Agabetes sp. (adults)			1																					

Table A-1. (continued)

Taxa	Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
	Season	W		S		F		W		S		F		W		S		F		W		S		F	
	Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																									
Coleoptera																									
Dytiscidae (continued)																									
Hydroporous americanus (adults)																					1	1			
Hydroporous/Hygrotus sp.									1																
Uvarus sp.						1																			
Elmidae																									
Dubiraphia bivittata (adults)																	3	1							
D. vittata (adults)									1																
D. quadrinotata (adults)						1							1												
D. sp. (larvae)																			1						
Macronychus glabratus (adults)				13	6	6	10												1						
Microcylloepus sp. (avittate)					1																				
Optioservus ovalis (adults)											8*	3	7			2		2	4			1	1	1	2
O. trivittatus (adults)		1	1	7	23	8	13										1		1						
O. sp. (larvae)			2		4	3	3		2				8		1			1			1	1			2
Oulimnius latiusculus (larvae)										2	2		1										1		
O. latiusculus (adults)				1		1					3								1						2
Promoresia elegans (larvae)									6			1	1												
P. elegans (adults)				17*	1	19*	31		1		2	2	1												
P. tardella (larvae)			1	2*	1	3	11		1		3	1	4												2
P. tardella (adults)		1		1*	1	1	1		5	3	10*	12	6									1	1		6
Stenelmis sp. (larvae)				12*	23	16*	32								1										
S. sp. (adults)						22*					1	1	3									2	8	3	3
S. sp. 1 (adults, larger species)				24*	31		27																		
S. sp. 2 (adults, smaller species)				6*	4		11																		
Eubriidae																									
Ectopria sp.				1			2	3	2	1		2	3		1						1		1	1	
Gyrinidae																									
Gyrinus marginellus					2																				
G. sp. (larvae)					4	2	3																		
G. sp. (adults)						1													1						

Table A-1. (continued)

Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
Season	W		S		F		W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																								
Coleoptera (continued)																								
Hydrophilidae																								
Berosus sp.																		1						
Enochrus sp. (adults)			2																					
Helobata striata (adults)															1			3						
Helochares maculicollis (adult)							1																	
Hydrobius sp. (adult)													2		2									
Sperchopsis tessellatus (adults)																1								
S. tessellatus (larva)				1																				
Psephenidae																								
Psephenus herricki	13	7	24*	25	20*	23	6	11	18*	27	16	22	1	2	2	7	4	8	17	6*	14	11	17	25*
Ptilodactylidae							8																	
Anchytarsus bicolor	1	1	1			1																1	2	
Diptera																								
Athericidae																								
Atherix lantha	11	7	2	4	13*	27	11*	13	3	2	15	5		3			6	17	13	25	13	1	30*	35*
Blephariceridae																								
Blepharicera sp.	9	2*	11	12	2				6						2					3	18*	2		
Ceratopogonidae																								
Atrichopogon sp.				1				1																
Palpomyia/Bezzia sp. complex		1*		5				3		4	1	2		4	3	2			1	5	2	5	3	
Chironomidae	150	173*	155	162	76	86	52	160	7	61	110	55	13	91	12	59	19	29	128	106	47	81	116*	94
Culicidae																								
Anopheles sp.															1									
Dixidae																								
Dixa sp.	7					1	7	3		1						2			1	x	1	7		2
Empididae								1															1	
Hemerodromia sp. (larvae)						1																		
H. sp. (pupae)												1				1								1
Ptychopteridae																								
Bittacomorpha clavipes																							1	
Simuliidae	38*	5*	16	30	40*	28	6	6	17	7	31*	24	2	8	2	3	9	2	61*	60*	13	8	50*	

Table A-1. (continued)

Site	Abrams 1						Abrams 2						Abrams 3						Abrams 4					
Season	W		S		F		W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																								
Diptera (continued)																								
Tabanidae																								
Chrysops sp.					1			3					2	5	1		1							
Tabanus sp.																							1	
Silvius sp.				1																				
Tanyderidae																								
Protoplasa fitchi				1					1				1	1			1	1						
Tipulidae																								
Antocha sp.	22	11	8	4	3	10		1	2	4	7	3	5	4	5	5	2	10	1	1	3	15	2	5
Dicranota sp							1	15	3	21	2	3		1					2	10	21	25	5	7
Helius sp.													1											
Hexatoma sp.		1					4	11*	4	6	7	6	3	1	2		2	2	9	12*	19	20	25	20
Limnophila sp.1 cf. *macrocera* (spir. lobes w/ long curly hairs)																							2	1
L. sp. 2 (minute spir. lobes w/ long tufts of hairs; little, leg-like gills)																	1							
L. sp. 3 (spir. lobes w/ fine hairs)								1		3	1	1			1				1	3	11	2		1
Leptotarsus sp.																								
Molophilus sp.							1	1																
Pseudolimnophila sp.																								
Tipula sp. 1 cf. *abdominalis*	4	6	3	1			9*	10*	1	3				8*	3	4			4*	7*	2	5		
T. sp. 2 cf. *abdominalis* (straight spir. lobes)																			1					
T. sp. 3 (spir. lobes as fig. 11.3 Brigham et al., lobes w/ short hairs; 6 gills; light longitudinal bands)	2	1		6			11	13*		7	1	1	1	13*				2	4	7*				2
T. sp. 4 (spir. lobes as in. 11.3 Brigham et al., lobes w/ longer hairs; 8 gills; dark mottling fused into dark long. bands)													1	1			1							
T. sp. 5 (spir. lobes as in. 11.3 Brigham et al., but shorter lobes; body slender, grey w/ light or dark long. bands; gills long)													9*	1	7	12								

Table A-2. Total macroinvertebrate taxa collected *in all* samples at all sites on Anthony and Mill creeks, December 1993 - September 1995. (W= winter, S= spring, F= fall; * denotes taxa recorded as abundant in field notes)

Site	Anthony						Mill 1						Mill 2					
Season	W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Nematomorpha																		
Gordioidea						1												
Annelida																		
Oligochaeta	4	6	3	26	18	18	23	23	2	21	16	12	1	10	1	12	14	13
Hirudinea																		
Glossiphoniidae																		
Placobdella sp.					1	1			1		2					1		
Mollusca																		
Gastropoda																		
Ancylidae																		
Ferrisia rivularis							6	7		1	5	3	2				2	1
Pelycypoda																		
Sphaeriidae						1		3			1							1
Arachnoidea																		
Trombidiformes (="Hydracarina", in part)			2			4		1		3		6				1		
Crustacea																		
Amphipoda																		
Gammaridae																		
Gammarus sp.			2															
Decapoda																		
Cambaridae																		
Cambarus bartoni	3			3	4	8		3	2	3	3			2	4		3	2
C. longirostris								5	1	1	3	7					2	1
C. sp. (juvenile)					4													
Isopoda																		
Asellidae																		
Lirceus sp.			1													1		
Insecta																		
Plecoptera																		
Capniidae																		
Allocapnia sp.	3						198	4					1					
Paracapnia angulata	1																	

Table A-2. (continued)

Site	Anthony						Mill 1						Mill 2					
Season	W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																		
Plecoptera (continued)																		
Chloroperlidae																		
Alloperla sp. 1				1														
A. sp. 2	1																	
Haploperla brevis			6	4									1		5	2		
Sweltsa sp.	7	17	9		5	6	6	44	6		9	2	11	27	2		10	3
Leuctridae																		
Leuctra sp.		27	1	26	7	46		18		9	26	43	1	7		7	38	38
Nemouridae																		
Amphinemura delosa/nigritta	2	10	2							1						2		
A. sp. (*appalachia*?)		2	14	21										2				
A. sp. (early instars)					3													
Peltoperlidae																		
Tallaperla sp.	21	12*	29*	1	35*	59*	53*	21*	30*	8	25*	11*	8	23*	*	6	15*	18
Perlidae																		
Acroneuria abnormis	39	19	52	37	32	47	12	28*	25*	12	12	9	44*	14*	60*	21	30*	20
A. carolinensis							11	1	5	6	3	4						
A. felicis/perplexa											2							
Beloneuria georgiana/stewarti			1		1	1												
Eccoptura xanthenes	1			5												1	2	
Paragnetina immarginata										1	1	2						1
P. sp. cf. *nelsoni*		1	8	35					6	17					20	50	1	
Perlodidae																		
Clioperla clio			32*															
Cultus decisus							13	2					1					
Diploperla sp.	2							17	6									
Isogenoides hansoni							4	9			8	7	1				16	3
Isoperla bilineata		45						153						35				
I. dicala				2														
I. holochlora		6		24			14	24	16	21	4	4			4	25	3	
I. sp. cf. *holochlora* (head w/smaller, trident-shaped ant. spot; abd. w/o long. bands)	11	1	16*	2			12		4	11						1		

Table A-2. (continued)

Taxa	Site: Anthony						Mill 1						Mill 2					
Season	W		S		F		W		S		F		W		S		F	
Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																		
Plecoptera																		
Perlodidae (continued)																		
Isoperla similis		6												9				
I. nana									2									
I. orata			1	1														
I. sp. (early instar)			4*		1			88					30					
Malirekus hastatus	11	8	12*	2	45	16	38	32			38	3	12	12			17	6
Remenus bilobatus			6	3					13	6						3		
Yugus arinus	3	3	1				1	9	10				7	6	2			
Y. bulbosus		1																
Pteronarcyidae																		
Pteronarcys dorsata							1						1					
P. (*Allonarcys*) sp. cf. *proteus*	21	10	58*	13	28*	35*	27*	11*	8	18	17*	12*	33*	10*	13	16	11	7*
Taeniopterygidae																		
Oemopteryx/*Taenionema* sp.							22*	77*										
Taenionema atlanticum	5																	
Taeniopteryx sp.							33*	28*										
Ephemeroptera																		
Ameletidae																		
Ameletus cryptostimulus		5	2	1				9						4				
A. lineatus	20		1				4		2				8	1	1			
Baetidae																		
Acentrella sp.1 cf. *ampla* (broad & short; cerci <or= body length w/ light setal fringe; ab.terg. w/ long stout setae most numerous near post. margin; palm of tarsal claw broader- teeth longer)			1		2		1	18*	7	13	2	4			12	2	18*	1
A. sp. 2 (slender; cerci as long as body w/mod. fringe; ab.terg. w/ minute setae, 7 & 8 sometimes appear to have 4 dots; fringe of long setae on femur only; palm of tarsal claw more slender-teeth shorter)			27	67	29*	19		2	34*	54	55	27			5	50	48*	45*
Acerpenna pygmaeus			2		1													

Table A-2. (continued)

Site	Anthony						Mill 1						Mill 2					
Season	W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																		
Ephemeroptera																		
Baetidae (continued)																		
Baetis sp. cf. *brunneicolor* (longer, narrower head; cerci w/heavy setal fringe; med.caud.fil. >or= .5 cerci length; labial palp cf. *intercalaris*/*flavistriga*)				1														
B. intercalaris (abd. w/ paired pale commas)			3															
B. flavistriga					48*	9				9	8	6			1	5	16*	4
B. pluto						6				2	6	6					4*	1
B. tricaudatus	37	48	13	34		3	1	113*	2	3			6	15			30*	
Procloeon sp. 1 (dorsal flaps on gills 1-4, tarsal claws <0.5 tarsi length)				6							1							1
Baetiscidae																		
Baetisca carolina							32*	15*	11	24		2						3
Ephemerellidae																		
Drunella tuberculata (=conestee)					40	52					37	30					31	19
D. cornuta/cornutella									19	58*						13*		
D. longicornis			6	2														
D. wayah			7	34*					33	33*					1	85*		
Ephemerella catawba									1	16*					12*	9		
E. dorothea	3	19*	98*	6*					172*	6*			26	1	11*	4		
E. hispida		1	58*	1						9*				9				
E. invaria/rotunda		4		13*				86*	1*									
E. rossi	10	5	66*	143*			6*	20*	48*	15*			5		134*	75		
E. subvaria	3	2					85*	10*					61	49	7*	6		
E. sp. cf. *dorothea* (more robust; pronotum w/ lat. flange ext. ant. as rounded projections)			3*															
E. sp. (early instar)		46*	130*	2			8			6				30				1
Eurylophella doris gr.				2						5								
E. funeralis	3	6	2	8			4	4	12	3			1	1	8	9	4	
E. sp. (early instar)					12	13	5								1			5

Table A-2. (continued)

Site	Anthony						Mill 1						Mill 2					
Season	W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																		
Ephemeroptera																		
Ephemerellidae (continued)																		
Serratella carolina					1												1	
S. deficiens				1						24*						2		
S. spiculosa												6						2
S. sp. (early instar)								2	3		2							
Timpanago lita				8												14		
T. simplex										22*						6		
Ephemeridae																		
Ephemera sp.			1	1			8	1	4	4	9	9				3	1	
Heptageniidae																		
Cinygmula subaequalis		20	23	12*					118	19*				25*	25	6	1	
Epeorus dispar	100*	45*	86*	39*	8	26	7*	13*	56*	2*			125*	3*	80*	1	2*	6*
E. sp. cf. *pleuralis*		64*	7*	34*			12*	78*		36*				88*		25		
E. rubidus/subpallidus	3	6		4	37	25		5*	26*	108*	78*	41	2	7*		69	48*	17*
E. sp. (early instar)		4		20*	6		60*		21*				68*	19*				
Heptagenia maculipennis											1							
Heptagenia/Leucrocuta sp. (early instar)			8					1				4		6*				
Leucrocuta juno					2					9*								2
L. thetis		1		1	14	17			14		3				10	1	5	3
L. sp. cf. *aphrodite*				1														
L. sp. cf. *maculipennis*											1							
Rhithrogena sp. cf. *amica*										3*				21*		9		
R. sp. cf. *fuscifrons*			10	16*	1					35*	1				3	15		
R. sp.	7						6	4	23	9			42				1	
Stenacron carolina	1			1		1										1	1	
S. pallidum			5	3	2	5	5	1	2	7	3		1		2		2	1
S. sp. (early instar)													6				5	
Stenonema carlsoni	6																	
S. femoratum															1			
S. pudicum (*meririvulanum* in part?)	111*	76	23	75*	9	46	258*	203*	71*	41*	29	32	36*	83*	89*	60	82	88*
S. sinclairi			9	1														

Table A-2. (continued)

Taxa	Site: Anthony						Mill 1						Mill 2					
Season	W		S		F		W		S		F		W		S		F	
Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																		
Ephemeroptera																		
Heptageniidae (continued)																		
Stenonema terminatum		1																
S. mediopunctatum			11															
S. sp. (early instar)				36*	110	149				10*		22	26	31*			1	17
Isonychiidae																		
Isonychia sp.				1	7	x	89*	17*	21*	17*	14	24	1			2	1	46
Leptophlebiidae																		
Habrophlebia vibrans			2	3	2					1								
Habrophlebiodes sp.			7	23		15				17	1	28			4	14		21
Leptophlebia sp.								3										
Paraleptophlebia adoptiva/mollis		29*	3	31				104*					68*	69	1			
P. sp. cf. *guttata*					1	12				3	13						8	34
P. sp. (early instar)	34						109		10							10		
Odonata																		
Aeschnidae																		
Boyeria graffiana					1	1			2	1		3			1	3		
B. vinosa							2	3	1	3	4	4	3	2		1	7	1
Calopterygidae																		
Calopteryx maculata/dimidiata				1		4	4	11*	8	19	9	8	2	5	3	14	10	11
Cordulegastridae																		
Cordulegaster erronea	5	2	2	4		1							1	1		2	3	13
C. maculata							16*	5	23*	19*	11	13	7	12	9	14	9	9
C. sp. (early instar)					2		3*	5		3		2				2	3	
Gomphurus (=Genus A.) *rogersi*							6	11	15	19*	15	26	4	4	2	3	6	12
Gomphus lividus									8									
Lanthus vernalis	24	4	35	27	20	28*	12	11	3	8	10	8	9	18*	31*	22	17	16
Ophiogomphus sp. (early instar)							1											
Stylogomphus albistylus							5	8	11	7	4	1	2	1	2	3	3	3
Macromiidae																		
Macromia sp. cf. *taeniolata*												1						
M. sp. (e.i.)											3					2	1	

Table A-2. (continued)

Taxa	Site: Anthony						Mill 1						Mill 2					
Season	W		S		F		W		S		F		W		S		F	
Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																		
Heteroptera																		
Gerridae																		
Aquarius remigis	1	3	4	5	6	7				8	3	2	7	3	2	2	4	5
Veliidae																		
Microvelia paludicola												1						
Rhagovelia obesa						1					2						1	
Megaloptera																		
Corydalidae																		
Nigronia serricornis							27	12	23*	22	18	27	9	6	9	4	17	11
Sialidae																		
Sialis sp.							3						1					
Trichoptera																		
Apataniidae																		
Apatania sp.	4						30	51	5	2			7	6				
Arctopsychidae																		
Arctopsyche irrorata					7	10							1		1		11	8
Parapsyche cardis	1	1	12	1	6									1				
Brachycentridae																		
Micrasema burksi	3				1	1								1				
M. charonis								5										
M. charonis (male pupae)										2						3		3
M. rickeri								2										
M. scotti				1														
M. wataga									10	7	1							
M. sp. (early instar)							2					1						
Calamoceratidae																		
Anisocentropus pyraloides							1				2	1						
Heteroplectron americanum								3	1		5			2		3	3	3
Glossosomatidae																		
Agapetus tomus																		
A. sp.									22	4						5		7
Glossosoma nigrior (larvae and male pupae)		3		20		49	3	24	2	17	7	3		4	1	29	15	15

Table A-2. (continued)

Taxa	Anthony						Mill 1						Mill 2					
Season	W		S		F		W		S		F		W		S		F	
Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																		
Trichoptera																		
Glossosomatidae (continued)																		
Matrioptila jeanae			4															
Goeridae																		
Goera calcarata	1																	1
G. fuscula						1	3	4	2		1	2	15	20	1		2	2
G. sp. (female pupa)			3	3														
G. sp. (empty cases)										6						3		
Hydropsychidae																		
Ceratopsyche alhedra														2				
C. macleodi	13	18	6		128*	99							5	8			15	
C. macleodi (male pupae)				1														
C. slossonae				3			7	6	26	8	9	6	4	2	3	11	17	3
C. sparna						1	6	9		2	5	32				2	2	45
Cheumatopsyche sp.							60*	27	28	21	11	14	5	1	1	7	2	5
Diplectrona modesta	22	15	124*	44	23*	50	6	6	33	6	6	6	5	25	97	28	7	5
Hydropsyche betteni/depravata								1			1							
H. simulans																		1
Hydroptilidae																		
Hydroptila sp.			1													2		
Lepidostomatidae																		
Lepidostoma latipenne (male pupae)																	1	
L. lydia (male pupae)				3														
L. sp.	6	30*		11	2	16	5	4	14	7		1	3		15	25		5
L. (*Mormomyia*) sp. (light muscle scars on brown head and thoracic nota)														26				
Leptoceridae																		
Ceraclea sp. cf. *transversa*						1												
C. sp. (empty cases)				1														
Triaenodes sp. cf. *ignitus*								2			3	1				4*		4
Limnephilidae																		
Hydatophylax argus											4							

Table A-2. (continued)

Taxa	Anthony W 1	Anthony W 2	Anthony S 1	Anthony S 2	Anthony F 1	Anthony F 2	Mill 1 W 1	Mill 1 W 2	Mill 1 S 1	Mill 1 S 2	Mill 1 F 1	Mill 1 F 2	Mill 2 W 1	Mill 2 W 2	Mill 2 S 1	Mill 2 S 2	Mill 2 F 1	Mill 2 F 2
Insecta																		
Trichoptera																		
Limnephilidae (continued)																		
Pseudostenophylax uniformis (female pupae)				1														
Pycnopsyche flavata	1																	
P. gentilis	2																	
P. guttifer species group				7*		1	5	30*	3*	8*		4*	1	15		6*		1
P. luculenta/sonso	29*	27*	7	34*			3	5*	15*	25*	11	11*	36*	54	14*	15*	6*	9*
P. sonso (pupae)					3	23					1	2					18	2
Molannidae																		
Molanna blenda	2	1				9		4				4	1	1	1	10	1	5
Odontoceridae																		
Psilotreta frontalis	1	3			1	9							6	14	2	10	12	20*
P. rossi	3																	
P. sp. (early pupae)			1															
P. sp. (empty case)							1		1	1								
Philopotamidae																		
Chimarra sp.													1		7			
Dolophilodes distinctus	3	12	11	37	7	53	12	75*	18	68	61	31	5	28*		96*	36	33
Wormaldia sp.		1																
Phryganeidae																		
Ptilostomis sp.							1											
Polycentropodidae																		
Nyctiophylax nephophilus (male pupae)				1														
N. sp.			1	2		3	2	6*			3	5	2	6	1	4*	3	1
Phylocentropus sp.									1	2	4	5					1	1
Polycentropus maculatus (male pupae)				1														
P. sp.		1		12	1				7	7	1	1		2	1	10	2	
Psychomyiidae																		
Lype diversa			2			4	1				2							1
Psychomyia flavida												2					3	
P. sp.							1		1									

Table A-2. (continued)

Site	Anthony						Mill 1						Mill 2					
Season	W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																		
Trichoptera (continued)																		
Rhyacophilidae																		
Rhyacophila amicis				1										3				
R. atrata	4							1					10	5				
R. carolina		3																
R. fuscula	17	14	42	14	16	2	7	16	17	15	5	2	3	10	23*	18	2	3
R. glaberrima	1																	
R. minora								3						2				
R. nigrita (male pupae)				1												1		
R. sp. cf. *carolina* gr.			3	4			2		11	4			2	3	2	5	3	
R. sp. cf. *nigrita*			2		4	6		4			2			2				
R. sp. (early instar)		1									2							
R. sp. (early pupae)			2						1	2								
Sericostomatidae																		
Agarodes sp.														1				
Fattigia pele	3	1				2												
Uenoidae																		
Neophylax aniqua									1									
N. auratus/oligius							13											
N. consimilis	5	2	1								6							
N. consimilis (male pupae)												13						
N. consimilis/ornatus													3					
N. mitchelli (larvae & male pupae)			22	7		9					11			1				1
N. oligius								25*		2								
N. sp. cf. *auris*									1	8			3					
N. sp. (early instar)	1	5	1					31*						1				4
N. sp. (early pupae)						2						24					3	
Coleoptera																		
Carabidae																		
Chlaenius sp.?				1														
Dryopidae																		
Helichus basalis (adults)							1	1	2	1	1	2						3

Table A-2. (continued)

Site	Anthony						Mill 1						Mill 2					
Season	W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																		
Coleoptera (continued)																		
Elmidae																		
Macronychus glabratus (adults)									3			2						
Optioservus ovalis (adults)	2	1	6	10	3	10*		3	2	1	2	8		1		2	2	1
O. sp. (larvae)	1	2	1	2		3	1	4	3		2	4	1		1			
Oulimnius latiusculus (larvae)														1	3			4
O. latiusculus (adults)			2	1	1	2			2			3	1	1		3	1	1
Promoresia elegans (larvae)		1	4		1	5				1		15						8
P. elegans (adults)								10			11							
P. tardella (adults)		1	6	6	5	10*	1	2	4	21*	23	20					9	11
Stenelmis sp. (larvae)																		1
S. sp. (adults)								4	3	3	2	4		1		1	3	6
Eubriidae																		
Ectopria sp.	9	1		1	2	7		3		1		2		6*			2	2
Psephenidae																		
Psephenus herricki						1	15	16	18	22	24*	34*	15*	13*	10*	15	17*	22*
Ptilodactylidae																		
Anchytarsus bicolor												1						
Diptera																		
Athericidae																		
Atherix lantha	9	15	8	31*	36*	46	10	19	6	16	24	24	17	10		14	19*	25
Blephariceridae																		
Blepharicera sp.	11				1				25	3	3		3		2	2	5	
Ceratopogonidae																		
Dasyhelea sp.												1						
Palpomyia/Bezzia sp. complex	2	8		2	4	5	2	4		3		2		6				
Chironomidae	28	183	94	135	105	77	46	367	29	40	48	48	28	94	15	58	70	x
Dixidae																		
Dixa sp.		1	1	1	1	5	1			1							3	1
Empididae				4														
Hemerodromia sp. (larvae)																		
Simuliidae	14*	16	59*	28*	67*			38	9	5	17*	15	34	19		10	30	5

Table A-2. (continued)

Site	Anthony						Mill 1						Mill 2					
Season	W		S		F		W		S		F		W		S		F	
Taxa / Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Insecta																		
Diptera (continued)																		
Tabanidae																		
Chrysops sp.							1											
Tabanus sp.																		1
Tipulidae																		
Antocha sp.	1	1						2	2	3	1	2		3		3	6	
Dicranota sp	1	20	12	39*	2	24	1	6	9	22	2	2		2	9	10	3	5
Eriopterinae (5 spir. lobes dark and movable, like petals, w/ pale med. vein)				1														
Hexatoma sp.	6	18*	6	13	13	25	24	18*	5	23	17	10	6	10*	1	15	13*	11
H. sp. 2													3					
Limnophila sp.1 cf. *macrocera* (spir. lobes w/ long curly hairs)	1				2		1		2	1	1			2				
of hairs; little, leg-like gills)																		
L. sp. 3 (spir. lobes w/ fine hairs)		3	3	8	1	1	1			1	2	1		9		1	1	
Leptotarsus sp.										1								
Pseudolimnophila sp.																		
Tipula sp. 1 cf. *abdominalis*	21	8*	1	1	1	1	20*		3	2	3		3	6*	4	4		
T. sp. 3 (spir. lobes as fig. 11.3 Brigham et al., lobes w/ short hairs; 6 gills; light longitudinal bands)						1	5	5*		3		1	3	1	4			
Tipula sp. 4 (spir. lobes as in. 11.3 Brigham et al., lobes w/ longer hairs; 8 gills; dark mottling fused into dark long. bands)	5		5		1								1	1				1

VITAE

Stephen J. Fraley was born on June 2, 1965 in Rogersville, Tennessee. He graduated from Cherokee High School in June 1983. He entered the University of Tennessee in August 1983, but left after two quarters to pursue other interests. The next seven years were spent traveling, working and learning valuable lessons in the "school of hard knocks." He returned to the University of Tennessee in August 1990, and earned a Bachelor of Science degree in Wildlife and Fisheries Science in May 1994. He entered graduate school in August of the same year. He received his Master of Science degree in May 1998.

In May 1992, he married Nancy K. Dagley. They reside in Knoxville, Tennessee. He is currently employed by American Aquatics, Inc. as an aquatic biologist.