2011

Spatiotemporal responses of macroinvertebraes to timber harvesting in low-gradient headwater streams of central Louisiana

Derrick Klimesh
Louisiana State University and Agricultural and Mechanical College

SPATIOTEMPORAL RESPONSES OF MACROINVERTEBRATES TO TIMBER HARVESTING IN LOW-GRADIENT HEADWATER STREAMS OF CENTRAL LOUISIANA

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
In partial fulfillment of the
Requirements for the degree of
Master of Science

in

The School of Renewable Natural Resources

by
Derrick Klimesh
B.S., Upper Iowa University, 2009
May 2011

AKNOWLEDGEMENTS

First of all, I would like to thank my major professor, Dr. Jun Xu for the inception of this dynamic project and ultimately giving me this research opportunity, and by trusting that a non-traditional student could benefit his research project. I also would like to thank Dr. Xu for his guidance and providing me with additional scientific goals to achieve. Additionally, I thank you also for providing financial support while I managed a life in and away from academia and making my graduate experience memorable.

I would like to thank my committee members, Dr. Michael Kaller, and Dr. Bill Kelso for their support, motivation, and genuine interest and enthusiasm in my research. Additionally, thank you for the generous support in the scientific process and the comfortable atmosphere, your guidance through the basic scientific writing process, as well as support in the advanced statistical and ecological data analyses beyond what general coursework has provided me.

I would never have been able to succeed if it weren't for the many helpful fellow lab mates communicating and sharing knowledge and ideas, as well as many other students that had a contribution to my successful experience at Louisiana State University. These students include, in no particular order: Kris Brown, Abram DaSilva, Tim Rosen, April BryantMason, Biao Zhong, Ryan Mesmer, Den Davis, Steve Beck, Brandt Thibodeaux, and Aviane Aguillard.

Most of all, I would like to thank my wife, Penelope, for her hours of patience, and for stepping up to contribute more than her share in household duties, and the raising of our children. Without her optimism, her unequivocal encouragement, and the support of helping me complete my goals, I would have never succeeded. To Isaac, Miranda, Mariah, Madison, and Ivan, thank you for being good kids for the most part, and not giving your mother too much grief while I was focusing on my coursework, field trips, attending conferences, writing in the office, and overall education away from home. I would also like to thank my parents and sister for their support in my academic pursuits, even if it meant moving more than one thousand miles away. Thanks also to other numerous friends, family, and in-laws for their support and help moving our family, and by their visits and phone calls during our moments away from them and the Midwest.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Macroinvertebrates are reflective of their nearby environment and are popularly used to detect changes in water quality. In this thesis research, macroinvertebrates were collected to investigate aquatic effects of timber harvesting operations with and without the use of best management practices (BMPs) in a forested, low-gradient, subtropical watershed in central Louisiana. Habitat assessments, physicochemical and hydrologic measurements, and macroinvertebrate sampling were conducted nine times from 2006 to 2010 during the spring and late summer, at 13 site locations ranging from plot level to watershed outlet. Timber harvesting occurred in September of 2007. A total of 86,183 macroinvertebrates were identified from 634 samples and grouped into 31 metrics describing taxonomic and functional feeding groups (FFGs). Timber harvesting, regardless of BMP implementation, negatively affected 14% of the collected macroinvertebrates. Additionally, bivalve taxa and FFG scraper densities increased at all of the sites downstream of harvesting activities in the spring sampling events post-harvest. Macroinvertebrates were further explored with principal component (PC) analysis (PCA), generalized linear mixed models and zero-inflated models to discern their relationships with physical instream and riparian characteristics, and water chemistry parameters representative of the low-gradient, seasonal intermittent headwater streams. PCA composed 19 PCs that explained 81% of the variation within the physical and riparian parameters. Two PCs interpreted as describing stream intermittency helped explain densities in 5 of 19 interpretable metrics that made up over 83% of collected macroinvertebrates. Bivalve, scraper, and collector-filterer metrics were positively associated with PCs describing open canopy and immature or thinned riparian zones. Ephemeroptera, Plecoptera, and Trichoptera (EPT) densities were positively associated with dissolved oxygen (DO), and undercut banks, and negatively associated

with higher levels of woody-debris, and nitrite concentrations. Intensively collected DO data suggested that the densities of amphipods, chaoborids, and isopods showed significantly positive relationships with increasing DO. This adds critical knowledge to spatiotemporal dynamics of macroinvertebrate communities in Louisiana's low-gradient headwaters and the effectiveness of timber-harvest BMP implementation on stream health protection. The information can be utilized for the development of biological indices to help manage morphologically similar streams in subtropical climates.

CHAPTER 1: INTRODUCTION

Forest management activities such as timber harvesting can potentially have adverse impacts on stream biological conditions. To address these impacts, stream monitoring usually includes measurements of physical and chemical parameters; however, these brief moment-in-time measurements may not accurately portray the impairments of dynamic lotic systems (Karr and Chu, 1999). Organisms living in freshwater for all or part of their life cycle are dependent on specific resources provided by local geographic and riparian characteristics, and many organisms are specialized to endure a diversity of harsh conditions. Their community structure can therefore be helpful to understand changes in water quality and quantity gradients and could be used as potential bioindicators. Bioindicators can serve many purposes when used to monitor water quality such as: identifying impaired waters, determining aquatic stressors and impacts, and indicating improvement (Kenney et al., 2009). Bioindicators can be members of many different types of organisms including plants, fish, amphibians and invertebrates, each having some advantages over the others. Many government agencies use macroinvertebrates as their choice of bioindicator. Macroinvertebrates are ubiquitous and can reflect the overall condition or health of a stream (Norris and Thoms, 1999) because some portion of their life cycle is closely linked to biotic and abiotic stream characteristics. The linkage between macroinvertebrate life cycles and stream conditions may be used to infer stream condition from macroinvertebrate presence, absence, or density.

Forests cover approximately half of Louisiana’s land surface, and forestry is the largest agricultural commodity in the state. Because of a large number of water bodies in close proximity to the forests, silvicultural activities could affect immediate and downstream water

quality. To help industry and landowners abate potential impacts of land use activities contributing to water quality degradation, forestry best management practices (BMPs) were developed and are currently voluntary in Louisiana. Timber harvesting BMPs can encompass a wide array of management guidelines such as: pre-harvest planning, minimally invasive stream crossings, removal of slash from stream beds, locating road and skidder trails away from water, and inclusion of streamside management zones. All of these guidelines are designed to reduce sediment runoff and nutrient input into nearby streams, thus minimizing effects on the physical, chemical, and biological integrity of the water. Over the past two decades, studies involving silvicultural impacts on streams and the BMP effectiveness of water quality protection have been conducted in many climatic regions. However, most of the studies concentrated on upland fast flowing streams, such as those in the Pacific Northwest (e.g. (Price et al., 2003; Gravelle et al., 2009). Until now relatively little information is available about whether BMPs are effective in low-gradient, organic-rich subtropical streams.

Louisiana streams, particularly forested headwaters, are mostly low-gradient, and contain high amounts of organic material. The headwater streams are susceptible to intermittency, especially in the drier summer season, and from accumulation of the organic matter. which further contributes to debris dams. Headwater streams can account for 60% to 80% of cumulative length for river networks (Benda et al., 2005) and are major sources of water, nutrients, and organic and inorganic material, ultimately making up the larger more anthropogenically important downstream systems (Wipfli et al., 2007; Binckley et al., 2010). There is minimal information on macroinvertebrate communities that inhabit forested stagnant headwaters of Louisiana, particularly streams that are seasonally intermittent.

To understand and explore an area where little information exists, a multi-disciplinary project was initiated in a low-gradient watershed in north-central Louisiana to investigate hydrology, water quality, and stream macroinvertebrates at the local and watershed scale, with particular focus on the headwater streams and temporal differences among headwaters and main-stem reaches. The Flat Creek watershed is a representative watershed located in central Louisiana, and is dominated by actively managed forestland. The project began with a two year calibration period from December 2005 through August 2007, utilized the paired watershed design at four harvested plots, with and without the use of BMPs, and monitored a series of stream hydrologic and physicochemical parameters in addition to collecting macroinvertebrates in the spring and late summer each year. Three graduate students used this calibration time for their thesis research (Saksa, 2007; Viosca, 2007; BryantMason, 2008) to characterize the hydrology, water chemistry, and macroinvertebrate communities to provide baseline information for this project. In September of 2007, four timber stands were harvested in the watershed, including thinning in riparian areas, with and without the use of BMPs. Additional monthly monitoring and macroinvertebrate collections continued throughout 2010. Two additional graduate students focused on the hydrology and water chemistry in the post harvest period, and used the collaborative collected data in their theses research (Brown, 2010; DaSilva et al., In Review).

This thesis research focuses on macroinvertebrate ecology in low-gradient headwater streams characteristic of this region. The thesis research presents findings from three sub-studies, and is divided into five chapters. Following this introduction, Chapter 2 presents the study of timber harvest BMP effectiveness in low-gradient headwater streams. This chapter focuses strictly on changes in the benthic macroinvertebrate communities collected during two years,

each before and after timber harvest at seven sites in the Flat Creek watershed. Chapter 3 presents the research on the associations of all macroinvertebrate communities with instream and riparian habitat characteristics, using principal component analysis. This study encompassed nine sampling events over five years, at 13 different stream sampling sites throughout the watershed, to understand spatial and temporal differences of local conditions with macroinvertebrate communities and functional feeding groups. Chapter 4 focuses on associations of macroinvertebrate taxonomic and functional feeding groups with water physical and chemistry parameters, including intensively measured dissolved oxygen. This chapter is similar to Chapter 3, and concentrates on all macroinvertebrates collected throughout five years in the watershed. Chapters 2, 3, and 4 are written as stand-alone manuscripts for submission to peer-reviewed journals. There is some repetition between chapters, because each chapter has its own introduction, methods, results, discussion, and conclusions sections.

CHAPTER 2: RESPONSES OF STREAM BENTHIC MACROINVERTEBRATE COMMUNITIES IN A LOW-GRADIENT, SUBTROPICAL WATERSHED TO TIMBER HARVESTING

2.1 Introduction

Timber harvesting activities have the potential to increase sediments (Beasley and Granillo, 1988; Stott and Mount, 2004), streamflow (Bosch and Hewlett, 1982; Hicks et al., 1991; Stednick, 1996), water temperature (Brown and Krygier, 1970; Corbett et al., 1978), and nutrient export (Likens et al., 1970)) in adjacent stream systems. These changes negatively affect the abundance and species composition of sensitive macroinvertebrates such as most Ephemeroptera, Plecoptera and Trichoptera (EPT)(Kaller and Hartman 2004), while favoring disturbance tolerant taxa, such as Diptera (Collier and Bowman, 2003; Martel et al., 2007). Forests are the dominant land-use and the most valuable agricultural commodity in Louisiana, covering about half of the state (approximately 14 million acres) (LSU AgCenter, 2010).

Currently, implementation of forest best management practices (BMPs) is voluntary, and overall compliance has dipped from 96% in 2002, to 74% in 2009, according to two surveys conducted by the Louisiana Department of Agriculture and Forestry (Xu and Rutherford, 2005; Kaller, 2010). Recommended BMPs include maintenance of streamside management zones (SMZs) to help protect water quality and reduce nonpoint source pollution during and after forestry operations. The SMZs provide a minimal basal area to be retained during harvesting activities. Louisiana BMPs are devised to educate forest land owners and operators to help reduce forest soil movement towards waters of the state (LDEQ, 2000), minimize environmental impacts, and maintain water quality. Forestry BMPs have been described for pre-harvest planning, site preparation, road building, felling, skidding, chemical applications, minimization of stream crossings, and fire management. BMPs encompass SMZs or buffer zones in riparian

areas to ensure bank stabilization, allow vegetative filtration of sediment and fine organic matter, and protect streams from changes in thermal regimes. These SMZs vary in width and are dependent on the size and intermittent nature of the stream. BMPs also include timing of activities to consider soil moisture conditions, and avoiding activities during high-precipitation periods.

Headwater stream systems can be ephemeral, perennial, or intermittent, and the definition of which can vary depending on map scale resolution. Consequently, identification of headwater streams can present a management dilemma, because riparian zones and delineated SMZs, which can be subject to harvest restrictions, can ultimately cover a large portion of the watershed. Headwater streams are the sources for larger, more anthropogenically-important downstream reaches, and can strongly influence the biological, physical, and chemical characteristics in higher-order streams. During episodic rain events, low-gradient headwater streams carry enormous loads of organic material that often serves as the most important energy source for invertebrate production (Vannote et al., 1980; Wallace and Webster, 1996).

There are few studies regarding macroinvertebrates and forested headwater streams, especially low-gradient, low-flow, high-organic content streams of Louisiana. Although Sloey (1992) reported changes in macroinvertebrate community structure after various successive years of forest harvesting in the Kisatchie National Forest, Louisiana, Carroll et al. (2004) found no differences in pre- to post-harvest macroinvertebrate abundance in samples collected from control and SMZ-treated streams in Mississippi. Similarly, Kaller and Kelso (2006a) showed that such disparate factors as riparian zone alterations and feral swine activities could alter benthic macroinvertebrate communities, whereas Williams et al. (2005) showed no negative

effects on stream biota related to military training activities, including partial timber harvest and road building.

In 2005 a multi-disciplinary project was initiated in a low-gradient watershed in north-central Louisiana to monitor hydrology, water quality, and stream benthic macroinvertebrates at the watershed scale, with particular focus on the headwater streams and temporal differences among headwaters and main-stem reaches. The Flat Creek watershed has been intensively managed for timber harvesting operations since the 1970's. This chapter focuses on benthos ecology in low gradient headwater streams characteristic of this region, specifically the responses of the benthic macroinvertebrate community to timber harvest.

In the past two decades, characterization of the structure of stream biotic communities such as benthic macroinvertebrates has become an essential tool for state and federal water quality assessment programs in the U.S. Macroinvertebrate communities can reflect the overall condition or health of a stream (Norris and Thoms, 1999) because some portion of the life cycle of all taxa is closely linked to biotic and abiotic stream characteristics. Contrary to physicochemical parameters that are often collected at specific points in time, biological indicators of water quality may reflect more of a longer-term, integrated response to conditions in these dynamic ecosystems (Karr and Chu, 1999). For example, macroinvertebrates have been found to be sensitive to changes in temperature (Swift and Messer, 1971) and light levels (Haggerty et al., 2004), as well as anthropogenic changes in sediment (Lenat et al., 1981) and organic inputs from domesticated livestock operations (Davis et al., 2003).

Currently, Louisiana does not have a biological index system for its surface water quality assessment program, and data continues to be collected to determine how stream biota respond to changes in stream conditions, and whether these responses can be used to assess stream health.

Our study was designed to further enhance our understanding of stream-biota relationships by investigating the structure of the benthic macroinvertebrate community in a low-gradient, forested, headwater stream, its response to timber harvesting activities, and whether significant changes in community composition are related to BMP implementation.

2.2 Methods

2.2.1 Site Description

The Flat Creek watershed is located in north-central Louisiana, and is part of the Ouachita River basin which belongs to the northern portion of the U.S. Environmental Protection Agency Level III Southern Coastal Plain Ecoregion (SCPE) (Daigle et al., 2006). The watershed is predominantly forestland (84%) managed for harvest of loblolly pine (*Pinus taeda*), but also includes some pastureland, agricultural fields and hardwoods in riparian areas. The Flat Creek watershed drains 369 km^2 and receives an average of 1508 mm of precipitation annually. The climate is subtropical and precipitation is mostly seasonal, with the majority falling from November through April. Annual rainfall amounts from 2006 through 2009 in the area were 1301, 893, 1266, and 1269 mm, respectively (Brown, 2010). Average monthly temperatures fluctuated between 8.0°C in January and 28.6°C in July, with an annual average of 18.2°C. Soils consist of well drained fine sandy loam at higher elevations to less porous clayey-silt in stream beds and riparian areas (NRCS, 2007).

Seven monitoring sites were designated for macroinvertebrate sampling on three 1st-order streams (Figure 2.1). The sites were designed to use a paired approach to determine impacts of harvesting at the plot scale by comparing BMP implemented and non-implemented sites, upstream and downstream of harvest sites, and harvested sites with a control (Table 2.1).

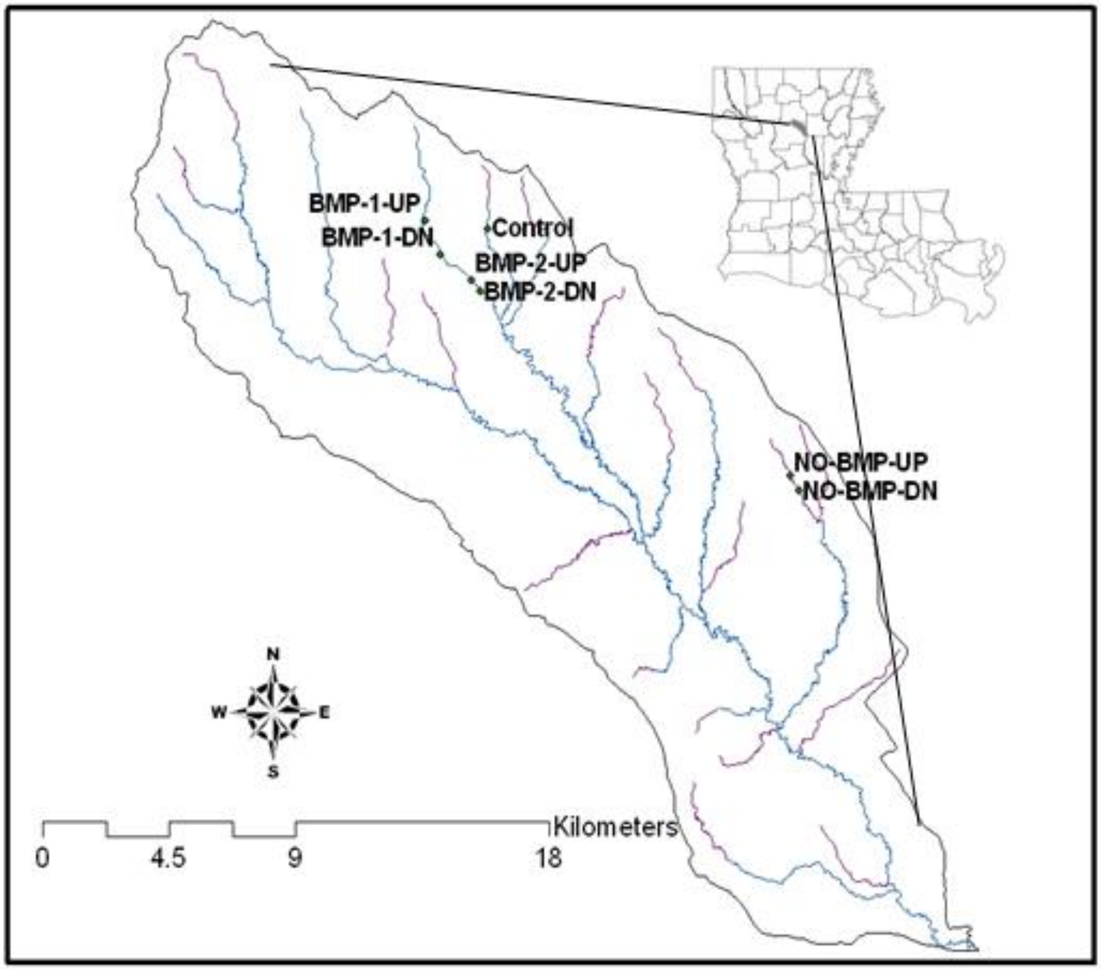

Figure 2.1. Flat Creek watershed, Winn Parish, Louisiana, USA, benthic macroinvertebrate monitoring site locations.

The control site was spatially distant from forest harvesting activity and was located in the adjacent Spring Creek watershed. Paired sites upstream and downstream from a harvested stand with BMP implementation included BMP-1-UP and BMP-1-DN, and BMP-2-UP and BMP-2-DN. These four sites were located on Turkey Creek, upstream of the junction of Spring Creek. Sites No BMP-UP and No BMP-DN were designated on Big Creek where timber harvest was executed without BMP implementation.

Table 2.1. Description of sites in the Flat Creek watershed and harvested areas.

Site	Drainage area (km^2)	Stream order	Harvested area above (km^2)	Harvested area cumulative (km^2)	Designation
Control	3.0	1	0	0	Reference
BMP-1-UP	12.4	1	0	0	Plot reference
BMP-1-DN	14.3	1	0.24	0.24	Plot treatment
BMP-2-UP	17.8	1	0.24	0.24	Plot reference/ cumulative treatment
BMP-2-DN	18.3	1	0.12	0.36	Plot treatment/ cumulative treatment
No BMP-UP	2.1	1	NA	NA	Plot reference
No BMP-DN	3.4	1	0.25	0.25	Plot treatment

2.2.2 Field Sampling and Measurements

The selected headwaters in the Flat Creek watershed had low baseflow and shallow depths, which required a modification of a conventional core sampler for quantitative sampling. The streams were relatively stagnant except for episodic rain events that deliver most woody debris and organic matter into the stream systems. These low-flow conditions, which precluded the use of drift nets or Surber samplers for macroinvertebrate collections, resulted in the use of a modified stovepipe sampler (Merritt et al., 2008) that measured 0.2057 m by 0.2057 m (8.1 inch by 8.1 inch) square, with a benthic sampling area of 0.0423 m^2. For each sample, the top 2.5 cm of substrate was removed and placed into a 2-L jar, and the water column within the core was swept for one minute with an aquarium net to capture suspended organisms (Viosca, 2007).

Figure 2.2a. Macroinvertebrate collection method measuring random reach length.
Figure 2.2b. Setting the modified stovepipe aluminum corer for sample collection.

To determine the location of sampling points, we generated eight random stream reach length measurements between 8 and 150 m (Figure 2.2a), and took core samples (Figure 2.2b) at the randomly selected sites along these reaches in April and August 2006, August 2007, May and August 2008, and April and August 2009. Spring collections included all eight random reach samples; however, some late summer sample reaches were dry and samples were not collected. Spring and late summer samples were analyzed separately, as macroinvertebrate communities in Louisiana streams show significant seasonal changes in species composition (Kaller and Hudson, 2010), and we did not want seasonal turnover to confound the detection of differences among our planned comparisons. We collected a total of 333 samples that were subsequently preserved in 95% ethanol, filtered through a 500-µ sieve and treated with Rose Bengal stain to aid in sorting.

Although present in most of the samples, arachnids, oligocheates, cladocerans, copepods, hemipterans, homopterans, and ostracods were not included in these analyses due to either fragility or possible association away from benthic material. Organisms were identified to the lowest practical taxonomic level, usually family or genus, and were grouped taxonomically and by functional feeding group (i.e., shredders and scrapers) according to identification guides and

keys (McCafferty, 1981; Merritt et al., 2008). Shannon-Weiner's index of diversity calculated as:

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

where p_i is the proportion of individuals found in the *i*th species and ln is natural logarithm. Additionally, Shannon's evenness index was calculated as:

$$E = H' / H_{max}$$

Scores range from 0 to 1, where a value of 1 would mean all species were equally abundant.

2.2.3 Statistical Analysis

Prior to analyses, we selected a limited number of descriptive community metrics for analyses, and hypothesized their responses to harvesting (Table 2.2). These metrics were selected because other macroinvertebrate studies in southeastern U.S. streams have found relationships between these metrics and stream health (Barbour et al., 1996; Davis et al., 2003; MDEQ, 2003). Data analyses were performed with a generalized linear mixed model framework (GLMMs, PROC GLIMMIX, SAS version 9.1.3 June 2006 release version) separately for spring and late summer. For these GLMMs, all taxa were converted to individuals per m^2. A negative binomial distribution was used along with a log link to compensate for overdispersion in the data.

We tested for differences between the control and treatment sites, as well as before and after timber harvesting. Additionally, because the sites were designed for specific comparisons, *a priori* contrasts were performed before and after harvesting, and between harvested and unharvested sites.

Table 2.2. Selected benthic macroinvertebrate metrics and their predicted responses after increasing perturbation according to Barbour et al., (1996), Fore et al., (1996). Davis et al., (2003), MDEQ (2003).   EPT abbreviates Ephemeroptera, Plecoptera, and Trichoptera, and FFG abbreviates functional feeding group.

Metrics	**Predicted response**
Percent EPT	Decrease
Total Abundance	Decrease
Shannon Wiener Index	Decrease
Evenness	Decrease
Taxonomic richness	Decrease
Percent Dominant Taxa	Increase
EPT per m^2	Decrease
Amphipods per m^2	Variable[a]
Bivalves per m^2	Decrease
Chironomids per m^2	Variable[a]
Coleopterans per m^2	Variable[a]
Dipterans per m^2	Variable[a]
Gastropods per m^2	Decrease
Malacostracans per m^2	Variable[a]
Megalopterans per m^2	Variable[a]
FFG Scrapers per m^2	Variable[a]
FFG Predators per m^2	Variable[a]
FFG Shredders per m^2	Variable[a]
FFG Piercers per m^2	Variable[a]

[a] Previous studies suggested conflicting outcomes.

Table 2.3. Planned site comparisons and *a priori* contrasts to explain timber harvest effects.

Contrasts	**Explanation of contrasts**
BMP-1-UP vs BMP-1-DN before	Adjacent BMP implementation similarity validation
BMP-1-UP vs BMP-1-DN after	Adjacent BMP implementation timber harvest effect
BMP-2-UP vs BMP-2-DN before	Adjacent BMP implementation similarity validation
BMP-2-UP vs BMP-2-DN after	Adjacent BMP implementation timber harvest effect
BMP-1-DN before vs after	Plot timber harvest site effect
BMP-2-UP before vs after	Plot timber cumulative harvest site effect
BMP-2-DN before vs after	Plot timber harvest site effect and cumulative effect

2.3 RESULTS

2.3.1 Spring Sampling

We collected a total of 48,461 benthic macroinvertebrates, representing 29 orders and 66 families from 333 samples during the seven sampling events. Total abundance per m^2 varied between 3,504 and 39,963 in the spring sample sets (mean = 15,378, standard error = 2,002). Taxa richness at the family level remained similar (mean =17.14, standard error = 1.17) for all three sampling events, and ranged from 9 to 26. Shannon-Weiner diversity ranged 0.64 to 2.07 in the spring samples (mean = 1.53, standard error = 0.07), and Shannon evenness for all sites varied between 0.28 and 0.69 (mean = 0.55, standard error = 0.02). The percent dominant families in pre-harvest samples were mostly dipterans, although asellid isopods were dominant in two of the seven sampled sites (BMP-2-UP, and BMP-2-DN) (Table 2.4). Bivalves (97.53% Sphaeriidae) were dominant in the Big Creek (no BMP) samples in the immediate post-harvest samples of 2008, although culicids dominated pre-harvest samples. In 2009, spring samples were exclusively dominated by Chironomidae.

Bivalve densities increased significantly at BMP-1-DN, BMP-2-UP, and No BMP-DN after timber harvest in the spring samples (Table 2.5) (Figure 2.3). Additionally, at sites downstream of BMP implementation (BMP-1-DN, BMP-2-UP, and BMP-2-DN), malacostracan and shredder densities decreased significantly (Figures 2.4 and 2.5). The number of scraper taxa increased significantly at BMP-2-UP (Figure 2.6). Amphipod densities were significantly lower after timber harvest at BMP-1-DN, as well as all of the downstream sites collectively. Ephemeroptera, Trichoptera, and Plecoptera (EPT) taxa (0.9% of total collected macroinvertebrates) were mostly uncommon, but were abundant (up to 13.7%) at the control site before harvest during spring.

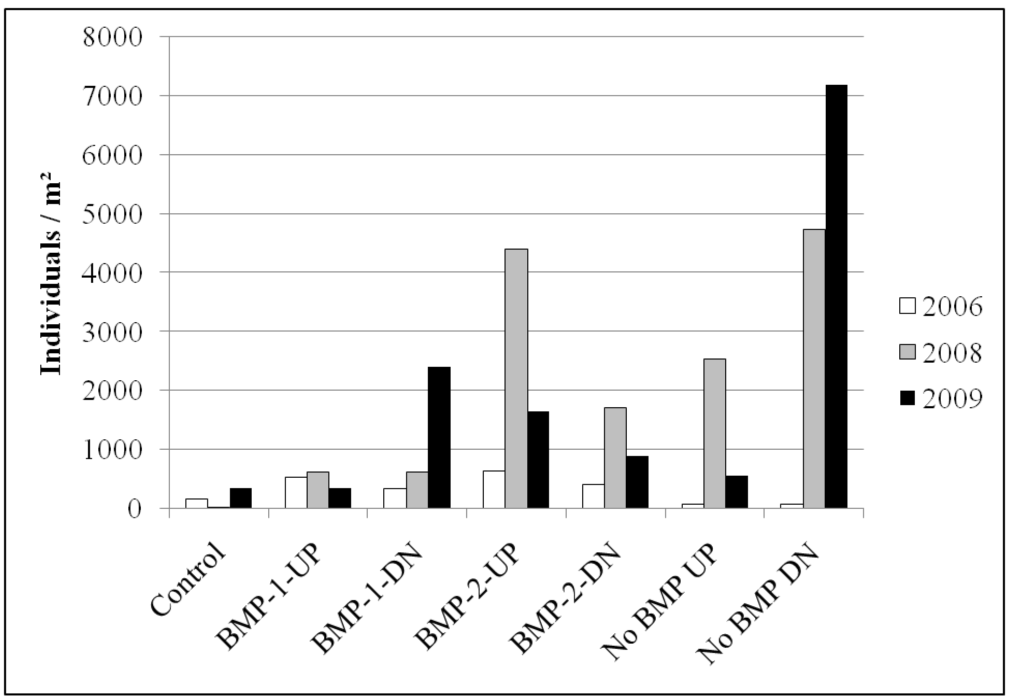

Figure 2.3. Annual bivalve abundances in spring sampling events at seven sites in the Flat Creek watershed, Winn Parish, Louisiana, USA.

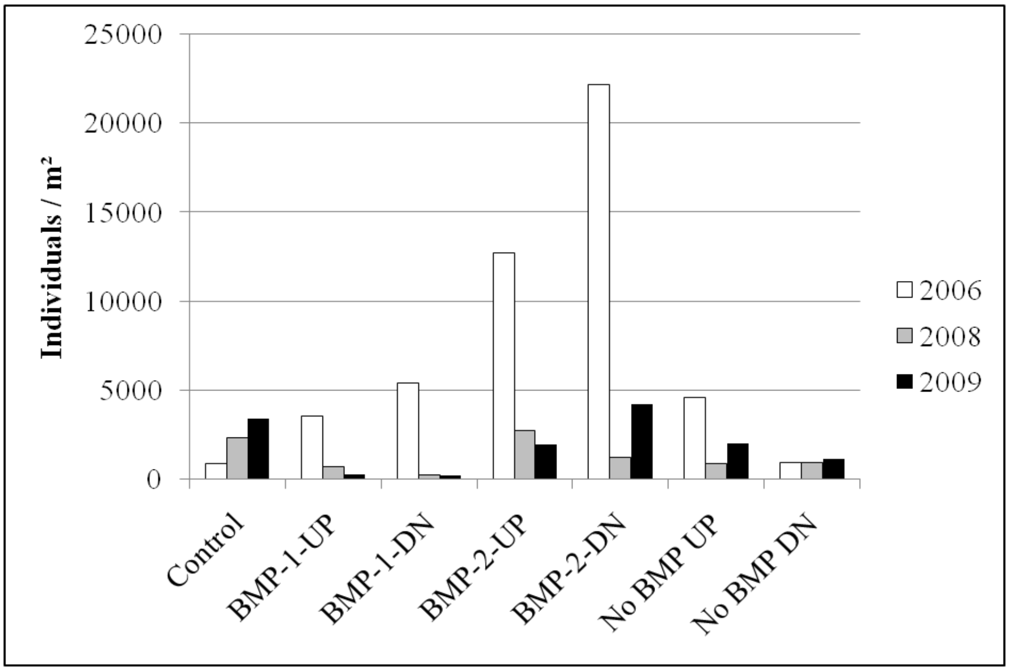

Figure 2.4. Annual malacostracan abundances in spring sampling events in the Flat Creek watershed, Winn Parish, Louisiana, USA.

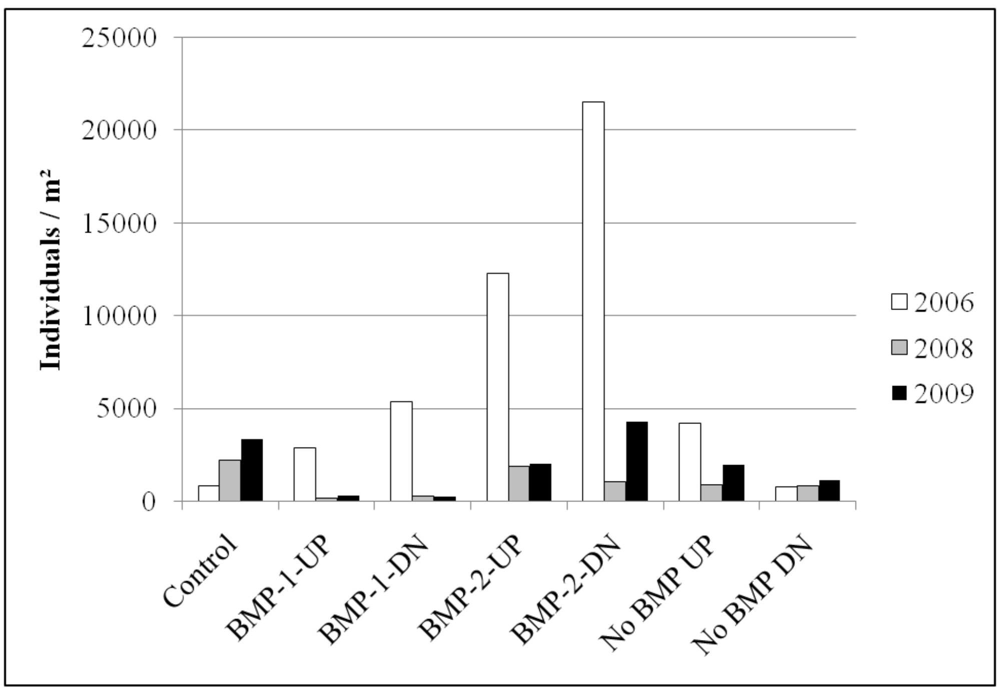

Figure 2.5. Annual shredder abundances in spring sampling events in the Flat Creek watershed, Winn Parish, Louisiana, USA.

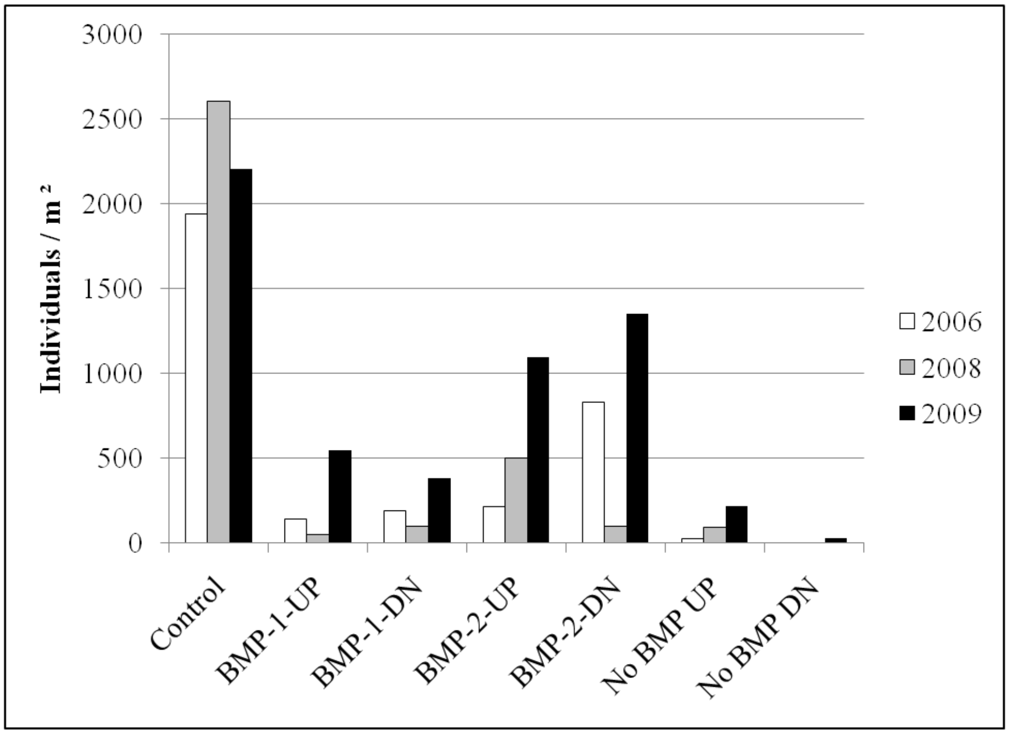

Figure 2.6. Annual scraper abundances in spring sampling events in the Flat Creek watershed, Winn Parish, Louisiana, USA.

2.3.2 Summer Sampling

Total abundance varied between 3,033 and 153,286 per m² for the late summer samples (mean = 41,605, standard error = 7,410). Taxa richness (family level) varied between 11 and 28 (mean = 17.77, standard error = 0.92), and Shannon-Weiner diversity ranged from 0.48 to 1.87 (mean = 1.04, standard error = 0.07). Shannon evenness for all sites varied between 0.15 and 0.66 (mean = 0.37, standard error = 0.03). Total percent dominant taxa were overwhelmingly dipterans, as 22 of 23 site totals were comprised exclusively of Chironomidae, with one site dominated by Ceratopogonidae (Table 2.4). Additionally, bivalve densities increased significantly at BMP-2-UP and BMP-2-DN with respect to pre-harvest and post harvest abundances (Table 2.5) (Figure 2.7).

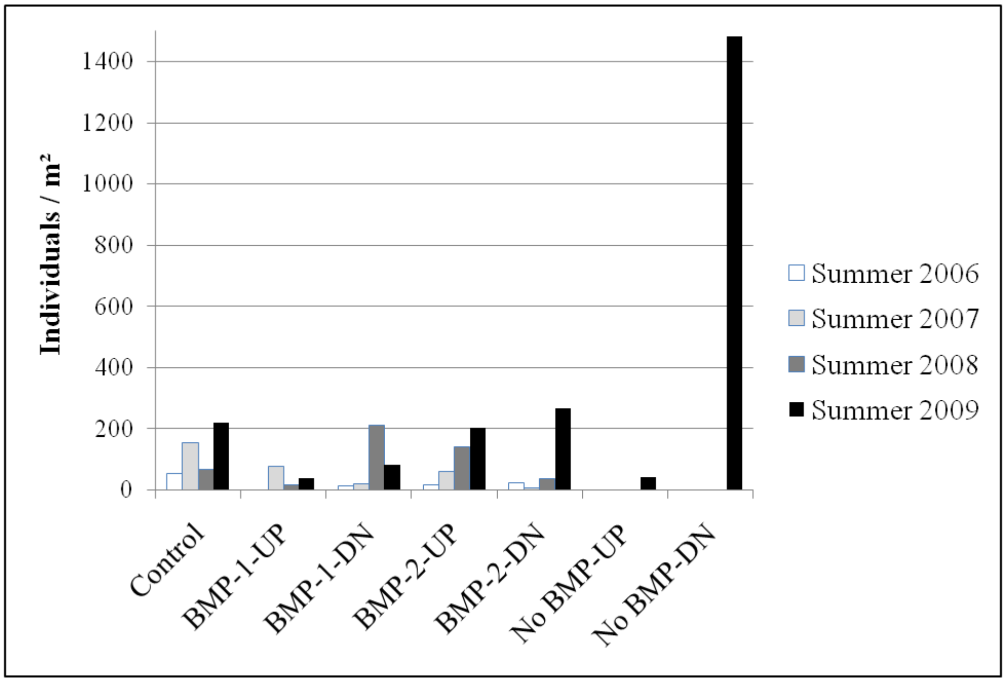

Figure 2.7. Annual bivalve abundances in late summer sampling events in the Flat Creek watershed, Winn Parish, Louisiana, USA.

2.3.3 Results Summary

In summary, 2 out of 13 metrics, which represented 7.0% of collected macroinvertebrates, increased in association with timber harvesting activities. Conversely, 3 of 13 metrics, which represented 13.6% of collected macroinvertebrates, decreased in association with the timber harvest. More importantly, 8 metrics, which represented up to 83.3% (Table 2.5) of macroinvertebrates collected during the study, demonstrated no statistically detectable relationships with timber harvesting or BMP implementation.

Table 2.4. Dominant Families[a] in the Flat Creek watershed sampling events followed by (%) of total taxa collected for that event.

Sites	Control	BMP-1-UP	BMP-1-DN	BMP-2-UP	BMP-2-DN	No BMP-UP	No BMP-DN
Spring 2006	CH (54.7)	CE (52.0)	CH (37.9)	AS (45.1)	AS (42.4)	CU (83.6)	CU (53.7)
Spring 2008	CH (49.9)	CH (48.7)	CH (55.8)	CH (45.1)	CH (51.6)	SP (37.0)	SP (41.1)
Spring 2009	CH (74.1)	CH (72.3)	CH (52.6)	CH (45.0)	CH (36.1)	CH (75.4)	CH (47.4)
Summer 2006	CH (41.7)	CE (49.6)	CH (78.1)	CH (90.9)	CH (85.5)	NA	NA
Summer 2007	CH (78.3)	CH (74.7)	CH (70.4)	CH (71.1)	CH (68.5)	NA	NA
Summer 2008	CH (52.6)	CH(78.9)	CH (58.0)	CH (84.9)	CH (85.6)	NA	NA
Summer 2009	CH (67.9)	CH (70.3)	CH (66.5)	CH (55.5)	CH (63.8)	CH (73.8)	CH (56.8)

[a] AS= Asellidae, CH = Chironomidae, CE = Ceratopogonidae, CU = Culicidae, SP = Sphaeriidae, NA = Not applicable

Table 2.5. Generalized linear mixed modeling results (α = 0.05) for both spring and late summer samples for sites compared before and after timber harvest. Late summer samples are shaded. Signs (+ or -) indicate positive or negative changes in metric value after harvest.

Site	Metric	F-Value (P>F)
BMP-1-DN	**Amphipods (-)**	**4.17 (0.0414)**
	Bivalves (+)	**4.00 (0.0456)**
	Malacostracans (-)	**10.25 (0.0014)**
	Shredders (-)	**8.23 (0.0042)**
BMP-2-UP	**Bivalves (+)**	**260.06 (0.0001)**
	Bivalves (+)	**6.10 (0.0136)**
	Malacostracans (-)	**3.94 (0.0472)**
	Scrapers (+)	**4.41 (0.0358)**
	Shredders (-)	**3.97 (0.0463)**
BMP-2-DN	**Malacostracans (-)**	**5.47 (0.0195)**
	Shredders (-)	**4.41 (0.0358)**
	Bivalves (+)	**250.15 (0.0001)**
No BMP-DN	**Bivalves (+)**	**11.14 (0.0009)**

2.4 DISCUSSION

Differences observed in the abundance of taxonomic and functional feeding groups during our study suggest that some members of the benthic macroinvertebrate community assemblages in the Flat Creek watershed changed in response to timber harvesting activities. We observed decreases in proportions of amphipods and malacostracans post-harvest, which is in contrast to results reported from a similar study in New Zealand (Thompson et al., 2009). In contrast to Stone and Wallace (1998) and Haggerty et al. (2004), who documented increases in shredders and decreases or non-responses of scrapers to logging, we observed increases in the proportion of bivalves and scrapers in post-harvest samples. However, many more organisms appeared to be unaffected by timber harvesting based on our predicted responses from the literature (Barbour et al. 1996; Fore et al. 1996; Davis et al., 2003; MDEQ, 2003). Consequently, it appears from our study that incorporation of BMPs in forestry operations in low-gradient coastal-plain streams is effective in minimizing significant negative impacts for most members of the benthic macroinvertebrate community.

The increases in the densities of bivalves immediately downstream of two of the three plots suggests timber harvesting activities may have improved bivalve habitat quality, as before-harvest comparisons showed no significant differences. Additionally, late summer samples at the No BMP sites showed supporting evidence for bivalve enhancement, but we were unable to statistically examine these data because pre-harvest data was not obtained. In a recent study in New Zealand, Thompson et al. (2009) found sphaeriid bivalves to increase in total biomass from pre-harvest to post harvest consistently in their study streams. Scraper taxa in our study, which were largely gastropods (Ancylidae, Planorbidae, Viviparidae, and Physidae), also increased in relative abundance downstream of the BMP-1 implemented harvest area (Figure 2.7). However,

gastropod densities did not statistically differ, suggesting other members (Scirtidae, Caenidae) of this FFG had increased as well. Scraper increases have been widely recognized as a common macroinvertebrate response to timber harvest (Murphy and Hall, 1981; Price et al., 2003). This is likely due to stimulated periphyton growth resulting from a reduction in canopy cover. Contrary to our predictions, there were no significant increases in total suspended solids in the studied streams post-harvest (Brown, 2010). Kaller and Kelso (2006c) found that gastropods, but not most bivalves, were positively correlated with feral hog streamside rooting and wallowing in a Louisiana coastal plain stream. Feral hogs are present in the Flat Creek watershed and may have been attracted to the open spaces created by timber harvesting (Lipscomb 1989). We did not measure sediment deposition, but this harvesting-related impact has been shown to be tolerated by sphaeriid bivalves (Voshell, 2002).

Although caenid and heptageniid mayflies were included in the scraper FFG (Voshell, 2002), all EPTs exhibited a non-significant trend of post-harvest decline, suggesting the scraper community and EPTs did not share common responses to timber harvesting. Consequently, it appears that taxa making up the majority of the scraper communities took advantage of post-harvest conditions. Decreases in EPT taxa abundance were evident at the control site in the absence of timber harvesting, which likely contributed to the lack of significance in EPT abundance at harvested sites. Although EPT abundances are generally low in low-gradient streams of coastal plains (Sloey, 1992; Davis et al., 2003; Kaller and Kelso, 2006a, 2007), their relative abundance has been shown to be a reliable indicator of disturbance in the southeastern United States (Gage et al., 2004). The lack of substantial declines in the relative abundance of EPT taxa post-harvest suggests that BMP implementation minimized habitat impacts for these organisms.

Shredders have been documented to decrease in abundance following perturbations such as timber harvest (Haefner and Wallace 1981, but see Stone and Wallace 1998) or decreased input of particulate organic matter (Wallace et al. 1997), which was supported by our observations at sites below the BMP-implemented harvests. In this study, shredders were mostly made up of asellid isopods (72.9%), amphipods and crayfish, all of which are malacostracans, suggesting a common response to harvesting within this phylogenic group. Similarly, Davis et al. (2003) noted that reference sites in low-gradient intermittent streams in the Middle Atlantic Coastal Plain had significantly higher crustacean and isopod densities compared to impacted streams. In contrast; however, Haggerty et al. (2004) found densities of shredders increased in clear-cut and buffered streams of coastal Washington relative to uncut references. Differences among these studies could be related to the timing of invertebrate collections (i.e., high inputs of organic matter soon after cutting, with reduced inputs during subsequent years), the taxonomic composition of the invertebrate community, and the nature of particulate organic matter inputs in these systems.

Dominant taxa in the spring samples changed over the course of the study at the seasonally dry stream sites of the No BMP implementation plot, with dipterans replaced by bivalves in 2008 and vice versa in 2009. However, the No BMP-DN site was otherwise statistically similar to No BMP-UP in all other metrics used for spring contrasts. Bivalves have been shown to be in decline in the southeastern United States (Williams et al., 1993; Lydeard and Mayden, 1995; Haag and Warren, 1998), and our results suggest that bivalves may benefit in some, as yet undetermined, manner from timber harvesting in these stream systems.

Because sites without BMP implementation could not be sampled in late summer pre-harvest and immediate post-harvest periods, we were unable to examine immediate benthic

macroinvertebrate community responses to timber harvesting. Additionally, the characteristic extreme variability of macroinvertebrate relative abundance in pre-harvest samples hindered statistical assessment of community responses, especially for assessing reference stream community composition. Some of this variability was likely due to substantial differences in environmental conditions during the study. For example, total rainfall for 2007 (893mm) was much lower than the long-term average (1508mm), which may have played a role in harvest-related changes in macroinvertebrate abundances, such as EPT taxa (e.g., Wagner and Schmidt, 2004) as well as other macroinvertebrates (Parr and Mason, 2003). Recruitment failure associated with lack of sufficient flow during this unusually dry period may have been a significant factor affecting the densities of many macroinvertebrate taxa we collected (Doisy and Rabeni, 2001).

2.5 CONCLUSIONS

This study investigated stream benthic macroinvertebrates in a low-gradient subtropical watershed before and after a timber harvesting operation over a period of four years. BMP effectiveness in forestry operations appears to minimize significant density effects for most members of the benthic macroinvertebrate communities. Our study showed that few groups (less than 14% of total abundance) of taxa or FFGs had negative associations with intensive silvicultural activities. In headwater streams of the SCPE, we suggest that, relative to natural stream impacts resulting from seasonal low flows and associated changes in water quality and stream-riparian zone relationships, stream perturbations related to forestry operations may be relatively unimportant regarding macroinvertebrate community composition and dynamics. Further, adaptations to these environmentally-dynamic stream systems may have already selected for more resilient taxa that may be better able to adapt to short-term changes in riparian

and upland forest cover than organisms in more temperate systems. Generalist dipteran taxa appear to be the dominant group of benthic macroinvertebrates in our study area. Unlike other parts of the U.S., EPT taxa (0.87% of collected macroinvertebrates) are not abundant in these streams, and they were not useful indicators of harvest-related changes in due to high variation in densities among and within control and treatment sites. Decreases in shredder and malacostracan abundance, as well as increases in scraper and bivalve densities may provide insight to effectively managing timber stands in low-gradient watersheds typical of Louisiana. However, most benthic macroinvertebrate taxa, including dipterans, odonatans, coleopterans, gastropods, predators, and piercers exhibited no discernable pre-harvest to post-harvest changes in abundance, and there were no significant differences in taxa richness, diversity, or evenness related to harvesting activities. Discerning the differences in macroinvertebrate responses to natural environmental variation and timber harvesting activities is problematic at best, and is further hindered when study streams can be seasonally (and stochastically) intermittent. Our results do suggest, however, that forest management activities, regardless of BMP implementation, had limited short-term impacts on resident macroinvertebrates in these low-gradient, subtropical streams. Continued monitoring at the study sites will allow us to better understand the long-term effects of timber harvesting in these stream systems, particularly the resilience of stream biota to harvesting-related stream conditions.

CHAPTER 3: RELATIONSHIPS BETWEEN MACROINVERTEBRATES AND INSTREAM AND RIPARIAN HABITAT CHARACTERISTICS IN SEASONALLY INTERMITTENT HEADWATER STREAMS IN CENTRAL LOUISIANA

3.1 INTRODUCTION

Aquatic macroinvertebrates are common biological organisms that can be used to describe increasing water quality perturbation. They are part of a larger suite of organisms used to develop and understand water quality relationships (Hawkins et al., 2000). Macroinvertebrates and other organisms are used by many local, state, tribal, and federal organizations (Carter and Resh, 2001) as a means to regulate and manage water bodies of interest so that they meet their intended uses. Macroinvertebrates are ubiquitous and are especially diverse in subtropical regions (Vinson and Hawkins, 2003). Macroinvertebrates have been known to specialize in distinct habitats, such as headwaters, filling unique niches produced from stream conditions resulting from various processes and characteristics associated with a riparian environment (Vannote et al., 1980). Headwater streams have been a focus of attention recently, with debate on the definition of a headwater and whether or not to include them as "protected waters" under the Clean Water Act (Nadeau and Rains, 2007). Viable definitions of headwaters are not agreed upon as finer resolutions are not included on maps used by some regulatory agencies (Meyer et al., 2007). Depending on definition, these stream systems can account for more 60% to 80% of cumulative length for river networks (Benda et al., 2005) and are major sources of water, nutrients, and organic and inorganic material, ultimately making up the larger more anthropogenically important downstream systems (Wipfli et al., 2007; Binckley et al., 2010). Relationships of macroinvertebrates to their surrounding ecosystems have been studied considerably in upland, temperate headwaters (e.g., (Collins et al., 2007; Danehy et al., 2007) and perennial small streams (e.g., (Dewson et al., 2007a; Beugly and Pyron, 2010);

however, very few studies have investigated low-gradient, intermittent, subtropical headwater streams. Macroinvertebrate relationships with intermittent streams have been studied in regions outside of the United States, including the United Kingdom (Smith and Wood, 2002), Portugal (Pires et al., 2000; Hughes et al., 2008), and Australia (Boulton, 2003; Clarke et al., 2010). These streams are located in climates much different than the southeastern U.S. Many low-gradient streams in the southeastern U.S. often become seasonally intermittent, and the large amounts of organic matter contribute to debris dams (Feminella, 1996). Forested headwater macroinvertebrates can be affected by flow permanence (Clarke et al., 2010), and the sedimentation that results from decreased flow (Dewson et al., 2007b). Published research on macroinvertebrates in seasonally intermittent streams in the southeastern U.S. is limited and usually focused spatially, such as animal agricultural impacts in Georgia (Davis et al., 2003), Texas prairies (Hax and Golladay, 1998) and upland streams in Alabama (Feminella, 1996).

Several studies have investigated relationships of macroinvertebrates with woody debris (Drury and Kelso, 2000; 2007), feral swine activity(2006c), bivalves(2006b), riparian clearing (Williams et al., 2005; Kaller and Kelso, 2006a) and temporal patterns (Kaller and Hudson, 2010), as well as distributions (Alley, 2004) in central and southwest Louisiana. These studies provide some basic information on macroinvertebrate communities in a region where stream intermittency is common. However, the authors did not examine, 1) relationships between macroinvertebrate community composition, variable flow conditions, and the related environmental changes; and 2) multiple scales ranging from local reach to watershed. Instream habitat structure and allochthonous inputs are driven by local reach scale conditions and riparian characteristics such as vegetative cover and type, whereas the supply of nutrients, sediment, velocity, and channel structure are consequences of regional conditions, including soil types,

geomorphology, and landscape features (Benda et al., 2005). The low gradient forested headwater streams typical of central Louisiana are shaped by flood events that carry large amounts of organic material into these stream systems. High flows in these streams are predominantly driven by storms, being very responsive to single precipitation events (Richardson and Danehy, 2007), and account for a large portion of annual discharge (McBroom et al., 2008). Recent research in headwater organic matter processes (Clapcott and Barmuta, 2010) has shown that there are strong relationships with organic matter processes and habitat structure. These relationships are more common in upstream than downstream reaches and perhaps more important because of the increased terrestrial/aquatic interface in headwater systems. Macroinvertebrate communities are directly related to these processes and have unique associations with the contributions of small and large woody debris (Hrodey et al., 2008; Ogren and King, 2008; Lester et al., 2009; Kaller and Kelso, 2010) and sediment (Longing et al., 2010) from the riparian areas and systems (Richardson and Danehy, 2007).

In 2005, a multidiscipline study was initiated in several low-gradient, forested headwater streams in the Flat Creek watershed of central Louisiana. The study monitored changes in stream hydrology, chemistry, and benthic macroinvertebrates to determine the effectiveness of silvicultural best management practices in water quality protection. A comprehensive assessment completed by Klimesh et al. (In Review) found no significant differences in pre- to post-harvest functional feeding groups (FFGs) and taxonomic groups of benthic macroinvertebrates could be attributed to timber harvesting operations. This paper further investigates the resilient nature of the entire macroinvertebrate community in little studied sub-tropical, low-gradient, seasonally intermittent, low-order streams in Louisiana. This study aimed to 1) assess macroinvertebrate communities and their relationships to subtle differences in

headwater streams physical and riparian characteristics including intermittency, and also 2) describe other physical or abiotic properties associated with densities of macroinvertebrates at spatial scales ranging from local reach to watershed.

3.2 METHODS

3.2.1 Site Description

The Flat Creek Watershed is located in north-central Louisiana, which is within the northern portion of the U.S. Environmental Protections Agency Level III Southern Coastal Plain Ecoregion (SCPE) (Daigle et al., 2006), and eventually drains into the Ouachita River. The watershed is actively managed for timber harvest of loblolly pine (*Pinus taeda*) and is primarily forestland (84%), recently harvested and planted pine stands (12%), and some pastureland (4%). Riparian areas include bottomland hardwoods are composed of magnolia (*Magnolia grandiflora*), sweet gum (*Liquidambar styraciflua*), water oak (*Quercus nigra*), and bald cypress (*Taxodium distichum*). The Flat Creek watershed drains 369 km^2 and receives an average of 1508 mm of precipitation annually. The climate is subtropical and precipitation is mostly seasonal, with the majority falling from November through April. Annual rainfall amounts in the Flat Creek watershed from 2006 through 2010 were 1301, 893, 1266, 1269, and 804 mm, respectively (Brown, 2010). Average monthly temperatures ranged between 8.0°C in January and 28.6°C in July, while the annual average is 18.2°C. The Flat Creek watershed is low-gradient with channel slopes decreasing from the headwaters (0.5%) to the watershed outlet (0.1%) (Saksa, 2007; Brown, 2010). Soil type ranges from the moderately well-drained fine sandy loam (Sacul-Savannah series) in the upland regions to the poorly drained silt loam (Guyton series) along the Flat and Turkey Creek floodplains to less porous clayey silt in stream beds and riparian areas (Saksa, 2007; Brown, 2010).

Monitoring sites were designated for macroinvertebrate sampling on several 1st-, 2nd- and 3rd-order streams (Figure 3.1). The study design was to determine spatial characterization of macroinvertebrates across the watershed (Table 3.1). Two 1st-order sites, I1 and I2, were located in Spring Creek. Site E3, another 1st-order stream was located on Fish Creek. Seven sites: I3, I4, I5, I6, N1, N2, and E2, were located on Turkey Creek, with I3 being furthest upstream and on the middle 1st-order section, and E2 as the outlet on the lower section designated as a 2nd-order stream. I3 and I4 were located upstream of the junction of Spring Creek. Sites 9U and 9D were located on Big Creek. Site E1 was located on Flat Creek, the watersheds' mainstem, upstream of the junction with Turkey Creek and was the only site on a 3rd-order system.

3.2.2 Field Sampling

The selected headwaters in the Flat Creek watershed have very low baseflow and shallow depths (Figure 3.2), which required a modification of a conventional core sampler for quantitative sampling. The streams are relatively stagnant except for episodic rain events that deliver most woody debris and organic matter into the stream systems, which precluded the use of drift nets or Surber samplers. Instead, we used a modified stovepipe sampler (Merritt et al., 2008) measuring 0.2057 m by 0.2057 m (8.1 inch by 8.1 inch) with a benthic sampling surface area of 0.0423 m^2 to collect macroinvertebrates. The top 2.5 cm of substrate was removed and placed into 2 liter jars. The corer water column was swept for one minute with an aquarium net to capture suspended organisms (Viosca, 2007), and collected contents were added to the 2-liter jars.

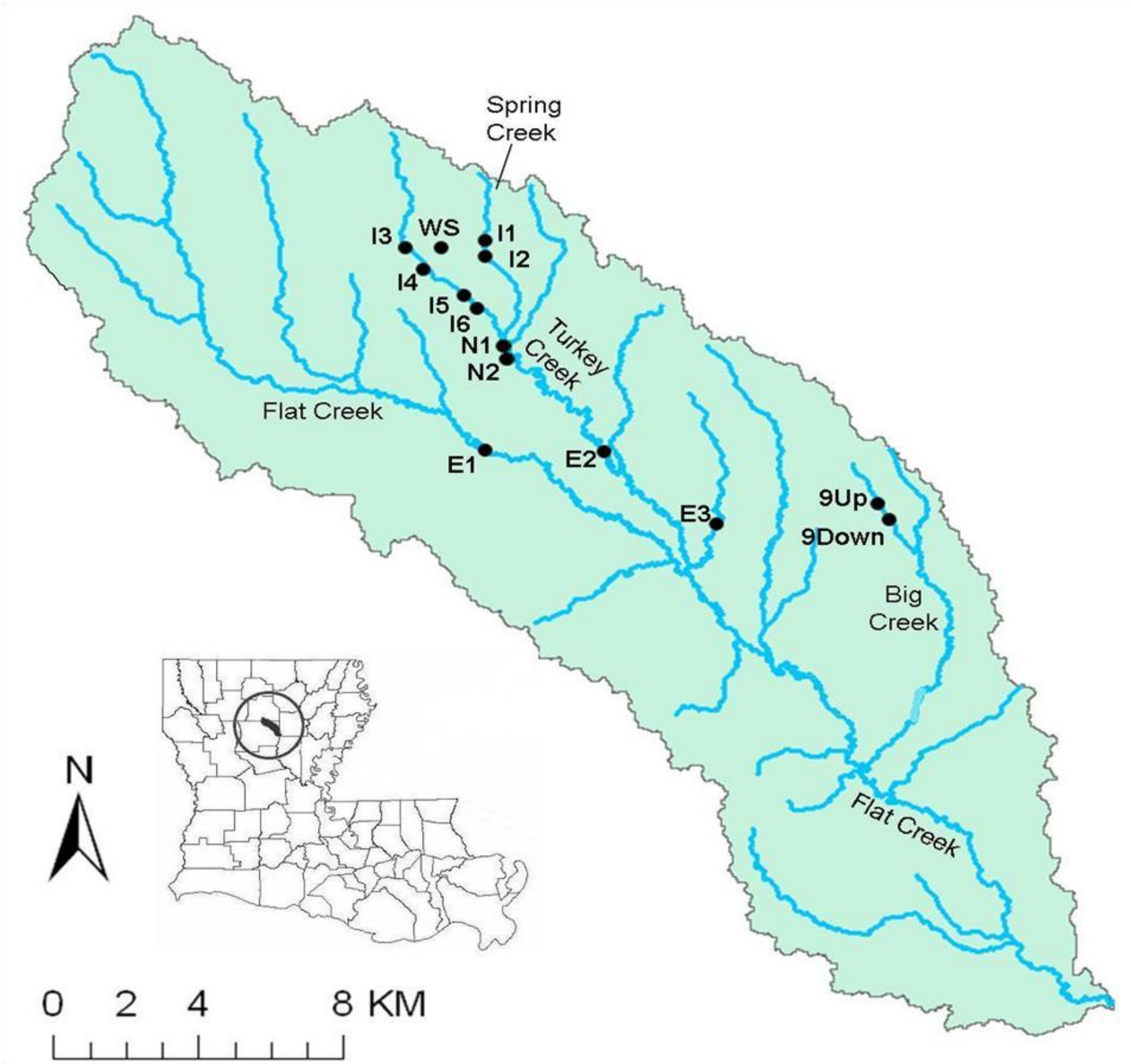

Figure 3.1. Site locations in the Flat Creek watershed, Winn Parish, Louisiana, USA.

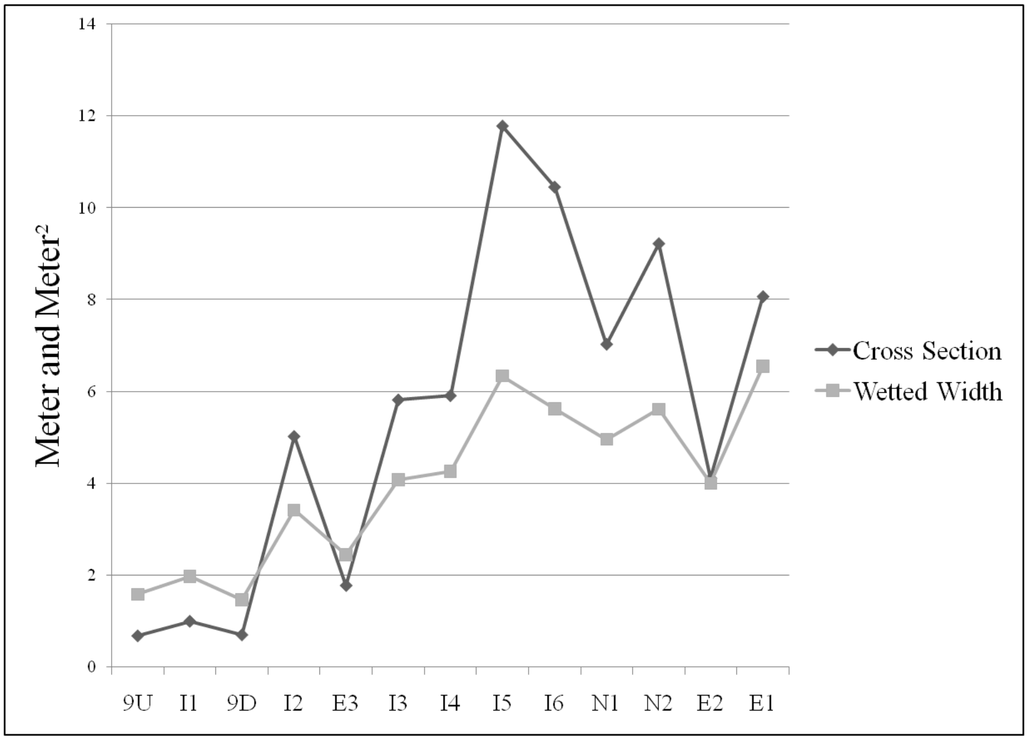

Figure 3.2. Mean wetted width and cross sectional area measurements for stream site reaches where macroinvertebrates were collected in the Flat Creek watershed, Winn Parish, Louisiana, USA, from April 2006 to August 2010. Streams are shown from smallest drainage area on the left to largest on the right.

Eight random stream reach measurements between 8 and 150 meters were generated for each site, and core samples were taken at along these reaches in April and August 2006, August 2007, April, early May and August 2008, April and August 2009, and April and August 2010. Spring collections included all eight random reach samples; however, some late summer sample reaches fell upon intermittent or dry areas and were not collected. Sites N1 and N2 were added in 2008 and were the only sites sampled in 2010. All samples were collected at baseflow conditions.

Samples were preserved in 95% ethanol in the field. Sample containers were treated with Rose Bengal to aid in sorting the organisms from substrate material. Substrate material was retained and weighed after drying in oven for at least 3 days at 37º Celsius. The samples were

rinsed and filtered through a 500-micron sieve. Organisms were identified to the lowest practical taxonomic level, usually family level, and occasionally genus, and then grouped to various taxonomic levels and by functional feeding groups (FFGs) according to identification guides and keys (McCafferty, 1981; Merritt et al., 2008). Taxonomic resolution was set to family for consistency with earlier collections (Viosca, 2007) and because finer precision would unlikely yield additional information (Bowman and Bailey, 1997; Chessman et al., 2007). We did not include chironomid taxa in our FFG predator group, although some members of Chironomidae (Tanytarsini) are described as predators (Merritt et al., 2008).

3.2.3 Instream and Riparian Assessments

Substrate composition, channel type, velocity (during visible flow), depth and width measurements, channel composition, bank angle measurements, canopy cover, and riparian characteristic estimates were recorded (Figure 3.3) according to methods described by Lazorchak (1998). Intermittency was determined by observations made during monthly water collection events from December 2005 through September 2010. Velocity measurements were taken with a SonTek 30 FlowTracker (SonTek/YSI, Inc., San Diego, CA, USA) at each sampling location during each macroinvertebrate collection events. Stream velocity was measured with the USGS mid-section velocity-area method (Brown, 2010). In addition, velocity was taken monthly from December 2005 to December 2009 providing an overall sample of flow conditions at each of our sampling locations (Table 3.2). Velocity in late summer samples were assigned zeros at all visually stagnant pools because flow was not measurable, allowing interpretation for these analyses.

Dominant substrate size-class categories were visually estimated at the location of every macroinvertebrate sample included; coarse gravel, fine gravel, sand, silt/clay/muck, hardpan, wood, leaf pack, and other. Channel composition types were designated as run or pool or dry. Riffle habitats were not observed in the Flat Creek watershed. Canopy cover percentage was recorded with a concave reflective densiometer. Instream cover was estimated as absent (0%), sparse (1 - 40%) and dominant (> 40%) for filamentous algae, macrophytes, large woody debris, small woody debris, live trees or roots, overhanging vegetation, and undercut banks.

Figure 3.3. Measuring physical cross section, wetted width, and instream and riparian characteristics in the Flat Creek watershed, Winn Parish, Louisiana, USA.

Riparian characteristics were estimated perpendicular to macroinvertebrate collections on each side of the stream and combined. Categories of vegetation type for canopy, understory, and ground cover included deciduous, coniferous, broadleaf evergreen, mixed, or none. Vegetation

estimates for the canopy included large trees (trunk > 0.3m DBH) and small trees (trunk < 0.3m DBH). Vegetation estimates for the understory and ground cover included woody shrubs and saplings, and non-woody grasses, herbs, and forbs, and barren soil at each of the random sample locations. Estimates were categorized as absent, sparse (1-40%), and dominant (> 40%). Late summer 2007 physical riparian habitat characterizations were not recorded and are not part of the analysis. Means of the canopy cover percentage estimates were tested for similarity with analyses of variance (ANOVAs) in SAS (PROC MIXED version 9.2, SAS Institute, Inc., Cary, North Carolina, USA) among sites to help explain density differences in the macroinvertebrate communities. Differences between sites were interpreted as significant at alpha < 0.05.

3.2.4 Macroinvertebrate Metrics

Prior to analyses, we selected 31 descriptive macroinvertebrate community metrics (Table 3.1) for analyses based on previous work in the southeastern U.S. and results outlined in Klimesh et al.(In Review). These metrics were selected because other southeastern U.S. macroinvertebrate studies have found relationships useful in their studies (Barbour et al., 1996; Davis et al., 2003; MDEQ, 2003; Klimesh et al., In Review). Metrics included familial taxonomic groups and assigned FFGs according to Merritt et al. (2008). All metrics were transformed to densities of individuals collected per meter squared (# in sample X correction factor, 23.64066 for eight samples or an inflated factor appropriate for samples less than eight).

Analyses with and relating instream and riparian habitat variables to macroinvertebrate metrics were performed with one or more of the following methods: principal component analysis (PCA; PROC FACTOR), generalized linear (gamma) mixed models (GLMMs)(PROC GLIMMIX), and zero-inflated negative binomial models (PROC GENMOD) with the statistical software package SAS (version 9.2, SAS Institute, Inc., Cary, North Carolina, USA). Our data

set included all macroinvertebrates collected in the nine sampling events, grouped into the 31 *a priori* metrics and 55 instream and riparian habitat variables, along with 14 physicochemical variables. Instream and riparian habitat variables were analyzed with PCA to establish explanatory physical instream and riparian habitat variables (principal components or PCs). Of these, the top 19 PCs selected by scree plot were chosen for subsequent analyses with the 31 *a priori* metrics (Table 3.3). Physicochemical variables were not included with instream and riparian PCs to minimize confounding effects of variables, and results of analyses of physicochemical data are presented in Chapter 4.

Statistical procedures used generalized linear mixed or zero-inflated models to test for relationships, because our data did not satisfy the assumptions of normality, requiring non-Gaussian error distributions. Eighteen metrics were interpretable in our initial GLMMs when the Pearson Chi-Square / degree of freedom (hereafter X^2/DF) were between 2.0 and 0.50 (Table 3.4). The ephemeropteran and the metric describing members in the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) metrics were used with statistical families of zero-inflation models (Table 3.4), because our high incidence of zeros (densities) was greater than expected for the underlying probability of counts in our data. Goodness-of-fit criteria were assumed appropriate when all PC zero-inflated model X^2/DF were between 0.50 and 2.0. Associations were interpreted as significant at alpha < 0.01 to compensate for multiple comparisons following Bonferroni's correction. Application of zero-inflated models followed a two-step procedure. First, each of the 19 PCs was allowed to function as the presence/absence determining variables and assessed by X^2/DF. Once the presence/absence PC was determined, the remaining PCs were then interpretable for influencing density.

3.3 RESULTS

3.3.1 Instream and Riparian Conditions and Variations

Observed velocity, wetted width, cross sectional, and canopy coverage percentages and measurement results are summarized in Table 3.1 for each of the thirteen sites where macroinvertebrates were collected. Wetted width and cross-sectional area are shown in Figure 3.2 from the smallest drainage area (9U) to the largest (E1) moving left to right across the X axis. Channel-type classification observations were mostly pools (80%) and runs (16%), with the remaining sites being dry. Mean linear-wetted width in meters was less than cross section per meter squared in four of the sampling sites (I1, 9U, 9D, and E3), suggesting relative shallow stream conditions. Canopy-cover percentage (Figure 3.4) was significantly different only when streams drainage areas were grouped separately in late summer samples or all sampling events together. Spring canopy-cover percentages failed to show a significant difference between sites regardless of the stream-size grouping, albeit the results were nearly significant ($p = 0.0869$ and $p = 0.0747$) when grouped into smallest first-order streams and all-together respectively. Late summer canopy percentages in the small drainage 1st-order stream groups revealed that sites I3 and 9D had significantly less canopy cover. Site I6 was significantly less than site E1 in the larger stream order group in the late summer samples, but all other sites were similar. When all of the sites were grouped together for late summer samples, there were a few significant differences. Sites E3 and I1 were significantly higher in canopy cover percentage than sites I6, N2, I3, and 9D. Sites I6 and N2 had significantly less coverage than sites E3 and I1, but were statistically higher than sites I3 and 9D. The canopy cover percentages at sites I3 and 9D were significantly less than each of the other sites in the late summer.

Table 3.1. Site reaches in the Flat Creek watershed, Winn Parish, Louisiana, USA, with observed and recorded physical attributes and measurements.

Stream Order	**Site**	**Drainage area (km^2)**	**Stream permanence spring**	**Stream permanence late summer**	**Mean wetted width m ±SD**	**Mean Cross section m² ±SD**	**Mean velocity* m^3/s ± SD**	**% Canopy cover ****
Upper 1st	9U	2.1	Intermittent	Intermittent	1.58 ±0.59	0.69 ±0.62	N=38 0.001±0.003	80.7 AB
	I1	3.0	Continual	Intermittent	1.97 ±0.67	1.01 ±0.89	N=47 0.005±0.006	86.9 A
	9D	3.4	Intermittent	Intermittent	1.46 ±0.80	0.71 ±1.01	N=29 0.003±0.006	48.9 C
Middle 1st	I2	3.6	Continual	Continual	3.42 ±1.34	5.03 ±2.78	N=39 0.005±0.009	79.0 A
	E3	6.1	Continual	Intermittent	2.44 ±1.04	1.79 ±1.58	N=44 0.005±0.008	83.5 A
	I3	12.4	Continual	Intermittent	4.08 ±1.57	5.82 ±3.65	N=46 0.013±0.024	59.2 BC
	I4	14.3	Continual	Intermittent	4.26 ±1.12	5.92 ±3.81	N=47 0.019±0.033	84.8 A
Lower 1st	I5	17.8	Continual	Continual	6.35 ±1.08	11.79 ±5.42	N=38 0.026±0.052	79.3 A
	I6	18.3	Continual	Continual	5.63 ± 1.01	10.46 ±5.05	N=37 0.018±0.042	72.5 AB
Upper 2nd	N1	33.8	Continual	Continual	4.96 ±1.33	7.04 ±4.68	N=41 0.026±0.045	83.4 A
	N2	34.2	Continual	Intermittent	5.62 ±1.65	9.23 ±6.20	N=41 0.048±0.089	70.7 AB
Middle 2nd	E2	45.1	Continual	Intermittent	4.00 ±1.48	4.12 ±3.25	N=44 0.060±0.102	80.2 A
Upper 3rd	E1	109.6	Continual	Intermittent	6.55 ±2.91	8.07 ±6.62	N=32 0.285±0.652	79.8 A

* Monthly measured discharge from December 2005 to December 2009
**Differing letters indicate statistical differences ($p < 0.05$) between different sites

3.3.2 Macroinvertebrates and Habitat Relationships

A total of 86,183 macroinvertebrates in 634 samples were collected from the nine sampling events. Macroinvertebrate family and order percentages are summarized in Figures 3.5 and 3.6. The highest densities of macroinvertebrates were found at I3 (Figure 3.7), a 1st-order seasonally intermittent stream section (Table 3.1).

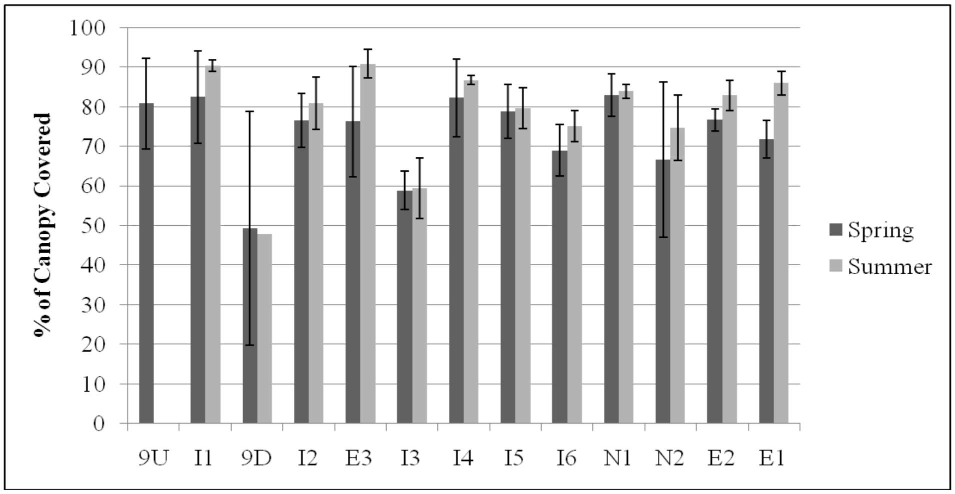

Figure 3.4. Mean canopy cover percentages by season at 13 low-order streams in the Flat Creek watershed, Winn Parish, Louisiana, USA. from Spring 2006 to Summer 2010.

Nineteen PCs describing instream or riparian observations were derived from correlations of 55 instream and riparian variables (Table 3.3). The 19 PCs together explained 81.1% of variation among the 55 variables. The interpretations and contribution percentages of each PC are summarized in Table 3.2. Two PCs (7 and 13) did not contribute to the explanation of densities in any of the *a priori* metrics. Overall density associations with the metrics are listed in Table 3.4. Nineteen macroinvertebrate metrics were interpretable in our statistical models (Table 3.4). Hemipteran, isopod, and megalopteran metric densities were not significantly associated with any of the 19 PCs. The 2nd PC, interpreted as explaining perennial reaches and increased stream velocity, was associated with decreased densities of dipteran predators. Additionally, PC

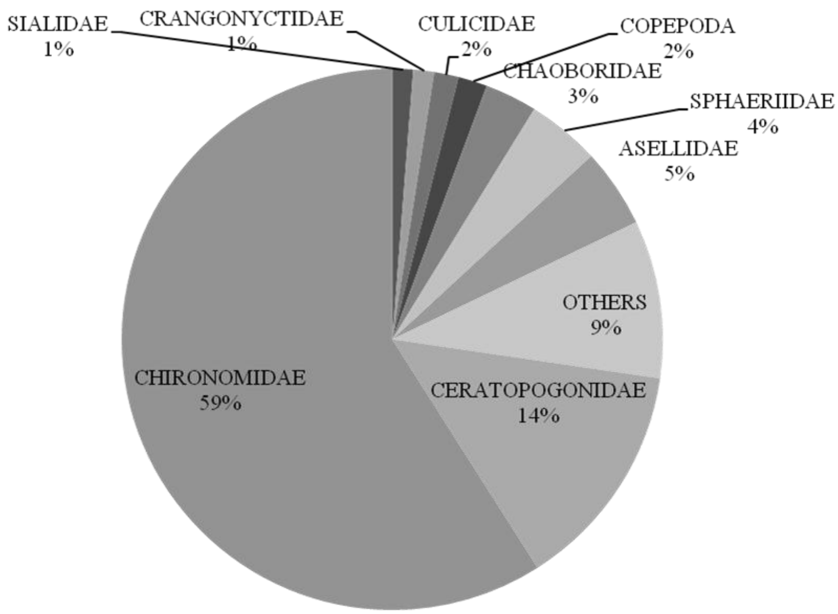

Figure 3.5. Percentages of Families of macroinvertebrates collected from 2006 to 2010 in the Flat Creek watershed, Winn Parish, Louisiana, USA.

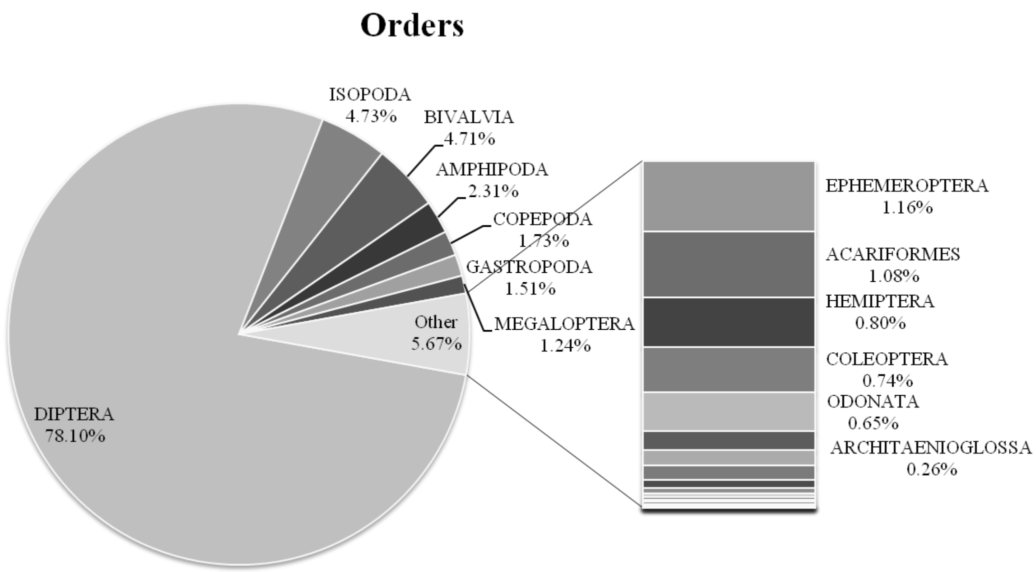

Figure 3.6. Percentages of Orders of macroinvertebrates collected from 2006 to 2010 in the Flat Creek watershed, Winn Parish, Louisiana, USA.

Table 3.2. Interpretation of principal components used in statistical analyses with macroinvertebrate communities collected from the Flat Creek watershed in Winn Parish, Louisiana, USA.

Principal component	**% Variance explained by each**	**Explanation of riparian and physical attributes**
1	11.19	Open canopy with filamentous algae and no woody debris
2	8.15	Perennial, high stream velocity
3	6.63	Undercut banks
4	6.54	Intermittent, Dominant filamentous algae
5	6.00	Open canopy and lots of woody debris
6	5.24	Closed canopy and no macrophytes
7	4.95	Woody substrate
8	4.33	Brushy understory with overhanging vegetation
9	3.99	Stream size
10	3.42	Mixed canopy and understory vegetation type
11	3.22	Moderate instream large woody debris
12	3.04	Woody and hardpan substrate
13	2.57	Overhanging vegetation with heavy organic substrate
14	2.27	Overhanging vegetation with inorganic substrate
15	2.08	Immature riparian zone
16	1.93	Immature riparian zone and dominant instream large woody debris
17	1.88	Riparian deciduous
18	1.87	Mature riparian zone, dense or heavy collected debris
19	1.83	Parkland-like hardwoods, and moderate barren ground

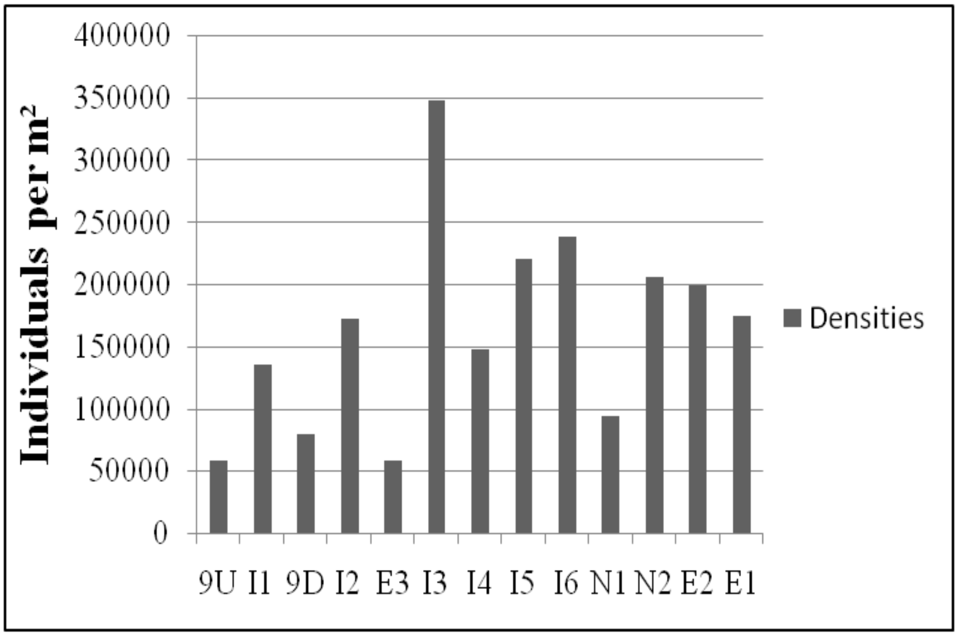

Figure 3.7. Densities of macroinvertebrates at sites where macroinvertebrates were collected from April 2006 until August 2010 in the Flat Creek watershed, Winn Parish, Louisiana, USA.

4 describing intermittency and instream filamentous algae was negatively associated with chironomid, malacostracan, piercer, and shredder densities (Figure 3.8). Chironomid densities were positively associated with a PC (9) interpreted as describing increased stream size. Densities of chironomids were also positively associated with a PC (12) interpreted as describing instream woody and hardpan substrate, and negatively associated with a PC (10) describing canopy and understory vegetation type “mixed”. Densities of amphipods were positively associated with PC 10 and negatively associated with PC 15 describing immature riparian zones. Bivalve densities were negatively associated with PC 19, interpreted as parkland riparian conditions. Bivalve and gastropod densities were positively associated with two PCs describing immature riparian zones (15 and 18). Collector filterer densities were also negatively associated with PC 19 and positively associated with the 1st PC describing open canopy, and a PC (16)

Table 3.3. Variables contributing to the principal component analyses. Variables were measured where macroinvertebrates were collected at 13 sites in the Flat Creek watershed, Winn Parish, Louisiana, USA. (-) after variable name indicates a negative relationship.

Principal Component	**Variables with correlations > 0.30**
1	Mean canopy cover, Large trees in canopy absent, Small trees in canopy absent, Ground wood absent, Sparse filamentous algae, Instream small woody debris absent
2	Perennial, Mean stream velocity, Mean canopy cover(-), Collected debris weight(-),Channel type run, Channel type pool(-)
3	Undercut banks
4	Intermittent , Big trees in canopy sparse, Understory wood sparse, Filamentous algae dominant
5	Mean canopy cover(-), Instream woody debris dominant
6	Instream macrophytes absent, Instream macrophytes sparse(-),
7	Ground cover barren dominant, Wood substrate, Live trees and roots absent
8	Understory wood dominant, Instream overhanging vegetation sparse
9	Mean stream depth, Mean wetted-width, Collected debris weight(-)
10	Canopy vegetation type mixed, Canopy vegetation type deciduous, Understory vegetation type deciduous
11	Instream large woody debris sparse
12	Ground wood dominant, Wood substrate, Hardpan substrate
13	Wood substrate, Leafpack substrate, Canopy vegetation type mixed(-), Instream overhanging vegetation dominant
14	Understory wood sparse, Ground cover barren(-), Fine substrate, Instream overhanging vegetation dominant
15	Small trees in canopy sparse, Instream large woody debris dominant
16	Instream live trees and roots dominant
17	Canopy vegetation type deciduous, Canopy vegetation type mixed, Collected debris weight(-)
18	Large trees in canopy dominant, Understory wood sparse, Collected debris weight
19	Ground cover barren sparse

Table 3.4. Taxonomic and functional feeding group metrics associated with principal components (+/-), and presence / absence (P) determining principal components for zero-inflated negative binomial models. GLMM= Generalized liner mixed model, ZINB= Zero-inflated negative binomial. EPT = Orders of Ephemeroptera, Trichoptera, and Plecoptera NA = Not applicable

Metric	**Model**	**Principal Component**
Amphipods m^{-2}	GLMM	10(+), 15(-)
Arachnids m^{-2}	GLMM	14(+), 16(+), 17(-), 18(+)
Bivalves m^{-2}	GLMM	15(+), 16(+), 19(-)
Ceratopogonids m^{-2}	GLMM	14(+), 16(-), 19(+)
Chaoborids m^{-2}	GLMM	5(-)
Chironomids m^{-2}	GLMM	4(-), 8(-), 9(+), 10(-), 12(+), 14(+), 16(-)
Collector filterers m^{-2}	GLMM	1(+), 16 (+), 19 (-)
Copepods m^{-2}	GLMM	6(-), 12(-), 19(+)
Dipteran predators m^{-2}	GLMM	2(-), 11(-), 14(+), 16(+), 19(-)
EPTs m^{-2}	ZINB	19(P+), 3(+), 5(-), 6(+), 11(-)
Gastropods m^{-2}	GLMM	6(-), 15(+), 16(+)
Hemipterans m^{-2}	GLMM	No significant associations
Isopods m^{-2}	GLMM	No significant associations
Malacostracans m^{-2}	GLMM	4(-)
Megalopterans m^{-2}	GLMM	No significant associations
Piercers m^{-2}	GLMM	4(-), 10(+)
Predators m^{-2}	GLMM	16(-)
Scrapers m^{-2}	GLMM	14(+)
Shredders m^{-2}	GLMM	4(-), 11(+), 17(-)

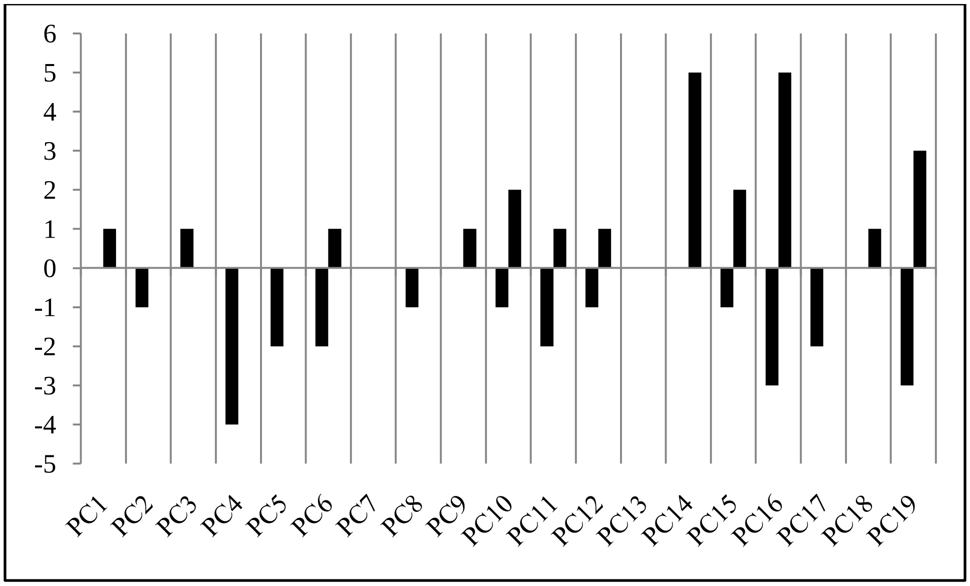

Figure 3.8. Number of principal components showing significant ($p < 0.01$) differences on the macroinvertebrate metrics used in the generalized linear mixed models. Positive direction indicates an increase in densities, and negative indicates a decrease in densities.

describing immature riparian zone with instream woody debris. Gastropod and copepod densities were negatively associated with a PC (6), interpreted as closed canopy without instream macrophytes. Shredders were positively associated with the 11th PC interpreted as moderate amounts of instream large woody debris, and negatively associated with PCs describing intermittency and filamentous algae (4), and deciduous vegetation type (11). The EPT densities were positively associated with PCs describing parkland-like hardwoods (19; i.e., very open understory with large, mature trees), closed canopy without instream macrophytes (6), and undercut banks (3). EPT densities were negatively associated with the PCs describing open canopy with lots of instream woody debris, and moderate instream woody debris (5 and 11).

Chironomid, chaoborid, and ceratopogonid densities were the highest represented family metrics, making up close to 75% of our collected taxa (Figure 3.5). Chaoborids and ceratopogonids made up a large portion (>90%) of the FFG dipteran-predator group. Chironomids were associated with seven PCs (Table 3.4), and EPTs and dipteran-predators were

associated with five PCs each. The PCs involved with the most associated density differences were PCs 16, 19, 14, and 4 (Figure 3.8). PCs interpreted as explaining immature versus mature riparian ages (15, 16, and 19) were associated with over half of the interpretable metrics (11 of 19). Six of the nineteen PCs (1, 2, 3, 8, 9, and 18) explained density differences in one metric each.

3.4 DISCUSSION

3.4.1 Canopy Conditions and Macroinvertebrates

Canopy cover often changes predictably with stream size (Hawkins et al., 2000), and this phenomenon was evaluated in this watershed as a test of the generalizability of our analyses (i.e., similar patterns in canopy cover change would suggest similar habitat dynamics). Our results indicate that the overwhelming physical or habitat component determining densities of important macroinvertebrate groups was related to riparian canopy cover and stand age (condition). Immature riparian PCs suggest few large diameter trees, which can be a result of stand age or, can also be indicative of thinned riparian stands. In this forested watershed, riparian areas (streamside management zones) were managed by leaving an unharvested basal area of 11 m^2 per hectare as part of best management practices. Principal components correlated with variables associated with canopy cover or mature/immature riparian zones, described density differences in 12 of 19 (63%) of interpretable metrics. The metrics were made up of over 83% of total collected taxa in the study.

Based on the results, bivalves, collector-filterers, and gastropods were consistently found in greater densities where riparian areas were immature (thinned) or where canopy cover was open, or were negatively associated where canopy cover was mostly or completely closed. Increased canopy cover can decrease available sunlight to streams, therefore limiting periphyton

growth. Canopy cover differences observed during our study suggest heterogeneity at our sampling locations. Sponseller et. al. (2001) suggested that riparian forest patches may be critical to distribution patterns of macroinvertebrates in headwater streams. Increased densities of bivalves and scrapers would have likely increased from thinned or open riparian areas. This inference fits well with the timber harvest effects study by Klimesh et al. (In Review) in this same watershed, where bivalve and scraper densities were shown to increase significantly at most timber harvest plot level and cumulative treatment effect sites, post-harvest.

Analyses in the Flat Creek watershed indicate two PCs related to increased canopy cover were important factors on explaining increased EPT densities, which is in agreement with a study in Ontario, Canada, where, at the local reach scale, invertebrate communities including EPTs related to forest cover canopy variables (LeCraw and Mackereth, 2010).   Additionally, EPTs collected from half-log additions in forested Indiana streams were positively related to canopy cover across streams (Hrodey et al., 2008).

3.4.2 Intermittency and Stream Velocity Associations with Macroinvertebrates

Intermittency was shown to be correlated with two of the 19 descriptive PCs, explaining significant variation in macroinvertebrate densities in five of 19 interpretable metrics. Importantly, the most common family in the study increased in reaches that were perennial. Similar studies describing spatial relationships have found that headwaters susceptible to drought (which can lead to intermittency) can decimate several groups of macroinvertebrates such as members of some crustaceans and EPTs (Boulton, 2003).   Malacostracan taxa, which included crangonyctid shrimp densities, were negatively associated with the described intermittent PC 4. Muenz (2006) found in their study in Georgia that EPTs were helpful indicating stream health in perennial streams. Experimentally-reduced flow has also shown to decrease densities of EPTs in

small streams (Dewson et al., 2007a). Conversely, other studies have found little to no differences in macroinvertebrate communities in seasonal compared to perennial streams (Beugly and Pyron, 2010). Although EPT densities were not directly associated with one of our two PCs describing intermittency, we suggest riparian habitat conditions, and not intermittent nature, are more influential to EPT taxa in low-gradient subtropical streams.

Five of our 19 interpretable metrics were statistically associated with stream size or intermittency; however, and most importantly, the metrics making up the majority of collected densities of macroinvertebrates (chironomids) responded positively with increased stream size and perennial reaches. Similarly, dipteran (including chironomids) abundances were found to be in the deeper pool sections of an intermittent stream study in the Guadiana Basin in Portugal (Pires et al., 2000). Chironomids are a diverse family and have been shown to inhabit many specialized habitats (Merritt et al., 2008), and further focus on more precise resolution might provide clearer relationships of this diverse, widespread taxa. Although our PCs do not support that chironomid densities are associated with the common intermittent features of the watershed, they may be the most efficient at colonizing intermittent pools in low-gradient streams. Conversely, we do show associations with dipteran-predators, and they made up at least 17% of collected macroinvertebrates in this study. Their densities were found to be associated to stream conditions related with low stream velocity and intermittency. Similarly, in a low-gradient stream in Missouri, community composition, as well as diversity, and densities of some FFGs, were highly correlated to velocity variables (Doisy and Rabeni, 2001) which suggest that intermittency (no velocity) is also important. However, this may not be true for all southeastern U.S. streams, as differences in velocity and sedimentation in a recent study in Georgia (Longing et al., 2010) were not shown to adversely affect the stream biota in streams.

Our results indicate that even subtle differences in stream velocity can influence macroinvertebrate densities, as stream velocity was rarely measured in late summer samples. Shredders were shown in our study to have decreased densities in intermittent reaches with dominant filamentous algae. This may be explained by the allochthonous material unable to be processed further downstream. Stream-flow regime is a keystone function in headwater streams, as it controls the metabolic processes (Clapcott and Barmuta, 2010), and has been shown to influence macroinvertebrate community structure and diversity (Clarke et al., 2010).

Taxa such as chironomids are extremely efficient at colonizing seasonally dry stream reaches (low streamflow) from nearby perennial streams (Clarke et al., 2010). In a swamp environment in Georgia, resident communities were also found to be made up mostly of ecological generalists that exploit a wide range of conditions, and clear patterns of only a limited number of taxa showed spatial or temporal variation in abundance (Kratzer and Batzer, 2007). Intermittency may become more frequent if water resources become limited by further climate change (Lawrence et al., 2010). For example, considerable less than long term precipitation averages fell in our watershed in two of the five years of our study. Macroinvertebrates in headwater streams in central Florida appear to be influenced more by drought conditions than any type of land use (Cowell et al., 2004). Increased intermittency can also lead to increased sedimentation, which has been found to reduce flow (Dewson et al., 2007a) and increase macroinvertebrate drift (Larsen and Ormerod, 2010). This is similar in the Flat Creek watershed which has abundant beaver dams (Saksa, 2007), and debris dams observed have been shown to increase sedimentation (Smock et al., 1989; Saksa, 2007; Entrekin et al., 2008; Longing et al., 2010).

3.4.3 Undercut Banks and EPT Relationships

EPTs were the only metric positively associated with the PC describing undercut banks. EPTs have made minimal contributions to collected macroinvertebrates in other studies in the Southeast, especially Louisiana (Davis et al., 2003; Kaller and Kelso, 2006c, a, 2007; Kaller and Hudson, 2010). EPTs are more abundant in upland fast-flowing streams, not typical of the Gulf Coastal Plain. EPTs have been widely accepted as a pollution-intolerant metric for biotic assessments (Wallace et al., 1996). Caenid mayflies made up over 67% of our collected EPT metric. In recent work focused on caenid mayflies in the western panhandle of Florida, undercut banks were important habitats for nymphs (Pescador and Richard, 2006). Undercut banks were also uncommon in our study, and were observed in only 13% of our riparian assessments. This association may have implications for further studies of EPT taxa in low gradient streams typical of the southeastern U.S. We recommend that consideration should be taken when sampling to include undercut bank microhabitats to ensure the potential collection of proper EPT densities in these low-gradient, subtropical headwater streams.

3.4.5 Woody-Debris Relationships with Macroinvertebrates

Woody debris was helpful in showing associations with some of the most common taxa found in our study. The most common family in our samples (Chironomidae) displayed a positive affinity for instream woody debris substrate. Drury and Kelso (2000) and Kaller and Kelso (2007) also reported greater abundances of chironomids in woody debris. Conversely, EPTs were negatively associated with any habitat related to the presence of woody debris (2 PCs); however caenid mayflies made up a large portion (67%) of our sampled EPTs, and Trichoptera and Plecoptera taxa were generally rare in our samples (together less than 0.05%). Studies in Louisiana by Drury and Kelso (2000) and Kaller and Kelso (2007) have shown caenid

mayflies are not strongly associated with woody debris (Kaller and Kelso, 2010). Conversely, a study in Texas reported higher caenid abundance in woody debris (Phillips, 2003). Further taxonomic resolution is needed to determine if the mayflies in our study are xylophilic. Collector-filterers were positively associated with PC 1 that was interpreted as describing an open canopy with filamentous algae and no woody debris. However, collector filterers were also associated with the 16th PC describing immature riparian zone with dominant instream large woody debris. We suggest that the canopy cover and immature or thinned riparian zones are the dominant variables in these PCs and that woody debris in both PCs were negligible in correlating to these riparian conditions.

We acknowledge that considerable variability of results is common, even from mostly pristine streams that have less diversity such as indicated in a recent study in a homogeneous boreal drainage basin (Heino et al., 2008). Additionally, variation in small segments in headwater streams in Missouri have accounted for more than the variation in the total stream system (Doisy and Rabeni, 2001). This implies that headwater, intermittent, stream fauna relationships with riparian and instream characteristics are still rather unknown. The legacy of land-use has further complicated with interpretations as previous disturbances may be the ultimate determining factors on stream-community complexity (Allan, 2004). Historical factors may have influenced evolutionary adaptations of certain invertebrates and may predominate when relative disturbance rates are lower, such as in years with less flooding (Fritz and Dodds, 2005). However, the variation describing differences of instream habitats and riparian characteristics in our study can only provide increasing support that macroinvertebrate communities in forested headwaters of Louisiana are well adapted to the low baseflow, high organic material, intermittent nature of these systems, and are resilient to anthropogenic impacts.

3.5 CONCLUSIONS

Our results indicate some additional relationships between physical instream and riparian habitat characteristics with macroinvertebrates in low-gradient, organic-rich headwater streams in subtropical Louisiana, which is in stark contrast to limited associations in a number of shorter duration studies in the region (Alley, 2004; Kaller and Kelso, 2006a, 2007; Viosca, 2007; Markos, 2010). The most important discernible characteristics are canopy cover and riparian age or condition. Decreased canopy cover explained the presence of some of the most common macroinvertebrate taxa collected in our study, besides generalist dipterans. These groups included collector-filterers, bivalves, and gastropods. Stream intermittency and woody debris are also found to be important characteristics explaining variation in macroinvertebrate communities. EPT taxa, albeit rare in our study, are made up mostly of pollution tolerant caenid mayflies, appears to have an affinity for undercut banks, and conditions not associated with woody debris or open canopy. These results imply that the potential development of indices for assessing biological integrity of low-gradient intermittent headwaters need to consider undercut banks, stream intermittency, and riparian visual estimates to accurately investigate the macroinvertebrate communities. Future studies should also concentrate on some of the rarer taxa to further investigate macroinvertebrate associations with physical instream and riparian habitat characteristics in order to determine relationships more vulnerable to change from disturbances.

CHAPTER 4: RELATIONSHIPS BETWEEN MACROINVERTEBRATES AND PHYSICOCHEMICAL MEASUREMENTS IN A HUMID, SUBTROPICAL, LOW GRADIENT WATERSHED IN CENTRAL LOUISIANA

4.1 INTRODUCTION

Aquatic macroinvertebrates are common biological organisms that can be used to describe increasing water quality perturbation. They are part of a larger suite of organisms being used to develop and understand water quality relationships (Hawkins et al., 2000). The Environmental Protection Agency (EPA) mandates that states and tribes implement water quality monitoring programs for assessing total maximum daily loads (TMDLs) with a wide range of water quality parameters. Currently, Louisiana does not use macroinvertebrates to monitor stream system integrity. Conversely, macroinvertebrates and other organisms are used by many other local, state, tribal, and federal organizations (Carter and Resh, 2001) as tools to regulate and manage water bodies of interest so that they meet their intended uses. Macroinvertebrates have also been used in other industrialized countries in different climates and locations for linking with physicochemical, riparian, and spatiotemporal gradients of many types of variables including: sediments (Longing et al., 2010), discharge (Dewson et al., 2007a), and drought (Griswold et al., 2008). However, assessing streams with macroinvertebrates can be labor intensive, and alternatively, physicochemical parameters may be used. Nevertheless, macroinvertebrates are ubiquitous and are especially diverse in subtropical regions (Vinson and Hawkins, 2003), and should be considered as part of an assessment of water quality integrity, because they represent more than just point-in-time measurements.

Macroinvertebrates have been the biological choice of many studies in upland regulated rivers and lotic systems in temperate climates with steeper topographies, such as rocky and hilly to mountainous. However, the biota may be utilizing different conditions in water chemistry,

such as high dissolved oxygen (DO) levels resulting from constant surface re-aeration of mixing moving water, and applicability to lowland systems may not be appropriate. The DO conditions of fast flowing streams are different than the relatively flat terrain and stagnant conditions of streams in central Louisiana. Ice and Sugden (2003) have shown DO levels in 43 least-impaired and reference streams in central Louisiana to be naturally very low, with levels below 5mg/L. Most macroinvertebrates studied in upland, fast flowing streams are sampled in riffles, whereas riffles in Louisiana low-gradient streams are rare (Felley, 1992; Isphrording, 1992; Brown, 2006). Similarities between upland and low-gradient systems are limited and negligible at best. Additionally, many studies fail to use numerous available physicochemical measurements to understand relationships with water quality and the macroinvertebrates that inhabit the waters of interest. Furthermore, there is little data involving low-gradient headwater streams, and the water chemistry links that are associated with macroinvertebrate communities.

In 2005, a multidiscipline study was initiated in several low-gradient, forested headwater streams in the Flat Creek watershed of central Louisiana. The study monitored changes in stream hydrology, chemistry, and benthic macroinvertebrates to determine the effectiveness of silvicultural best management practices in water quality protection. The watershed has been intensively managed for timber harvest for more than half of the last century. A comprehensive assessment completed by Klimesh et al. (In Review) discovered that in this watershed, only minimal differences in pre- to post-harvest functional feeding groups (FFGs) and taxonomic groups of benthic macroinvertebrates could be attributed to timber harvesting operations. These results indicate that even intensively managed timber stands in close proximity to the abundant stream systems in the area have little, if any, negative associations on the benthic macroinvertebrate communities two years after timber harvest; whereas, harvesting contributed

to the success of some groups and increased their densities. In an earlier investigation of the watershed, relationships were found between DO with the burrowing mayfly *Hexagenia* sp.(Viosca, 2007), but the data consisted only of limited (one year) temporal variation during the early calibration period for the timber harvest study. Conclusions from limited short term studies may be misleading, and more research is needed to corroborate these findings. Consequently, we continued the investigation by collecting macroinvertebrates and physicochemical measurements for a total of five years in the Flat Creek watershed to understand relationships with physical and water chemistry variables including: nutrient, seasonal, and sediment gradients. This study aims to 1) determine macroinvertebrate communities and their relationships to subtle differences in headwater stream observed physicochemical parameters and measurements, 2) assess the parameters associated with densities of macroinvertebrates at spatial scales ranging from local reach to watershed, and 3) make recommendations of including macroinvertebrate communities metrics that show consistent relationships to potential water quality monitoring assessment programs.

4.2 METHODS

4.2.1 Site Description

The Flat Creek watershed is located in north-central Louisiana, within the northern portion of the U.S. EPA Level III Southern Coastal Plain Ecoregion (SCPE) (Daigle et al., 2006), and drains a total area of 369 km^2 to the Ouachita River. The watershed is primarily forestland (84%) and is actively managed for timber harvest of loblolly pine (*Pinus taeda*), recently harvested and planted pine stands (12%), and some pastureland (4%).

Riparian areas include bottomland hardwoods are composed of magnolia (*Magnolia grandiflora*), sweet gum (*Liquidambar styraciflua*), water oak (*Quercus nigra*), and bald cypress (*Taxodium distichum*). The Flat Creek watershed receives an average of 1508 mm of precipitation annually. The climate is subtropical and precipitation is mostly seasonal, with the majority falling from November through April. Annual rainfall amounts in the Flat Creek watershed from 2006 through 2010 were 1301, 893, 1266, 1269, and 804 mm, respectively (Brown, 2010). Average monthly temperatures ranged between 8.0°C in January and 28.6°C in July, while the annual average is 18.2°C. The Flat Creek watershed is low-gradient with channel slopes decreasing from the headwaters (0.5%) to the watershed outlet (0.1%) (Brown, 2010). Soil type ranges from the moderately well-drained fine sandy loam (Sacul-Savannah series) in the upland regions to the poorly drained silt loam (Guyton series) along the Flat and Turkey Creek floodplains to less porous clayey silt in stream beds and riparian areas (NRCS, 2007; Brown, 2010).

Monitoring sites were designated for macroinvertebrate sampling on several 1^{st}-, 2^{nd}- and 3^{rd}-order streams (Figure 4.1). The 13 sites were designed to use a spatial approach to determine characterization of macroinvertebrates at different locations in the watershed (Table 1). The control sites of I1 and I2 were located in the adjacent Spring Creek watershed. Site E3 was located on Fish Creek. Seven sites, I3, I4, I5, I6, N1, N2, and E2, were located on Turkey Creek, with I3 being furthest upstream, and E2 as the outlet. I3 and I4 were located upstream of the junction of Spring Creek. Sites 9U and 9D were located on Big Creek. Site E1 was located on Flat Creek, the watersheds' mainstem, upstream of the junction with Turkey Creek.

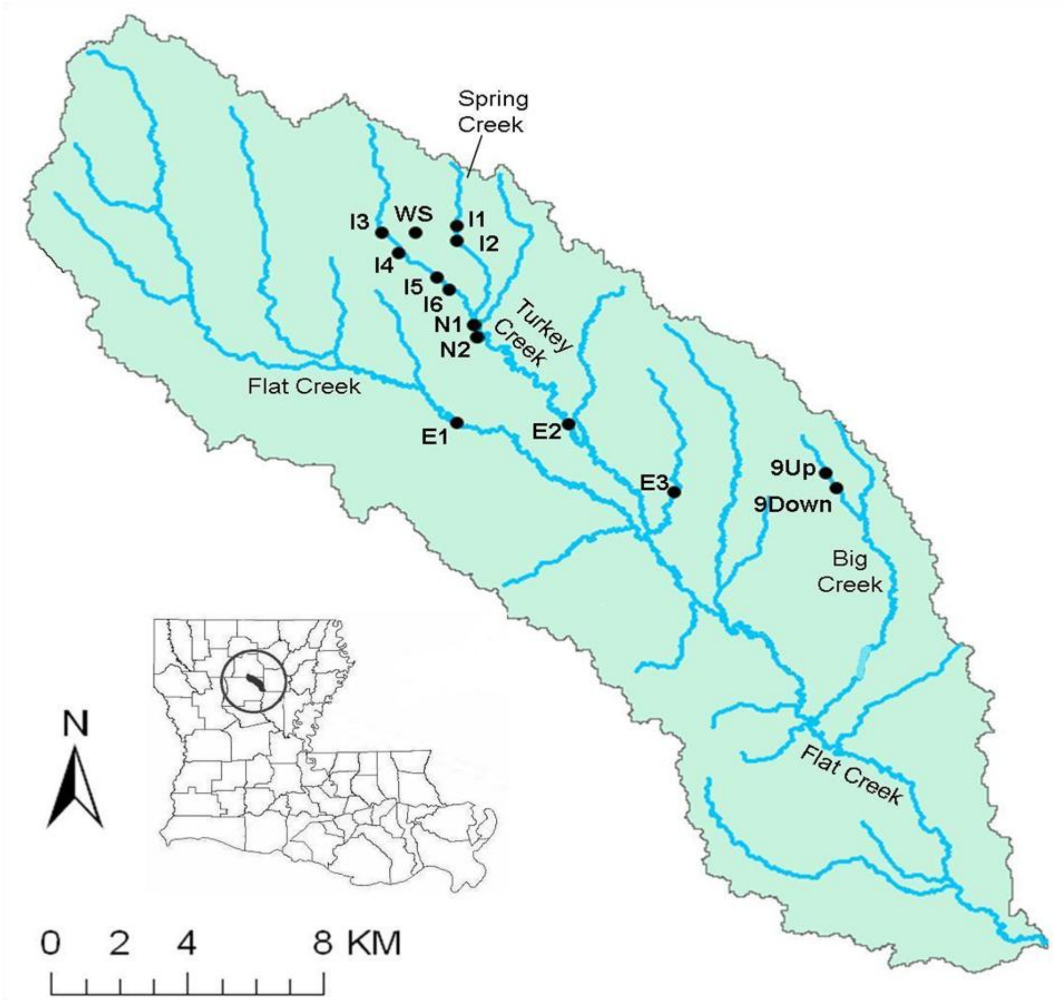

Figure 4.1. Site locations in the Flat Creek watershed, Winn Parish, Louisiana, USA.

4.2.2 Field Sampling

The selected headwaters in the Flat Creek watershed have very low baseflow and shallow depths, which required a modification of a conventional core sampler for quantitative sampling. The streams are relatively stagnant except for episodic rain events which deliver most woody debris and organic matter into the stream systems, which precluded the use of drift nets or Surber samplers. Instead, we used a modified stovepipe sampler (Merritt et al., 2008) measuring 0.2057 m by 0.2057 m (8.1 inch by 8.1 inch) with a benthic sampling surface area of 0.0423 m^2 to collect macroinvertebrates. The top 2.5 cm of substrate was removed and placed into 2-liter jars.

The corer water column was swept for one minute with an aquarium net to capture suspended organisms (Viosca, 2007), and collected contents were added to the 2-liter jars.

Eight random stream-reach measurements between 8 and 150 meters were generated, and core samples were taken at the randomly selected sites along these reaches in April and August 2006, August 2007, April, early May and August 2008, April and August 2009, April and August 2010 during baseflow conditions. Spring collections included all eight random reach samples; however, some late summer sample reaches fell upon intermittent or dry areas and were not collected. Sites N1 and N2 were added in 2008 and were the only sites sampled in 2010.

Samples were preserved in 95% ethanol in the field. Sample containers were treated with Rose Bengal to aid in sorting the organisms from substrate material. The samples were rinsed and filtered through a 500-micron sieve. Organisms were identified to the lowest practical taxonomic level, usually family level, and occasionally genus, and then grouped to various taxonomic levels and by functional feeding groups (FFG) according to identification guides and keys (McCafferty, 1981; Merritt et al., 2008). Taxonomic resolution was set to family for consistency with earlier collections (Viosca, 2007) and because finer precision would unlikely yield additional information (Bowman and Bailey, 1997; Chessman et al., 2007). We did not include chironomid taxa in our FFG predator group, although some members of Chironomidae (Tanytarsini) are described as predators (Merritt et al., 2008).

These metrics were selected because of their contributions to densities and other southeastern macroinvertebrate studies that have found relationships to be useful in their studies (Barbour et al., 1996; Davis et al., 2003; Quality, 2003; Klimesh et al., In Review). Metrics included familial taxonomic groups and assigned FFGs according to Merritt et al. (2008). All metrics were transformed to densities of individuals collected per meter squared (# in sample X

correction factor, 23.64066 for eight samples or an inflated factor appropriate for samples less than eight).

4.2.3 Physicochemical Measurements

In situ water chemistry measurements of DO and temperature were measured monthly with a YSI 556 (Yellow Springs Instruments, Yellow Springs, OH, USA). Additionally, two YSI Model 6920 (Yellow Springs Instruments, Yellow Springs, OH, USA) sondes (Figure 4.2) were deployed at sites N1 and N2 from 2006 through 2010, gathering continuous 15-minute DO and temperature data.

Figure 4.2. YSI 6920 sonde, used for 15 minute dissolved oxygen and temperature data collection at two monitoring sites in the Flat Creek watershed, Winn Parish, Louisiana, USA.

Water grab samples were collected at the same macroinvertebrate collection sites monthly from December 2005 through August 2010. Water samples were analyzed for total suspended solids (TSS) by the Louisiana State University Agriculture Center Chemistry Laboratory in Baton Rouge, LA., USA. Samples were processed according to U.S. EPA procedures, with a holding time of seven days and storage at 4°C. The detection limit for TSS was 5.0 mg/L. Water samples with TSS concentrations below the detection limit were estimated at 2.5 mg/L (Brown, 2010). Water grab samples were also analyzed for nutrients including ammonium, nitrate,

nitrite, total Kjeldahl nitrogen (TKN), total and dissolved phosphorus (TP and DP), total carbon (TC), and total organic carbon (TOC). The samples were filtered and processed as outlined in BryantMason (2008).

Physicochemical data were grouped (Table 4.2) and were used to explore any relationships with our *a priori* macroinvertebrate community metrics. The groups of data consisted of minimum and maximum temperature measurements, minimum, maximum, and mean DO concentrations, and observed maximum concentrations of nutrients for all months previous to collected biological data. It was assumed that the macroinvertebrates successfully resided in the conditions represented by the maximum or minimum conditions. Data used for analyses on macroinvertebrate metrics collected during spring sampling events included months from September (December for the initial sampling event) of the previous year, up through and included the month that macroinvertebrates were collected (April). The data used for analyses with macroinvertebrate metrics collected during the late summer sampling events included the months collected from after the previous macroinvertebrate collection event, up through, and included August (the month that all of late summer macroinvertebrates were collected). To avoid confusion with the intensively collected DO data, these data will be termed extensive. Macroinvertebrates were not collected in the spring of 2007; therefore, all data (one full year) between September 2006, and August 2007 were grouped, and the means for each month were used in our analysis.

4.2.5 Extensive and Intensive Analyses

All data were analyzed with generalized linear mixed models (GLMMs) (PROC GLIMMIX) with SAS, SAS Institute version 9.2, Cary, North Carolina, USA. We used GLMMs to test for relationships because our data did not satisfy the assumptions of normality, requiring

non-Gaussian error distributions. We used gamma distributions with a log-link on our data. Seventeen metrics were interpretable in our initial extensive gamma models when the Pearson-Chi-Square / degree of freedom (hereafter X^2/DF) was between 2.0 and 0.60. All analyses were deemed significant if p were < 0.01 to follow Bonferroni's correction for multiple comparisons. Additionally, as confirmatory statistics, we used intensive DO concentration and temperature (seasonal) data gathered from two Model 6920 sondes at sites N1 and N2, with macroinvertebrates collected from the same sites that they were deployed. All extensive physicochemical analyses were used along with all physical instream and riparian principal components together outlined earlier in Chapter 3.

DO concentrations are negatively correlated to increasing water temperature, and can fluctuate diurnally in the summer months. These additional intensive data were used to ensure that *in situ* collection timing did not confound our results. Temperature data was used to verify the seasonal differences in increasing densities of our samples, where positive relationships indicate higher densities in late summer samples. We used the same *a priori* metrics from all of the macroinvertebrate data collected from the two sites in our supplemental analysis. The intensively collected DO data were processed into daily means, and were further averaged per temporal-event previous to the macroinvertebrate collection event, identical to the methods described for the initial physicochemical data described above.

4.3 RESULTS

4.3.1 Physicochemical Nutrient Relationships

A total of 86,183 macroinvertebrates were found in the 634 benthic samples collected from nine sampling events (Figures 4.3 and 4.4). These data were used in analyses with fourteen

Table 4.1. Macroinvertebrate metrics collected from the Flat Creek watershed, Winn Parish, Louisiana, USA, used with extensive and intensive physicochemical variables in the generalized linear mixed models.

Metric	**Model (s) Interpretable Yes or No**	**Variables (+/-) significantly different at p < 0.01**	**Intensive DO and seasonal data**
All taxa m^{-2}	No	NA	NA
Amphipods m^{-2}	Yes	MaxDO(+)	DO(+) confirmed
Arachnids m^{-2}	Yes	No significant associations	NA
Asellids m^{-2}	Yes	NA	Season(-)
Bivalves m^{-2}	Yes	MaxDO(+), DO(-), MinDO(+), MaxTemp(+)	NA
Ceratopogonids m^{-2}	Yes	No significant associations	NA
Chaoborids m^{-2}	Yes	TKN(+)	DO(+)
Chironomids m^{-2}	Yes	MaxTemp(-), MinTemp(+), TOC(-), TC(+), Nitrite(-), TKN(-)	Not interpretable
Collector filterers m^{-2}	Yes	DO(-), MinDO(+), MaxTemp(+)	Not interpretable
Coleopterans m^{-2}	Yes	NA	Season not significant
Collector gatherers m^{-2}	No	NA	NA
Copepods m^{-2}	Yes	DO(-), Ammonium(+), TKN(+), MaxTemp(+), MinTemp(-),	Not interpretable
Dipterans m^{-2}	Yes	NA	Season(+)
Dipteran predators m^{-2}	Yes	No significant associations	NA
EPTs m^{-2}	Yes	MinDO(+), MaxTemp(+), Nitrite(-)	Not interpretable
Ephemeropterans m^{-2}	No	NA	NA
Gastropods m^{-2}	Yes	No significant associations	NA
Hemipterans m^{-2}	Yes	No significant associations	NA
Hirudineans m^{-2}	No	NA	NA
Isopods m^{-2}	Yes	MaxTemp(+)	DO(+) and Season(-)
Malacostracans m^{-2}	Yes	MaxDO(+), MaxTemp(+), TKN(-)	Not interpretable
Megalopterans m^{-2}	Yes	No significant associations	NA
Odonatans m^{-2}	No	NA	NA
Plecopterans m^{-2}	No	NA	NA
Piercers m^{-2}	Yes	MinTemp(+)	Not interpretable
Predators m^{-2}	Yes	No significant associations	DO(+)
Scrapers m^{-2}	Yes	MinTemp(+)	Not interpretable
Shredders m^{-2}	Yes	MaxDO(+), MaxTemp(+)	Not interpretable
Turbellarians m^{-2}	No	NA	NA
Trichopterans m^{-2}	No	NA	NA
Viviparids m^{-2}	No	NA	NA

EPT = Orders of Ephemeroptera, Trichoptera and Plecoptera, NA = Not applicable,
DO = Dissolved oxygen, TSS = Total suspended solids, TKN = Total Kjeldahl nitrogen,
TP = Total phosphorus, DP = Dissolved phosphorus, TC = Total carbon,
TOC = Total organic carbon

Table 4.2. Monthly relevant physicochemical parameters and their observed ranges from December 2005 to August 2010 at 13 monitoring locations at headwater streams in the Flat Creek watershed, Winn Parish, Louisiana, USA.

Variable	**Unit**	**Observed Range (Mean ± Standard deviation)**
Season	º Celsius	3.91 to 31.87 (16.94 ± 5.75)
Dissolved oxygen	mg / L	0.03 to 11.94 (4.19 ±2.89)
Total suspended solids	mg / L	2.5 to 417 (22.63 ±31.09)
Total phosphorus	mg / L	0 to 0.99 (0.08 ±0.09)
Dissolved phosphorus	mg / L	0 to 0.199 (0.034 ±0.025)
Total Kjeldahl nitrogen	mg / L	0 to 24.8 (2.75 ±1.96)
Ammonium	mg /L	0 to 2.28 (0.20 ±0.22)
Nitrate	mg / L	0 to 5.94 (0.25 ±0.44)
Nitrite	mg / L	0 to 0.19 (0.02 ±0.02)
Total carbon	mg / L	0 to 58.06 (24.02 ±9.09)
Total organic carbon	mg / L	0.13 to 43.21 (18.84 ±7.93)

physicochemical variables derived from the parameters listed in Table 4.2. A total of 31 metrics were initially analyzed with the physicochemical variables in GLMM's. Eighteen of the original 31 macroinvertebrate metrics were interpretable (Table 4.1) with the initial extensive models and satisfied the criteria described above. Arachnids, ceratopogonids, dipteran predators, gastropods, hemipterans, and megalopterans were interpretable, but the physicochemical parameters did not provide any associations of observed density differences. Maximum observed TP, DP, nitrate, TSS, TC, and TIC were not associated with explaining densities in any of the interpretable macroinvertebrate metrics. Increased chironomid densities were associated with higher

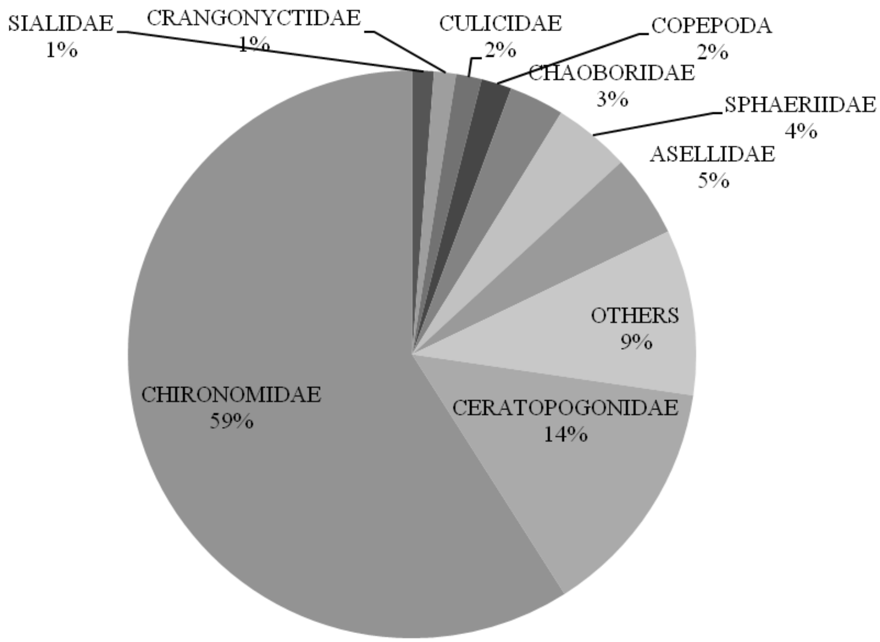

Figure 4.3. Percentages of Families of macroinvertebrates collected from 2006 to 2010 in the Flat Creek watershed, Winn Parish, Louisiana, USA.

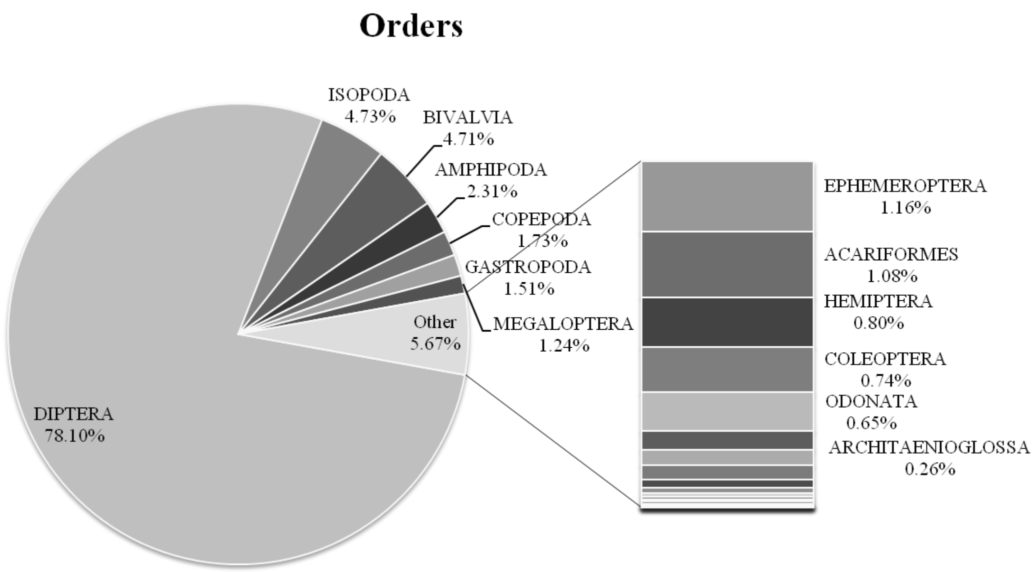

Figure 4.4. Percentages of Orders of macroinvertebrates collected from 2006 to 2010 in the Flat Creek watershed, Winn Parish, Louisiana, USA.

concentrations of TC and higher nitrite concentrations were associated with decreased chironomid densities. Maximum observed ammonium concentrations were associated with increased copepod densities. TKN concentrations were associated with increased densities of chaoborids and copepods, and also associated with decreased densities of malacostracans and chironomids. Total organic carbon concentrations were also associated with decreased chironomid densities.

4.3.2 Temperature, Seasonal, and Dissolved Oxygen Relationships

Extensive maximum observed temperatures were associated with increased densities of seven macroinvertebrate metrics. Temperature and seasonal differences in densities were observed for twelve of eighteen overall interpretable metrics in both extensive and intensive analyses. Maximum monthly observed temperatures were associated with density increases in seven of eight metrics. The macroinvertebrate metric densities that increased with sites measured with higher maximum stream temperatures were bivalves, collector filterers, copepods, EPTs, isopods, malacostracans, and shredders (Figure 4.5). Monthly minimum observed temperatures were negatively associated with copepods, and positively associated with chironomids, scrapers, and piercers. Seasonal variability was contradictory for the intensive versus the extensive data for isopods and dipterans, but suggested dipteran densities increased in late summer samples, whereas isopods and asellids decreased in densities.

Monthly observed DO did not display a spatial pattern (Figure 4.6). Extensive highest-maximum observed monthly DO was positively associated with increased densities of amphipods, bivalves, malacostracans, and shredders (Table 4.1). Extensive mean monthly DO was negatively associated with bivalves, collector filterers, and copepods. Extensive highest

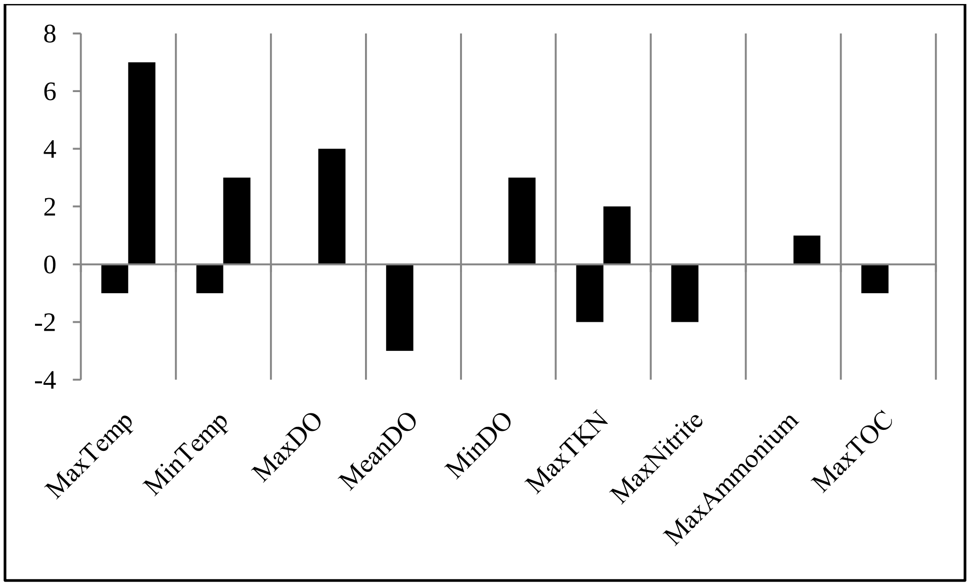

Figure 4.5. Numbers of macroinvertebrate metrics affected by relevant physicochemical variables. Positive relationship indicates the variable explained increased densities of a macroinvertebrate metric, and negative explained a decrease in densities of a metric.

minimum observed monthly DO was positively associated with bivalves, collector filterers, and EPTs. Intensive DO analyses confirmed positive associations of amphipod densities with increased DO concentrations, and provided additional positive associations with chaoborids, isopods, and predators. Some metrics that were interpretable in the overall extensive analyses were not with the intensive DO data and included: bivalves, collector filterers, copepods, EPTs, malacostracans, and shredders (Table 4.1). EPTs were highest in densities at two sites (Figure 4.6) where monthly DO concentrations were highest (above 5 mg/L)(Figure 4.7). DO in the Flat Creek watershed was significantly lower in the summer months (May-October) and pooled perennial sites of I2 and I6 had significantly higher concentrations of DO throughout the year (BryantMason, 2008). Monthly DO samples were not obtained at the seasonally dry sites of 9U and 9D in the summer months.

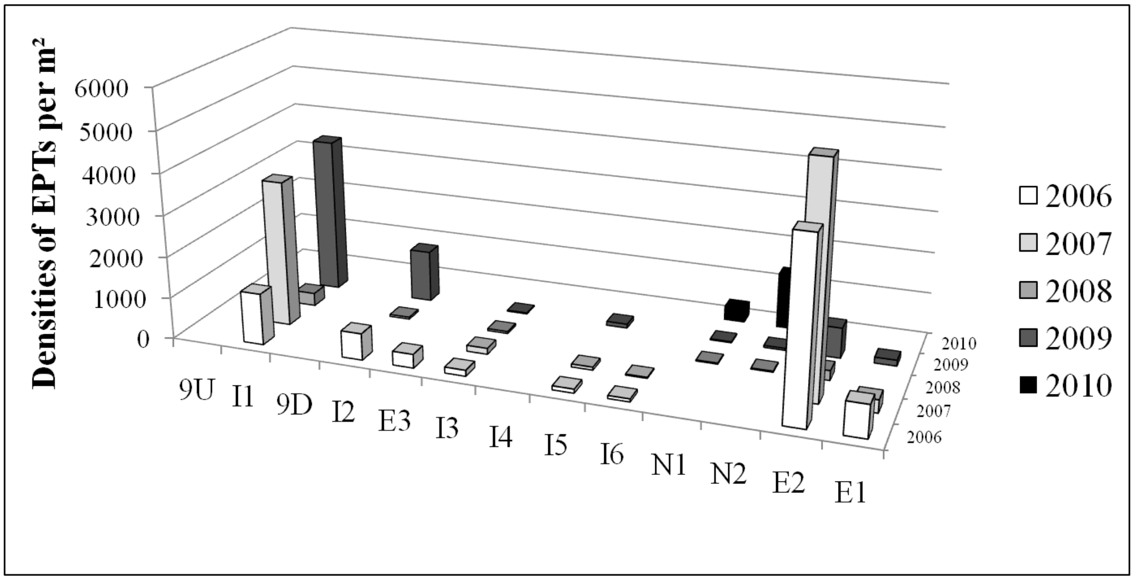

Figure 4.6. Densities of Ephemeroptera, Plecoptera, and Trichoptera (EPTs) collected in the Flat Creek watershed, Winn Parish, Louisiana, USA, between 2006 and 2010.

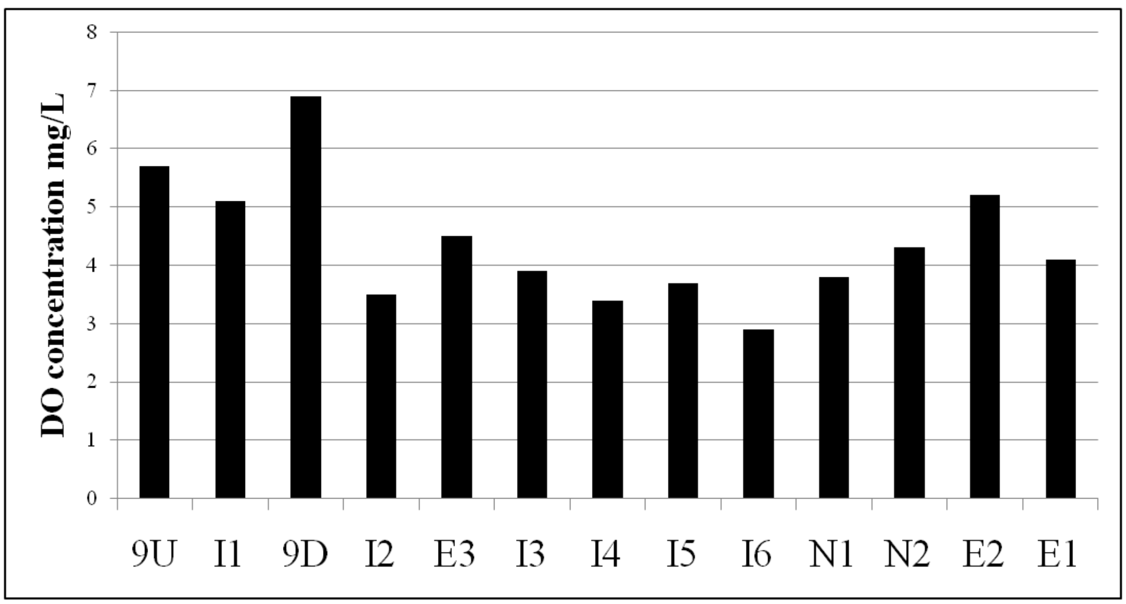

Figure 4.7. Mean monthly *in-situ* dissolved oxygen (DO) measurements in 13 sites from January 2006 through December 2010 where macroinvertebrates were collected in the Flat Creek watershed, Winn Parish, Louisiana, USA.

4.4 DISCUSSION

4.4.1 Seasonal Effects

Temperatures and seasonality appears to be a strong explanatory variable in our results. Our results indicate that there is merit for collecting taxa in the two seasons as we did. Stream temperatures in Louisiana headwater streams cover a wide range throughout the year. Initial studies done on early collections by Viosca (2007) and in nearby headwater streams of west-central Louisiana by Williams et. al (2005) and Kaller and Hudson (2010) support that macroinvertebrates display seasonal variation. Our measurements can only provide qualitative understanding of spring and late summer seasons. Of most importance is the intensively collected temperature data suggesting dipterans, the highest collected taxa in our study, was associated with higher temperatures, evident in the late summer. Seasonal trends are evident, and provide a need for additional studies in these unique streams, perhaps at monthly intervals to reveal relationships. In addition to our study, studies on six headwater streams in central Florida showed increases in macroinvertebrate densities in fall and winter samples (Cowell et al., 2004). Kaller and Hudson(2010) showed that community composition differed temporally in a subtropical, coastal plain stream in Louisiana based on monthly macroinvertebrate samples over the course of one year. The authors mention that an unusually high numbers of taxa exhibited asynchrony among con-familials throughout the year. These taxa were mostly EPTs or riffle beetles, which were uncommon in this study. The most common taxa in our study were dipterans and their densities appeared to be driven by temperature or season. The intensively collected seasonal temperature data suggest that warmer conditions help explain where the predator densities are greatest. Predators need to reside nearby to their prey, and the abundance of dipteran (potential prey) taxa, support this basic trophic premise.

4.4.2 Dissolved Oxygen and Macroinvertebrates

Concentrations of DO are seasonally low in central Louisiana, and in the Flat Creek watershed (Ice and Sugden, 2003; BryantMason, 2008; DaSilva et al., In Review); however, many of the macroinvertebrate communities found in these conditions are numerous and diverse (Klimesh et al., In Review), and appear to be resilient to these extreme conditions. Higher DO concentrations are ideal for certain macroinvertebrates, such as members of the widely-accepted pollution-sensitive metric EPTs. EPTs have been shown to be generally low in densities in Louisiana (Williams et al., 2005; Kaller and Kelso, 2006a, 2007; Viosca, 2007; Kaller and Hudson, 2010), but our results suggest similar responses of, albeit low, densities as in upland streams. The highest densities of EPTs in our study were at the sites collected in the spring with highest average monthly DO concentrations and coolest temperatures. The highest EPT densities were statistically significantly associated with the highest minimum dissolved oxygen. Our results help confirm the early indications of *Hexagenia* associations to high DO as reported by Viosca (2007). Amphipods and the phantom midge (Chaoboridae) may also be potential useful indicators in low gradient headwater stream systems when DO is a target variable of interest. Other metrics, including EPTs and malacostracans suggest relationships may occur with DO; however, they were not supported by our intensive confirmatory statistics. Our intensive data was collected at two sites where DO was generally lower as shown by monthly mean measurements. It is possible that the macroinvertebrate metrics that were not supported may have not been well represented in the sites of N1 and N2, since some macroinvertebrates have been found to be endemic to special conditions such as upmost headwaters (Gooderham et al., 2007). Samples utilized by Viosca (2007) did not include the sites of N1 and N2. Amphipods were mentioned to be potential indicators of stream health in perennial streams of southwestern

Georgia (Muenz et al., 2006). We acknowledge some similarities in the streams in the southeastern U.S., including Georgia with those in the Flat Creek; however, instream physical and riparian characteristic associations may provide better macroinvertebrate density relationships than monthly physicochemical data. DO relationships with bivalve and collector-filterer densities is not clear. Bivalves were shown to significantly increase after timber harvest in the watershed, suggesting increased canopy openings stimulated food source production at sites downstream of harvesting (Klimesh et al., In review). Habitat relationships suggest that open canopy and immature riparian zones were positively associated with bivalve and collector-filterer densities (Chapter 3). Decreases in canopy cover would allow more sunlight to penetrate, thus increasing water temperatures. Maximum observed water temperature associations are consistent with bivalve and collector-filterer densities; however, contradict shredder and EPT density results. Stimulated algal growth can temporarily increase DO concentrations; however, this is usually limited by nutrient availability. Additional research is needed on macroinvertebrate relationships, particularly bivalves and collector-filterers in low-gradient streams of Louisiana.

4.4.3 TKN, Nitrite and Macroinvertebrates

Total Kjeldahl Nitrogen is the total organic nitrogen, ammonia (NH_3), and ammonium (NH_4^+) in water quality analyses. TKN, nitrate, and nitrite make up total nitrogen. Chironomid densities in the Flat Creek watershed were positively associated with decreased TKN and nitrite concentrations. Conversely, copepod densities were positively associated with increased concentrations of TKN and ammonium. Chironomids densities were positively associated with TOC, and the differences in temporal densities suggest that energy flows (organic carbon) may be different seasonally. Utilizing preliminary data collected in this study, BryantMason (2008)

found a seasonal difference in inorganic carbon. This was also found in a recent lowland river study in Australia (Hladyz et al., 2010), where streams are dominated by different carbon sources during high and low flow periods. Our study did not determining source inputs of organic carbon, and further investigation is needed to explore and confirm these trends, especially with macroinvertebrates. The low-gradient forested headwater streams typical of central Louisiana are affected by episodic flood events which can carry large amount of organic material into these stream systems. We are hesitant to conclude nutrient relationships based upon our low observed nutrient concentrations and agree with Williams et al.(2005) that "fauna in central Louisiana must be resilient to abrupt changes in stream flow and seasonal influxes of silt and shifting sand" which would include nutrients, and our results may indicate fallible associations.

4.5 CONCLUSIONS

Very few studies have multiple years of collections of macroinvertebrate communities along with a range of intensive stream physicochemical measurements in low-gradient, subtropical headwaters. Such information and knowledge of relationships between macroinvertebrate communities and physicochemical parameters in this unique environment are valuable for future bioassessment development. Our results indicate that densities of some macroinvertebrate metrics living in these atypical streams can be explained by temperatures, seasonality, DO, and nitrogen species. Of particular interest are the metrics linked with DO and seasons. DO concentration is a critical part of most stream monitoring assessments, and together with temporal considerations, are perhaps the most important variables to be used in conjunction with biological indicators. Our results suggest that the highest EPT densities were statistically significantly associated with the highest minimum DO, indicating a possible threshold level of toleration. The macroinvertebrate amphipod, chaoborid, and isopod metrics were verified or

evident with positive relations to intensively collected 15-minute DO and seasonal temperature data spanning three years. Our findings suggest that if macroinvertebrates are used in monitoring low-gradient, high-organic content streams like those in the Flat Creek watershed, relationships of DO should include these metrics, and include, but look beyond commonly used macroinvertebrates such as EPTs. We suggest further studies are needed to understand relationships of macroinvertebrate members such as amphipods, chaoborids and isopods, with seasonal DO fluctuations. EPTs in low-gradient headwaters streams in this subtropical environment seem to be few; however, further studies are needed to explore linkage between EPT and nutrients such as nitrite by sampling stream reaches across a range of nutrient and water chemistry parameters. We suggest additional physicochemical studies should focus on inclusions of macroinvertebrates, to help understand the associations with parameters used in our study. These studies should involve more temporal variation (greater than one year). Multiple seasonal (greater than two) continuous monitoring studies are needed to further understand and verify temporal changes and relationships observed in headwater low-gradient streams.

CHAPTER 5: SUMMARY

This thesis research involved a multidisciplinary approach conducted from 2006 through 2010 to understand hydrological, chemical and ecological effects on macroinvertebrates of low-gradient, subtropical, seasonally intermittent headwater streams in a central Louisiana watershed. Monitoring locations were located at four 1st-order, two 2nd-order, and one 3rd-order streams in a forest dominated watershed that has been continuously managed for timber production in the last half century. The primary goal of this research was to investigate changes in macroinvertebrate communities after timber stands were harvested with and without utilizing best management practices (BMPs). Specifically, the research addressed the questions of (1) Do timber harvest activities utilizing BMPs impact the resident benthic macroinvertebrate communities? (2) What members of the benthic macroinvertebrate communities changed after the timber harvesting event? (3) What drives macroinvertebrate community densities and what groups are associated with different observed instream and riparian habitat conditions? (4) What physicochemical measurements can be related to macroinvertebrate communities and their densities? Major findings from this investigation are summarized below.

Based on 48,461 benthic macroinvertebrate communities collected in 333 samples, before and after timber harvesting activities at three different plots in the watershed, timber harvesting regardless of BMP implementation, did not negatively affect the majority of the communities in the streams. Our results indicate that fewer than 14% of the collected community had limited decreases in densities, and furthermore, some benthic macroinvertebrate taxa and feeding groups including bivalves and scrapers, increased in densities following the harvest event. Statistical differences in *a priori* metrics were more evident in spring sampling event communities,

possibly due to dry stream conditions that were observed in some streams and restricted collections during late summer sampling events.

A total of 86,183 macroinvertebrates were collected from 634 samples during our nine sampling events from 2006-2010, and used with observed instream, habitat, and riparian characteristics to investigate relationships. Nineteen principal components (PCs) were derived from correlations of 55 physical instream and riparian variables measured during macroinvertebrate collections. The PCs explained over 81% of variation in our variables and were used with taxonomic and FFG macroinvertebrate metrics to describe density associations.

Stream intermittency was an important characteristic contributing as an explanatory variable for two of my PCs. Additionally, these PCs explained increases and decreases with 83% of the macroinvertebrate metrics. Densities of EPTs were negatively associated with PCs describing woody debris, and decreased canopy cover, and were positively associated with undercut banks. These results imply that development of indices for assessing biological integrity of low-gradient, subtropical, intermittent headwaters need to consider undercut banks, intermittent reaches, stream velocity, and riparian canopy-percentage estimates to accurately investigate the macroinvertebrate communities.

Physicochemical measurements collected for five years were helpful in explaining densities of some of our macroinvertebrate metrics. Extensive dissolved oxygen (DO) and stream temperatures were useful in explaining densities of important metrics including EPTs, shredders, bivalves, and collector-filterers. The macroinvertebrate metrics of amphipods, chaoborids, and isopods were corroborated or evident with relations to intensively collected 15-minute DO data spanning three years. Because of the strong connections of macroinvertebrate metrics with temperature, season, and DO, I suggest that seasonal density shifts in

macroinvertebrate are evident, and therefore, seasonal collection is important to understand the communities. Furthermore, maximum observed TKN and nitrite concentrations helped explain densities differences of some important metrics including EPTs and chironomids.

I have described many relationships of common macroinvertebrates with instream and riparian habitat characteristics, and physicochemical parameters. Consequently, these relationships discovered can serve as baseline data and a starting point to potentially develop indices for low-gradient headwater streams of Louisiana, should bioindicators become an essential part of established monitoring programs. Relationships of water quality parameters to aquatic macroinvertebrate community metrics is a developing discipline, and additional information continuously contributed and aiding in our understanding of the relationships to unique or common features of the world's stream systems. Research with macroinvertebrates in forested, subtropical, low-gradient, intermittent, headwater streams is different than what has been investigated elsewhere in the world, and our contributions can help better understand their resiliency to timber harvesting, as well as relationships with measureable habitat and physicochemical parameters.

BIBLIOGRAPHY

Allan, J.D., 2004. Landscapes and riverscapes: The influence of land use on stream ecosystems. Annu. Rev. Ecol. Evol. Syst. 35, 257-284.

Alley, V.E., 2004. Analysis of benthic macroinvertebrate associations in low gradient streams of the Kisatchie National Forest (Central Louisiana, USA). In. University of Louisiana, Monroe, Louisiana.

Barbour, M.T., Gerritsen, J., Griffith, G.E., Frydenborg, R., McCarron, E., White, J.S., Bastian, M.L., 1996. A framework for biological criteria for Florida streams using benthic macroinvertebrates. J. N. Am. Benthol. Soc. 15, 185-211.

Beasley, R.S., Granillo, A.B., 1988. Sediment and water yields from managed forests on flat Coastal-Plain sites. Water Resources Bulletin 24, 361-366.

Benda, L., Hassan, M.A., Church, M., May, C.L., 2005. Geomorphology of steepland headwaters: The transition from hillslopes to channels. J. Am. Water Resour. Assoc. 41, 835-851.

Beugly, J., Pyron, M., 2010. Variation in fish and macroinvertebrate assemblages among seasonal and perennial headwater streams. Am. Midl. Nat. 163, 2-13.

Binckley, C.A., Wipfli, M.S., Medhurst, R.B., Polivka, K., Hessburg, P., Salter, R.B., Kill, J.Y., 2010. Ecoregion and land-use influence invertebrate and detritus transport from headwater streams. Freshwater Biology 55, 1205-1218.

Bosch, J.M., Hewlett, J.D., 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapo-transpiration. J. Hydrol. 55, 3-23.

Boulton, A.J., 2003. Parallels and contrasts in the effects of drought on stream macroinvertebrate assemblages. Freshwater Biology 48, 1173-1185.

Bowman, M.F., Bailey, R.C., 1997. Does taxonomic resolution affect the multivariate description of the structure of freshwater benthic macroinvertebrate communities? Canadian Journal of Fisheries and Aquatic Sciences 54, 1802-1807.

Brown, A.V., and Matthews, W.J., 2006. Stream ecosystems of the United States. In: Cushing, C.E., Cummings, K.W., nd G.W. Minshall (Ed.), River and stream ecosystems of the world. University of California Press, Berkeley, California, pp. 89-116.

Brown, G.W., Krygier, J.T., 1970. Effects of clear-cutting on stream temperature. Water Resour. Res. 6, 1133-&.

Brown, K.R., 2010. Effectiveness of forestry best management practices in minimizing harvesting impacts on streamflow and sediment loading in low-gradient headwaters of the Gulf Coastal Plain. In, School of Renewable Natural Resources. Louisiana State University, Baton Rouge, Louisiana, p. 75.

BryantMason, A., 2008. Spatial and temporal dynamics of stream water chemistry in a headwater catchment of central Louisiana. In. Louisiana State University, Baton Rouge, Louisiana, p. 109.

Carroll, G.D., Schoenholtz, S.H., Young, B.W., Dibble, E.D., 2004. Effectiveness of forestry streamside management zones in the sand-clay hills of Mississippi: Early indications. Water, Air, and Soil Pollution: Focus 4, 275-296.

Carter, J.L., Resh, V.H., 2001. After site selection and before data analysis: sampling, sorting, and laboratory procedures used in stream benthic macroinvertebrate monitoring programs by USA state agencies. J. N. Am. Benthol. Soc. 20, 658-682.

Chessman, B., Williams, S., Besley, C., 2007. Bioassessment of streams with macroinvertebrates: effect of sampled habitat and taxonomic resolution. J. N. Am. Benthol. Soc. 26, 546-565.

Clapcott, J.E., Barmuta, L.A., 2010. Metabolic patch dynamics in small headwater streams: exploring spatial and temporal variability in benthic processes. Freshwater Biology 55, 806-824.

Clarke, A., Mac Nally, R., Bond, N., Lake, P.S., 2010. Flow permanence affects aquatic macroinvertebrate diversity and community structure in three headwater streams in a forested catchment. Canadian Journal of Fisheries and Aquatic Sciences 67, 1649-1657.

Collier, K.J., Bowman, E.J., 2003. Role of wood in pumice-bed streams - I: Impacts of post-harvest management on water quality, habitat and benthic invertebrates. Forest Ecology and Management 177, 243-259.

Collins, B.M., Sobczak, W.V., Colburn, E.A., 2007. Subsurface flowpaths in a forested headwater stream harbor a diverse macroinvertebrate community. Wetlands 27, 319-325.

Corbett, E.S., Lynch, J.A., Sopper, W.E., 1978. Timber harvesting practices and water-quality in eastern United-States. J. For. 76, 484-488.

Cowell, B.C., Remley, A.H., Lynch, D.M., 2004. Seasonal changes in the distribution and abundance of benthic invertebrates in six headwater streams in central Florida. Hydrobiologia 522, 99-115.

Daigle, J.J., Griffith, G.E., Omernik, J.M., Faulkner, P.M., McCulloh, R.P., Handley, L.R., Smith, L.M., Chapman, S.S., 2006. Ecoregions of Louisiana (color poster with map, descriptive text, summary tables, and photographs). In: Survey, U.S.G. (Ed.), Reston, VA.

Danehy, R.J., Chan, S.S., Lester, G.T., Langshaw, R.B., Turner, T.R., 2007. Periphyton and macroinvertebrate assemblage structure in headwaters bordered by mature, thinned, and clearcut Douglas-Fir stands. Forest Science 53, 294-307.

DaSilva, A., Xu, Y.J., Beebe, J., Ice, G., In Review. Dissolved oxygen analysis of a northern Louisiana headwater stream during timber harvesting operations.

Davis, S., Golladay, S.W., Vellidis, G., Pringlea, C.M., 2003. Macroinvertebrate biomonitoring in intermittent Coastal Plain streams impacted by animal agriculture. Journal of Environmental. Quality 32, 1036–1043.

Dewson, Z.S., James, A.B.W., Death, R.G., 2007a. Invertebrate community responses to experimentally reduced discharge in small streams of different water quality. J. N. Am. Benthol. Soc. 26, 754-766.

Dewson, Z.S., James, A.B.W., Death, R.G., 2007b. A review of the consequences of decreased flow for instream habitat and macroinvertebrates. J. N. Am. Benthol. Soc. 26, 401-415.

Doisy, K.E., Rabeni, C.F., 2001. Flow conditions, benthic food resources, and invertebrate community composition in a low-gradient stream in Missouri. J. N. Am. Benthol. Soc. 20, 17-32.

Drury, D.M., Kelso, W.E., 2000. Invertebrate colonization of woody debris in Coastal Plain streams. Hydrobiologia 434, 63-72.

Entrekin, S.A., Tank, J.L., Rosi-Marshall, E.J., Hoellein, T.J., Lamberti, G.A., 2008. Responses in organic matter accumulation and processing to an experimental wood addition in three headwater streams. Freshwater Biology 53, 1642-1657.

Felley, J.D., 1992. Medium-low-gradient streams of the Gulf Coastal Plain. In: Hackney, C.T., S.M. Adams, and W.H. Martin (Ed.), Biodiversity of the Southeastern United States. Aquatic communities. John Wiley & Sons, Inc., New York, New York, pp. 233-270.

Feminella, J.W., 1996. Comparison of benthic macroinvertebrate assemblages in small streams along a gradient of flow permanence. J. N. Am. Benthol. Soc. 15, 651-669.

Fritz, K.M., Dodds, W.K., 2005. Harshness: characterisation of intermittent stream habitat over space and time. Mar. Freshw. Res. 56, 13-23.

Gage, M.S., Spivak, A., Paradise, C.J., 2004. Effects of land use and disturbance on benthic insects in headwater streams draining small watersheds north of Charlotte, NC. Southeastern Naturalist 3, 345-358.

Gooderham, J.P.R., Barmuta, L.A., Davies, P.E., 2007. Upstream heterogeneous zones: small stream systems structured by a lack of competence? J. N. Am. Benthol. Soc. 26, 365-374.

Gravelle, J.A., Link, T.E., Broglio, J.R., Braatne, J.H., 2009. Effects of timber harvest on aquatic macroinvertebrate community composition in a northern Idaho watershed. Forest Science 55, 352-366.

Griswold, M.W., Berzinis, R.W., Crisman, T.L., Golladay, S.W., 2008. Impacts of climatic stability on the structural and functional aspects of macroinvertebrate communities after severe drought. Freshwater Biology 53, 2465-2483.

Haggerty, S.M., Batzer, D.P., Jackson, C.R., 2004. Macroinvertebrate response to logging in coastal headwater streams of Washington, USA. Canadian Journal of Fisheries and Aquatic Sciences 61, 529-537.

Hawkins, C.P., Norris, R.H., Hogue, J.N., Feminella, J.W., 2000. Development and evaluation of predictive models for measuring the biological integrity of streams. Ecol. Appl. 10, 1456-1477.

Hax, C.L., Golladay, S.W., 1998. Flow disturbance of macroinvertebrates inhabiting sediments and woody debris in a prairie stream. Am. Midl. Nat. 139, 210-223.

Heino, J., Mykra, H., Kotanen, J., 2008. Weak relationships between landscape characteristics and multiple facets of stream macroinvertebrate biodiversity in a boreal drainage basin. Landsc. Ecol. 23, 417-426.

Hicks, B.J., Beschta, R.L., Harr, R.D., 1991. Long-term changes in streamflow following logging in western Oregon and associated fisheries implications. Water Resources Bulletin 27, 217-226.

Hladyz, S., Nielsen, D.L., Suter, P.J., Krull, E.S., 2010. Temporal variations in organic carbon utilization by consumers in a lowland river. River Research and Applications, n/a-n/a.

Hrodey, P.J., Kalb, B.J., Sutton, T.M., 2008. Macroinvertebrate community response to large-woody debris additions in small warmwater streams. Hydrobiologia 605, 193-207.

Hughes, S.J., Ferreira, T., Cortes, R.V., 2008. Hierarchical spatial patterns and drivers of change in benthic macroinvertebrate communities in an intermittent Mediterranean river. Aquat. Conserv.-Mar. Freshw. Ecosyst. 18, 742-760.

Ice, G., Sugden, B., 2003. Summer dissolved oxygen concentrations in forested streams of northern Louisiana. South. J. Appl. For. 27, 92-99.

Isphrording, W.C.a.J.F.F., Jr., 1992. Geologic and evolutionary history of drainage systems in the southeastern United States. In: Hackney, C.T., S.M. Adams, and W.H. Martin (Ed.), Biodiversity of the Southeastern United States. Aquatic communities. John Wiley & Sons, Inc., New York, New York, pp. 19-56.

Kaller, M.D., 2010. Forestry Best Management Practice – 2009 Results. In: (LDAF), L.D.o.A.a.F. (Ed.), Baton Rouge, LA, p. 31.

Kaller, M.D., Hudson, J.D., 2010. Phenological partitioning among drifting insect genera within families in a subtropical, coastal plain stream (Louisiana, USA). Journal of Freshwater Ecology 25, 607-615.

Kaller, M.D., Kelso, W.E., 2006a. Effects of a small-scale clearing on habitat and macroinvertebrates of a coastal bottomland stream in Louisiana. Southwestern Naturalist 51, 143-151.

Kaller, M.D., Kelso, W.E., 2006b. Occurrence of freshwater bivalves in a chronically hypoxic coastal stream in Louisiana, USA. Journal of Freshwater Ecology 21, 355-357.

Kaller, M.D., Kelso, W.E., 2006c. Swine activity alters invertebrate and microbial communities in a coastal plain watershed. Am. Midl. Nat. 156, 163-177.

Kaller, M.D., Kelso, W.E., 2007. Association of macroinvertebrate assemblages with dissolved oxygen concentration and wood surface area in selected subtropical streams of the southeastern USA. Aquatic Ecology 41, 95-110.

Kaller, M.D., Kelso, W.E., 2010. The importance of small woody debris in stream restoration: invertebrate community diversity in lowland, subtropical streams in the Gulf of Mexico Coastal Plain. In: Hayes Gillian D., Flores, T.S. (Eds.), Stream restoration halting disturbances, assisted recovery and managed recovery. Nova Science Publishers, Inc., New York, pp. 1-40.

Karr, J.R., Chu, E.W., 1999. Restoring life in running waters:Better biological monitoring. Island PressWashington, DC.

Kenney, M.A., Sutton-Grier, A.E., Smith, R.F., Gresens, S.E., 2009. Benthic macroinvertebrates as indicators of water quality: The intersection of science and policy. Terrestrial Arthropod Reviews 2, 99-128.

Klimesh, D.D., Xu, Y.J., Kaller, M.D., In Review. Responses of stream benthic macroinvertebrate communities in a low-gradient, subtropical watershed to timber harvesting. Forest Ecology and Management In Review.

Kratzer, E.B., Batzer, D.P., 2007. Spatial and temporal variation in aquatic macroinvertebrates in the Okefenokee Swamp, Georgia, USA. Wetlands 27, 127-140.

Larsen, S., Ormerod, S.J., 2010. Low-level effects of inert sediments on temperate stream invertebrates. Freshwater Biology 55, 476-486.

Lawrence, J.E., Lunde, K.B., Mazor, R.D., Beche, L.A., McElravy, E.P., Resh, V.H., 2010. Long-term macroinvertebrate responses to climate change: implications for biological assessment in mediterranean-climate streams. J. N. Am. Benthol. Soc. 29, 1424-1440.

Lazorchak, J.M., Klemm, D.J., Peck, D.V., 1998. Environmental monitoring and assessment program-Surface waters: Field operations and methods for measuring the ecological condition of wadeable streams. In: Agency, E.P. (Ed.).

LDEQ, 2000. Recommended forestry best management practices for Louisiana. In. Louisiana Department of Environmental Quality, Baton Rouge, Louisiana, p. 84.

LeCraw, R., Mackereth, R., 2010. Sources of small-scale variation in the invertebrate communities of headwater streams. Freshwater Biology 55, 1219-1233.

Lenat, D.R., Penrose, D.L., Eagleson, K.W., 1981. Variable effects of sediment addition on stream benthos. Hydrobiologia 79, 187-194.

Lester, R.E., Wright, W., Jones-Lennon, M., Rayment, P., 2009. Large versus small wood in streams: the effect of wood dimension on macroinvertebrate communities. Fundamental and Applied Limnology 174, 339-351.

Likens, G.E., Bormann, F.H., Johnson, N.M., Fisher, D.W., Pierce, R.S., 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in Hubbard Brook watershed-ecosystem. Ecol. Monogr. 40, 23-&.

Longing, S.D., Voshell, J.R., Dolloff, C.A., Roghair, C.N., 2010. Relationships of sedimentation and benthic macroinvertebrate assemblages in headwater streams using systematic longitudinal sampling at the reach scale. Environ. Monit. Assess. 161, 517-530.

Markos, P., 2010. The influence of channel stability and morphology on macroinvertebrate community structure in southeastern Louisiana streams. In, School of Renewable Natural Resources. Louisiana State University, Baton Rouge, Louisiana, p. 83.

Martel, N., Rodriguez, M.A., Berube, P., 2007. Multi-scale analysis of responses of stream macrobenthos to forestry activities and environmental context. Freshwater Biology 52, 85-97.

McBroom, M.W., Beasley, R.S., Chang, M.T., Ice, G.G., 2008. Storm runoff and sediment losses from forest clearcutting and stand re-establishment with best management practices in East Texas, USA. Hydrol. Process. 22, 1509-1522.

McCafferty, W.P., 1981. Aquatic entomology the fishermen's and ecologists' illustrated guide to insects and their relatives. Science Books International, Boston, Massachusetts.

Merritt, R.W., Cummins, K.W., Berg, M.B., 2008. An introduction to the aquatic insects of North America, 4th edition. Kendall Hunt Publishing Dubuque, Iowa.

Meyer, J.L., Strayer, D.L., Wallace, J.B., Eggert, S.L., Helfman, G.S., Leonard, N.E., 2007. The contribution of headwater streams to biodiversity in river networks. J. Am. Water Resour. Assoc. 43, 86-103.

Muenz, T.K., Golladay, S.W., Vellidis, G., Smith, L.L., 2006. Stream buffer effectiveness in an agriculturally influenced area, southwestern Georgia: Responses of water quality, macroinvertebrates, and amphibians. Journal of Environmental Quality 35, 1924-1938.

Murphy, M.L., Hall, J.D., 1981. Varied effects of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon. Canadian Journal of Fisheries and Aquatic Sciences 38, 137-145.

Nadeau, T.L., Rains, M.C., 2007. Hydrological connectivity between headwater streams and downstream waters: How science can inform policy. J. Am. Water Resour. Assoc. 43, 118-133.

Norris, R.H., Thoms, M.C., 1999. What is river health? Freshwater Biology 41, 197-209.

NRCS, 2007. Official soil series descriptions. In: Natural Resources Conservation Service, U.S.D.o.A. (Ed.).

Ogren, S.A., King, D.K., 2008. The effect of large woody debris on macroinvertebrate communities and epilithon detritus composition in a channelized headwater stream. Journal of Freshwater Ecology 23, 65-77.

Pescador, M.L., Richard, B.A., 2006. A new species of Caenis (Ephemeroptera : Caenidae) from Florida, USA. Zootaxa, 61-68.

Phillips, E.C., 2003. Habitat preference of aquatic macroinvertebrates in an east Texas sandy stream. Journal of Freshwater Ecology 18, 1-11.

Pires, A.M., Cowx, I.G., Coelho, M.M., 2000. Benthic macroinvertebrate communities of intermittent streams in the middle reaches of the Guadiana Basin (Portugal). Hydrobiologia 435, 167-175.

Price, K., Suski, A., McGarvie, J., Beasley, B., Richardson, J.S., 2003. Communities of aquatic insects of old-growth and clearcut coastal headwater streams of varying flow persistence. Can. J. For. Res.-Rev. Can. Rech. For. 33, 1416-1432.

MDEQ., 2003. Development and application of the Mississippi benthic index of stream quality (M-BISQ). In: Mississippi Department of Environmental Quality. (Ed.), Jackson, MS.

Richardson, J.S., Danehy, R.J., 2007. A synthesis of the ecology of headwater streams and their riparian zones in temperate forests. Forest Science 53, 131-147.

Saksa, P., 2007. The hydrology and sediment transport of low-gradient, forested headwater streams. In, School of Renewable Natural Resources. Louisiana State University, Baton Rouge, Louisiana, p. 104.

Sloey, D.J., 1992. Effects of physicochemistry and forest management practices on benthic macroinvertebrates in small streams of central Louisiana. In, School of Renewable Natural Resources. Louisiana State University, Baton Rouge, Louisiana.

Smith, H., Wood, P.J., 2002. Flow permanence and macroinvertebrate community variability in limestone spring systems. Hydrobiologia 487, 45-58.

Smock, L.A., Metzler, G.M., Gladden, J.E., 1989. Role of debris dams in the structure and functioning of low-gradient headwater streams. Ecology 70, 764-775.

Sponseller, R.A., Benfield, E.F., Valett, H.M., 2001. Relationships between land use, spatial scale and stream macroinvertebrate communities. Freshwater Biology 46, 1409-1424.

Stednick, J.D., 1996. Monitoring the effects of timber harvest on annual water yield. J. Hydrol. 176, 79-95.

Stott, T., Mount, N., 2004. Plantation forestry impacts on sediment yields and downstream channel dynamics in the UK: a review. Prog. Phys. Geogr. 28, 197-240.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., Cushing, C.E., 1980. River continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37, 130-137.

Vinson, M.R., Hawkins, C.P., 2003. Broad-scale geographical patterns in local stream insect genera richness. Ecography 26, 751-767.

Viosca, A.D., 2007. Relationships between macroinvertebrate communities and environmental characteristics of headwater streams in central Louisiana. In, School of Renewable Natural Resources. Louisiana State University, Baton Rouge, Louisiana, p. 99.

Voshell, J.R.J., 2002. A guide to common freshwater invertebrates of North America. The McDonald & Woodward Publishing Company, Blacksburg, Virginia.

Wallace, J.B., Grubaugh, J.W., Whiles, M.R., 1996. Biotic indices and stream ecosystem processes: Results from an experimental study. Ecol. Appl. 6, 140-151.

Wallace, J.B., Webster, J.R., 1996. The role of macroinvertebrates in stream ecosystem function. Annu. Rev. Entomol. 41, 115-139.

Williams, L.R., Bonner, T.H., Hudson, J.D., Williams, M.G., Leavy, T.R., Williams, C.S., 2005. Interactive effects of environmental variability and military training on stream biota of three headwater drainages in western Louisiana. Transactions of the American Fisheries Society 134, 192-206.

Wipfli, M.S., Richardson, J.S., Naiman, R.J., 2007. Ecological linkages between headwaters and downstream ecosystems: Transport of organic matter, invertebrates, and wood down headwater channels. J. Am. Water Resour. Assoc. 43, 72-85.

Xu, Y.J., Rutherford, D.A., 2005. Final report on analyses of LDAF 2003/2004 survey on forestry BMP implementation in Louisiana. In: Forestry, L.D.o.A.a. (Ed.), Baton Rouge, LA, p. 37.

APPENDIX: List of Taxa

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Amphipoda	1	2												
Asellidae	1	15												
Cambaridae	1	5												
Chironomidae	1	32												
Collembola	1	1												
Corixidae	1	2												
Crangonyctidae	1	17												
Culicidae	1	94												
Dytiscidae	1	6												
Sphaeriidae	1	3												
Tipulidae	1	1												
Amphipoda	1		7											
Asellidae	1		108											
Cambaridae	1		12											
Ceratopogonidae	1		1											
Chironomidae	1		3											
Collembola	1		1											
Crangonyctidae	1		68											
Culicidae	1		1004											
Curculionidae	1		1											
Homoptera	1		1											
Pisauridae	1		1											
Planorbidae	1		1											
Sphaeriidae	1		3											
Tipulidae	1		4											
Amphipoda	1			14										
Ancylidae	1			1										
Asellidae	1			167										
Baetidae	1			1										
Bivalvia	1			6										
Ceratopogonidae	1			28										
Chironomidae	1			188										
Chrysomelidae	1			1										
Collembola	1			1										
Corixidae	1			14										
Crangonyctidae	1			107										
Culicidae	1			1										
Curculionidae	1			2										
Dytiscidae	1			34										
Ephemeridae	1			1										
Gomphidae	1			1										
Haliplidae	1			1										
Hirudinea	1			4										
Homoptera	1			6										
Hydrachnidia	1			1										
Hydrochidae	1			1										
Libellulidae	1			3										
Odonata	1			1										

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Perlidae	1			1										
Physidae	1			6										
Planorbidae	1			2										
Sisyridae	1			1										
Sphaeriidae	1			17										
Tabanidae	1			1										
Amphipoda	1				24									
Asellidae	1				46									
Bivalvia	1				20									
Ceratopogonidae	1				47									
Chironomidae	1				222									
Corixidae	1				11									
Crangonyctidae	1				55									
Dytiscidae	1				7									
Ephemeridae	1				116									
Ephemeroptera	1				6									
Haliplidae	1				5									
Hirudinea	1				10									
Libellulidae	1				1									
Palaemonidae	1				1									
Perlidae	1				2									
Physidae	1				1									
Sphaeriidae	1				9									
Unionidae	1				1									
Amphipoda	1					2								
Ancylidae	1					4								
Asellidae	1					67								
Bivalvia	1					55								
Cambaridae	1					1								
Ceratopogonidae	1					16								
Chironomidae	1					95								
Collembola	1					2								
Corixidae	1					20								
Crangonyctidae	1					13								
Culicidae	1					17								
Dytiscidae	1					11								
Elmidae	1					1								
Ephemeridae	1					2								
Ephemeroptera	1					12								
Homoptera	1					3								
Hyalellidae	1					1								
Hydrachnidia	1					1								
Libellulidae	1					5								
Odonata	1					1								
Perlidae	1					1								
Ptiliidae	1					1								
Pyralidae	1					1								
Sphaeriidae	1					18								
Tipulidae	1					1								

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Amphipoda	1						1							
Ancylidae	1						6							
Asellidae	1						18							
Baetidae	1						4							
Bivalvia	1						1							
Caenidae	1						33							
Cambaridae	1						2							
Ceratopogonidae	1						21							
Chironomidae	1						210							
Crangonyctidae	1						11							
Dytiscidae	1						4							
Ephemeridae	1						1							
Ephemeroptera	1						5							
Gomphidae	1						3							
Gyrinidae	1						1							
Heptageniidae	1						7							
Homoptera	1						1							
Lepidoptera	1						1							
Palaemonidae	1						4							
Perlidae	1						1							
Physidae	1						2							
Planorbidae	1						2							
Psychodidae	1						1							
Sisyridae	1						1							
Sphaeriidae	1						5							
Tenebrionidae	1						1							
Tipulidae	1						9							
Unionidae	1						1							
Viviparidae	1						31							
Amphipoda	1							13						
Asellidae	1							582						
Baetidae	1							4						
Bivalvia	1							47						
Caenidae	1							15						
Cambaridae	1							2						
Ceratopogonidae	1							278						
Chironomidae	1							138						
Collembola	1							1						
Corethrellidae	1							1						
Corixidae	1							26						
Crangonyctidae	1							16						
Culicidae	1							22						
Dixidae	1							1						
Dytiscidae	1							4						
Elmidae	1							1						
Ephemerellidae	1							2						
Ephemeroptera	1							4						
Haliplidae	1							1						
Hirudinea	1							5						

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Hyalellidae	1							78						
Hydrachnidia	1							5						
Hydrophiloidea	1							1						
Lepidoptera	1							1						
Palaemonidae	1							1						
Physidae	1							9						
Sialidae	1							1						
Sphaeriidae	1							12						
Viviparidae	1							36						
Amphipoda	1								29					
Ancylidae	1								1					
Asellidae	1								61					
Bivalvia	1								7					
Caenidae	1								4					
Ceratopogonidae	1								433					
Chironomidae	1								178					
Coenagrionidae	1								3					
Collembola	1								1					
Corduliidae	1								1					
Corixidae	1								4					
Crangonyctidae	1								45					
Culicidae	1								7					
Dytiscidae	1								9					
Gomphidae	1								2					
Haliplidae	1								1					
Hirudinea	1								13					
Homoptera	1								1					
Hyalellidae	1								11					
Hydrachnidia	1								1					
Libellulidae	1								1					
Palaemonidae	1								3					
Planorbidae	1								1					
Sialidae	1								5					
Sphaeriidae	1								12					
Tabanidae	1								2					
Unionidae	1								3					
Amphipoda	1									4				
Ancylidae	1									2				
Asellidae	1									190				
Bivalvia	1									6				
Ceratopogonidae	1									38				
Chironomidae	1									239				
Collembola	1									1				
Corixidae	1									9				
Crangonyctidae	1									19				
Culicidae	1									92				
Dytiscidae	1									4				
Haliplidae	1									1				
Hirudinea	1									2				

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Hyalellidae	1									15				
Hydrachnidia	1									3				
Lepidoptera	1									1				
Physidae	1									5				
Sialidae	1									5				
Sphaeriidae	1									7				
Tipulidae	1									1				
Unionidae	1									1				
Amphipoda	1										17			
Ancylidae	1										1			
Asellidae	1										396			
Bivalvia	1										16			
Caenidae	1										3			
Ceratopogonidae	1										39			
Chaoboridae	1										1			
Chironomidae	1										181			
Collembola	1										3			
Corixidae	1										2			
Crangonyctidae	1										33			
Culicidae	1										23			
Elmidae	1										1			
Ephemeroptera	1										1			
Gastropoda	1										4			
Hirudinea	1										45			
Homoptera	1										3			
Hyalellidae	1										86			
Hydrachnidia	1										6			
Libellulidae	1										5			
Palaemonidae	1										5			
Physidae	1										1			
Planorbidae	1										1			
Saldidae	1										1			
Sialidae	1										5			
Sphaeriidae	1										11			
Tabanidae	1										1			
Tipulidae	1										2			
Valvatidae	1										2			
Amphipoda	1											56		
Ancylidae	1											1		
Asellidae	1											718		
Bivalvia	1											2		
Cambaridae	1											2		
Ceratopogonidae	1											188		
Chaoboridae	1											1		
Chironomidae	1											382		
Coenagrionidae	1											1		
Collembola	1											6		
Corixidae	1											4		
Crangonyctidae	1											121		

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Culicidae	1											26		
Dytiscidae	1											23		
Ephemeroptera	1											3		
Haliplidae	1											5		
Hirudinea	1											35		
Homoptera	1											5		
Hyalellidae	1											39		
Hydrachnidia	1											4		
Lepidoptera	1											1		
Libellulidae	1											29		
Physidae	1											4		
Planorbidae	1											3		
Scirtidae	1											26		
Sialidae	1											2		
Sphaeriidae	1											15		
Tipulidae	1											1		
Ancylidae	2			35										
Arachnida	2			1										
Asellidae	2			16										
Bivalvia	2			27										
Caenidae	2			27										
Cambaridae	2			1										
Ceratopogonidae	2			90										
Chaoboridae	2			33										
Chironomidae	2			1623										
Corduliidae	2			14										
Corixidae	2			57										
Crangonyctidae	2			1										
Culicidae	2			1										
Dytiscidae	2			4										
Gomphidae	2			6										
Haliplidae	2			1										
Hirudinea	2			8										
Homoptera	2			9										
Hydrachnidia	2			38										
Lepidoptera	2			1										
Libellulidae	2			17										
Limnephilidae	2			1										
Palaemonidae	2			10										
Planorbidae	2			5										
Sialidae	2			42										
Tabanidae	2			15										
Bivalvia	2				7									
Caenidae	2				25									
Cambaridae	2				3									
Ceratopogonidae	2				81									
Chaoboridae	2				44									
Chironomidae	2				306									
Collembola	2				1									

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Corduliidae	2				1									
Corixidae	2				41									
Ephemeridae	2				5									
Gastropoda	2				12									
Homoptera	2				2									
Hydrachnidia	2				20									
Palaemonidae	2				6									
Sialidae	2				8									
Ancylidae	2					9								
Arachnida	2					3								
Asellidae	2					6								
Bivalvia	2					16								
Cambaridae	2					6								
Ceratopogonidae	2					38								
Chaoboridae	2					106								
Chironomidae	2					539								
Corixidae	2					10								
Culicidae	2					1								
Dytiscidae	2					23								
Gerridae	2					3								
Homoptera	2					3								
Palaemonidae	2					5								
Planorbidae	2					1								
Sphaeriidae	2					1								
Tipulidae	2					2								
Amphipoda	2							1						
Ancylidae	2							6						
Asellidae	2							3						
Bivalvia	2							8						
Cambaridae	2							1						
Ceratopogonidae	2							568						
Chironomidae	2							1141						
Coenagrionidae	2							3						
Collembola	2							2						
Corduliidae	2							1						
Corixidae	2							25						
Crangonyctidae	2							3						
Culicidae	2							2						
Dytiscidae	2							4						
Elmidae	2							1						
Ephemeroptera	2							2						
Gastropoda	2							1						
Hirudinea	2							7						
Hyalellidae	2							10						
Hydrachnidia	2							2						
Libellulidae	2							27						
Naucoridae	2							1						
Physidae	2							1						
Scirtidae	2							6						

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Sialidae	2							11						
Tipulidae	2							1						
Viviparidae	2							6						
Zygoptera	2							1						
Ancylidae	2								2					
Ceratopogonidae	2								1606					
Chaoboridae	2								2					
Chironomidae	2								1546					
Corixidae	2								4					
Ephemeroptera	2								1					
Hemiptera	2								1					
Homoptera	2								1					
Hyalellidae	2								3					
Hydrachnidia	2								72					
Libellulidae	2								48					
Naucoridae	2								1					
Odonata	2								1					
Palaemonidae	2								7					
Planorbidae	2								1					
Scirtidae	2								1					
Sialidae	2								18					
Tabanidae	2								6					
Ancylidae	2										16			
Arachnida	2										5			
Asellidae	2										1			
Bivalvia	2										6			
Ceratopogonidae	2										111			
Chaoboridae	2										7			
Chironomidae	2										2539			
Corduliidae	2										3			
Corethrellidae	2										1			
Corixidae	2										1			
Cosmopterigidae	2										1			
Culicidae	2										5			
Gerridae	2										2			
Gyrinidae	2										1			
Hirudinea	2										5			
Homoptera	2										1			
Hyalellidae	2										2			
Hydrachnidia	2										10			
Hydrochidae	2										1			
Hydrophiloidea	2										1			
Libellulidae	2										22			
Palaemonidae	2										1			
Physidae	2										1			
Planorbidae	2										8			
Pleidae	2										1			
Scirtidae	2										5			
Sialidae	2										56			

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Amphipoda	2											4		
Ancylidae	2											2		
Anisoptera	2											3		
Arachnida	2											5		
Asellidae	2											2		
Bivalvia	2											8		
Ceratopogonidae	2											448		
Chaoboridae	2											42		
Chironomidae	2											3547		
Coenagrionidae	2											2		
Collembola	2											3		
Corixidae	2											6		
Corydalidae	2											1		
Crangonyctidae	2											1		
Culicidae	2											10		
Decopoda	2											1		
Dytiscidae	2											3		
Haliplidae	2											1		
Hemiptera	2											4		
Hirudinea	2											9		
Hyalellidae	2											6		
Hydrachnidia	2											43		
Hydrochidae	2											3		
Lepidoptera	2											1		
Libellulidae	2											16		
Physidae	2											4		
Planorbidae	2											2		
Plecoptera	2											1		
Pleidae	2											9		
Scirtidae	2											5		
Sialidae	2											20		
Sisyridae	2											1		
Tabanidae	2											2		
Tipulidae	2											1		
Zygoptera	2											2		
Ancylidae	3			10										
Asellidae	3			3										
Baetidae	3			1										
Caenidae	3			12										
Ceratopogonidae	3			78										
Chaoboridae	3			26										
Chironomidae	3			319										
Copepoda	3			5										
Corixidae	3			33										
Gerridae	3			3										
Gyrinidae	3			1										
Hirudinea	3			3										
Hydrachnidia	3			27										
Libellulidae	3			4										

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Sialidae	3			17										
Sphaeriidae	3			5										
Turbellaria	3			4										
Ancylidae	3				9									
Asellidae	3				2									
Caenidae	3				57									
Ceratopogonidae	3				76									
Chironomidae	3				268									
Corixidae	3				4									
Ephemeridae	3				1									
Gastropoda	3				1									
Hydrachnidia	3				3									
Limnephilidae	3				3									
Sialidae	3				2									
Sphaeriidae	3				2									
Unionidae	3				1									
Ancylidae	3						16							
Caenidae	3						104							
Cambaridae	3						3							
Ceratopogonidae	3						60							
Chironomidae	3						1201							
Corydalidae	3						1							
Crangonyctidae	3						4							
Dytiscidae	3						1							
Elmidae	3						4							
Ephemeridae	3						1							
Ephemeroptera	3						4							
Gerridae	3						8							
Heptageniidae	3						40							
Hydrachnidia	3						6							
Hydropsychidae	3						1							
Palaemonidae	3						11							
Sialidae	3						4							
Sphaeriidae	3						52							
Turbellaria	3						1							
Viviparidae	3						26							
Amphipoda	3							2						
Ancylidae	3							3						
Asellidae	3							1						
Ceratopogonidae	3							155						
Chaoboridae	3							3						
Chironomidae	3							692						
Coenagrionidae	3							1						
Corixidae	3							35						
Culicidae	3							2						
Gerridae	3							2						
Hirudinea	3							2						
Hydrachnidia	3							11						
Hydrophiloidea	3							5						

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Libellulidae	3							22						
Palaemonidae	3							4						
Scirtidae	3							1						
Sialidae	3							29						
Sphaeriidae	3							3						
Turbellaria	3							3						
Amphipoda	3								17					
Ancylidae	3								13					
Baetidae	3								2					
Caenidae	3								4					
Ceratopogonidae	3								393					
Chaoboridae	3								1					
Chironomidae	3								1624					
Coenagrionidae	3								1					
Corixidae	3								12					
Culicidae	3								6					
Dytiscidae	3								1					
Gyrinidae	3								1					
Haliplidae	3								1					
Hydrachnidia	3								53					
Hydrometrida	3								1					
Libellulidae	3								34					
Limnephilidae	3								5					
Palaemonidae	3								2					
Planorbidae	3								2					
Sialidae	3								38					
Sphaeriidae	3								26					
Turbellaria	3								1					
Zygoptera	3								1					
Ancylidae	3									16				
Arachnida	3									1				
Asellidae	3									1				
Ceratopogonidae	3									7				
Chaoboridae	3									18				
Chironomidae	3									193				
Coenagrionidae	3									1				
Corduliidae	3									1				
Corixidae	3									3				
Culicidae	3									2				
Hemiptera	3									1				
Hirudinea	3									13				
Hyalellidae	3									1				
Hydrachnidia	3									3				
Hydrophiloidea	3									1				
Libellulidae	3									1				
Megaloptera	3									6				
Noctuidae	3									1				
Physidae	3									1				
Planorbidae	3									2				

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Scirtidae	3									1				
Sialidae	3									1				
Sphaeriidae	3									7				
Ancylidae	3										16			
Asellidae	3										1			
Baetidae	3										1			
Caenidae	3										2			
Ceratopogonidae	3										122			
Chaoboridae	3										31			
Chironomidae	3										658			
Copepoda	3										8			
Corixidae	3										6			
Gerridae	3										1			
Hirudinea	3										2			
Hydrachnidia	3										31			
Libellulidae	3										8			
Planorbidae	3										1			
Salpingidae	3										3			
Scirtidae	3										2			
Sialidae	3										51			
Sphaeriidae	3										21			
Turbellaria	3										6			
Amphipoda	3											13		
Ancylidae	3											3		
Baetidae	3											1		
Ceratopogonidae	3											44		
Chaoboridae	3											24		
Chironomidae	3											250		
Copepoda	3											3		
Corixidae	3											14		
Culicidae	3											5		
Gerridae	3											1		
Hydrachnidia	3											3		
Scirtidae	3											2		
Sialidae	3											16		
Sphaeriidae	3											2		
Turbellaria	3											2		
Viviparidae	3											3		
Acariformes	4	47												
Amphipoda	4	5												
Asellidae	4	34												
Brachycera	4	1												
Ceratopogonidae	4	30												
Chironomidae	4	136												
Copepoda	4	64												
Corixidae	4	4												
Culicidae	4	1												
Empididae	4	65												
Hypogastruidae	4	1												

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Sphaeriidae	4	200												
Tabanidae	4	2												
Tipulidae	4	18												
Acariformes	4		16											
Amphipoda	4		2											
Asellidae	4		36											
Ceratopogonidae	4		11											
Chaoboridae	4		5											
Chironomidae	4		43											
Copepoda	4		14											
Dytiscidae	4		1											
Empididae	4		22											
Isotomidae	4		1											
Planorbidae	4		2											
Pulmonata	4		1											
Scirtidae	4		2											
Sphaeriidae	4		107											
Staphylinidae	4		2											
Tabanidae	4		3											
Tipulidae	4		52											
Trichoptera	4		1											
Veliidae	4		2											
Acariformes	4			6										
Amphipoda	4			36										
Asellidae	4			182										
Ceratopogonidae	4			14										
Chaoboridae	4			1										
Chironomidae	4			215										
Copepoda	4			43										
Corixidae	4			3										
Dytiscidae	4			1										
Empididae	4			3										
Hydrophiloidea	4			2										
Isopoda	4			2										
Isotomidae	4			1										
Physidae	4			2										
Sialidae	4			3										
Sphaeriidae	4			38										
Tipulidae	4			4										
Viviparidae	4			3										
Acariformes	4				8									
Amphipoda	4				102									
Ancylidae	4				11									
Asellidae	4				194									
Caenidae	4				3									
Ceratopogonidae	4				44									
Chaoboridae	4				14									
Chironomidae	4				473									
Copepoda	4				98									

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Corixidae	4				24									
Culicidae	4				2									
Dytiscidae	4				8									
Empididae	4				3									
Entomobryidae	4				2									
Gastropoda	4				2									
Hydrophiloidea	4				8									
Hypogastruidae	4				1									
Lymnaeidae	4				3									
Physidae	4				5									
Planorbidae	4				5									
Poduridae	4				1									
Potamanthidae	4				7									
Prosobranchia	4				2									
Ptilodactylidae	4				1									
Sialidae	4				6									
Simuliidae	4				1									
Sphaeriidae	4				142									
Tabanidae	4				6									
Viviparidae	4				1									
Acariformes	4					3								
Asellidae	4					153								
Carabidae	4					1								
Ceratopogonidae	4					1								
Chironomidae	4					7								
Copepoda	4					129								
Culicidae	4					4								
Curculionidae	4					1								
Empididae	4					7								
Hydrophiloidea	4					1								
Isotomidae	4					1								
Libellulidae	4					4								
Nymphomyiidae	4					1								
Planorbidae	4					5								
Sphaeriidae	4					25								
Staphylinidae	4					2								
Tabanidae	4					17								
Amphipoda	4						2							
Ancylidae	4						39							
Asellidae	4						76							
Caenidae	4						9							
Cambaridae	4						3							
Ceratopogonidae	4						20							
Chironomidae	4						219							
Copepoda	4						9							
Crangonyctidae	4						16							
Dytiscidae	4						3							
Elmidae	4						1							
Ephemeridae	4						2							

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Gyrinidae	4						1							
Heptageniidae	4						2							
Hydrachnidia	4						2							
Palaemonidae	4						2							
Planorbidae	4						6							
Sialidae	4						1							
Sphaeriidae	4						1							
Tabanidae	4						1							
Viviparidae	4						53							
Acariformes	4							4						
Amphipoda	4							11						
Asellidae	4							20						
Ceratopogonidae	4							44						
Chironomidae	4							487						
Cladoceran	4							1						
Copepoda	4							55						
Corixidae	4							13						
Curculionidae	4							1						
Dytiscidae	4							1						
Empididae	4							1						
Gomphidae	4							1						
Libellulidae	4							2						
Planorbidae	4							5						
Prosobranchia	4							1						
Sialidae	4							12						
Sphaeriidae	4							17						
Viviparidae	4							9						
Acariformes	4								9					
Amphipoda	4								23					
Ancylidae	4								1					
Asellidae	4								6					
Ceratopogonidae	4								81					
Chaoboridae	4								5					
Chironomidae	4								153					
Copepoda	4								26					
Corixidae	4								1					
Culicidae	4								1					
Dytiscidae	4								1					
Gastropoda	4								1					
Gomphidae	4								1					
Hydrophiloidea	4								1					
Physidae	4								1					
Sciomyzidae	4								1					
Sialidae	4								11					
Sphaeriidae	4								26					
Staphylinidae	4								1					
Tipulidae	4								1					
Acariformes	4									2				
Asellidae	4									11				

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Bivalvia	4									8				
Ceratopogonidae	4									4				
Chaoboridae	4									2				
Chironomidae	4									82				
Copepoda	4									31				
Corixidae	4									1				
Empididae	4									1				
Gastropoda	4									1				
Hydrophiloidea	4									2				
Planorbidae	4									4				
Sialidae	4									1				
Sphaeriidae	4									18				
Staphylinidae	4									1				
Viviparidae	4									13				
Acariformes	4										3			
Amphipoda	4										35			
Ancylidae	4										13			
Asellidae	4										80			
Ceratopogonidae	4										71			
Chaoboridae	4										26			
Chironomidae	4										367			
Collembola	4										2			
Copepoda	4										97			
Corixidae	4										1			
Culicidae	4										7			
Dytiscidae	4										1			
Empididae	4										1			
Gomphidae	4										1			
Hydrophiloidea	4										2			
Libellulidae	4										4			
Planorbidae	4										8			
Sialidae	4										3			
Sphaeriidae	4										186			
Tabanidae	4										6			
Amphipoda	4											7		
Asellidae	4											45		
Ceratopogonidae	4											45		
Chaoboridae	4											23		
Chironomidae	4											224		
Copepoda	4											101		
Corixidae	4											2		
Hydrophiloidea	4											2		
Planorbidae	4											4		
Sialidae	4											9		
Sphaeriidae	4											72		
Tabanidae	4											3		
Acariformes	4												30	
Amphipoda	4												224	
Ancylidae	4												1	

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Asellidae	4												43	
Bivalvia	4												1	
Caenidae	4												1	
Ceratopogonidae	4												57	
Chaoboridae	4												3	
Chironomidae	4												242	
Copepoda	4												61	
Corixidae	4												2	
Culicidae	4												5	
Dytiscidae	4												9	
Empididae	4												3	
Hydraenidae	4												1	
Hydrophiloidea	4												14	
Hypogastruidae	4												1	
Isopoda	4												1	
Isotomidae	4												16	
Libellulidae	4												3	
Physidae	4												8	
Protoneuridae	4												2	
Scirtidae	4												1	
Sialidae	4												8	
Sminthuridae	4												2	
Sphaeriidae	4												37	
Tabanidae	4												6	
Tipulidae	4												23	
Acariformes	4													11
Amphipoda	4													29
Asellidae	4													28
Bivalvia	4													13
Ceratopogonidae	4													57
Chironomidae	4													454
Copepoda	4													61
Corixidae	4													3
Culicidae	4													4
Dytiscidae	4													1
Empididae	4													2
Ephemerellidae	4													1
Gastropoda	4													2
Isopoda	4													1
Isotomidae	4													1
Libellulidae	4													2
Physidae	4													2
Planorbidae	4													2
Sialidae	4													4
Sphaeriidae	4													99
Tabanidae	4													2
Tipulidae	4													1
Acariformes	5			14										
Asellidae	5			1										

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Ceratopogonidae	5			2										
Chaoboridae	5			424										
Chironomidae	5			106										
Copepoda	5			11										
Corixidae	5			11										
Gerridae	5			1										
Hirudinea	5			1										
Palaemonidae	5			6										
Sialidae	5			7										
Sphaeriidae	5			1										
Tabanidae	5			1										
Acariformes	5				2									
Ancylidae	5				1									
Canacidae	5				1									
Ceratopogonidae	5				24									
Chaoboridae	5				30									
Chironomidae	5				265									
Copepoda	5				5									
Crambidae	5				1									
Dolichopodidae	5				2									
Dytiscidae	5				2									
Gerridae	5				1									
Psychodidae	5				1									
Scirtidae	5				16									
Sialidae	5				9									
Sphaeriidae	5				4									
Tipulidae	5				4									
Unionidae	5				1									
Zygoptera	5				1									
Acariformes	5					3								
Asellidae	5					3								
Ceratopogonidae	5					10								
Chaoboridae	5					10								
Chironomidae	5					37								
Copepoda	5					2								
Corixidae	5					1								
Culicidae	5					1								
Dolichopodidae	5					30								
Dytiscidae	5					12								
Gerridae	5					1								
Hyalellidae	5					1								
Isotomidae	5					1								
Odonata	5					4								
Palaemonidae	5					1								
Planorbidae	5					1								
Ptilodactylidae	5					1								
Sialidae	5					1								
Sphaeriidae	5					19								
Tabanidae	5					15								

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Thaumaleidae	5					1								
Tipulidae	5					8								
Veliidae	5					1								
Ancylidae	5						1							
Asellidae	5						1							
Cambaridae	5						1							
Canacidae	5						17							
Ceratopogonidae	5						143							
Chironomidae	5						332							
Crambidae	5						1							
Crangonyctidae	5						2							
Dolichopodidae	5						13							
Elmidae	5						12							
Empididae	5						3							
Homoptera	5						1							
Hydrophilidae	5						1							
Isotomidae	5						1							
Lepidoptera	5						1							
Libellulidae	5						1							
Sialidae	5						1							
Sphaeriidae	5						23							
Stratiomyidae	5						1							
Tabanidae	5						27							
Tipulidae	5						22							
Viviparidae	5						27							
Zygoptera	5						1							
Acariformes	5							14						
Asellidae	5							3						
Baetidae	5							1						
Ceratopogonidae	5							142						
Chaoboridae	5							3						
Chironomidae	5							776						
Copepoda	5							4						
Corduliidae	5							1						
Corixidae	5							9						
Crangonyctidae	5							4						
Hemiptera	5							1						
Heptageniidae	5							1						
Homoptera	5							1						
Isotomidae	5							1						
Libellulidae	5							5						
Odonata	5							1						
Physidae	5							5						
Planorbidae	5							1						
Sialidae	5							59						
Sphaeriidae	5							13						
Thysanoptera	5							2						
Tipulidae	5							2						
Acariformes	5								18					

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Ancylidae	5								1					
Ceratopogonidae	5								271					
Chaoboridae	5								111					
Chironomidae	5								1542					
Copepoda	5								24					
Corixidae	5								3					
Dolichopodidae	5								1					
Ephemeroptera	5								2					
Gomphidae	5								1					
Haliplidae	5								1					
Hirudinea	5								1					
Hydrophilidae	5								3					
Libellulidae	5								4					
Mesoveliidae	5								1					
Palaemonidae	5								3					
Plecoptera	5								1					
Ptilodactylidae	5								1					
Scirtidae	5								1					
Sialidae	5								3					
Sphaeriidae	5								6					
Tenebrionidae	5								1					
Turbellaria	5								1					
Acariformes	5									7				
Ancylidae	5									1				
Asellidae	5									1				
Ceratopogonidae	5									182				
Chaoboridae	5									71				
Chironomidae	5									477				
Copepoda	5									15				
Corixidae	5									2				
Dytiscidae	5									1				
Libellulidae	5									2				
Limnephilidae	5									1				
Palaemonidae	5									5				
Physidae	5									1				
Scirtidae	5									1				
Sialidae	5									7				
Sphaeriidae	5									71				
Turbellaria	5									1				
Acariformes	5										29			
Ancylidae	5										3			
Asellidae	5										4			
Ceratopogonidae	5										217			
Chaoboridae	5										84			
Chironomidae	5										2278			
Copepoda	5										15			
Corduliidae	5										4			
Corixidae	5										5			
Crangonyctidae	5										1			

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Dytiscidae	5										1			
Haliplidae	5										2			
Hebridae	5										1			
Hirudinea	5										2			
Hydrophilidae	5										2			
Libellulidae	5										6			
Orthoptera	5										1			
Palaemonidae	5										1			
Planorbidae	5										1			
Psychodidae	5										1			
Sialidae	5										26			
Sphaeriidae	5										48			
Veliidae	5										1			
Zygoptera	5										1			
Acariformes	5											22		
Ancylidae	5											10		
Asellidae	5											1		
Ceratopogonidae	5											145		
Chaoboridae	5											57		
Chironomidae	5											1622		
Copepoda	5											26		
Corduliidae	5											1		
Corixidae	5											1		
Corydalidae	5											1		
Crangonyctidae	5											1		
Hydrophilidae	5											2		
Libellulidae	5											9		
Mesoveliidae	5											1		
Odonata	5											1		
Pelecorhynchidae	5											1		
Physidae	5											1		
Planorbidae	5											5		
Sialidae	5											11		
Sisyridae	5											1		
Sphaeriidae	5											13		
Tabanidae	5											1		
Veliidae	5											1		
Zygoptera	5											4		
Acariformes	5												3	
Asellidae	5												4	
Belastomatidae	5												1	
Bivalvia	5												3	
Carabidae	5												1	
Ceratopogonidae	5												7	
Chaoboridae	5												107	
Chironomidae	5												690	
Copepoda	5												17	
Dytiscidae	5												3	
Empididae	5												2	

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Hydrophiloidea	5												2	
Libellulidae	5												4	
Noteridae	5												1	
Sialidae	5												10	
Sphaeriidae	5												2	
Tabanidae	5												2	
Acariformes	5													7
Bivalvia	5													7
Ceratopogonidae	5													94
Chaoboridae	5													20
Chironomidae	5													580
Copepoda	5													29
Corixidae	5													7
Culicidae	5													1
Dytiscidae	5													1
Gomphidae	5													1
Haliplidae	5													2
Hydrophiloidea	5													21
Isotomidae	5													1
Libellulidae	5													7
Sialidae	5													29
Sphaeriidae	5													47
Tipulidae	5													1
Acariformes	6	1												
Asellidae	6	25												
Cambaridae	6	1												
Ceratopogonidae	6	45												
Chironomidae	6	376												
Copepoda	6	26												
Crangonyctidae	6	22												
Dolichopodidae	6	1												
Haliplidae	6	1												
Isotomidae	6	2												
Planorbidae	6	1												
Psocodea	6	1												
Saldidae	6	3												
Sialidae	6	1												
Simuliidae	6	1												
Sphaeriidae	6	304												
Tabanidae	6	1												
Thysanoptera	6	5												
Tipulidae	6	4												
Zygoptera	6	1												
Acariformes	6		17											
Asellidae	6		62											
Cambaridae	6		4											
Ceratopogonidae	6		6											
Chironomidae	6		470											
Collembola	6		1											

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Copepoda	6		21											
Corixidae	6		1											
Crangonyctidae	6		20											
Dytiscidae	6		10											
Elmidae	6		1											
Homoptera	6		2											
Libellulidae	6		1											
Planorbidae	6		8											
Sialidae	6		1											
Sphaeriidae	6		24											
Tanyderidae	6		1											
Thysanoptera	6		2											
Tipulidae	6		12											
Acariformes	6			8										
Ancylidae	6			45										
Asellidae	6			317										
Caenidae	6			3										
Ceratopogonidae	6			18										
Chironomidae	6			324										
Copepoda	6			19										
Corixidae	6			3										
Corydalidae	6			1										
Crangonyctidae	6			140										
Dolichopodidae	6			1										
Dytiscidae	6			11										
Hirudinea	6			12										
Homoptera	6			2										
Isotomidae	6			2										
Palaemonidae	6			1										
Physidae	6			10										
Planorbidae	6			122										
Sphaeriidae	6			225										
Thysanoptera	6			1										
Tipulidae	6			12										
Turbellaria	6			4										
Zygoptera	6			1										
Acariformes	6				7									
Ancylidae	6				94									
Asellidae	6				49									
Caenidae	6				24									
Cambaridae	6				4									
Ceratopogonidae	6				40									
Chaoboridae	6				2									
Chironomidae	6				423									
Copepoda	6				37									
Corixidae	6				3									
Corydalidae	6				1									
Crangonyctidae	6				95									
Dytiscidae	6				21									

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Hirudinea	6				1									
Homoptera	6				2									
Hydrophilidae	6				1									
Libellulidae	6				1									
Physidae	6				23									
Planorbidae	6				70									
Sialidae	6				2									
Sphaeriidae	6				90									
Tabanidae	6				1									
Thysanoptera	6				1									
Tipulidae	6				3									
Acariformes	6					2								
Ancylidae	6					1								
Asellidae	6					26								
Cambaridae	6					1								
Ceratopogonidae	6					6								
Chironomidae	6					149								
Copepoda	6					8								
Crangonyctidae	6					8								
Dolichopodidae	6					1								
Dytiscidae	6					8								
Homoptera	6					1								
Hydrophilidae	6					1								
Isotomidae	6					1								
Libellulidae	6					1								
Sphaeriidae	6					32								
Thysanoptera	6					8								
Tipulidae	6					33								
Acariformes	6						1							
Ancylidae	6						1							
Asellidae	6						69							
Baetidae	6						14							
Caenidae	6						58							
Cambaridae	6						5							
Ceratopogonidae	6						36							
Chironomidae	6						998							
Copepoda	6						5							
Crangonyctidae	6						70							
Dytiscidae	6						7							
Ephemeridae	6						5							
Ephemeroptera	6						1							
Heptageniidae	6						21							
Homoptera	6						1							
Leptophlebiidae	6						3							
Palaemonidae	6						1							
Psychodidae	6						1							
Ptilodactylidae	6						4							
Sialidae	6						1							
Sphaeriidae	6						15							

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Tipulidae	6						23							
Viviparidae	6						13							
Zygoptera	6						1							
Acariformes	6							9						
Ancylidae	6							1						
Asellidae	6							73						
Baetidae	6							2						
Caenidae	6							30						
Cambaridae	6							1						
Ceratopogonidae	6							49						
Chironomidae	6							724						
Copepoda	6							3						
Corixidae	6							1						
Crangonyctidae	6							16						
Dytiscidae	6							5						
Ephemeridae	6							4						
Heptageniidae	6							4						
Isotomidae	6							1						
Libellulidae	6							2						
Ptilodactylidae	6							1						
Sialidae	6							4						
Sphaeriidae	6							7						
Thysanoptera	6							8						
Tipulidae	6							2						
Acariformes	6								3					
Ancylidae	6								2					
Asellidae	6								2					
Ceratopogonidae	6								54					
Chironomidae	6								296					
Copepoda	6								5					
Crangonyctidae	6								10					
Dolichopodidae	6								1					
Dytiscidae	6								2					
Homoptera	6								1					
Hypogastruidae	6								1					
Physidae	6								1					
Planorbidae	6								20					
Sialidae	6								2					
Sphaeriidae	6								15					
Tipulidae	6								11					
Acariformes	6									3				
Ancylidae	6									8				
Asellidae	6									5				
Ceratopogonidae	6									61				
Chironomidae	6									235				
Copepoda	6									7				
Crangonyctidae	6									4				
Dytiscidae	6									2				
Hemiptera	6									2				

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Hirudinea	6									4				
Hydrophilidae	6									1				
Physidae	6									1				
Planorbidae	6									6				
Psychodidae	6									1				
Sialidae	6									3				
Sphaeriidae	6									102				
Thysanoptera	6									1				
Tipulidae	6									13				
Acariformes	6										10			
Ancylidae	6										6			
Asellidae	6										61			
Caenidae	6										1			
Ceratopogonidae	6										90			
Chironomidae	6										286			
Collembola	6										1			
Copepoda	6										46			
Corixidae	6										7			
Corydalidae	6										1			
Crangonyctidae	6										19			
Culicidae	6										1			
Dytiscidae	6										10			
Gastropoda	6										1			
Gerridae	6										1			
Hyalellidae	6										4			
Isotomidae	6										4			
Physidae	6										3			
Planorbidae	6										36			
Pleidae	6										1			
Sialidae	6										6			
Sphaeriidae	6										70			
Thysanoptera	6										8			
Tipulidae	6										30			
Turbellaria	6										2			
Zygoptera	6										2			
Acariformes	6											3		
Ancylidae	6											25		
Asellidae	6											124		
Canacidae	6											1		
Ceratopogonidae	6											60		
Chaoboridae	6											1		
Chironomidae	6											224		
Copepoda	6											45		
Crangonyctidae	6											55		
Culicidae	6											2		
Dolichopodidae	6											1		
Dytiscidae	6											20		
Hirudinea	6											4		
Isotomidae	6											2		

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Libellulidae	6											4		
Physidae	6											8		
Planorbidae	6											22		
Pseudoscorpionida	6											1		
Scirtidae	6											1		
Sialidae	6											6		
Sminthuridae	6											2		
Sphaeriidae	6											38		
Thysanoptera	6											9		
Tipulidae	6											12		
Acariformes	6												4	
Ancylidae	6												20	
Asellidae	6												51	
Caenidae	6												1	
Ceratopogonidae	6												34	
Chironomidae	6												94	
Copepoda	6												21	
Crangonyctidae	6												77	
Dytiscidae	6												2	
Hirudinea	6												12	
Homoptera	6												1	
Mesoveliidae	6												2	
Physidae	6												27	
Planorbidae	6												28	
Sialidae	6												1	
Sphaeriidae	6												63	
Tabanidae	6												2	
Thysanoptera	6												2	
Tipulidae	6												3	
Acariformes	6													3
Ancylidae	6													16
Asellidae	6													34
Cambaridae	6													1
Ceratopogonidae	6													26
Chaoboridae	6													3
Chironomidae	6													214
Copepoda	6													22
Corduliidae	6													1
Crangonyctidae	6													28
Dytiscidae	6													1
Hirudinea	6													3
Physidae	6													9
Planorbidae	6													7
Sialidae	6													5
Sphaeriidae	6													146
Tipulidae	6													2
Cambaridae	7	1												
Ceratopogonidae	7	261												
Chaoboridae	7	1												

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Chironomidae	7	1077												
Chrysomelidae	7	2												
Copepoda	7	17												
Corduliidae	7	3												
Corixidae	7	7												
Crangonyctidae	7	1												
Culicidae	7	1												
Dolichopodidae	7	1												
Dytiscidae	7	10												
Homoptera	7	1												
Hydrophilidae	7	6												
Isotomidae	7	2												
Lepidostomatidae	7	7												
Noctuidae	7	1												
Odonata	7	1												
Sphaeriidae	7	501												
Tabanidae	7	20												
Thysanoptera	7	1												
Tipulidae	7	3												
Ceratopogonidae	7		5											
Chaoboridae	7		16											
Chironomidae	7		180											
Copepoda	7		1											
Corixidae	7		1											
Culicidae	7		3											
Dytiscidae	7		18											
Homoptera	7		1											
Libellulidae	7		2											
Perlidae	7		1											
Planorbidae	7		5											
Pseudoscorpionida	7		1											
Sphaeriidae	7		10											
Tabanidae	7		1											
Tipulidae	7		3											
Acariformes	7			6										
Ancylidae	7			10										
Asellidae	7			85										
Caenidae	7			3										
Ceratopogonidae	7			77										
Chaoboridae	7			91										
Chironomidae	7			760										
Copepoda	7			7										
Corixidae	7			48										
Culicidae	7			1										
Gerridae	7			4										
Hirudinea	7			9										
Lepidostomatidae	7			2										
Libellulidae	7			9										
Palaemonidae	7			2										

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Physidae	7			1										
Sialidae	7			16										
Sphaeriidae	7			112										
Tabanidae	7			13										
Turbellaria	7			6										
Veliidae	7			1										
Acariformes	7				13									
Ancylidae	7				27									
Asellidae	7				1									
Caenidae	7				7									
Canacidae	7				1									
Ceratopogonidae	7				316									
Chaoboridae	7				108									
Chironomidae	7				1501									
Copepoda	7				8									
Corixidae	7				1									
Gerridae	7				3									
Gyrinidae	7				1									
Hirudinea	7				4									
Libellulidae	7				5									
Palaemonidae	7				12									
Physidae	7				1									
Planorbidae	7				17									
Scirtidae	7				2									
Sialidae	7				35									
Sphaeriidae	7				134									
Tabanidae	7				1									
Tipulidae	7				1									
Trichoptera	7				3									
Turbellaria	7				1									
Veliidae	7				1									
Acariformes	7					1								
Ancylidae	7					2								
Canacidae	7					1								
Ceratopogonidae	7					4								
Chaoboridae	7					168								
Chironomidae	7					68								
Copepoda	7					7								
Corixidae	7					3								
Elmidae	7					1								
Entomobryidae	7					1								
Gerridae	7					5								
Physidae	7					2								
Sialidae	7					2								
Sphaeriidae	7					25								
Ancylidae	7						2							
Baetidae	7						1							
Caenidae	7						49							
Cambaridae	7						17							

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Ceratopogonidae	7						159							
Chaoboridae	7						5							
Chironomidae	7						853							
Copepoda	7						6							
Corixidae	7						1							
Crangonyctidae	7						3							
Elmidae	7						39							
Ephemeridae	7						1							
Heptageniidae	7						6							
Hirudinea	7						2							
Scirtidae	7						1							
Sialidae	7						2							
Sphaeriidae	7						74							
Tabanidae	7						17							
Tipulidae	7						9							
Viviparidae	7						15							
Acariformes	7							18						
Ancylidae	7							4						
Asellidae	7							1						
Caenidae	7							8						
Ceratopogonidae	7							62						
Chaoboridae	7							11						
Chironomidae	7							432						
Copepoda	7							5						
Corixidae	7							1						
Elmidae	7							1						
Ephemeridae	7							1						
Gomphidae	7							1						
Heptageniidae	7							4						
Hirudinea	7							2						
Homoptera	7							1						
Hyalellidae	7							25						
Isotomidae	7							1						
Libellulidae	7							24						
Muscidae	7							3						
Palaemonidae	7							2						
Planorbidae	7							10						
Scirtidae	7							2						
Sialidae	7							53						
Sphaeriidae	7							23						
Tabanidae	7							1						
Tanyderidae	7							1						
Turbellaria	7							18						
Viviparidae	7							7						
Zygoptera	7							4						
Acariformes	7								38					
Ancylidae	7								2					
Baetidae	7								1					
Ceratopogonidae	7								658					

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Chaoboridae	7								30					
Chironomidae	7								1780					
Copepoda	7								16					
Corduliidae	7								1					
Corixidae	7								5					
Culicidae	7								1					
Elmidae	7								1					
Hirudinea	7								1					
Homoptera	7								2					
Hyalellidae	7								2					
Libellulidae	7								14					
Palaemonidae	7								1					
Planorbidae	7								3					
Scirtidae	7								4					
Sialidae	7								15					
Sisyridae	7								1					
Sphaeriidae	7								13					
Tipulidae	7								1					
Zygoptera	7								4					
Acariformes	7									7				
Ancylidae	7									7				
Ceratopogonidae	7									345				
Chaoboridae	7									102				
Chironomidae	7									1040				
Copepoda	7									5				
Corixidae	7									2				
Gomphidae	7									1				
Hyalellidae	7									2				
Libellulidae	7									10				
Planorbidae	7									1				
Scirtidae	7									1				
Sialidae	7									28				
Sphaeriidae	7									27				
Acariformes	7										18			
Ancylidae	7										7			
Asellidae	7										5			
Baetidae	7										2			
Caenidae	7										1			
Ceratopogonidae	7										67			
Chaoboridae	7										4			
Chironomidae	7										303			
Copepoda	7										12			
Corixidae	7										3			
Hirudinea	7										1			
Homoptera	7										1			
Hyalellidae	7										7			
Libellulidae	7										13			
Mesoveliidae	7										2			
Palaemonidae	7										4			

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Physidae	7										4			
Planorbidae	7										1			
Sialidae	7										59			
Sphaeriidae	7										68			
Thysanoptera	7										1			
Turbellaria	7										4			
Acariformes	7											9		
Ancylidae	7											11		
Asellidae	7											1		
Cambaridae	7											4		
Ceratopogonidae	7											90		
Chironomidae	7											579		
Copepoda	7											2		
Corixidae	7											18		
Dolichopodidae	7											3		
Dytiscidae	7											8		
Gomphidae	7											1		
Haliplidae	7											3		
Hemiptera	7											1		
Hirudinea	7											2		
Hyalellidae	7											3		
Isotomidae	7											1		
Libellulidae	7											7		
Palaemonidae	7											2		
Physidae	7											1		
Planorbidae	7											1		
Pleidae	7											1		
Scirtidae	7											3		
Sialidae	7											99		
Sphaeriidae	7											90		
Tabanidae	7											1		
Tipulidae	7											1		
Turbellaria	7											1		
Zygoptera	7											1		
Acariformes	7												2	
Ancylidae	7												5	
Ceratopogonidae	7												19	
Chaoboridae	7												141	
Chironomidae	7												377	
Copepoda	7												19	
Corixidae	7												10	
Dytiscidae	7												3	
Hirudinea	7												1	
Sialidae	7												43	
Sphaeriidae	7												19	
Tabanidae	7												7	
Tipulidae	7												1	
Viviparidae	7												1	
Acariformes	7													17

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Aeshnidae	7													1
Ancylidae	7													27
Asellidae	7													1
Caenidae	7													1
Ceratopogonidae	7													495
Chaoboridae	7													31
Chironomidae	7													1872
Collembola	7													1
Copepoda	7													21
Corduliidae	7													2
Corixidae	7													3
Culicidae	7													3
Dytiscidae	7													1
Ephemeroptera	7													1
Hirudinea	7													3
Libellulidae	7													9
Mesoveliidae	7													2
Physidae	7													3
Scirtidae	7													2
Sialidae	7													47
Sphaeriidae	7													213
Tipulidae	7													1
Trichoptera	7													1
Viviparidae	7													1
Zygoptera	7													1
Acariformes	8												4	
Aphididae	8												4	
Asellidae	8												37	
Caenidae	8												7	
Cambaridae	8												2	
Canacidae	8												2	
Ceratopogonidae	8												78	
Chironomidae	8												575	
Copepoda	8												87	
Corixidae	8												3	
Crangonyctidae	8												27	
Dytiscidae	8												3	
Hirudinea	8												2	
Isotomidae	8												1	
Physidae	8												1	
Planorbidae	8												2	
Sialidae	8												5	
Sphaeriidae	8												41	
Tipulidae	8												2	
Turbellaria	8												1	
Acariformes	8													14
Ancylidae	8													11
Aphididae	8													6
Asellidae	8													47

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Caenidae	8													31
Cambaridae	8													1
Ceratopogonidae	8													356
Chironomidae	8													2054
Collembola	8													1
Copepoda	8													115
Corixidae	8													2
Crangonyctidae	8													37
Culicidae	8													1
Dytiscidae	8													5
Haliplidae	8													1
Hirudinea	8													44
Libellulidae	8													1
Noctuidae	8													1
Palaemonidae	8													1
Physidae	8													2
Planorbidae	8													59
Psychodidae	8													1
Saldidae	8													1
Scirtidae	8													1
Sialidae	8													24
Sisyridae	8													2
Sphaeriidae	8													52
Tipulidae	8													4
Turbellaria	8													62
Viviparidae	8													1
Acariformes	9												10	
Ancylidae	9												14	
Caenidae	9												8	
Ceratopogonidae	9												92	
Chaoboridae	9												35	
Chironomidae	9												409	
Copepoda	9												11	
Corixidae	9												1	
Crambidae	9												1	
Gerridae	9												1	
Haliplidae	9												1	
Homoptera	9												1	
Libellulidae	9												9	
Planorbidae	9												2	
Scirtidae	9												1	
Sialidae	9												7	
Sphaeriidae	9												7	
Tabanidae	9												2	
Viviparidae	9												3	
Acariformes	9													15
Ancylidae	9													20
Caenidae	9													25
Ceratopogonidae	9													284

Family Or Order	Event	9D	9U	E1	E2	E3	I1	I2	I3	I4	I5	I6	N1	N2
Chaoboridae	9													17
Chironomidae	9													684
Coenagrionidae	9													1
Copepoda	9													44
Corixidae	9													3
Haliplidae	9													1
Heptageniidae	9													1
Hirudinea	9													1
Hyalellidae	9													4
Hydrophilidae	9													1
Libellulidae	9													18
Naucoridae	9													1
Physidae	9													2
Planorbidae	9													10
Scirtidae	9													2
Sialidae	9													18
Sphaeriidae	9													50
Tabanidae	9													3
Viviparidae	9													1

Event 1 = Spring 2006, Event 2 = Late summer 2006, Event 3 = Late summer 2007,
Event 4 = Spring 2008, Event 5 = Late summer 2008, Event 6 = Spring 2009,
Event 7 = Late summer 2009, Event 8 = Spring 2010, Event 9 = Late summer 2010

VITA

Derrick Klimesh is originally from the Driftless Area of northeast Iowa, where his affinity for water and the outdoors began. He also lived in Missoula, Montana for a short period in 1997. He worked for nearly ten years at Featherlite Inc. in Cresco as a craftsman assembler/welder, quality control/assurance inspector, leadman, and supervisor. He attended the University of Northern Iowa in Cedar Falls, Northeast Iowa Community College in Calmar, and graduated from Upper Iowa University in Fayette, in 2009. He earned his Bachelor of Science degree in conservation management *summa cum laude* with a minor in biology. Derrick is an avid family man, antique collector, wood-worker, fisherman, and enjoys hunting and trapping. Derrick began his environmentally focused career monitoring stream quality in northeast Iowa with one of his professors; Dr. Rick Klann at Upper Iowa University, where he became interested in stream macroinvertebrates. He is married to Penelope (Shaw) and they have five children together. When finished at Louisiana State University, Derrick plans to utilize his education to pursue a career working with a government agency, protecting and understanding environmental conservation practices.