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# Macroinvertebrate community of ecology of lowland, subtropical streams in Louisiana

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MACROINVERTEBRATE COMMUNITY  
ECOLOGY OF LOWLAND,  
SUBTROPICAL STREAMS IN LOUISIANA

A Dissertation  
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  
Doctor of Philosophy

in

The School of Renewable Natural Resources

by

Michael Douglas Kaller  
B.S., Lake Superior State University, 1997  
M. S., West Virginia University, 2001  
May 2005

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## DEDICATION

“Discovery consists of seeing what everybody has seen and thinking what nobody has thought -- Albert Szent-Gyorgyi.” Sometimes, I think that these streams in this dissertation certainly must have been examined previously, but I just could not find it. Yet, as I proceed further into science, I realize that there are vast numbers of discoveries to be made, and some are right in front of us. I dedicate this dissertation to family and close friends who pushed, prodded, or otherwise inspired a curiosity of science, the arts, and life. These individuals are: Douglas, Eileen, and Matthew Kaller; Joseph and Barbara Jones; Joseph, the late Nancy, Michael, and Allison Kasprzak; Irene, Matthew, and Julie Gough; and recently Ray, Ann, and Rebecca Sweany. These individuals and others are a part of this work, and I specially thank each and every one of them.

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## ABSTRACT

Freshwater ecosystems, particularly streams and rivers, have been the subject of prodigious research. Unfortunately, in comparison to neighboring regions, the Gulf of Mexico coastal plain has not received as much attention. Therefore, I collected data on the macroinvertebrates of these streams to begin the understanding of the relationships between community structure and environmental characteristics. In contrast to the hypothesized ancestral streams of these macroinvertebrates, coastal plain streams are commonly devoid of rocks leaving only woody debris as usable hard substrates and are typically lower in dissolved oxygen. I examined habitat selection by colonization of woody debris with large and small surface areas. Secondly, given a similar surface area, I examined colonization in different levels of dissolved oxygen. Concurrently, I conducted biota and habitat surveys in three streams over four periods from August 2002 until April 2004 to collect baseline data for future investigations. The survey data included macroinvertebrate collections, microbial population estimations, water chemistry, and habitat descriptions. Finally, over the same time period, I collected macroinvertebrate, microbial, water chemistry, and habitat data in a stream with a potentially strong biotic disturbance, feral swine (*Sus scrofa*). All data were examined with appropriate multivariate statistics. The in-stream experiment suggested similar colonization of both sizes of woody debris for 20 of 21 taxa examined. Some potential high and low dissolved oxygen specialization was detected in the experiment, however, many macroinvertebrates (37%) appeared to be dissolved oxygen generalists. Further, survey data suggested more than 50% of collected macroinvertebrates also may be generalists with regard to other abiotic factors, but did demonstrate some affinity for woody debris. The single stream biotic disturbance appeared to significantly alter the macroinvertebrate community



with a potential shift in favor of collecting organisms against scraping organisms. Therefore, in contrast with other regions, I suggest that coastal plain macroinvertebrates are tolerant to many abiotic factors, but are intolerant of some biotic disturbances.

## CHAPTER 1. INTRODUCTION

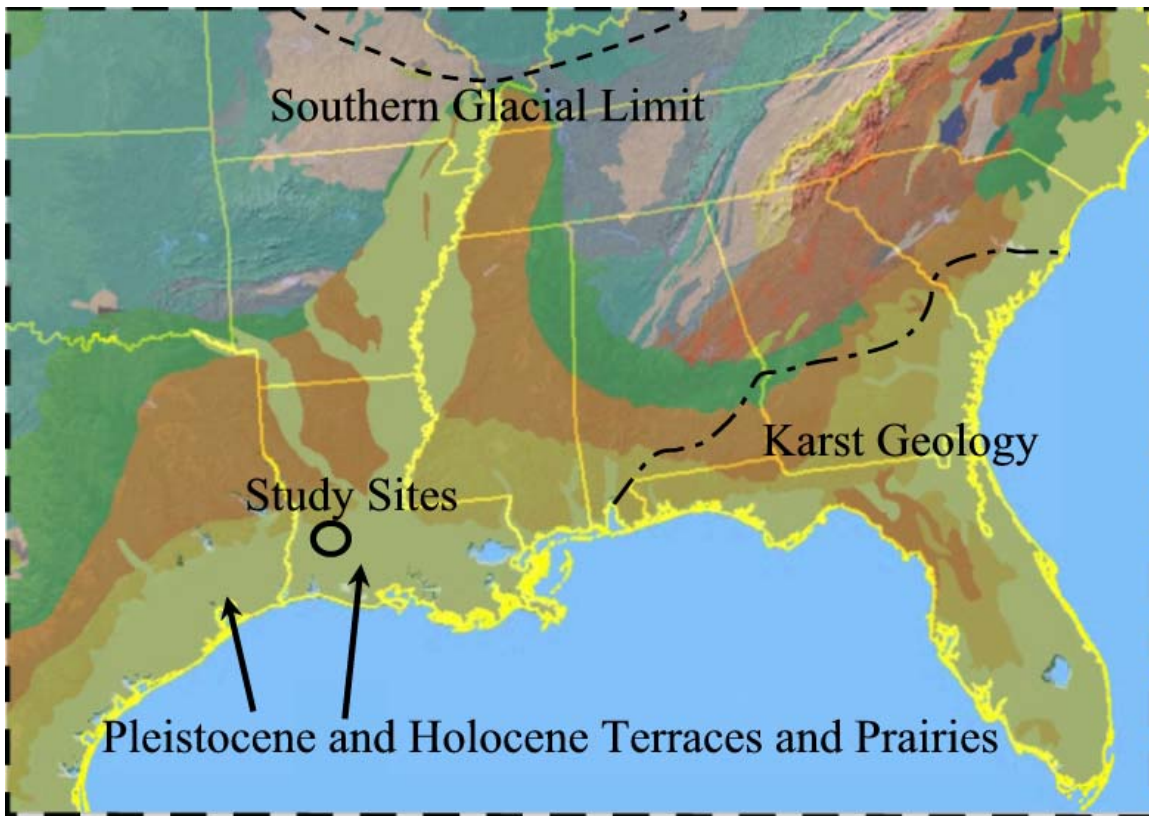
Streams and their biota have been a popular topic of research (Cushing and Allan 2001). However, the lowland and coastal streams and rivers of the Gulf of Mexico, despite potentially containing a diversity of species rivaling the tropics, have received comparatively little attention (Lydeard and Mayden 1995). Whereas extensive freshwater investigations have been conducted in the highlands of Gulf coastal states and Atlantic coastal plain, basic research is still very needed in the Gulf coastal plain. Unfortunately, this region is distant from major centers of stream research, and conclusions drawn on the abiotic and biotic characteristics of Gulf highland and Atlantic coastal plain streams have been applied, perhaps erroneously, to Gulf coastal plain streams and rivers.

Coastal plain streams and rivers differ considerably in habitat and water chemistry from each other. Northern Atlantic coastal plain streams are characterized by low-gradients, sandy substrates, woody debris, low pH, and, most importantly, exchange with groundwater and surrounding surface waters (e.g. Benke et al. 1984; Golladay and Battle 2002). Southern Atlantic coastal plains differ from northern streams in increased buffering (Cushing and Allan 2001). Eastern Gulf coastal plains, i.e. east of Mobile Bay, are similar to southern Atlantic coastal plains in that they share karst, or shallow topsoil with porous bedrock, geology (e.g., Epstein et al. 2002; Didonato et al. 2003; Cowell et al. 2004; Figure 1.1). The central Gulf coastal plain, between Mississippi and Mobile Bays, is composed of slightly older and larger alluvium and has greater topographical differences yielding greater stream gradients and higher levels of dissolved oxygen, and has very limited connectivity with groundwater sources. Finally, the western Gulf coastal plains, from the Mississippi Embayment west into Mexico, are composed of Pleistocene terraces and Holocene prairies where streams are

characterized by low-gradients, silt and sand substrates, large amounts of woody debris, relatively low levels of dissolved oxygen, but very limited connectivity to groundwater because of impermeable clay layers preventing exchange with aquifers (Welch 1942; Holland et al. 1952). Gulf highland streams are characterized by rockier substrates, steeper gradients, and greater oxygenation from turbulence (e.g., Grubagh et al. 1996). Most of the differences among these regions are due to geological origins, which has been addressed, to a degree, by the ecoregion concept (e.g., Omernik 1987). Hynes (1970) stated that one cannot separate the stream from its valley, implying underlying geology and local geomorphological processes are primary determinants of water quality, substrate, and gradient, which ultimately influence stream biota (Allan 1995). Therefore, the differences in geology among these regions suggests biotic differences probably exist as well.

Further exacerbating differences among Gulf coastal plain, Gulf highlands, and Atlantic coastal plain streams are different temperature regimes. The Gulf coastal plain has a long growing season, which can input tremendous amounts of organic material into a stream from riparian and watershed vegetation. This organic matter combined with low flows and warm temperatures creates a nearly perfect environment for microbial breakdown and respiration, to which the characteristic low dissolved oxygen of Gulf plain streams may be attributed (e.g., Scheiring 1984; Whitman and Clark 1984).

Louisiana streams have been degraded by a variety of point and non-point sources of pollution (Louisiana Department of Environmental Quality 2004). As a result, total maximum daily loads (TMDL) of pollutants guidelines are needed to assist in the assessment and regulation of water quality. A TMDL guideline, which is required by the Clean Water Act of 1972, is the sum of the waste load allocation (from specific, or point, sources of



**Figure 1.1.** Karst geology dominates the landscape to the east of Louisiana. Darkening colors (from tan to blue to red) indicate progressively older formations. Geologic image courtesy United States Geological Service GEO-DATA (<http://geode.usgs.gov>). Overlain karst data from Epstein et al. (2002).

pollutants) plus the load allocation (from non-specific, or non-point, sources of pollutants) plus the background loading (natural sources of pollutants) plus margin of safety (based on biological responses to pollutants) (Jarrell 1999). Some pollutants that are commonly included in TMDL guidelines include total phosphorus, pathogens, and biochemical oxygen demand. Management practices, therefore, attempt to keep pollutants below the level specified by the TMDL guideline in order to meet, and possibly exceed, water quality standards for streams. TMDL guidelines, however, arise from extensive study and development that is not completed nationwide. Freshwater invertebrates are often used in

TMDL studies (e.g., Benham et al. 2003), and in Louisiana, aquatic macroinvertebrates are collected as part of TMDL compliance measurements (Louisiana Department of Environmental Quality 2004). Statewide surveys within Louisiana have suggested macroinvertebrate metrics, or community descriptors, that may be useful in stream assessment for TMDL development and monitoring (Dewalt 1995). Although these techniques have been used widely in other streams, a lack of knowledge regarding aquatic macroinvertebrate distribution and autecology may limit the development of these protocols.

Aquatic macroinvertebrate are commonly used in freshwater investigations (Merritt and Cummins 1996). Macroinvertebrates are typically defined as organisms that would be retained on sieves greater than 0.2 mm through 0.5 mm in diameter (Rosenberg and Resh 1993). The concept of macroinvertebrates as indicators of disturbance and other ecological processes dates from early 1900s (Hellowell 1986), but has varied in popularity being attacked as having little validity, particularly for insects (Roback 1974). Regardless of the debate, macroinvertebrates continue to be used in investigations because macroinvertebrate community structure often reflects stream processes (e.g., Thorne and Williams 1997; Usseglio-Polatera et al. 2000; Kaller and Hartman 2004; Hartman et al. 2005). However, successful identification of indicating organisms or communities requires some knowledge of individual species autecology (Hellowell 1986) and some type of reference community condition to serve as a benchmark (Reynoldson et al. 1997; Karr and Chu 1999).

The freshwater macroinvertebrates of Gulf coastal plain streams are poorly described. Specific identification keys exist only for dragonflies [Odonata (Bink 1957)], stoneflies [Plecoptera (Stewart et al. 1976)], and some beetles [Dryopidea (Barr and Chapin 1988)]. Keys describing Florida insects exist for more beetles [Coleoptera (Epler 1996)] and mayflies

[Ephemeroptera (Berner and Pescador 1988)], but given the geological and potential biotic differences between Florida and Louisiana, some caution must be taken when using these keys.

Louisiana statewide surveys resulted in recommendations for biomonitoring macroinvertebrates (Dewalt 1995), however, given the tremendous geological, and therefore, stream characteristic differences within the state, these recommendations may not be widely applicable. Further, specific investigations of disturbance using macroinvertebrates have yielded inconclusive results (e.g. Sloey 1992; Williams et al. 2005). Therefore, following the admonitions of Hellawell (1986) and Karr and Chu (1999), I conducted experiments and surveys in streams across a gradient of land uses with the goal of identifying relationships between macroinvertebrates and stream characteristics to provide the baseline for future assessment. Specifically, my objectives were to: 1) examine the influence of two distinctive coastal plain stream characteristics, woody debris and low dissolved oxygen, on macroinvertebrate community structure; 2) relate stream characteristics to aquatic macroinvertebrate communities; 3) examine in detail impacts to stream macroinvertebrates in a single watershed.

## **DISSERTATION OVERVIEW**

In Chapter 2, I experimentally examined two questions regarding macroinvertebrate colonization. First, I tested whether macroinvertebrates differentially colonize woody debris based on size. Second, given similar sized woody debris, I examined the role of dissolved oxygen level on colonization. In Chapter 3, I used stream survey data to search for correlations between stream characteristics, land use, and macroinvertebrates. In Chapter 4, I examined the effects of a specific stream disturbance on aquatic macroinvertebrates. Finally,

in Chapter 5, I summarized the conclusions of the previous chapters and synthesized the results with regard to the overall goal of providing baseline data for future research.

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## **CHAPTER 2. EFFECTS OF WOODY DEBRIS SURFACE AREA AND DISSOLVED OXYGEN ON COASTAL PLAIN STREAM MACROINVERTEBRATE COMMUNITIES**

### **INTRODUCTION**

Woody debris is an important stream habitat component (Benke and Wallace 2003) that can provide food (Anderson et al. 1978; Dudley and Anderson 1982), cover and foraging habitat (Anderson et al. 1978; Barr and Chapin 1981; Dudley and Anderson 1982), and aestivation sites (Roeding and Smock 1989) for resident macroinvertebrates. Although ephemeropterans often exhibit little affinity for woody substrates (Anderson et al. 1978; Dudley and Anderson 1982; Phillips and Kilambi 1994), the diversity and abundance of many macroinvertebrate taxa are often higher in woody debris than in surrounding habitats (Benke et al. 1984; Drury and Kelso 2000; Burcher and Smock 2002; Johnson and Kennedy 2003), and some taxa are exclusively epixylic (Wood and Sites 2002; Johnson et al. 2003). Woody debris provides a relatively stable and persistent habitat (Benke and Wallace 1990) that may be a particularly important substrate in the low gradient, sand and silt-dominated coastal plain streams along the northern Gulf of Mexico. Because of episodic high storm flows and relatively erosive soils in southern Louisiana, fallen trees are often quickly buried in the stream channel. As a result, the majority of available woody substrate consists of small diameter debris, which may be more ephemeral in space and time, but is regularly replaced from the riparian canopy.

Considerable research on the effect of low dissolved oxygen (DO) on fishes has led to a 5 mg/L minimum standard as advocated by Ellis (1937), Doudoroff and Shumway (1970), and the United States Environmental Protection Agency (1986). However, little consensus exists concerning low dissolved oxygen criteria for stream macroinvertebrates or fishes, and

tolerance to hypoxic conditions are quite taxa-specific. For example, Hirudinea and Decapoda can tolerate DO levels below 1.0 mg/L (Hobbs and Hall 1974; Sawyer 1974), which is similar to LC50 values reported for *Hyallela azteca* and *Gammarus lacustris* (Nebecker et al. 1992). Roback (1974) reported that all aquatic insect orders except Plecoptera included taxa that could tolerate dissolved oxygen below 5 ppm, and several ephemeropterans, trichopterans, and plecopterans were found to survive without emergence below 3 mg/L, although tolerance decreased through time (Nebecker 1972). Some molluscs seem to be particularly sensitive to hypoxia, exhibiting decreased growth below 6 mg/L and decreased survival below 2.5 mg/L DO (Fuller 1974).

At the macroinvertebrate community level, Ruse (1996) found minimum DO levels to be both positively (7 taxa) and negatively (8 taxa) correlated with abundance. In Gulf coastal plain streams in Florida, Didonato et al. (2003) reported depauperate macroinvertebrate communities at sites where DO levels were at or below 2 mg/L. In contrast, macroinvertebrate communities in upland and lowland Australian streams were reported to be highly tolerant of DO saturation down to 10% for 5 days, with upland Ephemeroptera and lowland Chironomidae being the most and least sensitive taxa, respectively (Connolly et al. 2004).

In Louisiana, 152 rivers and streams are currently listed as not meeting DO standards (a mean of 3.0 mg/L, or a median of 5 mg/L following monthly measurements; Louisiana Department of Environmental Quality 2004), and a recent study of 43 randomly-selected streams indicated that 80% did not meet the 5 mg/L standard and 58% did not meet 3 mg/L standard (Ice and Sugden 2003). Whether these DO conditions occur naturally or are the result of anthropogenic impacts is a critical question regarding total maximum daily loading

(TMDL) development and application of water quality standards. Equally important are questions concerning indices of stream impairment, and the integrity of the biotic community inhabiting chronically low-DO streams. Many low-DO streams in Louisiana support relatively diverse fish and invertebrate communities (William E. Kelso, unpublished data), but there have been few studies relating macroinvertebrate community structure and dynamics to ambient DO conditions. These data are needed to assess current DO standards, as well as determine water quality conditions that are potentially stressful or lethal to organisms inhabiting southeastern coastal plain streams.

In this experiment, I studied the effects of habitat and water quality on macroinvertebrate colonization, specifically I evaluated the roles of woody debris size (surface area) and DO concentration on the abundance and diversity of the developing macroinvertebrate assemblages. I hypothesized that macroinvertebrates would be more diverse and abundant on larger woody debris because of increased habitat for feeding and cover related to greater surface areas. I also hypothesized that macroinvertebrate communities within each woody debris treatment group would be more abundant and diverse in the highest DO habitat available.

## **METHODS**

I conducted this experiment in Mill Creek and West Fork of Six Mile Creek (hereafter Six Mile Creek), both 2<sup>nd</sup> order bottomland streams in southwestern Louisiana Mill Creek originates on the flat and poorly-drained Pleistocene terrace and remains in this geologic formation, which was formed from alluvial deposits of sand and silt from the advancing and retreating shoreline of the Gulf of Mexico and the wandering delta of the Mississippi River, until its confluence with the Calcasieu River (Holland et al. 1952). In contrast, Six Mile

Creek originates in Vernon Parish, Louisiana, and cuts through the sandy Fleming formation onto the Pleistocene terrace before joining the Calcasieu River (Welch 1942). Although both streams flow through similar geologic formations, the terrain around Mill Creek differs from surrounding regions in being exceptionally flat and relatively un-eroded (Holland et al. 1952). The riparian zones of both streams are southern hardwood tree species with pine forests dominating upland areas within the watersheds. Mill Creek is in silvicultural rotations jointly managed by Boise Cascade Holdings, LLC, Roy O. Martin Lumber Company, and the Louisiana Department of Wildlife and Fisheries, whereas Six Mile Creek is managed by the United States Department of Agriculture Forest Service as a safety zone surrounding the United States Army Fort Polk and Joint Readiness Training Center. Although only 21 km apart, the streams differ substantially in gradient, flow, and DO levels. Six Mile Creek has clear water, a sandy bottom, low gradient (1.1m/km; Welch 1942), steady flow (mean 0.316 m/s), relatively high DO (mean 7.2 mg/L, 81% saturation; MDK, unpublished data) and was designated a Louisiana Natural and Scenic River in 1997. In contrast, Mill Creek has organically-stained water, a mud bottom, very low gradient (0.6m/km; Holland et al. 1952), very low flow (mean 0.086 m/s), and relatively low DO (mean 3.0 mg/L, 33% saturation; MDK, unpublished data).

In June 2003, I collected woody debris from randomly selected debris piles on the floodplain of each creek, and sterilized the wood in an autoclave at 120°C for 45 minutes to eliminate microbial and fungal colonies that could influence macroinvertebrate colonization patterns during the experiment (Dudley and Anderson 1982). I divided the woody debris into 2 treatment groups, larger coarse woody debris (> 10 mm in diameter) and smaller coarse

woody debris ( $\geq 1$  mm and  $\leq 5$  mm in diameter). Each treatment consisted of 10 pieces of wood of similar length and width.

In July 2003, I placed my experimental wood treatments into cylindrical plastic mesh enclosures (490 mm in length x 88 mm in diameter, 12 mm mesh openings) that retained the wood pieces and allowed macroinvertebrates to move into and out of the enclosures. To reduce colonization avoidance from “unfamiliar” wood types, I returned the debris enclosures to the collection stream and secured pairs of larger and smaller treatments to a 1-m length of rebar inserted into the stream bottom. Riffle, pool, and backwater sites, selected to represent a range of dissolved oxygen levels, received 10 replicates of each treatment, yielding a total of 120 experimental units (2 streams x 3 sites x 2 treatments x 10 replicates). Experimental units remained in the stream for 5 weeks, which I believed would allow sufficient time for colonization before the onset of the hurricane season.

In August 2003, I removed enclosures from the streams and preserved the wood and macroinvertebrates in plastic bags with 95% ethanol. I recorded temperature, dissolved oxygen, specific conductance, and water velocity with YSI model 85 handheld probe and a Sontek velocity probe (both Yellow Springs Inc., Yellow Springs, OH, U.S.A.) at the beginning of the experiment, and weekly thereafter until the enclosures were harvested. I also collected 2 samples of woody debris in a 0.25 mm mesh bag (472 mm x 127 mm x 127 mm) at each placement site to detect potential bias of the results due to avoidance of the plastic mesh (Mason 1976).

Macroinvertebrate samples were frozen until processing, and were then sorted under magnification and placed in 95% ethanol prior to identification. Members of Chironomidae, Ceratopogonidae, Tipulidae, and all Annelida were mounted on glass microscope slides with

CMC-10 (Master's Chemical Company, Elk Grove, IL, U.S.A.) following protocols outlined by Epler (2001) and identified to lowest practical taxon, occasionally species, but more often sub-family, under high magnification. All other macroinvertebrate taxa were identified to lowest practical taxon, occasionally species, but more often genus, and head capsule measurements were made for each individual. A small percentage of samples were set aside for identification quality control, and remaining samples were placed in 95% ethanol for long-term storage.

I performed multivariate analysis of variance (MANOVA), with a post-MANOVA Tukey-Kramer test of least-squared means to assess differences in physicochemistry between the enclosure sites (PROC GLM, SAS, version 9.0, SAS Institute, Cary, NC, U.S.A), with log transformation of water velocity and DO data to closer approximate normality. I calculated total abundance, taxa richness, and Shannon-Wiener diversity ( $H'$ ) for each experimental unit and performed analysis of variance (ANOVA), with a priori comparisons based on my hypotheses among woody debris treatments and sites (PROC MIXED, SAS, version 9.0, SAS Institute, Cary, NC, U.S.A).

The macroinvertebrate data presented a problem for analyses of colonization patterns of specific taxa, as I identified a large number of taxa (77) and a relatively low number of individuals (7,564) resulting in sparse data. Therefore, I reduced the data to 21 more common taxa (Table 2.1), which were collected in more than 10% of the samples, and 56 less common taxa, from which I selected 8 groups (Philopotamidae, Planorbidae, Simuliidae, *Basiaeschna* spp., Anisoptera, *Taphromysis* spp., Perlidae, *Ancyronyx* spp., and *Optioservus* spp.) that were abundant enough for analyses. Because I was most interested in the influence of woody debris surface area on macroinvertebrate colonization, I converted macroinvertebrate



abundances to a standard wood volume to account for boring invertebrates for each treatment, and used a multi-source regression (backward selection process) of the 21 more common taxa in a multivariate analysis of covariance (MANCOVA) to assess the need to retain temperature, flow, and specific conductance in subsequent analyses (Dowdy et al. 2004). These variables were not significant sources of variance regarding macroinvertebrate abundance and diversity, so I used MANOVA on log-transformed abundances of the 21 more common taxa, with a priori comparisons based on my hypotheses among woody debris treatments and sites, which now represented only differing levels of dissolved oxygen. I analyzed the 8 groups of less common taxa with individual logistic regression models, with a small constant (0.00001) added following a sensitivity analysis to ensure maximum likelihood algorithm convergence (Agresti 1996; PROC GENMOD, SAS, version 9.0, SAS Institute, Cary, NC, U.S.A). I limited the number of logistic regression tests to 8 to protect the overall experiment-wise error rate.

**Table 2.1.** Taxa selected for multivariate-analysis-of-variance (MANOVA) based on their relative common occurrence (>10% of enclosures).

<i>Atherix</i> spp.	<i>Corbicula fulminea</i> Muller	Lumbricidae
Baetidae	<i>Corynoneura</i> spp.	<i>Macronychus glabratus</i> Say
Cambaridae	<i>Crangonyx</i> spp.	<i>Pomacea</i> spp.
<i>Caenis hilaris</i> Say	<i>Dubiraphia</i> spp.	<i>Stenacron floridense</i> Lewis
Ceratopogonidae	<i>Helobdella</i> spp.	<i>Stenelmis</i> spp.
<i>Cheumatopsyche</i> spp.	<i>Laevepex</i> spp.	<i>Stenonema</i> spp.
Chironominae	<i>Lirceus</i> spp.	Tanypodinae

## RESULTS

Overall site characteristics (Table 2.2) differed significantly ( $p < 0.01$ ) among sites, but were not consistent among streams. Temperature and specific conductance did not significantly differ among sites. In contrast, flow was significantly higher ( $p < 0.01$ ) in the Six Mile Creek riffle and pool than the Six Mile Creek backwater and all 3 Mill Creek sites, but did not significantly differ among the 4 remaining sites. Dissolved oxygen was similar within streams, but was significantly higher ( $p < 0.01$ ) in Six Mile Creek.

**Table 2.2.** Summarized physical and chemical characteristics measured at each site. Mean values over the 5 week experiment are listed with standard deviation in parentheses. Asterisks indicate sites that would not have met LA DEQ DO standards.

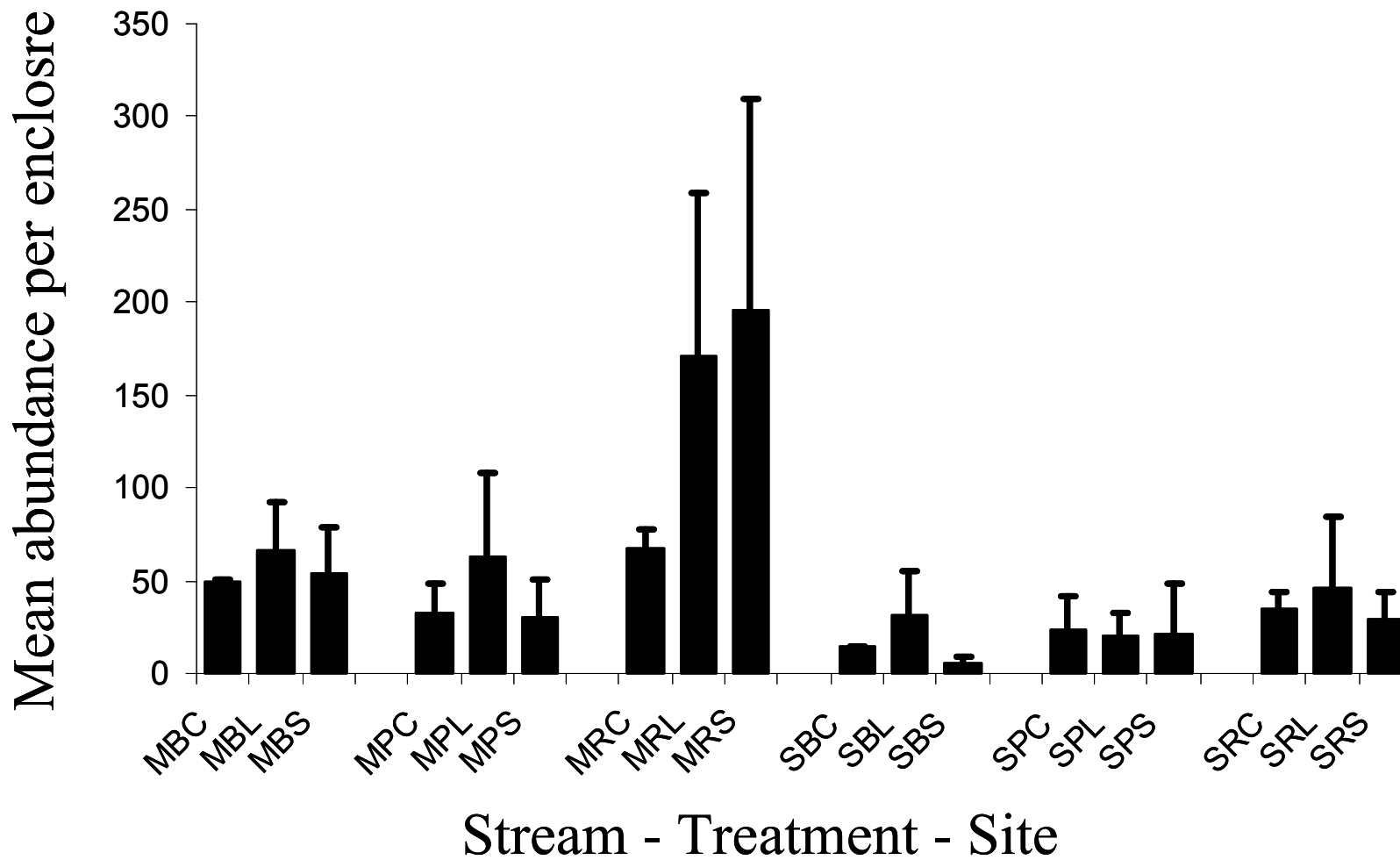
Stream	Site	Flow (cm/s)	Specific Conductance ( $\mu\text{u/s}$ )	Temperature ( $^{\circ}\text{C}$ )	Dissolved Oxygen (mg/L)	Saturation (%)
Mill	Backwater	1.5 (1.1)	85.6 (36.1)	25.2 (0.8)	3.1 (0.7) *	37
Mill	Pool	0.6 (0.3)	86.7 (36.9)	25.4 (0.9)	2.8 (0.9) *	34
Mill	Riffle	2.65 (1.0)	31.1 (17.2)	25.3 (1.0)	2.7 (0.8) *	33
Six Mile	Backwater	0	17.2 (2.3)	24.6 (1.2)	3.5 (0.6) *	42
Six Mile	Pool	14.9 (1.5)	21.7 (0.5)	23.4 (0.8)	6.9 (0.03)	81
Six Mile	Riffle	21.2 (1.3)	22 (0.4)	23.8 (0.8)	7.3 (0.08)	86

Total macroinvertebrate abundance was significantly higher in the larger debris treatment in the Mill Creek riffle compared to Six Mile riffle ( $p < 0.01$ ) and in Mill Creek riffle compared to the other Mill Creek sites ( $p < 0.01$ ) (Figure 2.1). In the smaller debris treatments, Mill Creek sites yielded significantly greater total macroinvertebrate abundances than Six Mile Creek sites in site-to-site comparisons ( $p < 0.01$ ) and the Mill Creek riffle was also higher in total macroinvertebrate abundance than the other two Mill Creek sites ( $p < 0.01$ ). Taxa richness (generic level) did not depend on woody debris treatment but was significantly

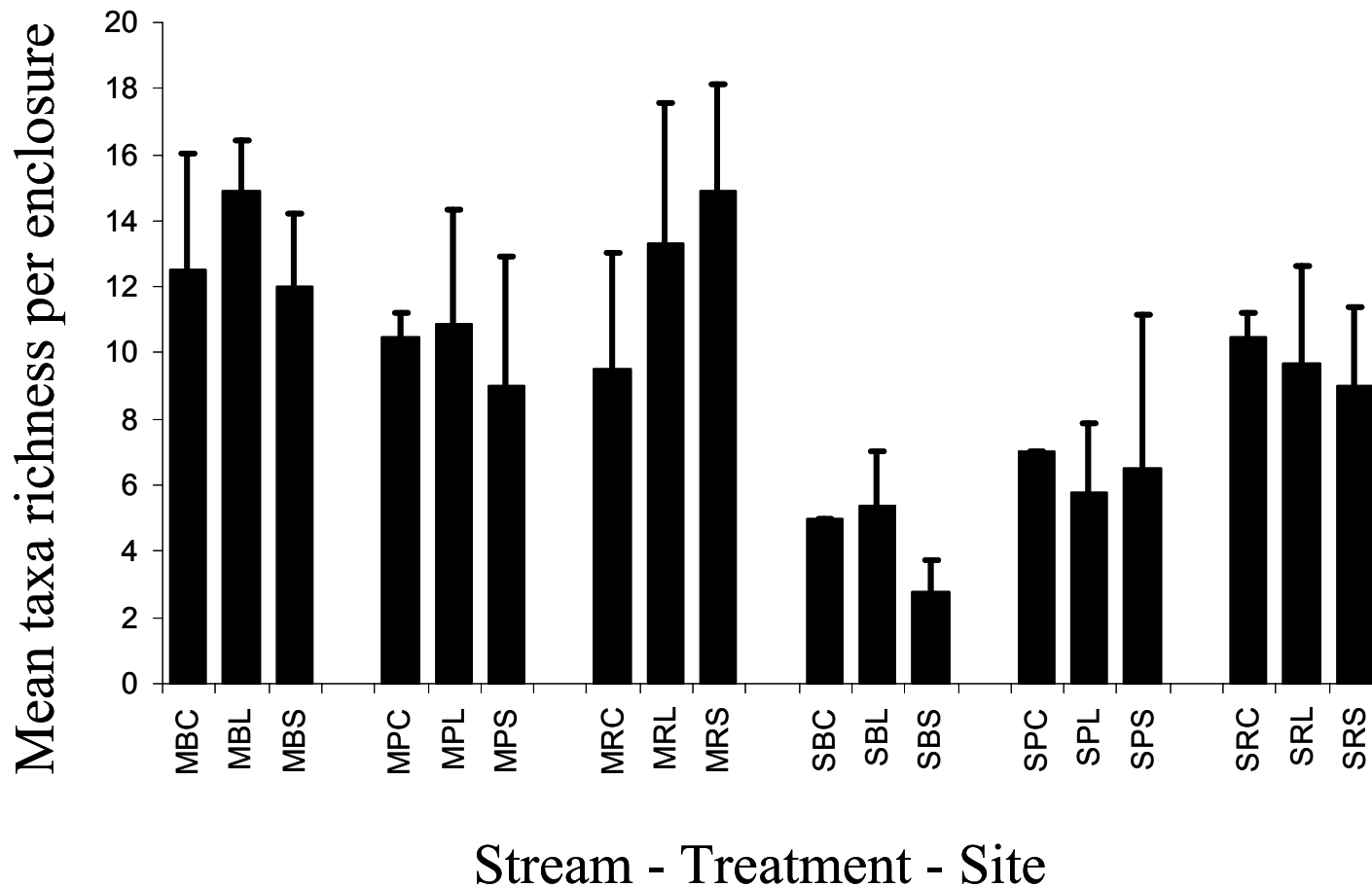
higher ( $p < 0.01$ ) in the riffle sites in both creeks (Mill Creek,  $14.1 \pm 0.58$  SE; Six Mile Creek,  $9.4 \pm 0.86$  SE taxa per enclosure; Figure 2.2). In site-to-site comparisons, Mill Creek (an average of  $12.5 \pm 0.99$  SE taxa per enclosure), had significantly higher taxa richness (all  $p < 0.01$ ) than Six Mile Creek (mean  $6.5 \pm 0.78$  SE taxa overall per enclosure). However, the overall number of taxa identified was slightly higher in Six Mile Creek (57 taxa with 26 taxa restricted to Six Mile Creek) than in Mill Creek (54 taxa with 22 taxa restricted to Mill Creek). Finally, Shannon-Wiener diversity was significantly higher ( $p < 0.01$ ) in the larger debris treatments in the Six Mile Creek backwater site. Within treatment groups, diversity was higher in the Mill Creek backwater and pool habitats (mean  $H' = 2.95 \pm 0.11$  SE) compared to the Mill Creek riffles ( $2.0 \pm 0.11$  SE; both  $p < 0.01$ ), and was higher in backwater and pool habitats in Mill Creek than in Six Mile Creek ( $1.9 \pm 0.16$  SE; both  $p < 0.01$ ; Figure 2.3).

Because the MANOVA performed on the reduced set of macroinvertebrates revealed significant interactions between treatments and sites, subsequent comparisons among sites and between streams were only performed within each treatment group and site type (Tables 2.3, 2.4, and 2.5). Abundances of *Bezzia* spp., *Cheumatopsyche* spp., *Corbicula* spp, *Corynoneura* spp, *Cragonyx* spp., and *Stenacron floridense* did not differ among any treatments or sites.

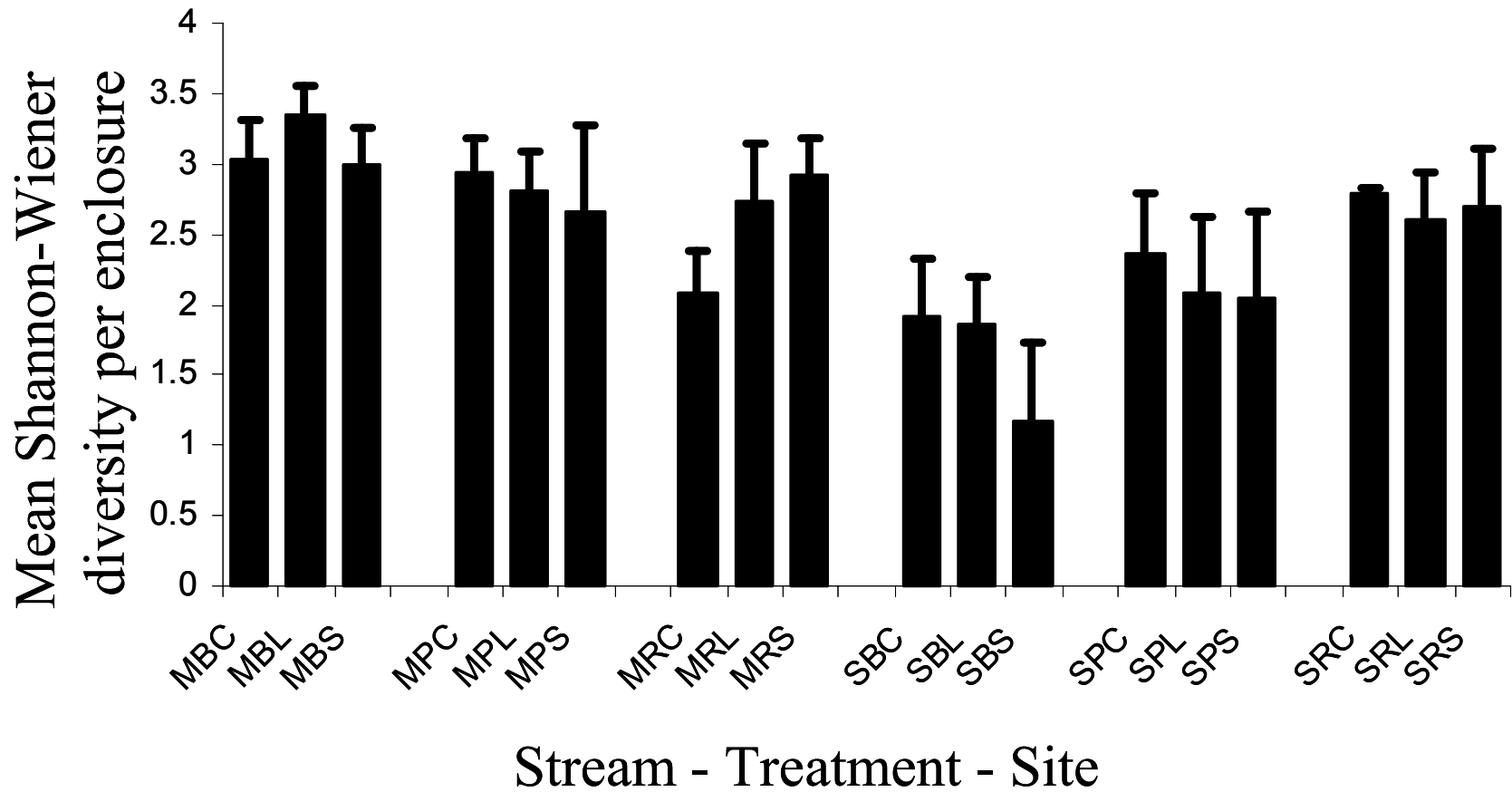
Individual logistic regression models indicated that philopotamids were significantly more likely ( $p < 0.01$ ) to be found in riffles than pools in Six Mile Creek, and anisopterans were more likely ( $p < 0.01$ ) to be found in the large woody debris than small woody debris in Mill Creek pools. Planorbidae, Simuliidae, *Taphromysis* spp., Perlidae, *Dubiraphia* spp., and *Ancyronyx* spp. did not exhibit any significant differences in abundance among habitats.



**Figure 2.1.** Mean abundance per enclosure for each stream, site, and treatment was significantly ( $p < 0.05$ ) higher in Mill Creek (M) compared to Six Mile Creek (S), in riffles (R) compared to pools (P) or backwaters (B), and in large (L) compared to small (S), and control (C) treatments. Standard error bars are included for each mean.



**Figure 2.2.** Mean taxa richness (generic level) per enclosure was significantly ( $p < 0.05$ ) higher in Mill Creek (M) compared to Six Mile Creek (S) and riffles (R) compared to backwaters (B) or pools (P), but similar among large (L), small (S), and control (C) treatments. Standard error bars are given for each mean.



**Figure 2.3.** Mean Shannon-Wiener diversity per enclosure was significantly ( $p < 0.05$ ) higher in Mill Creek (M) compared to Six Mile Creek (S) and backwater (B) and pool (P) sites compared to riffle (R) sites, but similar among large (L), small (S), and control (C) treatments. Standard error bars are given for each mean.

**Table 2.3.** MANOVA results indicate few differences among treatments. Letter codes indicate stream-site-treatment with greater abundances. “S” indicates Six Mile Creek, and “M” indicates Mill Creek. “R,” “B,” and “P” indicate riffle, backwater, and pool sites, respectively. “C,” “T,” “L,” and “S” denote control, treatment, large debris, and small debris, respectively. The p-values for each comparison are in parentheses. Asterisks denote non-significant comparisons.

<b>Taxa</b>	<b>Treatment vs. Control</b>	<b>Small vs. Large</b>
<i>Atherix</i> spp.	SRC (0.01)	SRL (0.01)
Baetidae	*	*
Cambaridae	*	*
<i>Caenis hilaris</i> Say	MRT (0.01)	*
Ceratopogonidae	*	*
<i>Cheumatopsyche</i> spp.	*	*
Chironominae	*	*
<i>Corbicula fluminea</i> Muller	*	*
<i>Corynoneura</i> spp.	*	*
<i>Crangonyx</i> spp.	*	*
<i>Dubiraphia</i> spp.	*	*
<i>Helobdella</i> spp.	*	*
<i>Laevepex</i> spp.	*	*
<i>Lirceus</i> spp.	*	*
Lumbricidae	SRT (0.01)	MPL (0.01)
<i>Macronychus glabratus</i> Say	*	*
<i>Pomacea</i> spp.	*	*
<i>Stenacron floridense</i> Lewis	*	*
<i>Stenelmis</i> spp.	MRT (0.01) / SRT (0.01)	SRL (0.01)
<i>Stenonema</i> spp.	*	*
Tanypodinae	MRT (0.02)	*

**Table 2.4.** MANOVA results demonstrate significant difference for 24% (36 of 137) of comparisons within the smaller treatment group. Letter codes indicate streams or sites with greater abundances. “S” indicates Six Mile Creek, and “M” indicates Mill Creek. “R,” “B,” and “P” indicate riffle, backwater, and pool sites, respectively. Bold letters denote higher dissolved oxygen habitats. The p-values for each comparison are in parentheses. Asterisks denote non-significant comparisons.

Taxa	Back vs. Back	Pool vs. Pool	Riffle vs. Riffle	Mill Back vs. Pool	Mill Pool vs. Riffle	Mill Riffle vs. Back	Six Riffle vs. Back
<i>Atherix</i> spp.	*	*	*	*	*	*	*
Baetidae	*	*	*	*	R (0.01)	R (0.01)	<b>R (0.01)</b>
Cambaridae	*	*	*	*	*	*	*
<i>Caenis hilaris</i> Say	*	*	*	*	*	*	*
Ceratopogonidae	*	*	M (0.01)	*	R (0.01)	R (0.01)	*
<i>Cheumatopsyche</i> spp.	*	*	*	*	*	*	*
Chironominae	*	<b>S (0.01)</b>	*	*	R (0.03)	R (0.01)	<b>R (0.01)</b>
<i>Corbicula fluminea</i> Muller	*	*	*	*	*	*	*
<i>Corynoneura</i> spp.	*	*	*	*	*	*	*
<i>Crangonyx</i> spp.	*	*	*	*	*	*	*
<i>Dubiraphia</i> spp.	M (0.01)	*	M (0.01)	<b>B (0.01)</b>	*	R (0.01)	*
<i>Helobdella</i> spp.	*	*	*	P (0.01)	*	*	*
<i>Laevepex</i> spp.	M (0.01)	*	*	*	*	<b>B (0.01)</b>	*
<i>Lirceus</i> spp.	M (0.01)	M (0.01)	M (0.01)	<b>B (0.01)</b>	R (0.01)	R (0.01)	*
Lumbricidae	*	*	*	*	*	*	*
<i>Macronychus glabratus</i> Say	M (0.01)	*	M (0.01)	<b>B (0.01)</b>	R (0.01)	R (0.01)	*
<i>Pomacea</i> spp.	*	M (0.01)	*	P (0.01)	<b>P (0.01)</b>	*	*
<i>Stenacron floridense</i> Lewis	*	*	M (0.01)	*	R (0.01)	R (0.01)	*
<i>Stenelmis</i> spp.	*	*	*	*	*	*	*
<i>Stenonema</i> spp.	*	*	*	*	*	*	*
Tanypodinae	M (0.01)	M (0.01)	*	*	*	*	*



**Table 2.5.** MANOVA results demonstrate significant differences for 25% (37 of 147) of comparisons within the larger treatment group. Letter codes indicate streams or sites with greater abundances. “M” indicates Mill Creek, “S” indicates Six Mile Creek, “R,” “B,” and “P” indicate riffle, backwater, and pool sites, respectively. Bold letters denote higher dissolved oxygen habitats. The p-values for each comparison are in parentheses. Asterisks denote non-significant comparisons.

Taxa	Back vs. Back	Pool vs. Pool	Riffle vs. Riffle	Mill Back vs. Pool	Mill Pool vs. Riffle	Mill Riffle vs. Back	Six Riffle vs. Back
<i>Atherix</i> spp.	<b>S (0.01)</b>	*	*	*	*	*	<b>R (0.01)</b>
Baetidae	*	*	*	*	*	R (0.01)	<b>R (0.01)</b>
Cambaridae	*	*	*	*	*	*	*
<i>Caenis hiliaris</i> Say	M (0.01)	*	M (0.01)	<b>B (0.01)</b>	R (0.01)	R (0.01)	*
Ceratopogonidae	*	*	*	*	*	*	*
<i>Cheumatopsyche</i> spp.	*	*	*	*	*	*	*
Chironominae	*	*	*	*	*	*	*
<i>Corbicula fluminea</i> Muller	*	*	*	*	*	*	*
<i>Corynoneura</i> spp.	*	*	*	*	*	*	*
<i>Crangonyx</i> spp.	*	*	*	*	*	*	*
<i>Dubiraphia</i> spp.	M (0.01)	*	M (0.01)	<b>B (0.01)</b>	R (0.01)	<b>B (0.01)</b>	*
<i>Helobdella</i> spp.	M (0.01)	M (0.01)	*	P (0.01)	*	<b>B (0.01)</b>	*
<i>Laevepex</i> spp.	M (0.01)	*	*	<b>B (0.01)</b>	*	*	*
<i>Lirceus</i> spp.	*	*	*	*	*	*	*
Lumbricidae	*	M (0.01)	*	<b>B (0.01)</b>	*	<b>B (0.01)</b>	B (0.01)
<i>Macronychus glabratus</i> Say	M (0.01)	*	M (0.01)	<b>B (0.01)</b>	R (0.01)	R (0.01)	<b>R (0.01)</b>
<i>Pomacea</i> spp.	M (0.01)	M (0.01)	*	P (0.01)	*	R (0.01)	*
<i>Stenacron floridense</i> Lewis	*	*	M (0.01)	*	R (0.01)	R (0.01)	*
<i>Stenelmis</i> spp.	*	*	*	*	*	*	*
<i>Stenonema</i> spp.	*	*	*	*	*	*	*
Tanypodinae	*	*	*	*	*	*	*

## DISCUSSION

I am confident that the results of this experiment reflect normal site selection of macroinvertebrates within each stream. Although I prevented microbial and fungal conditioning of the debris, which may have interfered with normal woody debris colonization patterns (Anderson et al. 1978; Dudley and Anderson 1982; Collier and Halliday 2000), only *Atherix* spp. colonized the enclosures at lower abundances than control woody debris, and greater abundances of *Caenis hilaris*, Lumbricidae, *Stenelmis* spp., and Tanypodinae in the enclosures indicate that macroinvertebrates were not avoiding the unconditioned wood. Because so few taxa [5 of 21 (24%) analyzed by MANOVA] exhibited any detectable statistical treatment effect compared to controls, I believe the enclosures themselves added little bias to the inferences drawn from the analyses.

Results of the experiment revealed complex interactions among debris size, sites, and streams. Although colonization patterns of *Atherix* spp., Lumbricidae, and *Stenelmis* spp., and Anisoptera supported my hypothesis that macroinvertebrates would be more abundant in larger debris, overall species richness, and Shannon-Wiener diversity were not related to debris size. The importance of woody debris as macroinvertebrate habitat varies considerably among taxa and stream systems (Anderson et al. 1978; Dudley and Anderson 1982; Roeding and Smock 1989), and studies have reported greater macroinvertebrate abundance on more complex (O'Conner 1991), and smaller, less complex (Mathooko and Otieno 2002) debris. Although larger debris would appear to provide greater opportunities for xylophagy, epixylic grazing, and predatory cover for stream macroinvertebrates (O'Conner 1991), the usefulness of woody debris habitat for many taxa in Mill and Six Mile creeks is not based solely on available surface area. Interestingly, all 21 macroinvertebrate taxa examined in the

MANOVA except *Cheumatopsyche* spp. were found on both large and small woody debris, indicating that the proportions of taxa present rather than taxonomic composition of the macroinvertebrate assemblages differed between woody debris treatments.

Although colonization patterns of several taxa also supported my hypothesis that macroinvertebrates would be most abundant and diverse at higher DO levels regardless of woody debris size, abundances of a larger number of taxa suggest that this prediction is not generally applicable in these streams. Total macroinvertebrate abundances in both treatment groups were higher in the lower-DO sites within Mill Creek, and higher in all 3 lower-DO sites in Mill Creek compared to all Six Mile Creek sites. Taxa richness was greatest at the highest DO sites in each creek, but the lower-DO stream, Mill Creek, yielded higher mean numbers of taxa per enclosure than Six Mile Creek. Shannon-Wiener diversity also was higher in lower-DO sites within Mill Creek and in comparisons between streams. Among the treatments, 28 of 36 (78%; small debris) and 25 of 37 (68%; large debris) significant comparisons revealed greater macroinvertebrate abundances in lower-DO habitats. Most of the organisms included in the MANOVA are considered somewhat to very tolerant of reduced water quality (Barbour et al. 1999), and although Mill Creek is not significantly impacted by anthropogenic sources of pollution, it is an oxygen-depressed system due to high organic enrichment and elevated microbial populations from animal activity within the watershed (Kaller and Kelso 2003). These environmentally tolerant organisms, relative to their abundances in a high dissolved oxygen stream, appear to be thriving in spite of the low DO conditions in Mill Creek.

Low DO (< 5mg/L) is common in Louisiana streams (Ice and Sugden 2003), but not necessarily across the Gulf of Mexico coast (see Lewis and Harrell 1978; Schiering 1985;

Cowell et al. 2004). The geology of Louisiana is unique and reflects the legacy of retreating coastlines and the wandering Mississippi River delta. Much of south Louisiana is relatively young geologically (Pleistocene and Holocene deposits) and is formed of alluvial and, occasionally, loess deposits. This gentle topography is reflected in low gradient streams and rivers, which, when combined with warm temperatures, long growing seasons, and abundant riparian vegetation, results in high organic matter loads, high microbial decomposition, and low DO levels. Bick (1957), Stewart et al. (1976), and Barr and Chapin (1981) indicated that macroinvertebrates colonized this region predominantly from northern and eastern highlands, and these invertebrates likely encountered numerous slow moving rivers and streams crossing the Red River and Mississippi River floodplains (the Mississippi Embayment). These low-gradient, low-DO streams and rivers may have acted as a taxonomic filter that restricted the movement of organisms that were intolerant of coastal plain physicochemistry [see Barr and Chapin (1981) regarding the elmids beetles, and Bick (1957) regarding odonates].

Most research into the relationships between DO levels and macroinvertebrate community structure has focused on lethal and sub-lethal tolerances (e.g., Philipson 1954; Nebecker 1972; Nebecker et al. 1992; Connolly et al. 2004) and the relationships between macroinvertebrate distributions and environmental characteristics at the collection locations (Roback 1974; Ruse 1996). Connolly et al. (2004) report that DO concentrations under 10% saturation are lethal to all insects, and they suggest DO concentrations of 25-35% and 10-20% may have detrimental effects on emergence and survival, respectively, over long periods of time. In this study, DO saturation levels in Mill Creek ranged from 33-37%, with much lower values, down to 11%, recorded from field observations from 2002-2004 (MDK, unpublished data), indicating a high tolerance of resident macroinvertebrates to seasonally hypoxic

conditions characteristic of Louisiana's coastal plain streams. Leeches (Sawyer 1974) and gastropods (Harman 1974) are often abundant under low DO conditions, and, although generally less tolerant as a group, certain aquatic insects can tolerate DO levels below 5 ppm (51 of 300 taxa, 17%) and even 3 ppm (11 of those 51 taxa, 21%) for extended periods of time (Roback 1974). I found 22 of 77 macroinvertebrate taxa (29%) exclusively in low DO sites (2.7-3.1 mg/L) and 26 of 77 taxa (34%) exclusively in high DO sites (all above 3.5 mg/L), and I believe that observed colonization patterns during the experiment ultimately reflected the DO sensitivity of the underlying populations in these streams.

The taxonomic composition of the macroinvertebrate assemblages in Mill Creek streams supports previous studies of low-DO intolerance and tolerance among macroinvertebrate taxa. For example, philopotamids, which have been reported to inhabit waters exhibiting DO levels of at least 6 mg/L (Roback 1974) and greater than 8% saturation (Connolly et al. 2004), were not found in sites with DO levels below 3.5 mg/L (42% saturation), all of which were in Mill Creek. Similarly, 25 other taxa were only found in high DO sites in Six Mile Creek, also suggesting an intolerance to hypoxia. The 33 taxa common to both streams exhibited few statistical differences among DO levels, which is evidence of substantial tolerance to reduced DO levels for a diversity of macroinvertebrates, including many taxa that are often considered indicative of good water quality (e.g., baetids, Barbour et al. 1999; *Macronychus glabratus*, Sinclair 1964; Barbour et al. 1999; and *Stenonema* spp., Barbour et al. 1999, although wide tolerances also have been noted in *Stenonema* spp., Roback 1974). Davis et al. (2003) also reported few differences between macroinvertebrate assemblages inhabiting reference and agriculturally-impacted sites, which they attributed to

natural fluctuations in water quality that selected for high macroinvertebrate tolerance of reduced water quality during low flow periods.

Of particular interest are the 22 taxa exclusive to Mill Creek, which included 12 insects, 3 pelecypods (including *Corbicula fluminea*, a sphaerid, and a unionid), and 2 crustaceans. In lotic systems, many of these taxa have been reported to be relatively intolerant of hypoxia (e.g., *C. fluminea*, Johnson and McMahon 1998; *Dubiraphia* spp., Sinclair 1964; Barbour et al. 1999; and gastropods in the families Ancyclidae, Planorbidae, and Physidae, Ellis 1931; Smith 2001), yet my data suggest that general statements of DO sensitivity may be too simplified, particularly in low-energy, coastal streams. Assemblages in these streams may include numerous lentic taxa that may be able to regulate internal oxygen levels and exploit the typically low flow conditions characteristic of Mill Creek. Sinclair (1964) suggested *Dubiraphia* spp. was better adapted to lentic habitats than other elmids, and Brown (2001) reports many planorbids and physids to be lentic dwellers. In addition, the unionid, *Pyganodon grandis*, collected in Mill Creek, although not during this experiment (MDK, unpublished data), has been reported to be a DO-regulating, lentic habitat-associated mussel (Chen et al. 2001). However, Mill Creek still supports many taxa such as *Caenis hilaris* (Berner and Pescador 1988) and *Cheumatopsyche* spp. (Wiggins 1998) that are characteristic of lotic systems. Although my collections were taken from 2 physicochemically-distinct streams, which may confound analyses due to unmeasured water quality or habitat parameters, spatially disjunct immigration patterns, or stream-specific responses to the enclosures, I believe the large number of diverse taxa present exclusively in Mill Creek suggests a thriving community of macroinvertebrates in a seemingly inhospitable, chronically hypoxic stream.

In summary, colonization patterns of macroinvertebrates inhabiting Mill and Six Mile creeks provided some support for my hypothesis that more taxa colonized larger than smaller woody debris treatments, although substantial variability among taxa was evident. However, abundances of many individual taxa, as well as greater total abundance, taxa richness, and Shannon-Wiener diversity suggest my prediction of more diverse and abundant colonization in higher DO habitats was incorrect. Based on this experiment, I believe macroinvertebrates in these bottomland, coastal streams are highly tolerant of seasonally low-DO conditions. In fact, these streams may support a much more diverse and abundant assemblage than I would have predicted from assessments of stream physicochemistry. If aquatic macroinvertebrates are to be used in coastal bottomland stream assessments, such as IBIs, I suggest further research in these systems is needed to identify the important structuring factors for resident macroinvertebrate communities, particularly the role of physicochemical tolerance in determining community composition, because of the wide DO tolerances exhibited by many macroinvertebrate taxa in this experiment.

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## **CHAPTER 3. GENERALIST MACROINVERTEBRATE COMMUNITIES OF COASTAL PLAIN STREAMS: WEAK LINKAGES TO STREAM CHARACTERISTICS**

### **INTRODUCTION**

In recent decades, stream researchers and land managers have invested tremendous time and effort into the assessment of land use effects on aquatic habitats and biota, with an entire volume (19) of the *Journal of the North American Benthological Society* dedicated to the topic. A regulatory impetus [Clean Water Act (1972), sections 303 (d) and 305 (b)] has prompted investigations of non-point, or land use, sources of pollution, which, although regionally variable in severity, have been reported to have an almost universally important role in shaping community structure in stream ecosystems (Resh et al. 1988; Richards et al. 1996). Resh et al. (1988) identified removal of woody debris, large-scale agriculture, silviculture, and hydroelectric projects as important sources of anthropogenic disturbance in low-gradient southeastern streams. Land use has been used as a predictor of local stream communities in studies in the United States (Roth et al. 1996; Allan et al. 1997) and elsewhere (Quinn and Hickey 1990; Collier 1995; Townsend et al. 1997), although the magnitude of land-use effects is scale dependent (Allan et al. 1997). Land use that disturbs the stream-bed has been reported to be the best predictor of community composition (Townsend and Scarsbrook 1997). Because alterations in stream communities may persist for long periods after land use perturbations have ceased (Harding et al. 1998; Matthaei and Townsend 2000), past disturbances as well as current stream impacts have important roles in shaping stream community structure.

Numerous studies have documented changes in stream water quality and habitat with increasing anthropogenic disturbance. Huryn et al. (2002) reported significant increases in

nitrate with increasing urbanization, and storm events in urban areas can significantly affect flow volume, nutrient concentrations, and pollutant levels in receiving streams (Stadelmann and Brezonik 2002). In forested landscapes, timber harvesting in riparian and near-stream upland areas typically reduces canopy cover, increases stream flow volume and stochasticity, reduces water quality, increases sedimentation, alters detritus loads and organic matter export, and reduces in-stream woody debris (Campbell and Doeg 1989; Webster et al. 1990; Chamberlin et al. 1991). When land uses such as silviculture or recreational road use increase erosion and in-stream sedimentation, the effects are generally negative for aquatic macroinvertebrates (Waters 1995, Kaller and Hartman 2004). However, stream buffers (streamside management zones) can be effective in mitigating some of these effects (Richards et al. 1996, Kochenderfer et al. 1997).

Biomonitoring programs typically employ indices and metrics of community structure [predominant North American approach, Karr and Chu (1999)] or multivariate statistical models [predominant European approach, Norris (1995)] to assess the impacts, or lack thereof, of land uses on aquatic macroinvertebrate communities. Along the Gulf of Mexico and Atlantic coastal plains, recent studies assessing the relationship between physio-chemical parameters and macroinvertebrate taxa, generally with the goal of detecting community changes as a result of land use, have produced mixed results (Davis et al. 2003; Didonato et al. 2003; Cowell et al. 2004; Maul et al. 2004). In the north-central Gulf of Mexico coastal plain, which I define as the area bounded on the west by the Sabine drainage, on the east by the Tunica uplands, and encompassing the Holocene coastal prairie, the Mississippi Embayment, and the Pleistocene sandy hills and plains, the landscape has most recently (70,000-135,000 years ago for Pleistocene and 10,000-15,000 years ago for Holocene) been

influenced by the wandering delta of the Mississippi River and the advance and retreat of the Gulf of Mexico. The coastal plain has a myriad of land uses, including urban centers, crawfish/rice agriculture, oil and gas extraction, industrial forestry, recreation, and military training, but has been the subject of comparatively little published research. Several reports have documented macroinvertebrate and physio-chemical relationships to the west (Johnson and Kennedy 2003; Phillips 2003) and east (Scheiring 1985; Payne and Miller 1991; Drury and Kelso 2000), but few studies have focused on macroinvertebrates in this large region. Initially, I was interested in using aquatic macroinvertebrates for bioassessment of land uses in the western portion of the coastal plain. However, because of high ecoregional variability in the southeast (Feminella 2000) and limited background data, I lacked sufficient data to develop a reference condition for stream comparisons (Karr and Chu 1999); therefore, I elected to investigate the correlations between common land uses, stream characteristics, and aquatic macroinvertebrates to provide a baseline for future research.

## **METHODS**

During summer 2002, I selected three 2<sup>nd</sup> and 3<sup>rd</sup> order streams in the north-central Gulf of Mexico Coastal plain in Louisiana that represented three common types of coastal plain streams [see Bolden and Brown (2002) and Ice and Sugden (2003) for comparison]. The West Fork of Six Mile Creek (hereafter Six Mile Creek) in Vernon Parish is a moderate gradient, highly oxygenated, system typical of streams in the forested sandy hills and plains of western Louisiana, with sand (>50% between 4 mm and 1 mm in diameter) and woody debris as dominant substrates. Big Brushy Creek, also in Vernon Parish, is similar to Six Mile Creek, although woody debris is limited and gravel substrate (>50% greater than 4 mm in diameter) is common. Mill Creek, located 20 km south in Allen Parish, has a low gradient

and seasonal hypoxia, very fine silt substrate (>50% less than 1 mm in diameter) and large amounts of woody debris, which is typical of streams on the forest/coastal prairie border. These streams drain the gently sloping coastal plain or terrace formed from the southward retreat of the deltaic plain of the Gulf of Mexico during the Pleistocene. The flat, swampy, and poorly-drained Pleistocene terrace is composed of alluvial sands and silts, which are quite similar in chemical composition throughout the region, but differ in particle size, with the uppermost reaches of Six Mile and Big Brushy Creeks draining the sandy Fleming formation (larger particles) and Mill Creek draining the exceptionally flat and un-eroded terrace (fine alluvium; Welch 1942; Holland et al. 1952). All three streams have southern hardwoods in the bottomlands and loblolly and longleaf pine forests in the uplands with increasing fragmentation into urban and agricultural use in the Mill Creek watershed, extensive riparian clearing in the Big Brushy Creek watershed, and very limited riparian disturbance in the Six Mile Creek watershed (Figure 3.1). The Six Mile Creek watershed is a primarily closed to silviculture and recreational activity for safety reasons and is 92.3% forested, 4.1% open, and 3.6% wetland. The Big Brushy Creek watershed is used for military training in the upper reaches, cleared for gas line crossings in middle reaches, recreationally used in lower reaches and is 85.2% forested and 14.8% open land. In these creeks, military training may have introduced potentially toxic explosive residues (Phillips and Perry 2002). The Mill Creek watershed is representative of the many multiple-use watersheds of the coastal plain and is 88.7% forested, 7.5% agricultural land, 2.6% open land, and 1.2% urbanized land. The sampled portions of Six Mile and Big Brushy Creeks lie entirely within the Kisatchie National Forest managed by the United States Department of Agriculture Forest Service as safety zones surrounding the United States Army Ft. Polk and Joint Readiness Training Center,



whereas Mill Creek drains the West Bay Wildlife Management Area managed for recreation and silviculture jointly by the Louisiana Department of Wildlife and Fisheries, Boise Cascade Holdings, LLC, and Roy O. Martin Lumber Company.

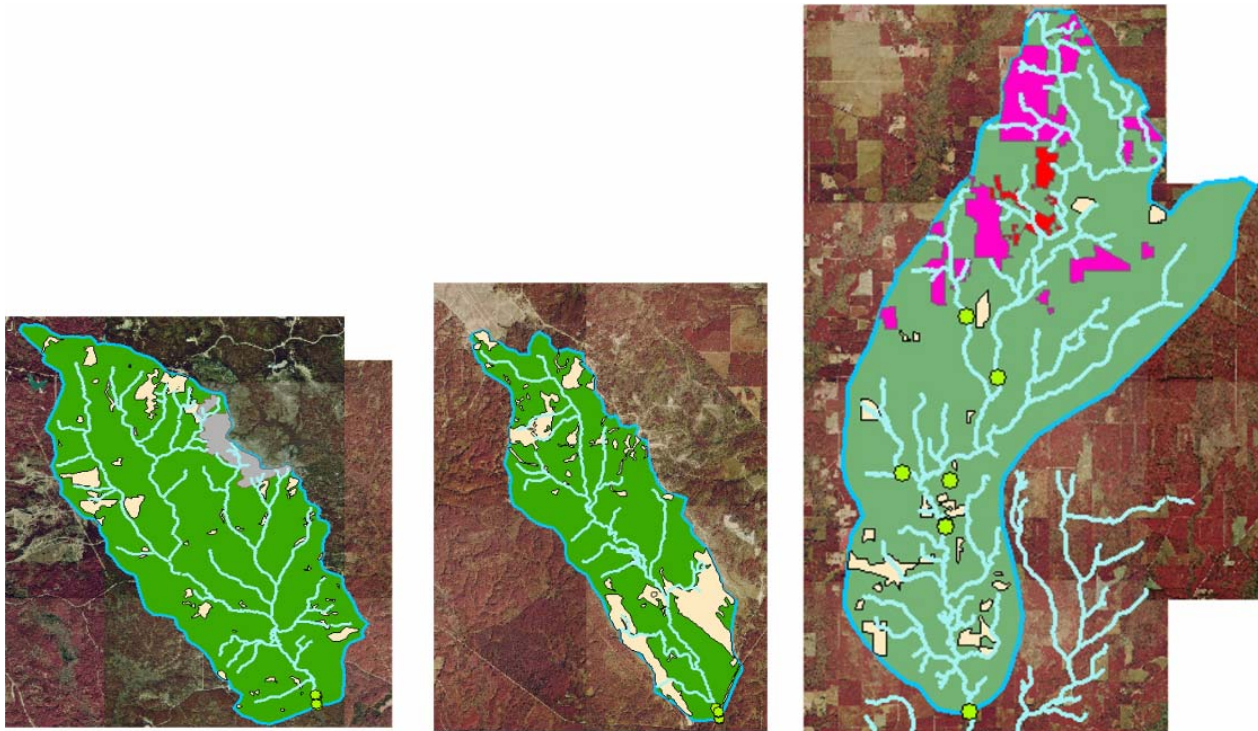
Beginning in August 2002, I selected sampling sites in each stream that included a site that I suspected, based on land manager input, to be impacted by adjacent land use, and two sites at varying distances upstream and downstream to serve as reference locations. The suspected impacts were limited recreational use, intensive riparian clearing and road crossing, and silviculture (with streamside management zones) in Six Mile, Big Brushy and Mill Creeks, respectively. At each site, I collected 9 benthic samples with a modified Hess sampler (0.0182 m<sup>2</sup>, 250 µm mesh), and 9 woody debris samples that each consisted of 10 sticks ranging in diameter from 10 and 50 mm in diameter, which were placed in a mesh (250 µm) 472-mm x 127-mm x 127-mm bag. All 648 samples (4 sampling periods x 3 streams x 3 sites x 9 Hess samples and 9 woody debris samples) were preserved in 70% ethanol in the field. The number of samples collected was based on a power analysis of preliminary data collected in July 2002 (Peterman 1990). I also collected two 1 L water column samples for fecal coliform (FC) and heterotrophic plate counts (HPC) at each site, following collection protocols outlined by the American Public Health Association (1998), and a 1-L water sample for analyses of biochemical oxygen demand (BOD), total carbon (TC), inorganic carbon (IC), total organic carbon (TOC), dissolved organic carbon (DOC), and total nitrogen (TN). At each site in each stream, I measured dissolved oxygen (DO), specific conductance (SpC), and temperature with a handheld YSI Model 95 probe (YSI Incorporated, Yellow Springs, OH, U.S.A.). I then measured depth, flow (Sontek velocity meter, YSI Incorporated, Yellow Springs, OH, U.S.A.), number, size, orientation, and complexity (single or multiple pieces) of

woody debris, canopy cover, riparian vegetation, habitat type, and presence of benthic fine organic detritus (FOD) at three points along 10 transects located at approximately 10-m intervals along a 100-m stream reach, with transect length determining wetted stream width. I collected my data in August 2002 and 2003 when summer flows were low and temperatures were high, and in April 2003 and 2004 following episodic and torrential high water events from winter tropical storms and Hurricane Lili (Figure 3.2).

Macroinvertebrate samples were frozen until processing, and were then sorted under magnification and placed in 95% ethanol prior to identification. Members of Chironomidae, Ceratopogonidae, Tipulidae, and all Annelida were mounted on glass microscope slides with CMC-10 (Master's Chemical Company, Elk Grove, IL, U.S.A.) following protocols outlined by Epler (2001) and identified to lowest practical taxon, rarely species, but more often family and sub-family under high magnification. All other macroinvertebrate taxa were identified to lowest practical taxon, occasionally species, but more often genus, and head capsule measurements were made for each individual. A small percentage of samples were set aside for identification quality control, and remaining samples were placed in 95% ethanol for long-term storage.

Water samples collected for chemical analyses were stored and split into BOD samples and carbon samples. BOD samples were tested at five and twenty days. Carbon samples were analyzed with a Shimadzu TOC-V Combustion Analyzer (Shimadzu North America, Columbia, MD, U.S.A) via Method 5310.B (APHA 1998).

Laboratory procedures for FC and HPC estimation followed protocols of the American Public Health Association (1998). Six subsamples of 1, 10, and 50 mL volume (2 of each) were filtered through a Millipore HC fecal coliform testing filter (Millipore Incorporated,

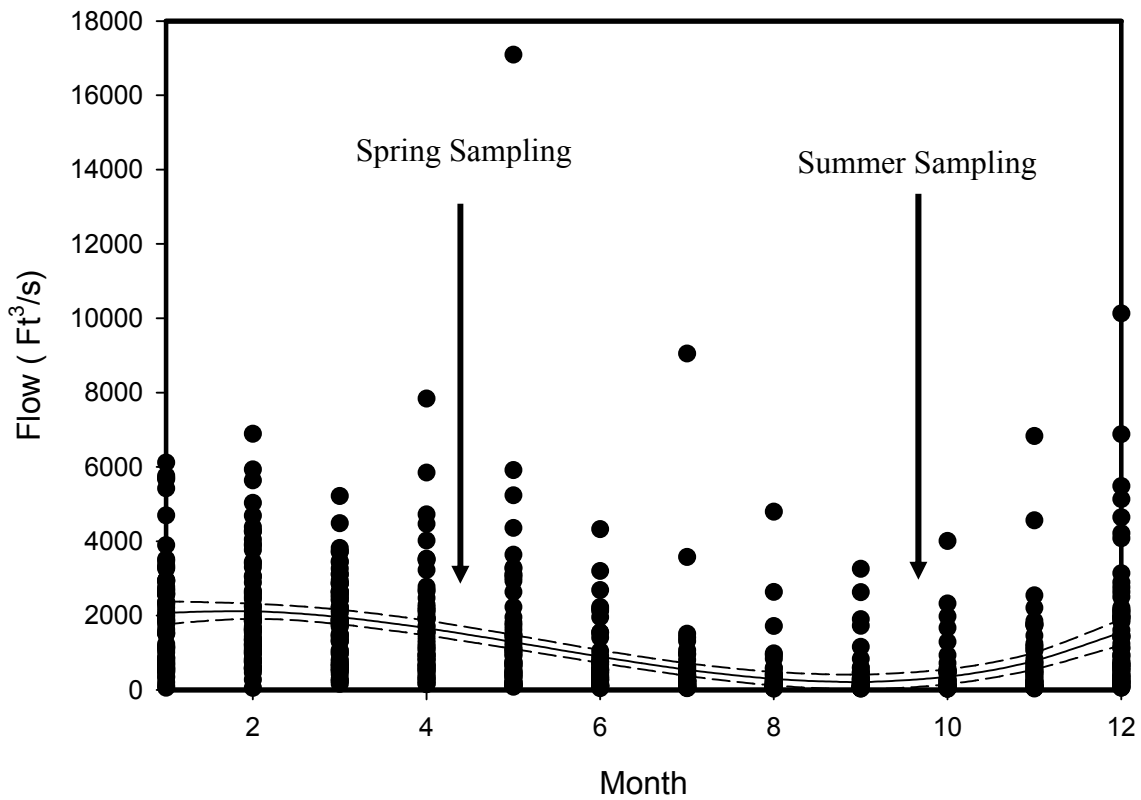


Six Mile Creek  
47,097 Ha

Big Brushy Creek  
27,200 Ha

Mill Creek  
161,470 Ha

**Figure 3.1.** Land use maps generated from GIS (ARC GIS 8.0, ESRI, Redlands, CA) analysis of digital photos show the breakdown of land use in each watershed. Dark blue denotes watershed boundary. Light blue indicates the streams and their tributaries. Green, red, magenta, and tan denote forest, urban, agricultural, and cleared land. Green dots indicate sampling locations.



**Figure 3.2.** Stream discharge varies throughout the year in this hydrograph constructed from United States Geologic Survey data indicating mean discharge (solid line) and 95% confidence intervals (dashed lines) from 1922-2002 on the Calcasieu River, which receives water from all three creeks. Sampling was timed with spring high, but workable flows, and later summer low flows

Billerica, MA, U. S. A.). I added Millipore FC media and incubated the samples for 24 h at 38°C. Twelve additional subsamples of 1, 1/10, 1/100, 1/1000, and 1/10,000 mL were taken for heterotrophic plate counts, which were mixed with R2A media in pour plates and incubated for 48 h at 35°C. FC and HPC were made under magnification with a darkfield Quebec colony counter (Leica Microsystems, Buffalo, NY, U. S. A.).

I reduced the dimensionality of habitat, physiochemical, and bacterial parameters from 19 variables to six principal components with principal component analysis (PCA; PROC FACTOR, SAS, version 9.0, SAS Institute, Cary, NC, U.S.A) with Horn's test for stopping criteria (Jackson 1993) and a varimax rotation. I then compared scores for the resulting principal components among sites with multivariate analysis of variance (MANOVA) and a post-MANOVA Tukey-Kramer test of least-squared means (PROC GLM, SAS, version 9.0, SAS Institute, Cary, NC, U.S.A). The relationship among sites, streams, and seasons was assessed with canonical discriminant function analysis (CDFA) (PROC CANDISC and PROC DISCRIM, SAS, version 9.0, SAS Institute, Cary, NC, U.S.A.), with cross-validation, to highlight variables that differed among sites, streams, and seasons.

For analysis of the macroinvertebrate community, I converted the macroinvertebrate count data to density data based on a standard volume (500 mL), which was the volume of substrate sampled by the Hess sampler, for comparisons between benthic and woody debris habitats. I analyzed the macroinvertebrate data with both multivariate statistical analyses (i.e. Norris 1995) and 18 macroinvertebrate community metrics used by other coastal plain researchers (DeWalt 1995; Barbour et al. 1996; Davis et al. 2003) to differentiate stream communities. I avoided indices based on intolerance/tolerance of pollution because of wide tolerances of some coastal plain taxa (Chapter 2), and performed nested analysis of variance

(ANOVA) with adjusted p-values to reduced experiment-wise error rate to compare community metrics among seasons and streams and between impact and reference sites (PROC MIXED, SAS, version 9.0, SAS Institute, Cary, NC, U.S.A.). Log transformation was necessary to more nearly approximate assumptions of normality for % Amphipoda, % Crustacea, % Dominant family, % Diptera, Filter-feeder taxa, % Ephemeroptera, % EPT (Ephemeroptera, Plecoptera, and Trichoptera) taxa, % Exposed gills, % Oligochaeta, and Elmid richness. Because so many taxa (91) were fairly uncommon (< 1% of samples) and statistical inference on rare taxa is difficult, if not impossible, I reduced the number of taxa to 54 taxa that were present in more than 1% of samples (Table 3.1). I selected principal components and canonical correlation analyses for my multivariate analyses rather than detrended correspondence and canonical correspondence analyses that are often used in macroinvertebrate studies (e.g., Legendre and Gallagher 2001; Eyre et al. 2005) because, I believed linear transformation was the most appropriate for my data. Subsequently, I grouped macroinvertebrate taxa with PCA (PROC FACTOR, SAS, version 9.0, SAS Institute, Cary, NC, U.S.A) to establish community structures using Horn's test to determine component retention (Jackson 1993) and varimax rotation. I analyzed relationships between macroinvertebrate taxa and land use, sampling period, habitat, physiochemical, and bacterial parameters with canonical correlation analysis (CCA; PROC CANCORR, SAS, version 9.0, SAS Institute, Cary, NC, U.S.A). All reported differences are significant at  $p < 0.05$ .

**Table 3.1.** Reduced set of macroinvertebrate taxa found in greater than 1% of samples and used in stastical analyses. An asterick indicates taxonomic level used in analyses.

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Annelida	Oligochaeta	Lumbricidae*
		Rhychobdellidae
		<i>Helobdella</i> spp.*

**Table 3.1.** Continued.

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Crustacea	Amphipoda	Crangonyctidae	<i>Crangonyx</i> spp.*	
	Decapopda	Cambaridae*		
	Isopoda	Asellidae	<i>Lirceus</i> spp.*	
Insecta	Coleoptera	Elmidae	<i>Ancyronyx</i> spp.*, <i>Gonielmis</i> spp.*, <i>Macronychus glabratus</i> *, <i>Promoresia</i> spp.*, <i>Stenelmis</i> spp.*, Unidentified Elmidae*	
			Psephenidae	<i>Ectopria</i> spp.*
		Diptera	Athericidae	<i>Atherix</i> spp.*
			Ceratopogonidae	<i>Bezzia</i> spp.*, <i>Forcipomyia</i> spp.*, Other Ceratopogonidae*
			Chironomomidae	Chironominae*, <i>Corynoneura</i> spp.*, Orthocladinae*, Tanypodinae*, Unidentified Chironomidae*
			Simuliidae*	
			Tipulidae	<i>Pedicia</i> spp.*
			Unidentified Diptera*	
		Ephemeroptera	Baetidae*	
			Caenidae	<i>Caenis hilaris</i> *
			Heptageniidae	<i>Stenacron floridense</i> *, <i>Stenacron</i> <i>interpunctatum</i> *, <i>Stenonema</i> spp.*

**Table 3.1.** Continued.

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		Leptophlebiidae*	
Megaloptera	Sialidae		<i>Sialis</i> spp.*
Odonata	Coenagrionidae		<i>Argia</i> spp.*
	Gomphidae		<i>Dromogomphus</i> spp.*
Plecoptera	Leuctridae		<i>Leuctra</i> spp.*, Other Leuctridae*
	Perlidae		<i>Agnatina</i> spp.*, <i>Eccoptura</i> spp.*, <i>Neoperla</i> spp.*, <i>Perlesta</i> spp., <i>Perlinella</i> spp.*, Unidentified Perlidae*
Trichoptera	Hydropsychidae		<i>Cheumatopsyche</i> spp.*, <i>Macrostenum</i> spp.*
	Philopotamidae		<i>Chimarra</i> spp.*, <i>Wormaldia</i> spp.*
	Polycentropodidae		<i>Polycentropus</i> spp.*
Mollusca			
Gastropoda	Ampullaridae		<i>Pomacea</i> spp.*
	Ancylidae		<i>Laevepex</i> spp.*
	Physidae*		
	Planorbidae*		
Pelecypoda	Corbiculidae		<i>Corbicula</i> spp.*
	Unionidae*		
	Sphaeridae*		
	Unidentified Pelecypoda*		

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## RESULTS

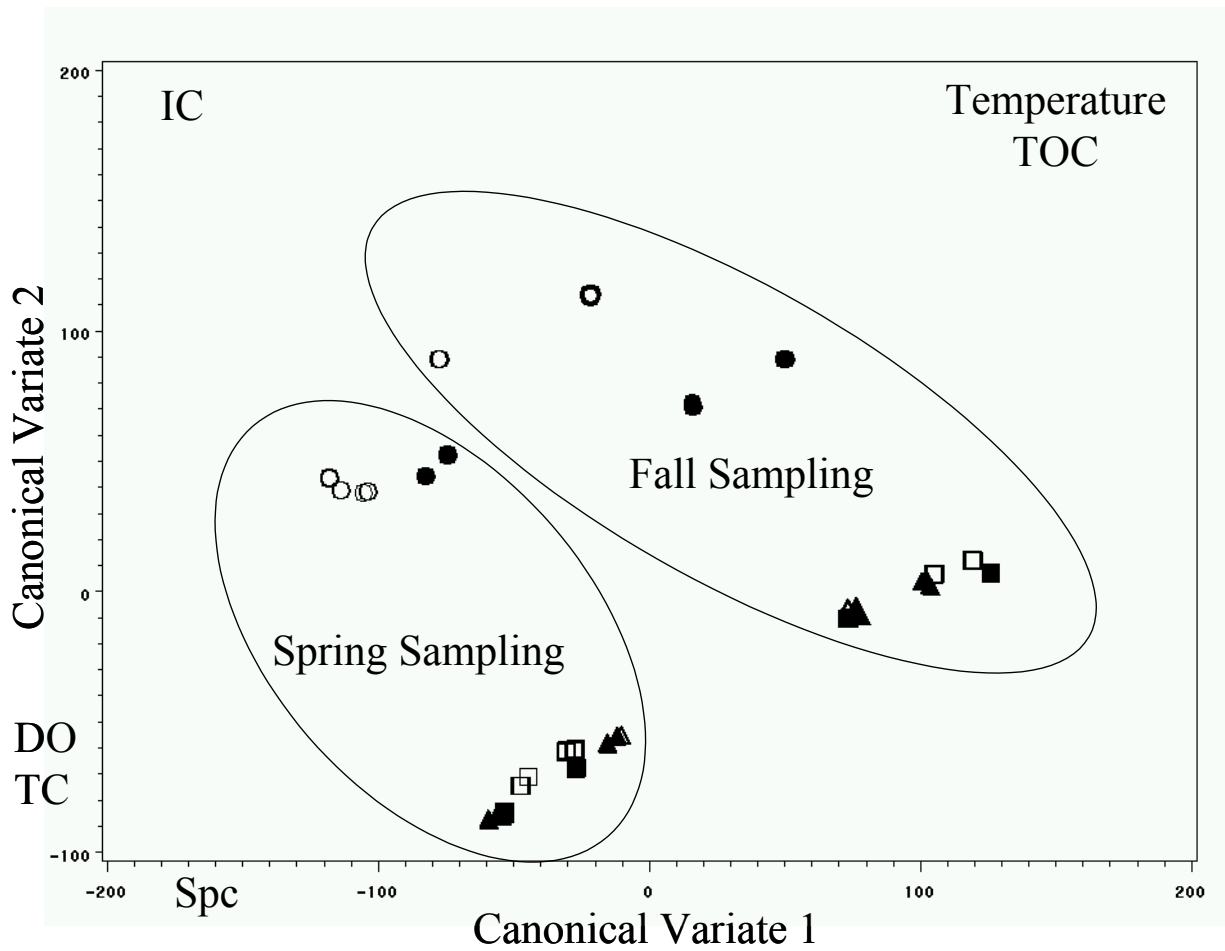
The six principal components constructed from the physical, habitat, and bacterial data, which accounted for 76% of the variance in the data, will hereafter be referred to as the water quality, woody debris complexity, woody debris size, discharge, bacterial, and temperature components, respectively (Table 3.2). The interaction of sampling period, stream, and site and the interaction of stream and site within sampling period were significant in the MANOVA; therefore, I conducted subsequent MANOVA examining site differences within each sampling period and season combination (Table 3.3). Overall, 49 of 72 (68%) comparisons were significantly different between impacted and reference sites, with the water quality (11 of 72, 15%) and bacterial (10 of 72, 14%) components yielding the greatest number of differences.

Results of the CDFA show that sites can also be classified by temperature, TC, IC, TOC, Spc, DO, BOD, and FC (Table 3.4), and that site separation is based on time of year, stream, and impact (Figure 3.3). Cross-validation of the CDFA indicated a 100% correct classification of sites with the discriminant function.

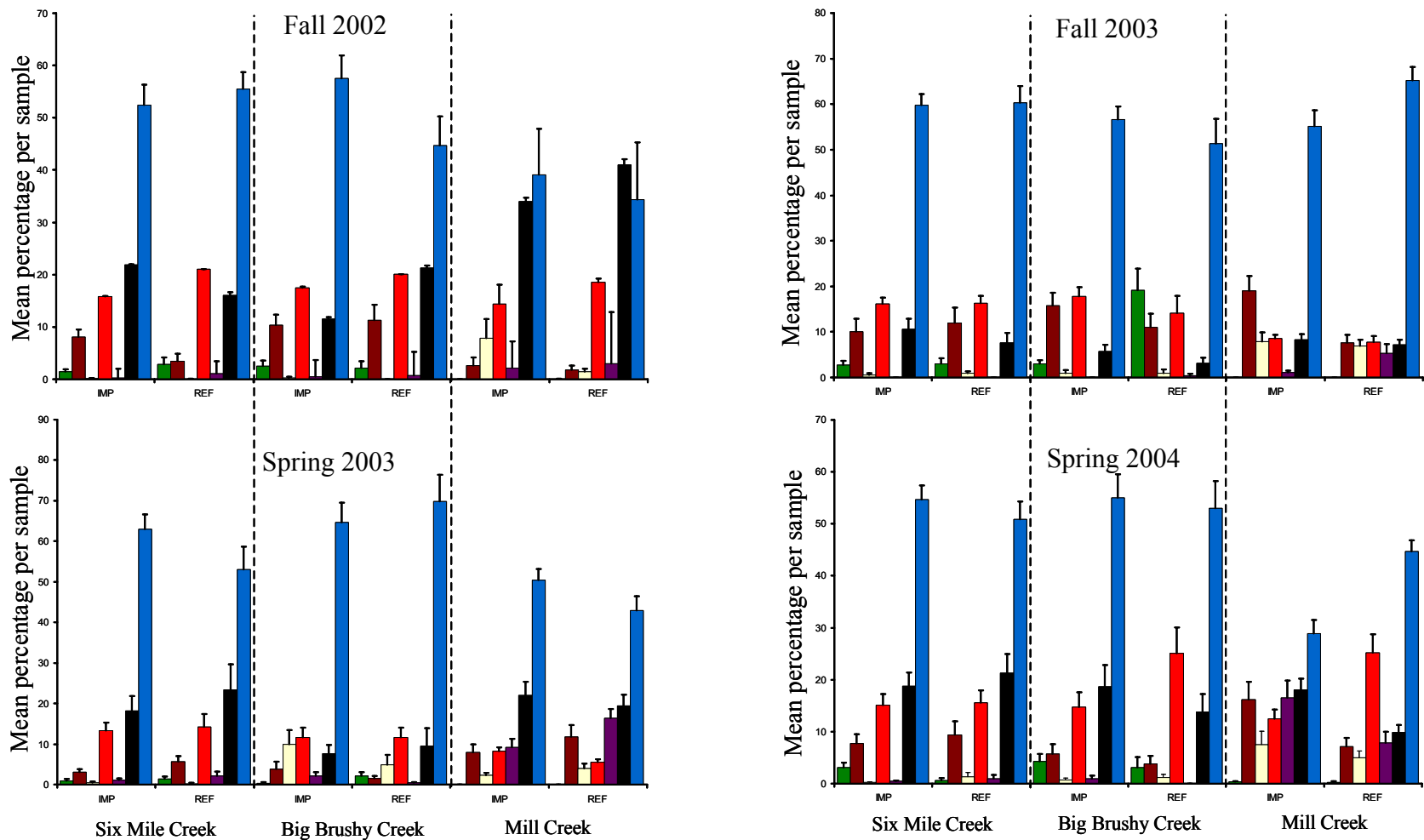
I identified a total of 26,209 individuals in 145 taxonomic and 5 feeding groups during the study (Figure 3.4). Mill Creek contained 87 taxa (60% of potential taxa), Big Brushy Creek contained 89 (61%) taxa, and Six Mile Creek contained 95 (66%) taxa. Mill Creek had 23 unique taxa (16% of overall taxa and 26% of taxa found in Mill Creek), whereas 16 taxa (11% of overall taxa and 18% of Big Brushy Creek taxa) were unique to Big Brushy Creek and 18 taxa (12% of overall taxa and 19% of Six Mile Creek taxa) were unique to Six Mile Creek. Forty-eight taxa (33% of overall taxa) were found in all three streams, and 88 taxa (61%) were found in at least two of the three streams.

**Table 3.2.** Principal component loadings for the six habitat components (PC 1-6) which explain 76% of the variance in the data. The coefficients listed below indicate the loadings of the original variables on the principal components. Shading indicates loadings greater than 0.30.

<b>Initial Variable</b>	<b>PC 1</b>	<b>PC 2</b>	<b>PC 3</b>	<b>PC 4</b>	<b>PC 5</b>	<b>PC 6</b>
Dissolved oxygen	-0.94	-0.05	-0.08	< 0.01	< 0.01	-0.17
Temperature	0.13	0.03	0.05	-0.09	-0.01	0.90
Specific conductance	0.75	0.06	-0.01	0.06	0.07	0.10
Heterotrophic plate count	0.23	-0.10	-0.04	-0.14	0.68	0.24
Fecal coliform count	0.13	-0.04	-0.09	-0.28	-0.74	0.33
Biochemical oxygen demand (20 day)	0.90	0.05	0.06	-0.16	-0.05	-0.22
Dissolved organic carbon	0.78	0.13	<0.01	-0.47	-0.06	-0.11
Total carbon	0.97	0.13	0.07	-0.10	-0.04	0.06
Inorganic carbon	0.94	0.11	0.10	0.14	0.09	0.10
Total organic carbon	0.79	0.13	< 0.01	-0.46	-0.05	-0.01
Total nitrogen	0.69	0.01	<0.01	-0.07	0.12	0.17
Depth	-0.02	-0.44	-0.15	-0.40	0.37	0.32
Discharge	-0.17	0.17	-0.04	0.80	0.03	-0.13
Coarse woody debris(>1 mm)	0.10	0.86	0.04	0.03	0.05	0.03
Wood diameter	0.10	0.26	0.89	< 0.01	<0.01	0.02
Wood volume	0.05	-0.08	0.96	-0.02	-0.02	0.02
Wood complexity	0.11	0.88	0.08	-0.07	0.02	-0.12
Wood orientation	-0.13	-0.62	-0.01	-0.29	0.13	-0.19
Fine organic detritus	0.48	0.29	0.03	-0.32	0.39	-0.08
% Variance explained	35.4	13.6	8.4	7	6.2	5.7



**Figure 3.3.** An ordination of the first two linear functions of the canonical discriminant function represents Mill (circles), Big Brushy (squares), and Six Mile Creeks (triangles). Filled shapes are reference sites, and opened shapes are impacted sites.



**Figure 3.4.** Functional feeding groups were similar among streams and between impacted (IMP) and reference (REF) sites. Macroinvertebrates were placed into shredders (green), scrapers (brown), filterers (yellow), predators (red), detritivores (purple), and collectors (blue). Macroinvertebrates with unknown or uncertain affiliations were kept separate (black). Dotted lines divide the streams. Standard error bars are given for each mean.

**Table 3.3.** MANOVA results indicated a large number of significant ( $p < 0.05$ ) differences between sites. Mean component scores and p-values (P) are shown for reference and impacted sites. Empty cells are not significantly different.

<b>Summer 2002</b>									
<b>Principal components</b>	<b>Mill Creek</b>			<b>Big Brushy Creek</b>			<b>Six Mile Creek</b>		
	<b>R</b>	<b>I</b>	<b>P</b>	<b>R</b>	<b>I</b>	<b>P</b>	<b>R</b>	<b>I</b>	<b>P</b>
<b>Water quality</b>	0.99	1.7	<0.01	-0.62	-0.41	<0.01	-0.69	-0.61	0.01
<b>Woody debris complexity</b>	1.12	0.45	0.02	-0.29	-0.59	<0.01			
<b>Woody debris size</b>				-0.02	-0.18	<0.01			
<b>Discharge</b>	-0.48	1.9	<0.01	-0.12	-0.69	<0.01	-0.78	-0.54	0.007
<b>Bacterial</b>	-0.14	-0.70	<0.01	-1.5	-2.0	<0.01	0.08	0.15	0.002
<b>Temperature</b>	1.12	1.10	<0.01						
<b>Spring 2003</b>									
<b>Water quality</b>	0.79	1.34	<0.01	-0.77	-0.54	<0.01	-0.88	-0.62	<0.01
<b>Woody debris complexity</b>							0.66	-0.29	<0.01
<b>Woody debris size</b>	0.12	-0.13	<0.01						
<b>Discharge</b>	-1.19	-0.68	<0.01				0.27	0.86	<0.01
<b>Bacterial</b>	-0.20	0.34	<0.01				0.65	0.27	<0.01
<b>Temperature</b>	-2.05	-1.20	<0.01	-0.51	-0.75	<0.01			
<b>Summer 2003</b>									
<b>Water quality</b>	1.0	1.66	<0.01	-0.22	-0.63	0.03			
<b>Woody debris complexity</b>	-0.83	0.09	0.02	0.44	-0.26	0.01	0.13	0.79	0.03
<b>Woody debris size</b>				0.77	0.10	0.03	-0.22	-0.63	0.03
<b>Discharge</b>	-0.80	0.53	<0.01	-0.22	-0.63	0.03	0.20	0.85	<0.01
<b>Bacterial</b>	2.93	0.80	<0.01	0.34	0.79	0.04			
<b>Temperature</b>	1.1	0.68	<0.01	0.35	0.83	<0.01			

**Table 3.3.** Continued.

Spring 2004									
Principal components	Mill Creek			Big Brushy Creek			Six Mile Creek		
	R	I	P	R	I	P	R	I	P
	<b>Water quality</b>	1.02	1.56	<0.01	-0.87	-0.67	<0.01	-1.06	-0.95
<b>Woody debris complexity</b>	0.64	0.12	0.03	0.44	-0.69	<0.01	0.87	0.03	0.02
<b>Woody debris size</b>				-0.14	-0.04	<0.01			
<b>Discharge</b>	-1.34	-0.76	<0.01	1.06	0.38	<0.01	0.70	0.16	0.01
<b>Bacterial</b>				0.09	-0.24	<0.01	-0.05	0.12	0.03
<b>Temperature</b>	-1.55	-0.69	<0.01						

**Table 3.4.** Standardized coefficients generated for each variable from the canonical discriminant function analysis for the 7 significant canonical variates (CV). Shadings indicate coefficients larger than 1.0.

Initial variable	CV 1	CV 2	CV 3	CV 4	CV 5	CV 6	CV 7
<b>DO</b>	1.25	1.60	-0.79	1.15	0.35	-0.51	-0.19
<b>Temperature</b>	0.52	0.81	1.56	0.02	0.08	0.10	-0.01
<b>Spc</b>	-0.03	-3.03	-0.04	-0.74	1.10	0.16	0.09
<b>FC</b>	0.04	0.06	-0.05	-0.21	0.55	0.04	0.30
<b>HPC</b>	-0.40	0.37	-0.13	0.38	-0.41	0	0.56
<b>BOD</b>	0.82	-0.74	0.05	-0.52	-0.02	0.61	-0.06
<b>DOC</b>	-0.88	2.69	-0.24	0.04	0.06	0.30	0.04
<b>TC</b>	2.56	-43.41	5.04	-4.32	9.85	-0.69	-0.49
<b>IC</b>	-5.32	32.38	-3.72	4.59	-8.34	0.52	0.28
<b>TOC</b>	-2.64	33.22	-4.13	3.37	-7.54	-0.33	0.19
<b>TN</b>	3.45	5.49	-2.37	-0.22	0.47	0.55	0.06
<b>Depth</b>	-0.12	0.07	-0.04	0.37	0.15	-0.24	-0.24
<b>Discharge</b>	-0.22	-0.07	0.36	-0.08	0.24	-0.41	-0.05
<b>CWD</b>	-0.05	0	0.06	0.34	0.03	-0.14	0.28
<b>Wood diameter</b>	-0.20	0.03	0.23	0.23	0.01	-0.98	0.10
<b>Wood volume</b>	0.08	-0.02	-0.19	-0.12	0.11	0.76	0.05
<b>Wood complexity</b>	0.04	0.06	-0.34	-0.12	0.19	0.25	0.08
<b>Wood orientation</b>	0.04	-0.09	-0.09	0.13	-0.12	-0.35	0.40
<b>FOD</b>	-0.12	-0.01	0.21	-0.23	-0.04	0.24	-0.61
<b>Stream width</b>	0.08	0.31	-0.42	0.40	0.07	0.07	0.45

Community metrics identified significant differences in macroinvertebrate community structure between impacted and reference sites in 25% (18 of 72) of comparisons (Table 3.5). Community metrics were more often dissimilar among streams and sampling periods than between impacted and reference sites.

The 14 taxonomic groups identified with PCA included taxa associated with Six Mile Creek (PC 1), taxa I associated with Mill Creek (PC 2), organic matter collecting taxa (PC 3), biofilm and algal scraping taxa (PCs 4 and 6), detritivorous taxa (PC 7), wood-associated taxa (PC 8), potentially predaceous taxa (PC 9), mostly filtering and fine detrital feeders (PC 10), taxa associated with the limited swift, gravelly sites (PCs 11 and 12), and several groups of uncertain association (PCs 5, 13, and 14; Table 3.6). Macroinvertebrate communities exhibited substantial overlap among sampling sites (Figure 3.5).

**Table 3.5.** Few actual responses of macroinvertebrate community metrics (from DeWalt 1995<sup>3</sup>; Barbour et al. 1996<sup>1</sup>; Davis et al. 2003<sup>2</sup>) to impacts matched expected responses. The metric Elmid richness was designed for this study. EPT is Ephemeroptera, Plecoptera, and Trichoptera taxa. Asterisk indicates only enough samples to calculate for Mill Creek.

<b>Metric</b>	<b>Expected response</b>	<b>Actual impact response</b>	<b>Actual stream response</b>	<b>Actual seasonal response</b>
% Amphipoda <sup>2</sup>	Decrease	No significant increases	Significant differences	Significant differences
% Burrowers <sup>2</sup>	Increase	Too few observations	Too few observations	Too few observations
% Crustacea <sup>2</sup>	Decrease	3 (of 12) significant decreases	Significant differences	No significant differences

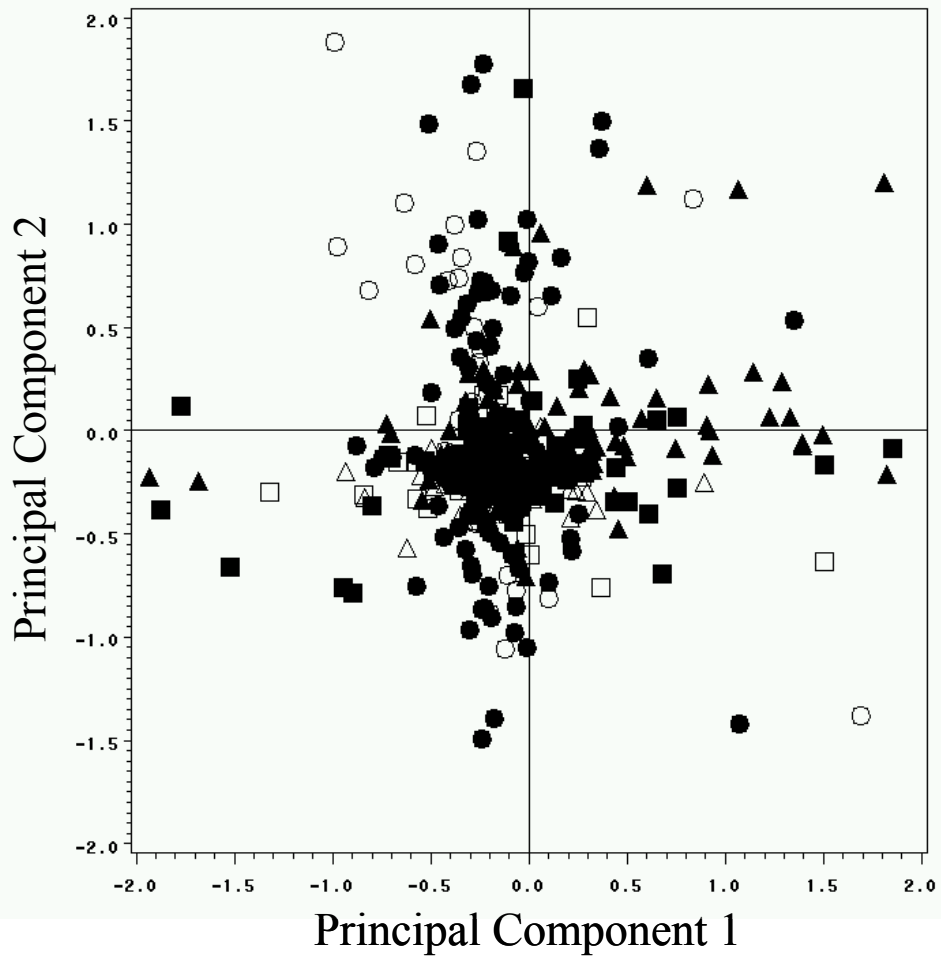


**Table 3.5.** Continued.

<b>Metric</b>	<b>Expected response</b>	<b>Actual impact response</b>	<b>Actual stream response</b>	<b>Actual seasonal response</b>
Chironomid richness <sup>1</sup>	Increase	4 (of 12) significant increases	Significant differences	Significant differences
% Diptera <sup>1,2</sup>	Increase	1 (of 12) significant increase	Significant differences	Significant differences
% Dominant <sup>1,2</sup>	Increase	1 (of 12) significant increase	Significant differences	Significant differences
% Ephemeroptera <sup>2</sup>	Decrease	1 (of 12) significant decrease	Significant differences	Significant differences
% EPT <sup>2</sup>	Decrease	3 (of 12) significant decreases	Significant differences	Significant differences
EPT richness <sup>1,3</sup>	Decrease	Nearly identical	Significant differences	No significant differences
Filter-feeder richness <sup>1</sup>	Increase	Non-significant increases	No significant differences	No significant differences

**Table 3.5.** Continued.

<b>Metric</b>	<b>Expected response</b>	<b>Actual impact response</b>	<b>Actual stream response</b>	<b>Actual seasonal response</b>
% Gastropoda <sup>2</sup>	Decrease	Too few observations	Too few observations	Too few observations
Elmid richness	Unknown	4 (of 12) significant increases	Significant differences	Significant differences
% Exposed gills <sup>2</sup>	Increase	Non-significant differences	Significant differences	Significant differences
% Isopoda <sup>2</sup>	Increase or Decrease	Too few observations	Too few observations	Too few observations
Number of taxa <sup>1</sup>	Decrease	Non-significant decrease or same	Significant differences	No significant differences
% Odonata <sup>2</sup>	Increase	Too few observations	Too few observations	Too few observations
% Oligochaeta <sup>2</sup>	Increase	No significant increases	Significant differences	Significant differences
% Pelecypoda <sup>2</sup>	Decrease	1 (of 4) significant decrease*	Significant differences	No significant differences



**Figure 3.5.** An ordination of the first two principal components constructed from macroinvertebrate taxa illustrates substantial taxonomic overlap among Mill (circles), Big Brushy (squares), and Six Mile Creeks (triangles). Filled shapes are summer samples, and opened shapes are spring samples.

**Table 3.6.** Principal components constructed from the reduced (54 taxa) macroinvertebrate taxa. The coefficients listed below indicate the loadings of the original variables on the principal components. Shading indicates loadings greater than 0.30.

Initial variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	PC 11	PC 12	PC 13	PC 14
<i>Agnatina</i> spp.	-0.04	-0.03	0	0.54	-0.04	0.04	0-0.05	0.04	0.01	-0.11	0.09	0.08	-0.02	0.17
<i>Ancyronyx</i> spp.	0.15	-0.03	0.04	-0.07	-0.04	-0.02	0	-0.02	0.66	-0.01	0.03	-0.01	0.1	-0.06
<i>Argia</i> spp.	-0.10	-0.01	0	0.01	-0.03	0.04	-0.06	0.23	0.08	0.02	-0.04	0.20	0	-0.18
<i>Atherix</i> spp.	0.74	0.01	0.01	-0.02	0.03	-0.04	-0.02	0.35	0.16	-0.02	-0.02	-0.06	-0.02	0.05
Baetidae	-0.05	0.08	-0.01	0.64	-0.02	0.06	-0.13	0.12	0.30	-0.13	-0.07	-0.01	-0.18	0.08
<i>Bezzia</i> spp.	-0.08	-0.02	-0.05	-0.03	0.02	-0.10	0.04	-0.02	-0.14	-0.03	0.03	0.06	0.16	0.59
<i>Caenis hilaris</i> Say	-0.05	0.18	0.04	0	0.53	0.47	0.30	-0.08	-0.03	-0.05	0	-0.10	-0.05	-0.02
Cambaridae	0	0.05	-0.04	0	0.65	-0.08	-0.04	0.02	-0.02	0.07	-0.01	0.17	0.01	-0.05
Ceratopogonidae	0.12	0.05	-0.06	0	0.10	0.08	-0.10	0.12	0.06	-0.08	-0.09	-0.06	-0.14	-0.05
<i>Cheumatopsyche</i> spp.	0.18	0.05	0.69	-0.02	-0.08	0.03	-0.05	-0.04	0.02	-0.09	0.07	0.07	0.10	-0.04
<i>Chimarra</i> spp.	0.53	0	0.09	-0.07	-0.08	0.10	-0.06	0.16	-0.19	-0.03	-0.06	0.01	0.13	-0.08
Chironominae	0.08	-0.05	-0.03	0	0.15	0	0.74	0.14	0	0.03	0.02	0.03	0.07	0.05
<i>Corbicula</i> spp.	-0.05	0.01	0.02	-0.04	0.21	0	0.11	-0.02	0	0.66	-0.02	-0.08	-0.06	0.07
<i>Corynoneura</i> spp.	0.10	-0.04	0	0.36	0.01	-0.02	0.05	0.15	-0.05	0.01	0.22	0.26	0.38	0.26
<i>Crangonyx</i> spp.	-0.08	0.30	0.11	0.26	0.57	0.22	0.01	-0.08	0.05	-0.03	0.01	-0.08	0.10	-0.06
<i>Dromogomphus</i> spp.	-0.03	-0.05	-0.04	-0.08	0.64	-0.06	0.09	-0.08	0.06	0	-0.02	-0.06	-0.04	0.05
<i>Eccoptura</i> spp.	0.50	-0.04	0	0.18	0	-0.01	-0.02	-0.06	-0.15	0.03	0.31	0.01	0.02	-0.05
<i>Ectopria</i> spp.	0.04	0	0.02	-0.05	-0.02	0.02	-0.01	-0.01	0.42	0.01	-0.08	-0.03	0.49	-0.02
<i>Forcipomyia</i> spp.	0.03	0	-0.02	0.01	-0.01	-0.06	0.06	0	0.77	0.05	0.02	0.13	-0.02	-0.12
<i>Gonielmis</i> spp.	0.17	0	0.03	-0.05	-0.02	0.34	-0.03	0.10	-0.05	-0.10	-0.03	-0.09	0.42	0.01
<i>Helobdella</i> spp.	-0.02	0.14	0.06	0.11	0.16	0.26	0.68	0.01	-0.08	0.15	-0.04	0.04	0.08	-0.06
<i>Laevepex</i> spp.	-0.03	-0.08	0.06	0.65	0.17	-0.02	0.15	-0.13	-0.12	0.21	-0.06	-0.07	0.07	-0.23
Leptophlebiidae	-0.02	0.01	0.06	-0.02	0.06	-0.01	0.01	0.11	0	-0.04	-0.02	0.82	-0.01	-0.13
<i>Leuctra</i> spp.	-0.07	-0.01	0.01	0.01	-0.05	0.04	0.02	0.03	-0.03	-0.04	0.64	0	-0.04	0.04
<i>Lirceus</i> spp.	-0.02	0.40	-0.03	0.53	0.21	0.21	0.12	0.01	-0.04	0.17	-0.06	-0.06	0.06	-0.12
Lumbricidae	0.09	0.39	-0.04	-0.04	0.20	-0.05	0.19	0.29	-0.09	-0.03	-0.02	-0.06	-0.07	0.18
<i>Macronychus glabratus</i> Say	0.17	0.07	0.32	-0.05	0.02	0.13	-0.06	0.48	0.12	0.46	-0.07	0.12	0.03	0.15
<i>Macrostenum</i> spp.	0.22	-0.01	-0.02	-0.01	0.07	-0.06	0	0.03	0.20	0	0.48	-0.03	0.15	0.06
<i>Neoperla</i> spp.	-0.05	0	0.01	0.04	-0.04	0.02	-0.01	0.04	-0.03	0.03	-0.01	0	-0.01	0.58
<i>Pedicia</i> spp.	-0.07	0.05	-0.05	-0.03	-0.02	-0.05	0.07	-0.08	0.58	-0.01	0.11	-0.02	0.06	0.03
<i>Perlesta</i> spp.	-0.08	0.02	0.86	0.04	0.02	-0.05	0	-0.01	-0.08	0.03	0.01	-0.02	-0.03	0
Perlidae	0.07	0.08	0	0.08	0.04	-0.01	0	0.01	0.07	-0.04	-0.02	-0.04	0.66	0.15

**Table 3.6.** Continued.

Initial variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	PC 11	PC 12	PC 13	PC 14
<i>Perlinella</i> spp.	0.13	0	0.01	0.09	-0.02	0.03	-0.06	0.52	0.05	-0.10	-0.09	-0.09	0	0.10
Physidae	-0.03	-0.07	0.39	0.08	0.23	-0.04	0.16	-0.04	-0.16	-0.20	-0.02	-0.07	-0.02	-0.15
<i>Polycentropus</i> spp.	0.38	-0.03	0	-0.02	0.06	-0.09	0	0.60	-0.06	-0.01	0.25	-0.03	-0.06	0
<i>Pomacea</i> spp.	0	0.01	-0.02	0.01	0.05	0.81	0.13	0.48	-0.03	0.09	0	-0.01	0	-0.06
<i>Promoresia</i> spp.	-0.09	-0.03	0.03	0.02	-0.01	0.01	0.02	0.48	0.02	-0.01	-0.02	-0.04	0.02	0.01
<i>Sialis</i> spp.	-0.02	0.57	0	-0.02	-0.03	-0.03	0.38	-0.12	0.07	0.06	0	-0.04	-0.12	0
Simuliidae	0.01	0.02	0.02	0.02	-0.01	0.04	-0.04	-0.01	-0.01	0	0.78	-0.02	-0.08	-0.05
Sphaeriidae	-0.03	0.77	0.01	0.05	0.22	0.05	0.04	0.05	-0.04	0.01	0.01	-0.02	0.09	0.02
<i>Stenacron floridense</i> Lewis	-0.02	0.05	0.01	-0.02	0.46	0.45	0.04	0.02	-0.03	0.46	0.01	-0.01	0.02	-0.04
<i>Stenacron interpunctatum</i> Say	-0.05	0.56	0.02	-0.01	-0.03	-0.02	0	-0.10	-0.04	0.06	0	0.26	0.23	-0.12
<i>Stenelmis</i> spp.	-0.06	-0.02	0.81	-0.02	-0.04	0.01	-0.05	0.03	0.22	0.10	-0.05	0	-0.06	0.04
<i>Stenonema</i> spp.	0.14	-0.04	0	0.23	-0.05	0.49	-0.06	0.03	0.09	-0.11	0.09	0.12	0.05	0.32
Tanypodinae	0.29	-0.05	0.49	0.17	0.06	-0.02	0.17	0.05	0.08	0.32	-0.02	0.06	0.03	0.03
Unidentified Chironomidae	0.01	0.06	0.05	0.59	-0.08	-0.07	0.09	-0.10	-0.01	0.06	0.04	0	0.13	-0.05
Unidentified Coleoptera	-0.03	-0.02	-0.02	-0.01	-0.05	0.54	0.02	-0.04	0.02	0.04	0.01	0.01	0.02	-0.06
Unidentified Diptera	0.58	-0.01	0.04	-0.02	-0.05	0.05	0.07	-0.05	-0.05	0.03	-0.05	0.02	0.01	-0.05
Unidentified Elmidae	0.73	0.07	-0.03	-0.04	-0.02	-0.02	0.06	0.12	0.10	-0.02	0.04	0.02	0.12	-0.03
Unidentified Leuctridae	0.01	-0.02	-0.02	0.06	0	0.03	0.02	-0.08	-0.01	-0.03	-0.03	0.70	-0.09	0.26
Unidentified Pelecypoda	0.01	0.35	-0.02	0	-0.16	0.09	0.69	-0.05	0.05	-0.03	-0.02	-0.04	0.13	0.01
Unidentified Planorbidae	0	0.02	-0.05	0.06	-0.12	0.03	-0.01	-0.05	-0.06	0.66	-0.01	-0.01	-0.03	-0.07
Unidentified Unionidae	-0.01	0.77	0	0.03	-0.03	-0.02	-0.01	0	-0.02	-0.03	0	-0.07	-0.05	0.01
<i>Wormaldia</i> spp.	0.34	-0.03	0.11	0.1	0.04	0.05	-0.09	0.04	0.31	-0.06	-0.10	0.01	-0.37	0.33

The first canonical variate identified by the CCA (Tables 3.7 and 3.8) was spatially associated with Mill Creek, which reflected the greater carbon processing and lower dissolved oxygen conditions present, and was correlated with filtering and collecting macroinvertebrates. The second canonical variate was associated with woody debris substrate and was correlated positively with 2 Elmidae genera and negatively with benthic-associated macroinvertebrates. The third canonical variate was associated with land use and was correlated positively with collecting and predaceous, but negatively with scraping, macroinvertebrates. The fourth canonical variate was correlated to water-borne bacteria (positively with heterotrophic plate counts and negatively with fecal coliform counts) and was

correlated with collecting Ceratopogonidae. The fifth canonical variate was a temporal axis that was correlated positively with collecting, but negatively with predaceous, macroinvertebrates. The sixth canonical variate was spatially associated with Six Mile Creek and was correlated with collecting and predaceous macroinvertebrates. The seventh canonical variate described water quality and correlated positively with filtering, collecting, and predaceous macroinvertebrates. The eighth canonical variate was associated with the impacted site of Big Brushy Creek, which was positively correlated with FC and HPC, and was correlated positively with collecting, but negatively with predaceous, macroinvertebrates. The ninth canonical variate was associated with the reference sites of Big Brushy Creek, which were negatively correlated with TN, and was correlated with collecting macroinvertebrates. The tenth canonical variate also was associated with woody debris and was negatively correlated with collecting macroinvertebrates.

**Table 3.7.** Canonical variates (CV 1-10) constructed from the combined macroinvertebrate and habitat data. Values listed are simple correlations between initial habitat variables and the canonical variate. Shading indicates correlation greater than 0.30.

<b>Initial Variable</b>	<b>CV 1</b>	<b>CV 2</b>	<b>CV 3</b>	<b>CV 4</b>	<b>CV 5</b>	<b>CV 6</b>	<b>CV 7</b>	<b>CV 8</b>	<b>CV 9</b>	<b>CV 10</b>
DO	-0.64	0.13	0.18	-0.02	-0.12	-0.01	-0.42	-0.18	0.04	0.17
Temperature	-0.29	0.43	-0.09	0.01	0.33	0.26	0.22	0.37	0.06	-0.20
SPC	0.60	0.03	-0.15	0.11	-0.08	0.03	0.53	0.15	0.12	-0.14
FC	0.13	0.04	-0.09	-0.38	-0.14	0.17	0.05	0.45	0.25	0.22
HPC	0.08	0	0.19	0.43	0.45	-0.24	0.35	0.21	0.06	0.19
BOD	0.79	-0.20	0.11	-0.04	0.14	-0.09	0.25	0.20	-0.12	-0.17
DOC	0.73	-0.13	0.23	0.11	0.20	0.30	0.07	0.23	-0.23	-0.09

**Table 3.7.** Continued.

<b>Initial Variable</b>	<b>CV 1</b>	<b>CV 2</b>	<b>CV 3</b>	<b>CV 4</b>	<b>CV 5</b>	<b>CV 6</b>	<b>CV 7</b>	<b>CV 8</b>	<b>CV 9</b>	<b>CV 10</b>
TC	0.70	-0.09	-0.05	0.11	0.14	0.08	0.40	0.18	-0.17	-0.23
IC	0.62	-0.08	-0.18	0.09	0.05	-0.03	0.53	0.07	-0.14	-0.30
TOC	0.67	-0.08	0.19	0.12	0.26	0.25	0.09	0.31	-0.19	-0.08
TN	0.37	-0.19	-0.45	0.34	0.11	0.24	0.35	0.13	-0.35	0.12
Depth	-0.07	0.15	0.03	0.22	0.14	-0.13	0.17	0.10	-0.07	0.16
Discharge	-0.29	-0.04	-0.07	-0.03	-0.33	-0.25	-0.02	-0.46	-0.17	-0.23
CWD	0.20	0.11	0.06	-0.01	-0.17	0.04	0.08	-0.08	-0.02	-0.44
Wood diameter	0.11	0	-0.06	0.01	-0.09	0.02	0.04	0.05	0	-0.26
Wood volume	0.04	0.05	-0.05	0.04	-0.02	0.02	0.11	0.02	0.05	0
Wood complexity	0.29	0.04	0.013	-0.06	-0.23	0.07	-0.05	-0.15	0.06	-0.28
Wood orientation	-0.12	-0.05	-0.03	0.11	0.18	-0.05	0	0.10	0.15	0.16
FOD	0.43	-0.11	0.07	0.32	0.18	0.14	-0.06	0.08	0	-0.10
Six Mile Creek	-0.45	0.11	0.31	0.23	-0.15	0.32	-0.13	-0.51	-0.13	0.17
Big Brushy Creek	-0.32	0.08	-0.35	-0.29	0.02	-0.29	-0.27	0.39	0.32	-0.02
Mill Creek	0.77	-0.19	0.04	0.05	0.13	-0.02	0.40	0.12	-0.19	-0.14
Time (linear)	0.33	0.09	0.15	0.42	-0.50	-0.30	-0.13	0	-0.02	0.17
Time (quadratic)	-0.32	0.08	-0.35	-0.29	0.02	-0.29	-0.27	0.39	0.32	-0.02
Time (cubic)	0.30	0.18	0.16	0.11	-0.63	-0.17	-0.02	0.06	-0.13	0.27
Land use	0	0.04	0.52	-0.17	0.07	-0.18	0.06	-0.08	0.27	0.04
Wood habitat	0.33	0.59	-0.33	-0.09	0.29	-0.15	-0.20	-0.36	0.02	0.22
Riffle habitat	-0.41	0.04	0.07	0.03	-0.22	0.03	-0.10	-0.10	0.24	-0.08

**Table 3.8.** Canonical variates (CV 1-10) constructed from the combined macroinvertebrate and habitat data. Values listed are simple correlations between initial macroinvertebrate taxa and the canonical variate. Shading indicates correlation greater than 0.30.

Macroinvertebrate taxa	CV 1	CV 2	CV 3	CV 4	CV 5	CV 6	CV 7	CV 8	CV 9	CV 10
<i>Agnetina</i> spp.	-0.05	-0.29	-0.14	0.12	0.19	-0.03	-0.18	-0.23	-0.10	0.14
<i>Ancyronyx</i> spp.	-0.11	0.45	-0.17	-0.02	0.19	-0.01	-0.45	0.11	0.03	0.20
<i>Argia</i> spp.	-0.08	0.14	0	0.13	0	-0.10	-0.23	0.21	-0.15	-0.04
<i>Atherix</i> spp.	-0.12	0.24	0.08	-0.01	0.20	0.47	-0.07	-0.18	-0.18	0.04
Baetidae	0	-0.33	-0.07	0.21	0.14	-0.02	-0.23	0.22	-0.42	-0.08
<i>Bezzia</i> spp.	-0.24	-0.32	0.16	0.03	-0.39	-0.22	0.05	-0.32	-0.03	0.18
<i>Caenis hilaris</i> Say	0.38	-0.14	0.16	-0.07	0.14	0.01	0.08	-0.01	-0.04	-0.52
Cambaridae	0.04	-0.05	0.16	0.03	0.12	0.12	0.22	0.07	0.08	-0.03
Ceratopogonidae	-0.13	0.07	0.22	0.42	-0.04	0.22	-0.03	0.12	0.13	-0.17
<i>Cheumatopsyche</i> spp.	0.03	0.18	0.12	-0.19	0.03	0.04	-0.18	0.05	0.17	0.05
<i>Chimarra</i> spp.	-0.13	0.16	0.11	-0.05	0.15	0.49	-0.08	-0.17	0.09	0.05
Chironominae	0.05	-0.02	-0.09	-0.11	0.19	-0.03	0.13	-0.07	0.02	-0.27
<i>Corbicula</i> spp.	0.32	0	0.15	0.27	0.02	-0.13	0.38	0.16	0.12	0.02
<i>Crangonyx</i> spp.	0.51	-0.39	0.27	-0.02	0.08	0.13	-0.10	0.13	-0.15	-0.02
Other Chironomidae	0.14	-0.08	-0.14	0	0.13	0	0.01	-0.10	-0.29	0.02
Other Coleoptera	0.10	-0.02	0.01	-0.03	0.27	-0.07	-0.03	-0.09	0.08	-0.04
<i>Corynoneura</i> spp.	-0.10	-0.52	-0.11	0.08	0.30	0.08	-0.21	-0.11	0.22	0.17
Other Diptera	-0.14	0	0.03	-0.17	0.06	0.24	0.04	0.08	0.12	0.03
<i>Dromogomphus</i> spp.	0.09	-0.05	-0.05	0.12	0	0.04	0.34	0.03	0.04	-0.28
<i>Eccoptura</i> spp.	0	-0.01	-0.04	-0.03	0.18	0.23	-0.02	-0.13	-0.12	0.04
<i>Ectopria</i> spp.	-0.05	0.12	0.03	0.08	0.07	0.18	-0.10	-0.08	0.01	0.01
Other Elmidae	-0.17	0.19	0.05	-0.26	0.26	0.53	0.07	-0.11	-0.17	0.12
<i>Forcipomyia</i> spp.	-0.12	0	0.01	-0.09	0.06	0.17	0.04	0.06	-0.14	-0.01



**Table 3.8.** Continued.

<b>Macroinvertebrate taxa</b>	<b>CV 1</b>	<b>CV 2</b>	<b>CV 3</b>	<b>CV 4</b>	<b>CV 5</b>	<b>CV 6</b>	<b>CV 7</b>	<b>CV 8</b>	<b>CV 9</b>	<b>CV 10</b>
Other Coleoptera	0.10	-0.02	0.01	-0.03	0.27	-0.07	-0.03	-0.09	0.08	-0.04
<i>Corynoneura</i> spp.	-0.10	-0.52	-0.11	0.08	0.30	0.08	-0.21	-0.11	0.22	0.17
Other Diptera	-0.14	0	0.03	-0.17	0.06	0.24	0.04	0.08	0.12	0.03
<i>Dromogomphus</i> spp.	0.09	-0.05	-0.05	0.12	0	0.04	0.34	0.03	0.04	-0.28
<i>Eccoptura</i> spp.	0	-0.01	-0.04	-0.03	0.18	0.23	-0.02	-0.13	-0.12	0.04
<i>Ectopria</i> spp.	-0.05	0.12	0.03	0.08	0.07	0.18	-0.10	-0.08	0.01	0.01
Other Elmidae	-0.17	0.19	0.05	-0.26	0.26	0.53	0.07	-0.11	-0.17	0.12
<i>Forcipomyia</i> spp.	-0.12	0	0.01	-0.09	0.06	0.17	0.04	0.06	-0.14	-0.01
<i>Gonielmis</i> spp.	0.02	-0.09	0.17	-0.15	0.22	0.17	-0.12	-0.10	0.03	-0.08
<i>Helobdella</i> spp.	0.44	0.09	0.14	-0.16	0.11	-0.07	-0.04	-0.16	0.07	-0.28
<i>Laevepex</i> spp.	0.63	-0.01	-0.31	0.22	0.16	0.14	0.10	-0.07	-0.03	0.09
<i>Lirceus</i> spp.	0.36	-0.17	0.25	-0.09	0.38	-0.13	-0.04	0.02	-0.19	-0.10
Leptophlebiidae	-0.13	-0.02	-0.02	-0.04	0.03	0.04	-0.09	0.38	0.13	-0.04
Other Leuctridae	-0.11	-0.03	0.03	-0.07	-0.11	0	-0.01	-0.03	0.16	0.01
<i>Leuctra</i> spp.	-0.03	-0.12	-0.13	-0.14	0.17	-0.13	-0.08	-0.22	0.29	0
Lumbricidae	0	-0.15	0.29	-0.04	-0.10	0.25	0.18	0.02	-0.13	-0.12
<i>Macrostenum</i> spp.	-0.10	0.02	-0.07	-0.13	0.06	0.07	-0.04	0.13	0.08	0.01
<i>Macronychus glabratus</i> Say	-0.06	0.17	0.63	0.18	0.28	0	0.08	0.11	-0.03	0.26
<i>Neoperla</i> spp.	-0.11	-0.17	0.04	-0.01	-0.01	0.11	0.03	-0.06	0.04	0.08
<i>Pedicia</i> spp.	-0.20	-0.15	0.01	-0.13	0.01	0.10	0.02	0.18	0.09	0.02
Other Pelecypoda	0.05	0.11	-0.06	-0.19	0.04	-0.09	0.17	-0.16	-0.30	-0.16
<i>Perlesta</i> spp.	0.48	0.06	0.31	-0.23	-0.31	0	-0.20	0.12	0.06	0.25
Other Perlidae	-0.03	-0.20	0.08	-0.03	0.16	0.19	-0.08	-0.04	0.01	-0.08
<i>Perlinella</i> spp.	-0.14	-0.10	0.16	0.15	0.02	0.14	-0.12	-0.26	-0.07	0.13
Physidae	0.34	-0.01	-0.04	0.05	-0.24	0.14	0.04	0.12	0.16	0.17

**Table 3.8.** Continued.

<b>Macroinvertebrate taxa</b>	<b>CV 1</b>	<b>CV 2</b>	<b>CV 3</b>	<b>CV 4</b>	<b>CV 5</b>	<b>CV 6</b>	<b>CV 7</b>	<b>CV 8</b>	<b>CV 9</b>	<b>CV 10</b>
Other Planorbidae	0.25	0.13	0.03	0.08	0.08	-0.13	0.16	-0.03	0.09	-0.10
<i>Polycentropus</i> spp.	-0.11	0.23	-0.16	-0.19	0.17	0.08	-0.18	0.04	0.07	0.12
<i>Pomacea</i> spp.	0.22	0	0.29	-0.15	0.35	-0.13	-0.07	-0.12	0.03	-0.16
<i>Promoresia</i> spp.	-0.03	0.21	-0.04	0.21	0.06	-0.04	-0.25	0.06	-0.04	0.03
<i>Sialis</i> spp.	0.11	0.14	0.01	-0.01	0.03	-0.11	0.24	-0.03	-0.08	-0.13
Simuliidae	-0.03	-0.02	-0.10	-0.04	0	-0.12	-0.06	-0.12	0.04	-0.12
Sphaeridae	0.24	-0.20	0.24	-0.18	0.21	0.02	0.01	0	-0.10	-0.20
<i>Stenelmis</i> spp.	0.22	0.32	0.31	0.03	-0.18	-0.18	-0.29	-0.13	0.04	0.11
<i>Stenacron floridense</i> Lewis	0.29	0.02	0.29	0.11	0.42	-0.25	0.31	0.04	0.23	-0.19
<i>S. interpunctatum</i> Say	-0.01	-0.01	0.10	-0.21	0.15	-0.01	0.08	0.13	0.09	-0.08
<i>Stenonema</i> spp.	-0.12	-0.10	0.07	-0.05	0.11	0.12	-0.18	-0.03	0.20	-0.22
Tanypodinae	0.22	0.19	0.11	-0.12	0.11	0.03	0.01	0.11	0	0.22
Unionidae	0.12	-0.12	0.10	-0.06	0.10	0.02	0.10	0.05	-0.22	-0.08
<i>Wormaldia</i> spp.	-0.12	0.20	0.09	0.24	-0.01	0.15	-0.21	-0.06	0.08	-0.18

## DISCUSSION

Macroinvertebrate taxonomic diversity in any given water body is a function of habitat availability, water chemistry, and the regional taxonomic pool. In the southern U.S., a wide variety of stream habitat and water chemistry offers the potential for a high diversity of aquatic macroinvertebrates (Cushing and Allen 2001). Indeed, collecting 145 taxa appears to support this contention. However, many taxa (91) were uncommon, and it was difficult to identify environmental parameters that contributed to macroinvertebrate community structure of the remaining 54 taxa despite numerous differences in habitat and physiochemistry among

sampling sites. My interest in this study was to establish correlations between macroinvertebrate taxa and stream characteristics as baseline data for future study, with a potential goal of linking land use to macroinvertebrate taxa. Unfortunately, commonly used assessment metrics were inconclusive, and few taxa (23) demonstrated any correlation with stream characteristics.

From the results of MANOVA, impacted sites were generally significantly lower in DO, woody debris complexity, woody debris amount, and fecal coliform counts, but higher in BOD, TC, IC, DOC, TN, woody debris size and volume, discharge, heterotrophic bacteria plate counts, and temperature. Potentially, these differences in stream characteristics, specifically lower DO, higher BOD, fewer woody debris, and higher average size of woody debris could be reflective of decreased input of small sticks and branches from riparian vegetation and increased input of herbaceous vegetation, which increased microbial decomposition. However, this generalization was not always consistent among sampling periods and streams. For example, in Mill Creek, lower DO and increased BOD, carbon, and nitrogen were associated with the impacted site in the late summer sampling of 2002 and 2003, but the reverse pattern was detected in the spring of 2003 and 2004. Similar switching occurred in each stream with the common reversals regarding the first, or water quality, principal component, and the fifth, or bacterial, principal component.

An alternative method to examine these phenomena is with the CDFA (Figure 3.3). In CDFA, greater distance between sites indicates greater, but not necessarily significant, differences in measured variables among sites. In Figure 3.3, the CDFA suggests sites are most different based on stream, sampling period, and to a lesser extent impacts. The substantial distance between Mill Creek sites and the other streams suggests, as I suspected,

that Mill Creek is quite different from the other two streams. However, the CDFA also illustrates surprising seasonal patterns in the habitat data, i.e., substantial changes in habitat occur between season, sites are more similar in spring, sites are similar within a given stream within a given season even in different years, and seasonal differences are more pronounced in Big Brushy and Six Mile Creeks. In Louisiana, Bonner et al. (2003) also noted strong seasonal variability in water quality and habitat variables. Therefore, although impacted sites may differ from reference sites in water quality and habitat variables, these differences appear to be modified by seasonal and spatial variation.

Given the substantial differences detected in habitat and water quality between reference and impacted sites (Table 3.3), it is surprising that community metrics used successfully by other researchers in the past were inconsistent, with actual responses matching expected responses only 25% of the time in contrast to detectable physiochemical differences in 68% of the same comparisons (Table 3.5). Macroinvertebrates are typically strongly linked to their habitats and to water quality (Wallace and Anderson 1996 and references therein), and these predictable and replicable relationships are the basis for using aquatic macroinvertebrates for ecological investigations (Hellawell 1986; Metcalfe 1989; Rosenberg and Resh 1996; Karr and Chu 1999). However, in my streams these metrics appeared to be more sensitive to stream and sampling period than to impacted stream sections, similar to the conclusions of Davis et al. (2003). Multivariate analyses provided some explanation of these results. The PCA of macroinvertebrate taxa suggest that 4 groups (PCs 1, 2, 11, and 12) were probably spatially-oriented, reflecting macroinvertebrates inhabiting particular streams (PCs 1 and 2) or sites (gravelly reaches in Big Brushy Creek) within a stream (PC 11 and 12). Trophic role most likely explains 7 additional groups (PCs 3, 4, 6, 7, 8, 9, and 10). Yet, an

ordination of the first two PCs, which I associate with particular streams, shows substantial overlap among sites (Figure 3.4). Other plots of other combinations of PCs not shown also demonstrate similar overlap. Whereas 33% of all taxa were shared among all 3 streams, 61% were shared between at least 2 streams. The PCs were mostly associated with feeding strategies available in all streams, and ordination suggested that the most numerous taxa appear to be very similar among streams and sites.

When I attempted to correlate macroinvertebrate taxa to spatial, temporal, and physiochemical variables in CCA, I found only 45% of my most numerous and 16% of overall macroinvertebrate taxa demonstrated measurable correlations to my potential explanatory variables. Of these 23 taxa, most (13) exhibited complex correlations with more than 1 canonical variate. Of the detected correlations, macroinvertebrates correlated with 4 spatial variates [CVs 1, 6, 8, and 9 (with the Big Brushy gravelly sites (CV 9) being differentiated from the impacted site (CV 8)], 2 water quality variates [CVs 4 (microbial) and 7(dissolved oxygen and carbon)], 2 woody debris variates (CVs 2 and 10), 1 temporal variate (CV 5), and land use (CV 2). I interpreted these results to suggest some macroinvertebrate taxa were correlated, in declining importance, to particular streams and sites (which I also noted in the PCA), woody debris habitat, land use, water quality, and seasonal patterns. Yet, the majority of taxa were uncorrelated to these stream characteristics. I believe these analyses suggest that, in these streams, few macroinvertebrate taxa are bound to particular locations or physio-chemistries, and most macroinvertebrate taxa are physio-chemical and habitat generalists.

Therefore, the macroinvertebrate communities in these streams appear to be composed of habitat and water quality generalists, whose distribution within a stream may have, unlike

streams discussed by Resh et al. (1988), little relationship to land use at all.

Macroinvertebrates have been shown to be functionally plastic with regard to food source (Dangles 2002), plastic in phenotypic response to environmental risks (Peckarsky et al. 2005), and, in some cases, to respond with increased diversity to unstable habitats (Death and Winterbourn 1995). Similarly, Johnson and Kennedy (2003) suggested macroinvertebrate distribution in western Gulf of Mexico coastal plain streams may be a result of generalist habitat use. Roback (1974) reports broad tolerances of environmental conditions of many insect species in eutrophic waters, such as Mill Creek. In colonization experiments in Mill and Six Mile Creeks, few macroinvertebrate taxa exhibited differential colonization when offered woody debris of different surface areas and DO levels, which are stream characteristics with temporal and seasonal variation. Further, although 25 and 22 taxa were restricted to high and low oxygen habitats, respectively, 33 taxa were found in all levels of DO suggesting a large number of DO generalists (Chapter 2). Many habitat and water chemistry components in these streams exhibited tremendous instability. In Six Mile Creek, the reference sites changed from 22% riffle to 100% riffle, 89 cm to 50 cm in depth, and 1/3 of a piece of wood per sampling point to 2.6 pieces of wood per sampling point from the first to last sampling period. Adams et al. (2004) suggested that continual habitat fluctuations kept coastal plain stream fishes in ‘colonizing assemblages.’ Habitat flux may also be selecting for particular generalist macroinvertebrate communities that are responding to seasonal variation in habitat and water quality. Potentially, this may explain the large number (33%) of shared macroinvertebrate taxa found in all three watersheds.

Another alternative suggests selection for these macroinvertebrate communities occurred prior to the study. Macroinvertebrates have been reliable ecological indicators of

many types of perturbation (e.g., Waters 1995; Clayton and Menendez 1996; Hartman et al. 2005), even with some seasonal influences (e.g., Kaller and Hartman 2004). My difficulty in detecting relationships between macroinvertebrates and stream characteristics may reflect prior selection of macroinvertebrates in this region by evolutionary processes. Rebertus et al. (1993) and Glitzenstein et al. (1995) indicated plants in the southeastern United States evolved in highly stochastic ecosystems with a dynamic landscape in a mosaic of successional stages from fire and weather-related disturbances. Similarly, taxonomically similar highland terrestrial insect populations (now found in the Ozark plateau and the Appalachian Mountains) that were the likely ancestors of coastal plain taxa have evidence of strong selection pressures in the past (Noonan 1988). Further, terrestrial insects appear to have been strongly influenced by Pleistocene extinctions (Howden 1969; Hammond et al. 1979) where more vagile and tolerant insects survived to disperse. By analogy, aquatic macroinvertebrates may have evolved a generalist response to habitat and water quality because of constant flux in habitat in these relatively new habitats, where the only strong habitat and water quality correlations are to woody debris (CV 2) and carbon sources (components of CV 1), which were present, to a lesser degree, in their ancestral highland populations [analysis of present-day descendents (terrestrial) Noonan (1988) and (aquatic) Phillips (1995) and description of hypothesized pre-Pleistocene highlands in Connor and Suttikus (1986) and Mayden (1988); see Bink (1957), Stewart et al. (1976), and Barr and Chapin (1988)] for hypothesized colonization patterns]. Macroinvertebrates colonizing the coastal plain as the Gulf of Mexico retreated post-glaciation would need broad tolerances of flow, dissolved oxygen, and riparian disturbance as they crossed the broad and swampy Mississippi Embayment into the coastal plain, where fire and weather-related disturbances

created a dynamic landscape with newly created and constantly changing stream channels draining the alluvial deposits. Without broad tolerances, macroinvertebrates would have great difficulty in the transition from ancestral upland habitats through the Mississippi Embayment and into the coastal plain. Similar to fishes (Mayden 1985; 1988; Connor and Suttkus 1986), subsequent release from these selection pressures once macroinvertebrates colonized newly formed stream habitats may have allowed for differentiation into communities of upland and lowland streams, such as Six Mile and Mill Creeks, where some colonists out-competed others leading to the subtle community differences among streams detectable today. Other similar alternatives that involve past selective pressures include toxic effects in Big Brushy and Six Mile Creeks from explosive residues and early 20<sup>th</sup> century logging that removed tremendous amounts of riparian vegetation from all three creeks. Therefore, rather than past anthropogenic disturbance shaping present communities (i.e. Harding et al. 1998), past selection from one of these sources may act as a filter for present taxonomic diversity.

Along the Gulf Coast, Cowell et al. (2004) and Maul et al. (2004) were able to detect macroinvertebrate community changes in response to physiochemical parameters. However, Bonner et al. (2003), Davis et al. (2003), and Sloey (1992) also experienced limited success in evaluation of anthropogenic impacts in coastal plain streams. Hellowell (1986) recommended ecological indicators have abundant autecological data, but, although I endeavored to gather these data, it is evident that not nearly enough is known about the autecological or community structure of macroinvertebrates of the Gulf coastal plain. I suggest substantial research is needed in this area, particularly with controlled experiments testing specific habitat and water quality parameters, if macroinvertebrates are to be considered effective indicators of land use impacts in southern coastal plain streams.



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## **CHAPTER 4. FERAL SWINE (*SUS SCROFA*) ALTER AQUATIC MACROINVERTEBRATE AND MICROBIAL COMMUNITIES IN A COASTAL PLAIN STREAM: PIGS, PATHOGENS, AND PATHWAYS**

### **INTRODUCTION**

Feral swine (*Sus scrofa*) are considered to be one of the 100 worst invasive species on a global scale (Invasive Species Specialist Group 2000). Swine arrived in North America in 1493 (Sweeney and Sweeney 1982; Mayer and Brisbin 1991) and quickly spread by escape throughout what would become the southeastern United States (Hanson and Karstad 1959). Feral populations were augmented by domestic escapees brought by settlers (Sweeney and Sweeney 1982) and, later, by intentional releases for hunting (Igo et al. 1980; Mayer and Brisbin 1991; Cox 1999). Some of these populations are primarily domestic in origin. However, others are feral domestic-European wild boar mixes from hunting-related introductions (Laycock 1966; Waithmann et al. 1999). Regardless of origin, feral swine are found throughout the southeastern United States (Wood and Barrett 1979) and are expanding to the west and north (Gipson et al. 1998).

Feral swine achieved notoriety as an invader because of their population growth potential and ecological role. Feral swine are remarkably fecund (Kozlo 1970; Barrett 1978) and have open populations (Hampton et al. 2004). They compete with native wildlife for food (Wood and Barrett 1979; Singer et al. 1984; Focardi et al. 2000) and serve as reservoirs for wildlife diseases (Wood and Barrett 1979; Wood et al. 1992; Mason and Fleming 1999; Gresham et al. 2002). Native vegetation abundance and diversity, including vegetation regeneration rates, have been reported to decline with increasing feral swine activity (Bratton 1975; Howe et al. 1981; Lipscomb 1989; Ford and Grace 1998; Ickes et al. 2003).

In large-scale agricultural production systems, swine wastes caused decreased dissolved oxygen and increased levels of fecal coliform and pathogenic bacteria (Burkhoder et al. 1997; Mallin et al. 1997; Stone et al. 1998). In non-agricultural systems, feral swine are often found near water bodies (Wood and Brenneman 1980; Barrett 1982; Bowman and Panton 1991), but the relationship between swine activity and water quality has only been described observationally by Belden and Pelton (1975, 1976), who suggested that swine were detrimental to native trout and contributed to increased bacterial loads near wallows. Feral swine change the bacterial composition of streams (Kaller and Kelso 2003), but no studies have quantitatively documented the effects of feral swine on other aquatic biota.

Although the effects of feral swine on stream organisms have received little attention, free-ranging cattle have been found to have negative effects on resident fishes in streams adjacent to public grazing lands in the western United States (Taylor et al. 1989). However, with the exception of Rinne and Tharlson (1986) and Reed (2003), few studies exist on the effects of cattle on macroinvertebrates in rangeland streams. Rinne and Tharlson (1986) could not draw strong conclusions about grazing effects on insects, and Reed (2003) reported both positive and negative correlations between cattle grazing and macroinvertebrates abundance. However, Reed's (2003) study only encompassed a brief summer visit by cattle to a stream, and it is likely that a more prolonged disturbance may have shown more obvious effects.

In Louisiana, the study of feral swine is complicated by a heritage, which is still legal in a few parish wards, of free-ranging domestic swine on publicly held lands. It is difficult to ascertain whether forest and stream damage in some parts of Louisiana are caused by truly feral swine, free-ranged swine, or a mixture of the two groups. Whereas swine populations



are open (Hampton et al. 2004), swine have little affinity to their relatives and may join or interbreed with other groups, which makes it difficult to identify swine responsible for ecological damage. However, damage to forests and streams occurs in Louisiana, and swine populations, feral or otherwise, appear to be increasing. Therefore, I decided to quantify the relationship between feral swine, microbes, and stream macroinvertebrates to determine whether these terrestrial invaders could influence macroinvertebrates and microbes with prolonged disturbance.

## **METHODS**

During summer 2002, I selected 2 tributary [Alligator (site A) and Cottonmouth (site C) Creeks] and 3 main stem sites (sites B, D, and E) along Mill Creek within the West Bay Wildlife Management Area, Allen Parish, Louisiana. Until its confluence with the Calcasieu River, Mill Creek drains an exceptionally flat, uneroded, and poorly drained bay, or depression, within the terrace region of Louisiana. Soils in this region were formed from alluvial deposits from the wandering Mississippi River delta and receding Gulf of Mexico during the Pleistocene (Welch 1942). Riparian vegetation is southern bottomland hardwood trees, and upland vegetation is managed pine plantation. A population of resident feral and free-ranging swine exists in the watershed. The West Bay Wildlife Management Area is jointly administered by the Louisiana Department of Wildlife and Fisheries, Boise Paper, and Roy O. Martin Lumber Company.

At each site, I established one 100-m transect parallel to flow. I measured dissolved oxygen (DO), specific conductance (SpC), temperature, and pH with a handheld YSI Model 95 probe (YSI Incorporated, Yellow Springs, OH, U.S.A.) at the downstream end of each transect. Habitats were surveyed at 10 randomly determined, regular intervals by bank-to-

bank transects perpendicular to flow. At 3 equidistant points along each bank-to-bank transect, I measured flow (Sontek velocity meter, YSI Incorporated, Yellow Springs, OH, U.S.A.), depth, number, length, and width of woody debris, woody debris complexity (whether each piece was single or in a group), woody debris orientation to flow, habitat type, canopy cover, and the presence or absence of fine benthic organic matter (FOD). Stream wetted width was determined by bank-to-bank transect lengths. I sampled macroinvertebrates by collecting 9 samples of 10 pieces of woody debris (10 – 50 mm in diameter) each in a mesh (250  $\mu$ m) 472-mm x 127-mm x 127-mm bag (for a total of 180 samples, 4 seasons x 5 sites x 9 samples), and field preserved the samples in 70% ethanol. I collected two 1 L water column samples for fecal coliform and heterotrophic plate counts, following collection protocols outlined by the American Public Health Association (1998). In addition, I collected 1 L water sample at each site for analyses of biochemical oxygen demand (BOD), total carbon (TC), inorganic carbon (IC), total organic carbon (TOC), dissolved organic carbon (DOC), and total nitrogen (TN). Whereas I were interested in macroinvertebrate response to stress, I collected my data in August 2002 and 2003 during the period of lowest summer flows and highest temperatures, and in April 2003 and 2004 following episodic and torrential high water events from winter tropical storms and hurricane Lili (2002).

I estimated swine density and stream use by counting the number of tracks, scats, and wallows at each site to establish swine presence/absence. Further, I measured riparian plant disturbance along each transect. Because plant disturbance may be caused by many mammals, such as muskrats and beaver, riparian disturbance was recorded as a separate variable than swine presence/absence. Finally, in December 2003, I placed 4 heat-sensing

cameras (Camtrakker, Watkinsville, GA, U.S.A.) at the sites to obtain photographic evidence of swine using Mill Creek.

Macroinvertebrate samples were frozen until processing, and were then sorted under magnification and placed in 95% ethanol prior to identification. Members of Chironomidae, Ceratopogonidae, Tipulidae, and all Annelida were mounted on glass microscope slides with CMC-10 (Master's Chemical Company, Elk Grove, IL, U.S.A.) following protocols outlined by Epler (2001) and identified under high magnification. All other macroinvertebrate taxa were identified to lowest practical taxon, occasionally species, but more often genus, and head capsule measurements were made for each individual. A small percentage of samples were set aside for identification quality control, and remaining samples were placed in 95% ethanol for long-term storage.

Laboratory procedures for fecal coliform and heterotrophic plate counts followed the water assessment protocols outlined by the American Public Health Association (1998). Six subsamples of 1, 10, and 50 mL volume (2 of each) were filtered through a Millipore HC fecal coliform testing filter (Millipore Incorporated, Billerica, MA, U. S. A.). I added Millipore fecal coliform media and incubated the samples for 24 h at 38°C in a water bath. Twelve additional subsamples of 1, 1/10, 1/100, 1/1000, and 1/10,000 mL were taken for heterotrophic plate counts. These subsamples were mixed with R2A media in pour plates, incubated for 48 h at 35°C. Fecal coliform and heterotrophic plate counts were made under magnification with a darkfield Quebec colony counter (Leica Microsystems, Buffalo, NY, U. S. A.). Two colonies from each sample were randomly selected from the darkfield colony counter for identification. These colonies were isolated on individual plates (2 per colony), gram stained (Fisher Diagnostics, Middleton, VA, U. S. A.; 1 plate), incubated in anaerobic

conditions (1 plate), and, prior to anaerobic incubation, a small amount was transferred to a tube of 13 different medias for biochemical identification [15 tests; similar to Leff and Meyer (1991)] testing (Enterotube II, BD Biosciences, Franklin Lakes, NJ, U. S. A.).

Water samples collected for chemical analyses were split into BOD samples and carbon samples. BOD samples were tested at five and twenty days. Carbon samples analyzed with a Shimadzu TOC-V Combustion Analyzer (Shimadzu North America, Columbia, MD, U.S.A) via Method 5310.B (APHA 1998).

Initially, I used principal component analysis (PCA; PROC FACTOR, SAS, version 9.0, SAS Institute, Cary, NC, U.S.A), with varimax rotation, to reduce dimensionality of habitat, physio-chemical, and bacterial parameters from 18 variables to 6 principal components, using Horn's test for stopping criteria (Jackson 1993). Subsequently, I compared the resulting principal components among sites with multivariate analysis of variance (MANOVA) and a post-MANOVA Tukey-Kramer test of least-squared means to assess differences in principal component scores among the sites (PROC GLM, SAS, version 9.0, SAS Institute, Cary, NC, U.S.A).

For analysis of the macroinvertebrate community, I converted the macroinvertebrate count data to density data based on a standard volume of wood (500 mL). Because some taxa (25) were fairly uncommon (< 1% of samples) and statistical inference on rare taxa is difficult, if not impossible, I reduced the number of taxa to 60 taxa that were present in more than 1% of samples (Table 4.1). I selected principal component and canonical correlation analyses for my multivariate analyses rather than the more commonly used detrended correspondence and canonical correspondence analyses (e.g., Legendre and Gallagher 2001; Eyre et al. 2005) because, after consultation with a statistician, I believed linear

transformation was more appropriate for my data. Subsequently, I grouped macroinvertebrate taxa with PCA, (PROC FACTOR, SAS, version 9.0, SAS Institute, Cary, NC, U.S.A), with varimax rotation, to establish community structures, using Horn's test to determine component retention (Jackson 1993). To visualize the relationship between macroinvertebrate taxa and sites, I used correspondence analysis (CA; PROC CORRESP, SAS, version 9.0, SAS Institute, Cary, NC). I analyzed relationships between macroinvertebrate taxa and swine activity (presence and % riparian area disturbed), sampling period, habitat, physio-chemical, and bacterial parameters using canonical correlation analysis (CCA; PROC CANCORR, SAS, version 9.0, SAS Institute, Cary, NC, U.S.A).

**Table 4.1.** Macroinvertebrate taxa used in multivariate analyses that were found in greater than 1% of samples.

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**Taxonomic Group**

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**Crustacea:**

Amphipoda: Crangonyctidae: *Crangonyx* spp.

Decapoda: Cambaridae

Isopoda: Asellidae: *Lirceus* spp.

**Insecta:**

Coleoptera: Carabidae

Coleoptera: Elmidae: *Ancyronyx* spp.

Coleoptera: Elmidae: *Dubiraphia* spp.

Coleoptera: Elmidae: *Gonielmis* spp.

Coleoptera: Elmidae: *Macronychus glabratus* Say

Coleoptera: Elmidae: *Microcylleopus* spp.

**Table 4.1.** Continued.

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Coleoptera: Elmidae: *Optioservus* spp.

Coleoptera: Elmidae: *Promoresia* spp.

Coleoptera: Elmidae: *Stenelmis* spp.

Coleoptera: Elmidae: Unidentifiable

Coleoptera: Dytiscidae

Coleoptera: Gyrinidae

Coleoptera: Haliplidae

Coleoptera: Hydrophilidae

Coleoptera: Scirtidae

Coleoptera: Unidentifiable

Collembola

Diptera: Ceratopogonidae: *Bezzia* spp.

Diptera: Chironomidae: Chironominae

Diptera: Chironomidae: *Corynoneura* spp.

Diptera: Chironomidae: Orthocladiinae

Diptera: Chironomidae: Others

Diptera: Chironomidae: Tanypodinae

Diptera: Culicidae

Diptera: Simuliidae

Diptera: Tipulidae: *Pedicia* spp.

Ephemeroptera: Baetidae

Ephemeroptera: Caenidae: *Caenis hilaris* Say

**Table 4.1.** Continued.

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Ephemeroptera: Heptageniidae: *Stenacron floridense* Lewis

Ephemeroptera: Heptageniidae: *Stenacron interpunctatum* Say

Ephemeroptera: Heptageniidae: *Stenonema* spp.

Ephemeroptera: Leptophlebiidae

Megaloptera: Sialidae: *Sialis* spp.

Odonata: Aeshnidae

Odonata: Aeshnidae: *Boyeria* spp.

Odonata: Coenagrionidae: *Argia* spp.

Plecoptera: Perlidae: *Agnatina* spp.

Plecoptera: Perlidae: *Perlesta* spp.

Plecoptera: Perlidae: *Perlinella* spp.

Trichoptera: Hydropsychidae: *Cheumatopsyche* spp.

**Annelida:**

Oligochaeta: Entotrychidae: *Eclipidrilus* spp.

Oligochaeta: Lumbricidae

Rhynchobdella: Glossosiphonidae: *Helobdella* spp.

**Mollusca:**

Gastropoda: Ancyliidae: *Laevepex* spp.

Gastropoda: Hydrobiidae

Gastropoda: Physidae

Gastropoda: Planorbidae: *Heliosoma* spp.

**Table 4.1.** Continued.

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Gastropoda: Planorbidae: Others

Gastropoda: Pleurocerdiae: *Lithasia* spp.

Gastropoda: Viviparidae

Gastropoda: Viviparidae: *Pomacea* spp.

Pelecypoda: Corbiculidae: *Corbicula* spp.

Pelecypoda: Sphaeridae

Pelecypoda: Unionidae

Pelecypoda: Unionidae: *Amblema* spp.

Pelecypoda: Unionidae: *Anodotodes* spp.

Pelecypoda: Unionidae: *Toxolasma* spp.

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## RESULTS

Swine were active in Mill Creek throughout the study based on scat, track, and wallow evidence (Table 4.2). However, I was unable to photograph swine visiting Mill Creek, largely because 1 of the 4 cameras placed along the stream was destroyed by a shotgun blast, and I removed the remaining cameras the following morning to prevent further vandalism.

The PCA reduced the habitat and water quality data into 6 principal components (Table 4.3), two of which (PCs 1 and 3) were associated with water quality and habitat conditions in Mill Creek when swine were active in the stream. Two principal components (PCs 2 and 6) were associated with woody debris, and the other 2 principal components (PCs 4 and 5) were associated with water quality when swine were not present in the stream. The



**Table 4.2.** Mean habitat and water quality data (standard errors in parentheses) measured in Mill Creek. Volume, orientation (1 = parallel, 0 = perpendicular to flow) and complexity (1 = complex, 0 = single piece) refer to woody debris. FC counts over 200 colonies per mL (shaded) are above legal limits.

<b>Summer 2002</b>										
Site	Swine	% Riparian disturbance	DO (mg/L)	Temperature (°C)	Spc (mu/s)	Discharge (m <sup>3</sup> )	FC (#/100mL)	HPC (#/1 mL)	CWD	Volume (m <sup>3</sup> )
A	No	0	2.04	17.2	24.9	0 (0)	195.3 (6.2)	340.5 (4.4)	9.3 (1.5)	4.7 (2.7)
B	No	0	2.98	16.5	129.2	0 (0)	75.6 (4.2)	129.6 (11.1)	16.9 (2)	11.1 (16.9)
C	Yes	0	1.07	16.3	1.5	0 (0)	336.7 (51.0)	157.5 (23.6)	11.3 (2)	23.6 (11.3)
D	No	0	2.99	17.9	56.4	0 (0)	83.6 (0.9)	1968.4 (25)	49.7 (2)	25.2 (49.7)
E	Yes	10	4.30	17.6	32.5	0 (0)	121.7 (1.4)	3525 (144)	4.3 (1)	6,468 (6361)
	Swine	Orientation	Complexity	FOD (% cover)	BOD (mg/L)	TC (mg/L)	TOC (mg/L)	DOC (mg/L)	IC (mg/L)	TN (mg/L)
A	No	0 (0)	0.67 (0.11)	0 (0)	13.4 (0)	17.3 (0)	15.3 (0)	14.4 (0)	2.0 (0)	0.7 (0)
B	No	0 (0)	0.77 (0.08)	23 (8)	6.3 (0)	28.3 (0)	7.6 (0)	6.3 (0)	20.7 (0)	1.0 (0)
C	Yes	0 (0)	0.71 (0.09)	100 (0)	16.46 (0)	37.2 (0)	32.0 (0)	27.8 (0)	5.2 (0)	2.0 (0)
D	No	0 (0)	0.89 (0.04)	100 (0)	9.1 (0)	31.2 (0)	12.5 (0)	10.7 (0)	17.8 (0)	0.6 (0)
E	Yes	0 (0)	0.53 (0.13)	100 (0)	10.5 (0)	24.7 (0)	14.4 (0)	12.2 (0)	10.3 (0)	0.6 (0)

**Table 4.2.** Continued.

<b>Spring 2003</b>										
Site	Swine	% Riparian disturbance	DO (mg/L)	Temperature (°C)	Spc (mu/s)	Discharge (m <sup>3</sup> )	FC (#/100mL)	HPC (#/1 mL)	CWD	Volume (m <sup>3</sup> )
A	No	1	4.20	17.0	41.4	0 (0)	372.5 (14.2)	107,400 (20,478)	0 (0)	0 (0)
B	Yes	0	4.85	18.0	240.0	0.33 (0.09)	908.0 (52.2)	102,300 (2191.6)	1.8 (0.39)	947.9 (752)
C	Yes	10	2.29	17.0	33.9	0.16 (0.08)	978.9 (38.8)	64,555.6 (6387)	0.17 (0.09)	0 (0)
D	No	0	4.40	17.5	68.6	5.9 (4.9)	78 (14.6)	24,833 (181)	3.9 (1.2)	286 (218)
E	No	0	4.76	16.2	50.8	1.9 (0.4)	30.4 (2.1)	18,130 (1810)	2.6 (0.4)	9,125 (7936)
	Swine	Orientation	Complexity	FOD (% cover)	BOD (mg/L)	TC (mg/L)	TOC (mg/L)	DOC (mg/L)	IC (mg/L)	TN (mg/L)
A	No	0 (0)	0 (0)	0 (0)	13.84 (0)	17.7 (0)	13.0 (0)	13.2 (0)	4.7 (0)	1.1 (0)
B	Yes	0.1 (0.07)	0.4 (0.1)	80 (10)	11.05 (0)	20.6 (0)	14.6 (0)	12.5 (0)	6.0 (0)	0.8 (0)
C	Yes	0.17 (0.1)	0 (0)	80 (10)	11.11 (0)	22.7 (0)	18.5 (0)	18.3 (0)	4.1 (0)	1.2 (0)
D	No	0.17 (0.1)	0.4 (0.1)	90 (0.90)	10.70 (0)	27.2 (0)	16.0 (0)	15.3 (0)	11.2 (0)	0.8 (0)
E	No	0.34 (0.1)	0.5 (0.1)	80 (0.80)	12.85 (0)	24.8 (0)	16.7 (0)	16.0 (0)	8.1 (0)	0.01 (0)

**Table 4.2. Continued.**

<b>Summer 2003</b>										
Site	Swine	% Riparian disturbance	DO (mg/L)	Temperature (°C)	Spc (mu/s)	Discharge (m <sup>3</sup> )	FC (#/100mL)	HPC (#/1 mL)	CWD	Volume (m <sup>3</sup> )
A	No	1	2.36	20.6	48.1	0 (0)	21.3 (0.69)	30,277 (3037)	0.3 (0.22)	45.7 (42)
B	No	5	1.80	21.4	155.1	0.1 (0.06)	6.4 (2)	36,111 (2169)	2.5 (0.7)	2,812 (2683)
C	Yes	20	2.05	23.0	104.6	0 (0)	1.0 (0.1)	180,444 (36,454)	0.8 (0.4)	2.2 (1.6)
D	Yes	10	2.05	23.0	104.6	0.2 (0.13)	3.2 (0.13)	308,222 (73,203)	6.2 (2.1)	889 (625)
E	Yes	20	3.15	23.3	74.0	0.4 (0.23)	0.8 (0.3)	120,422 (32,273)	7.5 (3.2)	37.7 (27)
	Swine	Orientation	Complexity	FOD (% cover)	BOD (mg/L)	TC (mg/L)	TOC (mg/L)	DOC (mg/L)	IC (mg/L)	TN (mg/L)
A	No	0.17 (0.09)	0.17 (0.1)	100 (0)	13.68 (0)	17.26 (0)	15.31 (0)	14.36 (0)	1.95 (0)	0.73 (0)
B	No	0.22 (0.1)	0.33 (0.1)	100 (0)	6.3 (0)	29.29 (0)	7.58 (0)	6.29 (0)	20.71 (0)	1.0 (0)
C	Yes	0.06 (0.06)	0.06 (0.06)	100 (0)	16.46 (0)	37.18 (0)	31.98 (0)	27.83 (0)	5.20 (0)	2.0 (0)
D	Yes	0.22 (0.1)	0.28 (0.1)	100 (0)	9.09 (0)	31.24 (0)	12.47 (0)	10.71 (0)	18.77 (0)	0.6 (0)
E	Yes	0.22 (0.1)	0.33 (0.1)	94 (6)	10.48 (0)	24.70 (0)	14.43 (0)	12.15 (0)	10.27 (0)	0.6 (0)

**Table 4.2.** Continued.

<b>Spring 2004</b>										
<b>Site</b>	<b>Swine</b>	<b>% Riparian disturbance</b>	<b>DO (mg/L)</b>	<b>Temperature (°C)</b>	<b>Spc (mu/s)</b>	<b>Discharge (m<sup>3</sup>)</b>	<b>FC (#/100mL)</b>	<b>HPC (#/1 mL)</b>	<b>CWD</b>	<b>Volume (m<sup>3</sup>)</b>
A	No	0	2.44	15.3	49.0	0 (0)	116.7 (13.4)	3,811 (200)	0.06 (0.06)	0 (0)
B	Yes	0	7.05	14.4	234.7	0.34 (0.1)	425.6 (28.5)	8,488 (316)	4.5 (0.9)	5,989 (7,936)
C	No	0	1.37	13.7	90.3	0 (0)	234.4 (27.3)	4,666.7 (129)	0.6 (0.2)	0 (0)
D	Yes	60	2.46	17.2	122.2	0.86 (0.3)	482.2 (44.1)	3,444 (204)	1.6 (0.4)	5,989 (5,916)
E	Yes	20	3.88	17.0	160.3	0.38 (0.3)	937.8 (113)	4,933 (200)	1.8 (0.4)	6.7 (6.3)
	<b>Swine</b>	<b>Orientation</b>	<b>Complexity</b>	<b>FOD (% cover)</b>	<b>BOD (mg/L)</b>	<b>TC (mg/L)</b>	<b>TOC (mg/L)</b>	<b>DOC (mg/L)</b>	<b>IC (mg/L)</b>	<b>TN (mg/L)</b>
A	No	0 (0)	0 (0)	0.8 (0.08)	13.84 (0)	17.65 (0)	12.97 (0)	13.23 (0)	4.68 (0)	1.13 (0)
B	Yes	0.7 (0.1)	0.6 (0.1)	0.8 (0.1)	11.05 (0)	20.59 (0)	14.61 (0)	12.51 (0)	5.99 (0)	0.80 (0)
C	No	0.3 (0.1)	0.3 (0.1)	0.9 (0.08)	11.11 (0)	22.68 (0)	18.54 (0)	18.35 (0)	4.14 (0)	1.21 (0)
D	Yes	0.5 (0.1)	0.7 (0.1)	1.0 (0)	10.70 (0)	27.16 (0)	15.97 (0)	15.30 (0)	11.19 (0)	0.85 (0)
E	Yes	0.2 (0.1)	0.7 (0.1)	0.9 (0.06)	12.85 (0)	24.77 (0)	16.65 (0)	15.96 (0)	8.11 (0)	0.09 (0)

MANOVA detected a significant interaction between season and site. Therefore, subsequent within-season MANOVA identified significant differences among sites in 83% (397 of 480) of comparisons (Table 4.4). Principal components 1 and 3 differed between sites with and without evidence of swine in 75% (6 of 8) of comparisons. The other most numerous differences involved water quality (PC 4; 88% of comparisons) and woody debris (PC 2; 86% of comparisons).

**Table 4.3.** Six principal components (PCs 1-6) constructed from the habitat data with variance explained in parentheses. Shadings indicate loadings greater than 0.30.

Initial variable	PC 1 (25.4)	PC 2 (15.5)	PC 3 (13.0)	PC 4 (10.0)	PC 5 (5.8)	PC 6 (5.7)
Swine presence	0.41	0	0.75	0.29	0.12	-0.05
% Riparian disturbance	0.05	0.08	0.59	0.24	0.07	-0.29
Dissolved oxygen	-0.30	-0.18	0.21	-0.12	0.63	0.28
Temperature	-0.05	-0.10	-0.01	0.86	-0.06	-0.12
Specific conductance	-0.39	-0.24	0.67	0.04	0.25	0.15
Fecal coliform count	0.14	-0.18	0.71	-0.40	0.02	0.03
Heterotrophic plate count	0.02	0.75	0.15	0.76	-0.11	0.12
Coarse woody debris	-0.27	0.19	-0.32	-0.17	-0.02	0.06
Wood volume	0.02	0.06	-0.04	0.09	0.09	0.82
Wood orientation	0.09	0.06	0.18	-0.06	0.74	-0.13
Wood complexity	-0.08	0.68	-0.04	-0.34	0.38	0.14
Fine organic detritus	0.18	-0.27	0.11	0.34	0.18	-0.49
Biochemical oxygen demand	0.91	0.79	-0.09	-0.02	0.07	-0.01
Total carbon	0.22	0.10	0.11	0.29	-0.33	-0.07
Total organic carbon	0.96	0.01	0.13	0.07	-0.12	-0.05
Dissolved organic carbon	0.97	0.61	0.11	0.07	-0.11	-0.07

**Table 4.3.** Continued.

Initial variable	PC 1 (4.2)	PC 2 (2.4)	PC 3 (2.1)	PC 4 (2.0)	PC 5 (1.7)	PC 6 (1.2)
Inorganic carbon	-0.71	0.12	-0.02	0.19	-0.17	-0.01
Total nitrogen	0.61	0.12	0.12	0.02	-0.55	-0.02

**Table 4.4.** MANOVA results indicated many significant ( $p < 0.05$ ) differences among sites. Mean principal component scores associated with the same letter are not significantly different. Shaded sites indicate swine presence.

<b>Summer 2002</b>					
Principal components	Site A	Site B	Site C	Site D	Site E
Swine and organic carbon	0.30 a	-1.54 b	2.49 c	-0.65 d	-0.09 e
Woody debris and BOD	-1.13 a	0.45 b	1.17 c	1.71 c	-0.09 d
Swine and FC	-1.22 a	0.29 b	0.09 c	-0.74 d	-0.03 c
Temperature	-0.84 a	-0.63 b	-0.58 b	-0.19 c	0.19 d
DO	-0.22 a	-1.10 b	-1.12 b	-0.08 a	0.50 c
Woody debris	0.47 a	0.63 a	-0.05 a	-0.10 a	-0.05 a
<b>Spring 2003</b>					
Principal components	Site A	Site B	Site C	Site D	Site E
Swine and organic carbon	0.01 a	-0.41 b	0.53 c	0 d	0.26 e
Woody debris and BOD	-1.79 a	-0.93 a,b	-0.81 b	-0.08 b	-0.45 b
Swine and FC	-0.62 a	1.83 b	1.04 c	-0.61 a,b,c,d	-1.13 d
Temperature	-0.38 a	-0.24 a,b	-0.58 a	-0.03 a,b,c	-0.04 b,c
DO	-0.48 a, b	0.31 a,b	-0.82 a	0.50 b	1.44 c
Woody debris	-0.94	0.84	-0.28	0.01	0.44

**Table 4.4.** Continued.

<b>Summer 2003</b>					
<b>Principal components</b>	<b>Site A</b>	<b>Site B</b>	<b>Site C</b>	<b>Site D</b>	<b>Site E</b>
Swine and organic carbon	0.33 a	-1.57 b	2.13 c	-0.72 d	-0.23 e
Woody debris and BOD	-1.28 a	<u>0.08 b</u>	<u>0.44 b</u>	<u>0.11 b</u>	<u>-0.23 b</u>
Swine and FC	<u>-1.47 a,b</u>	0.07 b	<u>0.50 a,b</u>	<u>0.30 a,b</u>	<u>-0.01 a,b</u>
Temperature	<u>0.66 a</u>	<u>0.89 a</u>	<u>1.95 b</u>	2.66 c	<u>1.75 b</u>
DO	<u>0.62 a</u>	<u>-0.86 b</u>	<u>-0.71 b</u>	<u>-0.18 b</u>	<u>0.64 a</u>
Woody debris	<u>-0.57 a</u>	<u>-0.52 a</u>	<u>0.13 b</u>	<u>-0.02 b</u>	<u>-0.44 a</u>
<b>Spring 2004</b>					
<b>Principal components</b>	<b>Site A</b>	<b>Site B</b>	<b>Site C</b>	<b>Site D</b>	<b>Site E</b>
Swine and organic carbon	<u>0.14 a</u>	<u>-0.10 b</u>	0.49 c	<u>-0.04 b</u>	<u>0.02 a,b</u>
Woody debris and BOD	-1.36 a	<u>-0.42 b</u>	<u>-0.55 b</u>	0.50 c	<u>-0.21 b</u>
Swine and FC	-0.99 a	1.26 b	-0.36 c	1.96 d	1.62 e
Temperature	<u>-0.63 a</u>	<u>-0.73 a</u>	-1.05 b	-0.12 c	<u>-0.59 a</u>
DO	-0.40 a	2.17 b	<u>-0.41 a</u>	<u>0.37 c</u>	<u>-0.87 c</u>
Woody debris	-0.79 a	1.03 b	<u>-0.46 a</u>	-1.27 c	<u>-0.21 a</u>

I was able to identify 61% (14 of 23) of the colonies I isolated from the R2A plates. Following gram staining and biochemical testing, I identified several taxa that were always found in conjunction with swine activity, including *Aeromonas* spp., *Azomonas* spp., *Azotobacter* spp., *Bacillus* spp., *Eikenella* spp., *Enterococcus* spp., *Leconostoc lactis*, *Providencia alcalifaciens*, *Staphylococcus aureus*, and *Zooglea* spp. Fifty percent of the water samples containing *Shigella* spp. were from sites with swine activity, whereas *Listeria* spp. and *Proteus penneri* were never found at swine active sties. The remaining isolated colonies were grouped into unknown categories A through L (Table 4.5).

I collected 10,220 macroinvertebrates in 85 taxa and 5 feeding groups during the study (Figure 4.1). From the reduced set of 60 taxa, PCA constructed 14 PCs that I identified as: fine particulate organic matter filtering and predaceous taxa (PCs 1 and 11); coarse organic matter collecting taxa (PCs 2 and 9); filtering, collecting and biofilm (a surface matrix of bacteria, fungi, and algae held in mucous) scraping taxa (PC 3); filtering, collecting, and predaceous taxa (PCs 6,7, and 8); filtering and biofilm scraping taxa (PC 10); seasonally abundant taxa (PC 12); a crustacean dipole (PC 13); and an upstream/downstream taxonomic dipole (PC 14; Table 4.6).

The CA constructed 2 dimensions that accounted for 73% of the variation in macroinvertebrate taxa and revealed some relationships between the amount of riparian disturbance and stream macroinvertebrate distribution (Figure 4.2).

The first variate identified by the CCA (Tables 4.7 and 4.8) was associated with swine presence at site B and was correlated with a group of collecting, filtering, and predaceous taxa. The second, third, and fourth variates were associated with site E (CV 3 contrasted site E with site B) describing different sample seasons and were correlated to predominantly collecting, with some filtering and biofilm scraping, taxa. The fifth variate was associated with temporal changes in organic matter, inorganic carbon, and bacteria and was correlated with predaceous taxa. The sixth and seventh variates were associated with riparian disturbances (negatively in CV 6 and positively in CV 7) describing bacterial and carbon processing and were correlated with predominantly scraping, with some collecting, taxa. The eighth variate was associated with site C describing water quality, habitat, and bacterial conditions at that site and was correlated with collecting, filtering, and scraping taxa. The ninth variate was a DO-riparian disturbance dipole and was correlated with collecting and



predaceous taxa. The tenth and eleventh variates were associated with water quality and bacteria and were correlated with collecting, filtering, predaceous, and scraping taxa. The twelfth and fourteenth variates were associated with swine presence (negatively in CV 12 and positively in CV 14) describing carbon processing and bacteria and were correlated with predominantly collecting, with some filtering, taxa. The fifteenth variate was associated with one microbe and was correlated with still water taxa. The sixteenth variate was associated with habitat and bacteria and was correlated with filtering taxa.

**Table 4.5.** Isolated bacterial colonies that could not be identified with Bergey’s Manual of Deterministic Bacteriology (Holt 2000). Colonies B, C, and E were described from other streams not included in this study.

Unknown	Gram stain	Shape	Anaerobic growth	Color	Metabolizes
A	Negative	Cocci	Facultative	White	Glucose
D	Negative	Paired cocci	Facultative	White	Glucose, adontinol, lactose, arabinose, sorbitol
F	Negative	Cocci	Facultative	Yellow	Glucose, ornithine, adontinol, lactose, arabinose, sorbitol
G	Negative	Rod	Facultative	Opaque	Glucose
H	Negative	Cocci	Facultative	Opaque	Glucose
I	Negative	Cocci	Facultative	Yellow	Glucose, ornithine, urea
J	Negative	Cocci	Facultative	Orange	Glucose
K	Negative	Cocci	Facultative	White	Glucose, lysine, ornithine, adonitol, lactose, arabinose, sorbitol
L	Negative	Cocci	Facultative	Opaque	Glucose, lysine, ornithine, adonitol, lactose, arabinose, sorbitol

**Table 4.6.** Fourteen principal components constructed from the reduced set of macroinvertebrate taxa. Shadings indicate loadings greater than 0.30.

Macroinvertebrate taxa	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	PC 11	PC 12	PC 13	PC 14
<i>Crangonyx</i> spp.	0.01	0.10	0.54	0.08	-0.04	-0.08	-0.03	0.13	0.03	0.05	0.28	0.39	0.08	-0.11
Cambaridae	0.87	0.01	0.10	-0.07	0.02	-0.04	-0.07	0	-0.01	0.07	0.03	0.07	0	-0.10
<i>Lirceus</i> spp.	0	-0.08	0.50	-0.01	-0.07	-0.02	0.18	0.40	0.20	0.13	0.20	0.02	-0.36	0.01
Carabidae	-0.01	-0.01	-0.04	-0.04	-0.04	-0.01	0.11	-0.04	0.02	-0.03	-0.07	-0.01	-0.03	-0.01
<i>Ancyronyx</i> spp.	0.75	-0.03	0.03	-0.04	0.01	0.39	0.23	-0.06	0	-0.10	0.15	-0.10	0.02	-0.05
<i>Dubiraphia</i> spp.	0.01	-0.03	-0.09	0.62	0.49	-0.09	0.11	-0.05	-0.7	0	-0.04	0.06	0.01	-0.04
<i>Gonielmis</i> spp.	-0.03	-0.02	0.20	-0.07	0.07	0	0.01	-0.02	-0.03	-0.09	0.01	0.08	0.03	0.69
<i>Macronychus glabratus</i> Say	0.04	0.40	0.09	-0.05	-0.03	0.07	0.82	0.08	-0.06	0.16	-0.01	-0.04	-0.08	0
<i>Microcylleopus</i> spp.	-0.01	0.05	-0.03	0.05	0.88	0	-0.09	-0.02	-0.02	-0.02	-0.03	-0.06	-0.02	0.05
<i>Optioservus</i> spp.	0.11	-0.01	-0.01	0.73	-0.24	0.33	-0.05	-0.04	-0.03	-0.06	-0.01	-0.08	0.01	0.01
<i>Promoresia</i> spp.	0.20	0.06	-0.02	0.09	0.88	-0.04	-0.11	-0.05	-0.01	0.02	0.01	-0.07	-0.04	-0.05
<i>Stenelmis</i> spp.	-0.04	0.85	-0.04	0.08	0.14	0.31	0.11	-0.01	0.02	0	-0.04	0.05	0.01	0.02
Elmidae: Unidentifiable	-0.01	0.03	0	0.64	0.50	-0.07	-0.03	0	0.06	0.02	0.03	-0.01	0.01	-0.02
Dytiscidae	0.13	0.07	0.22	-0.04	-0.05	0.03	0	-0.01	0.20	-0.03	0.12	-0.12	0.01	-0.02

**Table 4.6.** Continued.

Macroinvertebrate taxa	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	PC 11	PC 12	PC 13	PC 14
Gyrinidae	0	0.02	-0.04	0.04	-0.02	0.85	-0.03	-0.04	0.17	0	0.02	0.04	0.07	-0.02
Haliplidae	-0.01	-0.03	0	-0.02	0.03	0.05	0.12	0.77	0.18	0	-0.09	0.05	0.15	0.02
Hydrophilidae	-0.01	-0.03	0.06	-0.03	0	0.02	-0.12	0.67	-0.06	-0.08	0.13	-0.11	-0.17	-0.04
Scirtidae	-0.03	0.06	-0.08	0	0.01	0.82	-0.06	-0.06	-0.09	0.06	0.12	0.09	0.02	0.02
Coleoptera: Unidentifiable	0.28	0	0.23	-0.06	-0.03	0.10	-0.08	0	0	0.12	-0.18	-0.03	0.06	0.05
Collembola	-0.01	0.02	0	-0.03	-0.06	0	-0.06	0	0	0.70	-0.02	-0.06	0.07	0.05
<i>Bezzia</i> spp.	0.07	0	0.08	-0.01	0.03	0.61	0.05	0.20	0.02	-0.15	-0.08	-0.13	-0.04	0
Chironominae	0.32	-0.08	0.15	0.08	0.07	-0.08	0.19	-0.12	0.05	0.63	0	0.18	-0.25	-0.05
<i>Corynoneura</i> spp.	-0.04	0.03	0	-0.04	-0.02	0.12	-0.03	0.03	0.74	0.03	-0.11	0.05	0.40	-0.08
Orthoclaadiinae	-0.05	0.38	0.06	-0.10	-0.10	0.17	0.29	0.20	0.26	0.18	0.32	0.07	0.22	-0.06
Tanypodinae	0.01	0.68	-0.02	0.05	0.41	0.10	0.27	-0.04	0	0.32	0.06	-0.03	-0.10	-0.01
Chironomidae: Others	-0.06	0.08	-0.05	0.06	-0.06	0.09	-0.09	-0.03	0.77	0.02	-0.09	-0.02	-0.16	0.02
Culicidae	-0.02	-0.02	-0.06	-0.04	-0.06	-0.04	-0.04	-0.01	-0.14	-0.04	-0.04	0.04	0.09	-0.15
Simuliidae	0	0.01	-0.06	-0.02	-0.01	-0.03	-0.01	0.80	-0.11	0.03	0.05	0.01	0.04	-0.02

**Table 4.6.** Continued.

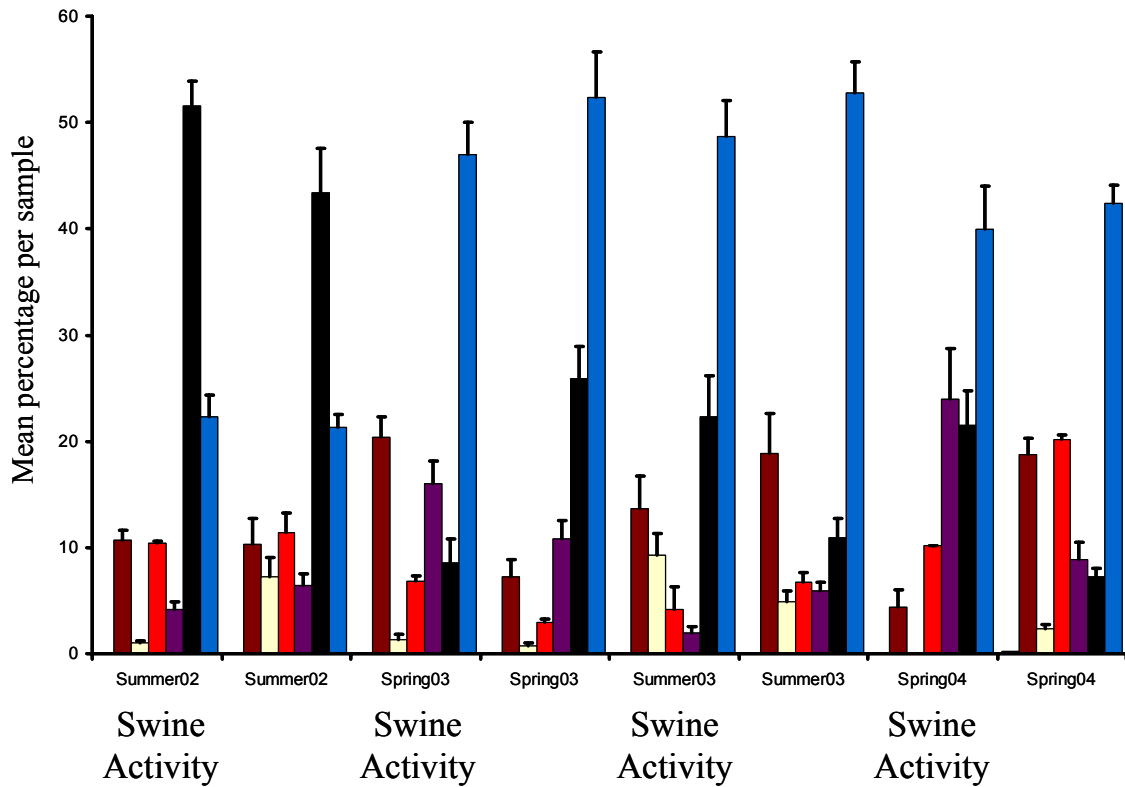
Macroinvertebrate taxa	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	PC 11	PC 12	PC 13	PC 14
<i>Pedicia</i> spp.	-0.01	0	-0.03	0.15	-0.12	0	-0.07	0.02	0.06	0.16	-0.05	-0.01	-0.07	0.33
Baetidae	0	0.41	-0.04	-0.05	-0.09	-0.09	-0.04	-0.05	0.49	-0.10	0.02	-0.01	-0.28	0.04
<i>Caenis hilaris</i> Say	-0.01	-0.01	0.85	-0.01	0.02	-0.10	-0.07	-0.03	-0.05	0.05	0.03	0.23	0.13	0.07
<i>Stenacron floridense</i> Lewis	-0.02	-0.03	0.49	0.05	0	0.05	0.29	-0.06	0	0.56	0.01	-0.14	-0.04	0.04
<i>Stenacron interpunctatum</i> Say	0.74	-0.03	-0.04	0.10	-0.04	-0.05	0.26	0	-0.02	-0.01	-0.03	0.04	0.04	0.10
<i>Stenonema</i> spp.	-0.04	-0.02	0.37	-0.03	0.02	0.04	0.02	-0.05	0.03	-0.08	-0.08	0.76	-0.02	0.12
Leptophlebiidae	0.01	0.59	0.05	-0.02	-0.10	-0.11	-0.08	-0.03	0.23	-0.06	0.01	-0.10	0.31	-0.05
<i>Sialis</i> spp.	0.78	0.03	0	0.04	0.53	-0.04	-0.08	-0.04	0	0	0.02	-0.02	-0.03	-0.02
Aeshnidae	0.46	0.03	-0.17	-0.06	-0.08	-0.05	-0.03	0.32	-0.08	0.47	-0.08	0.15	0.14	0.019
<i>Boyeria</i> spp.	-0.01	0.07	-0.03	-0.03	-0.03	-0.01	0.11	-0.04	0.01	-0.01	0.01	0.01	-0.14	-0.02
<i>Argia</i> spp.	0.12	-0.05	0.01	0	-0.05	-0.04	0.56	-0.03	0.01	-0.30	-0.01	-0.06	0	0.10
<i>Agneta</i> spp.	-0.02	-0.03	-0.08	-0.05	-0.01	-0.12	0.03	0.03	0.68	-0.02	0.18	0.05	0.21	0.02
<i>Perlesta</i> spp.	-0.03	0.95	-0.02	-0.04	-0.08	-0.02	0.07	0	-0.05	-0.06	0.05	0.03	-0.07	0
<i>Perlinella</i> spp.	0.01	-0.06	-0.13	-0.04	0	-0.07	0.09	-0.12	0.09	0.01	0.59	0.01	0.28	0.09
<i>Cheumatopsyche</i> spp.	0.05	0.84	-0.02	-0.01	0.02	-0.10	-0.07	-0.03	0.03	-0.04	0.02	-0.04	-0.07	0.01

**Table 4.6.** Continued.

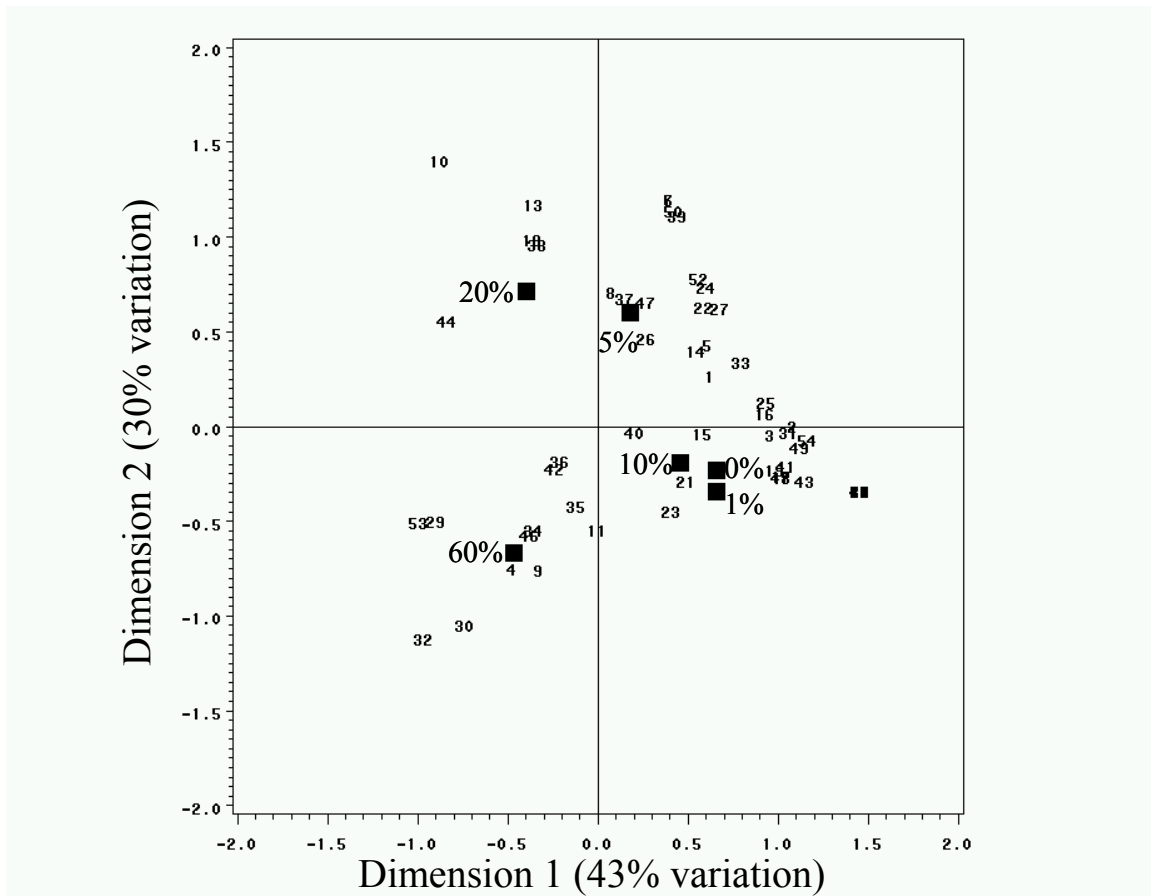
Macroinvertebrate taxa	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	PC 11	PC 12	PC 13	PC 14
Entotrychidae	0.04	-0.03	-0.08	-0.01	0	-0.06	-0.03	0.02	-0.04	0.02	0.04	0.01	0.03	0.76
Lumbricidae	-0.06	-0.11	0.17	-0.07	-0.10	-0.11	-0.02	0.20	-0.02	0	0.20	0.25	0.02	-0.33
<i>Helobdella</i> spp.	-0.02	-0.02	0.50	0.16	-0.01	0.07	0.36	0.41	0.05	-0.08	0.02	0.35	0.06	0.12
<i>Laevipea</i> spp.	-0.03	0.02	0.16	0.01	-0.01	-0.07	-0.12	0.22	0.11	0.05	0.49	-0.07	-0.28	-0.05
Hydrobiidae	0.27	-0.01	0.02	-0.04	-0.01	-0.01	-0.05	-0.02	0.02	0.05	-0.03	0.81	-0.13	-0.05
Physidae	0.04	0.08	0.05	0	-0.12	0.08	-0.01	0.08	0	-0.14	0.65	-0.13	-0.13	-0.05
<i>Heliosoma</i> spp.	-0.04	0.06	-0.03	-0.01	-0.01	0.38	-0.04	-0.05	-0.12	-0.01	0.59	0.16	0.12	0.02
Planorbidae: Others	-0.01	-0.05	0	-0.06	-0.06	0.52	0.13	-0.05	-0.07	0.31	0.42	-0.09	-0.11	-0.03
Pleuroceridae	0.10	0	-0.01	0.91	-0.15	-0.04	-0.02	0	-0.01	0	-0.01	-0.01	0	0.11
Viviparidae	0.82	0.01	-0.02	0.27	-0.08	0.01	-0.07	-0.03	-0.05	-0.01	-0.03	0.02	0.01	-0.05
<i>Pomacea</i> spp.	0.03	-0.02	0.78	-0.05	0	0.02	-0.05	-0.09	-0.09	-0.01	-0.07	0.02	0.15	0.15
<i>Corbicula</i> spp	0	-0.01	0.11	-0.04	0.01	0.03	0.77	0.03	0	0.34	0.09	-0.06	-0.17	-0.09
Sphaeriidae	0	-0.02	0.57	-0.02	-0.03	-0.04	-0.04	0.01	-0.03	0.01	0	-0.02	-0.06	-0.10

**Table 4.6.** Continued.

<b>Macroinvertebrate taxa</b>	<b>PC 1</b>	<b>PC 2</b>	<b>PC 3</b>	<b>PC 4</b>	<b>PC 5</b>	<b>PC 6</b>	<b>PC 7</b>	<b>PC 8</b>	<b>PC 9</b>	<b>PC 10</b>	<b>PC 11</b>	<b>PC 12</b>	<b>PC 13</b>	<b>PC 14</b>
Unionidae	-0.08	-0.07	-0.09	0.05	0.05	-0.06	0.31	-0.02	-0.11	-0.02	-0.03	0.02	0.01	-0.05
<i>Amblema</i> spp.	0.85	0.01	-0.05	0	0	-0.06	-0.05	0.13	-0.02	0.08	-0.01	0.09	0.01	0.10
<i>Anodotiodes</i> spp.	-0.05	-0.02	-0.01	-0.03	0.22	0.02	0.04	0.03	-0.03	-0.03	-0.03	0.04	0.02	0.02
<i>Toxolasma</i> spp.	0.02	0	0.02	0.89	0.16	-0.06	-0.02	-0.01	0.01	0.03	0.01	0	-0.02	0



**Figure 4.1.** Scrapers were less abundant in sites with swine activity. Macroinvertebrates were placed into shredders (green), scrapers (brown), filterers (yellow), predators (red), detritivores (purple), and collectors (blue). Macroinvertebrates with unknown or uncertain affiliations were kept separate (black). Dotted lines divide the streams. Standard error bars are given for each mean.




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1) Aeshnidae	11) <i>C. hilaris</i>	21) Cambaridae	31) Hydrobiidae	41) <i>Optioservus</i> spp.	51) Sciritidae
2) <i>Agnatina</i> spp.	12) Carabidae	22) <i>Dubiraphia</i> spp.	32) Hydrophilidae	42) Orthoclaadiinae	52) <i>Sialis</i> spp.
3) <i>Amblema</i> spp.	13) <i>Cheumatopsyche</i> spp.	23) Dytiscidae	33) <i>S. interpunctatum</i>	43) <i>Pedicia</i> spp.	53) Simuliidae
4) <i>Crangonyx</i> spp.	14) Chironominae	24) Elmidae	34) <i>Lirceus</i> spp.	44) <i>Perlesta</i> spp.	54) Sphaeriidae
5) <i>Ancyronyx</i> spp.	15) Chironomidae	25) Entocytrichidae	35) <i>Laevepex</i> spp.	45) <i>Perlinella</i> spp.	55) <i>Stenelmis</i> spp.
6) <i>Anodiotes</i> spp.	16) Coleoptera	26) <i>S. floridense</i>	36) <i>Helobdella</i> spp.	46) Physidae	56) <i>Stenonema</i> spp.
7) <i>Argia</i> spp.	17) Collembola	27) <i>Gonielmis</i> spp.	37) Leptophlebiidae	47) Planorbidae	57) Tanypodinae
8) Baetidae	18) <i>Corbicula</i> spp.	28) Gyridae	38) <i>M. glabratus</i>	48) Pleuroceridae	58) <i>Toxolasma</i> spp.
9) <i>Bezzia</i> spp.	19) <i>Corynoneura</i> spp.	29) Haliplidae	39) <i>Microcylleopus</i> spp.	49) <i>Pomacea</i> spp.	59) Unionidae
10) <i>Boyeria</i> spp.	20) Culicidae	30) <i>Heliosoma</i> spp.	40) Lumbricidae	50) <i>Promoresia</i> spp.	60) Viviparidae

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**Figure 4.2.** Spatial orientation of the macroinvertebrate data along the two dimensions explaining the greatest variance suggests most taxa are associated with lower levels of disturbance.



**Table 4.7.** Canonical variates (CV 1-16) constructed from combined macroinvertebrate, bacterial, water quality, and habitat data. Correlations between habitat, water quality, and bacterial parameters with canonical variates are listed below. Shadings indicate correlations greater than 0.30.

Initial variable	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV
(swine and water quality)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Swine presence	0.52	0.10	0.10	0.20	-0.05	-0.05	0.05	0.17	-0.14	0.07	0.13	-0.47	0.15	0.34	-0.01	0.08
% Riparian disturbance	0.19	0.23	0.29	0	0.01	-0.45	0.45	0.07	-0.38	-0.03	-0.04	-0.24	0.31	0.04	-0.09	0.05
DO	0.53	0.07	-0.11	0.23	0.26	0.31	0.16	-0.34	0.33	0.22	-0.11	-0.02	0.06	-0.25	-0.03	-0.06
Temperature	-0.14	-0.12	0.26	-0.03	-0.29	0.02	-0.09	0.26	-0.11	0.37	0.33	-0.04	0.09	0	-0.30	0.08
Spc	0.78	0.01	-0.22	-0.27	0.10	0.12	0.19	0.01	-0.11	0.24	0.06	0.14	0.03	-0.14	0.02	0.07
FC	0.59	0.10	0.17	-0.12	-0.19	-0.01	0.15	0.12	-0.08	0	-0.41	-0.21	-0.19	0.08	0.23	0.11
HPC	0	-0.11	0.09	-0.05	-0.02	0.11	0.03	0.24	-0.09	0.12	0.35	-0.26	-0.34	0.13	-0.09	0.35
BOD	0.01	0.04	0.34	0.11	0.18	0.11	-0.34	0.11	0.16	-0.26	-0.32	-0.39	-0.13	0.43	-0.05	-0.12
TC	-0.27	-0.16	0	-0.05	-0.24	0.27	-0.05	-0.29	0.04	-0.05	0.24	0.16	0.08	0.28	0.07	0.04
TOC	-0.07	-0.04	0.22	0.08	0.12	0	-0.27	0.15	0.12	-0.27	-0.21	-0.31	-0.05	0.49	0.09	-0.09
DOC	-0.07	0.01	0.29	0.05	0.17	0	-0.23	0.19	0.12	-0.32	-0.24	-0.31	-0.08	0.47	0.10	-0.10
IC	-0.17	-0.10	-0.21	-0.12	-0.32	-0.24	0.21	-0.39	-0.08	0.22	0.40	0.44	0.11	-0.23	-0.02	0.12
TN	-0.21	-0.17	-0.31	-0.13	0.04	-0.16	-0.17	0.42	0.02	-0.16	-0.14	-0.09	0.04	0.41	0.07	0.12

**Table 4.7.** Continued.

Initial variable	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV
(habitat)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
CWD	-0.24	-0.36	-0.17	-0.05	-0.29	-0.29	-0.19	-0.47	0.06	-0.01	0	0.15	0.02	-0.09	0.10	-0.16
Wood volume	-0.05	0.02	-0.09	0.03	0.02	0	0.01	-0.07	0.02	0.05	-0.04	0.01	0	-0.01	-0.11	-0.10
Wood orientation	0.26	0.08	0.06	-0.01	0.42	-0.14	0.12	0.07	-0.05	0.18	0.01	0	-0.04	0.13	0.09	-0.28
Wood complexity	0.05	0.02	-0.25	-0.05	-0.14	-0.26	-0.01	-0.35	0.03	0.11	-0.13	0.15	0.03	0.28	-0.20	-0.55
FOD	0.11	-0.19	0.41	0.31	-0.06	-0.19	-0.11	0.02	0.02	0	0.11	0.08	0.07	0.08	-0.17	0.19
Site 1	-0.17	0.01	0	-0.04	0.08	0	-0.25	0.22	0.04	-0.08	-0.26	-0.14	-0.21	0	-0.29	0.02
Site 2	0.39	-0.02	-0.63	-0.29	0.06	0.27	0.14	-0.01	-0.08	0.27	-0.03	0.32	0.15	-0.03	-0.03	0.23
Site 3	-0.20	-0.02	0	-0.07	0.14	-0.02	-0.23	0.41	-0.09	-0.31	-0.13	-0.18	-0.13	0.28	0.25	-0.03
Site 4	-0.08	-0.47	0.22	0.04	-0.16	-0.56	0.30	-0.30	0.16	-0.05	0.29	0.13	-0.06	-0.15	0.01	-0.08
Site 5	0.04	0.57	0.39	0.35	-0.09	0.39	-0.05	-0.25	-0.04	0.16	0.05	-0.16	0.24	-0.08	0.01	-0.13
Period 1 (linear)	0.48	0.26	0.36	-0.14	0.42	-0.15	0.04	0.32	-0.22	0.12	0.11	-0.07	0.03	-0.02	0.11	-0.08
Period 2 (quadratic)	0.51	0.30	0.27	-0.12	0.40	-0.31	-0.01	0.21	-0.24	0.06	0.08	-0.09	0.04	-0.04	0.16	-0.10
Period 3 (cubic)	0.53	0.31	0.22	-0.10	0.39	-0.36	-0.01	0.13	-0.23	0	0.04	-0.09	0.04	-0.05	0.20	-0.10

**Table 4.7.** Continued.

Initial variable (bacteria)	CV 1	CV 2	CV 3	CV 4	CV 5	CV 6	CV 7	CV 8	CV 9	CV 10	CV 11	CV 12	CV 13	CV 14	CV 15	CV 16
A	0.04	-0.09	0.11	0	-0.02	-0.08	0.17	0.03	-0.10	0.18	0.79	-0.09	-0.43	0.21	-0.11	0.08
D	-0.11	0.04	-0.01	-0.04	0.21	0	-0.10	0.37	-0.18	-0.18	0.07	-0.02	-0.19	-0.16	0.42	-0.26
F	-0.09	-0.13	0.04	-0.01	-0.08	0.09	-0.12	-0.07	0.04	-0.01	0.49	-0.15	-0.13	0.72	0.01	0.11
G	-0.21	0.35	-0.67	-0.40	-0.13	0.07	0.29	-0.20	-0.02	0.03	0.05	0.04	0.04	-0.11	-0.08	0.17
H	-0.14	-0.10	-0.04	-0.02	-0.08	-0.05	-0.29	-0.10	0.13	-0.16	-0.03	-0.12	0.19	0.74	0.11	0.08
I	-0.14	-0.10	-0.04	-0.02	-0.08	-0.05	-0.29	-0.10	0.13	-0.16	-0.03	-0.12	0.19	0.74	0.11	0.08
J	-0.18	0.51	0.02	0.06	-0.27	-0.32	-0.22	-0.47	0.04	-0.05	-0.01	0.17	-0.05	-0.36	0.06	-0.12
K	0.53	-0.45	-0.11	-0.08	-0.32	0.52	0.22	0.11	-0.06	0	-0.16	-0.09	-0.03	0.07	-0.01	-0.04
L	-0.04	0.01	0.14	-0.05	-0.01	-0.06	0.34	0.26	0.84	-0.07	0.06	0.20	0.09	-0.01	0.07	-0.09
<i>Aeromonas</i> spp.	-0.22	-0.03	0.11	-0.07	-0.13	0.05	-0.32	0.03	0.08	0.20	0.09	-0.41	0.52	0.46	0.06	0.01
<i>Azobacter</i> spp.	0.19	0.04	0.18	0.14	0.71	0	0.38	-0.40	-0.12	0.09	-0.17	-0.02	0.14	0.10	0	-0.02
<i>Azomonas</i> spp.	0.53	-0.45	-0.11	-0.08	-0.32	0.52	0.22	0.11	-0.06	0	-0.16	-0.09	-0.03	0.07	0	-0.04
<i>Bacillus</i> spp.	0.27	0.34	0.28	-0.14	-0.05	-0.10	-0.11	0.13	-0.16	-0.11	0.51	-0.05	-0.42	-0.01	0.21	-0.14
<i>Eikenella</i> spp.	0.04	-0.09	0.11	0	-0.02	-0.08	0.17	0.03	-0.10	0.18	0.79	-0.08	-0.43	0.21	-0.11	0.08
<i>Enterococcus</i> spp.	0.35	-0.31	-0.04	-0.09	-0.16	0.39	0.24	0.33	-0.14	-0.14	-0.21	-0.15	-0.10	-0.03	0.02	0.08

**Table 4.7.** Continued.

<b>Initial variable</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>
<b>(bacteria)</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>
<i>Leconostoc lactis</i>	0.04	-0.09	0.11	0	-0.02	-0.08	0.17	0.03	-0.10	0.18	0.79	-0.08	-0.43	0.21	-0.11	-0.08
<i>Listeria</i> spp.	-0.21	0.35	-0.67	-0.40	-0.13	0.07	0.29	-0.20	-0.02	0.03	0.05	0.04	0.04	-0.11	-0.08	0.17
<i>Proteus penneri</i>	-0.18	-0.51	0.02	0.06	-0.27	-0.32	-0.22	-0.47	0.04	-0.05	-0.01	0.17	-0.05	-0.36	0.06	-0.12
<i>Providencia alcalifaciens</i>	0.04	-0.09	0.11	0	-0.02	-0.08	0.17	0.03	-0.10	0.18	0.79	-0.08	-0.43	0.21	-0.11	0.08
<i>Shigella</i> spp.	-0.16	-0.33	-0.10	0.48	-0.37	0.27	-0.17	-0.40	0.02	-0.07	0.01	0.16	-0.02	-0.34	-0.08	-0.11
<i>Staphylococcus aureus</i>	-0.16	0.06	0.20	-0.08	-0.10	0.13	-0.14	0.16	-0.02	0.48	0.17	-0.47	0.56	-0.16	-0.04	-0.07

**Table 4.8.** Canonical variates (CV 1-16) constructed from combined macroinvertebrate, bacterial, water quality, and habitat data. Correlations between macroinvertebrate taxa with canonical variates are listed below. Shadings indicate correlations greater than 0.30.

Macroinvertebrate taxa	CV 1	CV 2	CV 3	CV 4	CV 5	CV 6	CV 7	CV 8	CV 9	CV 10	CV 11	CV 12	CV 13	CV 14	CV 15	CV 16
<i>Crangonyx</i> spp.	-0.01	0.09	0.30	0.10	0.20	0.03	0.47	-0.27	-0.24	0.04	-0.24	0.02	0.01	0.12	0.01	-0.04
Cambaridae	-0.03	0.08	0.01	0.23	0	0.05	0.09	-0.06	-0.03	0	-0.03	0	0.02	0.03	0.10	0.03
<i>Lirceus</i> spp.	-0.01	-0.05	0.33	0.09	0.12	0.06	0.41	-0.16	-0.20	0.03	-0.07	-0.20	0.31	0.08	-0.05	-0.01
Carabidae	-0.02	0	0.03	-0.04	-0.01	0	0.11	0.06	0.26	-0.05	0.05	0.06	0.11	0	0.29	-0.04
<i>Ancyronyx</i> spp.	0.19	0.05	-0.15	0.20	0.21	-0.02	-0.10	0	0.04	0.20	0.05	0.04	0.16	-0.08	0.07	0.13
<i>Dubiraphia</i> spp.	-0.18	0.27	-0.46	0.13	-0.22	0.07	-0.02	-0.02	-0.06	0.02	0.09	0.08	0.36	0.40	0.05	-0.02
<i>Gonielmis</i> spp.	-0.06	0.08	-0.04	0.08	0.02	0.10	0.08	-0.09	0.02	-0.02	0.01	0.01	0	-0.08	-0.09	0.22
<i>Macronychus glabratus</i> Say	0.21	0.36	0.37	-0.13	-0.15	0.07	-0.21	0.01	-0.09	0.42	0.11	-0.03	0.40	-0.14	0.08	0.07
<i>Microcylleopus</i> spp.	-0.12	0.27	-0.60	-0.32	-0.15	0.11	0.28	-0.16	-0.05	0.01	0.05	0.05	0.07	-0.08	-0.08	0.07
<i>Optioservus</i> spp.	0.20	0.16	-0.31	0.64	-0.02	0.02	0.03	0.03	0.04	0.15	-0.04	-0.03	0.01	0.02	0.01	-0.07
<i>Promoresia</i> spp.	-0.19	0.34	-0.67	-0.35	-0.14	0.07	0.29	-0.19	-0.07	0.04	0.06	0.06	0.07	-0.05	0.05	-0.01
<i>Stenelmis</i> spp.	0.56	0.44	-0.04	-0.14	-0.08	0.09	-0.17	0.08	0.01	-0.12	0.10	0.02	0.09	-0.11	0.03	-0.13
Elmidae: Unidentifiable	-0.06	0.19	-0.39	0.02	-0.14	0.09	0.17	-0.09	-0.04	-0.03	0.07	0.02	0.08	-0.07	0.11	0.02

**Table 4.8.** Continued.

<b>Macroinvertebrate</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>
<b>taxa</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>
Dytiscidae	-0.38	-0.20	-0.07	0.07	0.16	0.25	0.12	-0.07	0.02	0.05	-0.11	-0.07	0.04	0.03	-0.09	0.12
Gyrinidae	0.37	-0.08	-0.25	0.02	0.37	0.01	-0.10	-0.07	0.08	0.13	0.03	-0.05	0.07	-0.02	0.14	-0.14
Haliplidae	0.24	0.11	0.15	-0.06	-0.13	-0.15	0.17	-0.05	-0.11	0.09	-0.21	-0.04	-0.07	0.11	0.03	-0.07
Hydrophilidae	0.05	-0.03	0.10	0.01	0.15	-0.24	0.28	0.04	-0.23	-0.02	0	0.06	0.21	0.03	0.10	0.02
Scirtidae	0.29	-0.02	-0.22	0.04	0.39	-0.07	-0.12	-0.09	0.09	0.18	0.02	-0.03	0.05	-0.02	0.14	-0.11
Coleoptera: Unidentifiable	0.04	-0.08	0.12	0.13	0	0.28	0.17	-0.11	-0.06	0.08	0.26	-0.08	-0.20	0.04	0	0.17
Collembola	0.01	-0.04	0.05	0	-0.01	-0.05	0.09	0.03	-0.06	0.12	0.51	-0.08	-0.36	0.22	-0.10	0.14
<i>Bezzia</i> spp.	0.34	-0.09	-0.16	0.02	0.31	-0.10	0.04	-0.02	-0.04	0.11	-0.04	0.2	0.14	0.06	-0.09	-0.14
Chironominae	-0.26	-0.04	0.07	0.08	-0.12	0.17	0.02	-0.24	0.03	0.28	0.42	-0.27	0.18	-0.02	0.05	0.03
<i>Corynoneura</i> spp.	0.34	-0.31	-0.02	-0.09	-0.16	0.40	0.27	0.19	0.14	-0.15	0.11	-0.02	0.05	0	0.16	0.01
Orthoclaadiinae	0.51	0.19	0.35	-0.11	0.09	-0.23	0.36	0.09	0.07	0.22	-0.02	-0.04	0.11	0.06	0.09	0.08
Tanypodinae	0.32	0.57	-0.08	-0.30	-0.22	-0.02	0	-0.24	0.06	0.06	0.24	-0.15	0.19	-0.04	0.08	-0.04
Chironomidae: Others	0.22	-0.47	-0.06	-0.01	-0.38	0.05	0.02	-0.24	0.08	-0.15	0.01	0.09	0.09	-0.06	0.24	-0.06
Culicidae	0.03	0.10	0.22	-0.07	-0.05	0.11	-0.11	0.08	-0.11	-0.17	0.11	-0.02	-0.03	-0.12	0.46	-0.25

**Table 4.8.** Continued.

<b>Macroinvertebrate</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>
<b>taxa</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>
Simuliidae	0.17	0.17	0.20	-0.04	-0.07	-0.20	0.14	-0.09	-0.08	0.01	-0.13	-0.06	0	0.03	0.13	0.12
<i>Pedicia</i> spp	-0.04	0.02	0	0.15	-0.09	-0.02	-0.03	-0.03	0.05	0.06	-0.06	-0.07	-0.01	0.18	0.23	0.19
Baetidae	0.19	0.22	0.18	-0.11	-0.07	-0.03	0.06	0.08	0.51	-0.30	0.15	0.17	0.15	-0.07	-0.13	-0.17
<i>Caenis hilaris</i> Say	-0.13	0.06	0.31	0.11	0.31	0.37	0.28	-0.35	-0.13	0.04	-0.07	0.17	-0.04	0.08	-0.06	-0.06
<i>Stenacron floridense</i> Lewis	-0.12	0.10	0.25	0.08	0.11	0.34	0.12	-0.14	-0.08	0.36	0.33	-0.13	0.22	-0.04	-0.11	-0.07
<i>Stenacron interpunctatum</i> Say	0.02	0.05	-0.02	0.23	-0.07	0.04	-0.02	0.11	-0.11	0.07	0.11	0.32	0.12	-0.02	0.07	0.19
<i>Stenonema</i> spp.	-0.08	0.05	0.18	0.05	0.23	0.34	0.10	-0.22	-0.07	0.07	-0.05	0.22	-0.01	0.05	0.07	-0.05
Leptophlebiidae	0.32	0	0.07	-0.08	-0.11	0.21	-0.06	-0.03	-0.02	-0.33	0.11	-0.04	0.13	-0.08	-0.09	0.10
<i>Sialis</i> spp.	-0.09	0.25	-0.40	0.03	-0.15	0.05	0.17	-0.10	-0.04	-0.01	0.06	0.03	0.06	-0.08	0.10	0.05
Aeshnidae	0.11	0.17	0.13	0.04	-0.16	-0.08	-0.01	-0.05	0.02	0.17	0.06	-0.02	-0.21	0.12	0.09	-0.01
<i>Boyeria</i> spp.	0.07	0.09	0.10	-0.04	-0.04	0.04	-0.09	-0.02	0	-0.05	0.11	-0.10	0.19	-0.11	-0.02	0.03
<i>Argia</i> spp.	0.02	-0.01	0.05	-0.02	0	0.03	-0.08	0.16	-0.15	0.13	0.04	0.50	0.18	0.02	0.03	0.24
<i>Agnatina</i> spp.	0.10	-0.10	0.13	0.04	-0.16	-0.08	-0.01	-0.05	0.56	0.03	-0.05	0.12	0	0.01	0.09	-0.03
<i>Perlesta</i> spp.	0.47	0.45	0.26	-0.16	-0.12	-0.10	-0.18	-0.18	-0.03	-0.33	0.08	0.01	0.08	-0.08	-0.07	-0.10

**Table 4.8.** Continued.

<b>Macroinvertebrate</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>	<b>CV</b>
<b>taxa</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>
<i>Perlinella</i> spp.	0.15	-0.02	-0.02	0.03	0.22	-0.05	0.05	0.04	0.44	0.03	0.06	0.04	0.08	-0.08	0.09	0.20
<i>Cheumatopsyche</i> spp.	0.28	0.35	0.09	-0.17	-0.12	0.02	-0.13	-0.13	0.04	-0.36	0.19	0.04	0.11	-0.11	-0.09	-0.03
Entotrychidae	-0.05	0.04	-0.04	0.15	-0.04	0.02	-0.02	0	0.03	-0.05	-0.01	-0.07	-0.01	-0.07	0.04	0.24
Lumbricidae	-0.02	0.03	0.18	-0.06	0.20	0.18	0.17	0.24	-0.29	-0.07	0.02	-0.01	0.11	0.06	0.09	0.08
<i>Helobdella</i> spp.	0.15	0.20	0.28	0.19	0.22	0.14	0.23	-0.24	-0.17	0.16	-0.08	0.19	0.12	0.04	0.05	0.17
<i>Laevipep</i> spp.	0.16	-0.08	0.17	0.01	0	-0.28	0.54	-0.14	-0.10	0.11	0.32	0.08	0.08	0.04	-0.14	-0.19
Hydrobiidae	-0.09	0.06	0.10	0.08	0.14	0.24	0.09	-0.19	-0.04	-0.02	0	0.06	0	0.01	0.16	-0.11
Physidae	0.43	-0.13	-0.07	0	0.14	0.01	0.11	-0.02	-0.03	0.12	-0.07	-0.06	0.03	0.06	-0.05	0
<i>Heliosoma</i> spp.	0.30	-0.03	-0.11	0.06	0.40	-0.25	0.09	-0.09	-0.01	0.15	-0.08	-0.08	0.11	0.05	0.08	0.01
Planorbidae: Others	0.24	-0.04	-0.03	-0.01	0.23	0.11	-0.09	0.06	-0.02	0.33	0.16	-0.07	0.15	-0.04	0.07	-0.08
Pleuroceridae	0	0.25	-0.22	0.80	-0.23	0.05	0.06	0.07	-0.02	-0.04	0.03	0	0.07	0.01	0.06	-0.02
Viviparidae	0.01	0.18	-0.16	0.58	-0.17	0.03	0.05	0.05	-0.02	0.02	0.02	0.01	0.04	0	0	-0.06
<i>Pomacea</i> spp.	-0.18	0.09	0.27	0.10	0.28	0.43	0.15	-0.34	-0.02	0.03	-0.08	0.09	-0.04	0.03	-0.08	-0.02
<i>Corbicula</i> spp	0.03	0.10	0.22	-0.07	-0.05	0.11	-0.11	0.08	-0.05	0.47	0.14	-0.20	0.48	-0.16	-0.02	0.06



**Table 4.8.** Continued.

Macroinvertebrate	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV
taxa	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Sphaeriidae	-0.16	0.07	0.26	0.08	0.27	0.39	0.14	-0.01	-0.01	-0.01	-0.07	0.09	-0.05	0.04	0.01	0.10
Unionidae	-0.01	0.02	0.04	-0.05	-0.02	0.02	-0.10	0.17	-0.14	0.23	0.02	0.37	0.22	0.09	-0.03	0.03
<i>Amblema</i> spp.	0	0.09	-0.08	0.34	-0.09	0.04	0.03	0.02	-0.01	-0.05	0.05	-0.01	0.05	-0.05	0.10	0.08
<i>Anodotodes</i> spp.	-0.05	0.07	-0.12	-0.07	-0.02	0.02	0.07	-0.06	0.03	-0.01	0.03	-0.01	0	-0.13	-0.17	0.30
<i>Toxolasma</i> spp.	-0.04	0.20	-0.29	0.47	-0.20	0.03	0.10	-0.03	-0.04	-0.02	0.06	0.04	0.05	-0.14	0	-0.03

## DISCUSSION

Invasive feral swine have devastated terrestrial ecosystems where they have been introduced (reviewed in Wolf and Conover 2003). Feral swine populations are increasing in North America (Gipson et al. 1998; Waithman et al. 1999) and remain problematic in South America and Oceania (Sicuro and Oliveria 2002; Hone 2002; Landsburg and Crowley 2004), and potentially in Asia and Europe as well (Ickes 2001; Goulding and Roper 2002).

Confirming the suspicions of Belden and Pelton (1975,1976), I documented evidence that invasive feral swine activity altered aquatic communities in adjacent streams. Invasive feral swine activity shifted the macroinvertebrate community from a mix of organic matter filterers and collectors, biofilm scrapers, and predators to a community dominated by collectors and general detritivores, with reductions in scraping taxa. Whereas the mechanism behind the community shift is as yet undetermined, the shift occurred nonetheless, with potentially damaging effects to nutrient spiraling and to other organisms dependent on the presence or activities of scraping taxa.

Feral swine are known to trample stream banks and increase erosion (Singer et al. 1982; McIlroy 1983; Russell-Smith and Bowman 1992). In this study, I was further able to link feral swine activity to reductions in dissolved oxygen, probably through increases in BOD and HPC, and to decreases in CWD, probably through stream-bed disturbance. Changes in habitat and dissolved oxygen alone, however, are likely inadequate explanations of the macroinvertebrate community shift. CWD is an important habitat component in streams lacking other hard surfaces, such as rocks, for attachment and feeding (Drury and Kelso 2000; Wood and Sites 2002; Johnson and Kennedy 2003; Phillips 2003). However, reductions in CWD would also likely reduce the less-mobile filtering taxa as well, if such

reductions were responsible for the decreases in scraping taxa, which was not evident in Mill Creek. Similarly, low dissolved oxygen, which can affect the abundance of macroinvertebrates in some systems (e.g., Connolly et al. 2004), does not appear to be an important physiochemical problem for many taxa in these coastal plain streams (Chapter 2). Therefore, it is unlikely that either of these two factors alone or in combination led to decreases in scraping taxa in favor of collecting taxa.

Instead, the effects of feral swine on Mill Creek macroinvertebrates may be most related to the microbial data. My identification methods were designed more for clinical than environmental needs (Holt 2000), and freshwater aquatic microbiology, as a whole, is poorly described (Leff and Lemke 1998). However, the CCA consistently linked particular bacteria with swine activity, and it is possible that the reduction of scraping taxa was a result of a change in the bacterial composition of substrate biofilms. The water-borne bacteria I sampled originate, for the most part, in substrate biofilms and sediment where they exist in higher concentrations than the water column. Aquatic microbes vary in their ability to process different sources of carbon (Koetsier et al. 1997; Strauss and Lamberti 2002), and feral swine activity may change the predominant form of organic carbon in the biofilms, which could favor certain bacterial taxa that are not suitable food for scraping macroinvertebrates. Introduction of feces, in particular, is associated with feral swine activity, and was evident in the elevated fecal coliforms reported by Kaller and Kelso (2003) and in this study. Whereas I do not understand the mechanism of this change, I suggest that swine activity is either introducing or favoring particular microbes in the biofilms that may possess herbivory inhibitors (e.g. Van Alstyne and Houser 2003) or are otherwise not palatable to scraping macroinvertebrates.

Given the documented wide tolerances of coastal plain macroinvertebrates (e.g., Davis et al. 2003; Johnson and Kennedy 2003; Chapters 2 and 3), it is remarkable that 50% (66% of detected correlations) of macroinvertebrate taxa demonstrated some correlation to swine activity. Further, unlike mixed correlations of individual taxa with land use (Chapter 3), entire feeding groups, i.e., scrapers and collectors, were negatively and positively correlated with swine activity, respectively. In this study, heptageniid (*Stenacron floridense*, *Stenacron interpunctatum*, and *Stenonema* spp.) abundance was negatively correlated with feral swine, whereas chironomids, elmids and leptophlebiids were abundant at sites impacted by feral swine activity. Reed (2003) also reported positive correlations between cattle grazing and elmids and leptophlebiids, but also reported positive correlations between grazing and abundance of the heptageniid *Cinygulma* spp., and negative correlations between grazing and chironomid abundance. Presumably, the differences in response of heptageniids and chironomids between the studies were examples of regional taxonomic differences, such as *Cinygulma* spp. in highland Oregon compared to *Stenacron floridense*, *Stenacron interpunctatum*, and *Stenonema* spp. in lowland Louisiana. Regional differences in macroinvertebrate response to cattle manure addition were also noted by Del Rosario et al. (2002), who reported increases in leptophlebiids and chironomids with increases in carbon from manure, but did not notice substantial changes in feeding groups. I believe the scraping taxa of Gulf coastal plain streams may be particularly sensitive to changes in biofilm species composition, and changes in biofilm composition associated with swine activity may disproportionately affect scraping taxa.

The long-term consequences of a loss of a feeding group may include the interruption of nutrient cycling and a shift in energy transfer from biofilm-feeding to a microbial loop.

Fortunately, the effects of swine activity do not appear to have any long-term ramifications, at this time, because swine move about the watershed and do not appear to use individual sites for long periods of time. However, if swine populations increase, long-term and intensive use of the streams could lead to permanent declines in scraping taxa with potentially negative consequences not only for the individual stream, but also for downstream rivers, lakes, and estuaries.

Despite my findings, many potential impacts of invasive feral swine on aquatic animals, such as fish and amphibians, remain unknown. However, I believe my results should be seriously considered by water quality and wildlife management agencies given the continual expansion of feral swine populations and their potential effects on aquatic microbial and macroinvertebrate communities. In any event, substantial research efforts are needed to further document impacts of feral swine activity in other riverine systems throughout the U.S. and to investigate mitigation and restoration protocols.

#### **LITERATURE CITED**

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## CHAPTER 5. CONCLUSION

The data and inferences drawn from the experiments and surveys addressed macroinvertebrate community colonization of different sizes of woody debris and different levels of dissolved oxygen, linkages, or lack thereof, to stream characteristics, and the effect of a strong localized biotic disturbance. In the Chapters 2 and 3, I suggested that the apparent generalism of many taxa may be the results of geologic forces acting as a taxonomic filter on evolutionary selection where broadly tolerant taxa successfully colonized the newly formed terraces of the Gulf coastal plain. Yet, in Chapter 4, I suggested feral swine (*Sus scrofa*) may be capable of altering macroinvertebrate communities. Perhaps, the introduction of feral swine into the environment 400 years ago was too evolutionarily recent for tolerances to be exhibited or, alternatively, unlike the baetid mayflies studied by Peckarsky et al. (2005), these macroinvertebrates do not possess the genetic flexibility to alter their phenotypic expression in response to swine as Peckarsky et al. (2005) demonstrated with baetid response to fish, and may never exhibit tolerant response to feral swine. Therefore, I believe the most interesting conclusions were the wide tolerances of abiotic characteristics exhibited by macroinvertebrates as demonstrated by the general lack of colonization differences, and the evidence that a biotic factor, feral swine, exhibited a detectable effect upon the macroinvertebrate community when so many abiotic factors did not appear to significantly alter the community.

Abiotic influences, whether natural or anthropogenic in origin, as the most important structuring factors for lotic macroinvertebrate communities have been considered the norm (e.g., Ward 1992; Allan 1995). However, in this study, despite wide ranges of stream characteristics [e.g dissolved oxygen ranging from below 1 (13% saturation) to above 9 mg/L

(93% saturation)], many taxa were distributed throughout the streams (Chapter 3) and demonstrated similar colonization patterns (Chapter 2). I believe, although without supporting fossil evidence, that analogous to fish (Connor and Suttkus 1986; Mayden 1988), terrestrial insects (Noonan 1988), and plants (e.g., Reberetus et al. 1993), ancestral coastal plain macroinvertebrates split, by glacial events, from the once contiguous eastern highlands into eastern (Appalachian) and western (Ozark) groups colonized the gradually forming Gulf coastal plain during the Pleistocene, but were confronted by greatly disparate ecosystems from their ancestral cool, high-gradient, rocky, and swift highland streams. These macroinvertebrates likely were filtered, I believe, with only taxa that could tolerate warm, slow, and wood-choked rivers and streams, which existed in a mosaic of frequently disturbed habitats, successfully colonizing the coastal plain. Over time, these macroinvertebrates reached streams, such as Big Brushy Creek and Six Mile Creek, reminiscent of their origins and streams that were far different, such as Mill Creek. Perhaps, with the aforementioned phenotypic plasticity, some organisms were successful in colonizing all types of streams they encountered as demonstrated by the widely dispersed taxa identified in Chapters 2 and 3, whereas, others quickly became abundant in particular types of streams as demonstrated by the limited stream-specific taxa described in Chapter 3. Whereas I do not have the fossil evidence to support these contentions, I do believe these to be reasonable conclusions to explain the large number of apparently generalist taxa and the fewer, but notable, stream and dissolved oxygen specialists.

Similarly, macroinvertebrate communities are known to be correlated with fish and other predators (e.g., Dahl and Greenberg 1999; Kilgour and Barton 1999; Marklund et al. 2002). However, biotic effects of other organisms, particularly terrestrial herbivores outside

of large-scale agricultural operations (e.g., DeLong and Brusven 1998), typically have been unclear (e.g., Reed 2003). Yet, evidence may exist that terrestrial herbivores may actually alter macroinvertebrate community structure apart from large-scale agricultural operations (Chapter 4). I believe, although at this time I cannot substantiate this claim, that feral swine changed microbial communities by some mechanism where the new biofilm communities are unsuitable for macroinvertebrate scrapers. Potentially, without macroinvertebrate grazing, greater amounts of energy could remain in a microbial loop than would a typical system with macroinvertebrate scrapers. I am aware of few other examples of terrestrial organisms in a forested setting, beside humans, that are capable of significantly altering macroinvertebrate communities, and I believe this to be a fairly unique finding, although I predict evidence will show this is probably not restricted to Mill Creek.

As early as 1970's, Roback (1974) questioned the use of insects as indicators citing experimental evidence of broad tolerances of many species and difficulty with correct identification of cryptic taxa. However, successful application of insects as bioindicators in ensuing decades suggests, with refinement, insects and other aquatic macroinvertebrates may be useful (Karr and Chu 1999). From this study, it appears some taxa may be useful as indicators of low dissolved oxygen, both by absence and abundance (Chapter 2). Further, some taxa, especially elmid genera may be positive indicators of disturbance by land use (Chapter 3). Finally, the absence of scrapers may be indicative of biotic disturbance, such as feral swine rooting and wallowing (Chapter 4). However, the large number of apparent generalists (Chapter 2 and 3), potentially contradictory and uncertain relationships (Chapter 3), limited replication (Chapter 4), and the lack of background data, as compared to neighboring regions, indicate a substantial need for further research, particularly with

reciprocal transplants, additional replication of disturbances, and more frequent sampling to assess seasonal patterns. Therefore, the conclusions and explanations of this dissertation remain preliminary and provide, hopefully, a framework for further research.

The underlying goal of this dissertation was to provide baseline relationships between macroinvertebrate communities and environmental characteristics across a range of conditions. These relationships have been extensively documented elsewhere and successfully utilized in ecological studies and investigations of anthropogenic disturbance (e.g., Angradi 1999). Initially, I expected the disparate land uses, or at least, stream characteristics potentially related to land use, to be a powerful influence on the stream communities and to be important community discriminating structuring factors. However, although many relationships remain uncertain, my best explanations, at present, appear to be wide-spread habitat and physiochemical generalism among macroinvertebrates, but some sensitivity on the part of the macroinvertebrate community, particularly scrapers, to biotic disturbance.

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## APPENDIX 1. SUMMARY OF TAXA COLLECTED DURING THE EXPERIMENT

LETTER CODES DENOTE STREAM, SITE AND TREATMENT. "M" = MILL CREEK. "S" = SIX MILE CREEK. "B" = BACKWATER. "P" = POOL. "R" = RIFFLE, "L" = LARGER TREATMENT. "S" = SMALLER TREATMENT. "C" = CONTROL.

Stream/Site/Treatment	<i>Ablabesmyia</i> spp.	Aeshnidae	<i>Agnatina</i> spp.	<i>Crangonyx</i> spp.	<i>Ancyronyx</i> spp.	<i>Argia</i> spp.	<i>Atherix</i> spp.	Baetidae
SBC	0	0	0	0	0	1	0	0
SBL	0	0	0	0	0	1	0	0
SBS	0	0	0	0	0	0	0	0
SPC	0	0	0	0	2	0	0	0
SPL	0	0	0	0	0	0	3	3
SPS	1	0	0	0	2	0	0	5
SRC	0	0	1	0	6	0	3	0
SRL	0	0	1	1	2	0	12	13
SRS	0	0	0	1	1	0	2	21
MBC	0	0	0	3	0	0	0	2
MBL	0	1	0	21	0	0	0	2
MBS	0	0	0	38	0	0	0	3
MPC	0	0	0	0	0	0	0	0
MPL	0	0	0	72	0	0	0	0
MPS	0	0	0	31	0	0	0	1
MRC	0	0	0	2	0	0	0	0
MRL	0	0	0	57	0	0	0	13
MRS	0	0	0	97	0	0	0	31



APPENDIX 1. CONTINUED.

Stream/Site/Treatment	<i>Basiaeschna</i> spp.	Behningiidae	<i>Beloneuria</i> spp.	<i>Boyeria</i> spp.	<i>Brachycentrus</i> spp.	<i>Caenis hilaris</i> Say	<i>Calopteryx</i> spp.	Cambaridae
SBC	0	0	0	0	0	0	0	0
SBL	0	0	0	0	1	0	0	2
SBS	0	0	0	0	0	0	0	0
SPC	0	0	0	0	0	0	0	0
SPL	0	2	0	1	4	0	0	4
SPS	0	0	0	0	3	0	0	1
SRC	0	0	0	0	1	0	0	0
SRL	0	0	2	1	1	0	0	2
SRS	1	0	0	0	1	0	1	0
MBC	0	0	0	0	0	2	0	0
MBL	0	0	0	0	0	79	0	2
MBS	0	0	0	1	0	71	0	0
MPC	0	0	0	0	0	1	0	0
MPL	0	0	0	0	0	3	0	1
MPS	0	0	0	0	0	8	0	1
MRC	0	0	0	0	0	2	0	0
MRL	4	0	0	1	0	187	0	4
MRS	0	0	0	0	0	349	0	5

APPENDIX 1. CONTINUED.

Stream/Site/Treatment	Ceratopogonidae	<i>Cheumatopsyche</i> spp.	<i>Chimarra</i> spp.	Chironominae	Unidentified Chironomidae	Unidentified Coleoptera	<i>Corbicula fluminea</i> Muller
SBC	0	0	0	0	12	0	0
SBL	0	0	0	0	148	0	0
SBS	0	0	0	0	19	0	0
SPC	0	1	0	0	12	0	0
SPL	1	3	0	1	50	0	0
SPS	0	2	0	2	14	0	0
SRC	1	0	0	0	2	0	0
SRL	2	2	21	5	123	0	0
SRS	0	13	19	0	68	0	0
MBC	0	0	0	0	13	0	1
MBL	15	0	0	0	130	0	5
MBS	7	1	0	4	122	0	10
MPC	0	0	0	0	16	0	9
MPL	12	0	0	12	142	0	26
MPS	4	0	0	8	44	5	20
MRC	0	1	0	0	7	0	0
MRL	3	16	0	0	232	0	65
MRS	8	14	0	1	167	0	20

APPENDIX 1. CONTINUED.

Stream/Site/Treatment	Corduliidae	Corixidae	<i>Corynoneura</i> spp.	Curculionidae	<i>Dromogomphus</i> spp.	<i>Dubiraphia</i> spp.	Dytiscidae	Unidentified Elmidae
SBC	0	0	3	0	0	0	0	0
SBL	0	1	34	0	0	0	1	0
SBS	0	0	5	0	0	0	0	0
SPC	0	0	6	0	0	0	0	0
SPL	0	0	28	2	0	0	0	0
SPS	0	0	49	0	3	0	1	0
SRC	0	0	6	0	0	0	0	1
SRL	0	0	49	0	0	0	0	2
SRS	0	1	47	0	0	0	0	1
MBC	0	0	9	0	0	3	0	0
MBL	0	0	35	1	0	11	0	1
MBS	0	0	27	0	0	5	0	3
MPC	0	0	4	0	0	0	0	0
MPL	2	0	36	0	0	0	0	0
MPS	0	0	20	0	0	0	0	0
MRC	0	0	0	0	0	4	0	0
MRL	0	0	97	0	0	10	1	0
MRS	0	0	83	0	2	13	0	0

APPENDIX 1. CONTINUED.

Stream/Site/Treatment	<i>Cercobrachys etowah</i>	Soldan	<i>Stenacron floridense</i>	Lewis	<i>Gonielmis</i> spp.	<i>Hagenius</i> spp.	Haliplidae	Unidentified Heptageniidae	<i>Hexagenia</i> spp.
SBC	0		0		0	0	0	0	0
SBL	0		0		0	0	0	0	1
SBS	0		0		0	0	0	0	0
SPC	0		0		0	0	0	0	0
SPL	0		0		0	0	0	2	0
SPS	0		0		0	1	0	2	0
SRC	0		0		0	0	0	0	0
SRL	0		0		0	0	0	1	0
SRS	0		0		1	0	0	1	0
MBC	0		0		0	0	0	0	0
MBL	1		6		0	0	0	3	0
MBS	0		3		1	0	1	1	0
MPC	0		0		0	0	0	0	0
MPL	0		0		0	0	0	0	0
MPS	0		0		0	0	2	0	0
MRC	0		0		2	0	0	0	0
MRL	0		51		0	0	0	3	1
MRS	0		32		0	0	0	1	0

APPENDIX 1. CONTINUED.

Stream/Site/Treatment	Hydroptilidae	<i>Laevepex</i> spp.	<i>Lirceus</i> spp.	<i>Helodabella</i> spp.	<i>Leptophlebia</i> spp.	Leucritidae	Libellulidae	Lumbricidae
SBC	0	1	0	0	0	0	0	2
SBL	0	2	0	0	0	0	1	6
SBS	0	0	0	0	1	0	0	0
SPC	0	1	0	0	0	0	0	0
SPL	0	0	0	0	0	0	0	4
SPS	0	0	0	0	3	1	0	3
SRC	0	0	0	0	0	0	0	2
SRL	0	0	0	0	0	1	0	0
SRS	2	0	0	1	0	0	0	1
MBC	0	1	2	4	0	0	0	0
MBL	0	25	31	24	0	0	3	4
MBS	0	5	39	55	0	0	1	2
MPC	0	8	4	6	0	0	0	2
MPL	0	89	18	4	0	0	5	18
MPS	0	22	14	20	0	0	2	6
MRC	0	0	4	1	0	0	0	1
MRL	0	8	155	3	0	0	1	4
MRS	0	4	196	3	0	0	0	11

APPENDIX 1. CONTINUED.

Stream/Site/Treatment	<i>Macrostenum</i> spp.	<i>Macronychus glabratus</i> Say	<i>Marisa</i> spp.	<i>Nixe</i> spp.	Unidentified Odonata	<i>Optioservus</i> spp.	Orthocladinae	Ostracoda
SBC	0	0	0	0	0	0	8	0
SBL	0	1	0	0	0	0	52	0
SBS	0	0	0	0	0	0	5	0
SPC	1	17	0	0	0	0	0	0
SPL	0	10	0	0	0	0	17	0
SPS	0	28	0	1	0	0	18	0
SRC	0	11	0	0	0	0	4	0
SRL	0	21	0	0	0	3	35	0
SRS	1	17	0	0	0	0	9	0
MBC	0	30	0	0	0	2	10	0
MBL	0	68	2	0	1	0	64	0
MBS	0	44	0	0	0	0	43	5
MPC	0	1	0	0	0	0	7	0
MPL	0	1	0	0	0	0	28	0
MPS	0	3	0	0	0	0	20	0
MRC	0	79	0	0	0	0	4	0
MRL	3	324	0	0	0	4	87	2
MRS	6	307	0	0	0	0	43	0

APPENDIX 1. CONTINUED.

Stream/Site/Treatment	Ostracoda	<i>Perlesta</i> spp.	Perlodidae	Unidentified Perlidae	Unidentified Philopotamidae	Physidae	Planorbidae	Unidentified Plecoptera	<i>Polycentropus</i> spp.
SBC	0	0	0	0	0	0	0	0	0
SBL	0	0	0	0	0	0	0	0	0
SBS	0	0	0	0	0	0	0	0	0
SPC	0	0	0	0	0	0	0	0	0
SPL	0	1	0	0	0	0	0	0	3
SPS	0	0	0	0	0	0	0	1	3
SRC	0	0	0	0	0	0	0	0	0
SRL	0	0	2	5	0	0	0	0	1
SRS	0	0	0	2	3	0	0	0	1
MBC	0	0	0	0	0	0	2	0	0
MBL	0	0	0	0	0	5	3	0	0
MBS	5	0	0	0	0	7	0	0	0
MPC	0	0	0	0	0	0	0	0	0
MPL	0	0	0	0	0	6	7	0	0
MPS	0	0	0	0	0	1	2	0	0
MRC	0	0	0	0	0	0	0	0	0
MRL	2	0	0	0	0	0	1	0	0
MRS	0	0	0	0	0	0	1	0	0

APPENDIX 1. CONTINUED.

Stream/Site/Treatment	<i>Pomacea</i> spp.	<i>Radix</i> spp.	Scirtidae	<i>Sialis</i> spp.	Simuliidae	Sphaeridae	<i>Stenelmis</i> spp.	<i>Stenonema</i> spp.	<i>Stomatochlora</i> spp.
SBC	0	0	0	0	0	0	0	0	0
SBL	0	0	0	0	0	0	0	0	0
SBS	0	0	0	0	0	0	0	0	0
SPC	0	0	0	0	0	0	2	1	0
SPL	0	0	0	0	1	0	3	5	0
SPS	0	0	1	0	0	0	1	3	0
SRC	0	0	0	0	0	0	8	0	0
SRL	0	0	0	0	8	0	1	12	0
SRS	0	0	0	0	11	0	6	4	0
MBC	0	0	0	0	0	2	0	2	0
MBL	11	0	0	2	0	4	0	11	0
MBS	4	1	0	1	1	1	1	0	0
MPC	1	0	0	0	0	2	0	0	0
MPL	91	0	0	0	1	2	0	1	7
MPS	39	0	0	0	0	9	0	0	0
MRC	0	0	0	0	0	0	6	2	0
MRL	0	1	0	5	0	1	2	10	0
MRS	0	2	0	4	0	0	4	0	0



**APPENDIX 1. CONTINUED.**

Stream/Site/Treatment	Tanypodinae	Tipulidae	Unionidae	<i>Wormaldia</i> spp.
SBC	3	0	0	0
SBL	66	0	0	0
SBS	18	0	0	0
SPC	4	0	0	0
SPL	46	0	0	1
SPS	67	1	0	1
SRC	22	0	0	1
SRL	121	2	0	2
SRS	29	0	0	1
MBC	11	0	0	0
MBL	96	0	1	0
MBS	35	0	0	0
MPC	4	0	0	0
MPL	49	0	0	0
MPS	14	0	0	0
MRC	18	3	0	0
MRL	352	1	0	0
MRS	352	1	1	0

**APPENDIX 2. MEAN VALUES, WITH STANDARD ERRORS (SE), OF HABITAT, WATER QUALITY, AND PHYSIOCHEMICAL VARIABLES MEASURED AT EACH SITE BY SAMPLING PERIOD COLLECTED IN STREAM SURVEYS**

<b>Stream</b>	<b>Site</b>	<b>Rifle (%) SE</b>	<b>Canopy (%) SE</b>	<b>Depth (cm) SE</b>	<b>Discharge (cm<sup>3</sup>) SE</b>	<b>Width (m) SE</b>
<b>August 2002</b>						
SMC	I	0.50 0.08	100.00 0.00	89.39 13.47	16.75 4.86	5.12 NA
	R	0.22 0.10	98.89 0.76	141.78 20.04	10.08 3.57	5.90 NA
BBC	I	0.67 0.08	45.00 7.67	79.75 14.47	24.70 7.23	3.87 NA
	R	0.78 0.10	100.00 0.00	16.06 1.01	23.40 4.02	1.50 NA
MC	I	0.17 0.06	91.94 1.81	32.83 7.14	165.51 27.55	5.08 NA
	R	0.00 0.00	73.33 2.80	52.44 3.22	0.00 0.00	5.00 NA
<b>April 2003</b>						
SMC	I	0.67 0.08	100.00 0.00	57.97 2.18	43.42 2.40	5.42 0.11
	R	0.67 0.11	99.44 0.38	96.17 18.08	46.57 9.02	5.94 0.20
BBC	I	0.50 0.08	49.94 8.44	31.08 2.54	112.23 23.30	4.81 0.20
	R	0.33 0.11	100.00 0.00	25.78 2.83	130.73 44.16	2.87 0.08
MC	I	0.00 0.00	93.46 2.45	59.84 4.98	4.02 0.59	6.89 0.19
	R	0.33 0.11	99.00 0.49	54.83 5.25	4.10 1.19	8.39 0.37
<b>August 2003</b>						
SMC	I	0.68 0.08	100.00 0.00	83.27 13.53	44.61 6.82	5.12 0.11
	R	0.67 0.11	100.00 0.00	86.89 19.44	42.81 9.00	5.90 0.04
BBC	I	0.22 0.07	100.00 0.00	137.56 14.94	26.44 14.47	3.87 0.34
	R	0.78 0.10	100.00 0.00	12.17 1.59	169.49 61.45	1.50 0.21
MC	I	0.17 0.06	83.33 6.30	109.39 15.36	2.08 1.45	5.08 0.18
	R	0.00 0.00	100.00 0.00	181.22 12.88	0.00 0.00	5.00 NA
<b>April 2004</b>						
SMC	I	0.50 0.08	100.00 0.00	106.94 12.77	48.24 9.35	6.62 0.10
	R	1.00 0.00	91.11 6.10	50.44 1.70	53.63 4.93	5.82 0.11
BBC	I	0.00 0.00	50.00 8.45	59.83 10.81	16.41 2.72	4.52 0.17
	R	1.00 0.00	100.00 0.00	18.22 1.33	152.97 27.95	2.45 0.12
MC	I	0.00 0.00	100.00 0.00	64.89 10.51	3.81 0.91	6.03 0.16
	R	0.11 0.08	100.00 0.00	44.56 3.43	2.09 1.04	8.93 0.06

APPENDIX 2. CONTINUED.

Stream	Site	Coarse woody debris SE	Wood diameter (cm) SE	Wood volume (cm <sup>3</sup> ) SE	Complexity (1=Yes) SE	Orientation (1=Parallel to flow) SE	Fine organic detritus (%) SE
<b>August 2002</b>							
SMC	I	0.72 0.24	6.46 3.11	0.00 0.00	0.17 0.06	0.78 0.07	0.28 0.08
	R	0.33 0.16	2.22 1.36	0.00 0.00	0.11 0.08	0.89 0.08	0.33 0.11
BBC	I	0.06 0.04	1.94 1.36	0.00 0.00	0.00 0.00	1.00 0.00	0.11 0.05
	R	0.22 0.10	10.44 5.00	0.00 0.00	0.00 0.00	0.78 0.10	0.00 0.00
MC	I	1.83 0.21	38.97 8.72	0.00 0.00	0.50 0.08	0.33 0.08	0.67 0.08
	R	2.89 0.33	48.57 15.25	0.00 0.00	0.67 0.11	0.33 0.11	0.89 0.08
<b>April 2003</b>							
SMC	I	0.28 0.08	12.17 5.86	15.84 10.01	0.06 0.04	0.78 0.07	0.56 0.08
	R	0.67 0.11	15.78 3.58	468.42 299.05	0.67 0.11	0.67 0.11	0.89 0.08
BBC	I	0.11 0.05	13.44 7.82	1868.92 1295.38	0.06 0.04	0.94 0.04	0.22 0.07
	R	0.11 0.08	6.11 4.19	69.27 47.52	0.11 0.08	1.00 0.00	0.11 0.08
MC	I	0.59 0.13	17.14 3.70	46.84 21.57	0.32 0.08	0.95 0.04	0.95 0.04
	R	1.00 0.36	36.79 11.43	684.50 265.54	0.33 0.11	0.78 0.10	0.78 0.10
<b>August 2003</b>							
SMC	I	1.57 0.25	14.30 2.35	49.83 13.47	0.51 0.08	0.68 0.08	1.00 0.00
	R	0.78 0.25	13.42 5.86	178.31 116.04	0.33 0.11	0.78 0.10	0.22 0.10
BBC	I	0.39 0.16	19.99 10.16	2900.30 2012.15	0.11 0.05	0.89 0.05	0.61 0.08
	R	0.89 0.37	82.49 29.46	1731.96 1043.81	0.44 0.12	0.89 0.08	0.33 0.11
MC	I	2.50 0.58	63.51 25.53	29873.08 17854.55	0.44 0.08	0.72 0.08	0.89 0.05
	R	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	1.00 0.00	1.00 0.00
<b>April 2004</b>							
SMC	I	1.61 0.47	10.04 2.75	36.28 23.75	0.33 0.08	0.89 0.05	0.06 0.04
	R	2.56 0.41	21.96 2.91	254.06 119.03	0.67 0.11	0.56 0.12	0.00 0.00
BBC	I	0.11 0.05	2.17 1.04	21.11 10.46	0.00 0.00	0.89 0.05	0.06 0.04
	R	1.22 0.38	7.36 2.10	16.85 9.42	0.33 0.11	0.44 0.12	0.56 0.12
MC	I	0.89 0.14	21.32 5.35	175.19 53.84	0.50 0.08	0.61 0.08	1.00 0.00
	R	1.67 0.32	20.72 4.28	110.55 65.80	0.78 0.10	0.78 0.10	0.89 0.08

APPENDIX 2. CONTINUED.

Stream	Site	Temperature (°C) SE	Dissolved oxygen (mg/L) SE	Specific Conductance (µm/s) SE	Fecal coliform count (per 100mL) SE	Heterotrophic plate count (per 1 mL) SE
<b>August 2002</b>						
SMC	I	24.15 0.01	7.46 0.03	20.60 0.05	174.75 9.89	291.50 23.04
SMC	R	24.00 0.00	7.60 0.00	20.60 0.00	123.00 5.16	326.50 46.09
BBC	I	25.05 0.13	6.14 0.03	27.30 0.11	1825.00 122.39	4396.25 377.19
BBC	R	25.80 0.00	7.09 0.00	27.40 0.00	1162.50 41.96	10010.50 371.68
MC	I	25.65 0.01	1.19 4.23	116.65 0.02	222.50 13.14	12287.50 401.48
MC	R	25.60 0.00	2.15 0.00	92.40 0.00	780.00 14.20	8800.00 645.50
<b>April 2003</b>						
SMC	I	18.20 0.00	6.75 0.00	16.90 0.06	5.50 1.71	5125.00 199.34
SMC	R	18.40 0.00	6.74 0.00	16.90 0.00	4.50 1.16	6540.00 67.13
BBC	I	17.55 0.03	6.51 0.36	23.05 0.11	0.00 0.00	9400.00 827.65
BBC	R	17.70 0.00	6.70 0.00	21.30 0.00	0.00 0.00	14200.00 309.84
MC	I	17.35 0.02	3.71 0.69	64.34 0.03	87.25 11.78	33793.75 2425.40
MC	R	16.20 0.00	4.76 0.00	50.80 0.00	30.00 0.77	18500.00 2194.69
<b>August 2003</b>						
SMC	I	22.70 0.02	7.74 0.01	21.15 0.00	3.50 0.09	26750.00 2947.46
SMC	R	22.50 0.00	7.63 0.00	20.00 0.00	3.50 0.13	14750.00 839.15
BBC	I	24.25 0.13	6.25 1.16	20.95 0.05	2.50 0.09	33500.00 5555.44
BBC	R	23.00 0.00	6.75 0.00	25.90 0.00	2.50 0.13	29500.00 645.50
MC	I	22.75 0.04	1.88 25.10	253.10 0.11	2.00 0.18	32125.00 1814.34
MC	R	23.50 0.00	3.15 0.00	74.00 0.00	1.00 0.00	190000.00 29692.87
<b>April 2004</b>						
SMC	I	15.35 0.04	9.10 0.37	18.40 0.04	167.25 10.64	603.75 24.65
SMC	R	15.50 0.00	9.30 0.00	16.60 0.00	147.50 13.30	772.50 43.25
BBC	I	16.45 0.01	7.42 0.03	23.95 0.02	135.25 7.80	1281.25 31.79
BBC	R	16.00 0.00	8.02 0.00	23.90 0.00	107.50 5.41	1042.50 38.81
MC	I	17.10 0.02	2.39 0.06	122.55 0.01	1041.88 89.43	4465.63 196.23
MC	R	17.00 0.00	3.88 0.00	160.30 0.00	866.88 120.60	4443.75 222.53

APPENDIX 2. CONTINUED.

Stream	Site	Biochemical oxygen demand (mg/L; 20 day) SE	Dissolved organic carbon (mg/L) SE	Total carbon (mg/L) SE	Inorganic carbon (mg/L) SE	Total organic carbon (mg/L) SE	Total nitrogen (mg/L) SE
<b>August 2002</b>							
SMC	I	3.76 0.04	10.05 0.04	11.70 0.00	0.83 0.04	10.87 0.01	0.42 0.03
	R	3.99 0.00	10.25 0.00	11.34 0.00	0.82 0.00	10.52 0.00	0.34 0.00
BBC	I	5.16 0.02	8.22 0.35	11.89 0.01	1.25 0.37	10.64 0.00	0.35 0.12
	R	4.09 0.00	8.57 0.00	9.74 0.00	1.15 0.00	8.59 0.00	0.34 0.00
MC	I	9.75 0.06	11.07 0.03	31.42 0.03	18.93 0.00	12.49 0.00	0.62 0.11
	R	10.48 0.00	12.15 0.00	24.70 0.00	10.27 0.00	14.43 0.00	0.62 0.00
<b>April 2003</b>							
SMC	I	4.00 0.04	6.73 0.07	7.96 0.00	0.89 0.05	7.00 0.01	0.34 0.18
	R	3.32 0.00	6.55 0.00	7.77 0.00	0.99 0.00	6.78 0.00	0.29 0.00
BBC	I	6.15 0.03	5.75 0.02	7.41 0.01	1.46 0.01	5.96 0.00	0.30 0.03
	R	3.51 0.00	5.37 0.00	6.65 0.00	1.20 0.00	5.45 0.00	0.29 0.00
MC	I	10.58 0.01	15.22 0.08	26.64 0.09	10.65 0.00	15.99 0.00	0.84 0.02
	R	12.85 0.00	15.96 0.00	24.77 0.00	8.11 0.00	16.65 0.00	0.09 0.00
<b>August 2003</b>							
SMC	I	3.76 0.04	10.04 0.04	11.69 0.00	0.83 0.04	10.86 0.01	0.42 0.03
	R	3.99 0.00	10.25 0.00	11.34 0.00	0.82 0.00	10.52 0.00	0.34 0.00
BBC	I	5.16 0.02	8.22 0.35	11.89 0.01	1.25 0.37	10.64 0.00	0.35 0.12
	R	4.09 0.00	8.57 0.00	9.74 0.00	1.15 0.00	8.59 0.00	0.34 0.00
MC	I	9.75 0.06	11.07 0.03	31.42 0.03	18.93 0.00	12.49 0.00	0.62 0.11
	R	10.48 0.00	12.15 0.00	24.70 0.00	10.27 0.00	14.43 0.00	0.62 0.00
<b>April 2004</b>							
SMC	I	4.00 0.04	6.73 0.07	7.96 0.00	0.89 0.05	7.00 0.01	0.34 0.18
	R	3.32 0.00	6.55 0.00	7.77 0.00	0.99 0.00	6.78 0.00	0.29 0.00
BBC	I	6.15 0.03	5.75 0.02	7.41 0.01	1.46 0.01	5.96 0.00	0.30 0.03
	R	3.51 0.00	5.37 0.00	6.65 0.00	1.20 0.00	5.45 0.00	0.29 0.00
MC	I	10.58 0.01	15.23 0.09	26.65 0.09	10.66 0.00	15.99 0.00	0.84 0.02
	R	12.85 0.00	15.96 0.00	24.77 0.00	8.11 0.00	16.65 0.00	0.09 0.00

**APPENDIX 3. TOTAL ABUNDANCES OF EACH TAXONOMIC GROUP COLLECTED  
DURING STREAM SURVEYS SUMMED BY STREAM AND SEASON**

NUMBERS 1, 2, 3, AND 4, REPRESENT SUMMER 2002, SPRING 2003, SUMMER 2003,  
AND SPRING 2004, RESPECTIVELY.

Macroinvertebrate Taxa	Mill Creek				Big Brushy Creek				Six Mile Creek			
	1	2	3	4	1	2	3	4	1	2	3	4
Heptageniidae: <i>Stenacron interpunctatum</i> Say	2	4	1	0	7	0	0	0	2	0	0	0
Heptageniidae: <i>Stenonema</i> spp.	0	18	0	0	9	31	17	0	17	13	7	3
Leptophlebiidae: <i>Paraleptophlebia</i> spp.	0	1	0	1	11	1	9	0	1	0	0	0
Siphonuridae	0	0	0	0	0	1	0	0	0	0	1	0
Unidentified Baetidae	0	39	1	3	0	3	19	6	7	7	6	6
Unidentified Caenidae	1	0	0	0	0	0	0	0	0	0	0	0
Unidentified Ephemeroptera	0	0	0	0	0	1	0	0	0	0	0	0
Unidentified Heptageniidae	1	1	0	1	2	3	4	0	3	2	1	0
Hemiptera												
Corixidae	1	0	0	0	0	0	0	0	0	0	0	0
Megaloptera												
Corydalidae: <i>Corydalus</i> spp.	0	0	0	1	0	0	2	0	0	0	0	0
Sialidae: <i>Sialis</i> spp.	6	0	7	2	2	0	0	0	0	0	0	0
Unidentified Corydalidae	0	0	0	0	0	0	0	0	1	0	0	0
Odonata												
Aeshnidae: <i>Aeshna</i> spp.	0	0	1	0	0	0	1	0	0	0	0	0
Aeshnidae: <i>Basiaeschna</i> spp.	0	0	0	1	0	0	0	0	3	0	1	0
Aeshnidae: <i>Boyeria</i> spp.	0	0	1	1	0	1	0	0	2	1	0	0
Aeshnidae: <i>Epiaeschna</i> spp.	0	0	0	0	0	1	0	1	1	0	0	0
Calopterygidae	0	0	0	0	0	1	0	0	0	0	0	0
Coenagrionidae: <i>Argia</i> spp.	0	0	0	0	0	1	12	1	1	0	6	1
Cordulidae: <i>Cordulia</i> spp.	1	0	0	0	0	0	0	0	3	0	0	0
Cordulidae: <i>Macromia</i> spp.	0	0	0	0	0	0	0	0	2	0	0	0
Cordulidae: <i>Neurocordulia</i> spp.	0	0	0	0	0	0	0	0	1	0	0	0
Cordulidae: <i>Stomatochlora</i> spp.	1	0	0	0	1	0	0	0	1	0	0	0
Gomphidae: <i>Arigomphus</i> spp.	0	1	0	2	1	0	0	0	2	0	0	0
Gomphidae: <i>Dromogomphus</i> spp.	1	2	8	1	0	0	0	0	2	0	0	0
Gomphidae: <i>Gomphus</i> spp.	0	0	0	0	0	0	0	0	0	1	0	0
Gomphidae: <i>Progomphus</i> spp.	0	0	1	0	0	0	0	0	0	0	0	0
Libellulidae: <i>Pseudoleon</i> spp.	0	0	0	0	0	0	0	0	1	0	0	0
Unidentified Aeshnidae	0	0	0	1	0	0	1	2	0	0	1	0
Unidentified Gomphidae	0	2	1	0	0	25	0	1	0	0	0	0

APPENDIX 3. CONTINUED.

Macroinvertebrate Taxa	Mill Creek				Big Brushy Creek				Six Mile Creek			
	1	2	3	4	1	2	3	4	1	2	3	4
Unidentified Libellulidae	1	4	0	0	0	1	0	0	0	0	0	0
Unidentified Odonata	0	0	0	2	0	0	0	0	0	0	0	0
Plecoptera												
Chloroperidae	0	0	0	0	0	0	0	0	0	2	0	0
Leuctridae: <i>Leuctra</i> spp.	0	0	0	0	0	13	0	0	0	0	0	0
Perlidae: <i>Acroneuria</i> spp.	0	8	0	0	0	0	1	1	0	0	0	0
Perlidae: <i>Agnentina</i> spp.	0	45	0	1	0	16	1	0	2	32	7	8
Perlidae: <i>Attaneuria</i> spp.	0	0	0	0	0	0	0	0	2	0	0	0
Perlidae: <i>Beloneuria</i> spp.	0	0	0	0	0	0	0	0	0	0	0	1
Perlidae: <i>Eccoptura</i> spp.	0	3	0	0	0	2	0	0	6	0	1	0
Perlidae: <i>Neoperla</i> spp.	0	1	0	0	1	1	0	0	2	6	0	1
Perlidae: <i>Paragnetina</i> spp.	0	0	0	0	0	1	0	0	2	0	0	2
Perlidae: <i>Perlesta</i> spp.	0	16	0	310	0	8	0	20	0	13	2	24
Perlidae: <i>Perinella</i> spp.	0	11	0	0	1	4	2	1	12	19	18	13
Perlodidae	0	0	0	0	0	1	1	0	1	0	0	1
Taeniopterygidae	0	0	0	0	0	0	0	0	1	0	0	0
Unidentified Leuctridae	0	0	0	0	3	0	0	1	1	2	0	3
Unidentified Perlidae	0	8	0	0	3	3	0	0	5	5	1	0
Unidentified Plecoptera	0	0	0	0	1	0	0	0	1	2	0	0
Trichoptera												
Brachycentridae	0	0	2	0	0	0	0	0	0	0	1	1
Glossosomatidae: <i>Agapetus</i> spp.	0	0	0	0	0	0	0	0	0	0	0	2
Hydropsychidae: <i>Cheumatopsyche</i> spp.	1	6	1	26	34	18	4	7	18	1	27	11
Hydropsychidae: <i>Macrostenum</i> spp.	0	0	0	0	11	4	0	0	5	1	0	0
Hydroptilidae: <i>Ithytrichia</i> spp.	0	0	0	0	3	0	0	0	0	0	0	0
Hydroptilidae: <i>Orthotrichia</i> spp.	0	0	0	0	2	0	0	0	1	0	0	0
Leptoceridae: <i>Nectopsyche</i> spp.	0	0	0	0	0	0	0	0	1	0	0	0
Leptoceridae: <i>Oecetis</i> spp.	0	1	0	0	0	0	0	0	0	0	0	1
Leptoceridae: <i>Setodes</i> spp.	0	0	0	0	0	0	0	0	1	0	0	0
Philopotamidae: <i>Chimarra</i> spp.	0	0	0	1	14	5	3	0	116	11	43	2
Philopotamidae: <i>Wormaldia</i> spp.	0	0	1	1	1	4	21	3	13	10	36	6
Polycentropodidae: <i>Neureclipsis</i> spp.	0	0	0	0	1	0	0	0	5	1	0	0
Polycentropodidae: <i>Nyctiophylax</i> spp.	0	0	0	0	8	0	0	0	0	3	0	0

**APPENDIX 3. CONTINUED.**

<b>Macroinvertebrate Taxa</b>	<b>Mill Creek</b>				<b>Big Brushy Creek</b>				<b>Six Mile Creek</b>			
	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
Polycentropodidae: <i>Polycentropus</i> spp.	0	0	0	0	27	20	12	13	23	2	9	3
Psychomyiidae: <i>Lype</i> spp.	0	0	0	0	1	0	0	0	1	0	0	0
Rhyacophilidae: <i>Rhyacophila</i> spp.	0	0	0	0	0	4	0	1	1	0	0	0
Unidentified Hydroptilidae	0	0	0	0	0	0	0	0	0	0	0	1
Unidentified Leptoceridae	0	0	0	0	0	0	0	0	0	1	1	0
Unidentified Philopotamidae	0	0	0	0	0	0	0	0	0	0	1	0
Unidentified Psychomyiidae	0	0	0	0	0	1	0	1	0	0	0	0
Unidentified Trichoptera	0	1	0	0	0	0	0	0	0	0	0	0
<b>Phylum Mollusca</b>												
<b>Class Gastropoda</b>												
Ampullaridae: <i>Pomacea</i> spp.	6	19	3	0	0	0	0	0	0	0	0	0
Ancyclidae: <i>Laevepex</i> spp.	20	239	364	275	0	1	2	0	0	0	0	0
Helobiidae: <i>Lyogyrus</i> spp.	6	0	0	0	0	0	0	0	0	0	0	0
Hydrobiidae	0	5	0	0	0	0	0	0	0	0	0	0
Lymnaeidae: <i>Fossaria</i> spp.	0	2	0	0	0	0	0	0	0	0	0	0
Physidae	0	0	3	7	0	0	0	0	0	0	0	0
Planorbidae: <i>Heliosoma</i> spp.	0	0	0	4	0	0	0	0	0	0	0	0
Unidentified Lymnaeidae	1	0	0	0	0	0	0	0	0	0	0	0
Unidentified Planorbidae	0	1	10	2	0	0	0	0	0	0	0	0
Valvatidae: <i>Valvata</i> spp.	7	0	0	0	0	0	0	0	0	0	0	0
<b>Class Pelecypoda</b>												
Corbiculidae: <i>Corbicula</i> spp.	11	36	294	156	0	1	0	0	0	0	3	0
Sphaeridae	17	42	0	11	0	1	0	0	1	0	0	1
Unidentified Pelecypoda	63	0	0	1	0	0	0	0	2	0	0	0
Unidentified Unionidae	9	12	1	4	0	0	0	0	1	0	2	0
Unionidae: Leptodea spp.	2	0	0	0	0	0	0	0	0	0	0	0
Unionidae: <i>Toxolasma</i> spp.	7	0	0	0	0	0	0	0	0	0	0	0
Unionidae: <i>Unionmerus</i> spp.	0	0	0	0	1	0	0	0	0	0	0	0
<b>Phylum Nematomorpha</b>	0	0	0	0	1	0	0	0	2	0	0	0



**APPENDIX 4. TOTAL ABUNDANCES OF EACH TAXONOMIC GROUP COLLECTED IN MILL CREEK SUMMED BY SITE AND SEASON.**

SHADING INDICATES SWINE PRESENCE.

Macroinvertebrate taxa	Summer 2002					Spring 2003					Summer 2003					Spring 2003				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
<b>Amphipoda</b>																				
Crangonyctidae: <i>Crangonyx</i> spp.	2	3	2	12	43	0	14	31	5	127	0	11	0	11	1	0	4	1	109	24
<b>Coleoptera</b>	0	0	0	1	4	0	2	9	0	2	0	0	0	2	1	0	3	0	0	0
Carabidae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
Dytiscidae	0	0	0	0	1	0	5	0	0	2	0	0	0	0	0	1	6	0	1	0
Elmidae	0	2	0	1	9	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Elmidae: <i>Ancyronyx</i> spp.	0	1	0	0	6	0	0	0	0	0	0	2	0	0	1	0	7	0	0	0
Elmidae: <i>Dubiraphia</i> spp.	0	2	1	1	8	0	0	0	0	0	1	5	0	0	2	0	0	0	0	0
Elmidae: <i>Gonielmis</i> spp.	0	4	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Elmidae: <i>Macronychus glabratus</i> Say	0	0	0	0	20	0	4	0	0	48	0	189	0	29	329	0	76	0	17	250
Elmidae: <i>Microcylleopus</i> spp.	0	4	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Elmidae: <i>Optioservus</i> spp.	0	1	0	0	6	0	1	0	0	1	0	0	0	0	0	0	3	0	0	0

APPENDIX 4. CONTINUED.

Macroinvertebrate taxa	Summer 2002					Spring 2003					Summer 2003					Spring 2004				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Elmidae: <i>Promoresia</i> spp.	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elmidae: <i>Stenelmis</i> spp.	0	17	0	0	17	0	48	0	0	6	0	11	0	2	14	1	50	0	0	104
Gyrinidae	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	7	0	0	0
Haliplidae	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	2
Hydrophilidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0
Lampyridae	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Sciritidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
<b>Collembola</b>	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
<b>Diptera</b>																				
Ceratopogonidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratopogonidae: <i>Bezzia</i> spp.	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	6	0	1	0
Chironomidae	32	23	133	272	134	0	536	67	266	13	17	82	13	68	26	2	45	6	81	109
Chironomidae: Chironominae	18	39	62	84	109	1	7	0	20	80	4	0	0	132	121	0	0	0	0	0

APPENDIX 4. CONTINUED.

Macroinvertebrate taxa	Summer 2002					Spring 2003					Summer 2003					Spring 2004				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Chironomidae: <i>Corynoneura</i> spp.	0	0	0	0	0	28	506	96	145	17	1	5	0	18	13	0	3	0	7	3
Chironomidae: Orthoclaadiinae	2	0	0	1	0	33	157	151	226	48	14	95	11	174	107	10	179	23	291	275
Chironomidae: Tanypodinae	3	50	24	8	37	1	21	8	29	12	0	3	0	48	76	2	49	0	29	186
Culicidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
Simuliidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Tipulidae: <i>Pedicia</i> spp.	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tipulidae: <i>Polymera</i> spp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<b>Decapoda</b>																				
Cambaridae	0	3	1	0	12	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0
<b>Ephemeroptera</b>																				
Baetidae	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	3

APPENDIX 4. CONTINUED.

Macroinvertebrate taxa	Summer 2002					Spring 2003					Summer 2003					Spring 2004				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Caenidae: <i>Caenis hilaris</i> Say	0	0	0	11	4	0	3	0	0	56	0	9	0	6	0	0	0	0	14	1
Ephemeridae: <i>Eurylophella</i> spp.	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Heptageniidae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Heptageniidae: <i>Stenacron floridense</i>	0	5	1	0	29	0	6	0	0	60	0	27	0	43	53	0	17	0	4	8
Lewis																				
Heptageniidae: <i>S. interpunctatum</i>	0	0	0	1	14	0	0	0	0	2	0	4	0	1	0	0	0	0	0	0
Say																				
Heptageniidae: <i>Stenonema</i> spp.	0	0	0	0	0	0	2	0	1	16	0	5	0	0	0	0	1	0	0	0
Leptophlebiidae: <i>Paraleptophlebia</i> spp.	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1
<b>Gastropoda</b>																				
Ancyclidae: <i>Laevepex</i> spp.	0	21	0	103	13	0	25	1	76	34	0	42	0	159	29	0	16	0	162	34

APPENDIX 4. CONTINUED.

	Summer 2002					Spring 2003					Summer 2003					Spring 2004				
Macroinvertebrate taxa	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Hydrobiidae	0	0	0	1	14	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
Lymnaeidae: <i>Lymnaea</i> spp.	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Physidae	0	0	0	0	0	0	3	0	0	0	0	1	1	2	0	0	4	0	3	1
Planorbidae	0	0	0	0	0	0	1	0	0	1	0	2	0	2	3	0	3	1	0	1
Planorbidae: <i>Heliosoma</i> spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	2	0
Planorbidae: <i>Menetus</i> spp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pleuroceridae: <i>Pleurocera</i> spp.	0	0	2	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Viviparidae	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Viviparidae: <i>Pomacea</i> spp.	0	0	0	0	1	0	0	0	0	19	0	0	0	0	2	0	0	0	0	0
<b>Isopoda</b>																				
Asellidae: <i>Lirceus</i> spp.	2	0	7	16	27	0	14	21	43	62	0	0	2	13	38	2	0	10	96	5
<b>Megaloptera</b>																				
Sialidae: <i>Sialis</i> spp.	0	2	0	2	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

APPENDIX 4. CONTINUED.

Macroinvertebrate taxa	Summer 2002					Spring 2003					Summer 2003					Spring 2004				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
<b>Mysidacea</b>																				
<i>Taphromysis</i> spp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
<b>Odonata</b>																				
Aeshnidae	1	0	1	0	4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Aeshnidae: <i>Basiaeschna</i> spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Aeshnidae: <i>Boyeria</i> spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Calopterygidae: <i>Calopteryx</i> spp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Coenagrionidae: <i>Argia</i> spp.	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
Gomphidae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Gomphidae: <i>Arigomphus</i> spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Gomphidae: <i>Dromogomphus</i> spp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Libellulidae	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Libellulidae: <i>Erythemis</i> spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX 4. CONTINUED.

	Summer 2002					Spring 2003					Summer 2003					Spring 2004				
Macroinvertebrate taxa	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
<b>Oligochaeta</b>																				
Entocytheridae	4	1	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lumbricidae	0	1	0	1	0	0	3	6	1	5	0	3	3	4	2	0	0	10	3	1
<b>Pelecypoda</b>																				
Corbiculidae: <i>Corbicula</i> spp.	1	9	0	2	0	0	4	0	0	11	0	43	0	10	108	0	14	0	6	30
Sphaeridae	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	3
Unionidae	0	0	0	0	0	0	0	0	0	0	0	7	0	0	1	0	0	0	0	0
Unionidae: <i>Amblema</i> spp.	0	0	0	0	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unionidae: <i>Anodotiodes</i> spp.	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unionidae: <i>Ptychobranthus</i> spp.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unionidae: <i>Toxolasma</i> spp.	0	3	1	12	26	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
<b>Plecoptera</b>																				
Perlidae: <i>Agnatina</i> spp.	0	0	0	0	0	0	2	0	5	0	0	0	0	0	0	0	0	0	0	0

APPENDIX 4. CONTINUED.

Macroinvertebrate taxa	Summer 2002					Spring 2003					Summer 2003					Spring 2004				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Perlidae: <i>Attaneuria</i> spp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Perlidae: <i>Beloneuria</i> spp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Perlidae: <i>Perlesta</i> spp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	15	0	35	196
Perlidae: <i>Perlinella</i> spp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
<b>Rhynchobdella</b>																				
Glossosiphonidae: <i>Helobdella</i> spp.	0	7	0	6	24	0	10	0	0	36	0	26	0	7	9	0	16	3	25	20
<b>Trichoptera</b>																				
Hydropsychidae: <i>Cheumatopsyche</i> spp.	0	1	0	0	3	0	1	0	3	0	0	0	0	1	0	0	1	0	0	26
Leptoceridae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Philopotamidae: <i>Chimarra</i> spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Philopotamidae: <i>Wormaldia</i> spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Polycentropodidae: <i>Polycentropus</i> spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0



## VITA

Michael Douglas Kaller was born April 25, 1975, in Detroit, Michigan, to Douglas and Eileen Kaller. Michael resided in Detroit until a brief stint in Toledo, Ohio, ultimately settling in Pleasant Ridge, Michigan, and graduating from Shrine High School, Royal Oak, Michigan, in May 1993. Michael graduated cum laude with a Bachelor of Science in Fisheries and Wildlife Management in May 1997 from Lake Superior State University, Sault Ste. Marie, Michigan. His undergraduate thesis was entitled, "Validation of aging techniques for walleyes (*Stizostedion vitreum*) from Munuscong Bay, Michigan." He was employed as a fisheries technician with the Wyoming Game and Fish Department, Pinedale, Wyoming, between May 1997 and August 1998. In August 1998, Michael enrolled in West Virginia University where he graduated in May 2001, with a Master of Science in wildlife and fisheries resources under the direction of Kyle J. Hartman. His thesis was entitled, "Effects of sedimentation upon benthic macroinvertebrates in forested northern Appalachian streams." He also was involved in downstream evaluation of mountain-top removal/valley fill mining. These projects yielded three peer-reviewed publications and were presented on numerous occasions at state, regional, and national conferences. In addition, Michael served as an officer in both the student chapter of the Wildlife Society and the Division of Forestry Graduate Student Association. In May 2001, he enrolled in the Doctor of Philosophy program at Louisiana State University beginning a dissertation entitled, "The macroinvertebrate community ecology of lowland, subtropical streams of differing land uses," under the direction of William E. Kelso. Michael also pursued a full minor in applied statistics completing both in May 2005. He was an officer of the Aquaculture and Fisheries Club, served on faculty, graduate, and professional society committees, extensively participated in recruiting activities, and represented the university at state, regional, and national conferences.