

ABSTRACT

Title of Document: EFFECT OF URBANIZATION ON STREAM
INSECT COMMUNITIES IN ADJACENT
HEADWATER AND DOWNSTREAM REACHES

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Watershed urbanization causes decreased diversity in aquatic insect communities. Recent studies have focused on effects to aquatic life stages without consideration of impacts to adult terrestrial stages. Here, I review the potential impacts of urbanization on adult aquatic insects. The review suggests that urbanization may limit adult dispersal, limit taxa richness in urban headwaters, and increase similarity between communities in urban headwater and downstream reaches. Empirically, I compared communities in urban and rural headwater streams, compared community similarity between headwater and main-stem reaches in urban and rural watersheds, and examined longitudinal patterns of richness and community similarity along headwater streams in rural and urban watersheds. Diversity was lower for urban headwater communities. Similarity between headwater and main-stem communities was higher for urban watersheds. Longitudinal patterns of richness and similarity differed between urban and rural watersheds. These

results support predictions that regional factors are partly controlling composition in urban headwater streams.

EFFECT OF URBANIZATION ON STREAM INSECT COMMUNITIES IN
ADJACENT HEADWATER AND DOWNSTREAM REACHES

By

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Dedication

This work is dedicated to those in my family that wished me luck at the beginning, supported me along the way, but are not here to see what their love and support allowed me to accomplish.

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Chapter 1: Impacts by watershed urbanization on terrestrial stages of aquatic insects

Introduction

Urbanization and other forms of land use change are the leading causes of native aquatic species loss worldwide (Sala et al. 2000, McKinney 2002). Urban development results in the creation of storm-water drainage systems and increased impervious surfaces. These actions increase flow variability, increase toxic chemical inputs, and cause greater daily temperature fluctuations (Dunn and Leopold 1978, Paul and Meyer 2001). In addition, riparian deforestation decreases allochthonous inputs and alters the food base for insect communities (Sweeney 1993, Gomie et al. 2002). As a result, insect communities generally experience increased environmental unpredictability, decreased habitat and water quality, and local extirpations as a result of the physical changes brought on by human activities (Paul and Meyer 2001). This process of impairment followed by local population extinctions, now termed the “Urban Stream Syndrome” (Walsh et al. 2005), decreases aquatic insect community richness along a rural to urban gradient (Paul and Meyer 2001, Walsh et al. 2001, Moore and Palmer 2005).

While the importance of local habitat for determining insect community composition is well known, regional scale factors may be important for determining composition but are often ignored. Regional processes, such as adult dispersal, and landscape characteristics, such as the location of streams, may work in conjunction with local habitat and water quality degradation to shape community composition in urban headwater streams (Palmer et al. 1996, Malmqvist 2002, Heino et al. 2003). However,

the focus of urbanization's impact on aquatic insect communities is usually on the reaction of aquatic, larval stages to habitat degradation and ignores impacts on the adult stage (Petersen et al. 2004). Local habitats occurring at different spatial scales are thought to filter out species from the regional species pool (Poff 1997, Lamouroux et al. 2004). Only species whose habitat requirements are met become part of the local community. The composition of the regional pool depends on individual species abilities to disperse and the distance to source populations (Heino et al. 2003, Sanderson et al. 2005). Thus, urbanization could negatively impact adult activity and decrease the size of the regional species pool. In addition, urban land use may be a regional habitat filter that removes a large proportion of the species pool from potentially inhabiting a stream draining an urbanized watershed.

Urbanization is particularly important for headwater streams. Insect community composition in higher order streams is dependent on recruits gained from other streams through drifting insects and ovipositing migrants (Townsend 1989, Fuchs and Statzner 1990, Mackay 1992, Vinson and Hawkins 1998, Bilton et al. 2001). Headwater streams, on the other hand, do not receive immigrants through drift and must rely on oviposition for recruitment (Gomi et al. 2002). This is especially true since crawling by larvae is not considered an important mechanism for dispersal between streams (Moser and Minshall 1996, Humphries 2002, Elliot 2003). As a result, headwater streams are naturally more isolated than downstream reaches and urbanization can result in further isolation if it limits adult immigration. Urbanization can directly limit adult immigration by decreasing adult survival or activity and indirectly when streams in urban watersheds become fragmented following the physical elimination of other headwater streams, such as when

they are piped underground in drainage systems (Meyer and Wallace 2001). A lack of adult colonists to counteract local extirpations resulting from habitat degradation may facilitate persistently low diversity in urban headwater streams (Suding et al. 2004).

Limited adult dispersal as a mechanism for decreased community diversity in urbanized watersheds has important implications for stream restoration. The potential immigrant species pool must be considered in conjunction with habitat degradation in order to restore biodiversity (Palmer et al. 1997). Abundant source populations increase colonization success and population development (Alhroth et al. 2003). In contrast, species absent as adults from the regional species pool cannot colonize a restored headwater stream. Aquatic insects may be the community targeted for improvement through restoration activities or used in bioassessments to measure project success. More accurate predictions are needed to improve our ability to choose relevant reference reaches and set realistic goals to assess the success of restoration projects (Palmer et al. 2005).

Here, I review the known impacts of urbanization on aquatic insects during terrestrial adult phases and apply this knowledge to known patterns of adult dispersal to demonstrate that impacts from urbanization on adults can be important for determining community composition in urban headwater streams. I attempt to answer three general questions about the impacts of urbanization on adult aquatic insects. First, what are the potential negative effects on adult aerial dispersal resulting from urbanization? Second, what are the potential negative effects of urbanization on the abilities of stream insects to oviposit in and emerge from urban headwater streams? Lastly, what are the potential

effects of larval habitat degradation resulting from urbanization on the ability of aquatic insects to move between streams?

Review

Potential negative effects on adult aerial dispersal resulting from watershed urbanization

Urbanization can potentially limit recruitment by decreasing adult survival and activity. Genetic evidence and observational studies suggest that population recruitment relies on successful oviposition by emerging adult residents and adult immigrants from other streams (Bunn and Hughes 1997, Alhroth et al. 2003). Thus, urban streams that lack significant resident populations may rely on immigrants for recruitment.

Most studies examining dispersal measure adult flight distance away from the natal stream and do not assess the ability for dispersing adults to contribute offspring to other stream reaches (except see Briers et al. 2004). The studies that have measured the potential to move between reaches have found the maximum Euclidean distance separating reaches in undisturbed watersheds that exchange adult dispersers to be on the order of kilometers apart (Table 1A). This distance is surprising since the majority of adult insects remain above or near the stream channel (Sode and Wiberg-Larsen 1993, Petersen et al. 2004) and only fly on the order of ten's of meters into the riparian zone away from the stream (Table 1B). The tendency for adult insects to remain above the channel implies that migrants may travel long distances to other streams along the stream corridor in addition to traveling through upland habitats (Sode and Wiberg-Larsen 1993, Petersen et al. 2004). However, studies that suggest migration mostly occurs along the

stream channel did not measure the distance traveled longitudinally (except see related study by Hershey et al. 1993). Also, simply observing more insects moving across the stream boundary at its mouth than along its shores per unit length (e.g. the width of a malaise trap) does not necessarily indicate overall greater movement longitudinally. The greater length of shoreline compared to the stream width at the mouth could result in a larger overall abundance of adult emigrants moving laterally into upland environments (Griffith et al. 1998). While current research indicates that aquatic insects can fly long distances between streams, no general consensus exists about the route insects take or the number of individuals flying long distances to other streams.

Human activity in the watershed may affect adult movement along the stream corridor and in upland environments. Adults of some aquatic insect species prefer to disperse into forested versus open riparian zones (Petersen et al. 1999). This suggests that removal of riparian vegetation, which is common in urbanized watersheds, may deter lateral dispersal. Anthropogenic structures, such as asphalt roads (Kriska et al. 1998) or streetlights, may draw flying adults away from aquatic habitat and act as ecological traps (Pulliam 1996). Riparian deforestation in urban watersheds can also lower survival and fecundity for species that utilize riparian vegetation for roosting, feeding, or mating (Sweeney 1993). Decreased vertebrate and invertebrate predator abundances in urban terrestrial environments may result in reduced predation on adult aquatic insects (McIntyre 2000). However, the abundance of insect generalist ground predators (e.g. carabid beetles) is expected to increase in urban riparian zones (McIntyre 2000). As a result, the species that emerge when these predators are present and have adult stages that utilize the habitats where these generalist predators exist (e.g. under-story habitat as

adults) could experience increased predation in urban watersheds (Paetzold and Tockner 2005). While anthropogenic alterations to the riparian zone and upland environments may discourage insect flight away from their natal reach, the type and spatial patterns of these alterations will have different impacts on different insect species.

Potential decreases in oviposition rate resulting from watershed urbanization

A lack of structures required for oviposition can limit recruitment even if fecund adults successfully move between streams. Increasing evidence has shown that certain physical features are actively selected and required for successful oviposition (Hoffmann and Resh 2003, Reich and Downes 2003). Some species will not oviposit unless certain structures, such as emergent rocks, are present in the stream (Peckarsky et al. 2000). Increased flashiness or the removal of riparian vegetation may make these structures undetectable to adult females or eliminate the structures all together. Some taxa may even oviposit on anthropogenic structures they mistake for aquatic habitats (Kriska et al. 1998).

Reduced structural complexity in streams does not limit oviposition for all species of aquatic insects. Many species simply oviposit on the open water and their egg masses eventually become attached to some in-stream structure (Hoffmann 2000). However, egg masses may not settle in the intended stream reach if urbanization resulted in the absence of in-stream structures or caused high periodic discharges to move unstable in-stream structures. Genetic evidence also suggests that aquatic insect populations are usually the result of only a few fecund adult females (Bunn and Hughes 1997) and larval abundance is sometimes unrelated to the quantity of oviposition habitat (Reich and Downes 2004).

When oviposition is limited in urban watersheds, a few oviposition structures may be all that is required for recruitment. As a result, oviposition may not be a limiting factor for recruitment except for those species that have specific oviposition requirements not met by impacted urban streams.

Potential decreases in emergence success because of watershed urbanization

Emergence from the aquatic larval stage to the terrestrial adult stage also may require specific in-stream habitat that may be eliminated by the effects of urbanization. Some species of aquatic insects crawl out of the stream to emerge on specific structures (Sweeney 1993). Other taxa attach their pupal cases to specific structures in the stream, such as woody debris (Hoffman 2000). Anthropogenic disturbances that remove these structures may decrease successful emergence. Some insects alter their development time based on certain environmental cues such as predator abundance (Peckarsky et al. 2002) and flow regime (Lytle 2002). Altered flow regimes and decreased predator abundance resulting from urbanization (Paul and Meyer 2001) may disrupt emergence patterns. Emergence is also correlated with temperature. Asynchronous emergence because of altered temperature regimes could decrease mating success which leads to fewer gravid females (Vannote and Sweeney 1980). Similar to oviposition, some exceptions exist. Aquatic insect taxa with a long lived adult stage capable of utilizing oxygen from the atmosphere, such as many species in the order Coleoptera, sometimes do not require specific structures to facilitate emigration from the stream. Regardless of these exceptions, structural changes to the stream channel resulting from human activities may result in average decreases in emergence and mating success.

Potential effects of larval habitat degradation resulting from watershed urbanization

Impacts to streams from watershed urbanization may also limit adult movement between streams. Basin wide impacts from human activities that decrease larval survival at large spatial scales (Morley and Karr 2002) may also limit the pool of adult migrants. Decreased larval survival results in fewer adults emerging and fewer adults dispersing between streams (Briers et al. 2002). Low abundance of adults also decreases the probability of long distance migrations. Severely degraded habitat in headwater streams or the destruction of headwater streams may lead to greater fragmentation of headwater communities (Meyer and Wallace 2001). The greater distance between viable habitats in fragmented urban watersheds decreases the probability of successfully moving between habitat patches (Soons et al. 2004). The greater distances between urban streams also increases the exposure of adults to potential direct impacts from urbanization discussed above (Ricketts 2001). The impact of fragmentation is especially problematic for short lived adult dispersing stages that may not survive as adults long enough to move between distant headwater streams. Together, localized disturbances and stream destruction may lower the abundance of dispersing adults and decrease the probability of successful migrations from one headwater stream to another.

Conclusion

Impacts to adult insect activity, impacts that limit insects' abilities to complete their life cycles, lower abundances of adult insects, and greater distances between reaches that limit movement between urban headwater streams may affect community composition and diversity. For communities to maintain their composition over time,

each species population must recolonize the stream after mass emergences to the adult stage. In natural settings insect emergence, oviposition, and adult activity are not constrained, and recruitment is sufficient to maintain a diversity of species in the community. However, poor water and habitat quality may prevent headwaters from producing enough recruits to support its own populations. In addition human activities that affect adult insects limit the number of recruits from other communities. As a result, limited recruitment through adult immigration influences community composition and contributes to decreased diversity. The populations that persist are those that are tolerant of local conditions and are those species with nearby source populations of gravid females. The distance to source populations becomes important because nearby source populations have the greatest likelihood of supplying gravid female migrants.

Limited dispersal and the degradation or elimination of streams resulting from urbanization may make downstream, higher order reaches the primary source of migrants to urban headwater tributaries. The downstream reach the headwater flows into is the closest source of emerging adults within highly fragmented urban watersheds, as long as it is not degraded. Poor habitat in urban headwaters is unsuitable for the few headwater species remaining in the regional pool. However, the species pool may consist mostly of species from higher order reaches whose habitat requirements are not met in headwater streams if the downstream reach is the primary supplier of adult dispersers. Thus, the regional species pool in urban watersheds may consist of fewer species and species that regardless of the quality of habitat in headwater streams, may be maladapted for survival there. This regional process may cause a lack of suitable colonists and could decrease

taxa richness of in-stream headwater communities in addition to local habitat and water quality degradation.

The dependence of urban headwaters for immigrants from downstream habitats is expected to result in greater similarity to each other compared to more pristine conditions. Furthermore, the compositional similarities between their communities in urbanized watersheds may take on a specific nested structure. A nested community structure is defined by a less diverse community being composed entirely of a subset of taxa found in the more diverse community (Wright et al. 1998). Nested community structures can result when movement is limited and when populations turnover and are recolonized frequently (Wright et al. 1998). I believe that limited adult movement coupled with high population turnover may limit the headwater community to a subset of the species found in the main-stem community (Taylor and Warren 2001).

Measuring patterns of similarity between headwater and downstream reaches in urban watersheds may indicate if regional processes and landscape patterns influence species loss and community composition. Direct impacts on adult aquatic insects are difficult to measure because of the size of adult insects, their short life spans, and difficulties handling them for mark-recapture studies. Similarity between insect communities in urban reaches is more feasible and could suggest that regional processes such as dispersal are important determinants for community composition. Studies of adult activity, emergence, oviposition, and the effects of landscape scale patterns of watersheds would be warranted if community similarity between headwater and downstream aquatic insect communities is greater for urbanized watersheds than more pristine watersheds.

Table 1. (A) Values presented are the maximum Euclidean distance between reaches that individual insects were observed to or suggested to travel. (B) Studies measured adult abundances at several distances lateral to the stream channel. A curve was fit to the data to estimate the number of individuals that travel a certain distance into the riparian zone. All studies do not use the same species of aquatic insects.

A.

Source	Method	Maximum Distance Traveled
Briers et al. 2004	Mark – Recapture	1 kilometer
Kovats et al. 1996	Light Trapping	5 kilometers
Wilcock et al. 2001	Genetic Analysis	10 kilometers

B.

Source	50% Travel	90% Travel
Petersen et al. 1999	< 11-16 meters	< 51 meters
Petersen et al. 2004	< 18 meters	< 60 meters
Briers et al. 2002	NA	< 11 meters

Chapter 2: Comparison of aquatic insect communities between adjacent headwater and main-stem streams in urban and rural watersheds

Abstract

Watershed urbanization causes decreased diversity and taxa richness in aquatic insect communities. The current paradigm suggests that degraded local habitat quality is the primary cause. Recent research examining patterns of community composition suggests that regional processes, while secondary, may influence the response of aquatic insect communities to watershed urbanization. I compared headwater communities in urban and rural watersheds, and investigated if community similarity in adjacent stream reaches were greater in urban watersheds. I sampled insect communities in paired headwater and main-stem streams belonging to three urban and three rural watersheds during three seasons in Montgomery and Howard Counties, Maryland. Taxa richness and the Shannon diversity index were lower in urban than rural headwater streams, and the Simpson's diversity index was greater in urban than rural headwater streams. The Jaccard similarity index calculated between headwater and main-stem communities was greater for urban streams during one season. The Morisita-Horn similarity index was not significantly different, but the proportion of headwater taxa shared with the main-stem community was greater for urban than rural stream pairs. These results suggest that urbanization expectedly decreased diversity, but the increased similarity suggests that a regional process partly controls taxa loss. A significant interaction between watershed

type and the riffle location longitudinally along the headwater for the Jaccard index further suggests that this process had a component dependent on the proximity to the main-stem. Regardless of the process, understanding how regional effects shape stream insect communities is important for developing successful conservation and restoration plans for urban headwater streams.

Introduction

Watershed urbanization and other human initiated land use changes are resulting in the loss of native aquatic species worldwide, including aquatic insects (Sala et al. 2000, Paul and Meyer 2001, Walsh et al. 2001, McKinney 2002, Moore and Palmer 2005). Human activities lead to local impairment of stream water and habitat quality, which in turn cause local extinctions of intolerant taxa, decreased community richness, and increased dominance of tolerant taxa (Walsh et al. 2005). However, indirect effects operating at larger spatial scales that are often ignored may also determine species richness of insect communities in urban streams (Vinson and Hawkins 1998). For example, the composition of insect communities in surrounding streams (Sanderson et al. 2005), the dispersal capabilities of aquatic insect adults (Palmer et al. 1996, Hoffsten 2004, Petersen et al. 2004), and constraints placed on dispersal at the watershed scale (Bond and Lake 2003) have all been proposed as important factors affecting insect community composition in streams draining urbanized watersheds. Therefore, watershed properties such as the distance between adjacent stream reaches and habitat fragmentation resulting from human activities are expected to influence the diversity and composition of local insect communities (Meyer and Wallace 2001).

The purpose of this study was to determine if patterns of species composition in headwater streams and differences between headwaters and downstream reaches in urban and rural watersheds suggest that large-scale effects of urbanization impact stream insect communities in conjunction with local habitat and water quality degradation. Headwater streams make up an estimated 70 to 75% of the stream miles in the United States, and they are unique environments that often contain many rare species (Leopold et al. 1964, Meyer and Wallace 2001, Gomi et al. 2002, Meyer et al. 2003, Lowe and Likens 2005). The health of headwater streams also impacts the health of the entire stream network (Meyer and Wallace 2001, Gomi et al. 2002). However, these small streams are the lotic ecosystems most threatened by anthropogenic activities (Meyer and Wallace 2001, Gomi et al. 2002, Meyer et al. 2003). They are often unaccounted for on maps and surveys (Leopold et al. 1964, Meyer and Wallace 2001, Meyer et al. 2003), ignored by permitting agencies, and excluded from conservation and mitigation programs (Meyer and Wallace 2001). As a result, headwater streams are sometimes converted to drainage systems and destroyed altogether in urbanized watersheds (Meyer and Wallace 2001). Increased impervious surfaces within the watershed, toxic chemical inputs, and riparian deforestation impair headwater streams that remain in urban watersheds (Sweeney 1993, Gomi et al. 2002, Gage et al. 2004). Understanding the effects of such impairments on headwater streams and their biota is important for restoring the structure and function of stream networks (Palmer et al. 1997).

Patterns of community similarity between headwater streams and downstream reaches in urban watersheds may provide information about regional processes controlling local community composition. Altered regional scale processes, such as

dispersal, in urban watersheds may potentially augment the impacts of local habitat and water quality degradation on stream insect communities (Petersen et al. 2004). Also, impacts to large scale habitat types in adjacent streams may promote community similarity.

Large scale impacts to riparian forests may promote similarity between headwater and downstream reaches. The river continuum concept predicts a shift from species that utilize allochthonous food sources in headwater communities to a greater abundance of species that utilize autochthonous food sources in mid-order streams in response to physical changes in the riparian forest (Vannote et al. 1980). However, urbanization may cause riparian deforestation, decrease allochthonous inputs, and decrease the organic matter retentiveness along the entire stream network (Paul and Meyer 2001). Decreased allochthonous food sources and increased light penetration may shift the trophic structure of headwater insect communities to a form representative of mid-order reaches where the riparian canopy is open and autochthonous food resources are important (Sweeney 1993, Delong and Brusven 1998, Meyer and Wallace 2001). The shift in trophic structure may result in greater similarity between communities in headwater and higher order reaches.

Besides food resources, the type and quality of habitats occurring at various spatial scales determine local species composition in streams by filtering out species from the regional species pool whose habitat requirements are not met (Poff 1997, Lamouroux et al. 2004). Headwaters and downstream reaches in unimpacted watersheds contain different habitats and are expected to possess different species assemblages (Meyer and Wallace 2001). However, restricted adult movement and survival and habitat fragmentation may limit the regional species pool to taxa found only in downstream

higher order reaches (Chapter 1). The lack of headwater taxa in the regional species pool and decreased habitat and water quality in headwater streams may lead to similar communities in impacted headwaters and healthy downstream reaches.

The objective of this study was to compare the composition of insect communities in headwaters and their main-stem streams within urban and rural watersheds. I compared the communities associated with headwaters in urban and rural watersheds, expecting reduced diversity in urban headwaters. With the loss of taxa in urban headwaters, immigrants from the nearby less impacted main-stem may play a large role in determining which taxa persist in urban headwaters. Thus, I hypothesized that the insect community within a headwater tributary was more similar to its respective main-stem community in urban watersheds than in rural watersheds. I also hypothesized that a larger portion of taxa in each headwater are shared between with the main-stem stream in urban watersheds than in rural watersheds. Finally, I compared communities at individual riffles at three different locations along headwater tributaries to the main-stem communities. I hypothesized that longitudinal patterns of similarity along headwaters differ in urban and rural watersheds.

Methods

Site selection and classification

Headwater and main-stem stream pairs were located in the Piedmont region of Montgomery and Howard Counties, Maryland (Table 2, Figure 1). Headwaters were perennial streams with no perennial tributaries, and only the headwater at RBR had an intermittent tributary. The associated main-stem streams were second order or higher.

Stream order for main-stems was determined using USGS 1:24,000 scale quadrangles by counting all streams listed as perennial and intermittent. Land use associated with the headwater streams was determined based on Maryland Department of Planning GIS land coverages available in the ArcView supplement program GISHydro2000 (GISHydro 2000, Moglen 2005). Three urban and three rural headwater / main-stem stream pairs were selected for use in the study on the basis of the land use surrounding the headwater streams of each pair. Headwater streams were defined as urban if at least 75% commercial or residential land use comprised the watershed, and headwater streams were defined as rural if at least 75% agricultural or forested land use comprised the watershed.

Physical and chemical characteristics of the stream were measured at three riffles along each urban and rural headwater stream. Headwater streams were visited in random order and sampled during baseflow conditions. The riffles sampled were located near the mouth, near the source, and a point midway along each headwater tributary (Figure 1). Conductivity and pH were measured at each riffle using a YSI model 556 multiprobe during the summer in 2004. The physical characteristics of each headwater stream were measured during the summer in 2006. Ten transects spaced two meters apart were set out along a 20 meter stream reach centered at the middle of each riffle. The reach included riffle, run, and pool habitat. Percent slope between each end of the reach was measured using a clinometer. Stream width, thalweg depth, and the dominant substrate type were measured at each transect. The substrate type that comprised over 50% of a one X one meter square area of the stream bottom was designated the dominant substrate type at each transect. Riparian canopy coverage was measured from digital photos of the canopy directly above the middle of each reach. The open area was analyzed with ImageJ

(National Institutes of Health, Washington, DC). Discharge was determined at the most downstream reach using the cross sectional area and stream flow measured with a Marsh-McBirney Flow-Mate model 2000 flow meter.

Insect sampling and processing

Benthic communities were sampled in the headwater and main-stem streams belonging to each stream pair during the spring (May – June), summer (July – August), and fall (September – October) of 2004. Sites were visited in random order during baseflow. A single sample was collected from a randomly selected location within each riffle using a 0.04m² Surber sampler (mesh size = 250 μ m) to a depth of 8-10 centimeters. Aquatic insects were collected from the same headwater riffles described above for water chemistry and habitat sampling. In addition, two individual samples were collected along the main-stem from the first riffle habitat located upstream and downstream of the headwater tributary's confluence. Only riffles were sampled because this habitat usually contains a highly diverse community of aquatic insects that responds to urbanization and can be quantitatively sampled for aquatic insects (Roy et al. 2003). Samples were preserved in 100% ethanol in order to reach a final concentration of at least 80%. In the lab, sample debris was sorted in entirety under magnification. All aquatic insects except Chironomidae were removed from the sample debris and identified to the lowest practical taxonomic level (genus or species in most cases) using local and regional keys (listed in Appendix A).

Analysis

For headwater comparisons, the mean number of taxa (S), the mean Shannon Diversity Index (H'),

$$H' = -\sum p_i (\ln p_i)$$

the mean Simpson's Index (D),

$$D = \sum p_i^2$$

and the mean relative abundances of functional feeding groups (predators, filterers, collector gatherers, scrapers, and shredders) were calculated, where p_i is the proportion of individuals belonging to the i^{th} taxa (Magurran 1988). Differences were examined between watershed types (urban versus rural) for three seasons with a repeated measures ANOVA (Proc Mixed SAS v9.1). During data analysis, the three individual riffle samples from a single sampling date in each headwater were combined to create one artificial composite sample for each headwater stream for each season. The taxa were pooled for each composite, and the abundance for each taxa was standardized by dividing individual abundances by the number of riffle samples. Values for the Shannon Diversity Index usually fall between 1.5 (low diversity) and 3.5 (high diversity) and rarely exceed 4.5. The range of values for the Simpson's index depends on the underlying distribution of the population, and low values represent high evenness (Magurran 1988). Functional feeding groups were assigned to taxa based on Barbour et al. (1999) and Merritt and Cummins (1996). The Simpson's Diversity Index values were log transformed and the percent predators, scrapers, and shredders were arcsine square-root transformed in order to meet the assumptions of homogeneity of variance.

For comparisons among headwater and main-stem stream pairs, the mean Jaccard index (C_j),

$$C_j = j / (a + b - j)$$

the mean Morisita-Horn index (C_{mH}),

$$C_{mH} = 2\sum(an_i * bn_i) / (da + db) aN * bN$$

$$da = \sum an_i^2 / aN^2$$

$$db = \sum bn_i^2 / bN^2$$

and the mean proportion of headwater taxa shared with their respective main-stem community (C_p)

$$C_p = j / a$$

were calculated, where j is the number of taxa shared by the headwater and the main-stem streams, a is the total number of taxa in the headwater stream, b is the total number of taxa in the main-stem stream, an_i is the number of individuals in the i^{th} species in site A, bn_i is the number of individuals in the i^{th} species in site B, aN is the total number of individuals in site A, and bN is the total number of individuals in site B (Magurran 1988). Differences were examined between watershed types for three seasons with a repeated measures ANOVA (Proc Mixed SAS v9.1). During data analysis, separate headwater and main-stem communities were created by compositing the individual riffle samples for each stream as described above for the previous set of ANOVAs. The similarity indices were calculated between the headwater and main-stem community for each stream pair. Each similarity index ranges between 0 (no taxa in common) and 1 (the same communities). The Jaccard index and the proportion of shared taxa measure similarity between species and the Morisita-Horn index measures similarity between

species and their abundances. All assumptions of analysis of variance were met.

Because the ANOVA calculated for the Jaccard index produced a significant interaction effect, post-hoc examinations of treatment means for each time period using a Tukey-Kramer adjustment were performed instead of examining treatment main effects (Sokal and Rohlf 1981).

Watershed type X riffle location interactions for mean taxa richness (S) and mean abundance along headwater streams and mean Jaccard index (C_j) and mean Morisita-Horn index (C_{mH}) between each headwater riffle and the main-stem were examined between watershed types for three seasons with a repeated measures ANOVA (Proc Mixed SAS v9.1). A significant interaction indicates that the level of the response variable in each watershed type depends on riffle location. The data were analyzed as a completely randomized split-split-plot design in space and time using the REPEATED option of SAS (v9.1). Values for individual riffles along the headwater and index values calculated between individual riffle and composited main-stem communities (during data analysis) were subplots within stream pair whole plots. Mean taxa richness and mean abundance were both (+1)log-transformed to satisfy the requirement of equal variances. Individual riffle means were compared using a Tukey-Kramer adjustment. An extended description of all the methods is provided in Appendix B.

Results

Characteristics of watersheds and headwater streams

By design, forested and agricultural land use dominated the watersheds for the rural headwaters used in this study, and urban land use dominated the watersheds for the

urban headwaters (Table 2). Land use in main-stem watersheds varied between stream pair types. The SPD main-stem watershed was almost completely urbanized, and the main-stem watershed for DRK has the lowest amount of urban land use. Headwater watershed sized varied between stream pair type and ranged from 0.13 km² to 3.4 km². Main-stem watershed size also varied between stream pair type. The two largest main-stem watersheds (SNC and MPE) belonged to rural stream pairs and the two smallest main-stem watersheds (SPD and RBR) belonged to urban stream pairs. Fig. 1 shows the locations, stream length, and sampling locations for each stream pair.

Table 3 summarizes the physical and chemical characteristics of the headwater streams used in this study. Measurements were done to describe the physical characteristics of headwater streams sampled in this study and do not infer anything about the effect of urbanization on the physical characteristics of urban streams. The means for depth and width for each of the three urban headwater streams were greater than the means for the three rural headwater streams. The means for canopy cover measured for the three rural headwater streams were greater than the means for the three urban headwater streams. Only one riffle at an urban headwater stream had no canopy cover over the stream, but at that riffle the riparian zone was forested a few meters from the stream bank. No pattern between urban and rural headwaters existed for the means for percent slope. Cobble substrate was the most commonly measured benthic substrate in urban streams. The most commonly measured benthic substrate varied between rural headwater streams. The means for conductivity and pH measured for the six streams used in this study varied between urban and rural headwaters.

Insect communities

Nine orders including 101 taxa of aquatic insects were collected from all six stream pairs (Appendix C). Across all samples insect density was 3,819/m². Ninety-three taxa were collected across all rural headwater and main-stem streams, and 43 taxa were collected from all urban headwater and main-stem streams. Insect density across all rural headwater and main-stem streams was 5,085/m², and across all urban headwater and main-stem streams was 2,554/m². *Baetis* (Ephemeroptera: Baetidae) and *Hydropsyche* (Trichoptera: Hydropsychidae) were found in all streams, and *Cheumatopsyche* (Trichoptera: Hydropsychidae) was found at all streams except the headwater tributary at MPE. *Baetis*, *Leuctra* (Plecoptera: Leuctridae), *Hydropsyche*, and *Cheumatopsyche* were the taxa with the highest abundances in a single stream for one season.

Sixty-three taxa were collected across all main-stem streams, and the insect density across all main-stem streams was 2,790/m². Fifty-three taxa were collected across all rural main-stem streams, and 38 taxa were collected across all urban main-stem streams. Insect density across all rural main-stem streams was 2,971/m², and across all urban main-stem streams was 2,618/m². Urban and rural main-stem streams were dominated by *Cheumatopsyche* and/or *Hydropsyche*. *Baetis* was abundant in the three urban main-stem stream communities, and less common in the rural main-stem streams. *Stenelmis* (Coleoptera: Elmidae) was abundant in one urban and one rural main-stem stream. Less abundant taxa varied greatly between urban and rural main-stem streams. Insect density for individual urban main-stem streams ranged from 475/m² to 8,663/m² and for rural main-stem streams ranged from 1,163/m² to 5,525/m².

Headwater comparisons

Across all headwater streams, 85 taxa were collected, and insect density was 4,849/m². Across all urban headwater streams, 24 taxa were collected, and insect density was 2,490/m². Across all rural headwater streams, 78 taxa were collected, and insect density was 7,209/m². Hydropsychid caddisflies were abundant in urban and rural headwater streams. *Cheumatopsyche* and/or *Hydropsyche* were dominant most headwater streams of both types, and *Diplectrona modesta* (Trichoptera: Hydropsychidae) dominated the headwater at one rural headwater stream. *Baetis*, *Dolophilodes* (Trichoptera: Philopotamidae), and *Leuctra* were abundant in some rural headwater streams, and most Plecoptera were found in rural headwaters. *Stenelmis* was abundant in some urban headwater streams. Less abundant taxa varied greatly between urban and rural headwater streams. Density of insects in each urban headwater stream ranged from 17.5/m² to 15,200/m² and in each rural headwater stream ranged from 1,343/m² to 19,868/m².

The number of taxa found in the headwater but not in the main-stem ranged from 19 to 34 for the rural stream pairs and 1 to 4 for urban stream pairs (Table 4). The headwater only taxa in rural headwaters comprised 8 orders including many Ephemeroptera, Plecoptera, and Trichoptera taxa, whereas in urban headwaters taxa were only from Odonata and Diptera. Four of the six urban headwater taxa, including *Ishnura* (Odonata: Coenagrionidae), *Calopteryx maculata* (Odonata: Calopterygidae), *Aedes* (Diptera: Culicidae), and *Odontomyia* (Diptera: Stratiomyidae) were not unique to rural headwater streams.

Mean taxa richness ($F_{(1,4)}=20.85$, $P=0.01$, Fig. 2A) and Shannon diversity index ($F_{(1,6.35)}=45.68$, $P=0.0004$, Fig. 2B) were significantly lower in urban than rural headwater streams, and the mean Simpson's index was significantly greater ($F_{(1,5.14)}=18.92$, $P=0.007$, Fig. 2C) in urban than rural headwater communities. The mean number of taxa for each season in the urban headwaters was always less than in rural headwaters. The Shannon diversity and Simpson's indices were more variable for urban than rural headwaters. Trends for the Simpson's index between sites and across seasons were the inverse seen for the Shannon diversity index, but indicated similar patterns in diversity (Magurran 1988).

Only one functional feeding group differed between urban and rural headwater communities. Percent predators ($F_{(1,4)}=11.43$, $P=0.03$) was reduced in urban (0.38%) compared to rural headwater communities (14.4%). There were no to few predators in urban headwater streams. The mean percent filterers ($F_{(1,4)}=5.04$, $P=0.08$), collector/gatherers ($F_{(1,4)}=0.10$, $P=0.77$), scrapers ($F_{(1,4)}=2.12$, $P=0.22$), and shredders ($F_{(1,4)}=1.61$, $P=0.27$) were not significantly different between urban and rural headwater communities. Scrapers were absent from the communities for headwater streams belonging to SAL and SPD for all three seasons. The relative abundance of shredders was greatest in the spring in urban (26.2%) and rural (33.7%) headwater streams. Overall, filterers tended to exhibit the greatest relative abundances of any group in both urban (69.3%) and rural (36.6%) headwater streams.

Headwater / main-stem comparisons

A significant watershed type X date interaction existed for the Jaccard index ($F_{(2,4.17)}=13.18$ $P=0.02$). This indicates that the difference for the Jaccard index between watershed types was dependent on the date, and that analyzing overall treatment effects is inappropriate. The mean Jaccard index for the spring (adjusted $P=0.95$) and summer (adjusted $P=1.00$) were not significantly different between rural and urban stream pairs (Fig. 3A). The Jaccard index for the fall (adjusted $P=0.02$) was greater in urban than rural headwater streams (Fig. 3A). The Morisita-Horn ($F_{(1,4)}=0.74$, $P=0.44$) index was not significantly different between rural and urban stream pairs (Fig. 3B). The values for the Morisita-Horn were highly variable. Values of the Morisita-Horn index calculated for rural stream pairs ranged from 0.95 to 0.01, and for urban stream pairs ranged from 0.96 to 0.05. The Morisita-Horn values for SNC were particularly different than the other rural stream pairs. Values for SNC ranged from 0.55 to 0.95 while the highest value for MPE or DRK was 0.36.

The proportion of shared taxa in the headwater communities, C_p , ($F_{(1,4)}=9.58$, $P=0.04$) was greater in urban than rural stream pairs (Fig. 3C). Values were not as variable as for the Morisita-Horn index and ranged from 50.0% to 90.0% for urban stream pairs and from 13.9% to 66.7% for rural stream pairs. The individual measurements of the proportion of shared taxa in headwater communities in urban stream pairs was always highest for RBR, which also had the greatest number of taxa each season for any urban headwater stream.

Longitudinal headwater and headwater / main-stem comparisons

The watershed type X riffle location interaction was significant for abundance ($F_{(2,31)}=5.85$ $P=0.007$) (Fig. 4A) and taxa richness ($F_{(2,9)}=8.7$ $P=0.008$) (Fig. 4B). The only significant difference for abundance was that the abundance for the upstream urban riffle was greater than for the downstream urban riffle ($P = 0.02$) (Fig. 4A). However, the high variability of abundance data suggested that this difference was not biologically relevant. The taxa richness at the upstream and downstream rural riffles were greater than at the upstream (adjusted $P = 0.009$, adjusted $P = 0.01$ respectively) and midstream (adjusted $P = 0.03$, adjusted $P = 0.05$ respectively) urban riffles, and taxa richness at the midstream rural riffle was greater than the upstream (adjusted $P = 0.02$) urban riffle (Fig. 4B). The upstream urban riffle had greater taxa richness than the downstream urban riffle (adjusted $P = 0.007$), and no rural riffles were significantly different from each other (Fig. 4B).

The watershed type X riffle location interaction was significant for the Jaccard index ($F_{(2, 31.1)}=3.63$, $P=0.038$) (Fig. 4C) but was not significant for the Morisita-Horn index ($F_{(2,8.54)}=1.61$, $P=0.25$) (Fig. 4D). The Jaccard value for the downstream riffle in urban streams was greater than both the midstream (adjusted $P = 0.04$) and upstream (adjusted $P = 0.0002$) riffles (Fig. 4C). All individual riffle means for the Morisita-Horn index were not significantly different (Fig. 4D). Values for the Morisita-Horn index were again extremely variable.

Discussion

Watershed urbanization was associated with differences in community composition between urban and rural headwater streams. The significantly lower numbers of taxa (Figure 2A), lower Shannon Diversity index values (Figure 2B), and greater Simpson's index values (Figure 2C) found for the urban headwater streams indicated that urban headwater communities were less diverse than communities in rural headwater streams. As expected from previous studies, watershed urbanization negatively impacted headwater insect communities (Paul and Meyer 2001, Walsh et al. 2001, Moore and Palmer 2005, Walsh et al. 2005). The significantly lower relative abundance of predators also indicated that human activities negatively impacted urban streams (Kerans and Karr 1994, DeWalt et al. 2005). However, similar relative abundances of the other functional feeding groups indicated that urbanization only altered higher trophic levels and had not shifted overall food web structure or function (Sweeney 1993, DeLong and Brusven 1998, Meyer and Wallace 2001).

Insect communities in urban headwaters were more similar to their respective main-stem communities than rural headwater communities were to their main-stem communities. The mean Jaccard index for the fall was greater for urban stream pairs than rural stream pairs but not for spring or summer (Figure 3A). The mean Morista-Horn index was not significantly different between treatments (Figure 3B). However, no significant difference was a reasonable outcome since this measure takes into account species abundance which is often extremely variable between riffles (Brooks et al. 2002, Heino et al. 2005). The mean proportion of headwater taxa shared with its paired main-stem community was greater for urban than rural stream pairs (Fig. 3C). The greater

proportion of shared taxa in the urban headwater communities did represent greater similarity between headwater and main-stem communities in urban than rural watersheds.

The decreased diversity and increased proportion of shared taxa in urban headwater streams suggested that headwater communities become less diverse subsets of downstream communities as taxa are lost following urbanization. Only two taxa unique to rural headwater streams and missing from the rural main-stem were found in urban headwater streams (Table 4). The numbers of unique taxa in the three rural headwater streams were 19, 29, and 34, but only seven taxa (e.g. *Aedes*) were unique to all urban headwater streams (Table 4). Taxa unique to rural headwater habitats appeared to be the taxa most susceptible to extinction following urbanization. The greater proportion of headwater taxa shared with the main-stem in urban watersheds indicated that the less diverse communities in urban headwaters were mostly species found in the main-stem. The large number of unique headwater taxa found in this study reaffirmed the belief that headwaters contain unique assemblages and these taxa are at risk (Meyer and Wallace 2001, Gomi et al. 2002).

The statistically significant interaction between watershed type and riffle location for the Jaccard similarity index (Figure 4C) suggested that urbanization changed patterns of similarity longitudinally along headwater streams. The Jaccard index was significantly greater in the urban downstream riffle community (Figure 4C) than both the urban midstream ($p=0.04$, Tukey-Kramer adjustment) and urban upstream ($p=0.0002$, Tukey-Kramer adjustment) riffle communities. This pattern suggested that overall similarity was related to proximity to the main-stem. Greater similarity between downstream riffles and the main-stem was expected if a regional process such as dispersal had become more

important for determining community composition in urban headwaters and the main-stem was the primary source of immigrants. However, longitudinal differences in habitat and water quality could also have produced these patterns.

I did not directly examine the processes that were occurring, but the importance of distance to the main-stem suggested that dispersal between streams was altered by urbanization. Longitudinal differences would not have occurred if dispersal from other headwater streams was important. Headwater streams are naturally isolated ecosystems where resident populations experience natural disturbances such as periodical drying after which immigrants from neighboring communities are needed to rescue populations. Generally, the absence of drifting or crawling immigrants cause headwater streams to rely primarily on oviposition by gravid females for recruitment (Mackay 1992, Moser and Minshall 1996, Bunn and Hughes 1997, Humphries 2002, Elliot 2003). Piping headwater streams underground (Meyer and Wallace 2001), decreasing the overall pool of potential immigrants at a watershed scale (Briers et al. 2002), or even directly impacting adult immigrants (Kriska et al. 1998) may cause the main-stem to become the primary supplier of immigrants to urban headwaters. In urban headwaters, my data suggested that habitat and water quality degradation made resident populations more susceptible to local extirpation and made community composition more dependent on immigration from the main-stem. I did not thoroughly measure water and habitat quality at each riffle, and I cannot rule out its effect on the longitudinal patterns of community composition. However, the short length of headwater streams and the lack of lateral inputs from other streams made large longitudinal differences in habitat and water quality unlikely.

Understanding the factors that are responsible for determining community composition in urban streams is important for successful stream restoration and conservation. Knowledge of how regional scale factors such as immigration affect diversity at local scales may improve our ability to predict the response and resiliency of aquatic insect populations to anthropogenic stressors (Suding et al. 2004). For example, a lack of adult immigrants to counteract local extirpations and poor quality habitat may facilitate persistently low diversity in urban headwater streams (Suding et al. 2004). In fact, severe anthropogenic impacts potentially cause headwater streams to become sink habitats for aquatic insect populations supported by adjacent main-stem source populations (Pulliam 1996, Johnson 2004). The dispersal abilities of individuals, proximity to potential sources, and species abundance in source populations determine colonization success and population development following restoration (Whiles and Wallace 1992, Alhroth et al. 2003). As a result, prior knowledge of species distributions and their likelihood of immigrating to a restored patch lead to better choices of reference reaches, more realistic goals to assess the success of restoration projects, and ultimately increased success (Palmer et al. 1997, Palmer et al. 2005). Restoration strategies may also need to address impacts to adults in upland environments and impacts to structures required for emergence and oviposition to ensure that potential immigrants can successfully colonize a restored site.

Local habitat and water quality may interact with regional processes such as dispersal to determine community composition in rural and urban watersheds (Sanderson et al. 2005). Other regional factors such as the distance to and composition of neighboring communities are particularly important for headwater streams that are

naturally isolated (Malmqvist 2002, Heino et al. 2003). I found that urbanization was associated with decreased aquatic insect richness, moderately increased similarity between headwater and main-stem streams, and altered longitudinal relationships for similarity between individual riffle and main-stem communities. The patterns of community composition suggested that watershed urbanization may increase the influence of regional scale processes on community composition in urban headwater streams. Habitat and water quality were most likely more important than regional processes for determining community composition in rural headwater streams. Also, habitat and water quality most likely acted in concert with regional processes in urban watersheds. However, if the patterns I found were the result of limited dispersal and migration from the main-stem, this suggests that the composition of the main-stem may mediate the response of insect communities to poor habitat and water quality in urban headwaters. I did not measure dispersal, immigration, or oviposition of adult insects. However, the patterns I found warranted further research to determine the role of such regional processes for determining the composition of insect taxa in urban headwater communities.

Table 2. Watershed land use statistics for all streams.

Stream type	Stream pair	Main-stem stream	Latitude/longitude	Headwater Stream				Main-stem Stream			
				Watershed Area (km ²)	Urb	Agr	For	Watershed Area (km ²)	Urb	Agr	For
Rural	DRK	Little Bennet Creek	39°16.61 N 077°18.43 W	1.3	12.8%	28.4%	58.9%	30.6	10.7%	36.6%	52.8%
	MPE	Middle Patuxent River	39°13.34 N 076°54.80 W	0.13	0.0%	0.0%	100%	98.7	35.1%	40.4%	24.4%
	SNC	Great Seneca Creek	39°07.89 N 077°20.11 W	2.3	1.7%	82.6%*	15.7%	162.1	49.9%	20.8%	29.3%
Urban	RBR	Reddy Branch	39°10.70 N 077°03.67 W	3.4	88.6%	1.2%	10.2%	9.1	39.1%**	35.3%	25.6%
	SAL	Paint Branch	39°02.68 N 076°58.38 W	1.0	84.1%	0.0%	15.9%	31.6	72.6%	5.1%	22.2%
	SPD	Joseph Branch	39°02.60 N 077°04.89 W	0.78	98.9%	0.0%	1.1%	7.0	98.2%	0.0%	1.8%

Urb = Urban, Agr = Agriculture, For = Forested

* The agriculture area in SNC's headwater watershed is over estimated because some of the land is currently being replanted with deciduous trees. Also, all agriculture occurs within a state park.

** The urban area in RBR's main-stem watershed is underestimated because of new construction within the watershed not accounted for in GISHydro2000.

Table 3. Physical and chemical characteristics of headwater streams.

Stream type	Stream pair	Base-flow discharge (m ³ s ⁻¹)	Mean Slope ¹ (%)	Mean Width ² (m)	Mean Depth ² (cm)	Dominant Substrate ³	Mean Canopy Cover ¹ (%)	Conductivity ¹ (mS/cm)	pH ¹
Rural	DRK	0.0071	1.2	1.8	7.0	Gravel	84.4	0.12	7.1
	MPE	0.0029	3.7	0.6	3.8	Sand	84.9	0.04	6.8
	SNC	0.0271	2.3	2.5	11.7	Cobble	82.7	0.22	7.2
Urban	RBR	0.0182	0.5	2.5	19.6	Cobble	55.6	0.16	7.1
	SAL	0.0096	3.2	3.0	18.0	Cobble	63.4	0.42	7.2
	SPD	0.0086	1.3	3.0	21.1	Cobble	79.0	0.27	6.9

1 Mean of 3 riffles.

2 Mean of 10 measures at 3 riffles.

3 Substrate type that composed over 50% of the stream bottom in a 1 X 1 meter² area in the middle of the stream of 10 transects at 3 riffles, possible substrates include fine silt, sand (<2mm and granular), gravel (2-10mm), pebble (1-6.4cm), cobble (6.4-25.6cm), boulder (>25.6cm), and bedrock.

Table 4. Taxa found in the headwater stream and not the main-stem for each stream pair.

Taxa	Rural			Urban		
	DRK	MPE	SNC	RBR	SAL	SPD
Ephemeroptera						
Baetidae						
<i>Acerpenna</i> sp.			+			
<i>Fallceon</i> sp.	+					
Ephemerellidae						
<i>Ephemerella</i> sp.	+					
<i>Serratella</i> sp.			+			
<i>Timpanoga</i> sp.			+			
Tricorythidae						
<i>Tricorythodes</i> sp.			+			
Odonata						
Cordulegastridae						
<i>Cordulegaster</i> sp.	+	+				
Coenagrionidae						
<i>Argia</i> sp.		+				
<i>Ischnura</i> sp.				+		
Calopterygidae						
<i>Calopteryx maculata</i>				+		
<i>Hetaerina</i> sp.		+	+			
Plecoptera						
Leuctridae						
<i>Leuctra</i> sp.		+				
Chloroperlidae						
<i>Suwallia</i> sp.			+			
Perlidae						
<i>Eccopectura xanthenes</i>		+	+			
<i>Perlesta</i> sp.			+			
<i>Perlinella</i> sp.	+		+			
Perlodidae						
<i>Isoperla</i> sp.	+	+				
Genus 2	+					
Nemouridae						
<i>Amphinemura</i> sp.	+		+			
Genus 2		+				
Hemiptera						
Veliidae						
<i>Microvelia</i> sp.	+	+	+			
<i>Rhagovelia</i> sp.			+			
Megaloptera						
Corydalidae						
<i>Nigronia serricornis</i>			+			
<i>Nigronia fasciatus</i>		+				
Sialidae						
<i>Sialis</i> sp.			+			

Table 4. Continued.

Taxa	Rural			Urban		
	DRK	MPE	SNC	RBR	SAL	SPD
Trichoptera						
Hydropsychidae						
<i>Ceratopsyche slossonae</i>			+			
<i>Diplectrona modesta</i>	+	+	+			
Odontoceridae						
<i>Psilotreta</i> sp.		+	+			
Lepidostomatidae						
<i>Lepidostoma</i> sp.		+				
Limnephilidae						
<i>Pycnopsyche</i> sp.		+				
Philopotamidae						
<i>Dolophilodes</i> sp.			+			
Polycentropodidae						
<i>Cyrnellus</i> sp.		+				
<i>Polycentropus</i> / <i>Cernotina</i>			+			
Psychomyiidae						
<i>Lype diversa</i>		+	+			
Rhyacophilidae						
<i>Rhyacophila</i> sp.	+		+			
Uenoidae						
<i>Neophylax concinnus</i>	+	+	+			
<i>Neophylax oligius</i>	+		+			
<i>Neophylax mitchelli</i>		+				
Coleoptera						
Dryopidae						
<i>Helichus</i> sp.		+	+			
Diptera						
Tipulidae						
<i>Dicranota</i> sp.			+			
<i>Hexatoma</i> sp.	+	+				
<i>Limnophila</i> sp.		+				
<i>Molophilus</i> sp.		+				
<i>Ormosia</i> sp.		+				
<i>Pseudolimnophila</i> sp.		+				
<i>Pilaria</i> sp.		+	+			
<i>Tipula</i> sp. 1			+			+
Culicidae						
<i>Aedes</i> sp.				+	+	
Dolichopodidae		+				
Ephydriidae		+				+
Dixidae						
<i>Dixa</i> sp.	+	+				
Empididae						
<i>Chelifera</i> sp.	+		+			
<i>Clinocera</i> sp.	+	+				

Table 4. Continued.

Taxa	Rural			Urban		
	DRK	MPE	SNC	RBR	SAL	SPD
Stratiomyidae						
<i>Nemotelus</i> sp.		+				
<i>Odontomyia</i> sp.				+		
Ceratopogonidae						
<i>Alluaudomyia</i> sp.		+				
<i>Atrichopogon</i> sp.	+					
<i>Bezzia-Palpomyia</i> complex	+					
<i>Ceratopogon</i> sp.		+				
<i>Culicoides</i> sp.		+				
Tabanidae						
<i>Chrysops</i> sp.	+	+	+			
<i>Hybomitra</i> sp.		+				
<i>Taxa Restricted to the Headwater =</i>	19	34	29	4	1	2
<i>Total Taxa in Headwater =</i>	42	59	46	21	6	7

Figure Legends

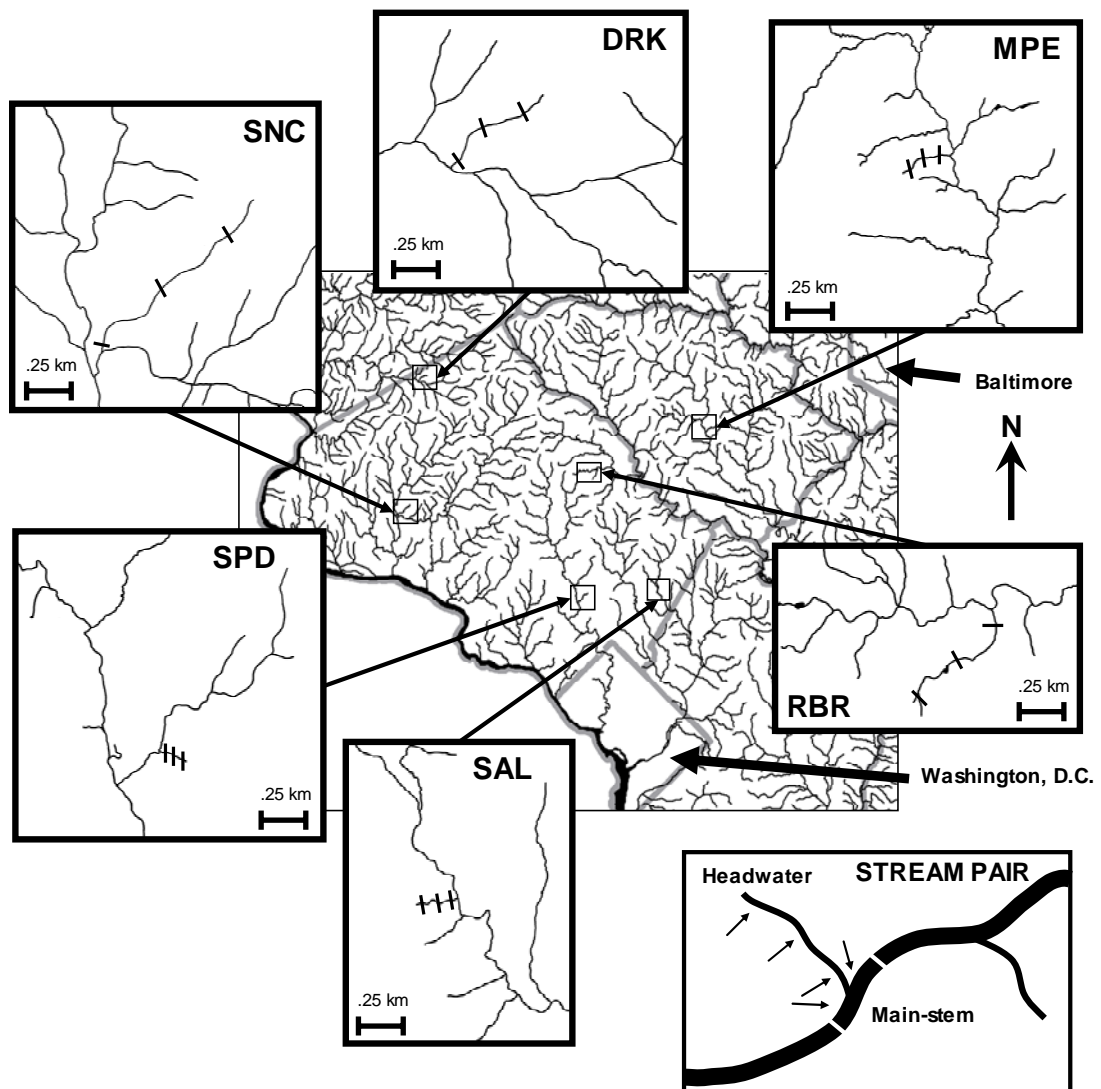
Figure 1. Map of stream pair locations in Montgomery and Howard Counties, Maryland. Inset on the bottom right shows a generalized schematic of the sampling locations. The headwater refers to the headwater stream. The main-stem is the reach on the higher order stream that the headwater flows into and is generally located between the white lines along the main-stem. These two components of the stream system are referred to as a stream pair. Each arrow represents a sampling location. The three small lines on each small scale map represent the actual locations of the three riffles sampled on each headwater. Riffles on the main-stem were not marked because all were directly upstream and downstream of the headwater's confluence with the main-stem and their position can be inferred from the schematic.

Figure 2. Means \pm one standard error for (A) the number of taxa, (B) Shannon Index Value, and (C) Simpson's Index Value for rural versus urban headwater streams.

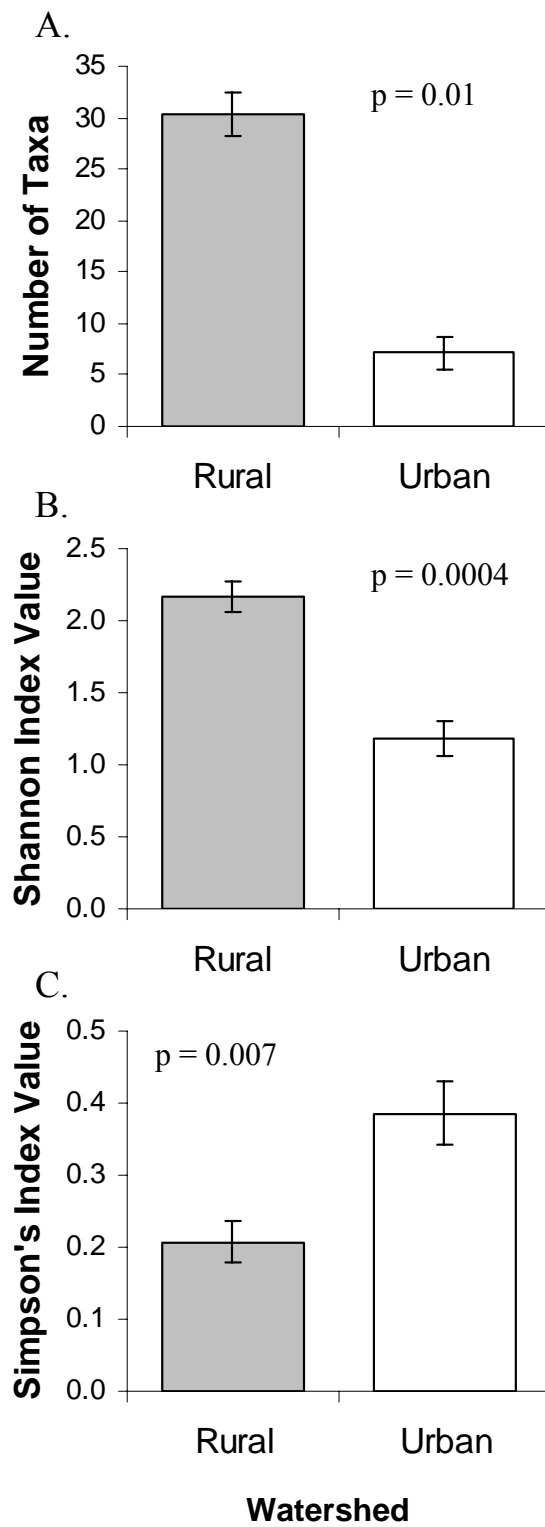
Figure 3. Means \pm one standard error for (A) Jaccard index value for each season, (B) Morisita-Horn index value and (C) proportion of headwater taxa shared with the main-stem community sampled for urban versus rural stream pairs.

Figure 4. (A) Mean abundance and (B) taxa richness calculated for each riffle community for rural versus urban headwater streams, and (C) the mean value for the Jaccard index and (D) Morisita-Horn index calculated between the main-stem community and each individual riffle community for rural versus urban stream pairs.

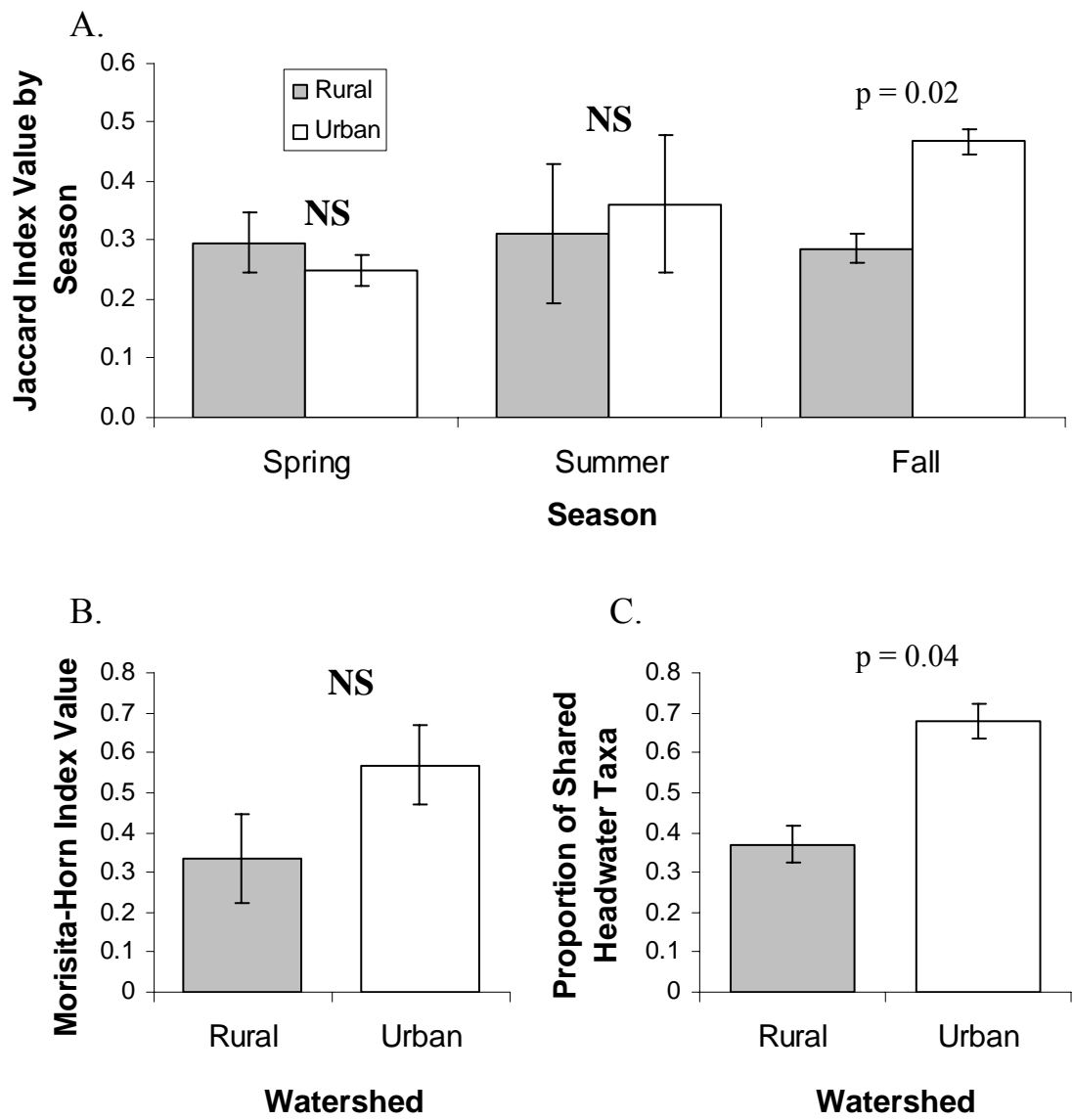
(Figure 1)



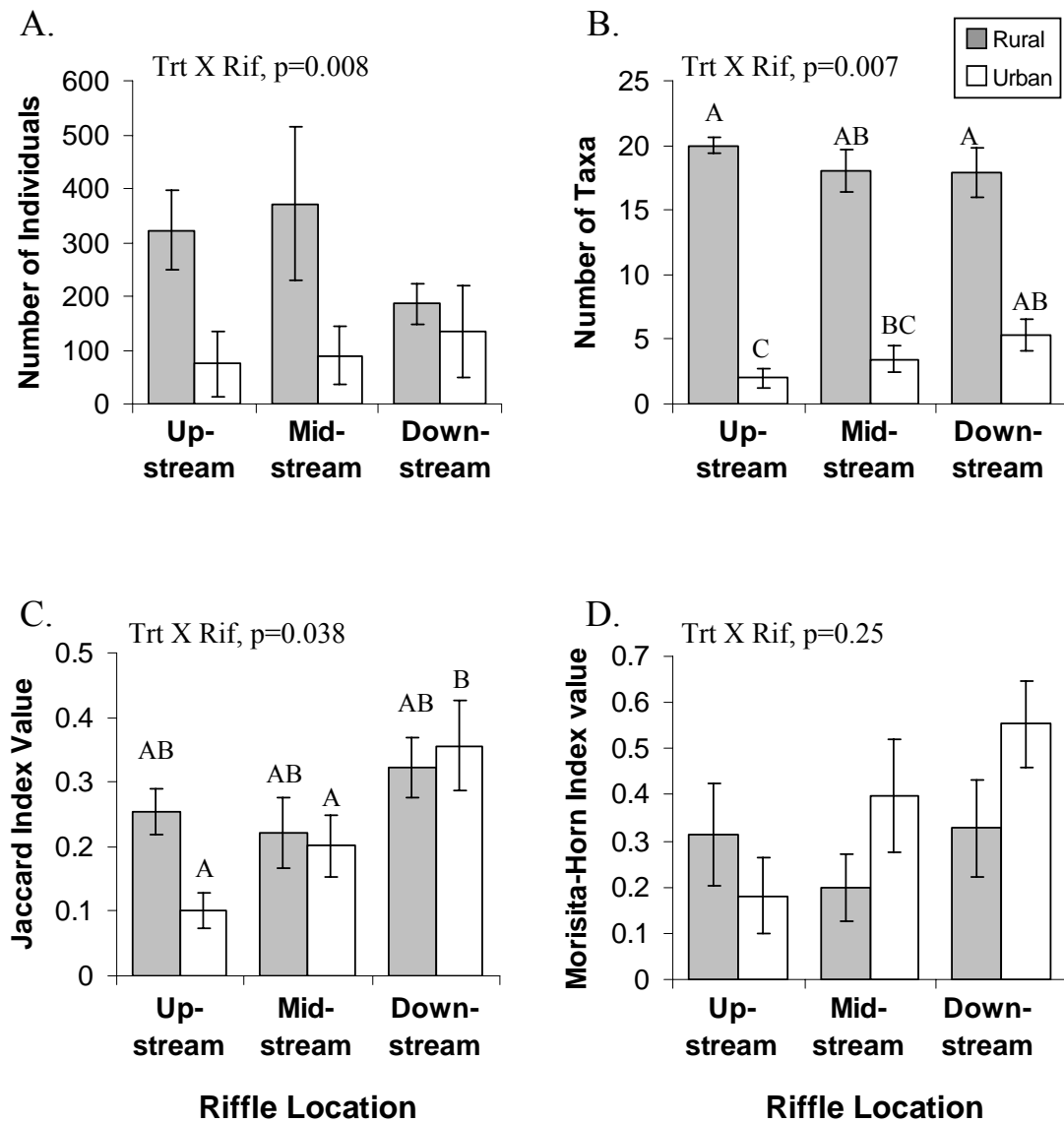
(Figure 2)



(Figure 3)



(Figure 4)



Appendices

Appendix A – List of Macroinvertebrate Identification Keys

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Appendix B – Extended Description of Methods

The following sections are extended descriptions of the methods presented in Chapter 2. The descriptions are provided to increase the repeatability of the study and to provide other researchers the opportunity to evaluate the specific procedures and study sites used for this experimentation.

Stream Pair Selection

The watershed for the headwater belonging to SNC contained much more agriculture than the watersheds of the other two rural headwater streams. The site selection protocol allowed for agricultural land use to be included in the definition of rural land-use. The headwaters found in watersheds with the most forested land-use were chosen. SNC was the third most rural of the sites selected, and the search was not expanded because this site would make an appropriate control. The agricultural fields in SNC's headwater watershed were in parkland and were almost always surrounded by forest.

Riffle Selection

Aquatic insects were sampled from riffles near the mouth, near the source, and in the middle of each headwater stream. Determining which riffles to sample in urban headwater streams required a selection process that allowed for a lack of habitat that could be sampled. Periodic high flow events sometimes changed the morphology of streams and the locations of riffles. The riffle defined as the downstream riffle was the second riffle upstream from the headwater's confluence with the main-stem. If this riffle

could not be sampled (e.g. it consisted of rip-rap), the next riffle upstream was sampled. The furthest accessible riffle upstream along the headwater was designated the upstream riffle. At SNC, the furthest upstream riffle was in a firing range and was not accessible. The most upstream riffle closest to the border of this area was selected.

Flow conditions sometimes created the need to sample different riffles in different seasons. For instance, the most upstream riffle at the headwater belonging to MPE in the spring did not have enough flow to be sampled with a Surber Sampler in the fall. As a result, the first riffle downstream with sufficient flow was sampled for that season.

For all headwater streams, the middle riffle was defined as the first riffle upstream from a point halfway between the two riffles designated as the upstream and downstream riffles in the spring. This location was determined using a handheld GPS unit. This riffle did not change from season to season even if the upstream riffle did change.

Sample Collection

The dates for sample collection were randomized during each field season. Ideally, all samples should be collected on the same day. However, this was not possible given the amount of work needed to perform the collections at one stream pair. Also, the occurrence of rain events and other impacts between sampling periods may have introduced variance into my study. More appropriate sampling procedures do exist, such as a stratified random design. In this case, the stream pairs were visited in random order. The randomized order of sampling dates turned out to be similar to what could be expected from a stratified random design. Table 5 shows the actual sample dates for my study. In the spring and fall, the first / second, third / fourth, and fifth / sixth sampling

date pairs each were assigned to one urban and one rural stream pair. The one exception occurred in the summer. The third and fourth sampling dates were assigned to rural stream pairs and the fifth and sixth sampling dates were assigned to urban stream pairs.

Riffle Location

Benthic samples were collected at three locations within each riffle. Each location was randomly determined. I determined these random locations by choosing three random numbers from a random number table to determine a distance upstream from the bottom of the riffle and laterally from the thalweg. The first number chosen was used to determine the distance upstream from the bottom of the riffle. The number represented the percentage of the total length of the riffle. The second number determined if the location was on the left or right side of the thalweg (while facing upstream). The right side of the stream was chosen when an even number was selected and the left side was chosen if an odd number was chosen. The third number determined the lateral distance from the thalweg to the bank. Again, the number represented the percentage of the length from the thalweg to the bank on the appropriate side. For example if the random numbers chosen were seven-two-five and the total longitudinal length of the riffle was 20 meters and width was 10 meters, the sampling location was 14 meters upstream from the most downstream part of the riffle (70% of 20 meters). The location would have been on the right side of the stream because the second number was even. Finally, the location would have been 2.5 meters from the thalweg on the right side because the distance from the thalweg to the bank is five meters, and 50% of five meters is 2.5 meters. If location determined by this method could not be sampled (e.g. because

the substrate was a large boulder), the first suitable area within the same riffle directly upstream was selected. If there was no suitable riffle location upstream, a new location within the riffle was selected.

Sample Processing

A 50 cm X 5.5 cm plexiglass tray, containing two 2 cm wide lanes (Fig. 5) was used to aid in removing organisms from the sample debris. Only enough debris to cover the bottom of both lanes in a single layer was added at a particular time to ensure that small aquatic insects would be visible between pieces of substrate. The tray was slid under a dissecting scope and the debris was picked through a few individual particles at a time. This was method developed at Stroud Water Research Center. This is a more efficient method than using square trays when the entire sample is sorted.

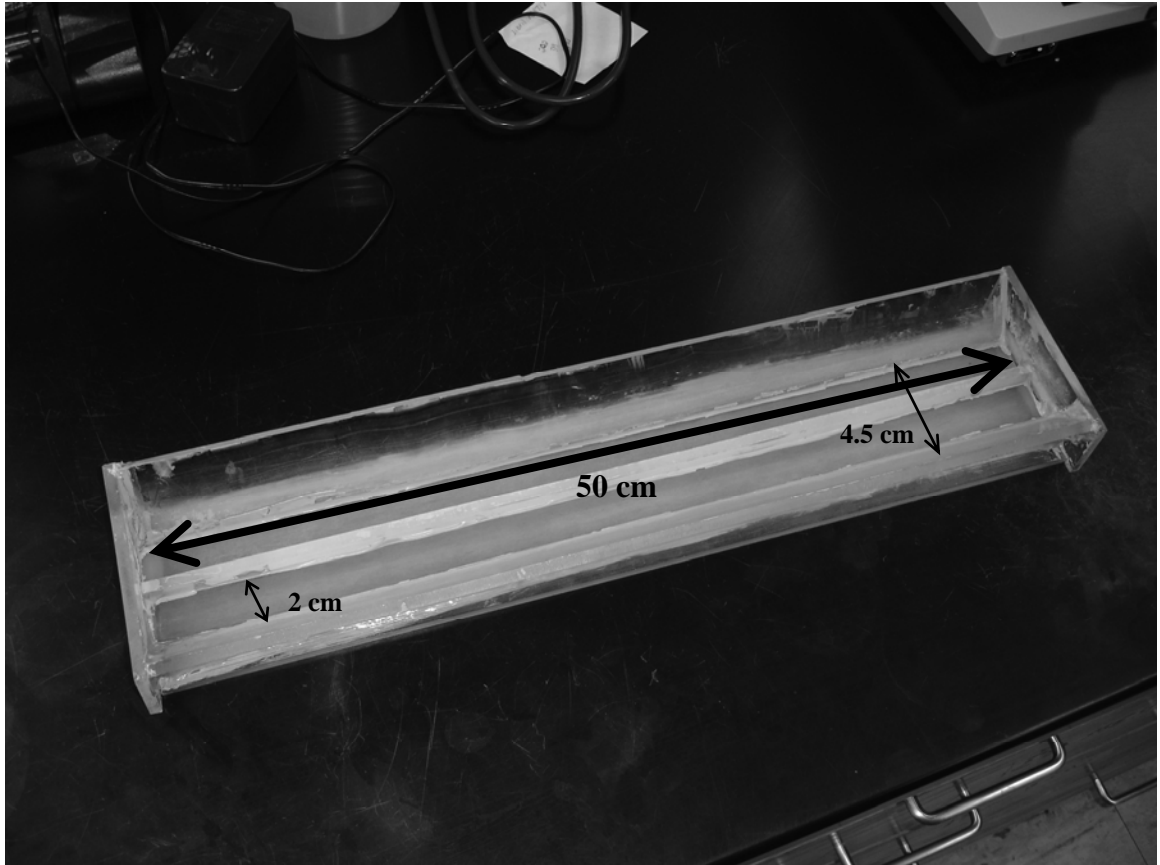
Table 5. Sampling dates for each site during the three seasons sampled in 2004.

Type	Location	Spring	Summer	Fall
Rural	DRK	24-May	3-Aug	2-Oct
	MPE	15-May	4-Aug	9-Oct
	SNC	25-May	30-Jul	24-Sep
Urban	SAL	9-May	9-Aug	23-Sep
	SPD	28-May	10-Aug	11-Oct
	RBR	20-May	2-Aug	26-Sep

Figure Legends

Figure 5. The sorting tray used to sort benthic invertebrate samples was a 50 cm by 5.5 cm plexiglass tray divided into two 2 cm wide lanes. The sample debris was placed in the lanes and picked through a few particles at a time.

(Figure 5)



Appendix C – Raw Data

The following tables are the raw and composited data used for all calculations. Each table is for an individual stream pair and for an individual season. HW signifies the sample was taken from the headwater. R1, R2, and R3 represent the upstream, mid-stream, and downstream riffles respectively. MAIN signifies the sample was taken from the main-stem reach. RD and RU represent the downstream and upstream riffles along the main-stem.

Table 6. DRK – Spring

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Acentrella</i> sp.	GC			5	1.7	1	2	1.5
<i>Acerpenna</i> sp.	SH							
<i>Baetis</i> sp.	GC	92	454	49	198.3		3	1.5
Isonychiidae								
<i>Isonychia</i> sp.	FC						1	0.5
Ephemerellidae								
<i>Ephemerella</i> sp.	GC		1		0.3			
Leptophlebiidae								
<i>Paraleptophlebia</i> sp.	GC	2	11	4	5.7	1		0.5
Plecoptera								
Leuctridae								
<i>Leuctra</i> sp.	SH	240	565	201	335.3	14	4	9.0
Perlidae								
<i>Perlesta</i> sp.	PR	1	9	5	5.0	1	1	1.0
Perlodidae								
<i>Isoperla</i> sp.	PR	5	13		6.0			
Nemouridae								
<i>Amphinemura</i> sp.	SH	3			1.0			
Megaloptera								
Corydalidae								
<i>Nigronia serricornis</i>	PR					1		0.5
Trichoptera								
Hydropsychidae								
<i>Ceratopsyche bronta</i>	FC					2	3	2.5
<i>Cheumatopsyche</i> sp.	FC	1	4	5	3.3	30	11	20.5
<i>Diplectrona modesta</i>	FC	1	3		1.3			
<i>Hydropsyche</i> sp.	FC	21	11	1	11.0			
Philopotamidae								
<i>Dolophilodes</i> sp.	GC	215	77	69	120.3			
Rhyacophilidae								
<i>Rhyacophila</i> sp.	PR	1	1		0.7			
Glossosomatidae								
<i>Glossosoma</i> sp.	SC	1		4	1.7	4	1	2.5
Uenoidae								
<i>Neophylax oligius</i>	SC	5			1.7			
Coleoptera								
Elmidae								
<i>Oulimnius latiusculus</i>	SC	3	55	9	22.3	2	2	2.0
<i>Optioservus ovalis</i>	SC	3			1.0			
Diptera								
Tipulidae								
<i>Antocha</i> sp.	GC	3			1.0	6		3.0
<i>Dicranota</i> sp.	PR	4			1.3			

Table 6. Continued

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
<i>Hexatoma</i> sp.	PR	4	15		6.3			
<i>Tipula</i> sp. 1	SH		1	1	0.7		1	0.5
Simuliidae	FC	160	160	33	4	65.7		1
Dixidae								
<i>Dixa</i> sp.	GC			1	0.3			
Empidae								
<i>Chelifera</i> sp.	GC	1	3		1.3			
<i>Hemerodromia</i> sp.	PR			1	0.3			
Stratiomyiidae								
<i>Nemotelus</i> sp.	GC				0.0			
Athericidae	PR						1	
Ceratopogonidae								
<i>Bezzia-Palpomyia</i> complex	PR	1		2	1.0			

Table 7. DRK – Summer

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Acentrella</i> sp.	GC					2		1.0
<i>Baetis</i> sp.	GC	44	50	28	40.7	13	10	11.5
<i>Fallceon</i> sp.	GC	11			3.7			
Isonychiidae								
<i>Isonychia</i> sp.	FC					8		4.0
<i>Paraleptophlebia</i> sp.	GC	67	11	5	27.7	1		0.5
Heptageniidae								
<i>Stenonema allegeniense</i>	SC						2	1.0
<i>Stenonema modestum</i>	SC	1	1		0.7	2	1	1.5
Caenidae								
<i>Caenis</i> sp.	GC					7	2	4.5
Odonata								
Gomphidae								
<i>Stylogomphus albistylus</i>	PR						1	0.5
Plecoptera								
Leuctridae								
<i>Leuctra</i> sp.	SH	39	37	32	36.0	24		12.0
Chloroperlidae								
<i>Suwallia</i> sp.	PR	3			1.0	1		0.5
Perlidae								
<i>Perlinella</i> sp.	PR	2	2		1.3			
Hemiptera								
Veliidae								
<i>Microvelia</i> sp.	PR	1			0.3			
Megaloptera								
Corydalidae								
<i>Nigronia serricornis</i>	PR		1	1	0.7		1	0.5
Trichoptera								
Hydropsychidae								
<i>Ceratopsyche bronta</i>	FC					31	8	19.5
<i>Ceratopsyche sparna</i>	FC		12		4.0	5		2.5
<i>Ceratopsyche slossonae</i>	FC		1		0.3	3		1.5
<i>Cheumatopsyche</i> sp.	FC	2	3	3	2.7	62	26	44.0
<i>Diplectrona modesta</i>	FC	9		1	3.3			
<i>Hydropsyche</i> sp.	FC	16	1	1	6.0	6		3.0
<i>Dolophilodes</i> sp.	GC	22	9	13	14.7	2	1	1.5
Rhyacophilidae								
<i>Rhyacophila</i> sp.	PR	2	2		1.3			
Glossosomatidae								
<i>Glossosoma</i> sp.	SC	10	2		4.0	2	1	1.5
Uenoidae								
<i>Neophylax concinnus</i>	SC	1			0.3			

Table 7. Continued

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Coleoptera								
Elmidae								
<i>Oulimnius latiusculus</i>	SC	10	12	21	14.3	1		0.5
<i>Optioservus ovalis</i>	SC			6	2.0	1		0.5
Diptera								
Tipulidae								
<i>Dicranota</i> sp.	PR		7	1	2.7	3		1.5
<i>Hexatoma</i> sp.	PR		2		0.7			
Simuliidae	FC	37	28	4	23.0			
Empidae								
<i>Hemerodromia</i> sp.	PR			1	0.3	4	1	2.5
Ceratopogonidae								
<i>Culicoides</i> sp.	PR					1		0.5

Table 8. DRK – Fall

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Acentrella</i> sp.	GC		1		0.3			
<i>Acerpenna</i> sp.	SH							
<i>Baetis</i> sp.	GC	31	52	6	29.7			
<i>Baetisca</i> sp.	GC					1		0.5
Isonychiidae								
<i>Isonychia</i> sp.	FC					3		1.5
Ephemerellidae								
<i>Timpanoga</i> sp.	GC					2		1.0
Leptophlebiidae								
<i>Paraleptophlebia</i> sp.	GC	101	134	2	79.0	2		1.0
Heptageniidae								
<i>Stenonema modestum</i>	SC	1	1		0.7	3		1.5
Caenidae								
<i>Caenis</i> sp.	GC					2	1	1.5
Odonata								
Cordulegastridae								
<i>Cordulegaster</i> sp.	PR	2			0.7			
Gomphidae								
<i>Stylogomphus albistylus</i>	PR			1	0.3			
Plecoptera								
Leuctridae								
<i>Leuctra</i> sp.	SH	7		1	2.7	5		2.5
Capniidae	SH					1	3	2.0
Chloroperlidae								
<i>Suwallia</i> sp.	PR	31	19	11	20.3			
Perlodidae								
Genus 2	PR	3	1		1.3			
Megaloptera								
Corydalidae								
<i>Nigronia serricornis</i>	PR					1		0.5
Trichoptera								
Hydropsychidae								
<i>Ceratopsyche bronta</i>	FC					2	9	5.5
<i>Ceratopsyche slossonae</i>	FC		8		2.7			
<i>Cheumatopsyche</i> sp.	FC	8	6	4	6.0	73	50	61.5
<i>Diplectrona modesta</i>	FC		9		3.0			
<i>Hydropsyche</i> sp.	FC	75	35	2	37.3		2	1.0
Philopotamidae								
<i>Dolophilodes</i> sp.	GC	8	76	12	32.0			

Table 8. Continued

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Polycentropodidae								
<i>Polycentropus / Cernotina</i>	PR		1		0.3	1		0.5
Rhyacophilidae								
<i>Rhyacophila</i> sp.	PR	10	6		5.3			
Glossosomatidae								
<i>Glossosoma</i> sp.	SC	3		1	1.3		22	11.0
Coleoptera								
Elmidae								
<i>Oulimnius latiusculus</i>	SC	26	110	46	60.7	3	14	8.5
<i>Optioservus ovalis</i>	SC	6			2.0	3	9	6.0
Diptera								
Tipulidae								
<i>Antocha</i> sp.	GC		1	1	0.7	4	6	5.0
<i>Dicranota</i> sp.	PR							
<i>Hexatoma</i> sp.	PR	2	2		1.3			
<i>Tipula</i> sp. 1	SH	11	6		5.7	1		0.5
Simuliidae	FC	13	24		12.3			
Empidae								
<i>Clinocera</i> sp.	PR	1			0.3			
Ceratopogonidae								
<i>Atrichopogon</i> sp.	PR			1	0.3			
<i>Bezzia-Palpomyia</i> complex	PR	2		1	1.0			
Tabanidae								
<i>Chrysops</i> sp.	GC	1			0.3			

Table 9. MPE – Spring

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Acentrella</i> sp.	GC			1	0.3	9	2	5.5
<i>Acerpenna</i> sp.	SH					2		1.0
<i>Baetis</i> sp.	GC			1	0.3	56	15	35.5
Isonychiidae								
<i>Isonychia</i> sp.	FC					1		0.5
Ephemerellidae								
<i>Drunella</i> sp.	PR					3		1.5
<i>Ephemerella</i> sp.	GC			1	0.3	8	8	8.0
<i>Serratella</i> sp.	GC					15	11	13.0
<i>Timpanoga</i> sp.	GC			1	0.3	2		1.0
Leptophlebiidae								
<i>Paraleptophlebia</i> sp.	GC	1			0.3			
Tricorythidae								
<i>Tricorythodes</i> sp.	GC					4	1	2.5
Odonata								
Cordulegastridae								
<i>Cordulegaster</i> sp.	PR	1	1		0.7			
Gomphidae								
<i>Stylogomphus albistylus</i>	PR					1		0.5
Plecoptera								
Leuctridae								
<i>Leuctra</i> sp.	SH	6	17	194	72.3			
Perlidae								
<i>Eccopectura xanthenes</i>	PR		9	2	3.7			
<i>Perlesta</i> sp.	PR					10	4	7.0
Perlodidae								
<i>Isoperla</i> sp.	PR	1	8	6	5.0			
Pteronarcidae								
<i>Pteronarcys</i> sp.	SH					1		0.5
Nemouridae								
<i>Amphinemura</i> sp.	SH	41	13	5	19.7			
Taeniopterygidae								
<i>Taeniopteryx</i> sp.	SH					18	8	13.0
Hemiptera								
Veliidae								
<i>Microvelia</i> sp.	PR		1		0.3			
Megaloptera								
Corydalidae								
<i>Nigronia fasciatus</i>	PR		1	1	0.7			

Table 9. Continued

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Trichoptera								
Hydropsychidae								
<i>Ceratopsyche bronta</i>	FC					1	3	2.0
<i>Cheumatopsyche</i> sp.	FC					5		2.5
<i>Diplectrona modesta</i>	FC	12	17	13	14.0			
<i>Hydropsyche</i> sp.	FC			3	1.0	6		3.0
Brachycentridae								
<i>Micrasema</i> sp.	SH					2		1.0
Odontoceridae								
<i>Psilotreta</i> sp.	SC	6	1		2.3			
Lepidostomatidae								
<i>Lepidostoma</i> sp.	SH	6		1	2.3			
Limnephilidae								
<i>Pycnopsyche</i> sp.	SH		3		1.0			
Philopotamidae								
<i>Dolophilodes</i> sp.	GC	6	3		3.0			
Polycentropodidae								
<i>Cyrnellus</i> sp.	FC		1		0.3			
Rhyacophilidae								
<i>Rhyacophila</i> sp.	PR		4	1	1.7			
Glossosomatidae								
<i>Glossosoma</i> sp.	SC						8	4.0
Uenoidae								
<i>Neophylax concinnus</i>	SC			1	0.3			
<i>Neophylax mitchelli</i>	SC	1	1		0.7			
Coleoptera								
Elmidae								
<i>Dubiraphia</i> sp.	GC					1		0.5
<i>Oulimnius latiusculus</i>	SC	3	2	3	2.7	4	3	3.5
<i>Optioservus ovalis</i>	SC	2			0.7	6		3.0
<i>Stenelmis</i> sp.	SC	5	1		2.0			
Ptilodactylidae								
<i>Anchytarsus bicolor</i>	SH	5	7	1	4.3	1		0.5
Diptera								
Tipulidae								
<i>Antocha</i> sp.	GC			1	0.3	33	2	17.5
<i>Dicranota</i> sp.	PR	5	5	16	8.7			
<i>Hexatoma</i> sp.	PR	3	1		1.3			
<i>Molophilus</i> sp.	SH			1	0.3			
<i>Pseudolimnophila</i> sp.	PR			1	0.3			
<i>Tipula</i> sp. 1	SH			2	0.7			
Dolichopodidae	PR			1	0.3			
Ephydriidae	GC	2			0.7			
Simuliidae	FC		1		0.3	19	9	14.0

Table 9. Continued

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN CU	MAIN ALL
Dixidae								
<i>Dixa</i> sp.	GC	1			0.3			
Empididae								
<i>Hemerodromia</i> sp.	PR					2	1	1.5
Ceratopogonidae								
<i>Alluaudomyia</i> sp.	PR	7			2.3			
<i>Bezzia-Palpomyia</i> complex	PR	10		6	5.3		2	1.0
<i>Culicoides</i> sp.	PR		1		0.3			
<i>Stilobezzia</i> sp.	PR	40	4	3	15.7			

Table 10. MPE – Summer

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Baetis</i> sp.	GC					4	4	4.0
Leptophlebiidae								
<i>Paraleptophlebia</i> sp.	GC	5	1		2.0		1	0.5
Heptageniidae								
<i>Stenonema modestum</i>	SC			2	0.7			
Tricorythidae								
<i>Tricorythodes</i> sp.	GC					1		0.5
Odonata								
Gomphidae								
<i>Stylogomphus albistylus</i>	PR						1	0.5
Coenagrionidae								
<i>Argia</i> sp.	PR	2			0.7			
Calopterygidae								
<i>Hetaerina</i> sp.	PR			7	2.3			
Plecoptera								
Leuctridae								
<i>Leuctra</i> sp.	SH	1		4	1.7			
Perlidae								
<i>Eccopectura xanthenes</i>	PR			7	2.3			
<i>Perlinella</i> sp.	PR	1			0.3			
Nemouridae								
Genus 2	SH	1	1	1	1.0			
Hemiptera								
Veliidae								
<i>Microvelia</i> sp.	PR		1		0.3			
Megaloptera								
Corydalidae								
<i>Nigronia fasciatus</i>	PR		3	3	2.0			
Trichoptera								
Hydropsychidae								
<i>Ceratopsyche bronta</i>	FC					2	14	8.0
<i>Ceratopsyche sparna</i>	FC					1	12	6.5
<i>Cheumatopsyche</i> sp.	FC					1	33	17.0
<i>Diplectrona modesta</i>	FC	349	4	25	126.0			
<i>Hydropsyche</i> sp.	FC					8	2	5.0
Hydroptilidae								
<i>Hydroptila</i> sp.	SC						2	1.0
Odontoceridae								
<i>Psilotreta</i> sp.	SC	32	14		15.3			
Lepidostomatidae								
<i>Lepidostoma</i> sp.	SH	3			1.0			

Table 10. Continued

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Limnephilidae								
<i>Pycnopsyche</i> sp.	SH	4			1.3			
Philopotamidae								
<i>Dolophilodes</i> sp.	GC	2			0.7			
Psychomyiidae								
<i>Lype diversa</i>	SC		1	1	0.7			
Rhyacophilidae								
<i>Rhyacophila</i> sp.	PR	2	1	1	1.3			
Coleoptera								
Elmidae								
<i>Oulimnius latiusculus</i>	SC	4			1.3		6	3.0
<i>Optioservus ovalis</i>	SC					7	13	10.0
<i>Stenelmis</i> sp.	SC	2	1	4	2.3		2	1.0
Dryopidae								
<i>Helichus</i> sp.	SH			2	0.7			
Hydrophilidae								
<i>Hydrobius</i> sp.	PR					1		0.5
Ptilodactylidae								
<i>Anchytarsus bicolor</i>	SH	22	4	5	10.3			
Diptera								
Tipulidae								
<i>Antocha</i> sp.	GC					1	2	1.5
<i>Dicranota</i> sp.	PR	15	3	6	8.0	1		0.5
<i>Hexatoma</i> sp.	PR	1		2	1.0			
<i>Limnophila</i> sp.	PR		2		0.7			
<i>Molophilus</i> sp.	SH		2	1	1.0			
<i>Ormosia</i> sp.	GC		2		0.7			
<i>Pilaria</i> sp.	PR	5	1		2.0			
<i>Tipula</i> sp. 1	SH			1	0.3			
Simuliidae	FC	1			0.3			
Dixidae								
<i>Dixa</i> sp.	GC	4			1.3			
Empidae								
<i>Clinocera</i> sp.	PR			1	0.3			
<i>Hemerodromia</i> sp.	PR			1	0.3	21	11	16.0
Ceratopogonidae								
<i>Bezzia-Palpomyia</i> complex	PR	16	2		6.0			
<i>Ceratopogon</i> sp.	PR	107	20		42.3			
<i>Stilobezzia</i> sp.	PR	14	19		11.0			
Tabanidae								
<i>Hybomitra</i> sp.	PR	1	1		0.7			

Table 11. MPE – Fall

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Baetis</i> sp.	GC						3	1.5
Isonychiidae								
<i>Isonychia</i> sp.	FC						1	0.5
Ephemerellidae								
<i>Timpanoga</i> sp.	GC	3	6	6	5.0			
Heptageniidae								
<i>Stenonema modestum</i>	SC	1		5	2.0	2	4	3.0
Tricorythidae								
<i>Tricorythodes</i> sp.	GC					1		0.5
Odonata								
Cordulegastridae								
<i>Cordulegaster</i> sp.	PR		1	2	1.0			
Calopterygidae								
<i>Hetaerina</i> sp.	PR			2	0.7			
Plecoptera								
Leuctridae								
<i>Leuctra</i> sp.	SH	19			6.3			
Capniidae	SH		27	7	11.3		4	2.0
Perlidae								
<i>Eccoptura xanthenes</i>	PR		1	2	1.0			
<i>Perlinella</i> sp.	PR			1	0.3		1	0.5
Perlodidae								
<i>Isoperla</i> sp.	PR		3		1.0			
Nemouridae								
Genus 2	SH	1		1	0.7			
Taeniopterygidae								
<i>Taeniopteryx</i> sp.	SH					21	3	12.0
Hemiptera								
Veliidae								
<i>Microvelia</i> sp.	PR		3	1	1.3			
Megaloptera								
Corydalidae								
<i>Nigronia fasciatus</i>	PR		1	13	4.7			
Trichoptera								
Hydropsychidae								
<i>Ceratopsyche bronta</i>	FC					1	5	3.0
<i>Ceratopsyche slossonae</i>	FC						3	1.5
<i>Cheumatopsyche</i> sp.	FC					42	73	57.5
<i>Diplectronea modesta</i>	FC	115	146	39	100.0			0.0
<i>Hydropsyche</i> sp.	FC					6	30	18.0
Hydroptilidae								
<i>Hydroptila</i> sp.	SC					9	1	5.0

Table 11. Continued

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Brachycentridae								
<i>Micrasema</i> sp.	SH					2		1.0
Odontoceridae								
<i>Psilotreta</i> sp.	SC	3	1		1.3			
Philopotamidae								
<i>Dolophilodes</i> sp.	GC						1	0.5
Psychomyiidae								
<i>Lype diversa</i>	SC	1		5	2.0			
Rhyacophilidae								
<i>Rhyacophila</i> sp.	PR	1	4	3	2.7	1		0.5
Glossosomatidae								
<i>Glossosoma</i> sp.	SC			1	0.3		1	0.5
Coleoptera								
Elmidae								
<i>Oulimnius latiusculus</i>	SC	3			1.0	2	2	2.0
<i>Optioservus ovalis</i>	SC					3	3	3.0
<i>Stenelmis</i> sp.	SC		1		0.3		1	0.5
Dryopidae								
<i>Helichus</i> sp.	SH			2	0.7			
Hydrophilidae								
<i>Hydrobius</i> sp.	PR		2	3	1.7			
Ptilodactylidae								
<i>Anchytarsus bicolor</i>	SH	56	97	10	54.3			
Diptera								
Tipulidae								
<i>Antocha</i> sp.	GC			1	0.3	4	7	5.5
<i>Dicranota</i> sp.	PR	1	3	11	5.0			
<i>Hexatoma</i> sp.	PR	5	1	1	2.3			
<i>Limnophila</i> sp.	PR		2	2	1.3			
<i>Molophilus</i> sp.	SH	6	1	6	4.3			
<i>Ormosia</i> sp.	GC	1			0.3			
<i>Pseudolimnophila</i> sp.	PR			11	3.7			
<i>Pilaria</i> sp.	PR	1		4	1.7			
<i>Tipula</i> sp. 1	SH	11	14	106	43.7	1	1	1.0
Dixidae								
<i>Dixa</i> sp.	GC	4	5	2	3.7			
Empidae								
<i>Hemerodromia</i> sp.	PR			2	0.7	3	3	3.0
Stratiomyiidae								
<i>Nemotelus</i> sp.	GC			1	0.3			
Ceratopogonidae								
<i>Bezzia-Palpomyia</i> complex	PR	18	21	5	14.7		1	0.5
<i>Ceratopogon</i> sp.	PR	40	38	5	27.7			
<i>Stilobezzia</i> sp.	PR	8	2		3.3		1	0.5

Table 11. Continued

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Tabanidae								
<i>Chrysops</i> sp.	GC	1			0.3			
<i>Hybomitra</i> sp.	PR	1			0.3			

Table 12. SNC – Spring

Taxa	FFG	HW R1	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera							
Baetidae							
<i>Acentrella</i> sp.	GC		4	2.0	2		1.0
<i>Baetis</i> sp.	GC	3	9	6.0	5	5	5.0
Ephemerellidae							
<i>Serratella</i> sp.	GC		2	1.0			
Leptophlebiidae							
<i>Paraleptophlebia</i> sp.	GC	1		0.5			
Heptageniidae							
<i>Stenonema modestum</i>	SC				1		0.5
Plecoptera							
Leuctridae							
<i>Leuctra</i> sp.	SH	1	2	1.5		1	0.5
Perlidae							
<i>Perlesta</i> sp.	PR		2	1.0			
Nemouridae							
<i>Amphinemura</i> sp.	SH	1	2	1.5			
Hemiptera							
Veliidae							
<i>Microvelia</i> sp.	PR	1		0.5			
Megaloptera							
Sialidae							
<i>Sialis</i> sp.	PR	2	1	1.5			
Trichoptera							
Hydropsychidae							
<i>Ceratopsyche bronta</i>	FC		17	8.5	7		3.5
<i>Ceratopsyche sparna</i>	FC		4	2.0		6	3.0
<i>Ceratopsyche slosonae</i>	FC	1		0.5			
<i>Cheumatopsyche</i> sp.	FC	170	113	141.5	25	28	26.5
<i>Diplectronea modesta</i>	FC	14		7.0			
<i>Hydropsyche</i> sp.	FC	8		4.0			
Philopotamidae							
<i>Dolophilodes</i> sp.	GC		6	3.0			
Glossosomatidae							
<i>Glossosoma</i> sp.	SC		11	5.5			
Uenoidae							
<i>Neophylax concinnus</i>	SC	2		1.0			
<i>Neophylax oligius</i>	SC	2		1.0			
Lepidoptera							
Pyrilidae	SH					1	0.5

Table 12. Continued

Taxa	FFG	HW R1	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Coleoptera							
Elmidae							
<i>Oulimnius latiusculus</i>	SC				1		0.5
<i>Optioservus ovalis</i>	SC	1		0.5			
<i>Stenelmis</i> sp.	SC	2		1.0	5	5	5.0
Psephenidae							
<i>Psephenus herricki</i>	SC				1		0.5
Diptera							
Tipulidae							
<i>Antocha</i> sp.	GC	1	46	23.5	5	7	6.0
<i>Dicranota</i> sp.	PR	14	14	14.0			
<i>Tipula</i> sp. 1	SH	3		1.5			
Simuliidae	FC	2	6	4.0	1		0.5
Ceratopogonidae							
<i>Bezzia-Palpomyia</i> complex	PR	1	1	1.0		1	0.5
Tabanidae							
<i>Chrysops</i> sp.	GC	1		0.5			

Table 13. SNC – Summer

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Acentrella</i> sp.	GC		2		0.7			
<i>Acerpenna</i> sp.	SH		6		2.0			
<i>Baetis</i> sp.	GC	1	58	19	26.0	20	27	23.5
Leptophlebiidae								
<i>Paraleptophlebia</i> sp.	GC					1		0.5
Heptageniidae								
<i>Stenonema modestum</i>	SC	5	2	3	3.3		2	1.0
Tricorythidae								
<i>Tricorythodes</i> sp.	GC						1	0.5
Odonata								
Calopterygidae								
<i>Hetaerina</i> sp.	PR	2	1		1.0			
Plecoptera								
Leuctridae								
<i>Leuctra</i> sp.	SH		18	8	8.7			
Chloroperlidae								
<i>Suwallia</i> sp.	PR		2		0.7			
Perlidae								
<i>Perlinella</i> sp.	PR		5	2	2.3			
Megaloptera								
Corydalidae								
<i>Corydalus</i> sp.	PR					2		1.0
<i>Nigronia serricornis</i>	PR	1	3	18	7.3			
Trichoptera								
Hydropsychidae								
<i>Ceratopsyche bronta</i>	FC	7		1	2.7	4	4	4.0
<i>Ceratopsyche sparna</i>	FC					2	3	2.5
<i>Cheumatopsyche</i> sp.	FC	29	54	40	41.0	84	84	84.0
<i>Diplectrona modesta</i>	FC	15	12	1	9.3			
<i>Hydropsyche</i> sp.	FC	8	217	33	86.0	12	55	33.5
Hydroptilidae								
<i>Hydroptila</i> sp.	SC					7	4	5.5
Odontoceridae								
<i>Psilotreta</i> sp.	SC	5			1.7			
Philopotamidae								
<i>Chimarra</i> sp.	FC	1	10	18	9.7	4		2.0
Polycentropodidae								
<i>Polycentropus</i> / <i>Cernotina</i>	PR			1	0.3			
Rhyacophilidae								
<i>Rhyacophila</i> sp.	PR	1	1		0.7			
Glossosomatidae								
<i>Glossosoma</i> sp.	SC		48	51	33.0		6	3.0

Table 13. Continued

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Uenoidae								
<i>Neophylax oligius</i>	SC	6			2.0			
Coleoptera								
Elmidae								
<i>Oulimnius latiusculus</i>	SC					2		1.0
<i>Optioservus ovalis</i>	SC			6	2.0	10	2	6.0
<i>Stenelmis</i> sp.	SC	7	7	15	9.7	41	23	32.0
Diptera								
Tipulidae								
<i>Antocha</i> sp.	GC	4	11	3	6.0	25	13	19.0
<i>Dicranota</i> sp.	PR	14	2	1	5.7			
<i>Tipula</i> sp. 1	SH	1			0.3			
Simuliidae	FC		1	1	0.7			
Empidae								
<i>Chelifera</i> sp.	GC	1	2		1.0			
<i>Clinocera</i> sp.	PR		1		0.3			
<i>Hemerodromia</i> sp.	PR		11	9	6.7	2	2	2.0
Tabanidae								
<i>Chrysops</i> sp.	GC	1			0.3			

Table 14. SNC – Fall

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Baetis</i> sp.	GC	5			1.7	11	10	10.5
Ephemerellidae								
<i>Timpanoga</i> sp.	GC	1			0.3			
Heptageniidae								
<i>Stenonema modestum</i>	SC	2		1	1.0	5	7	6.0
Plecoptera								
Chloroperlidae								
<i>Suwallia</i> sp.	PR	3	1		1.3			
Perlidae								
<i>Eccoptura xanthenes</i>	PR			1	0.3			
Hemiptera								
Veliidae								
<i>Rhagovelia</i> sp.	PR	1			0.3			
Megaloptera								
Corydalidae								
<i>Nigronia serricornis</i>	PR		1		0.3			
Trichoptera								
Hydropsychidae								
<i>Ceratopsyche bronta</i>	FC					3		1.5
<i>Cheumatopsyche</i> sp.	FC	26		2	9.3	28	78	53.0
<i>Diplectrona modesta</i>	FC	29	1	2	10.7			
<i>Hydropsyche</i> sp.	FC	28		4	10.7	18	11	14.5
Hydroptilidae								
<i>Hydroptila</i> sp.	SC					4		2.0
Brachycentridae								
<i>Micrasema</i> sp.	SH					3		1.5
Philopotamidae								
<i>Chimarra</i> sp.	FC	3			1.0	2	15	8.5
<i>Dolophilodes</i> sp.	GC			7	2.3			
Psychomyiidae								
<i>Lype diversa</i>	SC			2	0.7			
Rhyacophilidae								
<i>Rhyacophila</i> sp.	PR	1	1		0.7			
Glossosomatidae								
<i>Glossosoma</i> sp.	SC		1	1	0.7			
Coleoptera								
Elmidae								
<i>Oulimnius latiusculus</i>	SC						5	2.5
<i>Optioservus ovalis</i>	SC	1			0.3	7	3	5.0
<i>Stenelmis</i> sp.	SC	8	1	2	3.7	62	59	60.5
Dryopidae								
<i>Helichus</i> sp.	SH			1	0.3			

Table 14. Continued

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Diptera								
Tipulidae								
<i>Antocha</i> sp.	GC	1		2	1.0	13		
<i>Dicranota</i> sp.	PR	3	2	4	3.0			
<i>Pilaria</i> sp.	PR	1			0.3			
<i>Tipula</i> sp. 1	SH	4	1		1.7			
Simuliidae	FC	3		1	1.3	1	1	1.0
Empidae								
<i>Hemerodromia</i> sp.	PR					1	1	1.0
Ceratopogonidae								
<i>Bezzia-Palpomyia</i> complex	PR			1	0.3			
Tabanidae								
<i>Chrysops</i> sp.	GC	1			0.3			

Table 15. RBR – Spring

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Acentrella</i> sp.	GC					20	3	11.5
<i>Baetis</i> sp.	GC		4	63	22.3	52	18	35.0
Heptageniidae								
<i>Stenonema modestum</i>	SC					3	2	2.5
Odonata								
Aeshnidae								
<i>Boyeria vinosa</i>	PR					1		0.5
Plecoptera								
Leuctridae								
<i>Leuctra</i> sp.	SH					4	5	4.5
Perlidae								
<i>Eccopectura xanthenes</i>	PR						1	0.5
<i>Perlesta</i> sp.	PR					2	2	2.0
Perlodidae								
<i>Isoperla</i> sp.	PR					1		0.5
Nemouridae								
<i>Amphinemura</i> sp.	SH					10	1	5.5
Megaloptera								
Sialidae								
<i>Sialis</i> sp.	PR						1	0.5
Trichoptera								
Hydropsychidae								
<i>Cheumatopsyche</i> sp.	FC	5	77	76	52.7	122	23	72.5
<i>Diplectrona modesta</i>	FC						3	1.5
<i>Hydropsyche</i> sp.	FC		7	41	16.0	26	8	17.0
Philopotamidae								
<i>Chimarra</i> sp.	FC			1	0.3	13		6.5
<i>Dolophilodes</i> sp.	GC					5	1	3.0
Glossosomatidae								
<i>Glossosoma</i> sp.	SC					8	12	10.0
Uenoidae								
<i>Neophylax oligius</i>	SC					19	3	11.0
Coleoptera								
Elmidae								
<i>Oulimnius latiusculus</i>	SC					7	5	6.0
<i>Optioservus ovalis</i>	SC					4	5	4.5
<i>Stenelmis</i> sp.	SC		3	27	10.0	51	5	28.0
Hydrophilidae								
Genus 2	PR		1		0.3			0.0
Psephenidae								
<i>Psephenus herricki</i>	SC			5	1.7	4	3	3.5

Table 15. Continued

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ptilodactylidae								
<i>Anchytarsus bicolor</i>	SH					1		0.5
Diptera								
Tipulidae								
<i>Antocha</i> sp.	GC	5	2	59	22.0	35	33	34.0
<i>Dicranota</i> sp.	PR			2	0.7		5	2.5
<i>Tipula</i> sp. 1	SH					1		0.5
<i>Tipula</i> sp. 2	SH						2	1.0
Simuliidae	FC	78	49	3	43.3	156	3	79.5
Empidae								
<i>Clinocera</i> sp.	PR					1		0.5
Ceratopogonidae								
<i>Bezzia-Palpomyia</i> complex	PR					2	1	1.5

Table 16. RBR – Summer

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Baetis</i> sp.	GC		1	26	9.0	22	17	19.5
Isonychiidae								
<i>Isonychia</i> sp.	FC					1		0.5
Ephemerellidae								
<i>Serratella</i> sp.	GC						3	1.5
Leptophlebiidae								
<i>Paraleptophlebia</i> sp.	GC						1	0.5
Heptageniidae								
<i>Stenonema modestum</i>	SC			2	0.7	13	78	45.5
Odonata								
Gomphidae								
<i>Stylogomphus albistylus</i>	PR						1	0.5
Plecoptera								
Leuctridae								
<i>Leuctra</i> sp.	SH						3	1.5
Hemiptera								
Veliidae								
<i>Microvelia</i> sp.	PR		1		0.3			
Megaloptera								
Corydalidae								
<i>Nigronia serricornis</i>	PR					1	14	7.5
Trichoptera								
Hydropsychidae								
<i>Ceratopsyche bronta</i>	FC						4	2.0
<i>Cheumatopsyche</i> sp.	FC	6	39	18	21.0	24	33	28.5
<i>Diplectrona modesta</i>	FC					1		0.5
<i>Hydropsyche</i> sp.	FC	16	64	7	29.0	8	37	22.5
Philopotamidae								
<i>Chimarra</i> sp.	FC			1	0.3	6	2	4.0
Glossosomatidae								
<i>Glossosoma</i> sp.	SC			1	0.3	1	14	7.5
Uenoidae								
<i>Neophylax oligius</i>	SC						4	2.0
Coleoptera								
Elmidae								
<i>Ancyronyx</i> sp.	OM			3	1.0		1	0.5
<i>Oulimnius latiusculus</i>	SC			3	1.0		4	2.0
<i>Optioservus ovalis</i>	SC	1			0.3	3	23	13.0
<i>Stenelmis</i> sp.	SC	2	40	15	19.0	24	25	24.5
Ptilodactylidae								
<i>Anchytarsus bicolor</i>	SH						6	3.0

Table 16. Continued

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Diptera								
Tipulidae								
<i>Antocha</i> sp.	GC		2		0.7	2	7	4.5
<i>Dicranota</i> sp.	PR						1	0.5
Culicidae								
<i>Aedes</i> sp.	FC	1			0.3			
Simuliidae	FC	5		1	2.0	1		0.5
Stratiomyiidae								
<i>Odontomyia</i> sp.	GC			1	0.3			

Table 17. RBR – Fall

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Acentrella</i> sp.	GC						1	0.5
<i>Baetis</i> sp.	GC		8	81	29.7	13	5	9.0
Leptophlebiidae								
<i>Paraleptophlebia</i> sp.	GC						1	0.5
Heptageniidae								
<i>Stenonema modestum</i>	SC		1	1	0.7	28	30	29.0
Odonata								
Aeshnidae								
<i>Boyeria vinosa</i>	PR					1		0.5
<i>Ischnura</i> sp.	PR		1		0.3			
Calopterygidae								
<i>Calopteryx maculata</i>	PR	1			0.3			
Plecoptera								
Leuctridae								
<i>Leuctra</i> sp.	SH					6		3.0
Hemiptera								
Veliidae								
<i>Microvelia</i> sp.	PR		2		0.7			
Megaloptera								
Corydalidae								
<i>Nigronia serricornis</i>	PR					1	2	1.5
Trichoptera								
Hydropsychidae								
<i>Cheumatopsyche</i> sp.	FC	410	322	366	366.0	96	13	54.5
<i>Hydropsyche</i> sp.	FC	135	72	227	144.7	19	8	13.5
Philopotamidae								
<i>Chimarra</i> sp.	FC		1	62	21.0	57		28.5
Glossosomatidae								
<i>Glossosoma</i> sp.	SC			1	0.3	4	7	5.5
Coleoptera								
Elmidae								
<i>Oulimnius latiusculus</i>	SC			1	0.3	10	7	8.5
<i>Optioservus ovalis</i>	SC					4	10	7.0
<i>Stenelmis</i> sp.	SC		80	40	40.0	41	9	25.0
Psephenidae								
<i>Psephenus herricki</i>	SC			1	0.3	3		1.5
Diptera								
Tipulidae								
<i>Antocha</i> sp.	GC		4	5	3.0	6		3.0
<i>Tipula</i> sp. 1	SH	1			0.3			
Simuliidae	FC	1			0.3			

Table 18. SAL – Spring

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Baetis</i> sp.	GC					15	22	18.5
Trichoptera								
Hydropsychidae								
<i>Cheumatopsyche</i> sp.	FC	1			0.3	1		0.5
<i>Hydropsyche</i> sp.	FC					1	4	2.5
Philopotamidae								
<i>Dolophilodes</i> sp.	GC						1	0.5
Coleoptera								
Elmidae								
<i>Oulimnius latiusculus</i>	SC					2	1	1.5
Diptera								
Tipulidae								
<i>Tipula</i> sp. 1	SH		2		0.7	1	1	1.0
Culicidae								
<i>Aedes</i> sp.	FC			1	0.3			
Simuliidae	FC						2	1.0
Empidae								
<i>Hemerodromia</i> sp.	PR						1	0.5

Table 19. SAL – Summer

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Baetis</i> sp.	GC						4	2.0
Heptageniidae								
<i>Stenonema modestum</i>	SC					1		0.5
Odonata								
<i>Stylogomphus albistylus</i>	PR					1		0.5
Trichoptera								
Hydropsychidae								
<i>Ceratopsyche bronta</i>	FC					5	13	9.0
<i>Cheumatopsyche</i> sp.	FC			1	0.3	3	5	4.0
<i>Hydropsyche</i> sp.	FC					4	1	2.5
Philopotamidae								
<i>Dolophilodes</i> sp.	GC			1	0.3			
Diptera								
Simuliidae	FC						1	0.5

Table 20. SAL – Fall

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Baetis</i> sp.	GC			3	1.0	16		8.0
Trichoptera								
Hydropsychidae								
<i>Ceratopsyche bronta</i>	FC					26	8	17.0
<i>Cheumatopsyche</i> sp.	FC			4	1.3	25	4	14.5
<i>Hydropsyche</i> sp.	FC	1	1	10	4.0	5		2.5
Philopotamidae								
<i>Dolophilodes</i> sp.	GC			1	0.3			
Diptera								
Tipulidae								
<i>Tipula</i> sp. 1	SH		1		0.3			
Culicidae								
<i>Aedes</i> sp.	FC	1			0.3			

Table 21. SPD – Spring

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Baetis</i> sp.	GC					4	9	6.5
Heptageniidae								
<i>Stenonema modestum</i>	SC						1	0.5
Megaloptera								
Sialidae								
<i>Sialis</i> sp.	PR						1	0.5
Trichoptera								
Hydropsychidae								
<i>Cheumatopsyche</i> sp.	FC			3	1.0	6	8	7.0
<i>Hydropsyche</i> sp.	FC			2	0.7	6		3.0
Diptera								
Tipulidae								
<i>Antocha</i> sp.	GC					6	1	3.5
<i>Tipula</i> sp. 1	SH		2		0.7			
<i>Tipula</i> sp. 2	SH					2		1.0
Simuliidae	FC						3	1.5

Table 22. SPD – Summer

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Baetis</i> sp.	GC			1	0.3	26	17	21.5
Trichoptera								
Hydropsychidae								
<i>Cheumatopsyche</i> sp.	FC		1	1	0.7	2	3	2.5
<i>Hydropsyche</i> sp.	FC		7	9	5.3	3	27	15.0
Hydroptilidae								
<i>Hydroptila</i> sp.	SC						2	1.0
Diptera								
Tipulidae								
<i>Antocha</i> sp.	GC					1		0.5
Ephydriidae	GC			1	0.3			

Table 23. SPD – Fall

Taxa	FFG	HW R1	HW R2	HW R3	HW ALL	MAIN RD	MAIN RU	MAIN ALL
Ephemeroptera								
Baetidae								
<i>Baetis</i> sp.	GC			10	3.3	3	10	6.5
Trichoptera								
Hydropsychidae								
<i>Cheumatopsyche</i> sp.	FC		1	5	2.0	9	11	10.0
<i>Hydropsyche</i> sp.	FC		7	18	8.3	41	35	38.0
Hydroptilidae								
<i>Hydroptila</i> sp.	SC						2	1.0
Diptera								
Tipulidae								
<i>Antocha</i> sp.	GC					10		5.0
<i>Tipula</i> sp. 1	SH		2	1	1.0			
Simuliidae	FC			1	0.3			
Empidae								
<i>Hemerodromia</i> sp.	PR	1			0.3		2	1.0

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