Long-term Spatial and Temporal Variability of Benthic Macroinvertebrate Communities: Implications for Bioassessment of Lotic Systems

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Long-term Spatial and Temporal Variability of Benthic Macroinvertebrate Communities: Implications for Bioassessment of Lotic Systems

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at Virginia Commonwealth University.

by

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Richmond, Virginia
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Abstract

LONG-TERM SPATIAL AND TEMPORAL VARIABILITY OF BENTHIC MACROINVERTEBRATE COMMUNITIES: IMPLICATIONS FOR BIOASSMENT OF LOTIC SYSTEMS

By Eve E. O’Connor, Master of Science

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at Virginia Commonwealth University.

Virginia Commonwealth University, 2010

Thesis director: Dr. Leonard Smock, Director, VCU Rice Center

The structure and composition of benthic macroinvertebrate communities can vary spatially and over time. Spatial and temporal variation along a stream has many implications for population and community dynamics, which may influence bioassessment programs. I examined variability in the benthic community of eight streams within the Polecat Creek, Virginia watershed. These streams vary in size from 1st to 4th order. The streams were sampled once every season for eleven years using standard bioassessment protocols. Macroinvertebrates were sampled from both sediment and submerged wood habitats at each site. The coefficient of variation (CV) was used to quantify among season, among year and among site variability of eight community metrics from both the sediment and wood samples. ANOVAs were calculated using Tukey post-hoc test to determine if there were statistically significant differences in taxonomic richness and mean CV values across seasons, years and sites for both sediment and wood samples. Sorenson’s Quotient of Similarity was used to examine the extent of differences in the taxonomic composition of the macroinvertebrate communities among the four seasons.
over the 11 years of the study and among the 8 sampling sites. A high amount of variability was observed among seasons, sites and years. A wide range of CV values was observed among community metrics, with certain metrics exhibiting low overall mean CV values and others exhibiting very high overall mean CV values. It is important to understand the temporal and spatial variability of macroinvertebrates when planning biomonitoring programs.
Introduction

The structure and composition of benthic macroinvertebrate communities can vary spatially and over time. Discharge, temperature, and riparian zone phenology are a few of many variables that cause the physical characteristics of a stream to change (McElravy 1989), which in turn may elicit a response by macroinvertebrate species and communities. Macroinvertebrate spatial and temporal distribution also varies due to differences in the life history, emergence patterns, and micro- and macro-spatial preferences of species (Reece 2001). Understanding this variation in the structure and composition of macroinvertebrate communities is essential for understanding their ecology and also for their use in water quality regulatory programs, for example the application of the United States Environmental Protection Agency’s Rapid Bioassessment Protocol (Barbour et al. 1999).

Macroinvertebrate communities change on a temporal scale, both seasonally (intra-annually) and over years (inter-annually). Macroinvertebrate life histories are influenced by seasonal changes in, among other factors, food availability, temperature and discharge (Hynes 1972, 1973; Huryn 2000; Robinson 2000). Populations can respond to physical and chemical changes occurring throughout each season in their environment. These changes can have an effect on the entire community structure of a given stream or throughout an entire watershed (Sporka 2006). It is important to be able to distinguish between naturally occurring changes and those that occur due to anthropogenic causes on both seasonal and inter-annual time scales (Wooten 2006).

Little is known about inter-annual changes that occur naturally in macroinvertebrate communities (Hutchinson 1998). Year to year changes may result from many different factors. Changes in hydrology, food availability, timing of emergence, and natural and anthropogenic
disturbances are among the factors that can significantly alter community structure and be reflected in species composition for several years. It is important to consider a stream community on a yearly scale because of the implications for biomonitoring programs. For instance, many biomonitoring programs rely on the use of a reference condition, with the assumption that macroinvertebrate community structure in a reference stream remains consistent over a long period of time (Robinson 2000). The extent of this potential natural variability in macroinvertebrate community structure in reference streams needs to be understood in order to effectively employ biomonitoring data.

The spatial distribution of macroinvertebrates within a watershed is influenced by a variety of factors, including discharge, substrate type and biotic factors such as species composition, predation and competition (Vannote 1980; Murphy 1998). Physical characteristics of streams are dynamic. Sediment, woody debris and other physical features that can be transported can vary with natural changes in the hydrologic regime of a stream (Poff 1997). Individual organisms and thus their communities respond to these changes, and along with random colonization events, can result in distinct variation in the taxonomic composition of macroinvertebrate communities throughout a watershed. In biomonitoring programs, understanding the natural variability in the spatial distribution of macroinvertebrates can assist in the accurate assessment of the streams throughout a watershed.

Long-term studies of macroinvertebrate communities have been important for assessing community stability and the response of a community to physical conditions of a stream (McElravy 1989). The effects of anthropogenic disturbances on macroinvertebrate communities have also been emphasized in long-term studies (McElravy 1989). Wooten et al. (2006) compared a present day community with historical data and concluded that variability in
macroinvertebrates resulted from a variety of changes to a river, including introduction of species, increased flow regulation and improved water quality. They noted that the changes observed in the macroinvertebrate community over the 20 year life of their study should help in the development of bioassessment protocols and that the availability of historical data should aid in the development of metrics that can reflect past river conditions (Wooten 2006).

Most studies of macroinvertebrate variability have been based on short-term data (McElravy et al. 1989, Jackson et al. 2006). However, there are benefits to collecting data over many years. During their seven-year analysis of a California stream, McElravy et al. (1989) examined year to year variability in macroinvertebrates and illustrated the response of the community to changes in hydrologic conditions. They concluded that seasonal changes in discharge were a factor in the observed community changes and that spatial and temporal change in macroinvertebrate communities are difficult to interpret in the short term. An advantage to having long-term data is to observe natural seasonal and year-to-year variation in macroinvertebrates along with natural spatial variation and then to apply this knowledge to planning monitoring programs (McElravy 1989).

The purpose of Rapid Bioassessment studies is to describe water quality and stream channel impairment, identify sources of impairment and characterize reference conditions of lotic systems. These data can then be used to make decisions concerning watershed management and protection (Plafkin et al. 1989, Resh, 1995). To accurately characterize lotic systems, it is assumed that a single sample is sufficiently precise to accurately characterize a system (Hannaford 1995). Because most bioassessment protocols used by regulatory agencies only sample once a year, it is of interest to explore the extent of variability during different seasons to determine which season might exhibit the least natural year to year variability. Examining
Macroinvertebrate communities in long term ecological studies offers insight into temporal variation that naturally occurs in macroinvertebrate communities. By better understanding natural variability, bioassessments can be better used as an evaluation tool.

Anthropogenic effects can have long lasting consequences on aquatic communities that are detectable though bioassessment (Linke 1999). However, without an understanding of the natural variability that occurs in aquatic communities, bioassessment can inaccurately quantify stream health. The objective of this study thus was to document the extent of spatial and temporal variability of macroinvertebrate communities within a watershed. This variability was examined by seasonal sampling of multiple tributaries within a watershed over 11 years. Within each tributary, samples were collected from two habitats: sediment and submerged wood. The variation in macroinvertebrate community-level metrics in a given stream among the four seasons in a given year addressed intra-annual variation. Variation in the metrics, for a given stream and season, over multiple years addressed inter-annual variation. The analysis of spatial variation focused on differences in the macroinvertebrate community in different tributaries during each season over the 11 years of sampling.

**Methods**

*Sampling sites and period:* Sampling of macroinvertebrates was conducted in the Polecat Creek watershed, located in Caroline County in the lower piedmont and upper costal plain physiographic region of Virginia (Fig. 1). This watershed is 12,338 ha and drains into the Mattaponi River, which is a major tributary of the York River. The majority of the watershed is located in the costal plain physiographic region of Virginia, with stream sediments consisting primarily of gravel and sand. Streams in the upper portion of the watershed, located in the Piedmont physiographic region, have sediments with areas of pebble and bedrock along with the
predominant gravel and sand. The land use in the Polecat Creek watershed was 71% forest, 15% agriculture and 14% residential and commercial, with no significant changes in land use throughout this study (Wynn et al. 2005).

The sampling sites for this study consisted of eight 1st to 4th order streams. Each site was sampled seasonally (winter, spring, summer, autumn) over 11 years from 1994 to 2005. Samples were taken within the same 100-m stretch of stream on approximately the same date each year, although occasionally high or no flow periods caused one or more sites to not be sampled in a given year.

*Macroinvertebrate sampling methods*: Macroinvertebrates were sampled from both sediment and submerged wood habitats at each site. Sediment samples were collected in riffles and runs using a 425-μm-mesh D-frame dip net. Macroinvertebrates on wood were collected from the surface of submerged branches and logs, typically about 1 m in length and 2-7 cm in diameter. Samples were preserved in the field using 70% isopropyl alcohol with Rose Bengal dye. In the laboratory, 200 organisms were picked under a stereomicroscope at random from each sample and identified generally to the genus level, though some taxa were grouped at higher levels of classification.

*Data analysis*: Eight metrics, all frequently used in stream bioassessments (Plafkin et al. 1989, Barbour et al. 1999), were used to characterize benthic community structure in each stream. 1. Richness is an indicator of a stream’s ability to support many different species. 2. Percent dominance reflects the extent to which the preponderance of the community consists of one or a few taxa and thus also is an important indicator of community diversity. 3. Percent EPT (Ephemeroptera + Plecoptera + Trichoptera) is a metric often used in bioassessment because these taxa are quite sensitive to perturbations to streams and thus are a good indicator of stream
health. The fourth through eighth metrics consisted of feeding guild metrics, including percent collector gatherers, percent collector filterers, percent predators, percent scrapers and percent piercers), chosen for their ability to illustrate the extent of stability of the trophic structure within a stream.

Data analysis in this study focused on determining the extent of variability in the macroinvertebrate community of the streams of the watershed both temporally and spatially. The coefficient of variation (CV; standard deviation divided by the mean) was used to quantify temporal and spatial variability of the eight community metrics from both the sediment and wood samples at various temporal and spatial scales. Temporal variability included examining variability of the metrics both among the four seasons (intra-annual) and across multiple years (inter-annual). Spatial variability was examined by comparing changes in the metrics across the eight sampling sites.

a. Intra-annual variability: The CV for each metric was calculated for each of the four sampling seasons at each site and year. The mean of these CV values expressed the extent of variation that a metric exhibited during a season within the watershed (i.e. pooling data by season across all sampling sites over all years of the study).

b. Inter-annual variability: The extent to which the macroinvertebrate metrics differed from year to year was determined by calculating the mean CV value for a given metric, pooled across all seasons and sampling sites, within each of the 11 years of sampling. CV values for each metric and for each of the years could then be compared across multiple years.

c. Spatial variability: The extent of variability in the macroinvertebrate metrics at multiple sites within the watershed was examined by comparing the CV of each of the metrics
among the 8 sampling sites. For each sampling site, this variability was expressed as the mean CV for a metric calculated across all sampling seasons and years of the study.

ANOVAs were calculated using SPSS 17. ANOVAs with Tukey post-hoc analyses were calculated to determine if statistically significant differences occurred for mean taxonomic richness values and for mean CV values across seasons, years and sites for both sediment and wood samples. \( P \) values less than 0.05 were considered to be statistically significant.

Whereas use of the coefficient of variation provided information on the variability associated with community level metrics, Sorenson’s Quotient of Similarity was used to examine the extent of differences in the taxonomic composition of the macroinvertebrate communities among the four seasons over the 11 years of the study and among the 8 sampling sites. This value specifically expresses the percent similarity in the taxonomic composition of two communities based on the presence-absence of taxa (Looman 1960) and is calculated as 2 times the number of taxa occurring at both sites divided by the sum of the number of taxa at site x and the number of taxa at site y.

**Results**

*Seasonal variation:* A total of 175 taxa were identified from the sediment samples and 164 taxa from the wood samples. Mean taxonomic richness during each season ranged from 13-18 taxa in the sediment and 14-17 taxa on the wood (Fig. 2). As indicated by an ANOVA followed by Tukey’s post-hoc analysis, richness was lowest in the sediment during the winter (\( p < 0.05 \)). For wood samples, the lowest, but not statistically significant, mean richness values also occurred in the winter.

The relative abundance of taxa within each functional feeding group differed among seasons. Collector-filterers and collector-gatherers consistently were the more abundant feeding
guilds during all seasons both in the sediment and on the wood (Fig. 3a, b). Collector-filterers were more predominant during the winter and least predominant during the autumn for both sediment and wood. Relative abundance of collector-gatherers varied in reverse of the filterers, having greatest relative abundance in the autumn and lowest in the winter. The relative abundance of the other functional feeding groups, although being far lower than that of the collectors, also showed substantial seasonal differences (Fig. 3a, b). There was high similarity in the taxonomic composition of the macroinvertebrate communities that occurred in the sediment and on the wood, as indicated by Sorenson’s Quotient of Similarity values, calculated for each season across all sampling sites and years, all being greater than 80%.

The overall mean coefficient of variation (CV), reflecting the variation associated with all metrics over all sites and years combined, was over 100% for each season for both sediment and wood samples (Fig. 4a). Mean CV values for wood samples had a range of 38% compared to sediment samples that had a range of 23%. ANOVA, followed by Tukey’s post-hoc analysis, indicated no significant difference is CV values among all seasons. Although there were no significant differences among seasons, the greatest mean CV values, for both sediment and wood samples, were observed in the winter and the lowest mean CV values were observed during the spring (Fig. 4a).

There was considerable difference in CV values when comparing the metrics to each other during each season (data pooled from all sampling years and sites; Fig. 4b,c). Whereas this difference among metric occurred, most metrics showed little difference in their CV values across the seasons, showing fairly consistent variability no matter what season sampling was conducted. There also were no obvious differences in the extent of variability in most metrics among seasons between sediment and wood samples.
**Yearly Variation:** Mean taxonomic richness ranged from 13-20 taxa in the sediment and 11-23 taxa on the wood during each year of sampling (Fig. 5). ANOVA indicated that there were significant differences (p < 0.05) in richness among sampling years. Lowest overall richness occurred in 1994 (11 and 13 taxa for the wood and sediment samples, respectively), whereas 2000 (22 and 18 taxa the wood and sediment samples, respectively) and 2003 (23 and 20 taxa the wood and sediment samples, respectively) had the highest overall richness. Tukey’s post-hoc analysis indicated that richness in 2000 and 2003 were significantly different from 1994 (p < 0.05) (Table 1).

The relative abundance of taxa within each functional feeding group differed among years. Collector-gatherers and collector-filterer were the more abundant feeding guilds across all years for both sediment and wood (Fig. 6a, b). The other functional feeding groups had generally low relative abundances that exhibited considerable differences over the years. Sorenson’s Quotient of Similarity, calculated for both sediment and wood samples to show the similarity in taxonomic composition for those substrates over the years, ranged from 40% to 81%. The lowest Sorenson value of 40% occurred for 2002; values for all other years were above 60%.

Mean CV values for wood samples had a greater range at 80% over the sampling years compared to the range for sediment samples at 57% (Fig. 7a). ANOVA indicated no significant difference (p>0.05) in mean CV values occurred among years for either the sediment or wood samples.

There was a considerable difference in CV values when comparing the metrics to each other in a given year (Fig. 7b, c). For sediment samples, richness, dominant taxa, collector-gather, collector-filter and % EPT metrics showed little difference in CV values across all years, indicating consistent variability over the years sampling was conducted (Fig. 7 b). Predator,
scraper and plant piercer metrics on the other hand, had ranges in CV values well above 100%. For wood samples, richness, dominant taxa and collector-gather metrics were the only metrics with ranges of CV values below 100% (Fig. 7c).

Spatial Variation: Mean taxonomic richness at individual sampling sites ranged from 12-19 taxa for sediment samples and 10-19 taxa for wood samples over the 11 years of the study (Fig. 8). The ANOVA indicated that there were significant difference in richness among sites for both the sediment and wood. Lowest overall taxonomic richness occurred at Site A (10 and 12 taxa for wood and sediment, respectively) while sites E and R had the highest overall richness at 18 to 20 taxa associated with the two habitats. Tukey’s post-hoc test indicated that sites E and R were significantly different from site A ($p < 0.05$) (Fig. 8).

The relative abundance of collector-filterers ranged from 18-42% in the sediment and from 8-30% on wood across the sampling sites (Fig. 9a, b). Collector-gatherers ranged in relative abundance from 40-60% and 55-75% in the sediment and on wood, respectively. The relative abundances of the remaining feeding guilds were low and varied among sampling sites. The similarity in taxonomic composition of the macroinvertebrate communities inhabiting the sediment and the wood, as indicated by Sorenson’s Quotient of Similarity, ranged from 69% to 80%.

The mean CV for the sampling sites ranged from 80-130% for the sediment and 79-158% for wood (Fig. 10a). An ANOVA, followed by Tukey’s post-hoc test, indicated no significant difference’s in mean CV values among sites. The range of CV values within a given site was considerable for both the sediment and wood; however most metrics showed little variation among sites (Fig. 10b, c). Only the piercer and scraper metrics for the wood, and those metrics plus predators, had large differences in CV values among the sites.
The overall mean CV values for each metric were calculated by averaging the CV for each metric across all years and sites for both sediment and wood (Fig. 11). Richness, dominant taxa, percent collector-gatherers, collector/filterers and EPTs were the metrics with the lowest mean CV values for the sediment (all below 100%; Fig. 11a). Wood samples had similar results excluding collector/filter mean CV which was 102% (Fig. 11b). Mean CV value for percent scraper and piercer had mean values above 170% indicating a substantial amount of seasonal variation in those feeding guilds (Fig. 11).

**Discussion**

Rapid Bioassessment using macroinvertebrates is a popular method of assessing the health of lotic systems because of its ease of use and low cost (Barbour et al. 1999). Macroinvertebrate community metrics, often used in bioassessment programs, are particularly important for describing the community structure of lotic systems and providing important information about different processes taking place within the system. Certain specialized functional feeding groups such as shredders and piercers are vital to bioassessment due to their sensitivity to pollution compared to other functional feeding groups (Barbour et al. 1999, Rawer-Jost et al. 2000), but many metrics used in bioassessment are known to exhibit a relatively large amount of variability (Alvarez-abria et al 2010, Hutchinson et al 1998, Li et al 2001, McElravy et al 1989, Sporka 2006). It has been well documented that biomonitoring programs must pay close attention to variability in macroinvertebrate communities over time and space (Hutchinson et al 1998, Li et al 2001, McElravy et al 1989, Sporka 2006). Our results suggest that macroinvertebrate community metrics have different degrees of variability through space and time.
**Temporal:**

Mean taxonomic richness is an important measure of diversity within lotic ecosystems because it is an indicator of how many taxa can be supported within a given stream. Our analyses indicated that there were differences among seasons with respect to taxonomic richness for sediment samples, whereas there were no significant differences in richness among seasons for wood samples. There also were significant differences in mean taxonomic richness among years for both sediment and wood. McElravy et al. (1989) observed significant changes in macroinvertebrate community structure over a 7 year period, with significant differences in mean taxonomic richness between wet and dry seasons. They attributed their findings to changes that occurred in discharge and its effects on the substrate-dwelling macroinvertebrates.

Substrate that is colonized by macroinvertebrates is important to take into consideration when examining variability (McElravy et al. 1989). For instance, variability may be substantial in organisms whose substrate can easily move and shift, consequently displacing or moving large numbers of organisms during periods of high flow. This relates to our study in the examination of the variability within community metrics associated with both sediment and wood. We found that 7 out of 12 years resulted in greater taxonomic richness in substrate samples versus wood samples. However, the range of average CV values for richness was 56% in the substrate and 76% for wood, indicating greater variability and thus less consistency for wood versus sediment samples.

Our results show that certain functional feeding groups were consistently more abundant over time than were other functional feeding groups. The least abundant functional feeding groups corresponded with the highest CV values within each season and year. For instance,
shredders, scrappers and piercers exhibited consistently low relative abundances and high variability within each season and year. Although less abundant taxa are important in bioassessment because they can be more sensitive to disturbance, it is important to keep in mind that low abundances during a particular sampling event may be the result of inherent high variability. Cao et al. (1998) observed that when rare taxa were excluded from data analysis, there were significant changes to taxonomic richness. Removing the rare taxa from any study decreased mean taxonomic richness, with the potential loss of valuable information.

Sporaka et al. (2006) observed differences among macroinvertebrate community metrics when comparing seasonal samples and indicated that because many metrics have differing abundances at different times of the year, and therefore exhibit inter-annual variation, it is difficult to select an appropriate sampling season. Sporka et al. (2006) as well as others (McElravy 1989, Hanaford 1995) emphasize the importance of selecting a preferable season for each metric which coincides with when that metric is least variable. This requires more long-term studies specific to the region in question. The large amount of variation within specific metrics observed in our study demonstrates that setting an appropriate time frame for sampling can be challenging and understanding how much individual metrics vary within a watershed is important.

Mean CV values of metrics for yearly sediment and wood samples exhibited a wide range of values, as well as large standard error, indicating a considerable variation among all years. These findings were consistent with several studies addressing yearly variation (e.g., McElravy 1989). Hutchinson et al. (1998) found that macroinvertebrate functional feeding group abundances were significantly different among years following an anthropogenic disturbance. They attributed the observed yearly variability to changes in life-histories caused by the addition
of pesticide chemicals. This illustrates that although variability can occur in response to anthropogenic disturbance, a high level of natural variability may also occur.

We observed no significant difference in mean CV values for metrics among seasons for sediment and wood, whereas there was a wider range of mean CV values among years. Overall, mean CV values of metrics indicated consistently high variation within each season (above 100%). This suggests that there is considerable variability that can occur within the macroinvertebrate community throughout the year. The high overall temporal variation further addresses problems that may be associated with trying to choose the best season for sampling for bioassessment.

McElravy et al. (1989) stress the importance of long-term data sets in reference to biomonitoring programs. Many studies dealing with aquatic macroinvertebrates are short-term studies that comprise at best only a few years (e.g. McElravy 1989, Jackson 2006) and only sample once or twice a year. The consistently high CV values observed within each season of my study are important to take into consideration when establishing a sampling schedule for a biomonitoring program. Also, the inconsistent variability among years supports the need for more studies involving long term datasets to gather more information on yearly changes in communities within different regions. Many biomonitoring programs may sample a given watershed once every year; however, as my results suggest, the site being sampled may change from season to season or even year to year. The high average CV values may illustrate the amount of variation within the watershed for a given season, which is an indicator of how variable macroinvertebrate communities are within the entire watershed.

Although there is a considerable difference in CV values among metrics within a given season or year, each CV value for a specific metric followed no seasonal or yearly pattern and,
for most metrics, the CV for each metric was relatively consistent across seasons and years. Piercers and scrappers had a wider range of CV values among seasons and years; however they also did not exhibit observable seasonal or annual patterns. Due to the extent of variability within piercers and scrappers, these metrics may not make them a reliable metric for bioassessment. It is important to continue to explore how rare taxa influence the results of bioassessment analyses (Cao 1998, Resh 2005).

*Spatial Variation*

Understanding variation that occurs within macroinvertebrate communities among different sites is important in order to accurately interpret results of bioassessment. For this to occur it is imperative to be confident that the structure of the selected stream is comparable to nearby streams. We found significant differences between taxonomic richness and abundances among sites. This is consistent with many other findings (Gebler 2004). For instance, Sandin et al. 2003 observed variability in taxonomic richness among local and regional spatial gradients which they attributed to differences in physical and chemical environmental gradients.

Although not statistically significant, there were differences in mean CV values among sites. A wide range of variability was observed among individual metrics within a given site for both sediment and wood. Gebler (2004) suggested that an individual site may not be able to accurately represent an entire watershed, but in terms of variability of community structure, our selected streams appear to be quite similar. Spatial variation is an important factor to take into consideration when conducting bioassessment as many monitoring programs only choose a single site to represent a given watershed despite variability that can occur in community structure (Hannaford and Resh 1995.)
Li et al. (2001) observed differences in taxonomic richness and EPT taxa between streams. They sampled once a year within a wide geographic region in Oregon. They observed greater variation between stream sites that were further apart from one another and saw more similarity in metrics between streams located close together. They also observed some within site variability in reference to community metrics that they attributed to the rare taxa. They concluded that assemblage metrics do change spatially and that variation does decrease at smaller spatial scales.

Few studies have examined the potential differences of macroinvertebrate communities within a watershed sampled from different habitat types. Gerth and Herlihy (2006) found that macroinvertebrate richness measures differed between the two habitats they sampled. Although there were observed differences in assemblages, they went on to explain that these differences did not hinder the ability of metrics such as EPT richness to classify a site as impaired. However, it can be confusing to distinguish the cause of these variations as to whether they are from habitat differences or from anthropogenic differences within a site. We found some differences between sediment and wood with respect to richness and abundances. It should not be overlooked that changes can occur in substrate types that can affect the overall variability of the organisms which colonize them.

There are studies that suggest that variation can occur at multiple spatial scales (Kerans 1992, Johnson 2004, Gerth 2006). Variation within sites (such as riffles vs. pools) has been observed and can be attributed to distribution patterns of macroinvertebrates, colonization and emigration patterns (Murphy et al. 1998) and differences in physical characteristics of a given reach (Vannote 1980, Kerans 1992). Li et al. (2001), however, suggest that variability can occur within a single site, with sampling area and variability increasing together (Gebler 2004)
**Individual Metrics**

It is also important to examine the amount of variability of individual metrics over spatial and temporal scales. Whether looking at variation seasonally, yearly or between sites, our data had several metrics with consistently high mean CV values. Scrapers, predators, shredders and piercers had the greatest amount of variation among seasons, sites and years. Taxonomic richness, percent dominant taxa and collector-filterers exhibited the least amount of variability for all samples. Our findings were in agreement with Robinson et al. (2000) who noted that taxonomic richness was one of the least variable metrics among seasons, years and sites, as well as between habitat types. They suggest for biomonitoring, it is important to choose metrics that are relatively constant across temporal and spatial scales. Many studies found EPT taxa to be minimally variable at multiple spatial and temporal scales (Feminella 1996, Gebler 2004). In this study, we found EPT taxa to be moderately variable compared to other metrics among years, seasons, and sites, as well as between substrate and wood. The moderate variability was, however, consistent among seasons, years, sites and habitat types. As discussed above, we also observed differences in relative abundances of functional feeding groups and the associated increased variability. The high mean CV values observed at temporal and spatial scales can mask the presence of metrics that exhibit limited variability. Therefore it is important to choose the appropriate metrics for a given area in bioassessment.

Extension of this research should include examining the causes of the variability documented in this study. However, I stress the importance of understanding the variability that can occur within a watershed on a temporal and spatial basis and the need for more long-term data to be applied to the bioassessment of streams and rivers.
Table 1: ANOVA with Tukey post-hoc was calculated to determine if statistically significant differences in mean taxonomic richness occurred between years. Years that were significantly different are listed in the following table for both wood and sediment. Mean taxonomic richness values for sampled years are presented graphically in Figure 5.

<table>
<thead>
<tr>
<th>Sediment</th>
<th>Wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003 * 2005</td>
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</table>
Figure 1. Sample site distribution in the Polecat Creek watershed, Caroline County, Virginia.
Figure 2. Mean (± 1 SE) taxonomic richness during each season, calculated as the mean across all sites for both sediment and wood samples. ANOVA with Tukey’s post-hoc test was conducted to indicate significant differences among seasons ($p < 0.05$). Different capitalized letters indicate significant differences for sediment samples and lower case letters indicate significant differences for wood samples.
Figure 3. Relative abundance of taxa within each functional feeding group in the sediment and on wood during each season, calculated across all sampling sites and seasons. Functional feeding groups are PI = piercer, SC = scraper, PR = predator, CF = collector-filter, CG = collector-gatherer and SH = shredder.
Figure 4. Fig. 4a shows the overall mean (± 1 SE) coefficient of variation (CV) for both sediment and wood samples in each season, calculated by pooling CV values of all metrics across all sampling sites and years. ANOVA with Tukey’s post-hoc test was conducted and indicated no significant differences among seasons. Figs. 4b and 4c show CV values for macroinvertebrate metrics for sediment and wood samples, respectively, by season. Data were pooled across all sampling sites and years. Metrics are % Dom Taxa = % dominant taxa, SH = shredder, CG = collector-gatherer, CF = collector-filter, PR = predator, SC = scraper, PI = piercer and % EPT = % composition of Ephemeroptera + Plecoptera + Trichoptera. Note difference in scale.
Figure 5. Mean (± 1 SE) taxonomic richness for each year for both sediment and wood samples, calculated by pooling data across all sampling seasons and sites. (Results of ANOVAs and Tukey’s Post-hoc analyses provided in Table 1.)
Figure 6: Relative abundance of taxa within each functional feeding group for sediment and wood samples. Functional feeding groups are PI = piercer, SC = scapper, PR = predator, CF = collector filter, CG – collector gatherer and SH = shredder.
Figure 7: Fig 7a shows the overall mean (± 1 SE) coefficient of variation (CV) for both sediment and wood samples for each sampling year, calculated by pooling CV values of all metrics across all sampling sites and years. ANOVA with Tukey’s post-hoc test was conducted and indicated no significant differences among years. Figs. 7b and 7c show CV values for macroinvertebrate metrics in both sediment and wood samples for each year. Data were pooled across all sampling seasons and sites. Metrics are % Dom Taxa = % dominant taxa, SH = shredder, CG – collector gatherer, CF = collector filter, PR = predator, SC = scapper, PI = piercer and % EPT = % composition of Ephemeroptera + Plecoptera + Trichoptera. Note difference in scale for CV values.
Figure 8. Mean (± 1 SE) taxonomic richness at each sampling site, calculated as the mean across all sampling years for both sediment and wood samples. ANOVA with Tukey’s post-hoc test was conducted to indicate significance differences among sites ($p < 0.05$ was significant). Different capitalized letters indicate significance differences for sediment samples and lower case letters indicate significant differences for wood samples.
Figure 9. Relative abundance of taxa within each functional feeding group in sediment and on wood at each sampling site, calculated across all sampling years. Functional feeding groups are PI = piercer, SC = scraper, PR = predator, CF = collector-filterer, CG = collector-gatherer and SH = shredder.
Figure 10: The top graph (a) represents mean (± 1 SE) coefficient of variation (CV) for both sediment and wood samples at each sampling site, calculated by pooling CV values of all metrics across all sampling years. ANOVA with Tukey’s post-hoc test was conducted to indicate no significant differences among sites. Bottom graphs (b and c) represent Coefficient of variation (CV) for each macroinvertebrate metrics in both sediment and wood samples for each site. Data were pooled across all sampling seasons and years. Metrics are % Dom Taxa = % dominant taxa, SH = shredder, CG – collector gatherer, CF = collector filter, PR = predator, SC = scraper, PI = piercer and % EPT = % composition of Ephemeroptera, Plecoptera + Trichoptera. Note difference in scale.
Figure 11: Mean (± 1 SE) percent coefficient of variation (%CV) for each metric in sediment and wood samples. The mean CV was calculated by averaging a given metric’s CV values from all sampling years and sites. The metrics represented in the above graph include % Dom Taxa = % dominant taxa, SH = shredder, CG = collector gatherer, CF = collector filter, PR = predator, SC = scaper, PI = piercer and % EPT = % composition of Ephemeroptera, + Plecoptera + Trichoptera. Note difference in scale.
Literature Cited


Vita

Eve Elizabeth O’Connor was born on October 2, 1981, in Dinwiddie County, Virginia. She graduated from Dinwiddie County High School, Dinwiddie, Virginia in 1999. She received her Bachelor of Science in Biology from Virginia Commonwealth University, Richmond, Virginia in 2003. She received a Master of Teaching in Biology from Virginia Commonwealth University in 2006. Eve taught Biology and Ecology for two years at Atlee High School, Hanover County, Virginia and is currently teaching Biology, Marine Science, Forensic Science and Environmental Science at Northside High School, Tuscaloosa County, Alabama.