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Correlation Between Bioassessments of Macroinvertebrates and Fishes and Natural Land Cover in Virginia Coastal Plain Watersheds

Warren Hunter Smigo
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Correlation between bioassessments of macroinvertebrates and fishes and natural land cover in Virginia Coastal Plain watersheds

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

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Twenty five first through third order streams in the Coastal Plain of Virginia were sampled for benthic macroinvertebrates and fishes to determine whether a predictable relationship between areas of Unfragmented Natural Land Cover (UNLC) and biotic integrity could be established. I hypothesized that as the area of UNLC increased in a watershed at either the whole catchment or riparian scale, biotic indices measuring stream water and habitat quality would increase. Biotic integrity was measured through the scores from the Coastal Plain Macroinvertebrate Index (CPMI) for benthic macroinvertebrates and the VCU Index of Biotic Integrity (IBI) for fishes. Using GIS, the percentage of UNLC at the catchment and riparian scale was calculated for each stream's watershed. Physicochemical parameters, habitat metrics and other

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Abstract

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Unfragmented Natural Land Cover ranged from 7% to 82% at the catchment scale and 10% to 96% in the riparian area. There were no significant correlations between the biological assessment scores for either the benthic macroinvertebrate or the fish communities and UNLC at either scale. Analyses of physicochemical parameters and habitat metrics did show some significant correlations between those variables and biotic metrics. Dissolved oxygen (DO) and pH were positively correlated with the CPMI and DO was positively correlated with the IBI scores. Several habitat metrics were significantly correlated with the CPMI, including pool variability, which was positively correlated with the CPMI, and bank stability, sediment deposition, and channel flow status, which were negatively correlated with the CPMI.

The results of this study indicated that streams with unconstrained channels score significantly lower on the CPMI and have significantly lower DO concentrations than streams with constrained channels despite some streams with unconstrained channels having high percentages of UNLC in the watershed. Although there were other biotic and abiotic factors that may have introduced variability into the study, such as severe weather, beaver activity, and changing land use, it is likely that the CPMI was not an appropriate bioassessment tool for swampy Coastal Plain streams. It is therefore imperative from assessment and management perspectives for state agencies and researchers to develop appropriate bioassessment indices for Coastal Plain streams that have limiting water quality influenced by natural processes.

Introduction

The structure and function of freshwater stream and river ecosystems are linked to the condition and characteristics of the watersheds they drain (Snyder et al. 2003). Currently, the degradation of biological communities in streams and rivers in the United States is mostly caused by non point-source pollution and habitat alteration associated with the cumulative impacts of changing land use in the watershed (Allan and Flecker 1993, Snyder et al. 2003). These impacts may either be due to direct alterations of the riparian area or by run-off into the stream from areas in the watershed. Activities such as agriculture, livestock farming, silviculture, and urban land uses have been associated with runoff of nutrients, fecal bacteria, sediment, nutrients and toxins into streams (Allan and Flecker 1993, Allan 1995, Hunsaker and Levine 1995, Barbour et al. 1996). Urban/ suburban land use has also been associated with increased flow due to impervious surfaces (Snyder et al. 2003). Depending on the proximity to the stream, each land use has the potential to alter the riparian corridor which may directly affect the stream by increasing the potential for erosion, changing the thermal regime and altering its energy base (Allan 1995, Storey and Cowley 1997). It is vital that the relationships between watershed characteristics and the status of the biological communities be understood in order to predict how changes in the watershed can influence and/or degrade biological communities.

With the development of Geographical Information System (GIS) technology, land use/ land cover at various spatial scales has become an important component of predicting and analyzing human impact on the biotic integrity of free flowing freshwater streams (Allan et al. 1997, Johnson and Gage 1997). Biological integrity was defined by Karr and Dudley (1981) as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having species composition, diversity, and functional organization comparable to that of natural habitats of the region". GIS allows quantitative assessment of lateral, longitudinal and vertical characteristics of the landscape as well as land cover and land use information. There have been numerous studies using GIS investigating whether land use/ land cover close to stream channels is a better predictor of water quality than land use over the entire watershed. The results of these studies have reached mixed conclusions.

Catchment-wide land use patterns were more strongly related to biological integrity of fish assemblages than riparian land use patterns in West Virginia (Snyder et al. 2003). The effects of adjacent land uses were detectable at distances up to 4 km for sediments and nutrients in wetlands of southeastern Ontario (Houlahan and Findlay 2004). Conversely, Richards et al. (1997) found that reach-scale properties were a better predictor of macroinvertebrate species traits than catchment scale variables and results from Sponseller et al. (2001) showed that macroinvertebrate indices were most closely related to land cover patterns within a 60 m riparian corridor 200 m upstream from the sampling site. Benthic macroinvertebrate communities changed from a more nutrient enriched fauna to a fauna more indicative of clean water after a stream impaired by pastoral agriculture passed though 600 m of native forest, suggesting the importance of riparian cover (Storey and Cowley 1997). Stream water chemistry, sediment delivery, hydrology and channel alteration were generally related to characteristics at the catchment scale (Hunsaker and Lavine 1995, Allan et al. 1997, Sponseller et al. 2001, Snyder et al. 2003, Houlahan and Findlay 2004) whereas stream temperature, in-stream biological habitat variability, organic matter inputs and substratum characteristics were influenced by land cover patterns in the riparian corridor (Allan et al. 1997, Storey and Crowley 1997, Sponseller et al. 2001).

The conflicting conclusions of these studies are most likely due to several factors. Water quality was determined based on different criteria, including abiotic factors such as nutrients and sediment and biotic factors such as fish or macroinvertebrate communities. Also, the complexities of interactions between abiotic and biotic characteristics of watersheds and aquatic communities often were not incorporated into the studies. The relative magnitude of the effects on biological communities may depend upon topography, geology, types of land use, and spatial arrangement of different land uses within catchments and riparian corridors (Poff 1997, Snyder et al. 2003). In addition, the historical land use in the catchments may not be known, confounding the analysis of present-day information. Whole watershed and riparian land use in the 1950's, compared with land use patterns from 1970 and 1990, was the best predictor of benthic macroinvertebrate and fish biodiversity in North Carolina streams (Harding et al. 1998).

Surficial geology can be an important factor in influencing stream biological communities (Richards et al. 1997). Gradient is a primary determinant of channel morphology (Rosgen 1994); therefore, streams draining high gradient catchments may experience greater disturbance by channel-modifying floods in catchments with higher percentages of impervious surfaces. Fish Index of Biotic Integrity (IBI) scores indicated very poor water quality when about 9% of the high gradient catchments were in urban land use, whereas urban land use had to exceed 21% in low gradient catchments for IBI scores to categorize streams as having very poor water quality (Snyder et al. 2003). Also, biotic communities in high gradient streams are generally adapted to a habitat of well sorted cobble. Increased sediment load from erosion has deleterious effects on riffle dwelling benthic macroinvertebrates by embedding cobble substrate (Roy et al. 2003). Jenkins and Burkhead (1993) suggested that sedimentation is the most widespread and pervasive deleterious factor to fishes in Virginia's high gradient streams. In low gradient streams which have predominately sand, silt or organic substrates, the effects of increased sediment load may not have as significant of an impact on the biotic communities since those communities are pre-adapted to those conditions. Macrophytes and trunks, roots and branches of trees, which provide a more stable substrate than do fine-grained sediment, typically are the more productive habitats for benthic macroinvertebrates in these streams (Benke et al. 1984, Smock et al. 1985, Maxted et al. 2000).

Understanding the spatial influence and magnitude of human disturbances in watersheds is important for the assessment of biotic integrity of streams and rivers. Section 305(b) of the Clean Water Act requires each state to conduct water quality assessments in order to determine whether their streams and rivers are of sufficient quality to meet their designated uses (Barbour et al. 1999). Aquatic biological communities are often used for these assessments. In order to make accurate assessments of water quality, there must be some understanding of the expected composition and structure of the communities in the absence of human influences. This often is accomplished by identifying reference streams or by establishing reference conditions to which the biological community of a stream to be assessed can be compared (Reynoldson et al. 1997, Barbour et al. 1999).

Few streams remain in Virginia that can be considered as pristine due to current and historical logging, with nearly the entire state having been logged between 1880 and 1920 (Yarnell, 1998). Therefore, streams that are "best available" or "least disturbed" are chosen as reference streams for comparison of biological communities. GIS technology has emerged as a useful tool for determining the percentage and types of anthropogenic land use in watersheds. Land use/ land cover criteria have been incorporated in reference stream and reference condition development with the assumption that as anthropogenic land use in the watershed increases, whether at the catchment or riparian level, the biological integrity of streams in the watershed will decrease (Maxted et al. 2000). This concept is especially important for low gradient Coastal Plain streams in Virginia that may not naturally exhibit physicochemical characteristics usually associated with high water quality. Coastal Plain streams are characterized as low gradient and low velocity and often with naturally low pH and dissolved oxygen concentrations (Smock et al.1985). Therefore land use/ land cover information may provide the only practical means of understanding which streams most likely exhibit reference biological communities in these streams.

The objectives of this study were to determine if large areas of unfragmented natural land cover (UNLC), determined using GIS technology at the catchment and riparian level, are positively correlated with biotic integrity in the low gradient streams of the Coastal Plain of Virginia. In addition, I examined if there is a correlation between stream geomorphology, physicochemical attributes, and other biological factors with biotic integrity in these streams. Biological integrity was determined by evaluating fish and benthic macroinvertebrate communities using bioassessment indices calibrated for the Coastal Plain ecoregion of Virginia.

Methods and Materials

Site Selection

Sites on the Coastal Plain of Virginia were chosen based on the extent of riparian and watershed Unfragmented Natural Land Cover (UNLC) to test the hypothesis that there is a positive correlation between UNLC and biotic integrity and whether this relationship is stronger at the riparian or watershed level. Sites were also chosen to include the full geographic range of the Coastal Plain as well as other factors such as Strahler's stream order (1-3) and stream geomorphology (constrained and unconsonstrained channels). Other factors such as stream substrate (organic and sand bottom), beaver activity, and water physicochemical characteristics were not used in site selection but were incorporated into the data analyses.

Areas of UNLC were identified using land cover data derived from satellite imagery of the Coastal Plain ecoregion of Virginia by the Virginia Department of Conservation and Recreation's (DCR) Division of Natural Heritage (Weber and Carter-Lovejoy, 2004). These natural habitats were used to develop the Natural Landscape Assessment (NLA), which is a landscape-scale GIS analysis for identifying, prioritizing and linking natural habitats in Virginia. Natural habitats, which consist of forests, wetlands and barrens greater than 100 acres, were identified as UNLC and visually displayed in a GIS layer. The main premise of the NLA is that large, unfragmented areas of natural vegetation protect terrestrial species that are dependent on interior habitat conditions (Weber and

Carter-Lovejoy, 2004). It was suggested by Weber and Carter-Lovejoy (2004) that aquifers and streams would also be protected by preserving areas of UNLC.

Twenty five sampling sites were chosen based on percentages of UNLC in the watershed, ranging from a high of 82% to a low 7 %. Sites were also chosen to represent a wide geographic range (Fig. 1) including seven of the primary Coastal Plain drainages. ArcMap GIS software provided visual representation of the study area. ArcMap GIS software was used to calculate the percentage of UNLC in each watershed and the percentages of stream length within a watershed that flowed through areas of UNLC. Using GIS software, buffer zones of 60 m and 120 m were also created around each stream and the percent UNLC in each buffer zone was calculated.

Each sampling site consisted of a 100-m stretch of stream that was considered representative of the characteristics of the stream reach. Sites were sampled for benthic macroinvertebrates and fishes using the EPA's Rapid Bioassessment Protocols (Barbour et al. 1999) in 2003 - 2004. Bioassessment scores were derived from established metrics that respond to stream degradation in the Coastal Plain of Virginia. These scores were then compared to reference condition indices, which were developed from multiple reference streams in the Coastal Plain. An assessment of biotic integrity was based on the percent comparability of the sampling site's multimetric score to the reference condition score. Additional data collected for each site included basic water quality data, the EPA's Habitat Assessment for low gradient streams, and other pertinent information such as beaver activity, stream geomorphology and sediment type. The percent comparability scores were then analyzed using Pearson correlation to determine the strength of the relationship among the biological assessment scores, UNLC, and habitat and water quality data for each site.

Benthic Macroinvertebrates

Benthic macroinvertebrates were sampled at each site in the winter to early spring using the multiple habitat sampling approach for low gradient streams developed by the Mid-Atlantic Coastal Streams Workgroup (MACS) (USEPA 1997). Benthic macroinvertebrate diversity and abundance are usually highest in cobble substrates associated with the riffle/run portions of high gradient streams. Streams in the Coastal Plain of Virginia, however, are low gradient and characterized by sand or silt sediments, necessitating use of the MACS sampling protocol. According to the multiple habitat approach, macroinvertebrate samples consisted of jabbing a D-frame dip net with a mesh size of 600 μm 20 times into productive macroinvertebrate habitats. A single jab consisted of thrusting the net into the target habitat over approximately one meter, followed by 2-3 sweeps of the same area to collect dislodged organisms (USEPA 1997). The three major productive habitats of these low gradient streams were woody snags, banks and submerged macrophytes (USEPA 1997). The locations of the 20 jabs were selected according to the proportion of these habitats in the assessment area (USEPA 1997).

The sampling began at the downstream end of the sampling reach and proceeded upstream. The material collected with each jab was emptied into a bucket. The final contents of the bucket were run through a 600-μm mesh sieve to remove excess water and then preserved in isopropyl alcohol (70%) with Rose Bengal stain. In the laboratory, samples were first rinsed through a sieve to remove the preservative and fine sediment. Large material was rinsed and visually inspected for macroinvertebrates. Two hundred macroinvertebrates were then removed from the sample under a stereomicroscope and identified, typically to the genus level except for Chironomidae and Simuliidae which were identified to the family level.

Fishes

Sampling of fishes also used a multi-habitat approach, with habitats being sampled in relative proportion to their representation in the reach. Fishes were collected in the 100 m sampling reach in fall and late spring using a backpack Smith-Root electrofisher and a dip net. Electrofishing has proven to be the most comprehensive and effective method for collecting fish for biomonitoring (Barbour et al. 1999). Fishes were temporarily held in a plastic jug, identified to species, and released. Individuals that were not identifiable in the field were returned to the laboratory for identification.

Data Analysis

Geographical Information System

The National Landscape Assessment (NLA) data layer created by the Virginia DCR was imported into ESRI ArcMap software. Stream data were added through the National Hydrology Dataset (NHD), the Virginia Hydrologic Unit Code (HUC) polygons were added for geographic orientation, and a road layer was added to assist with the analyses. Sampling sites were visually chosen from the ArcMap data in order to capture a range of UNLC, stream orders and geographic distribution. The proximity to roads was also considered due to the difficult conditions associated with traversing Coastal Plain streams and watersheds. Forty sites were originally chosen; however, fifteen of the sites were not accessible due to ponds created by large beaver dams, were on military property or had barbed-wire fencing and posted with no trespassing signs.

After the remaining 25 sites were sampled, the percentage of UNLC in each watershed was calculated as was the percentage of UNLC in a 60-m and 120-m buffer zone area on both sides of the streams. Finally, the percentage of each stream length in each watershed that flowed through areas of UNLC was calculated. The final GIS results were used to determine if correlations between the percentages of UNLC and measures of biotic integrity in streams could be established at the watershed and/or the riparian level.

Biotic Indices

In order to quantify biotic integrity, appropriate indices were chosen for the benthic macroinvertebrate and fish data for the Coastal Plain ecoregion of Virginia. The Coastal Plain Metric Index (CPMI) developed by Maxted et al. (2000) was chosen for the macroinvertebrate data since it was the only published reference condition index for the Mid-Atlantic Coastal Plains. An Index of Biotic Integrity (IBI) that was established by biologists at Virginia Commonwealth University (VCU) (G. C. Garman, personal communication) was chosen for the fish data. The premise of these indices is that they had the ability to distinguish between streams of high biotic integrity and those degraded by anthropogenic activities.

The CPMI consists of five metrics: total taxa, the Hilsenhoff Biotic Index (HBI), the number of Ephemeroptera + Plecoptera + Tricoptera taxa (EPT), percent

Ephemeroptera taxa (%E), and the percent taxa that exhibit clinging behavior (% clingers). The VCU IBI consists of 12 metrics: number of species, abundance, number of darter species, number of sunfish species, number of sucker species, number of intolerant species, percent tolerant individuals, percent omnivorous individuals, percent insectivorous cyprinid individuals, percent piscivorous individuals, percent introduced individuals, and percent individuals with anomalies. The CPMI uses categorical scoring from zero to six in multiples of two for scoring each metric. With five metrics, the total possible score was 30. At each site the sum of the metrics was divided by 30 to get a percent comparability to the reference condition. Narrative bioassessment categories were assigned to the percent comparability to reference scores (Plafkin et al. 1989). Streams were rated as Non-Impaired, Slightly Impaired, Moderately Impaired and Severely Impaired (Table 1). The same procedure was used in scoring of the fish IBI with the exception that the IBI metrics score as a one, three or five with a maximum total score of 60; no narrative bioassessment categories have been developed for this index. In order to determine correlations between UNLC, biotic and abiotic environmental factors, and biotic integrity, the final index scores as well as the individual metrics scores for both indices were used in Pearson correlation analyses. Only the individual metric scores were used to produce the ordinations.

Environmental variables

Environmental data were collected at each site during both sampling events in order to determine what other biotic or abiotic factors might be contributing to any difference found between the UNLC data and biotic integrity. Dissolved oxygen (DO), pH, temperature and conductivity were measured using a Hydrolab multiprobe. The lower DO concentration measured during the warmer sampling period (fall and late spring) was used in the data analyses since biological communities integrate the effects of water quality over time and the amount of DO available in streams may be the limiting factor for survival for biological communities.

Habitat assessment was conducted at each site following the Rapid Bioassessment Protocol III (RBPIII) scoring criteria developed by Barbour et al. (1999) for low gradient streams. Each of the 10 habitat parameters was scored on a scale from zero to 20. Of the four habitat condition categories, scores of zero to 5 are rated as "poor", 6 to 10 are rated as "marginal", 11 to 15 are rated as "suboptimal", and 16 to 20 are rated as "optimal". The ten habitat parameters scored were epifaunal substrate/ available cover, pool substrate characterization, pool variability, sediment deposition, channel flow status, channel alteration, channel sinuosity, bank stability, vegetative protection, and riparian vegetation zone width. With ten parameters, the total possible score was 200. At each site the sum of the metrics was divided by 200 to get a percent comparability to the reference condition. Habitat assessment categories were assigned to the percent comparability scores (Barbour et al. 1999). Streams were rated as Comparable to reference station, Supporting, Partially supporting, or Non-supporting (Table 2). Other environmental data collected included beaver activity, stream substrate type (sand or organic), stream morphological characteristics (constrained or unconstrained channels), stream order, and drainage basin (James, York, etc.).

Statistical analyses

Statistical analyses were performed in SPSS 12.0.2 and PCORD4. Pearson correlation analyses in SPSS were used to determine the correlations between the GIS UNLC data and index scores for both benthic macroinvertebrates and fish. Simple linear regressions were run between significantly correlated ($p<0.05$) physicochemical parameters and habitat metrics and the index scores. The regressions were run using the index scores as the dependent variables and the UNLC data as separate independent variables. ANOVA was used to determine if the index and habitat metrics and the two indices showed significant differences between streams with different substrate and geomorphological characteristics. Box and whisker plots were then produced for the significantly different metric and index scores. Ordinations were run to arrange sites along axes on the basis of the metric data. Nonmetric Multidimentional Scaling (NMS) was chosen as the ordination technique because it avoids the assumption of linear relationships among variables and tends to linearize the relationship between species space distances and environmental space distances (McCune and Grace 2002).

Results

GIS analyses of UNLC

The percentage of UNLC in watersheds ranged from 7% at Walls Run to 82% at UT2 Dragon (Table 3). Buzzard's Branch was removed from the dataset and not used for further analyses since there was no UNLC identified in the watershed as defined by the NLA GIS model. It was decided that UNLC may exist in this watershed (up to 99 acres) but was not identified by the NLA model. Therefore, zero values for UNLC may underestimate the potential quantity of UNLC in the watershed. The percentage of UNLC in the 60-m riparian buffer zones ranged from 12% at Walls Run to 98% at Hazel Swamp. The percentage ranged from 10% at Walls Run to 95% at UT2 Dragon for the 120-m riparian buffer zones. The percentage of stream length flowing through areas of UNLC ranged from 13% at Walls Run to 100% at Hazel Swamp. These percentages were used in the Pearson correlation and ordination analyses reported later in this section.

Benthic Macroinvertebrates

CPMI assessment scores represented as percent comparability to the reference score ranged from 13% (severely impaired) at Timber Branch and Otterdam Swamp to 100% (non-impaired) at Walls Run (Table 4). For the individual metrics, total taxa was highest at Walls Run (30 taxa) and lowest at Bush Mill (7 taxa). The HBI score was lowest at

Bush Mill (5.4) and highest at Otterdam Swamp and Timber Branch (7.4). The number of EPT taxa was highest at Walls Run (15 taxa) and lowest at East Run and Otterdam Swamp (0 taxa). Percent Ephemeroptera was highest at UT1 Dragon (56%), whereas no Ephemeroptera taxa were found at Collins Run, Hazel Swamp, Dymer Creek, East Run and Otterdam Swamp. Finally, Bush Mill had the highest percentage of clingers (87%), whereas no clingers were found at Timber Branch and West Run. Overall, five streams were assessed as non-impaired, seven as slightly impaired, ten as moderately impaired and two as severely impaired.

Fishes

The VCU fish IBI metric scores ranged from 20 to 40, yielding percent comparability to the reference scores ranging from 33% at Timber Branch and East Run to 67% at Nickelberry Swamp (Tables 5a and 5b). No data were collected at Walls Run and Green Swamp due to landowner concerns over electrofishing. Total taxa was highest at Totuskey Creek (12 species) and lowest at Dymer Creek (3 species). Abundance was highest at UT Bush Mill (10.6) and lowest at West Run (0.4). The maximum number of sunfish species (4) was found at Mitchell Hill, Bookers Mill, Totuskey Creek, and UT Upper Chipokes and no sunfish were found at Dymer Creek and Bush Mill. The highest percent of pollution tolerant individuals was found at Dymer Creek (93%) and was lowest at Bookers Mill (2%). The percent of introduced individuals was highest at Mitchell Hill (77%) and Tastine Swamp (72%) and was below 23% at all other sites. The percent of fishes with anomalies was highest at Timber Branch (82%) and Mitchell Hill (77%) and below 18% at all other sites. All of the streams received the lowest possible score (1/5) for two of the IBI metrics: number of intolerant species and percent insectivorous cyprinids. Conversely, 18 of the 22 streams received the highest score (5/5) for percent omnivorous individuals and percent piscivorous individuals.

Environmental Factors

Habitat, categorical variables, and physicochemical data

Results from the habitat assessments indicate that most streams had the potential to support an acceptable, healthy biological community. For the winter and early spring habitat assessments (Table 6), only Hazel Swamp, Bellwood Swamp, and Shiminoe Creek had habitat scores that noted a partially supporting ranking. For the fall and late spring habitat assessments (Table 7), Hazel Swamp and Bush Mill had habitat scores that were partially supporting. Only East Run during the winter and early spring, and Tastine Swamp during the fall and late spring received reference habitat scores. There were no significant differences ($p>0.05$) between the individual habitat metric scores and the total habitat scores between the two sampling events at each site. Only slight variations in the scores were observed, which may have been a factor of beaver activity and damage caused by Hurricane Isabel in September 2003.

Categorical environmental variables used in the data analyses consisted of substrate type, beaver activity, drainage basin, stream order, and geomorphology (Table 8). Substrate type was divided into two classes: sandy substrate and organic substrate streams. Fifteen streams were classified as having a sandy substrate and nine streams had an organic substrate. For the stream geomorphology categories, 15 streams had constrained channels and 12 streams had unconstrained channels, where flow in the channel and floodplain were connected. Ten streams showed evidence of beaver activity during the winter/ early spring sampling and eight during the fall/ late spring sampling. Streams from seven major drainages were sampled: James River (7); Rappahannock River (4); Chowan River (4); Piankatank River (3); Chesapeake Bay (3); York River (2); Potomac River (1). Of the 24 streams, six were 1st order, eleven were 2nd order and seven were 3rd order.

Physicochemical data were measured twice at most streams, once during the macroinvertebrate sampling in the winter and early spring (Table 9) and once during the fish sampling in the fall and late spring (Table 10). Stream conductivity and pH were not significantly different between sampling events at any of the streams ($p>0.05$, paired t-test). DO concentration, however, was significantly different because of the water temperature differences between the two sampling periods.

Data Analysis

Results from the Pearson correlation analyses showed no significant correlation ($p>0.05$) between the UNLC data and the biological integrity metrics for the benthic macroinvertebrates (Table 11) and only the abundance metric was significantly correlated with the UNLC data for the fishes (Table 12). However, several of the physicochemical parameters and habitat metrics were significantly correlated ($p<0.05$) with both the macroinvertebrate and fish indices. Conductivity, DO and pH were positively correlated with the CPMI; only DO was significantly correlated with the IBI values. Although the total RBP habitat scores were not significantly correlated with the CPMI, several habitat metrics were. Pool variability was positively correlated with the

CPMI, whereas sediment deposition, bank stability, and channel flow status were negatively correlated. There were no significant correlations between the total habitat score or any of the metrics and the IBI values. The UNLC data, physicochemical parameters and habitat metrics were also tested for correlations with the individual metrics that make up the CPMI and IBI. There were no obvious trends in these correlations, with both positive and negative significant correlations occurring for a variety of the habitat metrics with both of the macroinvertebrate metrics (Tables 11-12).

Simple linear regressions were run to determine the relationships, and the strengths of these relationships, between the CPMI and physicochemical parameters and habitat metrics. Among the physicochemical parameters, DO had the strongest coefficient of determination (r^2=0.53) with the CPMI (Fig. 2). The regression of CPMI scores on conductivity resulted in a weaker relationship (r^2= 0.33). Stream pH had somewhat of a lower coefficient of determination (r^2=0.23). The regressions for three of the four habitat metrics analyzed had negative correlations with the CPMI, with only pool variability showing a moderate positive relationship with the CPMI (Fig. 3).

One way ANOVA's were run on two of the categorical variables, stream substrate and geomorphology, to determine if significant differences in macroinvertebrate, fishes, physicochemical, and habitat metric scores existed between different stream types. For substrate type, the number of EPT taxa, the total number of macroinvertebrate taxa, and CPMI scores all showed significant differences between organic bottom and sand bottom streams (Fig. 4). For geomorphology, there were significant differences between streams with constrained and unconstrained channels in the number of EPT taxa, HBI, percent Ephemeroptera, DO, sediment deposition, channel flow status, bank stability and the

CPMI (Figs. 5 and 6). The only IBI metric that was significantly different between streams with constrained and unconstrained channels was the number of darter species, in which one species was found at eight constrained streams and one species at one stream with an unconstrained channel. No significant differences were found between substrate type and the IBI metrics.

Ordinations using Nonmetric Multidimentional Scaling (NMS) were performed using the metric data for both the CPMI and the IBI. The main objective of the ordination analyzes was to determine what characteristics sites of certain assessment categories might share to determine what factors might be limiting the potential for higher biological integrity. The initial benthic macroinvertebrate ordination showed a rough gradient of biotic integrity from non-impaired to severely impaired streams (Fig. 7). Some of the moderately impaired sites, however, were distinctly separate from the others (upper right quadrant of Fig. 7). These sites had high numbers of blackflies (Simuliidae). Although this taxon is somewhat pollution tolerant (HBI = 6), blackflies are considered clingers, which is one of the metrics in the CPMI that is associated with better water quality. The sites with relatively low scores for the other metrics, but very high percent clinger scores, clustered together away from the impairment gradient on the ordination. The NMS ordinations were then rerun after removing the percent clinger metric from the CPMI calculation. The new ordination showed a clear impairment gradient (clusters) without the confounding clustering caused by the blackflies and clinger metric (Fig. 8). Percent Ephemeroptera explained 99% of the variability on axis one and total taxa explained 95% of the variability on axis two.

Attempts were made to produce an ordination based on the IBI metric data. The first attempt produced a conclusion by NMS that a useful ordination could not be derived because the data may be weakly structured or that there may be problems with the data, including outliers, that interfere with the analysis. Separate ordinations were seen after removing three different outlier IBI metrics; however, no meaningful ordinations were produced.

The macroinvertebrate ordination minus the percent clinger metric was used as a template by which to visually inspect the categorical data as well as some physicochemical data for trends among the impairment clusters. Sites classified by substrate type showed that no trend between sand or organic substrate existed. The substrate classes are intermixed except that all of the organic substrate sites were impaired to some degree and the five non-impaired sites had sand substrate (Fig. 9). The geomorphology classes also showed no trends. Sites with constrained and unconstrained channels were intermixed except that all of the sites with unconstrained channels were impaired to some degree and the five non-impaired sites had constrained channels (Fig. 10).

The five non-impaired sites and the two severely impaired sites had no beaver activity (Fig. 11) and no patterns were seen regarding stream order (Fig. 12). Physicochemical data were split into categories for visual interpretation on the ordination. Sites were classified based on DO greater than 4 mg/L and less than 4 mg/L (Fig. 13) and pH greater than five and less than five (Fig. 14). The categorical threshold for DO was based on the VADEQ's threshold for DO impairment and the pH categorical threshold was based on the CPMI and pH regression analysis. The visual interpretation of the physicochemical categories showed expected trends with increasing biological integrity with increasing percent DO concentration and pH values.

Discussion

The primary objective of this study was to quantify the relationship between Unfragmented Natural Land Cover (UNLC) and biotic integrity in streams for the Coastal Plain ecoregion of Virginia. Biotic integrity was measured using the CPMI for benthic macroinvertebrates and an IBI developed by VCU biologists for fishes. Since the structure and function of freshwater stream and river ecosystems are linked to the condition and characteristics of the watersheds they drain (Snyder et al. 2000), it was hypothesized that large areas of natural land cover would be positively correlated to biotic integrity. However, from the results of this study, correlations between areas defined as UNLC at the watershed and riparian level, and biotic integrity were not established. The second objective of the study was to determine what effect instream physicochemical parameters and other biotic and abiotic factors may have on biotic integrity. It was concluded that several physicochemical parameters, habitat metrics, stream geomorphology, and substrate type had significant correlations with biotic integrity.

The lack of relationships between land use and biotic integrity and/or assemblage composition for macroinvertebrates and fishes in coastal plain regions of the southeastern United States was observed in several studies. Feminella (2003) found no strong relationship between a number of land-use variables and benthic macroinvertebrate assemblages involving Coastal Plain streams in several southeastern states. In a Coastal Plain watershed in Alabama, Morris et al. (2003) discovered that the depth of fine grained particles on the stream bottom from erosion and deposition from agricultural land use was unable to explain the variability of fish species diversity and Sawyer et al. (2004) showed that water chemistry and instream habitat had a greater relationship to macroinvertebrate and fish community structure than did land use.

Natural land cover and land use characteristics in Coastal Plain watersheds may not be strongly correlated with stream biotic integrity. The effects of anthropogenic land disturbance are likely less pronounced in low gradient streams of the coastal plain for several reasons. First, gradient is a primary determinant of stream channel morphology including the distribution and stability of stream habitat (Rosgen 1994). Low gradient streams of the Coastal Plain may be subjected to fewer disturbances than high gradient streams such as channel modifying floods due to the increased contact time between the surface and subsurface water flows across floodplains (Snyder et al. 2003). Second, sediment inputs, which are well known for the loss of biotic integrity of benthic macroinvertebrates and fishes in high gradient streams (Harding et al. 1998, Plafkin et al. 1989, Jenkins and Burkhead 1993, Barbour et al. 1999, Roy et al. 2003, and Snyder et al. 2003) may not have as much of a deleterious effect on stream biota in low gradient streams. Organisms living in coastal plain streams may either be pre-adapted to sediment input or not affected due to their adaptation for survival on substrate other than the stream bottom. Many fish species common in the Coastal Plain are adapted for fine-grained substrate (Jenkins and Burkhead 1993). Macrophytes and trunks, roots and branches of trees, which provide a more stable substrate than do fine-grained sediment, typically are the more productive habitats for benthic macroinvertebrates in these streams (Benke et al. 1984, Smock et al. 1985, Maxted et al. 2000). Roy et al. (2003) found that benthic macroinvertebrate richness increased in stream bank habitats as a function of disturbance in high gradient streams, which suggests the importance of alternative habitats when riffle quality is affected by sediment inputs. Due to their low gradient characteristics, organisms in Coastal Plain streams may not be as negatively affected by the loss of natural land cover/ increase in human land disturbance at the catchment or riparian level than that of high gradient streams.

Several studies, however, showed evidence that anthropogenic land use can negatively affect biotic integrity in Coastal Plain streams. According to an Invertebrate Community Index (ICI), benthic macroinvertebrates scored significantly lower in streams influenced by urban, pasture, and row crop land uses compared to reference sites in Coastal Plain streams in Alabama (Bennett et al. 2004). Darters were less diverse and abundant in Coastal Plain streams in Mississippi that experienced extreme sediment dynamics as compared to streams with relatively stable substrate (Tipton et al. 2004). A study by King et al. (2005) reached mixed conclusions. Residential and commercial (developed) land cover classes were an important source of stressors to Coastal Plain stream ecosystems based on the benthic macroinvertebrate assemblages, whereas watershed-scale cropland land cover was not as clearly linked to overall stream condition. King et al. (2005) suggested that the developed land cover classes may have had a greater influence on stream biota due to the correlation between developed land and impervious surfaces.

There may have been multiple confounding factors that contributed to the lack of significant correlations between UNLC and biotic integrity in this study. The National Landscape Assessment (NLA), for example, had several limitations. The NLA was based upon land cover derived from Landsat Thematic Mapper imagery with pixel sizes of 30 m by 30 m; therefore, small units in land cover data were not identifiable (Weber and Carter-Lovejoy 2004). Although the acceptable accuracy levels for the NLA were 80% or higher, thousands of pixels are incorrectly identified. The authors suggest that the NLA is not a tool for fine-scale analyses (Weber and Carter-Lovejoy 2004), which could have influenced the accuracy of the 60 m and 120 m riparian buffer data. Also, coniferous forests were included as natural land cover, which is significant since silviculture is prevalent in the coastal plain. Stands of pines of varying age were noticed throughout the study area as well as recent clear-cuts. Without knowing the frequency and magnitude of past logging activity, the expected condition of the biological communities may be difficult to predict (Harding et al. 1998). Current logging activity likely influenced the stream biological community during this study. Hazel Swamp had approximately 69% of its watershed containing UNLC and 100% of the stream flowed through UNLC according to the NLA GIS analysis. However, the land along the entire sampling reach and beyond had been logged right up to the stream since the Landsat Thematic Mapper imagery was acquired in 2000. This site was not removed from the dataset since current logging activities in the other watersheds were not known. A more refined, detailed GIS analysis which recognizes silviculture as an anthropogenic land use may be necessary in order to better characterize the condition of watersheds in the Coastal Plain.

Another factor that may have added variability to the study was stream type. Although the Coastal Plain physiographical province is relatively homogeneous in regards to soils and geology, two types of streams in the Coastal Plain exhibit significant differences for environmental variables and benthic macroinvertebrate communities (Marques 1998). Streams with organic substrate differed from streams with sandy substrate in a number of environmental variables such as dissolved oxygen, conductivity and alkalinity as well as macroinvertebrate metrics including EPT and total taxa richness, HBI values and percent contribution of EPT (Marques 1998). The number of EPT taxa and total taxa richness also differed between these two types of streams in this study. Streams with varying geomorphological characteristics were also found to have significant differences for environmental variables and benthic macroinvertebrate communities between streams with constrained and unconstrained channels. Streams with both organic substrate and unconstrained channels showed a lower potential to support high biotic integrity, which may be due to these streams having characteristics more typical of swamps than streams and therefore are more likely to have lower DO concentrations and pH values.

Almost all sampling was conducted between two weeks and six months after Hurricane Isabel hit Virginia on September 18, 2003. Isabel was the largest hurricane to hit Virginia in 49 years and caused extensive flooding and wind damage in the Coastal Plain. Although disturbances such as floods have been considered the dominant organizing factor in stream ecology (Resh et al. 1988), the effects on the stream biota in the Coastal Plain from such a large disturbance event and the rates of recolonization for benthic macroinvertebrates and fishes were not known. Many of the streams were greatly affected by riparian alteration due to the high winds. Trees that fell into the stream increase the available epifaunal habitat and cover whereas trees that fell away from the stream tended to alter the stream channel by creating large holes left by the uprooted rootball. Streams with unconstrained floodplains seemed less altered by riparian damage and stream channel scouring. Although floods play a vital role in shaping the biological communities, it is possible that the magnitude of the disturbance associated with Hurricane Isabel introduced some variability into the study.

It was also possible that the CPMI was not an appropriate assessment tool for all of the streams in this study. For example, in the development of the CPMI, Maxted et al. (2000) only sampled streams with constrained channels and pH values > 4.5 in order to reduce variability in the data. Therefore, streams with unconstrained channels may not have been properly assessed. The North Carolina Department of the Environment and Natural Resources (NCDENR 2003) developed "swamp stream criteria" for benthic macroinvertebrates to assess the Coastal Plain streams in NC. The development of biological criteria for Coastal Plain streams suggested six different regions grouped along several physical and chemical gradients associated with channel type, soil characteristics, and pH. Such differentiation of streams suggests that the CPMI may have been too general of an index for the Coastal Plain.

Beaver activity and the spatial association of swamps to the sampling sites may have also added variability into the study. Swamps, which are common in Coastal Plain regions, alter the physical and chemical characteristics of streams by changing flow rates, DO concentrations, and sediment characteristics. Therefore, stream characteristics downstream of a swamp may be different from those found upstream and within the swamp. Changes in macroinvertebrate assemblage composition and production between upstream and downstream reaches of a stream can be expected to occur due to the influence of swamp systems (Smock et al. 1985). Beaver dams affect stream habitats by decreasing current and increasing stream depth and width, often creating an environment more indicative of lentic ecosystems. Increased stream temperature and reduced DO concentrations and benthic invertebrate species richness have been observed downstream of beaver ponds (Smith et al. 1991). Snodgrass and Meffe (1998), however, found that beaver ponds actually had a positive effect on fish species richness in low order, blackwater streams in the coastal plain of South Carolina as long as the spatial and temporal dynamics of beaver pond creation and abandonment were maintained. No conclusions concerning the effects of beaver activity on stream biotic integrity were discernable in this study.

Significant correlations that were found in this study included correlations between physicochemical parameters and habitat metrics with biotic integrity. Dissolved oxygen had the strongest positive correlation with biotic integrity for the macroinvertebrates and was the only correlated physicochemical parameter for the fishes. These correlations were not surprising due to the importance of DO to aquatic organisms. In Coastal Plain streams, the lowest annual DO level experienced in a stream may be the limiting environmental factor for survival since fishes and many benthic macroinvertebrate taxa have lifespans of one year or more. It is likely that a stronger correlation between DO with biotic integrity would have been discovered if DO levels were measured during the hottest part of the summer, when stream flows are the lowest and Coastal Plain streams exhibit their lowest annual DO levels.

Stream pH was also significantly correlated with CPMI. The relationship between pH and the CPMI may not be linear but rather a threshold response. Visual interpretation of the regression for these two variables shows a clear decrease in CPMI scores when the pH is at 5 or less. Many Ephemeroptera are sensitive to pH values < 5.0 (Johnson et al. 1993). It is possible that pH may also be a limiting environmental factor for survival.

The regressions for three of the four habitat metrics analyzed had significant negative correlations with the CPMI. As the scores for these metrics increased, the CPMI scores decreased. This may be attributed to low flowing swampy streams with unconstrained channels often having less sediment deposition, a full channel and stable banks; however, these streams are characterized by low pH values and DO concentrations which may explain why the results from this study indicate that streams with unconstrained channels receive lower CPMI scores than streams with constrained channels (7 out of the 9 unconstrained channel streams were assessed as moderately impaired or worse).

Streams in the Coastal Plain of Virginia have received relatively little attention from the scientific and regulatory communities until the last several years. Many of these streams are located in swampy low laying areas with thick extensive under-story brush which makes access difficult. The natural variability and lack of undisturbed reference sites has made accurate water quality assessments a difficult task. The first assessment framework for mid-Atlantic Coastal Plain streams was not published until 2000 (Maxted et al. 2000).

Assessment of freshwater coastal plain streams has proved difficult for the Virginia Department of Environmental Quality (VDEQ 2004). Seven streams listed as impaired due to pH and/or DO criteria violations have been reclassified as “swamp waters” and have been removed from the 303 (d) impaired waters list citing the low pH and DO are due to “natural conditions”. Over 15 more streams are being considered for removal from the 303 (d) list due to natural conditions. It has not yet been determined if streams listed as impaired due to the results of the benthic macroinvertebrate assessments will be removed from the 303 (d) list if the biological communities in these streams are considered “naturally impaired”.

Conclusion

The results of this study, although not conclusive, shed light on the difficulty of determining stream biotic integrity in the Coastal Plain of Virginia using UNLC data. Detailed GIS imagery which can distinguish between different types of land cover as well as land uses should be used. Streams should be grouped based on channel type, soil characteristics and pH and biological assessment tools should be calibrated based on each group. The effects of beaver dams on stream biota should be studied in greater detail. Also, legacy land use should be investigated as well as the spatial orientation of swamps to sampling sites.

The results of this study indicated that streams with unconstrained channels score significantly lower on the CPMI and have significantly lower DO concentrations than streams with constrained channels despite some streams with unconstrained channels having high percentages of UNLC in the watershed. Although there were other biotic and abiotic factors that introduced variability into the study, it is likely that the CPMI was not an appropriate bioassessment tool for swampy Coastal Plain streams. It is therefore imperative from assessment and management perspectives for state agencies and researchers to develop appropriate bioassessment indices for Coastal Plain streams that have limiting water quality influenced by natural processes.

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Tables

Table 1. Bioassessment categories for macroinvertebrate metrics based on percent comparability of a study stream to the reference score (Plafkin et al. 1989).

Percent Comparability to Reference Score	Biological Condition	
	Category	Attributes
≥80%	Non-Impaired	Comparable to the best situation to expected within an ecoregion. Balanced trophic structure. Optimum community structure (composition and dominance) for stream size and habitat quality.
55-79%	Slightly Impaired	Community structure less than expected. Composition (species richness) lower than expected due to loss of intolerant forms. Percent contribution of tolerant forms increases.
20-55%	Moderately Impaired	Fewer species due to loss of most intolerant forms. Reduction in EPT index.
<20%	Severely Impaired	Few species present. If high densities of organisms, then dominated by one or two taxa.

Table 2. Habitat assessment categories for habitat metrics based on percent comparability of a study site to the reference score (Barbour et al. 1999). The categories reflect a stream's apparent potential to support an acceptable, healthy biological community.

Percent Comparability to Reference Score	Assessment Category
>90%	Comparable to reference condition
74-88%	Supporting
60-73%	Partially supporting
<58%	Non-supporting

Table 3. Results of GIS analysis for Unfragmented Natural Land Cover in sample site watersheds. Tot acres UNLC = total acres of UNLC in each watershed; % UNLC = the percentage of each watershed containing UNLC; % 60 m = the percentage of UNLC within a 60 m buffer of each side of each stream; %120 m = the percentage of UNLC within a 120 m buffer of each stream; % length = the percentage of the stream length that flows through areas of UNLC.

Stream Name	% UNLC	% 60 m	% 120 m	% Length
Nickelberry Swamp	45	88	84	90
Collins Run	48	87	82	92
Hazel Swamp	69	98	92	100
Timber Branch	71	84	83	85
Mitchell Hill Creek	74	90	90	90
UT2 Dragon	82	97	95	96
Bailey Branch	41	75	71	78
Dymer Creek	18	29	30	35
Bellwood Swamp	26	54	53	53
UT Bush Mill	29	56	59	55
Bookers Mill	38	65	59	68
Totuskey Creek	41	57	51	58
Coan Mill	60	72	66	73
Bush Mill	43	46	48	45
UT1 Dragon	60	96	93	100
Tastine Swamp	43	61	60	61
Green Swamp	11	18	18	17
UT Upper Chippokes	61	77	73	77
Cypress Swamp	52	67	66	68
West Run	34	53	52	55
East Run	38	61	58	62
Shiminoe Creek	75	78	79	78
Otterdam Swamp	56	63	62	65
Walls Run	7	12	10	13

Table 4. Metric data and associated metric scores used to determine final CPMI score and percent comparibility to the reference condition. TotTax = total number of invertebrate taxa; HBI = Hilsenhoff Biotic Index; EPTTax = number of Ephemeroptera, Plecoptera, and Tricoptera taxa; %Ephem = percent Ephemeroptera taxa; %Cling = percent clinger taxa; Sc = metric scores derived from metric data; CPMISc = Final CPMI score; %Comp = percent comparability of stream scores to reference condition scores; NI = non-impaired; SL = slightly impaired; MI = moderately impaired; SE = severely impaired

													Assessment			
Stream Name	TotTax	HBI	EPTTax	%Ephem	%Cling	TotTaxSc	HBISc	EPTSc	%EphemSc	%ClingSc	CPMISc	%Comp	NI	SL	MI	SE
Nickelberry Swamp	27	6.8	11	14	19	6	2	6	2	4	20	67		*		
Collins Run	13	6.2	1	0	46	2	4	0	0	6	12	40			*	
Hazel Swamp	9	6.1	2	0	50	2	4	0	0	6	12	40			*	
Timber Branch	15	7.3	2	3	0	2	2	0	0	0	4	13				*
Mitchell Hill	19	7.4	7	10	2	4	2	4	2	0	12	40			*	
UT Dragon 2	24	7.1	4	7	1	4	2	2	0	0	8	27			*	
Bailey Branch	25	6.7	12	27	45	4	2	6	6	6	24	80	*			
Dymer Creek	14	7.3	3	0	5	2	2	2	0	0	6	20			*	
Bellwood Swamp	23	6.1	8	19	19	4	4	4	4	2	18	60		*		
UT Bush Mill	17	6.4	4	22	34	4	4	2	4	4	18	60		*		
Bookers Mill	31	6.4	13	14	14	6	4	6	2	2	20	67		*		
Totuskey Creek	25	5.7	10	24	57	4	4	6	4	6	24	80	*			
Coan Mill	21	6.2	10	21	32	4	4	6	4	4	22	73		*		
Bush Mill	7	5.4	3	3	87	0	6	2	0	6	14	47			*	
UT Dragon1	25	6.0	7	56	47	4	4	4	6	6	24	80	*			
Tastine Swamp	19	7.2	7	22	41	4	2	4	4	6	20	67		*		
Green Swamp	12	7.1	3	1	25	2	2	2	0	4	10	33			*	
UT Upper Chipokes	21	7.2	7	13	26	4	2	4	2	4	16	53		*		
Cypress Swamp	9	6.5	2	4	48	2	4	0	0	6	12	40			*	
West Run	13	6.9	2	12	0	2	2	0	2	0	6	20			*	
East Run	12	6.3	0	0	47	2	4	0	0	6	12	40			*	
Schiminoe Creek	21	6.3	8	41	44	4	4	4	6	6	24	80	*			
Otterdam Swamp	13	7.4	0	0	2	2	2	0	0	0	4	13				*
Walls Run	30	5.6	15	25	42	6	6	6	6	6	30	100	*			

Table 5a. Fish metric data used to determine metric scores in Table 5b. TotTax = Total number of fish species; Abun = total number of fishes collected divided by sampling effort and multiplied by 100; Darterspp = number of darter species; Sunfishspp = number of sunfish species; Suckerspp = number of sucker species; Intolspp = number of pollution intolerant species; %Tol = percent of pollution tolerant individuals; %Omniv = percent of omnivorous individuals; %InsctCyprin = percent of insectivorous cyprinid individuals; %Pisc = percent of piscivorous individuals; %intro = percent of introduced individuals; % Anom = percent of individuals with anomalies

Stream Name	TotTax	Abun	Darterspp	Sunfishspp	Suckerspp	Intolspp	%Tol	%Omniv	%InsctCyprin	%Pisc	%Intro	%Anom
Nickelberry Swamp	8	3.2	1	2	1	0	14	9	0	9	5	0
Collins Run	7	1.6	1	1	0	0	35	18	0	0	0	0
Hazel Swamp	5	1.3	0	1	1	0	59	12	0	6	0	0
Timber Branch	4	2	0	1	0	0	82	0	0	6	6	82
Mitchell Hill	9	1.1	1	4	1	0	46	15	0	23	77	77
UT Dragon 2	9	1.4	0	2	1	0	55	10	0	35	5	5
Bailey Branch	8	2.6	1	1	0	0	4	22	0	0	22	7
Dymer Creek	3	9.3	0	0	0	0	93	0	0	0	0	0
Bellwood Swamp	10	6.3	1	2	1	0	26	6	0	5	0	5
UT Bush Mill	7	10.6	1	1	1	0	45	21	0	4	0	5
Bookers Mill	11	5.1	1	4	1	0	2	7	0	9	4	2
Totuskey Creek	12	2.2	1	4	0	1	23	0	13	7	3	0
Coan Mill	6	6.5	1	1	1	0	65	28	0	19	0	4
Bush Mill	7	2.8	1	0	1	0	39	30	0	21	3	0
UT Dragon1	6	1.4	0	1	0	0	20	13	0	47	7	0
Tastine Swamp	4	1.5	0	2	0	0	5.6	0	0	22	72	0
UT Upper Chipokes	8	2.7	0	4	1	0	13	13	0	42	8	17
Cypress Swamp	4	1.6	0	1	0	0	5	5	0	42	0	0
West Run	4	0.4	0	1	0	0	70	0	0	20	10	0
East Run	7	0.8	0	2	1	0	40	10	0	20	20	5
Schiminoe Creek	4	0.5	0	2	0	0	33	0	0	44	0	0
Otterdam Swamp	7	1.6	0	2	1	0	22	4	0	61	0	0

Table 5b. Fish metric data scores used to calculate final IBI score and the percent comparibility to reference condition. TTaxSc = total taxa metric score; AbunSc = abundance metric score; DartsppSc = darter species metric score; SunsppSc = sunfish species metric score; SucksppSc = sucker species metric score; IntolsppSc = intolerant species metric score; %TolSc = percent tolerant individuals metric score; %OmSc = percent omnivorous individuals metric score; %InCypSc = percent insectivorous cyprinid individuals metric score; %PiscSc = percent piscivorous individuals metric score; %IntroSc = percent introduced individuals metric score; %AnomSc = percent individuals with anomalies metric score; IBI = Index of Biotic Integrity final score; %Comp = percent comparability of stream IBI scores to reference condition scores

Stream Name	TTaxSc	AbunSc	DartsppSc	SunsppSc	SucksppSc	IntolsppSc	%TolSc	%OmSc	%InCypSc	%PiscSc	%IntroSc	%AnomSc	IBI	%Comp
Nickelberry Swamp	5	3	3	3	3	1	3	5	1	5	3	5	40	67
Collins Run	3	1	3	1	1	1	1	5	1	1	5	5	28	47
Hazel Swamp	3	1	1	1	3	1	1	5	1	5	5	5	32	53
Timber Branch	1	1	1	1	1	1	1	5	1	5	1	1	20	33
Mitchell Hill	5	1	3	3	3	1	1	5	1	5	1	1	30	50
UT Dragon 2	5	1	1	3	3	1	1	5	1	5	1	1	28	47
Bailey Branch	5	1	3	1	1	1	3	3	1	1	1	1	22	37
Dymer Creek	1	5	1	1	1	1	1	5	1	1	5	5	28	47
Bellwood Swamp	3	5	3	1	1	1	1	5	1	5	5	1	32	53
UT Bush Mill	3	5	3	1	3	1	1	3	1	3	5	1	30	50
Bookers Mill	3	3	3	3	1	1	5	5	1	5	3	5	38	63
Totuskey Creek	5	1	3	3	1	1	3	5	1	5	5	3	36	60
Coan Mill	3	5	3	1	3	1	1	3	1	5	5	3	34	57
Bush Mill	3	1	3	3	1	1	1	3	1	5	3	5	30	50
UT Dragon1	3	1	1	1	1	1	3	5	1	5	1	5	28	47
Tastine Swamp	1	1	1	1	1	1	5	5	1	5	1	5	28	47
UT Upper Chipokes	5	1	1	3	3	1	3	5	1	5	1	1	30	50
Cypress Swamp	3	1	1	1	1	1	5	5	1	5	5	5	34	57
West Run	1	1	1	1	1	1	1	5	1	5	1	5	24	40
East Run	1	1	1	1	1	1	1	5	1	5	1	1	20	33
Schiminoe Creek	1	1	1	3	1	1	1	5	1	5	5	5	30	50
Otterdam Swamp	1	1	1	1	1	1	3	5	1	5	5	5	30	50

Table 6. Habitat metric scores and assessment for winter and early spring. % Comp = percent comparability of stream habitat scores to habitat reference condition

Stream Name	Epifaunal Substrate/ Available Cover	Pool Substrate	Pool Variability	Sediment Deposition	Channel Flow Status	Channel Alteration	Channel Sinuosity	Bank Stability	Vegetative Protection	Riparian Vegetative Width	TOTAL	% Comp	Assessment
Nickelberry Swamp	13	9	13	14	18	18	17	18	18	20	158	79	Supporting
Collins Run	16	14	14	16	18	18	17	20	18	17	168	84	Supporting
Hazel Swamp	15	14	16	15	16	18	18	14	12	10	148	74	Part. Supporting
Timber Branch	14	14	14	18	20	18	17	20	18	18	171	86	Supporting
Mitchell Hill Creek	14	14	17	13	15	18	15	16	14	20	156	78	Supporting
UT2 Dragon	13	14	13	17	20	18	16	20	20	20	171	86	Supporting
Bailey Branch	15	12	17	13	15	18	16	14	14	19	153	77	Supporting
Dymer Creek	16	13	17	15	14	18	18	14	14	18	157	79	Supporting
Bellwood Swamp	11	12	12	15	14	17	14	12	14	18	139	70	Part. Supporting
UT Bush Mill	18	15	18	16	17	19	19	18	18	20	178	89	Supporting
Bookers Mill	17	15	16	15	15	15	14	18	18	20	163	82	Supporting
Totuskey Creek	14	17	17	16	16	14	12	16	20	20	164	82	Supporting
Coan Mill	18	10	16	14	15	18	16	16	16	19	158	79	Supporting
Bush Mill	14	13	16	13	15	18	16	16	16	20	157	79	Supporting
UT1 Dragon	13	14	16	17	19	19	19	20	16	20	173	87	Supporting
Tastine Swamp	18	14	14	17	20	18	17	20	20	20	178	89	Supporting
UT Upper Chippokes	15	14	14	17	20	18	15	20	20	19	172	86	Supporting
Cypress Swamp	17	15	15	18	19	18	16	18	18	17	171	86	Supporting
West Run	17	17	14	19	20	16	17	20	18	20	178	89	Supporting
East Run	18	18	18	18	19	19	18	18	20	18	184	92	Reference
Shiminoe Creek	14	11	14	13	15	13	11	16	16	18	141	71	Part. Supporting
Otterdam Swamp	17	15	18	20	20	18	16	20	18	17	179	89	Supporting

Table 7. Habitat metric scores and assessment for fall and late spring. % Comp = percent comparability of stream habitat scores to habitat reference condition.

Stream Name	Epifaunal Substrate/ Available Cover	Pool Substrate	Pool Variability	Sediment Deposition	Channel Flow Status	Channel Alteration	Channel Sinuosity	Bank Stability	Vegetative Protection	Riparian Vegetative Width	TOTAL	% Comp	Assessment
Nickelberry Swamp	15	10	14	16	18	18	18	18	14	20	161	81	Supporting
Collins Run	9	9	15	18	18	16	14	20	16	18	153	77	Supporting
Hazel Swamp	16	13	17	14	15	18	18	16	10	8	145	73	Part. Supporting
Timber Branch	11	11	14	18	18	16	15	20	18	20	161	81	Supporting
Mitchell Hill Creek	13	13	15	16	19	16	15	16	18	20	161	81	Supporting
UT2 Dragon	10	13	17	17	18	16	10	20	16	20	157	79	Supporting
Bailey Branch	15	12	17	13	14	18	17	13	16	20	155	78	Supporting
Dymer Creek	15	14	15	15	16	17	17	18	18	17	162	81	Supporting
Bellwood Swamp	14	14	18	17	17	17	16	18	18	19	168	84	Supporting
UT Bush Mill	17	14	17	16	15	19	19	18	14	20	169	85	Supporting
Bookers Mill	13	10	15	15	14	18	18	16	16	19	154	77	Supporting
Totuskey Creek	15	15	16	14	13	18	18	12	16	20	157	79	Supporting
Coan Mill	15	10	15	17	18	15	11	20	18	20	159	80	Supporting
Bush Mill	11	11	15	15	17	14	12	10	18	18	141	71	Part. Supporting
UT1 Dragon	14	14	16	15	15	18	17	20	16	20	165	83	Supporting
Tastine Swamp	18	16	17	16	19	18	18	20	18	19	179	90	Reference
Green Swamp	15	10	10	19	19	17	16	20	16	14	156	78	Supporting
UT Upper Chippokes	16	14	16	18	19	16	15	20	18	18	170	85	Supporting
Cypress Swamp	18	16	17	19	18	16	16	19	19	18	176	88	Supporting
West Run	17	17	14	19	20	16	16	20	20	18	177	89	Supporting
East Run	15	18	14	18	19	19	18	20	19	16	176	88	Supporting
Shiminoe Creek	15	10	15	15	18	14	11	16	18	20	152	76	Supporting
Otterdam Swamp	15	15	10	19	20	18	15	20	20	17	169	85	Supporting
Walls Run	17	15	18	10	11	17	17	12	16	20	153	77	Supporting

Table 8. Categorical environmental variables used in data analysis. Substrate = type of material located at the bottom of each stream; Beaver macroinvert = beaver activity noticed during macroinvertebrate sampling; Beaver fish = beaver activity noticed during fish sampling; Geomorphology = stream geomorphology as it relates to its connectivity to the floodplain.

Stream Name	Substrate	Beaver Macroinvert	Beaver Fish	Drainage Basin	Stream Order	Geomorphology
Nickelberry Swamp	sand	yes	yes	Rappahannock	2	constrained
Collins Run	organic	yes		James	1	unconstrained
Hazel Swamp	sand			Chowan	1	constrained
Timber Branch	organic			Piankatank	2	unconstrained
Mitchell Hill Creek	sand	yes		York	2	constrained
UT2 Dragon	sand	yes	yes	Piankatank	1	unconstrained
Bailey Branch	sand			James	2	constrained
Dymer Creek	organic			Ches. Bay	1	constrained
Bellwood Swamp	sand			Rappahannock	3	constrained
UT Bush Mill	organic			Ches Bay	2	constrained
Bookers Mill	sand			Rappahannock	3	constrained
Totuskey Creek	sand			Rappahannock	3	constrained
Coan Mill	organic	yes	yes	Potomac	2	constrained
Bush Mill	sand	yes	yes	Ches. Bay	2	constrained
UT1 Dragon	sand			Piankatank	1	constrained
Tastine Swamp	sand	yes	yes	York	3	unconstrained
Green Swamp	organic			Chowan	1	unconstrained
UT Upper Chippokes	organic	yes	yes	James	2	unconstrained
Cypress Swamp	organic		yes	Chowan	2	unconstrained
West Run	sand	yes	yes	James	3	unconstrained
East Run	sand	yes		James	3	constrained
Shiminoe Creek	sand			James	2	constrained
Otterdam Swamp	organic			Chowan	3	unconstrained
Walls Run	sand			James	2	constrained

Table 9. Physicochemical data collected during winter and early spring. Cond = conductivity (µS/cm); DO = dissolved oxygen (mg/L); Temp = temperature (°C)

Stream name	Date	Cond	DO	pH	Temp
Nickelberry Swamp	1/21/2004	138	13.2	6.2	0.1
Collins Run	3/1/2004	47	11.0	5.7	8.2
Hazel Swamp	1/4/2004	35	7.9	3.7	12.1
Timber Branch	3/1/2004	51	10.1	5.7	11.4
Mitchell Hill Creek	1/21/2004	62	12.9	5.9	0.6
UT2 Dragon	12/28/2003	62	10.6	5.5	3.7
Bailey Branch	1/4/2004	202	9.6	6.9	13.7
Dymer Creek	2/20/2004	87	10.7	5.7	9.0
Bellwood Swamp	4/6/2003	107	9.9	6.4	16.6
UT Bush Mill	2/20/2004	160	10.7	6.4	11.3
Bookers Mill	2/20/2004	71	11.7	5.5	4.8
Totuskey Creek	2/20/2004	96	11.9	5.6	4.3
Coan Mill	2/20/2004	86	11.8	5.5	4.9
Bush Mill	2/20/2004	73	11.9	5.6	6.5
UT1 Dragon	12/28/2003	59	11.1	5.5	5.3
Tastine Swamp	12/28/2003	103	12.6	6.1	4.3
Green Swamp	2/23/2004	86	10.8	5.3	8.8
UT Upper Chippokes	12/21/2003	106	11.8	6.0	6.5
Cypress Swamp	1/4/2004	32	9.4	3.8	11.2
West Run	1/4/2004	40	8.5	5.0	9.4
East Run	12/16/2003	36	11.8	4.8	4.5
Shiminoe Creek	12/16/2003	50	12.2	5.3	3.0
Otterdam Swamp	12/21/2003	29	11.5	3.5	1.7
Walls Run	2/23/2004	135	12.4	6.1	4.1

Table 10. Physicochemical data collected during fall and late spring. Cond = conductivity (μS/cm); DO = dissolved oxygen (mg/L); Temp = temperature (°C)

Stream name	Date	Cond	DO	pH	Temp
Nickelberry Swamp	10/6/2003	135	7.8	6.1	15.4
Collins Run	9/17/2003	46	4.3	4.9	20.9
Hazel Swamp	10/15/2003	43	5.7	3.7	16.3
Timber Branch	10/4/2003	57	4.4	5.3	12.4
Mitchell Hill Creek	10/4/2003	63	8.9	5.6	12.6
UT2 Dragon	10/26/2004	71	5.3	5.4	13.2
Bailey Branch	10/15/2003	196	7.8	6.6	16.2
Dymer Creek	5/6/2004	81	6.7	5.8	15.2
Bellwood Swamp	5/6/2004	90	8.8	6.1	15.7
UT Bush Mill	5/6/2004	148	8.3	6.6	21.1
Bookers Mill	5/6/2004	63	9.2	5.8	16.6
Totuskey Creek	5/6/2004	75	9.0	5.8	17.3
Coan Mill	10/23/2003	93	8.7	5.5	10.8
Bush Mill	10/23/2003	89	7.0	5.7	11.1
UT1 Dragon	10/26/2003	70	7.4	5.4	13.8
Tastine Swamp	10/6/2003	115	5.6	5.8	14.7
UT Upper Chippokes	10/10/2003	158	6.0	6.2	17.3
Cypress Swamp	10/10/2003	34	3.5	3.8	18.0
West Run	9/17/2003	35	3.3	4.7	19.1
East Run	9/17/2003	41	4.8	4.7	18.7
Shiminoe Creek	9/30/2003	65	7.8	5.7	14.7
Otterdam Swamp	10/15/2003	38	3.0	4.6	17.2

Table 11. Pearson correlation matrix for CPMI and associated metrics correlated with physicochemical parameters across all sites. Bolded values are significantly correlated ($p<0.05$). CPMI = Coastal Plain Macroinvertebrate Index; EPT = number of Ephemeroptera, Plecoptera, and Tricoptera taxa; % E = percent Ephemeroptera individuals; HBI = Hilsenoff Biotic Index

	CPMI	Total Taxa	EPT	% E	% Clingers	HBI
% UNLC area	0.18	0.14	0.05	-0.02	0.13	-0.23
% UNLC in 60 m buffer	0.06	0.08	-0.09	0.14	-0.08	0.15
% UNLC in 120 m buffer	0.10	0.04	-0.14	0.14	-0.09	0.18
% stream length in UNLC	0.21	0.08	-0.09	0.14	-0.08	0.15
pH	**0.48**	**0.57**	**0.58**	0.40	0.00	-0.04
DO	**0.73**	**0.66**	**0.78**	**0.50**	0.16	-0.37
Conductivity	**0.57**	**0.53**	**0.64**	0.35	0.12	-0.08
Total RBP habitat score	0.21	-0.09	-0.25	0.02	-0.35	**0.45**
Epifaunal substrate	0.28	0.01	0.18	0.23	0.08	0.04
Pool substrate	0.12	-0.16	-0.23	-0.01	-0.03	0.06
Pool variability	**0.51**	0.35	**0.41**	0.38	0.32	**-0.42**
Sediment deposition	**-0.71**	**-0.53**	**-0.69**	**-0.46**	-0.39	**0.51**
Channel flow status	**-0.64**	-0.51	**-0.61**	-0.39	-0.37	**0.61**
Channel alteration	0.11	0.22	0.07	0.04	-0.07	0.07
Channel sinuosity	0.16	0.11	0.13	0.04	0.04	-0.02
Bank stability	**-0.49**	-0.21	**-0.48**	-0.17	**-0.54**	**0.59**
Vegetative protection	-0.29	-0.18	-0.22	-0.08	-0.24	0.30
Riparian vegetation	0.39	**0.59**	**0.49**	**0.51**	-0.14	0.00

Table 12. Pearson correlation matrix for the IBI and associated metrics correlated with physicochemical parameters across all sites. Bolded values are significantly correlated ($p<0.05$). IBI = Index of Biotic Integrity; TotalTax = Total number of fish species; Abun = total number of fishes collected divided by sampling effort and multiplied by 100; Darterspp = number of darter species; Sunfishspp = number of sunfish species; Suckerspp = number of sucker species; Intolspp = number of pollution intolerant species; %Tol = percent of pollution tolerant species; %Omniv = percent of omniverous individuals; %InsectCyprin = percent of insectivorous cyprinid individuals; %Pisc = percent piscivorous individuals; %Intro = percent introduced individuals; %Anom = percent individuals with anomolies

	IBI	TotTax	Abun	Darterspp	Sunfishspp	Suckersspp	Intolspp	%Tol	%Omniv	%InsctCyprin	%Pisc	%Intro	%Anom
% UNLC area	-0.05	-0.07	**-0.57**	-0.31	0.21	0.10	-0.12	0.07	0.05	-0.12	**0.50**	0.13	**0.43**
% UNLC 60m buffer	0.03	0.10	**-0.51**	-0.08	0.20	0.10	-0.17	-0.13	0.15	-0.17	0.21	0.11	0.30
% UNLC 120m buffer	-0.01	0.04	**-0.50**	-0.12	0.15	0.10	-0.23	-0.10	0.15	-0.23	0.25	0.14	0.35
% stream length UNLC	0.02	0.08	**-0.50**	-0.09	0.17	0.05	-0.17	-0.12	0.14	-0.17	0.18	0.09	0.28
pH	0.08	-0.23	**0.50**	**0.51**	0.23	0.08	0.10	-0.19	0.22	0.10	-0.29	0.15	0.07
DO	**0.47**	-0.09	**0.51**	**0.69**	0.38	0.23	0.32	-0.23	0.26	0.32	-0.40	0.05	0.03
Conductivity	0.05	-0.06	0.39	0.38	0.06	0.10	-0.04	-0.33	0.38	-0.04	-0.26	0.13	-0.06
Total RBP habitat score	-0.34	-0.14	-0.15	-0.37	0.02	-0.07	-0.01	-0.04	-0.12	-0.01	0.29	0.13	0.00
Epifaunal substrate	-0.14	-0.34	0.17	-0.15	-0.12	-0.04	-0.15	0.03	0.06	-0.15	0.02	0.12	-0.22
Pool substrate	-0.35	0.09	-0.25	-0.31	0.22	-0.12	0.33	0.03	-0.30	0.33	0.09	0.10	0.02
Pool variability	-0.13	0.06	0.21	0.10	-0.02	0.11	0.20	0.06	0.26	0.20	0.00	0.08	-0.01
Sediment deposition	-0.32	-0.22	-0.25	**-0.62**	-0.01	-0.15	0.02	0.04	**-0.47**	0.02	0.40	-0.12	-0.04
Channel flow status	-0.33	-0.25	**-0.48**	**-0.60**	0.02	-0.13	-0.12	-0.09	-0.30	-0.12	**0.47**	0.08	0.06
Channel alteration	-0.32	-0.21	0.17	-0.09	-0.41	0.27	**-0.49**	0.13	**0.46**	**-0.49**	-0.01	0.16	0.15
Channel sinuosity	-0.36	**-0.43**	0.20	-0.23	**-0.58**	0.04	-0.45	0.31	0.25	**-0.45**	-0.16	0.03	-0.02
Bank stability	-0.19	-0.16	-0.38	-0.40	0.11	-0.13	-0.13	-0.11	-0.17	-0.13	**0.46**	0.08	0.09
Vegetative protection	-0.03	0.17	-0.21	-0.19	0.35	-0.04	0.27	-0.27	-0.26	0.27	0.28	0.02	-0.11
Riparian vegetation	0.03	0.32	0.15	0.32	0.26	-0.07	0.15	-0.20	0.07	0.15	0.08	0.27	0.09

Figures

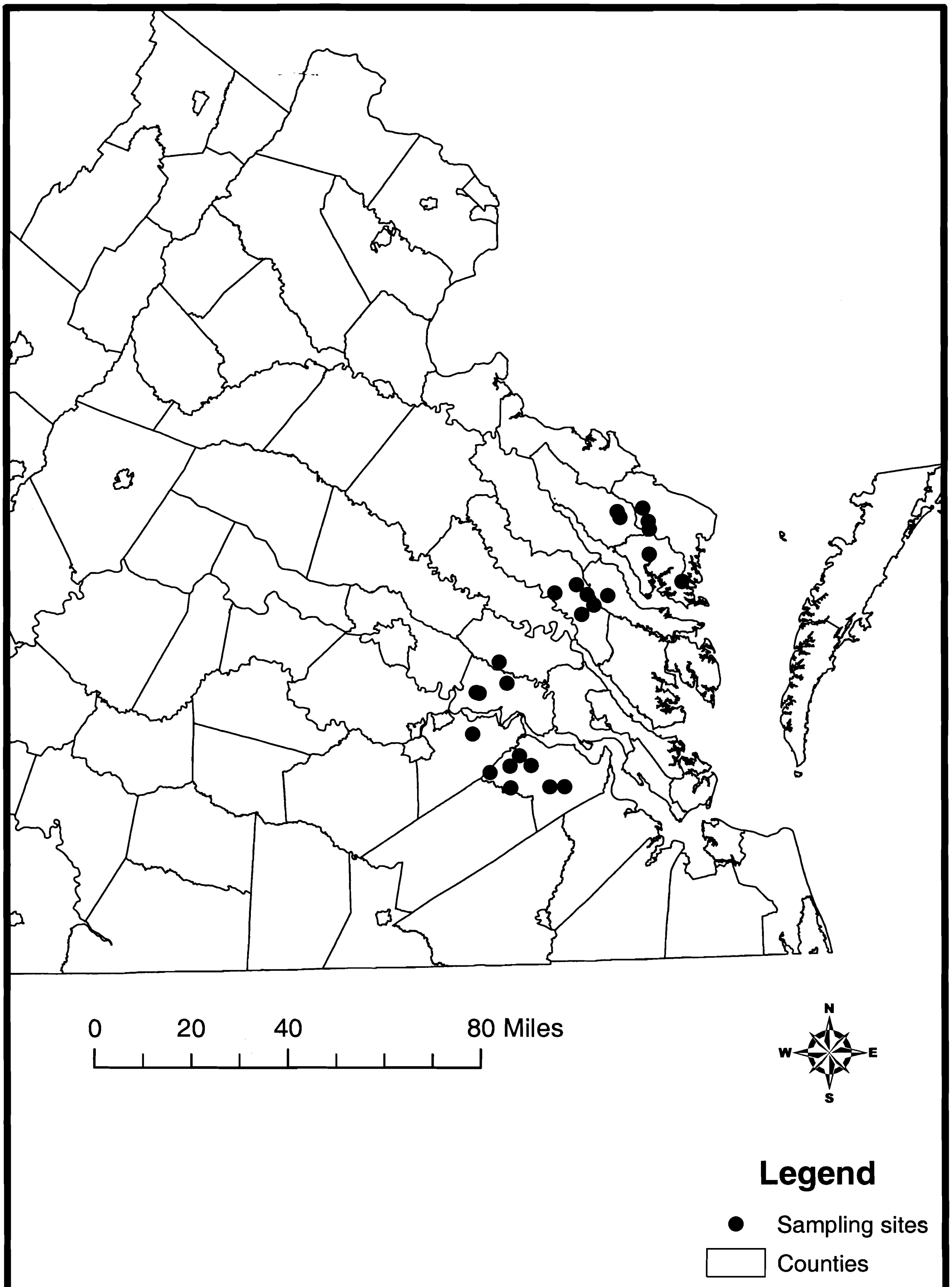

Figure 1. Location of sampling sites in the Coastal Plain of Virginia

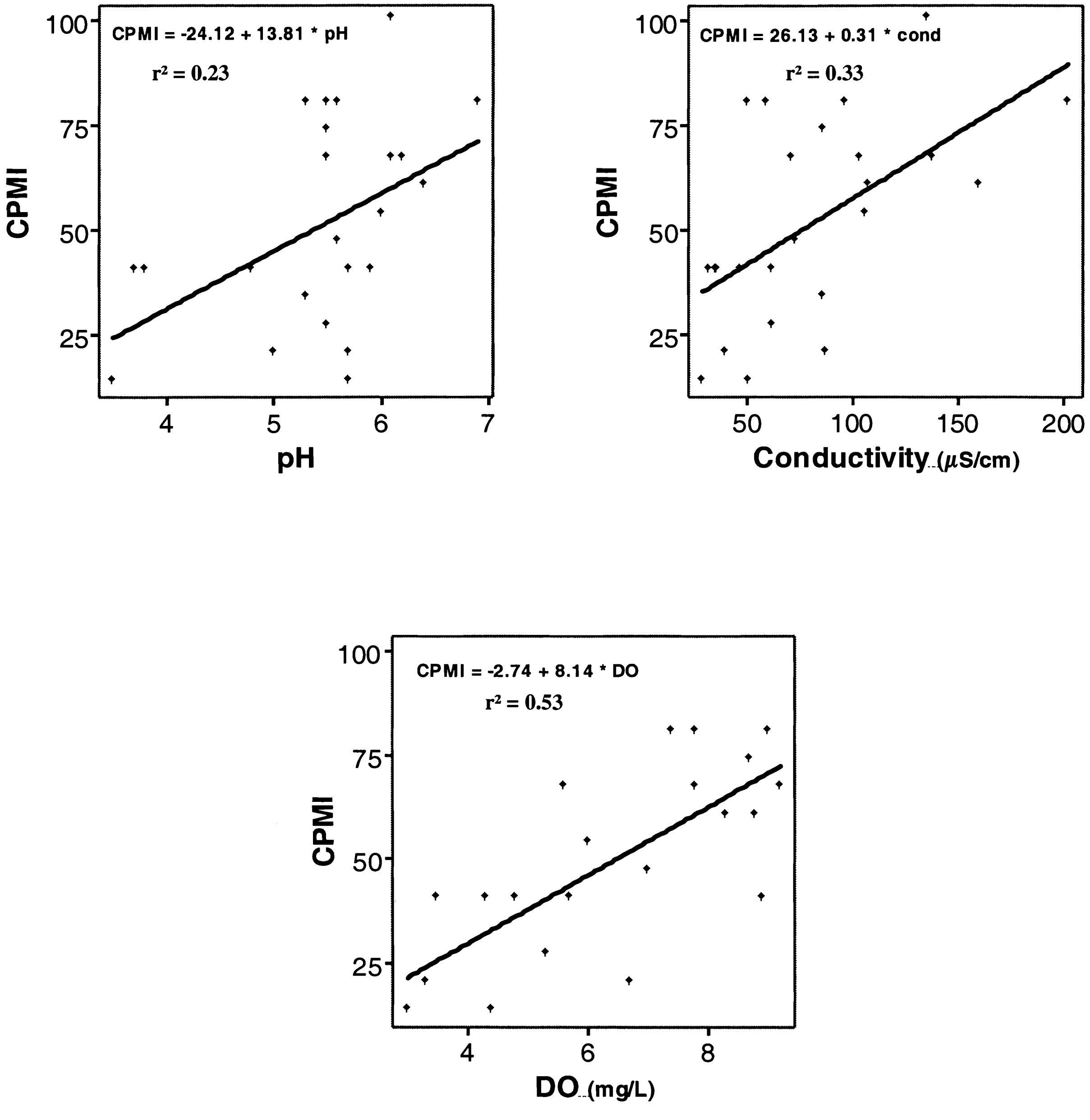

Figure 2. Simple linear regressions and associated r^2 values of the relationships between physicochemical parameters and the CPMI.

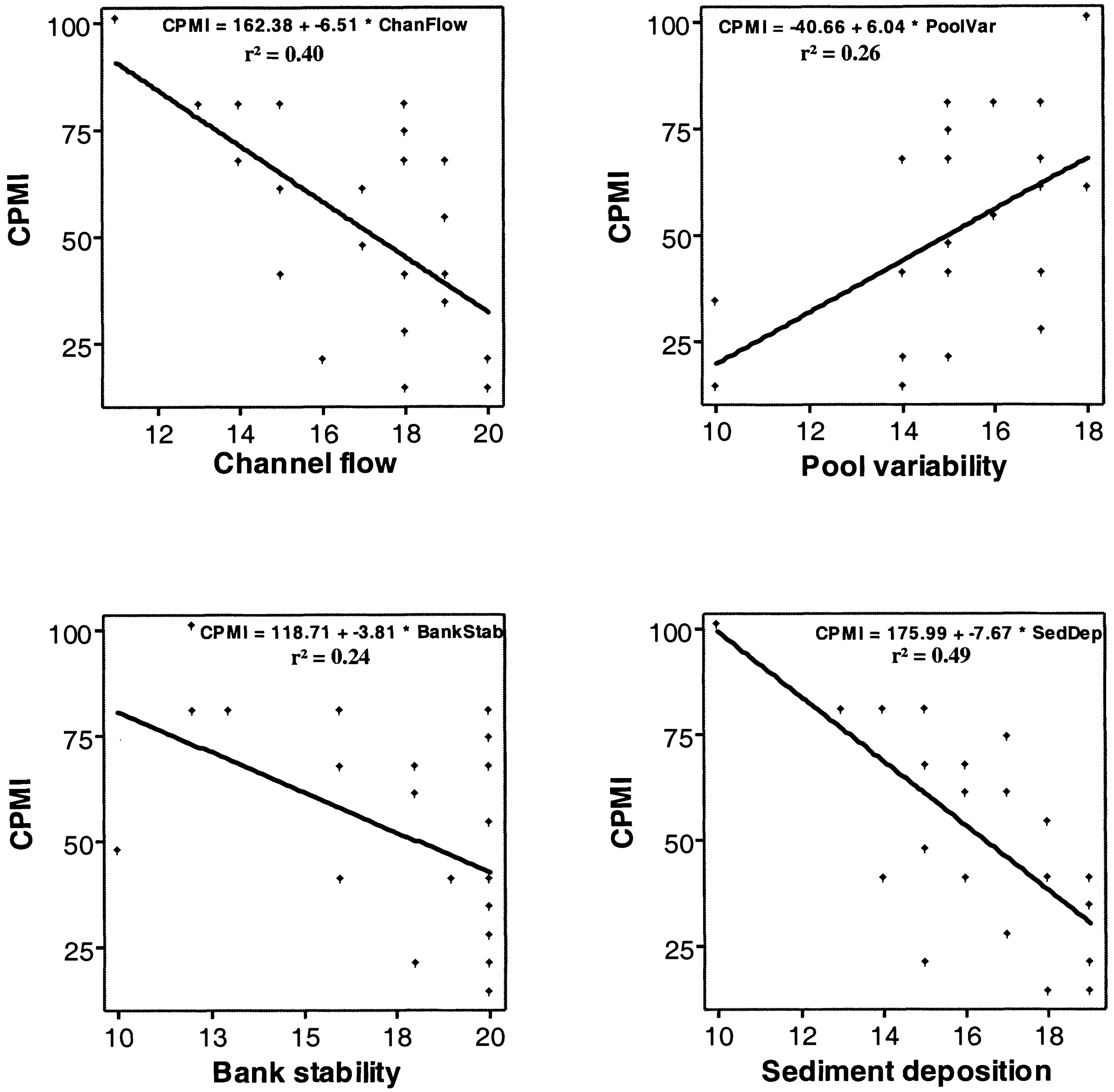

Figure 3. Simple linear regressions and associated r^2values of the relationships between habitat metrics and the CPMI.

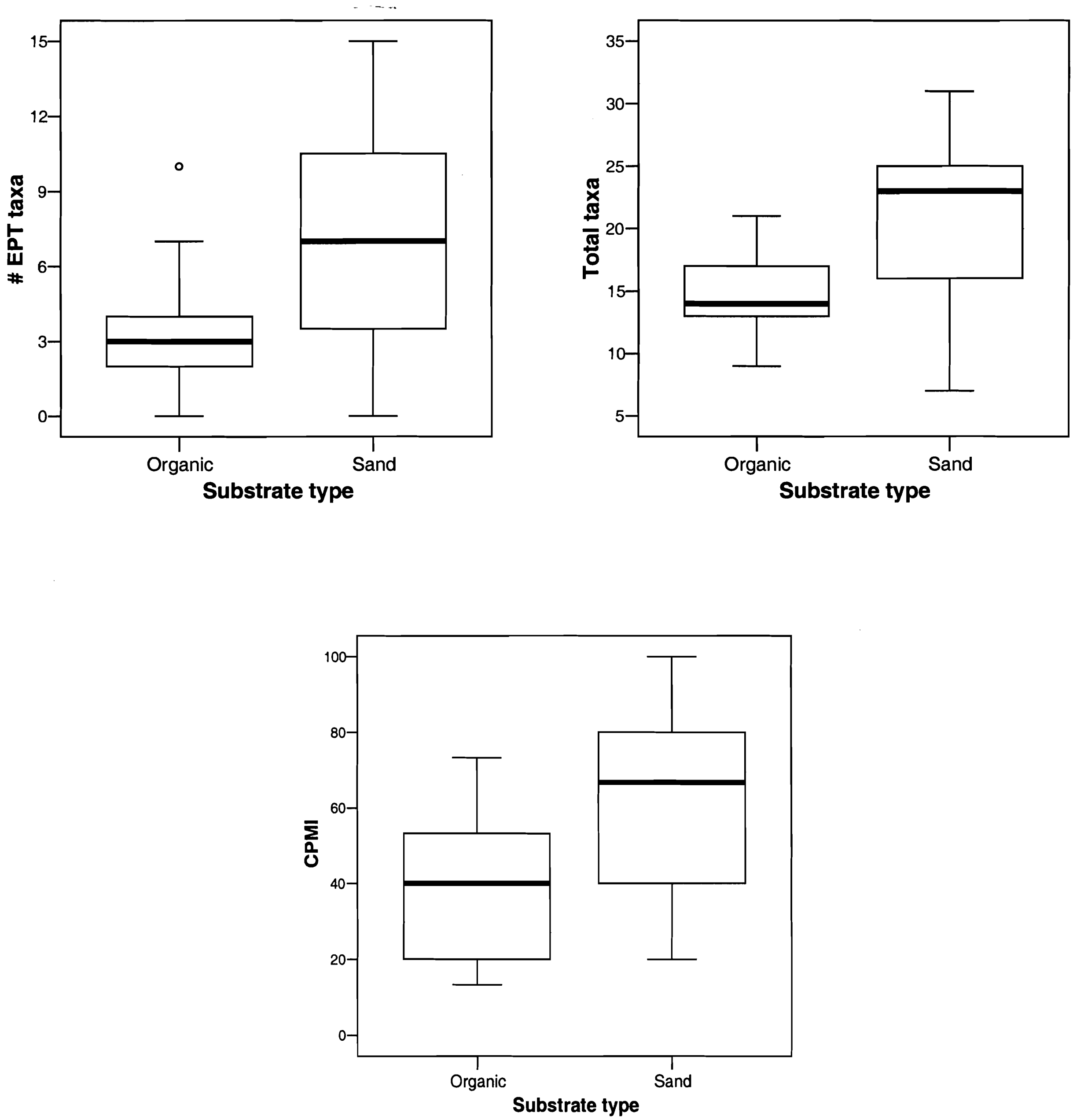

Figure 4. Box and whisker plots for significantly different (ANOVA, $p<0.05$) macroinvertebrate metrics and the CPMI for streams with organic and sand substrate. The CPMI values are percent comparability to the reference condition. Shown are the median, 75th and 25th percentiles, and the range of scores.

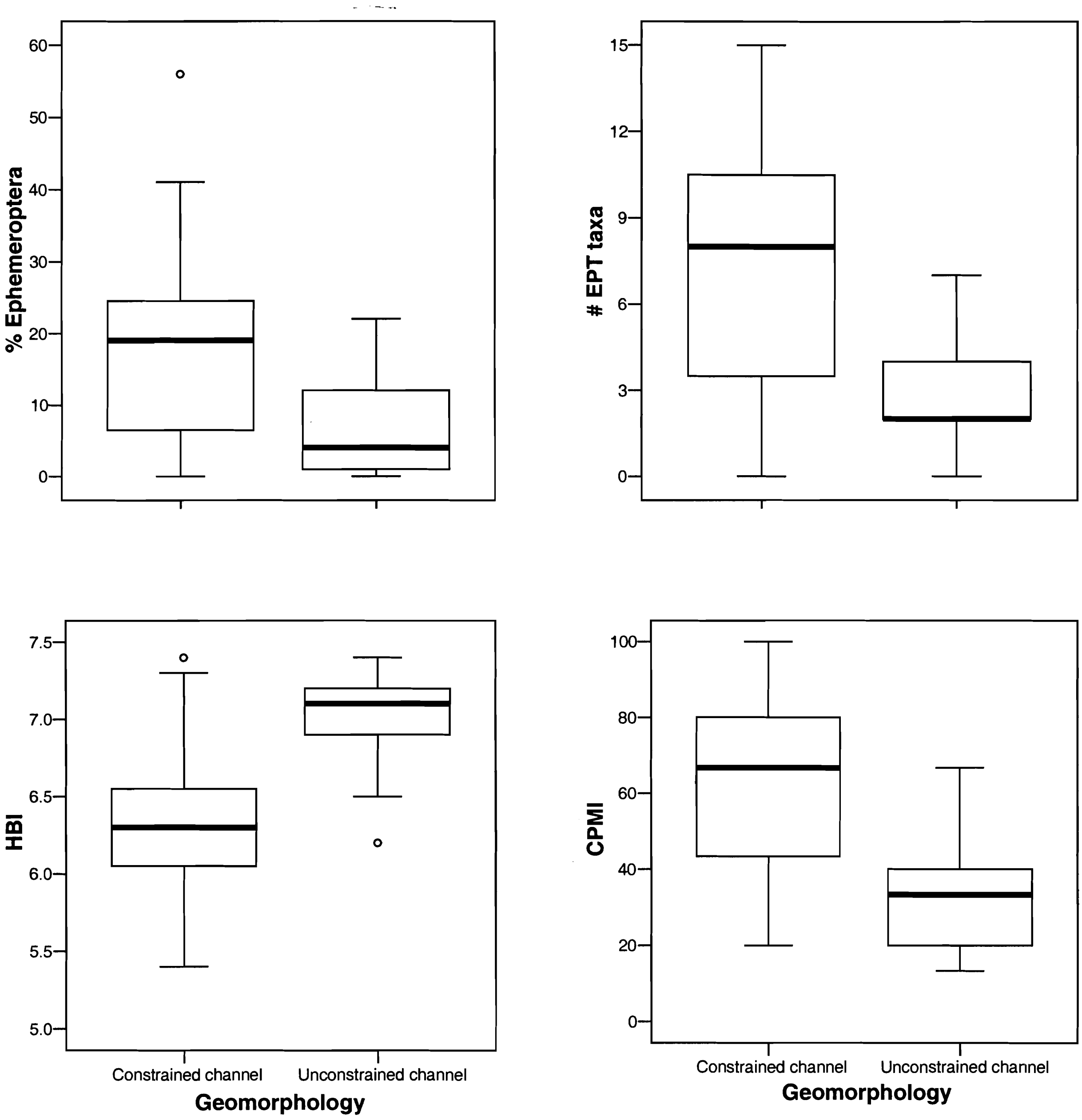

Figure 5. Box and whisker plots for significantly different (ANOVA, $p<0.05$) macroinvertebrate metrics and the CPMI for streams with constrained and unconstrained channels. The CPMI values are percent comparability to the reference condition. Shown are the median, 75th and 25th percentiles, and the range of scores.

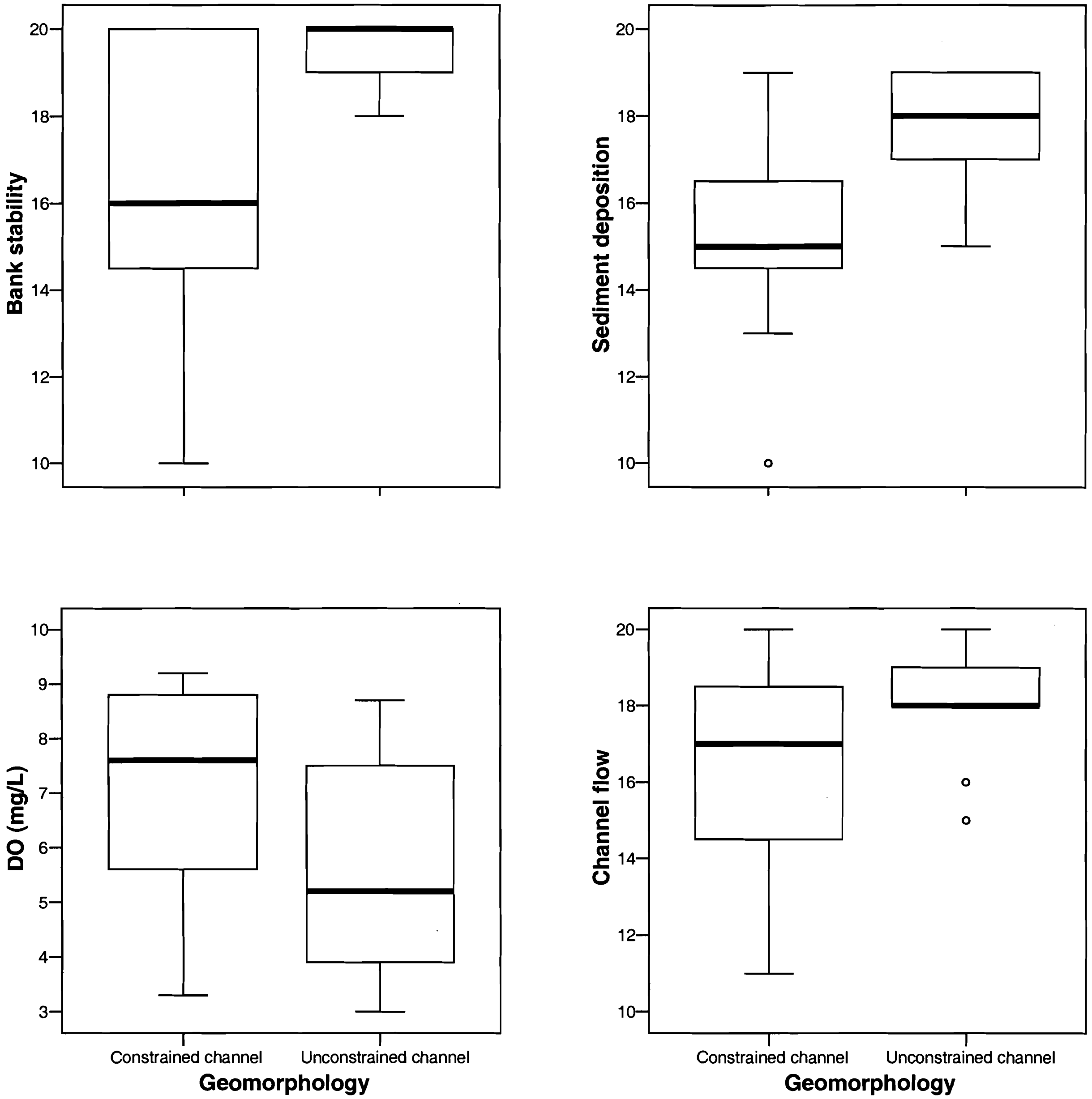

Figure 6. Box and whisker plots for significantly different (ANOVA, $p<0.05$) habitat metrics and DO for streams with constrained and unconstrained channels. Shown are the median, 75th and 25th percentiles, and the range of scores.

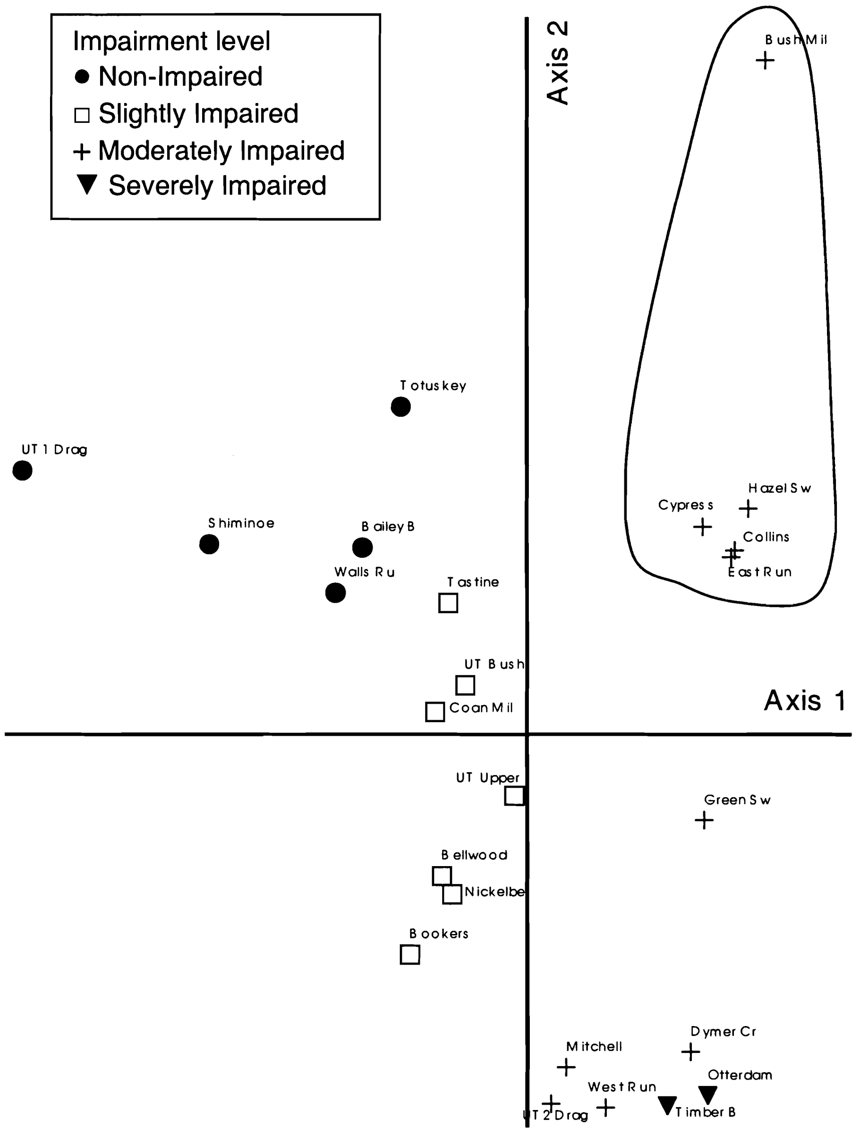

Figure 7. Classification of streams by impairment level based on NMS ordination derived from all CPMI metrics.

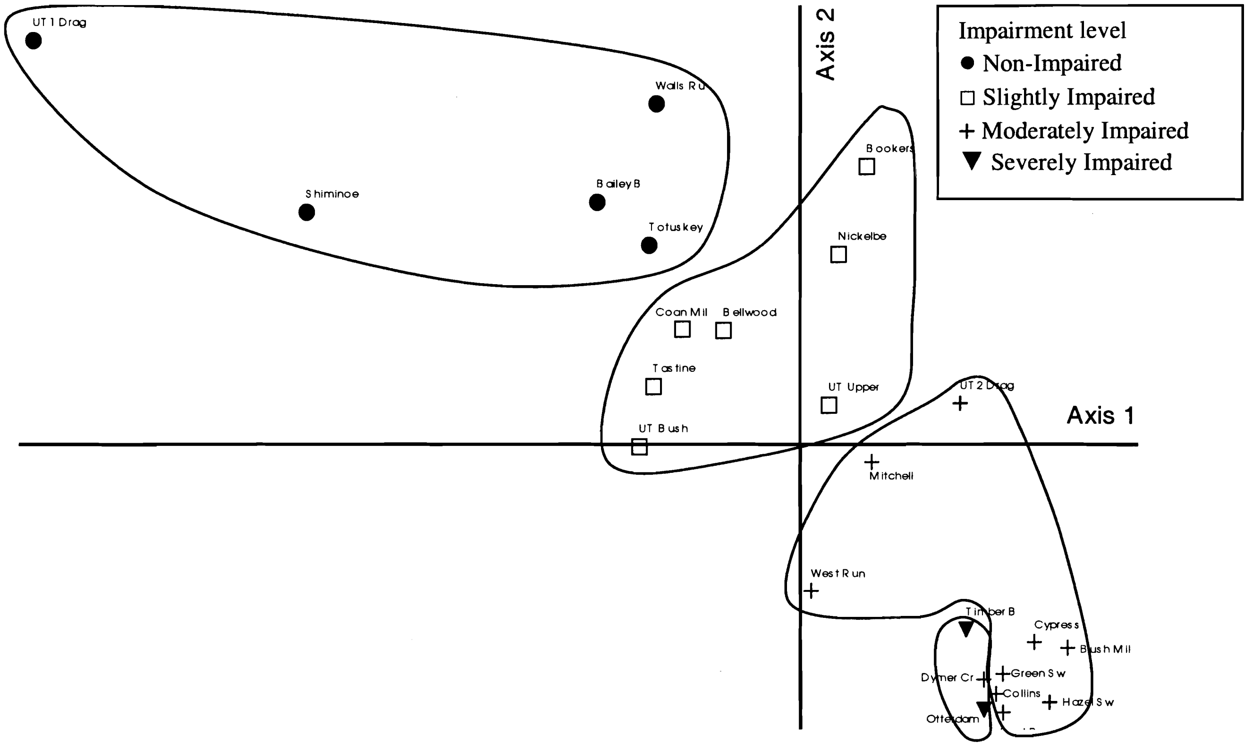

Figure 8. Classification of streams by impairment level based on NMS ordination derived from CPMI metrics less percent clingers.

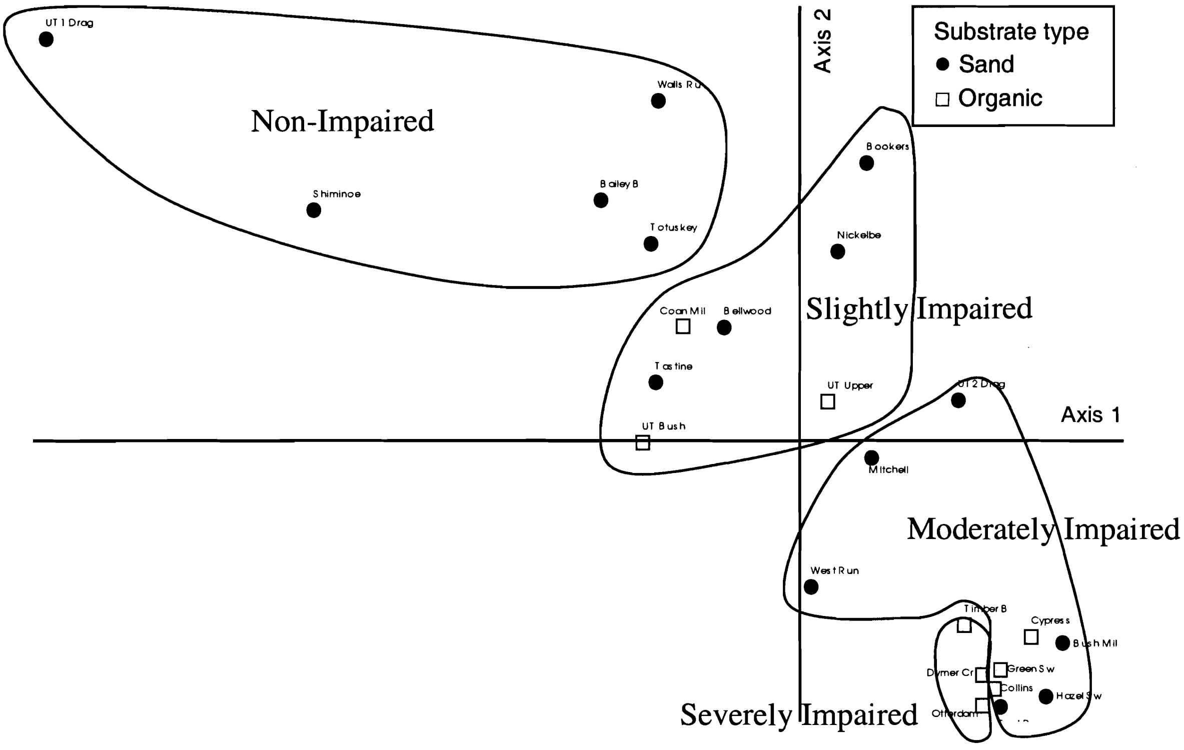

Figure 9. Classification of streams by impairment level based on NMS ordination derived from CPMI metrics less percent clingers. Streams are categorized by substrate type.

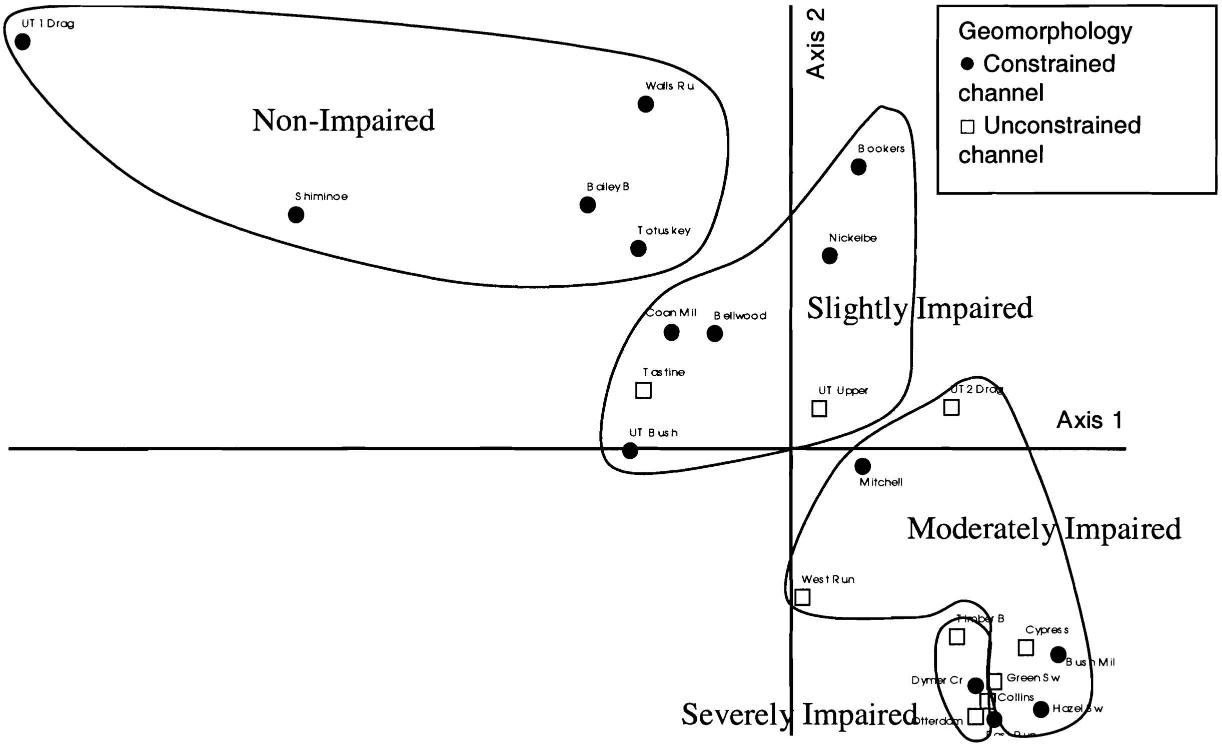

Figure 10. Classification of streams by impairment level based on NMS ordination derived from CPMI metrics less percent clingers. Streams are categorized by geomorphological characteristics

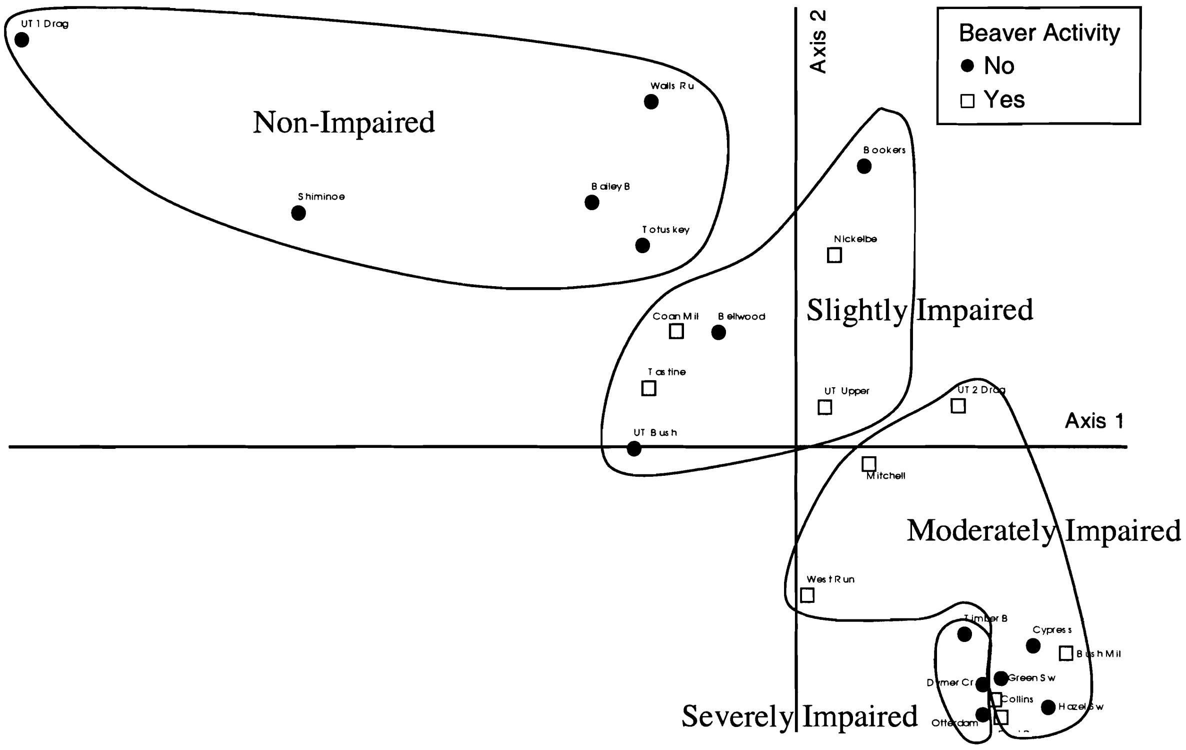

Figure 11. Classification of streams by impairment level based on NMS ordination derived from CPMI metrics less percent clingers. Streams are categorized by beaver activity.

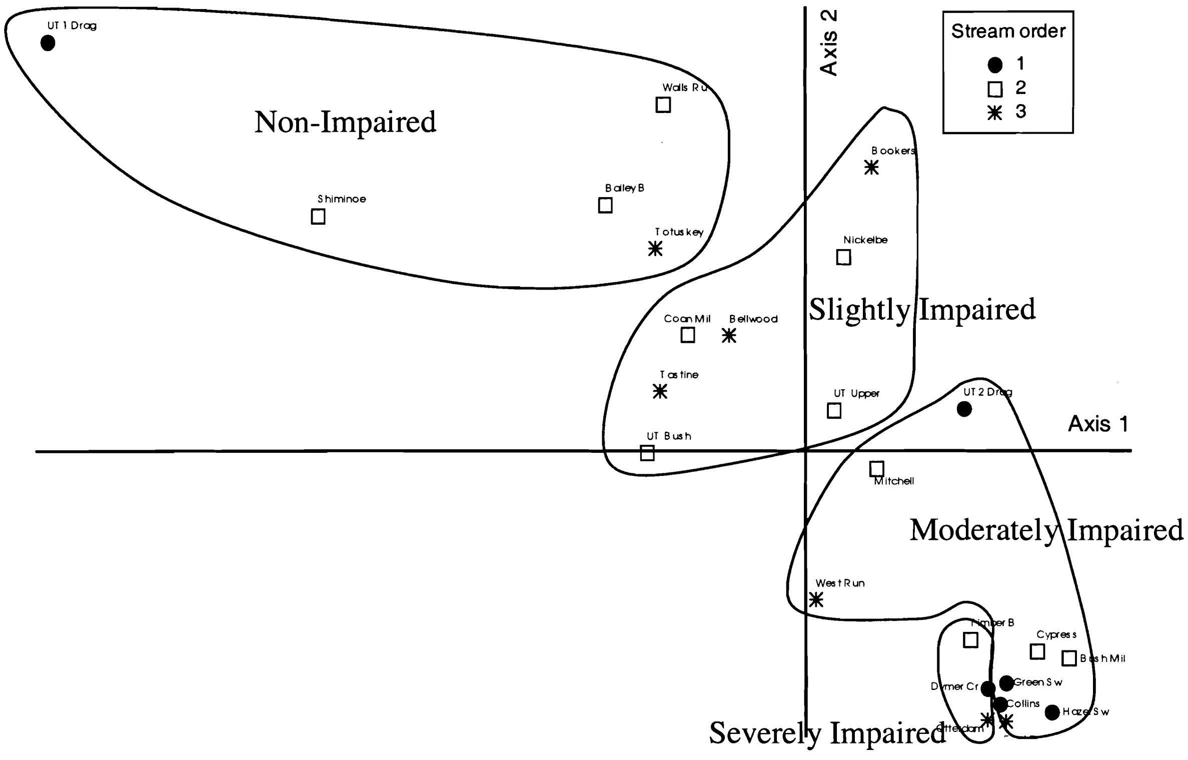

Figure 12. Classification of streams by impairment level based on NMS ordination derived from CPMI metrics less percent clingers. Streams are categorized by stream order.

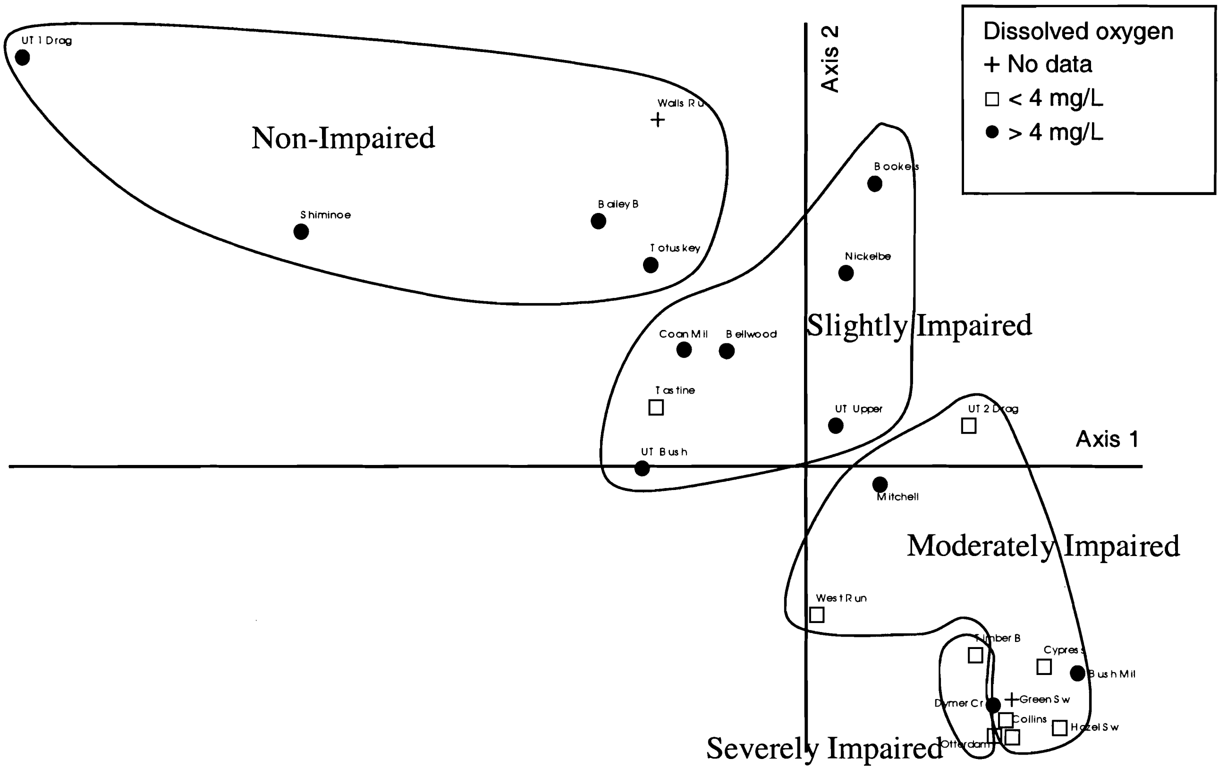

Figure 13. Classification of streams by impairment level based on NMS ordination derived from CPMI metrics less percent clingers. Streams are categorized by DO concentration.

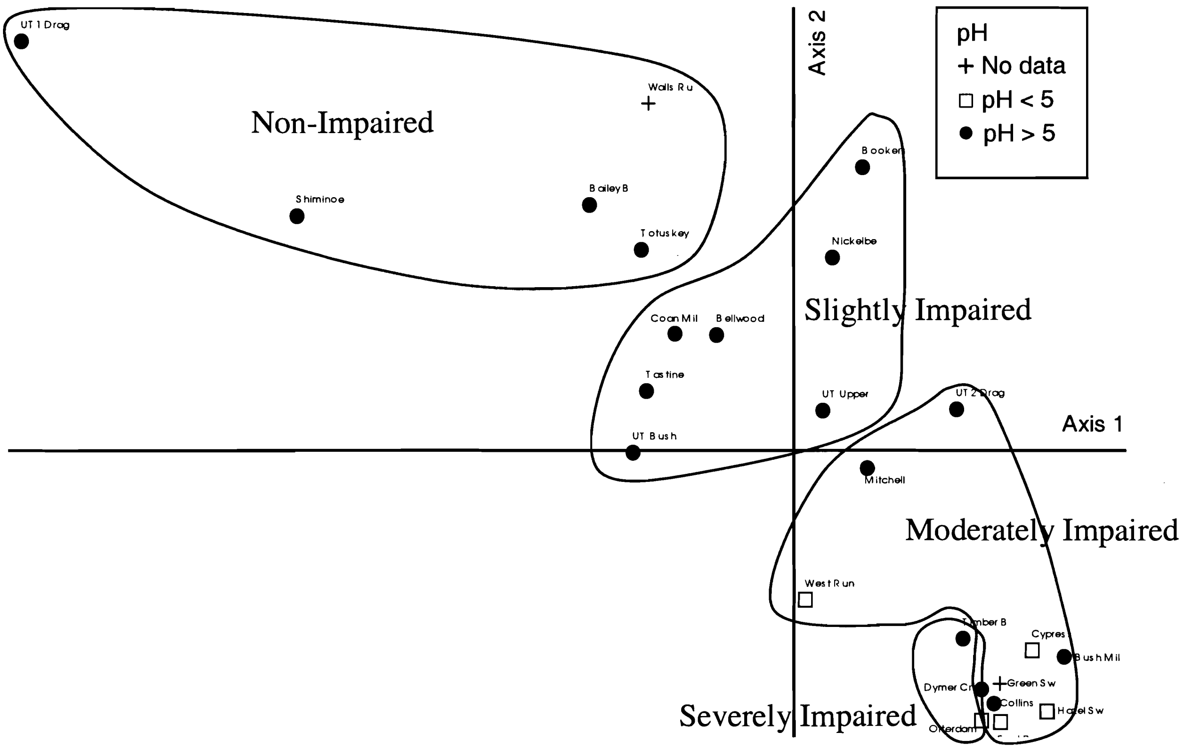

Figure 14. Classification of streams by impairment level based on NMS ordination derived from CPMI metrics less percent clingers. Streams are categorized by pH measurements.

Appendix

Site Locations

Stream Name	Lat	Long	County	Location
Nickelberry Swamp	37.65611	-76.65889	Middlesex	Rt 17
Collins Run	37.39917	-77.41833	Charles City	Rt 155
Hazel Swamp	37.08097	-76.89889	Surry	Rt 616
Timber Branch	37.69244	-76.77644	King & Queen	Rt 610
Mitchell Hill Creek	37.66939	-76.85936	King & Queen	Rt 14
UT2 Dragon	37.66114	-76.73739	King & Queen	Rt 610 Coldwater
Bailey Branch	37.178	-77.01075	Surry	Rt 10
Buzzard's Branch	37.08089	-77.04636	Surry	Rt 601
Dymer Creek	37.69175	-76.37683	Lancaster	Rt 3
Bellwood Swamp	37.778	-76.49725	Lancaster	Rt 201
UT Bush Mill	37.85456	-76.49383	Northumberland	Rt 601
Bookers Mill	37.89161	-76.60275	Richmond	Rt 612
Totuskey Creek	37.90969	-76.61261	Richmond	Rt 607
Coan Mill	37.91736	-76.51594	Northumberland	Rt 638
Bush Mill	37.87769	-76.49606	Northumberland	Rt 601
UT1 Dragon	37.62886	-76.71294	King & Queen	Rt 610 Mascot
Tastine Swamp	37.60147	-76.75958	King & Queen	Rt 603
Green Swamp	37.07969	-76.84331	Surry	Rt 618
UT Upper Chippokes	37.146	-77.04675	Surry	Rt 607
Cypress Swamp	37.14756	-76.96728	Surry	Rt 647
West Run	37.37264	-77.16656	Charles City	Rt 607
East Run	37.37103	-77.15647	Charles City	Rt 609
Shiminoe Creek	37.46389	-77.07786	New Kent	private drive Rt 60
Otterdam Swamp	37.37103	-77.15647	Surry	Rt 602
Walls Run	37.24789	-77.18558	Prince George	Rt 635

Vita

Warren Hunter Smigo was born January 6, 1970 in Richmond, Virginia. He graduated from Monacan High School in Chesterfield, Virginia in 1988 and received his Bachelor of Science degree in biology from Radford University in 1992. After graduation, he spent several years of working as a lab technician for an industrial water treatment company. After an epiphany in 1999, he sold all of his possessions and headed out in his trusty Volkswagen Westfalia “Rupert”. After two years of working at a resort in the mountains of Utah and as a whitewater raft guide on the Chattooga River in Georgia, he returned in 2001to attend graduate school at VCU with a renewed desire to follow his interest in the study of aquatic ecology. While completing graduate studies at VCU, he was a biology laboratory instructor and a field and research technician for the aquatics and fish laboratories. He is presently employed by the Virginia Department of Environmental Quality as the biological monitoring program coordinator.