INVESTIGATING LANDSCAPE INFLUENCES ON STREAM MACROINVERTEBRATE COMMUNITIES

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Introduction

While much is known today about local reach-scale factors that influence the distribution and composition of stream macroinvertebrate communities, such as physical habitat and water chemistry, little is known about the influence of landscape-level factors, which include landuse/cover diversity, composition, and distribution. We believe that this is largely due to the fact that these parameters have, until recently, been difficult to quantify. Osborne and Wiley (1988), and Johnston, et al., (1988, 1990) used geographic information systems (GIS) to quantify landscape variables in relation to water quality of streams and wetlands; however, effects on the stream communities have not to date been well documented.

We are currently conducting two studies examining these issues in a series of small streams along the north shore of Lake Superior (North Shore project), and at 48 sites in the Saginaw River drainage basin in eastern Michigan (Saginaw project). These regions represent two distinct types of landscapes: the North Shore of Lake Superior is a sparsely populated, forested landscape. The Saginaw River drainage basin in eastern Michigan, is more densely populated, and has a diversity of landuse/cover types dominated by agricultural lands. Riparian forests and shrub zones are limited in extent.

Landscape Data and Analysis

An analysis of the effects of landscape-level factors on stream invertebrate communities requires integration of data over several spatial scales. Community and habitat variables occur at the reach scale; yet both the stream macroinvertebrate community and to a lesser extent the habitat variables reflect the impacts of large scale processes resulting from factors such as landuse practices and landscape structure and function. Several aspects of landscape form and landuse/land cover have been (or are being) quantified for the studies in Minnesota and Michigan using a geographic information system.

Several commonly available databases are being used for quantifying landscape variables in the North Shore project and the Saginaw project. The stream network itself was derived from a standard U.S. Geological Survey (USGS) digital map series, encoded in a Digital Line Graph (DLG) format (a common data exchange medium). While these maps are scaled at 1:100,000, they are derived from electronically scanned, 1:24,000 series topographic maps, and are essentially identical to those products. The same map series was used to derive the transportation layer (roads, railroads and trails).

Smaller scale (larger area) landuse/land cover (LUDA) maps (1:250,000) were also obtained from the USGS. These maps are derived from high altitude aerial photography (NHAP Program) from the late 1970's to early 1980's, and are classified into 36 landuse/cover categories in a hierarchical fashion (e.g., at Level I, 4 = forested land; at Level II categories, 41 = deciduous, 42 = evergreen, and 43 = mixed forested lands). The minimum mapping unit is 10 acres in urban areas and 40 acres in all other regions. The Michigan study is also utilizing a larger scale landuse map (1:24,000), with minimum mapping units of 2.5 acres. These two landuse maps will be used to analyze the appropriate scale for characterizing disturbance and stream biotic integrity. (See Table 2 for a list of data sources already in use, or to be used in these studies.)

Aerial measurements are standard output in a GIS. Thus, integration of GIS with a database management system allows us to perform queries such as- What is the cumulative area of each landuse/cover type in each watershed? Queries such as these can be performed on either spatial or thematic subsets of data...that is, we can query the landuse database to determine the cumulative area of only the forested land in the entire watershed (a thematic subset), or we can determine the cumulative area of individual landuse types directly adjacent to the streams or in a specific region of the watershed (a spatial subset) (Fig. 1). These queries take advantage of the unique ability of the GIS to analyze spatial relationships within and between data layers. The database component of the GIS also allows use to calculate diversity of landuse/cover types and measures of landscape heterogeneity (Forman and Godron 1986). These measures give us an idea of the complexity of the landscape mosaic.

Overlay operations (that is, the joining of two or more map layers into a single layer) permit us to determine intersections of different parameters at a point or region, e.g., elevation, slope, soil type, landuse, and yearly maximum/minimum temperature and precipitation. These are factors that largely determine the distribution of plant communities, thus coincidence of particular ranges of values may be used by plant ecologists to predict potential vegetation (Bailey 1983). The same general type of analysis could be conducted to predict distribution of stream communities, given appropriate data on water quality, discharge, and habitat data.

The map resulting from an overlay operation may also be used to analyze juxtaposition of spatial elements such as adjacency and connectivity. The question being asked in both the Saginaw and the North Shore streams studies is whether and how landuse and landscape form (the areal extent and distribution of landuse/cover types) affect stream macroinvertebrate communities. Landscape measures are exported as ASCII data into database management systems and statistical packages for analysis. As a result, the primary output of these GIS manipulations are data, not maps.

A comparison of representative watersheds from the North Shore and Saginaw studies indicates the potential for using GIS data for characterizing landcover both within and between geographic regions. With the exception of one watershed located in an urban area, the majority of landcover within 250 m of stream courses along the north shore of Lake Superior was composed of deciduous and mixed forest (Figure 2a). Agricultural landuses form a relatively small proportion of total watershed area within the 250 m buffered area. Other categories are more variable. The Saginaw watersheds (Figure 2b), in contrast, were largely dominated by agricultural landuse/landcover characteristics. Variation among watersheds in this region was attributable to differences in the proportion of wetland and forested landcover, although several watersheds also had significant amounts of urban landuses. Other landscape variables continue to be tabulated (Table 2).

Linkage of Landscape, Reach, and Biological Variables

Identification of the variables that most strongly influence biological communities is in itself often a complex task. A large variety of univariate and multivariate analytical techniques are available (see Green 1979). However, given the complex nature of spatial and temporal factors operating on watershed and reach scales that may effect stream ecosystems, multivariate techniques can be particularly effective for identifying relationships among variables that can be further delimited with other techniques. Multivariate analysis is essentially a means for summarizing complex data. A number of these methods can be employed depending on the nature of the data and the questions being examined (Gauch 1982).

Multivariate analysis can be particularly useful in relating community data to other types of environmental data and in determining the relative contribution of various types of environmental variables to community variation. One type of analysis, canonical correspondence analysis (CCA, ter Braak 1986), can be particularly effective when analyzing environmental data sets that contain intercorrelated data, as is the case with most environmental data. The results of CCA can be used to derive graphical diagrams that illustrate the relationship between environmental variables and biological data. For example, some of the landscape data described in the North Shore streams study described above was combined with other reach-scale environmental variables typically collected in streams to examine the distribution of several macroinvertebrate species. CCA was used to derive the biplot shown in Figure 3. The relative influence of each environmental variable is represented by arrows in the ordination diagram, where the orientation of the arrow reflects the direction of maximum change of that variable across the diagram and its length is proportional to the rate of change. Environmental variables with long arrows are more strongly correlated with the ordination axes than those with short arrows, and so more closely related to the pattern of community variation shown in the ordination diagram.

The biplot (Figure 3) indicates that the distribution of eight macroinvertebrate taxa are influenced by differing environmental factors. For example, Tipula A and Isopoda distributions were most strongly influenced by the presence of fine sediment. Simulium were most abundant in regions with low values of fine sediment and algae, and relatively high values of pool depth, woody debris, and total stream length. The diagram also indicates that in this case the relative importance of urban development in the watersheds was not as strong as other environmental variables in predicting the distribution of these macroinvertebrate taxa. Urban landuses were associated with the abundance of algae, however, and some invertebrate distributions appeared to influenced by algal abundance. Factors in the immediate vicinity of the stream channel had the strongest influence on distributions. The composition and resolution of the landscape data in this case was not sufficient to identify strong linkages between landscape features and reach-scale habitat variables. Still, the types of variables identified as important to community composition woody debris in channels, channel morphology, and fine sediment, can serve as endpoints for finer scale analysis of watershed and riparian buffer landcover analysis in future investigations.

Since we are assembling a GIS database with greater spatial resolution in the Saginaw study, a similar multivariate analysis of environmental variables was conducted with macroinvertebrate data to identify important reach-scale habitat factors on which to focus landscape analysis efforts towards developing relationships to key environmental factors. The relative strength of reach-scale habitat variables and surface water chemistry in describing macroinvertebrate communities was assessed. Reach-scale variables substrate and riparian characteristics played a larger role in influencing macroinvertebrate communities than several chemical parameters measured at the same sites (Figure 3b). In this region, activities that affect sediment characteristics in the stream (erosion, deposition) and riparian characteristics (landuse, buffer strips) have the strongest influence on stream macroinvertebrate communities. Since watershed activities strongly influence these variables (Menzel et al. 1984), an understanding and quantification of the landuse characteristics of these watersheds is required to understand the dynamic characteristics of these systems.

Conclusions

Geographic Information Systems have revolutionized the manner in which natural resource managers and land use planners collect, store and analyze mapped data; however, aquatic scientists have been slow to recognize the value of this technology. This may largely be due to 1) the perception that GIS is simply a tool for creating and displaying maps, 2) lack of inexpensive, user-friendly software, 3) lack of appropriate spatial data, 4) lack of appropriate interfaces between

GISs and quantitative tools such as statistical packages, models, and global positioning technologies. Many of these barriers have been removed; however, aquatic scientists still confront issues such as how to represent a three dimensional environment with two or pseudo-3D data models and how to represent data variability in a map product. Digital data are now easily imported and exported from and to standardized data exchange formats such as DLG and DXF (the AutoCad standard); however, some data formats are difficult or impossible to convert. Procedures for interconverting data between commercial software systems are well-developed for most of the major packages, but "buyer beware" still reigns when dealing with many vendors.

On the positive side, GIS now allows us to quantify characteristics of large regions that would have been prohibitive using manual methods. Furthermore, these measurements can easily be replicated, something that was difficult to do using manual methods such as planimeters and mylar map overlays. In addition, as global positioning technologies become cheaper and more useful, it is becoming possible to create maps with high degrees of precision directly from field measurements. Thus, decreasing substantially the cost of spatial database development, a significant barrier in the past. Water resource managers and scientists who recognize the importance of understanding spatial orientation of landscape features to environmental characteristics of streams will increasingly use these technologies in everday management.

References

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Figure 1. Creation of a stream buffer zone within a fixed distance from either side of the stream. 1a. Overlay of stream on a map of landcover characteristics, various shaped polygons represent areas of different landcover. 1b. Stream and buffer, cross-hatches denote differing landcover characteristics within the buffer zone.

Figure 2. Landuse characteristics of representative watersheds along the North Shore of Lake Superior (2a) and Saginaw River Watershed of Michigan (2b). Data were derived using GIS technology.

Figure 3a. Results of the ordination (CCA) of abundances of several macroinvertebrate species as a function of several landscape and reach-scale physical habitat attributes in several North Shore streams. 3b. Results of an ordination (CCA) of macroinvertebrate communities in streams (numbers) as a function of chemical and physical habitat parameters.

Table 1. Data layers and sources for use in Saginaw and North Shore projects. Stream reach and biological data were not integrated into a GIS for this component of the study. Methods are currently being examined and developed for performing this step.

Data Layer	Source	Scale	Format	Project
Hydrology	USGS	1:100,000 (1:24,000)	DLG	Saginaw, North Shore
Landuse	USGS;MI DNR	1:250,000 1:24,000	GIRAS, Intergraph	North Shore; Saginaw
Landuse	MI DNR	1:24,000	Intergraph	Saginaw
Topography	USGS	1:250,000	DEM	Saginaw
Wetlands	USFWS	1:24,000	paper - to scan	Saginaw
Riparian land/cover	USGS topo maps	1:24,000	paper - to digitize	Saginaw
Watershed Boundaries	USGS	1:24,000	paper - to digitize	Saginaw; North Shore

Table 2. Description of landscape variables to be measured.

Watershed Descriptors	Landuse Variables	Project
Landuse Type %	% Area in Watershed	North Shore; Saginaw
Slope: max, min	% Area in Corridor	Saginaw
Aspect: dominant	Heterogeneity	Saginaw
Elongation Ratio	Fractal Dimension	Saginaw
Compactness Ratio	Relative Position	Saginaw
Reach Gradient		North Shore; Saginaw

Figure 1a

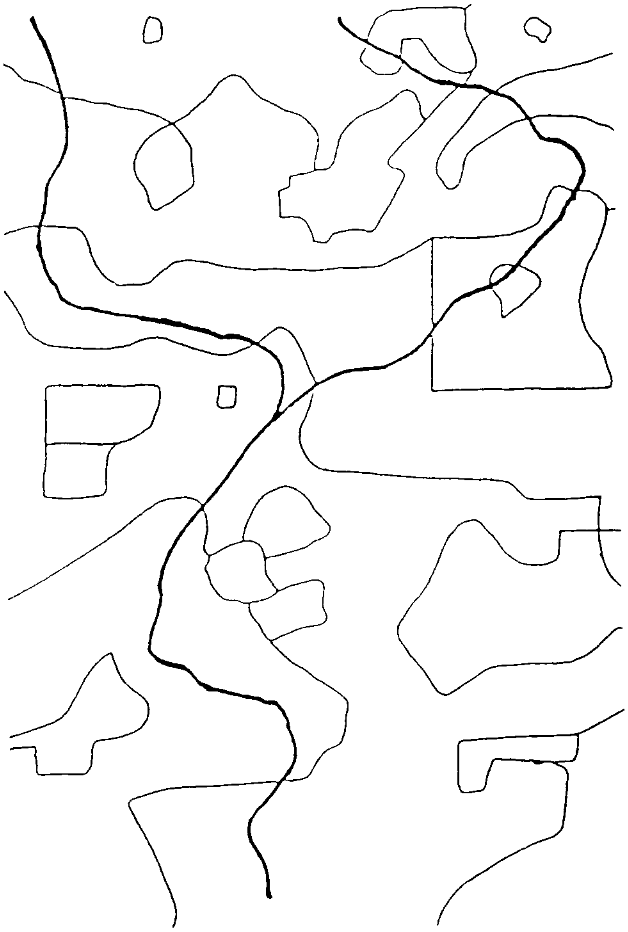
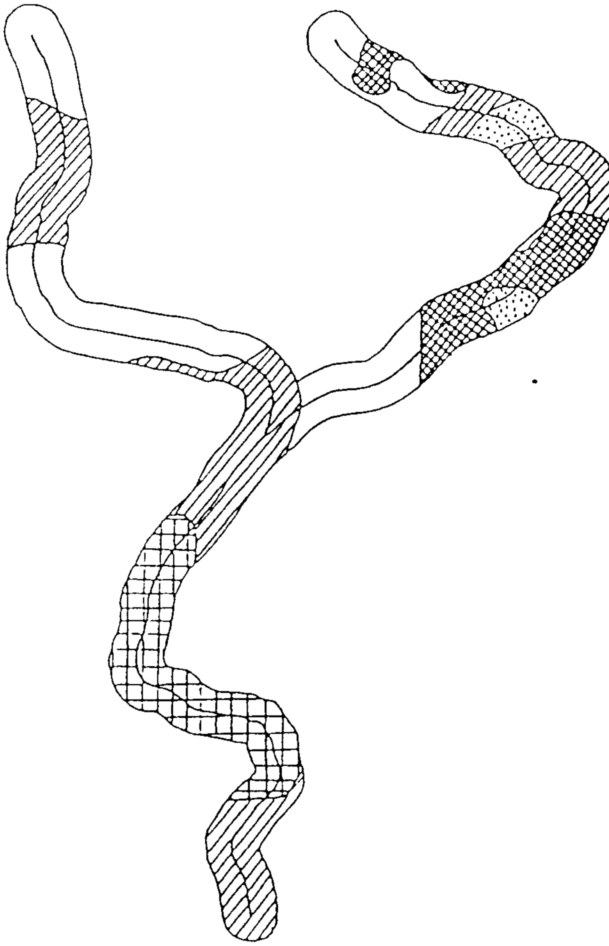
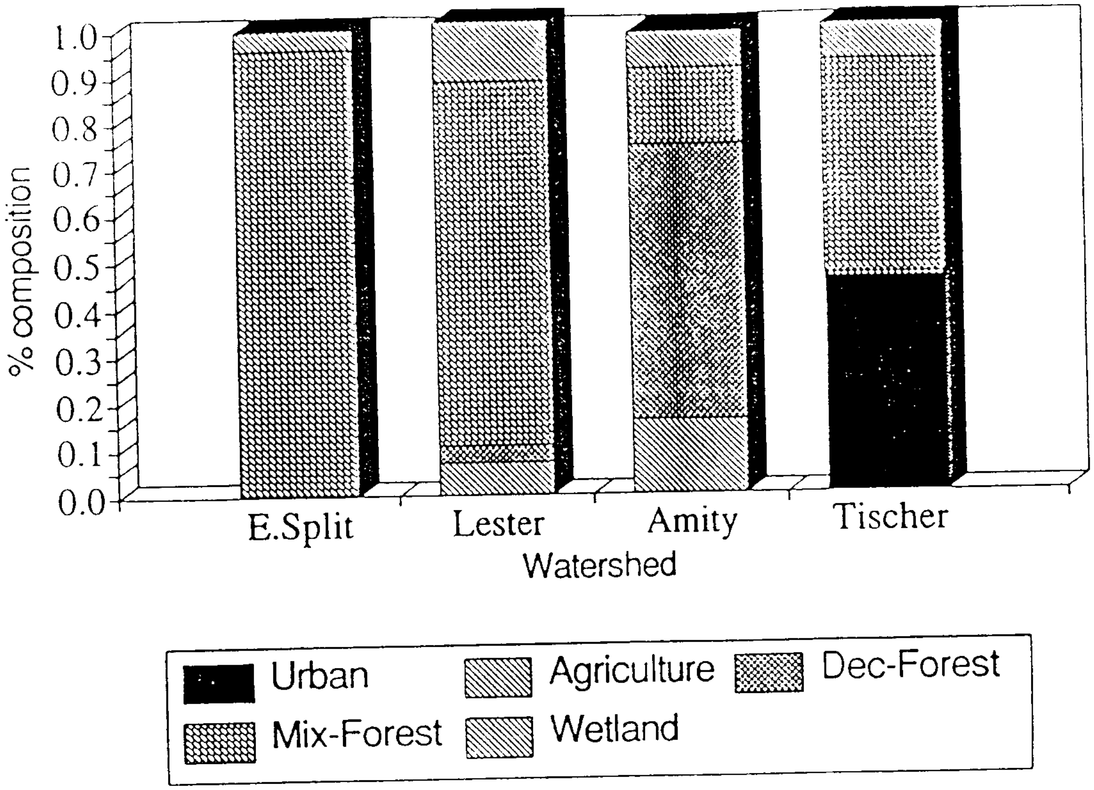


Figure 1b



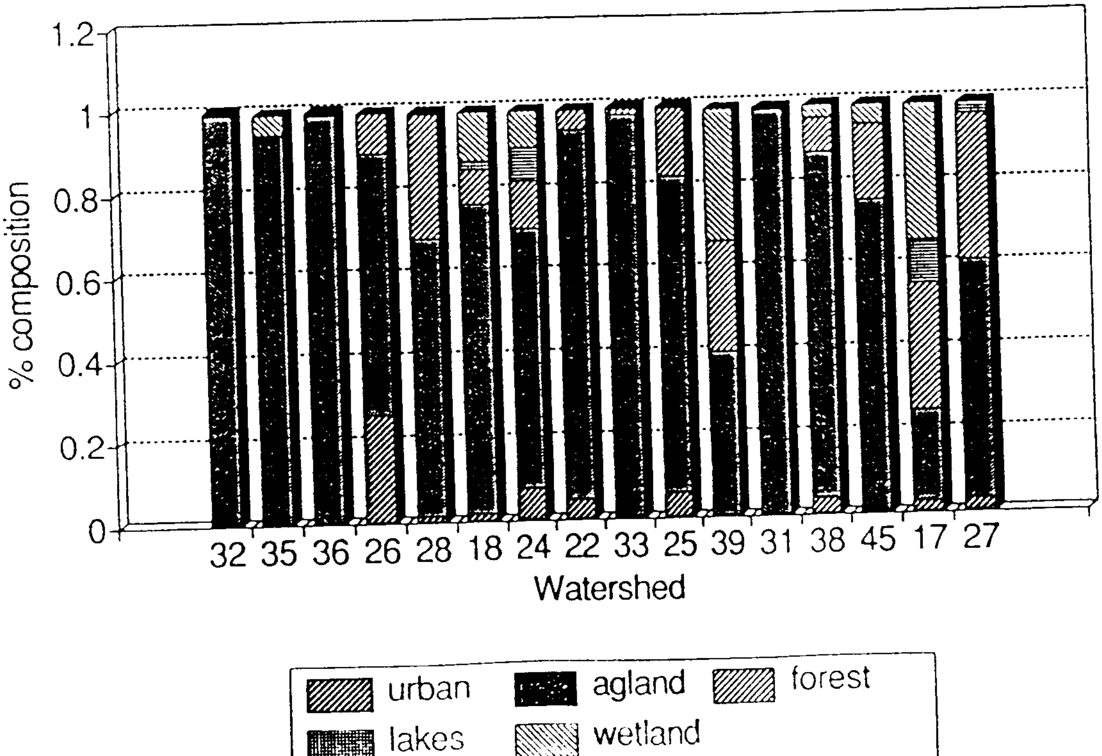
North Shore

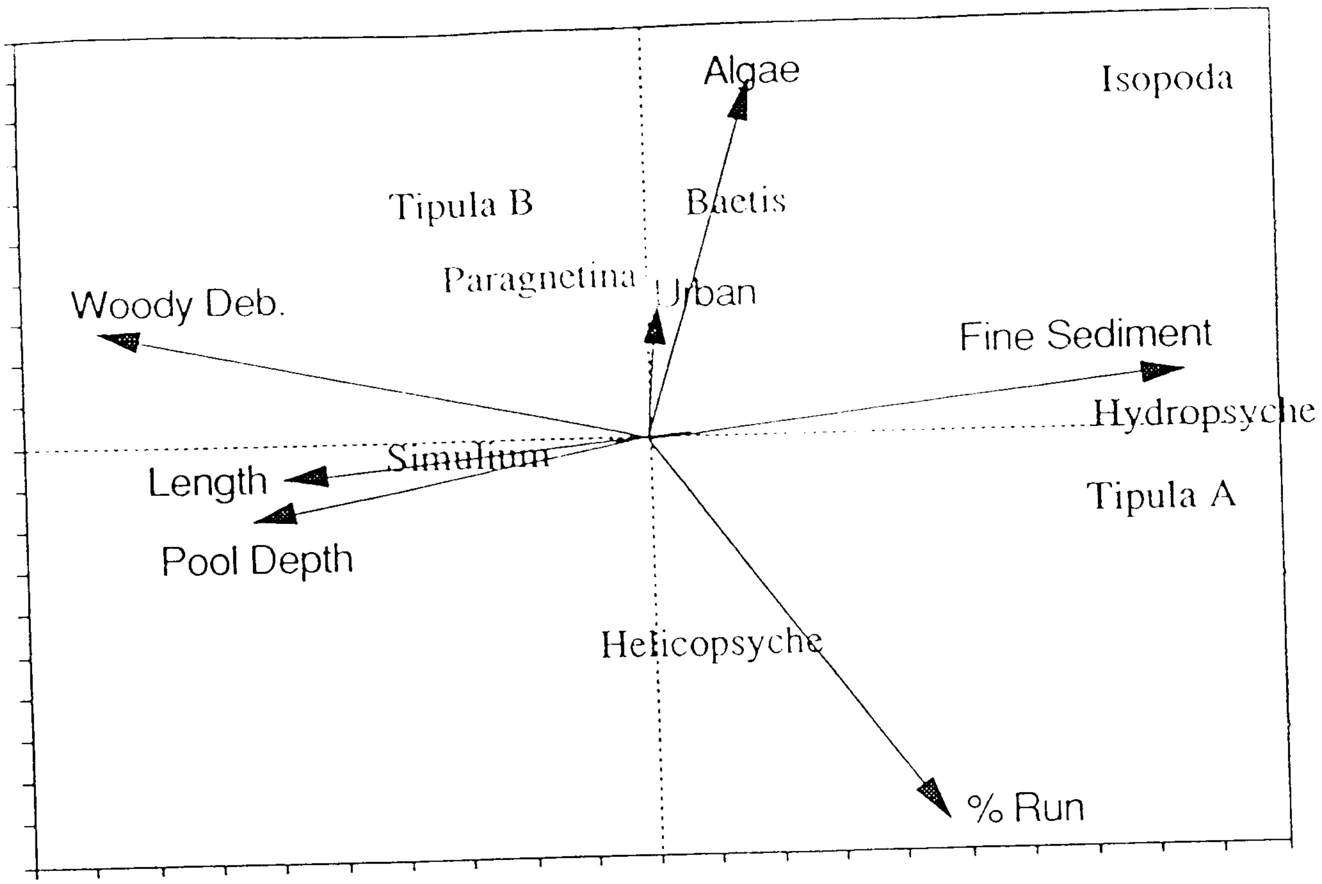
Figure 2a



Saginaw River Watershed

Figure 2b





3a

Figure 3a

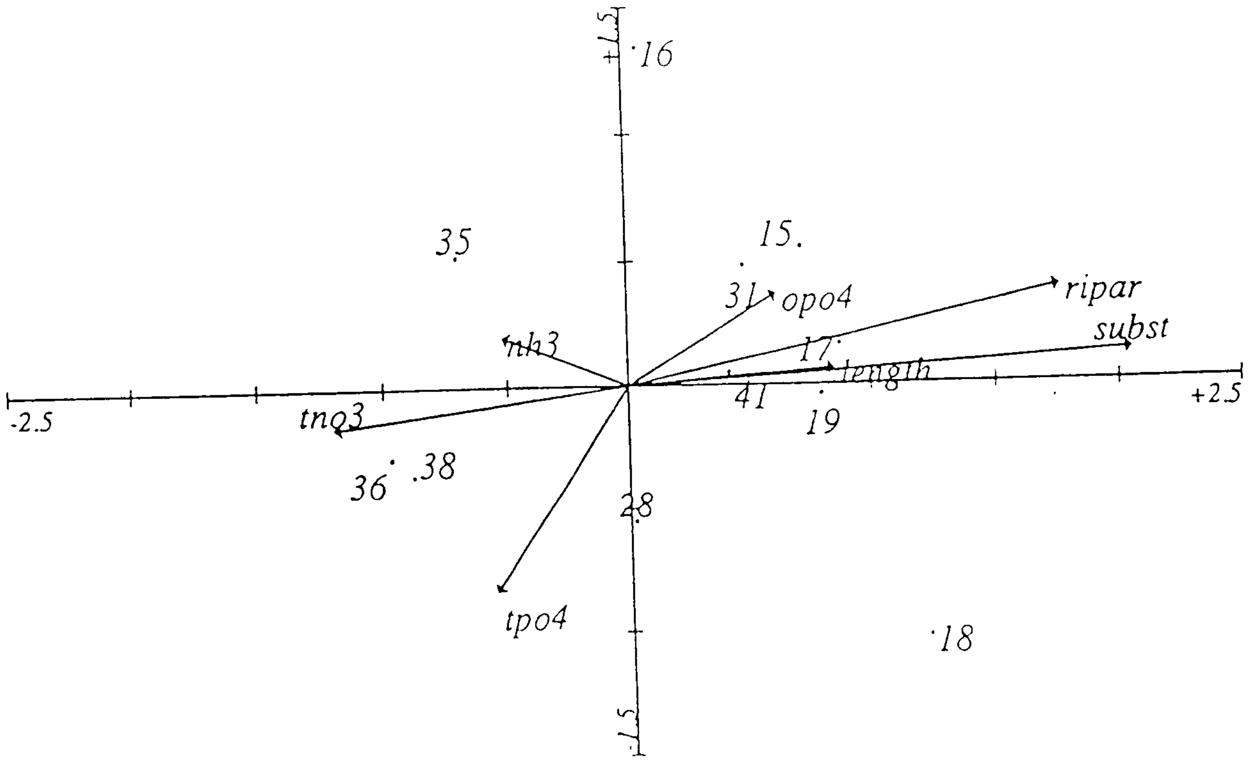


Figure 3b