EFFECTS OF CHANGING LAND USE ON MACROINVERTEBRATE INTEGRITY: IDENTIFYING INDICATORS OF WATER QUALITY IMPAIRMENT

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Abstract. We sampled macroinvertebrates in 30 streams (11-126 km^2 watersheds) within the Piedmont of the Etowah River basin in northern Georgia to examine the relationships between urban land use, physical and chemical characteristics of streams, and biotic assemblages. Percent urban land cover in 1973, 1987, and 1997 was negatively correlated with macroinvertebrate integrity, with the recent land cover exhibiting the highest correlations. The Environmental Protection Agency's visual-based habitat assessment was the single, best overall variable correlated with macroinvertebrate integrity. Specific conductance, average riffle particle size, and standard deviation of stream bed particle size were also highly correlated with indices of macroinvertebrate integrity. Out of the macroinvertebrate indices we calculated, total richness, the Invertebrate Community Index (ICI), and riffle insect richness formed the strongest predictive models with environmental variables, suggesting their importance as water quality indicators in this system. These results demonstrate that macroinvertebrate integrity can be used to assess stream water quality impacts that occur due to changing land use and suggest that stream protection relies on minimizing the percent urban land cover in the catchment.

INTRODUCTION

Suburban growth around Atlanta is threatening the water quality of numerous streams by converting forested and agricultural land into commercial and residential uses. Urbanization impacts the chemical and physical characteristics of streams, which, in turn, affect stream biota (Richards et al. 1996, Benke et al. 1981). Although relationships between urban land cover and water quality degradation have been identified, more research is needed to quantitatively assess the effects of urbanization, determine mechanisms of the impacts of recent land use, and identify thresholds of biotic impairment.

The purpose of this study was to (1) determine whether past land use, recent land use, or land use change was most related to macroinvertebrate integrity, (2) identify environmental indicators of biotic impairment, and (3) select good macroinvertebrate indices for detecting urban degradation. Understanding the influences of urbanization within the catchment on water quality, aquatic fauna, and stream processes is essential for determining how humans can live within the landscape without impacting aquatic ecosystems.

METHODS

Study Area

This study took place in 30 streams (11-126 km^2 watersheds) within the Piedmont physiographic region of the Etowah River basin in northern Georgia. For a description of the sites, see Leigh et al. in this volume.

Macroinvertebrate Sampling

Benthic macroinvertebrates were collected in three riffle, three pool, and three bank habitats within a 100 m reach between 6 and 19 March 1999. Quantitative samples were collected using a surber sampler, dip net, and stove-pipe corer and filtered over a 500 µm sieve. Samples were preserved in the field in ~8% formalin and returned to the laboratory for identification.

Taxa were counted, identified to genus, and used to calculate multiple macroinvertebrate indices. Total richness and insect richness in the riffle habitats were calculated. The number of taxa in the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT richness) was also determined. Total densities were multiplied by the proportion of riffle, pool, and bank habitat present at each site to estimate habitat-weighted density and were $\log_{10}(x)$ transformed. Macroinvertebrates were assigned to tolerance values (where high numbers indicate high tolerance) using Hilsenhoff's Family Biotic Index (FBI; Hilsenhoff 1988) and the North Carolina Biotic Index (NCBI; Lenat 1993). Finally, we calculated two multimetric indices, the Benthic Index of Biotic Integrity (B-IBI; Kerans and Karr 1994) and the Invertebrate Community Index (ICI; Ohio EPA 1989), adjusting the scoring criteria to encompass the macroinvertebrate distribution at the 30 sites.

Land Cover

The urban land cover variables were calculated from Landsat MSS (1973) and TM (1987, 1997) images (Lo and Yang 2000, Leigh et al. 2001). Total urban cover included high-density and low-density urban. Change in land cover was calculated by subtracting percentage values of the earlier date from the later date for the entire basin above the sample reach.

Environmental Sampling

Numerous bed texture and channel morphology data were collected in summer 1999 (Leigh et al., this volume). In addition, a team of 3 people separately determined scores for the Environmental Protection Agency's visual-based habitat assessment (Barbour et al. 1999) and the Natural Resource Conservation Service's Stream Visual Assessment Protocol (SVAP; Bjorkland et al. 2000) for the 30 sites. Water chemistry was sampled monthly from March 1999 to March 2000, and mean yearly values were used in this analysis. For an explanation of sampling methods and analysis of chemical data see Paul et al., this volume.

All independent variables were checked for normality and appropriately transformed, if necessary, to normalize variance. Site 2 was eliminated from analyses since beaver dams were constructed between sampling days (final n=29). Correlation and stepwise multiple regression analyses were performed using JMP statistical software (SAS Institute). The variables used in the regression analyses represent a subset of land use, geomorphic, and water chemistry variables that were not highly correlated with each other ($r < 0.70$) and were likely to affect the macroinvertebrates.

RESULTS

Land Use Change

Increased urban land cover, as a percentage of land in a catchment or the change in the percentage from recent times (1973-1997 or 1987-1997) was correlated with reduced biotic integrity (Table 1). There were significant correlations between many of the macroinvertebrate indices that were calculated and the urban land cover variables. However, the highest correlations were with the most recent measurements of urban land cover.

Environmental Indicators

Seventeen environmental variables were significantly correlated with macroinvertebrate indices (Table 2). EPA's visual-based habitat assessment was the single, best variable correlated with macro-invertebrate integrity followed by specific conductance. Average riffle particle size and standard deviation of total particle size were also among the top individual variables related to biotic communities (Table 2).

We used multiple regression analyses to determine which environmental factors or groups of factors could explain most of the variance in measures of biotic integrity. We found that specific conductance, standard deviation in particle size, and EPA's visual assessment were consistent predictors of macroinvertebrate integrity (Table 3). Specific conductance was selected in 6 of the 8 models and standard deviation in particle size was selected in 5 of the models. The overall best model included these two variables, average depth, and 1973 percent urban land cover (Table 3).

Macroinvertebrate Indicators

Out of the biotic indices we calculated, total richness was best predicted by the environmental variables (adjusted r^2=0.76), making it a good macroinvertebrate indicator (Table 3). The two multi-metric indices, the ICI and the B-IBI, were also highly predictable with environmental variables. Multiple regression models also accounted for 69% of the

Table 1. Pearson's pairwise correlations (r) between selected macroinvertebrate indices and percent urban land cover in the watershed. Sign indicates direction of the relationship.

	1997	1987	1973	Change 1973-1997	Change 1987-1997
Total Richness	-0.54*	-0.46*	-0.52*	-0.26	-0.37*
Total Density (no./m^2)	-0.46*	-0.33	-0.41*	-0.30	-0.29
EPT Richness	-0.56*	-0.53*	-0.39*	-0.36*	-0.36
Riffle Insect Richness	-0.48*	-0.44*	-0.33	-0.38*	-0.36
FBI†	0.53*	0.54*	0.36	0.40*	0.38*
NCBI†	0.54*	0.56*	0.32	0.45*	0.41*
B-IBI	-0.50*	-0.52*	-0.51*	-0.26	-0.29
ICI	-0.60*	-0.58*	-0.34	-0.49*	-0.44*
Mean	***0.53****	***0.50****	***0.40****	***0.36***	***0.36***

†Positive values indicate lower biotic integrity.
*Indicates significant relationship, p<0.05.

Table 2. Significant correlations ($p<0.05$) between macroinvertebrate indices (average of 8 variables, listed in Table 1) and environmental variables. Sign indicates the direction that these variables were related to increased macroinvertebrate integrity.

	r
EPA's visual-based habitat assessment	+0.66
Specific conductance (µm/cm)	-0.60
Average riffle particle size (phi)†	-0.59
Stream visual assessment protocol (SVAP)	+0.59
Standard deviation particle size (phi)†	+0.54
Dissolved oxygen (ppm)	+0.54
1997 Percent urban land cover	-0.53
Soluble reactive phosphorus (ppb)	-0.51
1987 Percent urban land cover	-0.50
Ammonium (ppb)	-0.48
Average emergent bar particle size (phi)†	-0.47
Energy grade line slope	+0.47
Local relief (m)	+0.45
Average particle size (phi)†	-0.44
Total suspended solids (mg/L)	-0.41
Percent riffle area	+0.40
1973 Percent urban land cover	-0.40

†Larger particles correspond to smaller phi.

variation in the riffle insect richness and 66% of the variation in the EPT richness across sites (Table 3).

DISCUSSION

Macroinvertebrates have been used consistently as water quality indicators because they are ubiquitous to all streams, sedentary in nature, have relatively long life cycles, and respond to multiple aquatic perturbations with a range of environmental stress (Rosenberg and Resh 1993). This study supports others showing that urbanization in the landscape can negatively impact the integrity of stream macroinvertebrates (Benke et al. 1981, Jones and Clark 1987, Kennen 1999). Previous studies have shown that biotic integrity can be a legacy of past land use practices (Harding et al. 1998). While this is obviously an important factor, our results showed that the most recent urban land use was the best predictor of biotic integrity compared to past urban land use or urban land use change.

Although urban land cover was correlated with macroinvertebrate integrity, multiple regression analyses showed that direct measures of bed texture and water quality characteristics, rather than measures of land cover, were most important in determining biotic integrity. Urban land cover likely affects macroinvertebrates by influencing reach-scale variables which, in turn, affect the biotic community. For example, 1997 urban land cover was correlated with specific conductance ($r = 0.69$, $p < 0.05$), and specific conductance was important in predicting macroinvertebrates.

Our results suggest which independent variables were important to measure to predict changes in stream biotic integrity. Specific conductance, bed texture, and average depth were highly related to biotic indices, suggesting that they would be important to measure when assessing impacts on macroinvertebrates in Piedmont streams. EPA's habitat-based visual assessment and the SVAP were also highly related to macroinvertebrate integrity, and serve as simple measurements to identify target sites of stream habitat degradation. However, these visual measurements are limited in their ability to explain the mechanism by which macroinvertebrates are impacted.

Several macroinvertebrate variables served as good indicators of water quality degradation due to urbanization. There is a national and international trend towards developing region-specific biotic indices using a large number of sites (e.g. >100) for metric calibration (e.g. Barbour et al. 1996, Kerans and Karr 1994). Our results suggest that in lieu of additional such studies, degraded sites can be detected by incorporating a range in site quality and using pre-existing indices (e.g. ICI) and adjusting the scoring criteria for the Georgia Piedmont. Total richness, riffle insect richness, and EPT richness have the advantages

Table 3. Multiple regression models for macroinvertebrate indices using stepwise regression (forward and backward selection, $p<0.05$).

	Adjusted R^2	Model
Total Richness (no. taxa)	0.76	average depth, 1973 % urban cover, standard deviation particle size, specific conductance
Invertebrate Community Index (ICI)	0.73	specific conductance, standard deviation particle size
Riffle Insect Richness (no. taxa)	0.69	specific conductance, standard deviation particle size
EPT Richness (no. taxa)	0.66	specific conductance, standard deviation particle size, average depth
Benthic Index of Biotic Integrity (B-IBI)	0.65	EPA's visual assessment, specific conductance, total suspended solids, bankfull size
Total Density (no./m^2)	0.50	standard deviation particle size, specific conductance
North Carolina Biotic Index (NCBI)	0.46	EPA's visual assessment
Hilsenhoff's Family Biotic Index (FBI)	0.37	EPA's visual assessment

of being simple to calculate and applicable to most physiographic regions, adding to their value as biotic measures of degradation.

The important macroinvertebrate and environmental indicators outlined in this study should serve as a baseline for future studies attempting to assess stream water quality in the Piedmont. Ultimately, understanding how urban land cover affects stream ecosystems is important to inform managers and land use planners about viable protection and rehabilitation options.

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