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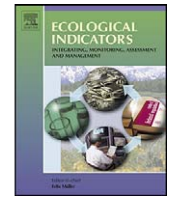

Environmental indicators of macroinvertebrate and fish assemblage integrity in urbanizing watersheds

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ABSTRACT

Urbanization compromises the biotic integrity and health of streams, and indicators of integrity loss are needed to improve assessment programs and identify mechanisms of urban effects. We investigated linkages between landscapes and assemblages in 31 wadeable Piedmont streams in the Etowah River basin in northern Georgia (USA). Our objectives were to identify the indicators of macroinvertebrate and fish integrity from a large set of best land cover ($n = 45$), geomorphology ($n = 115$), and water quality ($n = 12$) variables, and to evaluate the potential for variables measured with minimal cost and effort to effectively predict biotic integrity. Macroinvertebrate descriptors were better predicted by land cover whereas fish descriptors were better predicted by geomorphology. Water quality variables demonstrated moderate levels of predictive power for biotic descriptors. Macroinvertebrate descriptors were best predicted by urban cover (−), conductivity (−), fines in riffles (−), and local relief (+). Fish descriptors were best predicted by embeddedness (−), turbidity (−), slope (+), and forest cover (+). We used multiple linear regression modeling to predict descriptors using three independent variable sets that varied in difficulty of data collection. "Full" models included a full range of geomorphic, water quality and landscape variables regardless of the intensity of data collection efforts. "Reduced" models included GIS-derived variables describing catchment morphometry and land use as well as variables easily collected in the field with minimal cost and effort. "Simple" models only included GIS-derived variables. Full models explained 63–81% of the variation among descriptors, indicating strong relationships between landscape properties and biotic assemblages across our sites. Reduced and simple models were weaker, explaining 48–79% and 42–79%, respectively, of the variance among descriptors. Considering the difference in predictive power among these model sets, we recommend a tiered approach to variable selection and model development depending upon management goals. GIS variables are simple and inexpensive to collect, and a GIS-based modeling approach would be appropriate for goals such as site screening (e.g., identification of reference streams). As management goals become more complex (e.g., long-term monitoring programs), additional, easily collected field variables (e.g., embeddedness) should be included. Finally, labor-intensive variables (e.g., nutrients and fines in sediments) could be added to meet complex management goals such as restoration of impaired streams or mechanistic studies of land use effects on stream ecosystems.

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1. Introduction

As natural landscapes are altered by human disturbances, the health of streams and rivers draining the land are increasingly at risk (Schlosser, 1991; Allan et al., 1997; Allan, 2004). The global rise in human population is driving a continual conversion of land to anthropogenic uses (Cohen, 2003; Grimm et al., 2008), so there is a strong need for monitoring stream health. Indicators of stream health (e.g., biotic integrity) and stream stressors (e.g., sedimentation and water quality) are important tools not only for assessing stream condition, but also for determining the mechanisms of impacts and, accordingly, effective avenues for protecting and restoring stream ecosystems.

Increases in impervious cover and a concomitant reduction in forest cover in urbanizing landscapes alter stream biotic assemblages (see reviews, Paul and Meyer, 2001; Walsh et al., 2005). Typical responses of benthic macroinvertebrate assemblages include reduced richness and diversity, and increased

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abundances of tolerant organisms in urbanized streams (Jones and Clark, 1987; Lenat and Crawford, 1994; Kennen, 1999; Walsh et al., 2001; Morse et al., 2003; Roy et al., 2003; Cuffney et al., 2005, and others). Likewise, fish responses to urbanization include reduced biotic integrity (Klein, 1979; Steedman, 1988; Wang et al., 1997, 2000; Kennen et al., 2005; Morgan and Cushman, 2005) and increased homogenization of assemblages (Walters et al., 2003a; Marchetti et al., 2006; Scott, 2006). While these biota have been well studied with respect to land cover change, few studies have assessed differences in the strength and mechanism of responses between fish and macroinvertebrates at the same sites (but see Lenat and Crawford, 1994; Lammert and Allan, 1999; Passy et al., 2004).

There are several mechanisms by which land use change alters stream biota, including: riparian clearing and loss of large wood, hydrologic alteration, excessive sedimentation, nutrient enrichment, and contaminant pollution (Allan, 2004). A primary mechanism of stream disturbance in urbanizing areas is stormwater runoff from impervious surfaces, which alters the magnitude, volume, frequency, and timing of high flow events (see reviews, Shuster et al., 2005; Walsh et al., 2005). The physical force of stormwater runoff causes stream bank erosion, sedimentation, bed scouring, and channel morphology alteration (Booth, 1990; Trimble, 1997; Finkenbine et al., 2000; Pizzuto et al., 2000; Fitzpatrick et al., 2005). Runoff also delivers contaminants to streams resulting in increased nutrients, metals, pharmaceuticals, and other toxins in urban streams (Wilber and Hunter, 1977; Herlihy et al., 1998; Ometo et al., 2000; Kolpin et al., 2002; Hatt et al., 2004). This extensive suite of stressors and ecosystem responses compose the symptoms of the "urban stream syndrome" (Paul and Meyer, 2001; Walsh et al., 2005) and may be used to assess the severity of stream disturbance.

Given the wide variety of stressors in urban streams, a key management goal is to identify key indicators and mechanisms of stream alteration, so managers can rapidly diagnose stream health and work toward treating the symptoms. Here we assess biotic responses to watershed and reach-scale stressors in the Etowah River basin near Atlanta, Georgia, in an effort to identify key indicators of disturbance. The objectives of this paper are to (1) determine which attributes of land cover, geomorphology, and water quality best predict biotic assemblage health, and (2) evaluate the potential for variables measured with low or minimal cost and effort to effectively predict biotic integrity. We compare the responses of macroinvertebrate and fish assemblages to disturbance, assessing whether there are different mechanisms by which biotic health declines. The results are placed in a management context and used to recommend a tiered approach to monitoring and assessment, based on management goals and resource availability.

2. Methods

2.1. Study sites and environmental setting

The study area includes 31 catchments of the Etowah River basin in north Georgia (Fig. 1). All sample reaches are on the Piedmont, but a few of the catchments have headwaters in the Blue Ridge Mountains. Catchments varied in size from 11 to 126 km^2, with channel types ranging from low gradient (0.1%), sand-bed streams to high gradient (1.0%), cobble-bed streams. Detailed site characteristics are provided by Walters et al. (2003b) and Roy et al. (2003). Stream reaches were sampled in 1999 ($n = 29$) and 2000 ($n = 2$). Natural land cover was primarily forest which was cut and supplanted by various land uses including mining, agriculture,

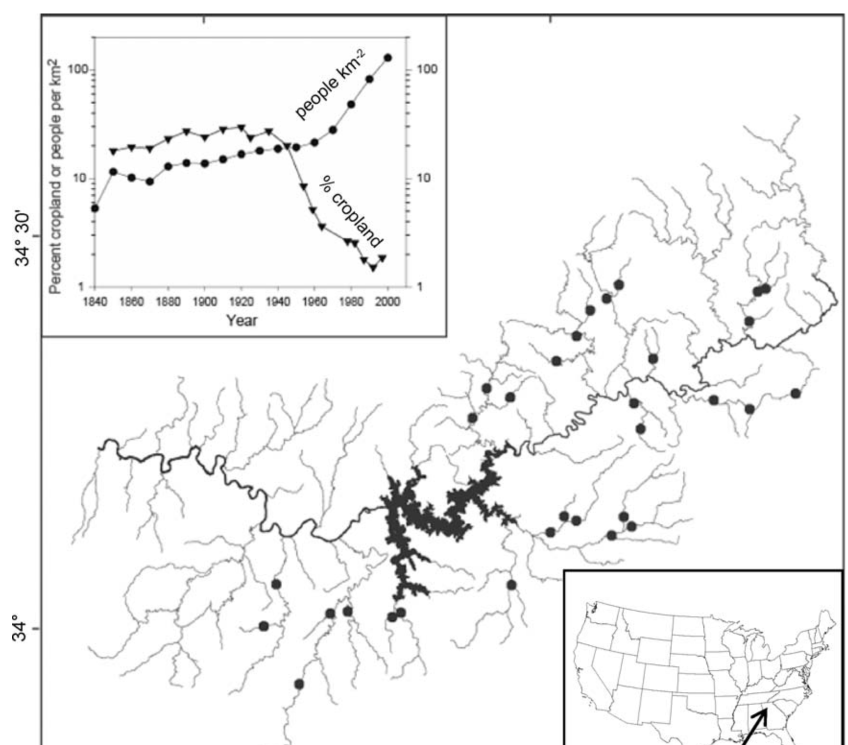

Fig. 1. Sample sites (filled circles) in the Etowah River basin. The shaded area in the center of the basin is Lake Allatoona, a reservoir on the main stem Etowah River. Inset graph shows temporal changes for cropland and population density in Cherokee County, which is centrally located in the basin.