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AQUATIC GAP ANALYSIS: TOOL FOR WATERSHED SCALE ASSESSMENT OF FLUVIAL HABITAT AND BIODIVERSITY

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ABSTRACT

Methods for the conservation of stream habitat and biodiversity at the watershed scale have not been developed. Watersheds span large land areas, encompass a connected range of stream sizes, and integrate natural and altered properties of a drainage area. Methods are needed to identify the locations of high biodiversity in watersheds, compare aquatic biodiversity distributions among regions, and provide watershed-scale information useful for targeting conservation measures. The National Biological Service (USA) in cooperation with other Federal and State agencies developed geographic information system (GIS) methodology called Gap Analysis to identify the distribution of biodiversity over large spatial areas. To date, it has been used to address only terrestrial conservation needs. We are developing an aquatic version of the Gap Analysis in the Allegheny River drainage in western New York State to define the methodology and evaluate the feasibility of predicting biodiversity distribution at the watershed scale.

Our standardized stream reach accounting system is based on the U. S. Environmental Protection Agency Reach File 3 System. Each stream reach is classified into one of 18 habitat types for fish faunal predictions and one of 8 habitat types for invertebrate faunal predictions. Habitat types were defined using the following sets of physicochemical attributes: stream size (headwaters, large streams/small rivers, large rivers), physical habitat (dominated by natural geomorphological processes, moderately altered, and dominated by human structures and controls), water quality (suitable for life support, biologically stressful), gradient (steep, low slope) and riparian forest cover (closed canopy over channel, open channel). Stream size was determined from drainage area using the GIS. Physical habitat, reach gradient, and riparian forest cover were classified from topographic and land use maps. Physicochemical data from the U. S. Environmental Protection Agency STORET database provides a means to classify water quality. Using our habitat typing system, we predict that the highest fish diversity will be found in medium size streams with natural fluvial channels and good water quality, whereas the most reduced fish faunas will be found in large rivers with highly modified channels and poor water quality. For invertebrates, we predict that the greatest diversity (in terms of ecological function groups) will be in small and medium size streams with primarily a closed canopy, steep gradient, and good water quality.

Our GIS modeling effort succeeded in predicting the expected distribution of fish and invertebrate diversity at the watershed scale. Adequate biological and physicochemical data appear available and compatible with watershed-scale GIS programs. We also have extensive biological survey data that provides an independent means to testing the validity of our biodiversity predictions.

KEY-WORDS: Biodiversity / Conservation / Gap Analysis / GIS / Allegheny River / Biotic indices / Stream habitat / Watersheds / Water quality

INTRODUCTION

Methods for the conservation of stream habitat and biodiversity at the watershed scale have not been developed. Watersheds span large land areas, encompass a connected range of stream sizes, and integrate natural and altered properties of a drainage area. Methods are needed to identify the locations of high biodiversity in watersheds, compare aquatic biodiversity distributions among regions, and provide watershed-scale information useful for targeting conservation measures. The National Biological Service (USA) in cooperation with other Federal and State agencies developed geographic information system (GIS) methodology called Gap Analysis (Scott et al. 1993) to identify the distribution of biodiversity over large spatial areas. To date, it has been used to address only terrestrial conservation needs. We are developing an aquatic version of the Gap Analysis in the Allegheny River drainage in western New York USA to resolve two main questions: (1) is there adequate biological information to link faunal composition to stream reaches (tributary confluence to confluence) on a large scale and (2) Can useful physicochemical data be assembled for stream reach habitat classification? This study seeks to create a methodology to answer these questions and evaluate the overall feasibility of predicting biodiversity distribution at the watershed scale.

METHODS

The basic elements of our GIS model are stream segments, where a segment is the portion from tributary confluence to tributary confluence or in lakes from stream mouth to stream mouth or outflow. A River Reach File version 3.0 Arc/Info layer was obtained from the U.S. Environmental Protection Agency to numerically and graphically catalog the stream segments in the Allegheny River basin. Each stream segment in this file is numbered and geospatially referenced at the 1:100,000 topographic (U.S. Geological Survey [USGS]) map scale. There are 1340 stream segments in the New York portion of the Allegheny River basin. All stream segments in the Reach File were highlighted on 1:24,000 USGS maps to ease identification of segments and help delineate drainage divides. The divides were then digitized and edge matched to form a complete map layer. A program to calculate accumulated drainage area can use this layer to obtain the total drainage area for any stream segment. The accumulated drainage area measurements are used in classifying stream size.

Models for predicting biodiversity

Each stream segment was designated as one of 18 habitat types which were used to classify flowing water habitats to make predictions of characteristic fish species. Habitat types were defined using the following sets of physicochemical attributes: stream size (headwaters, large streams/small rivers, large rivers), physical habitat (dominated by natural geomorphological processes, moderately altered, and dominated by human land use and controls), and water quality (suitable for life support, biologically stressful). As mentioned above, the drainage area GIS layer was used to determine stream size. Topographic and land use maps were used to determine physical habitat, reach gradient, and riparian forest cover. Physicochemical data from the U.S. Environmental Protection Agency STORET database provided a means to classify water quality.

A list of fish species recorded from the Allegheny River basin was developed to classify fish species by habitat type. Information was gathered from various "Fishes of" books and previous bioassessment and fish distribution studies (Bramblett and Fausch, 1991; Karr et al., 1986; Ohio EPA, 1989; Schlosser, 1982). Stream size preference was categorized as headwaters, large streams/small rivers, and large rivers. In cases where a species was associated with more than one stream size, both categories were used with the first designation indicating the primary stream size. Tolerance to habitat degradation was categorized as intolerant, moderately tolerant, or tolerant. Three water quality tolerance ratings have been used in past classifications (intolerant, moderately tolerant, tolerant). These were regrouped into two categories (intolerant, tolerant) by moving moderately tolerant species into the intolerant class. Thus, only the most tolerant fish species are considered tolerant in this study.

The classification of habitat types for invertebrate taxa was handled in a similar way as fish. Stream segments were classified into one of eight habitat types for invertebrate diversity predictions using the following sets of physicochemical attributes: gradient (steep, low slope), riparian forest cover (closed canopy over channel, open channel), and water quality (suitable for life support, biologically stressful). All large rivers were considered to have open channels regardless of riparian status. Physical habitat, reach gradient, and riparian forest cover were classified from topographic and land use maps for each stream segment. Physicochemical data from the U. S. Environmental Protection Agency STORET database was used to classify water quality.

The approach for predicting characteristic invertebrate taxa by habitat type was the same as the approach for fish. Eight hundred and seventeen taxa (mostly benthic insects) were recorded in stream and river samples in the New York portion of the Allegheny River basin. Almost half of these taxa were identified at the species level. Sample data is from bioassessment surveys completed in 1981 and 1989-1990 by the New York State Department of Environmental Conservation [NYDEC], Division of Water (Bode et al., 1991, 1993). Feeding guilds were assigned from Bode et al. (1991) as follows: predator, collector-gatherer, collector-filterer, scraper, or shredder. Species and genus-level tolerances for degraded water quality were based on Bode et al. (1991) using the categories: tolerant and intolerant. Family-level tolerances were taken from Hilsenhoff (1988). When taxa were not assigned a family tolerance by Hilsenhoff (1988), their species tolerance was used. The life style habit of each taxa was taken from Merritt and Cummins (1984) for the insects, and from Pennak (1978) for the other invertebrates. Life habit categories were: burrower, clinger, swimmer, climber, sprawler, and not specific. When several habits were listed for a taxa, the first was used for our classification.

<u>Testing the biodiversity predictions</u>

We are relying on GIS layers of measured data for fish and invertebrate assemblages to indicate biodiversity priority areas. Two map layers, fish species richness and biological integrity (a community quality index), were developed to test fish assemblage diversity. For the fish species richness layer, we assembled all known data in recent decades that reports on whole fish community collections. The primary sources were: intensive surveys of the French Creek portion of the Allegheny River basin and recent (late 1980s and 1990s) surveys conducted by the NY Department of Environmental Conservation. A total of 114 fish species have been recorded in the New York portion of the Allegheny River basin. For the index of biotic integrity map layer, we modified the original index of biotic integrity (Plafkin et al. 1989; reviewed in Karr et al. 1986; Karr 1991) for our study area. We need further refinement of the our index of biotic integrity because quality ratings are too low for species-poor, coldwater streams in forested areas. A headwater index of biotic integrity will soon be published (Lyons et al. 1996) to correct this problem.

We gathered data from the 1980s covering invertebrate assemblage collections (largely 100-organism, benthic kick-samples) to test the invertebrate biodiversity predictions. The primary sources were: intensive surveys of the French Creek portion of the Allegheny River and bioassessment surveys conducted by the NYDEC (Bode et al., 1993). The NYDEC bioassessment collections are the most extensive, and field sampling was done with multiplate samplers (1981) and 100-organism kick netting (1989-1990). Details of the sampling protocol and processing is fully described by Bode et al.

(1991). We are relying on GIS layers of taxa richness and six measures of community quality to indicate biodiversity priority areas due to the high taxonomic diversity of aquatic invertebrates. The six community parameters calculated for each invertebrate collection are taxa (species) richness, EPT index, biotic index, family-level biotic index, diversity (Shannon-Wiener), and percent model affinity. Methods and scoring criteria for each described in Bode et al. (1991) except for the family biotic index which was taken from Hilsenhoff (1988) with some scoring modifications.

RESULTS AND CONCLUSIONS

In the beginning of the study we were concerned that the Environmental Protection Agency River Reach File version 3.0 base layer of stream segments may not meet our needs. After extensive use it was determined to have many advantages for our purposes. The streams and lakes in the Reach File matched what was printed on the 1:100,000 scale USGS topographic maps. This was important for matching reach numbers from the Reach File to habitat classifications from the topographic maps. The reach numbers also served as a useful link to other data sets and coverages. In addition, the navigational attributes of the Reach File were useful for tracing upstream and downstream directions from any point on a stream and hence determining cumulative drainage area.

Our predictions for fish diversity indicate that mid-size streams should have the highest diversity (Figure 1). Although large rivers generally have longer species lists than smaller waters, the middle size class of streams had the greatest number of characteristic species. Water quality appears to diminish fish diversity to a much greater degree than habitat degradation. However, degraded water quality is much less common on the watershed scale than habitat alteration. Therefore, we expect that habitat alteration will have a more pervasive effect on fish diversity than water quality degradation, but water quality has a stronger effect in fish diversity when it is stressful.

As for fish, water quality degradation appears to have a much greater impact on invertebrate diversity than physical habitat alteration (Figure 2). Degraded water quality is much less common on the watershed scale than habitat changes like riparian deforestation and channelization. Riparian vegetation removal causes open canopy stream segments shifting the community to a new faunal composition more oriented to use of algae as a food source. The combination of a diverse food base (allocthonous input from riparian forest) and coarse substrate provides the widest range of feeding guilds and life habit groups. Consequently, we predict that shaded and high gradient streams will have the highest anticipated taxonomic diversity for invertebrates.

Combining predicted patterns for fish and invertebrates, we expect that overall biodiversity is likely to be highest in mid-sized streams with a high gradient, forested riparian zones and valley, and suitable water quality. Stream segments with this combination of attributes will be expected to have the highest diversity of fish and invertebrates. These high diversity stream segments are likely to be sparsely distributed throughout watersheds with abundant human land uses.

The measured data used to test the biodiversity predictions show a scattered distributional pattern of diverse, quality fish communities for both species richness and biological integrity. The highest rated stream segments are on mid-size streams spread across the river basin. Therefore, field data does not indicate clusters of high diversity and quality stream segments for fish in the Allegheny River basin. Rather, what appears to be priority conservation sites are well dispersed in the region.

Our GIS modeling effort succeeded in predicting the expected distribution of fish and invertebrate diversity at the watershed scale. Adequate biological information and useful physicochemical data appear available and compatible with watershed-scale GIS programs. However, more work needs to be done to develop a sound method for the conservation of stream habitat and biodiversity at the watershed scale. Further studies are planned to determine the predicted biodiversity of mussels in the Allegheny River basin and create an erosion model to link land cover to biodiversity.

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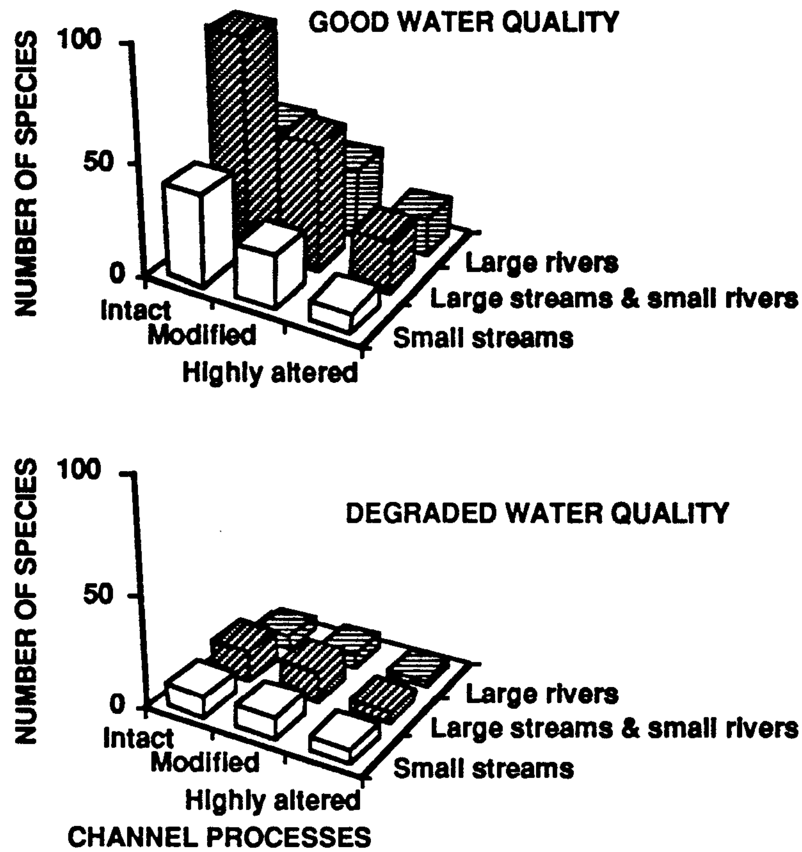

Figure 1: Predicted Fish Fauna

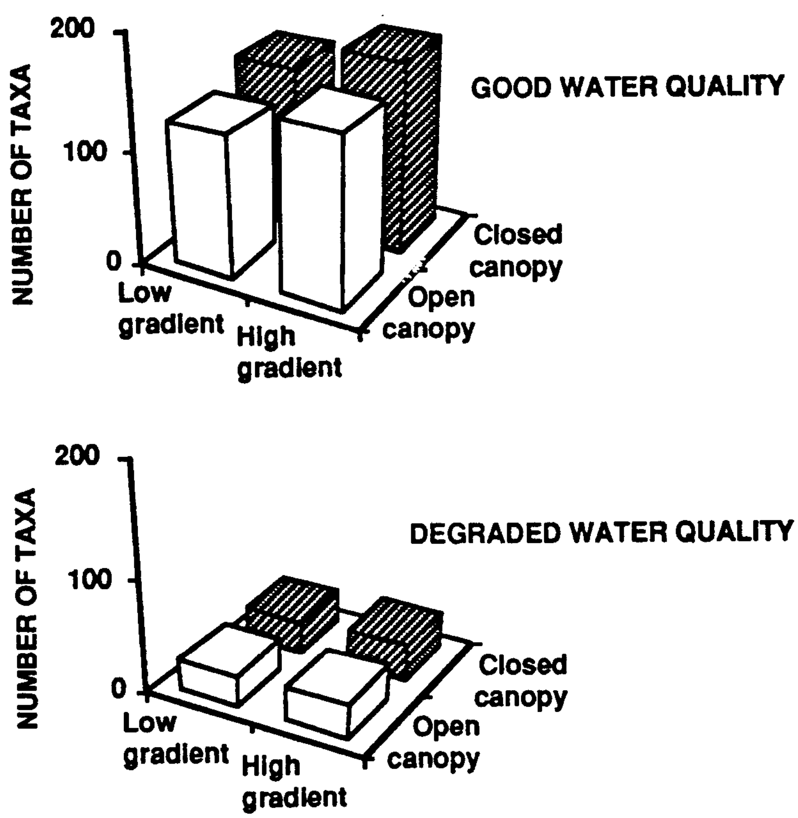

Figure 2: Predicted Macroinvertebrate Fauna