BEYOND THE INDICES: RELATIONS OF HABITAT AND FISH CHARACTERISTICS IN THE GEORGIA PIEDMONT

Brenda Rashleigh[1] and Jonathan G. Kennen[2]

AUTHORS: [1]Ecologist, U.S. Environmental Protection Agency, 960 College Station Road, Athens, Georgia, 30605; and [2]Aquatic Biologist, U.S. Geological Survey, 810 Bear Tavern Road, W. Trenton, NJ, 08628.

REFERENCE: Proceedings of the 2003 Georgia Water Resources Conference, held April 23-24, 2003, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, The University of Georgia, Athens, Georgia.

Abstract. Multivariate statistical techniques were used to gain additional insight about ecological variability and the dominant environmental gradients in biological and habitat data from Piedmont streams sampled by the Georgia Department of Natural Resources. Principal components analysis indicated that relevant patterns in the fish assemblage were related to the number of benthic invertivore, cyprinid, and simple lithophilic species; and pioneering versus sunfish species. In addition, principal components analysis indicated that habitat variability was related to number of riffles, sediment deposition and embeddedness, bank stability, and stream width and depth. Multiple regression analysis of fish assemblage metrics indicated that the number of benthic invertivore, cyprinid, and lithophilic species appeared to be negatively associated with many substrate characteristics that are indicative of sedimentation. Results also indicate that from a management perspective it may be necessary to evaluate small headwater streams separately from larger streams.

INTRODUCTION AND BACKGROUND

The Georgia Department of Natural Resources (GDNR) conducted biological sampling at 180 stream sites in the Georgia Piedmont (1998-99) and recorded several trophic and abundance characteristics of the fish assemblages and habitat at each site. Indices based on these characteristics were derived using established scoring criteria (Shaner 1999). Index scores are commonly used by many natural resource agencies for comparison of streams and as screening tools (Davis and Simon 1995, Shaner 1999, Karr and Chu 1999).

In this analysis we focus at the level of the characteristics, in order to gain additional insight about ecological variability and to identify the dominant environmental gradients across sites sampled. We perform an exploratory analysis using multivariate statistical methods to evaluate dominant patterns in fish assemblage data. Multivariate approaches have been shown to be powerful methods in ecological studies (Wright et al. 1984, Leland et al. 1986, Palmer et al. 1991, Kennen 1999). The advantages of multivariate techniques are greater precision and accuracy (Reynoldson et al. 1997) coupled with a minimal loss of information (Gauch 1982). Currently, multivariate analysis is not one of the techniques used to analyze biocriteria data by the GDNR. The results of these analyses can be used to guide protection and management activities in the Georgia Piedmont, and support restoration efforts of impaired streams throughout the state.

EXPERIMENTAL DESIGN AND METHODS

The initial data set of 180 sites was stratified to remove confounding variables and minimize the effects of natural variability. A subset of sites (N=88) that met a specific drainage area criterion (8-39 km^2), whereby no significant relation existed between drainage area and species richness, were selected for further analysis. A subset of biological metrics (N=13) used by GDNR in their biological index was selected. When necessary, biological metrics were standardized by reach length.

Habitat variables used in the analysis were reduced to a subset (N=21) of those measured that had sufficient variability, no missing values, and were uncorrelated ($r^2<0.9$; Spearman rank correlation). All habitat variables were checked for normality and homoscedasticity and appropriately transformed, if necessary. Two habitat variables, number of pools and number of riffles, were standardized by reach length. All subsequent statistical analyses were conducted on this reduced set of habitat variables.

Principal components analysis (PCA) (SAS Institute Inc. 1989) was used to evaluate dominant trends in the biological and habitat data and isolate a subset of variables that accounted for the greatest proportion of variance for use in multiple linear regression (MLR) analysis. PCA was run on the correlation matrix and two principal components were retained for evaluation in each analysis based on the broken-stick method (Jackson 1993).

Multiple linear regression analysis was conducted using only those biological metrics that loaded >0.5 on at least one of the first two PCA axes. Conservative stepwise selection criteria using a cutoff p-value of 0.1 to enter and 0.05 to leave the model were applied.

RESULTS

The first two PCA axes resulting from analysis of biological metrics explained 35 and 23-percent of the total variance, respectively. The first PCA axis was represented in the positive direction by higher numbers of native, benthic invertivore, cyprinid, and simple lithophilic species, as well as percent lithophils (Figure 1). A second axis was characterized by a shift from pioneering to sunfish species.

The first two PCA axes resulting from analysis of habitat variables explained 36 and 14-percent of the total variance, respectively. PCA indicated that habitat variability along the first axis was related to cover, epifaunal substrate, number of riffles, sediment deposition and embeddedness, and bank stability (Figure 2). The second PCA axis was represented in the positive direction by stream depth, width, and depth of pools.

MLR analyses describing the relation between fish metrics and the habitat variables were highly significant (Table 1). The fish metrics were related to the different habitat variables in various ways. In particular, embeddedness and sediment deposition showed significant positive relationships with native cyprinid and sensitive species, respectively. Epifaunal substrate (a measure of average particle size) was positively related to benthic invertivores, number of lithophilic species, and percentage of lithophilic individuals.

MLR analyses also indicated that depth was strongly and positively related with top carnivores and sunfish, and negatively related to percent of pioneering species. Depth of pools was positively related to number of native species and native sunfish species, and negatively related to the percentages of pioneering and insectivorous cyprinid individuals.

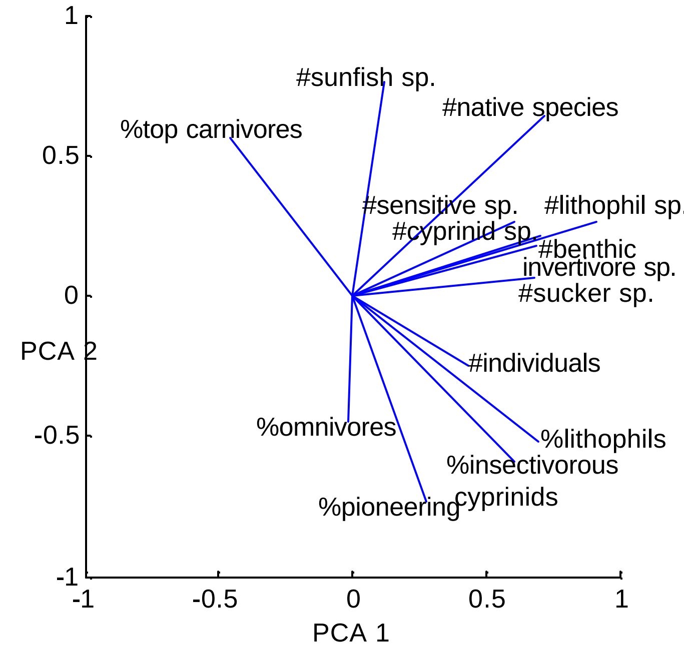

Figure 1. Principal components analysis of biological metrics for streams in the Georgia Piedmont, 1998-9.

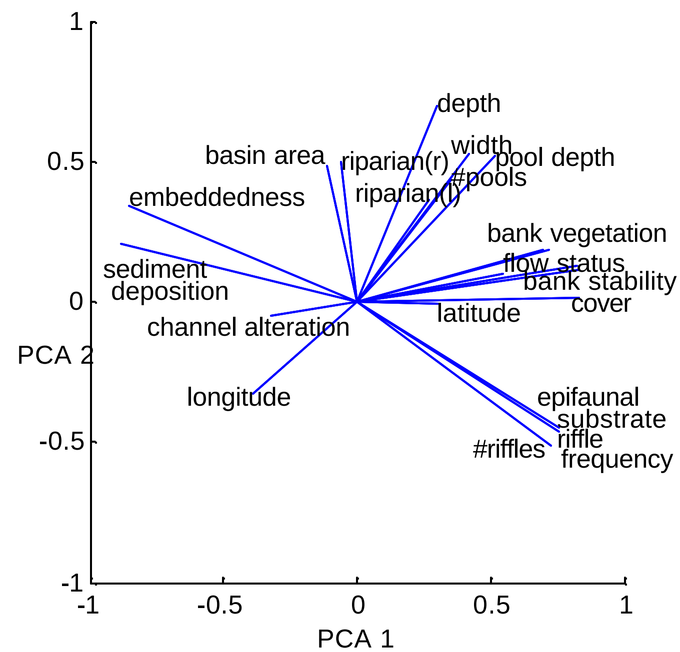

Figure 2. Principal components analysis of habitat variables for streams in the Georgia Piedmont, 1998-9.

Table 1. Results of significant multiple linear regression models relating selected biological metrics of the fish fauna to habitat characteristics in Piedmont Georgia streams, 1998-9

Biological Metric	Model r^2	Partial r^2	P-value	Habitat variables
Number of native species	0.30	0.15	<0.001	-Stream width
		0.11	<0.001	+Depth of pools
		0.04	0.033	-Sediment deposition
Number of benthic invertivores	0.07	0.07	0.015	+Epifaunal substrate
Number of native sunfish species	0.29	0.18	<0.001	-Stream width
		0.11	<0.001	+Depth of pools
Number of native sucker species	0.13	0.09	0.005	+Cover
		0.04	0.048	+Longitude
Number of native cyprinid species	0.31	0.20	<0.001	-Stream width
		0.04	0.045	-Embeddedness
		0.04	0.046	-Right bank stability
		0.03	0.050	+Left bank stability
Number of sensitive species	0.28	0.17	<0.001	-Sediment deposition
		0.08	0.004	-Right bank stability
		0.03	0.078	+Left bank stability
Number of simple lithophil species	0.19	0.11	0.002	-Stream width
		0.08	0.005	+Epifaunal substrate
Percent top carnivore individuals	0.24	0.19	<0.001	+Stream depth
		0.05	0.016	-Stream width
Percent simple lithophil individuals	0.35	0.23	<0.001	-Stream depth
		0.07	0.006	+Epifaunal substrate
		0.05	0.011	-Number of riffles
Percent of pioneering individuals	0.54	0.35	<0.001	-Depth of pools
		0.14	<0.001	+Longitude
		0.05	0.005	-Stream depth
Percent insectivorous cyprinid individuals	0.30	0.25	<0.001	-Stream depth
		0.05	0.024	-Depth of pools

DISCUSSION

Habitat variables of embeddedness, sediment deposition, and epifaunal substrate influenced many components of the fish assemblage and all are factors related to variation in particle size. Changes in particle size have been found to be indicative of sedimentation (see Waters 1995) and Wood and Armitage (1987) suggest that sedimentation is a key concern in streams threatened by anthropogenic disturbance. In addition, sedimentation has been recognized as a problem for fishes in the Georgia Piedmont (e.g., Barnes et al. 1996).

Results of this study suggest that the best biological indicators of habitat degradation by sediment in the Georgia Piedmont are the numbers of sensitive species, lithophils, and benthic invertivores. Numbers of native species and native cyprinids also appeared to respond to sedimentation effects. Other fish metrics showed little or no sensitivity to sediment. Because of the differential responses by the individual fish metrics, it may be better to use an indicator species approach, rather than an index approach, to monitor sediment effects in Piedmont streams.

The additional finding that many components of the fish assemblage are strongly influenced by width and depth indicates that natural differences in stream size are important. The changes shown in MLR results are consistent with those predicted by Schlosser (1987) for warmwater streams. The natural influence of stream size appeared to be significant in the results even though variability in drainage area was reduced and fish and habitat characteristics were standardized by reach length in an attempt to remove this effect. The influence of stream size on Piedmont fish communities was also identified by Schleiger (2000).

This sensitivity to differences in width and depth may also indicate that the fish assemblage may be highly sensitive to hydrologic alteration. However, habitat variables most likely to represent the effects of changing hydrology, such as channel alteration and channel flow status, did not appear to be significant in this analysis.

The role of depth and depth of pools may, in fact, also be indicative of excess sediment. Excess sediment can fill the pools and reduce pool habitat for fishes (Waters 1995). The role of sediment in pools needs to be separated from the influence of stream size.

Although habitat variables were significant in explaining patterns in Piedmont stream fish assemblages, less than half of the variation in biological metrics was typically explained by these variables. Other factors that were not considered here, but could explain additional variance, include variability in sampling time and conditions, chemical water quality factors, and historical watershed and instream influences.

CONCLUSIONS AND RECOMMENDATIONS

These results can be used to guide protection and management activities in the Georgia Piedmont, and support restoration efforts of impaired streams in the state. Our results indicate that the role of stream size needs to be considered carefully in stream assessment and management. It may be necessary to evaluate small headwater streams separately from larger streams, which are known to support different types of fish assemblages. This approach is being used or considered in other states (e.g., Ohio EPA 2002).

This analysis identifies sediment deposition, embeddedness, and bank stability as strong indicators of fish assemblage degradation in the Piedmont. These attributes need to be a top priority for stream restoration efforts aimed at maintaining or improving the biotic integrity of the fish assemblage. Some individual metrics that are common components of biological indices appear to be stronger indicators of degradation because they account for a greater proportion of the variability in the fish assemblage. Such biological metrics could be used as indicators to more closely monitor the recovery of streams that have been restored.

ACKNOWLEDGMENTS

Special thanks to the Stream Survey Team at the Georgia DNR for providing us with the data. We are grateful for the helpful comments of two anonymous reviewers. This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for publication.

LITERATURE CITED

Barnes, K.H., J.L. Meyer, and B.J. Freeman, 1996. Suspended sediments and Georgia's fishes: An analysis of existing information. Technical completion report for project #14-08-0001-G2013 (04). Georgia Water Resources Program, Georgia Institute of Technology, Atlanta GA.

Davis, W.S., and T.P. Simon, 1995. *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making.* CRC Press, Inc., Boca Raton, Florida.

Jackson, D.A., 1993. Stopping rules in principal components analysis: A comparison of heuristical and statistical approaches. *Ecology* 74(8):2204-2214.

Karr, J.R., and E.W. Chu, 1999. *Restoring life in running waters: better biological monitoring.* Island Press, Washington D. C.

Kennen, J.G., 1999. Relation of macroinvertebrate community impairment to catchment characteristics in New Jersey streams. *Journal of the American Water Resources Association* 35(4):939-955.

Leland, H.V., J.L. Carter, and S.V. Fend, 1986. Use of detrended correspondence analysis to evaluate factors controlling spatial distribution of benthic insects. *Hydrobiologia* 132:113-123.

Ohio EPA, 2002. Field evaluation manual for Ohio's primary headwater habitat streams. Division of Surface Water, Columbus, Ohio.

Palmer, C.G., J.H. O'Keeffe, and A.R. Palmer, 1991. Are macroinvertebrate assemblages in the Buffalo River, southern Africa, associated with particular biotopes? *Journal of the North American Benthological Society* 10:349-357.

SAS Institute Inc., 1989. SAS/STAT® users guide, version 6, 4th ed., v. 2, Cary, North Carolina, SAS Institute Inc., 943 p.

Schleiger, S.L., 2000. Use of an index of biotic integrity to detect effects of land uses on stream fish communities in West-Central Georgia. *Transactions of the American Fisheries Society* 129:1118-1133.

Schlosser, I.J., 1987. A conceptual framework for fish communities in small warmwater streams. In: W.J. Matthews and D. C. Heins, eds., Community and Evolutionary Ecology of North American Stream Fishes. University of Oklahoma Press, Norman, Oklahoma, pp. 17-24.

Shaner, B.L., 1999. Development of a standardized index of biotic integrity for the Piedmont region of Georgia. In: Proceedings of the 1999 Georgia Water Resources Conference, K.J. Hatcher, editor, University of Georgia, Athens, Ga., pp. 287-290.

Waters, T.F., 1995. *Sediment in streams: sources, biological effects, and control.* American Fisheries Society Monograph 7, Bethesda, Maryland.

Wood, P. J., and P. D. Armitage, 1997. Biological effects of fine sediment in the lotic environment. *Environmental Management* 21:203-217.

Wright, J.F., D. Moss, P.D. Armitage, and M.T. Furse, 1984. A preliminary classification of running-water sites in Great Britain based on macro-invertebrate species and the prediction of community type using environmental data. *Freshwater Biology* 14:221-256.