

Ecological Reference Models for Blackwater Streams: a Prerequisite for Successful Ecosystem Recovery and Management

Michael Paller, Jack Feminella, Ely Kosnicki, Stephen Sefick, Miller Jarrell, Dean Fletcher, Tracey Tuberville, Sean Sterrett, Andrew Grosse, Blair Prusha

AUTHORS: Michael Paller, Savannah River National Laboratory, Building 773-42A, Aiken, SC 29803; Jack Feminella, Ely Kosnicki, Stephen Sefick, Miller Jarrell, Auburn University, Department of Biological Sciences, 101 Rouse Life Science Building, Auburn University, AL 36849; Dean Fletcher, Tracey Tuberville, Sean Sterrett, Andrew Grosse, Savannah River Ecology Laboratory, P.O. Drawer E, Aiken, SC 29802; Blair Prusha, University of Georgia, Odum School of Ecology, Athens, GA 30602

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Abstract: Department of Defense (DoD) and Department of Energy (DOE) installations in the Southeast protect some of the largest remaining relatively intact coastal plain ecosystems including blackwater streams, a unique resource. The objective of recently awarded DoD Strategic Environmental Research and Development Program (SERDP) project No. 1694 is to develop ecological reference models (ERMs) for headwater to third/fourth-order blackwater streams. These models will specify end-states for ecosystem recovery efforts. Reference models represent the maximum process integrity, structural complexity, and biological diversity that can be achieved under prevailing conditions of land use and regional ecological integrity. Each model includes three hierarchical levels of habitat (landscape, watershed, and instream/riparian) plus biotic condition. Biota are the core of the models because they integrate all aspects of their environment and because of their intrinsic value. Models are being developed by quantifying biotic and abiotic structure and function at minimally disturbed sites in Fort Benning GA, Savannah River Site SC, Fort Bragg NC, and surrounding areas, as well as by predictive modeling. Geology, climate, hydrology, morphology, vegetation, and land use are being described by GIS; instream habitat, stream discharge, and water chemistry are being characterized from field data; and fish and benthic macroinvertebrates (BMIs) are being quantified with electrofishing and a multiple habitat sampling approach, respectively.

Results from the first year have provided preliminary estimates of key BMI and fish assemblage metrics for some installations and have shown that BMI assemblages are strongly influenced by habitat features such as the stream width/depth ratio and specific conductance. Redundancy analysis of pre-existing data from the Savannah River Site (SRS) shows that instream habitat had a greater influence than upland watershed disturbance on BMI assemblages, but that instream habitat quality appears to decline with increasing watershed

disturbance. These results and those of succeeding years will provide guidance needed by resource managers for the design of recovery efforts that produce cost-effective and quantifiable results.

INTRODUCTION

There are large DoD and DOE installations on the Atlantic Coastal Plain that protect important ecosystems including blackwater streams, a distinctive resource that supports high biodiversity. Degradation of blackwater streams can cause biodiversity loss and adversely affect nutrient cycling, natural water purification, and other valuable ecological functions of floodplain ecosystems. The DoD and DOE are committed to the recovery of degraded streams but are constrained by a lack of reference models that specify end-states representative of relatively undisturbed conditions. The objective of DoD SERDP project No. 1694, recently awarded to the Savannah River National Laboratory, Auburn University, and the Savannah River Ecology Laboratory, is to develop ecological reference models for streams on the Atlantic Coastal Plain and an assessment framework for evaluating ecosystem status and measuring progress towards recovery goals. This paper outlines the process being used to develop the reference models and presents some preliminary results from the first year of this four year study.

BACKGROUND

Blackwater streams

DoD and DOE installations in the Southeast are a unique ecological resource because they encompass a diversity of natural areas that have been largely excluded from agricultural, urban, and industrial development. These installations protect some of the largest remaining

relatively intact coastal plain ecosystems. However, the integrity of these ecosystems has been affected by onsite activities; offsite activities on local, regional, and global scales; and historical land uses.

Blackwater streams are among the most important and unique ecosystems on DoD and DOE holdings in the Southeast. These low-gradient, slow-flowing streams are typically fed by water seeping through sandy soils that underlie floodplains and swamps. The water is stained by decaying organic matter leached from the sand, usually acidic, and transports little sediment. Stream bottoms are typically sandy. Snags and other woody material form debris dams that affect detrital dynamics and provide important habitat for BMIs and fish.

Strong connectivity with their floodplains mediates many ecological processes in blackwater streams (Meyer et al. 1997). Dense floodplain forests contribute substantial organic matter that is processed by microbial and invertebrate communities. Inundation and runoff from the floodplain make fluvial fine particulate organic matter (FPOM) and dissolved organic C (DOC) available to stream organisms and drive blackwater stream food chains, which are largely allochthonous (heterotrophic), especially in smaller heavily shaded streams.

Blackwater streams support a diverse vertebrate and invertebrate fauna. A one-year study in Upper Three Runs, a relatively undisturbed blackwater stream on the SRS identified at least 551 species of aquatic insects, including 52 new species and two new genera (Morse et al. 1983), which, at the time, was the highest richness for any North American stream of comparable size. Streams on the SRS also support over 60 species of fishes, and streams on nearby Fort Gordon (DoD) support at least 44 species (Marcy et al. 2005).

Ecological reference models

Coastal plains streams are ideal for the development of ERMs because they are intrinsically important, highly visible, and of strong public interest. In addition, the integrity of stream ecosystems is a surrogate for the integrity of other ecosystems because of the connectivity between streams and their watersheds. Flood plains filter contaminants, supply organic C, and provide habitat for critical life stages of aquatic organisms, and upland ecosystems affect the quality and quantity of water in the watershed. Streams are also influenced by regional and global factors that affect climate, movement of atmospheric pollution, and dispersal or extirpation of species. Therefore, promoting the recovery of coastal plains streams necessitates promoting the recovery of other ecosystems within and outside the watershed.

ERMs for streams should represent the maximum process integrity, functionality, structural complexity, and biological diversity that can be achieved under prevailing conditions of land use and regional ecological integrity.

Ideally, an ERM depicts natural structure and function in the absence of human disturbance. In practice, this model is usually a minimally disturbed model that depicts structure and function in the absence of significant disturbance and acknowledges that it is usually impossible to completely avoid the influence of human activities.

ERMs for streams are best defined on the basis of the structure and function of the biota because biota integrate all aspects of the abiotic environment. They reflect both transient and chronic stressors and are generally more informative than physicochemical indicators of environmental quality. Functional aspects of ecosystem quality, which are difficult to measure directly, can often be inferred from structural features of the biota; for example, BMI functional feeding groups can be used as indicators of C processing in streams and flood plains.

ERMs are usually developed by quantifying biological structure and function at a group of reference sites that are undisturbed or minimally disturbed. Selection of reference sites involves the application of screening criteria to identify appropriate sites. The criteria are generally based on chemical and physical characteristics. Historical reconstruction and predictive modeling can also be used when acceptable sites are unavailable.

EXPERIMENTAL DESIGN

ERMs are being developed for headwater to third/fourth-order coastal plains streams in NC, SC, and GA. They are based largely on the characteristics of minimally disturbed or undisturbed (i.e., reference) sites. Several ERMs are being developed to encompass the variability associated with different locations and stream types. It is desirable to have several sites to represent each ERM but not to relax reference site criteria too greatly, necessitating development of screening criteria for reference site selection. In addition to reference sites, disturbed sites are being sampled to quantify relationships between disturbance and biotic and abiotic responses.

Each ERM will include three hierarchical habitat scales in addition to biotic condition:

Landscape. This is the geographic area surrounding the watershed emphasizing connectivity to source pools and dispersal routes, and potential regional disturbance, habitat fragmentation, and climatic changes. A watershed may suffer biotic impoverishment if isolated from source pools of colonizing aquatic organisms.

Watershed. The watershed upland of the riparian zone affects instream habitat (e.g., water quality/quantity).

Stream/riparian habitat. Stream and riparian habitat provide direct support for aquatic biota, and departures from natural conditions will have substantial effects on the stream biota.

Biotic condition. The biota are the core of the reference model because they integrate of all aspects of their environment and because of their intrinsic value. We hypothesize that the influence of habitat on stream biota will increase with progress from landscape to instream scales.

METHODS

Reference sites in Fort Benning GA, SRS SC, Fort Bragg NC, and surrounding areas are being selected on the basis of screening criteria developed at basin, segment, and stream reach scales and implemented through field surveys and GIS analyses. Basin and segment characterization employ digital elevation models to delineate watersheds, calculate disturbance levels from National Landcover Data (NLCD), and describe vegetation, drainage area, drainage density, basin length, drainage shape, basin relief, stream length, land use/land cover, and other watershed features. Field data are being used to characterize habitat, hydrology, and water chemistry in reaches within stream segments.

Both fish and BMI data are being collected from the study sites because these assemblages differ in requirements and sensitivities. Sample reaches range from 150 to 210 m in the smallest to the largest streams, respectively. Fish assemblage composition is being assessed by backpack electrofishing employing two passes through each site and division of the site into segments to quantify species-reach length relationships. BMI assemblage composition is being assessed using a quadrat (Surber sampler) and multiple habitat sampling approach. Pertinent pre-existing biological data are also being collected from all sites to provide historical information.

RESULTS AND DISCUSSION

The following preliminary results represent data collected from a small subset of reference sites sampled during the first year of the four year study plus a preliminary analysis of pre-existing data from the SRS.

BMI's are a critical component of blackwater stream ecosystems because they process allochthonous organic matter and constitute food for vertebrates. Key characteristics of BMI assemblages from reference streams on Fort Bragg NC are listed in Table 1. Some BMI metrics are strongly related to habitat. For example, percent shredders is inversely related to the stream bankfull width:depth ratio (Figure 1), and BMI density is related to specific conductance (Figure 2). These and similar relationships will be investigated further with additional sampling and compared among locations to determine their generally applicability to coastal plain blackwater streams.

Data from the SRS provide a preliminary view of fish community structure in first- and second-order coastal plains streams in the SC Sand Hills Ecoregion. Figure 3 represents a preliminary estimate of expected species richness under conditions of minimal disturbance. Similarly, Figure 4 depicts the percent abundance and occurrence of fish species suggesting the possible importance of several taxa as indicator species representing one class of undisturbed stream.

Pre-existing data were analyzed to determine the relative influence of habitat at two hierarchical spatial scales (watershed and in-stream) on BMI assemblages collected from SRS streams with a multiple habitat sampling protocol. Redundancy analysis (a multivariate method for identifying patterns among biotic and abiotic variables, Jongman et al. 1995) indicated that a combination of variables including stream width (a natural determinant of BMI assemblage structure), instream

Table 1. Metrics describing macroinvertebrate assemblages collected from Fort Bragg streams.

Variable	Mean	Standard deviation	Minimum	Maximum
Chironomidae richness	20.8	8.6	10	34
Total taxa richness	37.5	11.6	23	53
% Scrapers	12.2	6.6	2.5	18.8
% Shredders	8.0	7.3	0	20.9
Shannon <i>H'</i>	2.8	0.4	2.3	3.3
Density	1709.0	1297.0	412.2	3387.0
Pielou's <i>J</i>	0.8	0.1	0.7	0.8
% Hydropsychidae/ EPT	9.3	14.2	0	33.3
% Chironomidae	61.8	10.2	49.0	75.4
GA MMI	45.6	8.3	33.4	55.6
GA Biotic Index	5.1	0.7	4.3	5.9

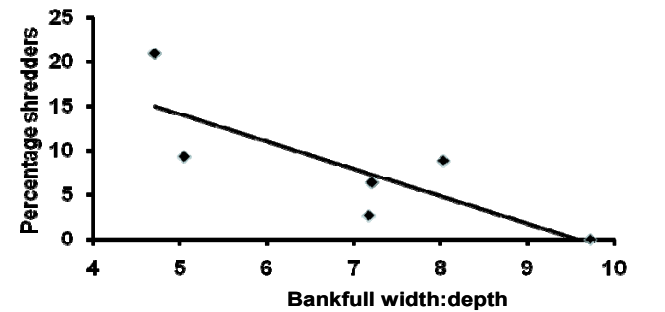


Figure 1. Relationship between stream morphometry as indicated by the bankfull width to depth ratio and percentage of the shredder benthic macroinvertebrate functional feeding group.

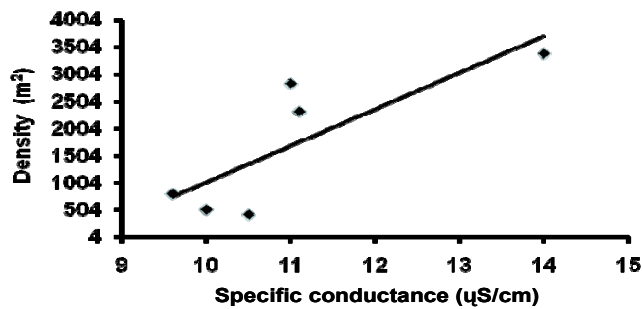


Figure 2. Relationship between streamwater specific conductance and benthic macroinvertebrate density.

habitat quality (computed as in SCDHEC 1998), and watershed disturbance (calculated from NLCD) accounted for 50% of the variance in six indices of BMI assemblage integrity (total richness; total number of individuals; % Ephemeroptera; % clingers; number of Ephemeroptera, Plecoptera, and Trichoptera [EPT] taxa; and the NC Biotic Index [Lenat 1993]) (Figure 5). Independent effects (i.e., % variances after fitting the other environmental variables as covariables) were 9% for width ($P \leq 0.05$), 10% for instream habitat ($P \leq 0.05$), and 2% for watershed disturbance ($P > 0.05$). These results indicated that instream habitat was more influential than upland watershed disturbance, as hypothesized. However, watershed disturbance and instream habitat were significantly ($P \leq 0.05$) and inversely correlated ($r = -0.42$) indicating that instream habitat declined with increasing watershed disturbance.

In succeeding years work will continue with the objectives of defining the reference condition and identifying key variables that influence biotic

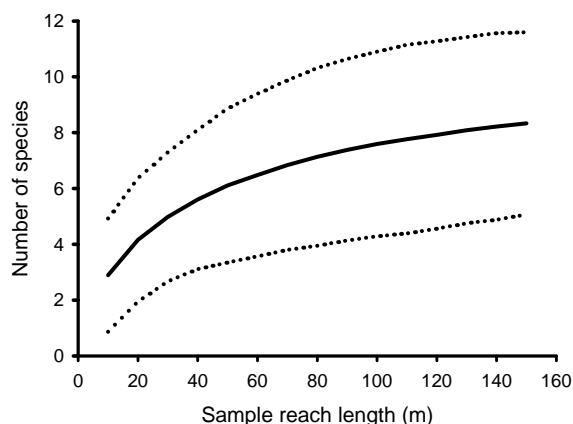


Figure 3. Average relationship (+/- 2SD) between observed number of fish species and sample reach length.

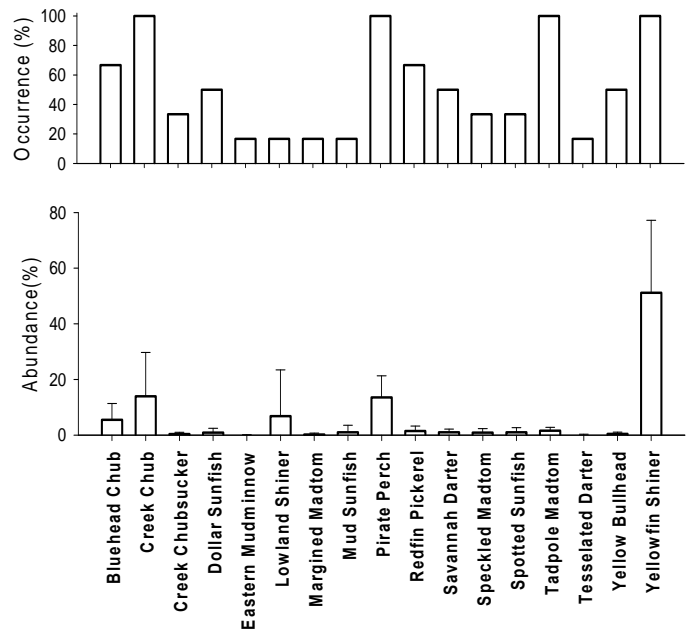


Figure 4. Percent occurrence and average percent composition of fish collected by electrofishing from small streams on the Savannah River Site.

communities. These results will provide guidance needed by resource managers in the Southeast for the design of prudent recovery efforts that produce quantifiable results for streams of the Atlantic Coastal plain.

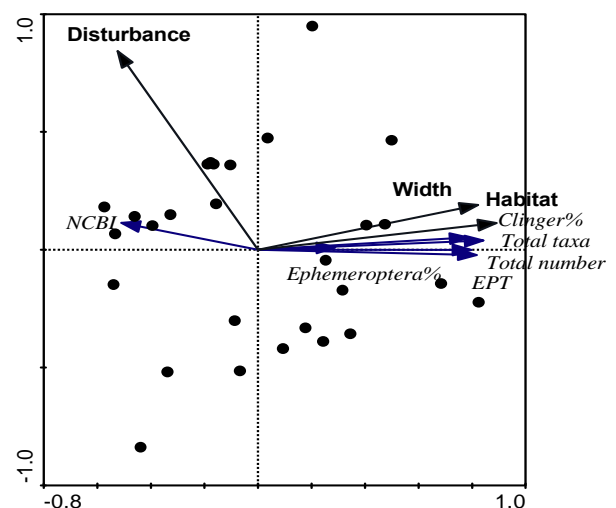


Figure 5. Biplot summarizing effects of watershed disturbance, instream habitat, and stream width on six stream benthic macroinvertebrate metrics that reflect assemblage integrity.

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