JOURNAL OF THE TENNESSEE ACADEMY OF SCIENCE 69(1):27-31 JANUARY 1994

MORPHOMETRY AND BENTHIC MACROINVERTEBRATE COMMUNITY STRUCTURE OF THE BLACKBURN FORK DRAINAGE AS A FUNCTION OF STREAM ORDER

STEVE BAKER

Division of Natural Science and Mathematics, Oxford College of Emory University, Oxford, GA 30267

ABSTRACT--Morphometric analysis and benthic macroinvertebrate community structure revealed definite relationships to stream-order delineation within the Blackburn Fork drainage system. Stream-order analysis revealed a highly dissected drainage and a straight-line relationship between log stream numbers and stream order. Benthic community structure reflected widely divergent species composition between first- and fourth-order sites, with relationship between second- and third-order sites being less distinct. Because streams of similar order are generally similar in size within habitat within a drainage, stream-order analysis is useful as a stream-classification device. Stream sites of same order or near order with more similar habitat were closely related in their benthic macroinvertebrate community structure, as illustrated by cluster analysis.

In lotic systems, several concepts have addressed energy transfer within the system as a whole. The river continuum concept describes the flow of nutrients through continuous lotic systems and predicts that animal communities vary predictably along the longitudinal profiles of stream systems (Vannote et al., 1979). In non-continuous systems, such as those interrupted by impoundments, trends still are observed in physico-chemical and biotic parameters. Shifts in parameters as a result of the lentic interruptions have been noted, as described by the serial discontinuity concept (Ward and Stanford, 1983).

In examining biotic or chemical changes along a river continuum, many studies have related these trends to the concept of stream order. Geomorphologists use the concept of stream order to delineate streams within a drainage basin based on the arrangement of their tributaries. Several schemes have been proposed for delineation of stream order, including those by Horton (1945), Strahler (1957), and Scheidegger (1965). Jones (1979) related physico-chemical conditions to stream order in Oklahoma. Seyfer and Wilhm (1977) described variation in periphyton communities with stream order. Barila et al. (1981), Denoncourt et al. (1980), Hooper (1976), and others have related distribution of fishes to stream order. Harrell and Dorris (1968) initially applied the stream-order concept to benthic community structure in Oklahoma. They noted that distinct relationships were present between benthic community structure and stream order.

Most studies relating structure of benthic macroinvertebrate communities to the river continuum concept have concentrated on the distribution of various functional feeding groups in streams of various orders. This is due to the fact that studies of functional groups can reduce the difficulties in identification of poorly known taxonomic groups and also can lead to increased information regarding processing of nutrients and energy transfers within the stream system. Studies by Faith and Norris (1989), Scheiring (1985), Hawkins and Sedell (1981), and others have in some cases reinforced and in other cases refuted the concept that patterns of distribution of functional groups occur as described by the river continuum concept.

The goal of the present study was to determine if streams of the same or similar order contain similar benthic macroinvertebrate communities. Assuming that sites of similar orders are similar in habitat makeup (and, therefore, niche structure), the benthic macroinvertebrate community at these sites within the drainage should be closely related. If species-group associations are present, they should be indicated by statistical indices of similarity and evident in the resulting cluster analysis of sampling sites.

MATERIALS AND METHODS

Study Area--The present study was conducted on the Blackburn Fork drainage, located east of Cookeville, Tennessee, in Jackson and Putnam counties. Blackburn Fork was a fourth-order, intermittent stream system with two main branches, the east and west forks. The macroinvertebrates of Blackburn Fork were previously described by Baker (1984), and these data were incorporated into the present study.

Order-one Sites--One of the first-order streams (LC1) was locally known as Little Creek and flowed through Shipley Farm approximately 3.2 km northeast of Cookeville. The stream flowed through pasture and cultivated farmland. The second first-order stream (EBF1) was a tributary of East Blackburn Fork and flowed through the community of Knight's Chapel. The stream was heavily overhung with sycamore (*Plantanus occidentalis*), and the stream itself contained large mats of watercress (*Nasturtium officinale*) and was surrounded by jewelweed (*Impatiens capensis*).

Order-two Sites--The LC2 site was located in the Little Creek section of West Blackburn Fork. The stream was in a relatively undeveloped section of the drainage. The second second-order site (WBF2) was located on the West Branch of Blackburn Fork near the community of Pippin in Putnam Co. The stream was almost completely overgrown with sycamore and ironwood (*Carpinus carolinae*).

Order-three Sites-Site EBF3 was located in a stream section which flowed through pasture near the community of Knight's Chapel. The stream had no canopy at this site and contained large mats of smartweed (*Polygonum coccineum*). The second third-order site (WBF3) was on the West Branch and flowed through uncleared thicket and woodland.

Order-four Sites--Site BFS4 was approximately 0.8 km above Cummings Falls. The stream flowed through a limestone gorge area in this section in the drainage and was overshadowed by sycamore and ironwood. The second fourth-order site (BFN4) was in Jackson Co. approximately 2.4 km north of Cummings Falls. This section was in a rugged, mountainous area with poor access.

Methods--A stream-order analysis of Blackburn Fork was conducted from maps at 1:24,000 scale according to Strahler's (1957) modification of Horton's (1945) system of stream-order classification. Unbranched, headwater streams were designated as order-one streams, with streams of higher order being formed by two like orders merging. The bifurcation ratio as described by Strahler (1957) also was calculated, which gives an indication of the degree of dissection of the stream drainage. This ratio is the number of streams of any order to the number of streams of the next highest order.

Eight stations were sampled bimonthly for benthic macroinvertebrates from September 1981 to August 1982. Two stations were selected for each stream order present in the drainage. Quantitative Surber samples were conducted as described by Surber (1969). Initially, three Surber samples were taken in riffle areas using a stratified random sampling design. Samples were randomly collected along a transect across the middle of each riffle selected. The same riffle at each sampling station was sampled throughout the study. This number was later increased to four to provide more complete data concerning the community diversity of riffle-dwelling organisms. Qualitative kick samples were taken in pool areas near each station. All representative pool-habitat areas were sampled in the qualitative sample to supplement information obtained by quantitative sampling and to provide more complete data concerning species composition.

All samples were initially preserved in 10% formalin in zip-loc plastic bags in the field. Samples were returned to the laboratory, washed through a sieve (United States standard no. 30), sorted, and stored in 70% ethyl alcohol. Specimens were identified to the lowest practical taxonomic level (usually genus). Due to their small size, some organisms (generally Dipterans) were mounted on microscope slides with CMC-10 mounting media for later identification.

Species diversity was evaluated by the Shannon-Weaver diversity index calculated by the following formula (Green, 1979): $H = -\Sigma n_i/N * [\ln(n_i/N)]$, where N is the total number of individuals in the sample and n_i is the total number of individuals in the ith taxa. Diversity of each community was also evaluated for sites of each stream order by species richness (the number of species present).

To evaluate the importance of major taxonomic groups to the structure of benthic macroinvertebrate communities, importance values for each selected taxonomic group were calculated. The importance value gives a quantitative indication of the contribution made by a particular taxonomic group to the total density and biomass of the benthic macroinvertebrate structure. This is calculated by the following formula, modified from Cottam and Curtis (1956): IV = percent total density + percent total weight. The sum of the importance values for a series of samples equals 200 since each parameter in the formula totals 100. The importance values were used to compare importance values of taxonomic groups in various stream orders. In evaluating data from importance values, taxonomic groups containing large, heavy organisms (i.e., Decapoda and Megaloptera) may have high readings due to the large size of a small number of organisms giving the impression that large numbers are present in the community.

Binary data analysis was utilized to evaluate taxonomic differences between stream sites of different orders. Green (1979) notes that presence-absence data can be very valuable in analysis of ecological communities. Although some information is lost due to lack of abundance data, it is possible that abundance data may be unreliable due to sampling error. Sampling error in benthic macroinvertebrate studies is frequently large due to the clumped nature of the distribution of these organisms, often requiring numerous replicates to reflect true abundances with acceptable precision.

The presence of an overall association between species was calculated as the variance ratio (VR) described by Ludwig and Reynolds (1988). This ratio was calculated as follows: $VR = S^2t/\sigma^2t$, where S^2 is the variance in total species number and σ^2 is the total sample variance for the occurrence of the S species in the sample. The expected value under the null hypothesis of independence is VR = 1. Values of VR > 1 indicate a positive association between species and, therefore, differences between sampling sites. Values of VR < 1 would indicate a negative association.

In order to evaluate similarity of sampling sites, both similarity indices and cluster analysis were utilized. To evaluate similarity of sampling sites, Jaccard's index of association was utilized. This index was calculated as follows: Jaccard's index = a/(a + b + c), where a is the number of species present at both sampling sites, b is the number of species present at site A but not B, and c is the number of species present at site B but not A. This index describes the similarity of two sampling sites based on the presence or absence of species and species that each share in common.

To describe the similarity of the benthic communities (described as taxonomic distance) between sampling sites, the Marczewshi-Steinhaus distance is calculated using Jaccard's index: MS distance = 1 - Jaccard's index. This analysis results in a data matrix indicating the taxonomic distance between sites on a pairwise basis. Pairs of sites with more similar benthic communities, therefore, would be separated by a shorter taxonomic distance.

Cluster analysis was utilized to separate groups of sampling sites by similarity. Using the squared Euclidean distance as a measure between similarities and the flexible method of hierarchical clustering, a dendrogram was generated. A beta-weighting value of -0.25 was used as recommended by Ludwig and Reynolds (1988). Statistical analysis was conducted using the Statistical Ecology computer software package (Ludwig and Reynolds, 1988).

RESULTS AND DISCUSSION

One hundred thirty-four first-order streams, 26 second-order streams, 5 third-order streams, and 1 fourth-order stream were identified from the Blackburn Fork drainage network. Typically, morphometric analyses of drainage networks illustrate the number of streams of each order such that a logarithmic plot results in a straight line (Strahler, 1957). A similar plot was obtained from morphometric analysis of the Blackburn Fork drainage (Fig. 1). Hooper (1976), in his analysis of the Blackburn Fork drainage, obtained similar results for number of streams with slight differences in number of first- and second-order streams.

A weighted mean bifurcation ratio of 5.15 was calculated for the Blackburn Fork drainage. Ratios of approximately 2.00 are found for flat basins, and ratios of ≥3.00 are obtained for mountainous or greatly dissected drainages. In the present study, the high bifurcation ratio reflects both the rolling hills of the local topography and the large numbers of adventitious streams in the northern part of the drainage. The Blackburn Fork system is, therefore, a highly dissected drainage with a predictable number of streams of each order.

In examining the benthic macroinvertebrate communities at each sampling site, a diverse assemblage of benthic fauna was collected. A total of 182 taxa was identified; these taxa were described by Baker (1984).

. Mean Shannon-Weaver diversity indices among sites of various orders ranged from 2.66 at BFN4 to 2.84 at EBF3 (Table 1). These values indicate that severe perturbation due to organic pollution had not occurred, although no sites could be described as pristine. The small

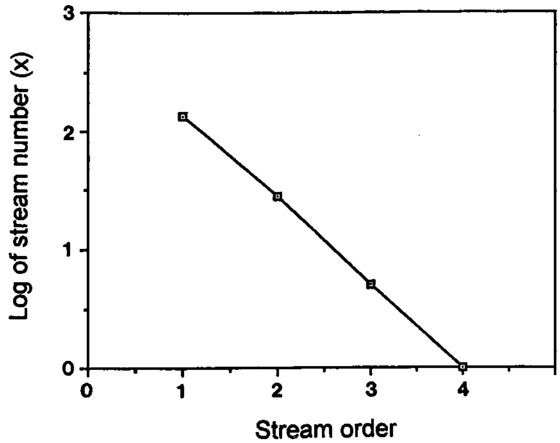

FIG. 1. Relative number of streams of each order, Blackburn Fork drainage, 1981.

variation in mean Shannon-Weaver diversity indices among the eight sites reflect no significant difference among streams of various orders. Values for species richness, described by Poole (1974) as one of the most reliable indices of diversity, ranged in value from 99 taxa at site LC2 to 71 taxa at LC1 (Table 1). The lower value at site LC1 reflects some degradation in stream habitat in comparison to other sites, as this site received some negative impact from agricultural runoff from the Shipley Farm.

In examining relationships that were present among species, a VR of 3.48 was obtained. This indicates that positive associations were present among species at particular sampling sites (i.e., species were not randomly distributed among all sampling sites).

Given that discrete associations were present among species at sampling sites, Jaccard's index was used in calculating the Marczewski-Steinhaus index of taxonomic distance between pairs of sampling sites based on presence-absence data (Table 2). If the benthic community structure can be related to stream order, differences should be most evident between sites on first- and fourth-order streams. The Marczewski-Steinhaus distance revealed that fourth-order sites, particularly site BFN4, were most distant from first-order sites, with associations between second- and third-order sites being more variable. A cluster analysis based on Jaccard's similarity data revealed the first-order sites to be different from all other sites (Fig. 2). Among second-, third-, and fourth-order sites, the fourth-order site BFN4 was most dissimilar.

Additional information was provided by analysis of the importance values of major taxonomic groups (Table 3). By comparing dominant groups in streams of various orders, general information can be obtained regarding composition of benthic communities present. Also, casual observation of this data can often explain distributions of organisms as they relate to the river continuum concept.

In evaluating site associations by stream order, initially it is important to note that the designation of stream order is quite useful in stream ecology. In lotic systems, with other environmental factors being similar, sites of the same or similar order within a drainage system should have similar ecological composition. In the present study, this was generally reflected in the species composition of benthic macroinvertebrates.

The similarity of the order-one sites and the distance between these sites and the BFN4 site reflect the differing habitat and niche availability at these sites. Both order-one sites were very similar in size, and both had, as would be expected, lower discharges and velocity than order-four sites. As a result, community composition of first-order sites had a greater representation of groups such as Odonata and Hemiptera that frequent such habitat. Although functional groups such as shredders were present at all sites, they were especially prevalent in lower-order streams, where many small pools were present holding leaf packs from adjacent canopies. The high importance value of the Plecoptera present in the first-order streams (Table 3) reflects the presence of large numbers of shredders, particularly members of the Nemouridae, Leuctridae, and Taeniopterygidae. Also, lower-order sites contained many Diptera, particularly large shredders such as members of the family Tipulidae, which, because of their large individual size, resulted in a large importance value. First-order sites were, therefore, quite similar in community composition, particularly because of their similar habitat and niche availability.

Second-order sites were also linked together in the cluster analysis, indicating their similarity in community composition. Both sites were extremely similar in size and microhabitat. It seems clear that the concept of stream order is quite useful in analyzing the community composition of lotic ecosystems. One cannot, however, expect to find two streams of the same order with differing habitats to be closely similar in species composition.

Examination of the third- and fourth-order sites make this quite clear. The most closely linked of any two sites were the third-order site WBF3 and the fourth-order site BFS4. Although site BFS4 was slightly larger in size, the two sites were quite similar in terms of canopy and riparian vegetation present. While the other third-order sites EBF3 and WBF3 were similar in size, site EBF3 was in an open field with virtually no canopy. Although of different orders, the sites WBF3 and BFN4 were more similar in habitat and, as a result, supported more similar benthic communities.

Other factors may also influence similarity in community composition in streams of like order. Local factors such as sedimentation, point-source pollution, and other perturbation would certainly result in different communities in streams experiencing these problems. Particularly in lower-order streams, temporal habitat loss as a result of low water levels and even loss of flow would create critical differences among these sites as compared to other streams of the same order.

TABLE 1. Mean species richness and mean Shannon-Weaver diversity indices (H) for each of eight sampling sites in the Blackburn Fork drainage, 1981-1982.

Species diversity parameter	Sampling site							
	LC1	EBF1	LC2	WBF2	WBF3	EBF3	BFS4	BFN4
Richness	71	94	99	93	88	92	87	84
H	2.67	2.75	2.69	2.70	2.71	2.84	2.76	2.66

TABLE 2. Marczewski-Sheinhaus distances for associating pairs of sampling sites by composition of benthic macroinvertebrate communities.

Sampling site	Sampling site							
	LC1	EBF1	LC2	WBF2	WBF3	EBF3	BFS4	BFN4
LC1		0.527	0.560	0.518	0.578	0.532	0.604	0.702
EBF1			0.519	0.496	0.537	0.471	0.525	0.634
LC2				0.439	0.441	0.387	0.441	0.512
WBF2					0.479	0.450	0.504	0.512
WBF3						0.452	0.381	0.478
EBF3							0.352	0.500
BFS4								0.478
BFN4								

In the streams of higher order, importance values indicate increased influence by the Coleoptera, Ephemeroptera, and Megaloptera. In terms of the river continuum concept, streams of third and fourth orders should show variation in benthic communities as the collector-grazer functional groups assume greater importance. Collectors such as the elmid beetles and their larvae were found in increased numbers as fine particulate organic matter was utilized. Increased primary production also is expected as canopies open, and this was reflected in larger numbers of Ephemeroptera, particularly the Heptageniidae, in the larger streams. The greater importance of the Megaloptera is likely due to the occurrence of large individuals of *Corydalus cornutus* which were commonly found in the large cobble riffles of these higher-order streams.

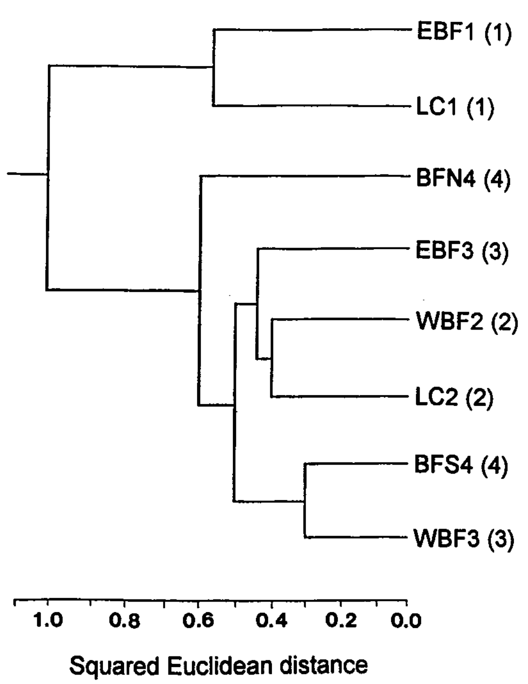

FIG. 2. Dendrogram depicting relationships (based on species composition) among stations sampled in the Blackburn Fork drainage during 1981. Stream order for each station is given in parentheses.

The concept of stream order is in general quite useful in stream classification. Certainly, the concept allows some generalization regarding the size of streams. Based on the river continuum concept, some implications may be drawn regarding the importance of the general functional groups, and casual observation coupled with importance values of major groups reveal that these basic trends were present in this study. Also, this study revealed clear associations between sites of near order in terms of species association. However, streams of the same order must be generally similar in habitat to expect strong associations in community composition. If local influences such as human impact or canopy coverage greatly differ between streams of the same order, it is probable that benthic community composition also will differ significantly.

ACKNOWLEDGMENTS

I would like to thank F. J. Bulow, B. L. Ridley, and O. R. Jordan for their encouragement and support throughout this study. Special thanks are given to B. Stout, B. Swartley, and B. Cook for their assistance in identification of benthic macroinvertebrates. Appreciation is also extended to J. Budensiek for typing the manuscript.

TABLE 3. Mean importance values of major taxa of benthic macroinvertebrates as a function of stream order in Blackburn Fork, 1981 and 1982.

Taxon	Stream order			
	1	2	3	4
Ephemeroptera	26.5	50.1	38.1	71.1
Plecoptera	16.7	7.7	4.3	7.1
Coleoptera	27.0	23.0	27.1	37.7
Trichoptera	20.7	18.4	27.3	18.1
Decapoda	19.9	44.5	44.8	22.5
Diptera	46.9	40.6	27.9	19.9
Megaloptera	9.0	2.2	2.3	18.4
Odonata	4.7	0.0	0.0	0.2
Mollusca	13.1	1.6	19.7	26.2
Others	6.5	6.7	9.4	3.5

LITERATURE CITED

BAKER, S. C. 1984. A checklist of the benthic macroinvertebrates of the Blackburn Fork drainage in Putnam and Jackson counties, Tennessee. J. Tennessee Acad. Sci., 59:83-85.

BARILA, T. Y., R. D. WILLIAMS, AND J. R. STAUFFER, JR. 1981. The influence of stream order and selected stream bed parameters on fish diversity in Raystown Branch, Susquehanna Drainage, Pennsylvania. J. Appl. Ecol., 18:125-132.

COTTAM, G., AND J. T. CURTIS. 1956. The use of distance measures in phytosociological sampling. Ecology, 37:451-460.

DENONCOURT, R. F., W. F. SKINNER, AND B. D. SNYDER. 1980. Fishes of the Chilliaquaque Creek Drainage, Montour County, Pennsylvania. Proc. Pennsylvania Acad. Sci., 53:145-150.

FAITH, D. P., AND R. H. NORRIS. 1989. Correlation of environmental variables with patterns of distribution of common and rare freshwater macroinvertebrates. Biol. Conserv., 50(1-4):77-98.

GREEN, R. H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons, New York.

HARRELL, R. C., AND T. C. DORRIS. 1968. Stream order, morphometry, physico-chemical conditions, and community structure of benthic macroinvertebrates in an intermittent stream system. Amer. Midland Nat., 80:200-251.

JAWKINGS, C. P., AND J. R. SEDELL. 1981. Longitudinal and seasonal changes in functional organization of macroinvertebrate communities in four Oregon USA streams. Ecology, 62:387-397.

HOOPER, R. C. 1976. Fish communities of Blackburn Fork as studied by diversity indices and factor analysis in relation to stream order. MS thesis, Tennessee Technological Univ., Cookeville.

HORTON, R. E. 1945. Erosional development of streams and their drainage basins, a hydrophysical approach to quantitative morphology. Bull. Geol. Soc. Amer., 56:275-370.

JONES, S. R. 1980. Stream order and physico-chemical conditions in House Creek, a tributary of Keystone reservoir, Oklahoma. Trans. Missouri Acad. Sci., 12:5-24.

LUDWIG, J. A., AND J. F. REYNOLDS. 1988. Statistical ecology--a primer on methods and computing. John Wiley and Sons, New York.

POOLE, R. W. 1974. An introduction to quantitative ecology. McGraw-Hill Book Company, New York.

SCHEIDEGGER, A. E. 1965. The algebra of stream-orders numbers. US Geol. Survey, Prof. Paper, 525B:187-189.

SCHEIRING, J. F. 1985. Longitudinal and seasonal patterns of insect trophic structure in a Florida USA sand-hill stream. J. Kansas Entomol. Soc., 58:207-219.

SEYFER, J. R., AND J. WILHM. 1977. Variation with stream order in species composition, diversity, biomass, and chlorophyll of periphyton in Otter Creek, Oklahoma. Southwestern Nat., 22:455-468.

STRAHLER, A. N. 1957. Quantitative analysis of watershed geomorphology. Trans. Amer. Geophys. Union, 38:913-920.

SURBER, E. W. 1969. Procedure in taking stream bottom samples with a square-foot bottom sampler. Ann. Conf. Southeastern Assoc. Game Fish Comm., 23:587-591.

VANNOTE, R. L., G. W. MINSHALL, K. W. CUMMINS, J. R. SEDELL, AND C. E. CUSHING. 1980. The river continuum concept. Canadian J. Fish. Aqua. Sci., 37:130-137.

WARD, J. V., AND J. A. STANFORD. 1983. The serial discontinuity concept of lotic ecosystems. Pp. 29-42 *in* Dynamics of lotic ecosystems (T. D. Thomas and S. M. Bartell, eds.). Ann Arbor Sci. Publ., Ann Arbor, Michigan.