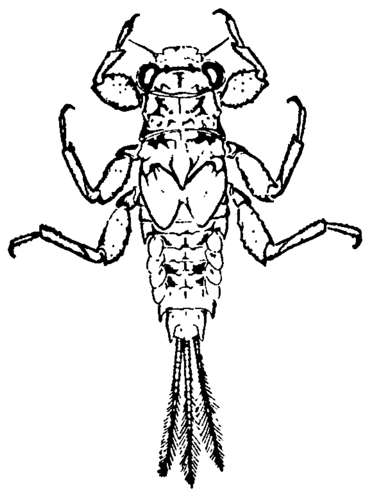
WATER-RESOURCES INVESTIGATIONS REPORT 85-4289

EVALUATION OF COAL-MINING IMPACTS USING NUMERICAL CLASSIFICATION OF BENTHIC INVERTEBRATE DATA FROM STREAMS DRAINING A HEAVILY MINED BASIN IN EASTERN TENNESSEE



U.S. GEOLOGICAL SURVEY

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Arthur D. Bradfield

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CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
square mile (mi^2)	2.590	square kilometer (km^2)
microsiemen per centimeter at 25° Celsius (µS/cm at 25° C)	1.00	micromho per centimeter at 25° Celsius (µmhos/cm at 25° C)

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ABSTRACT

Coal-mining impacts on Smoky Creek, eastern Tennessee, were evaluated using water-quality and benthic invertebrate data. Data from mined sites were also compared with water quality and invertebrate fauna found at Crabapple Branch, an undisturbed stream in a nearby basin. Although differences in water-quality constituent concentrations and physical habitat conditions at sampling sites were apparent, commonly used measures of benthic invertebrate sample data such as number of taxa, sample diversity, number of organisms, and biomass were inadequate for determining differences in stream environments. Clustering algorithms were more useful in determining differences in benthic invertebrate community structure and composition. Normal (collections) and inverse (species) analyses based on presence-absence data of species of Ephemeroptera, Plecoptera, and Tricoptera were compared using constancy, fidelity, and relative abundance of species found at stations with similar fauna. These analyses identified differences in benthic community composition due to seasonal variations in invertebrate life histories. When data from a single season were examined, sites on tributary streams generally clustered separately from sites on Smoky Creek. These analyses, compared with differences in water quality, stream size, and substrate characteristics between tributary sites and the more degraded main stem sites, indicate that numerical classification of invertebrate data can provide discharge-independent information useful in rapid evaluations of in-stream environmental conditions.

INTRODUCTION

Streams receiving drainage from mined areas exhibit the following characteristics usually not found in unmined basins: altered water-quality conditions (Hren and others, 1984), increased hydrologic response time to storm events (Bryan and Hewlett, 1981), increased sediment loads (Parker and Carey, 1980; Osterkamp and others, 1984), and changes in channel morphology (B.A. Bryan and C.R. Hupp, written commun., 1985). These changes in the physical and chemical properties of stream environments in Tennessee affect benthic invertebrate community structure and composition by reducing species diversity and the number of aquatic organisms (Bradfield, 1985).

Despite these severe alterations in the hydrologic environments of mined basins, no clear-cut criteria exist whereby coal-mining impacts can be evaluated. Particularly lacking have been adequate evaluations of biological data. Invertebrate sample data are often examined only by summary statistics that are difficult to relate to hydrologic conditions.

Because of the real and imagined problems of utilizing biological data in environmental assessments, decisions regarding the extent of mining effects often are based solely on suspended or dissolved constituent concentrations in water.

Although changes in water-quality properties and increases in suspended-sediment concentrations can indicate that mining has affected hydrologic conditions in a basin, these features are highly dependent upon flow conditions, therefore requiring a large number of samples over time to describe the range of concentrations. Concentrations of dissolved and suspended constitutents and sediment can range over several orders of magnitude and the concentration-discharge relations are often being altered by additional mining or changes in land-use. Because high concentrations of total and dissolved consituents are possible at a site, allowable limits for specific properties established by mining regulations have been set at high levels relative to premining conditions. Maximum allowable concentrations in mining effluents have been established for total manganese [4.0 milligrams per liter (mg/L)]),total iron (7.0 mg/L), total suspended solids (70 mg/L), and pH (6.0-8.0 units) (U.S. Department of the Interior, Office of Surface Mining, Reclamation and Enforcement, 1977, v. 42, no. 239). These limits generally are exceeded during storm events or high flows, making the regulations difficult to monitor and enforce. Additional measures of environmental quality that are independent of discharge are needed to adequately assess and monitor the effects of coal-mining.

Benthic invertebrate populations are critical elements of the trophic structure of aquatic systems, and possess many characteristics that make them potential indicators of instream conditions. Benthic invertebrates, in particular the class Insecta, occur in great abundance and diversity in most aquatic environments. Because their life cycles are short (6 months to 3 years), benthic invertebrate data can be used for periodic evaluations of environmental quality.

Although some invertebrate taxa are associated with general water-quality conditions, benthic invertebrates are still not effectively used in water-quality investigations. The limited application of invertebrate data in environmental assessments is due to the methods by which these data are most commonly evaluated. Diversity indices and other commonly employed measures of community structure such as number of species, number of organisms, or the presence or absence of particular "indicator species" are inappropriate for determining relations between community composition and environmental conditions (Cairns, 1974; Chadwick and Canton, 1984). These measures of biological communities are more useful for discerning gross differences in environmental quality due to the variation in species composition of invertebrate samples resulting from seasonal invertebrate life cycles, sampling error, and the clumped distribution of invertebrates on the streambed.

Linear regressions and related statistical tools that are commonly employed in hydrologic studies are also inappropriate for determining relations between biological data and environmental conditions. The distributions of most taxa, when aligned along environmental gradients such as increasing constituent concentrations, are nonlinear. Invertebrates species, just as species of plants, tend to form approximately bell-shaped binomial distributions that overlap with other taxa along specified environmental gradients (Whitaker, 1967). Multivariate statistical methods such as cluster analysis and ordination are more useful in the reduction and analysis of ecological data (Hill, 1973; Green, 1980; Hill and Gaugh, 1980; Gaugh and others, 1981; Sneath and Sokal, 1973; Boesch, 1977).

The purpose of this report is to (1) evaluate the differences in benthic invertebrate community composition and quality of water from several streams in eastern Tennessee affected by coal mining, and (2) compare several methods used to determine coal-mining effects on benthic invertebrate community structure and composition. Data on which this report is based were collected from the heavily mined Smoky Creek basin and the undisturbed Crabapple Branch in eastern Tennessee during March and November 1982 and March 1983.

PHYSICAL SETTING

Smoky Creek and its tributaries drain a 17.2 square mile watershed that is heavily strip mined. The Smoky Creek basin is located in the northern Cumberland Plateau section of the Appalachian Plateau physiographic province in northeastern Tennessee. The coal-bearing rocks of the study basin are of Early and Middle Pennsylvanian age and consist of sandstone, siltstone, shale, underclay, coal, ironstone, and a small amount of limestone (Leist and others, 1982). Altitudes range from 1,300 feet at the downstream Smoky Creek gage to more than 3,200 feet at peaks on the basin divide.

The dominant vegetation of the sparsely inhabited Smoky Creek basin is hardwood forest with a small percentage of conifers. Primary cultural influences are agriculture in the valley bottoms and coal mining by the contour strip method on the steeper hillslopes.

Stream substrate (bed material) consists of large cobble and gravel with some sand and very little clay. Much of this material has moved downstream from mined slopes. Average annual streamflow for the area ranges from 1.2 to 2.0 cubic feet per second per square mile [$(ft^3/s)/mi^2$]. Base flows can be extremely low due to the limited storage capacity of thin soils found in the basin.

Crabapple Branch drains an undisturbed 1.07-square-mile basin located in the Cumberland Mountain section of the Cumberland Plateau physiographic region. Lithology of the Crabapple basin is similar to that found in the nearby Smoky Creek basin, although different groups and formations appear in each. Differences or similarities in hydrogeologic properties that may exist between the two basins are overshadowed by the fact that the Smoky Creek basin is heavily mined.

METHODS FOR DATA COLLECTION

Benthic invertebrate and water-quality data were collected at 12 sites in the Smoky Creek basin and one site on Crabapple Branch (fig. 1). Data were collected at each site in March and November 1982 and in March 1983. Benthic invertebrates were collected from riffle areas at each site by vigorously disturbing the substrate and catching the dislodged organisms in a hand-held dip net (210 micron mesh). Semi-quantitative samples were collected for a timed 5-minute interval in an attempt to standardize sampling by expending equal effort at each site. Organisms were field preserved in 70 percent ethyl alcohol and later identified in the laboratory to species where possible.

Water-quality samples were collected at each site at the time invertebrates were sampled. Stream parameters measured included discharge, alkalinity, specific conductance, pH, and concentrations of dissolved manganese, sulfate, and iron. Although substrate particle-size distributions were not determined, attempts were made to sample similar riffle areas at each site.

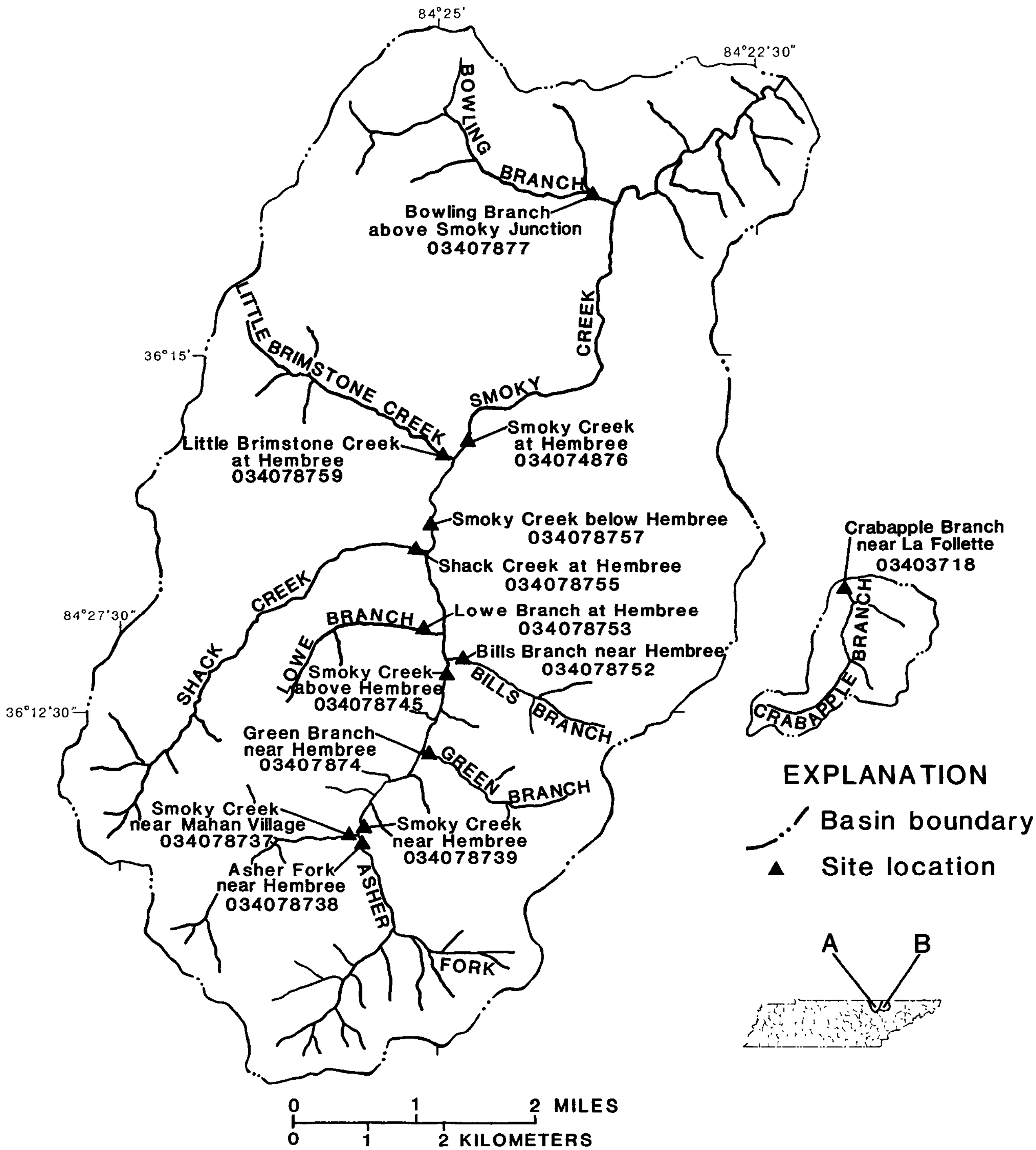


Figure 1.--Location of benthic invertebrate and water-quality sampling sites in the drainage basins of (A) Smoky Creek and (B) Crabapple Branch.

METHODS USED IN ANALYSIS OF BENTHIC INVERTEBRATE DATA

Benthic invertebrate data were first evaluated by examining general sample features such as number of taxa, number of individual organisms, percentage composition of various functional groups (Merritt and Cummins, 1978), and biomass (grams wet weight) of the numerically abundant groups of invertebrates.

Brillouin's measure of information per individual was selected as the index to express community diversity (Brillouin, 1962). Brillouin's index, though once cumbersome to compute because of factorials, is now favored over other commonly used indices for the types of biological collections available in this study (Pielou, 1966; Zand, 1976; Kaesler and others, 1978). Diversity was calculated for each sample using the formula

$$H = \frac{1}{N}\log_2 \frac{N!}{N_1!\,N_2!\,\ldots\,N_S!}$$

where H = diversity index,
N = total number of individuals,
N_1, N_2 = number of individuals of species 1,2..., and
S = total number of species.

The uniformity of the distribution of individuals among the taxa in a sample was also computed and is expressed as relative evenness (Zand, 1976). Relative evenness ranges from zero for the least even sample to one for the most even sample and is the ratio,

$$e = \frac{H-H_{min}}{H_{max}-H_{min}}$$

where

$$H_{max} = \frac{1}{N}\log_2 \frac{N!}{[m+1!]^r (m!)^{S-r}}$$

and

$$H_{min} = \frac{1}{N}\log_2 \frac{N!}{[N-(S-1)]!}$$

where
m = N/s, rounded to next lowest integer,
S = number of species,
N = total number of individuals, and
r = remainder of m in whole numbers.

In addition to these general measures of community structure, benthic invertebrate data were reduced and analyzed by numerical classification using clustering algorithms available on NTSYS (Numerical Taxonomy System of Multivariate Statistical Programs) (Rohlf and others, 1971). Species classifications (inverse analyses) and collection classifications (normal analyses) were obtained using the "unweighted pair-group method using arithmetic averages" or UPGMA (Sneath and Sokal, 1973). This method is both hierarchial and agglomerative and has been used extensively in ecological investigations (Boesch, 1977).

The Jaccard coefficient (Jaccard, 1908) was used as the measure of similarity in these classifications and is obtained from the formula:

$$S_j = \frac{a}{a+b+c}$$

where

S_j = Jaccard similarity coefficient,
a = number of taxa in both of two samples being compared,
b = the number of taxa in sample B and not in sample C, and
c = the number of taxa in sample C and not in sample B.

This coefficient is often used in classifications of presence-absence data and is considered appropriate for ecological investigations because mutual absence of a species is not an indication of similarity. Values range from zero for the least similar pairs of samples or taxa to one for the most similar pairs.

Distortion of the original similarity matrix incurred during the clustering process is an important consideration, since misrepresentation of the original data can lead to erroneous conclusions. Distortion of analyses generated by UPGMA clustering of invertebrate data were evaluated using a cophenetic correlation coefficient (r_{coph}) calculated by the method of least squares (Sokal and Rohlf, 1962). A value of one indicates a perfect linear relation between similarity levels on the dendrogram and values in the original similarity matrix, indicating that the similarities are accurately depicted by the dendrogram. Classifications with a cophenetic value less than 0.70 should be evaluated with caution since misclassifications may exist.

Analyses of data by numerical classification is a means by which large, complex data sets can be reduced to a more usable, interpretable form. However, the cluster dendrograms alone do not provide ecological answers. Comparison of normal analyses (collections with species as attributes) and inverse analyses (species grouped by occurrence patterns with other species) in two-way coincidence tables is an important and often neglected post-clustering operation. This comparison of normal and inverse analyses is called nodal analysis because an attempt is made to interpret the "nodes" or concentration of points at the intersection of a cluster of species and a cluster of collections (samples).

Other measures of the importance of clusters found in nodal analyses are needed in addition to similarity coefficients generated in the original classifications. Organisms that are rare and tend to occur together can result in clusters with high similarity coefficients, yet be of little importance in environmental assessments because of their scarcity. To evaluate the significance of "nodes" found in two-way coincidence tables, three measures known as constancy, fidelity, and relative abundance were employed in this study (Boesh, 1977).

Constancy (C) is based on the number of occurrences of species in a collection group relative to the total number of occurrences possible in the collection group. Constancy was computed from the formula:

$$C_{ij} = aij/(N_i N_j)$$

where

C_{ij} = constancy of species in the collection group,

a_{ij} = actual number of occurrences of members of species group i in collection group j,

N_i = number of species in species group i, and

N_j = number of stations in collection group j.

Constancy, although providing an indication of how consistently the species in a cluster are represented at a group of stations, has limited utility. A species group can have a high value of constancy and still provide little information in ecological investigations if the species group is constant at all collection groups in the normal analysis. Similarly, a group of rarely occurring organisms may cluster at a high similarity level and be highly constant in a collection group, but because of the rarity of occurrence of the species group, few ecological inferences can be made concerning environmental conditions. Constancy is arbitrarily graded as very high ($\geq$0.70), high (0.69-0.50), moderate (0.49-0.30, low (0.29-0.10) and very low (<0.10).

Another readily obtainable measure of the importance of a node is fidelity (F). Fidelity expresses the "faithfulness" of a species group to a collection group and can be regarded as an expression of the constancy of species in a collection group relative to the constancy of the species group over all collections. Fidelity is computed from the equation:

$$F_{ij} = (a_{ij} \sum_j N_j)/(N_j \sum_j a_{ij})$$

using the same terms as in the constancy index. This index is equal to 1 when the constancy of the species group is equal to its constancy over all collections, less than 1 when its constancy is less than its constancy overall collections and greater than 1 when the species group is more constant in the node than it is in other collections. Fidelity is arbitrarily graded as high ($\geq$2.0) moderate (1.9-1.5), low (1.4-1.0), and negative (<1.0). Interpretation of fidelity values should be made with characteristics of the data set in mind. For example, lower fidelity values may be more significant when the data are collected from dissimilar environments than high values obtained from a more homogenous study area.

A third measure referred to as relative abundance (RA) of taxa in the node is computed using the percentage composition of taxa in a sample. For each species in the collection group, the average percentage composition of the species in the collection group is divided by its average percentage composition over all collections. Ratios for each species are then averaged to determine the relative abundance of all taxa in the node with respect to their percentage composition in other collections.

COMPARISONS OF SITES USING WATER-QUALITY DATA AND BENTHIC INVERTEBRATE SAMPLE PARAMETERS

Because of increased concentrations of dissolved and suspended material transported from mined land, water-quality data are frequently used to evaluate the effects of mining operations on hydrologic systems. Although water-quality constituents are needed to determine the extent of impacts, dependence upon discharge-related constituent concentrations alone can present problems, both in data collection and in the interpretation of water quality. Differences in water-quality data collected at different flow regimes during March (tables 1 and 3) and November (table 2) illustrate the dependence of dissolved constituent concentrations on flow, particularly at disturbed sites.

Table 1.--Discharge and water-quality properties collected at study sites during March 1982

[ft^3/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees celsius]

Station No.	Station name	Date	Discharge (ft^3/s)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L)	Manganese, dissolved (µg/L)	Iron (µg/L)	Specific conductance (µS/cm)	pH (units)
03403718	Crabapple Br nr LaFollette	3/11/82	3.3	3	5	10	10	20	6.0
03407874	Green Br nr Hembree	3/11/82	3.7	32	130	100	10	360	7.6
034078752	Bills Br nr Hembree	3/10/82	11	26	32	20	10	133	7.2
03407876	Smoky Cr at Hembree	3/ 9/82	77	21	55	50	20	187	7.5
03407877	Bowling Br ab Smk Junction	3/ 9/82	13	6	21	320	40	65	7.2
034078737	Smoky Cr nr Mahan Village	3/11/82	6.6	34	71	10	10	280	7.2
034078738	Asher Fk nr Hembree	3/11/82	8.3	40	85	30	20	290	7.4
034078739	Smoky Cr nr Hembree	3/11/82	15	38	81	20	30	285	7.3
034078745	Smoky Cr above Hembree	3/10/82	26	32	77	30	10	260	7.4
034078753	Lowe Br at Hembree	3/10/82	2.4	24	30	10	30	125	7.1
034078755	Shack Cr at Hembree	3/10/82	18	23	61	60	10	203	7.2
034078757	Smoky Cr bl Hembree	3/10/82	54	22	65	40	20	210	6.8
034078759	Little Brimstone at Hembree	3/10/82	7.1	5	12	20	150	42	6.7

Table 2.--Discharge and water-quality properties collected at study sites during November 1982

Station No.	Station name	Date	Discharge (ft^3/s)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L)	Manganese, dissolved (µg/L)	Iron (µg/L)	Specific conductance (µS/cm)	pH (units)
03403718	Crabapple Br nr LaFollette	11/ 3/82	0.55	6	10	10	90	40	5.7
03407874	Green Br nr Hembree	11/ 2/82	.15	58	260	10	10	580	7.9
034078752	Bills Br nr Hembree	11/ 1/82	.06	28	98	10	10	260	7.2
03407876	Smoky Cr at Hembree	11/ 1/82	1.9	52	120	10	40	350	7.4
03407877	Bowling Br ab Smk Junction	11/ 1/82	.06	14	35	10	10	112	6.7
034078737	Smoky Cr nr Mahan Village	11/ 2/82	.34	65	200	10	10	545	7.2
034078738	Asher Fk nr Hembree	11/ 2/82	.32	94	260	10	20	700	7.4
034078739	Smoky Cr nr Hembree	11/ 2/82	.56	82	260	10	30	645	7.3
034078745	Smoky Cr above Hembree	11/ 2/82	.87	64	170	10	20	520	7.2
034078753	Lowe Br at Hembree	11/ 2/82	.02	48	33	10	10	180	7.5
034078755	Shack Cr at Hembree	11/ 2/82	.58	58	120	10	10	343	7.9
034078757	Smoky Cr bl Hembree	11/ 2/82	1.6	50	140	10	50	370	7.1
034078759	Little Brimstone at Hembree	11/ 2/82	.09	18	15	10	140	67	6.9

Table 3.--Discharge and water-quality properties collected at study sites during March 1983

Station No.	Station name	Date	Discharge (ft^3/s)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L)	Manganese, dissolved (µg/L)	Iron (µg/L)	Specific conductance (µS/cm)	pH (units)
03403718	Crabapple Br nr LaFollette	3/10/83	2.1	5	5	10	20	20	6.5
03407874	Green Br nr Hembree	3/ 9/83	4.2	36	130	80	30	360	7.7
034078752	Bills Br nr Hembree	3/ 9/83	3.4	12	58	30	50	160	7.4
03407876	Smoky Cr at Hembree	3/ 8/83	88	27	56	30	30	190	7.2
03407877	Bowling Br ab Smk Junction	3/ 8/83	12	8	17	160	20	56	7.3
034078737	Smoky Cr nr Mahan Village	3/ 9/83	6.8	38	86	10	20	285	7.7
034078738	Asher Fk nr Hembree	3/ 9/83	8.7	42	77	20	10	258	7.3
034078739	Smoky Cr nr Hembree	3/ 9/83	6.8	40	80	10	10	270	7.2
034078745	Smoky Cr above Hembree	3/ 9/83	23	34	81	30	20	208	6.8
034078753	Lowe Br at Hembree	3/ 9/83	2	28	32	10	20	138	6.7
034078755	Shack Cr at Hembree	3/ 9/83	15	30	67	30	20	220	7.8
034078757	Smoky Cr bl Hembree	3/ 8/83	67	30	63	30	20	210	7.5
034078759	Little Brimstone at Hembree	3/ 8/83	8	6	12	10	10	44	6.5

Of the water-quality data collected, dissolved sulfate concentrations and specific conductance were the most useful in evaluating the extent of mining impacts on water quality at sites in the Smoky Creek basin. Dissolved sulfate was identified in an earlier study in Tennessee as a good indicator of mining effects of water quality, with undisturbed streams usually having concentrations of sulfate less than 20 milligrams per liter (Parker and Carey, 1980). Streams draining disturbed basins in Tennessee may contain several hundred milligrams per liter dissolved sulfate under base flow conditions. Specific conductance values are also a good general measure of mining impacts since they reflect the total concentration of dissolved solids.

Examination of water-quality data indicated that Bowling Branch and Little Brimstone, two tributary streams to Smoky Creek, and Crabapple Branch, the undisturbed stream in Louse Creek basin, were the least affected by water-quality degradation. Water at these sites generally had dissolved sulfate concentrations less than 20 mg/L and specific conductance values less than 100 microsiemens per centimeter at 25° Celsius (µS/cm). Although water from Bills Branch and Lowe Branch had slightly higher values, these streams appear to be undisturbed relative to Shack Creek, Green Branch, Asher Fork, and sites on the Smoky Creek main stem. Sulfate concentrations at the more disturbed sites were generally between 55 and 85 mg/L during March and between 120 and 260 mg/L during the low-flow period in November. Specific conductance ranged from 187 to 360 µS/cm during March and from 343 to 700 µS/cm at disturbed sites during November low flows. Sulfate concentrations and specific conductance remained low at Bowling Branch, Little Brimstone, and Crabapple Branch regardless of flow, indicating minimal changes in water quality resulting from the effects of land-use practices.

Because constituent concentrations are greatly affected by flow conditions, additional information on other facets of hydrologic environments are useful in assessments of mining impacts. Biological communities integrate and reflect environmental conditions, therefore, benthic invertebrate data were collected to further investigate varying degrees of impacts indicated by differences in water-quality at each site. In this study it was found that commonly used measures of invertebrate community "health" such as number of species, number of organisms, and species diversity did not support differences in the degree of impacts indicated by water-quality conditions in the Smoky Creek basin.

Benthic invertebrate samples collected in March 1982 (table 4) showed subtle differences in the number of taxa at most sampling sites regardless of water quality. Samples from Little Brimstone and Crabapple Branch, two sites with relatively low constituent concentrations, contained 53 and 50 taxa, respectively. However, Bowling Branch, another site with low constituent concentrations and specific conductance, had only 38 taxa. Sites on Smoky Creek usually had less than 30 taxa. Green Branch, the site with the highest constituent concentrations had only 11 taxa represented in the sample. Number of organisms per sample was not useful in evaluating differences in water quality at individual sites. Although bed material was not measured, differences in the number of organisms at a site were undoubtedly affected by substrate characteristics. Bed material at Smoky Creek above Hembree and Smoky Creek below Hembree was particularly embedded, making sampling for invertebrates difficult.

Benthic invertebrate data collected in November 1982 (table 5) indicated a similar range in the number of taxa found during winter months in the study area. Samples from all sites contained 29 to 51 taxa with the exception of Green Branch which had only 13 taxa. Number of organisms, although greater at most sites during November than in

March, was not indicative of improved water quality because dissolved constituent concentrations were highest during this period of low flow. Increases in the number of organisms per sample collected in November were due to seasonal variation in benthic fauna, reflecting the increase in the number and density of Diptera taxa.

Number of taxa and number of organisms in the March 1983 collections (table 6) were similar to those found in the March 1982 collections. Most samples in 1983 had higher numbers of organisms per sample at most stations, particularly Green Branch and Crabapple Branch. The substantial increase in number of taxa (31) and organisms (902) at Green Branch in March 1983 was not due to improved water-quality conditions based upon available data.

Sample diversity and relative evenness values provided little differentiation between sites, with most collections having species diversity values between 3.0 and 4.0 regardless of season or water quality. Evenness values were difficult to interpret and were generally higher for collections with low numbers of organisms. Changes in community structures due to seasonal invertebrate life cycles resulted in lower evenness values for the November collections at most sites.

The inadequacy of diversity indices in differentiating sites with obviously different water quality in the Smoky Creek basin supports the finding of other studies (Chadwick and Canton, 1984). Although useful in determining environmental trends at the same site over time, diversity indices were inadequate for evaluations of water quality at sites in this study.

Biomass data for orders of invertebrates found in Smoky Creek were highly variable and provided little insight into differences in water quality at different sites. Seasonal effects were evident when comparing November to March data, reflecting the shift in abundance of different functional groups (table 7, 8). Collector gatherers, primarily <u>Cinygmula subaequalis</u>, made up a higher percentage of the March than the November samples (table 9). November samples were dominated by the dipteran predators <u>Psectrotanypus</u> and <u>Paracladopelma</u>. <u>Psectrotanypus</u> was also well represented in the March 1983 samples.

Biomass of different groups of invertebrates, like other aspects of biological communities, is dependent on water-quality conditions, physical habitat conditions such as the size distribution and arrangement of substrate material, and on sampling techniques. Biomass data for different orders of invertebrates should not be grouped for a sample and used in site comparisons because of size differences of the various taxa. A few large organisms can greatly influence the biomass of a sample and erroneously indicate a large population.

Table 4.--Number of taxa, number of organisms, sample diversity, maximum possible diversity, minimum possible diversity, and relative evenness values for benthic invertebrate samples collected during March 1982

[H = sample diversity; Hmax = Maximum possible diversity; Hmin = Minimum possible diversity; E = Relative Evenness]

Station No.	Station name	Date	Number of taxa	Number of organisms	H	HMax	HMin	E
03403718	Crabapple Br nr LaFollete	3/11/82	50	2573	3.96	5.56	0.21	0.14
03407874	Green Br nr Hembree	3/11/82	11	41	1.64	2.92	1.26	.16
034078752	Bills Br nr Hembree	3/10/82	39	558	3.71	5.06	.61	.37
03407876	Smoky Cr at Hembree	3/ 9/82	40	554	4.07	5.09	.63	.43
03407877	Bowling Br ab Smk. Junction	3/ 9/82	38	380	3.98	4.96	.82	.52
034078737	Smoky Cr nr Mahan Village	3/11/82	26	286	3.21	4.44	.70	.39
034078738	Asher Fk nr Hembree	3/11/82	27	197	3.39	4.39	.99	.54
034078739	Smoky Cr nr Hembree	3/11/82	25	220	3.48	4.33	.84	.51
034078745	Smoky Cr above Hembree	3/10/82	21	133	2.92	4.00	1.04	.49
034078753	Lowe Br at Hembree	3/10/82	34	834	2.96	4.94	.38	.20
034078755	Shack Cr at Hembree	3/10/82	33	321	3.10	4.75	.82	.39
034078757	Smoky Cr bl Hembree	3/10/82	28	148	3.64	4.35	1.29	.69
034078759	Little Brimstone at Hembree	3/10/82	53	1413	3.17	5.59	.38	.19

Table 5.--Number of taxa, number of organisms, sample diversity, maximum possible diversity, minimum possible diversity, and relative evenness values for benthic invertebrate samples collected during November 1982

Station No.	Station name	Date	Number of taxa	Number of organisms	H	HMax	HMin	E
03403718	Crabapple Br nr LaFollette	11/ 3/82	46	5033	4.01	5.48	0.11	0.07
03407874	Green Br nr Hembree	11/ 2/82	13	146	2.65	3.45	.58	.35
034078752	Bills Br nr Hembree	11/ 1/82	37	1436	3.66	5.11	.26	.17
03407876	Smoky Cr at Hembree	11/ 1/82	35	6296	3.34	5.09	.06	.04
03407877	Bowling Br ab Smk Junction	11/ 1/82	35	1535	2.67	5.04	.23	.11
034078737	Smoky Cr nr Mahan Village	11/ 2/82	33	2883	3.04	4.99	.12	.07
034078738	Asher Fk nr Hembree	11/ 2/82	41	2811	3.48	5.29	.16	.10
034078739	Smoky Cr near Hembree	11/ 2/82	51	6231	3.43	5.63	.10	.06
034078745	Smoky Cr above Hembree	11/ 2/82	40	1980	3.41	5.24	.21	.13
034078753	Lowe Br at Hembree	11/ 2/82	34	1870	3.06	5.01	.19	.11
034078755	Shack Cr at Hembree	11/ 2/82	32	886	3.21	4.87	.34	.20
034078757	Smoky Cr bl Hembree	11/ 2/82	29	572	3.25	4.69	.44	.26
034078759	Little Brimstone at Hembree	11/ 2/82	33	1612	2.53	4.96	.21	.09

Table 6.--Number of taxa, number of organisms, sample diversity, maximum possible diversity, minimum possible diversity, and relative evenness values for benthic invertebrate samples collected during March 1983

Station No.	Station name	Date	Number of taxa	Number of organisms	H	HMax	HMin	E
03403718	Crabapple Br nr LaFollette	3/10/83	43	7796	3.84	5.39	0.07	0.04
03407874	Green Br nr Hembree	3/ 9/83	31	902	2.87	4.83	.32	.17
034078752	Bills Br nr Hembree	3/ 9/83	25	500	3.43	4.48	.42	.28
03407876	Smoky Cr at Hembree	3/ 8/83	41	919	3.51	5.20	.42	.25
03407877	Bowling Br ab Smk. Junction	3/ 8/83	40	281	3.63	4.94	1.11	.56
034078737	Smoky Cr nr Mahan Village	3/ 9/83	37	753	3.59	5.04	.45	.28
034078738	Asher Fk nr Hembree	3/ 9/83	34	792	3.32	4.94	.40	.23
034078739	Smoky Cr near Hembree	3/ 9/83	34	699	3.57	4.92	.44	.28
034078745	Smoky Cr above Hembree	3/ 9/83	24	213	3.23	4.28	.82	.46
034078753	Lowe Br at Hembree	3/ 9/83	35	1044	3.33	5.00	.32	.19
034078755	Shack Cr at Hembree	3/ 9/83	22	213	3.21	4.17	.75	.44
034078757	Smoky Cr bl Hembree	3/ 8/83	37	364	4.15	4.88	.81	.55
034078759	Little Brimstone at Hembree	3/ 9/83	36	2298	3.44	5.10	.17	.10

Table 7.--Biomass (grams wet weight, per sample) of groups of benthic invertebrates collected during November 1982

Station name and No.	Insecta								Collembola	Crustacea			Oligochaeta	Total
	Ephemeroptera (mayflies)	Plecoptera (stoneflies)	Tricoptera (caddisflies)	Diptera (true flies)	Coleoptera (beetles)	Hemiptera (true bugs)	Odonata (dragonflies and damselflies)	Megaloptera (alderflies)	(springtails)	Amphipoda (scuds)	Isopoda (sow bugs)	Decapoda (crayfish)	(worms)	
Smoky Creek near Mahan Village (034078737)	0.0444	0.1638	0.0402	0.3872	0.0136	--	--	--	0.0006	--	--	--	0.0122	0.2307
near Hembree (034078739)	.3216	.9440	.8010	2.8124	.0136	0.0046	0.0149	0.0003	--	--	--	--	.0012	5.0809
above Hembree (034078745)	.3056	.3458	.1078	.3456	.0498	--	--	.0064	--	--	--	--	--	1.1610
below Hembree (034078757)	.0874	.0064	.0256	.3170	.0976	--	--	--	.0003	--	--	--	.0006	.5349
at Hembree (03407876)	3.2960	.3068	.3256	4.4720	--	--	--	2.5937	--	--	--	--	--	10.9941
Bowling Branch above Smoky Junction (03407877)	.3741	.0289	.1039	.3233	--	.0038	--	.0132	.0051	0.0046	--	0.4062	--	1.2631
Asher Fork near Hembree (034078738)	.2016	.0824	.4920	1.3540	.1356	--	.0137	--	--	--	--	--	--	2.2793
Green Branch near Hembree (03407874)	--	.1734	.0204	.2046	--	--	--	--	--	--	--	8.3924	--	8.7908
Bills Branch near Hembree at mouth (034078752)	.7462	.2686	.1104	.1316	.213	--	.3904	--	.0006	--	--	.2986	--	2.1594
Lowe Branch at Hembree (034078753)	.5876	.4984	.1738	.2748	1.1200	--	--	--	.0009	--	--	.6665	--	3.322
Shack Creek at Hembree (034078755)	.5420	.6836	--	.4802	.1720	.0156	--	--	--	--	--	12.6652	--	14.5586
Little Brimstone Creek at Hembree (034078759)	.5340	.0464	.1100	.3668	.0012	.0084	--	--	--	--	--	.7548	.0023	1.8239
Crabapple Branch near LaFollette (03403718)	.8424	4.0744	.6194	3.9904	.0002	--	.0005	--	.0003	--	0.0089	--	--	9.5365

Table 8.--Biomass (grams wet weight, per sample) of groups of benthic invertebrates collected during March 1983

Station name and No.	Insecta								Collembola	Crustacea	Mollusca	Oligochaeta	Total
	Ephemeroptera (mayflies)	Plecoptera (stoneflies)	Tricoptera (caddisflies)	Lepidoptera (aquatic caterpillars)	Diptera (true flies)	Coleoptera (beetles)	Odonata (dragonflies and damselflies)	Megaloptera (alderflies)	(springtails)	Decapoda (crayfish)	Gastropoda (snails)	(worms)	
Smoky Creek near Mahan Village (034078737)	0.1954	1.0292	0.1317	--	0.0472	0.0003	--	0.0796	--	0.4685	--	0.0090	1.9609
near Hembree (034078739)	.1708	.8959	.0359	--	.0144	.0015	--	.2982	--	--	--	.0003	1.4170
above Hembree (034078745)	.1690	.1480	.6240	--	.0372	.0024	--	--	--	--	0.5580	--	1.5386
below Hembree (034078757)	.4166	1.2526	.0204	--	1.2296	.1518	--	--	--	1.6770	--	--	4.7481
at Hembree (03407876)	.5446	.2100	.0920	0.0006	.8534	--	--	.1402	--	--	--	.0144	2.8552
Bowling Branch above Smoky Junction (03407877)	.3768	.0692	.0800	--	.0646	--	--	--	--	--	--	.0059	.5965
Asher Fork near Hembree (034078738)	.3400	.6279	.0808	--	.0344	.0046	--	.0186	--	--	--	.0003	1.1066
Green Branch near Hembree (03407874)	.6106	.4789	.1572	--	1.7317	--	--	--	--	--	--	--	2.9781
Bills Branch near Hembree at mouth (034078752)	.2036	.2130	.1000	--	.0284	.1526	--	--	0.0006	--	--	--	.6982
Lowe Branch at Hembree (034078753)	.7016	.8356	.1012	--	.1534	.0444	--	--	.0003	2.1627	--	--	3.9992
Shack Creek at Hembree (034078755)	.1582	.9690	.0394	--	.2962	.1170	--	--	.0003	6.0719	--	.0023	7.6543
Little Brimstone Creek at Hembree (034078759)	.1340	.2288	.2808	--	7.5776	--	0.0004	--	.0003	.3104	--	--	9.7383
Crabapple Branch near LaFollette (03403718)	4.0184	1.9240	.6952	--	9.3841	.0045	--	--	--	18.4837	--	--	34.5099

Table 9a.--Percentage composition of functional groups in benthic inverterbrate samples, for March 1982

[Functional groups are as follows: CF = collector-filterers; CFP = collector-filterers, predators; CG = collector-gatherers; CGP = collector-gatherers, predators; CGS = collector-gatherers, scrapers; CGSH = collector-gathers, shredders; P = predator, S = scrapers, Sh = shredder, * = identified to Chironomidae, no functional group assigned]

Station No.	Station name	CF	CFP	CG	CGP	CGS	CGSH	P	S	Sh	*
03403718	Crabapple Br nr LaFollette	0.07423	0.00077	0.16362	0.07267	0.22192	0.04391	0.16750	0.00155	0.24601	0.00777
03407874	Green Br nr Hembree	.00000	.00000	.07317	.65853	.00000	.00000	.12195	.00000	.09756	.04878
034078752	Bills Br nr Hembree	.00896	.00179	.10931	.18817	.39964	.01075	.12007	.04121	.09319	.02688
03407876	Smoky Cr at Hembree	.02527	.00000	.13357	.08483	.28700	.00180	.21299	.17328	.02888	.02707
03407877	Bowling Br ab Smk Junction	.02368	.00000	.08947	.08947	.16842	.00000	.23947	.06052	.26052	.06842
037078737	Smoky Cr nr Mahan Village	.01049	.00000	.18531	.13636	.29720	.00000	.25174	.04895	.05244	.01748
034078738	Asher Fk nr Hembree	.04060	.00000	.07614	.24365	.12182	.00000	.22842	.06091	.21827	.01015
034078739	Smoky Cr nr Hembree	.00454	.00000	.15454	.22727	.14545	.00000	.28636	.10000	.06818	.01363
034078745	Smoky Cr above Hembree	.03759	.00000	.07518	.28571	.08270	.00000	.33834	.13533	.04511	.00000
034078753	Lowe Br at Hembree	.00719	.00000	.10911	.28057	.42925	.00239	.12709	.00599	.03237	.00599
034078755	Shack Cr at Hembree	.00623	.00000	.12149	.39875	.28660	.00934	.10280	.03426	.04049	.00000
034078757	Smoky Cr bl Hembree	.02702	.00000	.14864	.12162	.14864	.00000	.27027	.14189	.12162	.02027
034078759	Lil Brimstone at Hembree	.01627	.00141	.16277	.02335	.45647	.00212	.27459	.00424	.05237	.00636

Table 9b.--Percentage composition of functional groups in benthic inverterbrate samples, for November 1982

Station No.	Station name	CF	CFP	CG	CGP	CGS	CGSH	P	S	Sh	*
03403718	Crabapple Br nr LaFollette	0.07470	0.01271	0.16650	0.00317	0.12239	0.14464	0.22769	0.00953	0.22431	0.01430
03407874	Green Br nr Hembree	.01369	.00000	.02739	.00000	.00000	.00000	.48630	.20547	.24657	.02054
034078752	Bills Br nr Hembree	.02089	.00278	.05849	.07590	.06267	.00974	.51740	.02924	.21727	.00557
03407876	Smoky Cr at Hembree	.10228	.00000	.10546	.00190	.03303	.00000	.57496	.10038	.07433	.00762
03407877	Bowling Br ab Smk Junction	.01368	.00000	.17524	.00130	.02149	.00195	.73289	.02280	.02801	.00260
037078737	Smoky Cr nr Mahan Village	.19909	.00000	.08116	.00312	.00624	.00000	.42351	.18522	.08463	.01699
034078738	Asher Fk nr Hembree	.04695	.00142	.04126	.01992	.03415	.00142	.60263	.04553	.19245	.01423
034078739	Smoky Cr nr Hembree	.06098	.00256	.22163	.01027	.02503	.00064	.57647	.02776	.06692	.00770
034078745	Smoky Cr above Hembree	.03636	.00101	.65858	.00606	.07272	.00000	.10505	.06464	.05151	.00404
034078753	Lowe Br at Hembree	.02780	.00107	.07540	.03048	.05775	.00427	.68448	.04919	.05668	.01283
034078755	Shack Cr at Hembree	.00451	.00000	.18058	.00451	.04966	.00225	.53047	.01805	.12866	.08126
034078757	Smoky Cr bl Hembree	.05244	.00000	.12237	.00000	.03496	.00000	.58391	.14335	.04195	.02097
034078759	Lil Brimstone at Hembree	.02481	.00000	.09429	.00372	.07444	.00248	.72456	.01612	.05955	.00000

Table 9c.--Percentage composition of functional groups in benthic inverterbrate samples, for March 1983

Station No.	Station name	CF	CFP	CG	CGP	CGS	CGSH	P	S	Sh	*
03403718	Crabapple Br nr LaFollette	0.05233	0.00102	0.24730	0.03604	0.14366	0.02770	0.39917	0.00115	0.08337	0.00820
03407874	Green Br nr Hembree	.02217	.00000	.31707	.03991	.08204	.00221	.43459	.00000	.07982	.02217
034078752	Bills Br nr Hembree	.03200	.00400	.09200	.08800	.30800	.02000	.30400	.04400	.10800	.00000
03407876	Smoky Cr at Hembree	.03046	.00217	.12187	.03482	.34167	.00217	.36017	.06311	.03917	.00435
03407877	Bowling Br ab Smk Junction	.03558	.00000	.30249	.02491	.16014	.00711	.35231	.01067	.09964	.00711
037078737	Smoky Cr nr Mahan Village	.01062	.00265	.16467	.12085	.17928	.00000	.39707	.01992	.09296	.01195
034078738	Asher Fk nr Hembree	.02777	.00252	.11363	.30303	.16919	.00000	.23257	.02272	.12121	.00505
034078739	Smoky Cr nr Hembree	.03433	.00143	.10872	.21173	.18884	.00000	.37482	.01716	.04721	.01573
034078745	Smoky Cr above Hembree	.03755	.00000	.12206	.10328	.29108	.00000	.07981	.08450	.00000	.00000
034078753	Lowe Br at Hembree	.01724	.00191	.15996	.11973	.29885	.00383	.34482	.01341	.04023	.00000
034078755	Shack Cr at Hembree	.01877	.00000	.14554	.06572	.30985	.00000	.06103	.03755	.06103	.30046
034078757	Smoky Cr bl Hembree	.02197	.00000	.21703	.01923	.18681	.00549	.37912	.08791	.02747	.05494
034078759	Lil Brimstone at Hembree	.05047	.00000	.15883	.02785	.38816	.00522	.26849	.00348	.09051	.00696

NUMERICAL CLASSIFICATION OF INVERTEBRATE DATA

Number of taxa, number of organisms, and species diversity indicate community structure but not community composition. These measures of community structure were not appropriate for determining mining effects on water quality in Smoky Creek because similar values were obtained for sites with different constituent concentrations. Numerical classification methods were more useful in evaluating benthic invertebrate data collected in this study. Hundreds of observations of species occurrences were reduced to a series of phenograms (cluster diagrams) so that differences in community composition could be compared with available water-quality data.

Differences in species occurrences at different sites with respect to season affect the way organisms and collections are clustered. Species and samples from different seasons group differently than do species and samples collected within a few days of each other. Therefore, samples from each sampling trip were evaluated separaterly and in combination. Because some groups of invertebrates may be more ecologically informative than others, major orders of invertebrates found in the study area also were examined individually in this report as well as in combination.

The following discussions are based on UPGMA clustering of presence-absence data. It should be noted that a wide variety of clustering algorithms and ordination techniques exist, each of which will produce different results. Selection of an appropriate method requires careful consideration of the structure of the data in question. High cophenetic correlation coefficients obtained in these analyses suggest the phenograms presented in this report are reasonable representations of distribution patterns of benthic invertebrates collected in the study basins.

Classifications of Species of Ephemeroptera Collected during March and November 1982 and March 1983

Seasonality was best illustrated by classifications of data from all three sampling trips combined. The classification of collection groups (normal analysis) was very effective in separating samples based on seasonal variations in benthic invertebrate life histories. March 1982 and March 1983 collections, although having many species in common, also clustered separately. Three clusters of ephemeropteran species exhibited high constancy and fidelity with respect to seasonal differences in samples of particular collection groups (fig. 2, table 10).

Drunella lata, *Serratella deficens*, *Cinygmula subaequalis*, and *Epeorus dispar* (species group 2) clustered at a high level of similarity as measured by a Jaccard coefficient $\geq$0.67. These species were well represented in March samples from all stations (constancy $\geq$0.75). Fidelity was less than 2.0 because two thirds of the samples used in these analyses were collected in the spring. Relative abundance figures indicate that these species were most abundant in the tributary sites (collection groups 2 and 3) with lower relative abundance at the main stem sites (collection groups 1, 4, and 5).

A second cluster (species group 3, Jaccard coefficient $\geq$0.49) comprised of *Baetis brunneicolor*, *Ameletus lineatus*, *Paraleptophlebia swannanoa*, *Stenonema terminatum*, and *Stenonema vicarium* was well represented at the tributaries in March 1982 and in the November 1982 samples. These species were more abundant at the tributary sites than at the main stem sites.

Ephemerella argo and *Baetis tricaudatus* (species group 4) formed a small cluster that was well represented in March 1982 collections (C $\geq$0.83, F $\geq$2.38). These organisms were rare in November 1982 and March 1983, resulting in high relative abundance values in collection groups 1 and 2. Small clusters are not as ecologically informative because of many problems associated with the use of single "indicator organisms" (Cairns, 1974).

Baetis intercalaris, *Eurylophella funeralis*, and *Stenonema modestum* (species group 5) were most abundant in the November samples, most of which are in collection group 6.

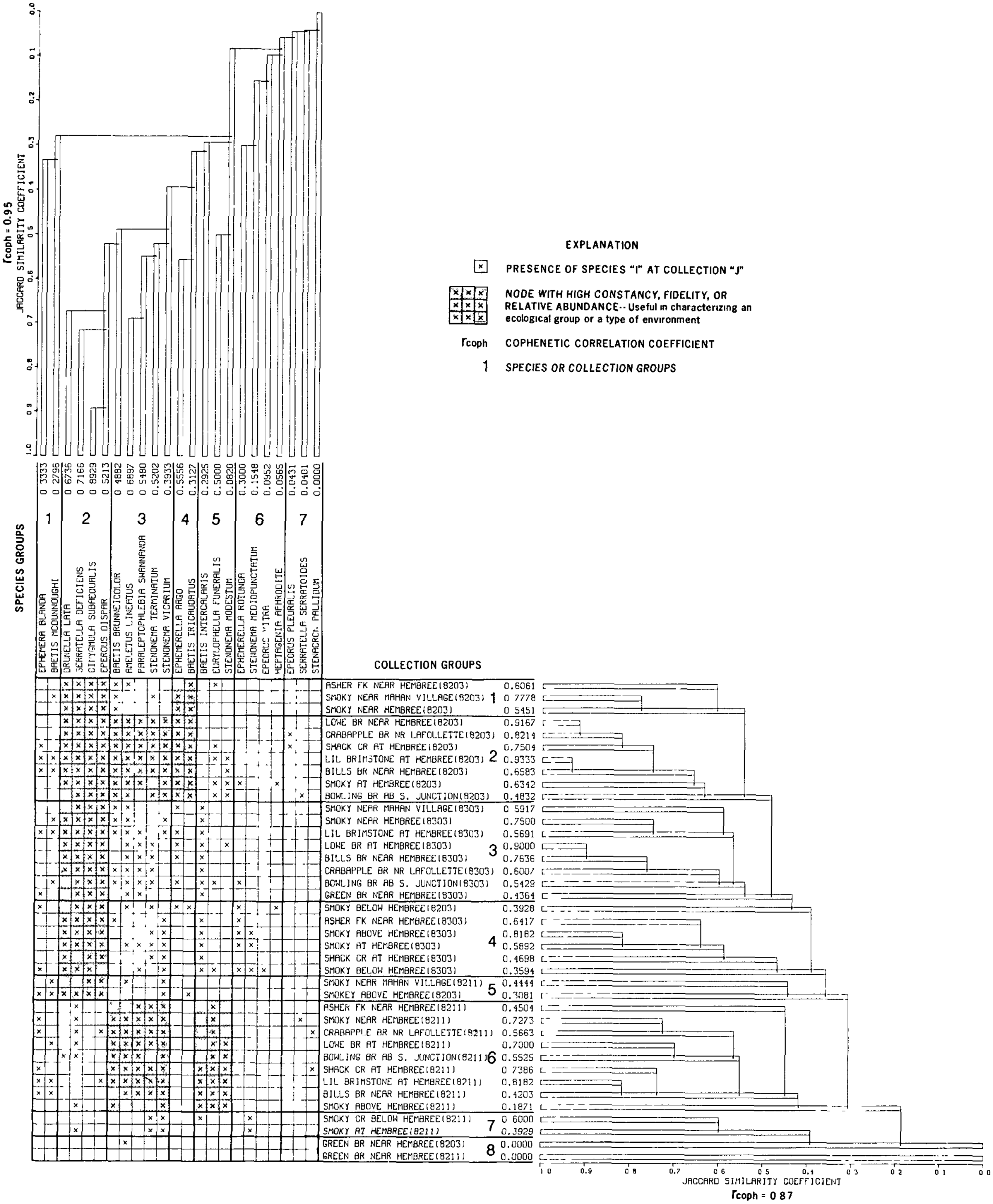


Figure 2.--Normal and inverse classifications of presence-absence data for species of Ephemeroptera collected during March and November 1982 and March 1983.

Table 10.--Constancy, fidelity, and relative abundance values for species groups of Ephemeroptera at collection groups in two-way tables of data collected during March and November 1982 and March 1983

Constancy values

Species groups	Collection groups 1	2	3	4	5	6	7	8
1	0.17	0.36	0.31	0.17	0.75	0.44	0	0
2	1.0	.96	.91	.88	.75	.75	.13	0
3	.33	.94	.63	.47	.30	.84	.40	.10
4	.83	1.0	.31	.17	.25	0	0	0
5	.11	.38	.42	.33	0	.70	.17	0
6	0	.07	.03	.42	0	0	.25	0
7	0	.14	0	0	0	.11	0	0

Fidelity values

Species groups	Collection groups 1	2	3	4	5	6	7	8
1	0.56	1.19	1.04	0.56	2.50	1.48	0	0
2	1.62	1.56	1.46	1.41	1.21	.40	.20	0
3	.52	1.48	.98	.73	.47	1.33	.63	.16
4	2.41	2.89	.90	.48	.72	0	0	0
5	.29	.99	1.08	.87	0	1.83	.43	0
6	0	.74	.32	4.53	0	0	2.60	0
7	0	2.86	0	0	0	2.22	0	0

Relative abundance values

Species groups	Collection groups 1	2	3	4	5	6	7	8
1	0.41	0.41	1.39	4.89	2.90	3.82	0	0
2	1.34	2.35	3.33	1.50	.35	.21	0	0
3	.21	2.17	1.62	.72	.06	2.53	.19	0
4	4.62	10.2	1.86	2.44	.34	0	0	0
5	.26	2.36	3.25	1.43	0	5.37	.32	0
6	0	1.56	.08	6.70	0	0	1.40	0
7	0	7.82	0	0	0	2.65	0	0

Classifications of Species of Ephemeroptera Collected during March 1982

Although classifications of data from mixed seasons provide insight into invertebrate life histories, clusters of collections and species obtained from data collected in one season are more likely to reflect different physical and (or) water-quality conditions. Normal classifications of collections were useful in illustrating differences in species composition at tributary sites relative to sites on Smoky Creek and Green Branch. Lowe Branch, Crabapple Branch, Shack Creek, Little Brimstone Creek, and Bills Branch (collection group 2) clustered at a high Jaccard coefficient (greater than 0.75) because of a substantially larger number of Ephemeropteran species compared to main stem sites (fig. 3, table 11).

Two large clusters of the inverse analysis (species groups 2 and 3) indicate 11 species of Ephemeroptera that may be useful in assessments of mining impacts in eastern Tennessee. Drunella lata, Serratella deficens, Baetis tricaudatus, Cinygmula subaequalis, Epeorus dispar, and Baetis brunneicolor were present at all sites but one. Not one of the taxa in group 2 was present at Green Branch, indicating the possibility of extremely degraded conditions at that site.

Species group 3, although joining at a lower level of similarity in the inverse analysis, may be more useful than other commonly occurring taxa in species group 2 in describing environmental conditions of higher order streams. Constancy and fidelity values of Ephemerella argo, Ameletus lineatus, Stenonema terminatum, Paraleptophlebia swannanoa, and Stenonema vicarium were higher at tributary sites (collection groups 2 and 3) than at other collection groups containing only sites on Smoky Creek (collection groups 1, 4, and 5). Constancy values for the species group 3 - collection groups 2 and 3 clusters were ≥0.80, twice as constant as in other collection groups. Fidelity values were ≥1.24 at these clusters. Although arbitrarily graded as low, these values may be significant due to the fact that 7 of the 13 sites were in collection groups 2 and 3.

Other groups of species (species groups 1, 4, 5, and 6) exhibited high constancy, fidelity, or relative abundance values but rarely exhibited all three. Most of these groups contain only two or three species. Because of their poorly defined occurrence patterns, additional data are needed before these groups could be used with confidence in environmental assessments.

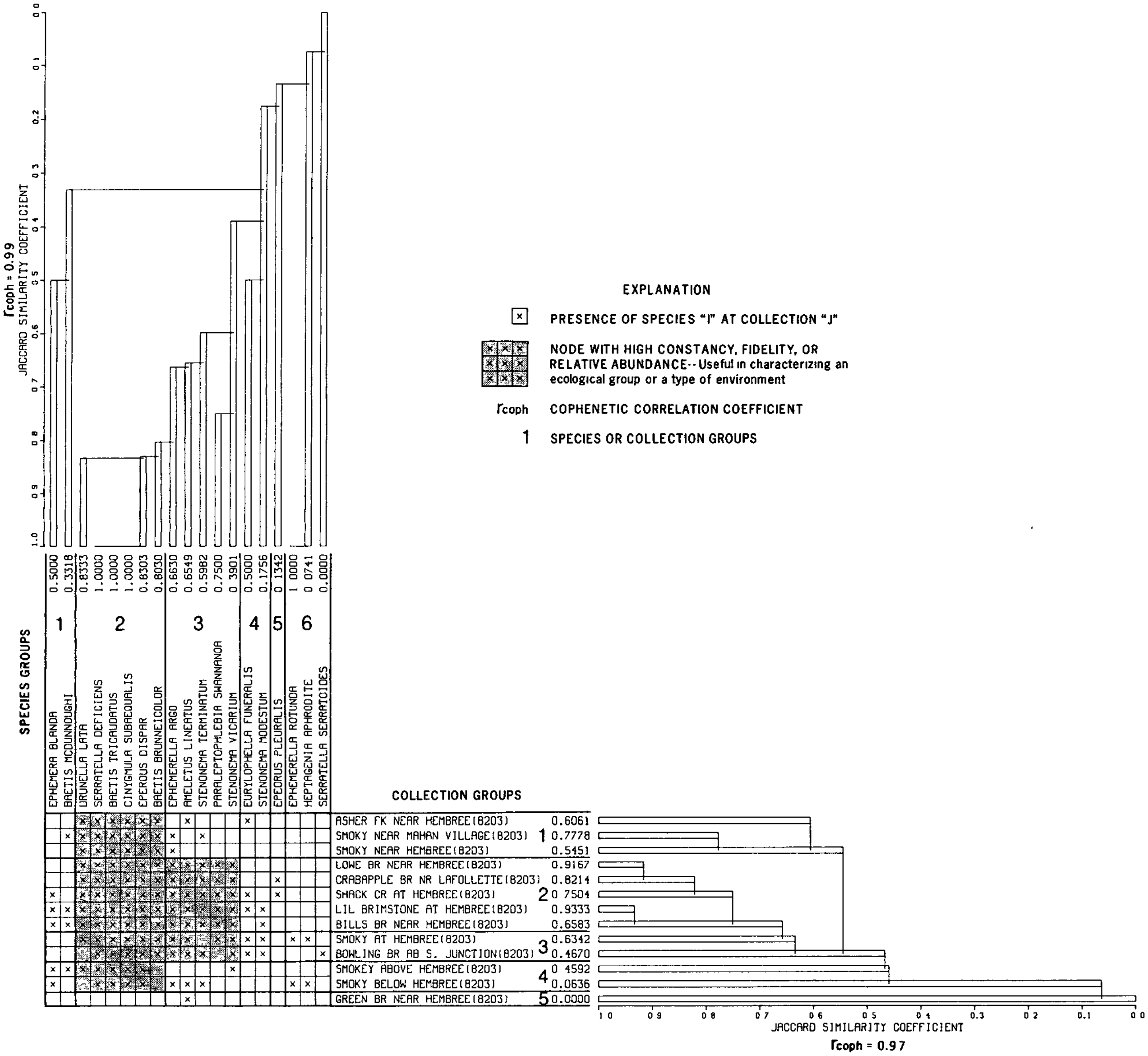


Figure 3.--Normal and inverse classifications of presence-absence data for species of Ephemeroptera collected during March 1982.

Table 11.--Constancy, fidelity, and relative abundance values for species groups of Ephemeroptera at collection groups in two-way tables of data collected during March, 1982

Constancy values

Species groups	Collection groups 1	2	3	4	5
1	0.17	0.50	0	0.75	0
2	1.0	1.0	.92	.75	0
3	.27	1.0	.80	.40	.20
4	.17	.40	1.0	0	0
5	0	.40	0	0	0
6	0	0	.50	.33	0

Fidelity values

Species groups	Collection groups 1	2	3	4	5
1	0.48	1.44	0	2.17	0
2	1.15	1.15	1.05	.86	0
3	.41	1.55	1.24	.62	.31
4	.48	1.16	2.89	0	0
5	0	2.60	0	0	0
6	0	0	3.90	2.60	0

Relative abundance

Species groups	Collection groups 1	2	3	4	5
1	0.45	1.52	0	4.53	0
2	.58	1.13	.25	.20	0
3	.18	1.46	.56	.27	.19
4	.70	1.71	4.09	0	0
5	0	11.6	0	0	0
6	0	0	2.65	1.68	0

Classifications of species of Ephemeroptera collected during November 1982

Species composition of samples collected in November were probably less influenced by insect emergence than were samples collected in the spring. Samples of winter fauna may provide more reliable classifications for differentiating environmental conditions at sites based on community composition than do samples of the spring fauna (fig. 4, table 12). Normal classification of November samples indicates distinct differences in benthic community composition found at most tributary sites (collection group 2) as compared with those groups of organisms found at the Smoky Creek main stem sites, Asher Fork, and Green Branch (collection groups 1, 3, and 4). Collection group 2 clustered separately because of a much more abundant and diverse mayfly population at tributary sites with the exceptions of Green Branch. The November collection from Green Branch contained no species of Ephemeroptera, indicating serious environmental degradation.

Ephemera blanda, *Eurylophella funeralis*, *Paraleptophlebia swannanoa*, *Ameletus lineatus*, and *Baetis brunneicolor*, species group 1, were well represented in collection group 2 (C = 0.91, F = 1.61, RA = 2.47) but were virtually absent from the main stem sites and from Green Branch (fig. 4, table 12). *Stenonema vicarium*, *Stenonema terminatum*, and *Serratella deficens* formed a less well defined cluster (Jaccard coefficient $\geq$0.46), which was representative of all sites except Green Branch. Although highly constant (C$\geq$0.67), fidelity figures were usually low (F$\leq$1.39) because of the species consistent occurrence in most collections.

A third cluster comprised of *Baetis intercalaris*, *Stenonema modestum*, and *Stenonema pallidum*, although not highly constant in any collection group, was better represented and was much more abundant in collection group 2 (RA = 3.83). Collection group 2 is comprised of five of the six tributary sites and Crabapple Branch.

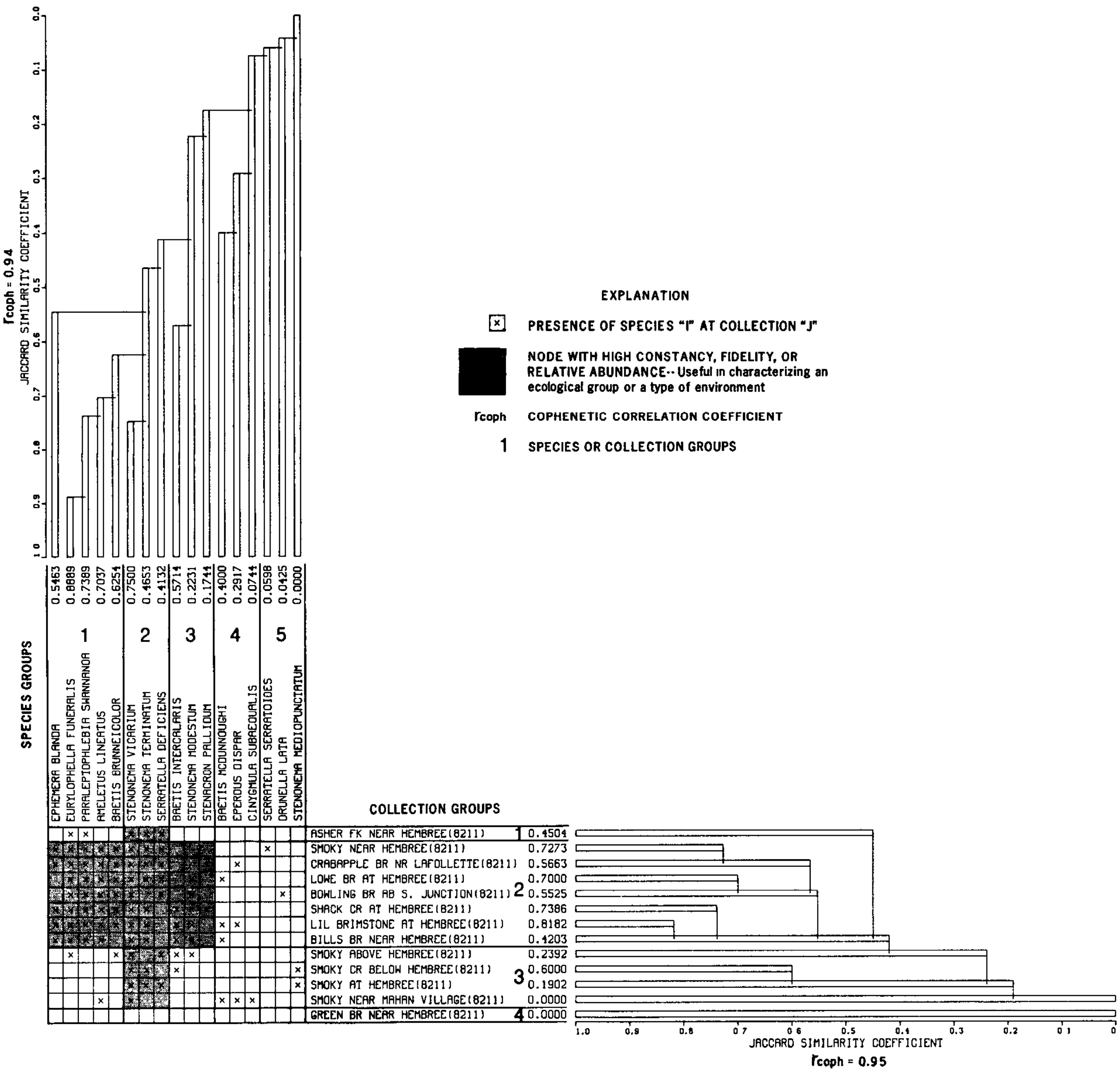


Figure 4.--Normal and inverse classifications of presence-absence data for species of Ephemeroptera collected during November 1982.

Table 12.--Constancy, fidelity, and relative abundance values for species groups of Ephemeroptera at collection groups in two-way tables of data collected during November, 1982

Constancy values

Species groups	Collection groups 1	2	3	4
1	0.40	0.91	0.15	0
2	1.0	.81	.67	0
3	0	.48	.25	0
4	0	.24	.25	0
5	0	.10	.17	0

Fidelity values

Species groups	Collection groups 1	2	3	4
1	0.70	1.61	0.26	0
2	1.39	1.13	.93	0
3	0	1.43	.75	0
4	0	1.16	1.22	0
5	0	.93	1.63	0

Relative abundance values

Species groups	Collection groups 1	2	3	4
1	0.067	2.47	0.080	0
2	.58	1.49	1.18	0
3	0	3.83	1.90	0
4	0	1.43	1.59	0
5	0	1.44	1.44	0

Classifications of species of Ephemeroptera collected during March 1983

The normal classification of collection groups in figure 5 shows the headwater sites and other Smoky Creek main stem sites (collection groups 1, 2, and 3) clustering separately from four of the five relatively undisturbed tributary sites (collection group 4). Green Branch, although having a surprisingly high number of mayfly species in the March 1983 sample, was the last collection to cluster with other March 1983 samples. Clusters containing main stem sites did not join the tributary sites until a Jaccard coefficient of 0.57 or less.

Drunella lata, *Serratella deficens*, *Baetis brunneicolor*, *Cinygmula subaequalis*, *Epeorus dispar*, *Ameletus lineatus*, and *Paraleptophlebia swannanoa* (species group 2) clustered at Jaccard coefficients greater than 0.73. These organisms were highly constant at all stations ($C \geq 0.64$) and, consequently, were not faithful to any one collection group (fidelity ≤ 1.11, table 13). Relative abundance values for this group indicated these organisms were twice as abundant at four tributary sites clustered in collection group 4 as in other samples collected from sites on Smoky Creek and Green Branch in March 1983.

Other clusters of species were difficult to interpret. Species group 3 was only moderately constant and faithful ($C \leq 0.58$, $F \leq 1.44$). Species group 4 was well represented at collections groups 1 and 2 (table 13) and was more abundant at these sites than at other sites in the study area.

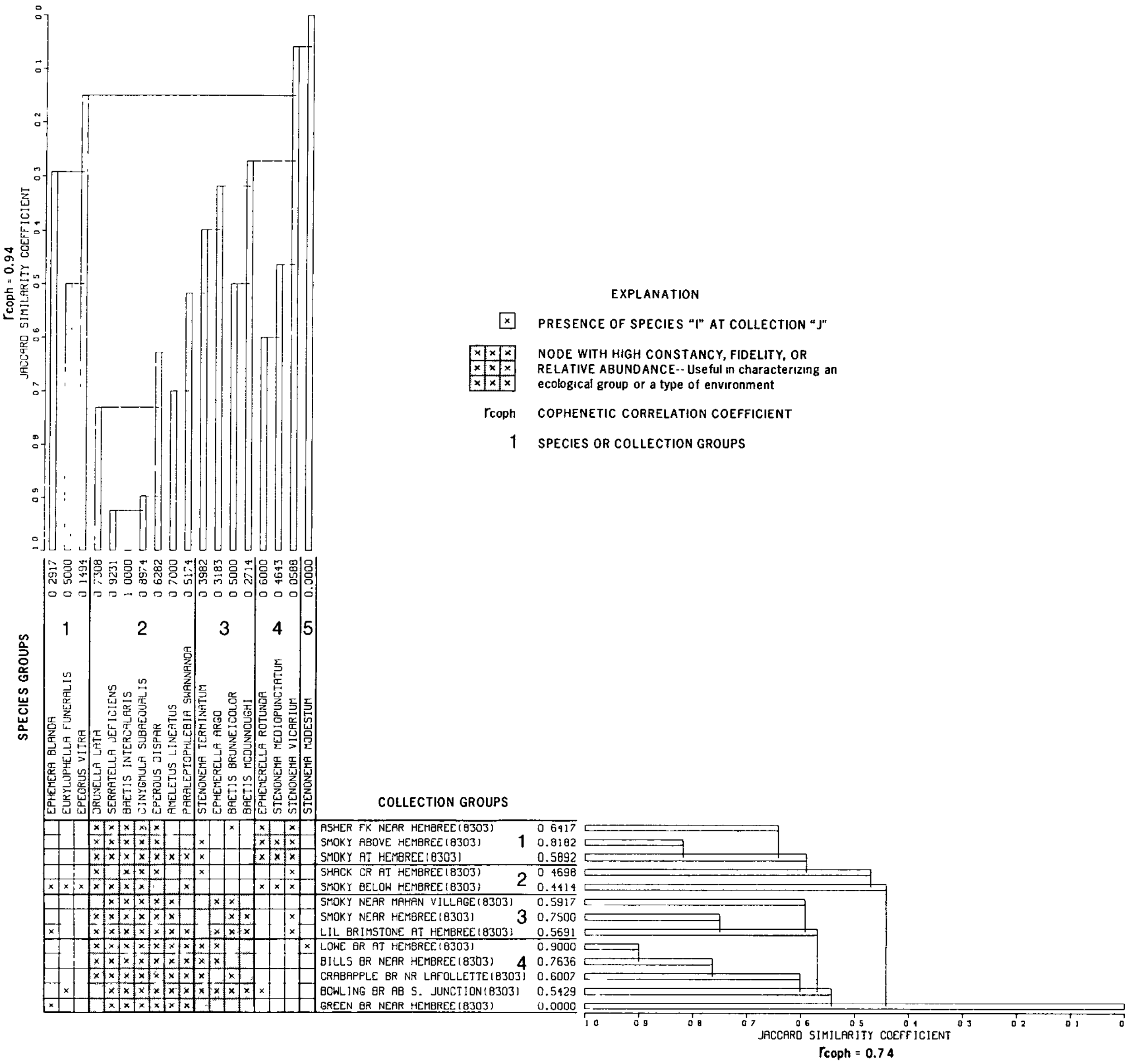


Figure 5.--Normal and inverse classifications of presence-absence data for species of Ephemeroptera collected during March 1983.

Table 13.--Constancy, fidelity, and relative abundance values for species groups of Ephemeroptera at collection groups in two-way tables of data collected during March, 1983

Constancy values

Species groups	Collection groups			
	1	2	3	4
1	0	0.50	0.11	0.20
2	.81	.64	.86	.94
3	.25	.13	.58	.50
4	.89	.67	.22	.07
5	0	0	0	.20

Fidelity values

Species groups	Collection groups			
	1	2	3	4
1	0	3.25	0.72	0.87
2	.96	.76	1.01	1.11
3	.62	.31	1.44	1.24
4	2.31	1.73	.58	.17
5	0	0	0	2.60

Relative abundance values

Species groups	Collection groups			
	1	2	3	4
1	0	3.38	0.17	0.78
2	.26	.15	.47	.97
3	.20	.16	.67	.76
4	2.19	1.68	.39	0
5	0	0	0	13.0

Classifications of Species of Plecoptera Collected during March and November 1982 and March 1983

Classifications of plecopterans collected in March and November were useful in illustrating seasonal trends in stonefly distributions (fig. 6, table 14). A cluster containing four of the more common species of Plecoptera (species group 1) indicated Peltoperla arcuata, Prostoia similis, Amphinemura nigritta, and Strophopteryx fasciata rarely occur in the study area during November. Distributions of these taxa were not limited to tributary or main stem sites, and collections from March 1982 were often clustered with March 1983 collections. Relative abundance values for collection groups containing March samples were usually high due to the scarcity of these organisms in the November samples. Relative abundance was lowest for collection group 4 containing Crabapple Branch and Bills Branch data from both March sampling trips.

A second cluster comprised of Acroneuria carolinensis and Isoperla holochlora joined at the highest level of similarity in the inverse analysis (Jaccard coefficient = 0.81). These organisms occurred at most stations regardless of season ($C \geq 0.81$) illustrating their relatively long life cycles. Relative abundance values were high for most collection groups indicating their high percentage composition at some stations in each collection group.

Paracapnia angulata was present in all samples collected in November. However, this stonefly did not cluster with other species until a low level of similarity because it occurred only in the November collections. Relative abundance values for Paracapnia angulata were variable when compared with water-quality conditions.

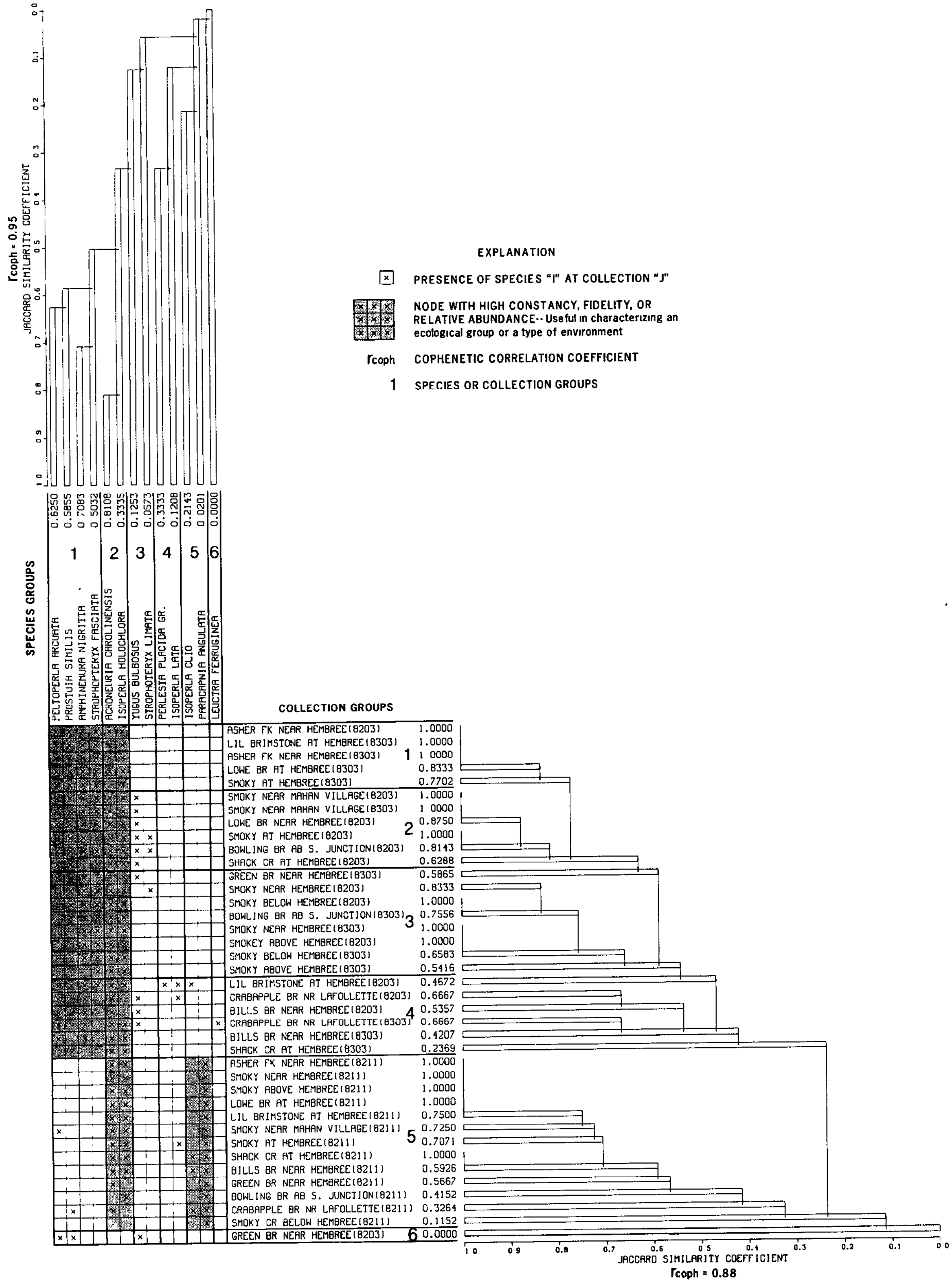


Figure 6.--Normal and inverse classifications of presence-absence data for species of Plecoptera collected during March and November 1982 and March 1983.

Table 14.--Constancy, fidelity, and relative abundance values for species groups of Plecoptera at collection groups in two-way tables of data collected during March and November 1982 and March 1983

Constancy values

Species groups	Collection groups 1	2	3	4	5	6
1	1.0	0.96	0.59	0.58	0.04	0.50
2	.90	1.0	.94	.83	.81	0
3	0	.67	.13	.25	0	.50
4	0	0	0	.25	.04	0
5	0	0	0	.08	.67	0
6	0	0	0	.17	0	0

Fidelity values

Species groups	Collection groups 1	2	3	4	5	6
1	1.95	1.87	1.16	1.14	0.08	0.98
2	1.05	1.16	1.09	.97	.94	0
3	0	3.71	.70	1.39	0	2.79
4	0	0	0	4.88	.75	0
5	0	0	0	.38	2.82	0
6	0	0	0	6.50	0	0

Relative abundance values

Species groups	Collection groups 1	2	3	4	5	6
1	1.92	3.29	2.23	1.36	0.02	0.93
2	2.18	4.40	5.94	2.44	4.53	0
3	0	6.62	5.46	.67	0	1.39
4	0	0	0	17.0	.94	39.0
5	0	0	0	0	10.6	0
6	0	0	0	0	0	0

Classification of Species of Plecoptera Collected during March 1982 and March 1983

Differences between tributary sites and those on Smoky Creek were not as apparent in normal analyses using Plecopteran species as they were when based on species of Ephemeroptera. Classifications of March 1982 and March 1983 data indicated there are less than seven species of Plecoptera that were prevalent in the study area. These species tended to cluster in much the same way in inverse analyses of March 1982 (fig. 7, table 15) and March 1983 (fig. 8, table 16) collections.

Inverse analysis of Plecoptera data collected in March 1982 showed that species group 2, Amphinemura nigritta, Isoperla holochlora, Acroneuria carolinensis, and Strophopteryx fasciata, occurred at most sites in the study area as indicated by high constancy at collection groups 1, 2, and 3 ($C \geq 0.67$). These organisms were equally abundant at most collection groups except for group 3 containing Crabapple Branch and Bills Branch, where their abundance as a group was considerably less ($RA = 0.30$).

A similar pattern was observed for plecopteran species collected in March 1983. The species just discussed formed species group 2 in the inverse analysis of March 1983 in figure 8, which clustered at a high level of similarity (Jaccard coefficient ≥ 0.74). As in the March 1982 classifications, these species were less abundant at Crabapple Branch and Bills Branch in collection group 3 (table 16).

Although tributary and main stem sites were mixed in most collection groups, relative abundance values of the major stonefly cluster indicated these organisms were more abundant in Smoky Creek than in the tributary streams. Higher abundance at these sites indicates the indifference of most Plecoptera to higher levels of constituent concentrations relative to the Ephemeroptera or to their need for the more sustained flow conditions found in Smoky Creek. Additional work with plecopteran species could provide information pertinent to evaluations of higher order or mining-affected streams that may not support a diverse population of Ephemeroptera.

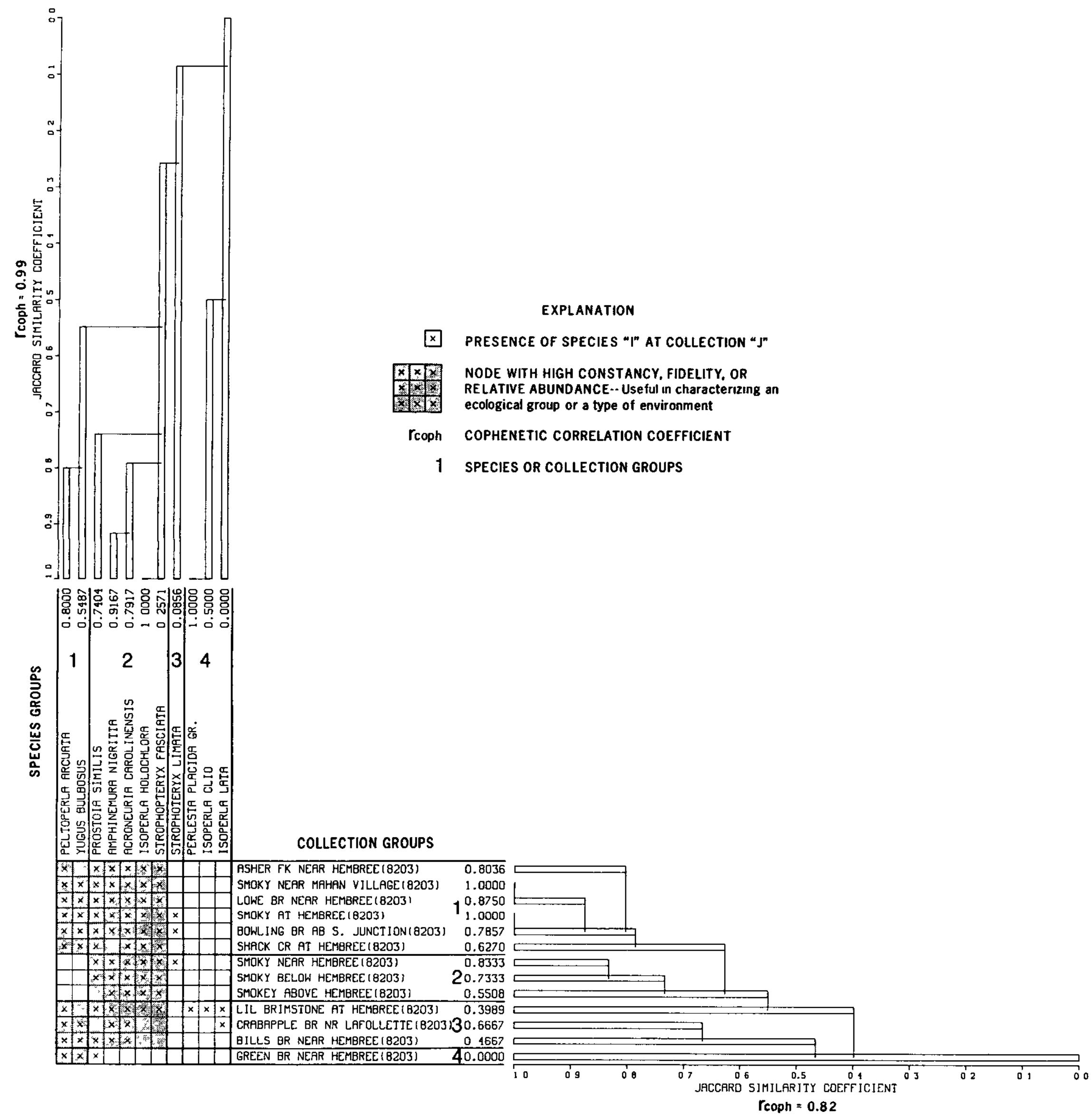


Figure 7.--Normal and inverse classifications of presence-absence data for species of Plecoptera collected in March 1982.

Table 15.--Constancy, fidelity, and relative abundance values for species groups of Plecoptera at collection groups in two-way tables of data collected during March 1982

Constancy values

Species groups	Collection groups 1	2	3	4
1	0.92	0	0.83	1.0
2	1.0	.93	.67	.20
3	.33	.33	0	0
4	0	0	.44	0

Fidelity values

Species groups	Collection groups 1	2	3	4
1	1.32	0	1.20	1.44
2	1.18	1.10	.79	.24
3	1.44	1.44	0	0
4	0	0	4.33	0

Relative abundance values

Species groups	Collection groups 1	2	3	4
1	3.74	0	0.82	1.0
2	1.44	.80	.30	.046
3	5.95	0	0	0
4	0	0	4.33	0

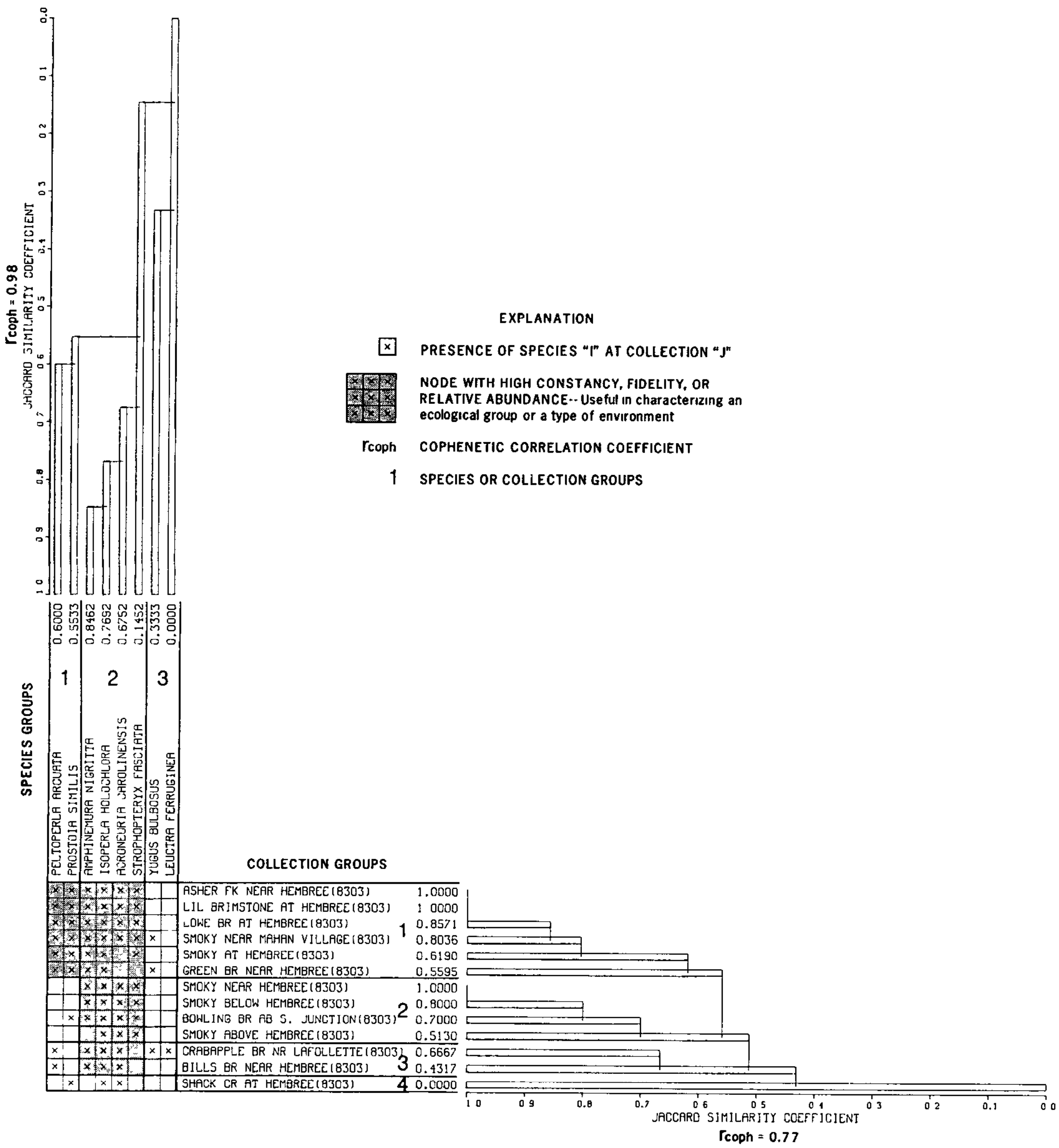


Figure 8.--Normal and inverse classifications of presence-absence data for species of Plecoptera collected in March 1983.

Table 16.--Constancy, fidelity, and relative abundance values for species groups of Plecoptera at collection groups in two-way tables of data collected during March 1983

Constancy values

Species groups	Collection groups 1	2	3	4
1	1.0	0.13	0.50	0.50
2	.88	.94	.75	.50
3	.17	0	.50	0

Fidelity values

Species groups	Collection groups 1	2	3	4
1	1.63	0.20	0.81	0.81
2	1.03	1.11	.89	.59
3	1.08	0	3.25	0

Relative abundance values

Species groups	Collection groups 1	2	3	4
1	4.84	0.36	1.00	0.30
2	1.37	1.30	.37	.22
3	2.98	0	3.52	0

Classification of Species of Plecoptera Collected during November 1982

Classification of November collections of Plecoptera indicated fewer stonefly species are prevalent during the winter months than in spring. *Acroneuria carolinensis* and *Isoperla holochlora*, two large stonefilies with relatively long nymphal periods, were common in spring as well as in the November collection. *Paracapnia angulata* was collected at all sites in the November samples but was not found in the spring collections. These three species formed the only meaningful cluster (species group 3) in the inverse analysis of Plecopterans collected in November (fig. 9, table 17). They were highly constant and abundant at collection groups 1 and 2, with more sporadic occurrences in collection group 3. Relative abundance of species group 3 in collection group 3 containing Green Branch, Bowling Branch, Crabapple Branch, and Smoky Creek below Hembree was considerably less than at collection groups 1 and 2.

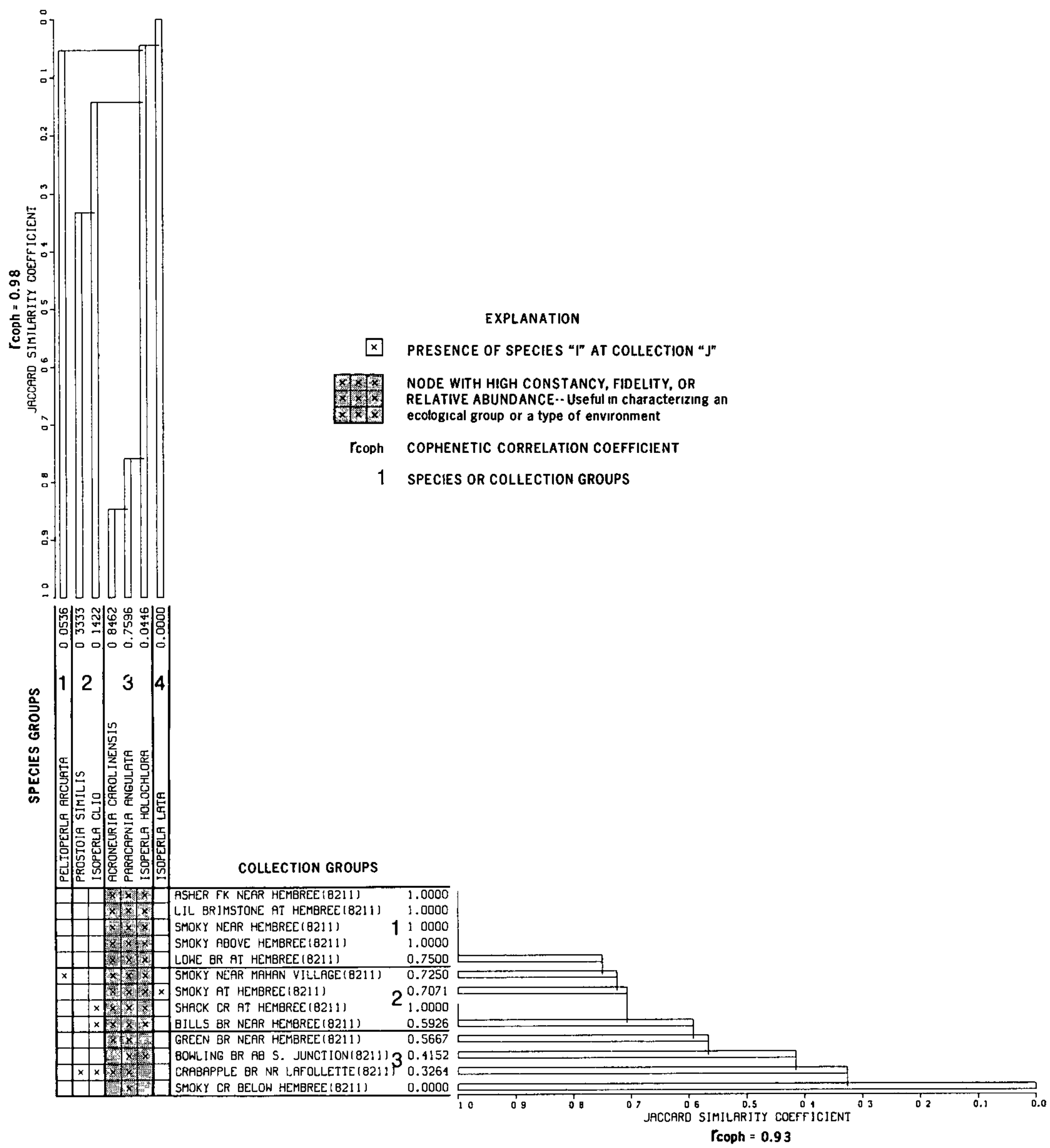


Figure 9.--Normal and inverse classifications of presence-absence data for species of Plecoptera collected during November 1982.

Table 17.--Constancy, fidelity, and relative abundance values for species groups of Plecoptera at collection groups in two-way tables of data collected during November 1982

Constancy values

Species groups	Collection groups		
	1	2	3
1	0	0.25	0
2	0	.25	.25
3	1.0	1.0	.58
4	0	.25	0

Fidelity values

Species groups	Collection groups		
	1	2	3
1	0	0.25	0
2	0	1.63	1.63
3	1.15	1.15	.67
4	0	3.25	0

Relative abundance values

Species groups	Collection groups		
	1	2	3
1	0	13.0	0
2	0	4.94	4.03
3	1.88	1.89	0.57
4	0	13.0	0

Classification of Species of Tricoptera and Diptera

Cluster diagrams for Tricoptera were difficult to interpret due to the low number of species and their seemingly erratic occurrence patterns throughout the study area. Jaccard coefficients for the three combined sets of Tricoptera data were less than 0.40 in the inverse analysis. Normal analyses did not indicate any seasonal trends, and tributary and main stem sites were usually mixed in collection groups. Distributions of Tricoptera were sufficiently represented in the figures which combine data for Ephemeroptera, Plecoptera, and Tricoptera, and therefore are not discussed separately.

Classifications of dipterans were also inconclusive due to a lack of species level identifications which may mask distribution patterns at lower taxonomic levels. Seasonal patterns were also unclear for Diptera, with March and November data mixed in collection groups in the normal classification (fig. 10, table 18).

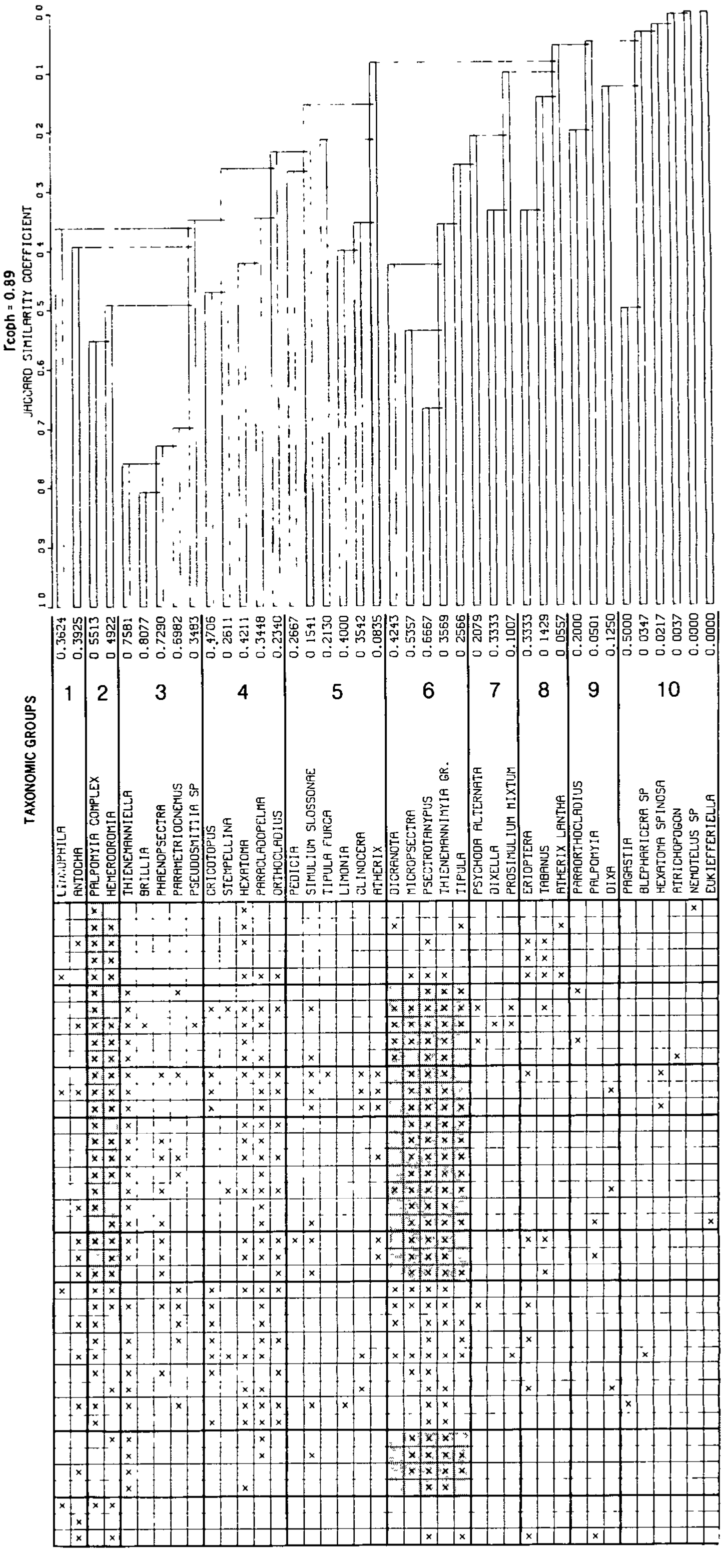


Figure 10.--Normal and inverse classifications of of Diptera during March and November

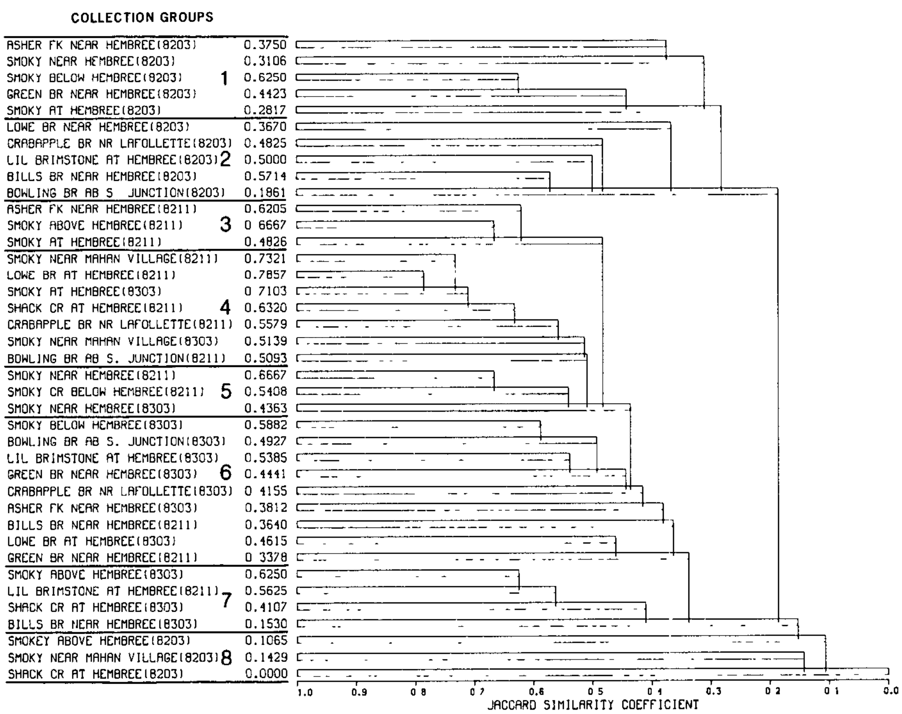
EXPLANATION

☒ PRESENCE OF SPECIES "I" AT COLLECTION "J"

NODE WITH HIGH CONSTANCY, FIDELITY, OR RELATIVE ABUNDANCE-- Useful in characterizing an ecological group or a type of environment

r_{coph} COPHENETIC CORRELATION COEFFICIENT

1 SPECIES OR COLLECTION GROUPS



r_{coph} = 0.86

presence-absence data for taxonomic groups
1982 and March 1983.

Table 18.--Constancy, fidelity, and relative abundance values for groups of Dipterans at collection groups in two-way tables of data collected during March and November 1982 and March 1983

Constancy values

Species groups	Collection groups							
	1	2	3	4	5	6	7	8
1	0.20	0.10	0.33	0.07	0.50	0.22	0.13	0.50
2	.90	.80	1.0	.71	.83	.61	.13	.50
3	0	.32	.33	.37	.33	.29	.20	0
4	.54	.40	.60	.43	.47	.58	.15	0
5	0	.07	.56	.05	.28	.09	.04	0
6	.24	.80	.67	.80	.67	.60	.65	.13
7	0	.33	0	0	0	.07	0	0
8	.53	.07	.11	0	.33	.11	0	.11
9	.03	.13	.11	.02	.11	.04	0	.11
10	.02	0	.11	.02	0	.04	0	0

Fidelity values

Species groups	Collection groups							
	1	2	3	4	5	6	7	8
1	0.92	0.46	1.53	0.33	2.29	1.02	0.57	2.29
2	1.32	1.18	1.47	1.05	1.23	.90	.18	.74
3	0	1.30	1.35	1.51	1.35	1.17	.81	0
4	.62	1.03	1.54	1.10	1.20	1.48	.38	0
5	0	.62	5.20	.45	2.60	.87	.39	0
6	.40	1.34	1.12	1.34	1.12	1.01	1.09	.16
7	0	5.57	0	0	0	1.24	0	0
8	3.67	.46	.76	0	2.29	.76	0	.76
9	0	1.95	1.62	1.39	1.62	.54	0	1.62
10	1.11	1.11	3.71	.80	0	1.24	0	0

Relative abundance values

Species groups	Collection groups							
	1	2	3	4	5	6	7	8
1	7.15	0	0.45	1.23	3.06	2.61	1.46	3.46
2	6.79	0.20	.38	0	3.39	3.39	1.54	2.54
3	0	3.19	.39	1.57	.65	1.70	.24	0
4	.70	.34	.78	2.01	.43	3.17	.37	0
5	0	.19	2.93	.11	1.73	1.50	.04	0
6	.56	.94	.48	1.97	.82	.18	.60	.25
7	0	8.72	0	0	0	4.28	0	0
8	7.56	.02	.10	0	.63	.42	0	2.17
9	0	4.33	.50	3.21	.39	1.08	0	3.87
10	1.08	1.25	1.08	1.08	0	2.17	0	0

Classifications of Species of Ephemeroptera, Plecoptera, and Tricoptera Collected during March and November 1982 and March 1983

Although separate analyses on individual orders of invertebrate were useful in identifying differences in invertebrate fauna at collection sites, these taxonomic breaks may be ecologically unfounded. Data on major orders were combined and analyzed to determine which species tend to occur together and if trends seen in separate analyses held true for analyses using more complete sample data.

The combination of Ephemeroptera, Plecoptera, and Tricoptera collected during the March and November 1982 and March 1983 sampling trips produced two prominent clusters of species (species groups 2 and 3; Jaccard coefficient ≥ 0.45). Two additional clusters, although at lower similarity levels provided additional information on the distributions of these invertebrates. Collection groups were obviously determined by the seasonal distribution of the taxa (fig. 11).

A large cluster of mayflies and stoneflies (species group 2) consisting of *Drunella lata*, *Cinygmula subaequalis*, *Epeorus dispar*, *Amphinemura nigritta*, *Strophopteryx fasciata*, *Peltoperla arcuata*, *Prostoia similis*, *Ephemerella argo*, and *Baetis tricaudatus* indicated high constancy in March samples from 1982 and 1983 at almost all stations (table 19). Fidelity values for this species group were moderate, generally ranging from 1 to 2, because of the large number of spring samples. These species were more abundant in the March 1982 than March 1983 samples based on relative abundance values for the nodes and occurred only sporadically in the November samples (collection group 6).

One cluster of mayflies and stoneflies (species group 1) had high constancy (C = 0.71) and fidelity (F = 2.22) at collection group 6 consisting of November samples. These high values were due primarily to the presence of the winter stonefly *Paracapnia angulata*. Relative abundance for the node was also high due to high percentages of *Paracapnia angulata* (RA = 6.25), *Eurylophella funeralis* (RA = 4.77) and *Stenonema modestum* (RA = 5.15).

Another large cluster with the highest level of similarity (species group 3; Jaccard coefficient ≥ 0.54) was present at all collection groups regardless of season: *Serratella deficens*, *Acroneuria carolinensis*, *Isoperla holochlora*, *Symphitopsyche alhedra*, *Stenonema vicarium*, *Ameletus lineatus*, *Paraleptophlebia swannanoa*, *Baetis brunneicolor*, and *Stenonema terminatum*. Constancy for species group 3 was high at most collection groups except for collection group 7 containing Green Branch. Relative abundance values were highly variable.

Occurrences of Tricoptera were sporadic and independent of season as illustrated by the distribution of species groups 4 and 5 among all collection groups. These organisms were well represented at collection group 3 containing the March 1982 and March 1983 samples from Crabapple Branch.

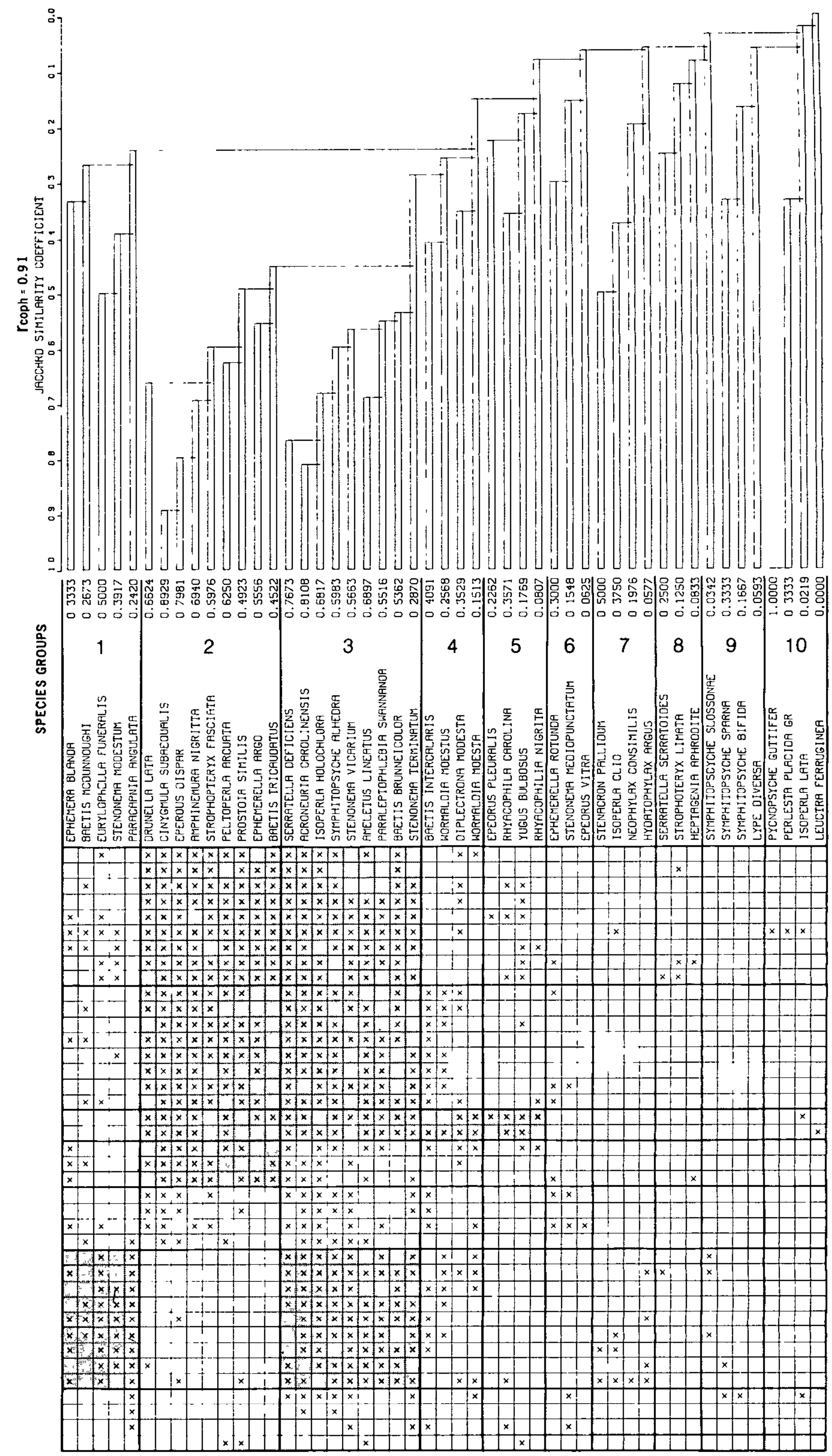


Figure 11.--Normal and inverse classifications Ephemeroptera, Plecoptera, and Tricoptera November 1982 and March 1983.

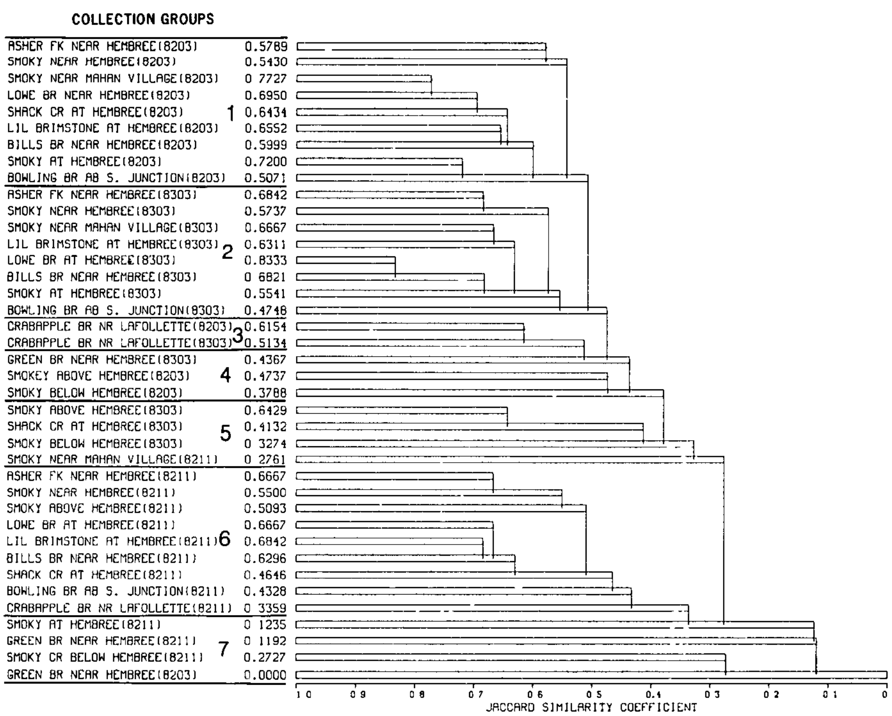
EXPLANATION

PRESENCE OF SPECIES "I" AT COLLECTION "J"

NODE WITH HIGH CONSTANCY, FIDELITY, OR RELATIVE ABUNDANCE--Useful in characterizing an ecological group or a type of environment

rcoph COPHENETIC CORRELATION COEFFICIENT

1 SPECIES OR COLLECTION GROUPS



rcoph = 0.91

of presence-absence data for species collected during March and

Table 19.--Constancy, fidelity, and relative abundance values for species groups of Ephemeroptera, Plecoptera, and Tricoptera at collection groups in two-way tables of data collected during March and November 1982 and March 1983

Constancy values

Species groups	Collection groups						
	1	2	3	4	5	6	7
1	0.33	0.15	0	0.27	0.20	0.71	0.15
2	.94	.75	.67	.67	.42	.04	.08
3	.80	.76	.89	.52	.58	.84	.31
4	.14	.53	.75	.33	.25	.42	.12
5	.31	.06	.75	.17	0	.03	.12
6	.04	.17	0	.11	.42	0	.17
7	.03	0	0	0	0	.28	0
8	.19	0	0	.11	0	.04	0
9	0	0	0	0	0	0.11	.13
10	.08	0	.25	0	0	0	.05

Fidelity values

Species groups	Collection groups						
	1	2	3	4	5	6	7
1	1.04	0.47	0	0.81	0.63	2.22	0.46
2	1.86	1.48	1.32	1.32	.82	.10	.11
3	1.15	1.09	1.27	.74	.83	1.20	.43
4	.41	1.56	2.22	.99	.74	1.23	.37
5	1.99	.41	4.88	1.63	0	.18	.81
6	.33	1.50	0	1.00	3.75	0	1.50
7	.40	0	0	0	0	4.04	0
8	3.10	0	0	1.86	0	.62	0
9	0	0	0	0	0	2.89	1.44
10	2.17	0	6.50	0	0	0	1.33

Relative abundance values

Species groups	Collection groups						
	1	2	3	4	5	6	7
1	1.34	0	0	0	0.39	3.85	0.27
2	2.06	1.08	0.32	0.45	0	0	2.33
3	1.26	.86	.31	.20	.36	1.17	.17
4	.86	3.06	.88	1.40	.22	2.75	.08
5	5.92	1.00	.94	0	0	.65	.63
6	.30	.63	0	0	7.53	0	2.49
7	.24	0	0	0	0	4.71	0
8	10.3	0	0	0	0	.85	0
9	0	0	0	0	0	7.25	5.75
10	6.29	0	2.83	0	0	0	.63

Classifications of Species of Ephemeroptera, Plecoptera, and Tricoptera Collected during March 1982 and March 1983

Normal and inverse analyses of Ephemeroptera, Plecoptera, and Tricoptera from March 1982 indicated several prominent clusters of species (species groups 2 to 5; Jaccard coefficient $\geq$0.56) which tended to differentiate collection group 2 containing five of the six tributaries to Smoky Creek (fig. 12). Constancy values were usually high for these species groups and fidelity values were low to moderate because of the widespread distribution of most species (table 20). Relative abundance values for species groups 2 to 5 were almost always larger at collection group 2 than at other collection groups, indicating a higher percentage composition of these taxa at tributary sites than at main stem sites and Asher Fork.

One cluster (species group 5) consisting of *Stenonema terminatum*, *Symphitopsyche alhedra*, *Paraleptophlebia swannanoa*, *Stenonema vicarium* was much better represented at the tributary sites in collection group 2 than elsewhere and had one of the highest relative abundance values for the two-way table. This group of species could be useful in characterizing environmental conditions of lower order streams.

Results of analyses of these organisms collected in March 1983 were similar to classifications of March 1982 data, although tributary sites were not separated as well from the main stem sites (fig. 13, table 21).

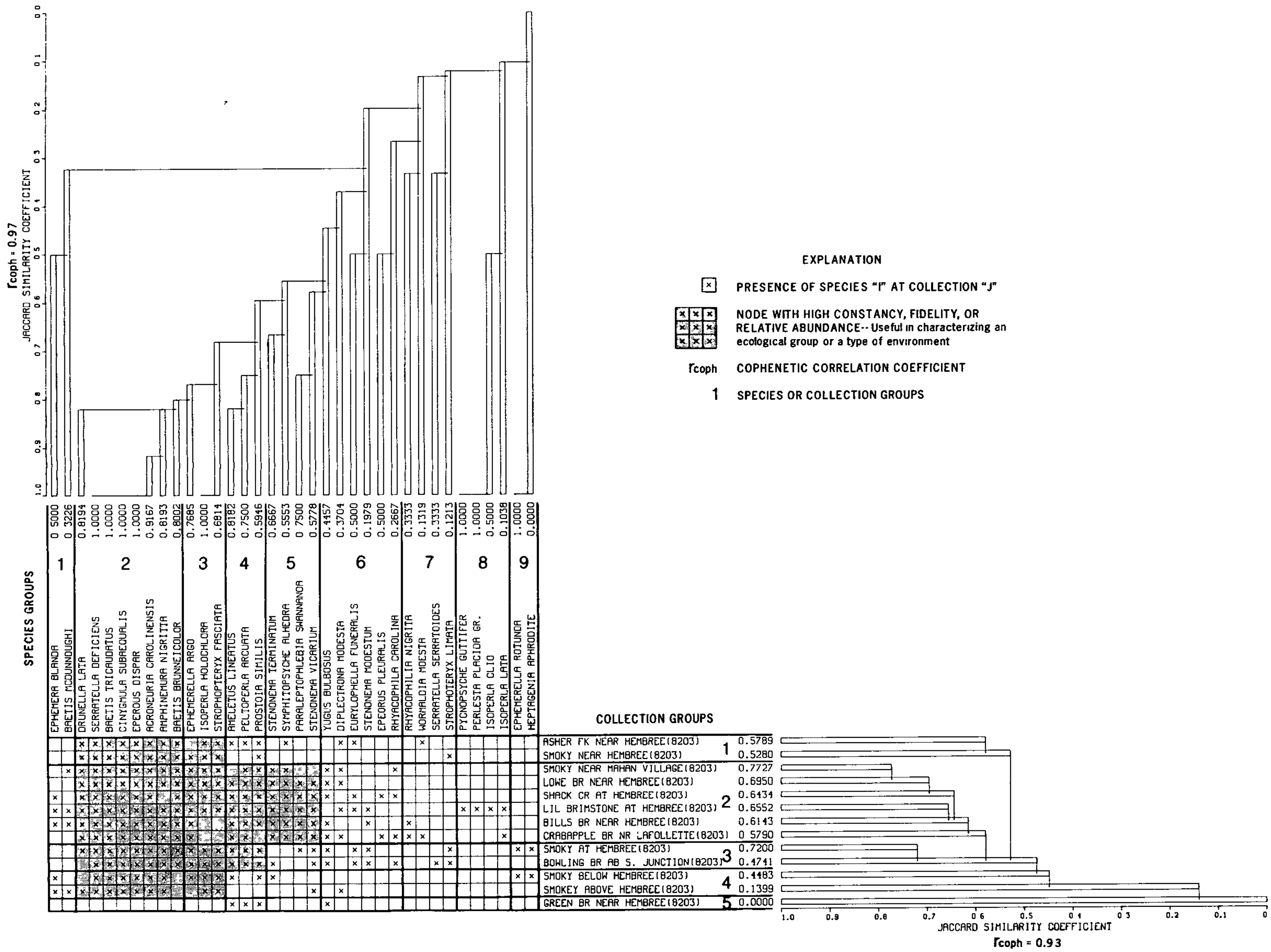


Figure 12.--Normal and inverse classifications of presence-absence data for species Ephemeroptera, Plecoptera, and Tricoptera collected in March 1982.

Table 20.--Constancy, fidelity, and relative abundance values for species groups of Ephemeroptera, Plecoptera, and Tricoptera at collection groups in two-way tables of data collected during March 1982

Constancy values

Species groups	Collection groups 1	2	3	4	5
1	0	0.50	0	0.75	0
2	1.0	.98	.94	.81	0
3	.83	.78	1.0	.83	0
4	.67	.89	1.0	.33	1.0
5	.13	.92	.50	.25	0
6	.17	.47	.58	.08	.17
7	.25	.13	.38	0	0
8	0	.21	0	0	0
9	0	0	.50	.50	0

Fidelity values

Species groups	Collection groups 1	2	3	4	5
1	0	1.44	0	2.17	0
2	1.14	1.12	1.07	.93	0
3	1.08	1.01	1.30	1.08	0
4	.84	1.12	1.26	.42	1.26
5	.22	1.64	.90	.45	0
6	.46	1.32	1.63	.23	46
7	1.63	.81	2.44	0	0
8	0	2.17	0	0	0
9	0	0	3.25	3.25	0

Relative abundance values

Species groups	Collection groups 1	2	3	4	5
1	0	1.97	0	4.53	0
2	.35	.93	.18	0	0
3	.82	1.54	.95	1.01	0
4	.55	1.23	1.05	.21	0
5	.27	2.15	.60	.22	0
6	.23	1.27	.53	.08	.06
7	.83	1.23	1.18	0	0
8	0	3.25	0	0	0
9	0	0	2.71	3.79	0

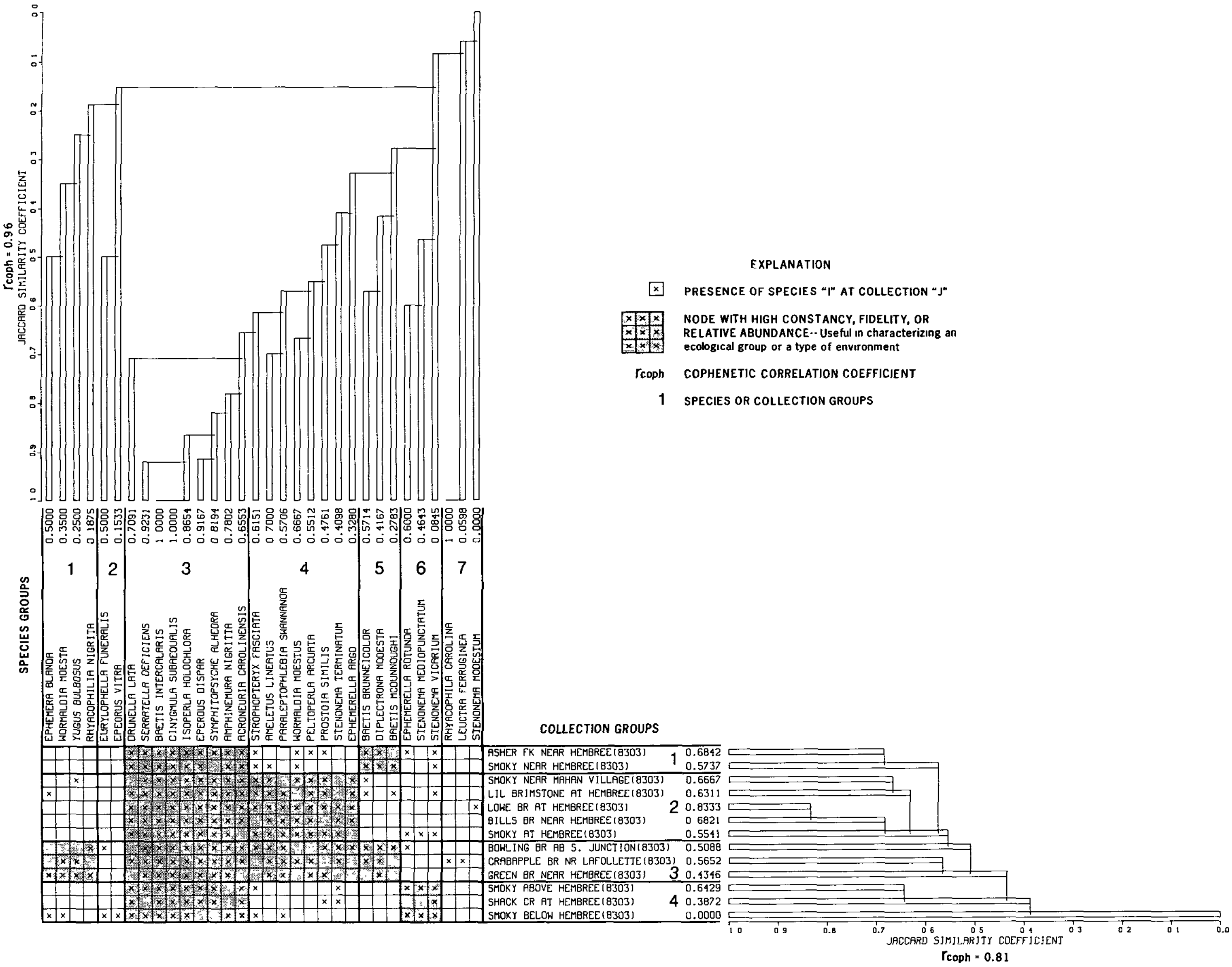


Figure 13.--Normal and inverse classifications of presence-absence data for species Ephemeroptera, Plecoptera, and Tricoptera collected in March 1983.

Table 21.--Constancy, fidelity, and relative abundance values for species groups of Ephemeroptera, Plecoptera, and Tricoptera at collection groups in two-way tables of data collected during March 1983

Constancy values

Species groups	Collection groups 1	2	3	4
1	0	0.10	.067	0.17
2	0	0	0.17	.33
3	.94	.96	.89	.81
4	.44	.83	.63	.25
5	.83	.20	.67	0
6	.50	.27	.11	.78
7	0	.07	.22	0

Fidelity values

Species groups	Collection groups 1	2	3	4
1	0	0.43	2.89	0.72
2	0	0	1.44	2.89
3	1.04	1.05	.98	.90
4	.75	1.41	1.07	.43
5	2.32	.56	1.86	0
6	1.30	.69	.29	2.02
7	0	.87	2.89	0

Relative abundance values

Species groups	Collection groups 1	2	3	4
1	0	0.62	1.58	1.05
2	0	0	1.28	5.22
3	.12	.37	.19	.17
4	.08	.58	.19	.13
5	.88	.34	3.10	0
6	.56	.87	.067	2.81
7	0	1.44	2.89	0

Classifications of Species of Ephemeroptera, Plecoptera, and Tricoptera Collected during November 1982

Analyses of November data produced several clearly defined species clusters (species groups 2 3, and 5). Tributary sites could be differentiated from main stem sites due to a more varied fauna in the tributaries. Two clusters, one consisting of Ephemera blanda and Hydatophylax argus (species group 1) and a second cluster of Eurylophella funeralis, Paraleptophlebia swannanoa, Ameletus lineatus, and Baetis brunneicolor (species group 2) were more constant and abundant at tributary sites than at main stem sites (fig. 14, table 22).

A third cluster of species consisting of Stenonema vicarium, Paracapnia angulata, Symphitopsyche alhedra, Acroneuria carolinensis, Isoperla holochlora, and Stenonema terminatum (species group 3) were well represented at all sites ($C \geq 0.71$) but were especially abundant at collection group 2 containing most of the tributary sites.

Baetis intercalaris and Stenonema modestum (species group 5) formed a fourth cluster that was highly constant ($C = 0.67$) and moderately faithful ($F = 1.58$) at the tributary sites and reached a maximum abundance at collection group 2 ($RA = 5.37$).

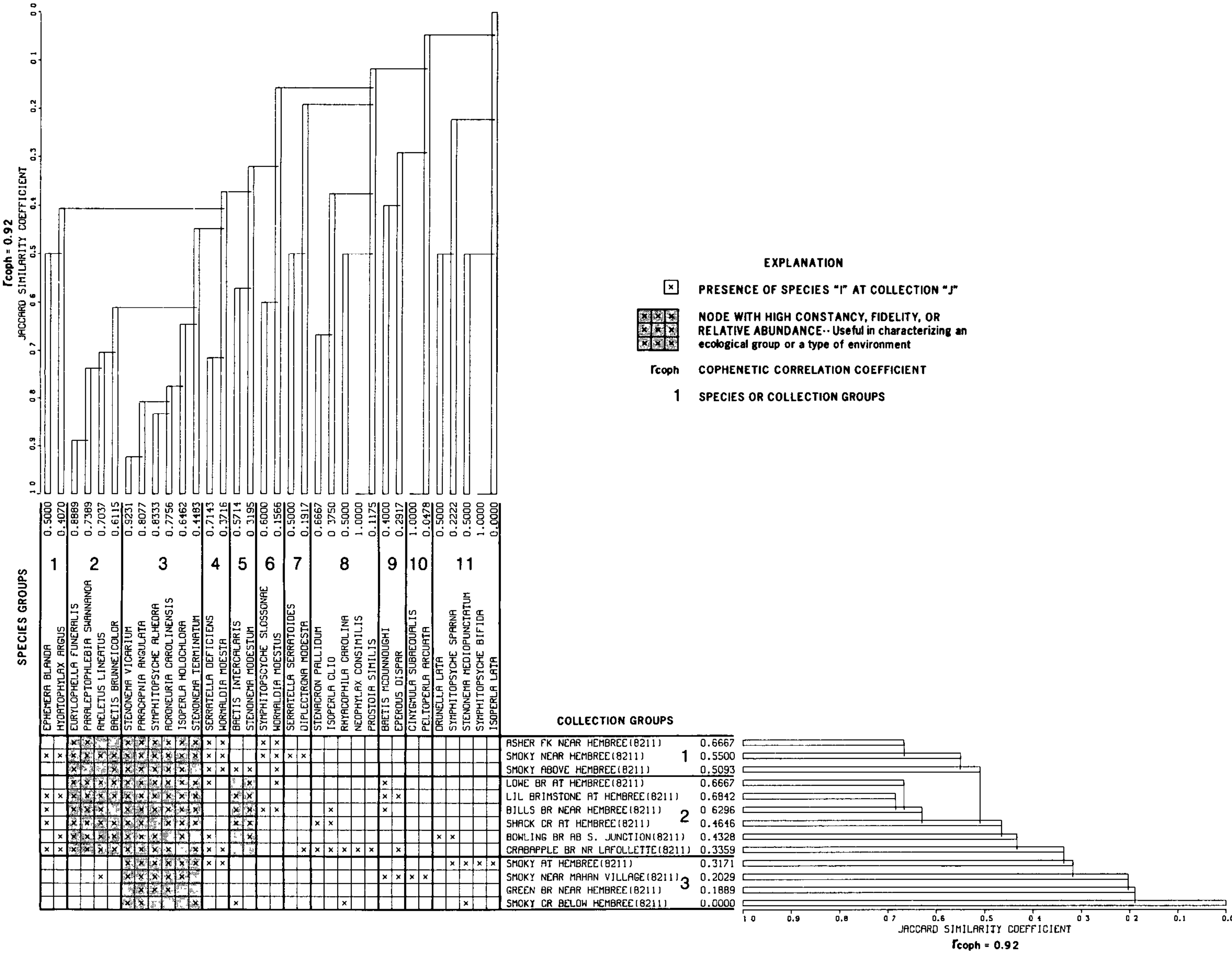


Figure 14.-- Normal and inverse classifications of presence-absence data for species Ephemeroptera, Plecoptera, and Tricoptera collected in November 1982.

Table 22.--Constancy, fidelity, and relative abundance values for species groups of Ephemeroptera, Plecoptera, and Tricoptera at collection groups in two-way tables of data collected during November 1982

Constancy values

Species groups	Collection groups		
	1	2	3
1	0.33	0.58	0.13
2	.67	.96	.06
3	.94	.92	.71
4	1.0	.33	.25
5	.33	.67	.13
6	.83	.25	0
7	.33	.08	0
8	0	.27	.05
9	0	.42	.25
10	0	0	.25
11	0	.07	.25

Fidelity values

Species groups	Collection groups		
	1	2	3
1	0.96	1.69	0
2	1.08	1.56	.10
3	1.12	1.05	.84
4	2.17	.72	.54
5	.79	1.58	.30
6	2.71	.81	0
7	2.89	.72	0
8	0	1.93	.36
9	0	1.55	.93
10	0	0	3.25
11	0	.62	2.32

Relative abundance values

Species groups	Collection groups		
	1	2	3
1	0.44	6.06	0
2	.34	2.86	.05
3	.62	1.25	.30
4	4.44	1.49	0
5	.72	5.37	.41
6	4.13	2.37	0
7	3.80	2.70	0
8	0	2.44	0.16
9	0	4.01	.33
10	0	0	6.50
11	0	.87	1.73

SUMMARY AND CONCLUSIONS

Data were collected from the heavily strip-mined Smoky Creek basin and from the undisturbed Crabapple Branch to evaluate the differences in benthic invertebrate communities and quality of water from several streams in eastern Tennessee affected by coal mining. Of the water-quality parameters collected, dissolved sulfate concentrations and specific conductance were the best indicators of the extent of water-quality degradation. Water from Bowling Branch, Little Brimstone Creek, and Crabapple Branch generally had dissolved sulfate concentrations less than 20 mg/L and specific conductance values less than 100 μS/cm. Bills Branch, Lowe Branch, Shack Creek, and Green Branch had increasing dissolved-sulfate and specific-conductance values, respectively. Water-quality data from sites on the Smoky Creek main stem and Asher Fork indicated that the poorest water-quality conditions were in the heavily mined headwater streams. Water quality improved in a downstream direction due to dilution from less mining affected tributary streams and drainage from less disturbed areas along Smoky Creek. Constituent concentration at Crabapple Branch remained low regardless of the flow regime indicating the lack of land disturbance in the basin.

Assessments of impacts, however, cannot be made by examining components of aquatic environments independently. Water-quality parameters, although invaluable in determining the extent of impacts, must be collected at similar flow regimes to allow valid comparisons of different streams, particularly when affected by mining. Consequently, water-quality data alone cannot provide adequate information needed to rapidly evaluate and monitor mining effects. Results of this study indicate that numerical classification of benthic invertebrate data can provide information regarding the degree of mining impacts without extensive sampling of flow-dependent hydrologic characteristics.

In comparisons of different measures of benthic invertebrate data, species diversity, number of taxa, and number of organisms per sample provided some insight into the extremes of invertebrate community structure found in the study streams. However, these parameters were of little value in determining differences between sites with intermediate impacts. Most sites had between 25 and 40 taxa and species diversity values between 3.0 and 4.0. Diversity values of this magnitude generally are assumed to indicate diverse populations (Wilhm and Dorris, 1968). Consequently, diversity values tended to mask rather than differentiate sites in the Smoky Creek basin with wide variations in environmental conditions and benthic invertebrate populations.

Biomass data were strongly influenced by seasonal variation in species composition. Biomass data for insects provided some evidence of habitat quality because streams with stable substrate tended to support larger populations than those streams with embedded substrate. Biomass data for Crabapple Branch were strikingly high when compared with data from mine-affected sites. This is due not only to pristine water quality but also to the lack of coarse material in Crabapple Branch usually found in streams draining mined lands. Because biomass had to be summed for entire insect orders so as to have sufficiently large samples to weigh, differences in community composition that may be evident at lower taxonomic levels were obscured. Because of these problems and the fact that biomass values can be greatly influenced by the presence of a few large individuals, biomass data are of little help in identifying sites with different environmental conditions or species composition.

Although commonly employed measures of invertebrate communities alone were inadequate for comparing the quality of stream environments, the results of numerical classification of benthic invertebrate data provided additional information that was useful in making such comparisons. Normal and inverse analyses of collections of invertebrate species, when combined in two-way tables, were effective in reducing invertebrate data to a form that could be used in assessments of mining impacts in the Smoky Creek basin. Nodal analyses using constancy, fidelity, and relative abundance of taxa in clusters of species were needed to evaluate the two-way tables. Classifications of different orders of invertebrates collected in different seasons identified seasonal variation in benthic community composition. However, addditional data are needed to document life histories of benthic invertebrates in the study area. Data collected in a single season were more appropriate for grouping sites with different environmenal conditions.

Of the taxa examined in this report, classification of species of Ephemeroptera were most useful in differentiating tributary sites from main stem sites. Analyses of ephemeropteran species collected in a single season showed several clusters in the March samples that were well represented in most collections. Most species of Ephemeroptera were more abundant in the relatively unimpacted tributary streams than in Smoky Creek and the two heavily mined tributary basins drained by Shack Creek and Green Branch. Similar occurrence patterns for these species were evident in March 1982 and 1983 collections.

Classification of Ephemeropterans collected in November yielded a distinct cluster consisting of Ephemera blanda, Eurylophella funeralis, Paraleptophlebia swannanoa, Ameletus lineatus, and Baetis brunneicolor. These species were constant and abundant at the tributary sites and virtually absent from sites on Smoky Creek and Green Branch. The absence of these organisms at sites, some of which have physical habitat conditions similar to the relatively unaffected tributaries, indicates that water-quality conditions could be limiting the occurrence and (or) abundance of these species. Rather than dependence upon a single indicator organism, groups of mayfly species that are known to occur regularly in certain types of environments can provide useful evidence of land-use impacts.

Two clusters of mayfly species with different life histories were apparent when data from March and November samples were combined. Drunella lata, Serratella deficens, Cinygmula subaequalis, and Epeorus dispar were found mainly in March samples with only sporadic occurrences in the November samples. Baetis brunneicolor, Ameletus lineatus, Paraleptophlebia swannanoa, Stenonema terminatum, and Stenonema modestum were present in March and November samples.

Classification of Plecoptera collected in March and November samples indicated seasonal variations by two clusters. Peltoperla arcuata, Prostoia similis, Amphinemura nigritta, and Strophopteryx fasciata were mainly present in March samples with only rare occurrences in the November samples. Acroneuria carolinensis and Isoperla holochlora were well represented at most sites regardless of season. Paracapnia angulata was found only in the November samples but was present at all sites.

Analyses of Plecoptera data by season did not differentiate tributary sites from main stem sites in the normal analyses. Plecopteran species were generally more abundant at the main stem sites, indicating their preference for larger streams and possibly their tolerance to higher constituent concentrations relative to species of Ephemeroptera. These taxa may be useful in evaluations of higher order or impacted streams that do not support diverse populations of Ephemeroptera.

Classification of Tricoptera were generally inconclusive due to their seemingly erratic occurrences throughout the data. Dipterans also provided little separation of sites based on seasonality, stream size, or water quality. Dipterans were only identified to genus, possibly obscuring community relations that may be more evident at the species level.

Classification of Ephemeroptera, Plecoptera, and Tricoptera species identified approximately 25 species in several clusters that were useful in grouping sites with similar water-quality and physical habitat conditions. Most of the distinct clusters in analyses using these orders of invertebrates were dominated by Ephemeropterans. Distribution patterns of these organisms indicate that sites in the Smoky Creek basin having similar number of taxa and species diversity support distinctly different fauna due to differences in environmental conditions.

Evaluations of water-quality and benthic invertebrate data collected in the Smoky Creek basin illustrate that a combination of chemical, physical, and biological data are needed to provide meaningful criteria for environmental assessments. Because strip mining affects many aspects of hydrologic systems, streams must be evaluated using potentially informative data, including the position of the site within the drainage net. Headwater streams, tributary streams, and downstream reaches with significantly different drainage areas, widths, depths, gradients, substrates, and water quality conditions support distinct fauna. Once these stream environments can be classified into groups with similar water-quality and physical-habitat conditions, assemblages of organisms occurring in those streams can provide discharge independent information needed to rapidly evaluate and monitor mining impacts.

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