Chironomid Midges as Indicators of Organic Pollution in the Scioto River Basin, Ohio[1]

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ABSTRACT. **Faunal and water chemistry data were derived from an extensive survey of streams in the Scioto River basin, Ohio and analyzed to determine biotic indicators of water quality. The data for 11 water chemistry characteristics were simplified by means of factor analysis, which generated three new axes (alkalinity-hardness, enrichment (sewage), agricultural runoff) that explained 71.5% of the total variance. The distributions of 14 common larval chironomid genera were then placed upon these new axes, based on coordinates generated for each sample site. These genera were found to occupy significantly different environments. Heuristic analysis of the data identified five groups of genera, each indicating particular water quality conditions: 1) *Stictochironomus* — hard, alkaline unpolluted water; 2) *Pentaneura, Cricotopus,* and *Tanytarsus* — sewage enriched water; 3) *Procladius* and *Dicrotendipes* — high agricultural runoff; 4) *Ablabesmyia* and *Tribelos* — general organic pollution, soft acid water; and 5) *Micropsectra, Microtendipes, Glyptotendipes, Chironomus, Polypedilum,* and *Cryptochironomus* — facultative genera.**

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INTRODUCTION

Continuing work in freshwater ecology has focused on the search for species that indicate certain environmental conditions, particularly forms of pollution (Hynes 1960, Curry 1965, Weber 1973, Persoone and DePauw 1979, Perkins 1983, Schaeffer et al. 1985). A review of methodology (Persoone and DePauw 1979) indicated that little standardization exists presently. This lack of standardization, in part, reflects both the complexity of the environment and variability in the superimposed pollution. Consequently, physical or chemical factors used as predictors in one case may not be important in another case.

An extensive data set on water chemistry and faunal information for an entire stream drainage system was analyzed to: 1) condense the water chemistry information from many variables (axes) to a few variables (axes) by means of factor analysis, 2) plot each sample site on the new two or three axes generated by computer, which will consequently allow the fauna from each site to be plotted on the new coordinates, 3) determine differences in faunal distribution on the new coordinates, and 4) identify any genera or groups of genera that would indicate differences in water quality in the drainage.

METHODS AND MATERIALS

Data for this study were drawn from a baseline survey conducted in the Scioto River basin, Ohio during 1967-1969 (Olive and Smith 1975, J. Olive, unpubl. data). Benthic faunal samples and water chemistry data were obtained from 76 stations in the basin on an irregular basis.

The faunal data base was developed through stratified random sampling in each of three microhabitats per site: a pool, a riffle, and a stream margin. A 0.1 m^2 benthic sample was taken with a Surber sampler (1 mm mesh) in shallow water or a shovel and hand screen in deeper water. The organisms in the three samples were then pooled, preserved, and identified to genus (Mason 1968, Johannsen 1937a, b). The organisms analyzed in the present study were limited to chironomid midge larvae because midges are found in all freshwater environments, are taxonomically diverse, and are frequently the most abundant group. Only summer (June-August) months were chosen for analysis since stress on the fauna is more likely in that season due to lower oxygen concentrations and/or high fertilizer and sediment runoff. Also, because midges exhibit annual succession, this further restriction had the added benefit of simplifying the data set. As a result, 66 samples from 56 stations located on 13 different fourth- and fifth-order streams (Fig. 1) were analyzed for 1968 and 1969. These stations represented a complete range of environmental conditions from natural through heavily polluted waters. All of the faunal abundance data were $\log(x + 1)$-transformed (Green 1979).

One limitation of the current analysis is that the midges were only identified to genus. Midge alpha taxonomy is still an active field. Improved keys (Simpson and Bode 1980, Wiederholm 1983) have been made available recently; however, species identifications are frequently not possible. Although Resh and Unzicker (1975) pointed out that species level identifications are important in water quality studies, this is not yet entirely possible for the midges.

Olive and Smith (1975) obtained all water chemistry data simultaneously with their stream fauna collections by means of a Hach (Hach Company, Loveland, CO) portable laboratory. The present analysis was done on 11 variables: total alkalinity, chlorides, calcium hardness, total hardness, nitrate, dissolved oxygen, orthophosphate, total phosphate, turbidity (NTUs), pH (no units) and sulfate (all units: mg/l except as noted).

"Organic wastes from municipal sewage treatment facilities and sediments from eroded soils were the most common pollutants encountered in the Scioto River system" (Olive and Smith 1975). To assess this further, water chemistry data from all samples were subjected to factor analysis (orthogonal varimax rotation; Dixon and Brown 1977) to condense and simplify the data. All water chemistry data except pH and oxygen were log-transformed (Green 1979). pH is inherently logarithmic, and the dissolved oxygen data were normally distributed. The dimensions of the system were then reduced from 11 water chemistry variables to three factors (new computer-generated composite variables). The analysis allowed each sample to be positioned at a locus in the new three-dimensional water chemistry coordinate system. The fauna collected in each sample was plotted on the structure at the same locus as the corresponding water chemistry data. Distributions of fauna were then assessed with respect to the new water chemistry factors and tested for differences with the Student-Neuman-Keuls (SNK) "a posteriori" test (Sokal and Rohlf 1969).

RESULTS AND DISCUSSION

The 14 most common genera of the 37 found in the survey were chosen for analysis (Fig. 2). The most ubiquitous genus, *Polypedilum,* was found in 38 samples; *Glyptotendipes,* the rarest, was found in only nine samples. *Chironomus* was the most numerous organism (3,980 larvae total) and *Tribelos* the rarest (95 larvae total). In all, 15,230 larvae were used in the present analysis.

Three significant (eigenvalue or variance explained > 1.0) factors were extracted from the water chemistry

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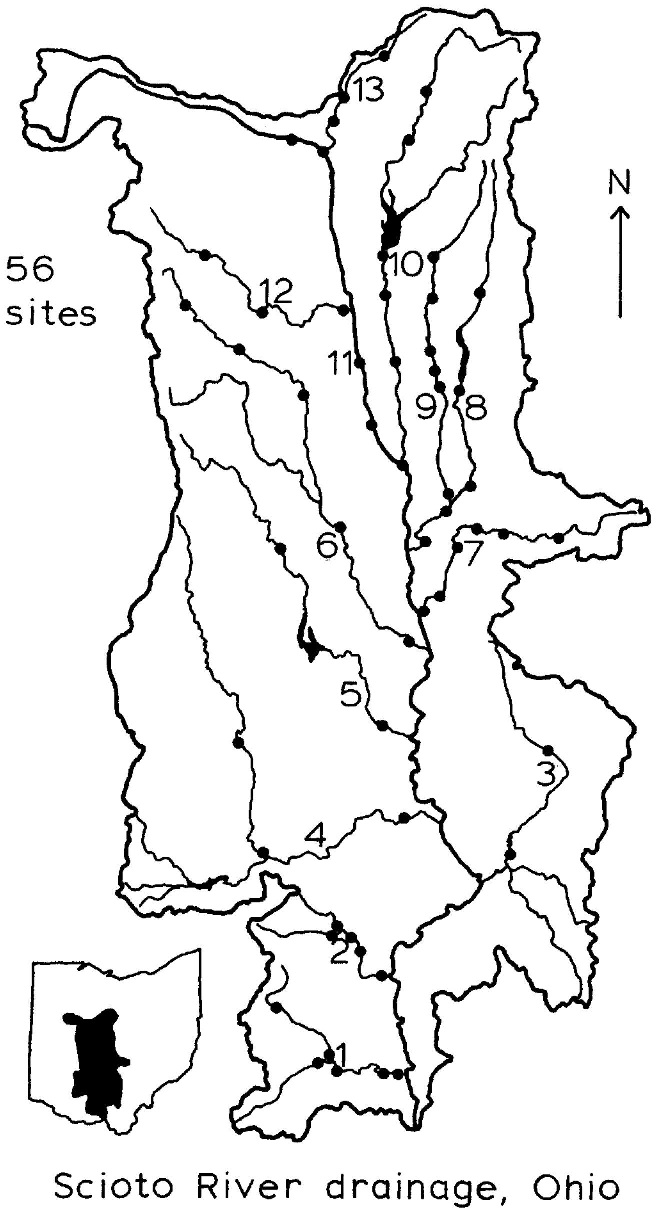

FIGURE 1. Locations of 56 stations in the Scioto River basin, Ohio, sampled for chemical and biological characteristics (adapted from Olive and Smith 1975). Creeks numbered as follows: 1, Scioto Brush Creek; 2, Morgan Creek; 3, Salt Creek; 4, Paint Creek; 5, Deer Creek; 6, Big Darby Creek; 7, Little Walnut Creek; 8, Big Walnut Creek; 9, Alum Creek; 10, Olentangy River; 11, Scioto River; 12, Mill Creek; 13, Little Scioto River.

data, which cumulatively explained 71.5% of the variance in the system (Table 1). Factor analysis was used to examine intercorrelations among the chemical parameters and to emphasize the most important. This produced a simpler three-dimensional space defined by the new factor axes that retained over 70% of the original information content. Factor 1 is defined as "alkalinity-hardness" based on highest loadings (underlined). It describes an axis, or gradient in chemical conditions, from low readings of total alkalinity, total hardness, calcium hardness, chlorides, sulfate, and pH to high readings in all of these. This is a general gradient reflecting the ionic character of the waters of the Scioto basin, which depends largely on the local edaphic geology. Factor 2 (enrichment) represents a gradient from oligotrophy (low total phosphate and orthophosphate with high oxygen values) to eutrophy (low oxygen readings and high values of phosphates). This factor is indicative of the amount of untreated domestic waste present. In streams, a drop in oxygen levels and a release of phosphates result from the addition of inadequately treated sewage. The third factor (agricultural runoff) constitutes an axis that ranges from low turbidity and nitrate readings to high values for both parameters. Areas of agricultural runoff experience generally higher turbidity due to silt runoff in addition to nitrate release from fertilizers (Olive and Smith 1975).

Each of the 66 samples has a specific computer-generated location in the new three-dimensional structure, allowing classification of sites based on edaphic geological factors (factor 1) and pollution (factors 2 and 3). The fauna of each sample was then placed on the new structure and its distribution was analysed. The mean values of the distributions of the 14 most common midge genera along factor 1 are shown in Figure 2 along with the SNK test results. A vertical SNK line includes all genera that do not differ significantly

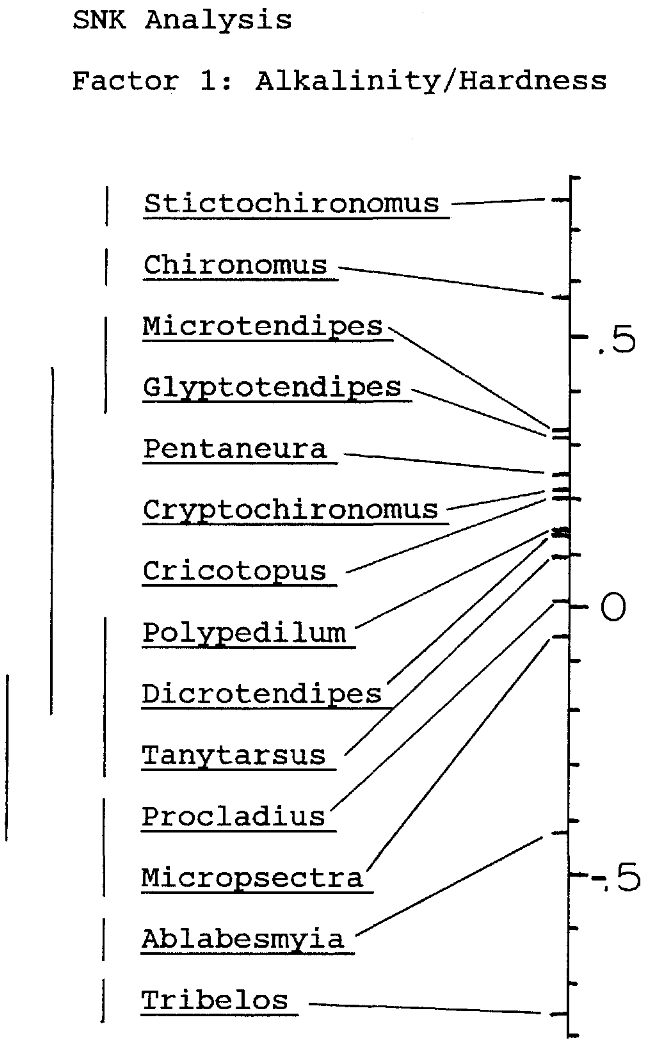

FIGURE 2. Means of distributions of 14 genera of midges along factor 1, a gradient from soft, acid waters (negative values) to hard, alkaline waters (positive values). A vertical Student-Neuman-Keuls (SNK) line joins those genera that have statistically ($P > 0.05$) similar distributions.

TABLE 1

Factor loadings for the three significant eigenvectors, based on 11 water chemistry measurements: 1, alkalinity-hardness; 2, enrichment; 3, agricultural runoff.

	Rotated factor loadings		
	Factor 1	Factor 2	Factor 3
Total alkalinity (mg/l)	.87	.19	.06
Chloride (mg/l)	.70	.04	−.06
Ca hardness (mg/l)	.87	.09	.06
Total hardness (mg/l)	.96	.17	.01
Nitrate (mg/l)	.29	.28	.60
Oxygen (mg/l)	.35	−.74	−.14
Orthophosphate (mg/l)	.30	.84	.08
Total phosphate (mg/l)	.38	.86	.06
Sulfate (mg/l)	.67	.43	−.09
Turbidity (NTU)	−.14	−.01	.89
pH	.72	.00	.13
Variance explained	4.33	2.33	1.21
Cumulative % explained	39.4%	60.5%	71.5%

($P > 0.05$) in their means. Clearly, there are great distributional differences. *Stictochironomus* and *Chironomus* were found in greatest numbers in hard, alkaline waters; *Tribelos* and *Ablabesmyia* were found in softer more acidic waters.

The means of the midge distributions on factors 2 and 3 were also tested for differences by the SNK test and found to be significantly ($P < 0.05$) different in both cases. These were plotted on both factors simultaneously (Fig. 3) in order to analyze the distributions with respect to enrichment and agricultural runoff. Using these and SNK results, a heuristic analysis of the data enabled isolation of the following groups of genera as indicators of various chemical conditions: 1) *Stictochironomus* (S) — hard, alkaline, clean unpolluted water; 2) *Pentaneura, Cricotopus, Tanytarsus* (P, C, T) — sewage enriched water; 3) *Ablabesmyia, Tribelos* (A, Tr) — general organic pollution, soft acid water; 4) *Procladius, Dicrotendipes* (Pc, D) — high agricultural runoff, moderate hardness; and 5) *Micropsectra, Microtendipes, Glyptotendipes, Chironomus, Polypedilum, Cryptochironomus* (Ms, Mt, G, Ch, Pp, Cc) — average conditions for all factors.

As mentioned previously, information was lost because species identifications are not often possible. This must be kept in mind while interpreting the above groups. Many of these genera are likely represented by one species apiece, but it is also possible that some are represented by two or more species. Those congeners may have different tolerances of pollution. The results shown here would then be an average response of those congeneric species. *Chironomus* is a good example. It is a large genus and many species are notable as being excellent indicators of organic pollution, whereas others are facultative (Simpson and Bode 1980).

The present study demonstrated that each chironomid midge genus is associated with a particular set of water chemistry conditions (Figs. 2 and 3). These population responses were distinct, despite the fact that data were collected from a variety of physical habitats within a large drainage system. These results are consistent with the findings of Paine and Gaufin (1956) and Gaufin (1973), who observed that different midge species occupied distinctly different zones downstream of a sewage treatment plant. Given sufficient baseline survey data, the important distributional trends of key species can be extracted by multivariate analysis techniques so that groupings of common indicator species reflect various types of organic pollution. Multivariate techniques have been used previously to summarize and quantify the niches of species assemblages (Green 1971, Rotenberry and Wiens 1980, Rae 1985); however, there has been little work of this nature applied to studies of pollution with the aim of identifying indicator species.

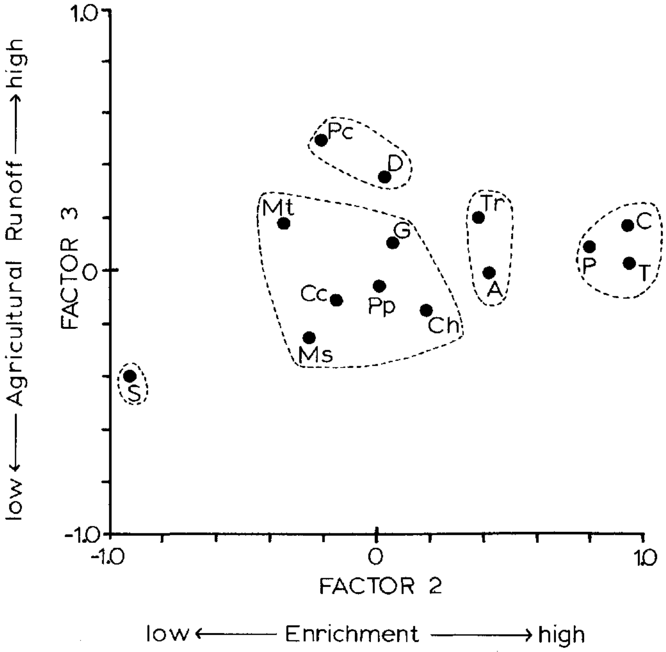

FIGURE 3. Means of distributions of 14 genera of midges on factor 2, a gradient from clean to sewage-enriched water, and factor 3, a gradient from low to high agricultural runoff. Abbreviations: S, *Stictochironomus;* P, *Pentaneura;* C, *Cricotopus;* T, *Tanytarsus;* A, *Ablabesmyia;* Tr, *Tribelos;* Pc, *Procladius;* D, *Dicrotendipes;* Ms, *Micropsectra;* Mt, *Microtendipes;* G, *Glyptotendipes;* Ch, *Chironomus;* Pp, *Polypedilum;* Cc, *Cryptochironomus.*

The present study showed *Dicrotendipes* associated with high nitrate and turbidity readings. Beckett and Keyes (1983) observed that *Dicrotendipes nervosus* Type 2 (Simpson and Bode 1980) was the most common midge at an Ohio River station having excessive coliform counts. The present study also indicated that *Cricotopus* dominates in sewage-enriched water in the Scioto River system. Several studies (Beckett 1978, Simpson and Bode 1980, Beckett and Keyes 1983) have shown that *Cricotopus bicinctus* is dominant in the most toxic conditions: oil, copper, cyanide and sewage effluent. *Cricotopus intersectus* gp. has been associated with high levels of sewage effluent (Beckett and Keyes 1983).

For each of 22 stations in the Ohio River, Beckett and Keyes (1983) listed the two dominant midges. In addition, their results showed that *Dicrotendipes* and *Cricotopus* appear to be the best indicators of toxic waters. For those stations in which either *Dicrotendipes* or *Cricotopus* were listed, the associated species were the following: *Tribelos* sp., *Ablabesmyia parajanta,* and *Polypedilum illinoense.* In the Scioto River system, *Ablabesmyia* and *Tribelos* are associated with water that is polluted by both agricultural and sewage inputs; additionally, these species are found associated with and midway between *Dicrotendipes* and *Cricotopus* in Figure 3. The status of *Polypedilum* is difficult to ascertain. The present study lists it as facultative, agreeing with the general interpretation of Simpson and Bode (1980). Roback (1974) noted that *P. illinoense* shows a wide range of tolerance. However Paine and Gaufin (1956) determined that *P. illinoense* indicates a clean habitat.

Simpson and Bode (1980) also indicated, as does this study of the Scioto River, that *Cryptochironomus* is facultative. In addition, they described *Micropsectra* as saprophobic. In Figure 3, *Micropsectra* groups with the facultative genera, but is the species closest to *Stictochironomus,* which was the most intolerant species in the present study. Roback (1974) reported that *Stictochironomus* has been found only in waters of very low nitrate and phosphate loadings.

The earliest attempts to predict water quality by means of biological indicators led to the development of the saprobic system (Kolkwitz and Marsson 1909), which involved a subjective general diagnosis of stream condition. Because results were not reproducible, efforts have focused on quantifying data so that results are more objective. This has led to the development of a variety of diversity indices which have had mixed reviews in theory and practice (Hurlbert 1971, Mason 1975, Godfrey 1978, Perkins 1983, Schaeffer et al. 1985). Primary criticism of these indices revolved around the difficulty in reducing a complex community to a single number. Moreover, an infinite number of communities can yield the same value (Hurlbert 1971). However, the Trent index (Woodiwiss 1964) and its modifications (Andersen et al. 1984) have been judged successful in Europe (Persoone and DePauw 1979). To determine the Trent index, kick and hand samples are taken from all microhabitats at a site with a handnet (780 μm). Streams are then classified on the presence or absence of certain key groups. The index is read from a chart based on a) the total number of taxa present, and b) the presence of certain key taxa listed in the order in which they tend to disappear with increasing pollution: Plecoptera, Ephemeroptera, Tricoptera, *Gammarus, Asellus,* red Chironomidae and Tubificidae. The scale ranges from 0 (polluted) to 10 (clean). In Illinois, Shiffman's (1953) index has been shown consistently to reflect stream quality as previously determined by water chemistry (Schaeffer et al. 1985). A thorough collection of microhabitats is made at a site for 30 min. Each species is categorized as intolerant, facultative, or tolerant. The index is calculated as a simple quotient: the total number of individuals that are classed as intolerant, divided by the total number of individuals collected. Values of the index can range from 1.0 (clean) to 0.0 (polluted).

The more successful indices focus on groups of species that are either extremely tolerant or extremely intolerant of organic pollution while applying different weights to members of either group. Little additional information is gained through examining the distributions of facultative or locally rare species. The method presented in this study can be used to determine the species that consistently occupy sites of either high or low pollution levels throughout an entire drainage system. This method of isolating indicator species may be helpful in the application of the Trent or Shiffman indices.

The Trent index uses presence-absence data, thereby weighting rare and common species equally. In the present study, however, abundance data were analyzed with emphasis on only dominant species. This produced a more accurate and parsimonious representation of the results. It also means that the sample in a stream survey would not have to be as large since only the most common species need be enumerated. As Gaufin (1973) noted, many species that are abundant in polluted water are found in low numbers in unpolluted water. If an index based on presence-absence data was used, these species would contribute misleading information.

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