CHIRONOMID COMMUNITIES AS INDICATORS OF WATER QUALITY AFFECTED BY ACID MINE DRAINAGE

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Abstract: Water and benthic samples were collected quarterly, May 1980 to May 1981, from 21 sedimentation ponds on the Ollis Creek strip mine in Campbell County, Tennessee. Water samples in general were low in pH and high in sulfate, hardness, iron, and manganese. A total of 63 discernable chironomid taxa was collected and identified. Low pH ponds were generally dominated by *Chironomus attenuatus* and *Tanytarsus,* while higher pH ponds contained variable chironomid assemblages. Diversity values (richness) were significantly correlated with pH values. The polar ordination of chironomid assemblages showed a distinct linear arrangement of stressed ponds to those containing viable Centrarchid populations.

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In response to the nation's growing environmental awareness and increasing demand for coal, the federal government has established minimum standards for surface mine reclamation. These standards (Surface Mine Control and Reclamation Act of 1977, P.L. 95-87) have emphasized the role of aquatic biologists in terms of their responsibility for assessment and prediction of surface mine impacts. The tools for this assessment vary from routine water quality analysis to complex and highly sophisticated computer models. Both may suffer limitations in that routine analysis indicates water quality characteristics only at the time of sampling, while modeling may contain weaknesses inherent in the model. Although these examples may be oversimplified, they reveal limitations and problems in developing criteria and management practices for the enhancement of aquatic biota.

Due to their relatively long life cycles, position in the food chain, limited mobility, and sensitivity to chemical perturbations, benthic macroinvertebrates are frequently used as indicators of the resilience and stability of an aquatic ecosystem (Cairns and Dickson 1971, Dills and Rodgers 1974). Specifically, the family Chironomidae, because of their habitat selectivity, have been found to be one of the most important indicator groups for assessing and detecting water quality degradation (Paine and Gaufin 1956). Though the literature is replete with information on chironomids as indicators of organic pollution and trophic states of reservoirs (Beck 1955, 1977, Saether 1970, 1975, 1979*a*, Mason, 1974, Wiederholm 1976, 1980), relatively little information exists concerning chironomid taxa as indicators of water quality affected by acid mine dranage (Curry 1965, Harp and Campbell 1967, Bell and Nebaker 1969, Bell 1970, Beck 1977). Curry (1965)

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discussed the pH tolerances of a large number of midges, while Bell (1970) reported the effects of pH on the life cycle of the midge *Tanytarsus dissimilis* and found the cycle could not be completed below a pH of 5.5.

Saether (1979*b*) maintains that chironomid communities are often useful in pinpointing local disturbances and indicating water quality conditions in trophic lake-type systems where chemical methods could not even approximate the results. If Saether's (1979*b*) assumptions of chironomid communities as water quality indicators are correct, and if chironomid assemblages do in fact accurately predict water quality conditions, the application of this method to the acid mine drainage problem in southern Appalachia may help to further refine and enhance rapid assessment techniques for surface mine impacts.

The existence of a large number of strip mine ponds on the 11-year-old Ollis Creek Mine, Campbell County, Tennessee, enabled us to study chironomid communities as possible indicators of water quality. This paper is a segment of a more detailed study to provide baseline ecological data on the chemical, physical, and biological nature of the strip mine ponds. These data would be used to formulate guidelines for the retention of sedimentation ponds on strip-mined areas that are currently drained, filled, and recontoured at the end of the reclamation phase under the provisions of P.L. 95-87 (3 Aug 1977).

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STUDY AREA

The study area, Ollis Creek Surface Mine, is situated on the 28-km^2 Ollis Creek watershed, located in Campbell County, Tennessee, approximately 1.1 km northwest of Lafollette, Tennessee. The mine land has an approximate surface elevation of 549 meters and is currently owned by the Koppers Company, Inc. In terms of commercial importance, the Coal Creek coal is the lowest of the 3 coal seams in the Slatestone Formation, but the most important in Campbell County, with recoverable reserves in the excess of 93,000,000 tons (Luther 1959). The major silvicultural system in the Ollis Creek watershed is the oak-hickory forest, with white (*Quercus alba*), northern red (*Q. rubra)*, and black (*Q. velutina*), oaks dominating.

Mine soil surface properties were tremendously influenced subsequent to mining activities. Considerable amounts of carbon-rich shale were left exposed on the surface. Toxic surface soils were left abandoned; pH and nutrient levels of the mine soil were low. The exposed carbon-rich shale, low hydrogen ion concentrations, and low fertility indicate that the favorable material was buried beneath the toxic surface, while the materials above the coal were left concentrated at the mine surface (Smith et al. 1976).

METHODS

Approximately 41 earthen or rock silt structures were constructed on the mine from May 1970 through November 1974. Twenty-one of the sedimentation ponds were chosen for analysis (Fig. 1). Individual pond selection was primarily based on the suitability of the substrate (mud, silt, etc.) for collecting grab samples and numerically based on time limitations.

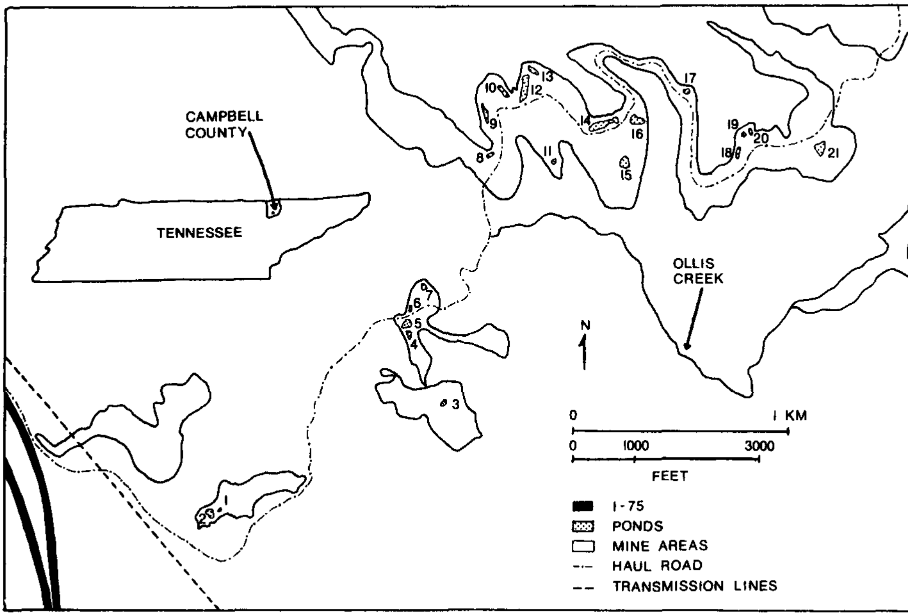

Fig. 1. Map of Ollis Creek watershed with pond locations, Campbell County, Tennessee, 1981.

Water samples were collected quarterly from each of the 21 sedimentation ponds from May 1980 to May 1981. At each sampling station the following parameters were analyzed from samples taken at 20% and 80% of the total depth: temperature, dissolved oxygen, specific conductance, pH, total hardness, and total alkalinity. Total phosphorus, nitrate, and sulfate were only analyzed from samples taken at 20% of the total depth. Heavy metal analysis, including zinc, lead, cadmium, aluminum, iron, manganese, copper and sodium, was conducted for the last quarterly sample during May 1981. Only the dissolved fraction or soluble portion of metal was analyzed. All samples were field preserved (APHA 1976) and analyzed in the laboratory following standard procedures (APHA 1976, EPA 1979).

Two methods of collection were used for aquatic invertebrates. Five replicate bottom samples were collected from each pond from May 1980 to February 1981. Samples were collected using an Ekman grab (0.023 m^2). Random areas were chosen on the ponds each quarter to ensure against sampling bias. After collection, the bottom samples were mixed and washed with water in the field in U.S. Standard No. 30 sieve buckets. One qualitative sample was obtained quarterly from each pond by the use of an aquatic kick net. The bottom organisms and remaining detritus were placed in labeled plastic bags and preserved in 10% formalin in the field.

All samples were returned to the laboratory and enumerated and identified to the lowest possible taxon. Weights were recorded to the nearest 0.001g on a Metler analytical balance after excess liquid had been blotted on filter paper for 1 min.

Importance values were calculated for selected benthic taxonomic groups at each pond though the 12-month sampling period according to Curtis and Cottam (1962). The importance value accounts for the number and weight of organisms in a particular taxon and should therefore represent their magnitude of importance in that community.

The analysis of existing relationships between the chironomid assemblages was performed by polar ordination (Wilhm 1972). Ordination techniques have long been employed in vegetation community analysis (Bray and Curtis 1957, Peet and Loucks 1977) and have recently entered the aquatic area as a tool for community assessment (Wilhm 1972, Beckett 1978, Gore 1980). Gauch et al. (1977) maintained that despite the limitations of polar ordination, it has the ability to produce effective ordinations for variable data and is relatively adaptable to the non-linearity of ecological data.

Polar ordination is a mathematical and graphical representation of the responses of communities to an environmental gradient (Culp and Davies 1980). Analysis of similarities of diversity and density place communities with similar responses to the environment at the same place along that gradient. The gradient was represented by arbitrarily assigned X- and Y-axes in which communities most dissimilar in species composition were designated as opposite end points of both axes. A factor of density of each species was used to weigh the similarity calculations so that communities with identical species compositions but different densities of each species were not determined to be similar.

Linear regressions were performed on species richness values and various chemical parameters to determine if any water quality characteristics were influencing the species variability among the ponds. Multiple linear regressions were performed to determine significant correlations between the results of the polar ordination and any chemical parameter.

RESULTS

A total of 24,371 chironomids represented by 63 taxa (Summers 1981) was collected through the 12-month sampling period with *Chironomus attenuatus* and *Tanytarsus* together dominating 72% of this total (Table 1). *Tanytarsus* was the only chironomid present in all the ponds, while *C. attenuatus* was present in 17 ponds. Although seasonal fluctuations (qualitative) in chironomid taxa are not presented, notable fluctuations occurred. An unidentified Orthocladiinae and *Corynoneura* were qualitatively collected in 10 and 2 ponds, respectively, with relatively large numbers occurring during February, but were not collected during dsany other sampling period. *Kiefferulus dux* exhibited similar trends, but was only collected during the November sample. The community structure of the ponds with pH values below 3.8 was generally dominated by *C. attenuatus* and/or *Tanytarsus*. The ponds with pH values above 3.8 contained variable chironomid assemblages.

Table 1. Estimated Total Number and Percent Composition of the Major Chironomidae Taxa Collected with an Ekman Grab in 21 Sediment Ponds, Ollis Creek Mine, Campbell County, Tennessee, 1981.

Taxa	Total Number	Percent Composition
All Chironomidae	24,371	100.0
Chironomus attenuatus	9,334	38.3
Tanytarsus	8,317	34.1
Procladius	1,346	5.5
Dicrotendipes leucoscelis	656	2.7
Djalmabatista pulcher	500	2.0
Cladotanytarsus	451	1.8
Cryptotendipes	377	1.5
Polypedilum illinoense	287	1.2
Polypedilum halterale	251	1.0
Nilothauma	231	0.94
Cryptochironomus fulvus	218	0.90
Psectrocladius vernalis	201	0.82
Pagastiella	179	0.73
Harnischia	168	0.69

Annual pond richness values were maximum at pond 16 and minimum at pond 19 (Table 2); the ponds being represented by 38 and 4 taxa, respectively. Extensive chemical data were generated from this study; however, only summarized results are reported herein. The chemical characteristics were comparable with values obtained from other studies done on ponds in the southeast and midwest, with total hardness, sulfate, iron, and manganese attaining relatively high concentrations (Gash 1968, Tobaben 1969, Campbell and Lind 1969, Davis 1971, Wilbert 1974). The ponds varied in pH from mildly acidic to highly acidic. Ponds with lower pH values consistently had higher specific conductance, sulfate, calcium, magnesium, iron, manganese, and cadmium concentrations than ponds with higher pH values. These spatial differences were expected because the former ponds were located near exposed highwalls and spoilbanks which were subject to continual leaching and dissolution of these substances as a result of pyrite oxidation and subsequent sulfuric acid formation (Struthers 1964, Barnes and Romberger 1968). Results from regression analysis indicate that pH was the only water quality parameter with a significant correlation (0.92) ($P < 0.05$, goodness of fit test, Elliott 1977) to species richness (Table 2).

The annual importance values for all ponds indicate the significance of the Chironomidae to the community structure (Fig. 2). The Chironomidae were present at all ponds and generally represented the dominant taxonomic group, particularly at chemically stressed stations. Oligochaeta were frequently collected but seldom represented the dominant taxa, except at pond 13 where unusually high densities occurred and high importance values were derived. The annual importance value for Oligochaeta at all ponds is misleading in that the value actually reflects only the importance of this group at pond 13. Approximately 97% of the annual importance value for Oligochaeta originated from annual values at pond 13, revealing

Table 2. Selected Mean Annual Water Quality Values for Each Pond and Corresponding Correlation Coefficients (r) Between Water Quality Parameters and Annual Richness Values.

Station	Richness #species	pH unit	Hardness mg/l $CaCO_3$	Sulfate mg/l SO_4	Iron mg/l Fe	Manganese mg/l Mn
1	6	3.0	860	1,139	23.0	26.9
2	5	3.4	316	539	4.0	3.7
3	29	6.1	100	47	0.30	0.47
4	9	3.2	230	317	5.2	3.3
5	34	6.5	143	114	0.24	0.14
6	6	3.8	476	421	0.64	8.9
7	7	3.5	463	471	2.3	13.2
8	11	4.2	324	486	0.33	4.7
9	15	4.1	333	254	0.43	4.2
10	11	3.7	137	121	0.61	0.71
11	11	3.9	51	38	0.39	0.94
12	15	3.8	198	188	0.72	4.2
13	28	4.2	195	219	1.02	2.81
14	28	5.6	287	246	0.27	1.65
15	5	3.8	345	298	1.29	8.5
16	38	6.4	281	209	0.59	1.51
17	10	4.1	274	242	0.34	3.8
18	6	3.2	155	199	1.45	0.59
19	4	2.8	203	904	21.0	7.5
20	7	3.6	117	168	1.84	3.3
21	16	4.9	121	140	0.24	1.7
r value		0.92	−0.30	−0.47	−0.37	−0.44

the relatively low importance of this group at all other stations. Ceratopogonid densities closely paralleled, and in some cases exceeded, chironomid densities for a large number of ponds, but their corresponding small weight decreased their overall importance. The megalopterans, coleopterans, and odonates were commonly collected from all stations.

Results of the polar ordination for chironomid communities exhibited an apparent linear relationship (Fig. 3). Two distinct clusters were evident, with stations 3, 5, and 19 removed from these 2 clusters. There was a noticeable linear progression of ponds containing fish within the clusters. Results of multiple linear regression analysis indicated a significant correlation between pH and the results of the community ordination.

DISCUSSION

It is generally assumed that the tolerance of aquatic insects to low pH can be sustained for periods of less than 1 week (Bell and Nebaker 1969). Although pH is usually the controlling factor in defining community structure, some believe that pH alone is not as crucial as the existing ionic composition of the water, which is directly related to the local geology (Warnick and Bell 1969).

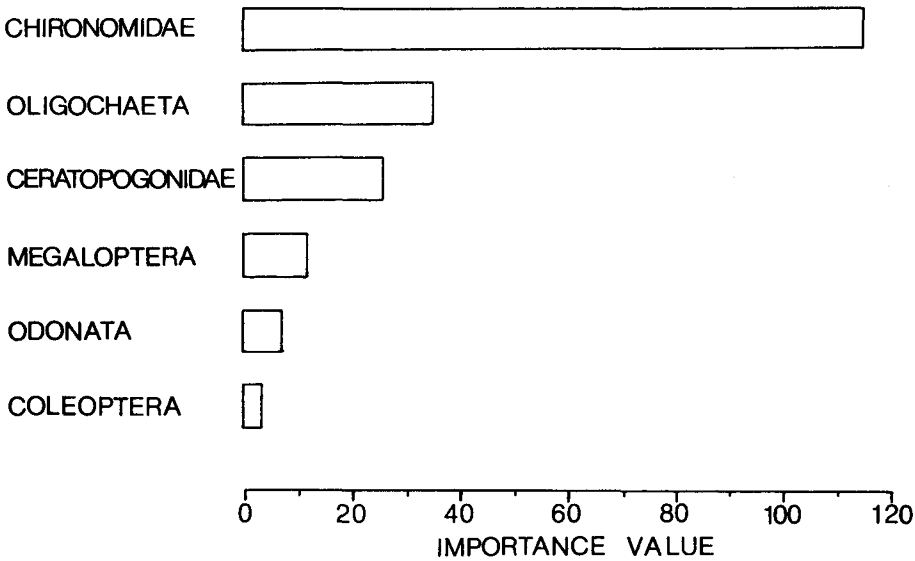

Fig. 2. Importance values, all ponds, Ollis Creek watershed, Campbell County, Tennessee, 1981.

The results of this study showed a strong positive correlation (0.92) between chironomid diversity (richness) and pH. At this level of examination, it appears pH is in fact the dominant factor controlling diversity and, in turn, chironomid community structure. None of the other selected water quality parameters showed significant correlations with richness. Although other investigators have found no relationship between benthic richness and acid mine drainage stress (Peckarsky and Cook 1981), it is possible that other variables (i.e. pH and heavy metals) are reacting synergistically (Schindler et al. 1980) to create this effect.

Various taxa collected in this study exhibited an indifference to pH, occurring in both highly and mildly acidic waters. Taxa exhibiting this response and their respective pH ranges were *Procladius* (3.8 - 6.5), *Ablabesmyia philosphangnos* (3.7 - 6.4), *Ablabesmyia peleensis* (4.2 - 6.5), *C. attenuatus* (2.8 - 6.4), *Djalmabastista pulcher* (3.2 - 6.1), *Dicrotendipes leucoscelis* (2.8 - 6.5), *Endochironomus nigricans* (4.1 - 6.5), *Larsia* (3.0 - 6.5), *Nilothauma* (3.6 - 6.5), *Polypedilum illinoense* (3.0 - 6.5), and *Tanytarsus* (2.8 - 6.5). Their use as water quality indicators is questionable at this point. Specifically, the use of *Procladius* as an indicator species has little merit due to its adaptability to a wide range of environments (Simpson and Bode 1980), while *Ablabesmyia parajanta* and *Ablabesmyia peleensis* also have been known to occur over a wide range of environmental conditions (Beck 1977, Simpson and Bode 1980). Curry (1965) and Roback (1974) noted *Polypedilum illinoense* inhabiting waters with a pH of less than 5, while Paine and Gaufin (1956) found this species to be an indicator of "non-polluted" systems. Mason (1974) provisionally classified *Corynoneura* as "pollution" sensitive, whereas Curry (1965) found this taxa in waters with a pH of 4. *Corynoneura* occurred in waters with a pH as low as 4.2 in the present study. The disparity in the results of the previous

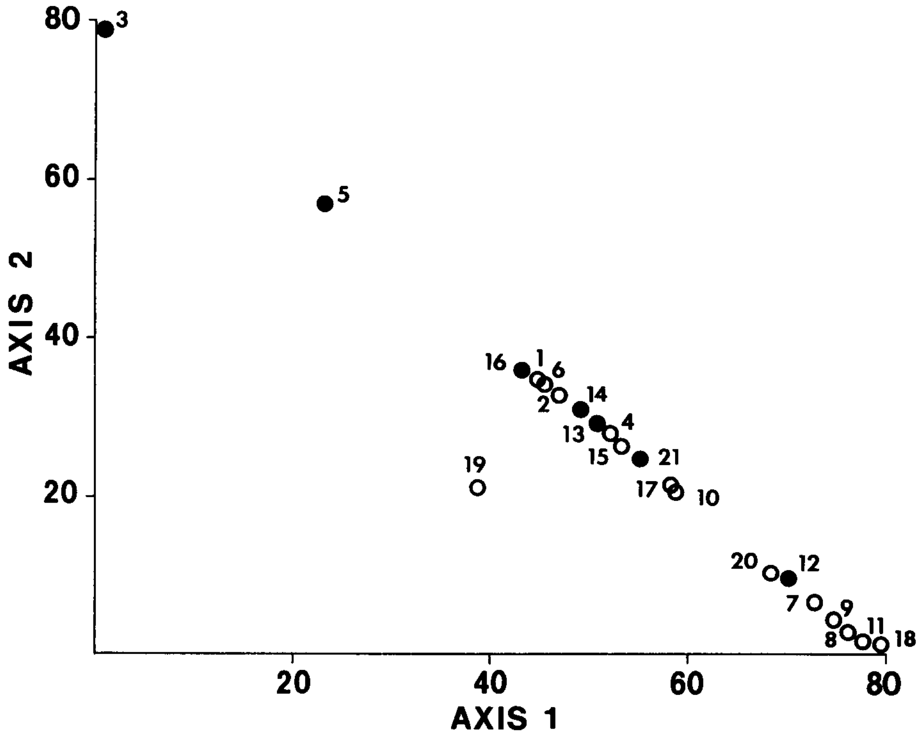

Fig. 3. Polar ordination of the chironomid communities for all ponds sampled in the Ollis Creek watershed, Campbell County, Tennessee, 1981. Pond numbers correspond to those on map, Fig. 1. Solid circles represent ponds containing viable Centrarchid populations.

studies for classifying chironomid pollution tolerance reveals that pH may not be the controlling factor in defining community structure. Synergistic actions also may be modifying these classifications. Regardless of the cause determining community structure, it appears at this point that chironomid richness or species diversity may be a more valuable tool for assessing water quality status rather than individual taxonomic tolerance levels.

There were taxa that displayed distinct pH tolerance ranges, including *Microtendipes, Paratendipes subaequalis, Einfeldia, Cryptochironomus fulvus, Ablabesmyia mallochi, Ablabesmyia aspera,* and *Ablabesmyia annulata.* Beck (1977) classified the previous genera as indifferent and/or acidophilous in terms of their pH tolerance, with the exception of *Einfeldia,* which was classified as alkaphilous. The previous classification is no doubt correct as the above midges occurred in water ranging in pH from 5.6 to 6.5 (slightly acidic), but all taxa demonstrated distinct sensitivities and tolerance ranges in pH. Thus, their indifference to water quality is debatable.

The community structure of ponds with a pH of 3.8 or less was generally dominated by *C. attenuatus* and/or *Tanytarsus.* These acid tolerant species (Katz

1969, Bell 1970) have burrowing and collecting habits (Merritt and Cummings 1978) that are particularly well suited to the silt and colloidal substrates of the sedimentation ponds. The stress of extremely low pH caused a reduction in the complexity of the community structure, thus creating a faunal assemblage dominated by few taxa. Additional mechanisms contributing to the dominance of *C. attenatus* and *Tanytarsus* in the highly acid environments may include a selective competitive advantage through buffering capacity in the hemoglobin (Jernelov et al. 1981) or resistance to heavy metal contaminants (Wentsel et al. 1978, Winner et al. 1980).

Annual importance values for all ponds combined showed six major taxonomic groups (Fig. 2). All of these genera are considered to be pioneer acid-tolerant groups (Katz 1969) are were generally important constituents of the benthic fauna of all ponds, with the exception of a single pond dominated by Oligochaeta. The high importance value of the Chironomidae in all ponds may represent an adequate food base for fingerling bluegill, sunfish, and largemouth bass (Howell 1942, Partriarche and Ball 1949). The importance value accounts for the number and weight of a benthic group and should represent their value to benthic feeding organisms.

Ordination of the chironomid communities followed a linear gradient. If a factor which influences community composition exists in the ecosystem being examined, the polar ordination will reveal an array of communities dissimilar to each other and placed along the arbitrary axes in relation to the intensity of the factor. Those communities with similar responses will be placed at the same ordinates on the gradient (Culp and Davies 1980). As previously stated, 2 distinct clusters were evident, with ponds 3, 5, and 19 removed from these 2 clusters. There was also a noticeable linear progression of ponds containing fish within the clusters. Explanation of the observed community relationships followed 2 lines of thought. Communities that were located high on the 2nd axis may reflect presences and/or absences of rare species, while the communities that clustered near the 1st axis represent a more general average of total species-complement. This in part explains the cluster arrangement, as stations 3 and 5 contained taxa distinctly different from one another, revealing why they did not occur together. These stations also contained taxa that were vastly different from all other stations, thus they clustered near the 2nd axis. Although stations 13, 14, and 16 were similar to 3 and 5 in that they also contained presences and absences of rare species, the presence of relatively large numbers of *C. attenuatus* in the 3 former ponds may have had a masking or blanking effect and eliminated ordination near axis 2. Ponds 3 and 5 contained no individuals of this genus. The ordination of communities 13, 14, and 16 near communities 2, 4, 6, and 1 probably stems from a high coefficient of similarity between the ponds for *C. attenuatus*. Communities 2, 4, 6, and 1 had extremely high densities (standing crops) of this taxa.

The 2nd explanation is that the linear gradient corresponds to and follows a successional pattern. Those communities clustered near axis 1 may represent an early successional stage, while those clustered near axis 2 reprensent the more advanced stage in succession. This scenario seems likely due to the presence or absence of fish in a pond community. The clusters near axis 1 contain only 1 pond supporting fish with other ponds in the cluster too early in the successional stage to support fish life. The 2nd cluster in the middle may be an intermediate stage of succession now represented by 4 ponds maintaining fish life, with the other ponds possibly able to support fish in the near future. The 2 communities (3 and 5) near axis 2 represented the highest level of succession maintaining diverse benthic populations and supporting fish life. The reason for the location of community 19 as an outlier is subject to discussion. The most probable cause for its location is its unusually low densities and species diversity causing it to be dissimilar to all other communities. These data indicated that the sediment ponds, although basically the the same age, succeeded at different rates. Although other factors undoubtedly interacted, the rate of succession was primarily a function of the local edaphic characteristics, in that the chemical, physical, and biological aging of the acid waters was delayed by continuous sulfuric acid production (Campbell and Lind 1969).

Multiple regression analysis indicated a significant ($P < 0.05$) correlation ($R^2 = 0.96$) between pH and the variables derived by polar ordination. The presence of a significant correlation between pH and richness and the results of the ordination indicates that pH alone may explain the community distributions. Although we do not imply that there may not be other chemical, physical, and biological parameters that are acting synergistically with pH to affect community composition, it is certainly evident that pH is one of the dominant factors controlling both the structural and functional development of the benthic communities. The implications of our results indicate that chironomid richness, rather than individual indicator species, can be a valuable tool for assessing and predicting water quality conditions on strip-mined areas. Additionally, in cases where stocking and maintaining viable sport fish populations is a desired postmining land use objective, chironomid community richness may be used to monitor and indicate the water quality suitablility for a potential or existing fishery. In a situation where the management objective was to provide fishable waters, the advantage of implementing this technique over sampling for fish population abundance may include:

1. A more timely and cost efficient method for detecting habitat suitability, and
2. The provision of baseline data concerning the capabilities and existing conditions of the fishery food base.

This paper concentrated on the use of chironomid communities as possible indicators of water quality impacted by acid mine drainage. Although we do not imply that chironomid richness as a biological indicator of water quality can replace chemical techniques, their combined use may facilitate and promote more accurate data evaluation where water quality is concerned. In the case of low budget or rapid assessment surveys, the analysis of chironomid communities may be effective indicators of general water quality.

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