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BENTHIC MACROINVERTEBRATES AS INDEXES OF WATER QUALITY IN WHETSTONE CREEK, MORROW COUNTY, OHIO (SCIOTO RIVER BASIN)[1]

JOHN H. OLIVE AND CHARLES A. DAMBACH[2]

The University of Akron, Akron, Ohio 44325 and Ohio Biological Survey, The Ohio State University, Columbus, Ohio 43210

ABSTRACT

During the summer of 1966, Whetstone Creek, a tributary of the Olentangy River in central Ohio, received (1) domestic wastes from a secondary sewage-treatment plant at Mt. Gilead, (2) septic-tank drainage near Cardington, (3) brines from oil-field operations between Mt. Gilead and Cardington, and (4) stormwater runoff from agricultural lands. Dissolved-oxygen levels as low as 4.3 ppm and total-phosphate concentrations as high as 4.2 ppm were noted 1 km below Mt. Gilead. Chlorides ranging from 105–276 ppm were recorded in the stream between Mt. Gilead and the Delaware Reservoir.

Seventy-nine taxa of benthic macroinvertebrates were collected from six sampling locations. The largest variety of organisms (35–39 respectively) was taken from a relatively unpolluted headwater area and from a site 1 km below the Mt. Gilead wastewater-treatment facility. Average *Shannon-Wiener* diversity indexes exceeded 3.0 at the uppermost sampling station and at two locations 7–15 km below Mt. Gilead. Values less than 2.0 were recorded 9 km above Mt. Gilead and at the lowermost station near the Delaware Reservoir. Low *Shannon-Wiener* diversity indexes for the latter two areas appear to be related to low diversity of habitat and temporal effects, rather than to poor water quality.

Pollution-sensitive and facultative organisms, including certain chironomids, stoneflies, mayflies, caddisflies, and gill-bearing snails, accounted for 98 percent of the benthic organisms collected from upstream stations. Pollution-tolerant tubificids, leeches, certain chironomids, and pulmonate snails increased in abundance and percentage composition at all stations below Mt. Gilead, accounting for as much as 50–60 percent of the benthic community at the lowermost station.

INTRODUCTION

The quality of water in natural waterways usually is evaluated in relation to chemical and physical criteria, including the concentrations of various dissolved solids, dissolved gases, and hydrogen ions, and to specific conductance, temperature, and rate of flow (U.S. Geological Survey, 1964–1972; McKee and Wolf, 1963; National Technical Advisory Committee, 1968). Bacteriological parameters frequently are included in evaluations of recreational waterways and of public drinking-water supplies. Methods for measuring the chemical constituents, the physical properties, and the abundance of certain bacteria of water supplies are well defined and can be determined with considerable precision (American Public Health Association, 1971). For most industrial, domestic, and recreational uses, water quality evaluated in relation to chemical-physical and bacteriological criteria is satisfactory.

Complete reliance upon chemical-physical and bacteriological water-quality criteria for the maintenance of healthy communities of aquatic organisms often is inadequate. More extensive use of biological criteria for evaluating water quality is required. Biological criteria for assessing water quality have many

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[2]Deceased October 30, 1969.

advantages over abiotic methods and are being incorporated more frequently into water-quality standards. During the past 70 years, numerous biological approaches to evaluating water quality have been developed (Kolkwitz and Marsson, 1908, 1909; Carpenter, 1924; Richardson, 1921, 1928; Surber, 1953; Lefleur, 1954; Butcher, 1947, 1955; Gaufin and Tarzwell, 1952, 1956; Paine and Gaufin, 1956; Patrick, 1949, 1950; Gaufin, 1958; Harrison, 1958; Hynes, 1960, 1962; Beak, 1964; Beck, 1955; Wilhm and Dorris, 1966, 1968; Stuckey and Wentz, 1969).

Generally, the kinds of organisms within a major biological group, such as the algae, the fungi, the vascular plants, the invertebrates, and the fish, are considered in relation to selected chemical-physical conditions of the water from which the organisms were collected. Certain species have well-defined ecological requirements and their presence and relative abundance in waterways can be used as an indication of past as well as present water-quality conditions. Numerical characteristics of bio-communities also have been applied to water-quality investigations. These methods may involve the number of species (or taxa) present, the density of organisms, the frequency of occurrence, or a variety of biological diversity indexes (Beck, 1955; Pantle and Buck, 1955; Wilhm, 1967; Wilhm and Dorris, 1966, 1968; Patrick, 1949; Cairns *et al.*, 1968). The most commonly used biological approaches for assessing water quality have been summarized and discussed by Hynes (1960), Mackenthun (1969), and Warren (1971).

Benthic macroinvertebrates have been one of the most widely used groups of organisms for evaluating the quality of flowing waters. These organisms are easier to sample than fish, are not as restricted in distribution as are aquatic vascular plants, and are easier to identify and to quantify than are algae or fungi. Because of their unusual respiratory, food-gathering, and reproductive adaptations, characteristic assemblages or communities of benthic invertebrates become associated with particular water-quality conditions. Characteristic changes in benthic invertebrate communities occur in response to changes in temperature regimes, to alterations in erosional and siltation patterns, and to changes in concentration of domestic or industrial wastes. Changes in the species composition and the relative abundance of each species most commonly occur in response to environmental changes. The nature and magnitude of the community alteration depends upon the nature and severity of the environmental change.

Every river and stream is unique. No two waterways contain the same type and distribution of substrates, the same hydrologic regimes, the identical kinds and amounts of dissolved solids and gases, nor do they receive identical inputs of allochthonous materials and radiant energy. Because of these natural differences, aquatic organisms in rivers vary considerably in their response to environmental changes introduced by man. For example, a load of organic matter that would severely damage aquatic life in a headwater trout stream may have little or no effect on the organisms of a base-level river (Hynes, 1962). Or a quantity of phosphates that would stimulate a major growth of aquatic plants in a river with numerous pooled areas may have very little effect on the flora of a rapidly flowing river of equal size with extensive riffle areas.

The objective of this study was to evaluate the quality of water in Whetstone Creek in relation to certain characteristics of six benthic invertebrate communities. The community characteristics included the kinds of organisms present, the density of the organisms, the number of taxa present, and the *Shannon-Wiener* index of biological diversity. Selected chemical constituents and physical properties of the water flowing through each community are correlated with the biological characteristics of each community.

BENTHIC MACROINVERTEBRATES AS INDEXES OF WATER QUALITY

Various parameters and characteristics of benthic macroinvertebrate communities have been used as criteria for assessing water quality. These criteria usually are based on community-structural features, such as the faunal composition, the number of species (taxa), the ratio of the number of species to an importance value such as the number of individuals in the community (species diversity), and the density of organisms.

One of the most widely used biological methods for evaluating water quality is to divide the organisms into categories depending upon the tolerance of each species to organic pollution (Gaufin, 1958; Gaufin and Tarzwell, 1952, 1956; Mackenthun, 1969; Schiffman, 1953; Surber, 1953; Mason *et al.*, 1971). Organisms that cannot tolerate organic pollution and are associated with clean, well-oxygenated water free from toxic materials, silt, and sludge deposits are classified as pollution-sensitive forms. This category is usually considered to include gill-bearing snails, certain clams such as the Unionidae, and insects such as stoneflies, mayflies, caddisflies, and alderflies.

Organisms that survive and commonly thrive in water heavily polluted with organic wastes are called pollution-tolerant forms. Oligochaetes, certain chironomids, leeches, and pulmonate snails usually are included in this category. Pollution-tolerant organisms have special respiratory, food-gathering, and reproductive adaptations that enable them to live under low-oxygen and/or highly turbid, muddy conditions.

Many organisms are capable of living under a wide variety of conditions and do not exactly fit either of the above classifications. These organisms are intermediate or facultative forms and may be associated with either clean or moderately polluted areas. Many beetles, dragonflies, damselflies, most chironomids, and other dipterans, such as blackflies and craneflies, are included in this group. Gill-bearing snails and fingernail clams also may be placed in this category (Mackenthun, 1969).

Benthic communities with a large proportion of pollution-sensitive organisms usually are associated with water of relatively high quality. In contrast, benthic communities in water badly polluted with organic wastes usually contain large proportions of pollution-tolerant organisms. The proportion of pollution-sensitive, facultative, and pollution-tolerant organisms to be expected in high-quality water varies slightly from stream to stream. Most streams contain clean-water areas that can be used as a standard for comparison with other sections of the waterway.

The number of species (or taxa) of benthic invertebrates may be used to evaluate water quality (Mackenthun, 1969). A large variety of benthic invertebrates is usually indicative of clean-water conditions. The assumption is made that high-quality water provides an optimum environment for the existence of a large number of species. Polluted water, on the other hand, imposes one or more limiting factors on the benthic community and restricts the variety of species that can survive in polluted areas.

The density of organisms also is a useful index of water quality. An optimal density of organisms exists in undisturbed areas of most natural waterways, although the density of some benthic invertebrates fluctuates widely with changes in the seasons (Hynes, 1960). The presence of toxic pollutants or sediments that destroy the natural substrates may drastically reduce the "natural" density of many benthic invertebrates. Organic pollutants in the absence of toxic substances, on the other hand, may cause dramatic increases in the density of certain invertebrates, such as oligochaetes and chironomids (Mackenthun, 1969).

For convenience, the number of species, the number of individuals per species, and the total number of organisms may be combined into a single numerical value referred to as a biological diversity index (Simpson, 1949; Margalef, 1956). Such an index has the advantage of summarizing large amounts of information about a community into a single value. Many diversity indexes have been developed and a few of them have been used extensively to characterize a variety of biological communities (Wilhm, 1967).

Recently Wilhm and Dorris (1966, 1968) suggested the widely used *Shannon-Wiener* diversity index ($\overline{H}$) as a means for establishing water-quality parameters. The usefulness of this diversity index for assessing water quality is based on the assumption that clean streams have high diversity indexes, because benthic communities of clean streams contain many species of relatively equal numbers of individuals per species (Wilhm and Dorris, 1968). In contrast, polluted streams are interpreted to have low diversity indexes because many pollution-sensitive species are eliminated from the community and only a few pollution-tolerant organisms flourish in the absence of competition and in the presence of an abundant food supply. According to Wilhm (1970), "$\overline{H}$ usually varies between three and four in clean-water stream areas and is usually less than one in polluted-stream areas."

THE STUDY AREA

Whetstone Creek is a tributary of the Olentangy River located in the northeastern portion of the Scioto River basin in central Ohio (fig. 1). The stream originates in farmland lying 15 km north of the city of Mt. Gilead at an elevation of 393 m and flows south-southwest for approximately 53 km into the Delaware Reservoir at an elevation of 272 meters. The stream gradient averages 2.3 m per km. The watershed occupies approximately 294 km^2, of which 85 percent is cropland and pasture, 10 percent is woodland, and 4 to 5 percent is urban (Ohio Division of Water, 1963). Two municipalities, Mt. Gilead (population = 2800) and Cardington (population = 1650), are located along the main stream channel in the central region.

Soils within the Whetstone Creek watershed are of glacial origin. In upland areas, the watershed contains predominantly associations of Alexandria-Cardington soils. These soils are formed in moderately calcareous clay-loam till on steep slopes. They are light colored, moderately acidic, and well drained, and are capable of moderate agricultural productivity. Headwater sections of Shaw Creek, a major tributary to Whetstone Creek, contain large areas of Blount-Pewamo soils and small areas of Blount-Pewamo-Morley soils. These soils, which occur on level-to-moderately sloping terrain, are formed in highly calcareous clay-loam till. They are relatively high in moisture-supplying capacity and in agricultural productivity. The floodplain contains Eel-Fox soil complexes that are developed in alluvium and outwash materials and are moderately well drained, slightly acidic, and moderately high in agricultural productivity (Smith, 1963).

Prior to and during the period of study, Whetstone Creek received moderate quantities of pollutants from two major sources: (1) organic effluents from the sewage-treatment plant at Mt. Gilead, which entered the stream between stations 31 and 42, and (2) brines from oil-field operations, which entered both small tributaries and the main channel at numerous points between Mt. Gilead and the Delaware Reservoir. Headwater stations 42 and 45 did not receive either organic or brine pollutants.

According to the annual summary of operations for the Mt. Gilead sewage-treatment plant, an average of 40,000 m^3 of sewage per month was handled by the facility in 1966. No raw sewage is recorded to have bypassed the treatment plant during the year. Five-day values for BOD (biochemical oxygen demand) below the wastewater outfall ranged from 7.3 to 7.9 ppm for 1966. The village of Cardington below Mt. Gilead on Whetstone Creek had no municipal sewage-treatment facility, but most homes were probably equipped with cesspools or septic tanks.

METHODS

Sampling Locations

Six locations for collecting benthic invertebrates were established at approximately equal intervals on Whetstone Creek. The location of each sampling sta-

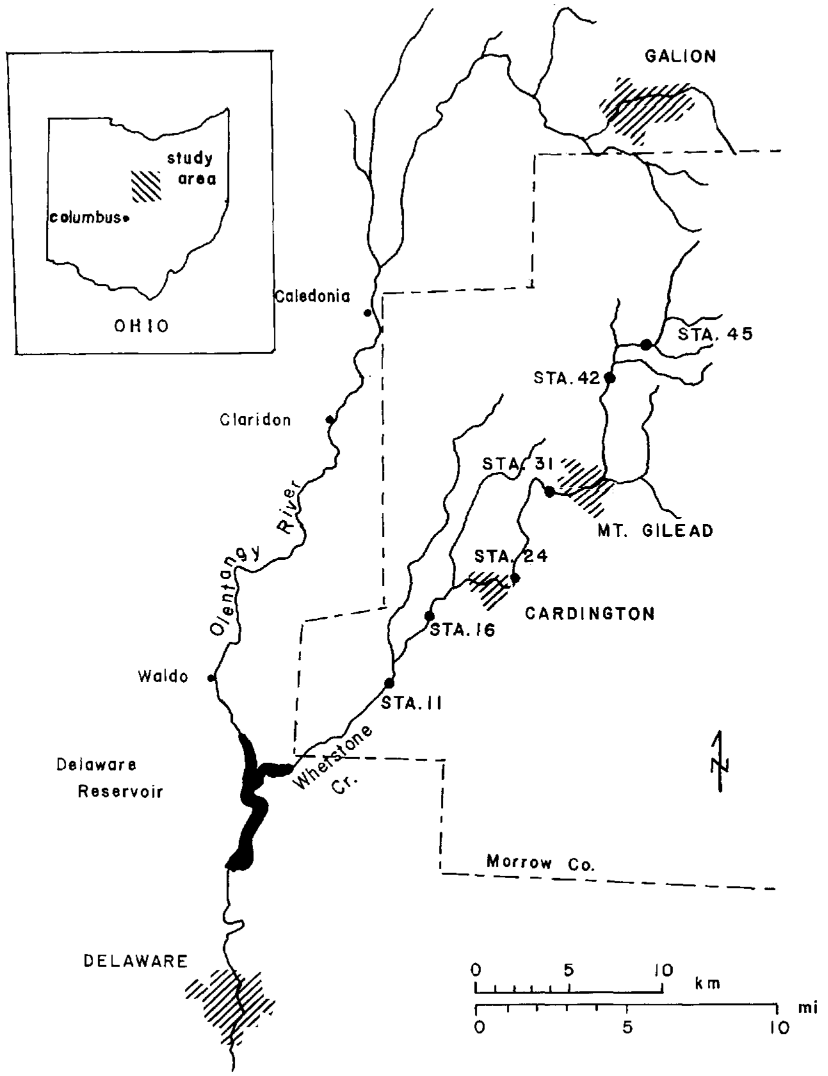

FIGURE 1. Map of Whetstone Creek study area. Sampling stations are designated by numbers which are the same as the number of kilometers from the station down to the confluence with the Olentangy River.

tion is shown in Figure 1. Each sampling location has been designated by a number (11, 16, 24, 31, 42, 45) that is equal to the distance in kilometers from the station to the mouth of the stream at the Delaware Reservoir. Stations 42 and 45 were located in the headwater region above all cities and villages and upstream from the major oil-field operations. Station 31 was located approximately 1 km below the outfall from the Mt. Gilead sewage-treatment facility and within the oil-field region. The remaining three stations (Nos. 11, 16, and 24) were established near or below the village of Cardington and within the region of major oil-field operations. Ideally, more stations would have improved the data, but limited financial resources and limited numbers of technical assistants restricted the number of stations that could be sampled within a reasonable time period.

Benthic Invertebrate Sampling

To improve sampling efficiency of benthic invertebrates, a stratified random sampling technique (Cummins, 1962; Elliott, 1971) was used to select sampling sites at each station. Except for Station 11, the available sampling sites included a riffle, a pool or run, and a margin at each station. Station 11 lacked a permanent riffle area. Approximately one-tenth square meter of substrate containing benthic invertebrates was removed from each site during each sampling period. A shovel and a U.S. Standard No. 30 soil sieve were used for these collections. Stations 16, 24, and 42 were sampled two times each between June and September of 1966. Stations 11, 31, and 45 were sampled three times each during the same period of time. Samples were taken only during the summer months, thus minimizing possible seasonal variations in the data on abundance of certain benthic invertebrates.

Organisms were washed and scrubbed from the larger substrate materials, concentrated by use of a No. 30 U.S. Standard soil sieve, preserved in 80 percent ethyl alcohol, before being transported to the laboratory. In the laboratory the organisms were sorted from the finer residual debris by elutriation and hand picking from white enamel pans, and were then transferred to fresh preservative. At a later date, the organisms were identified and counted. Whenever possible, organisms were identified to the species level. In many cases, however, species identifications of the benthic invertebrates were not possible because only immature organisms had been collected, adult forms being needed for complete species identification. Species identifications were not performed for organisms where complete identification would be extremely laborious and where knowledge of the actual species present would add negligible information of value for water-quality evaluations.

Shannon-Wiener Diversity Index

A *Shannon-Wiener* diversity index ($\overline{H}$) was computed for each benthic invertebrate community from the equation:

$$\overline{H} = -\sum_{i=1}^{m} \frac{n_i}{N} \log_2 \frac{n_i}{N}, \qquad \text{Equation 1}$$

where n_i = the number of individuals per taxon,
N = the total number of individuals, and
m = the number of taxa.

This formula is based on Shannon's (1948) suggested measure of information or entropy contained in a coded message. Margalef (1956) first applied information theories to the analysis of biological communities, following which Wilhm and Dorris (1966, 1968), among others, extended these concepts to becoming a means for establishing biological water-quality parameters. The index shown in Equation 1 is dimensionless; it reflects the importance of each species in the community and is independent of sample size. The advantages and limitations of this equation for describing various biological communities have been discussed by Patten (1962), Pielou (1966), Dickman (1968), Wilhm and Dorris (1968), and Wilhm (1970).

Benthic Invertebrate Community Ordination

To determine how benthic invertebrate community composition varied along Whetstone Creek, a community-ordination technique, based on the degree of similarity for community pairs, was used. A set of community-similarity coefficients (c) was calculated according to the following equation, taken from Sorensen (1948):

$$c = \frac{2c}{a+b}, \qquad \text{Equation 2}$$

where a = number of taxa in first community,
b = number of taxa in second community, and
c = number of taxa shared by communities a and b.

The remaining steps in the ordination procedure were calculated according to the method of Bray and Curtis (1957) from simplified procedures outlined by Cox (1967). These final steps included (1) the calculation of dissimilarity values between communities; (2) the positioning of communities along the X-axis based on dissimilarity values between stations; and (3) the positioning of communities on the Y-axis as determined from poorness-of-fit on the X-axis values.

Chemical-Physical Water-Quality Analyses

The concentration of various inorganic chemicals in the water flowing through each benthic invertebrate community was determined according to procedures in *Standard Methods for the Examination of Water and Wastewater* (American Public Health Association, 1965). A portable water-analysis kit (Hach Chemical Co., Ames, Iowa) was used for these procedures. Chemical analyses of the water included measurements of the concentrations of total hardness, total alkalinity, dissolved oxygen, chlorides, nitrates, total phosphates, silicates, sulfates, and hydrogen ions (pH). Water temperatures were taken with a mercury-bulb thermometer. Stream-flow rates were estimated by the "float method" of Robins and Crawford (1954). All of the above chemical-physical water analyses were determined at the time of each benthic invertebrate collection.

RESULTS

Benthic Invertebrates

Benthic invertebrates collected from Whetstone Creek are listed in Table 1.

TABLE 1

Benthic macroinvertebrates collected from Whetstone Creek (Scioto River Basin), Morrow Co. Ohio, summer 1966. Number of organisms/meter² rounded to nearest five.

	Station (Kilometers from mouth)														
	11			16		24		31			42		45		
	29 Jun 66	27 Jul 66	25 Aug 66	29 Jun 66	27 Jul 66	22 Jun 66	27 Jul 66	22 Jun 66	21 Jul 66	25 Aug 66	17 Jun 66	21 Jul 66	17 Jun 66	21 Jul 66	25 Aug 66
Platyhelminthes															
Turbellaria						15									
Annelida															
Hirudinea										5					
Erpobdella punctata (Leidy)										10					
Helobdella fusca (Castle)						5			5						
Helobdella stagnalis (Linn.)								10		5					
Oligochaeta															
Tubificidae															
Branchiura sowerbyi Beddard	10		10	60	70	25	50	10		5					
Limnodrilus sp. Claparède	70	1350	20		10	100	330	20		210		15			
Tubifex tubifex (Müller)		25													

TABLE 1—*Continued.*

	Station (Kilometers from mouth) 11			16		24		31			42		45		
	29 Jun 66	27 Jul 66	25 Aug 66	29 Jun 66	27 Jul 66	22 Jun 66	27 Jul 66	22 Jun 66	21 Jul 66	25 Aug 66	17 Jun 66	21 Jul 66	17 Jun 66	21 Jul 66	25 Aug 66
Arthropoda															
Eucrustacea															
Amphipoda															
Hyalella azteca (Saussure)		5	5		5	5	165	45	30	80		10			
Asellus militaris Hay					5										
Insecta															
Coleoptera				5						5			5		
Dytiscidae														5	
Bidessus sp. Sharp												5			
Celina sp. Aubé												5			
Dytiscus sp. Linneaus							5								
Elmidae															
Dubiraphia sp. Sanderson						5						5		5	
Stenelmis sp. Dufour					10	45	50	5							
Gyrinidae															
Gyretes sp. Brullé									10					5	
Gyrinus sp. (Geoffroy in Müller)									10						
Haliplidae															
Peltodytes sp. Règimbart			5												
Hydrophilidae				10			5	5							
Helophorus sp. Fabricius				5		5									
Psephenidae															
Psephenus herricki (DeKay)						10		5					5		
Diptera					5					10					
Anthomyiidae (=Muscidae)				5											
Chironomidae								5							
Chironomus (*Chironomus*) sp. Meigen	20			20	5	5									
Chironomus (*Cryptochironomus*) sp. Kieffer			5		5	5	20	90		10		5			
Chironomus (*Endochironomus*) sp. Kieffer														10	10
Chironomus (*Dicrotendipes*) sp. Kieffer		5			5										
Micropsectra sp. Kieffer			5												10
Microtendipes sp. Kieffer													5	30	25
Polypedilum sp. Kieffer					15	5	10		5	15		5		5	
Stictochironomus sp. Kieffer	100	30		20	10	5		5		5		10		50	5
Tanytarsus sp. Wulp			5												5
Orthocladiinae															
Cricotopus sp. Wulp										5					
Psectrocladius sp. Kieffer										5					
Tanypodinae															
Ablabesmyia sp. Johannsen							5			5				10	5
Pentaneura sp. Philippi					10	10	15	5	55	35		10		60	25
Procladius sp. Skuse			5				5								5
Tanypus sp. Meigen	5														
Dolichopodidae				5											
Empididae					5										
Ephydridae															
Ephydra sp. Fallén						5		5							
Heleidae (=Ceratopogonidae)															
Culicoides sp. Latreille						5									
Palpomyia tibialis (Meignen)						10		10							
Scatophagidae								5							

TABLE 1—*Continued.*

	Station (Kilometers from mouth)														
		11		16		24			31		42			45	
	29 Jun 66	27 Jul 66	25 Aug 66	29 Jun 66	27 Jul 66	22 Jun 66	27 Jul 66	22 Jun 66	21 Jul 66	25 Aug 66	17 Jun 66	21 Jul 66	17 Jun 66	21 Jul 66	25 Aug 66
Simuliidae															
Simulium sp. Latreille								5	5						
Syriphidae															
Tubifera sp. Meigen								5							
Tabanidae															
Chrysops sp. Meigen										5					
Tabanus sp. Linnaeus															5
Tipulidae															
Hexatoma sp. Latreille		5								5		5			
Limonia sp. Meigen															5
Pilaria sp. Sintenis		40													
Tipula sp. Linnaeus														5	
Ephemeroptera		5													
Baetidae													5		
Baetis sp. Leach										75		5			
Caenis sp. Stephens			10		30		40		25	10		5		10	10
Ephemeridae															
Ephemera simulans (Walker)														5	20
Heptagenidae															
Stenonema sp. Traver						5		5		5					5
Hemiptera															
Corixidae			5												
Veliidae															
Microvelia sp. Westwood														5	
Megaloptera															
Sialis sp. Latreille		10			25	20	20		10	5		15			5
Odonata															
Libellula sp. Linnaeus							25								
Plecoptera															
Perlidae															
Acroneuria sp. Pictet						15						5	20	5	10
Isoperla sp. Banks													5		
Perlesta sp. Banks													20		
Trichoptera															
Hydropsychidae															
Cheumatopsyche sp. Wallengren					30	110	50	10	45	25			100	20	
Hydropsyche sp. Pictet					20	60	40		50			20	65	10	
Limnophilidae															
Pycnopsyche gentilis (?)					5		10				35	20		5	
Philopotamidae									5						
Chimarra sp. Stephens													5	5	
Mollusca															
Gastropoda															
Goniobasis livescens (Menke)				5	5	365	120				70	115	75	95	35
Ferrissia rivularis (Say)						15		695		5					
Lymnaea (*Fossaria*) *parva* (Lea)													10		
Physa gyrina Say		15		10		20	90	110	5	30				10	
Pelecypoda															
Pisidium sp. Pfeiffer														5	
Sphaerium sp. Scopoli					10	150	75	20	5		265	450	10		20
Totals:															
No. of individuals/m²	205	1490	75	145	285	1025	1130	1075	265	585	370	710	335	360	205
No. of taxa	5	10	10	10	20	26	20	21	14	24	3	18	13	21	17

The number of taxa collected and the density of organisms calculated for each station are also given in Table 1 and Figure 2. The number of taxa collected from each station ranged from 18 at Station 42 to 39 at Station 31. The largest numbers of taxa were collected at Stations 24, 31, and 45. The average number of organisms per square meter (ecological density) for each station ranged from 215 at Station 16 to 1076 at Station 24. Except for Station 16, the density of organisms was greater for stations below Mt. Gilead.

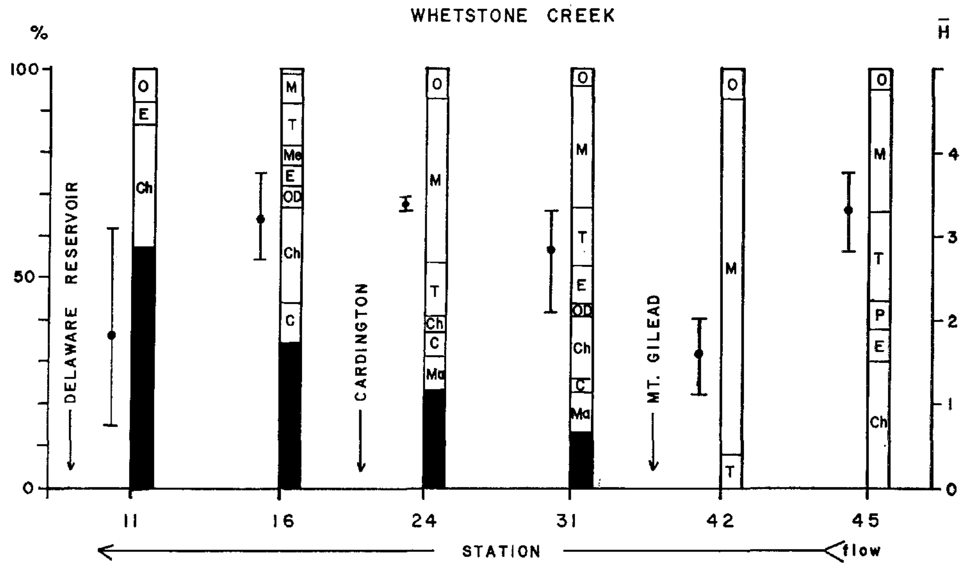

FIGURE 2. The percentage composition of benthic macroinvertebrate communities in Whetstone Creek, Morrow County, Ohio. Dark bars = tubificids, Ma = Malacostraca, C = Coleoptera, Ch = chironomids, OD = other Diptera, E = Ephemeroptera, Me = Megaloptera, P = Plecoptera, T = Trichoptera, M = Mollusca, O = other. Extreme and mean *Shannon* diversity indexes ($\bar{H}$) are shown to the left of each bar. Collections taken during the summer 1966.

Oligochaetes, particularly *Limnodrilus* sp., the amphipod *Hyalella azteca*, the chironomids *Stictochironomus* sp. and *Pentaneura* sp., the mayfly *Caenis* sp., the alderfly *Sialis* sp., the caddisflies *Cheumatopsyche* sp. and *Hydropsyche* sp., and the molluscs *Goniobasis livescens*, *Physa gyrina*, and *Sphaerium* sp. were the most abundant and widespread benthic invertebrates collected. Most of these organisms were collected at five of the six sampling stations. Only *Stictochironomus* sp. and *Sialis* sp. were taken at all six stations.

Station 45.—Thirty-five taxa of benthic invertebrates were collected at Station 45 (Table 1). This was the next-to-largest number of taxa collected from any of the stations. The density of organisms averaged 300 organisms/m^2 for three sampling dates. Chironomids, caddisflies, and molluscs were the most abundant organisms collected at Station 45. Collectively these animals accounted for 80 percent of the benthic invertebrate community at this station. Chironomids accounted for an average of 30.4 percent of the organisms. Most abundant of the chironomids were *Microtendipes* sp., *Stictochironomus* sp., and *Pentaneura* sp. *Stictochironomus* sp. and *Pentaneura* sp. were widely distributed at other stations, but *Microtendipes* sp. was collected only at Station 45.

Caddisflies accounted for 20.9 percent of the benthic invertebrate community. *Cheumatopsyche* sp. and *Hydropsyche* sp. were the most abundant forms collected.

Molluscs, mostly *Goniobasis livescens* and *Sphaerium* sp., accounted for 28.7 percent of the benthic organisms. Mayflies, including *Caenis* sp., *Ephemera simulans*, and *Stenonema* sp., were moderately abundant at Station 45. *Caenis* sp. was widely distributed in other areas of Whetstone Creek, but *Ephemera simulans* was collected only from Station 45. Stoneflies, including *Acroneuria* sp., *Isoperla* sp., and *Perlesta* sp., were more abundant at Station 45 than at any of the downstream stations.

Station 42.—Eighteen taxa of benthic invertebrates were collected at Station 42 (Table 1). This was the smallest number of taxa collected from any single station on Whetstone Creek. The density of organisms averaged 540 organisms/m^2 for two sampling dates. Molluscs, especially the snail, *Goniobasis livescens*, and the fingernail clam, *Sphaerium* sp., accounted for 85 percent of the organisms collected at this station. The remainder of the community was composed mostly of the caddisflies *Pycnopsyche gentilis* and *Hydropsyche* sp. and the chironomids *Chironomus* (*Cryptochironomus*) sp., *Polypedilum* sp., *Stictochironomus* sp., and *Pentaneura* sp.

Station 31.—Thirty-nine taxa of benthic organisms were collected at Station 31 (Table 1). This was the largest number of taxa collected from any of the six sampling stations on Whetstone Creek. The density of organisms averaged 642 organisms/m^2 for three sampling dates.

Molluscs, especially *Ferrissia rivularis* and *Physa gyrina*, were the most abundant benthic invertebrates collected, but these species accounted for only 28.8 percent of the benthic community. *Ferrissia rivularis* averaged 233 organisms/m^2 and was considerably more abundant at Station 31 than in other areas of Whetstone Creek. The remainder of the community consisted mostly of caddisflies, particularly *Cheumatopsyche* sp. (14.3 percent); chironomids, especially *Chironomus* (*Cryptochironomus*) sp. and *Pentaneura* sp. (15.4 percent); oligochaetes, mostly *Limnodrilus* sp. (12.9 percent); the amphipod *Hyalella azteca* (9.7 percent); and the mayflies *Baetis* sp., *Caenis* sp. and *Stenonema* sp. (9 percent).

Station 24.—Thirty-three taxa of benthic invertebrates were collected at Station 24 (Table 1). The density of organisms averaged 1076 organisms/m^2 for two sampling dates. This was the greatest density of organisms collected in Whetstone Creek and was almost double the average density of organisms collected from other stations.

Molluscs, especially *Goniobasis livescens*, *Sphaerium* sp., and *Physa gyrina*, accounted for 39.4 percent of the benthic organisms collected from Station 24. The oligochaetes *Limnodrilus* sp. and *Branchiura sowerbyi* were the next most abundant major group of invertebrates, accounting for 22.9 percent of the benthic community. The remainder of the community was composed mostly of caddisflies (12.7 percent), *Hyalella azteca* (7.5 percent), aquatic beetles, especially *Stenelmis* sp. (5.8 percent), chironomids (3.8 percent), and a few mayflies (2 percent), including *Caenis* sp. and *Stenonema* sp.

Station 16.—Twenty-six taxa of benthic invertebrates were collected at Station 16 (Table 1). The density of organisms averaged 215 organisms/m^2 for two sampling dates. This was the lowest average density of organisms recorded for any Whetstone Creek station. Oliogochaetes, particularly *Branchiura sowerbyi*, and the chironomids *Chironomus* (*Chironomus*) sp., *Polypedilum* sp., and *Stictochironomus* sp. accounted for more than half (57.5 percent) of the benthic community. The remainder of the community was composed of beetles (9 percent), caddisflies (9.5 percent), miscellaneous dipterans (5 percent), the mayfly *Caenis* sp. (5 percent), and the alderfly *Sialis* sp., (4.5 percent).

Station 11.—Twenty taxa of benthic invertebrates were collected at Station 11 (Table 1). An average of 590 organisms/m^2 were collected on three separate sampling dates. The range in density of organisms (75–1490 organisms/m^2) from this station was extremely large, greatly exceeding the range for other stations on Whetstone Creek.

Oligochaetes and chironomids were the most abundant organisms collected from Station 11, accounting for 87 percent of the benthic invertebrate community. *Limnodrilus* sp. and *Stictochironomus* sp. were, respectively, the most abundant oligochaete and chironomid collected. The remainder of the community was composed mostly of the mayfly *Caenis* sp. (4.6 percent), *H. azteca* (2.6 percent), the beetle *Peltodytes* sp. (2.3 percent), and the water boatman Corixidae (2.3 percent).

Chemical-Physical Data

Chemical and physical water-quality data determined for Whetstone Creek are given in Table 2. Total alkalinities (as $CaCO_3$) ranged from 130–295 ppm, but no patterns of concentration were discernable at any of the six sampling loca-

TABLE 2

Chemical-physical water quality data for Whetstone Creek, June-August 1966. All units given as mg/l unless otherwise noted.

Station (Km from mouth)	Date	T. Alkalinity ($CaCO_3$)	Chlorides	Hardness (Ca, Mg)	Nitrogen—NO_3	D. Oxygen	T. Phosphates	Silica	Sulfates	pH (units)	Water Temp (c)	Flow rate (m^3/sec)
11	29 Jun 66	248	245	375	1.2	7.0	.8	2.7	178	8.4	24	.56
	27 Jul 66	235	240	420		8.2	.75	6.5	85	8.2	26	.58
	25 Aug 66	130	175	350	.8	6.9	.85	33.0	70	8.3	21	
16	29 Jun 66	295	276	389	2.5	7.3	2.3	7.9	110	6.6	24	.90
	27 Jul 66	230	246	408	-0-	7.8	.94	13.0	95	8.2	26	.74
24	22 Jun 66	145	230	410	1.0	7.5	1.0	5.4	95	8.5	23	.25
	27 Jul 66	233	225	400	—	6.0	1.75	11.0	85	7.8	25	.28
31	22 Jun 66	253	273	379	1.0	4.3	4.2	12.6	115	7.8	—	.37
	21 Jul 66	225	190	360	2.6	6.4	1.0	12.0	74	7.4	19	.34
	25 Aug 66	220	105	350	.9	5.4	2.4	9.0	80	7.6	19	.47
42	17 Jun 66	239	8	295	0.8	6.8	.60	8.2	80	8.2	—	.20
	21 Jul 66	250	12	300	1.9	9.5	.42	4.5	67	7.9	17	.06
45	17 Jun 66	242	8	295	1.2	8.1	.40	8.3	78	8.3	—	.11
	21 Jul 66	230	8	185	.8	8.6	.85	12.2	74	7.5	17	.04
	25 Aug 66	190	8	210	2.3	7.8	.70	1.8	89	8.2	17	.04

tions. Total hardness ranged from 185–420 ppm, the highest values occurring at downstream stations 11, 16, and 24. Calcium hardness was approximately twice that of the magnesium hardness at all stations. Chlorides ranged from 8–12 ppm at headwater stations 42 and 45, but increased to 105–276 ppm at stations 11, 16, 24, and 31, located within the oil-field region.

Nitrate-nitrogen (NO_3-N) ranged from 0–2.6 ppm. The concentrations of NO_3-N did not differ significantly for different stations. Dissolved-oxygen (D.O.) levels ranged from 7.8–9.5 ppm at headwater stations 42 and 45, but declined to 4.3–8.2 at stations below Mt. Gilead. The lowest concentrations of D.O. (4.3–6.3 ppm) occurred at Station 31, located immediately below the Mt. Gilead sewage-treatment facility.

Total phosphates were only 0.40–0.85 ppm at headwater Stations 42 and 45, but increased to values ranging from 0.80–4.2 ppm at downstream stations 11, 16, 24, and 31. The largest total-phosphate concentrations (1.0–4.2 ppm) occurred at Station 31, located below the Mt. Gilead sewage-treatment facility. Phosphate levels gradually declined downstream from Station 31 to Station 11, where no value greater than 1 ppm was recorded.

Silicate concentrations ranged from 1.8–33 ppm. No significant differences in silicate concentration were noted between values for different stations. Sulfate levels ranged from 67–178 ppm, the highest values occurring at lowermost Stations 11 and 16. The hydrogen-ion concentration ranged from pH 6.6–8.5. For most stations (11, 24, 42, and 45), average pH values ranged from 8.0–8.3. At Station 16 below Cardington and Station 31 below the Mt. Gilead sewage-treatment facility, pH averaged 7.4 and 7.6, respectively.

Water temperatures ranged from 17°C at headwater stations to 26°C at downstream stations near the stream mouth. Flow rates determined by the float method ranged from 0.04 m^3/sec in the headwater areas to 0.90 m^3/sec at downstream Station 16.

DISCUSSION

Evaluation of Water Quality at Headwater Station 45

In Whetstone Creek the highest quality water suitable for the greatest variety of uses was found at headwater Station 45. Both chemical-physical water-quality data (Table 1) and biological criteria (fig. 1) support this conclusion. Therefore the nature of this station is described first, and is then compared with those of the other stations.

The water at Station 45 was always well oxygenated and contained low concentrations of phosphates, nitrates, chlorides, silicates, and sulfates. The water was relatively hard and alkaline, however, because of extensive solution of lime in glacial till underlying the Whetstone Creek basin. Erosion of moderate quantities of soil particles from adjacent agricultural lands was the only major source of pollution at Station 45.

The number of taxa (35) collected at Station 45 was relatively large. This compares favorably with the number of taxa reported from clean-water areas in other river systems within the State of Ohio, including the Muskingum River Basin (Federal Water Quality Administration, 1968), the Miami River system (Gaufin, 1958; Gaufin and Tarzwell, 1956), the main channel of the Ohio River (Mason *et al.*, 1971), and other tributaries of the Scioto River Basin (Federal Water Quality Administration, 1970).

In Whetstone Creek, the average $\overline{H}$ value of 3.35 calculated for Station 45 was relatively high (fig. 1). This value is comparable to $\overline{H}$ values reported by Wilhm (1970) from clean-water areas in a number of other river systems.

Station 45 contained the largest percentage of pollution-sensitive organisms such as the stoneflies *Isoperla* sp. and *Perlesta* sp., the mayfly *Ephemera simulans,* and the caddisfly *Chimarra* sp., which were collected only at Station 45. The remainder of the benthic community was composed mostly of pollution-sensitive chironomids. The status of chironomids in relation to varying degrees of pollution is less well understood and agreed upon than are those of other benthic fauna; some authors assign all chironomids to a facultative or pollution-tolerant category (Mackenthun, 1969). Most of the chironomids encountered at Station 45, however, including *Micropsectra* sp., *Microtendipes* sp., *Ablabesmyia* sp., and *Pentaneura* sp., are considered by many investigators to be pollution-sensitive (Mason *et al.*, 1971; Gaufin, 1958). Collectively, pollution-sensitive and facultative organisms accounted for approximately 90 percent of the benthic invertebrate community at Station 45.

Less than two percent of the organisms taken from Station 45 were pollution-tolerant forms such as the pulmonate snail, *Physa gyrina*. Station 45 was the only area where pollution-tolerant organisms such as tubificid worms and leeches were not found.

Comparison of Station 45 to Other Areas of Whetstone Creek

To determine the degree of difference between benthic invertebrate communities found at all stations in Whetstone Creek, a community-ordination technique, based on the methods of Beals (1960) and of Bray and Curtis (1957), was performed. This procedure involves the calculation of community-similarity coefficients, conversion to dissimilarity values, and subsequent arrangement of the communities

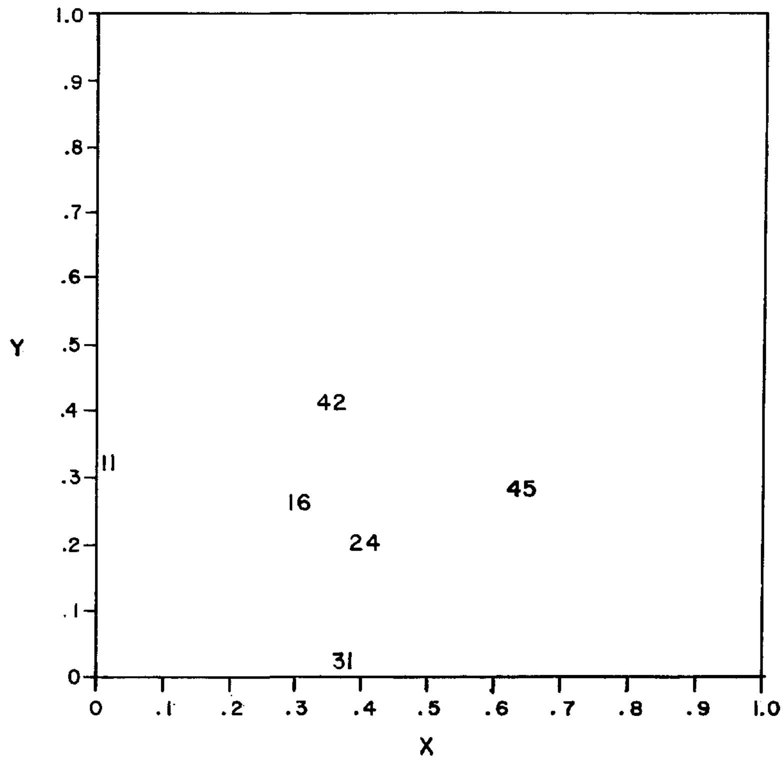

FIGURE 3. Two-dimensional ordination of benthic macroinvertebrate communities, Whetstone Creek, summer 1966. Communities are designated by a number corresponding to their distance in kilometers from the confluence of the stream with the Olentangy River.

in a two-axis system based upon differences in faunal composition. The distance (ordination interval) between communities on the graph represents the degree of dissimilarity in faunal composition between communities. The results of this ordination are shown in Figure 3.

The benthic communities in Whetstone Creek were distinctly different in composition and did not form a continuous gradient from one type of community to another. The greatest dissimilarity in faunal composition existed between Station 45 and Station 11. These stations were located at opposite ends of Whetstone Creek and differed considerably with respect to flow rates, to the variety of habitats available, and to at least two chemical constituents of the water (Table 2).

The benthic community at Station 11, in contrast to that at Station 45, was composed of a large proportion of pollution-tolerant oligochaetes, chironomids, and pulmonate snails. These organisms accounted for approximately 85 percent of the community. Less than 10 percent of the community consisted of pollution-sensitive organisms. The total number of taxa (20) collected at Station 11 and the average $\overline{H}$ value (1.84) calculated for this station were very low, compared to values obtained from Station 45. The density of organisms was considerably greater at Station 11 than at Station 45, but the differences probably are not significant because of the small number of samples and large variation in results.

The concentrations of total alkalinities, nitrates, dissolved oxygen, total phosphates, silicates, sulfates, and hydrogen ions are similar at the two stations. The differences in concentrations of these compounds between stations are probably due entirely to chance variations. Total hardness and chloride concentrations, however, are significantly higher for Station 11 than for Station 45. The flow-rate also is greater at Station 11. Despite these differences, it is improbable

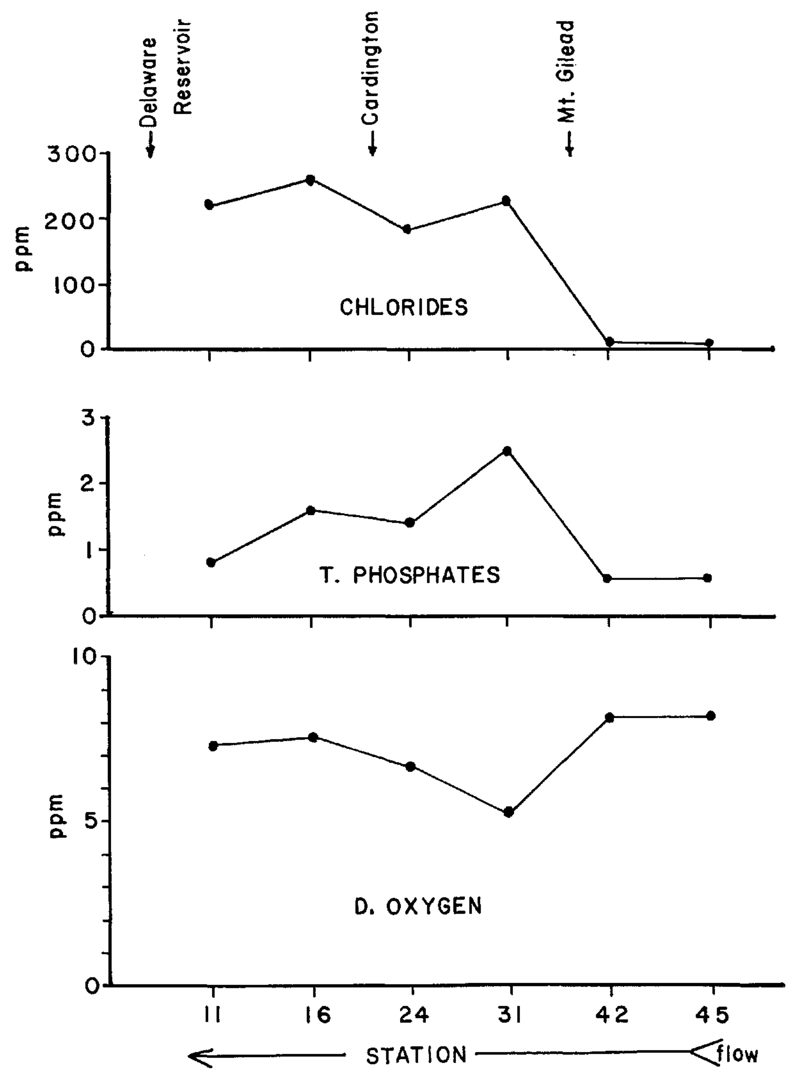

FIGURE 4. Mean dissolved oxygen, total phosphate, and chloride concentrations for sampling stations along Whetstone Creek, summer 1966.

that these factors solely account for differences in species composition between stations. Stations 16, 24, and 31 also have much greater concentrations of total hardness and chlorides, and a greater rate of flow than does Station 45 (Table 2 and fig. 4). Yet the resemblance between benthic communities at these stations and at Station 45 is much greater than the community resemblance between Stations 11 and 45 (fig. 2 and fig. 3).

A more plausible explanation for the differences between the benthic communities at Stations 11 and 45 lies with differences in the types of habitats between the two stations. Station 45 contained a wide variety of habitats, including a pool with a gravel-and-sand bottom, a riffle with eroding substrates ranging in size from gravel to large rocks 25 cm or more in diameter, and a mud-sand margin partially covered with aquatic vascular plants. The habitat at Station 11, in contrast, consisted mostly of a pooled area with a flat limestone bottom covered by a thick deposit of mud. A margin of mud and sand was sparsely covered with aquatic vascular plants.

The absence of a permanent riffle with eroding-type substrates at Station 11 greatly reduced the diversity of habitats available in the area. Many aquatic biologists have shown that the variety of benthic invertebrates occurring in riffles is usually much greater than the variety of organisms occupying pooled or marginal areas (Hynes, 1970). Presumably, riffles have more diverse habitats than do most other stream areas.

A directly proportional relationship between the number of species and the diversity of habitat probably was first proposed by A. Thienemann, an early student of stream invertebrates. As given by Hynes (1970), this ecological principal states that, "The greater the diversity of the conditions in a locality the larger is the number of species which make up the biotic community." This point must be fully considered when using biological diversity indexes for comparing benthic invertebrate communities. Clean streams with low habitat diversity, for example, may have very low biological diversity. For this reason, the low *Shannon-Wiener* diversity indexes calculated for Station 11 may have resulted from a low diversity of habitat rather than from poor chemical-physical water quality.

According to the community ordination (fig. 3), Station 45 most nearly resembles, although not closely, Station 24 in species composition. The number of taxa (33) collected and the average $\overline{H}$ value (3.34) calculated for Station 24 are almost identical to those for Station 45. These similarities, however, contrast sharply with differences between the stations in species composition and in density of organisms. Approximately 75 percent of the benthic community at Station 24 consisted of pollution-sensitive or facultative stoneflies, caddisflies, mayflies, alderflies, chironomids, and gill-bearing snails. Only 25 percent of the organisms were pollution-tolerant oligochaetes and pulmonate snails. In contrast (as noted above), the benthic community at Station 45 consisted almost entirely of pollution-sensitive or facultative organisms; pollution-tolerant organisms accounted for less than 2 percent of the benthic community.

Important differences between Stations 24 and 45 also occur with respect to the concentrations of total hardness, dissolved oxygen, total phosphates, and chlorides (Table 2). Dissolved-oxygen levels were slightly lower at Station 24, while the concentrations of total hardness, total phosphates, and chlorides were considerably higher than at Station 45. Because of these disparities in chemical water quality and in differences in faunal composition between the two stations, complete reliance upon diversity indexes and the number of taxa collected for water-quality assessments was avoided.

Station 24 closely resembles Station 31 in faunal composition (figs. 2 and 3) and in chemical-physical water quality (Table 2). Station 31 was located only 1 km below the Mt. Gilead wastewater outfall and contained approximately the same percentages of pollution-tolerant, facultative, and pollution-sensitive benthic invertebrates as Station 24, which was approximately 7 km downstream from this site (fig. 2). The number of taxa (39) collected from Station 31 was the largest recorded for any station; however, the average $\overline{H}$ value for this station (2.88) was somewhat less than those for Stations 24 and 45. Dissolved-oxygen levels at Station 31, approaching the lower limits acceptable under the Ohio Environmental Protection Agency (1972) water-quality criteria (4 ppm), were slightly lower than levels encountered at Station 24 and considerably below the levels of Station 45. The concentrations of total hardness, total phosphates, and chlorides were relatively high, but were not significantly different from concentrations at Station 24.

Organic effluents entering Whetstone Creek near Station 31 from the Mt. Gilead wastewater-treatment facility are undoubtedly the major cause for differences in chemical water quality and for variations in benthic community composition between Station 45 and the two Stations 24 and 31. Reduced levels of dissolved oxygen and increased concentrations of phosphates are typical changes in water quality expected below domestic wastewater outfalls (Hynes, 1960; Gaufin and Tarzwell, 1956; Gaufin, 1958; Paine and Gaufin, 1956).

Phosphates at the levels encountered in Whetstone Creek below Mt. Gilead probably do not directly affect the benthic invertebrates. Indirectly, they may affect the benthic communities by increasing the productivity of periphyton and aquatic vascular plants. Mean phosphate concentrations for Whetstone Creek are plotted for each station in figure 4. At unpolluted Stations 42 and 45, phosphate levels averaged less than 1 ppm, but below Mt. Gilead, phosphate concentrations were as high as 4.2 ppm, gradually declining downstream to less than 1 ppm at Station 11.

The faunal composition of the benthic invertebrate communities at Stations 24 and 31 was typical of that associated with moderately organically enriched streams. Biological conditions in zones of organic decomposition are well known (Hynes, 1960; Mackenthun, 1969; Warren, 1971). In the absence of toxic materials, organically enriched areas near domestic-waste outfalls often contain over 90 percent pollution-tolerant organisms, such as tubuficid worms, certain chironomids, and pulmonate snails. Facultative and pollution-sensitive organisms gradually increase in relative abundance toward the middle and lower sections of the decomposition zone. The lower limit of the decomposition zone in Whetstone Creek was not determined.

Pollution-tolerant organisms accounted for approximately 25 percent of the organisms collected at Stations 24 and 31. These organisms included the annelids *Branchiura sowerbyi*, *Limnodrilus* sp., *Helobdella stagnalis*, *Helobdella fusca*, and *Erpobdella punctata;* the snail *Physa gyrina;* and the chironomids *Cricotopus* sp. and *Procladius* sp. The remainder of the benthic communities consisted mostly of facultative organisms, such as *Hyalella azteca;* the chironomids *Chironomus* (*Cryptochironomus*) sp. and *Polypedilum* sp.; the mayfly *Caenis* sp.; the alderfly *Sialis* sp.; the caddisflies *Hydropsyche* sp. and *Cheumatopsyche* sp.; the gastropods *Goniobasis livescens* and *Ferrissia rivularis;* and the pelecypod *Sphaerium* sp. *Ferrissia rivularis* was collected only at Stations 24 and 31. A few pollution-sensitive organisms, including the beetle *Psephenus herricki;* the chironomids *Stictochironomus* sp., *Ablabesmyia* sp., and *Pentaneura* sp.; and the mayfly *Baetis* sp., were collected from either or both Stations 24 and 31.

Substrate dissimilarities are possible causes for the differences in species composition of the benthic community between Stations 24 and 31 and Station 45, but substrates were not analyzed in sufficient detail to assess adequately the importance of this factor. All three stations, however, contained a riffle area in addition to a pool, with small patches of aquatic vascular plants. Sediments at Stations 24 and 31 appeared to have a higher organic content than did sediments at Station 45.

The importance of brines as a possible cause for dissimilarities in faunal composition between stations can be minimized because the concentration of brines (e.g. chlorides) was similar at Stations 11, 16, 24, and 31 (fig. 4), even while the faunal composition, the *Shannon-Wiener* diversity indexes (fig. 2), and the density of organisms (Table 2) varied considerably among these stations. High chloride concentrations in Whetstone Creek result from seepage of oil-field brines into the stream and from direct dumping of brines into the stream channel. Although no chloride concentration greater than 276 ppm was recorded during the study, Pettyjohn (1971) reported that, during the peak drilling activity in the Whetstone Creek region (1969), chloride levels as high as 1350 ppm were noted in the stream. Based upon a collation of caddisfly records and associated chemical data, Robach (1962) found that, of twenty-nine reported genera, eight tolerated chloride concentrations greater than 2500 ppm. Most genera, however, occurred in water with chloride concentrations ranging from 3–50 ppm. Clemens and Finnell (1955) reported only four species of chironomids from a brine-polluted stream in southern Oklahoma where chloride concentrations ranged from 13,000–20,000 ppm. Thirteen species of invertebrates were found at chloride levels less than 1,000 ppm in the same stream.

Because of the large diversity of pollution-sensitive and facultative organisms in the brine-polluted areas of Whetstone Creek, it is doubtful that brines have damaged the benthic macroinvertebrate communities as much as have organic effluents. At Station 31, for example, where organic and brine pollution are most severe, *Goniobasis livescens*, *Acroneuria* sp., *Libellula* sp., and *Pycnopsyche gentilis* were absent. But the presence of these organisms at stations farther downstream, where organic pollution was less severe, but where chlorides remained high, suggests that brines were not as damaging to these populations as were the low dissolved-oxygen concentrations or the sludge deposits associated with decaying organic wastes at Station 31. *Goniobasis livescens*, *Acroneuria* sp., and *Pycnopsyche gentilis* also were collected above Station 31 in the absence of both organic and brine pollution.

The faunal composition of the benthic invertebrate community at Station 16 also shows the effects of organic effluents (fig. 2). According to the community ordination, Station 16 closely resembles Station 24 in species composition (fig. 3). Station 16 was located a short distance below Cardington, a small village that did not provide a wastewater-treatment facility for its residents. Septic-tank effluents and untreated domestic wastes from the village undoubtedly entered Whetstone Creek at numerous points near Station 16.

Pollution-tolerant tubificids, chironomids, and pulmonate snails accounted for approximately 38 percent of the benthic community. The remainder of the community was composed mostly of facultative organisms, such as the mayfly *Caenis* sp., the alderfly *Sialis* sp., the caddisflies *Hydropsyche* sp. and *Cheumatopsyche* sp., and the molluscs *Goniobasis livescens* and *Sphaerium* sp.

The number of taxa collected at Station 16 (26) was somewhat less than the number of taxa collected at Stations 24, 31, and 45 (Table 1). The average $\overline{H}$ value (3.21), however, was relatively high and not significantly different from those of Stations 24 and 45 (fig. 2).

Station 42 on Whetstone Creek was located in a clean-water area, but certain benthic community-structural features contrast sharply with those of headwater Station 45. Chemical water-quality data (fig. 4) and the species composition of the benthic community (fig. 2) at Station 42 indicate the presence of water of relatively high quality, suitable for most domestic and recreational uses. The water was well oxygenated, with relatively low concentrations of phosphates, nitrates, chlorides, silicates, and sulfates. Total hardness and total alkalinity concentrations were relatively high, but pH values were well within optimal limits for most aquatic life.

The benthic community at Station 42 was dominated by the facultative fingernail clam *Sphaerium* sp. and the snail *Goniobasis livescens*. These organisms accounted for 85 percent of the benthic community. Pollution-sensitive and facultative caddisflies, including *Hydropsyche* sp. and *Pycnopsyche gentilis*, and the chironomids *Stictochironomus* sp. and *Pentaneura* sp. also accounted for a large proportion of the organisms collected. Less than 2 percent of the community was composed of pollution-tolerant organisms.

In contrast to the favorable water-quality conditions indicated by selected chemical parameters and the benthic faunal composition, the number of taxa (18) collected at Station 42 was the lowest recorded for Whetstone Creek (Table 1). The average $\overline{H}$ value (1.6) for Station 42 also was the lowest calculated for Whetstone Creek (fig. 2) because only three taxa, *Pycnopsyche gentilis*, *Goniobasis livescens*, and *Sphaerium* sp., were collected on 17 June. Except for erosion of soil particles into the stream, no known domestic or industrial wastes were entering the water at this station. A local rainstorm prior to 17 June may have scoured the stream bottom of many invertebrates, because approximately one month later, eighteen taxa were collected from Station 42, which is comparable to the maximum number of taxa collected on a single sampling date from any other station.

According to Hynes (1970), a number of investigators have reported a reduction in the variety and abundance of benthic invertebrates as a result of high water. The length of the period of recovery after high water depends upon the severity of the rainstorm, the distance to the nearest benthic community from which recolonization can occur, the season of the year, and the kinds of organisms. Because of the favorable time of year and the proximity of other communities, partial recovery of Station 42 was very rapid. Since no samples were taken later in the summer, complete recovery of the benthic community may not have been observed. For this reason, the low total number of taxa and the low *Shannon-Wiener* diversity index probably does not provide a good indication of water quality at Station 42.

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