The Biotic Index as a Measure Of Organic Pollution in Streams

By RALPH D. HEISTER, JR.

The purpose of this study was to provide an index for measuring the sensitiveness of benthic organisms to organic pollution and to present a preliminary evaluation in terms of a currently accepted index.

The study was made in Chester County, southeastern Pennsylvania. This is primarily a rural county —agriculture is the major industry—but the eastern end of the county is highly urbanized. With this diversity of land use there are extremes in water quality in the streams of the county. The main contributors of pollution are sewage-treatment plants, agricultural fertilizers and manure, mushroom houses, and silt from erosion of soil.

Sampling Procedures

Sampling was done at 30 stations on 11 streams in Chester County (fig. 1) in the spring of 1971. Stations were located with respect to equal drainage area or multiples thereof and similar riffle substrate.

Because the land use in Chester County is primarily agricultural, the problems of water chemistry are organic. Measurements of dissolved oxygen, specific conductance, and pH were determined at each station in the spring of 1971.

The author is chairman of the biology department of Conestoga Senior High School, Conestoga and Irish Rds., Berwyn, Pa. 19312; he has taught there for 14 years. He received his doctorate in biology at Pennsylvania State University last year. "The data for this article were collected and collated by my advanced-biology students as part of a continuing study of streams in Chester County, Pennsylvania," Heister says. "Among other things, we are searching for better procedures in water analysis."

A technique for sampling benthic macroinvertebrates was used to capture the maximum number of species and individuals with a minimum of sampling. Samples were collected by rubbing organisms off the stones in a riffle area, disrupting the gravel, and allowing the current to wash the organisms into a Nitex hand screen immediately downstream. (The screen is a nylon cloth with openings of 471 microns.) Samples were collected until no new kinds of benthic organisms appeared. Organisms were hand-picked from the screen and immediately preserved in 10% formalin. Identification was made by consulting Ward and Whipple (1966) and Pennak (1953).

Biologic Indices

As a measure of water quality the biotic index expresses a relationship between the environment and the qualitative physiologic tolerances of organisms. These tolerances generally are known for genera, families, and orders, rather than for species. It has been established that some groups of organisms are more sensitive to organic pollution than others, either because they are unable to withstand a reduction of dissolved oxygen in the water or because of some other limiting environmental factor related to the pollutant.

The biotic index (BI) proposed by Beck (1955) has the following formula: $BI = 2\ (n \text{ class I}) + (n \text{ class II})$, where n is the number of species.

The biotic index has five classes, two of which are of greater importance. Class I organisms are those that cannot withstand any appreciable organic pollution. Class II organisms are those that withstand a moderate amount of organic pollution but are unable to live at or near anaerobic conditions. The other classes of organisms—those found in grossly polluted

Biotic classes of benthic macroinvertebrates found in 11 streams in Chester County, Pennsylvania, spring 1971, with the reference of their class assignment.

Organism	Biotic class					Reference of class assignment
	I	II	III	IV	V	
OLIGOCHAETA: NAIDIDAE			x			b
Herpobdella sp.			x			a
HIRUDIDAE			x			a
Lirceus sp. (Rafinesque)		x				b
Asellus sp.	x					b
Cambarus bartoni (Fabricius)			x			b
Paraleptophlebia packi	x					d
Ameletus sp. (Eaton)	x					d
Ephemerella margarita	x					d
Epeorus flavipenaiis	x					d
Caenis sp. (Stephens)		x				d
Baetis propinquus (Walsh)	x					d
Centroptilum sp. (Eaton)	x					d
Stenonema exiguum	x					b
Stenonema smithae	x					b
Stenonema sp.	x					b
Lanthus sp. (Needham)	x					b
Gomphus sp. (Leach)	x					b
Gomphus pallidus		x				b
Progomphus sp.	x					b
Somatochlora sp. (Selys)	x					b
Plathemis sp. (Hagen)	x					b
Amphiagrion sp. (Selys)	x					b
Hetaerina americana	x					b
Macromia sp.		x				b
Argia sp.	x					b
Chimarra sp.	x					b
Blepharocera sp. (Macquart)					x	f
Antocha sp. (Osten Sacken)				x		f
Tipula sp. (Linnaeus)				x		f
Pedicia sp. (Latreille)				x		f
Tendipes sp. (Meigen)			x			f, b
TENDIPEDINI			x			f, b
Pentaneura nr. *monilis*			x			b
Pentaneura flavifrons	x					b
Tanypus stellatus			x			b
Corynoneura sp.	x					b
Spaniotoma sp.		x				b
Tanytarsus exiguus	x					b
Tanytarsus gregarius	x					b
Polypedilum fallax		x				b
Cryptochironomus sp.			x			b
Cryptochironomus sp. B. (Joh.)	x					b
Chironomus decorus			x			b
Chironomus sp.			x			b
Simulium sp.	x					b
Physa gyrina (Say)				x		b
Physa sp.				x		b
Ferrissia sp.				x		b
Helisoma antrosa				x		b
Pisidium sp.			x			b
Anodonta sp. (Lamarck)			x			b
Pteronarcys sp. (Newman)	x					e, b
Peltoperla sp. (Needham)	x					e, b
Acroneuria sp. (Pictet)		x				e, b
Perlodes sp. (Claassen and Frison)	x					e, b
Isoperla sp. (Banks)	x					e, b
Sialis sp. (Latreille)		x				b
Corydalus cornutus (Latreille)	x					b
Chauliodes sp. (Latreille)		x				b
Psephenus herricki (Dekay)				x		b
Helichus sp. (Erichson)				x		b
UNIDENTIFIED COLEOPTERA LARVA					x	b
Stactobiella sp. (Martynov)	x					c
Leutrichia sp.	x					c
Lype sp. (McLachlan)	x					c
Polycentropus sp. (Curtis)	x					c
Glossosoma sp.	x					c
Rhyacophila sp. (Pictet)	x					c
Oxyethira sp.	x					b
Hydroptila sp.	x					b
Macronemum carolina	x					b
Hydropsyche incommoda	x					b
Hydropsyche sp.	x					b
Cheumatopsyche sp.		x				b
Occetis sp.		x				b
Leptocella sp.		x				b
Goniobasis sp.	x					b
Hyalella azteca		x				b
Palaemonetes paludosus		x				b
HYDRACARINA	x					b

[a] Keup, Ingram, and Mackenthun (1969).
[b] Beck (1954).
[c] Roback (1962).
[d] Leonard (1962).
[e] Gauffin (1962).
[f] Curry (1962).

waters (class III), those living independent of dissolved oxygen (class IV), and those for which physiologic knowledge or identification is lacking (class V)—are not given values. Beck did not use the total number of species captured in combination with the number of clean-stream organisms in calculating the biotic index, because he felt the resulting value would reflect diversity of habitat as well as cleanliness of water. He thus assigned values arbitrarily to class I and class II organisms. Class I organisms, by definition, are indicative of clean water and have been assigned twice the value of class II organisms, which are able to withstand a moderate amount of organic pollution.

In our study, collections of benthic macroinvertebrates were assigned biotic classes according to information available about the species, genus, family, or order to which the organisms belonged. Roback (1962) related the distribution of genera of Trichoptera to the range of their tolerance to alkalinity, carbon dioxide, dissolved oxygen, iron, total hardness, ammonia nitrogen, nitrate nitrogen, pH, phosphate, sulfate, temperature, turbidity, and biochemical oxygen-demand. Leonard (1962) related species of Ephemeroptera in selected Michigan streams and rivers to sand, mud, and gravel substrate, the underside of stones, submerged plant beds, little or no current, rapid current, high oxygen levels, high-to-medium conductivity, high nitrate and phosphate levels, and varying levels of other selected ions. Gaufin (1962) found the distribution of Plecoptera is associated with rapid current, oxygen saturation, stable substrate, and an altitudinal range of 900 to 3,600 m. Curry (1962) determined the maximum and minimum requirements of many species of Tendipedidae for temperature, pH, dissolved oxygen, carbon dioxide, phosphate, iron, chloride, sulfate, nitrate, carbonate, and biochemical oxygen-demand.

The biotic index may occupy any value ranging from zero to about 40. The lowest value that may be accepted as indicative of a clean stream is 10. A grossly polluted stream will have a biotic index of 1 to 6.

The biotic index is based on an organism's tolerance to organic pollution. The diversity index, on the other hand, relates mathematically the interaction of the number of species per total number of individuals, and the evenness of the species' abundances. The index of diversity described by Wilm and Dorris (1968) and Odum (1969) is based on the Shannon formula, a derivative of information theory. As a diversity index for biotic communities, the index describes the average degree of uncertainty of predicting the species of a given individual picked at random from a community. Diversity is equated with uncertainty; hence the more species present in a community and the more nearly equal their abundance, the greater the uncertainty and, therefore, the greater their diversity.

Because enriched streams frequently have many individuals and few species, a large probability exists that an individual organism picked at random belongs to a species previously recognized; thus con-

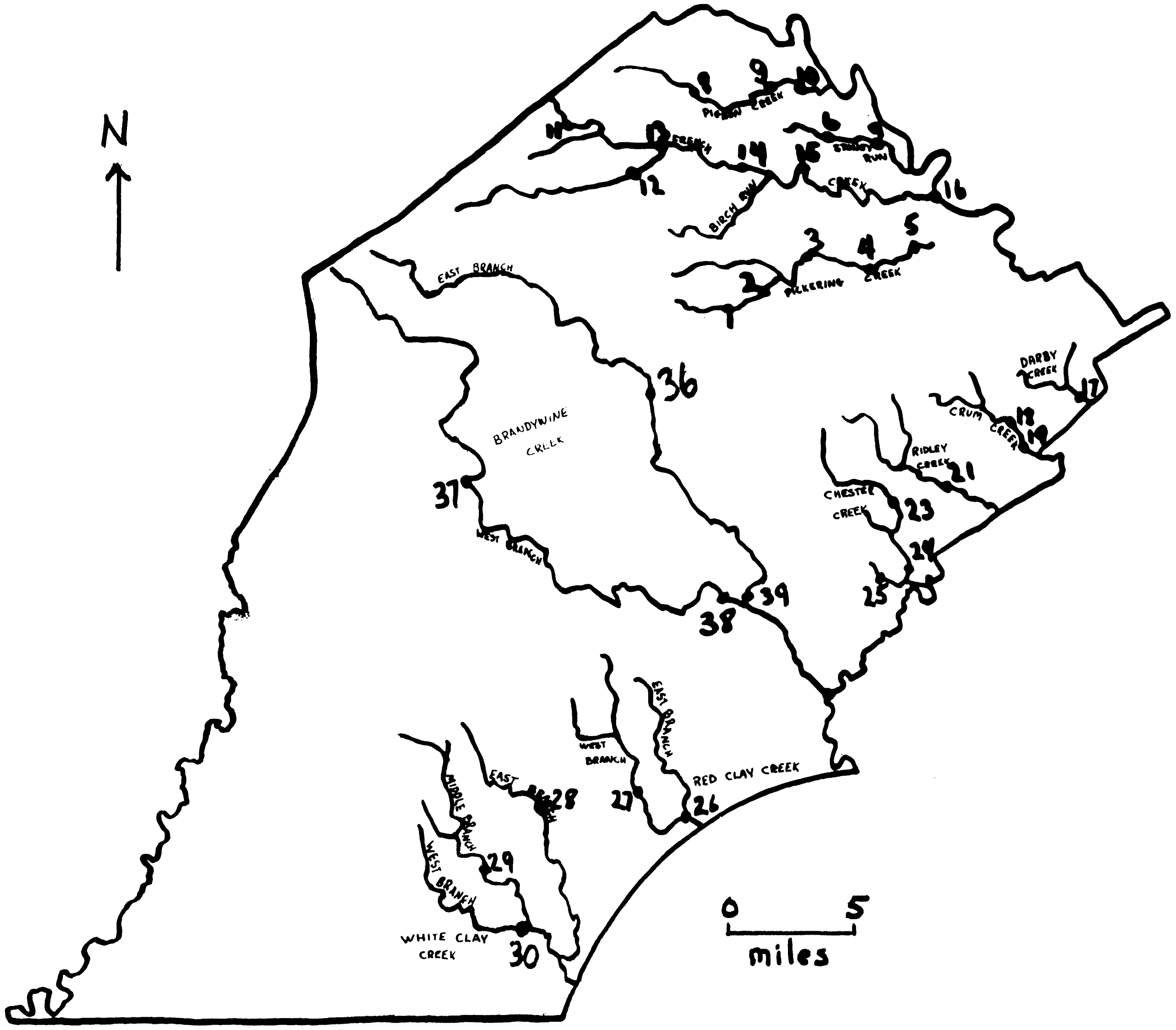

Fig. 1. Map of Chester County, Pennsylvania, showing streams surveyed and locations of sampling stations.

siderable repetition of information is to be expected. Information per individual is low and is reflected in a low diversity index. In clean streams less repetition of information per individual exists; thus information per individual is greater and is reflected in a higher diversity index.

The formula used to calculate the index is as follows:

$$d = -\sum \frac{ni}{N} \log_2 \frac{ni}{N}$$

where ni = number of individuals in each species (the ith species)
N = total number of individuals
d = diversity index

Wilm and Dorris (1968) proposed using the diversity index as a measure of pollution. They related indices of less than 1 to environments of gross pollution, of 1 to 3 to environments of moderate pollution, and of environments above 3 to clean water. The value of this diversity index in the study of water quality is that it is independent of sample size and that it reflects the relative importance of each species in the community.

Results

A relationship was established between specific conductance and the biotic and diversity indices. Generally, the higher the conductivity the lower the indices. Conductivity ranged from a high of 812 micromhos/cm^3 at 25 C (station 25 on Chester Creek, with a biotic index of zero and diversity index of 0.11) to a low of 84 micromhos/cm^3 at 25 C (at station 8 on Pigeon Creek, with a biotic index of 25 and a diversity index of 2.07). Specific conductance is a measure of the total ionized material in the water, and as such it reflects (for the most part) nitrates, phosphates, chlorides, and total dissolved solids, so often found in organic pollutants.

No relationship was established between dissolved oxygen, pH, and the indices. Dissolved oxygen values ranged from 6.8 to 12.8, and pH values ranged from 6.7 to 8.7.

A correlation ($r = 0.68$) between biotic index values and diversity index values (fig. 2) was established for the 11 streams studied. The diversity index has been a widely used and accepted biologic parameter for measuring water quality the past several years; this lends credulity to the concept of the biotic index.

81 species of benthic macroinvertebrates were taken by sampling 11 streams in Chester County. They are listed in the accompanying table.

Discussion and Conclusions

The biotic index may be a valuable measure of water quality that has long been neglected. The 11 streams in this study varied from clean to grossly polluted. The application of the biotic index to sensitive benthic macroinvertebrates did effectively relate qualitative physiologic tolerance of organisms to environmental degradation. It demonstrated that moderate pollution reduced the number of species present. The most sensitive ones disappeared as the concentration of a given organic pollutant increased.

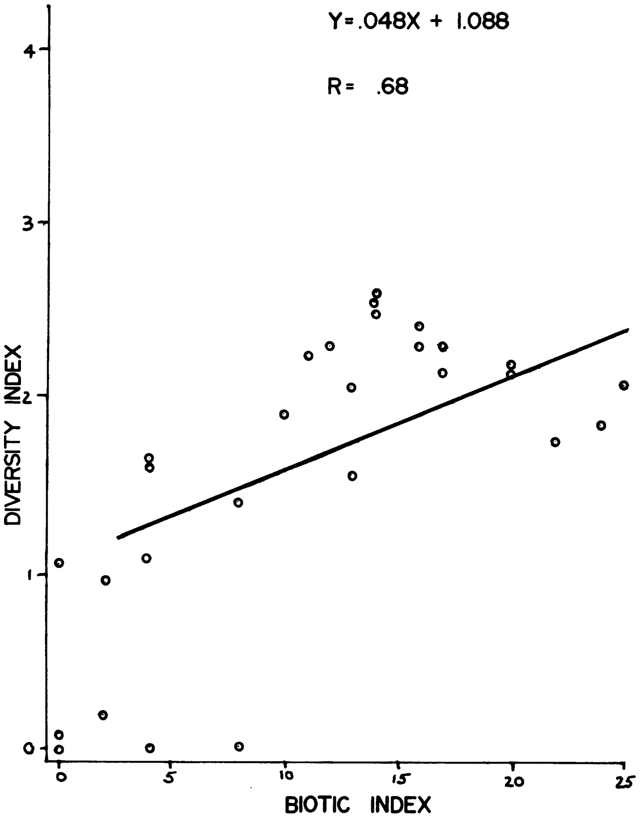

Fig. 2. Relationship between biotic index and diversity index for benthic macroinvertebrates in 11 streams of Chester County, Pennsylvania, during spring sampling, 1971.

The biotic index yields qualitative biologic information not inherent in the concept of the species-diversity index, and it is independent of sample size. It is limited, however, in that values from 6 to 9 occur for some clean streams and relatively high indices for moderately polluted streams. Such exceptions are rare, however. Use of the index presumes specific knowledge of the relationship of the organisms and the environment. Tolerance of most species of benthic macroinvertebrates to pollutants has not been determined. However, by qualitatively relating measurements of bioassay, water chemistry, gradient, substrate, and temperature to the occurrence of species, one can predict qualitatively the occurrence of any one species.

The literature is replete with evidence that substrate type and stability, drainage area, and spatial heterogeneity may affect the kinds of species, the evenness of distribution of species, and the relative importance of each species in the community. These physical features should, therefore, be considered when establishing sampling sites along a waterway.

Conductivity, as a measure of chemical water quality, is reflected in the biotic index except when the chemical change is minimal and not limiting upon the fauna.

Undoubtedly, dissolved oxygen plays a role in limiting sensitive benthic macroinvertebrates in certain polluted streams; however, no relationship was demonstrated in this study, because all sampling was done during daylight hours, when photosynthesis exceeded the respiratory demand.

It is hoped that the relationship established between the biotic index, the diversity index, and specific conductance in Chester County streams will stimulate further efforts in this direction. The physiologic tolerances of species to their environment, in comparison with the tolerances of higher taxa, are a vast unknown.

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"SCIENCE FOR SOCIETY" READINGS

The Commission on Science Education of the American Association for the Advancement of Science (AAAS) has published a 96-page survey of environmental literature, *Science for Society: a Bibliography.* It contains about 4,000 references, many of them annotated, to books and articles dealing with environmental subjects. The publication is designed primarily for use in physical-science and social-studies courses in high schools and colleges but would, of course, have interdisciplinary uses. Copies are available at $1 a copy, or 75¢ a copy for 10 or more, from Education Dept., AAAS, 1515 Massachusetts Ave., N.W., Washington, D.C. 20005.

Metabolism Game

. . . . . . **from p. 78**

7. Beginners commonly misunderstand the reaction catalyzed by the citrate-condensing enzyme. In order to carry out this reaction, the player must have *two* carbon atoms on "acetyl-CoA" and *four* on "citrate." On condensation, these become the *six* carbon atoms of citrate.

Uses in Teaching

The rules may seem complicated on first reading, but I have found that students learn them rapidly. I recommend supervision by the instructor while the students are learning "Metabolism."

I have used the game in two courses: a lower-division course in cell biology and an upper division course in molecular biology (fig. 3). In both, the game was enthusiastically received by the students. (I am indebted to my students for their many constructive suggestions.) I believe the game is a suitable learning device from high school through advanced-biochemistry courses. The instructor can emphasize the aspects he considers important; for example, in a high school class the names of the enzymes and the structures of substrates and products probably would not be emphasized, but in advanced courses they would be. I have found that if the game is placed in a conspicuous place in the laboratory or classroom, students will come in and play even when class is not in session.

Obviously "Metabolism" could be expanded to cover additional pathways, including biosynthetic ones. I would appreciate learning of successful modifications of the game.

Acknowledgments.—Fig. 1 and 2 photos are by Wayne Wilbanks; fig. 3 photo is by Edna Steinman.

STOPPING THE STREAM-BRUISERS

Utah's newly passed law requiring a permit before heavy equipment is allowed to muck about in state streams has been termed a landmark in fish and wildlife legislation by conservationists and legislators alike. Before any applicant can obtain a permit he must convince the state engineer in Utah's Department of Natural Resources that the project "will not unreasonably affect the natural stream environment, or recreational uses thereof."

It's hoped that the law, which one former legislator termed the most "notable achievement in environmental legislation in the past century in Utah," may spark new respect among those who have nonchalantly torn up state streams in the past.

The Utah Fish & Game Division and the Utah Wildlife Federation are credited with the successful launching of an aggressive educational drive, which spelled out why the bill was needed and what it was all about. *Conservation News*