Hydrobiologia vol. 57, 2, pag. 111-122, 1978

DIVERSITY AS A MEASURE OF BENTHIC MACROINVERTEBRATE COMMUNITY RESPONSE TO WATER POLLUTION[1]

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[1] Contribution No. 47 of the Massachusetts Cooperative Fishery Unit jointly supported by the U.S. Bureau of Sport Fisheries and Wildlife, the Massachusetts Division of Fisheries and Game, the Massachusetts Division of Marine Fisheries, and the University of Massachusetts.

Received June 1, 1977

Keywords: Diversity, Benthic Macroinvertebrates, Streams, Pollution

Abstract

The assumption that water pollution causes a depression in the diversity of benthic macroinvertebrates as measured by the Shannon index and similar diversity indices is questioned. An interpretation of the community response of benthic macroinvertebrates to pollution in the Millers River, Massachusetts is developed from species presence-absence and abundance data in conjunction with published information on the species' environmental tolerances as compared to chemical water quality data. This interpretation is compared with one derived solely from diversity index values. The interpretations are quite different; the differences may be attributed to other environmental factors such as impoundments and flow reductions which influence the fauna and thus the diversity index value, but which are not related to pollution. In addition, several intrinsic features of the diversity indices increase their bias.

Introduction

Diversity indices are being widely applied in stream pollution research. Their major advantage is in condensing large amounts of biological data into numbers comprehensible and useful to people not immediately familiar with the specific biota. My purpose in this paper is to examine their utility in stream pollution studies, first, by examining the effects of stream pollution on the benthic macroinvertebrates, second, by developing an interpretation based on species presence-absences, abundances, and published environmental tolerances and, third, by comparing this interpretation to one derived solely from the use of several popular diversity measures.

Most diversity indices may be conveniently classified as either 'species diversity' indices or 'dominance diversity' indices (Whittaker, 1965). 'Species diversity' indices emphasize the number of taxa, usually species, in the environment, i.e. the more species – the greater diversity. 'Dominance diversity' indices employ the percentage composition by numbers, biomass, etc. of the various species, i.e. diversity increases as more species are represented by more equal relative abundances. Information theory indices (Shannon, 1948; Brillouin, 1956) are perhaps the best known of this type. Pielou (1969) considers them to be 'descriptive statistics that can be used for any community no matter what the form of its species-abundance distribution and even when no theoretical series can be found to fit the data'.

Wilhm & Dorris (1968) suggest that water 'pollution results in depression in diversity d [the Shannon index] in the biotic community'. Because polluted streams often exhibit a reduced number of species with great abundances and unpolluted streams exhibit the converse, this hypothesis has gained wide acceptance. Research based on the use of the Shannon index has so proliferated (Wilhm, 1967, 1968, 1969, 1970, 1972; Wilhm & Dorris, 1966, 1968; Mathis & Dorris, 1968; Dambach & Olive, 1969; Benson-Evans *et al.*, 1975; Devaux, 1975) that the Shannon index has become an important tool of water quality studies (cf. Cairns & Dickson, 1971). Al-

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though some investigators have expressed skepticism about the theoretical validity of many dominance diversity indices including the Shannon index (Eberhardt, 1969; Hurlbert, 1971), the literature in stream ecology conveys the impression that a necessary (i.e. cause and effect) inverse relationship exists between stream pollution and dominance diversity index values. One is inclined to think that whatever the theoretical features of diversity indices, they are, in practice, useful for stream pollution studies as meaningful condensations of the biological data. This paper seeks to examine that premise within the context of a river's benthic macroinvertebrate community responding to a complex variety of natural and pollutional factors.

Description of study area

The Millers River is the smallest of the four main tributaries to the Connecticut River in Massachusetts. The watershed occupies 1013 km^2 of the 'central uplands' with glacially scoured valleys and gently rolling hills. Bedrock is predominantly igneous. Mixed stands of oak, yellow poplar, spruce, white birch, maple and white pine cover the basin. Population is concentrated in the industrial cities and towns of Gardner, Athol, Erving, Orange, Templeton, and Winchendon. The remainder of the watershed is thinly populated. Population density has remained stable for the past 35 years (Mullan, 1954).

The Millers River forms in the town of Ashburnham at the confluence of several streams that drain bog areas and the outflow of Lower Naukeag Pond (Fig. 1). The river flows westerly 73 km to the Connecticut River. There are small main river impoundments in the towns of Winchendon, Athol, Orange, Erving, and Millers Falls and two flood control dams, one on the East Branch of the Tully River and the other on the main river in South Royalston. The total gradient is 264 m, averaging 36 m/km.

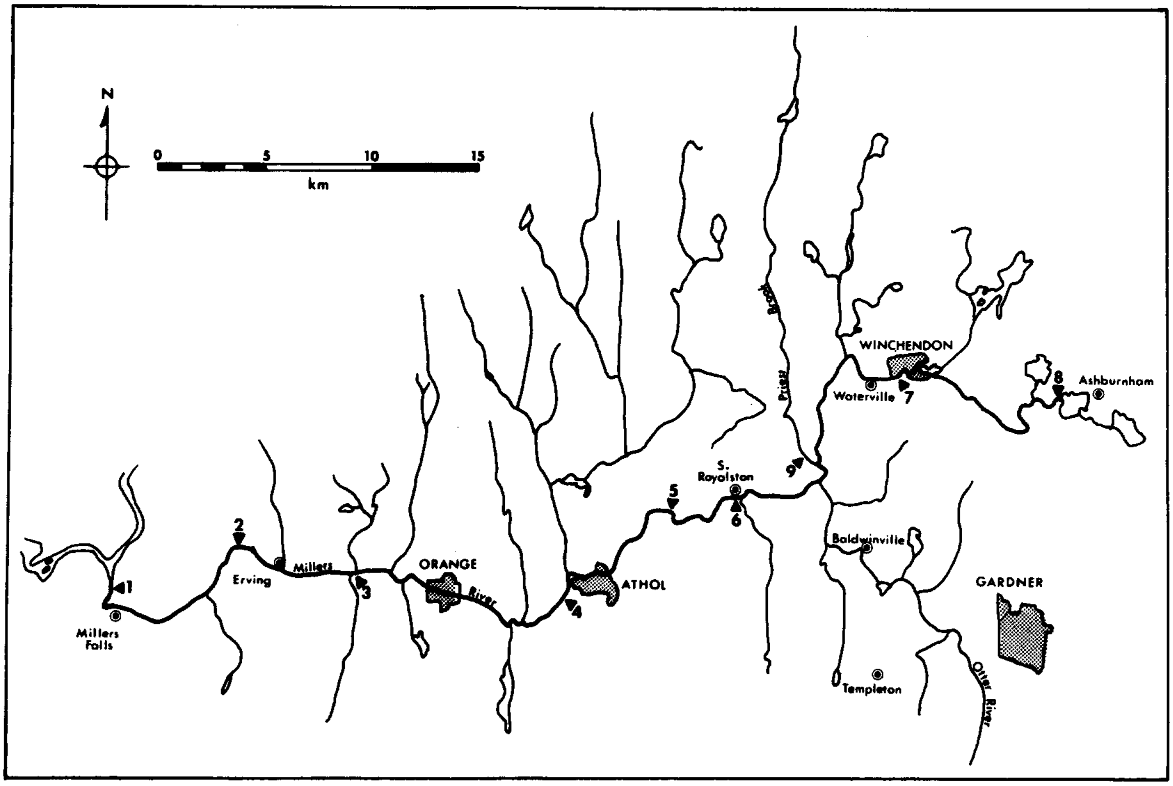

Fig. 1. The Millers River drainage basin showing sampling stations.

Sources of pollution

The upper reaches of the river are naturally acidic and colored by swamp drainage. Minor amounts of sewage effluent are added to the river in Ashburnham and Waterville; a more significant amount is added by the sewage treatment plant below Waterville. Further below Waterville, the Otter River enters carrying a significant pollution load described by Collings *et al.* (1969) as 'treated effluent from Gardner, untreated sewage from Baldwinville, industrial wastes from plating plants, paint manufacturing concerns, foundries and paper mills'. The Millers River assumes a clay-gray color; thick sediments cover the bottom with large chunks often breaking away to the surface and rafting downstream. More industrial and municipal wastes are added at Athol and Orange. Aeration and dilution below Orange aid recovery but paper mill wastes, sewage, and machine manufacturing, foundry and textile mill effluents are added between Orange and the river mouth. Collings *et al.* (1969) state that 'many portions of the main stem of the Millers River may be rated as poor and are suitable for recreational boating, irrigation of crops not used for consumption without cooking, and habitat for wildlife and common food and game fishes indigenous to the region. Limited portions of the Millers River and Otter River are suitable only for transportation of sewage and industrial wastes and for power and other industrial uses'.

Methods

Sampling stations were selected to represent the range of pollution intensities and types but controlled for gradient, water velocity, depth, substrate composition, and year-round submergence. The following description of stations emphasizes their differences.

Station 9 was a large, unpolluted tributary draining swamp areas. There were large patches of attached algae and macrophytes although these were avoided in sampling. Stream width was 4 m. Flow was more constant than at station 8. Station 8 was at the headwaters of the Millers River, 100 m below the outfall of a municipal water reservoir and 2 m wide. Attached macrophytes were moderately abundant. There was no significant swamp drainage above this station and consequently the water was clear. Stations 8 and 9 were well shaded. Station 7 received little pollution and lay below a recreational lake. It was 6 m wide, had no significant macrophyte population, and was slightly shaded.

Station 5 was 9 km below the confluence of the Otter River. The water had a milky-brown color and sulfurous odor. The substrate was heavily encrusted with slime, interstices were filled with sludge. The river was 20 m wide. Station 3 was 5 km below the town of Orange. The river was 35 m wide. The substrate had some algal and fungal coating with organic debris in the interstices. Station 1 was below Millers Falls near the confluence with the Connecticut River. Sewage fungi and iron oxide precipitates were conspicuous on the substrate. Stations 1 through 6 were not shaded. Stations 2, 4, and 6 were only sampled chemically.

Chemical determinations made with a portable Hach kit included pH, dissolved oxygen, alkalinity, and total hardness and were done bimonthly in summer and monthly in winter in 1968 and 1969. Flow data were obtained from the United States Geological Survey (1969) for gauging stations near stations 9, 7, 5, and 3.

Benthic macroinvertebrates were sampled with a Surber square foot sampler (0.093 m^2) in July and August. Samples were taken in 15 to 45 cm of water with a rock and rubble substrate. Substrate larger than 30 cm or with heavy growths of vegetation was avoided. The substrate was disturbed to a depth of 5 cm below the level of hard-packed sand and fine gravel. Each sample was bagged and kept cool for return to the laboratory. Within 24 hr, the samples were seived through a 40 mesh seive and both the filtered material and filtrate examined for organisms. Organisms were preserved in 80% denatured ethyl alcohol. Identifications were based on keys to aquatic invertebrates in Usinger (1956) and Pennak (1953). Results were based on three pooled samples representing a combined sampling area of 0.279 m^2.

Three measures of dominance diversity were used. Since I was unwilling to specify the extent of the total population which was sampled and unwilling to assume it was a random sample, the samples are best treated as finite collections. Diversity should be calculated with Brillouin's formula:

$$(1) \qquad H = \frac{1}{N} \ln \frac{N!}{N_1!\, N_2! \ldots N_s!} \qquad \text{(Brillouin, 1956).}$$

Computation is facilitated with the use of Stirling's approximation of the factorial:

$$(2) \qquad \ln N! \sim N(\ln N - 1) + \tfrac{1}{2} \ln 2\pi N \qquad \text{(Pielou, 1969).}$$

The more familiar Shannon's index can be shown to be

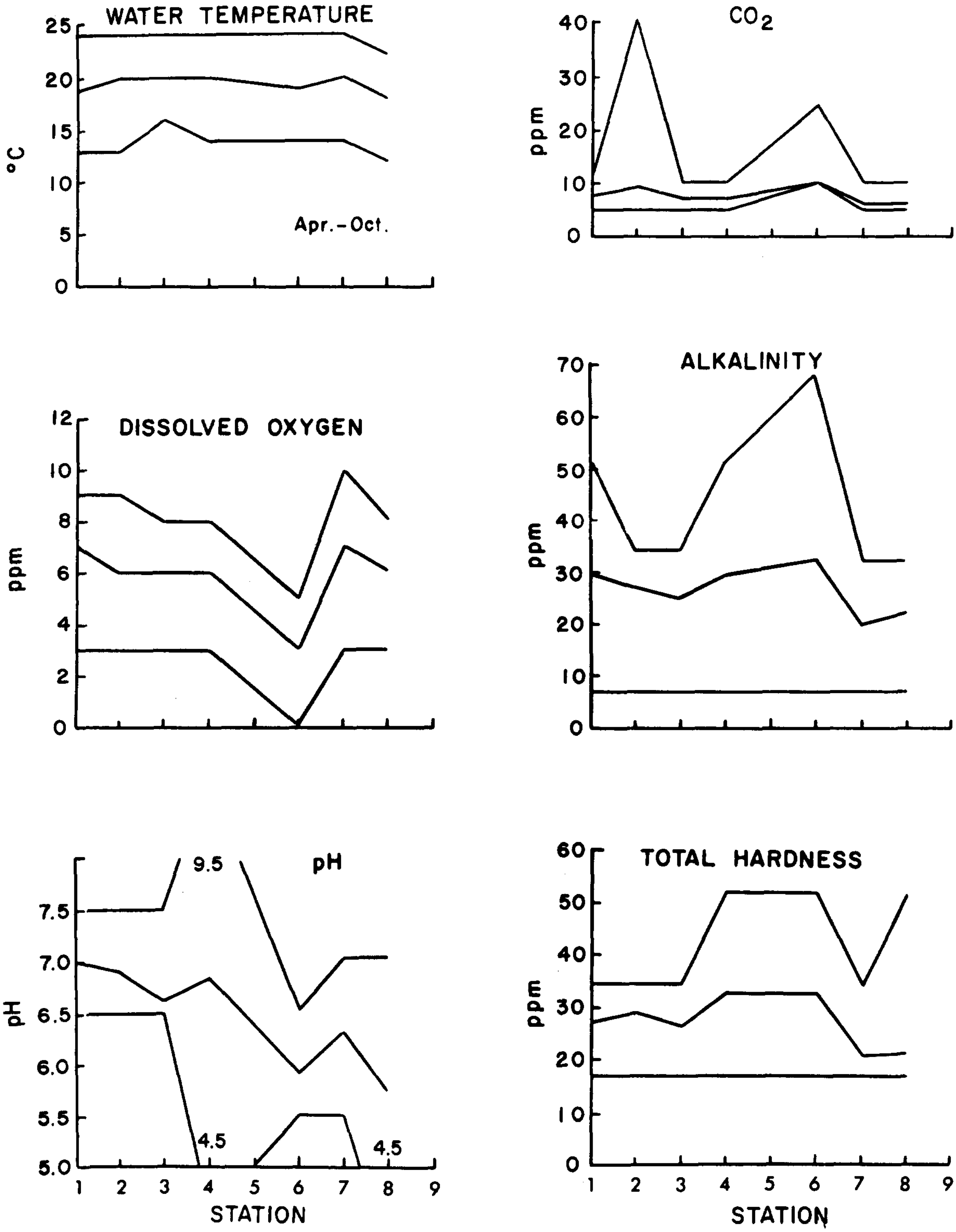

Fig. 2. Average, maximum and minimum chemical conditions for stations on the Millers River, 1969.

approximately equal to H (equation 1) if ln N is taken to be equal to N (ln N - 1) and converted to base 2 logarithms:

$$\text{(3)} \quad \text{DBAR} = -\sum_j (N_j/N) \log_2 (N_j/N) \quad \text{(Pielou, 1969).}$$

This approximation holds only if all the N's are very large which is rarely the case in biological collections (Pielou, 1969). DBAR was computed for comparative purposes. The equations use data from s-species collections containing N-individuals. N_j is the number of individuals in the jth species.

Theoretically, it is possible to have a community with few species of low abundance equal in diversity to a many-species community with one or a few species in great abundance. Knowledge of the relative contributions of dominance diversity and species richness to the index value is desirable. Maximum diversity for a certain number of species and individuals occurs if each species has equal numbers of individuals:

$$\text{(4)} \; \text{HMAX} = \frac{1}{N} \log \frac{N!}{\left\{\left[\frac{N}{s}\right]!\right\}^{s-r} \left\{\left(\left[\frac{N}{s}\right]+1\right)!\right\}^{r}} \quad \text{(Pielou, 1969).}$$

where r = the remainder after the division N/s. The ratio H/HMAX is the relative contribution of species richness to the diversity value, that is the evenness. According to Hurlbert (1971), this ratio is approximately equal to one minus the redundancy value used by Patten (1962) and Wilhm (1967). An estimate of the total number of species in the population is needed before evenness can be calculated for equation 3. The sample number of species can be used if samples are considered finite collections and equation 1 used to calculate diversity.

Calculations were made using a computer program developed by Mawson & Godfrey (1971) for the CDC 3600 computer.

Results and discussion

Chemical data obtained in conjunction with biological sampling do not reflect critical environmental conditions (Fig. 2). Only station 6 exhibited frequent oxygen depletion, but it was not sampled biologically because of basic dissimilarity in water velocity and substrate size from other sampling stations. Data from a 1965-66 study by Collings *et al.* (1969) provide greater insight into factors important in the distribution of invertebrates. No substantial changes in the levels of pollutants occurred between the two studies and their stations are close to those used in this study. Their data are summarized in Table 1.

Flow data for the water year 1968-69 from the United States Geological Survey (1969) are shown in Table 2. An unusual and substantial increase in flow may be noticed for the month of August. This unusually high flow approximates the high flows common to the period of spring runoff. High flows lasted about 2 weeks in August.

Table 1. Summary of chemical analyses for 1965-66 for stations on the Millers River (Collings *et al.*, (1969))

	Station							
	1	3	5	6	Otter River	7	8	9
BOD (ppm)	7.5	2.8	15	80	200	3.4	1.8	
Suspended Sediments (ppm)								
Mineral – mean		9		18	42	3		
– maximum		27		46	122	9		
– minimum		1		1	1	0		
Volatile – mean		6		14	77	5		
– maximum		18		38	242	14		
– minimum		1		2	3	1		
Dissolved solids (ppm)	77	75		105	420	40	29	19
Iron – mean (ppm)		0.34		0.91	1.34			
Manganese – mean (ppm)		0.07		0.08	0.08			
Silica – mean (ppm)		5.4		5.5	6.7			
Chloride (ppm)		13		18	33			
Hardness (ppm)		21		24	47			
pH range		5.5–7.0		5.5–7.0	5.4–7.4			

Table 2. Monthly average, maximum and minimum flow data for the water year 1968-69 (cfs) (U.S. Geological Survey, 1969)

Station	9			7			6			3		
Oct.	3	7	0.7	66	97	27	88	131	35	132	193	58
Nov.	22	89	3.1	92	241	54	199	596	74	351	1020	101
Dec.	51	136	21	212	483	100	446	908	210	825	1790	390
Jan.	18	34	11	81	166	55	179	350	125	344	620	250
Feb.	15	24	10	75	115	52	160	250	120	319	460	250
Mar.	37	133	12	133	341	62	351	1020	140	730	2110	270
April	150	338	41	675	1180	279	1209	2109	249	2210	3240	712
May	26	46	15	119	234	63	405	1760	143	799	2690	266
June	38	147	7.5	125	371	41	258	694	89	476	1120	116
July	14	185	2.2	52	352	19	93	469	50	223	1380	76
Aug.	48	194	2.8	167	730	27	346	1240	55	697	2530	105
Sept.	18	114	2.5	111	420	25	206	799	52	341	1110	105

Biological sampling was done immediately prior to the flood and one month later. Late August flow was comparable to that of July at all stations except station 8 where flow practically ceased.

Pollution produces changes in the pattern of species distributions. Ingram, Mackenthun & Bartsch (1966) describe the pattern for organic pollution as a reduction in the number of species and an accompanying increase

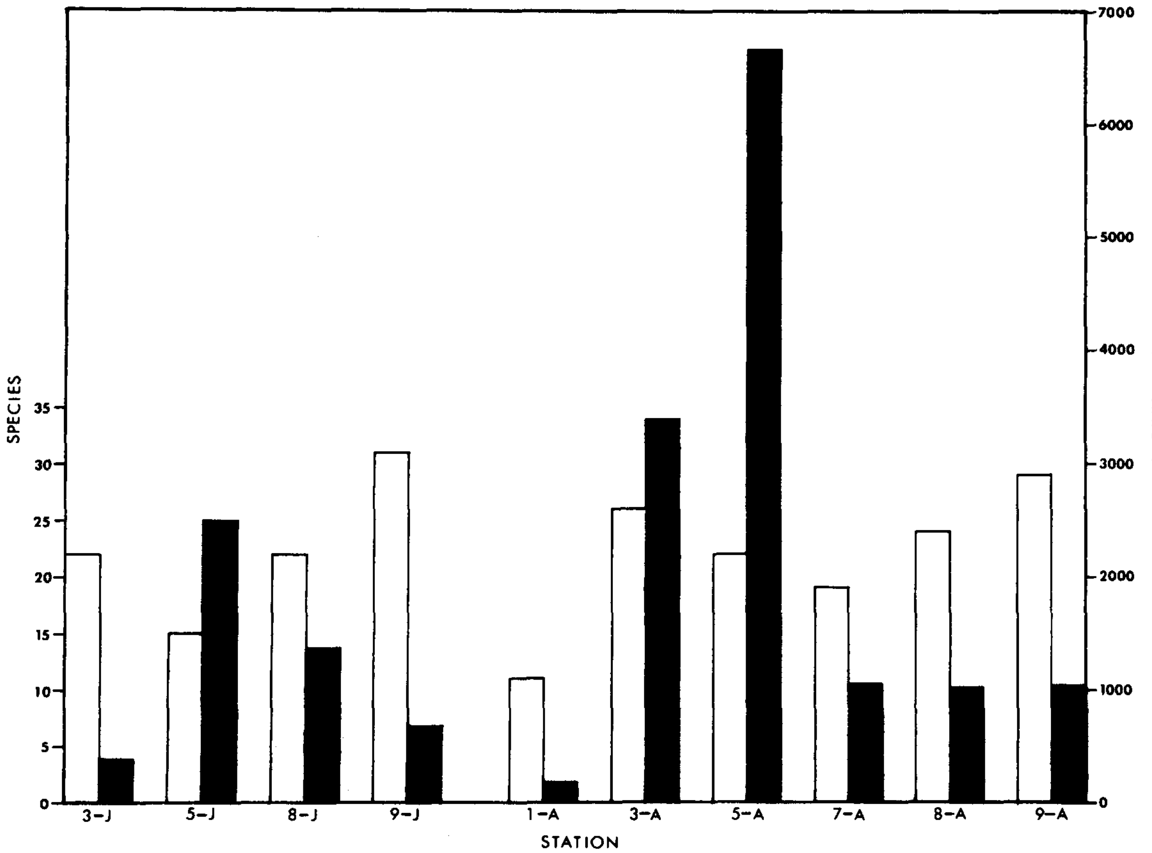

Fig. 3. Numbers of species (open bar) and individuals (solid bar) of benthic macroinvertebrates from stations on the Millers River-July and August, 1969.

in total abundance. Toxic pollution and inert silt reduce species numbers and abundances. The presence of a species will depend on its environmental tolerance, but its abundance will be determined by the resource available to it. If competition or predation is reduced or the food supply or suitable habitat increased, the species will become more abundant.

In general, stoneflies, mayflies, and caddisflies are intolerant of pollution. The taxa commonly remaining in organically polluted zones are *Tubifex*, Tendipedidae, *Asellus, Erpobdella, Glossiphonia,* and *Helobdella* according to Hynes (1960). Bartsch & Ingram (1959) classify zones of organic pollution by their dominant organisms: the *Tubifex* zone, the Chironomid zone and the *Asellus* zone. However, not all genera of caddisflies are intolerant of pollution. The caddisflies *Cheumatopsyche* and *Hydropsyche* have been found in organically polluted water (Hynes, 1960). Roback (1965) reports the occurrence of *Polycentropous, Oecetis, Brachycentrus,* and *Cheumatopsyche* in waters with up to 20 ppm BOD and *Hydropsyche, Chimarra,* and *Macronemum* at concentrations up to 40 ppm BOD. Leonard (1965) reports that *Caenis, Stenonema* and some Baetine naiads are quite tolerant of plating plant effluents. Hynes (1960) states that *Caenis* is more tolerant of suspended solids than Heptageniid mayflies. *Stenonema tripunctatum* can tolerate more silt than other *Stenonema* species (Burks, 1953). Many dipterans, in addition to Tendipedidae, are adapted to high levels of organic matter and low dissolved oxygen concentrations. Keeping such specific tolerances in mind, it should be possible to determine whether differences upstream and downstream in the Millers River as exhibited by the benthic macroinvertebrate communities are pollution controlled or more affected by other factors not directly related to pollution.

In July, the station with the lowest number of taxa was station 5 with 15 genera (Fig. 3). There were 22 genera at stations 3 and 8 and 31 genera at station 9. The impoverishment at station 5 coincides with the reported (Collings *et al.*, 1969) high values of BOD (15 ppm), suspended solids, dissolved solids, iron and chloride concentrations (Table 1). The richness at station 9 may have been a function of increased habitat near the sampling area, i.e. beds of *Fontinalis* and filamentous algae. The fact that station 3 was immediately below the confluence of two unpolluted tributaries may have accounted for its greater species richness than station 5. The diluting effect of tributaries lowered the BOD at station 3 from 6 ppm to 2.8 ppm, a value comparable to upstream unpolluted sections of the main river. Further downstream, BOD rose to 4 ppm. Total numbers of individuals ranged from 399 at station 3 to 2500 at station 5 (Fig. 3).

There were substantial differences in faunal composition between stations (Table 3). Stations 8 and 9 had 2-3 genera of herbivorous and predaceous Plecoptera, 1-2 genera of Ephemeroptera, 3-4 genera of Trichoptera (primarily net-spinning forms), and 2-4 genera of larval and adult herbivorous Coleoptera, but relatively few Diptera, leeches and *Asellus*. Station 3 had Ephemeroptera that are pollution tolerant or silt tolerant such as *Stenonema tripunctatum, Caenis, Baetis* and *Ephemerella,* only two Trichoptera – the tolerant *Hydropsyche* and *Cheumatopsyche,* and no Plecoptera. Except for larval *Psephenus,* Coleoptera were present only as adults. Dipterans, especially *Antocha,* were moderately abundant. Station 5 was more extreme. *Asellus* was very common (715 organisms). Three genera of Ephemeroptera were present: *Stenonema tripunctatum, Baetis,* and *Ephemerella. Hydropsyche* and *Cheumatopsyche* were each nearly as abundant as *Asellus. Simulium* and Tendipedidae were also very common. There were no Plecoptera or Coleoptera. Molluscs were found only at the downstream stations.

Profound changes occurred between July and August. By August, the number of taxa increased downstream from 15 to 22 at station 5 and 22 to 26 at station 3. Upstream stations remained more nearly constant with a gain of two at station 8 and a loss of two at station 9. The total number of organisms at downstream stations increased dramatically while upstream stations registered slight losses. Abundances increased from 2500 to 6669 organisms at station 5. The greatest gains were for *Asellus, Simulium, Tubifex, Hydropsyche,* Tendipedidae, *Baetis, Pseudocleon,* and *Helobdella,* respectively. Substantial losses occurred for *Cheumatopsyche* and *Caenis.* The number of organisms at station 3 increased from 399 to 3399. Greatest increases were for *Hydropsyche, Cheumatopsyche,* Tendipedidae, *Stenonema tripunctatum, Pisidium* and *Tubifex.* Only *Baetis* decreased noticeably. Upstream stations did not exhibit pronounced faunal fluctuations. At station 3, only *Stenonema tripunctatum* increased in number while *Leuctra, Hydropsyche, Chimarra, Cheumatopsyche,* and *Rhyacophila* decreased. At station 9, *Simulium,* Tendipedidae, *Stenonema tripunctatum,* and *Brachycentrus* increased while *Leuctra* decreased.

Under natural conditions, losses might be attributed to emergence, predation, competition, or drift and gains

Table 3. List of benthic macroinvertebrates and their abundances at sampling stations on the Millers River.

			Station									
			July				August					
Order	Family	Genus	3	5	8	9	1	3	5	7	8	9
Oligochaeta	Tubificidae	Tubifex	4	1			11	73	426	36	13	35
Hirudinea	Erpobdellidae	Erpobdella	8	1			9	78	20			2
	Glossiphonidae	Glossiphonia						1				
		Helobdella		2	1			1	69	2		1
Isopoda	Asellidae	Asellus	6	715	1		5	5	2930	5		10
Amphipoda	Talitridae	Hyallela azteca			3						3	
Decapoda	Astacidae	Orconectes						1				
Hydracarina	Lebertiidae	Lebertia	3	1				3	1			5
Plecoptera	Nemouridae	Leuctra			58	211					2	33
	Perlidae	Acroneuria				1						9
		Neoperla						2				
		Perlesta			1	6						
Ephemeroptera	Baetidae	Baetis	36	41		18	2	4	250	52		
		Caenis	3									
		Ephemerella	4	89		8		5	2		2	
		Paraleptophlebia				2					6	2
		Pseudocleon					45	29	21	17		
	Heptageniidae	Iron						1				
		Stenonema tripunctatum	47	34	43	73		177	22	58	174	122
Odonata	Aeshnidae	Oplonaeschna									1	
	Agrionidae	Agrion									4	
		Hetaerina							2			
	Coenagrionidae	Enallagma			1							
		Ishnura						2				
	Cordulegasteridæ	Cordulegaster			1							
	Gomphidae	Lanthus				2						1
	Libellulidae	Somatochlora				1						
Hemiptera	Veliidae	Microvelia			1						1	
Megaloptera	Corydalidae	Nigronia			32	4					40	1
Neuroptera	Sisyridae	Climacia	1									
Trichoptera	Brachycentridae	Brachycentrus				34						99
	Helicopsychidae	Helicopsyche borealis										2
	Hydrospsychidae	Cheumatopsyche	161	623	123	19	2	787	388	18	89	29
		Hydropsyche	52	452	581	23	34	1981	569	439	269	58
		Macronemum zebratum								318		4
	Leptoceridae	Oecetis									10	2
	Odontoceridae	Psilotreta						1				
	Philopotamidae	Chimarra			195	89	2			1	42	83
	Sericostomatidae	Sericostoma							12		1	
	Psychomyiidae	Neureclipsis									7	
		Polycentropous									43	
	Rhyacophilidae	Rhyacophila fuscula			38							
		Rhyacophila sp.									2	
Coleoptera	Chrysomelidae	Galerucella					2			1		
	Elmidae	Dubiraphia vittata							1		1	
		Limnius latiusculus (L)			1							
		(A)									2	
		Optioservus trivittatus (A)	1									
		Optioservus sp. (L)						1				1
		(A)				1		2				1
		Promoresia elegans							3			
		Promoresis sp (L)				38				1		78
		(A)				3		1		1		11
		Stenelmis (L)			142	33		2		20	132	41
		(A)	1		3	3					21	4
	Gyrinidae	Dineutus			1							
	Hydrophilidae	Helophorus	1									
	Psephenidae	Psephenus herricki	2			2				7		5
	Ptilodactylidae	Anchycteis			1							
Diptera	Ceratopogonidae	Palpomyia					1					
	Empididae				1							
	Rhagionidae	Atherix		3	8	6		2	2		3	1
	Simulidae	Simulium	1	277	4	34		5	1556	8		238
	Tendipedidae		12	228	138	76	81	115	385	88	142	150
	Tipulidae	Antocha	50	18					1	46		
		Hexatoma				4					1	1
		Tipula		14		3		7	3			4
Gastropoda	Ancylidae	Ferrissia							6			
	Physidae	Physa		2				3				
Pelecypoda	Sphaeriidae	Pisidium	6					110		22		

(L) - Larvae
(A) - Adult

attributed to recruitment, increased resource, loss of competition, or immigration from upstream areas. The consistent decrease in numbers of *Leuctra* was probably due to emergence. Increases in *Stenonema* and *Hydropsyche* were related to recruitment since the average length of individuals decreased throughout the summer. Hynes (1970) commenting on data from Cushing (1963) suggests that large increases in numbers of Hydropsychidae after the middle of summer are 'presumably caused by the life cycles of the insects'. The data of Glasgow (1936) similarly suggest recruitment of *Hydropsyche* in August. However, not all stations registered increases in the numbers of *Hydropsyche*. Station 8 exhibited heavy losses of *Hydropsyche, Cheumatopsyche,* and *Chimarra* from July to August. The most probable cause of these and other losses at station 8 was the reduced August flow. Radford & Hartland-Rowe (1971) report no losses due to spates but large increases in drift and loss of benthic fauna during periods of low flow, probably as a result of changes in water velocity, depth and width. It is very likely that nearly nonexistent flows most affect species dependent on flow for catching food as are the net-spinning caddisflies. The effect of a drastic flow increase in producing severe losses of invertebrates due to scouring or habitat destruction seems minimal. If at all, invertebrate communities on the upper river were only slightly affected. Downstream stations all showed large increases in community size. It is not clear whether the influx was due to recruitment, drift from upstream stations and tributaries, or an amelioration of pollution. The latter seems least likely since the increases tended to be primarily in pollution tolerant organisms. As for *Hydropsyche* and *Stenonema,* recruitment seems to be the most reasonable possibility.

The great abundances of *Hydropsyche* and *Cheumatopsyche* at stations 3, 5, and 8, at first, seem contradictory. However, the food resource of the net-spinning caddisflies are plankton and detritus (Hynes, 1970). The greatest amount of plankton in a river system is below the outfalls of natural lakes and impoundments (e.g. station 8). Hynes (1970) reports the occurrence of large populations of *Hydropsyche* and *Cheumatopsyche* below the outfalls of lakes. The greatest source of detritus is partially decomposed organic pollution such as might be expected at stations 5 and 3. Therefore, the Hydropsychidae abundances are not contradictory.

Two additional stations were sampled in August. Station 7 had a faunal composition intermediate to upstream stations 8 and 9 and downstream stations 3 and 5 (19 genera and 1140 individuals). In common with stations 3 and 5, it had modest populations of *Baetis, Pseudocleon, Antocha, Pisidium* and only a few *Stenelmis.* It was similar to stations 8 and 9 in having *Macronemum, Chimarra* and *Promoresia.* Relative abundances of selected taxa followed the upstream stations' pattern most closely. For example, station 7 had few *Tubifex, Asellus, Simulium,* and Tendipedidae and intermediate numbers of *Hydropsyche* and *Cheumatopsyche.* Station 1 was unlike any of the other stations (11 taxa and 194 organisms). Dominant taxa were Tendipedidae, *Pseudocleon, Hydropsyche, Tubifex, Erpobdella,* and *Asellus.* Tendipedidae encompassed nearly half the total number of organisms.

The literature on the response of the dominant taxa to pollution suggest that the downstream stations 3 and 5 had an invertebrate community controlled by at least moderate amounts of organic pollution. Station 5 was most extreme; station 3 was apparently refreshed by influxes of clean water from nearby tributaries. In spite of abnormally high flows in early August, the fauna at both stations was more dominated by pollution tolerant taxa than in July. Upstream stations 8 and 9 were not dominated by pollution tolerant taxa. Those dominant forms seemed to reflect differences in food supply and proximity of suitable habitat. Thus at station 8, taxa adapted for utilization of the plankton overflow from an upstream lake were dominant. Differences were also the result of sharply reduced flows in August. Dominance was more subdued at station 9. The faunal composition reflected the variety of nearby habitats. Station 7 was intermediate, but the invertebrate community in most ways best fit into the upstream group. Station 1 was unique. The fauna did not fit the pattern described for organic pollution but it could not be considered unpolluted. The appearance of the substrate is perhaps a simplified key to the explanation. It was prominently covered by iron oxide with patches of sewage fungi in sluggish pockets. Station 1 was the only station with heavy iron oxide deposits. The pattern of community composition seems to have been a response to toxic and organic pollution.

It is clear that, despite some modification by other factors, pollution was the dominant factor in determining the composition of downstream communities. If stations are arranged in order, from those exhibiting no pollution effects to those dominated by pollution, the order is: station 9-8, 7, 3, 5-1.

Table 4. Comparison of dominance diversity values for Millers River sampling stations and dates.

Station	*DBAR*	*H*	*H/HMAX*
3-July	2.797	1.878	0.620
5-July	2.620	1.834	0.684
8-July	2.705	1.850	0.605
9-July	3.394	2.319	0.689
1-August	2.343	1.537	0.673
3-August	1.938	1.330	0.411
5-August	2.420	1.727	0.561
7-August	2.674	1.820	0.628
8-August	3.162	2.141	0.687
9-August	3.554	2.401	0.729

Diversity

Benthic macroinvertebrate diversity (DBAR) in the Millers River ranges from 1.94 to 3.55 bits/individual. Diversity and evenness values for the Millers River are summarized in Table 4. Wilhm's (1969, 1970) survey of U.S. rivers and streams shows a range of diversity for 'clean and recovering' streams from 4.61 to 2.60, for 'polluted' streams from 2.60 to 0.42. Pooled diversities for August samples at stations 3, 5 and 1 fall below 2.60. Wilhm (1972) suggests the following ranges of index values with degree of pollution: heavy pollution - 0-1 bits/individual, intermediate pollution - 1-3, and clean water - 3+. Only station 8-August and 9-July and August fall within the range for clean water; the remainder fall into the intermediate pollution range.

Figure 6 presents the results of a Duncan's multiple range test of significance (p = 0.05) between the means of sample diversity (H) values. Stations 1 and 3-August differ from the other stations, and station 9 differs from stations 1, 3, and 5. But upstream unpolluted stations 7 and 8 do not differ significantly from downstream polluted stations 3-August and 5.

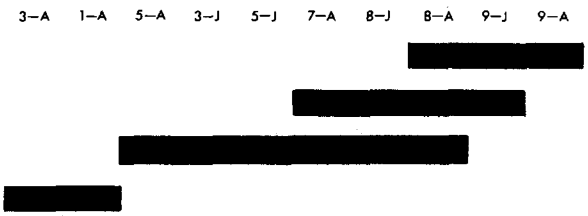

Fig. 4. Duncan's multiple range test (p = 0.05) applied to the means of diversity index values (H) for July and August samples from six stations on the Millers River. Means for stations not underscored by the same line are significantly different.

If diversity (H) values in July are ordered from highest to lowest, the order of stations is 9, 3, 8, and 5. The order in August is 9, 8, 7, 5, 1, and 3. The station order for evenness values in July is 9, 5, 3, and 8, and in August is 9, 8, 7, 1, 5, and 3. None of these agree well with the order determined via detailed analysis of the fauna (9-8, 7, 3, 5-1). Only station 9 is consistently placed. Much of the disarray can be traced to the improper placement of stations 3 and 8; and this can be further traced to abundances of *Hydropsyche* and *Cheumatopsyche.* The placement of station 8 improves from July to August when the abundances of net-spinning caddisflies were reduced, possibly by reduced flow. But the placement of station 3 worsens due to increased abundances of the same taxa. Since these two taxa are so critical to the array of diversity values, further examination of their effect on diversity is warranted. As previously mentioned, the abundances of *Cheumatopsyche* and *Hydropsyche* at stations 8, 3 and 5 might have been conditioned by different factors: lake outflow at station 8 and organic pollution at stations 3 and 5. Conditions at station 5 must have been suboptimal in other respects, since detrital load is undoubtedly greater there than at station 3. No caddisflies occurred two km further upstream of station 5, so it seems reasonable to conclude that other factors operate to limit *Cheumatopsyche* and *Hydropsyche.* While these two taxa responded to increased detrital loads, they were nevertheless moderately sensitive to other pollution effects. The caddisfly abundances at station 5 effected an increase in diversity. According to Wilhm (1968), the greatest contribution to diversity is made by species comprising 37% of the sample. The presence of large populations of Hydropsychidae in the station 5 assemblage increased diversity because other taxa were present in even greater abundances. The overall effect was to increase evenness and, consequently, diversity. When the two Hydropsychidae were deleted from the sample, diversity decreased by 19%. However, at station 3, the presence of the more modest populations of Hydropsychidae substantially reduced evenness and diversity because other taxa were not present in great abundance. Deletion of the two Hydropsychidae increased diversity by 48%.

Station 1 is misplaced as a result of its very depauperate community. Calculation of diversity on a per individual basis 'standardizes' the total number of organisms. This practically ignores the depauperate nature of a community and drastically increases the importance of rare species in the diversity index value. Wilhm (1968) argues that rare species should be of little importance because they

Table 5. Rank orderings of stations by diversity index value versus ordering by considerations of the fauna, water chemistry, and pollution sources.

	Rank	Faunal Analysis	H DBAR	H/HMAX
July	high	9	9	9
		8	3	5
		3	8	3
	low	5	5	8
August	high	9	9	9
		8	8	8
		7	7	1
		3	5	7
		5	1	5
	low	1	3	3

are often sampling artifacts. But their effect on diversity is actually quite variable – greater for depauperate communities and nearly nonexistent for populous communities. For example, the effect of deleting one species represented by one individual was 18% greater for station 1 than for station 5-August. The index of evenness as a measure of species richness is supposed to compensate for this insensitivity. But the placement of stations 1 and 5 in the evenness scale (Table 5) clearly suggest that this index was not adequate. Winner *et al.* (1975) also observed the inadequacy of information theory index values in delineating the effects of a toxic substance (copper) and suggest that the number of individuals and species are preferable indices. They would have discriminated between stations 1 and 5 but would not have helped in discriminating the unpolluted station 8 from the recovery zone station 3.

Diversity indices do not consider the taxonomic composition of the community. In effect, they may equate a *Tubifex*-Tendipedidae-*Asellus* community with a Plecoptera-Ephemeroptera-Trichoptera community. They require a great deal of effort in quantitative sampling and taxonomic identification but, since only relative abundance is considered, they ignore a wealth of information available on the environmental adaptations and responses of aquatic invertebrates.

I am not suggesting that diversity indices are ecologically meaningless, but that it may not be possible to use them as direct measure of pollution's effects on a segment of a natural stream community. To use dominance diversity indices in this context, one must assume that no other factors significantly affect 'community structure' and that pollution will create communities where a few species become very abundant and the rest become rare or disappear. If one cannot universally make these assumptions, as my data suggest, then dominance diversity indices can only be considered as descriptive parameters which may or may not aid in interpreting the community response to a changed environment when considered in conjunction with other parameters.

Acknowledgments

This work was supported by a grant from the office of Water Resources Research (WR B-004 Mass.). I would like to thank Dr. Roger J. Reed, Dr. C. A. Carlozzi, Dr. S. Ludlam, P. Oatis, A. Maki, and J. Fair for their assistance throughout the study. I thank Mr. J. Mawson for this indefatigable persistence and humor in writing the computer program and Drs. J. B. Wallace and R. M. Sinclair for taxonomic verification of the Trichoptera and Coleoptera respectively.

References

Bartsch, A. F. & Ingram, W. M. 1959. Stream life and the pollution environment, p. 65-80. In: W. M. Ingram, K. M. Mackenthun, and A. F. Bartsch (ed). Biological field investigative data for water pollution surveys. U.S.D.H. Fed. Water Pollut. Control Admin. Pub. No. WP-13.

Benson-Evans, K., Williams, P. F., McLean, R. O. & Prance, N. 1975. Algal communities in polluted rivers of South Wales. Verh. Internat. Verein. Limnol. 19: 2010-2019.

Brillouin, L. 1956. Science and information theory. Academic Press, New York. 320 p.

Burks, B. D. 1953. The Mayflies or Ephemeroptera of Illinois. Bull. Illinois Nat. Hist. Survey 26 (1): 1-216.

Cairns, J., Jr. & Dickson, K. L. 1971. A simple method for the biological assessment of the effects of waste discharges on aquatic bottom-dwelling organisms. J. Water Pollut. Control Fed. 43: 755-772.

Collings, M. R., Wiesnet, D. R. & Fleck, W. B. 1969. Water resources of the Millers River basin, north-central Massachusetts and southwestern New Hampshire. U.S. Geological Survey Hydrologic Invest. Atlas HA-293.

Cushing, C. E. 1963. Filter-feeding insect distribution and planktonic food in the Montreal River. Trans. Amer. Fish. Soc. 92: 216-219.

Dambach, C. A. & Olive, J. H. 1969. Development of biological indices to pollution levels in streams affected by acid mine drainage and oil field brine wastes. Nat. Res. Inst. and the Water Res. Center Res. Proj. Completion Report, Proj. No. A-003-OHIO. 89 p.

Devaux, J. 1975. Succession écologique, diversité spécifique et production primaire dans un lac oligotrophe d'Auvergne (France). Verh, Internat. Verein. Limnol. 19: 1165-1171.

Eberhardt, L. L. 1969. Some aspects of species diversity models. Ecology 50: 503-505.
Glasgow, J. P. 1936. The bionomics of Hydropsyche colonica McL. and H. philpotti Till. Proc. Roy. Ent. Soc., London 11: 122-128.
Hurlbert, S. H. 1.71. The nonconcept of species diversity: A critique and alternative parameters. Ecology 52: 577-586.
Hynes, H. B. N. 1960. The biology of polluted waters. Liverpool Univ. Press, Liverpool. 202 p.
Hynes, H. B. N. 1970. The ecology of running waters. Univ. Toronto Press, Toronto. 555 p.
Ingram, W. M., Mackenthun, K. M. & Bartsch, A. F. 1966. Biological field investigative data for water pollution surveys. Fed. Water Pollut. Control Adm. Report No. WP-13, Cincinnati, Ohio. 139 p.
Leonard, J. W. 1965. Environmental requirements of Ephemeroptera, p. 110-117. In: C. M. Tarzwell (ed.). Biological problems in water pollution, third seminar, 1962. P.H.S. Div. Water Supply and Pollut. Control, Report No. 999-WP-25. 424 p.
Mathis, B, J. & Dorris, T. C. 1968. Community structure of benthic macroinvertebrates in an intermittent stream receiving oil field brines. Amer. Midl. Nat. 80: 428-439.
Mawson, J. C. & Godfrey, P. J. 1971. Diverse: A Fortran IV program to calculate diversity indices of stream bottom organisms. Water Resources Res. Center Pub., Univ. Massachusetts, Amherst. 23 p.
Mullan, J. W. 1954. A fisheries investigation of the Millers and Squannacook River drainages. 1953 D-J Completion Report (F-1-R-2). 287 p.
Patten, B. C. 1962. Species diversity in net phytoplankton of Raritan Bay. J. Mar. Res. 20: 57-75.
Pennak, R. W. 1953. Freshwater invertebrates of the United States. Ronald Press, New York. 769 p.
Pielou, E. C. 1969. An introduction to mathematical ecology. Wiley, New York. 286 p.
Radford, D. S. & Hartland-Rowe, R. 1971. A preliminary investigation of bottom fauna and invertebrate drift in an unregulated and a regulated stream in Alberta. J. Appl. Ecol. 8: 883-903.
Roback, S. S. 1965. Environmental requirements of Trichoptera, p. 118-126. In: C. M. Tarzwell (ed.). Biological problems in water pollution, third seminar, 1962. P.H.S. Div. Water Supply and Pollut. Control, Report No. 999-WP-25. 424 p.
Shannon, C. E. 1948. A mathematical theory of communication. Bell System Tech. J. 27: 379-423, 623-656.
United States Geological Survey. 1969. Water resources for Massachusetts. Part I. Surface water records. U.S.D.I. Geological Survey. p. 169-176.
Usinger, R. L. (ed.). 1956. Aquatic insects of California. Univ. California Press, Berkeley. 508 p.
Whittaker, R. H. 1965. Dominance and diversity in land plant communities. Science 147: 250-260.
Wilhm, J. 1967. Comparison of some diversity indices applied to populations of benthic macroinvertebrates in a stream receiving organic wastes. J. Water Pollut. Control Fed. 39: 1674-1683.
Wilhm, J. 1968. Biomass units versus numbers of individuals in species diversity indices. Ecology 49: 153-156.
Wilhm, J. 1969. Community diversity, p. 8-14. In: Amer. Assoc. Adv. Sci. The stream ecosystem. Michigan State Univ. Water Res. Tech. Rep. No. 7. 42 p.
Wilhm, J. 1970. Range of diversity index in benthic macroinvertebrate populations. J. Water Pollut. Control Fed. 42: R221-R224.
Wilhm, J. 1972. Graphic and mathematical analyses of biotic communities in polluted streams. Ann. Rev. Entomol. 17: 223-252.
Wilhm, J. & Dorris, T. C. 1966. Species diversity of benthic macroinvertebrates in a stream receiving domestic and oil refinery effluents. Amer. Midl. Nat. 76: 427-449.
Wilhm, J. & Dorris, T. C. 1968. Biological parameters for water quality criteria. BioScience 18: 477-481.
Winner, R. W., Van Dyke, J. S., Caris, N. & Farrel, M. P. 1975. Response of the macroinvertebrate fauna to a copper gradient in an experimentally-polluted stream. Verh. Internat. Verein. Limnol. 19: 2121-2127.