 0030-0950/81/0006-0259 $2.00/0

EFFECTS OF WATER QUALITY ON FISH AND MACROINVERTEBRATE COMMUNITIES OF THE LITTLE MIAMI RIVER[1]

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Abstract. The fish and benthic macroinvertebrates inhabiting 6 riffles in the Little Miami River, Ohio, were studied monthly from November 1977 to October 1978. Cluster analysis of the physical-chemical characteristics of the 6 sites revealed major differences between the 4 riffles above the confluence with Beaver Creek and the 2 downstream sites. Increased nutrient levels in the 2 downstream riffles coincided with the influx of domestic sewage. Moderate increases in nutrients had little effect on the composition of the biotic communities; however, sharp increases in nutrient levels from sewage plant effluents discharged into Beaver Creek resulted in downstream changes in the species composition of fish and macroinvertebrate communities. The dominant fishes at sites 1-4 were darters (*Etheostoma* spp.); the stoneroller (*Campostoma anomalum*) was the dominant species at sites 5 and 6. Fish distribution was affected by water quality and was positively correlated with food densities. Macroinvertebrate diversity was higher in the four riffles ($H'=2.22$-2.47) above Beaver Creek than in the two ($H'=1.19$ and 1.24) below this point. Macroinvertebrate communities at sites 1-4 were dominated by Ephemeroptera, Trichoptera, Plecoptera, and Diptera (Chironomidae), while the major forms at the two downstream sites were the Chironomidae and aquatic worms.

OHIO J. SCI. 81(6): 259, 1981

The effects of pollutants on the benthic macroinvertebrate communities of streams have been studied extensively. Early investigators emphasized relationships between the presence and abundance of stream insects and water quality (Gaufin and Tarzwell 1952 and 1956, Gaufin 1958, Olive and Dambach 1973). Certain groups of aquatic insects, including selected species of Trichoptera, Ephemeroptera, and Plecoptera, have been termed "clean water" forms (Gaufin and Tarzwell 1952) because of their decline in numbers or absence in portions of streams exhibiting poor water quality (Mackenthun 1966, Larimore 1974). Fishes have also been used as pollution indicators. Significant changes in the species diversity and abundance of stream fishes have been related to declining water quality (Katz and Gaufin 1952, Mackenthun 1966).

Distributional patterns of stream fishes can also be influenced by factors that may have no direct relationship to water quality. Starrett (1950) concluded that the distribution of fish species that are specialized feeders (e.g. *Notropis* spp. and *Etheostoma* spp.) is limited by food availability. Gibson and Galbraith (1975) reported higher fish biomass in areas where invertebrate drift was higher, and from their data concluded that fish distribution can be affected by food supply.

The objectives of the present study were to analyze the structure of the fish and macroinvertebrate communities in riffles of the Little Miami River, Ohio, with relatively good water quality, and to contrast these sites with riffles affected by domestic sewage pollution.

[1]Manuscript received 13 June 1980 and in revised form 7 November 1980 (#80-32).

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Study Area

This study was conducted at 6 riffles in the upper 35 km of the Little Miami River in Greene County, Ohio (fig. 1). Site selection was based on similarities in the physical structure of the riffles and their location in relation to sewage treatment plants. All sites are fairly shallow (usually 15 cm to 25 cm deep) during most of the year; however, periodic flooding, particularly in the spring, may result in water depths increasing to over 2 m. Substrates at the six sites are composed primarily of gravel and cobblestone.

Sites 1 and 2, near the headwaters of the river, were relatively free of pollution. Site 1 lies within the boundaries of John Bryan State Park, and site 3 is located 2.9 km below the point where the river receives effluent from a secondary sewage treatment plant located at the confluence with Massies' Creek. There is a second sewage treatment plant along the east bank of the river between sites 3 and 4, and the latter site is

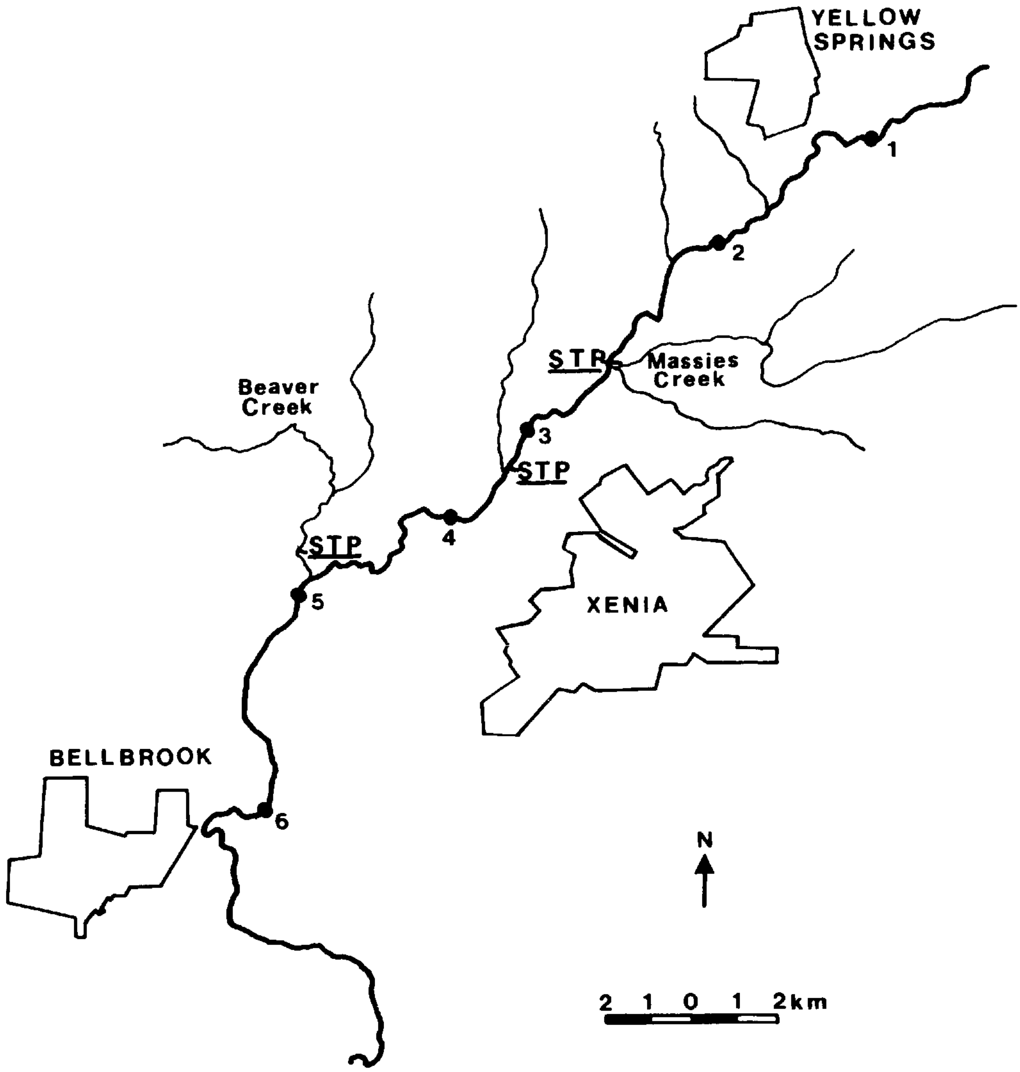

FIGURE 1. Location of the six (1-6) study sites along the Little Miami River, Greene County, Ohio. *STP*=sewage treatment plant.

located 2.1 km below this plant. The Little Miami River receives sewage effluent from two treatment plants located along Beaver Creek. The plant nearest the river is located approximately 0.6 km upstream from its confluence with Beaver Creek. Site 5 is located 0.5 km downstream from this point. There are no major point-sources of pollution between sites 5 and 6. Site 6 was selected to determine if the fish and macroinvertebrate communities had recovered from the impact of the sewage effluent which is received from Beaver Creek.

METHODS

Water quality analyses were conducted monthly from November 1977 to October 1978. Fishes and benthic macroinvertebrates were sampled monthly, with the exception of March 1978, when high water prevented access to the river. Monitored physical and chemical characteristics of the stream included temperature, pH, dissolved oxygen, biochemical oxygen demand, nitrate, nitrite, orthophosphate, total alkalinity, total hardness, total suspended matter, current velocity, and depth. The analysis were done with the procedures in *Standard Methods for the Examination of Water and Wastewater* (American Public Health Association 1975) or modifications of these as outlined by the U.S. Environmental Protection Agency (1971). Nitrates and total hardness levels were measured with prepackaged chemicals (Hach Chemical Company, Loveland, CO). We used a Hach Chemical Company, Model 17200 pH meter to measure H^+ ion concentrations in the field. Current velocity was determined with a digital flowmeter (General Oceanics, Model 2031).

The abundance and species composition of benthic macroinvertebrates at each site were determined from samples taken monthly with a Portable Invertebrate Box Sampler (Ellis-Rutter Associates). The area sampled was 0.1 m^2 along a transect extending across the stream. Samples were preserved in 10% formalin in the field, and rose bengal dye was added to aid in separation of the invertebrates from debris. All sorting and identification were conducted in the laboratory. Most organisms were identified to the generic or specific level, except for the Chironomidae (Diptera) which were taken only to family. Species diversity (H′) in the macroinvertebrate communities was calculated with the Shannon-Wiener equation (Margalef 1968).

Fish were collected with a drag-seine (2.44 m x 1.22 m; square mesh=4.76 mm). A standard length of riffle (6 m) was seined to establish consistency among the sites. Four 3-m samples were collected from the 6-m section and were combined at each site on each date.

A cluster analysis was used to analyze quantitatively similarities and differences among the fish and macroinvertebrate communities and the mean annual physical-chemical characteristics of the six sites (Sneath and Sokal 1973). All physical and chemical measurements were standardized ($\bar{x}=0$, SD=1) to give equal weight to each dimension. Each taxon in the fish and macroinvertebrate communities also represented a dimension, and each dimension was expressed as the proportion of the annual community (benthic or fish) that a particular taxon comprised at each site.

Two-way analysis of variance (ANOVA) and Duncan's Multiple Range Test (Steel and Torrie 1961) were used to test for significant differences in water quality among the six sites. The two-way ANOVA was used to adjust for seasonal fluctuations in values. Significance was considered at the 0.05 probability level.

RESULTS

Water Quality. Mean annual values for the physical and chemical characteristics of the Little Miami River are given in table 1. The following results were obtained:

1. temperature was not significantly different among the six riffles;
2. pH was essentially the same (7.8-7.9) at each site;
3. dissolved oxygen decreased downstream, with a significant decline (0.7 mg/ℓ) occurring between sites 4 and 5;
4. BOD levels increased by small, insignificant increments at sites 1-4, followed by a significant increase (4.3 mg/ℓ) at site 5 (site 6 was significantly lower than site 5 but higher than sites 1-4);
5. nitrate levels showed no significant change with distance downstream;
6. nitrites remained fairly constant at sites 1 through 4, with significant increases of 92.3 and 92.4 μg/ℓ at sites 5 and 6, respectively;
7. orthophosphate levels increased, with no significant change from sites 1-4 (a significant increase (469.1 μg/ℓ) was noted between sites 4 and 5);
8. total alkalinity increased slightly downstream, with sites 5 and 6 being significantly higher than the other stations;
9. total hardness increased steadily from sites 1-6, with no significant change between adjacent sites;

10. total suspended matter increased steadily from sites 1-6 and showed a significant increase (8 mg/ℓ) between sites 2 and 3;

11. current velocity showed no trend related to the order of the riffles; and finally,

12. depth varied significantly among several sites, but there was no pattern to these differences, and no area was significantly different from all the others.

TABLE 1

Mean values for water chemistry and physical characteristics of sites 1-6 in the Little Miami River, Ohio, November 1977-October 1978.

	Site					
	1	2	3	4	5	6
Temperature (°C)	11.8	11.7	11.9	11.7	12.0	12.1
	(−0.5-23.0)*	(−0.5-23.0)	(−0.5-24.0)	(0-24.0)	(0-23.0)	(0.3-24.0)
pH	7.8	7.8	7.9	7.9	7.9	7.8
	(7.4-8.2)	(7.5-8.2)	(7.5-8.2)	(7.6-8.2)	(7.4-8.3)	(7.6-8.1)
Dissolved O_2 (mg/ℓ)	9.4	9.3	8.9	8.8	8.1	7.9
	(7.0-12.7)	(6.3-12.0)	(6.1-11.7)	(5.6-12.4)	(5.1-11.6)	(4.3-12.7)
BOD (mg/ℓ)	1.1	1.2	1.4	1.7	6.0	4.4
	(0.1-1.8)	(0.3-2.4)	(0.2-2.8)	(0.4-2.8)	(2.0-14.4)	(2.3-7.0)
Nitrate (mg/ℓ)	3.23	3.50	3.50	3.61	3.42	3.31
	(1.50-6.75)	(1.50-5.89)	(1.20-6.81)	(2.00-6.69)	(1.50-3.95)	(1.70-5.31)
Nitrate (μg/ℓ)	13.5	13.6	16.0	22.4	114.7	114.8
	(0-28.5)	(1.7-28.5)	(3.4-30.0)	(6.1-38.7)	(18.5-300.0)	(16.3-285.0)
Orthophosphate (μg/ℓ)	46.4	90.9	92.8	172.7	641.8	530.9
	(0-116)	(37-160)	(47-155)	(57-400)	(146-1140)	(116-942)
Total Alkalinity (mg/ℓ)	251.5	253.6	263.4	261.1	278.1	281.3
	(214-292)	(196-300)	(202-310)	(202-320)	(210-336)	(215-336)
Hardness (mg/ℓ $CaCo_3$)	344.2	355.8	358.3	368.3	360.8	363.3
	(320-400)	(300-400)	(300-400)	(300-410)	(300-390)	(310-400)
Suspended Matter (mg/ℓ)	16.7	18.1	26.1	28.5	31.3	36.9
	(3.1-42.6)	(2.8-59.9)	(3.0-63.8)	(3.1-77.7)	(5.7-72.4)	(4.2-83.7)
Current Vel. (cm/sec)	88.3	98.4	92.1	115.4	87.9	89.7
	(61.4-137.3)	(79.2-141.3)	(69.7-143.5)	(92.9-169.8)	(63.5-125.8)	(70.0-133.6)
Depth (cm)	18.6	18.4	20.6	21.7	17.3	19.7
	(14.4-27.2)	(13.6-27.8)	(16.7-29.5)	(18.0-28.0)	(13.0-27.5)	(16.2-27.5)

*Range.

Cluster analysis of the physical-chemical data revealed a strong similarity between sites 1-4 and 5 and 6. Further analysis indicated that the characteristics primarily responsible for these results were dissolved oxygen, BOD, nitrite, orthophosphate, and total suspended matter. A similar analysis of the fish and benthic communities indicated the same general trend, with the sharpest division in the clustering sequence occurring between sites 1 through 4 and 5 and 6.

Benthic Macroinvertebrates. A variety of benthic macroinvertebrates was observed at sites 1-4 throughout the study (table 2). The dominant taxa shifted throughout the year, and seasonally dominant organisms included the chironomids, caddisflies (*Cheumatopsyche* and *Hydropsyche*), mayflies (*Baetis, Caenis,* and *Stenonema*), elmid beetles (*Stenelmis*), and stoneflies (*Plecoptera*).

The community composition at sites 5 and 6 during the year was quite different from sites 1-4. Chironomids dominated the two downstream sites at all times; other invertebrates that were seasonally abundant included blackflies, *Simulium* (site 5), the

TABLE 2

Benthic organisms at sites 1-6 in the Little Miami River, Ohio, November 1977 to October 1978.

	Site					
	1	2	3	4	5	6
Chironomidae (L)**	88.9*	65.5	103.2	68.8	297.2	181.6
Chironomidae (P)**	3.8	2.8	6.7	4.5	31.6	18.6
Simulium sp.	3.1	5.5	3.1	8.9	39.5	4.7
Cheumatopsyche sp. (L)	20.8	47.1	13.2	131.1	3.7	0.4
Hydropsyche bifida (L)	11.3	25.3	6.2	68.5	3.2	0.1
Hydropsyche demora (L)	0.0	0.0	0.0	0.3	10.9	1.0
Hydropsychidae (P)	0.8	2.7	1.0	5.1	0.7	0.0
Hydroptilidae	14.2	6.8	4.4	2.1	0.6	0.3
Chimarra obscura (L)	0.5	8.2	0.6	9.2	0.1	0.0
Baetis sp.	16.2	36.0	15.5	34.6	9.0	0.5
Caenis sp.	19.1	25.5	45.3	9.8	0.3	0.1
Isonychia sp.	18.0	12.1	7.0	21.3	0.5	0.1
Stenacron sp.	11.6	0.7	0.5	0.7	0.5	0.9
Stenonema sp.	48.1	38.3	20.9	39.0	1.6	0.4
Stenelmis sp.	24.0	21.7	6.0	40.6	1.5	1.3
Plecoptera	0.8	2.9	22.7	3.3	0.6	0.1
Oligochaeta	3.4	0.7	8.6	13.6	83.4	74.2
Ferrisia sp.	0.0	0.4	13.2	1.2	9.6	46.6
Fish eggs	0.4	1.0	0.7	0.2	0.0	0.5
Other	15.6	28.2	15.4	20.4	8.1	6.6
Total	300.6	331.4	294.2	483.2	502.6	338.0

*Mean/0.1 m^2.
**L=larva, P=pupa.

caddisfly, *Hydropsyche demora* (site 5), oligochaete worms, and the limpet, *Ferrisia* (site 6). The Shannon-Wiener diversity values for sites 5 ($H'=1.24$) and 6 ($H'=1.19$) were considerably lower than those for sites 1-4 (2.30, 2.47, 2.22, and 2.27, respectively).

Fishes. A total of 1192 fish was collected from the six riffles during the study (table 3). The most abundant (n=543) species was the rainbow darter, *Etheostoma caeruleum*. This form dominated the fish communities at sites 1-4, but was rare or absent at sites 5 and 6. The banded darter,

TABLE 3

Number of individuals of each fish species collected from six riffles in the Little Miami River, Ohio, (Nov. 1977 to Oct. 1978).

Species	Site						
	1	2	3	4	5	6	Total
Etheostoma caeruleum	53	195	149	144	2	0	543
Etheostoma zonale	0	67	65	57	0	0	189
Etheostoma blennioides	27	60	50	39	5	1	182
Campostoma anomalum	26	21	75	11	50	10	193
Cottus bairdi	21	5	1	0	0	0	27
Notropis spp. (7 species)	5	12	10	0	1	2	30
Hypentelium nigricans	0	0	4	1	0	0	5
Semotilus atromaculatus	0	2	0	0	1	3	6
Rhinichthys atratulus	0	0	0	0	2	8	10
Hybopsis micropogon	0	1	0	0	0	0	1
Exoglossum laurae	3	0	0	0	0	0	3
Percina caprodes	1	0	0	1	0	0	2
Lepomis macrochirus	0	1	0	0	0	0	1
Total	136	364	354	253	61	24	1192

E. zonale, was collected at sites 2-4, and was one of the most abundant fishes in those areas. The greenside darter, *E. blennioides,* was relatively abundant at sites 1-4 and rare at sites 5 and 6. *Campostoma anomalum* (stoneroller) was the dominant species at sites 5 and 6. The mottled sculpin, *Cottus bairdi,* was present at sites 1-3 and was one of the dominant species at site 1. The majority of the remaining 14 species collected during the study belonged to the family Cyprinidae.

Fish and Macroinvertebrate Densities. The high densities of benthic macroinvertebrates at sites 1-4 resulted in a relatively stable, and therefore predictable, food supply for the fishes in these areas (fig. 2). The only significant changes in the

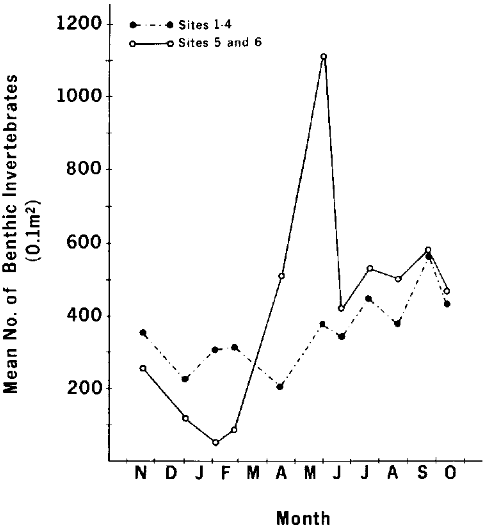

FIGURE 2. Mean number (per 0.1 m^2) of benthic macroinvertebrates at sites 1-4 and 5 and 6 in the Little Miami River, Ohio, November 1977 to October 1978.

mean density of benthic invertebrates at sites 1-4 were the increases observed from April to May and from August to September. Stability in the densities of benthic organisms did not occur at sites 5 and 6. Densities in these areas declined in the winter months, and were significantly lower ($P \leq 0.05$) at sites 5 and 6 than at sites 1-4 during January and February. These changes were followed by significant monthly fluctuations through June.

A highly significant correlation ($P \leq 0.01$; $R^2 = 0.65$) was observed between the number of fish and the density of benthic macroinvertebrates at sites 1-4, when April was excluded from the analysis (fig. 3). Data for April did not fit this relationship because of the intense reproductive activity of rainbow darters in the riffles at that time. No correlation between the numbers of fish and the densities of benthic organisms was observed at sites 5 and 6.

DISCUSSION

Changes in the water quality of streams can reflect increased nutrient loads associated with sewage discharge and probably, to a lesser degree, agricultural runoff (Gaufin and Tarzwell 1956, Gaufin 1958, Olive and Dambach 1973). In this study, the observed decreases in dissolved oxygen levels from sites 2-6 indicated an increased organic load in the stream. These and the changes in nitrite, orthophosphate, and total suspended matter were most dramatic between sites 4 and 5 and during the summer months. Though agricultural runoff could have accounted in part for the changes in these chemical characteristics, the fact that the changes were so great between sites 4 and 5 indicates that the sewage effluent entering the river from Beaver Creek was mainly responsible for this sharp decline in water quality.

Increases in nutrient load above the confluence of Beaver Creek with the Little Miami River appeared to have no detrimental effect on the benthos. High values (H′=2.22-2.47) of the diversity index at sites 1-4 reflected the seasonal succession of dominant taxa in the benthic community. There was no single dominant taxon at these sites, but rather a number of taxa exhibiting seasonal maxima in densities. Many of these forms have been categorized as "clean-water" insects (Gaufin and Tarzwell 1952). These same seasonal maxima were not observed at sites 5 and 6, where the diversity index was less than or equal to 1.24.

Peaks in abundance of individuals per taxon in the stream reflected successful reproduction and the development of the im-

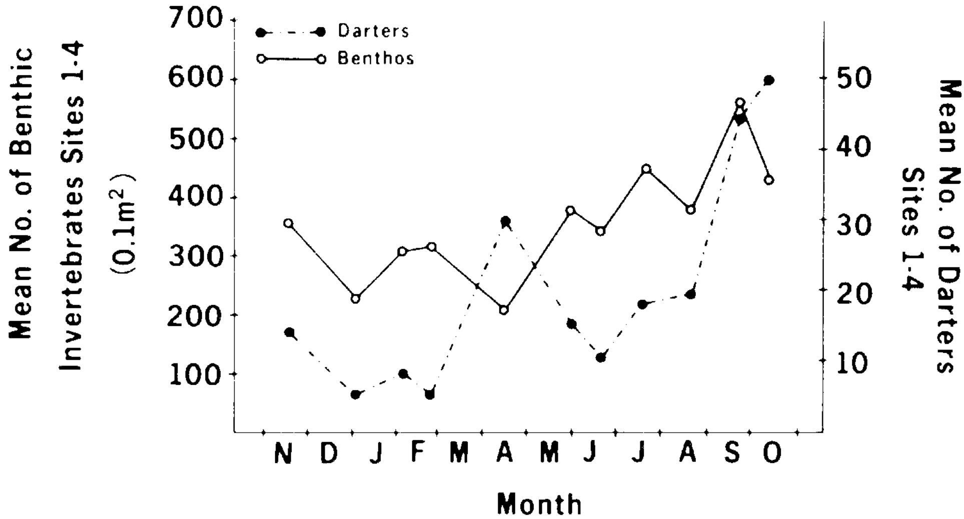

FIGURE 3. Mean number (per 0.1 m^2) of benthic macroinvertebrates and darters taken at sites 1-4 in the Little Miami River, Ohio (Nov. 1977 to Oct. 1978).

mature stages. The absence of seasonal pulses in "clean-water" taxa at sites 5 and 6 may indicate that these forms were unable to reproduce successfully in these areas. There was an increase in the density of *Baetis* at site 5 during June. It is impossible to determine whether this increase resulted from successful reproduction at the site or from drift originating upstream. The latter explanation seems most probable, as *Baetis* was absent or rare at site 5 during times when it was still abundant at sites 1-4.

The other observed differences among the benthic communities may have also been related to changes in water quality. Even though Chironomidae comprised a large portion of the benthos at all sites, it is likely that the species present were different, particularly between sites 1-4 and 5 and 6. Such differences have been well documented by other investigators (Winner *et al* 1980). In this study, pulses in the densities of chironomids at sites 1-4 were observed at different times than at sites 5 and 6. If the same chironomid species occurred at all sites, their abundance in one riffle should have occurred in synchrony with the others.

Replacement of one species by another closely related species in an area of low water quality was observed in the genus *Hydropsyche*. The most common species at sites 1-4 was *Hydropsyche bifida*. This species was rare or absent at sites 5 and 6, where the dominant species was *Hydrospyche demora*.

Effects oı the decline in water quality of the Little Miami River below its confluence with Beaver Creek were also evident in the fish communities, which exhibited reduced species numbers and individuals per species. Differences in biota between sites 1-4 and 5 and 6 were probably related to water chemistry, since the physical characteristics of the six riffles were very similar. Investigators have shown that in streams similar to the Little Miami River, constant or increasing numbers of fish species and individuals per species are observed along a gradient from upstream to downstream (Whiteside and McNatt 1972). The loss of species and individuals owing to man-related impacts on the stream environment altered this trend in the present study as well as in others (Katz and Gaufin 1952, Tramer and Rogers 1973).

Species diversity has often been related to the stability of the environment (Green 1969). In this study, the fish communities were subjected to environmental stress (e.g. changes in water quality), which was less predictable and more severe at sites 5 and 6 than in the other riffles. The dominance of a few invertebrate taxa resulted in greater seasonal variation in macroinvertebrate densities at sites 5 and 6. Fluctuations in food availability may have had a direct influence on the species composition of the fish communities found in these two riffles. This could be particularly true for the darters (*Etheostoma* spp.), which are relatively sedentary, and which may require several months to colonize an area temporarily unsuitable for habitation because of a low or nonexistent food supply (Larimore *et al* 1959).

The importance of food supplies to fishes in the riffles is shown in the positive correlation between the abundance of darters and the density of food items at sites 1-4. This relationship supports the view that food supply is at least partially governing the abundance of fishes in these riffles. The dominant fish species at sites 5 and 6 was the stoneroller (*Campostoma anomalum*), which feeds primarily on organic detritus (Lotrich 1973). Thus, this species should not be affected by macroinvertebrate densities.

Dissolved oxygen levels were much lower at the two downstream sites. Ultsch *et al* (1978) have shown that some darters (*e.g. Etheostoma rufilineatum*) characteristic of fast-water streams have strict oyxgen requirements that may restrict their distribution. The riffle areas themselves may have adequate oxygen supplies for most of the year, but this may not always be true of the tailwaters and pools. Since there is evidence that darters (especially juveniles) do not remain in the rapid, well-oxygenated portions of the riffles during all stages of the life cycle, the oxygen tensions in the quiet areas of the stream are also of importance (Winn 1958a and 1958b). Depressed oxygen levels owing to high BOD may actually exclude fish from these areas at times. This may be true for the darters and sculpins (*Cottus bairdi*), which have no air bladder and are therefore confined to the bottom.

Decreased oxygen tension is probably more important than the stability of the food supply in governing fish distribution. Decreases in food supply may result in increased competition and the displacement of some fish, but inadequate oxygen levels could result in total abandonment of an area or the death of those individuals who remain behind. The combination of low food levels during winter months and very low oxygen levels during summer months may create a very unstable and degraded environment at sites 5 and 6, and also act to restrict the time during which fish can inhabit these areas. These factors would also prevent any appreciable colonization of these areas by the 3 darter species (*E. caeruleum, E. zonale,* and *E. blennioides*) found further upstream.

The decline in water quality of the Little Miami River below its confluence with Beaver Creek may also have a marked effect on the spawning activities of the fishes at sites 5 and 6. Fish eggs were collected from all riffles except that at site 5. The eggs found at sites 1-4 were the same size (1 mm to 2 mm) as those in the ovaries of darters, but those collected at site 6 were approximately 4 mm in diameter. This size suggests that darter reproduction at sites 5 and 6 was probably absent during the study period. If fish do spawn in these areas, it is questionable whether the eggs could survive and develop. Darter eggs would probably not develop normally, if at all, because of the high suspended matter content of the stream, which would prevent adequate gas exchange between the water and the eggs. Smith (1971) lists the banded darter (*E. zonale*) as one of 14 species decimated by excessive siltation in Illinois rivers.

The major shift in species composition of the fish communities between sites 1-4 and sites 5 and 6, though indicative of changing water quality, was confounded somewhat by the presence of the black-nose dace (*Rhinichthys atratulus*) at the latter two sites. This form has been reported to avoid areas severely degraded by sewage wastes (Fava and Tsai 1976). Its occasional presence at sites 5 and 6 suggests that water quality may improve enough at times to allow this species to move into and to temporarily inhabit the riffles in this section of the stream.

Acknowledgments. This research was funded in part by the National Science Foundation (Grant #DEB78-17514). The assistance of the Greene County Department of Parks and Recreation was greatly appreciated. Chris Ingersoll, Steve Madewell, Steve Klemann, John Regensburg, Tom Runyan, and Rick Kuczmarski assisted in the field work, and Steve Seilkop helped with the statistical analyses.

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