Michael Hubbard

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AQUATIC INSECT DIVERSITY AND BIOMASS IN A STREAM MARGINALLY POLLUTED BY ACID STRIP MINE DRAINAGE

STANLEY M. TOMKIEWICZ, JR. and WILLIAM A. DUNSON

Department of Biology, Pennsylvania State University, University Park, PA 16802, U.S.A.

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Abstract—Upper Three Runs receives a point source of acid mine drainage from a small acid feeder stream and the pH of the main stream falls from above 6 to about 4.5. Over the 1.2 km study section below the introduction of acid drainage, the pH rises to 5.0. This moderate degree of mine acid pollution has severely affected aquatic insect populations. The acid feeder itself (pH near 3.2) was inhabited only by a chironomid, a megalopteran (*Sialis*), and the caddisfly *Ptilostomis*. Biomass was very low (140 mg dry weight/m^2). The drainage of the acid feeder into the stream caused a drop in the Shannon–Weiner diversity index from 3.10 to 1.95, and a drop in biomass from 6.5 g/m^2 to 2.2 g/m^2. At the two stations further downstream, the diversity index remained relatively constant and the biomass leveled off at about 1.2 g/m^2. The number of taxa declined steadily from 30 at the control station to 13 at the lowest site. Populations of Coleoptera, Ephemeroptera and Trichoptera showed little or no recovery as the acid pollution ameliorated slightly. Representatives of the orders Diptera and Plecoptera (especially *Nemoura*) showed a decided recovery and increase in numbers near pH 5.0. If fish were able to survive in acid mine polluted waters of pH's between 4.5 and 5.0 they should find sufficient insect food for maintenance of a limited population.

INTRODUCTION

One of the most serious side effects of strip and deep mining for coal is the pollution of streams by acid water runoff (Boccardy & Spaulding, 1968; Spaulding & Ogden, 1968). This problem is extensive in certain areas of Pennsylvania and seems likely to continue for many years since abandoned mines are apparently responsible for a substantial fraction of total acid runoff. In contrast to the poor ability of fish to tolerate mine acid polluted waters in Pennsylvania (Cooper & Wagner, 1973), insects are usually found even under the most severe conditions. The importance of insects as indicators of the degree of pollution, and as herbivores and predators in the aquatic ecosystem has stimulated many recent studies on their distribution and diversity in acid streams (Parsons, 1968; Bell & Nebeker, 1969; Sheaffer & Little, 1969; Warner, 1971; Roback & Richardson, 1971; Bell, 1971; Weed & Rutschky, 1972; Koryak *et al.*, 1972; Roback, 1974).

Since many of the previous studies have been carried out on severely polluted streams and have not measured biomass, we initiated the present study of aquatic insect diversity and biomass in a marginally polluted stream. The study site is of particular interest because the pH is just below that suitable for fish survival. Effects on populations of some of the most sensitive insect species should be apparent in this situation. This area is also representative of other marginally polluted sites where the insect food for fish may be present in adequate amounts, but fish are not present. A recent study (Robinson *et al.*, 1976) raises the possibility that tolerance to low pH in brook trout is heritable and that a selection program might be able to produce a fish capable of surviving indefinitely at pH's below 5.0 (due to mine acid pollution).

MATERIALS AND METHODS

The study area (Fig. 1) consisted of four stations along Upper Three Runs (No. 2, 3, 4, 5) and one station (No. 1) on the acid feeder stream running from a strip mine into Upper Three Runs (station 0.2 km above junction). Station 2, 10 m upstream along the main stream from this junction, was representative of normal conditions. Stations 3, 4 and 5 were placed 10 m, 0.85 km and 1.90 km downstream from the junction.

Upper Three Runs is located in Clearfield Country, Pa. (see Geological Survey topographical map, Pottersdale Quadrangle, 7.5 min. series). The stream flows from the Moshannon State Forest through an area of extensive strip mine operations. About 1.9 km upstream from the town of Pottersdale, Upper Three Runs receives a point source of acid mine pollution (from the acid feeder stream). This appears to be the only major source of acid drainage, and after the initial drop in pH, the stream undergoes a gradual recovery and rise in pH until it enters the severely polluted West Branch of the Susquehanna (pH 3.0–3.5) 2.4 km downstream from Pottersdale.

The pH of water samples was measured at 20–25°C with a Corning Model 7 pH meter in the laboratory within 5 h after collection on June 18, June 25, July 9 and July 16, 1974.

The collection of aquatic insects was made with a standard 1 ft^2 Surber bottom sampler (mesh opening 0.75 mm). Five Surber samples were taken in riffles at each station on June 25 and July 16, 1974. The substrate was mixed gravel and small rocks; it was disturbed to a depth of 5 cm during sampling. An attempt was made to take all five samples on a similar substrate, at the same depth, and in areas of similar current flow. The current was moderate, so that little silt deposition was occurring in

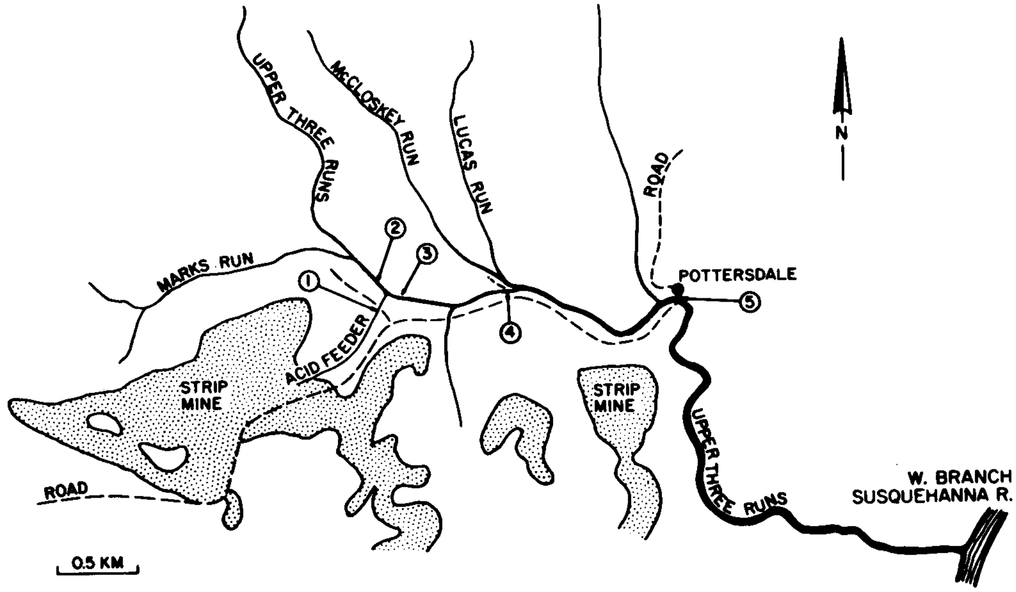

Fig. 1. Map of the study area on Upper Three Runs showing the sites of the five sampling stations. Station 1 is located on the acid feeder. Station 2 is the control and located upstream from the entrance of the acid feeder. Stations 3, 4, and 5 are located below the entrance of the acid feeder.

the riffles under study. All five samples collected at each station on one day were then combined to form one sample equal to 5 ft^2 of bottom area. Insects were removed from the substrate, placed in formaldehyde, separated into groups, and identified to the lowest taxonomic level possible with keys in Klots (1966) and Usinger (1956). In most cases the specimens were compared to identified material in the Frost Entomological Museum at the Pennsylvania State University. Each taxonomic unit is considered to represent a genus even though specific generic identifications were usually not made. All aquatic insects in this study were in the nymphal or larval stages of development with the exception of a group of unidentified coleopterans. Biomass for each group was determined by weighing all the specimens in each group after a 24-h drying period at 100°C. The data are based on the combined material of the two samples collected June 25 and July 16 and therefore figures for each order discussed represent the total number of individuals and the total biomass for that order based on ten square feet (0.93 m^2) of bottom area.

A transfer experiment was conducted on two genera of the Order Plecoptera. Two specimens of *Allonarcys* and three specimens of *Acroneuria* were confined on a gravel and stone substrate in a 15 × 30 cm nylon mesh sack. One sack was placed at each station and left undisturbed for 1 week. At the end of this time the sacks were opened and the number of surviving specimens was noted. All the specimens of both genera were collected from Upper Three Runs above the entrance of the acid feeder stream.

A diversity index ($\bar{d}$) for aquatic insects at the generic level was calculated at each station by using the Shannon–Weiner function (from Weed & Rutschky, 1972):

$$(\bar{d}) = 3.3219\left(\log_{10} N - \frac{1}{N}\sum n_l \log_{10} n_l\right)$$

where

N = total individuals of all species (genus here)

n_l = number of individuals of the lth species (genus here)

3.3219 = conversion from $\log_{10}$ to $\log_2$.

RESULTS

On a field meter water from station 2 had a pH near 6 (Table 1). This value and similar ones from the previous year confirm the biological data showing that station 2 is representative of normal unpolluted conditions. The lowest pH recorded in the acid feeder stream was a value of 3.0 on June 18. The lowest pH recorded in Upper Three Runs, a value of 4.43, was at station 3 just below the entrance of the acid feeder stream into the main stream (Table 1). The pH tended to increase downstream as did stream flow due to the entrance of nonpolluted tributaries. On May 11, 1970, the pH at station 5 was 4.8; thus it seems that there is considerable constancy in acid drainage in this area. Electro-fishing in 1970 yielded no fish at station 5; brook trout and sculpins were numerous at station 2. One unidentified fish was sighted at station 4 in 1974.

A marked decrease in biomass occurred at station 3 with a further decrease at station 4 (Fig. 2a). The biomass then leveled off at stations 4 and 5. It should be noted that 1540 mg of the total 2048 mg of biomass recorded at station 3 was contributed by only two specimens. One of these two individuals, *Acroneuria* (Order Plecoptera), was the only specimen of this genus to be collected below the entrance of the acid feeder stream. The other specimen belongs to the Family Corydalidae (Order Megaloptera) and was extremely large compared to other individuals of the same taxa collected in the stream. Without considering these two specimens (biomass at station 3 = 2048 mg–1540 mg = 508 mg) the lowest biomass would occur at station 3. The biomass at station 1 was only 131 mg.

Table 1. Temperature (°C) and pH levels recorded at each station from June 18 to July 16, 1974

	June 18		June 25		July 9		July 16		
Station	pH	Temp	pH	Temp	pH	Temp	pH	Temp	Average pH
1*	3.00	15	3.10	13	3.35	15.5	3.27	16	3.20
2†		13		12		15		15	>6
3	4.49	13	4.90	12	4.43	15	4.75	15	4.68
4	4.82	13	4.92	12	5.00	16	4.85	15	4.90
5	4.82	15	5.09	13	5.03	16	5.00	15.5	5.00

* acid feeder; † control.

From a high of 466 individuals at station 2 the number of individual insects dropped to a low of 143 at station 3 (Fig. 2b). There was an increase at station 4 to 250 and a further increase at station 5 to 359. Only 21 individuals were recorded at station 1 in a comparable sample.

From a high of 30 taxa at station 2 the number dropped to 17 at station 3, 15 at station 4, and to 13 at station 5 (Fig. 2c). Only two taxa were recorded at station 1 during quantitative sampling. These were *Sialis* (Order Megaloptera) and a genus of the Family Chironomidae (Order Diptera). An additional order (Trichoptera: *Ptilostomis*) was found in a later qualitative survey in the Spring of 1975.

The Orders Coleoptera (Fig. 3a), Ephemeroptera (Fig. 3b), and Trichoptera (Fig. 3g) showed similar changes in numbers and biomass after the introduction of the acid mine pollution. Below the entrance of the acid feeder stream the number of individuals and biomass were reduced and remained at a low level at stations 4 and 5. Trichoptera showed a slight recovery at station 5. Megaloptera and Odonata (Figs. 3c and d) showed a reduction in the number of individuals collected below the entrance of the acid feeder stream, but only a small number of individuals were collected at any one station. Due to the low numbers of individuals collected at any one station and the variable size of the individuals collected, the biomass responses of these two orders did not reflect the response in terms of numbers. The genus *Sialis* (Order Megaloptera) was recorded in the acid feeder stream and was more numerous there than at any station along Upper Three Runs. Diptera (Fig. 3e) and Plecoptera (Fig. 3f) showed a reduction in the number of individuals below the acid feeder stream's entrance into Upper Three Runs but increased again in numbers at station 4 with a further increase at station 5. The numbers of individuals of these two orders were higher at station 5 than at station 2, the control. Biomass responded similarly to numbers except that there was little "recovery" in the Plecoptera at station 5. One genus of the Family Chironomidae (Order Diptera) was one of the two taxa collected in the acid feeder stream but unlike *Sialis* it was more numerous in Upper Three Runs. In the Order Plecoptera the genera *Allonarcys* and *Peltoperla* were restricted to normal sections of the stream (station 2). However it is interesting that the genus *Nemoura* was most abundant in the samples taken at station 5 (Table 2).

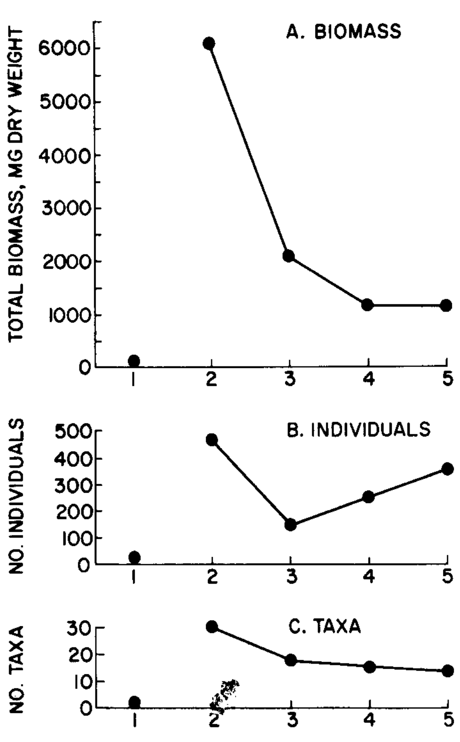

Fig. 2. Total biomass (A), number of individuals (B) and taxa (C) of aquatic insects recorded at each of the five stations. All data based on 10 ft^2 (0.93 m^2) bottom sample at each station.

The diversity indexes ($\bar{d}$) at each station calculated through the use of the Shannon–Weiner function are shown in Table 2. The numerical value for the diversity of highly polluted station 1 was 0.92. For the control station 2 it was 3.10. Below the entrance of the acid feeder stream, the index was relatively constant (1.95 at station 3, 1.46 at station 4, and 1.94 at station 5).

The results of the transfer experiment indicate that both *Acroneuria* and *Allonarcys* were able to survive at all stations along Upper Three Runs for a period of 7 days (100% survival) but were unable to survive in the acid feeder stream (0% survival). However *Allonarcys* and *Acroneuria* were only collected at

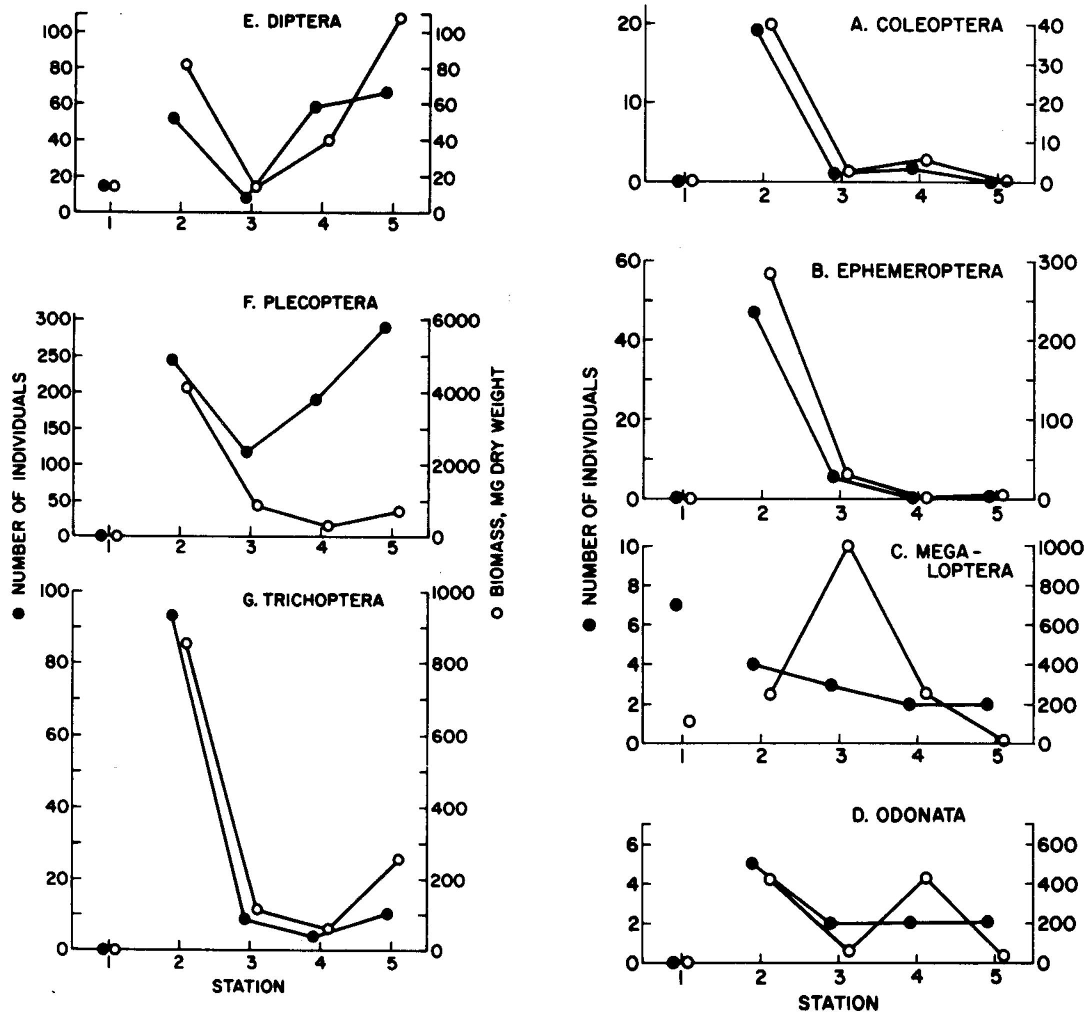

Fig. 3. Changes in biomass and numbers of individuals of various orders of aquatic insects in the acid feeder (station 1) and Upper Three Runs (station 2-control; stations 3 to 5-acid polluted). Data based on 10 ft^2 (0.93 m^2) bottom sample.

station 2, with the exception of one individual of the latter from station 3.

DISCUSSION

Upper Three Runs, below the entrance of the acid feeder stream, represents an interesting marginal situation in terms of pH for aquatic insects. The diversity indexes from the Shannon–Weiner function can be compared to those calculated for the Tioga River (in Tioga Country, PA) by Weed & Rutschky (1972). They considered a diversity greater than 3.0 to be unpolluted, a diversity of 1.0–2.0 moderately polluted and a diversity of less than 1.0 as severely polluted. Thus the acid feeder stream may be considered severely polluted (index 0.92), station 2 unpolluted (3.10), and stations 3, 4, and 5 with diversity indexes of 1.95, 1.46 and 1.94, respectively, as moderately polluted.

The stonefly *Acroneuria* which was only found once at stations 3–5, was capable of surviving at least 7 days at all stations along Upper Three Runs. *Acroneuria lycorias* had a LD_{50} for a 96-h period of pH 3.32 (Bell & Nebeker, 1969). The Plecopteran *Nemoura* fluorished better in moderately polluted water than at the control station. This same genus is reported to be abundant in Europe in areas of acid mine pollution (Koryak *et al.*, 1972) and may be an opportunistic species.

Aquatic insect populations were very severely affected even at pH's between 4.8 and 5.0 in Upper Three Runs. However a stable biomass of about 1100 mg dry wt/0.93 m^2 or about 1.2 g/m^2 (made up of approximately a dozen taxa) was present. Warner (1971) found more taxa (around 25) at pH 4.5 and above in a West Virginia stream. His sampling techniques may have been more thorough. Koryak *et al.* (1972) found a high benthic invertebrate biomass (mainly chironomids) at pH's (near 2.6) far too low to support fish life, whereas in moderately polluted conditions insect populations were diminished by iron deposition. We found that an insect community of reasonable diversity and biomass persisted at pH's between 4.8 and 5.0 and could provide adequate food

Table 2. Summary of the number of individuals collected in each taxa, the total number of individuals, total number of taxa and the diversity at each station based on the two samples (5 ft^2 each) of June 25 and July 16, 1974

Taxonomic units	Stations 1	2	3	4	5
Plecoptera					
Acroneuria		6/7	0/1		
Peltoperla		0/4			
Nemoura		1/10	4/5	0/1	31/72
Leuctra 1		96/113	43/57	109/70	85/86
Leuctra 2		4/1	4/1	0/1	0/3
Allonarcys		3/3			
Coleoptera					
Family Dytiscidae		0/2	1/0	1/0	
Unidentified Adult Beetle		2/15		0/1	
Ephemeroptera					
Family Heptageniidae 1		3/0	1/0		1/0
Family Heptageniidae 2			1/0		
Family Heptageniidae 3		0/2	0/3		
Family Heptageniidae 4		0/2			
Family Heptageniidae 5		0/2			
Family Heptageniidae 6		0/3			
Family Heptageniidae 7		0/3			
Family Baetidae 1		12/13			
Family Baetidae 2		1/0			
Family Baetidae 3		0/1			
Family Baetidae 4		0/2			
Family Baetidae 5		0/2			
Megaloptera					
Family Corydalidae		2/2	1/0	0/2	
Family Sialidae (*Sialis*)	7/0		2/0		1/1
Odonata					
Family Gomphidae		1/4	1/0	1/1	0/2
Family Cordulegasteridae			1/0		
Diptera					
Family Chironomidae 1				1/0	1/0
Family Chironomidae 2	13/1	15/30	5/2	33/16	33/26
Family Tipulidae		0/5	0/1	2/0	
Family Simuliidae		0/1		5/0	3/3
Unidentified Diptera				2/0	1/0
Trichoptera					
Family Hydropsychidae		17/14	1/3	2/0	3/4
Family Philopotamidae		3/49	2/1	0/1	
Family Lepidostomatidae		0/5		1/0	0/1
Unidentified Trichoptera 1					0/2
Unidentified Trichoptera 2		2/0	2/0		
Unidentified Trichoptera 3		0/2			
Unidentified Trichoptera 4		0/1			
Total Number of Individuals	21	467	143	250	359
Total Number of Taxa	2	30	17	15	13
Diversity index $\bar{d}$	0.92	3.10	1.95	1.43	1.94
Mean pH	3.20	~6	4.68	4.90	5.00

Data for each date are separated by a slash. Each taxonomic unit is considered to be the equivalent of a genus, even though many specimens were not identified to the generic level.

for a small population of fish. Whether or not fish can be developed through a process of acclimation or genetic selection to survive the hostile chemistry of these waters remains uncertain.

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