With best wishes,
Selwyn Roback

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ABSTRACT. — The effects of both constant and intermittent acid mine drainage on the insect fauna of some western Pennsylvania streams were studied. The results showed that under conditions of constant acid mine drainage, the Odonata, Ephemeroptera and Plecoptera were completely eliminated. The Trichoptera, Megaloptera and Diptera were reduced in number of species. *Ptilostomis* (Trichoptera), *Sialis* (Megaloptera and *Chironomus attenuatus* (Diptera) were tolerant of the conditions produced by acid mine drainage. The non-benthic Hemiptera and Coleoptera were little affected and developed large populations in the stations damaged by acid mine drainage.

Under intermittent acid mine drainage a diverse but slightly depressed insect fauna was able to develop.

INTRODUCTION

The data herein reported were gathered as part of an overall survey of Slippery Rock Creek and Wolf Creek (Butler County, Pennsylvania) with a view to assaying the damage caused by acid mine drainage. The studies were conducted by the Limnology Department of the Academy of Natural Sciences, under the direction of Dr. Ruth Patrick. Mr. Robert R. Grant, Jr. was in charge of the field operations and the authors are indebted to him and other members of the department for data on the stations and literature. The chemical determinations were done by Mr. Robert W. Haug of the Department of Limnology.

We are also indebted to Dr. Charles Hodge IV for the Coleoptera determinations, Dr. Minter J. Westfall, Jr. for the Odonata and Dr. Jon Hering for the determination of *Notonecta lunata* Hung.

PREVIOUS WORK

The literature concerning the effects of acid mine drainage on the aquatic insect fauna is both limited and scattered. The general picture that can be gleaned from these papers is that under constant acid mine drainage the benthic insect fauna of any body of water is completely eliminated or reduced to a small fraction of that present above the entrance of the pollutant. As the Ohio River Committee and U.S. Public Health Service state in 1944, "under acid mine drainage conditions, biological processes and characteristics of the streams are substantially altered. Normal biological activity is retarded. In other words, the stream is no longer the habitat for desirable aquatic life."

The most comprehensive series of papers documenting the effects of acid mine drainage are those by Oliff, Kemp and King (1960-1967), Harrison (1958, 1962) and Parsons (1968). These papers document the reduction in insect fauna as the result of acid mine wastes. In their 1965 paper, Oliff, Kemp and King found only Chironomidae well established (15 rock samples) in the Ebusi River (SO_4, 3000-3230 ppm) and elmid beetles in the Wasbaeck River (So_4, 2010-2310 ppm). In the marginal vegetation they found *Pseudagrion natalense* Ris, Chironomidae and *Palpomyia* in the Ebusi River and the first two and *Pentaneura* sp. in the Wasbaeck River. Oliff (1960) noted that in streams fed by colliery effluents the damage is severe, especially in winter. Kemp (1967) notes that the conversion of ferrous to ferric iron requires oxygen and that while the deposition of iron compounds does not change acidity, the decrease in pH and the combination of low pH, low O_2 and blanketing of the bottom destroy living organisms. Oliff (1963) cites a stream from an abandoned colliery with no fauna, pH 2.6 - 4.0 and a light-red covered bottom. Harrison (1958) in comparing the polluted Klip Creek with the unpolluted Sadelboom Creek notes that in riffles the fauna of the Klip is poor in species and numbers, about one-third that of the Sadelboom, and is dominated by Oribatoides (=Oribatei) and Chironomidae. Mayflies, caddisflies, aquatic beetles, *Simulium* spp. and Orthocladiinae were eliminated by the acid conditions. The same conditions prevailed in the stream vegetation. He mentions that some caddisflies such as *Leptocerus harrisoni* and *Argyrobothrus* sp. are tolerant.

Parsons (1968) in his very comprehensive paper on Cedar Creek, Missouri shows that an insect community composed of *Pantala hymenea* Say, *Procladius* sp., *Probezzia* sp., *Spaniotoma* sp. and *Sialis* sp. was well adapted to an acid mine drainage environment. These species or most of them were the residuum found under pollution conditions, of the communities he describes. He also points out that "there is no such thing as an indicator species by which water quality can be determined. It is possible that several species might be taken as an indication of the water quality; however it is felt that only the response of a community is indicative of such quality."

This same picture of the reduction or elimination of the insect fauna by acid mine drainage, is shown in papers by Riley (1960), Patrick et al. (1956), Jewell (1962), Walter (1966), Parsons (1952), Lackey (1939) and others. For a more comprehensive review of the literature the reader is referred to Parsons (1958). Though there are some gaps, this paper gives an extensive bibliography of papers related to all aspects of acid mine pollution. Papers by Campbell et al. (1965), Harp and Campbell (1967) and Parsons (1964) deal with strip-mine lakes.

Station Locations and Collection Data

A series of six stations, 5 on Slippery Rock Creek or its branches and one on Wolf Creek, were studied both in June-July and September. All are in Butler Co., Pennsylvania. The station locations, collection dates and collectors are as follows:

Station 1 — North Branch of Slippery Rock Creek, 2 mi. south of Barkeyville, 26-VI-67 (Richardson); 3-IX-67 (Roback)
Station 2 — North Branch of Slippery Rock Creek, 2.5 mi. west-northwest of Boyers 1-VII-67 (Richardson); 4-IX-67 (Roback)
Station 3 — North Branch of Slippery Rock Creek, 2 mi. west-southwest of Boyers, Roenizk Road bridge. 2-VII-67 (Richardson); 4-IX-67 (Roback)
Station 4 — Slippery Rock Creek, 1 mi. north of Hilliards. 30-VI-67 (Richardson); 2-IX-67 (Roback)
Station 5 — South Branch Slippery Rock Creek, 1 mi. north of Coaltown 28-VI-67 (Richardson); 2-IX-67 (Roback)
Station 6 — Wolf Creek, 1.5 mi. northwest of Slippery Rock 29-VI-67 (Richardson); 1-IX-67 (Roback)

Physical Aspects of the Stations

Station 1 — North Branch Slippery Rock Creek: The creek here was small, 8-14 feet wide and meandered through meadows and fields. At the upper limit of the station there was a moderate riffle created by rock rubble which formed the footing for a small bridge. Below this the stream widened out into a larger pool area with a soft mud bottom. This pool area was margined with some rocks, debris and vegetation. Below the pool the stream narrowed again, flowing over a sand and gravel bottom between steep eroded banks. There were some patches of mud and some stands of sedges.

Station 2 — North Branch Slippery Rock Creek: This station was 4 miles below Station 1. The creek here was wider than at Station 1 (15-25 feet) and the station was in the shape of an S. At the upper end there was a large slack water area margined on the right by extensive beds of emergent vegetation. Below this there was a pool area with a soft mud bottom extensively covered by leaf litter. At the lower end of this pool there were some scattered beds of emergent vegetation and some exposed roots. Another extensive bed of vegetation extended along the right bank below this. Up to this point the banks were clear, below both banks were largely tree lined. At one point the trees and shrubbery formed a cover which extended across the station. The bottom was sand and gravel with occasional patches of mud and floc. There were some scattered rocks and logs and other debris but a well developed riffle was absent. Extensive ferric hydroxide precipitate was present.

Station 3 — North Branch Slippery Rock Creek: Structurally this station was different from either of the above two. The stream was relatively straight and uniform in cross section. The bottom consisted of 1-3 feet of soft gray mud over a bed of firm sand and clay. There were few rocks except at the lower limit, at the footing of a small bridge. There were no clear riffle or backwater areas. A few scattered patches of *Potamogeton* were present, especially along the left bank. The banks except near the upper limit of the station were bare. Only a few submerged logs and snags were present. One of these (snags) was at the lower limit of the station. The current was rather sluggish and uniform throughout the station. There was no evidence of any ferric hydroxide precipitate.

Station 4 — Main Branch, Slippery Rock Creek: This station was surrounded by open-pit mining. There was a heavy precipitate of ferric hydroxide throughout the station. Probably due to the low pH, all the iron was not precipitated and the water, unlike that at the other stations, had a red-orange color. At the upper limit of the station there was some coarse gravel and rocks with some leaf litter over a hard clay bottom. Below this the bottom was clay. Toward the upper end of the left bank there were some logs and debris and opposite these a small mud bottomed ditch. The bottom, below this, was clay with some patches of gravel. At the lower limit of the station, there was a deep clay bottomed pool with clay-mud banks. The margins of the station had scattered small trees and there were scattered patches of debris and small snags. The stream was 10-18 feet wide and except in the pool, not over 2 feet deep.

Station 5 — South Branch Slippery Rock Creek: This station possessed a very varied selection of habitats. At the upper limit, the bottom was covered by twigs, leaves and other debris — the latter especially in areas of slower water. The depth was $1\frac{1}{2}$-$2\frac{1}{2}$ feet. The bottom substrate was composed of sand and twigs with some clay along the right bank. Just above the bridge (two-thirds from the upper limit of the station) there was a clay bar along the left bank. There were a few fallen trees here and some snags opposite them. Below the bridge there was an extensive riffle area. The substrate here was encrusted with heavy sulfide-like deposits. Below the riffle a large pool was formed by an extensive log jam, and the bottom was composed of soft clay and mud. The log jam itself provided a varied habitat of mud covered substrate and tangled debris. The margins of the stations were tree lined with some exposed roots, vegetation and soft sandy mud. The station was 12-21 feet wide. There was no evidence of ferric hydroxide precipitate, but the station periodically had received slugs of acid-mine drainage in the past.

Station 6 — Wolf Creek: This was the largest of the stations surveyed some places it was 40-50 feet wide and up to 3 feet deep. At the upper end of the station, at a narrowing of the creek, there was a large riffle composed of bed rock and rubble. Adjacent to and below the riffle there were several small backwater areas and quiet pools. These had soft mud bottoms and there was a great deal of both submerged and emergent aquatic vegetation. Below the riffle, the stream widened and flowed more slowly over a sandy cobblestone bottom. The banks were gently sloping and there was abundant marginal emergent vegetation. At the lower limit of the station the emergent vegetation and algae all but completely crossed the width of the station. There was little debris, logs or tree limbs within the station. As at Station 5, there were some sulfide-like deposits present. Some organic pollution was present but there was no acid mine drainage into this station.

Sources of Pollution

The entire area around the streams studied supports extensive coal mining operations. The oxidation of the pyrites exposed during such operations results in the production of sulfuric acid and ferric sulfate. In the area of study, this pollutant (acid mine drainage) finds its way into the North Branch of Slippery Rock Creek between Stations 1 and 2, (Map 1, solid arrow); into Slippery Rock Creek above Station 4 (Map 1, solid arrow) and intermittently into the South Branch of Slippery Rock Creek above Station 5 (Map 1, dashed arrow).

Chemical and Physical Effects

Four sets of chemical analyses were done at each station, two in June and two in September. The following procedures were observed in the performance of these analyses.

Collection of Water Samples for Chemical Analyses. — Samples for chemical analysis were collected in ½ gallon polyethylene bottles. Samples for heavy metal analysis were collected in 15 ml. glass test tubes and acidified with hydrochloric acid to prevent precipitation. Samples for dissolved oxygen (D.O.), initial D.O. samples for biochemical oxygen demand (B.O.D.) and initial and final D.O. samples for immediate dissolved oxygen demand (I.D.O.D.) were fixed in the field. Samples for I.D.O.D. were incubated at ambient stream temperature, but samples for B.O.D. were incubated at the field laboratory. All samples for oxygen determinations were collected in a 300 ml. B.O.D. bottle, with a minimum of aeration. Temperature measurements were made in the field at the time of collection.

Analysis of Water Samples. — The following analytical procedures were done in accordance with *Standard Methods,* 1965, 12th Edition; acidity, alkalinity, chloride, dissolved oxygen, biochemical oxygen demand, immediate dissolved oxygen demand, solids (total, volatile and fixed) sulfate, orthophosphate, silica, ammonia nitrogen, nitrate nitrogen, turbidity, total and calcium hardness. Calcium and magnesium values were calculated from the hardness. Iron, manganese, copper and lead were determined by atomic absorption. A Perkin-Elmer Model 303 atomic absorption spectrophotometer was used to determine each metal. Specific conductance was measured on an Analytical Instruments conductivity bridge. The pH was determined potentiometrically using a Beckman Zeromatic II meter.

RESULTS

The results of these analyses are shown in Tables 1-6. Station 1 is not affected by acid mine drainage and represents a base-line for Stations 2, 3 and 4. Table 1 shows its chemical parameters.

As can be seen from Table 2, the effect of the acid mine drainage entering above Station 2 was to increase the acidity (M.O.) and depress the M.O. alkalinity. As would be expected the sulfate and the specific conductivity took a marked jump upward and the pH dropped from a range of 7.2-7.3 at Station 1 to 4.4-5.6 at Station 2. There was little change in the iron at Station 2. The pH was still sufficiently high to precipitate the iron as ferric hydroxide. In general, the effects of the mine drainage appeared to be more pronounced in the spring when the runoff was greater. The ranges and means of the above mentioned analyses are shown graphically in Charts 1 and 2.

Station 3 showed little significant change in chemical analysis from Station 2. The sulfate was lower and the pH was higher but the differences were slight. There was little of the ferric hydroxide precipitate here. Undoubtedly most had already precipitated before reaching this station. The stream bed was covered with 1-3 feet of soft gray mud. This may have resulted from the erosion of mine tailings.

Station 4 on the main branch of Slippery Rock Creek showed the most severe effects from acid mine drainage. It had the highest acidity and specific conductance of any of the stations. The alkalinity (M.O.) was 0 and the sulfate about the same as Station 2. Though the bottom and all the rocks were rust colored, indicating ferric hydroxide precipitation, the pH 3.0-3.4 was apparently low enough to permit ferric, ferrous and colloidal iron to remain in solution. As a consequence the water itself here was orange colored and the iron readings were the highest of any of the stations (see Chart 2).

Station 5 (Table 5) was only subject to intermittent pollution by acid mine drainage and consequently while the sulfate and specific conductance

TABLE 1.—Chemical analysis of Station 1
(All results in ppm except where indicated)

Water characteristic	25-VI-67	26-VI-67	1-IX-67	3-IX-67
Acidity MO	0.0	0.0	0.0	0.0
Acidity P	4.0	5.0	14	12
Alkalinity P	0	0	0	0
Alkalinity MO	36	43	37	58
Hardness total as $CaCo_3$	64	68	72	109
Hardness, Calcium as $CaCo_3$	52	58	56	85
Hardness, Magnesium as $CaCo_3$	12	10	16	24
Calcium	21	23	22	34
Magnesium	2.9	2.4	3.9	5.8
Iron	0.81	4.97	0.83	0.61
Manganese	0.11	1.11	0.16	0.02
Lead	0.08	0.07	0.05	0.05
Copper	0.04	0.16	0.02	0.03
Silica	2.8	3.4	9.6	5.4
Sulfate	30	20	19	34
Nitrate-Nitrogen	0.70	0.46	.20	.22
Ammonia-Nitrogen	0.10	0.09	.17	.18
Orthophosphate-phosphorous	0.05	0.05	0.03	0.03
Chloride	6.4	6.0	16	12
Total solids	80	90	166	226
Volatile Matter	42	42	46	56
Fixed residue	38	48	120	170
Turbidity	27	13	13	10
Dissolved oxygen	8.4	—	10.7	—
B. O. D.	0.8	—	1.6	—
I. D. O. D.	0.1	—	0.3	—
pH	7.3	7.3	7.2	7.2
Specific conductance (micromhos at 25°C)	151	153	172	266
Temperature °C	16.0	—	12.5	—

TABLE 2. — Chemical analysis of Station 2
(All results in ppm except where indicated)

Water characteristic	25-VI-67	26-VI-67	1-IX-67	3-IX-67
Acidity MO	14	12	20	38
Acidity P.	14	15	0.0	0.0
Alkalinity P.	0	0	0	0
Alkalinity MO	0	0	2	2
Hardness total as $CaCo_3$	250	250	184	249
Hardness, Calcium as $CaCo_3$	179	199	132	181
Hardness, Magnesium as $CaCo_3$	71	51	52	68
Calcium	72	80	53	72
Magnesium	17	12	13	16
Iron	0.49	0.93	2.22	2.23
Manganese	3.43	3.91	2.09	3.11
Lead	0.05	0.06	0.06	0.05
Copper	0.11	0.05	0.03	0.03
Silica	4.3	4.0	8.4	7.4
Sulfate	315	330	183	261
Nitrate-Nitrogen	0.20	0.20	0.23	0.16
Ammonia-Nitrogen	0.40	0.31	0.26	0.17
Orthophosphate-phosphorous	00.04	0.05	0.03	0.03
Chloride	6.0	7.0	10	11
Total Solids	412	410	328	434
Volatile Matter	46	32	26	6
Fixed residue	366	378	302	428
Turbidity	3	1	32	35
Dissolved oxygen	8.6	—	9.7	—
B. O. D.	0.2	—	0.4	—
I. D. O. D.	0.1	—	0.1	—
pH	4.5	4.4	5.6	4.8
Specific conductance (micromhos at 25°)	541	540	368	532
Temperature °C	17.0	—	13.0	—

TABLE 3. — Chemical analysis of Station 3
(All results in ppm except where indicated)

Water characteristic	25-VI-67	26-VI-67	1-IX-67	3-IX-67
Acidity MO	12	11	12	17
Acidity P	2.0	1.7	0.0	0.0
Alkalinity P	0	0	0	0
Alkalinity MO	6	7	8	11
Hardness, total as $CaCo_3$	248	252	147	210
Hardness, Calcium as $CaCo_3$	174	190	104	150
Hardness, Magnesium as $CaCo_3$	74	62	43	60
Calcium	70	76	42	60
Magnesium	18	15	10	15
Iron	0.59	2.29	1.46	0.57
Manganese	3.41	3.47	1.78	2.35
Lead	0.05	0.08	0.05	0.05
Copper	0.02	0.06	0.03	0.03
Silica	3.3	4.7	4.2	5.8
Sulfate	295	265	130	194
Nitrate-Nitrogen	0.20	0.20	0.17	0.16
Ammonia-Nitrogen	0.26	0.22	0.27	0.17
Orthophosphate-phosphorous	0.05	0.05	0.02	0.03
Chloride	6.0	7.0	8.0	11.0
Total Solids	426	426	220	310
Volatile Matter	44	54	8	12
Fixed Residue	382	372	212	198
Turbidity	1	1	3	6
Dissolved oxygen	8.8	—	9.6	—
B. O. D.	0.8	—	0.5	—
I. D. O. D.	0.1	—	0.1	—
pH	4.7	4.7	5.9	6.0
Specific conductance (micromhos at 25°)	510	510	289	466
Temperature °C	19.0	—	19.0	—

TABLE 4. — Chemical analysis of Station 4
(All results in ppm except where indicated)

Water characteristic	27-VI-67	28-VI-67	1-IX-67	3-IX-67
Acidity MO	49	44	40	43
Acidity P	15	18	28	30
Alkalinity P	0	0	0	0
Alkalinity MO	0	0	0	0
Hardness, total as $CaCo_3$	154	176	147	174
Hardness, Calcium as $CaCo_3$	110	120	102	114
Hardness, Magnesium as $CaCo_3$	44	56	45	60
Calcium	44	48	42	46
Magnesium	11	14	11	15
Iron	11.8	21.4	8.50	9.0
Manganese	1.18	1.76	1.57	1.38
Lead	0.05	0.10	0.06	0.05
Copper	0.07	0.08	0.03	0.03
Silica	4.5	4.5	8.4	9.1
Sulfate	310	320	183	211
Nitrate-Nitrogen	0.20	0.32	0.25	0.54
Ammonia-Nitrogen	0.24	0.11	0.36	0.29
Orthophosphate-phosphorous	0.06	0.04	0.02	0.03
Chloride	10	8.0	44	50
Total solids	424	420	286	392
Volatile Matter	22	72	86	36
Fixed residue	402	348	200	356
Turbidity	1	6	13	13
Dissolved oxygen	—	7.8	8.3	—
B. O. D.	—	0.6	1.0	—
I. D. O. D.	—	0.2	0.2	—
pH	3.0	3.0	3.3	3.4
Specific conductance (micromhos at 25°C)	775	714	497	655
Temperature °C	—	20.0	17.0	—

TABLE 5. — Chemical analysis of Station 5
(All results in ppm except where indicated)

Water characteristic	27-VI-67	28-VI-67	1-IX-67	3-IX-67
Acidity MO	5.2	9.0	14	16
Acidity P	0.0	0.0	0.0	0.0
Alkalinity P	0	0	0	0
Alkalinity MO	62	60	32	40
Hardness, total as $CaCo_3$	318	326	306	272
Hardness, Calcium as $CaCo_3$	244	216	184	168
Hardness, Magnesium as $CaCo_3$	74	110	122	104
Calcium	98	86	74	67
Magnesium	18	27	30	25
Iron	1.13	2.48	0.36	0.29
Manganese	1.12	1.58	2.73	2.35
Lead	0.05	0.13	0.05	0.05
Copper	0.03	0.10	0.02	0.03
Silica	2.6	4.7	5.5	4.6
Sulfate	330	295	266	236
Nitrate-Nitrogen	0.14	0.09	0.11	0.05
Ammonia-Nitrogen	0.14	0.28	0.09	2.09
Orthophosphate-phosphorous	0.05	0.04	0.03	0.03
Chloride	24	22	30	30
Total solids	494	576	386	368
Volatile Matter	66	36	14	46
Fixed residue	438	540	372	422
Turbidity	20	33	6	6
Dissolved Oxygen	—	9.5	10.0	—
B. O. D.	—	1.5	0.8	—
I. D. O. D.	—	0.0	0.1	—
pH	7.3	7.2	6.6	6.8
Specific conductance (micromhos at 25°C)	683	673	606	633
Temperature	—	18.0	15.5	—

TABLE 6. — Chemical analysis of Station 6
(All results in ppm except where indicated)

Water characteristic	27-VI-67	29-VI-67	1-IX-67	3-IX-67
Acidity MO	—	—	0.0	0.0
Acidity P	—	—	6.0	4.0
Alkalinity P	17	0	0	0
Alkalinity MO	89	106	88	88
Hardness, Total as $CaCo_3$	218	214	194	200
Hardness, Calcium as $CaCo_3$	162	158	132	142
Hardness, Magnesium as $CaCo_3$	56	56	62	58
Calcium	65	63	53	57
Magnesium	14	14	15	14
Iron	0.59	0.62	0.37	0.36
Manganese	0.12	0.10	0.26	0.30
Lead	00.08	0.06	0.05	0.06
Copper	0.06	0.05	0.04	0.02
Silica	1.6	1.8	5.0	3.5
Sulfate	155	115	116	114
Nitrate-Nitrogen	2.20	2.42	1.08	1.28
Ammonia-Nitrogen	0.28	0.14	0.16	0.14
Orthophosphate-phosphorous	0.52	0.60	0.22	0.38
Chloride	10	12	12	16
Total solids	392	342	256	308
Volatile Matter	86	64	58	64
Fixed residue	306	278	198	244
Turbidity	27	30	25	13
Dissolved oxygen	—	10.7	9.8	—
B. O. D.	—	2.0	1.8	—
I. D. O. D.	—	0.2	0.0	—
pH	8.8	8.1	7.3	7.6
Specific conductance (micromhos at 25°C)	470	479	373	477
Temperature °C	—	20.0	14.0	—

were still high, the acidity was down (Chart 1), the alkalinity up and the pH was in the 6.7-7.3 range. Except for some sulfide-like encrustations there was no precipitate evident and the iron content of the water was in the range of Stations 1-3.

Station 6 was physically most like Station 5. It had a great variety of habitats and was not subject to direct acid mine drainage. As can be seen from Table 6, the acidity (M.O.) was 0 and the alkalinity in the 88-106 range. The values for sulfate and specific conductance were below those for Station 5 and the pH was in the 7.3-8.8 range.

The chemical data indicate that the stations most influenced by acid mine drainage were 2, 3, and 4. Station 5 was influenced but to a lesser degree and there is no evidence of any effect at Stations 1 or 6.

Effects on the Insect Fauna

Station 1: The insect fauna of the unpolluted Station 1, 132 species overall (92 species in June, 66 in September) was well developed, with a balanced assemblage of species in each order. This is shown visually in Chart 4. Elements of the benthic fauna, such as the Ephemeroptera nymphs, Trichoptera and Diptera larvae were especially well developed with 16, 19 and 41 species, respectively. All the insect orders were represented in the proportion which one finds in a normal healthy stream. There were no obvious population imbalances.

Station 2: The results of the introduction of the acid mine drainage on the benthic fauna are most striking. A glance at Chart 3 shows that the drop in species number at Station 2 was more precipitous in the spring than in the fall, possibly a result of the greater runoff at that season. Chart 4 shows that many of the columns present at Station 1 are absent at 2 and those that remain are depressed. The fauna of 14 species of insects found here in the spring and 20 species in the fall was dominated by the non-benthic Hemiptera and Coleoptera. They represented over 50% of the species and an even greater percentage of the specimens found. Since both these orders are atmospheric oxygen breathers, they are not as affected by the low pH and floc as are those truly benthic insect nymphs and larvae which take their oxygen from the water and must live on a bottom or vegetation substrate. In addition, the adults of both the aquatic Hemiptera and Coleoptera are, in most cases, strong flyers and consequently highly mobile. The fact that in the spring and in the fall only 7 species were common to both Stations 1 and 2 would indicate that a good part of the insect fauna at Station 2 did not arrive by drift from Station 1. The megalopteran *Nigronia* sp. and odonate *Aeshna umbrosa* were represented by one specimen at each collection. These and the chironomid larvae, which were not too abundant, probably arrived as the result of drift. *Sialis* sp., *Ptilostomis* sp., some chironomid and beetle larvae represent the total benthic fauna here.

Station 3: This station while not having the floc of Station 2 had very similar water quality (Tables 2, 3) and the bottom was covered with a fine gray silt. There was a paucity of suitable insect habitats. As can be seen from Table 7 and Chart 4 the overall insect faunal picture is similar to, but even more depressed than that at Station 2. The beds of aquatic vegetation which provided the best habitats for the non-benthic Hemiptera and Coleoptera at Station 2 were absent here. As a consequence, the total Hemiptera fauna dropped from 8 species at Station 2 to 3 at Station 3 and the beetles from 10 to 3. In the spring 3 of the 7 species found at Station 3 were common to both Stations 2 and 3 while in the fall 7 of 12 were common to both.

Of the overall fauna of 17 species found here only the adult beetles and

TABLE 7. — Number of insect species, by order at each station, both surveys combined.

Station	1	2	3	4	5	6
Odonata	7	1	0	0	8	12
Ephemeroptera	16	0	0	0	5	11
Plecoptera	5	0	0	0	2	0
Hemiptera	11	8	3	3	8	13
Megaloptera	2	2	1	1	2	2
Coleoptera	31	10	3	11	15	17
Trichoptera	19	1	3	1	11	4
Lepidoptera	0	0	1	0	1	1
Diptera	41	9	6	4	13	21
Totals	132	31	17	20	65	81

TABLE 8. — Number of insect species, by order at each station in June and September.

	June						September					
Stations	1	2	3	4	5	6	1	2	3	4	5	6
Odonata	5	1	0	0	7	6	6	1	0	0	5	9
Ephemeroptera	11	0	0	0	4	8	9	0	0	0	4	8
Plecoptera	5	0	0	0	1	0	0	0	0	0	1	0
Hemiptera	6	3	1	2	4	9	7	5	2	2	5	7
Megaloptera	1	2	1	1	2	1	2	1	1	1	2	2
Coleoptera	22	4	2	7	14	10	11	6	2	6	4	11
Trichoptera	15	0	0	0	6	3	10	1	3	1	6	4
Lepidoptera	0	0	0	0	0	0	0	0	1	0	1	1
Diptera	27	4	3	3	8	11	21	6	3	2	8	12
Totals	92	14	7	13	46	48	66	20	12	12	36	54

the benthic *Sialis* and chironomid larvae had well developed populations. The remaining species were represented by one or a few specimens and may have washed in. The *Sialis* larvae and the chironomid larvae were found primarily in the soft mud, while the other insects found were randomly scattered throughout the station. It would seem that the poor and unstable habitats as well as the effects of the acid mine drainage are responsible for the poor insect fauna here.

Station 4: This station had the lowest pH, alkalinity, the highest acidity (MO) and iron concentrations of any of those studied (See Charts 1, 2). The habitats were well developed and diverse, but all were covered by iron floc. Physically it is closer to Station 2 than 3. Despite the availability of niches, the insect fauna was sparse except for a large population of dytiscid beetles in June (adults and larvae), Corixidae, *Sialis* and chironomid larvae. There were smaller populations of beetles in September. All these insects though present as large populations were restricted as to number of species. From the population aspect, the single dominant insect family here was the Corixidae. The adult and nymphal Corixidae were found in both June and September in pool areas where they darted back and forth over the flocculent deposits.

The chironomids which were nearly as numerous, were found in the bottom and drifting downstream in great numbers. The *Sialis* larvae were also in the mud bottom. The larvae of the phrygeneid caddisfly *Ptilostomis* were fairly common in September but were absent in June. This is the only caddisfly, in this study, that appeared to be tolerant of acid mine pollution. Harrison (1958) found *Leptocerus harrisoni* and *Argyrobothrus* to be somewhat tolerant. Both of these live on submerged vegetation. Overall only 20 species of insects were found here compared to 31 at Station 2 (Table 7).

As can be seen from Chart 4, the faunal pattern is little different from that of Stations 2 and 3. As at the aforementioned stations, the atmospheric oxygen breathers and mobile species (Hemiptera and Coleoptera) dominated the insect fauna. The benthic fauna consisted of the above listed *Sialis* sp., *Ptilostomis* sp. and chironomid larvae, especially *Chironomus* (*C.*) *attenuatus?* (Walk.). The only truly benthic Coleoptera, the Elmidae, drop out at Stations 2, 3 and 4.

Station 5: This station has as great a variety of habitats as Stations 1 or 6 but due to the effects of intermittent acid mine drainage the insect fauna has not been able to develop to its full potential. The overall insect fauna of 65 species was, however, reasonably diverse and well balanced. None of the imbalance in species diversity and abundance, as evident at Stations 2 and 3, was found here. The sporadic pH changes and the encrustation undoubtedly eliminated some of the more sensitive benthic species especially in the Ephemeroptera and Diptera.

As can be seen from Chart 4 the histogram pattern approaches that of Station 1 and is very close to that of the more comparable Station 6. The magnitude of the increase in species number over that of Stations 2-4 is clearly evident in Chart 3.

Most of the Coleoptera, Odonata, and *Sialis* sp. were found in mats of twigs, leaves or other debris in slack water. The riffle areas were well developed but there were only a few Ephemeroptera nymphs and Trichoptera larvae present. The heavy encrustation of a sulfide-like material may have inhibited the development of the insect fauna in this habitat. In the pool areas, numerous chironomid larvae and sprawling Anisoptera nymphs were present. The two limnephilids found in each survey were on the logs in the snags where some Diptera also were present. The exposed roots and soft sandy mud along the banks were inhabited by Trichoptera, Diptera, Plecoptera, Coleoptera and Odonata. In the shallow stream margins, the dense stream-side vegetation was inhabited by Hemiptera and Coleoptera. They were more abundant in June than in September. This station represents the recovery response of Parsons (1968).

Station 6: This station though showing some of the same sulfide-like deposits (due to organic loading) as Station 5, had a diverse and balanced insect fauna. Except for the absence of Plecoptera, all the orders were present and represented by a variety of species. The only indication of any deleterious effects are the absence of the Plecoptera and the reduced Trichoptera fauna. The Odonata and Hemiptera were represented here by more species than at any other station. As can be seen from Chart 4, the faunal pattern is almost identical to that of Station 5 and approaches that of Station 1.

SUMMARY

Of all the elements of the benthic insect fauna, the Odonata, Ephemeroptera and Plecoptera appear to be most severely affected by the products of acid mine drainage. They are eliminated from all stations receiving constant acid mine drainage. The single odonate found at Station 2 was represented by one specimen at each season. Under intermittent conditions (Station 5) or slight organic pollution (Station 6) they can develop moderate populations. The results of Harrison (1958), Oliff (1963) and others seem to indicate that some species of *Caenis, Baetis,* and *Euthraulus* are more resistant to acid mine pollution than other mayfly nymphs. The Trichoptera, while not completely eliminated are, on the whole, as severely affected as the above orders. In the spring they were completely eliminated at Stations 2-4 while in the fall only the phryganeid *Ptilostomis* was common and appears able to tolerate the chemical and physical conditions at these stations. Of the Megaloptera, *Sialis* appears to be tolerant of acid mine drainage. Large populations were present at Stations 1-5 at both seasons. Of the Diptera,

only some Chironomidae appear tolerant of acid mine pollution. The other Diptera and a goodly portion of the chironomid fauna are eliminated at Stations 2-4. The bars for Diptera on Chart 4 (Stations 2, 3, 4) are represented only by Chironomidae. Of the latter only *C.* (*C.*) *attenuatus?* (Walk.) appeared to be able to attain considerable population size. Harrison (1958) found no Tanypodinae under acid mine conditions but *Procladius* sp. larvae were present here at Station 2 in June and Stations 2 and 3 in September. *Pentapedilum anale* Fr. and *Chironomus linearis* Kieff. were the dominant chironomids under acid mine conditions described by Harrison. Parsons (1968) found *Pantala hymenea, Procladius* sp., *Probezzia* sp. *Spaniotoma* sp., and *Sialis* sp. to be tolerant benthic organisms. The non-benthic Hemiptera and Coleoptera were relatively less affected. Even when the species number was depressed they were the dominant insects, in number of specimens, at Stations 2, 3, 4. The Corixidae (Hemiptera) and Dytiscidae (Coleoptera) had the largest populations under acid mine drainage conditions.

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Appendix A

Species Lists of insects collected on each survey.

J = June
S = September - October
1-6 = stations at which species were found

Order Odonata
Suborder Zygoptera
Family Agrionidae
Calopteryx maculata (Beauv.) J1, 5, 6; S1, 5, 6
Hetaerina americana (Fabr.) S6
Family Coenagrionidae
Argia violacea (Hagen) J5, 6; S1
Argia moesta (Hagen) J6; S6
Chromagrion conditum (Hagen) S6
Enallagma exsulans (Hagen) J5; S6
Enallagma signatum (Hagen) J6
Ischnura verticalis (Say) J5; S5, 6
Suborder Anisoptera
Family Cordulegasteridae
Cordulegaster obliquus (Say) J1
Cordulegaster maculatus (Selys) S1
Family Gomphidae
Gomphus (Gomphurus) rogersi (Gloyd) J1, 5, 6; S1, 5, 6
Family Aeschnidae
Aeshna umbrosa (Walk.) J1, 2, 5; S1, 2, 5, 6
Boyeria vinosa (Say) J1, 5; S1
Basiaeschna janata (Say) S5
Family Libellulidae
Libellula pulchella (Drury) J6; S6
Plathemis lydia (Drury) J6
Order Ephemeroptera
Family Ephemeridae
Subfamily Ephemerinae
Ephemera poss. *varia* Eaton J6; S1
Family Caenidae
Caenis sp. J6; S6
Brachycercus nr. *lacustris* (Ndm.) J1
Family Ephemerellidae
Ephemerella temporalis? (McD.) J1, 6; S1
Ephemerella bicolor Clem. J5
Ephemerella sp. J1
Ephemerella lita? Burks J1
Family Leptophlebiidae
Paraleptophlebia praepedita (Eaton) S1
Habrophlebiodes americana? (Banks) J1
Family Baetidae
Subfamily Isonychiinae
Isonychia sp. J1, 6; S6
Subfamily Baetinae
poss. *Heterocloeon* sp. J1
Pseudocloeon sp. J6; S6
Neocloeon alamance Traver J1, 5; S1, 5, 6
Callibaetis sp. S6
Baetis sp. 1 J5; S1, 5
Baetis sp. 2 J1, 6; S1
Family Heptageniidae
Stenonema nr. *heterotarsale* (McD.) J1, 5, 6; S1, 5, 6
Stenonema nr. *ithaca* Burks J1
Stenonema nr. *vicarium* (Walk.) S1, 6
Stenonema nr. *ares* Burks J6; S5, 6
Stenonema tripunctatum (Banks) S1
Order Plecoptera
Suborder Holognatha
Family Nemouridae
Nemoura (Amphinemoura) wui Classen J1
Suborder Systellognatha
Family Perlodidae
Isogenus sp.? J1
Family Perlidae
Perlesta placida Hagen J1, 6
Neophasganophora capitata Pict. J1; S5
Acroneuria ruralis (Hagen) J1
Order Hemiptera
Suborder Heteroptera
Series Cryptocerata
Family Corixidae
Hesperocorixa sp. J1, 4, 5; S1, 2, 3, 4, 5
Hesperocorixa sp. 2 S1
Callicorixa audeni Hung. J2
Family Notonectidae
Notonecta lunata Hung. S2, 6
Family Naucoridae
Pelocoris femoratus (P. de B.) S6
Family Belostomatidae
Lethocerus americanus (Leidy) S1

Belostoma flumineum Say S1, 2, 6
Family Nepidae
Ranatra fusca P. de B. S2
Family Gelastocoridae
Gelastocoris oculatus (Fabr.) S6
Series Gymnocerata
Family Gerridae
Gerris remigis Say J1
Gerris marginatus Say J1, 2, 4, 5, 6
Gerris comatus D. & H. J6
Gerris sp.? S1, 2, 4
Gerris sp. females J1, 3
Metrobates hesperius Uhler J5, 6; S6
Trepobates knighti D. & H. J6; S5, 6
Trepobates inermis Esaki J6
Trepobates pictus (H.-S.) S5
Trepobates sp. (nymphs) J6; S1, 5, 6
Rheumatobates rileyi Bergr. S3
Family Veliidae
Rhagovelia obesa Uhler J1, 6; S1, 5
Family Mesoveliidae
Mesovelia mulsanti White J5, 6
Mesovelia sp. (nymphs) S2
Family Saldidae
Saldula sp. J1, 6
Order Megaloptera
Family Sialidae
Sialis sp. J1-5; S1-5
Family Corydalidae
Nigronia sp. J2, 5, 6; S1, 5, 6
Corydalis cornutus (L.) S6
Order Coleoptera
Suborder Adephaga
Family Haliplidae
Haliplus cribrarius Lec. S1
Haliplus ruficollis De. G. J1; S6
Peltodytes tortulosus Rbts. S1
Peltodytes lengi Rbts. J6; S6
Peltodytes edentulus (Lec.) J6; S6
Peltodytes sexmaculatus Rbts. S6
Peltodytes simplex (Lec.) J6
Peltodytes muticus (Lec.) S1
Haliplus sp. (larva) J1
Family Dytiscidae
Subfamily Lacophilinae
Laccophilus maculosus (Germ.) J4, 6; S2, 6
Laccophilus sp. (larva) J1, 4, 6
Subfamily Hydroporinae
Deronectes sp. J5
Bidessus affinis (Say) J2, 5
Desmopachria convexa (Aubé) J1, *6*
Agaporus sp. S4
Hydroporus pulcher (Lec.) J1, 4, 5; S3, 4
Hydroporus blanchardi Sherman J1, 3
Hydroporus wickhami Zaitz. J1
Hydroporus hybridus Aubé S2
Hydroporus sp. S1, 4
Hydroporus (*niger* group) sp. S4
Hydroporus sp. (larva) J2; S4
Hydroporus dilatalus Fall J1
Hydroporus cocheconis Fall J2
Subfamily Colymbetinae
Agabus gagates Aubé J1, 3, 4; S2, 3, 4
Agabus taeniolatus (Harr.)? J4
Agabus stagninus (Say) J1
Agabus sp. (larva) J4
Ilybius ignarus Lec. S2, 4
Coptotomus interrogatus (Fabr.) S6
Subfamily Hydaticinae
Graphoderes liberus (Say) S1
Acilius sp. (larva) J4
Thermonectes basilaris (Harr.) S6
Family Gyrinidae
Dineutes assimilis Aubé J6; S6
Dineutes sp. (larva) J6
Gyrinus fraternus Coup. J5
Gyrinus lecontei Fall S2
Suborder Haplogastra
Superfamily Hydrophiloidea
Family Hydrophilidae
Subfamily Helophorinae
Helophorus nitidulus Lec. J4
Helophorus lacustris Lec. J1, 5; S1
Helophorus lineatus Say J1, 6; S1
Helophorus oblongus Lec. J1
Helophorus sp. (larva) J1
Subfamily Hydrophilinae
Tropisternus lateralis (Fabr.) S2
Tropisternus glaber (Hbst.) J1, 6
Tropisternus sublaevis (Lec.) S6
Tropisternus sp. (larva) J5, 6; S6
Hydrobius tumidus Lec. J4
Hydrobius fuscipes Linn. J6
Hydrobius tesselatus Zimm. J2
Anacaena infuscata (Mots.) J1
Paracymus digestus (Lec.) J1, 5; S5, 6
Paracymus infuscatus (Mots.) J5; S1
Paracymus suturalis (Lec.) J1
Paracymus sp. (larva) J1
Enochrus ochraceous (Melsh.) J5

Enochrus nebulosus (Say) J1, 2, 6
Laccobius agilis Rand. J1, 5
Suborder Polyphaga
Superfamily Dryopoidea
Family Dryopidae
Helichus fastigiatus (Say) J5; S5
Helichus sp. (larva) S6
Family Elmidae
Dubiraphia quadrinotata (Say) J1, 5
Dubiraphia vittata (Melsh.) J1, 5; S5
Dubiraphia sp. (larva) J1; S1
Stenelmis sinuata Lec. S5
Stenelmis sp. (larva) J1
Optioservus ovalis (Lec.) S1
Optioservus sp. (larva) S1
Promoresia sp. S1
Family Heteroceridae
Heterocerus undatus (Melsh.) J5
Heterocerus ventralis (Melsh.) J1
Superfamily Chrysomeloidea
Family Chrysomelidae
Subfamily Donaciinae
Donacia sp. (larva) J1
Order Lepidoptera
Family Pyralidae
Subfamily Nymphulinae
Parargyractis sp. S6
Parapoynx sp. S3, 5
Order Trichoptera
Family Glossosomatidae
Agapetus prob. *illini* Ross J1
Family Psychomyiidae
Polycentropus prob. *crassicornis* (Walk.) J1; S1, 3, 5
Lype prob. *diversa* (Banks) S1
Nyctiophylax prob. *vestitus* (Hagen) J1, 5
Family Hydropsychidae
Hydropsyche sp. S5
Hydropsyche betteni Ross J5, 6; S3, 5
Hydropsyche (*bifida* group) sp. J5, 6; S6
Cheumatopsyche spp. J1, 5, 6; S1, 6
Macronemum sp. J1
Family Hydroptilidae
Leucotrichia sp. S6
Family Phryganeidae
Ptilostomis sp. S1-5
Family Limnephilidae
Platycentropus nr. *radiatus* (Say) J1
Pycnopsyche scabripennis? Ramb. S1, 5
Pycnopsyche guttifer? (Walk.) J1, 5; S1, 5
Pycnopsyche prob. *lepida* (Hagen) J1, 5; S1
Neophylax nacatus Denn. J1; S1
Family Molannidae
Molanna poss. *uniophila* Vorhies S1
Family Odontoceridae
Psilotreta sp. J1; S1
Family Leptoceridae
Athripsodes sp. J1
Oecetis inconspicua (Walk.) J1
Triaenodes sp. (nr. sp. b Ross) J1; S5
Mystacides prob. sepulchralis (Walk.) J1
Family Lepidostomatidae
Lepidostoma sp. J1
Order Diptera
Suborder Nematocera
Superfamily Tipuloidea
Family Tipulidae
sp. S1
Subfamily Tipulinae
Tipula spp. J1
Tipula abdominalis (Say) J1, 2, 5
Tipula caloptera (Loew) J1
Tipula nr. *collaris* Say J1
Subfamily Limoniinae
Limonia (*Dicranomyia*) sp. J6
Antocha saxicola O. S. J6
Hexatoma megacera O. S. J1
Pilaria? sp. J1; S1
Superfamily Psychodoidea
Family Ptychopteridae
Ptychoptera rufocincta (O. S.) J1
Superfamily Culicoidea
Family Dixidae
Dixa sp. 1 S1
Dixa sp. 2 S1
Family Culcidae
Subfamily Anophelinae
Anopheles sp. 1 J1; S1, 6
Anopheles sp. 2 S1, 5
Family Ceratopogonidae
Subfamily Ceratopogoninae
Palypomyia? sp. 1 S1, 6
Palypomyia? sp. 2 S1
Bezzia sp. (pupa) S1
Family Chironomidae
Subfamily Tanypodinae
Conchapelopia spp. J1, 5; S5
Conchapelopia cornuticaudata (Walley)

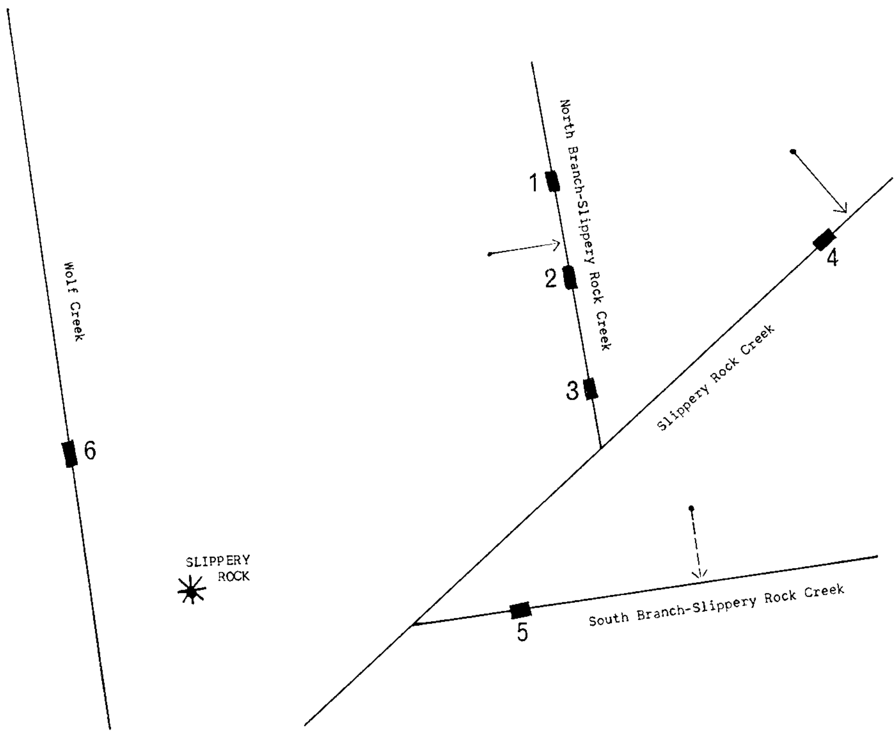
J1, 5
Conchapelopia prob. *currani* (Walley) J1
Zavrelimyia or *Paramerina* sp. S1
Tanypus carinatus? Subl. J6; S6
Procladius (*Ps.*) *bellus* (Loew) S5, 6
Procladius (*P.*) sp. 1 J1, 2; S2, 3, 6
Procladius (*P.*) sp. 2 S2
Coelotanypus poss. *scapularis* (Loew) S6
Subfamily Diamesinae
Diamesa sp. J1
Subfamily Orthocladiinae
Metriocnemus nr. *lundbecki* (Joh.) J1
Corynoneura (*T.*) *xena* Roback J1
Corynoneura (*C.*) nr. *scutellata* Winn. S1
Cardiocladius poss. *obscurus* (Joh.) J2, 6; S6
Cricotopus (*sylvestris* group) sp. 1 J6
Cricotopus (*sylvestris* group) sp. 2 S6
Cricotopus nr. sp. 1 Roback J6
Cricotopus nr. *exilis* (Joh.) J6
Cricotopus nr. *bicinctus* (Meig.) J1; S5
Psectrocladius nr. sp. 4 Roback S1, 6
Psectrocladius poss. *elatus* Roback S2, 3
Heterotrissocladius sp. ? S2
Subfamily Chironominae
Tribe Chironomini
Cryptochironomus nr. *fulvus* (Joh.) S1
Paratendipes albimanus ? (Meig.) J1
Stenochironomus (sensu Joh. 1937) sp. J3
Microtendipes caducus (Townes) S1
Chironomus (*C.*) *attenuatus ?* (Walk.) J1, 3, 4, 6; S1, 2, 4
Polypedilum nr. *fallax* (Joh.) J3, 5
Polypedilum nr. *convictum* (Walk.) J1, 2
Polypedilum illinoense? (Mall.) J4, 6; S1, 5
Polypedilum nr. *scalaenum* (Schrank) J4, 6
Phaenopsectra flavipes (Meig.) S6
Tribelos (sensu Townes) sp. S2, 3
Stictochironomus sp. 1 Roback J1; S1
Tribe Tanytarsini
Paratanytarsus sp.
Tanytarsus nr. *guerlus* (Roback) J1, 5; S5
Tanytarsus glabrescens ? (Walk.) S1
Tanytarsini (group A) sp. S4
Family Simuliidae
Simulium sp. 1 J1, 6
Simulium sp. 2 J5; S5
Suborder Brachycera
Superfamily Tabanoidea
Family Stratiomyinae
Stratiomyia sp. J5; S6
Family Tabanidae
Subfamily Pangoniinae
Chrysops sp. 1 J1; S1
Chrysops sp. 2 J1; S1
Family Rhagionidae
sp. S5, 6
Suborder Cyclorrhapha
Superfamily Drosophiloidea
Family Ephydridae
sp. J1
Superfamily Muscoidea
Family Muscidae
Limnophora sp. J1
sp. J1

APPENDIX B

The following species of adult Trichoptera were collected at the Stations indicated during the two surveys. Especially in June their emergence coincided with the survey. While not counted in the species number from each station, they were useful in indicating the probable identity of the larvae collected in the stream.

Adult Trichoptera
Family Glossosomatidae
Agapetus illini (Ross) J1
Family Psychomyiidae
Polycentropus crassicornis (Walk.) J1
Nyctiophylax vestitus (Hagen) J1
Lype diversa (Banks) J1
Family Hydropsychidae
Hydropsyche betteni Ross J1
Cheumatopsyche analis Banks J1
Cheumatopsyche oxa Ross J1
Family Hydroptilidae
Ochrotrichia anisca (Ross) J1
Family Limnephilidae
Pycnopsyche lepida (Hagen) S1, 5
Family Leptoceridae
Triaenodes nr. *ignita* (Walk.) J1
Mystacides sepulchralis (Walk.) J1

Map 1 — illustrates the physical relationship of the stations.



MAP 1. — Location of Survey stations. Solid arrow — steady pollution source; broken arrow — intermittent pollution source.

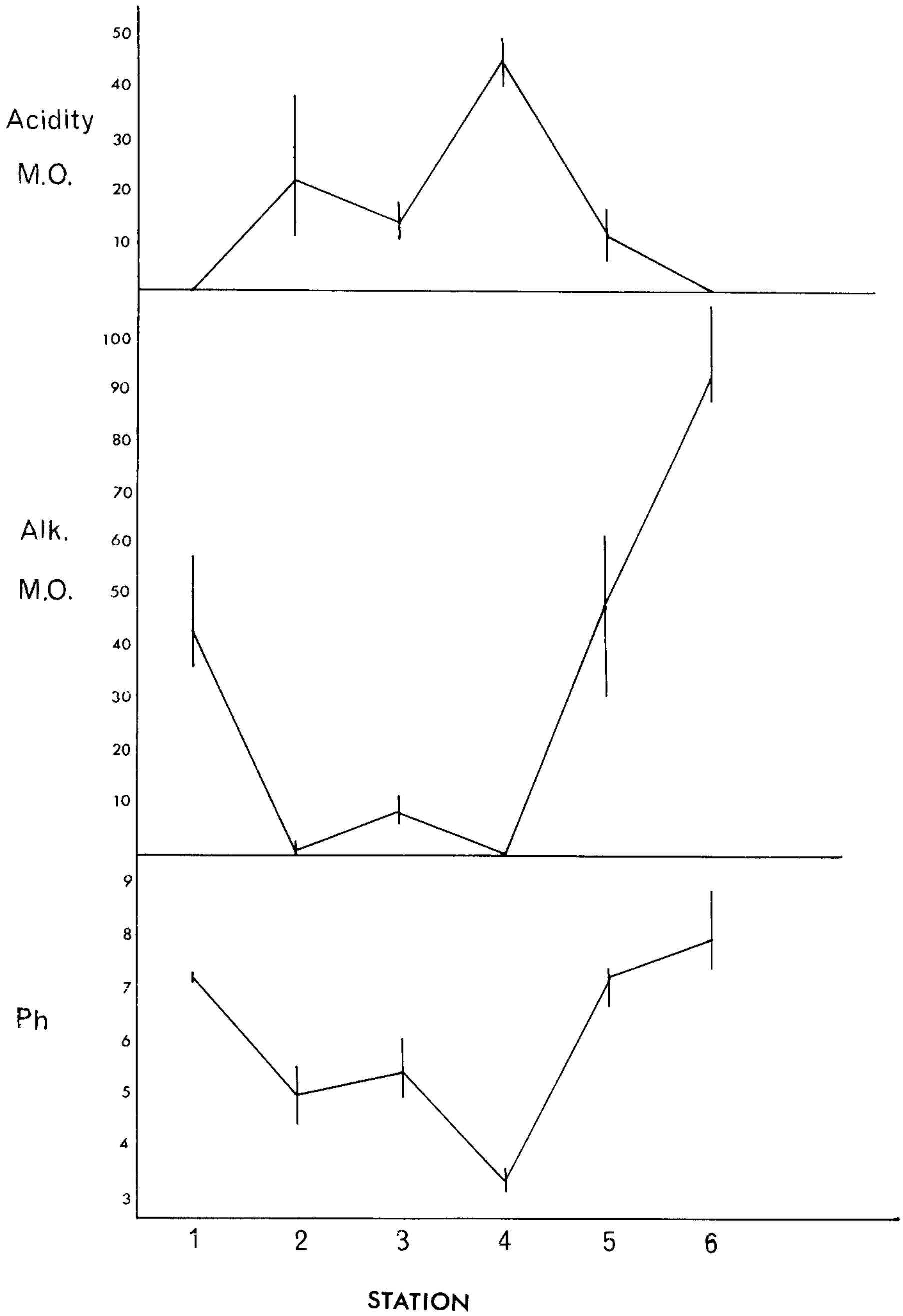


CHART 1. — Acidity (M.O.), alkalinity (M.O.) Ph at each station. Vertical lines indicate range, diagonal lines connect mean of each range.

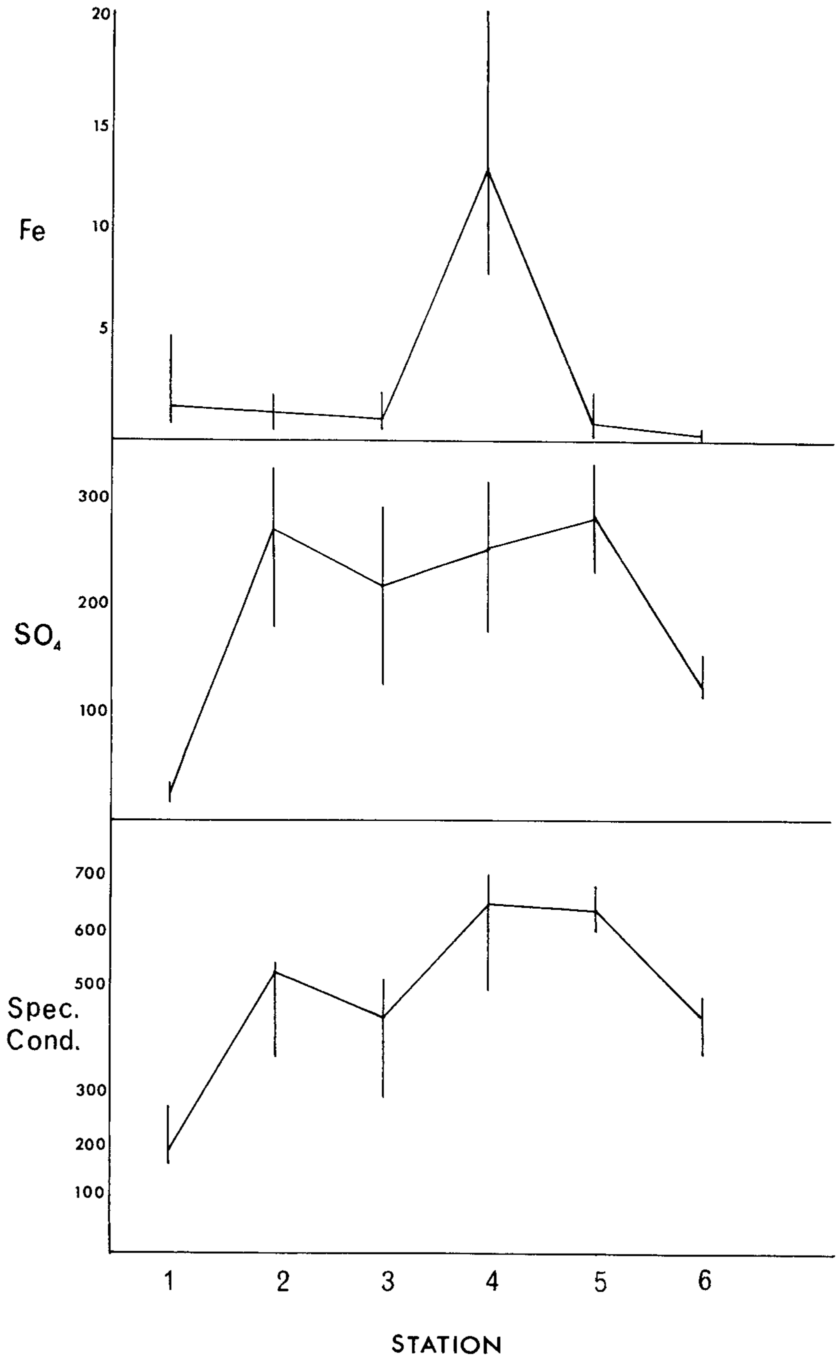


CHART 2. — Fe, SO_4 specific conductivity, at each station. Vertical lines indicate range, diagonal lines connect mean of each range.

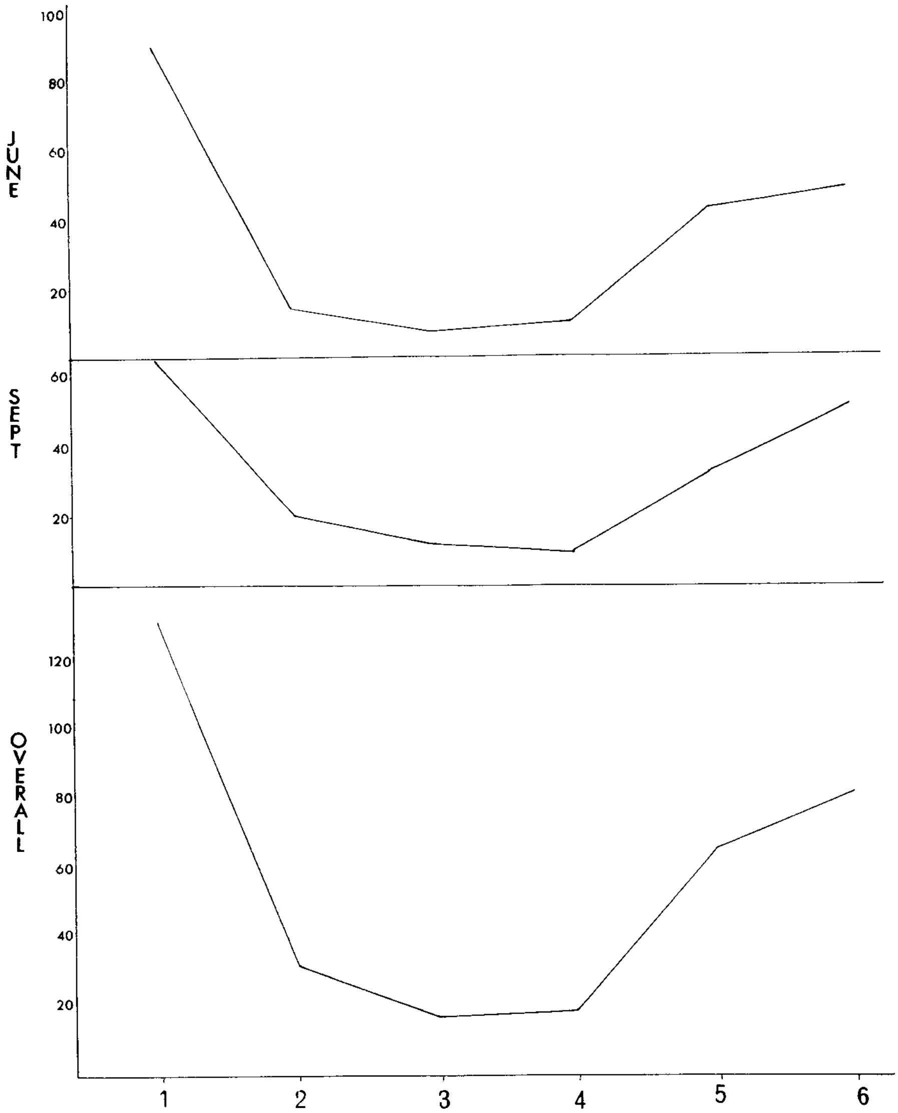


CHART 3. — Total number of Insect species at each station, June, September, combined total.

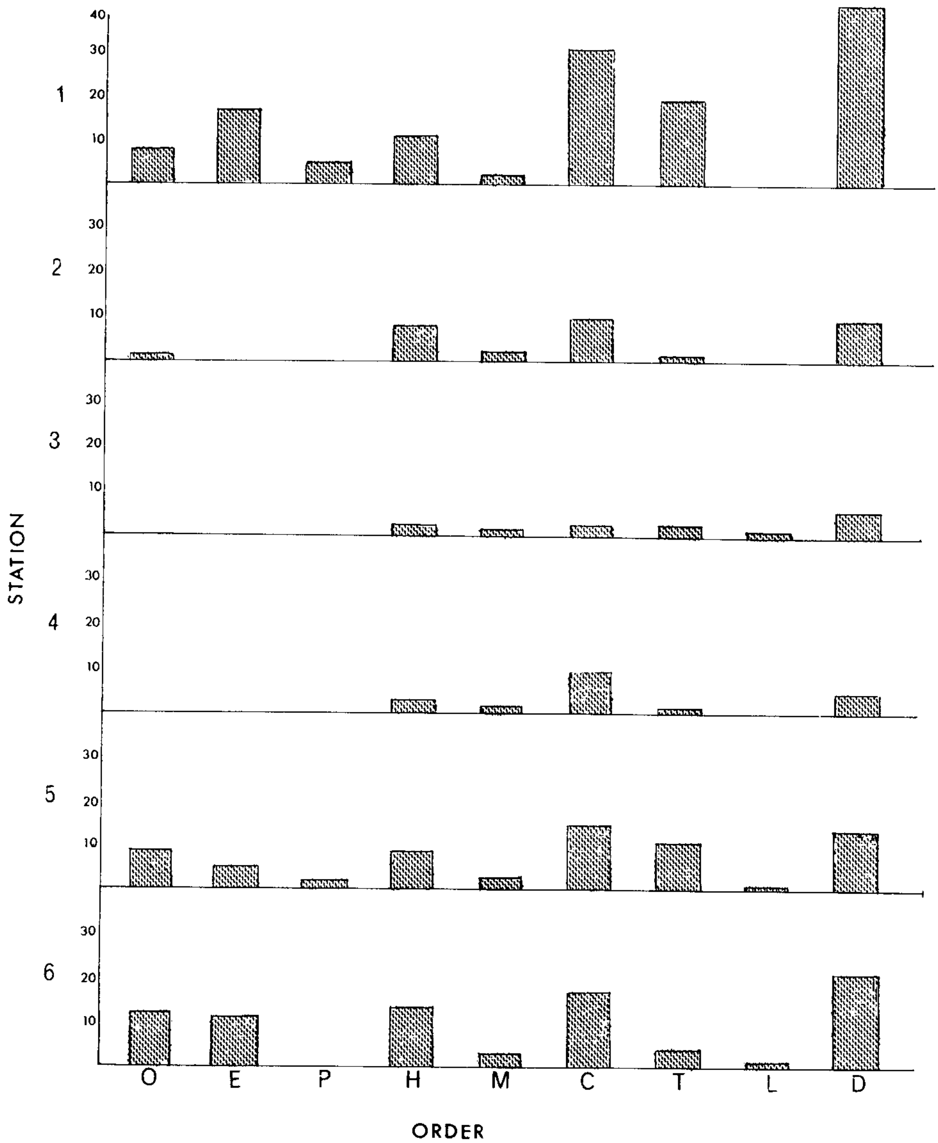


CHART 4. — Histograms of the number of species of each order at each station both surveys combined. O — Odonata, E — Emphemeroptera, P — Plecoptera, H — Hemiptera, M — Megaloptera, C — Coleoptera, T — Trichoptera, L — Lepidoptera, D — Diptera.