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# Environmental Effects of Western Coal Surface Mining

## Part I—The Limnology and Biota of Mine Spoils Ponds in Northwest Colorado

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# ENVIRONMENTAL EFFECTS OF WESTERN COAL SURFACE MINING

## Part I - The Limnology and Biota of Mine Spoils Ponds in Northwest Colorado

by

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# FOREWORD

This report is one of a series of reports describing the impact of surface mining coal. Several mine spoil ponds were compared to a control pond. Differences were apparent but in contrast to spoil ponds in the eastern U.S., these ponds had a relatively rich flora and fauna and appear to offer recreational utility.

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## ABSTRACT

Physico-chemical conditions, zooplankton, and benthos were investigated from June 1977 to May 1978 in coal strip-mine ponds in northwestern Colorado. Two spoils ponds received all of their drainage from the coal mine, but differed in age; one pond received partial drainage from the mine spoils; a control pond was located in an adjacent drainage basin. There were no discernible effects of mine drainage on a variety of physico-chemical parameters, such as temperature, dissolved oxygen, and hardness. In stark contrast to spoils ponds in the eastern and midwestern states, acid mine drainage was not observed. The pH was near or greater than neutrality and acidity was not detected in the ponds studied. Total dissolved solids, nitrate and sulfate values were higher in the spoils ponds than in the control pond. Net zooplankton abundance was lowest in the youngest spoils pond, but the standing crop of benthos exhibited a progressive decrease from the youngest spoils pond to the control pond. Zooplankton and benthos species diversity were lower in the spoils ponds. Certain groups of zooplankters (Cladocera) and benthos (caddisflies, amphipods, water mites, and fingernail clams) were rare or absent in the youngest spoils pond. Colonization phenomena (age and distance from a source of colonizers) are postulated as responsible, in part, for the faunal differences between ponds, although higher levels of nitrate, sulfate, and TDS in the spoils ponds may provide adverse conditions for certain species. If these data are typical of the western energy region, they suggest the potential for development of recreational lakes as a part of reclamation practices.

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# SECTION I

## INTRODUCTION

The deleterious effects of drainage from coal strip-mines on aquatic biota have been well documented in the eastern and midwestern United States (e.g., Appalachian Regional Commission 1969, Roback and Richardson 1969, Warner 1973). Strip-mine lakes receiving drainage from the high sulfur coal mines of those regions contain acidic waters which require extended recovery periods before supporting anything approaching a normal aquatic biota (Parsons 1964, 1977; Campbell and Lind 1969; Smith and Frey 1971; King *et al*. 1974; Riley 1977).

Remarkably little work has been done to assess the effects on aquatic systems of drainage from the low sulfur coal mines of the western United States (Reed 1975). Surface mining activity has been conducted for over 30 years at the Edna Mine in northwestern Colorado. Although low in sulfur compared to eastern coal, the 2.4% sulfur content and 30.8% iron oxide in the ash of Edna Mine coal are the highest values for coals studied in Colorado (Deurbrouck 1970). Yet a two-year study failed to indicate any distinctly deleterious effects of the Edna Mine on the adjacent stream (Canton and Ward 1978). The apparent lack of adverse effects was attributed to the presence of a buffer strip between the mine spoils and the stream and to climatic, hydrologic, and geochemical conditions (Ward *et al*. 1978).

Strip mining at the Edna Mine leaves the overburden in large spoil piles which are presently being regraded. Drainage from the spoils form ponds at the base of the coal seam against the highwall of the pit. In June 1977 research was undertaken on these spoils ponds which receive drainage directly from the mine. The purpose of the research reported herein was to investigate the limnological conditions, zooplankton and benthic communities of spoils ponds of different ages which were differentially influenced by mine drainage. Despite some differences in other variables such as morphometry, the ponds were similar enough to provide comparative data previously unavailable for spoils ponds of the western energy region.

## SECTION II

## CONCLUSIONS

The following conclusions are based upon a one-year study of two spoils ponds which received all of their drainage from a coal mine, but differed in age; one pond which received partial drainage from mine spoils, and a control pond in an adjacent drainage basin.

1. There were no apparent effects of mine drainage on temperature, dissolved oxygen, hardness, pH, acidity, alkalinity, calcium, iron, orthophosphate, or the organic content of the substrate.

2. Acid mine drainage was not observed in any of the ponds, in stark contrast to eastern mine spoils ponds where pH may remain below 4.0 50 years after cessation of mining activities.

3. Total dissolved solids and nitrate levels were higher in the spoils ponds than the control pond. The youngest spoils pond exhibited the highest values.

4. Sulfate levels were much higher in ponds receiving mine drainage, but this was due to gypsum ($CaSO_4 \cdot H_2O$) rather than the oxidized sulfides associated with acid mine drainage.

5. Net zooplankton densities were lowest in the youngest spoils pond and greatest in the control pond. Cladocerans appeared to be the group most adversely affected by conditions in spoils ponds. There was a progressive increase in the number of zooplankton taxa from the youngest spoils pond to the control pond. Shannon-Weaver diversity index values were lower in the two spoils ponds; highest values occurred in the control pond.

6. There was a progressive decrease in macroinvertebrate density and biomass from the youngest spoils pond to the control pond. Chironomids and tubificid worms were responsible for the high standing crop in the youngest spoils pond. The predominant groups in the control pond were amphipods, mayflies, leeches, and odonates. The following major taxa were not collected from the youngest spoils pond: Amphipoda, Hydracarina, Trichoptera, and Sphaeriidae. The fewest species occurred in the youngest spoils pond; the other three ponds had a larger number of species and were similar to each other in the total number of taxa. Shannon-Weaver index values showed similar trends.

7. Coefficient of Community and Percentage Similarity indices suggest that colonization phenomena (age and proximity to a source of colonizers) may be responsible, in part, for the zooplankton and macroinvertebrate communities of the ponds. The higher levels of nitrate, sulfate, and TDS in the spoils ponds may, however, provide adverse environmental conditions for some species.

## SECTION III

## RECOMMENDATIONS

1. Additional studies of physico-chemical conditions and biota are needed to determine whether or not the results contained herein are typical of spoils ponds in the western energy region.

2. These data suggest that spoils ponds in the western energy region have potential as recreational lakes.

3. These ponds may provide environmental conditions suitable for a variety of aquatic organisms. The feasibility of transplanting macrophytes, plankton, benthos, and fishes from local lentic habitats as a mechanism of speeding natural colonization processes, should be investigated.

## SECTION IV

## DESCRIPTION OF THE STUDY AREA

Edna Mine coal is mined from the Wadge seam in the Williams Fork Unit of the Mesa Verde group. The Williams Fork formation overburden consists primarily of shale, sandy shale, and thin beds of sand (McWhorter et al. 1975).

Four pond study sites were established to correspond to a gradient of mining effects (Figure 1). Two of the ponds received all of their drainage from the mine, but differed in age; one pond received only partial drainage from mine spoils, and the control pond received no drainage from mining activity.

Pond P1: 2164 m elevation. This pond, approximately 10 years old, formed where water accumulates against a highwall. The area of the pond is approximately 0.02 ha; the maximum depth is 1.0 m. The bottom of the pond was covered with the alga *Chara globularis* throughout the summer and fall. Ice covered the pond from November through early March.

Pond P2: 2170 m elevation. This pond, approximately 30 years old, is located at the base of a highwall where drainage from the area of oldest mining activity accumulates. This is the largest pond with an area of approximately 0.39 ha and a maximum depth of 3.8 m. Aquatic macrophytes were generally sparse, although *Carex, Juncus,* and *Typha* grew along the edge. *Potamogeton* became abundant in late summer-early autumn, but was limited to the shallow areas. Ice cover occurred from November through late March.

Pond P3: 2164 m elevation. This is an old stock pond formed by damming an intermittent drainage. Although not located directly in the mine, it receives some drainage from the mine spoils. This pond is similar in size to P1 with an area of 0.02 ha and a maximum depth of about 1.0 m. Throughout the summer, over 90% of the pond surface was covered with a floating mat of filamentous alga (*Spirogyra*). Due to the input of groundwater and the insulating effect of the algal mat, the water under the mat was at times 5-10°C cooler than the surface water. Ice covered the pond from November through early March.

Pond P4: 2133 m elevation. The control pond is located 5 km northeast of P1. This pond is also an old stock pond formed by damming a small drainage, but it is not affected by mining activity. The pond has an area of 0.05 ha and a maximum depth of 1.5 m. Dense growths of *Myriophyllum*

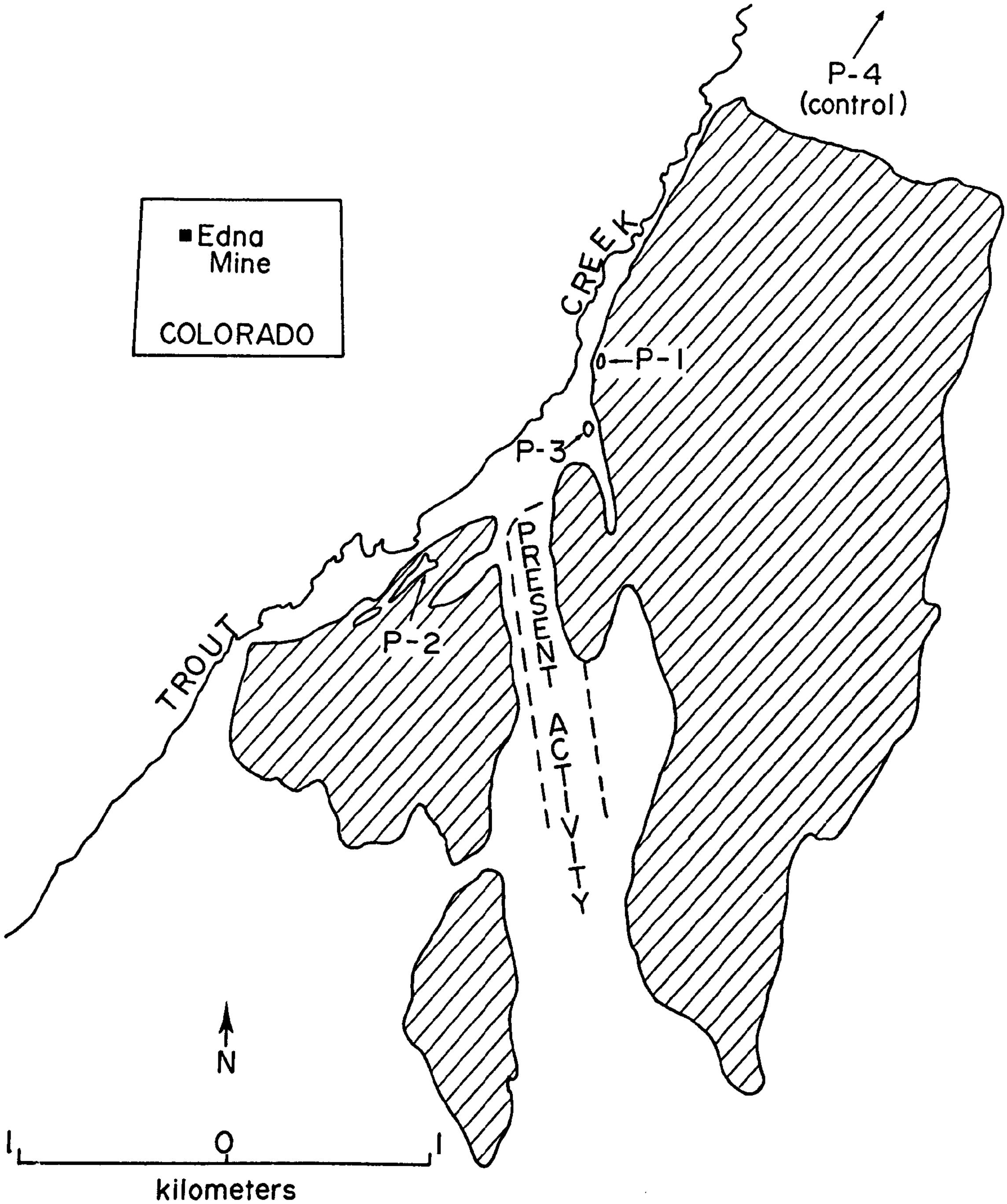


Figure 1. Pond locations in relationship to Edna Mine spoils (crosshatched) and present mining activity, Pond P4, the control pond is in an adjacent watershed.

occurred during summer. The emergents, *Carex* and *Juncus*, and the floating plant *Lemna* were present along the edges. Ice covered the pond from November through late March.

## SECTION V

## METHODS

The four ponds were sampled monthly from June 1977 through May 1978 except December and February. Ice conditions prevented the sampling of pond P4 in January.

### A. PHYSICO-CHEMICAL PARAMETERS

Water temperature was measured with a thermister at 10 cm depth intervals. Dissolved oxygen levels were measured in the field using the azide modification of the Winkler titration method. The pH was determined in the field using comparator discs. One-liter water samples were transported to the laboratory in an ice chest. Bound $CO_2$ (methyl orange alkalinity) was measured by titration with HCl using methyl orange as an indicator (Pennak 1977) and was recorded as mg/liter $CaCO_3$. Orthophosphate and nitrate levels were determined bimonthly using the colorimetric method of Lind (1974).

Total dissolved solids were determined bimonthly by filtration of 0.5 l water samples through cellulose discs (0.45 μm apertures) and subsequent evaporation of the filtrate in a sand bath at 60°C (Ward 1974). The residue was fired at 600°C in a muffle furnace to obtain loss on ignition values. In addition, water samples collected before and after spring runoff were subjected to more detailed analyses by the Colorado State University Chemistry Department.

Substrate samples were collected with an Ekman grab in June 1977 from the 0.5 m depth contour. Organic content was determined using wet digestion with dichromic acid; the hydrometer method was used for particle size analysis. The Colorado State University Soil Testing Laboratory performed the analyses.

### B. NET ZOOPLANKTON

Net zooplankton samples were taken by filtering 20 l of pond water from a depth of 10-20 cm through the bucket of a Juday plankton trap. Samples were preserved with 80% EtOH. In the laboratory 1 ml aliquots were transferred to a Sedgwick-Rafter counting cell with a Hensen-Stempel pipet and the zooplankters were enumerated at 100 X. Identifications to the generic (and in some cases specific) level were based on the keys of Brooks (1957), Edmondson (1959), and Pennak (1978).

The Shannon-Weaver index was used to calculate zooplankton species diversity using the computational formula in Weber (1973). Equitability, a component of species diversity, was calculated using the tables of Lloyd and Ghelardi (1964). Faunal similarity was calculated using two methods outlined by Whittaker (1975). Coefficient of Community is based solely on the presence or absence of species. Percentage Similarity also considers the quantitative representation of each taxon.

## C. BENTHIC MACROINVERTEBRATES

Benthic macroinvertebrates were collected by taking three Ekman grab samples from each pond. The samples were combined, stored on ice, and returned to the laboratory. The samples were washed through a 250 μm mesh sieve and preserved in 5% formalin. The organisms were sorted from the debris and placed in 80% ethyl alcohol for later identification and enumeration. Identifications to the generic (and in some cases specific) level were based on the keys of Edmondson (1959), Anderson (1962), Musser (1962), Hilsenhoff (1970), Mason (1973), Wiggins (1977), Zalom (1977), and Wu (1978).

Species diversity, equitability, and similarity coefficients were calculated in the same manner as for zooplankton.

Statistical analysis of variance was calculated for certain physicochemical, zooplankton, and benthic invertebrate data.

## SECTION VI

## RESULTS AND DISCUSSION

### A. PHYSICO-CHEMICAL PARAMETERS

Mean values and ranges for the physico-chemical parameters which were sampled monthly or bimonthly are shown in Table 1. Additional chemical parameters are presented in Table 2 in relationship to strip-mine lakes of the midwest.

The temperatures of the ponds were generally similar. Most differences were attributable to differences in the time readings were taken. The ponds were well exposed to wind action and thermal stratification was normally not apparent. Some stratification was observed at P3 in the summer when the algal mat formed a nearly opaque layer just below the surface. All ponds exhibited similar seasonal patterns (Figure 2).

Dissolved oxygen values were also similar between ponds; variations in mean values were primarily a function of the degree of supersaturation encountered. At P3 samples were taken under the algal mat when present.

The highest mean value for bound $CO_2$ was recorded from P3 (108 mg/l $CaCO_3$), a pond not directly associated with mining activity. The control pond, P4, also had a relatively high value of 77 mg/l $CaCO_3$. The ponds receiving drainage directly from the mine, P1 and P2, had the lowest values for bound $CO_2$ (57 and 37 mg/l $CaCO_3$, respectively).

According to Pennak (1971), the waters of P2 would be classified as "medium," P1 and P4 as "hard," and P3 as "very hard." It is not possible to account for the large seasonal variations observed, which appear unrelated to the influence of mine drainage. The control pond (P4) exhibited autumn values nearly seven times greater than those encountered during spring.

Acid mine drainage was not evident in any of the ponds. Median pH values ranged from 7.4 to 7.6; the lowest value was 6.8 (Table 1). The youngest spoils pond (P1), which receives all drainage directly from the mine, exhibited pH values from 7.1 to 8.1. This is in stark contrast to eastern mine spoils ponds where pH may remain below 4.0 fifty years after the cessation of mining (Campbell and Lind 1969). In the ponds in Colorado there was no relationship between pH levels and either age or extent of mining influence.

Nitrate levels were higher in ponds receiving mine drainage than in the control pond. In the semi-arid climate of this region, surface mining

TABLE 1. PHYSICO-CHEMICAL PARAMETERS FROM PONDS ASSOCIATED WITH COAL MINING IN NORTHWESTERN COLORADO (JUNE 1977-MAY 1978)

| Parameter | Ponds | | | |
|---|---|---|---|---|
| | P1 | P2 | P3 | P4 |
| Temperature (°C) 10 cm | 11.0 | 12.6 | 11.2 | 14.7 |
| Range | 0.0-20.0 | 0.0-23.0 | 0.0-17.5 | 2.0-24.0 |
| Dissolved $O_2$ (mg/l) | 15.6 | 11.1 | 12.7 | 15.0 |
| Range | 8.2-29.4 | 7.6-16.2 | 8.5-17.5 | 6.4-29.6 |
| Bound $CO_2$ (mg/l $CaCO_3$) | 56.6 | 36.6 | 108.2 | 77.0 |
| Range | 27.5-94.0 | 11.5-52.0 | 50.0-145.5 | 18.5-124.0 |
| pH (median) | 7.4 | 7.4 | 7.4 | 7.6 |
| Range | 7.1-8.1 | 6.8-7.7 | 7.0-7.5 | 7.0-8.1 |
| Nitrate (mg/l) | 16.34 | 0.55 | 0.89 | 0.14 |
| Range | 6.38-26.3 | 0.0-2.63 | 0.03-4.0 | 0.0-0.48 |
| Orthophosphate (mg/l) | 0.15 | 0.07 | 0.17 | 0.30 |
| Range | 0.0-0.34 | 0.0-0.11 | 0.13-0.21 | 0.0-0.89 |
| Total dissolved solids (mg/l) | 3811 | 1770 | 2632 | 547 |
| Range | 2504-5626 | 1429-2561 | 2422-2963 | 254-758 |
| Loss on ignition (mg/l) | 1079 | 412 | 749 | 193 |
| Range | 662-1725 | 204-604 | 645-1001 | 116-758 |
| Percentage of TDS | 28 | 23 | 28 | 35 |

TABLE 2. SELECTED CHEMICAL PARAMETERS OF NORTHWESTERN COLORADO COAL MINE STUDY PONDS COMPARED WITH COAL MINE PONDS IN MISSOURI AND OHIO

| | Ponds | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | P1[a] | P2[a] | P3[a] | P4[a] | A1[b] | A3[c] | O1[d] | O1[e] |
| Acidity (mg/l $CaCO_3$) | 0 | 0 | 0 | 0 | 227-4920 | 27-55 | 14 | 0 |
| Alkalinity (mg/l $CaCO_3$) | 66-189 | 98-143 | 283-316 | 167-282 | 0 | 0 | 2 | 80 |
| Sulfate (mg/l) | 2500-3180 | 940-1260 | 1360-1500 | 168-290 | 1620-5030 | 108-324 | 560 | 580 |
| Calcium (mg/l) | 350-360 | 57-364 | 330-340 | 200-300 | 82-253 | 29-79 | -- | 127 |
| Total iron (mg/l) | 0.03 | 0.13 | 0.09 | 0.14 | 74-272 | 0.44-1.88 | <1.0 | 0.81 |
| Manganese (mg/l) | <0.001 | 0.001-0.21 | 0.002-0.009 | 0.001-0.011 | 27-95 | 0.79-3.18 | -- | 0.02 |
| Magnesium (mg/l) | 400-550 | 82-140 | 226-340 | 56-118 | 65-175 | 6.3-17 | -- | 38.9 |
| Sodium (mg/l) | 98-160 | 19-36 | 20-21 | 19-23 | 8.9-23.3 | 1.3-4.6 | -- | -- |
| Potassium | 14.4-19 | 3-6.6 | 4.6-5.4 | 2.5-4 | 0.2-1.6 | 3.35-9.2 | -- | -- |
| Zinc (mg/l) | <0.01 | <0.01 | <0.01 | <0.01 | 24.8-86 | 0.58-1.56 | -- | -- |

[a] Colorado State University Chemistry Department, 29 April 1977 and 29 July 1977. P4 is a control pond.

[b] 34-year-old mine pond in Missouri (Campbell and Lind 1969).

[c] 50-year-old mine pond in Missouri (Campbell and Lind 1969).

[d] Ohio pond at 40 years (Riley 1977).

[e] Ohio pond at 55 years (Riley 1977).

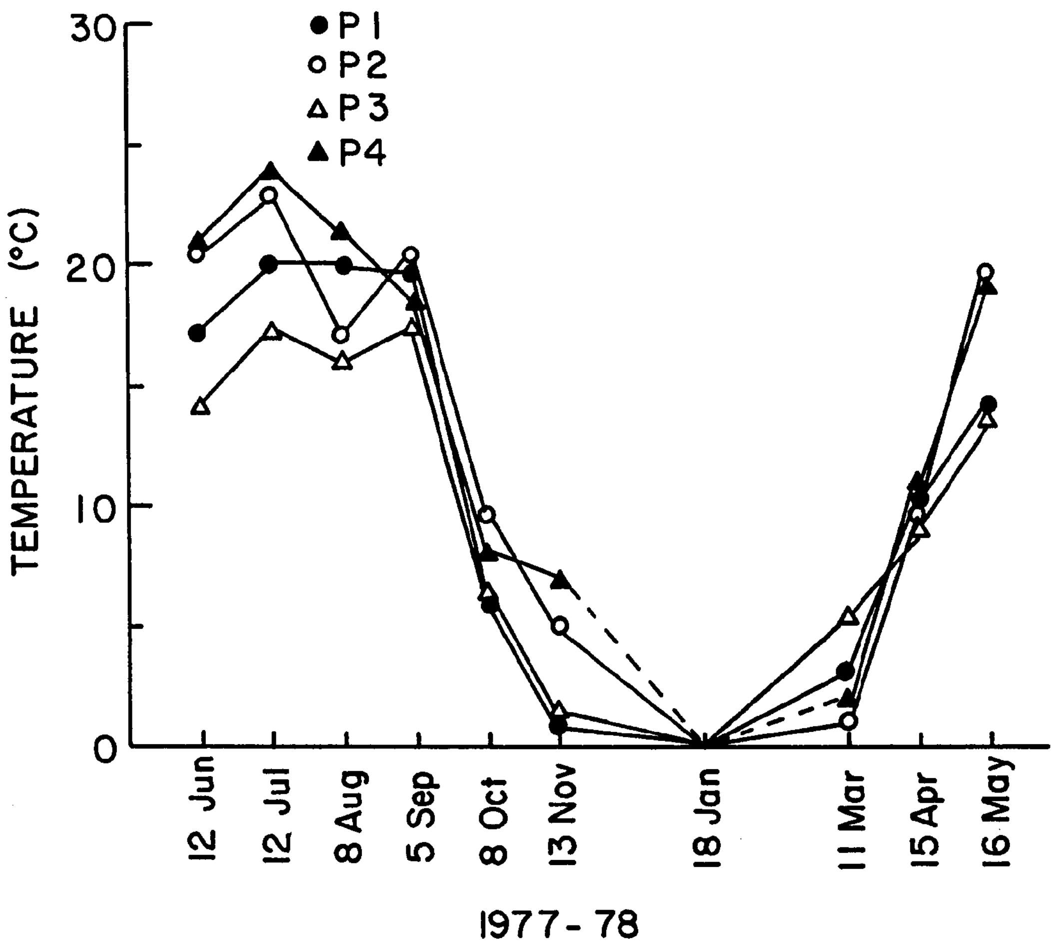


Figure 2. Seasonal trends in water temperature.

increases leaching of soluble salts (Ward et al. 1978). It appears that nitrate levels remain high for a number of years. The youngest mine spoils pond (P1) exhibited consistantly high values for nitrate (mean = 16.34 mg/l). Nitrate levels in the mine spoils, as measured by saturated paste analysis, were similar throughout the mined area (McWhorter et al. 1975) and cannot explain the high levels at P1. Orthophosphate values, however, did not exhibit any discernible relationship with age or degree of mining effects. The highest levels were found in the control pond.

Mean values of total dissolved solids (TDS) were 3-7 times greater in the spoils ponds than the control pond (Table 1). The highest value (3811 mg/l) occurred in the youngest spoils pond. TDS thus appears to be influenced by watershed disturbance from mining in a manner similar to nitrate. Statistical analysis of variance was run on the TDS values for the year's data to determine the strength of the relationship seen in Table 1 and Figure 3. The results indicate a significant difference between the ponds ($P < 0.01$). TDS exhibited little seasonality except in the youngest spoils pond (P1) which showed much lower values during late summer and autumn (Figure 3). Loss on ignition averaged 23-35% of the total dissolved solids.

To provide comparative data, selected chemical parameters from the Colorado ponds are related to mine ponds in regions of acid mine drainage (Table 2). The Missouri ponds studied by Campbell and Lind (1969) were 34 years old (A1) and 50 years old (A3). Riley (1977) studied a pond in Ohio (O1), which was formed in 1918, when it was 40 years old and when it was 55 years old. There is a striking difference between the Colorado ponds and those in areas of acid mine drainage (AMD). Acidity was never detected in the Colorado ponds, but was still measurable (27-55 mg/l $CaCO_3$) 50 years after mining in A3. Alkalinity was high in all the Colorado ponds, but was not detected in A1 or A3. Only in the Ohio pond, 55 years after mining, did alkalinity values approach those of the youngest pond in Colorado (80 mg/l $CaCO_3$ in Ohio; 66-189 mg/l $CaCO_3$ at P1). Sulfate levels were very high in the Colorado ponds associated with the mining activity (P1, P2, and P3) ranging from 940-3180 mg/l, which was comparable to levels observed in pond A1 (1620-5030 mg/l). However, the high levels of sulfates in the Colorado ponds are due to the gypsum ($CaSO_4 \cdot H_2O$) found in the overburden rather than the oxidized sulfides associated with the high pyritic content of the overburden in areas of AMD (McWhorter et al. 1975). The gypsum and the shale content of the overburden accounted for the generally high levels of calcium in the Colorado ponds (57-364 mg/l) compared to pond A3 (29-79 mg/l). Unlike areas of AMD where total iron levels can be quite high (74-272 mg/l at A1), the Colorado ponds had extremely low levels of iron (0.03-0.14 mg/l) comparable to mine ponds 50-55 years old. Other differences in the ionic composition between the ponds in Colorado and those in areas of AMD generally reflected differences in regional geology.

Table 3 summarizes the particle size distribution and organic content of the sediment in the four ponds. The particle size distribution at P1 was fairly evenly divided among the sand, silt, and clay fractions. The substrate at P2 was predominately sand (49%). The two ponds not directly

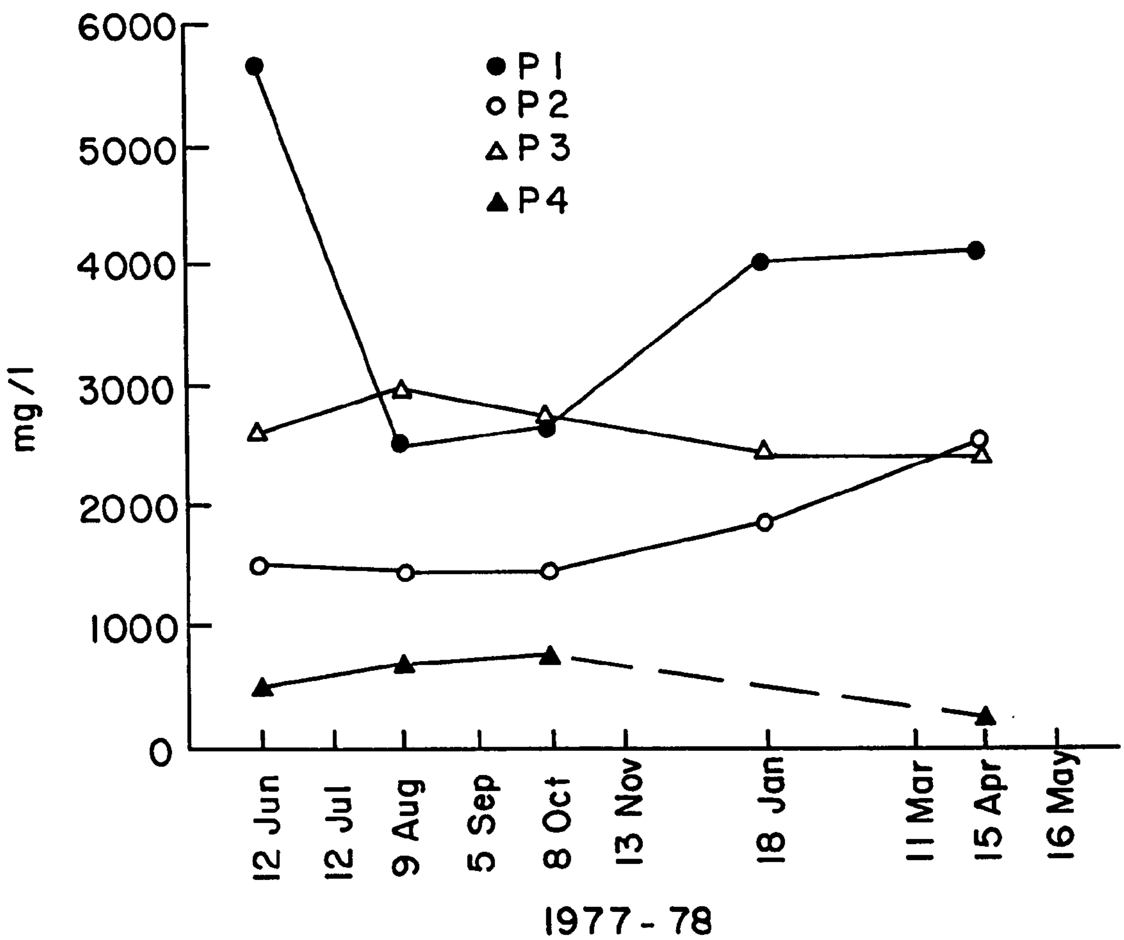


Figure 3. Seasonal trends in total dissolved solids.

TABLE 3. SEDIMENT PARTICLE SIZE AND PERCENTAGE ORGANIC MATTER FOR PONDS ASSOCIATED WITH COAL MINING IN NORTHWESTERN COLORADO

| | Ponds | | | |
|---|---|---|---|---|
| | P1 | P2 | P3 | P4 |
| % sand (0.0625-2.0 mm) | 34 | 49 | 22 | 36 |
| % silt (0.0039-0.0625 mm) | 38 | 25 | 57 | 41 |
| % clay (<0.0039 mm) | 28 | 26 | 21 | 23 |
| % organic matter | 6.7 | 11.4 | 8.4 | 9.2 |

associated with the mining, P3 and P4, had predominantly silt sediments (57% and 41%, respectively). The relative contribution of organic matter was similar at all ponds, ranging from 6.7% at P1 to 11.4% at P2.

## B. NET ZOOPLANKTON

During the study 21 zooplankton taxa were identified (Table 4). Annual mean density ranged from 39 organisms/l at P1 to 283 organisms/l at P4. Despite great differences in mean density values (Figure 4), no statistically significant difference ($P > 0.05$) between the ponds was indicated. The great temporal variations in density of individual species obscured between-pond differences when analyses were run on the raw numbers of zooplanters for the entire year's data.

Protozoa were present in all ponds, but abundant only at P2 (Table 4). Protozoans accounted for 33% of the zooplankton density at P1 (Figure 5), with *Difflugia* being the only representative. *Difflugia* and *Ceratium* accounted for 88% of the total density at P2. Protozoans were less important at the other ponds accounting for 17% of the density at P3 and only 8% at P4, with *Difflugia* the main representative. *Difflugia* was also an abundant zooplankter in a strip-mine lake in Kansas (Burner and Leist 1953).

Rotifers were collected in all ponds, but were abundant only at P4. Rotifer density was low at P1, but they accounted for 20% of the zooplankton density (Figure 5), with *Branchionus* and *Epiphanes* being most abundant. At pond P2, rotifers accounted for only 9% of the density; *Asplanchna* was the most abundant taxon. Although rotifers increased in absolute abundance at P3 (especially *Branchionus, Epiphanes, Notholca,* and *Lepadella*), they accounted for only 17% of the total density. The density of rotifers was much greater at P4, accounting for 29% of the total zooplankton density. *Keratella quadrata* and *Filinia longiseta* were abundant in P4.

Cladocerans were important only at P3 and P4, the ponds not directly associated with mining activity. A single specimen of *Bosmina longirostris* was the only Cladoceran collected from P1 during the year of study. At P2, Cladocerans made up only 2% of the zooplankton density; *Daphnia pulex* was the main representative. The greater Cladoceran abundance at P3 was due to *Chydorus sphaericus*, which accounted for 28% of the zooplankton density. Although Cladocerans were most abundant at P4, they accounted for only 17% of the zooplankton density at this pond. *Ceriodaphnia reticulata* was the most abundant species.

Limnetic copepods were represented by a single species, *Cyclops bicuspidatus thomasi*. This species was important in all the ponds, except P2, accounting for 46% of the density at P1, 38% at P3, and 46% at P4. In all cases, the nauplius stage accounted for most of the copepod abundance. *Cyclops* was also found to be abundant in a strip-mine lake in Kansas (Burner and Leist 1953).

TABLE 4. SPECIES LIST AND MEAN DENSITY (ORGANISMS/L) OF NET ZOOPLANKTON FROM PONDS ASSOCIATED WITH COAL MINING IN NORTHWESTERN COLORADO (JUNE 1977-MAY 1978)

| | Ponds | | | |
|---|---|---|---|---|
| | P1 | P2 | P3 | P4 |
| Protozoa | 13 | 96 | 15 | 22 |
| *Difflugia* sp. | 13 | 51 | 14 | 17 |
| *Ceratium* sp. | -- | 45 | 1 | 5 |
| Rotatoria | 8 | 10 | 15 | 83 |
| *Monostyla* sp. | 1 | 1 | 1 | 2 |
| *Lecane* sp. | 1 | 1 | a/ | 5 |
| *Keratella quadrata* (O. F. Muller) | -- | 1 | -- | 30 |
| *Branchionus* sp. | 3 | 1 | 4 | 4 |
| *Asplanchna* sp. | a/ | 3 | 1 | 7 |
| *Epiphanes* sp. | 2 | 2 | 4 | 5 |
| *Testudinella* sp. | -- | -- | 1 | -- |
| *Ascomorpha* sp. | a/ | -- | a/ | a/ |
| *Filinia longiseta* (Ehrenburg) | -- | -- | -- | 27 |
| *Notholca* sp. | a/ | 1 | 2 | a/ |
| *Lepadella* sp. | -- | a/ | 2 | -- |
| *Philodina* sp. | -- | -- | -- | 1 |
| *Polyarthra* sp. | -- | -- | -- | 1 |
| Cladocera | a/ | 2 | 25 | 47 |
| *Bosmina longirostris* (O. F. Muller) | a/ | a/ | -- | -- |
| *Daphnia pulex* (DeGeer) | -- | 2 | a/ | 4 |
| *Ceriodaphnia reticulata* (Jurine) | -- | -- | -- | 38 |
| *Alona guttata* Sars | -- | -- | a/ | 2 |
| *Chydorus sphaericus* (O. F. Muller) | -- | a/ | 25 | 3 |
| Copepoda | 18 | 1 | 34 | 131 |
| *Cyclops bicuspidatus thomasi* Forbes | 6 | -- | 8 | 26 |
| nauplii | 13 | 1 | 26 | 105 |
| Total | 39 | 109 | 89 | 283 |

a/ Present but less than 1 organism/l.

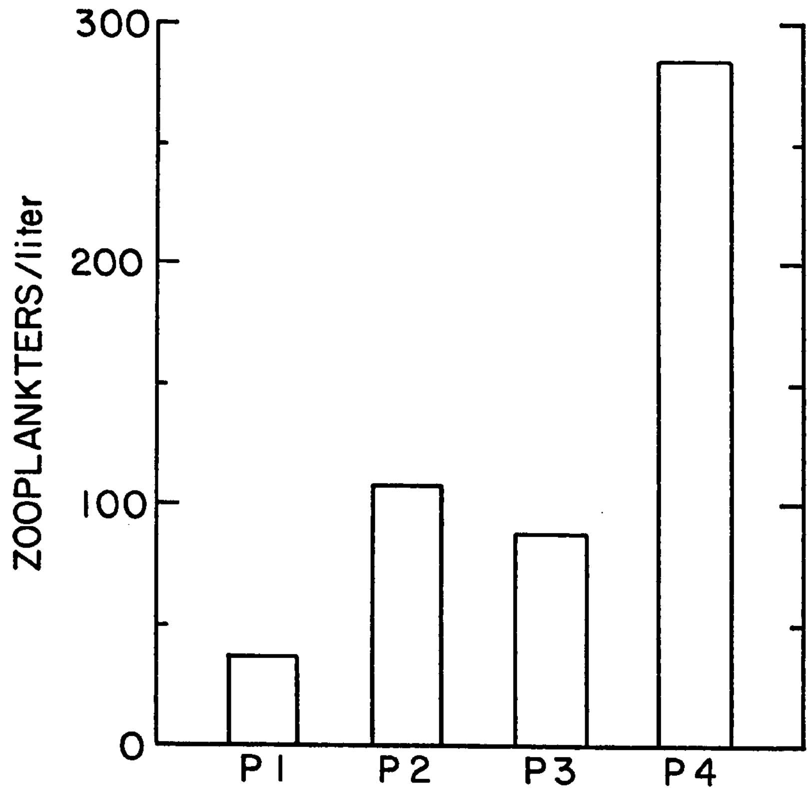


Figure 4. Annual mean densities of net zooplankton.

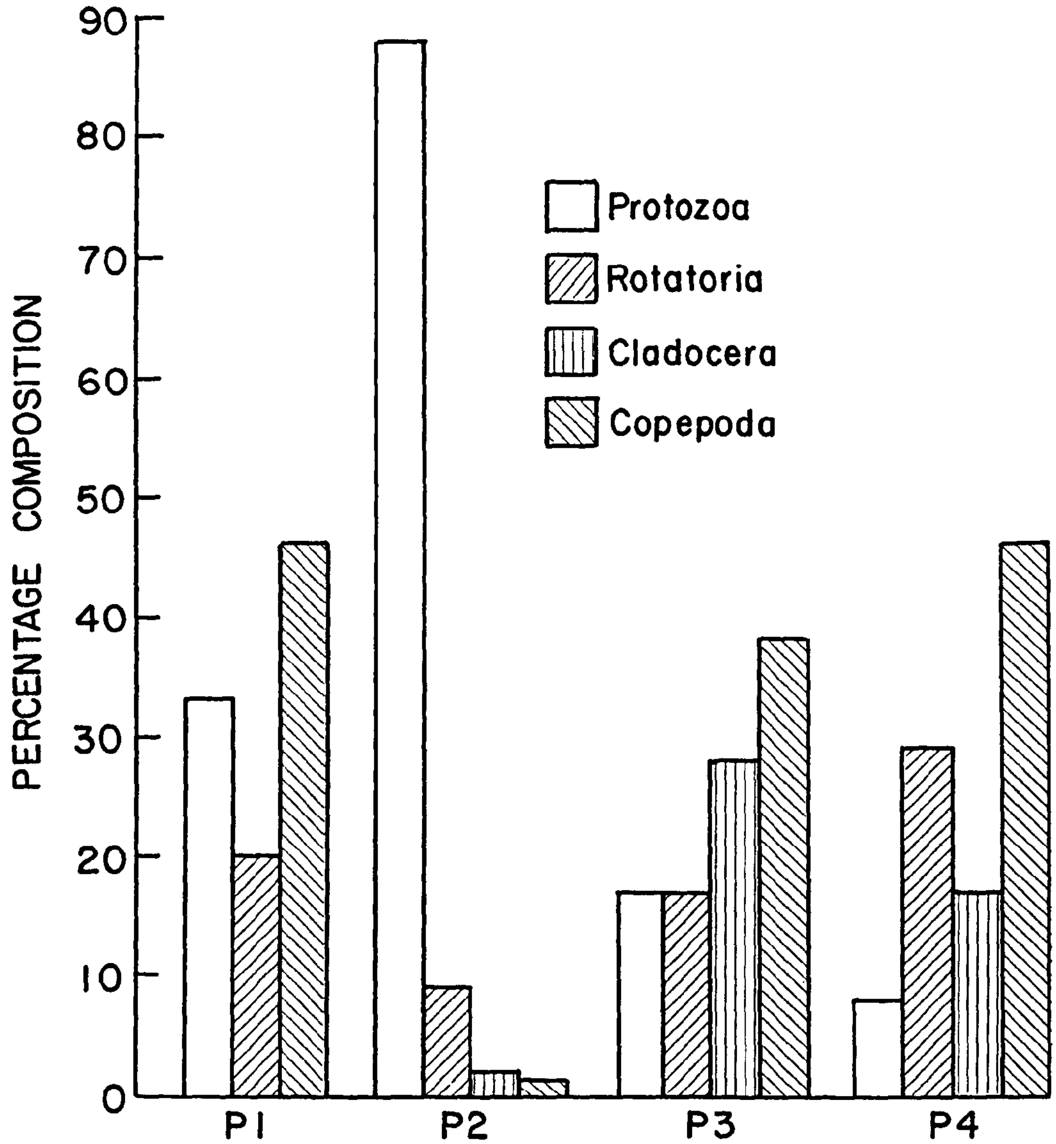


Figure 5. Percentage composition of major net zooplankton groups using density values.

Net zooplankton density exhibited various degrees of seasonality in the ponds (Figure 6). Pond P1 showed little seasonality with small peaks in density in late summer due to increased abundance of *Cyclops bicuspidatus thomasi* and *Branchionus*, and in January resulting from an increase in *Difflugia*. Greater seasonal trends were observed at P2, with a late summer peak of *Ceratium* and an early spring peak in the density of *Chydorus sphaericus* and *Cyclops bicuspidatus thomasi*, pond P3 exhibited little temporal variation. Pond P4 had the greatest zooplankton density in late summer, with a small peak in November. The high density in late summer-early fall was due to great abundance of *Cyclops bicuspidatus thomasi* from July through September, and August peaks in the density of *Keratella quadrata* and *Ceriodaphnia reticulata*. The peak in November was due to the occurrence of great numbers of *Filinia longiseta*.

The seasonal pattern in protozoan density, with late winter peaks at P1 and P2, was similar to the pattern for protozoans observed by Pennak (1949) in Gaynor Lake, Colorado. The August peak in the density of *Keratella quadrata* was also similar to late summer pulses observed by Pennak (1949). *Filinia longiseta* is considered dicyclic, with summer and autumn peaks (Pennak 1949), although it may exhibit only one of these peaks as in the fall peak at P4. The late summer peak density of *Ceriodaphnia reticulata* contrasted with early summer peaks for this species reported from a Kansas pond (Armitage and Smith 1968). *Cyclops bicuspidatus thomasi* had peak densities in late summer-early fall at P1, P3, and P4. This pattern was similar to seasonal trends for this genus observed by Pennak (1949) in Colorado and Young (1974b) in England, as well as Armitage and Smith (1968) for other cyclopoid copepods in a Kansas pond.

The ponds also differed in the number of taxa collected (Table 5). The fewest number of taxa (10) was found at the youngest spoils pond (P1). The control pond, P4, had the greatest number of taxa with 18. The trend was statistically significant ($P < 0.01$). Species diversity index values were lower in the ponds in the mine spoils (P1, P2) than the other two ponds (Table 5). The highest value was calculated for P4. Equitability did not exhibit a clear pattern.

The Coefficient of Community was used to test the similarity of the ponds with respect to the presence or absence of zooplankton taxa (Table 6). Using this index, ponds P2 and P3 exhibited the highest similarity (0.83); however, the index values were high for all combinations, which reflected the similar taxa found at the ponds. Percentage Similarity considers relative abundance as well as taxa present. Using this index (Table 6), ponds P1 and P3 exhibited the greatest similarity (0.66). This could be explained in the context of island biogeography (MacArthur and Wilson 1967). Pond P1, the youngest pond, would receive the greatest number of colonizers from the nearest source, which is P3. The similarity was greatest for the quantitative representation of the protozoans and rotifers in these ponds. Both of these groups (especially protozoans) have been shown to be dispersed passively with the action of the wind, flying insects, and birds (Maguire 1963, Stewart et al. 1970, Milliger et al. 1971, Solon and Stewart 1972).

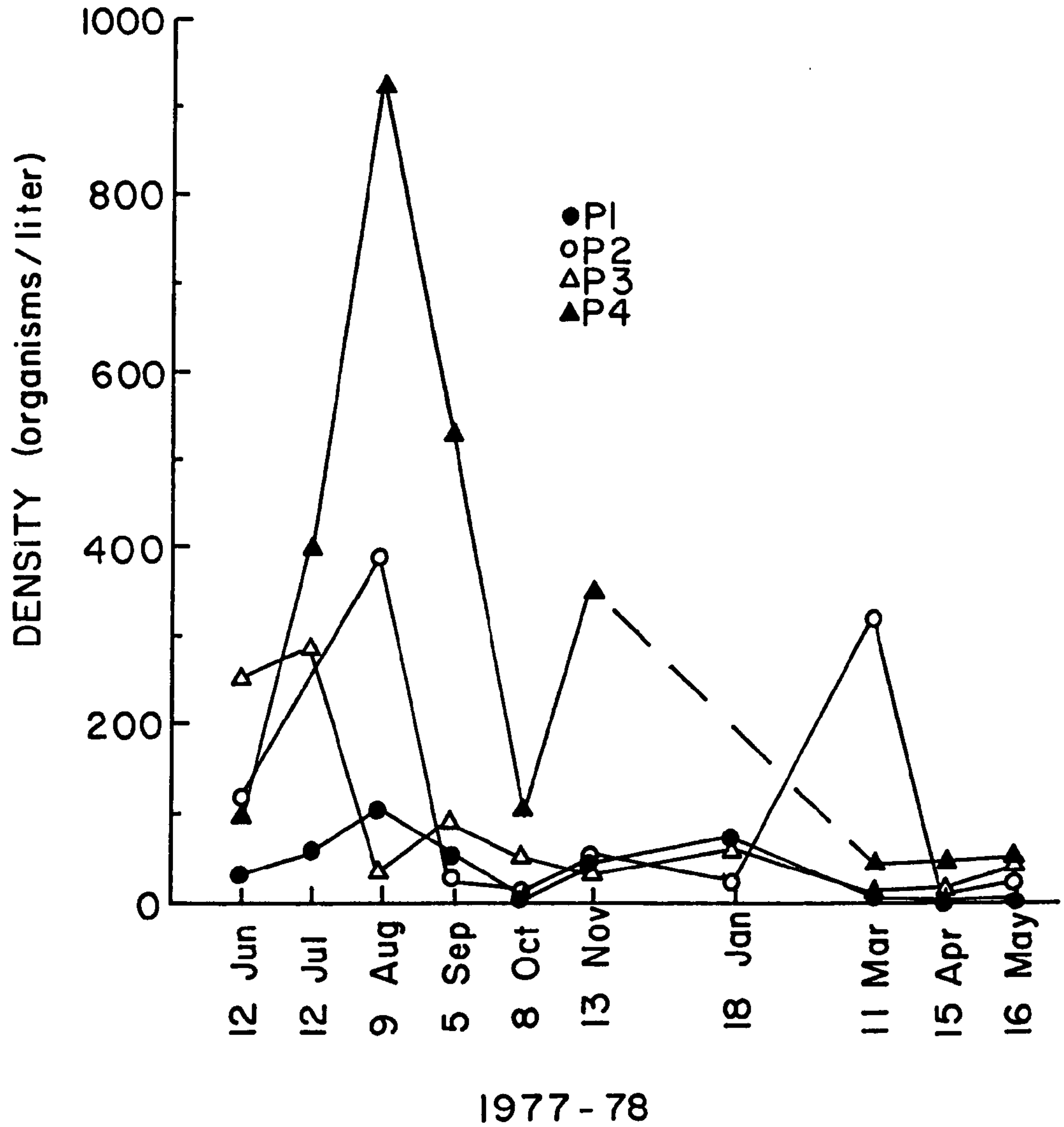


Figure 6. Seasonal trends in net zooplankton densities.

TABLE 5. NET ZOOPLANKTON SPECIES DIVERSITY, EQUITABILITY, AND NUMBER OF TAXA FOR PONDS ASSOCIATED WITH COAL MINING IN NORTHWESTERN COLORADO

| | Ponds | | | |
|---|---|---|---|---|
| | P1 | P2 | P3 | P4 |
| Shannon-Weaver Index | 1.95 | 1.78 | 2.49 | 2.68 |
| Equitability | 0.54 | 0.33 | 0.52 | 0.49 |
| Number of taxa | 10 | 14 | 15 | 18 |

TABLE 6. COEFFICIENT OF COMMUNITY AND PERCENTAGE SIMILARITY USING ZOOPLANKTON FOR PONDS ASSOCIATED WITH COAL MINING IN NORTHWESTERN COLORADO

| | | Coefficient of Community | | | |
|---|---|---|---|---|---|
| | | P1 | P2 | P3 | P4 |
| Percentage Similarity | P1 | -- | 0.75 | 0.72 | 0.64 |
| | P2 | 0.41 | -- | 0.83 | 0.75 |
| | P3 | 0.66 | 0.24 | -- | 0.79 |
| | P4 | 0.59 | 0.18 | 0.53 | -- |

## C. BENTHIC MACROINVERTEBRATES

During the study, 52 taxa of benthic macroinvertebrates were identified from the four ponds, although only 14 were considered numerically abundant (Table 7).

Standing crop (density and biomass) of the benthic invertebrates exhibited a marked pattern (Figure 7), with the greatest standing crop at P1, the youngest spoils pond, and the lowest standing crop at the control pond, P4. The large standing crop at P1 was due to the large numbers of tubificid worms and chironomids (Table 7). The density (5222 organisms/$m^2$) and biomass (28.7 g/$m^2$) at P2 was dominated by sphaeriid clams, with chironomids being less abundant (Tables 7 and 8). The lower standing crop at P3 was due to decreased abundance and biomass of tubificid worms and chironomids. The control ponds had the lowest standing crop (3160 organisms/$m^2$ and 24.7 g/$m^2$) due to low numbers of worms and midges. The standing crop at P4 was dominated by the density of amphipods and mayflies, and the biomass of amphipods, mayflies, leeches, and odonates. Statistical analysis of variance run on density and biomass values for the year's data failed to show a significant difference between the ponds ($P > 0.05$) due to the great temporal variations in the abundance of individual taxa.

Oligochaeta were present in all ponds, but abundant only in P1 and P3. At pond P1, oligochaetes comprised 44% of the invertebrate density (Figure 8a) and 65% of the invertebrate biomass (Figure 8b), with *Limnodrilus hoffmeisteri* the predominant species. Tubificid worms were less abundant at P2, accounting for only 11% of the density and 14% of the biomass. At P3, oligochaetes comprised 45% of the invertebrate density and 52% of the biomass, with *Limnodrilus hoffmeisteri* predominating. Oligochaetes were less abundant at P4, accounting for only 7% of the density and 8% of the biomass. In all ponds, *Limnodrilus hoffmeisteri* was more abundant than *Tubifex tubifex*, a relationship also observed by Young (1974a) in a small English pond.

Hirudinea were collected from all ponds, although only rarely in P1. Leeches were more abundant in the other ponds, accounting for approximately 5% of the density and 10% of the biomass, with *Helobdella stagnalis* the predominant species in all cases.

Molluscs varied in abundance in the ponds. At P1, molluscs accounted for only 4% of the density, but 14% of the biomass (shells removed) due to the abundance of *Physa*. Molluscs accounted for 43% of the density and 40% of the invertebrates biomass at P2, due primarily to large numbers of *Pisidium variabile*. Molluscs were relatively unimportant at P3, comprising only 1% of the density and 5% of the biomass. At P4, the molluscs were slightly more abundant, accounting for 12% of the density and 9% of the biomass. *Pisidium variabile* and *Gyraulus* were the predominant taxa.

Amphipods were represented by a single species, *Hyalella azteca*. This species was never collected at P1, the youngest spoils pond. At P2, amphipods accounted for 5% of the density and 3% of the biomass, while at P3

TABLE 7. SPECIES LIST AND DENSITY (ORGANISMS/$M^2$) OF BENTHIC MACROINVERTEBRATES FROM PONDS ASSOCIATED WITH COAL MINING IN NORTHWESTERN COLORADO (JUNE 1977-MAY 1978)

| | Ponds | | | |
|---|---|---|---|---|
| | P1 | P2 | P3 | P4 |
| Oligochaeta | 3425 | 591 | 2176 | 209 |
| *Limnodrilus hoffmeisteri* Claparède | 3223 | 532 | 1817 | 204 |
| *Tubifex tubifex* (O. F. Müller) | 202 | 59 | 356 | 5 |
| *Eiseniella tetraedra* (Savigny) | 1 | -- | 3 | -- |
| Hirudinea | 1 | 360 | 252 | 164 |
| *Helobdella stagnalis* (Linn.) | 1 | 359 | 251 | 134 |
| *Macrobdella* sp. | -- | 1 | -- | 6 |
| *Erpobdella punctata* (Leidy) | -- | -- | -- | 19 |
| *Glossiphonia complanata* (Linn.) | -- | -- | 1 | 5 |
| Mollusca | 296 | 2261 | 49 | 375 |
| *Physa* sp. | 260 | 78 | 14 | 3 |
| *Lymnaea* sp. | 32 | 23 | 6 | -- |
| *Gyraulus* sp. | 4 | 50 | -- | 153 |
| *Pisidium variabile* Prime | -- | 2110 | 29 | 218 |
| Amphipoda | | | | |
| *Hyalella azteca* (Saussere) | -- | 286 | 342 | 660 |
| Hydracarina | | | | |
| *Hydrachna* sp. | -- | -- | 1 | 5 |
| Plecoptera | | | | |
| *Malenka* sp. | -- | -- | 1 | -- |
| Ephemeroptera | 20 | 44 | 50 | 1192 |
| *Callibaetis* sp. | 9 | 10 | 49 | 3 |
| *Baetis* sp. | -- | -- | -- | 2 |
| *Caenis* sp. | 11 | 34 | 1 | 1188 |
| Hemiptera | 10 | 6 | 17 | 16 |
| *Hesperocorixa laevigata* (Uhler) | 6 | 6 | 13 | 5 |
| *Notonecta lobata* Hungerford | 4 | -- | 3 | -- |
| *N. unifasciata* Guerin | -- | -- | 1 | 11 |
| Odonata | 65 | 92 | 14 | 35 |
| *Neoneura* sp. | 23 | 20 | 4 | 11 |
| *Amphiagrion* sp. | 17 | 4 | 3 | -- |
| *Enallagma* sp. | 24 | 66 | 6 | 16 |
| *Anax* sp. | -- | 1 | -- | 2 |
| *Sympetrum corruptum* (Hagen) | -- | 1 | 1 | 6 |

TABLE 7. Continued

| | Ponds | | | |
|---|---|---|---|---|
| | P1 | P2 | P3 | P4 |
| Trichoptera | -- | 26 | 12 | 2 |
| *Agraylea* sp. | -- | -- | 1 | -- |
| *Ochrotrichia* sp. | -- | -- | 3 | -- |
| *Limnephilus* sp. | -- | 17 | 7 | 2 |
| *Phryganea cinerea* Walker | -- | 3 | -- | -- |
| *Oecetis* sp. | -- | 3 | -- | -- |
| *Nectopsyche* sp. | -- | 1 | -- | -- |
| Indet. larva | -- | 1 | -- | -- |
| Megaloptera | | | | |
| *Sialis* sp. | 1 | 6 | -- | -- |
| Coleoptera | 149 | 17 | 66 | 185 |
| *Hydroporus tenebrosus* LeConte | 59 | 1 | 10 | 24 |
| *Agabus disintegratus* (Crotch) | 9 | 3 | -- | 5 |
| *Hydaticus* sp. | -- | 1 | -- | 3 |
| *Tropisternus* sp. | -- | -- | -- | 13 |
| *Haliplus* spp. | 82 | 11 | 56 | 140 |
| Diptera | 3872 | 1531 | 1846 | 317 |
| *Tabanus* sp. | 9 | 56 | 1 | 22 |
| *Paralimna* sp. | -- | 1 | -- | 2 |
| *Euparyphus* sp. | -- | -- | 13 | 3 |
| *Tipula* sp. | -- | -- | 6 | -- |
| *Hexatoma* sp. | -- | -- | 1 | -- |
| *Bezzia* sp. | -- | -- | 20 | 21 |
| *Probezzia* sp. | -- | -- | 12 | 44 |
| *Palpomyia* sp. | 120 | 75 | 102 | 54 |
| *Chironomus* sp. | 13 | 29 | 528 | -- |
| *Procladius* sp. | 1682 | 771 | 21 | 8 |
| *Tanytarsus* sp. | 808 | 527 | 423 | 16 |
| *Orthocladius* sp. | 1210 | 21 | 684 | 43 |
| *Phaenopsectra* sp. | 30 | 52 | 22 | 104 |
| *Ablabesmyia* sp. | -- | 10 | 12 | -- |
| Total | 7840 | 5222 | 4826 | 3160 |

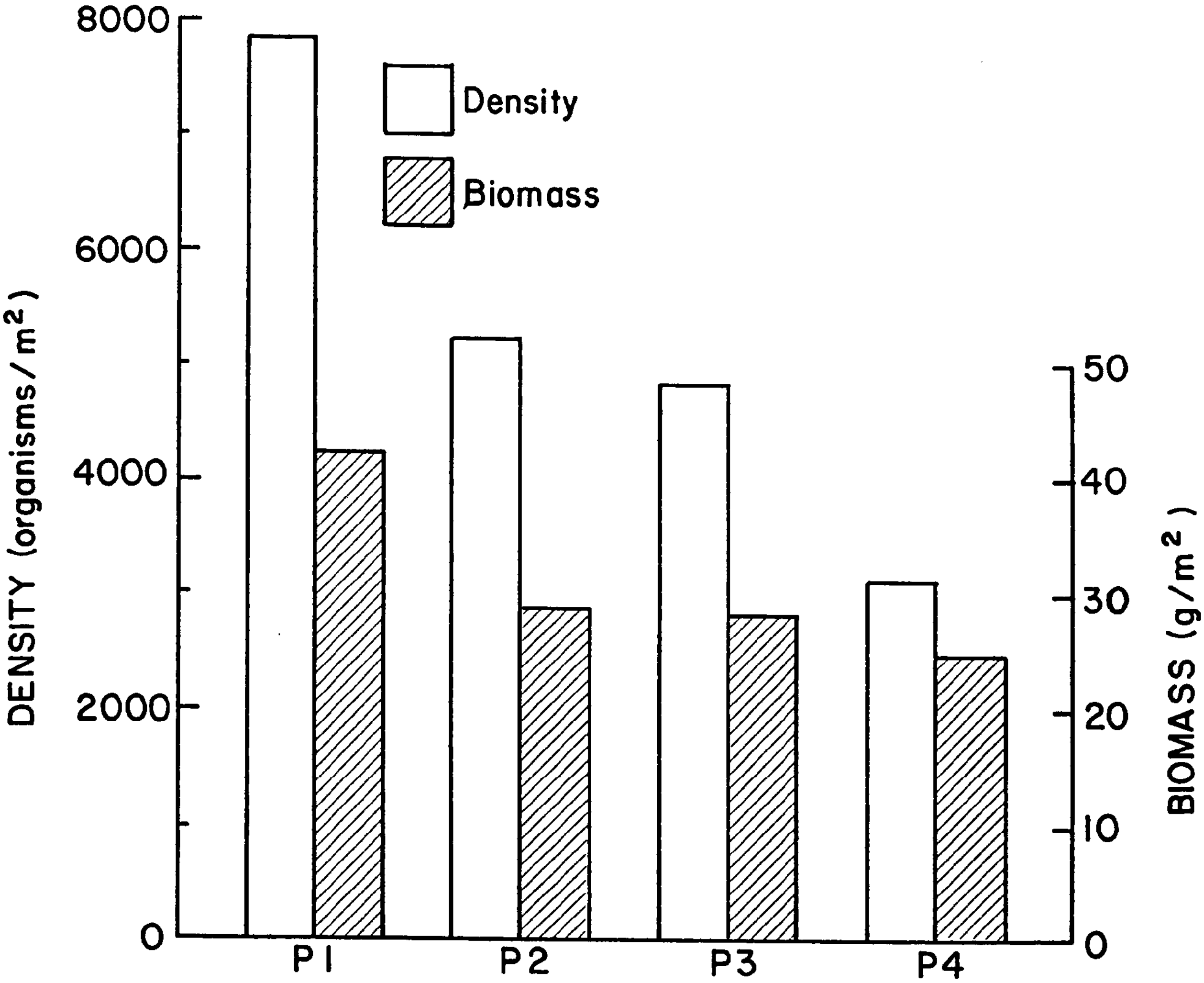


Figure 7. Annual mean density and biomass values of macrobenthos.

TABLE 8. BIOMASS ($G/M^2$) WET WEIGHT OF MAJOR INVERTEBRATE GROUPS FROM PONDS ASSOCIATED WITH COAL MINING IN NORTHWESTERN COLORADO (JUNE 1977-MAY 1978)

| | Ponds | | | |
|---|---|---|---|---|
| | P1 | P2 | P3 | P4 |
| Oligochaeta | 27.4 | 4.0 | 14.6 | 1.9 |
| Hirudinea | +[a] | 3.7 | 2.6 | 3.2 |
| Mollusca | 6.1 | 11.6 | 1.4 | 2.2 |
| Amphipoda | -- | 1.0 | 2.0 | 3.4 |
| Hydracarina | -- | -- | + | + |
| Plecoptera | -- | -- | + | -- |
| Ephemeroptera | 0.4 | 0.2 | 0.4 | 6.0 |
| Hemiptera | 0.8 | 0.1 | 0.6 | 0.8 |
| Odonata | 0.5 | 1.8 | 0.2 | 3.8 |
| Trichoptera | -- | 3.2 | 0.2 | 0.3 |
| Megaloptera | 0.1 | 0.3 | -- | -- |
| Coleoptera | 1.8 | 0.4 | 0.3 | 1.8 |
| Diptera | 5.0 | 2.5 | 5.8 | 1.2 |
| Total | 42.1 | 28.7 | 28.2 | 24.7 |

[a] + = present but less than 0.05 $g/m^2$.

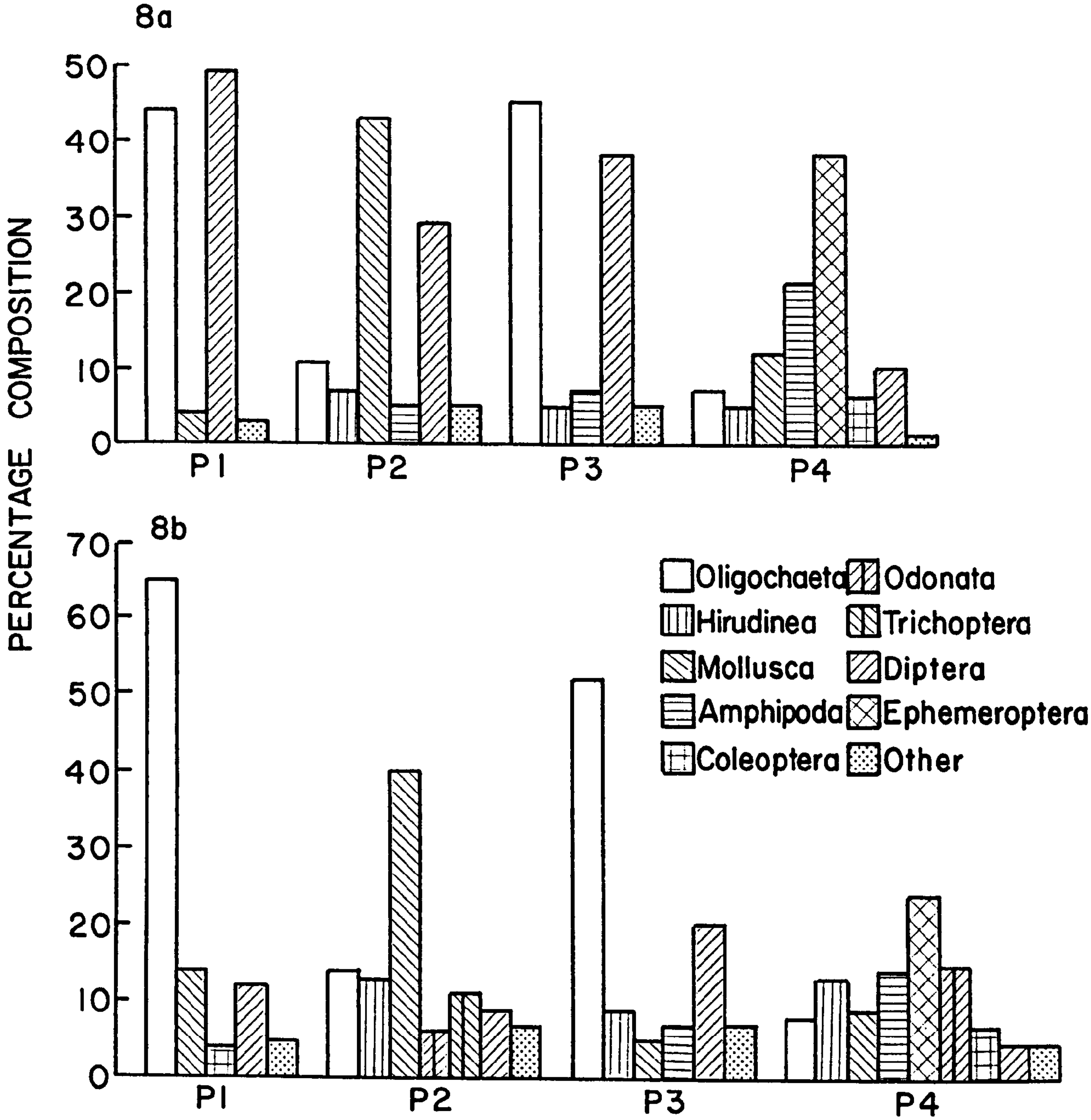


Figure 8. Percentage composition of major invertebrate group using density values (8a) and biomass values (8b).

they comprised 7% of the invertebrate density and biomass. Amphipods were most abundant in the control pond, P4, accounting for 21% of the density and 14% of the biomass.

Hydracarina were collected infrequently at P3 and P4, the ponds not directly associated with mining activity. Water mites were never collected at P1 or P2.

Plecoptera are generally not found in ponds. A single specimen of *Malenka* was collected at P3.

Ephemeropterans were collected at all ponds, but were abundant only at P4 where they accounted for 38% of the density and 24% of the invertebrate biomass due to large numbers of *Caenis*.

Hemiptera accounted for less than 1% of the invertebrate density at all ponds. This was partly due to the sampling method which is not designed to collect strong swimmers. *Hesperocorixa laevigata* was the most abundant species in all ponds.

Odonata were collected in all ponds with damselflies being the most abundant suborder. Odonates were unimportant at P1 and P3, accounting for approximately 1% of the invertebrate density and biomass. While the odonates accounted for only 2% of the density at P2 and 1% at P4, they accounted for 6% of the biomass at P2 and 15% at P4, due to the abundance of the damselflies, *Neoneura* and *Enallagma*.

Trichoptera occurred infrequently except at P2, where they accounted for 11% of the invertebrate biomass, due to the presence of the large caddisfly larvae *Phryganea cinerea* and *Limnephilus*. Caddisflies were never collected at P1, the youngest pond in the mine, and only rarely at P3 and P4.

The megalopteran *Sialis* was collected infrequently only at P1 and P2, the ponds in the mine spoils, where they accounted for less than 1% of the density and biomass.

Aquatic beetles (Coleoptera) were present in all ponds, but abundant only at P1 and P4. Coleopterans comprised 2% of the invertebrate density and 4% of the invertebrate biomass at P1, due to the abundance of *Haliplus* spp. and *Hydroporus tenebrosus*. Beetles were less important at P2 and P3, accounting for only 1% of the invertebrate density and biomass. Coleoptera were most important at P4, accounting for 6% of the density and 7% of the biomass due to the greater abundance of *Haliplus* spp. Species of *Haliplus* are often found in strip-mine ponds (Brigham and Sanderson 1974), which are used as refugia in areas with little standing water.

Dipterans were abundant at all ponds. They comprised 49% of the density, and 12% of the biomass at P1, due to the abundance of the midge larvae *Procladius, Tanytarsus,* and *Orthocladius*. Chironomids were also shown to be major members of the benthos in strip-mine lakes in Indiana (Smith and Frey 1971). At P2, the dipterans comprised 29% of the density and 9% of the biomass due to high numbers of the chironomids *Procladius* and *Tanytarsus*, as well as *Tabanus* and *Palpomyia*. Ceratopogonids (e.g., *Palpomyia*) were also abundant in a strip-mine lake in Kansas (Burner and Leist 1953). At P3, dipterans accounted for 38% of the density and 20% of the biomass, due to the abundance of *Chironomus*, *Tanytarsus*, *Orthocladius*, and *Palpomyia*. The control pond (P4) had the lowest density of dipterans, which comprised only 10% of the density and 5% of the biomass, primarily due to decreased abundance of chironomids.

Benthic macroinvertebrate density exhibited marked seasonal trends at the ponds (Figure 9), ranging from 15,326 organisms/m$^2$ at P1 in January to 474 organisms/m$^2$ at P4 in October. The seasonal pattern at P1 exhibited little fluctuation in summer and early fall, with major peaks in January and May. The peak in density in January was due to a large increase in *Orthocladius* and oligochaetes. The increased density in May was due to increased numbers of *Limnodrilus hoffmeisteri* and *Tanytarsus*. A spring maximum for *Limnodrilus hoffmeisteri* was also observed by Young (1974a) in a small pond in England.

The seasonal pattern at P2 exhibited marked peaks in density in summer and late fall. The peak in June was due to high numbers of *Pisidium variabile* and the chironomids *Procladius* and *Tanytarsus*. The increase in density in fall was due to *Pisidium variabile*, *Procladius*, *Tanytarsus*, *Hyalella azteca*, and *Limnodrilus hoffmeisteri*.

The pattern at P3 was similar to that observed at P2. Peak density in June was due to large numbers of *Chironomus*, *Tanytarsus*, *Orthocladius*, *Limnodrilus hoffmeisteri*, and *Tubifex tubifex*. The increase in fall was due to tubificid worms in October and *Hyalella azteca* in November. Increased density of *Tanytarsus* and *Orthocladius* in January offset decreases in the density of tubificid worms and amphipods.

The seasonal trends at P4 were less distinct. There was a peak in density in June due to the great abundance of the mayfly *Caenis*. The emergence of this mayfly resulted in lower density in July. Little change in density occurred through late fall. The higher density in March was due primarily to increased abundance of *Hyalella azteca* and to a lesser extent *Limnodrilus hoffmeisteri*. A more detailed analysis of seasonal trends in faunal abundance would require detailed examinations of life cycles of individual taxa which is beyond the scope of this study.

The fewest number of macroinvertebrate taxa were collected at P1, the youngest spoils pond, with only 25 taxa represented (Table 10). The other ponds had approximately the same number of species (36-38). This trend was not statistically significant ($P > 0.05$) due to the seasonal occurrence of the benthic taxa in the ponds. The increased number of species at the other ponds was due to more species of Hirudinea, Amphipoda, Odonata, Trichoptera, and Diptera (Table 9); organisms that may not have colonized P1 yet due to low dispersal ability (e.g., Amphipoda) or lack of adequate time to reach the pond. Species diversity values exhibited similar trends (Table 10), with the lowest value at P1, the youngest pond in the mine, and higher, more similar values at the other ponds, although equitability

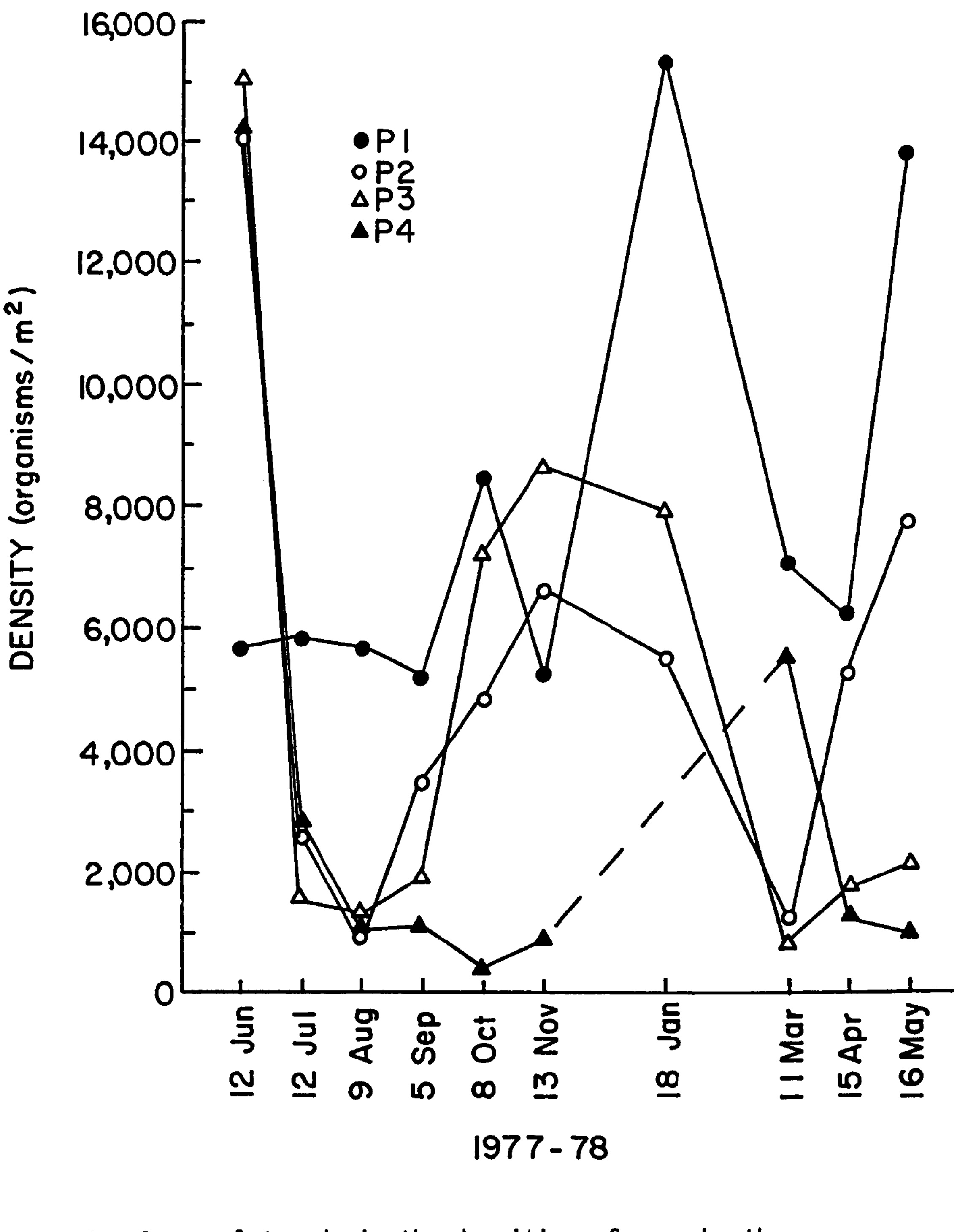


Figure 9. Seasonal trends in the densities of macrobenthos.

TABLE 9. NUMBER OF TAXA IN MAJOR INVERTEBRATE GROUPS FROM PONDS ASSOCIATED WITH COAL MINING IN NORTHWESTERN COLORADO (JUNE 1977-MAY 1978)

| | Ponds | | | |
|---|---|---|---|---|
| | P1 | P2 | P3 | P4 |
| Oligochaeta | 3 | 2 | 3 | 2 |
| Hirudinea | 1 | 2 | 2 | 4 |
| Mollusca | 3 | 4 | 3 | 3 |
| Amphipoda | 0 | 1 | 1 | 1 |
| Hydracarina | 0 | 0 | 1 | 1 |
| Plecoptera | 0 | 0 | 1 | 0 |
| Ephemeroptera | 2 | 2 | 2 | 3 |
| Hemiptera | 2 | 1 | 3 | 2 |
| Odonata | 3 | 5 | 4 | 4 |
| Trichoptera | 0 | 5 | 3 | 1 |
| Megaloptera | 1 | 1 | 0 | 0 |
| Coleoptera | 3 | 4 | 2 | 5 |
| Diptera | 7 | 9 | 13 | 10 |

TABLE 10. MACROINVERTEBRATE SPECIES DIVERSITY, EQUITABILITY, AND NUMBER OF TAXA FOR PONDS ASSOCIATED WITH COAL MINING IN NORTHWESTERN COLORADO

| | Ponds | | | |
|---|---|---|---|---|
| | P1 | P2 | P3 | P4 |
| Shannon-Weaver Index | 2.49 | 2.95 | 3.03 | 3.13 |
| Equitability | 0.31 | 0.30 | 0.30 | 0.34 |
| Number of taxa | 25 | 36 | 38 | 36 |

TABLE 11. COEFFICIENT OF COMMUNITY AND PERCENTAGE SIMILARITY USING MACROINVERTEBRATES FROM PONDS ASSOCIATED WITH COAL MINING IN NORTHWESTERN COLORADO

| | | Coefficient of Community | | | |
|---|---|---|---|---|---|
| | | P1 | P2 | P3 | P4 |
| Percentage Similarity | P1 | -- | 0.75 | 0.70 | 0.62 |
| | P2 | 0.42 | -- | 0.68 | 0.75 |
| | P3 | 0.68 | 0.36 | -- | 0.73 |
| | P4 | 0.14 | 0.31 | 0.26 | -- |

values exhibited no difference between ponds. It is felt that the less diverse benthic community at P1 is largely a function of colonization phenomena, although higher levels of nitrate, sulfate, and TDS may provide an adverse environment for some species.

Coefficient of Community was calculated to test the similarity of the ponds with respect to the presence or absence of benthic macroinvertebrate taxa (Table 11). As with the zooplankton, the values were high for all combinations. Using the Percentage Similarity index, which also takes relative abundance into account, ponds P1 and P3 were most similar (0.68), as was true for zooplankters. Pond P3 was the nearest source of colonizers for the younger pond. P1 and P4, the control pond, were the most dissimilar (0.14), as expected, since the control pond is in a watershed adjacent to the mine spoils.

## D. SUMMARY

Mine drainage appeared to have no effect on a variety of physico-chemical parameters measured in spoils ponds in Colorado. Acid mine drainage was not observed. Total dissolved solids, nitrate and sulfate levels, however, were higher in the spoils ponds than the control pond.

Zooplankton density was greatest in the control pond and lowest in the youngest spoils pond. Macroinvertebrate standing crop exhibited an opposite trend with the highest value in the youngest spoils pond.

Certain zooplankters (e.g., Cladocera) and benthic invertebrates (e.g., Amphipoda, Trichoptera) were rare or absent in the youngest spoils pond which also contained the fewest species of zooplankton and benthos.

Biological differences between ponds may be attributed to colonization phenomena and higher levels of nitrate, sulfate and TDS in the spoils ponds.

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**15. SUPPLEMENTARY NOTES**

**16. ABSTRACT**

Physico-chemical conditions, zooplankton, and benthos were investigated in coal strip-mine ponds in northwestern Colorado. There were no discernible effects of mine drainage on a variety of physico-chemical parameters. In stark contrast to spoils ponds in the eastern and midwestern states, acid mine drainage was not observed. Total dissolved solids, nitrate and sulfate values were higher in the spoils ponds than in the control pond. Net zooplankton abundance was lowest in the youngest spoils pond, but the standing crop of benthos exhibited a progressive decrease from the youngest spoils pond to the control pond. Zooplankton and benthos species diversity were lower in the spoils ponds. Certain groups of zooplankters and benthos were rare or absent in the youngest spoils pond. Colonization phenomena (age and distance from a source of colonizers) are postulated as responsible, in part, for the faunal differences between ponds. If these data are typical of the western energy region, they suggest the potential for development of recreational lakes as a part of reclamation practices.

**17. KEY WORDS AND DOCUMENT ANALYSIS**

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Spoil ponds<br>Invertebrates<br>Zooplankton<br>Macrobenthos<br>Effects of mining | Energy development<br>Coal mining<br>Water quality | 06/F<br>68/D |

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