The Zooplankton and Invertebrate Populations of Three Strip Mine Lakes, Spencer County, Indiana

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INTRODUCTION

Strip mines are a major source of coal in the United States. Most of the mines are located in the Appalachians, the South and the midwest. Over 100,000 acres have been mined in Indiana and it is estimated that a comparable amount of land can still be exploited. One result of the area strip mining method, in flat regions, is the formation of ponds and lakes ranging in area from a few hundred square meters to several acres. Approximately one acre of water forms for every 8 or 9 acres mined. (Smith, 1971; Coe, 1972)

Initially these strip mine lakes are acidic and have high ion concentrations due to leaching of material from the spoil banks by runoff and ground water. The acid condition is the result of oxidation of iron sulfide. With time the lakes becomes chemically and biotically related to the natural small lakes of the region, although the process of recovery is variable from lake to lake, and chronological and ecological age are not necessarily correlative. (Smith, 1971)

In Indiana strip mining is confined to the southwestern part of the state, on the easternmost portion of the Pennsylvanian zone, which extends into most of Illinois. The present study was done on three strip mine lakes located in Harrison Township of Spencer County, Indiana (T45, R4W, SW¼, Section7, NW¼, Section 18), one and one-half miles east of Mariah Hill, north of U.S. 460. Their bathymetric descriptions are as follows (Gladieux, 1975):

	Area (sq. m.)	Volume (cu.m.)
Lake I	17,981	33,620
II	4,972	19,552
III	23,192	58,561

A preliminary study of the three lakes by Coe (1972) included physical, chemical and biotic descriptions. Each lake was found to be in a different stage of recovery from its initial acid condition. Since each lake is of approximately the same age chronologically, the findings of Campbell (1964, 1969) concerning disparity between age and chemical condition were confirmed.

Lake I, pH 7.4, was found to be the most biologically productive of the lakes and in the alkaline stage of recovery.

Lake II, Ph 6.4, in the early alkaline stage of recovery, was the least productive of the three lakes.

Lake III, pH 7.0, was in the intermediate stage of alkaline recovery, although its biological productivity was closer to that of Lake II.

Sulfate was the predominant ion in all three lakes. This corresponds with the findings of Smith (1971). In all cases the sulfate concentration was higher than the natural lake Smith used as a control.

Lake populations are generally related to pH. Alkaline lake (pH <7.0) populations are more closely related to those of natural regional lakes. Acid lakes (pH >7.0) show lower productivity and deviant patterns of diversity (Pennak, 1953). Sulfate, as the predominant ion, may also be a factor in determining lake productivity.

Because of the broad scope and time limitation on Coe's work, data on aquatic invertebrates necessarily remained incomplete. The purpose of the study was 1) to expand the list of invertebrates living in the lakes, and 2) to discover what influence, if any, pH and sulfate concentration may have on the invertebrate populations of the lakes.

METHODS AND MATERIALS

All data were collected between September 28 and November 5, 1975. Benthic samples were collected on November 1 and 2. Work was done from a 16-foot flatbottom boat equipped with a trolling motor.

Plankton samples were taken with a plankton towing net (6 in. diameter, 16 in. deep; 81 cu. in. volume, number 20 standard silk bolting cloth). Two types of samples were made. Vertical samples were taken by lowering the net to within one foot of the lake bottom from the boat, and then slowly raising the net to the surface. Tow samples were made by trailing the net behind the boat at a depth of 1-10 feet for a distance of up to 300 feet and not less than 100 feet.

Tow samples were taken along the perimeters of each lake, down the centers of channels and across open areas. Vertical samples were taken at regular intervals where the water was more than six feet deep. At least one sample of each kind was taken in every extremity of each lake.

The number of samples taken was based on the assumed volume of each lake related to the surface area. Twenty-three samples were taken from Lake I, 16 from Lake II, and 31 from Lake III.

Samples were placed in jars of 5% formalin, generally three sample to a jar. An equivalent of one slide per sample was made from the settled contents of each jar. The coverslip of each slide was divided into 16 equal squares. A Whipple

Micrometer Reticel (21.15 mm. diameter disc) was placed in the eyepiece of the microscope used in identification. Animals lying within the micrometer grid were counted in one representative section of each square at low power. The presence of species within each square but not present within the micrometer grid was noted separately. Animals as large or larger than the grid were counted in the square as a whole.

A small homemade Caribbean type dredge (12 in. high by 10 in. wide by 24 in. deep: 2880 cu. in. vol.) was used to collect benthic samples. The dredge was lowered from the boat approximately 50 feet from shore and then pulled into shore with a one-half inch nylon rope, the cutting edge digging into the bottom for the entire distance. Approximately an one-third of a gallon sample was taken from each dredging and put in a gallon jar.

Samples were taken at random positions along the shore. The number of samples was determined by the size of the lakes: 5 samples were taken from Lake I, 4 from Lake II, and 7 from Lake III.

Approximately 500 ml. per sample, or 1500 ml. per gallon jar were taken and washed through a series of 6 seives, ranging in size from 10 to 230 meshes per linear inch. The contents from each seive (except the first, which in every case contained only rocks and large debris) were stored in jars of 5% formalin. Twenty-seven slides were made from Lake I samples, 12 from Lake II, and 21 from Lake III. Animals were counted on the slides as a whole.

Literature used in identification of the invertebrates included Ward and Whipple (1959), Pennak (1953), and Eddy and Hodson (1961). The phyletic scheme used in all tables was based on Ward and Whipple. In most cases limnetic organisms were classified to the species level, benthic organisms to phylum or order.

RESULTS AND DISCUSSION

Raw data for all tables on limnetic samples can be found in Appendix I. Animals counted within the micrometer grids were totalled (T), and species frequency (presence without regard for number) was recorded both within the grids (F1) and within the squares outside the grid (F2).

Calculations made from the grid totals were percentage frequency (% F1): the number of grids in which the species were found divided by the total number of grids (Table 1); diversity: d = S/N, where S was the number of species and N the number of organisms counted; density: total individuals divided by the number of slides; percentage composition: the number of individuals in a taxonomic group divided by the total individuals in the lake (Table 2).

A second percentage frequency (% F2) was calculated based on the frequency of animals within the squares into which the coverslip was divided (Table 1). Asplanchna, Cladocera, Copepoda, and Insecta larvae, as large or larger than the grid, were counted within the squares. A total percentage frequency was calculated for each lake by dividing the number of squares in which organisms of each species (F2, App. I) were present by the total number of possible squares:

	Lake I	Lake II	Lake III
Total % F	12	8.9	11

Table 1. Percentage frequencies of species in Lakes I-III. F1 based on presence within grids; F2 based on presence within squares.

	Lake I		Lake II		Lake III	
	F1	F2	F1	F2	F1	F2
PROTOZOA						
Rhizopoda						
Order Amoebaea						
Thecamoeba verrucosa	0.5	2.9	--	--	--	--
Pelomyxa palustris	3.3	14	--	--	7.9	15
Order Testacealobosa						
Arcella megastomata	0.5	7.3	--	--	0.2	0.2
A. mitrata	--	1.9	--	--	--	--
A. vulgaris	0.3	2.4	--	0.4	0.6	1.2
A. dentata	--	0.8	--	--	--	0.2
Centropyxis aculeata	--	1.1	--	--	--	--
C. arcelloides	--	--	--	--	--	0.2
Difflugia urceolata	--	--	1.2	2.3	41	43
D. lebes	5.7	12	--	3.9	6.3	15
D. oblonga	--	0.8	--	--	--	--
Lequereusia epistomum	--	--	--	--	--	1.4
L. spiralis	--	--	5.4	5.4	--	--
Order Actinophyridia						
Actinophyris sol	1.9	6.5	--	--	--	0.2
Ciliata						
Order Holotricha						
Paramecium caudatum	--	--	--	--	0.2	0.2
Order Spirotricha						
Histrio histrio	--	--	--	--	0.2	0.8
COELENTERATA						
Hydra nematocysts	14	14	--	--	64	76
ROTIFERA						
Order Ploima						
Branchionus plicatilis	--	0.3	--	--	0.2	0.6
Epiphanes clavulata	--	1.4	--	--	--	1.2
E. senta	--	0.5	--	0.4	--	--
Kellicotia longispina	1.9	2.7	30	47	0.2	0.6

Table 1 (cont'd).

ROTIFERA (cont'd)	Lake I F1	Lake I F2	Lake II F1	Lake II F2	Lake III F1	Lake III F2
Keratella cochlearis	92	97	30	92	94	95
Notholca acuminata	--	0.5	--	--	--	--
Lepadella ovalis	--	--	--	--	--	0.2
Lecane depressa	--	0.3	--	--	--	--
L. ohioensis	--	1.1	--	1.9	0.4	1.8
L. elasma	0.3	0.3	--	--	--	--
Monostyla lunaris	0.8	2.7	--	--	--	0.2
Scaridium longicaudum	--	0.2	--	--	--	--
Trichocerca similis	2.9	64	1.6	3.5	2.0	54
T. multicrinis	0.8	2.2	0.8	0.8	3.1	9.4
T. longiseta	0.3	1.9	--	--	--	0.8
Ascomorphella volvocicola	0.5	1.4	--	--	--	--
Ascomorpha saltans	24	53	--	0.8	0.5	16
A. ecaudis	--	3.5	--	--	--	0.4
Gastropus hyoptus	--	0.3	--	--	--	--
G. minor	0.3	1.4	--	--	0.2	0.2
G. stylifer	0.5	0.5	--	--	0.8	0.8
Chromogaster ovalis	0.6	3.8	--	--	0.6	4.2
Asplanchna spp.	9.8	9.8	--	--	19	19
Polyarthra vulgaris	65	90	--	--	40	64
Syncheata oblonga	29	58	--	0.8	13	29
S. pectinata	19	32	--	--	3.0	6.0
Order Flosculariacae						
Filinia minuta	--	0.5	--	--	1.0	2.0
F. longiseta	0.5	0.5	0.4	0.8	0.2	3.0
F. branchiata	0.5	1.4	--	--	0.2	0.6
F. terminalis	--	--	--	--	--	0.6
Pompholyx sulcata	4.3	4.3	--	--	0.6	2.8
Testudinella patina	0.3	0.5	--	--	--	--
Trochosphaera solstitialis	--	0.3	--	--	--	--
Order Collothecae						
Cupelopagis vorax	0.3	0.3	--	--	--	0.6
Unknown rotifer	13	38	--	--	3.4	10
Total rotifer species	22	33	5	9	19	26

Table 1 (cont'd).

	Lake I		Lake II		Lake III	
	F1	F2	F1	F2	F1	F2
ARTHROPODA						
Order Cladocera						
Sida crystallina	1.9	1.9	6.6	6.6	12	12
Holopedium gibberum	--	--	1.2	1.2	2.6	2.6
Daphnia longispina	40	40	7.0	7.0	19	19
Camptocercus oklahomensis	0.3	0.3	--	--	--	--
Chydorus ovalis	0.3	0.3	0.4	0.4	--	--
C. lacustris	--	--	--	--	0.4	0.4
C. faviform	--	--	0.8	0.8	--	--
Polyphemus pediculus	1.4	1.4	2.3	2.3	0.8	0.8
Order Ostracoda	0.3	4.9	1.2	1.6	0.4	0.4
Order Copepoda						
Nauplii spp.	41	76	47	72	29	67
Diaptomus siciloides	37	37	56	56	45	45
Cyclops vernalis	3.5	3.5	3.1	3.1	5.4	5.4
Orthocyclops	4.3	4.3	2.7	2.7	2.6	2.6
Ectocyclops	4.3	4.3	5.5	5.5	1.0	1.0
Paracyclops	5.7	5.7	32	32	5.6	5.6
Ergasilus chautauquensis	--	--	--	--	1.8	1.8
Insect larvae						
Order Diptera						
Chaoborus sp.	--	--	0.8	0.8	--	--
Other	0.3	0.3	0.4	0.4	0.2	0.2
Order Lepidoptera	0.5	0.5	--	--	--	--
Order Odonata	0.5	0.5	0.4	0.4	--	--
Total species	44	59	23	29	41	52

Table 2. Population parameters of taxonomic groups in limnetic samples. (Based on grid tabulations.)

	# Species			# Individuals		
	I	II	III	I	II	III
PROTOZOA	6	2	7	50	22	883
COELENTERATA	1	-	1	66	--	981
ROTIFERA	22	5	18	1838	847	1605
ARTHROPODA						
Cladocera	5	5	6	222	47	187
Ostracoda	1	1	1	1	3	2
Copepoda	6	6	7	477	695	704
Insecta larvae	3	3	1	4	4	1
TOTAL	44	23	41	2658	1618	4363
Diversity (S/N)	0.017	0.014	0.009			

	Density (#/slide)			% Composition		
PROTOZOA	2.0	1.4	28	1.9	1.4	20
COELENTERATA	3.0	--	31	2.4	--	22
ROTIFERA	80	53	51	69	52	37
ARTHROPODA						
Cladocera	10	3	6	8.4	2.9	4.3
Ostracoda	<1	<1	<1	<0.1	<0.1	<0.1
Copepoda	21	43	22	18	43	16
Insecta larvae	<1	<1	<1	<0.1	<0.1	<0.1
TOTAL	116	101	141			

Species unique to each lake and those found in two or three lakes are detailed in Table 3 and summarized in Table 4. *Hydra* nematocysts, Ostracoda, Copepod nauplii, and orders of Insecta larvae, while not divided into species, are separate taxonomic groups and are regarded as species for counting purposes.

Lake I showed the greatest number of species (44), the greatest diversity of species (0.017), and the highest frequency of species (12%) (Table 2). The density of individuals (116/slide) was intermediate. Of the total species on the three lakes, 21% were unique to Lake I (Table 4). The most important groups were Rotifera (69%), Copepoda (18%), and Cladocera (8.4%).

Lake II showed the smallest number of species (23), the lowest total frequency (8.9%) and density (101/slide), and a diversity (0.014) nearly as great as that of Lake I (Table 2). Only 4.2% of the total species were unique to the lake or found in common with either other lake (Table 4). Rotifera were the dominant group (52%), though of less importance than in Lake I. Copepoda were twice as important (43%) as the copepod population of Lake I. The cladoceran population was significantly reduced, from 8.4% to 2.9%.

The number of species (41) in Lake II fell between the totals for Lakes I and II, though the total was closer to that of Lake I (Table 2). The diversity (0.009) was the lowest of the three, because of the great numbers of *Hydra* nematocysts,

Table 3. Distribution of species in Lakes I-III: unique, common to 2-3 lakes. (Based on presence within squares.)

	Unique			Common			
	I	II	III	I,II,III	I,II	I,III	II,III
PROTOZOA							
Rhizopoda							
Order Amoebaea							
Thecamoeba verrucosa	X						
Pelomyxa palustris						X	
Order Testacealobosa							
Arcella megastomata						X	
A. mitrata	X						
A. vulgaris				X			
A. dentata						X	
Centropyxis aculeata	X						
C. arcelloides			X				
Difflugia urceolata							X
D. lebes				X			
D. oblonga	X						
Lequereusia epistomum			X				
L. spiralis		X					
Order Actinophyridia							
Actinophyris sol						X	
Ciliata							
Order Holotricha							
Paramecium caudatum			X				
Order Spirotricha							
Histrio histrio			X				
COELENTERATA							
Hydra nematocysts						X	
ROTIFERA							
Order Ploima							
Branchionus plicatilis						X	
Epiphanes clavulata						X	
E. senta					X		
Kellicotia longispina				X			

Table 3 (cont'd).

ROTIFERA (cont'd)	I	II	III	I,II,III	I,II	I,III	II,III
Keratella cochlearis				X			
Notholca acuminata	X						
Lepadella ovalis			X				
Lecane depressa	X						
L. ohoiensis				X			
L. elasma	X						
Monostyla lunaris						X	
Scaridium longicaudum	X						
Trichocerca similis				X			
T. multicrinis				X			
T. longiseta						X	
Ascomorphella volvocicola	X						
Ascomorpha saltans				X			
A. ecaudis						X	
Gastropus hyoptus	X						
G. minor						X	
G. stylifer						X	
Chromogaster ovalis						X	
Asplanchna spp.						X	
Polyarthra vulgaris						X	
Synchaeta oblonga				X			
S. pectinata						X	
Order Flosculariacae							
Filinia minuta	X						
F. longiseta				X			
F. branchiata				X			
F. terminalis			X				
Pompholyx sulcata						X	
Testudinella patina	X						
Trochosphaera solstitialis	X						
Order Collothecae							
Cupelopagis vorax						X	
Unknown rotifer						X	

Table 3 (cont'd)

ARTHROPODA	I	II	III	I,II,III	I,II	I,III	II,III
Order Claocera							
Sida crystallina				X			
Holopedium gibberum							X
Daphnia longispina				X			
Camptocercus oklahomensis	X						
Chydorus ovalis					X		
C. lacustris			X				
C. faviform		X					
Polyphemus pediculus				X			
Order Ostracoda				X			
Order Copepoda							
Nauplii spp.				X			
Diaptomus siciloides				X			
Cyclops vernalis				X			
Orthocyclops				X			
Ectocyclops				X			
Paracyclops				X			
Ergasilus chautauquensis			X				
Insecta larvae							
Order Diptera							
Chaoborus sp.		X					
Other				X			
Order Lepidoptera	X						
Order Odonata					X		

Table 4. Summary of species distribution in Lakes I-III.

	Number	%
Unique:		
Lake: I	15	21
II	3	4.2
III	8	11
Common:		
Lakes: I, II, III	21	29
I, II	3	4.2
I, III	19	26
II, III	3	4.2

Difflugia, and Keratella cochlearis. The density of individuals (141/slide) was highest. Of the total species, 11% were unique to Lake III, and 26% were common to Lake I (Table 4). The importance of Rotifera was reduced to 37%, while the importance of Protozoa (20%) and Coelenterata (22%) were greatly increased. Copepoda composed 16% of the population, which is comparable to Lake I. Cladocera composed 4.3% of the population.

Seasonal Variation

Maxima for zooplankton are reached in spring and autumn, although these maxima vary greatly within different lakes and for different species (Welch, 1961). Little information is available concerning the seasonal cycles of Protozoa and microcrusteceans; more information is available on variations in Rotifera, although this is incomplete.

Difflugia, the only protozoan genus of importance in the lakes (Table 1), are planktonic from June to October (Hutchinson, 1967). All lakes showed some Difflugia, Lake III more so than the others (Table 1).

Hydra shows a bloom in September-October (Pennak, 1953). Such a bloom was evident in Lake III.

Irregular activity is usual in rotifers, and predictable patterns are hard to find (Reid, 1961). The most abundant species in Lakes I, II and III was Keratella cochlearis. It shows a June maximum and a temporary autumn increase, and generally predominates year round (Hutchinson, 1967). Polyarthra vulgaris has an autumnal maximum (Hutchinson, 1967), and its relative importance in Lakes I and III (Table 1) was probably related to other factors. Synchaeta oblonga and S. pectinata generally show maxima in October, so their importance in Lakes I, II and III was probaly as great as it could be. Chromogaster ovalis, which was of small importance, generally reaches its maximum in September (Hutchinson, 1967), and so is probably never important in these lakes. The same is true of Filinia. Ascomorpha saltans, important in Lake I, as well as Pompholyx sulcata, are on the decline in October, their maxima having been reached in August (Hutchinson, 1967). Gastropus stylifer and Ascomorpha ecaudis reach their maxima in June and are normally rare in autumn (Hutchinson, 1967).

Cladoceran seasonal cycles are comparable to those of rotifers (Hutchinson, 1967) and may be highly irregular (Reid, 1961). Generally there is a summer maximum with a bloom possible in October. Holopedium gibberum generally reaches an October maximum, as does Daphnia longispina (Hutchinson, 1967), which is the dominant cladoceran species in Lakes I, II and III (Table 1). Sida crystallina and Polyphemus pediculus reach maxima in June (Hutchinson, 1967), and neither of these species were strongly represented in any of the three lakes.

There is no indication in the literature of exceptionally large copepod populations in October. Species other than the ones present in Lakes I, II and III generally reach their peaks in August and are on the decline by October. However, there is a possible emergence of copepods from diapuse in

October, which may include from a very few individuals to the total copepod population (Hutchinson, 1967).

Feeding

The majority of zooplankton are sedimenters (Pennak, 1953) and feed on algae of various sizes, flagellates and dinoflagellates. The precise relation of food to zooplankton as a limiting factor is difficult to determine in the case of sedimenters. Reid (1961) suggests that in some lakes the relation does not appear important. An unusually large phytoplankton bloom in not necessarily followed by a commensurate zooplankton bloom, and neither is an unusually large zooplankton bloom necessarily preceded by a commensurate phytoplankton bloom (Hutchinson, 1967). The relation between food distribution is at best uncertain (Welch, 1952). Phytoplankton data for the three lakes have been collected by Ernstberger (1975) but little correlation could be found.

Raptorial, or carnivorous, invertebrates include _Hydra_, _Asplanchna_, _Synchaeta_, _Trichocerca_, _Polyphemus pediculus_ and the cyclopoid copepods. They feed on protozoans and other rotifers and microcrustaceans (excluding ostracods). Some feed on diatoms as well (Pennak, 1953; Hutchinson, 1967; Welch, 1952).

Twelve predatory species were present in Lake I. _Trichocerca similis_ (F2 = 64%) and _Synchaeta oblonga_ (F2 = 58%) were the most important. _Synchaeta pectinata_ (F2 = 32%) was of relative importance.

Lake II contained only six predatory species, and only <u>Paracyclops</u> (F2 = 32%) was of relative importance.

Lake III contained the highest number of predatory species (14). <u>Hydra</u> nematocysts were of great importance (F2 = 76%). <u>Trichocerca similis</u> (F2 = 54%), <u>Synchaeta oblonga</u> (F2 = 29%) and <u>Asplanchna</u> (F2 = 19%) held positions of relative importance. The importance of the predatory species in Lake III may be related to the low density and percentage composition of rotifers in this lake (Table 2).

pH and Sulfates

Gladieux (1975) has updated Coe's (1972) data on sulfate concentration and pH in Lakes I, II and III:

	Lake I	Lake II	Lake III
pH	7.0	6.3	6.9
Sulfate (mg./l.)	55	105	95

The number of species within each lake corresponded roughly to the pH. Lake I, at the lowest pH and sulfate concentration, had the most species (59)(Table 1, F2). Lake II, at the highest pH and sulfate concentration, had only half as many (29)(Table 1, F2). Lake III, at nearly the same pH as Lake I, had fewer species (52)(Table 1, F2) but a higher density and a diversity only half that of Lake I (Table 2), which may indicate a limitation related to the higher sulfate content of the lake.

Species common to all three lakes and to Lakes I and III, with some exceptions, showed lower frequencies in Lake III than in Lake I. Species common to all three lakes generally showed the lowest frequencies in Lake II (Tables 1 and 3).

A great majority of protozoans live optimally at pH 6.5-8.0 (Pennak, 1953). The number of species (Table 1, F2) in Lake I (10)and Lake III (11) were similar, though only Lake III showed a high percentage composition (20%)(Table 2) and density (28/slide)(Table 2) and this of only one species, *Difflugia urceolata* (F2 = 43%)(Table 1). Lake II, falling below the optimal range, showed only 4 species, none of them important (Table 1). *Pelomyxa palustris*, identified by Pennak (1953) as a pollution species, was absent from Lake II, and showed only a slightly higher importance in Lake III (F2 = 15%) than in Lake I (F2 = 14%).

Most species of *Hydra* do well in medium hard waters, pH 7.6-8.0 (Pennak, 1953). Their presence in Lake I and III indicated that survival is possible at a higher pH. Their abundance in Lake III may be related to sulfate as it relates to water hardness.

Alkaline genera of rotifers include, *Asplanchna*, *Branchionus*, *Filinia* and *Notholca* (pH $<$7.0). Acid genera include *Lepadella*, *Monostyla*, *Lecane* and *Trichocerca* (pH $>$7.0). The vast majority of rotifers are transcursal and tolerate a wide variety of ecological conditions (Pennak, 1953).

Lake I contained members of all alkaline and acid genera. Only *Trichocerca similis* was important (F2 = 64%). Dominant species were: Keratella cochlearis (F2 = 97%), Polyarthra vulgaris (F2 = 90%), Trichocerca similis (F2 = 64%), Synchaeta oblonga (F2 = 58%), Ascomorpha saltans (F2 = 53%), and Synchaeta pectinata (F2 = 32%). Thirty-three species of rotifers were found in Lake I (Table 1, F2).

Lake II contained only one member of an alkaline genus and three members of two acid genera, none of importance. Dominant species were: Keratella cochlearis, (F2 = 92%), and Kellicotia longispina (F2 = 47%). The importance of K. coclearis was slightly reduced from Lake I (97% to 92%, F2), while K. longispina, negligible in Lake I, was greatly increased (1.9% to 47%, F2), suggesting an affinity for the conditions of Lake II. Nine species of rotifers were found in Lake II (Table 1, F2).

Lake III contained five members of three alkaline genera, of which only Asplanchna, (F2 = 19%) was relatively important, and six members of all four acid genera, of which Trichocerca similis (F2 = 54%) was important. Dominant species were: Keratella cochlearis (F2 = 95%), Polyarthra vulgaris (F2 = 64%), Trichocerca similis (F2 = 54%), Synchaeta oblonga (F2 = 29%), Asplanchna (F2 = 19%), and Ascomorpha saltans (F2 = 16%). The importance of K. cochlearis in Lake III was only slightly lessened from its importance in Lake I (97% to 95%, F2) and slightly increased from its importance in Lake II (92% to 95%). The importances of P. vulgaris (90% to 64%), T. similis (64% to 54%), S. oblonga (58% to 29%) and A. saltans (53% to 16%) were all significantly reduced from Lake I. The importance of Asplanchna was doubled from what it was in Lake I (9.8% to 19%). The four decreases and the one increase may be related to the sulfate concentration. Twenty-six species of rotifers were found in Lake III (Table 1, F2), although their importance within the total population was significantly less than in Lakes I or II (Table 2).

Most Cladocera occur in a range of pH 6.5-8.5 (Pennak, 1953). Cladocerans were of the greatest importance in Lake I (Table 2). The dominant species was Daphnia longispina (F2 = 40%). The importance of the cladocerans was significantly reuced in Lake II to about one third what it was in Lake I (8.4% to 2.9%, Table 2). D. longispina (F2 = 7%) and Sida crystallina (F2 = 7%) were of greatest importance. This relative scarcity compared to Lake I may be related to the harsher chemical environment of Lake II. Cladocerans were about half as important in Lake III (4.3 %, Table 2) as in Lake I (8.4%). D. longispina was again the most important species (F2 = 19%), but reduced in importance from Lake I by half. S. crystallina (F2 = 12%) is of second importance, increased from what it was in Lake I (F2 = 1.9%) or Lake II (F2 = 7%). Five species were found in Lakes I and III, 6 in Lake II (Table 1, F2).

Ostracods are tolerant of a wide variety of ecological conditions (Pennak, 1953) but were not important in any of the lakes. (Table 2).

Copepods are tolerant of a wider range of chemical conditions than are cladocerans (Pennak, 1953). Copepods were of similar importance in Lakes I (18%, Table 2) and III (16%).

Diaptomus siciloides was the dominant species in both lakes, though it was more important in Lake III (F2 = 45%) than in Lake I (F2 = 37%). Copepods were over twice as important in Lake II (43%, Table 2). D. siciloides was again dominant (F2 = 56%) and significantly more important than in Lakes I or III. Paracyclops, of second importance in Lake II (F2 = 32%), was much more frequent than in Lake I (F2 = 6%) or Lake III (F2 = 6%). This suggests that these species may have an affinity for higher pH and/or sulfates.

Insecta larvae tolerate a range of pH 5.6-8.5 and a very wide range of sulfate concentrations, but this is very closely related to individual species (Roback, 1974). Since larvae were not classified to this level, little can be said.

Seasonal variation among species and within the three lakes, and the effects of other chemical factors such as calcium and dissolved oxygen have not been measured. Smith (1971) indicates a correspondence between sulfate and total hardness, but this varies within each lake, as does pH. Sulfate concentrations and pH are related within each lake. Only general observations of patterns of species presence and abundance are possible from the present data.

Benthos

Raw data for Table 5 can be found in Appendix II. Counting was done on the slide as a whole. Taxonomic groups were analyzed for percentage frequency, density and percentage composition.

Table 5. Population parameters of taxonomic groups in benthic samples.

	% Frequency			Density-#/slide			% Composition		
	I	II	III	I	II	III	I	II	III
PROTOZOA									
Difflugia lebes	78	58	33	3.3	1.3	0.9	12	8.7	5.6
PLATYHELMINTHES									
Turbellaria	93	92	67	2.4	2.0	1.3	8.7	13	8.2
NEMATA	93	100	100	2.3	4.3	2.3	8.3	28	14
GASTROTRICHA	19	33	10	0.9	0.7	0.1	0.1	4.4	0.6
ARTHROPODA									
Ostracoda	100	100	100	15	5.0	9.0	57	33	55
Cladocera									
Ephippia	89	50	24	1.9	1.2	0.4	6.8	7.7	2.3
Copepoda		8.3			0.2			1.1	
Insecta larvae									
Diptera									
Chaoborus sp.	15		19	0.6		0.7	2.2		5.8
Lepidoptera			14			0.6			3.5
Trichoptera	56	26	52	1.1	0.5	0.8	4.2	3.3	4.7
TOTAL				27	15	16			

Gladieux (1975) has updated Coe's (1972) data concerning pH and sulfate concentrations in the benthic materials of Lakes I, II and III:

	Lake I	Lake II	Lake III
pH	4.4	4.3	4.4
Sulfates (mg./l.)	450	225	265

The benthos of all three lakes was of approximately the same pH; the sulfate concentrations varied widely.

Invertebrate groups present in Lakes I, II and III are all benthic organisms common in natural lakes (Table 5). However, rotifers and copepods, frequent in natural benthos, did not occur in Lakes I, II and III. Presence of these two groups may be chemically or depth related (Welch, 1952). The total density of individuals in Lakes I, II and III (Table 5) suggested that a higher sulfate concentration indicates a larger benthic crop.

Ostracods were the predominant organisms in each of the lakes. Their density and percentage composition in Lake I relative to Lakes II and III suggested that ostracods may be tolerant or thrive at higher sulfate concentrations.

Of second importance in Lakes I, II and III were Nemata, and the percentage composition indicated that these organisms may prefer a lower sulfate concentration, although the densities indicated that other factors may be involved.

The remaining groups did not correspond to the sulfate ratio, and explanations must be sought elsewhere.

Smith's work (1971) suggests that benthic maxima are reached in November-December. Since data were collected at the beginning of November, it is possible the one or the other lakes had reached its maximum, although it is more likely that maxima were yet to be reached by all three lakes.

All the benthic organisms feed on dead plant and animal material, except for Turbellaria and Paracyclops, which are predatory (Welch, 1952). There is no evidence to suggest that the predators have any significant effect on the rest of the benthic population.

SUMMARY

Data collected for this study showed Lake I to be most productive of zooplankton and invertebrates. Fifty-nine species were present as opposed to 29 in Lake II and 52 in Lake III. Lake III, however, showed the greatest density of individuals, Lake I an intermediate amount and Lake II the lowest. Species diversity was lowest in Lake III, highest in Lake I. Overall frequency of individuals was highest in Lake I, lowest in Lake II.

Sulfates and pH were considered as possible limiting factors. Lake I, pH 7.0, 55 mg./l. sulfate was the most fertile for the most species. Lake II, pH 6.3, 105 mg./l. sulfate, was the least fertile for the fewest species with two exceptions. Lake III, pH 6.9, 95 mg./l. sulfate, appeared the most fertile for some species, but not for others. *Keratella cochlearis*, *Polyarthra vulgaris*, *Trichocerca similis*, *Synchaeta oblonga*, *Ascomorpha saltans* and *Daphnia longispina* showed lower frequencies at higher pH or sulfate concentrations. *Kellicottia longispina*, *Asplanchna*, *Diaptomus siciloides* and *Paracyclops* showed higher frequencies at higher pH and sulfate concentrations.

Other factors possibly related to the population differences among the lakes could be seasonal variation, feeding habits of the invertebrates, and chemical factors not measured.

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Appendix I. Animals counted within grids (except Asplanchna, Cladocera, Copepoda and Insecta larvae, which were counted in the square as a whole), and species frequency within grids (F1) and within squares (F2).

	Lake I			Lake II			Lake III		
PROTOZOA	T	F1	F2	T	F1	F2	T	F1	F2
Rhizopoda									
Order Amoebaea									
Thecamoeba verrucosa	3	2	11	--	--	--	--	--	--
Pelomyxa palustris	15	12	51	--	--	--	41	39	72
Order Testacealobosa									
Arcella megastomata	2	2	27	--	--	--	1	1	1
A. mitrata	--	--	7	--	--	--	--	--	--
A. vulgaris	1	1	9	--	--	1	3	3	6
A. dentata	--	--	3	--	--	--	--	--	1
Centropyxis aculeata	--	--	4	--	--	--	--	--	--
C. arcelloides	--	--	--	--	--	--	--	--	1
Difflugia urceolata	--	--	--	5	3	6	805	203	214
D. lebes	21	21	45	--	--	10	31	31	74
D. oblonga	--	--	3	--	--	--	--	--	--
Lequereusia epistomum	--	--	--	--	--	--	--	--	7
L. spiralis	--	--	--	17	14	14	--	--	--
Order Actinophyridia									
Actinophyris sol	8	7	24	--	--	--	--	--	1
Ciliata									
Order Holothricha									
Paramecium caudatum	--	--	--	--	--	--	1	1	1
Order Spirotricha									
Histrio histrio	--	--	--	--	--	--	1	1	4
COELENTERATA									
Hydra nematocysts	66	52	52	--	--	--	981	316	377
ROTIFERA									
Order Ploima									
Branchionus plicatilis	--	--	1	--	--	--	3	2	3
Epiphanes clavulata	--	--	5	--	--	--	--	--	6
E. senta	--	--	2	--	--	1	--	--	--

Appendix I (cont'd).

ROTIFERA (cont'd)	Lake I T	Lake I F1	Lake I F2	Lake II T	Lake II F1	Lake II F2	Lake III T	Lake III F1	Lake III F2
Kellicotia longispina	7	7	10	93	76	121	12	12	23
Keratella cochlearis	1003	339	356	747	217	235	1004	467	469
Notholca acuminata	--	--	2	--	--	--	--	--	--
Lepadella ovalis	--	--	--	--	--	--	--	--	1
Lecane depressa	--	--	1	--	--	--	--	--	--
L. ohioensis	--	--	4	--	--	--	--	--	--
L. elasma	1	1	1	--	--	--	--	--	--
Monostyla lunaris	3	3	10	--	--	--	--	--	1
Scaridium longicaudum	--	--	2	--	--	--	--	--	--
Trichocerca similis	15	11	235	4	4	9	10	10	27
T. multicrinis	8	3	8	2	2	2	15	15	47
T. longiseta	1	1	7	--	--	--	--	--	4
Ascomorphella volvocicola	2	2	5	--	--	--	--	--	--
Ascomorpha saltans	105	89	195	--	--	2	24	23	79
A. ecaudis	--	--	13	--	--	--	--	--	2
Gastropus hyoptus	--	--	1	--	--	--	--	--	--
G. minor	1	1	5	--	--	--	1	1	2
G. stylifer	2	2	2	--	--	--	5	4	11
Chromogaster ovalis	2	2	14	--	--	--	3	3	21
Asplanchna spp.	36	36	36	--	--	--	92	92	92
Polyarthra vulgaris	355	238	330	--	--	--	298	197	317
Synchaeta oblonga	132	107	213	--	--	2	102	62	146
S. pectinata	81	68	118	--	--	--	17	15	30
Order Flosculariacae									
Filinia minuta	--	--	2	--	--	--	6	5	10
F. longiseta	2	2	2	1	1	2	1	1	15
F. branchiata	2	2	5	--	--	--	1	1	3
F. terminalis	--	--	--	--	--	--	--	--	3
Pompholyx sulcata	18	16	16	--	--	--	3	3	14
Testudinella patina	1	1	2	--	--	--	3	3	14
Trochosphaera solstitialis	--	--	1	--	--	--	--	--	--
Order Collothecae									
Cupelopagis vorax	1	1	1	--	--	--	--	--	3
Unkown rotifer	62	48	141	--	--	--	17	17	50

Appendix I (cont'd).	Lake I			Lake II			Lake III		
ARTHROPODA	T	F1	F2	T	F1	F2	T	F1	F2
Order Cladocera									
Sida crystallina	7	7	7	17	17	17	63	59	59
Holopedium gibberum	--	--	--	3	3	3	13	13	13
Daphnia longispina	206	148	148	18	18	18	105	92	92
Camptocercus oklahomensis	1	1	1	--	--	--	--	--	--
Chydorus ovalis	1	1	1	1	1	1	--	--	--
C. lacustris	--	--	--	--	--	--	2	2	2
C. faviform	--	--	--	--	--	--	1	1	1
Polyphemus pediculus	6	5	5	6	6	6	4	4	4
Order Ostracoda	1	1	18	3	3	3	2	2	4
Order Copepoda									
Nauplii spp.	201	151	278	207	120	183	239	145	330
Diaptomus siciloides	210	137	137	314	143	143	378	225	225
Cyclops vernalis	13	13	13	12	8	8	27	27	27
Orthocyclops	16	16	16	15	7	7	13	13	13
Ectocyclops	16	14	14	14	14	14	8	5	5
Paracyclops	21	21	21	133	81	81	30	28	28
Ergasilus chautauquensis	--	--	--	--	--	--	9	9	9
Insecta larvae									
Order Diptera									
Chaoborus sp.	--	--	--	2	2	2	--	--	--
Other	1	1	1	1	1	1	1	1	1
Order Lepidoptera	2	2	2	--	--	--	--	--	--
Order Odonata	2	2	2	1	1	1	--	--	--

Appendix II. Animals counted on slides made from benthic samples.

	# Individuals		
	Lake I	Lake II	Lake III
PROTOZOA			
Difflugia lebes	89	16	19
PLATYHELMINTHES			
Turbellaria	64	24	28
NEMATA	61	52	48
GASTROTRICHA	5	8	2
ARTHROPODA			
Ostracoda	417	61	188
Cladocera			
Ephippia	50	14	8
Copepoda	--	2	--
Insecta larvae			
Diptera			
Chaoborus sp.	16	--	20
Lepidoptera	--	--	12
Trichoptera	31	6	16
TOTAL	733	183	341