Aquatic Invertebrates and Water Chemistry of Strip-Mine Ponds in Western North Dakota

Donald Llewllyn Batema

AQUATIC INVERTEBRATES AND WATER CHEMISTRY OF STRIP-MINE PONDS IN WESTERN NORTH DAKOTA

by

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This thesis submitted by Donald Llewellyn Batema in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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Title Aquatic Invertebrates and Water Chemistry of Strip-Mine Ponds in Western North Dakota

Department Biology

Degree Master of Science

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Date March 15, 1979

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ABSTRACT

The chemical and biological properties of ponds artifically created as a result of the strip-mining process, were studied in Mercer County, North Dakota. The water in four of these ponds was analyzed for 25 chemical variables, pH and electrical conductivity. These same variables were also analyzed in bottom sediments and spoils surrounding the four ponds. Invertebrates were collected and identified from these ponds, as well as measuring certain attributes of community structure, including species composition, density, biomass and species diversity. Both the chemical and biological properties documented in strip-mine ponds were compared to a naturally occurring pond nearby (NBUN).

The strip-mine ponds studied showed high salinites (819-2029 ppm), with sodium and sulfate, as the dominant ions. Though salinities are higher than NBUN (250 ppm), they are not at levels which exceed the normal range (100-100,000 ppm) for alkaline ponds in North Dakota, Wyoming and Saskatchewan, Canada. Other chemical variables (Ca, Mg, K, Li, Mn, Ni, Sr, Cl and NO_3) which were also higher in strip-mine ponds when compared to NBUN, still were not unlike typical prairie potholes. Several ions (Al, Cu, Fe, Mo, NH_4, Pb, PO_4, Si and Zn) were essentially no different from NBUN. Heavy metal toxicity, which is a potential problem, is minimal because these metals are quickly precipitated into the bottom sediment as they are leached from surrounding spoil.

When a strip-mine pond is formed, it is almost immediately used by wildlife and soon becomes inhabited with aquatic organisms. A total of 97 species were identified in three strip-mine ponds and NBUN. The most

common phyla in these ponds are Mollusca and Arthropoda. The class Insecta comprises almost 80% of all species identified, with Diptera (26 species) and Coleoptera (24 species) the most common orders. Cnidaria, Nematomorpha, Bryozoa and Annelida are not common to strip-mine ponds. As amount of vegetation increases, it has a moderating effect on water chemistry, as well as providing food, shelter and support for aquatic invertebrates. This causes an increase in the various properties of community structure. Density increases from 1,337 ind./m^2 at NB1 to 13,453 ind./m^2 at DS30. Biomass increases from 15.4 lbs/acre to 1,133.1 lbs/acre. Species diversity at NB1 is 1.81 and 2.53 at DS30, using the Shannon-Wiener index. A similarity index comparing strip-mine ponds and NBUN shows that as the strip-mine pond increases in age, the more it resembles NBUN.

In general, surface mined waters will tend to resemble naturally occurring ponds, both chemically and biologically, within a few years.

INTRODUCTION

The use of coal to keep up with the rising energy demands has focused attention on strip-mining in the Northern Great Plains states. Extensive deposits of lignite and sub-butiminous coal are located in the Fort Union geologic group in North Dakota, Montana and Wyoming (Sandoval et. al., 1973). Extraction of the coal has created concern, particularly over environmental disturbance. As a result, universities and government and private agencies are interested in developing reclamation programs designed to solve the environmental problems caused by strip-mining.

Though definite progress has been made in reclaiming strip-mined lands in North Dakota (Sandoval et. al., 1973; Wali, 1973; Wali and Sandoval, 1975; and Wali and Freeman, 1973), information describing impacts on aquatic ecosystems is limited. Because of the fundamental difference in coal chemistry, climate and hydrology in North Dakota, Montana, and Wyoming, the impacts may be very different from the coal regions in the eastern United States (Dettman and Olsen, 1977).

Only small amounts of pyrite are present at mines in the western coal province, and the alkaline nature of the overburden and soils suggests that acid drainage would be minimal. Research in Colorado, Wyoming and Montana shows that the most important aquatic impact is leaching of soluble salts from mine spoils and transport of these salts to surface or ground waters (Dettman and Olsen, 1977; McWhorter et. al., 1975; and Olsen and Dettman, 1976). Another potential problem is toxicity of certain metal and non-metal ions (Thurston et. al., 1976).

In North Dakota, Sandoval et. al. (1973) have monitered certain chemical variables in strip-mine ponds to determine the value of such waters for irrigation purposes. Selected strip-mine ponds have been sampled periodically by the North Dakota Game and Fish Department as part of a continuing limnological survey of North Dakota surface waters. Hagen and Shaw (1974) have assessed possible impacts of coal development on the quality of surface waters in the Northern Great Plains. However, little information on ponds is presented since the primary responsibility of this group is assessment of impacts on the rivers and streams in or near the Fort Union-Powder River coal deposits.

Research on aquatic invertebrates in western North Dakota is also limited. An Environmental Analysis Record (Bennett, 1976) states that no surveys of aquatic animals are available for the Glenharold Mine Coal Lease tract, a section of land within the present study area. Bovee (1975) has investigated aquatic relationships in the Northern Great Plains, but confines his assessment to stream invertebrates. Organism diversity was determined at selected ponds in the immediate vicinity of a designated coal gasification site just west of the present study area (Comita and Whitman, 1976). Macroinvertebrate composition and density was determined in several types of aquatic ecosystems in Mercer County (Woodward-Clyde, 1978). And finally, Cvancara and Van Alstine (1977) have documented the distribution and limiting factors of aquatic snails south and west of the Missouri River.

Though these studies have contributed information on the nature of surface waters and aquatic invertebrates found in western North Dakota ponds, little is known about these factors in strip-mine ponds. This study was undertaken in order to add to the existing knowledge of the chemical and biological properties of the ponds formed from the drainage of strip-mining areas. The purposes of this study were to: (1) document the chemical characteristics of ponds in strip-mined areas with particular reference to a comparison of such factors among ponds of various ages; (2) determine composition, density and biomass of macroinvertebrates; (3) investigate species diversity and other properties of community with respect to ponds of various ages; and (4) determine effects of water chemistry on aquatic invertebrates.

STUDY AREAS

Climate

The climate of western North Dakota is a semi-arid, continental type and can be characterized as having high diurnal temperatures and infrequent precipitation. The mean temperatures for January and July are about -20.8 degrees C and 13.0 degrees C respectively (Sandoval, et.al., 1973). The average annual precipitation is about 40 to 50 centimeters, most of which falls within the growing season. June is commonly the wettest month. Rainfall is erratic, with short rainy periods followed by long dry periods. High winds generally occur throughout the year, and during the summer these winds cause water levels in the ponds to decline by increasing evaporation rates.

Geology and Spoils

Most of the North Dakota lignite deposits are in the Paleocene strata of the Tongue River and Sentinal Butte Formations of the Fort Union group. All the ponds in the present study are located in the Sentinal Butte Formation and within the Knife River Drainage area. The geology of this area consists of alternating layers of lignite, soft shales and some sandstone (Kulland, 1975). Lignite veins are approximately 2-13 meters in thickness.

The natural soils of North Dakota are mostly Orthent and Agriboralls (Wali, Freeman and Kollman, 1975). Orthents are loamy or clayey, and Agriboralls are rich, well developed soils with clay accumulation in subsurface horizons. The major use of Orthents is for rangeland, and Agriboralls support small grain farming, haying and pastures (Wali, Freeman and Kollman, 1975).

The spoils overturned by mining operations are high in clays, particularly montmorillite and illite. Other predominant minerals include quartz, feldspars and carbonates (Kulland, 1975). The high alkalinity and salinity of these spoils is due to high sodium, calcium and magnesium concentrations.

Ponds

Five ponds, ranging from one to thirty years of age, in three strip-mining areas in Mercer county, North Dakota were chosen as representative of artificially created ponds. These ponds are located at the Glenharold mine near Stanton, the Dakota Star mine northwest of Hazen, and the North Beulah mine east of Beulah (Fig. 1). Since these three mines are all located in the Sentinal Butte Formation of the Fort Union group, the ponds created at these sites have similar geological origins. In addition, a pond from an unmined area near the North Beulah mine was selected for comparative purposes.

A. Dakota Star pond (DS30)

The Dakota Star mine is an inactive mine eight miles northwest of Hazen, North Dakota (section 20, T145N, R86W). The pond in this mining area is at least thirty years old and is one of the oldest strip-mine ponds in Mercer county. It is 520 feet long, has an average width of 69.5 feet, an average depth of 1.7 feet and covers an area of .83 surface acres (Table 1).

Fig. 1. Map of North Dakota showing location of study sites.

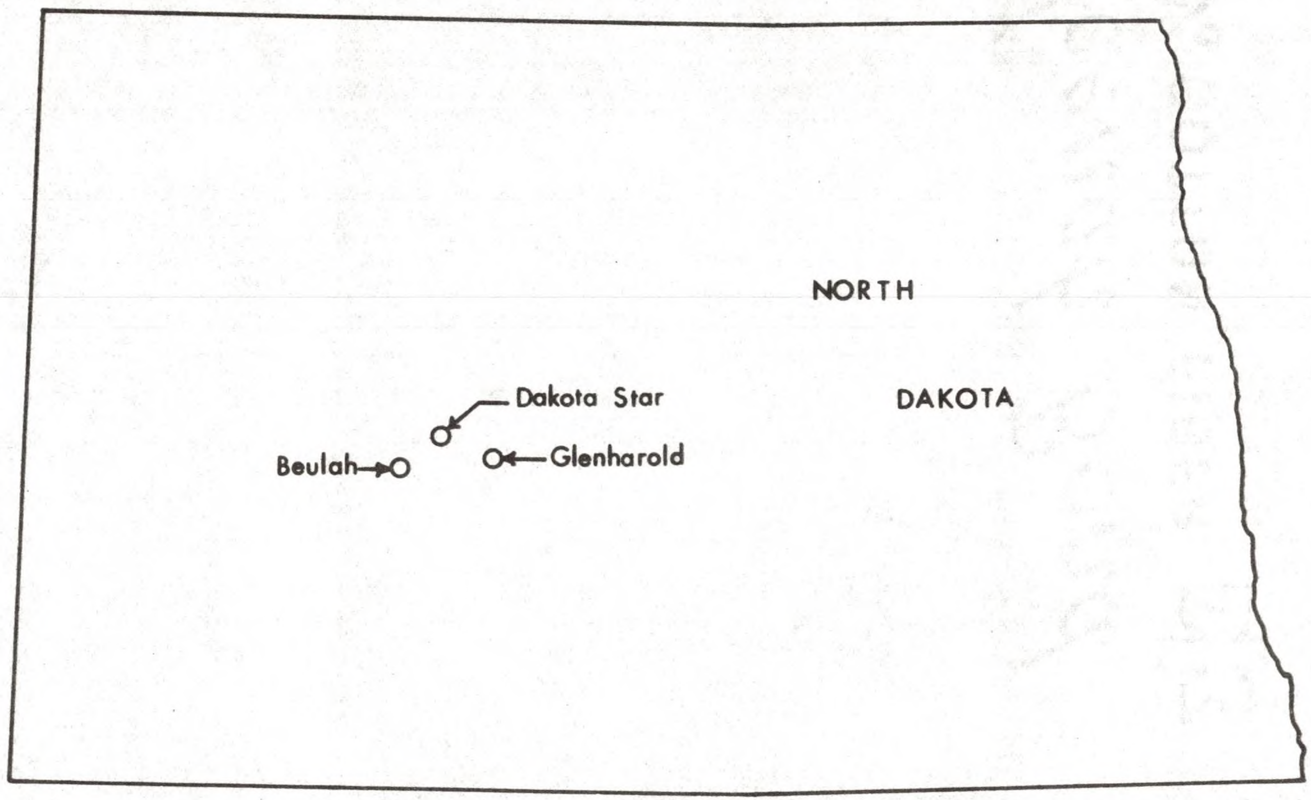

NORTH
DAKOTA
Dakota Star
Beulah
Glenharold

Table 1. Surface and subsurface dimensions of selected strip-mine ponds and NBUN in western North Dakota.

SURFACE DIMENSIONS

POND	YEAR FORMED	MAXIMUM LENGTH (ft.)	MAXIMUM WIDTH (ft.)	MEAN WIDTH (ft.)	SURFACE AREA (ft.^{2})	SURFACE AREA (acres)	SHORELINE LENGTH (ft.)	SHORELINE DEVELOPMENT INDEX
DS30	1945	520	92	69.5	36,120	.83	1303	1.93
NB15	1960	228	59	37.7	8,600	.20	591	1.80
G5	1970	728	328	184.6	134,418	3.18	1828	1.41
NB1	1974	272	119	80.9	21,995	.50	646	1.23
NBUN	--	251	132	87.9	22,059	.51	673	1.28

SUBSURFACE DIMENSIONS

POND	MAXIMUM DEPTH (ft.)	MEAN DEPTH (ft.)	VOLUME (ft.^{3})	VOLUME DEVELOPMENT	BASIN SLOPE %							
					0'-1'	1'-2'	2'-3'	3'-4'	4'-5'	5'-6'	6'-7'	7'-8'
DS30	3.8	1.7	60,000	1.34	9.7	7.0	10.3	7.3				
NB15	6.4	3.7	32,000	1.66	62.7	44.4	41.0	33.1	14.9	26.2		
G5	7.2	3.8	505,000	1.58	19.0	6.5	4.8	5.7	4.9	4.3	4.1	3.3
NB1	3.0	1.3	28,125	1.30	7.0	4.1	6.8					
NBUN	4.6	2.1	46,250	1.37	7.0	11.9	10.9	9.4				

Dakota Star 30 (DS30) is situated in an area which has never been regraded or recontoured and consequently is in a depression between high spoil piles (Fig. 2). The spoil banks are well vegetated with volunteer vegetation which includes such plants as *Bromus inermis, Melilotus officinalis, Brassica* sp., *Helianthus* spp., *Agropyron* spp., *Poa compressa* and *Aster* spp. Since the piles are well vegetated and they show little erosion, the pond water is clear. Along the edge of the pond there are scattered outcroppings of coal which cause an organic, brown-yellow color in the water.

The bottom sediment at DS30 is well developed with a thick organic layer, including coarsely to finely decomposed material. A thin mucky layer underlies the richer upper layer. The bottom and shoreline of DS30 are more stable than any other strip-mine pond studied.

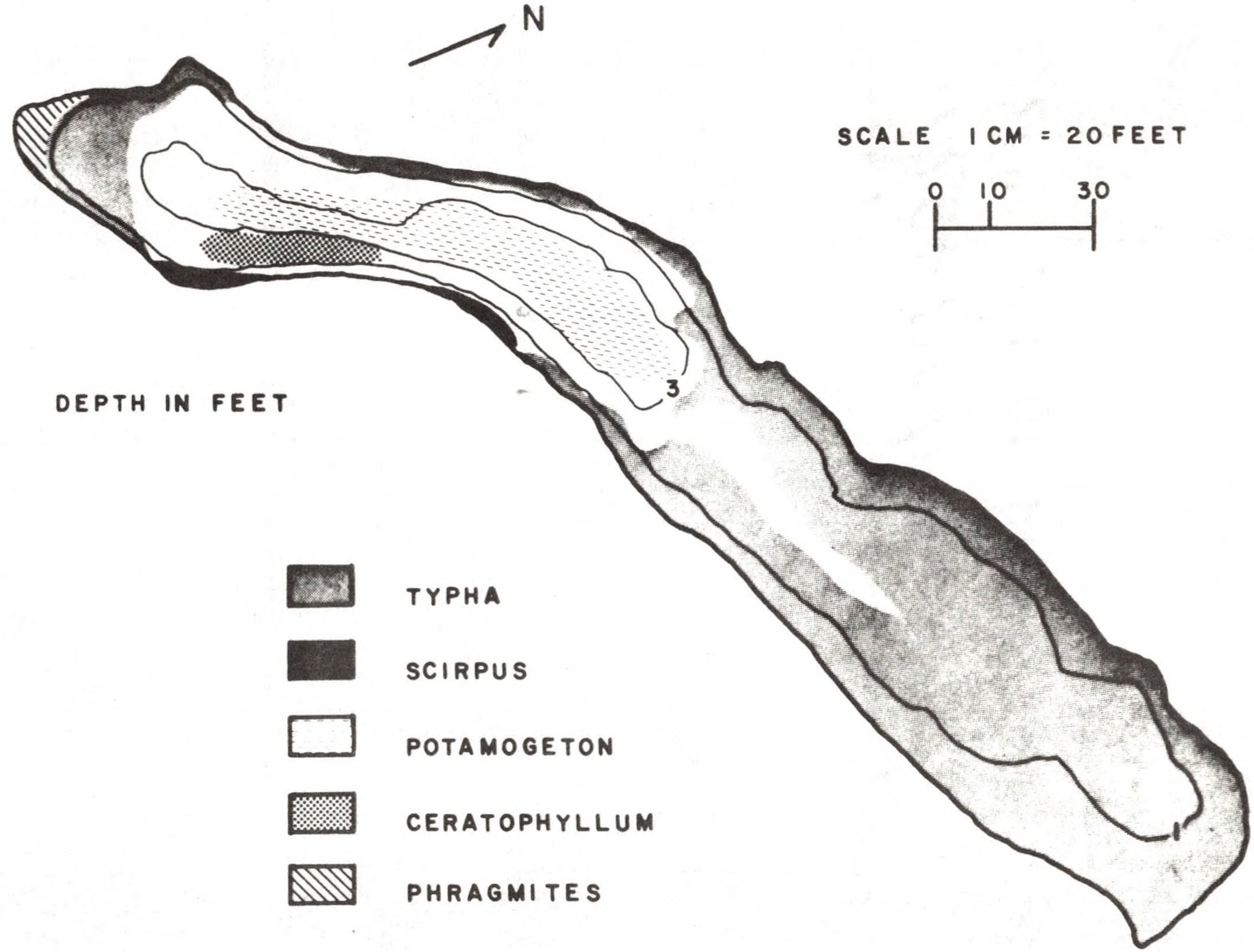
The pond is well stocked with rooted and emergent vegetation with *Typha angustifolia* abundant on the west end, eastern half and sections of the north and south shores (Fig. 3). *Phragmites communis* is common at the west end, intermingled with the *Typha*. *Scirpus* spp. appear on the southwest shore, and scattered elsewhere are grasses (Poaceae), sedges (Cyperaceae), *Sagittaria cuneata, Chara* sp., and *Ceratophyllum* sp. *Potamogeton* spp. are abundant and located centrally in the pond. *Populus deltoides* appear on the north and south sides of the pond.

B. North Beulah Pond (NB15)

North Beulah 15 (NB15) is a fifteen year old pond located four miles northeast of Beulah (section 8, T144N, R37W). NB15 is 228 feet long with an average width of 37.7 feet, an average depth of 3.7 feet and a surface area of .20 acres (Table 1).

Fig. 2. Photograph of Dakota Star 30.

Fig. 3. Morphometric and vegetative map of Dakota Star 30.


N
SCALE 1 CM = 20 FEET
0 10 30
3
DEPTH IN FEET
1
TYPHA
SCIRPUS
POTAMOGETON
CERATOPHYLLUM
PHRAGMITES

North Beulah 15 is also located in an area that has never been regraded or recontoured (Fig. 4). It lies in a depression between spoil banks above the general level of the roads in the mine. The spoil banks are not heavily vegetated. *Melilotus officinalis, Brassica* sp., and planted grasses such as *Agropyron* spp., are common on the banks surrounding NB15. The water in the pond is clear, colorless and there is little evidence of erosion.

The bottom sediment at NB15 has a very thin aerobic layer and a slightly thicker darker layer which overlie a rather soft and unstable clayey bottom. The dark layer is comprised of decayed and partly decayed plant (mostly *Typha* shoots) and animal material.

NB15 is only moderately vegetated with rooted and emergent plants (Fig. 5). *Typha angustifolia* is most abundant and encircles the entire pond except for a few places where *Scirpus* spp. and/or grasses (Poaceae) and sedges (Cyperaceae) are located. *Saggittaria cuneata* is rare. *Potamogeton* sp. is common in the central portions of the pond. In 1975 *Potamogeton* was abundant, but in 1976 it was reduced to a little patch at the north end. *Populus deltoides* and *Salix* sp. are located around the south end of the pond.

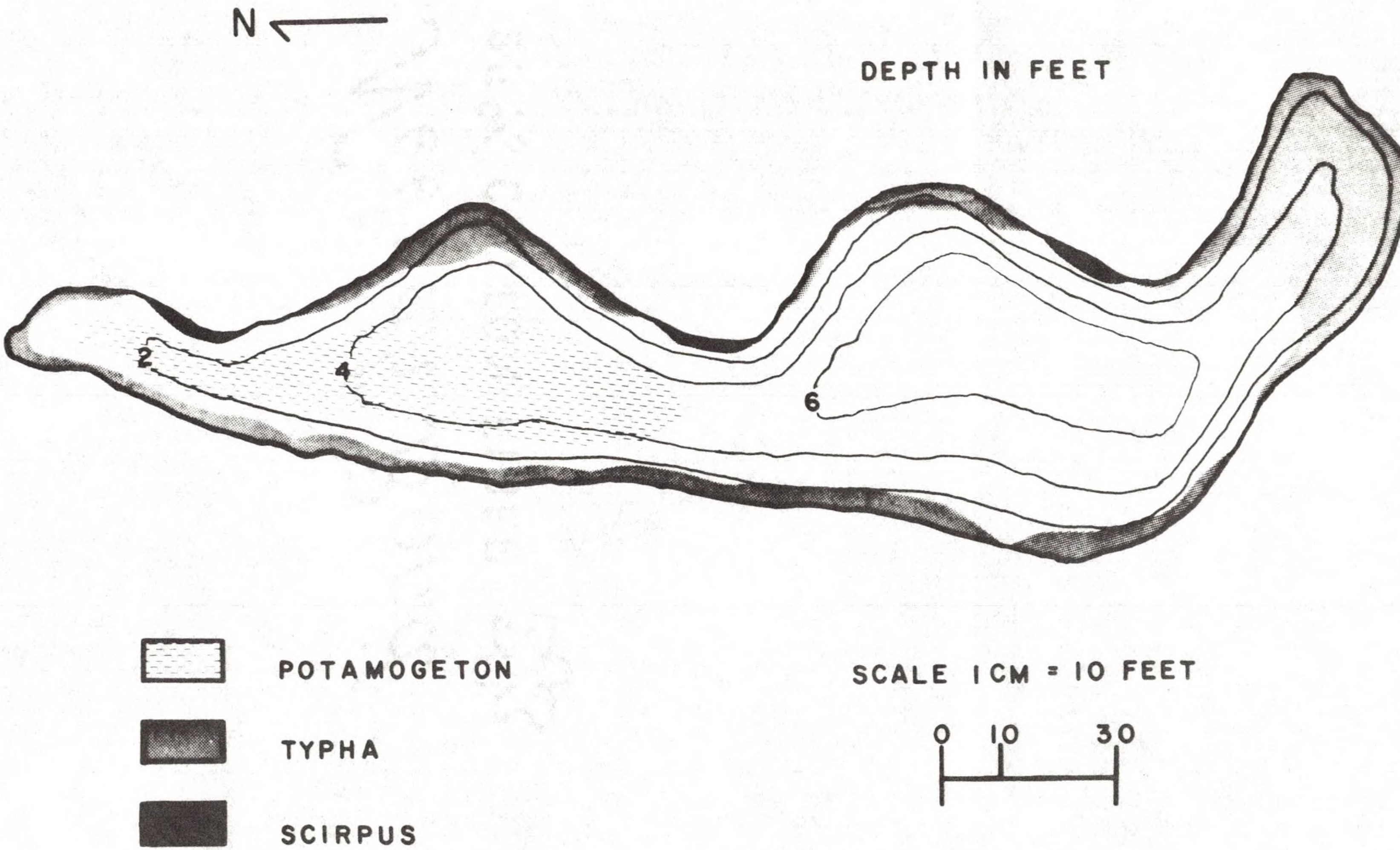
C. Glenharold Pond (G5)

The largest of the selected ponds (3.1 surface acres) is located seven miles southwest of Stanton, North Dakota (section 20, T144N, R84W). Glenharold 5 (G5) is a five year old pond 728 feet long with an average width of 184.6 feet and average depth of 3.8 feet (Table 1).

Extremely high and steep spoil banks surround this pond, except for a narrow strip at the northwest and southeast corners (Fig. 6). The

Fig. 4. Photograph of North Beulah 15.

Fig. 5. Morphometric and vegetative map of North Beulah 15.



N
DEPTH IN FEET
2
4
6
POTAMOGETON
TYPHA
SCIRPUS
SCALE 1 CM = 10 FEET
0
10
30

Fig. 6. Photograph of Glenharold 5.

vegetation on these spoils is poorly developed and mostly volunteer. Some attempt has been made to stabilize the spoil banks by planting trees. Because the vegetative cover is poor, erosion and landslides are common, and consequently the water is turbid. Due to prevailing northwesterly winds, the pond seems to be in a natural wind tunnel. This factor also contributes to the high turbidity. Outcroppings of exposed coal appear in a couple of places along the shoreline.

The pond edge and bottom sediment are soft and clayey in most places. A very thin aerobic layer lies above a very thin dark layer. These overlie the soft clay which makes up most of the bottom sediment. In some places the bottom consists of coarser, firmer materials.

Aquatic plants are few in number and scattered (Fig. 7). *Typha angustifolia* and *Scirpus* spp. are the most common emergent plants, while *Saggitaria cuneata* and *Chara* sp. are occasionally found. *Potamogeton* sp., not observed in 1975, was collected in restricted areas in 1976. *Populus deltoides* seedlings and *Salix* spp. trees are scattered along the pond edge.

D. Glenharold (G1) and North Beulah Pond (NB1)

The Glenharold pond (G1) and the North Beulah pond (NB1) were both one year old when the present study began. They were artificially formed through regrading and recontouring of spoil piles. Consequently, the surrounding area takes on the appearance of the gently rolling topography typical of nearby unmined areas (Fig. 8 and 9). Both G1 and NB1 are surrounded by planted grasses and *Kochia*, which is the first plant to invade these regraded areas.

Fig. 7. Morphometric and vegetative map of Glenharold 5.

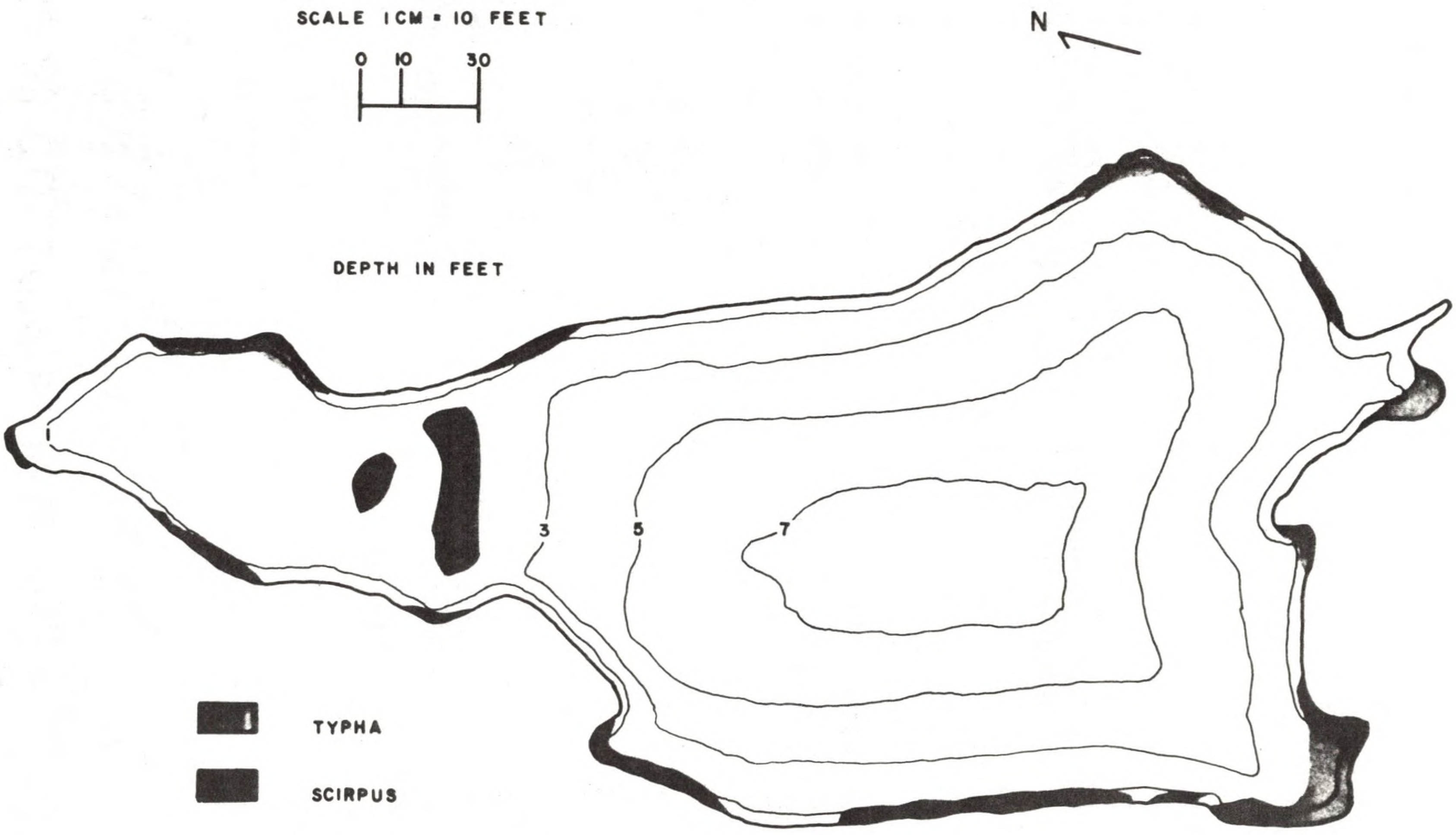

SCALE 1CM = 10 FEET
0 10 30
N
DEPTH IN FEET
1
3
5
7
TYPHA
SCIRPUS

Fig. 8. Photograph of Glenharold 1.

Fig. 9. Photograph of North Beulah 1.

The Glenharold pond (section 20, T144N, R84W) is 204 feet long, has an average width of 53.9 feet, and average depth of 1.8 feet and a maximum depth of 2.5 feet. NB1 (section 8, T144N, R87W) is 272 feet long, has an average width of 80.9 feet, an average depth of 1.3 feet and covers an area of .50 acres (Table 1).

The water in these ponds is clear and colorless, but is easily made turbid by wind activity. The pond edge and bottom sediments are extremely soft and clayey and very unstable. Sediments in the newly created ponds are physically no different from the naked spoil surrounding these ponds.

No true aquatic macrophytes were observed in these ponds in 1975. Only *Populus deltoides* seedlings were common along the shoreline. In the following year, *Potamogeton* sp., and *Typha angustifolia* were the first aquatic plants to be collected at G1 and NB1. Until the macrophytes became established, dried dead *Kochia* plants blown into the ponds provided the only support for the animal life (Figures 10 and 11).

E. North Beulah Unmined Pond (NBUN)

A naturally occurring pond, in an area adjacent to, but not included in the North Beulah mining area, was selected for comparative purposes. NBUN covers an area of .51 surface acres and is 251 feet long with an average width of 87.9 feet and average depth of 2.1 feet (Table 1).

A gently rolling topography surrounds NBUN (Fig. 12). The unmined area is covered primarily with a thick stand of *Bromus* sp. mixed with *Agropyron cristatum*. Since the area around the pond is heavily vegetated and there is an absence of steep banks, minimal erosion occurs. Consequently, the pond edge is well stabilized. The water is clear but is colored a yellow-brown.

Fig. 10. Morphometric map of Glenharold 1.

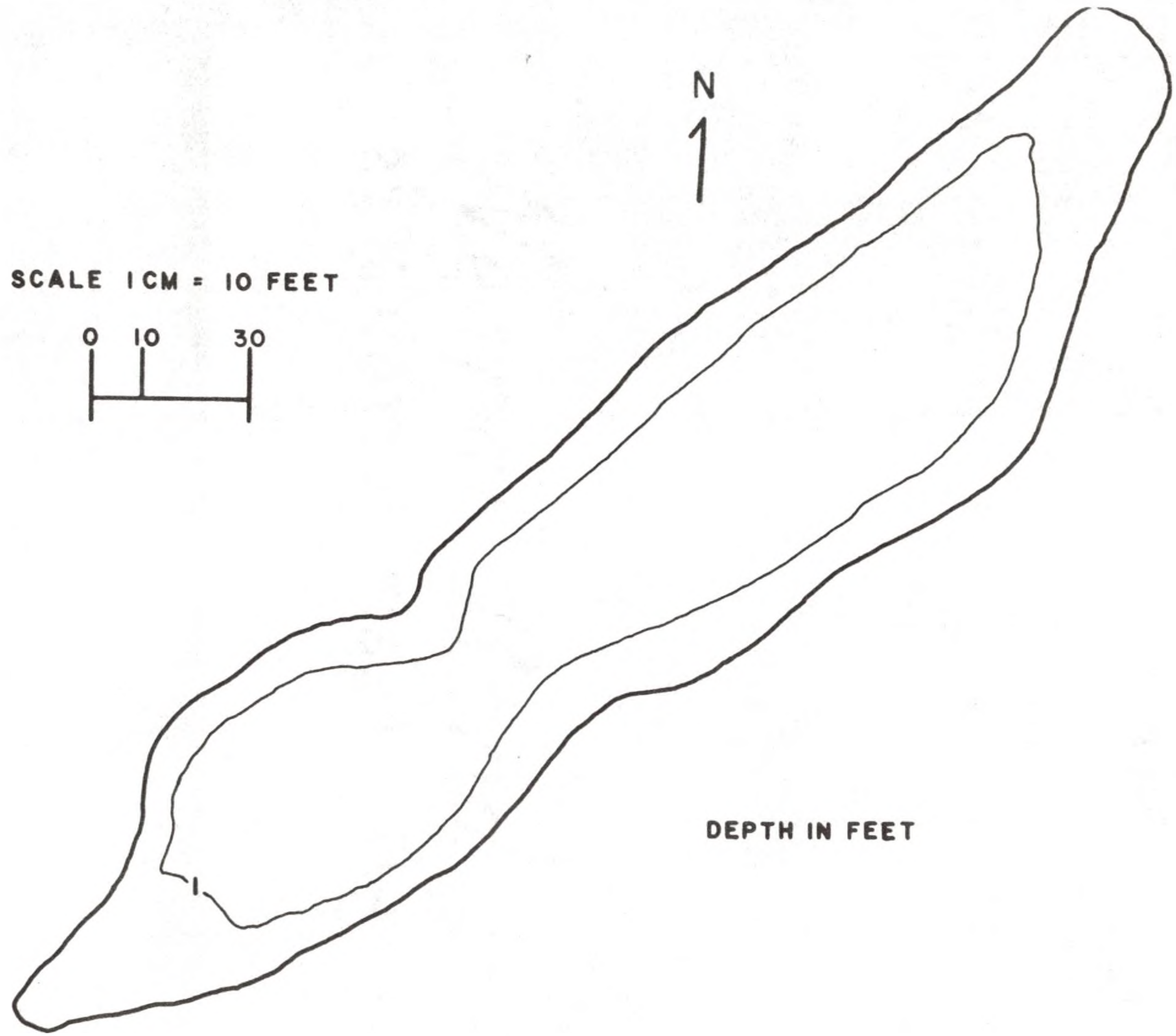

N
SCALE 1 CM = 10 FEET
0 10 30
DEPTH IN FEET
1

Fig. 11. Morphometric map of North Beulah 1.

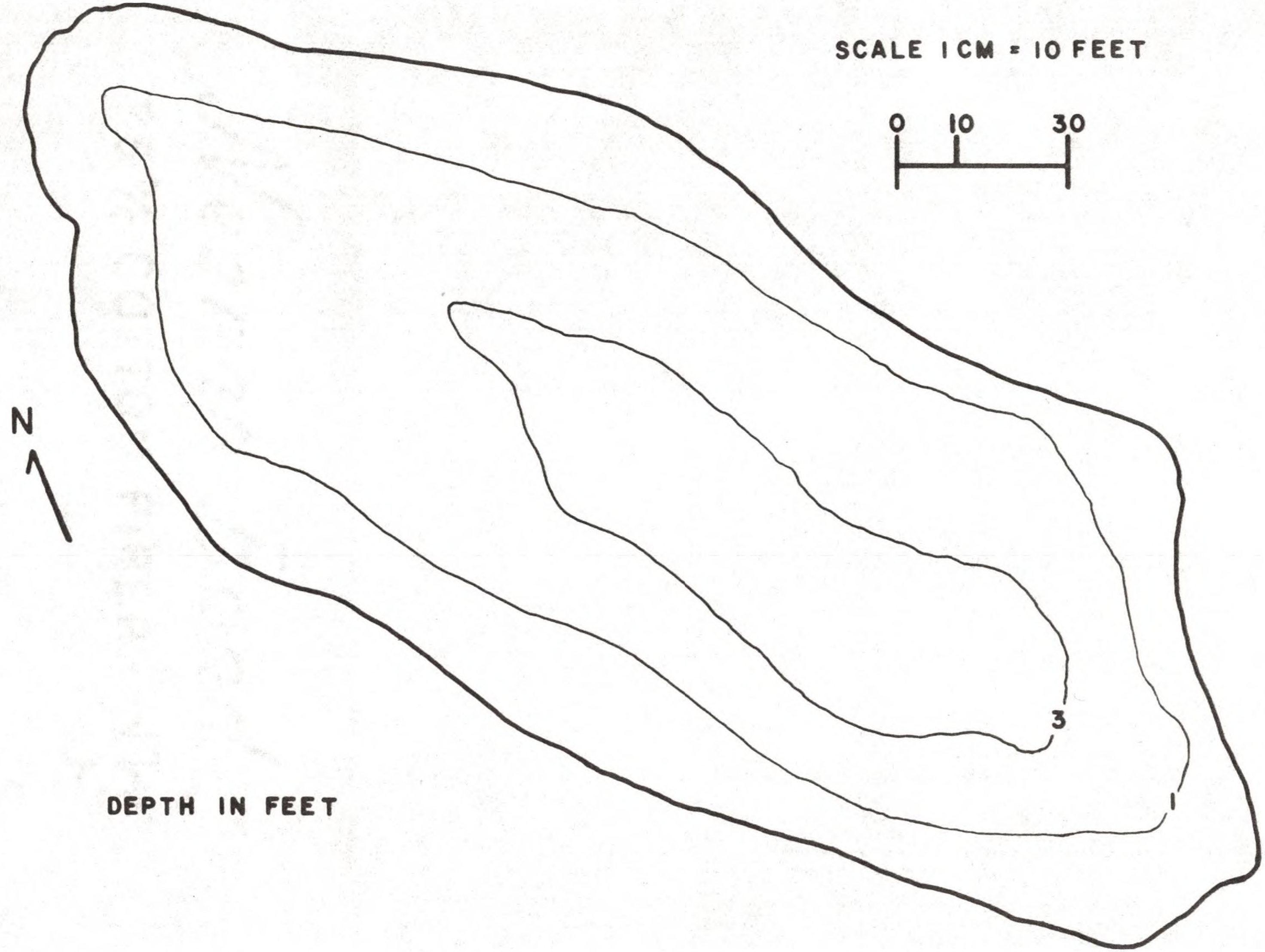
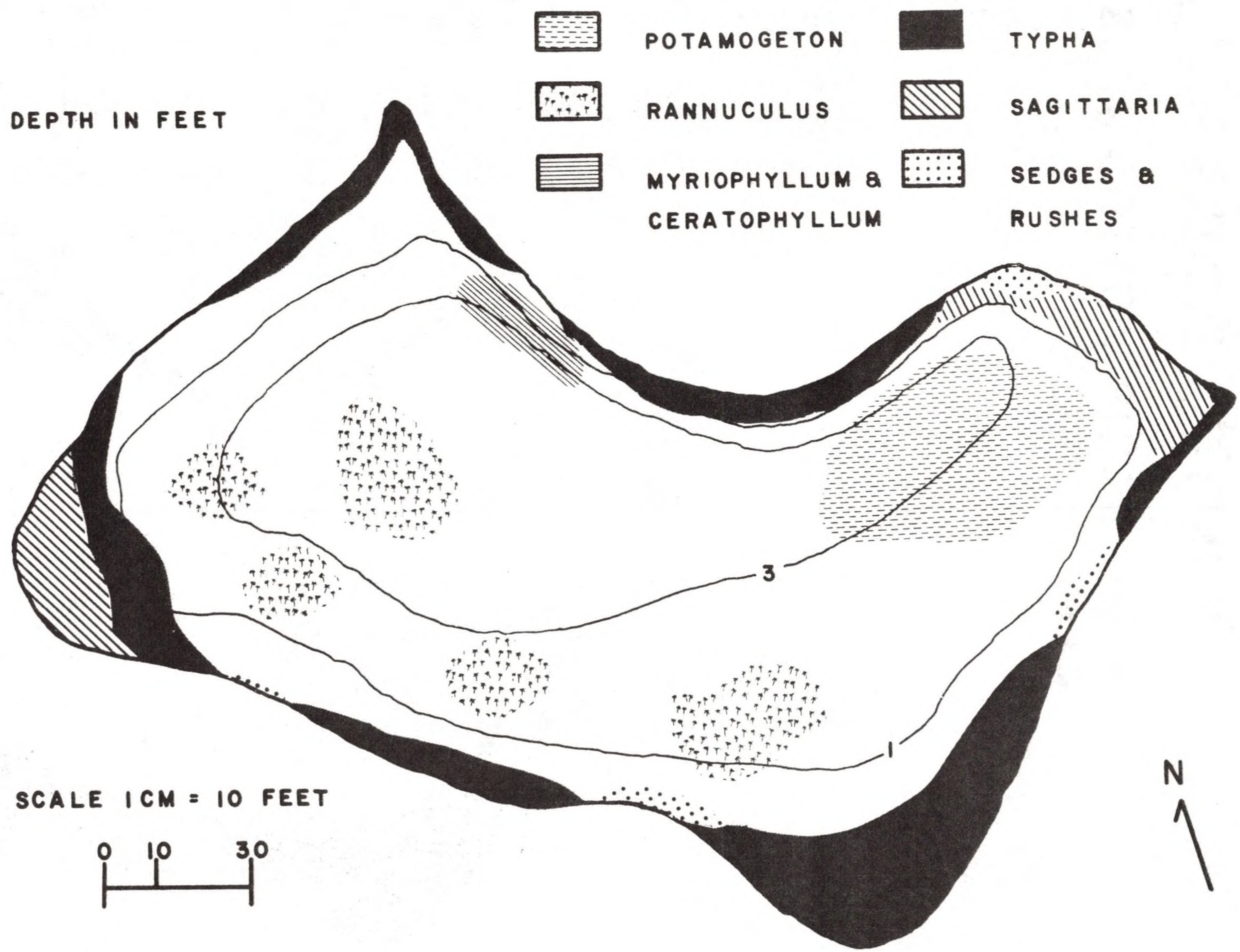

SCALE 1 CM = 10 FEET
0
10
30
N
DEPTH IN FEET
3
1

Fig. 12. Morphometric and vegetative map of North Beulah unmined.


POTAMOGETON
TYPHA
RANNUCULUS
SAGITTARIA
MYRIOPHYLLUM &
CERATOPHYLLUM
SEDGES &
RUSHES
DEPTH IN FEET
3
1
SCALE 1 CM = 10 FEET
0 10 30
N

The vegetation in NBUN is typical of a deep-marsh emergent wetland (Stewart and Kantrud, 1972). It consists of various members of the genus *Scirpus* and the dominant *Typha angustifolia.* A number of shallow marsh elements are characteristic as well: *Carex* spp., *Sium suave, Sparganium* sp., *Saggittaria cuneata* and *Alisma* sp. Also present are *Chara* sp., *Lemma trisulca, Ceratophyllum* sp., *Myriophyllum exalbescens, Ranunculus trichophyllus, Glyceria grandis, Utricularia vulgaris* and *Potamogeton* spp.

MATERIALS AND METHODS

I. FIELD METHODS - Soil and Water Chemistry

Water samples were collected every third or fourth week beginning September 15, 1975. This schedule continued until May 1976 when samples were collected once a week. Several surface sites within a pond were sampled during the open water season and combined to form a composite sample (APHA, Standard Methods, 1971). Samples were collected near the center of the pond during periods of ice cover. Dissolved oxygen samples were collected from the surface and ten centimeters from the bottom.

Composite samples were also obtained for bottom sediments. Several sites within a pond were sampled from the top five centimeters of the sediment, combined (Jackson, 1958) and placed in double lined plastic bags. Soil samples were collected at four locations around each pond; one site for each side of the pond. Samples from the top ten centimeters of the surface were placed in ice cream cartons.

After collection, the monthly water samples, bottom sediment samples, and soil samples were transported to the university laboratory for analyses. The weekly water samples were analyzed at the North Dakota Game and Fish laboratory at Riverdale, North Dakota.

II. LABORATORY METHODS - Soil and Water Chemistry

Before the water samples were frozen and within four to ten hours, pH, electrical conductivity, nitrates, ammonia, dissolved oxygen, alkalinity and ortho-phosphate were analyzed. Other chemical determinations were completed at a later date on the stored material. These tests included total phosphate, chlorides, sulfates, several major ions and trace elements.

A. WATER

Water samples were filtered and analyzed for the following cations by atomic absorption spectrophotometry: Aluminum (Al), Calcium (Ca), Copper (Cu), Iron (Fe), Potassium (K), Lithium (Li), Magnesium (Mg), Sodium (Na), Nickel (Ni), Lead (Pb), Silicon (Si), Strontium (Sr) and Zinc (Zn). A PHM62 standard pH meter (Radiometer) was used to determine pH, and electrical conductivity was measured with a Radiometer conductivity meter. Salinity was calculated using conductivity readings with the formula given in Jackson (1958). The barium chloride turbidometric method of Kollman (1974) was used to determine sulfates, and a Radiometer silver-chloride probe (Type P4011) was used for chlorides.

Carbonate and bicarbonate alkalinity was determined by titration with .02 *N* sulfuric acid to the phenophthalein and methyl orange endpoints (APHA, Standard Methods, 1971). The Winkler method, with the azide modification, was used to measure dissolved oxygen of samples fixed in the field.

Phosphorus was analyzed by the molybdenum blue-ascorbic acid method as given in APHA, Standard Methods (1971). Samples were filtered for the ortho-phosphate determination, but not for total phosphates. Direct nesslerization was used to measure ammonia (APHA, Standard Methods, 1971). The ultraviolet method of Goldman and Jacobs (1961) was used to determine nitrates. Ammonia, nitrates, and phosphates were measured spectrophotometrically.

B. Soil and Bottom Sediments

Soil and bottom sediment samples were air dried, ground and passed through a 2mm sieve. Analysis for major cations and trace elements were accomplished with a Perkin-Elmer atomic absorption spectrophotometer. Three extraction procedures were used to determine available cations: A 1 *N* ammonium acetate extraction to measure the replaceable (water soluble plus exchangeable) ions: Na, Ca, Mg, K, Mn, Sr, and Li; a .02 *N* EDTA extraction to determine the complexed and/or chelated (fixed) ions: Chromium (Cr), Cadmium (Cd), Molybdenum (Mo), Ni, Fe, Cu, Li, Sr, Mn, Zn, Pb, Si, and Al; and a water saturation extraction to determine water soluble Na, Ca, Mg, K, Fe, Mn, Zn, Li, and Sr. The methods outlined above are found in Jackson (1958), Perkin-Elmer Manual (1973), Wikum and Wali (1974), and Wali and Krajina (1973).

The water saturation extract was also used to measure pH, electrical conductivity, chlorides and sulfates by the same methods given for water analyses. Samples were analyzed for phosphorus in a dilute acid flouride extract with the molybdenum blue method of Bray and Kurtz (Jackson, 1958). Boron (B) was extracted with .02 *N* EDTA and measured spectrophotometrically by the carmine method of Hatcher and Wilcox (1950). The Walkley-Black method (1934) was used to find percent organic matter.

III. FIELD METHODS - Aquatic Invertebrates

Invertebrates were collected qualitatively with a .12 m^2 dip net, and dredge samples were obtained with an Ekman grab to include benthic organisms. Qualitative samples were used to determine total number of species for each pond.

Quantitative samples of invertebrates inhabiting littoral regions were collected with a modified Korinkova sampler (Edmundson and Winberg, 1971). The frame of the modified sampler was constructed with 1.9 cm diameter iron rods. These iron rods were cut and welded together to form top and bottom frames with a sampling area of 0.45 m^2. In addition, a washer was welded into the corner of the bottom frame so that 0.7 m long iron rods could be screwed in each corner. These iron rods extended 15 cm beyond the bottom frame to allow the sampler to be placed securely in the bottom substrate of the pond. Then the top frame was welded into place to complete the framework of the sampler. Unlike the Korinkova sampler, this sampler lacks a movable frame and therefore can only be used at a fixed depth. Also, it samples half the area of the original sampler. To compensate for this, two samples were collected at each site and combined. Other features are similar to the sampler originally described in Edmundson and Winberg (1971).

A 522.86 cm^2 Eckman dredge was used to sample benthic organisms. The bottom sediment in strip-mine ponds is soft and generally free from coarse, hard materials, so the Eckman proved to be a suitable device to sample benthos. Two grabs were obtained at each site and combined.

Samples from each site were transferred to a white enamel pan and then to plastic bags with a 10% formalin-70% alcohol mixture. No separation of invertebrates was accomplished in the field. These samples were then transported to the university laboratory and stored for future analyses.

For all ponds sampled quantitatively there were three sampling sites, each one located in a different vegetative type whenever possible. It was felt that three sites per pond was adequate to obtain a representative sampling of aquatic invertebrates.

IV. LABORATORY METHODS - Aquatic Invertebrates

Littoral organisms collected with the Korinkova sampler, and benthic animals obtained by an Eckman dredge were separated from vegetation or mud by two floatation techniques. Sodium sulfate in a saturated solution proved to be far superior to Anderson's (1959) sugar floatation technique. Sodium sulfate is a better method of separation because: 1) it is not sticky or messy to work with, 2) there is no need to measure specific gravity and then correcting for changes, 3) it can be reused many more times than sugar and 4) most importantly, sodium sulfate acts as a better dispersing agent to facilitate release of organisms from vegetation and mud.

Once separated, the organisms were sorted to major groups and identified. Authorities for invertebrate identification included: Pennack (1953), Ward and Whipple (1918), Johannson (1934-7), Usinger (1968), Malloch (1917), Needham and Needham (1962), and Eddy and Hodson (1961). Representatives of each species identified were preserved and stored in 70% alcohol with a few drops of glycerin.

Individuals within a taxon were counted and their density represented as individuals per meter square. Biomass was determined by obtaining dry weights. The Shannon-Wiener index was used as a measure of species diversity (Shannon and Weaver, 1949; Pielou, 1966a and b; Pielou, 1975), and the method of Lloyd and Ghelardi (1964) was used to determine equitibility.

V. MAPPING AND MORPHOMETRY

A transit was used to map ponds according to procedures specified by Welch (1948). Ponds were mapped in early May 1976 when water levels were near peak height. At most points where a reading on bearing and distance were taken for the transit map a cross section was obtained. Depth was measured by sounding at two foot intervals.

Several morphometric and bathymetric calculations based on transit map data and cross section data were obtained. A Gelman polar planimeter was used to determine surface area of the ponds. Length of shoreline was measured by stepping off segments with a dividers. Volume was computed by constructing hypsographic curves for each pond. These methods and methods for obtaining other surface and subsurface dimensions are given in Welch (1948) and Cole (1975).

VI. COMPUTER ANALYSES

Various statistical techniques were used to determine relationships of chemical variables to strip-mine ponds on the IBM 370/135 computer at the UND computer center. The Dunnett's test and other statistical methods using multiple linear regression are outlined in Williams (1974a).

RESULTS

WATER CHEMISTRY

Chemical Characteristics

The mean concentration of 25 ions, pH, and electrical conductivity are presented in Table 2. Temporal trends of these variables were analyzed and results indicate that they fall into four groups:

Group 1: Electrical conductivity (E.C.), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Strontium (Sr), Sulfate (SO_4), and Chloride (Cl)

Group 2: pH

Group 3: Nickel (Ni), Lead (Pb), Lithium (Li), Molybdenum (Mo), Aluminum (Al), Copper (Cu), Iron (Fe), Zinc (Zn), and Manganese (Mn)

Group 4: Silicon (Si), Nitrate (NO_3), total-PO_4 and ortho-PO_4.

The mean temporal trends of the variables in group 1 (Fig. 13 and 14) have a tendency to increase in summer and fall with maximum concentration reached under ice cover. Figure 15 shows that pH increases until fall, then decreases, reaching its lowest levels during periods of ice cover. Those ions in group 3 (Fig. 16) tend to remain constant throughout the seasons, except for slight to moderate increases in winter. Nitrates, phosphates and silicon (Fig. 17, 18, and 19) are correlated to biological activity and/or chemical changes and belong to group 4.

Table 2. Mean concentration of 25 ions, pH and electrical conductivity in four strip-mine ponds and NBUN from September 1975 to August 1976, in ppm.

Variable	DS30	NB15	G5	NB1	NBUN
pH	7.60	8.07	8.54	8.44	8.20
E.C., μmhos/cm	4080	2310	1580	1970	400
Ca	252.7	57.5	23.5	32.8	30.8
Mg	1100.6	51.8	11.4	46.2	14.7
K	19.6	16.5	11.7	16.3	10.4
Na	388.0	473.6	370.9	385.5	52.7
Al	.10	.16	.25	.11	.13
Cu	.03	.02	.02	.02	.02
Fe	.05	.04	.05	.03	.06
Li	.20	.09	.06	.21	.02
Mn	.06	.04	.01	.01	.01
Mo	.007	.003	.005	.005	.005
Ni	.08	.06	.04	.04	.02
Pb	.18	.11	.08	.09	.07
Si	3.8	1.8	1.4	1.4	1.7
Sr	5.05	1.04	.28	.83	.26
Zn	.06	.05	.05	.06	.03
SO_4	152.2	693.0	565.0	819.0	9.0
Cl	91.6	7.4	12.1	13.3	4.4
NH_4	1.04	.51	.99	.44	.73
NO_3	.233	.123	.123	.130	.100
NO_2	.0046	.0069	.0062	.0072	.0030
Ortho-PO_4	.07	.06	.08	.09	.09
Total-PO_4	.48	.23	.39	.37	.41
HCO_3	327	216	298	150	153
CO_3	4	22	71	45	39
D.O.					
Surface	5.9	8.5	7.7	9.3	12.1
Bottom	4.5	7.7	6.5	8.2	8.5

Fig. 13. Temporal trend of electrical conductivity in selected strip-mine ponds in western North Dakota. A group 1 variable.

DS 30

NB 15

G 5

NB 1

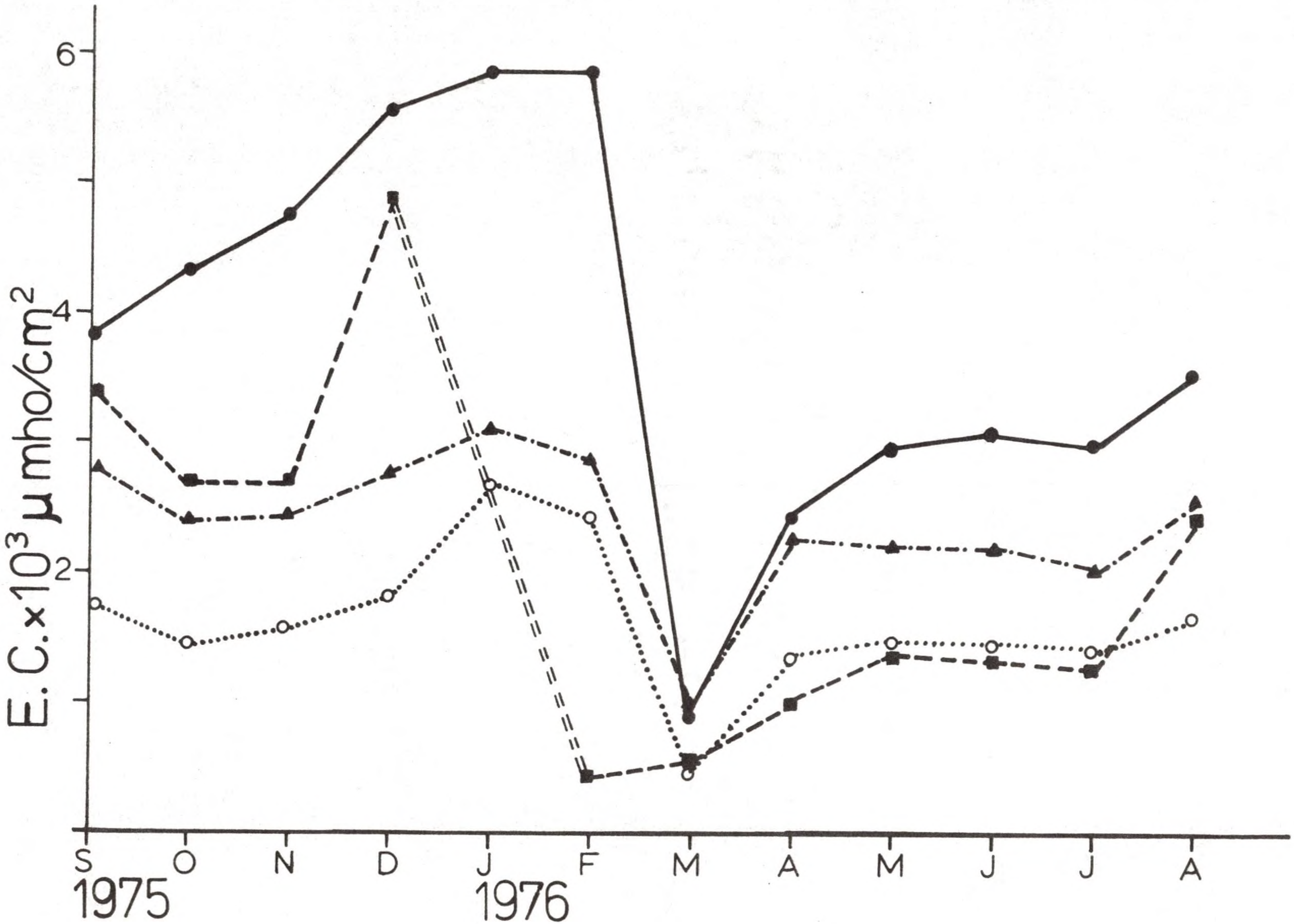

6
4
2
E. C. × 10³ µ mho/cm²
S
O
N
D
J
F
M
A
M
J
J
A
1975
1976

Fig. 14. Temporal trend of sodium in selected strip-mine ponds in western North Dakota. (see key, Fig. 13). A group 1 variable.

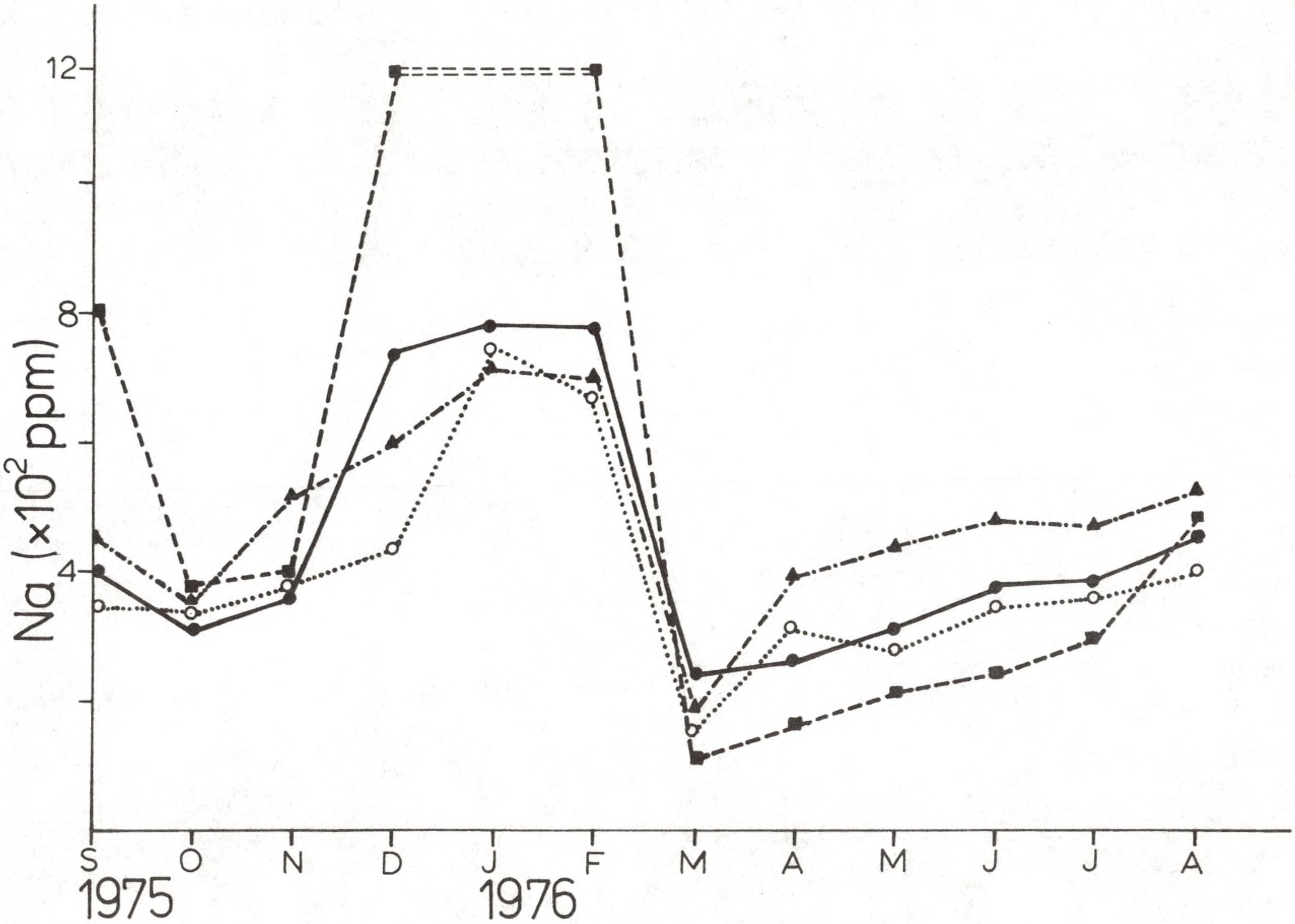

Na (×10² ppm)
12
8
4
S
O
N
D
J
F
M
A
M
J
J
A
1975
1976

Fig. 15. Temporal trend of pH in selected strip-mine ponds in western North Dakota. (see key, Fig. 13). A group 2 variable.

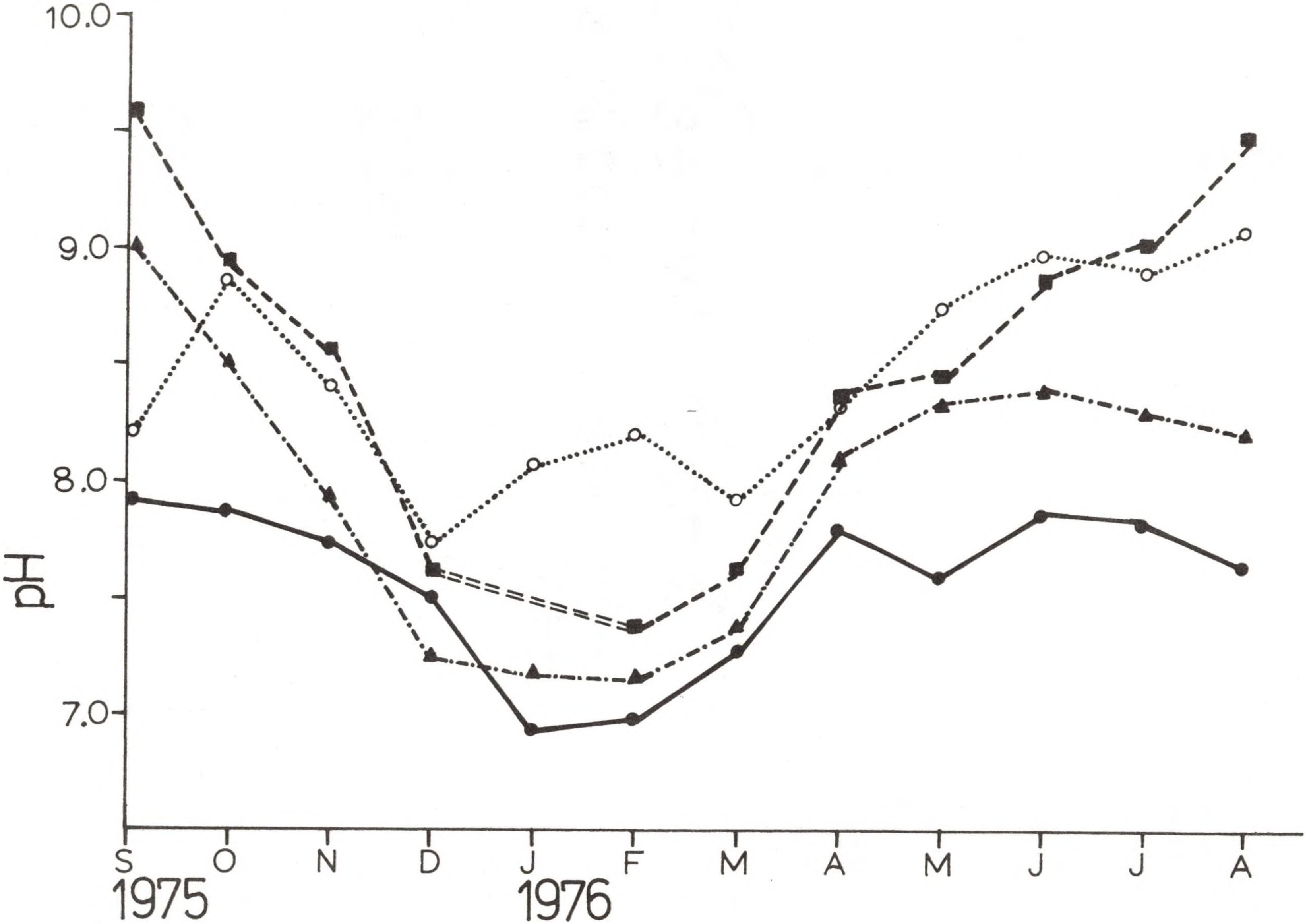

10.0
9.0
8.0
7.0
pH
S
O
N
D
J
F
M
A
M
J
J
A
1975
1976

Fig. 16. Temporal trend of copper in selected strip-mine ponds in western North Dakota. (see key, Fig. 13). A group 3 variable.

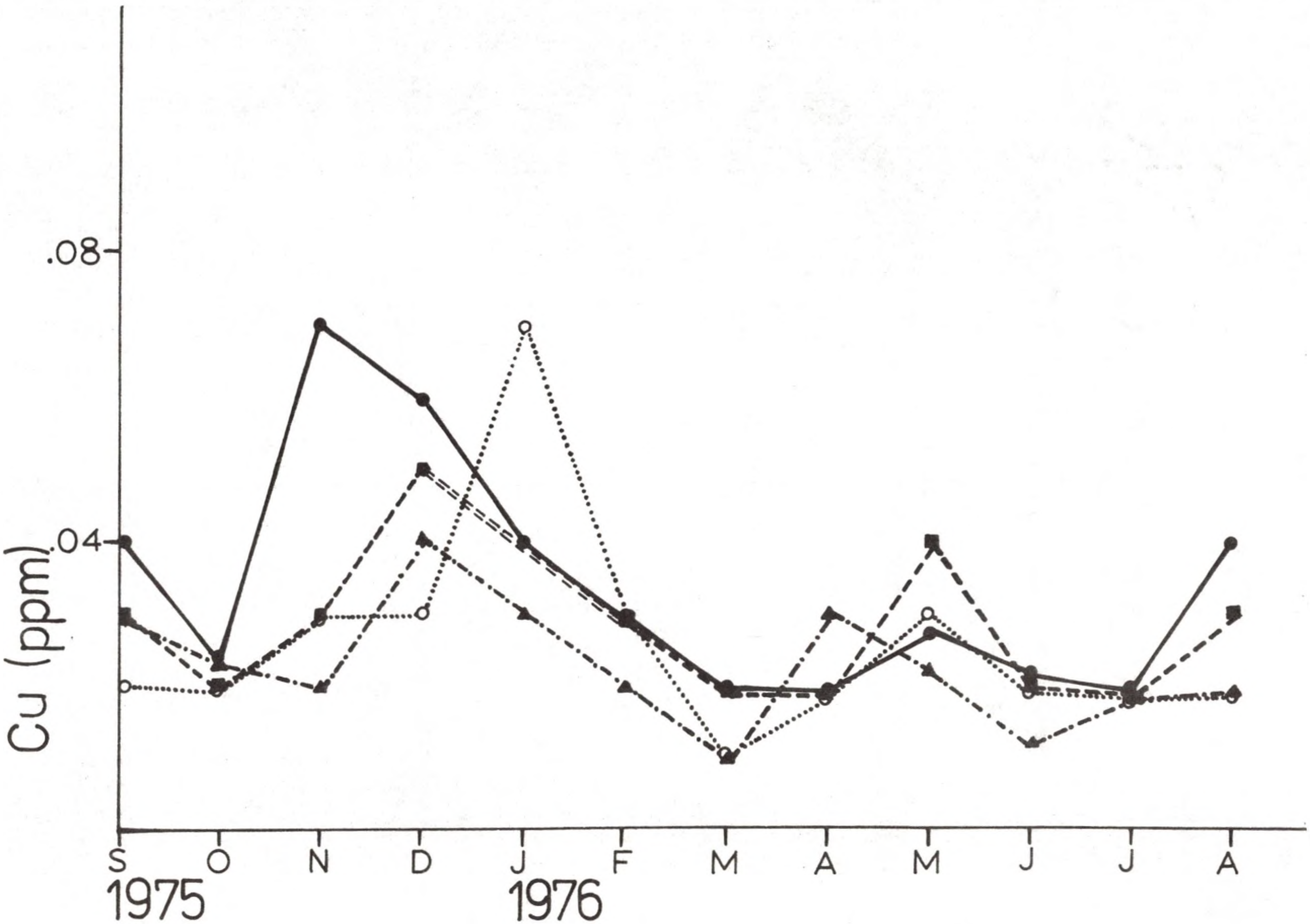
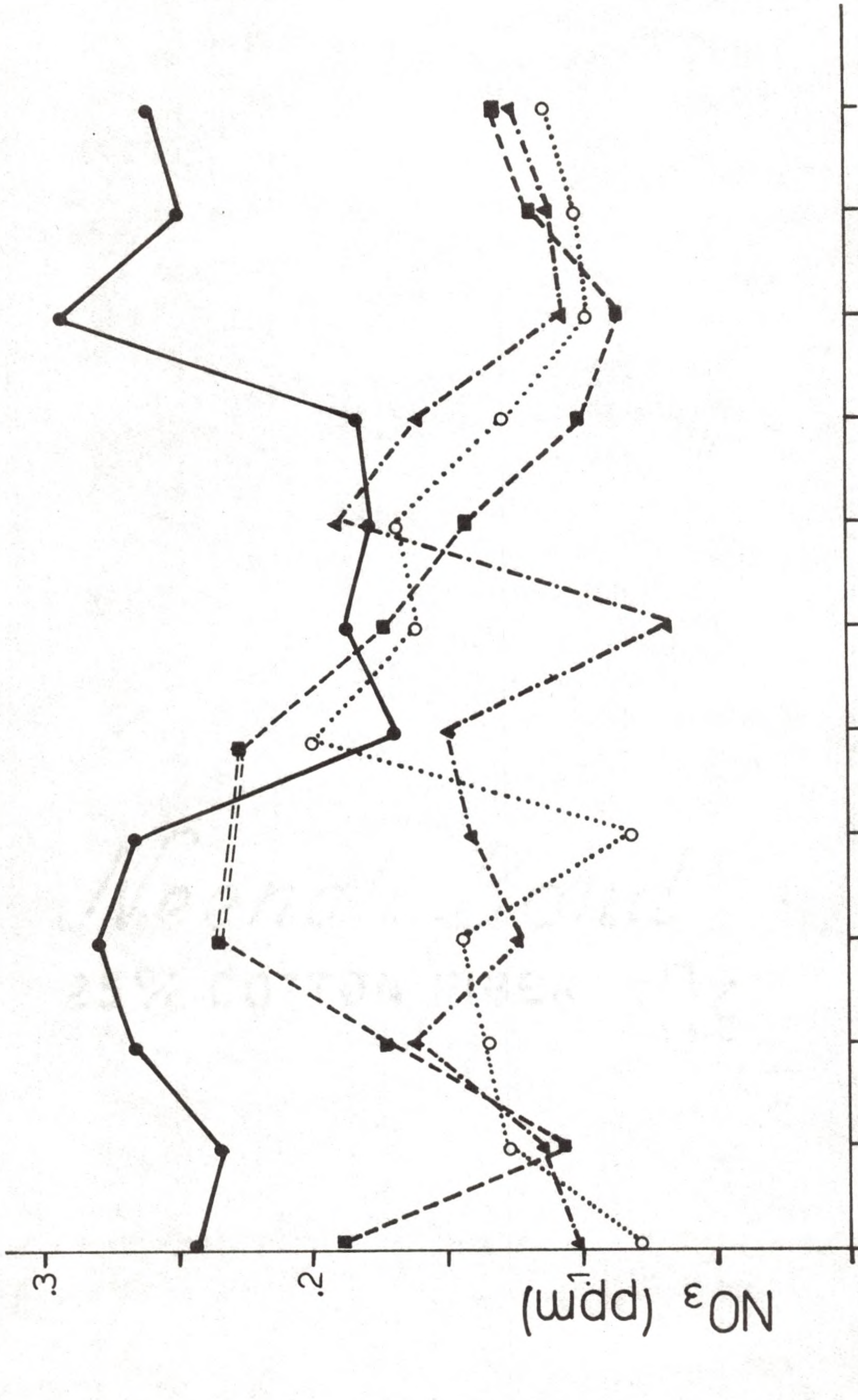

.08
.04
Cu (ppm)
S
O
N
D
J
F
M
A
M
J
J
A
1975
1976

Fig. 17. Temporal trend of nitrates in selected strip-mine ponds in western North Dakota (see key, Fig. 13). A group 4 variable.



NO3 (ppm)
.3
.2
.1
S
O
N
D
J
F
M
A
M
J
J
A
1975
1976

Fig. 18. Temporal trend of phosphates in selected strip-mine ponds in western North Dakota. (see key, Fig. 13). A group 4 variable.

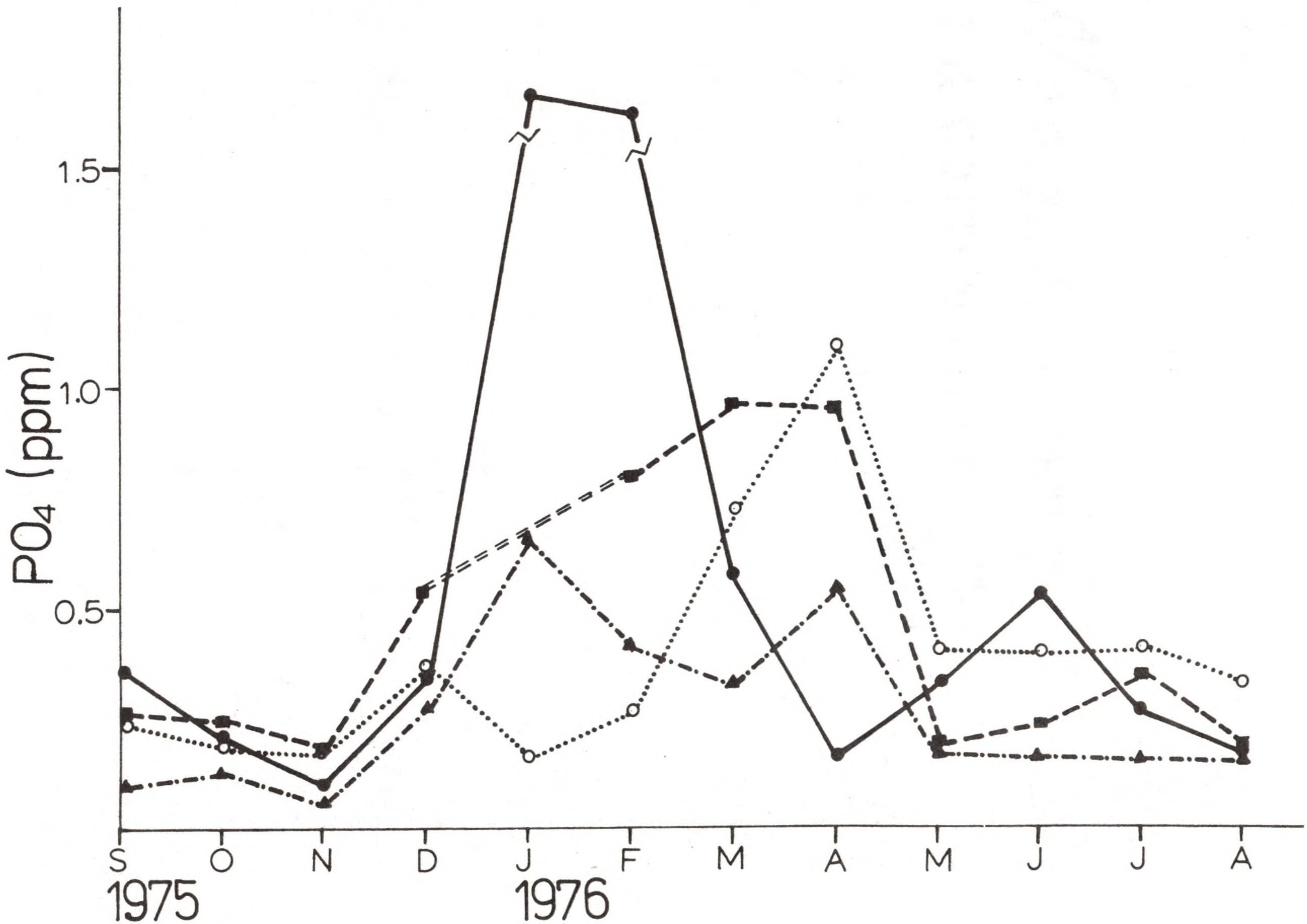
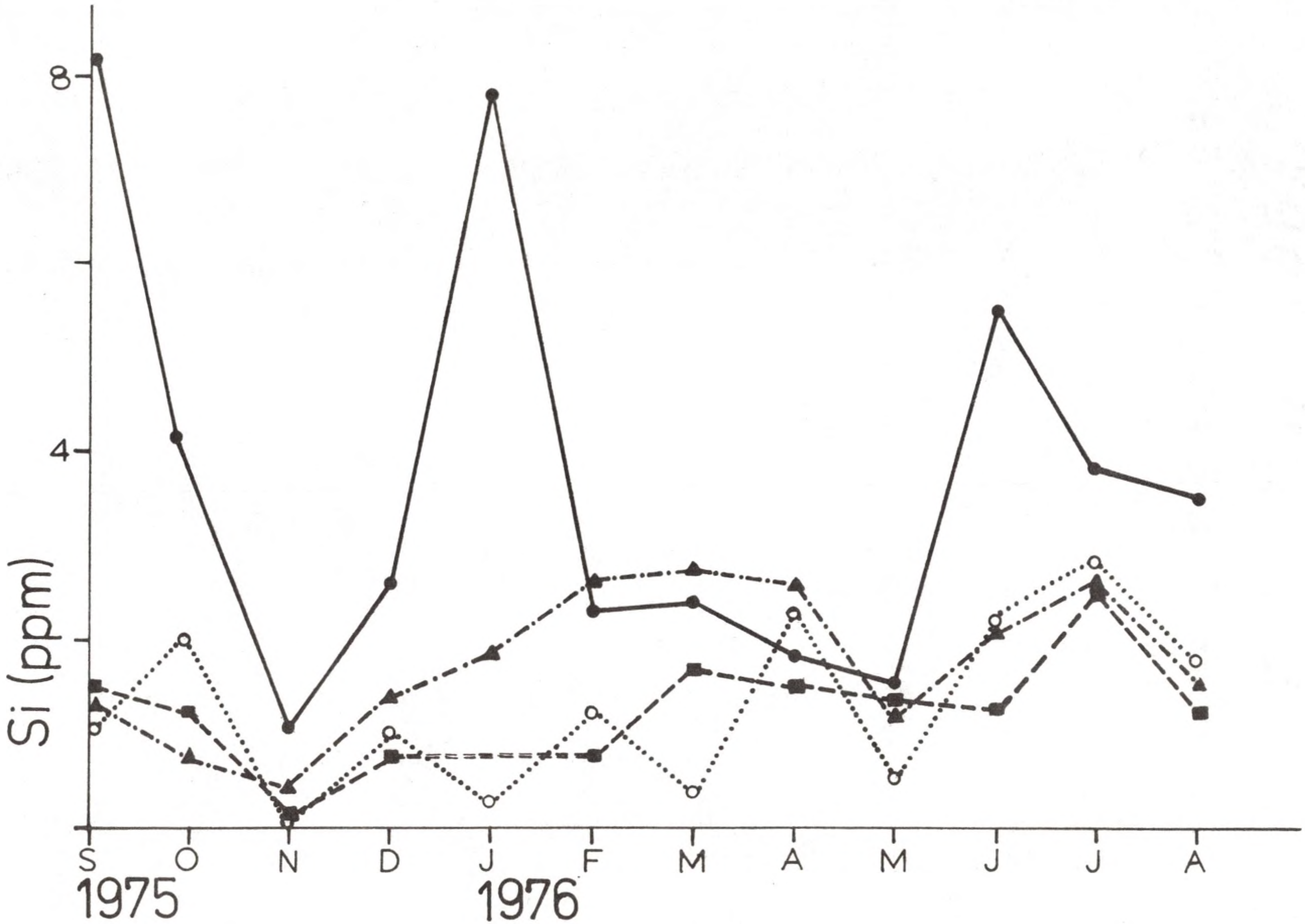

PO4 (ppm)
1.5
1.0
0.5
S
O
N
D
J
F
M
A
M
J
J
A
1975
1976

Fig. 19. Temporal trend of silicon in selected strip-mine ponds in western North Dakota. (see key, Fig. 13). A group 4 variable.


8
4
Si (ppm)
S
O
N
D
J
F
M
A
M
J
J
A
1975
1976

Examination of the water chemistry data (Appendix 1, Table 22) by analysis of variance (Table 3) shows that many ions vary significantly ($t \geq 2.78$ at $\alpha = .05$) between strip-mine ponds of various ages. Analysis of these differences (Table 4) indicate that certain water variables show increases in concentration with increasing age: Electrical conductivity, Ni, Mn, SO_4 and Pb. A decrease in concentration with increasing age is exhibited by pH. Water variables like Ca, Mg, Cl, NO_3, Li, Si, and Sr do not seem to correlate to the age of the pond; although in most cases DS30 has significantly higher concentrations. Phosphates, K, Na, Fe, Al, Cu, Mo and Zn are essentially the same from one strip-mine pond to the next, regardless of age.

Ionic Dominance, Conductivity and Salinity

The anion composition of the ponds in this study was divided into two dominance patterns: a bicarbonate-type ($HCO_3 > SO_4 > Cl$) and a sulfate-type ($SO_4 > HCO_3 > Cl$). The bicarbonate waters ranged from 350 to 1590 μmho/cm. Transition from bicarbonate to sulfate dominance began at 1010 μmho/cm, with complete dominance recorded at 1600 μmho/cm. Most strip-mine ponds show the sulfate-type pattern (Table 5 and Fig. 20).

The cation structure in all ponds but DS30 is sodium-calcium dominant. Above conductivities of 2300 μmho/cm magnesium becomes more common and therefore the waters tend to be sodium-magnesium dominant (Table 5).

A strong correlation exists between precipitation, changes in water level and conductivity (Fig. 21). As water levels decline due to decreasing precipitation and increasing evaporation there is an increase in conductivity values and therefore salinity. After spring runoff, water levels declined to June 5 when 3.75 cm of precipitation during June

Table 3. Analysis of variance of chemical variables in selected strip-mine ponds.

Variable	F-Value for Ponds
Ca	208.18*
Sr	118.80*
pH	60.94*
Li	40.00*
E.C.	37.82*
Cl	22.14*
Si	17.38*
NO_3	15.50*
Al	9.33*
Pb	7.75*
Mo	7.00*
K	6.72*
SO_4	5.10*
Mg	4.32*
Mn	4.00*
Cu	2.78*
Ni	2.62
Na	2.59
Fe	2.40
Total-PO_4	1.03
Ortho-PO_4	.78
Zn	.47

*Significance at the .05 level, $t \geq 2.78$

Table 4. Tukey's test: Analysis of differences of chemical variables between strip-mine ponds of various ages.

E.C.

	DS30	NB15	G5	NB1
DS30	--			
NB15	4.36*	--		
G5	7.29*	2.93	--	
NB1	6.21*	1.91	-.98	--

pH

	DS30	NB15	G5	NB1
DS30	--			
NB15	-3.27*	--		
G5	-6.69*	-3.42*	--	
NB1	-6.61*	-3.39*	-.02	--

Ca

	DS30	NB15	G5	NB1
DS30	--			
NB15	19.07*	--		
G5	22.52*	3.46*		
NB1	21.16*	2.34	-1.07	--

Mg

	DS30	NB15	G5	NB1
DS30	--			
NB15	2.85*	--		
G5	2.95*	.10	--	
NB1	2.84*	.04	-.06	--

K

	DS30	NB15	G5	NB1
DS30	--			
NB15	1.00	--		
G5	3.11*	2.10	--	
NB1	.15	-.84	-2.91*	--

Al

	DS30	NB15	G5	NB1
DS30	--			
NB15	-1.81	--		
G5	-4.38*	-2.57	--	
NB1	-.47	1.32	3.85*	--

Cu

	DS30	NB15	G5	NB1
DS30	--			
NB15	2.20	--		
G5	1.42	-.78	--	
NB1	.94	-1.23	-.46	--

Mn

	DS30	NB15	G5	NB1
DS30	--			
NB15	1.50	--		
G5	2.63*	1.13	--	
NB1	2.58	1.10	-.02	--

Li

	DS30	NB15	G5	NB1
DS30	--			
NB15	6.43*	--		
G5	7.72*	1.28	--	
NB1	6.66*	.31	-.96	--

Mo

	DS30	NB15	G5	NB1
DS30	--			
NB15	4.66*	--		
G5	1.43	-3.23*	--	
NB1	2.16	-2.44	.75	--

Si

	DS30	NB15	G5	NB1
DS30	--			
NB15	4.51*	--		
G5	5.50*	.99	--	
NB1	5.41*	.96	.02	--

Pb

	DS30	NB15	G5	NB1
DS30	--			
NB15	2.40	--		
G5	3.92*	1.53	--	
NB1	3.23*	.86	-.65	--

Sr

	DS30	NB15	G5	NB1
DS30	--			
NB15	13.33*	--		
G5	15.82*	2.49	--	
NB1	13.49*	.33	-2.13	--

Cl

	DS30	NB15	G5	NB1
DS30	--			
NB15	6.43*	--		
G5	6.14*	-.29	--	
NB1	5.84*	-.50	-.22	--

SO_4

	DS30	NB15	G5	NB1
DS30	--			
NB15	2.46	--		
G5	2.89*	.43	--	
NB1	1.70	-.73	-1.16	--

NO_3

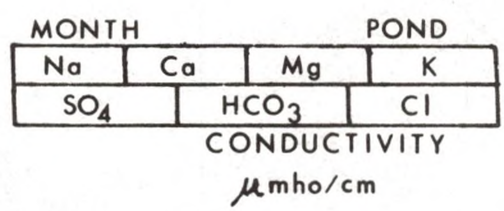
	DS30	NB15	G5	NB1
DS30	--			
NB15	7.17*	--		
G5	7.57*	.39	--	
NB1	6.76*	-.32	-.71	--

*significance at the $\alpha = .05$ level ≥ 2.63

Table 5. Major cations and anions in four strip-mine ponds and NBUN (summer 1976), in ppm.

	POND				
Variable	DS30	NB15	G5	NB1	NBUN
Na	361	452	344	305	55
Ca	237	69	25	37	31
Mg	290	50	11	30	16
K	15	17	12	16	10
Total cations	903	588	392	388	112
HCO_3	328	216	297	150	153
Cl	61	7	12	11	5
SO_4	892	511	203	284	10
Total anions	1181	734	512	445	168
Grand Total	2084	1322	904	833	280
E.C. μmho/cm	3170	2300	1420	1280	390
Salinity (calculated)	2029	1472	909	819	250

Fig. 20. Percent composition of the seven major ions in four strip-mine ponds and NBUN.



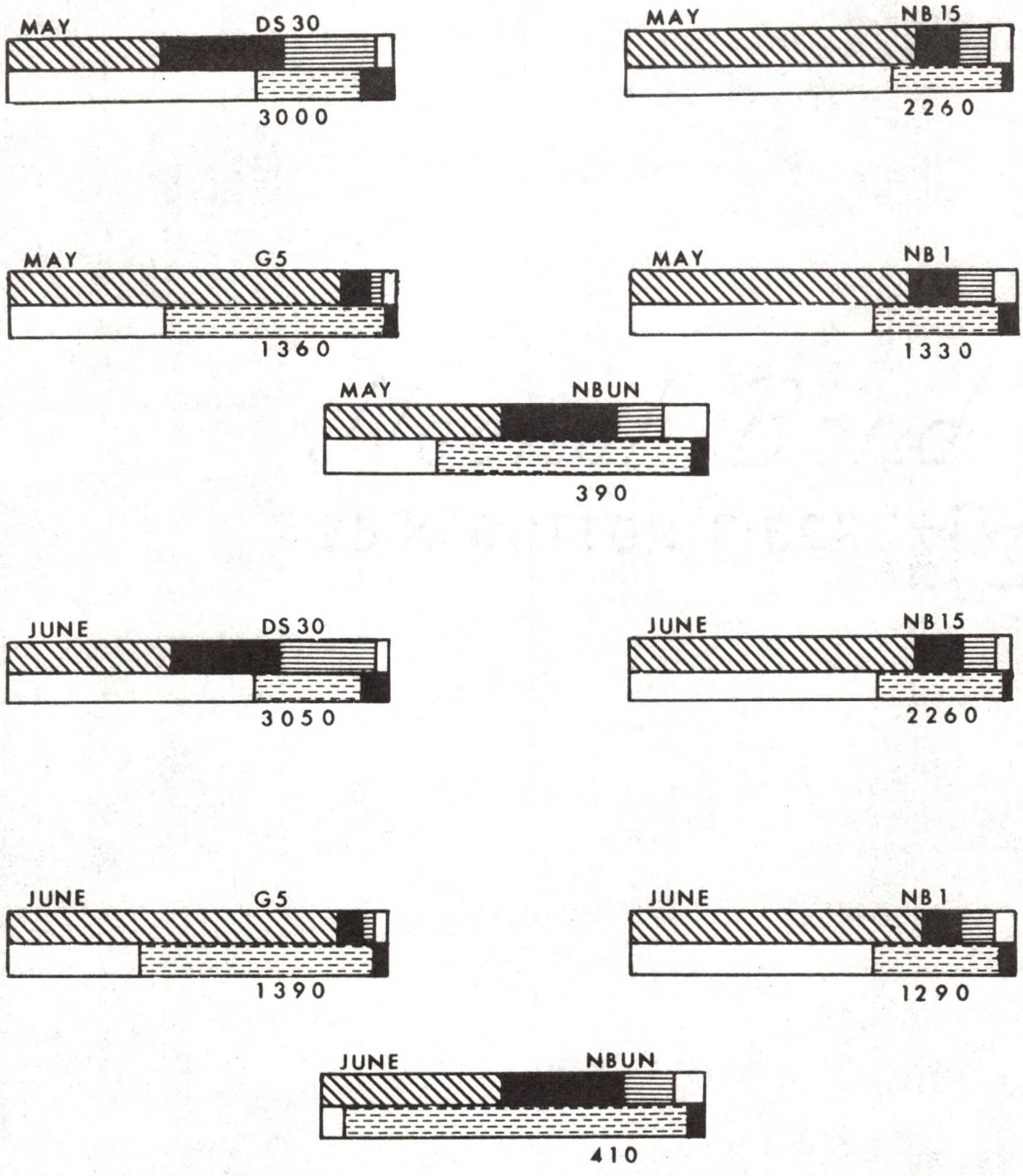

MAY
DS 30
3000
MAY
NB 15
2260
MAY
G5
1360
MAY
NB 1
1330
MAY
NBUN
390
JUNE
DS 30
3050
JUNE
NB 15
2260
JUNE
G5
1390
JUNE
NB 1
1290
JUNE
NBUN
410

Fig. 20 (continued)

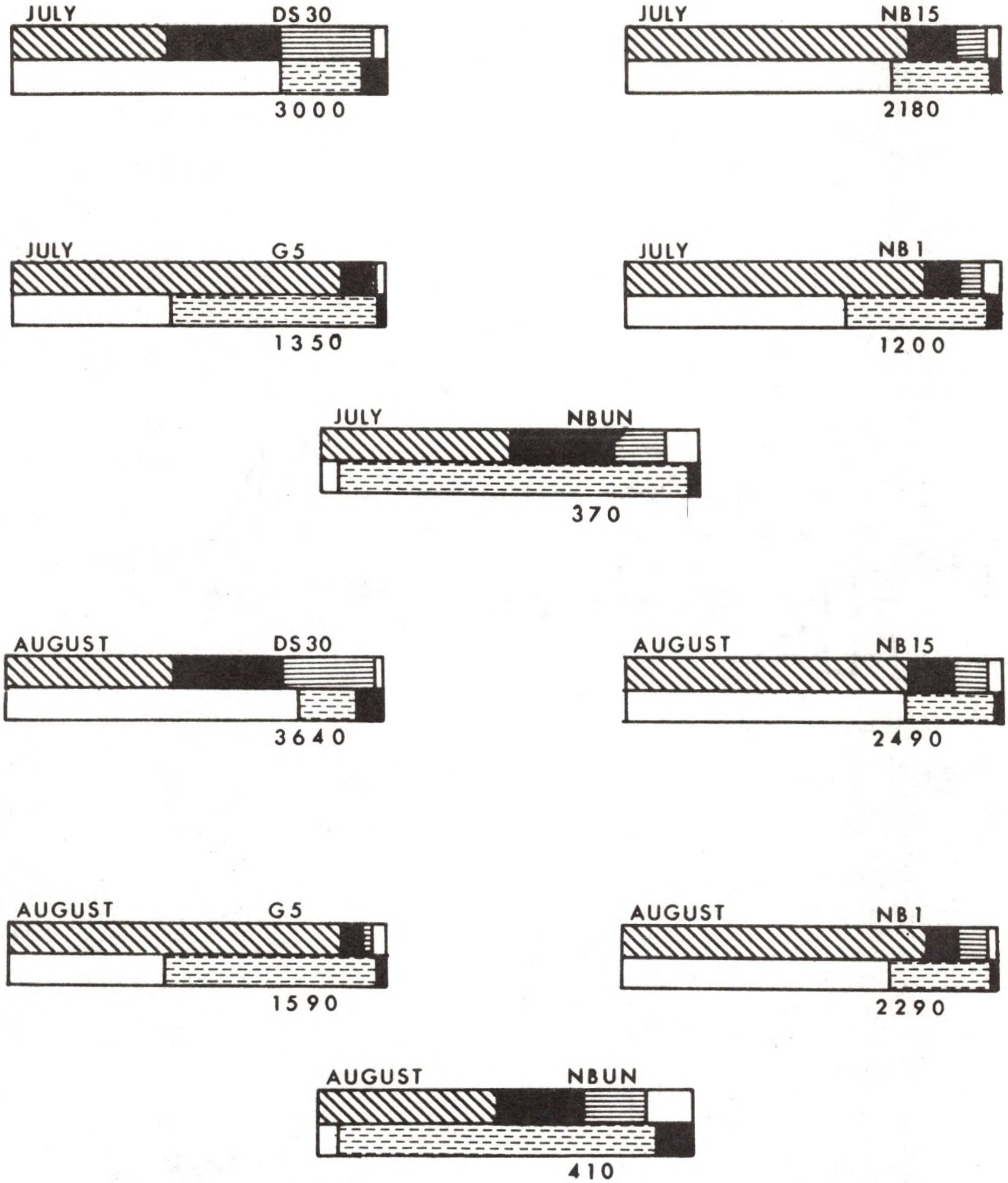
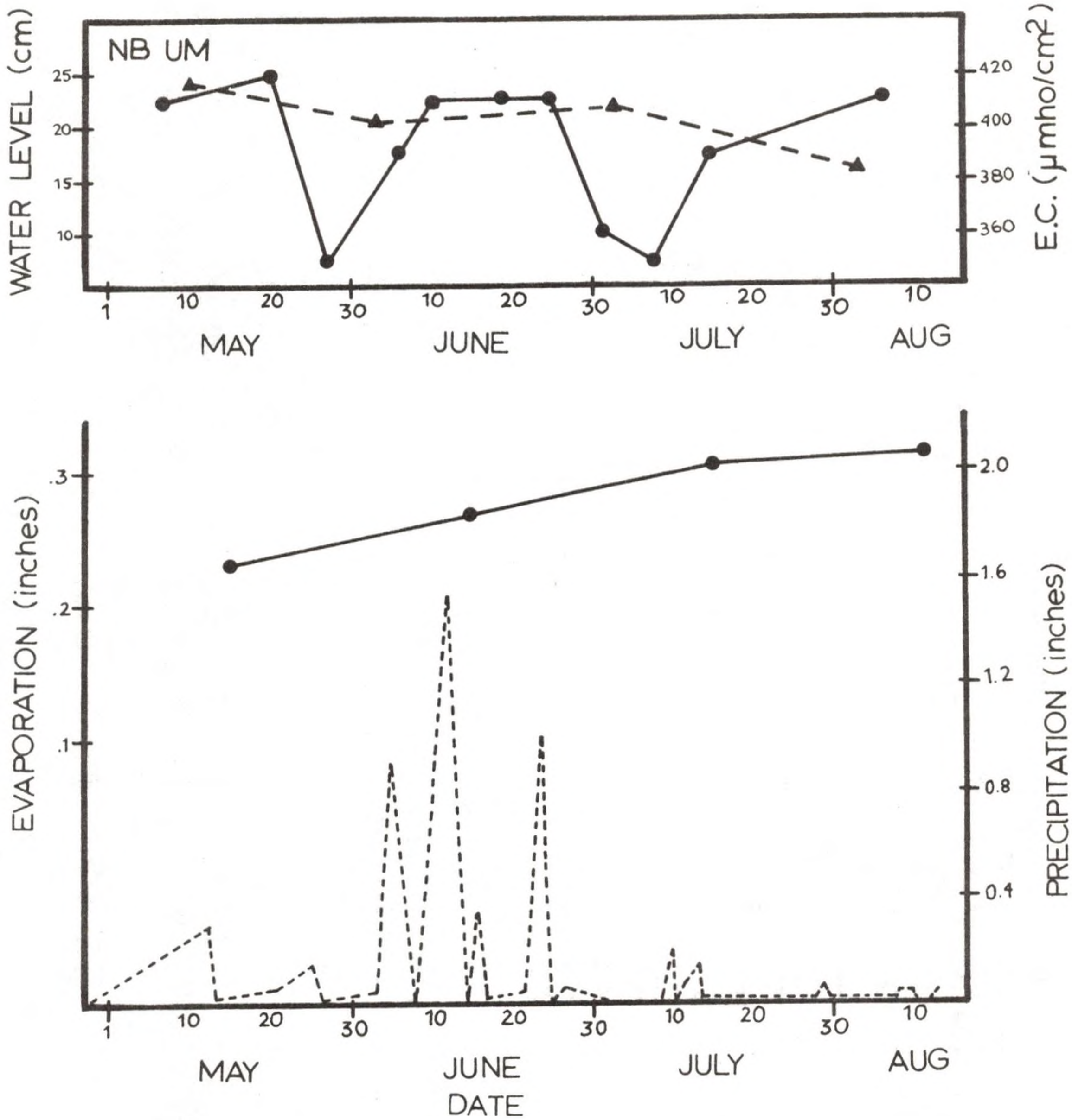

JULY DS 30
3000
JULY NB15
2180
JULY G5
1350
JULY NB1
1200
JULY NBUN
370
AUGUST DS 30
3640
AUGUST NB15
2490
AUGUST G5
1590
AUGUST NB1
2290
AUGUST NBUN
410

Fig. 21. Changes in precipitation, water levels and electrical conductivity in four strip-mine ponds and NBUN.

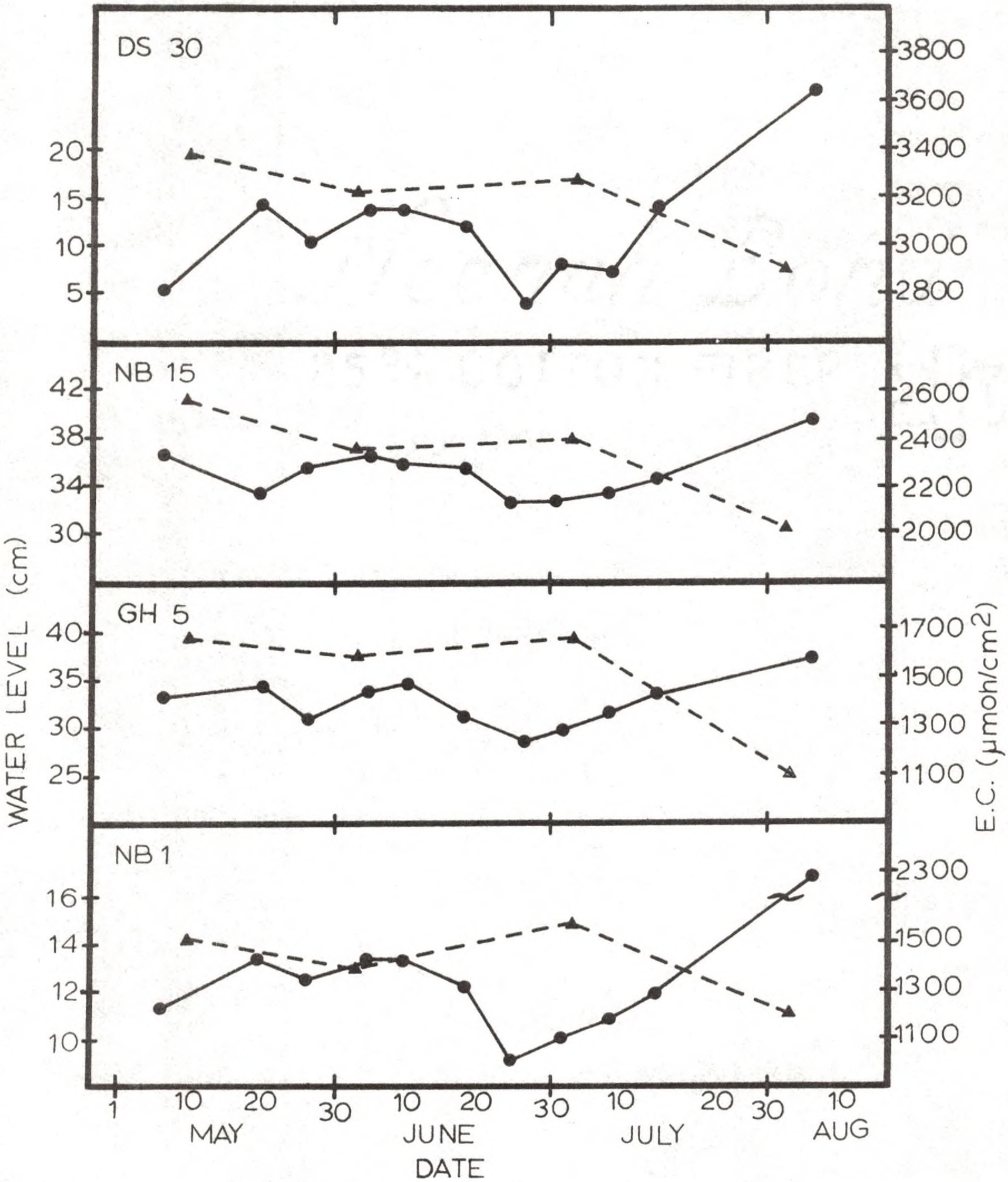
▲- - - -▲ Water level

●———● Conductivity



NB UM
WATER LEVEL (cm)
25
20
15
10
E.C. (µmho/cm2)
420
400
380
360
1
10
20
30
MAY
JUNE
JULY
AUG
EVAPORATION (inches)
.3
.2
.1
PRECIPITATION (inches)
2.0
1.6
1.2
0.8
0.4
DATE

Fig. 21 (continued)


DS 30
NB 15
GH 5
NB 1
WATER LEVEL (cm)
E.C. (µmoh/cm2)
20
15
10
5
42
38
34
30
40
35
30
25
16
14
12
10
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1700
1500
1300
1100
2300
1500
1300
1100
1
10
20
30
10
20
30
10
20
30
10
MAY
JUNE
JULY
AUG
DATE

combined with surface runoff increased water levels again and in some cases (e.g. NB1) beyond the spring reading. During this time conductivity values decreased. Conductivity then increased from 15 to 36 percent between late June and mid-August as the water levels began to decrease again.

Comparisons to NBUN

Comparisons of strip-mine ponds to the pond in the unmined area (NBUN) are given in Table 6 for each of the variables. Concentration of many ions in strip-mine ponds are significantly ($t \geq 2.54$ at $\alpha = .05$) higher than NBUN. Only Fe at NB1, pH at DS30, and total-PO_4 and Mo at NB5 are significantly lower than NBUN. The following ions, though not significant, are generally lower in strip-mine ponds: Fe, pH, Al, Mn, Mo, Si and phosphates.

Strip-mine ponds are compared to NBUN in Table 5 with respect to major ions, conductivity and salinity. Three noticeable differences exist between strip-mine ponds and NBUN: (1) strip-mine ponds are more highly mineralized and therefore have higher salinities than NBUN; (2) NBUN is bicarbonate-sulfate dominant. Though G5 exhibits a bicarbonate type pattern, it is not as pronounced as at NBUN and (3) NBUN is not as strongly sodium dominant as the strip-mine ponds.

Sediment and Spoil Chemistry

The concentrations of 23 ions, pH, electrical conductivity and percent organic matter are given in Tables 7-9 for bottom sediments. All the major cations and anions in the sediments are at lower levels than NBUN. Several trace ions are also lower: B, Cr, Li, Mo, Ni, pH, Si and Sr. Certain trace elements have concentrations higher than those

Table 6. Dunnet's test: comparisons between strip-mine ponds (experimental) and the unmined pond (control) from May 1976 through August 1976.

Variable	DS30	NB15	G5	NB1
E.C.	32.19*	22.38*	12.06*	11.71*
pH	-5.02*	-.68	3.49*	3.21*
Na	14.06*	19.19*	13.40*	11.32*
Ca	17.76*	3.27*	-.56	.66
Mg	32.65*	5.82*	-.63	2.64*
K	7.62*	7.62*	.45	6.71*
Al	-.62	.83	1.87	-.42
Cu	1.75	-.00	1.00	2.00
Fe	-1.97	-2.88*	-2.12	-3.56*
Li	32.28*	10.70*	6.67*	8.24*
Mn	2.49	-.28	-.69	.14
Mo	-.35	-3.39*	-1.06	-1.13
Ni	5.15*	2.75*	1.12	1.37
Pb	2.97*	.87	-.00	.59
Si	3.78*	.43	-.27	-.22
Sr	22.97*	4.50*	.01	2.88*
Zn	.28	.11	.45	2.29
SO_4	25.00*	14.28*	5.28*	7.54*
Cl	40.79*	2.01	4.67*	3.92*
NO_3	7.65*	1.47	.58	.37
Ortho-PO_4	-1.24	-2.19	-.24	-1.67
Total-PO_4	-.27	-3.11*	-.03	-1.85

*Significance at .05 level, $t \geq 2.54$

Table 7. pH, electrical conductivity (E.C.), and major ions in the sediments of strip-mine ponds and NBUN. Water saturation extract.

Sample Site	pH	E.C. mhos/cm	% O.M.	Ca	Mg	K	Na	P	SO_4	Cl
				ppm						
DS30[1] (1)[2]	7.15	1.00	-	567.7	83.5	.34	2.29	-	420	46.4
NB15[1] (1)	7.91	1.82	2.82	187.3	84.5	.61	4.69	.298	1400	39.8
G5[1] (1)	8.11	1.20	3.81	106.7	40.2	.35	4.14	.149	800	355.0
NB1[1] (1)	7.07	1.60	1.31	110.3	61.8	.46	3.30	.894	1025	23.1
NBUN[1] (1)	7.58	3.78	4.17	922.0	350.1	72.00	150.00	6.250	9400	876.5
DS30[3] (2)	7.55	3.45	1.58	891.7	381.6	1.13	5.68	.225	2775	88.9
NB1[3] (1)	8.93	.90	1.12	783.4	25.2	.19	2.57	2.979	475	23.1

1 Samples collected during summer 1975
2 Number in parenthesis are number of samples collected per site
3 Samples collected during winter 1975-1976

Table 8. Trace elements of sediments in strip-mine ponds and NBUN. Water saturation extractable and NH_4OAc extractable ions.

Sample Site	Li	Mn	Sr	Zn	Fe	Ca	Mg	Na	K	Sr	Mn	Li
	ppm Water Saturation					ppm NH_4OAc						
DS30[1] (1)[2]	.14	.39	1.80	.07	.11	4983.6	1769.0	3.84	1.80	31.20	28.91	.28
NB15[1] (1)	.13	.18	3.23	.09	.12	3800.0	1030.2	5.08	1.84	23.54	21.91	.18
G5[1] (1)	.08	.15	1.36	.22	.15	4550.0	1045.2	5.86	1.44	22.80	9.57	.18
NB1[1] (1)	.12	.07	2.84	.07	.11	2733.6	905.8	3.44	1.50	22.34	8.57	.18
NBUN[1] (1)	-	-	-	-	-	7432.0	4537.0	876.10	452.80	-	-	-
DS30[3] (2)	.32	.18	11.78	.10	.12	4866.8	2677.0	8.64	4.51	34.77	20.58	.60
NB1[1] (1)	.07	.05	.86	.16	.11	4483.6	1752.0	10.12	3.02	39.06	10.91	.34

1 Samples collected during summer 1975
2 Number in parenthesis are number of samples collected per site
3 Samples collected during winter 1975-1976

Table 9. Trace elements of sediments in strip-mine ponds and NBUN. EDTA extractable ions.

Sample Site	Al	B	Cd	Cr	Cu	Fe	Li	Mn	Mo	Ni	Pb	Si	Sr	Zn
	ppm													
DS30[1] (1)	1.50	.423	.30	.055	13.75	679.2	.18	169.28	.052	.52	.58	18.3	6.32	8.85
NB15[1] (1)	0.00	.070	.39	.022	17.08	340.0	.13	70.35	.064	.65	.52	10.5	6.49	10.68
G5[1] (1)	1.50	.088	.40	.200	14.17	433.2	.11	55.68	.059	.51	.45	14.3	5.16	7.93
NB1[1] (1)	2.25	.008	.34	.003	8.41	211.7	.13	39.51	.032	.37	.27	11.0	8.55	6.68
NBUN[1] (1)	2.00	1.570	2.23	.321	5.25	65.0	2.00	71.00	.120	2.42	4.17	74.8	32.06	2.21
DS30[1] (2)	2.13	.192	.43	.008	22.71	445.0	.40	56.14	.084	.47	.75	13.8	15.02	11.93
NB1[1] (1)	.25	.013	.40	.004	11.24	286.7	.23	52.51	.083	.35	.13	9.5	10.43	8.60

1 Samples collected during summer 1975
2 Number in parenthesis are number of samples collected per site
3 Samples collected during winter 1975-1976

in NBUN: Cu, Fe, Zn and Mn.

The same variables were analyzed for the spoil material, and the results appear in Appendix 1, Tables 23, 24 and 25. Table 10 gives the concentration of calcium and magnisium in the spoils surrounding the strip-mine ponds of various ages. The spoil around DS30 has higher levels of replaceable calcium and magnesium than any other spoil analyzed.

Table 10. Calcium and magnesium in the spoils surrounding strip-mine ponds of various ages, in ppm.

	Ca_1	Ca_2	Mg_1	Mg_2
DS30	4872	178	1444	57
NB15	3996	282	1025	100
G5	4260	198	981	78
NB1	3360	225	1069	122

1 Water extractable (soluble) Ca and Mg

2 Ammonium acetate extractable (exchangable) Ca and Mg

AQUATIC INVERTEBRATES

Species Composition

Ninety-seven invertebrate taxa were identified from NBUN and three strip-mine ponds (DS30, NB15, and NB1). Table 11 shows that six phyla are represented from the collections. Nematomorpha, Cnidaria, Bryozoa and Annelida are not common in strip-mine ponds. The bulk of the organisms present in these ponds belong to either Mollusca or Arthropoda. The class Insecta comprises almost 80% of all the species identified. A closer inspection of the Insecta (Table 11) reveals that there are two dominant orders; the Dipterans and Coleopterans, with 26 and 24 species respectively. Chironomidae and Dytiscidae are the most common families within the two dominant orders.

Species composition of NB1 is the simplest among the strip-mine ponds studied (Table 12). Many of the 27 species identified from NB1 are Dipterans. *Bezzia* (*Probezzia*) spp. are the most common Dipterans, followed by *Tanytarsus* sp., *Palpomyia* sp., *Chaoborus* sp., *Tabanus* sp., and *Chrysops* sp. Other common insects are Corixidae and *Notonecta* sp. The Coleopterans, *Haliplus* sp., *Berosus* sp., and *Hydraena* sp. are occasionally found associated with *Kochia* sp. The only common non-insect is Hydracarina.

The invertebrate fauna at NB15 includes a much larger and wider variety of species than exists at NB1 (Table 13). Mollusca, Amphipoda, Ephemeroptera, Odonata, and Tricoptera, which are rarely collected at NB1, have several common species at NB15. Characteristic species include: *Hyallela azteca*, *Lestes* spp., Hydracarina *Physa* spp., *Enallegma* spp., and *Lymnea* sp. *Glossiphonia complanata*, *Placobdella rugosa*, *Anax* sp.,

Table 11. Species collected from NBUN and three strip-mine ponds in western North Dakota, 1976.

PHYLUM	CLASS	ORDER	FAMILY	GENUS OR SPECIES
I. CNIDARIA	Hydrozoa	Hydroida	Hydridae	*Hydra* sp.
II. NEMATOMORPHA	Gordioidea		Chordodidae	*Paragordius* sp.
III. BRYOZOA	Phylactolaemata	Plumatellina	Plumatellidae	*Plumatella* sp.
IV. ANNELIDA	Oligochaeta	Plesiopora	Naididae	*Ophidonais* sp.
	Hirudinea	Rhynchobdellida	Glossiphoniidae	*Glossiphonia complanata*
				Helobdella stagnalis
				Placobdella rugosa
		Arhynchobdellida	Erpobdellidae	*Erpobdella punctata*
V. ARTHROPODA	Crustacea	Amphipoda	Talitridae	*Hyallela azteca*
	Arachnoidea	Hydracarnia		
	Insecta	Collembola		
		Ephemeroptera	Baetidae	*Caenis* sp.
				Centroptilum spp.
				Callibaetis spp.
		Odonata (Anisoptera)	Aeschnidae	*Aeschna* spp.
				Anax sp.
			Libellulidae	*Libellula* spp.
		Odonata (Zygoptera)	Coenagrionidae	*Ischnura* spp.
				Enallagma spp.
				Lestes spp.
		Hemiptera	Corixidae	
			Macroveliidae	*Macrovelia* sp.
			Notonectidae	*Notonecta* sp.
			Gerridae	*Gerris* sp.
			Pleidae	*Plea striola*

Table 11 (continued)

PHYLUM	CLASS	ORDER	FAMILY	GENUS OR SPECIES
			Nepidae	*Ranatra* sp.
			Belostomatidae	*Belostoma* sp.
		Tricoptera	Leptoceridae	
				Triaenodes tarda
			Limnephilidae	
				Limnephilus spp.
				Limnephilus submonilifer
				Glyphotaelius sp.
				Hesperophylax sp.
				Platycentropus sp.
			Phryganeidae	*Phryganea* sp.
		Coleoptera	Dytiscidae (Hydroporinae)	*Bidessus* sp.
				Hydroporus spp.
				Deronectes spp.
			Dytiscidae (Laccophilinae)	*Laccophilus* sp.
			Dytiscidae (Noterinae)	*Hydrocanthus* sp.
			Dytiscidae (Colymbetinae)	*Agabus* sp.
				Copelatus sp.
				Coptotomus sp.
				Colymbetes sp.
			Dytiscidae (Dytiscinae)	*Hydaticus* sp.
				Acilius sp.
				Dytiscus spp.
			Haliplidae	*Haliplus* spp.
			Gyrinidae	*Gyrinus* sp.

Table 11 (continued)

PHYLUM	CLASS	ORDER	FAMILY	GENUS OR SPECIES
			Hydrophilidae	
				Berosus sp.
				Tropisternus sp.
				Paracymus sp.
			Hydraenidae	*Hydraena* sp.
			Elmidae	*Narpus* sp.
				Ancyronyx sp.
			Chrysomelidae	*Donacia* sp.
			Curculionidae	*Hyperodes* spp.
				Lissorhoptrus simplex
		Diptera	Anthomyiidae	
			Brachydeutra	
			Ceratopogonidae	*Bezzia (Probezzia)* spp.
				Palpomyia tibialis
			Culicidae	*Chaoborus* spp.
				Culex sp.
				Anopheles sp.
			Tipulidae	*Tipula* sp.
			Tabanidae	*Tabanus* sp.
				Chrysops sp.
			Stratiomyiidae	*Odontomyia cincta*
			Ephydridae	*Ephydra* sp.
			Chironomidae (Tanypodinae)	*Pentaneura* sp.
				Tanypus stellatus
				Procladius sp.
				Anatopynia dyari
			Chironomidae (Orthocladiinae)	*Cricotopus* sp.

Table 11 (continued)

PHYLUM	CLASS	ORDER	FAMILY	GENUS OR SPECIES
				Spaniotoma sp.
			Chironomidae (Chironominae)	*Chironomus* spp.
				Chironomus tentans
				Chironomus plumosus
				Chironomus (Endochironomus) spp.
				Chironomus (Limnochironomus) spp.
				Chironomus (Cryptochironomus) spp.
				Chironomus (Glyptotendipes) spp.
				Tanytarsus spp.
VI. MOLLUSCA	Gastropoda	Pulmonata	Lymnaeidae	*Lymnaea* spp.
				Stagnicola sp.
			Physidae	*Physa* spp.
				Aplexa hypnorum
			Planorbidae	*Helisoma* spp.
				Helisoma companulata
				Gyraulus spp.
			Ancylidae	*Ferrissia* sp.
			Amnicolidae	*Amnicola* sp.
	Pelecyopoda		Sphaeriidae	*Sphaerium* spp.
				Musculium spp.

Table 12. List of invertebrate fauna collected from NB1,

NEMATOMORPHA

Paragordius

ARTHROPODA

CRUSTACEA

Hyallela azteca

HYDRACARINA

INSECTA

EPHEMEROPTERA
Centroptilum
Callebaetis

ODONATA
Enallegma

HEMIPTERA
Corixidae
Notonecta

TRICOPTERA
Triaenodes tarda

COLEOPTERA
Berosus
Paracymus
Hydranea
Haliplus
Gyrinus

DIPTERA
Tanytarsus
Pentaneura
Anaptopynia
Tanypus
Chironomus
Bezzia (Probezzia)
Palpomyia
Chaoborus
Tabanus
Chrysops
Ephydra

MOLLUSCA

GASTROPODA
Physa
Gyraulus

Table 13. List of invertebrate fauna collected from NB15.

ANNELIDA

Placobdella rugosa
Glossiphonia complanata

ARTHROPODA

CRUSTACEA

Hyallela azteca

HYDRACARNIA

INSECTA

EPHEMEROPTERA
Centroptilum
Callebaetis
Caenis

ODONATA
Enallegma
Ischnura
Lestes
Libellula
Anax

HEMIPTERA
Gerris
Ranatra
Corixidae
Notonecta
Plea striola

TRICOPTERA
Phryganea
Triaenodes tarda

COLEOPTERA
Copelatus
Berosus
Hydrocanthus
Bidessus
Laccophilus
Deronectes
Hydroporous
Hydaticus
Dytiscus
Tropisternus

COLEOPTERA (continued)
Hydranea
Haliplus
Gyrinus
Donacia

DIPTERA
Pentaneura
Anaptopynia
Tanypus
Chironomus (Endochironomus)
Chironomus (Glypotendipes)
Spaniotoma
Chironomus
Chironomus (Cryptochironomus)
Tabanus
Chrysops
Ephydra
Bezzia (Probezzia)
Palpomyia
Chaoborous

MOLLUSCA

PELECYOPODA

Musculium
Sphaerium

GASTROPODA

Lymnea
Physa
Gyraulus
Aplexa

Libellula spp., *Caenis* sp., *Ranatra* sp., and *Plea striola*, and many Dipteran and Coleopteran genera are collected for the first time at NB15.

Fifty-nine invertebrate species were identified from the oldest strip-mine pond, only seven more than at NB15. Although species numbers are similar at both ponds, this is no indication that species composition is similar (Table 14). In particular, the Tricoptera are more varied at DS30. Besides *Triaenodes* sp. and *Phryganea* sp., other Tricopterans include *Limnephilus* spp., *Hesperophylax* sp., and *Glyphotaelius* sp. Several species, like *Ophidonais* sp., *Odontomyia* sp., *Plumatella* sp., and *Hydra* sp. are not encountered in collections prior to DS30. And then there are those species which are absent from DS30, although they are characteristic of NB15; *Chrysops* sp., *Tabanus* sp., *Palpomyia* sp., *Bezzia (Probezzia)* spp., *Glossiphonia* sp., and *Placobdella* sp.

The unmined pond, NBUN, contains 78 species of invertebrates, more than any other strip-mine pond studied (Table 15). *Hyallela azteca*, *Gyraulus* spp., *Lymnea* sp., *Musculium* sp., *Helisoma* spp., *Enallegma* spp., and *Callibaetis* spp. are representative of invertebrates collected from NBUN. Although DS30 has fewer species than NBUN, the species composition is similar.

Some species characteristic to NBUN are absent in DS30 and the other strip-mine ponds. *Helisoma* is a genus not found in any strip-mine pond studied. Other species absent include: *Erpobdella* sp., *Helobdella* sp., *Tipula* sp., and Brachydeutra.

Annelids are poorly represented in strip-mine ponds. Oligochaetes are found in DS30 and leeches (*Glossiphonia* sp. and *Placobdella* sp.) are present at NB15, but not as commonly as they are found in NBUN.

To summarize the extent of similarity between the fauna of strip-mine

Table 14. List of invertebrate fauna collected from DS30.

CNIDARIA

Hydra

BRYOZOA

Plumatella

ANNELIDA

Ophidonias

ARTHROPODA

CRUSTACEA

Hyallela azteca

HYDRACARNIA

INSECTA

EPHEMEROPTERA
Centroptilum
Callebaetis
Caenis

ODONATA
Anax
Aeschna
Libellula
Enallegma
Ischnura
Lestes

HEMIPTERA
Plea striola
Notonecta
Corixidae
Belostoma
Ranatra
Gerris

TRICOPTERA
Leptoceridae
Limnephilidae
Phryganea
Limnephilus
Hesprophylax
Glyphotaelius

COLEOPTERA
Copelatus
Berosus
Hydrocanthus
Laccophilus
Deronectes
Hydroporous
Dytiscus
Paracymus
Hydraena
Haliplus
Gyrinus
Donacia
Elmidae
Ancryonyx
Hyperodes

DIPTERA
Chironomus
Chironomus tentans
Chironomus plumosus
Pentanura
Anaptopynia
Tanypus
Chironomus (Limnochironomus)
Chironomus (Endochironomus)
Chironomus (Glypotendipes)
Spaniotoma
Ephydra
Chaoboros
Odontomyia

MOLLUSCA

PELECYOPODA

Musculium
Sphaerium

GASTROPODA

Lymnea
Physa
Stagnicola
Gyraulus
Aplexa

Table 15. List of invertebrate fauna collected at NBUN.

BRYOZOA

Plumatella

ANNELIDA

Ophidonais
Glossiphonia complanata
Placobdella rugosa
Helobdella stagnalis
Erpobdella punctata

ARTHROPODA

CRUSTACEA

Hyallela azteca

HYDRACARNIA

INSECTA

EPHEMEROPTERA
Centroptilum
Callebaetis
Caenis

ODONATA
Anax
Aeschna
Libellula
Enallegma
Ischnura
Lestes

HEMIPTERA
Gerris
Ranatra
Corixidae
Notonecta
Plea striola

TRICOPTERA
Leptoceridae
Limnophilidae
Phryganea
Triaenodes
Limnephilus
Hesperophylax
Glyphotalius
Platycentropus

COLEOPTERA
Copelatus
Berosus
Hydrocanthus
Bidessus
Laccophilus
Coptotomus
Deronectes
Hydroporous
Dytiscus
Colymbetes
Paracymus
Tropisternus
Hydreana
Haliplus
Gyrinus
Donacia
Narpus
Hyperodes
Lissorhoptrus simplex

DIPTERA
Chironomus
Chironomus tentans
Chironomus plumosus
Tanylarsus
Pentanura
Anaptopynia
Tanypus
Chironomus (Limnochironomus)
Chironomus (Endochironomus)
Chironomus (Glypotendipes)
Spaniotoma
Cricotopus
Chironomus (Cryptochironomus)
Procladius
Tabanus
Chrysops
Ephydra
Tipula
Bezzia (Probezzia)
Pulpomyia
Chaoborous
Odonotomyia
Brachydeutra

MOLLUSCA

PELECYOPODA

Musculium
Sphaerium

GASTROPODA

Lymnea
Physa
Stagnicola
Helisoma
Gyraulus
Helisoma companulata

ponds and NBUN, a simple similarity index was used:

$$CC = \frac{2c \times 100}{a + b}$$

where 'c' is the number of species common to the compared ponds, 'a' is the number of species of one pond, and 'b' is the number of species in the other pond. Increasing values of the index were obtained when comparing the three strip-mine ponds to NBUN (Table 16). These increasing values show that as a strip-mine pond increases in age, the more it resembles NBUN.

Density and Biomass

The mean summer biomass and density of invertebrates in the three strip-mine ponds and NBUN are compared in Figure 22 and Appendix 2, Table 26. Both biomass and density increase through the strip-mine pond series. Biomass increases slowly at first then more quickly; whereas the increase in density is constant and progressive. This difference is due mostly to the lower snail biomass at NB15.

A slightly greater density and biomass is found at DS30 than at NBUN. The greater amounts are due to the large number of snails and chironomids at DS30.

The average weight of the animal population at NB1 for the summer is 15.4 lbs/acre, or 1,337 individuals/m^2. Maximum weights and density are obtained in July and August (Table 17). Figure 23 shows that numerically the Diptera account for almost 80% of all organisms present in NB1. Chironomidae and Ceratopogonidae greatly outnumber other organisms (Table 17). However, Hemipteran dry weight far exceeds the dry weight of the dominant Dipterans.

TABLE 16. Similarity values of the three strip-mine ponds compared to NBUN.

Pond Interval	MAY	JUNE	JULY	AUGUST	MEAN $\pm$ S.E.*
NB1-NBUN	26.1	33.8	25.8	46.8	33.1 $\pm$ 4.92
NB15-NBUN	52.2	59.4	45.6	63.0	55.1 $\pm$ 3.87
DS30-NBUN	71.6	72.6	54.5	62.0	65.2 $\pm$ 4.29

*S.E. = standard error of the mean ($s_{\bar{y}}$)

Fig. 22. Summer means of density and biomass in three strip-mine ponds and NBUN.

▲- - - -▲ Biomass

●———● Density

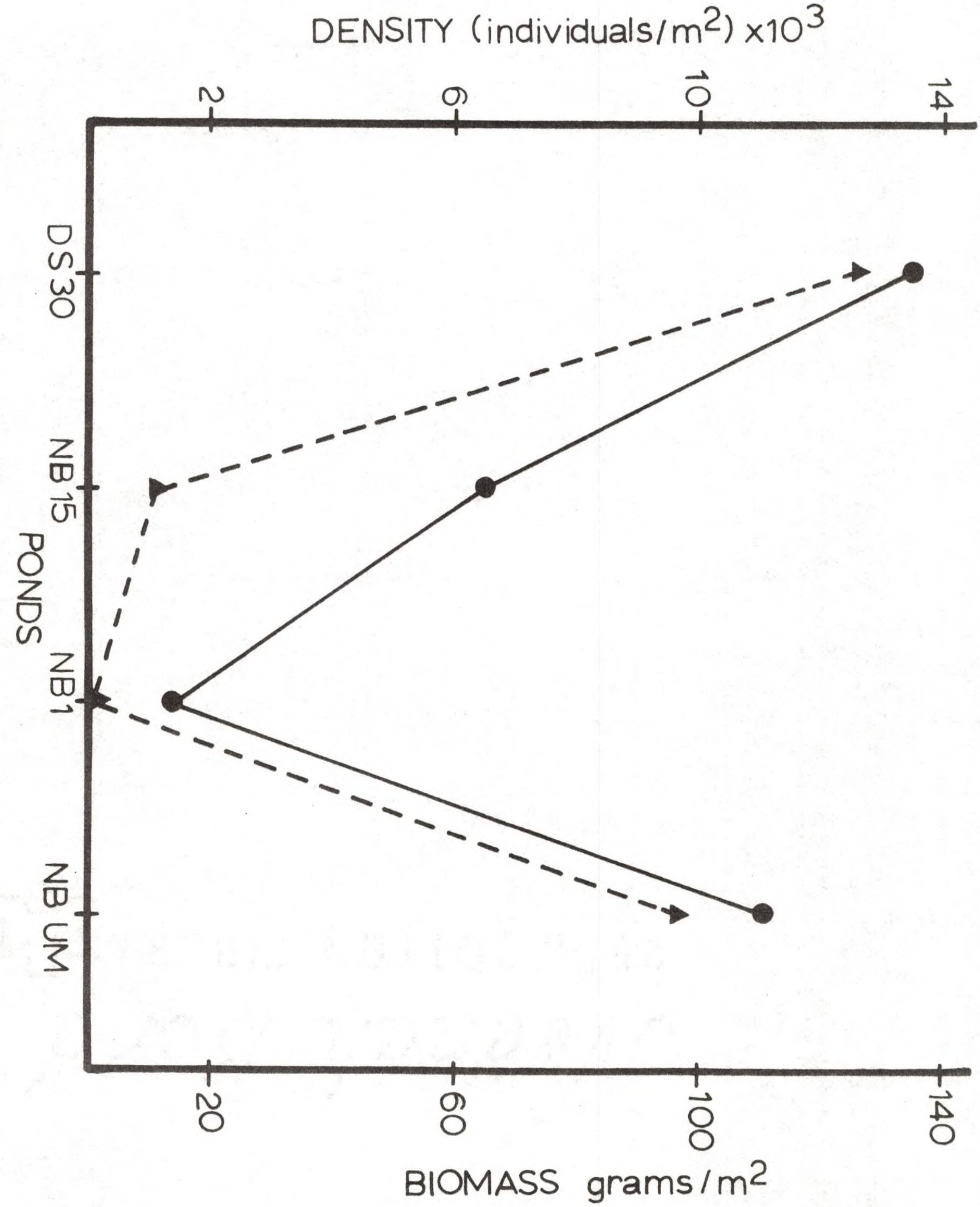

DENSITY (individuals/m2) x10
3
2
6
10
14
DS 30
NB 15
NB 1
NB UM
PONDS
20
60
100
140
BIOMASS grams/m2

Table 17. Biomass (g/m^2) and Density ($individuals/m^2$) for selected invertebrate groups at NB1.

	MAY		JUNE		JULY		AUGUST		TOTALS	
	ind/m^2	g/m^2	ind/m^2	g/m^2	ind/m^2	g/m^2	ind/m^2	g/m^2	ind/m^2	g/m^2
Nematomorpha	–	–	29	.043	38	.058	–	–	67	.101
Hydracarnia	–	–	–	–	183	.154	33	.004	217	.158
Amphipoda	–	–	–	–	8	.004	8	.004	17	.008
Hemiptera	–	–	96	.308	133	2.751	285	1.960	487	5.020
Coleoptera	–	–	42	.046	25	.039	61	.077	127	.163
Diptera*	17	.023	195	.123	1803	.119	1891	.499	3906	.763
Chironomidae	–	–	8	.029	682	.052	202	.017	884	.098
Tabanidae	–	–	29	.073	–	–	212	.397	240	.470
Chaoborinae	17	.023	51	.036	178	.041	33	.027	278	.127
Ceratopogonidae	–	–	116	.010	943	.026	1444	.058	2503	.094

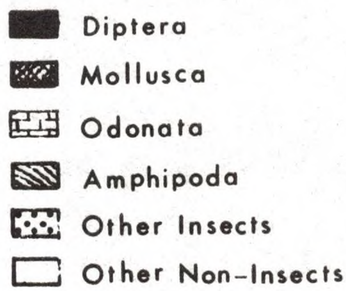
*includes: Chironomidae, Tabanidae, Chaoborinae, Ceratopogonidae.

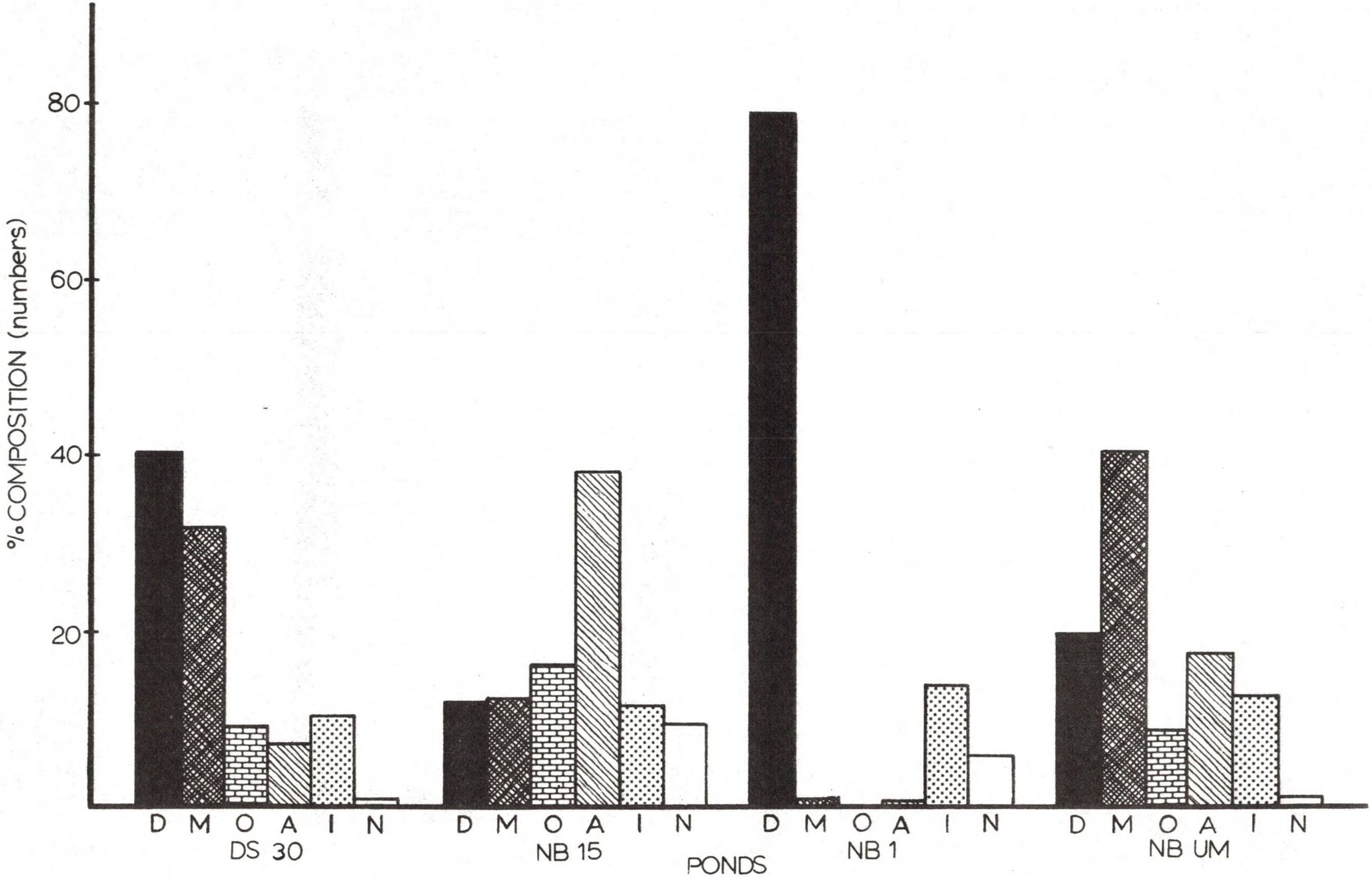
The mean weight of aquatic invertebrates at NB15 is 97.1 lbs/acre (6498 individuals/m^2). This is a substantial increase in the average weight compared to the fauna in NB1. Figure 23 shows that the Amphipoda account for 38% of the organisms present in NB15. *Hyallela azteca* is consistently numerous throughout the summer (Table 18), reaching 3856 individuals/m^2 in July. Odonata are also quite numerous, with peaks in June and August (Table 18). In June, the major contribution comes primarily from *Lestes* spp. and in August from *Enallegma* spp. Table 18 shows that Odonata and Mollusca make up the bulk of the biomass.

At DS30, the mean summer biomass of invertebrates is 1,133.1 lbs/acre (13,453 individuals/m^2). This is more than a 10-fold increase over NB15. Mollusca account for most of this increase (Fig. 24, Table 19). The dry weight of Odonata and Diptera also contribute to this increase in biomass. Besides high biomass, Mollusca are second only to Dipterans as the most numerous group of organisms. The dominance of the Dipterans is due to chironomids (Table 19), particularly *Chironomus tentans* and *C. plumosus*. The chironomids represent 76% of the total biomass and 75% of the total density among the Dipterans.

The average weight of the summer invertebrate population at NBUN is 854.7 lbs/acre (11,125 individuals/m^2). This value is similar to that obtained for DS30. The Mollusca make up the major portion of biomass and density. Recruitment of new individuals (*Helisoma*) is most apparent in June. Odonata are second only to Mollusca in total biomass (Table 20). Dipterans exist in large numbers, with peaks in June and August (Table 20). Though *Chironomus tentans* and *C. plumosus* are found at NBUN, they are not present in such numbers as in DS30. This means that other Dipteran families such as Tabanidae and Chaoborinae contribute more to total

Fig. 23. Percent composition of major invertebrate groups at three strip-mine ponds and NBUN, using numbers of organisms (density).

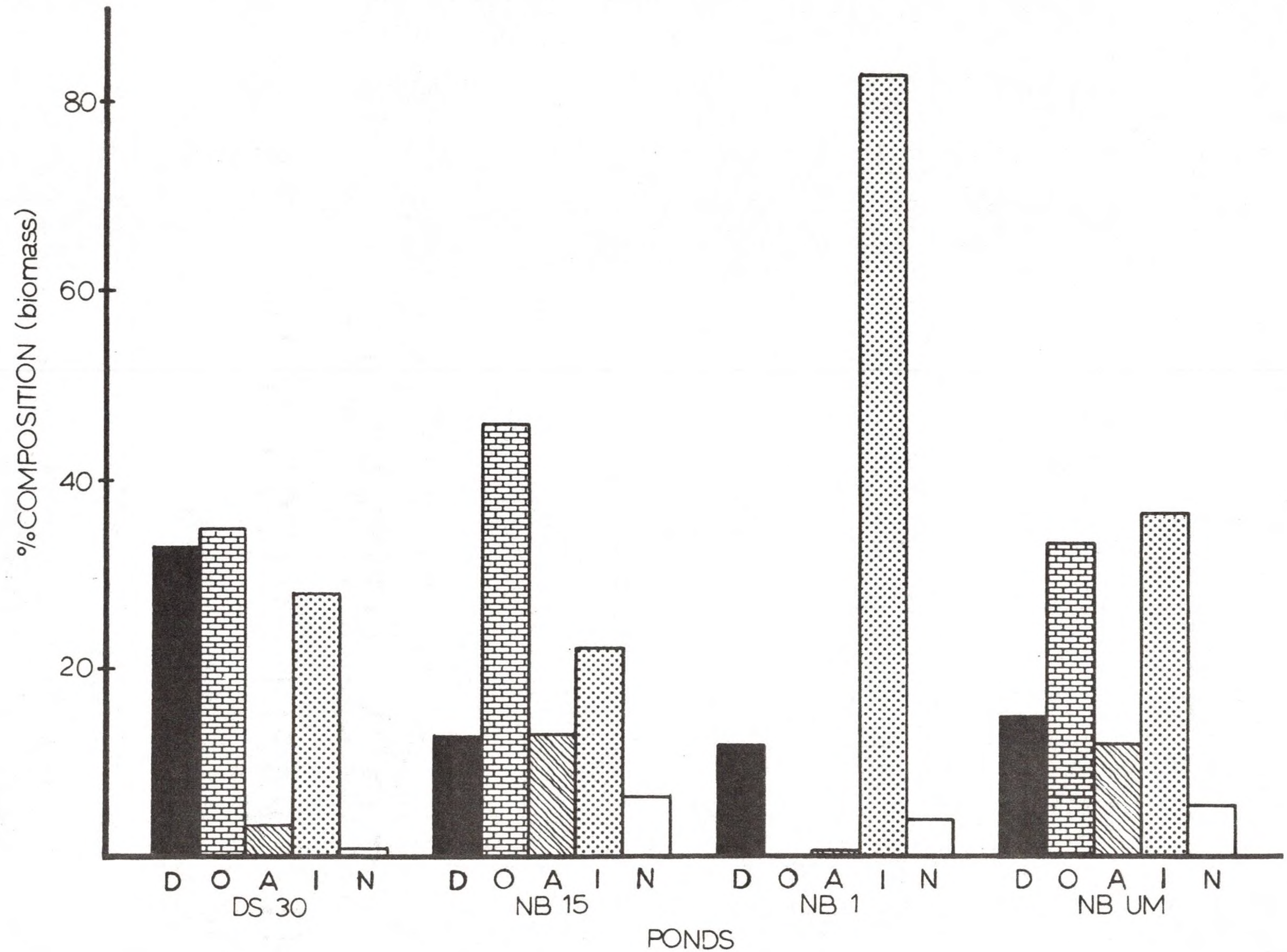




% COMPOSITION (numbers)
80
60
40
20
D M O A I N
DS 30
D M O A I N
NB 15
PONDS
D M O A I N
NB 1
D M O A I N
NB UM

Table 18. Biomass (g/m^2) and Density ($individuals/m^2$) for selected invertebrate groups at NB15.

	MAY		JUNE		JULY		AUGUST		TOTAL	
	ind/m^2	g/m^2	ind/m^2	g/m^2	ind/m^2	g/m^2	ind/m^2	g/m^2	ind/m^2	g/m^2
Annelida	8	.017	10	.010	-	-	-	-	18	.027
Hydracarnia	386	.239	1168	1.088	471	.308	333	.169	2359	1.805
Amphipoda	1693	1.064	1766	.620	3856	1.204	2595	.838	9910	3.727
Hemiptera	33	.242	650	1.638	408	1.497	317	.411	1408	3.789
Ephemeroptera	-	-	389	.497	28	.009	569	.530	985	1.036
Odonata	200	.797	1729	4.283	952	1.585	1221	7.006	4102	13.671
Tricoptera	8	.010	8	.010	17	.013	25	.029	58	.063
Coleoptera	50	.349	175	.503	158	.824	83	.042	467	1.717
Diptera	529	.471	670	1.075	634	.662	1265	1.710	3098	3.857
Mollusca	355	1.83	1082	6.63	344	1.95	1406	3.50	3187	13.9



% COMPOSITION (biomass)
80
60
40
20
D O A I N
DS 30
D O A I N
NB 15
D O A I N
NB 1
D O A I N
NB UM
PONDS

Table 19. Biomass (g/m^2) and Density ($individuals/m^2$) for selected invertebrate groups at DS30.

	MAY		JUNE		JULY		AUGUST		TOTALS	
	ind/m^2	g/m^2	ind/m^2	g/m^2	ind/m^2	g/m^2	ind/m^2	g/m^2	ind/m^2	g/m^2
Annelida	-	-	10	.016	19	.023	-	-	29	.039
Hydracarnia	67	.045	133	.145	108	.094	92	.082	400	.366
Amphipoda	533	.240	650	.382	913	.242	1655	.798	3750	1.662
Hemiptera	42	.276	771	2.062	425	1.110	558	6.087	1783	9.534
Ephemeroptera	-	-	408	.745	25	.011	1936	1.972	2369	2.728
Odonata	192	.628	2059	6.390	752	2.155	1866	8.022	4869	17.194
Tricoptera	-	-	82	.108	91	.120	103	.144	275	.372
Coleoptera	75	.108	476	.641	192	.123	192	.321	934	1.193
Diptera*	1819	1.886	4540	3.704	4691	4.424	9907	6.249	20958	16.263
Chironomidae	1694	1.631	4020	2.959	3617	3.501	6617	3.867	15948	11.958
Mollusca	1662	65.1	5125	146.5	3467	139.4	6425	108.4	16679	459.4

*includes Chironomidae

Table 20. Biomass (g/m^2) and Density (individuals/m^2) for selected invertebrate groups at NBUN.

	MAY		JUNE		JULY		AUGUST		TOTALS	
	ind/m^2	g/m^2	ind/m^2	g/m^2	ind/m^2	g/m^2	ind/m^2	g/m^2	ind/m^2	g/m^2
Annelida	25	.227	32	.044	55	.072	121	.272	233	.614
Hydracarnia	25	.013	71	.072	28	.018	17	.008	140	.112
Amphipoda	607	.465	1540	.921	2616	.852	2862	1.644	7625	3.882
Hemiptera	42	.050	517	1.332	325	1.246	550	4.140	1433	6.768
Ephemeroptera	-	-	231	.547	17	.099	1742	1.483	1990	2.129
Odonata	633	1.603	1033	3.837	600	1.684	1532	3.655	3798	10.779
Tricoptera	42	.143	139	.178	336	.389	409	.747	926	1.456
Coleoptera	58	.215	358	.513	430	.230	235	.392	1082	1.349
Diptera*	680	.615	3326	1.378	1213	.676	3327	2.134	8546	4.803
Chironomidae	166	.089	2124	.170	574	.148	188o	.395	4752	.802
Tabanidae	231	.213	218	.312	173	.220	250	.485	873	1.230
Chaoborinae	258	.313	625	.635	358	.161	1138	.901	2380	2.010
Misc. Diptera	-	-	358	.261	108	.148	50	.352	516	.761
Mollusca	1033	38.1	7719	114.6	4102	90.7	4717	107.7	17571	351.1

*includes: Chironomidae, Tabanidae, Chaoborinae, Ceratopogonidae and misc. Diptera biomass.

The Annelids in strip-mine ponds do not approach the density or biomass of the Annelids in NBUN (Tables 14-17). In contrast, the Hydracarina contribute more to the total biomass and density in strip-mine ponds than they do in NBUN (Tables 17-19).

Species Diversity

Diversity shows a distinct tendency to increase with increasing age of the pond (Fig. 25). Although diversity illustrates a distinct pattern, equitability values are all similar (Fig. 25). This suggests that evenness does not account for most of the differences observed in diversity. The increase in diversity throughout the strip-mine pond series is attributed primarily to species richness (Table 21 and Appendix 2, Tables 27 and 28).

However, the value of using H' rather than species richness alone is illustrated by the July collections at DS30 and NB15. The number of species is similar in both ponds (Table 21), however, H' indicates much higher species diversity at DS30.

Fig. 25. Species diversity in three strip-mine ponds and NBUN using the Shannon-Wiener index.

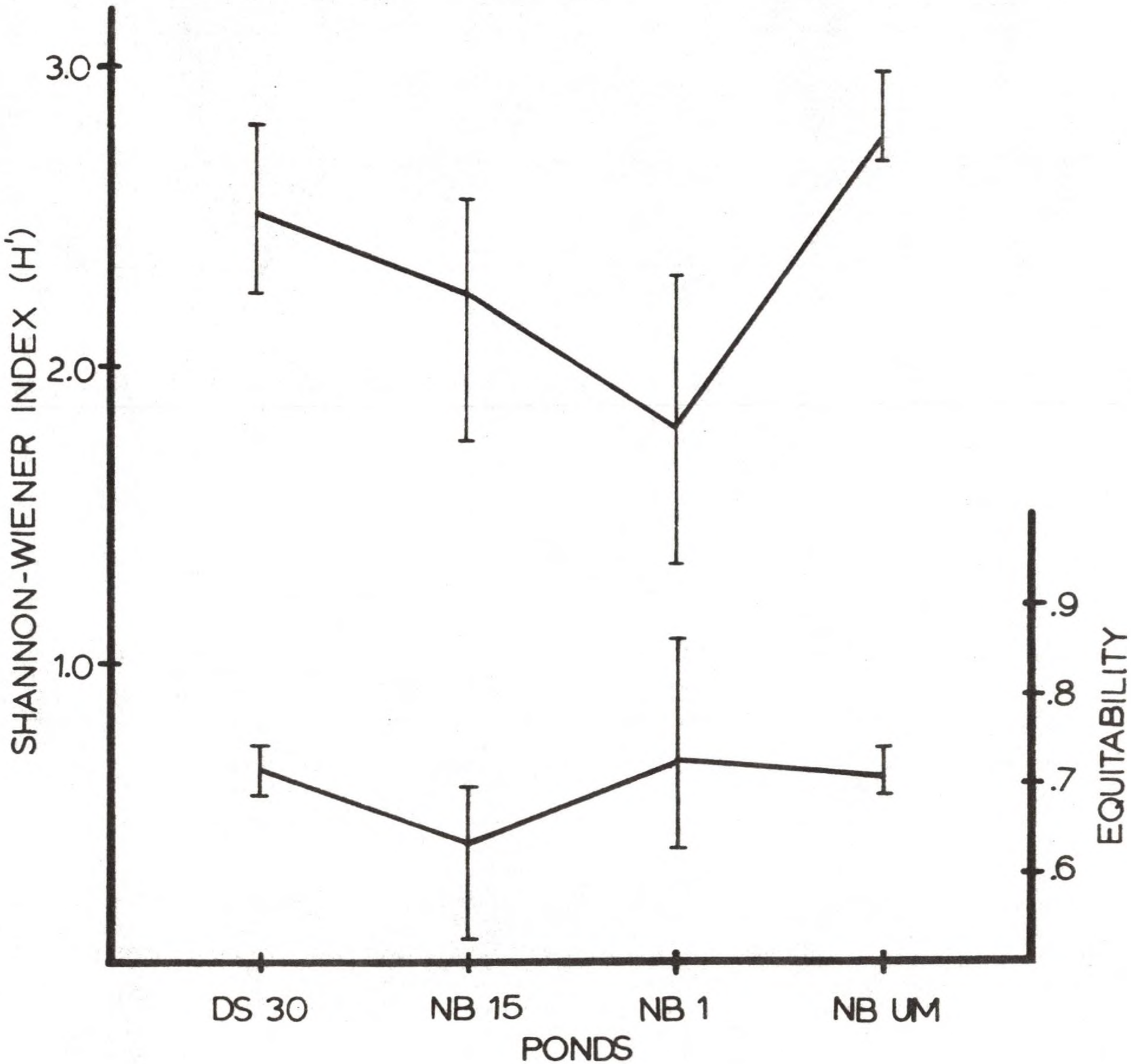

SHANNON-WIENER INDEX (H')
3.0
2.0
1.0
EQUITABILITY
.9
.8
.7
.6
DS 30
NB 15
NB 1
NB UM
PONDS

Table 21. Comparison of the Shannon-Wiener Diversity Index and species richness in three strip-mine ponds and NBUN.

POND	MAY H'	MAY s	JUNE H'	JUNE s	JULY H'	JULY s	AUGUST H'	AUGUST s	MEAN ± S.E.* H'	TOTAL s
DS30	2.26	27	2.68	52	2.32	29	2.87	43	2.53 ± .146	59
NB15	2.05	30	2.57	40	1.81	31	2.51	36	2.24 ± .183	54
NB1	1.33	6	2.38	16	1.78	13	1.74	20	1.81 ± .216	27
NBUN	2.70	40	2.75	61	2.71	48	2.94	55	2.78 ± .056	78

*S.E. = standard error of the mean ($s_{\bar{y}}$)

DISCUSSION

CHEMICAL CHARACTERISTICS

Driver and Peden (1977) have shown that an interdependent set of factors affect the water chemistry of Canadian prairie wetlands. Some of these factors also influence the chemistry of strip-mine ponds. They are: 1) the amount of soluble salts in the spoil material available for leaching, 2) permeability of the spoil material, 3) topography surrounding the ponds and 4) components of water loss, in particular evaporation and freezing out. In addition, ion-interaction (Kollman, 1974), bacterial decomposition and other abiotic processes have varying affects on strip-mine pond chemistry.

Seasonal variation in water chemistry is controlled largely by the semi-arid climate of western North Dakota, where evaporation exceeds summer precipitation. Strip-mine ponds, which have no outlets, act like large evaporating dishes as the water levels gradually decline. Evaporation, therefore, is probably the single most important factor affecting pond chemistry.

In the following sections, trends of certain elements in strip-mine ponds will be discussed with respect to these factors.

pH, carbonate buffer system

Highest pH values occurred in summer and autumn during peak photosynthetic activity, and the lowest values occurred in winter under ice when some carbonate is reconverted to bicarbonate by CO_2 arising from decomposition (Figure 16, Appendix 1). Changes in pH reflect variations in pond conditions, particularly photosynthesis in saline waters (Cole, 1975 and Farmer, 1973). During photosynthesis, plants can successively absorb CO_2, eliminate bicarbonates, precipitate CO_2 and form hydroxyl ions. All these events lead to a rise in pH. In contrast, when respiration and decomposition occur, pH decreases as CO_2 is liberated.

Seasonal variations in pH are also influenced by concentration of mineral ions. As with saline lakes in Washington (Anderson, 1958) and North Dakota (Farmer, 1973), the narrow pH range in DS30 reflects large amounts of ions that produce a high buffer effect. The increasingly wider range of pH with successively younger strip-mine ponds corresponds to a decrease in the amount of ions, and hence a decrease in the buffer effect (Tables 2 and 5, Appendix 1, Table 22).

The mean pH values decreased with increasing age of the pond (Tables 2 and 4). This trend is contrary to what one might expect. The older strip-mine ponds have more vegetation; and with more plants, photosynthesis would be greater and therefore a higher pH would be the result. This trend is not observed because there is an accumulation of acid forming substances with passage of time. This is substantiated by the trend in sulfates, which has the tendency to increase with the age of the pond (Table 5).

Sulfates in the form of calcium sulfate (gypsum) are a major source of H^+ to strip-mine ponds. Calcium sulfate is readily leached from spoil and is found encrusting the pyrite in Fort Union coal (Kulland, 1975). Any exchange between Ca^{++} and hydrogen ions forms sulfuric acid.

More pyrite is found within the drainage of DS30 than any other strip-mine pond. Oxidization of this mineral leads to the formation of sulfuric acid in the following manner:

$$4\ Fe\ O_2 + 15\ O_2 + H_2O \longrightarrow 2\ Fe_2\ (SO_4)_3 + 2\ H_2SO_4$$

DS30 has several oxidized coal outcroppings and consequently the water is stained with humic acids. Berg (1962) studied the brown-stained humic waters of the Congo and noted that the pH of these waters were controlled largely by organic acids. Though humic acids were not specifically analyzed, they are a potential source of H^+ to DS30.

Electrical conductivity

One of the major problems confronting aquatic impacts in western mining areas is the leaching of soluble salts (Dettman and Olsen, 1976). Electrical conductivity gives a quick and easy measure of the total concentration of salts in the water leached from the surrounding spoils.

In strip-mine ponds the conductivity shows an increase from spring to fall with maximum concentration in winter (Fig. 13). Seasonal changes in the conductivity of strip-mine ponds are pronounced for several reasons. First, the ponds are frozen over from 4-6 months each year. Second, during the summer period, rapid evaporation takes place. And third, in the spring the ponds receive a considerable amount of runoff, which is most of the inflow in some cases.

To illustrate the affect of the semi-arid climate on strip-mine ponds, changes in water level, conductivity and precipitation for the summer months appear in Fig. 21. As water levels decline due to decreasing precipitation, there is an increase in electrical conductivity. This relationship is especially true for the latter part of the summer. The decline in water levels and concentration of salts is attributed primarily to evaporation, and secondarily to seepage from the basin. These results are similar to those obtained by Driver and Peden (1977) in their study of Canadian prairie lakes.

The relative composition of the major ions (Fig. 20) shows that among the negative ions sulfate and bicarbonate predominant. The anionic composition of strip-mine ponds are of the sulfate type ($SO_4 > HCO_3 > Cl$) and the bicarbonate type ($HCO_3 > SO_4 > Cl$). The occurrence of high sulfates in strip-mine ponds can be explained by the leaching of soluble gypsum and other sulfate salts from the spoil surrounding the ponds. Glenharold 5 is the only pond with a bicarbonate-dominant pattern. Rawson and Moore (1944) have noted that the difference between sulfate lakes and bicarbonate lakes on the Canadian prairie is a result of differing soil, vegetation and climatic conditions. Riley (1960) has shown that spoil characteristics differ not only within the same geologic formation, but also between local areas. The difference between G5 and the other ponds is probably a result of the different spoil characteristics between mining sites. Therefore, lower levels of sulfate and higher levels of carbonates might occur at Glenharold relative to North Beulah.

The cation structure in all strip-mine ponds except DS30 are sodium-calcium dominant. In most temperate waters, calcium tends to predominate together with bicarbonates (Milbrink, 1977 and Hutchinson, 1957). Driver and Peden (1977) and Rozkowska & Rozkowski (1969) have shown that calcium also predominates in naturally alkaline waters in the semi-arid regions of southern Saskatchewan and Manitoba. However, in strip-mine ponds, sodium is by far the dominant cation (Table 5, Fig. 20).

Kulland (1975) has shown that Ca and Mg decrease, while Na increases through the profile of undisturbed soil at mining sites in Mercer and Oliver counties. As the overburden is overturned and exposed, then spoil higher in Na (in relation to Ca and Mg) is available for leaching. Sodium is very reactive and soluble, and when leached from soil, its compounds tend to remain in solution. Together, the increased availability and the high solubility of sodium make it the dominant cation in strip-mine ponds.

Above conductivities of 2300 µmho/cm, magnesium becomes more common than calcium and therefore DS30 is the only pond which is sodium-magnesium dominant. Because most magnesium compounds surpass similar calcium compounds in their ability to remain in solution, they precipitate at different rates. Calcium is usually more abundant than magnesium in fresh waters because there is a preponderance of calcium over magnesium in sedimentary rock (Cole, 1975). However, at the conductivities given above for DS30, the waters are saline and the solubility product of $CaCO_3$ is changed and calcite is precipitated. At this point magnesium assumes more importance.

Information on trends and differences between strip-mine ponds of the seven major ions is discussed further in the next two sections.

<u>Sodium, Potassium, Calcium and Magnesium</u>

The temporal trends of Na, K, Ca and Mg tend to increase through the summer and fall with the maximum reached in the winter months (Fig. 14). All of these ions probably show this trend because of evaporation in summer, freezing out under ice cover and dilution by spring runoff. Many authors have reported similar results (Rawson and Moore, 1944; Rozkowska & Rozkowski, 1969; Driver and Peden, 1977; Kollman, 1974; and Anderson, 1958). This trend has become expected in shallow, saline waters which have little or no major outflow. Rockett (1976) has shown that strip-mine ponds in Wyoming have similar levels of Na, K, Ca and Mg and presumably they have similar trends.

Levels of Ca and Mg are significantly higher at DS30 than the other strip-mine ponds (Tables 2, 5). Slightly higher levels of both Ca and Mg (replaceable) are present in the spoil surrounding DS30 (Table 10). This suggests that more of these two cations are available for leaching from the watershed.

Sulfate and Chloride

Sulfate in water is relatively low except in closed basins, where concentration is increased by evaporation. Another exception is the sulfate added to aquatic systems in mining areas (Heaton, 1951 and Crawford, 1942). The principal sources of sulfate, as has already been discussed, result from the leaching of gypsum and the oxidation of pyrite (FeS) leached from the lignite.

The temporal trend of sulfates and chlorides show the same trend as the four major cations (Tables 2, 5). These anions also show this trend because of evaporation and, therefore, increasing concentration.

Continuous leaching of gypsum and pyrite over the years has resulted in an increasing sulfate concentration in strip-mine ponds (Table 5). Herndon and Hodge (1936) long ago showed that in acid mine waters, any carbonate hardness in the lakes is converted into non-carbonate hardness, owing to the large amounts of sulfur leached from pyrite. This left minerals in the sulfate form causing acidic waters. Although sulfate minerals accumulate in strip-mine ponds of North Dakota, the naturally alkaline water maintains a carbonate-buffer system.

Chlorides are regularly present in waters, but are abundant only in very saline and brackish waters (Cole, 1975). Chloride levels are similar in all the strip-mine ponds studied except DS30 (Table 2).

DS30 is more saline than the other ponds and therefore would be expected to have higher levels. In addition, this pond may have contamination from animal wastes since cattle graze the surrounding banks. Frequently their waste were noted in the shallows of the pond. Since animal excretions contain, on the average, 5g Cl^-/liter (Cole, 1975), a source of soluble Cl^- is added to DS30 that may not be added to the other ponds.

Nitrogen

Nitrogen occurs in the elemental, organic and inorganic states. It is the inorganic compounds, ammonium salts, nitrate and nitrite which are important to biological growth. These forms of nitrogen are made available by decomposition, the agents being bacteria primarily and the ultimate end product being ammonia-nitrogen. Seasonal cycles of the three inorganic nitrogen forms are closely interrelated and are influenced by decomposition rates and peak utilization by aquatic organisms.

Summer maxima of ammonia-nitrogen occur when the rate of ammonification exceeds rate of assimilation by plankton. Farmer (1973) has shown that NH_3-N peaks were followed by plankton increases and a decrease in this form of nitrogen. Presumably a similar situation exists in strip-mine ponds, which show maxima about early May and late June (Appendix 1, Table 22).

Generally, high nitrate levels coincided with lowered ammonia-nitrogen concentrations. When ammonia values were high, it indicates that assimilation and/or decompsoition rates were predominate over bacterial oxidation. Oxidative processes surpass reductive processes to give nitrate peaks. These peaks vary from pond to pond, but tend to be in the spring and fall (Fig. 17, Appendix 1, Table 22).

Ammonia levels are higher at DS30 and G5 than the other two strip-mine ponds (Appendix 1, Table 22). Higher ammonia at DS30 is the direct result of more plant and animal matter available for decomposition. Ammonia levels at G5 exceed NB15 presumably because G5 has slightly higher temperatures. G5 has much greater turbidity and this causes an increase in temperature, and this results in a higher rate of ammonification.

Nitrates also do not seem to correlate with the age of the pond (Fig. 17, Appendix 1, Table 22), though levels are significantly higher at DS30 than any other pond. There are two probable reasons for this: 1. DS30 has more vegetation than any other pond. Therefore more organic matter is available for decomposition, 2. cattle feces add a source of nitrogen that is not added to any other pond.

Phosphates

Highest phosphate levels are observed under ice during the winter (Fig. 18, Appendix 1, Table 22). Hydrogen sulfide formed anaerobically under ice reacts with iron to form FeS and liberates phosphorous (Einsele, 1936; and Ohle, 1954). Increased phosphorous is also caused by reduced photosynthetic activity and lowered pH which enables precipitated phosphorous to be brought back into solution.

Phosphate in strip-mine ponds tends to decline through the summer (Appendix 1, Table 22). When ferrous ions and phosphate occur together under aerobic conditions, insoluble ferric phosphate is precipitated, thus tying up phosphate in the sediments (Einsele, 1936 and Ohle, 1954). The decline in phosphate also coincides with the onset of maccrophyte growth and plankton production (Driver & Peden, 1977).

Concentrations of total phosphorous in sulface waters of alkaline lakes are generally high, particularly soda lakes (Milbrink, 1977). Strip-mine ponds have phosphate levels similar to the alkaline lakes studied by Milbrink, both on the order of 300 μg/1. Most phosphate is bound in blue-green algae and suspended organic material.

Phosphates are essentially the same from one strip-mine pond to the next (Tables 2 and 3). Since the decay of plant and animal material is a source of phosphorous to the living components of aquatic ecosystems; then one might expect a difference in phosphorous content with age of the pond. DS30 with the greatest amount of vegetation and animal material should have higher phosphates than younger ponds. However, because of changing reclamation practices, the more recent ponds have phosphate levels similar to older ponds. The older ponds (DS30 and NB15) were formed in areas where active reclamation is the exception rather than the rule. In more recent areas, N-P-K fertilizers are applied to the recontoured surfaces to help promote growth of a cover species. Hence, it may be assumed that the higher-than-expected levels of phosphate in recent ponds are partially a result of fertilizers applied to and leached from the drainage area.

Trace elements

All the strip-mine ponds studied contain measurable amounts of Cu, Pb, Zn, Fe, Mn, Mo, Ni, Li, Sr, Al and Si. Rockett (1976) showed similar levels of trace elements in his study of Wyoming strip-mine ponds. The temporal trends of copper and lead remain relatively constant throughout the seasons (Appendix 1, Fig. 16), and do not seem to be correlated with biological activity or climatic and chemical changes. Køllman (1974) has shown that copper generally tends to increase in concentration through the season. The increase is attributed to either a factor of productivity (algal blooms) or may be tied to marl formation or adsorption to organics. These factors, which also occur in strip-mine ponds, do not seem to affect the trend of copper.

Aluminum, molybdenum, nickel, manganese, lithium and zinc have similar constant trends, but have slight to moderate increases in some ponds during periods of ice cover (Appendix 1, Table 22). Presumably the increase is due to freezing out or release of ions from the sediments due to decreasing pH.

Aluminum also seems to show a slight decrease through the summer season in the older strip-mine ponds. Kollman (1974) has shown that aluminum decreases due to precipitation of aluminum hydroxide or phosphate, plant uptake and complexing by dissolved organic matter after plant death. In the younger ponds there are few plants and therefore little dissolved organic matter. In contrast, DS30 and NB15 show decreases because they have good growths of plants which take up aluminum ions and complexing probably occurs on dissolved organic matter.

Nickel shows a decrease through the summer in some ponds. If pH is correlated with nickel in strip-mine ponds, it would be because of increasing pH. Dakota Star 30, which has the lowest pH retains constant nickel levels. However at NB1, where pH is highest, nickel decreases through the summer season.

The trend of manganese is a little different from the others in this group (Appendix 1, Table 22). A very rapid decrease occurs in the spring season and probably is a result of precipitation of manganic hydroxides in the presence of dissolved oxygen. This decrease is followed by constancy and then increase under ice due to freezing out and release of manganous ions from the sediments (Tables 7-9).

Strontium follows a trend similar to calcium (Appendix 1, Table 22). This is not unexpected since strontium chemically behaves like calcium in surface waters (Cole, 1975). The strontium levels are probably tied to marl formation as is calcium. When marl falls off plants as they begin to die, soluble strontium and calcium bicarbonate are formed. Therefore, the level of strontium and calcium are increased.

The seasonal trend of silicon is explained largely by the activity of diatoms (Fig. 19). Silicon is used by diatoms in the construction of frustules which are insoluble at high pH. During high pH, silicon levels are low and when the pH begins to decrease the concentration of silicon increases (Appendix 1, Table 22).

Heavy metal toxicity

Dettman and Olsen (1977) state that two major problems exist in the assessment of aquatic impacts in the western U.S. One, the leaching of soluble salts has already been discussed. The second is the potential toxicity from trace elements, particularly the heavy metals.

Studies on the acid lakes in the eastern coal province (Heaton, 1951; Crawford, 1942 and Smith & Frey, 1971) and the Missouri region (Campbell et. al., 1965a & b) have reported toxic levels of heavy metals. Skogerboe (1976) has noted that some heavy metals associated with western mining areas are in forms normally considered soluble. Therefore, the potential for high levels of heavy metals exist within the study area. However, Table 2 shows that concentrations of these heavy metals are generally low and are not acutely toxic to aquatic organisms.

Skogerboe (1976) states that seven variables are important in controlling the chemical equilibria which determine the solubilities of many heavy metals. These variables are: pH, total alkalinity, total hardness, total sulfate, chloride, nitrate and orthophosphate. The ranges of these variables are similar between Skogerboe's and the present study. Only a major flux of soluble metal ions would cause any observable shift in the chemical equilibrium, and once noted would give an indication of toxicity to aquatic communities.

Two types of chemical interactions may occur for a particular metal ion and any combination of the anionic species. Immobilization of the metal ion due to precipitation or to an ion exchange type process may occur, or the ion may be mobilized by complexation processes which enhance solubility of the metal ion (Stumm and Morgan, 1970).

Because levels of heavy metals are low in strip-mine ponds, precipitation processes are suspected. Probably precipitation by carbonate or hydroxide is the controlling equilibrium. Skogerboe (1976) showed that solubilities of most metals increase with pH due primarily to the formation of soluble hydroxy complexes. The solubilities also tend to increase in more acid solutions due to protonation of the carbonate. Metals in the strip-mine ponds studied showed no tendency to increase in solubility with changes in pH (Appendix 1, Table 22).

As a check on the hypothesis that precipitation accounts for the low levels of heavy metals, sediment samples were collected and analyzed. Tables 7-9 show that sediment samples from ponds contain higher concentrations for most heavy metals measured. This implies that those elements contained in the runoff are largely removed from solution and precipitated in the sediment fairly rapidly.

Comparisons to NBUN

The total amount of cations and anions and therefore salinity is far greater in the three strip-mine ponds when compared to NBUN (Table 5). In fact salinity is three to ten times higher in strip-mine ponds. Rawson and Moore (1944) have shown that salinities of Canadian prairie lakes range from 35 to 118,000 ppm. The strip-mine ponds fall within this range and would be considered moderately saline. NBUN, on the other hand, is in the range Rawson and Moore (1944) regard as having incipient salinity. They use a cut-off point of 200-300 ppm between fresh water and saline water.

Bicarbonate is the dominant anion at NBUN (Table 5), which is typical of alkaline waters in semi-arid regions (Driver and Peden, 1977 and Rawson and Moore, 1944). Unlike these waters, strip-mine ponds are dominated by sulfates (Table 5). Levels of sulfate are significantly higher ($t > 2.54$, $\alpha = .05$) in strip-mine ponds (Table 6) and are important in contributing to higher salinities.

Calcium is usually the dominant cation in naturally occuring alkaline waters in semi-arid regions (Milbrink, 1977), but sodium is slightly predominant at NBUN. This is even more evident with strip-mine ponds. NBUN has significantly lower levels of sodium (Table 6) and therefore is not so clearly sodium dominant.

Together sodium and sulfate account for the major differences between strip-mine ponds and NBUN. Reasons for higher levels of these ions have already been discussed. These ions result in the greater mineralization and salinity in strip-mine ponds as well as changing the anionic and cationic structure.

Milbrink (1977) states that phosphates are high in alkaline waters, usually on the order of .3 mg/l. Phosphate levels at NBUN average .4 mg/l. However levels at strip-mine ponds are lower, and in some cases significantly lower than NBUN (Table 6). Milbrink (1977) has also noted that nitrate-nitrogen is generally low in alkaline waters. Table 6 shows that NBUN has lower levels of nitrates when compared to strip-mine ponds.

One might conclude that nitrogen is probably more limiting than phosphorous at NBUN, but that phosphorous is more limiting than nitrogen in strip-mine ponds. There are a couple of reasons for this. First there may be a low nitrogen/phosphorous ratio in the sources of these elements. Sources from overburden material are different from natural soils. Also, phosphorous added because of fertilizers is a source of this element to strip-mine ponds. Second, phosphorous may regenerate more rapidly than does ammonia from decomposing organic matter in these ponds.

Certain trace elements are essentially no different between NBUN and strip-mine ponds (Table 6). Iron is significantly lower in strip-mine ponds. With the addition of iron in the form of SO_4, Cl and NO_3, the salts tend to dissociate. The resulting ferrous and ferric ions combine with hydroxide to form precipitates, with little iron remaining in solution. In waters like NBUN, which are not as strongly buffered, iron tends to remain in solution, hence the higher levels of this element in NBUN.

Lithium, an alakli metal related to Na & K, is significantly higher in all strip-mine ponds (Table 6). Nickel, lead, strontium and silicon show significance in certain strip-mine ponds and the trend of significance suggests that concentrations of these ions increase with the age of the pond. Therefore there is an accumulation of these elements, particularly in DS30. The higher levels in strip-mine ponds is probably due to geochemical origions or related to some biological activity.

COMMUNITY STRUCTURE

Species Composition, Species Density and Biomass

Distinct differences in species composition, species density and biomass exist in the three strip-mine ponds (Tables 11-14, Tables 17-19, Fig. 22 and 25). North Beulah 1 has fewer kinds of species, lower total density and lower biomass than the other two strip-mine ponds. North Beulah 15, in turn, has less organisms, lower density and lower biomass than Dakota Star 30. In the Mercer County ponds a progressive process of maturing is seen. Crawford (1942) and others (Campbell et. al., 1965a & b; Smith & Frey, 1971; Parsons, 1964; Gash, 1968; Heaton, 1951; Simpson, 1961 and Waller, 1967) have noted similar progressive changes in acidic strip-mine ponds.

North Beulah 1 is most unlike NBUN and the other strip-mine ponds. Chemically and physically it is the most severe environment for aquatic invertebrates. The ranges of several measured chemical variables are more extreme than any other pond studied (Table 2, Appendix 1, Table 22). In addition, NB1 is more exposed to climatic factors. The most frequently occurring species are the Dipterans *Bezzia* (*Probezzia*) sp., *Tanytarsus* sp., *Palpomyia* sp. and *Chaoborus* spp., and the Hemipterans *Notonecta* and Corixidae. They occur in such large numbers, in particular the Ceratopogonidae (2503 individuals/m^2), as to leave little doubt of their tolerance to this harsh environment. Roback (1974) states that the Ceratopogonidae are very common and very dense in places where chemical extremes exist.

The percent composition of the major invertebrate groups (Fig 23 & 24) gives an indication of the community structure found at NB1. The Diptera account for almost 80% of all organisms present in this pond. Roback (1974) states that the Diptera, represented chiefly by the Chironomidae, have members tolerant of many chemical extremes. They, along with the Ceratopogonidae, are extremely tolerant pioneer groups. Ordinarily they require only a small amount of food and have short life histories. At NB1 there are five genera of chironomids, *Tanypus* sp., *Tanytarsus* sp., *Chironomus* spp., *Pentanura* sp., and *Anaptopynia* sp., which represents half the number of Dipterans found.

The Insecta group (Figures 23 & 24), Hemiptera and Coleoptera primarily, comprises 14% of all organisms at NB1. They generally have powers of locomotion which enable them to move from one environment to another with more ease than most invertebrates (Pennack, 1958). For this reason, Roback (1974) does not consider the Haliplidae, Dytiscidae, Gyrinidae and Hydrophilidae to be of great significance in water quality studies. However, the fact that larval stages of some beetles (*Berosus* sp., and *Haliplus* spp.) have been found in bottom sediments of NB1 suggests that these genera are also tolerating the environmental extremes. The Hemipterans, in particular *Notonecta* sp., in addition to their mobility are usually common and abundant everywhere in a pond. The Hemipterans make up almost the entire total summer biomass at NB1 with 5.02 grams/m^2 (Table 17).

The successional trend in strip-mine ponds continues with NB15 which contains a larger and somewhat different assembledge of aquatic invertebrates. Amphipoda, Odonata, Ephemeroptera, and Mollusca are a familiar part of the structure of the faunal community. The primary reasons for the change in species composition are due to the presence of vegetation as a source for support and shelter and moderation of chemical extremes.

Chrysops sp. is the only Dipteran among the six most frequently occurring species. Other genera include; *Hyallela, Lestes,* Hydracarnia, *Physa,* and *Enallegma.* Amphipoda numbers attain a maximum of 9910 individuals/m^2. *Hyallela azteca* comprises almost 40% of all organisms found at NB15. Pennack (1958) states that amphipods are not generally well adapted to adverse environmental conditions. The dominance of *Hyallela azteca* at NB15 suggests that environmental conditions have moderated in comparison to NB1.

The increase in the number of species at NB15 has caused an increase in the number of food chains, and therefore a more complex community structure than is evident at NB1. Ephemeroptera, for example, fulfill all the basic requirements of an herbivore and perhaps are the prime grazers in the aquatic food web (Day, 1968). Ephemeroptera nymphs occupy an important place in the economy of NB15, since they are a major food source of birds and Odonata. At NB1, where Ephemeroptera are lacking, this food chain does not exist.

Some authors (Day, 1968; Needham, et. al., 1935) have stated that Ephemeroptera are sensitive to pollution and chemical extremes. However, many species can tolerate high alkalinity. *Caenis* sp., *Centroptilum* spp., and *Callebaetis* spp., common to NB15, are listed by Roback (1974) as tolerant to high levels of alkalinity, as much as 220 ppm. Alkalinity at NB15 ranges from 204 to 228 ppm. Alkalinity is even higher at DS30 where these same species are collected.

In the first summer of the study, Odonata were absent from NB1. However, during the second summer, *Enallegma* sp. was present among a small patch of *Potamogeton* sp. Since *Enallegma* sp. appeared at NB1 only when *Potamogeton* sp. is present, this suggests that vegetation, and not harsh chemical conditions limit certain Odonata populations. *Enallegma* sp. is sucessful in consistently maintaining good population sizes under chemical extremes (Roback, 1974). At NB15 where vegetation is more prominant, Odonata attain both high density and high biomass (4102 individuals/m^2 and 13.67 grams/m^2).

One of the most frequently occurring species at NB15 is *Physa* spp. Since physical and chemical conditions have a profound affect upon mollusca, they give an indication of the quality of the water. The most important features of a favorable habitat according to Mozley (1954) are (1) cleanliness of water, (2) absence of disturbance and (3) presence of $CaCO_3$. Calcium carbonate is necessary for shell formation and precipitation and agglutination of clay particles to produce clear waters. Clear waters allow light to enter so that vegetation can grow and give the support necessary for Mollusca.

Snails do not thrive at NB1 because some of the above criteria are not met. Chemically there is enough $CaCO_3$ to allow for shell growth. But the water is turbid and not at all protected from the wind. Because there is a good deal of clay still in suspension, a clear water is not available to let light in the pond. Therefore, a good supply of vegetation does not exist. However, in the second summer of the study some *Potamogeton* sp. and *Typha* sp. became established and the water was a little less turbid. With conditions improving, one specimen of *Gyraulus* sp. and one of *Physa* sp. was collected from NB1.

At NB15 the clay has precipitated to produce a clear, clean water; there is sufficient $CaCO_3$; and there is ample vegetation. However, there are aspects which cause molluscan distribution to be limited. The most fundamental condition governing snail populations is the form of the basin (Mozley, 1954). At NB15, the basin slope excedes 62%, making predation easier on snails and their eggs. Although molluscan distribution is limited it still accounts for the highest biomass (13.9 grams/m^2) (Table 18).

Pieczynski (1964) has evaluated the role of water mites and has shown that they assume a significant place in the lake ecosystem. The following observations at NB15 support some of Piecyznski's conclusions: (1) Water mites tend to occur abundantly in the relatively shallow parts of the pond. At their peak in June, Hydracarina reach 1168 individuals/m^2 (Table 18). (2) Water mites display a considerable amount of ecological activity. This ecological activity was not measured, but it was observed. The high trapibility of water mites together with the high abundance, caused a high degree of prevalence of water mites in the environment (Pieczynski, 1964). (3) Along with high abundance and activity, the predacious nature of water mites helps decrease invertebrate fauna. Laird (1947) has shown in his experiments on mosquitoes that water mites have a significant role in reducing *Anopheles* and *Culex*. Water mites may be responsible for *Culex* having lower abundance at NB15 than at any other pond studied. (4) Crisp (1959) reported on a decreasing fecundity of Corixidae caused by parasitism of Hydracarnia. Parasitism of water mites on corixids was observed, but not quantified. The Corixidae at NB15 account for 3.35% of all organisms, while at NB1 they make up 4.01% of the total number of organisms collected. This may be indicative of the reduction of numbers of the invertebrate fauna at NB15 by water mites. (5) Finally, Hydracarnia have few natural enemies and have high resistance to extreme environmental factors. Cloudsley-Thompson (1947) showed in laboratory experiments that neither invertebrate predators or fish fed on water mites. This, he pointed out, was due to vivid coloration and large, subcutaneous glands which secrete a repelling substance. In contradiction to this, Pennack (1958) has pointed out that Hydracarnia are preyed upon by a wide variety of aquatic invertebrates, especially Cnidarians and carnivorous insects. Cnidarians are not present at NB15, but carnivorous insects, especially Anisoptera, are abundant. Since water mite populations flourish in spite of the presence of an abundant predator, perhaps the vivid coloration and subcutaneous glands do repel Anisoptera. Anisoptera were only abundant where few water mites were present, and vice versa.

Continuing along the successional series, community structure and species composition are more varied at DS30 than at any other strip-mine pond studied. Total number of species is not very different from NB15, and many of the same species occur in both (Tables 13 and 14). However, DS30 resembles NBUN more so than NB15. The Tricoptera of DS30 include several species absent from the other strip-mine ponds, but which are found at NBUN. Most of these species belong to the family Limnephilidae. Cases of Limnephilidae are triangular, circular or flat in cross section; compact or loosely constructed; and composed of bits of a great variety of vegetable, or mineral matter (Pennack, 1958). At NBUN and DS30, Limnephilid cases are usually round in cross section, loosely constructed and composed of twigs, grass, mollusc shells, sand, gravel and leonardite. The absence of Limnephilidae at NB15 may be explained by the lack of most case materials.

Another indication of the increased community structure at DS30 is the absence of several species in the other two strip-mine ponds (Tables 11-14). *Odontomyia* is chiefly associated with flowers, and DS30 is the only strip-mine pond with a sufficient number of wild-flowers to support a population of *Odontomyia*. With so few flowers in the area surrounding the two other strip-mine ponds, soldier flies are not expected to have larval stages present in the ponds. *Hydra* require large pieces of debris or they do not occur on fine, muddy bottoms (Pennack, 1958). NB1 has a soft, clayey bottom devoid of debris. NB15 has a muddy bottom with some debris, but nothing like that which exists at DS30. Finally, *Plumatella* is characteristically found in unpolluted ponds on the underside of logs and stones or on twigs where the light is dim. The chemical environment and exposure to light prohibits *Plumetalla* at NB1. No logs, stones, or twigs are present at NB15, though presumably vegetation would support *Plumatella* if enough shade were available. Only at DS30 and NBUN where twigs or branches and enough shade exists is *Plumatella* present. Because of the increasing stabilization of the pond bottom and the area surrounding the pond, the community structure of DS30 becomes more like NBUN.

Comparing Dakota Star 30 with NBUN (Tables 15 and 16), a high degree of similarity is found between the biotas of the two. Other studies (Comita and Whitman, 1976; Cvancara and Van Alstine , 1977; and Woodward-Clyde, 1978) conducted within or near the present study area show that ponds in unmined areas and the strip-mine ponds studied have similar biota. This may be taken as evidence that the strip-mine ponds are in the process of returning to the biological norm found typically in natural ponds in Mercer County.

Although DS30 is most like NBUN, the benthic community differs significantly. *Chironomus tentans* and *C. plumosus* dominate the bottom fauna at DS30. Except for other chironomids, Mollusca and occasional oligocheates, all other organisms common to NBUN benthos are lacking.

Reasons for this are not understood, although fluctuating water levels may help explain the dominance of chironomids. Ponds within the study area continually go through severe changes in water level with spring thaw and summer drought. Rawson (1962) and Grimas (1962, 1964) have shown that fluctuating water levels favor chironomids by causing a change in the balance of the fauna.

Annelids are poorly represented in strip-mine ponds. No oligocheates are present until DS30. Since aquatic oligocheates occupy a niche equivalent to their terrestial counterparts, feeding on bottom mud and mixing surface layers, one would expect to find oligocheates at NB15, as well as DS30.

Sawyer (1972) has studied several factors which affect the ecological distribution of leeches. Of these, chemical and physical factors have little or no direct influence on abundance of leeches, except low levels of hardness, alkalinity and pH and high levels of salinity. Since DS30 has high levels of hardness and alkalinity and pH is on the alkaline side of neutral, perhaps the high salinity limits leeches at this pond. All other factors listed by Sawyer (1972) are found at DS30 and only the high salinity is suspect.

Species Diversity

Hutchinson (1959) was important in focusing attention on the subject and problems of species diversity. Since his paper, certain aspects of diversity have become better understood. Diversity and its converse, dominance, are not simply products of environmental conditions or species interactions alone, but contain aspects of both factors. Pielou (1975) and Pianka (1966) have summarized several mechanisms which have been proposed to explain the variations found in species diversity. Of these, three are of particular interest to the discussion of the diversity observed in strip-mine ponds: (1) environmental stability, (2) spatial hetergeneity, and (3) productivity.

The environmental stability hypothesis assumes that relative constancy and predictability of favorable conditions for a given group of organisms increases species diversity by guaranteeing the availability of critical resources, and ensuring favorable growth and reproduction. The high environmental stability leads to high community stability which, in turn, permits high diversity (Pielou, 1975).

A distinct increase in species diversity occurs through the pond series (Fig. 25 and Table 21). Correlated with this increase in diversity is an increase in environmental stability. Because NB1 is the most severe environment, experiencing the widest fluctuations in chemical and physical factors, instability and unpredictability act in two ways to decrease species diversity: (1) To survive in an unstable environment, a species needs to be flexible and highly tolerant. This has been shown for *Bezzia (Probezzia)* and the Chironomidae at NB1. As a result, a given type of habitat can contain fewer niches and hence fewer species the more strongly unstable or more widely fluctuating the conditions (Pielou, 1975). Since NB1 is the most unstable pond environmentally, it has the lowest species diversity. (2) Only those species that can quickly and surely become established in a newly created environment can persist; thus species-populations that can not establish themselves in a new environment will be automatically excluded from such environments. The Diptera, as a whole, are quick to establish themselves at NB1. Invertebrates like Ephemeroptera, Odonata and Mollusca are exluded from NB1 because they can not persist in such an unstable environment. Since few species are able to establish themselves quickly in such an environment as NB1, then species diversity is low.

Environmental stability with respect to species diversity has its greatest affect on NB1. This does not mean that it does not help determine diversity at NB15 or DS30, but other mechanisms of diversity are probably more important. With a substantial increase in the amount and kinds of aquatic macrophytes there is a larger amount of spatial variation in the ponds which provides a greater number and variety of available habitats for specialized species.

It has been inferred throughout this discussion that substrates, particularly vegetation, are important in determining the number of species in the various ponds. Long ago it was shown that vegetation was important in support of animal life in pond. The presence and distribution of macrophytes is of prime importance to the diversity of chydorid communities (Whitside and Harmsworth, 1967). Abele (1974), studying decopod crustaceans, found strong positive correlation between species number and the number of different substrate types available. A similar situation exists in strip-mine ponds and can be seen vividly in the succession of ponds.

Abele (1974) further noted that the substrates in the crustacean environment are used as shelter, feeding sites and as a source of nutrition. *Typha, Potamogeton* and other higher aquatic plants at NB15 and DS30 provide places of shelter for many invertebrates. As well as shelter, these aquatic plants provide feeding sites because of abundant epiphytic growth, particularly on *Typha*. In some instances vegetation (*Typha*) is an important food source, especially for the herbivores like Ephemeroptera, some Coleoptera, Tricoptera and Mollusca. A site for reproduction is another important utilization of aquatic macrophytes that should be considered in strip-mine ponds. For example, the eggs of *Haliplus* were found attached to aquatic vegetation.

Increasing the number of substrates in a pond would increase the number of species present. Theoretically a species can use one substrate for shelter, one for a reproductive site, another for a feeding site and yet another for a source of nutrition, thus reducing the competitive interaction for each one and thereby increasing the diversity (Abele, 1974).

The increase in number of substrates correlates with the increase in diversity. Therefore segregation is at a maximum at DS30 because of the greater number of vegetative substrates. The number of vegetative substrates is probably the most important factor in the diversity in strip-mine ponds.

Connell and Orias (1964) have argued that high diversity is strongly influenced by high productivity. The productivity hypothesis supposes that diversity is directly proportional to the rate of energy flow. This determines the abundance of species-populations and hence the sizes of their gene pools. All the energy assimilated by living organisms is allocated to two purposes; either it is used for reproduction and growth as expressed in density or biomass or both, or it is used and dissipated in maintenance of homeostatic regulatory processes (Connell and Orias, 1964).

Because of a widely fluctuating environment, it is expected that at NB1 a larger fraction of assimilated energy must be allocated to maintenance of homeostasis and hence a smaller fraction is available for population growth and reproduction. As the environment at NB15 and DS30 becomes less harsh, organisms can put more energy into growth and reproduction. This observation is confirmed by the increase in both density and biomass through the pond series (Fig. 22). Therefore a higher diversity at DS30 correlates with its higher biomass and density.

Equitibility

The diversity of a community depends on two things: the number of species and the relative abundance of each individual species. To adequately describe a community's diversity both factors of the diversity index should be considered. A community with a few, evenly represented species can have the same diversity index as one with many unevenly represented species. It is desirable to keep these two aspects of diversity separate.

It is predicted that in a rigorous environment diversity can be determined by relative abundance, and in a non-rigorous environment species richness alone is enough to determine diversity (Tramer, 1969). For phytoplankton communities Sager and Hasler (1969) found that relative abundance (J') accounted for most of the difference in community diversities. Tramer (1969) showed that breeding bird diversities can be adequately described by merely counting the number of species, and disregarding the relative abundance. Tramer (1969) suggested that these strategies are responses to the two basic types of environments, with phytoplankton at one extreme and breeding birds at the other extreme.

Community diversities at strip-mine ponds fall somewhere in between the extremes. The observation that most of the difference in diversity in strip-mine ponds is accounted for by species richness can be misleading. For many cases this may be true, but there are exceptions.

At NB1, the May and June diversities are higher than in July and August (Appendix 2, Table 23). This is because the Ceratopogonidae do not become dominant until mid to late summer. They cause the J' to increase and consequently the H' to decrease. Prior to their abundance the few species that were present had similar abundances and this caused higher H'. The variability of J' is greatest at NB1 and least at DS30. Goulden (1964) has noted that low and variable J' would appear to be a general characteristic either of early succession or of an ecosystem containing opportunistic species. NB1 is certainly in early succession and the Ceratopogonidae are opportunistic and probably gain advantages not shared by other species.

At NB15 the J' is not as variable as it is at NB1, but is also accounts for a significant part of the diversity. Species richness is similar at NB15 and DS30 in July, however H' indicates a much higher species diversity at DS30 (Appendix 2, Tables 27 and 28 and Table 21). *Hyallela azteca* accounts for over half the individuals collected at NB15. Inclusion of numbers of individuals of each species in the index, information which is not considered in species richness alone, provides a more complete description of community structure. And in this particular case, J' accounts for much of the diversity.

SUMMARY AND CONCLUSIONS

As a rule in the past, ponds in spoil banks of mined areas arose incidentally as a result of haphazard piling of overburden. Groundwater and runoff from rainfall would tend to fill any depression, without natural drainage. In several areas these ponds have been of secondary value, such as for recreation, wildlife and domestic animals.

Modern strip-mining practice includes leveling and recontouring the land, and encourages the growth of planted and volunteer vegetation. Since the land can be structured so that water does not accumulate in depressions, the question is, why make ponds in strip-mined areas? There is a tendency to think that chemicals leached from newly surfaced spoil might contain materials harmful to life. If drainage water were collected in basins and held there, then any such harmful material would stay in the mined area. Efforts are already underway to discourage pond formation and to eliminate existing ponds in certain mining areas of North Dakota because of this reasoning.

Certainly in some areas with high pyrite content it has been shown that sulfuric acid makes the waters so acidic that plant and animal life is inhibited. But, in the waters of mined areas of western North Dakota such harmful material is minimal. Geologically, this area is one of naturally occurring alkaline waters. The waters of all studied ponds are alkaline, but not so alkaline as to inhibit life, nor very different from naturally occurring bodies of water nearby.

This study also shows that newly formed ponds in strip-mine areas rapidly become similar to the chemical and biological norm in adjacent areas. Within the first year after formation, new ponds already contain some form of life - mostly aquatic insects. The chemical environment at NB1 is harsh, but by the second summer, cattails and pondweeds start to grow and begin to moderate the chemistry of the water. This causes an increase in the quantity and variety of animal life. As the amount of rooted and submerged vegetation increases, the chemical environment improves and the animal productivity, as shown by biomass, density and species diversity, increases, until, by the 30th year (DS30), the fauna of mined ponds are practically indistinguishable from those in naturally occurring prairie patholes.

The value of any body of water in a semi-arid area like North Dakota for recreational, wildlife and domestic purposes, is obvious. Since strip-mine waters have "good" water quality and support adequate animal populations, their recreational and wildlife values are likewise obvious. In fact, the North Dakota Game and Fish Department has long claimed that spoil banks provide game animals, birds and other wildlife with some of the best habitat in the area.

In conclusion it might be pointed out that:

Chemically:

1) Ponds in strip-mine areas (pH 7.6-8.5) and NBUN (pH 8.2) are alkaline.
2) Strip-mine ponds show high salinities, with sodium and sulfate as the dominant ions. Though salinities are higher than NBUN, they do not exceed the range of naturally occurring ponds of similar geologic setting in North Dakota, Wyoming and Saskatchawan, Canada.

3) Several other variables analyzed in strip-mine ponds have concentrations higher than NBUN (Sr, Ni, K, Mn, Ca, Li, Mg, NO_3, Cl). Although concentrations are higher, they are not above levels that would be expected in prairie potholes.

4) Other variables analyzed (Fe, Al, Pb, Si, Cu, Zn, Mo, NH_4, PO_4) are essentially no different from NBUN.

5) Trace ions and heavy metal toxicity is not a problem in strip-mine ponds. Levels are normal or low because they are quickly precipitated into bottom sediments. Therefore, there are no materials that are really harmful to life.

6) In general, surface mined waters will tend to resemble naturally occurring ponds located within the same geography after vegetation has become established in these waters. Moderation in water chemistry of strip-mine ponds is noticable within the first couple years of vegetative growth.

Biologically:

1) When an impoundment is formed, it is immediately used by wildlife and soon becomes inhabitated with aquatic organisms.

2) Six Phyla are represented in collections from strip-mine ponds. Nematomorpha, Cnidaria, Bryozoa and Annelida are not common in these ponds. The bulk of the organisms are Mollusca or Arthropoda, with the Insecta representing 80% of all species identified.

3) Vegetation is the key to limiting overall productivity in community structure. Not only does vegetation moderate water chemistry, it also provides food, shelter, sites for reproduction and support for aquatic insects.

4) As amount of vegetation increases from NB1 through DS30, so does the density, biomass and species diversity. Density increases from 1,337 ind./m^2 at NB1 to 13,453 ind./m^2 at DS30. Biomass increases from 15.9 lbs/acre to 1,133.1 lbs/acre. Species diversity, as measured by the Shannon-wiener index, increases from 1.81 at NB1 to 2.53 at DS30.

5) Increasing values of a similarity index were obtained when comparing three strip-mine ponds to NBUN. These values show that as a strip-mine pond increases in age, the more it resembles NBUN.

6) In general, ponds in strip-mine areas support a variety of aquatic life and exhibit a growth potential not unlike typical prairie potholes.

Table 22. Concentration of 26 chemical variables in four strip-mine ponds and NBUN, in ppm. (except pH and E.C. in μmmho/cm^2).

TABLE 22

	DATE	DS30	NB15	GS	NB1	NBUN
PH	9-15-75	7.92	9.00	8.20	9.60	----
PH	10-05-75	7.92	9.03	9.09	9.09	----
PH	10-25-75	7.90	8.07	8.69	8.83	----
PH	11-09-75	7.74	7.97	8.44	8.59	----
PH	12-06-75	7.50	7.27	7.70	7.60	----
PH	1-18-76	6.95	7.20	8.10	----	----
PH	2-21-76	6.97	7.19	8.27	7.34	----
PH	3-21-76	7.27	7.35	7.93	7.57	----
PH	4-17-76	7.75	8.10	8.34	8.35	----
PH	5-07-76	7.56	8.23	8.58	8.19	7.46
PH	5-20-76	7.60	8.34	8.73	8.53	7.75
PH	5-27-76	7.60	8.44	8.84	8.69	7.76
PH	6-06-76	7.76	8.53	9.04	8.65	8.30
PH	6-10-76	7.84	8.53	9.00	8.91	8.45
PH	6-18-76	7.84	8.46	9.05	9.10	8.70
PH	6-25-76	7.78	8.06	8.75	8.82	8.58
PH	7-01-76	7.62	8.33	8.94	9.22	8.62
PH	7-08-76	7.74	8.33	8.95	9.10	8.87
PH	7-14-76	7.94	8.16	8.95	8.80	8.60
PH	8-07-76	7.62	8.14	9.10	9.50	9.50
EC	9-15-75	3.90	2.74	1.64	3.39	---
EC	10-05-75	3.91	2.14	1.29	2.58	---
EC	10-27-75	4.57	2.49	1.45	2.79	---
EC	11-09-75	4.68	2.36	1.45	2.72	---
EC	12-06-75	5.54	2.68	1.74	5.14	---
EC	1-18-76	5.79	2.93	2.54	----	---
EC	2-21-76	5.79	2.79	2.35	.31	---
EC	3-21-76	.94	.93	.46	.49	---
EC	4-16-76	2.49	2.32	1.28	1.00	---
EC	5-07-76	2.81	2.33	1.41	1.23	.41
EC	5-20-76	3.19	2.17	1.46	1.43	.42
EC	5-27-76	3.01	2.29	1.32	1.35	.35
EC	6-06-76	3.17	2.32	1.45	1.42	.39
EC	6-10-76	3.17	2.30	1.49	1.42	.41
EC	6-18-76	3.09	2.29	1.35	1.32	.41
EC	6-25-76	2.77	2.13	1.25	1.01	.41
EC	7-01-76	2.93	2.14	1.29	1.10	.36
EC	7-08-76	2.90	2.17	1.35	1.19	.35
EC	7-14-76	3.17	2.22	1.42	1.30	.39
EC	8-07-76	3.64	2.49	1.59	2.29	.41
NA	9-15-75	410	440	360	800	--
NA	10-05-75	400	230	360	590	--
NA	10-25-75	180	500	340	140	--
NA	11-09-75	350	500	350	390	--
NA	12-06-75	710	590	450	1200	--
NA	1-18-76	750	690	710	---	--
NA	2-21-76	750	685	660	70	--
NA	3-21-76	220	190	130	105	--
NA	4-17-76	230	400	260	170	--
NA	5-07-76	250	400	250	200	50
NA	5-20-76	290	450	300	230	50
NA	5-27-76	330	450	310	270	40
NA	6-06-76	360	460	340	280	60
NA	6-10-76	360	460	360	290	50
NA	6-18-76	350	470	340	270	60
NA	6-25-76	310	420	300	210	50
NA	7-01-76	340	430	320	240	60
NA	7-08-76	340	440	340	410	50
NA	7-14-76	380	450	350	270	60
NA	8-07-76	450	490	400	470	50

Table 22 (continued)

	DATE	DS30	NB15	G5	NB1	NBUN
CA	9-15-75	204	35	10	41	--
CA	10-05-75	257	35	12	28	--
CA	10-25-75	256	48	11	26	--
CA	11-09-75	294	49	13	26	--
CA	12-06-75	320	58	16	48	--
CA	1-18-76	342	38	62	--	--
CA	2-21-76	357	61	31	15	--
CA	3-21-76	191	42	30	28	--
CA	4-17-76	262	63	23	29	--
CA	5-07-76	205	51	24	38	29
CA	5-20-76	261	76	31	45	46
CA	5-27-76	191	66	13	40	12
CA	6-06-76	84	86	30	36	41
CA	6-10-76	286	64	23	45	34
CA	6-18-76	248	72	23	33	35
CA	6-25-76	228	62	21	32	31
CA	7-01-76	251	67	23	27	30
CA	7-08-76	260	66	22	48	33
CA	7-14-76	252	68	35	28	26
CA	8-07-76	285	68	24	49	22
MG	9-15-75	273	48	11	82	--
MG	10-05-75	181	24	10	55	--
MG	10-25-75	82	51	10	10	--
MG	11-09-75	116	53	11	35	--
MG	12-06-75	4200	66	16	140	--
MG	1-18-76	6400	69	31	--	--
MG	2-21-76	8200	74	30	7	--
MG	3-21-76	112	22	6	11	--
MG	4-17-76	142	48	9	19	--
MG	5-07-76	159	45	10	30	13
MG	5-20-76	185	51	13	32	11
MG	5-27-76	201	50	12	33	12
MG	6-06-76	219	52	13	32	15
MG	6-10-76	229	50	12	32	15
MG	6-18-76	214	54	10	30	15
MG	6-25-76	187	44	9	18	14
MG	7-01-76	197	46	9	20	16
MG	7-08-76	215	47	10	39	17
MG	7-14-76	224	49	12	26	16
MG	8-07-76	276	56	11	44	18
K	9-15-75	22	14	11	36	--
K	10-05-75	15	6	11	25	--
K	10-25-75	6	15	10	4	--
K	11-09-75	9	15	11	16	--
K	12-06-75	33	20	14	47	--
K	1-18-76	32	21	21	--	--
K	2-21-76	30	23	20	13	--
K	3-21-76	14	7	5	8	--
K	4-17-76	16	15	10	12	--
K	5-07-76	15	16	8	12	10
K	5-20-76	19	16	7	16	11
K	5-27-76	19	16	10	17	10
K	6-06-76	20	17	11	17	11
K	6-10-76	19	17	13	17	11
K	6-18-76	17	16	12	16	10
K	6-25-76	14	16	11	12	9
K	7-01-76	15	17	11	14	10
K	7-08-76	14	16	11	18	9
K	7-14-76	14	17	12	17	10
K	8-07-76	17	19	14	19	14
SO4	9-15-75	2825	675	2475	5625	--

Table 22 (continued)

	DATE	DS30	NB15	G5	NB1	NBUN
SO4	10-05-75	1400	660	200	760	--
SO4	10-25-75	1325	500	150	725	--
SO4	11-09-75	1050	635	240	675	--
SO4	12-06-75	4065	1960	2545	5670	--
SO4	1-18-76	6045	770	420	---	--
SO4	2-21-76	2650	800	445	30	--
SO4	3-21-76	205	225	75	175	--
SO4	4-17-76	1235	650	525	225	--
SO4	5-07-76	685	455	180	225	15
SO4	5-20-76	830	505	200	285	10
SO4	5-27-76	780	575	250	350	180
SO4	6-06-76	935	515	220	320	5
SO4	6-10-76	785	450	170	230	10
SO4	6-18-76	900	430	205	315	10
SO4	6-25-76	935	445	150	255	10
SO4	7-01-76	780	575	195	170	10
SO4	7-08-76	830	535	240	255	10
SO4	7-14-76	1045	505	200	235	10
SO4	8-07-76	1125	630	245	490	10
Cl	9-15-75	132	5	18	48	-
Cl	10-05-75	92	4	7	11	-
Cl	10-25-75	78	5	8	13	-
Cl	11-09-75	69	7	9	14	-
Cl	12-06-75	210	11	23	67	-
Cl	1-18-76	380	10	17	--	-
Cl	2-21-76	146	9	17	4	-
Cl	3-21-76	5	19	5	4	-
Cl	4-17-76	52	7	8	6	-
Cl	5-07-76	55	8	7	7	4
Cl	5-20-76	60	9	10	8	4
Cl	5-27-76	67	7	10	9	3
Cl	6-06-76	69	8	12	10	4
Cl	6-10-76	67	8	13	11	4
Cl	6-18-76	65	9	13	11	4
Cl	6-25-76	52	6	10	9	4
Cl	7-01-76	53	6	10	11	3
Cl	7-08-76	57	5	11	11	4
Cl	7-14-76	57	7	13	11	4
Cl	8-07-76	67	5	11	8	11
Al	9-15-75	.2	.1	.2	.1	--
Al	10-05-75	.2	.5	.4	.2	--
Al	10-25-75	.1	.1	.4	.2	--
Al	11-09-75	.1	.2	.2	.2	--
Al	12-06-75	0	.1	.2	0	--
Al	1-18-76	0	0	.4	--	--
Al	2-21-76	.1	.2	.2	.2	--
Al	3-21-76	.2	.1	.3	.1	--
Al	4-17-76	0	.1	.3	0	--
Al	5-07-76	.2	.3	.2	.2	.1
Al	5-20-76	.1	0	.3	0	.3
Al	5-27-76	.1	.1	.2	.1	.1
Al	6-06-76	.2	.4	.2	.1	.1
Al	6-10-76	0	.1	.1	.1	.1
Al	6-18-76	.1	.2	.1	.2	.1
Al	6-25-76	.1	.2	.1	.2	.1
Al	7-01-76	.1	.1	.1	.1	.1
Al	7-08-76	.1	.1	.1	.1	.3
Al	7-14-76	.1	.2	.6	0	0
Al	8-07-76	0	.1	.3	.1	.1
CU	9-15-75	.04	.03	.02	.03	---
CU	10-05-75	.03	.02	.01	.02	---
CU	10-25-75	.02	.03	.03	.02	---
CU	11-09-75	.07	.02	.03	.03	---

Table 22 (continued)

	DATE	DS30	NB15	G5	NB1	NBUN
CU	12-06-75	.06	.04	.03	.05	---
CU	1-18-76	.04	.03	.07	---	---
CU	2-21-76	.03	.02	.03	.03	---
CU	3-21-76	.02	.01	.01	.02	---
CU	4-17-76	.02	.03	.02	.02	---
CU	5-07-76	.03	.03	.03	.05	.02
CU	5-20-76	.03	.01	.03	.05	.02
CU	5-27-76	.02	.03	.03	.02	.02
CU	6-06-76	.02	.01	.02	.02	.02
CU	6-10-76	.02	.01	.01	.02	.02
CU	6-18-76	.03	.01	.02	.02	.02
CU	6-25-76	.02	.02	.02	.01	.01
CU	7-01-76	.01	.02	.02	.01	.01
CU	7-08-76	.03	.02	.02	.03	.02
CU	7-14-76	.02	.02	.02	.02	.02
CU	8-07-76	.04	.02	.02	.03	.02
FE	9-15-75	.05	.06	.04	.03	---
FE	10-05-75	.03	.02	.1C	.02	---
FE	10-25-75	.03	.04	.08	0	---
FE	11-09-75	.05	.01	.04	.01	---
FE	12-06-75	.07	.06	.07	.08	---
FE	1-18-76	.07	.05	.74	---	---
FE	2-21-76	.06	.04	.04	.08	---
FE	3-21-76	.06	.03	.08	.06	---
FE	4-17-76	.04	.04	.03	.03	---
FE	5-07-76	.05	.03	.04	.04	.07
FE	5-20-76	.09	.05	.11	.04	.05
FE	5-27-76	.06	.05	.08	.03	.15
FE	6-06-76	.05	.03	.05	.06	.07
FE	6-10-76	.02	.04	.05	.03	.03
FE	6-18-76	.02	.02	.01	0	.09
FE	6-25-76	.03	0	.02	0	.05
FE	7-01-76	.02	0	.02	.02	.02
FE	7-08-76	.03	0	0	0	.02
FE	7-14-76	.04	.08	.03	0	.09
FE	8-07-76	.04	.03	.02	.02	.07
PB	9-15-75	.3	.1	.1	.2	--
PB	10-05-75	.3	.2	.2	.1	--
PB	10-25-75	.2	.2	.2	.2	--
PB	11-09-75	.2	.2	.1	.1	--
PB	12-06-75	.1	0	0	.1	--
PB	1-18-76	.2	.1	.2	--	--
PB	2-21-76	.2	.1	0	0	--
PB	3-21-76	.1	.2	0	.1	--
PB	4-17-76	.1	.2	.1	.1	--
PB	5-07-76	.2	.2	.1	.1	.2
PB	5-20-76	.2	.2	.1	.2	.1
PB	5-27-76	.2	.2	.1	.2	.2
PB	6-06-76	.2	.1	.1	.2	0
PB	6-10-76	.2	0	0	.1	.1
PB	6-18-76	0	0	.1	.1	0
PB	6-25-76	.2	0	0	0	0
PB	7-01-76	.1	.1	0	0	.1
PB	7-08-76	.2	.1	.1	.1	0
PB	7-14-76	.1	.1	.1	0	0
PB	8-07-76	.2	.1	.1	0	.1
LI	9-15-75	.23	.09	.06	.20	---
LI	10-05-75	.17	.16	.04	.06	---
LI	10-25-75	.04	.08	.06	.03	---
LI	11-09-75	.11	.08	.05	.09	---
LI	12-06-75	.36	.10	.08	.30	---
LI	1-18-76	.38	.10	.12	---	---
LI	2-21-76	.38	.11	.11	.03	---

Table 22 (continued)

	DATE	DS30	NB15	G5	NB1	NBUN
LI	3-21-76	.11	.04	.03	.03	---
LI	4-17-76	.13	.07	.05	.04	---
LI	5-07-76	.15	.07	.05	.05	.02
LI	5-20-76	.17	.08	.04	.06	.02
LI	5-27-76	.18	.08	.06	.06	.02
LI	6-06-76	.19	.08	.06	.07	.02
LI	6-10-76	.20	.08	.06	.07	.02
LI	6-18-76	.19	.08	.06	.06	.02
LI	6-25-76	.17	.07	.05	.05	.02
LI	7-01-76	.18	.07	.05	.05	.02
LI	7-08-76	.19	.07	.06	.08	.03
LI	7-14-76	.20	.07	.05	.06	.01
LI	8-07-76	.24	.08	.06	.08	.02
NI	9-15-75	.10	.06	.05	.06	---
NI	10-05-75	.09	.03	.06	.07	---
NI	10-25-75	.08	.06	.05	.05	---
NI	11-09-75	.10	.08	.06	.06	---
NI	12-06-75	.12	.08	.06	.09	---
NI	1-18-76	.15	.08	.13	---	---
NI	2-21-76	.14	.09	.05	.06	---
NI	3-21-76	.08	.04	0	.03	---
NI	4-17-76	.09	.06	.04	.06	---
NI	5-07-76	.07	.05	.05	.05	.03
NI	5-20-76	.10	.09	.04	.03	.04
NI	5-27-76	.08	.07	.05	.08	.03
NI	6-06-76	.11	.07	.06	.06	.05
NI	6-10-76	.07	.07	.06	.03	.03
NI	6-18-76	.09	.03	.02	0	0
NI	6-25-76	.04	.02	0	0	0
NI	7-01-76	.04	.04	0	0	0
NI	7-08-76	.06	.04	.03	.04	0
NI	7-14-76	.05	.02	0	.05	0
NI	8-07-76	.07	0	0	0	0
MN	9-15-75	.10	.01	0	0	---
MN	10-05-75	.07	0	0	0	---
MN	10-25-75	.02	.03	.02	0	---
MN	11-09-75	.18	.02	.05	0	---
MN	12-06-75	.23	.06	0	0	---
MN	1-18-76	.27	.14	.03	---	---
MN	2-21-76	1.08	.35	.02	.05	---
MN	3-21-76	.05	.28	.02	.03	---
MN	4-17-76	.08	.16	.01	.01	---
MN	5-07-76	.06	.02	.01	.01	.01
MN	5-20-76	.02	.01	.01	.02	.02
MN	5-27-76	.11	.02	.02	.02	.02
MN	6-06-76	.04	.01	.02	.01	.02
MN	6-10-76	.01	.01	.01	.03	0
MN	6-18-76	.02	.02	.01	.01	.01
MN	6-25-76	.01	.01	.01	.01	.02
MN	7-01-76	.01	.02	0	.02	0
MN	7-08-76	.02	0	0	.01	0
MN	7-14-76	.02	.01	.01	.01	.02
MN	8-07-76	.02	.01	.01	.02	.04
MO	9-15-75	.016	.011	.010	.009	----
MO	10-05-75	.007	.008	.006	.007	----
MO	10-25-75	.014	.007	.007	.012	----
MO	11-09-75	.006	.002	.003	.007	----
MO	12-06-75	.005	.002	.006	.003	----
MO	1-18-76	.009	0	.009	----	----
MO	2-21-76	.007	.002	.009	.008	----
MO	3-21-76	.006	.001	.005	.006	----
MO	4-17-76	.011	.003	.005	.004	----
MO	5-07-76	.009	.002	.004	.005	.003

Table 22 (continued)

	DATE	DS30	NB15	G5	NB1	NBUN
MO	5-20-76	.005	.002	.008	.005	.006
MO	5-27-76	.001	0	.004	.002	.005
MO	6-06-76	.002	0	.002	.005	.006
MO	6-10-76	.011	0	.006	.004	.003
MO	6-18-76	.001	.001	.003	.003	.003
MO	6-25-76	.006	0	.003	.005	.003
MO	7-01-76	.005	.001	.004	.003	.002
MO	7-08-76	.007	.001	.003	.007	.021
MO	7-14-76	.003	.004	.005	.003	.005
MO	8-07-76	.005	.001	.003	.002	.003
SI	9-15-75	8.1	1.4	1.2	1.5	---
SI	10-05-75	6.1	.7	2.2	1.5	---
SI	10-25-75	2.3	1.2	1.6	.9	---
SI	11-09-75	1.1	.4	.2	.2	---
SI	12-06-75	2.5	1.6	1.0	.8	---
SI	1-18-76	7.8	1.8	.3	---	---
SI	2-21-76	2.3	2.6	1.2	.7	---
SI	3-21-76	2.4	2.7	.4	1.7	---
SI	4-17-76	1.8	2.5	2.3	1.6	---
SI	5-07-76	.8	1.5	.7	.7	2.3
SI	5-20-76	1.6	2.3	.7	1.0	.4
SI	5-27-76	2.3	.3	.3	2.4	.4
SI	6-06-76	3.7	.3	.4	.1	.6
SI	6-10-76	5.0	2.1	1.4	2.0	3.0
SI	6-18-76	7.4	3.0	3.6	2.3	2.3
SI	6-25-76	5.5	2.9	3.2	.7	1.8
SI	7-01-76	3.9	3.1	2.2	2.0	3.0
SI	7-08-76	3.1	3.1	2.0	1.5	1.0
SI	7-14-76	4.3	1.4	1.3	3.7	2.9
SI	8-07-76	3.5	1.4	1.5	1.2	1.2
SR	9-15-75	3.87	1.13	.18	2.10	---
SR	10-05-75	4.30	.63	.13	1.26	---
SR	10-25-75	5.90	1.16	.17	.68	---
SR	11-09-75	7.20	1.17	.17	.95	---
SR	12-06-75	7.90	1.21	.20	3.13	---
SR	1-18-76	7.90	1.03	1.03	----	---
SR	2-21-76	9.10	1.04	.41	.24	---
SR	3-21-76	3.20	.54	.19	.30	---
SR	4-17-76	3.66	1.00	.24	.50	---
SR	5-07-76	3.54	.77	.27	.77	.21
SR	5-20-76	4.76	1.02	.29	.77	.37
SR	5-27-76	3.56	.96	.16	.76	.16
SR	6-06-76	4.51	1.43	.33	.87	.34
SR	6-10-76	3.69	.92	.21	.94	.21
SR	6-18-76	4.16	1.13	.20	.64	.20
SR	6-25-76	3.85	1.08	.23	.57	.28
SR	7-01-76	4.05	1.00	.22	.47	.24
SR	7-08-76	4.53	1.01	.26	1.07	.36
SR	7-14-76	4.59	1.11	.35	.55	.23
SR	8-07-76	6.70	1.28	.36	1.12	.27
ZN	9-15-75	.05	.36	.07	.09	---
ZN	10-05-75	.15	.06	.09	.11	---
ZN	10-25-75	.14	.02	.05	.17	---
ZN	11-09-75	.05	.03	.03	.06	---
ZN	12-06-75	.06	.07	.06	.06	---
ZN	1-18-76	.04	.06	.24	---	---
ZN	2-21-76	.05	.02	.01	0	---
ZN	3-21-76	.08	.04	.01	.02	---
ZN	4-17-76	.05	.02	.02	.07	---
ZN	5-07-76	.01	.05	.05	.13	.04
ZN	5-20-76	.07	.07	.05	.10	.02
ZN	5-27-76	.05	.03	.18	.02	.05
ZN	6-06-76	.07	.02	.05	.06	.04

Table 22 (continued)

	DATE	DS30	NB15	G5	NB1	NBUN
ZN	6-10-76	.01	0	.01	.21	.01
ZN	6-18-76	.03	.06	.04	.08	.05
ZN	6-25-76	.04	.07	.04	.02	.04
ZN	7-01-76	.03	.02	.03	.03	.01
ZN	7-08-76	.03	.02	0	.06	.03
ZN	7-14-76	.05	.05	.01	.01	.02
ZN	8-07-76	.04	.01	0	.07	.07
OPO4	9-15-75	.04	.03	.03	.05	---
OPO4	10-05-75	.03	.04	.08	.06	---
OPO4	10-25-75	.03	.03	.04	.06	---
OPO4	11-09-75	.04	.03	.04	.05	---
OPO4	12-06-75	.08	.11	.12	.23	---
OPO4	1-18-76	.16	.02	.02	---	---
OPO4	2-21-76	.19	.17	.08	.44	---
OPO4	3-21-76	.08	.04	.10	.24	---
OPO4	4-17-76	.06	.05	.09	.09	---
OPO4	5-07-76	.25	.05	.06	.05	.04
OPO4	5-20-76	.06	.04	.04	.05	.09
OPO4	5-27-76	.04	.03	.12	.02	.10
OPO4	6-06-76	.03	.07	.09	.05	.19
OPO4	6-10-76	.04	.02	.05	.04	.06
OPO4	6-18-76	.04	.02	.01	.04	.06
OPO4	6-25-76	.02	.03	.16	.06	.12
OPO4	7-01-76	.04	.08	.14	.06	.08
OPO4	7-08-76	.02	.02	.03	.02	.04
OPO4	7-14-76	.02	.01	.05	.02	.03
OPO4	8-07-76	.02	.01	.04	.08	.03
TPO4	9-15-75	.36	.12	.28	.29	---
TPO4	10-05-75	.31	.16	.27	.28	---
TPO4	10-25-75	.13	.10	.13	.21	---
TPO4	11-09-75	.11	.08	.16	.16	---
TPO4	12-06-75	.34	.29	.37	.52	---
TPO4	1-18-76	---	.66	.16	---	---
TPO4	2-21-76	2.86	.42	.25	.81	---
TPO4	3-21-76	.58	.36	.70	.97	---
TPO4	4-17-76	.16	.55	---	.95	---
TPO4	5-07-76	.21	.18	.24	.28	.32
TPO4	5-20-76	.51	.19	.43	.13	.31
TPO4	5-27-76	.34	.15	.54	.23	.71
TPO4	6-06-76	.59	.08	.47	.57	.47
TPO4	6-10-76	1.06	.23	.41	.08	1.06
TPO4	6-18-76	.35	.18	.47	.16	.35
TPO4	6-25-76	.19	.14	.28	.22	.24
TPO4	7-01-76	.17	.09	.42	.35	.28
TPO4	7-08-76	.23	.14	---	.28	.16
TPO4	7-14-76	.44	.25	---	.44	.25
TPO4	8-07-76	.16	---	.34	.14	.33
NO3	9-15-75	.224	.105	.079	.188	----
NO3	10-05-75	.280	.110	.094	.098	----
NO3	10-25-75	.181	.113	.157	.114	----
NC3	11-09-75	.265	.160	.135	.170	----
NO3	12-06-75	.278	.126	.144	.240	----
NO3	1-18-76	.264	.140	.085	----	----
NO3	2-21-76	.167	.146	.202	.236	----
NO3	3-21-76	.185	.065	.160	.170	----
NO3	4-17-76	.175	.187	.165	.141	----
NO3	5-07-76	.187	.180	.082	.090	.070
NO3	5-20-76	.178	.129	.106	.111	.120
NO3	5-27-76	.178	.149	.172	.100	.130
NO3	6-06-76	.374	.123	.142	.140	.178
NO3	6-10-76	.317	.115	.159	.086	.083
NO3	6-18-76	.235	.113	.028	.070	.083
NO3	6-25-76	.213	.080	.056	.032	.049

Table 22 (continued)

	DATE		DS30	NB15	G5	NB1	NBUN
NO3	7-01-76		.243	.083	.049	.046	.070
NO3	7-08-76		.277	.147	.180	.161	.098
NO3	7-14-76		.237	.115	.084	.155	.065
NO3	8-07-76		.265	.140	.125	.147	.112
AM	5-07-76		1.62	.32	.74	.36	.65
AM	5-20-76		1.09	.42	.76	.32	.68
AM	5-27-76		.86	.48	1.48	.46	.71
AM	6-06-76		1.12	.64	1.09	.62	.84
AM	6-10-76		1.22	.66	.65	.49	1.00
AM	6-18-76		.76	.41	.84	.39	.63
AM	6-25-76		.78	.50	1.35	.43	.58
AM	7-01-76		.88	.63	1.01	.48	.74
AM	7-08-76		1.42	.55	.89	.61	1.00
AM	7-14-76		1.24	.55	1.07	.65	.83
AM	8-07-76		1.27	.49	.91	.77	.83
HCO3	6-10-76		350	228	336	170	154
HCO3	6-18-76		526	216	308	150	156
HCO3	6-25-76		286	216	272	120	126
HCO3	7-01-76		288	210	258	124	152
HCO3	7-14-76		290	220	286	160	204
HCO3	8-07-76		224	204	326	178	124
CO3	6-10-76		0	28	72	32	20
CO3	6-18-76		0	24	64	52	24
CO3	6-25-76		0	0	32	28	28
CO3	7-01-76		0	20	68	80	24
CO3	7-14-76		24	28	76	0	24
CO3	8-07-76		0	28	112	80	116
DOT	6-10-76	TOP	3.4	8.9	9.4	9.7	10.7
DOB		BOT	2.4	8.2	8.6	8.9	8.7
DOT	6-27-76	TOP	10.0	11.0	---	11.5	14.3
DOB		BOT	7.9	10.3	---	10.6	11.7
DOT	8-07-76	TOP	4.3	5.7	5.9	6.6	11.2
DOB		BOT	---	4.5	4.3	5.0	5.2

Table 23. pH, electrical conductivity, and major ions in the spoils surrounding strip-mine ponds - water saturation extraction.

Sample site		pH	E.C.	Ca	Mg	K	Na	SO_4	Cl
			mhos/cm	ppm					
DS30	June (4)*	8.28	.89	97	53	56	16	833	22.0
	August (4)	8.38	1.54	260	61	58	19	975	13.7
NB15	June (4)	8.21	5.36	344	107	58	1125	3650	17.2
	August (4)	8.16	5.74	219	94	56	1462	3700	13.8
G5	June (4)	8.35	4.52	198	81	58	1000	2376	18.7
	August (4)	8.54	4.11	199	76	58	940	2438	20.3
NB1	June (4)	8.16	4.62	240	126	50	962	2675	13.7
	August (4)	8.36	5.13	210	117	62	1185	3188	18.3

( )* - number of samples

Table 24. Trace elements of spoils surrounding strip-mine ponds - water saturation and NH_4OAc extracts

Sample site		Li	Mn	Sr	Zn	Fe	Ca	Mg	Na	K	Sr	Mn	Li
		ppm Water saturation					ppm NH_4OAc extract						
DS30	June (4)*	.07	.12	1.48	.08	.11	4756	1444	70	370	74	5.80	.19
	August (4)	.11	.21	3.82	.06	.13	4988	1606	71	360	72	8.22	.24
NB15	June (4)	.16	.16	5.17	.08	.10	4850	1025	2600	283	62	6.60	.35
	August (4)	.18	.08	5.39	.04	.07	3141	825	2594	285	70	7.56	.35
G5	June (4)	.22	.13	3.05	.06	.08	4238	981	1924	345	59	6.93	.44
	August (4)	.22	.25	2.76	.04	.14	4281	1000	1756	329	60	6.34	.40
NB1	June (4)	.23	.19	5.21	.05	.05	3638	1069	1524	283	62	8.46	.41
	August (4)	.25	.14	5.85	.05	.08	3093	706	1846	319	71	9.86	.43

( )* - number of samples

Table 25. Trace elements of spoils surrounding strip-mine ponds - EDTA extractable.

Sample site		Al	B	Cd	Cr	Cu	Fe	Li	Mn	Mo	Ni	Pb	Si	Sr	Zn
		ppm													
DS30	June (4)	5.25	1.11	.30	.012	6.95	154.7	.12	114.1	.013	3.12	3.81	16.1	9.0	7.5
	August (4)	8.62	2.01	.28	.018	7.88	287.2	.15	167.8	.011	3.81	4.12	21.9	10.5	10.5
NB15	June (4)	1.38	.57	.33	.021	10.38	191.2	.22	55.6	.036	4.31	3.50	15.7	11.8	13.2
	August (4)	1.32	.89	.30	.013	9.04	134.7	.26	43.1	.032	3.19	3.25	19.4	14.4	12.6
G5	June (4)	.44	1.37	.30	.016	6.46	107.2	.30	132.8	.018	2.12	2.88	16.4	8.2	5.7
	August (4)	1.06	1.53	.28	.013	5.66	118.1	.28	47.6	.026	2.06	3.00	15.6	7.8	6.2
NB1	June (4)	1.25	.73	.28	.013	6.58	219.4	.28	63.8	.024	2.88	3.31	18.1	9.6	8.4
	August (4)	1.12	.67	.24	.007	5.36	136.9	.24	38.4	.026	2.19	2.38	11.8	11.8	8.1

( )* - number of samples

Table 26. Density and biomass values for invertebrates at selected strip-mine ponds. D = density (ind/m^2) and B = Biomass (g/m^2).

		MAY	JUNE	JULY	AUGUST	TOTAL	MEAN
	I. NEMATOMORPHA						
DS30	D						
	B						
NB15	D						
	B						
NB1	D		29	38		67	16.8
	B		.043	.058		.101	.025
NBUN	D						
	B						
	II. ANNELIDA						
DS30	D		10	19		29	7.3
	B		.016	.023		.039	.010
NB15	D	8	10			18	6.8
	B	.017	.010			.027	.007

Table 26 (continued)

		MAY	JUNE	JULY	AUGUST	TOTAL	MEAN
NB1	D						
	B						
NBUN	D	25	32	55	121	233	58.3
	B	.227	.044				
	III. HYDRACARNIA						
DS30	D	67	133	108	92	400	100
	B	.045	.145	.094	.082	.366	.091
NB15	D	386	1168	471	333	2358	589.6
	B	.239	1.088	.308	.169	1.805	.451
NB1	D			183	33	217	54.2
	B			.154	.004	.150	.040
NBUN	D	25	71	28	17	140	35
	B	.013	.072	.018	.008	.112	.028

Table 26 (continued)

		MAY	JUNE	JULY	AUGUST	TOTAL	MEAN
	IV.	AMPHIPODA					
DS30	D	533	650	913	1654	3750	937.6
	B	.240	.382	.242	.798	1.662	.415
NB15	D	1693	1766	3856	2595	9910	2477.6
	B	1.064	.620	1.204	.838	3,727	.932
NB1	D			8	8	16	4
	B			.004	.004	.008	.002
NBUN	D	607	1540	2616	2862	7625	1906.2
	B	.465	.921	.852	1.644	3,882	
	V.	HEMIPTERA					
DS30	D	42	770	425	558	1783	445.7
	B	.276	2.062	1.110	6,087	9,534	2.384
NB15	D	33	650	408	316	1408	352.0
	B	.242	1.638	1,497	.411	3,789	.947

Table 26 (continued)

		MAY	JUNE	JULY	AUGUST	TOTAL	MEAN
NB1	D		96	133	285	487	121.9
	B		.308	2.751	1.960	5.020	1.255
NBUN	D	42	517	325	550	1433	358.3
	B	.050	1.332	1.246	4.140	6.768	1.692
	VI.	EPHEMEROPTERA					
DS30	D		408	25	1936	2369	592.3
	B		.745	.011	1.972	2.728	.682
NB15	D		389	28	569	985	246.3
	B		.497	.009	.530	1.036	.259
NB1	D		38	25		63	15.6
	B		.078	.030		.108	.027
NBUN	D		231	17	1742	1990	497.5
	B		.547	.099	1.483	2.129	.532

Table 26 (continued)

		MAY	JUNE	JULY	AUGUST	TOTAL	MEAN
	VII. ODONATA						
DS30	D	192	2059	752	1866	4869	1217.3
	B	.628	6.390	2.155	8.022	17.194	4.299
NB15	D	200	1727	952	1221	4102	1025.6
	B	.797	4.283	1.585	7.006	13.671	3.418
NB1	D		-	-	-	-	-
	B		.024	.035	.318	.377	.094
NBUN	D	633	1033	600	1532	3798	949.5
	B	1.603	3.837	1.684	3.655	10.779	2.695
	VIII. TRICOPTERA						
DS30	D		82	91	102	275	68.8
	B		.108	.120	.144	.372	.093
NB15	D	8	8	17	25	58	14.6
	B	.010	.010	.013	.029	.063	.016

Table 26 (continued)

		MAY	JUNE	JULY	AUGUST	TOTAL	MEAN
NB1	D				8	8	2.1
	B				.010	.010	.003
NBUN	D	42	139	336	409	926	231.4
	B	.143	.178	.389	.747	1.456	.364
	IX.	COLEOPTERA					
DS30	D	75	476	192	192	934	233.6
	B	.108	.641	.123	.321	1.193	.298
NB15	D	50	175	158	83	467	116.6
	B	.349	.503	.824	.042	1.717	.429
NB1	D		42	25	61	127	31.9
	B		.046	.039	.077	.163	.041
NBUN	D	58	358	430	235	1082	270.5
	B	.215	.513	.230	.392	1.349	.337

Table 26 (continued)

		MAY	JUNE	JULY	AUGUST	TOTAL	MEAN
	X.	DIPTERA					
DS30	D	1819	4540	4691	9907	20,958	5239.5
	B	1.886	3.704	4.424	6.249	16.263	4.066
NB15	D	529	670	634	1265	3098	774.6
	B	.471	1.075	.662	1.710	3.857	.964
NB1	D	17	195	1803	1891	3906	976.5
	B	.023	.123	.117	.499	.763	.191
NBUN	D	680	3326	1213	3327	8546	2136.5
	B	.615	1.378	.676	2.134	4.803	1.201
	XI.	MOLLUSCA					
DS30	D	1661	5125	3467	6425	16,679	4169.7
	B	65.1	146.5	139.4	108.4	459.4	114.9
NB15	D	355	1082	344	1406	3187	796.7
	B	1.83	6.63	1.95	3.50	13.90	3.50

Table 26 (continued)

		MAY	JUNE	JULY	AUGUST	TOTAL	MEAN
NB1	D				38	38	9.6
	B				.23	.23	.06
NBUN	D	1033	7719	4102	4717	17,571	4392.8
	B	38.1	114.6	90.7	107.7	351.1	87.8

Table 27. Species Diversity: ANOVA for species number (s).

	MAY	JUNE	JULY	AUGUST
DS30	27	52	29	43
NB15	30	41	31	36
NB1	6	16	13	20
NBUN	40	61	48	55

SUMMARY TABLE

Source of Variation	df	SS	MS	F
Months	3	697.5	232.5	13.7
Sites	3	2852.5	950.8	55.9
Error	9	153.0	17.0	
Total	15	3703.0		

Table 28. Species Diversity: ANOVA for Shannon-Wiener Diversity Index (H').

	MAY	JUNE	JULY	AUGUST
DS30	2.26	2.68	2.32	2.87
NB15	2.05	2.57	1.81	2.51
NB1	1.33	2.38	1.78	1.74
NBUN	2.70	2.75	2.71	2.94

SUMMARY TABLE

Source of Variation	df	SS	MS	F
Months	3	.83	.28	5.6
Sites	3	1.94	.65	13.0
Error	9	.42	.05	
Total	15	3.19		

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