LIMNOLOGICAL CHARACTERISTICS OF MINE PIT LAKES IN NORTHEAST MINNESOTA[1]

by

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Abstract. In northeast Minnesota, a typical mine reclamation technique for inactive iron mine pits has been to allow the pits to fill with groundwater, forming mine pit lakes. These deep, cold lakes have been stocked with salmonids to provide a fishery for anglers. Thirteen iron mine pit lakes in northeast Minnesota were studied to determine habitat and food available to stocked trout. Temperature and oxygen profiles were made, water samples were collected to assess water quality and heavy metal concentrations, and zooplankton and benthic macroinvertebrates were sampled in various seasons of the year. Though six of the mine pit lakes stratified in mid-summer and oxygen levels were low in the hypolimnion, the thermocline layer had adequate oxygen and was within the preferred temperature range for trout. High levels of sulfate were found in some of the mine pit lakes. Sulfate is not directly toxic to fish but if reduced to hydrogen sulfide in hypolimnions with low oxygen, would restrict trout movement into the hypolimnion. Aquatic plant production would be inhibited in most of the pit lakes by the low phosphorus concentrations measured. Zooplankton and benthos abundances were similar to or lower than those found in natural, oligotrophic lakes. Given sparse food abundance, trout could be stocked at a catchable size to provide an immediate fishery to anglers. If trout are expected to grow, either low numbers could be stocked or productivity could be increased by altering the shoreline to make it less steep, adding more littoral area.

Additional Key Words: mine pit lakes, iron mine reclamation, trout stocking, oligotrophic lakes, oligotrophic zooplankton, oligotrophic benthos, mine pit lake water chemistry.

Introduction

Allowing abandoned iron mine pits in northeast Minnesota to fill with groundwater and form lakes is a useful reclamation technique. The Minnesota Department of Natural Resources and IronRange Resources and Rehabilitation Board(IRRRB) have created new fisheries in some mine pit lakes by stocking rainbow trout (Oncorhynchus mykiss), brook trout(Salvelinus fontinalis) and lake trout (Salvelinus namaycush). Limited information on water temperatures and dissolved oxygen concentrations shows the mine pit waters are suitable for trout; however, the carrying capacities of these lakes are not known. The lakes may not be productive enough to permit good trout growth at current stocking densities. Lack of information about limnological parameters and productivity of the lakes has precluded making adequate long-term management plans. Knowledge of plankton and benthos densities and water quality is vital for managing these lakes. The

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Table 1. Location, age, and size of mine pit lakes studied during April 1987-February 1988. Lake maps were not available for Embarrass, Miners, Mott and Sagamore pit lakes. Closing dates indicate when the pits were allowed to begin filling with water.

Mine pit lake	County	Closing date	Surface area (ha)	Maximum depth (m)
Embarrass	St. Louis	1977	-	approx. 165
Forsyth	St. Louis	1956	3	18
Gilbert	St. Louis	1971	90	135
Huntington	Crow Wing	1961	40	79
Judson	St. Louis	1961	7	25
Kinney	St. Louis	1937	21	49
Miners (Pioneer)	St. Louis	1967	-	approx. 48
Mott	St. Louis	1951	-	approx. 24
Pennington	Crow Wing	1960	23	79
Sagamore	Crow Wing	1969	-	approx. 43
St. James	St. Louis	1963	40	116
Stubler	St. Louis	1957	5	11
Tioga	Itasca	1961	21	69

purpose of this study was to characterize the present status of fish food organisms and the physical and chemical characteristics of mine pit lakes in northeast Minnesota.

Study Sites

Thirteen mine pit lakes in the Cuyuna, Mesabi and Vermilion iron ranges (Table 1) were chosen for the study because of available boat or walk-in accesses and because of previous attempts to establish fisheries in these lakes by stocking.

Due to their common origin from iron mining, the lakes have many similar characteristics: rocky bottom substrates, steep shorelines, limited littoral area. They are also deep in relation to their surface area. Surface areas ranged from 3 to 90 ha and maximum depths from 11 to 165 m. Littoral areas (depths less than 4.6 m) of lakes for which contour maps were available ranged from 7-32% of the total surface areas, though the littoral area was greater than 17% for only one small lake, Forsyth pit lake. Mine pit lakes are relatively new features on the landscape in northeast Minnesota with the age of the study lakes ranging from 10 to 50 years (Table 1).

Methods

Water Quality and Stratification

Water temperature, dissolved oxygen, and conductivity profiles were obtained from deep-water locations during winter (in 1988) and summer stratification, after ice-out in the spring, and before freeze-up in the fall in 1987 (Pierce and Tomcko 1989). Secchi disc transparencies were measured during spring and summer sampling periods.

Water samples were obtained from the epilimnion, metalimnion, and near the bottom of each lake during spring, summer, and winter sampling periods with a Kemmerer water sampler. Samples were tested for sulfate ion, total and ortho phosphate, nitrate, nitrite and total Kjeldahl nitrogen, pH, total and phenolphthalein alkalinity, total hardness, total dissolved solids, and chlorophyll a as described in Pierce and Tomcko (1989)

Hypolimnetic water samples for heavy metals analyses were obtained from eight of the 13 pit lakes in September 1986 (Pierce and Tomcko 1989). Ammonia concentrations were determined in surface samples taken at the same time.

The morphoedaphic index (Ryder 1965) is used to calculate potential fish yields of lakes based on the relationship between fish production, mean depth and amounts of dissolved solids. It was used to estimate potential fish yields for St. James, Gilbert, Kinney, and Huntington, the four pit lakes considered to be representative of the other pit lakes. Carlson's trophic status indices (Carlson 1977) for all 13 lakes were also calculated based on total phosphorus, chlorophyll a, and secchi disc transparency.

Colonizing Macroinvertebrates

Artificial substrates for colonizing macroinvertebrates were placed in St. James, Gilbert, Kinney, and Huntington pit lakes from June to August 1987. Concrete spheres of known surface area (Jacobi 1971) were used because they provided a surface similar to the rock available to benthic organisms in mine pit lakes. Spheres contained in wire baskets were placed at three different depths (Pierce and Tomcko 1989).

Benthos

Benthic macroinvertebrates were sampled in the littoral zone of St. James, Gilbert, Kinney, and Huntington lakes in August 1987. Nonparametric tests were used to compare benthos densities between pits. Shannon diversity indices were also calculated (Pierce and Tomcko 1989).

Zooplankton

Zooplankton were sampled in St. James, Gilbert, Kinney, and Huntington pit lakes in the spring, summer and fall of 1987 and winter 1988 (Pierce and Tomcko 1989). A nylon plankton net was towed vertically at dusk at the deepest point in the lake.

Results

Stratification

All the pit lakes stratified thermally, with the thermoclines in midsummer occurring between 3-6 m. The shallowest thermocline (Stubler pit lake) was located at 4-7 m and the deepest (Embarrass and St. James pit lakes) between 7-13 m in the water column. Surface water temperatures reached a maximum of 21-24 C during July.

In addition to thermal stratification, Miners, Pennington, and Sagamore lakes showed evidence of chemical stratification in all seasons. The evidence consisted of increased conductivity and temperature with depth in the hypolimnion. For example, conductivity measured in July nearly doubled, increased from 421 to 820 micromhos/cm as the depth increased from 45 to 55 m in the water column of Pennington lake (Figure 1). July water temperatures below the chemocline were higher than in other levels of the hypolimnion. Water temperatures in Pennington lake were 5-6 C from 14-45 m but increased to 8 C below 45 m (Figure 1).

Thermal or chemical stratification resulted in depletion of dissolved oxygen in hypolimnia of half of the lakes (Pierce and Tomcko 1989). Dissolved oxygen levels near zero were recorded from Forsyth, Miners, Mott, Pennington, Sagamore, and Stubler lakes in July. Dissolved oxygen levels less than 5 mg/l were first encountered between depths of 6-30 m in those lakes. The other lakes maintained well-oxygenated water (7-12 mg/l) in depths down to 67 m. All but the shallowest lake, Stubler, exhibited positive heterograde oxygen curves in midsummer (Figure 1).

Water Chemistry

Measurements of all water quality parameters varied greatly during the study (Pierce and Tomcko 1989). In spite of differences in water quality observed among lakes, some consistencies were also noted. High sulfate concentration was one of the more distinguishing characteristics of mine pit lake water quality. Sulfates ranged from 10-400 mg/l with an overall mean epilimnetic value of 69 mg/l (Figure 2). In contrast, most Minnesota lakes have sulfate concentrations of 10 mg/l or less.

Hardness and total alkalinity levels were also high. Most lakes contained hard (121-180 mg-$CaCO_3$/l) or very hard (greater than 180 mg/l) water (Pierce and Tomcko 1989). Hardness was comprised mostly of calcium and magnesium. Total alkalinity in the mine pit lakes ranged from 77-439 mg-$CaCO_3$/l with an overall mean epilimnetic value of 132 mg/l (Figure 2). In comparison, median total alkalinity for natural lakes in northeast Minnesota is 75 mg/l.

Fertility

Total and ortho phosphate levels in the lakes were indicative of low fertility. Mean total phosphates in epilimnetic waters were less than 0.02 mg/l in every lake except Pennington (Figure 2), which may be receiving nutrient contamination from an adjacent pit lake. Mean epilimnetic ortho phosphate concentration for each study lake was less than 0.01 mg/l.

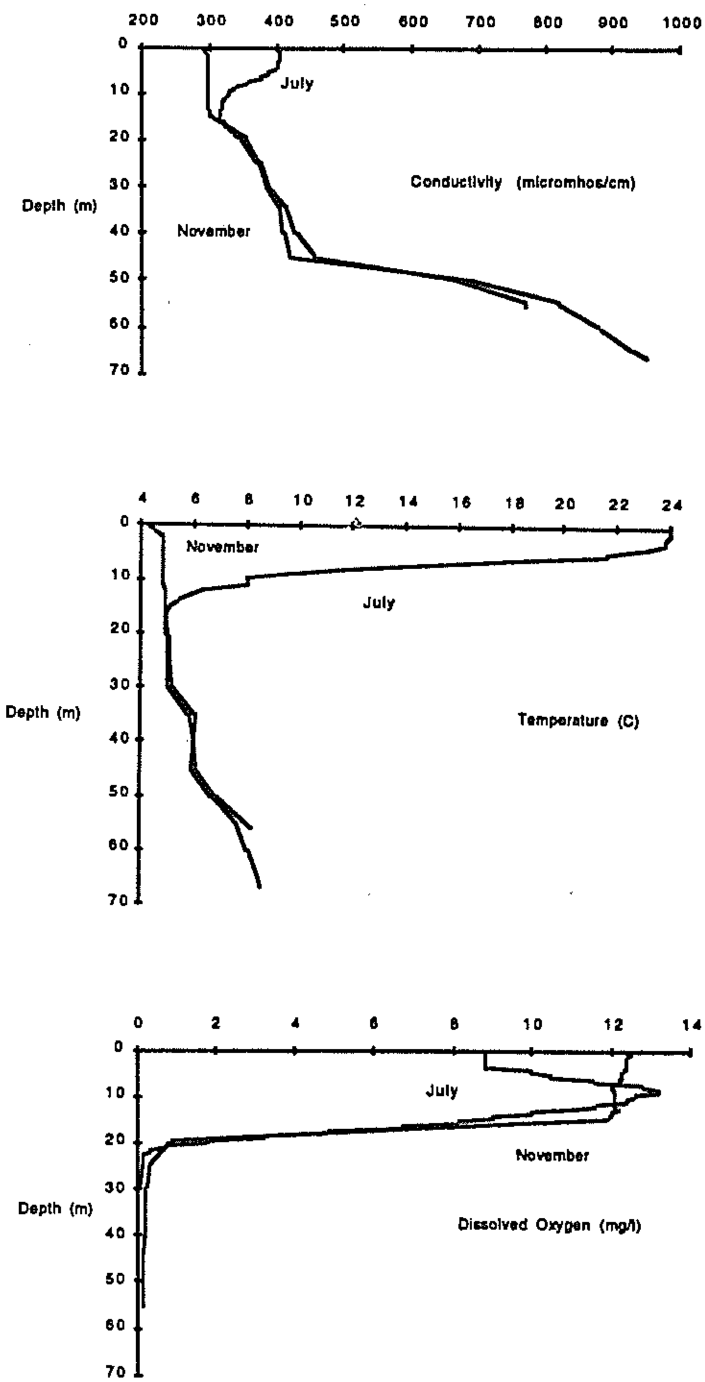

Figure 1. Conductivity, temperature, and dissolved oxygen profile for Pennington mine pit lake, 11 July and 23 November 1987.

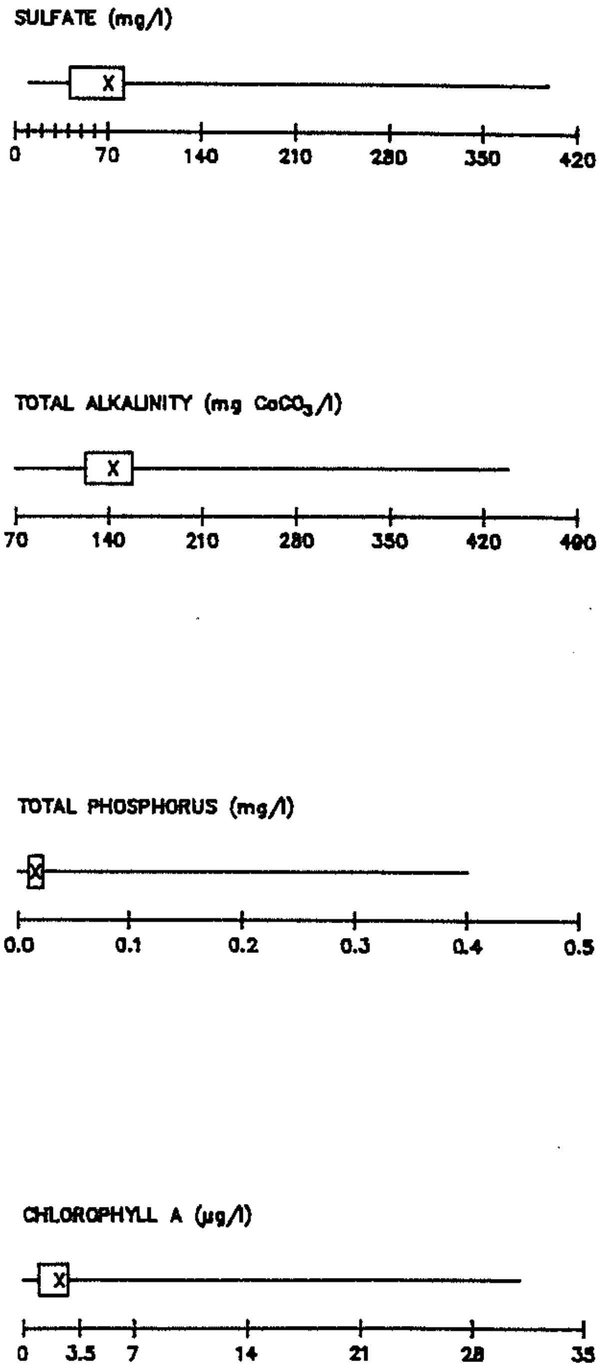

Figure 2. Box and whisker plots for sulfate (mg/l), total alkalinity (mg $CaCO_3$), total phosphorus (mg/l), and chlorophyll a (ug/l) measured in thirteen mine pit lakes in northeast Minnesota in 1987-88. In the plots, X denotes the mean, the box encompasses the middle half of the data, and the whiskers indicate 'typical' data values (Velleman and Hoaglin 1981).

Mine pit lakes were fertile with respect to inorganic nitrogen but organic nitrogen concentrations were typical for northeast Minnesota.

Indices of Productivity and Trophic Status

Algal biomass, as measured by the indicator chlorophyll a, was highest in July (mean in epilimnetic samples - 2.4 micrograms/l, Figure 2) and slightly greater than might be expected in lakes that are typically managed for trout (1-2 micrograms/l).

The morphoedaphic indices (MEIs) calculated for the four mine pit lakes ranged from 2.8-4.7. In comparison, MEIs for nine trout lakes in Ontario ranged from 2-10 (Ryder et al. 1974).

Carlson's trophic status indices are numerical rankings of a lake's trophic condition on a scale of 0-100 with 0 representing hypotrophy (or oligotrophy), 50 representing mesotrophy and 100 indicating hypertrophy. Carlson's indices calculated for the mine pit lakes classified them as intermediate between oligotrophy and mesotrophy.

Colonizing Macroinvertebrates

Both density and species diversity of invertebrates colonizing artificial substrates were low, especially below the littoral zone. Invertebrate densities ranged from 0-2452 organisms/m^2 (Table 2). The highest number of taxonomic groups sampled was 9 taxa, on spheres placed at the shallowest depth, less than 5 m.

Table 2. Total densities (organisms/m^2) of invertebrate taxa sampled with artificial substrates suspended at various depths in St. James and Gilbert mine pit lakes. Depths (m) were estimated using sonar. One organism per substrate equals a density of 43.1 organisms/m^2.

Mine pit lake			
St. James		Gilbert	
Depth	Density	Depth	Density
3	517	5	2452
8	129	9	43
21	43	24	0

Benthos

No differences among lakes were seen in densities of benthos species common to the four sampled lakes. Mean density of benthic species was low (605-3755 organisms/m^2, Table 3). Chironomidae or oligochaetes were the most important taxa. Shannon diversity indices ranged from 0-2.5 with 9-14 taxa found in each lake.

Table 3. Mean and total densities (organisms/m^2) of benthic invertebrate taxa in ponar samples from St. James, Gilbert, Kinney, and Huntington mine pit lakes on 11 August 1987. For mean density, percent of total density is in parentheses.

Pit	Mean density		Total
Lake	Chironomidae	Oligochaeta	density
St James	560 (74)	-	759
Gilbert	1264 (34)	129	3755
Kinney	237 (39)	108 (18)	605
Huntington	1236 (34)	1667 (46)	3620

Zooplankton

Mean total zooplankton density for each pit in each sampling period varied from 0.5-11.0 organisms/l (Table 4). A majority of samples contained less than 5 organisms/l. Three taxa dominated the zooplankton communities though some seasonal changes in relative abundance of these taxa were observed. Calanoida, Cyclopidae and Daphnia spp. contributed 78-99% of the total densities of zooplankton measured.

Table 4. Total densities (organisms/m^2) of zooplankton taxa for three replicate tows from St. James, Gilbert, Kinney, and Huntington mine pit lakes.

	Month				
Mine pit lake	May	Jun	Aug	Sep	Jan
St James	1	3	2	2	1
Gilbert	2	1	2	1	2
Kinney	6	11	5	2	2
Huntington	4	4	5	6	3

Discussion

Statification and Water Chemistry

Chemical and thermal stratification reduced the total volume of water available to fish in midsummer but did not affect dissolved oxygen in depths where preferred temperatures for trout were found. Except for the smallest lake, Stubler, depths of preferred temperatures for rainbow trout and lake trout (Becker 1983) were well-oxygenated.

With some notable exceptions, water quality in the mine pit lakes met standards proposed for trout and salmon culture (Piper et al. 1982) and criteria for aquatic life adopted by the Minnesota Pollution Control Agency (MPCA 1986). Iron concentrations in Forsyth and Miners lakes and copper concentrations in Gilbert and St. James lakes were higher than the recommended standards. Manganese and zinc concentrations in all hypolimnetic samples were higher than the water quality criteria.

High sulfate concentrations may originate from metallic sulfide deposits such as pyrite (FeS_2) associated with iron ore. Pyrites contribute to high sulfate concentrations in surface mine lakes (Jones et al. 1985) and mine drainage (APHA 1975). Pyrites are oxidized to yield sulfates when exposed to weathering and aerated water (Hem 1975). In several water samples from the mine pit lakes we studied, sulfate levels were greater than the 250 mg/l which, if present in drinking water, induces catharsis in humans (Lind 1979). The St. James pit, which contained high sulfate levels in April, is used by the city of Aurora as a water supply source.

High sulfate levels in the mine pit lakes may indirectly affect fish by limiting their movements. High sulfate concentrations apparently pose no risk to fish (Moyle 1956) but the reduced form of sulfate, hydrogen sulfide, is toxic in very low concentrations (Piper et al. 1982) and may restrict excursions by fish into the hypolimnion of lakes where the gas is present.

Phosphorus was the nutrient limiting primary production in mine pit lakes. Total nitrogen to total phosphorus ratios during July exceeded the range of 14-17 when phosphorus becomes limiting to algae and plants.

Invertebrate Communities

Compared to more productive waters, colonizing invertebrate and benthos densities and species diversity in the mine pit lakes were low. Density of invertebrates colonizing artificial substrates in midsummer averaged 20,000 organisms/m^2 for 12 taxa in the Upper Mississippi River (Hall 1982) and was over 150 organisms/m^2 and 7 taxa in the Ohio River (Mason et al. 1973). Total mean density of benthos sampled in eutrophic Lake St. Clair was 9,464 organisms/m^2 for 55 taxa (Hudson et al. 1986).

Benthos densities in the mine pit lakes were more comparable to densities found in relatively sterile water and to other waters associated with surface mining. Hamilton (1971) found densities of 236-3,556/m^2 in 15 oligotrophic Canadian Shield lakes. Surface coal mine lakes in Illinois and Missouri contained 274-4,321 organisms/m^2 and 7-51 taxa (Jones et al. 1985). Somewhat higher densities, 5,222-7,840 organisms/m^2, were found in two ponds receiving coal mine drainage in Colorado (Canton and Ward 1981). The low numbers and small sizes of invertebrates that we observed may be due to some combination of the young age and low productive capacity of the pits as well as heavy predation by stocked trout.

Shannon-Weaver diversity indices for benthos samples were low compared to natural lakes. Shannon diversity indices in natural lakes typically range from 3-4 but can be less than one in stressed environments. Jones et al. (1985) found diversity indices for benthos ranged from 0.6-4.2 in surface coal mine lakes in Illinois and Missouri. Ponds receiving coal mine drainage in Colorado had diversity indices for benthos ranging from 2.5-3.0 (Canton and Ward 1981).

Zooplankton densities were lower than or similar to densities measured in natural oligotrophic or in mesotrophic lakes. Balcer (1988) reported mean concentrations of 19.6 organisms/l in western Lake Superior. Watson and Wilson (1978) reported crustacean densities ranging from 0.4-5.2 organisms/l in a lake-wide survey of Lake Superior. Whiteside et al. (1985) found total densities of 35.3-69.0 organisms/l in the mesotrophic Lake Itasca, Minnesota.

Zooplankton concentrations were similar to concentrations in other surface mine lakes. Two ponds at a coal mine in Colorado had 6-36 organisms/l (Canton and Ward 1981). Tews (1986) recorded mean seasonal densities of 3-13 organisms/l from a coal sediment pond in Montana. Three other iron mine pit lakes in northeast

Minnesota contained 3-24 organisms/l (Margaret Rattei, Barr Engineering Co., personal communication 1988).

Productivity

Evidence that the mine pit lakes are relatively unproductive was obtained from measurements of phosphorus, the morphoedaphic index, and from the low abundance of benthos and colonizing invertebrates. MEIs were low because the deep, steep-sided nature of the pits was reflected in mean depths used to calculate the MEIs. The steep-sided nature of the pits restricts to a small area the distribution of rooted macrophytes, and thus the invertebrates and fish which use macrophytes.

This study also provided evidence that mine pit lakes have the potential to become more productive if additional phosphorus becomes available as they age. Evidence consisted of high levels of nitrates and dissolved materials in the water, chlorophyll a measurements, and Carlson's trophic status indices which were higher than expected.

One possible technique to increase productivity in mine pit lakes would be to alter shoreline of the mine pits before they are filled. Mitigation procedures requiring the steep slopes to be made more gradual would result in more productive, shallow, littoral areas in the mine pit lakes. The entire shoreline need not be altered. Buckeye mine pit lake, in Itasca County, has steep slopes around most of its shoreline but has one shallow bay (about 9m) which apparently produces enough food for stocked rainbow trout to exhibit good growth. Increasing littoral area will refine the reclamation technique of filling abandoned iron mine pits to form the mine pit lakes of northeast Minnesota.

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