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Limnology of Four Bauxite Open-Pit Lakes

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ABSTRACT

The aquatic flora and fauna and 18 physicochemical characteristics of four bauxite open-pit lakes were studied from September 1969 to August 1970. The least acid lake (pH 3.4-4.4) supported 49 different aquatic insects, plankton, and higher aquatic plants. The most acid lake (pH 2.7-3.2) supported only 26 different plants and animals. Bauxite open-pit lakes within the pH range studied appear to be as relatively unproductive as their coal strip-mine lake counterparts, with which they share physicochemical and biological characteristics. Benthic macrofaunal diversity and abundance appear to be related more closely to distribution and abundance of leaf detritus than to hydrogen-ion concentration.

INTRODUCTION

The process of open-pit mining for aluminum ore, or bauxite, commonly leaves pits which subsequently fill with water. Initially, such lakes may contain water contaminated with sulfuric acid formed from the oxidation of sulfur compounds associated with the bauxite. To date, 2,835 ha near Bauxite, Saline County, and Little Rock, Pulaski County, Arkansas, have been mined for bauxite. As recently as 1966, 96.6% of the bauxite mined in the continental United States came from Arkansas (Stroud et al., 1969).

No investigation has been conducted previously concerning the physicochemical or biological characteristics of open-pit lakes resulting from bauxite mining (Spaulding and Ogden, 1968). A preliminary survey in Saline County, Arkansas, concerning acid water drainage from bauxite pits into nearby streams was conducted by the Arkansas Pollution Control Commission in 1964, but the resulting report had a limited distribution.

The purpose of this study is to describe qualitatively and quantitatively the physicochemical characteristics and the aquatic flora and fauna of four open-pit lakes resulting from bauxite mining. The lakes studied are 40 km southwest of Little Rock in Saline County, Arkansas. Lake 1 is in the NE ¼ Sec. 26, T2S, R15W; lake 2 is in the NE ¼ Sec. 24, T2S, R14W; lakes 3 and 4 are in the SE ¼ Sec. 11, T2S, R14W.

MATERIALS AND METHODS

Surface samples for physicochemical analysis and qualitative samples of the aquatic insects were collected monthly from each lake from September 1969 through August 1970. In addition, during June-August 1970, monthly quantitative samples of benthos and plankton and vertical series for physicochemical analysis were taken from each lake. The vertical series consisted of a surface sample, one at a depth one-half the distance of the bottom, and one near the bottom.

Potential free acidity of 59 water samples was determined by hot titration (Rainwater and Thatcher, 1960); pH by Beckman Expandomatic pH meter; specific conductance by wheatstone bridge; NO_3 by phenoldisulfonic acid method, SO_4 by turbidimetric method, and Al by spectrophotometric method (APHA, 1965); and Ca, Co, Cu, total Fe, K, Mg, Na, Ni, Sr, and Zn by atomic absorption (Reid, 1970).

Bottom samples (48) were secured from the shallow and deep parts of each lake with a 15.2 x 15.2-cm Ekman dredge, washed through a screen of 11.8 sq/linear cm, preserved in 5% formalin, and later sorted mechanically and transferred to 70% ethanol. Qualitative samples were procured with a dip net. Sample size for net plankton was 100 l, obtained by a Kemmerer water bottle and strained through a standard Wisconsin net of No. 25 nylon bolting cloth. Preservtion was by 70% ethanol. Plankton enumeration was by the differential count method (Welch, 1948). Triplicate determinations of primary production in lakes 3 and 4 on 18-19 July were by a modification (McConnell, 1962) of the diel oxygen curve procedure of Odum (1956) and Odum and Hoskin (1958), which are methods especially applicable to small, quiet bodies of water.

RESULTS AND DISCUSSION

The salient physicochemical feature of the four lakes studied is the clear, highly acid nature of their waters. The source of acidity is apparent inasmuch as the sulfate ion is the predominant anion, 106-1130 ppm (Table I). The acid nature of these waters is reflected further in the pH values, range 2.7 to 4.4, and potential free acidity, range 11 to 497 mg/l. The acid condition facilitates the solution of many other minerals. Aluminum, calcium, magnesium, and sodium are present in high concentrations. The heavy load of dissolved materials results in high specific conductance values, range 180 to 1940 mhos at 25 C. The high hydrogen-ion concentration flocculates the naturally occurring suspended clay particles of waters in the study area, resulting in such clarity that objects on the lake bottom may be seen at depths of up to 7.5 m.

The morphometry of these lakes augments both degree and duration of acid pollution. Steep slopes and restricted watershed, consisting largely of spoil banks, are characteristic of all four lakes.

Seasonal fluctuations in the ionic concentrations of the bauxite-lake surface waters were not great and their patterns were not discernable. Whereas some ions decreased during the winter, others increased or remained relatively constant. Also, the pattern for a specific ion varied between lakes. Although thermal stratification occurred during the summer, vertical distribution of the ionic concentrations was essentially constant, suggesting a homogenous condition for these waters.

Table I. Mean Values for Physicochemical Characteristics of Four Bauxite Open-Pit Lakes, Saline County, Arkansas, September 1969-August 1970 (sample numbers were 12 for lakes 1 and 2, 18 for lakes 3 and 4).

Item	Lakes 1	2	3	4
Approximate year formed	1960	1948	1948	1948
Maximum depth (m)	2.5	8	18	8
Specific conductance (υmhos@25C)	302	1198	1044	1564
pH	3.9	2.9	3.4	2.9
Potential free acidity (mg $CaCo_3$/1)	44	282	194	433
Sulfate (ppm)	132	443	575	879
Nitrate[1] (ppm)	0.08	0.12	0.13	0.13
Aluminum (ppm)	5.2	24.3	23.5	49.7
Calcium (ppm)	18	47	110	120
Cobalt (ppm)	0	0.4	0	0.3
Copper (ppm)	0.04	0.1	0.3	0.2
Total iron (ppm)	0.2	10.3	0.4	13.9
Magnesium (ppm)	6.2	13.4	31.2	29.5
Nickel[1] (ppm)	0	0	0	0
Potassium (ppm)	2.9	3.9	5.4	3.87
Sodium (ppm)	6.1	7.1	18	13.8
Strontium (ppm)	0.9	1.8	4.0	4.0
Zinc (ppm)	0.21	0.27	0.45	0.78

[1] One or two determinations only.

If decline in potential free acidity is used as a criterion for ecological age of an acid lake, lake 4 appears to be the youngest, followed in order by lakes 2, 3, and 1. As noted in acid coal strip-mine lakes (Campbell and Lind, 1969), a distinct reduction in specific conductance is associated with a decrease in acidity; ionic concentrations in general diminish with decreasing acidity (Table I).

It has long been recognized that species diversity decreases with increased pollution (Patrick, 1950). In this study, lake 1 supported 35 different aquatic insects (Table II). Four species of higher aquatic plants (*Typha angustifolia* Linnaeus, *Juncus diffusus* Bulk., *Scirpus atrovivens* Willd, and *Sphagnum magellanicum* Brid.) and 10 plankton taxa (Table III) also were described from lake 1. It was the least acid lake (Table I). Conversely, the most acid lake, lake 4, supported only 16 different aquatic insects, one higher aquatic plant, *Typha angustifolia*, and nine plankton taxa (Tables I-III).

Table II. Aquatic Insects in Four Bauxite Open-Pit Lakes: Frequency of Occurrence in 12 Monthly Samples, September 1969-August 1970

Taxa	Lake 1	2	3	4
DIPTERA				
Ceratopogonidae	0	3	0	0
Chironomus n. sp.	9	11	6	7
Culex territans Walker	1	0	0	0
Tabanus sp.	1	0	0	0
COLEOPTERA				
Onychylis nigrirostris (Boh)	2	1	0	0
Agabus disintegratus (Crotch)	0	1	0	1
Coptotomus interrogatus obscurus Sharp	5	9	2	0
Cybister fimbriolatus crotchi Wilke	0	0	0	1
Cybister L[1]	2	0	0	0
Graphoderus sp.	0	1	0	0
Hydroporus consimilis LeConte	0	9	0	0
H. pilatei Fall	0	5	0	1
Ilybius confusus Aubé	2	0	0	0
Ilybius L[1]	1	1	0	0
Laccophilus maculosus maculosus Say	3	0	9	2
Laccophilus L[1]	1	0	2	1
Thermonectus basillaris Harris	1	4	0	2
T. ornaticollis Aubé	2	0	1	0
Dineutus assimilis (Kirby)	12	11	11	6
D. carolinus LeConte	1	0	0	0
Dineutus L.[1]	2	4	3	1
Gyrinus affinis Aubé	0	3	4	3
Haliplus triopsis Say	1	4	0	0
Peltodytes dunavani Young	0	2	0	0
Berosus fraternus LeConte	0	1	0	0
B. infuscatus LeConte	1	1	3	0
B. pallescens LeConte	0	3	2	0
B. pennsylvanicus Knisch	10	7	9	5
Berosus L.[1]	5	3	4	0

Enochrus ochraceus (Melsh.)	1	1	1	0
Helophorus sp.	1	0	0	0
Paracymus subcupreus (Say)	1	0	1	0
Tropisternus lateralis nimbatus (Say)	5	6	5	3
Hydrocanthus iricolor atripennis Say	0	1	0	0
Suphisellus bicolor (Say)	0	1	0	0
MEGALOTA				
Chauliodes	2	1	0	0
Sialis	6	10	0	0
ODONATA				
Anax junius (Drury)	7	2	2	3
Celithemis elisa (Hagen)	2	0	0	0
Ladona sp.	1	0	0	0
Libellula luctosa Burmeister	1	0	0	0
Sympetrum madidum (Hagen)	2	0	0	0
Tramea lacerata Hagen	8	0	0	0
Enallagma	1	0	0	0
Ischnura	5	0	0	0
HEMIPTERA				
Lethocerus griseus (Say)	0	0	0	1
Hesperocorixa sp.	0	1	0	0
Sigara pectinata (Abbott)	0	5	6	10
Gerris marginatus Say	3	1	1	1
Trepobates inermis Esaki	1	0	0	0
Hydrometra martini Kirkaldy	1	2	4	0
Buenoa confusa Truxal	5	1	0	0
B. scimitra Bare	0	1	2	0
Notonecta indica Linnaeus	9	1	2	1
Mesovelia mulsanti White	3	0	4	5
Total Taxa	35	32	19	16

[1] L=larval beetle.

Typha angustifolia was the only higher aquatic plant in lakes 1, 2, and 3, and in each instance it was limited to a small delta which was caused by erosion and covered by shallow water. The senior author has observed that this cattail species is the first higher aquatic plant to invade coal strip-mine lakes with an approximate pH value of 3.6 or less. Only with diminished acidity do other species appear.

Qualitatively and quantitativley the plankton community was limited in all four lakes. Each lake supported 9-10 taxa and a standing crop of 0.5-29 organisms per liter (Table III). Nelson and Harp (in press), studying the new plankton of a relatively unproductive lake, reported a mean summer standing crop of 284 organisms per liter, representing 55 genera. In lakes devoid of limiting factors, mean annual standing crop values commonly reach several hundred thousand organisms per liter or more (Harris and Silvey, 1940; Pennak, 1946, 1949).

The most diverse community in these acid lakes was the benthic macrofauna. Even their diversity was limited in comparison with unpolluted lentic communities of similar size. Harp and Campbell (1964) reported 79 benthic macroinvertebrate taxa from a Missouri pond. Kenk (1949) recorded 79-127 benthic faunal forms from four ponds in Michigan.

The paucity of benthic macroinvertebrate species in the acid bauxite lakes is emphasized when one realizes that most species found were not present throughout a given lake. Characteristically, many were found only in the restricted stands of cattails. The quantitative data further support this observation. The benthic fauna ranged from 511 (lake 1) to 5479 organisms per square meter (lake 2). The larger populations were invariably in the deep water and were composed almost entirely of *Chironomus* n. sp. Presumably this species is favored by an acid environment. Because it can develop in these acid waters, it profits from the lack of competition (e.g. other chironomids) and predation (fish) and builds these characteristically dense populations (Harp, 1969).

The absence of benthic macrofauna other than insects is due to the absence of calcium carbonate for shell development in mollusks. Also, the epidermis of soft-bodied forms is susceptible to potential coagulation in this mineral-acid environment.

Species diversity did not correlate precisely with hydrogen-ion concentration. The second most acid lake supported the second largest number of species, 42, whereas only 29 taxa were identified from the less acid lake 3. The writers observed a closer relationship between species diversity and the distribution and abundance of leaf detritus. Lakes 1 and 2 have trees around significant portions of their shorelines, whereas lakes 3 and 4 have practically none. The leaf detritus apparently provides shelter and a direct or indirect food source for the aquatic insects in an otherwise barren habitat. Harp and Campbell (1967) first reported this correlation between leaf detritus and a midge larva which was identified mistakenly as *Tendipes plumosus* Linne[4]. In fact it is a still undescribed species, which was taken from the acid bauxite lakes by the writers and is designated as *Chironomus* n. sp. (Table II).

The primary production in lakes 3 and 4 on 18-19 July 1970 was nonexistent. Differences in dissolved oxygen values never varied more than 0.5 ppm in triplicate series, and dawn values

Table III. Net Plankton Collected in Surface Samples from Four Bauxite Open-Pit Lakes, Saline County, Arkansas, June-August 1970

Taxon	Lake									
	1		2		3			4		
	6/27	8/15	6/27	8/15	6/27	7/18	8/15	6/27	7/18	8/15
Cladophora			X							
Mougeotia			X					X	X	
Zygnema			X							
Arcella	X	X	X	X		X	X	X	X	
Difflugia	X				X	X			X	
Ceratium		X	X	X		X		X		
Diatoma	X									
Brachionus	X	X	X	X	X	X	X	X	X	X
Keratella					X	X		X		
Notholca		X	X							
Tetramastix	X				X	X	X	X	X	
Tardigrada		X								
Ostracoda						X				
Calanoida									X	
Cyclopoida	X					X				
Nauplii	X		X	X		X				
Ceriodaphnia	X	X	X	X	X	X	X	X	X	X
Hydracarina		X								
Total No./Liter	11	2	5	0.5	8	3	29	3	1	4
Total Taxa/Lake	10		9		9			9		

after presumed respiration all night were on occasion higher than the preceding dusk values. Minute changes in dissolved oxygen content were probably due to temperature change and simple diffusion.

In conclusion, the four bauxite open-pit lakes appear to be relatively unproductive. They can be compared with coal strip-mine lakes of similar pH, with which they share physicochemical and biological characteristics (Campbell and Lind, 1969; Harp, 1969). Finally, within the pH range studied, benthic macrofaunal diversity and abundance appear to be more responsive to distribution and abundance of leaf detritus than to hydrogen-ion concentration.

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