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FISHERIES DIVISION

TECHNICAL REPORT

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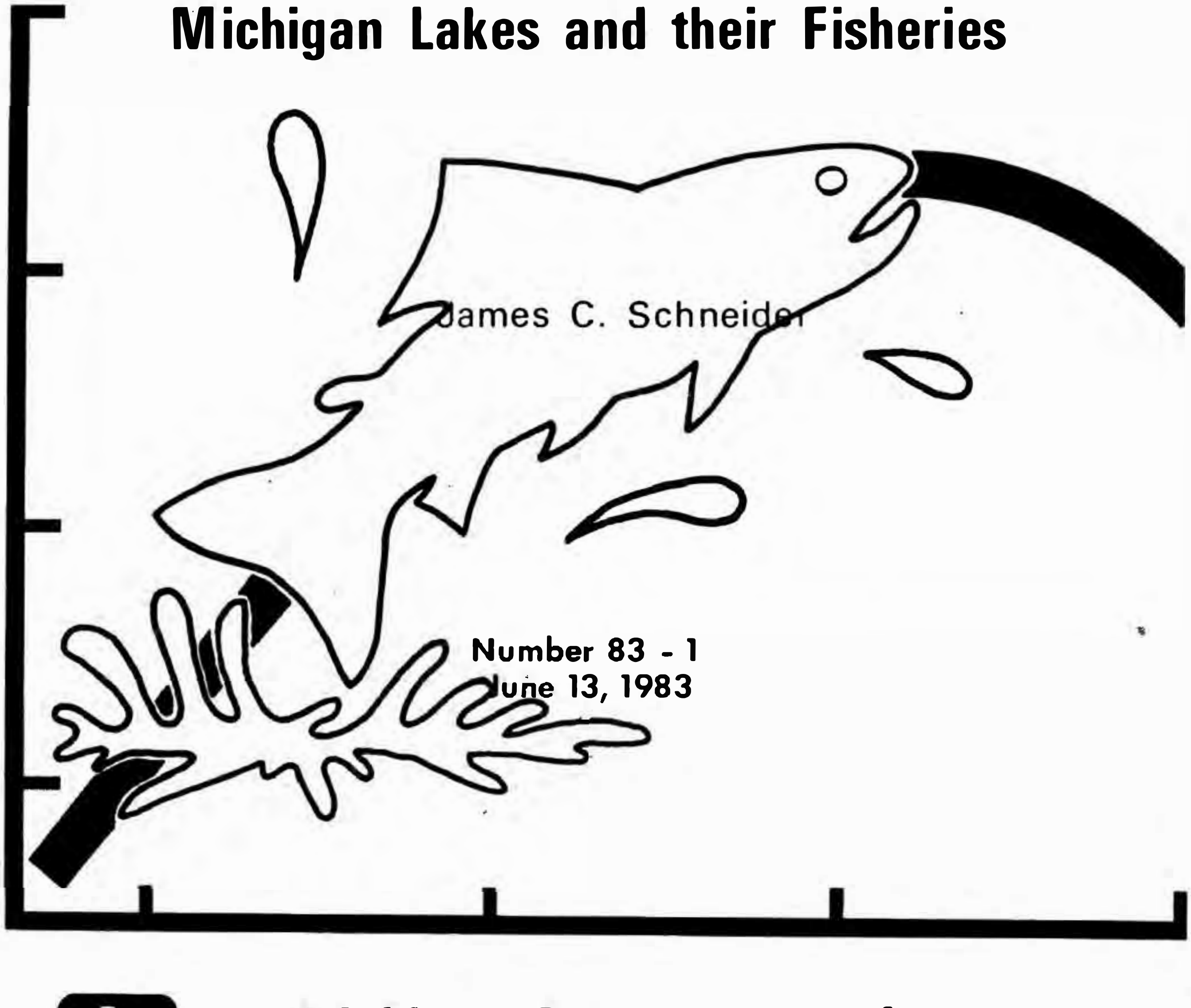

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Introduction

"Acid rain" is a term applied to rain and snow with a pH lower than 5.6, the theoretical norm. Haines (1981) recently published a very thorough review of the acid rain problem which contains a wealth of information useful for focusing on the significance of the problem to lakes in Michigan.

Acid rain is largely the result of discharges of sulfur (SO_2) and nitrogen (NO_x) into the atmosphere. During the last 30 years the pH of rain has markedly decreased in areas downwind of industrial-urban complexes. By the 1970's, the average pH of precipitation falling on a large area of eastern North America had dropped to 4.2. For the Lower Peninsula of Michigan, the average pH of rain and snow decreased from 4.7-5.6 (lowest in the southeastern corner) in the mid-1950's, to 4.7 in the mid-1960's, to 4.4-4.7 in the early 1970's, to 4.4 in 1979. For the Upper Peninsula, the pH of precipitation declined from 4.7-5.9 in the mid-1960's and early 1970's to 4.4-4.6 in 1979.

Acidification of lakes by contaminated rain and snow is a world-wide problem of great magnitude. Hundreds of fish populations have been destroyed in Ontario, New York, and Scandinavia in recent decades and thousands more are in jeopardy.

Lakes with low concentrations of carbonates (poorly buffered, soft water) are the most vulnerable to acidification and subsequent ecological change. Acid precipitation lowers the pH of the water, enhances the toxicity of trace amounts of dissolved metals, and induces stress on aquatic organisms of all types. Organisms may be killed outright, suffer reproductive failure or poor growth, or lose out in competition with acid-tolerant species.

Status of Michigan Lakes

So far as is known, acid precipitation has not yet damaged lakes or fisheries in Michigan. Since 1930, measurements of pH and alkalinity have been made at many lakes during fisheries surveys. Close inspection of these data reveal that they are not adequate for detecting a trend. However, they do provide some baseline information for future monitoring.

Some insight into the potential effects of acid fallout on the state's lakes can be gained by considering the following questions. First, how many lakes are poorly buffered and, therefore, are susceptible to acidification? Second, what is the relationship between alkalinity (easily measured and already known for many lakes) and pH (difficult to accurately measure and unknown for many lakes)? Third, what is the relationship between pH and fish populations?

Lake alkalinities

Earlier I reviewed data on the methyl orange alkalinities of Michigan lakes which had been collected by the Fisheries Division (Schneider 1975). Poorly buffered lakes, with alkalinities of 0-19 ppm $CaCO_3$, comprised 20% of the statewide sample. They were concentrated in the Upper Peninsula, and to a much lesser extent in Osceola, Lake, and Kalkaska counties. The low lime content of these waters can usually be attributed to small watersheds, basins of acidic sand or bedrock, or dystrophic conditions.

Soft-water lakes make up a large fraction of the lakes in the Upper Peninsula, especially in Gogebic, Houghton, Baraga, Iron, Marquette, and Alger counties (Table 1). Out of 551 Upper Peninsula lakes which have been sampled, 49% had alkalinities of 0-19 ppm, and about 34% (187) were just 0-10 ppm. It is difficult to expand these percentages to the entire lake resource because this sample may not be representative, the number of water bodies in the Upper

Peninsula is not precisely known (published estimates of the number of water bodies in the Upper Peninsula range from 4,303 to 12,775), and an unknown fraction (probably large) of the lakes are too shallow to support sport fish.

Relationship between alkalinity and pH

Unfortunately, alkalinity and pH are not strongly correlated for Michigan lakes (Fig. 1). Thus critical changes in pH cannot be reliably predicted from existing alkalinity data. Figure 1 is based on one sample from each of 114 lakes. The samples were taken between 1930 and 1964, a period when standard methods were used for determining methyl orange alkalinity and colorimeters (Hellige) were used for estimating pH as low as 5.2. These methods may have somewhat overestimated pH and alkalinity in soft-water lakes (Haines 1981).

Note that extremely soft-water lakes ranged from pH 7.3 to less than 5.2. Generally, lakes less than 10 ppm were acidic. An extensive bog mat was often a fairly reliable indicator of acidity but brown water color was not.

The pH of soft-water lakes may vary considerably from one year to the next (as well as diurnally and seasonally). At Sid Lake, Luce County, surface alkalinity has varied from 1 to 4 ppm and pH from 4.0 to 5.9 over several years of observation (M. Galbraith, personal communication). Such variation makes it difficult to determine long-term trends in acidification or net effects on aquatic organism.

Relationship between fish and pH

The effect of falling pH on fish populations is a function of species, life stage, and synergism with toxic metals, so it is not easily predicted. Poor recruitment is often the first signal of acidification because eggs, embryos, and juveniles are usually more sensitive than adults (Haines 1981).

Based on the literature summarized in Table 2, the following sequence is likely as pH declines. As pH falls below 6 populations of walleye, smallmouth bass, rainbow trout, common shiner, bluntnose minnow, Iowa darter, and johnny darter may be impaired. Before pH 5 is reached brown trout, northern pike, golden shiner, white sucker, brown bullhead, largemouth bass, rock bass, and pumpkinseeds may be effected. By the time pH 4 is reached even the most acid tolerant species -- bluegill, yellow perch, lake herring, and brook trout -- will have been eliminated.

Lakes too acidic to support sport fisheries seem to be relatively rare in Michigan at present. Readings between pH 4 and pH 5 are on file for only seven lakes. For six of these lakes measurements were made with Hach colormetric equipment; for one of the lakes a more accurate electronic pH meter was used. The lakes contained fish, but at some of these lakes (plus a few others) there have been problems, which seem to be pH related, in establishing or maintaining a sport fishery.

The presence or absence of fish species were tabulated in relation to pH for Michigan's soft-water lakes. The pH of the most acidic lake in which each species lived is given in Table 2. Generally, these values are compatible with those in the literature, considering that (1) the accuracy of the lowest pH values is questionable (note smallmouth bass, northern pike, bluegill, and yellow perch at pH 4.0), and (2) absence of a species from lakes of lower pH may have been due to other reasons (e.g., lack of spawning habitat for walleye). The Michigan data confirm that walleyes, bluntnose minnows, and possibly other forage fish are relatively sensitive to acidity. This has implications for the management of walleye fisheries in particular.

Management Implications

Acid rain poses a threat to a significant number of Upper Peninsula lakes and fisheries. The pH of the poorly buffered lakes will decline, approaching that of rainwater -- currently about 4.4. In addition, large diurnal and seasonal fluctuations in pH will increase the stress on fish and other aquatic organisms.

As lake pH falls below 6, the effects on fish populations are likely to become evident and fisheries management will have to adjust accordingly. Walleye recruitment will be affected first. It will probably not be possible to manage lakes of pH less than 5.5 for walleyes. Smallmouth bass are fairly sensitive to pH also. As pH drops below 5.0 management will be restricted to perch, bluegills, largemouth bass, and stocked trout. By the time pH reaches 4.0, probably no fishery can be maintained. Management options may improve if acid-tolerant strains of fish can be developed (Haines 1981).

Liming may be a cost-effective management tool for acid Michigan lakes with high fisheries potential. Liming experiments were conducted in Michigan and Wisconsin during the 1940's and 1950's (Waters 1957; Waters and Ball 1957; Hasler et al. 1951; Johnson and Hasler 1954; Stross and Hasler 1960). The results were not consistent but were basically favorable. Alkalinity, pH, and dissolved phosphorous were raised, and sometimes brown color was reduced and fish production improved. More lime was required to effect chemical changes than anticipated because bottom soils tied up much of the lime. It was concluded that periodic treatment would be required to prevent reacidification.

Waters (1957) and Waters and Ball (1957) worked on two meromictic bogs and a shallow, sandy-bottomed lake in Michigan. For the bogs, much lime and phosphorus (regenerated within the lake) became locked up in the hypolimnion and was unavailable for production. The pH improved from 5 to 6-7 in one lake and from 5 to 7-8 in the other lake. Liming did not clear the brown color. For the more typical lake with a sandy bottom, addition of hydrated lime and limestone at the rate of 238 pounds per acre-foot of lake water over a 10-year period resulted in a modest improvement in the growth of stunted perch and some increase in the aquatic weed *Myriophyllum*, but no clearing of the brown coloration. Alkalinity increased only from 6 to 14 ppm and pH remained near 7.

Currently, millions of dollars are being spent liming acid waters in New York, Ontario and, especially, Scandinavia (Haines 1981). Generally, mixtures of hydrated lime and limestone are applied at rates of 10-20 g/m^3 (25-50 lb/acre-ft). Cost estimates in New York range from \$55 to \$420 per hectare, and averaged \$150 (\$60 per acre). Populations of sport fish have been restored in most of the limed waters, but a transition period, sometimes as long as a couple of years, may be required for organisms of all types to recover from the abrupt chemical changes caused by liming. Some limed lakes have remained toxic to fish, apparently because concentrations of toxic metals remained too high.

Table 1. Total number of lakes, and the methyl orange alkalinity of lakes that have been sampled, in the Upper Peninsula of Michigan (Schneider 1975).

County	Total lakes[a] per Brown	per Humphrys	Number sampled	Alkalinity in ppm 0-19	20-39	40-200
Western Upper Peninsula						
Gogebic	488	1,133	77	51	14	12
Ontonagon	81	592	17	9	4	4
Houghton	197	1,248	30	22	5	3
Keweenaw	125	349	8	--	5	3
Baraga	206	1,080	27	21	4	2
Iron	528	2,130	77	29	12	36
Marquette	835	1,783	94	40	18	36
Dickinson	125	353	15	2	1	12
Menominee	50	75	7	--	--	7
Eastern Upper Peninsula						
Alger	253	803	68	43	11	14
Delta	148	543	15	3	3	9
Schoolcraft	340	1,035	48	15	11	22
Luce	571	692	44	26	3	15
Chippewa	169	520	14	7	1	6
Mackinac	187	439	10	1	1	8
Totals	4,303	12,775	551	269	93	189

[a] Brown (1943) estimated 4,303 lakes (and ponds) in the Upper Peninsula; Humphrys and Colby (1962) estimated 12,775. Note that many of these so-called lakes are too shallow to support sport fish.

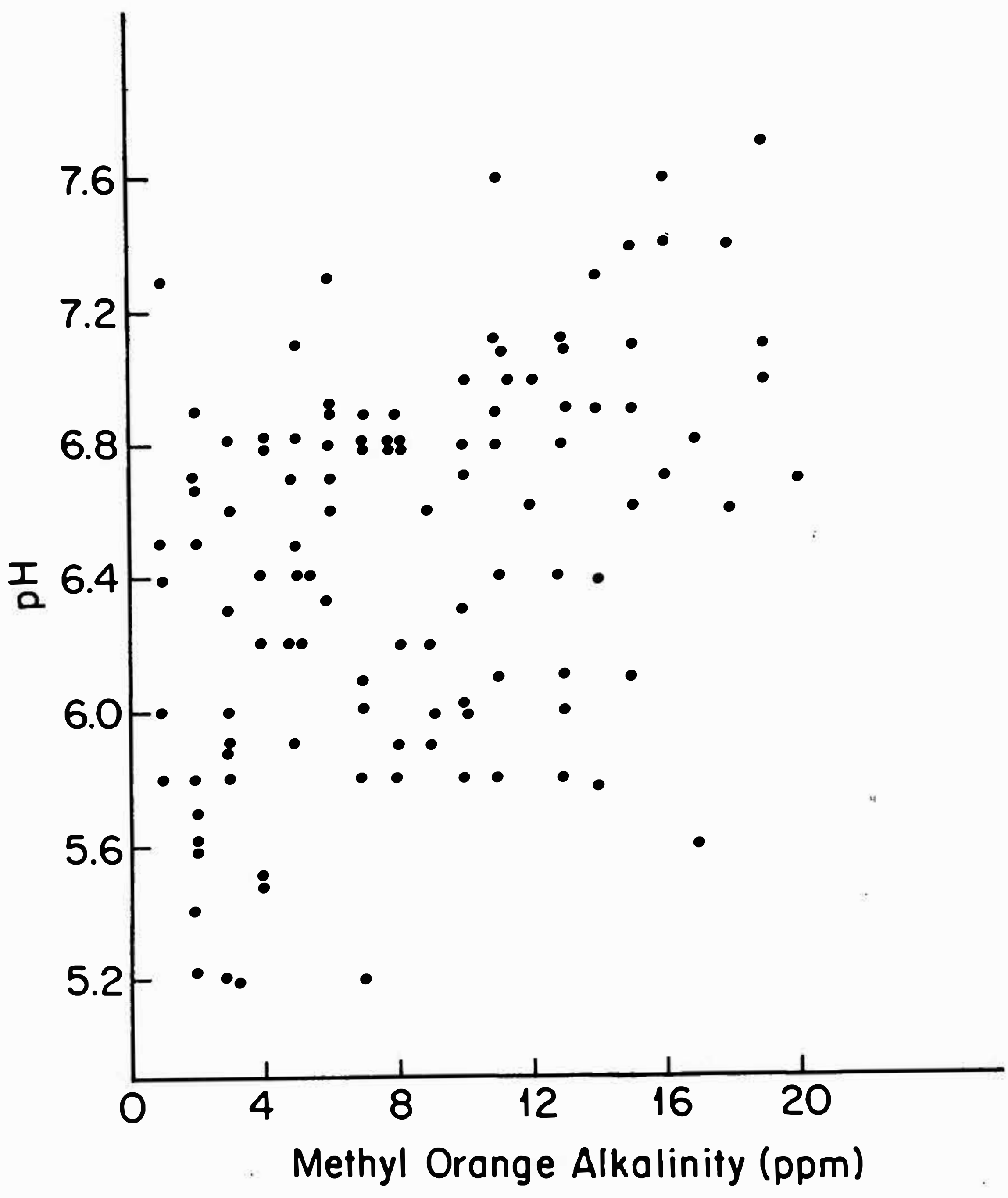
Table 2. Critical pH (range in apparent pH's at which a population ceased reproduction, declined, or disappeared from literature review by Haines, 1981) and pH of the most acidic Michigan lake in which the species is known to have lived.

Species	Critical pH in literature	Lowest pH[a] in Michigan
Lake trout *Salvelinus namaycush*	4.4-6.8	5.5
Brook trout *Salvelinus fontinalis*	4.5-5.0	4.4
Rainbow trout *Salmo gairdneri*	5.5-6.0	5.4[b]
Brown trout *Salmo trutta*	4.5-5.5	5.5
Splake *Salvelinus namaycush* *S. fontinalis*	--	5.2
Lake herring *Coregonus artedii*	4.4-4.7	5.5
Northern pike *Esox lucius*	4.2-5.2	4.0
Smallmouth bass *Micropterus dolomieui*	4.4-6.0	4.0
Largemouth bass *Micropterus salmoides*	4.4-5.2	5.4
Rock bass *Ambloplites rupestris*	4.2-5.2	5.5
Bluegill *Lepomis macrochirus*	<4.2	4.4
Pumpkinseed *Lepomis gibbosus*	<4.2-5.2	4.0
Black crappie *Pomoxis nigromaculatus*	--	5.3
Green sunfish *Lepomis cyanellus*	--	5.2
Walleye *Stizostedion vitreum*	5.2-6.0	6.0
Yellow perch *Perca flavescens*	4.2-4.8	4.0
Brown bullhead *Ictalurus nebulosus*	4.5-5.2	5.0
Black bullhead *Ictalurus melas*	--	5.0
Yellow bullhead *Ictalurus natalis*	--	5.5
White sucker *Catostomus commersoni*	4.2-5.2	5.2
Brook stickleback *Culaea inconstans*	--	4.0
Mudminnow *Umbra limi*	--	4.5
Johnny darter *Etheostoma nigrum*	5.0-5.9	5.5
Iowa darter *Etheostoma exile*	4.8-5.9	5.5
Golden shiner *Notemigonus crysoleucas*	4.8-5.2	5.4
Common shiner *Notropis cornutus*	<5.7	5.5
Fathead minnow *Pimephales promelas*	--	5.8
Bluntnose minnow *Pimephales notatus*	5.7-6.0	5.8
Blacknose dace *Rhinichthys atratulus*	--	5.5
Redbelly dace *Phoxinus eos*	--	5.5
Pearl dace *Semotilus margarita*	--	5.5
Creek chub *Semotilus atromaculatus*	--	5.5

[a] The lowest pH values were obtained with Hach kits.

[b] A previously fishless lake, in which pH has varied from 4.0 to 5.9, was successfully stocked with rainbow trout. The lowest pH the trout tolerated is not known.

Figure 1.--Relationship between alkalinity and pH for 114 soft-water Michigan lakes.



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