EFFECTS OF HYPOLIMNETIC AERATION ON NITROGEN AND PHOSPHOROUS IN A EUTROPHIC LAKE [1]

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Abstract

The effects of hypolimnetic aeration on total P, and NH_4-N in eutrophic Lake Waccabuc (N.Y.) are described. This lake was aerated for two consecutive summers, 1973 and 1974. Although reductions in hypolimnetic P concentrations appeared in the first-summer, they failed to reproduce during the second summer. NH_4-N and NO_3-N concentrations are compared to those in an unaerated control lake, Lake Oscaleta (N.Y.) and some effects are seen. The overall results suggest that the aerated lake is subjected to substantial external loading which may mask aeration effects on the internal nutrient cycle.

INTRODUCTION

Hypolimnetic aeration is a restorative technique for ameliorating symptoms of excessive nutrient flow into lakes. Hypolimnetic aeration, as distinguished from complete mixing or 'artificial destratification', retains thermal stratification of the water column while adding oxygen to the lake's deeper waters. Maintaining high oxygen concentration and thermal stratification has several advantages for lakes that would normally suffer hypolimnetic oxygen depletion. Some of these advantages are: creation of habitat suitable for the year-long survival of cold water fish, e.g. salmonids; enhancement of municipal water supplies by maintaining low temperature water with low concentrations of hydrogen sulfide, iron and manganese; restoration or creation of a habitat suitable for fish forage organisms. Fast, Overholtz & Tubb (1975) and Fast, Dorr and Rosen (1975) discuss these benefits in more detail as well as various mechanical means of adding oxygen to the hypolimnion.

Under certain circumstances, hypolimnetic aeration may do more than treat the symptoms of excessive eutrophication. Hypolimnetic aeration may reduce the release of nutrients, from bottom sediments, or increase the nutrient binding properties of the sediments. Either event ultimately may decrease the concentration of nutrients in the overlying water; and therefore reduce the amount available for plant growth. This would directly reduce eutrophication, not just treat symptoms. This report briefly discusses the rationale for believing that nutrient reduction in the hypolimnion will reduce eutrophication, and presents our observations concerning the influence of hypolimnetic aeration and nutrient concentrations in a eutrophic lake.

RATIONALE FOR EUTROPHICATION REVERSAL

Mortimer (1941) shows that P release from the sediments to the water increases when oxygen is depleted, and that P is removed from the water at relatively low oxygen levels. Mortimer suggests that the formation of nearly insoluble precipitates of P with oxidized ions of Fe and Mg are likely causes of the P removal. Graetz, Keeney and Aspiras (1973) report the bacterial oxidation of ammonia to nitrate and the physical binding of nitrate to sediments when oxygen is present. Their results also suggest a net release of N as ammonia-N from the sediments when oxygen concentrations are indetectable. We originally anticipated that aerating an anaerobic hypolimnion would reduce P and N levels in the hypolimnion, just as in Mortimer's and Graetz's laboratory columns. Further, we anticipate that the chemical and biological features that control nutrient binding or release from hypolimnetic sediments are similar in most lakes. Hence a successful demonstration of hypolimnetic aeration in one lake would strongly suggest that the same result would occur in other lakes with anaerobic hypolimnion regions.

Hypolimnetic nutrient concentrations have no immediate influence on algae, because the nutrients are available for algal growth only after thermal destratification. Nutrient concentrations at the surface directly relate to eutrophication, however. For example, P concentrations in the spring epilimnion can be used to accurately predict mean summer chlorophyll concentrations in lakes with an N:P molar ratio greater than 15 (Dillon and Rigler, 1974 and 1975). Consequently, a reduction in algal growth would be suggested if it could be shown that hypolimnetic aeration reduced springtime surface concentrations. If hypolimnetic aeration were conducted during winter in a lake with prolonged winter stratification and oxygen depletion, the effect of aeration on springtime nutrient concentrations would be more obvious. However, our study lakes have only intermittent winter stratification and they do not become anaerobic during the winter period. Hence we aerated only during the summer, and the only immediate effects on surface nutrients would occur during fall turnover. Our sampling program was not able to accurately measure the relative amounts of nutrients coming from the watershed, or those recycled within the lake, i.e. we could not measure how long the oxidation of hypolimnetic sediments during one summer would continue to affect nutrient exchange. Nor did we measure retention of nutrients in the surface waters from fall turnover to spring stratification. For most lakes, it seems likely that a reduction of fall nutrients would have a small affect on nutrient concentrations the next spring. The effect would be most significant in lakes with a low winter flushout rate, and a high proportion of internal to external nutrient loading.

LAKE DESCRIPTION AND AERATION PROGRAM

Lakes Waccabuc and Oscaleta, the former treated by hypolimnetic aeration, the latter observed as a control, are located in Westchester County, New York, some fifty-two miles north of New York City (41° 17' 30" N. and 73° 35' 00" W.). Waccabuc has a surface area of 54 ha. (124 A.) , a maximum depth of 14.5 m, and a hypolimnion volume of 7.7×10^8 1. Oscaleta has a surface area of 27 ha. (62 A.) a maximum depth of 10.5 m, and a hypolimnion volume of 2.0×10^8 1. Both lakes have been under study since mid-August 1972, and this paper presents data that were obtained through November 1974. Except for the periods Dec.-March during which the lakes were highly oxygenated and usually ice-free, temperature, dissolved oxygen, and Secchi disk data were taken weekly (Fast, et. al., 1975). The Limno® hypolimnetic aeration system used in Lake Waccabuc has been described in the paper by Fast, et. al., ibid.; it was used to aerate Lake Waccabuc between July 15, 1973 and October 15, 1973 and again between May 14, 1974 and October 27, 1974. During 1973, dissolved oxygen levels in the aerated hypolimnion of Lake Waccabuc reached 4.5 ppm by the end of the summer, starting from the mid-summer anoxic condition. During 1974, dissolved oxygen levels between 5 and 7 ppm were maintained in the hypolimnion throughout the aeration period except for short intervals when the compressor component of the system was shut off. Lake Oscaleta, the control lake, had an anoxic hypolimnion during both summer stratification periods. Thermal profiles show that the aerators had a minimal effect on thermal stratification (Fast, et. al., ibid).

METHODS

Nutrients were sampled periodically during 1973 and 1974. For most nutrient analysis, three liter samples were drawn from each of five depths at one station on each lake. For a short time, we sampled from three stations on each lake, but this procedure was discontinued when our between-station results proved similar. Subsamples were withdrawn within two to three hours after sampling. Nitrogen and phosphorous nutrients were sampled sixteen times in 1973 and only seven and five times, respectively, in 1974.

Nitrogen nutrients were analyzed in two forms: nitrate nitrogen (NO_4-N) and ammonium nitrogen (NH_4-N). Analysis of the former involved colorimetric determination following treatment of samples with a brucine sulfanilic acid solution. Analysis of the latter employed hydrochloric acid titration into a boric acid solution. Both methods are discussed in detail by Taras, Greenberg, Hoak and Rand, 13th ed., 1971. Samples were collected in Van Dorn flasks and stored in PVC containers to which 1 ml/l conc. H_2SO_4 was added as a short term preservative. On four occasions samples were frozen within twelve hours and later thawed for analysis. For the remainder of the data, processing was initiated within twelve hours following sampling. One-liter samples concentrated to 50 cc by boildown were used for NH_4-N analysis, while 4 cc samples were directly pipetted for NO_3-N analysis. Limits of accuracy in nutrient analysis come largely from reading inaccuracies of the instruments: the microburette in titration and the Beckmann spectrophotometer (model DU with 10 cm cell) in colorimetry. We estimate these limits as ± 10 µg/l for NO_3-N samples.

For phosphorous analysis, 50 cc subsamples from 5-gallon PVC containers (without preservative) were added to Kjeldahl flasks with 1 cc perchloric acid within a few hours of collection. Triplicate subsamples were analyzed for all data points except for the few instances when subsamples were lost. P analyses were also determined on all dates on water passed through a 0.45µ filter. Digestion was done in the same flask in which the subsamples were stored. Total P analyses were done according to the method of Dillon and Rigler (1974) except that we used the Kjeldahl flasks in which the samples had been stored for digestion. Samples were read in a spectrophotometer with a 10 cm path length.

RESULTS

Figure 1 and Table I show NH_4 concentrations in the hypolimnion of both aerated and control lakes rising to late summer peaks of the order of 1 mg/l. NO_3-N hypolimnetic concentrations decline throughout the summer on both lakes to levels of approximately 50-100 µg/l. These concentrations are shown in Figure 2 and Table II; for completeness, we present whole lake data in Table III.

A number of researchers (Dunst, 1974 and Lee, 1970) have predicted that a pronounced buildup of hypolimnetic nitrogen in the nitrate form, accompanied by a reduction of ammonia nitrogen is one consequence of hypolimnion aeration. This trend may be present in the data above, but the shift from NH_4-N to NO_3-N is much less dramatic than we had expected. Hypolimnetic NO_3-N did appear somewhat higher in Waccabuc during summer 1974 than it was during summer 1973, but the expected decline in NH_4-N was not present; actually, NH_4-N increased slightly during summer 1974. Nevertheless, comparison of the aerated lake with the control lake shows a set of ratios that progress in the right direction for the hypolimnion nutrients in the aerated lake vs. the control lake. At the conclusion of the 1973 aeration season, the hypolimnetic NH_4-N ratio for aerated Lake Waccabuc: control Lake Oscaleta was 1.59 ± 0.03. This ratio declined to 1.30 ± 0.02 by the end of the 1974 season. The hypolimnetic NO_3-N ratio rose from 0.45 ± 0.06 to 2.64 ± 0.36 in that same period. This result may be due to influences other than the aeration system on each lake (i.e. external loading), as discussed in the conclusion of the paper.

Phosphorous values for 1973 strongly suggest that aeration decreased hypolimnetic P concentrations. Figure 3 shows the total P concentration expressed as µg PO_4-P/l in the hypolimnion and epilimnion and Table IV shows total P expressed as kg P O_4-P. Aeration of Lake Waccabuc began on July 9. Hypolimnetic P, which had been increasing before aeration, shows approximately a 25% decrease from July 10 to September 9. From to September 9 to October 19 the amount of P remains essentially constant, which implies that P added to the hypolimnion by detrital sinking was balanced by loss to the sediments. Control Lake Oscaleta has a smaller hypolimnetic volume and lower P concentrations; hence the total kg P for Lake Oscaleta shown in Table IV are lower than those for Lake Waccabuc. Total P in the hypolimnion of Lake Oscaleta continued to rise during the time that hypolimnetic P in Lake Waccabuc was decreasing. The contrast in trends between these two lakes suggests that aeration of an anaerobic hypolimnion caused a net movement of P to the sediments and reversed the expected trend of a continuous increase in hypolimnetic P concentration.

A hypolimnetic P decrease in Lake Waccabuc from October 26 to November 2 occurred when stratification broke down rapidly and mixed nutrient-low surface waters with the hypolimnion. In the entire water body there is a 15% increase in P between these same dates. This should not be interpreted as a failure of hypolimnetic aeration to reduce surface nutrients after turnover for the following reasons. From October 31 to November 1, a storm system passed through the region, causing complete circulation in both lakes. P analyses were also determined on all dates on water passed through a 0.45µ filter; while the total P for the - entire water body increased after circulation, the filtrate P decreased by 15% at the same time. Consequently, the change in total P for the entire lake is due to an increase in suspended particulate P which may be of little use to algae.

P results during 1973 suggest that the aeration reduced the mass of hypolimnetic P from 460 kg to 340 kg. This reduction is about 10% of the maximum total for the entire water body which occurred in July. This is a minimum estimate of the effect of aeration on the lake's total P supply because, without aeration, additional P might have been released from hypolimnetic sediments.

Aeration began shortly after thermal stratification set in during 1974. We hoped that the increased duration of aeration and the prevention of any anaerobic period would reduce P concentrations in the hypolimnion below 1973 levels. Instead, hypolimnetic P levels were considerably higher in 1974 in both Lakes Waccabuc and Oscaleta (Table IV). There is a similar percent reduction in hypolimnetic P in Lake Waccabuc from late June to September, as occurred from early July to mid-September 1973. However, in 1974 the hypolimnetic P of unaerated Lake Oscaleta also decreased. Hence, comparing the 1974 results between the two lakes does not suggest that hypolimnion aeration had any influence on hypolimnetic P. This was surprising because both the laboratory studies of Graetz, et al (1973) and of Mortimer (1971), and the first year's field results had shown a significant P reduction in the hypolimnetic waters due to aeration.

INTERPRETATION AND CONCLUSION

In order to explain our results, we have looked briefly at the problem of external versus internal loading. Although hypolimnion aeration with the Limnox system might be sufficient to decrease P and increase the rate of conversion of NH_4-N to NO_3-N for internally cycled nutrients, considerable loading from external non-point sources can easily overwhelm the system, as pointed out by Uttormark, Chapin, and Green (1974). According to some data on the input streams and estimates by Cowley and Miller (1975), neither precipitation nor runoff from forested areas and town roads make very large contributions to the loading of either Lakes Oscaleta or Waccabuc; septic system runoff, how- ever, provides a major source. Lake Waccabuc is surrounded by some one hundred houses, which could account for anywhere from 200 to 600 kg/yr P and about 2600 kg/yr N input to the lake, depending on assumptions about soil type and detergent use. Consequently, N-loading is roughly 5.2 $g/m^2/yr$ for the lake and the lower estimate for P input yields 0.4 $g/m^2/yr$. According to Vollenweider (1968), the ballpark estimate for dangerous loading of a lake like Waccabuc is 0.20 $g/m^2/yr$ - P and 3.0 $g/m^2/yr$ - N.

Thus, external loading could be responsible for the marginal response of Lake Waccabuc nutrients to hypolimnion aeration and the lack of consistent large-scale nutrient reduction. Hypolimnion aeration can best achieve nutrient reduction in cases where internal loading is dominant. For those watersheds in which external loading dominates, other means of treatment, such as sewage diversion, may be necessary.

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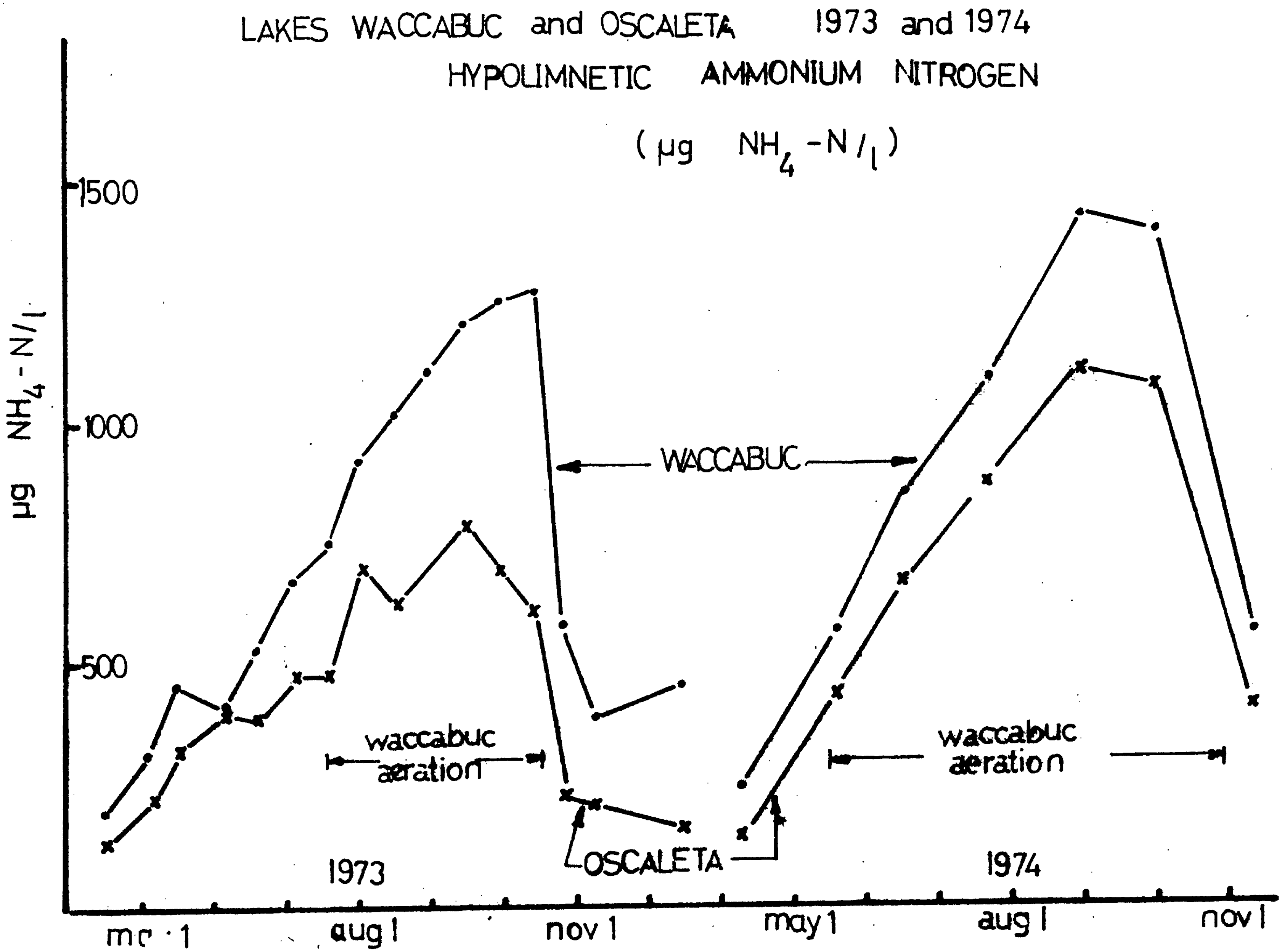
Figure Legend

Figure 1: Hypolimnetic ammonium nitrogen in μg NH_4-N/l for 1973 and 1974 in Lakes Waccabuc and Oscaleta.

Figure 2: Hypolimnetic nitrate nitrogen in μg NO_3-N/l for 1973 and 1974 in Lakes Waccabuc and Oscaleta.

Figure 3: Total phosphorous in μg PO_4/l for 1973 in Lake Waccabuc.



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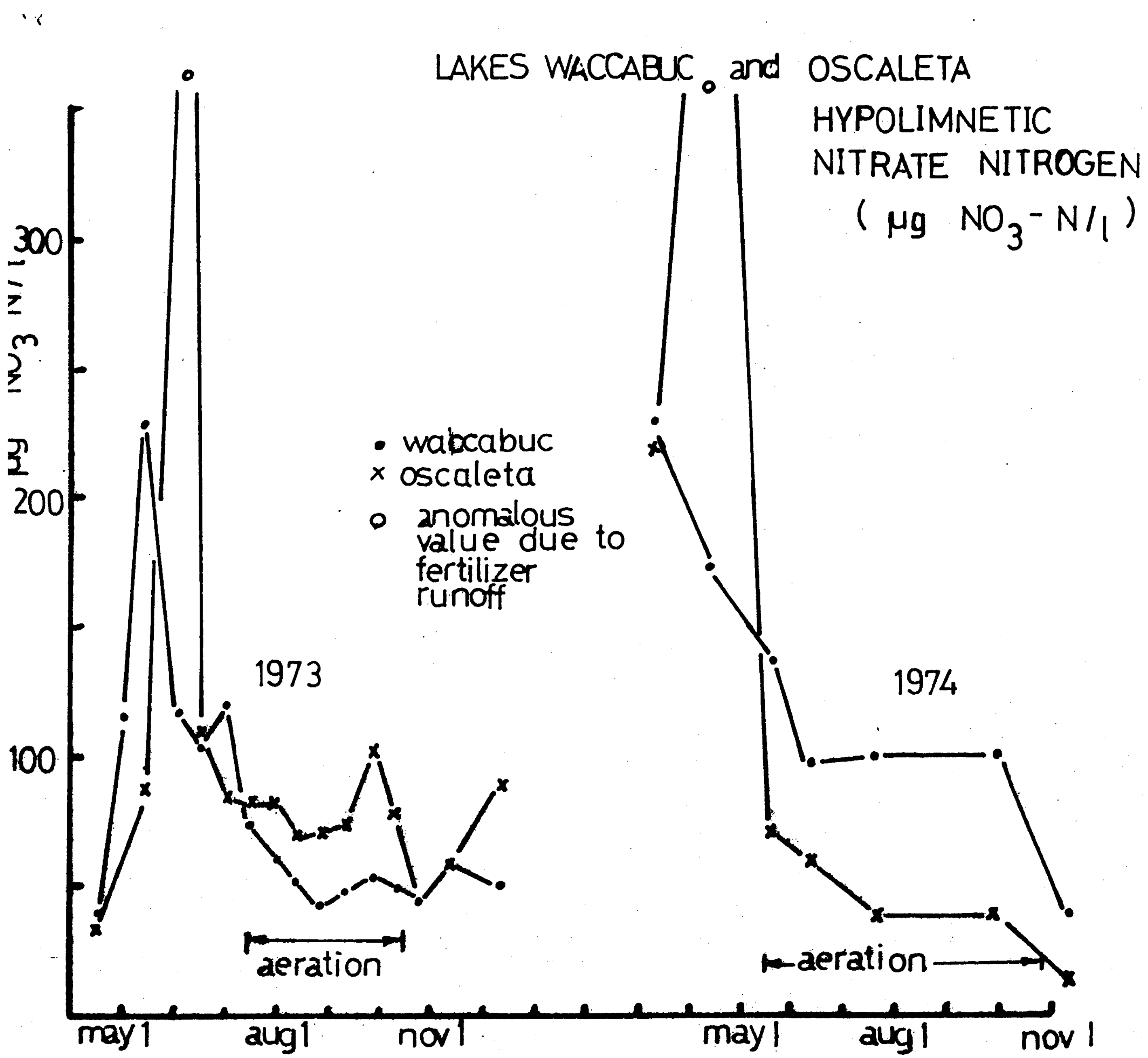
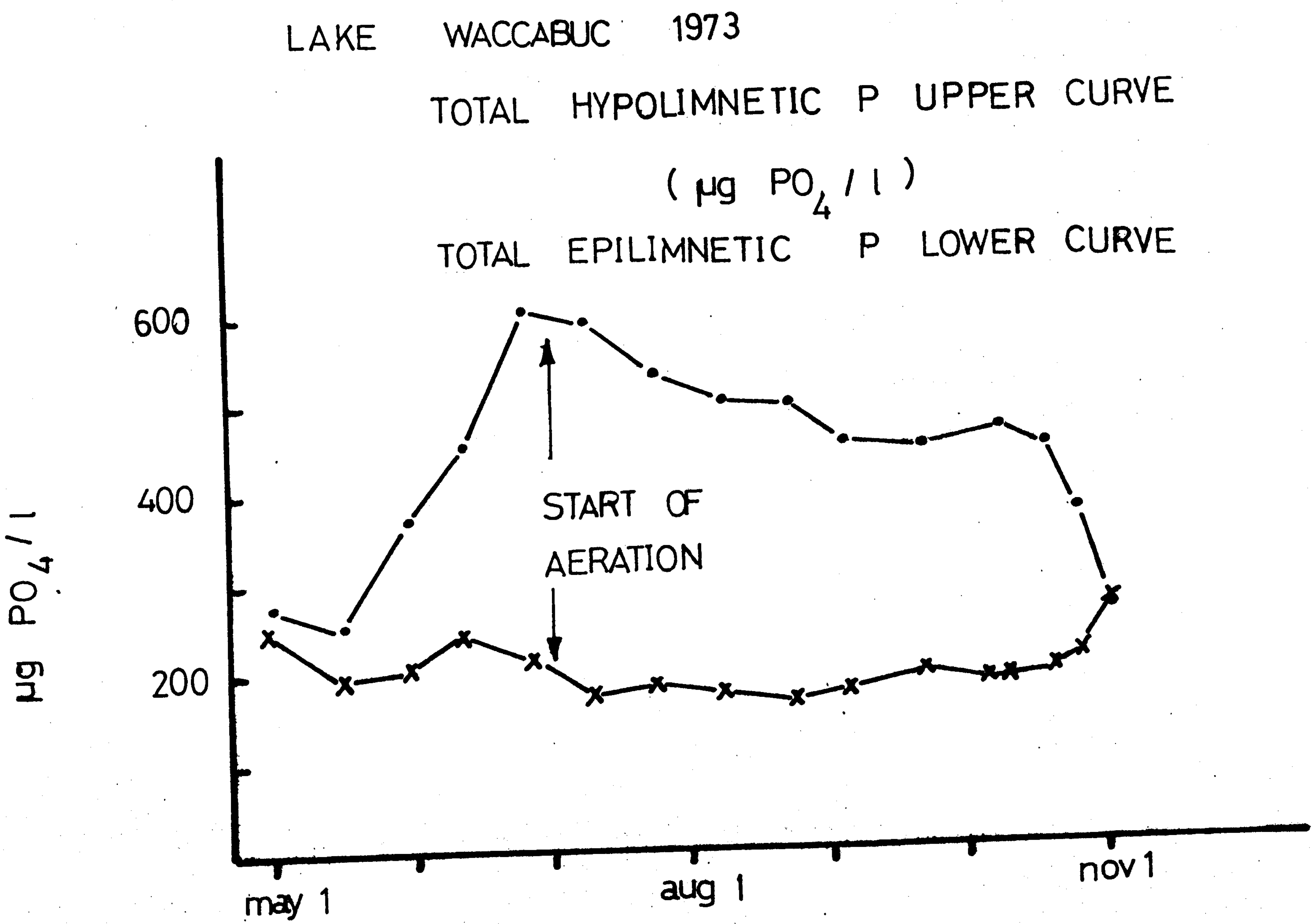

LAKES WACCABUC and OSCALETA
HYPOLIMNETIC
NITRATE NITROGEN
(μg NO3 - N/l)
μg NO3 N/l
300
200
100
wabcabuc
oscaleta
anomalous value due to fertilizer runoff
1973
1974
aeration
aeration
may 1
aug 1
nov 1
may 1
aug 1
nov 1



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Tables

Table I — Hypolimnion NH_4-N in Lakes Waccabuc and Oscaleta during 1973 and 1974. Data given in µg NH_4-N/l and kg NH_4-N.

Table II — Hypolimnion NO_3-N in Lakes Waccabuc and Oscaleta during 1973 and 1974. Data given in µg NO_3-N/l and kg NO_3-N.

Table III — Whole lake nitrogen nutrients in Lakes Waccabuc and Oscaleta during 1973 and 1974. Data given in kg- N.

Table IV — Total P in Lakes Waccabuc and Oscaleta during 1973 and 1974. Data given in kg PO_4-P.

TABLE I

Hypolimnion NH4-N (Concentrations in µg/l; Amounts in kg.)

1973 Dates		4/16	5/4	5/15	6/6	6/18	7/3	7/17	7/31	8/14	8/28	9/13	9/28	10/11	10/25	11/8	12/13
Lake Waccabuc																	
hypolimnion	(µg/l)	189	310	456	411	530	673	747	922	1020	1105	1210	1255	1275	585	371	462
	(kg.)	136	223	328	296	381	485	537	664	735	796	870	904	917	421	267	333
Lake Oscaleta																	
hypolimnion	(µg/l)	132	219	325	404	386	484	471	705	630		790	697	616	231	209	163
	(kg.)	39	65	110	119	114	143	139	208	186		233	206	182	68	61	48

1974 Dates		4/9	5/17	6/13	7/18	8/26	9/27	11/8
Lake Waccabuc								
hypolimnion	(µg/l)	251	574	855	1100	1440	1405	476
	(kg.)	181	414	615	791	1035	1012	343
Lake Oscaleta								
hypolimnion	(µg/l)	132	426	654	864	1112	1080	406
	(kg.)	31	126	193	255	328	319	120

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TABLE II

Hypolimnion NO_3-N (Concentrations in μg/l; Amounts in kg.)

1973 Dates		4/16	5/4	5/15	6/6	6/18	7/3	7/17	7/31	8/14	8/28	9/13	9/28	10/11	10/25	11/8	12/13
<u>Lake Waccabuc</u>																	
hypolimnion	(μg/l)	44.2	116.0	230.0	117.0	104.0	121.0	75.0	62.6	51.7	42.6	48.0	53.7	51.0	45.0	57.5	52.3
	(kg.)	31.9	83.4	165.0	83.7	75.0	86.9	54.0	45.1	37.2	30.7	34.6	38.7	36.8	32.4	41.3	37.6
<u>Lake Oscaleta</u>																	
hypolimnion	(μg/l)	31.8		82.6	anom	109.0	84.1	82.5	82.5	68.2	69.6	72.5	101.0	77.0	38.9	52.9	87.8
	(kg.)	9.4		25.5	anom	32.3	24.9	224.1	24.1	20.2	20.6	22.6	29.9	22.8	11.5	15.6	25.9

1974 Dates		3/8	4/9	5/17	6/13	7/18	8/26	9/27	11/8
<u>Lake Waccabuc</u>									
hypolimnion	(μg/l)	228.0	173.0	138.0	98.0	101.0		101.0	38.0
	(kg.)	164.0	124.0	99.1	70.6	73.0		73.0	27.2
<u>Lake Oscaleta</u>									
hypolimnion	(μg/l)	214.0	anom	70.0	59.0	37.0		48.0	12.0
	(kg.)	63.0	anom	20.7	17.3	10.8		14.2	3.5

anom = anomalous result, probably due to fertilizer runoff

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TABLE III

Whole Lake Nitrogen Nutrients - Amounts in kg.

1973 Dates	4/16	5/4	5/15	6/6	6/18	7/3	7/17	7/31	8/14	8/28	9/13	9/28	10/11	10/25	11/8	12/13
<u>Lake Waccabuc</u>																
kg. NH_4-N	669		875	561	606	842	827	1060	1131	1087	1196	1192	1108	1133	1425	1742
kg. NO_3-N	208	398	541	265	343	317	325	229	198	159	226	150	162	163	226	204
<u>Lake Oscaleta</u>																
kg. NH_4-N			305	223	203	238	243	350	290		342	318	306	352	290	
kg. NO_3-N	68.8	anom	126	anom	150	171	149	113	76.6	78.5	82.8	96.7	78.6	64.3	85.8	123

1974 Dates	3/8	4/9	5/17	6/13	7/18	8/26	9/27	11/8
<u>Lake Waccabuc</u>								
kg. NH_4-N		434	584	1145	1242	1387	1384	1420
kg. NO_3-N	1132	720	504	460	175		105	218
<u>Lake Oscaleta</u>								
kg. NH_4-N			294	312	365	462	483	400
kg. NO_3-N	314		101	63.2	17.3		40	48.9

anom = anomalous result, probably due to fertilizer runoff

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TABLE IV

Total P (as kg. PO_4-P)

1973 Dates	2/28	6.27	7/10	8/23	10/5	11/2
Lake Waccabuc						
above hypolimnion	680	660	620	650	590	910
hypolimnion	290	460	450	380	350	200
Lake Oscaleta						
above hypolimnion	290	280	270	230	240	280
hypolimnion	40	40	50	60	70	30
1974 Dates		5/4	6/28	8/20	10/1	11/1
Lake Waccabuc						
above hypolimnion		720	640	540	400	800
hypolimnion		150	750	560	570	60
Lake Oscaleta						
above hypolimnion		260	320	210	100	160
hypolimnion		90	70	90	60	10