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ALGAL NUTRIENT LIMITATION IN LAKE ONTARIO AND TRIBUTARY WATERS

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INTRODUCTION

To determine the possible limiting nutrient for planktonic algal growth in Lake Ontario, a nutrient enrichment study was conducted during 1972–1973 as part of the International Field Year for Great Lakes (IFYGL). The study included the measurements of the growth response of laboratory-grown and natural algae in nutrient enriched Lake Ontario water and tributary waters.

SAMPLING

During the summer and fall of 1972 and spring of 1973, water samples were collected from Lake Ontario at five locations and from the mouths of the Niagara, Genesee, Oswego and Black Rivers.

Four to eight liter water samples from the surface of Lake Ontario were collected in pre-washed polyethylene containers and transported to Madison, Wisconsin, via commercial airliners or by car, depending upon when the samples were collected. The day of arrival at Madison ranged from 2 to 7 days depending upon the mode of transportation. A comparison was made between the results obtained for samples that were run within 2 days of collection and those that had been stored for one week. No differences were found in any algal assay responses between the two sets of samples indicating that the one week storage period did not significantly affect the results of the test. Upon arrival, the water samples were kept in the dark and stored at approximately 4°C. Figure 1 identifies the sampling stations in the open lake and its tributaries. Table 1 presents the sampling dates and the initial phosphorus and nitrogen concentrations of the samples collected. These samples were not filtered prior to analysis.

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REAGENTS

A stock phosphate solution was prepared by dissolving KH_2PO_4 in glass-distilled water. Nitrogen added to the Lake Ontario cultures was added in the form of nitrate. A stock nitrate solution was prepared by dissolving $NaNO_3$ in glass-distilled water.

The stock micronutrient solution (EPA, 1971) contained 185.52 mg l^{-1} H_3BO_3, 265.26 mg l^{-1} $MnCl_2$, 32.709 mg l^{-1} $ZnCl_2$, 0.780 mg l^{-1} $CoCl_2$, 0.009 mg l^{-1} $CuCl_2$, 7.26 mg l^{-1} $Na_2MoO_4 \cdot 2H_2O$, 96.0 mg l^{-1} $FeCl_3$ and 300 mg l^{-1} $Na_2EDTA \cdot 2H_2O$.

For the experiments where ^{14}C-technique was used, carbon-14 was added to the samples as a basic carbonate solution. Sealed ampules of ^{14}C-bicarbonate were purchased and diluted to the appropriate volume to produce

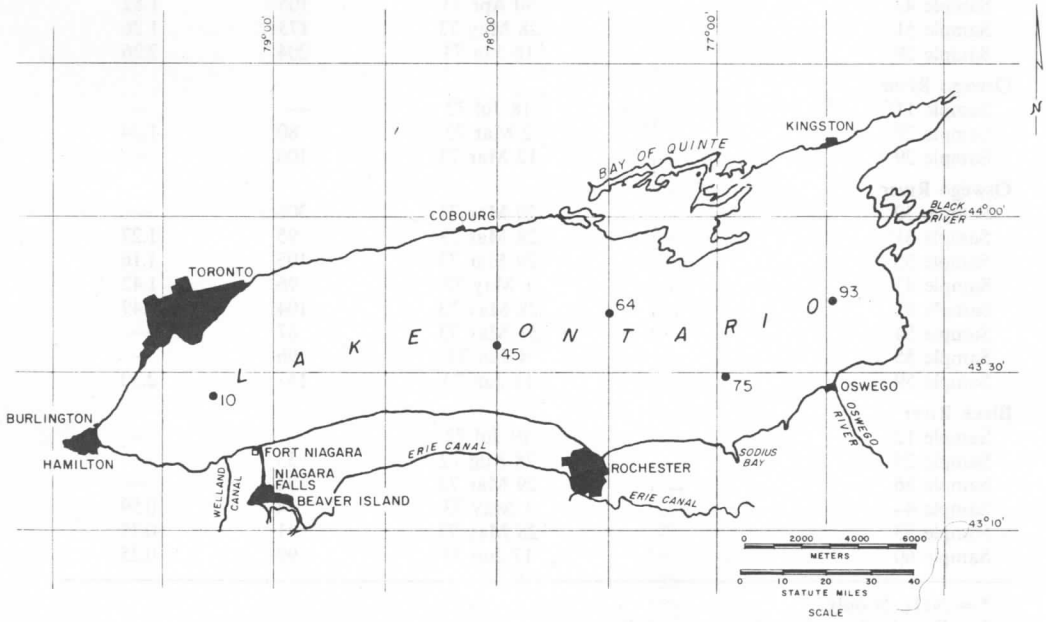

Fig. 1. Location of Sampling Sites in Lake Ontario and Tributaries.

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Table 1. Sampling dates and initial phosphorus and nitrogen concentrations for Lake Ontario and tributary waters

Location Sample or Station No.	Date collected	TP $\mu g\,l^{-1}$ P	TN‡ $\mu g\,l^{-1}$ N
Lake Ontario			
Station 10	26 Jun 72	18	*0.07
Station 10	5 Mar 73	+3	—
Station 10	1 Apr 73	5	—
Station 10	2 May 73	+19	0.31
Station 10	15 Jun 73	9	*0.05
Station 93	24 Aug 72	15	—
Station 64	23 Aug 72	17	—
Station 75	19 Jul 72	36	*0.05
Station 75	5 Mar 73	+3	0.39
Station 75	1 Apr 73	3	0.35
Station 75	2 May 73	13	0.28
Station 75	15 Jun 73	10	*0.05
Station 45	5 Mar 73	+6	0.40
Station 45	1 Apr 73	4	0.35
Station 45	2 May 73	14	0.27
Station 45	15 Jun 73	10	*0.05
Sample 19—Near Niagara	3 Aug 72	25	—
Sample 7—Near Niagara	23 July 72	14	*0.05
Sample 9—Near Rochester NY	19 July 72	100	*0.10
Sample 17—Near Rochester NY	2 Aug 72	43	—
Sample 20—Near Rochester NY	14 Aug 72	37	—
Fort Niagara–Niagara River			
Sample 6	10 Jul 72	8	*0.05
Sample 18	2 Aug 72	22	—
Sample 27	26 Feb 73	18	—
Sample 33	28 Mar 73	34	—
Sample 41	30 Apr 73	22	0.45
Sample 50	27 May 73	26	0.82
Sample 56	15 Jun 73	59	1.13
Beaver Island–Niagara River			
Sample 32	28 Mar 73	30	—
Sample 40	30 Apr 73	15	—
Sample 49	27 May 73	51	—
Sample 57	15 Jun 73	86	—
Genesee River			
Sample 14	20 Jul 72	—	0.69
Sample 16	2 Aug 72	167	–
Sample 34	29 Mar 73	386	2.21
Sample 42	30 Apr 73	105	1.52
Sample 51	28 May 73	173	1.26
Sample 58	16 Jun 73	204	2.26
Oswego River			
Sample 11	18 Jul 72	—	—
Sample 28	2 Mar 73	80	1.34
Sample 29	12 Mar 73	106	—
Oswego River			
Sample 30	20 Mar 73	306	—
Sample 31	28 Mar 73	95	1.27
Sample 35	29 Mar 73	105	1.16
Sample 43	1 May 73	96	1.42
Sample 52	28 May 73	104	1.49
Sample 54	31 May 73	87	—
Sample 55	4 Jun 73	96	—
Sample 59	17 Jun 73	147	2.30
Black River			
Sample 12	19 Jul 72	—	—
Sample 25	28 Aug 72	53	—
Sample 36	29 Mar 73	34	—
Sample 44	1 May 73	34	0.59
Sample 53	28 May 73	41	0.75
Sample 60	17 Jun 73	99	0.25

* = NO_3^--N only.
† = Dissolved reactive phosphorus only.
‡TN = NO_3^--N + total Kjeldahl N.

Table 2. Synthetic algal nutrient medium, NAAM

Compound	Concentration ($mg\,l^{-1}$)	Element	Concentration ($mg\,l^{-1}$)
$NaNO_3$	25.50	N	4.20
K_2HPO_4	1.05	P	0.186
$MgCl_2$	5.70	Mg	2.90
$MgSO_4 \cdot 7H_2O$	14.70	S	1.91
$CaCl_2 \cdot 2H_2O$	4.41	C	2.14
$NaHCO_3$	15.00	Ca	1.20
		Na	11.00
		K	0.47
H_3BO_3	185.52	B	32.46
$MnCl_2$	264.26	Mn	115.37
$ZnCl_2$	32.7	Zn	15.69
$CoCl_2$	0.78	Co	0.35
$CuCl_2$	0.009	Cu	0.004
$Na_2MoO_4 \cdot 2H_2O$	7.26	Mo	2.88
$FeCl_3$	96.00	Fe	33.05
$Na_2EDTA \cdot 2H_2O$	300.00		

1 μCi $^{14}C\,ml^{-1}$ solution. Sodium hydroxide solution was added to the ^{14}C-bicarbonate solution to raise the pH to 10.4 to prevent losses of ^{14}C-CO_2.

The scintillation cocktail used in the counting procedure contained 75.0 g napthalene, 10.5 g 2,5-diphenyl oxazole (PPO) and 0.45 g 1,4-bis-[2-C4-methyl-5-phenyloxazolyl]-benzene (dimethyl PoPoP) diluted to 1 liter with 300 ml ethylene glycol monoethyl ether (cellusolve) and 1,4-dioxane. All reagents used in the preparation of this cocktail were scintillation grade.

Sample activity was determined by liquid scintillation counting using a Packard 3320 Tri-Carb Scintillation Spectrometer. All samples were counted for 10 mins and the activity of each sample was reported in counts/min (CPM) after correcting the observed data for counting time and quenching.

EXPERIMENTAL PROCEDURE

Filtered lake water

One liter of the sample was autoclaved at 15 psi for 15 min, cooled to room temperature and let stand for a few hours. The sample was then filtered through 0.45 μm pore size membrane filter. The pH of the test water was then measured. If the pH of the filtered sample was not between 7.0 and 8.5, an adjustment of pH was made by passing air or CO_2 through the sample. The bioassays were run on 40 ml vol of the autoclaved filtered samples in 125 ml flasks. The preparation of the glassware followed the recommended procedure in "Algal Assay Procedure, Bottle Test" (EPA, 1971). *Selenastrum capricornutum* was the test algae grown in a synthetic algal nutrient medium (Table 2) with 3X phosphorus and 3X nitrogen. One-to two-weeks' old culture was used as a source of inoculum. The cells from the *Selenastrum* culture were centrifuged for 30 min at 1500 rpm, and the supernatant was discarded. The sedimented cells were resuspended in sodium bicarbonate solution (15 mg $NaHCO_3\,l^{-1}$) and centrifuged again for 30 min at 1500 rpm. The sedimented algal cells were resuspended in the bicarbonate solution, and the number of cells in suspension was counted using a hemocytometer. The suspension was then diluted with bicarbonate solution to give the final cell concentration of 2×10^5 cells ml^{-1}. An initial cell concentration of 10^3 cells ml^{-1} was used.

Phosphorus, nitrogen or micronutrients were added to the water samples to give the final concentration of 100 μg $P\,l^{-1}$, 1000 μg $N\,l^{-1}$ and the concentration equivalent of AAP micronutrients, respectively. Phosphate, nitrate, and micronutrients were added individually and in combination, to identify the growth limiting nutrient(s). Table 3 is an outline of the procedure which was employed to

Table 3. Algal assay experimental design

Treatment	No. Flasks
Lake water control-40 ml lake water	3
Phosphorus added-lake water + 100 μg $P\,l^{-1}$	3
Nitrogen added-lake water + 1000 μg $N\,l^{-1}$	3
N & P added-lake water + 100 μg $P\,l^{-1}$ + 1000 μg $N\,l^{-1}$	3
Micronutrient added-lake water + micronutrients	3
Nitrogen plus micronutrient added-lake water + micronutrients + 1000 μg $N\,l^{-1}$	3
Growth reference-Phosphorus	
NAAM-P* medium	3
NAAM-P† + 100 μg $P\,l^{-1}$	3
Growth reference-Nitrogen	
NAAM-N‡ medium	3
NAAM-N + 100 μg $N\,l^{-1}$	3
Total	30

* Synthetic algal assay medium (Table 2).
† NAAM-P = algal assay medium without phosphorus.
‡ NAAM-N = algal assay medium without nitrogen.

assess the nutrient status of Lake Ontario water. The flasks with the test samples were incubated at 24° ± 3°C under cool white fluorescent lighting-400 ft-c ± 10% illumination. Measurement of *in vivo* absorbance was made on days 8–16 of the incubation, using 10 cm cells and Beckman DU Spectrophotometer. Aliquots taken for absorbance measurements were returned to their flasks after the reading.

The absorbance reading at 750 nm for an algal culture was calibrated with the dry weight of algae. A known aliquot of a dense culture of *Selenastrum capricornutum* was filtered through a glass fiber filter, ovendried at 110°C, cooled and weighed. The same culture was diluted by different volumes of water and the absorbance measured for each dilution. A calibration curve is presented in Fig. 2.

Unfiltered lake water

In the present nutrient spiking study, ^{14}C-technique was used to assess the growth of the "natural" algae present in unfiltered lake water. The first step in processing the unfiltered samples was to determine the initial productivity of the sample. Six 25 ml aliquots of the sample were spiked with 0.5 μCi ^{14}C-$CO_3^=$ each and incubated for 4 h. Three of the replicates were incubated under 400 ft-c of light supplied by fluorescent lights. The remaining three samples were incubated at the same temperature as the first three samples, but in the dark. After a four hour incubation period, the samples were filtered through 0.45 μm pore size Millipore filters at a pressure differential equivalent to six inches of mercury. During the filtration step, the sample bottles were rinsed twice with distilled water and the filters were rinsed five times with distilled water. The total wash volume was approximately 50 ml.

Filters were placed in a desiccator containing concentrated HCl for 30 min and then dried overnight in a second desiccator containing silica gel. The filters were dissolved in a 10 ml scintillation cocktail and five ml dioxane. The samples were counted for 10 min to determine the amount of carbon-14 incorporation. Net carbon fixation for the sample was calculated by subtracting the dark bottle fixation from the light bottle fixation.

Once the initial productivity of the sample was determined, the experiment was continued to determine the effect of nutrient additions. Fifty ml aliquots of the lake water samples were placed in 125 ml culture flasks. The phosphate, nitrate and micronutrient solutions were then added singularly and in combination to the lake water sample. Triplicate samples were prepared for each experimental condition. The flasks were then sealed with parafilm paper and incubated for one week at 22 ± 2°C under 400 ft-c of light.

A set of screw-capped 125 ml jars was prepared for dark incubation by thoroughly painting the glass wall black. A set of unpainted 125 ml jars was used for the incubation of the samples in light.

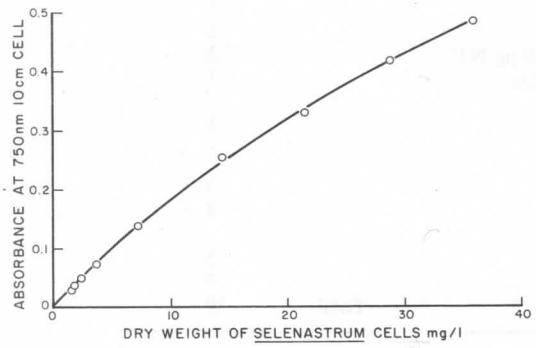

Fig. 2. Relationship between Absorbance and Dry Weight of *Selenastrum capricornutum* cells.

Following the incubation period of one week, two 25 ml samples were taken from each of the triplicate flasks. One sample was placed in a 125 ml jar painted black for dark incubation and the other sample was placed in the unpainted jar. To each of the jars, one-half μCi ^{14}C-$CO_3^=$ was added and the jars were incubated for an additional four-hour period.

The short four-hour incubation period was completed under the same conditions of temperature and light intensity as the longer one-week period except for keeping the designated dark bottle samples out of the light. The samples were filtered and the filters were processed as described earlier. The net carbon assimilation was calculated as the difference between the light and dark bottle fixation and compared to the initial and incubated lake water samples.

EXPERIMENTAL RESULTS AND DISCUSSION

Lake Ontario

The bioassay response of a laboratory-grown culture of *Selenastrum capricornutum* in filtered Lake Ontario water samples with and without the addition of nutrients was studied by measuring the increase in absorbance with time. A total of 21 surface water samples from Stations 10, 45, 64, 75, and 93 was collected and used in the algal assay studies. The water samples had total phosphorus concentrations in the range of 5–43 μg P l^{-1} and the total nitrogen of 0.25–0.4 mg N l^{-1}. The AAP tests on the 21 water samples from Lake Ontario showed phosphorus or phosphorus and nitrogen limitation. A typical growth response curve is presented in Fig. 3. The figure is a plot of absorbance vs. time for Lake Ontario water samples collected from Station 45 on 5 March 1973.

The vertical lines at each date indicate the absorbance range obtained for triplicate samples. An increase in algal growth in water samples with phosphorus (100 μg P l^{-1}) was observed. The addition of phosphorus (100 μg P l^{-1}) and nitrogen (1000 μg N l^{-1}) to the water sample showed an increase in the growth of algae when compared to the samples with the addition of phosphorus alone. In some of the Lake Ontario water samples, the addition of phosphorus alone did not increase the growth response of the laboratory algae while a markedly increased growth was observed in the samples with phosphorus and nitrogen additions. Under these conditions, phosphorus and nitrogen are limiting algal growth in Lake Ontario waters. This situation was generally found in the summer where the total phosphorus concentration was 10 μg P l^{-1} or less and the total nitrogen concentration was also low. The addition of both phosphorus and nitrogen in the same samples will alleviate the phosphorus and nitrogen limited conditions and increase the growth of algal cells. A typical example of such a situation is seen in Fig. 4 for the water sample from Station 75 collected on 15 June 1973.

Based on variations in the absorbance values which correlate with the algal cell counts, nine of 21 samples receiving phosphorus showed greater growth than the incubated lake water controls. Seventeen of 21

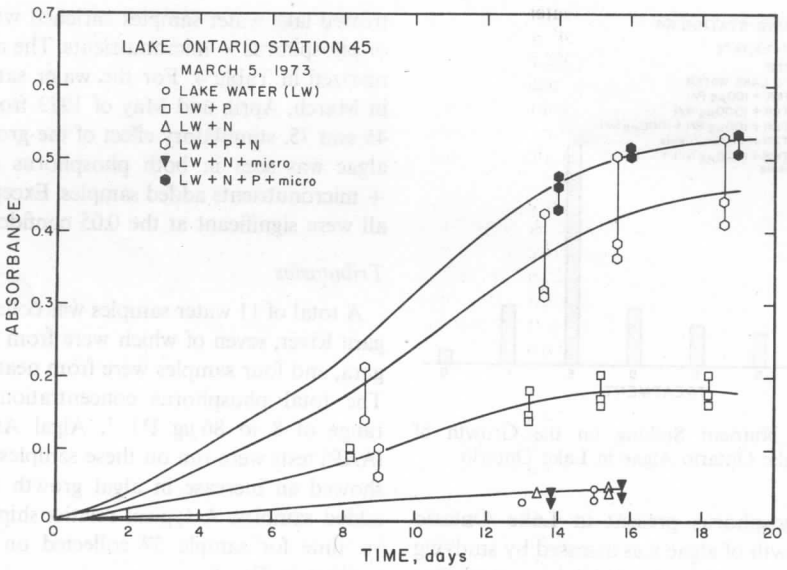

Fig. 3. Growth of *Selenastrum* in Lake Ontario Water.

samples showed increased growth in samples with phosphorus plus nitrogen additions.

To assess the growth of "natural" lake algae in Lake Ontario water, absorbance measurement was replaced by ^{14}C technique. The unfiltered lake water was processed as described in the experimental procedure. The first sample was collected from Station 64 in August, 1972. The lake water sample was enriched with 100 μg $P l^{-1}$ or 1000 μg $N l^{-1}$ or 100 μg $P l^{-1}$ + 1000 μg $N l^{-1}$ or 1000 μg $N l^{-1}$ + micronutrients. All additions were made as 1.25 ml from working solutions to a 50 ml unfiltered lake water sample. A set of lake water samples without any nutrient additions was also included in each experiment.

Net carbon fixation results for water samples from Station 64 are presented in Fig. 5. Incubation of lake water alone and lake water with nutrients for one week did result in increased carbon fixation; however, based on variations in the C-14 activity values in the light minus dark bottles, eight of 26 samples receiving phosphate + nitrate showed significantly greater growth than the incubated lake water controls at the 0.05 confidence level (95% probability that the response is actually greater than the incubated lake water controls). For samples with phosphate + nitrate + micronutrients, seven of seven samples showed significantly greater growth than the incubated lake water controls at the 0.05 confidence level.

Alum treatment

The potential benefit that may be derived from a

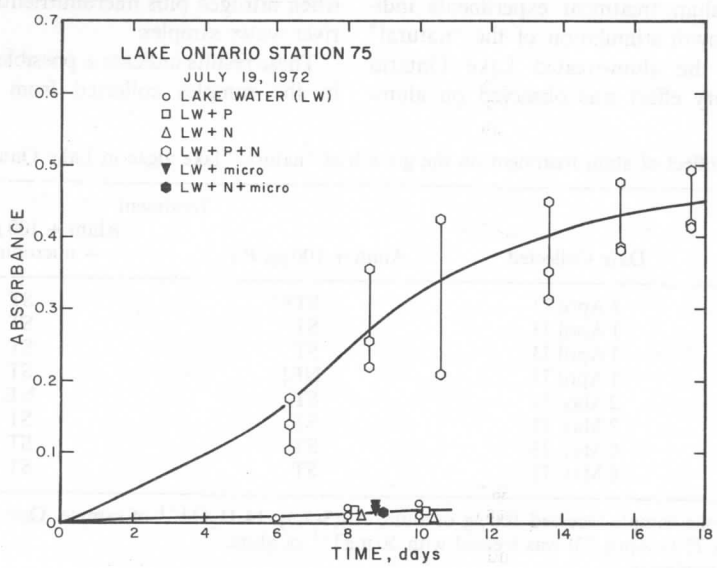

Fig. 4. Growth of *Selenastrum* in Lake Ontario Water.

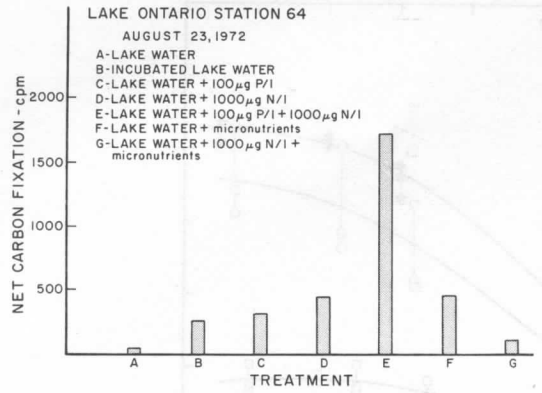

Fig. 5. Effect of Nutrient Spiking on the Growth of "Natural" Lake Ontario Algae in Lake Ontario.

reduction of phosphorus present in Lake Ontario water on the growth of algae was assessed by studying the algal response in alum-treated lake water. One liter water samples in Imhoff Cones were treated with 5 or 10 ml of alum (10 g l^{-1} of $Al_2(SO_4)_3$ 14 H_2O), stirred continuously for 30 s and allowed to settle. After 24 h, the supernatant was filtered through 0.45 µm pore size filters. The phosphorus content of the filtered sample was measured to be sure that phosphorus had been removed by alum treatment. Fifty ml samples of filtrate were taken in 120 ml capacity Erlenmeyer flasks and treated with 100 µg P l^{-1} or 100 µg P l^{-1} + micronutrients. A set of controls of filtered alum-treated lake water was used in each experiment. All treatments and controls were run in triplicate. One ml of untreated lake water was added as seed to all the test flasks. After seven days of incubation the samples received ^{14}C-$CO_3^=$ and were incubated in light and dark environments for four hours. The difference in the ^{14}C counts between the light and dark bottles in each set of treatment was used to assess the algal growth.

The results of alum treatment experiments indicated a lack of growth stimulation of the "natural" phytoplankton in the alum-treated Lake Ontario water. A stimulatory effect was observed on alum-treated lake water samples enriched with phosphorus or phosphorus + micronutrients. The results are summarized in Table 4. For the water samples collected in March, April, and May of 1973 from Stations 10, 45 and 75, stimulatory effect of the growth of natural algae was seen in both phosphorus or phosphorus + micronutrients added samples. Except in two cases, all were significant at the 0.05 confidence level.

Tributaries

A total of 11 water samples was collected from Niagara River, seven of which were from near Fort Niagara, and four samples were from near Beaver Island. The total phosphorus concentrations were in the range of 8 to 86 µg P l^{-1}. Algal Assay Procedure (AAP) tests were run on these samples and the results showed an increase in algal growth in phosphorus-added samples. A typical relationship of absorbance vs. time for sample 57 collected on 15 June, 1973 is given in Fig. 6.

All 11 samples from Niagara River showed phosphorus-limited condition as determined by the growth of *Selenastrum*. Some water samples which had low total nitrogen concentration showed an increased algal growth response in flasks with phosphate + nitrate added. These results are similar to the results obtained with Lake Ontario water samples.

Six samples were collected from Genesee River near Rochester, N.Y., and the total phosphorus concentrations were in the range of 105–386 µg P l^{-1}, and the total nitrogen concentrations were in the range of 0.69–2.26 mg N l^{-1}. AAP tests were run on these water samples. The results showed an increase in growth response with the addition of nitrogen in the presence of micronutrients. A typical growth response curve is presented in Fig. 7. The growth of *Selenastrum* as measured by absorbance did not show any change when phosphorus was added to the river water samples, but there was an increased growth when nitrogen plus micronutrients were added to the river water samples.

These results indicate a possible nitrogen limitation in the samples collected from Genesee River. It

Table 4. Effect of alum treatment on the growth of "natural" lake algae in Lake Ontario water

Station	Date Collected	Treatment	
		Alum + 100 µg P l^{-1}	Alum + 100 µg P l^{-1} + micronutrients
10	1 April 73	ST†	ST
45	1 April 73	ST	ST
75*	1 April 73	ST	ST
75	1 April 73	NE‡	ST
10	2 May 73	ST	NE
75	2 May 73	ST	ST
45	6 May 73	ST	ST
75	6 May 73	ST	ST

* All but one sample received 100 µg of alum, $Al_2(SO_4)_3 \cdot 14\ H_2O$ l^{-1} of sample. One water sample from station 75 (1 April 73) was treated with 50 mg l^{-1} of alum.

† ST = Stimulation.

‡ NE = No effect in comparison to the alum treated sample.

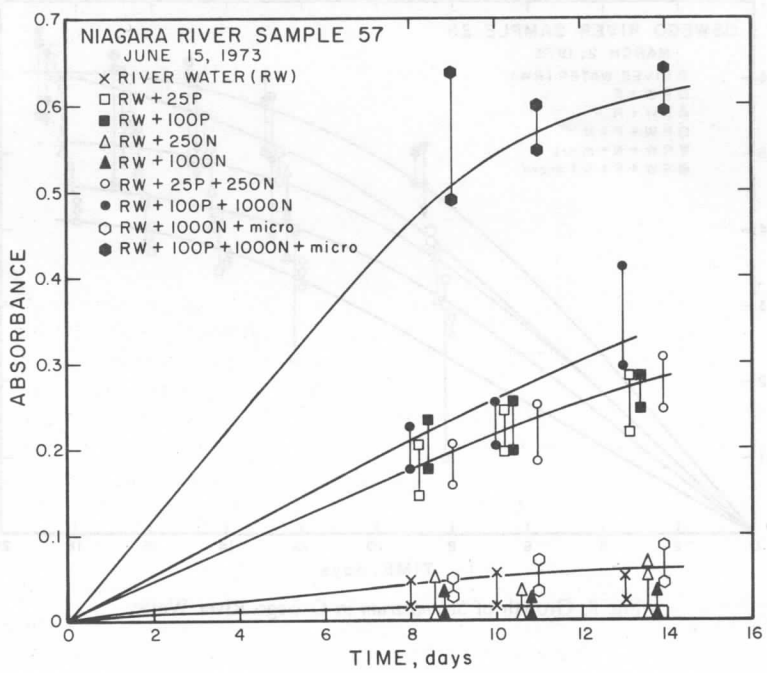

Fig. 6. Growth of *Selenastrum* in Niagara River Water.

should be noted, however, that only six samples were obtained from Genesee River over a period of one year, four of them collected during March–June, 1973. More samples should be assayed before any conclusions can be drawn on the overall characteristics of the Genesee River.

Eleven water samples were collected from Oswego River, and the total phosphorus concentrations of these samples were in the range of 80–306 μg $P l^{-1}$, and the total nitrogen concentrations were in the range of 1.2–2.3 mg $N l^{-1}$. AAP tests were run with all 11 samples.

Seven samples showed no increase in growth of *Selenastrum* with any of the added nutrients individually or in combinations. The algae showed good growth response in all the samples including the control river water samples. This indicates a nutrient enriched condition in these water samples. A typical

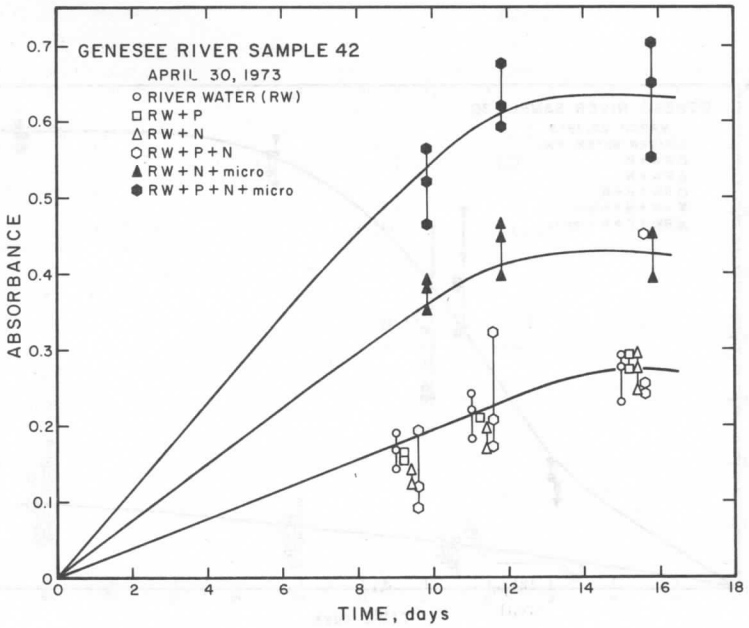

Fig. 7. Growth of *Selenastrum* in Genesee River Water.

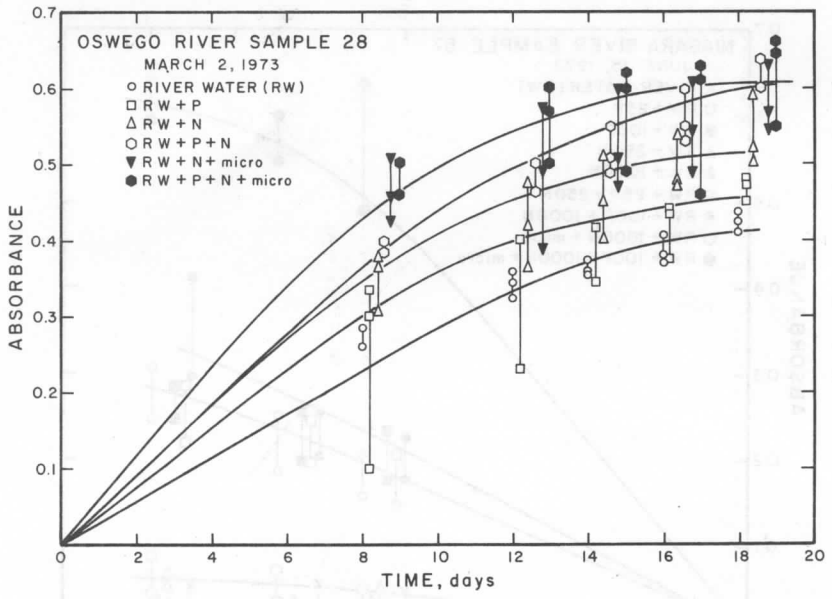

Fig. 8. Growth of *Selenastrum* in Oswego River Water.

growth curve is presented in Fig. 8. The figure is a plot of absorbance vs. time for Oswego River water sample 28. Although a slight change in the growth is noted for different treatments as seen by the family of curves, the overlap of absorbance values of one treatment over the other indicates that there is no significant difference in growth responses with various treatments.

Four water samples from Oswego River showed a micronutrient-limited condition, based on the AAP tests. In these samples, an increased growth of *Selenastrum* was observed when micronutrients was added to the samples. When the same samples were treated with phosphate or phosphate + nitrate, there was no resultant increase in the growth of *Selenastrum*. A typical growth curve is presented in Fig. 9.

Six Black River water samples were collected, and AAP tests were run on all these samples. The total phosphorus concentrations were in the range of 34–99 μg $P\,l^{-1}$, and the total nitrogen concentrations were in the range of 0.59–1.25 mg $N\,l^{-1}$. All six samples showed an increase in algal growth when phosphorus plus nitrogen were added to the water samples. A typical growth curve is shown in Fig. 10 for Black River water sample 53. Neither phosphorus nor nitrogen added individually increased the growth

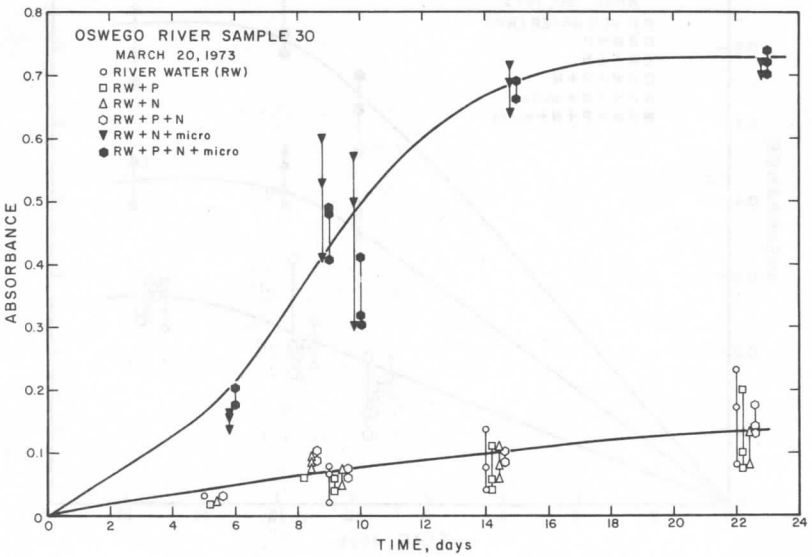

Fig. 9. Growth of *Selenastrum* in Oswego River Water.

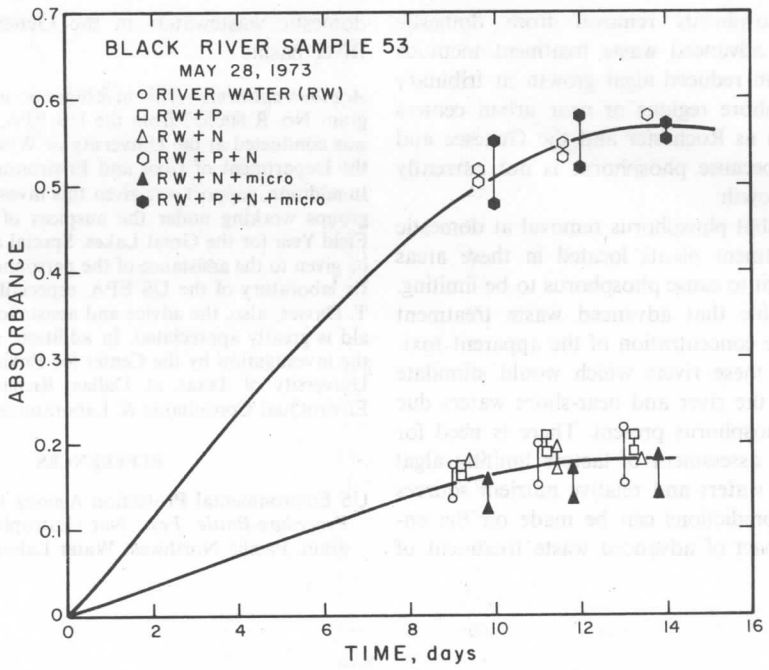

Fig. 10. Growth of *Selenastrum* in Black River Water.

of *Selenastrum* in Black River water samples. The river water showed phosphorus and nitrogen limited conditions in all six samples.

DISCUSSION

The nutrient spiking studies of Lake Ontario and the Niagara River during the late summer required both nitrogen and phosphorus for stimulation of growth of the test alga and "natural" algae. Similar results were observed for the Black River. These results indicate both nitrogen and phosphorus are limiting planktonic algal growth in Lake Ontario and at these river mouths.

The samples of the Genesee and Oswego rivers showed, in general, nitrogen stimulation. Also, many of the samples from these rivers demonstrated stimulation due to the addition of the micronutrients solution used in the NAA media for the AAP Procedure. Further, many of the samples studied in this investigation showed both N and P stimulation at a high level of N and P addition. Results of this type must be examined in light of the conditions of the test. In a bioassay of this type, it is possible to make any element limiting by adding large amounts of other essential elements and providing sufficient light for growth. Proper interpretation of the data for this type of bioassay requires that one consider the stimulation, or lack thereof, when small amounts of a potential limiting element are added.

Care must also be exercised in interpreting the micronutrient stimulation data found for the Genesee and Oswego Rivers. The micronutrient solution also contains EDTA, a strong complexing agent. There is increasing evidence that algal growth in many waters near urban centers is inhibited by toxic elements in the water. Often, this toxicity can be eliminated by addition of a complexing agent. The stimulation noted in this study by the micronutrient solution may have been due to a removal of toxicity present in the water by the EDTA in the solution. Additional study of these waters in which the various components of the micronutrient solution are tested individually or in certain combinations must be conducted before it will be possible to ascertain the cause of stimulation.

The results of this investigation provide valuable information on the approaches that should be used to reduce the excessive algal growth in Lake Ontario. Since essentially all lake water samples showed phosphorus limitation, efforts should be directed to limiting potentially available phosphorus inputs to the lake. The fact that the Lake Ontario open water samples taken during late summer showed both phosphorus and nitrogen limitation does not change the excessive fertilization control strategy since, in general, nitrogen control is considerably more difficult and expensive than phosphorus control.

Based on the results of this study it is concluded that a substantial reduction of immediate and potentially available phosphorus will tend to reduce planktonic algal growth in Lake Ontario. It is readily apparent based on the estimated phosphorus sources that immediate steps should be taken to provide advanced waste treatment removal of P from all major domestic wastewater sources entering Lake Ontario or its tributaries from the US and Canada.

However, phosphorus removal from domestic wastewaters by advanced waste treatment methods may not result in reduced algal growth in tributary rivers and nearshore regions or near urban centers of the lake such as Rochester and the Genesee and Oswego rivers because phosphorus is not currently limiting algal growth.

It is possible that phosphorus removal at domestic wastewater treatment plants located in these areas could be sufficient to cause phosphorus to be limiting. It is also possible that advanced waste treatment could reduce the concentration of the apparent toxicant present in these rivers which would stimulate algal growth in the river and near-shore waters due to the excess phosphorus present. There is need for a more detailed assessment of factors limiting algal growth in these waters and relative nutrient sources before reliable predictions can be made on the environmental impact of advanced waste treatment of domestic wastewaters in the Genesee and Oswego River basins.

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