93-25

Environment Canada

Water Science and Technology Directorate

Direction générale des sciences et de la technologie, eau

Environnement Canada

How to Keep Green Algae in Eutrophic Lakes

By:
Jan Barica

NWRI Contribution # 93-25

93-25

MANAGEMENT PERSPECTIVE

This is an invited synthesis paper prepared for the International Symposium "Biology and Taxonomy of Green Algae II" to be held in the Tatra Mountains, Slovakia, in September, 1993. It summarizes Dr. Barica's previous experimental work with a literature review on the role of N:P ratios in controlling the composition of algae species in eutrophic lakes with particular reference to prairie lakes in western Canada and Hamilton Harbour in Lake Ontario. The focus is on manipulation of the ratios by additions of nitrogen or removal of phosphorus. The expected success rate of the method in lake management is evaluated.

HOW TO KEEP GREEN ALGAE IN EUTROPHIC LAKES

Jan Barica
Lakes Research Branch
National Water Research Institute
867 Lakeshore Road, P.O. Box 5050
Burlington, Ontario L7R 4A6
Canada

Abstract.

The role of N:P ratios in controlling the eutrophication process and particularly the algal species composition, is demonstrated on two types of lakes: 1) small hypereutrophic prairie lakes in western Canada, and 2) Hamilton Harbour, a large embayment of Lake Ontario. While low N:P ratios in the prairie lakes (5:1 and less) lead to the development of Cyanophyte blooms, which cause massive fish kills after their die-off, higher ratios (20:1 and more) increased by the addition of nitrogen fertilizer, lead to the pre-dominance of Chlorophytes. High N:P ratios in Hamilton Harbour (over 150:1), resulting from high ammonia loadings from treated municipal effluents, seem to be protecting the lake from the onset of Cyanophytes expected from high P loadings. It can be concluded that N:P ratios play an important role in determining the phytoplankton species composition in eutrophic lakes, and can be manipulated either by the addition of nitrogen or the removal of phosphorus for lake management purposes.

INTRODUCTION

Development of nuisance blooms of *Cyanophyta* (also termed *Cyanobacteria* or blue-green algae) in eutrophic lakes appears to be the major cause of serious problems related to their water quality and fish habitat. At high primary productivity levels, characteristic for these lakes, blue-green algae are known to form surface scums (*Microcystis* *sp.*), to cause severe oxygen depletion and fish mortalities upon their die-off (*Aphanizomenon sp.*) and death of cattle and other farm animals from ingestion of algal toxins (*Anabaena sp.*). Cyanophyte blooms can also cause off-flavors and odors in the water and fish, as well as clogging of filters in water treatment plants and other nuisances. Green algae, Chlorophytes, on the other hand, are not known to cause these problems, with the exception perhaps of filamentous species which may clog filters and cause off-flavors in drinking water also (*Cladophora sp.* in the Great Lakes). For the overall health of a lake or a reservoir and its management, it is preferable to maintain green rather than blue-green algal populations.

Why the blue-green algae become dominant in eutrophic lakes and outcompete and take over other algal genera is not known with certainty. They are known to have high energy, light, nutrient (particularly phosphorus) and water column stability requirements, and ability to assimilate atmospheric nitrogen. Forsberg (1979) presented a general graph showing that N:P ratios are low in eutrophic lakes and high in meso- and oligotrophic ones. Schindler (1977) observed a cyanophyte bloom in his experimental lake after reducing the loading N:P ratio from 15 to 5. This author (Barica *et al.* 1978, Barica 1990) observed that dissolved nitrogen concentrations in highly eutrophic lakes in western Canada prior to the onset of Aphanizomenon flos-aquae bloom are at their minimum with N:P ratios as low as 1 to 6 for a short period of time (approximately one week). He concluded that it was these short-lasting spring minima of N:P ratios which triggered the onset of nitrogen-fixing cyanophyte blooms. Moreover, the seasonal mean values of the N:P ratios in these lakes were as high as 20 to 30 and therefore misleading in assessing nitrogen limitation, as nitrogen fixation rapidly restored the N:P values to normal levels of 15 and over. This suggests that N-deficit may trigger the appearance of nitrogen fixing species which can alter the N:P ratio by increasing the value of the numerator by higher input of atmospheric nitrogen and rectify the overall nutrient balance.

Smith (1983) and Pick and Lean (1987) presented an in-depth review of the N:P ratio role in controlling cyanophyte dominance in temperate lakes in general. Smith (1983) noted that cyanophytes tended to dominate lakes where N:P ratios (seasonal mean values) were below 29 and were rare when greater than 29. Pick and Lean (1987) concluded that there was a discrepancy between the lake and laboratory experiments: while experimental manipulations of N:P ratios in enclosures or entire lakes may often stimulate or suppress relative cyanophyte biomass, laboratory studies on cyanophyte cultures do not clearly link low N:P ratios with cyanophytes, and other factors such as temperature, mixing regimes, transparency, and iron and carbon availability may influence cyanophyte dominance in lakes.

In this paper, a summary of experimental field studies on eutrophic lakes in western Canada, reported separately elsewhere (Barica *et al.* 1980, Barica 1990) is presented in support of the role of N:P ratios in controlling cyanophyte dominance, and applied to a lake system with extremely high N:P ratios (over 150) due to the input of treated municipal wastewater with high residual nitrogen concentrations (Hamilton Harbour in Lake Ontario, Barica 1989).

RESULTS

Experimental Manipulation of Algal Bloom Composition by Nitrogen Addition

The lakes studies are located near Erickson, southwestern Manitoba (50°30'N, 100°10"W). The area is a gently rolling terminal moraine, at an altitude of about 500 m. Most of it is under cultivation, with mixed farming operations. The lakes are all eutrophic, with nearly half of them hypereutrophic, experiencing heavy cyanophyte blooms (usually *A. flos-aquae*) and massive summer fish kills. The lakes are shallow and unstratified, of a prairie "pothole" type used for experimental summer trout farming. Two water bodies, one lake (885) and one dugout pond (014), were selected for N-addition experiments, using plastic tubes and limnocorrals in Lake 885. Morphometric and limnological characteristics of both are presented in Barica *et al.* (1980) together with fertilizer addition and sampling schedules.

In the tube experiments, using NH_4Cl and $NaNO_3$ as a N-fertilizer at concentrations of 0.75 $g{\cdot}m^{-3}{\cdot}wk^{-1}$, which corresponded to about 15:1 N:P ratio, N-additions appeared to stimulate chlorophyte representation besides decreasing the *Aphanizomenon* biomass. In the control tubes and the lake, chlorophytes (species of *Monoraphidium, Chlorella, Oocystis,* and *Scenedesmus*) were prominent only for a short time and formed about 6-14% of the total biomass. In the N-treated tubes, namely the NH_4 tubes, they formed over 50% of the total biomass and showed an extended presence, which lasted until the summerkill in the control tubes and the lake. Takeover of the tubes by *Aphanizomenon* was less successful in the NH_4 than the NO_3 tubes. N, mainly NH_4, appeared to enhance the growth of chlorophytes, likely by suppressing growth of *Aphanizomenon*. Although *Aphanizomenon* eventually became predominant in all treated tubes, its biomass was much lower than in the control tubes and the lake, and the clumping of flakes characteristic of the summerkill period did not develop.

As a parallel to the tube experiment, additions of NH_4NO_3 as a combined N-fertilizer were made into a pond (dugout) 014, about 25 km east of Lake 885, in the same geological area. This dugout has a long history of *Aphanizomenon* blooms and summerkills, and was monitored with limited frequency during 1973-77. Data showed maximum chlorophyll concentrations in the 160-201 $\mu g \cdot L^{-1}$ range (a very high summerkill hazard) and almost pure *A. flos-aquae* cultures.

Fertilizer was applied in concentrations 10x higher than that added to the limnocorrals in Lake 885 (7 g $m^{-3} \cdot wk^{-1}$) i.e., to N:P ratios over 150. The algal biomass appeared to be suppressed. The maximum chlorophyll *a* concentrations were 100 $\mu g \cdot L^{-1}$, about 50% of those recorded in previous years. Oxygen conditions were normal and without any substantial fluctuations. The most dramatic change was noticeable in the bloom composition. Instead of the usual pure *Aphanizomenon* bloom of previous years, the pond developed first a mixed population of cryptomonads and chlorophytes, and then a dominance of small chlorophyte species (*Scenedesmus, Oocystis, Collodictyon, Monoraphidium, Coenococcus,* and *Ankyra*). The latter group accounted for over 90% of algal biomass after mid-July. N:P ratios rose steeply also (up to over 200), and the equilibrating mechanism observed by in the limnocorral experiments did not appear to be functioning under these high loading conditions. However, the dugout did not develop a summerkill. For the first time the fish yield and recoveries were comparable to the most successful ponds in the area.

Hamilton Harbour in Lake Ontario

Hamilton Harbour, the westernmost embayment of Lake Ontario, is separated from the main lake by a sandbar. It contains about 2.8×10^8 m^3 of water, and has a surface area of 21.5 km^2, a maximum depth of 23 m, and a mean depth of 13 m. It is one of the most polluted sites in the Great Lakes, designated as an Area of Concern by the Canada-U.S. International Joint Commission. The harbour receives 4.3 $m^3 \cdot s^{-1}$ of treated wastes from municipal utilities. Loadings of phosphorus in 1985 were 609 kg/day, resulting in concentration ranges of total P of 40-200 $\mu g \cdot L^{-1}$.

Due to high ammonia loadings from two municipal wastewater treatment plants (Hamilton and Burlington) totalling about 7,000 $k \cdot day^{-1}$, and concentration ranges of about 0.1 to 4 $mg \cdot L^{-1}$ for NH_3-N, 1.5 to 2.5 $mg \cdot L^{-1}$ for NO_3-N, and 0.040 to 0.020 $mg \cdot L^{-1}$ for TP, the N:P ratios reach values as high as 150:1 and greater (compared to about 20:1 in Lake Ontario; MOE 1981, Stevens and Neilsen 1987).

High total ammonia levels (in mg/L range) contribute also to additional oxygen uptake due to nitrification (Klapwijk and Snodgrass 1986, Murphy 1987). It is noteworthy that nitrate levels in Hamilton Harbour have been dramatically increasing for the past three decades (fivefold since 1950; Forde 1979). With TP levels remaining the same, N:P ratios have been increasing proportionally with the nitrate increases.

These extremely high N:P ratios in Hamilton Harbour favor development of Chlorophytes, which are indeed the predominant algal group in the harbour in summer, together with Cryptophytes and Chrysophytes (Harris and Piccinin 1980, Barica and Vieira 1988). If the N-loadings were as low as in other parts of the Great Lakes and P-loadings as high as they are now, Hamilton Harbour would likely develop heavy blue-green blooms. The toxic effect of un-ionized ammonia on algae may also explain reduced phytoplankton levels, as ammonia concentrations over 2.5 $mg \cdot L^{-1}$ (common levels in parts of Hamilton Harbour) were reported to inhibit photosynthesis and growth of several species of algae (U.S. EPA 1985).

These beneficial effects of otherwise adverse environmental factors, particularly extremely high N-loadings may appear a paradox, but they can be credited for the fact that Hamilton Harbour has not shown the true extent of its concentrated pollutant load. Hypothetically, because of high phosphorus loadings the harbour could look as bad as any hypereutrophic lake in western Canada, with obnoxious blooms of blue-green algae and periodic massive fish kills.

DISCUSSION AND LAKE MANAGEMENT PERSPECTIVE

The objectives of enclosure and whole-lake experiments with N-additions were:

1) to find out if increasing the N:P ratio by addition of nitrogen fertilizer to a hypereutrophic lake will affect the phytoplankton composition and reduce the *Aphanizomenon* bloom and summerkill risk, and

2) to find out if this method can be used as an alternative to the widespread use of copper sulphate for algae control and summerkill prevention in this region. After a decade since the original design of the project, it is possible to view the

whole issue in retrospect and make conclusions on feasibility of this method for lake management.

As for the objectives, the former was successfully achieved: increasing the N:P ratios did cause a shift in phytoplankton composition, resulting either in suppression of the *Aphanizomenon* bloom (tube experiments, 15:1 N:P ratio), or its complete inhibition and replacement with a Chlorophyte bloom, but at substantially higher ratios (150:1 and over) which were fully successful in Cyanophyte elimination (pond 014 and Hamilton Harbour). Originally adjusted N:P ratio levels to 15-20:1 were obviously not high enough to ensure complete elimination of Cyanophytes, but certainly provided some effect on their biomass reduction. At these high levels, however, several adverse effects took place: concentrations of both ammonia and nitrate continued to build up in the water column and bacteria were taking over the system. High ammonia levels were also potentially threatening to cause acute toxicity to fish at elevated pH values and water temperatures (Trussel 1972). The whole nitrogen cycle of nitrogen-overloaded system could become distributed, as the high ammonia levels would inhibit the nitrification process (Barica 1991).

As for the second objective, the additions of nitrogen as a lake management tool appeared to be not sufficiently cost-effective and detrimental to overall water quality of the manipulated aquatic system by build-up of ammonia and nitrate levels.

N:P ratios, however, can be manipulated differently: instead of increasing the value of the numerator (addition of N), the ratio can be increased by reducing the value of the denominator (reduction of phosphorus loadings). This can be achieved by an effective phosphorus removal in sewage treatment plants for large lakes, or by whole- lake precipitation of phosphorus in small lakes or lakes with non-point P-sources (Murphy *et al.* 1988).

Preventive methods of P-reduction should be applied whenever possible (e.g., ban on polyphosphates in laundry detergents, as legislated in North America). A successful example of this approach can be found in the Great Lakes basin, where the eutrophication process has been halted or even reversed, with the N:P ratios rising steadily as a result of phosphorus reductions (Barica 1989).

REFERENCES

Barica, J., Kling, H. and Gibson, J. 1980. Experimental manipulation of algal bloom composition by nitrogen addition. Can. J. Fish. Aquat. Sci. 37: 1175-1183.

Barica, J. and Vieira, C. 1988. Nitrogen, phosphorus and chlorophyll *a* regime of Hamilton Harbour. National Water Research Institute Contribution No. 88-43.

Barica, J. 1989a. Unique limnological phenomena affecting water quality of Hamilton Harbour, Lake Ontario. J. Great Lakes Res. 15(3): 519-530.

Barica, J. 1989b. Recovery of the Laurentian Great Lakes, 1970-1985: Eutrophication aspects. Symp. Biol. Hung. 38: 43-59. Akadémiai Kiadó, Budapest.

Barica, J. 1990. Season variability of N:P ratios in eutrophic lakes. Hydrobiologia 191: 97-103. Biro, P. and Talling, J.F. (Eds.), Trophic Relationships in Inland Waters, Kluwer Academic Publishers, Printed in Belgium.

Barica, J. 1991. Deformation of the nitrogen cycle in a late receiving excessive loadings of ammonia. Environmental Pollution, 1-ICEP.1: 795-801.

Forde, A.V. 1979. A historical study of pollution of Burlington Bay. Reg. Mun. Hamilton-Wentworth, Ham. Munic. Lab. Report, Hamilton, Ontario.

Forsberg, C. 1979. Die physiologischen Grundlagen der Gewässer-Eutrophierung. Wasser Abwasser Forsch. 12(2): 40-45.

Harris, G.P. and Piccinin, B.B. 1980. Physical variability and phytoplankton communities IV. Temporal changes in the phytoplankton community of a physically variable lake. Arch. Hydrobiol. 89: 447-473.

Klapwijk, A. and Snodgrass, W.J. 1986. Lake oxygen Model 2: Simulation of nitrification and denitrification in Hamilton Harbour using laboratory data. In: Sediments and Water Interactions, Sly, P.G. (Ed.,), pp. 251-264, New York: Springer-Verlag.

Ontario Ministry of the Environment (MOE). 1981. Hamilton Harbour Study 1977, Volume 1. Water Resources Branch, Toronto, Ontario.

Murphy, T. 1987. Report to Remedial Action Plan for Hamilton Harbour writing team. (Unpublished.)

Murphy, T.P., Hall, K.G. and Northcote, T.G. 1988. Lime treatment of a hardwater lake to reduce eutrophication. Lake and Reservoir Management 4(2): 51-62.

Pick, F.R. and Lean, D.R.S. 1987. The role of macronutrients (C, N, P) in controlling cyanobacterial dominance in temperate lakes. New Zealand Journal of Marine and Freshwater Research 21: 425-434.

Schindler, D.W. 1977. Evolution of phosphorus limitation in lakes. Science 195: 260-262.

Smith, V.H. 1983. Low nitrogen to phosphorus ratios favor dominance by blue-green algae in lake phytoplankton. Science 221: 669-671.

Stevens, R.J.J. and Neilson, M.A. 1987. Response of Lake Ontario to reductions in phosphorus load: 1967-1982. Can. J. Fish. Aquat. Sci. 44: 2059-2068.

Trussel, R.P. 1972. The percent of un-ionized ammonia in aqueous ammonia solutions at different pH levels and temperatures. J. Fish. Res. Board Can. 29: 1505-1507.

U.S. Environmental Protection Agency (U.S. EPA) 1985. Ambient water quality criteria for ammonia - 1984. Report No. PB 85-227114.

Environment Canada   Environnement Canada

Canada

Canada Centre for Inland Waters
P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario
L7R 4A6 Canada

National Hydrology Research Centre
11 Innovation Boulevard
Saskatoon, Saskatchewan
S7N 3H5 Canada

St. Lawrence Centre
105 McGill Street
Montreal, Quebec
H2Y 2E7 Canada

Place Vincent Massey
351 St. Joseph Boulevard
Gatineau, Quebec
K1A 0H3 Canada

Centre canadien des eaux intérieures
Case postale 5050
867, chemin Lakeshore
Burlington (Ontario)
L7R 4A6 Canada

Centre national de recherche en hydrologie
11, boul. Innovation
Saskatoon (Saskatchewan)
S7N 3H5 Canada

Centre Saint-Laurent
105, rue McGill
Montréal (Québec)
H2Y 2E7 Canada

Place Vincent-Massey
351 boul. St-Joseph
Gatineau (Québec)
K1A 0H3 Canada