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The effects of abiotic conditions on release of biogenic substances from bottom sediments

Tadeusz Sobczyński[1]

Department of Water and Soils Analysis, Faculty of Chemistry
Adam Mickiewicz University
ul. Drzymały 24, 60-613 Poznań, Poland

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Abstract

The effects of abiotic environmental conditions, such as water oxygen content, pH and temperature, on the release of biogenic substances (mainly orthophosphates) from bottom sediments were examined in freshly collected samples from Lake Góreckie, Wielkopolski National Park. It was observed that their release was favoured by anaerobic conditions, alkaline pH and elevated temperatures, which are conditions naturally occurring in surface waters, especially in reservoirs of higher trophy.

[1] Corresponding autor: *sobczyn@amu.edu.pl*

INTRODUCTION

Increasing lake trophy is one of the major ecological problems of today. Strong anthropogenic pressures on aquatic ecosystems increase their fertility, leading to bloom formation, deterioration of the organoleptic and hygienic properties of water, and degradation of reservoirs. Increasing ecological awareness and developed legal regulations have brought about a reduction in the amount of harmful substances, including biogenic ones, introduced into surface waters. Better education and effective economic mechanisms have stimulated the more rational use of fertilisers in agriculture, and hence a reduction in the amount of substances washed into reservoirs from fields. Unfortunately, even a radical reduction of such external sources of biogenic substances does not always bring the desired results, since over time these substances have accumulated in bottom sediments, which have subsequently become internal sources of them (Wiśniewski 1995, Wiśniewski 1995, Kentzer 2001). As a result of physical, chemical and biological transformations biogenic substances are released back into the water column. The type and intensity of the processes depends on the physico-chemical conditions in the near-bottom layer of water (Perkins and Underwood 2001, Gnauck et al. 2002, Bartoszek 2007). The aim of this study was to establish the effects of water oxygen content, temperature and pH on the release from bottom sediments of biogenic substances that influence lake trophy.

MATERIALS AND METHODS

Sediment samples were collected in April 2008 from the bottom of Lake Góreckie in the Wielkopolski National Park. Lake Góreckie is a dimictic channel lake, largely surrounded by forest, with an area of 104.1 ha, a maximum depth of 17.2 m and a mean depth of 8.97 m. In the 1990^{s} hypertrophy of the lake was indicated (Szyper et al. 2001) accompanied by a significant accumulation of biogenic compounds in the bottom sediments (Sobczyński et al. 1997). Bottom samples were collected from areas of the lake where the overlying water column was anoxic most of the year. Samples were collected using a Nurek sampler. Tests were performed on the upper 10 cm of the sediments, thus incorporating the layer actively involved in physico-chemical exchange with the water column (Wiśniewski 1995, Bartoszek 2007). The organic matter content of samples was determined as the loss on calcination at 550°C, the silica content determined as the remains after calcination and hot etching with concentrated HCl. Total nitrogen was determined using the Kjeldahl method, and total phosphorus by the spectrophotometric method using molybdate after wet mineralization with HNO_3 and H_2SO_4. The contents of iron,

aluminium, calcium and magnesium were determined by the FAAS method after mineralization with HNO_3 and H_2O_2 [Hermanowicz et al.1999]. The content of aluminium was determined only in the fraction dissolved in the acids, the fraction bound with the hardly soluble aluminosilicates, which does not participate in bonding phosphorus, was neglected (Table 1). The laboratory tests were performed with the water from the lake characterised by pH = 7.73, conductivity 450 μS cm^{-1}, content of nitrates (NO_3^-) – <0.2 mg dm^{-3}, content of nitrites (NO_2^-) 0.013 mg dm^{-3}, ammonia (NH_4^+) 1.5 mg dm^{-3}, orthophosphates (PO_4^{3-}) 0.6 mg dm^{-3}, basicity 2.2 mval dm^{-3}. When necessary for certain laboratory tests some of these indices were modified.

Table 1

Chemical compositions of samples of Lake Góreckie bottom sediments.

Component	unit	Sample no.								
		1	2	3	4	5	6	7	8	9
Organic matter	%	28.1	27.1	27.1	26.3	27.2	26.2	27.1	26.4	27.2
Silica	%	35.4	36.5	35.4	35.7	35.5	35.7	35.7	35.7	36.5
Calcium	%	7.5	8.3	7.1	12.2	1.2	12.8	11.4	8.8	11.2
Iron	%	0.68	0.60	0.36	0.52	0.65	0.50	1.02	1.15	1.07
Aluminium	%	0.49	0.51	0.37	0.37	0.35	0.30	0.44	0.61	0.69
Total nitrogen	%	1.10	1.12	1.12	1.26	1.20	1.09	1.33	1.18	1.28
Total phosphorus	mg kg^{-1}	1095	1150	1035	1170	1260	1065	1275	1010	1260

Release of biogenic substances from bottom sediments in aerobic and anaerobic conditions

Investigations into the effects of water oxygenation on the release of biogenic substances from bottom sediments were performed on nine samples. The lake water used for the tests was thermally deoxygenated with a proportion of oxygen-saturated water then added back to it. Sub-samples from the nine sediment samples were mixed with deoxygenated water, to a ratio of 1:50, and mixed on a rotating shaker for 24 hours in air-tight containers. In parallel, another set of sub-samples were mixed, to the same ratio, with lake water saturated with oxygen and mixed for 24 hours on a rotating shaker, but ensuring contact with atmospheric air throughout. After 24 hours the water extracts were centrifuged and the contents of orthophosphates determined using molybdate with reduction by ascorbic acid, the content of nitrites determined by the same method with reduction by sulfanilowy acid and α-naphthyl amine, the content of nitrates by the same method with reduction by sodium salicylate and the

content of ammonium nitrogen by the same method with the Nessler reagent (Hermanowicz et al.1999).

Effect of water pH on the release of orthophosphates from bottom sediments

Six sediment sub-samples were mixed with lake water at a sediment to water ratio of 1:50. The water pH was adjusted to 5, 6, 7, 8, 9 and 10 in the six samples by addition of either HCl or NaOH. The samples were mixed on a rotating shaker for 24 hours, centrifuged and subjected to determination of orthophosphates as above.

Effect of temperature on the release of orthophosphates from bottom sediments

Nine 30 cm^3 sediment sub-samples were placed in glass cylinders and flooded with water from Lake Góreckie. Six of the cylinders were left at room temperature in the dark, of which three had 1 cm^3 of chloroform added to inhibit biological activity. The other three cylinders were incubated at 4°C. 10 cm^3 of water was collected from each cylinder every seven days, from which the content of orthophosphates was determined as above.

RESULTS AND DISCUSSION

The results of the tests performed under aerobic and anaerobic conditions are presented in Figs. 1-3. The release of orthophosphates was more intense under anaerobic conditions than in the aerobic samples (Fig. 1). Such conditions are often seen in the near bottom layer, especially in lakes in which stratification occurs, causing the hypolimnion to become deoxygenated during periods of stagnation, as is seen in Lake Góreckie. The release of orthophosphates under reducing conditions is related to the reduction of trivalent iron (insoluble iron (III) phosphate with orthophosphate ions) to divalent iron (forming water soluble complexes with orthophosphate ions). The analogous reduction of manganese (IV) to manganese (II) leads to the release of orthophosphates bound to this element (Gonsiorczyk et al. 1998, Kajak 1998, Perkins and Underwood 2001, Dojlido 2005). The mechanism of release of these elements is indicated by the results of fractionation of iron, manganese and phosphorus in the Lake Góreckie bottom sediments. Under the conditions simulating anaerobic environments, significant releases of these elements to water was observed (Zerbe et al.1999, Sobczyński and Siepak 2001, Sobczyński 2006).

Under anaerobic conditions an increased release of ammonium nitrogen was observed, compared to aerobic samples (Fig. 2). This represents the first stage of mineralization (ammonification) of organic compounds that contain nitrogen

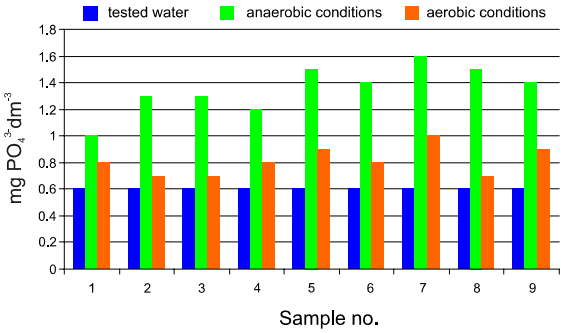

Fig. 1. The effect of oxygen access on the release of orthophosphates from Lake Góreckie bottom sediments.

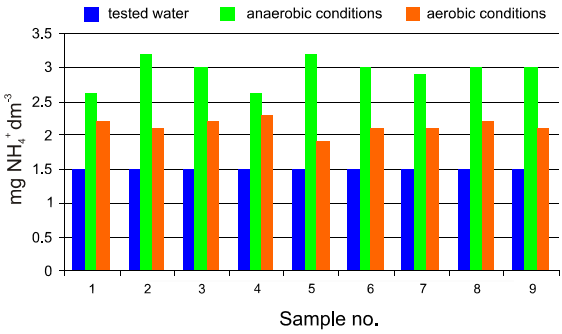

Fig. 2. The effect of oxygen access on the release of ammonium nitrogen from Lake Góreckie bottom sediments.

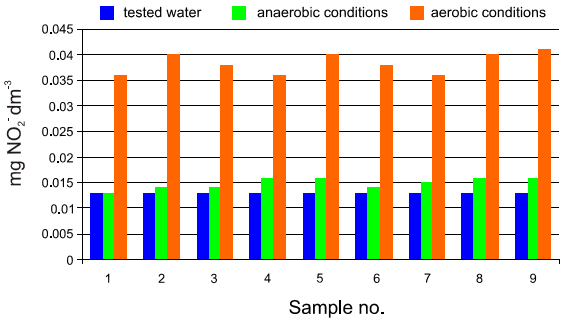

Fig. 3. The effect of oxygen access on the release of nitrites from Lake Góreckie bottom sediments.

(Kajak 1998, Dojlido 2005). In aerobic conditions the ammonium nitrogen was oxidised to nitrites (Fig. 3). Both of these reactions are mediated by bacteria (Kajak 1998, Dojlido 2005). Further oxidation of nitrites to nitrates under anaerobic conditions was not observed (and so nitrates in those samples were not studied). It is probable that this was as a result of the relatively short time over which the experiment was run.

The results of the tests for phosphorus release from the bottom sediments at different water pH are presented in Fig. 4. Decreasing the water pH to 5 resulted in an increase in phosphorous release, although only a little different from the release rate in the neutral environment. In natural conditions water in the near bottom layer rarely reaches pH 5, so this mechanism of phosphorus release to the water column does not pose a considerable threat to lake ecosystems. Of much greater effect on phosphate release into the water column is alkalinity of the near bottom water, at pH of 9 or even 10. Such conditions favour the release into the water column of phosphorus connected into organic matter and, perhaps most importantly that bound to aluminium (Forsberg 1989, Sobczyński and Joniak 2008). Under natural conditions, in particular in strongly eutrophic lakes during periods of increased photosynthesis, alkaline water pH is often observed. Although water with highly alkaline pH generally occurs in the well-illuminated epilimnion, in polymictic lakes with no or little stratification, such water can have direct contact with bottom sediments.

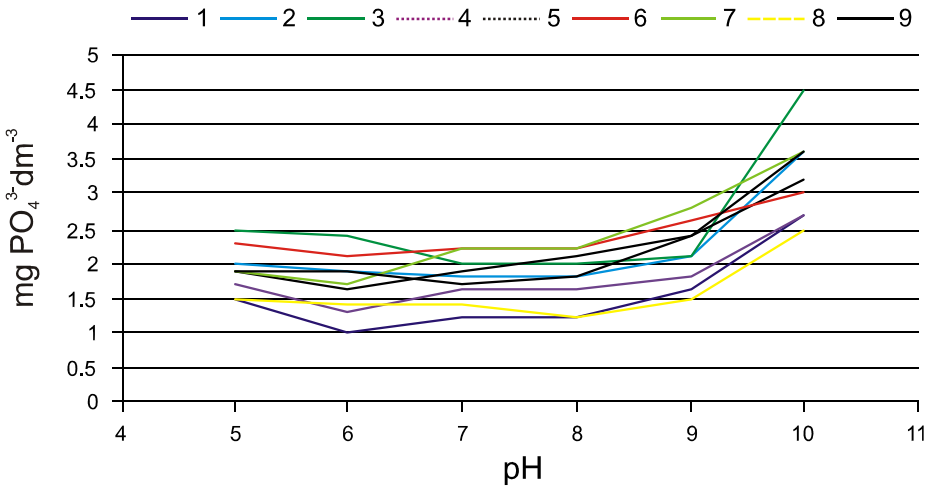

Fig. 4. The effect of water pH on the release of orthophosphates from Lake Góreckie bottom sediments.

The effect of temperature on the release of phosphorus from bottom sediments is shown in Fig. 5. At higher temperatures the rate of phosphorus release was much higher than at lower temperatures, which is probably related to the increased activity of micro-organisms responsible for the process. This result was confirmed by a decrease in the release of phosphorus in samples which had chloroform added, causing the inhibition of microbial activity.

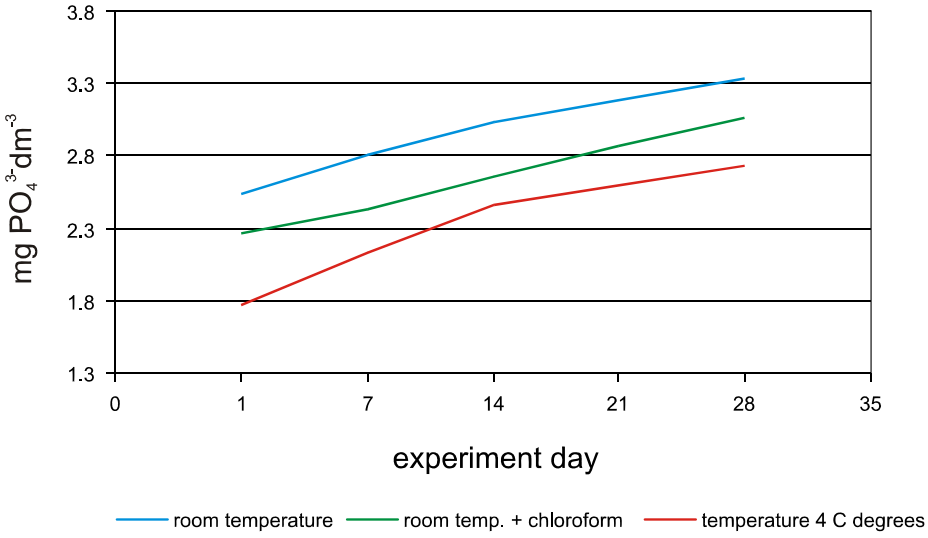

Fig. 5. The effect of temperature on the release of orthophosphates from Lake Góreckie bottom sediments.

CONCLUSIONS

The results presented show that the release of phosphorus and nitrogen from bottom sediments into the water column is favoured by anaerobic conditions. Oxygen deficit in the near bottom layer of water occurs during periods of stagnation, especially in lakes with well-developed thermal stratification. Phosphorus, released in the form of dissolved orthophosphates, and ammonia nitrogen penetrate the waters of the hypolimnion, to which sunlight necessary for photosynthesis usually has limited access. In periods of stagnation the stratification of the water column considerably inhibits the migration of biogenic compounds to the epilimnion, where the processes of primary production are most abundant. As is seen in Lake Góreckie, in spite of full lake stratification the level of lake trophy has been steadily increasing.

In shallow polymictic lakes oxygen usually penetrates to the bottom of the lake. However, even in such lakes the content of dissolved oxygen rapidly decreases in the sediment, and the reducing conditions thus achieved favour the release of phosphorus. Low temperatures inhibiting the activity of micro-organisms occur in the near bottom layer in deep lakes with full thermal stratification. Shallow polymictic lakes, in which the bottom is normally in direct contact with epilimnion water (the so-called active bottom), and which are usually characterised by high pH and relatively high temperature, are particularly susceptible to increased trophy caused by the activity of an internal source of phosphorus. However, their eutrophication is hindered by the presence of submerged macrophytes absorbing and accumulating in their tissues considerable amounts of biogenic substances.

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