

PHOSPHORUS RELEASE FROM LAKE BOTTOM SEDIMENTS
AFFECTED BY ABIOTIC FACTORS

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Keywords: Lake, bottom sediments, abiotic factors, phosphorus release, sequential extraction.

Abstract: The likelihood of phosphorus release from lake bottom sediments into bulk water as a result of changes in the physicochemical conditions in the lake has been analyzed by the method of sequential extraction proposed by Tessier *et al.* The procedure developed for estimation of the threat to water ecosystems posed by heavy metals accumulated in the bottom sediments, can be successfully applied in estimation of the release of other substances, including biogenic ones, as the subsequent states of extraction simulate the abiotic conditions and processes that can naturally take place in the near-bottom water layer and in the bottom sediment.

INTRODUCTION

In lake water phosphorus occurs in relatively low amounts, however, the effect of its presence can be profound. In natural conditions this element is usually a factor limiting primary production [16, 17]. In the bulk phosphorus occurs in the form of suspension as an abioseston (mineral trypton), bioseston (plankton) and organic trypton and in the dissolved form – mainly as orthophosphates. The above phosphorus species occur in water at a dynamic equilibrium. The phosphates are absorbed by phytoplankton and in the periods of its abundant development the concentration of phosphates in bulk water practically decreases to zero. The possible excess of phosphates is bound by the ions of iron, aluminium and calcium or is adsorbed on the surface of the suspension [2]. The phytoplankton and organic trypton are consumed by the zooplankton and as products of metabolism phosphates are released back to bulk water. Phosphorus can be also released from organic matter by biochemical reactions with phosphatases. However, the greatest amounts of phosphorus are accumulated in the bottom sediments fed with sedimenting suspensions. It is the main process eliminating phosphorus from bulk water, especially in deep lakes in which its migration back to epilimnion is difficult [6, 8, 18]. The reverse process, i.e. the release of phosphorus from the bottom sediments is often the main source of phosphates in lake water and it is referred to as the “inner source” of phosphorus in lakes [4, 17]. From the surface layers of the bottom sediment phosphorus is released into the bulk by the biotic path (enzymes, bacteria and benthonic organisms) and as a result of abiotic physical and chemical factors such as pH, redox potential, temperature, etc.

[1, 4, 7, 9, 16, 17]. There are many methods of phosphorus fractionation in bottom sediments addressed to different forms of its binding to the matrix [1, 4, 7]. This study was undertaken to estimate the likelihood of phosphorus release from the bottom sediments as a result of changes in the abiotic conditions that can happen in near-bottom water layer in the lake.

MATERIALS AND METHODS

The analyses were made of 16 samples of lake bottom sediments collected from Lake Góreckie in the area of the Wielkopolski National Park. It is a typical dimictic channel lake surrounded mainly by forests. The lake area is 104.1 ha, its maximum depth is 17.2 m and its mean depth is 8.9 m. Analysis of the lake trophy showed an increase in its fertility up to hypertrophy [14].

The concentration of total phosphorus in the samples studied varied from 0.004% to 0.117% of dry mass of the sediment. Depending on the sample collection site and on the depth of sample collection the sediment contained (for dry mass) 2.6% to 23.4% of organic matter, 0.19% to 1.50% of iron, 0.008% to 0.069% of manganese and 3.4% to 15.6% of calcium. The samples collected in deeper sites of the lakes contained greater amounts of organic matter, iron, manganese, calcium and phosphorus. The samples collected at shallow sites were characterized by a greater amount of silica. These results indicate that the main mechanisms of sediment formation are precipitation and sedimentation.

Estimation of the likelihood of phosphorus release from the bottom sediments as a result of changes in abiotic factors was performed by the way of sequential extraction, simulating at particular stages different conditions that can happen in a near-bottom layer of the lake. The well-known scheme of metal extraction proposed by Tessier *et al.* [15, 19] was used. The method is based on distinction of the five main fractions:

- I the exchangeable fraction – the most mobile one;
- II the fraction released under acidification of the environment up to pH 5.0, bound to carbonates;
- III the fraction released in the reducing conditions, bound to hydrated iron and manganese oxides;
- IV the fraction released on mineralization, bound to organic matter;
- V the residual fraction permanently immobilized in the natural conditions.

The same division can be applied not only to the release of metals but also other components of bottom sediments, including phosphates. In particular fractions the phosphates were determined by the spectrophotometric method based on the use of molybdenum and ascorbic acid as a reducing agent [5]. Absorbancy was measured at the wavelength of 700 nm on a UV-1601 spectrophotometer made by Shimadzu.

RESULTS AND DISCUSSION

Distribution of phosphorus among the particular fractions is presented in Figure 1. At pH 7, at the liquid-solid state equilibrium only a small part (3.5% on average) of the phosphorus accumulated in the sediment was released to the bulk water. Acidification of the water to pH 5, usually characterizing the near-bottom layer, resulted in the release of further 11.4% of phosphorus, on average. The strongest release of phosphorus from the

bottom sediments was observed in strongly reducing conditions, when about 30% of the total content of phosphorus (on average) was released to the bulk. This high release is related to reduction of iron(III) and formation of soluble iron(II) phosphate [2, 6, 13, 17]. Relatively small percentage of phosphorus was released as a result of mineralization of organic matter. In the conditions applied only 9.2% (on average) of its total content was released into the water. The fractionation of phosphorus in sediments according to the Psenner scheme [7] showed a considerable contribution of the fraction bound to organic matter and aluminium. The potential threat with the phosphorus released from this fraction is not much and can be well approximated by fraction 4 in the sequential extraction according to Tessier. By far the greatest amount of phosphorus (~ 46% on average) is bound permanently in the sediment, most probably in the form of apatite [6], and its liberation to the bulk water would require treatment with concentrated acids at elevated temperatures. Therefore, this fraction can be treated as permanently immobilized in the bottom sediments in the natural conditions.

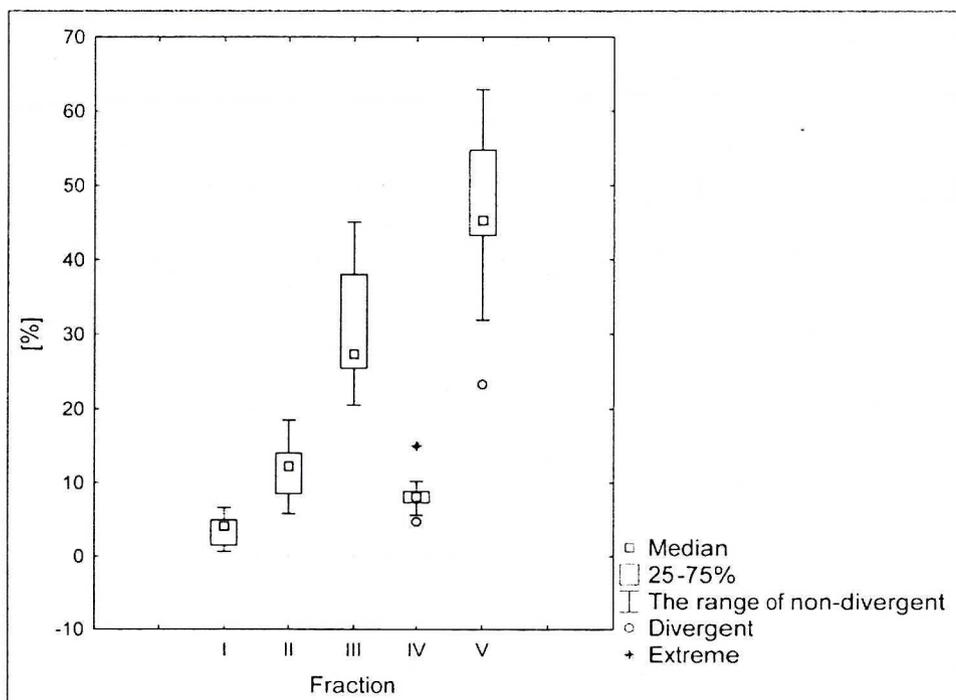


Fig. 1. Distribution of phosphate from Lake Góreckie bottom sediments in particular fractions

Because of a considerable contribution of fraction 3, bound to hydrated iron and manganese oxides, a possible correlation between the content of iron, manganese and phosphorus in the bottom sediments was tested.

The plot illustrating a correlation between the content of phosphorus and that of iron in the lake bottom sediments is shown in Figure 2. The correlation is rather strong as follows from the correlation coefficient value $r = 0.6502$ [12] and indicates an important role of iron in binding of phosphorus in bottom sediment.

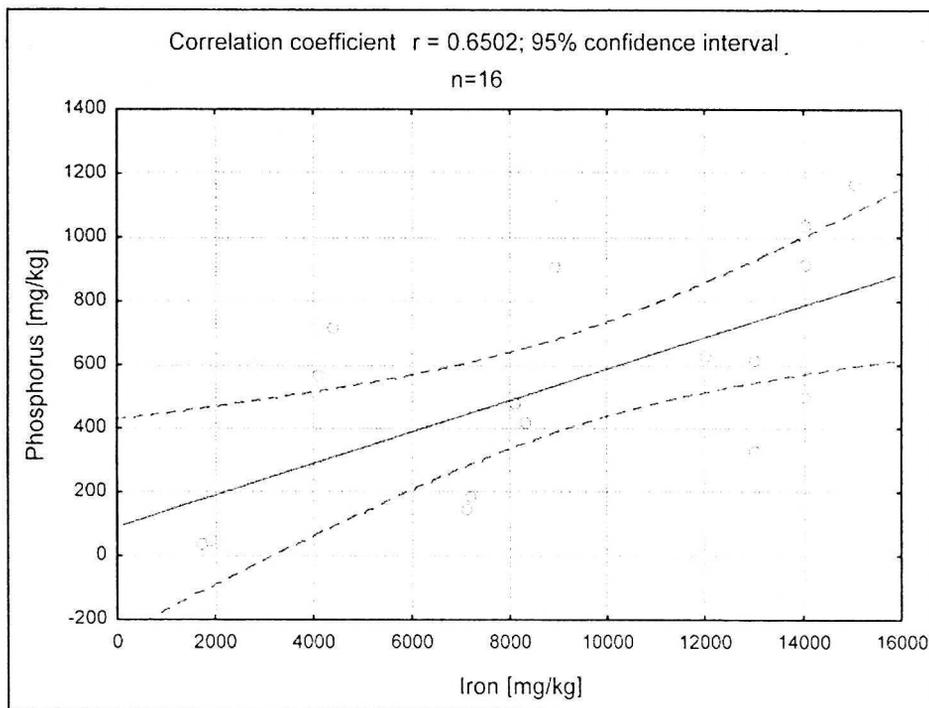


Fig. 2. The content of total phosphorus versus the content of iron in the samples of bottom sediments from Lake Góreckie

The correlation between the content of phosphorus and that of manganese in the Lake Góreckie bottom sediment is shown in Figure 3. The correlation is characterized by the much lower coefficient than that obtained for the correlation between the content of phosphorus and iron, of 0.3775, indicating weak correlation [12]. Also the correlation between the content of phosphorus and that of calcium characterized by the coefficient $r = 0.2555$ was very weak [12]. The relatively low correlation coefficients describing the correlations between the content of phosphorus and that of iron, manganese and calcium are a consequence of a diversity of the mechanisms of phosphorus binding with these elements. Phosphorus can make with them the insoluble phosphates and can be adsorbed on the precipitating hydrated oxides. The poorest correlation with the content of calcium additionally follows from the fact that in the sediment samples studied calcium occurred in considerable amounts many times greater than the stoichiometric equivalents of the bound phosphorus.

Fractionation of phosphorus in the bottom sediments by the sequential extraction proposed by Tessier [15, 19] does not allow for a differentiation of the phosphorus fraction bound to aluminium. The acidification at stage 3 of the extraction leads to its partial release and incorrect classification as the phosphorus bound to iron and manganese. The main pool of phosphorus bound to aluminium is released in the last (the fifth) stage of extraction and adds to the residual fraction assumed as biologically unavailable. This distribution of the phosphorus bound to aluminium among the fractions distinguished is indicated by the results of aluminium fractionation in the lake bottom sediment samples

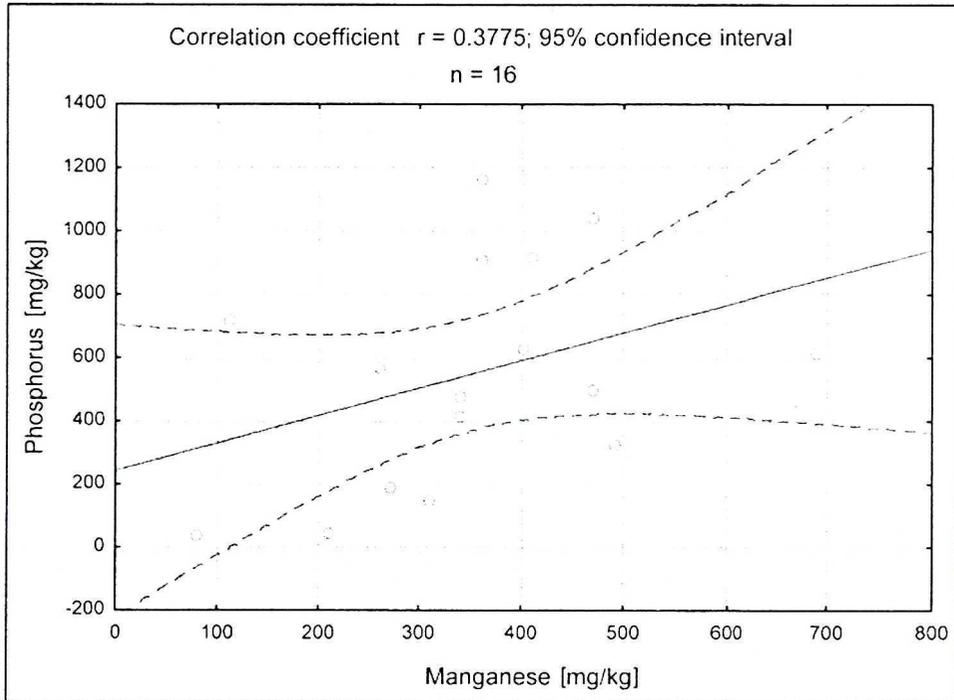


Fig. 3. The content of total phosphorus versus that of manganese in Góreckie Lake bottom sediment samples studied

performed according to the Tessier scheme [10]. The above problem does not have a significant effect on the evaluation of the threat to the lake ecosystem related to the phosphorus bound with aluminium as this fraction is relatively low mobile. However, in shallow polymictic lakes in which the epilimnion is in direct contact with bottom sediments, the significance of this fraction can increase. A strong alkalization of the lake water caused by intense photosynthesis can result in pH increase even up to 10, which may induce a significant release of orthophosphates bound to aluminium [11].

CONCLUSION

The release of phosphate from the lake bottom sediments to the bulk water significantly depends on the red-ox conditions in the near bottom layer and in the sediment. This dependence is a consequence of the profound role of iron in the bonding of phosphates. In the reducing conditions the insoluble iron(III) salts convert into well-soluble iron(II) salts, which is accompanied by the release of orthophosphates whose presence exerts negative effect on the lake ecosystem. Unfortunately, such conditions occur usually in the strongly eutrophic water and additionally decrease their quality.

The research has been financially supported by the Ministry of Science and Education within the project no. N305 022 32/1103.

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Received: September 4, 2008; accepted: February 18, 2009.

BADANIA NAD UWALNIANIEM FOSFORU Z JEZIORNYCH OSADÓW DENNYCH POD WPLYWEM CZYNNIKÓW ABIOTYCZNYCH

W pracy przedstawiono wyniki badań nad potencjalną możliwością uwalniania fosforu z osadów dennych do wody w wyniku zmian warunków fizyko-chemicznych panujących w jeziorze. W badaniach posłużono się ekstrakcją sekwencyjną, zaproponowaną przez Tessiera i współpracowników. Procedura ta, opracowana do

oceny zagrożenia ekosystemu wodnego ze strony skumulowanych w osadach dennych metali ciężkich, może być zastosowana również do oceny podatności na uwalnianie innych składników osadów, w tym i substancji biogennych. Poszczególne etapy ekstrakcji symulują bowiem warunki abiotyczne, jakie mogą zaistnieć w strefie naddennej i w samym osadzie w warunkach naturalnych.