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Total phosphorus and organic matter content in bottom sediments of lake under restoration measures with iron treatment

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Abstract: Rusałka Lake is a shallow, man-made, strongly eutrophicated reservoir, being a place of recreational activities for Poznan citizens. Restoration measures with the use of iron sulphate were conducted in years 2006-2007. Phosphorus and organic matter concentrations in lake sediments were analyzed in years 2005-2007 at two research stations (profundal and littoral) to determine its changes under the influence of restoration. Greater phosphorus concentrations were noted in profundal (max 1.55 mg P g^{-1} dry weight (DW)) than in littoral (max 0.98 mg P g^{-1} DW). An increase of P amount in sediment was observed after iron treatment. Among phosphorus fractions Res-P dominated, i.e. phosphorus biologically unavailable for organisms. Organic matter content reached 23.1% in profundal, while 14.8% in littoral. Its amount decreased in following years.

Key words: bottom sediments, lake, organic matter, phosphorus, restoration

Introduction

Phosphorus has been recognized as the most critical nutrient limiting lake productivity, as the trophic status of the lake is usually dependent on the P-concentration in the water. In addition, the trophic development of the ecosystem is also influenced by the phosphorus in lake sediments, which usually act as sink of phosphorus. However, under certain environmental conditions, the sediments may become a potential phosphorus source (Kaiserli et al. 2002).

Rusałka Lake is a polymictic and strongly eutrophicated reservoir. Thermal stratification is weak and comprise only ca 8% of the bottom surface. Epilimnion in summer is oversaturated with oxygen, due to intensive phytoplankton growth (chlorophyll *a* up to 80.2 μg l^{-1}), while hypolimnion has anaerobic conditions. High concentration of ammonium nitrogen and low N:P ratio stimulated intensive growth of cyanobacteria in the period from June till November (Gołdyn et al. 2010). Additionally, significant phosphorus release from bottom sediments was noted (Kowalczewska-Madura et al. 2010b). As a place of recreational activity, lake has been an object of restoration measures with iron treatment. The addition of iron aimed in increase of the iron buffer within the sediment. The objectives of iron treatment are: precipitation of phosphorus from the water body, increase of the sediment's phosphorus-binding capacity and decontamination or precipitation of surplus hydrogen sulphide (Søndergaard et al. 2002).

The goal of studies done in 2005-2007 was to determine the changes of total phosphorus and organic matter in bottom sediments under the influence of iron sulphate.

Materials and methods

The Rusałka Lake is a shallow, man-made reservoir, situated within the City of Poznań. It was created as a result of flooding a valley of the Bogdanka River. Its surface area is 36.7 ha, average depth – 1.9 m and maximum depth – 9.0 m. Direct catchment area is covered by forests in 90%. Despite this fact, Rusałka Lake is highly vulnerable to degradation. The reasons are almost all morphometric and hydrographic features of the lake, especially its small average depth (Pułyk, Tybiszewska 1995; Gołdyn et al. 1996) (Fig. 1).

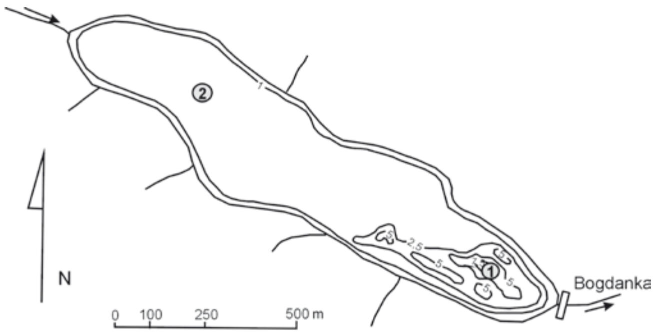

Fig.1. Stations of bottom sediments sampling in Rusałka Lake (bathymetry acc. to Pułyk, Tybiszewska 1995, modified)

This lake was restored in 2006-2007 with the use of iron sulphate (PIX-112), which was dosed 6 times during vegetation season of 2006 and 3 times in 2007. Restoration measurements were done with the use of prototype mobile pulverized aerator (Podsiadłowski 2008) by AERATOR company from Poznań.

Analyses of phosphorus and organic matter concentration in bottom sediments were conducted monthly from March/April till November during 3 years (2005 – preliminary research, 2006 and 2007 – research during treatment). The samples were taken from two appointed research stations, located in profundal (station 1) and littoral (in the depth of 2 meters – station 2) (Fig.1).

The samples of bottom sediments were collected with a Kajak tube sampler. The surface layer of sediments (10 cm thick) was being analyzed. Sediments samples were dried and then, incinerated at 550˚C. Phosphorus content was analyzed by the molybdate method with ascorbic acid as a reducer (Elbanowska et al. 1999). In collected sediment samples phosphorus was fractionated by modified protocol proposed by Psenner (Psenner et al. 1988, Lewandowski et al. 2003). The fractions were: loosely bound phosphorus (NH_4Cl-P), phosphorus bound with iron (BD-P), phosphorus bound with aluminum and organic matter (respectively, NaOH-P-Al and NaOH-NRP), phosphorus bound with calcium (HCl-P) and the residue (Res-P), which was the difference between total P concentration and the sum of the first four fractions. In the air dry samples assayed concentration of organic matter as loss ignition at 550˚C (Myślińska 2001). Pore waters were separated by centrifugation for 1 h at 3000 revolutions per minute in closed containers to prevent the samples oxidation. In the supernatant, SRP level was measured with the molybdenum blue method with ascorbic acid, and TP with the same method, after sample thermal mineralization (Elbanowska et al. 1999). Statistical calculations were made with STATISTICA version 8.0 software.

Results

Greater phosphorus content in sediments was observed in samples from profundal (station 1) than form littoral site (2). At the deepest place it varied from 0.67 to 1.55 mg P g^{-1} dry weight (DW), while at the depth of 2 m from 0.47 to 0.98 mg P g^{-1} DW. Seasonal variability manifested in higher values in colder months (Fig. 2). The comparison of mean concentrations in following years indicated highest values in 2007 (1.23 mg P g^{-1} DW), while the lowest in 2006 (1.13 mg P g^{-1} DW). In littoral sediments greater amount of phosphorus was noted in year previous to restoration and lower in the second year of treatment (Fig. 3).

Phosphorus fractions content was analysed only in the last year of research. Dominating fraction was Res-P, i.e. phosphorus compounds of the lowest solubility and bioavailability, with mean concentration of 0.69 mg P g^{-1} DW in profundal and 0.45 mg P g^{-1} DW in littoral (respectively, 56.1 and 64.2% in total phosphorus content). NaOH-NRP fraction was the second contributor with a mean percentage share of 18% in profundal and 14.2% in littoral. Total contribution of the most mobile fractions (i.e. NH_4Cl-P, BD-P and NaOH-P) was slightly greater in sediments from the deepest place (13.8%) than from the depth of 2 m (10.2%; Fig. 4 and 5).

Phosphorus concentrations in the pore water of Rusałka Lake was analyzed in years 2006 and 2007. In both years higher values were observed in profundal sediment samples. At station 1 it varied from 1.14 to 6.2 mg P l^{-1} for orthophosphates and from 1.39 to 7.1 mg P l^{-1} for total phosphorus (Fig. 6). At station 2 these values were respectively lower – from 0.14 to 0.91 mg P l^{-1} for orthophosphates and from 0.29 to 1.21 mg P l^{-1} for total phosphorus (Fig. 7). Greater values were noted at early spring and at the turn of summer and autumn. The comparison of mean content indicated slightly elevated values in 2007 (Fig. 8).

Organic matter content at profundal site changed from 15.1 to 23.1% and higher amount was stated in the end of summer, while lowest in spring. In littoral this parameter indicated lower values, reaching 13.1-14.8%, and no significant seasonal differences

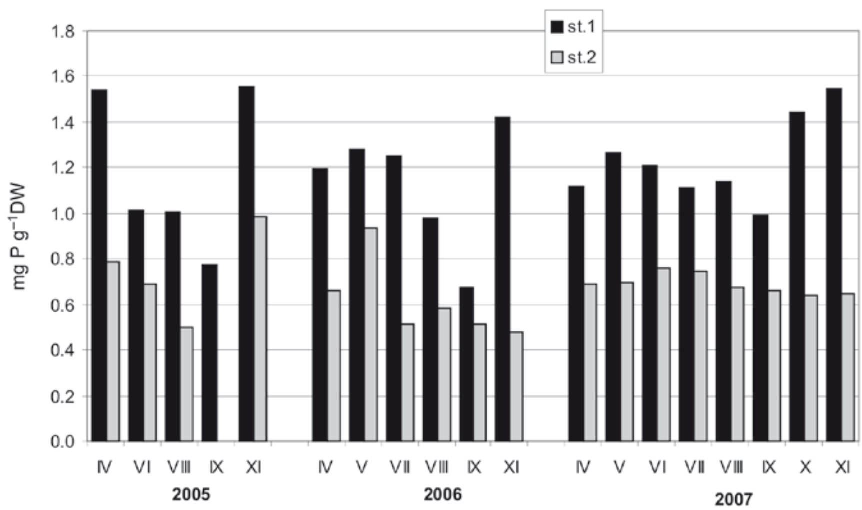

Fig.2. Total phosphorus content in bottom sediments of Rusałka Lake at both study sites

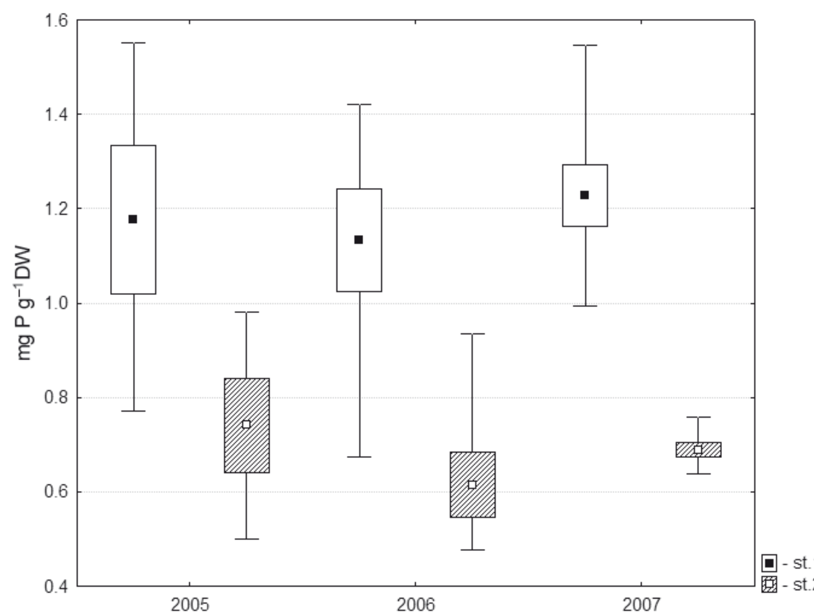

Fig. 3. The mean phosphorus content in bottom sediments of Rusałka Lake at both study sites

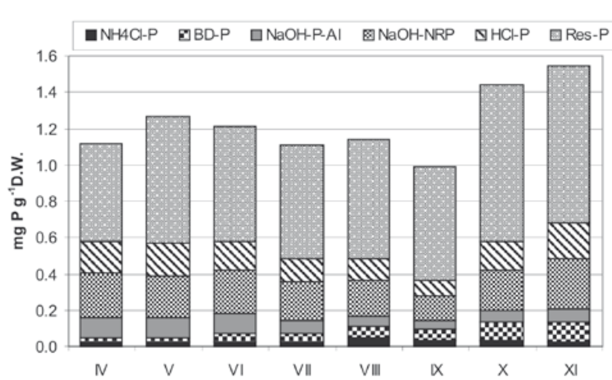

Fig. 4. Phosphorus fractions content in bottom sediments in profundal zone of Rusałka Lake in 2007

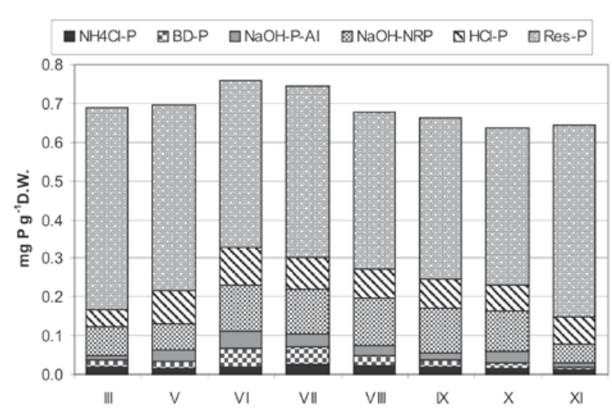

Fig. 5. Phosphorus fractions content in bottom sediments in the littoral of Rusałka Lake in 2007

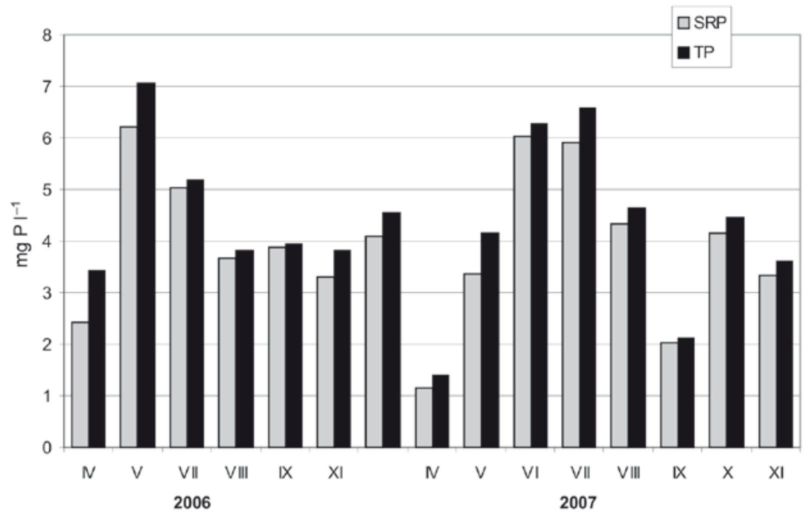

Fig. 6. The variability of orthophosphates (SRP) and total phosphorus (TP) concentrations in interstitial water in profundal of Rusałka Lake

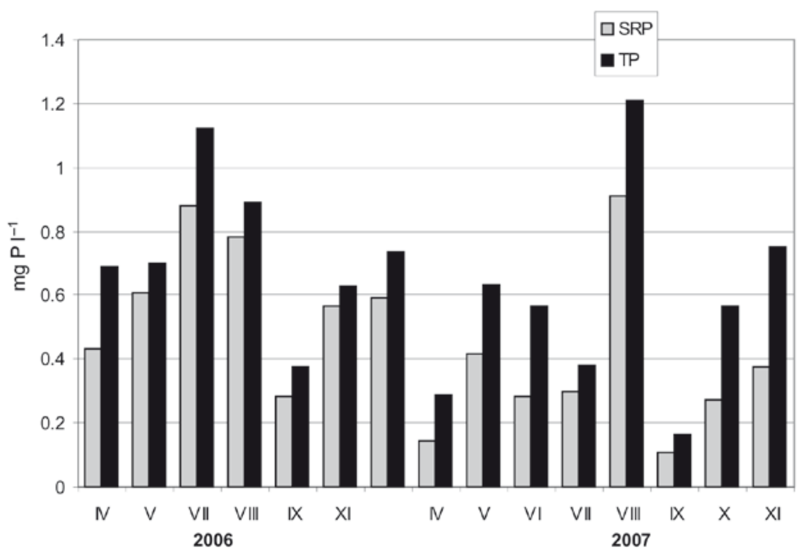

Fig. 7. The variability of orthophosphates (SRP) and total phosphorus (TP) concentrations in interstitial water in littoral of Rusałka Lake

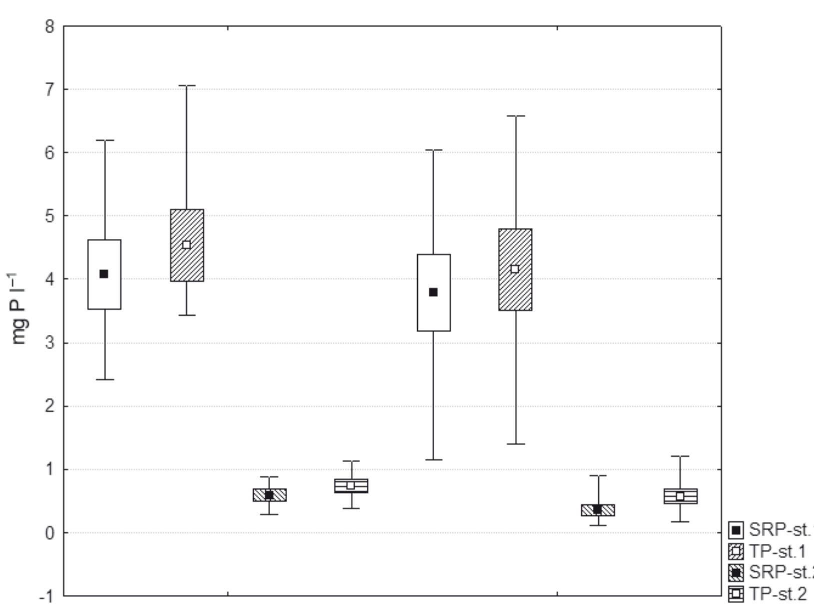

Fig. 8. The comparison of mean orthophosphates (SRP) and total phosphorus (TP) concentrations in interstitial water of profundal (st.1) and littoral (st.2) of Rusałka Lake

occurred (Fig. 9). Mean organic matter content was greater at both analyzed stations in 2006. The lowest value at the deepest place was observed in 2005, whilst in littoral in 2007 (Fig. 10).

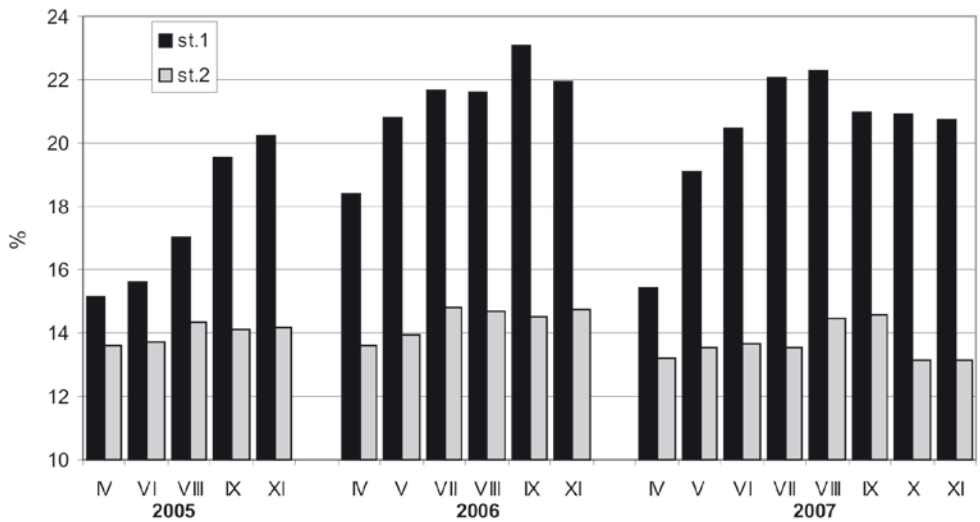

Fig. 9. The variability of organic matter concentrations in bottom sediments of Rusałka Lake

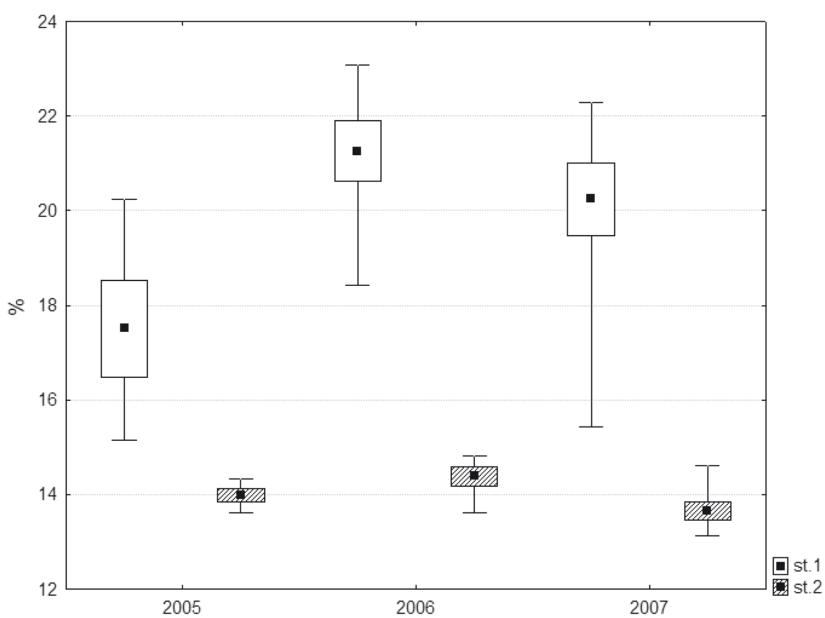

Fig. 10. The mean organic matter content in bottom sediments of Rusałka Lake at both study sites

Discussion

Restoration measure with the use of iron compounds is well known method aimed at decrease of available phosphorus in water column and its inactivation in bottom sediments (Wiśniewski 2000; Gawrońska et al. 2003). An increase of sorption complex in sediments limits internal phosphorus loading ad well.

High total phosphorus content was stated in Rusałka Lake sediments, especially in profundal zone. This part of lake, with oxygen deficits in summer, comprise only 8% of lakes bottom (Gołdyn et al. 2010), but it plays a significant role in phosphorus circulation. Wind induced sediment resuspension cause phosphorus transport to water column and final deposition in the deepest part of lake. Iron sulphide dosage intent to boost sorption complex in sediment to prevent from phosphorus release especially from this lake zone. Slight increase of phosphorus content in sediments of profundal zone in following years in comparison to 2005 confirmed that this goal was achieved and the conditions of phosphorus accumulation in sediments improved. Similar sediment reaction on restoration measures was observed in Uzarzewskie Lake (Kowalczewska-Madura et al. 2010a) and in Wolsztyńskie Lake (Gawrońska et al. 2007). However, in littoral zone no such effect was clearly noted, probably due to permanent water mixing allowing the return of phosphorus to water column. Conducted restoration measures decreased also the intensity of phosphorus internal loading, what was confirmed in experimental conditions in years 2005-2007 (Kowalczewska-Madura et al. 2011). Mean phosphorus content was lowest at both sites in the first year of treatment as a result of its release, especially in summer period (Kowalczewska-Madura et al. 2011).

Res-P, i.e. phosphorus in practically indissoluble organic and mineral compounds (Kentzer 2001) was the dominating fraction in sediments. Such a phenomenon is positive in the light of phosphorus release possibility in internal loading process. Similar results were noted in lakes Swarzędzkie (Kowalczewska-Madura et al. 2005), Uzarzewskie (Kowalczewska-Madura et al. 2010a) and Licheńskie (Brzozowska et al. 2007).

Coagulant dosage caused also decrease of phosphorus forms in pore water at both analyzed sites due to its transport into sediments as a result of restoration treatment. Permanent phosphorus accumulation in sediments caused its lower amounts in interstitial water, what is considered as a positive lake reaction as the concentration of phosphorus in interstitial water influence the potential ability to P release (Søndergaard et al. 2002). Also in Uzarzewskie Lake similar phenomenon was noted (Kowalczewska-Madura et al. 2010a).

Organic matter content in Rusałka Lake sediments was typical for eutrophic water bodies. Higher amounts noted in profundal zone were a consequence of organic matter deposition in this area favoured by lower water temperatures and, therefore lower rate of mineralization processes (Brzozowska et al. 2005). Significantly poorer amount in littoral area in comparison with much deeper bottom parts indicated both (i) more intense decomposition process in shallow, thus well-oxygenated and well-heated zone and (ii) its resuspension in sediments and deposition in profundal. Increase of organic matter content in the first year of treatment at both study sites occurred due to the absorption of the organic matter suspended in the water column and deterioration of the mineralization conditions, what was also stated in Długie Lake (Brzozowska and Gawrońska 2006). A decrease in 2007 indicated lower primary production in lake as a result of conducted treatment.

Conclusion

Phosphorus inactivation method with the use of iron sulphide caused an increase of total P content in sediments of profundal zone, what confirms improvement in accumulation conditions in his part of lake. Additionally, lower P concentrations were observed in pore water and as a consequence poorer internal loading occurred. Organic matter content boost in the first year of treatment and finally decreased.

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