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Phosphorus release from the bottom sediments of Lake Rusałka (Poznań, Poland)

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Key words: bottom sediments, phosphorus, internal loading, hypertrophic lake

Abstract

Experimental research conducted on bottom sediments from the eutrophic Lake Rusałka (Poznań, Poland) indicated that the phosphorus release process has a significant influence on the functioning of the ecosystem. Internal loading was very intense in the deepest part of the lake, where it reached up to 29.84 mg m^{-2} d^{-1} P under anaerobic conditions. This part of the lake, however, was insignificant to overall internal loading. The highest loading was from the lake shallows, which covered 92% of the bottom area. Total mean annual loading to the ecosystem was 1214.5 kg $year^{-1}$ P, i.e., 3.31 g m^{-2} $year^{-1}$ P.

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INTRODUCTION

Lakes are loaded with phosphorus not only from external sources (tributaries, surface overland flow, ground waters, rainfall, wastewater), but also from internal sources, mainly bottom sediments (Ryding and Rast 1989). Sediments participate in phosphorus cycling in water ecosystems through the accumulation, processing, and release of its compounds into the water. Phosphorus exchange between the sediments and the near-bottom water layer is one of the most important ways it circulates in water ecosystems (Wiśniewski and Rzepecki 1996). The phosphorus release process is considered to be very significant in the eutrophication of water bodies (Wiśniewski 1994, Wiśniewski 1995). The return of phosphorus to the water column is the result of many interconnected processes including biological (e.g., binding and biological mobilization), physicochemical (e.g., desorption, solubility), and physical (e.g., diffusion). All these processes effect very diverse release rates of this element not only in response to different lakes, but also to the situation in the bottom sediments and the season (Boström et al. 1982, Kelderman 1984, Psenner 1984, Forsberg 1989, Wiśniewski 1995, Kentzer 2001, Kowalczewska-Madura and Gołdyn 2009). This means that phosphorus release should be studied individually in every lake in which the functioning of the ecosystem is evaluated.

Since plans had been made to restore Lake Rusałka, it was decided to perform ex situ experiments to estimate phosphorus release from the bottom sediments to the water column. The aim of the research was to determine the intensity of phosphorus release from the sediments and the seasonal and spatial variability of this process.

MATERIALS AND METHODS

Lake Rusałka is an artificial reservoir located in the northwestern part of the city of Poznań. The lake was created in 1943 by flooding a valley on the Bogdanka River and the clay mining pits located in the area. The surface area of the lake is 36.7 ha, maximum depth is 9.0 m, and the average depth is 1.9 m. The catchment area covers 25.1 km^2, while its immediate catchment area is 0.893 km^2 (Pułyk and Tybiszewska 1995, Gołdyn et al. 1996). The immediate catchment area is 90% forest and 10% meadows. The most important tributary is the Bogdanka River, but five other streams also supply Lake Rusałka: Golęciński Stream and four nameless tributaries drain the immediate catchment area (Gołdyn et al. 1996).

Intact sediment samples for ex situ experiments were collected with a modified tube sampler at two stations from April to November 2005 and in

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February 2006. The samples were collected five times: on 27 April, 29 June, 31 August, 28 September, and 10 November from sampling stations that were located in both the deepest and shallowest parts of the lake (Fig. 1). Each transparent tube, 6 cm in diameter, containing the collected sample of intact sediment core (ca. 10 cm in length) and the overlying water, was sealed with rubber stoppers. After transporting them to the laboratory, the tubes were stored in darkness under constant thermal conditions (±2ºC) that were similar to those in the lake. The analyses of total phosphorus were done spectrophotometrically with ascorbic acid as the reducer (ISO, 2004). Five cores were always collected from each station, and the experiment lasted from 13 to 15 days. This enabled calculating the changes in total phosphorus content in the water above the sediment and to estimate the mean internal loading per 1 m^2 of sediment during a 24 h period. The experiment performed with 5 cores from the deepest site in the lake (station 1) is presented in Fig. 2, and that of station 2 in Fig. 3. The mean value and standard deviation from all the cores from each experiment were calculated and are presented in Table 1.

Statistical analysis revealed a positive linear correlation between the values of released phosphorus rate and temperature of the near-bottom water layer. For station 1, the correlation equation was y=3.4889+1.6677 x (where r=0.643 and p=0.000) and for station 2 it was y=1.056+0.6264 x (where r=0.698 and p=0.000). Changes in internal loading for the whole year were calculated based on these relationships and the water temperature in different months.

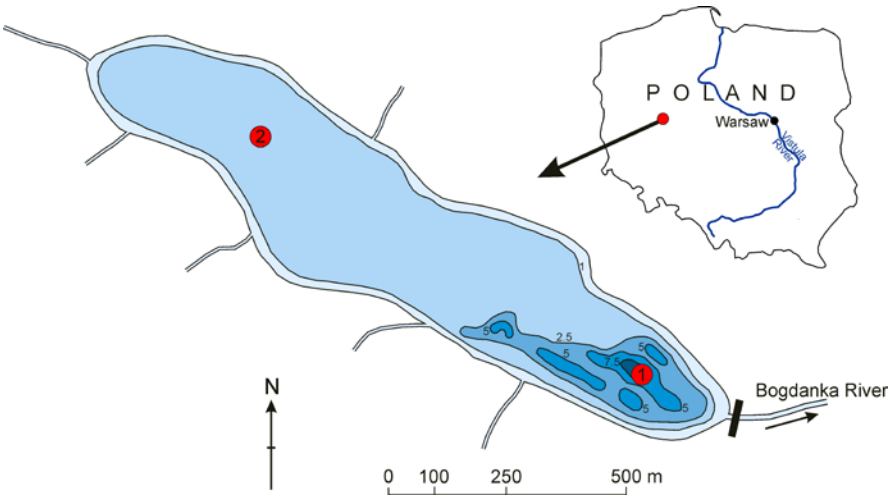


Fig. 1. The position of research stations in Lake Rusałka (bathymetry after Pułyk and Tybiszewska 1995, modified).

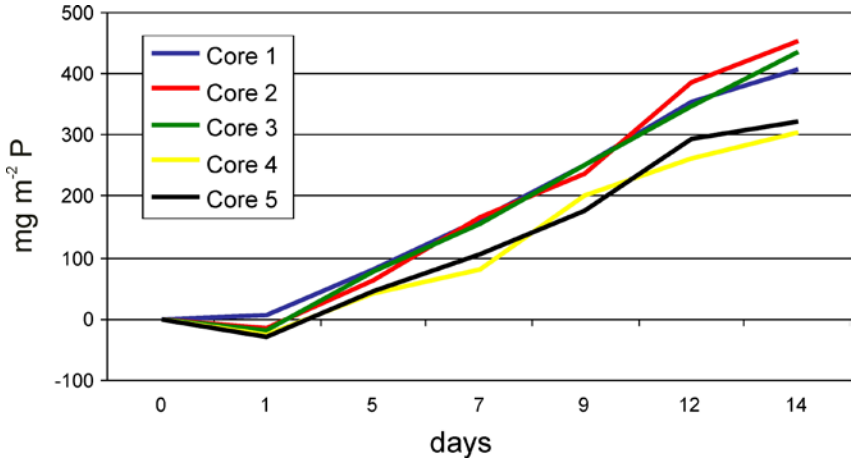


Fig. 2. The release of phosphorus from bottom sediments from the deepest place (station 1) in September 2005 in anaerobic conditions.

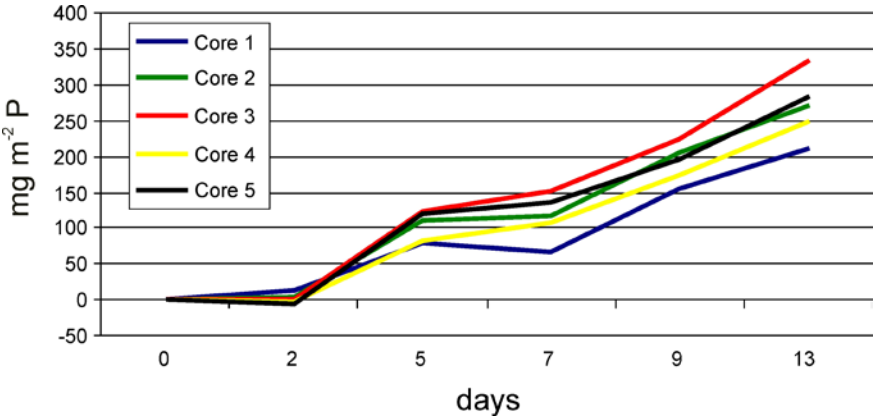


Fig. 3. The release of phosphorus from bottom sediments from the active bottom (station 2) in June 2005 in aerobic conditions.

Two zones were identified in the lake that differed with respect to rates of phosphorus release from the bottom sediments. These were based on the morphometry of the lake basin, the character of the bottom sediments, and a bathymetric map of the lake. Zone I is the bottom at depths of 0-4 m (area 33.9 ha), while zone II is situated in the region where water depth is 4-7 m (area 2.8 ha). The annual internal phosphorus loading into the lake was calculated as the sum of phosphorus released from both zones.

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Table 1

Mean value of phosphorus release (mg m^{-2} d^{-1} P) and standard deviation from all cores of each experiment.

Station		27.IV.2005	29.VI.2005	31.VIII.2005	28.IX.2005	10.XI.2005
1	average	22.06	52.03	37.01	27.56	6.06
	standard deviation	3.7	29.7	27.6	4.8	3.5
2	average	10.85	20.76	8.48	10.03	3.67
	standard deviation	1.4	3.5	2.6	2.6	2.3

RESULTS

Data relating to P release from bottom sediments were gathered in five terms at both stations (Table 1). They showed distinct seasonal variations. The lowest were noted in November, and the highest in August at station 1 and in June at station 2.

Higher phosphorus loading was observed in Lake Rusałka in zone II, situated in the deepest part of the lake. Lower values were noted in zone I, situated in the active bottom area, which was in contact with the epilimnion waters (Fig. 4). Strong seasonal differences in the rate of release were observed and ranged from 2.31 to 29.84 mg m^{-2} d^{-1} P. The lowest loading was noted in January in both zones and the highest occurred earlier in zone I (June) than in zone II (September) (Fig. 4).

To estimate the real internal loading in both zones, the unit value was multiplied by the surface of the individual zones. This revealed that the greatest share of phosphorus loading in Lake Rusałka was in zone I, i.e., the shallow part with the active bottom, because it covers 92% of the lake area (Table 2). Phosphorus release from this zone almost always exceeded 1 kg d^{-1} P (except in January) and reached 5.3 kg d^{-1} P in June. Although high release values were noted in the deeper part of the lake, this contributed a rather insignificant share to the internal loading of the lake at just 0.84 kg d^{-1} P (September) (Fig. 5).

In consideration of the intensity of loading (from both zones) in different seasons, it was noted that the highest mean release value occurred in summer (37.3 mg m^{-2} d^{-1} P), and higher values were noted in all seasons in zone II than in zone I (Fig. 6). The average annual release of phosphorus from bottom sediments in Lake Rusałka was 8.46 mg m^{-2} d^{-1} P in zone I and 16.46 mg m^{-2} d^{-1} P in zone II.

The average annual internal loading in Lake Rusałka was 1214.5 kg $year^{-1}$ P (Table 2). Divided by the lake surface area, this value gives a mean annual internal loading figure of 3.31 g m^{-2} $year^{-1}$ P. Calculations done for different

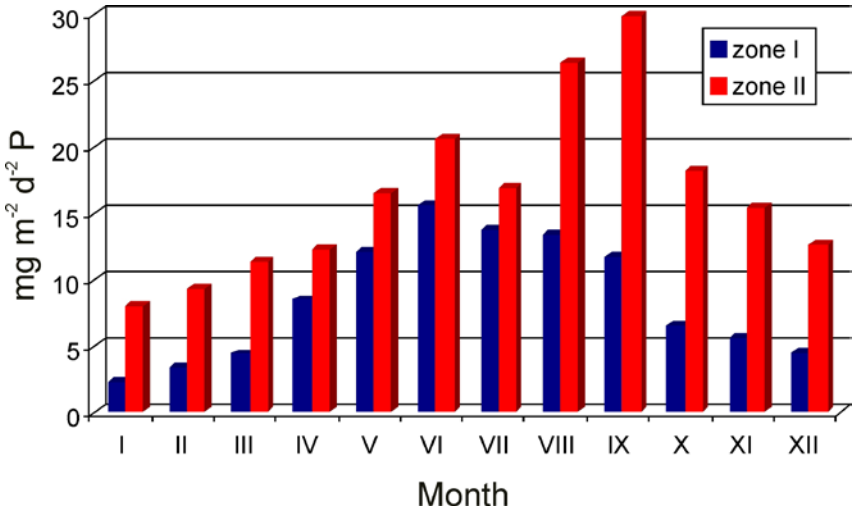


Fig. 4. Unit internal phosphorus loading from bottom sediments calculated for particular months in zones I and II.

Table 2

Mean annual internal phosphorus loading from bottom sediments in Lake Rusałka in particular zones.

Zone	Mean P release (mg m^{-2} d^{-1} P)	Zone area (m^2)	Internal loading (kg r^{-1} P)
I (0-4 m)	8.46	338800	1046.18
II (4-9 m)	16.46	28020	168.34
Total			1214.52

zones of the lake showed that total internal loading from the shallow, active bottom was over six times higher than that from the deeper part (Table 2).

DISCUSSION

The research carried out in Lake Rusałka indicated there is a well-known and frequently confirmed relationship between the process of phosphorus releasing from bottom sediments and temperature (Kelderman 1984, Psenner 1984, Forsberg 1989). The highest intensity of phosphorus release, which was observed at the end of summer and the beginning of fall, was also noted in other lakes (Golosov and Ignatiewa 1999, Kowalczewska-Madura and Gołdyn 2009). Moreover, an increase in the intensity of this process was probably caused by

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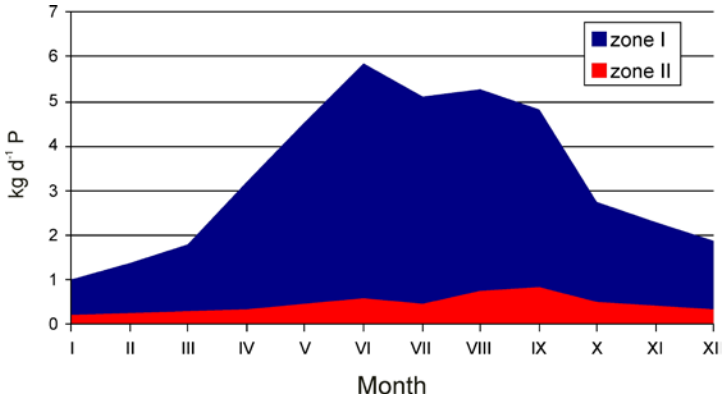


Fig. 5. The comparison of internal loading from bottom sediments in particular zones.

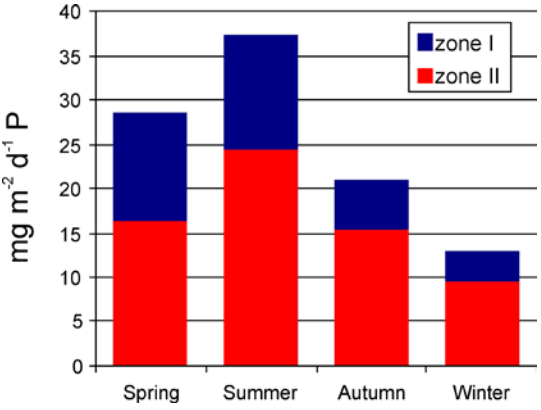


Fig. 6. The variability of internal loading in particular seasons.

the bubbles of gas released from bottom sediments into the overlying water, which are responsible for sediment resuspension. This was observed distinctly in the experimental cores a few times, when the upper part of the sediment core became detached and emerged. A similar phenomenon was observed in Lake Gościąż (Kentzer 2001). The oxygen concentration in the surface layer of sediments and in the near-bottom water also determined the amount of phosphorus released. This influenced the direction and intensity of phosphate flow i.e., its adsorbtion or release (Wiśniewski and Planter 1987, Ishikawa and Nishimura 1989, Graca and Bolałek 2000). However, in the shallow part of Lake Rusałka the near-bottom water layer was well oxygenated. Even in summer, the concentration of oxygen at a depth of 2 meters did not decrease

below 7 mg l^{-1} O_2 (Gołdyn et al. 2010). Nevertheless, phosphorus release into the water was also observed. Therefore, it confirms the hypothesis that the release of phosphorus also occurred under oxygenated conditions. This phenomenon was also observed in Lake Swarzędzkie, located near Poznań (Kowalczewska-Madura and Gołdyn 2009). Analogous observations were reported by many researchers (Boström et al. 1982, Peters and Cattaneo 1984, Drake and Heaney 1987, Fowler et al. 1987, Marsden 1989, James and Barko 1991, Behrendt et al. 1993, Uchmański et al. 1993, Kleeberg and Dudel 1997, Andersen and Ring 1999). The high rate of phosphorus loading from the littoral zone was due to its size. The mean release per 1 m^2 and year was half as low in the shallow than in the deep parts of the lake (Table 2). The phosphorus released contributed to the very intensive growth of phytoplankton in this zone, especially that of Cyanobacteria (Gołdyn et al. 2010, Zagajewski et al. 2006).

In spite of the well-mixed water in spring and fall, oxygen depletions occurred in the deepest water layers in summer. The lack of dissolved oxygen was observed as soon as in April at depths from 6 m to the bottom, and this state lasted until fall mixing, which started in September (Gołdyn et al. 2010). However, the area of this zone is small, thus increased phosphorus release was insignificant to the overall lake ecosystem. As a result of anaerobic conditions, increased temperature, and, most of all, the lack of mixing in the near-bottom waters, the phosphorus released from the sediments was retained in a small volume of water throughout the summer, which was confirmed by the high, increasing concentrations of phosphorus in the analyzed samples of the near-bottom water layer (Gołdyn et al. 2010).

Based on literature considering this problem, it can be concluded that the lake has significant internal phosphorus loading from the bottom sediments. Lower values were found in Mazurian lakes from 0.0 to 21.1 mg m^{-2} d^{-1} P (Planter and Wiśniewski 1985, Wiśniewski and Planter 1985, Wiśniewski and Rzepecki 1996). Similar values were observed in Lake Swarzedzkie, where phosphorus release reached 26.86 mg m^{-2} d^{-1} P (Kowalczewska-Madura and Gołdyn 2009). Greater loading from sediments, as high as 145.0 mg m^{-2} d^{-1} P, was noted in lakes in Germany and Denmark (Kleeberg 1997, Kleeberg and Kozerski 1997, Kozerski and Kleeberg 1998, Søndergaard et al. 2001).

CONCLUSIONS

The experimental research of phosphorus release from bottom sediments in Lake Rusałka indicated that very significant releases occurred in the deeper part of the lake (4-9 meters) and reached 29.84 mg m^{-2} d^{-1} P. Lower values were observed in the shallow zone. It was confirmed that under anaerobic conditions phosphorus release was two-fold more intense than under aerobic conditions.

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Considering the size of the internal load originating from different zones, it was revealed that the active bottom was the main source of phosphorus for the epilimnetic waters in this lake. 86% of total internal load was released from this zone, mainly due to the size of this zone (92% of bottom), not to the value of unit releasing.

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