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Internal phosphorus loading from bottom sediments of a shallow preliminary reservoir

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Key words: internal loading, shallow preliminary reservoir, bottom sediments, phosphorus

Abstract

The aim of the studies done in a shallow preliminary reservoir (western Poland) was to determine the intensity and seasonal variability of phosphorus release from bottom sediments. Ex situ studies were done using intact sediment cores taken in succeeding seasons at 3 research stations. The highest phosphorus loading was observed in spring (May and April), both in 2005 and 2006. The range of loading was between 23.7 and 66.6 mgP m^{-2} d^{-1}. More intensive phosphorus release during warmer months was caused by microbiological decomposition of fresh organic matter, comprised of decaying filamentous algae from the previous vegetation season. Spatial variability resulted from differences in water depth between stations and in the biomass of filamentous green algae in 2005.

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INTRODUCTION

The phenomenon of nutrient exchange across the water-sediment interface is of a common character in both natural and artificial lakes (Wiśniewski 1995). Nevertheless, in shallow water bodies it is much more important for water quality than in deeper reservoirs, as the area of the sediments that are in contact with the epilimnion is much greater in relation to the water volume (Granéli 1999, Søndergaard et al. 2003). The release of phosphorus from bottom sediments in shallow reservoirs occurs in two ways (1) the release on the water-sediment interface and diffusion of dissolved phosphorus to the entire water volume and (2) the wind-induced resuspension of sediments (Sellig 2003). The first process is influenced by many factors including bacterial activity, mineralization processes, redox conditions, pH, and the Fe:P ratio. Submerged macrophyte vegetation can also have both a negative and positive impact on the exchange of phosphorus between the water and sediments, especially when it is abundant in shallow lakes (Søndergaard et al. 2001). The resuspension of sediments from wind action causes particulate forms of phosphorus to return to the water several times before long-term burial in the sediments. A combination of all these factors affects the amount of phosphorus that is released into the water column.

Experimental research on phosphorus release from bottom sediments has only been conducted in few artificial water bodies. In the artificial Lake Rusałka (Gołdyn et al. 2007) the lowest values of release were observed in the cold period of the year (8.06 mgP m^{-2} d^{-1}), while the greatest were noted in late summer and early fall (29.84 mgP m^{-2} d^{-1}). Phosphorus release in the large, deep Polish reservoirs (Zegrzyński and Sulejowski) was as high as 22.5 mgP m^{-2} d^{-1} in summer and was intensive at low concentrations of dissolved oxygen (Wiśniewski 1995).

The experimental analysis of seasonal and spatial variability of phosphorus release in a shallow, preliminary reservoir was the main aim of the current study. The very shallow depth of this reservoir and the influence of mats of filamentous green algae were also considered.

MATERIALS AND METHODS

The Antoninek Reservoir is a shallow, lowland, artificial reservoir, which is the first step in a cascade of four preliminary reservoirs situated on the Cybina River in the city of Poznań (western Poland). This cascade was created in the 1980s to protect the main Maltański Reservoir (Gołdyn and Grabia 1998). The main source of external loading for the Antoninek Reservoir is the Cybina River. Several natural lakes and artificial reservoirs are located along its course.

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The sedimentation of allochthonous suspended matter and the deposition of autochthonous organic matter has resulted in a significant reduction of water depth. For this reason, the restoration of the reservoir was carried out in 2002 and 2003. All emergent macrophytes, which had overgrown the reservoir, were removed together with their rhizomes and the accumulated sediments. Now its surface area is 7.2 ha, its average depth is 0.5 m, and its water residence time ranges from 0.65 to 38 days.

Undisturbed sediment cores for ex situ experiments were collected with a modified Kajak bottom sampler between August 2004 and April 2006. The three sampling stations were situated along the main axis of the reservoir from the inflow to the outflow (Fig. 1). The cores were collected seven times at station 1, six times at stations 2 and 3. Due to thin ice cover and technical problems with the bottom sampler, cores were not collected in March 2005 at station 3 or in January or March 2006 at station 2. Three replicates were collected from each station at every sampling event, except in January 2006 at station 1 and February 2006 at station 3, when five replicates were taken.

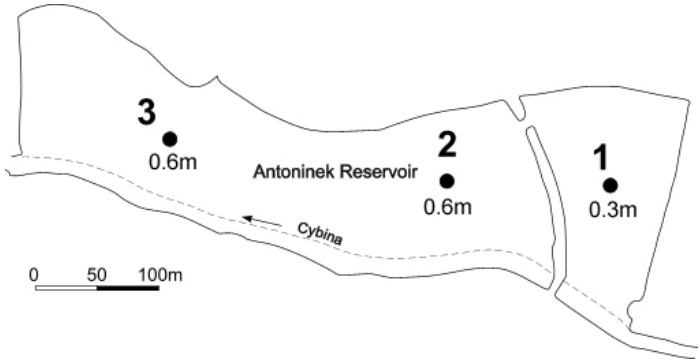


Fig. 1. Location of research stations and mean depths (after Buczkowski and Zgrabczyński, changed).

Altogether, 61 cores were collected from all the stations during the period analyzed. Each transparent tube containing the collected sample of sediment and the overlying water was closed with rubber stoppers. The tubes were kept in darkness after being transported to the laboratory, placed in a water-bath stabilizing temperature change, at thermal and oxygen conditions similar to those in situ, as far as it was possible. During the experiments, the phosphorus content of the water (after gently mixing in the tube) was monitored, initially every two days and later every three days. The experiment lasted about two weeks, and samples were collected seven times, on average. Total phosphorus

concentration was measured spectrophotometrically after mineralization with ascorbic acid as the reducer (Hermanowicz et al. 1999) in 10 ml samples diluted to 50 ml with redistilled water. The results of analyses permitted determining changes in total phosphorus content in the water layer above the sediment and calculating the mean internal loading per 1 m^2 of sediment over a 24 h period.

Values of temperature and dissolved oxygen concentration were measured both in situ in the water above the bottom and in the cores (Table 1) with a HACH SensION 156 meter. In May 2005, August 2005, and January/March 2006 oxygen concentrations in the reservoir water were assessed with the

Table 1

Values of temperature and dissolved oxygen concentration in water above the bottom and in cores (mean values).

cores						
station / month	1		2		3	
	°C	$mgO_2\ l^{-1}$	°C	$mgO_2\ l^{-1}$	°C	$mgO_2\ l^{-1}$
Aug 2004	19.0	3.37	19.3	2.68	19.5	3.88
Oct 2004	14.7	5.97	14.6	6.64	14.8	6.81
Mar 2005	8.8	8.44	9.4	7.93	.	.
May 2005	15.9	.	16.2	.	17.1	.
Aug 2005	19.9	.	19.9	.	20.4	.
Jan/Mar 2006	6.0	6.84	.	.	7.8	6.30
Apr 2006	14.1	5.85	14.2	4.99	14.3	4.72
above bottom						
station / month	1		2		3	
	°C	$mgO_2\ l^{-1}$	°C	$mgO_2\ l^{-1}$	°C	$mgO_2\ l^{-1}$
Aug 2004	21.1	1.07	16.8	2.24	21.3	6.75
Oct 2004	11.5	6.24	11.5	8.62	11.1	11.17
Mar 2005	6.6	11.32	6.3	12.32	5.8	10.76
May 2005	15.7	10.00*	15.5	12.60*	13.9	14.00*
Aug 2005	19.8	3.60*	20.8	6.40*	20.7	3.40*
Jan/Mar 2006	0.6	8.80*	.	7.00*	1.2	8.60*
Apr 2006	12.8	13.20	12.5	12.00	11.7	.

* Winkler method

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Winkler method. Statistical analyses were performed with *Statistica* version *6.0* software. The goal of these analyses was to estimate the influence of temperature and dissolved oxygen concentration on the intensity of the phosphorus release process.

RESULTS

The experimental research performed on the sediment cores from Antoninek Reservoir indicated seasonal and spatial differences in internal phosphorus loading. The highest values of released phosphorus were observed in late spring in both 2005 and 2006. They varied between 39.4 and 66.6 mgP m^{-2} d^{-1} in May 2005 and between 8.9 and 88.2 mgP m^{-2} d^{-1} in April 2006. The amount of released phosphorus also increased in summer and reached 32.1 mgP m^{-2} d^{-1} in August 2004 and 45.4 mgP m^{-2} d^{-1} in August 2005. The values found during the colder part of the year were significantly lower and did not exceed 12.9 mgP m^{-2} d^{-1}. The accumulation of phosphorus in sediments was observed only in March 2005 at station 2.

The analysis of the variability of phosphorus release at the three stations showed that the greatest amounts of phosphorus were released at station 1 (Fig. 2), situated in the shallowest part of reservoir (mean depth ca. 0.2 m), except in samples taken in 2006, when much higher amounts of phosphorus were released from the cores from stations 2 and 3 (Fig. 3). Only at station 3 did values not exceed 40 mgP m^{-2} d^{-1} (Fig. 4).

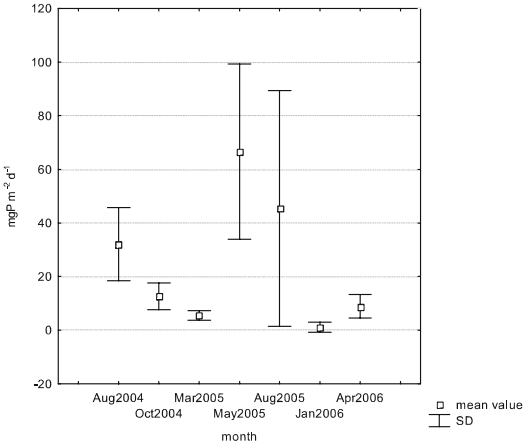


Fig. 2. Individual internal phosphorus release (positive values) or accumulation (negative values) at station 1.

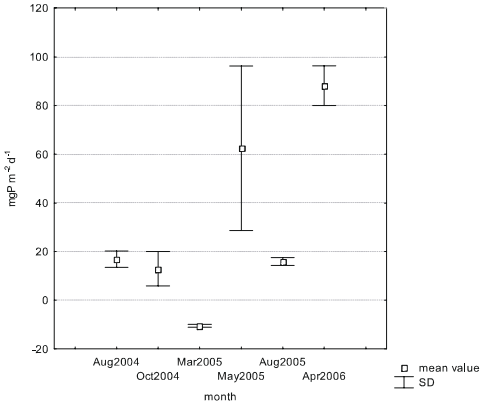


Fig. 3. Individual internal phosphorus release (positive values) or accumulation (negative values) at station 2.

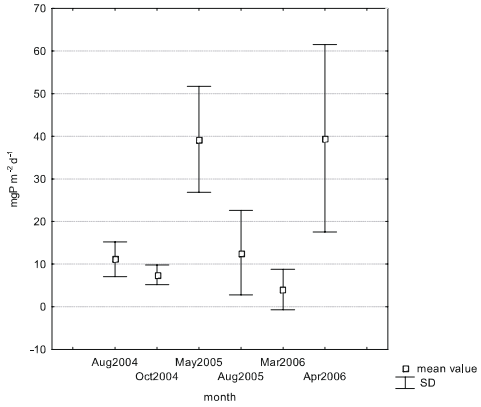


Fig. 4. Individual internal phosphorus release (positive values) or accumulation (negative values) at station 3.

The statistical analysis shows that there is a significant ($P < 0.01$) linear correlation between the values of phosphorus release from bottom sediments and water temperature above the bottom ($r = 0.58$, $n = 23$) and between the values of phosphorus release and dissolved oxygen concentration ($r = -0.83$, $n = 17$) only at station 1. At the other stations the correlations were not significant.

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DISCUSSION

The seasonal character of internal phosphorus loading from bottom sediments indicated that this process was related to the temperature and biological activity of organisms (Søndergaard et al. 2003). The high release in late spring was a result of sudden microbiological decomposition of decaying organic matter from filamentous green algae from the previous vegetation season (Dondajewska et al. 2007). The biological activity of microorganisms increased together with temperature (Søndergaard et al. 1999), when there also was increased production of bacteria enzymes (Petterson 1998). The amount of phosphorus released could also have risen as a result of the high density of macrophytes, in this case macroalgae. Dense mats of filamentous algae induce anoxia in the sediments, which enabled phosphorus release from iron compounds (Søndergaard et al. 2003). Kleeberg and Kozerski (1997) also reported that under experimental conditions the amount of phosphorus released increased after adding organic matter.

Temperature and the concentration of dissolved oxygen were also the most important factors which influenced the release of phosphorus in summer. Increasing temperature still decomposed the organic matter, both allochthonous and autochthonous. The intensity of this process may cause the formation of thin anaerobic microlayers in sediments and, therefore, the reduction of sulfur compounds and the immobilization of Fe (Kleeberg and Kozerski 1997). However, in anaerobic conditions, as Sellig (2003) reported, bioavaiable forms of phosphorus are released, which can stimulate primary production, as well as the production of macroalgae. Nevertheless, when at the sediment-water interface within the littoral a low concentration of dissolved oxygen occurred, significant amounts of phosphorus might be released (Andersen and Ring 1999). Such sediments could occur in Antoninek Reservoir due to the shallowness of the water.

During the cold period of the year, the sedimentation and mineralization of organic matter in the sediments were lower and they were probably well oxygenated, therefore, the release of phosphorus from the sediments was not as intensive as in the warm period.

The differences in the spatial variability of internal phosphorus loading were caused by two factors: (1) the difference in water depth between stations 1 and 2-3, and (2) the biomass of filamentous green algae at stations 2 and 3 in 2005. At the shallower station 1 the influence of the temperature increasing in spring and summer was more significant. The bottom sediments collected the heat faster than at other stations, and it influenced the rate of organic matter decomposition. This may also explain the significant statistical relationship between temperature and the value of released phosphorus, which was

confirmed by literature data (Forsberg 1989). The negative correlation between the concentration of dissolved oxygen and the release rate of phosphorus was also reported by other authors (Wiśniewski 1995, Kleeberg and Kozerski 1997, Søndergaard et al. 2003). The deeper water at stations 2 and 3 (Fig. 1) may limit the influence of temperature, and, therefore, the occurrence of lower concentrations of oxygen.

The remarkable difference between the value of phosphorus released in April 2006 at individual stations was probably caused by the longer growth of filamentous green algae at stations 2 and 3 in summer 2005 (Dondajewska et al. 2007). Therefore, the process of decomposition occurred as late as in spring 2006. At station 1, however, the algae grew only at the beginning of summer 2005 and were already mineralized in the same year.

CONCLUSIONS

The experimental research done on sediments from the shallow preliminary reservoir indicates that the most intensive internal phosphorus loading occurred in late spring. This was the result of the microbiological decomposition of decaying macroalgae from the previous vegetation season and anoxia in the sediments below the algal mats. Spatial variability was the result of the difference in water depth between stations 1 and 2-3 and also the difference in the biomass of filamentous green algae in 2005.

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