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Spatial and seasonal changes of phosphorus internal loading in two lakes with different trophy

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ABSTRACT

Two lakes with different trophy, Strzeszyńskie Lake and Uzarzewskie Lake (Western Poland), were studied in *ex situ* experiments with the aid of intact bottom sediment cores in order to analyse the internal loading as well as the spatial and seasonal changes of total phosphorus (TP) release from bottom sediments. It was stated that the TP release from a hypereutrophic Lake Uzarzewskie, despite its earlier restoration using iron treatment, was over 6 times higher than in a mesotrophic one. The observed values in both lakes were higher in the deepest part of the lake than in the littoral zone. TP release in Strzeszyńskie Lake was very similar in all four seasons of the year with the maximum value of 2.8 mgP m^{-2} d^{-1} in winter. TP release did not exceed 1.3 mgP m^{-2} d^{-1} in the littoral zone and in winter its accumulation prevailed over release from bottom sediments. TP release in Uzarzewskie Lake was 44.7 mgP m^{-2} d^{-1} in autumn in the profundal zone and 6.8 mgP m^{-2} d^{-1} in the littoral zone. A domination of P accumulation in sediments over release was observed at both stations in winter (0.33 mgP m^{-2} d^{-1} in the deepest place and 0.62 mgP m^{-2} d^{-1} in the littoral). Knowledge of the internal loading of P in lakes allows managers to compare changes in human impact on the ecosystem and to design practical treatments for limiting their trophy and approaches to the management of restoration measures.

1. Introduction

The estimation of total phosphorus (TP) accumulation in bottom sediments as well as its release to overlying water is one of the most important hydrobiological issues. The process of phosphorus release plays a significant role in the process of eutrophication of water bodies (Søndergaard et al., 2003). Lake sediments act as a temporary or permanent sink for settling P and play a key role in the P cycle (Hupfer and Lewandowski, 2005). A lake's bottom sediments, instead of fulfilling the role of a trap for phosphorus, often become its source (Boström et al., 1988; Golterman, 1995; Kentzer, 2001; Wang et al., 2003). Some of the phosphorus accumulated in the sediments can be mobilized to the overlying water in algal-available form (Graneli, 1999). Phosphorus can be released from sediment depths of as great as 20 cm below the water-sediment interface (Søndergaard et al., 2003). A number of factors influence the exchange of phosphorus between water and sediments, including redox conditions, pH, Fe:P ratio and resuspension (Søndergaard et al., 2002; Kleeberg et al., 2013).

Shallow lakes are very vulnerable to internal loading because nutrients stored in their sediments have a greater impact on water quality than in deeper lakes (Granéli, 1999). However, in deep lakes mechanisms which allow phosphorus transport from the hypolimnion to surface water layer also exist; it may be transported with methane bubbles or phytoplankton vertical migration (Head et al., 1999).

Phosphorus released from bottom sediments can significantly contribute to the lake eutrophication. The internal phosphorus loading in Swarzędzkie Lake was 26.9 mgP m^{-2} d^{-1} and it was higher in summer than the external loading (Kowalczewska-Madura and Goldyn, 2009). Sometimes internal loading could be very high e.g. in Grosser Müggelsee was up to 100 mgP m^{-2} d^{-1}, in Søbygaard Lake to 145.0 mgP m^{-2} d^{-1} (Kleeberg 1997; Søndergaard et al., 2001). The current data suggest that one of the major factors responsible for the load of phosphorus released from the bottom sediments is the trophic state of the lake (Kentzer, 2001). Typically, it can be explained by the anaerobic conditions in the water layer above bottom of eutrophic lakes, causing a very low redox potential, which promotes the release of TP accumulated on metal compounds, especially iron oxyhydroxides (Søndergaard et al., 2002; Kleeberg et al., 2013). However, in many cases in mesotrophic or slightly eutrophic lakes oxygen depletion in the hypolimnion and low redox potential are also observed, but the

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internal phosphorus loading from bottom sediments is much lower than in hypereutrophic lakes (Psenner, 1984; Sen et al., 2007). It is typical for thermally stratified lakes that aerobic conditions vary in different seasons. It is believed that these changes entail a change in the intensity of phosphorus release. It is not known whether this occurs with the same intensity in mesotrophic and hypereutrophic lakes. A high phosphorus release is often observed in the littoral zone of eutrophic lakes, despite the fact that the bottom is in contact with well oxygenated waters of epilimnion (James and Barko, 1991; Andersen and Ring, 1999; Dondajewska 2008; Kowalczewska-Madura et al., 2008b). We suppose that greater sedimentation of organic matter to the bottom sediments results in a higher oxygen demand in sediments and periodic oxygen deficits. Therefore, these spatial as well as seasonal changes of phosphorus release or accumulation in different parts of lakes with different trophic states were one of the main objects of this study.

Lake restoration processes can significantly change the conditions responsible for the release of phosphorus from sediments. One of such restoration method is the iron sulphate treatment, which increases iron content in the sediments, thus contributing to the intensification of phosphorus adsorption on its oxyhydroxides (Katsev and Dittrich, 2013; Kleeberg et al., 2013). Hypereutrophic Lake Uzarzewskie had been restored with iron treatment two years prior to this study (Gołdyn et al., 2008b). Therefore, the second aim of this study was to determine the extent of a decrease of phosphorus release from the bottom sediments of this lake as a result of iron treatment and whether this release approached the level observed in the mesotrophic Strzeszyńskie Lake.

We hypothesize that internal phosphorus loading is much higher in hypereutrophic lakes compared to lakes of lower trophic state, and it is very important for the eutrophication of lakes. During summer time, phosphorus released from bottom sediments in the profundal zone is accumulated in the water layer near the bottom of the lake. In the littoral zone, which is in contact with the warm epilimnetic waters in summer, phosphorus release also dominates on its accumulation in bottom sediments. This is due to optimal thermal and changeable oxygen conditions in the sediment-water interface and due to constant organic matter supply of phytoplankton origin. Moreover, in lakes with a higher trophic state more pronounced seasonal variations of this process are observed than in mesotrophic lakes.

2. Materials and methods

Bottom sediments from two lakes with different trophy were tested: mesotrophic Strzeszyńskie Lake and hypereutrophic Uzarzewskie Lake. Strzeszyńskie Lake is dominated by submerged macrophytes, has high water transparency (over 6 m) and low chlorophyll-a content (up to $7.5\,\mu g\,l^{-1}$) (Szeląg-Wasielewska, 2006, 2007). Strongly eutrophicated Uzarzewskie Lake, on the other hand, is of poor water quality (SD ca. 0.5 m, chlorophyll-a up to $170\,\mu g\,l^{-1}$) and there are strong cyanobacteria blooms in summer (Gołdyn et al., 2008a,b,b).

Strzeszyńskie Lake is a natural postglacial lake which fills a wide depression in the upper part of the River Bogdanka, in the north-western part of Poznań (52°27′N, 16°49′E). Its area is 34.9 ha and the mean depth is 8.2 m. The lake is divided into 2 parts: the maximum depth of the smaller part is 3.1 m and in the other part there are two deep places – 16.9 and 17.8 m. The lake is thermally stratified and dimictic and, as regards trophy, mesotrophic (Szeląg-Wasielewska, 2006).

Uzarzewskie Lake is a postglacial lake in the shape of a kettle, located in the 17th km of the course of the River Cybina, which is an eastern tributary of the River Warta (52°27′N, 17°08′E). Its surface area is 10.6 ha, maximum depth is 7.3 m and mean depth −3.4 m (Jańczak, 1996). It is a hypereutrophic, dimictic and bradymictic lake with short mixing periods. It was treated with iron sulphate solution (commercial name PIX-112, containing 12% of Fe) in 2006–2007. The lake was treated six times in 2006 and three times in 2007, with doses of 60–70 kg of chemicals (380 kg and 180 kg in total, respectively), but the lake is still highly eutrophic (Gołdyn et al., 2008a,b,b).

Higher concentration of iron was stated in bottom sediments of restored Uzarzewskie Lake in the profundal zone at station 1 ($8.35\,mgFe\,g^{-1}DW$) than in the littoral at station 2 ($4.47\,mgFe\,g^{-1}DW$). In turn, in Strzeszyńskie Lake its content was lower reaching $4.07\,mgFe\,g^{-1}DW$ in the profundal zone and $1.29\,mgFe\,g^{-1}DW$ in the littoral zone.

Phosphorus release and accumulation in bottom sediments was studied between March 2008 and February 2009. Four *ex situ* experiments (one in each season) were carried out with the aid of intact bottom sediment cores from each lake. The cores for laboratory experiments were sampled using a modified Kajak core sampler from 2 stations – from the deepest part of the lake (station 1) and from the littoral zone (at a depth of approximately 2 m – station 2) (Fig. 1). Three replicate cores were collected in transparent and rigid plastic tubes (PMMA – polymethyl methacrylate), 6 cm in diameter. Each tube contained ca. 15 cm of sediment together with ca 25 cm of the above lying water. The cores were incubated in the laboratory in darkness at constant thermal conditions similar to the temperature within the lake during sampling. Depending on the oxygen content of the water above the sediments within the lake, the cores were incubated in

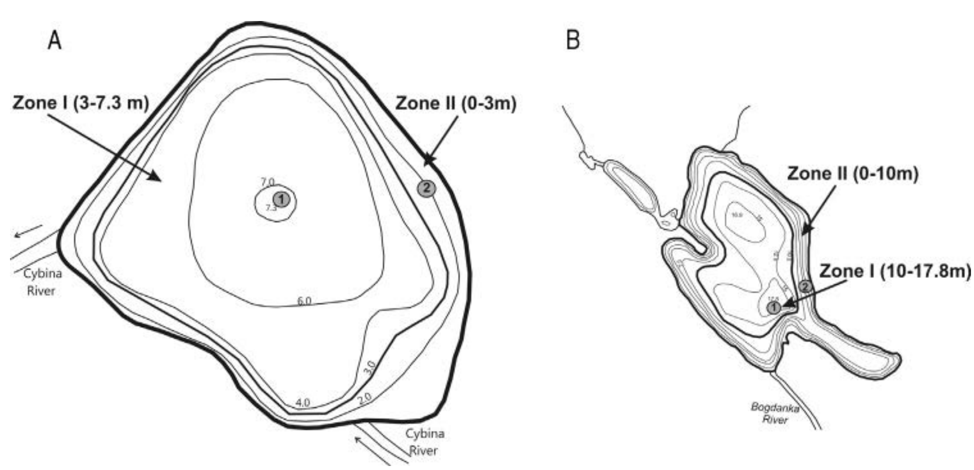

Fig. 1. Location of the sampling stations and the depth ranges of the profundal (I) and the littoral (II) zones (A – Uzarzewskie Lake, B – Strzeszyńskie Lake).