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Research paper

Water quality response to sustainable restoration measures – Case study of urban Swarzędzkie Lake

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ABSTRACT

Accelerated eutrophication and requirements of the Water Framework Directive impose searching for effective restoration methods Recently positive effects are achieved by means of sustainable restoration methods that are cheap because they are limited to activities initiating natural changes in the ecosystem. Despite previous research, there is still not enough accurate data on ecosystem response (i.e. changes in the physico-chemical variables and phytoplankton composition in shallow lakes) to the sustainable restoration based on simultaneous application of several methods The restoration of shallow urban hypertrophic Swarzędzkie Lake started in autumn 2011. Three methods: were applied: (i) aeration of waters above the bottom sediments using a wind-driven aerator, (ii) phosphorus inactivation in water column using small doses of iron sulphate and magnesium chloride and (iii) biomanipulation with cyprinids catching and pike fry stocking. The aim of the study was to analyse the phytoplankton succession as well as physico-chemical variables of water quality in a shallow urban lake as a response to restoration measures. Samples were taken monthly from 2012 to 2014 at the deepest place of the lake, every 1m in the depth profile. Due to the restoration process, the Secchi depth increased to 1.00m. The oxygenation improved, as the anaerobic period in the deep water layer shortened to one month. The concentration of nutrients slightly decreased (mainly total nitrogen, from 5.5 to 4.0 mg N l^{-1}), especially above the bottom. These changes had an impact on phytoplankton, which decreased twofold. The dominating cyanobacteria was eliminated or reduced and an increase in the number of chlorophytes, chrysophytes and cryptophytes has been observed. Nevertheless, the observed changes were not stable yet, so the restoration process should be continued to achieve permanent improvement.

1. Introduction

Accelerated eutrophication emerged in form of e.g. strong cyanobacterial blooms in various locations around the world (Padisák and Reynolds, 1998; Dokulil and Teubner, 2000) and requirements of the Water Framework Directive (Directive, 2000) for recovery and maintenance of good water quality motivate to strive for effective lake restoration (Dokulil and Teubner, 2000). These measures are intended to improve ecological state of lakes (Krienitz et al., 1996) to obtain high biodiversity and to enable recreational use. It is important to eliminate potentially toxic cyanobacteria which are a threat to the organisms living in the lake and people benefiting from ecosystem services (Bonisławska et al., 2012; Merel et al., 2013; Dunalska et al., 2015).

Restoration treatments, especially dredging and chemical methods, cause strong and sometimes drastic changes (Rybak et al., 2017) in the entire lake ecosystem. Sustainable restoration is based on the use of methods that initiate natural processes which have a beneficial effect on water quality, e.g. moderate oxygenation of the water above the bottom using wind power, increase of phosphorus adsorption in sediments, using low, precisely selected doses of chemical agents (familiar to the ecosystem, like iron sulphate or magnesium chloride) for phosphorus inactivation, increase of the stock of predatory fish, stimulation of the development of macrophytes, invertebrate fauna, etc. Most often several methods are used simultaneously, for example phosphorus inactivation together with deep water oxygenation and biomanipulation. Such a strategy can improve lake water quality (Langeland, 1990; Grochowska et al., 2015; Kozak et al., 2015) in a slower but less aggressive way (Gołdyn et al., 2014). Gradual rebuilding of the ecosystem is far more beneficial for the biodiversity within the lake, which brings better results in the future. This strategy is also less expensive than other methods which are strongly interfering in the ecosystem and allows more effective management of changes occurred in the lake.

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The overriding priority of restoration is to limit the availability of phosphorus for algae (Jeppesen et al., 2002) as in most cases it allows to limit their growth and cause significant changes in the phytoplankton composition (Srivastava et al., 2008; Lv et al., 2011). Several chemicals are used in order to reduce primary production and eliminate Cyanobacteria, from algaecides to phosphorus inactivating compounds. The chemical phosphorus binding agents cause its precipitation from the water column and sedimentation to the bottom sediments. The use of iron coagulants also increases the sorption capacity of bottom sediments and reduces the intensity of internal loading (Immers et al., 2014, 2015). It also allows natural binding of phosphorus to insoluble iron phosphate (Immers et al., 2014, 2015; Bakker et al., 2016). However, the accumulation of adsorbed phosphorus in sediments requires a high level of redox potential, which prevents iron reduction and phosphorus release into the water (Kleeberg et al., 2013; Bakker et al., 2016). Therefore, the oxygenation of waters above the bottom is used to maintain the appropriate redox potential in the sediment-water interface (Hilt et al., 2006; Kleeberg et al., 2013), e.g. using a wind-driven aerator (Gołdyn et al., 2014). Biological methods such as biomanipulation can support chemical methods to obtain better results. Biomanipulation is usually based on removal of cyprinids and stocking the lake with predatory fish, resulting in the food-web rebuilding (Shapiro et al., 1975), i.e. an increase of abundance of herbivorous zooplankton, contributing to an increase of water transparency by grazing on phytoplankton (Krienitz et al., 1996; Tátrai et al., 2003; Hilt et al., 2006).

Restoration measures cause changes in the physical and chemical parameters of water, which directly affects phytoplankton growth. The rapid response of algae to environmental condition changes, their primary role in food web and their impact on other organisms (Willén, 2001; Ptacnik et al., 2008; Eigemann et al., 2016) cause that they properly reflect the effectiveness of restoration. However, despite long-term studies on changes in water quality under various restoration methods, they mainly concerned individual methods. There is still insufficient data on the physical and chemical parameters of water and phytoplankton response to sustainable restoration based on several methods used simultaneously (Padisák and Reynolds, 1998; Kozak et al., 2015).

This paper concentrates on the reaction of phytoplankton community versus physical and chemical variables of water quality in a shallow urban lake as a response to the sustainable restoration. Consequently, the following hypotheses were made: 1) the use of sustainable restoration methods affects the phytoplankton composition causing the elimination or limitation of cyanobacterial blooms; 2) phosphorus inactivation using iron sulphate and magnesium chloride improves water quality by decreasing of phosphorus and nitrogen concentrations; 3) deep-water aeration by increasing oxygenation of sediment-water interface decreases internal phosphorus loading from sediments; 4) all the treatments together result in an improvement of water transparency due to the reconstruction of qualitative and quantitative composition of phytoplankton, i.e. reduction of abundance and re-appearing of organisms typical for lakes with lower trophic state.

2. Material and methods

Swarzędzkie Lake (52°24′49″N, 17°03′54″E), is a strongly degraded urban lake located near Poznań (West Poland). It is shallow, elongated, medium-sized, flow-through lake (Fig. 1). There is no full thermal stratification during summer (lack of hypolimnion). Only about 15% of the bottom surface is within the metalimnion, the rest is within the epilimnion (so-called active bottom) (Kowalczewska-Madura and Gołdyn, 2006). The northeast part is broader and deeper, while the southwest part is narrower and shallower (up to 2 m). The catchment area has large capacity to provide nutrient loads, while the lake is highly susceptible to pollution as it has no natural protective barriers (Kowalczewska-Madura and Gołdyn, 2006) (Fig. 1). The lake was included in bream-zander type of fishery characteristics of lakes (Rosińska and Gołdyn, 2015).

Long-lasting (ca. 50 years) supply of nutrients from many sources of pollution (untreated sewage discharged directly to the lake until 1991, surface runoff, contaminated water of two tributaries: Cybina River and Mielcuch Stream, outflow from fish ponds in the catchment area and internal loading) in Swarzędzkie Lake caused strong cyanobacterial blooms (Stefaniak et al., 2007; Kozak et al., 2014; Rosińska et al., 2017a). Therefore, the lake was classified as hypertrophic (Kowalczewska-Madura and Gołdyn, 2009).

Protective and restoration treatments have been applied in Swarzędzkie Lake to improve water quality, slow down eutrophication, eliminate blooms and enable recreational use. Water and sewage management was organized within the catchment area (for example, a rain sewage system was built). Then sustainable restoration was conducted basing on three methods: aeration of waters above bottom sediments with the use of a wind-driven aerator, phosphorus inactivation using small doses of iron sulphate and magnesium chloride, and biomanipulation (Fig. 2). The treatments started in autumn of 2011 from cyprinids removal (mainly roach *Rutilus rutilus* (L.) and bream *Abramis brama* (L.)) (Kozak et al., 2014; Rosińska and Gołdyn, 2015; Rosińska et al., 2017b). Then during the next three years (2012–2014), the lake was stocked four times (with pike and pike-perch fry), small doses (2–5 kg ha^{-1} each time) of chemicals ($Fe_2(SO_4)_3$ and $MgCl_2$) were applied 19 times. Pulverising aerator worked according to prevailing weather conditions (wind power, ice cover, etc.). Transformations in the ecosystem were monitored throughout the restoration period, i.a. taking into account the physical and chemical parameters of water and phytoplankton composition and abundance.

Physico-chemical and biological samples were taken monthly from January 2012 to December 2014 at the sampling station located at the deepest place in the lake, near the aerator (Fig. 1) in a depth profile every meter (from the surface layer to the bottom), using bathometer with the volume of 5 L. Field measurements (water temperature, oxygen content, conductivity, pH) were conducted using a YSI multiparameter meter. Water transparency was measured with Secchi disc. Phytoplankton samples were fixed with Lugol's solution. Samples to analyse the concentration of nitrogen and phosphorus were preserved with chloroform in the field, while samples to analyse chlorophyll *a* and total suspended solids were transported to the laboratory without fixing. The analyses were carried out according to Polish Standards (Elbanowska et al., 1999). Chemical analyses were performed by spectrophotometric method.

The concentration of ammonium nitrogen was determined by a method with Nessler's reagent, the concentration of nitrate nitrogen by a method with sodium salicylate, the concentration of nitrite nitrogen by a method with sulphanilic acid, the concentration of organic nitrogen by Kjeldahl's method, the concentration of orthophosphates by a method with ascorbic acid, the concentration of total phosphorus by a method with ascorbic acid after mineralisation. The concentration of total suspended solids was determined by weight method (the samples were filtered on GF/C using Coli 5, then dried at 105 °C), the concentration of chlorophyll *a* by the spectrophotometric method with 90% acetone. Analyses of qualitative and quantitative composition of phytoplankton were performed using the light microscope Olympus CX 21 LED in a Sedgewick-Rafter chamber (0.46 ml volume). For larger organisms, the sample was studied at 100x magnification and then other organisms were counted at 400x magnification. Keys were used to determine the organisms, i.a. Huber-Pestalozzi (1983); Starmach (1983); Komárek (2005). The results obtained during the vegetative season (April-September) in 2012–2014 were compared and analysed with the data obtained before the restoration in 2011 (Kozak et al., 2014). Some data of phytoplankton and relating physico-chemical data concerning cyanobacteria dominance was already published (Rosińska et al., 2017a).

To verify if the physico-chemical and phytoplankton composition