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Original Research

Changes in Phytoplankton Structure due to Prematurely Limited Restoration Treatments

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Abstract

Sustainable restoration using three methods – water aeration, phosphorus inactivation, and biomanipulation – was applied in Swarzędzkie Lake to slow progressive eutrophication. The treatments were limited to wind aeration alone after three years of restoration as a result of lack of funding. The research was carried out in a period of limited restoration. Phytoplankton was sampled monthly from the surface layer. Samples were preserved with Lugol's solution and counted using a Sedgewick-Rafter chamber with a light microscope. The fluctuation of phytoplankton abundance and biodiversity were determined, comparing data before (2011), during (2012-14), and after the main restoration measures (2015-16). Mean phytoplankton abundance ranged from ca. 31.0×10^3 spec. ml^{-1} (2011) by 23.6×10^3 spec. ml^{-1} (2012-2014) to 17.5×10^3 spec. ml^{-1} (in 2016). Although cyanobacterial bloom occurred in 2013, the average amount of cyanobacteria decreased at least three times during the restoration and one year after the limitation of treatments. The abundance of cyanobacteria again increased sharply in 2016 (ca. 18×10^3 spec. ml^{-1}). H' index was rising from 1.29 in 2011 to 2.63 in 2015 and started to decrease in 2016. Despite the fact that the total phytoplankton abundance decreased during the restoration processes (2012-16), the abundance of cyanobacteria, which was the main problem of Swarzędzkie Lake, increased when the restoration was limited to wind-aeration (2015-16). An increase of biodiversity and low abundance of cyanobacteria prognosticated the stabilization of the lake's ecosystem. However, a drastic limitation of restoration treatments resulted in another increase of cyanobacteria abundance, which ruined the lake repair. Restoration should not be ceased before the end of the stabilization phase of the ecosystem.

Keywords: phytoplankton, sustainable restoration, iron treatment, aeration, biomanipulation

Introduction

Phytoplankton plays an important role in the structure and functioning of an aquatic ecosystem, thus affecting other groups of organisms [1]. The growth of phytoplankton depends mainly on the availability of nitrogen and phosphorus [2-4]. Excessive eutrophication caused by high nutrient concentrations (especially phosphorus and nitrogen) along with strong cyanobacterial blooms results in decreasing aquatic ecosystem biodiversity [5]. Water

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framework directive (WFD) requirements for obtaining good ecological status of lakes implies that restoration treatments have to be applied to improve water quality [6] (Directive, 2000). The main aim of restoration is to reduce the concentration of nutrients, especially phosphorus [7-8].

The simultaneous use of several restoration methods in the lake is exerting the best effect [9-12]. However, some treatments (e.g., chemical agents, dredging, artificial mixing) may be an additional factor causing lake degradation or stress for phytoplankton [13]. This is why sustainable restoration seems to be the best solution, which is based on the use of several methods (phosphorus inactivation, oxygenation above the bottom water layer, and biomanipulation) and the application of low doses of chemicals (2-5 kg per ha), causing the lake to be able to slowly improve water quality with minimal external intervention [14-15].

Termination or limitation of restoration treatments before sufficient nutrient depletion and obtaining ecosystem stability results in a rapid return to pre-restoration conditions (increase of cyanobacteria's abundance, decrease of water transparency, increase of phosphorus concentration) [16-17].

The aim of the study was to analyze how the phytoplankton in a restored (with sustainable restoration using three methods: wind aeration, biomanipulation, and phosphorus inactivation with small doses of iron sulphate and magnesium chloride) shallow, urban lake responds to limitation of treatments to one method alone, i.e., wind aeration.

Methods

Monthly samples were taken from the surface layer at the deepest place of Swarzędzkie Lake in a period of limited restoration (2015-16; Fig. 1). Data from 2011-14 [18-19] is used in this article for comparison. Samples were preserved with Lugol's solution and determined with identification keys to the lowest feasible taxonomic level. Quantitative analyses were done using a Sedgewick-Rafter chamber with a light microscope (400x magnification). The Shannon-Weaver diversity index (H') was calculated using the Past programme [20]. The fluctuation of phytoplankton abundance and the Shannon-Weaver diversity index were compared for three periods: 2011 – before restoration, 2012-14 – during restoration, and 2015-16 – within limited restoration, to check if there were any significant differences (Mann-Whitney U test, Past programme/Statistica 12.5 software). The number of samples was not equal due to weather conditions (e.g., too thin ice) (n = 7 in 2011, n = 12 in 2012, 2013, 2014, n = 9 in 2015, and n = 10 in 2016).

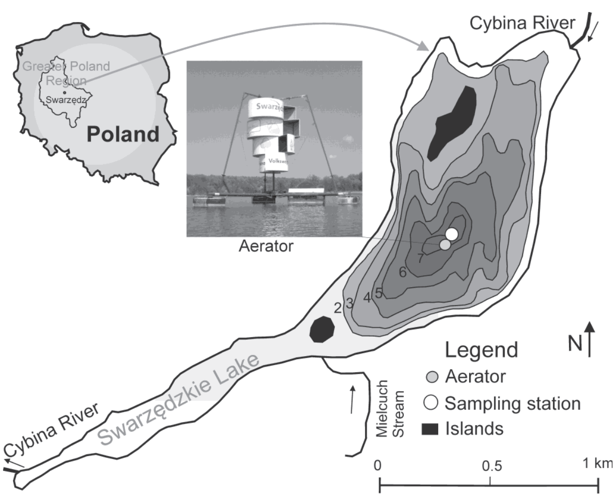

Fig. 1. Location of the sampling station at Swarzędzkie Lake ([19], changed).

Study Area

Shallow urban Swarzędzkie Lake is located near Poznań (Greater Poland Region, Western Poland) (52°24′49″N, 17°03′54″E). The lake area is 93.7 ha, and volume is 2 million m^3, with maximum and average depths of 7.2 and 2.6 m, respectively [21-22]. The lake was hypertrophic and with intensive cyanobacterial blooms caused by *Aphanizomenon gracile* (Lemm.) Lemm., *Pseudanabaena limnetica* (Lemm.) Kom., *Planktothrix agardhii* (Gomont) Anagnostidis and Komárek, and *Limnothrix redekei* (Goor) Meffert for many years [18, 23-24]. There were three main sources of pollutants: raw sewage discharged directly into the lake (until November 1991), tributaries rich in nutrients (Cybina River and Mielcuch Stream), and internal loading [23]. Cyanobacterial blooms were still present 20 years after sewage diversion [18]. Therefore, three methods of sustainable restoration were applied in autumn 2011 to improve water quality and slow the eutrophication process. Aeration of waters above bottom sediments with the use of a wind-driven aerator, phosphorus inactivation in water column using small doses of iron sulphate and magnesium chloride, and biomanipulation were used to limit the availability of phosphorus and nitrogen, improve oxygen content, rebuild the food-web, and eliminate cyanobacteria [18, 25]. The sustainable restoration is based on natural processes and does not use high doses of coagulants in contrast with aggressive restoration; therefore the effects require more time [14]. Sustainable restoration treatments influenced water quality and led to the reconstruction of phytoplankton abundance and species composition. The abundance of chlorophytes, chrysophytes, cryptophytes, and diatoms increased in place of cyanobacteria due to the restoration [19]. Unfortunately, in 2015, after three years of sustainable restoration, the treatments were limited to one method, i.e., wind aeration, due to lack of funds.

Results

Nine taxonomical groups of phytoplankton were determined in the water of Swarzędzkie Lake. Chlorophytes (42-55% of all taxa identified in each year), diatoms (12-17%), and cyanobacteria (8-17%) contribute most to species diversity in the lake. The other groups (Cryptophyceae, Chrysophyceae, Euglenophyceae, Conjugatophyceae, Xantophyceae, and Dinophyceae) were represented by fewer taxa. The highest number of taxa was noted in the first year of research (136) and the lowest in 2012 (98).

Mean phytoplankton abundance ranged from ca. 31.0×10^3 specimens ml^{-1} (2011) by 13.6×10^3, 33.4×10^3, 23.8×10^3 spec. ml^{-1} (in 2012-14, respectively) to 13.6-21.3×10^3 spec. ml^{-1} (in 2015-16; Fig. 2). Phytoplankton fluctuated seasonally during the studied period (Fig. 3). The contribution of cyanobacteria to total phytoplankton abundance in 2011 was very high and reached 96% in September. Afterward, a significant decrease in their abundance was noted in 2012 (maximum 34% in February), which was followed by an increase in 2013 (71% in August), then another decline in 2014 and finally the next increase in 2015 and 2016. Before and during limited restoration, cyanobacteria dominated over a longer period of time, especially in 2011 and 2016. Cyanobacteria abundance reached even 66.8×10^3 spec. ml^{-1} before and 42.3×10^3, as well as 48.6×10^3 spec. ml^{-1} during the restoration (in 2013 and 2016, respectively). However, when cyanobacterial bloom occurred in 2013, their mean abundance was three times lower than before restoration (2011). Nonetheless, their abundance was higher during the limited restoration; only two-four times lower in comparison to 2011. Species that dominated during cyanobacterial blooms within the whole studied period were *Aphanizomenon gracile*, *Limnothrix redekei*, *Planktothrix agardhii*, *Pseudanabaena limnetica*, *Planktolyngbya limnetica* (Lemm.) Komárková-Legnerová and Cronberg.

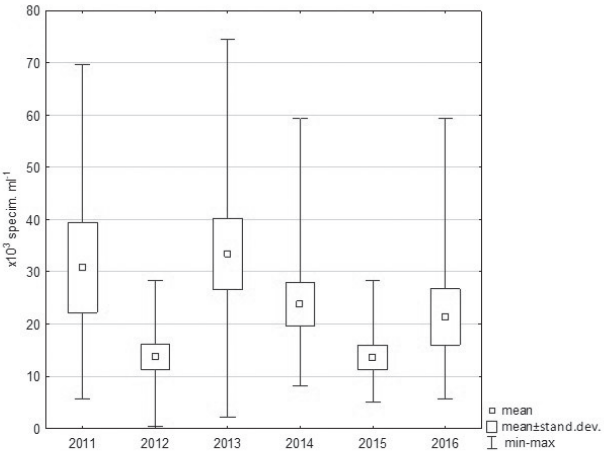

Fig. 2. Mean, standard error, and standard deviation of phytoplankton abundance in 2011-16.

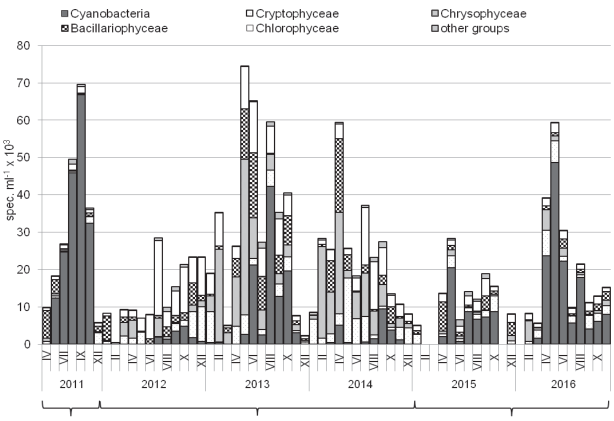

Fig. 3. Abundance of phytoplankton at the surface layer in 2011 – before restoration (BR, [17]), 2012-14 – during sustainable restoration (SR, [18]), and 2015-16 – during limited restoration (i.e., only wind aeration) (LR).

The abundance of chlorophytes (maximum 78% in June 2012), cryptophytes (maximum 47% in May 2012), or chrysophytes (maximum 87% in February 2014) increased during the sustainable restoration (2012-14) and slightly decreased within the period of the limited procedure (2015-16). The most abundant taxa were *Rhodomonas lacustris* Pascher and Ruttner, *Cryptomonas* spp., *Dinobryon* spp., *Chrysococcus* sp., *Chrysochromulina parva* Lackey, *Dictyosphaerium* sp., *Koliella longiseta* (Vischer) Hindák, *Monoraphidium contortum* (Thuret) Kom.-Legn., *Scenedesmus acuminatus* (Lagerheim) Chodat, and *Tetraedron minimum* (A. Braun) Hansgirg.

Significant differences between the mean abundance of taxonomic groups in subsequent years were stated in the case of chlorophytes, cryptophytes, chrysophytes, and cyanobacteria (K-W test, $p<0.05$; Fig. 4).

The lowest value of H' index (1.29) was noted before the restoration. Biodiversity increased almost twofold during the sustainable restoration, reaching an average value of 2.2-2.4. The highest value of Shannon-Weaver index was observed in 2015 at 2.6. Then it decreased to 2.3 in the next year (Fig. 5). The differences between values of H' were significant in comparison to 2011 ($p<0.05$, Mann-Whitney U test).

Discussion

Cyanobacterial blooms have a negative impact on the functioning of aquatic ecosystems [26]. The taxa that achieved the highest abundance in Swarzędzkie Lake have been reported as commonly dominant in toxic water blooms from other Polish water bodies [27-28]. They have caused loss of diversity of organisms, decreased water transparency, etc. [29]. Therefore, restoration treatments which are used to reduce nitrogen and phosphorus concentrations in the lake and to improve the ecological state of the water should first of all reduce the abundance or eliminate cyanobacteria from the phytoplankton composition [30-31].

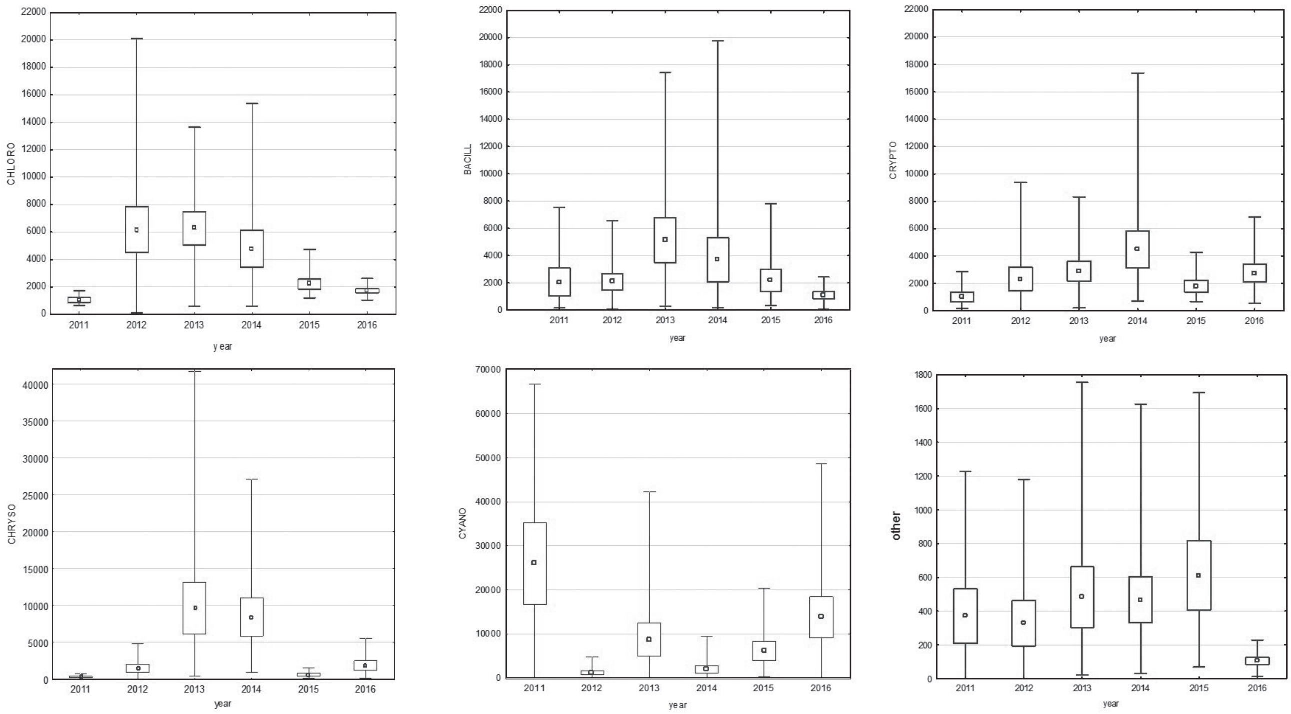

Fig. 4. Changes in mean values of phytoplankton group abundance (specimens·ml^{-1}) in the studied years (□: mean, □: mean ±standard deviation, ⌶: min-max).

Phytoplankton responds rapidly to restoration [32-33], which was also observed in Swarzędzkie. However, the general pattern of phytoplankton change during restoration has not yet been determined [34]. The elimination/decrease of cyanobacterial blooms, changes in species composition, and decreases of phytoplankton abundance that were observed in Swarzędzkie were related to the use of biomanipulation (fish removal and fish stocking) [19]. Phytoplankton decrease has also been recorded in other lakes under restoration, e.g., Durowskie [33], Ringsjön [35], Bärensee [36], and hypereutrophic ponds [37]. Fluctuations of phytoplankton abundance and biomass observed in Swarzędzkie as well as in Durowskie [33], Rusałka [38], Lake Głęboczek [39], or Maltański Reservoir [10] are a significant feature of the phytoplankton reaction to restoration. The fluctuations were caused by variable top-down effects (in the case of biomanipulation) as well as bottom-up control (changes in phosphorus inactivation)[40], or other variables that did not depend on restoration treatments like wind aeration, strong precipitation, temperature, etc. [12, 19, 41-43].

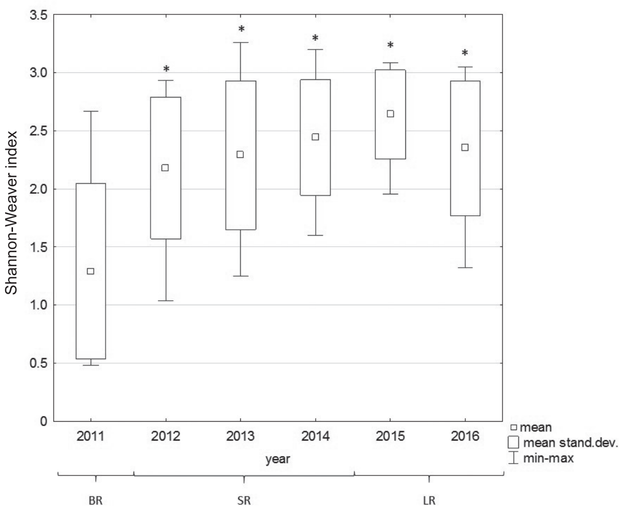

Fig. 5. The mean with standard error and standard deviation of Shannon-Weaver diversity index (H') of phytoplankton at the surface layer in 2011 – before restoration (BR), 2012-14 – during sustainable restoration (SR), and 2015-16 – during limited restoration (i.e., only wind aeration (LR); *p<0.05 vs. 2011 (Mann-Whitney U test).

The reduction of nutrient loads causes changes in community structure at each trophic level [44]. An increase in the abundance of such phytoplankton groups as Chlorophyceae, Cryptophyceae, and Chrysophyceae was observed during the sustainable restoration, as in other restored lakes [12-13, 45-46]. Chrysophytes and cryptophytes are noted as prevalent in P-deficient sites [47-48]. In freshwater lakes dinophytes, chrysophytes, and cryptophytes have appeared or increased during the re-oligotrophication process [49-50]. The domination of a number of species of Chlorophytes has also been reported in many other eutrophic water bodies [51-52]. Diatoms are very sensitive, which makes them good bioindicators and enables them to assess water quality [53-54].

As a consequence of P-inactivation, there was also a statistically significant increase in the diversity index resulting from the redevelopment of the species composition [14]. Nutrient reduction might have increased phytoplankton richness and diversity by releasing the competitive pressure as a consequence of restoration in the lake [46]. The highest values of H' index were also noted in other restored lakes, e.g., Rusałka [38], Maltański Reservoir [12], and Uzarzewskie [13]. The decrease in the diversity index found during the limited restoration indicates the instability of the lake and deterioration of its water quality.

Limitation of restoration treatments to aeration alone was insufficient for the elimination of cyanobacteria. Oxidation with an aerator of sediment-water interface was ineffective, so the decrease in nutrient concentrations due to sediment sorption was insufficient [16, 27, 33]. Although total phytoplankton did not increase, the share of cyanobacteria was significantly higher than during the sustainable restoration and was only two-four times lower than in 2011.

Conclusions

Changes in the taxonomic composition of phytoplankton were the most visible effects of the restoration treatments. Seasonal dynamics in the phytoplankton community were observed before, during, and after the restoration, but during the restoration period the phytoplankton composition depended on the intensity of the restoration treatments beside the weather conditions. Despite restoration, Swarzędzkie Lake was still an unstable ecosystem. The low amount of cyanobacteria, higher abundance of chlorophytes, chrysophytes or cryptophytes, and an increase of biodiversity during the sustainable restoration forecast slow stabilization of the lake ecosystem. However, the drastic limitation of restoration treatments resulted in a renewed increase of cyanobacteria, which ruined the lake repair. Restoration is a long-lasting process and it should not cease before sufficient reduction in nutrient loads and ecosystem stabilization. This research emphasizes the need for appropriate long-term monitoring in order to ascertain the efficacy of intervention.

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