Lake Restoration Using Iron Treatment: Preliminary Results

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ABSTRACT

The Rusalka Lake is a man-made reservoir, situating within the City of Poznań (Western Poland). Its surface area is 36.7 ha, average depth – 1.9 m, maximum depth – 9.0 m. The restoration measures were undertaken with the use of iron sulfide (commercial name PIX-112), which was dosed 6 times during vegetation season of 2006. The amounts of coagulant varied from 100 to 200 kg each time. Monitoring of water quality was conducted before and after every measure. As a result of iron treatment SRP and ammonium nitrogen concentrations decreased to zero at first, few days later it increased to values higher than noted before the treatment and finally (after a week) it fell again. Chlorophyll-a concentration in the first part of season was reduced only slightly as the water temperature was high and stimulated the phytoplankton growth. From September chlorophyll-a concentration decreased radically, which was caused not only by iron treatment (limited the concentrations of phosphorus and ammonium nitrogen), but also by lower water temperature. The analysis done in spring, after first and second treatment, results in a little increase of phytoplankton abundance instead of its reduction. This phenomenon was caused by occurrence of diatoms in water, which were stimulated by addition of iron. The oxygen conditions were improved only in epilimnion of the lake as a result of restoration. Water transparency increased especially in the second part of research period (autumn).

Key words: shallow lake, restoration, iron treatment, water bloom, cyanobacteria, phytoplankton, zooplankton

INTRODUCTION

Restoration measures of Rusalka Lake were conducted due to low water quality, especially Cyanobacteria water blooms in summer, which unable the recreational use of the lake. Iron treatment method was chosen as the used compound (ferrum sulfide, commercial name PIX-112) has a natural character, is easy for application and costs are reasonable (Søndergaard et al. 2002). Initial analyses of lake ecosystem functioning were conducted in the year 2005 (Goldyn et al. 2007), which enable the comparisons and evaluation of the results of restoration measures.

MATERIALS AND METHODS

The Rusalka Lake is a man-made reservoir, situated within the City of Poznań, in its northwestern part. It was created in 1943 as a result of flooding a valley of the Bogdanka River and clay mining pits placed within this area. Its surface area is 36.7 ha, average depth – 1.9 m, maximum depth – 9.0 m. Direct catchment area is covered by forests in 90% and by meadows in 10%. Because of its location close to the center of Poznań and attractive grasslands around the banks Rusalka Lake is used for recreation, being a popular place of summer rest for citizens of Poznań (Pulyk, Tybiszewska 1995; Goldyn et al. 1996) (Fig. 1).

Restoration measures were conducted with the use of prototyped device by Aerator company from Poznan. Initially, PIX-112 dosing was planned 4 times in vegetation season, however the results of analyses persuade to raise the frequency of measures to 6 times. Used doses are presented in Table 1.

Lake research were performed during restoration, before and after each measure. Water samples were collected in depth profile every meter (from the surface to 7m) at the deepest place of the lake (station 1 – Fig.1). Concentration of nitrogen (ammonium, nitrite, nitrate, organic and total), phosphorus (orthophosphates and total), BOD₅, weight of suspended matter, chlorophyll-a, qualitative and quantitative analyses of phytoplankton and zooplankton were done in each sample. Samples of benthic invertebrates were taken at two stations – in littoral (2m) and profundal (7m). Water temperature, pH, conductivity, dissolved oxygen concentration and Secchi depth were measured in situ. Physico-chemical variables were analysed according to Polish standards (Siepak 1992; Elbanowska et al. 1999).
Figure 1. Location of sampling stations on the Rusalka Lake (bathymetry acc. to Pulyk and Tybiszewskaja 1995, modified).

Table 1. List of used PIX-112 doses and effectiveness of iron treatment in Rusalka Lake in 2006.

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>24.04.06</th>
<th>25.05.06</th>
<th>16.06.06</th>
<th>13.07.06</th>
<th>14.08.06</th>
<th>9.09.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIX-112 dose (kg)</td>
<td>200</td>
<td>100</td>
<td>150</td>
<td>140</td>
<td>190</td>
<td>150</td>
</tr>
<tr>
<td>Mean orthophosphates concentration (mg l⁻¹) before measurement</td>
<td>0.12</td>
<td>0.05</td>
<td>0.28</td>
<td>0.22</td>
<td>0.33</td>
<td>0.26</td>
</tr>
<tr>
<td>Mean orthophosphates concentration (mg l⁻¹) after measurement</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.05</td>
<td>0.04</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

In Rusalka Lake substantial part of bottom surface area remained in contact with epilimnion (92%), what indicates polymictic character of this reservoir. Throughout almost entire research period water oxygenation in epilimnion was very good, varying between 7.2 and 12.8 mgO₂ l⁻¹. In small hypolimnion oxygen depletion occurred in summer. During restoration measure water aeration was not applied to avoid returning of orthophosphates, accumulated in hypolimnion, to surface water layer.

Water transparency varied between 0.4 and 2.9 m. It diminished slightly as a result of restoration measures, except May and September, when it raised significantly. Lower transparency was not an effect of chlorophyll-a concentrations increase, but rather greater water turbidity caused by mineral suspended solids (Fe compounds), which appeared after PIX dosing and remained during few days. A considerable difference in water transparency was observed in autumn, when it was 0.5 m greater than in previous year, due to less intensive growth of autotrophic organisms. Undoubtedly, it was a consequence of iron treatment. Accumulation of a large load of Fe compounds in lake ecosystem as a result of restoration and good water oxygenation in depth profile due to autumn mixing, led to rapid decrease of phosphorus concentration in water column and limited phytoplankton growth.

A slight decrease in pH value was noted after iron treatment. A maximal difference occurred in July, when on the depth of 1m it was 0.72.

The highest ammonium nitrogen concentrations were observed in summer in hypolimnion (12.9 mgN l⁻¹). Restoration measures caused increase of concentration in surface layer at first, due to convectional water mixing in vertical profile, and diminish after a few days. Changes in ammonium nitrogen concentration in depth profile confirmed this process. Significant short-term decrease of concentrations in water layer just above the bottom was observed after each iron treatment (reaching even lower concentrations than those found in epilimnion). Ammonium nitrogen concentrations in entire water column decreased strongly at the end of
summer, i.e. after accumulation of sufficient content of Fe in ecosystem and improvement of oxygen conditions.

Nitrate nitrogen occurred in greater amounts only at the beginning of April, however, at the end of that month it was not detectable at all. It appeared again in low concentrations in the end of May and remained in water till end of July. In August and September nitrate nitrogen was undetectable, but occurred later in autumn. Such irregular presence of that mineral nitrogen form indicated unequal usage by organisms in vegetation season. From the one hand, it depended on restoration measures, from the other – on changes of physico-chemical variables, especially water temperature.

Nitrate nitrogen deficits in trophogenic layer of water, together with high ammonium nitrogen concentrations, favored Cyanobacteria domination in phytoplankton in summer and autumn (Blumquist et al. 1994). Good conditions for Cyanobacteria growth existed especially at the end of August, when ammonium nitrogen concentration in surface water layer reached 3 mg N l\(^{-1}\). Permanent presence of mineral forms of nitrogen in water indicated that primary production was not limited by this element.

Orthophosphates concentrations changed in Lake Rusałka waters seasonally, in the similar way as ammonium nitrogen, and reached the highest values at the end of August. In a result of sweltering in the first part of summer 2006, strong warming of water and shallow situated bottom sediments was observed. It enhanced intensive phosphorus release from sediments and, as a consequence, substantial increase of orthophosphates concentration in water. Changes of phosphorus concentration after each PIX dosage was similar to that of ammonium nitrogen. It was decreased just after treatment, than it raised to dosage was similar to that of ammonium nitrogen. It increased as a result of autumn water mixing in depth profile after iron treatment and its sedimentation do deeper layers. It may occur on different depths, including bottom sediments. Oxygenation of sediments also caused lowering of the phosphorus release from bottom sediments. It was positive (increase of abundance), in others – negative (decrease). In the period when zooplankton abundance fell in surface water (May, September) we observed its strong increase in deeper layers, probably as a result of vertical migration in search of easy available food. Phytoplankton decay as a result of iron treatment and its sedimentation do deeper water layers could be the reason of such zooplankton migration. It may occur on different depths, depending on time which last from the treatment and current weather conditions, influencing the water mixing in the lake. Taxa observed in Rusałka Lake have broad ecological scale and are common in

The total N to total P ratio in 2005 was low (2.8-33.7). It raised significantly in 2006 (13.5-184.6), probably as a result of restoration.

Chlorophyll-a concentration increased from spring till summer, reaching maximum in August. Data noted in 2005 were very similar throughout major part of research period. Maximum concentration found in 2005 (80.2 µg l\(^{-1}\)) was slightly lower than the value in 2006 (81.0 µg l\(^{-1}\)), however in 2005 it was observed at depth of 2m, while in 2006 – at the surface. Concentrations analyzed after each restoration measure were lower then before, except May. In the first part of research period the decrease was small and short-term due to high water temperature, which stimulated phytoplankton growth. Strong fall of chlorophyll-a content since September was a result of (i) limited phosphorus concentrations and (ii) lower water temperature. Considerable increase of chlorophyll-a in May was connected with domination of Chlorophyceae and Bacillariophyceae. Fe was probably depleted by intensive diatoms growth in April and was a limiting factor, so its addition caused stimulation of phytoplankton growth.

The abundance of phytoplankton in Rusałka Lake in surface water layer varied between 6,300 cells ml\(^{-1}\) in winter and over 1,000 000 cells ml\(^{-1}\) in summer. Chrysophyceae together with Chlorophyceae and Bacillariophyceae grew most intensively in winter and early spring. Chlorophyceae with Cyanobacteria, Cryptophyceae and Bacillariophyceae became dominants later on. In summer Cyanobacteria were the most abundant group, while in autumn – again Chrysophyceae, Cryptophyceae, Chlorophyceae and Bacillariophyceae. Restoration measure in spring caused increase in the abundance of autotrophic organisms (in comparison with 2005), as the lake was supplied with Fe compounds. Advantageous light and thermal conditions had also beneficial influence on phytoplankton. Expected mechanism of decrease in phytoplankton abundance occurred finally in the second part of summer, when Fe load was sufficiently high and water temperature decreased.

Iron treatment had probably indirect impact on qualitative and quantitative zooplankton composition. In some months in surface water layer the impact was positive (increase of abundance), in others – negative (decrease). In the period when zooplankton abundance fell in surface water (May, September) we observed its strong increase in deeper layers, probably as a result of vertical migration in search of easy available food. Phytoplankton decay as a result of iron treatment and its sedimentation do deeper water layers could be the reason of such zooplankton migration. It may occur on different depths, depending on time which last from the treatment and current weather conditions, influencing the water mixing in the lake. Taxa observed in Rusałka Lake have broad ecological scale and are common in
eutrophic lakes (Karabin 1985). Small amount of Crustacean as well as low share of Cladocera indicated undesirable fish composition for water quality (Perrow et al. 1997). Probably cyprinids dominated in fish composition, which are known as zooplankton grazers. To increase the pressure of Crustacean on phytoplankton and therefore improve water quality, increase in the amount of predatory fish is necessary.

Qualitative and quantitative composition of macroinvertebrates in Lake Rusalka changed slightly in comparison with the year 2005. The abundance of Chironomidae pupae reached 1288 ind. m⁻² in littoral and 92 ind. m⁻² in profundal, while in previous year it was 1104 and 29 ind. m⁻² respectively. Noted changes inform about some improvements of benthic fauna life conditions. Nevertheless, the biomass was still low (up to 30 g m⁻²), as the food pressure of dominating in ichthiofauna benthivorous fish was strong. To decrease this pressure, the stocking with predatory fish is recommended.

CONCLUSIONS

Iron treatment as a restoration method was conducted in Rusalka Lake between April and September 2006. The amount of measures increased to 6 and coagulant was used in slightly greater doses than it was planned initially, due to sweltering summer and increase in water and bottom sediments temperature. 930 kg of PIX-112 was used as total. Physico-chemical and biological analyses of water quality indicated a significant reaction of lake ecosystem:

- water transparency increase in the second part of research period (especially in autumn);
- slight decrease of pH value;
- irregular in the first and strong in second part of research period diminish of ammonium nitrogen concentrations in water;
- spatial and vertical variety of phosphorus concentrations and decrease in late summer and in autumn;
- raised N:P ratio in water;
- periodical decrease of chlorophyll-a concentrations, especially in the second part of research period;
- diminish of phytoplankton abundance after treatments, except spring and early summer, when the amount of Bacillariophyceae, Chlorophyceae and Cyanobacteria increased;
- increase in zooplankton abundance (especially Rotifera) in surface water layer and Crustacean (especially Copepoda) in metalimnion;
- slightly raised abundance and biomass of macroinvertebrates, which indicated gradual improvement of conditions in bottom sediments;
- maintaining permanent improvement of water quality in restored lake requires additional activities to increase dissolved oxygen concentration in hypolimnion. It may be gained by (i) aeration device installed in the deepest place of the lake to oxygenate hypolimnion waters and (i) measure aimed to increase redox potential of bottom sediments i.e. calcium nitrate treatment. Further iron treatment by few, small PIX-112 doses in next year is also necessary. Moreover, it is advisable to plan fish stocking in early summer with pike fry, to supplement restoration with biomanipulation effect of zooplankton grazing impact on phytoplankton.

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