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# THE CONDITION AND POTENTIAL METHODS OF RESTORATION OF SHALLOW, URBAN LAKE JELONEK

Lake Jelonek is a shallow lake situated within the town of Gniezno. For many years it was a receiver of storm waters, as well as wastewaters from unidentified sources. For more than ten years, attempts have been undertaken to improve the situation in the lake. Among others, a retention pond was dug on the main tributary and aerators were installed. In this paper, the results of monitoring studies are presented, performed in 2005, with special consideration of the extended research program on sediments.

It was found that for future attempts at improving the condition of Lake Jelonek, it is very important to identify the causes of high pH, both in the channel and in the lake, before the period of intensive phytoplankton development. It is necessary to optimize the work of aerators in order to increase the efficiency of water oxygenation. Since no dredging of sediments is possible, at least in the immediate future, the only way of improving the situation is inactivation of phosphorus in bottom sediments and bringing the ecosystem to stable condition of macrophytic domination.

## 1. INTRODUCTION

Lake Jelonek is a small, shallow lake situated within the town of Gniezno. For many years the lake served as a receiver of storm waters as well as wastewaters from unidentified sources. In consequence, this small reservoir shows symptoms of significant overeutrophication and degradation, such as small water transparency, high concentration of phosphorus in sediments, which, is the cause both of the intensive cyanobacterial blooms and extinction of macrophytes.

For more than ten years, studies were made (e.g., [9]) and attempts undertaken to improve the situation. The retention pond was dug on the main tributary. Three lines of aerators are still in operation. However, no improvement was noted. In 2005, monitoring studies of the lake were started, taking into consideration changes in the chemical composition of water in the retention pond, in the tributary and at two sites in the lake. Par-

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ticular attention was paid to the extended program of studies on the sediments.

## 2. MATERIAL AND METHODS

### 2.1. DESCRIPTION OF THE LAKE

The main morphometric parameters of the lake are presented in table 1, and the distribution of sample collection sites in the figure.

Table 1

Morphometric characteristics of Lake Jelonek

| Feature | |
|---|---|
| Surface, ha | 14.4 |
| Volume, thous. $m^3$ | 172.8 |
| Max depth, m | 2.4 |
| Mean depth, m | 1.2 |
| Length, m. | 670 |
| Max width, m | 300 |
| Depth index | 0.5 |
| Lakeshore line develop. | 1.23 |


Lake Jelonek. Location of sampling stations

The lake is very shallow and has a regular shape, confirmed by a small value of the shoreline development index. Urban building development in the direct drainage area and the lack of natural vegetation filter zones create exceptionally difficult conditions for the protection of the lake against anthropopressure.

Measurements of the water parameters were done on the following dates: 31.05, 28.06, 26.08, 09.08. On the same dates, samples of water, phyto- and zooplankton as well as sediments were collected. Additional measurements of the water parameters in the lake were carried out in August (24, 30, 31). Part of the studies and analyses were carried out only in the retention pond and on the lake's tributary on the following dates 18.05, 07.07, 23.08 and 08.11.

2.2. METHODS

During the investigation, measurements of the main water parameters were performed at all sites. Water samples for chemical analyses, determination of phytoplankton and zooplankton were collected in accordance with the standards valid in laboratories of PIOŚ (the State Inspectorate for Environmental Protection). Sediments were the focus of the present study. Samples of bottom sediments were collected with Eckman's sampler.

#### 2.2.1. PHOSPHORUS FRACTIONS

Fresh sediment was carefully homogenized and subjected to chemical analysis. Total phosphorus was determined as a sum of individual fractions. Phosphorus fractions in sediments were determined through consecutive extractions: (1) $NH_4Cl$, (2) $Na_2S_2O_4$, (3) NaOH and (4) HCl (according to [5] and [8]). This way the following forms of phosphorus (P) were determined: (1) loosely bound phosphorus, adsorbed on the surface of Fe and $CaCO_3$ molecules, SRP – soluble reactive phosphorus; (2) phosphorus susceptible to changes of the redox potential, mainly bound to FeOOH and Mn compounds; in the text, this fraction is denoted as BD-P (bicarbonate/dithionite phosphorus); (3) phosphorus bound to metal oxides, mainly Al and Fe as well as phosphorus contained in organic matter of microorganisms, detritus and humins; (4) phosphorus bound to carbonates and apatite phosphorus, slightly hydrolysed organic P; (5) total phosphorus – the sum of all fractions.

#### 2.2.2. EPC-0 – DETERMINATION OF THE SORPTION CAPACITY OF SEDIMENTS IN RELATION TO PHOSPHATES. MEASUREMENT OF EPC-0 – EQUILIBRIUM PHOSPHATE CONCENTRATION

In order to measure the phosphate sorption capacity of sediments, a simplified procedure was applied that enables a relatively accurate evaluation of the degree of phosphorus accumulation in bottom sediments [12]. The measuring procedure consists of the following stages: (1) refilling 4 × 1-$dm^3$ cylinders with tap water – up to 0.9 $dm^3$; (2) adding $KH_2PO_4$ (0, 2, 4, 8 $cm^3$; which corresponds to 0, 2, 4, 8 mg $PO_4$) after mixing, the measurement of temperature (°C), conductivity (μS), pH, Eh; (3) adding the sediment – 40 $cm^3$ to each cylinder; (4) replenishing with water up to 1 $dm^3$; (5) 10-minute resuspension (a magnetic mixer); (6) resedimentation of suspended matter – 1.5 hours; (7) collection of water samples 85 $cm^3$ – measurements of temperature (°C), conductivity (μS), pH, Eh; (8) determination of the terminal $PO_4$.

## 3. RESULTS AND DISCUSSION

### 3.1. INFLUENCE OF THE DRAINAGE BASIN

The retention pond and the channel flowing into the lake exert the most significant influence on the water quality of Lake Jelonek. Also, a restaurant located on the island could constitute a source of incidental, substantial discharge of wastewaters, which contribute to sudden deterioration of water parameters. The influence of the stream reaching the retention pond seems to be the smallest as compared with the retention pond and the channel flowing from the pond. Its water (results dated 07.07) is more oxygenated and carries three times less phosphorus than the water in the channel flowing from the pond.

Influence of the channel on the quality of lake waters is difficult to grasp if measurements are taken only few times a year. High variability of parameters for the channel water is proved by the results of measurements performed during the previous studies. On May 18th, a number of parameters for the channel water were similar to those recorded in the lake – pH, conductivity, $PO_4$. The content of mineral phosphorus amounted to 0.062 mg P/dm$^3$. A significant water supersaturation with oxygen was observed – up to 168%. On July 7th, there was already as much as 1.432 mg P/dm$^3$ of $PO_4$ in the channel, and the water saturation with oxygen came to nearly 10%. There was 10 times more organic phosphorus in the channel than in the pond, which could evidence the additional supply for the channel along the section between the pond and the lake. On August 23rd, $O_2$ saturation amounted to 62% (almost the same as in the lake water); there was two times less $PO_4$ than in the pond and in the lake, and six times less organic phosphorus than in the pond and almost 15 times less than in the lake. On August 24th, the redox potential of the channel water amounted to 232 mV, and on August 30th only to 124 mV. On November 8th, measurements in the stream and in the retention pond revealed significant water deoxidation – ca. 25% and 8%, respectively.

Unmonitored discharge of wastewaters from the restaurant on the island could also be a serious problem as far as the quality of lake waters in concerned. This is proved by the results of July 7th. The analysis of water collected in the moat surrounding the island, revealed that organic pollutants ($BOD_5$ as much as 52 mg $O_2$/dm$^3$), and even faecal pollutants (coli titre 0.005 as compared with 50.0 in the lake water) could be discharged to the lake. The concentration of mineral phosphorus was also very high – 2.404 mg P/dm$^3$, and per $PO_4$ it makes up as much as 7.356 mg/dm$^3$. Already during the lake survey and measurements of conductivity performed on March 31st in the moat, the presence of cyanobacterial scums was recorded on the water surface. High pH in the retention pond and in the channel reaching the lake is also worth paying attention (table 2). In many cases, an increase of pH up to the value of ca. 8.5 takes place in the high season and it results from phytoplankton blooms. In the case of Lake Jelonek, very high pH values were recorded during all collections of samples in the retention pond and in the channel, starting already on May 18$^{th}$ (values from 7.9 to 8.3).

Table 2

Water chemistry

| Parameter | | Station 2 | Station 2 | Pond | Canal |
|---|---|---|---|---|---|
| Date | | 07 July | 23 August | 23 August | 23 August |
| Temperature | °C | 20.0 | 22.0 | 21.1 | 15.5 |

| | | | | | |
|---|---|---|---|---|---|
| Secchi disk visibility | m | 0.4 | 0.35 | 0.35 | 0.15 (bottom) |
| pH | | 8.48 | 8.47 | 7.28 | 7.93 |
| Conductivity | μS/cm | 675 | 679 | 544 | 863 |
| Oxygen – surface (0–0.5 m) | mg $O_2/dm^3$ | 0.90 | 5.60 | 4.40 | 6.40 |
| Oxygen – surface (0–0.5 m) | % | 9.58 | 61.81 | 47.77 | 62.56 |
| Oxygen – bottom (1.9–2.4 m) | mg $O_2/dm^3$ | | 5.20 | | |
| $BOD_5$ – surface (0–0.5 m) | mg $O_2/dm^3$ | | 10.93 | | |
| $BOD_5$ – bottom (1.9–2.4 m) | mg $O_2/dm^3$ | | 10.37 | | |
| $BOD_5$ | mg $O_2/dm^3$ | | 10.56 | 7.22 | 1.85 |
| $NH_4$ – N | mg N/$dm^3$ | 0.7049 | 0.4824 | 0.3828 | 0.3034 |
| $NO_3$ – N | mg N/$dm^3$ | 0.0045 | 0.0615 | 0.0556 | 0.0188 |
| $NO_2$ – N | mg N/$dm^3$ | 0.0082 | 0.0009 | 0.0006 | 0.0044 |
| Mineral N | mg N/$dm^3$ | 0.7176 | 0.5448 | 0.4390 | 0.3266 |
| Organic N | mg N/$dm^3$ | 1.0080 | 0.6720 | 1.4000 | 1.2320 |
| Total N | mg N/$dm^3$ | 1.7256 | 1.2168 | 1.8390 | 1.5586 |
| Mineral P | mg P/$dm^3$ | 1.4880 | 0.592 | 0.582 | 0.282 |
| Organic P | mg P/$dm^3$ | 0.0140 | 0.118 | 0.048 | 0.008 |
| Total P | mg P/$dm^3$ | 1.5020 | 0.710 | 0.630 | 0.290 |
| COD | mg $O_2/dm^3$ | | 43.84 | 31.51 | 27.40 |
| Seston | mg/$dm^3$ | | 35.29 | | |
| Chlorophyll | μg/$dm^3$ | | 135.922 | | |
| Coliform count | | | 50 | | |

### 3.2. BLOOMS OF BLUE-GREEN ALGAE

In Lake Jelonek there are exceptionally favourable conditions for the development of cyanobacterial blooms. In the water, significant quantities of $PO_4$ were recorded. The concentration of phosphates was clearly increasing from 0.058 mg/$dm^3$ on May 31$^{th}$ up to 0.360 mg P–$PO_4$ on August 09$^{th}$ (that is up to more than 1 mg $PO_4/dm^3$). A clear upward trend was also recorded in the channel (from 0.089 on May 18$^{th}$ up to 0.282 mg P–$PO_4/dm^3$ on August 23$^{rd}$). The pond could also be a source of substantial amounts of $PO_4$. Almost 1.5 mg of P–$PO_4/dm^3$ recorded on July 7$^{th}$, both in the pond and in the channel, constitutes almost 5.0 mg of pure $PO_4$.

The third and the major source of P is sediments (table 3). Analyses of the composition of bottom sediments and phosphorus fractions allow the following statements:

- Sediments contain quite a lot of calcium ions (more than 100 g/kg), which should be favourable to phosphorus-binding in sediments ([1]–[3]). This is confirmed by a high contribution of the fraction HCl-P (Ca-bound phosphorus, apatite) in $P_{tot}$, that is in total phosphorus.
- They also contain lots of silica, which unfortunately could be favourable to P emission, and this is indicated by the latest studies conducted in different lakes of the same climatic zone ([4], [6]).
- The contribution of Fe is too small for the natural effective fixation of P.

From table 3, it clearly follows that during the period from 28.06 to 09.08 the content of Fe in sediments decreased more than twice (from more than 4 to nearly 2 g/kg d.m.). In sediments of Lake Jelonek, the Fe/P ratio amounts to ca. 2. As numerous studies indicate ([7], [10], [11]), the effective fixation of P in sediments occurs with the ratio of Fe/P above 20. Small efficiency of P-fixation in sediments of Lake Jelonek is demonstrated also by relatively small contribution of the fraction $NH_4$Cl-P and BD-P.

Table 3

Chemical composition of sediment at station 2

| Date | Org. mat. | $SiO_2$ | Ca | Mg | $SO_4$ | $N_{NH4}$ | $P_{og}$ | Fe | Mn | Fe/P | EPC-0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | % | g/kg | g/kg | g/kg | g/kg | g/kg | mg/kg | mg/kg | | mg $PO_4$ $dm^{-3}$ |
| 31 May | 23.4 | 38.8 | 107 | 29.3 | 48 | 0.60 | 1.88 | 3956 | 456 | 2.1 | 2.568 |
| 28 June | 20.9 | 52.2 | 115 | 22.8 | 82 | 0.51 | 1.95 | 4028 | 477 | 2.1 | 0.334 |
| 09 August | 18.4 | 27.5 | 193 | 52 | 20.5 | 0.44 | 2.24 | 1950 | 432 | 0.9 | 0.642 |
| 31 August | | | | | | | | | | | 0.956 |

The analysis of the sorption capacity of sediments in relation to phosphates (table 3) also provided the important information. On May 31st, this capacity, measured as EPC-0, that is, the sorption capacity for the equilibrium state amounted to 2.568 mg $PO_4/dm^3$, almost as much as the content of total phosphorus recorded in sediments. This proves nearly the maximum P accumulation possible for these sediments. After experimental addition of 2.0 mg $PO_4$ to the benthic water, the sediment absorbed only 0.043 mg of $PO_4$. On June 28th, the situation changed quite suddenly. Despite slightly altered water parameters, EPC-0 decreased up to 0.334 mg $PO_4/dm^3$. Now, after adding 2.0 mg of $PO_4$, sediments absorbed almost half of the phosphorus added. This could prove that substantial amounts of $PO_4$ were released from sediments to the water depths and the conditions for the development of cyanobacterial blooms were created. Such a possibility is demonstrated by the threefold decrease of the fraction $NH_4$Cl-P and decrease of the $P_{tot}$ content (table 4). On subsequent dates (09.08 and 31.08), a slow increase of natural sorptive capacity of sediments is observed – up to 0.642 and 0.956 mg $PO_4/dm^3$, respectively.

Table 4

Phosphorus fractions in sediments at stations 1 and 2 (mg P · $g^{-1}$ d.m.)

| | P fractions | | | | | |
|---|---|---|---|---|---|---|
| Date/Station | $NH_4$Cl-P | BD-P | NaOH-P | HCl-P | Res.-P | $P_{tot}$ |
| 31 May/St. 2 | 0.060 | 0.093 | 0.559 | 1.768 | 0.115 | 2.595 |
| 28 June/St. 2 | 0.020 | 0.111 | 0.577 | 1.225 | 0.071 | 2.005 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 09 August/St. 2 | 0.028 | 0.088 | 0.450 | 1.024 | 0.121 | 1.711 |
| 09 August/St. 1 | 0.034 | 0.085 | 0.378 | 1.075 | 0.101 | 1.673 |

### 3.3. THE COMPOSITION OF PHYTO- AND ZOOPLANKTON

Structural impairment of hydrobionts in the degraded ecosystem of Lake Jelonek is clearly reflected in the composition of phyto- and zooplankton (tables 5 and 6). In the phytoplankton, blue-green algae evidently dominate, and particularly *Aphanizomenon flos-aquae* and *Planktothrix aghardii* during the June bloom.

Table 5

Composition of phytoplankton dominating species

| Sampling date | 31 May | 28 June | 09 August |
|---|---|---|---|
| Chlorophyll a, µg $dm^{-3}$ | 89.6 | 279.2 | 182.3 |
| Density, $dm^{-3}$ | 18 395 500 | 91 799 500 | 57 304 000 |
| Species composition | | | |
| Cyanoprocaryota | | | |
| *Anabaena flos-aquae* | | 4335500 | 3016000 |
| *Anabaena solitaria* | | 7163000 | |
| *Aphanizomenon flos-aquae* | | 39019500 | 942500 |
| *Limnothrix redeckei* | 618750 | | 377000 |
| *Oscillatoria limnetica* | 41250 | 377000 | 4524000 |
| *Planktothrix aghardii* | 4372500 | 20923500 | 40150500 |
| Cryptomonadales | | | |
| *Cryptomonas* sp. | 165000 | 5655000 | 3204500 |
| Pyrrophyta | | | |
| *Peridinium* sp. | 6500 | 188500 | |
| Bacillariophyceae | | | |
| *Asterionella formosa* | 41250 | | |
| *Cyclotella meneghiniana* | 82500 | | 188500 |
| *Fragilaria ulna* | 618750 | | |
| Euglenophyta | | | |
| *Phacus longicauda* | 3000 | | |
| *Trachelomonas* cf. *volvocinopsis* | 206250 | | |
| Chlorophyta | | | |
| *Actinastrum hantzschii* | 1320000 | | 3770000 |
| *Closterium limneticum* | 82500 | 188500 | |
| *Scenedesmus quadricauda* | 8208750 | 5655000 | 377000 |
| Number of species | 89 | 58 | 76 |

Table 6

Zooplankton dominating species composition

| | 31 May | | 28 June | | 09 August | |
|---|---|---|---|---|---|---|
| | L | B | L | B | L | B |
| Rotatoria | | | | | | |
| *Asplanchna priodonta* | 992 | 12583 | 40 | 507.4 | 16 | 202.96 |
| *Brachionus angularis* | 48 | 25.1 | 40 | 20.92 | 32 | 16.74 |
| *Brachionus calyciflorus* | 48 | 105.74 | 184 | 405.352 | 16 | 35.25 |
| *Brachionus diversicornis* | 32 | 43.46 | 1168 | 1586.14 | 168 | 228.14 |
| *Filinia terminalis* | 304 | 158.69 | 864 | 441.61 | 136 | 70.99 |
| *Keratella cochlearis* | 1448 | 224.44 | 1144 | 177.32 | 392 | 60.76 |
| *Keratella cochlearis f. tecta* | 2832 | 308.68 | 568 | 61.91 | 3024 | 329.62 |
| *Keratella quadrata* | | | 592 | 500.83 | 24 | 20.3 |
| *Polyarthra longiremis* | 208 | 126.26 | | | 8 | 4.86 |
| *Pompholyx sulcata* | 656 | 154.82 | 176 | 41.54 | 680 | 160.48 |
| Total – A | 6968 | 13921 | 4880 | 3781.76 | 4536 | 1143.79 |
| Cladocera | | | | | | |
| *Alona quadrangularis* | 8 | 83.36 | | | | |
| *Bosmina longirostris* | 1552 | 8199.21 | 16 | 84.53 | 32 | 169.06 |
| *Chydorus sphaericus* | 48 | 259.25 | 120 | 648.12 | 64 | 345.66 |
| *Daphnia cucullata* | | | 16 | 135.46 | 16 | 136.46 |
| Total – B | 1608 | 8541.82 | 152 | 868.11 | 112 | 651.18 |
| Copepoda | | | | | | |
| *Acanthocyclops vernalis* | 8 | 285.94 | | | 40 | 1429.68 |
| *Eudiaptomus graciloides* | 24 | 487.01 | | | | |
| Nauplii | 400 | 401.6 | 512 | 514.05 | 112 | 246.74 |
| Copepodites | 24 | 165.98 | 16 | 110.72 | 48 | 331.97 |
| Total – C | 456 | 1340.53 | 544 | 962.85 | 208 | 2177.43 |
| TOTAL A+B+C | 9032 | 23803.3 | 5576 | 5612.72 | 4856 | 3972.4 |

L – density ind. · $dm^{-3}$.
B – biomass μg f.w. $dm^{-3}$.

Similarly, in the zooplankton, significant maladjustment and simplification of trophic networks is demonstrated by the domination of rotifers and small contribution of efficient filtrators, that is, cladocerans.

## 4. SUMMARY

Lake Jelonek demonstrates an exceptionally high degree of overeutrophication. This is indicated by physicochemical and biological studies. During the entire period of studies, the Secchi disk visibility did not exceed 0.40 m. Very high concentrations of mineral phosphorus recorded in the water – as much as 1.488 mg P $dm^{-3}$ and 2.595 mg P · $g^{-1}$ d.m. in sediments, as well as 279.2 μg $dm^{-3}$ of chlorophyll a prove almost extreme overeutrophication.

Future studies should concentrate mainly on identification of all sources of nutrients, pollutants and their load carried from the direct drainage area. This concerns the channel supplied with water from Struga Gnieźnieńska (the Gnieźnieńska Stream), the retention pond and unidentified discharges directly to the channel along the pond–lake section.

If dredging of sediments in Lake Jelonek is not possible for geomorphological reasons, the only possibility to improve the situation, after putting the drainage basin in order, is inactivation of phosphorus in bottom sediments and bringing this hypereutrophic ecosystem to alternative stable state of macrophytic domination.

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## STAN I POTENCJALNE METODY REKULTYWACJI PŁYTKIEGO, PRZYMIEJSKIEGO JEZIORA JELONEK


Jezioro Jelonek jest płytkim jeziorem leżącym w obrębie miasta Gniezno. Od wielu lat było odbiornikiem zarówno spływów burzowych, jak i ścieków z niezidentyfikowanych źródeł. Od ponad dziesięciu lat podejmowano próby naprawy tej sytuacji. Między innymi wykopano staw retencyjny na głównym dopływie i zainstalowano aeratory. W pracy prezentowane są wyniki badań monitoringowych wykonanych w 2005 roku ze szczególnym uwzględnieniem rozszerzonego programu badań osadów.

Stwierdzono, że bardzo ważne jest zidentyfikowanie przyczyn wysokiego pH w kanale i w jeziorze przed okresem intensywnego rozwoju fitoplanktonu. Konieczna jest optymalizacja pracy aeratorów w celu zwiększenia efektywności natleniania wody. W sytuacji, gdy bagrowanie osadów, przynajmniej w najbliższym okresie, nie jest możliwe, jedyną możliwością naprawy sytuacji jest inaktywacja fosforu w osadach dennych i przeprowadzenie ekosystemu w stabilny stan dominacji makrofitowej.