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FUNCTIONING OF THE GRAVEL PIT LAKE IN OWIŃSKA (WEST POLAND) IN THE YEARS 2001-2005

Ryszard Gołdyn, Elżbieta Szeląg-Wasielewska,
Katarzyna Kowalczewska-Madura, Renata Dondajewska, Halina Szyper,
Tomasz Joniak, Monika Piechowiak, Piotr Domek

Department of Water Protection, Adam Mickiewicz University
Umultowska str. 89, 61-614 Poznań, Poland, e-mail: rgold@amu.edu.pl

Summary. Deterioration of water quality in the gravel pit lake in Owińska, observed in 2002-2003, was manifested with increase of nutrient concentration, very abundant phyto- and zooplankton, high pH and chlorophyll *a*. Surface water layer was oversaturated with oxygen, while near the bottom sediments oxygen was completely depleted. Very dangerous for drinking water supply from wells situated near the lake were cyanobacteria species known as toxin producers. The reason of water deterioration was stocking the lake with grass carp and big amount of lures applied by anglers.

Key words: mining lake, water quality, phytoplankton, zooplankton, grass carp, biomanipulation

INTODUCTION

Mining lakes may originate as a result of exploitation of various resources. They form when open-pit mining operations are discontinued and dewatering ceases. The most frequent are lakes in former peat and clay mines. In some regions also vast reservoirs made after lignite mining can be found. Water bodies in the area of former gravel mines, like that studied lake in Owińska, are relatively rare. It is probably the consequence of frequent occurrence of gravel resources on hills. Good permeability of the bed is the reason of water lack in such excavations. Gravel deposits in Owińska are located on relatively flat, wide sands, with shallow water table. Good quality of this water favours its usage as a source of drinking water supply, hence two infiltration wells being exploited close to the lake.

Mining lakes created as a result of peat mining were most frequently studied, especially in the Netherlands, because of their frequent occurrence. Lignite lakes were well diagnosed in former East Germany, where they covered large surfaces [e.g. Geller *et al*. 2000, Totsche *et al*. 2003, Nixdorf *et al*. 2005]. Gravel mining lakes are almost entirely unrecognised. A few references found in databases concern only some aspects of limnology of those ecosystems [Hoffmann 1987, Helmer and Labroue 1993, Maier and Buchholz 1996, Hyankova 1997, Borcherding and Sturm 2002, Auer *et al*. 2004].

Comprehensive studies of the gravel pit lake in Owiñska were undertaken to fill this gap. Their purpose was to investigate the functioning of the ecosystem of that mining lake, with special attention to the processes influencing water quality, analysed from the point of view of drinking water supply. The present publication involves only a part of the results. Data concerning phytoplankton and microbiological loop have been published in separate papers [Szeląg-Wasielewska and Gołdyn 2005, Szeląg-Wasielewska 2006, Szeląg-Wasielewska *et al*. 2006].

STUDY AREA

The studied lake filled the excavation of the gravel mine in Owińska during the years 1983-1992. It is situated ca. 20 km north from Poznań (West Poland), within the southern, exploited part of aggregate deposits area. The reservoir is divided into 4 parts of unequal size, separated by narrows. There are three islands in the area of the biggest, central part. This part and the eastern one placed next to it have similar maximal depth, approximately 5.5 m. Despite accurate sonar measurements, the previously published depth of 7.3 m (Tab. 1) has not been found.

Table 1. Morphometric data of the gravel pit lake in Owińska [acc. to Pleczyński 1998 and Błasiak 2001]
Tabela 1. Dane morfometryczne zbiornika w Owińskach [za Pleczyńskim 1998 i Błasiakiem 2001]

Variables	Unit – Jednostka	Value – Wartość
Surface area of the lake – Powierzchnia zbiornika	ha	13.1
Surface area of islands – Powierzchnia wysp	ha	0.6
Bank length – Długość brzegu	m	3200
Development of bank – Rozwój linii brzegowej	m ha^{-1}	256
Mean depth – Średnia głębokość	m	4.7
Maximum depth – Maksymalna głębokość	m	7.3

The area of aggregate deposits „Owińska" was shaped in the result of fluvio-glacial activity in the foreground of Poznań Phase of the Baltic Glaciation. In the place of clays, which were washed out, a sandy plain arose to an elevation of 80-85 m, with average width of 1.2 km [Pleczyńki 1998]. The gravel pit lake in Owińska has no surface inflow; it owes its existence to direct contact with local groundwater reservoir placed within sand and gravel of this plain [Pleczyński 1998]. Except for the studied lake, four other water bodies exist within the plain. When open-pit mining operations on the southern part of „Owińska" deposit were finished, mining in the northern part was launched and continues until now. In this place two new water reservoirs emerged. One of them is separated from the studied lake by a dyke which is only 10-50 m wide. It is predicted that after finishing the exploitation of gravel, the area of this reservoir will be ca. 17 ha.

In the southern part, at distances of 60 and 120 m from the studied lake, two wells of ground water intake are located. Before starting of the intake, water level in all the water bodies kept at an elevation of 77.7-78.4 m. Its fluctuations were scant, dependent on the precipitation variability during the year. Water level in the studied lake was changing between 78.06 and 78.40 m above see level, i.e. by 34 cm per year [Pleczyński 1998]. In 2001 this elevation was 77.54 m, therefore it showed a tendency to decline, which was probably connected with water exploitation from the wells.

The lake is used for angling. The number of anglers systematically increased between the years 1993 and 2001 from 132 to 680. However, during the last 4 years it did not exceed 400. During the period before the studies, the lake had been intensively stocked with various species of fish, especially with roach, carp, bream and grass carp (Fig. 1). From 2001, the number of introduced fish was reduced. Grass carp was entirely eliminated and pikeperch and wels were introduced in its place.

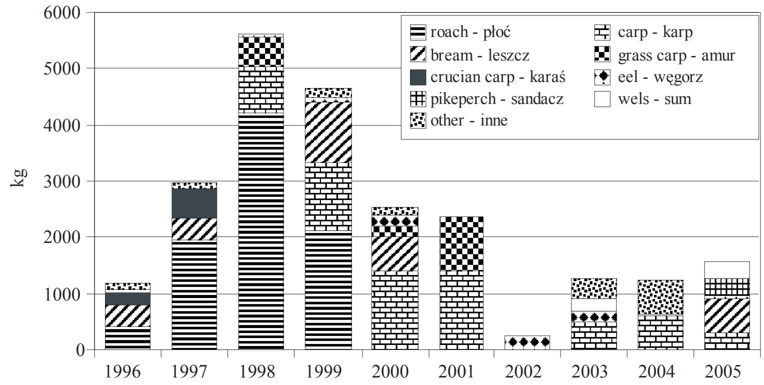

Fig 1. Stocking with fish of the gravel pit lake in Owińska during last 10 years
Rys. 1. Zarybienia zbiornika powyrobiskowego w Owińskach w ciągu ostatnich 10 lat

MATERIALS AND METHODS

Field studies on the gravel pit lake in Owińska were undertaken mainly in spring and summer periods in the years 2001-2005, with the exception of 2001 (autumn). They included analysis of chosen physicochemical and biological variables of water quality in the vertical profile of water column at two stations located within two parts of the lake with maximum depth of 5.5 m. The first station was situated in the eastern part, the second in the central part. From both stations 3 samples of water were taken each time: from the surface and at depths of 2.5 and 5 m.

The examinations of water quality were usually made in April (during the period of spring water circulation) and in August (during summer thermal stratification). Only in the first year the study was taken during autumn (in November). Some of the variables were measured *in situ*: water transparency, its temperature, content of oxygen dissolved in water, oxygen saturation, electrolytic conductivity and pH. Water transparency was measured using Secchi discs, other variables in vertical profile at 1 m intervals – using YSI 610-DM-meter. In the taken samples the following analyses were made in the laboratory: BOD_5, ammonium, nitrite, nitrate and organic nitrogen, soluble reactive phosphorus (SRP) and total phosphorus, suspended solids (seston), chlorophyll *a* and pheophytin *a*, qualitative and quantitative analyses of phyto- and zooplankton.

Physicochemical analyses were made according to the Polish Standards [Dojlido 1995]. Qualitative and quantitative analyses of phytoplankton were made from uncondensed samples fixed with Lugol solution in Utermöhl modification, using an inverted microscope and sedimentation chambers of 14 ml in volume. Zooplankton analyses were made using 20-liter samples, filtered through a plankton net with 40 μm mesh diameter and preserved with Lugol solution. For quantitative analysis Sedgwick-Rafter plankton chamber with volume of 0.5 ml was used.

RESULTS

Water transparency in the gravel pit lake in Owińska during the studied period ranged from 1.8 (Aug. 2005, station 1) to 3.9 m (Nov. 2001, station 2, Fig. 2). Average value for the whole study period was 2.6 m at station 1 and 2.95 m at station 2. Higher values were always noticed in spring (or in autumn) rather than in summer. These values for some time were similar at both stations, however at the beginning and before the end of the study period – visibly higher at the second station (Fig. 2).

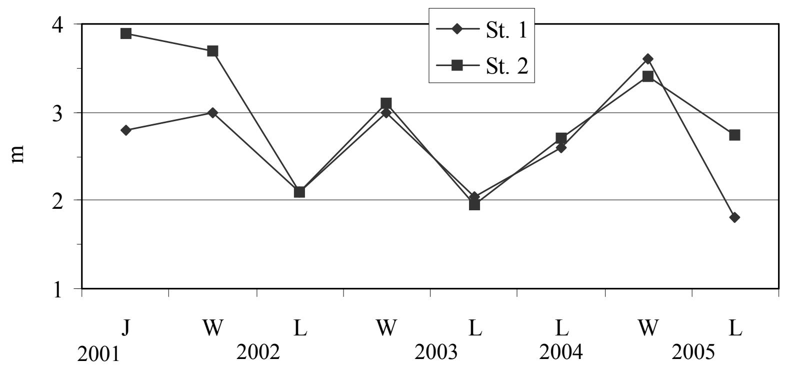

Fig 2. Changes in Secchi disc transparency in the gravel pit lake in Owińska in the years 2001-2005 at both sampling stations (J – autumn, W – spring, L – summer)
Rys. 2. Zmiany widzialności krążka Secchiego w zbiorniku w Owińskach w latach 2001-2005 na obu stanowiskach badawczych (J – jesień, W – wiosna, L – lato)

Temperature values in vertical profile of the lake during springs were aligned from the surface to the bottom, however during summer months usually a partial thermal stratification was formed, with two layers: the epi- and metalimnion. The biggest differences of temperature between the surface and the bottom were observed in the year 2003 – 10.9ºC at the first station and 8.9ºC at the second. However, during the last year the metalimnion did not appear and differences between the surface and near the bottom water layers were small – 1.1ºC and 1.4ºC.

Water saturation with oxygen in the studied lake was similar in the whole vertical profile, reaching values of ca. 80-90%. During summer distinct stratification was usually observed, with over-saturated epilimnion and de-oxygenated metalimnion. Very high oxygen saturation, reaching up to 180% at the depth of 1 meter in August 2003, was observed at both stations. During the same period in near the bottom water layer, beginning from the depth of 3 meters, a sharp gradient of oxygen saturation was observed. The depletion reached 2.5% at 4 m depth and zero at 5 m. Significant differences of water saturation with oxygen in vertical profile were not observed only in summer of 2005.

Values of conductivity were in the range from 378 $\mu S\ cm^{-1}$ (Aug. 2003) to 676 $\mu S\ cm^{-1}$ (Aug. 2002) at the first station and from 372 $\mu S\ cm^{-1}$ (Aug. 2003) to 526 $\mu S\ cm^{-1}$ (Aug. 2004) at the second. In the water column the smallest values were always observed near the surface, the highest above the bottom of the lake. The amplitude of values during summer was higher at the first station (especially in 2002 and 2003, reaching 277 $\mu S\ cm^{-1}$) than at the second (maximal 124 $\mu S\ cm^{-1}$ in the year 2003).

Values of pH fluctuated in the range from 7.4 (Aug. 2002) to 9.13 (Aug. 2003), usually reaching higher values at the first station than at the second. The highest values in the water column were observed near the surface or in the middle water layer, the smallest above the bottom. High differences in vertical profile were noticed in the year 2002 (1.3 unit) and in 2003 (1.2 unit). During spring periods pH was almost equal in the whole water column.

At both stations in, most of the spring periods, presence of SRP was not observed. Only in 2005 0.003-0.008 mg P l^{-1} was detected. However, higher concentration of SRP occurred during summer seasons, reaching 0.149 mg P l^{-1} above the bottom at the first station (in 2002) and 0.070 mg P l^{-1} at the second (in 2003). Lack of total phosphorus was noticed in spring 2003; the highest values were observed near the bottom during the summers of the same years as in case of SRP – 0.192 mg P l^{-1} and 0.156 mg P l^{-1} at the first and second stations, respectively. Considering variability of concentrations of this element in the water column, it can be stated that both of its forms showed an increase from the surface to the bottom. The biggest differences in total phosphorus content were observed during the years 2002-2003. At the first station the difference was 0.157 mg P l^{-1}, at the second – 0.066 mg P l^{-1}. Increase of phosphorus concentrations in water during the succeeding first 3 years of study at both stations was clearly visible. In the years 2004-2005 concentrations distinctly decreased (Fig. 3).

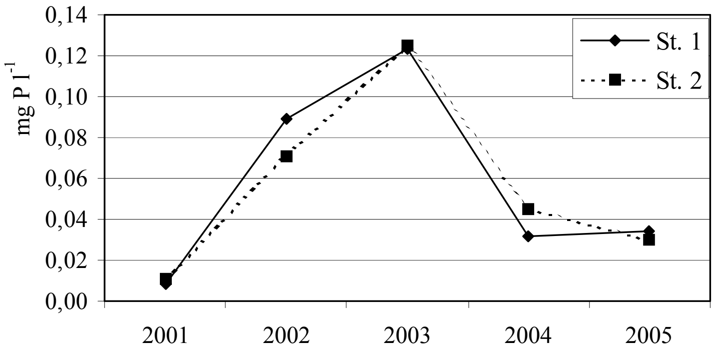

Fig. 3. Changes of mean values of total phosphorus in summer season of succeeding years
Rys. 3. Zmiany średnich stężeń fosforu ogólnego w sezonie letnim kolejnych lat badań

Concentration of total nitrogen visibly and systematically increased during springs of the consecutive years of the study period, from 0.50 to 1.52 mg N l^{-1}. In summer they increased for the first 4 years, reaching the highest values in 2004 – 2.84 mg N l^{-1} (average in the water column was 2.55 mg N l^{-1}). In the last year they decreased to a maximal value of 2.58 mg N l^{-1} (average – 1.87 mg N l^{-1}). The highest values in vertical profile occurred in the middle water layer or above the bottom. In relation to particular forms of nitrogen, presence of nitrite and nitrate were only observed during the last two years of the study period. Their concentration reached 0.008 mg N l^{-1} in the case of nitrites and 0.134 mg N l^{-1} in the case of nitrates. Ammonium nitrogen, except for spring 2002, was always present in waters of the lake. In springs its concentration systematically increased during the successive years. During summer seasons they changed similarly to phosphorus concentration, showing an increase during the first three years and then a decrease in 2004-2005 (Fig. 4). Maximal value of 1.44 mg N l^{-1} was noticed in August, 2003, near the bottom of the lake at station 1.

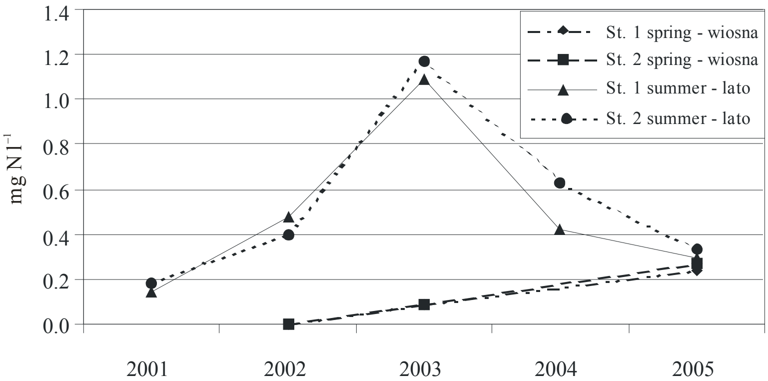

Fig. 4. Changes of mean concentrations of ammonium nitrogen in succeeding years
Rys. 4. Zmiany średnich stężeń azotu amonowego w kolejnych latach badań

Chlorophyll *a* concentrations in water of the gravel pit lake in spring were very low and stable during the consecutive years, reaching from 1.18 to 4.05 µg l^{-1}. They showed distinct variability in summer seasons. During the first three years of study they intensely increased, during the next two – decreased again (Fig. 5).

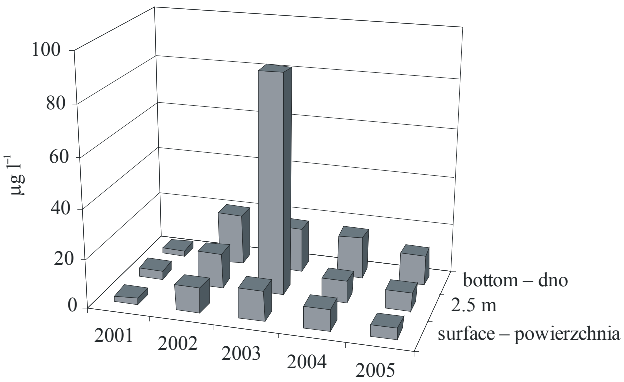

Fig. 5. Variability of chlorophyll *a* content in summer seasons (in 2001 – autumn) at station 2
Rys. 5. Zmienność stężeń chlorofilu *a* w lecie (w 2001 roku jesienią) na stanowisku 2

The highest concentrations were observed in August, 2003, in the middle layer of water, at 84.9 µg l^{-1} at the first station and at the second one – 88.6 µg l^{-1} (Fig. 5). During the remaining years of study they did not exceed 30 µg l^{-1}. Differences of concentrations between the stations calculated for the whole study period were not statistically significant.

Similarly to values of chlorophyll *a*, also numbers of phytoplankton changed. However, the maximal value – 113.5 thousands cells ml^{-1} – was reached not in the summer of 2003 but in 2002. This was connected with domination, in 2002, of thin filiform cyanobacteria (*Lyngbya limnetica, Aphanizomenon gracile*) with small biomass. From analysis of chlorophyll *a*, it results that phytoplankton created higher biomass in 2003, when the most numerous was *Anabaena affinis*, with much bigger cells than the cyanobacteria mentioned above. Domination of cyanobacteria during summer was typical for most of the studied years, except 2001 and 2004, when green algae and haptophytes dominated [Szeląg-Wasielewska and Gołdyn 2005, Szeląg-Wasielewska 2006]. In vertical profile the most numerous phytoplankton was usually observed near the surface or in the middle water layer. However, biomass of phytoplankton was often highest near the bottom [Szeląg-Wasielewska and Gołdyn 2005], which coincides with variability of chlorophyll *a* (Fig. 5). During spring, the number of phytoplankton was small and did not exceed 10 thousands cells ml^{-1}, the dominants being chrysophytes, haptophytes and diatoms.

Summer zooplankton, similarly to phytoplankton, was the most numerous during 2002-2003. During the remaining years it was about 3 times less numerous. During the first three years of the study it was strongly dominated by rotifers, during the last two years it was rather equal. The number of rotifers in 2004-2005, in comparison to the previous years, was rather small (up to 387 specimens l^{-1}), however, the number of copepods (especially naupli and copepodites) and cladocerans (espedially *Daphnia cucullata*) visibly increased. During spring in the successive years the number of zooplankton highly decreased (from average of 1200 to 150 specimens l^{-1}), especially rotifers which were the dominating group. At the same time, the number of crustaceans plankton somewhat increased. A high increase, however, was observed in the share of crustaceans in the total number of zooplankton – from a few percent in 2002 to over 30% in 2005.

DISCUSSION

Doubtless, the reason of rapid deterioration of water quality in summer of 2002 and 2003 was intensive stocking of the lake with grass carp in 1998, 2000 and 2001, the total stock being 1690 kg. As a herbivorous fish with very huge aliment demand, grass carp living in a big population can cause the disappearance of all submerged plants in the lake during a short period of time. Every day the fish graze a quantity of plants equal to 50-120% of their weight [Brylińska 1986]. Because of short alimentary canal, most of components are not assimilated by the organism. Therefore, grass carp release to water huge loads of nutrients accumulated before in water plants. Intensive mineralization of organic matter from excrement causes an increase of concentration of mineral forms of nutrients and microbial oxygen consumption. As a result, a sharp gradient of oxygen concentration below 2 m depth was observed. Oxygen depletion within the bottom sediments caused an additional release of phosphorus adsorbed on metal compounds (especially iron) as a result of their reduction. Increased nutrient concentration in the water column caused an increase of phytoplankton abundance and biomass, measured as the content of chlorophyll *a*. Very dangerous for drinking water quality in the wells situated near the lake were cyanobacteria, very abundant as a result of favourable conditions for their growth [Shapiro 1990, Blomqvist *et al.* 1994]. Determined dominants of cyanobacteria are known as the producers of toxins which are dangerous for health and even life of water consumers [Szyper and Gołdyn 2000].

Removal of all the grass carp stock, which was recommended by the authors, led to the elimination, during the last two years, of the most important source of lake eutrophication.

Stocking the lake with predatory fish contributed to an effect characteristic for bio-manipulation [Shapiro *et al.* 1975, Gołdyn and Mastyński 1998] – decrease of rotifers abundance and their contribution to the total zooplankton density and biomass, increase of the significance of crustaceans, and consequently – decrease of abundance and biomass of phytoplankton.

Additional source of nutrients, and therefore eutrophication of the gravel pit lake, were lures used by anglers. It was established from a survey among anglers that mean time of angling was 28.6 days per year and usage of lure was 1.3 kg per day. Assuming, according to Szyper *et al.* [1995], that 1 kg of lure contains as much as 78 g of nitrogen and 14.4 g of phosphorus, we estimated the maximal annual load of nutrients which was thrown by anglers into the lake during the year 2001 amounted to 2726 kg of nitrogen and 503 kg of phosphorus. Those loads exceeded the critical loads estimated according to Vollenweider criteria [Vollenweider 1976] by a factor of 11 in the case of nitrogen and of phosphorus – by a factor of 31. Reduction in the number of licences for angling in the lake and limitation of angling competitions organised during subsequent years, led to a decrease of influence of this eutrophication source approximately by a half. However, it is still probably the most important pollution source after the elimination of grass carp stock from the lake.

CONCLUSION

The main reason of water quality deterioration in the gravel pit lake in Owińska was its intensive use by anglers, especially its stocking with big stock of grass carp and applying by anglers of big amount of lures. Elimination of the grass carp, stocking the lake with pikeperch and wells, as well as reduction of licences for angling in the lake caused a decrease of nutrient concentration and abundance of phytoplankton.

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FUNKCJONOWANIE ZBIORNIKA POŻWIROWEGO W OWIŃSKACH (ZACHODNIA POLSKA) W LATACH 2001-2005

Streszczenie. Badania zbiornika powstałego po eksploatacji żwiru w Owińskach prowadzono w latach 2001-2005. W latach 2002-2003 stwierdzono gwałtowne pogorszenie jakości wody. Objawiało się ono wzrostem stężeń związków biogennych oraz liczebności fito- i zooplanktonu. Odczyn pH epilimnionu był wyraźnie alkaliczny (do 9,13) a wartość chlorofilu *a* osiągała bardzo wysokie wartości (88,6 $\mu g \cdot l^{-1}$). Woda epilimnionu była silnie przetleniona, natomiast w metalimnionie obserwowano silne deficyty tlenowe, z całkowitym brakiem tlenu w strefie naddennej. Fitoplankton zdominowany został przez gatunki sinic znane z literatury z produkcji toksyn. Było to szczególnie niebezpieczne dla ujęcia wodociągowego z dwu studni, usytuowanych w bezpośrednim sąsiedztwie zbiornika. Przyczyną pogorszenia jakości wody było intensywne zarybienie zbiornika amurem, który uruchomił do toni wodnej dużą ilość biogenów, zakumulowanych uprzednio w makrofitach. Drugą przyczyną była duża ilość zanęt, stosowanych przez wędkarzy. Odłowienie amura oraz ograniczenie ilości zezwoleń na wędkowanie przyczyniło się do wyraźnej poprawy jakości wody w dwu kolejnych latach (2004-2005).

Słowa kluczowe: zbiornik powyrobiskowy, jakość wody, fitoplankton, zooplankton, amur, biomanipulacja