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The influence of the ecohydrological rehabilitation in the cascade of Arturówek reservoirs in Łódź (Central Poland) on the cyanobacterial and algae blooming

by

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Abstract

The objective of the studies included a complex of three reservoirs (upper, middle and lower Arturówek) which play an important recreational role for the residents of the Łódź city and the surrounding areas. The reservoirs were constructed on the Bzura River and are located in the area of the Łódź Hills Landscape Park. The river, the ecological status of which was defined as moderate, has a great influence on the quality of water in the Arturówek reservoirs. A total of 36 planktonic samples were collected in 2011-2013 during spring, summer and autumn seasons. During the studies, the selected physical and chemical parameters were measured. In addition to taxonomic analysis of Cyanobacteria and algae, the analyses of abundance and biomass of phytoplankton and the concentration of microcystins in water were conducted. In 2013, ecohydrological rehabilitation of the Arturówek reservoirs was carried out. Investment works included: removal of the bottom sediments to reduce internal loads, construction of buffer vegetation zones (ecotones) and sedimentation-biofiltration systems to reduce the amounts of pollutants flowing into reservoirs with rainwater. Significant changes in the structure of phytoplankton were observed in 2013. Every year, the disappearance of Cyanobacterial blooms was observed in favor of an increasing contribution of algae.

Key words: Arturówek reservoirs, blooms, Cyanobacteria, algae, eutrophication, ecohydrology

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Introduction

Reservoirs and lakes are those ecosystems which are particularly exposed to eutrophication, and the main factors affecting the rapid growth of Cyanobacteria and algae in these ecosystems include: high concentration of biogenic compounds in water (e.g. nitrogen and phosphorus), insolation, water temperature in the range of 15-30°C, reduced waving, pH in the range between 6 and 9, the size of a reservoir and long water retention (Skulberg et al. 1984; Carmichael 1994; Tarczyńska et al. 1997; Kaebernick, Neilan 2001; Figueiredo et al. 2004). High concentration of biogenic compounds in reservoirs may result from, among others, Schindler's coefficient (Kajak 1998), the surface runoff from intensively used and degraded catchments, a slow course of the river, and the increased sedimentation of the organic and mineral matter contributed by tributaries (Kajak 1979, 1995; Hilbricht-Ilkowska et al. 1995; Tarczyńska et al. 1997; Wagner, Zalewski 2000). The growing human impact combined with instability of hydrological processes in urban catchments significantly affect the dynamics of biogeochemical cycles (Wagner, Breil 2013). As a result of disruption in the functioning of aquatic ecosystems, the abundant growth of phytoplankton can be observed among other effects. The integrated approach which takes into account the biological and hydrological processes occurring within the catchment area and the reservoir itself, is the basis for using specific treatments in order to improve the quality of water in a reservoir by reducing the number of factors affecting the eutrophication process.

Materials and methods

The complex "Arturówek" consists of 3 large reservoirs (Fig. 1). The lower reservoir (AL) has an area of 3.05 ha and the capacity of 40 600 m^3, the middle reservoir (AM) has an area of 2.58 ha (with an island of 0.03 ha) and the capacity of 34 900 m^3 and the upper reservoir (AU) with an area of 1.08 ha and the capacity of 10 000 m^3 plays a role of a sedimentation tank. The deepest reservoir is the lowest one, whereas the upper reservoir is the shallowest one. Their shores are reinforced with concrete blocks and the bottoms are covered with deposits of a small thickness (Jurczak et al. 2012). The reservoirs are located on the Bzura River, which is a left-bank tributary of the Vistula River and flows across the Łódź and Mazovia Provinces. It is a typical lowland river, 166.2 km long, with sources

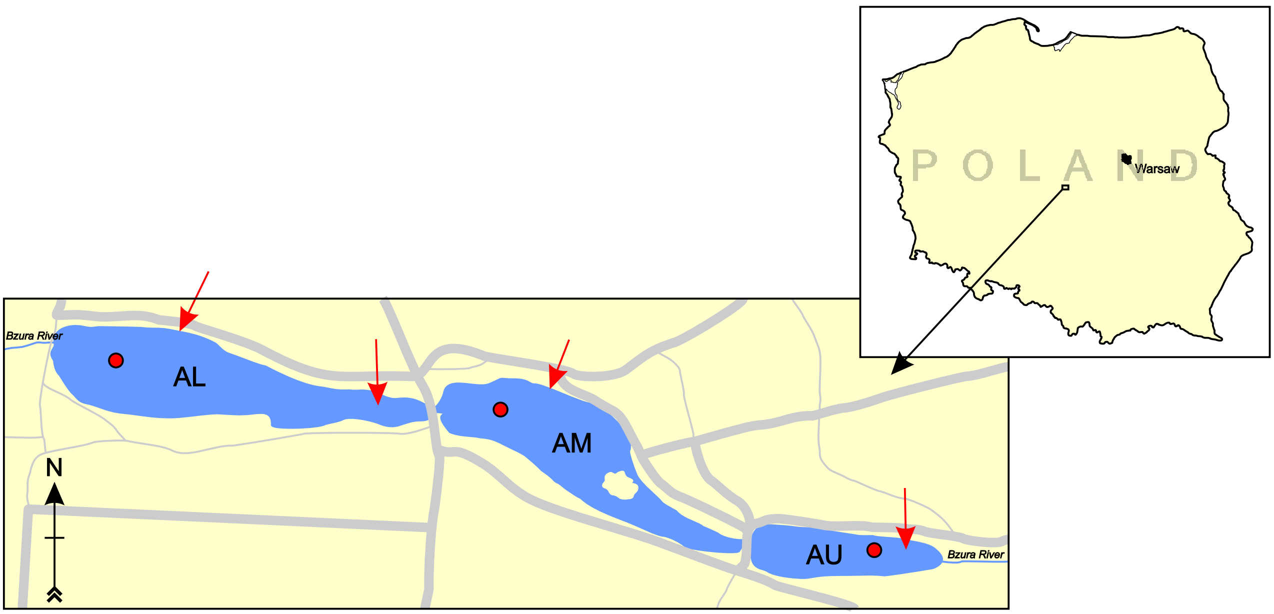

Figure 1

Location of the sampling sites marked with red dots (buffer vegetation zones and buoyant vegetation mats are marked with red arrows) in the town of Łódź and the outflows at the town of Wyszogród (Szczepocka & Szulc 2009).

Samples for the research were collected from 3 main reservoirs: AL, AM and AU (Fig. 1) before and after the fieldwork including: removal of the bottom sediments to reduce internal loads, construction of vegetation mats and zones (ecotones were constructed on the basis of the following species of aquatic plants: *Carex acutiformis, C. riparia, C. rostrate, Iris pseudacorus, Schoenoplectus lacustris, Scirpus sylvaticus, Typha angustifolia*) and sedimentation-biofiltration systems to reduce pollutants flowing into the reservoirs with rainwater.

Planktonic samples of Cyanobacteria and algae were collected in 2011-2013. A total of 36 samples were collected during spring, summer and autumn seasons. In order to determine the qualitative and quantitative phytoplankton composition of the Arturówek reservoirs, the collected samples were poured into sedimentation cylinders with a volume of 1 liter and fixed with Lugol's solution. After two weeks, samples were concentrated to a volume of 50 ml and subjected to microscopic analysis. The qualitative and quantitative analyses of diatoms were based on the methods described by Siemińska (1964), while for other groups of phytoplankton – the method by Starmach (1989) was used. Identification of diatom species was performed using iconographic identification keys by Bąk et al. (2012), Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b), Krammer (2000, 2002, 2003), Lange-Bartalot (2001), Lange-Bertalot, Metzeltin (1996), Lange-Bertalot, Genkal (1999), while for Cyanobacteria and other algae species – identification keys by Förster (1982), Hindák (1977, 1984, 1988, 1990), Komárek, Fott (1983) and Komárek, Jankovska (2001).

The cyanobacterial and algae biomass was estimated with the method proposed by Hutorowicz (2005). The method consists in multiplying the average volume of a cell (SOK_x) by taxa abundance (L_x) (Hutorowicz 2005).

$$OT_x\left(mm^3 \times l^{-1}\right) = \frac{SOK_x\left(\mu m^3\right) \times L_x\left(ind. \times ml\right)}{1000000}$$

where:

OT_x – volume of a taxa, which is a total volume of the counted individuals (e.g. cells, colonies) of selected taxa

SOK_x – average volume of a cell

L_x – taxa abundance

During sampling at each site, parameters such as temperature of water, conductivity, dissolved oxygen concentration and pH were measured. The physical parameters of water were measured using a portable device WTW Multi 340i. The content of total phosphorus was determined using a modified method with ascorbic acid according to the PN-88/C-04537.04 methodology. In order to determine the total nitrogen concentration, a spectrophotometric method was used with a reagents kit of the HACH company. For qualitative and quantitative analyses of ions contained in water, high-performance ion chromatography (HPIC) was used.

Samples for the determination of ionic forms were filtered through filters of the GF/C Whatman company before being poured into containers and frozen. Qualitative and quantitative analyses of microcystins were performed using a liquid chromatograph Agilent Technologies model 1100 (Hewlett Packard formerly). To separate microcystins, LiChroCartC™ (55 mm × 4 mm) columns with filling by Purospher™ STAR RP-18e (3 mm) were used, operating at 40°C.

Results

During the studies, a total of 36 phytoplankton samples were collected. After the identification of the phytoplankton species composition, the biomass of Cyanobacteria and algae was also calculated. On the basis of the calculations, the highest biomass of Cyanobacteria was noted in 2012 at the sampling site located at the upper Arturówek reservoir and it was 18990.77 mg l^{-1}. The highest biomass of algae was recorded at the lower Arturówek reservoir in 2011 and it amounted to 83401.16 mg l^{-1}. After the implementation of all hydrotechnical works, the significant decrease in the phytoplankton biomass was observed. The conducted works consisted in the construction of buffer vegetation zones to reduce the surface run-off (Fig. 2B – F), the construction of buoyant vegetation mats in the AL and AM reservoirs (Fig. 2A), while in the AU reservoir – the transformation of the upper part of the reservoir into the sequential sedimentation and biofiltration system. As a result of the conducted works, the

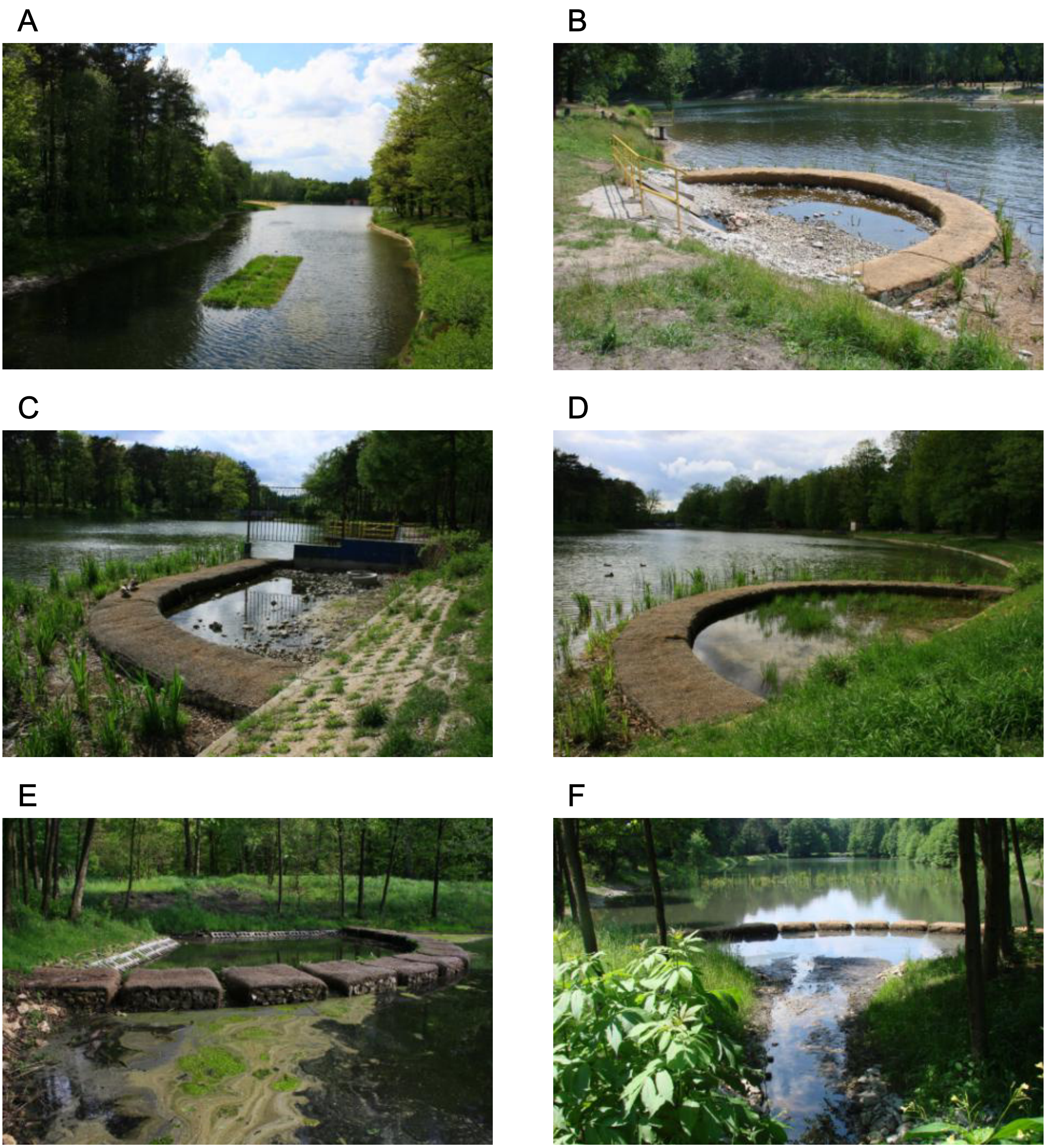

Figure 2

(A) Buoyant vegetation mat on the AL reservoir photo by B. Szulc, (B) Buffer vegetation zone on the AL reservoir photo by T. Jurczak, (C) Buffer vegetation zone on the AM reservoir photo by B. Szulc, (D) Buffer vegetation zone on the AM reservoir photo by B. Szulc, (E) Buffer vegetation zone on the AU reservoir photo by B. Szulc, (F) Buffer vegetation zone on the AU reservoir photo by T. Jurczak

highest biomass of Cyanobacteria was observed in 2013 in the upper Arturówek reservoir and it amounted to 909.99 mg l^{-1} and the lowest biomass was recorded at the middle Arturówek reservoir where

Cyanobacteria communities were not found. In the case of algae, the highest biomass was recorded in the lower Arturówek reservoir and it was only 1779.31 mg l^{-1}, while the lowest biomass was noted at the middle Arturówek sampling site where it amounted to 583.82 mg l^{-1} (Figs. 3, 4, 5). According to Nebaeus (1984), it is possible to identify the algae bloom in waters when the biomass value is higher than 3.0 mg l^{-1}. In the case of the Arturówek reservoirs, high values of both Cyanobacteria and algae biomass were clearly observed, which may indicate the hypertrophic status of these reservoirs. In 2013, a clear decline in the concentrations of nutrients has also been observed at all sampling sites (Table 1).

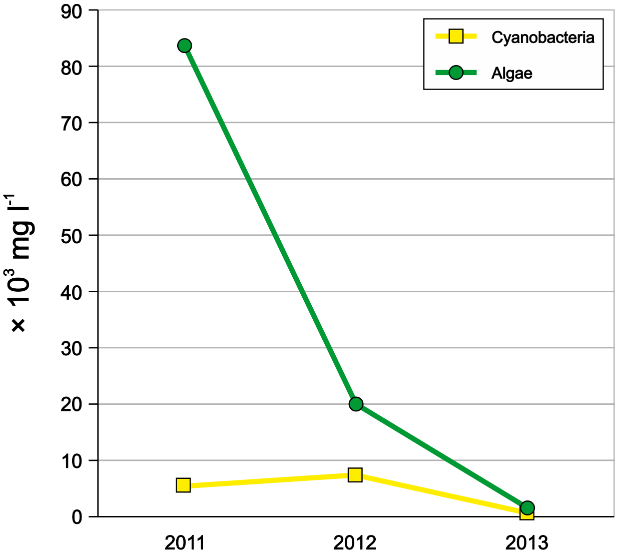

Figure 3

Biomass of Cyanobacteria and algae at the sampling site AL

During the studies, the concentration of microcystins in all reservoirs was also monitored. The highest concentration was recorded in 2012, while in 2013 there were no microcystins in any of the studied reservoirs (Table 1).

The main Cyanobacteria dominants were *Anabaena flos-aquae* Brébisson ex Bornet & Flauhault, *Aphanizomenon flos-aquae* Ralfs ex Bornet & Flahault, *Microcystis aeruginosa* (Kützing) Kützing, *Microcystis wesembergii* Komarek. The most numerous algae belong to the Chlorophyta division, and the main dominants were *Desmodesmus communis* (E. Hegewald) E. Hegewald, *Monoraphidium concortum* (Thuret)

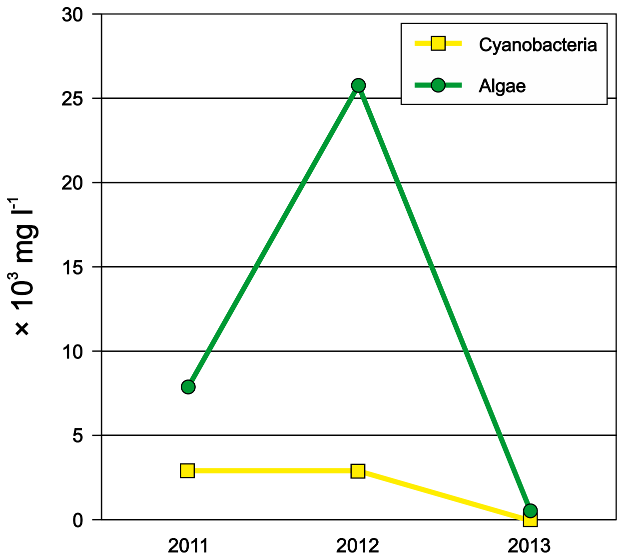

Figure 4

Biomass of Cyanobacteria and algae at the sampling site AM

Komárková-Legnerová, *Pediastrum boryanum* (Turpin) Meneghini, *P. duplex* Meyen, *P. simplex* Meyen, *Scenedesmus arcuatus* (Lemmermann) Lemmermann. Diatoms were also noted as frequent in the collected samples. The main dominants were species that are characteristic of eutrophic waters such as *Asterionella formosa* Hassall, *Aulacoseira granulata* (Ehrenberg) Simonsen, *Cocconeis*

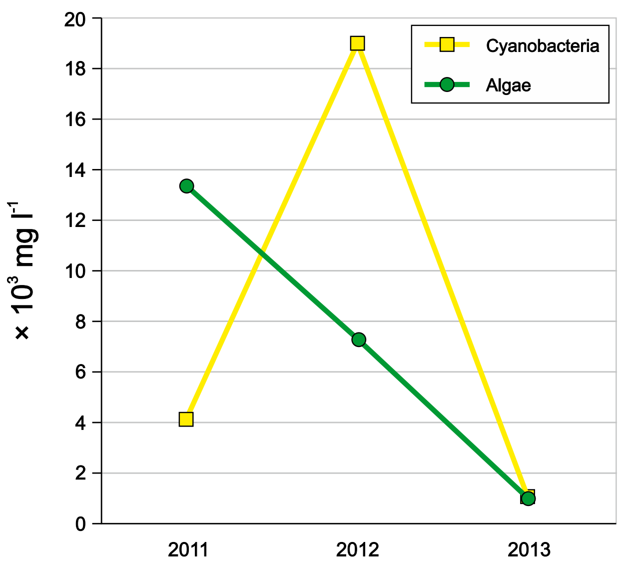

Figure 5

Biomass of Cyanobacteria and algae at the sampling site AU

Table 1

The average concentration of physical and chemical parameters of water in 2011-2013 – sampling sites for the lower (AL), middle (AM) and upper (AU) reservoirs in Arturówek (Łódź, Poland)

Parameters			Site								
			AL			AM			AU		
			Date								
			2011	2012	2013	2011	2012	2013	2011	2012	2013
physical	Temp. water	(°C)	15.16	18.37	18.47	14.83	17.04	17.93	14.72	17.27	18.63
	cond.	(μS cm^{-1})	334.94	315.17	366.67	359.88	347.00	311.00	359.56	360.83	325.33
	pH		8.40	8.45	7.87	8.18	8.49	8.38	7.99	8.92	8.24
	DO	(mg l^{-1})	12.32	11.89	11.56	11.62	11.84	13.28	8.81	12.62	11.02
chemical	TN	(mg l^{-1})	1.50	5.07	0.50	1.36	4.55	0.37	1.34	5.07	0.47
	TP		0.09	0.14	0.05	0.11	0.12	0.07	0.14	0.54	0.08
	NO_2		0.02	0.13	0.01	0.02	0.11	0.00	0.01	0.10	0.00
	NO_3		0.89	0.47	1.14	0.40	0.07	0.05	0.10	0.12	0.04
	PO_4		0.10	0.06	0.11	0.11	0.07	0.07	0.10	0.07	0.06
microcystin concentration	MC-RR	(μg l^{-1})	0.01	0.28	0.00	0.00	0.17	0.00	0.00	4.90	0.00
	MC-YR		0.22	0.41	0.00	0.00	0.09	0.00	0.01	4.49	0.00
	MC-LR		0.54	1.76	0.00	0.01	0.21	0.00	0.02	4.21	0.00

placentula var. *placentula* (Ehrenberg) Grunow, *Fragilaria crotonensis* Kitton, *Stephanodiscus hantzschii* Grunow.

Discussion and conclusions

Phytoplankton plays a very important role in the water ecosystems as it is a primary food source for higher trophic levels. In properly functioning ecosystems, a certain regularity in the seasonal succession can be observed, according to which the dominance of Cryptophyta and diatoms can be noted in early spring, then Cyanobacteria occur in summer and the dominance of diatoms returns in autumn (Reynolds 1999). Due to the rapid growth and reproduction, phytoplankton is exposed to dynamic changes under the influence of physicochemical factors (Szoszka et al. 2012).

The increase in the availability of nutrients significantly interferes with the functioning of aquatic ecosystems. High concentrations of nutrients (especially nitrogen and phosphorus) contribute to a trophic level increase, which consequently results in a massive growth of phytoplankton and simultaneously has a great impact on the species composition. This is particularly dangerous because it leads to the occurrence of summer Cyanobacterial blooms, which are responsible for the production of toxins that could pose a serious threat to the human life and health. The most common toxins are microcystins belonging to hepatotoxins, such as MC-LR, MC-RR and MC-YR, which are commonly found in the Polish reservoirs (Jurczak et al. 2004).

In order to assume that Cyanobacterial blooms will occur in a given reservoir, specific conditions have to occur, such as high concentrations of nutrients, high water temperature in the range of 20-25°C, windless weather and pH between 6 and 9 (Tarczyńska et al. 1997).

In the case of Arturówek reservoirs, factors determining the Cyanobacterial blooms were high temperature (20-25°C), insolation and the inflow of nutrients (temporarily very high phosphorus concentration >3 mg l^{-1}) (Schreurs 1992, Tarczyńska et al. 1997).

During the conducted studies, the main Cyanobacterial dominants were species that are characteristic of eutrophic waters such as *Microcystis aeruginosa* and *Aphanizomenon flos-aquae*. The similar species composition was described in other Polish reservoirs, e.g. Goczałkowicki (Krzyżanek et al. 1986, Spider 1986), Rożnowski (Buck 1987), Jeziorsko (Galicka, Lesiak 1998) and Sulejowski (Rakowska et al. 2005). Together with Cyanobacteria blooms, an increased growth of algae, mainly from the Chlorophyta division could also be observed, with the dominance of species: *Desmodesmus communis* (E.Hegewald) E.Hegewald, *Monoraphidium concortum* (Thuret) Komárková-Legnerová, *Pediastrum boryanum* (Turpin) Meneghini, *P. duplex* Meyen, *P. simplex* Meyen, *Scenedesmus arcuatus* (Lemmermann) Lemmermann. These species were also recorded in the reservoirs Jeziorsko (Galicka, Lesiak 1998) and Sulejowski (Rakowska et al. 2005). In addition to Cyanobacteria and green algae, diatoms could also be identified in the samples and the most numerous species were *Asterionella formosa* Hassall, *Aulacoseira granulata* (Ehrenberg) Simonsen, *Cocconeis placentula* var. *placentula* (Ehrenberg) Grunow, *Fragilaria crotonensis* Kitton, *Stephanodiscus hantzschii* Grunow, which are specific to eutrophic waters (Rakowska et al. 2005). In the studies conducted in 1970-1972 by Rakowska (1974), the occurrence of Cyanobacterial blooms composed of the same species as today was observed from June to September. Among numerous Chlorophyta species occurring in samples analyzed at that time, the presence of *Desmodesmus communis* (E. Hegewald) E. Hegewald, *Monoraphidium concortum* (Thuret) Komárková-Legnerová, *Pediastrum boryanum* (Turpin) Meneghini, *P. duplex* Meyen, *P. simplex* Meyen or *Scenedesmus arcuatus* (Lemmermann) Lemmermann could also be noted (Rakowska 1974).

The obtained results show that the species composition of both Cyanobacteria and algae did not change despite the passage of time. Comparing the results of the current analysis of physicochemical parameters with the analysis carried out in 1970-1972, it can be noted that pH values increased from 6.5 to 8.32. A slight increase in the concentration of nutrients, such as nitrites, nitrates and phosphates, was also observed in the samples (Rakowska 1974). This may indicate a progressive increase in the trophic conditions of water, and consequently more abundant blooms of Cyanobacteria and algae in the reservoirs. Such blooms negatively affect morphological conditions of the reservoir and the hydrological regime (Reynolds 1994), so a number of measures have been implemented to reduce the inflow of nutrients into the Arturówek reservoirs, and thus to eliminate the Cyanobacteria and algae blooms. The conducted works consisted in the construction of buffer vegetation zones and buoyant vegetation mats in the reservoirs. The literature data indicate that depending on the materials used for the construction of zones and mats, the effectiveness of this method varies, and so in the case of nitrogen compounds it is effective in 39.6% to 96%, and in the case of phosphorus compounds in 47.1% to nearly 92% (Haberl et al. 1995, Bratieres et al. 2008, Blecken et al. 2010). Usually buffer zones are constructed using gravel, wood chips, sand, mud, plants and sedges, mainly *Melaleuca ericifolia, Microleana stipoides, Dianella rezoluta* and *Leucophyta brownii*. In the case of Arturówek reservoirs, it can be assumed that the buffer zones will reduce the inflow of nutrients into the reservoirs in the amount of about 2.5 kg per year. The effectiveness of the buffer zones is being currently evaluated. The ecohydrological adaptation of the upper reservoir in Arturówek was implemented to intensify the water self-purification process. It is estimated that the efficiency of such construction in the process of phosphorus accumulation can be up to 55% (Scharf 1998). However, the efficiency of this type of construction is dependent on the duration of retention. When it takes between 2 and 12 days, the effectiveness of phosphorus accumulation varies from 22% to 46% (Putz Jürgen 1998). Additionally the bottom sediments were removed from the lower Arturówek reservoir and the removed layer was in the range of 0.4-0.6 m. According to Munsiri et al. (1995), the highest concentrations of nutrients are in the layer from 0.1 to 0.2 m. The removal of this layer reduces the availability of total phosphorus by 60%, and in the case of total nitrogen – by 40% (Yuvanatemiya, Boyd 2006).

Hydrotechnical works carried out on Arturówek reservoirs during the LIFE+ project (EH-REK) have had a great impact on the water quality in the cascade of these ecosystems. Based on the conducted research, a significant improvement of water quality was observed consisting in the reduction of concentrations of biogenic substances, which have had a direct influence on the qualitative and quantitative phytoplankton composition. As a result of the conducted works, the Cyanobacterial blooms were almost completely eliminated and the phytoplankton biomass was considerably reduced. In 2013, no microcystins occurred, and they are particularly hazardous to human health and life.

Acknowledgments

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