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ATTEMPTS TO ELIMINATE CYANOBACTERIAL BLOOMS IN LAKE ŁASIŃSKIE

In the years 1998–2001, investigations of Łasińskie Małe and Zamkowe Lakes were conducted. The two lakes are shallow and very susceptible to degradation. Very high trophic level, high pollution level and recurring annual cyanobacterial blooms have caused that lakes have not been recreationally used since 1994. The aim of investigations was to work out the programme of reservoirs restoration.

In order to test the methods, in June 1998 trials of cyanobacterial bloom inhibition in natural, isolated bath area were undertaken. Main measures were exposure of barley straw bales and addition of $FeCl_3$.

After one month considerable changes in the composition of phytoplankton were recorded. The drastic slump in the biomass of *Aphanizomenon flos-aquae* and domination of eucariotic algae were observed. Water transparency substantially increased. The measures were repeated and the method was modified and developed in the successive years.

The main causes of temporarily worse effects were damage of isolating barriers in the bathing area and seasonal increase in BOD_5 caused by influx of fine-grained organic suspension from unidentified source.

1. INTRODUCTION

Lake Małe and Lake Łasińskie (Zamkowe) are located in the Iława Lakeland. The area of Lake Małe amounts to 18.4 ha, whereas that of Lake Łasińskie (Zamkowe) – up to 155.2 ha. The detailed description of both morphometry and physicochemical features of those two lakes is presented in Wiśniewski's paper [4]. Below there are described their most important features. In the morphometry of Lake Łasińskie, two separate basins can be distinguished. They are connected with a channel. The direct watersheds of the lakes cover the area of 2.6 km^2 for Lake Małe and above 8 km^2 for Lake Łasińskie. The predominant part of the drainage

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area is utilised agriculturally. Urban development is also of a substantial proportion there. Both lakes are shallow and very susceptible to degradation. Untreated municipal sewage has been discharged into the lakes for years, which has resulted in their extreme hypereutrophication. The concentration of total phosphorus exceeds 1.8 mg $\cdot$ dm $^{-3}$ in Lake Małe and reaches 1.3 mg $\cdot$ dm $^{-3}$ in Lake Łasińskie. Mean concentrations of total nitrogen are also high – approximately 22 mg $\cdot$ dm^{-3} in Lake Małe, and 6.5 mg $\cdot$ dm^{-3} in Lake Łasińskie. Very high trophic level, high pollution level and recurring annual cyanobacterial blooms have caused that the municipal bathing area situated in the well equipped Centre of Sport and Recreation at Lake Łasińskie has not been used since 1994. The Sanitary and Epidemiological Service (SANEPID) decided to close the bathing area down because the allowable concentration standards of chlorophyll, phosphates and BOD_5 had been exceeded.

Intensive hydro-chemical and hydro-biological investigations of both the lakes have been carried out in different years by MIENTKI [21], a Danish company Poul Hauberg-Jensen (MAEHL and PENDIX [18]), the Voivodeship Inspectorate of Environment Protection (WIOŚ) in Toruń [31], and WIŚNIEWSKI [32]–[36]. The attempts to improve the biological condition of the lakes have also been undertaken. These included both the implementation of the MINIFLOX aerator in the deepest part of a small basin, which could aerate the lake water, and sediment dredging confined to the littoral zone. In the subsequent years 1998–2000, there were attempts to eliminate cyanobacterial blooms from the bathing area.

The mechanisms responsible for the development of cyanobacterial blooms have been examined for a very long time. There are, therefore, several hypotheses attempting to explain the fundamental dependencies which lead to cyanobacteria dominance (for instance MUR [23], DOKULIL and TEUBNER [11]). Consequently, the development of cyanobacterial blooms results not only in the disqualification of the water body as a recreational area, but also in serious oxygen deficit (organic matter mineralisation), or massive fish deaths. During cyanobacterial blooms considerable amounts of toxic substances (hepato- and neurotoxins) are released into water. Through a food chain they might be accumulated in the tissues of the fish which are caught in the lake (e.g. CARMICHAEL [6]). Those toxins may cause the death of hydrobionts and land animals. In the contact with the water containing cyanobacterial blooms, humans are found to reveal allergic reactions and epithelium inflammation. If this water is drunk it may cause diarrhoea, vomiting and muscular pains. Accidental usage of cyanobacterial toxin-bearing water in dialyses may result in the death of the dialysed patients (PIZZOLON et al. [27]). Table 1 presents the examples of the harmful effects of toxins on animals and people which have been discussed in literature.

Table 1

Effect of neuro- and hepatotoxins produced by cyanobacteria in water upon animals and humans

Year, country	Reservoir	Case	Source
		Cases of animal death	
1955, Argentine	Pond, *Anabaena*	Fish population	RINGUELET et al. [29]
1973, Argentine	Pond, *Microcystis*	Fish population	GARCIA de EMILIANI [15]
1995, Japan	Pond, *Microcystis*	Waterfowl (20 ducks)	MATSUNAGA et al. [19]
1993, USA	Pond, *Microcystis aeruginosa*	Dog	DeVRIES et al. [10]
1995, South Africa	Hypertrophic lake, *Nodularia, Microcystis*	Dog	HARDING et al. [16]
2000, The Netherlands	Pond, *Microcystis*	Dogs	Personal information
1989, USA	Pond, *Anabaena spiroides*	Pigs (7)	CHENGAPPA et al. [8]
1988, Australia	Pond, *Anabaena circinalis*	Sheep	RUNNEGAR et al. [30]
1995, Australia	Fram reservoir, *Anabaena circinalis*	Sheep (14)	NEGRI et al. [24]
1968, Sweden	Lake, *Microcystis*	Herd of calves	CRONBERG et al. [9]
1997, Switzerland	Oligotrophic lake, *Microcystis*	Herd of calves (~ 100)	MEZ et al. [20]
1998, USA	Pond, *Microcystis*	Herd of calves (24)	PUSCHNER et al. [28]
1987, USA	Pond, *Microcystis aeruginosa*	Cows (9)	GALEY et al. [14]
1984, Argentine	Pond, *Microcystis*	Cows (72)	ODRIOZOLA et al. [25]
		Cases of influence on humans	
1974, Argentine	Natural swimming pool, *Microcystis*	Skin irritations, diarrhoea	APESTEGUIA et al. [2]
> 1980, Sweden	Eutrophic Lake Finjasjon, different species	Skin and intestine epithelim irritations	ANNADOTTER et al. [1]
1996, Brazil	Reservoir, microcystine presence in water used for dialysis	In 130 dialysed patients toxic effects. Death of 56 persons	CARMICHAEL [7] PIZZOLON et al. [27]
Poland, recently	Sulejowski reservoir, drinking water source for the city of Łódź	Microcystin L.R, > 900 μg/g of d.m. of phytoplankton	ZALEWSKI [37]
Poland, recently	Sulejowski reservoir	Microcystin L.R., < 900 μg/g of d.m, chromosomal disfunctions and aberrations	KONTEK et al. [17]

2. MATERIALS AND METHODS

The main objective of the investigations conducted in 1998 was to give a report on the possibilities of Lake Łasińskie restoration and to justify the choice of the methods proposed. The entire programme of the investigations comprised two major problems:

- developing a programme of reducing bioavailable PO_4 concentration (conditioning permanent and intensive cyanobacterial blooms) for a smaller 40-hectare part of Lake Zamkowe, with a possibility of continuing the programme in the remaining part of the lake (WIŚNIEWSKI [33], [34]);
- attempting to inhibit or curb intensive cyanobacterial blooms in the bathing area – so as to make the bathing area exploitable.

Information derived from professional literature was applied to design the method of inhibiting the development of cyanobacteria in the vicinity of the sports and recreational centre bathing area. A considerably large number of papers describe the use of barley straw in order to control cyanobacterial blooms (e.g. the papers by BARRETT et al. [3], CAFFREY and MONAHAN [5]). Several authors claimed that aerobic mineralisation of barley straw in water (with portion of protozoans, aerobic bacteria and fungi) resulted in releasing the substances, which contained phenolic groups decomposing into quinones and acting as algistat, into water.

Making use of the inhibitory action of potassium ions (K^+) may be another method of supporting the bloom development control. According to the reports on several attempts (PARKER et al. [26]), a relatively small concentration of 1–3 mM dm^{-3} KCl inhibited the *Microcystis* cyanobacterium growth. This method is cheap and relatively easy in application. Right concentration of KCl ensures that the method affects only some selected groups of hydrobionts.

Practical realisation of the programme of inhibiting cyanobacterial blooms involved:

- Spreading a foil curtain along water piers (outside the bales) reaching 10 cm above the water surface. It was to protect an approximately two-metre surface layer inside the bathing area against the surge of cyanobacteria scum from the remaining part of the lake, providing free exchange of deeper water layers at the same time.
- Installing 30 straw bales near the bathing area in 1998, 50 bales in 1999, and other 30 in 2000.
- Fitting several (7–10 in different years) 1.5-metre semi-permeable Cuprophane sleeves filled with KCl onto the pier pillars.
- Performing a trial inactivation of PO_4 in the sediments inside the bathing area by means of a simple technical system which could simulate the work of a device specifically designed to inactivate PO_4 over the large parts of the lakebed.

3. RESULTS

Very interesting results were obtained as early as in the first year. The procedures to inhibit cyanobacterial blooms were conducted on 11 June, 1998. Before the works commenced, cyanobacteria had been dominant in the samples of phytoplankton taken from the bathing area (approximately 200 000 trichomes of *Aphanizomenon flos-*

aquae in a litre of water). At other stations of the basin examined, the concentration of this cyanobacterium reached twice as high a value. The composition of phytoplankton in the samples taken on 10 July differed considerably from that in the samples taken on 11 June. There was a drastic slump in the biomass of *Aphanizomenon flos-aquae* – only individual trichomes of this cyanobacterium were found. There was an increase in eucariotic algae.

Table 2

Effects of barley straw exposure (30 bales) and chemical treatment (phosphate inactivation with $FeCl_3$) inside 500 m^2 enclosure in spring 2000

Feature		Sampling date			
		26 May, 14 days after implementation of barley straw bales and chemical treatment	30 May	10 June	6 July, damage of enclosure screens
Sechi disk, cm	Outside	40	40	45	30
	Inside	60	60	70	35
pH		8.2	7.9	7.4	8.1
Conductivity,	$\mu S \cdot cm^{-1}$	580	560	490	650
PO_4, $mg \cdot dm^{-3}$	Outside	0.645	0.840	0.915	0.820
	Inside	0.240	0.245	0.350	0.455
Cyanobacteria	Outside	Dominance of *Aphanizomenon flos-aquae* 260 000 dm^{-3}			
	Inside	Dominance of eucariotic algae	Eucariotic algae	Eucariotic algae	Mass scums of cyanobacteria
Chlorophyll,	$\mu g \cdot dm^{-3}$	69	65	40	139
Oxygen,	$mg \cdot dm^{-3}$	9.4	10.7	12.3	9.2
BOD_5,	$mg \cdot dm^{-3}$	8.6	8.9	8.2	12.0

The works were repeated and the method was modified and developed in the successive years. The investigation results are presented in table 2. They proved that even a simplified procedure (in comparison to the designed) for immobilising phosphates in the bathing area resulted in 2–3 times smaller concentration of phosphates in the bathing area than in the water beyond it. It could be noticed that despite restructuring taxonomic composition of phytoplankton, the overall concentration of phytoplankton (the level of chlorophyll) still remained high, even twice as high as the standard for the second class of water quality, which could guarantee opening of the bathing area. BOD_5 also remained at a high level.

In the year 2000, a change in the domination system in phytoplankton occurred as early as two weeks after the treatment had started (table 2). For several weeks the concentration of both chlorophyll and BOD_5 remained on the level permitting the recreational utilisation of the bathing area water. Damaging the isolating curtains, destroying several plates of the insulating barrier all resulted in a violent deterioration of the water parameters at the beginning of July.

Another procedure was undertaken in 1999 in order to decrease the concentration of chlorophyll and to restore the recreational values of the bathing area. The artificial substrata with zebra mussel bivalve (*Dreissena polymorpha*) were introduced into the bathing areas. Numerous publications (among others: WIŚNIEWSKI [32], BASTVIKEN et al. [4]) confirm a very great filtration efficiency of this bivalve. One individual of *Dreissena* is able to filter 24–63 cm^3 of water in an hour. What is more important, cyanobacteria are filtered as efficiently as eucariotic phytoplankton. With the appropriate population in the lakes (on average 2000 specimens per m^2 in natural conditions), this mussel is able to filter the whole volume of water several times a year. Due to its own ecophysiological features it can be easily transplanted.

In the works related to the restoration of Lake Łasińskie, another method was chosen to collect and store bivalves in the constructions which would implement the appropriate population of the bivalves in any reservoir. A modular breeding construction (comprising a relatively big area in a small volume) facilitates technical operations related to transport and implementation. Should there be any critical situation in the reservoir which would endanger the breeding and pose some danger of leaving a very big amount of decomposing bivalve tissues in the reservoir (as it was in the case of Dutch experiments – De Vaate, unpublished information), there is some possibility of removing the modules from the water and keeping them on the side for a period of three days – solely protecting the breeding against drying out.

On the grounds of the previous experience and studies (WIŚNIEWSKI [32]), the indispensable quantity of the bivalves introduced was determined to provide some control over the excessive development of phytoplankton. The modules of a total area of approx. 10 m^2 were sunk. The measurements of those few bivalves recovered in 2000 and 2001 proved that bivalves could grow and breed in Lake Łasińskie.

4. DISCUSSION

Recent investigations, particularly those conducted in 2000 (table 2), show that the attempts to control cyanobacterial bloom encourage further research. The implementation of the barley straw bales and the supportive KCl activity lead to the inhibition of cyanobacterial tissue development and such a change in taxonomic structure of phytoplankton that promotes the dominance of eucariotic algae.

Introducing zebra mussel as a natural and effective biofiltrator of excessively growing algae appears purposeful. *Dreissena polymorpha* is a species of unique biological features – the stage of planctonic larva in the development cycle, the ability to stick to the substratum by means of byssus threads, a high tolerance for pollution, and a big filtration efficiency of seston. All these features cause that the attempts are being undertaken to use it as a very good object in biomanipulation procedures. A strong resistance to air exposure allows a considerably easy transport and exposition in the water reservoirs where this bivalve does not exist due to the lack of a favourable substratum, and where there is too high concentration of seston.

Dreissena polymorpha may be used as an element supporting other restoration procedures. A very big efficiency of this biological filtering system (also eliminating mineral particles removed as pseudofaeces from the depths) allows its implementation in the waters rich in seston.

Table 3

a) Factors determining zooplankton growth, *Daphnia* sp. Role of polyunsaturated fatty acids. Regression parameters ($y = ax + b$) (MULLER-NAVARRA et al. [22])

Independent variable	Slope a	Cross-section of the y-axis b	P	r^2
C, mg · dm^{-3}	−0.05	0.52	0.002	0.55
P/C, mol/mol	27.11	−0.005	0.0087	0.45
N/P, mol/mol	−0.013	0.48	0.0031	0.53
N/C, mol/mol	−4.39	1.04	<0.0001	0.85
Chl-a/C, μg/mg	−0.01	0.37	0.445	0.05
		Polyunsaturated fatty acids		
18:3ω3/C μg/mg linolenoic acid	−0.02	0.42	0.063	0.26
18:4ω3/C μg/mg octadecatetraenoic acid	0.14	0.04	<0.0001	0.80
20:5ω3/C μg/mg eicosapentaenoic acid EPA	0.11	0.04	<0.0001	0.95

b) Growth and breeding in *Daphnia magna* (hypertropic pond)

Group	Parameter	Summer	Spring
Phytoplankton	C amount	*Oscillatoria, Anabaena* 3.9–9.4 mg C · dm^{-3}	*Bacillariophyceae* 1.7–3.8 mg C · dm^{-3}
Zooplankton, *Daphnia magna*	Growth, egg production	Minimal 0–0.5 individual $^{-1}$	Maximal 9.1–17 individual $^{-1}$
Phytoplankton, zooplankton	C transfer efficiency, producers–consumers	5–26%	50–60%

The analysis of the results of implementing zebra mussels on artificial substrata in Lake Łasińskie leads to a conclusion that providing an appropriate tough substratum is not enough, as it has been widely believed. In many cases of bio-manipulation, where the definite reduction of planktivorous fish pressure did not restore crustacean zooplankton, the lack of noticeable effects – a small pace of growth and reproduction decline – may have been linked with the biochemical composition of bioseston and its dietetic value (MULLER-NAVARRO et al. [22]). Table 3 indicates that eucariotic algae (*Cryptophyceae, Dinoflagellata, Bacillariophyceae*) are the primary producers of polyunsaturated fatty acids (HUFA), particularly eicosapentaenoic acid (EPA). Cyanobacteria do not contain the HUFA forms indispensable to plankton development. Their periodic dominance may have a negative influence upon the biochemical composition of the restoring eucariotic phytoplankton, while decreasing its nutritional quality. The studies on the growth of zebra mussels, particularly on the development of *veliger* larvae through a shell formation process, indicated that the appropriate quantity of the HUFA in the feed was decisive also in that case (WRIGHT et al. [36]).

Numerous contemporary researches deal with the complexity of the mechanisms which lead to the elimination of cyanobacteria and bloom growth as well as the limited possibilities of predicting, modelling and, therefore, controlling these phenomena (for instance, DOKULIL and TEUBNER [11]). According to ELSER [12] cyanobacterial blooms are driven by simple interdependencies, such as N:P ratio, the ability of bacteria to assimilate nitrogen, minor light requirements, buoyancy regulation, etc. They result from a series of the key-mechanisms, many synergistic factors related to nutrient load, hydrodynamics, and above all, to the microscale dependencies and interactions in the food-web of the reservoirs.

In the case of the investigations conducted in the bathing area, anthropogenic factor turned out to be the most essential, yet the least expected, element causing negative effects. The undirected curiosity of the users resulted in the recurring damage of isolating barriers of the bathing area. Even a one-day lack of isolation thwarted the results, which had been accomplished after weeks of exposure. The notorious destruction of the plates caused some kind of evolution of insulating barrier – from the aesthetic light structure made of colourful plates, which could facilitate the regulation of suspension height depending upon the changes in the water level, to a solid welded shield made of stainless steel. Another cause of the water quality deterioration lay in a big inflow of fine colloid-like suspension from the unknown sources.

When evaluating this three-year investigations, it must be stressed that most premises set in 1998 have proved to be accurate. It is necessary to carry out some additional studies into the problems which have arisen, i.e. seasonal increase in BOD_5 caused by the influx of fine-grained organic suspension, a high concentration of chlorophyll, and most of all, the influence of cyanobacteria upon the nutritive value of eucariotic algae.

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PRÓBY ELIMINACJI ZAKWITÓW SINICOWYCH W JEZIORZE ŁASIŃSKIM

W latach 1998–2001 prowadzono badania na Jeziorze Łasińskim Małym i Jeziorze Zamkowym. Obydwa jeziora są płytkie i bardzo podatne na degradację. Powtarzające się corocznie intensywne zakwity sinicowe stanowią główną przyczynę ograniczonego wykorzystywania rekreacyjnego obydwu zbiorników. Celem badań było opracowanie programu rekultywacji zbiorników.

Aby przetestować zaproponowane metody, w czerwcu 1998 r. podjęto zabiegi zmierzające do ograniczenia zakwitu sinic w rejonie odizolowanego, naturalnego kąpieliska miejskiego. Sprowadzały się one głównie do zastosowania zarówno balotów słomy jęczmiennej, jak i chlorku żelaza.

Po miesiącu odnotowano znaczne zmiany w składzie fitoplanktonu. Stwierdzono drastyczny spadek biomasy *Aphanizomenon flos-aquae* i dominujący udział glonów eukariotycznych. Istotnie wzrosła przezroczystość wody. Prace w rejonie kąpieliska powtarzano w następnych latach, modyfikując i wzbogacając metodę.

Powodem gorszych okresowo efektów, zwłaszcza w 2001 r., było rozszczelnienie osłony izolującej kąpielisko i wzrost BZT$_5$ spowodowany dopływami drobnej zawiesiny organicznej z niezidentyfikowanego źródła.

Reviewed by Jerzy Chmielowski