Cyanobacterial blooms in shallow lakes of the Iławskie Lake District

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Abstract: The dominance of blue-green algae observed in many lakes is related to a high trophic level. Shallow eutrophic lakes are particularly often abundant in blue-green algae. The research on phytoplankton, the results of which are presented in this paper, was carried out between 2002 and 2005 in six lakes. These lakes differed considerably in their size and management methods applied in the catchment (drainage) area. A few types of water blooms were distinguished, which is related to the catchment area management, the intensity of mixing and the trophic level. Algal blooms of the *Planktothrix* type appeared in lakes situated in an open area of agricultural catchment basins. Algal blooms of the *Limnotherix* type were characteristic of lakes with a forest-agricultural catchment area but surrounded by high shores, which reduced the wind influence on the mixing. Sporadic mixed algal blooms were typical of lakes situated in forest catchment areas.

Key words: Blue-green algae, cyanobacteria, water bloom, phytoplankton, shallow lakes, turbulent species

Introduction

Algal blooms in inland waters are a frequently observed phenomenon occurring constantly in lakes with extremely high trophy (poly- and hypertrophy), or periodically in less fertile lakes. Special attention is given to water blooms of Cyanobacteria. The success of blue-green algae in many aquatic ecosystems is possible due to the high flexibility of this group in relation to changes in environmental parameters, such as temperature, pH or salinity (Reynolds et al. 1987). This group of organisms is particularly distinctive due to the cosmopolitan distribution and potential toxicity of some species, which create problems for human health and the environment (Berg et al. 1987; Carmichael 1994, 1996; Codd 2000).

Phytoplankton blooms are a typical phenomenon of shallow and over-eutrophicated water bodies. According to the concept of “alternative stable states” by Scheffer & Jeppesen (1998), such lakes are

characterised by little water transparency. Plankton algae are the main primary producer, and their usual mass development results in high water turbidity, which consequently leads to a self-shading effect. In a turbid environment, the development of submerged vegetation is limited by poor light availability. Wind mixing disturbs short-term stagnation. Sediments are more frequently resuspended here, mainly as a result of wave motion, which brings about a further increase in turbidity. Resuspension of bottom sediments can lead to sudden, but short-term (pulsatory) enrichment of the pelagic zone with nutrients. Due to the lack of rooted vegetation, zooplankton is exposed to strong pressure from fish, and this in turn affects the further development of phytoplankton. According to Wallace et al. (2000), Mischke (2003), as well as Mischke & Nixdorf (2003), phytoplankton communities of very shallow ($z_{max} < 5\text{m}$) eutrophic lakes are often dominated by blue-green algae. Cyanobacteria have several, potentially important adaptations, which fa-

cilitate their functioning in the changing environmental conditions that prevail in shallow eutrophic lakes (Wallace et al. 2000).

The present paper aims at evaluating the species composition and the biomass of blue-green algae forming water blooms in several shallow lakes of the Iławskie Lake District, which are located in different types of drainage basin. Based on the analyses of the cyanobacterial community, an attempt was undertaken to evaluate the relationship between the species composition and the abundance of this group, and the trophic status and the management methods applied in the drainage basin.

Material and methods

The research covered six lakes from the territory of the Iławskie Lake District: Gardzień, Iławskie, Kolmowo, Silm, Stęgwica and Tynwałdzkie. Two lakes – Iławskie and Tynwałdzkie – belong to the drainage basins of the River Iława, the others: Gardzień, Kolmowo, Silm and Stęgwica – to the drainage basin of the upper River Osa. The studied lakes are located within a short (max. several kilometres) distance from the town of Iława. A small depth is typical of these water bodies (the maximum less than 6 m, and the average from 1.1 to 3.1 m). Morphometric (Jańczak 1997) and physicochemical data of the lakes are presented in Tables 1 and 2.

Table 1. Morphometric data on the lakes in the Iławskie Lake District (after Jańczak 1997)

Morphometric data	Lake					
	Gardzień	Iławskie	Kolmowo	Silm	Stęgwica	Tynwałdzkie
Latitude	53°40'4" N	53°35'5"N	53°40'0"N	53°36'2"N	53°38'4"N	53°39'4"N
Longitude	19°33'4"E	19°36'7"E	19°28'2"E	19°31'1"E	19°32'2"E	19°38'1"E
Area [km ²]	0.86	1.55	0.43	0.59	0.40	0.30
Volume [hm ³]	1.02	1.77	1.34	1.20	0.48	0.54
Maximum length [m]	4175	3700	1050	1625	1880	1090
Maximum width [m]	350	750	550	800	290	615
z_{max} [m]	2.1	2.8	5.7	3.7	1.7	2.6
z [m]	1.2	1.1	3.1	2.0	1.2	1.8

Table 2. Physicochemical properties of the lakes' water

Parameter	Lake					
	Gardzień	Iławskie	Kolmowo	Silm	Stęgwica	Tynwałdzkie
SD visibility [m]	0.6 (0.3-1.4)	0.8 (0.5-1.3)	0.7 (0.3-1.0)	1.4 (0.8-2.1)	0.9 (0.5-1.4)	0.5 (0.3-1.0)
pH ^a	9.0	8.4-8.9	7.6-9.1	n.d.	7.2-8.6	8.0-9.5
EC [μS cm ⁻¹]	172 (158-188)	349 (322-444)	383 (360-412)	369-435	197 (166-213)	284 (242-335)
Chl <i>a</i> [μg l ⁻³]	40 (21.9-73.2)	23.7 (12.1-35.3)	47 (19.2-105.3)	8.8 (6.2-11.2)	11.6 (6.5-14.7)	60 (41.6-111.4)
TN [μg l ⁻³] ^a	2950	2120	2040	1890	3200	2380
TP [μg l ⁻³] ^a	28	128	112	68	36	80
N:P	105	17	18	28	89	30
TSI SD	67	63	65	55	62	70
TSI chl <i>a</i>	67	62	68	52	55	71
TSI TP	52	74	72	65	56	67
TSI TN	70	65	65	64	71	67
TSI average	64	66	68	59	61	69

^a – measurements taken only once in the summer

n.d. – no data available

The research was carried out in 2002-2005 in each lake for two consecutive seasons, except for Lake Iławskie where the research was conducted for only one year. The material for the studies was collected from one site situated in the central part of each lake. Samples were usually collected every month during the growing season and only once during winter. Several physicochemical parameters were determined in the lake water: Secchi disk visibility, temperature, pH and electrolytic conductivity. Water was collected for the analyses of the chlorophyll *a* content. One time during the summer, the water was collected for the analyses of the nitrogen and phosphorus content.

For qualitative studies, the material was collected with a plankton net with a mesh diameter of ca. 55 μm from the whole water column. Samples were preserved with formaldehyde. For quantitative analyses, the material was collected at a depth of ca. 0.5 m. This material was not thickened. Quantitative samples were preserved with Lugol's solution (J in KJ). The count of algae was determined with Utermöhl's method (1958), the biomass by the volumetric method. The content of chlorophyll *a* was analysed with Nusch's method (1980). Standard methods of analyses were applied for the determination of the concentration of biogenic substances (Hermanowicz et al. 1999).

Based on the Secchi disc visibility, the concentration of chlorophyll *a* and the concentration of total phosphorus, the trophic state index was calculated: TSI SD, TSI chl *a*, TSI TP (Carlson 1977; Carlson & Simpson 1996), and based on the concentration of total nitrogen, the trophic state index TSI TN of Kratzer & Brezonik (1981).

Results and discussion

During the summer months, the SD visibility in Lakes Kolmowo, Gardzień and Tynwałdzkie was only 0.3 m. Lake Tynwałdzkie was already investigated more than 30 years ago by Bogaczewicz-Adamczak (1978) and Rejewski (1979), and later by Luścińska & Dogadalska (1993). Water-transparency values recorded previously in this lake in the spring-summer season were similar to the present-day results and ranged from 0.3-0.5 m. The minimum value of water transparency in Lakes Stęgwica and Iławskie was 0.5 m, whereas in Lake Silm, 0.8 m.

All the investigated lakes were characterised by alkaline pH. The lowest pH – 7.2 – was recorded in Lake Stęgwica, the highest pH – 9.5 – in Lake

Tynwałdzkie. Electrolytic conductivity was also heterogeneous – from 160 μScm^{-1} in Lake Gardzień to almost 450 μScm^{-1} in Lake Iławskie. The conductivity recorded in Lake Gardzień is characteristic of lakes with a moderate trophic state. All measured physicochemical parameters are presented in Table 2.

In the studied lakes, the presence of 54 taxa of blue-green algae was recorded (Table 3). The largest number of species – 38 – occurred in Lake Gardzień, the least – 17 species – in Lake Iławskie. The presence of the following eight species was recorded in all the lakes: *Aphanizomenon flos-aquae*, *Aphanocapsa incerta*, *Microcystis aeruginosa*, *Microcystis viridis*, *Microcystis wesenbergii*, *Planktolyngbya limnetica*, *Pseudanabaena limnetica*, *Woronichinia naegeliana*. Most of the recorded species of blue-green algae are planktonic forms (31 taxa), 19 species are sedentary (benthic, periphytonic) or metaphytonic forms. Also one endoglyc and one aerophytic species was recorded.

The occurrence of water blooms results from excessive eutrophication, which may even assume the form of pollution. Algal blooms lead to excessive production of organic matter posing a threat to the remaining part of the biocenosis of the water body (Bucka & Wilk-Woźniak 2005). Bucka (1987) quotes, after different authors, the criteria determining the water bloom, i.e. the number of algae amounting to 10^4 - 10^6 specimens per ml^{-1} , biomass 1- $5 \cdot 10^2$ mg l^{-1} , or even only 10 mg l^{-1} , and the average biomass within the range of 10-30 mg l^{-1} . During algal blooms, water transparency decreases below 1m (the value measured as Secchi disk visibility). The concentration of chlorophyll *a* in the water during algal blooms exceeds 50 $\mu\text{g l}^{-1}$.

Bucka (1987) also lists species capable of creating water blooms. The following species of blue-green algae can do so: *Microcystis aeruginosa*, *M. wesenbergii*, *M. viridis*, *Limnothrix planctonica*, *Planktolyngbya limnetica*, *Planktothrix agradhii*, *Aphanizomenon gracile*, and *Anabaena oscillarioides*. Reynolds (2006) reports that plankton algae from group S1 (potentially dominant in temperate-lake species: *Planktothrix agradhii*, *Limnothrix redekei*, *Pseudanabaena*) can occur in quantities excluding other groups of phytoplankters, particularly in shallow, intensively mixed water bodies with usual light deficits. In shallow lakes, the success of blue-green algae from Oscillatoriales can result from the survival ability in deeper zones and the ability to grow in large numbers, as well as to replace green algae (Van den Hoeck et al. 1995). Reynolds

Table 3. Species composition of blue-green algae in lakes of the Iławskie Lake District: Ga – Gardzień, Ił – Iławskie, Ko – Kolmowo, Si – Silm, St – Stęgowica, Ty – Tynwałdzkie

No	Species	Ga	Ił	Ko	Si	St	Ty	Ecological characteristic
1	<i>Aphanizomenon flos-aquae</i> (L.) Ralfs ex Born. et Flah.	+	+	+	+	+	+	planktic
2	<i>Aphanocapsa grevillei</i> (Berkeley) Rabenh.	+					+	benthic
3	<i>Aphanocapsa incerta</i> (Lemm.) Cronb. et Kom.	+	+	+	+	+	+	planktic
4	<i>Aphanothece clathrata</i> W. et G.S. West	+						planktic
5	<i>Aphanothece stagnina</i> (Sprengel) A. Braun in Rabenh.	+			+			periphytic
6	<i>Chroococcus minimus</i> (Kissl.) Lemm.					+		planktic
7	<i>Chroococcus minutus</i> (Kütz.) Näg.	+			+	+		planktic/ periphytic
8	<i>Chroococcus limneticus</i> Lemm.	+	+		+	+		planktic
9	<i>Chroococcus minor</i> (Kütz.) Näg.						+	periphytic
10	<i>Chroococcus turgidus</i> (Kütz.) Näg.	+		+	+		+	periphytic
11	<i>Cyanothece aeruginosa</i> (Näg.) Kom.		+					benthic
12	<i>Dolichospermum flos-aquae</i> ([Lyngbye] Brébisson ex Bornet et Flahault) comb. n.	+		+				planktic
13	<i>Dolichospermum planctonicum</i> (Brunnthal) comb. n.	+		+				planktic
14	<i>Dolichospermum solitarium</i> (Klebahn) comb. n.	+		+			+	planktic
15	<i>Dolichospermum spiroides</i> (Klebahn) comb. n.			+				planktic
16	<i>Gloeotheca rupestris</i> (Lyngbye) Bornet in Wittr. et Nordst.						+	aerophytic
17	<i>Jaaginema woronichinii</i> (Anis.) comb. n. Anagn. et Kom.			+				benthic
18	<i>Jaaginema pseudogeminatum</i> (Schmid) Anagn. et Kom.	+						periphytic
19	<i>Leptolyngbya gelatinosa</i> (Voronich.) Anagn. et Kom.						+	mineral springs
20	<i>Leptolyngbya lagerheimii</i> (Gom.) Anagn. et Kom.	+						planktic/ periphytic
21	<i>Limnothrix lauterbornii</i> (Schmidle.) Anagn.	+		+			+	benthic /secondary planktic
22	<i>Limnothrix planctonica</i> (Wolosz.) Meff.			+				planktic
23	<i>Limnothrix redekei</i> (Van Goor) Meff.	+	+	+	+		+	planktic
24	<i>Lyngbya martensiana</i> Menegh. ex Gom.	+						metaphytic/ periphytic
25	<i>Merismopedia elegans</i> A. Braun in Kütz.	+				+		benthic
26	<i>Merismopedia glauca</i> (Ehr.) Kütz.			+				planktic / benthic
27	<i>Merismopedia punctata</i> Meyen	+		+			+	planktic
28	<i>Merismopedia tenuissima</i> Lemm.	+	+	+		+		planktic /metaphytic
29	<i>Microcystis aeruginosa</i> (Kütz.) Kütz.	+	+	+	+	+	+	planktic
30	<i>Microcystis firma</i> (Kütz.) Schmid.						+	planktic
31	<i>Microcystis flos-aquae</i> (Wittr.) Kirchn.		+	+	+	+	+	planktic
32	<i>Microcystis viridis</i> (A. Br. in Rabenh.) Lemm.	+	+	+	+	+	+	planktic
33	<i>Microcystis wesenbergii</i> (Kom.)	+	+	+	+	+	+	planktic
34	<i>Oscillatoria curviceps</i> Agardh ex Gom.	+						periphytic
35	<i>Oscillatoria janus</i> Skuja	+		+			+	planktic/ metaphytic
36	<i>Oscillatoria limosa</i> Ag. ex Gom.		+			+		benthic/ periphytic
37	<i>Oscillatoria princeps</i> Vaucher ex Gom.	+		+				benthic
38	<i>Phormidium granulatum</i> (Gardn.) Anagn.	+		+			+	benthic/epipelic
39	<i>Phormidium irriguum</i> (Kütz. ex Gom.) Anagn. et Kom.						+	periphytic
40	<i>Phormidium molle</i> Gom.		+				+	periphytic/ metaphytic
41	<i>Phormidium terebriforme</i> (Agardh ex Gom.) Anagn. et Kom.	+					+	periphytic/ benthic
42	<i>Phormidium tergestinum</i> (Kütz.) Anagn. et Kom.	+		+		+		benthic
43	<i>Planktolyngbya contorta</i> (Lemm.) Anagn. et Kom.	+			+			planktic
44	<i>Planktolyngbya limnetica</i> (Lemm.) Kom.-Legn.et Cronb.	+	+	+	+	+	+	planktic
45	<i>Planktothrix agardhii</i> (Gom.) Anagn. et Kom.	+	+	+	+		+	planktic
46	<i>Planktothrix clathrata</i> (Skuja) Anagn. et Kom.	+				+		planktic/benthic
47	<i>Planktothrix cryptovaginata</i> (Škorbatov) Anagn. et Kom.					+		periphytic
48	<i>Pseudanabaena limnetica</i> (Lemm.) Kom.	+	+	+	+	+	+	planktic/benthic
49	<i>Pseudanabaena mucicola</i> (Neum. et Hub.-Pest.) Schwabe	+		+	+	+		endogloeic/epiplanktic
50	<i>Spirulina laxa</i> Smith	+				+		planktic
51	<i>Spirulina major</i> Kütz. ex Gom.		+					periphytic
52	<i>Spirulina</i> sp.	+		+				
53	<i>Woronichinia compacta</i> (Lemm.) Kom. et Hindi.	+		+	+	+	+	planktic
54	<i>Woronichinia naegeliana</i> (Unger.) Elenk.	+	+	+	+	+	+	planktic

(l.c.) also writes that *Planktothrix agardhii* can replace *Microcystis aeruginosa* and form a plankton of low diversity (monospecies) during conditions with light deficit. In Lake Gardzień, the average biomass of blue-green algae during the entire research period was 39 mg l⁻¹, which makes up 85% of the total phytoplankton biomass (Table 4). Algal blooms in this lake are a year-round phenomenon. Only once, in December 2004, did the biomass of phytoplankton not exceed the value of 10 mg l⁻¹. The maximum value of phytoplankton biomass in 2003 was recorded in September – 47.7 mg l⁻¹, including as much as 36.7 mg l⁻¹ of blue-green algae, mainly *Planktolyngbya limnetica* and *Aphanizomenon flos-aquae* (Fig. 1). The pronounced presence

of *Aphanizomenon flos-aquae* in the summer probably results from higher thermal and light requirements of this species (Dokulil & Treubner 2000). Yamamoto (2009) describes that *Aphanizomenon flos-aquae* usually bloomed in summer but could also tolerate low temperatures in the winter. In April, June, October and November 2003, the dominance of *Limnithrix redekei* was recorded. In 2004, the maximum biomass was recorded earlier, already in July. At that time, the biomass of phytoplankton reached the value of almost 176 mg l⁻¹. The development of blue-green algae from the order of Chroococcales was most abundant, i.e. *Woronichinia naegeliana*, the biomass of which was as much as 146 mg l⁻¹. A slightly lower value of blue-

Table 4. Dominant species of blue-green algae, average values of the total phytoplankton biomass (mg l⁻¹), as well as average and maximum values of the blue-green algae biomass (mg l⁻¹)

	Lake					
	Gardzień	Iławskie	Kolmowo	Silm	Stęgwica	Tynwałdzkie
dominants	<i>Planktolyngbya limnetica</i> <i>Aphanizomenon flos-aquae</i> <i>Woronichinia naegeliana</i> <i>Limnithrix redekei</i>	<i>Limnithrix redekei</i> <i>Pseudanabaena limnetica</i>	<i>Planktothrix cryptovaginata</i>	<i>Woronichinia naegeliana</i> <i>Chroococcus limneticus</i> <i>Microcystis aeruginosa</i>	<i>Aphanocapsa incerta</i> <i>Pseudanabaena limnetica</i> <i>Microcystis viridis</i>	<i>Planktothrix agardhii</i> <i>Limnithrix redekei</i>
Average phytoplankton biomass	46	25	56	4	9	75
Average blue-green algae biomass	39	17	31	3	1	49
Maximum blue-green algae biomass	164	37	111	10	6	133

Fig. 1. Biomass (mg l⁻¹) of Cyanobacteria and others phytoplankton groups in Lake Gardzień

green algae biomass was recorded in April of 2004. At that time, the biomass of almost 150 mg l^{-1} was made up by filamentous *Limnothrix redekei*. In spring and autumn, and even in winter (beneath the ice), species of Oscillatoriales dominated among blue-green algae: apart from *Limnothrix redekei*, also *Planktolyngbya limnetica*. Based on German research conducted in shallow lakes, Mischke (2003) reports that *Limnothrix redekei* develops in the largest numbers in winter and spring. These data indicate the preferences of this species for low temperatures. The situation in Lake Gardzień was similar to German studies. At that time, *Aphanizomenon flos-aquae* and *Pseudanabaena limnetica* occurred in smaller, but also significant quantities. The concentration of chlorophyll *a* was monitored in this lake starting from June 2003 to May 2004. The average value of the chlorophyll *a* concentration was $42.3 \mu\text{g l}^{-1}$ and ranged from $22.0 \mu\text{g l}^{-1}$ to $73.2 \mu\text{g l}^{-1}$. The concentration of chlorophyll *a* was three times higher than the value of $50 \mu\text{g l}^{-1}$. This took place in September 2003, January and April 2004.

Studies on water blooms in Lake Iławskie were conducted only for one season, i.e. from April 2002 to November 2002 and in February 2003. During that time, the average biomass of phytoplankton (Table 4) came to almost 25 mg l^{-1} , including the biomass of blue-green algae, which constituted 17 mg l^{-1} (i.e. 67%). The maximum value of blue-green algae biomass was recorded in September 2002, when almost 36 mg l^{-1} of the biomass was made up by *Pseudanabaena limnetica* (Fig. 2). In this lake, water blooms of blue-green al-

gae were not recorded only in the coldest months – in April 2002 and January 2003. At that time, the biomass of blue-green algae was insignificant, below 1 mg l^{-1} , with the dominant species *Limnothrix redekei*. In the remaining lakes, cyanobacterial blooms occurred, and their biomass ranged from 13 to 37 mg l^{-1} . These algal blooms were created by *Limnothrix redekei* in June, and in the subsequent months by *Pseudanabaena limnetica*.

The average biomass of phytoplankton in Lake Kolmowo (Table 4) was almost 56 mg l^{-1} , including the biomass of blue-green algae, which constituted 31 mg l^{-1} (i.e. 56%). In Lake Kolmowo, cyanobacterial blooms were observed from June to October. Outside these months, the contribution of blue-green algae in the phytoplankton reached just a few percent at most. The maximum values of blue-green algae (109 mg l^{-1}) in this lake were recorded in September 2002 and in August 2003 (111 mg l^{-1}), when almost 100% of them were filamentous blue-green algae *Planktothrix cryptovaginata* (Fig. 3). It is a metaphyton and tycho-plankton species (Wehr & Sheath 2003, Komárek & Komárkova 2004). The mass development of this blue-green alga in the plankton can be related to vertical migrations in the summer, with considerable light deficiency.

In Lake Swarzędzkie, as in Lake Kolmowo, algal blooms occur also in September. Stefaniak et al. (2007) report that algal blooms of filamentous blue-green algae *Planktothrix agardhii* and *Limnothrix redekei* reach the value of 52 mg l^{-1} . In Lake Kolmowo, the concen-

Fig. 2. Biomass (mg l^{-1}) of Cyanobacteria and others phytoplankton groups in Lake Iławskie

Fig. 3. Biomass (mg l^{-1}) of Cyanobacteria and others phytoplankton groups in Lake Kolmowo

tration of chlorophyll *a* was investigated from June 2003 to January 2004. The average value of the chlorophyll *a* concentration was $40.3 \mu\text{g l}^{-1}$ and it ranged from $5.8 \mu\text{g l}^{-1}$ to $105.3 \mu\text{g l}^{-1}$. The concentration of chlorophyll *a* exceeded the value of $50 \mu\text{g l}^{-1}$ only in September 2003, when it reached the maximum value.

The average biomass of phytoplankton in Lake Silm was 4.1 mg l^{-1} (Table 4), including the biomass of blue-green algae of 2.8 mg l^{-1} (i.e. 70%). In Lake Silm, cyanobacterial bloom was observed in August 2005 (Fig. 4). It was a mixed water bloom with the dominant species: *Woronichinia naegeliana*, *Chroococ-*

cus limneticus and *Microcystis aeruginosa*. During that month, the biomass of phytoplankton was 11.5 mg l^{-1} , including 10.0 mg l^{-1} of blue-green algae. Species of Chroococcales are less common in intensively mixed zones; therefore it is likely that in Lake Silm the conditions for stabilisation of water masses occur more often and for a longer time, as compared to other studied lakes. Probably, such conditions result from the location of this reservoir in the forest and more effective protection against wind mixing. In the other months, the biomass of phytoplankton did not exceed 10 mg l^{-1} . Nevertheless, the proportion of blue-green

Fig. 4. Biomass (mg l^{-1}) of Cyanobacteria and others phytoplankton groups in Lake Silm

algae in phytoplankton in the summer was considerable. In the summer of 2005 from June to September, the average biomass of phytoplankton was 8.7 mg l^{-1} , and blue-green algae 7.2 mg l^{-1} . It makes up 83% of blue-green algae in the summer and can give a negative forecast for the future, especially that the dominant blue-green algae were as follows: *Woronichinia naegeliana*, *Microcystis aeruginosa* and *Microcystis wesenbergii*. Interestingly enough, in water bodies of southern Poland, *Woronichinia naegeliana* tends to be found in autumn at temperatures below 15°C (Bucka & Wilk-Woźniak 2005). *Microcystis aeruginosa* is reported from water reservoirs situated in agricultural areas (Bucka & Wilk-Woźniak l.c.), whereas Lake Silm is situated in a forest drainage basin.

In the phytoplankton of Lake Stęgwica, the average biomass of phytoplankton (Table 4) came to almost 8.8 mg l^{-1} , whereas the average contribution of blue-green algae was just 1.1 mg l^{-1} . In this lake, cyanobacterial blooms occurred only twice – in August of 2002 and September/October of 2003. (Fig. 5). At that time, blue-green algae made up 52% of the whole phytoplankton biomass. *Aphanocapsa incerta*, *Pseudanabaena limnetica* and *Microcystis viridis* dominated in this lake. The concentration of chlorophyll *a* was studied from June 2003 to January 2004. The average value of the chlorophyll *a* concentration was $10.3 \mu\text{g l}^{-1}$ and it ranged from $4.8 \mu\text{g l}^{-1}$ to $14.8 \mu\text{g l}^{-1}$. It seems that the considerable proportion of blue-green algae in Lake Stęgwica was an insignificant phenomenon and algal blooms do not pose a threat to the functioning of this water body.

The average biomass of phytoplankton in Lake Tynwałdzkie (Table 4) was 75 mg l^{-1} , and the average blue-green algae biomass was 49 mg l^{-1} (i.e. 66%). The maximum values of blue-green algae biomass (Fig. 6) were recorded in July 2002 (i.e. 133 mg l^{-1} – *Planktothrix agardhii* dominating in 88%), in June 2003 (83 mg l^{-1} , including 82% *Limnothrix redekei*) and interestingly enough, in January 2004 (84 mg l^{-1} , including 60% *Planktothrix agardhii*, and 37% *Limnothrix redekei*). Kozak et al. (2007) report even higher values of cyanobacteria during water blooms in the Maltański Reservoir. In August, the biomass of blue-green algae *Planktothrix agardhi*, *Pseudanabaena limnetica*, *Anabaena (Dolichospermum) spiroides* and/or *Anabaena (Dolichospermum) flos-aquae* reached the value of 186 mg l^{-1} . In Lake Tynwałdzkie, algal blooms occur almost all the time. Only in February of 2003, the value of the phytoplankton biomass was very low – 0.3 mg l^{-1} . Also the biomass of blue-green algae at the beginning of 2003, i.e. in February and in April, was very low. Nevertheless, the phytoplankton bloom occurred in April of 2003, but it appeared due to the abundant development of centric diatoms. On other dates, cyanobacteria are responsible for algal blooms. The results of the research on phytoplankton in Lake Tynwałdzkie from 1991 obtained by Luścińska & Dogadalska (1993) were compared with the results obtained 15 years previously by Bogaczewicz-Adamczak (1978). In 1972, the abundant development of two algal taxa from the class of Chrysophyceae was observed in spring, which in the 1990s was replaced by coccal green algae char-

Fig. 5. Biomass (mg l^{-1}) of Cyanobacteria and others phytoplankton groups in Lake Stęgwica

Fig. 6. Biomass (mg l^{-1}) of Cyanobacteria and other phytoplankton groups in Lake Tynwałdzkie

acteristic of polytrophic water bodies. In the phytoplankton from 2002-2003, cyanobacteria were the definitive dominants. The above-described changes in the dominance structure of algae in the plankton of Lake Tynwałdzkie prove that the trophic level of lake waters is still increasing. In this lake, the concentration of chlorophyll *a* was monitored from June 2003 to January 2004. The average value of the chlorophyll *a* concentration was $74.1 \mu\text{g l}^{-1}$ and it ranged from $41.6 \mu\text{g l}^{-1}$ to $117.1 \mu\text{g l}^{-1}$. The concentration of chlorophyll *a* fell below the value of $50 \mu\text{g l}^{-1}$ only twice. This took place in June and August of 2003.

In all the studied lakes, the maximum values of blue-green algae biomass were recorded in the summer months, usually late summer. Optimal conditions for the growth of blue-green algae are at the temperature of ca. 25°C , and then algal blooms can develop (Kobos et al. 2005).

The studied lakes can be arranged in respect of the size and duration of cyanobacterial blooms. The longest algal blooms occur in Lake Gardzień; they last almost throughout the year. In this reservoir, the maximum biomass values for cyanobacteria were also the highest ones. The duration of algal blooms in Lake Tynwałdzkie is a bit shorter; values for the maximum biomass of cyanobacteria are also smaller, but the average values of cyanobacteria biomass are the highest among the studied lakes. Lake Kolmowo comes third with blooms continuing for half a year. In this lake, the intensive development of phytoplankton is also reflected in a very high value of the average and maxi-

mum biomass. Lake Iławskie had much lower values of the maximum and average cyanobacteria biomass compared to other lakes. The research was carried out, however, for a considerably shorter time, i.e. for just seven months. Incidental algal blooms occur in Lake Stęgwica and Lake Silm.

Lakes with permanent algal blooms are characterised by a considerable contribution of cyanobacteria from the order of Oscillatoriales. According to Dokulil & Teubner (2000), these species – tolerant to mixing – do not have the ability of N_2 assimilation, they are not subjected to stratification and they do not migrate. According to Rucker et al. (1997), lakes of this type are characterised by a low average depth ($z_{\text{max}} < 3 \text{ m}$) and low transparency ($< 0.3 \text{ m}$), and are called “*Oscillatoriaceae* lakes”. Depending on the dominant species and the dynamics of water masses, these authors classify such lakes into two types: “*Planktothrix*-lakes”, where the influence of disturbances (turbulence) is stronger and “*Limnothrix*-lakes”, where the influence of wind is less. Mischke (2003) quotes the results of field and experimental studies by Wiedner (1999) which confirm that *Planktothrix* is a more tolerant species to water mixing compared with *Limnothrix* and *Pseudanabaena*. This tolerance to mixing provides the possibility of faster trapping of phosphorus that reaches the pelagic zone “in pulses” during resuspension. In the case of Iławskie Lakes, Lakes Tynwałdzkie and Kolmowo can be classified as “*Planktothrix*-lakes”. These two lakes are situated within an open territory surrounded by arable fields. Certainly, the water mixing intensity in

both lakes is strongly affected by wind. Unfortunately, the abundant development of *Planktothrix* influences the considerable production of microcystins (Mischke 2003). Among the studied lakes, Lakes Tynwałdzkie and Kolmowo are also included among lakes with the highest trophic status. The average value of the TSI coefficient comes to 68 for Lake Kolmowo and 69 for Lake Tynwałdzkie.

Lakes Ławskie and Gardzień can be classified as "*Limnothrix*-lakes". These reservoirs are characterised by high shores. Lake Gardzień is particularly protected against wind, because it is situated in a valley overgrown with forest. Probably in these water bodies, the influence of wind on water mixing is limited. The trophic level of these water reservoirs is also lower than in the case of the previous ones, and comes to 66 for Lake Ławskie and 64 for Lake Gardzień.

The state of the ecosystems in Lakes Silm and Stęgwica does not appear to be endangered. In these water bodies, algal blooms were occasional phenomena. In Lake Silm, the intensive development of blue-green algae was recorded four times a year. The amount of biomass was reflected in the water bloom only once. A similar situation was observed in Lake Stęgwica, where the increased contribution of blue-green algae was recorded just twice. Both lakes are situated in a forest drainage basin, and the forests protect the lakes against the excessive supply of nutrients. Despite the fact that the trophic status of both lakes is relatively high (the average value of TSI – 59 for Lake Silm and 61 for Lake Stęgwica), these lakes are, however, characterised by a small proportion of blue-green algae in phytoplankton. In the case of Lake Stęgwica, this obviously results from a high content of humus compounds. According to Starmach et al. (1976), the presence of a large amount of humus substances limits the development of some algae, i.a. blue-green algae.

The research on shallow lakes reveals a close relationship between the species composition of a water bloom, its intensity and duration, and the trophic state of a reservoir and the nature of a drainage basin. The ratio N:P in the studied lakes was high enough to prevent the mass occurrence of N-fixing cyanobacteria from the order of Nostocales. This high level of N:P is suitable for cyanobacteria Chroococcales, but their occurrence is also determined by stable conditions, i.e. no water mixing. Hence their periodic presence in lakes Silm, Stęgwica and Gardzień, whose direct catchment area is overgrown with forest reducing water mixing. Consequently, a combination of suitable

conditions, i.e. high dynamics and a high level of biogenic substances in the remaining lakes, determines the characteristic species composition, with the dominance of Oscillatoriales incapable of assimilating atmospheric nitrogen and favouring intensively mixed water bodies.

This high biomass of phytoplankton with a particularly high contribution of blue-green algae negatively influences the whole ecosystem. The main problem is related to an extremely high production of organic matter, which during the processes of decomposition induces intensive oxygen consumption. In turn, the oxygen deficits affect the course of chemical processes taking place in the water. Animals are particularly exposed to cyanobacterial water blooms, due to the fact that species such as *Aphanizomenon flos-aquae*, *Planktothrix agardhii*, *Planktothrix cryptovaginata*, *Microcystins aeruginosa*, and *Woronichinia naegelianiana* are potential producers of toxins. Toxins can be accumulated in animal bodies; therefore indirectly the problem may also affect humans. Among the studied water basins, Lake Tynwałdzkie is overexploited in terms of fishing, and Lakes Kolmowo and Ławskie constitute watering places for farm animals.

In the end, algal blooms prevent the development of submerged vegetation, which would stabilize the bottom sediments and would constitute an additional "consumer" of biogenic substances, and thus it would control the biocenotic relations in these lakes. Unfortunately, the long-term dominance of blue-green algae occurring in shallow lakes of the Ława Lake District may be difficult to eliminate if modern methods of lake reclamation are applied.

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