

POLISH JOURNAL OF ECOLOGY (Pol. J. Ecol.)	58	1	3-12	2010
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Regular research paper

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## WINTER VERSUS SUMMER BLOOMING OF PHYTOPLANKTON IN A SHALLOW LAKE: EFFECT OF HYPERTROPHIC CONDITIONS

**ABSTRACT:** The comparison of species richness, abundance and diversity of phytoplankton blooms, which developed both in winter and summer seasons as an effect of lake hypertrophy, was the aim of this study. In the ice-covered lake (0.30 mg PO<sub>4</sub>-P L<sup>-1</sup>, 1.35 mg NH<sub>4</sub>-N L<sup>-1</sup>; TSI<sub>SD</sub> = 64; TSI<sub>chl</sub> = 93), the algal bloom, responsible for high concentration of dissolved oxygen in water, consisted mainly of the centric diatom *Stephanodiscus minutulus* (3.9 × 10<sup>7</sup> ind. L<sup>-1</sup>) accompanied by *Limnothrix redekei* (Cyanobacteria), *Koliella longiseta* (Chlorophyceae), > 1.1 × 10<sup>6</sup> ind. L<sup>-1</sup> each, as well as *Mallomonas* sp. (Chrysophyceae) and *Monoraphidium komarkovae* (Chlorophyceae), >5.0 × 10<sup>5</sup> ind. L<sup>-1</sup> each. The toxic cyanobacterium *Planktothrix agardhii* of extremely long trichomes (up to 0.93 mm) and potentially toxic dinoflagellate *Peridinium aciculiferum* f. *inermis* occurred also in high numbers (1.9 × 10<sup>5</sup> ind. L<sup>-1</sup> and 7.7 × 10<sup>4</sup> ind. L<sup>-1</sup>, respectively). In summer (0.05 mg PO<sub>4</sub>-P L<sup>-1</sup>; 0.42 mg NH<sub>4</sub>-N L<sup>-1</sup>; TSI<sub>SD</sub> = 78; TSI<sub>chl</sub> = 102), the phytoplankton bloom consisted of *P. agardhii* (average total abundance 49.4 × 10<sup>6</sup> ind. L<sup>-1</sup>) and ten other taxa of Cyanobacteria, Bacillariophyceae, Chlorophyceae and Cryptophyceae (average total abundance 17.9 × 10<sup>6</sup> ind. L<sup>-1</sup>). The total phytoplankton abundance was 1.5 times higher in summer than in winter and the total biomass of the most abundant species was approximately 4 times higher in warm (139.8 mg L<sup>-1</sup>) than in cold season (32.5 mg L<sup>-1</sup>). The values of the Shannon-Weaver diversity index were

very low, however, over 2 times higher in summer (0.60) than in winter (0.31). The obtained results revealed that in the hypertrophic lake the very high nutrient concentrations (especially NH<sub>4</sub>-N and PO<sub>4</sub>-P), found both in winter and summer, were responsible for year-long mass development of phytoplankton. The winter phytoplankton was composed mainly of very small centric diatoms, whereas summer blooms were created by filamentous cyanobacteria (mainly Oscillatoriales; 98%).

**KEY WORDS:** hypertrophic lake, phytoplankton blooms, phytoplankton diversity, Cyanobacteria, *Planktothrix agardhii*, *Peridinium aciculiferum*

### 1. INTRODUCTION

Eutrophic/hypertrophic lakes are mostly dominated by phytoplankton (Scheffer 1998, Nixdorf *et al.* 2003) and therefore this ecological group plays an especially important but sometimes controversial role in functioning of lake ecosystems (Scheffer 1998, Dodds 2002, Naselli-Flores *et al.* 2003). Phytoplankton development in nutrient-rich lakes has been investigated intensively in recent years but reports concern mainly warm seasons and Cyanobacteria for their cyanotoxin production abilities (Wiedner

*et al.* 2002, Willame *et al.* 2005, Pawlik-Skowrońska *et al.* 2008). Reports of phytoplankton growth under the ice cover in nutrient-rich lakes are very scarce (Wiedner and Nixdorf 1998, Wojciechowska *et al.* 1998, Rengefors and Legrand 2001). Phytoplankton blooms influence physicochemical features of water by increasing the pH and redox potential of water, decreasing the accessibility of nutrients and affecting light conditions (Oliver and Ganf 2000, Dodds 2002). As a result, disappearance of submerged macrophytes may occur (Kajak 1998, Scheffer 1998). Moreover, many bloom-forming species of freshwater Cyanobacteria, some Dinophyceae and Euglenophyceae are potential producers of toxins which may be harmful for humans, animals and hydrobiota (Carmichael 1992, Rengefors and Legrand 2001, Zimba *et al.* 2004, Burchardt and Pawlik-Skowrońska 2005). Succession of phytoplankton and its species diversity may reflect the lake's resistance to harmful algal blooms (Roelke and Buyukates 2002). Algal dynamics are very complex and there is difficulty of their predictability (Scheffer 1998), hence, study at the species level appears to be very important.

We hypothesized that in shallow, nutrient-rich lakes perennial phytoplankton blooms occur both in cold and warm seasons. Therefore, the comparison of species richness, abundance and diversity of phytoplankton community, which developed in winter (under the ice cover) and in summer in a hypertrophic lake, was the aim of this paper.

## 2. STUDY AREA

Lake Syczyńskie is a small (5.6 ha) and shallow (max. depth: 2.9 m, mean depth: 0.9 m) water body located in Eastern Poland (51°17'12"N, 23°14'16"E). Over 80% of the lake catchment is of agriculture use and coupled with unfavourable morphometric parameters of the water body it leads to its high trophy and low water quality (Kornijów *et al.* 2002). In addition, liquid manure from a nearby farm of several hundreds of animals was carried into the lake from 1972 to 1997. Present annual external loading of P and N to the lake (Smal *et al.* 2005) is very high (76 kg and 3170 kg, respectively). The lake degrada-

tion has revealed itself in frequent and long-lasting cyanobacterial blooms, simplification of aquatic biocenosis, periodical oxygen depletion and fish death (Kornijów *et al.* 2002).

## 3. MATERIAL AND METHODS

Surface water (0–0.5 m) in the central part of the lake was sampled from February to October 2004. However, in this paper results of winter (February) and summer (July–September) studies are presented. In winter the water samples were collected from the ice-(12 cm) and snow-(3 cm)covered lake. The ice cover occurred for about 2.5 months. Phytoplankton samples were fixed with Lugol's solution and 4% formalaldehyd with glycerin. Basic physicochemical parameters of water including temperature, transparency – SD, pH, conductivity, NH<sub>4</sub>-N, PO<sub>4</sub>-P were determined. Dissolved oxygen and oxygen saturation were measured with a Field DO Meter (Elmetron). Chlorophyll-*a* was analyzed spectrophotometrically after phytoplankton filtration (GF/C filters) and its 1h extraction at 65°C in dimethylsulfoxide (DMSO) in the dark (Wellburn 1994). The algal systematics was made according to Van den Hoek *et al.* (1995). The phytoplankton abundance was estimated by means of an inverted microscope. Only alive cells, colonies or trichomes were counted. Species with abundance higher than 50% of the total algal abundance were considered as the dominants, and those with abundance of 25–50% as subdominants (Wojciechowski 1972). Biomass of the most abundant species was estimated by cell volume measuring. Indexes of phytoplankton diversity, dominance and evenness were calculated as follows:

Shannon-Weaver index of diversity (1963):

$$H' = -\sum (n_i/N) \log(n_i/N) \quad (1)$$

Duffy index of dominance (1968):

$$C = \sum (n_i/N)^2 \quad (2)$$

Pielou evenness index (1975):

$$J' = H'/\log S \quad (3)$$

where in formula (1) and (2):  $n_i$  is the abundance of  $i$ -th taxon,  $N$  is the total abundance of phytoplankton taxa (Shannon and

Weaver 1963, Duffy 1968). In formula (3)  $H'$  is the Shannon-Weaver index,  $S$  is the total number of taxa (Pielou 1975).

Trophic status indexes ( $TSI_{SD}$  and  $TSI_{chl}$ ) were determined according to Carlson (1977).

4. RESULTS

Physicochemical conditions occurring in the hypertrophic ( $TSI_{SD} = 64$  and  $78$ ;  $TSI_{chl} = 93$  and  $102$  in winter and summer, respectively) Lake Syczyńskie (Table 1) supported the development of phytoplankton blooms both in winter under the ice cover (water temperature  $1.7^{\circ}C$ ) and in summer ( $19.2-20.4^{\circ}C$ ). The lake water was very rich in  $PO_4-P$  and  $NH_4-N$ , however, the nutrient concentrations were several times higher in winter ( $0.30\text{ mg } PO_4-P\text{ L}^{-1}$ ,  $1.35\text{ mg } NH_4-N\text{ L}^{-1}$ ) than in summer ( $0.05\text{ mg } PO_4-P\text{ L}^{-1}$ ,  $0.42\text{ mg } NH_4-N\text{ L}^{-1}$ ).

Water transparency decreased from  $0.75\text{ m}$  (in winter) to  $0.28\text{ m}$  (in summer). Dissolved oxygen (DO) and oxygen saturation measured in winter in the ice-covered lake were higher ( $16.7\text{ mg L}^{-1}$  and  $114\%$ , respectively) than in warm period ( $9.3\text{ mg L}^{-1}$  and  $103\%$ , respectively).

During the study year, altogether 122 phytoplankton taxa were identified (data not shown). Despite the very low water temperature, species richness of algal community in winter was high (44 taxa), however, lower than in summer (61). In both studied seasons Chlorophyceae (31 and 42% of the total taxa number, in winter and summer, respectively) and Cyanobacteria (30 and 36%) dominated over other taxonomic groups (Fig. 1).

In winter, in the ice- and snow-covered lake, among the most abundant algal groups (Fig. 2A) centric diatoms dominated and

Table 1. Physicochemical characteristics (average values) of water of the hypertrophic Lake Syczyńskie in winter and summer.

Parameters	Winter	Summer
Water temperature ( $^{\circ}C$ )	1.7	19.8
pH	8.5	8.4
Conductivity ( $\mu S\text{ cm}^{-1}$ )	537	536
Transparency – SD (m)	0.75	0.28
$NO_3-N$ ( $mg\text{ L}^{-1}$ )	<1.0	<1.0
$NH_4-N$ ( $mg\text{ L}^{-1}$ )	1.354	0.418
$PO_4-P$ ( $mg\text{ L}^{-1}$ )	0.298	0.052
Dissolved oxygen ( $mg\text{ L}^{-1}$ )	16.7	9.3
Oxygen saturation (%)	114.2	103.2
Chlorophyll- <i>a</i> ( $\mu g\text{ L}^{-1}$ )	77.7	145.0
$TSI_{SD}$	64	78
$TSI_{chl}$	93	102

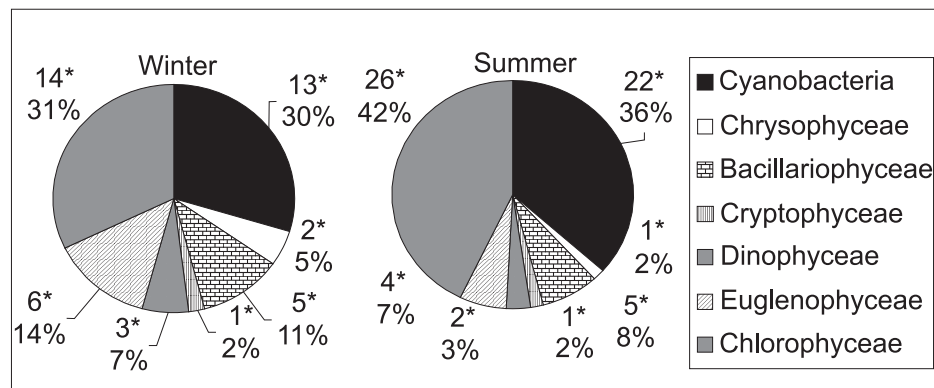


Fig. 1. Taxa number (\*) of particular taxonomic groups and their share (%) in the total taxa number of phytoplankton recorded in the hypertrophic lake in winter and summer. The total taxa number of phytoplankton was set as 100%.

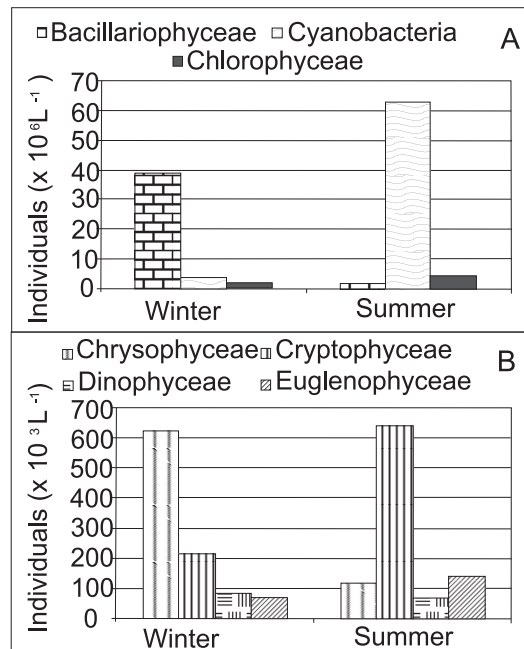


Fig. 2. Abundance of particular algal groups in the hypertrophic lake in winter and summer: A – the most abundant ( $> 1 \times 10^6$  ind. L<sup>-1</sup>), B – less abundant ( $< 1 \times 10^6$  ind. L<sup>-1</sup>).

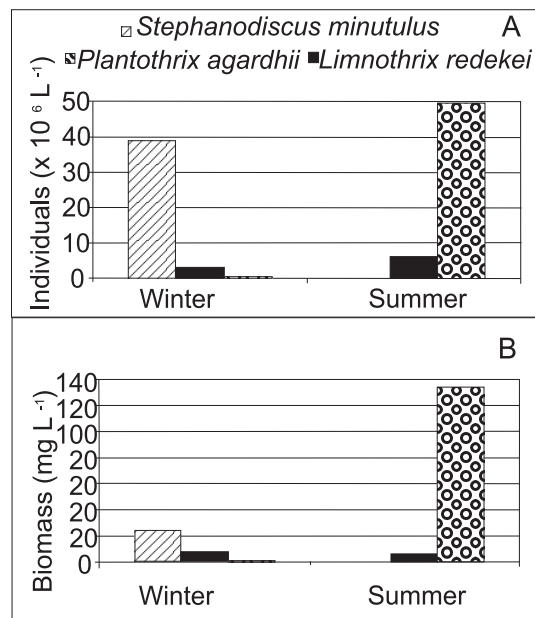


Fig. 3. Comparison of abundance (A) and biomass (B) of dominants and accompanied species in winter and summer.

*Stephanodiscus minutulus* (Kütz.) Grun. in Cleve and Möller occurred in the highest abundance ( $3.9 \times 10^7$  ind. L<sup>-1</sup>, 85% of the total algal abundance) (Fig. 3A). At the same period four other phytoplankton species: *Limnithrix redekei* Van Goor (Cyanobacteria), *Koliella longiseta* (Vischer) Hind. (Chloro-

phyceae), as well as *Mallomonas* sp. (Chrysophyceae) and *Monoraphidium komarkovae* Nygaard (Chlorophyceae) also reached high densities ( $> 1.1 \times 10^6$  ind. L<sup>-1</sup> and  $> 5.0 \times 10^5$  ind. L<sup>-1</sup>, respectively). Moreover, the toxic cyanobacterium *Planktothrix agardhii* (Gom.) Anagn. et Kom. ( $1.9 \times 10^4$  ind. L<sup>-1</sup>)

Table 2. Species diversity of phytoplankton community in winter and summer in the hypertrophic lake according to the different indexes (formula 1, 2, 3).

Indexes	Winter	Summer
Shannon-Weaver	0.31	0.60
Duffy dominance	0.73	0.42
Pielou evenness	0.06	0.10

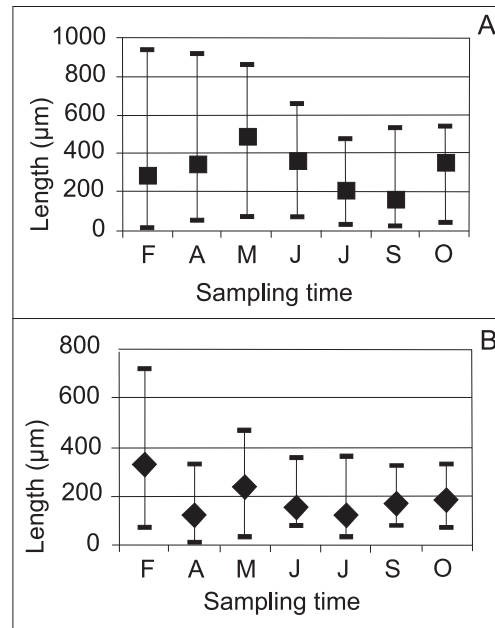


Fig. 4. Average lengths of trichomes of (A) *Planktothrix agardhii* ( $n = 50$ , width range 3.6–5.4  $\mu\text{m}$ ) and (B) *Limnothrix redekei* ( $n = 50$ , width range 3.4–3.6  $\mu\text{m}$ ) in the hypertrophic lake. Bars represent minimum and maximum values.

(Fig. 3A) and potentially toxic dinoflagellate *Peridinium aciculiferum f. inerme* Lemm. ( $7.7 \times 10^4 \text{ ind. L}^{-1}$ ) occurred in high amounts. Among less abundant algal groups (Fig. 2B) Chrysophyceae dominated. In summer season, Cyanobacteria with *P. agardhii* (average abundance  $49.4 \times 10^6 \text{ ind. L}^{-1}$ ) dominated, however, many other taxa like the cyanobacteria *L. redekei*, *Planktolyngbya limnetica* (Lemm.) Kom.-Legn. et Cronberg, the diatoms (*Fragilaria ulna* (Nitzsch) Lange-Bertalot, *N. acicularis* (Kütz.) W. Smith, *Navicula* sp.), the cryptophyte (*Cryptomonas* sp.) as well as the green algae (*Actinastrum raphidioides* (Reinsch) Brunthaler, *Dictyosphaerium tetrachotomum* Printz, *Monoraphidium contortum* (Thur.) Kom.-Legn., *Monoraphidium minutum* (Näg.) Kom.-Legn.) occurred in very high amounts (totally  $17.9 \times 10^6 \text{ ind. L}^{-1}$ ). Among less abundant phytoplankton groups (Fig. 2B) Cryptophyceae dominated.

In winter the total biomass of the most abundant three species ( $32.5 \text{ mg L}^{-1}$ ) was very

high, however, 4.3 times lower than in summer ( $139.8 \text{ mg L}^{-1}$ ) (Fig. 3B). The biomass of the dominant *S. minutulus* (found only in winter) reached  $24 \text{ mg L}^{-1}$ . The biomass of the filamentous cyanobacterium *L. redekei* was similar in winter and summer ( $7.6$  and  $6.1 \text{ mg L}^{-1}$ , respectively), whereas the biomass of *P. agardhii* increased from  $0.9 \text{ mg L}^{-1}$  in winter to  $133.7 \text{ mg L}^{-1}$  in summer. Interestingly, the average length of *P. agardhii* trichomes fluctuated considerably within the studied periods (Fig. 4A). It increased from  $286 \mu\text{m}$  in winter to  $493 \mu\text{m}$  in spring, then decreased to  $163 \mu\text{m}$  in late summer, and increased again in autumn to  $351 \mu\text{m}$ . The maximum length of *P. agardhii* trichomes (up to  $0.93 \text{ mm}$ ) were observed from February to April. The longest *L. redekei* trichomes were also found in winter (max.  $719 \mu\text{m}$ , average  $324 \mu\text{m}$ ) (Fig. 4B).

The changes between winter and summer phytoplankton communities were also evaluated by the Shannon-Weaver, Duffy and evenness indexes (Table 2). The Shannon-

Weaver index (formula 1) of phytoplankton diversity was two-fold lower in winter (0.31) than in summer (0.60). The Duffy dominance index (formula 2) was higher in winter than in summer. Evenness index (formula 3) was slightly higher in warm (0.10) than in cold (0.06) period.

## 5. DISCUSSION

The term “algal bloom” is frequently described as a rapid increase in the population of algae in an aquatic system (Oliver and Ganf 2000), which causes a change in a colour of water (Reynolds and Walsby 1975, Kawecka and Eloranta 1994). According to Bednarz *et al.* (2002) and Hitzfeld *et al.* (2000) abundance of phytoplankton higher than  $5 \times 10^5$  ind. L<sup>-1</sup> or  $1 \times 10^6$  ind. L<sup>-1</sup> is typical for bloom. The phytoplankton biomass from 10 to a few hundreds mg L<sup>-1</sup> was reported as characteristic for algal blooming (Oliver and Ganf 2000). In the studied lake (very rich in NH<sub>4</sub>-N and PO<sub>4</sub>-P – the nutrients supporting eutrophication process and phytoplankton mass development, Kajak 1998), the phytoplankton abundance and biomass fulfill those criteria, both in winter and summer.

Species richness of phytoplankton community found in the studied lake (122) was similar to a few reports on other shallow eutrophic/hypertrophic water bodies. For example, in the eutrophic lake in Germany 119 taxa were found (Nixdorf *et al.* 2003) and in the hypertrophic Lake Gineitiskis (Lithuania) 136 taxa were reported (Kasperoviciene and Koreiviene 2005). In the studied Lake Syczyńskie, the highest species richness (61 taxa) of the phytoplankton community was observed in summer, during the strongest bloom of microcystin-producing *P. agardhii* (Wiśniewska *et al.* 2007, Pawlik-Skowrońska *et al.* 2008).

The species diversity (Shannon-Weaver index) changed during the studied seasons in the very narrow range of 0.31–0.60. To the best of our knowledge, there are no reports of such low values of this index. The low number of taxa as well as a dominance of one or a few taxa may diminish considerably the value of the Shannon-Weaver diversity index (Kawecka and Eloranta 1994, Bürgi and

Stadelmann 2002). The lower value of this index in winter was a consequence of the lowest species richness and the highest dominance value of Duffy index at the very high abundance of *S. minutulus*. Generally, in the temperate zone the diversity index of phytoplankton is the highest in warm seasons (Kawecka and Eloranta 1994), what was observed also in the studied hypertrophic lake. However, in Lake Syczyńskie the difference between periods was much lower than those reported for other lakes. Broader range of values of the Shannon-Weaver index was found for different hypertrophic (2.3–5.1), eutrophic (0.1–4.4), and mesotrophic lakes (0.3–2.9) (Bürgi and Stadelmann 2002, Krupa and Czernaś 2003, Stefaniak *et al.* 2007). There is very little published information on winter phytoplankton diversity in hypertrophic lakes. According to a few reports (Kamjunke *et al.* 1997, Wiedner and Nixdorf 1998), winter phytoplankton of hypertrophic water bodies may be dominated by cryptophytes, chrysophytes, microchlorophytes or diatoms. The dominant, in the studied lake, the small (cell diameter 8.1–10.5 µm), centric diatom *S. minutulus* was previously reported as a bloom-forming species mostly in eutrophic lakes and rivers with elevated ion concentrations (Kiss and Genkal 1993, Phillips and Fawley 2002b). The very high DO concentration (16.7 mg L<sup>-1</sup>), observed in the studied lake in winter during algal bloom, was rarely reported *e.g.* 9.2 mg O<sub>2</sub> L<sup>-1</sup> (Phillips and Fawley 2002a). This phenomenon is very important in eutrophic/hypertrophic lakes because it may prevent anoxia and diffusing of PO<sub>4</sub>-P from sediments into the water column (Doods 2002). High DO concentration in the ice-covered lake was observed during a bloom of the dinoflagellate *Peridinium aciculiferum* (Phillips and Fawley 2002a). The relatively high abundance of this toxic species (Rengefors and Legrand 2001) together with the mass development of the *L. redekei* and *P. agardhii* (Oscillatoriales) were found in winter in Lake Syczyńskie. Occurrence of these Cyanobacteria in cold period was rarely reported from other fertile lakes (Seip and Reynolds 1995, Wojciechowska *et al.* 1998). Usually, in shallow, highly eutrophic water bodies cyanobacterial blooms

were observed in warm periods (Wiedner *et al.* 2002, Pawlik-Skowrońska *et al.* 2004, Kasperoviciene and Koreiviene 2005, Stefaniak *et al.* 2005). However, summer/autumn blooms may be also composed of algae belonging to other classes like Cryptophyceae, Chlorophyceae (Kawecka and Eloranta 1994) and Euglenophyceae (Polučkova *et al.* 2004).

In the studied lake the high abundance and biomass of the cyanobacterium *P. agardhii* were observed in all seasons. However, its density was almost 250-times higher in summer than in winter. There is very scarce information on the biomass of particular algal species in hypertrophic lakes. The total biomass of the most abundant cyanobacteria (Oscillatoriales) in Lake Syczyńskie was extremely high, with the biomass of *P. agardhii* being a 100-fold higher than in another hypertrophic lake (Kasperoviciene and Koreiviene 2005). Interestingly, in autumn, we observed above two-fold decrease in *P. agardhii* abundance in comparison with late summer, however, its biomass did not change due to higher length of *P. agardhii* trichomes in autumn than in summer. Our observations suggest that the autumnal elongation of *P. agardhii* trichomes may be an adaptation to overwinter, although, an autumnal shortening of trichomes was previously reported by Polučkova *et al.* (2004). Overwintering of Cyanobacteria is controlled by various factors: *e.g.* duration of ice-snow-cover influencing light and temperature conditions (Meffert 1989) and by nutrient concentrations (Wiedner and Nixdorf 1998). The trichome elongation observed in the studied lake, was probably due to high concentrations of  $\text{PO}_4\text{-P}$  and low light intensity in the lake water. As reported by Hašler *et al.* (2003), trichome fragmentation can be a consequence of decrease in  $\text{PO}_4\text{-P}$  level and increase in light intensity. Water temperature (*ca.* 15°C) also seems to be optimal for elongation of *P. agardhii* trichomes (Polučkova *et al.* 2004). However, contrary to the report of Polučkova *et al.* (2004), *P. agardhii* overwintered in the studied lake mostly in vegetative forms, not as hormogonia. According to Wiedner and Nixdorf (1998), the lowest part of water column of temperature at 4°C may provide a niche for Cyanobacteria,

whereas water temperatures closer to freezing point, occurring during periods without the ice cover, are less favourable. Contrary to this statement, in the studied lake *P. agardhii* and *L. redekei* occurred in high densities even at temperatures lower than 2°C. Interestingly, maximum lengths of *P. agardhii* trichomes, observed in Lake Syczyńskie in cold period, were much longer (up to 0.93 mm) than reported for this species by other authors (Polučkova *et al.* 2004, Stefaniak *et al.* 2005). The mass development of Oscillatoriales in Lake Syczyńskie seems to be mainly connected with high  $\text{NH}_4\text{-N}$  concentrations (Wiśniewska *et al.* 2007). As reported by other authors (Zotina *et al.* 2003, Pawlik-Skowrońska *et al.* 2004), high levels of different organic and inorganic forms of nitrogen or ammonium may intensify the development of the genus *Planktothrix*. Some  $\text{N}_2$ -fixing cyanobacteria *Anabaena* and *Aphanizomenon* (Nostocales) occurred in Lake Syczyńskie, too, although in 20–5000 lower densities with maximum share 2.5 % (Wiśniewska *et al.* 2007). The dominance of Cyanobacteria may be an alternative stable state of lake under hypertrophic conditions (Scheffer 1998), and the lakes dominated by *P. agardhii* were classified as *Planktothrix*-lakes (Rücker *et al.* 1997). These filamentous Cyanobacteria are able to reach higher biomass with the same phosphorus level like other algae (Scheffer 1998).

As reported previously by Pawlik-Skowrońska *et al.* (2008) the population of *P. agardhii* occurring in Lake Syczyńskie produced hepatotoxic microcystins. Interestingly, beside *P. agardhii*, 19 of over 40 species of potentially toxic Cyanobacteria like *Anabaena* spp., *Aphanizomenon gracile* (Lemm.) Lemm., *Coelomorion pusillum* (Van Goor), *Microcystis aeruginosa* (Kütz.) Kütz., *Oscillatoria limosa* Ag. ex Gom., *Oscillatoria* sp., *Planktolyngbya limnetica*, *P. contorta*, *Snowella lacustris* (Chod.) Kom. et Hind., *Woronichinia fusca* Skuja were found, however, only 4 taxa in winter, and 9 taxa in summer (Wiśniewska *et al.* 2007). Microcystins may inhibit growth (Babica *et al.* 2007) of some green algae (*Chlamydomonas reinhardtii*, *Chlorella kessleri*, *Pseudokirchneriella subcapitata* and *Pediastrum duplex*). However, the negligible impact of *P. agardhii* on the development of

eukaryotic algae in the studied lake may be a consequence of high intra-cellular and low extra-cellular concentrations of microcystins in water (Pawlik-Skowrońska *et al.* 2008).

In the hypertrophic lake the very high concentrations of  $\text{NH}_4\text{-N}$  and  $\text{PO}_4\text{-P}$ , occurring both in winter and summer seasons, were responsible for year-long phytoplankton blooms. The phytoplankton abundance and biomass were very high, however, species diversity was very low. The winter phytoplankton, was dominated by small centric diatoms, whereas the summer blooms were created mainly by filamentous cyanobacteria (Oscillatoriales). *L. redekei* and microcystin-producing *P. agardhii* found extremely favourable growth conditions, both in very cold and warm water. Algal blooms in winter may have some positive environmental effect in ice-covered water bodies due to the intensive oxygen production, however, the presence of cyanotoxins in water is a serious hazard for lake biocenosis.

**ACKNOWLEDGMENTS:** Authors thank to Dr hab. J. Kwadrans and prof. P. Eloranta for their consultancy for taxonomical identification of *Stephanodiscus minutulus* and to Heather M. Malcom for help with English expressions. This work was partially supported by the grant No 304396636 of The Ministry of Science and Higher Education of Poland.

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*Received after revision September 2009*