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RESEARCH ARTICLE

Diversity and dynamics of phytoplankton in lakes Licheńskie and Ślesińskie in 2004-2005

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Abstract. The aim of the study was to identify the similarities and differences in the phytoplankton in lakes Licheńskie and Ślesińskie based on the phytoplankton species composition and biomass. Quantitative and qualitative studies of phytoplankton from two heated lakes were conducted in 2004-2005. A total of 280 and 240 taxa were identified belonging to six phyla: Chlorophyta, Cyanoprokaryota, Cryptophyta, Dinophyta, Euglenophyta, and Heterokontophyta. Most of the taxa were incidental species with frequencies of less than 25%. The phytoplankton biomass in Lake Licheńskie ranged from 0.2 to 8.6 mg dm^{-3}. Throughout the growing season of 2004, the phytoplankton observed was comprised of diatoms and green algae, while in 2005 it was comprised of diatoms, green algae, and cryptophytes. The phytoplankton biomass in Lake Ślesińskie ranged from 0.4 to 13.2 mg dm^{-3}. Diatoms dominated in this lake in the spring and fall of both years (54-90%), while in summer 2004 diatoms and green algae dominated and in summer 2005 the dominants were cryptophytes, dinophytes, and cyanophytes.

Keywords: phytoplankton, diversity, lake, heated water, Lake Licheńskie, Lake Ślesińskie

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Introduction

Lakes Licheńskie and Ślesińskie are trough lakes with developed shorelines and similar water surface areas (153.6 and 148.1 ha, respectively). They do differ, however, with regard to maximum (13.3 and 25.7 m, respectively) and mean (4.9 and 7.5 m, respectively) depths and mixing type (monomictic and dimictic). Both lakes are important elements of a cooling system for nearby electric power facilities. Lake Licheńskie is heated to a greater degree than is Lake Ślesińskie. The lakes also differ with regard to the length of time they are heated each year. Lake Licheńskie is heated throughout the year, while Lake Ślesińskie is only heated from May to September. Phytoplankton, which is a bioindicator of change in aquatic ecosystems (Burchardt et al. 1994), was shaped in both lakes by abiotic factors, primarily temperature, productivity, water flow rates, and epiphytic algae (Pyka et al. 2007, Stawecki et al. 2007, Socha and Hutorowicz 2009). Additional elements that differentiated the environmental conditions included mixing, the occurrence of lotic and lentic habitats in the same vicinity, and strong and varied anthropogenic pressure (Zdanowski 1998).

The aim of the study was to identify the similarities and differences in the phytoplankton assemblages in lakes Licheńskie and Ślesińskie based on species composition and biomass.

Materials and methods

Lakes Licheńskie and Ślesińskie have different thermal regimes. In winter the waters of Lake Licheńskie froze sporadically and only in the northern stagnant section, and were heated to a maximum temperature of 30.0°C in summer (Table 1). Ice cover occurred irregularly throughout Lake Ślesińskie, while in summer the maximum temperature was 27.6°C. The surface water layers of these lakes were well oxygenated, and had similar contents of nitrogen and phosphorus. However, their water retentions differed sometimes, as did the chlorophyll content in the epilimnion (Pyka et al. 2007, Stawecki et al. 2007).

Table 1
Physico-chemical parameters in surface water layers in lakes Licheńskie and Ślesińskie

Parameters	Lake Licheńskie	Lake Ślesińskie
Mean water temperature: January – Aust (°C)[1]	5.7-27.0	0.6-25.0
Max water temperature (°C)[1]	30.0	27.6
Oxygen content ($mgO_2\ dm^{-3}$)[1]	6.3-17.0	9.0-19.6
Water retention time (days)[1]	3-5	7-9
Mean nitrogen content N_{tot} ($mg\ dm^{-3}$)[2]	1.3	1.3
Mean phosphorus content P_{tot} ($mg\ dm^{-3}$)[2]	0.089	0.099
Mean chlorophyll content ($\mu g\ dm^{-3}$)[2,3]	22.7	15.8

[1]data after Stawecki et al. (2007), [2]data after Pyka et al. (2007), [3]content in the epilimnion

The studies of the plankton were conducted in 2004-2005. Samples were collected at 1 m intervals from the 0-5 m layer from March to November in the deepest part of the lakes. Quantitative analysis of the phytoplankton was performed with an inverted microscope according to the Utermöhl method (1958) and international monitoring norms (Kelly 2004). Organisms, so-called units, were single cells, cenobia, colonies, and threads, and they were counted in sedimentation chambers (10 ml) using various magnifications: large taxa in the whole chamber at 100x; medium-sized taxa in 2-4 bands at 200x; nanoplankton in 100 fields at 400x. The biomass was calculated by measuring the volume of the cells (Pliński et al. 1984, Kawecka and Eloranta 1994). A Jenamed light microscope (Carl Zeiss Jena, Germany) was used to observe the phytoplankton in immersion oil at magnifications of 200x, 400x, and 1000x.

The frequency of the individual phytoplankton taxa was estimated, and species were classified according to the Tichler scale (Trojan 1975): incidental (0-25%), accessory (26-50%), permanent (51-75%), and absolutely permanent (76-100%). The Shannon-Weaver species diversity index was calculated based on the number (H_n') and biomass (H_b') of the taxa. The Pearson correlation coefficient was used to determine the dependence between the values of the diversity index. Significant changes in the value of the biomass of total phytoplankton in the waters of lakes Licheńskie and Ślesińskie were tested with the U Mann-Whitney test, which was designated for comparing two independent samples (groups) (Stanisz 2006).

Results

Taxa and frequency groups

The phytoplankton of Lake Licheńskie consisted of 280 taxa belonged to Chlorophyta, Cyanoprokaryota, Cryptophyta, Dinophyta, Euglenophyta, and Heterokontophyta (Table 2). The most taxa belonged to green algae (132), followed by diatoms (74)

Table 2

Number of species, varietes or forms of phytoplankton in Lake Licheńskie and Lake Ślesińskie in years 2004-2005

	Species, variety, form	
Phytoplankton group	Lake Licheńskie	Lake Ślesińskie
Cyanoprokaryota	34	31
Heterokontophyta:		
Chrysophyceae	5	3
Xanthophyceae	2	2
Bacillariophyceae	74	57
Euglenophyta	17	6
Dinophyta	9	8
Cryptophyta	7	6
Chlorophyta	132	127
Total	280	240

belonging to the phylum Heterokontophyta, and cyanophytes (34). Chrysophyceae and Xanthophyceae were the least common among the representatives of the lake phytoplankton. In Lake Ślesińskie at least 240 taxa were recognized (Table 2), with the most taxa represented by green algae (127), and the fewest among cryptophytes and euglenophytes (Table 2).

The frequency structure of the phytoplankton taxa in the two lakes differed, and in both lakes the majority of taxa had frequencies of less than 25%. In Lake Licheńskie the number of taxa in subsequent groups on the Tichler scale decreased significantly (Table 3), while in Lake Ślesińskie these changes were less pronounced (Table 4). The most taxa among the incidental species belonged to the green algae and diatom groups. All of the euglenophyte taxa occurred at frequencies not exceeding 50%, while those of the cryptophytes occurred in excess of 50%.

Table 3

The species frequency groups and the numbers of individuals in Lake Licheńskie over the growth seasons (from March to November) in years 2004-2005

	Species			
	absolutely constant	constant	accessory	accidental
Phytoplankton group	76-100%	51-75%	26-50%	0-25%
Cyanoprokaryota	-	1	13	20
Heterokontophyta:				
Chrysophyceae	-	-	2	3
Xanthophyceae	-	-	1	1
Bacillariophyceae	3	12	20	39
Euglenophyta	-	-	3	14
Dinophyta	-	1	5	3
Cryptophyta	3	3	-	1
Chlorophyta	4	15	23	90
Total	10	32	67	171

Table 4
The species frequency groups and the numbers of individuals in Lake Ślesińskie over the growth seasons (from March to November) in years 2004-2005

	Species			
	absolutely constant	constant	accessory	accidental
Phytoplankton group	76-100%	51-75%	26-50%	0-25%
Cyanoprokaryota	2	6	11	12
Heterokontophyta				
Chrysophyceae	-	-	1	2
Xanthophyceae	-	1	1	-
Bacillariophyceae	10	11	10	26
Euglenophyta	-	-	-	6
Dinophyta	4	2	1	1
Cryptophyta	4	2	-	-
Chlorophyta	20	20	21	66
Total	40	42	45	113

Ten taxa were confirmed to be absolutely permanent in Lake Licheńskie, and five of these occurred at 100% frequency. These were *Fragilaria ulna* (Nitzsch) Lange-Bertalot var. *ulna*, *Pediastrum boryanum* (Turp.) Menegh., *P. duplex* Meyen, *Cryptomonas erosa* Ehr., and *C. rostrata* Troitz. emend. I. Kis. In Lake Ślesińskie, there were 40 absolutely permanent taxa, among which nine occurred at 100% frequency. These were *F. crotonensis* Kitt., *Chlamydomonas* sp., *P. boryanum*, *P. duplex*, *Planctonema lauterbornii* Schmidle, *Scenedesmus* sp., *Chroomonas acuta* Unterm., *C. rostrata*, and *Rhodomonas* sp.

Phytoplankton biomass

The overall phytoplankton biomass in Lake Licheńskie in 2004 ranged from 0.7 (November) to 5.8 mg dm^{-3} (April) (Table 5), but in 2005 the phytoplankton developed most intensively in March (8.6 mg dm^{-3}). From April to September, the

Table 5
Seasonal total phytoplankton biomass (mg dm^{-3}) in lakes Licheńskie and Ślesińskie in years 2004-2005 (mean ± SD)

	Lake Licheńskie		Lake Ślesińskie	
	2004	2005	2004	2005
March	3.52	8.59	13.24	nd
April	5.77	2.83	5.49	3.41
May	1.24	2.01	0.43	1.30
June	3.83	2.99	2.21	3.07
August	2.48	3.41	1.04	2.62
September	3.55	2.86	6.39	3.26
October	2.63	0.92	4.01	6.10
November	0.67	0.91	1.05	0.43
Mean ± SD	2.96 ± 1.60	2.98 ± 2.52	4.23 ± 4.25	2.88 ± 1.80

nd – no date

Table 6
Dominant species (≥10% total biomass) of phytoplankton in Lake Licheńskie during the growth season in years 2004-2005

	2004	2005
March	*Stephanodiscus hantzschii* (19%)	*Cyclotella* sp.+*Stephanodiscus hantzschii* (76%)
	Peridinium sp. (15%)	*Stephanodiscus neoastrea* (11%)
	Cyclotella cf *stelligera* (14%)	
	Cyclotella sp. (14%)	
April	*Cyclotella* sp. (40%)	*Stephanodiscus neoastrea* (28%)
	Cyclotella comta (31%)	*Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (23%)
		Chroomonas acuta (11%)
		Chlorella sp. (11%)
May	*Cyclotella* sp. (18%)	*Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (26%)
	Peridinium sp. div. (14%)	*Cyclotella* sp.+*Stephanodiscus neoastrea* (23%)
	Cryptomonas rostrata+*C. erosa*+*C. marssonii* (11%)	*Chroomonas acuta* (14%)
	Stephanodiscus hantschii+*S. neoastrea* (11%)	
June	*Stephanodiscus hantschii*+*S. neoastrea* (35%)	*Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (18%)
	Cyclotella cf *stelligera* (14%)	*Scenedesmus* sp.+*S. quadricauda* (15%)
		Peridinium sp. div. (12%)
August	*Cyclotella* sp. (27%)	*Cyclotella* sp. (15%)
	Planctonema lauterbornii (15%)	*Nitzschia pusilla*+*N. palea* (11%)
	Stephanodiscus hantschii+*S. neoastrea* (11%)	*Aulacoseira granulata*+*A. islandica* (10%)
	Nitzschia pusilla+*N. palea* (10%)	
September	*Cyclotella* cf *stelliger*a (36%)	*Nitzschia* sp. (14%)
	Cryptomonas rostrata+*C. erosa*+*C. marssonii* (16%)	*Cyclotella* sp. (12%)
		Aphanocapsa incerta (11%)
		Anabaena sphaerica f. *conoidea* (11%)
		Cryptomonas rostrata+*C. erosa*+*C. marssonii* (11%)
October	*Fragilaria capitata*+*F. ulna* var. *ulna* (53%)	*Cyclotella* sp. (21%)
		Cryptomonas rostrata+*C. erosa*+*C. marssonii* (19%)
November	*Oocystis marssonii* (37%)	*Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (23%)
	Fragilaria ulna var. *ulna* (21%)	*Stephanodiscus hantschii*+*S. neoastrea* (18%)
	Stephanodiscus hantschii+*S. neoastrea* (15%)	*Cyclotella* sp. (14%)
		Chroomonas acuta (14%)

phytoplankton biomass was similar to that in 2004; however, the minimum in November 2005 was about fourfold lower.

In Lake Ślesińskie in 2004 the overall phytoplankton biomass ranged from 0.4 (May) to 13.2 mg dm^{-3} (March) (Table 5). A second, twofold smaller planktonic alga biomass peak was noted in September. In October, a quite high phytoplankton biomass was still noted, but in November, like in August, there was only 1.0 mg dm^{-3}. The maximum phytoplankton biomass was 6.1 mg dm^{-3}, but this was not noted until October. There was no statistically significant difference in the phytoplankton biomass in either lake (U test = 99.0, N = 30, P = 0.576).

Phytoplankton composition

The structure of the planktonic algae in Lake Licheńskie in the studied years was variable. In March and April 2004, the phytoplankton observed was

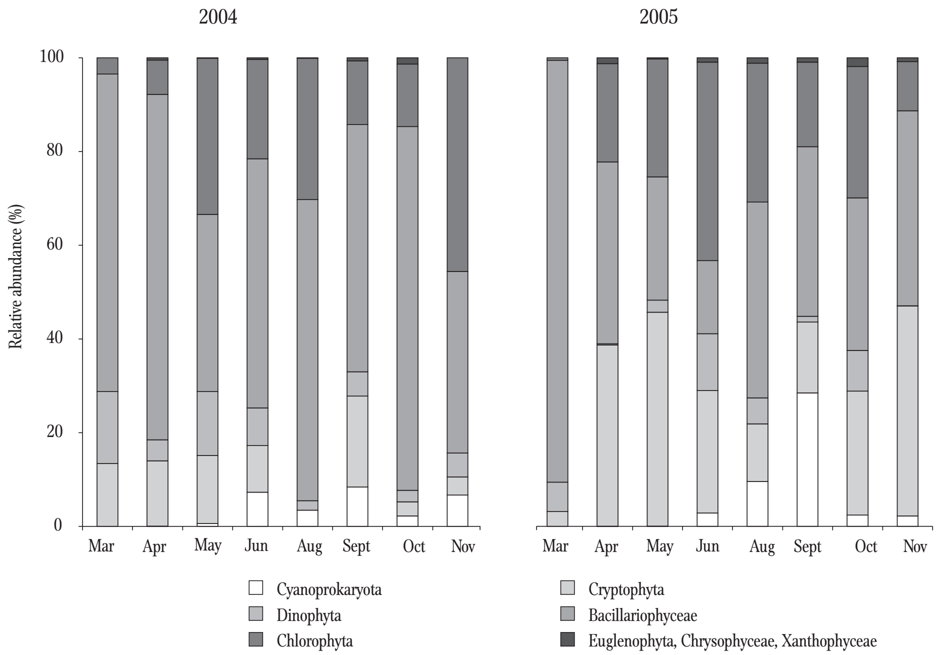

Figure 1. Phytoplankton composition in Lake Licheńskie in 2004-2005.

mainly comprised of diatoms, while from May to November it was comprised of diatoms and green algae (Fig. 1). The assemblages were dominated mainly by diatoms: *Stephanodiscus hantzschii* Grun. (in Cl. & Grun.), *S. neoastrea* Håk. et Hick., *F. ulna, F. capitata* Ehr., and *Cyclotella* sp., *C.* cf *stelligera*, *Nitzschia pusilla* Grun., and *N. palea* (Kütz.) W. Smith (Table 6). Green algae were also numerous, including *Oocystis marssonii* Lemm., *Scenedesmus quadicauda* (Turp.) Bréb. sensu Chod., *S. acuminatus* (Lagerh.) Chod., *S. intermedius* Chod., and *Planctonema lauterbornii*. Among the remaining groups of planktonic algae, the greatest share was of cryptophytes, mainly of the genus *Cryptomonas*, and dinophytes.

The diatom structure of the algal phytoplankton in March 2005 was remarkable, with *S. neoastrea*, *S. hantzschii*, and *Cyclotella* sp. comprising the bulk of the biomass (Table 6). As early as in April, the dominants were diatoms, cryptophytes, and green algae. Along with species from the genus *Stephanodiscus*, the small cryptophytes *Cryptomonas rostrata*, *C. erosa*, *C. ovata* Ehr., *C. marssonii* Skuja, and *Chroomonas acuta* developed abundantly. The green alga *Chlorella* sp. also contributed a large share. The phytoplankton structure changed very similarly in the subsequent two months, with slight differences in the increasing role of *Chlorophyta*, the declining significance of *Bacillariophyceae* in the lakes, and the increasing share of *Cryptophyta* (in May). In June abundant representatives of the genera *Cryptomonas*, *Scenedesmus*, and *Peridinium* were noted. From August to November, *Bacillariophyceae* developed the most intensively and co-dominated with green algae (August, October), cyanophytes (September), and cryptophytes (October, November). At this time, the largest diatom biomass was comprised of species from the genera *Cyclotella*, *Nitzschia*, and *Stephanodiscus*, similarly to the assemblage of 2004, and *Aulacoseira granulata* (Ehr.) Sim. and *A. islandica* (O. Müll.) Sim. Among cyanophytes, the most intense development was noted for *Aphanocapsa incerta* (Lemm.) Cronb. et Kom., *Anabaena sphaerica* Born. et Flah. f. *conoidea* Elenk., *A. flos-aquae* (Lyngb.) Bréb. ex Born. et Flah., *A. solitaria* Kleb., *A. affinis* Lemm., and *A. spiroides* Kleb.

Diatom phytoplankton was observed in Lake Ślesińskie in spring and fall 2004 similarly to that in Lake Licheńskie, except in November (Fig. 2). The assemblage was dominated by the same species from the genera *Stephanodiscus*, *Cyclotella*, *Fragilaria*, and *Aulacoseira* as well as *Asterionella formosa*

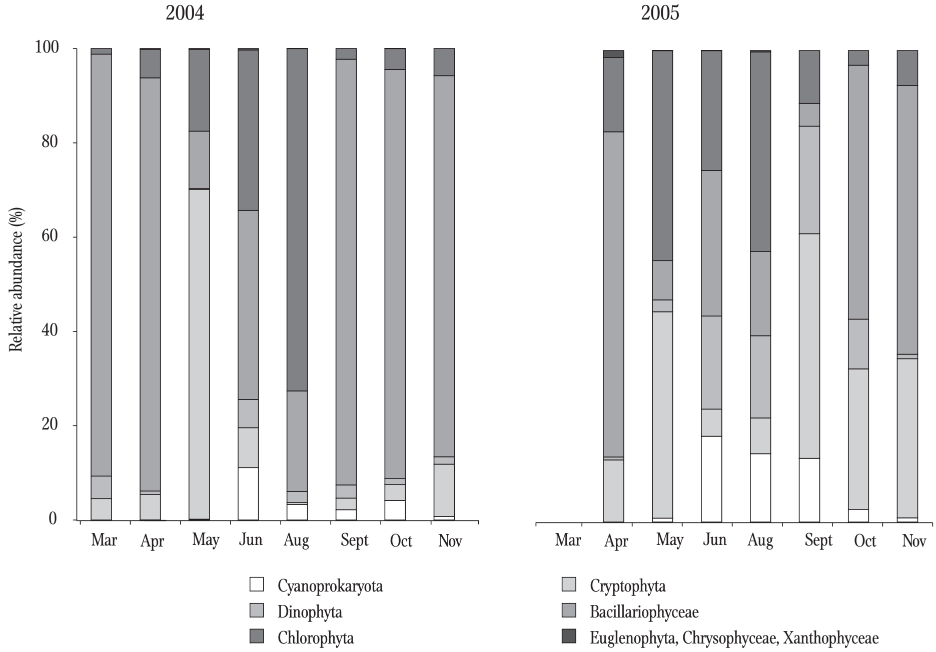

Figure 2. Phytoplankton composition in Lake Ślesińskie in 2004-2005.

Table 7

Dominant species (≥10% total biomass) of phytoplankton in Lake Ślesińskie during the growth season in years 2004-2005

	2004	2005
March	*Stephanodiscus neoastrea* (63%)	
	Cyclotella cf *stelligera* (25%)	
April	*Stephanodiscus hantschii+S. neoastrea* (66%)	*Stephanodiscus neoastrea* (58%)
May	*Chroomonas acuta* (54%)	*Chroomonas acuta* (38%)
	Cryptomonas rostrata+C. erosa+C. marssonii (15%)	*Chlamydomonas* sp. div. (20%)
June	*Stephanodiscus hantschii+S. neoastrea* (16%)	*Stephanodiscus neoastrea* (16%)
	Planctonema lauterbornii (13%)	*Ceratium hirundinella+C. furcoides* (14%)
	Aulacoseira granulata (10%)	*Aphanocapsa incerta* (10%)
August	*Planctonema lauterbornii* (42%)	*Planctonema lauterbornii* (13%)
		Anabaena solitaria (11%)
		Ceratium hirundinella+C. furcoides (11%)
September	*Fragilaria ulna* var. *ulna* (74%)	*Cryptomonas rostrata+C. erosa+C. marssonii* (38%)
	Aulacoseira granulata (10%)	*Peridinium* sp. div. (15%)
October	*Aulacoseira granulata* (77%)	*Stephanodiscus neoastrea* (48%)
		Cryptomonas rostrata+C. erosa+C. marssonii (27%)
		Peridinium sp. div. (10%)
November	*Aulacoseira granulata* (49%)	*Stephanodiscus neoastrea* (47%)
	Stephanodiscus hantschii+S. neoastrea (14%)	*Cryptomonas rostrata+C. erosa+C. marssonii* (25%)
	Asterionella formosa (12%)	

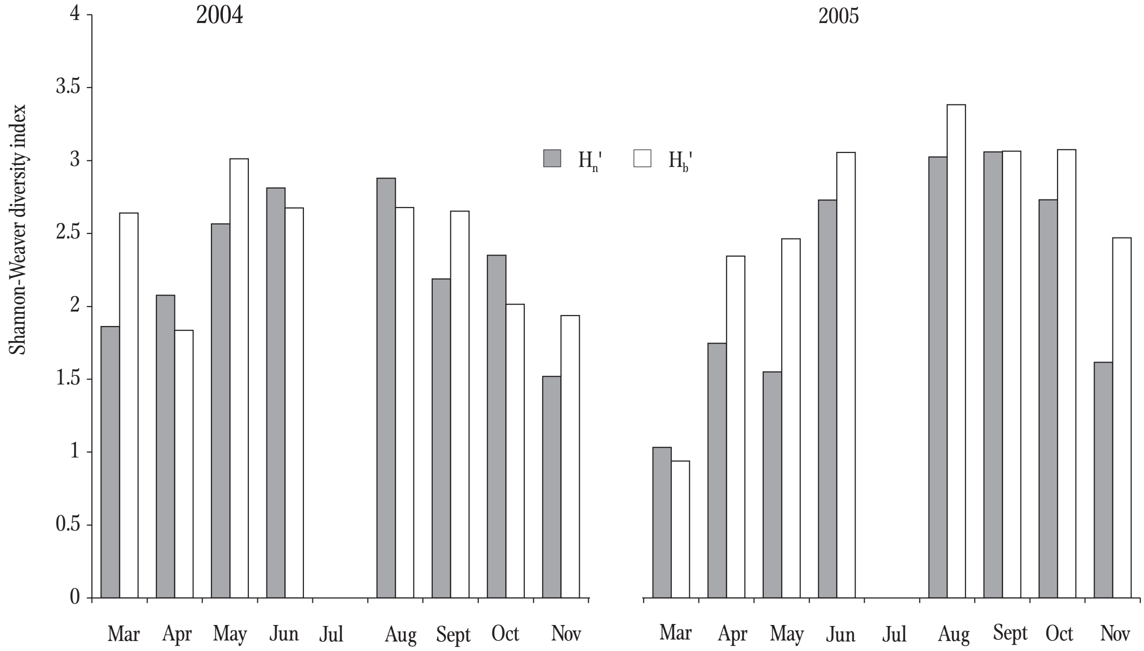

Figure 3. Shannon-Weaver diversity index based on the taxa numbers (H_n') and biomass (H_b') of phytoplankton in Lake Licheńskie in 2004-2005.

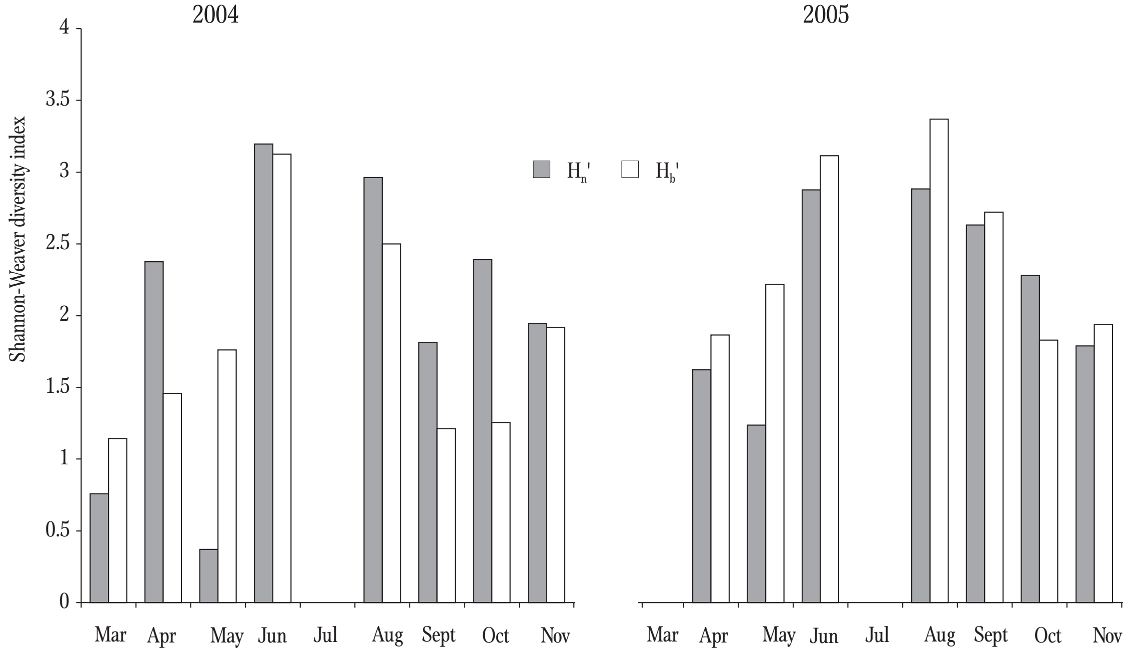

Figure 4. Shannon-Weaver diversity index based on the taxa numbers (H_n') and biomass (H_b') of phytoplankton in Lake Ślesińskie in 2004-2005.

Hass. (Table 7). In May the most intense development was noted among small cryptophytes from the genera *Chroomonas* and *Cryptomonas*. However, in June and August the phytoplankton was dominated by green algae and diatoms. The highest mass was formed at this time by diatoms of the genera *Stephanodiscus* and *Aulacoseira* as well as the filamentous green algae *Planctonema*. In April and May 2005 the phytoplankton was comprised primarily of diatoms, green algae, and cryptophytes (Fig. 2);

however, their respective shares of the overall biomass were variable. The algal plankton assemblage was totally different in summer. In June and August dinophytes, *Ceratium hirundinella* (O. F. Müll.) Duj. and *C. furcoides* (Lev.) Langh., and cyanophytes (*Aphanocapsa incerta* and *Anabaena solitaria*) co-dominated with diatoms (mainly *S. neoastrea*) and green algae (*Planctonema lauterbornii*). Cryptophytes, mainly from the genus *Cryptomonas*, contributed the largest share to the biomass in September. Dinophytes, including *Peridinium* sp. div., as well as cyanophytes and green algae made quite large contributions. Similarly to the assemblage in Lake Licheńskie, the phytoplankton was co-dominated by diatoms and cryptophytes in October and November.

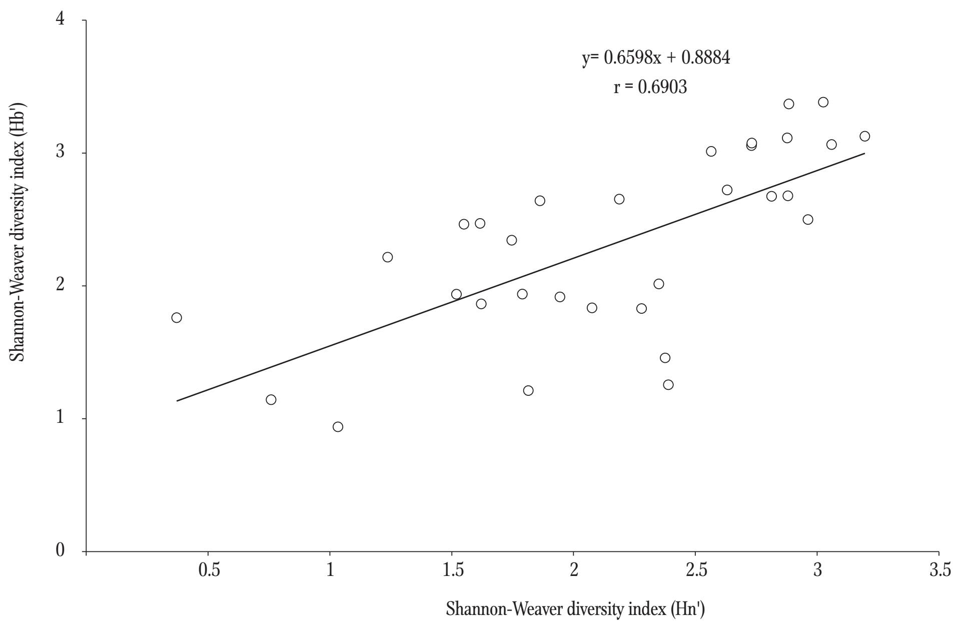

Figure 5. Relationship between the Shannon-Weaver diversity indices of taxa numbers (H_n') and biomass (H_b') of the phytoplankton in Lake Licheńskie and Lake Ślesińskie.

Phytoplankton diversity

The Shannon-Weaver index of diversity (H_n') in Lake Licheńskie ranged from 1.03 to 3.06 at a mean of 2.23 (Fig. 3), while that of biomass (H_b') fluctuated from 0.94 to 3.38 (mean 2.52). In turn, H_n' in Lake Ślesińskie ranged from 0.37 to 3.20 at a mean of 2.08, while H_b' ranged from 1.14 to 3.37, at a mean for the 2004-2005 period of 2.10 (Fig. 4).

The lowest species diversity was observed in both lakes in spring when phytoplankton biomass was the highest, while the greatest species diversity was noted in summer. Larger differences in the value of this index for number and biomass were noted in Lake Licheńskie, which indicates that small forms of nanoplankton occurred less abundantly than they did in Lake Ślesińskie. There was, however, a strong positive correlation between the values calculated based on number and biomass (Pearson correlation, N = 62, r = 0.690; Fig. 5).

Discussion

The dynamics and structure of the phytoplankton assemblages throughout the growing season in the Konin lakes is shaped mainly by the impact of higher water temperatures, productivity, and the high water flow rates (Socha and Hutorowicz 2009). The varied impact of these factors was reflected in the phytoplankton development in Lake Licheńskie that differed slightly from that in Lake Ślesińskie. These differences referred primarily to the numbers of taxa and their relationships with the biocoenosis based on frequency in the studied assemblage. In the warmer ecosystem of Lake Licheńskie, about 15% more taxa were generally noted than in Lake Ślesińskie, including more diatoms, euglenophytes, and green algae. The higher temperature, faster water exchange, lack of ice cover (Stawecki et al. 2007), and the quite shallow maximum and mean depths were advantageous for taxonomic diversity of the algal phytoplankton in Lake Licheńskie. The greatest share of taxa belonged to the group of incidental species (frequency from 0 to 25%), and these were observed mainly in spring (Lake Licheńskie) and summer (Lake Ślesińskie). Absolutely permanent species that occurred throughout the growing season were noted in the smallest numbers. In Lake Licheńskie there were only 10 such taxa, while in Lake Ślesińskie there were 40, among which 5 and 9 species, respectively, occurred at frequencies of 100%. These were primarily species that are widely distributed, frequent plankton components, cosmopolitan, and ubiquitous (Bucka and Wilk-Woźniak 2002).

The phytoplankton in the lakes in 2004 and 2005 were quite similar, particularly with regard to overall biomass. The slight differentiation in phytoplankton dynamics during the growing season was impacted by the mixing in these two lakes. In Lake Licheńskie, which has features of a monomictic lake and is also the most intensely heated of the Konin lakes (Stawecki et al. 2007), the phytoplankton dynamics were characterized by the occurrence of one peak in March or April, with a dominance of diatoms. Although the maximum biomass value noted in March 2005 is characteristic of eutrophic lakes (Spodniewska 1978, 1979), the course of changes in abundance was most indicative of the development of planktonic algae in basins with poor food resources (Oleksowicz 1988). The dynamics of zooplankton development in Lake Licheńskie was similar to that observed in in the 1970s, 1980s, and in the early 1990s (Sosnowska 1988, Socha 1994, 1997). According to authors, exceptions were observed in 1990 and 1993 when the maximum biomass was, respectively, two- and threefold higher than the maximum noted in the present paper. According to Socha and Hutorowicz (2009), a second peak of similar biomass levels was observed in July from 2000 to 2003.

Two peaks were observed in the dimictic Lake Ślesińskie in 2004; the first was in March and the second, which was about twofold lower, in September. In accordance with a model developed by the Plankton Ecology Group, this is typical of eutrophic lakes in the temperate zone (Sommer et al. 1986, Kawecka and Eloranta 1994). The development of phytoplankton from 1989 to 1993 was similar, however, the biomass was a maximum of twofold larger (Socha 1994, 1997). In the 1960s only one peak in biomass was observed in summer (Sosnowska 1988). In the 2004-2005 period, the biomass of the Lake Ślesińskie phytoplankton was a maximum of approximately 13.0 mg dm^{-3}, similar abundance was observed in 1965-1970, 1977-1980, 1983-1984, and 1991 (Spodniewska 1984, Sosnowska 1987, Simm 1988 cited in Socha 1994, Socha 1997). The maximum noted in March 2004 substantially exceeded the biomass limit (8.0 mg dm^{-3}) that is noted for eutrophic lakes in the Mazurian Lakeland (Spodniewska 1978, 1979).

Substantially higher maximum phytoplankton biomass in both lakes (49.3 mg dm^{-3} in Licheńskie and 46.7 mg dm^{-3} in Ślesińskie) was noted from 1994 to 2003 (Socha and Hutorowicz 2009). Changes in the quantitative analysis methods applied to the phytoplankton could have influenced certain divergences in the ranges of abundance noted in 2004-2005. However, analogous higher mean contents of chlorophyll a and seston were confirmed with maxima in 1994 and 2003 followed by another decrease in 2004 (Skawińska 1998, Pyka et al. 2007). The possibility of increased algal phytoplankton development in this period was also indicated by the mean value of Secchi disk visibility (Pyka et al. 2007).

Throughout the growing season in Lake Licheńskie in 2004 the phytoplankton assemblage observed was comprised of diatoms and green algae, while in 2005 it was comprised of diatoms, green algae, and cryptophytes. This was linked with the intense mixing of lake waters. While in 1989-2003 the most intense development was noted in diatoms and cryptophytes (admittedly the same species as in 2004-2005), and the share of green algae in the phytoplankton biomass was about or under 10%, but in summer it increased sporadically to 30% (Socha 1994, 1997, Socha and Hutorowicz 2009). The increased share of green algae in 2004-2005 throughout the growing season was linked mainly to the development of organisms of the genus *Oocystis* (cosmopolitan) and *Scenedesmus*, including species that often develop in meso- and eutrophic basins and which tolerate high temperatures (Huber-Pestalozzi 1983, Socha 1993, Bucka and Wilk-Woźniak 2002). *Scenedesmus quadricauda* and *S. acuminatus* are in very high permanence of occurrence classes in the Warta River (Sitkowska and Dukowska 1999), which is connected to the Konin lakes system by the Warta-Gopło Canal. The intense development of the filamentous green alga, *Planctonema lauterbornii*, mainly in August 2004 is a phenomenon that has been observed since the 1970s in both lakes Licheńskie and Ślesińskie (Spodniewska 1984, Simm 1988 cited in Socha 1993). The upward trend in the biomass of green algae in Lake Licheńskie was linked to the heating of the water (Stawecki et al. 2007).

The development of cyanophytes in the summer months was more intense in 2005 (maximum to 29% of total biomass) than in 2004 (up to 8%); however, it was much lower than that in the 1989-1993 period (up to 50%; Socha 1994, 1997). Similarly, the dominant was *Aphanocapsa incerta*, which also developed on a mass scale in the 1970s and in the second half of the 1980s (Spodniewska 1984, cited in Socha 1993, Sosnowska 1988, Socha 1993). The greatest contributions to the biomass from the genus *Anabaena* were made by *A. sphaerica* f. *conoidea*, although *A. flos-aquae*, *A. solitaria*, *A. affinis* and *A. spiroides*, which dominated in the heated Konin lakes in the 1991-1993 period, were also present (Socha 1994). A similar relation in changes of abundance occurred among dinophytes (up to 14% of the biomass in the 2004-2005 period and 35% in the 1989-1993 period) (Socha 1994, 1997). At this time, however, the dominants were probably species from the genera *Peridinium* and *Ceratium*.

The series of studies from the 1989-2003 (Socha 1994, 1997, Socha and Hutorowicz 2009) and 2004-2005 periods indicated great similarity in the phytoplankton structure in Lake Ślesińskie. In spring and summer, diatoms developed the most intensively. In May, when the water was clean and the lake was included in the water cooling system, the nanoplankton cryptophytes of the genera *Cryptomonas* and *Chroomonas* made the largest contribution to the biomass. These rapidly reproducing pioneer algae are highly adaptable. Their *r* life strategy permits them to dominate environments quickly after the collapse of alga development, and they play a linking role in the succession of summer phytoplankton (Szyszka 1990). Exceptionally in May 2005 the greatest share of the biomass was formed by green algae (45%). Higher green alga biomass was registered in the summers of 2004 and 2005. The increase in the biomass of *Chlorophyta* was also noted after the waters of Lake Ślesińskie began to be heated in 1970 (Sosnowska 1988). The filamentous green algae *Planctonema lauterbornii*, which developed most intensively in August and to a greater degree than in Lake Licheńskie, dominated the phytoplankton as quickly as in the 1970s and 1980s (Spodniewska 1984, Simm 1988 cited in Socha 1993). A different phytoplankton structure was observed in September; diatoms dominated (90%) in 2004 as they had in 1990, while cryptophytes and dinophytes were dominant in 2005, and dinophytes comprised about 60% of the biomass in 1995-1999, but the co-dominants were diatoms and cryptophytes in 2000-2003.

With regard to Lake Licheńskie, the mass development of the same small species of centric diatoms of the genera *Stephanodiscus* and *Cyclotella*, created a biomass that substantially exceeded the border limit of 3.0 mg dm^{-3} (Antaeus 1984). These diatoms are excellent at adapting to environmental turbulence. Small, flagellate forms of cryptophytes and green algae (with *r* life strategies) also occurred in the phytoplankton and dominated when conditions were unstable (Reynolds 1984). The greatest differences regarded the structure of the algal plankton that was prominent from May to September. This was noted in either the greater or smaller shares in the overall biomass of cryptophytes, diatoms, green algae, and cyanophytes. Additionally, in Lake Ślesińskie, lower values of the species diversity index were usually noted. However, the mean averages in both lakes indicated that, according to the water quality classification for the Shannon-Weaver index (Wilhm 1975 cited in Junshum et al. 2008), the waters were moderately polluted. Diversity indices based on biomass were usually higher than those based on numbers, but in Lake Ślesińskie similar values confirmed that the most frequently occurring organisms were small nanoplankton. The greatest phytoplankton taxonomic diversity in both lakes was observed in the summer months, which is linked to seasonality, and thus, with water temperature.

The phytoplankton of lakes Licheńskie and Ślesińskie was shaped by the different characteristics of these two basins, including their morphometrics, mixing type, water retention time, oxygen content, thermal regime, and the bioavailability of phosphorus (Zdanowski and Korycka 1976, Zdanowski 1994, Zdanowski, Prusik 1994, Stawecki et al. 2004, Pyka et al. 2007, Stawecki et al. 2007). Differences in the phytoplankton of the two lakes was determined mainly by the number of taxa and their frequencies, including mainly the occurrence of absolutely permanent and permanent species, as well as the composition of the summer assemblage. The dependencies were confirmed by the various values of the Shannon-Weaver index. A fairly high degree of similarity was noted in the overall biomass as well as phytoplankton structure in the spring and fall.

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Streszczenie

Różnorodność i dynamika fitoplanktonu w jeziorach Licheńskim i Ślesińskim w latach 2004-2005

Na podstawie ilościowej i jakościowej analizy fitoplanktonu (skład gatunkowy, różnorodność taksonomiczna, biomasa ogólna wraz ze strukturą dominacji) wykazano podobieństwa i różnice rozwijającego się planktonu roślinnego w jeziorach Licheńskim i Ślesińskim. Badania prowadzono od marca do listopada w latach 2004-2005. Zidentyfikowano odpowiednio: 280 (J. Licheńskie) oraz 240 taksonów (J. Ślesińskie), które należały do 6 gromad: *Chlorophyta*, *Cyanoprokaryota*, *Cryptophyta*, *Dinophyta*, *Euglenophyta* oraz *Heterokontophyta*. Większość taksonów należała do gatunków przypadkowych, z frekwencją 0-25%. W J. Ślesińskim zaobserwowano ponadto większą liczbę gatunków absolutnie stałych i stałych niż w J. Licheńskim.

W Jeziorze Licheńskim glony planktonowe utworzyły biomasę w zakresie od 0,2 do 8,6 mg dm^{-3}. W całym sezonie wegetacyjnym 2004 roku obserwowano fitoplankton o charakterze okrzemkowo-zielenicowym, a w 2005 roku okrzemkowo-zielenicowo-kryptofitowym. W Jeziorze Ślesińskim fitoplankton utworzył biomasę w zakresie od 0,4 do 13,2 mg dm^{-3}. Wiosną i jesienią w zbiorowiskach dominowały okrzemki (54-90%), natomiast latem współdominowały okrzemki i zielenice w 2004 roku oraz kryptofity, dinofity i sinice w 2005 roku. Wartości wskaźnika różnorodności Shannona-Weavera w Jeziorze Licheńskim średnio wynosiły: H_n' – 2,23; H_b' – 2,52, natomiast w Jeziorze Ślesińskim były niższe – H_n' – 2,08; H_b' – 2,10.

Fitoplankton Jeziora Licheńskiego i Ślesińskiego kształtował się w obliczu odmiennych cech tych zbiorników, uwzględniających morfometrię, typ mieszania, czas retencji wody, zawartość tlenu, termikę wód oraz biodostępność fosforu. O odrębności planktonu roślinnego w obu jeziorach zadecydowała głównie różna liczebność i frekwencja taksonów oraz skład letniego zbiorowiska. Potwierdzeniem stały się różne wartości wskaźnika różnorodności gatunkowej Shannona-Weavera. Dość duże podobieństwo stwierdzono natomiast pod względem biomasy ogólnej oraz struktury wiosennego i jesiennego fitoplanktonu.