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Spatial distribution of phytoplankton in macrophyte-dominated lake Długie

Przestrzenne rozmieszczenie fitoplanktonu w makrofitowym jeziorze Długie

SUMMARY

Studies on phytoplankton distribution were carried out in lake Długie during vegetation season (April–November) of 2000. Water was sampled monthly in four sites with different plant communities (S – *Scirpetum lacustris*, T – *Typhetum latifoliae,* M – *Myriophylletum spicati* and N – *Nuphareto-Nymphaeetum albae*). The analysis of phytoplankton comprised fresh biomass, chlorophyll-a concentration and domination structure. Additionally, there were measured physical and chemical factors (temperature, pH, conductivity, alkalinity, TP, TN, DIN and A_{254}). Phytoplankton was dominated mainly by dinophyte and cyanobacteria species. The largest differences of phytoplankton abundance and their diversity were between the middle part of lake growing by submerged vegetation (M) and sites with rushes vegetation (S, T). Large differentiation of physical-chemical parameters between sites was observed only for nutrients concentration (higher phosphorus content in the middle part of the lake). Used CCA indicated that domination of flagellate species in spring was correlated with A_{254} and cyanobacteria species in summer with TP and PO_4.

STRESZCZENIE

Badania fitoplanktonu w jeziorze Długie wykonano w sezonie wegetacyjnym (kwiecień–listopad) 2004 r. Próby wody pobierano co miesiąc w czterech stanowiskach z różnymi zespołami roślin (S – *Scirpetum lacustris*, T – *Typhetum latifoliae*, M – *Myriophylletum spicati* and N – *Nuphareto-Nymphaeetum albae*). Analizy fitoplanktonu obejmowały pomiary świeżej biomasy i stężenia chlorofilu-a oraz ustalenie struktury dominacji. Dodatkowo mierzono fizyczno-chemiczne czynniki (pH, przewodność elektrolityczna, zasadowość, TP, TN, DIN i A_{254}). W fitoplanktonie dominowały głównie gatunki bruzdnic i cyjanobakterii. Największe zróżnicowanie w ilości i różnorodności fitoplanktonu występowało między środkową częścią jeziora porośniętą roślinnością zanurzoną (M) i stanowiskami szuwarowymi (S, T). Duże zróżnicowanie wśród parametrów fizyczno-chemicznych stwierdzono w przypadku stężenia nutrientów (wyższa zawartość fosforu w środkowej części jeziora). Wykorzystana CCA wykazała, że dominacja form wiciowcowych wiosną związana była z A_{254}, a gatunków cyjanobakterii latem z zawartością TP i PO_4.

Keywords: phytoplankton, macrophyte-dominated lake, spatial distribution

INTRODUCTION

Algae and macrophytes have a significant influence on the functioning of lakes. There is an interrelationship between them which can be realized by competition for light, nutrients and allelopathy. In meso- and moderate eutrophic lakes macrophytes gain the advantage mainly by shading, reducing nutrient concentrations, luxury uptake and enhanced denitrification. The domination of phytoplankton in most of eutrophic lakes is the result of the high availability to nutrients, especially in the spring period. Algae take nutrients from water more efficiently than plants and hence, their high growth can eliminate submersed vegetation by shading (20). The allelopathic substances can be produced by macrophytes as well as phytoplankton (26). The decrease of phytoplankton biomass can take place due to grazing by zooplankton. Some authors emphasize the role of plants which are used by zooplankton as a refuge against fish predation (9).

In macrophyte-dominated lakes the presence of vegetation influences spatial distribution of different phytoplankton community (14). The enhanced heterogeneity of habitats is mainly the result of lower wave motion and supports the process of organic matter deposition (23).

The aim of the paper is to investigate whether in macrophyte-dominated lake Długie the phytoplankton composition and biomass may be influenced by occurrence of diverse macrophyte associations. Special attention is paid to distribution of dominant species with regard to differentiation of physical-chemical properties of habitats.

STUDY AREA

Lake Długie is a nature reserve created for conservation of the adjacent peat bog. It is situated in the National Polesie Park (Łęczna-Włodawa Lakeland). This is a polymictic reservoir having the surface area of 28.4 ha and maximum depth of 1.3 m. According to Radwan and Kornijów (24) lake Długie is characterized as dystrophic.

The catchment belongs to one large area (426.15 ha) compared with other lakes of the Lakeland. In the catchment, forests (60%) and shrubs (16%) dominate but about 3% of the area is occupied also by wetlands. The low value of Ohle index (14.8) indicated that the lake is exposed to low influence by catchment (4). The lake is, however, subjected to negative influence by Wieprz-Krzna Channel (built in the 60's), which causes a decrease of water level in the lake (15).

Seventy per cent of the lake surface is overgrown by macrophytes, among which the majority is rushes vegetation (about 40%) with species like *Scirpus lacustris*, *Phragmittes australis*, *Typha latifolia*. Relatively small patchiness create plants with floating leaves (3%) such as *Nymphea alba* and *Nuphar lutea*. Submersed vegetation is represented only by one association *Myriophylletum spicati* (28%) occurring mainly in the middle part of the lake (29).

METHODS

Studies were carried out in the year 2000 between April and November. Water was sampled monthly from two sites with rushes vegetation (S – *Scirpetum lacustris* creating large patchiness within lake's area, T – *Typhetum latifoliae* occurred in the littoral), one from site with nymphaeid (N – *Nuphareto-Nymphaeetum albae*) and one from site with submerged vegetation (M – *Myriophylletum spicati*) (Fig. 1).

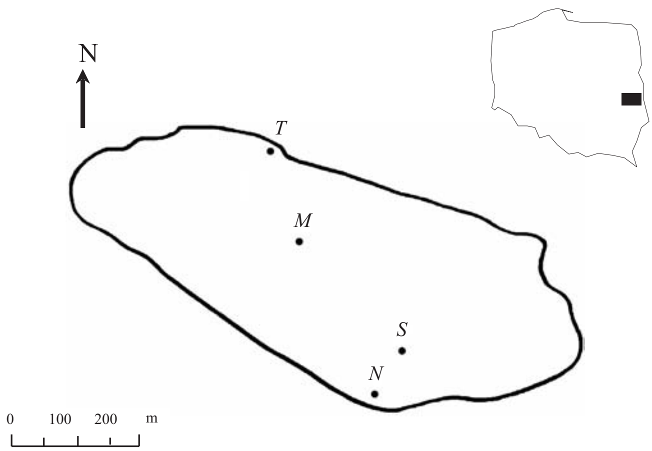

Fig. 1. Location of sampling sites in Lake Długie depending on domination of plant communities. T – *Typhetum latifoliae*, M – *Myriophylletum spicati*, S – *Scirpetum lacustris*, N – *Nuphar-Nymphaeetum albae*

Samples were taken with Ruttner type sampler (2 dm^3 volume) from which two subsamples were designated for later chemical and phytoplankton analysis. Direct measurements in the lake comprised temperature, pH and conductivity with automated probes. In the laboratory chemical analysis was conducted by using methods described by Hermanowicz et al. (6). Alkalinity was determined by titration method. Total phosphorus and nitrogen were determined after prior digestion and dissolved forms (phosphates, DIN – ammonium + nitrates) after filtration by GF/C Whatman membrane. All phosphorus and nitrogen compounds were determined by spectrophotometric methods. The absorbance of water at 254 nm was also measured as a relative content of dissolved organic matter.

Phytoplankton species was determined according to Starmach (27) and Anagnostidis and Komarek (1). Phytoplankton abundance was measured as chlorophyll-a concentration and estimation of fresh biomass. Chlorophyll-a concentration was determined spectrophotometrically according to Nusch (19). Phytoplankton abundance was estimated by Utermöhl method with an inverted microscope (31). Fresh biomass was calculated by measurements of phytoplankton cells and compared to adequate geometric figures for calculating their volumes (7). It was taken as the dominant species, one of contribution to total biomass > 30% (13). Phytoplankton diversity was estimated according to the formula of Shannon-Weaver index (10).

In a statistical analysis Canonical Correspondence Analysis (CCA) was used. Values of biomass were transformed (ln) to maintain normal distribution and to avoid "arch effect" (30). All computations were done with computer program MVSP 3.11 (11).

RESULTS

Phytoplankton abundance was analyzed on the basis of fresh biomass and chlorophyll-a concentration measurements. Fresh biomass ranged from 0.30 to 15.3 mg/dm^3 and chlorophyll-a concentrations varied between 4.2 and 98.6 µg/dm^3. Between these two parameters the high correlation was stated ($r = 0.88$, $p < 0.05$).

Phytoplankton biomass changed first of all seasonally. In spring the biomass was not higher than 3.2 mg/dm^3, in summer it increased about twice and in autumn dropped to 1–2 mg/dm^3 (Table 1). There was a small differentiation of biomass between sites. The biggest differences were mostly between the middle part of the lake (M) and other sites. In M-site the highest value of biomass was noted in spring and the lowest one in summer and autumn (Table 1). In autumn the lower biomass was also in T-site.

Among 43 species found in lake Długie there were identified everytime 32–34 taxa at each site (Table 3). Phytoplankton was dominated mainly by flagellates dinophytes and cyanobacteria species. Besides seasonal changes of phytoplankton composition there appeared significant differences of domination structure between sites (Fig. 2).

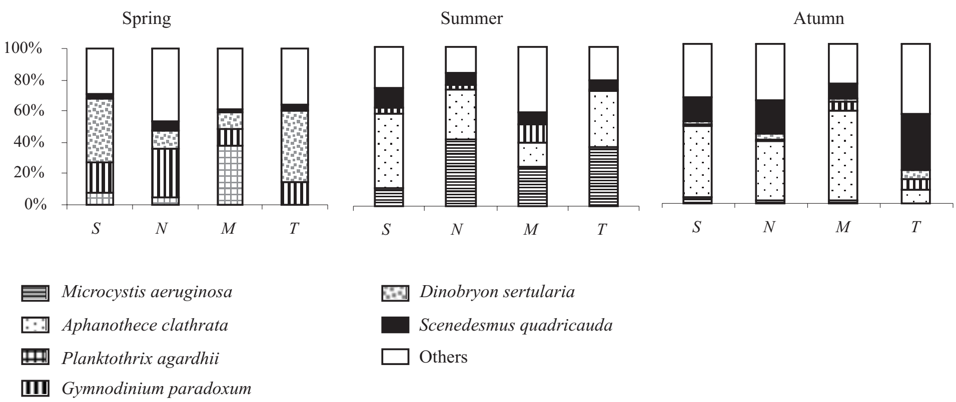

Fig. 2. Composition of dominant species in particular sites in lake Długie. T – *Typhetum latifoliae*, M – *Myriophylletum spicati*, S – *Scirpetum lacustris*, N – *Nuphar-Nymphaeetum albae*

During the spring in two sites with rushes vegetation (S and T) chrysophyte *Dinobryon sertularia* (Lemmermann) Krieger (41% and 46%, respectively) and in N-site *Gymnodinium paradoxum* Schilling (31%) dominated. In the site with elodeid *Myriophyllum spicatum* (M) cyanobacteria *Planktothrix agardhii* (Gom.) Anagh. et Kom. dominated, shared 38% of total biomass.

In summer two blue-green algae *Microcystis aeruginosa* Kütz. and *Aphanothece clathrata* W. et. G.S. West dominated. In M-site apart from blue-green algae, the high share reached dinophytes *Gymnodinium paradoxum, Peridinium bipes* Stein and *Ceratium hirundinella* (O. F. Müller) Dujardin (together 24%). Domination of *Aphanothece clathrata* was observed also in autumn except for T-site which was dominated only by *Scenedesmus quadricauda* (Turp.) Bréb. sensu Chod (35%).

The species richness and domination of one or two species influenced biodiversity expressed by Shannon-Weaver index (Table 1). In spring significant lower values of index were in sites with rushes vegetation. In summer the higher biodiversity was in the middle part of the lake and in autumn the indices reached similar values except for T-site.

Table 1. Physical-chemical parameters of water in particular sites in lake Długie

	Spring				Summer				Autumn			
	S	*N*	*M*	*T*	*S*	*N*	*M*	*T*	*S*	*N*	*M*	*T*
Biomass [$mg \cdot dm^{-3}$]	2.42	1.36	3.23	1.98	6.52	7.39	5.61	7.37	1.84	1.61	1.08	0.91
Chlorophyll-a [$\mu g \cdot dm^{-3}$]	11.3	15.7	16.7	11.2	71.0	51.6	49.0	75.6	38.1	17.6	6.9	19.1
Shannon-Weaver index	1.94	2.24	2.11	1.92	1.86	1.61	2.23	1.72	1.83	1.75	1.64	2.10
Eveness	0.65	0.81	0.69	0.64	0.59	0.49	0.68	0.54	0.60	0.63	0.59	0.69

T – *Typhetum latifoliae*, M – *Myriophylletum spicati*, S – *Scirpetum lacustris*, N – *Nuphar-Nymphaeetum albae*

Among basic physical-chemical properties of lake water, two groups of parameters can be distinguished (Table 2). The first group consists of parameters whose changes were seasonal (temperature, alkalinity, electrolytic conductivity, A_{254}). In the second group of parameters (pH, phosphorus and nitrogen compounds) horizontal differentiation between sites was also observed (Table 2).

The water reaction was mostly neutral. Only in M-site (summer, autumn) higher pH values (8.0–8.4) were noted. The largest differences between the sites were observed in nutrients concentrations (Table 2). In M-site the highest phosphate concentrations during study periods were noted and also TP concentration in spring. The mean total nitrogen concentrations ranged mostly between 2.0 and 2.7 mg/dm^3. Only the higher concentrations (> 3 mg/dm^3) were noted in S- and M-site (spring) and in T-site (summer, autumn). The small differentiation of dissolved inorganic nitrogen concentrations was observed between sites. Only in autumn the higher values were noted in M- and T-site. In spring and summer the concentrations in M-site were little lower because the nitrates decreased to an undetectable level (Table 2).

Table 2. Biological parameters of phytoplankton in particular sites in lake Długie

	Spring				Summer				Autumn			
	S	N	M	T	S	N	M	T	S	N	M	T
Temp [°C]	20	20	20	20	20	20	20	20	11	11	11	11
A_{254}	0.440	0.440	0.438	0.439	0.376	0.365	0.371	0.388	0.323	0.312	0.310	0.312
Alkalinity [mval]	0.98	0.85	0.87	1.00	1.2	1.1	1.2	1.1	1.4	1.0	1.0	1.1
pH	7.2	7.2	7.5	7.1	7.6	8.0	8.4	7.5	7.0	7.0	8.0	6.9
Conductivity [$\mu S \cdot cm^{-1}$]	142	148	147	237	175	216	169	179	195	172	155	161
TP [$mg \cdot dm^{-3}$]	0.072	0.086	0.115	0.062	0.076	0.083	0.090	0.095	0.039	0.096	0.060	0.056
P-PO4 [$mg \cdot dm^{-3}$]	0.007	0.014	0.020	0.005	0.012	0.010	0.015	0.010	0.010	0.009	0.019	0.011
TN [$mg \cdot dm^{-3}$]	3.7	2.1	3.6	1.0	2.0	2.0	2.5	3.3	2.2	2.7	2.7	3.4
$DIN_{(NH4+NO3)}$ [$mg \cdot dm^{-3}$]	0.84	0.87	0.77	1.00	1.06	0.99	0.87	1.06	1.01	0.95	1.70	1.58

T – *Typhetum latifoliae*, M – *Myriophylletum spicati*, S – *Scirpetum lacustris*, N – *Nuphar-Nymphaeetum albae*

In statistical analysis there was applied Canonical Correspondence Analysis in order to establish environmental variables mostly correlated with biomass of dominant species. From the ordination diagram it resulted that two groups of the distinguished variables explain 39% of variation (Fig. 3). The first group consists of phosphorus forms (TP, PO_4) which are positively correlated with bio-

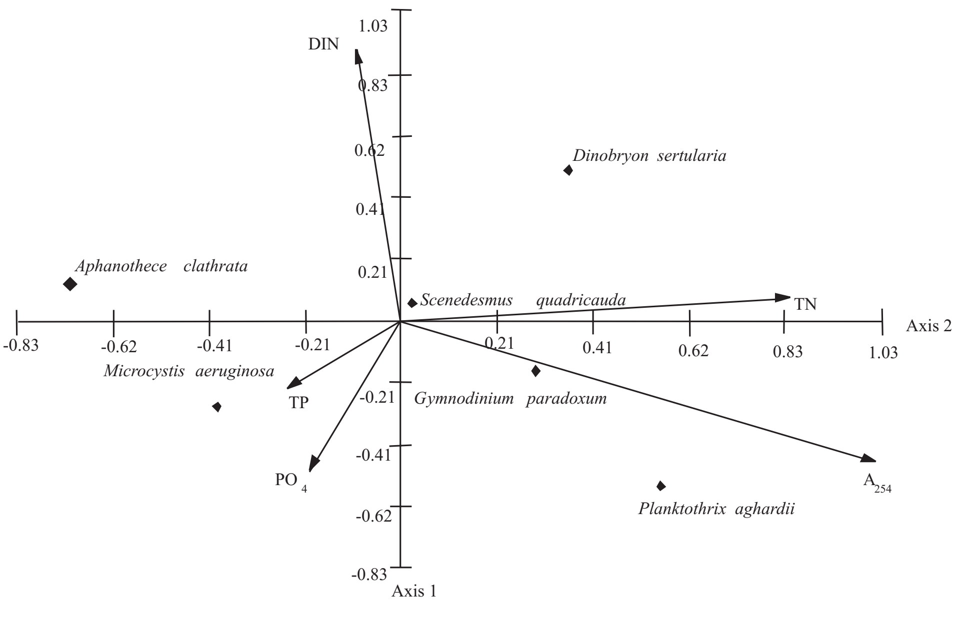

Fig. 3. Ordination diagram (CCA) of the dominant species in lake Długie in relation to axes I and II

mass of two blue-green algae *Microcystis aeruginosa* and *Aphanothece clathrata*. The other group consists of TN and A_{254}, which are positively correlated with *Planktothrix agardhii* and with flagellate forms: *Gymnodinium paradoxum* and to a lower degree with *Dinobryon sertularia*. There was lack of relationships for green-algae *Scenedesmus quadricauda* located at the beginning of the coordinates system.

Table 3. List of taxa in particular sites in lake Długie

Taxa	Sites			
	S	N	M	T
Cyanoprokaryota				
Merismopedia tenuissima Lemmermann		+	+	+
Chroococcus limneticus Lemmermann	+	+	+	+
Aphanothece clathrata W. et G.S. West	+	+	+	+
Microcystis aeruginosa Kützing	+	+	+	+
Arthrospira jenneri Sitzenberg ex Gomont				+
Planktothrix agardhii (Gom.) Anagh. et Kom.	+	+	+	
Euglenophyta				
Euglena acus Ehrenberg	+	+	+	+
Trachelomonas volvocina Ehrenberg	+	+	+	+
Trachelomonas sp.	+		+	
Phacus acuminatus Stokes	+			
Dinophyceae				
Gymnodinium paradoxum Schilling	+	+	+	+
Peridinium bipes Stein	+	+	+	+
Ceratium hirundinella (O.F. Müller) Dujardin	+	+	+	+
Cryptophyceae				
Cryptomonas marssonii Skuja	+	+	+	+
Chrysophyceae				
Dinobryon sertularia (Lemmermann) Krieger	+	+	+	+
Synura uvella Ehrenberg	+	+	+	
Bacillariophyceae				
Tabelaria fenestrata (Lyngbye) Kützing	+	+		
Fragilaria crotonensis Kitton	+		+	
Fragilaria ulna var. *ulna* (Kützing) Lange-Bertalot	+	+	+	+
Chlorophyta				
Coenococcus planctonicus Koršikov	+	+	+	+
Coenocystis planctonica Koršikov	+	+		
Eudorina elegans Ehrenberg			+	
Botryococcus braunii Kützing	+	+	+	+
Oocystis lacustris Chod.			+	+
Ankistrodesmus fusiformis Corda	+	+	+	+
Micractinium pusillum Fres.		+	+	
Crucigeniella apiculata (G.M. Smith) Kom.	+	+	+	+
Coleastrum cambricum Archer	+	+	+	+

Coleastrum sphaericum Nägeli	+	+	+	+
Pediastrum angulosum (Ehrenb.) Menegh.	+			
Pediastrum boryanum (Turp.) Menegh.	+	+	+	+
Pediastrum teras (Ehrenb.) Ralfs	+	+	+	+
Kirchneriella lunaris (Kirchn.) Moeb.	+	+	+	+
Quadrigula closterioides (Bohl.) Printz		+		
Tetraedron minimum (A.Br.) Hansg.	+			
Scenedesmus quadricauda (Turp.) Bréb.	+	+	+	+
Nephrocytium lunatum W. West		+		
Cosmarium humile (Gay) Nordstedt In de Tony				+
Cosmarium pyramidatum Brébisson in Ralfs	+	+	+	+
Cosmarium reniforme (Ralfs) Arch.	+	+	+	+
Staurastrum cuspidatum Brébisson ex Ralfs	+	+	+	+
Staurastrum pseudopelagicum W. et G.S. West	+	+	+	+
Closterium acutum Brébisson in Ralfs	+		+	

T – *Typhetum latifoliae*, M – *Myriophylletum spicati*, S – *Scirpetum lacustris*, N – *Nuphar-Nymphaeetum albae*

DISCUSSION

The study indicated a degree of phytoplankton differentiation between sites with different vegetation associations. Most differences were observed between the middle part of the lake overgrown with elodeid *Myriophyllum spicatum* and sites with rushes vegetations. Similar observations, but only for summer period, were made by Pełechaty and Owsianny (22). The rushes vegetation constitutes a barrier against too intensive water movements and it may form phytolittoral habitats with different water properties.

Except seasonal changes of phytoplankton composition, differences of species domination between sites also appeared. The studies of Kowalczewski and Pieczyńska (12) confirmed that flagellate forms prefer mainly the littoral zone with macrophyte vegetation. It also concerns the flagellates in lake Długie such as *Gymnodinium paradoxum* and *Dinobryon sertularia* dominating in spring in rushes sites. Additionally, the domination may be connected with the higher content of the organic matter (measured by A_{254}) indicating conditions of humic lake. Intensive flow from peat catchments is confirmed by systematic observations of the water level. The maximum occurs in spring and the decrease of the water level takes place in summer and autumn (16). The flagellates are the most important contributors to biomass in humic lakes because of broad ecological amplitude (8).

In spring, when the vegetation did not reach the optimum of its development in the middle part of the lake, phytoplankton reached the highest biomass and was dominated by blue-green algae *Planktothrix agardhii*. From the studies of Celewicz et al. (3) it can be concluded that phytoplankton reaches the high abundance in zones of lakes without vegetation and is subjected to domination of blue-green algae. The cyanobacteria *Planktothrix agardhii* is characteristic of low light conditions (25) and these conditions in lake Długie may be caused by higher contents of humic substances.

The domination of coccoidal blue-green algae (*Microcystis aeruginosa*, *Aphanothece clathrata*) occurred during the period of optimal macrophyte growth (summer) and also in autumn. The domination was conditioned by a higher content of phosphorus. This is the element commonly accepted as the main limiting factor for blue-green algae growth (4, 27). However, the phytoplankton biomass in the middle part of the lake was little lower than in other sites. There also followed the increase in the share of flagellate dinophytes (*Gymnodinium paradoxum*, *Peridinium bipes*, *Ceratium hirundinella*) and the decrease of the share of cyanobacteria species. Taking into account high availability to dissolved forms of phosphorus and nitrogen and also a lack of grazing pressure (too large sizes of colonial forms), this decrease may be connected with allelopathic interactions between blue-green algae and submerged vegetation. The allelopathic influence of *Myriophyllum spicatum* on *Microcystis aeruginosa* growth was observed by Nakai et al. (17, 18). The appearance of dinophytes after domination of blue-green algae in Lake Długie was observed by Wojciechowska and Krupa (30). These organisms reach the competitive advantage mainly by assimilation of the particular matter (mixotrophy) and the possibility of migration (2).

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