Teka Kom. Ochr. Kszt. Środ. Przyr. – OL PAN, 2013, 10, 291–305

PHYTOPLANKTON DIVERSITY RELATED TO HABITAT HETEROGENEITY OF SMALL AND SHALLOW HUMIC LAKE PŁOTYCZE (EASTERN POLAND)

Wojciech Pęczuła

Department of Hydrobiology, University of Life Sciences in Lublin
Dobrzańskiego str. 37, 20-062 Lublin, wojciech.peczula@up.lublin.pl

Co-financed by National Fund
for Environmental Protection
and Water Management

Summary. Qualitive and quantitive investigations of the phytoplankton community were carried out in a shallow and small humic Lake Płotycze (E Poland) to study horizontal variation relative to horizontal habitat differentiation as well as to answer the question which of the factors contribute to horizontal distribution of planktonic algae. Samples were taken during two growing seasons (1996–1997), four times a year from three different habitats along a horizontal transect: the open water, helophyte and *Sphagnum* zone, which were differentiated as to vegetation and water chemistry. Dominant groups and species were very similar in the open water and helophyte sites (greens with *Closterium acutum* as dominant) although they differed from those in the *Sphagnum* site (where various desmid species dominanated). However, the analysis of similarity showed that a list of species is common for all sites, but they appeared at various abundances and sampling ocassions. Canonical Correspondence Analysis revealed that pH and conductivity were the factors most responsible for phytoplankton differentiation in the studied transect.

Key words: phytoplankton, habitats, macrophytes, humic lake

INTRODUCTION

Macrophytes can strongly modify food webs in shallow lake ecosystems [Scheffer *et al.* 1993, Jeppesen *et al.* 1998] but they also play a structural role by creating complex habitats and by sustaining a high diversity of life forms [Vakkillainen 2005]. Although they are most important for epiphytic organisms, plankton communities are also connected with macrophyte habitats. Tychoplanktonic algae, like desmids, which usually live on macrophyte surfaces (as metaphyton) could temporarily acceded to the plankton communities, thus interlinking various habitats [Brook 1959]. A lot of studies have been performed to test the impact of macrophytes on phytoplankton communities. Interactions between these groups may cover: the competition for nutrients [Sondergaard and Moss 1998], the allelopathy [Jasser 1995, Gross 2003], the changing of resuspension and sedimentation rates [Balls *et al.* 1989] or the developing refugia for zooplankton, which, in turn, impacts the phytoplankton structure [Timms and Moss 1984, Lauridsen *et al*. 1998]. The majority of studies focus on the role of submerged macrophytes in shallow uncoloured lakes, usually in regard to the risk of eutrofication or the restoration of degraded lake ecosystems [for rewiev see: Van Donk and Van de Bund 2002]. Little is known about relationships between macrophytes and phytoplankton in humic lakes, in which – because of water pigmentation – specific vegetation occurs: emergent and floating leaves plants usually dominate but submerged vegetation is often very sparse. In the absence of vascular submerged plants the important role is played by mosses, including *Sphagnum*, which are known as „the ecosystem engineers" as they can strongly modify the water chemistry [Van Breemen 1995].

Although phytoplankton horizontal distribution in relation to within-lake heterogeneity was studied in large lakes [Tolonen *et al.* 2005], there is little detailed research concerning small and shallow water bodies [Wojciechowska and Solis 2001, Pełechaty and Owsianny 2003]. There is lack of studies on in-lake phytoplankton diversity in humic waters.

The paper aims to get the detailed description of phytoplankton diversity patterns in small humic lake in relation to its habitat heterogeneity as well as to answer the question which of the factors contribute to horizontal distribution of planktonic algae within the studied lake.

MATERIALS AND METHODS

The study was performed in Lake Płotycze, which is located in the polish part of Polesye Region (East European Plain). The lake is shallow (mean depth = 2.2 m, max depth = 6.0 m) and small (area = 0.16 km^2). It is surrounded by coniferous forests, shrubs and peatlands (70% of the catchment area) which in turn, determines the mesohumic character of the lake [Pęczuła 2002]. Only emergent vegetation in the near-shore zone was distinctly developed during the research. There were some patches of rushes, with *Schoenoplectus lacustris* (L.) PALLA and *Phragmittes australis* (Cav.) Trin. ex Steud. The water lilies were represented by *Nymphaea candida* C. Presl., and submerged plants by moss *Scorpidium scorpioides* (Hedw.) Limpr., in both cases very sparsely. On the southern shore the specific phytolittoral is formed by *Sphagnum magellanicum* Brid. with some vascular species (specified below).

Phytoplankton sampling was carried out during two ice-free seasons in 1996 and 1997 in May, June, August and September. Samples for biological and chemical analyses were taken (once a month) from three points representing three different habitats situated along the horizontal transect. The sampling points were: a) in the open water zone (PEL) in the center of the lake (of 6 m depth), b) amongst the helophytes (LIT1) and c) in the *Sphagnum* littoral (LIT2). Distances between the sites (PEL – LIT1 – LIT2) were ca. 100 and 20 m, respectively. Samples were taken from a surface layer (integrated sample between 0 and 0.5 m). Sites in the littoral zone were differentiated by vegetation: in the rush littoral (LIT1) *Schoenoplectus lacustris* dominated with dense *Scorpidium scorpioides* cover whereas the *Sphagnum* site (LIT2) was overgrown by *Sphagnum magellanicum* along with various *Carex* species as well as *Utricularia minor* L., *Eriophorum angustifolium* Honck., *Potentilla palustis* L. Scop. and *Menyanthes trifoliate* L..

Temperature, dissolved oxygen concentration, pH and conductivity were measured directly in the lake using electronic instruments (WTW OXI 96 oximeter, Elmetron CP-401 pH-meter, Elmetron CC-401 conductometer). Water for laboratory analyses was taken with a water sampler of 2 dm^3 capacity. From this, two sub-samples of 0.2 dm^3 for phytoplankton examination and chemical analyses and one of 1 dm^3 for chlorophyll *a* determination were taken. The abundance of phytoplankton was determined by means of an inverted microscope (Zeiss Axiovert), using Utermöhl's method [Vollenweider 1969]. In each sample the abundance of every algal species were determined, as well as the volume (and then the biomass), by comparing them with the appropriate geometrical solids [Hillebrand *et al*. 1999]. The chlorophyll *a* examination was carried by the ethanol method, and the final concentration of chlorophyll *a* was calculated using the Lorenzen's formula [Nusch 1980]. The concentrations of: calcium, nitrogen and phosphorus compounds were analysed according to Hermanowicz *et al.* [1976]. The UV absorbency was determined in the filtered water (acetate aldehyde filters with 0.45 um pores) with the use of Beckman UV-VIS spectrophotometer at a wavelength of 254 nm.

The species diversity was expressed as a Shannon-Wiener index, calculated on the basis of the natural logarithm. Cluster analysis based on the physical and chemical properties of water (the variables used shown in Table 1, excluding the UV absorbency) was used to identify the differences among the sites (using an Euclidean distance, standarised data for two years). To receive the similarities between the phytoplankton communities in the different sites, Jaccard's coefficient was calculated for every sampling date. Similarity analysis (ANOSIM) based independently on both Bray-Curtis (species abundance) and Jaccard (species presence/absence) measures was applied to calculate the general similarity between the communities [Clarke 1993]. To determine the factors which correlate with the phytoplankton variation, the Canonical Correspondence Analysis was performed, in which only the most frequent species (which occurred in > 50% of samples; their $\log_{10}$ transformed abundances were taken to the analysis) and the environmental variables which correlated weakly (r < 0.5) to one another were used in the analysis. The factors taken into consideration included: temperature, reaction (a concentration of H^+ ions), electrolytic conductivity, and the concentrations of O_2, N-NO_3, N-NH_4 and P-PO_4. The statistical analyses were carried out using MVSP ver. 3.1. software [Kovach 1999], excluding ANOSIM, which was done with Microsoft Excel, by means of Visual Basic script written by Jarosław Kobak (Nicolaus Copernicus University in Toruń).

RESULTS

Physico-chemical parameters of the water in studied sites during the observation are shown in Table 1. All sites had a similar level of total nitrogen (0.293–0.946 mg · dm^{-3}) and the total phosphorus content (0.084–0.292 mg · dm^{-3}); likewise the temperature, which usually had ranged from 14 to 28°C and oxygenation level (8.0–12.4 mg · dm^{-3}). Phosphate phosphorus in the PEL (open water) site was lower than in other sites, reaching maximum 0.012 mg · dm^{-3}. The S*phagnum* zone site (LIT2) had two-three times lower values of the calcium content (6.4–13.5 mg · dm^{-3}) and electrolytic conductivity (44.0–63.0 μS · cm^{-1}) in opposite to the other research sites. The water reaction was also slightly lower in this zone, ranging from pH 5.8 to 6.7. Ammonium nitrogen has dominated the nitrate nitrogen here, unlike in the other sampling points, and the UV absorbency was the highest (0.60–1.43). These relationships were verified by the cluster analysis, showing that the LIT1 and PEL sites were grouped together (Fig. 1).

A total number of 136 taxa of the phytoplankton was recognized. *Chlorophyta* (94 taxa), with *Zygnematales* (56 taxa) were the richest group of algae. Other groups consisted of several species, excluding *Cyanophyceae*, among which 17 taxa were recorded. The total abundance of the phytoplankton ranged between 410 and 19 574 ind. 10^3 · dm^{-3}, but usually did not exceed the value of 10 000 ind. 10^3 · dm^{-3} (Fig. 2). The mean seasonal values of this parameter were the highest in the LIT2 site, and amounted to 2728 and 5500 ind. 10^3 · dm^{-3}. The total biomass of the phytoplankton in the studied lake was relatively high, exceeding often 10 mg · dm^{-3}. The highest values of the phytoplankton biomass, as well as the highest mean seasonal values of this parameter, were recorded in the LIT1 site. In September 1996 they amounted to 65.8 mg · dm^{-3}, which resulted in mean values ranging as high as 29 mg · dm^{-3}. A similar relationship was found for chlorophyll *a* concentrations (Fig. 2).

The taxonomical structure of the dominating groups and species was very similar in the PEL (open water) and LIT1 (helophytes) sites. In both sites the most numerous group was usually *Zygnematales* (Fig. 3), with *Closterium acutum* Breb. predominating (Tab. 2). Blue-greens were also abundant in the summer, with *Aphanothece clathrata* W. et G.S. West, as well as *Raphidophyceae* with *Gonyostomum semen* (Ehr.) Diesing predominating in September 1997. Other *Chlorophyta* species, like *Coenococcus plantonicus* Korsch., Table. 1. Physical and chemical characteristics of the water in sampling sites of Lake Płotycze – mean values and ranges for 1996–1997

Parameters		PEL		LIT1		LIT2	
		mean	range	mean	range	mean	range
temperature	^{o}C	20.2	14.9–27.4	20.6	15.0–27.9	20. 6	14.1–28.5
O_2	$mg \cdot dm^{-3}$	9.2	8.0–10. 9	10.1	8.5–12.4	8.8	8.2–9.8
pH		7.2	6.6–7.6	7.3	6.7– 8.3	6.4	5.8–6.7
conductivity	$\mu S \cdot cm^{-1}$	98.8	90.0–109.0	99.2	90.0–109.0	51.1	44.0–63.0
Ca	$mg \cdot dm^{-3}$	21.2	10.6–27.6	30.6	19.9–43.7	9.9	6.4–13.5
$N\text{-}NO_3$	$mg \cdot dm^{-3}$	0.168	0.002–0.442	0.131	0.061–0.291	0.089	0.048–0.146
$N\text{-}NH_4$	$mg \cdot dm^{-3}$	0.092	0.002–0.215	0.120	0.021–0.223	0.211	0.033–0.452
TN	$mg \cdot dm^{-3}$	0.588	0.293–0.901	0.686	0.421–0.861	0.603	0.301–0.946
$P\text{-}PO_4$	$mg \cdot dm^{-3}$	0.006	0.002–0.012	0.020	0.004–0.050	0.018	0.002–0.038
TP	$mg \cdot dm^{-3}$	0.145	0.112–0.222	0.192	0.084–0.292	0.163	0.092–0.222
ABS_{254}		0.53	0.21–0.90	0.53	0.22–0.88	0.90	0.60–1.43

PEL – open water, LIT1 – helophytes, LIT2 – *Sphagnum*

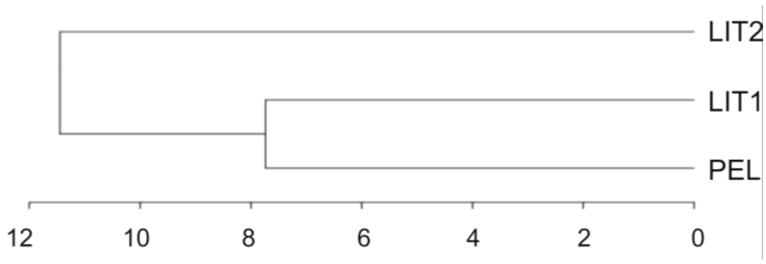

Fig. 1. A dendrogram of the cluster analysis based on physical and chemical properties of water

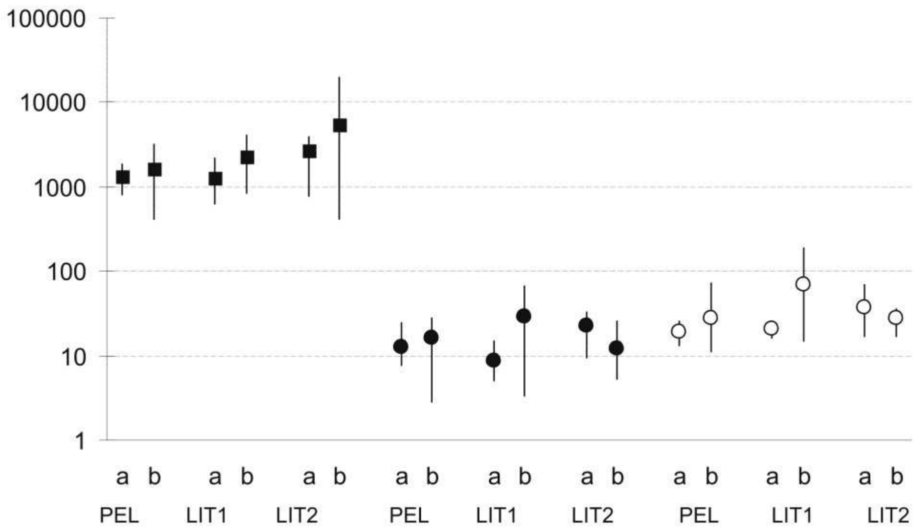

Fig. 2. Mean values and the range of phytoplankton total numbers (N – black squares, ind. $10^3 \cdot dm^{-3}$), fresh biomass (B – black dots; $mg \cdot dm^{-3}$) and chlorophyll *a* concentration (chl *a* – white dots; $\mu g \cdot dm^{-3}$) in three study sites in Lake Płotycze in 1996 (a) and 1997 (b)

Tetraedron minimum (A. Braun) Hansgirg, *Quadrigula closterioides* (Bohlin) Printz and *Staurastrum gracile* Ralfs. were abundant only in single samples (Tab. 3). In the LIT2 (*Sphagnum*) site *Zygnematales* were also the most abundant group, especially in 1997, they were more numerous than in the other sites, and they were not predominated by *Closterium acutum* at all (Fig. 3, Tab. 2). The structure of the group was mainly built on several species from the genus *Cosmarium* and *Staurastrum*. Other dominant taxa (*Gymnodinium* sp., *Chrysococcus* sp., *Koliella longiseta* (Vischer) Hindák, *Actinastrum* sp.) were also differed from those in the PEL and LIT1 sites. *Gonyostomum semen* which appeared in masses in the open water and helophyte sites (only in September 1997), was frequently present in the *Sphagnum* site but had never dominated the phytoplankton community (Tab. 2).

Table. 2. Dominating species of phytoplankton in Lake Płotycze in 1996 and 1997

Species	PEL								LIT1								LIT2							
	1996				1997				1996				1997				1996				1997			
	V	VI	VII	IX	V	VI	VII	IX	V	VI	VII	IX	V	VI	VII	IX	V	VI	VII	IX	V	VI	VII	IX
Aphanothece clathrata	+	12	+	+	+	41	+		+	18	14	+	+	39	+			+	+			15		
Gymnodinium sp.																	+			14	+	+	+	+
Peridinium bipes	+	+	+	46	+	+	28		+	+	+	10		+	30	+	+	+	11	+	+	+	+	+
Gonyostomum semen	+	+	+	+	+	+	+	50	+	+	+	+	+	+	+	65	+	+	+	+	+	+	+	+
Chrysococcus sp.																	52							
Naviculaceae																				14				
Koliella longiseta																					+		29	
Coenococcus planctonicus						+	11								+									
Tetraedron minimum	+	+	+	+	+		23		+	+	+	+	+	+	+					+		+		
Quadrigula closterioides	+	+	+	+	+	40	+		+	+	+		+	40	+		+	17	+	21	+	+	+	
Scenedesmus quadricauda	+	+	+	+	+	+	+		+	+		14					+	+	+	+				
Actinastrum sp.																			27					
Closterium acutum	62	12	36	39	76	12		41	32	12	34	46	65	10	+	24	+		+	+				
Cosmarium praemorsum									+	+	+					+		13	+	+	+	+	+	+
Cosmarium tenue																					50	+	61	70
Staurastrum crenulatum		+	+						+	+	+	+	+		+		+	11	12	+	28	+	+	+
Staurastrum gracile		10	40	+	+	+	+	+	12	17	31	+	+	+	+	+	+	+	15	+	+	+	+	+

PEL – open water, LIT1 – helophytes, LIT2 – *Sphagnum*; numbers represent % of abundance, + = < 10%

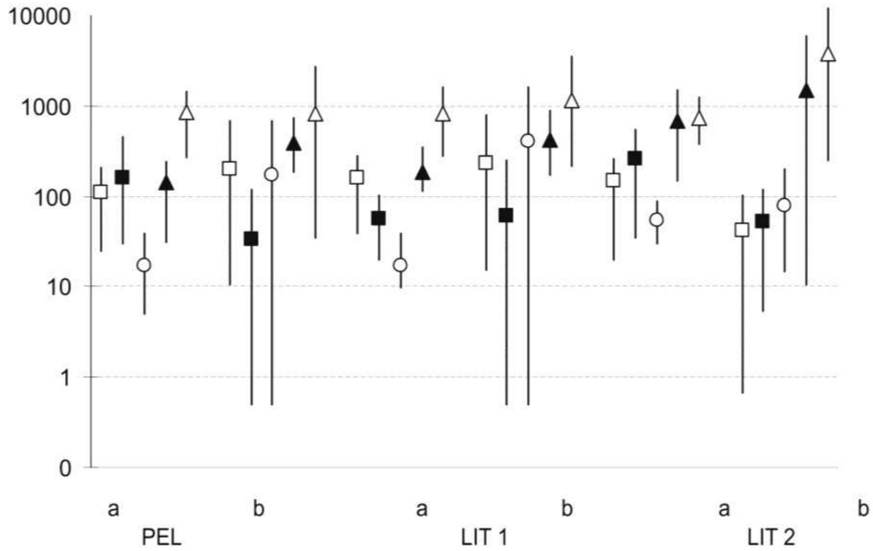

Fig. 3. Mean values and the range of abundances (ind. $10^3 \cdot dm^{-3}$) of main five taxonomical groups in three study sites in Lake Płotycze in 1996 (a) and 1997 (b): □ – Cyanophyceae, ■ – Dinophyceae, ○ – Raphidophyceae, ▲ – Chlorophyceae, Δ – Zygnematales

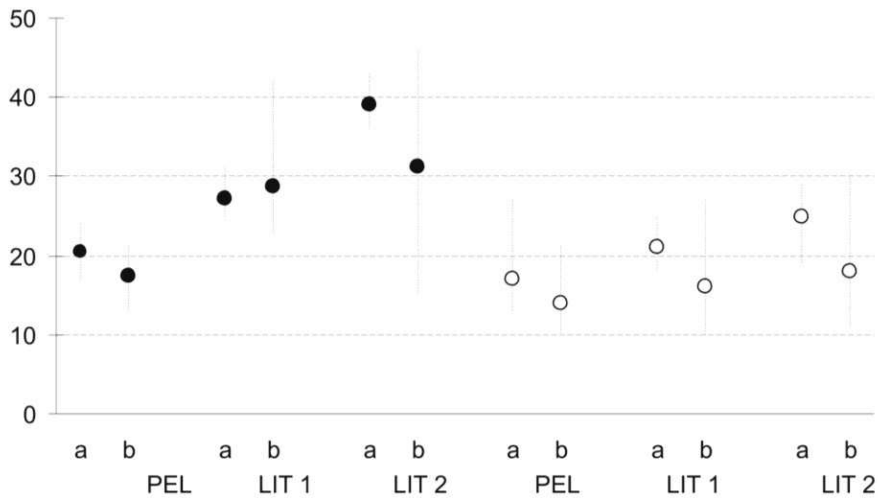

Fig. 4. Mean values and the range of species richness (S – black dots) and Shannon's index (white dots, H 10^{-1}) in three study points in Lake Płotycze in 1996 (a) and 1997 (b)

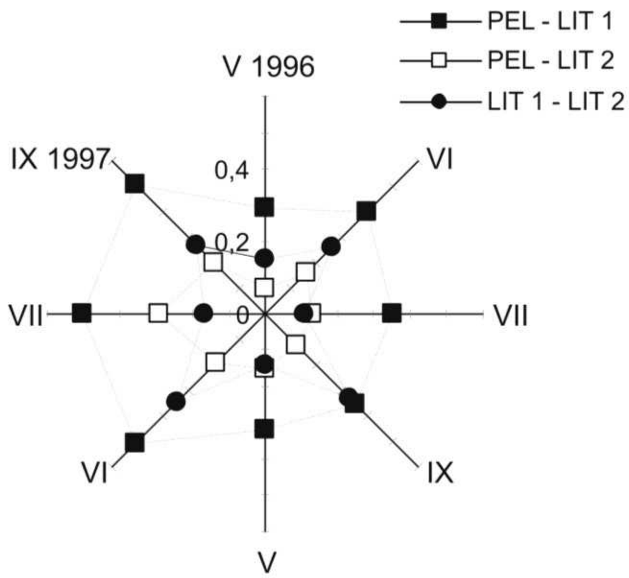

Fig. 5. A diagram of the similarity (Jaccard's coefficient) between phytoplankton communities in Lake Płotycze – the comparison of the pairs of three study sites in each month (May 1996 to September 1997 – clockwise)

Table 3. Results of the ANOSIM analysis performed on the basis of a Jaccard coefficient and a Gray-Curtis distance between phytoplankton assembles in Lake Płotycze

		R	p
Jaccard			
Global		0.018	0.360
P	L1	-0.366	1.000
L1	L2	0.305	0.009*
P	L2	0.125	0.114
Gray-Curtis			
Global		0.282	0.001*
P	L1	-0.118	0.866
L1	L2	0.442	0.001*
P	L2	0.535	0.000*

P – open water, L1 – helophytes, L2 – *Sphagnum*; asterix means statistical significance

The LIT2 site was also characterized by the highest species richness, which often exceeded 40 species in the sample (Fig. 4). The species richness was usually the lowest in the open water zone, while having medium values amongst the helophytes. The values of Shannon's index ranged from 1.1 to 3.0 in LIT2, but from 1.0 to 2.7 in LIT1 and PEL, with the mean seasonal values slightly higher in the helophyte zone. The floristic similarity between the sites (Jaccard's coefficient) was calculated for every sampling date. The comparison of the pairs of three study sites showed that the most similar phytoplankton structure (> 0.4) was in the PEL and LIT1 sites in the second year (Fig. 5). The similarity between LIT2 (the *Sphagnum* site) and other two sites was much lower – usually the lowest in the

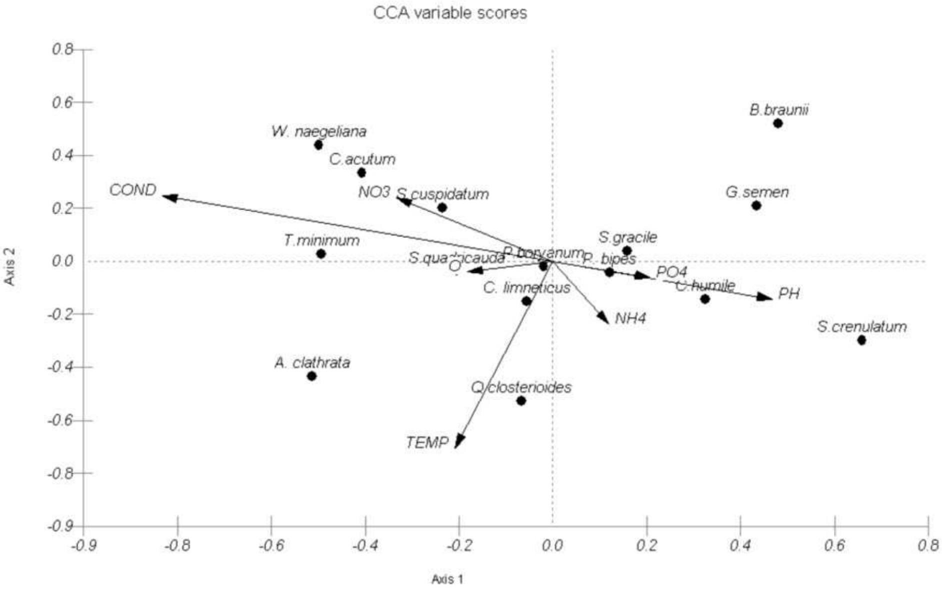

Fig. 6. The ordination scater plot of the CCA performed on the species-environmental relations in Lake Płotycze: COND – conductivity, PH – H^+ ions concentration, TEMP – temperature, NH4, NO3, PO4 – concentration of NH_4, NO_3 and PO_4

case of the PEL – LIT2 pair. Quite different results gave the ANOSIM analysis, in which the total similarity – including all the species occurring at any given time in the given site – was calculated. The total similarity between all the sites was very high, although in majority of cases not significant (Tab. 3). The statistical significance was noted only in the case of the L1–L2 pair ($R = 0.302$, $p < 0.01$). The results of the ANOSIM analysis differed while the abundance of species was included and the Bray-Curtis distance was measured. Both the total distance ($R = 0.282$) and the two particular distances: L1–L2 ($R = 0.442$) and P–L2 ($R = 0.535$), were significant ($p < 0.01$). The P-L1 pair showed negative values of R statistics in both measurements (Jacaard and Bray-Curtis). Interesting results gave the CCA analysis. The two ordination axes had eigenvalues of 0.113 and 0.071 respectively, and they cumulatively explained 37.7% of the species variation. The pH level and the conductivity were two variables which correlated best with Axis 1, while the temperature correlated best with Axis 2 (Fig. 6). Three factors: water reaction, P-PO_4 and N-NH_4 concentrations show a similar direction for their arrows, towards down right quarter of the diagram. Two species which are shown in this quarter, *Staurastrum crenulatum* Delponte and *Cosmarium humile* (Gay) Nordst., were frequent and abundant in both of the littoral sites, although much more in LIT2. In the top left quarter one can find species connected with the change of other factors which correlate with Axis 1: conductivity (the strongest change) and the N-NO_3 concentration. *Closterium acutum*, *Woronichinia naegeliana* (Unger) Elenkin, *Tetraedron minimum* and *Staurastrum cuspidatum* Breb. were virtually absent in LIT2 but very frequent both in PEL and LIT1.

DISCUSSION

Phytoplankton diversity was studied in three various habitats of lake Płotycze, differed from one another with macrophyte presence and structure. It was shown that dominant species and groups of planktonic algae were very similar in both open water and helophytes sites, while completely different in the *Sphagnum* site. The result was opposite when all species (not only dominant ones) were taken into consideration. The ANOSIM procedure showed that a list of species is quite common for all sites (when the Jaccard coefficient was used to calculate similarity), although they appeared in various abundances (which was shown using Gray-Curtis measure). The similarity calculated by means of Jaccard formula between the pairs was not usually high (< 0.5), which points to the fact that species from this common list appeared in the sites at different sampling occasions. Also the negative values of the ANOSIM R statistics between the PEL and LIT1 sites points to the fact that the seasonal variation was more important than the floristic differences between these sites.

One of factors driving the phytoplankton similarity in lakes is the water mixing caused by wind [Webster and Hutchinson 1994]. If the water reservoir is small, this factor may play a significant and crucial role [George and Heaney 1978]. It could explain that the list of species in studied lake was similar for all three different habitats. In the other hand, some seasonal differences in the species abundance could be shaped by physical and chemical parameters of the water in every habitat. Different macrophytes structure (or the lack of macrophytes) could modify the water parameters (i. e. oxygen and inorganic carbon concentrations, pH and temperature) as a result of their different photosynthetic activity and decomposition processes [Vitt and Bayley 1984]. In studied lake the phytoplankton composition in the *Sphagnum* site were characterized as being the most distinctive – both on the descriptive and on the statistical level. These differences were connected mostly with desmid flora. It was shown that some physical and chemical properties of the water, like: pH and conductivity, played an important role in the phytoplankton variation in the studied transect. The *Sphagnum* mosses could strongly modify the water chemistry due to an easy uptake of chemical elements, including calcium ions [Kruk 1991]. This can lower the pH and can enhance the amount of free carbon dioxide. This form of carbon is preferred by desmids [Moss 1973], which readily occur in conditions of lower water reaction [Gough and Woelkerling 1976, Mataloni 1999]. The *Sphagnum* activity also results in lower conductivity, which promotes the domination of some desmid species, too [Woelkerling 1976]. Lower water reaction could also promote the frequent *Gonyostomum semen* occurrence in the *Sphagnum* site, which additionally delivers more dissolved organic matter [Willen *et al.* 1990, Hörnström 2002]. Thus, its mass appearance in September 1997 only in the helophyte and pelagic zone is hard to explain. *G. semen* when blooming, might prefer deeper open water habitats, as it is motile and could avoid both grazers and intensive light by being able to migrate to deeper water layers [Lepistö *et al*. 1994, Salonen and Rosenberg 2000, Pęczuła and Kowalczyk-Pecka 2002].

The small green algae *Closterium acutum* had a tendency to dominate the phytoplankton community in helophytes and in the open water (spring and autumn), while it was virtually absent in the *Sphagnum* site. Although it belongs to desmids, it is known to occur – even en masse – in nutrient rich and slightly alkaline habitats [Rosen 1981, Coesel 1993], which was confirmed in Lake Płotycze (the CCA analysis). This species has a high growth rate in low temperatures and weak light climate [Coesel and Wardenaar 1990], and because of its small dimensions and lack of flagella it prefers well mixed water column [Tremel 1996].

Besides the chemical composition of the water (which explained only about 38% of the phytoplankton variability in the transect) some other factors could be taken into consideration to explain phytoplankton variation. The dense vegetation in the *Sphagnum* site which diminished the water movement [Madsen *et al.* 2001] could be the one of them. Dense macrophyte structures also promote higher diversity of life forms [Vakkillainen 2005], including periphytic algae, which temporarily – as tychoplankton – enrich phytoplankton communities [Brook 1959].

CONCLUSIONS

1. Dominant groups and species were very similar in the open water and helophyte sites (greens with *Closterium acutum* as dominant) although they differed from those in the *Sphagnum* site (where various desmid species dominated).

2. The analysis of similarity showed that a list of species is common for all sites, but they appeared at various abundances and sampling ocassions.

3. Canonical Correspondence Analysis revealed that pH and conductivity were the factors most responsible for phytoplankton differentiation in the studied transect.

Acknowledgements. I want to thank Władysława Wojciechowska for the help in microscopic analyses. Andrzej Zykubek is acknowledged for help in the field and laboratory work. The study was carried out in the Department of Botany and Hydrobiology at Catholic University of Lublin.

REFERENCES

Balls H., Moss B., Irvine K., 1989. The loss of submerged macrophytes with eutrophication. I. Experimental design, water chemistry, aquatic plant and phytoplankton biomass in experiments carried out in ponds in the Norfolk Broads. Fresh. Biol., 22, 71–87.

Brook A.J., 1959. The status of desmids in the plankton and the determination of phytoplankton quotients. J. Ecol., 47, 429–444.

Clarke K.R., 1993. Non-parametric multivariate analyses of changes of community structure. Aust. J. Ecol., 18, 117–143.

Coesel P.F.M., 1993. Poor physiological adaptation to alkaline culture conditions in Closterium acutum var. variabile, a planktonic desmid from eutrophic waters. Eur. J. Phycol., 28, 53–57.

Coesel P.F.M., Wardenaar K., 1990. Growth responces of planktonic desmid species in a temperature-light gradient. Fresh. Biol., 23, 551–560.

George D.G., Heaney S.I., 1978. Factors influencing the spatial distribution of phytoplankton in a small productive lake. J. Ecol., 66, 133–155.

Gough S.B., Woelkerling W.J., 1976.Wisconsin desmids. II. Aufwusch and plankton communities of selected soft water lakes, hard water lakes and calcareous ponds. Hydrobiologia, 49, 3–25.

Gross E.M., 2003. Allelopathy of aquatic autotrophs. Crit. Rev. Plant Sci., 22, 313–339.

Hermanowicz W., Dożańska W., Dojlido J., Kosiorowski B., 1976. Fizyczno-chemiczne badanie wody i ścieków. Wyd. Arkady, Warszawa.

Hillebrand H., Dürselen,C.D., Kirschtel D., Pollingher U., Zohary T., 1999. Biovolume calculation for pelagic and benthic microalgae. J. Phycol., 35, 403–424.

Hörnström E., 2002. Phytoplankton in 63 limed lakes in comparison with the distribution in 500 untreated lakes with varying pH. Hydrobiologia, 470, 115–126.

Jasser I., 1995. The influence of macrophytes on a phytoplankton community in experimental conditions. Hydrobiologia, 306, 21–32.

Jeppesen E., Lauridsen T. L., Kairesalo T., Perrow T.M., 1998. Impact of submerged macrophytes on fish-zooplankton interactions in lakes, in: E. Jeppesen, Ma. Søndergaard, Mo. Søndergaard, K. Christoffersen (eds), The structuring role of submerged macrophytes in lakes. Springer-Verlag, New York, p. 91–114.

Kovach W.L., 1999. MVSP-A Multi Variante Statistical Package for Windows, ver. 3.1., Kovach Computing Services, Pentraeth.

Kruk M., 1991. The processing of elements by mires in agricultural landscape: mass balances based on sub-surface hydrology. Ekol. Pol., 38, 73–117.

Lauridsen T.L., Jeppesen E., Søndergaard M., Lodge D.M., 1998. Horizontal migration of zooplankton: predator mediated use of macrophyte habitat, in: E. Jeppesen, Ma. Søndergaard, Mo. Søndergaard, K. Christoffersen K. (eds), The structuring role of submerged macrophytes in lakes. Springer-Verlag, New York, p. 233–239.

Lepistö L., Antikainen S., Kivinen J., 1994. The occurance of *Gonyostomum semen* (Ehr.) Diesing in Finnish lakes. Hydrobiologia, 273, 1–8.

Madsen J.D., Chambers P.A., James W.F., Koch A., Westlake D.F., 2001. The interaction between water movement, sediment dynamics and submersed macrophytes. Hydrobiologia, 444, 71–84.

Mataloni G., 1999. Ecological studies on algal communities from Tierra del Fuego peat bogs. Hydrobiologia, 391, 157–171.

Moss B.,1973. The influence of environmental factors on the distribution of freshwater algae: an experimental study. II. The role of pH and carbon dioxide – bicarbonate system. J. Ecol., 61, 157–177.

Nusch E.A., 1980. Comparison of different methods for chlorophyll and pheopigment determination. Arch. Hydrobiol. Beih. Erg. Limnol., 14, 14–36.

Pełechaty M., Owsianny P.M., 2003. Horizontal distribution of phytoplankton as related to the spatial heterogeneity of a lake – a case study from two lakes of the Wielkopolski National Park (western Poland). Hydrobiologia, 510, 195–205.

Pęczuła W., 2002. Lake Płotycze – between dystrophy and eutrophy (about difficulties in obtaining trophic status of some lakes). Limnol. Rev., 2, 303–311.

Pęczuła W., Kowalczyk-Pecka D., 2004. Distribution and diel vertical migrations of invasive algal species *Gonyostomum semen* (Ehr.) Diesing (Raphidophyceae) in humic lakes of Polesie Region (CE Poland), in: SIL XXIX Congress, Lahti – Finland, Book of Abstracts, 260.

Rosen G., 1981. Phytoplankton indicators and their relations to certain chemical and physical factors. Limnologica, 13, 263–290.

Salonen K., Rosenberg M., 2000. Advanteges from diel vertical migration can explain the dominance of Gonyostomum semen (Raphidophyceae) in a small, steeply-stratified humic lake. J. Plankton. Res., 22, 1841–1853.

Sheffer M., Hosper S.H., Meijer M.L., Moss B., Jeppesen E., 1993. Alternative equilibra in shallow lakes. Trends Ecol. Evol., 8, 275–279.

Sondergaard M., Moss B., 1998. Impact of submerged macrophytes on phytoplankton in shallow freshwater lakes. Ecol. Stud., 131, 115–132.

Timms R.M., Moss B., 1984. Prevention of growth of potentially dense phytoplankton populations by zooplankton grazing, in the presence of zooplanktivorous fish, in a shallow wetland ecosystem. Limnol. Ocean., 29, 472–486.

Tolonen K.T., Holopainen I.J., Hämäläinen H., Rahkola-Sorsa M., Ylöstalo P., Mikkonen K., Karjalainen J., 2005. Littoral species diversity and biomass: concordance among organismal groups and the effects of environmental variables. Biodiv. Conserv. 14, 961–980.

Tremel B., 1996. Autoecology of Chlorophyta in a gravel pit near Cologne, Germany. Arch. Hydrobiol., 135, 361–376.

Vakkillainen K., 2005. Submerged macrophytes modify food web interactions and stability of lake littoral ecosystems. Academic dissertation in environmental ecology, University of Helsinki, Lahti.

Van Breemen N., 1995. How Sphagnum bogs down other plants? Trends Ecol. Evol., 10, 270–275.

Van Donk E., Van de Bund W., 2002. Impact of submerged macrophytes includng charophytes on phyto- and zooplankton communities: allelopathy versus other mechanisms. Aquat. Bot., 72, 261–274.

Vitt D.H., Bayley S., 1984. The vegetation and water chemistry of four oligotrophic basin mires in northwestern Ontario. Can. J. Bot., 62, 1485–1500.

Vollenweider R.A.,1969. A manual on methods for measuring primary production in aquatic environments. Blackwell, Oxford – Edinburgh.

Webster I.T., Hutchinson P.A.,1994. Effect of wind on the distribution of phytoplankton cells in lakes revisited. Limnol. Oceanogr., 39, 365–373.

Willen E., Hajdu S., Pejler Y., 1990. Summer phytoplankton in 73 nutrient-poor Swedish lakes. Classification, ordination and choice of long-term monitoring objects. Limnologica, 20, 217–227.

Woelkerling W.J., 1976. Wisconsin desmids. I. Aufwusch communities of selected acid bogs, alkaline bogs and closed bogs. Hydrobiologia, 48, 209–232.

Wojciechowska W., Solis M., 2001. Small-scale distribution and composition of phytoplankton in a shallow lake. Pol. J. Ecol., 49, 87–89.

RÓŻNORODNOŚĆ FITOPLANKTONU NA TLE ZRÓŻNICOWANIA SIEDLISKOWEGO MAŁEGO I PŁYTKIEGO JEZIORA HUMUSOWEGO PŁOTYCZE (WSCHODNIA POLSKA)

Streszczenie. W płytkim i małym humusowym jeziorze Płotycze (wschodnia Polska) przeprowadzono jakościowe i ilościowe badania fitoplanktonu w aspekcie zróżnicowania poziomego w trzech różnych siedliskach (strefa otwartej wody, szuwar, litoral torfowcowi). Celem badań była ocena różnorodności zbiorowisk fitoplanktonu na tle zróżnicowania siedliskowego, jak również odpowiedź na pytanie, które czynniki chemiczne kształtują poziome zróżnicowanie tego zespołu? Próby pobierano w ciągu dwóch sezonów wegetacyjnych (1996–1997) cztery razy w roku z trzech różnych siedlisk wzdłuż poziomej transektu. Stwierdzono podobieństwo dominujących grup i gatunków pomiędzy strefą otwartej wody i szuwarem (zielenice z dominującym C*losterium acutum*) i odmienność siedliska torfowcowego (gdzie dominowały różne gatunki desmidii). Analiza podobieństwa (ANOSIM) wykazała jednak, że lista gatunków jest podobna dla wszystkich siedlisk, chociaż pojawiały się one w różnym czasie i przy różnej liczebności. Z kolei wyniki kanonicznej analizy korespondencji wskazują na dużą rolę pH i przewodności elektrolitycznej jako czynników różnicujących zbiorowiska fitoplanktonu w badanym transekcie.

Słowa kluczowe: fitoplankton, siedliska, makrofity, jezioro humusowe