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Research Article

**RELATIONSHIPS BETWEEN SELECTED ABIOTIC VARIABLES AND
PHYTOPLANKTON COMPOSITION IN DEEP MESOTROPHIC
LAKE ZAGŁĘBOCZE**

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Abstract

Variation of phytoplankton biomass and species composition were examined in relation to selected abiotic environmental variables (temperature, light, mixing, phosphorus and nitrogen content). Studies were carried out in mesotrophic Lake Zagłębcze in the 1999-2001. Samples were taken from three pelagic layers (epi-, meta-, hypolimnion) and from sub- and eulittoral. Successional changes of diatoms (*Asterionella formosa*, *Cyclotella comta*, *Fragilaria ulna* var. *acus*) was connected with perturbation of temperature, SD and Z_{eu}/Z_{mix} . Dinophytes *Ceratium hirundinella*, *Peridinium bipes* dominated at low phosphate phosphorus concentration and blue-green algae *Coelomoron pusillum*, *Woronichinia naegeliana* reached high biomass at higher TP and NO₃-N concentrations.

INTRODUCTION

Seasonal domination of algal organisms is periodic and cyclic process which take place from year to year and is often similar in lakes with similar morphometric and chemical properties. This process, named as succession, is controlled by combination of physical factors (light, temperature, turbulence), chemical properties of water (mainly nutrient availability) and biological interactions between organisms (competition, grazing) (Sommer et al. 1986).

Seasonal succession is characterized by shift from small r-selected forms dominated in spring to large K-selected forms dominated in summer (Reynolds 1984a). Group of r-selected species favour unstable environmental conditions with strong water mixing, relative low light intensity and with high availability to phosphorus and nitrogen resources. After nutrients depletion but under the same physical conditions phytoplankton was often composed by large algal species called as ruderals.

Species of K-strategy grow under environmental conditions which characterize by stable physical structure (stratification) and under nutrient depletion. Domination is here result of specific species responses due to morphological and physiological adaptations to critically changing of resource-ratio gradient. Competitive advantage for nutrients these species gain by their ability to store them (luxury uptake) and also by searching for them due to motility (e.g. *Ceratium hirundinella*) or buoyancy (e.g. coccoidal blue-green algae as *Coelomonon pusillum*) (Bucka and Wilk-Woźniak 2002).

The study comprised a description of phytoplankton composition in relation to measurements of some environmental variables during three years in Lake Zagłębcze. The aim of the paper is attempt to identify variables related to the interseasonal variability of phytoplankton considered at classes and species level.

MATERIALS AND METHODS

The mesotrophic, dimictic Lake Zagłębcze is situated in the buffer zone of National Polesie Park (Łęczyńsko-Włodawskie Lakeland). The lake have the area of 59 ha, max. depth of 25 m and average depth of 7.3 m (Fig. 1).

The catchment area covers 463.6 ha in which forests and meadows predominate (about 70 %) (Furtak et al. 1998). Near the water table is also present a rest-home and a great number of private rest houses.

Studies were carried out in the 1999–2001 between April and November every year. Samples were taken monthly in the deepest point of pelagial from three layers (epi-, meta-, hypolimnion) stating every time from the temperature

profile. In the 2000–2001 there also paid attention to horizontal differentiation of phytoplankton (Fig. 1). Additionally water was sampled from eulittoral (1.5 m depth) near the rush vegetation composed mainly by *Phragmites australis* and covered by large patches of submerged vegetation with *Myriophyllum spicatum*. The second site was typed at sublittoral (6 m depth) on the border of occurrence of *Myriophyllum spicatum* patches.

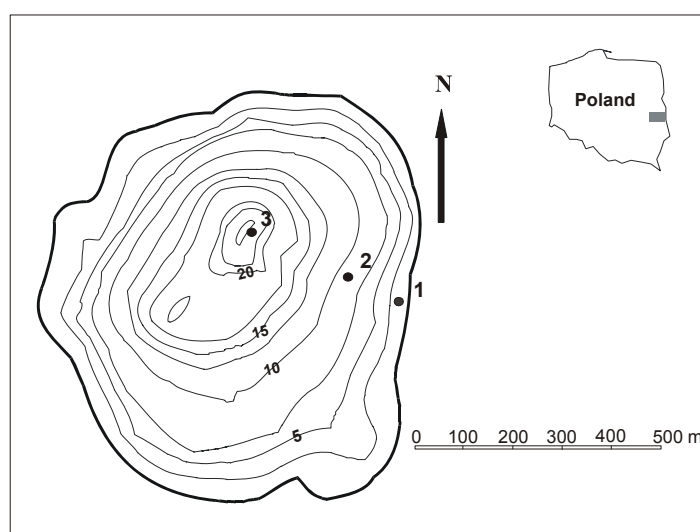


Fig. 1. Bathymetric map of Lake Zagłębocze and location of sampling sites.

Direct water measurements comprised transparency by means of a Secchi disc and temperature, pH, conductivity with sensors.

The mixed depth (Z_{mix}) was stated for each temperature profile and the euphotic depth (Z_{eu}) on the grounds of SD measurements. The Z_{eu} to Z_{mix} ratio was taken as the relative light availability for phytoplankton (Reynolds 1984b).

For every layer or site an integrated water sample was taken with a Ruttner type sampler (2 dm³ volume) at interval 2 m depth. From samples it was taken two separate subsamples for nutrients (250 ml) and phytoplankton analysis (200 ml). For phytoplankton analysis samples were fixed with Lugol's iodine and solution of formalin with glycerin.

Chemical analyses were done as soon as possible after field sampling. The phosphorus (TP, PO₄-P) and nitrogen (TN, NO₃-N) compounds were determined by spectrophotometric methods described by Hermanowicz et al. (1976). Phosphate phosphorus and nitrate nitrogen were analyzed after filtration through GF/C Whatman membranes whereas the total amounts after prior digestion.

Numbers of phytoplankton were evaluated with an inverted microscope (Zeiss Axiovert 135) according to the Utermöhl method (Vollenweider 1969). Prior quantification subsamples of phytoplankton were settled in chambers (5 ml volume) and then counted at a magnification of 400x. Fresh biomass was calculated by measurements of phytoplankton cells and by comparing with adequate geometric figures for calculating their volumes (Hillebrand et al. 1999). Phytoplankton cell volume data was converted to biomass (mg dm^{-3}) by assumption that specific density of algal cells is 1 g cm^{-3} . Average cell size was based on the measurements of 10 cells. It was taken as dominant species a one of contribution to total biomass $> 30 \%$ (Krienitz 1992).

In statistical analysis were used Pearson's correlation coefficient and Canonical Correspondence Analysis (CCA). The biomass values (y) were transformed ($\ln(y) + 1$) to maintain of normal distribution and to avoid the "arch effect" in CCA (Ter Braak 1986). Statistical significance of factors (CCA) was tested by χ^2 test. All computations were done using MVSP 3.11 and Statistica 5.0.

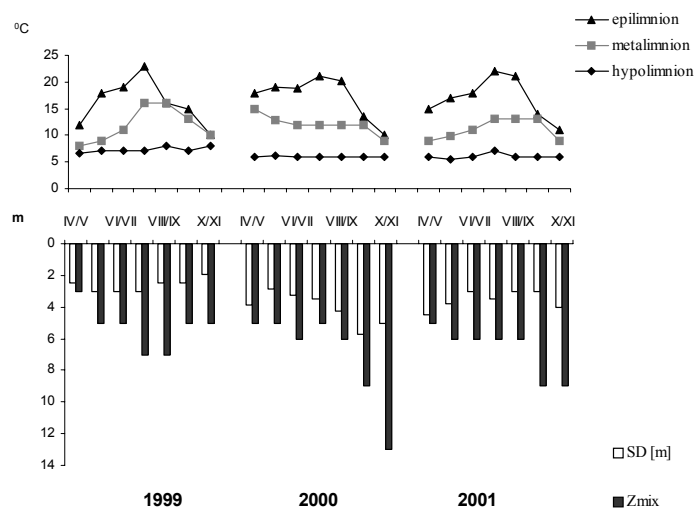


Fig. 2. Changes of water temperature and variation of water transparency (SD) and mixed depth in pelagial of Lake Zagłębcze.

RESULTS

Environmental conditions

Lake water stratification was full developed from May to September every year (1999-2001) (Fig. 2). The start of stratification was observed in April and

the end in October-November. Surface water temperature in April-May varied between 12-18 °C, and in June-September it was 22-23 °C and in October-November was 10-11 °C. In metalimnion temperature decreased 2.6-3.2 °C for every metre whereas in hypolimnion not changed (6-7 °C). Horizontal differentiation of temperature conditions depended on seasonal changes and were similar in all sites.

The transparency of water (SD) varied between 2-6 m for whole period while lower values were noted in 1999. The following years the values were highest mainly in April and October-November (Fig. 2). The mixed zone was always quite shined in vernal months and mostly in summer ($Z_{eu}/Z_{mix} = 1.5-2$) while in autumn was 50-90 %. The range of the mixed zone comprised in spring a 3-5 m water column, in summer 5-6 m and in autumn 9-13 m.

The water pH was around neutral (6.5-7.5). Only in summer the surface water pH was higher (8.0-8.5). Values of conductivity varied between 160 and 463 $\mu\text{S cm}^{-1}$. In spring similar values was noted in the total water column but in summer the highest ones were in hypolimnion.

The differentiation of phosphorus and nitrogen contents in the lake water is demonstrated in Fig. 3.

Total phosphorus (TP) concentrations varied between 0.02-0.27 mg dm^{-3} . In 2001 its content in the water was in most cases higher than in the previous years. Between pelagial layers neither differences occurred, only in hypolimnion in 1999 TP concentrations was twice as high than in epilimnion. In horizontal sites the highest concentration was always noted in eu littoral and the lowest one in epilimnion. In surface water phosphate phosphorus content ($\text{PO}_4\text{-P}$) shared total phosphorus 17-23 % and their share increased with depth reached in hypolimnion 31-49 %. In horizontal sites $\text{PO}_4\text{-P}$

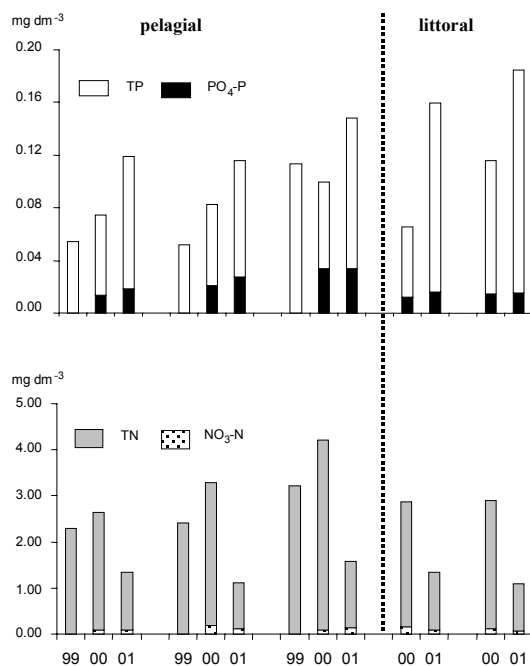


Fig. 3. Concentrations of phosphorus and nitrogen compounds (mg dm^{-3}) in Lake Zagłębcze (means for each year). The sites are successively - in pelagial: epilimnion, metalimnion, hypolimnion; in littoral: sublittoral, eu littoral.

percentage were lower in eulittoral (9–15 %) and higher in epilimnion (17–23 %).

Total nitrogen (TN) concentrations varied from 0.2 to 5.8 mg dm⁻³. In 2001 there followed over twice a decrease of TN concentration (mean from 2.6–3.3 in the previous years to 1.2 mg dm⁻³). Also in 2001 in most cases the higher concentrations were noted in deeper rather than surface water. All over the study season nitrate nitrogen (NO₃-N) concentrations were similar in all sites of pelagial and transect. In epilimnion NO₃-N decreased below the detectable level between July and August every year.

Qualitative and quantitative composition of phytoplankton

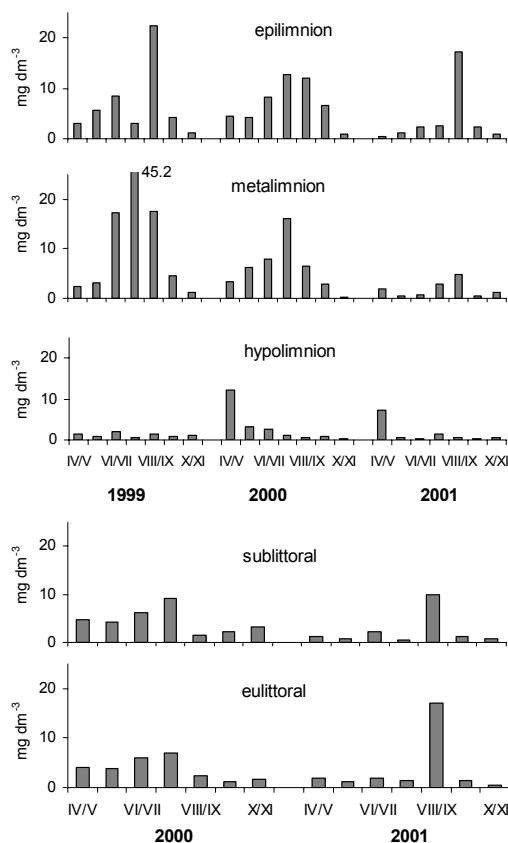


Fig. 4. Changes of phytoplankton biomass (mg dm⁻³) in Lake Zagłębcze.

The phytoplankton abundance measured as fresh biomass varied on a large scale (0.2–45.5 mg dm⁻³). This is resulted mainly on the one hand by irregular distribution of biomass between pelagial layers and on the other hand by seasonal domination of species with different sizes.

Phytoplankton biomass decreased constantly from year to year. In 1999 their mean value for whole period of study and for thermal layers was 7.7 mg dm⁻³, in 2000 - 5.4 mg dm⁻³ and in 2001 - 2.4 mg dm⁻³. Every year the highest biomass was noted in summer (13.2; 7.5; 3.6 mg dm⁻³, mean for consecutive years), in April-May was respectively 2.8, 5.6, 2.0 mg dm⁻³ and in October-November the biomass was lowest (2.2, 2.0, 1.0 mg dm⁻³) (Fig. 4).

The highest phytoplankton biomass was noted in epilimnion waters from June to August (11.9 –22.4 mg dm⁻³) during

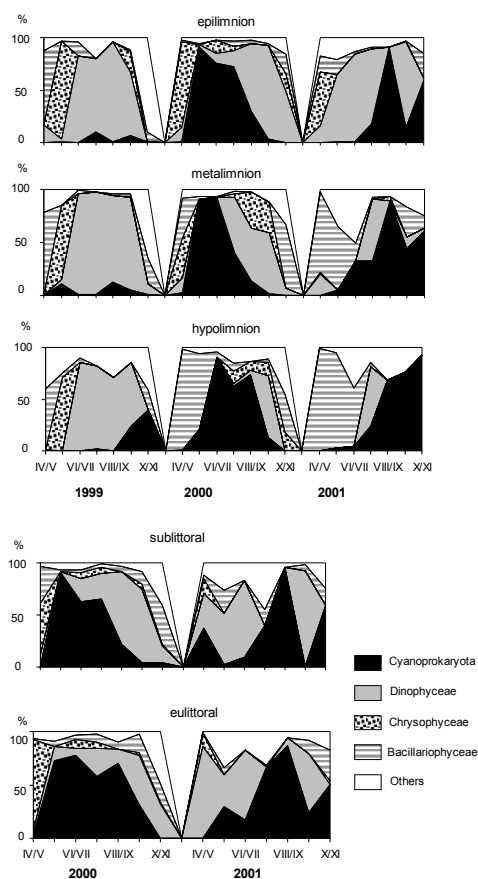


Fig. 5. Changes of phytoplankton composition in Lake Zagłębcze.

Among dinophytes *Ceratium hirundinella* (O. F. MÜLLER) DUJARDIN was the most prominent species (50-90 % of phytoplankton biomass). In the 1999 year it dominated in three pelagial layers reached the highest biomass in metalimnion and the lowest one in oxygen depleted hypolimnion. The next years interchangeably with dinophytes (*Ceratium hirundinella*, *Peridinium bipes* STEIN), blue-green algae *Aphanothece clathrata* WEST (2000) and *Coelomon pusillum* (VAN GOOR) KOMÁREK (2001). They reached their highest biomass in epilimnion and also in sub- and eulittoral (Fig. 5). Blue-green algae species included also *Woronichinia naegeliiana*

domination dinophytes and blue-green algae. The exception was 1999 when biomass accumulated in metalimnion ($17.5\text{--}45.5\text{ mg dm}^{-3}$) due to the migration of dinophyte *Ceratium hirundinella* population to deeper waters. Every year the lowest biomass was in hypolimnion. Only at the turn of April and May of 2000 and 2001 the values in hypolimnion was a many times higher (12.1 and 7.2 mg dm^{-3} ; respectively) than in surface waters (4.4 and 0.4 mg dm^{-3} ; respectively) caused by high biomass of diatoms (Fig. 4).

A less different distribution of biomass was noted in the transect of littoral-pelagial. Mean values in every site were usually similar, only in the summer of 2000 phytoplankton biomass was highest in epilimnion (mean 10.9 mg dm^{-3}) and successively decreased to the lowest in eulittoral (5.1 mg dm^{-3}) (Fig. 4).

Dinophytes and blue-green algae were major elements in the algal biomass and dominated mainly in the summer months (Fig. 5).

(UNGER) ELENKIN dominated between September and November 2001. In the 2001 *Peridinium bipes* dominated first of all among dinophytes.

Diatoms and chrysophytes were other important components of the phytoplankton assemblages. Their main period of domination occurred at the onset of stratification (April-May) (Fig. 5). Chrysophytes dominated in epilimnion while diatoms mainly in deeper waters.

Among chrysophytes dominated *Dinobryon sertularia* var. *protuberans* (LEMMERMANN) KRIEGER every year shared the phytoplankton biomass from 50 to 80 %. Additionally species included *Dinobryon divergens* IMHOF and *D. sociale* EHRENBERG but their share of biomass was low (< 10 %). Abundant chrysophytes appeared also in the summer period of 2000. The metalimnetic population was then dominated by *Mallomonas mirabilis* CONRAD with about 35 % share of phytoplankton biomass.

Among diatoms species in pelagial there was observed a exchange of dominants from year to year. In 1999 *Cyclotella comta* (EHRENBERG) KÜTZING dominated in the total water column while the next years dominated in hypolimnion *Fragilaria ulna* var. *acus* (KÜTZING) LANGE-BERTALOT (2000) and *Asterionella formosa* HASSALL (2001). The high biomass was persistent in hypolimnion until June. In April diatoms were also numerous in sublittoral. The species included *Fragilaria ulna* var. *acus* and *F. crotonensis* KITTON shared about 38 % of phytoplankton biomass (Fig. 5).

Diatoms appeared again also in autumnal months at the end of stratification (October-November). In deeper waters of pelagial dominated in the 2000 diatoms *Asterionella formosa* (39 % in metalimnion) and *Aulacoseira granulata* (EHRENBERG) SIMONSEN (35 % in hypolimnion). In eulittoral abundant were *Asterionella formosa* (29 %) and in sublittoral a benthic species *Navicula* sp. (25 %).

Green algae species contributed significantly to phytoplankton biomass occasionally in 2001 year. On the turn of June and July *Coenococcus planctonicus* KORŠIKOV, *Staurastrum cingulum* W. ET G. S. WEST, *Staurastrum pseudopelagicum* W. ET G. S. WEST were dominant in metalimnion contributed about 50% the total biomass (Fig. 5). In sub- and eulittoral *Closterium acutum* BREBISSON IN RALFS was abundant in July of 2001 (26 %, 16% ; respectively) while *Botryococcus braunii* KÜTZING was numerous in the autumnal months of 2000 (19 % and 18 %; respectively).

Phytoplankton was also composed of cryptophytes *Cryptomonas marssonii* SKUJA and *Rhodomonas pusilla* (BACHMAN) JAVORNICKÝ. Their highest share of biomass was noted at the end of stratification in 1999 year during fast decrease of biomass. In epilimnion they shared 60 % of biomass and in metalimnion 38 %.

Table 1

Values of Person's correlation coefficients ($p < 0.05$) between phytoplankton biomass (ln) and environmental variables (n. s. = not significant).

	Pelagial (n=57)						Transect (n=42)		
	temp.	SD	Z_{eu}/Z_{mix}	TN	TP	PO ₄ -P	temp.	TN	TP
Phytoplankton	0.54	n.s.	n.s.	n.s.	n.s.	n.s.	0.49	n.s.	n.s.
Cyanoprokaryota	0.37	-0.61	n.s.	n.s.	n.s.	n.s.	0.58	n.s.	n.s.
Dinophyceae	0.41	0.34	n.s.	n.s.	-0.33	-0.41	n.s.	0.42	-0.40
Chrysophyceae	n.s.	0.36	0.49	0.30	-0.33	n.s.	n.s.	0.43	-0.51
Bacillariophyceae	n.s.	0.33	0.32	n.s.	n.s.	n.s.	n.s.	0.44	-0.31

Relationships between phytoplankton composition and abiotic variables

Correlations coefficients between phytoplankton biomass and environmental variables were calculated separately for samples from pelagial and from horizontal sites at significant level $p < 0.05$. The results were demonstrated in Table 1.

The total phytoplankton biomass was connected with temperature taking into account pelagial as well as transect samples.

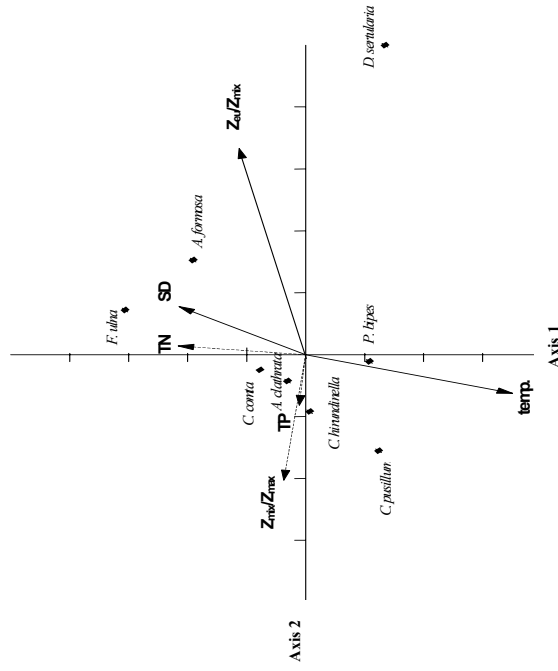
With regard to phytoplankton composition at classes level more relationships with physical variables were found in pelagial. The biomass of blue-green algae and dinophytes was correlated positively with temperature whereas biomass of chrysophytes and diatoms with relative light availability (Z_{eu}/Z_{mix}). All classes was correlated also with SD, biomass of blue-green algae negatively and the others positively.

The correlations with chemical variables in pelagial were insignificant or very low. Only dinophytes biomass was significantly correlated with PO₄-P concentrations ($r = -0.41$).

In horizontal sites more relationships were found with chemical variables (Tab. 1). Without blue-green algae, the relationship appeared only with temperature, biomass of remaining correlations groups were positive with TN and negative with TP. The correlations of phytoplankton classes with phosphate phosphorus and nitrate nitrogen were insignificant.

Statistical analysis comprised also Canonical Correspondence Analysis, for pelagial and for horizontal samples, in order to determine relationships between the biomass of phytoplankton species and environmental variables. Calculations were done for nine species: *Aphanothece clathrata*, *Coelomoron pusillum*,

Pelagial 1999-2001



Transect 2000-2001

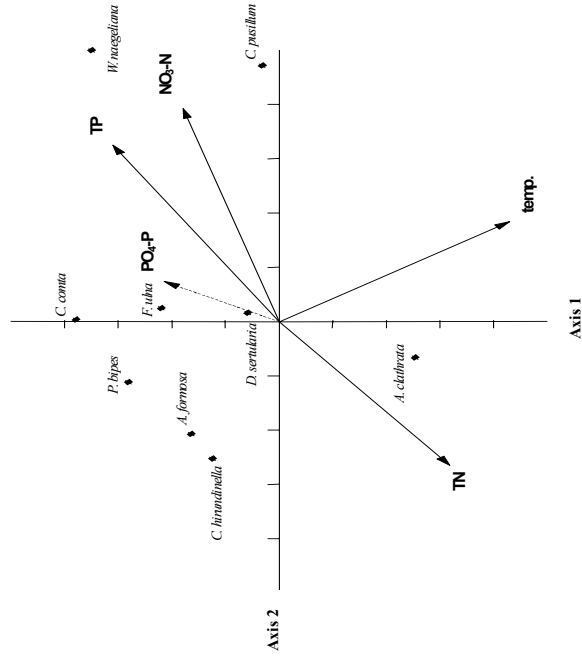


Fig. 6. Ordination diagrams (Canonical Correspondence Analysis) of dominated species for pelagial's and for transect's samples in relation to environmental variables. Line of vectors indicate: solid line – variables statistically significant ($p < 0.05$), dashed line – variables statistically insignificant.

Woronichinia naegeliana, *Ceratium hirundinella*, *Peridinium bipes*, *Dinobryon sertularia* var. *protuberans*, *Cyclotella comta*, *Asterionella formosa* and *Fragilaria ulna* var. *acus*. All species were characterized by high frequency in samples (> 50 %) and also a share of biomass always > 10 %.

The percentage of explained variance by significant variables separately for both analysis shared 32 % of the total variance.

In pelagial the biomass of species was correlated with physical variables: temperature, SD and Z_{eu}/Z_{mix} (Fig. 6). From ordination diagram resulted out that the group of diatoms species (*Fragilaria ulna* var. *acus*, *Asterionella formosa*, *Cyclotella comta*) was correlated negatively with temperature and positively with transparency (SD). The second group was dinophytes *Peridinium bipes*, *Ceratium hirundinella* and blue-green alga *Coelomorion pusillum* which appeared in inverse dependences with these variables.

In transect the biomass of species was connected with chemical variables: TP, NO_3-N and less TN (Fig. 6).

In relation to TP it may be separate two groups of species. To the first belongs blue-green algae *Coelomorion pusillum* and *Woronichinia naegeliana*, both having optimal growth of biomass at higher concentration of TP and NO_3-N . To the second group belongs species of dinophytes and diatoms. Their optimal growth conditions may be at lower TP concentrations and also at lower temperature.

DISCUSSION

The periodicity of phytoplankton in Lake Zagłębcze agrees with the classification described by Reynolds (1984a) and was typical for the mesotrophic line. Perturbation of allogenic factors (temperature, mixing) governed successional changes of diatoms and chrysophytes while autogenic succession based on competition for nutrients concerned dinophytes and blue-green algae.

Large diatoms *Asterionella formosa*, *Cyclotella comta* and *Fragilaria ulna* var. *acus* were characterized as ruderal species (Bucka and Wilk-Woźniak 2002). Their domination in April, October or November is connected with their preference to deeper vertical mixing of water. Under these conditions diatoms penetrate more of the water column to gain new nutrient resources.

However, in Lake Zagłębcze the correlation with variable described relative range of mixed depth (Z_{mix}/Z_{max}) was insignificant. Statistical analysis confirmed that besides temperature more important appeared water transparency (SD) and relative light availability (Z_{eu}/Z_{mix}). The positive correlation between diatoms biomass and SD and Z_{eu}/Z_{mix} values may be indicate that they prefer to

growth increasing light availability. According to Jørgensen (1969) and Harris (1973) diatoms are organisms able to efficiently photosynthesize at low light intensity. This divergence was caused by fact that in period of high diatoms biomass in hypolimnion there was noted as well the high water transparency. Long lasting high water transparency (SD = 4–4.5 m) allow diatoms to survive in hypolimnion until June.

The negative correlation between diatoms biomass and phosphorus indicate that they dominate at low phosphorus concentration. Diatoms may be better competitors for phosphorus than other algae. Better competition was confirmed by laboratory experiments (Smith and Kalh 1983). Their competitive superiority may be explain by catalytic property of silica in cell wall which affect as adsorbent for low phosphorus concentration (Werner 1977). However diatoms are usually out competed due to depletion of the other component – silica (Sommer 1988).

Domination of chrysophytes in early summer is observed in shallow and in deep lakes (Dokulil and Skolaut 1986, Wojciechowska 1986). According to Rott (1984) their domination in this period is connected with short time of homothermy during spring. The highest biomass of *Dinobryon* species in epilimnion of Lake Zagłębcze near the lake surface indicate a preference for high irradiance. During the chrysophyte domination surface water temperature was not higher than 18 °C. For *Dinobryon cylindricum* IMHOF Lehman (1976) state that its massive development dropped at water temperature over 12 °C.

According to Reynolds (1986) for chrysophytes metabolism is important also a water pH which may be not higher than 8.5. Over this value chrysophytes not uptake CO_3^{2-} because of impossibility to produce of carbon anhydrasis. During the chrysophytes domination in Lake Zagłębcze values of pH were between 7.1–8.3.

In summer phytoplankton of Lake Zagłębcze dominated large forms of dinophytes and blue-green algae were named as stress tolerant species (Bucka and Wilk-Woźniak 2002). These species dominate during stable thermal conditions without strong vertical mixing. They can good fit to conditions of low nutrients content. Large size allow them to store necessary nutritional components and to survive. The domination of particular species is mostly outcome of competition for nutritional components. These planktonic species are characterized by long life and long time of reproduction and they are typical K-strategists.

The massive appearance of dinophytes in summer is restricted in most cases to meso-eutrophic and eutrophic lakes (Spodniewska 1983, Trifonova 1998). In Lake Zagłębcze biomass of dinophytes dominated by *Ceratium hirundinella*, *Peridinium bipes* depended on temperature and phosphorus. They are not

stenothermic organisms but their high biomass is often noted in the warmest period. The range of water temperature in Lake Zagłębcze (17–22 °C) during domination of *C. hirundinella* covers the range given by other authors (16–23 °C) (Krupa 1981).

The negative correlation between dinophytes biomass and phosphate phosphorus indicate that their domination occurs at low concentrations. Similar observations are given by Serruya and Pollinger (1977). At higher concentrations dinophytes are suppressed by blue-green algae (Padisak 1985).

Accumulation of biomass in metalimnion in 1999 was caused by *Ceratium hirundinella*. It reaches competitive advantage over other phytoplankters by motility ability. In deeper water it allows them to sporadically penetrate hypolimnion water and to gain new resources (Frempong 1984).

Blue-green algae was dominated by large colonial forms. Their high biomass caused a decrease of water transparency in summer (negative correlation with SD).

In Lake Zagłębcze blue-green algae reached high biomass usually at water temperatures over 19 °C. This is generally in agreement with observations made by other authors which given value > 20 °C (Shapiro 1990, Zhang and Prepas 1996).

Besides temperature the growth of blue-green algae depends on the increased total phosphorus and nitrate concentration (Chow-Fraser et al. 1994, Dokulil and Teubner 2000). In Lake Zagłębcze the correlation coefficient between total phosphorus and total biomass of blue-green algae was insignificant. Only in CCA a positive correlation was obtained for species *Coelomoron pusillum* and *Woronichinia naegeliana* and the negative one for *Aphanothece clathrata*. This may be connected with different environmental requirements of these species. The species *Coelomoron pusillum* and *Woronichinia naegeliana* prefer eutrophic water but *Aphanothece clathrata* – mesotrophic (Rosen 1981, Komárek and Anagnostidis 1999). In Lake Zagłębcze the higher biomass of blue-green algae was correlated with higher nitrate nitrogen concentrations. Enrichment of water by inorganic nitrogen cause an exchange of dominant *Ceratium hirundinella* by coccoidal blue-green algae e.g. *Microcystis aeruginosa* (Bucka and Wilk-Woźniak 2002).

CONCLUSIONS

Studies carried out in Lake Zagłębcze confirmed that phytoplankton periodicity was related to seasonal changes of allogenic and autogenic variables. Diatoms dominated in period of deeper mixed depth (April, October and

November) but statistically their biomass was connected with perturbation of temperature and SD and Z_{eu}/Z_{mix} .

Successional changes of dinophytes and blue-green was connected with autogenic variables (nitrogen and phosphorus content). Dinophytes dominated at low phosphate phosphorus concentration. Blue-green algae reached higher biomass at higher TP and NO_3-N concentrations.

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