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PHYTOPLANKTON AS AN INDICATOR OF TROPHIC CHANGES IN A LAKE (LAKE KORTOWSKIE, NORTHERN POLAND)

***Bożena Jaworska*[1], *Bogusław Zdanowski*[2]**

[1] Department of Applied Ecology
University of Warmia and Mazury in Olsztyn
[2] Department of Hydrobiology
Institute of Fisheries in Olsztyn

Key words: phytoplankton, lake, taxonomic structure, biomass, trophic status.

Abstract

The aim of this study was to analyze multi-annual changes of the taxonomic structure and the intensity of the algal community development in phytoplankton of Kortowskie Lake, as a basis for determination of trophic state in the lake. There were observed qualitative and quantitative changes in the phytoplankton community. Species richness decreased in the subsequent years of the study. The number of Bacillariophyceae and Chlorophyta species declined, while the opposite trend was recorded in case of Cyanoprokaryota. The analysis of shifts in species composition revealed that the rate of species disappearance from the biocenosis was higher than appearance of new ones. The most intensive changes in the species composition affected the Bacillariophyceae and Chlorophyta associations. The stability of the Cyanoprokaryota biocenosis was remarkably higher and their constancy of occurrence increased. The rate of phytoplankton growth was high and was increasing in time. The intensity of phytoplankton development was determined by cyanoprokaryotes dynamics, which share in the total biomass was gradually increasing. The the blue-green algae limited the development of other plankton groups. The analysis of the multi-annual variations in the phytoplankton community of Kortowskie Lake indicated a trophic state in the ecosystem that were identified as progressing eutrophic status.

Address: Bożena Jaworska, University of Warmia and Mazury, Michała Oczapowskiego 5, 10-957 Olsztyn, Poland, phone: +48 (89) 523 35 95, e-mail: bozena.jaworska@uwm.edu.pl

FITOPLANKTON JAKO WSKAŹNIK ZMIAN TROFICZNYCH W JEZIORZE (JEZIORO KORTOWSKIE, POLSKA PÓŁNOCNA)

***Bożena Jaworska*[1], *Bogusław Zdanowski*[2]**

[1] Katedra Ekologii Stosowanej
Uniwersytet Warmińsko-Mazurski w Olsztynie
[2] Zakład Hydrobiologii
Instytut Rybactwa Śródlądowego w Olsztynie

Słowa kluczowe: fitoplankton, jezioro, struktura taksonomiczna, biomasa, stan trofii.

Abstrakt

Celem badań było przeanalizowanie wieloletnich zmian w strukturze taksonomicznej i intensywności rozwoju fitoplanktonu oraz określenie na tej podstawie stanu troficznego jeziora. Fitoplankton Jeziora Kortowskiego zmieniał się zarówno w aspekcie jakościowym, jak i ilościowym. Jego bogactwo taksonomiczne zmniejszało się w kolejnych latach. Malała liczba gatunków Bacillariophyceae i Chlorophyta, a zwiększała się Cyanoprokaryota. Wymianę gatunkową charakteryzowało większe tempo ustępowania gatunków niż pojawiania się nowych. Największe zmiany w składzie gatunkowym występowały w Bacillariophyceae i Chlorophyta, stabilność biocenozy Cyanoprokaryota była największa. Wzrastała również stałość występowania sinic. Rozwój fitoplanktonu był bardzo intensywny i z czasem wzrastał. O intensywności jego rozwoju decydowały Cyanoprokaryota, których udział w biomasie ogólnej był coraz większy. W warunkach postępującej dominacji sinic rozwój innych grup glonów był coraz słabszy. Analiza wieloletnich tendencji zmian w zbiorowisku fitoplanktonowym Jeziora Kortowskiego dała postawę do wnioskowania o stanie trofii jeziora i określeniu go jako stanu postępującej eutrofii.

Introduction

Lakes are relatively dynamic ecosystems that change over time. Their progressing trophic stage is a natural course of their development on condition that it runs in equilibrium state considering, both, physico-chemical and biotic features. The modification of factors, which combined acting determines the maintenance of the ecological equilibrium, may stimulate the increase in eutrophication rate (DILLON, RIGLER 1975, VEZJAK et al. 1998, ANNEVILLE et al. 2002). This process, understood as a set of symptoms resulting from an excessive supply of nutrients, causes significant changes in the structure and functioning of particular trophic units of the ecosystem (FORSBERG et al. 1978, CURRIE 1990, CARPENTER et al. 1997, BURGI et al. 1999, DANILOV and EKELUND 1999, REYNOLDS 2000). The phytoplankton community is one of them.

Algal associations respond sensitively to changes in water quality indicating even weak variations in, both, abiotic or biotic features. Phytoplankton development may modify physico-chemical properties of water and also, as a first link of a trophic chain, determine further trophic relations in the environment (SCHINDLER 1978, MCQUEEN et al. 1986, DAUTA et al. 1990, LAFFORGUE et al., BAIRD et al. 2001, HAY and KUBANEK 2002). Analysing of the algal species composition, taxonomic structure and the intensity of phytoplankton development is highly useful in the assessment of the trophic state of the reservoir.

The aim of the research was to analyze multi-annual changes in the taxonomic structure and the estimation of the intensity of algal community development in phytoplankton of Kortowskie Lake as a basis for determination of trophic state in the lake.

Study area

The studies were conducted on Lake Kortowskie. It is located in north-eastern part of Poland, in the Mazurian Lakeland, within the limits of the town of Olsztyn. The lake has an elongated shape along the axis north-south. The reservoir is created by three distinct parts: the south basin of a maximal depth of 17.2 m, the north basin of a maximal depth of 15.7 m and the middle part that is relatively shallow, of a maximal depth of 6 m, that separates the two basins. The lake's surface area is 94 ha and its volume is 5 323 000 m^3 at water table of 103.3 m above the sea level (SYNOWIEC 1965). The total drainage basin of the lake is 38.0 km^2. The direct drainage basin of the lake is 102 ha. The lake is supplied by 5 inflows. There is only one river outflow – the Kortówka River – the tributary of the Łyna River, that is located in the southeastern part of the reservoir. The amount of waters flowing out of the lake is regulated by a weir that enables the removal of hypolimnion water by a pipeline installed in the southern part of the lake (Lake Kortowskie has been restored by the method of removal of nutrient-rich hypolimnion water to impede progressing eutrophication of the reservoir). The northern part of the lake is separated from the southern one (by shallows of a depth of 6 m) and is not indirectly influenced by pipeline activity similarly as the water layer from 0 to 6 m depth in the entire lake.

Materials and Methods

Studies of phytoplankton were carried out at two sites located in the deepest part of the two local basins: in the southern (S site) and northern (N site) part of the lake. Both stations had been recognized by CHUDYBA (1974, 1975) as representative. Phytoplankton analyses began in 1987, during spring mixing, and were finished in 1991 during winter water stagnation; next studies lasted from spring 1999 to winter 2000. The frequency of sampling depended on the season. Samples were taken three times during summer periods, and two times in spring, autumn and winter periods. Preliminary qualitative phytoplankton analysis was conducted on living organisms collected by plankton net. Fundamental qualitative and quantitative plankton analyses were carried out basing on fixed samples obtained from water column (0–5 m) and concentrated by settling method. Qualitative analysis was performed according to STARMACH (1989) using drop method to calculate the number of individuals. Phytoplankton biomass was calculated basing on cell volume measurements (HEUSDEN 1972, STARMACH 1989). Qualitative and quantitative phytoplankton analyses were performed using the following microscope magnifications: $1.25 \times 10 \times 40$ or $1.25 \times 10 \times 100$.

Statistical characteristics of results included: minimal values (min.), maximal values (max.), mean values (x) and standard deviation (SD). Normality was assessed with the Shapiro-Wilks test. Significance of differences in mean phytoplankton biomass recorded at particular sites and years were tested using the Mann-Whitney test or Kruskal-Wallis test. Similarity of algal associations in the successive years was measured by hierarchical classification of cluster analysis. The relationships between changes of phytoplankton biomass and the content of chlorophyll *a* and the selected physico-chemical water properties were tested by means of the Pearson correlation. The following water features were taken into account: a Secchi disk visibility, water temperature, nitrogen and phosphorus contents.

Results

Phytoplankton qualitative structure

In the first period of the study (1987–1991), it was recorded from 233 to 251 species in Lake Kortowskie, but the species number was successively decreasing. Particularly low species richness of phytoplankton was found in 1999/2000 – 198 algal taxa. The differences between sites in taxonomic structure barely reached 4.4%. Bacillariophyceae and Chrysophyceae were the most taxonomically diversified groups which were represented by 97–103 species in 1987–1991. Their share in the total number of phytoplankton taxa ranged from 40.6 to 41.6%. Within this systematic groups the proportion of Bacillariophyceae amounted to 80%, while Chrysophyceae reached only 20%. Considering the limnological year 1999/2000, only 72 species from Bacillariophyceae and Chrysophyceae were present that constituted 36.4% of the total number of taxa. The flora of diatoms was predominated by the following genera: *Asterionella, Fragilaria, Aulacosiera, Stephanodiscus, Diatoma* and *Tabellaria*. *Dinobryon* was the most frequent taxon among chrysophytes.

Chlorophyta showed pattern of changes similar to Bacillariophyceae. Eighty-seven of their species were recorded in 1987/1988 while in the successive years – 87, 86 and 80 algal species, respectively. Chlorophyta constituted about 34–35% of the total number of algal taxa in the lake. In 1999/2000 their share decreased to 30.3%, while the number of their species dropped to 60. The most frequent were the species from the following genera: *Pediastrum, Coelastrum, Crucigenia, Kirchneriella, Oocystis, Scenedesmus, Tetraedron, Tetrastum* and *Dactylosphaerium* and *Pandorina*, *Eudorina, Phacotus.* In group of Cyanoprokaryota, 39, 40, 41 and 35 species were described in the lake in the successive years during the period 1987–1990. The proportion of cyanoprokaryotes was estimated at the level 15–16.4% of the total number. In the 1999/2000, the growth of Cyanoprokaryota proportion by about 10% (up to 24%) was recorded. Then, the number of their species reached 48. Among them, most often recorded species were the representatives of the following genera: *Microcystis, Anabaena, Aphanizomenon, Woronichinia, Planktothrix, Limnothrix, Aphanocapsa* and *Aphanothece.* The share of Euglenophyta and Dinophyta was low and did not exceed 8% and 4%. Twenty one species representing Euglenophyta belonged to the three genera i.e. *Euglena, Phacus* and *Trachelomonas*. There were recorded only 15 species from the Dinophyta and their contribution to the planktonic community was similar (Figure 1).

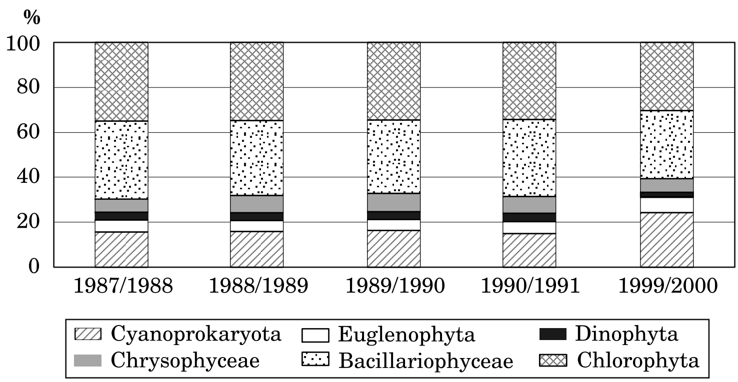

Fig. 1. The share of the numbers of species in particular systematic groups of phytoplankton in Lake Kortowskie in the years 1987–1991 and 1999–2000

Phytoplankton quantitative structure

The mean annual biomass reached 8.2 mg dm^{-3} (SD ± 4.6) in the years 1987–1991 and it varied in from 7.9 (SD ± 5.2) to 8.5 mg dm^{-3} (SD ± 4.4). This parameter value significantly increased up to 18.5 mg dm^{-3} (SD ± 9.6) in 1999/2000 (H = 100.74, $p < 0.001$). In Lake Kortowskie, phytoplankton showed

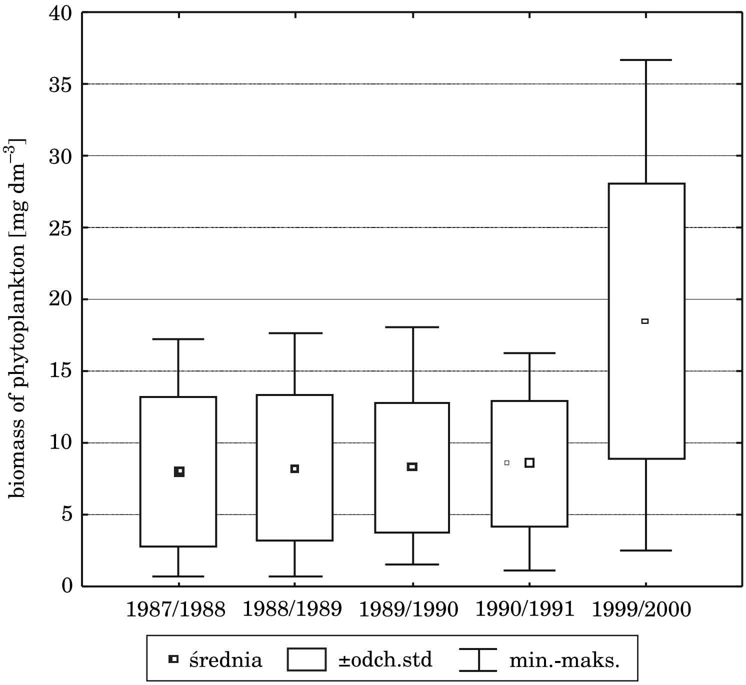

Fig. 2. Dynamics of algal biomass in the epilimnion of Lake Kortowskie in the years 1987–1991 and 1999–2000

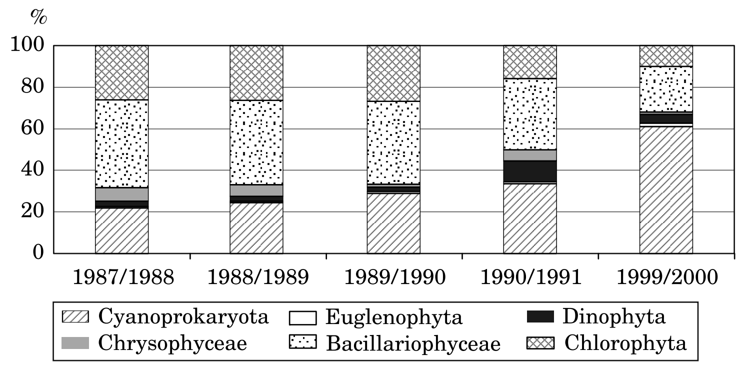

Fig. 3. The share of particular systematic groups in the biomass of phytoplankton in Lake Kortowskie in the years 1987–1991 and 1999–2000

similar quantitative structure at particular sites ($p > 0.001$, during the whole period of the study). In 1987–1991, phytoplankton biomass dynamics was determined by the development of Bacillariophyceae and Chrysophyceae. The most important species among them were: *Asterionella formosa* Hass., *Fragilaria crotonensis* Kitt. and *Fragilaria capucina* Des. and also, at the end of the period of study, *Aulacosiera granulata* (Ehr.) Sim., *Aulacosiera islandica* (O. Müll.) Sim. and *Stephanodiscus rotula* (Kutz.) Hend.. Then, the biomass of this algal group and its share in the total phytoplankton biomass slightly dropped from 4.8 mg dm^{-3} (SD ± 4.2) to 3.5 mg dm^{-3} (SD ± 2.6) on average, and from 48.8% to 39.5%. In 1999/2000, the contribution of Bacillariophyceae and Chrysophyceae declined to 23.1%. At one time, the Chlorophyta mean biomass reached 2.5 mg dm^{-3} (SD +2.6) in 1987-1989 constituting about 26% of the total. This proportion decreased to 15.9% in 1990/1991 and the mean biomass dropped to 1.4 mg dm^{-3} (SD ± 1.5). Then a slight increase was recorded, to 1.9 mg dm^{-3} (SD ± 1.8), which value constituted barely 10% of the total algal biomass in 1999/2000. The share of Chlorophyta gradually decreased and the same was recorded in case of dominants i.e. *Pandorina morum* (O.F. Müll.) Bory, *Pediastrum boryanum* (Tur.) Men., *Coelastrum microporum* Näg. A. Braun and *Phacotus lenticularis* (Her.) Stein. Considering Cyanoprocaryota, their mean annual biomass showed the trend to rise from 2.1 mg dm^{-3} (SD ± 2.4) to 3.0 mg dm^{-3} (SD ± 2.5) and their share in the community went up from 21.9 to 33.6% considering the time between 1987 and 1991. More intensive growth of this algal group was detected in 1999/2000 when their mean annual biomass reached 12.1 mg dm^{-3} (SD ± 8.5) and their proportion in the algal community increased up to 61%. Among Cyanoprokaryota, the most abundant were the following taxa: *Microcystis aeruginosa* (Kütz.) Kutz., *Anabaena spiroides* Kleb., *Anabena flos-aquae* (Lyng.) Breb. and additionally *Aphanizomenon flos-aquae* (L.) Ralfs, *Woronichinia naegeliana* (Unger) Elen., *Limnothrix planctonica* (Wolosz.) Meff. and *Limnothrix redeckei* (Van Goor) Meff., and their contribution was gradually increasing. The biomass of Euglenophyta did not reach 0.7 mg dm^{-3} and the proportion – 1.6% of the total. The biomass of Dinophyta usually did not exceed 0.4 mg dm^{-3} and 4% by share, except for the year 1999/2000 when it reached 0.8 mg dm^{-3} (SD ± 1.0), on average, and constituted about 10% of the total algal biomass. *Ceratium hirundinella* (O.F. Müll.) Duj. was the taxon that was responsible for a sudden development of this algal group (Figure 2, Figure 3).

The relationships between phytoplankton and selected physico-chemical parameters

In order to estimate the relationships between physico-chemical water properties and phytoplankton dynamics, the following features were selected: the Secchi disc visibility, water temperature, nitrogen and phosphorous contents in lake water. It was shown that phytoplankton biomass was growing

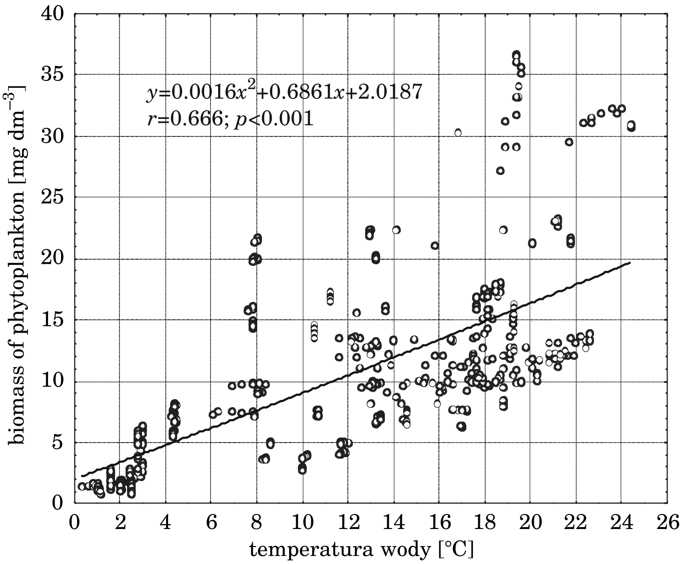

Fig. 4. The correlation coefficient between phytoplankton biomass and water temperature in the epilimnion of Lake Kortowskie in the years 1987–1991 and 1999–2000

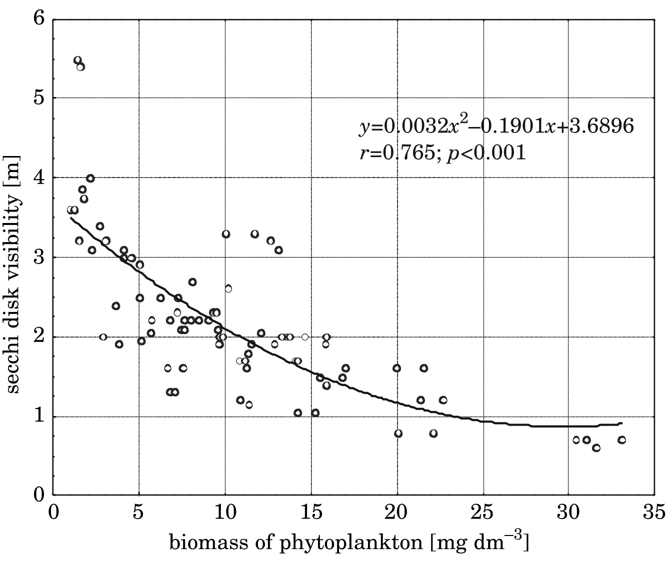

Fig. 5. The correlation coefficient between the Secchi disk visibility and phytoplankton biomass in the epilimnion of Lake Kortowskie in the years 1987–1991 and 1999–2000

together with increasing water temperature (r = 0.666, p < 0.001) – Figure 4. This rise of phytoplankton biomass significantly influenced water turbidity (r = -0.765; p < 0.001) causing its decrease (Figure 5). Algal growth was also

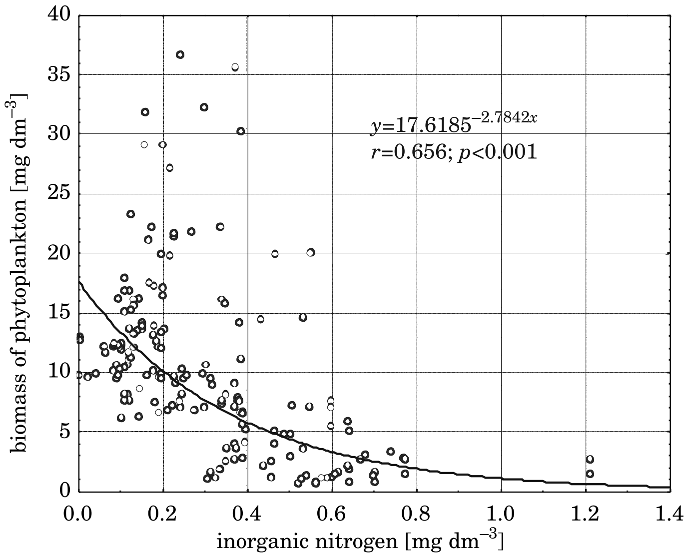

Fig. 6. The correlation coefficient between algal biomass and inorganic nitrogen contents in the epilimnion of Lake Kortowskie in the years 1987–1991 and 1999–2000

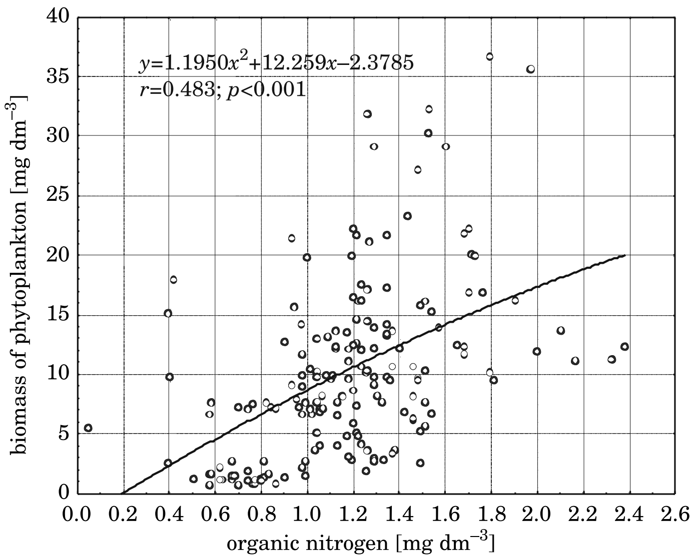

Fig. 7. The correlation coefficient between algal biomass and organic nitrogen contents in the epilimnion of Lake Kortowskie in the years 1987–1991 and 1999–2000

correlated with a decline in the content of the sum of inorganic nitrogen (r = -0.656; p < 0.001) – Figure 6 as well as with the increase in organic nitrogen concentrations in the water (r = 0.483; p < 0.001) – Figure 7 and

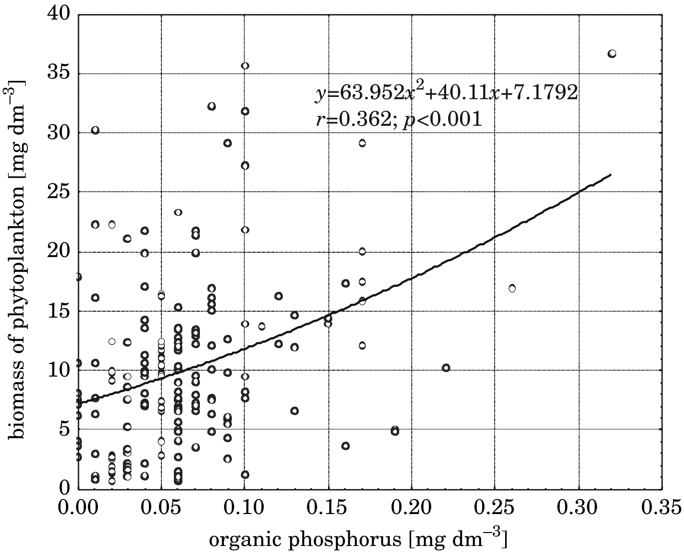

Fig. 8. The correlation coefficient between algal biomass and organic phosphorous contents in the epilimnion of Lake Kortowskie in the years 1987–1991 and 1999–2000

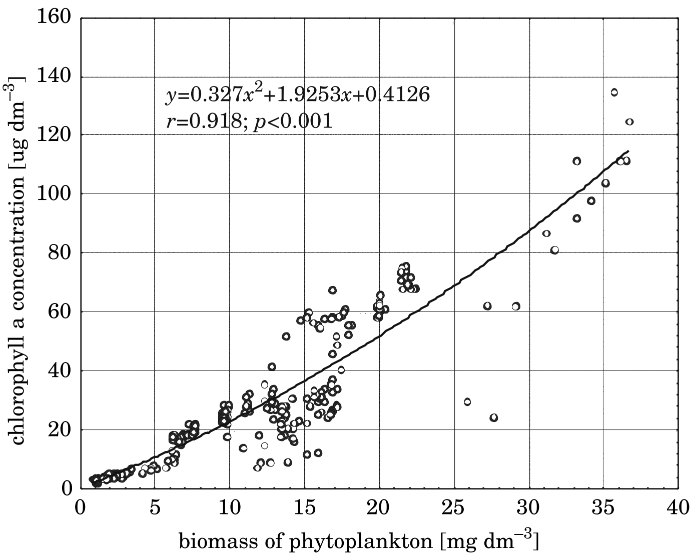

Fig. 9. The correlation coefficient between phytoplankton biomass and chlorophyll *a* levels in the epilimnion of Lake Kortowskie in the years 1987–1991 and 1999–2000

organic phosphorous (r = 0.362; p < 0.001) – Figure 8. The relationships between algal biomass and total phosphorous, total nitrogen contents as well as available form of phosphorous (orthophosphates) were not statistically important. It was recorded that chlorophyll a concentration in epilimnion water was significantly correlated with algal biomass ($r = 0.918$; $p < 0.001$) – Figure 9.

Discussion

Species richness, shifts in composition and taxonomic structure and dynamics of phytoplankton development may indicate, beside other ecosystem components, a direction of trophic changes in lakes (DILLON and RIGLER 1975, MCQUEEN et al. 1986, BURCHARDT 1993, BURCHARDT and ŁASTOWSKI 1999, REYNOLDS 2000, REYNOLDS et al. 2002).

All of the algae community changes are the result of compositional shifts in phytoplankton (LAFFORGUE et al. 1995, SNIT'KO and ROGOZIN 2002). In Lake Kortowskie, the highest rate of taxonomic variations was recorded in case of the Bacillariophyceae and Chlorophyta, whereas Cyanoprokaryota showed the highest stability of their biocenosis. The rate of species exchange within this phylum was relatively low but the number of their taxa was permanently increasing. It was also shown that in the remaining taxonomic groups the proportion of the number of taxa retreating from the environment was higher than species appearing for the first time. Therefore, the rate of taxa extinction was higher than the rate of their emergence. It is noteworthy that new species usually represented taxa typical of eutrophic waters (STARMACH 1989, BURCHARDT 1993, REYNOLDS 2000). Despite the fact that the number of Cyanoprokaryota species increased, their species diversity was lower in comparison to diatoms and chlorophytes retreating from the environment what additionally enhanced the observed decrease in the overall taxa number. Such a direction of phytoplankton changes resulted in lowering of the species richness in Lake Kortowskie. Species richness usually rises together with a gradual growth of trophic state. HEINONEN (1980) documented that a moderate increase of a trophic level, with a corresponding biomass not exceeding 3.5 mg dm^{-3}, usually caused variations in algal number only in narrow limits. In turn, remarkable impoverishment of species resources takes place, when a progress in eutrophication is significant (CRONBERG 1999, DANILOV and EKELUND 1999, REYNOLDS et. al. 2002). Compositional modifications in phytoplankton and shifts in taxonomic structure coincided with intensified phytoplankton development. This increasing rate of algal growth did not exceed 10% in 1987–1991; however, in 1999/2000 it was higher by 50%. Recorded in the earlier period slight but progressing growth of phytoplankton development might have been the first symptom of a slow, trophic shift that manifested itself in a much more distinct way in 1999/2000. The most important group which conditioned the pattern of phytoplankton dynamics were Cyanoprokaryota, which proportion in the total algal biomass was permanently increasing. Cyanoprokaryota occurred in large numbers and achieved very high biomass not only in summer, but also in spring and autumn. The blue-green algae decided of earlier regression of the diatoms in spring and their weaker development in autumn, also succeeded in competition with the remaining phytoplankton taxa in summer. The species that dominated were *Microcystis aeruginosa* (Kütz.) Kütz., *Anabaena spiroides* Kleb. or *Anabaena flos-aqae* (Lyng.) Breb. and *Aphanizomenon flos-aqae* (L.) Ralfs., which are typical of eutrophic waters (STARMACH 1989, BURCHARDT et al. 1994, REYNOLDS 2000). The community of the blue-green algae limited the development and stability of other plankton groups. In turn, the development of Bacillariophyceae and Chlorophyta was limited in the successive years. It was recorded a 3-fold drop of Bacillariophyceae biomass and 6-fold in case of Chlorophyta. The comparison of the values of algal biomass in Lake Kortowskie with the biomass recorded in other temperate lakes of different trophic stage (KAJAK 1983, HILLBRICHT-ILKOWSKA, KAJAK 1986) revealed that in 1987–1991 the level of the lake trophic state was moderate, while in 1999/2000 the obtained results indicated that the lake was highly eutrophicated. SPODNIEWSKA (1983) documented, basing on the studies on a series of Mazurian lakes, that the eutrophy occurred when the phytoplankton biomass exceeded 8 mg dm^{-3}. Whereas in pursuance of the trophic classification of Finnish lakes by HEINONEN (1980), the indicative to eutrophy value of algal biomass ranged from 3.5–10.0 mg dm^{-3}. In Lake Kortowskie, chlorophyll *a* levels, commonly regarded as an indicator of algal biomass (SCHMID et al. 1998), varied in limits indicative of eutrophic waters (KUFEL 2001) and phytoplankton biomass explained 84% of variations in that pigment content.

Multi-annual shifts in composition and taxonomic structure of phytoplankton together with intensified algal development that characterize phytoplankton communities subject to variations in trophic state usually reflect changes in physico-chemical water properties (HILLBRICHT-ILKOWSKA and ZDANOWSKI 1983, SPODNIEWSKA 1983, DAUTA et al. 1990, VEZJAK et al. 1998, BAIRD et al. 2001). The community of phytoplankton in Lake Kortowskie also responded to modifications in physico-chemical features of water among which the most important were: water turbidity, temperature and availability of inorganic forms of nutrients. Water temperature rise stimulated phytoplankton biomass growth and that, in turn, resulted in significant increase of water turbidity. About 60% of the biomass variations can be explained by water turbidity fluctuations. The Secchi disc visibility decreased proportionally to phytoplankton growth (DAUTA et al. 1990). In Lake Kortowskie, the most intensive growth of water turbidity was recorded when phytoplankton biomass exceeded 10 mg dm^{-3}. However, light conditions were mainly determined by intensive development of cyanoprokaryotes (SPODNIEWSKA 1986), which occurred even in spring when water temperature suddenly arose. Weak correlation between algal biomass and water turbidity occurred only then, when Cyanoprokaryota appeared in large quantities forming colonies. BROOKES'A et al. (1999) documented that this sort of algal aggregations absorbed and dispersed light weaker than the suspension of fine planktonic organisms. The development of phytoplankton caused a significant drop in contents of the sum of inorganic nitrogen forms and increase in organic nitrogen and phosphorous concentrations. Variations in inorganic nitrogen contents determined 43% of phytoplankton biomass changes, whereas organic nitrogen and phosphorous concentrations were responsible for only 23% and 13% (respectively) of the recorded changes. It was probably due to the fact that their contents that corresponded to the particular biomass values varied in wide limits (CURRIE 1990, MIENTKI and DUNALSKA 2001). In a consequence, the correlation coefficients between phytoplankton biomass and total phosphorous and nitrogen were not significant. The same was recorded in case of the content of soluble reactive phosphorus (orthophosphates) which contribution to total phosphorous was always high (about 60%). In turn, the N/P ratio might have had a significant input to the development of phytoplankton and its composition, which dropped even to 5 in the studied lake. Average values of this ratio varied from 8 to 11 in 1987–1991 and to about 14 in 1999/2000. Such N/P values suggest accumulation or regeneration of phosphorus in epilimnion (SCHINDLER 1978, ZDANOWSKI 1982, UCHMAŃSKI 1988, MIENTKI and DUNALSKA 2001). The recorded values might have also had impact on phytoplankton composition and structure. Relatively low nitrogen contents and high phosphorus concentrations in water stimulate cyanoprokaryotes growth (SCHINDLER 1977, LAFFORGUE et al. 1995, HAY and KUBANEK 2002). Another important factor that should be considered when explaining the rate and character of phytoplankton changes in Lake Kortowskie is the hydrological regime of the lake. Limited inflow of waters (from Lake Ukiel by the main tributary) could cause that amounts of water flowing out of the were higher than overall water supply from all sources. In a consequence, in summer, water table in the lake dropped by 40 cm and the periods of low water table lasted from June to November (DUNALSKA et al. 2001, DUNALSKA 2002). Such hydrological conditions can stimulate phytoplankton growth and may also have an impact on taxonomic structure and the rate of phytoplankton development affecting pace and direction of trophic changes in the epilimnion of lake.

The multi-annual variations in the taxonomic structure and the estimation of the intensity of algal community development in phytoplankton of Kortowskie Lake indicated a trophic changes in the ecosystem that were identified as progressing eutrophic status.

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