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SEASONAL CHANGES IN THE STRUCTURE OF THE COMMUNITY OF PHOTOTROPHS IN A SMALL MID-FOREST LAKE

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Summary. In a small, mid-forest Lake Kociołek, located in the Wielkopolska National Park (west Poland), phytoplankton diversity, abundance and biomass were studied from March till November 2003. Special attention was paid to picoplankton. Green algae were the most diverse, as they accounted for nearly 50% of all recorded phytoplanktonic species, while picocyanobacteria were the most abundant. The biomass of phototrophs, measured as chlorophyll *a* concentration, ranged from 1.1 to 17.4 $\mu g\ l^{-1}$ (mean 5.9 $\mu g\ l^{-1}$). The mean contribution of picoplankton to the total biomass of phytoplankton was high, as it reached 32%.

Key words: phytoplankton, picocyanobacteria, chlorophyll *a*, seasonal variation, small lake

INTRODUCTION

The seasonal cycle of phototrophic populations in temperate lakes has been studied in lakes of all trophic types. As a result, a variety of successional patterns have been presented [Sandrgen 1988]. The inclusion of the smallest phototrophic cells, i.e. picophytoplankton, even further increased the variety. They often reach very high numbers and, usually in spring and late summer, two peaks of picophytoplankton abundance are observed, separated by a period of low abundance in June and July [Stockner *et al*. 2000]. Picophytoplankton abundance and biomass usually increase with growing trophic level, but their contribution to the total biomass of primary producers is generally negligible, higher only in oligotrophic lakes [Stockner and Shortred 1991, Weisse 1993]. Preliminary studies of lakes in the Wielkopolska National Park, which differ in trophic state, showed that the contribution of picophytoplankton was the highest in the mesotrophic Lake Kociołek [Szeląg-Wasielewska 2003]. Consequently, seasonal variation and quantitative relations between picoplanktonic (< 2 μm) and larger (> 2 μm) algae needed to be analysed in detail in this lake. It is noteworthy that small lakes are poorly studied in this respect. That is why in this study, the diversity, abundance and biomass of phytoplankton (picophytoplankton in particular) in Lake Kociołek were investigated.

STUDY AREA, MATERIALS AND METHODS

Lake Kociołek is a small, postglacial water body situated in the Wielkopolska National Park (west Poland) and protected as a nature reserve. This closed lake is surrounded by hills covered with oak-hornbeam forest. There are no point sources of pollution in the direct catchment, but the lake is affected by pollution from diffuse and dispersed sources. It is classified as mesotrophic [Szyper and Gołdyn 2002]. According to Karcz and Schubert [1997], the area of the lake is 4.2 ha, while its maximal and mean depths are 6.6 m and 3.9 m, respectively.

Water samples for analyses of phytoplankton, concentration of chlorophyll *a* and suspended solids, were collected from one station 0.5 m below the surface in 2003, from March to November, once a month in spring and autumn and usually twice a month in summer (14 sampling sessions). Samples were preserved and examined with the use of exactly the same methods as described earlier for the nearby Lake Skrzynka [Szeląg-Wasielewska 2003, 2004, 2005].

RESULTS

Within phototrophs in Lake Kociołek 132 taxa were identified. Most of them were green algae (Chlorophyta) whose contribution to the total number of phytoplankton species was 46%. Cyanobacteria ranked second and were followed by diatoms and chrysophytes; their contributions to the total number of species in the study period were 14, 11 and 9.8%, respectively. The other five classes – dinoflagellates, cryptomonads, euglenoids, xanthophytes, and haptophytes – had small contributions to the phycoflora.

Total phytoplankton abundance ranged between 4.17×10^3 and 1.09×10^6cells ml^{-1} (mean 3.61×10^5 cells ml^{-1}) (Tab. 1). The mean abundance of cells < 2 μm (i.e. picoplankton) was 14 times higher than that of cells > 2 μm (i.e. nano- and microplankton), and the mean contribution of picoplankton to total phytoplankton abundance was 80%. Only on two sampling sessions picoplankton was less abundant than cells >2 μm. This happened at the beginning of the study, in March, when the dominant species was a nanoplanktonic chrysophyte, *Chrysococcus triporus,* as well as in mid-June, when nanoplanktonic green algae of the genus *Chlorella* dominated.

Table 1. Abundance of picoplankton (<2 μm) and larger phytoplankton (>2 μm) and their contributions to total phytoplankton abundance in Lake Kociołek from March to November, 2003
Tabela 1. Liczebność pikoplanktonu (<2 μm) i większego fitoplanktonu (> 2 μm) oraz ich udział w liczebności ogólnej fitoplanktonu jeziora Kociołek od marca do listopada 2003 r.

Size group Grupa wielkościowa	Abundance (cells ml^{-1}) Liczebność (kom. ml^{-1})		Contribution (%) Udział (%)	
	Range Zakres	Mean Średnia	Range Zakres	Mean Średnia
< 2 μm	1636-1 082 150	337 081	34.4-99.1	80
> 2 μm	1211-62 465	23 925	0.9-65.6	20

The largest populations were formed by picocyanobacteria. Their abundance was highly variable; it peaked in mid-July and September and was the lowest in June or generally in the first half of the year and then single-celled organisms dominated (Fig. 1).

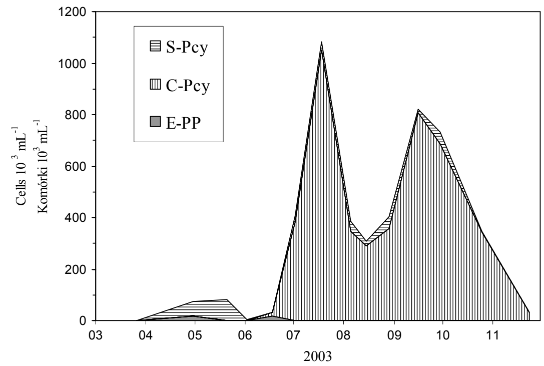

Fig. 1. Abundance of single-celled picocyanobacteria (S-Pcy), colonial picocyanobacteria (C-Pcy) and eukaryotic picophytoplankton (E-PP) in Lake Kociołek from March to November, 2003
Rys.1. Liczebność pojedynczych komórek pikocyjanobakterii (S-Pcy), kolonijnych pikocyjanobakterii (C-Pcy) i eukaryotycznego pikofitoplanktonu (E-PP) w jeziorze Kociołek od marca do listopada 2003 r.

In the second half of the year, picoplanktonic cells formed colonies varying in morphology. They were identified as species of the genera *Aphanocapsa*, *Aphanothece* and *Cyanodictyon,* mainly *Aphanocapsa holsatica* (Lemm.) Cronberg & Komárek*, Aphanothece minutissima* (W. West) Komárková-Legnerová & Cronberg and *Cyanodictyon planctonicum* Meyer. The contribution of colonial forms to the total number of picocyanobacteria was the highest from July to November, when it ranged between 89 and 99%, whereas the mean for the whole study period was 68%. Eukaryotic picoplankton was composed of the smallest green algae. Their abundance reached the highest value of 1.7×10^4 cells ml^{-1} in late April (mostly *Stichococcus* and *Choricystis* species) and 1.6×10^4 cells ml^{-1} in mid-June (mostly *Chlorella* species). The proportion of chlorophyll *a* contributed by picoplankton was between 0.1 and 5.1 μg l^{-1}. Their contribution to total chlorophyll *a* was highly variable during the study period: from about 1 to 87% (Fig. 2). It must be noted that in the second half of the year this contribution was higher than in the period from March to June and their mean contribution to total chlorophyll *a* content was 32%.

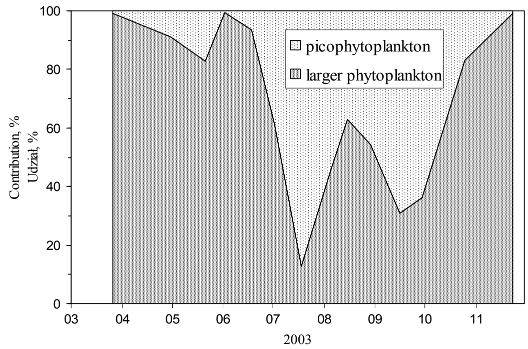

Fig. 2. Seasonal changes in contributions of picoplankton (< 2 μm) and larger phytoplankton (> 2 μm) to total chlorophyll *a* in waters of Lake Kociołek from March to November, 2003
Rys. 2. Sezonowe zmiany udziału pikoplanktonu (< 2 μm) i większego fitoplanktonu (> 2 μm) w ogólnym chlorofilu *a* w wodzie jeziora Kociołek od marca do listopada 2003 r.

Total phytoplankton biomass, measured as chlorophyll *a* concentration, varied widely, from 1.1 to 17.4 μg L^{-1}, but the mean value for the whole study period, 5.9 μg l^{-1}, was not high. Values of this parameter peaked in April, mid-June and July, and autumn (October and November). In April the increase was due chiefly to chrysophytes (mostly *Dinobryon sociale* var. *americanum* (Brunth.) Bachmann, *D. bavaricum* Imhof), whereas in summer to small green algae and/or picocyanobacteria, and in autumn to chrysophytes again (mostly *Uroglena americana* Calkins), diatoms (mostly *Asterionella formosa* Hassal) and/or cryptomonads and dinoflagellates (mostly *Cryptomonas* spp. and *Peridinium gatunense* Nygaard). Only on 2 out of 14 sampling sessions, chlorophyll *a* concentration exceeded 10 μg l^{-1} (Fig. 3).

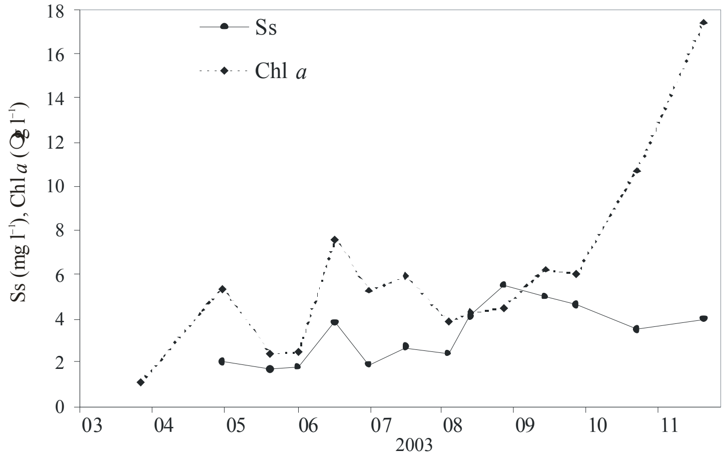

Fig. 3. Suspended solids (Ss, mg l^{-1}) and total chlorophyll *a* (Chl *a*, μg l^{-1}) in waters of Lake Kociołek from March to November, 2003
Rys. 3. Zawiesiny (Ss, mg·l^{-1}) i ogólny chlorofil *a* (Chl *a*, μg·l^{-1}) w wodzie jeziora Kociołek od marca do listopada 2003 r.

The concentration of suspended solids in waters of Lake Kociołek varied between 1.7 and 5.5 mg l^{-1} (mean 3.3 mg l^{-1}) (Fig. 3). Usually it changed parallel to the changes in chlorophyll *a* concentration, but from the statistical point of view, those two parameters were not significantly correlated (r = 0.32. p = 0.282). The contribution of chlorophyll *a* to suspended solids varied between 0.08% and 0.44%. Its contribution was the highest at the end of the study period, when the densities of *Uroglena americana* and cryptomonads were high.

DISCUSSION

The first study of the phytoplankton of Lake Kociołek was conducted in 1930 and 1931 by Danowska-Krawiecowa [1934], who concluded that this lake was eutrophic. At that time, the most diverse groups in the lake were diatoms and green algae. Also further research by Dąmbska *et al*. [1978], like the results of the present study, showed high contributions of those groups of algae to total phytoplankton diversity, followed by cyanobacteria or chrysophytes. In the early 1990s, as reported by Messyasz [2001], the phytoplankton abundance dominants changed, attesting to a decrease in trophic level. The qualitative and quantitative analyses of phytoplankton performed in 1990-1991 showed a great diversity of phytoplankton and indicated that the lake was mesotrophic [Machowiak and Burchardt 2001]. Those conclusions were confirmed by results of research carried out in 1996 [Messyasz 2001].

In 2003, total phytoplankton abundance was high, but this resulted chiefly from the inclusion of picoplanktonic phototrophs which were earlier ignored. It was much higher than values reported earlier for that lake and even for other, more fertile lakes in the Wielkopolska National Park [Pełechata 2002]. The density of single-celled picoplankton in Lake Kociołek fell within the range of published values for mesotrophic lakes. However, the inclusion of colonial forms of picocyanobacteria resulted in much higher values than earlier recorded in more fertile lakes, e.g. eutrophic or even hypertrophic [Stockner *et al.* 2000].

Seasonal variation in picocyanobacteria in 2003 in Lake Kociołek – as in seven Danish lakes [Sondergaard 1991], several Canadian lakes [Pick and Agbeti 1991], and Lake Biwa in Japan [Maeda *et al.* 1992] – did not show any spring peak of abundance. In spring, picocyanobacteria in Lake Kociołek was nearly exclusively single-celled and its abundance was low. This was probably due to the presence of a large population of *Dinobryon* spp. The phagotrophic ability of the genus *Dinobryon* to ingest particles of bacterial size has been known for several years [Bird and Kalff 1987]. Also other phagotrophic species, like *Cryptomonas* and *Rhodomonas,* which were less frequent then, could contribute to the lack of a noticeable spring peak in picophytoplankton abundance. In Lake Kociołek considerable annual variation in picocyanobacteria abundance with mid- and late summer peaks occurred as in some temperate lakes [Weisse 1993]. The seasonal cycle of eukaryotic picoplankton differed markedly from that of picocyanobacteria. Eukaryotic picoplankton was abundant during the cold water period preceding the summer and autumn peaks of picocyanobacteria and larger phytoplankton. Dominance of eukaryotic picoplankton biomass over picocyanobacterial biomass during spring was observed in several lakes [Pick and Agbeti 1991, Sondergaard 1991].

In Lake Kociołek in the spring of 2003, most of picocyanobacteria were present as single cells, but in the second half of the year usually over 90% of picophototrophs formed colonies varying in morphology. Their appearance in some periods of the year in Lake Kociołek, observed in summer and autumn, can result from various causes. As reported by Passoni and Callieri [2000], microcolonies are more efficient in nitrogen fixation and nutrient cycling, and therefore they could prevail during nutrient shortage. Moreover, the formation of colonies should alter specific density and increase sinking velocity, which enables picocyanobacterial cells to be transported downwards to zones of higher nutrient concentration.

CONCLUSION

Results of this study, as in the case of the nearby dystrophic Lake Skrzynka [2005], show that to make a comprehensive analysis of phytoplankton diversity in Lake Kociołek it is also necessary to take into account the smallest phototrophs, i.e. picophytoplankton, mainly picocyanobacteria. Eukaryotic picoplankton is important only in some months. Lake Kociołek at the present stage of its development is characterized by a high abundance of picoplanktonic phototrophs, whose abundance in 2003 peaked in July and September. Picoplankton accounted for an average of 32% (range 1-87%) of phototrophic biomass. Nevertheless, the high proportion of colonial forms within picoplankton indicates that they can be hardly available as food to many small consumers. Besides, the large populations of flagellates (particularly in spring and autumn) suggest that mixotrophy is their prevalent physiological behaviour in this lake.

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SEZONOWE ZMIANY W STRUKTURZE ZBIOROWISKA FOTOTROFÓW W MAŁYM ŚRÓDLEŚNYM JEZIORZE

Streszczenie. W małym śródleśnym jeziorze Kociołek położonym w Wielkopolskim Parku Narodowym (zachodnia Polska) przeprowadzono w okresie od marca do listopoada 2003 r. badania fitoplanktonu, ze szczególnym uwzględnieniem pikoplanktonu, w celu poznania składu taksonomicznego, liczebności i biomasy fototrofów. Największym bogactwem gatunkowym charakteryzowały się zielenice, których udział w fykoflorze wynosił prawie 50%, natomiast najliczniejsze populacje utworzyły pikocyjanobakterie. Biomasa fototrofów wyrażona jako koncentracja chlorofilu *a* wahała się w zakresie 1,1-17,4 $\mu g \cdot l^{-1}$ (średnia 5,9 $\mu g \cdot l^{-1}$). Średni udział pikoplanktonu w biomasie ogólnej fototrofów był wysoki – 32%.

Słowa kluczowe: fitoplankton, pikocyjanobakterie, chlorofil *a*, zmiany sezonowe, małe jezioro