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Trophic state assessment based on late summer phytoplankton community structure: a case study for epilimnetic lake water

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Key words: Phytoplankton, species composition, dominant species, biomass, trophic index

Abstract

Phytoplankton species composition, abundance and biomass were studied in samples taken from the epilimnion of Lake Strzeszyńskie in late August of each year from 2000-2005. The number of phytoplankton species was relatively low, with the greatest species diversity observed in the Chlorophyceae. Total phytoplankton abundance was high, with major contributions by picophytoplanktonic cyanobacteria, which formed aggregations. Total phytoplankton biomass was generally low, with the sum of the 2–5 biomass-dominant species always exceeding 50% of the total phytoplankton biomass. The taxonomic composition of the group of biomass dominants was relatively stable inter-annually. On the basis of phytoplankton biomass and chlorophyll *a* concentration, Lake Strzeszyńskie can be classified as oligo-mesotrophic and mesotrophic,

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respectively. Trophic index values calculated on the basis of abundance of phytoplankton indicator taxa were higher than the values based on their biomass, and mean values indicate that the lake is mesotrophic or intermediate between mesotrophic and eutrophic.

INTRODUCTION

Phytoplankton abundance and biomass in lakes tend to increase with trophic state, these escalations being preceded or accompanied by changes in the taxonomic composition of the community (Hutchinson 1967, Spodniewska 1978, Reynolds 1987, Trifonova 1998). Thus qualitative modifications can be the first signal of quantitative changes in pelagic phytoplankton. In contrast to early spring, when changes in phytoplankton are very dynamic, late summer phytoplankton communities in temperate lakes are generally regarded as quite stable, as a result of the stability of environmental conditions (temperature, light) at that time (Arhonditsis et al. 2004). Consequently it seems that late summer is a good time for water quality assessment. Nevertheless, in that period some factors do cause cell losses, resulting in a relatively low biomass, which may cause underestimation of the lake trophic state.

The aim of this study was to analyse the taxonomic composition, abundance and biomass of phytoplankton in the epilimnion of Lake Strzeszyńskie, and to assess its trophic state on the basis of data collected in the late summer of several years. In contrast to earlier research on this lake, autotrophic organisms smaller than 2 μm, i.e. picophytoplankton, were taken into account in this study.

MATERIALS AND METHODS

Description of the study lake

Lake Strzeszyńskie is located in a subglacial depression within the city of Poznań (western Poland). This small urban lake, with a surface area of 35 ha, total volume of 2.8×10^6 m^3 and maximum depth of 17.8 m, is dimictic, with well-developed thermal and oxygen stratification in summer. The summer epilimnion depth is typically 4 m and is well oxygenated; in the metalimnion oxygen concentration declines rapidly, and the hypolimnion (below about 10 m) is anoxic (Jańczak, Sziwa 1995; Szeląg-Wasielewska 1991, 2004b). Except for the north-western part of the lake, emergent vegetation form only small patches, while submerged vegetation is well developed, and is dominated by stoneworts (Characeae). The direct catchment of the lake is about 4 times larger than the lake surface, and nearly 2/3 of this area is covered by woodland. Both the lake and the neighbouring areas are intensively used for recreation and the lake is stocked with fish, and is thus markedly influenced by anglers (Mastyński, Szeląg-Wasielewska 1989).

Sampling and analytical methods

Water samples were collected from one station in the epilimnion, 0.5 m below the water surface, in the pelagic zone in late August (between 24th and 31st) each year from 2000-2005. For picophytoplankton (0.2–2.0 μm) analyses, samples were preserved at the site with buffered glutaraldehyde to a final concentration of 1%. Samples of nano- (2–20 μm) and micro- (>20 μm) plankton, were preserved with Lugol's solution.

Organisms were identified to at least genus level, and to species level where possible. Phytoplankton larger than 2 μm were analysed under an inverted microscope at magnification of 40, 150 and 600× after sedimentation in 14-ml or 24-ml chambers, according to the method described by Wetzel & Likens (1991). Picophytoplankton numbers were determined by epifluorescence microscopy, using instrumentation and protocols as previously reported (Szeląg-Wasielewska 2004a). Abundance was expressed as numbers of cells per ml. The biovolume of each species was calculated on the basis of cell shape, size, and number, while their biomass was expressed as wet weight. Biomass was estimated assuming that the volume of 10^9 μm^3 is equivalent to 1 mg.

The trophic state was assessed on the basis of the presence of indicator taxa as described by Järnefelt (according to Kawecka, Eloranta 1994), Hutchinson (1967), Hörnström (1981), and Rosén (1981), with state being expressed on a scale of 1–3 (where 1 = oligotrophic, 2 = mesotrophic, and 3 = eutrophic). If a taxon was classified differently by those authors, the mean value of the index was used. The trophic index of the community was calculated on the basis of the abundance and biomass of trophic state indicators according to the Hörnström formula (1981):

$$Ist = \frac{\sum (fs \cdot Is)}{\sum fs}$$

where: *Ist* = total trophic index, *Is* = trophic index of individual species, *fs* = frequency of the given species (number of specimens or biomass).

The physicochemical characteristics (temperature, transparency, chlorophyll *a*, total seston dry weight, and conductivity) of the water samples were measured. Chlorophyll *a* concentration was determined spectrophotometrically after filtration through Whatman GF/F fibreglass filters and calculated using Lorenzen's formula (Polish Standard 1986). Water transparency was determined as Secchi depth. Total seston dry weight was measured after condensation on Whatman's GF/F filters and drying at 105ºC. Statistical analyses were undertaken using STATISTICA 5 software.

RESULTS

The water temperature and conductivity of Lake Strzeszyńskie were quite stable inter-annually in late August from 2000 to 2005, with values of 21.1-24.0ºC (mean 22.6ºC) and 568-609 µS cm^{-1} (mean 587 µS cm^{-1}), respectively. Secchi transparency varied from 1.3 to 4.2 m (mean 2.9 m), total seston dry weight from 1.15 to 5.90 mg l^{-1} (mean 2.6 mg l^{-1}), while chlorophyll *a* concentration ranged from 1.2 to 3.5 µg l^{-1} (mean 2.44 µg l^{-1}) over that time period.

In total, 109 phytoplankton taxa were identified in the samples collected in the course of this study. 49.5% of the taxa identified were members of the Chlorophyceae, the majority being Chlorococcales. Seven other groups were represented to lesser extent: Cyanobacteria 17.4%, Chrysophyceae 10.1%, Bacillariophyceae 9.2%, Dinophyceae 8.3%, Cryptophyceae 3.7%, Haptophyceae 0.9%, and Xanthophyceae 0.9%. Numbers of taxa recorded on individual sampling dates ranged from 41 to 51 (Fig. 1), the samples from any one date hence only ever including less than 50% of the total number of taxa observed over the six years. This was largely as a result of a number of species being observed on only one (36 taxa, comprising 33% of the total) or two (23 taxa, 21% of the total) sample dates. Only 11 taxa (10% of the total) were observed in samples from all six years. Some species uncommon to Poland were recorded sporadically, such as *Aphanocapsa parasitica* (Kütz.) Komárek et Anagnostidis*, Diplopsalis acuta* (Apstein) Entz*, Dinobryon crenulatum* W. West et G.S. West, and *Tetraedriella yovetii* Bourelly.

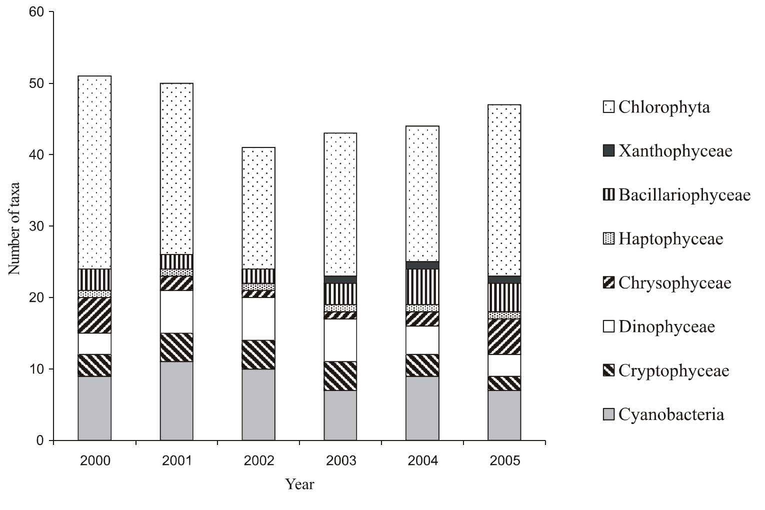

Fig. 1. Floristic spectrum of Lake Strzeszyńskie in late August of 2000-2005.

Cell abundances were highest (9.2×10^5 cells ml^{-1}) in 2001, and lowest (2.5×10^5 cells ml^{-1}) in 2005. Total phytoplankton abundances were primarily affected by cyanobacteria, whose abundance ranged from 2.47×10^5 to 9.09×10^5 cells ml^{-1} (Table 1). Small cells, i.e. picophytoplankton, were the most numerous. This size fraction was usually dominated by colonial cyanobacteria of the genera *Aphanocapsa* and *Aphanothece*, with cells of 0.8–2.5 µm in diameter or length, and colonies of about 50–150 cells. Their cell abundance was high, but as a result of their small volume the biomass remained low. Eukaryotic picophytoplankton (small chlorophytes) were not numerous, and their contribution to total phytoplankton numbers did not exceed 0.2%. Contributions of larger size fractions – nanoplankton and microplankton – ranged from 1.5 to 8%.

Table 1

Abundance of taxonomic groups of phytoplankton and their contributions to total phytoplankton abundance in Lake Strzeszyńskie in late August of 2000–2005

Phytoplankton Group	Abundance (cells ml^{-1})		Contribution (%)	
	Range	Mean	Range	Mean
Cyanobacteria	247341–909474	576123	97.98–99.79	99.10
Cryptophyceae	26–138	84	0.003–0.055	0.02
Dinophyceae	3–6	5	0.001–0.002	0.001
Chrysophyceae	3–71	24	0.001–0.028	0.006
Haptophyceae	1316–3988	2424	0.016–1.58	0.63
Bacillariophyceae	1–171	63	0.000–0.068	0.02
Xanthophyceae	0–20	4	0.000–0.008	0.002
Chlorophyta	330–4174	1387	0.04–0.46	0.22

Phytoplankton biomass was low and varied from 0.569 to 1.052 mg l^{-1} fresh weight (mean 0.782 mg l^{-1}). In 2000–2002 it fluctuated around 1 mg l^{-1}, whereas in 2003–2005 it was about 40% lower, ranging from 0.568 to 0.637 mg l^{-1} (Fig. 2). This biomass decline was principally a consequence of a decline in cyanbacterial numbers. Chlorophyll *a* concentrations were also low (mean 2.4 µg l^{-1}). Chlorophyll *a* concentration per 1 mg of phytoplankton fresh weight reached 2.0–4.20 µg, its mean contribution to biomass amounting to 0.31%. Phytoplankton biomass and chlorophyll *a* concentration were positively correlated ($r = 0.78$).

Most often, phytoplankton biomass was dominated by cyanobacteria and members of Dinophyceae. In 2000 the contribution of Chlorophyta to biomass was quite high, but this finding was not repeated on successive sampling dates. In 2004 and 2005 the biomass of members of Haptophyceae increased (Fig. 2). On all sampling dates, species of these groups (except Chlorophyta) were

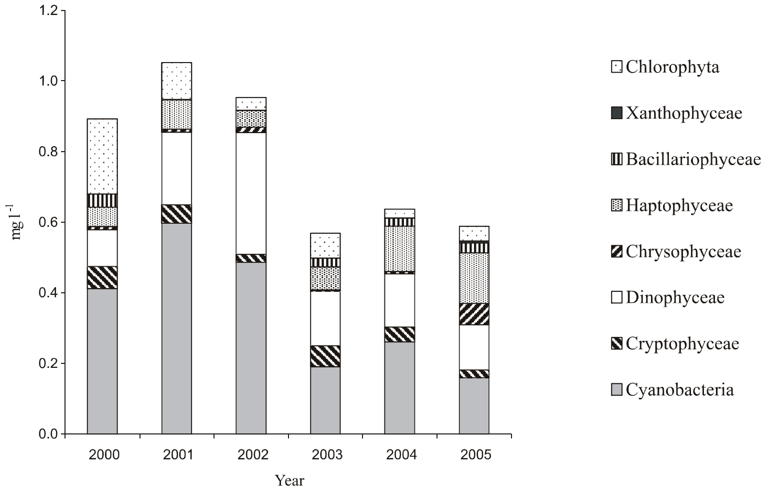

Fig. 2. Biomass of phytoplankton taxonomic groups in Lake Strzeszyńskie in late August of 2000–2005.

present among the five dominant taxa, in terms of biomass (Table 2). *Chrysochromulina parva* and *Aphanocapsa* species were always among the biomass dominants, whereas the presence of other dominant taxa was more variable. For example, *Ceratium hirundinella* and *Aphanothece* species were among the dominant species in five of the six annual samples. More than 50% of the total phytoplankton biomass was always comprised of no more than five species, and in certain years this proportion of the biomass was accounted for by only two (2002) or three (2005) taxa.

Among the identified taxa, 52 are indicators of trophic state: 12 of eutrophic, 18 of mesotrophic, and 22 of oligotrophic waters. On the basis of their abundance, trophic state index values were calculated, which varied between 2.48 and 2.50 (mean 2.49) (Table 3). This indicates that the lake is intermediate between mesotrophic and eutrophic. The values calculated on the basis of biomass were lower, decreasing gradually from 2.15 to 1.66 on consecutive sampling dates (mean value 1.94), so they suggested that the lake is mesotrophic (index limits: 1.5–2.5).

The decrease in trophic state index values in 2005 was partly due to the appearance of *Dinobryon crenulatum* (previously absent from the samples), which is regarded as an indicator of oligotrophic waters. Indicators of eutrophic waters, e.g. green algae of the genera *Scenedesmus*, *Pediastrum*, *Lagerheimia*, or *Tetrastrum*, and cyanobacteria of the genera *Microcystis* or *Aphanizomenon*, were generally not abundant then, so their influence on the value of the index

Table 2

The five the most important taxa in terms of contribution to phytoplankton biomass of Lake Strzeszyńskie in August of 2000-2005

	Biomass (mg l^{-1})	Contribution (%)
2000		
Aphanocapsa spp.	0.261	29.2
Ceratium hirundinella	0.088	9.9
Chrysochromulina parva	0.055	6.2
Aphanothece spp.	0.051	5.7
Cryptomonas ovata	0.048	5.4
2001		
Aphanocapsa spp.	0.219	20.8
Ceratium hirundinella	0.146	13.9
Aphanothece spp.	0.143	13.6
Radiocystis geminata	0.106	10.1
Chrysochromulina parva	0.083	7.9
2002		
Peridinium spp.	0.322	33.8
Aphanocapsa spp.	0.245	25.7
Radiocystis geminata	0.122	12.8
Aphanothece spp.	0.051	5.4
Chrysochromulina parva	0.047	4.9
2003		
Aphanothece spp.	0.073	12.8
Peridinium spp.	0.069	12.1
Chrysochromulina parva	0.065	11.4
Ceratium hirundinella	0.062	10.9
Aphanocapsa spp.	0.062	10.9
2004		
Chrysochromulina parva	0.130	20.4
Aphanocapsa spp.	0.082	12.9
Radiocystis geminata	0.074	11.6
Ceratium hirundinella	0.073	11.5
Peridinium spp.	0.061	9.6
2005		
Chrysochromulina parva	0.144	24.5
Ceratium hirundinella	0.109	18.5
Aphanocapsa spp.	0.060	10.2
Aphanothece spp.	0.059	10.0
Dinobryon spp.	0.057	9.7

Table 3

Trophic state index values based on abundance (A) and biomass (B) of phytoplankton indicator species

Year	Estimation based on	
	A	B
2000	2.50	2.15
2001	2.50	2.04
2002	2.50	2.09
2003	2.49	1.88
2004	2.49	1.81
2005	2.48	1.66

was small. In the case of biomass, index values depended mainly on species with large cells, e.g. *Ceratium hirundinella* and *Peridinium* spp., which are considered characteristic of meso-eutrophic waters. It is noteworthy that many of the species that formed large populations in Lake Strzeszyńskie (e.g. *Rhodomonas* and *Cryptomonas* spp.) are cosmopolitan, found in various water types and so are of no value as bioindicators.

DISCUSSION

The total number of taxa (109) observed in the late summer epilimnion of the study lake over the six years, is slightly lower than the total number of taxa recorded in the epilimnion during a typical series of 12−14 sampling dates from spring till autumn (Szeląg-Wasielewska 2004b, 2006). In late summer, the pelagic phytoplankton diversity of this lake is always dominated by the Chlorophyceae, like in many other lakes in this region (Gołdyn et al. 1997).

As a result of the inclusion of picophytoplankton in the counts (the smallest but most abundant size fraction in this study), total phytoplankton abundance was much higher than previously observed (Szeląg-Wasielewska 1991). Although the phytoplankton of Lake Strzeszyńskie were characterized by high numbers of cells, their total biomass was low, as a result of low mean biomass per cell, i.e. the most abundant taxa had small cells. Those taxa were usually observed every year in a similar configuration of dominants, and their dominance was always accompanied by a low total biomass of the whole community.

The high contribution of cyanobacteria and dinophytes to total biomass, and the insignificant number of diatom species, are the most characteristic features of the quantitative composition of phytoplankton in the lake. However, there were no large filamentous forms among cyanobacteria, which contrasts to other water bodies in Poznań city (Gołdyn et al. 1997). The cyanobacteria found in Lake Strzeszyńskie were small, spherical or ovoid cells of chrococcal species, and usually formed aggregations. On the one hand, the lack of diatoms of the genera *Aulacoseira* and *Fragilaria* (which are regarded as indicators of eutrophic waters) and of euglenophytes (classified as indicators of advanced eutrophic state) suggest that the lake has a low trophic level. On the other hand, certain *Scenedesmus* species (considered to be indicators of strong eutrophication), as well as typical indicators of eutrophic waters, like *Anabaena* sp., *Microcystis aeruginosa*, and *Aphanizomenon flos-aquae* (Rosén 1981) were found in Lake Strzeszyńskie, although their abundances were low, and they were never biomass dominants.

The observed range and mean concentrations of chlorophyll *a* were within the limits reported by Nicholls & Dillon (1978) for natural waters of various types with a range of algal communities, and by Desortová (1981) for five dam reservoirs. However, they were closer to those recorded by Eloranta (1980) for phytoplankton in the Finnish reservoir Vasikkalampi, the means being nearly identical and the ranges overlapping to large extent. In late summer, on the basis of mean phytoplankton biomass (0.78 mg l^{-1}), the studied lake should be classified as oligo-mesotrophic according to Heinonen's criteria (according to Kawecka, Eloranta 1994). However, the chlorophyll *a* concentration suggests that the trophic state of the lake is slightly higher, and according to Likens (1975) thresholds, the lake is mesotrophic.

In Lake Strzeszyńskie the lowest biomass in the latter three summers could be directly related to the fact that since 2001 the lake has not been stocked with grass carp (*Ctenopharyngodon idella*). This has certainly exerted a favourable influence on the growth of submerged vegetation. The lake is morphometrically variable, so this type of vegetation has spread widely, particularly in two shallow inlets, but also in many parts of the main basin. Submerged vegetation can affect phytoplankton directly or indirectly. In lakes with well-developed macrophytes, water is clear and phytoplankton are usually not abundant. Submerged macrophytes, which bind nutrients from open water and from surface runoff, can eliminate even cyanobacterial blooms, as suggested by Engel (1988), who studied the shallow Lake Wisconsin. Moreover, low phytoplankton biomass may result from competition with periphyton algae (Hansson 1998). In lakes with well-developed macrophytes, sessile microscopic organisms colonizing their surface are also abundant. Phytobenthos does seem to play an important role in this lake because of the reduced loading of nutrients from the bottom zone to open water.

CONCLUSIONS

In the epilimnetic phytoplankton of Lake Strzeszyńskie, in six successive late summer samples, chlorophytes dominated in respect of species diversity, cyanobacteria and haptophytes dominated in respect of abundance, and cyanobacteria and dinoflagellates dominated in respect of biomass. Total phytoplankton abundance was high but biomass was low due to the high contribution of the small cells of picoplanktonic cyanobacteria. The trophic state of the lake seemed to be lower when assessed on the basis of biomass and chlorophyll *a* concentration than when assessed on the basis of indicator taxa. Thus in summer, if phytoplankton biomass is maintained at a low and relatively stable level by some factors (e.g. sedimentation, zooplankton grazing) that cause its losses, the trophic state assessment should be based on the taxonomic composition of the community and contributions of indicator taxa for eutrophic, mesotrophic and oligotrophic waters. In the study lake, the low trophic state of epilimnetic water, and additionally its slightly decreasing trend observed in the last 3 years of the study, are partly due to interactions between phytoplankton and submerged macrophytes.

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