Original Research

Trophic Status of Lake Water Evaluated Using Phytoplankton Community Structure – Change after Two Decades

E. Szeląg-Wasielewska*

Department of Water Protection, Adam Mickiewicz University, Drzymały 24, 60-613 Poznań, Poland

Received: January 30, 2005
Accepted: May 30, 2005

Abstract

Phytoplankton composition and biomass were studied in a small suburban lake within the city of Poznań (western Poland) on the basis of water samples taken in epilimnion. Results obtained in 1999 were compared with the first study period, of 1978. In the first period, 100 phytoplankton taxa were found and diatoms were the largest group of species (29% of all taxa), while in the second period 117 phytoplankton taxa were recorded and green algae dominated (50%). The mean phytoplankton biomass increased nearly 2-fold over the two decades and the trophic state index was higher in 1999. Picophytoplankton, whose seasonal fluctuations were analyzed only in 1999, accounted for 0.6% to 31.5% (mean 12.8%) of total phytoplankton biomass.

Keywords: lake phytoplankton, seasonal fluctuations, trophic index, biomass

Introduction

The state of lake ecosystems and its changes can be assessed on the basis of biotic and abiotic elements. Phytoplankton are the main primary producers in open waters, so they condition the structure and density of consumers as well as physico-chemical properties of water. Moreover, phytoplanktonic organisms are sensitive indicators, as phytoplankton structure and metabolism changes quickly in response to environmental changes. Growth rate and variability of phytoplankton are subject to cyclic changes: fluctuation and succession [1, 2, 3]. The term succession in phycology is often considered equivalent to seasonal changes, which is reflected in the terms annual succession and seasonal succession. Within phytoplankton, several dozen generations of organisms appear during each growing season [4, 5]. The community varies widely in respect to taxonomic composition and cell size. Most recent studies focus on cells smaller than 2 µm, i.e. picophytoplankton. General findings suggest that lacustrine picophytoplankton may be the most numerous size fraction of phytoplankton, with abundance varying between 10^4 and 10^6 cells per 1 ml and their biomass increases with increasing trophic state, whereas the contribution of picoplankton to total phytoplankton biomass declines [6, 7, 8].

The present paper describes the composition and biomass of the phytoplankton community and its dynamics in epilimnion in 1999 and two decades earlier, in 1978. The aims of this study were:

1. to assess the trophic level on the basis of phytoplankton biomass and indicator species;
2. to compare phytoplankton composition in both study periods;
3. to assess the contribution of picoplankton to total phytoplankton biomass, as this size fraction was not studied in the first study period.

The study initiated the monitoring of this lake, which is subject to a strong human impact.

*e-mail: eszelag@amu.edu.pl

Table 1. Some physical and chemical variables in Lake Strzeszyńskie in 1978. Total phosphorus (TP) and total nitrogrn (TN) refer to depth of 1 m, other variables to the water column from surface to 5 m depth (0.2 m; 1 m; 3 m; 5 m).

Variable (unit)	Range	Mean
Temperature (°C)	6.5-23.0	16.6
Secchi depth (m)	2.2-6.2	3.47
pH – value	7.5-8.5	7.9
Conductivity (µS cm^{-1})	460-540	518
Dissolved oxygen (mg l^{-1})	7.6-12.8	9.8
Oxygen saturation (%)	66-140	104
PO_4-P (µg l^{-1})	0-33	7
TP (µg l^{-1})	16-49	33
NO_2-N+NO_3-N+NH_4-N (µg l^{-1})	60-560	237
TN (mg l^{-1})	1.48-1.93	1.13
Chlorophyll-a (µg l^{-1})	0.4-7.5	3.6

Description of the Studied Lake

Lake Strzeszyńskie is of glacial origin, located in the headwaters of a small river within the city boundaries of Poznań (52º28'N, 16º49'E). Its area is 34.9 ha, volume 2.8×10^6 m^3, maximum depth 17.8 m, and mean depth 8.2 m [9]. Lake Strzeszyńskie is characterized by neutral--to-slightly-alkaline water, good oxygenation of surface waters, oxygen deficits below a depth of 10 m as early as in May, and anoxic conditions in July-October [9, 10, 11, 12]. Other physical and chemical variables are given in Table 1. For decades the lake has been used for recreational purposes and swimming, water sports and fishing.

Materials and Methods

Water samples were collected from one station in the pelagic zone, 0.5−1 m below the water surface, every 2−4 weeks between May and November, 1999, on exactly the same dates as in 1978. The samples were preserved immediately at the site with Lugol's solution and in 1999 also for picophytoplankton study with buffered glutaraldehyde to a final concentration of 1%.

In the laboratory, phytoplanktonic organisms were identified to the species level or − if this was impossible − they were only assigned to a genus. Organisms were concentrated by settling in 14-ml and 24-ml chambers and analyzed under an inverted microscope according to the method by Utermöhl [13] at a magnification of 40, 150 and 600×. In both study periods I counted the cells with the use of the same microscope and chambers. Picophytoplankton (0.2−2.0 µm) were determined by epifluorescence microscopy, using instrumentation and protocols similar to those previously reported [14, 15]. 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 10^6 μm^3 is equivalent to 1 µg.

The trophic state was assessed on the basis of indicator taxa listed by Järnefelt (according to Kawecka and Eloranta [5], Hutchinson [16], Hörnström [17], Rosén [18] and was calculated according to the Hörnström formula [17]. The trophic index of the community was calculated on the basis of the biomass of trophic state indicators. The index values ranged from 1 to 3 (1 = oligotrophic, 2 = mesotrophic, 3 = eutrophic).

Results

Phytoplankton Composition

Within phytoplankton, 100 taxa were found in 1978 and 117 in 1999 (but 111 excluding picoplankton). In terms of species number, the largest group were diatoms in the first year and green algae in the second year. In 1999, the number of taxa increased by 34 for green algae (including 2 taxa assigned to picoplankton), but decreased by 16 for diatoms and by 4 for chrysophytes (Table 2). The total number of taxa in individual samples varied from 12 to 42 in 1978 and from 30 to 49 in 1999. The species that

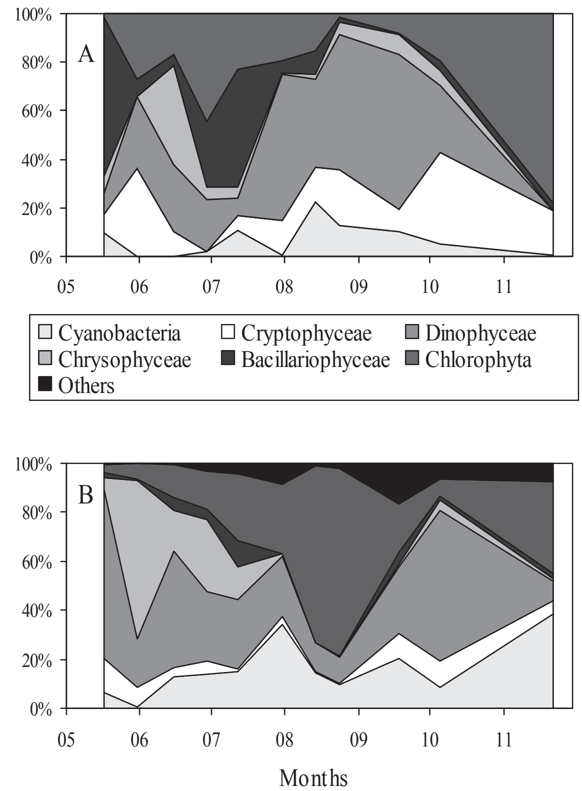

Fig. 1. Changes in the relative biomass of taxonomic groups of phytoplankton in Lake Strzeszyńskie in 1978 (A) and in 1999 (B).

Table 2. Floristic spectrum of pelagic plankton in Lake Strzeszyńskie in both investigated periods.

Taxonomic group	1978		1999	
	Number of taxa	Share (%)	Number of taxa	Share (%)
Cyanobacteria	14	14	14(18*)	15.4
Cryptophyceae	8	8	6	5.1
Dinophyceae	5	5	6	5.1
Chrysophyceae	17	17	13	11.1
Bacillariophyceae	29	29	13	11.1
Chlorophyta	25	25	57(59*)	50.4
Others	2	2	2	1.8
Total	100	100	111(117*)	100

*Number of taxa including picoplankton

occurred in more than 50% of all samples were considered common. This category included 13 species in 1978 and 29 species (including 3 taxa belonging to picoplankton) in 1999. Only 10 taxa were common in both years: 1 chrysophyte (*Dinobryon divergens*), 2 cryptophytes (*Cryptomonas marssonii*, *Rhodomonas lacustris*), 2 dinophytes (*Ceratium hirundinella*, *Peridinium cinctum*) and 5 green algae (*Closterium acutum* var. *variabile, Oocystis lacustris, Phacotus lenticularis, Tetraedron minimum, Willea irregularis*).

Phytoplankton Biomass

Phytoplankton taxa with the highest biomass on successive sampling occasions in both analyzed periods are presented in Table 3. Few of them were dominants, i.e. exceeding 50% of the total phytoplankton biomass. More numerous were subdominants, accounting for 25−50% of total biomass. Usually the biomass of the main 2−3 taxa jointly accounted for at least 50%. The periodically dominant species were green algae or chrysophytes, while subdominants also included cyanobacteria, dinophytes and diatoms. However, only five taxa were dominants and/or subdominants more than once: *Ceratium hirundinella* (7 times), *Peridinium* spp. (3 times), and *Phacotus lenticularis, Closterium acutum* var. *variabile, Dinobryon divergens* and *Carteria* sp. (2 times each).

In 1999 the mean contribution of cyanobacteria to total phytoplankton biomass was about twice as high as in 1978. Mean contributions of green algae and chrysophytes only slightly increased, while mean contributions of cryptophytes and diatoms decreased. In both periods the dinophytes and green algae constituted a substantially larger fraction of phytoplankton biomass than other taxonomic groups. Their joint contribution to the total phytoplankton biomass reached 54% in 1978 and 59% in 1999. (Table 4, Fig. 1).

The phytoplankton community shows a wide seasonal variation in biomass. In the first year, we observed frequent fluctuations of biomass, with peaks in June, July, September and November. By contrast, 20 years later only two conspicuous peaks were recorded: in June and August (Fig. 2). The total phytoplankton biomass ranged between 0.157 and 1.743 mg l^{-1} (mean 0.839 mg l^{-1}) in 1978 and from 0.071 to 2.688 mg l^{-1} (mean 1.316 mg l^{-1}) in 1999. Cells of <2 µm in size, whose seasonal variation was first analyzed in this lake in 1999, formed small peaks in June and August. Their biomass ranged from 0.01 mg l^{-1} in November to 0.438

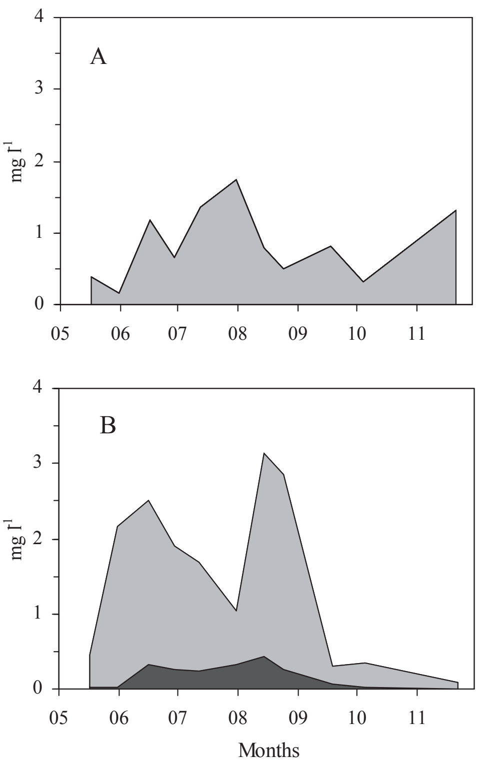

Fig. 2. Changes in phytoplankton biomass in Lake Strzeszyńskie in 1978 (A) and in 1999 (B). The black area shows the picoplancton biomass.

Table 3. Relative biomass (%) of the major phytoplanktonic species in Lake Strzeszyńskie in 1978 and 1999. Dominants are boldfaced, while subdominants are underlined.

Sampling date	1978		1999	
	Takson	%	Takson	%
17.05.	*Synedra acus* var. *angustissima* Grunow	45.4	*Ceratium hirundinella* (O.F. Müll.) Bergh	36.4
	Cyclotella comta (Ehr.) Kütz.	16.9	*Peridinium* spp.	28.8
	Ceratium hirundinella (O.F. Müll.) Bergh	8.9	*Rhodomonas lacustris* Pascher et Ruttner	7.8
31.05.	*Rhodomonas lacustris* Pascher et Ruttner	36.1	***Dinobryon divergens*** **Imhof**	**64.3**
	Ceratium hirundinella (O.F. Müll.) Bergh	29.6	*Ceratium hirundinella* (O. F. Müll.) Bergh	15.1
	Phacotus lenticularis (Ehr.) Stein	26.9	*Cryptomonas ovata* Ehr.	4.7
15.06.	*Dinobryon divergens* Imhof	36.9	*Ceratium hirundinella* (O. F. Müll.) Bergh	34.7
	Ceratium hirundinella (O.F. Müll.) Bergh	23.5	*Dinobryon divergens* Imhof	16.4
	Closterium acutum var. *variabile* (Lemm.) W. Krieg.	13.9	*Aphanothece* spp.	12.1
29.06.	*Phacotus lenticularis* (Ehr.) Stein	36.5	*Ceratium hirundinella* (O. F. Müll.) Bergh	20.3
	Fragilaria crotonensis Kitton	19.6	*Ochromonas ornata* Skuja	17.1
	Ceratium hirundinella (O. F. Müll.) Bergh	14.2	*Aphanothece* spp.	13.1
12.07.	*Fragilaria crotonensis* Kitton	43.8	*Ceratium hirundinella* (O. F. Müll.) Bergh	20.3
	Keratococcus braunii (Näg.) Kom.	17.2	*Eutetramorus fottii* Hindák	14.8
	Anabaena flos aquae Bréb. ex Born. et Flah.	10.7	*Aphanocapsa* spp.	12.5
31.07.	*Ceratium hirundinella* (O.F. Müll.) Bergh	34.6	*Aphanocapsa* sp.	28.7
	Peridinium cinctum (O.F. Mül.) Ehr.	21.9	*Carteria* sp.	15.7
	Chlamydomonas sp.	11.9	*Ceratium hirundinella* (O. F. Müll.) Bergh	12.3
14.08.	*Peridinium cinctum* (O.F. Müll.) Ehr.	24.4	***Carteria*** **sp.**	**68.9**
	Synechocystis aquatilis Sauvageau	12.6	*Aphanocapsa* spp.	13.5
	Ceratium hirundinella (O.F. Müll.) Bergh	11.9	*Ceratium hirundinella* (O. F. Müll.) Bergh	8.3
24.08.	*Ceratium hirundinella* (O.F. Müll.) Bergh	36.6	***Carteria*** **sp.**	**74.3**
	Peridinium cinctum (O.F. Müll.) Ehr.	18.8	*Aphanocapsa* spp.	8.8
	Cryptomonas ovata Ehr.	16.1	*Ceratium hirundinella* (O. F. Müll.) Bergh	8.0
18.09.	*Peridinium cinctum* (O.F. Müll.) Ehr.	35.3	*Chrysochromulina parva* Lackey	16.6
	Ceratium hirundinella (O. F. Müll.) Bergh	28.7	*Ceratium hirundinella* (O. F. Müll.) Bergh	14.6
	Cryptomonas ovata Ehr.	7.8	*Aphanocapsa* spp.	13.6
5.10.	*Cryptomonas ovata* Ehr.	24.8	*Ceratium hirundinella* (O.F. Müll.) Bergh	30.4
	Ceratium hirundinella (O. F. Müll.) Bergh	14.5	*Peridinium* spp.	26.7
	Peridinium cinctum (O.F. Müll.) Ehr.	13.1	*Cryptomonas* spp.	10.0
22.11.	***Closterium acutum*** **var.** ***variabile*** (Lemm.) W. Krieg.	**77.9**	*Closterium acutum* var. *variabile* (Lemm.) W. Krieg.	37.2
	Cryptomonas ovata Ehr.	14.1	*Planktothrix agardhii* (Gom.) Anagn. et Kom.	24.8
	Cyclotella comta (Ehr.) Kütz.	2.9	*Synechocystis* sp.	11.1

mg l^{-1} in mid-August (mean 0.181 mg l^{-1}), whereas its contribution to total phytoplankton biomass varied from 0.6 to 31.5%. It is noteworthy that with picoplankton, phytoplankton biomass would be on average 12.8% higher, ranging from 0.081 and 3.125 mg l^{-1} (mean 1.497 mg l^{-1}).

Indicator Species

Among indicator taxa in 1978, 43% were oligotrophic, 21% were mesotrophic, and 36% were eutrophic, whereas in 1999 the corresponding values were: 31%, 19% and 51%. Trophic index values in 1999 were slightly higher and the range of variation was narrower (1.56–2.69, mean 2.02) than in 1978 (1.48-2.92, mean 1.9, Fig. 3). The mean value shows that the lake is mesotrophic, although in some periods it could be classified as eutrophic.

Discussion

The number of species recorded in Lake Strzeszyńskie increased by about 20% between the late 1970s and the late 1990s. On the one hand, this was due to the inclusion of picoplanktonic organisms, which enriched the phytoplankton community composition of the lake with 6 taxa. On the other hand, the rise may result from the higher trophic level. As shown by Heinonen (acc. to Kawecka and Eloranta [5]) in Finnish lakes, species number increased with increasing trophic state and was the highest when phytoplankton biomass exceeded 3.5 mg l^{-1}. The total number of phytoplankton species in Lake Strzeszyńskie in 1978 was in the middle and in 1999 was near the upper limit of values regarded as the most usual number of species for lake phytoplankton, i.e. 50–150 [19].

Substantial differences in numbers of taxa between the two study years occurred in some taxonomic groups.

Table 4. Mean contribution (%) of the major taxonomic groups to total phytoplankton biomass in Lake Strzeszyńskie in both investigated periods.

Taxonomic group	1978	1999
Cyanobacteria	6.7	15.9
Cryptophyceae	16.1	5.7
Dinophyceae	30.8	30.6
Chrysophyceae	7.2	12.3
Bacillariophyceae	16.0	3.0
Chlorophyta	23.2	27.9
Others	0	4.6

Firstly, many new taxa of the group Chlorococcales appeared, especially *Scenedesmus* spp. This genus, as reported by Rosén [18], is a sign of strong eutrophication. However, in terms of biomass, other species prevailed, so the latter affected the functioning of the ecosystem more strongly. It must be emphasized that dominance was observed more often in 1999 and that dominants did not include any euglenophytes and filamentous cyanobacteria, such as *Aphanizomenon flos-aquae* (indicators of high trophic levels). Most often, the main contributor to phytoplankton biomass was the dinophyte *Ceratium hirundinella*, the chrysophyte *Dinobryon divergens*, and the green alga *Closterium acutum* var. *variabile*, which are regarded as indicators of meso-eutrophic, oligo-mesotrophic and eutrophic waters, respectively, by Rosén [18]. Hence it can be concluded that Lake Strzeszyńskie is in transition between the meso- and eutrophic states or is only slightly eutrophic.

On the basis of the maximal summer phytoplankton biomass, according to Heinonen's (acc. to Kawecka and Eloranta [5]) criteria, in the first period Lake Strzeszyńskie may be classified as mesotrophic and in the second period as meso-eutrophic. The mean biomass in both periods was

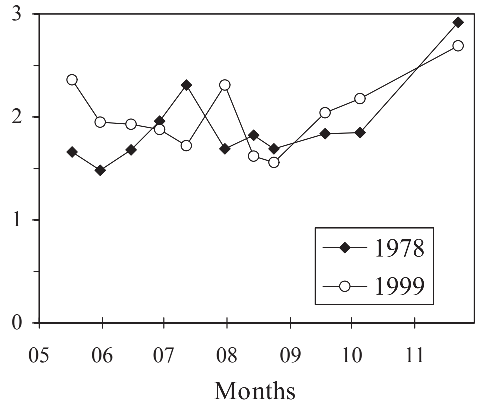

Fig. 3. Phytoplankton trophic index of Lake Strzeszyńskie in both investigated periods.

ca. half as high as the maximum value but increased nearly 2-fold over 20 years: from 0.8 to 1.3 mg l^{-1}, but from 0.8 to 1.5 mg l^{-1} if picoplankton was also considered. In the first period the total phytoplankton biomass was underestimated in 1978 because picoplankton were not taken into account then. As shown with the use of fluorescence microscopy in 1999 picophytoplankton were quite numerous there [15]. Its contribution to phytoplankton biomass was similar to that recorded by Weisse and Kenter [20] in the mesotrophic Lake Constance.

As reported earlier the size of the pelagic phytoplankton community in Lake Strzeszyńskie, expressed as biomass or chlorophyll *a* concentration, was not correlated at the significance level $\alpha \leq 0.05$ with concentrations of mineral forms of nitrogen, soluble phosphates and some other limnological parameters [21, 11], so those parameters were not measured in 1999. On the basis of total phosphorus concentration, this lake may be classified as slightly eutrophic, but the anoxic hypolimnion attests to a much higher trophic level [10].

Conclusions

The assessment of this aquatic ecosystem after two decades reveals only slight changes in the pool of dominants within phytoplankton. The analyses made in the 1990s, in comparison with those made in the 1970s, showed that the same dominants or subdominants appeared in both periods, often in the same seasons or even months. However, phytoplankton biomass doubled and its seasonal fluctuations changed towards higher values in summer. Besides, the contribution of cyanobacteria to total biomass markedly increased. Currently it is difficult to say if this increase is a symptom of water quality deterioration as a result of the growing human impact or a phase in a cyclic course, or − perhaps − it is somehow related to more favourable weather conditions. If the process of eutrophication is allowed to continue, and phytoplankton biomass is going to double again after some time, water quality may soon become unsuitable for recreation. In order to explain the increase in phytoplankton biomass (especially the increase in cyanobacteria) and the modification of the structure and composition of the phytoplankton community, it is necessary to undertake further studies, including other elements of the pelagic biocoenoses.

References

1. REYNOLDS C.S. The response of phytoplankton communities to changing lake environments. Schweiz. Z. Hydrol. **49**, 220, **1987**.
2. REYNOLDS C.S. Functional morphology and the adaptive strategies of freshwater phytoplankton, pp 388-433, in Sangren C.D. (ed.) Growth and reproductive strategies of freshwater phytoplankton. Cambridge University Press, New York, **1988**.

3. ARHONDITSIS G.B., WINDER M., BRETT M.T., SCHINDLER, D. E. Patterns and mechanisms of phytoplankton variability in Lake Washington (USA). Water Research **38**, 4013, **2004**.
4. DEVAUX J. Succession écologique, diversité spécifique et production primaire dans un lac oligotrophe d'Auvergne (France). Verh. Internat. Verein. Limnol. **19**, 1165, **1974**.
5. KAWECKA B., ELORANTA P.V. The outline of algae ecology in freshwater and terrestrial environments. Wydawnictwo Naukowe PWN, Warszawa, pp 252, **1994** (in Polish).
6. STOCKNER J.G. Phototrophic picoplankton: An overview from marine and freshwater ecosystems. Limnol. Oceanogr. **33**, 765, **1988**.
7. STOCKNER J.G. Autotrophic picoplankton in freshwater ecosystems: The view from the summit. Int. Rev. ges. Hydrobiol. **76**, 483, **1991**.
8. WEISSE T. Dynamics of autotrophic picoplankton in marine and freshwater ecosystems, pp 327-370, in Advances in Microbial Ecology. Jones J.G. (ed.), Plenum Press, New York, Vol. **13**, **1993**.
9. JAŃCZAK J., SZIWA R. A morphometric and hydrological characteristic of lakes and reservoirs of Poznań, pp 345-355, in Kaniecki A., Rotnicka J. (eds), Surface waters of Poznań. Water problems of urban areas. Sorus, Poznań, **1995** (in Polish).
10. MASTYŃSKI J., SZELĄG-WASIELEWSKA E. Possibilities of producing vendace in a eutrophic lake, such as Lake Strzeszyńskie. Gospodarka rybna **5**, 6, **1989** (in Polish).
11. SZELĄG-WASIELEWSKA E. The phytoplankton and the abiotic elements in the pelagial of the Strzeszyńskie Lake, pp 361-373, in Kaniecki A., Rotnicka J. (eds), Surface waters of Poznań. Water problems of urban areas. Sorus, Poznań, **1995** (in Polish).
12. SZELĄG-WASIELEWSKA E. Seasonal fluctuations of phytoplankton as a reflection of changes in the pelagic zone of lakes, pp 245-254, in Choiński A., Jańczak J. (eds), Natural and anthropogenic transformations of lakes. IMGW, Warszawa, **1999** (in Polish).
13. UTERMÖHL H. Zur Vervollkommung der quantitativen Phytoplankton-Methodik. Mitt. Internat.Verein. Limnol. **9**, 1, **1958**.
14. SZELĄG-WASIELEWSKA E. Picoplankton versus other size fractions of phytoplankton in lakes with varied trophic state. Limnological Review **3**, 229, **2003**.
15. SZELĄG-WASIELEWSKA E. Seasonal fluctuations of the autotrophic picoplankton and its contribution to total phytoplankton community in a eutrophic lake (Lake Strzeszyńskie, Poland), pp 395-406, in Elektorowicz M., Sozański M.M. (eds), Water supply and water quality. Poznań, **2004** (in Polish).
16. HUTCHINSON G.E. A treatise on limnology. II. Introduction to lake biology and limnoplankton. John Wiley & Sons Inc. New York, London, Sydney, pp 1115, **1967**.
17. HÖRNSTRÖM E. Trophic characterization of lakes by means of qualitative phytoplankton analysis. Limnologica (Berlin) **13** (2), 249, **1981**.
18. ROSÉN G. Phytoplankton indicators and their relations to certain chemical and physical factors. Limnologica (Berlin) **13** (2), 263, **1981**.
19. TRIFONOVA I.S. Phytoplankton composition and biomass structure in relation to trophic gradient in some temperate and subarctic lakes of north-western Russia and the Prebaltic. Hydrobiologia **369/370**, 99, **1998**.
20. WEISSE T., KENTER U. Ecological characteristics of autotrophic picoplankton in a prealpine lake. Int. Rev. ges. Hydrobiol. **76**, 493, **1991.**
21. SZELĄG-WASIELEWSKA E. Le phytoplancton d'un lac et d'un reservoir d'accumulation situés dans le cours d'une même rivière. Verh. Internat. Verein. Limnol. **24**, 1340, **1991**.