ANNALES
UNIVERSITATIS MARIAE CURIE-SKŁODOWSKA
LUBLIN – POLONIA
VOL. LXI, 5 SECTIO C 2006

TOMASZ LENARD

Department of Botany and Hydrobiology, The John Paul II Catholic University of Lublin
Norwida 4, 20-061 Lublin, Poland

Long-term and seasonal variability of phytoplankton in mesotrophic lake Rogóźno

Wieloletnia i sezonowa zmienność fitoplanktonu w mezotroficznym jeziorze Rogóźno

SUMMARY

The studies of seasonal and long term variability of phytoplankton were done in mesotrophic Rogóźno Lake of Łęczna-Włodawa Lakeland. Seasonal changes were studied in one year period in the year 2003. There was investigated the quantitative (chlorophyll-a, abundance) and qualitative structure (dominant species and domination of taxa) of phytoplankton and physico-chemical variables like pH, conductivity, oxygenation of water column, water transparency (SD), and concentration of total nitrogen and phosphorus. Long-term variability of phytoplankton was examined taking into account the above-mentioned factors measured in the summer season in the 12-year period (1992–2003). The majority of the studied factors (chlorophyll-a concentration, SD, total nitrogen and phosphorus concentrations) confirms a mesotrophic character of this water body. The other factors like oxygenation of hypolimnion (many times anoxia was observed) and qualitative structure (domination of species that belong to filamentous cyanobacteria) demonstrated the evolution of this lake in the direction of eutrophy. The schema of that seasonal succession of phytoplankton also corresponds to eutrophic lakes pattern with reference to the PEG model (Plankton Ecology Group).

STRESZCZENIE

Badania nad sezonową i wieloletnią zmiennością fitoplanktonu przeprowadzono w mezotroficznym jeziorze Rogóźno na Pojezierzu Łęczyńsko-Włodawskim. Zmiany sezonowe badano w cyklu rocznym w 2003 roku. Badano strukturę ilościową (chlorofil-a, liczebność) i jakościową (gatunki i grupy dominujące) fitoplanktonu oraz czynniki fizyko-chemiczne jak: pH, przewodnictwo elektrolityczne, nasycenie wody tlenem, przezroczystość wody (SD) oraz stężenie azotu i fosforu całkowitego. Wieloletnią zmienność fitoplanktonu prześledzono uwzględniając wyżej wymienione czynniki mierzone w sezonie letnim na przestrzeni ostatnich 12 lat (1992–2003). Większość badanych czynników (koncentracja chlorofilu-a, SD, stężenie azotu i fosforu całkowitego) potwierdzało mezotroficzny charakter badanego zbiornika. Pozostałe czynniki jak natlenienie wód hypolimnionu (częsta anoksja), skład jakościowy fitoplanktonu (dominacja gatunków należących do nitkowatych cyanobakterii) wykazują ewolucję tego zbiornika w kierunku eutrofii. Również schemat sezonowej sukcesji fitoplanktonu odpowiada jeziorom eutroficznym w odniesieniu do modelu PEG (Plankton Ecology Group).

Keywords: PEG model, mesotrophic lake, subdomination, domination species, cyanobacteria, abundance of phytoplankton

INTRODUCTION

The phytoplankton dynamics determines quantitative and qualitative changes in this community in time and space (4). The variability of phytoplankton community is the effect of the influence of physical, chemical and biological variables. Important physical factors which influence the growth and structure of phytoplankton are temperature (thermal stratification of water) and intensity of light (1, 5). The chemical factors are nutrient concentrations (16). Studies of the biomass variability and species composition of phytoplankton were carried out by Reynolds (11), Rosen (12), Sommer (14); the schema of seasonal succession of phytoplankton for European lakes is represented by the PEG – model (Plankton Ecology Group) worked out by Sommer and others (15).

The aim of the work was an analysis of seasonal and long term succession of phytoplankton in deep, medium fertile lake Rogóźno.

MATERIAL AND METHODS

Lake Rogóźno is located in the south-eastern part of Łęczna-Włodawa Lakeland in the area of Landscape Park “Łęczyńskie Lakeland” (7). This is a deep, dimictic and mesotrophic lake. 37% of the catchment is covered by forests and 38% is used by agriculture (9). The surface of this water body cover 57.1 ha; its maximum depth is 25.4 m, and mean depth is 7.4 m (7).

The studies of physical, chemical and biological factors were made in the pelagial zone of the lake once a month over one year.

The water samples for analysis were collected in the field by the Ruttner-type water-sampler (2 dm^3 capacity) from the three thermal zones (epilimnion, metalimnion, hypolimnion) and transported to the laboratory. The samples were taken from two depths (poured into collective sample) in each of the zones. In April and November when the water column mixed (from surface to the bottom of the lake) the water samples were taken from six depths and poured into one collective sample.

Temperature and oxygen concentrations in the water were measured with the aid of a WTW OX1 96 at one – meter depth intervals (from the surface to the bottom). pH with use of pH-meter, conductivity with a conductivity meter, and water transparency with a Sechi disc (SD) were also measured in the lake. Total nitrogen (TN) and total phosphorus (TP) concentrations were determined according to the standard methods described by Hermanowicz (2).

The studies also concerned biological factors like chlorophyll-a concentration according to standard methods described by Nush (8), and algal number that was determined with inverted microscope by the Utermöhl method (17).

Phytoplankton species composition was determined with the use of light microscope. In winter (December–March) qualitative and quantitative composition of algal flora was determined only in the samples from the surface layer (1–3 m) because the lake was ice-covered (max thickness of ice – 0.4 m) and the ice was covered by snow. This conditions considerably limit penetration of light and growth of photoautotrophic plankton on every depth (6). In other seasons (spring, summer, autumn) the biological parameters were determined in the three zones (epilimnion, metalimnion, hypolimnion).

RESULTS

1. Physico-chemical variables

From December to the end of March the lake was ice-covered (max. thickness of ice is 0.4 m in March). From May to October 2003 the thermal stratification (epilimnion stretched on average to 5 m, metalimnion to 8 m and hypolimnion from 8 m to the bottom) occurred in the lake. In April and November the homothermy phase (mixing) took place. Sechi disc values (SD) in the vegetation season ranged from 2 to 4.3 m. The greatest transparency (4.3 m) was measured in June (Table 1).

Table 1. Average values of physico-chemical variables in each part of water column in each season during the year

Seasons	Water zones	pH	Conductivity [$\mu S \cdot cm^{-1}$]	Total nitrogen [$mg \cdot dm^{-3}$]	Total phosphorus [$mg \cdot dm^{-3}$]	SD [m]
Winter	Up	7.6	498	3.91	0.095	–
	Down	7.5	511	3.69	0.11	
Spring	E	7.9	477	3.62	0.1	3.1
	M	8.0	486	2.45	0.083	
	H	7.7	484	2.93	0.057	
Summer	E	7.9	464	2.64	0.036	3.9
	M	7.7	467	2.55	0.036	
	H	7.8	501	2.41	0.028	
Autumn	E	7.6	441	1.57	0.093	2.4
	M	7.8	487	2.12	0.105	
	H	7.9	505	1.89	0.151	

E – epilimnion, M – metalimnion, H – hypolimnion

Mean conductivity values demonstrated small seasonal differentiation and ranged between 504 $\mu S \cdot cm^{-1}$ in winter, 482 $\mu S \cdot cm^{-1}$ in spring, and 477 $\mu S \cdot cm^{-1}$ in summer and autumn.

Mean concentrations of the total nitrogen were low differentiated. The highest concentrations (3.6–3.9 $mg \cdot dm^{-3}$) were measured in winter and in early spring, and the lowest in autumn (1.57 $mg \cdot dm^{-3}$). Mean total phosphorus concentrations were small and ranged from 0.03 in summer to 0.09 $mg \cdot dm^{-3}$ in other seasons. Periodically (winter, autumn) in the water layer above the bottom (hypolimnion) total phosphorus values exceeded 0.1 $mg \cdot dm^{-3}$.

The values of oxygenations differed considerably depending on seasons and depth (Fig. 1).

The total water column was well oxygenated in winter, the average oxygenation ranged from 80% in the surface layers to 20% above the bottom of the lake. At the beginning of spring (April) and late autumn (November) there was observed homooxygeny – the total column of water was saturated in 80% by oxygen. In the late of spring (May) the total anoxia was observed from 17 m. In summer oxygenation of total water column was fair (15% oxygenation above the bottom). The least amount of oxygen in the water was observed in autumn (before November circulation) when the total anoxia occurred from 10 m.

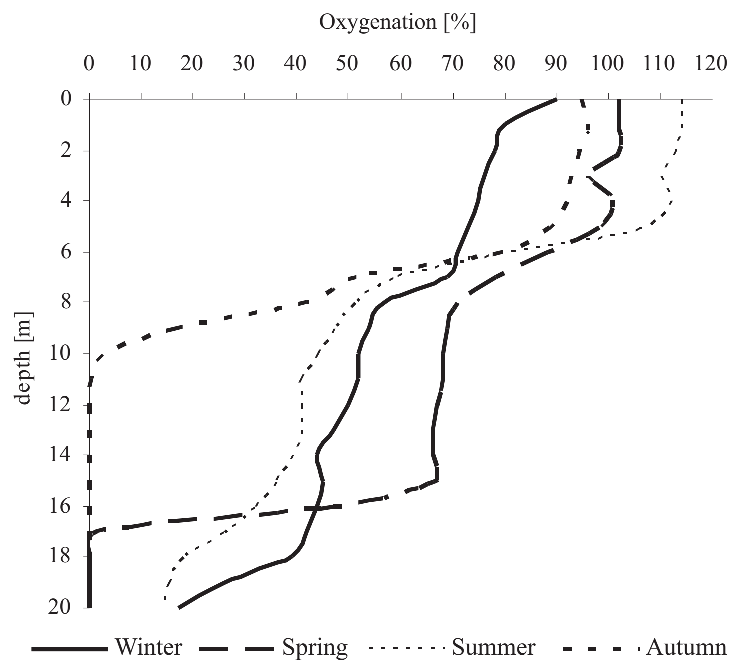

Fig. 1. Average values of oxygenation percentage in total water column in each season during the year

2. Biological factors

2.1. Quantitative variability of total phytoplankton

Quantity of phytoplankton was measured by its abundance and chlorophyll-a concentrations. The average values of those parameters in total water column (from surface to the bottom) are demonstrated in Table 2.

Table 2. Average abundance of phytoplankton and average values of chlorophyll-a in total water column in each season during the year

Seasons	Abundance [N·103 indiv.·dm^{-3}]	Chlorophyll-a [µg·dm^{-3}]
Winter	55	7.5
Spring	333	6.9
Summer	253	6.8
Autumn	179	8.4

The lowest number of algal specimens was ascertained in winter and the highest in spring and summer. There was not ascertained linear relationship between the number and chlorophyll-a concentrations. The highest values of chlorophyll-a concentrations occurred in winter and autumn (7.5–8.4 µg·dm^{-3}) (Table 2).

During the three seasons (spring, summer and autumn) the quantity of phytoplankton was also determined for each thermal zones (Table 3).

Table 3. Average abundance of algal specimens and average values of chlorophyll-a in each part of water column during the year

Seasons	Abundance [N·103 indiv.·dm^{-3}]			Chlorophyll-a [µg·dm^{-3}]		
	E	M	H	E	M	H
Winter	55	–	–	7.5	–	–
Spring	294	570	136	8.2	7.1	5.4
Summer	289	404	66	8.0	8.2	4.3
Autumn	238	160	142	11.5	8.1	5.6

E – epilimnion, M – metalimnion, H – hypolimnion

From spring till autumn the number of phytoplankton in epilimnion demonstrated very small differentiation (from 238 to 294 thousand specimens per dm^3). The highest number was ascertained in metalimnion (570–404 indiv.·10^3 per dm^3), especially in spring and summer, and the lowest one in hypolimnion. Small quantity of algal specimens in hypolimnion was also confirmed by small values of chlorophyll-a concentrations (Table 3).

In the trophogenic layer which comprised epi- and metalimnion in lake Rogóźno the values of chlorophyll-a concentrations were low differentiated, and the differences that occurred especially in autumn were not directly proportional to the algae numbers.

2.2. Qualitative and quantitative variability of phytoplankton taxa

During the studies 66 species belonging to the six systematic groups were indicated. The smallest number of species (19) was indicated in winter and the greatest (42–46) in summer and autumn. The quantity of species decreased also with depth. The least number of species were indicated in hypolimnion and the most number in metalimnion. The highest species richness (25) characterized green algae (*Chlorophyta*). The species belonging to blue-green algae (*Cyanoprokaryota*) (17) and diatoms (*Bacillariophyceae*) (10) had also a large number. In other systematic groups occurred from 1 to 5 species.

Percentage shares of taxonomic groups in total phytoplankton number in whole water column during the year are presented in Figure 2. Taking into consideration the mean values of phytoplankton number from the one year of studies, it was determined that the highest percentage shares in total phytoplankton number (37%) had *Cyanoprokaryota* and *Bacillariophyceae* (24%). *Euglenophyta* and *Chlorophyta* constituted 13–15%. Percentage shares of the other systematic groups were less than 10%.

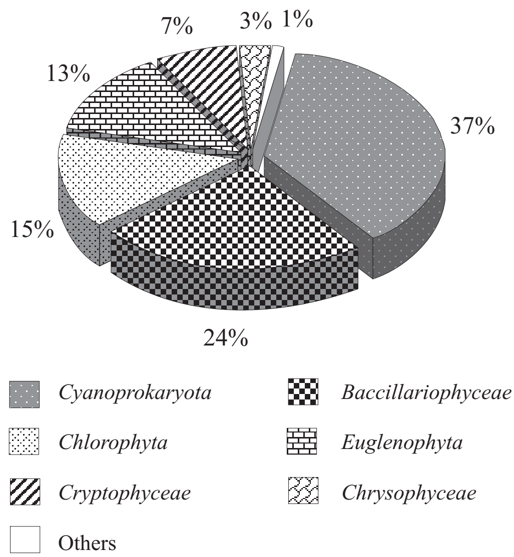

Fig. 2. Percentage shares of taxonomic groups in total phytoplankton number in the whole water column during the year

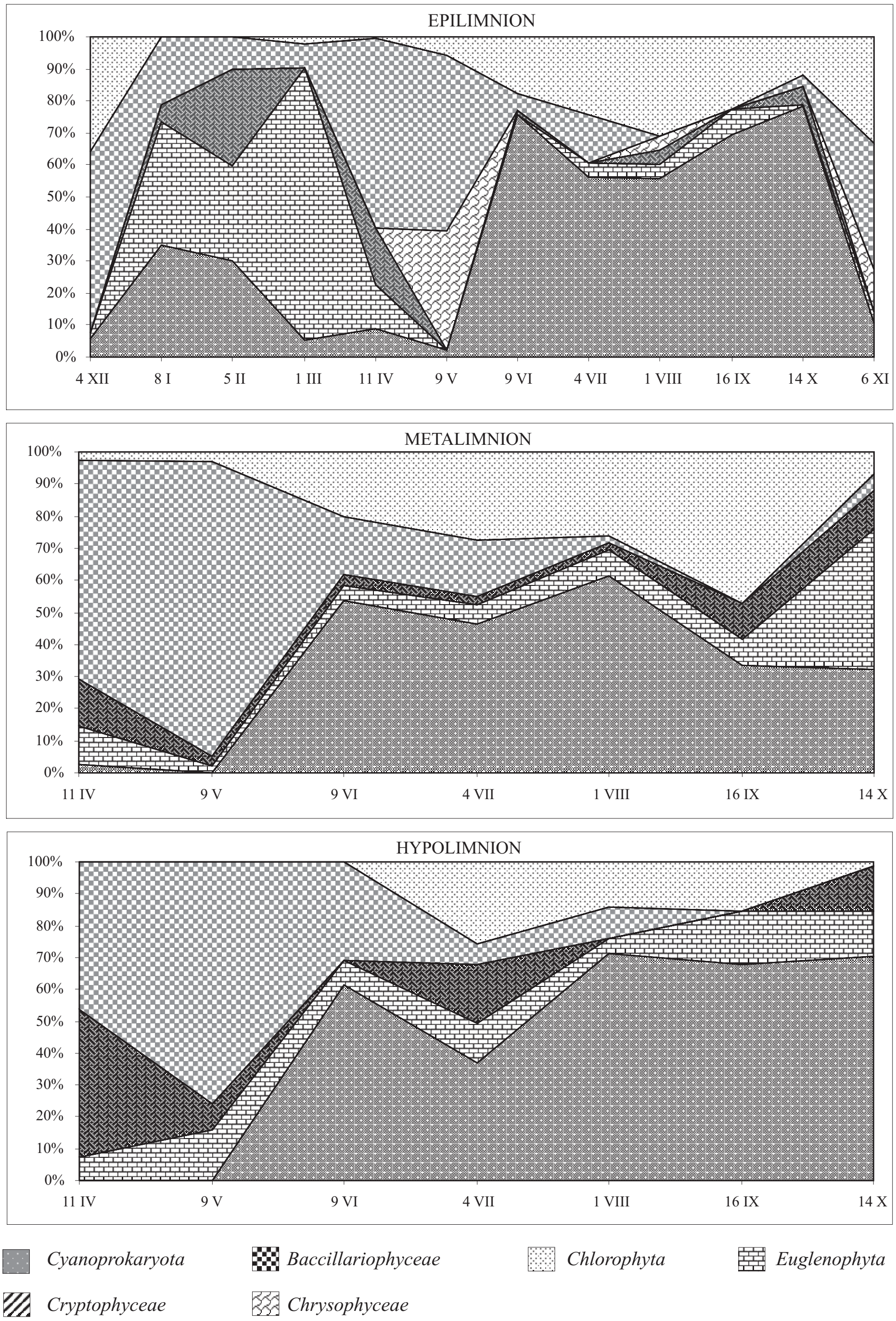

Fig. 3. Percentage shares of taxonomic groups in total phytoplankton number in epilimnion, metalimnion and hypolimnion

Variability of abundance of the main systematic groups under discussion in each of the thermal layers and months is presented in Figure 3. The structure of phytoplankton in the surface layer was variable in winter. In December the dominant groups were *Bacillariophyceae* (percentage share in total phytoplankton number about 56%) and *Chlorophyta* – 36%. In January and February species belonging to three groups: *Cyanoprokaryota*, *Euglenophyta* and *Cryptophyceae* had the largest share in phytoplankton. All those three systematic groups have got about 90% share of the total phytoplankton number (Fig. 3). The structure of phytoplankton underwent considerable changes in March; at that time only one group dominated (*Euglenophyta* – the highest share is 85%). In spring (April, May) in every thermal zones diatoms had a high (above 50) percentage share. Their quantity distinctly increased in metalimnion at the beginning of May and their share in total phytoplankton number was over 90%. At the same time, *Chrysophyceae* made up 37% in the total number, developed in the surface layer of water (epilimnion). From June to October in every thermal layer the highest percentage share had cyanobacteria (often above 50%). In the epi- and metalimnion the green algae had large percentage shares (from 20 to 35%) (Fig. 3). The number of the other main systematic taxa was small (less than 10%).

There were also considered the dominant species in the structure of phytoplankton. In the majority of the studied samples domination of one species excluded domination of other species. Most often the same dominant species were present in epi- and metalimnion and others in hypolimnion. The dominant species and their percentage shares in total phytoplankton number in every thermal zones are presented in Table 4.

Table 4. Abundance of phytoplankton and percentage shares of dominant species in every thermal zones during the year

Months	Water zones	Dominant species	Abundance of total phytoplankton [$N \cdot 10^3$ indiv.$\cdot dm^{-3}$]	Abundance of dominant species [$N \cdot 10^3$ indiv.$\cdot dm^{-3}$]	Percentage share of dominant species in total phytoplankton
January	under ice	*Trachelomonas volvocina* *Planktothrix agardhii*	27.2	10.4 9.5	38 35
February	under ice	*Trachelomonas volvocina* *Planktothrix agardhii* *Cryptomonas sp.*	55.9	16.7 16.7 16.7	30 30 30
March	under ice	*Trachelomonas volvocina*	37.2	31.6	85
April	E	*Asterionella formosa*	114.4	49.2	43
	M	*Asterionella formosa*	202.3	103.4	51
	H	*Cryptomonas sp.* *Asterionella formosa*	137.9	64 59.1	46 43

May	E	*Dinobryon cylindricum* *Cyclotella ocellata*	475.4	172.4 152.7	36 32
	M	*Cyclotella ocellata*	937	595.9	64
	H	*Cyclotella ocellata* *Synedra acus*	133.2	39.4 34.5	30 26
June	E	*Snowella lacustris*	532.5	349.6	66
	M	*Snowella lacustris*	439.4	152.7	35
	H	*Aphanizomenon flos-aquae*	64	29.5	46
July	E	*Aphanotece clathrata*	227.8	83.7	37
	M	*Aphanotece clathrata*	530.3	169.9	32
	H	*Cryptomonas sp.*	84.6	14.8	17
August	E	*Aphanotece clathrata*	108.1	24.6	23
	M	*Aphanizomenon gracile*	248.9	78.8	32
	H	*Aphanotece clathrata*	48.8	24.6	50
September	E	*Aphanizomenon gracile*	251.6	98.5	39
	M	*Closterium acutum*	182.6	68.9	38
	H	*Limnothrix redekei*	321.9	211.7	66
October	E	*Aphanizomenon gracile*	262.5	113.3	43
	M	*Trachelomonas volvocina*	296.3	123.1	42
	H	*Planktothrix agardhii*	105.2	73.9	70
November	E	*Cyclotella ocelata* *Chlamydomonas sp.*	199.1	57.7 40.9	29 21
December	under ice	*Cyclotella ocellata*	99.2	55.8	56

E – epilimnion, M – metalimnion, H – hypolimnion

At the beginning of winter (December) diatom *Cyclotella ocelata,* which took 56% in total phytoplankton number, was the dominant species. In January, February and March *Trachelomonas volvocina* (*Euglenophyta*) had large share (30–85%). In January and February filamentous cyanobacteria – *Planktothrix agardhii* (30–35%) and *Cryptophyceae* – *Cryptomonas* sp. 30% had also large share. In the early spring (April) in the mixing period diatom *Asterionella formosa* of percentage share 43–51% was the most numerous species. In May in every thermal layer *Cyclotella ocellata,* which made in phytoplankton 30–64% was dominant species. At the same time in the surface layer of water there occurred also subdominant species – *Dinobryon cylindricum* (*Chrysophyceae*) (its share in total phytoplankton number was above 30%). In the summer period (June, July, August) every thermal layer was dominated by four species belonging to *Cyanoprokaryota*: *Snowella lacustris*, *Aphanizomenon flos-aquae*, *Aphanizomenon gracile* and *Aphanotece clathrata*. In June the most numerous was *Snowella lacustris* (35–66%), in July – *Aphanotece clathrata* (> 35%) and besides *Aphanotece clathrata, Aphanizomenon gracile* (> 30%) was also numerous in August. In autumn (September, October) from 10 m to the bottom (hypolimnion) developed numerous filamentous cyanobacteria (*Limnothrix redekei* and *Planktothrix agardhii*) which made up about 70% in the total number of phytoplankton. In the superstratum of water (epilimnion, metalimnion) *Aphanizomenon gracile*, *Closterium acutum* and *Trachelomonas volvocina* occurred in large quantities. In the mixing period (November) and in December phytoplankton was dominated by *Cyclotella ocellata* (*Bacillariophyceae*).

3. Long-term variability of phytoplankton

On the basis of the published papers and my own studies it was also possible to demonstrate the quantitative and qualitative variability of phytoplankton in the 12-year period. The variability of physico-chemical and biological variables is presented in Table 5.

Table 5. Variability of physico-chemical and biological variables in lake Rogóźno in the 12-year period

Date	Trophic status	SD [m]	Oxygen over the bottom [$mg \cdot dm^{-3}$]	Chlorophyll-a [$\mu g \cdot dm^{-3}$]	Abundance of phytoplankton [$N \cdot 10^3$ indiv.$\cdot dm^{-3}$]	Dominant species
1992	mesotrophy	4.1	6.8	–	654	*Cryptomonas* sp. *Anabaena* sp.
1998	mesotrophy	3.2	–	11.2	1470	*Planktothrix agardhii*
1999	mesotrophy	4.3	Anoxia from 18 m	9.5	864	*Pseudoanabaena limnetica*
2000	mesotrophy	3.7	3.9	8.1	590	*Closterium acutum* *Asterionella formosa*
2001	mesotrophy	3.5	2.2	9.3	730	*Pseudoanabaena limnetica*
2002	first phase of eutrophy	2.2	0.7	14.1	407	*Pseudoanabaena limnetica* *Closterium acutum*
2003	mesotrophy	3.9	2.1	6.8	253	*Snowella lacustris* *Aphanotece clathrata* *Aphanizomenon flos-aquae*

The values of physico-chemical (SD, oxygenation) and biological (concentration of chlorophyll-a, abundance, dominant species) variables are average of the summer period (June, July, August). Since 1992 to 2003 transparency of the water was fluctuated, and it ranged from about 2.2 m in 2002 to the values above 3.5 m in the other years.

From the end of the nineties in lake Rogóźno also small oxygenation of water or anoxia in hypolimnion occur. Long-term studies of phytoplankton demonstrate its large quantitative variability in different years of the undertaking studies. In the lake characteristic is also keeping up domination or subdomination species belonging to filamentous cyanobacteria (*Anabaena* sp., *Planktothrix agardhii*, *Pseudoanabaena limnetica*, *Aphanizomenon flos-aquae*). In some years non- filamentous cyanobacteria *Snowella lacustris*, *Aphanotece clathrata* and green algae *Closterium acutum* were equally numerous (as the subdominants).

DISCUSSION

The general schema of seasonal variability of phytoplankton for both shallow and deep lakes, as well as for oligotrophic and eutrophic ones was described as PEG-model (Plankton Ecology Group) (15). The seasonal succession of phytoplankton demonstrated in lake Rogóźno correspond to the model for eutrophic lakes, in which summer maximum of quantity of phytoplankton with the domination of large algae like *Cyanoprokaryota* is often observed. The smallest quantity of algae is recorded in winter, and their growth is limited mainly by temperature and light (10). The small, nanoplanktonic algae dominated in winter, for example in the studied lake there were: *Cyclotella ocellata, Trachelomonas volvocina* and *Cryptomonas* sp., which size did not exceed 15 μm.

There was also recorded a short-term numerous occurrence of some species like *Asterionella formosa* (*Bacillariophyceae*) in April and *Dinobryon cylindricum* (*Chrysophyceae*) in May. Occurrence of these species in these seasons in the other lakes of Łęczna-Włodawa Lakeland was ascertained by Solis (13), Wojciechowska (19), as well as in other freshwater lakes by Reynolds (10, 11).

Although lake Rogóźno has been characterized till now as mesotrophic, phytoplankton succession (seasonal and long-term), species composition, and physico-chemical and biological factors also indicated that it demonstrates evolution in the direction of eutrophy.

Mesotrophic character of lake Rogóźno in regard to trophic classification of lakes from mid-latitude zone presented by Hilbricht-Ilkowska (3) was confirmed by: the values of chlorophyll-a, which kept lower than 10 $\mu g \cdot dm^{-3}$, total phosphorus values always kept in summer lower than 10 $\mu g \cdot dm^{-3}$, and large transparency of water (> 3 m). Mesotrophic character of this water body based on the above-mentioned factors is also consistent with OECD classification (18).

However, there are also factors which show that the studied lake demonstrates the tendency to eutrophy. Among these factors very important are often measured oxygen deficits or complete anoxia of water layer near the bottom of the lake, which in accordance to criterion OECD (18) allow to classify Rogóźno as the eutrophic lake. A similar qualitative composition of phytoplankton and predominant species belonging to filamentous cyanobacteria like *Pseudoanabaena limnetica*, *Snowella lacustris*, *Planktothrix agardhii*, *Aphanizomenon gracile*, *Aphanizomenon flos-aquae* shows that this water body is probably in the first phase of eutrophy.

REFERENCES

1. Agbeti M. D., Smol J. P. 1995. Winter limnology: a comparison of physical, chemical and biological characteristics in two temperate lakes during ice cover. Kluwer Academic Publishers, Hydrobiologia 304: 221–234.
2. Hermanowicz W. 1999. Fizyczno-chemiczne badanie wody i ścieków. Arkady, Warszawa.
3. Hillbricht-Ilkowska A., Kajak Z. 1986. Parametry i wskaźniki przydatne do kontroli zmian funkcjonalnych i strukturalnych w ekosystemach jeziornych ulegających procesowi eutrofizacji. [In:] Monitoring ekosystemów jeziornych. A. Hillbricht-Ilkowska (eds.), Ossolineum, Wrocław, 23–45.
4. Kawecka B., Eloranta P. V. 1994. Zarys ekologii glonów wód słodkich i środowisk lądowych. PWN Warszawa.
5. Lampert W., Sommer U. 2001. Ekologia wód śródlądowych. PWN Warszawa.
6. Mencfel R., Pasztaleniec A. 2004. Characteristics of the winter phytoplankton in Rogóźno Lake. Annales UMCS, Sectio C, 59: 67–72.
7. Michalczyk Z., Wilgat T. 1998. Stosunki wodne Lubelszczyzny. Wydawnictwo UMCS Lublin.
8. Nush E. A. 1980. Comparison of different methods for chlorophyll and pheopigment determination. Arch. Hydrobiol. Beih. Ergebn. Limnol. 14: 14–36.
9. Radwan S., Kornijów R. 1998. Hydrobiologiczne cechy jezior – stan aktualny i kierunki zmian. [In:] Jeziora Łęczyńsko-Włodawskie. Monografia przyrodnicza. M. Harasimiuk, Z. Michalczyk, M. Turczyński (eds), Wydawnictwo UMCS Lublin, 129–144.
10. Reynolds C.S. 1982. Phytoplankton periodicity: its motivation mechanisms and manipulation. Freshwater Biol. Assoc. Ann. Rep. 50: 60–75.
11. Reynolds C. S. 1984. The Ecology of Freshwater Phytoplankton. Cambridge University Press, Cambridge, London, New York, New Rochelle, Melbourne, Sydney.
12. Rosen G. 1981. Phytoplankton indicators and their relations to certain chemical and physical factors. Limnologica 13: 263–290.
13. Solis M. 2005. Relationships between selected abiotic variables and phytoplankton composition in deep mesotrophic Lake Zagłębocze. Oceanolog. Hydrobiol. Studies. XXXIV: 81–96.
14. Sommer U. 1986. The periodicity of phytoplankton in lake Constance (Bodensee) in comparison to other deep lakes of central Europe. Hydrobiologia 138: 1–7.
15. Sommer U., Gliwicz Z. M., Lampert W., Duncan A. 1986. The PEG model of seasonal succession of planktonic events in fresh waters. Arch. Hydrobiol. 106: 433–471.
16. Tilman D. 1982. Resource Competition and Community Structure. Princeton University Press, Princeton NY.
17. Vollenweider R. A. 1969. A Manual on Methods for Measuring Primary Production in Aquatic Environments. Blackwell, Oxford–Edinburgh.
18. Vollenweider R. 1989. Global problems of eutrophication and its control. Symp. Biol. Hung. 38: 19–41.
19. Wojciechowska W. 1986. Phytoplankton fluctuations in pond type Lake Bikcze. Ekol. Pol. 34: 133–143.