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EFFECT OF ENVIRONMENTAL CONDITIONS ON THE STRUCTURE OF PHYTOPLANKTON COMMUNITY OF LAKE PIASECZNO DURING TWO DIFFERENT WINTER PERIODS

Tomasz Lenard

Department of Botany and Hydrobiology, The John Paul II Catholic University of Lublin
Konstantynów 1H, 20–708 Lublin, tomekl@kul.lublin.pl

Summary. During two winter seasons, winter 2006 with thick ice/snow cover and winter 2007 without ice, the biomass and phytoplankton structure were analysed in comparison with selected environmental factors. Generally, higher values of biomass and chlorophyll *a* were recorded during the ice-free winter, when the whole water column was mixed and the thermal and light conditions were much better than in winter with the ice cover. The studies have evidenced that penetration of light into the aquatic environment was strongly reduced by thinner ice with thick snow cover, as well as by thicker ice with thinner snow cover. However, in winter 2006, just beneath the ice cover, phytoplankton was dominated mainly by nanoplanktonic flagellates from the genus *Mallomonas*, whereas in the deeper part of the water column, in spite of low light intensity, microplanktonic green alga – *Botryococcus braunii* were most numerous. Next year, due to water mixing, vertical distribution of phytoplankton through the water column was less diverse and mainly composed again by big algal species belonging to green algae – *Botryococcus braunii* and occasionally to blue-green algae – *Aphanothece clathrata*. In both winter seasons, the biomass and chlorophyll *a* values were low and never exceeded 0.9 mg·dm^{-3}. Additionally, they were at the comparable levels to the values from the winter seasons during the 1970s and 1990s, what indicates the long-term stability of the phytoplankton community in Lake Piaseczno.

Key words: winter phytoplankton, photosynthetically active radiation, ice/snow cover, mesotrophic lake

INTRODUCTION

Lake Piaseczno is the deepest and one of the best studied lakes of the Łęczna-Włodawa Plain. Its waters are highly transparent and the number of phytoplankton is generally low. The studies of the winter phytoplankton community in this lake were carried out previously during the 1970s by Lecewicz *et al*. [1973], Wojciechowska [1976a, b] and 1990s by Wojciechowska *et al*. [1998].

Winter period is often treated as less important for phytoplankton development. However, in temperate zone, frequent changes of environmental conditions in winter significantly affects the functioning of lakes ecosystems [Spaulding *et al*. 1993, Adrian *et al*. 1999, Dokulil and Herzig 2009]. It has been shown that the most important abiotic factors affecting on phytoplankton community are light regime and temperature [Bolsenga and Vanderploeg 1992, Leppäranta *et al*. 2003]. That's why in winter periods, because of unfavourable conditions, phytoplankton is often present in small number [Barone and Naselli-Flores 2003]. Nevertheless, when the abiotic conditions are advantageous, phytoplankton can develop in great number or sometimes even cause a bloom [Spaulding *et al*. 1993, Philips and Fawley 2002a, b]. In consequence, the change of structure and amount of winter phytoplankton, as a reaction on presence or absence of ice cover, could affect on the functioning of water ecosystems not only in winter but also during the whole year [Adrian *et al*. 1999, Dokulil and Herzig 2009, Laugaste *et al*. 2010].

The aim of this study was to investigate the variability of biomass and structure of the phytoplankton community in relation to selected environmental factors in Lake Piaseczno during two different winter periods.

MATERIALS AND METHODS

The studies were carried out in mesotrophic and dimictic Lake Piaseczno situated in Eastern Poland within the Łęczna-Włodawa Plain. Lake Piaseczno is deep (max depth about 39 m), with a surface area of 84.7 ha [Harasimiuk *et al*. 1998].

The lake was sampled once a month (January, February, March) during two winter seasons: in 2006 when the lake was permanently covered with ice, and in 2007 when the lake was completely devoid of ice and the whole water column was mixed.

Water samples were always taken from the pelagial zone using a Ruttner water sampler (2.0 dm^3 capacity). Samples for biological analysis were taken from the water layer of 0–7 m at 1 m intervals and poured into two consecutive samples: the first one called „up" was a mixture of water from the depth of 0.5–3 m, the second one called „down" from 5–7 m.

Phytoplankton samples for biomass analysis were fixed with formalin-glycerine mixture. Then the samples were transferred to a settling chamber of 100 ml capacities. After sedimentation, algal abundance was evaluated according to Utermöhl's [1958] method. At least 100 specimens of the most numerous algae were counted per sample. Algal biovolume was calculated using the formula according to Hillebrand *et al*. [1999]. Additionally, also samples for taxonomical analysis were collected using a plankton net (20 µm mesh size), which were left without fixation in order to observe live specimens under a light microscope. The concentration of chlorophyll *a* was determined according to the standard method described by Nush [1980].

The physical analysis (temperature, oxygen concentration, conductivity, pH, ice and snow thickness, water transparency – SD) were measured in situ. Additionally, the depth profiles of the photosynthetically active radiation (PAR) intensity were measured with a Li–Cor meter (Li–250A) with an underwater quantum sensor (Li–192SA).

In statistical analyses, Spearman's rank correlation coefficient was used.

RESULTS

During two years of research, mean values of basic physicochemical data in examined water layer (0–7 m) were similar. The reaction (pH) values ranged within 7.3–7.7 and waters were always well oxygenated 11.6–18.0 mg·dm^{-3}. Only the electrolytic conductivity values were different and varied between 127–136 and 91–92 µS·dm^{-3}, respectively in winter 2006 and 2007 (Tab. 1).

Table 1. Physicochemical and biological parameters of Lake Piaseczno

Year	Month**	Thickness, cm, of		Transparency, m	T*, ºC	DO*, mg·dm^{-3}	pH*	EC*, µS·cm^{-1}	N*, %	M*, %	Biomass*, mg·dm^{-3}	Chlorophyll *a**, µg·dm^{-3}
		ice	snow									
2006	J	20	0	-	0.9	18.0	7.7	127	54	46	0.29	5.2
	F	26	22	-	1.0	17.8	7.5	136	39	61	0.33	2.7
	M	45	5	-	1.1	13.3	7.3	131	33	67	0.31	2.6
2007	J	-	-	7.2	2.9	11.6	7.4	91	23	77	0.74	4.6
	F	-	-	6.6	1.3	13.6	7.3	92	31	69	0.59	3.7
	M	-	-	6.0	2.4	12.8	7.7	91	34	66	0.64	5.2

*mean values (from 0–7 m) of: T – temperature, DO – dissolved oxygen, EC – electrolytic conductivity, pH – reaction, N, M – shares of nano- and microplankton in biomass
**J – January; F – February; M – March

During freezing − the season with ice cover (2006), the ice thickness was increasing from month to month. At the beginning of winter (January) Lake Piaseczno was covered with thin layer of white ice (barely transparent) without snow cover on the surface of ice. In the following months, thickness of ice/snow cover highly increased to the maximum in March (Tab. 1). Mean values of water temperature were then ≈1 ºC. Next winter (2007), when the ice cover were absent and the water transparency was high (SD = 6.0–7.2), the water temperature was generally two or three times higher than the previous year (Tab. 1).

With these environmental data corresponded the values of biomass and chlorophyll *a*, which were generally two times higher in the winter period without ice-cover (Tab. 1). Moreover, when the ice was not covered with snow (January 2006), higher shares in phytoplankton community had nanoplankton fraction (54% in biomass). In the following months, when the ice was covered with thick snow layer, as well as during winter 2007 shares of nanoplankton were rather low and the microplankton fraction prevailed (Tab. 1). However, in both years of study, Spearman's rank correlation coefficient between the concentration of chlorophyll *a* and phytoplankton biomass was very low and statistically insignificant, $r_s = -0{,}10$ ($N = 12$, $p > 0$–0.5).

In both years of the research, due to the presence or absence of ice and snow cover, the wide range of light conditions was observed in the water. The amount of photosynthetically active radiation (PAR) just above the lake surface increased from month to month during both winters. The lowest light intensity (below 135 $\mu mol \cdot m^{-2} \cdot s^{-1}$) was always in January and the highest (600–800 $\mu mol \cdot m^{-2} \cdot s^{-1}$) in March (Tab. 2). It has been evidenced that only 10 to 40% of the surface light (PAR) entered to the water column through the ice/snow cover (Tab. 2). In January when the ice cover was the thinnest and the snow-cover was absent, the light conditions in the water column (0–7 m), compared to the following months, were most favourable. The boundary of the euphotic zone was then 7 m. In February and March, due to thick ice/snow cover, values below 1% of PAR (aphotic zone) were recorded already from the depth of 2 m (Tab. 2).

Table 2. Vertical distribution of light (% of PAR)

Depth, m	2006			2007		
	January 134.6*	February 195.8*	March 763.2*	January 36.7*	February 170.9*	March 664.3*
0**	34	11	8	84	91	72
1	26	3	3	44	45	48
2	16	0.8	0.9	37	31	27
3	10	0.4	0.4	28	22	20
4	7	0.2	0.2	24	15	13
5	4	0.1	0.1	18	11	9
6	3	0	0	12	8	5
7	2	0	0	8	5	5

*real values ($\mu mol \cdot m^{-2} \cdot s^{-1}$) of surface PAR – adopted as 100%
**measured values just under ice-cover (year 2006) or just under water surface (year 2007)

In winter without ice cover (from January to March), from 70 to 90% of the surface light entered the water column. Compared to the winter with the ice cover, values of the surface light were lower (Tab. 2), sometimes even extremely low (e.g. 36.7 $\mu mol \cdot m^{-2} \cdot s^{-1}$ in January 2007), in spite of this, the euphotic zone still reached the depth of over 7 m.

In Lake Piaseczno in winter 2006, the structure of phytoplankton was differentiated in the vertical profile, because of limiting role of light. During this season, very low and similar values of phytoplankton biomass in the whole water column were noted. In spite of this, in January and March just under the ice cover (0.5–3 m) the nanoplanktonic chrysophycean *Mallomonas akrokomos* was the dominant species, whose biomass rapidly decreased with the depth. At the same time, the biomass of microplanktonic green alga *Botryococcus braunii* increased in the deeper part of the water column (5–7 m) which was connected with the increased of chlorophyll *a* values (Fig. 1).

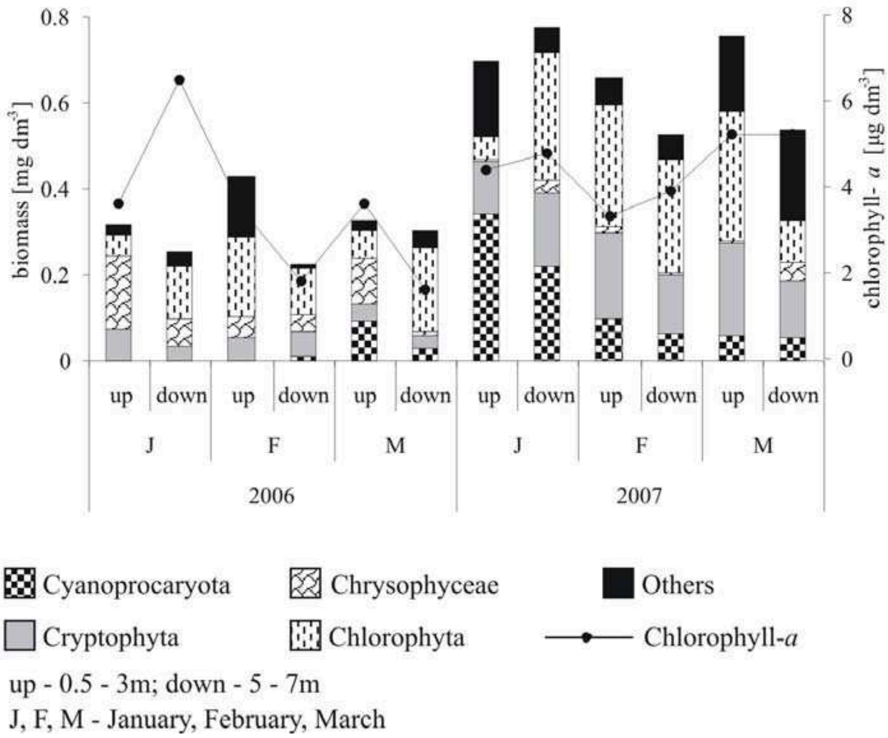

Fig. 1. Biomass variations of main phytoplankton groups and chlorophyll *a* values during two winter periods

In winter 2007, when the ice cover was absent, the water was constantly mixed and the euphotic zone reached 7 m (Tab. 2), the biomass and chlorophyll *a* values, as well as the taxonomic structure (Fig. 1) were almost homogenous in the whole water column. The phytoplankton community was dominated again by microplanktonic green algae – *Botryococcus braunii* and occasionally (January) by blue-green algae – *Aphanothece clathrata*.

In both winter seasons, there were also other algal groups, in which cryptomonads had higher (especially in winter 2007) shares in the phytoplankton biomass (Fig. 1). In this group considerable contribution in the amount of phytoplankton had generally nanoplanktonic species – *Rhodomonas minuta*. However, because of its very small biovolume (240–595 μm^3, which was approximately ten times smaller than species from the genus *Cryptomonas*), the biomass of cryptomonads has never reached high values (of over 30%).

DISCUSSION

During two winter seasons, the light and thermal conditions in Lake Piaseczno were variable. The amount of light in the water was affected not only by the ice cover or the lack thereof, but also by the thickness of ice, as well as by the snow cover on the ice surface. These factors are always considered as limiting the amount of light (PAR) in the water column [Wright 1964, Bolsenga *et al*. 1991, Bolsenga and Vanderploeg 1992]. The studies have evidenced that penetration of light into the aquatic environment was strongly reduced by thinner ice (20–30 cm) with thick (20 cm) snow cover, as well as by thicker ice (45 cm), with thinner snow cover (5 cm), which was also reported by Leppäranta *et al*. [2003].

During two studied winters, the water temperature was highly changed. In winter 2006 thick ice/snow cover separated and created a barrier between the atmosphere and the aquatic environment, in consequence, inverse thermal stratification appeared. This separation led to the change of thermal as well as light regime under ice/snow cover. Next winter (2007), Lake Piaseczno was devoid of ice and its waters were completely mixed during the whole season. Mild winter affected on higher values of water temperature and better light conditions in studied water column. Changes of thermal and light conditions significantly affected the functioning of lake ecosystems and were the main cause of variability in values of both biomass and chlorophyll *a* values between compared seasons. Similar dependences were also reported by Spaulding *et al*. [1993], Adrian *et al*. [1999] and Dokulil and Herzig [2009].

Additionally, in Lake Piaseczno, the biomass and chlorophyll *a* values were rather low and at the comparable level to the values from the winter seasons during the 1970s and 1990s [Lecewicz *et al*. 1973, Wojciechowska 1976a, b, Wojciechowska *et al*. 1998], what indicates the long-term stability of the phytoplankton community in this lake.

During two winter seasons, phytoplankton was generally dominated by species from the groups of *Cyanoprocaryota*, *Chrysophyceae*, *Chlorophyta* and occasionally (in winter 2007) of *Cryptophyta*. The dominance of species from these groups is often reported in the winter seasons, in different types of lakes [Rott 1988, Agbeti and Smol 1995, Wiedner and Nixdorf 1998].

Green algae, with the dominant species – *Botryococcus braunii*, were an important component of phytoplankton in Lake Piaseczno in both winter seasons.

Significant (on the subdominance level) contributions of green algae in the biomass of winter phytoplankton is not often reported by other authors. If the green algae are present, however, the genera *Monoraphidium* spp. or *Ankistrodesmus* spp. are represented by the largest numbers of species [Phillips and Fawley 2002a]. The green alga *Botryococcus braunii* reached high biomass in Lake Piaseczno, not only during the studied winter seasons, but also in the 1970s [Lecewicz *et al*. 1973]. During the season with ice cover (winter 2006), it was observed that despite the fact that the species is characterised by positive buoyancy, it occurs with the highest density at a depth of 5–7 m. At this depth, clear discrepancies were also found between the biomass values and chlorophyll *a* concentrations, especially in March 2006, which with the shortage of nitrogen in the water $N\text{-}NO_3 = 0.7\ mg \cdot dm^{-3}$, $N\text{-}NH_4 = 0.08\ mg \cdot dm^{-3}$ (unpublished data) could result from the accumulation of large amounts of carotenoids in the cells of *Botryococcus braunii* [Canter-Lund and Lund 1995].

There were also species that had high contribution (often over 40%) in the total biomass of phytoplankton, but only in a short period of time. Golden alga – *Mallomonas akrokomos* was the species, which reached high contribution in biomass, but only in January and March 2006 just under ice-cover. This is the flagellate species defined as a cryophilic alga, which is able to mixotrophy and grow in large numbers under the ice cover [Harris 1958, Starmach 1980]. Other species belonging to blue-green algae – *Aphanothece clatrhrata* was present in large biomass only in winter without ice (2007), when the water was warmer and light conditions a lot better than in winter 2006. In Lake Piaseczno, the presence of other species belonging to *Cyanoprocaryota* group like *Aphanocapsa* sp. or *Planktothrix agardhii*, were reported during previous winter seasons also by Wojciechowska *et al*. [1998] and Pasztaleniec and Lenard [2008].

CONCLUSIONS

1. Presence of ice/snow cover significantly affect on the functioning of water environment.
2. Changes of the biomass and structure of phytoplankton community were highly connected with the changes of environmental factors, especially light and thermal regime.
3. During winter with ice-cover, phytoplankton community can be dominated not only by small mixotrophic flagellate forms, but also by microplanktonic species like e.g. *Botryococcus braunii*.
4. Low values of biomass and chlorophyll *a*, at the comparable levels to the values from the winter seasons during the 1970s and 1990s, indicates the long-term stability of the phytoplankton community in Lake Piaseczno.

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WPŁYW CZYNNIKÓW ŚRODOWISKOWYCH NA STRUKTURĘ ZBIOROWISKA FITOPLANKTONU W JEZIORZE PIASECZNO PODCZAS DWÓCH RÓŻNYCH SEZONÓW ZIMOWYCH

Streszczenie. Podczas dwóch okresów zimowych, zima 2006 r. z grubą pokrywą lodowo-śnieżną i zima 2007 r. bez lodu, badano zmiany biomasy i struktury fitoplanktonu w relacji do wybranych czynników środowiskowych. Na ogół wyższe wartości biomasy i chlorofilu *a* stwierdzano zimą bez pokrywy lodowej, kiedy cały słup wody ulegał mieszaniu, a warunki termiczne i świetlne były znacznie lepsze niż zimą z pokrywą lodową. Badania wykazały, że przenikanie światła do środowiska wodnego było silnie ograniczane zarówno przez cienki lód z grubą pokrywą śnieżną, jak i przez gruby lód z cienką pokrywą śnieżną. Jednak zimą 2006 r., tuż pod pokrywą lodową, fitoplankton zdominowany był przez nanoplanktonowe wiciowce z rodzaju *Mallomonas*, podczas gdy w głębszych warstwach wód, pomimo niskich wartości światła, najliczniejsza była mikroplanktonowa zielenica – *Botryococcus braunii*. Następnego roku, z powodu miksji mas wody, wertykalny rozkład fitoplanktonu był mniej zróżnicowany i na ogół ponownie złożony z dużych gatunków glonów należących do zielenic – *Botryococcus braunii* i okresowo sinic – *Aphanothece clathrata*. W obu okresach zimowych wartości biomasy i chlorofilu *a* były niskie i nigdy nie przekraczały 0,9 $mg \cdot dm^{-3}$. Dodatkowo były one na poziomie porównywalnym do wartości mierzonych w okresach zimowych lat 70. i 90. XX wieku, co wskazuje na długoterminową stabilność zbiorowiska fitoplanktonu w jeziorze Piaseczno.

Słowa kluczowe: zimowy fitoplankton, promieniowanie fotosyntetycznie czynne, pokrywa lodowa/śnieżna, jezioro mezotroficzne