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Distribution of phytoplankton of Bohemian Forest lakes

Linda Nedbalová & Ondřej Vrtiška

Charles University, Faculty of Science, Department of Parasitology and Hydrobiology, Viničná 7, CZ–128 44 Prague 2, Czech Republic

Abstract
Phytoplankton of Černé, Čertovo, Plešné and Prášilské Lake were studied within years 1997–1998. Species composition, total biomass, vertical distribution and seasonal development were examined. Phytoplankton structure corresponds to the situation in acidified lakes elsewhere. Nevertheless, considerable differences caused mainly by different trophic status were found among lakes.

Key words: phytoplankton biomass, vertical distribution, phytoplankton diversity, acidification

Introduction

The research of phytoplankton of Bohemian Forest lakes has a long history. Steinich and Hansgirg in Frič & Vávra (1898) published the first list of algae of Černé Lake. Bohuslav Fott examined the phytoplankton of Černé Lake in 1935–1936 and he described three new species – *Bitrichia ollula, Katodinium bohemicum* and *Katodinium planum* (Fott 1937, 1938). The history of investigation of the Bohemian Forest lakes was reviewed by Veselý (1994). The most recent research was done at Černé and Prášilské Lake in 1991–1992 (Hoffmanová 1993) and at Černé and Čertovo Lake in 1992–1994 (Ambrožová 1995). Their scope was limited because of the lack of inverted microscope. The species composition of phytoplankton of Černé Lake was recently examined by Lukavský (in prep.). Our data from 1997 and 1998 cover all the four lakes. We wanted to bring the information on species composition and biomass of phytoplankton with reference to its vertical distribution (1997) and seasonal development (1998). We hope that the present study can help to better understanding the mechanism of microbial loop in acid lake ecosystems. It may be also important for long-term study of recovery of the four Bohemian Forest lakes.

Material and methods

Phytoplankton samples were taken using a van Dorn sampler at the deepest point of the lakes during two ice-free periods. In 1997 we focused mainly on the vertical distribution of phytoplankton: the lakes were sampled three times (May, July, October) from 6–10 sampling depths. In 1998 we concentrated more on seasonal changes : the samples were taken 6 times (May to October) from 5 depths, with the exception of Černé Lake, where the sampling was reduced. Samples (at least 500 ml) were preserved with Lugol solution and stored in PET bottles (Straškrabová & al. 1999).

Counting was performed using Utermöhl's sedimentation method (Utermöhl 1958, Lund & al. 1958) (chambers of 25 mm inner diameter and 20–30 mm height) on the inverted mi-

croscope Nikon Diaphot equipped with phase contrast (objectives 40x and 60x). A concentration (5:1) was necessary for samples from all the lakes except Plešné. This was done by pre-sedimentation of samples in cylinders and siphoning the supernatant water. At least one hundred cells of the most abundant species were counted. The whole bottom of a chamber was checked for large algae, which contributed significantly to the biomass even when their abundance was low. Small species were counted in transects and randomly selected fields.

Biomass was expressed as biovolume. Measuring of cells (at least 30 individuals of dominant species in each sample) was carried out using an electronic calliper (LEGNER & SPRULES 1993). The estimates of cell volume for each species were obtained by application of the geometric formula best fitted to the shape of the cell (HINDÁK 1978, ROTT 1981).

The length of filamentous Cyanobacteria was estimated using method described by NEWMAN (1966). The method is based on counting intersections of filaments with the rectangular net of lines of known length. The biovolume was calculated by approximation of the filament shape to a cylinder.

Results

The list of taxa found in examined lakes is in Table 1. The majority of species were present in all the four lakes. *Gymnodinium uberrimum* was almost missing in Plešné Lake and *Katodinium planum* was found only in Černé and particularly in Plešné Lake.

Černé Lake

In 1997 total biomass in particular depths varied within 0.07 – 0.8 $mm^3.l^{-1}$ through the season (Fig. 1). Above the bottom there was much higher variance of total biomass than in the water column. Maximal biomass was always found in the hypolimnion. Regular increase in biomass in the top – down direction was observed in May (with one smaller peak in 20 m), more regular distribution with no well-marked maximum in July and maximum in 18 m in October were found. The biomass was dominated by dinoflagellates (96 – 61 %), mostly by *Peridinium umbonatum*. In October, *Gymnodinium uberrimum* was the most important alga in 0–12m (72 – 66 %). *Chrysophyceae* were the second important group of algae, especially in July (as much as 37 % of total biomass in 20m), represented mostly by *Dinobryon* spp. and *Ochromonas* sp. (large). Other algae were present but with low share in the biomass.

Čertovo Lake

In 1997 total biomass in particular depths varied within 0.05 – 0.97 $mm^3.l^{-1}$ through the season (Fig. 1). Maximum of the biomass was always found in the epilimnion and it was well developed. The average biomass values in the hypolimnion were usually more than 3 times lower. In July, smaller peak of the biomass appeared above bottom, represented mostly by *Peridinium umbonatum* (94 %). *P. umbonatum* was in general the dominant alga, with the exception of epilimnion in July and October, when *Gymnodinium uberrimum* (up to 24 %) and even more *Chrysophyceae* (42 – 63 %) shared in the biomass. Their biomass was represented mostly *by Dinobryon* spp. in July and *Ochromonas* sp. (large) in October. The most diversified species composition was observed in October when *Cryptophyceae*, green flagellates and *Pseudanabaena* sp. (Cyanobacteria) were of some importance.

In 1998 the biomass value range, vertical distribution as well as species composition was comparable to 1997. The analysis of samples from December and March has shown that the biomass in the surface layer under the ice is comparable with that found in the same depth during the ice-free period. The highest values were recorded from May to the end of June. In

Table 1. – List of phytoplankton taxa found in preserved samples from Bohemian Forest lakes (x – present, xx – important component of total biomass).

	SPECIES	Černé L.	Čertovo L.	Plešné L.	Prášilské L.
Cyanophyceae	*Pseudanabaena* sp.	x	x	xx	x
	Limnothrix sp.	x	x	xx	x
Dinophyceae	*Peridinium umbonatum* Stein	xx	xx	xx	xx
	Gymnodinium uberrimum (Allman) Kofoid et Sweezy	xx	xx	x	xx
	Katodinium bohemicum (Fott) Litvinenko	x	x	x	x
	Katodinium planum (Fott) Loeblich III	x	–	x	–
	Gymnodinium sp.	x	x	x	x
Cryptophyceae	*Cryptomonas erosa* Ehrenberg	x	x	x	xx
	Cryptomonas marssonii Skuja	–	x	x	x
	Cryptomonas gracilis Skuja	–	x	x	x
Chrysophyceae	*Dinobryon pediforme* (Lemmermann) Steinecke *Dinobryon* sp.	xx	xx	x	xx
	Bitrichia ollula (Fott) Bourrelly	x	x	x	x
	Chromulina sp.	x	x	x	x
	Ochromonas sp. (large)	x	x	x	x
	Ochromonas sp. (small)	–	x	x	x
	Synura echinulata Korschikov	x	x	x	x
	Mallomonas sp.	x	x	x	x
Xanthophyceae	*Isthmochloron trispinatum* (W. et G. S. West) Skuja	x	x	x	x
Chlorophyta	*Chlamydomonas* sp.	x	x	x	x
	Chlorogonium fusiforme Matwienko	x	x	x	x
	Chloromonas angustissima (Ettl) Gerl. et Ettl	x	x	x	x
	Carteria multifilis (Fres.) Dill. *Carteria radiosa* Korschikov	x	x	x	x
	Monoraphidium cf. *dybowskii* (Wołosz.) Hind. et Kom.-Legn.	x	x	xx	x
	Koliella corcontica Hind.	x	x	x	x
	Tetraedron minimum (A. Br.) Hansg.	x	x	x	x

August the biomass declined sharply and it was not restored to previous level till October (Fig. 2).

Plešné Lake

In 1997 total biomass in particular depths varied within 0.46 – 3.82 $mm^3.l^{-1}$ through the season (Fig. 1), with the exception of 3m in May, where the biomass reached 7.74 $mm^3.l^{-1}$, caused by the development of *Peridinium umbonatum*. The biomass values were quite similar through the column with sharp decrease above the bottom. Maximum lied in 3, 6 and 9 m through the season, respectively. The most of the biomass (51 – 81 %) was formed by

green alga *Monoraphidium* cf. *dybowskii* and (8 – 20 %) by cyanobacteria *Pseudanabaena* sp. and *Limnothrix* sp. *Monoraphidium* cf. *dybowskii* was not yet observed in Bohemian Forest lakes. Two green filamentous algae of the shape similar to *M.* cf. *dybowskii* (*Koliella corcontica* and *Raphidonema nivalis*) are present in the lakes but we were not able to distinguish between the two filamentous algae in preserved samples.

In 1998 the range of biomass values, vertical distribution and species composition of phytoplankton community were similar as in 1997. The only exception was the low abundance of *Monoraphidium cf. dybowskii* in March, which was replaced by a small chrysomonad *Chromulina* sp. During the study period in 1998, we observed two maxima of biomass in the depth of 0.5 m, the first one in July and the second one, more prononced, in October (Fig. 2).

Prášilské Lake

In 1997 total biomass values and species composition were different in all 3 sampling dates (Fig. 1). In May the biomass was between 0.19–1.82 $mm^3.l^{-1}$ with the maximum in 1 m. It consisted mostly of *Peridinium umbonatum* (58 – 95 %). In July, the total biomass decreased to 10 % of May values (0.05 – 0.17 $mm^3.l^{-1}$). The epilimnetic maximum was created mostly by *Chrysophyceae* at surface and by *Gymnodinium uberrimum* at 2 – 4m. Hypolimnion was dominated by *Cryptophyceae*, especially *Cryptomonas erosa*, which created second maximum of total biomass above bottom. *P. umbonatum* almost disappeared. In October, new increase of total biomass was observed in epilimnion (0.49 – 0.54 $mm^3.l^{-1}$) , made by *Gymnodinium uberrimum* (91 – 93 %). In hypolimnion, the total biomass reached values within 0.04 – 0.08 $mm^3.l^{-1}$ only, because of the low abundance of *Gymnodinium uberrimum* (2.3 – 0.4 $cells.ml^{-1}$). Nevertheless, this alga and *Cryptomonas erosa* dominated the total biomass.

In 1998, the phytoplankton of Prášilské Lake was dominated by *Gymnodinium uberrimum* during the whole study period. From May to July, *Dinobryon* spp. were also important, especially in terms of abundance. After its sharp decline observed in August, the prevalence of *Gymnodinium uberrimum* was still more pronounced. The total biomass in the depth of 0.5 m was relatively constant with values that did not exceed 1 $mm^3.l^{-1}$ (Fig. 2).

Discussion

The phytoplankton of acidified lakes is characterized by low number of species (Almer & al. 1978). In strongly acidified lakes of Swedish West coast area about twenty species occurred in August compared to about fifty species in lakes at pH values above 6 (Hörnström & al. 1985). During our study of Bohemian Forest lakes, we found about thirty species, but occurrence of some of them was limited to a particular lake or season.

The majority of species are flagellates. Only in Plešné lake, non–motile forms predominate. High proportion of flagellates is frequently observed in small forest lakes. This phenomenon is primarily determined by the need to minimize sinking and to regulate vertical position in order to maximize the efficiency of light utilization (Jones 1991).

As regards Černé and Čertovo Lakes, our results show similar species composition and total biomass values of phytoplankton. But there is obvious difference in vertical distribution (Fig. 1, 2). Both lakes are oligotrophic (Vrba & al. 1996), Čertovo Lake is more acid (pH 4.4 – 4.6) than Lake Černé (4.7 – 4.8). The hypolimnetic maxima in Černé Lake can be explained by Secchi-depths, which were twice as high (10 m in May, 8 m in July and 12 m in October 1997) as in Čertovo Lake (5.5 m in May, 4 m in July and 6 m in October 1997). The higher turbidity in Čertovo Lake was caused by the presence of particulate matter. The dominance of two dinophycean species – *Peridinium umbonatum* and *Gymnodinium uberri-*

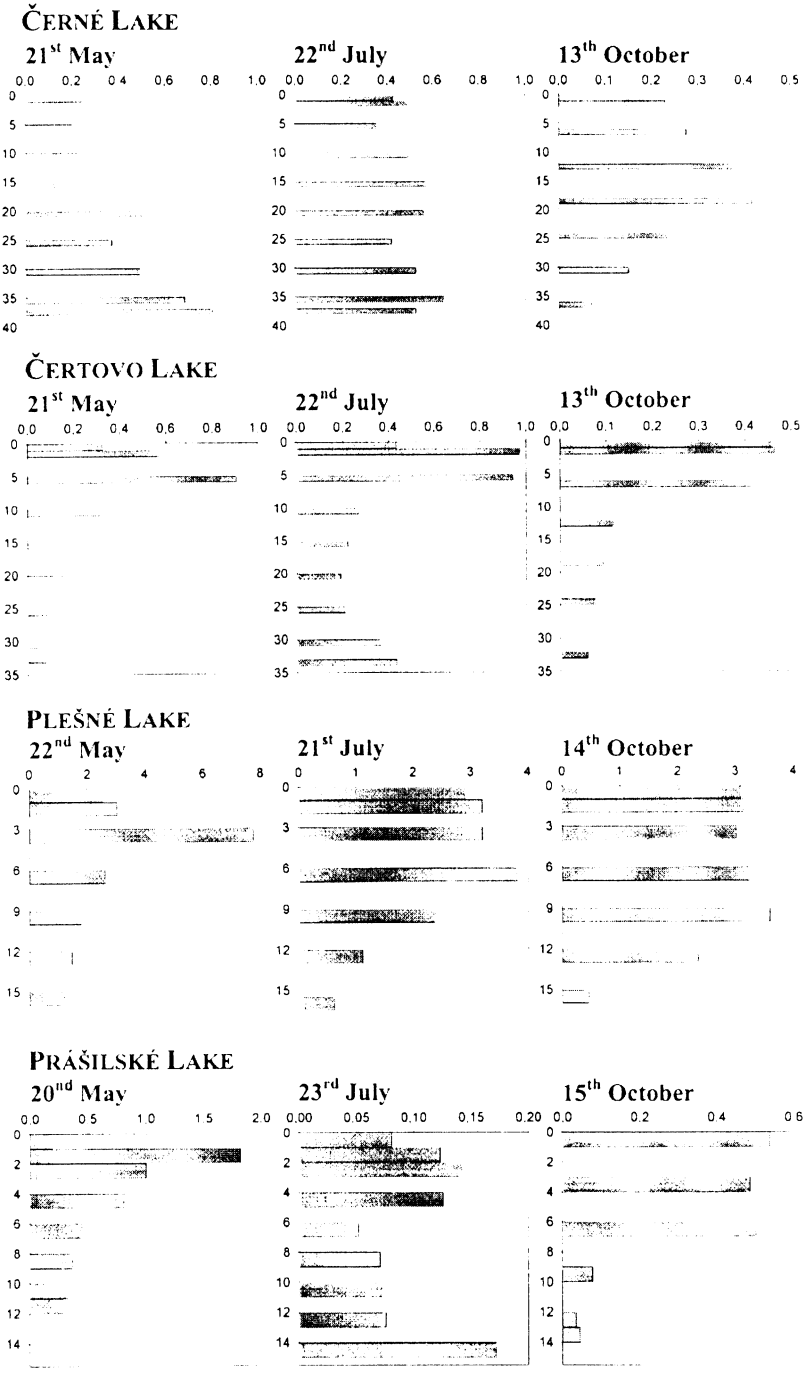

Fig. 1. – Vertical distribution of phytoplankton biomass in 1997 (x – axis : biomass [$mm^3.l^{-1}$], y – axis: depth [m]).

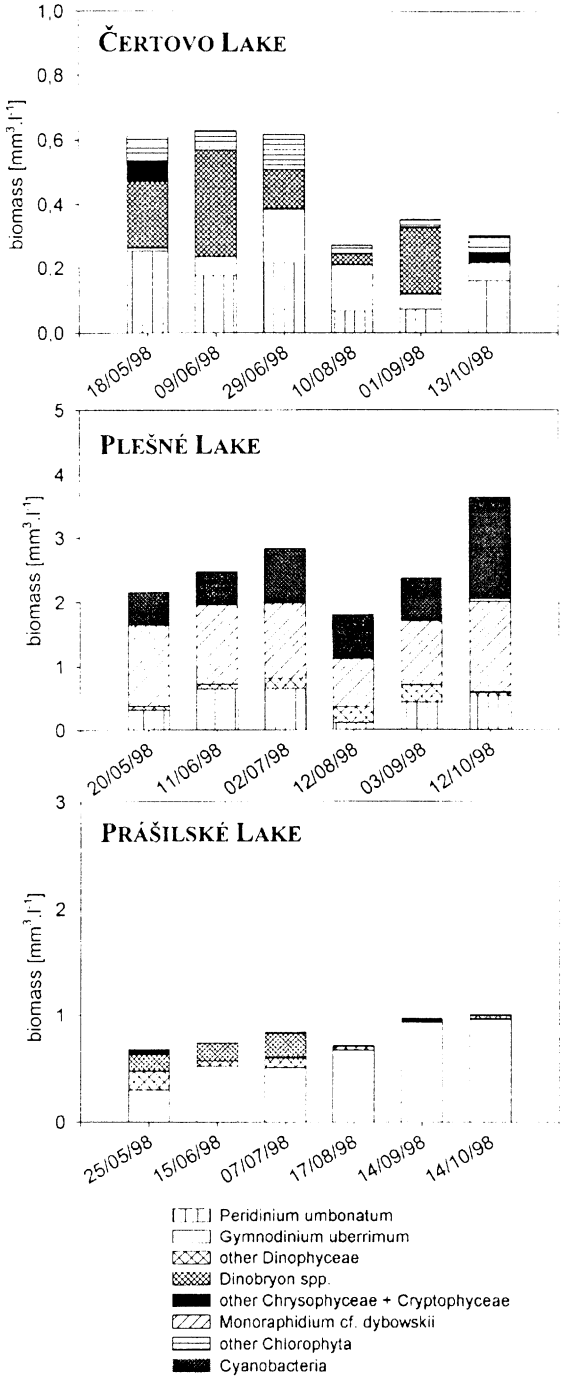

Fig. 2. – Seasonal changes of phytoplankton biovolume in Bohemian Forest lakes in 1998 (samples from 0,5 m).

mum, such as the high abundance of chrysophycean flagellates corresponds with the situation in other acid lakes (ALMER & al. 1978, ROSÉN 1981). Because of their high cell volume, dinoflagellates may dominate the total biomass even in low abundance.

The great fluctuation of phytoplankton biomass in Prášilské Lake through the study period in 1997 could be explained by the occurrence of *Daphnia longispina*. The increase of its abundance in July (up to 41 ind.l^{-1} in 6 m in comparison to 0-0.2 ind.l^{-1} in May, KOHOUT pers. comm.) was connected with the sharp decrease of phytoplankton biomass. *Peridinium umbonatum*, the dominant species in May, almost disappeared, *Gymnodinium uberrimum* and *Cryptomonas* spp. constituted the majority of biomass. In October, the increase of biomass was caused by development of *Gymnodinium uberrimum*. We suppose this species is not grazed by *Daphnia longispina* because of its size (over 35 μm) which is at the upper limit for particles consumed by herbivorous zooplankton (WATSON & MCCAULEY 1988). The abundance of *Daphnia longispina* decreased to 50 % of July values. In 1998, the phytoplankton biomass fluctuation was much lower than in the previous year. The grazing-resistant *Gymnodinium uberrimum* dominated biomass through the whole study period. The abundance of *Daphnia longispina* never exceeded the values from October 1997.

The phytoplankton of Plešné Lake differed markedly from that of the other lakes. Relatively high values of total biomass could be explained by increased input of phosphorus, which is mainly in form of soluble reactive phosphorus (SRP) (KOPÁČEK & HEJZLAR 1998). However, the concentrations of SRP in the lake water were under detection limit during the most of the study period in 1998 (KOPÁČEK, pers. comm.). The availability of phosphorus is strongly affected by precipitation of aluminium in the lake (KOPÁČEK & al. 2000). Consequently, the phytoplankton in Plešné Lake is also P- limited. The species structure of Plešné Lake phytoplankton is singular, being dominated by three components: *Monoraphidium* cf. *dybowskii*, *Peridinium umbonatum* and filamentous Cyanobacteria. The common presence of *Peridinium umbonatum* in acid lakes was mentioned above. The dominance of *Monoraphidium dybowskii* and Cyanobacteria is not so frequently observed in acidified waters. Some Swedish lakes with pH 6.0–6.5 are characterized by the blue-green alga *Merismopedia tenuissima* accompanied with *Monoraphidium dybowskii* and *Monoraphidium griffithii* (ROSÉN 1981, BLOMQUIST & al. 1993). *Monoraphidium dybowskii* is also known from acid lakes (pH<5.3) at especially rich nutrient supply (HÖRNSTRÖM & al. 1985). Its importance in acid waters is explained by the fact that the growth of this taxa is not affected by high concentration of toxic aluminium (HÖRNSTRÖM & al. 1995). As far as we know the dominance of *Pseudanabaena* sp. and *Limnothrix* sp. was never recorded in acidified lakes.

When interpreting the results of phytoplankton research we should be very cautious. The limitation caused by chosen sampling strategy should not be neglected. Our results from years 1997 and 1998 illustrate that obtained information depends on the density of sampling depths and the frequency of sampling dates through the year.

As regards the vertical distribution of algae, the impossibility of interpolating obtained results through the water-column should be kept on mind. Individual species may create very sharp maxima of their abundance, e.g. *Peridinium umbonatum* in Plešné Lake in May 1997. In 3 m, its abundance reached 1000 cells.ml^{-1}, while in 1 m and 6 m it was only 65 and 92 cells.ml^{-1}. It means that it is easy to miss the real maximum even if sampling the whole column in 5 m interval. Our information about total phytoplankton biomass is distorted in that case.

When sampling a few times through the year only, some species and their maximal increase may not be noticed. *Katodinium planum* was very important species in Plešné Lake in late summer 1998, while in 1997, the maximal abundance only 4.3 cells.ml^{-1} was found probably due to different sampling strategy.

Results obtained in one year can not be expected to be generally valid. They show just basic picture about the lake. Details of species composition, total biomass and vertical distribution are quite changeable through the years, being dependent on climatic factors.

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