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The diel pattern of changes in vertical distribution of phytoplankton in two eutrophic stratified lakes*

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Abstract – The study on vertical fluctuation of the phytoplankton community in relation to some physical and chemical properties of the water was carried out in two lakes of the Wielkopolska region on 25 July 1995 at 4-hour intervals. In Lake Kobyleckie (surface area 65.7 ha, max. depth 14.3 m) the most frequent species with large biomass were *Monoraphidium arcuatum* (Korš.) Hindák, *Tetraedron minimum* (A. Br.) Hansg., *Cyclotella ocellata* Pantocsek, *Peridinium inconspicuum* Lemm., while in Lake Durowskie (143.7 ha, 14.6 m) *Cyclotella radiosa* (Grun.) Lemm., *T. minimum*, *Sphaerocystis planctonica* (Korš.) Bourr., and *Oocystis lacustris* Chod. The presence of dense populations of these species was connected with a range of variations of temperature and concentration of oxygen and nutrient compounds.

Key words: diel-vertical distribution, phytoplankton, eutrophic lakes.

1. Introduction

The plankton algae by their physiological abilities react very rapidly to the changes in environmental conditions. The structure of phytoplankton in each lake reflects many physico-chemical episodes of water, as just the value of the biomass of planktonic algae changes in succeeding hours of the diel cycle. The state of research on this subject (Reynolds 1984, Lampert and Sommer 1996) allows the claim that the water temperature (Barbosa et al. 1989), light intensity (Wernicke and Nicklisch 1986), and concentrations of nutrients (Pick et al. 1984, Pańczakowa and Szyszka 1983) are the more important environmental conditions which create vertical distribution of the plankton algae. During the summer stratification, when the physical conditions are relatively stable, chemical factors and the activity of the planktonic organisms are of more importance in the species composition of the phytoplankton (Reynolds 1984, 1989, Sommer 1989).

The aim of the investigation was to determine the diel changes in vertical distribution of planktonic algae in the stratified water column of eutrophic lakes.

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2. Study area, material, and methods

This study was based on measurements and water samples from two eutrophic lakes, Lake Kobyleckie and Lake Durowskie (Table I) during the stratification period on 25 July 1995. These lakes are situated in the northern part of the Wielkopolska region, western Poland, near the town of Wągrowiec. Data on the physical and chemical characters of the water and of some aspects of the phytoplankton seasonal succession have been published (Messyasz 1995, 1997*a*, 1997*b*). The sampling stations were located in the deepest parts of the lakes.

Table I. Basic morphometric data of the studied lakes.

Parameters		Lake Kobyleckie 52°50' N, 17°14' E	Lake Durowskie 52°49' N, 17°12' E
Altitude (m)		78.8	78.1
Surface area (ha)		65.7	143.7
Max. length (km)		2.02	4.34
Max. width (km)		0.52	0.54
Depth (m)	Max.	14.3	14.6
	Mean	7.4	7.9
Shoreline (km)		4.85	11.02

Water samples were taken at a vertical profile at depth intervals of 1 m from the surface to a depth of 12 m. For assessment the diel changes in the phytoplankton distribution, water samples were taken at 4-hour intervals. In consideration of the weather conditions (sudden storm) water samples were not taken from Lake Kobyleckie at 1:00. In the samples the water temperature, pH, concentration of dissolved oxygen and of nutrient compounds were measured. Chlorophyll *a* concentration (corrected for phaeopigments) was determined fluorometrically according to the procedures described by Strickland and Parsons (1972). Quantitative and qualitative phytoplankton samples were fixed and preserved with concentrated Lugol solution. Phytoplankton biovolume was estimated from cell numbers and specific volumes.

3. Results

The patterns of temperature in the vertical profile in the two studied lakes were similar to those of dissolved oxygen (Figs 1 and 2). The changes in chlorophyll *a* concentration were parallel to those concentrations of oxygen in the epilimnion. Distinct differences were observed in the deeper layer. The hypolimnion of Lakes Kobyleckie and Durowskie was characterized by highly anaerobic conditions and high concentrations of ammonium nitrogen. In Lake Kobyleckie the concentrations of NH_4-N in the epilimnion ranged from 0.10–1.12 mg L^{-1}, while in the hypolimnion they were higher (0.16–8.00 mg L^{-1}). In Lake Durowskie the concentrations NH_4-N ranged from 0.06–0.24 mg L^{-1} in the epilimnion, 0.12–0.60 mg L^{-1} in the metalimnion, and 0.12–4.00 mg L^{-1} in the hypolimnion. The small concentrations of orthophosphate (0.02–0.20 mg L^{-1}) in the bottom layer were directly connected with the anaerobic conditions. The pH ranged from 6.97–9.95 in Lake Kobyleckie and 7.38–9.20 in Lake Durowskie. There were small fluctuations of the water

reaction within 2.5 degrees of pH as a result of buffering by a high concentration of calcium, over 78.5 mg Ca L^{-1}.

In both lakes, chlorophyll a concentration fluctuated mainly in the metalimnion layer with a depth from 4 to 8 m, from 6.16 μg L^{-1} (Lake Kobyleckie) and 11.88 μg L^{-1} (Lake Durowskie) at night to 10.49 μg L^{-1} (Lake Kobyleckie) and 28.6 μg L^{-1} (Lake Durowskie) in the afternoon (Figs 1 and 2). The highest concentration of chlorophyll *a* was observed between 9:00 and 20:00, but the concentration of pigment fell between 12:00 and 13:00. The greatest values of chlorophyll *a* were recorded at the depth range of 4–8 m, 13.29 and 31.24 μg L^{-1} in Lake Kobyleckie and Lake Durowskie, respectively. The decrease in concentration of chlorophyll *a* in the surface layer was connected with its increase in the deeper layers of water, including the bottom one (e.g. at 17:00 to 21:00 in Lake Kobyleckie and from 12:00 to 20:00 in Lake Durowskie).

When analysing the percentage share of algal cells in vertical profile, differences in the concentrations of Cyanoprokaryota, Chlorophyta, Bacillariophyceae, and Dinophyceae in the diel cycle were recorded. In Lake Kobyleckie, the group of Chlorophyta was abundant and equally distributed in the water column with small peaks in the metalimnion. In the evening, however, this group was more abundant in the hypolimnion. The quantity of Dinophyceae, mainly *Peridinium inconspicuum* Lemm., varied (Fig. 3). In the morning hours, these algae were mostly found at 9:00 in the hypolimnion, at 13:00 at a depth of 4 m, and at 21:00 at the depth of 6–7 m. In Lake Durowskie, the percentage of Chlorophyta fluctuated and the total number of algal cells fell from 80% (in the morning) to 60% (at midnight). In the afternoon great numbers of Chlorophyta was observed at a depth of 1–3 m. Chlorophyta contributed up to 50% of the total number of algal cells in the layer from the surface to 7 m.

The changes in the number of Cyanoprokaryota cells in both lakes were mostly connected with fluctuations in the numbers of *Planktothrix agardhii* (Gom.) Anagn. et Kom. and *Limnothrix redekei* (Van Goor) Meffert (Figs 3 and 4). These taxa tended to move in great numbers from the hypolimnion to the metalimnion layer, where they stayed for the whole day. Bacillariophyceae usually contributed more to the hypolimnion, with the highest concentration of cells in the vertical profile at midnight. The tendency to changes in the percentage of the biomass of every phytoplankton group in the total biomass in both lakes was parallel and Chlorophyta distinctly dominated, whilst Bacillariophyceae also strongly contributed. The biomass of *Cyclotella* spp. varied mostly in the morning and evening hours. The mean value of biomass of this genus was close to 0.5 mg L^{-1} and small peaks occurred in the epi-, meta- and hypolimnion layer (Figs 3 and 4).

The highest concentration of the biomass of *Monoraphidium arcuatum* (Korš.) Hindak were noted in the morning and in the evening. The great concentrations of biomass of this species occurred, however, only in Lake Kobyleckie (max. 1.049 mg L^{-1} at depth of 3 m) but in Lake Durowskie they were much smaller (max. 0.181 mg L^{-1} at a depth of 5 m, at 12:00) (Figs 3 and 4). *Tetraëdron minimum* (A. Br.) Hansg. showed a constant value of the concentration of biomass at all the depths in both lakes. The quite high peak of its biomass at a depth of 2 m (0.054 mg L^{-1}) was similar in Lake Kobyleckie in the morning and in Lake Durowskie (0.044 mg L^{-1}) in the afternoon.

Peridinium inconspicuum, owing to its size, causes a high biomass. This species was more abundant in Lake Kobyleckie and formed its maxima throughout the water column in the afternoon (Figs 3 and 4). Its distribution in Lake Durowskie was similar although the concentration was lower. The maximum concentration of

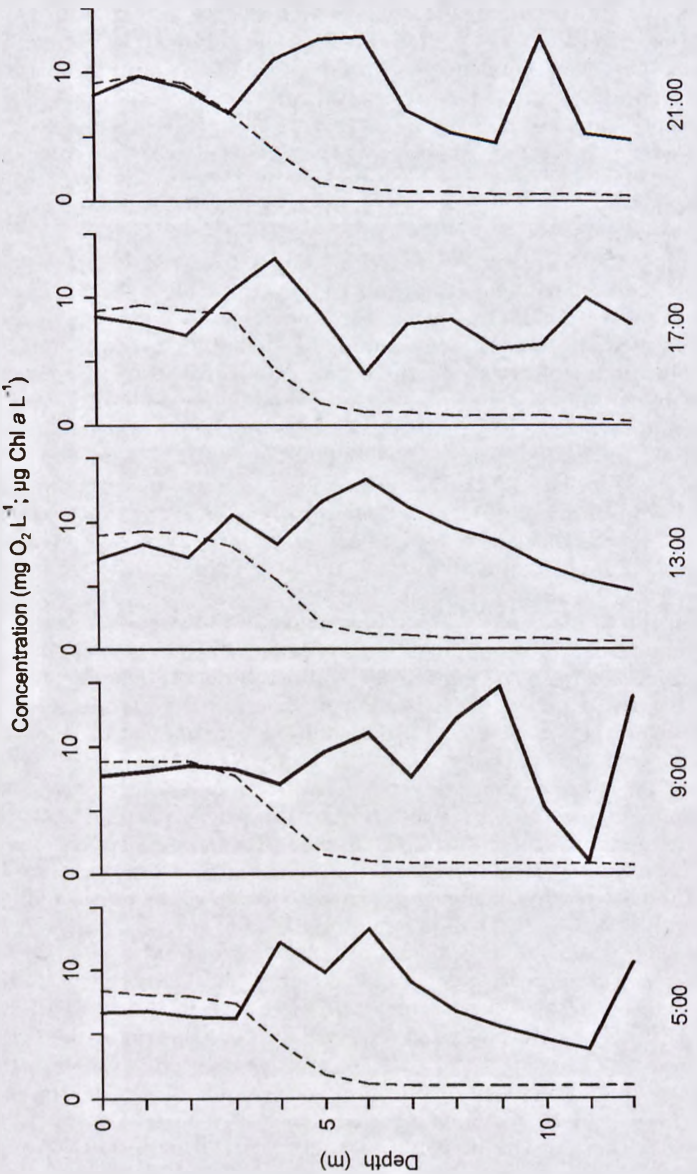


Fig. 1. Diel changes of vertical distribution of concentration of dissolved oxygen (dashed line) and chlorophyll *a* (solid line) in Lake Kobyleckie on 25 July 1995.

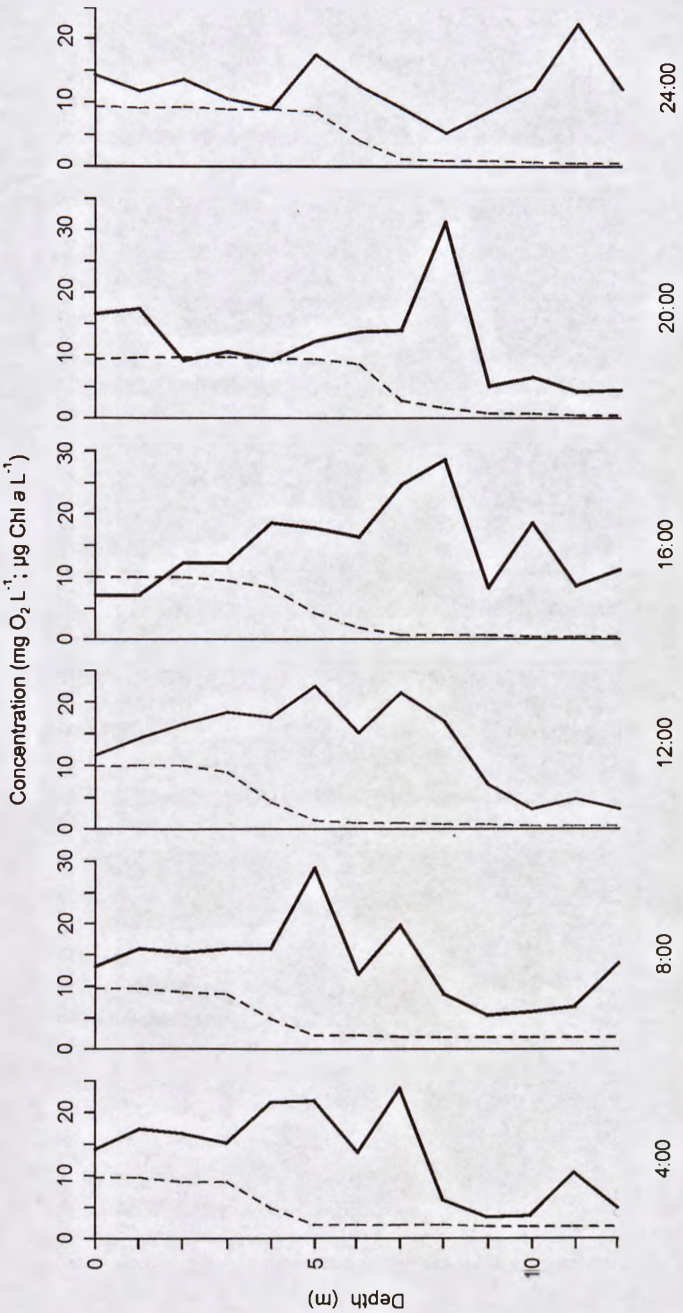


Fig. 2. Diel changes of vertical distribution of concentration of dissolved oxygen (dashed line) and chlorophyll *a* (solid line) in Lake Durowskie on 25 July 1995.

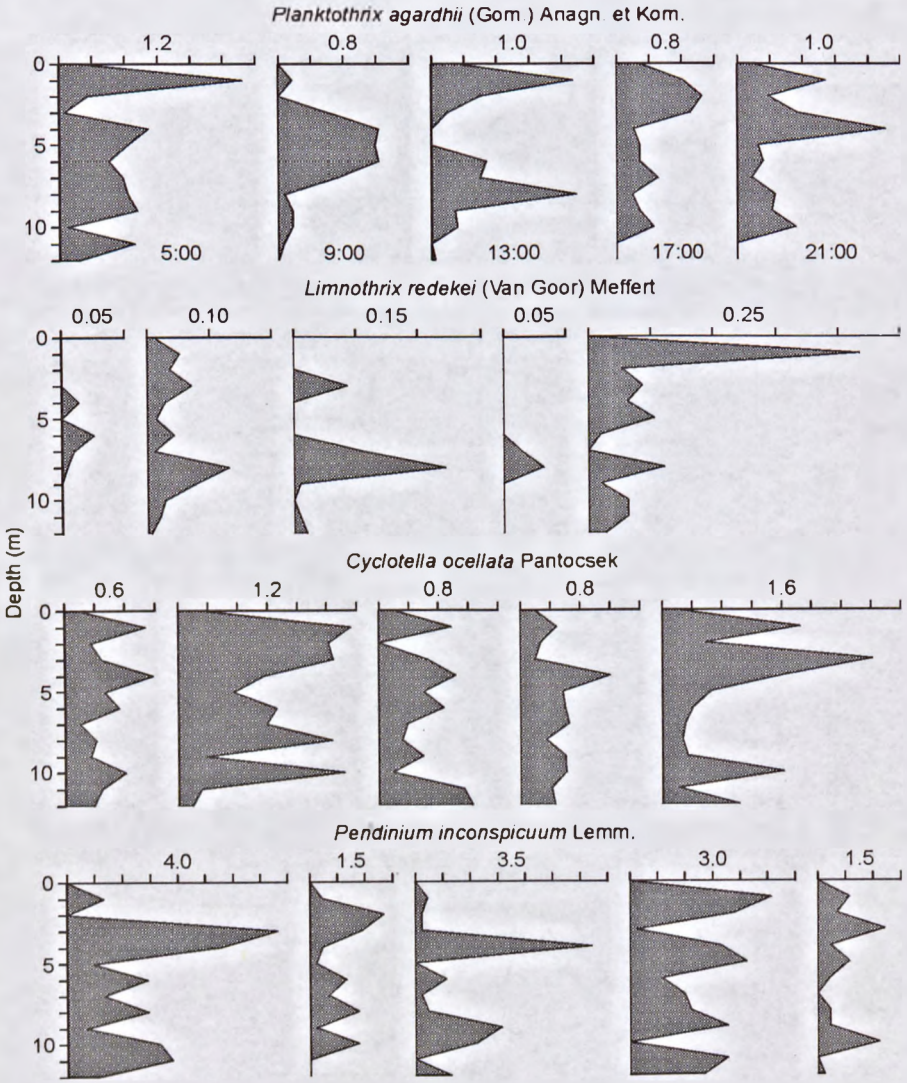
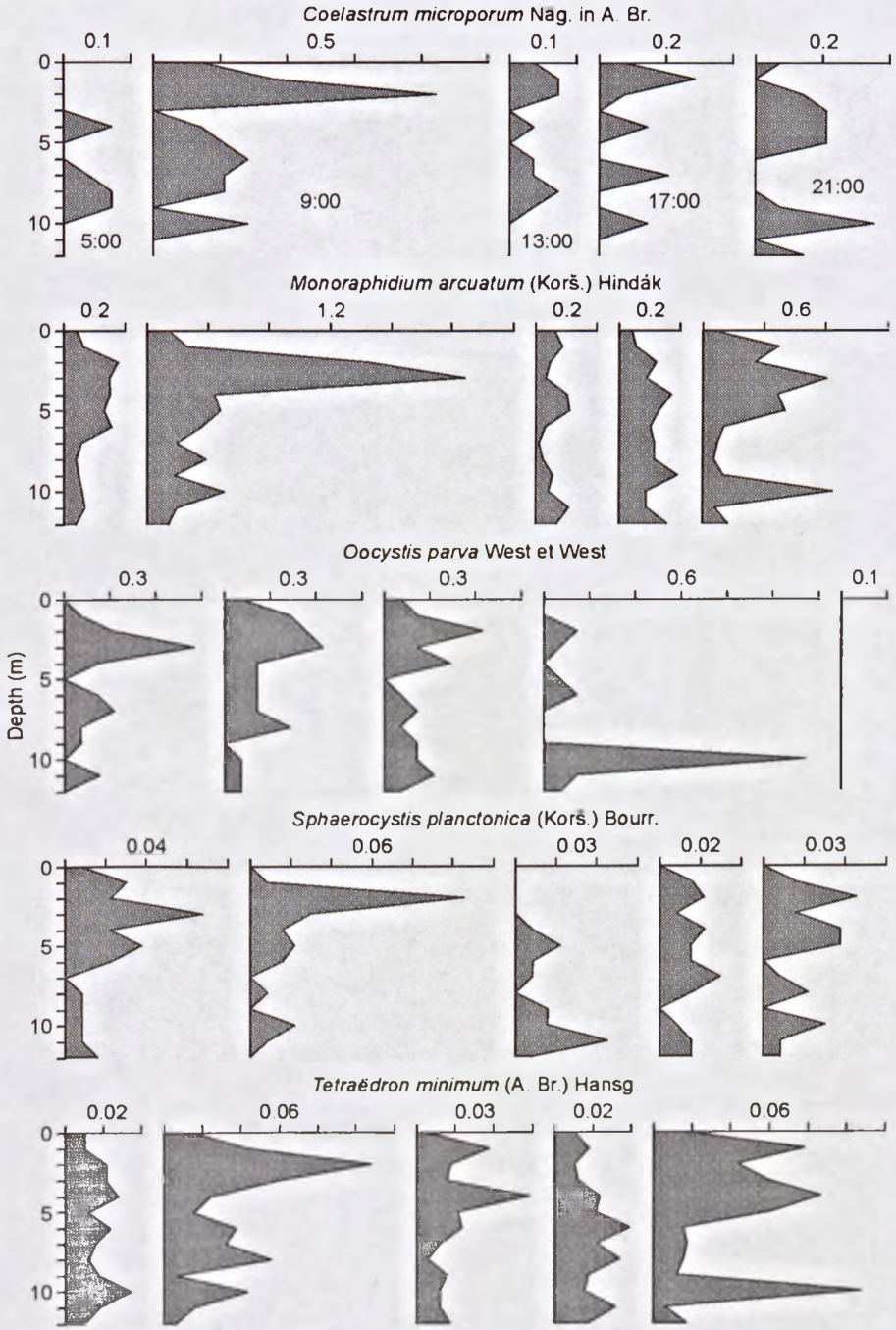


Fig. 3. Diel changes of vertical distribution of selected phytoplankton species in Lake Kobyleckie



on 25 July 1995 (biomass; mg L^{-1}).

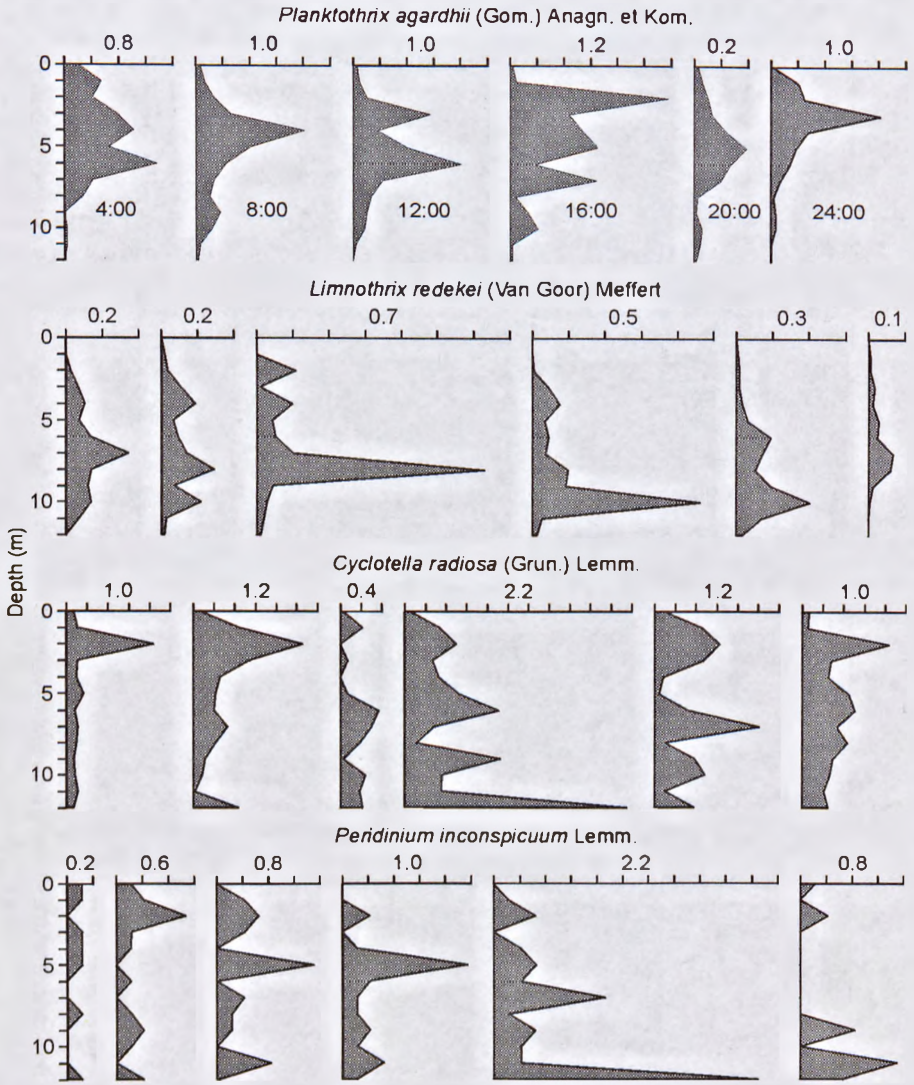
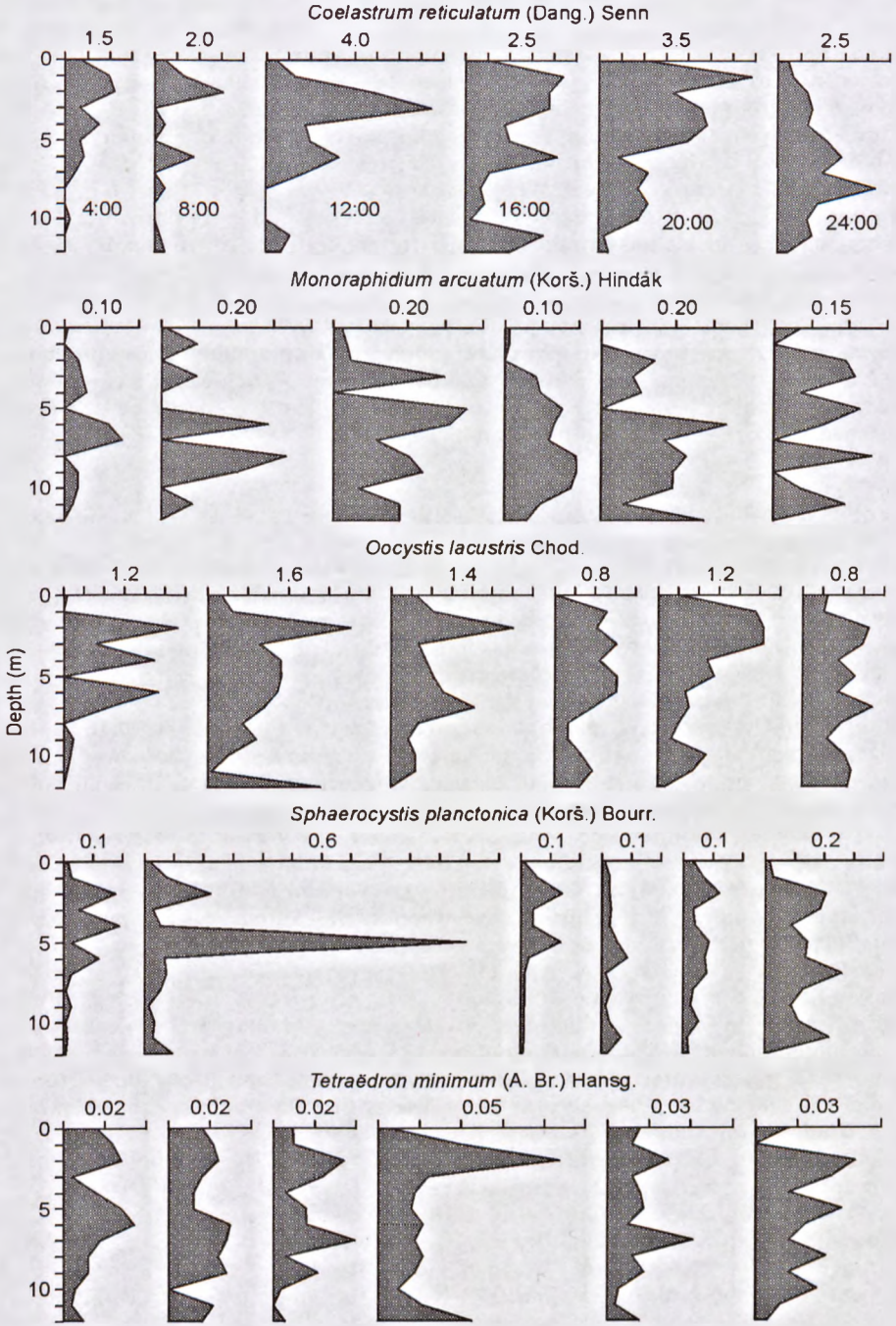


Fig. 4. Diel changes of vertical distribution of selected phytoplankton species in Lake Durowskie



on 25 July 1995 (biomass; mg L^{-1}).

its biomass was 3.808 mg L^{-1} and 2.067 mg L^{-1} in Lakes Kobyleckie and Durowskie, respectively. *Oocystis parva* W. et G.S. West, numerously occurring in Lake Kobyleckie, formed its maxima in the epilimnion (Fig. 3). The high concentration (0.572 mg L^{-1}) at 17:00 at the depth of 10 m is accidental in this lake. The greatest quantity and biomass of *Oocystis lacustris* Chodat in Lake Durowskie occurs in the epilimnion layer and partly in the metalimnion; at 8:00 at the depth of 2 m the greatest biomass of this species (1.424 mg L^{-1}) was observed (Fig. 4). The concentrations of the biomass of *Coelastrum* spp. in the two lakes were similar. This species of Chlorophyta formed maxima in the epilimnion layer. The average values of biomass were 0.035 mg L^{-1} (max. 0.424 mg L^{-1} at 9:00, at the depth of 2 m) in Lake Kobyleckie, and 0.055 mg L^{-1} (max. 3.447 mg L^{-1} at 20:00, at the depth of 1 m) in Lake Durowskie (Figs 3 and 4).

The diel-vertical mutability of Cyanoprokaryota, *Planktothrix agardhii* and *Limnothrix redekei* in the two lakes was similar. Maximum abundance and biomass of *L. redekei* were noted in the meta- and hypolimnion. *P. agardhii* occurred mainly in the epilimnion (and partly in the metalimnion). The population of this species reached a lower value in the hypolimnion.

4. Discussion

The collected results complete the data indicating differences between the investigated lakes despite the similarities in water mixing. The processes developing within deep, stratified, ecosystems, particularly nitrification and denitrification, affect the vertical distribution of nutrient concentration. As for the mineral form of nitrate and phosphate, no changes in its concentration with passing time were noted, although the concentrations of these nutrients were different in the successive hours. The pattern of temperature in the vertical profile changed together with oxygenation of the water. The investigation showed a stable thermocline, low concentrations of oxygen in the hypolimnion with simultaneous high concentrations of ammonium nitrogen in both lakes.

The values obtained for conductivity, concentration of nitrate, and nitrite nitrogen practically did not differ in the diel cycle. Paluch et al. (1975) pointed out that the concentration of nitrate nitrogen in the vertical profile of the water column in summer is higher in the surface layer than in the bottom one. During the study this dependence was not observed in Lakes Kobyleckie and Durowskie. Lake Kobyleckie is distinctly reacher in nitrogen compounds in the hypolimnion than Lake Durowskie. Both the analysed lakes are eutrophic, with a summer stratification developed in mid-May. A stable stratification with thickness of the metalimnion about 3–4 m occurring at a depth of 5 to 8–9 m was observed in both lakes. The greatest fluctuations of the analysed factors were noted during the day when the phenomenon of a constant decrease in dissolved oxygen concentration in the whole water column was observed. This phenomenon is not associated with a diel change of concentration of nutrients. The strong fluctuations in the concentration of chlorophyll *a* also occurred.

Despite the high similarity of the two studied sampling stations great differences in the composition of phytoplankton were recorded. In Lake Kobyleckie, throughout the water column at each metre during the 24-hours there mainly appeared: *Monoraphidium arcuatum*, *Tetraëdron minimum*, *Cyclotella ocellata* Pantocsek, and *Peridinium inconspicuum*, while in Lake Durowskie: *Cyclotella radiosa* (Grun.) Lemm., *Tetraëdron minimum*, *Sphaerocystis planctonica* (Korš.)

Bourr., *Oocystis lacustris*. Their biomass constituted the bulk of the total biomass of phytoplankton. The diel fluctuations of the biomass of phytoplankton depended mainly on the time of day and weather conditions. In both lakes, chlorophyll *a* formed maxima in the metalimnion (4–8 m) and coincided with abundance maxima of *Planktothrix agardhii* and *Limnothrix redekei*. The results concerning the distribution of phytoplankton biomass in the vertical profile showed that the number of cells in both taxa was lowest in the bottom layer. The highest values of biomass occurred in the epi- and metalimnion. Most species of phytoplankton usually demonstrated a stable value of the biomass in the successive hours of diel cycle.

The composition and biomass of phytoplankton were similar in the vertical profile of the water column in the diel cycle. This phenomenon could be associated with the sedimentation mechanism and migration of phytoplankton taxa. Gervais (1991) suggests that sedimentation of live diatoms, e.g. *Cyclotella* spp., may cause rapid movements of concentration of chlorophyll *a* and biomass from the epilimnion to the hypolimnion layer. The high concentration of chlorophyll *a* in deeper layers in Lakes Kobyleckie and Durowskie occurred in the afternoon. It is possible that this phenomenon is connected with the ability of planktonic algae to migrate to gain the best environmental conditions (Gervais 1991, Vasconcelos 1991), such as *Peridinium* spp. and *Cryptomonas* spp. In Lake Durowskie the population of *Peridinium inconspicuum* was numerous in the hypolimnion but not in the epilimnion layer. The value of biomass of this taxon was higher in the hypolimnion, especially at 20:00 The vertical migration of algae depends considerably on the physiological abilities of individuals. It is associated with individual photosynthetic intensity of species. Therefore, frequent studies on qualitative and quantitative changes in the distribution of plankton algae in the diel cycle permit recognition of species present both in algal assemblages in the epilimnion and hypolimnion layers of stratified lakes.

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