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Diel microdistribution of physical and chemical parameters within the dense *Chara* bed and their impact on zooplankton

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Abstract: Research on the diurnal distribution of physical and chemical parameters within a single macrophyte bed was carried out on the shallow Wielkowiejskie Lake (Poland). A non-parametric statistical analysis was used to compare the water quality features in different parts of a *Chara hispida* habitat including the middle, both edge (vertical and horizontal) parts of a macrophyte plant, and the open water next to- and above the stonewort stand.

The obtained results showed a differentiation in the physical-chemical parameters of the environmental conditions within the *Chara hispida* stand. The greatest variability was found for dissolved oxygen. Its lowest concentrations were noted in the central part of the macrophyte stand, irrespective of the sampling time.

The zooplankton communities within the examined *Chara* bed were strongly influenced by the concentration of dissolved oxygen. It was also found that two main components of zooplankton communities (rotifers and cladocerans) had a similar trend in their spatial and diurnal distribution within the stonewort stand.

Key words: habitat characteristics; macrophytes; *Chara hispida*; nutrients; shallow lake; spatial distribution; oxygen; temperature

Introduction

Macrophyte stands may differ in their physical parameters with regard to cover percentage, density and biomass (Canfield et al. 1984; Scheffer 2001). These macrophyte characteristics change with different spatial structure, length, width and surface structure of the stems. The biomass of particular macrophyte taxa depends on their ability to grow to the water surface and in the case of the *Chara* bed there is usually a layer of free water above the plant stand. This allows the variation in the environmental factors of both vertical and horizontal gradients to be examined.

The morphology of the plant habitat indirectly affects the structure of the biotic assemblages as well as the physical and chemical parameters within the macrophyte substratum. It has already been proved that there is a great variation in habitat characteristics between particular macrophyte species, especially considering various ecological groups of aquatic plants (Kuczyńska-Kippen & Nagengast 2003; Kuczyńska-Kippen et al. 2005). There is also some data referring to the impact of the spatial distribution of various macrophyte species on different organisms, including phytoplankton (Kuczyńska-Kippen et al. 2005), zooplankton (Kuczyńska-Kippen & Nagengast 2003; Irvine et al. 1990), macrocrustacea (Dvorak & Best 1982), gastropods (Lodge 1985), snails (Pip & Steward 1976; Sheldon 1987) or fish (Chick & McIvor 1994). It is known that abiotic factors vary within the littoral zone of lakes and may change in the diurnal cycle (Burks et al. 2002). However, there is still little information concerning the differentiation of environmental factors, which are often essential for growth and development of organisms within a single macrophyte bed. Furthermore, some authors (Carpenter & Lodge 1986; Frodge et al. 1990) state that physical and chemical factors may change within the 24-h cycle in the lake, however, no literature data is available on such changeability within habitats adhering to each other.

Physical and chemical factors may directly affect an animal's life history or influence it indirectly, e.g. through the primary producers, which rely on the nitrogen and phosphorus concentration in the surrounding environment (Sheffer 2001; Lampert & Sommer 2001).

Apart from the problem associated with variation of physical and chemical parameters within the aquatic habitat there is also another presently discussed topic connected with chemical substances released by macrophytes (Burns & Dods 1999; Gross et al. 2003), which can inhibit phytoplankton growth (Wium-Andersen et al. 1982; Nakai et al. 1999) or zooplankton development (Hasler & Jones 1949; Dorgelo & Heycop 1985). Aquatic plants, competing with epiphyton for light and carbon, have developed an adaptive strategy called allelopathy (Gopal & Goel 1993). Stands of stoneworts in particular have been subject to sets of experiments on allelopathic activity (Kleiven & Szczepańska 1988), as it has been observed that *Chara* beds were often surrounded by remarkably clear water compared to other vegetated stands (Blindow 1987).

Thus, the hypothesis was stated that physical and

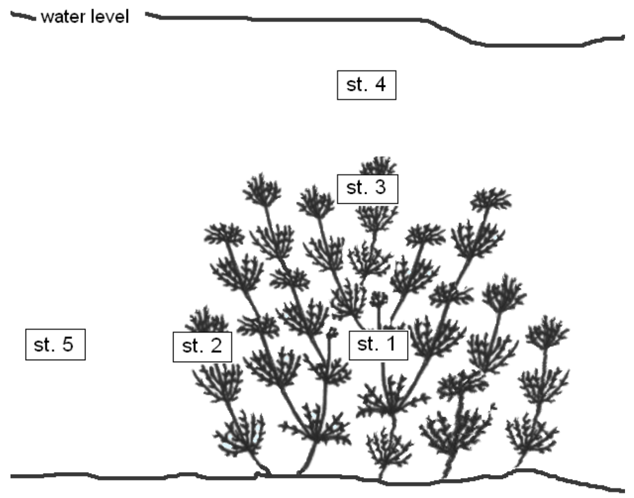


Fig. 1. The sampling stations within the *Chara* stand and the adjacent open water zones (st. 1 – middle; st. 2 – the edge; st. 3 – upper; st. 4 – above; st. 5 – water).

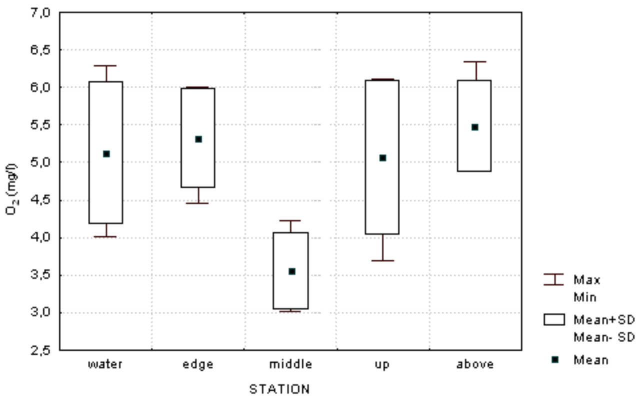


Fig. 2. Oxygen concentration within Chara stand and the neighbouring open water zones ($n = 12$).

chemical parameters would differ within one single macrophyte bed with the emphasis on its central and ecotone parts. Detailed analysis should reveal whether the environmental conditions change also in regard to time, considering the 24-h cycle. There will also be an attempt undertaken towards answering the question of which abiotic factors have the strongest influence on the distribution of biotic communities represented by zooplankton.

Material and methods

Lake Wielkowiejskie, which is situated in the Wielkopolski National Park, is a typical shallow macrophyte-dominated lake with an area of 13.3 ha, maximum depth of 2.8 m and a mean depth of 1.4 m (Jańczak et al. 1996). Peat bogs adjoin the northern part of the lake. The lake is surrounded by a belt of *Typha angustifolia* L. and *Phragmites australis* (Cav.) Steud. Nearly the whole basin is covered by submerged macrophytes, usually creating single species beds of *Chara tomentosa* L., *Ch. hispida* L., *Myriophyllum verticillatum* L., *Nitellopsis obtusa* (Desvaux) Groves or *Utricularia vulgaris* L. Additionally, stands of *Nymphaea alba* L. cover around 20% of the water surface along the rushes.

According to the Carlson index Wielkowiejskie Lake was estimated as a mesotrophic reservoir (Messyasz 2001). The dominating fish species were: roach (*Rutilus rutilus* L.), bream (*Abramis brama* L.) and perch (*Perca fluviatilis* L.) (Mastyński et al. 1998). A numerous population of pike (*Esox lucius* L.) has also been introduced there.

Research on the spatial distribution of physical and chemical factors within a single *Chara* bed was carried out in August 2004. Water samples were taken four times within a 24-h period, including dusk, night, morning and day time, using a sucking pump supplied by hoses adapted to bring up water from a particular sampling station into a calibrated vessel (ø 5 mm).

Samples were collected from five sites along horizontal and vertical profiles extending from the middle part of the stonewort bed up to the open water near the macrophyte bed: from the central part of the *Chara* bed (st. 1), through the border part of the macrophyte bed in the horizontal (st. 2) and vertical profile (st. 3), to the zone of water immediately above the vegetation (st. 4) and the open water adhering vertically to the *Chara* stand (st. 5) (Fig. 1).

The plant material was cut from a known area (0.25 × 0.25 m) and depth (the entire water column occupied by macrophytes). The length of macrophyte stems, which should be understood as the plant density, was estimated at particular station.

Physical parameters such as temperature, oxygen concentration, conductivity and pH were measured using the multiparameter field analyzer YSI 650MDS. Chlorophyll *a* concentration (corrected for pheopigments) was determined fluorometrically according to the procedures described by Strickland & Parsons (1972). The concentrations of chlorophyll 'a' are given as active photosynthetic pigments. The chemical analysis was conducted according to Standard Methods for Examination of Water and Wastwater (1992).

The Mann-Whitney U-test was used in order to determine the effect of site within the *Chara* habitat on the concentrations of particular physical and chemical factors ($N = 20$).

Results and discussion

Our results demonstrated that the spatial distribution of environmental factors within a single bed created by a dense *Chara hispida* did not represent a uniform model; even though no significant differences in plant stem densities ($p > 0.05$) were found concerning the middle and edge part of the examined plant stand. Based on the data presented in Table 1, differentiation in physical-chemical parameters of the environmental conditions within the stonewort stand was observed. The greatest variability was recorded for dissolved oxygen. The lowest concentrations of this element were found in the central part of the macrophyte stand, irrespective of the sampling time (Fig. 2). The mean content of the oxygen in water in the middle part of the stonewort bed was of over 30% lower compared to the remaining examined stations. There may be two reasons explaining this phenomenon. Firstly, the compact and dense structure of the vegetated stand may impede the free flow of water within the macrophyte bed and the decomposition of organic matter depletes the oxygen

Table 1. Mean values and standard deviation (SD) of physico-chemical parameters of water sampled in *Chara* stand.

			edge		middle		water		above		up	
		n	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
temp	(°C)	12	**23.4**	0.85	**23.2**	0.78	**23.7**	1.06	**23.7**	1.26	**23.6**	1.03
O_2	(mg O/L)	12	**5.24**	0.58	**3.57**	0.48	**5.12**	0.95	**5.51**	0.59	**5.1**	1.02
el. cond.	(μSm/cm)	12	**577.5**	3.9	**580.5**	2.6	**576.5**	5.1	**578.8**	2.2	**578.3**	3.9
pH		12	**7.31**	0.84	**7.28**	0.47	**7.44**	0.87	**7.16**	0.76	**7.16**	0.81
NH_4	(mg N/L)	12	**0.90**	0.15	**0.80**	0.13	**0.79**	0.27	**0.83**	0.12	**0.77**	0.10
NO_2	(mg N/L)	12	**0.002**	0.001	**0.0013**	0.001	**0.001**	0.001	**0.001**	0	**0.001**	0.001
NO_3	(mg N/L)	12	**0.11**	0.08	**0.11**	0.11	**0.12**	0.06	**0.14**	0.03	**0.10**	0.05
PO_4	(mg P/L)	12	**0.013**	0.012	**0.009**	0.005	**0.037**	0.052	**0.010**	0.003	**0.012**	0.003
P tot.	(mg P/L)	12	**0.05**	0.030	**0.032**	0.006	**0.036**	0.010	**0.029**	0.006	**0.029**	0.007
Chl *a*	(μg/L)	12	**3.8**	1.38	**4.2**	2.2	**5.0**	0.62	**3.7**	1.8	**4.8**	1.5
Pheophyt.	(μg/L)	12	**0.91**	0.71	**1.5**	1.6	**0.84**	0.13	**0.86**	0.54	**1.41**	1.76

supply. Secondly within the thick *Chara* bed light conditions are also worse (as a result of shading), which slows down the process of photosynthesis. Similar results have been obtained by other authors (Frodge et al. 1990; Burks et al. 2002), who found out that lower dissolved oxygen concentrations usually appear beneath the macrophyte bed, which is therefore related to the limitation of gaseous exchange between surface water and the atmosphere. Similarly, Chic & McIvor (1994), examining the distribution of small foraging fish and juveniles of larger species among differentiated macrophyte types in Lake Okeechobee, Florida, found that stands of *Hydrilla verticillata* as well as of *Potamogeton illinoensis* tended to have higher water temperature and dissolved oxygen concentration at the surface than at the bottom part of the vegetated bed. However, they also recorded that in *Panicum hemitomon* water temperature tended to be higher near the bottom and lower at the surface whereas dissolved oxygen was higher at the surface and lower near the bottom section of this macrophyte stand.

Statistical analysis revealed that the oxygen conditions in the central part of a *Chara hispida* stand in Wielkowiejskie Lake were significantly different from those in the edge part of a macrophyte bed ($Z = 2.03$; $p < 0.05$) and from water adhering the vegetated bed in the horizontal direction ($Z = 2.02$; $p < 0.05$).

The concentration of biogenic elements was similar in the particular stations of the *Chara* stand. It should be mentioned that the content of orthophosphates was lowest in the central part of the plant stand. The reason responsible for such phosphorus distribution might be related to the use of this readily available form by stoneworts in the process of primary production (Frodge 1990). The concentrations of the total phosphorus within the *Chara* bed had similar distribution as the orthophosphates. Low concentration of total phosphorus was found in the *Chara* stand (Table 1). Such a distribution emerges probably from the lowest densities of plankton communities (containing great amounts of phosphorus in their bodies) in this part of a vegetation stand (Klimaszyk et al. 2003).

Analyzing the impact of abiotic factors on the distribution of rotifer and crustacean communities within the dense stonewort stand it was noticed that only in regard to rotifers did the dissolved oxygen have a significant influence (Fig. 3B).

Table 2. Statistically significant differences (U-Man test) in concentrations of the examined elements and between the sampling times (1 – day, 2 – dusk, 3 – night, 4 – morning), (n = 12).

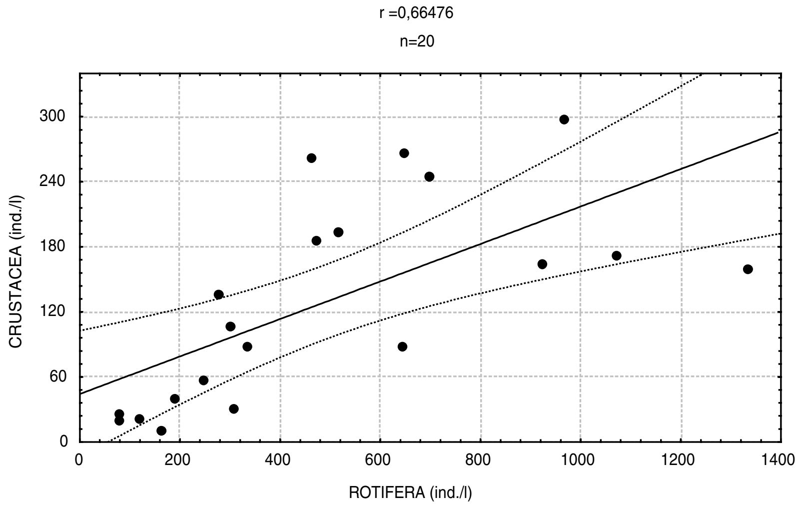
	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
NH_4	–	–	*	*	*	*
NO_2	–	–	–	–	–	–
NO_3	*	–	*	*	–	*
PO_4	–	*	*	–	–	–
P tot.	–	–	–	*	–	*
Chl a	–	*	–	–	–	*
Feofit	–	*	–	*	–	–
el. cond.	*	–	*	*	*	–
oxygen	–	–	–	–	*	–
pH	*	*	–	*	*	–
temp.	*	***	***	***	***	**

– – no significant difference; * $p < 0.05$; ** $p < 0.005$; ***$p < 0.001$.

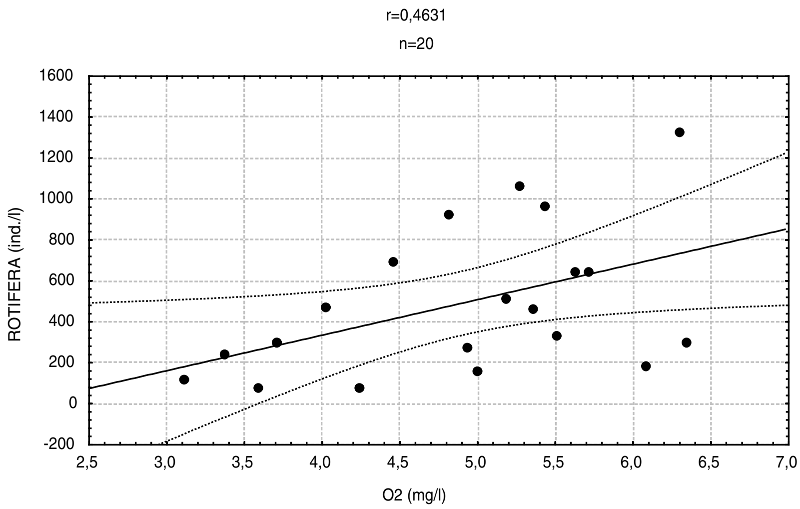
Significant differences of physical-chemical factors of the environmental conditions within the *Chara* stand were also observed when analyzing diurnal fluctuations (Table 2). The highest and most significant diel changes were recorded in the case of temperature (Table 2). Comparing the night and day samplings, the mean water temperature within the macrophyte stand showed increase in 2 °C. Such a phenomenon is characteristic of shallow water bodies and the littoral zone of water reservoirs (Carpenter & Lodge 1986; Kuczyńska-Kippen 2006), and it is due to fast heating of water by macrophytes during the day time, which easily absorb the solar radiation and pass the warmth at night from the shallow water column (Lampert & Sommer 2001).

Furthermore, considerable and significant diurnal changes were found for the pH (Table 2), although during the whole 24-h cycle its values oscillated around 7.

Analyzing the diel concentrations of dissolved oxygen, statistically significant differentiation was noticed only when comparing the morning and dusk samplings. This fully reflects two distinctive diurnal periods in



A



B

Fig. 3 Correlation coefficient between crustacean and rotifers density (A), between rotifers density and oxygen concentration within the sampling stations (B).

water reservoirs, with typical night oxygen decrease (Burks et al. 2002). The day is characterized by dominance of photosynthesis and oxygen production (maximum O_2 concentrations occurred at dusk) and night by dominance of respiration and oxygen consumption (minimum concentrations in the morning).

The obtained results on diel differentiation in the concentrations of nitrogen and phosphorus forms within the stonewort bed (Table 2) may be due to different activities of the auto- and heterotrophic processes within the 24-h cycle as well as the live excretion of these elements by water organisms.

Comparing some parameters of water adhering the stonewort bed (Table 1) with the open water of Lake Wielkowiejskie (Kuczyńska-Kippen & Nagengast 2003) significant differences appear. According to the authors the concentrations of chlorophyll *a* in the open water in the mid-lake area exceeded 10 μg L^{-1} in the course of the spring-summer-autumn seasons, while our investigations carried out within the macrophyte bed indicated maximum concentrations of about 6 μg L^{-1} and, in most cases not exceeding 5 μg L^{-1}. This seems contrary to the results obtained by Basu et al. (2000) who found out that Chl-*a* and bacterial abundance were higher at dense vegetation sites than in sparsely vegetated or open water sites. Lower concentrations of chlorophyll *a* within the *Chara* bed were probably due to its spatial and morphological building, which resulted in the very dense character of this macrophyte species overshading phytoplankton communities, and restricting the primary production.

It was also found that concentrations of mineral forms of nitrogen were much higher within the *Chara* stand compared with the open water.

The obtained positive correlation (Fig. 3A) indicates that two basic components of the zooplankton community – rotifers and cladocerans – revealed a similar distribution pattern within the stonewort bed in the diel and spatial aspects. It seems contrary to the observations that both these groups of animal plankton remain in strong competitive interaction (Gilbert 1989; Wickham & Gilbert 1990). The reason for such phenomenon is probably a strong diurnal and spatial differentiation of physical as well as chemical parameters within the examined habitats which consequently forces migrations of all groups of the zooplankton community.

To summarize, it was found that the distribution of environmental factors within a single macrophyte bed was differentiated spatially and diurnally. Lillie & Budd (1992) suggested that aquatic plant architecture affects the habitat quality, which then may influence the animal communities inhabiting a macrophyte bed. Chic & McIvor (1994) stated that a particular macrophyte type differs in regard to the amount of branching and size, amount and the position of leaves, of which the parameters may change in the vertical plane, thus modifying the habitat quality within the vegetated stand. Additionally, the vertical changeability of physical and chemical features may be due to the fact that periphyton, which overgrows macrophyte underwater stems differs vertically (Albay & Akcaalan 2003) and therefore may change the quality of the habitat in the vertical profile, as was recorded in the case of the examined *Chara hispida* stand. It has also been proved that epiphytic communities may restrict the light that reaches the plant by as much as 80% (Ondok 1978) and may also limit the diffusion of some nutrients among the vegetated station (Sand Jensen & Borum 1984; Sheffer 2001).

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