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SIZE SPECTRA AND ABUNDANCE OF PERIPHYTIC CILIATECOMMUNITIES IN SMALL EUTROPHIC LAKE (EASTERN POLAND)

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Summary. Body size, community structure and abundance of periphytic ciliates were compared on various stands of macrophytes in small, eutrophic lake Rotcze. Periphyton samples were collected from *Phragmites, Typha, Ceratophyllum, Elodea, Stratiotes* and *Chara*. Differences in numbers of ciliate taxa between micro-sites were statistically significant. The highest numbers were found on *Chara* and *Ceratophyllum* stands, lower numbers on *Stratiotes* and *Elodea* stands and the lowest on the *Phragmites* and *Typha*. Based on differences in macrophyte structure, two groups of habitats with similar patterns of size-related ciliate distribution were distinguished. The first group consisted of two vegetated zones of sparse stem structure (*Phragmites* and *Typha*), the second group comprised submerged macrophyte species, which were more dense and complex. Generally, the abundance of periphytic ciliates correlated positively with total suspension solid (TSS) and total organic carbon (TOC) concentrations. In the *Chara* and *Ceratophyllum* stands, relations between ciliate numbers, TSS and TOC were stronger.

Key words: shallow lakes, periphyton, ciliates, macrophytes

INTRODUCTION

Littoral habitats serve as important links for nutrients that enter the lake and are major regulators of nutrient dynamics in lake ecosystems through habitat coupling [Wetzel 2001]. The vegetation zone in shallow lakes comprises a mosaic of vertical and horizontal microhabitats, provided by emergent and submerged macrophytes and open patches. Due to structural and spatial heterogeneity, it maintains a very diverse niche space which may allow the coexistence of different life forms [Scheffer 1999]. The littoral zone, owing to its great heterogeneity and complex conglomeration of macrophytes, provides animals with favourable conditions to hide [Phillips *et al.* 1996]. The littoral zone in shallow lakes consist a mosaic of vertical and horizontal microhabitats, provided by macrophytes and open patches [Mészános *et al.* 2003]. These habitats generally reflect a very diverse composition with successive development being essential due to emergent and submerged vegetation that comprises a number of life forms. One of the fascinating roles of macrophytes is their potential as a refuge for large zooplankton species, which, in turn, control the phytoplankton, which may also affect the structure and function of the microbial community [Jürgens and Jeppesen 1997]. However, macrophytes constitute a vast substrate for the growth of periphytic communities [Messyasz and Kuczyńska-Kippen 2006].

Periphyton is a biological layer found in various substrata in natural waters and consists of a mucilage of slime, bacteria, algae, fungi, protozoa and small metazoans. Many recent studies have shown that ciliates play a very important trophic role in periphytic communities, and as an indication of the degree of pollution in rivers and lakes [Mieczan 2005, 2006]. Up to now most studies of natural and inert substrata concerned periphytic algae [Messyasz and Kuczyńska-Kippen 2006], while little work has been done to identify higher trophic levels of periphyton such as ciliates in lentic environments. The aim of the present study, therefore, was to establish the following: whether differences exist between periphytic ciliate communities on different substrates; the effect of physical and chemical factors on the distribution of periphytic ciliates in small eutrophic lake.

STUDY AREA, MATERIAL AND METHODS

The study area comprised small eutrophic Lake Rotcze (area: 54.8 ha, max. depth: 4.3 m), with well developed belts of emergent (*Phragmites australis* (Car.) Trin. ex Stend. and *Typha latifolia* L.) and submerged (*Ceratophyllum demersum* L., *Elodea canadensis* L. and *Stratiotes aloides* L.) macrophytes dominating in eulittoral and littoral. Nearly 40% of the lake is covered with *Chara hispida* L. and *Chara fragilis* Desvaux. The periphyton samples were collected from May to October 2009 in belts of *Phragmites, Typha, Ceratophyllum, Elodea, Stratiotes* and *Chara*. The sites had ca. 35–40 m^2 belts of macrophytes. The distance between the belts was ca. 40 m. At each type of habitat, four samples were collected from the each microhabitats (centre and edge zones). From each zone, eight samples were collected by washing 10 g wet mass of plant material. First, the periphyton was rinsed off of each plant in 50 ml of distilled water and then it was removed manually, using a knife and a small brush. The abundance of microorganisms was calculated on 1 g wet weight of the plant material. Observations *in vivo* were used for taxonomic and trophic identification. The samples with ciliates were condensed by the sedimentation method. Taxonomic identifications of ciliates were based on the keys by Foissner and Berger [1996] and Foissner *et al*. [1999].

The water samples for chemical analyses were taken simultaneously with periphyton samples. Conductivity and pH were determined *in situ* using the electrode JENWAY 3405; total organic carbon (TOC) and total suspension solid (TSS) were determined using the PASTEL UV; and the remaining factors (nitrate nitrogen – $N\text{-}NO_3$, ammonia nitrogen – $N\text{-}NH_4$, total phosphorus – TP) were analyzed in the laboratory, according to Golterman [1969].

The frequency of occurrence of a particular species was calculated as a percentage of collected samples in which the species occurred. All species that were found were classified into 4 groups as follows: very constant species (occurring in 61–100% of samples); constant species (occurring in 41–61% of samples); accidental species (occurring in 21–40% of samples); accessory species (occurring in less than 20% of samples). Ciliates were divided into six body size groups (I–VI): < 20 μm, 20–30 μm, 30–40 μm, 40–60 μm, 60–80 μm and > 80 μm, respectively.

All data collected was statistically analysed by means of GLM and CORR procedures of the SAS Programme (SAS Institute Inc. 2001). One-way ANOVAs with *post-hoc* Bonferroni tests were run on abundance data to assess separately the protozoan variability between periphytic communities on macrophytes. Correlations between physical and chemical parameters and ciliate density were analysed by calculating Pearson's correlation (n = 48).

RESULTS

The chemical characteristics of water at these micro-sites are summarized in Table 1. They were similar and only conductivity, TSS and TOC concentrations were significantly different between the micro-sites (ANOVA, F = 21.07–30.27, P = 0.011–0.030). Conductivity was 377–389 $\mu S \cdot cm^{-1}$ in the *Chara* and *Ceratophyllum* beds and 360–380 $\mu S \cdot cm^{-1}$ in the *Phragmites* and *Typha* beds. The contents of TOC and TSS reached the highest values in the *Ceratophyllum* bed (7.8 $mgC \cdot dm^{-3}$ and 8.6 $mg \cdot dm^{-3}$, respectively) and the lowest were in the *Phragmites* stand (6.2 $mg\ C \cdot dm^{-3}$ and < 5 $mg \cdot dm^{-3}$, respectively) (Tab. 1).

Thirty seven species were found in Lake Rotcze. Differences in numbers of ciliate taxa between microsites were statistically significant (F = 22.2, P = 0.0011, ANOVA). The highest number (26 species) was found on *Chara* and *Ceratophyllum* stands, 21–23 species were found on *Stratiotes* and *Elodea* stands, 10–13 species on *Phragmites* and *Typha*. On the submerged macrophytes *Cinetochilum margaritaceum* was a very constant species; on the emergent macrophytes *Chilidonella uncinata.* Within size groups I–III mostly small Scuticociliatida and Oligotrichida occurred. For groups IV to VI, larger, typically periphytic ciliates were found (Tab. 2).

Table 1. Physical and chemical characteristics of the water of investigated microsites (average values for period May–October 2009, mean ±SD)

Microsites	pH	Conductivity $\mu S \cdot cm^{-1}$	N-NO$_3$ $mgN \cdot dm^{-3}$	N-NH$_4$ $mgN \cdot dm^{-3}$	TP $mgP \cdot dm^{-3}$	TOC $mgC \cdot dm^{-3}$	TSS $mg \cdot dm^{-3}$
Phragmites	7.20	370	0.176	0.115	0.280	6.2	<5
	±0.63	±21.4	±0.08	±0.02	±0.54	±0.94	±0.94
Typha	7.31	360	0.176	0.33	0.280	6.0	<5
	±0.83	±141.8	±0.05	±0.06	±0.14	±2.48	±2.48
Ceratophyllum	7.46	389	0.047	0.141	0.238	7.8	8.6
	±0.65	±31.7	±0.01	±0.08	±0.07	±3.05	±3.05
Elodea	7.37	378	0.046	0.131	0.226	7.4	5.3
	±0.65	±11.7	±0.01	±0.08	±0.03	±3.05	±3.05
Stratiotes	7.39	370	0.046	0.141	0.225	7.2	5.0
	±0.65	±61.6	±0.01	±0.08	±0.40	±2.05	±3.01
Chara	8.36	377	0.045	0.145	0.294	8.7	8.1
	±0.65	±51.7	±0.01	±0.08	±0.09	±2.05	±3.01

The mean numbers of periphytic ciliates formed changed on the individual macrophytes, with the lowest numbers on *Stratiotes* (12 ind. · g^{-1}) and the highest on the *Chara* and *Ceratophyllum* stands (32–36 ind. · g^{-1}) (ANOVA, F = 29.09, P = 0.0122) (Fig. 1). In Lake Rotcze, bacterivorous Cyrtophorida *(Chilodonella*

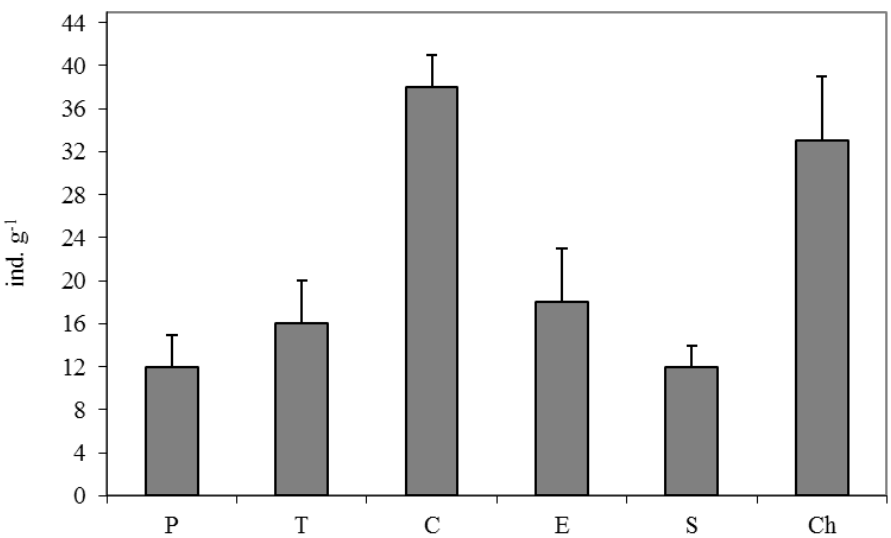

Fig. 1. Average density of periphytic ciliates found on various types of macrophytes in investigated lake (± SD): P – Phragmites, T – Typha, C – Ceratophyllum, E – Elodea, S – Stratiotes, Ch – Chara

Table 2. Representatives of ciliates of particular body size groups in Lake Rotcze

Group I (< 20 µm)	Group II (20–30 µm)	Group III (30–40 µm)	Group IV (40–60 µm)	Group V (60–80 µm)	Group VI (> 80 µm)
Balanion planctonicum (Foissner, Berger, Kohmann, 1994), Pr *Cyclidium* sp., Sc *Mesodinium* spp., H *Trochilia* sp., O	*Acineta sp.,* S *Cinetochilum margaritaceum* (Ehrenberg, 1831), Sc *Halteria gradinella* (Mueller, 1973), O *Uronema* sp., Sc	*Askenasia spp.,* H	*Chilodonella uncinata,* C *Codonella cratera* (Leidy, 1877), O *Coleps hirtus* (Meuller, 1786), Pr *Coleps spetai* (Foissner, 1984), Pr *Strombidium viride* (Stein, 1867), O *Strombilidium* sp., O	*Actinobolina radians* (Strand, 1833), G *Metopus* sp., He *Paramecium bursaria* (Ehrenberg, 1831), H *Trithigmostoma* spp., C *Urotricha* spp., Pr *Vorticella convallaria-Komplex,* P	*Amphileptus pleurosigma* (Stokes, 1884), Pl *Aspidisca* sp., Hy *Bursellopsis* sp. Pr *Didinium* sp., H *Dileptus* sp., H *Euplotes* sp., Hy *Frontonia* sp., Hy *Holophrya* sp., Pr *Lembadion* sp., Hy *Litonotus* sp., Pl *Loxophyllum meleagris* (Mueller, 1773), Pl *Prorodon* sp., Pr *Spathidium sensu lato,* H *Stentor amethystinus* (Leidy, 1880), Ht *Stentor coeruleus* (Pallas, 1766), Ht *Stylonychia mytilus-Komplex,* Hy

C – Cyrtophorida, G – Gymnostomatida, H – Haptorida, Ht – Heterotrichida, Hy – Hymenostomatida, O – Oligotrichida, P – Peritrichida, Pl – Pleurostomatida, Pr – Prostomatida, Sc – Scuticociliatida, S – Suctorida.

uncinata) and Scuticociliatida *(Cinetochilum margaritaceum, Cyclidium* sp.), mixotrophic Oligotrichida (*Strombidium viride, Halteria gradinella*) constituted > 50% of the total ciliate abundance. Pleurostomatida *(Litonotus* sp.) and Prostomatida (*Coleps hirtus*) constituted 15–20%, respectively. Ciliates belonging to the other orders reached 25–30% of the total numbers. On *Chara* and *Cerato-*

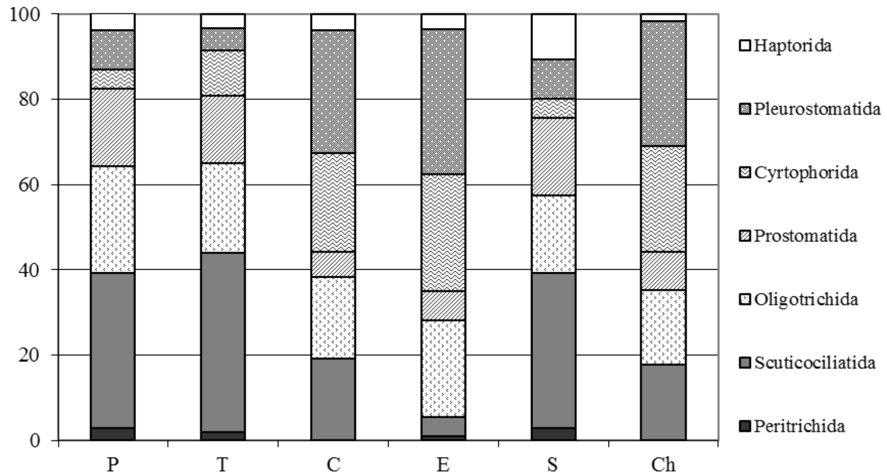

Fig. 2. Domination structure of periphytic Ciliata orders found on various types of macrophytes in investigated lake (% of total numbers): P – Phragmites, – Typha, C – Ceratophyllum, E – Elodea, S – Stratiotes, Ch – Chara

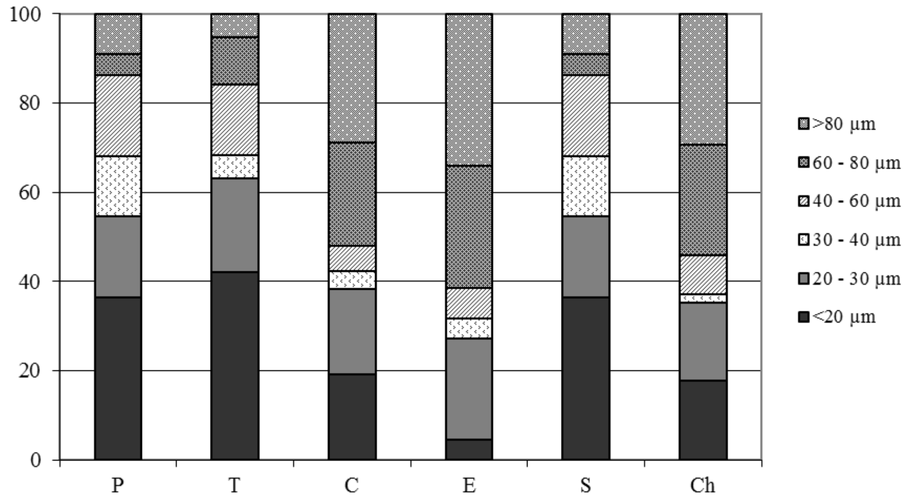

Fig. 3. Percentage of particular body size groups (μm) on various types of macrophytes in investigated lake: P – Phragmites, T – Typha, C – Ceratophyllum, E – Elodea, S – Stratiotes, Ch – Chara

phyllum stands, Pleurostomatida, Scuticocoliatida and Peritrichida constituted 45–56% of the total ciliate abundance, while species of the other orders reached only < 7% of the total numbers. In *Phragmites, Typha, Elodea, Stratiotes* stands ciliate species belonging to the Cyrtophorida constituted > 30% (Fig. 2). Ciliates on *Phragmites*, *Typha* and *Stratiotes* stands were mainly smaller than 40 μm, while species on submerged macrophytes were within the size range of 40–80 μm (Fig. 3).

Table 3. Linear correlation coefficients between ciliate density and physico-chemical factors on various types of macrophytes

Microsites	pH	Conductivity uS · cm $^{-1}$	N-NO$_3$ mgN · dm $^{-3}$	N-NH$_4$ mgN · dm $^{-3}$	TP mgP · dm $^{-3}$	TOC mgC · dm $^{-3}$	TSS mg · dm $^{-3}$
Phragmites	-	-	-	-	0.33	0.33*	0.33
Typha	-	-	-	-	-	0.34*	0.33*
Ceratophyllum	-	-	-	-	-	0.58**	0.52**
Elodea	-	-	-	-	-	0.43*	0.41*
Stratiotes	-	-	-	-	-	0.35*	0.45*
Chara	-	-	-	-	0.42	0.34*	0.56**

$^{*}P \leq 0.05$, $^{**}P \leq 0.01$, , – not significant, n = 48.

The abundance of periphytic ciliates correlated positively with total phosphorus, concentrations of total organic carbon (TOC), and total suspension solids (TSS). In the *Ceratophyllum* stands, relations between ciliate numbers and chemical parameters were stronger (from r = 0.52, $P \leq 0.05$ to r = 0.58, n = 32, $P \leq 0.01$, respectively) (Tab. 3).

DISCUSSION

The species diversity and density of ciliate community overgrowing submerged macrophytes of the lakes considered in this study are generally much higher than, for example, on emergent macrophytes in eutrophic Croatian lakes [Primc-Habdija *et al.* 1997, 2000]. On the other hand, no data was found in the accessible literature on the occurrence of periphytic ciliates on submerged macrophytes.

Qualitative and quantitative structure of small Metazoa inhabiting individual macrophyte clusters is relatively well examined for Rotifera, Cladocera and Copepoda [Kuczyńska-Kippen and Nagengast 2003, Kuczyńska-Kippen 2005]. However, almost no research studies have been conducted concerning the periphytic ciliates between separate patches of lake vegetation. In the present study ciliates showed significantly higher numbers on submerged macrophytes *(Ceratophyllum, Elodea* and *Chara*) as compared to emerged plants *(Phragmites, Stratiotes, Typha)*. Aquatic vegetation may influence protozoan density probably by modifying food availability and increasing the spatial heterogeneity. Macrophytes may limit light intensity and effectively compete for nutrients and consequently limit protozoans [Biyu 2000]. In Lake Rotcze densities of ciliates of various size groups differed between the investigated stands. With regard to body size distribution of ciliates, stands of submerged macrophytes (*Chara* and *Ceratophyllum*), having longer stems and higher biomass, were mostly characterised by higher species diversity and than zones of sparsely growing plants (*Phragmites* and *Typha*). Changes in macrophyte morphology and architectural design depend on the fineness and density of leaves and the heterogeneity of plant surface [Kuczyńska-Kippen 2005]. Increasing complexity of macrophytes creates an increased diversity of microhabitats and provide numerous micro-niches. Similar dependencies have been observed in the present studies. Both the diversity of species and numbers of ciliates increased with increasing degree of complexity of macrophyte spatial structure. Clear impact of macrophyte spatial structure was also observed for other groups of water organisms. Downing and Cyr [1986] observed that the number of invertebrates inhabiting a cluster is related to the biomass of a specific macrophyte species. Furthermore Walsh [1995] demonstrated that the degree of morphological complexity of a plant positively correlates with the diversity of the qualitative and quantitative structure of rotifers.

The periphyton of the studied lake contained the greatest number of small, bacterivorous ciliates along with the lowest number of large algivorous ciliates. Bacterivorous ciliates reached the highest proportion on the *Ceratophyllum* and *Chara*, and a slightly lower one on the emergent macrophytes. The low participation of algivorous ciliates in the periphyton of the examined lake could have been caused by problems with their access to food resources. Likewise, the increase in abundance of ciliates on *Chara* and *Ceratophyllum* may be the result of profitable food conditions. It also seems that the reason for abundant ciliates on precisely this kind of substrate may be partly explained by the higher concentration of total organic carbon. This type of environment might also be conducive to the increase in the number of bacteria. The present study revealed that the concentrations of total organic carbon and biogenic substances were higher at sites dominated by these plant species. In the group of periphytic ciliates, the species of typically ubiquitous character were numerous, however these of planktonic and benthic character were also present. In Polish and international literature there is also a lack of detailed information concerning the formation of the periphytic ciliates on different types of substrate. However, the results of some studies on planktonic ciliates indicate that their density may increase with the eutrophication of waters [Biyu 2000].

CONCLUSIONS

Differences in numbers of periphytic ciliate taxa between micro-sites were statistically significant. The highest numbers were found on *Chara* and *Ceratophyllum* stands, lower numbers on *Stratiotes* and *Elodea* stands and the lowest on *Phragmites* and *Typha*. The differences in the community composition and ciliate numbers on various plant hosts may be a result of differences in chemical (e. g. organic matter), physical (e. g. the structure of plants), and biological factors.

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STRUKTURA WIELKOŚCI I OBFITOŚĆ ORZĘSKÓW PERYFITONOWYCH W MAŁYM EUTROFICZNYM JEZIORZE (WSCHODNIA POLSKA)

Streszczenie. Celem badań było poznanie struktury, wielkości oraz obfitości orzęsków peryfitonowych zasiedlających poszczególne fitocenozy małego, eutroficznego jeziora Rotcze. Próby peryfitonu pobierano z *Phragmites, Typha, Ceratophyllum, Elodea, Stratiotes* i *Chara.* Stwierdzono wyraźne zróżnicowanie struktury jakościowej i ilościowej orzęsków w zależności od stopnia skomplikowania struktury przestrzennej makrofitów. Pierwsza grupa orzęsków charakterystyczna była dla strefy roślinności o prostej strukturze pędów (*Phragmites* i *Typha*), druga zaś dla roślinności zanurzonej, o znacznie bardziej skomplikowanej strukturze morfologicznej. Wykazano, że liczebność orzęsków peryfitonowych korelowała pozytywnie z zawartością w wodzie zawiesiny oraz całkowitego węgla organicznego i fosforu ogólnego. W siedliskach zdominowanych przez *Chara* i *Ceratophyllum* siła tych powiązań była największa.

Słowa kluczowe: płytkie jeziora, peryfiton, orzęski, makrofity