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CHANGES IN PERIPHYTIC CILIATE DENSITIES WITH TROPHIC STATUS IN TWO SHALLOW LAKES

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Summary. Periphytic ciliate communities were investigated in two lakes of different trophic status of the Łęczyńsko-Włodawskie Lake District (eastern Poland). The periphyton was collected from the reed stems at a depth of 25–50 cm. Sampling was done in spring, summer and autumn 2010. Four three ciliate taxa occurred in the studied lakes. Numbers of periphytic ciliates of reed surface significantly differed between the studied lakes, with the lowest numbers in the eutrophic lake (37 species), and the highest in the hypertrophic lake (40 species). The same distribution pattern was observed to ciliates abundance. Generally, the abundance of ciliates was positively correlated with total organic carbon, nutrients and chlorophyll *a.* However, the number of significant correlations between the numbers of ciliates and environmental variables was different in the studied lakes. In the eutrophic lake, the density of ciliates was strongly correlated with the concentrations of chlorophyll *a* and total organic carbon; whereas in hypertrophic lake, density of ciliates correlated with concentrations of ammonium-nitrogen, nitrate-nitrogen and total phosphorus.

Key words: trophy, lake, periphyton, ciliates

INTRODUCTION

The periphyton formed on the surface of artificial and natural substrata located in the photolytic layer of freshwater lakes and rivers are very sophisticated systems consisting of algae, bacteria, fungi, protozoa and small metazoans [Wetzel 1983]. Many recent studies have shown that ciliates play a very important trophic role in periphytic communities and as the indication of pollution degree in rivers and lakes [Primc-Habdija *et al.* 1998, 2000, Buosi *et al.* 2011]. These microorganisms are significant consumers of bacteria and algae. They participate in transformations of the organic matter and nutrients and they constitute the components of diet of rotifers and crustaceans [Putland 2000, Sonntag *et al.* 2002]. Periphytic ciliates as well other periphyton components have been investigated on both natural (stems, leaves, stones) and artificial substrates. However, still more attention is paid to periphytic ciliates of river and stream ecosystems [e.g. Baldock *et al*. 1983, Kaur and Mehra 1998, Madoni and Zangrossi 2005]. In recent years, the interest has been renewed in studies of colonisation and successional patterns of periphytic communities on artifical substrates in eutrophic waters [Boothroyd and Dickie 1989] reported the presence of similar epiphytic communities on macrophytes and on natural and artifical substrates (i. e. glass-slides). However, little has been known about the periphytic ciliate communities on natural substratum in shallow lakes of different trophic status. Till now the research focused on periphytic ciliates on reed stems in relation to physical and chemical parameters of hypertrophic lakes are not common. The aim of the investigations was to determine the abundance and taxonomic composition of periphytic ciliates in relation to selected physical and chemical factors in two shallow lakes of different trophic status.

STUDY AREA, MATERIAL AND METHODS

The study area comprised two shallow, polymictic lakes in the Polesie Lubelskie region of eastern Poland. These were the hypertrophic Lake Syczyńskie (surface area 6.0 ha, max depth 4.0 m) and eutrophic Lake Sumin (surface area 91.5 ha, max depth 6.5 m). Lake Syczyńskie was characterized by intensive development of emergent vegetation, dominated by reed (*Phragmites communis* Trin.) and temporal blooms of *Planktothrix agardhii* (Gomont). In Lake Sumin the emergent macrophytes were dominated by *Phragmites communis* Trin. and nymphaeide (*Nymphaea candida* Presl.) [Kornijów *et al.* 2002]. In hypertrophic lake the periphyton community was dominated by filamentous chlorophytes (mostly *Cladophora* sp.). Diatoms, small chlorophytes and blue-green algae occurred in the greatest proportion of the total abundance in eutrophic lake. The physical, chemical and biological characteristics of water at these lakes are summarized in Table 1.

The periphyton was collected from the reed stems at a depth of 25–50 cm. Sampling was done in spring (April), summer (July) and autumn (October) 2010. During each sampling occasion 6 periphyton samples were collected. One sample consisted of 10 cm^2 of periphyton taken from the macrophyte stems by means of a scalpel. In order to determine the density of ciliates, 4 samples were fixed with Lugol's solution (1% v/v) and settled for at least 24 h in plankton chambers. The ciliates were counted and identified with an inverted microscope at magnification × 400–1000. Taxonomic identification was based primarily on Foissner and Berger [1996]. The water samples for chemical analysis were taken simultaneously with the periphyton samples. The following physical and chemical factors were examined: temperature, pH, conductivity, total organic carbon (TOC), chlorophyll *a*, ammonium-nitrogen, nitrate-nitrogen, phosphates and total phosphorus. Temperature, conductivity and pH were recorded *in situ* using a multiparametric probe (Hanna Instruments). Total organic carbon was determined

Table 1. Physical, chemical and biological characteristics of the water of investigated lakes (average values April–October 2010 ±SD)

Lake	Temp °C	pH	Cond. µs cm^{-1}	Dissolv. oxygen mg dm^{-3}	$N\text{-}NO_3$ mgN dm^{-3}	$N\text{-}NH_4$ mgN dm^{-3}	Ptot mgP dm^{-3}	$P\text{-}PO_4$ mg PO_4^{3-} dm^{-3}	TOC mgC dm^{-3}	Chl. *a* µg dm^{-3}
Sumin (E)	17.3 ±8.2	7.8 ±1.2	416 ±46	9.98 ±2.3	0.399 ±0.02	0.338 ±0.11	0.048 ±0.03	0.012 ±0.03	15.0 ±1.1	11.44 ±2.3
Syczyńskie (H)	15.8 ±7.3	6.9 ±1.2	575 ±33	11.08 ±2.0	0.292 ±0.11	0.213 ±0.08	0.464 ±0.12	0.270 ±0.12	6.9 ±1.8	74.71 ±12.6

Key: trophic type: (E) – eutrophic, (H) – hypertrophic

by using the multiparametric UV analyzer (Secomam, France), and the remaining factors were analyzed in the laboratory [Hermanowicz *et al.* 1976]. Chlorophyll *a* was determined by spectrophotometric analysis of the acetone extract of the algae [Golterman 1969]. The diversity index was expressed with the Shannon-Wiener method [Krebs 1989]:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

were: n_i – the number of individuals of i species; the abundance of I species, S – the number of species (species richness), N – the total number of individuals, p_i – the relative abundance of each species, calculated as the proportion of individuals of a given species to the total number of individuals in the community: $\frac{n_i}{N}$.

All data collected were analysed statistically by means of GLM and CORR procedures of the SAS Programme [SAS Institute INC 2001]. Species abundance was analysed by main effects ANOVA. Correlation between physical and chemical parameters and ciliate density were analysed by calculating Pearson's correlation.

RESULTS

Forty three ciliate taxa occurred in the studied lakes. The greatest species richness (40 species) was found in the hypertrophic lake, 37 species was found in eutrophic lake. The diversity analysis revealed a mean Shannon-Wiener diversity index of 3.1 ±0.05. The highest diversity was measured in hypertrophic lake (H' = 3.6), and the lowest diversity was observed in eutrophic lake (H' = 2.6). In hypertrophic lake the greatest number, namely 4 taxa exclusive to this lake were noted. These were: *Litonotus varsaviensis, Paradileptus sp. Paramecium caudatum* and *Pseudovorticella monilata*. In eutrophic lake *Chilodontopsis depressa*

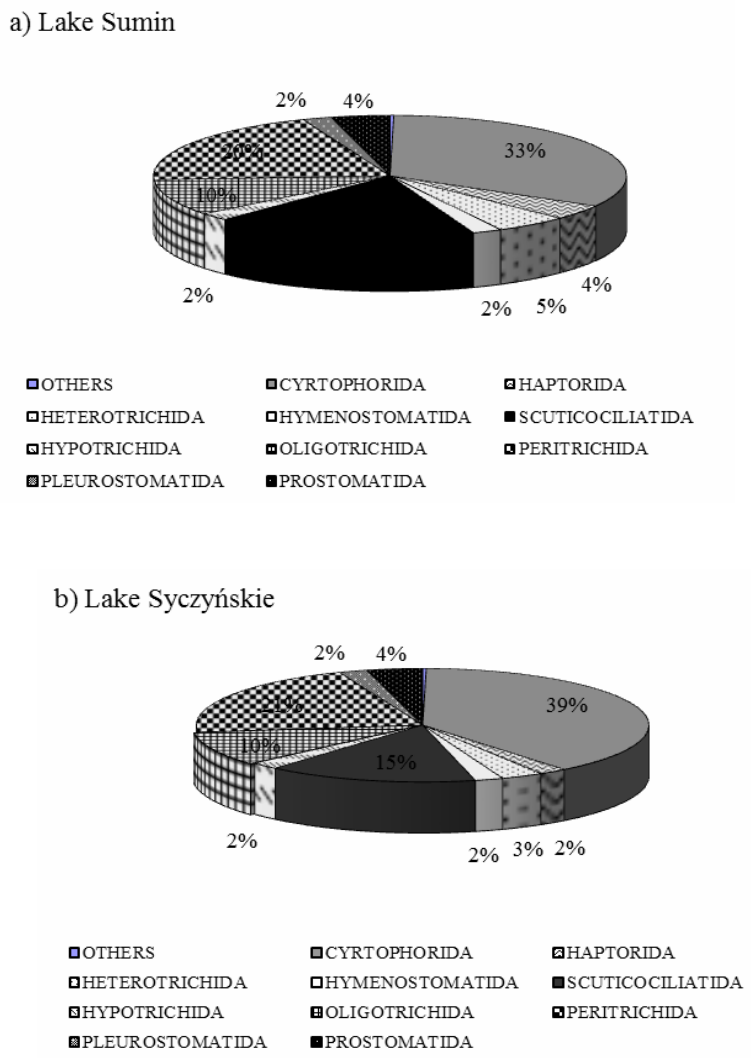

Fig. 1a, b. Domination structure of periphytic Ciliata orders in investigated lakes (% of total numbers)

and *Philasterides* sp. occurred. Numbers of periphytic ciliates of reed surface significantly differed between the studied lakes, with the lowest numbers in the eutrophic lake lake (42 ind.cm^{-2}), and the highest in the hypertrophic lake (86 ind. cm^{-2}) (F = 15.3; p < 0.0001, ANOVA). The dominance structure in all of the lakes was similar. All of the studied lakes were generally dominated by ciliates belonging to Cyrtophorida (*Chilodonella uncinata*), Peritrichida and Scuticociliatida constituted > 50% of the total numbers. The species belonging to Cyrtophorida, Peritrichida and Scuticociliatida constituting 39, 21 and 15% of the total numbers in hypertrophic lake as well as the species from the orders of Hete-

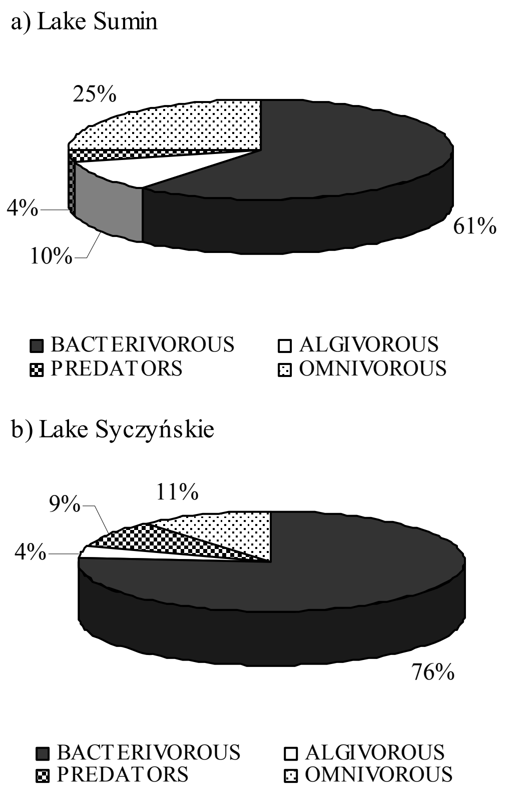

Fig. 2. Trophic groups of periphytic ciliates found in investigated lakes (% of total numbers)

rotrichida, Oligotrichida, Pleurostomatida and Prostomatida (2 to 10%). The species belonging to order Cyrtopharida, Peritrichida and Scuticociliatida constituting from 33, 20 and 18% of the total numbers in eutrophic lake. The other orders of ciliates reached 2% to 10% of the total population (Fig. 1a, b). In all lakes bacterivorous ciliates occurred in the highest numbers, while algivorous ones in the lowest. Bacterivorous ciliates occured in the greatest proportion of the total abundance in hypertrophic lake, where they constituted 76%. They are found in a smaller proportion (61%) in eutrophic lake. Omnivorous species also occurred in greater numbers in the eutrophic lake, while lower in hypertrophic lake, constituting 25% and 11% of the total numbers of ciliates, respectively. Predatory ciliates reached the highest proportion in hypertrophic lake, constituting 9% of the total numbers, while making up 4% of the total community in the eutrophic lake. Algivorous ciliates constituted < 10% of the total abundance (Fig. 2a, b). Generally, the abundance of ciliates was positively correlated with total organic carbon, nutrients and chlorophyll *a.* However, the number of significant correlations between the numbers of ciliates and environmental variables was different in the studied lakes. In the eutrophic lake, the density of ciliates was strongly correlated with the concentrations of chlorophyll *a* ($r = 0.73$, $p < 0.01$) and total

Table 2. Linear correlation coefficients between ciliate density and physical, chemical and biological factors in various types of lakes

Lake	Temp °C	pH	Cond. µS cm^{-1}	Dissolv. oxygen mg dm^{-3}	$N-NO_3$ mgN dm^{-3}	$N-NH_4$ mgN dm^{-3}	Ptot mgP dm^{-3}	$P-PO_4$ mg PO_4^{3-} dm^{-3}	TOC mgC dm^{-3}	Chl. *a* µg dm^{-3}
Sumin (E)	-	-	-	-	0.41**	0.39**	-	0.53*	0.63*	0.73*
Syczyńskie (H)	-	-	-	-	0.68*	0.62*	0.78*	0.54*	0.43**	0.42**

Key: trophic type: (E) – eutrophic, (H) – hypertrophic, $^{*}p \leq 0.01$, $^{**}p \leq 0.05$, – not significant, n = 53.

organic carbon ($r = 0.63$, $p < 0.01$). In turn, in the hypertrophic lake, there was a significant rise in the strong correlation between the number of ciliates and the ammonium-nitrogen, nitrate-nitrogen and total phosphorus concentrations (r = 0.68–0.78, $p < 0.01$) (Tab. 2).

DISCUSSION

In the lakes examined, the highest species diversity of ciliates was registered in hypertrophic lake, while the least in eutrophic lake. The total number of species in the eutrophic lake (40 taxa) was lower than observed in other studies [Mieczan 2005]. To date, however, there is a lack of data concerning the comparison of periphytic ciliates in the other types of lakes. Characteristic species (occuring in one lake) constituted a relatively small group. The most of these species were found in hypertrophic lake. They included *Litonotus varsaviensis, Paradileptus sp., Paramecium caudatum* and *Pseudovorticella monilata*, the species observed in various trophic types of European lakes [Foissner and Berger 1996, Finlay *et al.* 1999]. The species characteristic of eutrophic lake, namely *Chilodontopsis depressa* and *Philasterides sp.*, were also observed in strongly contaminated waters [Foissner *et al.* 1994]. Mieczan [2005] investigated periphytic ciliates in 3 lakes of different trophic status in Poland, and has stated that Cyrtophorida, Scuticociliatida, as well as Oligotrichida appeared in lakes from oligo- to eutrophic. The domination of Cyrtophorida (mainly *Chilodonella uncinata*) in all the studied lakes could have resulted from its wide ecological valency [Foissner and Berger 1996, Mieczan 2005]. The high density of Peritrichida species in the present study is related to its way of life, because the most common Peritrichida species are stalked, sessile and filter-feeding and thus require a substrate for their fixation [Foissner and Berger 1996]. However, our study results evidenced several scuticociliates as the most abundant in the periphyton followed by peritrichs. According to Mieczan [2008], bacterivorous peritrichs and scuticociliates demonstrate a significant connection with macrophyte beds. High amounts of TOC in macrophyte beds clearly facilitate the occurrence of bacteria, which are a potential food source for these ciliates.

The polulation density of ciliates ranged from 42 ind. cm^{-2} in the eutrophic lake to 86 ind. cm^{-2} in the hypertrophic lake. For comparison, on glass slides that were exposed in Lake Visivac (Croatia), ciliate numbers were from 40–2400 ind. cm^{-2} [Primc-Habdija *et al.* 1997, 2000]. On the other hand, no data was found in accessible literature on the occurrence of periphytic ciliates on natural substrates in hypertrophic lake. The higher numbers of ciliates in hypertrophic lake are most likely a consequence of the high conductivity, concentrations of total organic carbon and nutrients. A significant correlation with organic matter has also been observed in European lakes [Amblard *et al.* 1995, Mieczan 2005, 2008]. Sarvala *et al.* [1999] have shown a definite correlation between the number of ciliates, conductivity, and trophic parameters in lakes with a different trophic state. According to Velho *et al.* [2005] the trophic state is essential for determination of the pattern of variation in the spatial and temporal distribution of ciliates. It seems that nutrients have an indirect influence on the prevalence of ciliates through the control of food abundance (mainly bacteria and algae). The periphyton of the studied lakes contained the greatest number of bacterivorous ciliates while the smallest of algivorous. Therefore, it can be supposed that periphytic ciliates become a significant link in the flow of matter and energy between bacteria and higher invertebrates. Bacterivorous ciliates reached the highest proportion in hypertrophic lake and the smallest in eutrophic lake. In investigated lakes the proportion of particular trophic groups of ciliates in the total community was similar to that observed on natural and artifical substrates in eutrophic lakes in Croatia [Primc-Habdija *et al.* 2000]. A slight proportion of algivorous ciliates in the periphyton of the examined lakes could have been caused by problems with access to the food. The dominating algae were filamentous and colonial ones, inaccessible or hardly accessible for ciliates.

CONCLUSIONS

It seems that the abundance of periphytic ciliates to the highest degree is determined mainly by concentrations of organic matter, nutrients and chlorophyll *a*. In the eutrophic lake ciliate abundances are impacted by concentrations of chlorophyll *a* and total organic carbon. In turn, in the hypertrophic lake, the influence of concentrations of ammonium-nitrogen, nitrate-nitrogen and total phosphorus increased. However, with the aim of clarifying the understanding of the role of factors conditioning the presence of periphytic ciliates, it is necessary in future research to explain the biotic factors such as, among others, the abundance of bacteria and small metazoa.

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ZMIANY OBFITOŚCI ORZĘSKÓW PERYFITONOWYCH W POWIĄZANIU ZE STATUSEM TROFICZNYM DWÓCH PŁYTKICH JEZIOR

Streszczenie. Badania orzęsków peryfitonowych prowadzono w dwóch jeziorach o zróżnicowanym statusie troficznym, położonych na obszarze Pojezierza Łęczyńsko-Włodawskiego. Próby peryfitonu pobierano z łodyg trzciny pospolitej na głębokości 25–50 cm w okresie wiosny, lata i jesieni 2010 roku. Łącznie stwierdzono występowanie 43 taksonów orzęsków. Różnorodność tych pierwotniaków była istotnie zróżnicowana w obu jeziorach. Najmniejszą liczbę taksonów (37) stwierdzono w jeziorze eutroficznym, największą zaś (40) w jeziorze hipertroficznym. Podobną tendencję wykazywała liczebność tych mikroorganizmów. Obfitość orzęsków korelowała głównie z zawartością w wodzie całkowitego węgla organicznego, stężeniami biogenów oraz chlorofilu *a*, przy czym siła wzajemnych powiązań była zróżnicowana w zbiornikach. W jeziorze eutroficznym liczebność orzęsków najsilniej korelowała z zawartością w wodzie chlorofilu *a* oraz materii organicznej, w jeziorze hipertroficznym wzrastał natomiast wpływ azotu amonowego, azotu azotanowego oraz fosforu ogólnego.

Słowa kluczowe: trofia, jezioro, peryfiton, orzęski