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Relationships among ciliated protozoa and water chemistry in small peat-bog reservoirs (Łęczna-Włodawa Lakeland, Eastern Poland)

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Abstract

The aims of this study were to identify the taxonomic and trophic diversity of planktonic ciliate communities occurring in small peat-bog reservoirs of various acidities (from about 3 to 6), and to assess the effects of chemical factors on them. Generally the highest numbers of ciliate taxa were recorded in high pH (>6) reservoirs, and the lowest in low pH (3.28-4.6) reservoirs. The mean numbers of planktonic ciliates in the high pH reservoirs were about three times higher than in the low pH reservoirs. However, the greatest biomass of ciliates occurred in low pH reservoirs.

The results suggest that pH, conductivity and total organic carbon (TOC) are more important than total phosphorus (P_{tot}) in the distribution of planktonic ciliates in peat-bog reservoirs. In the low pH peat-bog reservoirs, the biggest factor affecting ciliate distribution is the pH of the water, whilst in the higher pH reservoirs the role of organic matter becomes increasingly important with increasing pH.

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INTRODUCTION

In small peat-bog reservoirs animal communities, especially invertebrates, are well known (Deneke 2000, Błędzki & Ellison 2003). However, less is known about the protozoa and their relationships to environmental factors in these ecosystems. Ciliates play a very important trophic role in planktonic communities, and act as indicators of pollution in rivers and lakes (Kaur & Mehra 1994). These microorganisms are significant consumers of bacteria and algae. They participate in transformations of organic matter and nutrients, and they comprise a significant component of the diet of rotifers and crustaceans (Sonntag et al. 2002, Ventelä et al. 2002).

Small pea-bog reservoirs with low pH and high concentrations of humic matter have low levels of nutrients and a typical brown water colour, which reduces light penetration, thus primary productivity is usually low. Low pH, down to about 4.0-5.0, or even as low as 3.0, is a biological effect of peat-moss *(Sphagnum)* occurring around reservoirs, or expanding over the water in the form of a mat (Tranvik 1988). Studies examining the effect of pH on zooplankton communities have concentrated on rotifers and crustacean zooplankton (Dillon et al. 1984). Ecology and spatial distribution of ciliates have been studied only in humic lakes (Beaver & Crisman 1981, 1982; Kalinowska 2000), which indicate that with increased acidity the abundance, biomass, diversity and species richness of ciliates decreases. Studies performed by Amblard et al. (1995) in a moderately acid lake in central France indicate that the major factors in the development of microorganism communities there are the concentration of organic carbon and the turbidity of the water. Until now studies examining the influences of chemical factors on ciliates in small peat-bog reservoirs have not been common.

In this study the structure of ciliate communities in relation to four environmental variables (pH, conductivity, total phosphorus (P_{tot}) and total organic carbon (TOC) in six small peat-bog reservoirs of different acidity (from about 3 to 6) were studied. The primary aims were the identification of the taxonomic and trophic diversity of the planktonic ciliates communities of these reservoirs, and to assess the impacts of chemical factors on their distribution.

MATERIALS AND METHODS

Experiments were carried out in six small, peat-bog reservoirs (area <0.5 ha, mean depth 1.5-2.5 m) of different acidities (pH 3.28 to 6.5). The reservoirs are located in Łęczna-Włodawa Lakeland (Eastern Poland) and were created as a result of peat extraction. Most of the reservoirs adjoin a peat bog formed by *Sphagnum* and covered by other plants characteristic of peat lands: *Carex* *acutiformis* Ehrhart., *Carex gracilis* Curt. and *Equisetum limosum* (L.). From April to October 2006 samples were collected monthly from each peat-bog reservoir; on each occasion eight samples were collected with a 5-litre Bernatowicz sampler, at 0.5-metre depth intervals. Samples were collected at two stations: pelagic (located in the deepest part of each reservoir) and littoral. Samples from all layers were pooled together, carefully mixed and a 500 ml sub-sample was fixed with Lugol's solution (0.2% final concentration). Numbers of ciliates were determined with an inverted microscope using the settling chamber technique: 50 ml of sample was sedimented for at least 24 h after which half of the bottom of the chamber was counted at 300× magnification. To identify the ciliates four microscope slides were prepared from each sample and examined. Taxonomic identifications were primarily based on the key in Foissner & Berger (1996).

Ciliate biomass was estimated by multiplying the numerical abundance by the mean cell volume calculated from direct volume measurements using appropriate geometric formulas (Finlay 1982). An obvious shrinkage of stained ciliates was noticed to the protargol preparation. Therefore calculated cell volumes were multiplied with a correcting factor of 0.4 (Jerome et al. 1993).

The similarity of planktonic ciliate communities between the peat-bog reservoirs was calculated using of Jaccard's method:

$$S_{xy} = \frac{c}{a+b-c} \times 100\%$$

where: S_{xy}- faunistic similarity between data sets x and y, c- number of taxa common for sets x and y, a- number of taxa in set x, b- number of taxa in set y.

Once a month, water samples for chemical analyses were collected simultaneously with ciliate samples. Conductivity and pH were determined *in situ* using a JENWAY 3405 electrode, TOC was determined using the PASTEL UV and P_{tot} was analysed in the laboratory, according to Hermanowicz et al. (1976).

All data collected were analysed statistically by means of GLM and CORR procedures of the SAS Programme. One-way ANOVAs with post-hoc Bonferroni tests were run on abundance and biomass data to separately assess the protozoan variability between the reservoirs. Principal Components Analysis (PCA) was undertaken in order to determine the dominant taxa and the relative contributions of other groups of ciliates. Canonical Correspondence Analysis (CCA) was performed to relate water chemistry variability to ciliate occurrence.

In the table and figures the study reservoirs are positioned according to their mean pH (Table 1, Figs. 1a-b, 2).

RESULTS

Chemical properties of water

Of the studied peat-bog reservoirs, the highest pH was observed in Bagno Bubnów reservoir (pH>6) and the lowest in Jelino reservoir (pH=3.28). The chemical properties of these waters were significantly different (ANOVA, F=23.02-32.12, P=0.0112-0.0301). Conductivity and P_{tot} reached the highest values in high pH reservoirs, whereas TOC content was highest in the low pH reservoirs. The chemical characteristics of the studied reservoirs are summarized in Table 1.

Table 1

Chemical characteristics of the water of the studied peat-bog reservoirs (average values April – October 2006, ±SD)

Peat-bog reservoir	pH	Conductivity (μS cm $^{-1}$)	P_{tot} (mgP dm $^{-3}$)	TOC (mgC dm $^{-3}$)
Jelino 1 (J1)	3.28 ±0.51	26.6 ±4.4	0.201 ±0.54	152.2 ±12.4
Jelino 2 (J2)	3.52 ±0.33	29.4 ±3.8	0.200 ±0.11	146.0 ±15.6
Moszne 1 (M1)	4.2 ±0.45	87.7 ±8.9	0.205 ±0.03	114.0 ±19.2
Moszne 2 (M2)	4.6 ±0.33	90.3 ±8.7	0.204 ±0.03	121.0 ±23.4
Bagno Bubnów 1 (BB1)	6.18 ±0.40	367 ±31.2	0.235 ±0.04	18.6 ±3.4
Bagbo Bubnów 2 (BB2)	6.51 ±0.65	426 ±36.7	0.234 ±0.08	19.8 ±4.33

Taxonomic composition, abundance, biomass and relationship to chemical parameters

The number of ciliate taxa visibly differed between peat-bog reservoirs, ranging from 10 to 16. Generally the highest numbers were seen in high pH (>6) reservoirs, the lowest in low pH (3.28-4.6) reservoirs. Three taxa: *Cinetochilum margaritaceum*, *Strombidium viride* and *Strombilidium* sp. were the most frequently observed species. The calculated Jaccard's index of similarity ranged from 65% to 70%. The mean numbers of planktonic ciliates were about four times higher (26 ml^{-1}) in high pH reservoirs than in low pH (7 ml^{-1}) reservoirs (Fig. 1a). However, the greatest biomass of ciliates occurred in low pH reservoirs (6-8.3 µg ml^{-1}) (Fig. 1b). The differences between the mean

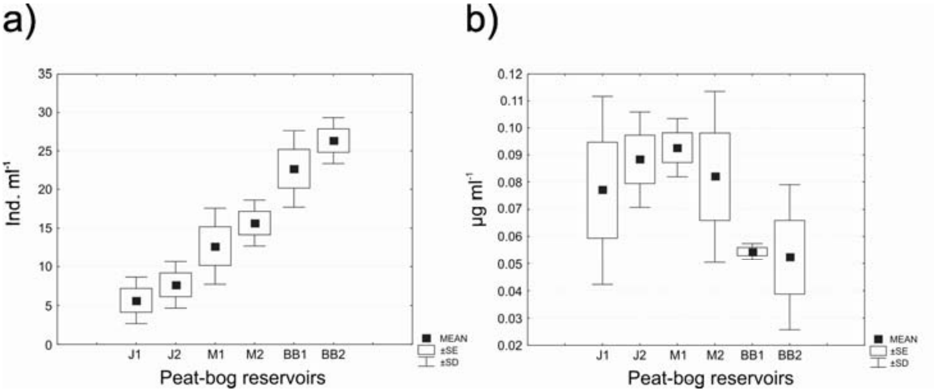

Fig. 1. Average density (a) and biomass (b) of planktonic ciliates in the studied peat-bog reservoirs (peat-bog reservoirs: J1 – Jelino 1, J2 – Jelino 2, M1 – Moszne 1, M2 – Moszne 2, BB1 – Bagno Bubnów 1, BB2 – Bagno Bubnów 2).

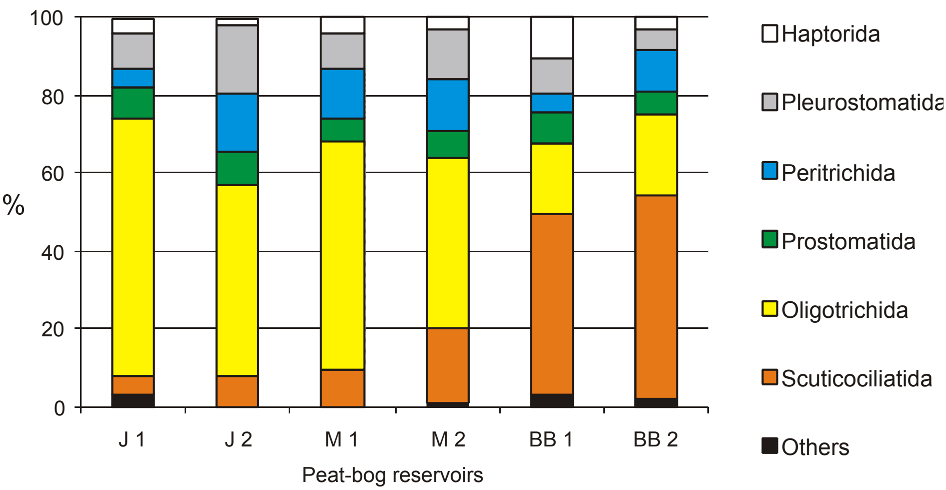

Fig. 2. Community structure of dominant planktonic ciliate orders in the studied peat-bog reservoirs (peat-bog reservoirs: J1 - Jelino 1, J2 - Jelino 2, M1 – Moszne 1, M2 Moszne2, BB1 – Bagno Bubnów 1, BB2 – Bagno Bubnów 2).

densities and biomass of ciliates in the different reservoirs were statistically significant (ANOVA, F=30.22, P=0.015 and ANOVA, F=29.4, P=0.0014, respectively). The community compositions of ciliates were related to pH of the particular peat-bog reservoirs. In low pH reservoirs the most abundant were Oligotrichida *(Strombidium viride*, *Strombilidium* sp.*)*, whilst in high pH reservoirs Scuticociliatida *(Cinetochilum margaritaceum, Cyclidium* sp.*)* were the most abundant (Fig. 2). The seasonal changes of ciliate communities in the reservoirs were quite similar, with lowest densities in July, dominated by mixotrophic Oligortichida, and peak values reached in October, when large numbers of small Scuticociliatida were seen. Overall three types of planktonic ciliate community were seen, with different structures (as determined by PCA). The first type were from low pH reservoirs, the second from reservoirs with pH>4, and the third from reservoirs with pH close to neutral (Fig. 3). The first community type was the biggest and contained 86% of the ciliate groups, whilst the second contained only 6% of ciliate groups.

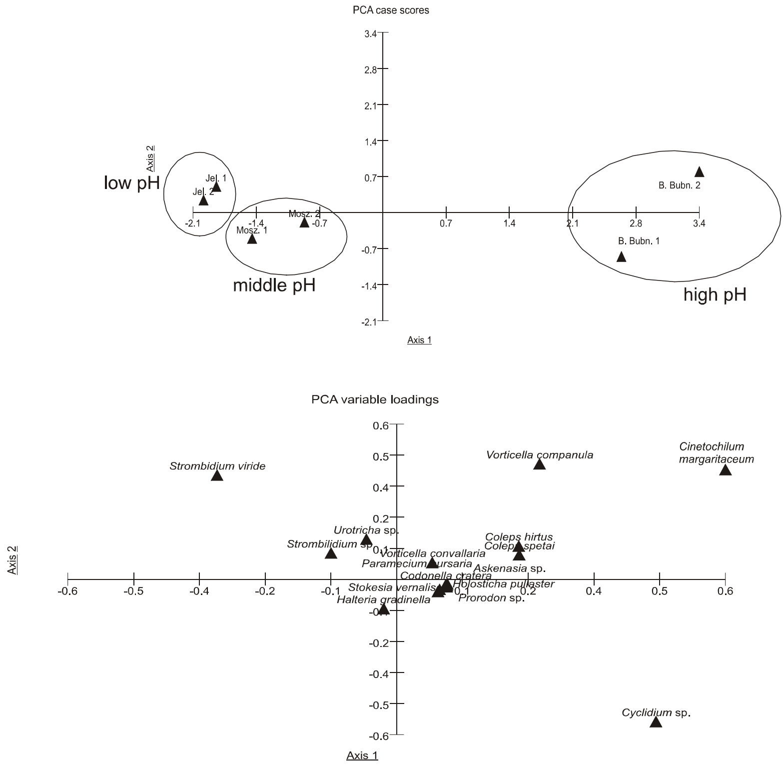

Fig. 3. Diagram of the Principal Components Analysis (PCA).

The protozoan community was numerically dominated by bactivorous taxa (35-60% of the total numbers), which occurred in the greatest proportion in high pH reservoirs. Omnivorous species (known to feed on autotrophs, other protozoans and even on small metazoans) also occurred in great numbers constituting 20%-46% of the total numbers of protozoa. Microorganisms feeding on mixed food (bacteria, flagellates and algae), predatory, mixotrophic and algivorous constituted from 10% to 15% of the total community.

CCA illustrated that certain chemical properties of water had a clear effect on the community structure of the microorganisms. In the studied reservoirs, the classification of environmental changes shows that axis 1 is most closely related to the pH, conductivity and TOC of the water and reflects the reaction of ciliates to these factors, while axis 2 is more closely related to the P_{tot} of the reservoir (Fig. 4). In the CCA diagram axis 1 accounted for 86% of the total cumulative variance in the ciliate data, while axis 2 accounted for only 6.3%. The results show that planktonic ciliate abundance is most dependent on pH in the summer ($r=0.63$, $p\leq0.01$), whist in spring and autumn TOC and conductivity are probably the major regulators ($r=0.45$-0.53 and $r=0.40$-0.43, $p\leq0.05$, respectively).

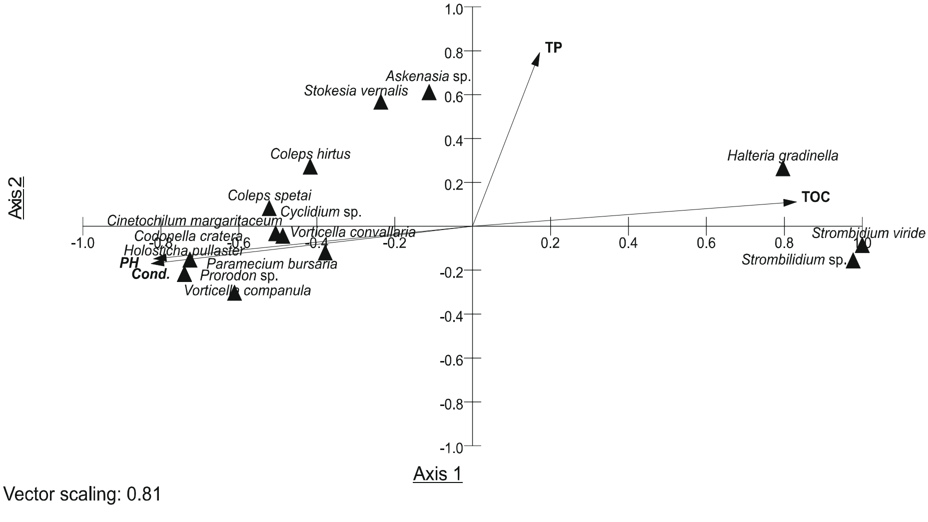

Fig. 4. Canonical Correspondence Analysis (CCA) ordination diagram showing the relation between ciliates and environmental variables.

DISCUSSION

The diversity of species of planktonic ciliates in the investigation of peat-bog reservoirs of Polesie Lubelskie were similar to those observed in humic lakes (Beaver & Crisman 1989, Kalinowska 2000). To date, the taxa of planktonic ciliates in small peat-bog reservoirs have not been investigated because it is difficult to cross compare results. However, it seems that by establishing the diversity of protozooplankton in peat-bog reservoirs and humic lakes, and their relationships to the chemical properties of these two types of water body, such a comparison may be possible.

In the studied reservoirs the number of ciliate species increased with increasing pH. This characteristic was also observed by Crisman & Brezonik (1980) in subtropical, acid lakes. The number of ciliates in low pH reservoirs was close to that observed in humic lakes in Poland (Kalinowska 2000) and in mesohumic lakes in Finland (Järvinen 1993); although comparisons with other reports in the literature were less obvious, e.g. slightly acid lakes in Florida (Carrias et al. 1994), as well as boreal lakes in Finland (Sarvala et al. 1999). These differences may be as a result of the lower pH values seen in the reservoirs investigated in this study. Lower numbers of ciliates might also result from humus originating from the peat limiting light penetration, and hence limiting autotrophic and mixotrophic microorganisms that constitute a food source for them (Amblard et al. 1995). In the high pH reservoirs the species composition and number of ciliates were close to those observed in eutrophic lakes (Mieczan 2007).

In the peat-bog reservoirs with the lowest pH large mixotrophic ciliate taxa *(Strombidium viride)* were prevalent. In the reservoirs with low pH and highest TOC concentrations, the majority appeared to be Oligotrichida *(Strombidium viride, Strombilidium* sp.*)*, throughout the period of investigation. However, with increasing pH, there was an increased abundance of Scuticociliatida *(Cinetochilum margaritaceum, Cyclidium* sp.*)*, these organisms apparently having a moderate capacity for propagation in all water types. The dominance of the *Strombidium* was consistently observed, as it had been previously in lake and river planktonic communities (Foissner & Berger 1996, Madoni et al. 2000), and in oligotrophic, mesotrophic and eutrophic water. Generally the next most abundant were members of the Scuticociliatida, which have been observed in eutrophic, mesotrophic and humic lakes previously (Järvinen 1993). Beaver and Crisman (1981), reported dominance of Oligotrichida in waters with a pH<5, while investigations carried out in recent years have shown a distinct increase in the activity of Prostomatida, Hypotrichida and Peritrichida in reservoirs with very low pH (Packroff 2000). In all investigations of reservoirs very small ciliates are distinctly dominant, as was also reported for strongly acid humic lakes (Carrick & Fahnenstiel 1990). The size fraction of ciliates reported by Beaver & Crisman (1981) increased with increasing acidity. The dominance of small ciliates observed in such reservoirs may result from poor food quality, for example the low abundance of bacteria. It is probable that in peat-bog reservoirs not only the pH, but also the conductivity and organic content of the water influence microorganism abundance. In all the reservoirs studied TOC was positively correlated with ciliate numbers. A significant correlation with organic matter was also reported in European humic lakes (Amblard et al. 1995). Fisher et al. (1998) reported that the abundance and production of bacteria were positively correlated with the content of organic matter in water. The higher densities of ciliates observed here, dominated by small taxa, in high pH reservoirs probably reflect such advantageous feeding conditions. Beaver & Crisman (1989), Sarvala et al. (1999) and Mieczan (2005) have shown a definite correlation between ciliate numbers and conductivity and total phosphorus in lakes of various trophic types. The results presented show ciliate abundances are impacted by pH in summer, whilst in spring and autumn the total organic carbon content and conductivity are probably the major regulators of abundance. Similarly Kalinowska (2000) demonstrated that ciliate community structure is primarily determined by pH in summer, whilst in spring additional factors may be important – probably concentration of the appropriate food.

The results of this study suggest that pH, conductivity and TOC are more important than trophic parameters (P_{tot}) in the distribution of planktonic ciliates in peat-bog reservoirs (CCA analysis). In low pH peat-bog reservoirs, the biggest factors limiting the ciliate communities are the water chemistry. In peat-bog reservoirs with higher pH the role of organic matter is a significant determining factor of the abundance and diversity of ciliates in these ecosystems.

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