Krystyna KALINOWSKA

Hydrobiological Station, Polish Academy of Sciences, Institute of Ecology,
Leśna 13, 11-730 Mikołajki, Poland,
fax: +48 087 4216 051, e-mail: panmikol@polbox.com

CILIATES IN SMALL HUMIC LAKES (MASURIAN LAKELAND, POLAND): RELATIONSHIP TO ACIDITY AND TROPHIC PARAMETERS

ABSTRACT: Ciliate communities of 16 midforest humic lakes (Masurian Lakeland, Poland) were examined in relation to abiotic (pH, calcium, conductivity) and trophic (chlorophyll a, total phosphorus) parameters. Studies were carried out in pelagial and littoral zones twice a year: in spring and summer 1997. In most lakes Oligotrichida, mainly representing of the genera *Strombidium*, *Strobilidium*, *Halteria* and Prostomatida (*Urotricha*, *Coleps*) dominated. Densities of the community varied from 0.1 to 25.0 ind. ml^{-1} and from 0.04 to 33.4 ind. ml^{-1} in pelagial and littoral, respectively. Ciliate abundance was not dependent on trophic parameters, but there were correlations between ciliate abundance and abiotic parameters (pH, calcium and conductivity), though different in spring and summer.

KEY WORDS: ciliates, humic lakes, pH, chlorophyll a

1. INTRODUCTION

Ciliates constitute an important component of the planktonic food webs in lake ecosystems (Beaver and Crisman 1982, Gates 1984, Porter *et al.* 1985, Finlay *et al.* 1988). They play a special role as consumers of bacteria, detritus and phytoplankton in environments rich in organic matter (Finlay 1978, Sherr and Sherr 1984, Güde 1989, Sanders *et al.* 1989) and in the nutrients. They are an important food resource for higher organisms (macrozooplankton) and therefore constitute a link in the food chain from bacteria to metazoans (Porter *et al.* 1979, Azam *et al.* 1983, Fenchel 1987, Weisse 1991). In addition, ciliates have been shown to serve as very sensitive indicators of water quality (Henebry and Cairns 1980). The primary factor controlling the distribution of planktonic ciliates is quality and quantity of available food resources (Pace 1982, Beaver and Crisman 1990). Bick and Drews (1973) suggested that physicochemical conditions may be important as limiting factors for ciliates. Taxonomic replacements in ciliate communities occur along gradients of both increasing productivity (Beaver and Crisman 1982) and increasing acidity in softwater lakes (Beaver and Crisman 1981). In Polish ecology studies was noted only a few publications regarding abundance and taxonomic composition of ciliate communities in lakes of different trophy (Węgleńska *et al.* 1983 – mainly eutrophic lakes) and in humic Lake Smolak and Piecek (Ejsmont-Karabin *et al.* 1980).

Humic lakes with high concentrations of humic matter have low levels of inorganic nutrients and typical brown water colour re-

duces light penetration, thus primary productivity is usually low (Tranvik 1988, Tranvik and Sieburth 1989).

Data reported for softwater subtropical lakes of Florida indicated that ciliates contributed to 2–7% of the total zooplankton biomass in the most acid lakes (pH 4.7–4.9) and 20–30% in lakes near pH 5.2 (Beaver and Crisman 1981). These authors showed that with increased acidity, both the abundance and biomass of total ciliates (Beaver and Crisman 1981) and diversity and species richness decreased (Beaver and Crisman 1989). However, studies performed by James (1991) in five acid lakes on the Katharine Ordway Preserve in Florida indicate that protozoa appear to be unaffected by pH. Also Amblard *et al.* (1995) demonstrated that the major role in the development of communities of microorganisms (bacteria, picoplankton, flagellata and ciliata) in moderately acid lake in central France play the high concentration of organic carbon of allochtonous origin and the turbidity of the water.

The aim of this study was to determine the taxonomic diversity of ciliates related to pH, and to identify an impact of abiotic (pH, calcium, conductivity) and trophic (chlorophyll *a*, total phosphorus) parameters on ciliate community in lake water in a series of 16 small mid-forest humic lakes in Masurian Lakeland (Poland).

2. MATERIAL AND METHODS

Studies have been carried out in sixteen small mid-forest lakes of different morphometry, depth, acidity (from about 3.6 to 7.5) and trophic status (total phosphorus concentration of 13 to 229 μg l^{-1}, chlorophyll *a* 1.9 to 365.9 μg l^{-1}). The lakes are located in Masurian Landscape Park of south region of the Great Masurian Lakes (Poland). Most of the lakes adjoins a peatbog formed by *Sphagnum* spp. and covered by other plants characteristic of peatlands and surrounded by pine-spruce forest watershed. Of the sixteen studied lakes twelve are brown water with low pH values, calcium content and conductivity, four are typical hardwater lakes (Tables 1 and 2).

Samples were taken on two stations: pelagic – located in the deepest part of each lake and littoral – at a border of a moss vegetation zone, twice a year: in April/May and July 1997. Ciliates were collected with a 5-litre Bernatowicz sampler, every 0.5-metre in shallow lakes and 1-metre in deeper ones, from the surface to the bottom. Samples from all layers were pooled together, carefully mixed and 500 ml sample was fixed with Lugol's solution and stored in the dark at 4° C. Each sample was condensed to 5–15 ml and ciliates were determined and counted under the NIKON microscope within 1 month storage. Three to four slides were prepared from each sample and examined. Ciliates are highly perishable and their type of motility is species specific feature, thus species determination and measurements were carried out on live material immediately after return to the laboratory. Taxonomic identifications were based especially on keys in Foissner and Berger (1996).

Temperature and dissolved oxygen were determined *in situ* with an oxygen probe. Chlorophyll *a* was determined by the spectrophotometric analysis of acetone extracts of algae (Golterman 1969). Total phosphorus was analysed by spectrophotometric determination according to Standard Methods (1960). Total nitrogen was analysed by the standard Kjeldahl procedure. Calcium content was determined by method with EDTA addition and conductivity by the Standard Methods.

In all tables and figures the study lakes are ranked according to the increasing values of their mean pH.

Table 1. Physical characteristic of the study lakes. Abbreviations: MVZ – moss vegetation zone, SV – submerged vegetation, SC – sedge communities, D – dimictic, P – polymictic, M – meromictic. Lakes are ranked according to the increasing values of their mean pH (see Table 2).

Lake	Mixis	Area (ha)	Max. depth	Type of littoral zone
Smolak Mały	P	3.4	2	MVZ
Kruczy Staw	D	2.1	8	MVZ
Kruczek	P	4.2	4	MVZ
Kruczek Mały	D	2.6	9	MVZ
Wesołek	P	7.0	3	MVZ+SC
Zdrużno	P	6.8	5	MVZ
Borkowskie	P	2.9	5	MVZ
Smolak n. Mal.	P	2.0	2	MVZ
Smolak Wielki	P	9.9	3	MVZ+SV
Sęczek	P	3.8	3.5	MVZ
Klimunt	P	12.8	4	SC
Gryżlewskie	P	4.3	5	MVZ+SC
Nicponek	P	9.3	3	SC+SV
Lisunie	M	3.8	9	SC+SV
Oczko	P	9.5	4	SV
Linówko	P	7.0	1.5	SV

3. RESULTS

3.1. TAXONOMIC DIVERSITY OF CILIATES RELATED TO PH

The numbers of ciliate taxa in studied lakes ranged from 2 to 13 in spring and from 1 to 17 in summer. The highest number of ciliate taxa was noted in Lake Lisunie (13 in spring, 17 in summer), the lowest in Lake Zdrużno (2 in spring, 1 in summer). In more acidic lakes markedly more ciliate species were found in spring than in summer. In spring, in lakes of pH 5.0 or lower more ciliate taxa were observed in littoral than in pelagial and the lakes were both poor (Zdrużno –

2 taxa, Wesołek – 3) and relatively rich (Kruczek, Kruczek Mały – 11) in species (Table 3). This may suggest that pH does not have decisive effect on ciliate diversity. During summer stagnation period both sampling sites of the study lakes were similar as regards the number of ciliate taxa. In lakes of pH below 6.2 maximum 5 taxa were recorded, whereas in lakes of pH 6.9–7.5 the number of ciliate taxa varied between 6 and 17 (Table 4). Thus, it seem that in summer the number of species is dependent on pH.

During the study period most of the lakes were dominated by species belonging to the order of Oligotrichida (*Strombidium* sp.,

Table 2. Chemical characteristics of the study lakes – spring (left) and summer (right) values are given of pH, chlorophyll a (μg l^{-1}), total phosphorus (μg l^{-1}), calcium (mg l^{-1}), and conductivity (μS cm^{-1}). Lakes are ranked according to the increasing values of their mean pH.

Lake	pH		Chlorophyll a		Total phosphorus		Calcium		Conductivity	
	Pelagial	Littoral	Pelagial	Littoral	Pelagial	Littoral	Pelagial	Littoral	Pelagial	Littoral
Smolak Mały	3.7 ; 3.9	3.6 ; 4.2	31.1 ; 65.5	365.9;32.8	77 ; 51	163 ; 229	6.0 ; 12.5	7.0 ; 10.8	73 ; 80	73 ; 73
Kruczy Staw	3.9 ; 4.4	3.7 ; 4.2	6.6 ; 1.6	2.0 ; 1.3	29 ; 33	18 ; 36	1.20 ; 3.1	9.0 ; 2.41	20 ; 28	22 ; 25
Kruczek	4.1 ; 4.4	4.0 ; 4.3	7.9 ; 3.6	12.1 ; 1.3	46 ; 22	37 ; 31	2.6 ; 2.24	3.2 ; 2.05	; 23	; 20
Kruczek Mały	4.2 ; 4.5	4.3 ; 5.0	4.3 ; 6.6	4.6 ; 1.6	26 ; 34	43 ; 26	1.6 ; 1.52	3.8 ; 1.09	; 18	; 18
Wesołek	3.9 ; 4.8	4.5 ; 4.6	4.3 ; 1.9	5.9 ; 3.8	48 ; 13	20 ; 27	3.4 ; 5.2	2.8 ; 2.08	38 ; 37	23 ; 23
Zdrużno	5.4 ; 4.6	5.0 ; 4.8	4.5 ; 27.9	4.7 ; 35.2	15 ; 38	5 ; 32	4.2 ; 5.4	4.2 ; 3.44	28 ; 32	28 ; 27
Borkowskie	4.6 ; 5.7	4.7 ; 5.3	19.7 ; 4.6	6.0 ; 6.0	99 ; 26	52 ; 30	3.0 ; 4.95	3.0 ; 4.38	27 ; 28	25 ; 28
Smolak n. Mal.	4.1 ; 5.9	4.2 ; 6.0	18.8 ; 20.8	12.6;20.8	30 ; 20	22 ; 31	2.8 ; 4.23	4.0 ; 4.6	80 ; 20	70 ; 22
Smolak Wielki	4.9 ; 5.1	5.0 ; 5.2	43.1 ; 29.5	43.1;14.4	127 ; 52	69 ; 37	6.2 ; 18.3	7.0 ; 8.32	43 ; 60	48 ; 50
Sęczek	4.0 ; 6.1	4.8 ; 6.0	60.8 ; 23.6	65.5;24.9	63 ; 36	82 ; 34	6.2 ; 4.73	7.0 ; 6.99	37 ; 23	28 ; 23
Klimunt	5.3 ; 5.7	5.3 ; 5.7	13.4 ; 8.2	12.1;12.2	49 ; 27	43 ; 28	3.8 ; 4.39	7.2 ; 3.86	25 ; 40	35 ; 35
Gryżlewskie	5.4 ; 6.2	5.1 ; 6.2	14.7 ; 4.4	10.9 ; 2.2	61 ; 34	36 ; 73	6.6 ; 5.18	3.6 ; 4.57	48 ; 25	32 ; 30
Nicponek	6.5 ; 7.5	5.4 ; 7.3	27.0 ; 24.6	2.5 ; 3.8	85 ; 68	78 ; 76	6.8 ; 3.74	7.2 ; 6.29	48 ; 47	50 ; 30
Lisunie	7.0 ; 7.1	6.8 ; 6.9	9.2 ; 4.1	6.1 ; 1.6	19 ; 33	17 ; 19	66.8; 5.7	50.0;3.37	372;379	392;379
Oczko	7.0 ; 7.3	7.0 ; 7.1	13.0 ; 22.5	14.7;19.3	73 ; 49	195 ; 56	53.4;31.2	50.6;19.8	266;206	266;212
Linówko	7.1 ; 7.3	7.1 ; 7.1	4.2 ; 17.9	16.7;28.9	48 ; 129	74 ; 98	54.0;32.4	54.0;31.7	259;193	259;199

small *Strobilidium*, *Strobilidium* > 30 μm and *Halteria* sp.); second in importance were the Prostomatida (*Coleps spetai, Coleps hirtus, Urotricha* sp., *Holophrya* sp.) and Peritrichida. In spring Scuticociliatida (in littoral of Lake Kruczek Mały and Linówko) and Tintinnids (in pelagial of Lake Kruczy Staw and in littoral of Lake Gryżlewskie) dominated (Table 3). In summer ciliates bearing algae: *Stentor* sp. (Heterotrichida) in pelagial of Lake Nicponek and probably *Bursellopsis* sp. (Prostomatida) in littoral of Lake Smolak Wielki were more abundant (Table 4). Mixotrophic *Strombidium* sp. with symbiotic zoochlorellae was the most frequent species occurring in both pelagial and littoral samples of lakes with pH of a range 3.9–7.1. The genus constituted 32–86% of the total ciliate numbers in spring and 49–82% in summer. In five lakes (Kruczy Staw, Kruczek, Zdrużno, Borkowskie, Smolak n. Malinówko) it was the only species noted in summer. *Strobilidium humile* markedly dominated in pelagial of Lake Smolak Wielki in spring, contributing to 94% of the total abundance of ciliates. Small filter-feeding bacterivorous scuticociliates (mainly *Cyclidium* sp. and *Uronema* sp.) and the order of Peritrichida were most abundant in lakes of high pH. In spring Peritrichida were limited to littoral zone of more acidic lakes, whereas in summer they occured only in lakes of the highest pH. *Coleps spetai* and *C. hirtus* showed the maximum abundance mainly in lakes with high pH (Lisunie and Linówko).

3.2. ABUNDANCE OF CILIATES RELATED TO PH AND TROPHIC PARAMETERS

The abundance of ciliate community during spring circulation period varied from 0.1 to 25.0 ind. ml^{-1} and from 0.04 to 5.7 ind. ml^{-1} in pelagial and littoral zones, respectively (Fig. 1). The highest number of ciliates in pelagial was observed in Lake Smolak Wielki (pH 4.9) during the mass

development of small *Strobilidium* sp., which constituted about 96% of the total density of ciliates In lakes Wesołek and Zdrużno (pH 3.9 and 5.4) the lowest abundances of ciliates (<0.2 ind. ml^{-1}) were recorded. In littoral the highest numbers of ciliates were noted in Lake Kruczy Staw (pH 3.7) and Lisunie (pH 6.8). The abundances of ciliate communities in spring both in pelagial and littoral were high in lakes with both low and high pH.

In summer stagnation period the abundance of ciliates ranged from 0.2 to 10.8 ind. ml^{-1} and from 0.04 to 33.4 ind. ml^{-1} in pelagial and littoral, respectively (Fig. 1). Only one lake – Smolak Mały (the most acidic of pH 3.9 in pelagial and 4.2 in littoral) was completely devoid of ciliates. The maximum numbers of ciliated protozoa were noted in lakes with the highest pH values, i. e. Linówko, Lisunie, Oczko and Nicponek (Table 4). In summer, generally, ciliate numbers decreased with increased acidity. They were higher in pelagial than littoral, except of Lake Linówko where littoral values were ten times higher than pelagial ones.

Statistical analysis using data from both types of sites and periods revealed that trophic parameters (chlorophyll *a* and total phosphorus) were no significantly related to ciliate numbers (Table 5). The only significant and positive linear correlations occurred between ciliate densities and pH (Fig. 2), conductivity (Fig.3) and calcium (Fig. 4). However, as shown in Table 5, ciliate abundances were more dependent on these abiotic parameters in summer than in spring.

The absence of statistical relationship between ciliate numbers and chlorophyll *a* concentrations in both study periods may be explained by the fact that ciliates are selective to algae food. Total phosphorus is the another factor not influencing directly the abundance of ciliates.

Table 3. The composition and abundance of the major ciliate taxa in pelagial (P) and littoral (L) of humic lakes of Masurian Lakeland in spring. • <0.1 ind. ml^{-1}, + 0.1–1.0 ind. ml^{-1}, ++ between 1.0 and 10.0 ind. ml^{-1}, +++ >10.0 ind. ml^{-1}. Lakes are ranked according to the increasing values of their mean pH (see Table 2).

Taxa		Smolak Mały	Kruczy Staw	Kruczek	Kruczek Mały	Wesołek	Zdrużno	Borkowskie	Smolak n. Mal.	Smolak Wielki	Sęczek	Klimunt	Gryźlewskie	Nicponek	Lisunie	Oczko	Linówko
Oligotrichida																	
Strombidium sp.	P			++		+			no	+	+	++	+		+	++	•
	L	•		+	+			+	data	+	+	++			+	++	
Strobilidium <30 μm	P		+	+			+			+++			+	+	++	+	
	L			•		•		+		+	+			+	++	+	
Strobilidium >30 μm	P				+									+			+
	L	+										+		+			+
Halteria sp.	P	+	+	+								+			+		
	L		+	+							+	+			+		•
Tintinnids	P		+					+		+					+		
	L		•	+	•								++				+
Prostomatida																	
Coleps spetai	P	+								+					++		
	L	•	+						+	•							
Coleps hirtus	P												+	•	++		++
	L		++	+						+					+		
Urotricha sp.	P															+	
	L		++		+				•								
Other prostomatids	L							+								+	
	P			+	•									+			

Taxon	P/L	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Haptorida																
Askenasia sp.	P				•				+	+	+			+		
	L			+	•				+		+	+		+		
Other haptorids	P							•								
	L				•					•				•		
Peritrichida	P							+				•	•	+		
	L		+	•	+		•		•	+	+	•	+	•		
Scuticociliatida	P		•								+			+	+	
	L		•		+					+				•	•	++
Hymenostomatida	P												•	+		
	L		+	+	+					•		•			+	+
Pleurostomatida	P															
	L			+	+									+	•	
Heterotrichida	P				•											
	L				+									•		+
Unidentified ciliate	P															
	L								+	+						
Total number of taxons	P	2	4	3	2	2	1	4	4	3	4	5	4	9	8	4
	L	3	9	11	10	2	1	2	10	8	7	3	4	9	5	5

Table 4. The composition and abundance of the major ciliate taxa in pelagial (P) and littoral (L) of humic lakes of Masurian Lakeland in summer. $\bullet$ <0.1 ind. ml^{-1}, + 0.1–1.0 ind. ml^{-1}, ++ between 1.0 and 10.0 ind. ml^{-1}, +++ >10.0 ind. ml^{-1}. Lakes are ranked according to the increasing values of their mean pH (see Table 2).

Taxa		Smolak Mały	Kruczy Staw	Kruczek	Kruczek Mały	Wesołek	Zdrużno	Borkowskie	Smolak n. Mal.	Smolak Wielki	Sęczek	Klimunt	Gryżlewskie	Nicponek	Lisunie	Oczko	Linówko
Oligotrichida																	
Strombidium sp.	P	not found	++	++	•	++	+	+	+		+	+	+	•	+	++	
	L			•		+	+			+						++	+
Strobilidium <30 µm	P									+							
	L									+				•	•		
Strobilidium >30 µm	P													+			
	L				•											+	
Halteria sp.	P												+		+		++
	L					•						•			+	+	+++
Tintinnids	P													+	•		
	L																
Prostomatida																	
Coleps spetai	P														++		++
	L														+		+
Coleps hirtus	P											+			++	++	
	L													+	+		
Urotricha sp.	P													+			
	L					+						•		+			+
Other prostomatids	L				+					+				+	++		
	P									++							

Krystyna Kalinowska

Haptorida																
Askenasia sp.	P			•									+	•	•	
	L												+	•	+	
Other haptorids	P											+		•	+	
	L													•		
Peritrichida	P										•	+	++	+	+	•
	L											+	+	++		
Scuticociliatida	P										•			+		
	L												•			
Hymenostomatida	P							+				•	++	•		
	L										•					
Pleurostomatida	P												+		•	
	L											•				
Heterotrichida	P											++	•	•		
	L															
Unidentified ciliate	P											•			•	
	L										•		•			
Total number of taxons	P	1	1	3	1	1	1	1	3	1	4	4	9	14	8	7
	L	–	1	1	3	1	no data	no data	2	no data	5	no data	15	8	8	5
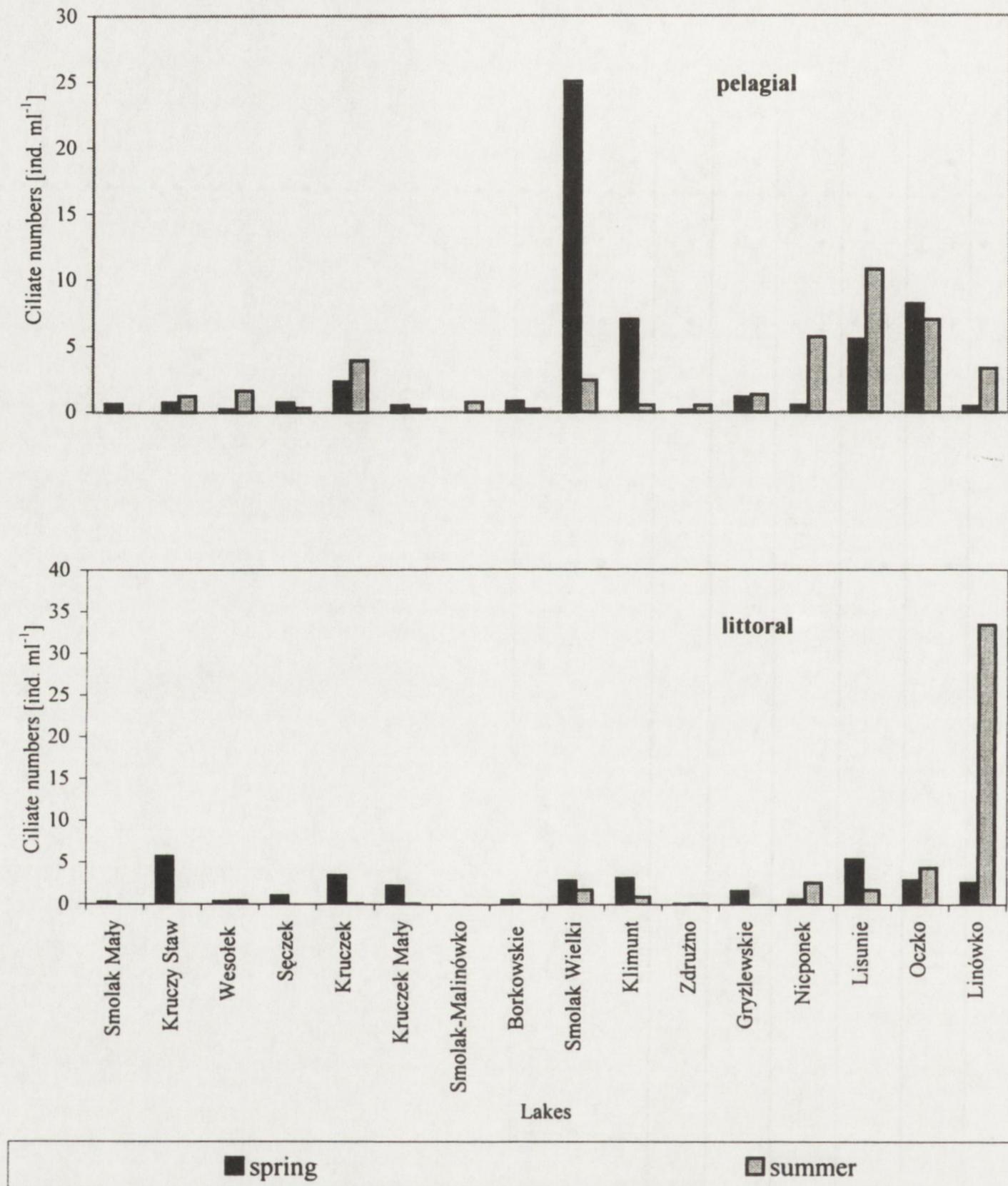
Fig. 1. The abundance of ciliates in humic lakes of Masurian Lakeland. Lakes are ranked according to the increasing values of their mean pH (see Table 2)

Table 5. Linear correlation coefficients between ciliate abundance and abiotic and trophic parameters in humic lakes of Masurian Lakeland. Ca – calcium, TP – total phosphorus. Significant correlations are marked with stars. Correlations are positive and significant at the 95 % confidence level.

Independent variable	Spring			Summer			Spring + Summer		
	r	*P*	n	r	*P*	n	r	*P*	n
pH	0.149	0.432	30	0.474	0.011	28 *	0.326	0.013	58 *
Ca	0.154	0.418	30	0.582	0.001	28 *	0.263	0.046	58 *
Conductivity	0.148	0.471	26	0.455	0.015	28 *	0.310	0.023	54 *
TP	0.218	0.247	30	0.215	0.271	28	0.210	0.220	58
Chlorophyll	−0.05	0.801	30	0.137	0.707	28	−0.01	0.819	58
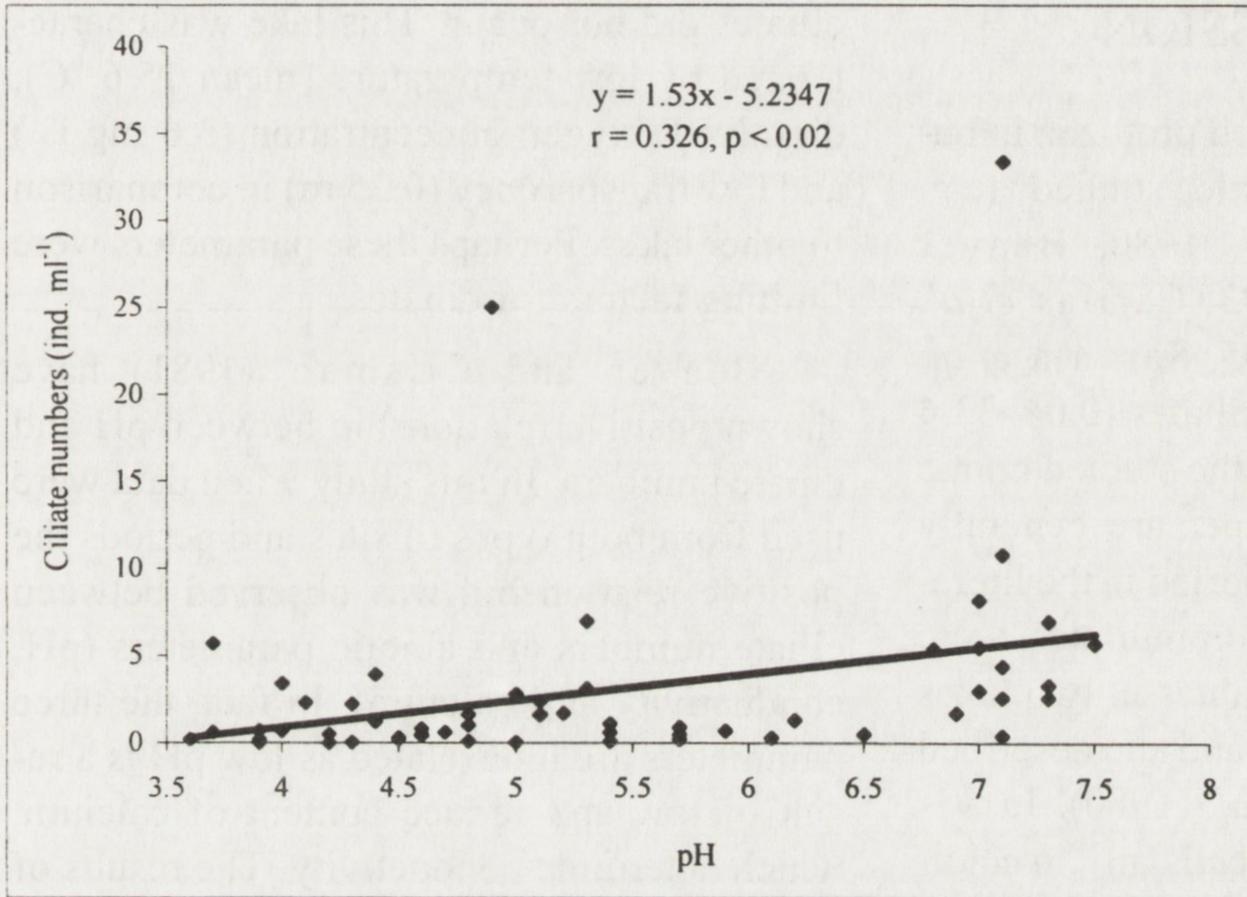
Fig. 2. Relationship between ciliate numbers and pH in humic lakes of Masurian Lakeland

$y = 1.53x - 5.2347$
$r = 0.326, p < 0.02$
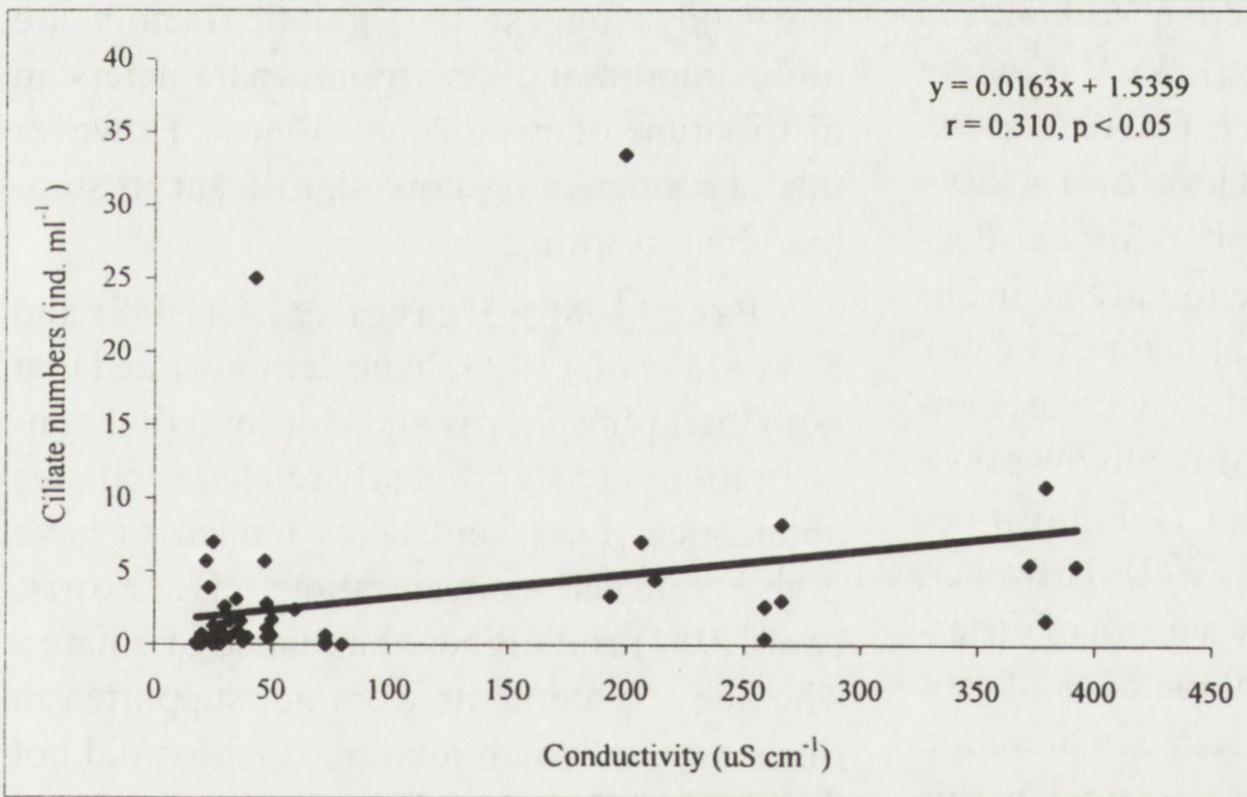
Fig. 3. Relationship between ciliate numbers and conductivity in humic lakes of Masurian Lakeland

$y = 0.0163x + 1.5359$
$r = 0.310, p < 0.05$
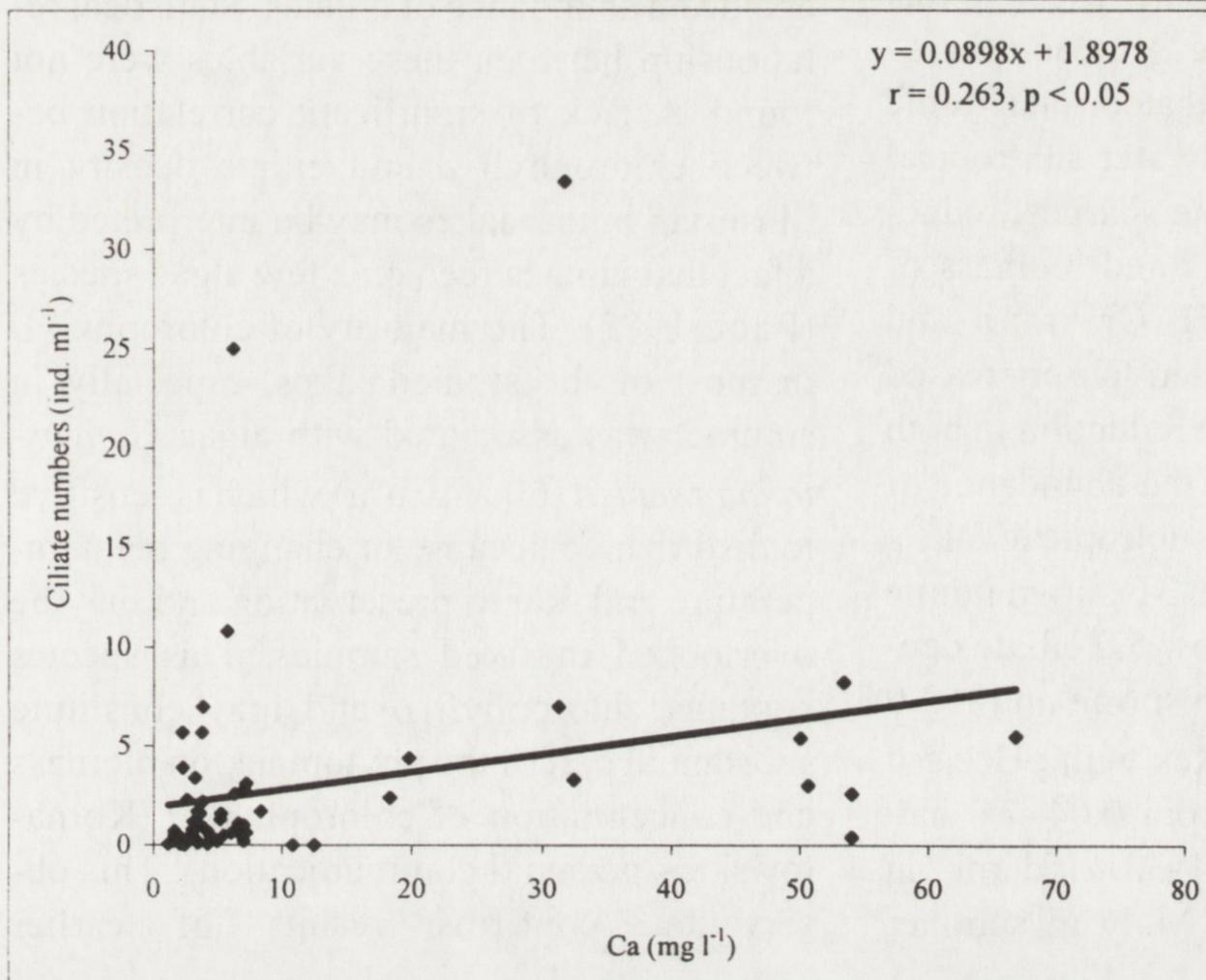
Fig. 4. Relationship between ciliate numbers and calcium in humic lakes of Masurian Lakeland

$y = 0.0898x + 1.8978$
$r = 0.263, p < 0.05$

4. DISCUSSION

Data referring to ciliated protozoa in humic lakes have been little studied (e.g. Ejsmont-Karabin *et al.* 1980, Beaver *et al.* 1988, Järvinen 1993, Carrias *et al.* 1994, Amblard *et al.* 1995, Sarvala *et al.* 1999). The abundance of ciliates (0.04–33.4 ind. ml^{-1}) found in most of the studied humic lakes presented in this paper are generally much lower than values reported in the literature. Number of ciliate communities were only similar to the study values in two lakes of pH < 4.5 reported for Poland and described in Ejsmont-Karabin *et al.* (1980). Järvinen (1993) recorded 5–26 cells ml^{-1} in acidified mesohumic forest Lake Iso Valkjärvi in southern Finland. In a humic Lake Vassiviere in Central Massif of France Carrias *et al.* (1994) noted ciliate abundance of 1.4–20.4 cells ml^{-1} (mean 4.8 cells ml^{-1}). Similar densities of > 20 cells ml^{-1} were found also in humic slightly acid subtropical lakes (Beaver *et al.* 1988), 1–27 cells ml^{-1} in Lake Constance in the 0–6 m layer of depth (Weisse 1990) and 3–12 cells ml^{-1} in 12 Finnish boreal lakes (Sarvala *et al.* 1999). However, this difference was probably a result of different pH of lakes and different methods of estimation. Range of pH values cited in literature was higher than that in lakes described in this paper (from 3.6 to 7.5). Beaver and Crisman (1981) who investigated planktonic ciliate communities in softwater subtropical lakes (pH 4.7–6.8) noted the sharpest reduction both the total numbers and biomass of ciliates in lakes < 5.0 pH. Crisman and Brezonik (1980), concluded that increased acidity is accompanied by a reduction in both the number of species and the abundance of the total zooplankton in subtropical lakes. This trend is less obvious in Masurian humic lakes. In lakes with pH below 5.0 ciliate density was < 25.0 ind. ml^{-1} in spring and < 3.9 ind. ml^{-1} in summer. In lakes with pH ≥ 5.0 ciliate abundance varied from 0.04–7.0 ind. ml^{-1} in spring and from 0.04–33.4 ind. ml^{-1} in summer. In Lake Smolak Mały in summer ciliates did not occur. This lake was characterized by low temperature (mean 15.6 °C), dissolved oxygen concentration (3.6 mg l^{-1}) and low transparency (0.25 m) in comparison to other lakes. Perhaps these parameters were limiting factors for ciliates.

Beaver and Crisman (1981) have shown positive relationship between pH and ciliate numbers. In this study when data were used from both types of sites and periods the positive relationship was observed between ciliate numbers and abiotic parameters (pH, conductivity and calcium). In fact, the three parameters are interrelated as low pH is a result of low and reduce content of calcium, which determine conductivity. The results of this study suggest that abiotic factors are more important than trophic parameters in distribution of protozoan ciliates. However this dependence is more significant in summer than in spring.

Pace (1986), Beaver *et al.* (1988) and Sarvala *et al.* (1999) have demonstrated that both total phosphorus and chlorophyll *a* concentrations are significantly related to ciliates abundance. Less acid lakes tended to have higher nutrient concentrations (Brezonik *et al.* 1984) and higher abundance of ciliates. The above statements were not supported in this study, in which total phosphorus did not decide on abundance of ciliates. Statistical relationship between these variables were not found. A lack of significant correlation between chlorophyll *a* and ciliate density in Masurian humic lakes may be interpreted by a fact that ciliates feed on a few algae species (Pace 1982). The majority of chlorophyll *a* in most of the studied lakes, especially in summer was associated with algae *Gonyostomum semen* (60 × 40 μm) which is sensitive to disturbance because of changing pH, temperature and due to preservation and may be overlooked in fixed samples. This species contains chlorophyll *a* and may constitute substantial part of the phytoplankton biomass and concentration of chlorophyll *a* (Kornatowska – personal communication). This observation confirms results of earlier

investigations in eutrophic lake Esthwaite (Laybourn-Parry *et al.* 1990). These authors stated that a large part of chlorophyll *a* is built in cells too large to be consumed by protozoa. Only high ciliate numbers in spring in Lake Smolak Wielki (about 25.0 ind. ml^{-1}) seem to be response to the phytoplankton spring bloom (chlorophyll *a* concentration amounted to 43 µg l^{-1}).

From one to seventeen ciliate taxa were found in pelagial and 1 to 12 in littoral. The values were similar to those noted in pelagial of other lakes of comparable pH. Henebry and Cairns (1984) found in wetland acid lakes 1–12 species, in lakes of pH 3.6 – 1 species and in lakes of pH 4.7 – 6 species. Ejsmont-Karabin *et al.* (1980) reported 11–13 species for the study conducted in two humic lakes in Poland. Several authors have reported decreasing numbers of species with decreasing pH in humic lakes. Beaver and Crisman (1989) concluded that the number of species was significantly lower in acid oligotrophic lakes (8–13) than in nonacid lakes (6–21).

Taxonomic replacements in ciliate communities occur along gradients of both increasing productivity and increasing acidity in softwater lakes (Beaver and Crisman 1981, 1982). The authors observed that smaller ciliates of 20–30 µm size were progressively replaced by larger ciliates (40–50 µm) with decreasing pH.

The ciliate species composition in humic lakes of Masurian Lakeland is similar to that reported in other papers (e.g. Carrias *et al.* 1994, Amblard *et al.* 1995).

In accordance with data reported for humic lakes (Pace 1982, Beaver and Crisman 1989) ciliates were dominated by the order Oligotrichida (mainly in lakes of low pH) which are typical of many lakes in the temperate region (e.g. Mathes and Arndt 1995) and the dominant order in oligotrophic situations (Beaver and Crisman 1982, Hunt and Chein 1983). In this study ciliate communities were mainly composed of mixotrophic *Strombidium* sp. The genus is a significant component and often dominate in ciliate communities in many lakes of all lake types (Beaver and Crisman 1989, Müller 1989). These results are in good agreement with the statement of Carrias *et al.* (1998), who demonstrated that the relative importance of *Strombidium* was markedly higher in summer than in spring.

Filter-feeding bacterivorous groups of ciliates (Scuticociliatida, Peritrichida and small *Strobilidium* sp.) were characteristic for lakes of higher pH. Müller (1989) showed that Scuticociliatida in Lake Constance form a significant part of the ciliate community only in profundal mainly in summer and autumn. Their importance increase with eutrophication (Beaver and Crisman 1990).

Omnivorous *Coleps* spp. the genus characteristic for eutrophic water bodies (James *et al.* 1995) dominated in pelagial of lakes of pH > 7.0.

The studies showed that ciliate community is determined by pH mainly in summer. In spring additional factors may be important or they may mask the pH effect (James 1991). Pace (1982), Gates (1984) and Weisse (1990) demonstrated that concentrations of appropriate food (bacteria, nanoflagellates, algae) are probably the major regulator of abundance, biomass and diversity of planktonic heterotrophic ciliates. However, most authors (Müller 1989, Carrick and Fahnenstiel 1990, Berninger *et al.* 1993, Laybourn-Parry 1994, Carrias *et al.* 1998) affirm that predation by copepods and cladocerans probably plays a major role in controlling the abundance of planktonic ciliates in temperate lakes. The study lakes contained high proportion of mixotrophic taxa, and thus may be less dependent on bacterial food. Further studies are needed to estimate an effect of food resource and the impact of macrozooplankton on ciliates .

5. SUMMARY

The ciliate abundance and species composition were analysed in 16 mid-forest humic lakes of Masurian Lakeland (Poland) in pelagial and littoral zones twice a year in relation to abiotic and trophic parameters. The lakes are characterized by the wide range of pH and other physicochemical parameters (Tables 1 and 2). Most of the studied lakes were generally dominated by ciliates belonging to the order of Oligotrichida (*Strombidium, Strobilidium, Halteria*) and Prostomatida (mainly *Coleps spetai* and *Coleps hirtus*). In summer pelagial and littoral were occupied mainly by mixotrophic *Strombidium* sp. In some lakes they were the only recorded species. *Strobilidium* spp., *Halteria* sp. and in less acid lakes *Coleps* spp. were often dominants (Tables 3 and 4). In spring the numbers of ciliates were high in lakes with both low and high pH. In summer the maximum numbers of ciliate were noted in lakes of high pH (Fig. 1). The numbers of ciliate were dependent on pH (Fig. 2) conductivity (Fig. 3) and calcium (Fig. 4), whereas correlation between ciliate numbers and trophic parameters (chlorophyll *a* and total phosphorus) was not observed (Table 5).

6. REFERENCES

Amblard C., Carrias J. F., Bourdier G. Maurin N. 1995 – The microbial loop in a humic lake: seasonal and vertical variations in the structure of the different communities – Hydrobiologia, 300/301: 71–84.

Azam C., Fenchel T., Field J. G., Gray J. S., Meyer-Reil L. A., Thingstad F. 1983 – The ecological role of water column microbes in the sea – Mar. Ecol. Prog. Ser.10: 257–263.

Beaver J. R., Crisman T. L. 1981 – Acid precipitation and the response of ciliated protozoans in Florida lakes – Verh. Int. Verein. Limnol. 21: 353–358.

Beaver J. R., Crisman T. L. 1982 – The trophic response of ciliated protozoans in freshwater lakes – Limnol. Oceanogr. 27: 246–253.

Beaver J. R., Crisman T. L. 1989 – The role of ciliated protozoa in pelagic freshwater ecosystems – Microb. Ecol. 17: 111–136.

Beaver J. R., Crisman T. L. 1990 – Seasonality of planktonic ciliated protozoa in 20 subtropical Florida lakes of varying trophic state – Hydrobiologia, 190: 127–135.

Beaver J. R., Crisman T. L., Biernert R. W. 1988 – Distribution of planktonic ciliates in highly coloured subtropical lakes: comparison with clearwater ciliate communities and the contribution of mixotrophic taxa to total autotrophic biomass – Freshwater Biol. 20: 51–60.

Berninger U. G., Wickham S. A., Finlay B. J. 1993 – Trophic coupling within the microbial food web: a study with fine temporal resolution in a eutrophic freshwater ecosystem – Freshwater Biol. 30: 419–432.

Bick H., Drews E. F. 1973 – Selbstreinigungund ciliatenbesiedlung in Saurem Milieu (Modellversuche) – Hydrobiologia, 42: 393–402.

Brezonik P. L., Crisman T. L., Schulze R. L. 1984 – Planktonic communities in Florida softwater lakes of varying pH – Can. J.Fish. Aquat. Sci 41: 46–56.

Carrias J. F., Amblard C., Bourdier G. 1994 – Vertical and temporal heterogeneity of planktonic ciliated protozoa in a humic lake – J. Plankton Research, 16: 471–485.

Carrias J. F., Amblard C., Bourdier G. 1998 – Seasonal dynamics and vertical distribution of planktonic ciliates and their relationship to microbial food resources in the oligomesotrophic Lake Pavin – Arch. Hydrobiol. 143: 227–255.

Carrick H. J., Fahnenstiel G. L. 1990 – Planktonic protozoa in lakes Huron and Michigan: seasonal abundance and composition of ciliates and dinoflagellates – J. Great Lakes Res. 16: 319–329.

Crisman T. L., Brezonik P. L. 1980 – Acid rain: Threat to sensitive aquatic ecosystems – Proc. 73rd Air poll Contr Assoc.

Ejsmont-Karabin J., Bownik-Dylińska L., Węgleńska T., Karabin A. 1980 – The effect of mineral fertilization on lake zooplankton – Ekol. pol.: 28: 3–44.

Fenchel T. 1987 – Ecology of Protozoa: The Biology of Free-living Phagotrophic Protists – Science Tec. Inc. Madison, WI.

Finlay B. J. 1978 – Community production and respiration by ciliated Protozoa in the bentos of a small eutrophic loch – Freshwater Biol. 8: 327–341.

Finlay B. J., Clarke K. J., Cowling A. J., Hindle R. M., Rogerson A., Berninger U. G. 1988 – On the abundance and distribution of protozoa and their food in a productive freshwater pond – Eur. J. Protistol. 23: 205–217.

Foissner W., Berger H. 1996 – A user-friendly guide to the ciliates (Protozoa, Ciliophora) commonly used by hydrobiologists as bioindicators in rivers, lakes, and waste waters, with notes on their ecology – Freshwater Biol. 35: 375–482.

Gates M. A. 1984 – Quantitative importance of ciliates in the planktonic biomass of lake ecosystems – Hydrobiologia, 108: 233–238.

Golterman H. L. 1969 – Methods for chemical analysis of freshwaters. IBP Handbook No. 8 – Blackwell Scientific Publications, Oxford, Edinburgh, 172 pp.

Güde H. 1989 – The role of grazing on bacteria in plankton succession – (In: Plankton Ecology: Succession in Planktonic Communities, Ed. U. Sommer) – Brock/Springer, Berlin, pp. 337–364.

Henebry M. S., Cairns J. Jr. 1980 – The effect of source pool maturity on the process of island colonization: an experimental approach with protozoan communities – Oikos, 35: 107–114.

Henebry M. S., Cairns J. Jr. 1984 – Protozoan colonization rates and trophic status of some freshwater wetland lakes – J. Protozool. 31: 456–467.

Hunt G. W., Chein S. M. 1983 – Seasonal distribution, composition and abundance of the planktonic Ciliata of Cayuga Lake – Hydrobiologia, 98: 257–266.

James T. R. 1991 – Microbiology and chemistry of acid lakes in Florida: II. Seasonal relationships – Hydrobiologia, 213: 227–240.

James M. R., Burns C. W., Forsyth D. J. 1995 – Pelagic ciliated protozoa in two monomictic, southern temperate lakes of contrasting trophic state: seasonal distribution and abundance – J. Plankton Res. 17: 1479–1500.

Järvinen M. 1993 – Pelagial ciliates in an acidified mesohumic forest lake before and after lime addition – Verh. Internat. Verein. Limnol. 25: 534–538.

Laybourn-Parry J., Olver J., Rogerson A., Duverge P. L. 1990 – The temporal and spatial patterns of protozooplankton abundance in a eutrophic lake – Hydrobiologia, 203: 99–110.

Laybourn-Parry J., Walton M., Young J., Jones R. I., Shine A. 1994 – Protozooplankton and bacterioplankton in a large oligotrophic lake – Loch Ness, Scotland – J. Plankton Res. 16: 1655–1670.

Mathes J., Arndt H. 1995 – Annual cycle of protozooplankton (ciliates, flagellates and sarcodines) in relation to phyto – and metazooplankton in Lake Neumühler See (Mecklenburg, Germany) – Arch. Hydrobiol. 134: 337–358.

Müller H. 1989 – The relative importance of different ciliate taxa in the pelagic food web of Lake Constance – Microb. Ecol. 18: 261–273.

Pace M. L. 1982 – Planktonic ciliates: their distribution, abundance, and relationship to microbial resources in a monomictic lake – Can. J. Fish. Aquat. Sci. 39: 1106–1116.

Pace M. L. 1986 – An empirical analysis of zooplankton community size structure across lake trophic gradiens – Limnol. Oceanogr. 31: 45–55.

Porter K. G., Pace M. L., Battey J. F. 1979 – Ciliate protozoans as links in freshwater food chains – Nature, 277: 563–565.

Porter K. G., Sherr E. B., Sherr B. F., Pace M., Sanders R. W. 1985 – Protozoa in planktonic food webs – J. Protozool. 32: 409–415.

Sanders R. W., Porter K. G., Bennett S. J., DeBiase A. E. 1989 – Seasonal paterns of bacterivory by flagellates, ciliates, rotifers, and cladocerans in a freshwater planktonic community – Limnol. Oceanogr. 34: 673–687.

Sarvala J., Kankaala P., Zingel P., Arvola L. 1999 – Food webs of humic waters. Zooplankton (In: Limnology of humic waters, Eds. J. Keskitalo, P. Eloranta) – Backhuys Publishers, Leiden, pp. 181–184.

Sherr B. F., Sherr E. B. 1984 – Role of heterotrophic protozoa in carbon and energy flow in aquatic ecosystems (In: Current Perspectives in Microbial Ecology, Eds. M. J. Klug, C. A. Reddy) – Amer. Soc. Microbiol., Washington, pp. 412–423.

Standard methods for the examination of water and wastewater. 1960 – Am. Publ. Health Assoc. Inc. New York, 626 pp.

Tranvik L. J. 1988 – Availability of dissolved organic carbon for planktonic bacteria in oligotrophic lakes of differing humic content – Microb. Ecol. 16: 311–322.

Tranvik L. J., Sieburth J. McN. 1989 – Effects of flocculated humic matter on free and attached pelagic microorganisms – Limnol. Oceanogr. 34: 688–699.

Weisse T. 1990 – Trophic interactions among heterotrophic microplankton, nanoplankton, and bacteria in Lake Constance – Hydrobiologia, 191: 111–122.

Weisse T. 1991 – The annual cycle of heterotrophic freshwater nanoflagellates: role of bottom-up versus top-down control – J. Plankton Res. 13: 167–185.

Węgleńska T., Bownik-Dylińska L., Ejsmont-Karabin J. 1983 – Biotic structure and processes in the lake system of r. Jorka watershed (Masurian Lakeland, Poland). VI. Structure and dynamics of zooplankton – Ekol. pol. 31: 679–717.