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HORIZONTAL DISTRIBUTION OF PSAMMONIC CILIATES IN TWO LAKES OF DIFFERENT TROPHIC STATUS: RELATIONSHIP TO PHYSICAL AND CHEMICAL PARAMETERS

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Abstract: The aims of this study were to identify the taxonomic diversity and abundance of psammonic ciliate communities in mesotrophic and eutrophic lakes (Łęczna-Włodawa Lakeland, eastern Poland). The effect of selected physical and chemical water parameters on ciliates community was also analysed. Psammon samples were collected during three seasons: spring, summer and autumn of 2010. In each lake, in the psammolittoral, samples were collected in the euarenal, higroarenal, and hydroarenal zones. A total of 53 ciliate taxa were recorded. The highest value of the Shannon-Weaver index was recorded in summer in eutrophic lake (2.79). At the same time in mesotrophic lake, a lower value of the index was determined (0.79). The mean numbers of ciliates ranged from 516 ind.cm^{-3} in the eutrophic lake to 191 ind. cm^{-3} in the mesotrophic lake. In eutrophic lake, the highest number of ciliates was recorded in the euarenal (649 ind. cm^{-3}), and the lowest in the higroarenal (425 ind. cm^{-3}). In the mesotrophic lake, the highest average numbers were determined in the higroarenal (235 ind. cm^{-3}), and the lowest in the hydroarenal (155 ind. cm^{-3}). Irrespective of the lake trophy, Hymenostomata (*Paramecium sp.*, *Glaucoma sp.*, *Uronema nigricans*) occurred in the highest numbers (from 13 to 95%). The results demonstrated that N-NH_4, P-PO_4 and TOC can strongly regulate the abundance and taxonomic composition of ciliates. The strongest correlations between numbers of ciliates and physical and chemical water parameters were observed in the higro- and hydroarenal zones of the eutrophic lake.

INTRODUCTION

Psammon is an assemblage of organisms living in the moist sand of coastal zones of seas, lakes and rivers [5]. Psammonic organisms inhabit beaches of water bodies at various depths. In rivers, the psammon zone can reach more than 40 cm deep into sand, in seas – up to a few centimeters, and in lakes it rarely exceeds 2 cm [6]. Wiszniewski [32] recognises three zones within the psammolittoral: the hydroarenal (permanently submerged, reaching approx. 1 m into the lake), higroarenal (fluctuation zone), and euarenal, including sand up to a distance of 1 m from the water line. Organisms inhabiting the zone live in spaces between sand grains filled with water. The granulometric composition of the sand may have certain influence on the species composition and numbers of microorganisms inhabiting spaces between its grains [7]. Psammon is a complex of various groups of organisms, e.g. algae, bacteria, protozoa, rotifers, gastrotrichs and nematodes.

So far, studies on the occurrence of psammonic rotifers have been relatively numerous [1, 5, 7]. Only a few studies relate to the occurrence of other groups of organisms, particularly ciliates. Ciliates are a significant group of microplankton of aquatic environments [8]. They are an important element of the trophic structure of aquatic ecosystems. They often constitute the main group of bacterial production consumers, transferring matter and energy into higher trophic levels [14, 22, 23, 24]. Ciliates can also be used as indicators of the purity of rivers and lakes [22, 24]. Studies on the structure of psammonic ciliates are usually fragmentary. So far, only one paper on those protozoa in the psammolittoral of a eutrophic lake (Lake Mikołajskie) has been published in Poland [14]. World literature includes a few publications describing ciliates in the psammon of the Caspian Sea [1], the White Sea [18, 19, 20] and Lakes: Kinneret [17], Tanganika [4] and Baikal [27].

According to Wiszniewski [32], "hydropsammon is the main zone of development of zoopsammon; however it cannot be recognised as a transitional stage between aquatic life and life on the beach. The zone is specific in all aspects". Therefore, the psammolittoral zone may constitute a type of ecotone, i.e. a transitional zone between adjacent ecological systems. Currently, the term is understood much more widely as a transitional zone between adjacent ecological systems, with unique features determined by the space and time scale, and distinct interactions between the systems [12]. Contact zone between water and land results in development of a new species structure within its zone, and in intensification of ecological processes in comparison to adjacent environments [26, 10]. Therefore, assemblages of psammonic ciliates should also show certain species diversity and abundance in the water/land transitional zone.

Studies on the structure of ciliates in aquatic ecosystems indicate strong correlations between numbers of those organisms and physical and chemical water parameters [14, 21, 22, 23]. The most numerous positive correlations were recorded between numbers of ciliates and chlorophyll *a*, TOC, and P_{tot} in water. This suggests a distinct relation of abundance of the microorganisms to nutrient concentrations in the lake waters. High horizontal variability of physical and chemical water parameters within the psammolittoral (euarenal, higroarenal, hydroarenal) suggests that a similar pattern should be observed in the species richness and abundance of psammonic ciliates.

Scarce information on horizontal distribution of psammonic ciliates led to undertake studies on that group of microorganisms. The main objective of the study was to determine the number of taxa and abundances of psammonic ciliates in lakes of different trophic status. The effect of selected physical and chemical water parameters on development of that microorganisms was also analysed.

STUDY AREA

Two lakes of Łęczna-Włodawa Lakeland (eastern Poland, 51º N, 23º E) (Fig. 1) were selected: mesotrophic Lake Piaseczno (area 84.7 ha, maximum depth 38.8 m) with well developed sandy psammolittoral, and eutrophic Lake Sumin (area 91.5 ha, maximum depth 6.5 m) with well developed psammolittoral [29].

In the eulittoral of Lake Piaseczno the emergent vegetation is very scarce (*Carex arenaria* L., *Phragmites australis* (Cav.)Trin. ex Steud) and the submerged macrophytes,

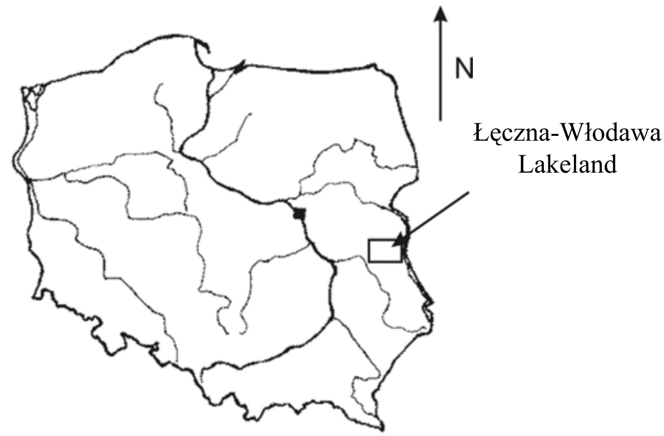

Fig. 1. Location of study area

such as *Myriophyllum alternifolium* DC. and *Ceratophyllum demersum* L. dominate. In Lake Sumin well developed belts of emergent (*Phragmites australis* (Car.), *Trinex stend* and *Typhalatifolia* L.) and submerged (*Myriophyllum spicatum*) dominate in littoral [15]. In Lake Piaseczno samples were taken in the North-East coast whereas in Lake Sumin in the South-East coast.

METHODS

Ciliates were collected in spring, summer and autumn in 2010. The samples of psammon were taken from three zones of arenal: euarenal − exposed sand, 1 m of shoreline; higroarenal − at the shoreline; hydroarenal − under water, 1 m from the shoreline.

The samples were collected with a plastic sharp-edged tube, 60 mm in diameter at four points of each zone. The samples were taken to the depth of 2 cm. From each 12 samples were collected in each season each sample was analysed at the depth of 2 cm (Fig. 2).

Each sample was shaken with saline solution and then condensed by filtering through a mesh net and fixed immediately with Lugol's solution (0.2% final concentration). Ciliate density was calculated per 1 cm^3 of sand. Observation of life samples was used for the taxonomic identification. Species identification was based on Foissner and Berger [9].

Ciliate biomass was estimated by multiplying the numerical abundance by the mean cell volume calculated from direct volume measurements using appropriate geometric formulas. Therefore, the calculated cell volume was divided by a correcting factor of 0.4 [13].

Each time the following physical and chemical parameters: pH, conductivity, temperature, total organic carbon (TOC), total phosphorus (P_{tot}), $P\text{-}PO_4$, $N\text{-}NO_3$, $N\text{-}NH_4$ and chlorophyll *a* were examined in three sites: euarenal (interstitial water), higroarenal and hydroarenal (water above the ground). Temperature, conductivity and pH were determined *in situ* using the multiparameter sensor 556 MPS (Envag). TOC was determined using the PASTEL UV, and the other parameters were analyzed in laboratory, according to Hermanowicz *et al*. [11]. Chlorophyll *a* was determined by the spectrophotometric analysis of alcohol extracts of the algae retained on polycarbonate filters.

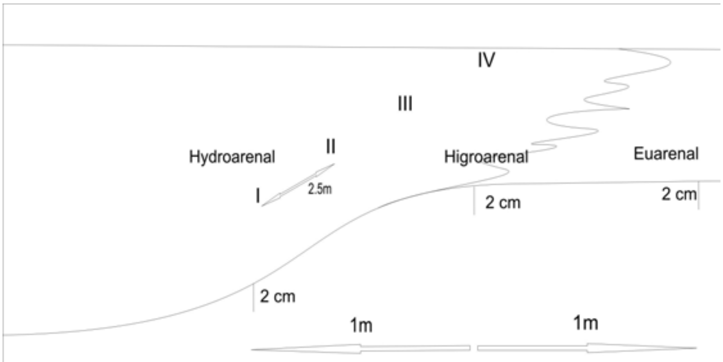

Fig. 2. The outline of beach – littoral zone with sampling station (I, II, III, IV)

The biodiversity index, expressed as the Shannon-Wiener index, was calculated using the formula [16]:

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

were: $n_{i\text{-}}$ 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: $\frac{n_i}{N}$.

The frequency of particular taxa was calculated as the percentage of collected samples in which the species occurs. All the species found were classified into the four groups: very constant species (occurring in 61–100 percent of the samples), constant species (occurring in 41–60 percent), accidental species (occurring in 21–40 percent of the samples), accessory species (occurring in less than 20 percent of the samples) [31].

The index of similarity between assemblages was calculated using the Jaccard formula:

$$JI = \frac{S_{ab}}{S_a + S_b - S_{ab}} \quad (2)$$

were: S_a − abundance taxa in assemblage *a*, S_b − abundance taxa in assemblage *b*, S_{ab} − abundance taxa in assemblage *a* and *b*.

Statistical analyses of results were carried out using the STATISTICA 7.0 software. The differences between samplings were analyzed using T-Student test. Pearson correlation coefficients were calculated between pairs of variables in order to determine the relationship between ciliates and physical and chemical parameters.

RESULTS

Physical and chemical parameters

Irrespective of the lake's trophic status and the zone analysed, neither water temperature, pH, nor chlorophyll a concentration differed significantly (Table 1).

Table 1. Physical and chemical characteristic of the psammon water of investigated lakes (* average and ** range)

Lake/ /Zone		Temp.	pH	Conductivity $\mu S \cdot cm^{-1}$	$N\text{-}NH_4$ $mgN \cdot dm^{-3}$	$N\text{-}NO_3$ $mgN \cdot dm^{-3}$	PO_4 $mgPO_4 \cdot dm^{-3}$	P_{tot} $mgP \cdot dm^{-3}$	TOC $mgC \cdot dm^{-3}$	Chlorophyll a $\mu g \cdot l^{-1}$
Piaseczno	euarenal	*19.34 **14.83-25.00	6.77 6.68-6.86	91.3 86-101	0.394 0.083-0.578	0.293 0.058-0.710	0.070 0.005-0.190	0.096 0.019-0.23	8.6 4.6-12.1	32.76 11.21-73.90
	higroarenal	*20.15 **16.80-27.44	7.13 6.74-7.50	76.0 62-89	0.423 0.015-0.94	0.326 0.065-0.840	0.049 0.001-0.140	0.175 0.025-0.390	9.2 4.0-17.8	23.40 3.44-53.07
	hydroarenal	*20.19 **16.33-26.74	7.47 6.60-8.60	111.7 90-137	0.111 0.010-0.275	0.280 0.054-0.630	0.035 0.002-0.100	0.153 0.015-0.150	4.2 3.0-5.9	25.91 13.40-50.42
Sumin	euarenal	*17.98 **13.25-21.00	8.33 7.27- 10.75	395.0 273-477	1.131 0.675-1.650	0.620 0.211-1.320	0.282 0.049-0.730	0.254 0.195-0.289	31.2 16.4-55.5	26.71 18.75-40.46
	higroarenal	*19.20 **15.27-24.58	7.37 7.24-7.63	384.7 361-412	0.362 0.246-0.430	0.334 0.102-0.750	0.028 0.001-0.080	0.337 0.029-0.870	15.2 14.6-16.4	26.31 20.26-32.97
	hydroarenal	*19.08 **15.35-24.78	7.33 7.14-7.70	417.7 403-427	0.342 0.199-0.420	0.366 0.087-0.860	0.005 0.001-0.010	0.062 0.016-0.101	14.8 13.4-16.4	23.79 17.38-29.86

Conductivity, N-NO_3, N-NH_4, P_{tot}, and TOC, in turn, reached their highest values in eutrophic Lake Sumin. The tendency was particularly distinct in the eu- and higroarenal zones. In mesotrophic Lake Piaseczno, conductivity reached from 62 µS cm^{-1} in the higroarenal to 137 µS cm^{-1} in the hydroarenal. P-PO_4 concentrations reached the highest values in the euarenal zone in both lakes (Sumin – 0.289 mg PO_4 dm^{-3}, Piaseczno – 0.190 mg PO_4 dm^{-3}). The highest content of TOC was noted in the euarenal of the eutrophic lake (55.5 mgC dm^{-3}), and the lowest in the hydroarenal of the mesotrophic lake (3.0 mgC dm^{-3}). The highest total phosphorus concentrations were recorded in the higroarenal of eutrophic lake (0.87 mgP dm^{-3}), and the lowest in the hydroarenal zone (0.015 mgP dm^{-3}) of the mesotrophic lake (Table 1).

Taxonomic composition and species frequency

In the lakes studied, a total of 53 ciliate taxa were recorded; in the eutrophic lake – 44 taxa, and in the mesotrophic lake – 35 ciliate taxa (Table 2).

Species diversity was highly varied between the studied zones. In the eutrophic lake, the highest number of taxa occurred in summer in the hydroarenal (23 taxa), and the lowest number of taxa (4 taxa) was observed in the higroarenal in autumn. In the mesotrophic lake, in turn, a considerable increase in the number of psammonic ciliate taxa occurred in autumn in the higroarenal zone, where 14 taxa of the protozoa were identified, and the lowest number of taxa (5 taxa) was observed in spring and summer.

The highest species similarity in the eutrophic lake, expressed by the Jaccard index, occurred between the hydroarenal and higroarenal zones. In the mesotrophic lake, the index was the highest between the hydro- and euarenal zones (Table 3).

The analysis of species frequency revealed one constant species in Lake Sumin, i.e., *Codonella cratera*. In Lake Piaseczno, no constant species were determined. Accessory species were recorded in each of the lakes − in Lake Sumin: *Cyclidium glaucoma*, *Paramecium sp*., *Brachonella spiralis*, *Euplotes sp*; and in Lake Piaseczno: *Cyclidium glaucoma*, *Paramecium sp*., *Glaucoma sp*. The remaining species were classified as random. Irrespective of the lake tropic status, within the euarenal and higroarenal, *constant* taxa were *Paramecium sp*. and *Codonella cratera*. In the hydroarenal, *Cyclidium glaucoma* reached the highest frequency.

The highest numbers of psammonic ciliates were determined in eutrophic Lake Sumin (516 ind. cm^{-3}). In mesotrophic Lake Piaseczno, densities were even twice lower, and amounted to 191 ind. cm^{-3}. In the zonal distribution the highest density of those microorganisms in Lake Sumin was observed in spring in the hydroarenal.

The lowest numbers in the lake were recorded in the higroarenal in autumn (Fig. 3).

In the mesotrophic lake, the highest abundance was observed in spring in the euarenal – 280 ind. cm^{-3}, and the lowest in the hydroarenal – 98 ind. cm^{-3}. Differences in protozoa biomasses were also distinctive, both between the zones and lakes (Fig. 4).

The average ciliate biomass in Lake Sumin amounted to 73.39 µg cm^{-3}, and in Lake Piaseczno to 27.65 µg cm^{-3}. The t-student analysis (level of significance $p = 0.05$) of numbers of ciliates between individual zones revealed no significant differences in numbers of the organisms between zones in individual lakes. The highest biomass was recorded in summer in the hydroarenal in Lake Sumin (240 µg cm^{-3}), and the lowest in autumn in the higroarenal (5.12 µg cm^{-3}). In Lake Piaseczno, the highest biomass occurred in spring in the hydroarenal (51.46 µg cm^{-3}), and the lowest within the same

Table 2. Taxonomic composition of psammonic ciliates of three zones in investigated lakes (Eu-euarenal, Hi-higroarenal, Hy-hydroarenal)

	Lake Piaseczno									**Lake Sumin**								
Season	Spring			Summer			Autumn			Spring			Summer			Autumn		
Zone	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy
Taxa																		
Colpodea																		
Colpoda sp.													+					
Cyrtrophorida																		
Trochilia minuta (Roux)		+		+									+			+		
Pseudochilodonopsis sp.																+		
Gymnostomatida																		
Lagynophyra acuminata (Kahl)				+	+			+	+									
Mesodinum pulex (Clap. & Lach.)								+										
Tracheophyllum sp.		+																
Spatidium spatula (Dujardin)																+		
Heterotrichida																		
Blepharisma sp.	+																	
Brachonella spiralis (Smith)				+		+							+		+	+		+
Hymenostomatida																		
Colpidium sp.		+					+		+	+		+			+			
Colpidium colpoda (Losana)		+													+			
Colpidium kleini (Foissner)											+						+	
Dexiostoma campylum (Stokes)	+	+	+					+			+	+	+		+			

Table 2. Taxonomic composition of psammonic ciliates of three zones in investigated lakes (Eu-euarenal, Hi-higroarenal, Hy-hydroarenal) – continuation

	Lake Piaseczno									**Lake Sumin**								
Season	Spring			Summer			Autumn			Spring			Summer			Autumn		
Zone	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy
Taxa																		
Dexiotricha granulosa (Kent)											+							
Dexiotrichides centralis (Stokes)																		+
Frontonia sp.			+	+		+				+	+	+						
Frontonia angusta (Kahl)																+		
Frontonia atra (Ehrenberg)								+						+				
Frontonia leucas (Ehrenberg)								+							+	+		
Glaucoma sp.	+	+	+	+	+		+		+				+		+			+
Glaucoma reniforme (Schewiakoff)		+							+						+	+		
Lembadion sp.													+	+				
Lembadion bullinum (Müller)													+	+				
Lembadion lucens (Maskell)						+							+					
Paracolpidium truncatum (Stokes)															+			
Paramecium sp.	+	+	+					+	+	+	+	+		+	+	+	+	+
Paramecium bursaria (Ehrenberg)		+					+			+	+	+			+	+		
Paramecium putrinum (Claparede)										+	+			+	+	+		+
Sathrophilus muscorum (Kahl)										+								
Stokesia vernalis (Werich)	+																	
Tetrahymena sp.		+						+					+		+			

Table 2. Taxonomic composition of psammonic ciliates of three zones in investigated lakes (Eu-euarenal, Hi-higroarenal, Hy-hydroarenal) – continuation

	Lake Piaseczno									**Lake Sumin**								
Season	Spring			Summer			Autumn			Spring			Summer			Autumn		
Zone	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy
Taxa																		
Uronema nigricans (Müller)	+				+			+	+	+	+	+	+		+	+		
Unindetified Hymenostomata								+					+		+			
Hypotrichida																		
Aspidisca cicada (Müller)								+										
Euplotes sp	+								+	+	+	+			+			
Euplotes affinis (Dujardin)											+							
Euplotes moebiusi (Kahl)	+					+							+				+	
Holosticha kessleri (Wrześniowski)										+								
Holostichia monilata (Kahl)		+							+									
Oxytrichia similis (Engelmann)										+								
Unindentified Hypotrichia															+			
Loxodes																		
Loxodes sp.	+																	
Nassulida																		
Chilodontopsis sp.								+										
Oligotrichida																		
Codonella cratera (Leidy)					+		+			+	+	+	+	+	+	+	+	+
Strombilidium humile (Penard)														+				

Table 2. Taxonomic composition of psammonic ciliates of three zones in investigated lakes (Eu-euarenal, Hi-higroarenal, Hy-hydroarenal) – continuation

	Lake Piaseczno									**Lake Sumin**								
Season	Spring			Summer			Autumn			Spring			Summer			Autumn		
Zone	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy	Eu	Hi	Hy
Taxa																		
Odontostomatida																		
Unindentified Odontostomatida	+																	
Peritrichida																		
Vorticella sp.															+			
Pleurostomatida																		
Acineria sp.															+			
Acineria incurvata (Dujardin)															+			
Litonotus sp.	+														+			
Litonotus lamella (Müller)																+		+
Prostomatida																		
Holophyra sp.	+								+									
Holophrya discolor (Ehrenberg)								+				+						
Scuticociliatida																		
Cinetochilum margaritaceum (Ehrenberg)					+		+	+			+		+	+		+		
Cyclidium glaucoma (Müller)			+	+		+	+	+	+	+	+	+		+	+	+		+
Suctoria																		
Actineta sp.															+			
Total number of taxa: 53	12	11	5	6	5	5	6	14	10	12	13	10	14	9	23	15	4	8

Table 3. Pearson correlation between ciliate density and physical and chemical factors of investigated lakes ($p \leq 0.05$)

Variables	Density					
	Lake Piaseczno			Lake Sumin		
	Euarenal	Higroarenal	Hydroarenal	Euarenal	Higroarenal	Hydroarenal
pH	-0.31	n.s.	-0.32	n.s.	0.51	-0.45
Conductivity	n.s.	n.s.	n.s.	n.s.	0.29	0.43
$N\text{-}NH_4$	n.s.	n.s.	0.31	n.s.	0.58	0.28
$N\text{-}NO_3$	0.40	n.s.	-0.31	n.s.	0.49	-0.51
$P\text{-}PO_4$	0.40	n.s.	0.50	n.s.	0.50	-0.58
P_{tot}	n.s.	n.s.	n.s.	n.s.	0.54	0.63
TOC	0.28	n.s.	0.31	n.s.	0.49	-0.63
Chlorophyll *a*	-0.27	-0.29	0.29	n.s.	0.31	-0.74

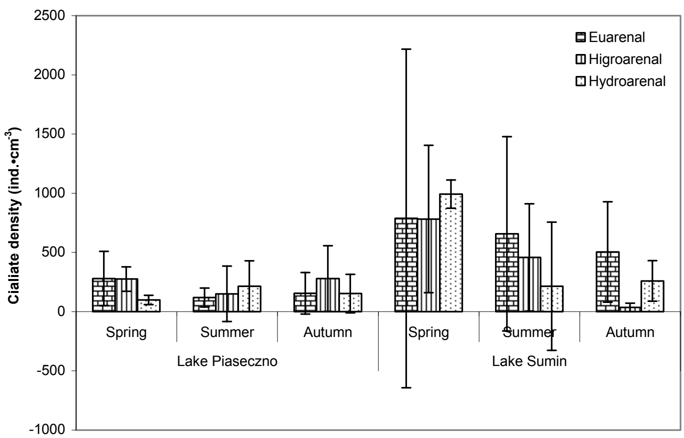

Fig. 3. Density of psammonic ciliates in investigated lakes (± standard deviation)

zone in autumn (11.93 µg cm^{-3}). The statistical significance analysis for biomass between zones and lakes revealed no significant discrepancy between the values compared.

Irrespective of the lake's trophic status, Hymenostomata reached the highest participation in total numbers (from 13 to 95% of total numbers of ciliates) (Fig. 5).

Irrespective of the season, the eulittoral zone was dominated by Hymenostomata. In the two remaining zones, participation of Oligotrichida (from < 1% to 40%) and Hypotrichida (from < 1% to 35%) increased. In the mesotrophic lake, participation of Scuticociliatida increased from 1% in spring to 60% in autumn.

Relationship between psammonic ciliates and physical and chemical factors

Total numbers of psammonic ciliates correlated positively with all of the physical and chemical water parameters analysed in the hydroarenal zone. The lowest correlation was

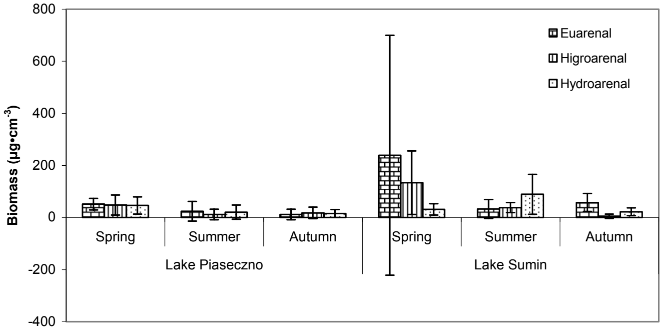

Fig. 4. Biomass of psammonic ciliates in investigated lakes (± standard deviation)

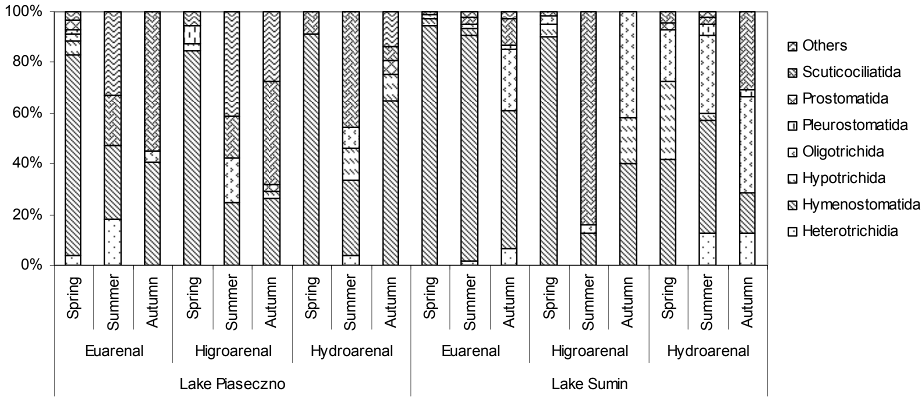

Fig. 5. Domination structure of psammonic Ciliata orders in psammolittoral of investigated lakes (% of total numbers)

determined between the numbers of ciliates and conductivity ($r = 0.29$, $p = 0.05$), and the highest between the numbers of ciliates and $N\text{-}NH_4$ concentration in water ($r = 0.58$, $p = 0.05$). In the eutrophic lake, the zone characterised by the strongest correlations between the physical and chemical factors analysed and ciliate numbers was the hydroarenal. In the mesotrophic lake, a significant correlation was observed in the hydroarenal between $N\text{-}NO_3$ concentration and ciliate numbers ($r = 0.50$, $p = 0.05$) (Table 4).

DISCUSSION

The number of psammonic ciliate taxa (53 taxa) in the lakes studied was similar to that determined in the hydroarenal of eutrophic Lake Mikołajskie in Mazury Lakeland (56 taxa) [14] and above 3 times higher than values observed by Madoni [16] in the psammolittoral of Lake Kinneret (Israel) (16 taxa). Such differences may result from local climatic conditions (rain, fluctuation, wind) [7]. Also Wiszniewski [33] mentioned the effect of atmospheric conditions and anthropopressure as the main reasons for the variability of taxonomic composition of psammonic organisms, even in the diurnal cycle.

Table 4. Jaccard similarity coefficient value for the analyzed zone

Lake Piaseczno	Spring	Summer	Autumn
Euarenal/Higroarenal	0.15	0.22	0.13
Higroarenal/Hydroarenal	0.21	0.00	0.22
Hydroarenal/Euarenal	0.23	0.38	0.23
Lake Sumin			
Euarenal/Higroarenal	0.47	0.21	0.12
Higroarenal/Hydroarenal	0.53	0.14	0.20
Hydroarenal/Euarenal	0.47	0.23	0.28

The factors are often difficult to measure or distinguish, due to their specificity and simultaneous occurrence. The average numbers of psammonic ciliates in the eutrophic lake Sumin (266−703 ind. cm^{-3}) were similar to those recorded in the eutrophic lake Mikołajskie [14]. In the psammolittoral of Lake Kinneret, the average numbers of ciliates amounted to 378 ind. cm^{-3} [17].

The available literature provides no information on the dynamics of seasonal changes in the abundance of psammonic ciliates. Studies by Pennak [28] revealed that psammonic organisms show high seasonal variability. Their numbers decrease significantly in autumn, and increase in spring and summer. A similar pattern was observed in the present research. In the lakes studied, a moderate effect (depending on the zone analysed) of a number of physical and chemical factors on protozoa occurrence was recorded. The influence of food abundance seems to be more significant (correlation between numbers of ciliates and chlorophyll *a* concentration). Studies by Czernaś [3] revealed substantial abundance of psammonic algae in the lakes studied. Significant correlations between numbers of psammonic ciliates and nutrient concentration in the eutrophic Lake Sumin also suggest a considerable importance of the food source for the occurrence of ciliates. Both TOC and nutrients influence bacteria abundance. Therefore, they may have direct impact on the occurrence of protozoa, feeding on bacteria [22]. The trophic structure of ciliates was dominated by omnivorous and bacteriovorous species, which is in accordance with data from the eutrophic lake [14].

The psammolittoral is a variable environment, and according to Schmid-Aray [30], it is suitable for organisms with the ability of fast population growth and wide ecological tolerance. Therefore, it seems that sand is an environment adequate for organisms easily adapting to changes in environmental conditions. Moreover, ciliates may play a significant role in phosphorus regeneration, which should also result in an increase in abundance of algae and bacteria. The process may be largely influenced by the participation of small ciliate taxa, due to their high metabolic activity and fast generation. They are able to provide much more phosphorus than organisms of higher trophic levels [7].

The edge effect also seems to have a significant impact on the organisms analysed. The distribution of numbers and biomass between individual zones and seasons suggests a substantial influence of rapid changes of environmental conditions on the occurrence of protozoa. A high water level in spring could also favour an increase in numbers of protozoa. The psammolittoral in the season included large amounts of decomposing plant remains which could condition the occurrence of bacteria constituting the main sustenance of ciliates. Irrespective of the lake trophic status, Hymenostomata reached a significant dominance. However, their participation changed depending on the season and zone analysed. This group (mainly taxa: *Paramecium sp*., *Glaucoma sp*., and *Uronema nigricans*) also prevailed in the hydroarenal of the eutrophic lake in Mazurian Lakeland [14]. In the psammon of Lake Kinneret, in turn, *Pleuronema sp*. predominated [17].

Typical (exclusive) taxa inhabiting only one of the zones analysed were species *Colpidium kleini* and *Frontonia atra*, occurring only in the higroarenal. Both species are categorised as benthic species. *Colpidium kleini* is bacteriovorous, and *Frontonia atra* prefers diatoms [9].

The analysis of the correlation between physical and chemical water parameters and numbers of ciliates reveals a variable relation between those values. In the hydro- and higroarenal of the eutrophic lake, a strong correlation between chemical parameters and numbers of the studied group of microorganisms was recorded. In the mesotrophic lake, a weak correlation occurred only between numbers of ciliates and nitrogen concentration. In the euarenal of both lakes, no correlations between chlorophyll *a* concentration and numbers of ciliates were observed, which is in accordance with results from the eutrophic lake [14].

The study confirms the presumption that psammon is a structure subject to continuous transformation. It also proves the thesis of higher concentrations of microorganisms in lakes of higher trophy, which is probably related to food availability. It seems that the factor has a crucial impact on the differences observed between the meso- and eutrophic lakes. Within the euarenal, no significant correlations between physical and chemical water parameters and numbers of ciliates were determined. In the remaining zones, positive correlations were observed, whereas the most numerous significant correlations occurred in the eutrophic lake. However, with the aim of clarifying the understanding of the role of factors conditioning the presence of psammonic ciliates, in future research it is necessary to explain the biotic factors such as the abundance of bacteria and flagellates, among others.

REFERENCES

[1] Alekperov I., E. Asadullayeva: *New, little-known and characteristic Ciliate species from the Absheron Coast of the Caspian Sea*, Tr. J. of Zoology, **23**, 215−225 (1999).

[2] Bielańska-Grajner I.: *The psammic rotifer structure in three Lobelian Polish lakes differing in pH*, Hydrobiologia, **446/447**, 149−153 (2001).

[3] Czernaś K.: *Function of phytopsammon in capturing biogenes at the land/water ecotone in mesotrophic lake Piaseczno*, Acta Agroph., **1**, 47−53 (2003).

[4] Dragesco J., A. Dragesco-Kerne: *Free-living ciliates from the coastal area of Lake Tanganyika (Africa)*, Eur J Protistol., **26**, 216–235 (1991).

[5] Ejsmont-Karabin J.: *Rotifera of lake psammon: community structure versus throphic state of lake waters*, Pol. J. Ecol., **51**, 5−35 (2003a).

[6] Ejsmont-Karabin J.: *Is sandy beach of the lake an ecotone? Psammon Rotifera in a mesotrophic Lake Kuc (Masurian Lakeland, Northern Poland)*, Pol. J. Ecol., **51**, 2, 219−224 (2003b).

[7] Ejsmont-Karabin J.: *Are community composition and abundance of psammon Rotifera related to grain--size structure of beach sand in lakes?* Pol. J. Ecol., **52**, 363−368 (2004).

[8] Fenchel T.: *Ecology of protozoa*, Springer-Verlag, Berlin (1987).
[9] Foissner W., H. Berger: *A user-friendly guide to the ciliates (Protozoa, Ciliophora) commonly used by hydrobiologist as bioindicators in rivers, lakes and waste waters, with notes on their ecology*, Freshwat. Biol., **35**, 375−470 (1996).
[10] Hansen A., F. Di Castri: *Landscape Boundaries: Consequences for Biotic Diversity and Ecological Flows*, New York, Springer-Verlag, 1−458 (1992).
[11] Hermanowicz W., W. Dożańska, J. Dojlido, B. Koziorowski: *Physical and chemical investigation methods of water and sewage*, Arkady, Warszawa, 846 p (1976) (in Polish).
[12] Hilbricht-Ilkowska A., T. Weglеńska: *River-lake system as mosaic pattern of landscape patches and their transition zones (ecotones)*, Pol. J. Ecol., **51**, 2, 163−174 (2003).
[13] Jerome C.A., D.J.S. Montagnes, F.J.R. Taylor: *The effect of the quantitative protargol stain and Lugols and Buinos fixatives on cell size: A more accurate estimate of ciliate species biomass*, J. Euk. Microbiol., **40**, 254−259 (1993).
[14] Kalinowska K.: *Psammon ciliates: Diversity and abundance in hygroarenal of eutrophic lake*, Pol. J. Ecol., **56**, 2, 259–271 (2008).
[15] Kornijów R., W. Pęczuła, B. Lorens, J. Rechulicz, S. Ligęza: *Shallow Western Polesie lakes from the view point of alternative stable states theory*, Acta Agrophysica, **68**, 2, 61–73 (2002).
[16] Krebs Ch.: *Ecological Methodology*, HarperCollins, New York (1989).
[17] Madoni P.: *The ciliated protozoa of the monomictic Lake Kinneret (Israel): species composition and distribution during stratification*, Hydrobiologia, **190**, 111–120 (1990).
[18] Mazei Y.A., I.V. Burkovsky: *Spatial and temporal changes of psammophilous cili ate community in the White Sea estuary*, Devel. Curr. biol. **122**, 183–189 (2002) (in Russian with English summary).
[19] Mazei Y.A., I.V. Burkovsky: *Species composition of benthic ciliate community in the Chernaya River estuary (Kandalaksha Bay, White Sea) with a total checklist of the White Sea benthic ciliate fauna*, Protistology, **4**, 107–120 (2005).
[20] Mazei Y.A., I.V. Burkovsky: *Patterns of psammophilous ciliate community structure along the salinity gradient in the Chernaya River estuary (the Kandalaksha Gulf, the White Sea)*, Protistology, **4**, 251–268 (2006).
[21] Mieczan T.: *Preliminary study on planktonic ciliates in slightly eutrophic lake Uściwierz*. Acta Agrophysica, **88**, 479−484 (2003).
[22] Mieczan T.: *Periphytic ciliates in littoral zone of three lakes of different trophic status*, Pol. J. Ecol., **53**, 105−111 (2005).
[23] Mieczan T.: *Relationships among ciliated protozoa and water chemistry in small peat-bog reservoirs (Łęczna-Włodawa Lakeland, Eastern Poland)*, Oceanol. Hydrobiol. Stud., **36**, 77−86 (2007).
[24] Mieczan T., A. Puk: *Influence of type of substrate and water chemistry on the structure and succession of periphytic ciliate communities in hypertrophic lake*, Archives of Environmental Protection **36**, 2, 13−24 (2010).
[25] Mori G., M. Mattioli, P. Madoni, N. Ricci: *The ciliate communities of different habitats of lake massaciuccoli (Tuscany): Species composition and distribution*, Ital. J. Zool., **65**, 191−202 (1998).
[26] Naiman, R. J., H. Decamps: *The ecology and management of aquatic-terrestrial ecotones. Man and the Biosphere Series*, UNESCO. Paris, France The Parthenon Publishing Group. Carnforth, United Kingdom, 1−285 (1990).
[27] Obolkina L.A.: *New species of the family Colepidae (Prostomatida, Ciliophora) from Lake Baikal*, Zool Zh., **74**, 3–19 (1995) (in Russian).
[28] Pennak R.W.: *Comparative ecology of the interstitial fauna of fresh-water and marine beaches*, Ann. Biol., **27**, 449–480 (1951).
[29] Radwan S., R. Kornijów: *Hydrobiological characteristics of lakes*, [in:] Harasimiuk M., Z. Michalczyk, M. Turczyński (eds.): *Lakes in Łęczna-Włodawa Lakeland*, Monographs, Lublin (1998).
[30] Schmid-Araya J.M.: *Small-sized invertebrates in a gravel stream: community structure and variability of benthic rotifers*, Freshwat. Biol. **39**, 25–39 (1998).
[31] Trojan P.: *General ecology*. PWN, Warsaw (1980) (in Polish).
[32] Wiszniewski J.: *Researches ecologiques sur le psammon et specialement sur les Rotiferes psammiques*, Arch. Hydrobiol. i Ryb., **6**, 149−165 (1934).
[33] Wiszniewski J.: *Differenciation ecologique des Rotiferes dans le psammon d'eaux douces*, Ann. Mus. Zool. Pol., **13**, 1−13 (1937) (in French).

HORYZONTALNE ROZMIESZCZENIE ORZĘSKÓW PSAMMONOWYCH W DWÓCH ZRÓŻNICOWANYCH TROFICZNIE JEZIORACH: ZALEŻNOŚCI Z PARAMETRAMI FIZYCZNYMI I CHEMICZNYMI

Celem pracy było poznanie struktury jakościowej i ilościowej orzęsków psammonowych w jeziorze mezotroficznym i eutroficznym (Pojezierze Łęczyńsko-Włodawskie). Analizowano również wpływ wybranych właściwości fizycznych i chemicznych wód na kształtowanie się tego specyficznego zespołu mikroorganizmów. Próby psammonu pobierano wiosną, latem i jesienią 2010 roku. W każdym zbiorniku, w psammolitoralu próby pobierano w euarenalu, higroarenalu i hydroarenalu. Łącznie stwierdzono 53 taksony orzęsków. Średnie zagęszczenie orzęsków wyniosło 516 osobn. cm^{-3} w jeziorze eutroficznym, zaś w mezotroficznym było niemal 2 razy niższe i osiągało 191 osobn. cm^{-3} piasku. W jeziorze Sumin najwyższe średnie zagęszczenie zanotowano w euarenalu 649 osobn.cm^{-3}, najniższe zaś w higroarenalu (425 osobn. cm^{-3}). W jeziorze mezotroficznym najwyższe średnie wartości liczebności zanotowano w higroarenalu 235 osobn. cm^{-3}, najniższe zaś w hydroarenalu 155 osobn. cm^{-3}. Najwyższą wartość wskaźnika Shanonna-Weavera odnotowano latem w jeziorze Sumin (2.79), w tym samym czasie w jeziorze Piaseczno odnotowano najniższą wartość tego współczynnika (0.79). Niezależnie od trofii jeziora największy udział w ogólnej liczebności orzęsków osiągały Hymenostomata (*Paramecium sp*., *Glaucoma sp*., *Uronema nigricans*) stanowiące od 13 do 95% ogólnej liczebności orzęsków. Stwierdzono istotne zależności pomiędzy obfitością orzęsków, a stężeniami w wodzie związków biogennych oraz całkowitego węgla organicznego, przy czym najsilniejsze korelacje odnotowano w strefach higro- i hydroarenalu jeziora eutroficznego.