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Effect of substrate on periphyton communities and relationships among food web components in shallow hypertrophic lake

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ABSTRACT

*We studied the role of natural (common reed) and artificial substrata (bamboo) in structuring the abundance and taxonomic composition of periphyton assemblages. Investigations were conducted in a shallow, hypertrophic lake situated in the area of Polesie Lubelskie (Eastern Poland). Periphyton communities (algae, ciliates, small metazoa and chironomids) on both types of substratum were sampled monthly, from May to November of 2007. Water samples for chemical analysis were collected together with biological samples. We selected the group of ten environmental variables which are the most important in determining the habitat conditions in highly eutrophic lakes: temperature, Secchi disc visibility, conductivity, dissolved oxygen, periphytic chlorophyll-*a*, $N\text{-}NO_3$, $N\text{-}NH_4$, TP, $P\text{-}PO_4$ and total organic carbon (TOC). The abundances of periphytic algae, ciliates, metazoa and chironomids were significantly affected by season and substrate. On natural substrata, in all studied months, periphyton communities showed higher abundances. The results of PCA analysis confirmed the distinction between periphyton communities on natural and artificial substrata. The Monte Carlo permutation test showed that the periphyton communities on common reed were the most significantly affected by temperature, $N\text{-}NO_3$, Secchi disc visibility and TOC. The communities on artificial substrata were significantly influenced by temperature, $P\text{-}PO_4$ and TOC. On natural substrata biomass of periphytic algae was significantly negatively correlated with abundances of all groups of potential grazers (ciliates, metazoa, chironomids). On artificial substrata the relations between components of periphytic food web were stronger; correlation coefficients between algae, protists and chironomids were significant at $P<0.01$. The results of analysis indicate that periphytic algae can play an important role as food source for higher trophic levels. These interactions are less significant on natural (reed) substrata, where algae during their growth may use nutrients releasing by plants. On inert substrata intensive feeding activity of grazers (ciliates, metazoan, chironomids) can markedly reduce algal biomass and affect their taxonomic composition.*

Key words: periphyton communities, artificial substrata, common reed, hypertrophic lake.

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INTRODUCTION

Shallow lakes, especially the small ones with extensive littoral area, have a high potential for periphyton growth (Wetzel, 1990). In such ecosystems periphyton develops on a wide range of submerged substrata, including macrophyte tissues (Vermaat, 2005). Periphyton assemblage associated with macrophytes is a complex structure with algae, protozoa, small metazoan, as well as macroinvertebrates. In general, both the structure and abundance of periphyton communities are affected by the available resources (nutrients, light) and predation by higher trophic levels (grazing) (Rosemond *et al.*, 1993; Liboriussen *et al.*, 2005). Another factor having an effect on periphyton is substrate specificity. Most studies stress the role of substrate in habitats of low nutrient availability because macrophytes may represent a substantial nutrient source, as they release nutrients (Riber *et al.*, 1983; Moeller *et al.*, 1988). In eutrophic lakes, where nutrient availability is high, the differences observed between inert and living substrates are not striking (Fairchild and Everett, 1988; Hillebrand and Sommer, 2000). On the other hand, studies by Kahlert and Pettersson (2002) showed that internal processes in the algal mat may regulate structure of periphytic algae more intensively than lake trophy.

We tested the effect of substrate on the structure of periphyton food web (Fig. 1) in highly eutrophic lake. In hypertrophic lakes, high nutrient loading often causes substantial reduction in submerged macrophytes and an intensive development of rush vegetation. Deterioration of environmental conditions leads to a decrease in the colonization area and diversity for communities associated with macrophytes (Scheffer *et al.*, 1993; Declerck *et al.*, 2005; Gonzalez-Sagrario *et al.*, 2005). However, studies which have been undertaken to describe the composition of algae as well heterotrophic components of periphyton are very scarce and hardly sufficient. Up to now most studies of natural and inert substrata concerned periphytic algae (Moschini-Carlos *et al.*, 2000; Kiss *et al.*, 2003; Lane *et al.*, 2003; Kralj *et al.*, 2006), while little work has been done to identify higher trophic levels of periphyton in lentic environments, such as ciliates (Mieczan, 2006; Henglong *et al.*, 2009), small metazoa (Sakuma *et al.*, 2004; Atilla *et al.*, 2005) and chironomid larvae (Francis and Kane, 1995; Chaloner and Wotton, 1996).

Different artificial substrata have been used to study their effect on periphyton communities. Glass slides are frequently used in algae and ciliates studies (Kaur and Mehra, 1998; Danilov and Ekelund, 2001; Albay and Akcaalan, 2003; Lane *et al.*, 2003). Ceramic tile substrates and plastic artificial plants are introduced for colonization of small metazoa and macroinvertebrates (Benoit *et al.*, 1998; Taniguchi *et al.*, 2003). In the present study, periphyton communities were identified on an artificial bamboo substratum. Such a substratum was previously used by Azim *et al.* (2002) to study the structure of heterotrophic components of periphyton (rotifers, crustaceans, oligochaetes and chironomids larvae) in aquaculture ponds. In the studied lake, the selection of the type of artificial substrata was closely related to the structure of vegetation. The lake is shallow and hypertrophic, surrounded by a dense, wide belt of emergent vegetation dominated by common reed (*Phragmites australis* (Cav.) Trin. ex Steud). Bamboo shoots show a high morphological similarity to reed stems and can be sited at the same habitat conditions (depth, orientation, light condition, water level) as plants.

The general hypotheses were: i) under hypertrophic conditions, where colonization area for communities associated with macrophytes is markedly reduced, the use of artificial bamboo substrata may increase colonization surface and enhance the growth of periphyton communities; ii) in hypertrophic lake, the biomass of periphytic algae on artificial substrata is determined by high nutrients concentration. The use of artificial substrata eliminates biological interactions between algae and host plant (Reid *et al.*, 1995; Lane *et al.*, 2003). Macrophyte tissues release biologically active chemicals which may influence algal growth (Gross *et al.*, 1996; Jones *et al.*, 2000); iii) the structure and biomass of periphytic algae associated with artificial substrata are structured by the grazing pressure of higher trophic levels. Invertebrate grazers may show preferential feeding, grazed mostly on highly edible and nutritious algae and keep periphyton biomass low (Jones *et al.*, 1998; Jones and Sayer, 2003); iv) the taxonomic composition and abundance of invertebrate grazers are influenced by substrate type and food (algae biomass and availability).

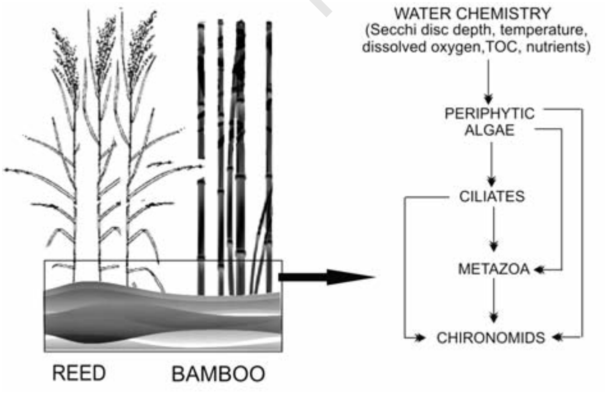

Fig. 1. Scheme of relations between components of periphyton communities on natural (reed) and artificial (bamboo) substrates. Arrows indicate the way of relations between periphyton communities.

The specific goals of the study were: i) to analyze the taxonomic composition and abundance of periphytic algae, ciliates, metazoa and chironomids on natural (reed) and artificial (bamboo) substrata; ii) to describe environmental variables responsible for the distribution of algae and invertebrates on natural and artificial substrata; iii) to evaluate the influence of a particular substratum on the interactions between components of the periphytic food web.

METHODS

Study area

Lake Syczyńskie (51°17'N and 23°14'E) is a small and shallow (surface area 5.9 ha, max depth 2.9 m) hypertrophic lake situated in the area of Polesie Lubelskie (Eastern Poland) (Fig. 2). Over 80% of the lake catchment is used for agriculture purpose (mostly arable lands and meadows). The lake is characterized by permanent and long lasting blooms of cyanophyte. Emergent vegetation is well developed (mean cover amounted to 24% of lake surface area), dominated by common reed (*Phragmites australis* (Cav.) Trin. ex Steud.) and three accompanying species: bulrush (*Schoenoplectus lacustris* (L.) Palla), broadleaf cattail (*Typha latifolia* L.) and sweet flag (*Acorus calamus* L.). Submerged vegetation is limited to very small, single stands of rigid hornwort (*Ceratophyllum demersum* L.) and sago pondweed (*Potamogeton pectinatus* L.).

Water sampling

Water for chemical analysis were taken monthly from May to November 2007, simultaneously with periphyton samples. Samples were collected 30 cm under the water surface. Three water samples were collected each month. Temperature, conductivity and dissolved oxygen were recorded *in situ* using YSI 556 MPS electrode. Concentrations of total organic carbon (TOC) were measured using Portable Multi Parameter Analyser of water quality, PASTEL UV (SECOMAM). Water for analysis of nutrients and chlorophyll-a concentration was filtered onto GF/C filters. Chlorophyll-a was extracted overnight in 90% acetone and measured with a spectrophotometer (Golterman, 1969). Concentrations of total phosphorous (TP) and dissolved orthophosphates (P-PO_4) were determined using spectrophotometric method with ammonium heptamolybdate; concentrations of N-NH_4 were determined with Nessler's method and concentrations of N-NO_3 using colorimetric method with brucine (Hermanowicz *et al.*, 1999).

Periphyton communities sampling

The periphyton communities were sampled from natural (common reed) and artificial substrata (bamboo) at a depth of 0.5-1 m in littoral zone. Artificial substrata were placed inside reed bed, after the decrease of ice cover (at the end of March). Number of bamboo shoots introduced to the lake was similar to density of reed beds. Sampling was done on a monthly basis from May to November 2007. During each sampling occasion 6 periphyton samples were collected from each substratum type.

Samples of periphytic algae were taken as a scrapings with a quadrant of 2×2 cm^2 (one scraping per one reed or bamboo stem) using sharp edged scalpel and soft toothbrush. Stems were collected very gently to minimize the loss of organisms during stem retrieval from the lake. Scrapings were done just after the stems were pulled from the water. Each scraping was gently put into a separate plastic bottle filled with 300 mL of distilled water and mixed. Next the suspension was filtered through a 250 μm mesh size to avoid contamination of small plant fragments or occasional invertebrates. Then, a 100-mL subsample was fixed with Lugol's liquid and by formaldehyde with glycerin solution and used for algae identification. From the subsample was taken 2 mL of aliquot and put on a glass slide with counting chamber. Each slide was than examined at 400× magnification. At least 200 algal cells were counted and classified to the genus level. The counts were based on cells and also for filaments (each filament of the length of 100 μm was counted as one cell). The algae identifications were based on Van den Hoek *et al.* (1995). Biomass of periphytic algae was calculated using the lengths and widths of algal cells and common geometric equations (Rott, 1981) and expressed in mg m^{-2} of reed (bamboo) surface. Relative abundances of taxonomic group of algae were estimated in total biomass of algae based on biomass of counted cells and filaments.

In order to determine the density of ciliates and small metazoan one sample consisted of 10 cm^{-2} of periphyton taken from the reed stems and bamboo by means of a scalpel. Samples were fixed with Lugol's solution (1% v/v) and settled for at least 24 h in plankton chambers. The ciliates and metazoan (rotifers, cladocerans and copepods) were counted and identified with an inverted microscope at magnification ×400-1000. Ciliates are highly perishable, and their type of motility is a species specific feature; for this reason, species determination and measurements were carried out on live material immediately after return to the laboratory and after silver impregnation (Augustin *et al.*, 1984). Taxonomic identification was based primarily on Foissner and Berger (1996), Foissner *et al.* (1999).

Chironomids were collected by an *Epi-Korn* apparatus (Kornijów and Kairesalo, 1994). The apparatus consists of a perspex tube and a circular sieve (mesh size 250 μm). One sample consisted of one stem (reed or bamboo). Field samples were transported to the laboratory, where the larvae of midges were removed from reed and bamboo stems and preserved in 4% formaldehyde solution, counted and identified. The nomenclature of Chironomidae larvae followed Wiederholm (1983). Lengths and diameters of reed and bamboo shoots collected in samples were measured in order to calculate density of midges per m^2 of reed (bamboo) surface.

Data processing

Mean densities of the different groups of periphytic organisms were compared between natural and artificial sub-

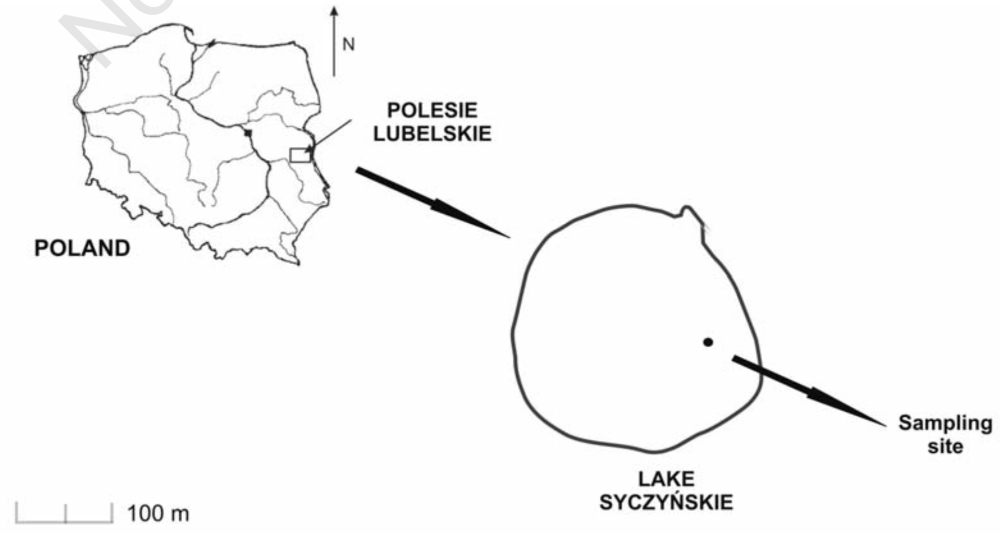

Fig. 2. Location of studied lake Syczyńskie.

strata and between months using two-way repeated measures ANOVA (substratum, time). Pearson's correlation coefficients were calculated in order to specify the interactions between components of periphytic food web. The analysis was performed using STATISTICA 7.0 software.

Ordination techniques were used to describe the relationships between the abundance of taxonomic groups (algae, ciliates, metazoan, chironomids) of periphytic organisms on natural (reed) and artificial (bamboo) substrata and environmental variables. An indirect multivariate method, DCA, was used to measure and illustrate gradients indicated by periphyton communities. Because the length of the gradient was <3 standard deviations, redundancy analysis (RDA) was used to explore the relationships between the abundance of taxonomic groups and physical and chemical variables (ter Braak and Šmilauer, 2002). The RDA method relates numerical character of analyzed data (Jongman *et al.*, 1987). Automatic forward selection of environmental variables, Monte Carlo permutation test (999 permutations) was used to determine the most important variables (Lepš and Šmilauer, 2003). Variables which level of significance exceeded 0.05 were marked passively on the diagrams. The principal component analysis (PCA) was performed in order to confirm the separation of periphyton communities on natural and artificial substrata. The ordination analyses were performed by means of CANOCO 4.5 for Windows.

RESULTS

Physical and chemical water parameters

Physical and chemical water parameters showed visible seasonal variability (Tab. 1). Observed values were typical for hypertrophic lakes. Secchi disc visibility was very low and ranged for 0.27 m (November) to 0.80 m (June). Planktonic chlorophyll-*a*, as an indicator of planktonic algae biomass, ranged from 11.90 (May) to 40.94 µg L^{-1} (October). Concentrations of total phosphorous were high during the whole study ranging from 76 µg L^{-1} in November to 321 µg L^{-1} in July. Concentrations of dissolved oxygen always exceeded 9.0 mg L^{-1}.

Periphytic algae

The biomass of periphytic algae (mg m^{-2}) showed visible seasonal variability (Fig. 3 A,B). Observed seasonal differences were significant on both natural (ANOVA; F=7.86; P<0.001) and artificial (ANOVA; F=15.95; P<0.001) substrata. Total algal biomass on natural substrata showed significantly higher values (ANOVA; F=151.81; P<0.001) than on artificial ones. On both substrata three taxonomic groups of algae were identified: cyanophyte, diatoms and chlorophytes. On natural and artificial substrata the highest algal biomass was observed in July, 56.79 mg m^{-2} and 48.26 mg m^{-2}, respectively. The lowest values were noted in November, 4.28 mg m^{-2} on natural substrata and 3.56 mg m^{-2} on artificial substrata. Cyanophyte were the dominant group on both substrata. The proportions of these algae varied from 44% (July, November) to 49% (June) on natural substrata and from 43% (June) to 51% (September, October) on artificial substrata. Domination structure of cyanophyte changed during the studied period: in May and June dominated *Microcystis* sp.; *Calothrix* sp. in August and September; whereas in July, October and November, *Oscillatoria* sp. prevailed.

Ciliates

ANOVA indicated that ciliates abundances were significantly affected by time on both natural (F=27.83; P<0.001) and artificial (F=43.29; P<0.001) substrata. Mean abundance of ciliates (25.4×10^2 cells m^{-2}) on artificial substrata was significantly higher (ANOVA; F=16.13; P<0.001) than on natural substrata (20.4×10^2 cells m^{-2}) (Fig. 4 A,B). Ciliate abundance was characterized by spring-autumn maxima on the artificial substrata, whereas on the natural substrata, abundance peaked in spring, summer, and late autumn. The highest abundances of ciliate communities on artificial substrata were noted in May and October with dominance by the bacterivorous *Chilodonella uncinata*, *Cinetochilum margaritaceum* and mixotrophic *Coleps hirtus*. On the reed stems, maxima were noted in May, July and October with the dominance

Tab. 1. Seasonal changes of physical and chemical parameters of water in lake Syczyńskie in 2007 (mean values for studied months).

	May	Jun	Jul	Aug	Sep	Oct	Nov
Temperature (°C)	14.2	25.5	22.1	21.4	16.8	8.5	6.4
Secchi disc depth (m)	0.72	0.80	0.40	0.30	0.37	0.55	0.27
Conductivity (µS cm^{-1})	563	502	323	341	477	480	437
Dissolved oxygen (µg L^{-1})	9.2	9.9	12.0	13.2	9.1	9.9	10.6
N-NH$_4$ (µg L^{-1})	166	248	485	223	531	100	900
N-NO$_3$ (µg L^{-1})	36	90	45	57	166	98	112
TP (µg L^{-1})	168	222	321	92	252	131	76
P-PO$_4$ (µg L^{-1})	47	172	28	36	186	24	34
Planktonic chlorophyll-*a* (µg L^{-1})	11.90	21.18	24.40	30.46	29.99	40.94	24.28
TOC (µg L^{-1})	7.7	6.4	7.1	6.6	6.4	7.0	7.4

of *Chilodonella uncinata*, *Amphileptus pleurosigma* and *Stylonychia mytilus*-complex.

Metazoa

Rotifer (Bdelloidae, *Lecane*, *Keratella*) abundances were significantly higher (ANOVA; F=57.27; P<0.001) on the natural substrata (mean 4.3×10^2 ind. m^{-2}) than on artificial ones (mean 3.7×10^2 ind. m^{-2}). Similarly to rotifers, mean abundances of cladocerans, were significantly higher (ANOVA; F=28.84; P<0.001) on the natural substrata (6.4×10^2 ind. m^{-2}). Copepods were never found on the artificial substrata (Fig. 5B). On both substrata, during the whole study period, rotifers were significantly more abundant than cladocerans and copepods (Fig. 5 A,B). On natural substrata, small metazoan were most abundant in spring, whereas on artificial substrata in autumn.

Chironomids

Macroinvertebrates on natural and artificial substrata were represented by larvae of Chironomidae (Fig. 6 A,B). Densities of midges showed significant differences among months on natural (ANOVA; F=22.54; P<0.001) and artificial substrata (ANOVA; F=10.62; P<0.001). Total abundances of chironomids were significantly higher (ANOVA; F=18.13; P=0.017) on natural substrata. On both substrata six chironomids taxa, were observed with varying proportions during the season (Fig. 6 A,B). The highest densities of chironomids on natural substrata were observed in May (5892 ind. m^{-2}) and the lowest in September (1744 ind. m^{-2}). In May, *Cricotopus* sp. (gr. *sylvestris*) larvae were dominant, while in September the larvae of *Glyptotendipes* sp. were the most abundant. On artificial substrata, the highest density of midges was observed in May (3154 ind. m^{-2}) and the lowest in July (1100 ind. m^{-2}). *Cricotopus* sp. (gr. *sylvestris*) larvae were the most abundant in May, while in July larvae of *Psectrocladius* sp. (gr. *sordidellus*) became dominant.

Relations between periphytic communities and environmental variables

PCA axis 1 (λ=0.279) and axis 2 (λ=0.166) explained 44.5% of the total variance in periphyton composition. The first two axes showed a clear separation of studied periphyton communities (Fig. 6A) and both studied substrata (Fig. 7B). The abundances of periphytic algae (cyanophytes, diatoms, chlorophytes) were most strongly correlated with the main direction of variation (axis 1), with samples collected on natural substrata (common reed) (Fig. 7A). Axis 2 was the most strongly correlated with abundance of chironomids. The density of larvae increased toward natural substrates and appeared to be closely related with season (the larvae show higher abundances in summer) (Fig. 7B). Axis 2 appeared to separate periphyton samples collected from natural and artificial substrata.

RDA performed in order to specify the direct relationships between abundances of taxonomic groups of periphyton and environmental variables; showed evident differences between studied substrata. On natural substrata all variables together explained 55.7% of total variance. However, variables that significantly (P<0.05, Monte Carlo permutation test) explained the variance in periphyton communities abundance on natural substrata included temperature (λ=0.17; F=10.48; P=0.004), Secchi disc depth (λ=0.04; F=2.72; P=0.049), N-NO_3 (λ=0.19; F=9.31; P=0.002) and TOC (λ=0.04; F=2.47; P=0.027). In the RDA biplot for periphyton taxonomic groups (Fig. 8A), axis 1 appeared to separate the different components of periphyton food web; microorganisms (periphytic algae and cili-

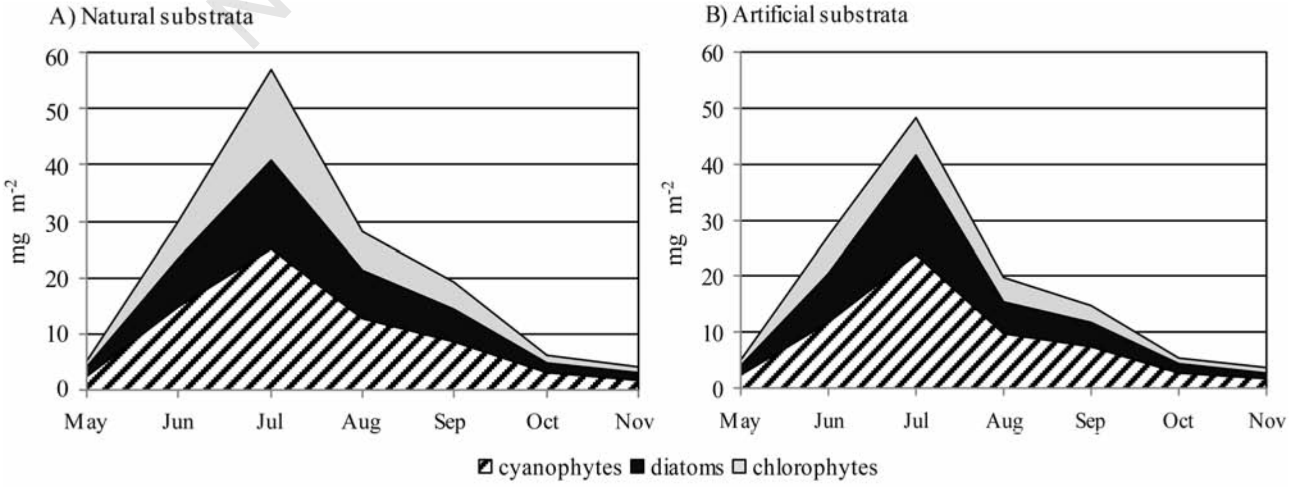

Fig. 3. Relative proportions (mg m^{-2}) of cyanophyte, diatoms and chlorophytes in total biomass of periphytic algae in studied months on A) natural substrata (reed) and B) artificial substrata (bamboo).

ates) are separated from their main consumers (metazoa and chironomids). The RDA biplot for sites shows the direct effect of season on periphyton community on natural substrata (Fig. 8B). On the biplot it can be observed that samples collected in spring (May, first group) are separated from those collected in summer (June, July and August, second group) and autumn (September, October and November, third group). RDA for artificial substrata showed that all variables explained 37% of the total variance. Monte Carlo permutation test showed the significance of three variables: temperature (λ=0.12; F=5.62; P=0.008), P-PO$_4$ (λ=0.01; F=5.50; P=0.006) and TOC (λ=0.06; F=2.98; P=0.048). On the RDA biplot for periphyton communities, axis 1 and 2 separate periphyton communities into three groups: i) algae; ii) ciliates with metazoa; and iii) chironomids (Fig. 9A). The RDA biplot for substrates, similarly to natural substrata, showed evident differences between studied months (Fig. 9B), and separating collected data into three groups; first group included samples collected in July and it may correspond with abundances of periphytic algae (Fig. 9A); second group included samples collected in June, August and September; third group included samples collected in May, October and November and this group may correspond with abundances of ciliates and metazoa (Fig. 9A).

Relationships among food web components

Generally, the biomass of algae was negatively correlated with the abundance of ciliates, small metazoa and chironomids (from r=-0.45, P≤0.05 to r=-0.77, P≤0.01). However, the number of significant correlations between the main group of organisms forming the periphytic food webs was differed between substrata. On artificial substrata the relations among food web components were stronger. Biomass of cyanophyte, diatoms and chlorophytes correlated negatively with the density of protists (r=-0.76, P≤0.01), copepods (r=-0.64, P≤0.01) and/or chironomids (r=-0.43, P≤0.05). The abundance of protists and small metazoa correlated positively with the density of macroinvertebrates (from r=0.48 to r=0.55, P≤0.05). On natural substrata, there was a significant and positive correlation between crustaceans density and small-sized rotifers (r=0.73, P≤0.01). Chironomid density correlated positively with the abundance of copepods (r=0.69, P≤0.01) and negatively with the biomass of cyanophyte (r=-0.43, P≤0.05).

DISCUSSION

The results confirmed that under hypertrophic conditions, artificial substrata markedly increased the colonization area for periphyton communities. The introduction of bamboo substrates lead to a rapid development of different groups of periphytic organisms. In general, the taxonomic composition of periphytic algae, ciliates, metazoan and chironomids was similar on artificial substrata and common reed, but their total densities on bamboo substrates were usually lower than on plants. Similar results were reported in the studies concerning colonization process on natural and artificial substrata by ciliates (Chadwick and Canton, 1983; Boothroyd and Dickie, 1989), metazoan (Pejler and Berzips, 1989; Duggan,

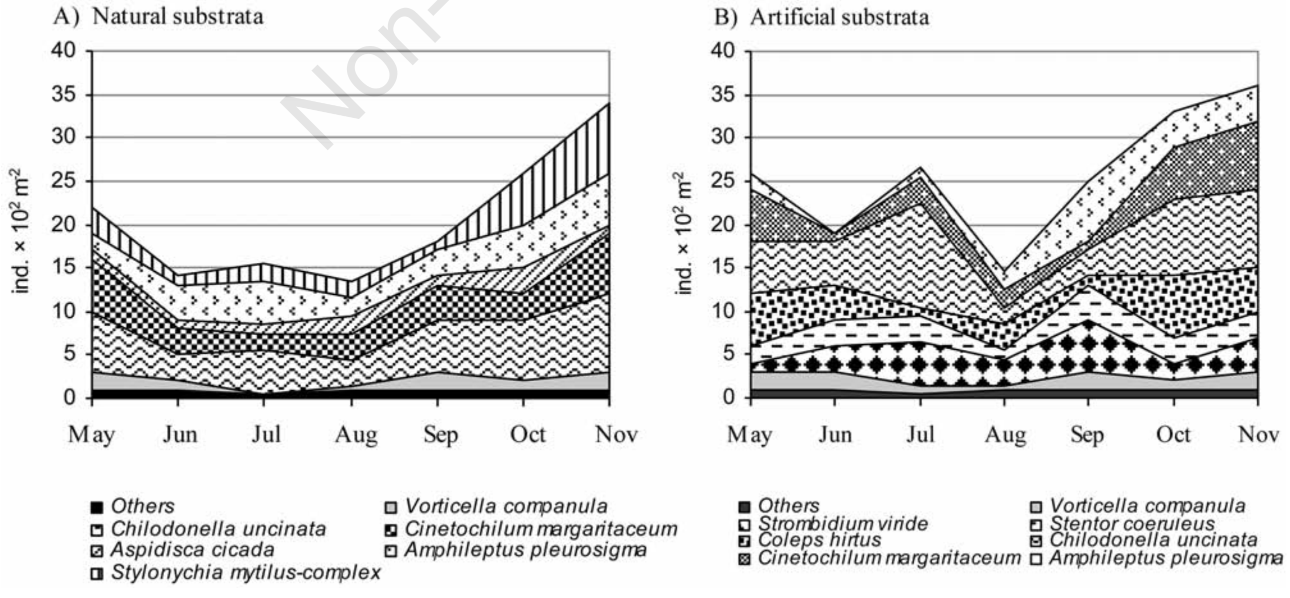

Fig. 4. Relative abundances (ind. 10^2 m^{-2}) of ciliates taxa in total density of periphytic ciliates in studied months on A) natural substrata (reed) and B) artificial substrata (bamboo).

2001) and chironomids (Wotton *et al.*, 1992; Francis and Kane, 1995). The increased growth of periphytic algae on reed stems, compared to artificial bamboo substrata, may be due to the nutrient exchange between the living reed and periphyton. This statement supports the results observed by Ács and Buczko (1994) and Ács *et al.* (2003) who reported the stimulation of algae growth through the secretion of nutrients from macrophytes.

The structure of periphyton communities on natural and artificial substrata was related to the high productivity of the studied lake ecosystem. Algae on both substrates were dominated by filamentous cyanophyte. These algae usually constitute an important component of periphyton assemblage at high phosphorous levels (McCormick and O'Dell, 1996; Gaiser *et al.*, 2005). High concentrations of phosphorous resulted in high biomass of periphytic algae. On natural and artificial substrata algae biomass in most studied months exceeded 10 mg cm^{-2}. This value is typical for hypertrophic lakes (Hitzfeld *et al.*, 2000). The observation is in agreement with nutrient loading studies by McCormick *et al.* (2002) and Gaiser *et al.* (2006), which have shown that periphyton rapidly accumulates phosphorous in proportion to the loading rate and usually the increase in phosphorous concentration is accompanied by high periphyton biomass. The biomass of periphytic algae observed during the study showed a negative rela-

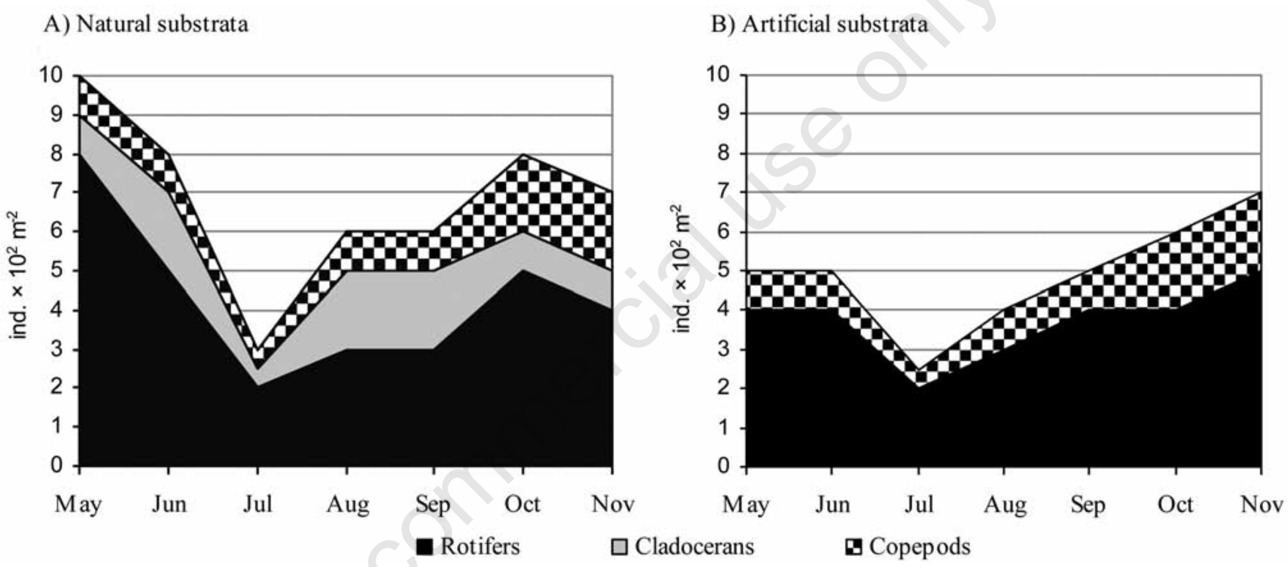

Fig. 5. Relative abundances (ind. 10^2 m^{-2}) of rotifers, cladocerans and copepods in total density of metazoa in studied months on A) natural substrata (reed) and B) artificial substrata (bamboo).

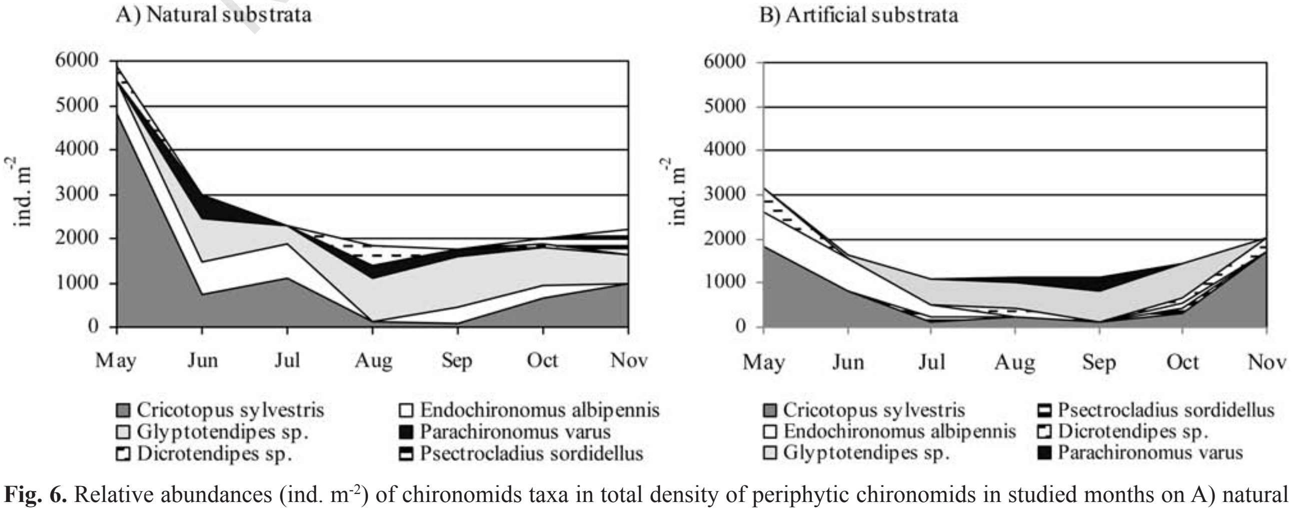

Fig. 6. Relative abundances (ind. m^{-2}) of chironomids taxa in total density of periphytic chironomids in studied months on A) natural substrata (reed) and B) artificial substrata (bamboo).

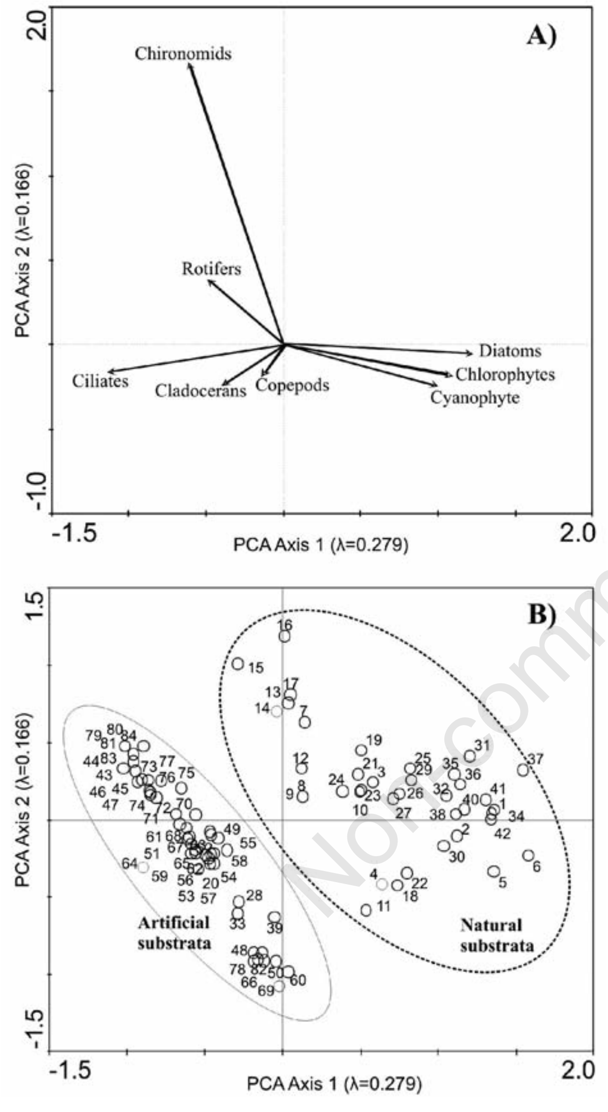

Fig. 7. Principal Components Analysis (PCA) biplots for axes 1 and 2 showing: A) periphytic communities, B) study substrata. Axes are derived from the variation in the taxonomic data -matrix. Samples collected in studied months are marked with an Arabic numeral: 1-6 May; 7-12 June; 13-18 July; 19-24 August; 25-30 September; 31-36 October; 37-42 November.

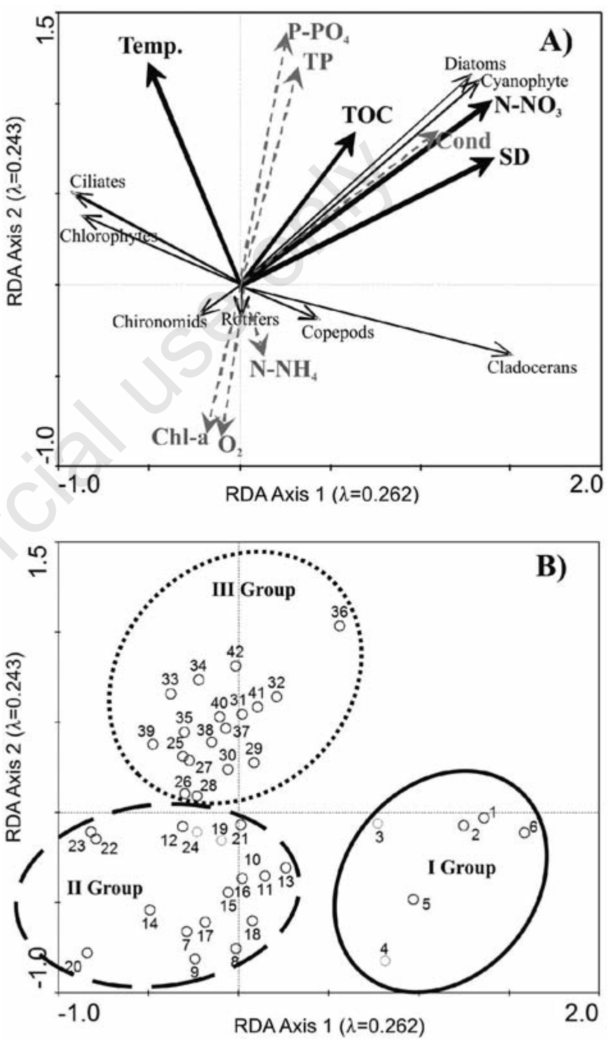

Fig. 8. Redundancy Analysis (RDA) biplots for natural substrata showing: A) periphytic communities and environmental variables, B) samples collected in studied months and environmental variables. Solid arrows indicate significant variables based on Monte Carlo permutation test ($P<0.05$). Samples collected in studied months are marked with an Arabic numeral: 1-6 May; 7-12 June; 13-18 July; 19-24 August; 25-30 September; 31-36 October; 37-42 November. SD, Secchi disc depth; Temp, water temperature; Cond, conductivity; O_2, dissolved oxygen; Chl-*a*, chlorophyll-*a*; N-NH_4, ammonium nitrogen; N-NO_3, nitrate nitrogen; TP, total phosphorous; P-PO_4, dissolved orthophosphates; TOC, total organic carbon.

tion with Secchi disc visibility; this may confirm the results recorded by Havens *et al.* (1996), who found that the trend of the periphytic algae amount is opposite to that of water transparency.

Periphytic algae community is structured by grazing (Jernakoff and Nielsen, 1997). According to Jones and Sayer (2003) and Danger *et al.* (2008), macroinvertebrates are known to prey intensively on algae and can easily affect their biomass. Most invertebrate grazers (cladocerans, copepods, chironomids) are scrapers or filter-feeders (Hart and Lovvorn, 2000). In lake Syczyńskie, which was the object of the study, the highest densities of chironomids on both natural and artificial substrata were observed in May when the biomass of periphytic algae was low. This observation may suggest high grazing pressure of midges on algae. Periphytic algae are regarded as an important source of food for chironomid larvae (Botts and Cowell, 1992; Pinder, 1992; Tall *et al.*, 2006). The larvae utilized as food the most abundant algae taxa (Botts, 1993). In lake Syczyńskie algal community was dominated by cyanophyte. These algae may constitute the important food source for grazing larvae. Studies of Dvorak (1996) on the chironomids and their food resources on *Typha angustifolia* and *Phragmites australis* showed that filamentous cyanophyte prevailed *Endochironomus albipennis* diet, making above 90% of its total food. In the investigated lake, the number of ciliates was significantly affected by the concentration of chlorophyll-*a*. Generally, the high content of chlorophyll-*a* during the summer period was accompanied by an increase in the number of species belonging to the omnivorous Cyrtophorida and algivorous Oligotrichida. It is probable that this is a result of advantageous feeding conditions. A significant influence of chlorophyll-*a* on the number of ciliates is confirmed by the studies of Beaver and Crisman (1990) in lakes of different trophic status.

As it was reported by many researchers, food availability has the primary influence on grazer community (Tokeshi, 1986; Francis and Kane, 1995; Gresens, 1997). The larvae of chironomids have been described as being able to grow on diverse food sources, including algae, metazoan or ciliates (Berg, 1995; Tarkowska-Kukuryk and Mieczan, 2008; Maasri *et al.*, 2010). In the present study, the abundance of chironomids was negatively correlated with the biomass of cyanophyte, diatoms and concentrations of chlorophyll-*a*. The highest abundances of ciliate and metazoa were noted in autumn when predation pressure was low, whereas their population was strongly reduced in summer at high abundance of epiphytic chironomids. A strong decline of ciliate populations in early summer was reported as a result of predation by chironomid larvae of *Cricotopus sylvestris* group (Tarkowska-Kukuryk and Mieczan, 2008). The growth in the abundance of small metazoa on *Phragmites australis* may result in profitable feeding conditions. In lake Syczyńskie, mostly filamentous algae appeared on both natural and artificial substrata. Studies by Ács *et al.* (2003) and Haglund and Hillebrand (2005) point to a distinct increase in the abundance of bacteria in the periphyton of the dominant filamentous algae. This may result in profitable feeding conditions for small metazoa (mostly rotifers) which usually colonize microsites formed in the mats of filamentous algae.

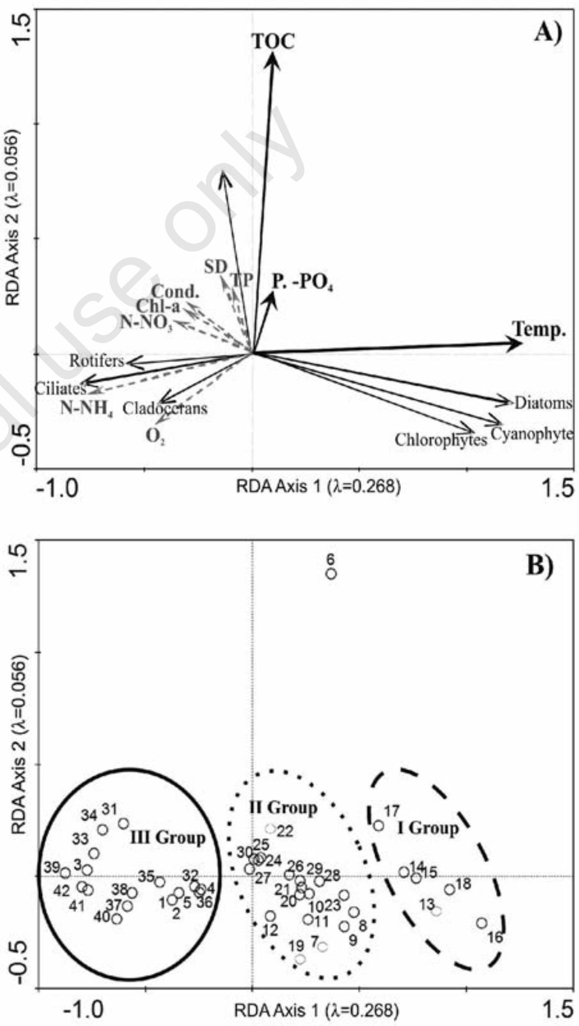

Fig. 9. Redundancy Analysis (RDA) biplots for artificial substrata showing: A) periphytic communities and environmental variables, B) samples collected in studied months and environmental variables. Solid arrows indicate significant variables based on Monte Carlo permutation test ($P<0.05$). Samples collected in studied months are marked with an Arabic numeral: 1-6 May; 7-12 June; 13-18 July; 19-24 August; 25-30 September; 31-36 October; 37-42 November. SD, Secchi disc depth; Temp, water temperature; Cond, conductivity; O_2, dissolved oxygen; Chl-*a*, chlorophyll-*a*; N-NH_4, ammonium nitrogen; N-NO_3, nitrate nitrogen; TP, total phosphorous; P-PO_4, dissolved orthophosphates; TOC, total organic carbon.

CONCLUSIONS

The abundances of periphyton communities (algae, ciliates, metazoan, chironomids) in shallow hypertrophic lake were closely related to substrate and season. Periphyton communities showed the strongest relations to five environmental variables (temperature, Secchi disc depth, N-NO_3, P-PO_4, TOC). The results suggest that under hypertrophic conditions, where soft vegetation is thick or absent, artificial substrates may spread colonization area and enhance the growth of different group of organisms. On artificial (bamboo) substrata interactions between components of periphytic food web are stronger in compare to natural plants. Moreover, high negative values of Pearson's correlation coefficient between periphytic algae and herbivores (ciliates, metazoan, chironomids) observed on artificial substrata, indicate intensive grazing pressure on algae.

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