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CHEMICAL COMPOSITION OF REED *PHRAGMITES AUSTRALIS* (CAV.) TRIN. EX STEUD. VERSUS DENSITY AND STRUCTURE OF PERIPHYTON IN VARIOUS AQUATIC ECOSTSEMS

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Abstract

Analyses of three macroelements and six microelements in reed stems, accompanied by investigation of periphyton density were carried out in two reservoirs: Żarnowieckie Lake and Puck Bay. To reveal the influence of chemical composition of biotic substrate on periphyton qualitative and quantitative characteristics, ordination methods were applied (PCA, CCA, DCA, RDA). The results indicated that Copoepoda (Harpacticoida) and Chlorophyta preferred reed substrate with relatively high zinc, sulfur and chromium but low manganese and carbon content. In turn, Nematoda reached the highest density on a substrate rich in manganese. Mercury in reed limited density of Arachnidae-Hydrachnella and Chironomidae larvae, an effect which was not observed for Ciliata libera. Copepoda (Harpacticoida) preferred low chromium and lead content and high carbon/nitrogen ratio, which meant low nitrogen concentration in the reed substrate. Moreover, preferences of Nematoda and Bacillariophyta for freshwaters and Copepoda for brackish waters were indicated

The results presented in this paper should be treated as a contribution to more detailed research on interactions between reed chemical composition and periphyton density.

Key words: reed, content of chemical elements, periphyton, ordination.

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WSTĘPNA OCENA WPŁYWU SKŁADU CHEMICZNEGO TRZCINY PHRAGMITES *AUSTRALIS* (CAV.) TRIN. EX STEUD. NA WIELKOŚĆ ZAGĘSZCZENIA OBRASTAJĄCEGO JĄ PERIFITONU

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Abstrakt

Dokonano analiz zawartości trzech makro- i sześciu mikroskładników w łodygach trzciny oraz zagęszczenia obrastającego ją perifitonu w dwóch akwenach: Jeziorze Żarnowieckim i Zatoce Puckiej. W celu uchwycenia wpływu składu chemicznego podłoża na skład jakościowy i ilościowy organizmów porośłowych zastosowano metody ordynacyjne (PCA, CCA, DCA, RDA). Stwierdzono, że Copepoda (Harpacticoida) oraz Chlorophyta preferują podłoże trzcinowe o relatywnie wysokiej zawartości cynku, siarki i chromu, natomiast niskiej manganu i węgla. Z kolei Nematoda w największym zagęszczeniu występuje na podłożu bogatym w mangan. Hg w trzcinie limituje zagęszczenie Arachnidae-Hydrachnella oraz *Chironomidae larvae*, czego nie obserwuje się w przypadku *Ciliata libera*. Copepoda (Harpacticoida) preferowały niskie stężenie chromu i ołowiu, wysoki stosunek zawartości węgla do azotu, a tym samym niskie stężenie azotu w podłożu trzcinowym. Ponadto wykazano słodkowodne preferencje Nematoda i Bacillariophyta i słonowodne Copepoda (Harpacticoida)

Prezentowane w niniejszej pracy wyniki należy traktować jako przyczynek do głębszych badań nad powiązaniem składu chemicznego trzciny i zagęszczeniem perifitonu.

Słowa kluczowe: trzcina, zawartość pierwiastków, perifiton, ordynacje.

INTRODUCTION

Occurrence of plant species in a reservoir is determined by its trophic state, oxygenation, thermal conditions and contamination. Biodiversity and chemical composition of plants may indicate the present condition and changes in a habitat (Hootsmansm, Vermaat 1992, Kiryluk 2005, Staniszewski et al. 2004). Common reed *Phragmites australis* is a widely-spread rush species in coastal lakes. This plant determines the trophic state as it influences concentration of biofile elements, which it accumulates in tissues and subsequently releases to a habitat, thus accelerating eutrophication (Pieczyńska 1988).

Due to its widespread occurrence as well as an ability to accumulate pollutants, reed is a preferred botanical treatment plant, referred to as "a reed treatment plant". Tissues of this macrophyte can accumulate both nutrients and heavy metals (De Laing et al. 2006, Kiryluk 2005 et al. 1997). Additionally, reed is an easily accessible vertical substrate for a large group of aquatic organisms, called periphyton or epiphytic organisms (Piesik, Obolewski 2000).

The first studies on periphyton concerned protection of hydrotechnical equipment against overgrowing by these organisms (Relini, Orsi 1970). Factors potentially influencing epiphytic communities are light, temperature, motion of waves, type of substrate, water chemistry and feeding on periphyton (Allan 1998, Mihaljević et al. 1998). Although the influence of the consecutive factors has been studied, scant information is available on chemical fight of reed against epiphytic organisms. Aquatic plants, including reed, release chemical substances containing heavy metals, which can reduce the density of more sensitive periphyton organisms (Burk et al. 2000, Lakatos et al. 1999). This has also been proved by comparative studies of epiphytic communities on artificial and biotic substrate (Piesik, Obolewski 2000, Obolewski 2006). Difficulties revealing the direct impact of a biotic substrate chemical composition on perihyton density are mainly caused by overlapping influences of the consecutive factors affecting the overgrowing processes. However, it has been observed that periphyton prefers some rocky substrates. In the streams of Montana, Chrysophyta (*Hydrurus* sp.) appeared mostly on limestone, Chlorophyta (*Monostroma* sp.) on rocks rich in iron, while Rhodophyta (*Batrachosperum* sp.) did not show any preferences of this kind (Allan 1998).

The objective of this study was to carry out a preliminary assessment of the relationships between chemical composition of reed, with special emphasis on heavy metals, and density of periphyton in reservoirs with different environmental conditions, namely in coastal Żarnowieckie Lake and Puck Bay.

MATERIALS AND METHODS

Sampling sites

The study was conducted in freshwater Żarnowieckie Lake (lying in a cryptodepression) and saline Puck Bay (Figure 1). The lake, located in the Wysoczyzna Żarnowiecka, covers an area of 1431 ha, is 7.6 km long and 2.6 km wide, and its maximum depth is 16 m. There is a river, the Piaśnica River, which flows through the lake. It is only the western shore of the lake which is covered with rushes, mainly reed and common club-rush. The sampled area of Puck Bay was an internal bay between Puck and Jastarnia, which is under influence of freshwaters from a tributary called the Plutnica.

Reed samples were collected in Żarnowieckie Lake in June, 2005, at 6 sampling sites, evenly distributed along the western shore of the lake. Recently, fields of reed in Puck Bay have been considerably reduced due to some earth-

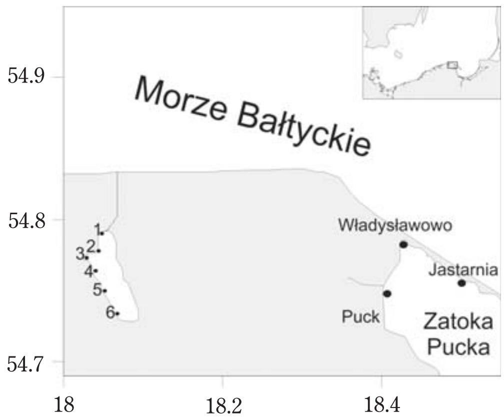

Fig.1. Location of sampling sites

works conducted in that area. Moreover, reed avoids saline waters, limiting its occurrence to a narrow, coastal strip. As a result, only 3 sampling sites were chosen.

Fragments of reed were sampled from the outer zone of fields of reed (depth 0.5–1.0 m) by cutting out 3 shoots at each sampling site. Then, 3 segments, 10–12 cm long, were cut out form every shoot at three levels: surface (just below the water surface), middle and bottom (in total 9 sub-samples). Reed sampling was followed by analyses of the periphyton removed from the reeds according to the methodology given by OBOLEWSKI (2006).

The dry plant material was homogenized in a laboratory mill. Concentrations of N, C and S were directly analyzed using an elementary analyzer CNS. Concentrations of heavy metals (Zn, Mn, Cd, Pb except for Hg), were determined after wet mineralization of the plant material in a closed microwave system, using a mixture of concentrated nitric and perchlorate acids (4:1 V/V) with addition of 30% hydrogen dioxide solution. The material was analyzed for metal concentrations with flame atomic absorption spectrometry. Hg content in the samples was determined by direct combustion in oxygen in an automatic mercury analyzer. In order to assess measuring errors, the concentrations obtained were compared to results for two certified plant materials (mixture of herbs and tea leaves): INCT-MPH-2 and INCT-TL-1. The calculated measuring error did not exceed 5% of the certified value.

Prior to statistical analyses, the data set was transformed in order to obtain normal distribution of the consecutive variables and to eliminate influence of rare species. The transformation was log(x+1), which is applicable to data with null values and, owing to subsequent ordination analyses, enables researchers to avoid negative values.

Significance of differences in reed chemical composition and periphyton density between the sampled reservoirs was determined by ANOVA. Homogeneity of variance was assessed by Brown-Forsythe test.

Next, ordinations, a widely-used family of multidimensional exploration methods, were applied in order to reveal the relationships between ecological communities. Interactions and redundancy between the predictors (content of chemical elements) were explored by Principal Component Analysis (PCA), based only on chemical data, and additionally with the Variance Inflation Factor (VIF) in Canonical Correspondence Analysis (CCA), which involved both reed chemical composition as well as periphyton taxonomic composition. Using Detrended Correspondence Analysis (DCA), the gradient of DCA first axis was determined and then interactions between reed chemical composition and epiphytic community structure were determined with the help of Redundancy Analysis (RDA) (TER BRAAK 1995).

ANOVA and PCA analyses were performed using STATISTICA 6.1 software (StatSoft 2002), while CCA, DCA and RDA in R environment (the R Foundation for Statistical Computing) (TER BRAAK 1986, LEGENDRE, LEGENDRE 1998, HILL, GAUCH 1980, OKSANEN, MINCHIN 1997).

RESULTS AND DISCUSSION

Chemical composition of reed

Reed from 6 sampling sites on Żarnowieckie Lake and 3 other sites on Puck Bay was analyzed. Content of the following chemical elements was determined: N, C, S, Hg, Zn, Cr, Mn, Cd and Pb (Table 1).

Plants absorbed considerable amounts of macroelements, with quantities of carbon reaching the highest concentration This is typical due to widespread occurrence of carbon in the environment (BALDANTONI et al. 2004). Nitrogen mass fraction varied between 0.538 and 1.006% for Żarnowieckie Lake and between 0.723 and 0.906% for Puck Bay. The highest N contents were observed in reed next to a ditch supplying Żarnowieckie Lake with water and near Puck in the Płutnica estuary. Reed can accumulate nitrogen in tissues, especially in places with high N concentration in environment (BERNATOWICZ 1969).

Availability of nitrogen released during organic matter decomposition depends on its C:N ratio. The ratio of carbon to nitrogen observed at all the sampling sites was high (over 32:1), which hampered mineralization of organic substance and intensified nitrogen accumulation in plants (THOMPSON, TROEH 1978). This ratio also indicated high vegetation level of the analyzed reed.

As for heavy metals, zinc reached the highest concentration in reed tissues - on average 12.21 mg kg^{-1} d.m. in Żarnowieckie Lake and 23.73 mg kg^{-1} d.m.

Table 1
Tabela 1

Content of macroelements and heavy metals in reed in the two reservoirs

Sampling site	Macroelements (%)			C/N	Heavy metals (mg kg^{-1} d.m.)					
	N	C	S			Hg	Zn	Cr	Mn	Cd
Żarnowieckie Lake										
1	0.628	46.155	0.031	73.5	0.029	10.45	0.05	15.40	0.45	2.30
2	0.848	45.495	0.067	53.7	0.010	9.00	0.05	19.35	0.15	0.05
3	0.750	45.537	0.020	60.7	0.008	21.10	0.05	15.60	0.20	1.05
4	1.006	44.558	0.033	44.3	0.008	14.40	0.05	28.20	0.40	0.05
5	0.921	45.643	0.084	49.5	0.034	8.30	0.05	30.70	0.60	0.05
6	0.538	45.992	0.000	85.5	0.009	10.00	0.05	20.80	0.45	0.05
Mean	0.782	45.563	0.039	61.2	0.016	12.21	0.05	21.68	0.38	0.59
SD	0.178	0.558	0.031	15.6	0.012	4.85	0.00	6.43	0.17	0.93
Puck Bay										
Puck	0.906	42.733	0.146	47.2	0.016	28.65	8.60	12.85	0.20	2.45
Władysławowo	0.787	43.460	0.158	55.2	0.011	28.60	0.05	6.50	0.30	0.25
Jastarnia	0.723	44.105	0.153	61.0	0.018	13.95	0.05	23.40	0.35	0.05
Mean	0.805	43.433	0.152	54.5	0.015	23.73	2.90	14.25	0.28	0.92
SD	0.093	0.686	0.006	6.9	0.004	8.47	4.94	8.54	0.08	1.33

SD - standard deviation

in Puck Bay. These values are two-fold lower than a content typical of reed growing in melioration ditches but comparable with plants from meadow moors (KIRYLUK 2005, URBAN, WOJCIECHOWSKA-KAPUSTA 1999).

Mercury concentration in reed was at a relatively stable level (SD – 0.004--1.012). The vicinity of Żarnowieckie Lake and the examined area of Puck Bay are generally free of heavy industry, therefore the environment is not polluted by mercury. In reservoirs contaminated by raw municipal sewage, concentration of Hg built in reed stem tissues is considerably higher, at a level of 10.5 mg kg^{-1} (SZYMANOWSKA et al. 1999).

ENDLER and GRZYBOWSKI (1996) analyzed aquatic plants in Wadąg Lake near Olsztyn. The amount of cadmium contained in common reed (on average 0.035 mg kg^{-1}) was similar to concentrations found in reed from Żarnowieckie Lake. In turn, the content of cadmium in reed from Puck Bay was comparable to the results cited by GRZYBOWSKI et al. (2005) for reed growing near an edge of forest, in a lake and in a melioration ditch (0.026-0.029 mg kg^{-1}). KABATA-PEDIAS and PENDIAS (1999) assayed the lead concentration in grass from areas free of direct contamination within the range 0.4-2.5 mg kg^{-1} and this suits the results from our study.

The amount of chromium in reed stems from Żarnowieckie Lake was low, which indicated lack of industrial contamination in this reservoir. The Cr content was comparable to concentrations from South American palustrine fields of reed (BURKE et al. 2000), but 30-times lower than in lakes near Poznań, influenced by raw municipal sewage (SZYMANOWSKA et al. 1999).

Compared to the investigation of reed chemical composition conducted by PEVERLY et al. (1995), the accumulation of manganese in reed from Żarnowieckie Lake was two-fold lower; in the case of reed from Puck Bay, four-fold less manganese was accumulated.

Periphyton density

In Żarnowieckie Lake, Nematoda was the dominant taxon among microzooperiphyton inhabiting reed (97% of the total periphyton density). Nematoda includes species feeding on epiphytic algae, which in turn absorb nutrients dissolved in water (PIESIK 1992). The remaining taxa reached much lower densities and did not contribute considerably to the epiphytic microfauna density (Table 2). Other investigations carried out in lakes and in Pomeranian Bay (OBOLEWSKI 2006, PIESIK, OBOLEWSKI 2000, PIESIK, WAWRZYNIAK-WYDROWSKA 2003) indicated Protozoa or Rotatoria as dominant taxa.

Density of macrozooperiphyton was dominated by Trichoptera, which were particularly abundant at the sampling site located in the ditch supplying the lake. High density of these larvae on biotic substrate in spring can be explained by their life cycle (CZACHOROWSKI 1998).

Table 2
Tabela 2

Density of zooperiphyton (indiv. m^{-2}) and phytoperiphyton (thou. cells m^{-2}) on reed in Żarnowieckie Lake

Taxa	Sampling sites						Mean SE
	1	2	3	4	5	6	
Microzooperiphyton							
Protozoa	1140.8	554.1	432.3	258.2	433.5	206.5	504.2±137.5
Rotatoria	347.3	184.8	48.1	103.1	48.3	103.1	139.1±46.4
Nematoda	6746.1	13204.2	26849.3	8617.0	24662.7	40815.2	20149.1±5333.0
Copepoda	0	0	0	0	0	51.7	8.6±8.6
Arachnidae	0	0	0	103.1	0	0	17.2±17.2
Total	8234.2	13943.1	27329.7	9081.4	25144.5	41176.5	20818.2±5224.8
Macrozooperiphyton							
Chironomidae larv.	0	0	48.1	51.7	0	51.7	25.3±11.3
Megaloptera	0	0	0	51.7	96.2	0	24.7±16.6
Hirudinea	0	0	0	103.1	0	0	17.2±17.2
Trichoptera larv.	0	46.3	240.1	103.1	144.5	103.1	106.2±33.8
Total	0	46.3	288.2	309.6	240.7	154.8	173.3±56.4
Microphytoperiphyton							
Bacillariophyta	9106.5	10805.8	5967.2	4125.3	7082.1	14568.2	8609.2±1527.5
Chlorophyta	12.8	47.5	68.0	33.2	6.2	6.2	29.0±10.3
Total	9119.30	10853.30	6035.20	4158.50	7088.30	14574.40	8638.2±1523.4

SE - standard error

Fitoperiphyton was dominated by Bacillariophyta, which made up 99% of the total epiphytic algae. Diatoms strongly prevail in periphyton inhabiting reed in reservoirs with moderate loading of nutrients ((PIESIK, OBOLEWSKI 2000).

The dominant taxa of microzooperiphyton in Puck Bay were Nematoda (43%) and Protozoa (26%). Eelworms feed on algae, which were abundant at the investigated substrate (PIESIK 1992), while high density of Protozoa could have been connected to abundant and easily available bioseston. The remaining microzooperiphyton taxa had low densities and contributed slightly to the overall epiphytic microfauna density (Table 3). The situation observed in Puck Bay is typical and confirmed by other studies from northern Poland (PIESIK, OBOLEWSKI 2000, OBOLEWSKI 2006).

Density of macrozooperiphyton was mostly influenced by Crustacea *Gammarus* sp., which occurred only in the Płutnica's estuary. Fitoperiphyton was dominated by Bacillariophyta (88% of the total epiphytic algae density), which is a typical situation (PIESIK, OBOLEWSKI 2000).

Table 3
Tabela 3

Density of zooperiphyton (indiv. m^{-2}) and phytoperiphyton (thou. cells m^{-2}) on reed in Puck Bay

Taxa	Sampling sites			Mean SE
	Puck	Władysławowo	Jastarnia	
Microzooperiphyton				
Protozoa	1 045.8	364.7	2 019.70	1143.4±480.2
Rotatoria	653.6	112.1	378.80	381.5±156.3
Nematoda	196.0	617.2	4 924.20	1912.5±1510.8
Copepoda	261.4	140.2	505.3	302.3±107.4
Arachnidae	0	84.2	0	28.1±28.1
Total	2156.8	1 318.3	7 828.0	3767.7±2044.5
Macrozooperiphyton				
Chironomidae larvae	20.1	0	0	6.7±6.7
Gammarus sp.	65.4	0	0	21.8±21.8
Total	85.5	0	0	28.5±28.5
Microphytoperiphyton				
Bacillariophyta	2 633.7	1 690.6	2 243.2	2 189.2±273.6
Chlorophyta	488.0	7.2	357.6	284.3±143.6
Total	3 121.8	1 697.8	2 600.8	2 473.5±415.9

SE -standard error

ANOVA and ordinations

Statistical analyses were performed for the whole data set (Żarnowieckie Lake and Puck Bay jointly) and for the taxa occurring in both reservoirs: Protozoa, Ciliata libera, Peritricha, Rotatoria, Nematoda, Copepoda-Harpacticoida, Arachnidae-Hydrachnella, Chironomidae larvae, Bacillariophyta and Chlorophyta.

Brown-Forsythe test revealed homogeneity of variance between variables for Żarnowieckie Lake and Puck Bay. Analysis of variance indicated significant ($p<0.05$) differences between the studied in concentrations of C, S and Zn in the biotic substrate and in density of Nematoda, Copepoda (Harpacticoida) and Bacillariophyta (Table 4).

Table 4
Tabela 4

ANOVA between Żarnowieckie Lake and Puck Bay

Variables	SS efect	df efect	MS efect	SS error	df error	MS error	F	*p*
C	0.0008	1	0.0008	0.0002	7	0.0000	25.553	0.0016
S	0.0041	1	0.0041	0.0008	7	0.0001	33.695	0.0007
Zn	0.1486	1	0.1486	0.1586	7	0.0227	6.556	0.0375
Nematoda	3.3514	1	3.3514	1.4769	7	0.2110	15.883	0.0053
Harpacticoida	8.8646	1	8.8646	2.6835	7	0.3834	23.124	0.0019
Total Bacillariophyta	0.6418	1	0.6418	0.2086	7	0.0298	21.531	0.0024
Colonial Bacillariophyta	0.8568	1	0.8568	0.3331	7	0.0476	18.004	0.0038
Unicellular Bacillariophyta	0.5969	1	0.5969	0.5306	7	0.0758	7.875	0.0263

SS – sum of squares; MS – mean square; df – degree of freedom; F – value of F – test;
p – significance level

Żarnowieckie Lake had higher content of C and S in reed but lower Zn concentration than Puck Bay. Nematoda and Bacillariophyta were more abundant in freshwaters, in contrast to Copepoda. As for Nematoda and Copepoda, preferences for the consecutive ecosystems can be explained- using ordinations- by chemical composition of reed substrate, but in the case of Bacillariophyta some other factors probably play a role.

PCA analysis (Figure 2) revealed strong redundancy between concentration of S, Zn and C (Pearson's linear correlation coefficient 0.8-0.9 for $p<0.05$).

According to Greger and Kautski (1992), increase in salinity expressed as electrolytic conductivity induces higher solubility of metals. Correlation between the above mentioned non-metals and zinc may be connected to Zn ability for fixing carbon and sulfur, forming carbonates and sulfates, which can accumulate

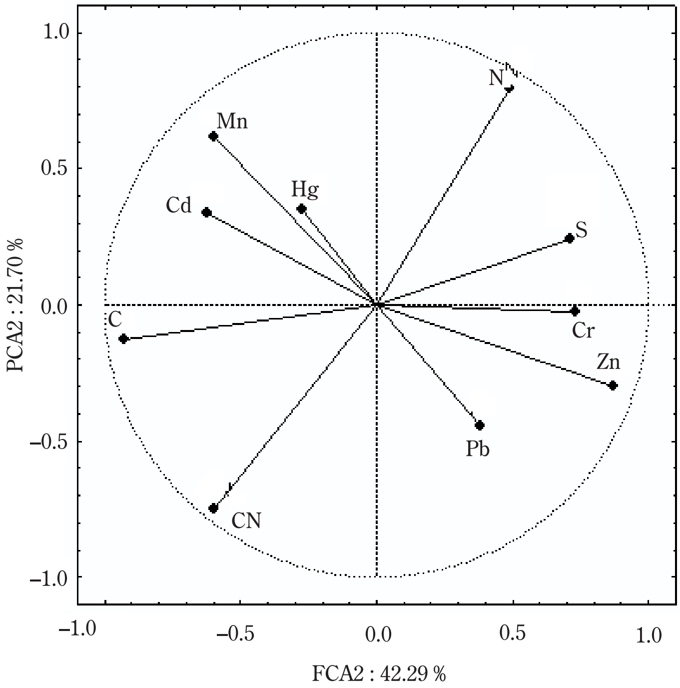

Fig. 2. PCA bibplot for Żarnowieckie Lake and Puck Bay

in plant's tissues during excessive absorption of this chemical element by a plant. Among the analyzed metals, zinc has the highest geochemical concentration, which allows an accurate analysis and high Pearson's correlation coefficient at the level of r=0.72 (SKORBILOWICZ 2003). Sulfur and carbon are the main components of organic matter. Metals, having considerable chemical affinity to organic substances, fix with them forming metaloorganic complexes. Therefore, higher concentration of C and N may also increase zinc concentration in plant's tissue, due to intensive fixation of metallic ions.

In order to assure orthogonality of the predictors, concentrations of C, Zn and N were excluded from the next analyses. CCA analysis for the new data subset and VIF values lower than 10 (1.6–6.3) confirmed fulfilling the orthogonality requirement (GROSS 2003).

The next stage of the investigation was a DCA analysis, used for determining environmental gradients for the consecutive periphyton taxa. Values <2 indicated monotonic responses for chemical element contents in biotic substrate for most of the studied taxa (TER BRAAK 1995).

Finally, an RDA analysis was applied. Figure 3 shows RDA biplot of axis 1 and 2.

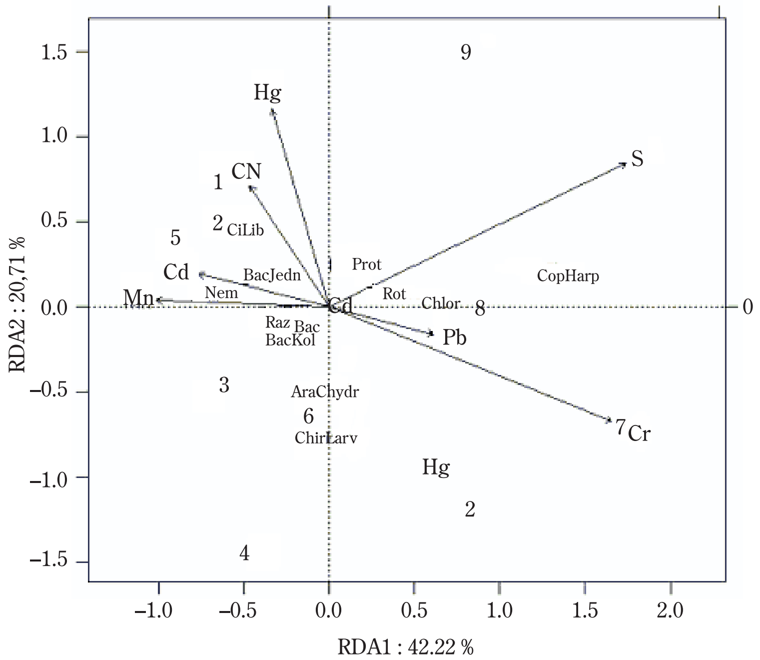

Fig. 3. RDA bibplot of axis 1 and 2 for Żarnowieckie Lake and Puck Bay

Axis 1, which explained 42.22% of the total variance, was connected to S, Cr and Mn concentration in the biotic substrate. As for the second axis (20.72% of the explained variance), the highest contribution was ascribed to Hg content (Table 5).

Table 5
Tabela 5

RDA biplot scores for constraining variables. Żarnowieckie Lake and Puck Bay

Chemical elements	RDA axis			
	RDA1	RDA2	RDA 3	RDA4
C/N	-0.2034	0.3122	0.1897	**0.7335**
S	**0.7614**	0.3668	-0.3250	-0.3002
Hg	-0.1470	**0.5074**	0.1051	-0.2432
Cr	**0.7246**	-0.2945	**0.4635**	-0.3015
Mn	**-0.4434**	0.0167	0.3890	0.0891
Cd	-0.3352	0.0847	-0.2123	0.3330
Pb	0.2673	-0.0708	**0.4082**	-0.4271

Biplot scores (Figure 3, Tables 5, 6) reveal that Harpacticoida and Chlorophyta preferred reed substrate with relatively high S and Cr but low Mn content. Taking into account correlations between the consecutive chemical element contents, we can conclude that the aforementioned taxa were typical of reed poor in elementary carbon (correlation C-S: r=-0.82, p<0.05) but rich in Zn (correlation Zn-Mn: r=-0.73, p<0.05). Zinc, as a microelement, performs an important biochemical role in plant, animal and human organisms. It takes part in oxidation-reduction processes and is an indispensable component or activator of many enzymes. In plants, it participates in transformation of organic acids, synthesis of chlorophyll, vitamins C, B, P and also influences growth and development of organisms. Axis 1 of RDA also suggested that Nematoda preferred reed substrate with high concentration of Mn but low Zn content (correlation Zn-Mn: :r=-0.73, p<0.05). The results confirm that Nematoda tend to develop better in freshwaters, while Copepoda grow more abundantly in saline reservoirs.

Table 6
Tabela 6

RDA biplot scores for periphyton taxa. Żarnowieckie Lake and Puck Bay

Epiphytic organisms (Periphyton)	RDA axis			
	RDA1	RDA2	RDA 3	RDA4
Total Protozoa	0.1552	0.2475	0.1009	-0.1346
Ciliata - libera	**-0.4847**	**0.5661**	-0.3731	0.1161
Peritricha	0.0722	0.2582	0.0980	-0.0914
Rotatoria	0.2889	0.1126	0.1534	-0.0587
Nematoda	**-0.7141**	0.0724	0.1589	**0.3178**
Harpacticoida	**1.1928**	0.2408	-0.1140	**0.4906**
Arachnidae	0.0773	**-0.4747**	**-0.7743**	-0.0905
Chironomidae larvae	0.0479	-0.7602	0.2936	0.2185
Total Bacillariophyta	-0.2644	-0.0167	0.1885	0.1235
Colonial Bacillariophyta	-0.2878	-0.1029	0.2167	0.11158
Unicellatr Bacillariophyta	-0.3399	0.1677	0.0485	0.1291
Chlorophyta	**0.4952**	0.0915	0.3556	**-0.3052**

The second RDA axis indicated that Arachnidae and Chironomidae larvae were particularly sensitive to Hg concentration, while Ciliata libera occurred in both reservoirs also at a high content of this metal. Mercury is very toxic or lethal to most higher organisms. Ciliata libera are primitive organisms, hence their sensitivity to Hg is lower and additionally – owing to their movement on reeds' surface – they can avoid places where substances against their overgrowth are secreted.

The next two RDA axes explained respectively 16.84% and 8.74% of the variance. RDA3 was connected to Cr and Pb content. The highest contribution of C/N ratio was observed in RDA4 (Figure 4, Tables 5, 6).

Analysis of biplot scores showed that Arachnidae occurred at high density on reed substrate rich in Pb and Cr (RDA3), which can be explained by movement of these taxa. Moreover, Nematoda and Harpacticoida preferred wide range of C/N ratio (RDA4), that is low nitrogen content in the reed substrate. The opposite dependencies were observed for Chlorophyta. Nitrogen in reed tissues is an ideal source of this nutrient, which is indispensable for green algae growth. Presence of high C concentration does not directly stimulate growth of either Harpacticoida or Nematoda, since both taxa belong to herbivores, feeding mostly on diatoms (PIESIK 1992).

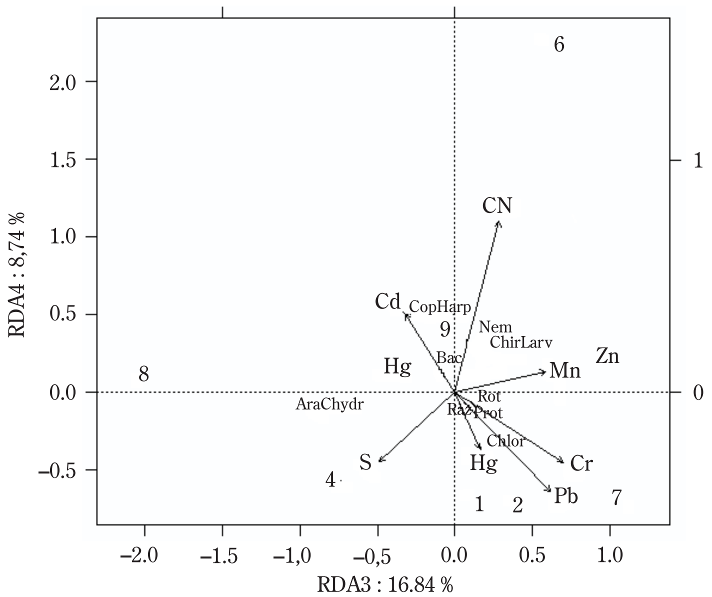

Fig. 4. RDA bibplot – axis 3 and 4 – for Żarnowieckie Lake and Puck Bay

CONCLUSIONS

1. Harpacticoida and Chlorophyta preferred reed substrate with relatively high Zn, S and Cr concentrations but low Mn and C content;

2. Nematoda had the highest density on reed substrate rich in Mn;

3. Hg in reed limited density of Arachnidae-Hydrachnella and Chironomidae larvae, an effect which was not observed in the case of Ciliata libera;

4. Nematoda and Copepoda (Harpacticoida) preferred low Pb and Cr concentrations and high C/N ratio, which meant low N content in the biotic substrate;

5. Nematoda were more abundant in freshwater Żarnowickie Lake, mostly due to relatively low Zn concentration in reed;

6. Copepoda (Harpacticoida) preferred saline water of Puck Bay, which was associated with higher content of Zn and S but lower C concentration in reed substrate;

7. Bacillariophyta were particularly abundant in the lake ecosystem but due to factors other than chemical composition of reed substrate.

This study should be treated as a contribution to more thorough investigations on periphyton density-reed chemical composition. It would be advisable to confirm the obtained results by experiments excluding interference factors, like feeding on periphyton or wave motion.

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