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# PERIPHYTON INHABITING REED, *PHRAGMITES AUSTRALIS* AND ARTIFICIAL SUBSTRATE IN THE EUTROPHICATED LUBOWIDZKIE LAKE

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## PERIFITON ZASIEDLAJĄCY TRZCINĘ *PHRAGMITES AUSTRALIS* ORAZ SZTUCZNE PODŁOŻE W ZEUTROFIZOWANYM JEZIORZE LUBOWIDZKIM

Organizmy poroślowe zasiedlające biotyczne i sztuczne podłoża w polskich jeziorach przymorskich i pomorskich są słabo poznane. W ramach opracowana stanu perifitonu jezior pomorskich w 2003 r. rozpoczęto badania tej formacji ekologicznej zasiedlającej *Phragmites australis* (CAV.) TRIN. ex STUED. oraz sztuczne foliowe podłoża Jeziora Lubowidzkiego. Wykazano, że średnie zagęszczenie glonów poroślowych na trzcinie w sezonach wiosna, lato i jesień 2001 r. w Jeziorze Lubowidzkim wyniosło 23,4 • $10^6$ komórek $m^{-2}$, mikrofauny poroślowej 184,9 • $10^3$ osobn. $m^{-2}$ oraz makrofauny 27,5 • $10^3$ osobn. $m^{-2}$. Zagęszczenie perifitonu na badanym podłożu biotycznym było niższe w porównaniu do porośli na sztucznym podłożu (folia) umieszczonym w Jeziorze Lubowidzkim. Na folii zagęszczenie glonów perifitonowych wyniosło 34,8 • $10^6$ komórek $m^{-2}$, mikrofauny poroślowej 399,6 • $10^3$ osobn. $m^{-2}$ oraz makrofauny 62,7 • $10^3$ osobn. $m^{-2}$. Zagęszczenie makrofauny perifitonowej było największe spośród wszystkich badanych cieków i jezior. Tylko w tym akwenie zaobserwowano wśród makrozooperifitonu przedstawicieli chruścików. Największą liczbę taksonów mikroperifitonu w Jeziorze Lubowidzkim zaobserwowano wiosną (6) a makrozooperifitonu jesienią (2). Wartości wskaźnika bioróżnorodności Shannona-Wienera (H') zmieniały się od 1,773 latem do 2,445 na wiosnę i był on niższy na sztucznym podłożu niż na trzcinie. W projekcie rewitalizacji jeziora formacja poroślowa będzie spełniać istotną rolę w doczyszczaniu, deeutrofizacji wód oraz tworzeniu dodatkowej obfitej bazy pokarmowej dla ichtiofauny zamieszkującej to jezioro.

Summary

Periphytic organisms inhabiting biotic and artificial substrates in Polish Pomeranian lakes have been poorly recognized, so far. Within the frame of interdisciplinary studies on the revitalization of eutrophicated Lubowidzkie Lake, a study on different ecological formations, including the periphyton formations inhabiting *Phragmites australis* (CAV.) TRIN. ex STEUD, and artificial substrates (foil), was carried out in 2003. It was demonstrated that the average concentration of periphytic algae on reed from spring to autumn in Lubowidzkie Lake amounted to 23.4 • $10^6$ cells $m^{-2}$, periphytic microfauna - 184.9 • $10^3$ individuals $m^{-2}$; and macrofauna - 27.5 • $10^3$ individuals $m^{-2}$. The concentration of periphyton on the studied biotic substrate was considerably lower in comparison to the organisms growing on the artificial substrate (foil). The average density of periphytic algae on foil amounted to 34.8 • $10^6$ cells $m^{-2}$, periphytic microfauna - 451.3 • $10^3$ individuals $m^{-2}$, and macrofauna 62.7 • $10^3$ individuals $m^{-2}$. The highest microperiphyton taxa number in Lubowidzkie Lake was six in spring and for macroperiphyton - two in autumn. The Shannon-Wiener biodiversity index was also the highest with H' = 1.773 in summer up to H' = 2.445 in spring, however it was lower for zooperiphyton inhabiting artificial substrate than biotic substrate. The periphytic formation will play a significant role in the project of lake revitalization by purification and deeutrophication of the waters, and in creating additional, abundant food base for ichtiofauna in Lubowidzkie Lake.

## INTRODUCTION

Until recently, the majority of studies conducted on Polish Pomeranian lakes have dealt with physical chemistry, plankton and benthos ecology, and ichthyology. The periphyton formation has been recognized insufficiently in these lakes. More quantitative and qualitative data have been collected for periphytic organisms from the Polish lagoon Lakes (Jamno, Bukowo, Kopań, Wicko Przymorskie) and low-salinity waters of the Odra River estuary and the Puck Bay [5, 19, 21-23, 26]. Periphytic organisms in Pomeranian lakes were studied in spring 2002 in Raduńskie Dolne Lake, in winter 2000 in Lubowidzkie Lake, Konradowo and Krzynia Lakes in 2002 [15-17]. Studies conducted by hitherto have shown that a particularly intensive qualitative-quantitative development of fouling organisms in the brackish waters mentioned above took place in artificial, openwork substrates - potato-bag fabric, stilon netting, artificial concrete reefs [3, 19]. In the proposed conception of revitalization and development of lakes [20] the periphytic formation developing on the installed artificial, openwork substrates will play a significant role in monitoring, water purification as well as creating a supplementary food base for the fish culture [19, 23]. The discussed conception of revitalization of highly degraded lakes assumes the improvement of water quality for recreational purposes. The change of the aquatic environment, the rearrangements of hydrobionts as well as the use of biological methods of purification and deeutrophication of waters (the active substrate method and ecological biomanipulation method) will contribute to the improvement of environment quality and will promote biodiversity [1].

The aim of the present study was a qualitative-quantitative assessment of periphytic organisms. Its next stage will enable monitoring of the expected rearrangement of periphytic organisms due to the change of the aquatic environment towards brackish waters. The study on periphyton will enable the assessment of the role of this formation in purification and deeutrophication of waters.

## MATERIAL AND METHODS

### Sampling

Lubowidzkie Lake is not large (158 hectares of the area) but quite deep (up to 16 m). Reed was found only on the eastern bank of the lake. The periphyton studies on the biotic substrate of *Phragmites australis* were conducted during three seasons of the year: spring (March), summer (July), and autumn (October) in 2003 at five sampling sites (Fig. 1).

In the outer reed zone (depth 0.5-1.0 m) three current-year shoots of *Phragmites* were obtained from each sampling site, and from each shoot three portions were cut out (9 sub-samples in total) to transfer them to a plankton net. A 5-7 cm - long piece was cut out from each *Phragmites* shoot in three places: the upper portion situated 15 cm below the water surface, the middle portion, and the near-bottom one. The fouling material from artificial substrate (foil) was sampled in summer and autumn and the substrates were placed on reed at the depth of up to 40 cm (sampling sites 4 and 5). The collected fragments of the substrate were preserved in 8% formaldehyde solution. In the laboratory the fouling was brushed off

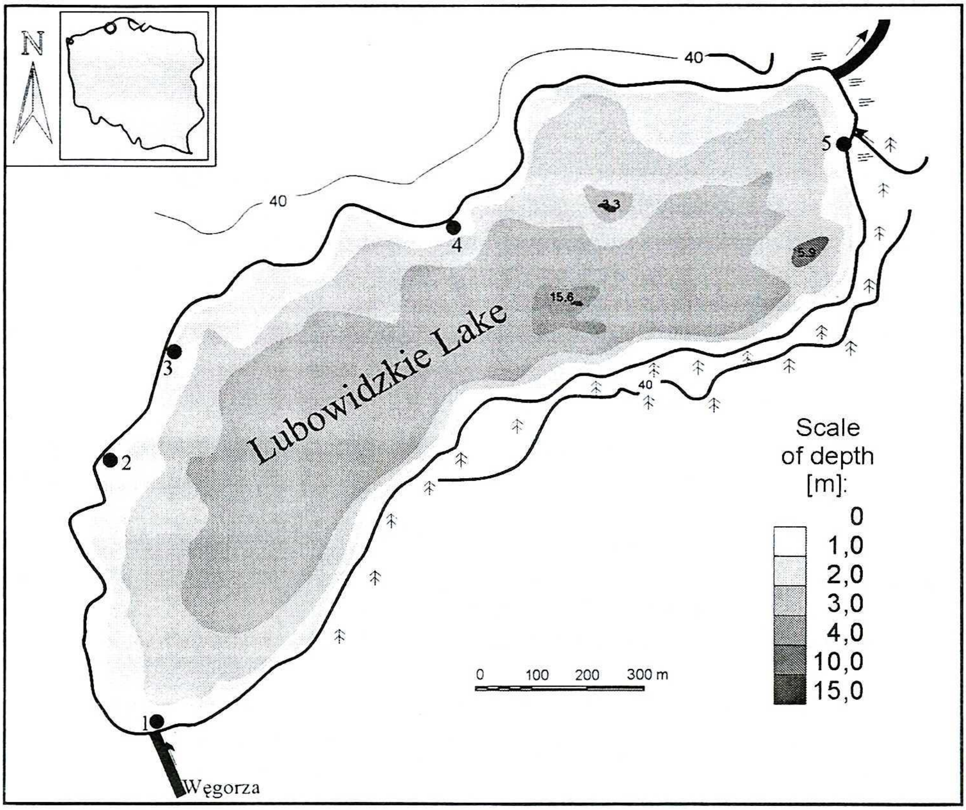



Fig. 1. Localisation of periphyton and physical-chemistry sampling sites

from the reed shoot fragments and foil collected from each sampling site. They were subsequently sieved through a No. 25 plankton net (300 µm mesh size) and placed, depending on the concentration of material, in a 50-250 $cm^3$ graduated cylinder. After even mixing of the material in the cylinder, three 1 $cm^3$ sub-samples were taken using a graduated pipette. The sub-samples were transferred to a plankton chamber and a quantitative analysis was performed under a microscope. The number of algae was determined by recording their number in nine view fields of the microscope (each field = 0.0157 $cm^2$) under a magnification of 180 times (10 × 1.5 × 12 × eyepiece). The average results from the nine fields of view of the microscope from three chambers served as a base for calculating the number of algae per 1 $m^2$ of the substrate surface. The amount of epiphytic microfauna was determined by recording their number in a chamber under a magnification of 90 times (5 × 1.5 × 12 × eyepiece). The average results from the three chambers, served as a base for calculating the number of epiphytic microfauna on a 1 $m^2$ surface of the substrate. The number of macrofauna was analyzed by microscope.

Density of the epiphytic organisms was determined according to the following formula

$$D_P = \frac{V_C \cdot L_O}{n \cdot P_P}$$

where: $D_p$ - density of epiphytic organisms [cells $m^{-2}$ or individuals $m^{-2}$],
$V_C$ - volume of cylinder [$cm^3$];
$L_O$ - number of individuals [specimens or cells];
$P_p$ - ground of basis area [$m^2$];
n - number of repetitions of analysis [$cm^3$].

During physical-chemical analysis of superficial waters of Lubowidzkie Lake, temperature, conductivity, BOD, COD, dissolved oxygen, percent saturations with oxygen, pH, nutrient and chlorides were determined. Physical-chemical analysis performed together with biological ones at the same sites were in accordance with accepted methods [10].

**Mathematical analysis**

The Shannon-Wiener biodiversity index was calculated according to the formula given by R. Margalef and Ch. J. Krebs:

$$H' = -\sum_{i=1}^{s} p_i \log_2 p_1 \quad \text{where} \quad p_i = \frac{n_i}{N}$$

$n_i$ = abundance of $i$-th taxa,
$N$ = total abundance of community,
$s$ = number of taxon in the studied community.

The value of the index changes together with changing taxon richness and even distribution of individual species.

Values of the Shannon-Wiener biodiversity index for the zooperiphyton in different parts of the lake were calculated from overall mean densities of the identified taxa.

The methods of descriptive statistics, i.e. cluster analysis were applied with the use of Statistica 5.1 software. In cluster analysis, during cluster formation, the measurements of distances between objects were employed after calculating Euclidean distances. The measurements determined actual geometric distances between compared control stands in Lubowidzike Lake.

The results were presented in the form of dendrites on the basis of similarity of taxa in the controlled stands in the lake, considering both concentrations. Special attention was paid to the comparison of the two contact zones - tributaries and lake.

The Cochran and Cox test (significance of differences between two means for small sets) was used to show significant arithmetic density differences of the zooperiphyton between seasons. C > Cα pointed at the important arithmetic difference between the examined average densities.

The test of Cochran and Cox: $$C = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{E_{\bar{x}_1}^2 + E_{\bar{x}_2}^2}}$$ E = standard error

$$C_\alpha = \frac{E_{\bar{x}_1}^2 \cdot t_{1_\alpha} + E_{\bar{x}_2}^2 \cdot t_{2_\alpha}}{E_{\bar{x}_1}^2 + E_{\bar{x}_2}^2}$$ $\alpha = 0.05$ (from distribution t-Student)

Additionally frequency ($F_r$), domination index (D) and the characteristic index (R%) were calculated [9].

## RESULTS

The lake water was moderately oxidized during the research. High values of the oxygen were at sampling site 5 and considerably lower at site 1. In spring on two positions over saturation of water was observed. Very low oxygen content in water was observed at site 1. The most stable parameter in Lubowidzkie Lake was pH, which fluctuated in a narrow range from 6.25 to 7.07 (Tab. 1) and indicated neutral character of water. High values of nutrients (nitrogen and phosphorus) were at site 1 and low at site 5. The chloride concentrations in the reservoir were also stable. However, in the stream inflow to the lake their concentrations were the highest (site 1).

Table 1. Physical and chemical properties of water in Lubowidzkie Lake

| Parameter | | Sampling sites | | | | | $\overline{x}$ |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| Temperature | $^{o}C$ | 13.30 | 14.20 | 14.70 | 14.70 | 13.00 | 14.00 |
| Conductivity | $\mu S\ cm^{-1}$ | 322.00 | 252.00 | 244.00 | 289.00 | 193.00 | 260.00 |
| Oxygen saturation | % | 52.80 | 87.00 | 82.10 | 82.10 | 97.20 | 80.20 |
| Dissolved oxygen | $mg O_2\ dm^{-3}$ | 4.92 | 8.44 | 7.65 | 7.65 | 9.53 | 7.64 |
| pH | | 7.07 | 6.27 | 6.51 | 6.51 | 6.25 | 6.52 |
| $BOD_5$ | $mg O_2\ dm^{-3}$ | 8.50 | 2.40 | 2.70 | 3.50 | 2.90 | 4.00 |
| $COD_{cr}$ | $mg O_2\ dm^{-3}$ | 33.60 | 14.90 | 17.50 | 17.9 | 17.40 | 20.30 |
| $N_{total}$ | $mgN\ dm^{-3}$ | 3.56 | 1.55 | 1.87 | 1.89 | 1.90 | 2.15 |
| $N_{mineral}$ | $mgN\ dm^{-3}$ | 1.01 | 0.50 | 0.54 | 0.65 | 0.59 | 0.66 |
| $P_{total}$ | $mgP\ dm^{-3}$ | 0.11 | 0.05 | 0.04 | 0.05 | 0.03 | 0.06 |
| $P\text{-}PO_4^{3-}$ | $mgP\ dm^{-3}$ | 0.08 | 0.06 | 0.02 | 0.03 | 0.03 | 0.04 |
| Chlorides | $mg\ Cl^{-}dm^{-3}$ | 8.45 | 7.25 | 7.20 | 7.20 | 6.55 | 7.33 |

Periphytic organisms represented by bacteria, algae and animals were recorded on the biotic substrates in Lubowidzkie Lake. A mass occurrence of bacteria was observed in the material obtained from the studied substrates, but their qualitative and quantitative aspects were not studied.

The biotic substrate of Phragmites australis was settled by periphytic algae, dominated by Bacillariophyta diatoms, which constituted 100% of the phytoperiphyton (Tab. 2). The concentration of diatoms on the reeds ranged from 0.3 to $75.4 \cdot 10^6$ cells $m^{-2}$ ($\overline{x} = 23.3 \cdot 10^6$ cells $m^{-2}$). The diatoms occurred in all studied sub-samples collected from the reed (Fr = 100%; R% = 0.99). Intensive development of diatoms on this biotic substrate took place in spring ($\overline{x} = 36.8 \cdot 10^6$ cells $m^{-2}$) and, which is unusual, in July ($\overline{x} = 2.8 \cdot 10^6$ cells $m^{-2}$).

Table 2. The average concentration (cells $m^{-2}$) and microflora distribution on different substrates in Lubowidzkie Lake

| Taxon | Foil | | *Phragmites* | |
|---|---|---|---|---|
| | $\overline{x}$ density | % proporcional participation | $\overline{x}$ density | % proporcional participation |
| Bacillariophyta | 34 823 292 | 99.9 | 23 321 310 | 99.7 |
| Chlorophyta | 0 | 0.0 | 32 700 | 0.2 |
| Cyanophyta | 15 846 | 0.1 | 21 048 | 0.1 |
| Total | 34 839 138 | | 23 375 058 | |

Chlorophyta developing on the reed in Lubowidzkie Lake constituted 0.2% of the periphytic algae (Tab. 2). The concentration on *Phragmites* at individual sampling stations varied from 0 to 38.7 • $10^3$ cells $m^{-2}$ ($\overline{x}$ = 32.7 • $10^3$ cells $m^{-2}$). The most favorable conditions for development of Chlorophyta were found during autumn, whereas the least convenient in spring, however it was not observed for this periphytic algal taxon on the reeds substrate. Among periphytic green algae, distinctly dominant were representatives of the genus Scenedesmus sp. The abundance of Chlorophyta on this plant substrate was low and amounted to $F_r$ = 38% and R% = 0.001. That taxon was not found at site 3.

Cyanophyta were permanent inhabitants of the reed substrate ($F_r$ = 78%, R% = 0.001). The percentage of cyanophytes among periphytic algae on the reed was low and amounted to merely 0.1%. The highest share of cyanophytes among periphytic algae on the reed was in summer (0.2%) and low in autumn (0.1%). The concentration of this periphytic algal taxon ranged from 12.6 to 50.7 • $10^3$ cells $m^{-2}$ ($\overline{x}$ = 21.0 • $10^3$ cells $m^{-2}$).

The most dominant epiphytic algae on the discussed artificial substrates (foil) were Bacillariophyta (97-99%), whereas Cyanophyta were subdominant (0.1-2.5%). Fouling Cyanophyta on the discussed artificial substrates reached the lowest concentration among phytoperiphyton (Tab. 2). Bacillarioophyta and Cyanophyta were permanent inhabitants of the artificial substrate ($F_r$ = 100%). An average density of epiphytic algae on the artificial substrate was 1.5-fold higher than on the biotic substrate.

Among periphytic algae, the distinctly dominant were representatives of the colony unicellular algae. The most convenient conditions for their development were found on the biotic substrate in Lubowidzkie Lake during spring 2001. In summer the decrease in the

Table 3. Mean density single cells and colony algae ($10^3$ cells $m^{-2}$) in the Phragmites australis in Lubowidzkie Lake

| | Density single cells algae | | | Density colony algae | | |
|---|---|---|---|---|---|---|
| Sampling sites | Spring | Summer | Autumn | Spring | Summer | Autumn |
| 1 | 178.6 | 11.3 | 7.2 | 0 | 80.3 | 92.0 |
| 2 | 42.2 | 13.0 | 41.2 | 1 553.1 | 138.4 | 633.6 |
| 3 | 586.6 | 12.2 | 26.3 | 854.6 | 140.8 | 475.0 |
| 4 | 950.6 | – | 24.0 | 454.6 | – | 226.0 |
| 5 | 160.5 | 18.4 | – | 104.0 | 136.7 | 0.0 |
| Total | 1 918.5 | 54.9 | 98.7 | 2 966.3 | 496.1 | 1 426.5 |

density of unicellular was noted, which was followed by slow increase in the density again in autumn (Tab. 3). The colony algae inhabited the reed substrate more intensively in spring and autumn, rather than in summer, when their density was the lowest. Densities of epiphytic colony algae were 2.4-fold higher than that of unicellular algae (Tab. 3).

Biotic substrates formed by Phragmites australis as well as artificial substrates in Lubowidzkie Lake were places of the development of fouling animals represented by Protozoa, Rotatoria, Nematoda, Oligochaeta, Crustacea, Hydracarina, Insecta and also Gastropoda.

The presence of seven microfauna taxa was noticed on the reed (Tab. 4), where their average density amounted to 184.9 • $10^3$ indiv. $m^{-2}$. The highest average concentration among the fouling microfauna was noted for rotifers. Sedentary ciliates of the class Peritricha amounted to 90.3 • $10^3$ zooids $m^{-2}$ (D = 4.9 - subdominant). It was a characteristic periphytic taxon R% = 0.49. The Peritricha made up in summer 65.9%, in autumn 48.8% and in spring 38.7% of total microzooperiphyton density. The best conditions for the development of Peritricha on the reed substrate were found at site 5 in the northern zone of the lake ($\overline{x}$ = 101.9 • $10^3$ zooids $m^{-2}$). The lowest development of sedentary ciliates was observed at sites 2 and 4 near the city beach (site 2 = 21.9 • $10^3$ zooids $m^{-2}$, site 4 = 22.3 • $10^3$ zooids $m^{-2}$). A significant concentration on this plant substrate was reached by Nematoda = 36.3 • $10^3$ spec. $m^{-2}$ (spring D = 2.9, autumn D = 19%, in summer the discussed taxon was not present). During summer among microzooperiphyton more abundant was Ciliata libera (D = 1.8), while in autumn it constituted only D = 0.8 of total epiphytic microfauna. In spring they were not observed.

Testacea, Rotatoria, Stylaria lacustris, Harpacticoida as well as Cladocera, settled on Phragmites in a considerably low degree. Their percentage in the fouling microfauna ranged from 3.1 to 6.4%. The concentration of individual taxa varied in a wide range, and some of the taxa were not found at any of the sampling sites (Ciliata libera, Nais sp., Chaetogaster sp., nauplius, Harpacticoida, Hydracarina). Concentrations of individual microfauna taxa settling Phragmites in Lubowidzkie Lake are presented in Table 4.

The reed macrofauna was not very abundant qualitatively and was represented by two taxa, among which Gastropoda as well as Chironomidae larvae reached significant concentrations (Tab. 4). The Chironomidae larvae were characterized by the highest average quantitative concentration in spring = 33.4 • $10^3$ spec. $m^{-2}$. Its frequency ($F_r$) reached 84% and characteristic index (R%) reached 0.52. Mean density of Chironomidae larvae amounted to 17.1 • $10^3$ spec. $m^{-2}$ (D = 6.2 - dominant). The periphyton Gastropoda appeared on the biotic substrate in summer and the highest average quantitative concentration reached in autumn. Gastropodas were sporadic on the reeds substrate ($F_r$ = 23%, R% = 0.09) and were characterized by the average density 10.4 • $10^3$ spec. $m^{-2}$.

The analysis of essential differences between density in consecutive seasons using the Cochran and Cox test showed no statistically significant differences at level $P < 0.05$ (Tab. 4).

Among the studied artificial substrates, significantly lower concentrations of microfauna characterized the foil substrate, where five taxa were stated (Tab. 5). Peritricha were dominant among the microfauna on this substrate (342 • $10^3$ spec. $m^{-2}$), and constituted in summer 56.7% and autumn 32% of epiphytic microfauna. Sedentary ciliates of the Rotatoria group turned out to be subdominant (in summer 21.6%, in autumn 32.7% of epiphytic microfauna). The taxa, except for Peritricha reached lower density on the foil or on the reed

Table 4. Mean density (specimens $m^{-2}$ of substrate), domination index (D) and frequency ($F_r$) of epiphytic fauna on reed *Phragmites australis* in Lubowidzkie Lake

| Taxon | Seasons | | | | $F_r$ | D |
|---|---|---|---|---|---|---|
| | Spring | Summer | Autumn | $\bar{x}$ | | |
| *Microfauna* | | | | | | |
| Total Protozoa | 79 956 | 52 073 | 196 395 | 109 474 | | 5.9 |
| Testacea | 5 592 | 0 | 16 648 | 7 413 | 46 | 0.4 |
| Ciliata – libera | 0 | 11 091 | 24 166 | 11 752 | 61 | 0.6 |
| Peritricha* | 74 364 | 40 982 | 155 581 | 90 309 | 100 | 4.9 |
| Total Rotatoria | 20 349 | 10 100 | 52 229 | 27 559 | 100 | 1.5 |
| Total Nematoda | 56 540 | 0 | 52 229 | 36 256 | 69 | 2.0 |
| Total Copepoda | 34 982 | 0 | 0 | 11 660 | | 0.6 |
| nauplius | 16 966 | 0 | 0 | 5 655 | 23 | 0.3 |
| Harpacticoida | 18 016 | 0 | 0 | 6 005 | 23 | 0.3 |
| *Macrofauna* | | | | | | |
| Chironomidae larvae | 33 416 | 4 660 | 13 125 | 17 067 | 84 | 6.2 |
| Gastropoda | 0 | 4 125 | 27 083 | 10 402 | 23 | 3.8 |
| Total of zooperiphyton | 225 243 ±25 651 | 70 958 ±13 152 | 341 061 ±48 0 92 | 212 418 ±27 563 | | |
| Shannon - Wiener index | 0.739 | 0.534 | 0.692 | | | |
| Cochran - Cox test | Spring – Summer $C < C_{(0.05)}$ 1.555 < 2.562 | | | | | |
| | | Summer – Autumn $C < C_{(0.05)}$ 1.728 < 2.486 | | | | |
| | Spring – Autumn $C < C_{(0.05)}$ = 0.789 < 2.447 | | | | | |

*concentration in zooids $m^{-2}$ of reed

(Tab. 4). The microfauna taxa: Ciliata libera, Peritricha and Rotatoria occurred in all the studied sub-samples collected from the foil ($F_r$ = 100%), however Testacea and Nematoda were rare ($F_r$ = 50%).

The foil macrofauna was very abundant qualitatively and was represented by five taxa, which appeared in autumn. The highest average quantitative concentrations among the fouling macrofauna was that of Chironomidae larvae 32.7 • $10^3$ spec. $m^{-2}$, and Isopoda - Asellus aquaticus 20.9 • $10^3$ spec. $m^{-2}$. The share in the fouling macrofauna of Trichoptera larvae, Gammarus sp., Gastropoda amounted to 4.8%, each. Beside the differences in zooperiphyton density on the artificial and biotic substrate, the analysis by essential Cochran and Cox test showed no specific differences $C < C\alpha$ (0.906 < 2.265) at the significance level $P < 0.05$.

The Shannon-Wiener biodiversity indices were calculated from overall mean densities of the identified ones in different parts of Lubowidzkie Lake. Biodiversity of periphyton on

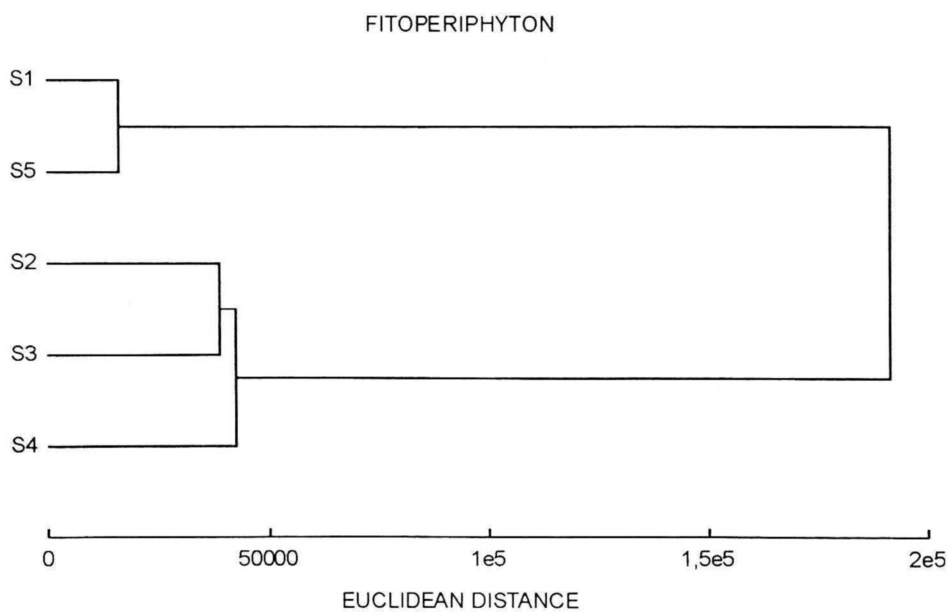
Table 5. Comparison of mean density (specimens $m^{-2}$ of substrate) of microperiphton and macrozooperiphyton growing on biotic and on artificial substrate in selected rivers and lake

| Taxon | *Phragmites australis* | | | | | Foil | |
|---|---|---|---|---|---|---|---|
| | Odra River [22] | Krzynia Lake [17] | Raduń-skie Dolne [16] | Lubowidz-kie Lake [15] | Lubowidz-kie Lake | Lubowidz-kie Lake [15] | Lubowidz-kie Lake |
| Microfauna | | | | | | | |
| 1. Total Protozoa | 924 383 | 4 149 | 1 883 | 58 791 | 109 474 | 10 119 046 | 399 648 |
| *Testacea* | 0 | 1 295 | 315 | 417 | 7 413 | 3 273 809 | 1 221 |
| Ciliata – libera | 0 | 451 | 76 | 2 653 | 11 752 | 297 619 | 4 807 |
| Peritricha* | 275 590 | 2 403 | 1 491 | 13 828 | 90 309 | 1 190 476 | 342 009 |
| Suctoria | 331 710 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2. Rotatoria | 46 570 | 933 | 602 | 5 480 | 27 559 | 3 273 809 | 27 900 |
| 3. Nematoda | 50 570 | 1 499 | 2 136 | 36 413 | 36 256 | 2 083 333 | 23 711 |
| 4. Total Oligochaeta | 1 866 | 13 | 288 | 1 254 | 0 | 3704 | 0 |
| *Stylaria lacustris* | + | 11 | 45 | 572 | 0 | 1 852 | 0 |
| *Nais* sp. | + | 0 | 51 | 0 | 0 | 0 | 0 |
| *Chaetogaster* sp. | + | 2 | 192 | 682 | 0 | 1 852 | 0 |
| 5. Total Copepoda | 0 | 0 | 296 | 2 249 | 11 660 | 3 273 809 | 0 |
| nauplii | 0 | 0 | 130 | 636 | 5 655 | 1 488 095 | 0 |
| Cyclopoidae | 3 500 | 0 | 19 | 0 | 0 | 0 | 0 |
| Harpacticoida | 1 920 | 0 | 146 | 1613 | 6 005 | 1 785 714 | 0 |
| 6. Cladocera (*Chydorus* sp.) | 0 | 139 | 28 | 855 | 0 | 595 238 | 0 |
| 7. Hydrachnellae | 0 | 109 | 32 | 0 | 0 | 0 | 0 |
| 8. Tardigrada | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| 9. Bivalvia (*Dreissena* – postveliger) | 711 706 | 0 | 0 | 0 | 0 | 0 | 0 |
| Number of taxa | 10 | 10 | 13 | 10 | 7 | 10 | 5 |
| Macrofauna | | | | | | | |
| 1. *Cordylophora caspia** | 3 013 | 28 | 0 | 0 | 0 | 0 | 0 |
| 2. Bryozoa* | 4 129 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. Hirudinea | 34 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4. *Corophium* sp. | 40 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5. *Gammarus* sp. | 80 | 0 | 0 | 0 | 0 | 0 | 3 035 |
| 6. *Asellus aquaticus* | 115 | 0 | 0 | 0 | 0 | 0 | 20 893 |
| 7. Chironomidae larv. | 4 030 | 581 | 159 | 5 165 | 17 067 | 297 620 | 32 678 |
| 8. Gastropoda | 40 | 0 | 0 | 0 | 10 402 | + | 3 035 |
| 9. Trichoptera larv. | 0 | 0 | 0 | 0 | 0 | 0 | 3 035 |
| Number of taxa | 8 | 2 | 1 | 1 | 2 | 2 | 5 |
| Shannon-Wiener index | 0.571 | 0.699 | 0.710 | 0.633 | 0.722 | 0.798 | 0.442 |

*concentration in zooids $m^{-2}$ of reed + occurrence single individuals biotic substrate in summer was lower than the one in spring and autumn. The Shannon-Wiener biodiversity index of zooperiphyton inhabiting artificial substrate was lower than on the biotic substrate.

| Taxonomic category | Shannon-Wiener biodiversity index | | | | |
|---|---|---|---|---|---|
| | *Phragmites australis* | | | | Foli |
| | Spring | Summer | Autumn | $\bar{x}$ | $\bar{x}$ |
| Microzooperiphyton | 2.046 | 1.276 | 1.830 | 1.717 | 0.877 |
| Macrozooperiphyton | 0.408 | 0.497 | 0.471 | 0.458 | 0.587 |
| Total zooperiphyton | 2.455 | 1.773 | 2.300 | 2.176 | 1.464 |

In the lake, when the concentration is taken into account, the control stands located in the northern and southern parts of the reservoir (control sites 1 and 5), where the stream inflow and outflow from the lake were located, showed the strongest similarity. When comparing the similarity of the stands, it can be observed that they got concentrated during forming of the stream and lake agglomeration (cluster). The distance between the sites, when compared to the lake, increased after being made passable (Fig. 2). In contact zones of the stream and lake (sampling sites 1 and 5) the uniformization of the stands in terms of the concentration of phyto- and zooperiphyton was observed (Fig. 2).



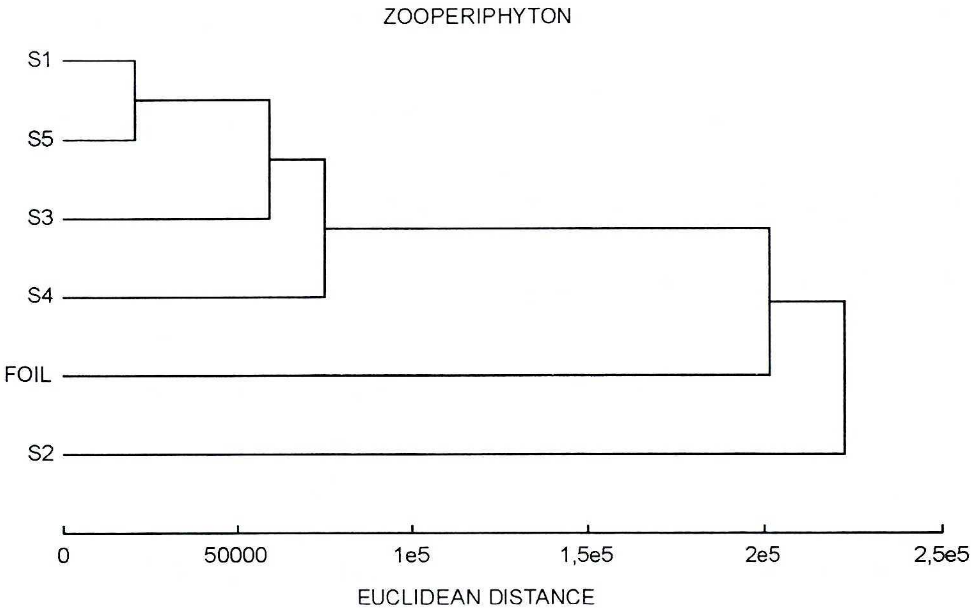



Fig. 2. Similarity dendrograms based on density dynamics of periphyton assemblages of Lubowidzkie Lake

## DISCUSSION

Eutrophication of Lubowidzkie Lake decreases water transparency which is connected to the phytoplankton development [6]. Lubowidzkie Lake is supplied by the Węgorza stream, where fishing ponds (mostly carp) are situated. The second stream dewaters the lake towards the Łeba River. Because of the Węgorza fishing ponds on the stream, the highest nitrogen and phosphorus concentrations are found upstream the lake. It influences the periphyton to be less abundant [14]. A significant difference between chloride concentrations was observed in spring, which was also observed in other examined lakes [21, 24]. Generally the most stable chemical indicator of water quality in the reservoir was pH in spring and autumn time [15]. The smallest physical-chemical fluctuations during the study were stated when there was winter stagnation in Lubowidzkie Lake [7]. The amount of dissolved oxygen classifying water into purity class I and II affected the periphytic organisms [1, 19]. Oxygen depletion happened mainly in summer and limited the hydrobionts development [12].

Epiphytic formation can play a significant role in the process of water ditrophication and create, together with zooplankton, food for moving fish species mainly [27]. The qualitative-quantitative development of fouling organisms in surface water depends on quality and availability of water, environmental type and a level of its pollution [19]. Similarly to all reservoirs, in Lubowidzkie Lake there are found representatives of all trophic levels: producers, consumers and reducers [19]. Diatoms domination is very common in periphyton research in different water environments [19]. Regardless of salinity and a significant pollution level Bacillariophyta dominated among phytoperiphyton [21]. They dominated mainly in warm seasons but also during winter [15].

In Lubowidzkie Lake three phytoperiphyton taxa were found: Bacillariphyta, Cyanophyta and Chlorophyta, which is typical for this formation [19]. Comparing the algae density on natural and artificial substrate, higher density of fouling algae was noticed on the artificial one. The results confirmed that artificial substrate (foil) is better overgrown by the algae than natural substrate [3, 7, 15, 19, 21]. Comparing density of fouling taxa at different substrates in Polish lakes and watercourses it appears that the phytoperiphyton density in Lubowidzkie Lake is high mainly on the artificial substrate. It is due to good environmental conditions in the lake for the intensive algae develop on these substrates [1].

Among microperiphyton eight animal taxa were found. Fouling microfauna reached the highest quantitative development on foil substrates in the examined lake ($451.3 \cdot 10^3$ cells $m^{-2}$). The amount of microfauna taxa at the substrate in Lubowidzkie Lake was 5 and it was lower than taxa stated at substrates in other water environments (Tab. 5).

According to the data presented in Table 5, it was observed that among fouling microfauna Peritricha reached the highest development level on the substrates mentioned above but also similar situation was noted for taxa Nematoda and Rotatoria [2]. On the biotic substrate (reed) these taxa dominated too, but presence of Nematoda was not stated in summer. Comparing the results from the warm seasons to the results from winter with other lakes, significant differences were observed [11, 15]. In winter, the fouling microfauna, intensively inhabit artificial substrates, withdrawn from the reed. By the appearance of a new reed generation it began slow development during spring - summer time. The artificial substrates (garden substrates) are becoming strongly inhabited in a pioneer periphyton association [13]. Petrircha does not always dominate in microperiphyton as it was in Lubowidzkie Lake.

The fouling macrofauna reached rather low qualitative amounts (max. 2 taxa) at the biotic substrate. According to the data presented in Table 5, it is observed that dominant fouling macrofauna representatives were also different species of Chronomidae larvae, which were examined on Phragmites in different water types [4]. Chironomidae larvae dominated also in macrozoobentos of Lubowidzkie Lake, attaining 160-fold lower density [18]. The Shannon-Wiener biodiversity indices for macrozoobenthos in littoral bottom were lower than for zooperiphyton on the biotic substrate. In littoral bottom the biodiversity index ranged from 0.432 to 1.011 and on reed from 1.034 to 3.002. Depending on environmental effects and biotic interactions, the Shannon-Wiener index for the total taxa varies usually within 0-4 [8]. When comparing the similarity of the stands, it can be observed that they concentrated during forming river and lake agglomeration (cluster) for macrobenthos, as well as for periphyton.

In autumn organisms living only on the foil (Asellus aquaticus L., Trichoptera larvae, Gammarus sp.) appeared. They were not found during winter research [15]. These taxa also were not noticed in the researched water regions and watercourses.

Presence of different substrate types creates good conditions for fouling organism's development which increase biodiversity mainly in degraded water environment. The reed elimination is not a useful phenomenon and it decreases water self-cleaning anility [26]. Another artificial substrate formed in Lubowidzkie Lake can be used as spawning site for some fish [19, 20, 27]. Newly hatched fish fry will find a lot of food on the foil substrate. Growing algae, mainly diatoms, compete for nutrients with phytoplankton. By a massive development they prevent unfavorable water color caused by algal blooms. As well as massive reducers and consumers occurrence influences the elimination of mineral salts, chemical compounds, and bioseston suspended in the water [19, 25].

It can be expected that artificial substrate introduction into Lubowidzkie Lake will cause improvement of biodiversity at each trophic levels. Other artificial substrates located in proper places can be used for cleaning of the water (biofiltration, bioaccumulation), [5]. It is important, because Lubowidzkie Lake is a part of the Łeba River catchment, and Łeba flows straight into the sea across Łebsko Lake and Słowiński National Park. Protection of this reservoir affects the purity state of the Polish Baltic Sea zone and the World Biosphere Reserve.

Table 6. Comparison density of epiphytic algas periphyton (in alga individuals) on basic biotic and artificial substrate in selected types of water

| Type of waters | Localization | Type of substrate | Algae density (cells $m^{-2}$ of substrate) | Author |
|---|---|---|---|---|
| Channel | Okunica | stilon net | 784 200 000 | [19] |
| River | Odra (Jasienica) | reed | 128 100 000 | [22] |
| River | Gunica | reed | 74 600 000 | [22] |
| Lake | Raduńskie Dolne | reed | 37 000 | [16] |
| Lake | Raduńskie Dolne | Typha | 151 000 | [16] |
| Lake | Krzynia | reed | 273 000 | [17] |
| Lake | Konradowo | Typha | 47 000 | [17] |
| River | Słupia | reed | 13 000 | [17] |
| Lake | Lubowidzkie | reed | 499 000 | [15] |
| Lake | Lubowidzkie | foil | 97 300 000 | [15] |
| Lake | Lubowidzkie | reed | 23 375 000 | |
| Lake | Lubowidzkie | foil | 34 839 000 | |

## CONCLUSIONS

1. Growth of organisms representing all trophic levels (producers, reducers, consumers) was stated on substrates (*Phragmites australis*, foil) in Lubowidzkie Lake.
2. Producers were represented mainly by Bacillariophyta on the studied substrate. Density of fouling microalgae (algae units) was high ($23.4\text{-}34.8 \cdot 10^6$ cells $m^{-2}$). The biotic substrate formed by *Phragmites australlis* in Lubowidzkie Lake was poorly inhabited in comparison to the artificial foil substrate. A complete fouling algae density was higher in winter than in warmer seasons.
3. Periphytic microfauna were represented by 5-7 taxa which reached the highest species diversity on *Phragmites australis*. Better conditions for periphytic organism's density were stated on abiotic substrate (451 300 species $m^{-2}$) than biotic one (184 900 species $m^{-2}$). Microzooperiphyton density was lower in winter time. The highest density was reached by Peritrcha, Rotatoria and Nematoda on the substrates in Lubowidzkie Lake. Testacea dominating in winter left the substrate.
4. Among periphytic macrofauna, Chronomidae larvae dominated on abiotic and biotic

substrate. Only two taxa were found (Chronomidae larvae, Castropoda) on Phragmites but in autumn on the foil appeared single individuals of Isopoda, Trichoptera and Gammarus. Macrozooperiphyton in spring - autumn time was much richer than winter periphytic macrofauna.

5. According to quantitative - qualitative data, fouling organisms in Lubowidzkie Lake were not as much developed as those on the biotic substrate in the Odra River or other lakes. Comparing densities of organisms in the lake, one can notice that better conditions for fouling organism's development are on the foil than the biotic substrate.
6. Artificial foil substrate employed mainly in the part of the lake of limited antropogenic influences, should affect tourist amenities to the reservoir and improve water quality of the Łeba River which flows trough Lubowidzkie Lake. Consequently, taking care about the lake, the improvement of water condition in the area of Łebsko Lake and the seaside resort in Łeba is supposed.

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