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PERIPHYTIC DIATOM COMMUNITIES IN THE LITTORAL ZONE OF THE URBAN LAKE JEZIORAK MAŁY (MASURIAN LAKE DISTRICT, POLAND)

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Abstract

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This study on plant periphyton (epilython, epiphyton, and periphyton communities on artificial substratum – separator pipes) was carried out in the littoral zone of lake Jeziorak Mały in 2002 and 2003. In addition to floristic analysis, changes in the abundance and biomass of periphytic diatoms with respect to physio-chemical water parameters in the season between April and October were analyzed. The highest number of periphytic diatoms was found in the pipes in June, and the highest biomass of epilython was established in September, in conditions of high contents of Ca and Si biogenes. Moreover, the indicator potential of diatoms was used to determine the trophy and saproby of the lake's waters. The largest participation of eutraphents in the biomass in all the diatom communities generally indicates the eutrophic character of the lake's waters, the dominance of meso-saprobes and a moderate content of organic matter. Moreover, a large proportion of α-mesosaprobes (dominant *Navicula gregaria*) in the biomass of periphytic diatoms in the pipes indicates the highest degree of contamination by organic matter there in comparison to other substrates, while the epilython had the highest biomass of β-α-meso-saprobes (dominant *Diatoma vulgaris*), an average degree of contamination with a dominance of β-meso-saprobes (subdominant *Cocconeis placentula*) and the least degree of contamination by organic matter.

Key words: lake, littoral zone, periphytic diatoms, trophic and saprobic status

Introduction

Periphyton is composed of communities of plant and animal organisms overgrowing submerged surfaces such as stones, macrophytes,and artificial substrata (Szlauer, 1996). Plant periphyton includes both large forms of algae such as filamentous and thallus-like chlorophytes and small organisms, including diatoms. The most significant factors influencing the development of periphytic algae – in addition to the type and texture of the substratum used by the organisms for habitat colonization (Whitton, 1975; Round, 1981) – are environmental factors such as light, temperature, water movement and also the water's biogene concentration,of phosphorus and nitrogen, and for diatoms the amounts of silicon and calcium (Reynolds, 1986; Krebs, 1996; Poulickova et al., 2004). An additional factor which may significantly influence periphyton communities is pressure of invertebrate organisms (Kajak, Warda, 1968; Hansson, 1990; Jones et al., 2000).

Periphyte communities include a large proportion of diatoms (Bohr, Miotk, 1979; Hansson, 1990) which, due to their very specific requirements of biogene salt content, are reliable indicators of the trophic status of waters, determining the rate of their production (Hofmann, 1994; Kawecka, Eloranta, 1994; Danilov, Ekuland, 2000; Poulickova et al., 2004; Ács et al., 2005; Stenger-Kovács et al., 2007). The near spectrum of water trophy is the spectrum of organic contaminants (saproby) determining the degree of organic matter mineralization. In general, the saprobic system was developed for running waters (Fjerdingstad, 1965; Sládeček, 1973). However, by using communities of littoral algae, they can also be applied to lakes (Hofmann, 1994).

A number of authors have carried out research to compare communities of periphyton algae inhabiting natural and artificial substrates in the littoral zone of lakes (Aloi, 1990; Cattaneo, Amireault, 1992; Danilov, Ekuland, 2000). Lake Jeziorak Mały is an example of a fertile lake with a diverse and anthropogenically transformed littoral zone in which periphyton algae, including diatoms, inhabit both natural and artificial substrates. The objective of this paper is to determine the diversity of communities of periphytic diatoms in separator pipes, on stones (epilython), and on the leaves of macrophytes (epiphyton), and to use this knowledge to determine the trophic and saprobic status of the waters of the littoral zone of lake Jeziorak Mały. This study was carried out in 2002 and 2003.

Research area, material and methods

Jeziorak Mały is an urban lake located in the Mazurian Lakeland in north-eastern Poland. The lake covers a total area of 26 ha with a maximum depth of 6.4 m and mean depth 3.4 m. For many decades, this lake received untreated municipal sewage from the town of Iława. Since 1991, however, effluent has been treated at a local wastewater treatment plant. Work to improve the lake's water quality began in 1997 and has been ongoing since that time, including the installation of separators for the pre-treatment of storm water influent, and a fountain-based water aeration system. The lake shores were partly covered with concrete or reinforced with fascine, and most of the bottom was composed of stones and gravel. In the 2002–2003 period, about 40% of the littoral zone was overgrown by vascular plants, mainly *Phragmites communis*, *Scirpus lacustris* (L.) P a l l a, *Acorus calamus* L. and *Glyceria aquatica* (L.) W a h l b., while the bottom was muddy and covered with decomposing plant debris.

Samples were collected monthly from April to October 2002 and 2003, on the three substrates located in the littoral zone of lake Jeziorak Mały:

1) periphyton from the pipes of separators which drain storm waters;
2) epilython from the stones constructed in 1997;
3) epiphyton from the leaves of vascular plants (*Acorus calamus* L.).

The periphyton was scraped from the pipes, from 1 cm^2 stones and from the macrophyte leaves which had been cut into 5 cm lengths. The pipes and stones were often found to be overgrown with *Cladophora glomerata* (L.) K ű t z i n g filamentous green algae which forming a natural substratum for periphytic diatoms. The periphyton was shaken carefully in distilled water to separate algae and diatoms from chlorophyte thalli, and remains were scraped off macrophytes leaves with a knife. The samples were rinsed and preserved using an ethanol and a formaldehyde solution. A total of 60 samples were collected. The following physio-chemical water parameters were determined: temperature (°C), oxygen content (mg O_2 l^{-1}) (using an HI 9143 oxygen meter), electrolytic conductivity (µS cm^{-1}) (using a CONMET 1 conductometer), and orthophosphate (mg PO_4 l^{-1}), silicon (mg Si l^{-1}) and calcium (mg Ca l^{-1}) concentrations (using a NOVA 400 spectrophotometer).

Diatom samples were prepared following standard procedures, as described by Battarbee (1979). Here, 10% hydrochloric acid was used to remove carbonates and 30% hydrogen peroxide was used to oxidize the organic matter. The diatoms were mounted onto slides using Naphrax, and qualitative and quantitative determinations of diatoms were performed with an Eclipse 800 optical microscope at 20x, 40x, 60x and100x magnifications, under oil immersion. Diatom identification was aided by following the works of Krammer and Lange-Bertalot (1986, 1988, 1991a, b). The specimens were counted in a 1 ml plankton chamber and the diatom biomass was calculated for bio-volume by comparing the algae with their geometrical shapes (Rott, 1981). The abundance and biomass of periphytic diatoms were calculated per 1 cm^2.

The diatom species diversity was analyzed to calculate the Shannon-Weaver index which provides information on the species abundance and the distribution of particular diatom species (Shannon ,Weaver, 1949). The similarity between the species composition of periphytic diatom communities was shown in the dendrogram of Euclidean distances (STATISTICA version 8). Diatoms were divided into groups of trophic and saprobic forms (Hofmann, 1994). In the analysis, means were applied which represented the sum of the numbers of individuals or biomass on the selected substrates in this littoral zone.

Results

Physico-chemical water parameters

Changes in physiochemical water parameters were analyzed at the stations with different substrates (separator pipes, stones and macrophytes) in the littoral zone of lake Jeziorak Mały in 2002 and 2003 to provide a comparative background for the periphytic diatom communities. The lowest mean water temperature (18.1 °C) and the highest mean electrolytic conductivity (405 µS cm^{-1}) and mean orthophosphate, calcium and silicon concentrations (0.55 mg PO_4 l^{-1}, 101 mg Ca l^{-1} and 0.81 mg Si l^{-1}, respectively) were noted at the stations with separators in comparison with the remaining stations. However, the lowest mean electrolytic conductivity and orthophosphates were recorded at the stations with stones (333 µS cm^{-1} and 0.34 mg PO_4 l^{-1}, respectively) and the highest water temperature (19.9 °C) and oxygenation (7.75 mg O_2 l^{-1}), and the lowest calcium concentration (74 mg Ca l^{-1} was found at stations with macrophytes (Table 1).

T a b l e 1. Physiochemical water parameters in the littoral zone of lake Jeziorak Mały (means of the years 2002 and 2003).

Variable	Pipes	Stones	Macrophytes
Water temperature (°C)	18.1	19.0	19.9
Oxygen content (mg O_2 l^{-1})	7.24	7.39	7.75
Electrolytic conductivity (µS cm^{-1})	405	333	389
Orthophosphates (mg PO_4 l^{-1})	0.55	0.34	0.35
Calcium (mg Ca l^{-1})	101	87	74
Silicon (mg Si l^{-1})	0.81	0.71	0.71

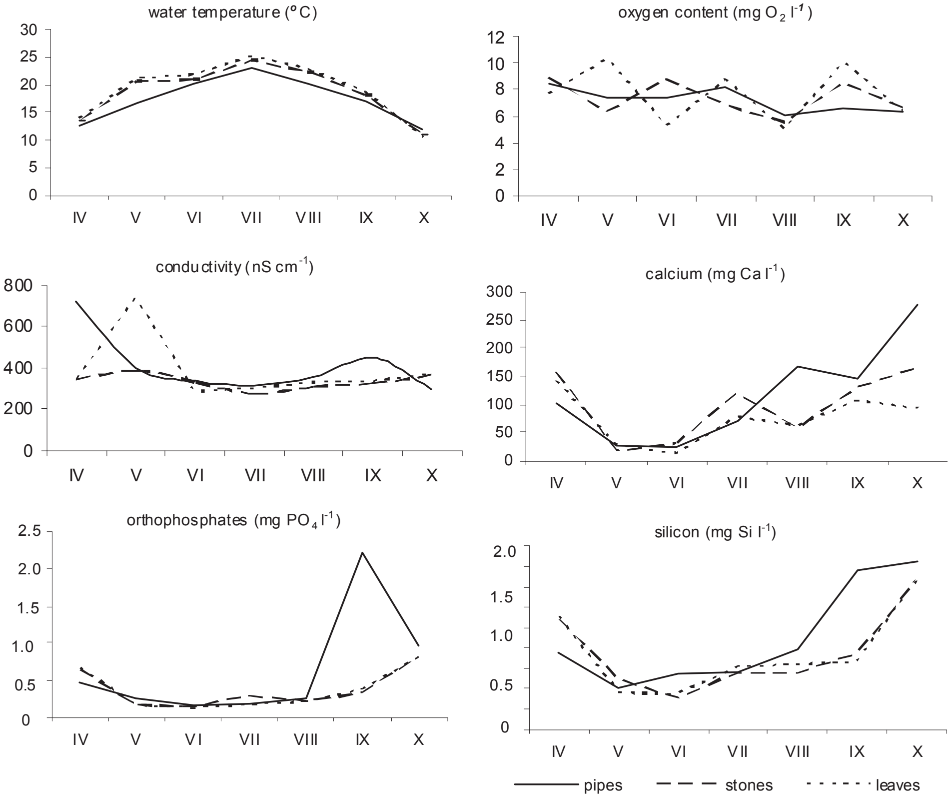

Fig. 1. Seasonal changes of physiochemical water parameters at the stations with different substrates in the littoral zone of lake Jeziorak Mały (means of the years 2002 and 2003).

Changes in water temperatures were similar from April to October in these pipes, stone and macrophyte substrate sites. Water temperature increased from April to July (maximums – 23.2; 24.4 and 25.2 °C, respectively), and then decreased to about 11 °C in October. Three water oxygenation maxima were observed at these stations (pipes of separators – April, July and September; stones – April, June and September, and macrophytes – May, July and September). The highest oxygen contents were recorded in April at the pipes and stones stations (8.52 and 8.89 mg O_2 l^{-1}, respectively) and in May at the macrophyte stations (10.34 mg O_2 l^{-1}). However, the highest electrolytic conductivity was noted in April at the stations with pipes at 723 µS cm^{-1}, and in May at the stone and macrophyte stations, with 388 and 739 µS cm^{-1} respectively. Changes in calcium, orthophosphate and silicon concentrations were similar from April to October at all stations. A decrease in the concentration of these biogenes was observed in spring, and then their increase was noted in the summer period, progressing to maximum values in autumn. The following maxima were recorded; (1)The highest calcium concentration was found in September at the stations with macrophytes (108 mg Ca l^{-1}), and in October at the stations with pipes (276 mg Ca l^{-1}) and stones (166 mg Ca l^{-1}); (2) the highest orthophosphates in September at the stations with pipes (2.22 mg PO_4 l^{-1}) and in October at the remaining stations (0.82 mg PO_4 l^{-1}); and (3) the highest silicon concentration in October at all stations (1.65 mg Si l^{-1} - pipes, 1.46 mg Si l^{-1} – stones and 1.49 mg Si l^{-1} for macrophytes; Fig. 1).

Characteristic of periphytic diatom communities

In the littoral zone of lake Jezorak Mały in 2002 and 2003, the proportion of periphytic diatoms in the total abundance of periphytic algae varied from 70.60% for epiphyton to 90.28% in the pipes, but in the total biomass this proportion ranged from 39.63% in the pipes to 68.84% in epiphyton. The highest mean abundance of periphytic diatoms was also noted in the pipes (3,017,213 individuals. cm $^{-2}$) and the lowest abundance for epiphyton (638,941 indiv. cm $^{-2}$). However, the highest mean biomass was recorded for epilython (1,448 mg cm^{-2}) and the lowest for epiphyton (0.644 mg cm^{-2}; Table 2).

In the period from April to October, the abundance of periphytic diatoms increased from April to June (maximum – 4,185,965 indiv. cm^{-2}), then decreased to a minimum in October in the pipes (1,110,163 indiv. cm^{-2}). In the case of epilython and epiphyton, the three highest abundances were observed in April, June and September (maximum – 1,296,631 indiv. cm^{-2} and 1,402,320 indiv. cm^{-2}, respectively). The lowest abundance of diatoms in both periphytic communities were noted in the summer season (366,748 indiv. cm^{-2} in July for epilython and 180,750 indiv. cm^{-2} in September for epiphyton). The periphytic diatoms attained the two greatest biomasses on all substrates. The biomass maxima for the algae were recorded in May and September in the pipes, while the highest biomass of diatoms was at the level of 2,355 mg cm^{-2} and the lowest one in April on the substratum at 0.454 mg cm^{-2}. In the case of epilython and epiphyton, the maximum diatom biomass was shifted in time and occurred in June and September (maximum – 3.228 mg cm^{-2} and 1.892 mg cm^{-2}, respectively). However, the lowest biomass of epilythic diatoms in July (0.737 mg cm^{-2}) and epiphytic diatoms in May (0.123 mg cm^{-2}) were also observed (Fig. 2).

The highest Shannon-Weaver species diversity index of 4.21 bit. indiv.$^{-1}$ was noted for epiphyton and the lowest was 2.53 bit. indiv. $^{-1}$ for periphytic diatoms in the pipes at taxa

T a b l e 2. Characteristics of periphytic diatom communities in the littoral zone of lake Jeziorak Mały (means of the years 2002 and 2003).

Variable	Periphyton in pipes	Epilython	Epiphyton
Abundance of diatoms (indiv. cm $^{-2}$)	3 017 213	870 083	638 941
Proportion of diatoms in the total abundance of periphytic algae (%)	90.28	74.34	70.60
Biomass of diatoms (mg cm^{-2})	1.334	1.448	0.644
Proportion of diatoms in the total biomass of periphytic algae (%)	39.63	39.67	68.84
Number of taxa	52	56	52
Shannon-Weaver species diversity index (bit indiv^{-1})	2.53	4.21	3.95

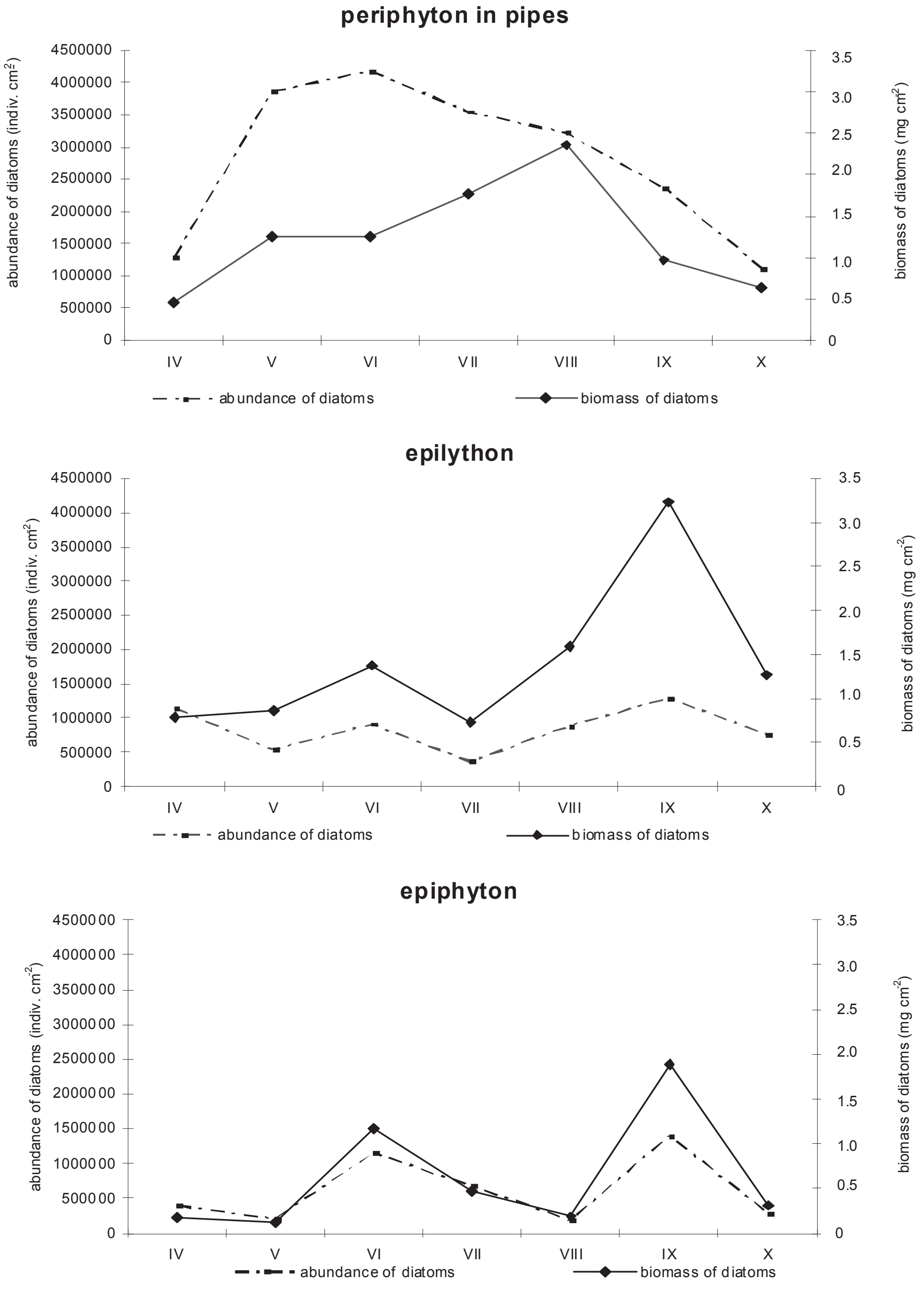

Fig. 2. Seasonal changes of abundance and biomass of periphytic diatoms in the littoral zone of lake Jeziorak Mały (means of the years 2002 and 2003).

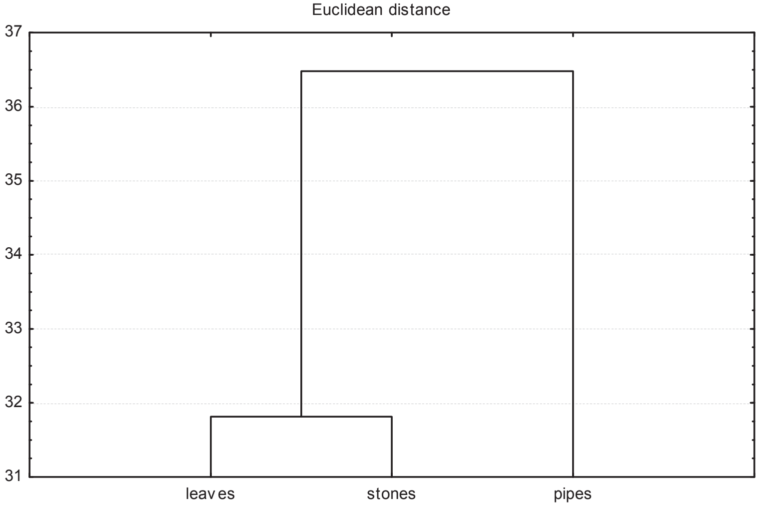

Fig. 3. Dendrogram of Euclidean distances for the periphytic diatom species composition in the litoral zone of the lake Jeziorak Mały in the years 2002 and 2003.

numbers 56 and 52, respectively (Table 2). The dendrogram of species composition similarity shows the smallest Euclidean distance between epilython and epiphyton, and largest between epiphyton and periphytic diatoms in the pipes (Fig. 3).

Five dominant taxa were subjected to detailed quantitative analysis for their total numbers and the biomass of periphytic diatoms on the separator pipes artificial substratum, and also in epilython,and epiphyton. In terms of numbers, *Navicula gregaria* (46.35% in the pipes), *Nitzschia frustulum* (15.20% in epilython), and genus *Gomphonema* sp. (18.15% in epiphyton) were dominant. *Fragilaria capucina*, *Fragilaria leptostauron* var. *martyi,* and *Gomphonema* sp. (small forms) were classified as subdominants on all of the substrates, *Cocconeis placentula* – as a subdominant in epilython and epiphyton, and *Nitzschia frustulum* – as a subdominant in the pipes. The highest proportion in the total biomass of periphytic diatoms was that of *Navicula gregaria* (21.22% in the pipes), *Diatoma vulgaris* (27.12% in epilython), and genus *Gomphonema* sp. (18.91% in epiphyton). Accompanying taxa were *Fragilaria leptostauron* var. *martyi* on all substrata*, Cocconeis placentula, Diatoma vulgaris* var. *linearis*, and *Rhoicosphenia abbreviata* in epilython and epiphyton, and *Fragilaria capucina* and *Nitzschia frustulum* in the pipes (Table 3).

The trophic and saprobic spectra of periphytic diatom communities

In the littoral zone of lake Jeziorak Mały, 56 taxa were identified, of which 41 species were characterized in terms of ecological requirements. Based on the classification by Hofmann (1994), the indicator species of periphytic diatoms were divided into groups in terms of trophy

T a b l e 3. Dominant diatom taxa (5) in the periphytic communities in the littoral zone in lake Jeziorak Mały (means of the years 2002 and 2003).

Taxa	Periphyton in pipes	Epilython	Epiphyton
Abundance (%)			
Cocconeis placentula Ehrenberg	-	7.99	8.70
Fragilaria capucina Desmazieres	16.64	7.88	8.08
Fragilaria leptostauron var. *martyi* (Heribaud) Lange-B.	6.09	12.24	14.08
Gomphonema sp. (małe formy)	5.36	10.65	12.09
Gomphonema sp.	-	-	**18.15**
Navicula gregaria Donkin	**46.35**	-	-
Nitzschia frustulum (Kütz.) Grunow in Cleve & Grunow	16.47	**15.20**	-
Biomass (%)			
Cocconeis placentula Ehrenberg	-	9.45	14.67
Diatoma vulgaris Bory	5.96	**27.12**	-
Diatoma vulgaris var. *linearis* Grunow in Van Heurck	-	6.08	11.97
Fragilaria capucina Desmazieres	11.13	-	-
Fragilaria leptostauron var. *martyi* (Heribaud) Lange-B.	11.46	6.65	10.92
Gomphonema sp.	-	-	**18.91**
Navicula gregaria Donkin	**21.22**	-	-
Nitzschia frustulum (Kütz.) Grunow in Cleve & Grunow	20.00	-	-
Rhoicosphenia abbreviata (Agardh) Lange-Bertalot	-	8.92	6.59

and saproby**.** In the trophic spectrum, oligotraphents, mesotraphents, eutraphents, saprotrophs and tolerant species were distinguished, and in the saprobic spectrum: oligosaprobes, β-mesosaprobes, β-α-mesosaprobes, α-mesosaprobes, and polysaprobes. In the former classification, the most numerous group of diatoms were species preferring eutrophic waters (20 species) and tolerant species with a wide trophic sprectrum (14). The highest biomass of eutraphents and their proportion in the total biomass was determined for communities of periphytic diatoms in the pipes (0.971 mg cm^{-2} and 72.80%, respectively), and the lowest for epiphyton (0.189 mg cm^{-2} and 29.48%, respectively). The highest biomass of tolerant species was determined for epilython (0.251 mg cm^{-2}), and the lowest in the pipes (0.065 mg cm^{-2}). The proportion of this group of diatoms in the total biomass varied from 4.85% in the pipes to 25.32% in epiphyton. Five diatoms species typical for mesotrophic waters were distinguished. The highest biomass and percentage share of this group of diatoms was also found in the pipes (0.071 mg cm^{-2} and 5.34%, respectively). Meso-eutraphents reached their lowest biomass in epiphyton, and the lowest percentage share in epilython. The least numerous diatoms were represented by oligotraphents and saprotrophs. In each of the two groups, 1 species was classified (*Fragilaria delicatissima* and *Amphora veneta*, respectively), while *Fragilaria delicatissima* reached its highest biomass and percentage share in epiphyton, and *Amphora veneta* in epilython (Table 4, Fig. 4).

In terms of saproby, the most numerous group of diatoms were β-α-meso-saprobes (16 species) and β-meso-saprobes (12 species). The former group of diatoms also reached the highest biomass and percentage share in the total biomass of periphytic diatoms in epilython and also in the pipes (0.850 mg cm^{-2} and 58.68%, respectively). In the case of

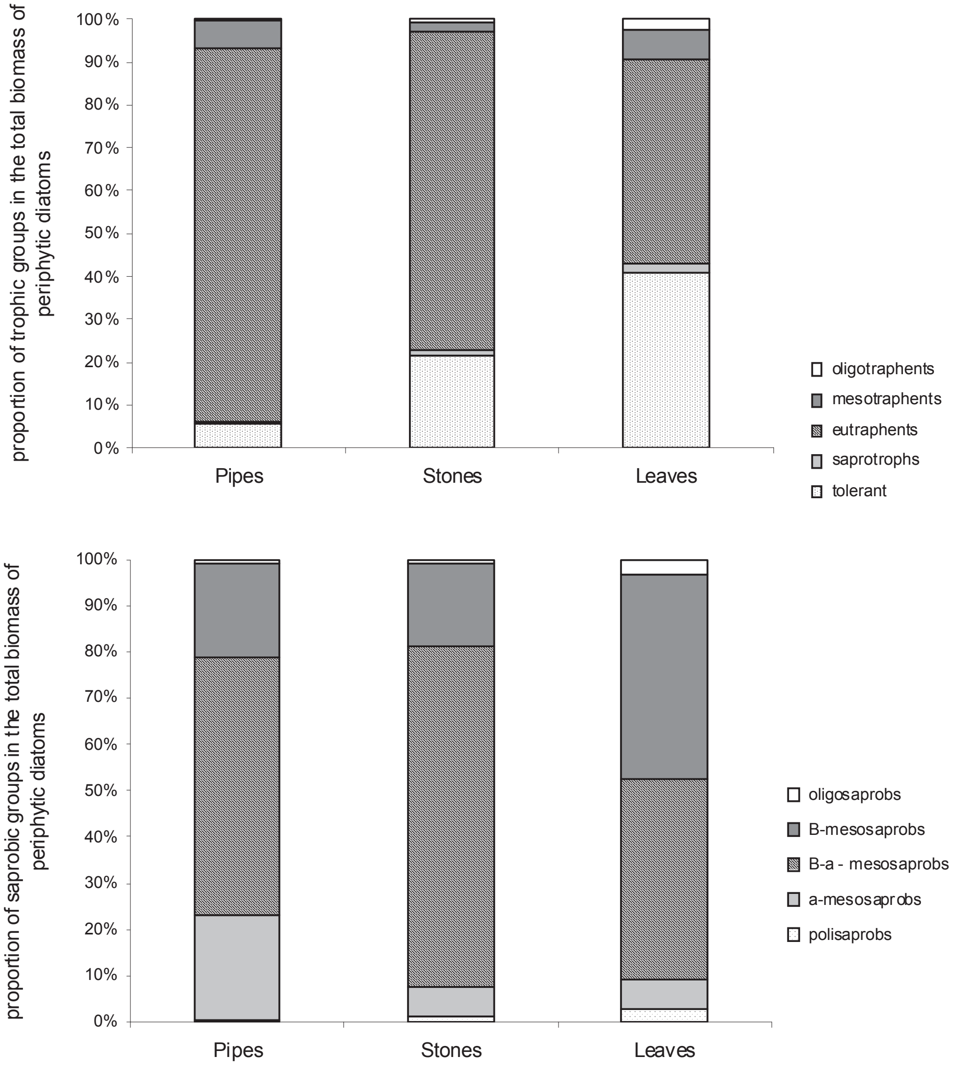

Fig. 4. Structure of the indicator periphytic diatoms in the littoral zone of lake Jeziorak Mały (means of the years 2002 and 2003).

β-meso-saprobes, the highest biomass was observed in the pipes (0.225 mg cm^{-2}), and the lowest in epiphyton (0.175 mg cm^{-2}). The proportion of this group of diatoms in the total biomass varied from 14.40% in epilython to 27.18% in epiphyton. L-mesosaprobes, in turn, were represented by 6 species. The highest biomass and percentage share of this group of algae were found in the pipes (0.254 mg cm^{-2} and 19.04%, respectively). The least numer-

T a b l e 4. Total biomass of the indicator periphytic diatom groups (mg cm^{-2}) in the trophy spectrum in the littoral zone of lake Jeziorak Mały (means of the years 2002 and 2003).

Diatom species	periphyton in pipes	epilython	epiphyton
Oligotraphents (oligo-α-mesotraphent) *Fragilaria delicatissima* (W. Smith) Lange-Bertalot	0.004	0.008	0.010
Mesotraphents (α-meso-eutraphent) *Amphora ovalis* (Kützing) Kützing *Epithema adnata* (Kützing) Brebisson *Gomphonema olivaceum* (Hornemann) Brebisson *Navicula clementis* Grunow *Navicula reinchardtii* Grunow	0.071	0.028	0.025
Eutraphents *Caloneis amphisbaena* (Bory Cleve) *Cocconeis pediculus* Ehrenberg *Cymatopleura solea* (Brebisson) W. Smith *Cymbella tumida* (Brebisson) Van Heurck *Diatoma vulgaris* Bory *Epithema turgida* (Ehrenberg) Kützing *Fragilaria capucina* Desmazieres *Gomphonema augur* Ehrenberg *Navicula capitata* Ehrenberg *Navicula gastrum* (Ehrenberg) Kützing *Navicula gregaria* Donkin *Navicula lanceolata* (Agardh) Ehrenberg *Navicula rhynchotella* Lange-Bertalot *Navicula slesvicensis* Grunow *Navicula tripunctata* (O.F. Müller) Bory *Navicula viridula* (Kützing) Ehrenberg *Nitzschia frustulum* (Kützing) Grunow *Nitzschia linearis* (Agardh) W. Smith *Nitzschia sigmoidea* (Nitzsch) W. Smith *Rhoicosphenia abbreviata* (Agardh) Lange-Bertalot	0.971	0.857	0.189
Saprotrophs *Amphora veneta* Kützing	0.004	0.014	0.008
Tolerant species *Amphora libyca* Ehrenberg *Amphora pediculus* (Kützing) Grunow *Cocconeis placentula* Ehrenberg *Cymbella cistula* (Ehrenberg) Kirchner *Cymbella microcephalla* Grunow *Cymbella silesiaca* Bleisch. *Fragilaria biceps* (Kützing) Lange-Bertalot *Fragilaria construens* (Ehrenberg) Grunow *Fragilaria crotonensis* Kitton *Fragilaria ulna* (Nitzsch) Lange-Bertalot *Gomphonema acuminatum* Ehrenberg *Gomphonema parvulum* (Kützing) Kützing *Gomphonema truncatum* Ehrenberg *Navicula pupula* Kützing	0.065	0.251	0.163

ous were oligosaprobes (4 species) and polysaprobes (2 species). The highest biomass and percentage share of the former group of diatoms was noted in epiphyton (1.330 mg cm^{-2} and 2.06%). In the case of polysaprobes, the highest biomass was determined for epilython (0.016 mg cm^{-2}), while the percentage share in the biomass was the highest for epiphyton (1.58%; Table 5, Fig. 4).

Discussion

The littoral zones of shallow lakes with insignificant surface areas, classified as polytrophic, are usually overgrown by emergent water vegetation such as reeds, calamus and bulrush. Within the scope of protection-reclamation activities, the littoral zone of lake Jeziorak Mały was transformed anthropogenically by installing separators and pouring off stones and crushed-brick concrete. As a result, new habitats for periphyton were created. Diatoms usually constitute a multitudinous group of plant periphyton (Bohr, Miotk, 1979). During 2002 and 2003, diatoms constituted the most numerous group on the artificial substratum in lake Jeziorak Mały, where separator pipes contributed 90.28% of the total number of periphytic algae. In terms of biomass, diatoms dominated in epilython (68.84% of the total biomass of periphytic algae; Table 2). Research by Kuczyńska-Kippen et al. (2004) in lake Wielkowiejskie, revealed that the proportion of diatoms there was 39% of the total number of epiphytic plant periphyton. The participation of diatoms in the total number, which amounted to only half of those in this paper, could have been due to a number of biotic and abiotic factors. These differences may result from the type of substratum and environmental conditions such as temperature, light, biogenes (phosphorus and nitrogen, and for diatoms – silicon, calcium), and water movement (Reynolds, 1986; Krebs, 1996; Poulickova et al., 2004).

According to a number of authors, substratum type is an important factor determining the species composition, distribution, and structure of periphyton algae (Whitton, 1975; Round, 1981; Kawecka, Eloranta, 1994). Algal communities in the littoral areas of still water bodies are strongly diversified depending on the substratum type. The best developed algal communities are epipelythic (on muddy sediments), epiphytic (on macrophytes), and epilythic (on stony ground). Rough substratum surfaces foster their colonization by organisms, as seen in the colonization of stones by large forms of filamentous chlorophytes. A perfect example are thalli of the genus *Cladophora* spp., often developing in lakes, and occurring in periphyton even at low visibility (Chudyba, 1968; Bohr, 1973). The presence and dominance of *C. glomerata* was often observed in eutrophic lakes on natural (Dodds, Gudder, 1992) and artificial substrates (Danilov, Ekuland, 2001). In lake Jeziorak Mały in 2002 and 2003, separator pipes and stones were often inhabited by the filamentous chlorophyte *C. glomerata* constituting a natural substratum for diatoms. On these substrates, the highest average number and biomass of diatoms was observed (3,017,213 indiv. cm^{-2} in pipes and 1.448 mg cm^{-2} in epilython, respectively). For epilython, the highest Shannon-Weaver species diversity index was also determined (4.23 bit $ind.^{-1}$) at the lowest number of taxa (56), whereas in pipes, the index was much lower, at the level of 2.53 bit $indiv.^{-1}$ with

T a b l e 5. Total biomass of indicator periphytic diatom groups (mg cm^{-2}) in the saproby spectrum in the littoral zone of lake Jeziorak Mały (means of the years 2002 and 2003).

Diatom species	periphyton in pipes	epilython	epiphyton
Oligosaprobes (oligosaprob/ β-mesosaprob) *Fragilaria delicatissima* (W. Smith) Lange-Bertalot *Cymbella microcephalla* Grunow *Epithema adnata* (Kützing) Brebisson *Navicula gastrum* (Ehrenberg) Kützing	0.010	0.011	0.013
β -mesosaprobes *Amphora ovalis* (Kützing) Kützing *Cocconeis placentula* Ehrenberg *Cymbella cistula* (Ehrenberg) Kirchner *Fragilaria biceps* (Kützing) Lange-Bertalot *Fragilaria capucina* Desmazieres *Fragilaria construens* (Ehrenberg) Grunow *Gomphonema acuminatum* Ehrenberg *Gomphonema truncatum* Ehrenberg *Navicula clementis* Grunow *Navicula reinchardtii* Grunow *Navicula slesvicensis* Grunow *Navicula tripunctata* (O.F. Müller) Bory	0.225	0.208	0.175
β -α mesosaprobes *Amphora libyca* Ehrenberg *Amphora pediculus* (Kützing) Grunow *Caloneis amphisbaena* (Bory Cleve) *Cocconeis pediculus* Ehrenberg *Cymbella tumida* (Brebisson) Van Heurck *Diatoma vulgaris* Bory *Fragilaria crotonensis* Kitton *Gomphonema augur* Ehrenberg *Gomphonema olivaceum* (Hornemann) Brebisson *Navicula lanceolata* (Agardh) Ehrenberg *Navicula rhynchotella* Lange-Bertalot *Navicula viridula* (Kützing) Ehrenberg *Nitzschia frustulum* (Kützing) Grunow *Nitzschia linearis* (Agardh) W. Smith *Nitzschia sigmoidea* (Nitzsch) W. Smith *Rhoicosphenia abbreviata* (Agardh) Lange-Bertalot	0.621	0.850	0.173
α – mesosaprobes *Cymatopleura solea* (Brebisson) W. Smith *Cymbella silesiaca* Bleisch *Fragilaria ulna* (Nitzsch) Lange-Bertalot *Navicula capitata* Ehrenberg *Navicula gregaria* Donkin *Navicula pupula* Kützing	0.254	0.072	0.027
Polysaprobes *Amphora veneta* Kützing *Gomphonema parvulum* (Kützing) Kützing	0.005	0.016	0.010

52 taxa (Table 2). This phenomenon was most likely influenced by the characteristics of the substratum and environmental conditions. Luttenton and Baisden (2006) obtained a higher periphyton species diversity on substrata with larger sizes. They observed a decrease in the diversity in the conditions of intensified water turbulence resulting, for example, from the inflow of contaminated waters from the catchment area. This situation could also occur in lake Jeziorak Mały, where the rough structure of stones could favour the abundance of a larger number of diatom taxa than in the pipes. This is due to intense and continuous water flow and the influx of various substances such as lead from the catchment area into the pipes. These factors could limit the colonization of a larger number of taxa and therefore influence species diversity. According to Kawecka and Eloranta (1994), algae react rapidly to contaminants and, in the majority of cases, this reaction is negative leading to decreased community biomass, productivity, and species diversity. Algae also tolerate the toxicity of heavy metals to various degrees (Whitton, Say, 1975). In earlier studies on the physio-chemical water parameters in lake Jeziorak Mały in 2001, a higher average lead content was revealed at separator sites than at sites with macrophytes, with recorded levels of 0.69 and 0.55 mg Pb l^{-1}, respectively (Zębek, 2005). This high lead content may have contributed to lowering the species diversity of periphyton communities in the separator pipes. Meanwhile, the lowest number and biomass of diatoms was determined in the lake's epiphyton. The suppressive influence on the development of algae by macrophytes excreting chemical substances into shallow lakes was reported by Wium-Andersen et al. (1982) and Nakai et al. (1999). This may also contribute to the development of periphytic communities in the littoral zone. This phenomenon could also be involved in formatting the development of epiphytic diatom communities in lake Jeziorak Mały, in combination with such factors as substratum type and environmental conditions.

The similarity indices allowed comparison of the properties of diatom communities between particular periphytic diatom communities in the littoral zone of lake Jeziorak Mały. The largest similarity in the species composition of periphytic diatoms was revealed between epilython and epiphyton, and the smallest was between epiphyton and periphytic diatoms in the pipes (Fig. 3). This may result from differences between the dominant diatom taxa inhabiting individual substrates. In terms of numbers in the pipes and epilython, *Navicula gregaria* and *Nitzschia frustulum* were dominant, while the genus *Gomphonema* sp. dominated in epiphyton. Moreover, high biomass values in the epilython were obtained for *Diatoma vulgaris.* The following species were identified in the sub-dominants ; *Fragilaria capucina*, and *F. leptostauron* var. *martyi* from the genus *Fragilaria* sp. in the pipes, and *Cocconeis placentula, Diatoma vulgaris* var. *linearis*, and *Rhoicosphenia abbreviata* in the epilython and epiphyton (Table 3). Jöbgen et al. (2004) also reported diatoms from the genera *Fragilaria*, *Diatoma*, and *Gomphonema* being dominant in plant periphyton overgrowing artificial substrata in a small eutrophic lake. *Diatoma vulgaris* often occurs in littoral zones of lakes, and it constitutes an important component of both epilython and plant periphyton (Goma, 2004; Kuczyńska–Kippen et al., 2004; Poulickova et al., 2004; Zębek, 2008, 2009). Moreover, Kuczyńska–Kippen et al. (2004) mentions *Fragilaria capucina* as a species dominating plant periphyton in a small eutrophic lake, and Kralj et al. (2006) revealed the frequent occurrence of *Cocconeis placentula* in periphyton on artificial substrates also in a eutrophic lake. The obtained results and cited literature lead us to suggest that the dominance of small forms of diatoms in the separator pipes may result from intensified water flow in the devices and the simultaneous inflow of a large amount of organic matter, which could limit the possibility of larger forms of these algae colonizing the pipes. *Navicula gregaria* and *Nitzschia frustulum* are mobile forms and they are more tolerant to being buried in organic suspensions and sediments than other diatom species. According to Hofmann (1994), these species were classified as α-meso-saprobes and β-α-meso-saprobes, tolerating large amounts of organic matter. The rough structure of stones, in turn, favoured colonization by large forms of diatoms such as *Diatoma vulgaris*.

Periphytic diatoms are good indicators of the chemical status of waters. Therefore, these are currently applied in river and lake monitoring to determine the water's trophic and saprobic constituents (Hofmann, 1994; Kawecka, Eloranta, 1994; Danilov, Ekuland, 2000; Poulickova et al., 2004; Ács et al., 2005; Stenger-Kovács et al., 2007). Based on his studies on phytoplankton communities in 1978, Spodniewska (1986) considered lake Jeziorak Mały to be polytrophic. In 2003 and 2003, species typical of eutrophic waters composed the most numerous group of diatoms in terms of trophy. Eutraphents dominated also in terms of biomass on all the substrata, varying from 55.21 % in epiphyton to 72.8% in the pipes. The highest biomass of this group of diatoms was found in the pipes (0.971 mg cm^{-2}; Table 4). The pipes and epilython also contained species typical of eutrophic waters, including the dominant *Navicula gregaria* and *Diatoma vulgaris* (Hofmann, 1994). These species accounted for more than 20% of the total biomass of periphytic diatoms (Table 3). A contrasting situation was found in the case of tolerant diatoms, which attained their largest proportion of biomass in epiphyton, and the lowest in the pipes, at 25.32% and 4.85%, respectively (Table 4). Tolerant diatoms in epiphyton were represented by the subdominant *Cocconeis placentula* which constituted 14.67% of the epiphyton biomass (Table 3). The highest biomass of tolerant species was noted in epilython due to the occurrence of diatoms with relatively large cells. Moreover, the largest proportion of mesoeutraphents was determined in the pipes (Fig. 4). These results suggest that the dominance of eutraphents in the biomass of periphytic diatoms indicates the eutrophic character of the waters. The highest mean biomass and proportion in the biomass of eutraphents in the pipes may be related to the increased content of biogenes there in comparison to other substrate sites. Here, the highest mean electrolytic conductivity of water was recorded at 405 µS cm^{-1} and the highest ortophosphorate, calcium, and silicon concentrations were 0.55 mg PO_4 l^{-1}, 101 mg Ca l^{-1}, and 0.81 mg Si l^{-1}, respectively (Table 1). Guzowska and Gasse (1990) mention the inflow of contaminated storm waters from the separators as an important factor influencing the chemical status of waters in lakes with an urbanized catchment area. These authors obtained maximum conductivity values at levels of 890 µS cm^{-1}, calcium content – 180 mg Ca l^{-1}, ortophosphorates – 0.08 mg PO_4 l^{-1}, and silicon – 13.4 mg Si l^{-1}. Poulickova et al. (2004) determined the water electrolytic conductivity values for the littoral zone of a eutrophic lake at the level of 273 µS cm^{-1} and silicon – 0.93 Si l^{-1}, while Kralj et al. (2006) obtained values of 566 µS cm^{-1} and 3.78 Si l^{-1} in the summer season. The above differences in physio-chemical water parameter values may result from the character of the catchment area and from the inflow of contaminated storm waters. This situation also occurred in lake Jeziorak Mały, where the inflow of water from separators, particularly following heavy precipitation, on the one hand diluted the

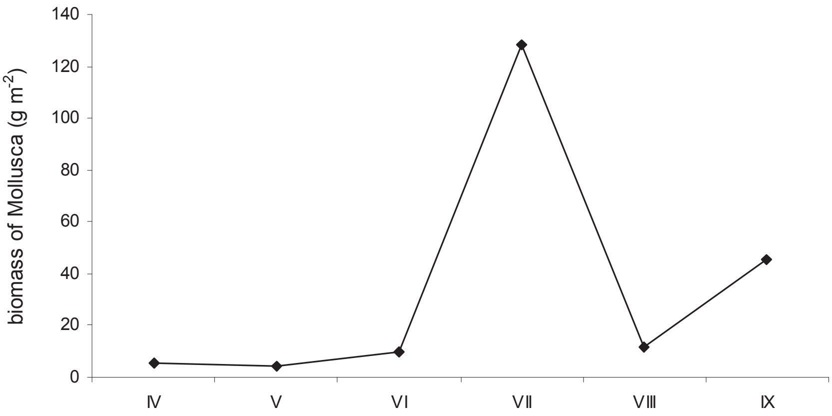

Fig. 5. Biomass of gastropods from April to September on the stones in the littoral zone of lake Jeziorak Mały (means of the years 2002 and 2003).

lake's waters, and on the other it may have served as an additional source of biogenes. This is indicated by the highest respective proportion of meso-eutraphents and eutraphents in the biomass of periphytic diatoms in pipes compared to the stone and macrophyte sites. Moreover, varying environmental conditions in pipes could also be a cause of the contrasting tendency in the development of periphytic diatoms from April to October.

The maximum electrolytic conductivity values of water in the pipe sites were determined at 723 $\mu S\ cm^{-1}$ in April and an orthophosphate level of 2.22 mg $PO_4\ l^{-1}$ was registered in September, while at the remaining sites, the highest respective values of these parameters were determined in May and October. The maximum abundance of diatoms in the pipes occurred already in June (Fig. 1).

Three peaks in terms of numbers were determined on the remaining substrates, with the maximum in September. A similar situation was observed in the case of biomass. Periphytic diatoms reached two biomass peaks, with maxima recorded in the pipes in May and August, and in epilython and epiphyton in June and September (Fig. 2). Moreover, an increase in the content of biogenes (PO_4, Ca, and Si) in the summer season at the stone and macrophyte sites was accompanied by an increase in the number and biomass of diatoms with maximum values registered in September (Figs 1, 2). However, no such relationship was observed in diatom communities in the pipes. The above analysis suggests that in lake Jeziorak Mały in 2002 and 2003, changes in environmental conditions at sites with particular substrates in the season from April to October could, to a certain degree, influence the development of periphytic diatoms. The influence of other factors should also be considered. These include the pressure of invertebrates and feeding selectively on the individual size fractions of algae (Jones et al., 2000). In the studied lake, this phenomenon could occur, for example, on stones in the summer season, when the lowest biomass of diatoms on these substrata was observed in July (Fig. 2). This recording coincided with the highest biomass of gastropods, at 128.20 g m^{-2} (Fig. 5).

In addition to the substratum type and environmental conditions, the development of periphytic diatom communities can also depend on the degree of organic contamination (Hofmann, 1994). In terms of biomass, the following were dominant in lake Jeziorak Mały; β-α-mesosaprobes in the pipes and epilython with 26.80% and 58.68%, respectively, while the β-mesosaprobes in epiphyton registered 27.18% (Fig. 4). The highest biomass of this group of indicator diatoms was also determined for epilython at 0.850 mg cm^{-2} (Table 5). β-α-mesosaprobes were represented by *Diatoma vulgaris* (dominant in the total biomass at 27.12%), and β-mesosaprobes by *Cocconeis placentula* (sub-dominant in biomass with 14.67%; Table 3). In epiphyton, the highest biomass and percentage share was determined for oligo-saprobes compared to the remaining communities of periphytic diatoms. Moreover, in the pipes, the highest biomass of α-mesosaprobes was observed, at 0.254 mg cm^{-2}, which accounted for 19.04% of the biomass of periphytic diatoms in the pipes (Table 5, Fig. 4). This group of indicator diatoms was represented by *Navicula gregaria*, which dominated on this substratum in terms of both number and biomass (Table 3). These results suggest that the individual substrates of pipes, stones, and macrophytes are characterized by varying degrees of contamination with organic matter. Periphytic algae communities were dominated by species of diatoms tolerating such conditions. In general, the dominance of mesosaprobes in periphytic diatom communities in lake Jeziorak Mały indicates an average content of organic matter (Fjerdingstad, 1965; Sládeček, 1973). However, the dominance of β-α-mesosaprobes in epilython and in the pipes suggests higher contamination with organic matter in these substrata than that present in macrophyte sites. A significant proportion of α-mesosaprobes in the pipes may indicate a large inflow of organic matter from the catchment areas, and the dominance of β-mesosaprobes and the presence of oligo-saprobes in epiphyton show the least degree of contamination with organic matter.

Conclusion

The transformation of the littoral zone of the urban lake Jeziorak Mały by installing separators and pouring off stones contributed to a change in environmental conditions and created new habitats for plant periphyton with a large proportion of diatoms. Based on results obtained in 2002 and 2003, diversification of periphytic diatom communities inhabiting separator pipes, stones and macrophytes was determined (Fig. 6). Sites with separators were characterized by increased contents of biogenes and significant inflow of organic matter from the catchment area, which can influence the development of periphytic diatoms. Although diatom communities in the pipes attained the highest numbers, they had the lowest species diversity and they exhibited less species similarity to other diatom communities, and especially to epiphyton. In terms of trophy, the highest proportion and biomass of eutraphents was observed, and in terms of saproby, there was significant participation of α-mesosaprobes with *Navicula gregaria* recording dominance. This fact suggests the eutrophic character of the waters with the highest degree of contamination with organic matter in comparison with the remaining sites. In epilython, the highest biomasses of diatoms and the highest similarity

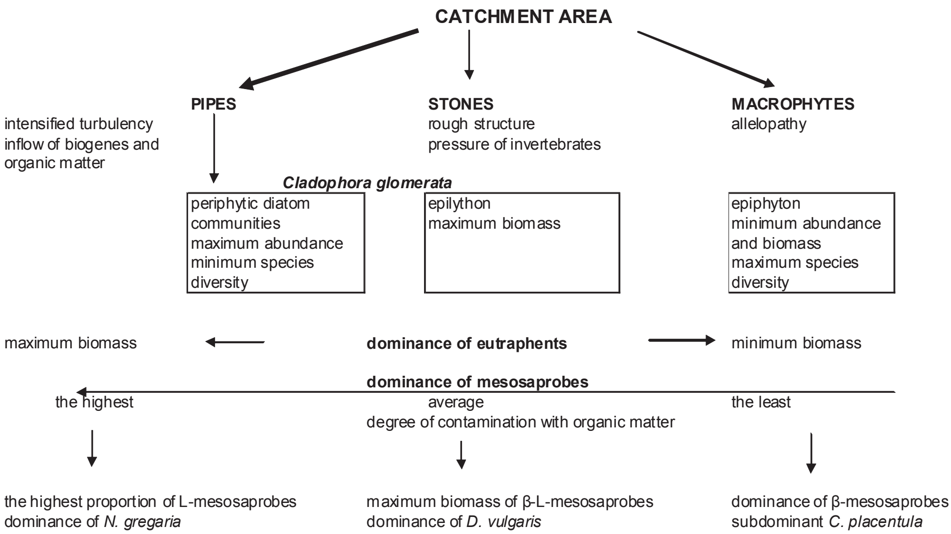

Fig. 6. Characteristics of periphytic diatom communities in the trophy and saproby spectrum with respect to environmental conditions in the littoral zone of lake Jeziorak Mały in the years 2002 and 2003.

in the species composition with epiphyton was determined. Eutraphents were shown to be dominant, as they also were in the pipes. In terms of saproby, the highest biomass of species typical of β-α-mesosaprobe waters with dominant *Diatoma vulgaris* was observed, and this indicates an average degree of contamination with organic matter. Epiphyton communities were characterized by the lowest number and biomass, but the highest species diversity. In terms of trophy, eutraphents were also dominant, with a large proportion of tolerant species, while β-mesosaprobes were dominant in saproby' represented by *Cocconeis placentula* (subdominant in the biomass) which indicates the lowest degree of contamination with organic matter in comparison with the remaining substrates. All the above results fully support the conclusion that the diversification of particular periphytic diatom communities can be fostered by a number of environmental conditions. These conditions particularly include the type of the substratum, seasonal changes in physio-chemical water parameters, pressure of invertebrates and the allelopathy of macrophytes.

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