

Epiphytic algae on *Stratiotes aloides* L., *Potamogeton lucens* L., *Ceratophyllum demersum* L. and *Chara* spp. in a macrophyte-dominated lake

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Abstract

Epiphytic algae occurring on submerged macrophytes were investigated as part of a study on the ecological status of a shallow macrophyte-dominated lake, Lake Skomielno, which has been used for recreation and fishery. Relatively high variability in biomass (DM) and chlorophyll *a* contents in epiphyton on particular plants was noted. Generally, the biomass of epiphytic algae was much higher in spring and autumn than in summer. In total, 335 taxa were found on the studied macrophytes with representatives of the Chlorophyta (143 taxa) and Heterokontophyta class Bacillariophyceae (131 taxa) dominating. The species composition of epiphytic algae was related to host plant and seasons, the highest species richness was observed on *Stratiotes aloides* in spring and on *Potamogeton lucens* in autumn. The Jaccard similarity index revealed differentiation of diatom communities between the macrophytes. Our data suggest that in the

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studied lake *S. aloides* and *P. lucens* can provide better habitat conditions for higher numbers of epiphytic taxa, abundances and epiphyton standing crop than *Ceratophyllum demersum* and *Chara* spp. can. The dominance of diatom species (e.g. *Pseudostaurosira brevistriata* (Grun.) Williams & Round, *Achnanthisidium minutissimum* (Kütz.) Czarnecki, and *Cocconeis placentula* Ehrenb.) that are known as bioindicators of slightly alkaline, sufficiently oxygen-saturated and meso-eutrophic waters corresponds well with the physico-chemical parameters of Lake Skomielno.

INTRODUCTION

Epiphytic algae are an important component of aquatic biocenosis. They are a source of food for invertebrates and fish in the littoral zone (Albay and Aykulu 2002, Balayla and Moss 2004, Abe et al. 2007). Since most of the world's lakes are shallow and have extensive littoral zones the productivity of the epiphytic algae frequently exceeds that of phytoplankton, and the importance of periphyton productivity is often greatly underestimated (Wetzel 1983).

The relationships between host plants and attached algae in the natural environment are still incompletely understood (e.g. Buczek 2007). Most plant substrata are highly dynamic in their physical characteristics and their chemical contribution to attached flora (Wetzel 1983). Epiphyton can reduce growth and production of macrophytes due to their shading (Takashi et al. 2004) and the faster uptake of nutrients by epiphytes than by macrophytes (Pelton et al. 1998). However, aquatic plants may also reveal allelopathic activity against epiphytic algae (Erhard and Gross 2006, Kufel et al. 2007), and as a result the development of epiphyton depends on macrophyte host species (Blindow and Hootsmans 1991, Cattaneo et al. 1998). Both the macrophyte habitat and the specific architecture of plants may also influence the growth of attached algae (Messyasz and Kuczyńska-Kippen 2005). However, data concerning changes in periphytic communities on different macrophytes are still limited.

The aim of this paper was to study the seasonal variability of species composition, biomass, and chlorophyll *a* contents of epiphytic algae on the submerged macrophytes *Stratiotes aloides* L., *Potamogeton lucens* L., *Ceratophyllum demersum* L. and *Chara* spp. inhabiting the internal belt of the littoral zone of Lake Skomielno.

STUDY AREA AND METHODS

Lake Skomielno is a shallow (3.2 m) water body (35.8 ha) located in Łęczyńsko-Włodawskie Lakeland (51°29'30'' N, 23°09'00'' E), Poland. The lake, in which submerged macrophytes are an essential component of the phytolittoral (Sender 2006), has been used for recreation and fishery for six

years. Lake water (Table 1) is very slightly alkaline, meso-eutrophic and oxygen-saturated. There are good light conditions in the littoral zone (0.5 – 1.5 m). Epiphytic algae were collected in spring (April), summer (July) and autumn (October) of 2006 from the definite biomass (20 – 200 mg plant dry mass) of *Stratiotes aloides*, *Potamogeton lucens*, *Ceratophyllum demersum* and *Chara* spp. occurring at 0.5 – 1.5 m deep, and from the definite surface (7 – 13 cm²) of *S. aloides* and *P. lucens*. Both algal and macrophyte samples were dried at 80°C

Table 1

The physico-chemical characteristics of water in the littoral zone of Lake Skomielno (average values, n = 2). (Data of Department of Hydrobiology)

Parameters	Spring	Summer	Autumn
Water temperature (°C)	10.9	27.25	9.8
pH	7.5	7.6	7.1
Conductivity (μS cm ⁻¹)	369	354	331
Transparency – SD (m)	1.1	0.9	1.1
NO ₃ -N (mg dm ⁻³)	0.089	0.037	0.050
NH ₄ -N (mg dm ⁻³)	0.032	0.260	0.178
PO ₄ -P (mg dm ⁻³)	n.d.	0.080	0.025
Oxygen content (mg dm ⁻³)	10.2	5.1	6.2

n.d. – not determined

for 24 hours for dry mass (DM) determination. Chlorophyll *a* concentrations were determined spectrophotometrically (SEMCO S91E) after extraction in 90% ethanol according to international standard (PN-ISO 10260, 2000). Results are expressed both per gram of plant DM and per unit of lake area (termed to epiphyton standing crop). Algae preserved with a formalin/glycerine mixture were counted by means of light microscopy in a 1 ml chamber. For taxonomic identification, diatoms were treated with 33% H₂O₂ and prepared as permanent slides in Pleurax. The species composition and relative frequencies of diatoms were assessed by identifying 300 frustules with light microscopy (1000× magnification). The similarities of diatom communities occurring on particular host plants were compared using the Jaccard index. The index varies from 0 to 1 and is calculated from the following formula:

$$Sj = \frac{a}{(a + b + c)}$$

where:

a = number of species in sample A and sample B (joint occurrences),

b = number of species in sample B but not in sample A,

c = number of species in sample A but not in sample B.

The identification and ecological classification of diatom species was based on specific taxonomic publications by Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b), and Van Dam et al. 1994. The identification of other algal groups was primarily based on Komárek and Anagnostidis (1999, 2005), Komárek and Fott (1983), and Starmach (1972, 1983, 1989). The nomenclature of diatom taxa followed the scheme given by Round et al. (1990), whilst algal systematics were based on Van den Hoek et al. (1995).

RESULTS

Relatively high variability in biomass (DM) and chlorophyll *a* contents of epiphyton inhabiting particular submerged macrophytes were observed (Figs 1A, B). Generally, the algal biomass and chl *a* contents were higher in spring and autumn than in summer. For example, on *Stratiotes aloides* 404 mg epiphyton DM g⁻¹ plant DM and 363 µg chl *a* g⁻¹ plant DM were found in spring and 1270 mg epiphyton DM g⁻¹ plant DM and 467.9 µg chl *a* g⁻¹ plant DM in

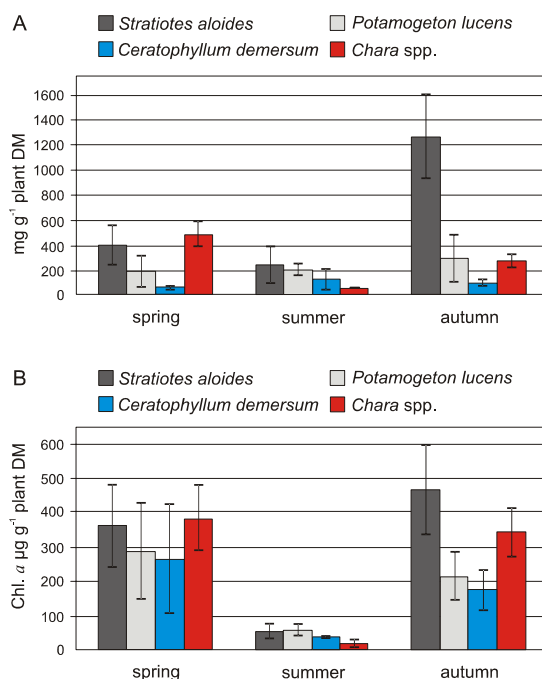


Fig. 1. Seasonal changes in the biomass (Dry Mass - DM) (A) and chlorophyll *a* contents (B) of epiphytic algae – per 1 g plant DM. (Data are expressed as means $\pm$ SD, $n = 3$)

autumn (Figs 1A, B). The epiphyton standing crops, expressed as biomass (DM) (Fig. 2A) and chlorophyll *a* contents (Fig. 2B) of epiphytic algae per unit area of lake bottom, were higher for *S. aloides* and *Potamogeton lucens* than for *Ceratophyllum demersum* and *Chara* spp.

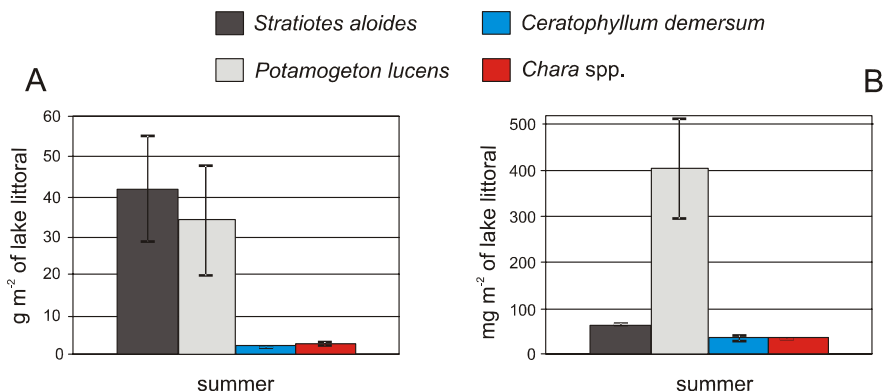


Fig. 2. The relationship between epiphyton standing crop expressed as (A) biomass dry mass (DM) and (B) chlorophyll *a* contents of epiphytic algae per unit of lake area. (Data are expressed as means $\pm$ SD, $n = 3$)

In total, 335 taxa of epiphytic algae were observed on the studied macrophytes, the numbers being dominated by Chlorophyta (143 taxa) and Heterokontophyta – class Bacillariophyceae (131 taxa). The highest numbers of epiphytic taxa were observed in spring on *S. aloides* (159) (Fig. 3A) and in autumn on *P. lucens* (135). The total number of diatom taxa on the macrophytes ranged from 69 to 77, and in most cases it was higher in autumn (42 – 46 taxa) than in the other seasons (Table 2). The community structure of diatoms (Table 2) and other epiphytic algae (Table 3) varied between plants and seasons. In spring and autumn higher numbers of members of classes Chlorophyceae, Zygnematophyceae and Bacillariophyceae were observed on *S. aloides* and *P. lucens* than on *C. demersum* and *Chara* spp. (Tables 2, 3). However, in summer a similar relationship was seen only for Zygnematophyceae. The abundances of epiphytic algae varied with plant hosts and seasons (Figs 3B, C), and ranged as follows: $5.5 - 59.1 \times 10^6$ ind. g⁻¹ DM host plant in spring (with the highest value on *S. aloides*); $8.5 - 35.8 \times 10^6$ ind. g⁻¹ DM host plant in summer (with the highest value on *P. lucens*); and $1.3 - 12.4 \times 10^6$ ind. g⁻¹ DM host plant in autumn (with the highest value on *S. aloides*). The epiphytic algal communities in all seasons and on all plants were dominated by Bacillariophyceae (Fig. 3B). Among them the most abundant species, of which

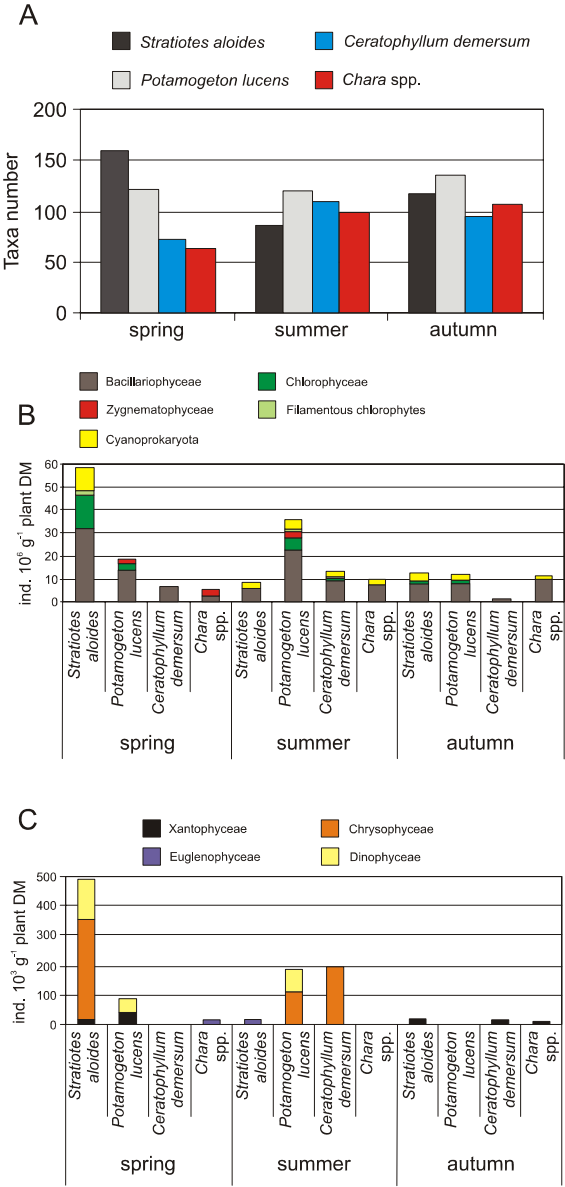


Fig. 3. The seasonal changes in the total number of taxa of epiphytic algae – A, and the abundances of epiphytic algae: B – more abundant taxonomical groups (ind. $\times 10^6$ g⁻¹ plant DM), C – less abundant taxonomical groups (ind. $\times 10^3$ g⁻¹ plant DM) found on individual macrophytes.

Table 2

The most abundant diatom taxa (of relative frequency higher than 5%) and number of diatom taxa found on individual macrophytes in Lake Skomielno.

Macrophytes and number of diatom taxa	Spring	Summer	Autumn
<i>Stratiotes aloides</i> 77 ^{a)} 46 – 35 – 46 ^{b)}	<i>Achnanthyrium minutissimum</i> (22.4) <i>Epithemia sorex</i> (11.8) <i>Encyonopsis microcephala</i> (10.3) <i>Navicula cryptocephala</i> (6.5) <i>Navicula cryptotenelloides</i> (5.9) <i>Staurosira construens</i> (5.9)	<i>Cocconeis placentula</i> (18.2) <i>Epithemia adnata</i> (14.6) <i>Mastogloia smithii</i> (7.2)	<i>Epithemia adnata</i> (12.4) <i>Staurosira construens</i> (11.2) <i>Staurosira pinnata</i> (6.5) <i>Achnanthyrium minutissimum</i> (5.9) <i>Epithemia sorex</i> (5.3)
<i>Potamogeton lucens</i> 72 ^{a)} 43 – 34 – 46 ^{b)}	<i>Staurosira construens</i> (35.9) <i>Epithemia adnata</i> (10.8) <i>Achnanthyrium minutissimum</i> (5.4) <i>Cocconeis placentula</i> (7.8)	<i>Staurosira construens</i> (47.9) <i>Achnanthyrium minutissimum</i> (13.3) <i>Pseudostaurosira brevistriata</i> (10.4)	<i>Achnanthyrium minutissimum</i> (16.7) <i>Staurosira construens</i> (15.8) <i>Staurosira pinnata</i> (5.5)
<i>Ceratophyllum demersum</i> 69 ^{a)} 39 – 43 – 44 ^{b)}	<i>Staurosira construens</i> (16.8) <i>Cocconeis placentula</i> (16.8) <i>Fragilaria</i> sp. (12.3) <i>Amphora pediculus</i> (7.3) <i>Epithemia sorex</i> (8.7) <i>Gomphonema</i> sp. (6.7)	<i>Staurosira construens</i> (32.3) <i>Fragilaria</i> sp. (18.2) <i>Achnanthyrium minutissimum</i> (16.3)	<i>Staurosira construens</i> (25.3) <i>Fragilaria</i> sp. (20.4) <i>Cocconeis placentula</i> (10.2)
<i>Chara</i> spp. 73 ^{a)} 35 – 33 – 42 ^{b)}	<i>Fragilaria</i> sp. (31.1) <i>Pseudostaurosira brevistriata</i> (8.8) <i>Tabularia fasciculata</i> (Kütz.) (7.2) <i>Mastogloia smithii</i> (6.6)	<i>Staurosira construens</i> (35.6) <i>Mastogloia smithii</i> (18.0) <i>Tabularia fasciculata</i> (10.8) <i>Pseudostaurosira brevistriata</i> (7.6) <i>Epithemia</i> sp. (6.2)	<i>Achnanthyrium minutissimum</i> (22.1) <i>Staurosira construens</i> (17.8) <i>Gomphonema</i> sp. (7.2) <i>Mastogloia smithii</i> (5.8)

^{a)} Total number of taxa found on individual macrophytes

^{b)} Number of taxa found in spring – summer – autumn on individual macrophytes

In parenthesis – share of individual species abundance in the total diatom abundance (%)

Table 3

Number of taxa of algal groups (except diatoms) occurring on individual macrophytes in Lake Skomielno.

Systematic groups	Spring				Summer				Autumn			
	S.a	P.I	C.d	Ch.	S.a	P.I	C.d	Ch.	S.a	P.I	C.d	Ch.
Cyanoprokaryota	21	18	14	10	16	21	16	17	16	20	20	16
Heterokontophyta class Chrysophyceae	3	—	—	1	1	1	5	—	1	—	—	2
Heterokontophyta class Xanthophyceae	1	1	—	—	—	—	—	—	—	—	1	2
Dinophyta class Dinophyceae	1	1	—	—	—	—	—	—	—	—	—	—
Euglenophyta class Euglenophyceae	—	1	—	—	1	1	—	—	1	—	—	1
Chlorophyta class Chlorophyceae	42	39	12	9	16	36	28	27	33	44	17	22
Chlorophyta class Zygnematomyceae	7	12	1	4	13	16	5	14	12	19	5	16
Filamentous chlorophytes	7	6	3	3	3	10	12	6	7	7	6	8
Total number of taxa	82	78	30	27	50	85	66	64	70	90	49	67

S.a – *Stratiotes aloides*; P.I – *Potamogeton lucens*; C.d – *Ceratophyllum demersum*; Ch. – *Chara* spp.

the relative frequency exceeded 5% (Table 2), were *Staurosira construens* Ehrenb., *Achnanthyidium minutissimum* (Kütz.) Czarnecki, *Cocconeis placentula* Ehrenb., *Epithemia adnata* (Kütz.) Bréb., and *Mastogloia smithii* Thwait. Some species, such as *Achnanthyidium minutissimum* and *Staurosira construens*, occurred on all studied macrophytes in most seasons, whilst others, such as *Navicula cryptocephala* (Kütz.), *N. cryptotenelloides* Lange-Bert. (on *S. aloides*) and *Amphora pediculus* (Kütz.) Grun. (on *C. demersum*) occurred in high numbers only in spring. *Scenedesmus obliquus* (Turp.) Kütz. was the most abundant green alga, and occurred on most of the macrophytes in all seasons, whereas *Tetraëdron minimum* (A. Braun) Hansg. predominated in summer, and *Desmodesmus brasiliensis* (Bohl.) Hegew. and *Tetraëdron triangulare* Korš. in autumn. Among the Cyanoprokaryota, *Planktolyngbya limnetica* (Lemm.) Kom.-Legn. et Cronberg dominated in all seasons, with *Aphanizomenon* sp. also abundant in summer and autumn.

The Jaccard similarity index for the diatom communities inhabiting the macrophytes had low values in all seasons (0.16 – 0.49), however, in most cases the dominance (>5%) of the same diatom species on particular plants was noted. Generally, the similarity of diatom communities between macrophytes was lower in summer (mean value 0.25), than in spring (mean value 0.33) and autumn (mean value 0.40) (Table 4). The similarity of diatom communities was the lowest between *S. aloides* and *Chara* spp., and highest between *P. lucens* and *Chara* spp.

Table 4

The Jaccard index of similarity of epiphytic diatom communities on macrophytes in Lake Skomielno.

Macrophytes	Spring	Summer	Autumn	Annual mean values
S.a – P.l	0.32	0.24	0.40	0.32
S.a – C.d	0.39	0.19	0.33	0.30
S.a – Ch. spp.	0.31	0.16	0.40	0.29
P.l – C.d.	0.35	0.33	0.39	0.36
P.l – Ch. spp.	0.34	0.28	0.49	0.37
C.d – Ch. spp.	0.28	0.31	0.39	0.33
Mean values	0.33	0.25	0.40	—

S.a – *Stratiotes aloides*; P.l – *Potamogeton lucens*; C.d – *Ceratophyllum demersum*; Ch. spp. – *Chara* spp.

DISCUSSION

The biomass (DM) and chl *a* contents of epiphyton on submerged macrophytes in Lake Skomielno varied between seasons, being lower in summer than in spring and autumn. These results are in agreement with published reports concerning submerged macrophytes in shallow eutrophic lakes in Germany (Gross et al. 2003a). Epiphytic biomass on submerged plants usually peaks in spring and autumn as nutrients are more readily available and grazing pressure is lower than in summer (Sand-Jensen 1983). Trifonova et al. (2002) reported higher biomass and chl *a* contents of epiphyton in summer than autumn in the shallow eutrophic Lake Vishnevskoe (Russia), although that report included emerged, submerged and floating macrophytes. In Lake Skomielno higher biomass and chl *a* contents of epiphyton occurring on *P. lucens* than on *C. demersum* were noted in all seasons, whereas in eutrophic lakes in Germany (Gross et al. 2003a) biomass and chl *a* contents of epiphyton on some macrophyte species fluctuated with seasons. For example, in Lake Rohrsee chl *a* contents and biomass of epiphyton were higher on *P. lucens* than on *C. demersum* in spring, whereas in summer they were higher on *C. demersum* than on *P. lucens*. However, in the lake Lengenweiler See in the same period those relationships were reversed, e.g. the chl *a* content in epiphyton was higher on *C. demersum* than on *P. lucens* in spring, and in summer higher on *P. lucens* than on *C. demersum*. Therefore, it seems that epiphyton biomass and chl *a* contents on individual macrophytes may depend not only on host plant and season but also on abiotic and biotic conditions in a lake. The epiphyton biomass on *P. lucens* and *C. demersum* in Lake Skomielno (expressed as dry mass – DM) was higher (e.g. 292.9 mg epiphyton DM g⁻¹ plant DM on *P. lucens* and 62.1 mg epiphyton DM g⁻¹ plant DM on *C. demersum*) than in Lengenweiler See in Germany (e.g. 103.7 mg epiphyton AFDM g⁻¹ plant DM on *P. lucens* and 25.8 mg epiphyton AFDM g⁻¹ plant DM on *C. demersum*), although the German epiphyton biomass data (Gross et al. 2003a) was expressed as Ash-free dry mass (AFDM). Dry mass is not a very precise indicator of biomass of epiphytic algae due to possible contamination with CaCO₃, but it is often used in studies (Trifonova et al. 2002), and in Lake Skomielno it corresponds well with chlorophyll *a* contents of epiphytic algae on particular macrophytes. In Lake Skomielno higher epiphyton standing crops were observed on *S. aloides* and *P. lucens* than on *C. demersum* and *Chara* spp., as a result of the higher biomass of *S. aloides* and *P. lucens* than of *C. demersum* and *Chara* spp. per unit area of lake area (M. Tarkowska-Kukuryk, personal communication).

The epiphyton community of Lake Skomielno is very rich in algal species (335 taxa) in comparison with other shallow water bodies. For example, in

macrophyte-dominated lakes (in Poland) *Typha angustifolia* L. and *Chara tomentosa* L. were seen to host 191 of periphytic algal taxa in Wielkowiejskie Lake, 183 taxa in Budzyńskie Lake, and 172 in Dębiniec Lake (Kuczyńska-Kippen et al. 2005). In comparison, in the macrophyte-dominated Lago di Candia (Italy) the total number of epiphytic taxa found on submerged as well as floating-leaved macrophytes was only 109 (Cattaneo et al. 1998). In Lake Skomielno the number of taxa of epiphytic algae on *S. aloides* in spring (159) was similar to the number of taxa of epiphytic algae on submerged macrophyte *Crinum natans* in a tropical estuary in Niger Delta (169) (Chindah 2004). The diatom dominance in epiphytic communities observed in all seasons on submerged macrophytes in Lake Skomielno is also reported for submerged plants in a mesotrophic Turkish lake (Albay and Aykulu 2002), and for submerged as well as floating macrophytes in a shallow Italian lake (Cattaneo et al. 1998). However, in the shallow Lake Vishnevskoe (Russia), Bacillariophyceae dominated on emerged, submerged and floating-lived macrophytes only in spring, whereas in other seasons Chlorophyta and Cyanoprokaryota were dominant (Trifonowa et al. 2002). Generally, in Lake Skomielno filamentous Chlorophyta, which usually dominate the epiphyton of hypereutrophic lakes (Laugaste and Reunanen 2005, Toporowska and Skowrońska, unpublished data), constituted 6.5% of the total number of epiphytic taxa.

The relationships between host plants and attached algae are complex and also reflect dynamic seasonal changes of environmental parameters. In Lake Skomielno low values of the Jaccard index of similarity of the diatom communities indicated great seasonal variations between the host macrophytes, confirming that the specific architecture of the particular macrophyte substratum may strongly impact the structure of periphytic algal communities (Cattaneo et al. 1998, Messyas and Kuczyńska-Kippen 2005). Also Messyas and Kuczyńska-Kippen (2005) reported low values of similarity indexes of epiphyton between plants in three shallow macrophyte-dominated lakes in Poland. Our data suggest that in the studied lake *S. aloides* and *P. lucens* can provide better habitat conditions for epiphyton (higher taxa numbers and abundances) than *C. demersum* and *Chara* spp. However, this may result not only from different plant architecture, but also from allelopathic activity of *Chara* spp. and *C. demersum* against some species of algae (Wium-Andersen et al. 1982, Gross et al. 2003b). Kufel et al. (2007) also recently reported that *P. lucens* may produce allelochemicals that affect both biomass and community structures of some phytoplankton species. Other factors such as grazing pressure, e.g. fish grazing, (Abe et al. 2007) and/or changes in light intensity (Albay and Aykulu 2002, Takashi et al. 2004) may modify biomass, species richness and abundances of epiphytic algae on submerged macrophytes.

Bacillariophyceae are frequently used as bioindicators of ecological status of aquatic environments (Round 1991, Hoffman 1994, Hal and Smol 1999, Pouličková 2004). Some of the most abundant diatoms found on the macrophytes in Lake Skomielno are indicators of meso-eutrophic (*Cocconeis placentula*, *Staurosira construens*, *Tabularia fasciculata* (Kütz.) Williams et Round, *Mastogloia smithii*, *Epithemia adnata* (van Dam et al. 1994, Hofmann 1994) and oxygen-saturated waters (*Achnanthes minutissimum*, *Pseudostaurosira brevistriata* Grun., *Staurosira pinnata* Ehrenb., *S. construens*, *Encyonopsis microcephala* (Grun.) Krammer, *Amphora pediculus* (Kütz.) Grun.) (van Dam et al. 1994). In this study most of the abundantly occurring epiphytic species, for example *Pseudostaurosira brevistriata*, *Staurosira construens*, *Mastogloia smithii*, *Encyonopsis microcephala*, and *Cocconeis placentula*, prefer slightly alkaline waters. Other species observed, for example *Epithemia adnata* and *E. sorex* (Kütz.), are alkalibiontic organisms (van Dam et al. 1994).

Despite seasonal changes in the number of taxa and the abundances of epiphytic algae on macrophytes in Lake Skomielno the qualitative and quantitative structure of epiphytic diatom communities occurring on particular plants was reflective of the lake water quality, being slightly alkaline, sufficiently oxygen-saturated and meso-eutrophic.

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