



Algal assemblage types of bog-lakes in Hungary and their relation to water chemistry, hydrological conditions and habitat diversity

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Abstract

Algal flora of 12 bog lakes was investigated during the period of March 1995 to August 1999 in Hungary. Of the 129 samples, 624 taxa of algae were identified. Species richness of individual samples ranged between 8 and 107 except the extraordinarily species rich Baláta-tó where 533 algal taxa were observed. Ordination of the samples resulted in five groups: (1) assemblages dominated by chlorococcalean algae and planktonic Cyanoprokaryota; (2) assemblages dominated by flagellates (Dinophyta, Cryptophyta, Euglenophyta, Chrysophyceae, Raphidophyceae); (3) chlorococcalean algae and cyanoprokaryotic assemblages with desmids, cryptophytes, dinoflagellates or euglenophytes as subdominants; (4) assemblages dominated by diatoms and (5) a group of samples where other taxa belonging to Xanthophyta and filamentous green algae dominated. The bogs were typically rich in inorganic N and P, moreover, their water chemical characteristics (including pH and conductivity) were rather uniform. Therefore, other factors than chemical properties were responsible for different flora. The above groups were characteristic to certain types of habitats. In the first group, plankton samples from relatively large pools with considerable open water can be found. The second group included samples taken from small bog pools. The third group contained the periphyton samples from macrophytes, living in bogs with constantly reliable water supply. Samples of group four and five comprised small bogs that occasionally dry up. Periphyton of lakes with *Sphagnum* belonged exclusively to the fifth group. This study has shown that small bog-pools are often inhabited by different species of flagellates and desmids are not as important as it has been widely believed. Hydrological properties and habitat diversity are the major factors influencing species richness of Hungarian bog-lakes.

Introduction

Peat bogs represent one of the major vegetation type at higher latitudes of the Northern hemisphere and they are, even though not that characteristic, abundant in the cooler and wet temperate regions. The climate of Hungary is neither cold nor humid and therefore peat bogs (with at least some *Sphagnum*) occur sporadically and due to edaphic reasons. However, as occurring at the margins of geographic distribution of this type of vegetation they deserve protection and distinguished scientific attention.

The beauty and large diversity of the algae living in the peat bogs has always attracted the attention of the algologists. The first reports of peat bog algae in Hungary were published in the late 19th century (Hazzlinszky, 1868; Schaarschmidt, 1882; Csató, 1885) and early data were followed by dozens of other works in the 20th century (for detailed literature review see Borics, 2001). In these works, it was recognized that they are similar to other bog systems in the Alps, in the Carpathians and in the northern part of Europe. Uherkovich et al. (1994) investigated the algal flora of several peat bogs and considered first environmental

factors like water balance, water chemistry, geomorphology, etc. that can be important for understanding assembly of algal flora in these ecosystems. These early publications, despite very low international publicity, are of great importance as being the only sources of information about the Hungarian peat bogs, and therefore they provide a solid basis for comparative studies (Stollmayer-Boncz, 1992).

The early investigators of peat bogs focused on detailed description of the desmid flora, while other taxa were largely neglected even though these groups include many interesting and unique species. More recent investigations have reported that many species of silica-scaled Chrysophyceae, (Kristiansen, 1986; Péterfi & Momeu, 1996; Kristiansen & Stoyneva, 1998; Péterfi et al., 1998; Padisák et al., 2000), Volvocales, Chlorococcales (Cambra & Hindák, 1998; Borics et al., 1998a, b) and dinoflagellates (Borics et al., 2000) can be useful in estimation of ecological status of the peat bogs. Other investigations have demonstrated that the rich desmid flora is not exclusive for acidic environments, rather, it can be remarkably rich in alkaline conditions. For example, Kiss (1977) found 40 species of desmids in the reed-belt of a salt marsh (dominant ions: HCO_3^- and Na^+ , pH between 8.5 and 10) in southern Hungary. Fehér (2000) described 43 taxa of desmids in one sample originating from a side-branch of Danube (pH: 8.2–8.4) some of which were considered previously as typical acidophylous organisms. The checklist of the Kiskunság National Park and the surrounding areas (with no acidic localities) contains 169 species of Desmidiaceae (Padisák, 1998). After investigating many types of water bodies, Coesel (1984) revealed that the alkaline seepage-lakes have the richest desmid flora in the Netherlands.

Quite often, algal flora of such small lakes has been more rich than that in deep lakes and they have continued to attract attention of florists but not of ecologists. They are difficult objects for ecologists because, due to their variable water balance, small water volume and spatial heterogeneity most are rather changeable with no clear patterns to estimate major processes. As a consequence, ecological knowledge of small lakes, representing the bulk of the World's biodiversity, is incomparably poorer than that of large ones.

Between 1995 and 1999 we performed a comprehensive research on 12 bogs in Hungary with the following main aims:

(i) What kind of algal assemblages characterize the small habitats that are typical in the bog systems?

(ii) Which taxa can be considered typical bog-dwellers?

(iii) What is the main group of environmental factors (hydrology, water chemistry, habitat diversity) that influences the species richness of the bogs?

(iv) Are there any differences in the composition of the algal flora in comparison to results of early investigators?

(v) What considerations are necessary when studying algal assemblages of such lakes?

Materials and methods

Study area

Plankton, metaphyton and periphyton samples were collected from the largest Hungarian bog-lake, Balátó, between 1995 and 1999. In 1999, we extended our investigations to 11 other bogs of different type located in the western part of Hungary (Fig. 1).

1. Fekete-tó (300 m a.s.l.) is a *Sphagnum*-bog, which is situated in a depression of a hill plateau. The surface area is about 0.06 ha, without any open water area. The whole basin is filled with *Sphagnum*. Typical macrophyte-association is the *Carici echinatae-Sphagnetum*. The bog is fed by precipitation.

2. Huszászi-patak lápja. This bog is situated in a depression along the Huszászi-streamlet (210 m a.s.l.). It was a small pond 30 years ago with considerable open water area, but as a result of a rapid natural succession the whole basin was invaded by macrophytes, mainly by *Carex elata*. Among the tussocks of this species several small pools are hidden. The stocks of the tussocks are covered by *Sphagnum*. The most of the small pools are densely covered by *Utricularia neglecta*. Surface area is 0.5 ha, mean depth is about 0.8 m. Water supply: precipitation, floods of the streamlet and groundwater seepage.

3. Grajka-patak lápja is a swampy area, which is situated in the westernmost part of Hungary. Thirty years ago the bog of Grajka-streamlet (about 200 m a.s.l.) was a typical mesotrophic spring-bog. After giving up the cutting of this area characteristic swamp vegetation (dominated by *Carex* species) developed during the last decades and parallel the *Sphagnum* decreased. Water is on groundwater level. Water is supplied by precipitation and groundwater seepage.

4. Ördög-tó (approx. 200 m a.s.l.) is a small, eutrophic pool of unknown origin in the westernmost

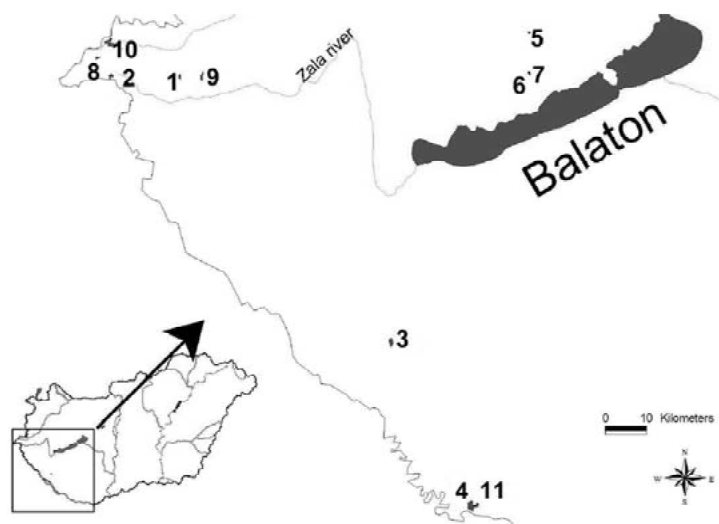


Figure 1. Map of the investigated localities 1. Vadkacsás-tó 2. Huszászi-patak lápja, 3. Baláta-tó, 4. Szűrthely-folyás, 5. Öcsi Nagy-tó, 6. Barkás-tó, 7. Monostori-tó, 8. Grajka-patak lápja, 9. Szőcei láp, 10. Ördög-tó, 11. Tiva-tó; 12 Fekete-tó.

part of Hungary. Surface area is 0.04 ha, mean depth is 0.4 m. *Sphagnum*-stands are present in the southern shore. The basin is divided by *Carex* tussocks. The water supply is exclusively by precipitation.

5. Vadkacsás-tó (about 180 m a.s.l.) is a transition bog, which is in an advanced successional phase. Almost the whole area of the bog (0.5 ha) is covered by *Salix cinerea*. Among the trees and bushes small pools (0.1–0.2 m depth) are found, with *Sphagnum* on the margin. Submerged aquatic macrophytes were not found. The bog is supplied by water from an artificial ditch that collects the runoff from the surrounding area.

6. Szőcei láp. In the vicinity of Szőce village (approx. 140 m a.s.l.) a small meadow is lying in the valley of a streamlet. Surface area is approx. 1 ha. Patches of *Sphagnum* species can be found in the small depressions of the area. *Drosera rotundifolia* is also present. Although open water-surfaces appear only temporarily, the meadow is always wet because of the relatively high precipitation and some leaking sources around.

Bogs of Fekete hegy. Several basalt hills can be found in the Balaton Upland. Some of these hills have a large plateau of irregular shape. In the depressions small swamps and bogs developed. Fekete-hegy (350–371 m a.s.l.) is a hill, which has five pools, of which Monostori-tó and Barkás-tó are the most interesting.

7. Monstori-tó is a relatively large (8–10 ha) bog-lake. Max depth is 2 m. In the central area, a typical

floating *Sphagnum*-island is developed which is quite unusual in Hungary. The pond is supplied exclusively by the precipitation. At the time of the sampling, the whole surface was covered by *Typha angustifolia*, hence we were able to take samples from the small pools, at the margin.

8. Barkás-tó is a small (0.5 ha), slightly acid, ephemeral pond, that is situated at the edge of the plateau. Mean depth is 0.4 m. Patches of *Schoenoplectus lacustris* and *Sparganium erectum* divide the basin. At the margin *Ceratophyllum submersum* and *Utricularia* sp. are dominating. The pond is fed by the precipitation.

9. Öcsi Nagy-tó (330 m a.s.l.) is a bog-lake that is situated in a depression of the southern slope of the Kab-hegy, the highest peak of the Bakony-mountains. The pond is divided into two different regions. The upper part is a typical transition bog with birch and *Sphagnum* in the centre and *Salix cinerea* in the edge. The lower part is an artificially dammed pond with considerable open water area, which collects the leaking water of the upper bog-area. Besides the precipitation, the pond is supplied by a source.

10. Lake Baláta (160 m a.s.l.) is the largest acid bog-lake in Hungary having a surface area of 174 ha. Various vegetation types cover approximately 80% of the surface. The lake has a mean depth of 1 m, maximum depth is 3–4 m with bottom deposits of 1–2 m thickness. The lake is fed primarily by precipitation.

11. Tiva-tó (120 m a.s.l.) is a small, artificial pond in the area of Barcs Nature Reserve, and during the

last decades it became similar to the natural transition bogs. Surface area is 1.5 ha, mean depth is 1 m. At the time of the sampling, macrovegetation was restricted to the shoreline of the basin. The pond is fed by precipitation and a small canal which originates from another marshland.

12. Szűrűhely-folyás (120 m a.s.l.) is a small, ephemeral forest-pool in the area of Barcs Nature Reserve. Surface area is about 0.14 ha, mean depth is 0.4 m. Earlier the basin was edged by *Sphagnum* (Uherkovich, 1981), but at the time of sampling *Sphagnum* was not observable. *Riccia fluitans* and *Lemna minor* covered the whole water surface. The pool is fed by precipitation.

Sampling and sample processing

Water samples were taken by filling bottles approximately 40 cm below the surface for phytoplankton and water-chemical analyses. For investigating the periphyton, parts of macrophytes, peat and other organic remnants were collected in 100 ml plastic bottles. In the laboratory 100–250 ml distilled water was added to them. After shaking they were allowed to settle in 500 ml cylinders, and were decanted some days later. The remnants were investigated with LEICA DMRB microscope equipped by brightfield, phase-contrast and Nomarski-contrast techniques. Both types of samples were fixed with Lugol's solution with acetic acid.

Water chemical analyses were performed according to the technical guidelines of the Hungarian Environmental Protection Inspectorates. These guidelines apply the internationally accepted analytical methods.

Data-analysis

For comparison of the microflora of the bog lakes hierarchical cluster analysis (Euclidean distance, Nearest neighbour methods; Florek et al., 1951) was applied. Non-metric multidimensional scaling was used to display the similarity of the algal flora of the bog-lakes (Legendre & Legendre, 1998). The similarity was measured by the Matusita similarity, which is defined in the following way:

$$s(p, q) = \sum_{i=1}^s \sqrt{p_i \cdot q_i},$$

where p_i is the relative frequency of the species i in the first compared bog-lake (p), and q_i is the relative

frequency of the species i in the second compared bog-lake (q), and S is the total number of species. We preferred to use this similarity, because it is based on the relative frequency of the species. Calculations were done by the NuCoSA program package (Tóthmérész, 1993).

Results

Water chemistry data (Table 1) allow describing these water-bodies as slightly acidic ones with very low conductivity and ionic concentrations. The lowest pH and conductivity values were measured in the samples taken from *Sphagnum* sites. In the majority of localities the PO_4^{3-} -P concentrations were fairly high (95–1240 $\mu\text{g l}^{-1}$) with exception of a small pool among *Carex* tussocks (Huszászi-patak lápja), and twice among *Sphagnum* hummocks (Fekete-tó, Szőcei láp) where concentrations $<10 \mu\text{g l}^{-1}$ were found. The inorganic-nitrogen ($\text{N}_{\text{inorg}} = \text{NH}_4^+\text{-N} + \text{NO}_3^-\text{-N} + \text{NO}_2^-\text{-N}$) concentration changed between 850 and 7540 $\mu\text{g l}^{-1}$.

A total of 624 taxa were identified during the study: Cyanobacteria – 50, Bacillariophyceae – 80, Chrysophyceae – 44, Xanthophyceae – 14, Chlorococcales – 99, Volvocales – 34, Desmidiaceae – 115, other Chlorophyta – 26, Euglenophyta – 126, Dinophyta – 23, Cryptophyta – 10, Raphidophyceae – 2 and Haptophyta – 1. Floristic composition both at level of main algal groups and species showed considerable differences among the localities (Table 2). Four groups of bog systems could be distinguished based on hierarchical cluster of the floristic compositions (Fig. 2):

I. Desmids, diatoms, and euglenophytes are dominant. Chlorococcalean algae also appear in these localities in relatively high number. The bogs that belong to the first group possess a large diversity of habitats (open-water areas, small pools, rich aquatic macroflora) and have relatively good water supply.

II. 'Typical' bog flora, with overwhelming dominance of desmids and diatoms, as well as epiphytic Cyanobacteria. These can also be characterised by sufficient and permanent water supply and rich macroflora but they do not have open surface areas.

III. The contribution of flagellated algae, mainly the euglenophytes, is high. This group comprises two bog-lakes. Both are quite nutrient rich and have relatively large open water areas and good water supply. Macrovegetation is of minor importance.

Table 1. Some physico-chemical parameters of the investigated localities. 1. Vadkacsás-tó 2. Huszászi-patak lapja, 3. Balata-to, 4. Szuruhely-folyas, 5. Ocsi Nagy-to, 6. Barkas-to, 7. Monostori-to, 8. Grajka-patak lapja, 9. Szocei lap, 10. Ordog-to, 11. Tiva-to; 12 Fekete-to

	1	2	3	4	5	6	7	8	9	10	11	12
NH ₄ ⁺ mg l ⁻¹	1.69	0.56	0.66	0.84	0.56	0.52	0.63	0.71	0.56	5.56	0.9	0.49
NO ₂ ⁻ mg l ⁻¹	0.06	0.02	0.03	0.07	0.04	0.03	0.05	0.04	0.02	0.08	0.04	0.02
NO ₃ ⁻ mg l ⁻¹	1.9	0.9	1	1.1	3	0.3	1.5	1.1	0.9	1.9	2.6	1.1
PO ₄ ³⁻ μg l ⁻¹	1042	<10	95	220	252	427	552	337	<10	1240	172	<10
pH	5.99	6.28	6.35	5.61	5.75	6.77	6.3	6.34	6.03	6.12	6.11	4.75
Conductivity. μS cm ⁻¹	70	92	92	43	89	142	75	60	52	102	73	25
Ca ²⁺ mg l ⁻¹	11.43	15.61	9.55	10.40	11.43	21.44	5.72	9.21	9.21	10.81	11.40	10.62
Mg ²⁺ mg l ⁻¹	5.2	3.04	7.53	3.65	3.47	6.07	3.47	3.29	3.81	4.74	3.04	0.97
Na ⁺ mg l ⁻¹	1.9	3.2	2.8	2.90	4.7	5.0	4.0	3.45	6.44	5.75	4.61	1.30
K ⁺ mg l ⁻¹	<1.0	<1.0	3.5	0.6	2.0	2.0	14.3	6.01	5.47	1.19	6.4	1.96
Cl ⁻ mg l ⁻¹	7.09	7.9	14.18	7.10	10.64	14.18	7.09	12.05	21.62	12.42	7.13	5.31
SO ₄ ²⁻ mg l ⁻¹	33.6	16.81	28.8	24.01	24.0	23.89	24.0	12.00	9.59	19.25	19.25	24.02
HCO ₃ ⁻ mg l ⁻¹	18.31	44.18	22.56	24.42	12.20	60.98	30.88	30.53	30.46	30.46	42.68	7.32

IV. Extraordinarily poor flora, desmids did not occur. This group comprises only one locality: the *Sphagnum*-bog of Fekete-to. (This bog-system cannot be considered typical: thirty years ago it was a transitory *Sphagnum*-bog, but as a result of the arid decades it desiccated which led to the impoverishment of the microflora.)

Despite the fact that the investigated localities differ from each other in their flora and habitat characteristics, quite a large number of common species were found. Species as *Eunota bilunaris*, *Gomphonema gracile*, *G. parvulum*, *Nitzschia palea*, *Closterium dianae*, *C. venus*, *Cosmarium regnellii*, *C. polymorphum* and *Euglena oxyuris* were present in almost each sample. These are species not exclusively associated with bogs and acidic environments. Well-known bog-dwellers like *Actinotaenium turgidum*, *A. cucurbita*, *Netrium digitus*, *Micrasterias truncata*, *Tetmemorus granulatus*, *T. laevis*, etc. were observable only in one, or two sites. Nevertheless we have found three taxa which appeared in the majority of the localities, but not being widespread. *Heimiochrysis actinotrychia* (Chrysophyceae), *Rhipidodendron huxlei* (Haptophyta), and *Peridinium bipes* tab. *γ travectum* fa. *tabulatum* (Dinophyta) are acidophylous organisms and proved to be constant dwellers of the investigated localities.

Physiognomies of certain types of habitats were very similar in the different bogs. In order to investigate whether this resemblance appears at microscopic level, similarity of the flora of each sample has been

analysed quantitatively. The basis for the comparison was the relative abundance of the specimens that belong to the following categories:

1. Diatoms that frequently occur in acidic environments (mainly *Eunotia* and *Pinnularia* species)
2. Diatoms not so specific, with wide ecological range
3. Chrysophyceae spp.
4. Xanthophyceae spp.
5. Unidentified cyst-like Xanthophyceae species
6. Chlorococcales and planktonic *Ulotrichales* species (*Koliella* sp.)
7. Volvocales spp.
8. Tetrasporales spp.
9. Filamentous green algae and *Vaucheria* sp.
10. Desmids
11. Euglenophytes
12. Dinophytes
13. Cryptophytes and Raphidophyceae spp.
14. Epiphytic Cyanobacteria
15. Planktonic Cyanobacteria

The ordination of the semi-quantitative data based on Matusita-similarities (Fig. 3) allowed distinguishing of five groups:

1. Group-C included the samples in which the chlorococcalean algae (*Radiococcus nimbatus*, *Scenedesmus ovalternus*, *Scenedesmus* spp., *Dicetyosphaerium pulchellum*, *Ankistrodesmus bibraianus*) and planktonic Cyanobacteria (*Aphanocapsa* sp., *Snowella lacustris*) were the dominants.

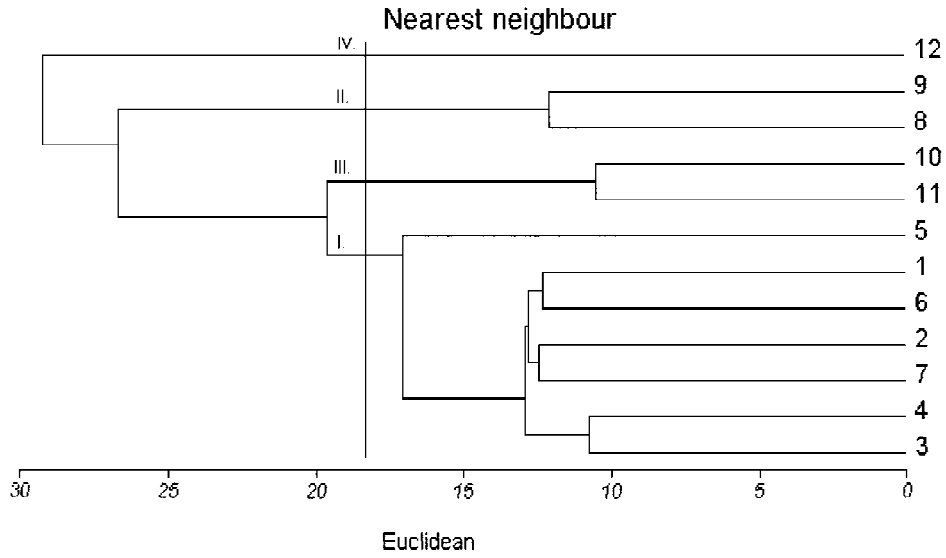


Figure 2. Dendrogram of the investigated localities on the basis of the floristic composition. 1. Vadkacsás-tó 2. Huszászi-patak lágja, 3. Baláta-tó, 4. Szűrűhely-folyás, 5. Öcsi Nagy-tó, 6. Barkás-tó, 7. Monostori-tó, 8. Grajka-patak lágja, 9. Szőcei lág, 10. Ördög-tó, 11. Tiva-tó; 12 Fekete-tó.

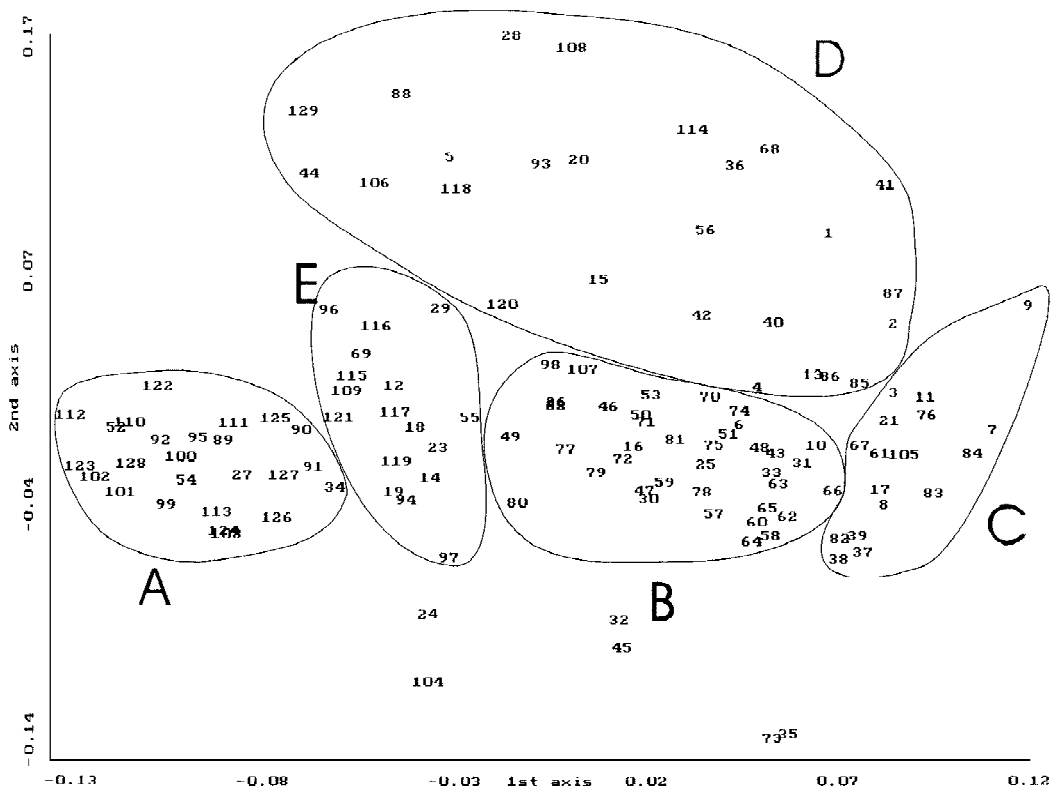


Figure 3. Ordination of the samples on the basis of relative abundance of the specimens that belong to the ecological categories mentioned above.

Table 2. Floristic composition of the localities arranging in accordance with the basic types of microvegetation. 1. Vadkacsás-tó 2. Huszászi-patak lápja, 3. Baláta-tó, 4. Szűrűhely-folyás, 5. Öcsi Nagy-tó, 6. Barkás-tó, 7. Monostori-tó, 8. Grajka-patak lápja, 9. Szőcei láp, 10. Ördög-tó, 11. Tiva-tó; 12 Fekete-tó

Taxa	Group I							Group II		Group III		Group IV
	1	2	3	4	5	6	7	8	9	10	11	12
Cyanobacteria	1	6	47	2	12	6	7	6	4	2	4	1
Bacillariophyceae	8	13	54	6	29	23	13	38	19	7	10	2
Chrysophyceae	1	2	44	3	1	3	2	1	0	3	3	0
Xanthophyceae	0	2	12	2	0	2	3	0	0	1	3	0
Raphidophyceae	1	1	1	0	0	1	0	0	0	0	0	0
Chlorococcales	1	5	85	13	2	11	9	0	0	5	17	2
Volvocales	0	3	28	2	4	3	7	2	1	6	8	1
Desmidiáles	4	18	99	12	13	12	18	20	7	4	6	0
Other Chlorophyta	1	1	23	3	1	2	2	0	1	0	4	1
Euglenophyta	9	14	109	17	17	25	27	2	1	22	44	1
Dinophyta	1	6	22	3	5	6	6	0	1	2	7	0
Cryptophyta	2	2	8	3	4	6	6	0	1	1	4	0
Haptophyta	1	1	1	1	1	1	1	0	0	1	1	0
Total number of taxa	30	74	533	67	89	101	101	69	35	54	111	8

2. Samples in Group-D were dominated by large sized flagellates (Dinophyta: *Peridinium umbonatum*, *P. bipes*; Cryptophyta: *Cryptomonas ovata*; Euglenophyta: *Euglena sanguinea*, *Lepocinclis* spp., *Phacus* spp.; Chrysophyceae: *Mallomonas* spp. and Raphidophyceae: *Gonyostomum semen*, *G. intermedium*).

3. In Group-B the above mentioned chlorococcalean algae and Cyanobacteria were dominants and desmids (*Cosmarium subprotumidum*, *Closterium gracile*, *C. diana*, *Staurastrum tetracerum*, *Staurodesmus dejectus*, *S. indentatus*), cryptophytes, dinoflagellates or euglenophytes appeared as subdominants.

4. Diatom dominated samples can be found in Group-A. (Characteristic species: *Eunotia bilunaris*, *Pinnularia* spp., *Gomphonema gracile*, *Nitzschia* cf. *fonticola*).

5. The fifth group (Group-E) contains all the samples in which other taxa, such as *Vaucheria dichotoma*, filamentous green algae: *Oedogonium* spp., *Cladophora* spp., *Microspora* spp. and *Microthamnion kuetzingianum*. prevailed.

Numbers, situated outside the encircled areas of Figure 2 indicate samples in which only one species (*Cladophora* sp. or filamentous blue green algae: *Anabaena solitaria*, *Nostoc* spp., *Microchaete tenera*), was found.

The groups mentioned above are closely linked with certain types of habitats.

In Group-A one can find samples dominated by planktonic species and they were collected from large pools with considerable open water area. Group-B contains the samples derived from small bog pools. Group-C includes sampled dominated by periphytic samples taken from bogs of good water supply. In Group-D also periphytic species dominate but these samples were collected from bogs that occasionally dry up. Exclusively samples collected in *Sphagnum* stands belong to Group-E.

Some of these bogs had been investigated previously. Therefore we tried to establish the basic trends that characterise the changes of the algal flora. In general (Table 3), there is a significant decrease of the total number of taxa that was observed at almost each sample-site. This decreasing tendency is attributable to the impoverishment of species rich algal groups such as diatoms, desmids and Cyanobacteria. The richer these taxa were in the past, the bigger is the drop in species number. Inverse trend has been found in case of Ördög-tó, that is an eutrophicated bog-pool. In this case, the larger species number is due to the increase of the species number of *Euglenophyta*.

Table 3. Floristic results (species numbers) from the previous and the present investigations. Abbreviations: 4: Szűrűhely-folyás; 5: Öcsi Nagy-tó; 7: Monostori-tó; 8: Grajka patak lápja; 9: Szöcei-láp; 10: Ördög-tó; 11: Tiva-tó; 12: Fekete-tó; a: Kol (1967); b: Vízkelety (1987); c: Uherkovich (1981); d: Uherkovich (1979); e: Uherkovich (1978); f: Kol (1970); g: Uherkovich et al. (1994); h: Uherkovich (1982); p: present study

locality reference	4 c	4 p	5 d	5 p	7 h	7 p	8 f	8 p	9 g	9 p	10 b	10 p	11 e	11 p	12 a	12 b	12 p
Cyanobacteria	12	2	25	12	21	7	15	6	3	4	3	8	5	4	15	2	1
Bacillariophyceae	67	6	100	29	41	13	0	38	54	19	10	7	23	10	4	20	2
Chrysophyceae	9	3	7	1	6	3	0	1	0	0	0	9	15	3	0	1	0
Xanthophyceae	5	2	6	0	6	3	1	0	0	0	3	1	3	3	0	2	0
Raphidophyceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chlorococcales	19	13	41	2	13	9	2	0	6	0	1	5	15	17	10	0	2
Volvocales	4	2	8	4	6	7	0	2	0	1	2	6	6	8	3	2	1
Desmiales	23	12	27	13	74	18	78	20	14	7	6	4	37	6	64	0	0
other Chlorophyta	11	3	5	1	9	2	14	0	3	1	2	0	13	4	8	2	1
Euglophyta	47	17	61	17	32	27	2	2	8	1	8	22	30	44	1	1	1
Dinophyta	3	3	4	5	6	6	0	0	0	1	1	2	8	7	0	0	0
Cryptophyta	7	3	6	4	1	6	0	0	0	1	0	1	2	4	0	0	0
Haptophyta	0	1	0	1	0	1	0	0	0	0	0	1	0	1	0	0	0
Number of taxa	207	67	290	89	212	102	112	69	88	35	36	66	157	111	105	30	8

Discussion

The expression 'bog systems' includes several types of wetlands, which differ from each other in many respects. Despite remarkable differences in origin, morphology, physiognomy and macroflora, the water-chemical properties of the localities proved to be rather uniform especially in context of nutrients. As threshold values for P_{inorg} and N_{inorg} were set as $10 \mu\text{g l}^{-1}$ and $100 \mu\text{g l}^{-1}$, respectively (Sas, 1989), no nitrogen limitation can arise in these bogs and P_{inorg} might be limiting in only three bogs. Nevertheless, the low phosphorus concentrations did not coincide necessarily with poor algal flora. For example, the species richness and the species composition of Huszászi-patak lápja was very similar to that of Szűrűhely-folyás, although the phosphorus content in the latter locality was much higher. These records allow the conclusion that water chemistry, and especially nutrient supply, cannot be considered as the major factor for the observed differences. It is worth to note that in large lakes with dominant phytoplankton water chemistry and its changes along different scales can be the major selecting force for species and a chief driving force for annual and interannual changes (Padisák & Dokulil, 1994; Sommer et al., 1996; Reynolds, 1997).

The total number of identified taxa per localities ranged from 8 to 107. The occurrence of algae was

quite variable within and among localities. These differences are due to several factors, especially water supply and habitat diversity. The richest flora was found in those localities where the water supply was stable and the encroachment of macrophytes resulted in various microhabitats.

Flora of Baláta-tó was neglected in the previous comparison because this transitional bog was investigated more in detail and for a longer period. Despite the Baláta-tó is a relatively small water body its algal flora is exceptionally rich (533 taxa). Such species richness is usually typical only for large lakes or rivers. As comparison, Kiss & Schmidt (1998) recorded 594 taxa from the Hungarian section of the Danube river during the last twenty years. The experienced large number of taxa is inconsistent with the generally accepted view, that the algal flora of dystrophic lakes is rather poor (Maitland & Morgan, 1997).

It has been widely accepted that the acidic environment is one of the most important factors that can determine the species pool of a bog. In this study, similarity of the water chemical parameters (including pH) of the investigated localities and the large differences of their algal flora suggest that other elements of the environment are also important. It seems that the character of these elements is rather physical than chemical. Because of their hypothesized terrestrial origin (Stebbins & Hill, 1980) most of the desmids are

benthic or metaphytic forms. Proportion of desmids, indeed, was relatively high in those localities where the lake basin was dominated by macrophytes. According to observations by Fehér (in press) desmids seem to be associated with certain species of macrophytes like *Utricularia vulgaris* and *Miryophyllum spicatum*. Taxonomic composition of those localities where the open surface areas are also present is characterised by the high ratio of flagellates. Dimensions of these open areas seem to be the most important factor. Because of the sheltering of the terrestrial macrovegetation, wind cannot induce significant water turbulences. In these largely undisturbed, lentic environments organisms that do not have capability of effective locomotion will sink to the sediments. It justifies that possession of flagella is the most advantageous strategy in this kind of environment. Additional factors might be that acidic waters are usually richer in dissolved organic material which can fulfil requirements of potentially mixotrophic species. The benthic or metaphytic life of chlorococcalean algae that are believed to be principally planktonic is another strategy of survival. They might be also favoured by the relatively high amount of available inorganic nutrients. The relevant physico-chemical parameters of the small pools of different localities proved to be very similar, but only in a few of them was observable the dominance of the same assemblage of flagellated species. In the majority of cases different species of Raphidophyceae, Cryptophyta or Euglenophyta groups prevailed in the small pools, which is a good example of the pseudovicarism of algae. It is important to note here that the large number of species in several groups (like Chlorococcales) is probably due to evolution in such environments rather than in large lakes where they are usually the most numerous in terms of species number but mostly insignificant in terms of biomass (Padisák & G.-Tóth, 1991; Dokulil, 1991; Padisák & Dokulil, 1994; Padisák et al., 1998).

In the large bog-pools the wind induced water turbulences enable permanent presence of chlorococcalean algae and Cyanoprokaryota species in the plankton. This type of microflora only appeared in the largest Hungarian bog lake, Baláta-tó.

Comparing our results with that of the previous investigations a drop in algal species number has been observed. Although it cannot be excluded that the differences in sampling techniques or the different number of the samplings can influence the results, impoverishment of the flora can be most likely attributed to other factors. On the basis of an algal floristic investig-

ation on a peat bog, which had lost considerable part of its catchment as a consequence of basalt-mining area in Balaton Upland region, Uherkovich (1984) concluded that the desmids are more sensitive to drying out than diatoms, consequently the impoverishment of the flora starts with the disappearance of desmids. The most dramatic changes have been shown in case of the *Sphagnum*-bog of Fekete-tó. This locality was described earlier as a very desmid rich habitat in Hungary (Kol, 1970). Impoverishment of the desmid flora was observed in the 1980s (Vízkelety, 1987). Very likely, the decreasing species number of the investigated bog systems is a reflection of the long lasting dry period that started in the early eighties, and lasted for one and half decade in Hungary. These observations indicate that such algal assemblages are sensitive indicators of both various human impacts at local scale or climate changes at global scales, moreover, that indication at species level is sometimes possible (*Heimiochrysis actinotrychia* [Chrysophyceae], *Rhpidodendron huxlei* [Haptophyta], *Peridinium bipes* tab. *γtravectum* f. *tabulatum* [Dinophyta]), but careful establishment of a functional classification system with different association types (Reynolds et al., 2002) has been probably more promising as evidenced by Padisák et al. (2003), Stoyneva (2003) and O'Farrell et al. (2003).

In accordance with results of this floristic studies and their ordination profile we may outline five basic types of the microvegetation that appear in the different habitats of a hypothetical bog system (Fig. 4).

- (1) Littoral algal vegetation in forested shores (trees are many times rooting in water) is rich in cryptomonads most probably because of its ability for chromatic adaptation (phycobiliproteins), good photosynthetic parameters in low-light environments and its good spatial orientation in small scale environments (utilization of varying sunshine-spots penetrating through the canopy of the trees). *Mallomonas* spp. might also be characteristic.
- (2) In dense, emerged macrophyte stands periphytic diatoms are the most characteristic type of association sometimes with periphytic filamentous algae (*Chlorophyta*).
- (3) In habitats with rich submerged higher plant vegetation, however with good light climate, species of *Euglenophyta* appear in large numbers. They are probably favoured because they are good swimmers and their need for organic substances are usually sufficed in such environments. In this as-

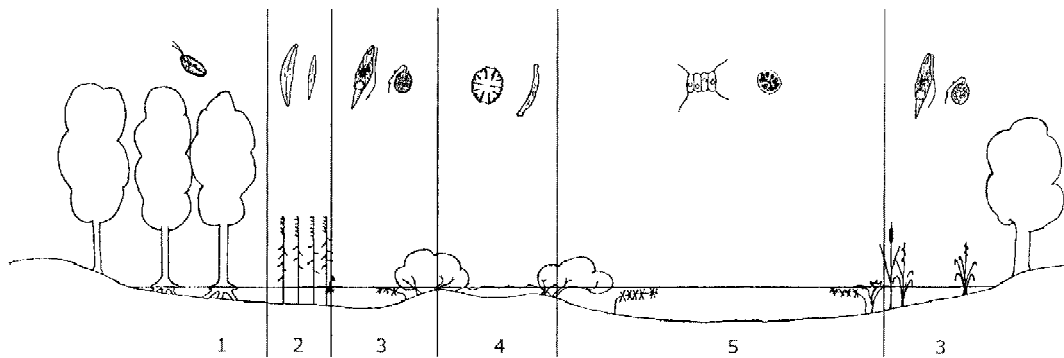


Figure 4. Vegetation profile of a hypothesised bog-lake with the characteristic types of habitats and the relevant members of the microflora. 1. Shallow, shaded and lentic area without macrophytes; 2. Emerged macrophytes; 3. Small, lentic bog pools with good light conditions and submerged macrophyte; 4. *Sphagnum* tussocks; 5. Large open water areas.

sociation type many of well-known planktonic organisms, such as *Scenedesmus*, *Dictyosphaerium*, *Eutetramorus*, species or a heterocytic cyanoprokaryotes like *Anabaena solitaria*, instead of being in the plankton, can sufficiently establish populations in the metaphyton where settling on leaves of macrophytes prevent them of sinking to aphotic layers.

- (4) *Sphagnum*-patches are inhabited by typical bog dwellers (desmids, diatoms like *Eunotia*).
- (5) Large open surfaces allow for typical planktonic associations of chiefly chlorococcalean, sometimes cyanobacterial types. In such habitats wind-driven mixing can keep non-motile planktonic green algae in suspension and their high demand for inorganic nutrients are mostly sufficed.

In more alkaline waters with similar physiognomy filamentous species of type two can be more characteristically periphytic *Oscillatoriales*. In such lakes a 6th association type may be present: dense benthic algal mats of oscillatorealean filaments with large benthic diatoms.

When dealing with such small-scale canopy systems one should consider spatial heterogeneity. With 'rough' sampling methods we may easily mix different association types which makes impossible to recognize them even though they are equilibrated (*sensu* Sommer et al., 1993) one by one.

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