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# Bryophytic diatoms from Hungary

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**Abstract**

Diatoms (Bacillariophyta) and chrysophyte statospores (Chrysophyta) were studied in 48 samples collected in mires in Hungary. Our aim was to study the similarities and differences of periphyton on 13 moss species from 11 localities. In two-thirds of the samples we found very low abundances of diatoms and statospores. One *Sphagnum fallax* sample supported a characteristic aerophytic flora; *S. fallax* from other localities have shown diverse and peculiar diatom flora, with *Chamaepinnularia mediocris, Eunotia exigua, Adlafia bryophila, Eunotia lapponica, Frustulia crassinervia,* and *Pinnularia subcapitata* var. *elongata* as dominant taxa. In compliance with the literature, *Pinnularia subcapitata* var. *elongata, Adlafia bryophila, Pinnularia stomatophora* are bryophytic (sphagnophilous) taxa; they represent the first records of bryophytic diatoms from Hungary.

Key words: mires, bryophytic diatoms, Chrysophyta statospores, peatmosses, coexistence, Hungary

## Introduction

*Sphagnum* dominated habitats are among the most thoroughly studied diatom habitats, particularly in the higher latitudes of the Northern hemisphere. However, in Hungary, little attention has been paid to this area of research because peatmoss habitats are rare in Hungary. In addition, total peat moss area has been shrinking alarmingly in the past decades.

It is known that 1% of the world`s land surface is covered by mires. Mires in Hungary also covered roughly 1.1% of land surface before water regulation commenced over 150 years ago. The extent of European mires has shrunk from an estimated 495,000 square km to the present 187,000 square km within the last few decades. This means a loss of about 62% of this habitat. Sulyok (2003) has estimated that about 97% of mires have been lost in Hungary. Hot and dry periods in the past few years have been responsible for the loss of large portions of our peatmoss populations, in addition to human destruction of these natural habitats. It is of great concern that these mires will disappear before we gain a thorough knowledge of these systems. Similar problems have been reported from other countries of Central Europe (Poulicková *et al.* 2002).

Records of Hungarian algological studies carried out on mires were summarised by Borics (2001) and Borics *et al.* (2003). Early studies of mires focused on detailed descriptions of the desmid flora, followed later by work on the silica-scaled Chrysophyceaea and dinoflagellates. Borics (2001) conducted a detailed study to create a taxonomical grouping of the algal assemblages of 12 mires.

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Diatoms living on mosses have been well-studied by Ando (1977, 1978), but the intensive studies are restricted mainly to the treeless Arctic and Antarctic regions (e.g. Van de Vijver 2001, Van de Vijver & Beyens 1997, Alfinito *et al.* 1998, Douglas & Smol 1995, 1999). Diatomists usually treat mosses and liverworts under the same 'umbrella', regarding them only as "substrata", where taxonomic identity is irrelevant. However, host specificity is one of the most interesting an unsolved problems of biology (e.g. Poulicková *et al.* 2004). The present study aimed to make a preliminary contribution to the knowledge of moss diatoms using data from the Hungarian mires. The inspiration for this work originated from Johansen (1999) recommending the use of the term "bryophytic diatoms" because mosses often have a diatom flora and vegetation exhibiting unique characteristics.

***Specific aims and questions of this study were the following:***

1. Are there differences in the diatom flora of different species of mosses?
2. Does diversity and evenness of diatom assemblages in samples correspond to the following question: are diatom assemblages stable with respect to low number of species in undisturbed habitats?
3. How does dry weather impact the diatoms assemblages? While diatoms in general are cosmopolitan, certain genera are associated with unique ecological niches (e.g. *Hantzschia amphioxys* and *Luticola mutica* are aerophilous).
4. Can the aerophytic diatoms settle in and survive within the former species spectrum as a consequence of long dry periods?
5. Is there any correlation between the species richness of diatoms and that of Chrysophycean statospores?

## Material and methods

Diatoms of 13 peatmoss species from 11 habitats were studied (Fig. 1 and Table 2). Two bogs near Kelemér are noteworthy among others in the country and play a special role in this study. These were Kis-mohos and Nagy-mohos, the best-known Hungarian mires and have been subjected to large-scale investigations by geologists, botanists, zoologists, and palaeoecologists. Recently, the mires have been under international palaeoecological investigation. In spite of this intense research to gain a wider knowledge of these "large" Hungarian mires, algological research was and there is no data available (Szurdoki & Nagy 2002).

The mosses were collected and identified by Erzsébet Szurdoki between 1993 and 1995, as a part of a doctoral thesis (Szurdoki 2005). Additional samplings were completed in 2003 by the present author.

Sampling method: dry samples (herbarium specimens) were soaked in water and washed to extract the diatom material from the samples. The diatoms were treated with hydrogen peroxide ($H_2O_2$), and cleaned material was embedded in Zrax®. Relative abundances were calculated after counting between 200 and 400 valves. The sampling and counting procedure was repeated several times, if after scanning the entire slide, only a few valves were present. Despite the comprehensive counting procedure it was not possible to produce statistically reliable data of diatoms in several samples. Total abundance was estimated in some cases and related to the dry moss mass. The ratio of diatom frustules to chrysophycean statospores was calculated according to Smol (1985).

The identication of diatoms was aided by means of Krammer & Lange-Bertalot (1986–1991a, b), Krammer (2000) and Lange-Bertalot (2001). The *Eunotia* taxa were checked following Petersen (1950) and Alles *et al.* (1991).

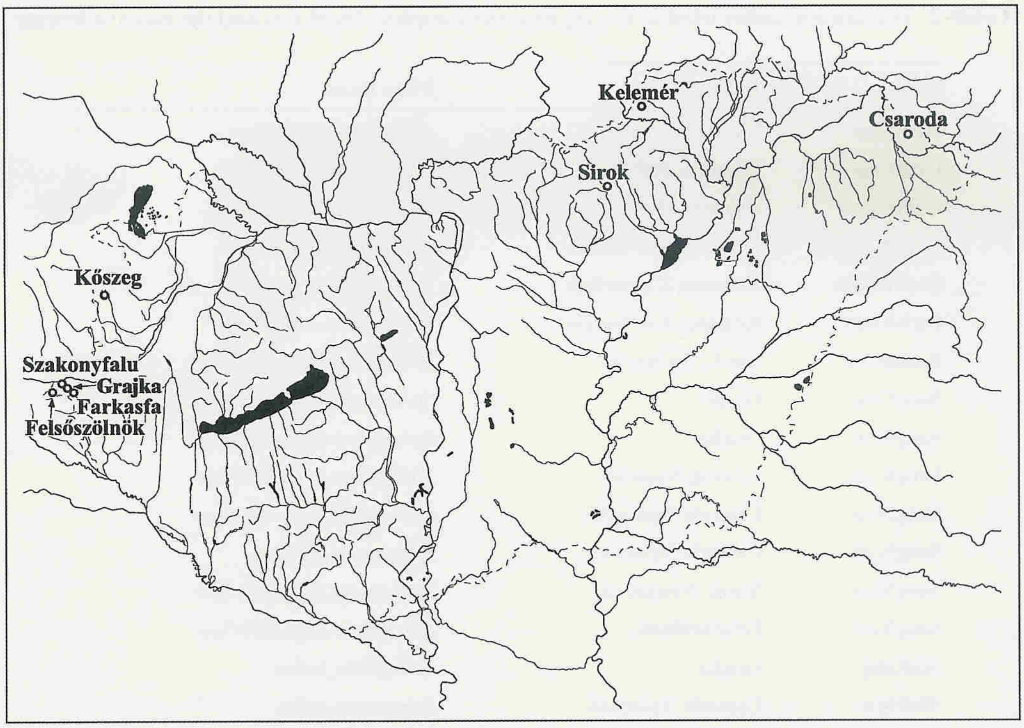


**Fig. 1**. The locations of mires in the Carpatian Basin sampled during this study. Samples were collected from 11 mires. At Kelemér there are two mires: Kis-mohos and Nagy-mohos. There are also two mires at Csaroda: Nyíres-tó and Bábtava; Fekete-tó and Ördög-tó are situated at Farkasfa. Szakonyfalusi brook and Grajka brook belong to Szakonyfalu.

**Table 1**. Study site characteristics.

| Name | Peatland type | Average pH |
|---|---|---|
| Csaroda Bábtava | Raised bog | 3.9–4.8 |
| Csaroda Nyíres tó | Basin fen | 4–4.5 |
| Kelemér Nagy-Mohos | Raised bog | 3.7–3.9 |
| Kelemér Kis-Mohos | Raised bog | 3.7–3.8 |
| Sirok Nyírjes tó | Raised bog | 3.9–4.3 |
| Kőszeg | Basin fen | No data |
| Farkasfa Ördög tó | Basin/floodplain fen | 5 |
| Farkasfa Fekete tó | Desiccating pond | No data |
| Grajka brook | Basin/floodplain fen | 6–6.5 |
| Szakonyfalusi brook | Basin/floodplain fen | 6–6.5 |
| Felsőszölnök | Basin/floodplain fen | No data |

**Table 2**. The sample codes used in the figures, the sampling localities and the moss substrate.

| Code | Locality | Moss taxon |
|---|---|---|
| ApalSiro | Sirok, Nyírjes tó | *Aulacomnium palustre* |
| CcorCsar | Csaroda, Bábtava | *Calliergon cordifolium* |
| CcorCsar | Csaroda Nyíres-tó | *Calliergon cordifolium* |
| DscoKism | Kelemér Kis-mohos | *Dicranum scoparium* |
| PcomKism | Kelemér Kis-mohos | *Polytrichum commune* |
| PschKism | Kelemér Kis-mohos | *Pleurozium schreberi* |
| S.magSiro | Sirok, Nyírjes tó | *Sphagnum magellanicum* |
| SangGraj | Grajka | *Sphagnum angustifolium* |
| SangGraj | Grajka | *Sphagnum angustifolium* |
| SangKosz | Kőszeg Nagyláp | *Sphagnum angustifolium* |
| SangNyir | Csaroda Nyíres-tó | *Sphagnum angustifolium* |
| SangNyir | Csaroda Nyíres-tó | *Sphagnum palustre* |
| SangSiro | Sirok, Nyírjes tó | *Sphagnum angustifolium* |
| SangSzol | Felsőszölnök | *Sphagnum angustifolium* |
| SfalGraj | Grajka | *Sphagnum fallax* |
| SfalNyir | Csaroda Nyíres-tó | *Sphagnum fallax* |
| SfalOrdo | Farkasfa Ördög tó | *Sphagnum fallax* |
| SfalSzak | Szakonyfalusi brook | *Sphagnum fallax* |
| SfimCsar | Csaroda Nyíres-tó | *Sphagnum fimbriatum* |
| SfimKism | Kelemér Kis-mohos | *Sphagnum fimbriatum* |
| SfimKosz | Kőszeg Nagyláp | *Sphagnum fimbriatum* |
| SfimSiro | Sirok, Nyírjes tó | *Sphagnum fimbriatum* |
| SmagKism | Kelemér Kis-mohos | *Sphagnum magellanicum* |
| SobtGraj | Grajka | *Sphagnum obtusum* |
| SpalCsar | Csaroda, Bábtava | *Sphagnum palustre* |
| SpalFeke | Farkasfa Fekete-tó | *Sphagnum palustre* |
| SpalKosz | Kőszeg Nagyláp | *Sphagnum palustre* |
| SpalKosz | Kőszeg Nagyláp | *Sphagnum palustre* |
| SpalNagm | Kelemér Nagy-mohos | *Sphagnum palustre* |
| SpalNagm | Kelemér Nagy-mohos | *Sphagnum palustre* |
| SpalSiro | Sirok, Nyírjes tó | *Sphagnum palustre* |
| SpalSiro | Sirok, Nyírjes tó | *Sphagnum palustre* |
| SsqaKosz | Kőszeg Nagyláp | *Sphagnum squarrosum* |
| SsquNagm | Kelemér Nagy-mohos | *Sphagnum squarosum* |
| SsubGraj | Grajka | *Sphagnum subsecundum* |
| SsubSzak | Szakonyfalusi brook | *Sphagnum subsecundum* |
| SfalFeke | Farkasfa Fekete-tó | *Sphagnum fallax* |

A LEICA DM LB2 microscope was used with x100 HCX PLAN APO objective for light microscopy (LM). SEM was performed by means of a Hitachi S–2600N. DCA analysis was carried out on the raw data using the software package CANOCO (Ter Braak & Šmilauer 1998).

## Results and discussion

In general, the diatom abundances were very low in the samples. Two hundred (200) valves were found in only 18 of the 48 samples studied. Diatoms were completely absent in 10 samples, even after several slides were checked out. One of these diatom barren samples was, however, very rich in Chrysophyceae statospores, and showed a diverse assemblage of cysts on *Sphagnum fallax*. This barren in diatom but statospores rich moss sample was collected at Fekete-tó. It cannot be considered typical since it was exposed to desiccation due to recent dry periods.

Mosses in sloping springs in the West Carpathians showed higher (concentrations) values, with average reaching $10^6$ of valves per 1 g of dry mosses (Poulicková *et al.* 2002). It was not our aim to collect data of absolute abundances of diatoms on peatmosses, but to confirm the unexpectedly low values. The total number of diatoms was about $10^2$ valves per 1 gram of dry moss, meaning it is 4 orders of magnitude lower than in Western Carpathian springs. This may relate to the well known fact that moisture is the most important factor for epiphytes in mires. A previous record of low abundances of diatoms in samples in extreme environments is given by Van de Vijver et Beyens (1997).

## General analysis

The ordination of 36 samples and 98 taxa confirms the importance of site (Fig. 2a). The plotted 20 samples were grouped according to the mires, and do not show separation by moss species. The samples from Kőszeg are shown to be grouped together, and those from Grajka form another group. The total inertia (sum of all eigenvalues of DCA) is 10.695. The percentage variance of species data of the first axis is 8,5 and the cumulative percentage variance of the first two axes is 15,4.

During the analysis of 48 samples 98 diatom taxa were identified. Taxa that occurred in at least 3 samples were included in the analysis (Table 3). The occurrence of *Eunotia bilunaris* var. *mucophila* and *Eunotia lapponica* is mostly related to Kőszeg (Fig. 2b).

The genera *Eunotia* and *Pinnularia* were dominant in every sample. *Eunotia paludosa* was the most abundant and constant species in that sample series. *Pinnularia subcapitata* var. *elongata*, was common in bogs, living on wet mosses, particularly on *Sphagnum* (Krammer 2000), was the second most constant one and is considered a sphagnophilous taxon.

*Adlafia bryophila* is frequently found on intermittently wet bryophytes, and is considered an aerophilous diatom (Lange-Bertalot 2001). In this study *Adlafia bryophila* was recorded from two localities (Sirok and Grajka) but apparently it has no preference to a substratum.

*Pinnularia stomatophora* var. *stomatophora* was identified only on *Calliergon cordifolium* and may also be considered a bryophytic diatom. This corresponds well with the present knowledge of the distribution of *P. stomatophora* which grows epiphytically most often on submerged mosses, such as *Sphagnum* (Krammer 2000).

Some species, regarded “in progression and stimulated by human impact” in Germany (Rumrich *et al.* 2000) were also found frequently in the studied mires, e.g. *Achnanthes hungarica*, *Achnanthidium minutissimum, Gomphonema parvulum* f. *parvulum*.

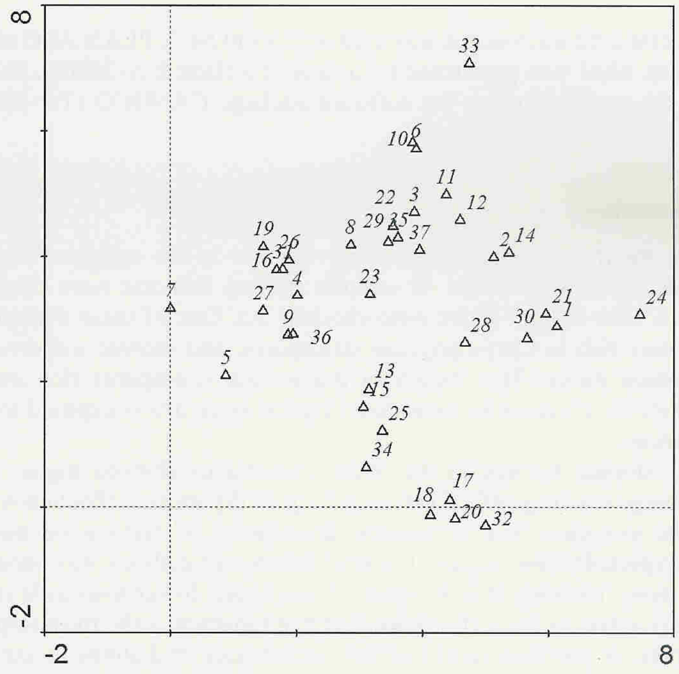


**Fig. 2a**. CA ordination diagram of diatom relative abundance for 20 sites. For site abbreviations see Table 2.

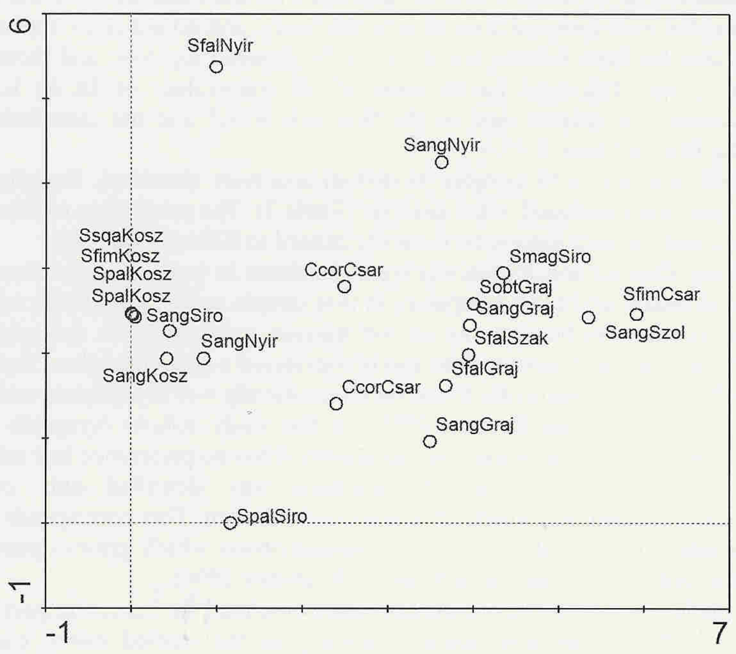


**Fig. 2b**. CA ordination diagram of the diatom species. Out of 98 taxa, 37 are plotted on the diagram (see Table 3).

**Table 3**. The list of diatom taxa – which occurred in at least 3 samples – from peatmosses, recorded in order of constancy. The relative abundances and their codes on ordination are given in Figures 2 and 3.

| | Abundance (*100) | Constancy | Code |
|---|---|---|---|
| *Eunotia paludosa* Grun. | 38.0 | 26 | 1 |
| *Pinnularia subcapitata* var. *elongata* Krammer | 1.3 | 10 | 2 |
| *Achnanthes hungarica* (Grun.) Grun. | 2.5 | 9 | 3 |
| *Adlafia bryophila* (Petersen) Moser, Lange-Bertalot et Metzeltin | 3.3 | 8 | 4 |
| *Eunotia lapponica* Grun. ex Cl. | 3.7 | 7 | 5 |
| *Eunotia bilunaris* (Ehrenb.) Mills | 1.2 | 7 | 6 |
| *Eunotia bilunaris* var. *mucophila* Lange-Bertalot et Nörpel-Schempp | 7.9 | 6 | 7 |
| *Pinnularia viridis* (Nitzsch.) Ehrenb. | 0.3 | 6 | 8 |
| *Eunotia steineckei* Petersen | 4.1 | 5 | 9 |
| *Gomphonema clavatum* Ehrenb. | 1.7 | 5 | 10 |
| *Nitzschia acidoclinata* Lange-Bertalot | 1.7 | 5 | 11 |
| *Eolimna minima* (Grun.) Lange-Bertalot | 1.3 | 5 | 12 |
| *Achnanthidium minutissimum* (Kütz.) Czarnecki | 0.6 | 5 | 13 |
| *Pinnularia subcapitata* Greg. | 0.4 | 5 | 14 |
| *Aulacoseira granulata* (Ehrenb.) Simonsen | 0.3 | 5 | 15 |
| *Chamaepinnularia mediocris* (Krasske) Lange-Bertalot | 9.8 | 4 | 16 |
| *Frustulia saxonica* Rabenh. | 1.0 | 4 | 17 |
| *Nitzschia* sp. | 0.9 | 4 | 18 |
| *Eunotia arcus* Ehrenb. | 0.7 | 4 | 19 |
| *Cymbella* cf. *gauenmanni* Meister | 0.6 | 4 | 20 |
| *Pinnularia microstauron* (Ehrenb.) Cleve | 0.4 | 4 | 21 |
| *Gomphonema pumilum* (Grun.) Reichardt et Lange-Bertalot. | 0.2 | 4 | 22 |
| *Pinnularia borealis* Ehrenb. var. *borealis* | 0.2 | 4 | 23 |
| *Eunotia groenlandica* (Grun.) Nörpel-Schempp et Lange-Bertalot | 0.2 | 4 | 24 |
| *Gomphonema parvulum* (Kütz.) Kütz. | 0.2 | 4 | 25 |
| *Eunotia exigua* (Bréb.) Rabenh. | 4.1 | 3 | 26 |
| *Eunotia microcephala* Krasske | 1.0 | 3 | 27 |
| *Hantzschia amphioxys* (Ehrenb.) Grun. | 0.6 | 3 | 28 |
| *Pinnularia neomajor* Krammer | 0.4 | 3 | 29 |
| *Pinnularia biceps* Gregory | 0.3 | 3 | 30 |
| *Eunotia meisteri* Hust. | 0.2 | 3 | 31 |
| *Tabellaria ventricosa* Kütz. | 0.2 | 3 | 32 |
| *Pinnularia brebissonii* (Kütz.) Rabenh. | 0.1 | 3 | 33 |
| *Eunotia rhomboidea* Hust. | 0.1 | 3 | 34 |
| *Pinnularia esoxiformis* Fusey | 0.1 | 3 | 35 |
| *Hippodonta hungarica* (Grun.) Lange-Bertalot, Metzeltin et Witkowski | 0.1 | 3 | 36 |
| *Frustulia* sp. | 0.1 | 3 | 37 |

Hungarian algological literature lacks information on the algae from the two mires at Kelemér, Kis-mohos and Nagy-Mohos. It is appropriate to list diatoms identified from these mires because of their importance for the country, and to provide background for current and future palaeoecological research. The diatom species included in this list are: *Achnanthes hungarica, Achnanthes* cf. *laevis, Achnanthes minutissima, Aulacoseira granulata, Cocconeis pediculus, Cocconeis placentula* var. *lineata, Cymbella minuta, Eolimna minima, Eunotia paludosa, Fragilaria virescens, Pinnularia brebissonii, Pinnularia obscura, Pinnularia sinistra, Pinnularia subcapitata, Pinnularia subcapitata* var. *elongata, Rhoicosphenia abbreviata.*

Only a few species were present in each sample and the abundances were very low, with sporadic occurrences in the Kis-mohos and Nagy-mohos mires.

The number of diatom taxa identified in the samples is shown in Figure 3. *Sphagnum fallax* showed the most diverse diatom flora with 20 and 21 taxa on this moss from two localities. The average number of taxa is 10.2 (standard deviation of 6.73). It was concluded that the number of taxa is low (Buczkó 2006) when compared with other studies of periphytic diatoms found growing on rocks and as algal mats. In that study, the average number of taxa was 25.5 on rocks and 16.6 in the algal mats, however, these numbers fit the results of algological studies on other mires in temperate zone (Nováková 2003, Poulíčková *et al.* 2004).

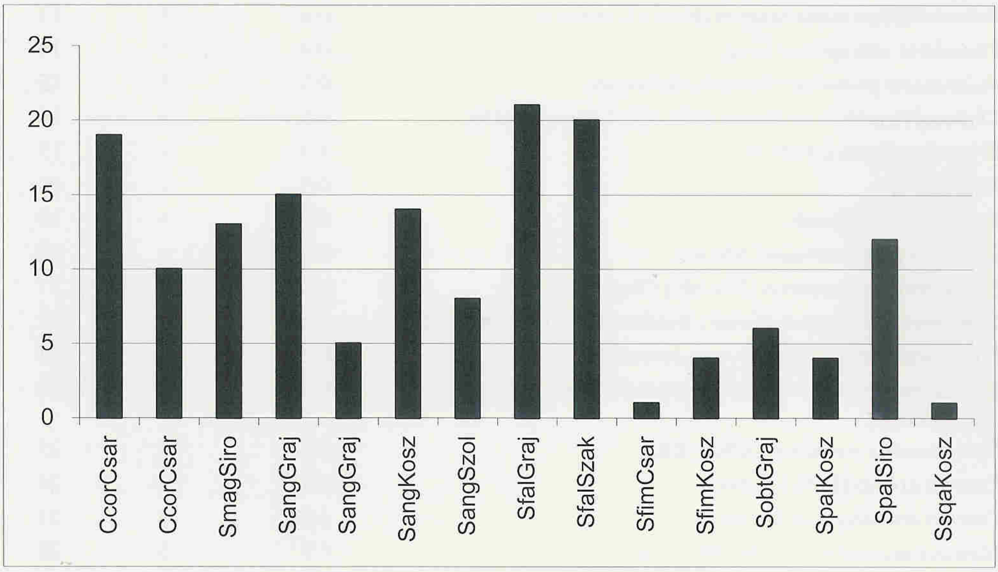


**Fig. 3**. The number of diatom taxa in the samples. The sample codes see in Tables 2 and 3.

Although the Shannon-Wiener diversity (H") minimum can be "0" (zero) – when all specimens in a sample belong to only one species – this algological phenomenon occurs very rarely in practice. Two species of diatoms co-occurred in two samples exclusively with two moss species. These were *Eunotia exigua* on *Sphagnum squarrosum* at Kőszeg Nagyláp and *Eunotia paludosa* on *Sphagnum fibriatum* at Csaroda. Both species are characteristic bog-diatoms. The highest value of diversity was calculated on *Calliergon cordifolium* and amounted to 3,2.

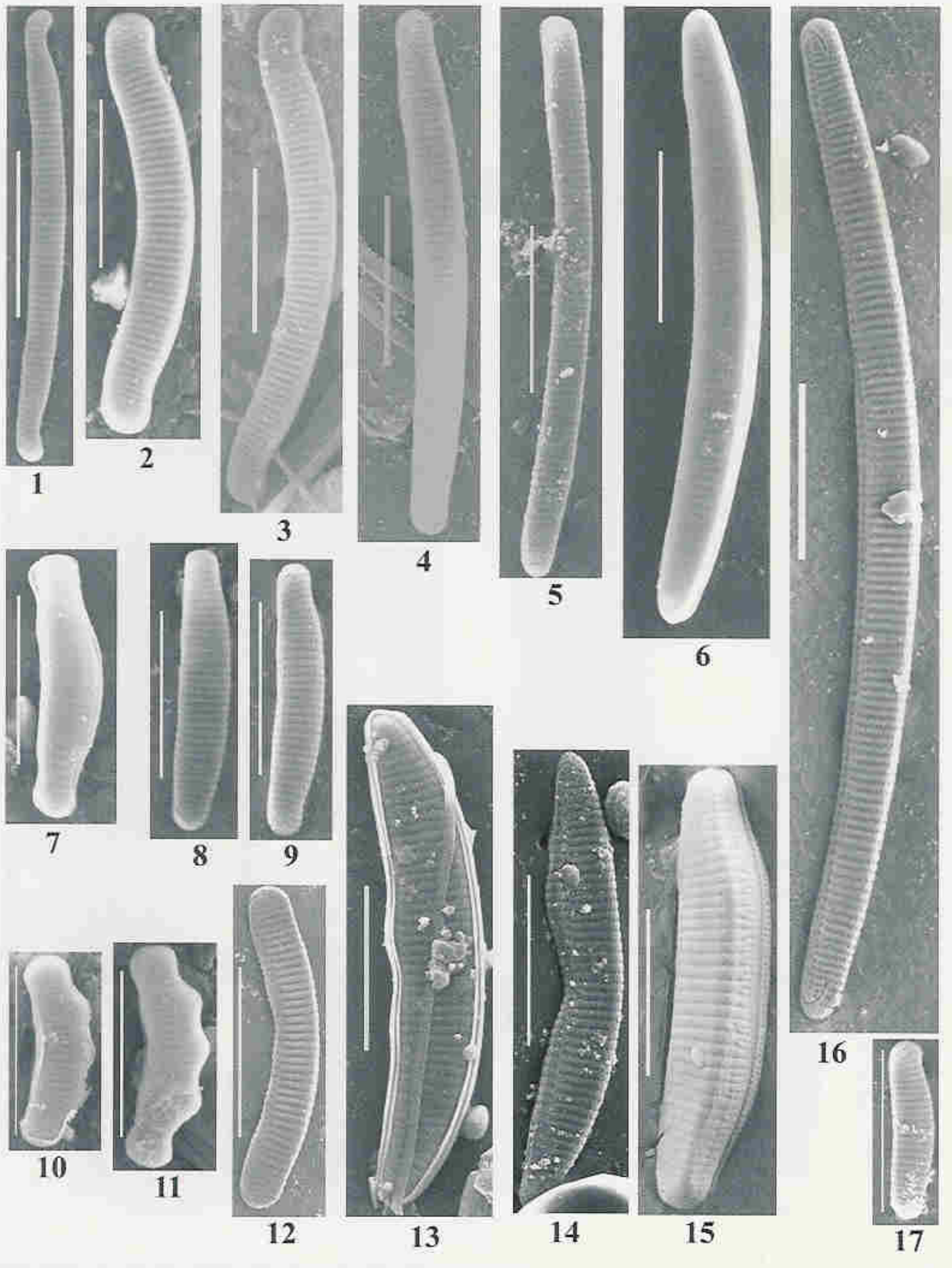


**Plate 1**: **Figs 1–17**. **Fig. 1**. *Eunotia groenlandica*. **Figs 2, 3, 12**. *E. steineckei*. **Figs 4, 5, 8, 9, 17**. *E. paludosa*. **Figs 6, 13, 14, 16**. *E. bilunaris* sensu lato. **Fig. 7**. *E. meisteri*. **Figs 10, 11**. *E. muscicola* var. *tridentula*. **Fig. 15**. *E. septentrionalis*. Scale bars = 10 µm.

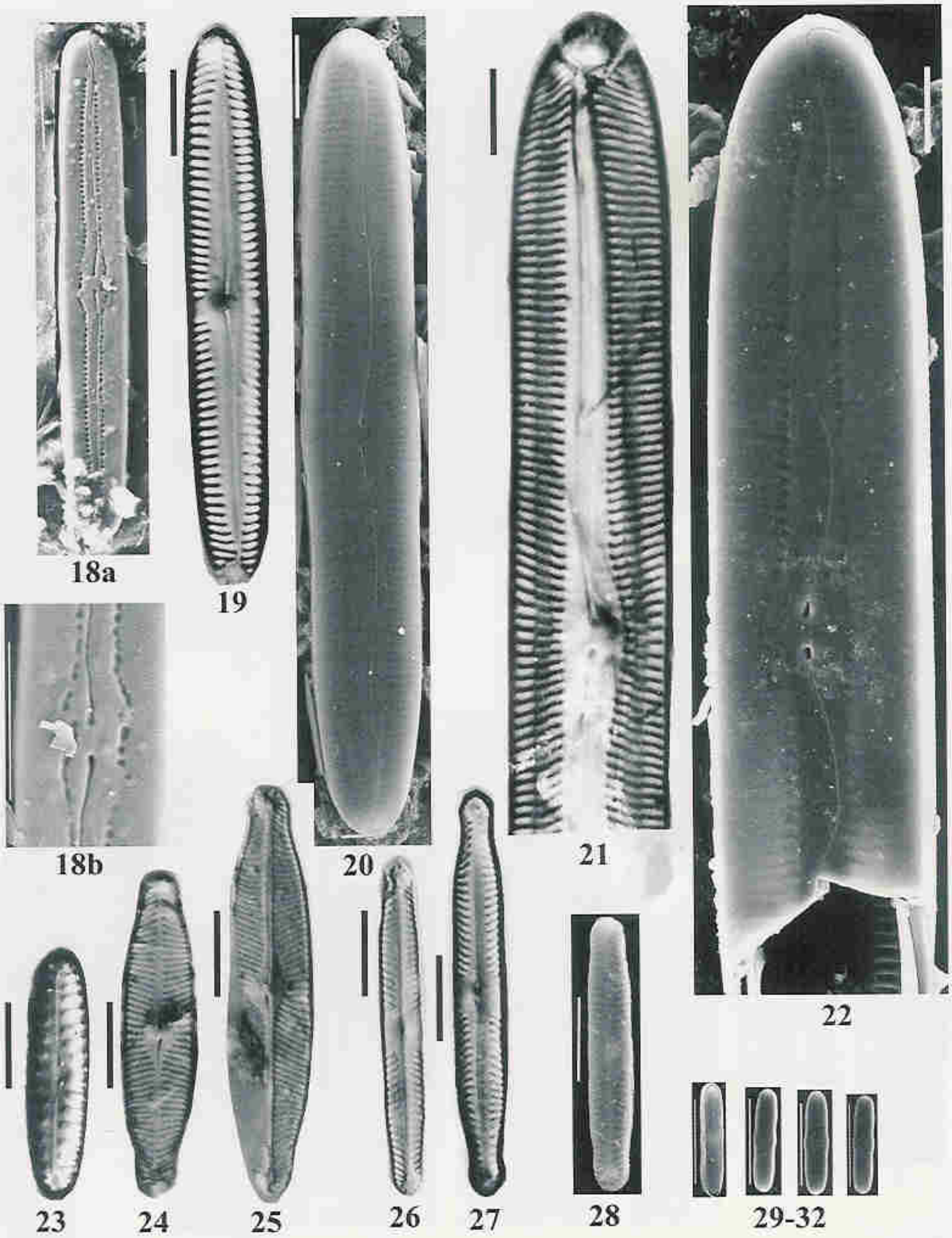


**Plate 2**: **Figs 18–28. Fig. 18**. *Pinnularia stomatophora*. **Fig. 19**. *P. subgibba*. **Figs 20–22**. *P. neomajor*. **Fig. 23**. *P. borealis*. **Fig. 24**. *P. microstauron* var. *microstauron*. **Fig. 25**. *P. microstauron* var. *nonfasciata*. **Figs 26, 27**. *P. subcapitata* var. *elongata*. **Fig. 28**. *P. sinistra*. **Fig. 29**. *Chamaepinnularia mediocris*.

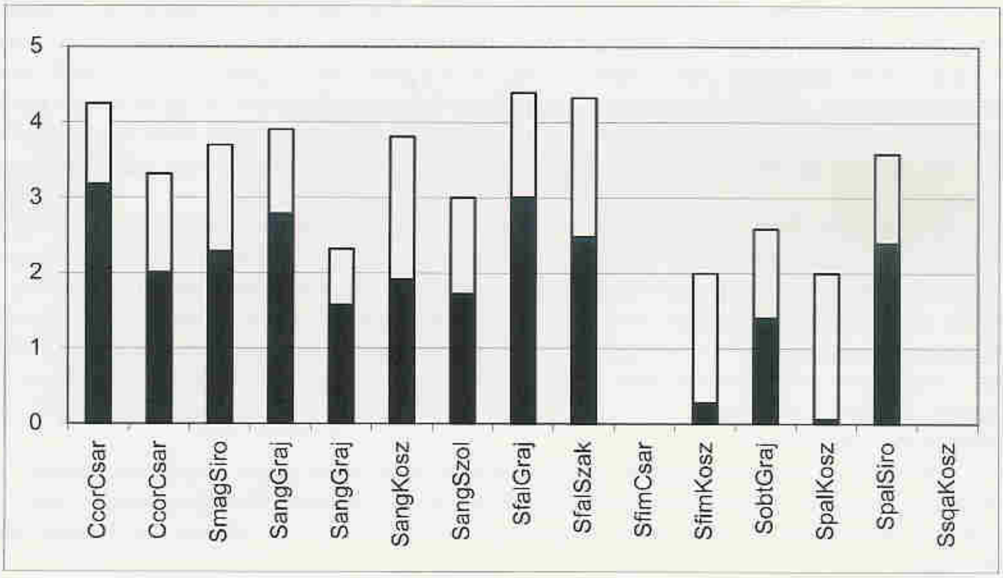


**Fig. 4**. The Shannon-Wiener index (black column) and its maximum value (white column).

The only remarkable aspects about the co-existence of characteristic diatom taxa were found on *Sphagnum fallax*. Very similar floristic composition was detected from different localities, as well as similaritiy in the distribution of species (Fig. 5). The major taxa in those samples were: *Chamaepinnularia mediocris, Eunotia exigua, Adlafia bryphila, Eunotia lapponica, Frustulia crassinervia, Pinnularia subcapitata* var. *elongata*. None of these species have been found to be common or abundant in this study or in other Hungarian studies generally.

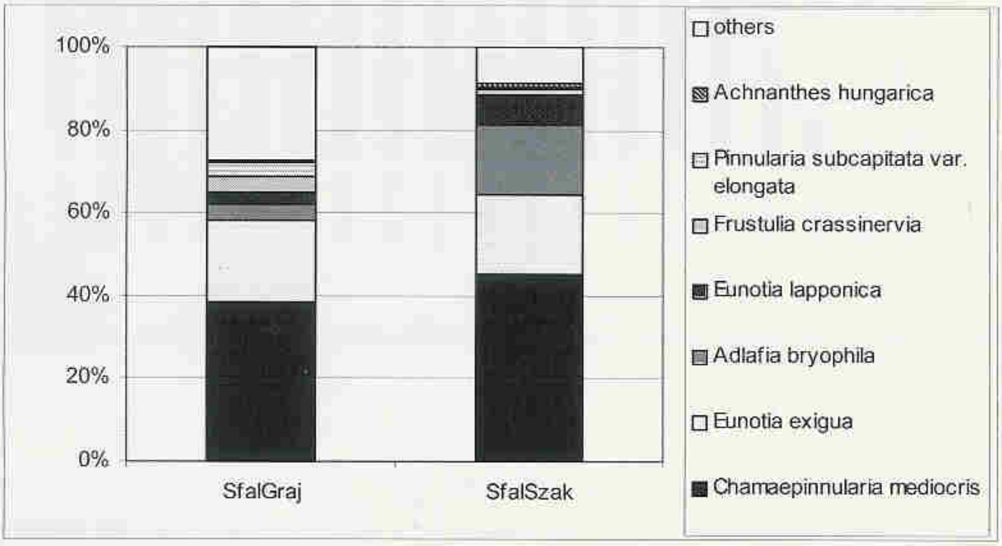


**Fig. 5**. The composition of diatoms on *Sphagnum fallax* from two localities, Grajka and Szakonyfalusi brook.

The highest extent of changes in the microflora, associated with dessication of mires, have been observed in the case of Fekete-tó. This bog has had a very rich desmid flora when compared with published earlier data, in the 1970's and 1980's, (Borics *et al.* 2003, and further references cited in that paper). According to Uherkovich (1984) the desmids are more sensitive to drying out than diatoms. In this study case, only statospores were found at this site. By the end of the $20^{th}$ century the diatoms had disappeared following the desmids at Fekete-tó.

We propose that, aerophytic diatoms settle on mosses following long dry periods. However, no sign of aerophytic diatoms was evident either at Fekete-tó or in other locations. One explanation may be that the occupation by aerophytes requires more time, or perhaps they do not prefer the acidic habitat. An exception to that statement, is the increase in number of *Hantzschia amphioxys*. Our findings can be contrasted with the statement by Johansen (1999) that "*Hantzschia amphioxys* is rare in acidic soils, but reaches high densities in neutral to slightly alkaline soils" because in our study areas *H. amhioxys* was found sporadically in between the mosses.

The ratio of diatoms and that of Chrysophyta statospores show a very wide range of variation (Figure 6). There are some samples barren in diatom where the statospores amount is high and conversely in some other samples there are no cysts at all but the diatoms are abundant.

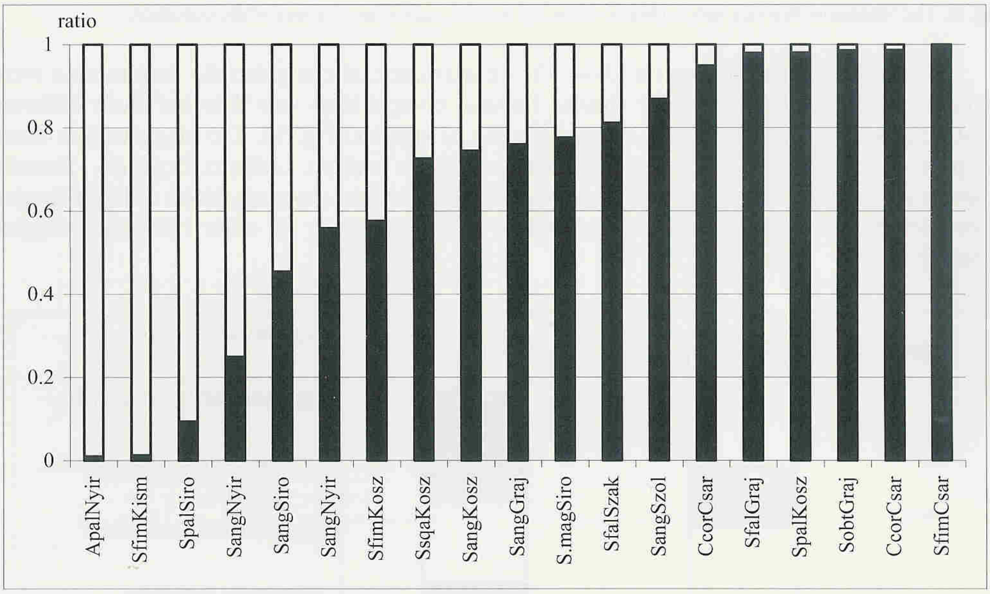


**Fig. 6**. Diagram of the relation between moss taxa and the ratio diatoms (black column) and chrysophyte statospores (white column).

## Conclusion

Our findings lead to the following conclusions:

1. A substantial relationship between the diatom flora and assemblages and the different peatmosses on which they live was not established. The location and the habitat does strongly impact the flora. The environment appears to be more important than the substrate. Although

the significance of the habitat's impact was expected. We hoped to discover relationships between diatom assemblages and different moss species. Our assumption was based on the heterogeneity and mosaic-like arrangement of the moss cushions in this unique habitat but it was not proved by the results we have obtained. Only *Sphagnum fallax* from two habitats possessed a peculiar and similar periphyton. These preliminary results, however, should contribute to palaeolimnological studies, because the various substrates have little influence on the co-existence of diatoms.

2. It is suggested that the most surprising and useful result of this study is the lack of diatoms in the "large" Hungarian bogs, Kis-mohos and Nagy-mohos. It is apparent from these observations that, the undisturbed and extended habitats in this area do not support diversified diatom assemblages. The number of species is limited and their abundance is very low. In other localities the number of taxa was also low.

3. The appearance of aerophytic taxa on mosses during long and dry periods remains unclear. Aerophytic species were found in one sample only and included *Pinnularia borealis*, *Hantzschia abundans*, *H. amphioxys* and *Adlafia bryophila*. The absence of diatoms was observed in the driest location while at the same time high abundances of statospores were recorded.

4. No correlation between diatoms and Chrysophyceae statospores was found. Their dynamics appear to be independent and variable. Interestingly, the diatoms were completely absent in the desiccating Fekete-tó while the statospores were abundant and diverse.

5. The so-called sphagnophilous diatoms (which we can be regarded as bryophytic diatoms) are recorded from Hungarian mires for the first time. One of the reasons for the absence of such data can be attributed to the standard sampling technique i.e. the samples were either collected from open water, from different substrates or by squeezing *Sphagnum* samples. The samples gained by squeezing moss contains lower concentrations of bryophytic diatoms while the these of diatoms characteristic for water samples are higher.

It can be concluded from these preliminary results that the *Pinnularia subcapitata* var. *elongata, Adlafia bryophila, Pinnularia stomatophora* are bryophytic (sphagnophilous) taxa and represent the first records of such diatoms in Hungary.

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