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CHANGES OF BRYOPHYTE VEGETATION AND HABITAT CONDITIONS ALONG A SECTION OF THE RIVER DANUBE IN HUNGARY

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SUMMARY — Saxicolous bryophytes were studied along a section of the Danube between Bratislava and Budapest and compared with water quality changes. A number of rare bryophyte species occur along the Danube. The threat to this valuable flora, caused by water pollution, is manifested by the decrease of the total cover of bryophytes as well as by the changes in species composition. Therefore, bryophytes can be used as indicator organisms for changes in the Danube ecosystem.

KEYWORDS — Water quality, saprobity, bioindication

ZUSAMMENFASSUNG — Veränderungen der Moosvegetation und der Standortsbedingungen entlang einem Abschnitt der Donau in Ungarn

Die gesteinsbewohnenden Moose an einer Strecke der Donau zwischen Bratislava und Budapest wurde untersucht und mit Änderungen der Wasserqualität in Beziehung gebracht. Entlang der Donau kommen einige seltene Moosarten vor. Die durch Wasserverschmutzung verursachte Gefährdung dieser wertvollen Flora zeigt sich sowohl im Rückgang des Moosbewuchses als Ganzem als auch in Veränderungen des Artenspektrums. Moose können daher als Zeigerorganismen für Veränderungen im Ökosystem der Donau verwendet werden.

Introduction

Only a few bryological investigations have been conducted along the Hungarian section of the Danube to date. The information on the bryophyte flora of the Danube is summarised in Boros (1968) and Boros & Vajda (1955), respectively.

The objective of the present study is to investigate the current condition of the moss vegetation inhabiting the stones on the bank of the Danube and, furthermore, to analyse the role of bryophytes as indicators of water quality, especially that of saprobity[1]. Similar studies were performed in other European countries as well (Frahm 1974, Empain 1973, 1978, Peñuelas & Sabater 1987, Vrhovšek & al. 1984, 1985). Bryophytes are very important primary producers in several rivers (Dawson 1973). For the phytoindication of changes in the water quality algae are usually used. Algae, however, should be sampled frequently to yield a satisfactory representation. Due to their generally longer lifetime, bryophytes are probably more suitable as bioindicators in that respect. Being present in the water the whole year, they can indicate the average water quality. Sudden pollution discharge or clean periods, however, hardly influence the bryophyte vegetation essentially.

Study area and methods

The saxicolous bryophyte vegetation of the Danube was studied from Dunakiliti (1839 river km) to Sződ (1674 rkm, Fig. 1). Heaps of stones exist everywhere on the slope of the dams along the river to protect the bank from the waves and the current. Therefore, the data obtained can be used for comparison between the various sections of the river. The only disadvantage

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[1] Saprobity is the organic material dissimilation capacity of the water ecosystem, which is related to the quantity of organic materials in the water.

of this semi-artificial habitat is that new layers of stones are occasionally deposited on top of the old ones.

In July 1991 sites on old dams with a rich flora and abundant growth of bryophytes were selected at distances of about 5 km. Species were recorded and sampled in plots of a width of 2-2.5 m and a surface of about 2 m^2. The abundance values of each species in the plots were estimated in September 1993 using a modified Braun-Blanquet (1964) scale from 1 to 7: 1, only a few stems within patches of other species; 2, cover < 1%; 3, cover 1-5%; 4, cover 5-25%; 5, cover 25-50%; 6, cover 50-75%; 7, cover 75-100%. At each site, sampling was conducted at three different levels according to the vegetation. The first level ('Level A') represents the zone that is generally submerged (Fig. 2). It dries out only in the extremely dry periods; this is the low water level zone. The second level ('Level B') is the medium water level zone. It contains the most characteristic river vegetation as the average water level moves within this zone. Waves are sweeping over the stones to a height of about 40-60 cm above the average water surface. The third level ('Level C') is the high water level zone. This zone is submerged only in the rare flood periods but is obviously affected by the river (extreme waves, morning dew above the water).

Synthetic tables with the species abundances from the sampling sites were made for each level separately (see Tab. 2 for level B). Hierarchical Cluster Analysis (Czekanowski measure, UPGMA fusion technique) and Principal Component Analysis (standardised PCA) were carried out with the raw data. For the computations, the program package SYN-TAX was used (Podani 1993).

The 1993 water chemistry data were obtained from the 'VM'[2] database of the Institute for Environment Protection. Along the investigated section of the Danube there are 6 standard measuring points (Rajka 1848.4 rkm, Medved'ov 1806.2 rkm, Komárom 1766.8 rkm, Almásneszmély 1751.8 rkm, Szob 1708 rkm, Budapest 1659 rkm – Fig. 1, open circles). We used the data obtained from sampling at each point every fortnight. The parameters used were pH, conductivity, total hardness, nitrate, nitrite, ammonium, organic nitrogen, phosphate, biological and chemical oxygen demand (BOD and COD). For the characterisation of the sampling sites arithmetic means of the data from 1993 were calculated.

The saprobity scale used for the qualification of the sites with different water quality follows Felföldy (1987). This scale qualifies the organic material pollution from xenosaprobic (not polluted) through oligosaprobic towards β-mesosaprobic, α-mesosaprobic and finally to polysaprobic (heavily polluted).

Results and discussion

The nature conservation value of the bryophyte flora of the Danube

48 species were recorded in the 152 sampling plots along the investigated section of the Danube during 1993. Three additional species were found only in 1991. The latter (*Cinclidotus danubicus*, *Fontinalis antipyretica* and *Marchantia polymorpha*) were rare at that time; they usually occurred only in one sampling plot and their abundances were very low. Thirty-five per cent (17 species) of the saxicolous Danube bryoflora are considered rare in Hungary or in the Hungarian lowland (Tab. 1).

The occurrences of these species in Hungary according to Orbán & Vajda (1983) are presented and compared with our recent findings:

Cinclidotus danubicus Schiffn. & Baumg. According to Boros (1968) this species occurs only in the Danube from the border (Rajka, 1850 rkm) to Piszke (1739 rkm) where it was collected at three places. In 1991, only one patch was found at Dunaremete (1825 rkm).

Cinclidotus fontinaloides (Hedw.) P. Beauv. Known from the Danube from Rajka to Visegrád (1693 rkm) and from two places in the mountains (Aggteleki-karszt: Telekes-völgy, Bükk:

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[2] VM is the abbreviation of 'Vízminőség', i.e. 'water quality' in Hungarian

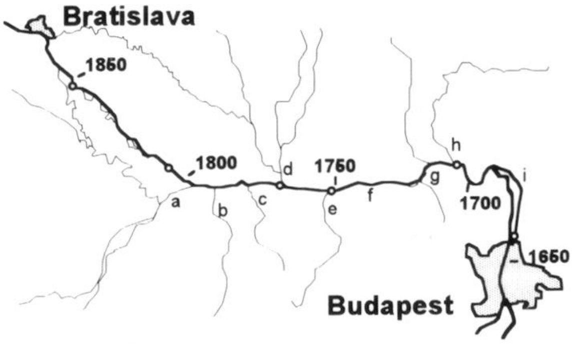

FIGURE 1. Map of the upper section of the Danube in Hungary. Numbers: distance from the mouth in kilometres (= 'river km', rkm); open circles: sampling points for the water quality measurements; lower case letters: important polluting agents. a - Mosoni-Duna, b - Bakony-ér, c - Concó-patak, d - Váh, e - Által-ér, f - paper mill and cement-plant near Lábatlan, g - Kenyérmezei-patak, Hron, chemical works in Štúrovo, h - Ipoly, i - Vác town.

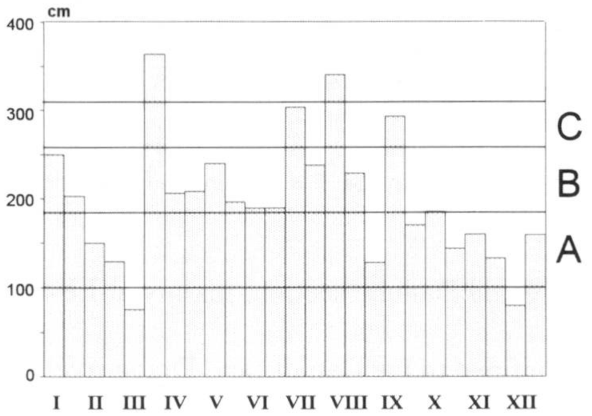

FIGURE 2. Water-level of the Danube at Komárom (1768.3 rkm) in 1993, measured every fortnight, based on the data of VM database. 0 = 103.88 m above the Baltic Sea level. A, B, C: three water level zones (see text).

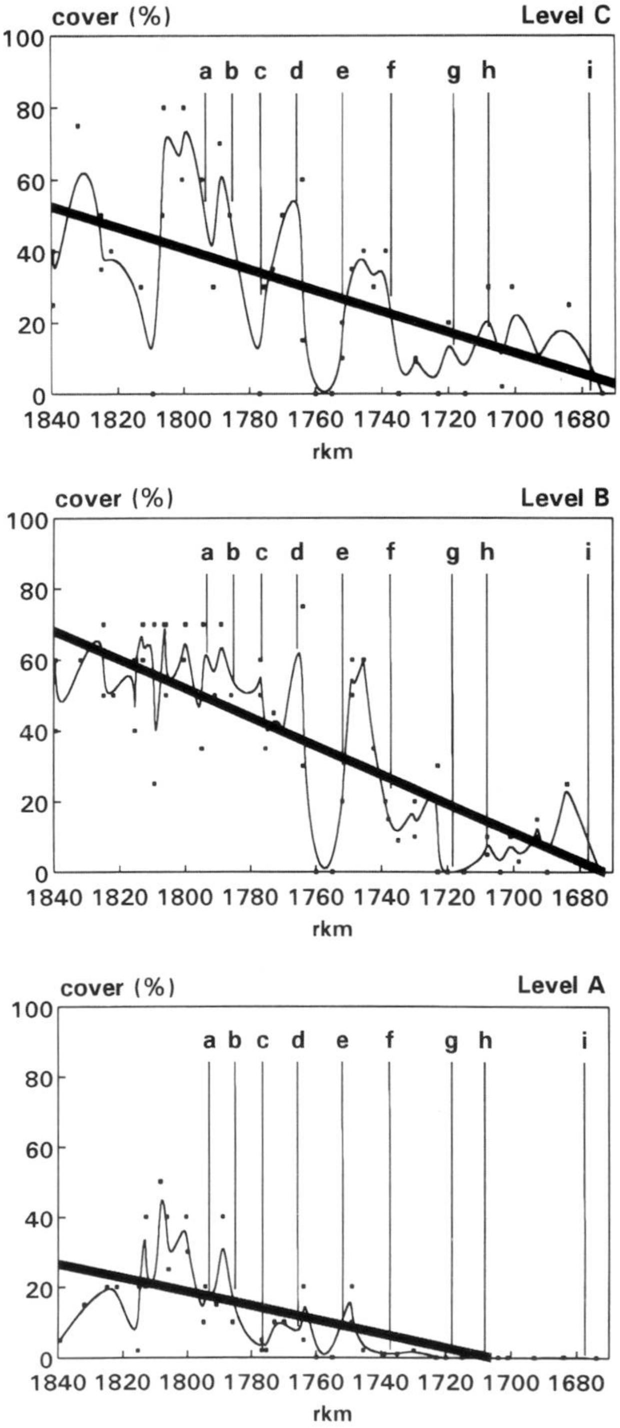

FIGURE 3. Total cover of bryophytes in the sampling plots as a function of the river km. Thin line: fitting curve; thick line: trend (for letters, see Fig. 1).

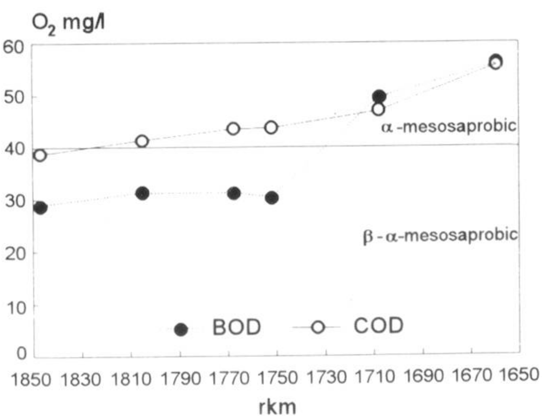

FIGURE 4. Annual mean of the values of biological (BOD) and chemical oxygen demand (COD) of the water quality samples as a function of the river km (based on the data of VM database). Horizontal line: limit value of the given saprobity levels for COD according to Felföldy (1987).

Marchantia polymorpha L.
**Pellia endiviifolia* (Dicks.) Dum.

Amblystegium humile (P. Beauv.) Crundwell
Amblystegium riparium (Hedw.) B., S. & G.
Amblystegium serpens (Hedw.) B., S. & G. var. *serpens*
Amblystegium varium (Hedw.) Lindb.
Barbula convoluta Hedw.
Barbula unguiculata Hedw.
Brachythecium populeum (Hedw.) B., S. & G.
Brachythecium rutabulum (Hedw.) B., S. & G.
**Bryoerythrophyllum recurvirostrum* (Hedw.) Chen
Bryum argenteum Hedw.
Bryum barnesii Wood
Bryum capillare Hedw.
Bryum laevifilum Syed
**Bryum pallens* (Brid.) Sw. ex Roehl.
**Bryum pseudotriquetrum* (Hedw.) Gaertn., Meyer & Scherb.
Bryum violaceum Crundw. & Nyh.
Bryum sp1
Bryum sp2
Ceratodon purpureus (Hedw.) Brid.
***Cinclidotus danubicus* Schiffn. & Baumg.
***Cinclidotus fontinaloides* (Hedw.) P. Beauv.
***Cinclidotus riparius* (Brid.) Arnott
**Cirriphyllum crassinervium* (Tayl.) Loeske & Fleisch.
**Dichodontium pellucidum* (Hedw.) Schimp.
Dicranella varia (Hedw.) Schimp.
Didymodon fallax (Hedw.) Zander
***Didymodon luridus* Hornsch.
Didymodon sinuosus (Mitt.) Delogn.
Didymodon vinealis (Brid.) Zander var. *vinealis*
Eurhynchium hians (Hedw.) Sande Lac.
Fissidens crassipes Wils. ex B., S. & G.
***Fontinalis antipyretica* Hedw. var. *antipyretica*
Funaria hygrometrica Hedw.
Grimmia pulvinata (Hedw.) Sm. var. *pulvinata*
***Hygroamblystegium fluviatile* (Hedw.) Loeske
**Hygrohypnum luridum* (Hedw.) Jenn.
Leskea polycarpa Hedw.
Mnium marginatum (With.) Brid. ex P. Beauv.
Orthotrichum anomalum Hedw.
Physcomitrium pyriforme (Hedw.) Brid.
Plagiomnium cuspidatum (Hedw.) T. Kop.
Pohlia melanodon (Brid.) J. Shaw
Pohlia wahlenbergii (Web. & Mohr) Andr.
Pylaisia polyantha (Hedw.) Schimp.
***Rhynchostegium murale* (Hedw.) B., S. & G.
**Rhynchostegium riparioides* (Hedw.) C. Jens.
***Rhynchostegium rotundifolium* (Brid.) B., S. & G.
Schistidium apocarpum (Hedw.) B. & S.
Tortula muralis Hedw. var. *muralis*

TABLE 1. List of bryophytes occurring in the investigated section of the Danube. * = rare in the Hungarian lowland, ** = rare in Hungary.

Imó spring). It was found in some parts of the investigated Danube section, mainly at Level C, with moderate abundance.

Cinclidotus riparius (Brid.) Arnott In Hungary, it is confined to the Danube and Dráva rivers. It was very abundant along the section studied.

Didymodon luridus Hornsch. Apart from some mountain sites, this species was only reported in the Danube downstream from the section investigated, at Ercsi (1614 rkm). However, we found it to be very abundant in some parts under study, mainly at Level C.

Didymodon sinuosus (Mitt.) Delogne. Its only lowland locality known so far is at Vácrátót. We have collected it at two places (Süttő, 1742 rkm and Visegrád, 1693 rkm), mainly at Level B.

Fontinalis antipyretica Hedw. It occurs in the Balaton lake, in the Danube from Rajka to Neszmély (1749 rkm) and in some mountain streams, but it is rare. Along the Danube, it was collected at five places being frequent in the Cinclidotetum (Boros 1968). We have found only two small patches of it in 1991, at Dunasziget (1836 rkm) and Dunaremete (1825 rkm).

Hygroamblystegium fluviatile (Hedw.) Loeske. It occurs in some mountain streams and was reported from the Danube only in the upper part of the section investigated (Dunaremete-Ásványráró, 1825-1815 rkm). Nowadays, it is abundant in some parts of the Danube under study, but surprisingly completely lacking in some other sections.

Rhynchostegium murale (Hedw.) B., S. & G. It was recorded at some places in the mountains, in the Balaton lake and in the Danube. We have found some patches at Sütto (1742 rkm), Tát (1730 rkm), and Visegrád (1693 rkm) at Level C.

species	1839.5	1832	1825	1822	1815.5	1813	1813	1809.5	1806	1800	1795	1794.5	1790	1786	1777	1774	1770	1764	1752	1749	1745.5	1742.5	1739	1738	1735	1730	1723	1708	1701	1698.5	1693	1684	1674
AMBLHUMI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
AMBLRIPA	-	-	2	2	2	-	-	-	2	-	1	-	-	-	-	-	1	3	1	-	3	-	4	-	2	-	3	-	2	2	-	1	-
AMBLSERP	-	-	-	-	1	1	-	-	1	1	1	-	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-
AMBLVARI	-	-	-	-	-	-	-	1	-	-	2	-	-	-	-	-	-	1	1	-	-	-	3	-	-	-	-	1	-	-	2	-	-
BARBUNGU	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-
BRACRUTA	-	-	-	-	-	1	-	-	-	-	-	-	2	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
BRYUBARN	-	-	-	-	-	-	-	-	-	-	-	-	2	-	1	1	2	-	3	-	-	2	-	-	-	1	-	-	-	-	1	1	-
BRYUCAPI	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BRYUPALL	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BRYUPSEU	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
CINCFONT	-	-	-	-	-	3	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	3	-	3	-	3	-	2	3	-	3	-	3
CINCRIPA	6	7	6	6	7	5	6	6	6	6	5	6	5	6	6	5	6	4	4	7	6	4	4	6	6	3	7	-	3	7	6	7	6
DIDYFALL	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DIDYLURI	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-
DIDYSINU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	1	-	-
DIDYVINE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EURHHIAN	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
FISSCRAS	-	-	-	1	2	3	4	2	4	3	3	5	3	3	4	5	4	6	5	4	4	4	6	2	4	3	3	4	4	4	2	1	-
FUNAHYGR	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HYGAFLUV	4	6	5	6	3	5	-	2	3	3	-	2	-	-	-	1	1	1	-	-	-	-	-	-	1	2	-	5	-	1	3	1	-
HYGHLURI	-	-	-	-	1	-	-	-	1	-	-	-	1	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-
LESKPOLY	5	4	5	4	4	5	6	5	5	5	6	4	6	4	4	4	4	3	4	4	6	5	2	3	4	5	5	-	5	4	5	6	4
POHLMELA	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
POHLWAHL	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
RHYNRIPA	2	3	2	2	-	3	2	2	-	2	1	-	-	-	-	-	-	-	-	1	-	3	-	3	-	5	-	2	-	-	2	-	-
RHYNROTU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
TORTMURA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	-	1	-	-	-	-	-

TABLE 2. Abundance estimates (1-7) of the moss species in the sampling plots of Level B. Abundance values see Methods, species names see Table 1.

Species	literature	modified	I.	II.	III.	IV.
	indicator value					
Amblystegium riparium	o-α*		0-2	0-3	0-1	1-4
Cinclidotus fontinaloides	β*		0	0	3	0
Cinclidotus riparius	β**		6-7	6-7	3-6	4
Fissidens crassipes	β*	α	0-2	3-4	3-4	5-6
Hygroamblystegium fluviatile	β-α*	β	3-5	0-3	0-2	0-1
Leskea polycarpa	α-β*		4-5	4	5-6	2-3
Rhynchostegium riparioides	x-o*		2-3	0-1	0-3	0

TABLE 3. List of the bryophyte species characterising the groups of sites with their characteristic abundance values and their indicator values for saprobity according to literature and modified according to the present results (* = Vrhovšek & al. 1984, ** = Frahm 1974). The Roman numbers correspond to the clusters in Fig. 5. α = α-mesosaprobic; β = β-mesosaprobic; o = oligosaprobic; x = xenosaprobic (see Methods).

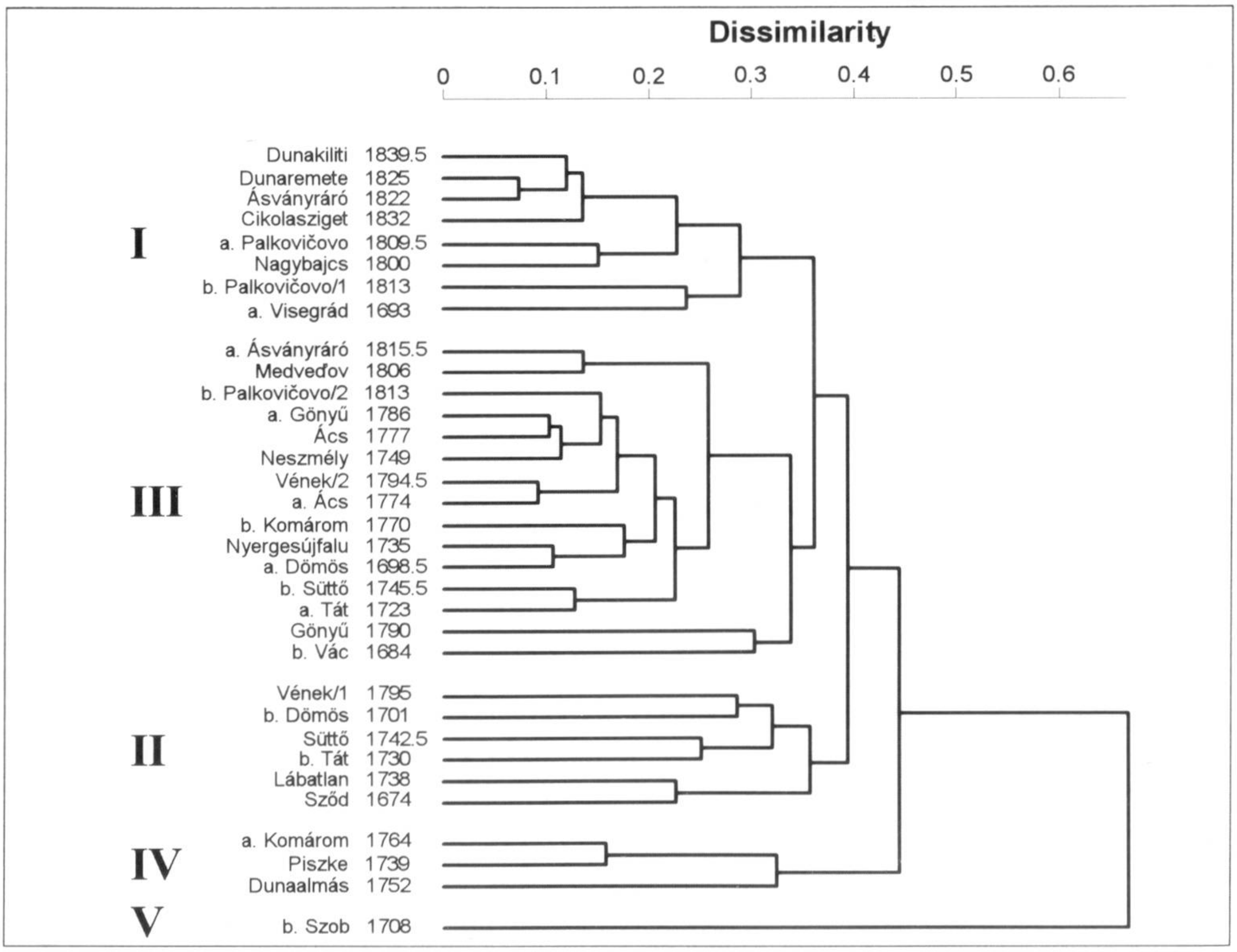

FIGURE 5. Dendrogram of the sampling sites. Numbers indicate rkm (see Fig. 1).

Rhynchostegium rotundifolium (Brid.) B., S. & G. It was known from some places in the mountains. We have found it mixed with other mosses in a patch at Visegrád (1693 rkm). This is its first record in the Danube.

We have found additional eight species that are rare in the Hungarian lowland: *Bryum pallens*, *Bryum pseudotriquetrum*, *Cirriphyllum crassinervium*, *Dichodontium pellucidum*, *Hygrohypnum luridum*, *Bryoerythrophyllum recurvirostrum*, *Rhynchostegium riparioides*, *Pellia endiviifolia*.

The species composition at the three levels

Level A. The total cover is usually about 20%, but decreases downstream to 1-2%. Bryophytes disappear completely from this level at the end of the investigated section (Fig. 3). The predominant species is generally *Cinclidotus riparius* (for nomenclature, see Tab. 1). *Fissidens crassipes* occurs frequently in moderate or low abundance. *Hygroamblystegium fluviatile* was found in considerable abundance mainly in the upper part of the investigated section, but it appears sporadically downstream, too.

Level B. The total cover is 50-60% in the upper part of the section studied, decreasing gradually downstream to about 10-20%. The flora is more diverse at this level. The predominant species is again *Cinclidotus riparius*, but there are other abundant species such as *Leskea polycarpa* and *Fissidens crassipes*. *Amblystegium riparium* and *Rhynchostegium riparioides* usually have considerable abundance, but in some places they are completely lacking. *Cinclidotus fontinaloides* appears sporadically in moderate abundance, too. Besides these main elements, *Barbula*, *Bryum* and *Pohlia* species and *Brachythecium rutabulum* may be present on mud deposited among the stones. The above-mentioned *Cinclidotus danubicus* and *Fontinalis antipyretica* occurred

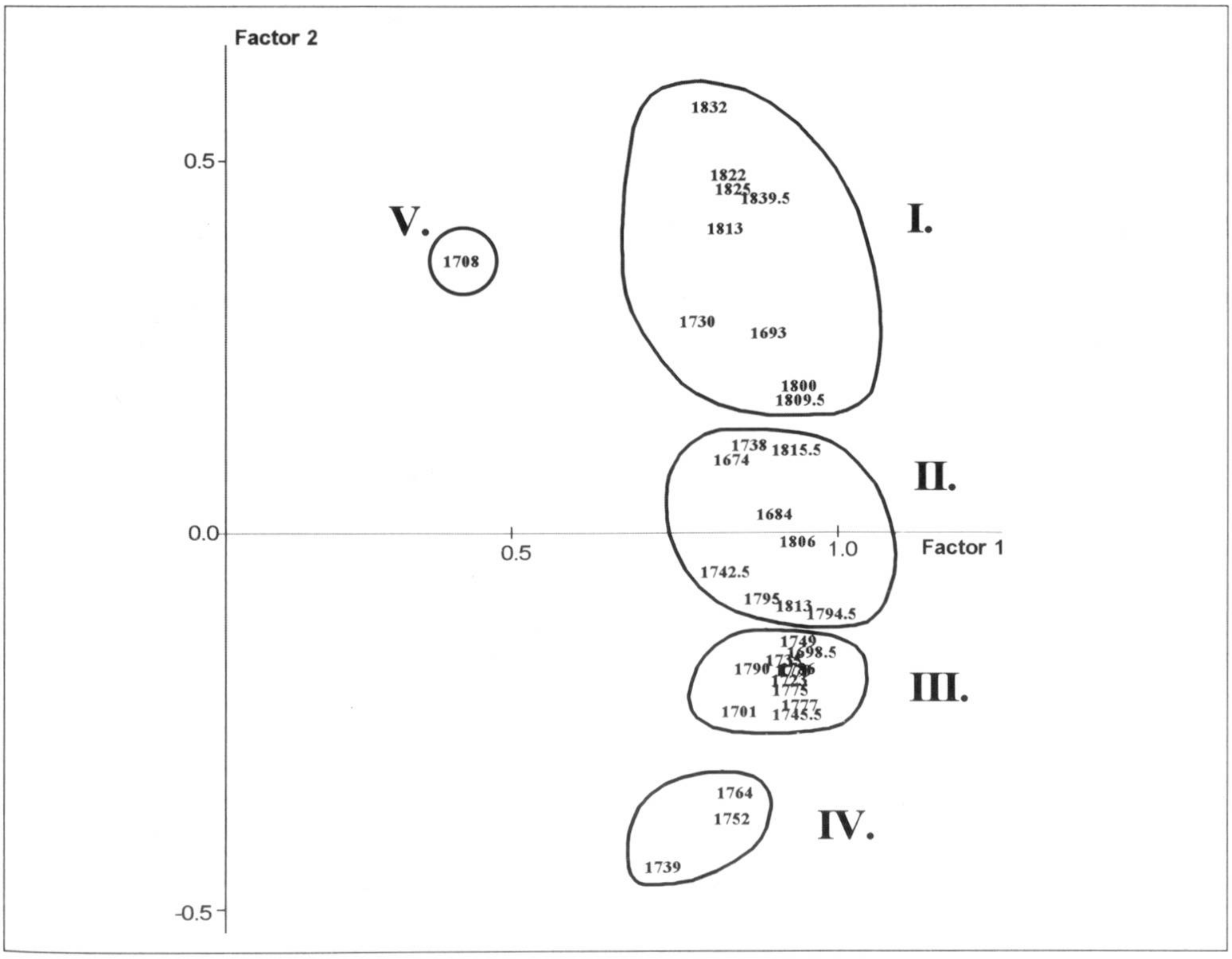

FIGURE 6. Ordination of the sampling sites. Numbers indicate rkm (see Fig. 1).

at this level as well. They have become so rare nowadays that we could not detect them in the sampling plots.

Level C. The total cover is similar to that of Level B (Fig. 3). The species composition of this level is very variable, with a usually high number of species. *Leskea polycarpa* predominates and many species of the second level can be found in moderate abundance, especially *Cinclidotus riparius*, and in some places *Fissidens crassipes*, *Hygroamblystegium fluviatile*, and *Amblystegium riparium*. *Cinclidotus fontinaloides* and *Brachythecium rutabulum* are also frequent here. Many colonist species such as *Bryum barnesii* and *Didymodon luridus* which are sometimes considerably abundant can be detected.

Water quality parameters in 1993

There were no considerable changes recorded along the investigated section of the Danube in nitrate (5-15 mg/l), nitrite (0.04-0.16 mg/l), orthophosphate content (0.01-0.6 mg/l), conductivity (300-450 μS/cm), total hardness (70-130 CaO mg/l) and pH (8.1-8.6) during the study period.

The organic N content increases downstream along the section investigated. From Rajka to Almásneszmély, organic N content usually fluctuates between 0.2 and 1.3 mg/l, while at the measuring points of Szob and Budapest it was almost always higher, usually between 1 and 1.7 mg/l. The ammonium content showed an opposite trend. Usually higher values (0.1-0.6 mg/l) were measured in the central part of the section investigated (Komárom and Almásneszmély) than at the end of the section where the ammonium content dropped to very low values (0-0.1 mg/l), except during the winter period.

Changes in the COD are similar to those of the organic N content, fluctuating between 30 and 60 mg O_2 per l in the upper and central parts of the section. Higher values were measured at Szob and Budapest (40-80 mg O_2 per l). With respect to this parameter, the water is α-mesosaprobic according to Felföldy (1978) throughout the year. In winter and sometimes also in summer, the water is β-α-mesosaprobic in the upper and central parts of the studied section. On the basis of the annual means the whole section is mesosaprobic. Using BOD, even the annual means, the difference in the saprobity levels between the upper and lower parts of the investigated river sections becomes more apparent (Fig. 4).

Bryophytes and water quality

The saprobity changes outlined above, indicating an increase in pollution, can be related to the total bryophyte cover changes (Fig. 3). There is a clear trend for decrease of the total cover at all levels. The first site where bryophytes are completely lacking at all three levels is at about 1760 rkm. This is the mouth of the river Váh, which no doubt brings polluted water in large quantities. The sampling point for the water quality measurements is just above the inflow. As the next sampling point is too far (Almásneszmély, 1750 rkm), the effect of this afflux can unfortunately not be detected in those parameters. The very low cover values and the lack of bryophytes at the lowest level (A) is characteristic from 1745 rkm onwards. In addition, bryophytes are absent at Level B between about 1720-1710 rkm. Downstream, the cover values are very low (<10%) except at 1693 rkm (Visegrád). The same trend is recognised at the upper

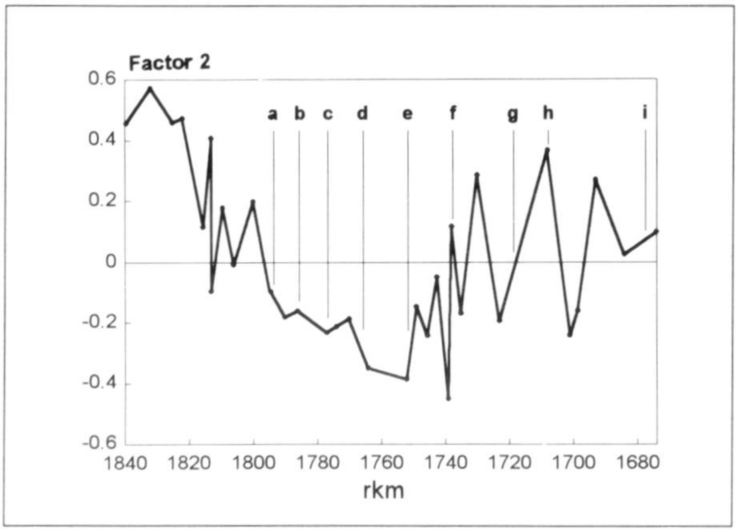

FIGURE 7. Position of sampling sites along the second PCA factor plotted against rkm (for letters see Fig. 1).

level (C). These changes correspond to the change in the saprobity level of the water between Almásneszmély (1749 rkm) and Szob (1707 rkm). No clear trend in the change of the species number along the section studied was detected.

The species composition, however, changes remarkably in relation to the water quality. Level B, the medium water level zone, is the most appropriate to analyse the species pattern. The flora is relatively rich here, and this level could be sampled along the whole river section studied, while in some parts of Levels A and C no bryophytes occurred. Moreover, this is the level that is directly affected by the river water during most of the year (Fig. 2). The mosses and their abundance values at Level B are summarised in Tab. 2. The indicator values of mosses are presented in Tab. 3.

The cluster analysis (Fig. 5) and the ordination of the sites (Fig. 6) based on their bryophyte vegetation yielded similar results. Five groups can be distinguished. The first (I) contains the least polluted sites. The third group (III) includes moderately polluted sites. The second group (II) occupies an intermediate position between the two groups. Group IV contains the very polluted, disturbed places. The fifth group (V) contains only one sample with a strongly deviating species composition, most probably due to the extraordinary substrate (waste bricks).

The ordination diagram (Fig. 6) shows that the above-mentioned groups of sites are rather distinctly separated along the 2nd factor. Hence, information on the water quality state indicated by the bryoflora composition at each sampling point can be inferred from this factor (Fig. 7). The values of the sampling sites along the 2nd factor decrease continuously from the inflow of Mosoni-Duna (a) and reach a minimum around the inflows of two strongly polluted affluxes, river Váh (d) and stream Által-ér (e). Beyond this point there is a very low value at Piszke (f). A trend of moderate increase can be observed downstream, but the values strongly fluctuate. There are similarly low values as in the section between the inflows of Mosoni-Duna and Váh. Higher values are found as well. However, they do not reach the highest values of the upper part (from Dunakiliti to Ásványráró, 1839-1822 rkm). The values of the 2nd PCA factor (Fig. 7) show a clear correlation with the number and volumes of the affluxes delivering polluted water. Unfortunately, the 'VM' database cannot be used to prove this correlation, because the sampling points are too far from each other (30 - 50 km) to trace the minor changes in the water quality. However, at the central part of the section, where the factor values are the lowest, water chemical measurements show higher ammonium content.

The most abundant and characteristic species of the flora indicate β- or β-α-mesosaprobic water along the section studied (Tab. 3). Less heavily polluted sites are characterised by remarkable abundance of *Hygroamblystegium fluviatile* and the oligosaprobic *Rhynchostegium riparioides* and by the low abundance of *Fissidens crassipes*. At the strongly polluted sites, the abundance of the latter is very high. *Amblystegium riparium* is usually also abundant, while the quantities of *Leskea polycarpa* and *Cinclidotus riparius* decrease. At the moderately polluted sites *Leskea polycarpa* is very abundant and *Cinclidotus fontinaloides* appears, but the abundance of *Cinclidotus riparius* is reduced.

These results suggest that the published saprobity indicator value of some mosses (Burton 1986) must be slightly modified in the Danube. *Hygroamblystegium fluviatile* occurs abundantly mainly at sites with less polluted water. Therefore, it is considered to be an indicator of β-mesosaprobic conditions in the Danube. *Fissidens crassipes* dominates at heavily polluted sites and is thus qualified as α-mesosaprobic (Tab. 3).

Conclusions

A number of rare bryophyte species occur along the Danube (see Tab. 1). The threat to this valuable flora, caused by the water pollution, is manifested by the decrease of the total cover of bryophytes along the Danube as well as by changes in the species composition. Therefore, bryophytes can be used as indicator organisms of changes in the Danube ecosystem. The sources of pollution and disturbance can be efficiently traced by means of bryophytes.

Most of the former investigations on indicator values of bryophytes were carried out in rivers with a better water quality than that of the Danube (Empain 1973, 1978, Peñuelas & Sabater 1987, Vrhovšek & al. 1984, 1985). These were mainly oligo- and β-mesosaprobic river sections. Only the water quality of the Rhine (Frahm 1974) can be compared to that of the Danube. However, the indication in Frahm's work is based on presence/absence of certain species and quantitative data of the bryophyte vegetation are not included in that investigation. Abundance values of each species and their subsequent numerical analysis may be more accurate for indication, especially in the Danube where the water is polluted everywhere and the range of saprobity changes is small (Fig 4). The indicator values of some species can be modified on the basis of our studies. Elaboration of the indicator values of the important bryophyte species along the Danube needs further investigations. However, we prefer the use of the vegetation to the use of single 'indicator species' (as stated above).

Our results call attention to the fact that the pollution source can sometimes not be traced over a distance longer than a few kms, as the dilution and purification capacity of the Danube is remarkable. Therefore, the 'VM' water quality database of the Institute for Environment Protection can only give a draft picture on the water quality in the Danube due to the large distances (30-50 km) between the measuring points. Though bryophytes cannot be used to detect the water quality changes in time, they can be used to survey the 'average' water quality changes in space.

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