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Distribution and expansion of *Sphagnum fimbriatum* in Hungary

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The distribution of *Sphagnum fimbriatum* in Hungary was studied by comparing floristic data before and after 1990. Before 1990, *S. fimbriatum* was known from nine regions. Now it occurs in 16 regions and the number of localities has increased from 13 to 32. The habitat preference of the species hardly changed during its expansion; it occurs mainly in *Salix* mires. At many of its recent localities, *S. fimbriatum* has a pioneer character; it has colonised earlier known (and well-studied) sites, or occupied new, young habitats. Due to the characteristic field morphology and very intensive earlier bryological studies it may be safely assumed that *S. fimbriatum* has expanded its distribution in Hungary. This expansion is observable both at local and regional spatial scales and the direction seems to be from the mountain region to the lowlands. The expansion of *S. fimbriatum* could be attributed to good sexual and vegetative reproduction and strong colonising and growth ability in more stressed and disturbed habitats. Other *Sphagna* do not show similar changes in their distribution and frequency.

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Twentyfour *Sphagnum* taxa occur in Hungary (Farkas 1999). Their major habitat types are small, disjunct mires and wet, acidic forest floor sites below 600 m elevation. The absence of high mountains, the high proportion of calcareous bedrock and the predominantly central-European climate of Hungary are not suitable for *Sphagna*, hence they are rare and protected by law. The *Sphagnum* flora of Hungary has been documented carefully since the late 19th century to the present, through numerous investigations, publications, species lists, field diaries and herbarium collections (BP, EGR) (Boros 1924, 1968, Simon 1953, Pócs 1958, Vajda 1969).

Hungarian mires have been considered relicts of glacial vegetation (Zólyomi 1931) but on the basis of new paleoecological studies (Willis et al. 1997), the recent vegetation of these mires is considerably younger. *Sphagnum* establishments are rather short-lived, especially in fens and on wet forest soils where the estimated lifetime of *Sphagnum* occurrences is on the scale of a few decades (Högström 1997, Szurdoki et al. 2000). Changes in the species composition of *Sphagna* are also considerable over years and decades in mires (Hogg et al. 1995, Ruthsatz 1996, Szövényi 1997).

Sphagnum fimbriatum Wils. is easily recognisable in the field. Its identification is usually based on the attractive prominent and attenuated apical bud of the capitulum, the pale-green colour of the plants and the characteristic fimbriate stem leaves (Daniels and Eddy 1985). It is a monoicous, potentially self-fertilizing species, which frequently develops sporophyte everywhere in its area (Smith 1978, Daniels and Eddy

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1985, Wilcox and Andrus 1987, Cronberg 1991, Zechmeister 1994, Soro et al. 1999, Feldmeyer-Christe et al. 2001). On the basis of earlier floristic works (up until the 1970s) it was rare in Hungary, but, recently more occurrences have been found both in new and in known peat moss localities, where it was previously unrecorded (Bakalár 1981, Lájer 1998, Szurdoki et al. 2000, 2001). The main European distribution of *S. fimbriatum* is confined to the north-western parts of the continent, where it occurs in mesotrophic, shaded places (*Salix* and *Betula* mires, among *Molinia* and tall sedge tussocks) and on open wet soils (Smith 1978, Daniels and Eddy 1985). In central Europe it is less abundant, occurring in similar habitats, but often also in abandoned peat-cuttings. Here it is a lowland species, restricted to elevations below 1000 m (Schröck and Krisai 1999, Feldmeyer-Christe et al. 2001).

The newly available floristic data indicate a requirement for more detailed studies on the Hungarian distribution of *S. fimbriatum* and raise several questions: what are the main features of the changes in the distribution and abundance of *S. fimbriatum* in the last decade? Are there any changes in the habitat preference of the species? What could be the reasons of its supposed expansion?

Methods

This work is part of an overall floristic study of peat mosses carried out between 1994 and 2000. All known *Sphagnum* localities have been visited 2–3 times in this period and their species composition and vegetation types described. In addition, identifications of earlier collections (BP, EGR) were revised. Based on these data the Hungarian distribution of *S. fimbriatum* was redrawn before and after 1990.

For this study we use the term "locality" and "region" for occurrences. Locality means a clearly separable site of *Sphagna*, e.g. one mire, meadow or peat moss patch on wet soil. There are 36 localities in this paper (Appendix 1). Region means a small area of the country, which could contain one or more localities. We distinguished 23 regions (Appendix 1). In the text, figures and Appendix the Arabic numerals refer to localities and Romanian numerals to regions.

The following habitat types of *S. fimbriatum* were recorded: *Salix* mire, tall sedge vegetation and wet soil. *Salix* mires are habitats on the edge of mires or small swamps dominated by *Salix cinerea* L. The tall sedge vegetation type includes all of the sedge-dominated habitats (dominated by *Carex*, *Typha*, *Eriophorum* species, *Juncus effusus* L., *Calamagrostis canescens* (Web.) Roth em. Druce). The wet soil habitat type was used to indicate wet, mineral soil of forests or open areas, or among streamlets and springs. In these habitats, mainly in open situations, the vegetation does not create a well-defined community.

The age of existing peat moss populations in localities was estimated using paleoecological investigations, historical data and field experiences. For the age estimations the following four categories were used: >1000 years, 100–1000 years, 50–100 years and 10-50 years old. The difference between the proportions of regions colonised by *S. fimbriatum* before and after 1990 was tested by McNemar's paired-sample test for nominal data (Zar 1999). The change of habitat preference of the species before and after 1990 was tested by chi-square statistics of contingency tables (Zar 1999).

Results

Changes at regional scale

Peat mosses have been found in 23 regions in Hungary. Before 1990 they had been found in 20 regions (Fig. 1), of which 17 still contain *Sphagnum*. *S. fimbriatum* was found in nine of the regions before 1990 and in 16 regions after 1990. The proportion of regions with *S. fimbriatum* increased significantly after 1990 (McNemar's test $p<0.05$, Table 1).

Changes at local scale

Before 1990 *S. fimbriatum* had been found in 14 localities (Table 2). Ten of them were described with *S. fimbriatum*, whereas in four localities *S. fimbriatum* established after the localities become known and *S. fimbriatum* disappeared from one locality. Since 1990 22 new localities have been found. Ten of them were described at the same time as the locality and 12 were found in already known localities (new establishments). *S. fimbriatum* disappeared from three localities, thus *S. fimbriatum* currently exists in 32 localities (Table 2).

The 20 localities that were found with *S. fimbriatum* (when the locality was discovered, *S. fimbriatum* was

Table 1. Number of geographic regions with (+) and without (–) *S. fimbriatum* before and after 1990. The proportion of regions occupied by *S. fimbriatum* significantly increased after 1990 from 0.391 to 0.696 (McNemar's paired sample test, chi-square=5.143, df=1, $p<0.05$).

		before 1990	
		+	–
after 1990	+	8	8
	–	1	6

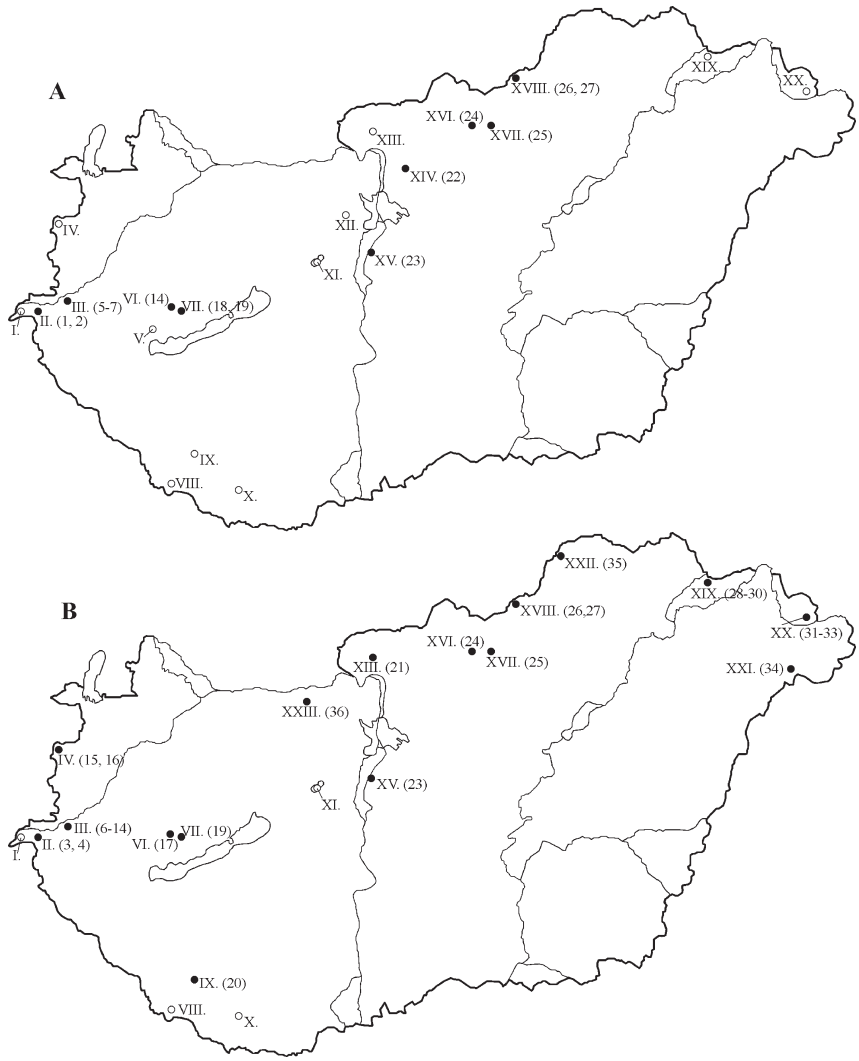

Fig. 1. Distribution of *Sphagnum fimbriatum* before 1990 (A) and after 1990 (B) in Hungary.
Key: ○ – Regions with *Sphagnum,* but without *S. fimbriatum* (potential habitat), ● – Regions with *S. fimbriatum*; Arabic numerals refer to localities of *S. fimbriatum* the names of localities are found in Appendix; Roman numerals of regions: I – Vendvidék (hills), II – Őrség (hills), III – Vasi-hegyhát (hills), IV – Köszegi-hegység (Mts), V – Tátika-Kovácsi-hegycsoport (Mt), VI – Bakony (Mts), VII – Balatonfelvidék (hills), VIII – Barcs (floodplain), IX – Somogyszob (floodplain), X – Somogyi-dombság (hills), XI – Velencei-tó (lake), XII – Pilis (Mts), XIII – Cserhát (Mts), XIV – Gödöllői dombság (hills), XV. Csepel-sziget (island), XVI – Mátra (Mts), XVII – Bükk (Mts), XVIII – Putnoki-dombság (hills), XIX – Zempléni hegység (Mts), XX – Bereg (plain), XXI – Nyírség (plain), XXII – Aggtelek (Mts), XXIII – Esztergom (hills).

Table 2. Number of *Sphagnum fimbriatum* localities before and after 1990.

	1886–1990	1990–2000
Known *S. fimbriatum* localities at the start of the periods	–	13
Localities with *S. fimbriatum* described during the period	10	10
Establishments of *S. fimbriatum* in known localities during the period	4	12
Extinction of *S. fimbriatum* localities during the period	1	3
Number of existing *S. fimbriatum* localities at the end of the periods	13	32

already found there) were young habitats showing a pioneer character of species composition. Of the ten localities, described before 1990, seven developed in the last 100 yr, as a potential habitat for peat mosses, and two in the last 1000 yr. Of the ten localities, described after 1990, nine originated in the second part of the 20th century as secondary wet habitats. The last one is of older origin. *S. fimbriatum* was established in four earlier known mires before 1990. Three of them are old bogs and one is a young *Salix* swamp. After 1990 establishment occurred in 12 earlier *Sphagnum* localities. Of these, only two are old bogs whilst the others are mostly relatively young (<100 years old) habitats.

Changes in habitat preference

The number of occurrences since 1990 among the three different habitats is 34, although the number of localities is 32, as it occurs in two habitat types in two localities. The number of occurrences was doubled after 1990 in all three categories. On the basis of chi-square statistics for the contingency table (Table 3) the proportions of habitats colonised by *S. fimbriatum* (its habitat preference) did not changed between the two time periods (chi-square=0.046, df=2, p>0.05).

Discussion

It can be assumed that the occurrences of *S. fimbriatum* found after 1990 are mainly young establishments, and not older occurrences that were previously overlooked. Most of the localities were found in the 1990s, although the activity of botanists did not increase. Unlike in the case of *S. fimbriatum*, other *Sphagnum* species do not appear to have expanded recently (Ódor et al. 1996, Szurdoki 2003).

There are two potential sources of propagules establishing new occurrences: (1) long range spore dispersal from surrounding mountains and (2) expansion of local Hungarian populations. Each of these is considered separately.

(1) Most of the regions in Hungary are situated at the foothills of the Alps and the Carpathians. It is supposed that the propagules of some newly occupied regions originate from populations in the Alps and Carpathians, which could show an expansion to the habitats of lower elevations (hills and lowlands below 1000 m a.s.l.). This expansion of *S. fimbriatum* can also be observed in other parts of Europe along the distributional border of the species. In Switzerland (Feldmeyer-Christe et al. 2001), Austria (Schröck and Krisai 1999) and Germany (Paul 1997) new occurrences were found recently, where it often colonises "young", pioneer habitats. It could be considerable in lowlands (as in Hungary) because it prefers lower altitudes also in other parts of its area (Daniels and Eddy 1985, Zechmeister 1994). Most of the *Sphagna* that prefer lower altitudes occur also in the subalpine zone of mountains (e.g. in Switzerland) but *S. fimbriatum* is an exception (Feldmeyer-Christe et al. 2001).

(2) Good reproductive ability of the species is supported by field observations of local populations. Hungarian populations visited by the authors carry capsules, and the plants of earlier collections also often contain capsules. This intensive spore production also could explain its regional expansion. It can be supposed that both sources have some importance, but this question requires population genetic investigations on the *S. fimbriatum* populations of Carpathian basin.

Table 3. Distribution of *Sphagnum fimbratium* occurrences among vegetation types before and after 1990 in Hungary. The proportions of habitats colonised by *S. fimbriatum* did not changed in the last decades (chi-square statistics of this contingency table, chi-squae=0.046, df=2, p>0.05).

Vegetation type	Before 1990	After 1990
Salix mire	12	25
Wet soil	2	5
Tall sedge vegetation	2	4

The new patches of *S. fimbriatum* show intensive biomass increase. In Sweden (Gotland) the annual horizontal increment was 1.4–2 cm (Högström 1997). On the basis of some preliminary measurements in an abandoned pebble-mine in Hungary, the patches produce up to 7 cm radial increment during one vegetation period (E. Szurdoki and P. Szövényi, unpubl.). This horizontal increment could be attributed to the intensive branching mechanism of the major stem, with most of the plants carrying two or three capitula. This phenomenon can be observed quite often in the case of presumably young occurrences. Unfortunately, any additional vegetative reproductive ability of the species is relatively unknown, because it has included in only a few autoecological studies of *Sphagna* (Wilcox and Andrus 1987, Cronberg 1991). In the abandoned pebble-mine, *S. fimbriatum* is far more abundant than other species, although the sources of propagules for each species are approximately the same (Szövényi 1997). In an autoecological study of peat mosses (Wilcox and Andrus 1987), *S. fimbriatum* showed higher vegetative reproductive ability (regeneration from branch fascicles and capitula) than other investigated peat moss species.

Most of the new Hungarian establishments of *S. fimbriatum* are connected with disturbed and/or stressed habitats (e.g. free soil surfaces of abandoned sand and pebble mines, open wet soil along streams, drainage). It often establishes at the base of sedges (*Carex*, *Eriophorum*, *Juncus* spp.) and shrubs (*Salix* spp.) or forms low hummocks around sedge tussocks, as also noted in earlier studies (Wilcox and Andrus 1987, Meade 1992, Malmer et al. 1995, Soro et al. 1999). It is well known that *S. fimbriatum* can be a successful coloniser of secondary, disturbed mires (Andrus 1986, Wilcox and Andrus 1987), abandoned peat-pits (Schröck and Krisai 1999, Soro et al. 1999, Feldmeyer-Christe et al. 2001), springs, wet roads and edges of small depressions (Paul 1997). Compared

with other peat mosses, *S. fimbriatum* is more tolerant of abiotic stress (base rich, dry conditions) and pollutants and it has a higher reproductive ability under stressed conditions (Wilcox and Andrus 1987).

It is not clear what are the most important abiotic conditions stimulating the expansion of the species in the 1990s. Some environmental changes can create new suitable habitats. Acid rains could decrease soil pH in regions with generally nutrient-rich soil like e.g. locality 35 in Appendix (T. Pócs, pers. comm., Högström 1997). In oligotrophic regions with poorly drained soils, clearcuts and forestry roads more often provide acidic, temporarily wet sites and depressions with standing water because of decreased evapotranspiration of the vegetation (e.g. locality 3, 28, 29, 30 in Appendix 1). The first colonisers of these new potential habitats are species with good dispersal and establishment abilities, like *S. fimbriatum*. However these influences have also existed before the 1990s.

Other *Sphagnum* species also could occur in these new localities (Szurdoki et al. 2000, Somlyai and Lökös 1999) but their abundance has only slightly increased in Hungary. Similar population changes were shown in the case of pioneer, acido-frequent vascular plants in Hungary (e.g. *Lycopodium* species; Ódor 1996, 1997).

Future changes will be easier to detect through comparison with the data now available. The understanding of the biological background of this process requires more autoecological and population genetic studies, as well as field and laboratory experiments.

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Appendix 1. Detailed data of *Sphagnum fimbriatum* localities in Hungary. * – Unpublished data of the authors.

Region	Locality number	Locality name	Description date of locality	Age of locality	Description date of *S. fimbriatum*	Date of extinction of *S. fimbriatum*	Habitat of *S. fimbriatum*
Örség (hills)	1	Csonkás -erdö (forest)	1954	10–50	1954	before 1995*	pine forest
Örség (hills)	2	Szöce(forest)	1954	10–50	1954	before 1995*	pine forest
Örség (hills)	3	Kacsás-tó (mire)	1964	10–50	1996*		*Salix* mire
Örség (hills)	4	Ispánk (mire)	1998	10–50	1998		*Salix* mire
Vasi-hegyhát (hills)	5	Gersekaráti legelö (meadow)	1973	10–50	1973	before - 1997*	tall sedge vegetation
Vasi-hegyhát (hills)	6	Köcse-tó (mire)	1973	100–1000	1973		*Salix* mire
Vasi-hegyhát (hills)	7	Közbirtokossági-tó(mire)	1973	10–50	1973		*Salix* mire
Vasi-hegyhát (hills)	8	Bertók-tó (mire)	1973	50–100	1996		*Salix* mire
Vasi-hegyhát (hills)	9	Templom-tó (mire)	1973	50–100	1996		*Salix* mire
Vasi-hegyhát (hills)	10	Rekettyés-tó (mire)	1973	10–50	1997		*Salix* mire
Vasi-hegyhát (hills)	11	Füzes-tó (mire)	1973	10–50	1997		*Salix* mire
Vasi-hegyhát (hills)	12	Fias-tó (mire)	1973	50–100	2000		*Salix* mire
Vasi-hegyhát (hills)	13	Kanász-tó (mire)	1973	50–100	2000		*Salix* mire
Vasi-hegyhát (hills)	14	Pizdi-tó (mire)	2000	50–100	2000		*Salix* mire
Köszegi-hegység (Mts)	15	Alsóerdö lápja I. (mire)	1936	100–1000	1994*		*Salix* mire
Köszegi-hegység (Mts)	16	Alsóerdö lápja II. (mire)	1996	10–50	1996		tall sedge vegetation
Bakony (Mts)	17	Öcsi Nagy-tó (mire)	1956	100–1000	1956		*Salix* mire; among *Typha Calamagrostis*
Balaton-felvidék (hills)	18	Barkás-tó (mire)	1956	50–100	1956	before 1990 burnt	

Region	Locality number	Locality name	Description date of locality	Age of locality	Description date of *S. fimbriatum*	Date of extinction of *S. fimbriatum*	Habitat of *S. fimbriatum*
Balaton-felvidék (hills)	19	Monostori-tó(mire)	1956	50–100	1980		*Salix* mire
Somogyszob (floodplain)	20	Somogyszob (mire)	1998	10–50	1998		
Cserhát(Mts)	21	Nádas lake	1958	50–100	1997*		*Salix* mire
Gödöllöi-dombság (hills)	22	Csömöri-tó (mire)	1976	50–100	1976	1987	*Salix* and *Betula* mire
Csepel-sziget (island)	23	Ráckeve-Soroksár Dunaág at Szigetcsép (mire)	1982	10–50	1982		*Salix* mire
Mátra(Mts)	24	Nyírjes-tó(mire)		1957	>1000	1981	*Salix* mire and tall sedge vegetation
Bükk(Mts)	25	Baktai-tó (mire)	1886	>1000	1886		*Salix* mire
Putnoki-dombság (hills)	26	Nagy-Mohos (mire)	1915	>1000	1960		*Salix* mire
Putnoki-dombság (hills)	27	Kis-Mohos (mire)	1915	>1000	1985		*Salix* mire
Zempléni-hegység (Mts)	28	Kréta-patak, (streamlet)	1999	10–50	1999		open wet soil
Zempléni-hegység (Mts)	29	Suta patak, (streamlet)	1999	10–50	1999		open wet soil
Zempléni-hegység (Mts)	30	Köves-patak (streamlets	1999	10–50	1999		open wet soil
Beregi-sík (plain)	31	Bence-tó (mire)	1952	>1000	1991*		*Salix* mire
Beregi-sík (plain)	32	Bábtava (mire)	1952	>1000	1994*		*Salix* mire
Beregi-sik (plain)	33	Zsid (mire)	1952	>1000	1998*		*Salix* mire
Nyírség (plain)	34	Júlia-liget (forest)	1995	100-1000	1995		*Salix* mire
Aggteleki Karszt	35	Lókosár	1997	10–50	1997		broad-leaved (forest) (on dead wood and soil)
Esztergom (hills)	36	Dorogi felhagyott homokbánya (abandoned sand pit)	1999	10–50	1999		open wet soil