

Preliminary data on the frequency and distribution of Hungarian bryophytes, based on 'recent' (1974–2022) records

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Introduction. The bryophyte flora of Hungary was relatively well studied during the twentieth century, but data on the present-day frequency and geographical distribution of Hungarian bryophytes are lacking. We present here our preliminary results based on recent fieldwork and herbarium studies.

Methods. We recorded bryophyte occurrences in grid cells (quadrants) of approximately 5.5 × 6 km. Frequency was determined based on the number of quadrants, and geographical distribution evaluated in terms of the 19 administrative units (counties) of the country. To investigate correlations between species richness and relevant environmental drivers, statistical analyses were carried out.

Key results. A total of 698 bryophyte taxa (2 hornworts, 151 liverworts and 545 mosses) have been found in the territory of Hungary. For each of the 637 taxa that have been observed since 1973, one of five frequency classes (very common, common, sporadic to frequent, rare, and very rare) has been assigned based on the relevant number of field records or herbarium specimens. Additionally, tabular distributional information (occurrence in each of the 19 counties) is presented for each taxon. In the statistical evaluation of the geographical distribution data, the elevational range and the size of the surveyed area were positively correlated with bryophyte richness, whereas arable land cover was negatively correlated.

Conclusions. Although the survey was not uniform or complete across the different counties, the results support some robust bryogeographical theories. We hope to have the opportunity in the near future to compile a new Hungarian bryophyte Red List, partly based on these national frequency data.

KEYWORDS

Hornworts; liverworts; mosses; rarity; counties

Introduction

Existing information about the rarity and frequency of the bryophytes in Hungary and their geographical distribution within the country is scarce. The three accounts summarising the Hungarian bryophyte flora (Boros 1953, 1968; Orbán and Vajda 1983) describe the situation in the twentieth century. They contain sporadic data on the frequency and rarity of taxa and list the floristic regions where they were found. A partial revision of the specimens in BP and EGR on which these accounts are based has shown that these reports must be interpreted with caution, because they sometimes follow outdated taxonomic concepts or are even erroneous when based on misidentified specimens (Erzberger 1999, 2002, 2005; Erzberger and

Schröder 2008; Erzberger 2009; Erzberger and Schröder 2013; Erzberger 2016; Erzberger et al. 2016, 2020).

It can be assumed that the bryophyte flora of Hungary has undergone considerable change since the era of Ádám Boros and László Vajda. Detailed research beyond the scope of the present study would be required to assess the extent of this change and the trends. However, there can be no doubt that our knowledge of the Hungarian bryoflora has greatly improved recently, as most obviously demonstrated by the fact that more than 30 additional taxa have been newly recorded for Hungary (Erzberger 2020). An updated checklist has recently been published (Erzberger and Papp 2020) containing nearly all taxa presently recognised, but

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without information on rarity or distribution. The existing Red List (Papp et al. 2010) contains some information on the frequency of taxa in the twenty-first century, assuming, for example, that species rated LC (Least Concern) are rather frequent while at the other extreme highly threatened taxa are rare. Strictly, however, Red List categories should not be equated with rarity or frequency alone. Although numerous floristic papers have been published in the past few decades (Nagy et al. 2019), an up-to-date synoptical treatment of the whole bryoflora of Hungary, containing information on rarity and distribution, is still lacking.

The bryophyte recording project (Erzberger 2012, 2020; Erzberger and Németh 2016) was initiated in 2012 to fill this gap, ultimately through the production of a distribution atlas based on the Central European mapping system, identical to the system used in the Hungarian atlas of vascular plants (Bartha et al. 2015). However, due to lack of manpower, it will probably still be a very long time before sufficient data have accumulated to enable publication of such an atlas. In the meantime, we decided to publish some preliminary results from our recording activity in such a way that they should not essentially be outdated by the progress of ongoing bryofloristical research, i.e. with a focus on overall frequency and rarity in the country and on distribution in the 19 administrative units of Hungary, the counties (Figure 1).

We aimed to classify the taxa of the Hungarian bryophyte flora according to frequency and rarity, and to present a preliminary overview of their geographical distributions. In accordance with questions Q1, Q4

and Q31 of Patiño et al. (2022), we also tried to test some general hypotheses on correlations between the species richness of Hungarian counties and a number of independent variables (elevational range, size of surveyed area, and forest and arable land cover).

Materials and methods

Biogeographical situation of Hungary

The Pannonian province or biogeographical region (Pannonicum) is a widely accepted separate region in Central Europe (Fekete et al. 2016), based not only on the flora (and fauna) but also on the vegetation pattern. The lower precipitation combined with higher temperature (aridity) values results in the appearance of the forest steppe zone (Borhidi 1961), especially in the lowlands and warm southern foothills. Such a massive transitional belt has served as a barrier for some forest and/or wetland (moss) species adapted to humid conditions typical in the Atlantic part of Europe (Boros 1968; Molnár et al. 2018).

Scope, taxonomy, nomenclature

The taxa evaluated in this study are those in the most recent Hungarian checklist (Erzberger and Papp 2020), which is also followed for taxonomy and nomenclature, with the exception that *Schistidium teretinerve* is used in place of *Grimmia teretinervis* Limpr., based on the results of the latest molecular analyses (Kiebacher and Meier 2020). There are eleven exceptions concerning

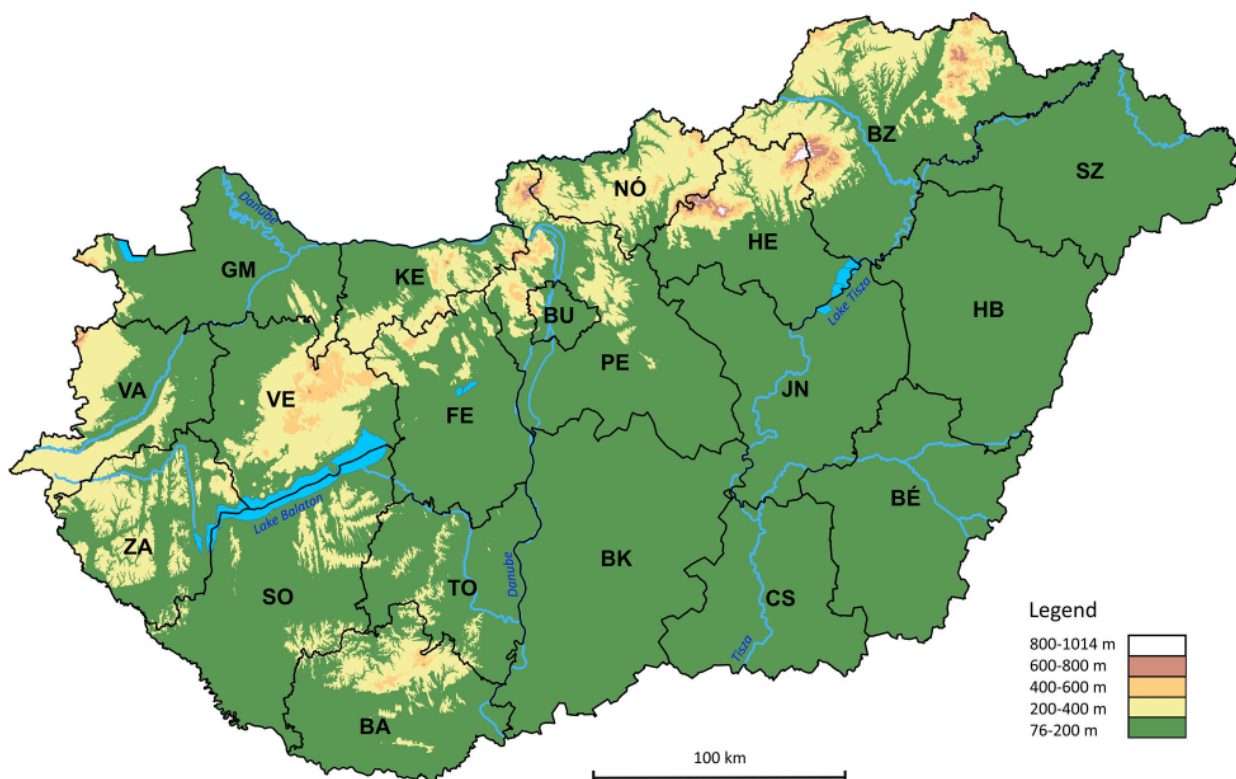


Figure 1. The administrative units of Hungary. See Table 1 for definitions of county abbreviations. Figure created by M. Gaál.

the set of taxa. The following ten additional taxa have been recognised after the publication of the checklist: *Rhytidadelphus loreus* (Németh in Ellis et al. 2021a); *Calyptopogea arguta*, *Hydrogonium croceum* and *Orthothecium rufescens* (Papp and Szurdoki, Németh and Schmotzer, and Németh and Schmotzer, respectively, in Ellis et al. 2021b); *Encalypta spathulata* and *Pohlia bulbifera* (Németh and Schmotzer, and Erzberger, Nagy and Németh, respectively, in Ellis et al. 2021c); *Marchantia polymorpha* subsp. *montivagans* (Aszalósné Balogh et al. 2021); *Hymenoloma crispulum* and *Sphaerocarpos michelii* (Németh and Erzberger, and Wolf, Németh and Erzberger, respectively, in Ellis et al. 2022); and *Lewinskya fastigiata* (Németh, Nagy and Erzberger unpublished). Conversely, *Neoorthocaulis floerkei* (F.Weber & D.Mohr) L.Söderst., De Roo & Hedd. has been excluded, because the only existing voucher turned out to have been collected outside the present territory of Hungary.

Some taxa have not been recorded consistently since the beginning of the project, for example infra-specific taxa of *Fissidens dubius*, *Streblotrichum convolutum* and *Tortula acaulon*. Therefore, their frequencies and distributions might be underestimated. All records of *Ulota crispa* before Caparrós et al. (2016) may include the segregate species (*U. crispula*, *U. intermedia*) as well; *U. crispa* s.s. seems to be rare according to more recent records. Additional data for *U. crispa* s.l. are shown in [Appendix 1](#).

Data sources

Most of the data evaluated are the result of the collective fieldwork intended for the production of a bryophyte distribution atlas of Hungary based on the Central European mapping scheme (Niklfeld 1971; Bartha et al. 2015). Other data sources include unrelated fieldwork mostly carried out in connection with the Natural History Museum of Budapest. Published records were not evaluated unless one of the authors had seen a specimen.

We distinguish between ‘historical’ records (mainly from the era of Boros and Vajda and to a small extent before) and ‘recent’ records by choosing the year 1974 as discriminant. Ádám Boros died in 1973, and afterwards bryofloristic activity rapidly sank to a low level, as can be demonstrated by analysing the numbers of specimens collected over the years (Erzberger and Schröder 2008, 2013). Our estimates of frequency are based exclusively on records after 1973, as are the distributional data with respect to the 19 Hungarian administrative units. However, in [Appendix 1](#), in some cases we have additionally indicated the presence of historical collections (before 1974) in a given county based on herbarium specimens housed mainly in BP and EGR (with a different symbol and only if not congruent with a recent record; herbarium codes follow Thiers [Continuously updated](#)). For species that have not been

recorded since 1973, the historical distribution is the only distributional information available. For species of more-or-less critical groups of taxa that have been the subject of a modern taxonomic revision, historical distributions reported in this paper are based exclusively on revised specimens and often differ significantly from the reports in the standard Hungarian treatments of the twentieth century.

County data on arable and forest cover and the sizes of county areas follow Központi Statisztikai Hivatal (2019). The digital topography model used to calculate elevational range data of counties was HydroDEM (the Hydrologically correct Terrain Model of Hungary), prepared by ESRI Magyarország Kft in 2014 on behalf of the General Directorate of Water Management (2022). To calculate these data, the ‘Zonal Statistics as Table’ function of ArcGIS Pro 2.9.1. (ESRI 2022) was used.

Fieldwork

The recording unit is the quadrant, i.e. a quarter of the Central European mapping grid (Niklfeld 1971). It has an extension of 3 minutes of latitude and 5 minutes of longitude, in Hungary corresponding to approximately 5.55 km × 6.25 km, respectively, or 34.6875 km² on average (Bartha et al. 2015). Field excursions were planned to include a maximum of different biotope types within a given quadrant, in order to observe as many different bryophyte taxa as possible. Species that could unequivocally be identified in the field were usually not collected. Samples collected for identification were mostly discarded after microscopy unless they represented rare or otherwise interesting taxa; these were kept and deposited in institutional herbaria (B, BP, EGR, JPU) or the private herbaria of the authors.

The richest quadrants were visited several times, but many were explored only once, thus a complete species inventory has probably not been observed in any of the examined quadrants except possibly the most species-rich ones (see Callaghan 2012).

The explored quadrants were chosen arbitrarily; they are geographically not representative of the country and show bias towards the capital as well as colline and mountain areas. This is reflected in the relative area investigated in each county (see [Table 3](#)).

Frequency

The frequency of Hungarian bryophytes is based on the number of quadrants in which they were found after 1973, in relation to the total number of investigated quadrants (cf [Table 4](#)). Quadrants with 20 or fewer in each were disregarded as being insufficiently explored. At the time of evaluation (July 2022), the number of quadrants with more than 20 different taxa recorded was 586 (see [Table 2](#)), this number being used in computing the threshold values for the frequency classes.

Table 1. The 19 counties of Hungary and their areas (following Központi Statisztikai Hivatal 2019).

Acronym	County	Area (km ²)
BA	Baranya	4430
BÉ	Békés	5630
BK	Bács-Kiskun	8445
BZ	Borsod-Abaúj-Zemplén	7247
CS	Csongrád-Csanád	4263
FE	Fejér	4358
GM	Győr-Moson-Sopron	4208
HB	Hajdú-Bihar	6210
HE	Heves	3637
JN	Jász-Nagykun-Szolnok	5582
KE	Komárom-Esztergom	2264
NÓ	Nógrád	2544
PE	Pest (including Budapest BU)	6916
SO	Somogy	6065
SZ	Szabolcs-Szatmár-Bereg	5936
TO	Tolna	3703
VA	Vas	3336
VE	Veszprém	4464
ZA	Zala	3784

County distribution

Our decision to evaluate the data on the basis of the 19 administrative units, i.e. the counties (with the capital, Budapest, included in the surrounding county, Pest), was motivated by the volume of data accumulated during recording. The amount of data seems insufficient for any finer-scaled partitioning. However, the borders of the counties are well defined, whereas other partitions, for example natural regions, are not sharply delimited and sometimes controversial.

In all cases, present-day county borders (Központi Statisztikai Hivatal 2019) were taken into account. The average county area (assuming the fusing of the areas of Budapest and Pest County) is approximately 4900 km², whereas the maximum (BK) per minimum (KE) ratio is 3.7 (Table 1).

Distribution of frequency classes in the counties

For each county we evaluated the number of taxa in the five frequency classes, based on Appendix 1, in comparison with the total number of taxa in each frequency class (see Table 4). The results were plotted on a map of Hungary showing the 19 administrative units in order to better visualise geographical patterns of frequency and rarity.

Data processing

Our study provides data at two geographical scales: the national scale (~100.000 km²) and the county-level scale (~5000 km²). We assume that our surveys more-or-less represent the true species richness of the counties – despite the significant and uneven bias at both scales – if the basic and robust bryogeographical rules can be verified with our data.

To measure correlations between species combinations and relevant environmental drivers, we used

simple linear (Pearson's) correlations (with 'r' and 'p (uncorr)' values) between the total number of bryophyte taxa per county (the dependent variable) and the independent variables, such as surveyed area (Area), elevational range (Elev), arable land cover (Arable) and forest cover (Forest).

The independent variables were selected based on the following bryogeographical assumptions:

- (i) the expected number of species increases with the size of the surveyed area (Callaghan 2012; Patiño and Vanderpoorten 2018);
- (ii) the number of species increases with elevational range (Theurillat et al. 2003; Hodgetts et al. 2019);
- (iii) the number of species increases with forest cover and decreases with arable land cover (Zechmeister and Moser 2001; Caners et al. 2013).

Arable land cover was highly correlated with forest cover. We performed linear correlation analysis using PAST 4.03 (Hammer et al. 2001). All the dependent and independent variables were normalised before analysis according to the following formula: $Z = (X - \mu) / \sigma$ (where X = original value, μ = mean of dataset, and σ = standard deviation of dataset).

Results

Mainly due to recent fieldwork, another 10 taxa have been added to the bryophyte flora of Hungary since the publication of the latest checklist (Erzberger and Papp 2020). We now recognise 698 taxa (2 hornworts, 151 liverworts and 545 mosses).

The preliminary evaluation of grid cell-based bryophyte recording in Hungary (Tables 2 and 3) gave rise to:

- (i) an assignment of all bryophyte taxa with 'recent' (after 1973) records known from the territory of Hungary, altogether 637 taxa, to one of five frequency classes (Table 4, Appendix 1); and
- (ii) an overview of their geographical distribution in the 19 counties (Appendix 1).

Data were obtained from a proportion of the total of 2832 quadrants covering the territory of Hungary. At the time of evaluation (July 2022), the number of quadrant/taxon records (i.e. the sum of the number of quadrants/taxon extended over all taxa) was 42,810. If we

Table 2. Present state of bryophyte recording (complemented by herbarium data after 1973) in Hungary.

Variable	No. (%) ^a
Quadrants with data	900 (31.8)
Quadrants with > 20 different taxa	586 (20.7)
Quadrants with ≥ 100 taxa	120 (4.2)
Quadrants with ≥ 200 taxa	8 (0.3)
Taxa in quadrants with > 20 taxa (mean)	68.4

^aAny value in parentheses is the proportion as a percentage of the total number of quadrants in the territory of Hungary (i.e. 2832).

Table 3. Statistically important descriptive data for the 19 counties of Hungary, including N_s = total number of species/county, N_{Qi} = number of investigated quadrants, and Area Q_i = area of investigated quadrants.

County abbreviation ^a	Taxa/quadrant					Area Q_i				Other independent variables		
	Minimum	Maximum	Mean	Median	SD	N_s	N_{Qi}	km ²	%	Elevation (m)	Forest cover (%)	Arable land cover (%)
BA	1	172	59.31	50	39.57	379	61	2115.94	47.76	599	25.2	48.90
BÉ	1	97	10.00	3	19.13	123	27	936.56	16.63	31	4.6	69.07
BK	1	52	21.82	23	17.11	141	28	971.25	11.50	96	20.8	42.10
BZ	1	192	56.64	49	50.91	460	85	2948.44	40.68	864	29.2	33.92
CS	1	40	19.91	25	12.99	124	35	1214.06	28.48	58	8.9	58.05
FE	1	181	49.64	40	44.40	295	39	1352.81	31.04	411	12.4	57.65
GM	1	159	34.43	27	35.93	300	47	1630.30	38.70	569	19	51.93
HB	1	59	18.13	13	17.20	152	40	1387.50	22.34	98	11.3	52.06
HE	1	199	59.42	41	51.12	387	48	1665.00	45.78	933	24.3	39.42
JN	1	40	13.00	8	13.08	88	17	589.69	10.56	56	5.9	62.93
KE	1	227	68.06	67	52.04	355	53	1838.44	81.20	620	27.3	44.50
NÓ	1	165	61.24	55	45.06	315	49	1699.69	66.80	827	39.2	26.01
PE (+ BU)	1	236*	71.87	56	60.22	474	82	2844.38	41.10	857	25.8	36.60
SO	1	84	33.77	33	24.09	247	56	1942.50	32.02	219	29.6	39.63
SZ	1	82	24.58	26	20.80	148	24	832.50	14.02	137	21.3	43.79
TO	1	64	17.88	6	19.44	184	33	1144.69	30.91	544	17.8	56.54
VA	1	236*	52.74	46	49.68	402	68	2358.75	70.70	757	28.2	45.53
VE	1	151	61.98	58	45.36	401	64	2220.00	49.73	613	30.2	31.43
ZA	1	123	41.00	38	32.37	283	44	1526.25	40.33	354	31.7	30.91

*Highest number of taxa/quadrant in Hungary.

^aSee Table 1 for definitions.**Table 4.** Definitions of frequency classes and number of taxa in each class.

Frequency class	Abbreviation	Percentage of total no. of quadrants investigated (586)	No. of taxa		
			Liverworts and hornworts	Mosses	Total
Very common	cc	> 65%	2	20	22
Common	c	40–65%	3	29	32
Sporadic to frequent	s-f	5–39.9%	33	193	226
Rare	r	1–4.9%	53	128	181
Very rare	rr	< 1%	37	139	176
Not seen since 1973	n.s.	0	25	36	61
Total			153	545	698

disregard the incompleteness (bias) of the survey, the coverage nationally of quadrants with any bryophyte data was 31.8%; considering only the quadrants with > 20 taxa, it was 20.7% (see Table 2). At the same time, if the territory of the country were to be divided into parts (counties in our case), their average completeness would be 38%, if we count all quadrants in which at least one bryophyte species was recorded. This apparent increase in completeness was due to the bias and the different size of the counties (cf Table 3).

Figure 2 shows for each county the number of taxa in each frequency class. Although all the very common species (cc) and nearly all the common species (c) were found in each county, the number of taxa of intermediate (s-f) and lower (r, rr) frequencies differs strongly among counties. The six counties with the highest proportion of taxa of intermediate and lower frequency are those with higher elevations (BA, BZ, HE, KE, PE, VA, VE), whose bryophytes comprise 86–99% of s-f taxa, 43–80% of r taxa, and 6–30% of rr taxa. At the other extreme, the six counties with the lowest proportions in these classes are the predominantly lowland counties (BÉ, BK, CS, HB, JN, SZ), having 20–35% of s-f taxa, 2–9% of r taxa, and 0–4% of rr taxa.

As shown in Table 5, strong correlations were found between the species richness of the counties and the selected independent variables. Excluding arable land cover, all independent variables were positively and significantly correlated with bryophyte richness; the strongest linear correlations with the total number of bryophyte species per county were found for surveyed area and elevational range. A negative significant correlation was found between arable land cover and species richness.

Discussion

When comparing the Hungarian bryophyte flora with that of other Central European countries, we have to exclude those with significant alpine or high-montane areas. This includes all the adjacent countries (Austria, Slovenia, Croatia, Serbia, Romania, Ukraine and Slovakia). Three German federal states (Niedersachsen, Brandenburg and Mecklenburg-Vorpommern) are, like Hungary, predominantly lowland. Although these states are individually much smaller in size, their areas ranging from 23,200 km² to 47,600 km², their bryophyte richness is not far behind that of Hungary or is even higher: Niedersachsen having

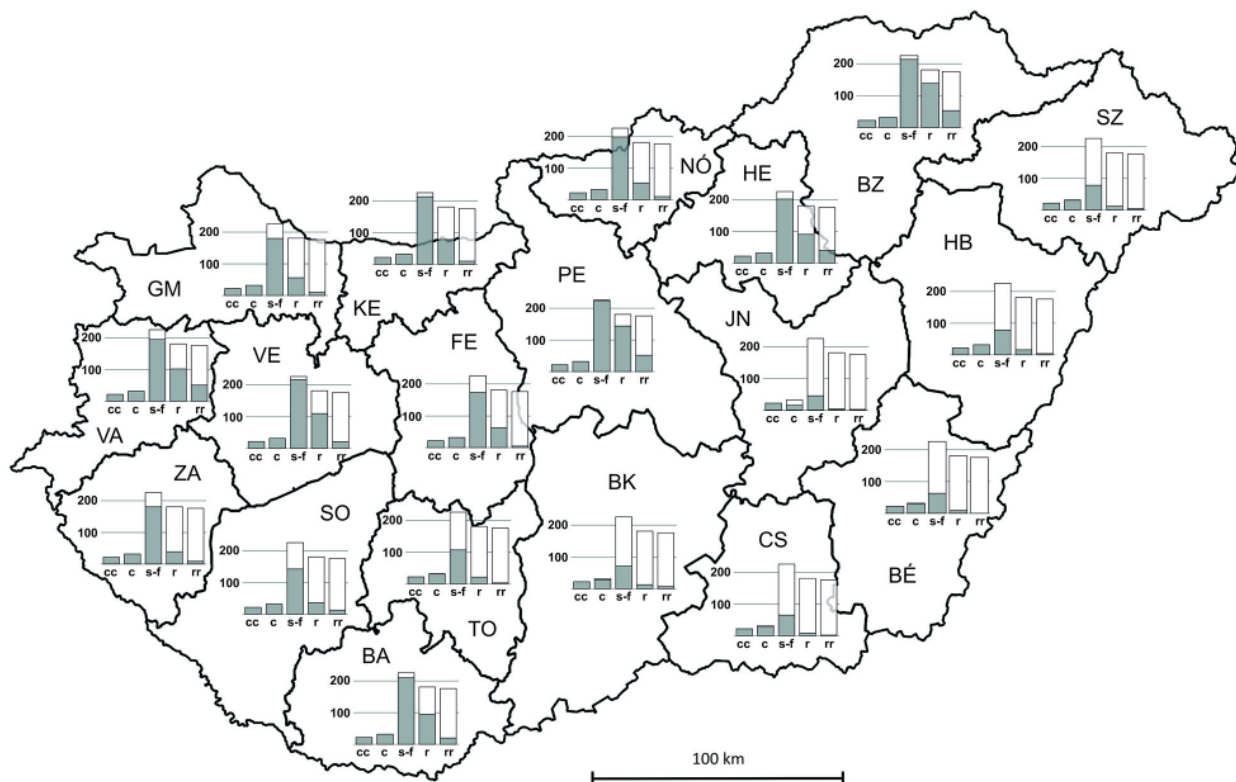


Figure 2. Distribution of frequency classes of bryophytes in the 19 counties of Hungary, based on the data in [Appendix 1](#). Column length is proportional to the number of taxa present (grey) or absent (white) in each county. cc = very common, c = common, s-f = sporadic to frequent, r = rare, rr = very rare. County abbreviations as shown in [Table 1](#).

Table 5. Pearson's linear correlations between dependent and independent variables.

Variable	Surveyed area	Forest cover	Arable land cover	Total no. of bryophytes/county
Elevational range	0.766**	0.680*	-0.582*	0.909***
Surveyed area		0.641*	-0.589*	0.917***
Forest cover			-0.928***	0.696**
Arable land cover				-0.623*

* $p_{\text{uncorr}} < 0.05$, ** $p_{\text{uncorr}} < 0.001$, *** $p_{\text{uncorr}} < 0.0001$.

758 taxa (Koperski et al. 2011); Brandenburg, 580 taxa (Klawitter et al. 2002); and Mecklenburg-Vorpommern, 557 taxa (Berg et al. 2009). These differences can be easily explained by the species richness trends in Europe (Hodgetts et al. 2019), according to which species richness from the Atlantic and northern areas shows a decreasing trend towards the interior of the continent, the east and the south.

The quadrants with the highest number of taxa were 7980.2 in Pest County and 8664.2 in Vas County; 236 taxa were found in each, representing 33.8% of the national bryophyte flora. Given the geographical situation of Hungary, these numbers compare favourably with corresponding results from Thuringia, Germany, where 355 species were recorded in the most species-rich quadrant (5072.2) (Meinunger

1992), and Carinthia, Austria, where the maximum species number of 361 (40.4% of the 893 bryophyte species of Carinthia) was found in the alpine quadrant 8942.4 (Köckinger et al. 2008).

Considering the geographical distribution of taxa in the country, we find a rather large group with no records from the predominantly lowland counties BÉ, BK, CS, HB, JN, SO, SZ and TO. Interestingly, for most of them this type of geographical distribution was already reported in Orbán and Vajda (1983) as being frequent in mountain and colline areas but mostly lacking or rare in the lowlands ([Appendix 1](#)). The only lowland records of some taxa are often in artificial rocky habitats in the Vácrtót Botanical Garden or similar arboreta.

As shown in [Figure 2](#), the above-mentioned lowland counties (cf also [Figure 1](#)) have low proportions of taxa of intermediate (s-f) and low (r, rr) frequency. This is not surprising, because unfavourable climatic conditions and lack of other than the most common habitats give rise to the presence of fewer specialist and rare taxa. The greater diversity in those counties with some mountainous area (in the western part of the country, GM and VA; in the transdanubian and the northern mountain ranges VE, KE, PE, NÓ, HE, BZ; and BA in the south) could be explained by the fact that areas of higher elevation provide more and different types of microhabitat for species normally restricted to colline and mountain areas, which therefore have

lower national frequencies. However, because our survey shows bias towards the higher parts of the country, this might also contribute to the observed pattern.

All the hypotheses derived from the literature were supported by our results: the total number of bryophytes increases with increasing survey effort (Callaghan 2012), size of the explored area (Patiño and Vanderpoorten 2018), increased forest cover (Caners et al. 2013) and elevational range (Theurillat et al. 2003; Hodgetts et al. 2019), as well as decreasing arable land cover (Zechmeister and Moser 2001). Although Hungary is a predominantly lowland country, as 82.4% of its territory is situated below 200 m a.s.l. and only 0.6% rises above 500 m a.s.l., elevational range was the most significant variable influencing the species richness of the counties. This also means that the very small part of the country at higher elevation will produce significantly higher numbers of species in counties (e.g. as is the case with GM). However, 46.6% of the national territory is arable land and 20.8% is forest (Kocsis 2018); these independent variables influenced species richness at almost the same level but in opposite directions. This also suggests that a small increase in forest cover can lead to a significant increase in species numbers, especially if the increase in (semi-natural) forest area is at the expense of arable land. We must also not forget that our data collection is biased: we have primarily visited the higher regions (which are also more forested than the lowlands). Despite these sampling deficiencies, in the best case a survey of only 31.8% nationally, and only 38% per county on average, proved to be sufficient to confirm some fundamental bryogeographical theories in Hungary. Moreover, for the first time we shall have the opportunity in the near future to compile a Hungarian bryophyte Red List based on national frequency data, with which we have been able to support some basic, robust bryogeographical trends.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix 1. Presence/absence data of bryophyte taxa according to the Hungarian county system.

Abbreviations: cc = very common, c = common, s-f = sporadic to frequent, r = rare, rr = very rare, n.s. = not seen since 1973, C&M* = confined to colline and montane areas according to Orbán and Vajda (1983), full circle = recent records (from 1974 on), empty circle = historical records (up to 1973).

