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TECHNIQUES AND STRATEGIES

A case study on the use of multivariate techniques in phytogeographic analysis of bryophytes in the Veľká Fatra Mountains

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Abstract. Classical phytogeographic analysis focuses on the analysis of areal types, floristic elements, vertical distribution of species, ecology, and threats. The focus of this study is the use of alternative approaches in phytogeographic analysis. The results of multidimensional analysis proved to be effective, revealing previously undiscovered relationships. For example, a common feature of species with Holarctic to North American distribution is the predominance of the (sub)boreal areal type, while a common feature of species with the European to African areal type is the predominance of the (sub)oceanic areal type.

Key words: phytogeographic analysis, bryophytes, distribution, areal types, multivariate analysis, Veľká Fatra Mountains

Introduction

460 taxa of bryophytes (99 liverworts and 361 mosses) were counted within Veľká Fatra National Park (Slovakia). They inhabit a wide range of habitats, including rocks, forests and scrubs, bare soil, tree bark, stumps, roots, rotting wood, meadows, pastures, fens, raised bogs, waterways, and other anthropogenic biotopes. Some species are characterized by a wide range of vertical distribution while others are bound to a narrower range of altitudes.

Phytogeography as a scientific discipline deals with the principles of the spread of vegetation, and is dedicated to the study of plant environments and their relationship to a habitat. It takes into account historical, climatic and pedological conditions, contributes to the protection of a specific location, identifies its characteristics, reveals vulnerable elements and the direction of conservation interventions. Phytogeography records the presence of areal types, floristical elements, and the occurrence of dealpine or thermophilic species.

The goal of the presented study is the use of multidimensional techniques that have not been used in phytogeographical analysis to-date. The study illustrates the possibility of an alternative use of data on horizontal distribution of bryophyte species for the study of their relationship to the habitat and also their preference for areal types. Multidimensional techniques offer the possibility of using other predictors for the study of the relationship between the plant environment and the habitat, (e.g., pedological, climatic, phytocenological and other parameters).

Material and Methods

Phytogeographical analysis is based on the works of Düll (1994a; 1994b) and Düll and Meinunger (1989). For the purpose of vertical differentiation, processed species were included in altitude levels: planar (average altitude 150 m a.s.l.), colline (average altitude 225 m a.s.l.), submontane (average altitude 750 m a.s.l.), montane (average altitude 1200 m a.s.l.), subalpine (average altitude 1650 m a.s.l.), alpine (average altitude 2000 m a.s.l.). These parameters are guided by literary data and previous records. In the case of occurrence of species in several vegetation stages, the average altitude was decisive for classifying the species in the vertical level. In the case of the alpine vegetation stage, this region included species that also descend to lower altitudes, but are optimum in the alpine stage, e.g., *Orthotrichum alpestre, Hylocomiastrum pyrenaicum, Tortula hoppeana* and others.

When tested by the detrended method, the length of the first gradient in the log report was 2.38, and we have available predictors that represent data on the horizontal distribution of bryophyte species and also their preference for types of areas. Taking into account the above, the linear method (RDA) (Lepš and Šmilauer 1999; Ter Braak and Šmilauer 2002) was used for ordination analysis. As distribution of data did not meet the criteria of a normal distribution (Gauss probability distribution), we subjected the data to a logarithmic transformation. Processing marginal vegetation stages, the vertical range is considerably reduced, therefore we used indirect unimodal correspondence analysis (CA).

In order to clarify the correlation structure, we used factor analysis (Kubíková *et al.* 2013), the result of the factor analysis are groups of variables (factor loadings) that explain the correlation structure. The advantage of this multivariate statistical method is the possibility of factor coordinate rotation, so that a distinct correlation structure is created.

The nomenclature of mosses follows Mišíková *et al.* (2020), while liverwort follows Mišíková *et al.* (2021).

Results and Discussion

97 species of liverworts and 348 species of mosses recorded in Veľká Fatra were processed.

I. Ordination analysis

We used the direct linear method (RDA) to analyze the relationship between the areal types, vertical levels and types of horizontal distribution of liverworts and mosses.

Liverworts

The input species data set of the ordination diagram illustrating the relationship between areal types (Fig. 1) and vertical levels consists of the numbers of liverwort species in the types of horizontal distribution represented in the vertical levels (Table 1). The number of liverwort species in the types of horizontal distribution represented in the areal types were used as environmental variables (Table 2).

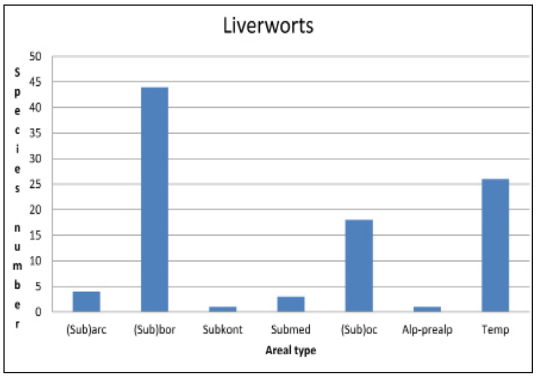

Fig. 1. Liverworts, species number in areal types.

Ordinal axis 1 explains 78.2% of the variance (Fig. 2), this axis is positively correlated, particularly for (sub)boreal (r = 0.8677), (sub)oceanic (r = 0.7995) and temperate (r = 0.7857) areal types. Holarctic species are predominantly presented and the species-environment correlation is 0.882. Ordinal axis 2 explains 3.9% of the variance, and this axis is negatively correlated with subcontinental (r = -0.1533) and alpine-pre-alpine (r = -0.2349) areal types. In Euro-Siberian and North American species, the species-environmental correlation is 0.118. While the temperate, (sub)boreal and (sub) oceanic areal types prefer species of the colline to montane vegetation level, the subcontinental and alpine-prealpine areal type often prefer the species of the subalpine to alpine vegetation level (Fig. 2) (*Scapania helvetica*). In addition to a high number of liverwort species with a (sub)boreal areal type and a distribution center in Northern Europe (e.g., *Neoorthocaulis attenuatus, Conocephalum conicum, Mylia anomala*). We recorded a high number of temperate liverwort species (e.g., *Marchantia polymorpha, Pellia epiphylla, Plagiochila asplenioides*), including species with a distribution center in the temperate zone. Some temperate species occur in the lowest areas of the territory, (e.g., *Riccia cavernosa, R. fluitans* in the planar to colline level (Fig. 2, upper left hand corner, the area consists of Eurasia, Africa, North America). Vertically higher, up to the submontane level, some temperate species occur (e.g., *Cephaloziella rubella, Cephaloziella*

Vertical levels	*altitude (m a.s.l.)	a	b	c	d	e	f	g	h	i	j	k	Sum
Plan-collin	200	1	0	0	0	0	0	1	1	0	0	0	3
Collin-submont	600	0	0	0	0	0	0	0	1	0	0	7	8
Submont-mont	950	1	0	3	3	2	2	1	5	3	1	32	53
Mont-subalp	1400	0	0	1	0	2	1	0	5	3	0	20	32
Subalp-alp	1900	0	1	0	0	0	0	0	0	0	0	0	1

* Altitude refers to the interface of the respective vertical levels.

Table 1. Numbers of liverworts in types of horizontal distribution presented in vertical levels. Ordinal values: a – cosmopol; b – eur; c – eur-afr; d – eur-afr-n.am; e – euras; f – euras-afr; g – eur-as-afr-n.am; h – eur-as-n.am; i – eur-n.am; j – eurosib-n.am; k – holarc.

Areal type	a	b	c	d	e	f	g	h	i	j	k	Sum
(Sub)arc	0	0	0	0	0	0	1	1	0	0	2	4
(Sub)bor	0	0	0	0	0	1	4	5	1	3	30	44
Subcont	0	0	0	0	0	0	0	0	0	1	0	1
Submed	0	0	0	0	0	1	1	0	0	0	1	3
(Sub)oc	0	0	1	2	2	1	3	1	0	0	8	18
Alp-prealp	0	1	0	0	0	0	0	0	0	0	0	1
Temp	2	0	0	1	1	2	4	0	1	0	15	26

Table 2. Numbers of liverworts in types of horizontal distribution presented in areal types. Ordinal values: a – cosmopol; b – eur; c – eur-afr; d – eur-afr-n.am; e – euras; f – euras-afr; g – eur-as-afr-n.am; h – eur-as-n.am; i – eur-n.am; j – eurosib-n.am; k – holarc.

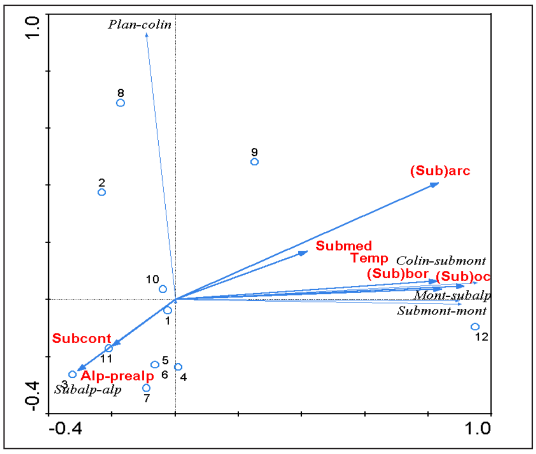

Fig. 2. RDA, liverworts, triplot, relationship of areal types, vertical levels and types of horizontal distribution. a – cosmopol; b – eur; c – eur-afr; d – eur-afr-n.am; e – euras; f – euras-afr; g – eur-as-afr-n.am; h – eur-as-n.am; i – eur-n.am; j – eurosib-n.am; k – holarc.

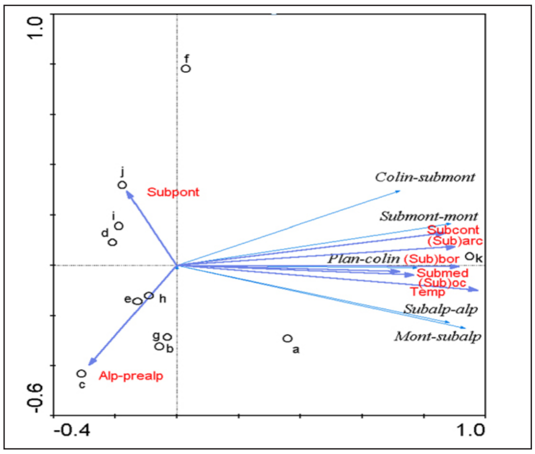

Fig. 3. RDA, moss species, triplot, relationship of areal types, vertical levels and types of horizontal distribution. a – subkosm; b – circpol; c – eur; d – eur-afr; e – eur-afr-n.am; f – euras; g – eur-as-afr; h – eur-as-afr-n.am; i – eur-as-n.am; j – eur-n.am; k – holarc.

**sullivantii* (Fig. 2, right hand section). There are numerous species with a suboceanic areal type, and they often occupy wetter habitats (e.g., *Fuscocephaloziopsis connivens, Scapania aspera, Trichocolea tomentella*). Several suboceanic species have a wide areal in Europe, Africa, North America, or Asia, (e.g., *Pedinophyllum interruptum, Calypogeia suecica* and others). Sub(boreal) and temperate species often have Holarctic distribution. We recorded four subarctic liverwort species, two of which are representatives of the genus *Scapania* (*Scapania apiculata, S. scandica*).

Mosses

The input species data set of the diagram illustrating the relationship between areal types and vertical levels (Fig. 3) are the numbers of moss species in the types of horizontal distribution presented in vertical levels (Table 3). As environmental variables, the numbers of moss species in the types of horizontal distribution presented in the areal types were used (Table 4).

Ordinal axis 1 explains 74.9% of the variance, (Fig. 3). (Sub)boreal (r = 0.8651), subcontinental

Vertical levels	***altitude (m a.s.l.)**	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**Sum**
Plan-collin	200	1	0	0	0	0	0	1	0	1	1	4	7
Collin-submont	600	2	0	1	1	4	6	1	1	5	1	29	51
Submont-mont	950	29	4	0	2	5	13	3	3	8	4	127	198
Mont-subalp	1400	12	2	1	0	2	1	1	1	1	0	45	66
Subalp-alp	1900	2	0	0	0	2	0	2	1	0	0	19	26

* Altitude refers to the interface of the respective vertical levels

Table 3. Numbers of moss species in types of horizontal distribution presented in vertical levels. Ordinal values: a – subcosm; b – circpol; c – eur; d – eur-afr; e – eur-afr-n.am; f – euras; g – eur-as-afr; h – eur-as-afr-n.am; i – eur-as-n.am; j – eur-n.am; k – holarc.

Areal type	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**Sum**
(Sub)arc	2	1	1	0	0	3	0	2	0	1	25	35
(Sub)bor	12	4	1	0	1	2	5	0	0	2	114	141
Subcont	0	0	0	0	0	3	3	1	0	0	13	20
Submed	1	1	0	0	1	3	7	1	0	0	8	22
(Sub)oc	0	1	1	2	1	2	6	8	1	1	18	41
Subpont	0	0	0	0	0	0	0	0	0	1	0	1
Alp-prealp	0	0	1	0	0	0	0	0	0	0	0	1
Temp	23	0	0	0	0	1	6	3	0	1	53	87

Table 4. Number of moss species in types of horizontal distribution presented in arealtypes. Ordinal values: a – subcosm; b – circpol; c – eur; d – eur-afr; e – eur-afr-n.am; f – euras; g – eur-as-afr; h – eur-as-afr-n.am; i – eur-as-n.am; j eur-n.am; k – holarc.

(r = 0.8213), subarctic (r = 0.8524) and (sub)oceanic (r = 0.7250) areal types, are positively correlated with this axis. Holarctic species are predominantly presented, preferring the planar level to the colline level. The species-environment correlation is 0.882. Ordinal axis 2 explains 5.0% of the variance. On the 2nd axis, the subpontic areal type is slightly positively correlated (r = 0.2351) with European to North American species, and the alpine-prealpine areal type is negatively correlated (r = -0.3185) with predominantly Eurasian, African and North American species. The species-environmental correlation is 0.802.

Similarly to liverworts, the most abundant (sub)boreal areal type and temperate areal type for mosses were recorded (Fig. 4). Species of (sub) boreal areal type have an optimum distribution in Northern Europe. In the study area, they are often found in the montane to subalpine vegetation level. Temperate species have a center of distribution in the temperate zone. Both (sub)boreal and temperate species have the most frequent Holarctic distribution (Fig. 3). In the Sub-mediterranean element, we noted the presence of rare thermophilic species, (e.g., *Pottiopsis caespitosa* and *Entosthodon muhlenbergii*). The vertical diversity of the territory lends it to a relatively high number of species with a subarctic areal type, and a preference for colder habitats (e.g., *Molendoa sendtneriana, Roaldia revoluta*). Some of these species prefer the highest locations of the studied area, (e.g., *Dicranum spadiceum, Lescuraea plicata, Stegonia latifolia,* and *Syntrichia norvegic*).

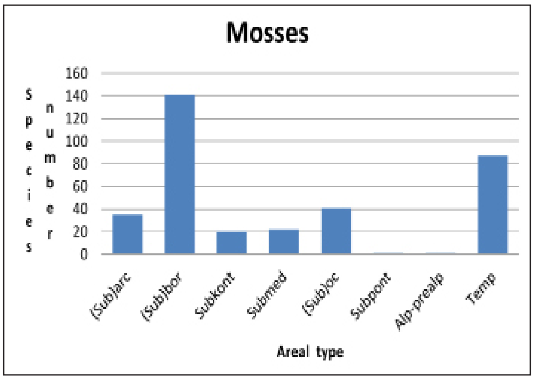

Fig. 4. Mosses, species number in areal types.

Phytogeographical analysis of bryophytes of marginal vegetation levels (lowest and highest locations of Veľká Fatra Mountains)

All bryophyte species presented in the Veľká Fatra orographic unit are analyzed, with a total of 340 species. Liverworts (*Hepaticopsida*) and mosses (*Muscopsida*) are distinguished. When analyzing the bryophytes from marginal vegetation levels, due to the limited number of species, these taxa are evaluated together. We omitted the variable "altitude" from the data matrix, because by focusing on a narrow vertical range, this parameter is considerably reduced. We used unimodal indirect correspondence analysis (CA).

Bryophytes with the occurrence center in the lowest levels of Veľká Fatra Mountains

In the analysis, we included a total of 30 species with a focus of occurrence in Slovakia in the planar to colline vegetation level. The vertical optimum for the occurrence of the selected species in the conditions of Veľká Fatra Mountains is at an altitude of approximately 400 to 650 m a.s.l. Some species with an optimum occurrence in the planar to colline vegetation level were also included (Table 5). In this case the limestone or dolomite substrate allows them to penetrate to higher altitudes (Table 6, Fig. 5). For example, the moss species *Grimmia tergestina* has an optimum occurrence in the colline level, but the moss was recorded above Plavecké Podhradie Settlement (300 m a.s.l.), on Pohanská hora Hill near Plavecký Mikuláš Settlement (300 m a.s.l.), on Súľovské skály Rocks (400 m a.s.l.), on the Silická planina Plain (400-600 m a.s.l.) as well as in other locations (Šmarda 1948). In the conditions of Veľká Fatra Mountains, we also recorded moss at significantly higher altitudes (Ostredok, 1520 m a.s.l.). The occurrence of the moss species *Trichostomum crispulum* in Veľká Fatra Mountains is recorded on the Súľovské skaly Rocks (380 m a.s.l.), in Manínska tiesňava Ravine (650 m a.s.l.), at the mouth of Suchá Belá Gorge (550 m a.s.l.), at the Kláštorisko Resort (600 m a.s.l.) (Šmarda 1961a) and in the Prielom Dunajca Gorge (450 m a.s.l.) (Blackburn *et al.* 1997). However, in the Veľká Fatra Mountains the moss also penetrated to altitudes of more than 1300 m a.s.l. (Haľamova kopa Mt, 1340 m a.s.l.; Tlstá Mt, 1370 m a.s.l.). The moss species *Pterygoneurum ovatum* is found in Slovakia on loess substrata in the planar to colline level, (e.g., near the villages of Veľké Zálužice (180 m a.s.l.), Bučany (140 m a.s.l.), Kamenica nad Hronom (300 m a.s.l.), near Trnava Settlement (140 m a.s.l.) (Peciar 1970). In the Veľká Fatra Mountains, this moss was recorded at an altitude of 950 m a.s.l. on Drienok Hill. The liverwort *Cephaloziella *sullivantii* was recorded in the Veľká Fatra Mountains at an altitude of 1000 m a.s.l. on the Kútnikov kopec Hill near Ľubochna Settlement (Duda and Váňa 1974). In Slovakia, this liverwort was also recorded at a significantly lower altitude, near Zemianske Podhradie Settlement at an altitude of 248 m a.s.l. m (Šmarda 1961b).

Ordinal axis 1 (Eigenvalue 0.393) explains more than 63% of the variance. The temperate areal type positively correlates with this axis, and sub-cosmopolitan, Holarctic, European to North American species as well. Ordinal axis 2 (Eigenvalue 0.168) explains 27% of the variance, and correlates positively with the subcontinental, (sub)oceanic areal types as well as some Eurasian and African species. In the lowest locations of the Veľká Fatra Mountains, the most numerous species are Holarctic (15 species, 46.8%) – includig *Anomodon viticulosus, Callicladium haldanianum, Drepanocladus aduncus, Leskea polycarpa* and others. Thermophilic species thrive at these altitudes, while the largest number of species have a temperate areal type: *Cephaloziella *sullivantii, Riccia cavernosa, Riccia fluitans - Aloina rigida, Brachythecium mildeanum, Dicranum fulvum, Pterygoneurum ovatum, Tortula acaulon, T. caucasica, T. lindbergii. Entosthodon*

Species	Horizontal distribution	Areal types	Vertical levels
Calypogeia fissa	eur-w.as-afr-n.am	suboc	planar-submont
*Cephaloziella *sullivantii*	eur-n.am	temp	planar-submont
Riccia cavernosa	eurosib-afr(m)-n.am	temp	planar-collin
Riccia fluitans	cosm	temp	planar-collin
Aloina rigida	holarc(-bip)	temp	planar-submont
Anomodon viticulosus	holarc	temp	(planar) collin-submont
Brachythecium mildeanum	holarc	temp	(planar) collin-submont
Brachythecium laetum	eur-w.as-n.afr-n.s.am	subcont	collin-submont
Callicladium haldanianum	dj-holarc	subcont	planar-submont
Didymodon vinealis	dj-holarc	submed	planar-collin
Ditrichum pusillum	holarc	temp	planar-submont
Drepanocladus aduncus	subcosm	temp	planar-submont
Entosthodon fascicularis	eur-n.afr-n.am	suboc	planar, collin (submont)
Entosthodon muhlenbergii	eur-w.e.as-afr-n.c.am	submed	collin
Hygroamblystegium varium	holarc(-bip)	temp	planar-submont
Grimmia tergestina	eur-as-afr	submed	collin
Isothecium myosuroides	dj-holarc	oc-mont	collin-submont
Leskea polycarpa	holarc	temp	planar-submont
Mnium hornum	dj-eur-w.e.as-afr-n.am	suboc	planar-submont
Oxyrrhynchium schleicheri	eurosib-w.as-afr(m)	submed	planar-submont
Oxyrrhynchium speciosum	eur-w.e.as-afr-n.am	temp	planar-submont
Plasteurhynchium striatulum	eur-w.as-afr	submed	collin-submont
Pottiopsis caespitosa	eur-w.as-n.afr	submed	collin
Pterygoneurum ovatum	dj-holarc(-bip?)	temp	planar-submont
Racomitrium heterostichum	eur-w.as-n.am-afr(mac)	suboc	planar-submont
Tortula acaulon	holarc(-bip)	temp	planar-submont
Tortula lindbergii	dj-holarc	temp	planar-submont
Thuidium tamariscinum	dj-holarc(-bip)	suboc	planar-submont
Trichostomum crispulum	eur-w.as-afr	suboc	planar/collin
Weissia condensa	dj-holarc	submed	collin-mont

Table 5. List of selected species of the lowest levels of the Veľká Fatra Mountains.

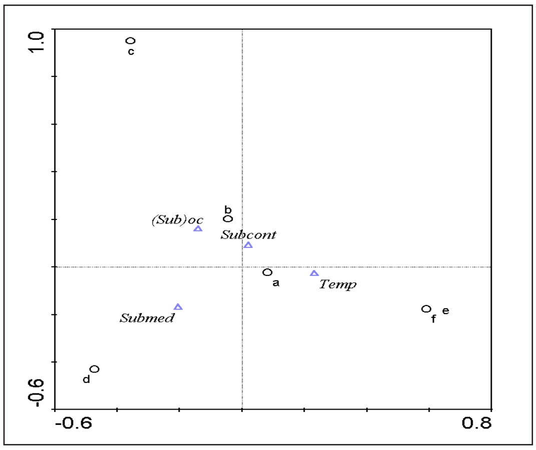

Fig. 5. Correspondence analysis (CA). Ordination of bryophytes of the lowest levels of the Veľká Fatra Mountains, relation of areal types and types of horizontal distribution. Types of horizontal distribution: a – holarc; b – eur-w.e.as-afr-n.am; c – eur-n.afr-n.am; d – eur-as-afr; e – eur-n.am; f – (sub)cosm.

Areal type	a	b	c	d	e	f
Subcont	1	1	0	0	0	0
Submed	2	1	0	4	0	0
(Sub)oc	2	3	1	1	0	0
Temp	9	2	0	0	1	2

Table 6. Numbers of bryophytes of the lowest level of the Veľká Fatra Mountains in the types of horizontal distribution. Types of horizontal distribution: a – holarc; b – eur-w.e.as-afr-n.am; c – eur-n.afr-n.am; d – eur-as-afr; e – eur-n.am; f – (sub)cosm.

muhlenbergii and *Pottiopsis caespitosa* have a sub-Mediterranean areal type, *Brachythecium laetum* has a sub-continental areal type and *Entosthodon fascicularis* has a suboceanic areal type. Temperate species make up 43.75% of the inventory of planar to submontane species. Species in the lowest vegetation zones are mostly bound to sunlit limestone rocks, though *Tortula acaulon* and *T. lindbergii* prefer soil covered rocks, *Dicranum fulvum* tolerates shaded limestone, and *Potiopsis caespitosa* occupies moist, limestone terraces.

Bryophytes with the occurrence center in the highest levels of Veľká Fatra Mountains

The highest point of Veľká Fatra is Ostredok, at 1595 m a.s.l. In the list of 20 selected species (Table 7), we have also included several species of bryophytes. In Slovakia, these have a distribution center in the alpine level, only descending down to lower vegetation levels on an exceptional basis. For example, *Mnium thomsonii* is a relatively abundant species in the Veľká Fatra Mountains in crevices and on limestone rock terraces, especially at the highest altitudes, but it descends down to 500 m a.s.l. *Plagiobryum demissum* is also a common species at the highest levels. Šmarda (1948) recorded this moss in the Necpalská dolina Valley at an altitude of only 1000 m a.s.l. The liverwort *Mesoptychia bantriensis* is a species widespread in higher altitudes, especially on limestone and dolomite rocks, but it also descends down to lower altitudes. Kochjarová *et al.* (2010) report the occurrence of liverwort in the Čertova brána Strait at an altitude of 630 m a.s.l. (Table 8, Fig. 6).

Ordinal axis 1 (Eigenvalue 1.0000) explains more than 62% of the variance. Alpine and pre-alpine areal types and the European species (*Scapania helvetica*) are positively correlated with this axis. Ordinal axis 2 (Eigenvalue 0.3259) explains more than 25% of the variance. (Sub)boreal species (moss *Mnium thomsonii*, liverworts *Bazzania tricrenata* and

Areal type	a	b	c	d	e	f
(Sub)arc	9	1	1	1	0	0
Arc-alp	2	1	0	0	0	0
(Sub)bor	2	0	0	0	0	1
(Sub)oc	1	0	0	0	0	0
Alp-prealp	0	0	0	0	1	0

Table 8. Numbers of bryophytes of the highest level of the Veľká Fatra Mountains in the types of horizontal distribution. Types of horizontal distribution: a – holarc; b – euras; c – circpol; d – eur-n.am; e – eur; f – eurosib-n.am.

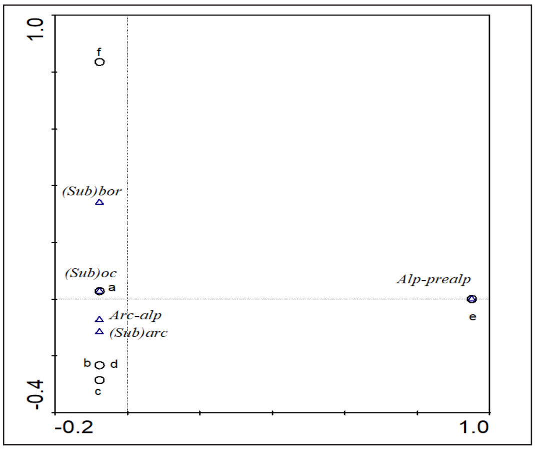

Fig. 6. Correspondence Analysis (CA). Ordination of bryophytes of the highest level of the Veľká Fatra Mountains, relation of areal types and types of horizontal distribution. Types of horizontal distribution: a – holarc; b – euras; c – circpol; d – eur-n.am; e – eur; f – eurosib-n.am.

Species	Horizontal distribution	Areal types	Vertical levels
Bazzania tricrenata	holarc	(sub)bor	mont-alp
Scapania helvetica	eur	alp-prealp	mont-alp
Mesoptychia bantriensis	eurosib-n.am	(sub)bor	mont-alp
Brachythecium erythrorrhizon	holarc	(sub)arc	(subalp) alp
Bryum archangelicum	euras	arc-alp	alp
Campylium bambergeri	circpo	(sub)arc	(subalp)alp
Dicranum elongatum	holarc	(sub)arc	(subalp)alp
Dicranum spadiceum	holarc	(sub)arc	(subalp)alp
Hylocomiastrum pyrenaicum	holarc	(sub)arc	(subalp)alp
Lescuraea plicata	eur-n.am.	(sub)arc	mont-alp
Mnium thomsonii	holarc	(sub)bor	mont-alp
Orthotrichum alpestre	holarc	(sub)arc	(subalp)alp
*Orthotrichum *fuscum*	euras	(sub)arc	(subalp)alp
Plagiobryum demisum	holarc	arc-alp	mont-alp
Plagiobryum zieri	holarc	(sub)arc	alp
Pseudostereodon procerrimus	holarc	(sub)oc	(subalp)alp
Roaldia revoluta	holarc	(sub)arc	(subalp)alp
Stereodon hamulosus	holarc	(sub)arc	(subalp)alp
Stegonia latifolia	holarc	arc-alp	alp
Tortula hoppeana	holarc	(sub)arc	(subalp)alp

Table 7. List of selected species of the highest levels of the Veľká Fatra Mountains.

Mesoptychia bantriensis) are positively correlated with this axis. (Sub)arctic species (*Dicranum spadiceum, Campylium bambergeri* and others) and some arctic-alpine species are negatively correlated with this axis (e.g., *Bryum archangelicum*). These species have circumpolar or European to North American distribution.

Bryophytes, which find their optimum occurrence at the alpine level. In the Veľká Fatra Mountains they often occupy limestone rocks, or rocky walls at altitudes from 1350 m a.s.l. (*Bryum archangelicum, Stereodon hamulosus, Roaldia revoluta, Stegonia latifolia, Orthotrichum *fuscum). Brachythecium erythrorrhizon* occupies moss-covered debris, *Dicranum spadiceum* occurs in grassy places up to an altitude of 1550 m a.s.l. *Orthotrichum alpestre* is an epiphyte, and was recorded at an altitude of 1300 m a.s.l.. The liverwort *Scapania helvetica* was recorded at the top of Majerova skala Rock (1283 m a.s.l., Boros *et al.* 1960; Šmarda 1961c). These are mostly species of the (sub)arctic areal type, of Eurasian and Holarctic species. *Scapania helvetica* has an alpine-prealpine areal type and is a European species.

II. Factor analysis

When determining the number of factors to extract for factor analysis, we opted for principal component analysis as the most frequently used method. Eigenvalues: PC1 8.057; PC2 6.352; PC3 3.885; PC4 2.359. An eigenvalue >1 belongs to the first four components and they explain 93.9% of the variance. We used the Varimax raw rotation because it transforms the factor loadings so that the variance of their values is maximal. This type of rotation offers the most meaningful interpretation. The factor loadings are shown in Table 9, and the ordination of types of horizontal distribution is depicted in Fig. 7.

Factor 1 explains 36.6% of the variance. In both liverworts (horizontal distribution types h,j,k) and mosses (horizontal distribution types m,v,z), this factor correlates primarily with European to North American and Holarctic species (Table 9). A common feature is the predominance of the (sub)boreal type of the areal (Fig. 7, bottom right hand corner).

Factor 2 explains 28.9% of the variance. In both liverworts (horizontal distribution types c,d,e) and mosses (horizontal distribution types o,t,u), this factor correlates with European to African (North American) species (Table 9). A common feature is the predominance of the (sub)oceanic areal type (Fig. 7, upper left hand corner).

Factor 3 explains 17.7% of the variance. The structure of factor loadings is mainly determined by liverworts (horizontal distribution types a,f,i, Table 9), and a common feature is the predominance of the temperate areal type.

Factor 4 explains 10.7% of the variance, the negative correlation of the European and Eurasian type of horizontal distribution is striking.

The graph of the ordination of types of horizontal distribution (Fig. 7) presents the correlation of the type of horizontal distribution of liverworts "f" (Eurasia, Africa) with the type of horizontal distribution of mosses "s" (Europe, Asia, Africa) (middle part of the graph), with the exception of the type of horizontal distribution, a common feature is also the prevailing temperate areal type.

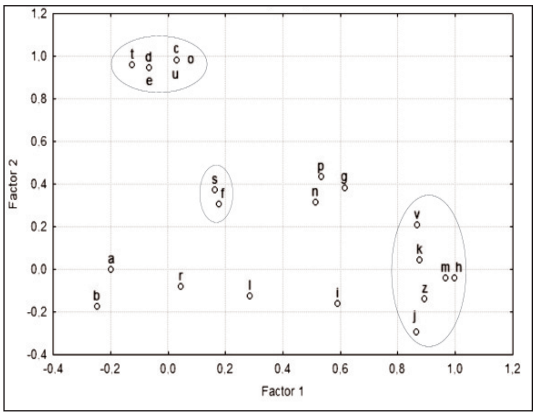

Fig. 7. Bryophytes, ordination of types of horizontal distribution, factor 1 vs. factor 2. Types of horizontal distribution: a – cosmopol; b – eur; c – eur-afr; d – eur-afr-n.am; e – euras; f – euras-afr; g – eur-as-afr-n.am; h – eur-as-n.am; i – eur-n.am; j – eurosib-n.am; k – holarc; l – subcosm; m – circpol; n – eur; o – eur-afr; p – eur-afr-n.am; r – euras; s – eur-as-afr; t – eur-as-afr-n.am; u – eur-as-n.am; v – eur-n.am; z – holarc.

Var.	Factor 1	Factor 2	Factor 3	Factor 4
a	-0.198	-0.002	**0.970**	-0.054
b	-0.246	-0.175	-0.212	**-0.826**
c	0.031	**0.983**	-0.158	0.030
d	-0.065	**0.943**	0.314	0.003
e	-0.065	**0.943**	0.314	0.003
f	0.179	0.304	**0.851**	0.280
g	0.616	0.383	0.675	0.102
h	**0.998**	-0.041	-0.047	0.007
i	0.592	-0.160	**0.787**	-0.028
j	**0.865**	-0.295	-0.029	0.117
k	**0.876**	0.041	0.472	0.014
l	0.286	-0.128	**0.944**	-0.025
m	**0.967**	-0.043	-0.106	0.170
n	0.514	0.313	-0.439	-0.611
o	0.031	**0.983**	-0.158	0.030
p	0,533	0.433	-0.168	0.473
r	0,047	-0.081	-0.390	**0.831**
s	0,165	0.373	0.462	0.672
t	-0,124	**0.959**	0.095	0.112
u	0,031	**0.983**	-0.158	0.030
v	**0.868**	0.206	0.303	-0.037
z	**0.895**	-0.140	0.406	0.061
Expl. Var.	6.548	6.493	5.037	2.577

Table 9. Factor loadings (Varimax raw; Extraction: Principal components). Types of horizontal distribution: a - k Liverworts: a – cosmopol; b – eur; c – eur-afr; d – eur-afr-n.am; e – euras; f – euras-afr; g – eur-as-afr-n.am; h – eur-as-n.am; i – eur-n.am; j – eurosib-n.am; k – holarc. l - z Mosses: l – subcosm; m – circpol; n – eur; o – eur-afr; p – eur-afr-n.am; r – euras; s – eur-as-afr; t – eur-as-afr-n.am; u – eur-as-n.am; v – eur-n.am; z – holarc.

Conclusion

Classical phytogeographical analysis focuses on the analysis of the areal types of the evaluated species, their abundance, vertical distribution, ecology, the presence of Dealpine species and threats. This is how we focused the floristic-phytogeographic characteristics of the bryophytes of the Veľká Fatra Mountains tin the monographic study of the Nature of the Veľká Fatra Mountains (Šoltés *et al.* 2008).

In the presented study, we used the linear method and entered the data of the horizontal distribution of bryophyte species into the ordination as predictors. The following redundancy analysis and factor analysis revealed new associations that were obscured by the usual approach, such as the preference of liverwort species of European to Europe-Siberian distribution in the alpine-prealpine areal type. In the case of mosses, the alpine-prealpine areal type is preferred by species with a distribution in Europe and Africa, and the subpontic areal type is preferred by species with a distribution Europe to North America. Within the lowest levels of the Veľká Fatra Mountains, species of (sub)oceanic and subcontinental areal types occupy a wide range (Europe, Asia, Africa, America), while the temperate areal type is preferred by species of Holarctic distribution. In the highest levels of the Veľká Fatra Mountains, the (sub) arctic areal type is the most common. In terms of horizontal distribution, they are of Eurasian and Holarctic species.

The analysis of factor loadings provided remarkable results. The common feature of species with North American and Holarctic distribution is the predominance of the (sub)boreal areal type, whereas the common feature of species with the European to African (North American) distribution is the predominance of the (sub) oceanic areal type.

When using climatic, pedological, orographic, phytocenological or ecological data as predictors, an alternative analysis from other points of view may also arise.

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