Classification of semi-dry grassland vegetation in Hungary

Klasifikace vegetace širokolistých suchých trávníků v Maďarsku

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Semi-dry grasslands are of high nature conservation interest both at national and European scales due to their high biodiversity and species richness. For effective conservation, however, the variation in floristic composition and distribution of these grasslands need first to be described. In Hungary, there is currently no comprehensive survey and classification of semi-dry grasslands. Therefore, the aim of this study was to (i) describe the variation in species composition of Hungarian semi-dry grasslands by a country-scale cluster analysis based on a large database; (ii) describe the types (clusters) and compare these descriptions with those in the phytosociological literature, and finally (iii) formulate a new syntaxonomical system for Hungarian semi-dry grasslands. For this analysis 699 relevés were selected in which the percentage cover of at least one of the grasses *Brachypodium pinnatum*, *Bromus erectus*, *Danthonia alpina*, *Avenula adsurgens*, *A. pubescens* or *A. compressa* reached >10%. A geographical stratification of the dataset was performed and then it was split randomly into two equal parts (training and test datasets). Following outlier exclusion and noise elimination, clustering was performed separately for both datasets. The optimal number of clusters was determined by validation. The number of valid clusters was the highest at the level of ten clusters, where seven clusters appeared to be valid. The valid clusters are separated geographically; however, there are considerable overlaps in the species compositions. According to our results, all the grasslands belong to the *Cirsio-Brachypodion* alliance. The seven valid clusters are assigned to five main groups of semi-dry grasslands in Hungary: 1. *Brachypodium pinnatum* (and partly *Bromus erectus*) dominated, species rich meadow-steppe-like grasslands occurring on deep loess in central Pannonia, identified as *Euphorbio pannonicae-Brachypodietum* Horváth 2009; 2. *Brachypodium pinnatum* dominated mountain grasslands restricted to the Bükk Mountains; identified as *Polygalo majoris-Brachypodietum* Wagner 1941; 3. mostly *Bromus erectus* dominated grasslands on shallow, calcium/rich soils of the Dunántúl region, proposed as a new association *Sanguisorbo minoris-Brometum erecti* Illyés, Bauer & Botta-Dukát 2009; 4. *Brachypodium pinnatum* and *Danthonia alpina* dominated stands occurring mainly in the Északi-középhegység Mts, characterized by species of nutrient poor soils, proposed as a new association *Trifolio medii-Brachypodietum pinnati* Illyés, Bauer & Botta-Dukát 2009; 5. transition towards meadows and successional stands dominated mainly by *Brachypodium pinnatum.*

K e y w o r d s : association, *Cirsio-Brachypodion*, clustering, phytosociology, training and test data sets, validation, vegetation classification

Introduction

Grassland habitats are integral parts of the landscapes of Europe and are of major importance for maintaining biodiversity (Wallis De Vries et al. 2002, Klimek et al. 2007). The semi-dry grasslands of central and northern Europe are one of the most species-rich communities (Klimek et al. 2007) and the focus of nature conservation (e.g., the EU Habitats Directive and Natura 2000 network) because of their high species richness and they are the habitat of many rare or endangered species (Riecken et al. 1994, Borhidi & Sánta 1999, Chytrý et al. 2001, Stanová & Valachovič 2002). Semi-dry grasslands of central Europe are recognized by the European Community as an endangered habitat, and "Sub-Pannonic steppic grasslands" (6240) as a Natural Habitat Type of Community Interest, according to Annex I of the Habitats Directive (92/43/EEC). Nevertheless, this habitat is only poorly delimited and not supported by data at the European level (Demeter 2002). For better recognition, effective inventory and monitoring at a country-level and internationally are needed. This paper focuses on calcifrequent semi-dry grasslands, since in Hungary there is hardly any acidic semi-dry grassland.

Classification of semi-dry grasslands was one of the first objectives of phytosociological studies (Klika 1931, Soó 1933, Braun-Blanquet 1936) and they still attract many botanists. There are several studies of semi-dry grasslands published for central and western Europe ranging in time from the beginning of phytosociology as a discipline (Klika 1933, Gauckler 1938, Meusel 1939, Wagner 1941, Knapp 1953, Wendelberger 1953, Eijsink et al. 1978, Willems 1982, Mucina & Kolbek 1993) to recent numerical analyses of large datasets (Denk 2000, Willner et al. 2004, Chytrý 2007, Illyés et al. 2007, Janišová 2007, Löbel & Dengler 2008). In contrast, in Hungary the initial enthusiasm quickly waned. It is possible that the reason for this is that in the 1950–1970s Hungarian phytosociological studies focused on primary vegetation and semi-dry grasslands were regarded as of secondary origin (Zólyomi 1950, Soó 1964, 1973). There are only comments in the Hungarian literature on their presence, but detailed syntaxonomical studies, as well as extensive surveys of their range and status quo are missing. At that time, the secondary origin of most of these grasslands was recognized and well accepted by the botanists in adjoining countries (e.g., Jäger & Mahn 2001), but this did not hinder their study or affect their botanical value.

In spite of the relative reluctance to study semi-dry grasslands in detail, most Hungarian authors emphasized the unique forest-steppe character of the Pannonian landscape influenced by sub-Mediterranean and continental climatic effects (Varga 1989, Zólyomi & Fekete 1994, Borhidi & Sánta 1999). The *Bromus erectus* and *Brachypodium pinnatum* dominated semi-dry grasslands are regarded as highly valuable remnants of the original Pannonian forest steppe vegetation (Zólyomi 1950, 1958, Schmotzer & Vojtkó 1996, 1997, Fekete et al. 1998, 2000, Varga et al. 2000, Bauer et al. 2001, Mojzes 2003).

In terms of the European phytosociological school semi-dry grasslands are classified in the class *Festuco-Brometea* Br.-Bl. & Tüxen ex Soó 1947. Within this class most of the Central-European calcifrequent semi-dry grasslands are assigned to the order *Brometalia erecti* Koch 1926, but *Stipetum tirsae* Meusel 1938 is assigned to *Festucetalia valesiacae* Soó 1947 by some authors (e.g., Chytrý 2007) and by others (e.g., Borhidi 2003) to *Brometalia erecti*. Some of the recent national syntheses omit the order level for practical purposes (Chytrý 2007, Janišová 2007) and only use the hierarchical levels of classes, alliances and associations. Most of the European calcifrequent semi-dry grasslands are assigned to two alliances: the grasslands of *Cirsio-Brachypodion pinnati* Hadač & Klika ex Klika 1951 contain several Continental species and develop on deeper, calcareous soils in the warm and dry areas of central Europe, while the grasslands of *Bromion erecti* Koch 1926 are distributed in the cooler regions and contain mainly oceanic species. Nevertheless, the ranges and the species compositions of these two alliances overlap considerably (Royer 1991). The third alliance, *Danthonio-Stipion stenophyllae* Soó 1947, described from Transylvania and containing two *Stipa tirsa* associations, was formerly mentioned from Hungary (Soó 1973), however it was never used by Romanian authors (Royer 1991, Sanda 2002), and recently regarded as a synonym of *Cirsio-Brachypodion* Hadač & Klika ex Klika 1951 (Borhidi & Sánta 1999, Borhidi 2003).

In Hungary, studies on the composition and evolution of semi-dry grasslands were revived from the 1990s and several papers published, the results of which are only partly reflected in the recent synthesis by Borhidi (2003). Despite the many studies completed in separate parts of the country, a country-level computer-aided synthesis is still lacking. This poses a problem since effective conservation and management planning at the country level needs information on the distribution and floristic composition of endangered habitats. Formalized names, definitions, lists of diagnostic species of semi-dry grasslands or associations would greatly facilitate biodiversity management. In Hungary, publications in journals on these grasslands usually do not include relevés, only names and sometimes descriptions of associations. Thus, Hungarian phytosociological syntheses (Soó 1964–1980, Borhidi 1996, 2003, Borhidi & Sánta 1999) review the associations described in adjoining countries, adopt some of them, add others described from Hungary, but unfortunately, in most cases lack detailed descriptions and tables. In the recent work of Borhidi (2003) the following system and associations, characterized by the dominance of *Brachypodium pinnatum* or *Bromus erectus*, are listed for Hungary:

Order: *Brometalia erecti* Br.-Bl. 1936

1. Alliance: *Bromion erecti* Br.-Bl. 1936
   - 1a Ass. *Onobrychido viciaefoliae-Brometum erecti* Müller 1966
   - 1b Ass. *Carlino acaulis-Brometum* Oberdorfer 1957
2. Alliance: *Cirsio-Brachypodion pinnati* Hadač & Klika 1944
   - 2a Ass. *Polygalo majoris-Brachypodietum pinnati* Wagner 1941
   - 2b Ass. *Lino tenuifolii-Brachypodietum pinnati* (Dostál 1933) Soó 1971
   - 2c Ass. *Hypochoerido-Brachypodietum pinnati* Less 1991
   - 2d Ass. *Carici montanae-Brachypodietum* Soó 1947
   - 2e Ass. *Poo badensis-Caricetum montanae* V. Sipos & Varga 1996

However, this system, presented in a university textbook, does not include a critical review of the literature or an analysis, thus the reasons for some of the syntaxonomical decisions remain unclear. First, according to Soó (1973) the *Bromion erecti* alliance does not reach the inner part of the Carpathian Basin and there is not a more recent publication that contradicts this statement. Second, except for 2c and 2e the associations are "adopted" from adjoining countries (1a, 2a: Austria; 1b: Germany; 2b: Slovakia; 2d: Romania – Transylvania). It is questionable, why these (and not other) associations were placed in the system, especially as there are no published relevés from Hungary for some of them (1a, 1b and 2d). Third, it is unclear why *Hypochoerido-Brachypodietum pinnati* Less 1991 (2c) described from Hungary, which also does not have any published relevés, only an informal textural description (by Z. Varga in Borhidi & Sánta 1999) was included but other associations, with more detailed descriptions such as *Euphorbio pannonicae-Brachypodietum* (Horváth 2002), excluded.

The current situation of the research on semi-dry grasslands in Hungary can be summarized as follows: (i) even the main types and their geographical differentiation, range and differences in composition are poorly known; (ii) the stands sampled in the field very often cannot be assigned to the associations mentioned in phytosociological syntheses; (iii) the transitional character and difficulty of identifying these grassland types is mentioned by several authors (Soó 1964–1980, Varga et al. 2000), implying that at least a part of the semi-dry grasslands of the central Pannonian Basin are special subtypes of European semi-dry grassland. This latter point is supported by a recent study by Illyés et al. (2007) in which large datasets on semi-dry grasslands collected along a climatic gradient in central Europe were analysed using numerical techniques. The results of this study revealed a distinct type of semi-dry grassland characteristic of the Pannonian region (central Hungary, southern Moravia and Slovakian Karst). In that study, the aim was to reveal the floristic changes in semi-dry grasslands along a 1000 km long gradient, not country-scale patterns.

The objectives of this paper are to (i) reveal the variation in species composition of Hungarian semi-dry grasslands using a country-scale cluster analysis based on a large database; (ii) describe the types (clusters) and compare the descriptions with those in the phytosociological literature, and finally (iii) propose a new syntaxonomical system for Hungarian semi-dry grasslands.

Materials and methods

The analysis follows the procedure used and explained in Illyés et al. (2007), so here we present a brief summary and explain only the points that differ.

Vegetation data

We compiled a database of 722 relevés of semi-dry grasslands from Hungary. This database is an extension of the one used for Hungary by Illyés et al. (2007). We tried to collect all the relevés of Hungarian semi-dry grasslands made prior to 2006, so we asked colleagues for hardcopies, personal databases, reports and dissertations. To obtain a better representation of semi-dry grasslands the database was extended by the addition of new data mainly from the Északi- and Dunántúli-Középhegység mountains. The new localities to be sampled were chosen with the help of the MÉTA database (Molnár et al. 2007, 2008), which contains data on the vegetation in 86 habitats in Hungary. Calcifrequent semi-dry grasslands correspond to habitat type 'H4 *Bromus erectus-Brachypodium pinnatum* xero-mesic grasslands, dry tall herb communities and forest steppe meadows' (Molnár et al. 2008). The dataset compiled is representative of Hungary according to the distribution map of the H4 habitat (Molnár et al. 2008). The relevés were partly collected from the literature and from various unpublished sources, including data of E. Illyés and N. Bauer and are now stored in the Hungarian national phytosociological database (COENODATREF, Lájer et al. 2008). Nearly all of the sites sampled are personally known to one of the authors (even if the particular relevé was taken by another person) as is the purpose of taking that particular relevé, and therefore the relevés are known to represent stands of semi-dry grasslands adequate for the present analysis. We used relevés from plots ≥4 m^2 and ≤100 m^2. A particular problem was the formal delimitation of the objective of the study. We could not base our relevé selection on associations, or characteristic species lists, because there is no consensus classification scheme for this grassland in Hungary. However, we did not want to include relevés based only on our expert judgment. Therefore, subjectively chosen but formalized and consistent selection criteria were used to select only those relevés in which at least one of the grasses *Brachypodium pinnatum*, *Bromus erectus*, *Danthonia alpina*, *Avenula pubescens* and *A. adsurgens* occurred with a cover >10%, since these species are known to be characteristic of and attain a higher cover in semi-dry grasslands in Hungary. Even though *Avenula* species can attain a high cover in *Molinio-Arrhenatheretea* Tüxen 1937 relevés they were not included in the analysis. A similar approach was applied successfully by Illyés et al. (2007). This selection resulted in a data set of 699 relevés.

For taxonomically difficult species, subspecies and species difficult to determine in the field species aggregates were used. All of these aggregates are documented and are available from the corresponding author upon request. In this study both *Festuca valesiaca* and *Festuca rupicola* were placed in *Festuca valesiaca* agg., since these two taxa are not distinguished unambiguously by many botanists. Bryophyte and lichen records were excluded since they are missing from most relevés; generally, cryptogams do not achieve a high cover or are not distinctive of grassland and are hardly ever recorded in Hungarian semi-dry grasslands. The nomenclature of plants follows Simon (2000) and the chorological data are from Horváth et al. (1995).

The Braun-Blanquet cover-abundance scale or percentage cover in the original relevés was converted to presence-absence values for the analysis (see Illyés et al. 2007). All relevés were georeferenced by latitude and longitude.

Data stratification, splitting the dataset into training and test data, and outlier analysis

We increased the representativeness of our data set by geographically stratified resampling (Knollová et al. 2005). To avoid local oversampling, we randomly selected a maximum of 10 relevés from each cell of a geographic grid of 3' latitude and 5' longitude (approx. 5 × 6 km). This stratification yielded 601 relevés.

After geographic stratification, we randomly split the data set into two subsets of equal size, hereafter called Training and Test. The former was used for creating the classification and the latter for validation of individual clusters resulting from this classification. Outlier analysis was performed separately for Training and Test data sets, using the PC-ORD 4 program (McCune & Mefford 1999): first the average Sørensen dissimilarity of each relevé from every other relevé was calculated. Relevés, whose average dissimilarity from others was higher than average plus double of standard deviation were considered to be outliers. After outlier exclusion, the Training data set contained 287 relevés with 504 species and the Test data set 290 relevés with 498 species.

Cluster analysis

During the numerical classification of large databases artifacts might be created because of the high level of noise, i.e. random variation, in the dataset (Lambert & Williams 1966, Gauch 1982a: 208). Noise can be reduced by using the coordinates of the relevés along the ecologically meaningful axes of metric ordination instead of the raw relevé data for the classification (Gauch 1982b, Botta-Dukát et al. 2005). Therefore, we performed principal coordinate analyses (PCoA; Legendre & Legendre 1998) in R software (R Development Core Team 2005) with the VEGAN package (Oksanen et al. 2005) using presence/absence data and Sørensen dissimilarity (Legendre & Legendre 1998). To calculate the number of interpretable axes, the percentage eigenvalues were compared with random expectations based on the broken-stick model (Jackson 1993, Legendre & Legendre 1998: 410). The number of significant axes was 46 in the Training and 44 in the Test data set. Classification was performed in the PC-ORD 4 program with Euclidean distance and Ward's algorithm of minimum increment of sum of squares (Legendre & Legendre 1998), using the coordinates of the relevés along the predefined significant axes of PCoA as input data.

Validation of classifications

To explore the structure of Hungarian semi-dry grassland, we used the method described in detail by Botta-Dukát (2008) and used in Illyés et al. (2007). The same classification was done independently on the Training and Test dataset; then, at each level of the classification hierarchy groups occurring in the corresponding Training and Test classifications were compared based on the relative occurrence frequency (constancy) of species. Here we give a brief explanation of the method (for details see Botta-Dukát 2008 and Illyés et al. 2007).

The relative frequencies (proportions) of each species were compared separately (Zar 1999) and then the corresponding Type I error probabilities were combined using the Fisher's omnibus test (χ^2; Sokal & Rohlf 1981.) First a χ^2 is calculated for the combined Training and Test data sets, and then cluster pairs with a χ^2 lower than this value are considered as similar.

A cluster of the Training data set is regarded to be valid, if there is one and only one cluster in the Test data set with similar characteristics (Illyés et al. 2007, Botta-Dukát 2008). The number of valid clusters depends on the total number of clusters in the partition (see Illyés et al. 2007), meaning that valid clusters need to be searched for in a wide range of partitions with different numbers of clusters to find the maximum number of valid clusters. In our data sets the partitions had from 2 to 12 groups.

Determination of diagnostic species

Diagnostic species of each cluster were determined at the highest level of the dendrogram that contained all the valid clusters (i.e., at a level of 10 clusters in our case) by the fidelity of species occurrence in the joint valid cluster pairs of the Training and Test data sets (Chytrý et al. 2002). Diagnostic species were determined by calculating the fidelity of each species to each cluster using the JUICE program (Tichý 2002) and the Φ coefficient applied to clusters of equal size (Tichý & Chytrý 2006). The threshold Φ value for diagnostic species was set to 0.3. Fisher's exact test in the JUICE program (Tichý 2002) was used to calculate the statistical significance of species concentration in the relevés of particular clusters ($\alpha = 0.01$). The results of the classification are summarized in a synoptic table (Table 1).

Table 1. – Synoptic table of the seven valid clusters of the combined Training and Test data sets with percentage frequency (constancy) of species. Within blocks of diagnostic species, species are ranked by decreasing fidelity, measured by the ϕ coefficient for relevé groups of equal size (*: $\phi > 0.3$; **: $\phi > 0.5$). Species with non-significant occurrence in a given cluster were not included in the groups of diagnostic species, even if they had $\phi > 0.3$ (Fisher's exact test, $P < 0.01$). The grass species used for relevé selection are in bold. Other species with a constancy > 20% in any cluster are listed in alphabetical order, except the grass species used as selection criteria. ▶

Group no.	A	B	C	D	E	F	G
No. of relevés	98	59	32	15	96	68	69
A. Core type of *Euphorbio pannonicae-Brachypodietum*							
Thalictrum minus	54 **	31	6	33	5	7	4
Viola ambigua	35 **	19	16	–	–	–	1
Thesium ramosum	21 *	8	–	–	–	9	–
Peucedanum arenarium	8 *	–	–	–	–	–	–
Elymus hispidus	58 *	46	44	–	6	28	7
Centaurea jacea s.l.	40 *	15	–	–	23	25	33
B. *Bromus erectus* sub-type of *Euphorbio pannonicae-Brachypodietum*							
Campanula rotundifolia	16	44 **	–	–	–	7	1
Seseli annuum	52	69 **	6	–	19	43	19
Galium verum	39	88 *	–	47	66	69	61
Dactylis glomerata	59	76 *	38	–	46	22	59
Camelina microcarpa	–	7 *	–	–	–	–	–
C. Transitional type of *Euphorbio pannonicae-Brachypodietum* from the area near Érd							
Chamaecytisus ratisbonensis	–	2	50 **	–	1	–	–
Stipa pulcherrima	7	3	47 **	–	1	7	–
Origanum vulgare	5	–	84 **	33	7	6	12
Hieracium umbellatum	33	7	72 **	–	3	10	19
Serratula tinctoria	17	–	59 **	7	–	9	4
Calamagrostis epigeios	2	7	56 **	–	7	19	23
Campanula glomerata	56	29	100 **	13	6	16	6
Serratula radiata	9	2	28 **	–	–	–	–
Scabiosa ochroleuca	7	12	78 **	33	16	22	13
Coeloglossum viride	–	–	12 **	–	–	–	–
Linum flavum	27	8	66 **	27	1	4	4
Colutea arborescens	–	–	16 **	–	–	–	4
Cornus sanguinea	2	2	28 **	–	1	3	10
Echinops sphaerocephalus	–	–	12 **	–	–	–	1
Rubus canescens	2	2	16 **	–	–	–	3
Rhamnus cathartica	8	–	28 **	–	2	1	4
Dorycnium germanicum	39	7	94 **	–	19	19	20
Aster amellus	26	2	81 **	33	1	3	4
Bupleurum falcatum	2	–	62 **	–	5	–	1
Inula ensifolia	31	3	97 **	53	7	10	14
Lembotropis nigricans	5	2	59 **	7	3	4	6
Peucedanum alsaticum	28	15	53 **	–	1	3	22
Scorzonera hispanica	1	–	69 **	–	1	3	4
Prunus cerasus	–	–	12 **	–	–	1	1
Linum tenuifolium	–	–	41 *	–	20	3	4
Thesium linophyllon	13	5	94 *	53	27	35	14
Viburnum lantana	1	–	22 *	–	1	1	4
Clematis vitalba	–	–	22 *	–	4	–	10
Campanula persicifolia	10	8	31 *	–	3	6	1
Prunus dulcis	–	–	9 *	–	–	–	1
Ulmus minor	3	2	12 *	–	–	1	3
Cotoneaster matrensis	–	–	6 *	–	–	–	–
Poa pratensis agg.	60	42	75 *	–	31	28	55
Buglossoides purpureo-coerulea	–	–	6 *	–	–	–	1
Koeleria cristata agg.	14	15	47 *	–	39	37	19
Prunus fruticosa	3	–	31 *	–	–	4	–
Peucedanum cervaria	23	7	94 *	40	9	32	13
Onobrychis arenaria	13	10	47 *	–	6	9	4
Inula hirta	46	7	53 *	–	1	21	1

Group no.	A	B	C	D	E	F	G
No. of relevés	98	59	32	15	96	68	69
D. *Polygalo majoris-Brachypodietum* grasslands in the Bükk Mountains							
Libanotis pyrenaica	–	–	–	80 **	1	–	–
Senecio erucifolius	–	–	–	33 **	–	–	–
Achillea setacea	3	3	–	40 **	–	–	–
Centaurea micranthos	3	–	3	47 **	9	–	12
Melampyrum arvense	1	–	–	53 **	2	3	3
Primula elatior	–	–	–	20 **	–	–	–
Ranunculus auricomus	–	–	–	33 **	–	–	–
Hieracium echioides	–	–	–	20 **	–	–	–
Thlaspi perfoliatum	2	2	–	27 **	4	3	–
Dracocephalum ruyschiana	–	–	–	13 **	–	–	–
Carex tomentosa	5	3	–	47 **	1	16	12
Iris sibirica	–	–	–	13 **	–	–	–
Verbascum chaixii s.l.	1	2	–	20 **	–	1	1
Dorycnium herbaceum	–	2	–	53 **	10	28	22
Carlina acaulis	–	–	–	20 **	–	4	1
Asperula cynanchica	15	44	19	100 **	34	50	16
Cruciata glabra	–	–	–	33 **	–	1	–
Fragaria vesca	–	–	–	47 **	9	–	1
Viola hirta	8	17	–	67 *	7	47	22
Euphorbia polychroma	–	–	–	27 *	–	7	3
Potentilla argentea agg.	–	–	–	13 *	2	4	–
Geranium rotundifolium	–	–	–	7 *	–	–	–
Lathyrus pratensis	–	–	–	13 *	1	3	4
Symphytum tuberosum s.l.	–	–	–	13 *	–	–	3
Hieracium pilosella agg.	–	3	–	27 *	25	6	1
Cirsium pannonicum	–	–	16	67 *	1	6	–
Geranium sanguineum	3	2	–	60 *	8	26	6
E. *Sanguisorbo minoris-Brometum erecti* grasslands of the highlands of the Dunántúli-Középhegység							
Thymus odoratissimus	18	22	3	7	71 **	22	3
Acinos arvensis	–	–	–	–	20 **	3	1
Daucus carota	5	–	3	–	17 *	3	7
Onobrychis viciifolia	–	–	–	–	6 *	–	–
Plantago lanceolata	3	5	–	–	21 *	10	4
Sanguisorba minor	7	–	41	33	67 *	18	12
Sedum sexangulare	–	–	–	–	9 *	1	–
Vicia angustifolia	3	2	–	–	16 *	4	9
Trinia glauca	–	–	–	–	9 *	–	–
Achillea collina	6	25	–	–	57 *	50	30
***Bromus erectus* s.l.**	8	32	3	–	71 *	13	16
Ranunculus sardous	–	–	–	–	5 *	–	–
F. *Trifolio medii-Brachypodium pinnatum* grasslands in the Északi-Középhegység							
Luzula campestris agg.	–	8	–	–	6	28 **	–
Danthonia alpina	–	–	–	–	2	44 **	–
Trifolium medium	–	3	–	–	2	19 *	1
Trifolium alpestre	29	8	9	7	7	60 *	6
Eryngium campestre	26	32	19	13	45	63 *	22
Cerastium brachypetalum	5	2	–	–	4	16 *	–
Seseli varium	6	–	9	–	1	19 *	1
Viola canina	–	–	–	–	–	10 *	3
Lychnis viscaria	–	–	–	–	–	7 *	1
Veronica officinalis	–	–	–	–	–	6 *	–

Group no. No. of relevés	A 98	B 59	C 32	D 15	E 96	F 68	G 69
Trifolium ochroleucum	–	–	–	–	–	6 *	–
Verbascum phoeniceum	7	2	–	–	4	21 *	7
Anthoxanthum odoratum	–	2	–	–	7	18 *	3
Medicago ×varia	–	–	–	–	–	4 *	–
Allium vineale	–	–	–	–	–	4 *	–
Trifolium montanum	33	31	–	40	24	65 *	10
G. Sites under succession and transition to meadows							
Helleborus odorus	–	–	–	–	2	–	10 *
Galium mollugo agg.	1	3	22	–	15	3	30 *
Knautia drymeia	–	–	–	–	–	–	6 *
Holcus lanatus	–	–	–	–	–	–	6 *
Scirpoides holoschoenus	–	–	–	–	–	–	4 *
Campanula trachelium	–	–	–	–	–	–	4 *
Species diagnostic for more than one cluster							
Bromus inermis	26 *	7	38 **	–	2	9	4
Euphorbia glareosa	95 **	80 **	91 **	–	8	15	7
Chamaecytisus austriacus	47 *	46 *	50 *	–	15	10	25
Galium glaucum	68 *	20	69 *	20	6	12	7
Filipendula vulgaris	93 *	92 *	75	47	19	84	33
Other species with frequency > 20%							
Brachypodium pinnatum	99	90	100	100	32	69	99
Avenula adsurgens	38	29	25	–	7	47	10
Avenula pubescens	34	12	9	–	6	10	12
Achillea pannonica	33	32	28	–	6	26	17
Adonis vernalis	42	25	31	27	8	19	28
Agrimonia eupatoria	24	47	34	7	47	38	42
Allium senescens subsp. *montanum*	–	–	–	27	2	–	–
Anthericum ramosum	19	19	66	7	3	21	4
Anthyllis vulneraria agg.	–	2	–	7	33	3	6
Arrhenatherum elatius	11	15	28	7	23	44	43
Aster linosyris	32	3	28	13	4	29	4
Briza media	30	22	3	–	30	38	41
Carex humilis	26	41	19	–	15	10	4
Carex michelii	56	27	22	20	7	25	7
Carlina biebersteini	6	3	34	27	17	15	26
Centaurea scabiosa agg.	73	63	91	80	33	35	52
Clinopodium vulgare	2	2	19	–	5	9	26
Crataegus monogyna	34	51	34	–	34	43	20
Dianthus pontederae	7	8	9	67	41	40	14
Dictamnus albus	3	8	28	–	–	4	1
Euphorbia cyparissias	12	24	–	33	52	43	26
Festuca valesiaca agg. (incl. *F. rupicola*)	96	95	100	100	86	96	58
Fragaria viridis	22	42	19	13	34	59	22
Genista tinctoria	27	8	–	–	–	35	3
Helianthemum nummularium s.l.	3	25	–	7	21	16	9
Hypericum perforatum	2	12	6	20	32	29	6
Hypochaeris maculata	4	2	47	7	7	10	9
Knautia arvensis	59	46	–	7	34	40	35
Lotus corniculatus	16	17	6	7	46	37	23
Medicago falcata	54	61	3	–	48	34	22
Ononis spinosa	11	15	–	–	10	12	22
Phleum phleoides	24	37	16	33	12	21	–

Group no. No. of relevés	A 98	B 59	C 32	D 15	E 96	F 68	G 69
Pimpinella saxifraga agg.	54	59	–	33	41	41	16
Plantago media	34	29	50	13	50	63	26
Polygala major	–	–	19	20	–	10	4
Potentilla arenaria	–	–	3	–	28	3	–
Prunella grandiflora	11	–	–	27	–	10	–
Prunus spinosa	10	12	3	–	11	28	13
Pseudolysimachion spicatum	7	17	–	–	7	29	3
Pulmonaria mollis	–	3	–	–	1	21	6
Pulsatilla grandis	2	–	6	47	–	13	–
Ranunculus acris	–	–	–	27	1	–	6
Ranunculus polyanthemos	46	47	22	–	10	24	23
Rosa canina agg.	7	3	25	7	11	13	7
Rumex acetosa	2	20	–	7	–	13	6
Salvia pratensis	64	49	62	13	58	56	48
Securigera varia	31	29	16	7	46	29	35
Silene vulgaris	12	25	22	7	14	4	12
Stachys officinalis	46	19	25	47	1	44	23
Stachys recta	41	12	9	27	11	18	10
Tanacetum corymbosum	48	7	62	20	1	28	3
Teucrium chamaedrys	62	73	19	53	71	59	42
Thymus pannonicus	3	15	19	–	–	37	–
Veronica austriaca	15	15	6	33	3	26	4

Results

Patterns in the species composition of Hungarian semi-dry grasslands

The optimal number of clusters appeared to be 10 of which seven were valid. The structures of the Training and Test dendrograms differed considerably. In our opinion it reflects the indistinct compositional differences among the clusters, at least at the higher levels and even the species lists of relevés from the same site can be highly variable. This partly explains why it is difficult to classify Hungarian semi-dry grasslands.

Nevertheless, the topologies of the two dendrograms (Fig. 1) have common features. Clusters A and B, which represent *Brachypodium pinnatum* or *Bromus erectus* dominated species-rich meadow steppes on deep loess from central Hungary, are the closest to each other in both of the dendrograms, and are furthest from the cluster composed of E, F and G, which comprises stands from the cooler and more humid regions or the hilly parts of the country. The positions of clusters C and D are variable, indicating the transitional character of these relevés. Both of these clusters comprise stands from a single small area (C – meadow steppes near Érd, D – montane semi-dry grasslands from the Bükk Mts). The structure of the dendrograms clearly reflects the geographical differentiation of the clusters.

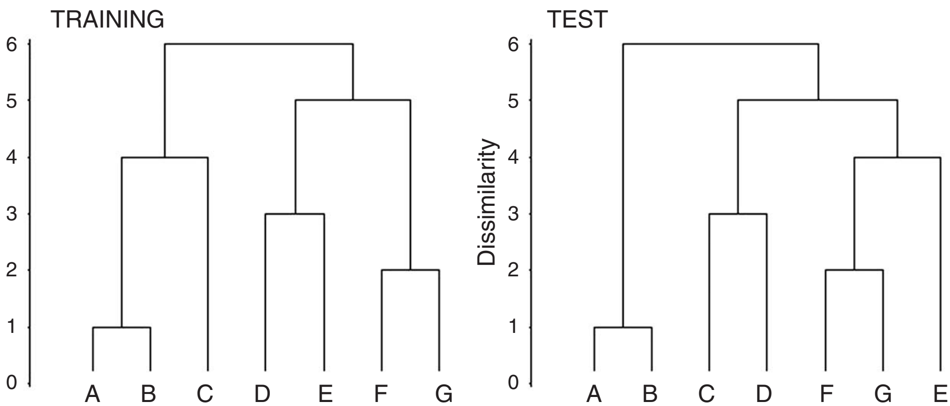

Fig. 1. – Topology of dendrograms based on the Training and Test data sets. Only the valid clusters are shown.

Description of the clusters

Cluster A

Most relevés in this cluster are from the Mezőföld region (loess plateau roughly in the middle of the country, western side of the Danube), others are from the eastern foothills of the Gerecse Mts. and some from the uplands along the Hernád River. These grasslands, typically dominated by *Brachypodium pinnatum,* grow in loess valleys on steep, mostly north-facing slopes. The most important diagnostic species (*Euphorbia glareosa*, *Thalictrum minus* and *Viola ambigua*) are characteristic of parts of the Alföld (Great Hungarian Plain) with a loess substrate and the foothills of the Középhegység (Hungarian Medium Mountains). High constancies of *Euphorbia glareosa, Festuca valesiaca* agg., *Brachypodium pinnatum*, *Filipendula vulgaris*, *Salvia pratensis*, *Thalictrum minus*, *Galium glaucum* and *Carex michelii* clearly define this cluster.

Cluster B

Most of the relevés originate from the Mezőföld region and from the Gödöllői-dombság, with some from the foothills of the Gerecse and Pilis Mts. The species composition is similar to Cluster A with which it shares many diagnostic species, which is reflected in both of the dendrograms. *Brachypodium pinnatum,* and occasionally *Bromus erectus* and *Festuca valesiaca* agg. dominate the relevés. Faithful species of the cluster (*Campanula rotundifolia*, *Galium verum*, *Seseli annuum*) reflect a more open structure of the grassland compared to Cluster A, which might be caused by differences between the former and recent land use, since we know that the sites of these relevés were burnt regularly or slightly grazed by sheep.

Cluster C

These relevés are from a very small area in the northeastern part of the Mezőföld region, close to the town of Érd. It is a relatively uniform cluster consisting of a small number of relevés, the separation of which is most probably due to the presence of a few rare species

(*Cotoneaster matrensis*, *Echinops spaerocephalon*) that occur in this area (or are overrepresented in the relevés) and the higher frequencies of some shrub species (*Cornus sanguinea*, *Rhamnus catharticus*, *Rubus canescens*). The diagnostic species are to some extent shared with Clusters A and B, and the geographical ranges of the three clusters are similar, as reflected in the Training dendrogram. Some of the species (*Aster amellus*, *Cirsium pannonicum*, *Linum flavum*, *Origanum vulgare*, *Peucedanum cervaria*) reach higher constancies only in Clusters C and D, which explains the structure of the Test dendrogram.

Cluster D

These relevés are from high altitudes in the most mountainous part of Hungary, the Bükk Mts. Their separation is clearly explained by the presence of montane elements (*Primula elatior, Dracocephalum ruyschiana, Carlina acaulis*, *Libanotis pyrenaica*), which indicate the montane influence. The relevés are from a well-defined small area, which accounts for the uniformity of the species composition. These are very species-rich stands where the typical elements of semi-dry grasslands (*Asperula cynanchica*, *Geranium sanguineum*, *Cirsium pannonicum*, *Centaurea scabiosa* agg., *Filipendula vulgaris*, *Pulsatilla grandis*, *Dianthus pontederae*) reach medium or higher constancies. Presence of mesophilous species accounts for the similarity of Clusters E, F and G in the Training dendrogram. The shared higher constancies of *Aster amellus*, *Cirsium pannonicum*, *Linum flavum*, *Origanum vulgare* and *Peucedanum cervaria* account for the similarity with Cluster C in the Test dendrogram.

Cluster E

Nearly all of the relevés are from the Dunántúli-középhegység and Dunántúli-dombság and dominated by *Bromus erectus* s.l. The relevés include common species of *Festuco -Brometea* (*Teucrium chamaedrys, Thymus odoratissimus, Galium verum* and *Salvia pratensis*). Species of higher and medium constancies indicate dry, shallow soils, but mesophilous species are also present. Some of the species reflect drier and locally bare surfaces (*Acinos arvensis*, *Sanguisorba minor*, *Medicago minima*, *Trinia glauca*, *Bothriochloa ischaemum*, *Sedum sexangulare*). Most of the stands are located close to or in the broad surroundings of the Bakony Mts and grow on dolomite bedrock. The formerly widespread and rather intensive sheep grazing combined with the shallow rocky soils resulted in a simple structure and lack of broad-leaved herbaceous plants at these sites. The other stands in the south-western part of the Dunántúli-dombság are in highly eroded, nutrient-poor loess soils, mostly abandoned vineyards and arable fields. It is interesting that overgrazing and succession on recently abandoned arable fields result in similar species compositions. Occurrence of some species of calcium-poor soils (*Luzula campestris*, *Anthoxanthum odoratum*) accounts for the similarity with Cluster F. The geographical distribution is rather similar to Cluster G and reflected in the shared constant species.

Cluster F

The relevés included in this cluster are mainly from the Északi-Középhegység (Fig. 2), with some from the edges of the Mezőföld region and Gödöllői-dombság hills. The cluster

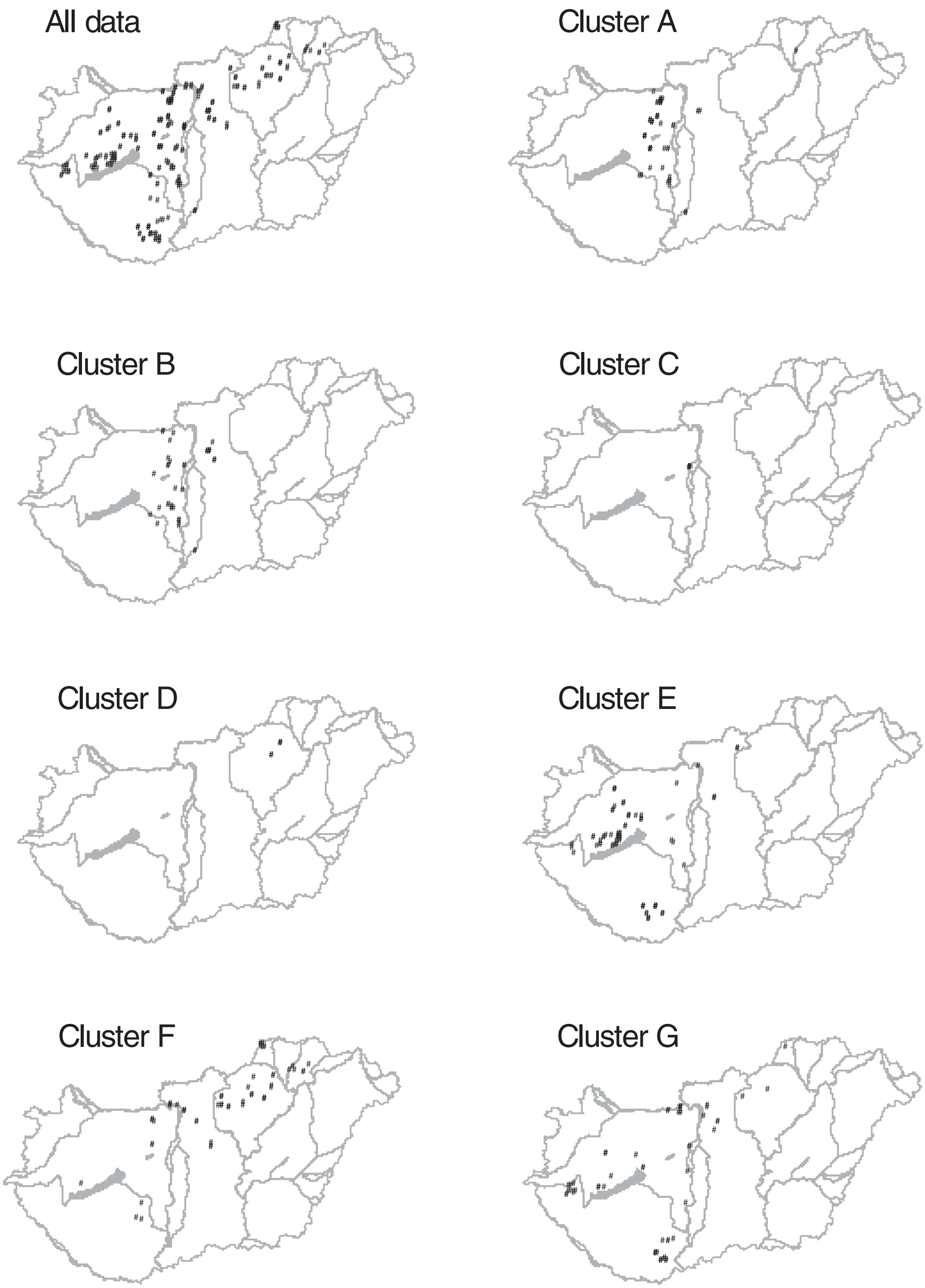

Fig. 2. – Distribution in Hungary of all the relevés included in the data set and relevés of the validated clusters A–G, based on the pooled data from the Training and Test data sets.

is characterized by the presence and dominance of *Danthonia alpina*, although this species is only present in half of the relevés. Diagnostic and constant species (*Luzula campestris*, *Lychnis viscaria*, *Viola canina*, *Veronica officinalis*) reflect mesic soils poor in calcium. Species with high constancies (*Filipendula vulgaris*, *Trifolium montanum*, *T. alpestre* and *Salvia pratensis*) are characteristic of calcareous semi-dry grasslands (Soó 1964–1980).

Cluster G

Most of the relevés included in this cluster are from the hilly parts of Dunántúl, not on the Mezőföld plateau but located in the cooler and moister parts of the country. In this landscape, semi-dry grasslands are located close to mesophilous forests and meadows, which is reflected in their species composition. Diagnostic species and species of medium constancies in Cluster G are mesophilous species (*Poa pratensis*, *Arrhenatherum elatius*, *Briza media*), or disturbance-tolerant species sensu Borhidi 1995 (*Galium mollugo* agg., *G. verum*, *Agrimonia eupatoria*, *Carlina biebersteini*, *Ononis spinosa*). Most of the relevés included in this cluster are from either: (i) young stands developing rapidly following recent abandonment of former arable land or a vineyard, or (ii) meadows that dried out after canalization. The lack of specialist dry- and semi-dry grassland species and the presence of meadow species indicate a transition towards wet meadows (*Arrhenatheretalia*), and accounts for the similarity with cluster F and shared constant species for the similarity with cluster E.

Discussion

The interpretation of the clusters in syntaxonomical terms is difficult because of the used selection criteria (at least 10% cover of particular species) of the analysis. Moreover, the fact that only semi-dry grasslands and not all vegetation types of Hungary were analysed means that the species that show fidelity to the clusters in our analysis are not characteristic species in the strict classical syntaxonomical sense; rather they are differential species (Botta-Dukát & Borhidi 1999), which delimit clusters from others in the dataset. Some of these species are not typical species of semi-dry grasslands but are characteristic of special site conditions (e.g., *Sedum sexangulare* in Cluster E) or geographical localities (e.g., *Primula elatior* in Cluster D) or both (e.g., *Helleborus odorus* in Cluster G).

Nevertheless, in order to compare our results with former classifications of semi-dry grasslands in Hungary and the recently revised systems of grassland vegetation in adjoining countries, we review the literature relevant to each cluster and the descriptions of all the clusters. We give a syntaxonomical interpretation whenever possible and assign the clusters to associations or propose new associations when necessary.

Syntaxonomical interpretation of the clusters

The results of clustering revealed a distinct semi-dry grassland type located in the center of the Pannonian range (clusters A, B and C), characterized by many Pontic-Pannonian species, like *Euphorbia glareosa*, *Chamaecytisus austriacus* and *Viola ambigua*, and dominated mostly by *Brachypodium pinnatum* and sometimes *Bromus erectus*. Based on the relevés from a loess valley in the Mezőföld region, Bauer et al. (2001) note that these stands are not identical to any *Brachypodium pinnatum* association described from Hungary, thus they seem to belong to a new association. Independently, Horváth (2002) described a new type of *Brachypodium pinnatum* grassland from the central part of the Mezőföld, which is extremely rich in Pontic-Pannonian species, and proposed the name *Euphorbio pannonicae-Brachypodietum*. However, their descriptions of this new association is not valid, since their papers do not include a table of relevés or indicate the holotype (see Weber et al. 2000). Recently Horváth (2009) published a paper with the description and validation of the *Euphorbio pannonicae-Brachypodietum* association. Nevertheless, prior to these two publications, these grasslands were referred to in an arbitrary way. In oral communications by Hungarian botanists they were often referred to as loess steppes or meadow steppes, sometimes even incorrectly specified as *Salvio-Festucetum rupicolae* Zólyomi ex Soó 1964, which is in fact a species-rich loess steppe dominated by narrow-leaved grasses (mainly *Festuca rupicola*, *F. valesiaca* and *Stipa capillata*). Clusters A and B possibly belong to the *Euphorbio pannonicae-Brachypodietum* Horváth 2009 (*Euphorbia pannonica* = *E. glareosa*). According to Horváth (2002, 2009) this association is characterized by a dense, multi-layered structure, consisting of broad-leaved graminoids and herbaceous plants dominated by *Brachypodium pinnatum*. *Festuca rupicola*, *Salvia pratensis* and *Euphorbia glareosa* also attain high levels of cover in these stands. Species of open oak woodlands (e.g., *Tanacetum corymbosum*, *Anthericum ramosum*, *Anemone sylvestris*, *Peucedanum cervaria*, *Campanula bononiensis*, *Ranunculus polyanthemos*, *Trifolium alpestre*) also frequently occur in these stands. Although Clusters A, B and C show many similarities with *Polygalo majoris-Brachypodietum* (especially Cluster C) as well, based on the presence of many Pontic-Pannonian species and the lack or low frequency of characteristic species of *Polygalo majoris-Brachypodietum* (*Scorzonera hispanica*, *Onobrychis arenaria*, *Cirsium pannonicum* according to Wagner 1941) we agree with Horváth (2002, 2009) and recommend to distinguish these clusters as a separate association. The 10 relevés of *Euphorbio pannonicae-Brachypodietum* presented in Electronic Appendix 1 give an indication of the structure of this association.

Cluster C is transitional and similar to *Polygalo majoris-Brachypodietum* Wagner 1941. The assignment of these relevés to any association, however, is questionable since the relevés are all from the same locality and made by the same author.

Semi-dry grasslands in the Bükk Mts are represented by cluster D in our analysis. These grasslands are intensively studied (Schmotzer & Vojtkó 1996, 1997, Vojtkó 1998) because of their high species richness and unique floristic composition. They are described as *Polygalo majoris-Brachypodietum* (Schmotzer & Vojtkó 1996, 1997, Vojtkó 1998). It is likely that the sites are secondary and the differences in species composition the consequence of them being derived from distinct patches of oak forest. We are not totally convinced that the stands of Cluster D belong to *Polygalo majoris-Brachypodietum* since the species composition of the relevés in this cluster differ considerably from the original description by Wagner (1941), and several characteristic species are missing (*Scorzonera hispanica*, *Seseli annuum*, *Onobrychis arenaria*, *Galium glaucum*) or are present only at a low frequency (e.g., *Hypochaeris maculata*). In addition, all of the relevés from the Bükk Mts in the dataset and for this cluster were made by the same authors (A. Schmotzer & A. Vojtkó) and a subjective preference for species of conservation interest is indicated by their extremely high frequency (*Asperula cynanchica*, *Cirsium pannonicum*, *Dianthus pontederae*, *Geranium sanguineum*, *Polygala major*). Nevertheless, we have to admit that the Bükk Mts are very rich in semi-dry grasslands and we have only a few relevés from the higher altitudes, which are not representative of the area. On the other hand, the species composition of the stands is similar to *Brachypodio pinnati-Molinietum arundinaceae* Klika 1939 (Chytrý et al. 2007, Janišová et al. 2007). This association is described from the White Carpathians, a mountain range at the border of the Czech and Slovak Republic, which could have similar ecological conditions to those in the Bükk Mts. Taking all these facts into consideration, we suggest that the relevés of Cluster D belong to *Polygalo majoris-Brachypodietum* Wagner 1941. Further studies of the semi-dry grasslands at high altitudes in the Bükk Mts most probably will support this interpretation. Sample relevés of this association are presented in Electronic Appendix 1.

In spite of the fact that the *Bromus erectus* dominated Cluster E shows some similarities to the *Bromion erecti* alliance, especially if one reads the description of the latter in Borhidi (2003) and refrains from consulting other sources (e.g., Mucina & Kolbek 1993), it lacks the typical meadow and Atlantic species of the alliance. In our opinion, Cluster E is not a member of the tall mown meadows of *Onobrychido viciaefoliae-Brometum erecti* or *Carlino acaulis-Brometum* because of the lack of mesophilous species and the presence of drought-adapted species (*Acinos arvenis*, *Sanguisorba minor*, *Teucrium chamaedrys*, *Thymus odoratissimus*). Moreover, the soils at these sites are not deep but shallow and rocky. Semi-dry grasslands in the Dunántúli-középhegység Mts have been little studied (or at least not published). Based on his own relevés and the work of Debreczy (1966), Isépy (1998) suggested that the "*Xerobrometum*-like" *Bromus erectus* dominated grasslands in this part of the country, which probably originated from former *Quercus pubescens-Q. cerris* forests and have a special species composition therefore should be treated separately. He also proposed the name *Lathyro pannonici-Brometum erecti* based on a synthetic table of 10 relevés (Isépy 1998); however, this name is not a valid since the description does not include the original relevés. Moreover, the study of Isépy (1998) covers only a small area of the Dunántúli- középhegység. Nevertheless, we place these grasslands in a distinct association. However, connections to and distinctions from *Festucion valesiacae* and *Bromo pannonici- Festucion pallentis* need to be studied in the future. This cluster is similar to the description of *Onobrychido viciifoliae-Brometum erecti* T. Müller 1966 in Janišová et al. (2007) but differs considerably from the description of the same association in the Hungarian syntaxonomical textbooks (Borhidi & Sánta 1999, Borhidi 2003). We propose a new association with the name *Sanguisorbo minoris-Brometum* Illyés, Bauer & Botta-Dukát ass. nova hoc loco, since the name proposed by Isépy (1998) is not adequate due to the absence of *Lathyrus pannonicus* from most of the grassland sites sampled (Weber et al. 2000). Sample relevés of this new association are presented in Electronic Appendix 1 and its holotype is relevé no. 19 (holotypus hoc loco).

Holotype of ***Sanguisorbo minoris-Brometum* Illyés, Bauer & Botta-Dukát 2009**
(Species covers are given in percentages).

Bromus erectus 40; *Festuca valesiaca* agg. (incl. *Festuca rupicola*) 10; *Teucrium chamaedrys* 10; *Carex humilis* 10; *Dorycnium germanicum* 10; *Salvia pratensis* 5; *Sanguisorba minor* 4; *Adonis vernalis* 3; *Anthyllis vulneraria* 1.5; *Hypericum perforatum* 1; *Thymus odoratissimus* 1; *Vincetoxicum hirundinaria* 1; *Potentilla arenaria* 0.5; *Medicago falcata* 0.2; *Poa angustifolia* 0.2; *Helianthemum ovatum* 0.2; *Sedum sexangulare* 0.2; *Teucrium montanum* 0.2; *Thlaspi perfoliatum* 0.2; *Galium verum* 0.1; *Achillea collina* 0.1; *Eryngium campestre* 0.1; *Asperula cynanchica* 0.1; *Agrimonia eupatoria* 0.1; *Fragaria viridis* 0.1; *Euphorbia glareosa* 0.1; *Koeleria* *cristata* 0.1; *Hieracium pilosella* 0.1; *Stipa pennata* 0.1; *Acinos arvensis* 0.1; *Campanula sibirica* 0.1; *Trifolium campestre* 0.1; *Trinia glauca* 0.1; *Alyssum montanum* 0.1; *Carduus nutans* 0.1

Additional data: Table no. in App. 1: 19, date: 6. 6. 2006; author: Eszter Illyés; plot size: 16 m^2; latitude (WGS84): 47°01"04.6'; longitude (WGS84): 17°45"30.6'; locality: Tótvázsony, Hungary.

Cluster F is characterized by the presence and dominance of *Danthonia alpina.* In the Hungarian syntaxonomical literature, there are few references to this species and no published relevés or association names for stands of this species. *Danthonia alpina* occurs frequently and in places even dominates (Varga & Varga-Sipos 1999: 52) semi-dry grasslands in Hungary, which is not the case in other countries (Chytrý 2007, Janišová et al. 2007). A recent study of *Danthonia alpina* grasslands in the Carpathian Basin and its surroundings (Kovács 2008) revealed that *Danthonia alpina* dominated stands belong to several alliances and associations, namely the *Cirsio pannonici-Brachypodion pinnati*, *Danthonio-Brachypodion* Boşcaiu 1972, *Danthonio-Brachypodietum pinnati* Soó (1946) 1947, *Danthonio alpinae-Stipetosum stenophyllae* Ghisa 1941 and *Danthonio-Chrysopogonetum grylli* Boşcaiu (1970) 1972. Sanda (2002) gives the constant species and localities of these associations in Romania. The geographical ranges of these alliances include Hungary, parts of Transylvania (Romania) and the Balkan Peninsula. A comprehensive international study of *Danthonia alpina* grasslands is needed, especially of those in the Balkan and East-Carpathian areas. Nevertheless, at present we propose a new association with the name *Trifolio medii-Brachypodietum pinnati* Illyés, Bauer & Botta-Dukát ass. nova hoc loco for the relevés of Cluster F. Sample relevés are presented in Electronic Appendix 1 and the holotype is relevé no. 32 (holotypus hoc loco).

Holotype of ***Trifolio medii-Brachypodietum pinnati* Illyés, Bauer & Botta-Dukát 2009**
(Species covers are given in percentages).

Brachypodium pinnatum 55; *Festuca valesiaca* agg. (incl. *Festuca rupicola*) 15; *Avenula adsurgens* 10; *Salvia pratensis* 8; *Trifolium alpestre* 8; *Carex montana* 6; *Arrhenatherum elatius* 5; *Cirsium pannonicum* 5; *Galium verum* 3; *Trifolium medium* 2; *Chamaecytisus albus* 2; *Agrimonia eupatoria* 1; *Fragaria viridis* 1; *Inula hirta* 1; *Briza media* 1; *Elymus hispidus* 1; *Asperula cynanchica* 0.7; *Tanacetum corymbosum* 0.7; *Coronilla varia* 0.7; *Genista tinctoria* 0.7; *Inula salicina* 0.7; *Malus sylvestris* 0.7; *Trifolium montanum* 0.5; *Dianthus pontederae* 0.5; *Medicago falcata* 0.5; *Adonis vernalis* 0.5; *Gentiana cruciata* 0.5; *Seseli annuum* 0.3; *Danthonia alpina* 0.3; *Pulmonaria mollis* 0.3; *Anthericum ramosum* 0.3; *Centaurea triumfettii* 0.3; *Filipendula vulgaris* 0.2; *Teucrium chamaedrys* 0.2; *Achillea collina* 0.2; *Sanguisorba minor* 0.2; *Lotus corniculatus* 0.2; *Viola hirta* 0.2; *Dorycnium herbaceum* 0.2; *Prunella grandiflora* 0.2; *Pulsatilla grandis* 0.2; *Cruciata laevipes* 0.2; *Festuca pratensis* 0.2; *Verbascum lychnitis* 0.2; *Eryngium campestre* 0.1; *Euphorbia cyparissias* 0.1; *Pimpinella saxifraga* agg. 0.1; *Thesium linophyllon* 0.1; *Plantago media* 0.1; *Geranium sanguineum* 0.1; *Leontodon hispidus* 0.1; *Linum catharticum* 0.1; *Euphorbia polychroma* 0.1; *Veronica chamaedrys* 0.1; *Allium vineale* 0.1; *Trifolium rubens* 0.1; *Campanula rapunculoides* 0.1

Additional data: Table no. in App. 1: 32; date: 5. 6. 2005; author: Eszter Illyés; plot size: 16 m^2; latitude (WGS84): 48°31"07.2'; longitude (WGS84): 20°30"37.5'; locality: Aggtelek, Magas-karszt, Hungary.

Stands transitional in character between alliances or stands that are undergoing succession always result in loose and subjective classifications. Based on both the species pool and site conditions the relevés of Cluster G are considered to be in transition to mesophilous meadows. Our field experience indicates that many relevés of Cluster G are from relatively young stands or recently abandoned ones. Thus, at present it is not possible to name this cluster as an association especially without an extended analysis of *Molinio-Arrhenatheretea*.

Proposed new system for Hungarian semi-dry grasslands

Since there was no detailed analysis of the Hungarian semi-dry grassland vegetation prior to this study, the recently published synopsis of Hungarian plant associations (Borhidi 2003) was based on small-scale or local studies of semi-dry grasslands. The results of the numerical analysis of a large amount of data enable us to propose a new system for semi-dry grasslands, which has resulted in considerable but not unexpected changes. We propose the following system for the Hungarian semi-dry grasslands (sample relevés of the associations of the system are presented in Electronic Appendix 1):

Order: *Brometalia erecti* Br.-Bl. 1936
Alliance: *Cirsio-Brachypodion pinnati* Hadač et Klika ex Klika 1951
Association: 1a *Polygalo majoris-Brachypodietum* Wagner 1941
1b *Euphorbio pannonicae-Brachypodietum* Horváth 2009
1c *Sanguisorbo minoris-Brometum erecti* Illyés, Bauer & Botta-Dukát 2009
1d *Trifolio medii-Brachypodietum pinnati* Illyés, Bauer & Botta-Dukát 2009

As revealed by a previous large scale analysis (Illyés et al. 2007) and earlier recognized by Soó (1973), there are probably no stands of *Bromion erecti* in Hungary. Our analysis of an extended dataset supports this finding. Therefore, we agree with Varga (1997) that all of the semi-dry grasslands in Hungary belong to the *Cirsio-Brachypodion* alliance and thus none of the relevés included in this analysis belong to the association *Onobrychido viciifoliae-Brometum erecti* or *Carlino acaulis-Brometum*.

This analysis does not support the presence in Hungary of the associations *Lino tenuifolio-Brachypodietum pinnati* (Dostál 1933) Soó 1971, *Hypochoerido-Brachypodietum pinnati* Less 1991 and *Poo badensis-Caricetum montanae* V. Sipos & Varga 1996 listed in Borhidi (2003). It even proved difficult to document these associations, although we revisited and sampled the localities given in the literature (Less 1991, Varga-Sipos & Varga 1998). In the case of *Hypochoerido-Brachypodietum pinnati* Less 1991 we were unable to find any grassland in the area mentioned in the original publication. In our opinion, the description of these stands as separate associations should be rejected, since there are no published tables for comparison and the repeatability of their species composition is rather questionable since none of them could be convincingly documented.

Non-valid clusters

There were 140 relevés (24.2%) that could not be assigned to any of the valid clusters. This is not high compared to the previous large scale analysis where it was around 50% (Illyés et al. 2007). The non-valid clusters comprise relevés from rather small, isolated areas, the species composition of which is very unique. These stands seem to have developed under unique site conditions (mesoclimate, soil properties, and surrounding vegetation types) with special management history, so there is little chance that a similar species composition occurs in any other place, which is a requirement for validity in this sense. We recommend interpreting these relevés on the level of alliance *Cirsio-Brachypodion pinnati* (compare deductive approach of Kopecký & Hejný 1974), together with stands undergoing succession, represented in our analysis by cluster G.
See www.preslia.cz for Electronic Appendix 1.

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Souhrn

Širokolisté suché trávníky jsou biotopem značné ochranářské hodnoty, a to jak v jednotlivých zemích, tak na celoevropské úrovni. Pro zajištění jejich účinné ochrany je nutno nejprve popsat jejich rozšíření a variabilitu floristického složení, pro Maďarsko však až dosud neexistoval ucelený přehled ani moderní klasifikace. Cílem práce je (i) popsat variabilitu druhového složení maďarských širokolistých suchých trávníků, (ii) vymezit existující typy a srovnat je s předchozím zpracováním v literatuře a (iii) navrhnout nový fytocenologický systém. Analýza zahrnovala 699 fytocenologických snímků, ve kterých pokryvnost alespoň jednoho z následujících druhů trav – *Brachypodium pinnatum*, *Bromus erectus*, *Danthonia alpina*, *Avenula adsurgens*, *A. pubescens* a *A. compressa* – přesahovala 10 %. Snímkový soubor byl geograficky stratifikován a rozdělen na dva podsoubory, „cvičný“ a „testovací“, které byly po vyloučení odlehlých snímků a eliminaci šumu analyzovány zvlášť. Celkem bylo pomocí shlukové analýzy vymezeno sedm typů (shluků); všechny patří do svazu *Cirsio-Brachypodion* a tvoří pět hlavních skupin širokolistých suchých trávníku v Maďarsku: 1. druhově bohaté porosty s dominancí druhů *Brachypodium pinnatum* (a zčásti *Bromus erectus*), luční stepi na hlubokých spraších centrální Panonské oblasti, patřící k asociaci *Euphorbio pannonicae-Brachypodietum* Horváth 2009; 2. horské louky s dominantním druhem *Brachypodium pinnatum*, vyskytující se pouze v pohoří Bükk, řazené do asociace *Polygalo majoris-Brachypodietum* Wagner 1941; 3. porosty s převahou *Bromus erectus* na mělkých vápnitých půdách v oblasti Dunántúl, pro něž je navržena nová asociace *Sanguisorbo minoris-Brometum erecti* Illyés, Bauer & Botta-Dukát 2009; 4. porosty s dominancí druhů *Brachypodium pinnatum* a *Danthonia alpina*, vyskytující se hlavně v pohoří Északi-középhegység; je pro ně typický výskyt druhů adaptovaných na živinami chudé půdy a jsou řazeny do nově popsané asociace *Trifolio medii-Brachypodietum pinnati* Illyés, Bauer & Botta-Dukát 2009; 5. přechody k loukám a sukcesním stadiím s dominantním druhem *Brachypodium pinnatum.*

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